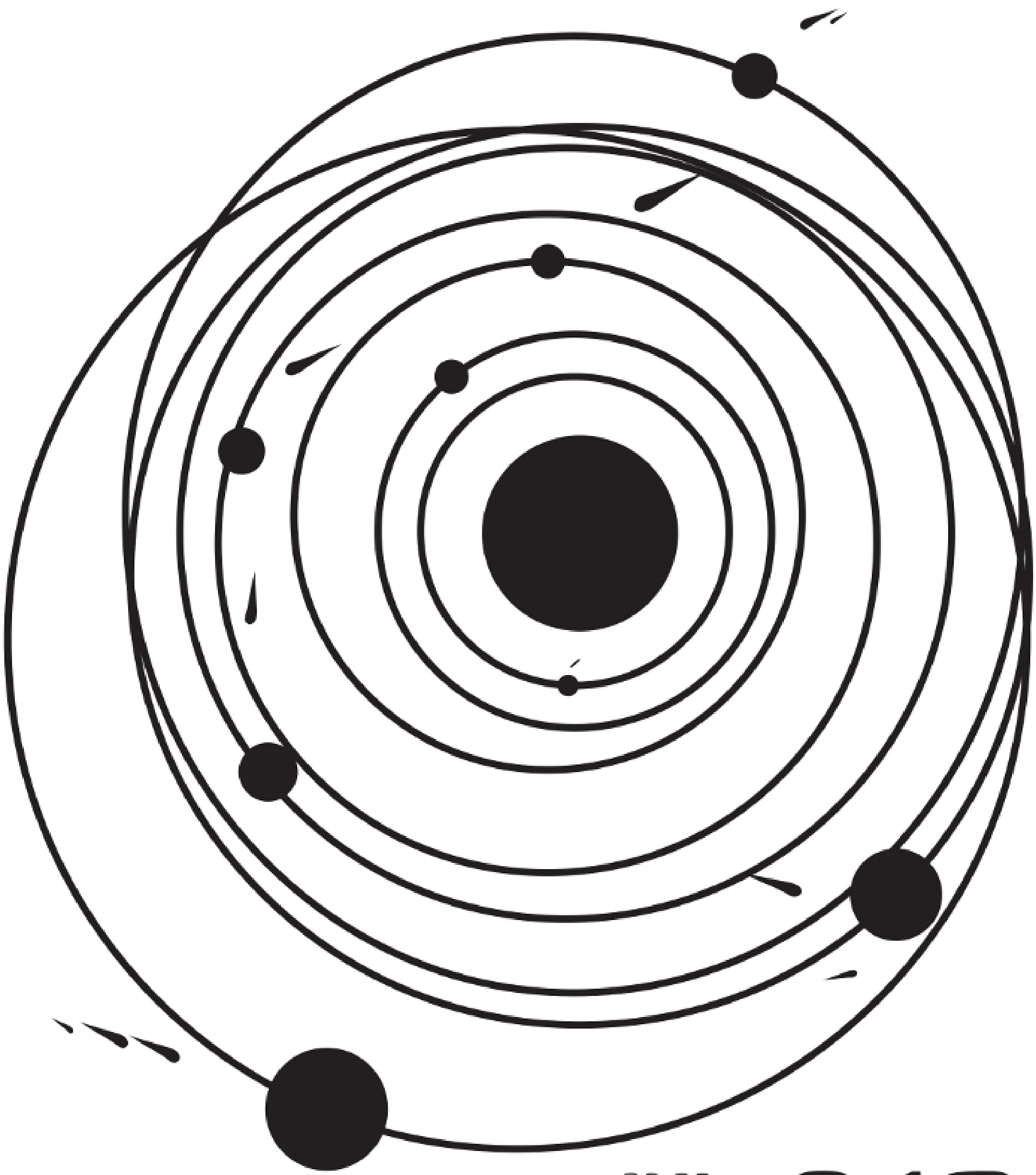

26-30
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POLAND
013

Conference Program and Abstracts

METEOROIDS

Meteoroids 2013

26-30 Aug. 2013, Poznań, Poland

Conference Program – Oral Contributions

Sunday, August 25

16:00-20:00 **Reception desk opens**

Conference reception and all sessions will take place at the Collegium Minus of A.M. University, Wieniawskiego 1 str.

Monday, August 26

8:00 - 9:00 **Registration**
8:30 - 9:00 Morning speakers upload and check presentations
9:00 – 9:20 **Opening event**
9:20 – 9:30 Organizational remarks

Session 1. Chelyabinsk superbolide

Chair: **Williams I.P.**

9:30+30 1.1. The Chelyabinsk superbolide of February 15, 2013.
Borovička J., Spurný P. (Invited). [001]

10:00+20 1.2. Chelyabinsk meteorite: Expedition to the field.
Kartashova A., Popova O., Jenniskens P., Emel'yanenko V., Dudorov A., Khaibrakhmanov S., Biryukov E., Glazachev D., Trubetskaya I. [037]

10:20+20 1.3. Chelyabinsk meteoroid entry and airburst damage.
Popova O., Jenniskens P., Shuvalov V., Emel'yanenko V., Rybnov Y., Kharlamov V., Kartashova A., Biryukov E., Khaibrakhmanov S., Glazachev D., Trubetskaya I. [052]

10:40+20 1.4. Chelyabinsk Meteorite: NEO/Meteorite Associations and the Origin in the Main-belt.
Abe S. [019]

11:00 - 11:30 Coffee break

11:30+30 1.5. The Chelyabinsk Airburst: Energy estimates and airblast analysis.
Brown P. (Invited). [002]

12:00+20 1.6. Studying ablation of the Chelyabinsk superbolide using a Runge-Kutta algorithm.
Dergham J., and Trigo-Rodríguez J.M. [028]

12:20 – 13:50 Lunch

13:30 - 13:50 Afternoon speakers upload and check presentations

Session 2. Meteorite falls

Chair: **Porubcan V.**

13:50+30 2.1. Invited review of recent documented meteorite falls
Jenniskens P.M. (Invited). [004]

14:20+20 2.2. Meteorite dropping Geminid recorded.
Spurný P., Borovička J. [061]

14:40+20 2.3. The meteorite Moss – a rare carbonaceous chondrite.
Bilet M. and **Roaldset E.** [054]

15:00+20 2.4. New Mars Meteorite Fall In Morocco: Collecting Observations And Spatial Distribution In The Strewnfield.
Ibhi A. [034]

15:20 - 15:50 Coffee break

15:50+20 2.5. Oborniki (Wargowo) 2012 possible space debris fall
Nowak M., Gołębiewska J., **Muszyński A.**, Wnuk E. [045]

Session 3. Historical records: bolides, meteors, meteorites

Chair: **Roaldset E.**

16:10+30 3.1. Meteor showers in the ancient Maya Hieroglyphic codices.
Kinsman H. (Invited). [006]

16:40+20 3.2. The historical and geological data of extraterrestrial matter fall in Great Poland Lowland.
Stankowski W. [062]

17:00+20 3.3. Documentation Of 250 Fireballs Observed In Norway About Hundred Years Ago.
Skorve J. [060]

Session 4. International Meteor Organisation

Chair: **Roaldset E.**

17:20+30 4.1. Status and history of the IMO Video Meteor Database.
Molau S. (Invited). [008]

Session 11. International Meteor Organisation

Chair: **Roaldset E.**

17:50+20 11.1 The IAU MDC - meteor showers database , current status.
Jopek T.J., Kanuchová Z. [036]

18:10 – 20:00 **Welcome party**

Tuesday, August 27

8:00-9:00	**Registration**
8:30 - 9:00	Morning speakers upload and check presentations
9:00 – 9:30	**Poster session**
Session 5	**Physical properties of meteoroids micrometeorites and dust**
	Chair: **Popova O. and Koschny D.**
9:30+30	5.1. Working with the fractal nature of a chondritic solar composition in studies of meteoric materials. **Rietmeijer F.** (Invited). [011]
10:00+20	5.2. Sampling of the constant drizzle of meteoric dust in the upper stratosphere. **Rietmeijer F.** [053]
10:20+20	5.3. Raman Microspectroscopy of particles RA-QD02-0158, RA-QD02-0187 and RA-QD02-0197 collected by the HAYABUSA sample return mission to Itokawa asteroid. **Pavlov S.G.,** Alwmark C., Bajt S., Böttger U., Busemann H., Gilmour J.D., Heitmann U., Hübers H.-W., Meier M.M.M., Schade U., Spring N.H., Weber I. [048]
10:40+20	5.4. Changes to meteoroid shape, porosity and internal structure during high velocity atmospheric entry. **Kohout T.,** Kallonen A, Suuronen J.-P., Rochette P., Hutzler A., Gattacceca J., Badjukov D.D., Skála R., Čuda J. [040]
11:00 - 11:30	Coffee break
11:30+30	5.5. The cosmic dust input to the earth's atmosphere: how large is it? **Plane J.M.C.** (Invited). [010]
12:00+20	5.6. Solid Hydrogen and Micrometeors of Interstellar Origin. **Walker M.A.** [067]
12:20+20	5.7. Radar observations during the ECOMA campaign on the Geminids 2010. **Stober G.,** Schult C., Baumann C., Dunker T., Hoppe U.-P., Latteck R., Rapp M., Keuer D. [063]
12:40 – 14:10	Lunch
13:40 - 14:10	Afternoon speakers upload and check presentations
14:10+30	5.8. Density of small meteoroids. **Kikwaya J.B.** (Invited). [005]
14:40+20	5.9. The MEMIN Research Unit: laboratory impact cratering experiments into geological materials (sandstone, quartzite, tuff). **Deutsch A.,** Kenkmann T., Poelchau M.H., Thoma K. [029]

Session 6	**Meteor spectra**
	Chair: **Borovička J.,**
15:00+30	6.1. Emission spectroscopy: clues on the continuous volatile delivery from cometary meteoroids. **Trigo-Rodriguez J.M.** (Invited). [014]
15:30+20	6.2. Development of a Spectroscopic Survey of Meteoroid Elemental Abundances Jenniskens P.M., **Gural P.,** Berdeu A. [031]
15:50 - 16:20	Coffee break
16:20+20	6.3. Is a 2004 Leonid meteor spectrum captured in a 182 cm telescope? **Kasuga T**., Iijima T., Watanabe J. [038]
16:40+20	6.4 Automated High-Resolution Spectral Meteor Camera. Oswald W. and Campbell-Brown M.D. [047]
Session 7	**Meteoroid streams: modeling, forecasting, parent bodies**
	Chair: **Kikwaya J.B.**
17:00+30	7.1. Modelling Meteoroid Streams in the Solar System. **Soja R.H.,** Gruen E., Srama R., Sterken V.J., Strub P., Vaubaillon J., Krueger H. (Invited). [013]
17:30+20	7.2. Dynamical Modelling of Meteoroid Streams. **Clark D.,** Wiegert P. [026]

Wednesday, August 28

8:30 - 9:00	Morning speakers upload and check presentations
9:00 – 9:30	**Poster session**
Session 7	**Meteoroid streams: modeling, forecasting, parent bodies (Follow up)**
	Chair: **Pellinen-Wannberg A. and Jenniskens P.M.**
9:30+30	7.3. The dynamics of meteoroid streams in the Solar System and the forecasting of meteor showers. **Vaubaillon J.** (Invited). [015]
10:00+20	7.4. The meteor showers of cometary asteroid (192642) 1999 RD32. **Christou A.A.,** Vaubaillon J. [025]
10:20+20	7.5. Recent discovery of few parent bodies: a review. **Rudawska R.**, Vaubaillon J. [055]
10:40+20	7.6. Forecast of Enhanced Activity of Eta-Aquariids in 2013. **Sato M.**, Watanabe J. [057]
11:00 – 11:30	Coffee break
11:30+20	7.7. The ecliptic-toroidal structure of the meteor complex of comet 96P/Machholz. **Neslušan L.**, Kanuchova Z., Tomko D. [046]
11:50+20	7.8. Saturnian resonances in meteor streams. **Sekhar A.**, Asher D. [058]
12:10 – 13:40	Lunch
13:10 - 13:40	Afternoon speakers upload and check presentations
Session 8	**Dust and meteoroids dynamics**
	Chair: **Spurný P.**
13:40+30	8.1. Dynamical Model for the Zodiacal Cloud and Sporadic Meteors **Nesvorný D.** (Invited). [009]
14:10+20	8.2. The rotation of cometary meteoroids. **Čapek D.** [024]
14:30+20	8.3. Öpik-type collision probability for high-inclination orbits: Targets on eccentric orbits **Pokorný P.**, Vokrouhlický D. [051]
14:50+20	8.4. A new model describing the orbits and absolute magnitudes of near-Earth objects. **Granvik M.**, Morbidelli A., Jedicke R., Bolin B., Bottke W.F., Beshore E, Vokrouhlicky D., Nesvorny D. and Michel P. [030]
16:30-19:00 19:00- X	Excursions 1 and 2 Banquet

Thursday, August 29

8:30 - 9:00 Morning speakers upload and check presentations

9:00 – 9:30 **Poster session**

Session 9 Meteoroid streams and populations

Chair: **Watanabe J. Asher D.**

9:30+30 **9.1**. Stream and sporadic meteoroids associated with Near Earth Objects.
Williams I.P., Jopek T.J. (Invited). [018]

10:00+20 9.2. The Capricornids asteroid-meteoroid complex.
Kokhirova G.I., Babadzhanov P.B., Khamroev U.Kh. [041]

.
10:20+20 9.3. Summary of results of 2011 Draconid aircraft mission.
Koten P., Vaubaillon J., Rudawska R., Tóth J., Margonis A., Gritsevich M. [043]

10:40+20 9.4. 60 years of the Geminid meteoroid stream modelling.
Ryabova G.O. [056]

11:00 - 11:30 Coffee break

11:30+20 9.5. On the Age and Formation of the Quadrantid Meteoroid Stream.
Abedin A.,Spurný P., Wiegert P., Borovička J., Brown P. [020]

11:50+20 9.6. Radar observations of the Daytime Arietid meteor shower by the Canadian Meteor Orbit
Radar.

Bruzzone S., Brown P., Weryk R.J., Wong D.K. [022]

12:10+20 9.7. An enhanced survey for meteor shower outbursts using the Canadian Meteor Orbit Radar (CMOR).
Brown P., Weryk R.J., Wong D.K. [021]

12:30 – 14:00 Lunch

13:30 - 14:00 Afternoon speakers upload and check presentations

Session 10 Observation techniques, data reductions, methods

Chair: **Ryabova G.O. and Rietmeijer F.**

14:00+30 10.1. The Canadian Automated Meteor Observatory.
Campbell-Brown M.D., Brown P., Weryk R., Wiegert P. (Invited). [003]

14:30+20 10.2. Meteor observations with the next generation geospace radar EISCAT 3D.
Kero J. [039]

14:50+20 10.3. The Southern Argentina Agile Meteor Radar (SAAMER): A platform for comprehensive meteor observations and studies
Janches D. [035]

15:10+20 10.4. BRAMS: a Belgian radio forward scatter network to study meteors.
Lamy H., Ranvier S., Gamby E., Calders S., Anciaux M., De Keyser J. [044]

15:30 - 16:00	Coffee break
16:00+20	10.5. Automatic Detection of Asteroid and Meteoroids - Wide Fields Survey. **Tóth J.**, Vereš J.P., Jedicke R., Tonry J., Denneau L., Wainscoat R., Kornoš L., Šilha J. [066]
16:20+20	10.6. Correction Effect to the Radiant Dispersion in case of Low Velocity Meteor Showers. **Watanabe J.**, Sato M. [068]
16:40+20	10.7. Transverse motion of fragmenting faint meteors observed with the Canadian Automated Meteor Observatory. **Stokan E.,** Campbell-Brown M.D. [064]
17:00+20	10.8. A new software application for all sky camera networks. **Peterson Ch. L.** [050]
17:20+20	10.9 High resolutiion Video and Light Curve analysis of Meteors. **Subasinghe D.**, Campbell-Brown M. [065]

Friday, August 30

8:30 - 9:00 Morning speakers upload and check presentations

9:00 – 9:30 Poster session

**Session 11 Meteor databases,
Follow up.**

Chair: **Campbell-Brown M.D.**

9:30+30 11.2. Using the Virtual Meteor Observatory – Geminids 2011.
Koschny D., Smit H., Barentsen G. (Invited). [007]

10:00+20 11.3. Hyperbolic orbits in the EDMOND,
Hajduková M. Jr., Kornoš L., Tóth J. [032]

10:20+20 11.4. Confirmation and characterization of meteor showers from IAU working list.
Kornoš L., Matlovič P., Tóth J., Koukal J., Piffl R. and EDMOND consortium [042]

Session 12 Fireballs

Chair: **Svoren J**

10:40+30 12.1. Physical properties of meteor shower fireballs.
Shrbený P., Spurný P. (Invited). [012]

11:10 - 11:40 Coffee break

11:40+30 12.2. Jovian Impact Flashes and their Implication to Meteoroids in Outer Region of Solar System.
Watanabe J. (Invited). [016]

12:10+20 12.3. Simultaneous Infrasonic and Optical observations of bright meteors: analysis of acoustic source heights and signal classification.
Silber E.A., Brown P. [059]

12:30 – 13:30 Lunch

13:00 - 13:30 Afternoon speakers upload and check presentations

13:30+20 12.3 The NASA Fireball Network
Cook. W. [027]

Session 13 Meteoroid interactions with the planetary atmospheres

Chair: **Kanuchova Z.**

13:50+30 13.1 Insights into meteoroid ablation from simultaneous radar-video observations.
Weryk R.J., Brown P.G. (Invited). [017]

14:20+20 13.2. Implications for meteoroid structure and ablation from multiple maxima meteor light curves.
Hawkes R.L. Roberts I.D., Weryk R.J., Campbell-Brown M.D., Brown P.G., Stokan E. [033]

14:40+20	13.3. Modeling of meteoroids at high resolution. **Campbell-Brown M.D.,** Borovička J., Brown P., Stokan E. [023]
15:00+20	13.4. Collective E-region ionisation caused by the 1767 trail during the 2002 Leonids. **Pellinen-Wannberg A.,** Häggström I. Westman A. [049]
15:20 – 15:50	**Conference Summary**

Meteoroids 2013

26-30 Aug. 2013, Poznań, Poland

Poster Program

Posters will be presented from 26 Aug. afternoon until 30 Aug. afternoon at the Lubrański Hall next to the conference lecture hall, Collegium Minus UAM.

All authors are asked to put their posters up on the poster boards on **Monday 26, Aug.** during the lunch time. The posters should be taken off, at the latest on **Friday 30, Aug.** during the lunch time.

Tuesday 27 Aug. - Wednesday 28 Aug.

Each day the poster sessions lasts from at 9:00-9:30. Within this interval, the presenting authors are kindly asked to be present near their posters.

Session P1. Chelyabinsk superbolide

P1.1 The Chelyabinsk bolide as a prove of cometary nature of Earth orbit crossing bodies.
Bagrov A.V., Leonov V.A., Popelenskaya N.V. [070]

P1.2 Physics of the Chelyabinsk fireball.
Churyumov K.I., Kruchynenko V.G., Mozgova A.M. [078]

P1.3 Chelyabinsk Superbolide: a detailed analysis of the passage through the atmosphere and orbit determination.
Wlodarczyk K., Wlodarczyk I. [125]

P1.4 Chelyabinsk meteorite: eye witnesses interviews.
Kartashova A., Popova O., Jenniskens P., Korotkiy S., Emel'yanenko V., Dudorov A., Khaibrakhmanov S., Biryukov E., Glazachev D., Trubetskaya I., Serdyuk I. [091]

Session P2. Meteorite falls

P2.1 Meteorites of Turkie.
Caliskan O. [074]

Session P3. Meteor flux

P3.1 Meteoroid stream flux profiles derived from the IMO Video Meteor Network.
Barentsen G., Molau S. [071]

Session P5. Physical properties of meteoroids micro-meteoroids and dust

P5.1 Chemistry of Benešov meteoroid.
Berezhnoy A.A., **Borovička J.** [072]

P5.2 On the chemical and mineral composition of the par"Turyi Remety" in Transcarpathian.
Churyumov K.I., Belevtsev R.Y., Spivak S.D. [079]

P5.3 Micro-Raman spectroscopy of meteorite Kosice
Kanuchová Z., Baratta G.A. [090]

Session P6. Meteor spectra

P6.1 Spectroscopy of the 2012 Geminids from AGM Marrakech observatory.
Daassou A., Ait Moulay Larbi M., Rudawska R., Benkhaldoun Z., Baratoux D.,Vaubaillon J., Bouley S. [080]

P6.2 Spectroscopic airborne observations of the 2011 Draconids meteor shower outburst.
Rudawska R., Zender J., Jenniskens P., Borovicka J., Vaubaillon J., KotenP., Koschny D., McAuliffe J. [107]

P6.3 Emission spectrum of a sporadic fireball afterglow.
Madiedo J.M., **Trigo-Rodriguez J.M.** [117]

Session P7 Meteoroid streams: modeling, forecasting, parent bodies

P7.1 Comets outbursts and the meteor showers.
Guliev A.S., Kokhirova G.I., Poladova U.D. [083]

P7.3 Presentation canceled. [096]

P7.4 Prediction of meteor shower of comet 161P/2004 V2.
Tomko D., Neslušan L. [114]

P7.5 2014 CAMELOP Airborne campaign preparation
Berard D., **Vaubaillon J.** [118]

Session P11 Meteor catalogues and databases

P11.1 Catalogue of meteoroid orbits with large eccentricities from the KhNURE database of radar observations in Kharkiv.
Kolomiyets S.V., Voloshchuk Yu.I. [093]

P11.2 Photographic IAU MDC Meteor Database - Version 2013.
Neslušan L., **Porubčan V.**, Svoreň J. [101]

Thursday 29 Aug. - Friday 30 Aug.

Each day the poster sessions lasts from at 9:00-9:30. Within this interval, the presenting authors are kindly asked to be present near their posters.

Session P9 Meteoroid streams and populations

P9.1 A Parent Body Search Across Several Video Meteor Data Bases.
Šegon D., **Gural P.**, Andreic Ž., Skokic I., Korlevic K., Vida D., Novoselnik F. [084]

P9.2 The Geminids' orbital dispersion derived from the European video meteor network database.
Hajdukova M., Jr [085]

P9.3 The distribution of the orbits within the meteor streams from the SonotaCo shower catalogue.
Hajdukova M., Jr [086]

P9.4 An initial meteoroid stream survey in the southern hemisphere using the Southern Argentina Agile Meteor Radar (SAAMER).
Janches D., Hormaechea J.L. , Brunini ., Hocking W., Fritts D.C. [088]

P9.5 The 2011 Draconids Airborne Observation Campaign: First results using the SPOSH camera.
Margonis A., Koschny D., Toth J., Koten P., Vaubaillon J., Oberst J., Zender J., Mc Auliffe J. [095]

P9.6 Video observations of the Geminids meteor shower in 2012 from Morocco.
Ait Moulay Larbi M., Daassou A., Benkhaldoun Z., Rudawska R., Baratoux D. [097]

P9.7 Physical and kinematic characteristics of meteoroids producing bright radio meteors
Narziev M. [098]

P9.8 Taurid Meteor Complex.
Buček M., **Porubčan V.** [100]

P9.9 CMOR Observations of the 2011–2012 October Draconid Outbursts.
Ye Q.-Z., Brown P. G., P. Wiegert A., Campbell-Brown M.D., Weryk R. J. [102]

P9.10 New meteor showers identified in the CAMS and SonotaCo meteor databases.
Rudawska R., Jenniskens P. [106]

P9.11 Observation of October Draconids 2011 in Maidanak Observatory and Study of its Peak time.
Sato M., Watanabe J., Ohkawa T. [108]

P9.12 Taurids in the IAU MDC Database
Kanuchova Z., **Svoreň J.** [113]

P9.13 Video observation of unexpected outburst Draconids 2012.
Tóth J., Koukal J., Kornoš L., Piffl R., Gajdoš Š. and EDMONd and EDMON consortium [116]

Session P10. Observation techniques, data reductions, methods

P10.1 On the standardization of photometric results of meteor registrations processing.
Bagrov A.V., Leonov V.A. [069]

P10.2 Radar detectability studies of slow and small Zodiacal Cloud Dust Particles.
Janches D., Plane J.M.C., Feng W. , Sanchez-Carrillo J.D., Nicolls M.J., Nesvorny , Marsh D. [087]

P10.3 The MU radar meteor head echo database.
Kero J., Szasz C., Nakamura T., Terasawa T., Nishimura K., Tsutsumi M., Fujiwara Y., Ueda M., Watanabe J., Abe S., Abo M., Tanaka Y., Yamamoto M. [092]

P10.4 Theory and practice of low light TV meteors photometry: an empirical approach.
Kozak P.M. [094]

P10.5 Meteor detection in wide-field survey telescopes.
Ocaña F., Ponz J.D., Zamorano J. [099]

P10.6 Radio Polarisation Measurements of Meteor Trail Echoes with BRAMS.
Ranvier S., Lamy H., Anciaux M.,De Keyser J., Calders S., Gamby E. [103]

P10.7 Evidence for a VLF propagation perturbation associated with a meteor.
Rault J-L. [104]

P10.8 The Norwegian Meteor Network.
Roaldset E. [105]

P10.9 Present state of the MAARSY meteor head echo analysis
Schult C. , Stober G., Latteck R. [109]

P10.10 Optical trail widths of faint meteors observed with the Canadian Automated Meteor Observatory.
Stokan E., Campbell-Brown M.D., Brown P.G., Hawkes R.L., Doubova M., Weryk R.J. [112]

P10.11 Slovak Video Meteor Network - AMOS Cameras - coverage, precision and results.
Tóth J., Spurný P., Kornoš, L. Zigo P., Šilha J., Gajdoš Š., Galád A., Kalmančok., Šimon J., Mäsiar J. 115]

P10.12 Meteoroid 3D-trajectory determination using FFT from shuttered image.
Clovirola A., **Vaubaillon J.** [119]

P10.13 Faint Meteor Observation by Large-Format CMOS Sensor with 1.05-m Kiso Schmidt Telescope.
Watanabe J., Kasuga T., Terai T., Miyazaki S., Ohta K., Murooka F., Ohnishi T., Yamasaki T., Mito H., Aoki T., Soyano T., Tarusawa K., Matsunaga N., Sako S., Kobayashi N., Doi M. [121]

P10.14 Determining meteor trail radii using the Canadian Meteor Orbit Radar (CMOR).
Weryk R.J., Brown P.G., Krzeminski Z., Stokan E. [122]

P10.15 Taiwan Elegant Meteor and TLE Network (TWEET)
Wu B.-X., Abe S., Lin H.-C., Lin C-S. [127]

Session P12 Fireballs

P12.1 Three bright bolides in Kiev sky on 29 March 2013.
Churyumov K.I., Vidmachenko A.P, Steklov A.F., Steklov E.A. [077]

P12.2 Bright Perseid fireball with exceptional beginning height observed by different techniques.
Spurný P., Koten P., **Shrbený L.**, Vojáček V., Borovička J., Štork R. [110]

P12.3 Trajectory and orbit of the Maribo CM2 meteorite from optical, photoelectric and radar records.

Spurný P., Borovička J., Haack H., Singer W., Jobse K., Keuer D. [111]

P12.4 PF191012 Myszyniec - highest Orionid meteor ever recorded.
Olech A., Żołądek P., **Wiśniewski M.**, Pietkiewicz K., MaciejewskiM., Tymiński Z., Krzyżanowski T., Krasnowski M., Kwinta M., Myszkiewicz M., Polakowski K., Zaręba P. [123]

Session P13 Meteoroid interactions with the planetary atmospheres

P13.1 Theoretical study of the ablation of Meteoroids in the upper atmospheres of Venus, Earth, Mars and Titan.
Carrillo-Sánchez J. D., O'D. Alexander C. M., Plane J. M. C. [075]

Session P14 Diverse subjects

P14.1 Polarimetric study of CB56 and CB69 cloud.
Chakraborty A. [076]

P14.2 Imaging Polarimetry of Comet C/2009 P1 Garradd.
Deb Roy P., Das H.S., Medhi B.J., Wolf S., Bertrang G., Chakraborty A. [081]

P14.3 Two mechanisms of the ejection of meteoroids from comets.
Gronkowski P., Wesołowski M. [082]

P14.4 Orbital Evolution and Impact Hazard of Asteroids on Retrograde Orbits.
Kankiewicz P., Włodarczyk I. [089]

P14.5 The potentially dangerous asteroid (99942) Apophis.
Włodarczyk I. [126]

P14.6 Calculation of the MOID – new numerical method
Wiśniowski T., Rickman H. [124]

P14.7 Impact probability calculations by Hill sphere method.
Wajer P. , Gabryszewski R. [120]

P14.8 Reliability of the orbital associations among the small bodies.
Bronikowska M., Jopek T.J. [073]

Meteoroids 2013

Abstracts

Poznań AD 2013

The Chelyabinsk superbolide of February 15, 2013

J. Borovička and P. Spurný

Astronomical Institute, Academy of Sciences of the Czech Republic, Ondřejov, Czech Republic (borovic@asu.cas.cz)

Introduction

The Chelyabisk superbolide, due to its magnitude, the effects caused on the ground, and the very good video coverage, was an important and unprecedented event not only for meteor community but also for people studying asteroids, impact hazards, cratering etc. In this talk, we will review the status of knowledge about half year after the event, concerning mainly the trajectory and orbit, the behavior in the atmosphere including fragmentation, dust trail formation and evolution, and fall of meteorites. The Chelyabinsk superbolide will be compared with other, much smaller, superbolides observed and analyzed in the past decades.

The Chelyabinsk Airburst: Energy estimates and airblast analysis

P. Brown (1,2)

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At 03:20 UT (09:20 local time) on Feb 15, 2013 an exceptionally energetic fireball occurred over the region near Chelyabinsk, Russia. Of particular note is the fact that the shock wave from the airburst was able reach the surface with sufficient overpressure (>500 Pa) to shatter windows and cause light structural damage in the region to the South of the city of Chelyabinsk, as well as in the city of Chelyabinsk proper.

The airwave from the event was recorded globally at more than 20 infrasound arrays operated as part of the International Monitoring System (IMS) of the Comprehensive Test Ban Treaty Organization (Fig.1). From the dominant airwave period at infrasound frequencies, the source yield for the airburst is estimated to be approximately 0.5 MT of TNT equivalent explosive energy. Some infrasound records show that the airwave made at least one full revolution of the planet (including antipodal returns), with acoustic signals detectable for more than 24 hours after the event.

The range of energy yields translates into a meteoroid with a mass of order 10^4 tonnes and diameter of approximately 20m. Many hundreds of video recordings of the event were obtained and posted to social media sites. Some videos show the distinct formation of strong local vertical plumes associated with intensive heating in the terminal detonation. The main airburst section of the trail shows a distinct double trail formation (Fig. 2) an effect caused by fast rising buoyant air parcels flowing into the center of the trail, an effect noted previously in the trains of bright fireballs. [1].

This fireball event is the most energetic confirmed airburst since the Tunguska fireball of 1908. Assuming a source yield of 0.5 MT, the Earth is hit, on average, by a similarly energetic object only once every ~75 years.

In this talk I will discuss details of the energy estimates for this event and other aspects of this remarkable fireball.

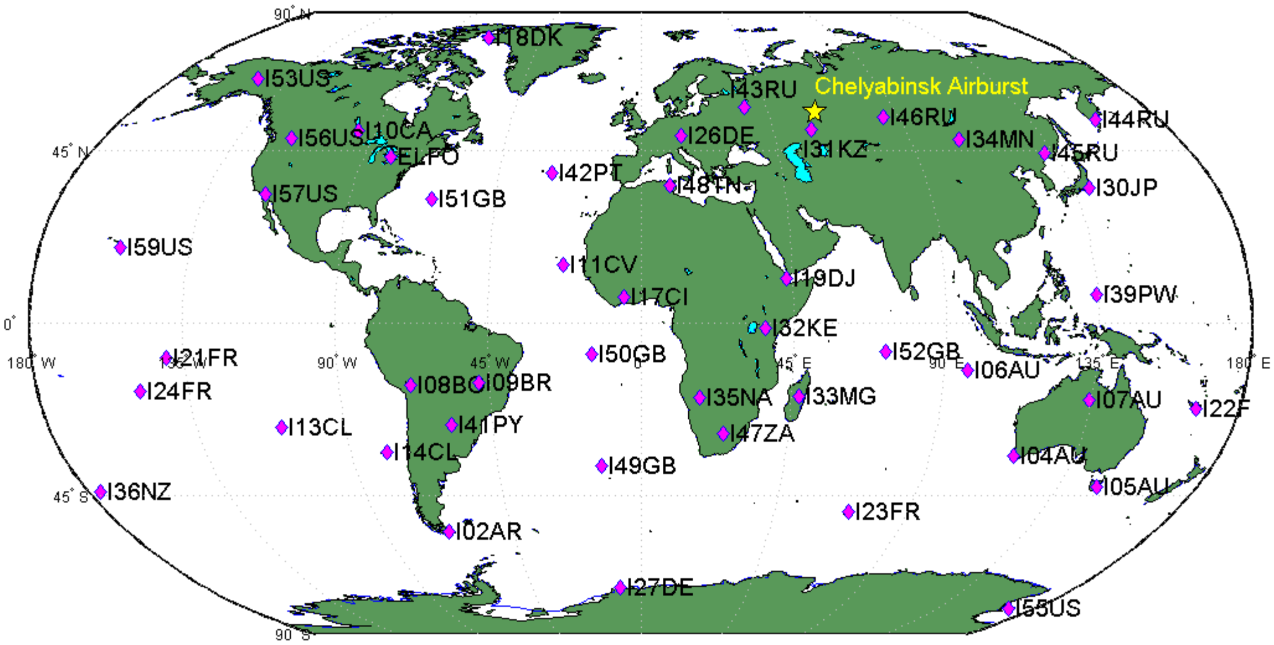

Fig. 1 The Chelyabinsk airburst (yellow star) in relation to Infrasound stations (purple diamonds) operated by the IMS CTBTO network.

Fig. 2 The Chelyabinsk airburst dust trail just over one minute after the fireball passage as imaged by an observer directly under the trajectory in the town of Pervomaysk.

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The Canadian Automated Meteor Observatory

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The Canadian Automated Meteor Observatory is an video meteor observing system operating in Ontario, Canada since 2010. Its purpose is to provide data on the flux, mass distribution and physical properties of meteoroids in the millimeter size range at 1 AU. The system is fully automated: an array of sensors allow the system to observe only under clear, dark skies without intervention.

CAMO is located at two sites, situated 44.6 km apart: Elginfield (43.193° N, 81.315° W) and Tavistock (43.264° N, 81.772° W). Each site has two camera systems, which are pointed at an overlapping volume of sky north of the two sites. The first system is the influx system; at each site a 1K x 1K intensified camera operates at 20 frames per second, with a field of view of 20 degrees, and a limiting magnitude of about +5.5. The common observing volume centres on 105 km. Data from this system is analysed using Meteorscan [1].

The second system at each of the sites consists of two intensified cameras, both 640x480 pixel progressive scan. One has a field of view of 26x19 degrees, and runs at 80 frames per second; the observing volume centres on 95 km. Meteors occurring on this system are detected with the ASGARD software [2] in real time, and tracked by directing the light from the meteor into an 80 mm refractor using a pair of orthogonally mounted mirrors. The second system runs at 110 frames per second, and the mirrors track smoothly so that there is minimal motion of the meteor in the 1.5 degree field of view of the mirror camera. This allows the meteor to be imaged over much of its trail with a resolution (depending on range) approaching 3 meters per pixel.

The influx system has been used to search for hyperbolic meteors [3] and will be used to examine meteor height, speed and mass distributions, and meteor fluxes. The mirror system has been used to study the physical width of meteor trails [4], and will be used to study meteoroid fragmentation, ablation and interactions with the atmosphere. A spectral system will shortly be added to the mirror system which should allow spectral measurements of spatially resolved areas in the meteor head and wake. The volume observed by both video systems is also observed by the Canadian Meteor Orbit Radar (CMOR), allowing simultaneous video/radar observations on a regular basis which will allow observing biases in both systems to be studied and addressed.

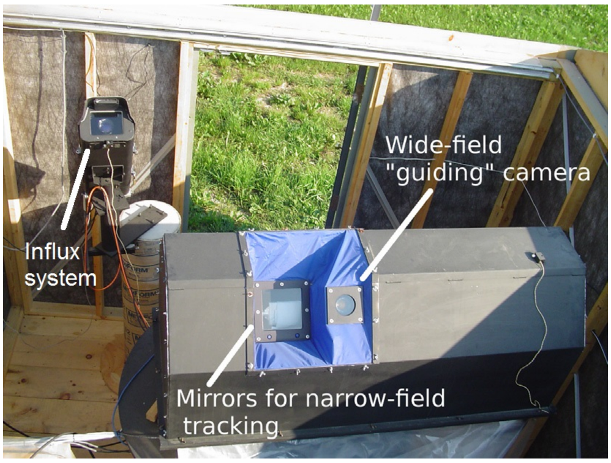

Figure 1: The CAMO system at Tavistock.

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Invited review of recent documented meteorite falls.

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Intense (social) media interest in end-of-the-world predictions for December 21, 2012, coincided with a record number of reported meteorite falls in 2012. Since the last Meteoroids meeting (2010 May 24-28), at least 23 confirmed meteorite falls have been reported (Table 1).

Table 1. Incomplete list of meteorite falls since Meteoroids 2010 meeting. Names in italic refer to those sited in news stories and are not yet been approved by the Meteoritical Society (italic).

Date of fall (local time)	Name (*unofficial)*	Country	Type
2013-05-09	*Oshika**	Namibia	o.c.?
2013-04-23	*Braunschweig*	Germany	o.c.?
2013-04-19	*Wolcott*	Connecticut	o.c.?
2013-02-15	**Chelyabinsk***	Russia	LL5
2013-01-15	*Planeta Rica*	Columbia	o.c.?
2012-10-30	*Addison**	Alabama	o.c.?
2012-10-17	**Novato***	California	L6
2012-10-12	*Beni Yacoub**	Morocco	H5?
2012-08-22	Battle Mountain*	Nevada	L6
2012-07-08	*Jalangi**	India	o.c.?
2012-06-03	*Comayagua*	Honduras	o.c.?
2012-05-22	*Katol**	India	achn?
2012-05-03	*Diplo**	Pakistan	o.c.?
2012-04-22	**Sutter's Mill***	California	CM2
2012-03-01	*Oslo**	Norway	H3?
2012-02-11	Xining*	China	L5
2011-09-14	Boumdeid (2011)*	Mauritania	L6
2011-07-18	Tissint*	Morocco	Sh.
2011-07-16	Thika*	Kenya	L6
2011-07-13	*Draveil*	France	H?
2011-04-30	Soltmany	Poland	L6
2010-07-13	Huaxi	China	H5
2010-06-19	Varre-Sai*	Brazil	L5

Many falls are now well documented by video security cameras, cell phone cameras, and digital still cameras. The number of bolides resulting in meteorite falls that are well enough documented with video and photographic cameras to derive an entry trajectory and pre-atmospheric orbit, has increased exponentially since the first such case of Peekskill in 1992 [1]. That said, it is still fairly rare that this information is collected and reduced. Of the 23 meteorite falls in Table 1, orbital elements were obtained for the Sutter's Mill, Novato, and Chelyabinsk falls. The associated fireball from sixteen of these 23 meteorites was observed by eye witnesses, so it is possible that more orbits could be derived.

In this invited review talk, I will discuss those falls that are not presented elsewhere at the meeting. I will focus on the Sutter's Mill (CM2) and Novato (L6) meteorite falls in California to show how trajectory information can help identify their source region in the asteroid belt.

Sutter's Mill was the biggest impact over land since the impact of asteroid 2008 TC3 in northern Sudan on October 7, 2008 [2]. A high altitude disruption created a cloud of debris that rained down over the villages of Coloma and Lotus in California, with one of the pieces landing at the Sutter's Mill site, the very location where gold was first discovered that resulted in the 1849 California Gold Rush. The falling meteorites were detected by Doppler weather radar, which made rapid recovery possible [3]. Thanks to a large crowd-sourcing effort, in the form of a second Gold Rush, a relatively large number of fragments were recovered. The meteorites were of a rare CM2 type, stronger than other CM2's by having been slightly heated, and the first showing clear evidence of being a breccia, part of a surface regolith. This fragment originated from near the surface of the CM2 parent body. The fresh recovery made it possible to recognize some components that are quickly altered by reactions with water. CM2 meteorites as a group have a short cosmic ray exposure age (< 2 My), and Sutter's Mill had one of the shortest on record, only 50,000-90,000 years. The short cosmic-ray exposure age implies that these meteorite orbits evolved relatively recently from the resonance that delivered them to Earth and also that they fall apart rapidly (within 2 My) once arriving in the inner solar system. The Sutters Mill fall was documented by three digital photographs and two videos. The meteor entered at a record entry speed of 28.6 km/s, the fastest entry so far for which material has been recovered. As did CM2 chondrite Maribo, the meteorite arrived in a low-inclined orbit with an orbital period close to that of the 3:1 resonance with Jupiter. CM2 meteorite Murchison, the type specimen of this class, also arrived on a low-inclined orbit. All point to the source region being a C-class asteroid family in a low inclined orbit very close to the 3:1 resonance. This could be the Eulalia family, recently identified as a potential source of C-class asteroids [3].

The Novato fall was a more common L6 ordinary chondrite, but it was recovered because it crossed the camera fields of the CAMS network in California [4]. Shocked L6 chondrites are thought to originate from the Gefion asteroid family [5]. They are typically encountered after many millions of years of evolution before hitting Earth. It is currently being determined whether or not Novato belongs to this group of shocked L6 chondrites. If so, its orbit, and that of other common shocked L6 chondrite falls, could help confirm the identity of the proposed source region.

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Density of small meteoroids

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Density is an important physical property of meteoroids. Knowing the density of meteoroids helps to determine the physical structure and gives insight into the composition of their parent bodies. The density of meteoroids can provide clues to their origins, whether cometary or asteroidal. Density is also an important parameter when characterizing the risk meteoroids may pose to artificial satellites. Calculating the density of meteoroids is difficult, but there have been several successful studies.

In this review talk, we will emphasize some of these attempts, their different results, and their contributions to the understanding of the physical properties, composition, and the orbital evolution of meteoroids. Ceplecha (1968) calculated the density of small meteoroids based on a parameter K_B (meteoroid beginning height) and classified them in four categories (A,B,C,D) with densities going from 2700 to 180 kgm^{-3}.Babadzhanov(2002) applied a model based on quasi-continuous fragmentation (QCF) on 413 photographic Super-Schmidt meteors by solely fitting their light curves and found their densities ranging from 400 to 7800 kgm^{-3}. Bellot Rubio et al. (2002) analyzed the same 413 photographic meteors assuming the single body theory based only on meteoroid dynamical properties and found densities ranging from 400 to 4800 kgm^{-3}. The estimated density of meteoroids depends strongly on the assumptions in the ablation model. A thermal erosion model was used by Borovicka et al. (2007) to analyze, for the first time simultaneously, the observed decelerations and light curves of six Draconid meteors. The density of the six Draconid meteors was found to be 300 kgm^{-3}, consistent with the fact that the Draconid meteors are porous aggregates of grains associated with the Jupiter-family-comet 21P/Giacobini-Zinner (Jacchia, L.G., 1950)).

We used the Campbell-Brown and Koschny (2004) model of meteoroid ablation to determine the density of faint meteoroids from the analysis of both observed decelerations and light curves of meteoroids (Kikwaya et al., 2009; Kikwaya et al., 2011). Our work was based on a collection of six and ninety-two sporadic meteors. The grain masses used in the modeling ranged from 10^{-12} Kg to 10^{-9} Kg. We computed the orbit of each meteoroid and determined its Tisserand parameter. We found that meteoroids with asteroidal orbits have bulk densities ranging from 3000-5000 kgm^{-3}. Meteoroids consistent with HTC/NIC parents have bulk densities from 400 kgm^{-3} to 1600 kg m^{-3}. JFC meteoroids were found to have surprisingly chondritic-like bulk densities, suggesting either the sintering of the meteoroids through evolutionary processes, or the original radial transportation of chondritic materials up to the Kuiper Belt region.

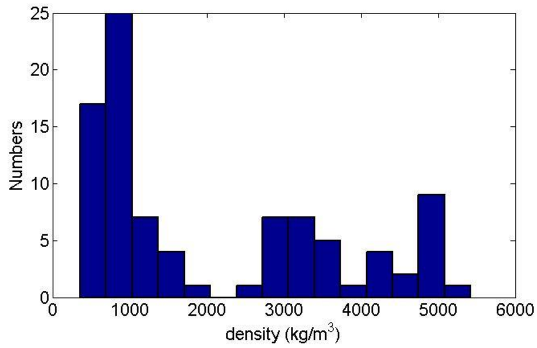

Fig 1. The bulk density distribution of our meteoroid sample (Kikwaya et al., 2011).

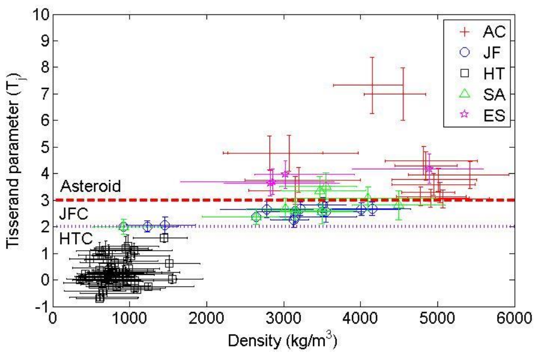

Fig 2. The bulk density of each meteoroid in our survey and its T_j. The uncertainty values in density come from the range of densities based on modeling, and those in T_j are based on the measurements of pre-atmospheric orbit (Kikwaya et al., 2011).

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Meteor Showers in the Ancient Maya Hieroglyphic Codices

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Introduction

Researchers of the ancient Maya culture have long been fascinated with the Maya obsession with different cyclical calendars and precise visual observations of astronomical bodies and phenomena, in particular the Sun, the Moon and Venus, and solar and lunar eclipses. Although considered likely, heretofore no recording of distinctive celestial activities such as comets or meteor showers has been firmly established by scholars. Besides difficulties with decipherment of the hieroglyphic script, investigators have had to grapple with an ancient Maya calendar that has not been accurately correlated to the European calendar. Recent examinations have made some progress in correcting that deficiency, and thus this researcher has found that it may be possible to recognize written accounts of meteor showers in the hieroglyphic corpus, especially the codices, the screen-fold books that were the tools of the astronomer-priests of that day. By proposing a new decipherment of an astronomical sign and using the accompanying hieroglyphic texts and illustrations with appropriate dates, this researcher believes it is possible to demonstrate that the Maya may have recorded meteor showers occurring in the seventh through the tenth centuries AD.

Using the Virtual Meteor Observatory – Geminids 2011

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Introduction

We have analyzed double-station observations of the Geminids 2011 from a camera setup called 'CILBO' in the Canary Islands. We compare the obtained orbital parameters with old literature values. The complete analysis was done using the Virtual Meteor Observatory (VMO) which was developed at ESA/ESTEC.

Observations

We use image-intensified video cameras with a field of view of 22° x 28° and a stellar limiting magnitude of 6.5 to record meteors with a typical positional accuracy of the order of one arcminute. The automated software MetRec [1] is used to detect meteors and determine their positions in the sky. Two cameras are located about 120 km apart from each other on Tenerife and La Palma under very good sky conditions. They monitor the same volume in the sky to allow orbit determination [2].

The Virtual Meteor Observatory (VMO)

The VMO [3], [4] was developed in the Meteor Research Group of ESA/ESTEC in collaboration with the International Meteor Organisation (IMO) as an on-line accessible repository for all kinds of meteor data. We currently focus on the finalization of the camera section of the VMO. We are in the process of ingesting the complete IMO video dataset (1997-2012) into the VMO. A converter for data produced with MetRec is available; additional converters (e.g. for data produced with UFOCapture) are under implementation.

The underlying database is based on SQL (Structured Query Language). A special 'Meteor Modeling Language' based on XML (Extended Markup Language) was developed to support the data handling [5].

The current VMO allows automatic searching of datasets for possible simultaneous observations of the same meteor with two cameras. It computes orbits from the data via an adaption of the MOTS (Meteor Orbit and Trajectory Software) algorithm [6]. It is possible to perform Monte-Carlo runs adding observational errors to the data to get covariance matrices to show the accuracy of the orbital elements.

Data processing and analysis

Data from the two cameras was ingested into the VMO via the on-line MetRec import routine. The on-line orbit computation functionality was used to search for simultaneous meteors and to compute their orbits. An external Python script was used to retrieve the orbit information for those meteors which were initially marked as Geminids by the MetRec software. Since this designation is made based on single-station observations, a number of identified double-station events were not corresponding to the same meter. By constraining the orbital elements to be within reasonable ranges (i.e. eccentricity < 1) false events were excluded. The resulting orbits are shown in Figure 1.

Results

Data from 13/14 Dec 2011 and 14/15 Dec 2011 was analyzed. We found 100 potential Geminid orbits. The orbital elements were plotted and compared to literature values [7], [8], and to the elements of the parent object (3200) Phaeton. Figure 1 shows exemplary the eccentricity and the inclination, both as a function of semi-major axis. As the shower identification was done from the MetRec-derived single-station analysis, some outliers can be seen in the data which are most likely not Geminids.

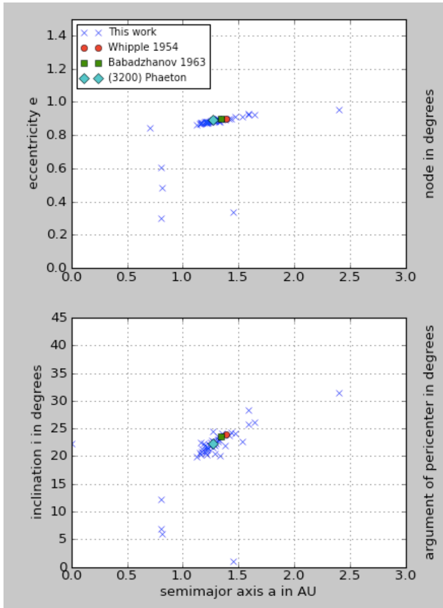

Fig. 1: Eccentricity and inclination of the Geminids 2011 as a fucntion of semimajor axis.

Conclusions

We have used the VMO for the analysis of data obtained during the Geminids 2011. The orbital elements are in good agreement with previous data from up to over 50 years ago, but show a systematic shift. Using dynamical analysis it should be possible to show whether this indicates a 'one-off' dust production activity or a continuous activity. Further it was shown that the VMO is an excellent data mining tool which allows to very easily access and analyze meteor data.

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Status and history of the IMO Video Meteor Network

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Introduction

The International Meteor Organization (IMO) Video Meteor Network is a joint effort of amateur astronomers who obtain video meteor observations on a regular basis. The network started in 1999 in Germany and has been growing continuously since. We present an overview of the history, the characteristics and the results of the network over nearly fifteen years of continuous operation.

History

The history of the network can be summarized in three stages.

Starting in 1999, the first stage was characterized by the setup of the network, software development and initial data collection. It provided a solid database for subsequent meteor shower analyses.

The second phase started in 2006, when the database contained astrometry for more than a quarter million of meteors. Comprehensive statistical analyses were started in this period to detect meteor showers and obtain their parameters automatically. The analyses were repeated whenever the database had approximately doubled in size.

The third stage from 2010 on saw the addition of flux density estimates. The flux data, which can be accessed through an online web service, extend the merely static shower information like radiant data by a dynamic component.

Network characteristics

The characteristics of the network are as follows:

- the participants are independent amateur astronomers from different, mainly European countries;
- observers operate one to five video cameras at either a single or multiple locations;
- nearly all stations are automated and operate every night;
- even though designed as single-station network to allow observers from anywhere in the world to join, the IMO network in central Europe is sufficiently dense to obtain multi-station data;
- all stations use identical digitizer hardware and the MetRec software for meteor detection and analysis;
- observations are reported to the IMO network database, which is centrally maintained and quality-controlled (all data are checked manually by at least two independent observers).

Current Status

In 2012, the network united 46 observers from 15 countries, operating a total of 81 video meteor cameras. By the end of 2012, the IMO Video Meteor Database had grown to more than 1.4 million meteors recorded in 4600 nights. The combined effective observing time equals 325000 hours or over 37 years.

Results

Multiple statistical analyses have been carried out using the database, many of them for the first time in meteor research. Major results include

- automated searches for meteor showers based on data in the optical domain sufficiently covering all solar longitudes [1],[2];
- the discovery of more than 20 unknown meteor showers [3],[4];
- the confirmation of about eighty meteor showers from the IAU Meteor Data Center (MDC) working list [4];
- the characterization of meteor shower variability not only as radiant drift in right ascension and declination, but also as a change of velocity [5];
- automated meteor shower flux density measurements in the optical domain, for certain high-profile events even in real-time [6],[7].

Outlook

Further analysis results and discoveries may be expected from the IMO Network thanks to a rapidly growing database, improving data quality and refined analysis techniques.

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Dynamical Model for the Zodiacal Cloud and Sporadic Meteors

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The solar system is dusty, and would become dustier over time as asteroids collide and comets disintegrate, except that small debris particles in interplanetary space do not last long. They can be ejected from the solar system by Jupiter, thermally destroyed near the Sun, or physically disrupted by collisions. Also, some are swept by the Earth (and other planets), producing meteors. Here we develop a dynamical model for the solar system meteoroids and use it to explain meteor radar observations. We find that the Jupiter Family Comets (JFCs) are the main source of the prominent concentrations of meteors arriving to the Earth from the helion and antihelion directions. To match the radiant and orbit distributions, as measured by the Canadian Meteor Orbit Radar (CMOR) and Advanced Meteor Orbit Radar (AMOR), our model implies that comets, and JFCs in particular, must frequently disintegrate when reaching orbits with low perihelion distance. Also, the collisional lifetimes of millimeter particles may be longer ($\gtrsim 10^5$ yr at 1 AU) than postulated in the standard collisional models ($\sim 10^4$ yr at 1 AU), perhaps because these chondrule-sized meteoroids are stronger than thought before. Using observations of the Infrared Astronomical Satellite (IRAS) to calibrate the model, we find that the total cross section and mass of small meteoroids in the inner solar system are $(1.7\text{-}3.5) \times 10^{11}$ km^2 and $\sim 4 \times 10^{19}$ g, respectively, in a good agreement with previous studies. The mass input required to keep the Zodiacal Cloud (ZC) in a steady state is estimated to be $\sim 10^4\text{-}10^5$ kg s^{-1}. The input is up to ~10 times larger than found previously, mainly because particles released closer to the Sun have shorter collisional lifetimes, and need to be supplied at a faster rate. The total mass accreted by the Earth in particles between diameters $D = 5$ μm and 1 cm is found to be ~15,000 tons yr^{-1} (factor of 2 uncertainty), which is a large share of the accretion flux measured by the Long Term Duration Facility (LDEF). Majority of JFC particles plunge into the upper atmosphere at <15 km s^{-1} speeds, should survive the atmospheric entry, and can produce micrometeorite falls. This could explain the compositional similarity of samples collected in the Antarctic ice and stratosphere, and those brought from comet Wild 2 by the Stardust spacecraft. Meteor radars such as CMOR and AMOR see only a fraction of the accretion flux (~1-10% and ~10-50%, respectively), because small particles impacting at low speeds produce ionization levels that are below these radars' detection capabilities.

The cosmic dust input to the earth's atmosphere: how large is it?

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This paper will address a fundamental problem – the size of the cosmic dust input to the earth's atmosphere [1]. Zodiacal cloud observations and spaceborne dust detection indicate a daily input of 100 – 300 tonnes, in agreement with the accumulation rates of cosmic elements (Ir, Pt, Os and super-paramagnetic Fe) in polar ice cores and deep-sea sediments. In contrast, measurements in the middle and upper atmosphere – by radars, lidars, high-flying aircraft and satellite remote sensing – indicate that the input is only 2 - 30 tonnes.

There are two major reasons why this huge discrepancy matters. First, if the upper range of estimates is correct, then vertical transport in the middle atmosphere must be considerably faster than generally believed; whereas if the lower range is correct, then our understanding of dust evolution in the solar system, and transport from the middle atmosphere to the surface, will need substantial revision.

The second reason is that cosmic dust particles enter the atmosphere at high speeds and in most cases completely ablate. The resulting metals injected into the atmosphere are involved in a diverse range of phenomena, including: formation of layers of metal atoms and ions; nucleation of noctilucent clouds; impacts on stratospheric aerosols and O_3 chemistry; and fertilization of the ocean with bio-available Fe, which has potential climate feedbacks.

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Working with the fractal nature of a chondritic solar composition in studies of meteoric materials

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Introduction

Over the long term the material that reaches the top of the Earth's atmosphere has a chondritic composition. This situation exists because this unique composition arises at different scaling lengths of most primitive solar system materials that accreted in the solar system.

A fractal distribution of chondritic matter

The origin of the solar photosphere composition is not known. Quite remarkably it is an exact match with the composition of CI carbonaceous chondrite meteorites that are basically dried-out chunks of clay with sulfate veins from the outer part of the asteroid belt [Fig. 1] [1].

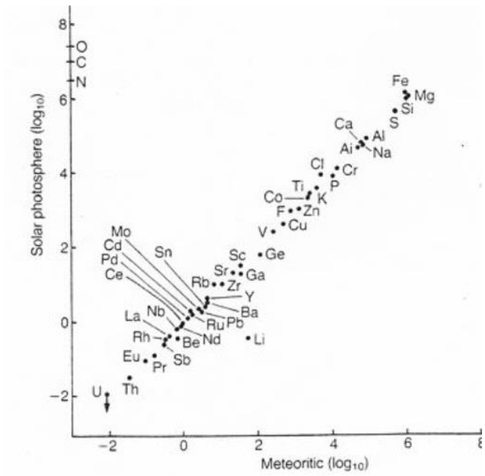

Fig. 1 Linear correlation of solar photosphere, and CI carbonaceous chondrite compositions that are H, He, O, C and N depleted [1]

It suggests that our part of the molecular cloud had a chondritic composition and that when all planets, asteroids and comet compositions are put together the result is a chondritic composition. After 4.56 Gyrs of solar system evolution mostly during the first ~10 Myrs, the bulk compositions of these objects are no longer chondritic. For example, the bulk composition of the Earth-Moon system has a low-Ca, Mg-rich olivine composition.

CI chondrite parent bodies are still around but there is a wide range of asteroid compositions as evidenced by the collected meteorites that include iron, stony-iron, achondrite (igneous), and wide variety of chondrite meteorites that originated in the asteroid belt. In the aftermath of the Stardust mission [2] it appears that Kuiper Belt comets are 'asteroid debris-on-ice'. Comet 81P/Wild 2 is chondritic for Si, Mg, Mn, Fe and Ni but not Ca and Ti, and has volatile element enrichments [3], but its loosely aggregated nanograins had a Fe- & CI-normalized chondritic composition for Mg, Al, S, Ca, Cr and Ni. This is also true for the ultrafine-grained matrix of chondritic [porous] aggregate interplanetary dust particles (IDPs) but they are Cr-free and Mn-enriched [4] [Fig. 2; dots)]. Cluster IDPs might not be chondritic aggregates.

While the calculated and observed mesospheric metal abundances are poorly matched [5], 0.2 to 3 micron meteoric aerosol particles in the lower stratosphere are chondritic for Fe, Mg, Ni, Na, Ca, K and Mn [6].

Deviations from the chondritic composition

Natural solar system processes will drive compositions away from the chondritic composition but aggregation tends to restore this ideal composition. A simple example is the measured comet Halley dust that has >CI element abundances (Fig. 2; squares);'adding' Fe-dust would shift the normalized abundances (here exaggerated; Fig. 2, triangles) to a chondritic pattern. The analyzed dust sample apparently lacked an iron nanograin suggesting this comet Halley sample was a loosely-bonded aggregate.

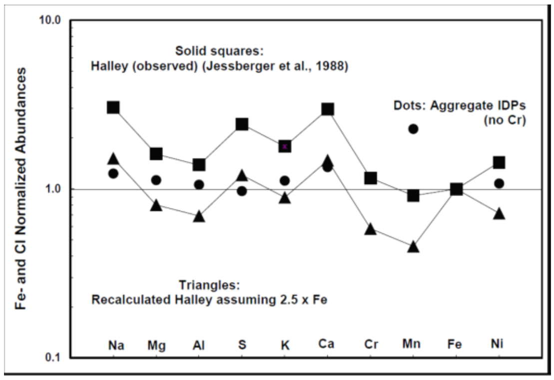

Fig. 2 Fe- & CI normalized compositions of chondritic aggregate IDPs (dots), observed (squares) and Fe-enriched hypothetical (triangles) comet Halley dust.

Conclusions

Bolides and meteors with a chondritic composition are no surprise. They are pristine matter. These same phenomena with non-chondritic compositions carry information about the chemical and physical processes in the early solar system but meteoroid size and strength will be critical.

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Physical properties of meteor shower fireballs

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Introduction

Instrumental observations of fireballs provide information on interplanetary bodies that cause them. Atmospheric behavior and heliocentric orbits can be described and measured from instrumental records of the short moment of interaction of meteoroids with the Earth's atmosphere. It is possible to describe material properties of meteoroids without studying a meteorite in a laboratory or realization of expensive return-sample space mission.

It is possible to compute heliocentric orbit for sporadic meteor but determination of its parent object is either very difficult or probably impossible. Bottke at al. published theoretical model that is able to integrate the orbital evolution of meteoroids and determine their probable source region [1] but physical properties of corresponding fireballs cannot be linked to individual objects. Identification of parent object is much easier for shower meteoroids. A statistically more significant set of similar orbits with similar atmospheric behavior indicates existence of interplanetary stream of particles that are probably remnants of asteroids or comets. Meteor shower fireballs provide information on material properties of parent bodies of meteor showers. In many cases, these parent bodies are known objects.

Source of data

The studied fireballs were observed and recorded by the same type of camera and measured and processed by the same standard procedures [2, 3]. Photographic cameras with large-format sheet film and Zeiss Distagon fish-eye objective were used [4]. Photometric mass was for studied fireballs determined by measuring of intensities on scanned copies of the films [5]. The resulting values can be compared directly.

Physical properties and orbits

Physical properties of meteor showers were studied in terms of different methods: beginning and end heights, apparent ablation coefficient, fragmentation, and dynamic pressure at the height of fragmentation or terminal flare. Photographic light curves and high-time-resolution radiometric light curves were also studied.

An example of mutual comparison of meteor showers is presented in Figure 1, where the dependency of PE coefficient on initial velocity is documented. PE coefficient describes ability of meteoroid to ablate [6] and depends on pre-atmospheric velocity and mass, and the terminal height of meteor. According to this comparison, it is possible to say which shower consists of the most fragile material and which of the hardest material.

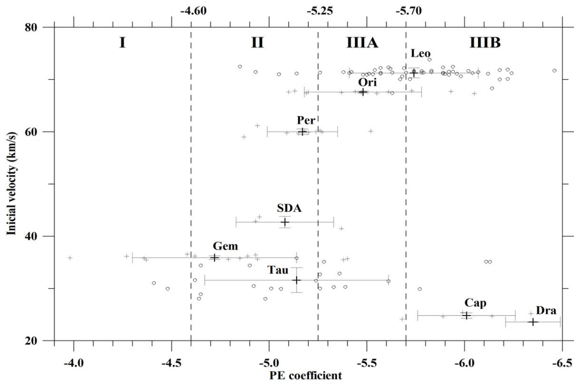

Fig. 1 Comparison of PE coefficients and initial velocities of studied meteor showers.

Draconids, α-Capricornids and Leonids have the most fragile meteoroids and Geminids and Taurids the hardest meteoroids.

From statistical point of view it is possible to study a range of values describing physical properties. From values of PE coefficients and dynamic pressures at the height of the first fragmentation it is possible to estimate heterogeneity or homogeneity of the material of individual showers. According to this assumption, the most heterogeneous material was observed for Leonids, Taurids, and Geminids. There are two possible explanations: the first is that there is more than one parent object of the showers, the second is that the parent object is heterogeneous. To distinguish between these two possibilities it is necessary to study also heliocentric orbits. On the basis of wide range of orbital elements of Taurids it is probable that the shower has more than one parent object, which was studied e.g. in [7].

We also studied physical properties and heliocentric orbits of individual showers. The most important results are e.g. discovery of a new filament of Orionids [8], detection of an altitude of 111 km as a height, where all Leonids reach absolute magnitude of about -2 mag [9], description of a method for identification of Taurid meteor on the basis of argument of perihelion and perihelion distance, or discovery of a dependency of dynamic pressure at the height of fragmentation on initial photometric mass.

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Modelling Meteoroid Streams in the Solar System

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Introduction

We are building a model to describe particles that have been recently released from a large number of periodic comets. This will allow us to calculate the properties of cometary dust streams as a function of time. The main goal of this model is to assess the impact hazard for interplanetary human spaceflight in the inner solar system (under the ESA IMEX project - Interplanetary Meteoroid Environment for Exploration). However, the model will also allow us to examine scientific questions. Existing meteoroid models, including the ESA Interplanetary Meteoroid Environment Model (IMEM) [1] and the NASA Meteoroid Engineering Model (MEM)[2, 3] are only designed to predict the static impact flux from the background interplanetary dust cloud. Our model is thus the first time- and space- dependent model for estimating the impact hazard from cometary meteoroid trails and streams in the inner Solar System (interior to Jupiter).

Modelling Cometary Dust

Cometary dust is expected to dominate the dust cloud in the inner part of the solar system. To understand the structure of this dust cloud, we must consider the location and activity of each parent comet, and the dynamics and processes that modify the dust and their orbits after emission from the comet. With this information, it is theoretically possible to model the cloud and its finer structures as a function of time.

The large number of known comets creates challenges for producing an accurate model: the JPL Small Body Database lists 548 comets under the 'Jupiter-family' classification alone. The resultant dust cloud depends on the comet orbit, its size and activity, as well as on dispersive forces of gravitational perturbations and non-gravitational effects, including radiation pressure force, Poynting-Robertson drag, and the seasonal Yarkovsky's effect. In particular, the gravitational effect of Jupiter can disperse individual particles, or 'warp' the stream. Furthermore, mutual collisions between particles in cometary streams can destroy particles, and produce smaller grains.

The Model

Our current model addresses a simplification of the above problem: we model the dust with sizes $\gtrsim 100\ \mu$m that is released from Jupiter-family, Encke-type and Halley-type comets, and that is subject to solar gravity and radiation pressure. This dust is ejected from each comet from generally within the period 1900-2100, being the range for which cometary orbital elements are generally available using the HORIZONS ephemerides system. We eject test particles uniformly from the sunlit side of the comet, at regular intervals in true anomaly within 3 AU of the Sun, and then scale the numbers of particles to reflect the dust production of the comet and an assumed mass distribution. This allows us to estimate the density and mean velocity of stream particles at a given point in space and time, within the orbit of Jupiter, and roughly within the time period 2000 to 2100.

We present details of the model, including applications to test cases 67P/Churyumov-Gerasimenko, 1P/Halley, 2P/Encke, and 55P/Tempel-Tuttle. We also discuss our plans to further develop this simple model, to include the limiting of particle lifetimes by gravitational perturbations and collisions, and the effects on the structure of the stream of close encounters with, in particular, Jupiter.

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Emission spectroscopy: clues on the continuous volatile delivery from cometary meteoroids

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Introduction

The Spanish Meteor Network (www.spmn.uji.es) has a fireball spectroscopy program to study the chemical properties of meteoroids ablating in Earth's atmosphere. By using diffraction gratings in front of state-of-the-art video systems we are able to infer chemical abundances frame to frame for the main rock-forming elements, but other important research can be done for those emission spectra that show organic bands or radicals as VIS or NIR emission bands. A general overview of current findings and the future goals of fireball spectroscopy are presented.

The relevance of emission fireball spectroscopy

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Comets and asteroids impacting the atmosphere of Earth are delivering volatile species, but the amounts of surviving water and organics are scarce if the impact geometry and velocity are not favorable for a moderate deceleration and settling of the materials in the atmosphere [1]. Their smaller fragments (so-called meteoroids) are another source of volatile materials to terrestrial planets [2-3]. Meteoric vapors leaving the meteoroid during ablation are usually at temperatures in the range of 4000-4500 K [4-7] that are reached by air plasma just behind the meteoroid. The different studies demonstrate that these vapors are in local thermodynamic equilibrium and that the majority of the spectral lines can be modeled using a simple model of chemical equilibrium. Using these ideas as a basis, were obtained the relative chemical abundances in meteor columns for a wide sample of meteoroids [6-7], that were found to be consistent with the expected mineralogy of meteoroids [8]. From spectroscopy in the visible we know that spectral lines associated with the wake are probably out of equilibrium [4-7]. On the basis of fireball spectroscopy I suspect that progressive fragmentation and catastrophic disruptions can disperse dust far from the shock wave frontal region where the bolide experiences higher temperatures. Having also in mind the effect of turbulence, the peak temperature and the exposure to heat of meteoroid fragments can be both minimized and there is room for a percentage of the body to survive, at least, as small fragments that are settling down towards the surface. This is a plausible surviving pathway for meteoroids penetrating Earth's atmosphere at moderate geocentric velocity that could explain the recovery of micrometeorites in the ground [9].

Thermal processing affects the materials subjected to ablation. Due to the collision with atmospheric gases, meteoric minerals are ablated, vaporized and dissociated. Elemental lines and molecular bands are remarkable features in bolide spectra. The later can be considered an evidence of incomplete vaporization [10-11]. In any case, it has been demonstrated that most of the fireball radiating light can be perfectly fit with a thermodynamic equilibrium model of the main rock-forming elements [4-7]. This behavior is probably a consequence of the quick mixing of air and meteoric plasma promoted by the supersonic movement, meteoroid spinning, and subsequent induced turbulence around the bolide.

Discussion and Conclusions

Meteor spectroscopy is an useful technique to infer bulk chemistry properties of cometary meteoroids. Even for a spectrum calibrated in a relative scale, having into account the right physical parameters deduced from a synthetic spectra fit, the ratio of number of atoms in the meteor column can be determined. The ablation of a meteoroid produces a characteristic rarefied flow in the upper atmosphere where the physical conditions are too complicated to simulate in the laboratory. Future spectral studies of bolides in the terrestrial atmosphere should focus in detection of water radicals and simple organics like the OH Meinel band, or the CN and N_2 bands [10-13]. CCD spectra can be also useful to detect and account for the appearance of O lines during meteoroid fragmentation as reported previously [see e.g. 12]. SPMN video spectroscopy using widely-distributed Watec cameras has been able to reach the IR until about 800 nm, being able to detect N I and N_2 contributions [14]. Column abundances measured with sequential systems can provide new clues on the delivery of organics to Earth. Simple molecules or radicals are potentially detectable, depending on their relative abundances in the meteor column. Consequently, the study of the temporal evolution in the atmosphere of meteor columns can allow us: 1) to quantify the relevance of this continuous delivery by meteoroids and, 2) to obtain new clues on relevant chemical processes probably associated with the organic enrichment of primeval Earth [3].

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The dynamics of meteoroid streamed in the solar system, and the forecasting of the meteor showers

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Because of their tiny size, the meteoroids have a unique dynamical behavior in the solar system. Being the results of an ejection or collision process, the understanding of their evolution helps us to link them with different small bodies, as well as to study the nature of the different elements in our system. We will first see a few results of the evolution of different categories of meteoroid streams in order to understand the different processes at work. An outcome of the studies of the dynamics of the meteoroid streams is the forecasting of the meteor showers. I will shortly present the few methods widely used today. After reminding us of the recent success of the forecasting of the meteor showers, we will see the limitations of the today methods. In addition, I will point out the need for advanced work on dynamics, in order to link the numerous old and new showers identified by recent surveys. Last but not least, I will present the results of the forecasting of the meteor shower for the coming years.

Jovian Impact Flashes and their Implication to Meteoroids in Outer Region of Solar System

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Introduction

Optical flashes on the surface of Jupiter were observed by amateur astronomers in June, and August in 2010, and in September 2012. These flashes are considered to be bright fireballs in the Jovian atmosphere. The meteor science developed so far in the Earth's case can be applied to such cases. There is a big difference in the impact velocity, which is almost constant. This gives us a unique opportunity to study size distribution of small bodies in this outer planet region. The present situation of Jovian optical flashes will be reviewed in this invited talk.

Example of Optical Flash

The optical flash occurred in August 2010 was observed by four amateur astronomers in Japan. The duration of the flash was about1.5 seconds, and the brightness was 6.2 magnitudes [1]. Figure 1 shows the image of the optical flash observed by Mr. M. Tachikawa. This is presumed to be an equivalent or slightly smaller scale than that in June [2]. These phenomena were bright meteors caused by the collision of small celestial bodies of a few to 10 m. The preliminary lightcurve is shown in figure 2.

Fig. 1 Optical flash detected at 18:20 UT on August 20 by Japanese amateur, Mr. M. Tachikawa.

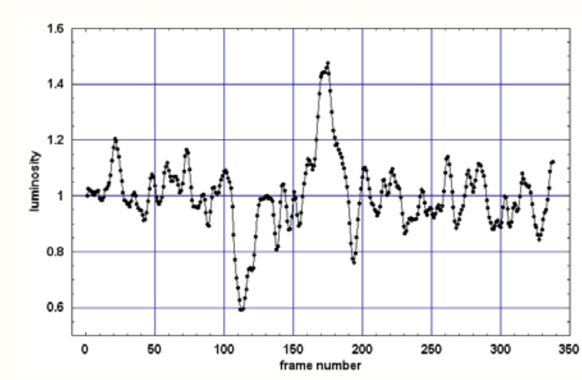

Fig. 2 Preliminary lightcurve of the flash in figure 1. One frame is 0.033sec.

Implication to the Meteoroids in Outer Region

If the frequency and the scale of these phenomena are investigated, the size distribution down to size of a few m can be estimated at around the giant planet region.
In case of Earth, the brightness of meteors depends not only on sizes but also on the entry velocity. However, in the case of Jupiter, the entry velocity becomes almost similar value (60-64km per second) which is almost independent on the impacting direction. We do not have any uncertainty for estimating size of impacting bodies from the brightness of the flashes.
On the other hand, we have large uncertainty in the size distribution of small bodies in the giant planet region [3], because we cannot see directly any bodies of less than 1 km. Therefore, if the systematic observation is achieved, it will be a unique attempt to use the giant planets as a natural detector of small bodies, and to derive size distribution of small bodies in the giant planet region.

Monitoring campaign and Development of Detection Software

For this purpose, we coordinated both professional and amateur astronomers in Japan and China, and performed monitoring campaign in September and November 2012. Unfortunately we cannot detect any optical flashes during the past campaign, we will continue similar effort. The software for automated detection is also developed by Hueso's group (Grupo de Ciencias Planetarias, UPV-EHU, Spain) which is opened at their web site http://www.pvol.ehu.es/software/.

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Insights into meteoroid ablation from simultaneous radar-video observations

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Meteor observations are often used to infer the physical properties of their associated meteoroids. However, certain determinations (such as mass) require knowing the conversion efficiencies to produce photons and electrons. While estimates have been available for many years [1], they all use different assumptions that may not be appropriate for observing faint meteors.

In this review, we first summarise past estimates of the luminous efficiency (τ_I). The ionisation theory of electron production in meteor trail formation is also briefly summarised and reasons for expecting estimates of the ionisation coefficient (β) to be more accurate than τ_I will be presented. In an effort to link these two fundamental efficiencies, we have performed simultaneous radar-video observations of $\sim$ 500 meteors using the Canadian Meteor Orbit Radar (CMOR) [3] and several Gen-III image-intensified CCD cameras. Photometry/ionisation comparisons were made to relate the radar electron line density (q) to video photon radiant power (I). The ratio q/I can be related to the ratio of conversion efficiencies β/τ_I (see Figure 1). By adopting an estimate of β [2], an independent estimate of τ_I was made (see Figure 2), which constrains mass estimates.

It was found that $7\% \pm 3\%$ of video events were simultaneously detected by the radar system. This is above the expected $2\% - 5\%$ value determined through modelling, suggesting simultaneous observations are biased towards larger, non-fragmenting meteoroids. It was also found that the majority of radar detections occur near the end of the observed video height interval, and that $\log_{10} q = \log_{10} I + (12.56 \pm 0.49)$. This leads to $M = (38.7 \pm 1.2) - 2.5 \log_{10} q$, where M is the meteor magnitude in our instrumental video bandpass corresponding to q at the radar specular point. Our determination of β/τ_I lead to a peak bolometric value of $\tau_I = 5.9\%$ at $41\,\mathrm{km/s}$. Our determined τ_I suggests that the video meteor mass scale is an order of magnitude smaller than previously thought at these higher speeds, implying that the total meteoroid mass influx between 10^{-5} and 10^{-8} kg is lower than previous studies would suggest.

The main uncertainties associated with this analysis is the unknown spectra of individual meteors which affects estimates of absolute radiant power, and uncertain values of the initial trail radius which makes estimates of q problematic.

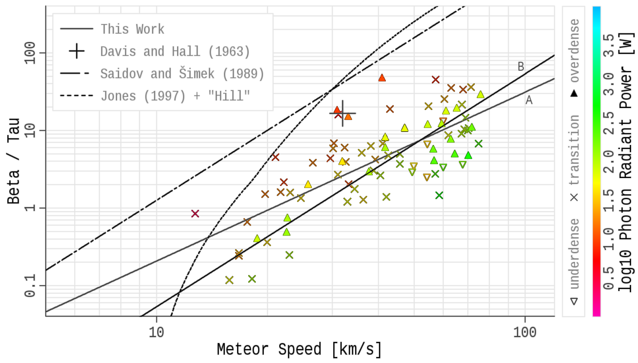

Figure 1: The ratio β/τ_I determined from observations of q/I [4]. Fit A depends only on meteor speed (v), while fit B includes dependence on the video radiant power (I).

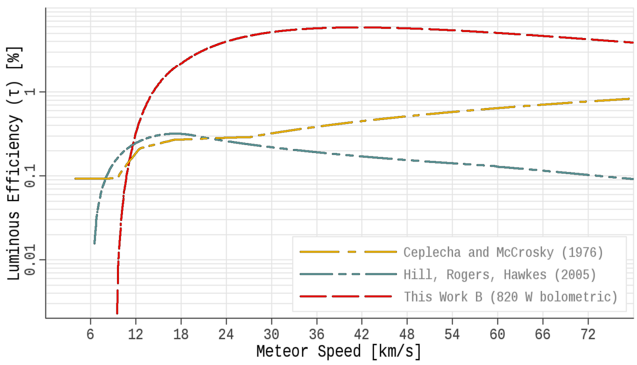

Figure 2: The determined τ_I by combining our determined β/τ_I [4] along with an estimate of β [2].

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Stream and sporadic meteoroids associated with Near Earth Objectst

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NEO's are objects that come close to the Earth's orbit. If dust is ejected from them through any process, a meteoroid stream will form which may be seen on Earth as a meteor shower.

As orbits evolve rapidly in this region of the solar system, just a similarity of orbits at the present time is not sufficient to prove a relationship, integrations are needed to show that the evolution is similar.

Characteristics of streams from a Cometary parent, where dust is ejected over a range of values of true anomaly and over several orbits will be very different, from an asteroidal formation where the ejection occurred at a single point in time. Hence a study of meteoroid streams related to NEO's may tell us whether the NEO is Cometary or asteroidal, in particular, several showers can be associated with the same stream from a Cometary origin.

Sporadic meteoroids can not be associated with a single parent body. Using several criteria, e.g. K-, Q-, we can classify them as cometary and asteroidal origin only. However, by using these criteria to the present day orbits, we don't classify all sporadic meteoroids properly. Again, integrations are needed to establish the source of their origin.

Chelyabinsk Meteorite: NEO/Meteorite Associations and the Origin in the Main-belt

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Introduction

Parent bodies of the most of major meteor showers have been identified as comets or dormant comets. On the other, it is still a matter of finding parent bodies of meteorites. 'Chelyabinsk meteorite' entered Earth's atmosphere over Russia at 03:20 UT (09:20 LST) on 15 February 2013. Approximate total impact energy of the Chelyabinsk fireball was estimated from the dominant airwave period at Infrasound frequencies to be 500 kilotons of TNT explosives (P. Brown, 2013). The estimated initial mass translated form this impact energy was approximately 10,000 tons which corresponds the diameter of approximately 20 m. The blast waves were generated between heights of 25 and 30 km. About 1,500 people were injured mainly due to broken windows the strong blast wave. Such impact events occur once per several tens of years. The population of about 99% of near-Earth Objects (NEOs) greater than 1 km diameter has been completed by NEO survey programs such as Catalina, PanSTARRS and WISE. However, 99% of NEOs smaller than ~50 m diameter have not been discovered. It is of great importance to know the origin and evolution of Chelyabinsk sized objects.

Method and Results

The Southworth-Hawkins (1963) D_{sh} criterion was used to quantify the similarity between current known NEOs and the orbital elements of Chelyabinsk fireball (Borovicka et al. CBET 3423, 2013). The same criterion was adopted for current known fireball orbits. Apollo asteroid *2011 EH* and a meteorite fireball (1996/Oct/8.248) were identified as possible associations. This fireball was observed by the Prairie network (1963-1975) at the mid-western, USA. The Chelyabinsk orbit has another intersection with the Earth at the end of September – beginning of October.

$$[D_{sh}]^2 = (e_2 - e_1)^2 + (q_2 - q_1)^2 + \left(2\sin\frac{I_{21}}{2}\right)^2 + \left(\frac{e_2+e_1}{2}\right)^2\left(2\sin\frac{\Pi_{21}}{2}\right)^2, \text{ where}$$

$$I_{21} = \cos^{-1}[\cos i_1 \cos i_2 + \sin i_1 \sin i_2 \cos(\Omega_2 - \Omega_1)],$$

$$\Pi_{21} = \omega_2 - \omega_1 + 2\Gamma \sin^{-1}\left(\cos\frac{i_2 + i_1}{2} \sin\frac{\Omega_2 - \Omega_1}{2} \sec\frac{I_{21}}{2}\right),$$

$$\Gamma = \begin{cases} +1, |\Omega_2 - \Omega_1| \le 180^\circ \\ -1, |\Omega_2 - \Omega_1| > 180^\circ \end{cases}$$

However, it is surprisingly difficult to prove that similar orbits are statistically significant within a near-Earth population. I checked the statistically significant level using a method modified from Schunova et al. (2012) based on Fu et al. 2005 and Gladman 2005.

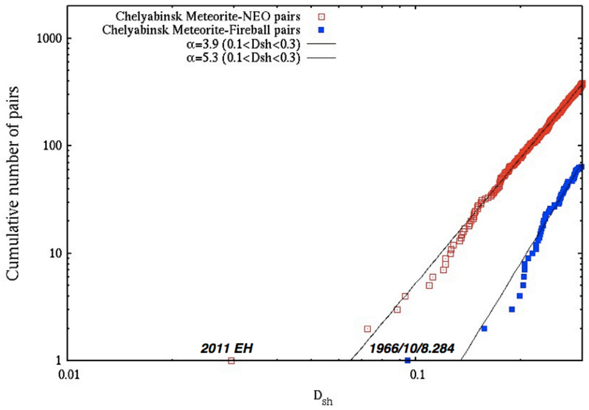

Fig. 1 Red open-squares represent *Dsh* criteria between Chelyabinsk meteorite and current known NEOs (number of ~10,000 as of May 2012). Blue filled-boxes represents *Dsh* criteria between Chelyabinsk meteorite and meteorite fireballs represents. Fitted lines show random fluctuations between pairs of objects.

Fig.1 indicates that a *2011 EH* and a fireball (*1966/10/8.284*) look outliers further away from random fluctuations both in NEO and fireball populations. The analysis result of statistical significant level will be shown in the presentation.

On the other hand, Bottke et al. model (2002) enabled to compute that a Chelyabinsk fragment had a 90%probability to have been reached the Earth collision orbit that escaped through the ν_6 resonance, a 10% probability through the 3:1 mean-motion resonance with Jupiter. This result is consistent in explaining of the origin of Chelyabinsk meteorite (LL5 chondrite) evolved from the most inner-main-belt region where chondritic asteroids are dominant. Further investigation of orbital evolution will be discussed in the presentation.

Table 1 NEO and Fireball associated with Chlyabinsk meteorite and their values of *Dsh* criterion. Note that meteor showers could be established by *Dsh* criterion whose value are less than 0.2

	D_{sh}
2011 EH	0.0295
1966/10/8.284	0.0946

Table 2 Orbital elements of Chelyabinsk meteorite and it's possible associations, Apollo asteroid *2011 EH* and a meteorite fireball on Oct 8.284, 1966. Note that U is unperturbed geocentric speed just prior to impact, and (θ,φ) is direction of radiant in a Earth moving frame.

	a	*e*	*i*	*ω*	*Ω*	*u*	*θ*	*φ*
Chelyabinsk Meteorite	1.55	0.5	3.6	109.7	326.41	0.45	81.00	-81.37
2011 EH	1.4793	0.4856	2.3500	96.60	339.18	0.45	81.97	-84.34
1966/10/ 8.284	1.626	0.524	2.1	69.9	15.0	0.46	79.38	-84.98

On the Age and Formation of the Quadrantid Meteoroid Stream

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Introduction

The Quadrantids are among the most active of the major meteor showers, having a peak ZHR $\sim$ 130 [1]. The stream has been recently linked with asteroid “2003 EH1“ [2].
The Quadrantid shower is unusual among streams presently visible at the Earth. First, the Quadrantid meteor shower has a very short duration in its core activity (about 0.3 days [1]) with overall duration of $\sim$ 4 days, implying that it is very young. Secondly, it has only become active in recent times, being first reported in 1835 [2]. Moreover, the activity of the shower has changed dramatically over the last 150 years, from a very weak shower to among the strongest visible at the Earth [3]. Presently 2003 EH1 is in a short-period comet-like orbit (with a Tisserand parameter with respect to Jupiter of T_J=2.065) but shows no evidence of cometary activity, suggesting that it is a strong candidate for either a recently dormant or extinct comet.

The purpose of this work is to estimate the probable age of the presently observable Quadrantids; specifically to constrain the probable epoch that meteoroids of varying masses were released by the parent body and their mode of ejection (i.e cometary activity or some form of break-up of the parent). Our approach is to use high precision orbital data from individually recorded Quadrantids together with explicit error estimates of their original state vectors to backward integrate a suite of probable orbits per event to compare with the parent orbit over time. Under the assumption that the stream was formed recently relative to the Lyapunov spreading time of the orbit, we aim to statistically link individual backward integrated orbits to specific epoch and modes of ejection from the parent. This approach follows closely that presented earlier for the Geminids by [4] and [5].

For our data, we use seven high-precision Quadrantid fireball orbits (observed by the European Network) appropriate to hundred gram - kilogram masses. At gram-sizes we make use of photographic data from the Harvard Super-Schmidt cameras [6]. Finally, we have also extracted several tens of the highest quality radar Quadrantids, sampling the stream at milligram masses, as observed by the Canadian Meteor Orbit Radar (CMOR) during 2013.

Previous numerical simulations have been carried out by several authors in order to address the origin of the Quadrantid stream. [7] investigated the secular perturbation on the Quadrantids by Jupiter over a timescale of 5000 years in the past. The authors concluded that the stream was $\sim$ 4000 years old. More recently, [8] used precisely reduced orbital data of Quadrantid meteoroids, acquired by means of photographic and video observations. The authors concluded that the stream must be $\sim$ 500 years old in order to explain the distribution of the present orbital elements and the width of the stream. [9] carried out a numerical simulation of orbits of Quadrantids, ejected in 1800 AD from 2003 EH1, and concluded that the core of the Quadrantid meteoroid stream is approximately two-hundred years old.

In this study, we sample the error distribution of our selected Quadrantid orbits, creating a large number of ”clones” (normally distributed in the six-dimensional phase space, composed of the six orbital elements) for each individual orbit. The clones are then integrated backwards in time along with the orbit of 2003 EH1 for one-thousand years. We look at the evolution of the minimum orbit intersection distance (MOID) between all clones and 2003 EH1 as a function of time. Moreover, we also calculate the relative velocity between the parent and the sampled meteoroids at the MOID and then compare them to possible ejection velocities of meteoroids from a comet by means of cometary sublimation. The most probable age for ejection for each meteoroid can then be estimated from a statistical point of view using MOID as an initial metric. Furthermore, we investigate the range of mean anomalies for the meteoroids at the MOIDs with the orbit of 2003 EH1. The purpose of this, is to determine the most probable ejection position on the parent’s orbit, which in turn may also suggest a formation mechanism. Our preliminary results suggest that the Quadrantid fireball-producing meteoroids were ejected about two-hundred years ago (assuming 2003 EH1 is the parent). In this talk we will discuss the results of these integrations with emphasis on probable formation mechanisms and formation epoch for the stream.

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An enhanced survey for meteor shower outbursts using the Canadian Meteor Orbit Radar (CMOR)

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The Canadian Meteor Orbit Radar [1,2,3] has been surveying meteor showers for more than a decade. In earlier studies [2,3], we identified long-lived annual showers using backscatter radar measurements of individual meteor echoes and their associated orbits applying variations of a wavelet-based search strategy sensitive to clustering of radiants (showers) in ecliptic sun-centred coordinates.

In this work we search for short-lived outbursts in shower activity. Our dataset is substantially larger than in earlier studies, totaling more than 6 million individually measured orbits, more than double our previous survey size reported in [3]. The large increase in measured orbits is due to the decadal timescale of the present survey, an upgrade in the transmit power of CMOR in early 2009 and refinement in our interferometry rejection algorithm.

To search for outbursts in our data we examine wavelet maxima in single solar longitude bins for every year of the CMOR survey. We then try to link each maxima with a known shower using a new shower linkage technique and adoption of a more complete estimate of background contamination levels than used in earlier works. The new method of computing background levels includes both statistical fluctuations and the physical background averaged throughout the year for a particular sun-centred radiant position; this approach has allowed us to improve our sensitivity in both locating individual local 3D wavelet maxima and linking them together as probable showers, either new or previously reported.

In most years >90% of all strong maxima are clearly associated with a previously identified CMOR shower. For the remaining unlinked maxima, each potential radiant was manually examined. In many cases it was found that the maxima were likely associated with a known CMOR shower, but slightly outside our chosen linkage values or found to be noise based on extended radiant area or location in the densest parts of the major sporadic sources. CMOR detects 1-2 true outbursts per year on average. Some of these probable shower outbursts we find are linked to streams given in the IAU Meteor Shower Catalogue, but not previously reported in [3].

Among the shower outbursts found in our survey were the Daytime Craterids in 2003 and 2008, linked to C/2007 W1 (Boattini) and the Andromedid outburst in 2011 both of which have been previously analysed based on CMOR data [4,5]. Of the other identified shower outbursts, the October Draconids and June Bootids were known to have produced outbursts in 2004 and 2005 respectively [6,7] - it is reassuring that these were clearly detected in our outburst survey.

More surprisingly is the detection of an outburst from the October Camelopardalids on Oct 8, 2003. This shower was first reported [8] from video data collected on Oct 5, 2005. That outburst was rich in bright meteors, showing a low population index; it was not detected by CMOR in that year (even to a lower threshold of 3σ relative to the background), consistent with the apparent lack of radio activity at the time of the outburst as noted in [8]. Our radiant lies ~8° from the radiant given in [8] and the detection is only slightly above the 8σ threshold. Nevertheless, more than 120 radiants are found within a few probe sizes of this point, so the statistics are good and we rate this a very probable pre-discovery outburst detection of this shower associated with a nearly isotropic or Halley-type comet.

One noticeable outburst is unlinked and unreported, having occurred on Aug 29, 2007 from a radiant at α_g=292.1° and δ_g=60.5° with V_g=28 km/s. The orbit suggests linkage with a nearly isotropic or Halley-type comet.

Three outbursts were identified with showers reported in the IAU working list of streams but not in [3]. On June 24, 2006 a very noticeable, compact, far southern cluster of radiants appeared only for one day at α_g=286.2°, δ_g=-19.1° with V_g=31 km/s. Given the uncertainties in the radiant catalogues this could be either the N or S. Sigma Sagittariids (SSS/NSS), though the time of maximum and radiant are a slightly better fit to the N. branch.

Finally, the July Gamma Draconids show a strong enhancement in our data on July 28, 2009 at α_g=281.8°, δ_g=49.6° with V_g=28 km/s. Though this shower was first reported in video observations [9] from 2007-2008, we find no annual activity or noticeable activity above our outburst threshold in any other year except the outburst in 2009.

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Radar observations of the Daytime Arietid meteor shower by the Canadian Meteor Orbit Radar.

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The Daytime Arietids meteor shower is among the strongest showers currently visible from the Earth. As a daytime stream, its properties are generally only measureable by radar techniques. Most of our understanding of this stream derives from radar studies more than half a century old, [1]; modern radar systems have considerably greater capabilities for meteor shower characterization, [2].

Here we present the results from two years of radar observations of the Daytime Arietid meteor shower using the upgraded Canadian Meteor Orbit Radar (also called CMOR II) during the years 2012 and 2013. Since its last upgrade in mid 2009, CMOR II has doubled its transmission power to 15 kW, featuring an extended size range with 6 remote stations routinely measuring 5000-6000 meteoroids orbits each day. The aim of this study is to better characterize the Daytime Arietid meteor shower at sizes ≥ 500 μm, by measuring the shower radiant position and drift, pre-atmospheric speed, mass index and orbital elements of the Arietids. At the time of the shower peak, CMOR II measures in excess of 500 Daytime Arietid orbits per day, with some 5000 Arietid orbits recorded over the entire active period of the shower in both 2012 and 2013.

By definition, meteor showers should all have geocentric radiants clustering near a single value in the ($\lambda_g - \lambda_\odot$, β_g,V_g) space at a given time. Here λ_g is the ecliptic longitude of the geocentric radiant, $\lambda_\odot$ is the solar longitude at that given time, β_g the ecliptic latitude of the geocentric radiant and V_g the geocentric velocity. To quantitatively measure meteor shower radiants, CMOR II implements a 3D Mexican hat wavelet transformation to find clustering in this geocentric radiant and velocity space, [3], see Figure 1. For this study we have implemented a new approach to automatically find the optimum probe sizes for the wavelet transform, improving the signal-to-noise-ratio of our detections. This study provides us with a suitable template to analyze other daytime showers, while allowing us to take full advantage of CMOR II capabilities.

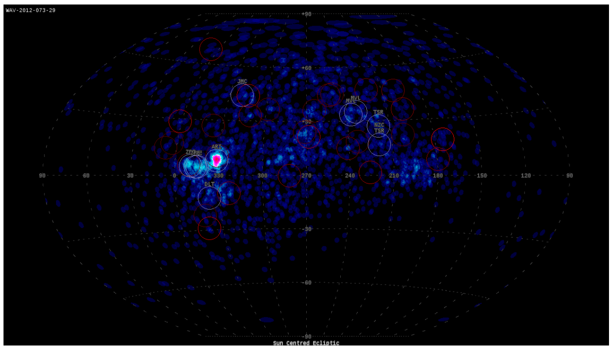

Figure 1: CMOR II radiant plot for $\lambda_0 = 73°$ in 2012. The plot is in sun-centred ecliptic coordinates, with the apex in the centre of the plot and the sun at (0,0). On this date (June 3, 2012) several showers are identified as active with the most notable, the Daytime Arietids (ARI), clearly seen at the center left of the image. Each dot represents a single measured radiant; the size of the individual radiants approximately reflects measurement uncertainty.

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Modelling of meteoroids at high resolution

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Meteoroid ablation models are often used with meteor light curves and/or deceleration measurements to investigate meteoroid properties, like density and fragmentation. One of the main difficulties in meteoroid ablation modelling is the abundance of free parameters, which makes it difficult to tell if a good match to the data indicates a true representation of the meteoroid properties. The nature of the fundamental constituent grains of meteoroids is of great interest, because of their links to the composition of their parent asteroids and comets.

Ten meteors observed by the Canadian Automated Meteor Observatory (CAMO) were used to test two models of meteoroid ablation. The image intensified video CAMO system records light curves and deceleration in wide field cameras in the standard way, but also uses a guided mirror system to observe the meteors with a resolution of up to 3 meters per pixel. The wide field data was modelled using a thermal disruption model, where the constituent grains of a meteoroid are released when the surface reaches a specific temperature [1], and a thermal erosion model, where grains are released from the surface of the meteoroid in a predetermined height interval [2]. Both models also predicted the brightness profile of the meteoroid, based on the spreading of the grains.

The two models produced satisfactory fits to the wide field data, but both were poor at predicting the narrow field brightness profiles of meteors. In nearly every case, both models overestimated the spread in the meteor brightness significantly. Models of meteoroid fragmentation require significant improvement; the constraints provided by CAMO observations will help to develop more realistic ablation models.

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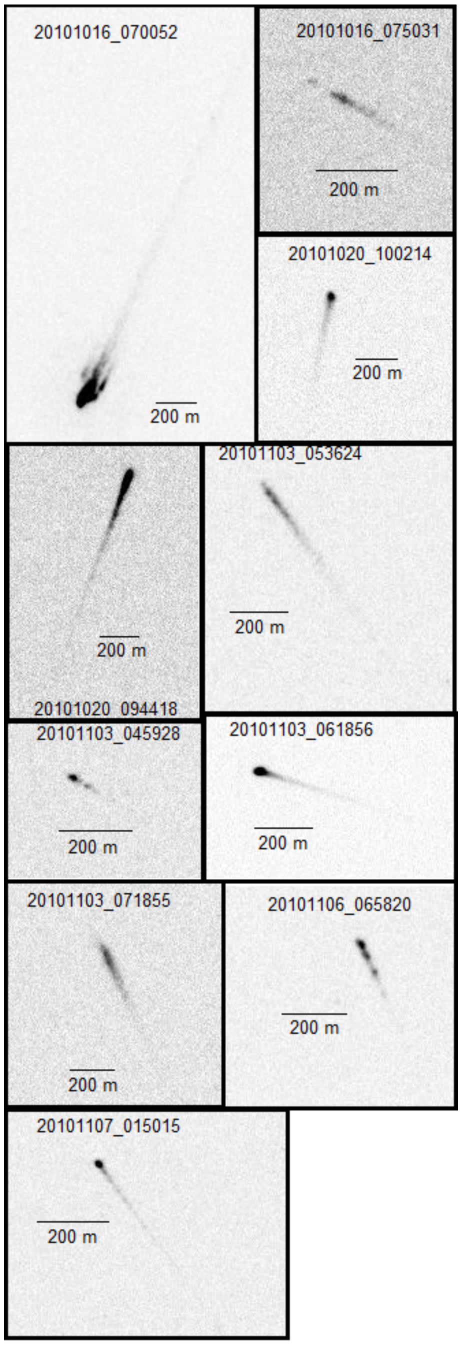

Figure 1: Ten meteors observed with the CAMO system, used to test models of meteor ablation.

The rotation of cometary meteoroids

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Introduction

The basic physics of a meteoroid ejection from comets have been well described since the work of Whipple [1]. The index of size distribution, ejection velocities and the mass of largest ejected particles and other quantities have been determined for many meteoroid showers. However, the rotation of meteoroids after the ejection has not been studied up to now. The presented numerical model describes the rotation of irregularly shaped meteoroids due to the action of gas escaping from the nucleus of a parent comet. Estimation of rotation parameters allows better understanding of some other aspects of physics of these bodies, e.g. the role of radiative effects on their orbits or origin of the meteoroid clusters [2].

The model

The solar heating causes the sublimation of ice on a cometary nucleus. The resulting gas flow blows the embedded particles away. If the particle has an irregular shape with a certain amount of "windmill asymmetry", the gas flow is also able to spin it up. In the model, the meteoroids are represented by polyherdons with several thousands of triangular facets. The shape models are derived from Gaussian random spheres or from digitized shapes of weak sedimentary rock fragments. The force and torque acting on each facet depends on gas velocity v and density ρ, which can be determined according to [3]. The total force and torque is computed as a sum over the whole surface of meteoroid. Gravitation is also taken into account. For a cometary nucleus at given heliocentric distance, the motion of a set of randomly oriented meteoroid shapes is computed. The computation starts at the surface of the nucleus and terminates at the distance of 25 radii of the nucleus. Equations of translational and rotational motion are solved numerically by four-order Runge-Kutta method.

Results

Up to now, the results for Taurid meteoroids represented by a set of Gaussian random spheres of sizes ranging from millimeters to meters have been finalized. The results can be summarized as follows:

- The median of the rotation frequencies f depends on meteoroid size D as

$$f[\mathrm{Hz}] \simeq 0.03\,(D[\mathrm{m}])^{-1.24}\,. \quad (1)$$

  An example of distribution of rotational frequencies of 1-cm Taurid meteoroids can be seen in Fig.1.

- The ratio of rotational and translational energy of ejected meteoroids E_{rot}/E_{tr} ranges from $\sim 10^{-6}$ for millimeter-sized particles to $\sim 10^{-5}$ for meter-sized bodies.

- Most of the meteoroids tumble. The degree of tumbling can be described by mean angle ε between a principal inertia axis and spin axis. It was found, that ε slightly increases with decreasing meteoroid size from $\sim 28°$ for 1-m bodies to $\sim 35°$ for millimeter particles.

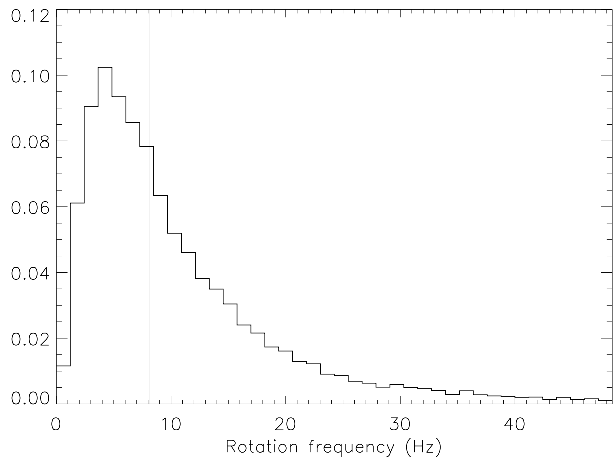

Figure 1: The distribution of the spin rates for 1-cm Taurid meteoroids ejected in the perihelion. The median (denoted by vertical line) is ~ 8 Hz.

In the talk, I will present also the results for meteoroids of Leonid and Perseid showers, which are being currently computed, as well as the results for meteoroid shape models derived from 3D laser scanning of rock fragments. Differences between these showers, the role of the proper choice of shape models and further evolution of the spin due to radiative effects will be discussed.

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The meteor showers of cometary asteroid (192642) 1999 RD32

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Introduction

The Near Earth Asteroid (192642) 1999 RD32 had previously been suggested as a parent body of the weak Northern Delta Leonids (IAU code NDL) and Daytime gamma Leonids (IAU code GLE) meteor showers (eg [1]) and also as a probable extinct or dormant cometary nucleus in near-Earth space [2, 3]. Recent observations [4, 5] showed it to be a large (∼5km), bi-lobed low albedo slow rotator ($P_{\rm rot}$ ∼17h), thus strengthening the case for this object being a former comet.

Investigation and Results

To examine further the relationship between this NEA and the meteor showers, we have carried out many-particle simulations of meteoroids ejected from 1999 RD32. We find that these yield two meteor showers at the Earth, one at SolLon=347±4 deg with radiant coordinates RA=168±2 deg, DEC=14.0±0.5 deg and geocentric velocity V_g=22.8±0.7 km s^{-1} and the other at SolLon=154±3 deg, RA=155±2 deg, DEC=1.5±1.0 deg and V_g=22.5±0.5 km s^{-1}. The former shower bears a striking resemblance to entry NDL (SolLon=334.7 deg, RA=168 deg, DEC=+17 deg, V_g=20.1 km s^{-1}) while the latter resembles GLE (SolLon=148.7 deg, RA=139.9 deg, Dec=+12.4 deg, V_g=19.6 km s^{-1}) within the IAU working list of meteor showers [6] where 1999 RD32 is cited as the suspected parent.

The observed offset in solar longitude is likely due to the formation of the stream well before the epochs sampled by the numerical simulations when the NEA was still actively populating it with meteoroids. The new observational information on the physical properties of this object, in combination with our simulations, confirm the association between this NEA and the meteor showers and highlight an opportunity to study an extinct/dormant cometary nucleus through its meteor activity at the Earth.

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Dynamical Modelling of Meteoroid Streams

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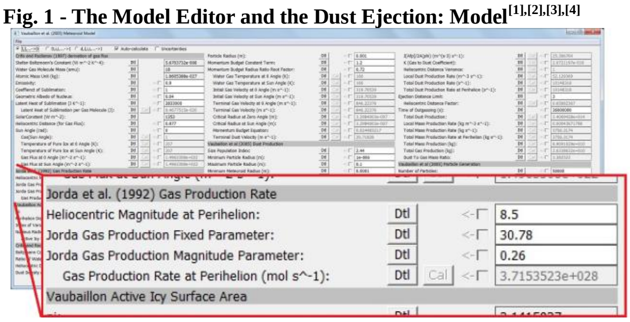
Accurate simulations of meteoroid streams permit the prediction of stream interaction with Earth, and provide a measure of risk to Earth satellites and interplanetary spacecraft. Current cometary ejecta and meteoroid stream models have been somewhat successful in predicting some stream observations, but have required significant assumptions and simplifications. Extending on the approach of Vaubaillon et al. (2005)[1], we model dust ejection from the cometary nucleus, and generate sample particles representing bins of distinct dynamical evolution-regulating characteristics (size, density, direction, albedo). Ephemerides of the sample particles are integrated and recorded for later assignment of weights based on model parameter changes. To assist in model analysis we are developing interactive software to permit the "turning of knobs" of model parameters, allowing for near-real-time 3D visualization of resulting stream structure. Using the tool, we will revisit prior assumptions made, and will observe the impact of introducing non-uniform cometary surface attributes and temporal activity.

The software uses a single model definition throughout model verification, sample particle bin generation and integration, and analysis. The tool supports adjustment with feedback of both dependent and independent model values, with the intent of supporting multivariate analysis. Propagations of measurement uncertainties are tracked rigorously throughout. We maintain a separation of the model itself from the operations of model definition, parameter manipulation, and real-time analysis and visualization. Therefore we are able to quickly adapt to fundamental model changes.

Fig. 1 - The Model Editor and the Dust Ejection: Model[1],[2],[3],[4]



The process of modelling begins with the definition of a model and selection of initial parameters (Fig. 1). We then generate a large cloud of frequency-unweighted particles varying in size, density and albedo, emitted at various velocities from the nucleus in a uniform distribution (Fig. 2). Multiple perihelion passages are modeled. The ejection position/velocity vectors, sun-angle, size and density of each particle is stored for later frequency manipulation. Each particle is integrated over hundreds of years, with ephemerides stored at sufficiently small time intervals as to permit accurate interpolation of positions at arbitrary epochs. The simulated particle stream is visualized for analysis of stream dynamics (Fig. 3) and Earth orbit intersections (Fig. 4). The particle frequency weightings are manipulated, driving near-real-time visualizations of meteoroid stream structure change. The entire process may be repeated at infinitum, introducing surface dynamic model variations, cometary nucleus rotation, non-homogeneous surface characteristics, and nucleus shape models.

Fig. 2 - 3D simulation of particle emission, with particle attribute-based colouration.

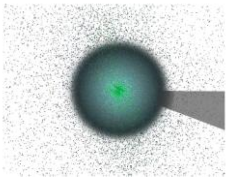


Fig. 3 - 3D representation of particle ephemerides, updated near-real-time based on model parameter changes.[5]

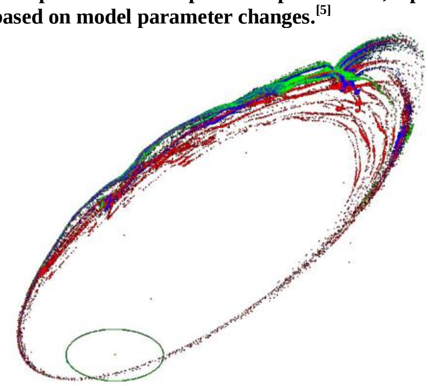
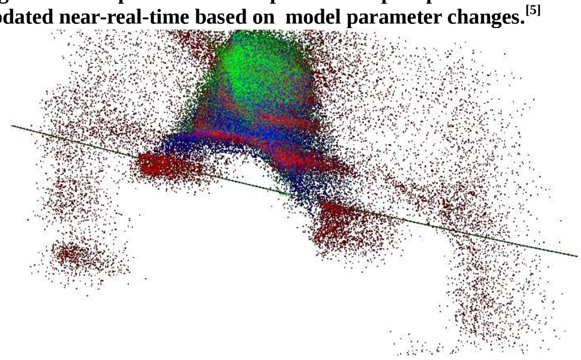


Fig. 4 - 3D representation of particle ecliptic plane intersections, updated near-real-time based on model parameter changes.[5]



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[027]

The NASA Fireball Network

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Introduction

In the summer of 2008, the NASA Meteoroid Environments Office (MEO) began to establish a video fireball network, based on the following objectives:

1) Determine the speed distribution of cm size meteoroids
2) Determine the major sources of cm size meteoroids (showers/sporadic sources)
3) Characterize meteor showers (numbers, magnitudes, trajectories, orbits)
4) Determine the size at which showers dominate the meteor flux
5) Discriminate between re-entering space debris and meteors
6) Locate meteorite falls

In order to achieve the above with the limited resources available to the MEO, it was necessary that the network function almost fully autonomously, with very little required from humans in the areas of upkeep or analysis. With this in mind, the camera design and, most importantly, the ASGARD [1,2] meteor detection software were adopted from the University of Western Ontario's Southern Ontario Meteor Network (SOMN), as NASA has a cooperative agreement with Western's Meteor Physics Group. 15 cameras have been built, and the network now consists of 8 operational cameras, with at least 4 more slated for deployment in calendar year 2013. The goal is to have 15 systems, distributed in two or more groups within the United States. The cameras send their data to a central server for storage and automatic analysis; every morning, this server also automatically generates an email and a web page (http://fireballs.ndc.nasa.gov) containing an automated analysis of the previous night's events. This analysis provides the following for each meteor: UTC date and time, speed, start and end locations (longitude, latitude, altitude), radiant, shower identification, light curve (meteor absolute magnitude as a function of time), photometric mass, orbital elements, and Tisserand parameter. Radiant/orbital plots (figures 1 and 2) and various histograms (figure 3) are also produced. After more than four years of operation, over 5,000 multi-station fireballs have been observed, 3 of which potentially dropped meteorites. A database containing data on all these events, including the videos and calibration information, has been developed and is being modified to include data from the SOMN and other camera networks.

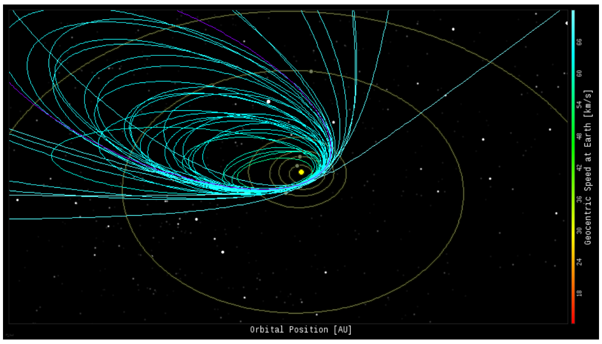

Fig. 1 eta Aquariid orbits observed by the network in 2013.

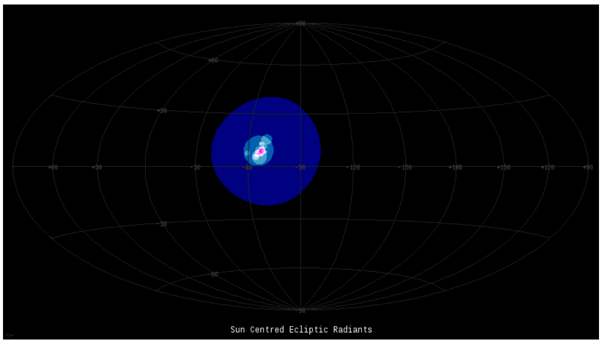

Fig. 2 eta Aquariid radiants observed by the network in 2013.

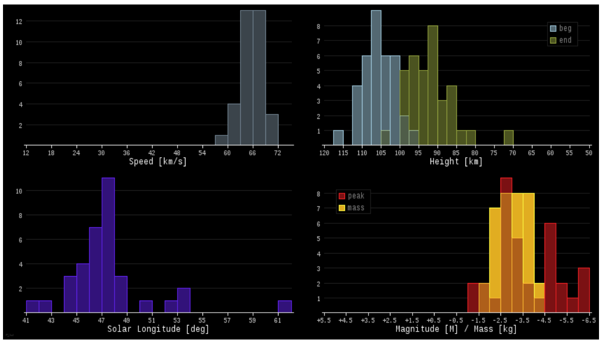

Fig. 3 Basic statistical data on eta Aquariid observed by the network in 2013.

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Studying ablation of the Chelyabinsk superbolide using a Runge-Kutta algorithm

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Introduction

We have started a program to study the dynamical properties of meteoroids ablating in Earth's atmosphere. By using classical approaches about the drag and mass loss equations we developed a Runge-Kutta algorithm capable to provide valuable ablation and bulk physical parameters of recorded fireballs. Using this approach, some results on the deceleration and relative mass loss of the Chelyabinsk superbolide occurred on Feb. 15th, 2013 are presented.

Chelysbinsk data

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The Chelyabinsk superbolide entered in the atmosphere at ~68,000 km/h and according to the DoD satellite images and infrasound data the maximum brightness occurred at an altitude of 23.3 km with a velocity of 18.6 km/s [1]. Fortunately, many casual videotapes of the bolide trajectory from the ground were obtained due to the nowadays common dash-cams available in private cars. According to the videotapes available it is possible to study this event as never before, and allowed the reconstruction of the heliocentric orbit in record time [2-4].

The possibility of studying superbolides as the one occurred in Chelyabinsk is a very attractive milestone to be considered. The software that is being developed by first author in the framework of his master thesis has being tested successfully for several cases discussed in [5] and also using events from the 25 video and all-sky CCD stations set up over the Iberian Peninsula by the SPanish Meteor Network (SPMN).

Technical procedure.

The motion and the ablation of a non-fragmentating meteoroid during atmospheric flight can be described by the drag and mass loss equations presented by Bronshten [6]:

$$\frac{dv}{dt} = -K \cdot \rho_{atr} \cdot m^{-\frac{1}{3}} \cdot v^2 \qquad (1)$$

$$\frac{dm}{dt} = -\sigma \cdot K \cdot \rho_{atr} \cdot m^{\frac{2}{3}} \cdot v^3 \qquad (2)$$

Many authors suggest that these equations cannot be used for cases where abrupt fragmentation takes place. However they can be applied in different parts of the trajectory where no disruption happens. We have tried to do that for the ending part of Chelyabinsk trajectory, just after the main fragmentation. From the dash-cam casual videotapes we reconstructed the trajectory, velocity and altitude of the superbolide. We have used the equations (1) and (2) to reproduce possible solutions adjusting the values of σ and $K \cdot m_o^{-1/3}$ the ablation coefficient and the product between the mass and the shape-density coefficient respectively in a similar way was performed previously [7]. To perform the integration of the ordinary differential equations the Runge-Kutta method has been used with a stepsize of 150 m. Fig.1 shows the direct result obtained by the equation of the velocity as function of the altitude the curve is the closest solution to the data points (cercles) that are velocity measurements from a videotape analysis made by Esko Lyttinen

Conclusions

Satellite and ground-based data supports that the maximum brightness occurred at an altitude of 23.3 km. It fits the maximum mass loss rate found by our dynamic model at an altitude of 23.5 km. We also got different parameters characterizing the dynamic behaviour of Chelyabinsk superbolide in the lower part of its atmospheric trajectory. For example, our Runge-Kutta model predict nicely the main observed characteristics of this superbolide, and provides an averaged ablation coefficient σ=0.034 s^2 km^{-2} inside the range expected for bright bolides [5].

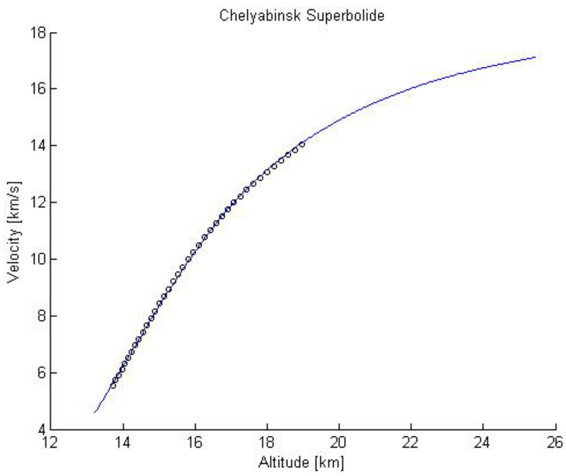

Fig. 1 Measured velocity of the Chelyabinsk bolide (dots) in the lower part of its trajectory and the obtained Runge-Kutta fit.

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[029]

The MEMIN Research Unit: laboratory impact cratering experiments into geological materials (sandstone, quartzite, tuff)

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Introduction

Impact cratering is the most important process that shapes planetary surfaces in the solar system. While analysis of impact structures by remote sensing techniques or field work provides data of the final "product", impact cratering experiments allow to observe, measure, and control the impact process itself: (i) Chemical and petrophysical parameters of the target material and the projectile are constrained. (ii) Experimental parameters such as mass and velocity of the projectile are known and can be varied. (iii) High-speed cameras allow real-time observations of contact, excavation and ejection processes. (iv) Ejecta can be collected with high spatial resolution, and these data can be combined with high-speed videos that trace the ejecta path. (v) The experimental craters and catched ejecta can be analyzed in an unaltered, uneroded state. (vi) Post-mortem analysis of shocked "fresh" target material is possible in a defined spatial context. This was the background and the rationale to set-up in Germany the delocalized research unit MEMIN (Multidisciplinary Experimental and Modeling Impact Crater Research Network) [1].

MEMIN

The MEMIN project is aimed to comprehensively quantify impact processes by conducting stringently controlled experimental impact cratering campaign on the meso-scale with a multidisciplinary analytical approach. As a unique feature we use two-stage light gas accelerators at the Fraunhofer-Inst. EMI, Freiburg (http://www.emi.fraunhofer.de/), that are able to produce impact craters in the decimeter size-range in solid rocks. The major results of the first three-years funding period have recently been published in a special issue of METEORITICS & PLANETARY SCIENCE [2].

In total, we have carried out 24 experiments at the facilities using spherical projectiles of steel, aluminum, and the iron meteorite Campo del Cielo. Projectile diameter was ranging from 2.5 to 12 mm, projectile mass was between 0.0224 and 7.34 g, and impact velocities were ranging from 2.5 to 7.8 km/s, yielding impact energies ranging from 830 to 42,627 J. Targets were solid SiO_2-rich rocks, namely sandstone, quartzite and tuff with a well-defined porosity. To constrain the effect of pore water, the target blocks were either dry or saturated with water. In the experimental setup, high speed framing cameras monitored the impact process. In order to complement the cratering experiments, we have performed planar shock recovery experiments and material test on the target materials. Most important, however, was and is the development and refinement of numerical simulations that are used to understand details of the cratering process.

Key results

① Porosity of the target matereial exponentially reduces crater volumes (Fig. 1) and cratering efficiency, yields increasing crater depth, and flattens ejecta angles (Fig. 2). P-wave velocity in sandstones is locally reduced by 18%.

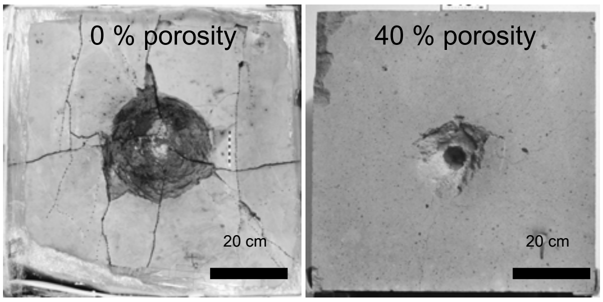

Fig. 1. Experimental craters in quartzite (left) and tuff (right).

② Pore space saturation with H_2O yields a 400% increase in crater volume, steeper ejection angles, higher ejection velocities (Fig. 2), and a faster growth of the transient crater; pore space crushing is minimized.

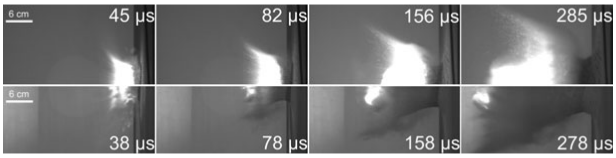

Fig. 2. Evolution of ejecta in an experimental with dry (upper) and wet sandstone as target (lower).

③ Analysis of projectile remnants, and mixed projectile – silicate target melts recovered from the ejecta catcher shows that the Fe of the projectile is preferentially partitioned into target melt over Ni and Co. This data has some consequences in the attempt to identify the projectile type in terrestrial craters via analysis of the so-called meteoritic component.

Outlook

In a second MEMIN period we plan to continue our systematic parameter study of experimental cratering but will include different target types, i.e., carbonates and layered material, with the final goal to create tools that allow extrapolation of the numerical models from the laboratory crater scale to real terrestrial craters.

Acknowledgements The MEMIN program is supported by the DFG (Research Unit FOR-887).

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A new model describing the orbits and absolute magnitudes of near-Earth objects

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Introduction

We construct a new model of the near-Earth-object (NEO) population which describes the debiased orbit and absolute-magnitude distributions of these objects. The model is developed using the same basic approach as the so-called Bottke model [1], but is based on more realistic NEO source regions, more accurate orbital integrations, improved estimations of the observational bias, and about 40 times more known NEOs to calibrate the model.

Efficiency equation

The approach we use can be described by the so-called efficiency equation:

$$n(a, e, i, H) = B(a, e, i, H) \sum_{k=1}^{N_S} f_k N_k(H) R_k(a, e, i) \,, \tag{1}$$

where $n(a, e, i, H)$ is the observed number of NEOs as a function of their semimajor axis a, eccentricity e, inclination i, and absolute magnitude H, $B(a, e, i, H)$ is the detection efficiency, N_S is the number of different escape routes and/or source regions included, f_k is the relative importance of a particular escape route or source region (that is, $\sum_{k=1}^{N_S} f_k = 1$), and $N_k(H)$ and $R_k(a, e, i)$ are the differential absolute-magnitude distribution and residence-time distribution (in orbital-element space) corresponding to escape route or source region k. We describe the absolute-magnitude distribution $N_k(H)$ using a function with 3 free parameters which produces a smoothly varying slope and is able to reproduce the wave-like feature known to exist at about $19 < H < 24$:

$$N(H) = N_0 10^{\int_{H_0}^{H} \alpha_0 + c(H' - H_m)^2 dH'} \,, \tag{2}$$

where N_0 is a scaling parameter which is given by the number of large NEOs. The free parameters are the minimum slope α_0, the curvature c, and the absolute magnitude corresponding to the minimum slope H_m.

NEO residence-time distributions

To build NEO residence-time distributions $R_k(a, e, i)$—that is, statistical representations of typical NEO orbital elements—we first select orbital elements of known mainbelt objects with absolute magnitudes below an approximate completeness limit. We then integrate these ~80,000 particles under the influence of a Yarkovsky drift for 100 Myr or until they enter the NEO region or escape the inner solar system. The source regions (such as Hungarias and Phocaeas) are defined based on the particles' initial orbital elements while escape routes (such as the ν_6 secular resonance and the 3:1 mean-motion resonance) are defined using the orbital elements at the instant when particles enter the NEO region. The particles that enter the NEO region are further integrated until they collide with a planet or the Sun, or escape the solar system. We keep track of the orbital elements when the particles are in the NEO region with a time resolution of 250 yrs and use this information to build up the residence-time distributions as a function of source region or escape route. We have identified more than two dozen potential source regions or escape routes but many of these can be combined such that the final model contains a dozen or so distinct source regions or escape routes.

Calibration and observational biases

We calibrate the model using NEO detections by Mt. Lemmon and Mt. Bigelow stations of the Catalina Sky Survey during 2005–2012. The stations have each discovered or serendipitiously detected about 2,500 NEOs that fulfill our criteria on, e.g., sky-plane motion and absolute magnitude. Using the nightly detection efficiencies that CSS compute as a function of apparent magnitude, we derive the detection efficiency $B(a, e, i, H)$. Finally, we solve for the weights f_k and the parameters describing the differential distributions for the absolute magnitude ($\alpha_{0,k}$, c_k, and $H_{m,k}$).

Acknowledgments

Funding is provided by grant #137853 from the Academy of Finland, grant NNX12AG10G from the NASA NEOO Program, and the ESA project "Synthetic Generation of the NEO-Population" awarded to the University of Braunschweig, Germany. Computing resources are provided by CSC – IT Center for Science, the Finnish Grid Infrastructure, U. Helsinki Dept. of Physics, Observatoire de la Cote d'Azur, and NASA Ames.

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Development of a Spectroscopic Survey of Meteoroid Elemental Abundances

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Introduction

The successful Cameras for All-sky Meteor Surveillance (CAMS) project [1] has been extended with the design and deployment of a spectral video camera battery, which will provide automated composition analysis of meteoroids and their associated parent bodies. The high dispersion grating spectroscopy required for elemental abundance analysis, presents several challenges in camera design, pointing, data capture, and post-detection processing. By deploying multiple cameras, automating the spectral processing [2], and coupling that to the CAMS video-to-orbit analysis capability [3], it is expected the CAMS Spectrograph (CAMSS) will dramatically scale up the collection and measurement of meteor spectra in the optical wavelength range of 380-880nm and include parent body association. Thus providing a year round survey of the main elemental composition (Mg, Fe, Na) of the comets and asteroids that pass close to Earth [4].

Methodology

Atmospheric ablation induced breakdown spectroscopy is the most direct way of measuring main element composition of meteoroid dust grains [2]. Coupling the spectral measurement to a trajectory [3] and orbit estimation capability from the multi-site CAMS battery of cameras, plus the light curves and deceleration estimates from the video content, provides the unique opportunity to identify the source, mass, density, fragmentation, and chemical abundance properties of each collected meteor record [4]. The project builds upon prior work in automated meteor video surveillance of the night sky [1,3] and has reached the point of system deployment (Figure 1) and nightly spectra collection. The spectral CAMS system is now fully automated for capture, archive, spectrum extraction, calibration, and elemental abundance estimation.

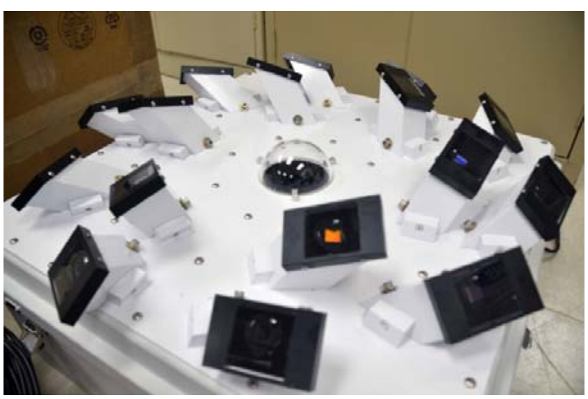

Fig. 1 CAMS Spectrograph: Sixteen-camera battery with dispersion grating attachments.

Planned Activity and Objectives

The spectral survey is currently funded to operate for three years and be tightly coupled to the basic CAMS meteor orbit estimation system deployed in California at Fremont Peak and Lick Observatory. In addition, the standard CAMS system will also be extended to the southern hemisphere. Goal is to complete the confirmation of as many as possible of the remaining unconfirmed nighttime meteor showers in the IAU Working List as well as provide spectroscopic information for both major and minor showers. The product of this work will be a study of the diversity of comets in the Oort cloud and in the Jupiter-family (Kuiper belt) populations. This data will be used to address the hypothesis that Oort cloud comets originated predominantly around other stars in the birth cluster of the Sun and that Jupiter family comets and outer belt C-type asteroids sample the same population of outer disc solar system objects [5].

Status

A sixteen-camera CAMS Spectrograph was deployed in the spring of 2013. The design, camera orientation considerations, software challenges, initial performance, and analysis results are to be presented. An example of a collected spectrum from early tests with the dispersion grating is shown in figure 2 as a temporally combined frame sequence from the video record.

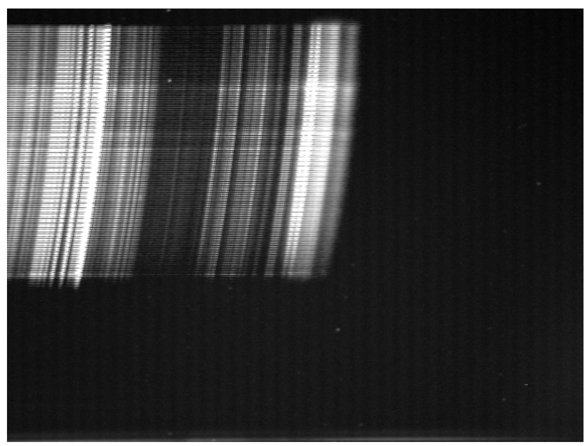

Fig. 2 Geminid fireball spectrum from multiple co-added video frames collected on 14-Dec-2012 4:43:54 UT in Sterling VA, USA.

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Hyperbolic Orbits in the EDMOND

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Introduction

The present work is based on an analysis of 79 402 meteor orbits collected in the European video meteor network database [1]. All orbits determined as hyperbolic (with semimajor axis $a < 0$ and eccentricity $e > 1$) were selected from the data for our analysis, with the aim of finding the reason for their hyperbolicity. A hyperbolic excess above the escape velocity in respect of the Sun could reveal a possible interstellar origin of a meteoroid. But there are also processes within the Solar System which can produce hyperbolic meteors, such as a planetary perturbation of a meteoroid, collisions of small bodies, or the ejection velocity of a meteor particle from the parent body. However, there is the possibility that hyperbolic meteor orbits are caused by measurement errors and inaccuracies in the velocity determination. Our analysis showed that the latter is responsible for the vast majority of hyperbolic orbits among the detected meteors.

EDMOND

For our analysis, a database of video meteor orbits EDMOND (European viDeo MeteOr Network Database), covering the years 2009 – 2012, was used. The database is the result of cooperation and data sharing among national networks and IMO VMDB (International Meteor Organization Video Meteor Database). Nowadays, the EDMOND network consists of observers from the following national networks (in alphabetical order) - BOAM (French amateur observers, France BOAM network), CEMeNt (Central European Meteor Network, cross-border network of Czech and Slovak amateur observers), HMN (Hungarian amateur observers, Hungarian Meteor Network), IMTN (Italian amateur observers in Italian Meteor and TLE network), PFN (Polish Fireball Network), SVMN (Comenius University network, Slovak Video Meteor Network), UKMON (British amateur observers, UK Meteor Observation Network) and individual observers in Bosnia and Serbia. The current version EDMOND 2.0 consists of 79 402 higher quality orbits after a careful selection. Details can be found in the paper Kornoš et al. [1].

Hyperbolic orbits caused by planetary perturbation

In our analysis, all of the 12 840 hyperbolic meteors from the video database were searched for meteoroids unbound due to a close accelerating encounter with one of the massive planets of the solar system. In order to follow their orbital evolution, all hyperbolic orbits were integrated backwards for 80 years. At this time, all meteors reached a heliocentric distance at least of 100 AU.

Table 1 Results of meteor observations by the European video meteor network and the proportion of the orbits determined as hyperbolic

Year	Number of detected meteors N_{all}	Number of hyperbolic orbits N_{hyp}	N_{all}/N_{hyp} (%)
2009	7200	1860	25.8
2010	17182	3337	19.4
2011	35428	4758	13.4
2012	19592	2885	14.7

Hyperbolic orbits due to inaccuracy in the velocity determination

The inaccuracy in the heliocentric velocity is a significant source of uncertainty in semimajor axes determination, and it can easily push the orbit over the parabolic limit and create a group of meteoroids apparently moving in hyperbolic orbits. The analysis showed a high concentration of shower meteors among the hyperbolic orbits and an increase in their proportion with decreasing values of $1/a$ close to the parabolic limit and beyond, which is clear evidence of errors arising, in most cases, from the velocity determination. Our task is to estimate the limits of possible errors and, hence, to determine the real proportion of hyperbolic meteors in the observed sample. The results are discussed and compared with our previous analysis of hyperbolic meteors observed using different techniques [2, 3], as well as with reports by other authors [4].

Conclusions

The hyperbolic orbits from the EDMOND were analysed with the aim of showing the real proportions of interstellar and perturbed meteors, and their contribution to all hyperbolic orbits. Possible interstellar meteoroids could be found only within the error bars of the determined heliocentric velocity. It was shown that the hyperbolicity of the vast majority of meteor orbits in the database is the result of inaccurate velocity determination. Other sources which can produce the hyperbolicity of the meteor orbit, including a planetary perturbation, are negligible by comparison.

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Implications for meteoroid structure and ablation from multiple maxima meteor light curves

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The Canadian Automated Meteor Observatory (CAMO) [1] detects occasional meteors with two distinct local maxima in the image intensified CCD based light curves. (see Fig. 1). We report early results from an ongoing analysis of the trajectories, orbits, and light curves for these events.

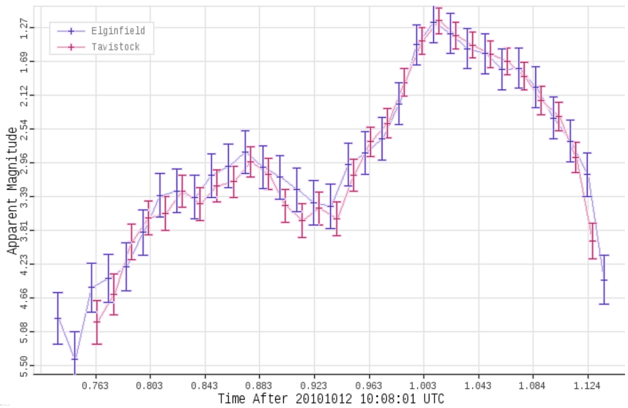

Fig. 1 A CAMO meteor showing two distinct local maxima in the light curve.. The light curves from the two stations are clearly consistent within error estimates.

A number of mechanisms could explain two (or more) maxima in the light curves. One possibility is differential chemical ablation of two primary luminous components. Alternatively two main bodies with differing physical properties would produce dual peak light curves. Several possibilities incorporating the two component dustball model [2,3] may be consistent with the light curves, including pre-separation of some grains prior to light production [2] or dustball grains with differing mass distributions.

The main goal of the research is to use the observations from both the wide field and tracking high resolution cameras of the CAMO system to place constraints on possible mechanisms.

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New Mars meteorite fall in Marocco: Collecting observations and spatial distribution in the strewnfield

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Abstract

The existence of Martian meteorites in the region of Tata had been notified to a group of scientists of the Ibn Zohr University of Agadir, Morocco, at the beginning of January 2012 by a nomad of Tata who had found a small fragment in the region. A soon as a scientific expedition arrived at the place of the meteorite fall, the members of the laboratory of Geo-heritage and Geo-materials science collected the debris of this Martian meteorite and many information's.

The Tissint fireball is the only fireball to have been observed and reported by numerous witnesses across the South-east of Morocco. The event was extremely valuable to the scientific community; show an extraordinary and rare event and were also the brightest and most comprehensively observed fireball in Morocco's known astronomical history. Now we are in a position to draw the distribution ellipse of the fall, which starts on Jbel Al Gallab continues in the east-south-east direction above big rocky plateaus.

The Southern Argentina Agile Meteor Radar (SAAMER): A platform for comprehensive meteor observations and studies

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Introduction

The Southern Argentina Agile Meteor Radar (SAAMER) is a new generation system deployed in Rio Grande, Tierra del Fuego, Argentina ($\sim 53^o$ S) in May 2008 (Figure 1a). SAAMER transmits 10 times more power than regular meteor radars, and uses a newly developed transmitting array, which focuses power upward instead of the traditional single-antenna-all-sky configuration. The system is configured such that the TX array can also be utilized as a receiver. The new design greatly increases the sensitivity of the instrument enabling the detection of large number of particles at low zenith angles. The more concentrated transmitted power enables additional meteor studies besides those based on the detection of specular reflections, such as routine detections of head echoes and non-specular trails (Figure 2), previously only possible with High Power and Large Aperture radars. In August 2010, SAAMER was upgraded to a system capable to determine meteoroid orbital parameters. This was achieved by adding two remote receiving stations approximately 10 km away from the main site in near perpendicular directions (Figure 1b). The upgrade significantly expands the science that is achieved with this new radar enabling us to study the orbital properties of the interplanetary dust environment (Figure 3). Because of the unique geographical location, the SAAMER allows for additional interhemispheric comparison with measurements from Canadian Meteor Orbit Radar, which is geographically conjugate. Finally, SAAMER is ideal for the deployment of complementary instrumentation in both, permanent and campaign, operational mode. Results from various radar meteor investigations as well as radar/optical observation campaign will be presented in this paper.

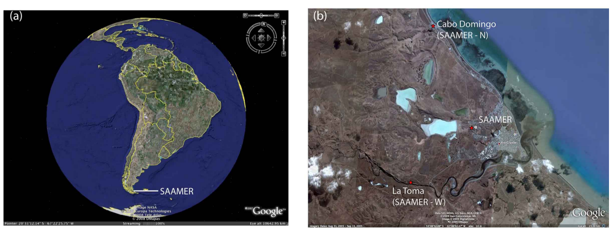

Figure 1: a) Geographical location of SAAMER; b) Location of remote sites with respect to the central SAAMER station.

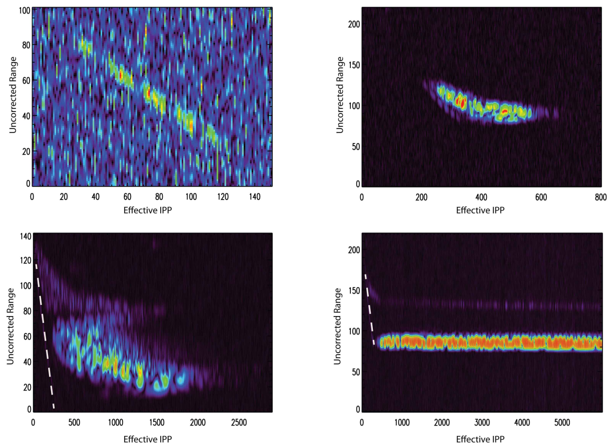

Figure 2: Range-Time-Intensity images for SAAMER's detections of Meteor Head-echoes, Non-Specular Trails and Specular Trails showing differential ablation.

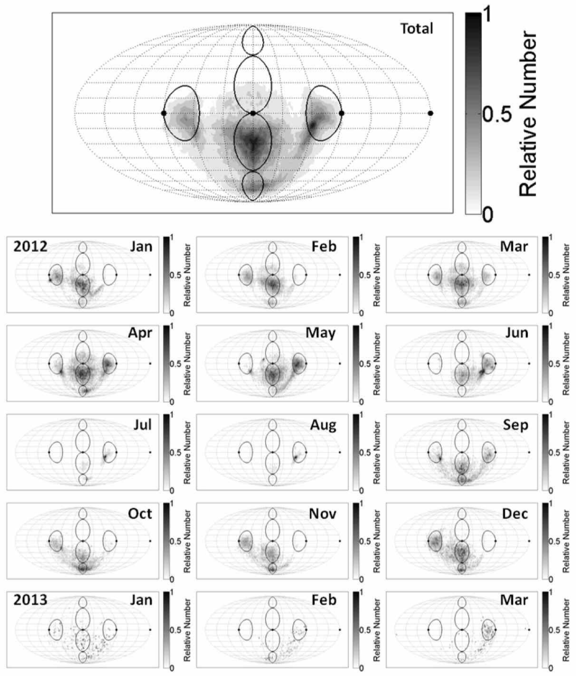

Figure 3: Sun-centered ecliptic maps showing the radiants of the sporadic meteor complex as observed by SAAMER throughout 2012.

The IAU MDC – meteor showers database current status

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At the IAU GA in Prague (2006) the Task Group on Meteor Shower Nomenclature established. The main objective for this group was to formalize the traditional meteor shower nomenclature practices and to formulate a descriptive list of established showers that can receive official names.

In 2007 a Working List of 230 showers was compiled using data collected and published in the book [1]. The Working List of shower radiants was posted on the IAU Meteor Data Center website [2]. To be used in future publications each shower was given a name, a unique number and a three-letter code.

During the Meteoroids 2007 meeting in Barcelona, the Task Group worked out the logistic of adding new streams to the Working List, and adding new information on streams already in the Working List.

In 2009, in Rio, at the business meeting of Commission 22 the Task Group presented a list of 64 established meteor showers that deserved to be officially named by the IAU GA [3]. Commission 22 agreed that the Task Group on Meteor Shower Nomenclature be transformed into the Working Group on Meteor Shower Nomenclature for the next triennium (2009-2012).

In August 2012 in Beijing, next 33 showers names were approved by the IAU GA, two showers were removed from the MDC list. Also the new members of the Working Group were elected for the next 2012-2015 triennium.

At the moment the IAU MDC shower database includes 493 showers, among them 95 established showers. The working list comprises 375 showers, among them 56 are the candidates to be established at the next IAU GA, another 82 showers have a status *pro tempore,* until their radiant and orbital parameters will be published.

Since 2009 the radiant data of 270 showers has bee completed by the orbital elements. Also we added 450 ADS references. For some showers another radiant and orbital data taken from the literature has been included to the database.

During the upgrading procedure we have found several errors, mistakes and inconsistences. Usually they were easy to correct, but some of them require decission of the Workin Group on the Shower Nomenclature.

Based on developed by us software we have made validity check of the shower names listed in the MDC, and we found many incorect cases. To avoid (reduce) such incorrect future assignemnt we propose some standarization based on the subset of the Bright Star Catallogue and the procedure of identification of a constellation from the radiant position [4].

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Chelyabinsk meteorite: Expedition to the field

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Introduction

In the morning of February 15 2013 (3:20 UT) the large space body entered the Earth atmosphere in the Chelyabinsk region. The uniqueness of this event consists in the fact that entry of large (20 m in size body) was well documented. This event was observed by numerous eyewitnesses and by a number of registration systems including more than 400 photos and videos, satellite observationsof bolide light curve and subsequent dust trail, records of infrasound and seismic signals etc.

Field study

In order to complete records of this unique event a fact-finding mission was organized by the Institute for Dynamics of Geospheres RAS (Moscow) and the Astronomical Institute RAS (Moscow). Two universities in Chelyabinsk: the South Ural State University and the Chelyabinsk State University as well as SETI participated in this field study. Official data on damage in the area was obtained.

Some 50 villages and towns were visited between 3 and 5 weeks after the event, during which time about 150 locals were questioned. The population is concentrated in villages and towns, with no houses in between, providing natural sampling points for information. The witnesses were asked whether the fireball was seen (blinding, pain in eye, was heat felt, sunburn?), how the impact of the shockwave was experienced (shaking, dust?), whether damages or injuries occurred (structural damage, flying glass?), whether unusual scents were smelled, and if meteorites were found locally. Several people in the each village were questioned, until reports of damage were confirmed.

The background star images for astrometric calibration were made during the field study. These images allow us to calculate the coordinates, the height, the velocity and the whole trajectory of the Chelyabinsk bolide.

The meteorit collections were photographed and their find locations were painted to the map.

Is a 2004 Leonid meteor spectrum captured in a 182 cm telescope ?

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Abstract

Spectra of high-speed meteors (e.g. Leonids) have been believed to consist of only two excitation temperature regimes: the 5000 K main component and another hot component at 10000 K [1]. This does not always satisfy observed spectra due to the lack of sufficient physical correlation among derived excitation temperatures, observed fluxes, upper energy levels ($E_{\rm u}$), and Einstein A coefficients ($A_{\rm ul}$) of each spectral emission line. In this study, we correlate them and discover new excitation temperature regimes in meteor spectra in the visual to near IR wavelength region. We focus on $E_{\rm u}$ and $A_{\rm ul}$ of observed spectral emission lines. A model fitting the first positive band of nitrogen ($\rm N_2$) and total number of Si II under quasi-neutral conditions proved the key to identifying of new components. We have identified another two excitation temperature regions in meteor spectra. One is a Mid component at 8000 K for $\rm N_2$ (see also [2]) and another a Jet component above 10000 K for Si II. This idea has allowed us to reproduce the meteor spectrum. The study concludes that the spectra of high-speed meteors may consist of more than two excitation temperature regions including the main, Mid, hot, and Jet components (Figs.1, 2 and [3]).

This work is published in *Astronomy & Astrophysics*, 474, 639-645 (2007).

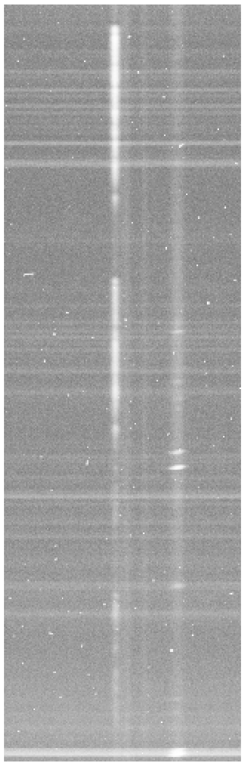

Figure 1: Spectra of V838 Mon (center) and a meteor taken by the 182 cm telescope at $2^{\rm h}15^{\rm m}24.3^{\rm s}$ UT 2004 Nov. 18. The meteor spectrum was captured to the east (right) of V838 Mon and a field star spectrum appears between them. Wavelength increases from bottom to top.

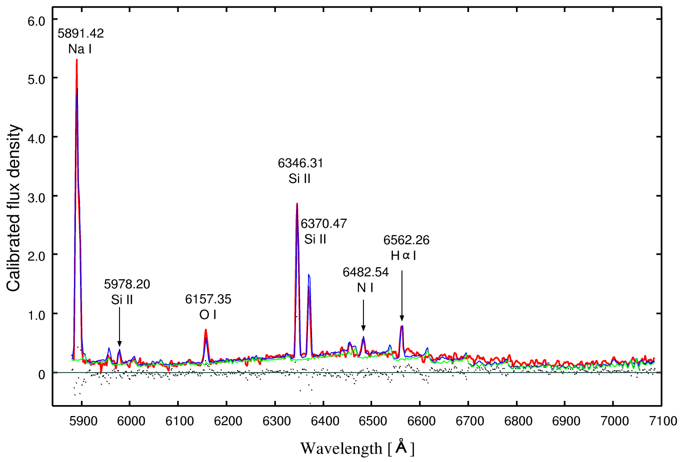

Figure 2: 1D meteor spectrum extracted from Fig1. Calibrated flux density is in units of $10^{-14}\,{\rm erg\,s^{-1}\,cm^{-2}\,Å^{-1}}$. The red curve shows the observed spectrum while the blue curve is the best fit model using atomic catalog lines and nitrogen first positive band.

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Meteor observations with the next generation geospace radar EISCAT_3D

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Summary

EISCAT_3D is a three-dimensional imaging radar project for atmospheric and geospace research. It will consist of multiple phased arrays located in northern Scandinavia. The multi-purpose experiment and data analysis approach will enable continuous meteor head echo observations, unique in terms of coverage and quality. The aim of this presentation is to give the meteor community a timely overview of EISCAT_3D and its future potential.

EISCAT_3D

EISCAT_3D [1] will be the next generation international atmosphere- and geospace research radar. It will consist of five phased-array antenna fields for transmission and reception of radio waves in the 230-240 MHz frequency band. The radar will measure the spectra of radio waves incoherently scattered from ionospheric acoustic- and plasma waves, as well as scatter from atmospheric structures that match the Bragg condition. Simultaneously, the orbits of meteoroids and space debris will be extracted from the data stream.

The total transmitted power at the core site, located close to the intersection of the Swedish, Norwegian and Finnish borders, will be 10 MW. It will be built with 10,000-16,000 crossed dipole antenna elements (for full dual polarisation capability) in a dense array. At least one of four remote receiving sites, all located within approximately 50 to 250 km from the core site, will have transmission capability of about 1 MW. Digital control of the transmission and low-level digitisation of the received signal will permit instantaneous beam-steering of the transmitted beam and measurements using multiple simultaneous (transmit and) receive beams, without moving mechanical structures. The central arrays at each site will be surrounded by smaller outlying antenna arrays. These outliers will facilitate aperture synthesis imaging to acquire sub-beam transverse spatial resolution.

EISCAT_3D is designed for novel measurement techniques, ones which have never been combined in one radar system: volumetric-, aperture synthesis- and multistatic imaging, tracking- and adaptive experiments, together with the possibility for continuous operations. This unique versatility will enable setting up challenging radar experiments to solve fundamental questions of cross-layer coupling in the atmosphere, solar-terrestrial interactions and plasma turbulence, as well as to study in detail meteoroid-atmosphere interaction processes. The EISCAT_3D radar sites should (must) be complemented by a set of supportive instruments. Multi-station video and spectral imaging systems would allow simultaneous head echo and optical meteor observations [2].

The EISCAT_3D project is in preparatory phase from 2010 through 2014, which aims to ensure that it reaches at a sufficient level of maturity with respect to technical, legal and financial issues to enter implementation phase. The Norwegian and Swedish science communities have in 2012-2013 submitted national proposals to partially fund the construction of EISCAT_3D, while preparations of similar proposals in e.g. Finland and Japan are underway. EISCAT_3D is on the roadmap in environmental sciences of the European Strategy Forum on Research Infrastructures (ESFRI). The planning of the radar is financed by the European Commission.

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Changes to meteoroid shape, porosity and internal structure during high velocity atmospheric entry

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Introduction

Cosmic dust recovered on Earth in the form of interplanetary dust particles (IDPs) and micrometeorites is, together with larger meteorites, a valuable source of primitive extraterrestrial material entering terrestrial atmosphere as meteoroids. Reliable determination of cosmic dust's bulk and grain density and porosity is an issue of key importance in planetology. It carries important information about the composition and structure of cometary dust or coma as well as of asteroid surfaces. Comparison of the physical properties of pristine cosmic dust particles to these significantly affected by atmospheric entry can give us insight into changes related to meteoroid their atmospheric entry.

Physical properties of the cosmic dust

In this study, we report physical properties measurements of cosmic dust in the form of micrometeorites collected from the northern ice cap of the Novaya Zemlya archipelago, Russia [1] and from soils collected in the Central depression of the Atacama Desert [2]. In total thirty-two samples were studied. Micrometeorites were investigated using x-ray microtomography (XMT) at the Department of Physics, University of Helsinki. Due to its high-voltage (20-180 kV) nanofocus x-ray tube, and variable imaging geometry, the XMT equipment allows scans of samples sized from 10 cm down to 50 µm, with sub-micron resolution in the case of small samples. Quantitative volumetric 3D calculations of various compositional fractions as well as of pore space within scanned particles were done in similarly as by [3] and [4], but with higher resolution.

Unmelted micrometeorites represent almost pristine cosmic dust which entered the atmosphere slowly and thermal changes, if any, are limited to the presence of a magnetite rim covering some particles. Such a magnetite rim is analogous to the fusion crusts of larger meteorites covering a pristine meteorite interior. Physical properties of these particles thus remain almost unchanged and are representative of the cosmic dust in Earth's vicinity. These particles seem to be rather inhomogeneous with wide range of porosity (0-12%, with one sample as high as 51%), similarly as reported in [4, 5, 6].

Partially melted, scoriaceous, micrometeorites enter the atmosphere at slightly higher velocities. While highly porous fragmental particles probably completely disintegrate at higher entry velocity, more compact particles survive the heating and stress during atmospheric entry. The heat generated during meteoroid deceleration causes partial melting and evaporation, resulting in growth of large vesicles within the silicate matrix. However, the extent of melting is not large enough to cause homogenization of the meteoroid or to change its shape from irregular to quasi-spherical. Partial melting results in a general increase in the porosity (23-27%). In contrast, cosmic spherules (melted micrometeorites) represent meteoroids entering the atmosphere at high velocities. Atmospheric entry heating causes meteoroid complete melting and change of its shape to droplet-like quasi-sphere. This is accompanied by almost complete reduction of porosity (0-3%). Their internal structure varies from glassy to barred or porphyritic olivine structure.

Changes to meteoroid properties during high velocity atmospheric entry

The comparison of the physical properties of cosmic spherules (melted micrometeorites) to those of partially melted or unmelted meteorites gives us the opportunity to evaluate the changes in meteoroid properties as a function of atmospheric entry velocity. At low velocities meteoroid melting does not occur and there is no change in meteoroid physical properties. At higher velocities, where partial meteoroid melting occurs, there is increase in the meteoroid porosity caused by volatile evaporation (scoriaceous phase). Metal distribution seems to be unaffected at this stage. At even higher velocities, complete melting follows the scoriaceous phase (characterized by initial increase of porosity). Complete melting is accompanied in metal oxidation and redistribution and loss of porosity. Especially, the porosity behavior (initial increase followed with almost total loss during high velocity impacts) is an important fact to be considered during meteor phenomena modeling.

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The Capricornids asteroid-meteoroid complex

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The near-Earth asteroid (NEA) 2008BO16 [1] is moving on the comet-like orbit according to its value of the Tisserand invariant (T_j=2.9). The orbital evolution of the asteroid shows that it is the quadruple crosser of the Earth's orbit. If the 2008BO16 has a developed meteoroid stream then this stream might produce the four meteor showers. Theoretical parameters of the predicted showers were calculated and identified with the observable nighttime σ-Capricornids and χ-Sagittarids, and daytime χ-Capricornids and Capricornids-Sagittarids showers. The comet-like orbit and association with the meteoroid stream producing the four active showers are strong indications that the NEA 2008BO16 has a cometary origin.

Investigation of the NEAs (2101) Adonis and 1995CS, which additionally is potentially hazardous asteroid (PHA) [1], realized that these objects are associated with the same meteoroid stream and are recognized as dormant comets [2]. It may be concluded, that either the 2008BO16 is 120 m in size a splinter of the Adonis, or all three objects - Adonis, 1995CS, and 2008BO16 are fragments of a larger comet that was the parent body of the Capricornids meteoroid stream, and whose break-up occurred several tens of thousands years ago.

During 2010-2011 yrs. three fireballs belonging to the σ-Capricornids meteor shower were photographed by the Tajikistan fireball network [3]. Taking into account the observations else six fireballs of this shower by the Prairie network (USA) [4] and the MORP (Canada) [5], the mean radiant coordinates, the period of activity, as well as the mean daily radiant drift of the σ-Capricornids were determined.

Further to the *PE* criterion [6], the values of bulk density of the nine fireball producing meteoroids are in the range from 0.2 to 3.5 g cm^{-3} that suggests a non-homogeneous compound of the comet-progenitor of the σ-Capricornids shower.

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Confirmation and characterization of meteor showers from IAU working list - EDMOND database

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Introduction

EDMOND (European viDeo MeteOr Network Database) is a database of video meteor orbits covering whole year interval 2009 – 2012. It is a result of cooperation and data sharing among national networks and IMO VMDB (International Meteor Organization Video Meteor Database). The network originated spontaneously. Nowadays, EDMONd (The European viDeo Meteor Observation Network), except IMO VMDB, consists of observers from following national networks (Fig. 1), in alphabetical order – BOAM (French amateur observers France BOAM network / Base des Observateurs Amateurs de Météores), CEMeNt (Central European Meteor Network, cross-border network of Czech and Slovak amateur observers), HMN (Hungarian amateur observers, Hungarian Meteor Network / Magyar Hullócsillagok Egyesület), IMTN (Italian amateur observers in Italian Meteor and TLE network), PFN (Polish Fireball Network / Pracownia Komet i Meteorów, PkiM), SVMN (Comenius University network, Slovak Video Meteor Network), UKMON (British amateur observers, UK Meteor Observation Network) and several individual observers in Bosna and Serbia [1].

Quality assessment

The current version EDMOND 2.0 contains 79 402 higher quality orbits after careful selection. Radiants distribution is depicted in Fig. 2. Basic parameters of the database and quality analyses will be presented.

Meteor streams identification

The substantial number of video meteor orbits allow us to undergo detail analyses of weak meteor showers and to better specify well known meteor streams. In the presentation, analyses of selected meteor streams with low numbers of orbits in the current databases will be presented. As a source of primal characterization of mentioned showers, the IAU MDC list of meteor showers was used.

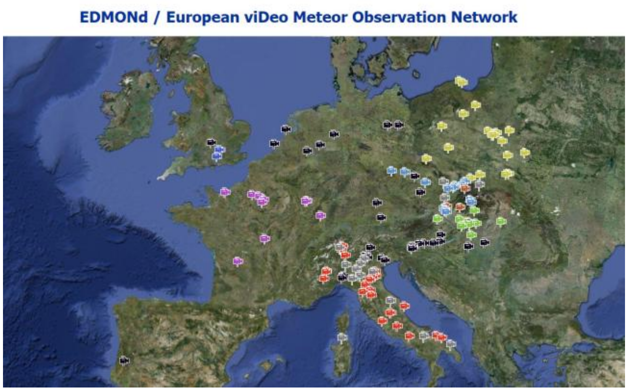

Fig. 1 The stations of EDMOND network in Europe.

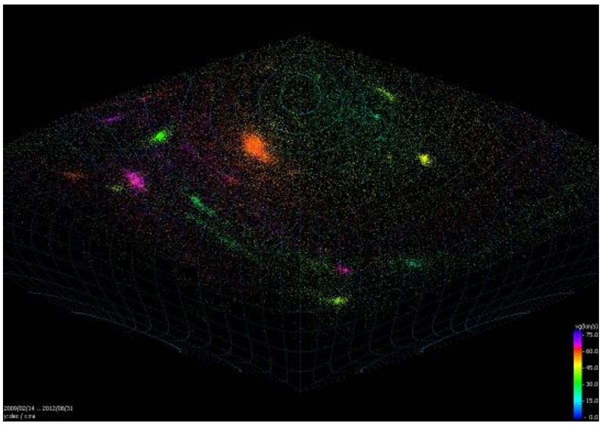

Fig. 2 Distribution of meteor radiants from EDMOND database in 2009-2012.

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Summary of results of 2011 Draconid aircraft mission

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Introduction

A Draconid aircraft mission (DRAMAC) was carried out on October 8, 2011, when an exceptional outburst of the meteor shower was predicted [1]. A number of instruments were deployed on board two aircrafts flying above Northern Europe and Atlantic Ocean. The flight path was selected to enable double station observations based on the flying formation of the aircrafts.
In this talk we present the overview of the results of this mission.

Activity of the meteor shower

The activity curve shows that the peak occurred at 20:15 ± 0:05 UT, what corresponds to solar longitude λ_{o} = 195º.039. This timing is consistent with the visual observations of IMO. The corrected instrumental hourly rate reached value cHR = 212 ± 38 at maximum.

The analysis of the all-sky camera data shows that the maximum of brighter meteoroids was recorded 15 to 20 minutes earlier (Fig. 1). The results are similar with SPOSH camera data, which also recorded two peaks of the activity. The first one occurred at 19^{h} 51^{m}, the second one at 20^{h} 18^{m} UT.

The mass distribution index was changing during the period of observation (Table 1). The abundance of fainter meteors became more significant after 20 UT.

Time interval	Number of meteors	Mass distribution index
19:30 – 20:00	79	1.84 ± 0.1
19:45 – 20:15	59	1.93 ± 0.1
20:00 – 20:30	72	2.30 ± 0.1

Table 1 Mass distribution index

Double station data

The suite of different cameras on board the two planes recorded few hundred Draconid meteors. At least 40 of them were identified as double station events. Measurements and calculations were quite difficult tasks due to the continuous motion of both aircrafts. Nevertheless, the atmospheric trajectories and heliocentric orbits were found for the meteors. The average geocentric radiant α_G = 261º.8 ± 1º.0; δ_G = 55º.4 ± 0º.7 is in good agreement with the model prediction.

We have reconstructed detailed trajectory and derived velocity profile for the double station meteors. Based on further analysis of deceleration height and rate we have calculated ablation coefficient and made estimates for the meteoroids' masses. The obtained results are consistent with the results published in [2].

Light curves

A light curve analysis shows significant variability of shapes. F parameter recently used for the light curves classification reaches values between 0.13 and 0.92, with an average value of 0.49. It is not possible to characterize this meteor shower using any single F value.

Spectra

We confirmed the fragile structure and early evaporation of volatile material from Draconid meteoroids. We observed an early start of the Na line. This might be due to the sodium evaporating early as a result of the entire fragmentation of the meteoroid.

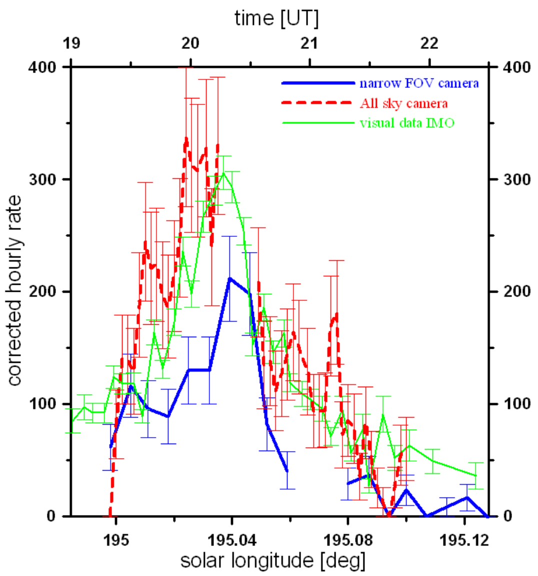

Fig. 1 Activity profile of 2011 Draconid outburst.

Acknowledgements

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BRAMS: a Belgian radio forward scatter network to study meteors

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The network

BRAMS, the Belgian RAdio Meteor Stations, is a project led by the Belgian Institute for Space Aeronomy (BISA) in the framework of the Solar Terrestrial Center of Excellence. It consists in a network of 24 radio receiving stations located in Belgium using forward scattering to detect and characterize meteors. A dedicated beacon, located in Dourbes, in the South-East of Belgium, emits a pure sine wave at 49.97 MHz with a power of 150 watts. All receiving stations use identical material provided by BISA and are synchronized by GPS receivers. One of these stations is an interferometer which has the additional capability to provide the direction of arrival of the echo with an accuracy of $\sim 1°$. Most stations are hosted by radioamateurs or groups of amateur astronomers making BRAMS a direct Pro-Am collaboration. A map of the current status of the BRAMS network is provided in Figure 1.

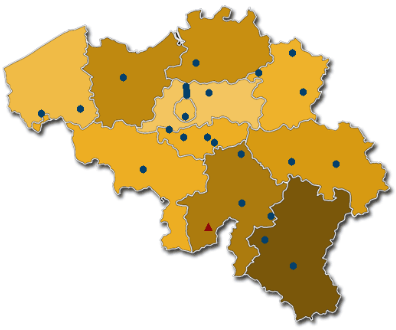

Figure 1: Map of the BRAMS network. The red triangle in the South-East of Belgium indicates the position of the beacon in Dourbes while the blue circles represent the 24 receiving stations.

The data

Each receiving station records continuously with a sampling rate of 5512 Hz. Around 1 GB of data is generated per day and per station. These data are first locally stored in the form of audio WAV files then transferred to BISA for analysis and archiving. Due to the proximity between the beacon and the receiving stations (maximum distance of ~ 200 km), in addition to meteor echoes, each station also records echoes due to reflexion on airplanes flying above Belgium. The interpretation of raw data becomes complicated due to these parasitic signals. However meteor echoes and airplane echoes can be more easily discriminated in a spectrogram as their spectral signatures are very different. An example is shown in Figure 2. Underdense meteor echoes appear as vertical lines while plane echoes are the long-lasting S-shaped signals.

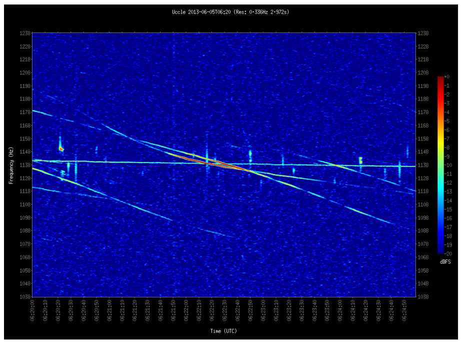

Figure 2: An example of a spectrogram obtained from data recorded at the Uccle station on 5 June 2013 at 06:20UT. Each spectrogram shows 5 minutes of data and a spectral range of 200 Hz centered on the "direct" signal coming from the beacon. The spectrogram is obtained using 5512 samples for the FFT and a 90% overlap.

Since each station generates 288 similar spectrograms per day, the challenge is to obtain an automatic detection method which provides a reliable counting of meteor echoes and does not produce too many false detections. Several methods will be discussed and comparisons will be provided.

Main goals of the BRAMS project

A first goal of the BRAMS project is to compute flux densities of meteoroids for meteor showers. An approximate method based on the observability function will be presented. Another more sophisticated method using techniques proposed by [1] and [2] will also be briefly discussed.

Another goal of the BRAMS project is to retrieve meteoroid trajectories from multi-stations observations synchronized by GPS receivers. Several methods of reconstruction will be discussed including the case where one of the stations that recorded the meteor echo is the interferometer.

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Oborniki (Wargowo) 2012 possible space debris fall

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Introduction

A fall of small objects took place at midnight of 27/28th April 2012 in Wargowo village near Oborniki, about 25 km NW from Poznań. According to a witness, the fall was associated with a loud sound, without any visible damage on the ground. Officially, two separate pieces were found (< 3cm, ca. 2 cm). However, there is some unconfirmed press information that additional pieces were also found [1].

Methods

During the night after the fall initial investigation was performed by Polish State Fire Fighting Force. The measurements were focused on the radiation level and chemical risk [1]. Nothing dangerous was reported. Few days later the smaller piece (ca. 18 g) has been provided to the Institute of Geology AMU for further research. Preliminary results of microscopic observations and chemical composition estimates using the SEM-EDS method excluded that the analysed sample had meteorite origin [2]. The probable source of the fall is the space debris, which re-entered the Earth's atmosphere.

Space debris

Space debris are all man-made objects, including their fragments and parts, whether their owners can be identified or not, in Earth orbit or re-entering the dense layers of the atmosphere that are non-functional with no reasonable expectation of their being able to assume or resume their intended functions or any other functions for which they are or can be authorized [definition proposed by Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful uses of the Outer Space].

From the launch of the first artificial satellite Sputnik in 1957, more than 4900 launches have placed some 6600 satellites into orbit, of which about 3600 remain in space. This large amount of space hardware has a total mass of more than 6 300 tonnes. All objects larger than 10 cm in diameter are routinely detected, tracked, and catalogued.
The most comprehensive data set for man-made objects on Earth orbits is the NASA Satellite Situation Report (SSR), together with the so-called Two-Line Element (TLE) catalogue of the US Strategic Command (USSTRATCOM). The Satellite Situation Report (SSR) is a listing of those satellites (objects) currently in orbit and those which have previously orbited the Earth. Satellite Situation Report and TLE catalogue are available on the web site www.space-track.org after approved register.
By 24 Jun 2013 a total number of objects in the Satellite Situation Report is 39 191. Of these all objects, 22 363 decayed into the atmosphere. In-orbit population is 16 828 objects, where number of payload objects is 3 744, rocked bodies – 1967, and debris – 11 117. [3]
For each object the SSR provides the following information: INT-ID/Name, catalogue number, source (owner), orbital period, inclination, apogee, perigee, RCS (radar cross section) parameter, launch Date and decay date if object re-entered the earth's atmosphere. Based on these data the source of a Wargowo fall can be identified.

Aim of the studies

Studies described in this contribution were focused on detailed chemical composition estimates using electron microprobe (EPMA) method together with the process of identifying the space object, that was the source of the Wargowo fall.

Chemical description

The studied sample is characterized by high porosity and rust. During preliminary studies three different phases were recognized [2]. Based on EPMA analyses Phase I (PI) shows internal heterogeneity. At the BSE images the PI structure is similar to dendrite with intergrowths of three sub-phases: dominating PIa (Cr ~ 60%, Fe ~ 40%), probably oxidized PIb (Cr ~ 80%, Fe ~ 15%) and minor PIc (Cr ~ 58%, Fe ~ 39%, P ~ 2,5%). Dendrite structure of PI is a result of solidification under cooling/supercooling condition, and is typical for crystallisation of metals and alloys [4]. During EPMA measurements Phase II was not identified and its higher Cu content was not confirmed. Phase III displays specific navy blue colour similar to silica glass (Fig. 1), its chemical composition is a mixture of SiO_2 ~ 40%, CaO ~ 30%, MgO ~ 10%, Al_2O_3 ~ 7%, Cr2O3 ~ 5% and minor content of Na, K, Ti, Mn and Fe.

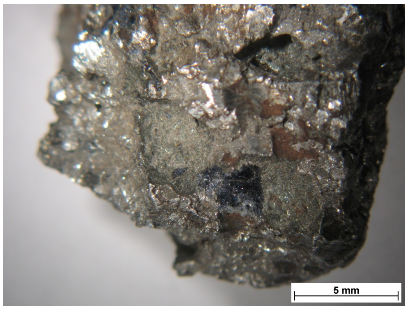

Fig. 1 Microscopic photograph of the studied sample

Conclusions

The studied sample is a part of space debris and its chemical composition and structure is the result of melting and rapid cooling during passing through the Earth's atmosphere.

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The ecliptic-toroidal structure of the meteor complex of comet 96P/Machholz

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Introduction

The meteors in the ecliptical showers come to the Earth's atmosphere from directions: (i) of solar apex, (ii) toward the Sun, i.e. helion, and (iii) outward of the Sun, i.e. antihelion. Another particular sources of meteors, northern and southern toroidal, are situated far from the ecliptic. In our work, we study the meteoroid complex of comet 96P/Machholz. Surprisingly, this complex exhibits the structure consisting of the showers all related to the above-mentioned cardinal directions. Concerning results are presented in the following.

Modeling of the stream

The theoretical meteoroid stream of comet 96P/Machholz is modeled for 8 moments of the comet's perihelion passages, in about 500, 1000, 2000, 2900, 3000, 3100, 3200, and 4000 years before the present. The particles are assumed to be ejected, from the comet nucleus, uniformly to all directions with velocity equal to 0.001 multiple of the comet's perihelion velocity. This modeling gives a stream, which, after a short relaxation period, fulfils the entire phase space of orbital elements of corresponding real stream, its central core. After modeling, the dynamical evolution of particles of each model is followed via numerical integration for period ranging from the moment of modeling to the present. The perturbations of 8 major planets are considered. When the integration is finished, we select the particles in orbits, which approach the Earth's orbit within 0.05 AU. These particles are used to predict the potential, from the Earth observable, meteor showers and, eventually, to identify these theoretical showers to their real counterparts.

Results – the theoretical showers of 96P

Comet 96P/Machholz appears to associate 6 meteor showers observable from the Earth. Four of these are the major, well-known showers: daytime Arietids, Southern and Northern δ-Aquarids, and Quadrantids. The Arietids occur to be the northern strand of the ecliptical, daytime shower of which the predicted southern part (the fifth theoretical shower of 96P referred below as ,,filament 4") probably does not exist due to a short lifetime of appropriate meteoroids. Namely, their perihelia are predicted extremely near the solar surface, therefore they can be expected to be destroyed within a short time. The sixth predicted shower, which we refer to as ,,filament 6", has the radiant area deeply in the southern sky. Its identification to a real shower has to be, thus, postponed to the future, when a larger sample of meteors glaring on the southern sky will be observed and measured. The characteristics of the individual showers of 96P complex were published in our earlier paper (Neslušan et al., 2013, A&A, 551, id. A87). Here, we would like to higlight the fact that the complex forms the ,,ecliptic-toroidal structure". This structure can transparently be seen in the distribution of geocentric radiants of the Earth-orbit approaching particles, constituting all 8 modeled streams. The distribution is shown in Fig. 1. We can see that the Southern and Northern δ-Aquarids, Arietids, and shower corresponding to the theoretical ,,filament 4", if exists, can be classified as the ecliptical streams of the 96P complex. Quadrantids and the theoretical ,,filament 6" represent the toroidal showers of this complex.

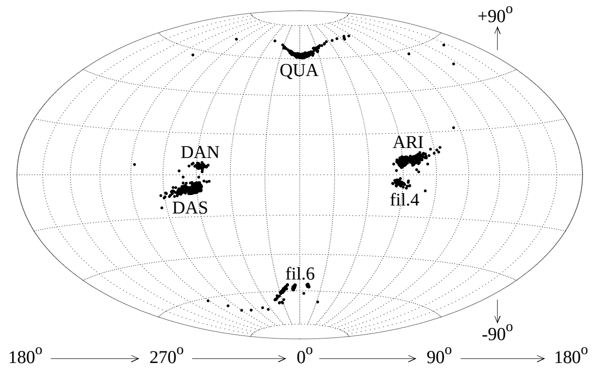

Figure 1: The theoretical radiants of particles supposed to collide with the Earth shown in the Hammer projection of the sky. The modified ecliptical coordinate frame is used The common ecliptical longitude is shifted in manner that the Earth's apex is in the origin of the coordinate frame. Abbreviations: DAN – δ-Aquarids N, DAS – δ-Aquarids S, ARI – Arietids, QUA – Quadrantids, fil.4 and fil.6 – theoretical filaments (No. 4 and 6) of the structure of 96P-meteor-shower complex, which cannot be reliably identified to the real showers. The plotted radiants appear to form an ecliptic-toroidal structure.

Conclusion

Studying the meteoroid complex of comet 96P/Machholz, we found that the toroidal meteor sources are not only real, but they can be a part of meteor complex constituted by as ecliptical as toroidal showers, which originate from the single parent body. In other words, we classify the Quadrantids as the toroidal shower of 96P/Machholz and δ-Aquarids N and S together with the daytime Arietids as the ecliptical showers of the meteor complex of this comet. (Asteroid 2003 EH1, which is situated in the same orbital phase space as 96P, but shifted in the phase, can also contribute to this complex and, thus, associate a similar ecliptic-toroidal structure.)

[047]

Automated High-Resolution Spectral Meteor Camera

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Most of the mass lost from comets as they pass perihelion is in millimeter-sized particles. Understanding the composition of these particles would help us to understand the origins of comets during solar system formation. Unfortunately they are too small to produce meteorites, and too large to be collected by sample return missions sampling the coma. We must therefore observe particles in this size range while they interact with the Earth's atmosphere. Spectral observations can provide clues as to an object's chemical composition, while high resolution observations can indicate whether and how meteoroids fragment in the atmosphere, which can indicate the size and bonding strength of each particle's fundamental grains.

We plan to add a blue-sensitive spectral camera to the existing Canadian Automated Meteor Observatory (CAMO) in order to capture both high-resolution video and meteor spectra. Data collected with this new system will be used to look for variations in meteor spectra between the head and wake of meteors, to look for inhomogeneities in fragmenting meteoroids, and variations in meteor spectra during fragmentation events. The data will be used to constrain models of meteoroid ablation, which should allow meteoroid grain compositions to be determined. The system design and preliminary results will be presented.

Raman Microspectroscopy of particles RA-QD02-0158, RA-QD02-0187 and RA-QD02-0197 collected by the HAYABUSA sample return mission to Itokawa asteroid.

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Introduction

The Hayabusa sample return mission was launched in 2003 by the Japan Aerospace Exploration Agency (JAXA). During this space mission material from the S-type, near-Earth asteroid (25143) Itokawa was sampled and returned to Earth [1]. Raman microspectroscopy measurements, which allow for a contactless mineralogical investigation, were performed on Hayabusa samples RA-QD02-0158, RA-QD02-0187 and RA-QD02-0197 subsequently named #158, #187 and #197.

Samples

Seven samples have been provided by JAXA to our consortium in the scope of their 1^{st} International Announcement of Opportunity [2]. For the noble gas research proposed in the project [3] it is essential that the samples do not come in contact with the Earth atmosphere. Therefore, three of the Hayabusa samples, #158, #187 and #197, have been allocated (and remained) in a N_2-filled container to avoid Earth atmospheric contamination and have been investigated through a transparent quartz glass port that replaced the original JAXA's top cover.The size of the samples ranges between 59 μm and 64 μm. SEM-EDX analysis at the curation facility of JAXA identified olivine and plagioclase mineral phases for sample #197 and olivine for the other two samples (JAXA sample documentation).

Measurements

Single Raman spectra were measured on the sample to identify the minerals. The samples were scanned manually covering the sample surface pointing towards the objective. The Raman measurements were carried out with a Witec Alpha 300 Raman microspectrometer. The laser wavelength was 532 nm. The spectral resolution was about 4 cm^{-1} and for the 10x objective the spot size on the sample was less than 1 μm. The measurement time was 120s and 240s and the power on the sample was 200 μW for each measurement.

Results and summary

In Figure 1, as an example, an averaged Raman spectrum, derived from 10 measurement points (spots 1-10) of sample #197, is presented with an enlargement in the range of the main olivine doublet between approximately 820 till 855 cm^{-1}. The bands of the doublet were fitted to a Gauss function. The estimated peak positions were compared with two-peak calibration data sets of Kuebler [4]. The derived peak positions indicate Mg-rich olivine (Fig. 1). Raman spectra at other measurement points on sample #197 indicate plagioclase and pyroxene, where the comparison with literature data [5] indicates high-Ca-pyroxene. For sample #197 Mg-rich olivine, high-Ca-pyroxene, and plagioclase are the identified minerals. Only olivine is identified for the samples #158 and #187. The results of the Raman measurements are consistent with an ordinary chondrite of high petrologic type.

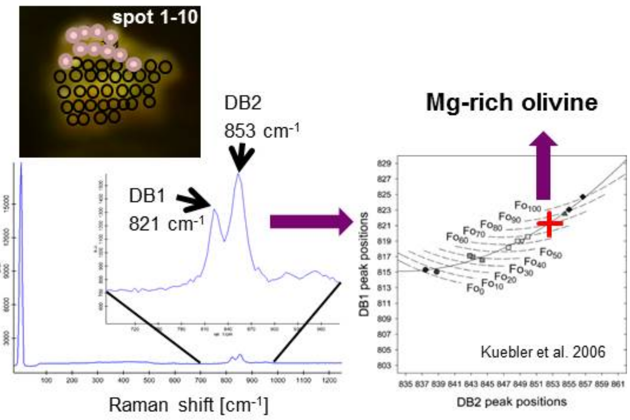

Figure 1: Microscopic image of sample #197 including the measurement points; averaged Raman spectrum of 10 (pink) measurement points and comparison with Kuebler [4].

Acknowledgements

We thank Dr. Abe and JAXA for the allocation and efficient delivery of the particles.

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Collective E-region ionisation caused by the 1767 trail during the 2002 Leonids

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Abstract

Intensive E-region ionisation extending up to 140 km altitude was observed with the mainland EISCAT UHF radar during the 2002 Leonids meteor shower maximum. The EISCAT Svalbard Radar (ESR) was operating simultaneously in a similar ordinary ionospheric mode, but did not observe any increased ionisation. The crucial difference between these radars for this observation might be their location in relation to the Leonids radiant. It was between 39° and 42° above the Tromso horizon during the meteor shower, while the elevation angle was 31-33 ° for the ESR. In the latter case the meteoroids must travel through a longer path in the atmosphere and might thus disintegate at higher altitudes.

Many strong optical meteors were seen above the EISCAT location in Northern Scandinavia, while there is not known observations from Svalbard. The K_p-index characterising the global geomagnetic activity level was 3^+ for this time period. The local geomagnetic activity was about 50 nT at the EISCAT UHF transmitter site and 30 nT at New Ålesund close to the ESR station, both corresponding to low level of disturbance.

The auroral activity was in agreement with the general geomagnetic disturbance level on the mainland area during the time period of interest. Thus auroral precipitation which would cause such an intensive E-layer for 3-4 hours as the observed one cannot be the explanation for the ionisation.

We will study whether the intensive E-region ionisation during the Leonid maximum was caused by meteors. From predicted and observed flux values in free space, we estimate how much excess ionisation the shower can induce at the E-region. We also study the ionisation profiles, their form compared to ordinary auroral Chapman layer form and the position of the bottom of the ionisation in relation to the elevation angle of the radiant.

A new software application for allsky camera networks

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Introduction

We report on a new software system for managing allsky cameras intended for meteor analysis. The software is split into a client component local to each camera, and a central server component which each camera supplies with data. The software is highly modular and major components are open source. Key analysis components are either open source or consist of published, publicly available code.

Client software

The client component runs on a computer local to each camera, and serves only to detect and capture meteor video and to submit the captured data to a central server. Initial detection is by a simple motion detection algorithm that can easily operate at a high video frame rate. A more discriminating algorithm runs in a low priority thread, discarding false events before they are submitted. Data are stored locally and submitted in near real time to the central server. Astrometric calibration is performed by the client module.

The client module also allows access to locally stored meteor events, including the ability to view video and to flag false detections.

The client system can receive specific configuration and operation instructions by querying the central server. No data are transmitted asynchronously to the client from the server.

Server software

The server component is written in PHP, and is therefore compatible with virtually all web server installations. All analysis resides in the server component. This consists of detecting synchronous events, flagging clients to upload video data, determining the local geocentric coordinates for each event, solving the state vectors, calculating the ground path, and solving the orbital parameters.

The server maintains the database which records all events. In typical configuration, every event is recorded but video and orbit solutions are only calculated for multiple station events.

The calculation code is modular and easily replaced as newer methods are developed. Emphasis is on the use of public code, or peer reviewed code modules in order to ensure consistency with other analysis systems.

In addition to its analysis and data management functions, the server software also presents a web-based user interface. This consists of a private management interface, an access interface for camera operators, and a public data portal with data embargo rules.

Öpik-type collision probability for high-inclination orbits: Targets on eccentric orbits

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Traditional evaluation of collision probability between two bodies on bound heliocentric or planetocentric orbits include assumptions that are often only an approximation of their real motion. In particular, these approaches require (i) the orbital eccentricity and inclination of both target and projectile long-term constant, and (ii) their longitude of ascending node and argument of pericenter precessing uniformly in time. Both conditions (i) and (ii) are satisfied for orbits with very small eccentricities and inclinations only. When either of these two elements is large, a tidal perturbation by planets, or the Sun in a planetocentric configuration, makes these elements oscillate in a correlation with the non-linear evolution of the secular angles. About a half century ago elements of these dynamical phenomena were introduced in space geodesy [5] and independently in planetary astronomy [3]. [6] developed an approach which allows the orbit of the projectile undergo such a general secular evolution. An assumption of the circular orbit of the target, however, was a significant drawback of their method.

Here, we extend work of [6] to allow a general eccentric and precessing orbit of the target (assuming though fixed orbital plane in space). We test predictions of our new approach, as well as previous theories, against a direct numerical integration and estimate their validity. A particular run is performed for E-belt projectiles impacting terrestrial planets. We conclude a surprisingly good correspondence of the directly obtained impact record from the numerical simulation and the estimate from our theory depicted in Fig. 1. Based on these results, we infer that the crater density from E- belt projectiles on the Mercury should be roughly comparable (or only slightly larger) to that on our Moon.

We also present simple model of the toroidal source of the sporadic meteoroid complex based on a model of Halley-type comets developed by [4]. Our model provides a distribution of the orbital elements and velocities for the toroidal source comparable to the data from the Canadian Meteor Orbit Radar (CMOR) [2] and also gives a hint for modeling other known sources of sporadic meteoroids.

We will discuss the derivation of our new formalism and its strengths and weaknesses compared to other theories for the evaluation of the collision probability. Further we will discuss predictions of our theory in comparison with the directly obtained impact record from the numerical simulation of the E-belt and predictions of Wetherill's theory and the importance of correct selection of the collision probability formalism in modeling of the sporadic meteoroid complex. Finally, we consider possibilities of further development of our approach: targets on orbits with non-zero inclination or planet-crossing orbits of the projectile.

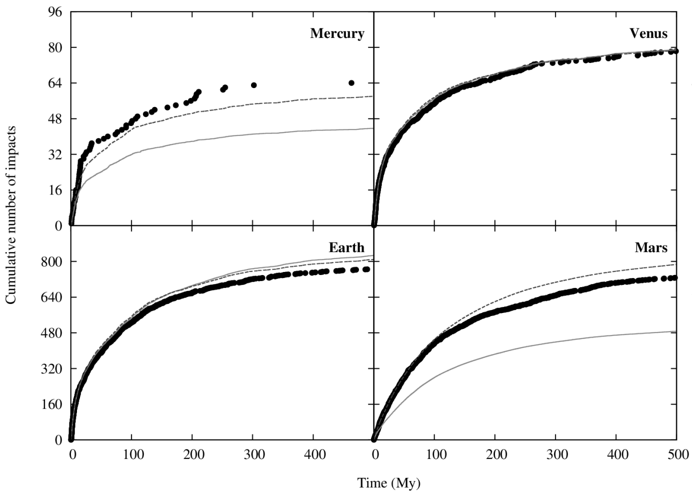

Figure 1: Cumulative number of E-belt particles impacting terrestrial planets. Time origin at the reconfiguration of giant planets (start of the LHB in [1]). Terrestrial planets had their radii multiplied by a factor 5 in our simulation, so the absolute number of impacts is larger than in reality; their ratio –if corrected for small focusing effects– is however correct. Symbols are directly recorded impacts in our numerical simulation. Dark-grey dashed line is a prediction of our theory, light-grey solid line is a prediction of Wetherill's approach [7].

The code providing intrinsic collision probability, position of radiants and impact velocities based on our approach written in FORTRAN 77 language is available at `http://sirrah.troja.mff.cuni.cz/~pokorny/Kozai/`.

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Chelyabinsk meteoroid entry and airburst damage

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Introduction

The Chelyabinsk event is extraordinary because the entry of a relatively large cosmic body occurred over a populated area and caused significant damage. This event was less energetic than the famous Tunguska impact, but comparable in energy to the historical 1963 August 3 bolide for which only infrasound signal was recorded. The Chelyabinsk event is much better documented than both, and provides a unique opportunity to calibrate the different approaches to meteoroid entry modeling and the damaging effects of a shock wave by a large cosmic body entry.

A fact-finding mission

A fact-finding mission was conducted in Chelyabinsk state 3-5 weeks after the event, in a collaborative effort between the Russian Academy of Sciences and local universities in Chelyabinsk and Yekaterinburg, to investigate the extend of the glass damage and calibrate records of the meteoroid entry path and brightness. An international consortium of scientists was formed to investigate the circumstances of the impact and the properties of the recovered meteorites.

Parameters of the Chelyabinsk meteoroid

Infrasonic waves are the important source of information about the fireball kinetic energy. A number of infrasound signals were recorded at different locations in Russia and Kazakhstan at distances 520-1600 km. This data were analyzed to determine the impact energy.

Further information about the kinetic energy is derived from the fireball's light curve and the extend of the glass damage by comparison between modeling of the meteor entry and the damaging effects of the shock wave at the ground with observations.

We find that the energy was not released in a single explosion. A number of numerical simulations were conducted that attempted a more realistic release of energy along the trajectory and these results were compared with observations of blast wave arrival times and the extend of the glass damage.

Blast arrival times measured from time-calibrated video records in the Chelyabinsk/Kopeysk, Chebarkul and Kurgan areas demonstrate a satisfactory agreement with the assumption that the energy deposition continued down to 23-25 km altitude.

Sampling the constant drizzle of meteoric dust in the upper stratosphere

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Introduction

Meteor ablation and evaporation release ionized metal species and molecules into the atmosphere where they contribute to the mesospheric metal 'complex'. Chemical interactions among these metals and ozone while settling through the mesosphere are thought to form meteoric [dust] particles ranging from 0.4 to 20 nm in diameter. These meteoric smoke particles form a layer between ~85 km ~to 35 km altitudes. With no presumption of completeness, meteoric dust appears to be dominated by Fe(Ni) metal, -oxide, and -oxyhydroxide species and carbon in both the mesosphere and stratosphere (Table 1).

TABLE 1: A summary of collected - balloon borne - (in bold) and observed - remote sensing - meteoric smoke particles in the upper stratosphere and mesosphere. Collected meteoric particles in the lower stratosphere and laboratory-produced meteoric dust analogs (in *italics*)

UPPER STRATOSPHERE-MESOSPHERE
CaO
Carbon
carbon(C),
Hematite (Fe_2O_3), wüstite (FeO), magnesiowüstite ($Mg_xFe_{(1-x)}O$; x = 0.1–0.6
Chain-like aggregates of nanoparticles (no chemistry available)
LOWER STRATOSPHERE
Individual ionized Fe, Mg, Ca, Ni, Mn, Na and K species
NiO, (Fe,Ni)O, taenite (high Ni metallic Fe)
α–FeOOH (goethite)
METEORIC DUST EXPERIMENTS
Hematite (Fe_2O_3)
FeOOH (goethite)
Fayalite (Fe_2SiO_4) – Forsterite (Mg_2SiO_4)(olivine);
$MgSiO_3$-$FeSiO_3$ (pyroxene)

This vertical distribution is to be expected for settling of meteoric smoke particles that had formed in the upper mesosphere. The formation of meteoric hematite and goethite dust was confirmed in laboratory experiments conducted to simulate the photochemical meteoric dust formation process. They also suggest the formation of aggregates of Mg,Fe-silicate (olivine; pyroxene; Table 1) that so far still remain to be collected. Condensed CaO smoke and carbon nanoparticles collected in the upper stratosphere (Table 1) may be linked to a bolide fragmentation event. They may represent a previously unanticipated new source of meteoric dust. The chain-like aggregates of nanoparticles (Table 1) resembles the morphology of simulated meteoric Mg,Fe-silicate particles produced in the laboratory experiments with high particle number densities. Meteoric smoke particles settling in the mesosphere and stratosphere could form highly porous aggregates (1) when local dust densities are enhanced or (2) as a result of long residence times. The relative abundances of ionized Fe, Mg, Ca, Ni, Mn, Na and K species in the lower stratosphere when normalized to Fe have a remarkable, but not perfect, chondritic composition, which is consistent with the bulk composition of incoming meteoroids. It is not known if this composition is an average of individual metal(-oxide?) nanoparticles, a porous aggregate of nanoparticles of individual meteoric smoke particles, or a single nanoparticle with a (near)chondritic bulk composition.

DUSTER (Dust in the Upper Stratosphere Tracking Experiment and Retrieval)

Meteoric smoke particles of these elements and/or combinations in this drizzle are collectable by DUSTER that is a balloon-borne, active collector for contamination-controlled retrieval and laboratory characterization of nano- and micrometer particles from the upper stratosphere. On 21 June 2008 DUSTER was launched from Svalbard (Norway; ~78° N). After 55 hours of continuous sampling between 37 and 38.5 km altitude the collecting chamber was sealed prior to recovery in Thule (Greenland; ~72° N). Twenty-four particles were collected in the range of 0.4 to ~9 microns (Fig. 1) plus a single ~25 micron-sized aggregate [1]. DUSTER will augment the still rudimentary database of collected meteoric dust.

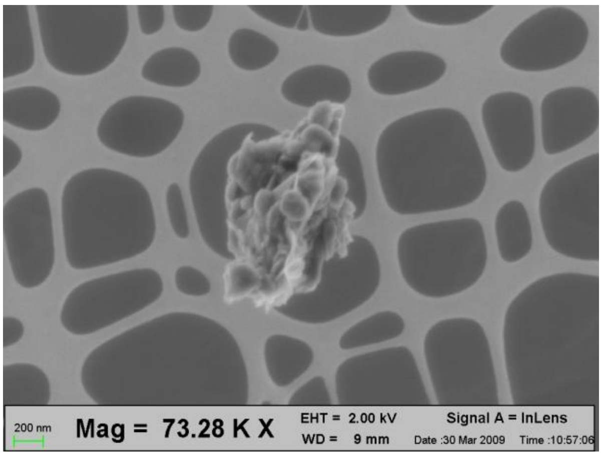

Fig. 1 An almond-shaped micron-size carbon aggregate of numerous (sub)spherical grains. This particle lacks the typical carbon smoke morphology of soot particles collected in the lower stratosphere.

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The meteorite Moss – a rare carbonaceous chondrite

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On July 14, 2006 at about 10:20 a.m. local daylight time (UT+2), a bright fireball traveling SSE-NNW was witnessed by many people, and a loud explosion and a rumbling sound was heard in the air above Moss and Rygge in south east Norway. Shortly after, a small fragment of the meteorite was heard to land on an aluminum sheet and was recovered. Extensive searches in the area resulted in the recovery of 5 stones with a total weight 3.76 kgs. The meteorite got the official name MOSS (Approved Sept. 25, 2006; final classification Jan 10, 2007, Meteorite Bulletin 91). It is classified as a carbonaceous CO3.6 chondrite being one of 6 in this group, and of significant scientific importance.

The Moss meteorite contains abundant small chondrules (most < 200 µm), small (<1 mm) amoeboid olivine aggregates and refractory inclusions, and isolated grains of olivine, troilite, and kamacite set in a gray matrix. The Cr_2O_3 content of fayalitic olivine is low. Image analysis gives 2.2 vol% metal and 2.4 vol% FeS. Refractory inclusions contain spinel, calcic pyroxene, and abundant nepheline that replaces melilite and other primary phases; some perovskite has been transformed to ilmenite, most of the olivine has been converted to more fayalitic compositions. Moss contains 0.21-0.25 wt % C as graphite and organic species with napthalene being the highest molecular weight aromatic species evident [1-5.].

The fall and extensive search for the Moss meteorite fragments will be briefly mentioned. The main focus will be on the mineralogical, petrological, isotope and organic chemical characteristics of the Moss meteorite.

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Recent discovery of few parent bodies: a review

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A concerted effort is underway to identify the parent bodies of meteor showers. Out of the 484 known meteoroid streams, only 102 have an associated parent body, leaving 382 orphan streams. This talk addresses the topic of meteoroids parent body in relation to Rudawska & Jenniskens [2] noticing a connection between comets/asteroids and several newly discovered meteor showers. We carry out a further search to investigate the possible genetic relationship between them.

The newly meteor showers were identified by Rudawska & Jenniskens [2], using a grouping algorithm based on the single linkage method. The method was applied to video meteors collected during the first year of CAMS network operation [1], and meteor orbits detected by the SonotaCo network in 2007-2009 [3]. For several of those newly identified streams they have identified possible parent bodies (see talk Rudawska & Jenniskens).

To confirm the reality of relation between the body and meteoroid stream it is necessary to investigate the evolution of their orbits. The model of generation and evolution of meteoroid stream in the solar system is taken from Vaubaillon et al. [4]. The objects' orbital elements and physical properties are taken from JPL horizons website. The ejections of meteoroids from the possible parent body surface took place when it was passing its perihelion between 1000 A.D. and 2005 A.D. Next, the orbits of ejected meteoroids were integrated to year 2050.

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60 years of the Geminid meteoroid stream modelling

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The Geminid meteor shower is one of the most intense and most studied annual showers. Its first reliable registration is referred to 1862 AD [1]. Parent body of the Geminid stream is asteroid (3200) Phaethon. A concise review of the (3200) Phaethon–Geminid meteoroid stream complex origin could be found in [2]. Recently a review of mathematical modelling of meteoroid streams was given by Ryabova [3]. In this work general principles of mathematical modeling were discussed, and in particular methods of calculations of the stream's age and the ejection velocity. But the objective of the mentioned work was not the historical review, while history of the Geminid stream mathematical modelling is interesting and instructive.

It seems to be that the first work devoted to the Geminid's modelling was that of Plavec [4]. He computed secular perturbations of the Geminid orbit to obtain possible period of the shower visibility. This was the fist stage of modelling when a single orbit was calculated or integrated. Later general features of the Geminid stream structure were studied by integration of small amounts of meteoroid orbits. There were a number of the Geminid stream simulations, every of which laid a stone into the wall of contemporary understanding of the stream structure and process of its formation. They are works of Fox, Williams & Hughes [5–6], Jones [7], Jones & Hawkes [8], Babadzhanov & Obrubov [9] and some others. We'll discuss highs and lows of these models and lessons learned from them.

The qualitative Geminid's model by Ryabova [10–11] which summarized results of 20-years efforts will be discussed *very* briefly. A new preliminary numerical Geminid's model will be presented.

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Forecast of Enhanced Activity of Eta-Aquariids in 2013

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Introduction

Eta-Aquariids (ETA) is one of the established meteor showers. The regular activity is middle level for meteor showers, its ZHR is about 50. The parent body is 1P/Halley which is the same as Orionids.
We tried to simulate distributions of dust trails from 1P/Halley, and found out that some trails would approach the Earth in 2013. Therefore, it was predicted that eta-Aquariids would be enhanced in 2013.

Dust trail model

We applied the simplest approach of the dust trail model. Each trail was assumed to be formed by meteoroids ejected during the perihelion passage of the parent comet. The trail was calculated by test meteoroids ejected parallel to the comet motion, both ahead of and behind the comet. To calculate the perturbations, we included the three largest main-belt asteroids in addition to the eight planets, Pluto and the moon. We did not take the effect of radiation pressure on the meteoroids into account in our calculation. The comet orbital elements were those calculated by Yeomans and Kiang [1]. The calculated trails were those generated from -1403 (1404 BC).

Forecast from simulation

Fig. 1 shows the distributions of dust trails in 2013. Two kinds of trails (-1197 and -910 trails) would be expected to approach the Earth's orbit. These dust trails were complicated because of the perturbations.

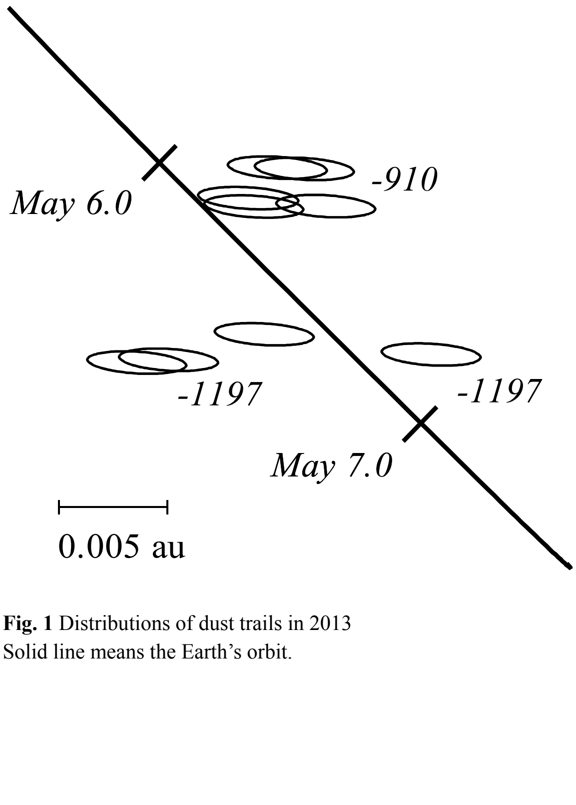

Fig. 1 Distributions of dust trails in 2013
Solid line means the Earth's orbit.

Table 1 gives the situation of the dust trails. The date is the time when the Earth passed the ascending node of the given trail particles. Delta-r is the difference in heliocentric distance between the Earth and each trail in the ecliptic plane. The peak would be expected to occur between 5:00 and 22:00 on May 6. We announced this forecast based on our simulation to meteorobs mailing list (by IMO) and NMS mailing list (by Nippon Meteor Society).

Table 1 Data of main trails in 2013

Ejection Year	Expected Peak Time (ut)	Delta-r (au)	Ejection Velocity (km/s)
-910	May 06.24 05:45	-0.0018	-2.12
-910	May 06.26 06:16	-0.0017	-2.05
-910	May 06.27 06:27	-0.0017	-2.11
-1197	May 06.53 12:37	+0.0021	+3.44
-1197	May 06.89 21:19	-0.0026	+3.43

Observation results

Enhanced activity of eta-Aquariids was actually observed in 2013. According to the summary by IMO, the peak was observed between about 2:00 and 18:00 on May 6, the ZHR reached about 130 [2]. The peak time was consistent with the expected time based on our simulation.

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Saturnian resonances in meteor streams

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Introduction

Various previous works,[1],[2],[3],[4],[5], have shown the relevance of Jovian mean motion resonances (MMR) in meteor streams. These resonant structures are known to have produced enhanced meteor phenomena, [6],[7],[8],[9],[10],[11],[12], in the past. Nevertheless there has been practically no work or detailed simulations by solar system dynamicists in the context of Saturnian resonances. Most scientists seem to have thought that such effects are practically negligible (because of Saturn's mass being lower compared to that of Jupiter's) when it comes to causing spectacular meteor activity on our Earth. However we find this is indeed not the case. Our work finds active Saturnian resonances in two major streams, namely Orionids and Leonids, which are known to exhibit exterior, [13],[14],[15], Jovian resonances.

Separation of Jovian and Saturnian resonances

Since there is a well known 2:5 near commensurability between the orbits of Jupiter and Saturn, widely known as the great inequality, [16],[17],[18], it is vital to cross check that the Saturnian resonances we found are real and not entwined with near commensurate Jovian resonances. Our careful verification confirms the presence of meteoroids librating with respect to Saturn.

Stream Dynamics in Orionids and Leonids

The effects of 1:6 and 5:14 MMR (Jovian) have already been studied quite elaborately in Orionids and Leonids respectively. Their influence, [19],[20],[21],[22],[23], on causing meteor outbursts or storms in the past and present times has been well understood. Now we find interesting evidence of 1:3 and 8:9 MMR (Saturnian) in Orionids and Leonids respectively. Our calculations show the presence of dust trails retaining their compact structures in real space for the order of thousand years, in strong contrast to the widespread dispersion of non-resonant meteoroids along the whole orbit. Highly dense resonant structures, formed due to Saturn, in these two streams can lead to intense meteor activity on Earth.

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Simultaneous Infrasonic and Optical observations of bright meteors: analysis of acoustic source heights and signal classification

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During their passage through the atmosphere, meteoroids produce a range of phenomena, including a hypersonic shock, which may be recorded at the ground in the form of infrasound in some cases. Infrasound from meteors offers an additional means to probe both meteoroid characteristics (mass and size) as well as ablation phenomena such as fragmentation [1]. In particular, comparison of infrasonic [Figure 1] and optical records [Figure 2] from bright meteors allow cross-calibration of mass scales and insight into the signal phenomenology of infrasonic meteor shocks.

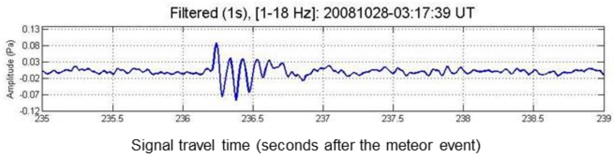

Figure 1: Example of an infrasound signal received at ELFO.

Figure 2: Example of a meteor seen by the All-Sky Camera Network.

In this study we have used the Elginfield Infrasound Array (ELFO), located near London, Ontario, Canada, in conjunction with optical instruments of the Southern Ontario Meteor Network (SOMN), to correlate over 75 simultaneously optically detected meteors with infrasonic signals recorded at the ground. In order to fully analyze the source dynamics of meteor infrasound production, it is necessary to establish where along the meteor trail the infrasonic signal is produced [Figure 3].

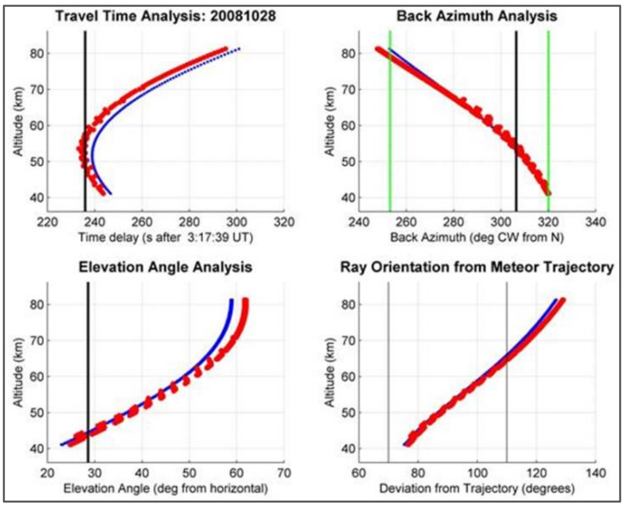

Figure 3: A composite plot showing the raytracing results for a single simultaneously detected meteor.

A unique aspect of our study is the fact that all simultaneously detected meteor events are at short ranges to the infrasound array (typically within only 200 km). This local detection minimizes the distorting effects produced by atmospheric propagation, allowing better reconstruction of the original source function in principle.

In this talk we will describe a proposed phenomenological classification system for our suite of meteor infrasound detections, together with analysis and interpretation of the meteor infrasound signals in relation to optically measured trajectories and lightcurves.

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Documentation of 250 fireballs observed in Norway about hundred years ago

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Abstract

In 1941 the Norwegian Academy of Sciences, presented a study in the Mathematical-Natural Sciences section, by the Norwegian astronomer Sigurd Einbu. The study was named "Observations of 250 fireballs seen in Norway during the 1903 – 1941 period", [1].

In this report, the information of each fireball is presented in a table containing 8 parameters, including their radiants. The report also contains several illustrations.

For about 60 of the most interesting fireballs, Einbu included additional information, as describing them in more details. Like, those fireballs producing infrasonic sounds, and/or having superbolide brightness. Also, the strong smell of sulfur, have been reported by a number of persons in a meteorite drop zone. Also, a unique incident of four bright fireballs that were observed within a period of 12 hours, all with the same radiant.

During this period, we also experienced the brightest fireball that ever has been observed in Norway, the Trysil superbolide, of 1927.

This paper discusses Einbu's report, and with respect to when it was published, is surprisingly well suited to also to be read and studied by interested researchers, at this Meteoroids 2013 meeting in Poznan.

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Meteorite dropping Geminid recorded

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Introduction

The Geminid meteor shower is one of the most active of the year with a stable peak activity regularly observed around December 14 [1]. Geminids are more cohesive than any other shower meteors [2,3]. The parent body is asteroid-comet transition object 3200 Phaethon, nature of which is subject to continuoius debate [4]. In this work we clearly show that Geminds can produce meteorites, which was only a matter of speculation up to now [5].

Observational data and results

We report observation of the unique Geminid fireball which was recorded in the Czech part [6] of the European Fireball Network (EN) on December 13, 2012 at 04:12:59 UT. It was recorded photographically by two all-sky automated fireball observatories at the most western stations Primda and Churanov (Fig.1).

Fig.1 EN131212 Geminid fireball recorded at the Czech station Churanov

Photoelectric light curve (Fig.2) was recorded altogether on 7 Czech stations (it was overcast at 5 stations) and it provides us with very detailed information about light production, exact time and also about fast processes accompanying atmospheric flight of this fireball. It is discussed in detail in [7]. This contribution is focused mainly on the analysis of the photographic records. It was perfectly clear at both stations and they were very suitably located in respect to the fireball trajectory, i.e. reasonably close to the fireball (distances from Primda 128-47 km, from Churanov 177-125km) and with the sufficiently high intersection angle between planes (49.4°). Very precise and reliable determination of atmospheric trajectory, all important physical characteristics, and heliocentric was possible. This moderately bright fireball, which reached –9.5 maximum absolute magnitude, was caused by a 1.2 kg Geminid meteoroid. From its heliocentric orbit defined by the elements a= 1.331 AU, e = 0.8953, q = 0.1393, ω=324.82°, Ω = 261.3778° and i = 24.00° it is no doubt that this meteoroid belonged to Geminids.

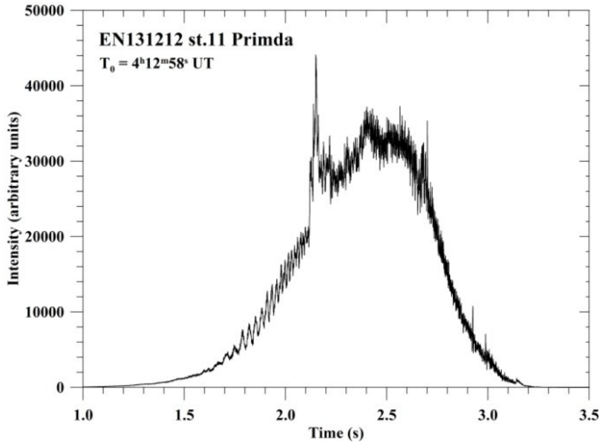

Fig.2 Light curve of the EN131212 Geminid fireball taken by the fast (5000 samples/s) photometer at the Czech station Primda.

The uniqueness of this Geminid fireball consists in its record deep penetration in the atmosphere (32.6 km) and in the fact that in all likelihood a small part of its initial mass survived severe deceleration in the atmosphere and landed on the ground near German town Gröbenstädt. Such deeply penetrating Geminid was never observed. The deepest known Geminids have terminal heights about 38km and terminal velocities around 15km/s [2,5]. This one penetrated 6 km deeper. A very impressive characteristic of its atmospheric flight is the observed deceleration. The maximum value -35 km^2/s^2 was reached at a height of 38.5 km and terminated with the value of only -12 km^2/s^2. During the flight this Geminid meteoroid slowed down from original speed 35.96 km/s to 6.9 km/s. This meteoroid is probably the fastest candidate for a meteorite dropping event ever observed. It was a particularly strong piece of material which withstood significant fragmentation. It is evident that we cannot expect large meteorite, maximally 10 grams but on the other hand even such small piece of Phaethon would have invaluable value. This is for the first time when we have irrefutable evidence that it is possible to find real meteorite which undoubtedly belongs to any meteor shower and its parent body. Brief meteorite search by a German team was not successful.

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The historical and geological data of extraterrestrial matter fall in Great Poland Lowland

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Falls of meteorites are a natural phenomena. The last well-documented events on Polish territory were noted near Oborniki (2012) in the Giżycko vicinity (2011) and Baszkowa near Piaseczno (1994). The oldest meteorites fall on the Great Poland Lowland (Wielkopolska) is suppose on early/middle Middle Ages (artifacts and paintings). Some press reports exist about meteorite falls too: Wilkanówko near Zielona Góra (1841), Górna Świdnica, Krobia, Wschowa (1856/57), Ratyń near Konin (1880), the meteorite passage observed in Wielkopolska (1886), Grzempy (1910).

Poland is an unique territory with the largest meteorite showers in Europe - Pułtusk chondrite shower (1868), Łowicz mesosiderite shower (1935) and Wielkopolska iron meteorites shower if to add up Morasko combine with Oborniki, Przełazy – Seeläsgen and Jankowo Dolne. The first information about the discovery of a Wielkopolska – Przełazy iron meteorite comes from 1847 year. The Morasko ones appeared in written in 1914, and signal about the findings two lamps near Oborniki few years before the second world war. The Jankowo Dolne iron meteorites were reported in 2004 year. According to latest interpretation the Przełazy, Morasko,and Jankowo Dolne represent a single large iron meteorite shower. This hypothesis is not fully proofed.

The most famous and the best documented is Morasko site, limited to a relative small area on the northern slope of the Moraska Góra/Moraska Hill and its surroundings. Among numerous meteorites, the micrometeorites and extraterrestrial spherules and ashes, the craters were recognized there. As a result of friction with the atmosphere of a meteorite surface not only heats up generating a thin melt-crust, but also luminescence zeroing occur there. The meteorite falling on the mineral ground, due to the impact heat generates sinter-coating/crust with zeroed luminescence. All the basic TL data obtained in both crusts varied in between 4.6 to 6.1 ka BP. The indirect confirmation of the Morasko impact age (OSL data), obtained for the alloy of Neogene and Quaternary mineral deposits in the bottom of two largest craters, received a significant number of luminescent indicators aged <10000 and <5000 years. This confirm the zeroing during impact, which also documented the origin of morasko's symmetrical depressions as a meteorite craters. The palynological estimations and radiocarbon dates assume that sedentation occurred there shortly after crater's generation, begun about 5500-5000 years BP. It should be add that radiocarbon dates of peat layer enriched with metal spherules in the kettle-holes near Oborniki gave results little less 5000 years ago. It should be good corroborate the trajectory of the Morasko meteorite fall from the north.

The time and exact place of meteorites fall in Przełazy and Jankowo Dolne is not known. The indirect data for Przełazy giving possible fall location in the south-west village neighbourhood, going on the end of Late Glacial and beginning of the Holocene. The trajectory of fall was probably from the north-north west.

Dating convergence in the luminescence and radiocarbon techniques as well as palynological and morphogenetic study, illustrate well the Morasko impact time to ~5000 years BP, getting there extraterrestrial matter and meteorite craters origin. The Przełazy event seems to be older. The Jankowo Dolne meteorite fall is totally unknown.

Radar observations during the ECOMA campaign on the Geminids 2010

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Introduction

The ECOMA (Existence and Charge state Of meteoric smoke particles in the Middle Atmosphere) sounding rocket campaign on the Geminids 2010 investigated optical parameters and number densities of meteoric smoke particles before, during and after the meteor shower. The rocket campaign was supported by three radars measuring the Geminid activity in order to gain information about the absolute meteor flux into the MLT (Mesosphere/lower Thermosphere).
The specular meteor radar (MR) observations were carried out using the Andenes MR on the island Andoya in Northern Norway and the Juliusruh MR on the island of Ruegen in Northern Germany. Both MR monitored the sporadic and meteor shower activity for December 2010 covering the complete campaign period. These two radars measured the meteor entry velocity and the source radiant. The position of the source radiant was used to separate potential Geminids from the sporadic meteor background to estimate the absolute meteor flux.
The meteor head echo observations were conducted with the new MAARSY radar on Andoya. The system employs an active phased array antenna and combines rapid pulse-to-pulse beam steering capabilities with a multi-channel receiver system, which permits to determine the trajectory and velocity for each individual detected head echo with high accuracy. Based on these measurements we were able to separate potential Geminids from the sporadic meteor background and perform a detailed comparison to the specular observations.
Further we compared the derived sporadic meteor fluxes to the sounding rocket measurements of the MSP column density and the Na column density measured with the Na Lidar at ALOMAR.

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Transverse motion of fragmenting faint meteors observed with the Canadian Automated Meteor Observatory

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Nine fragmenting faint meteors, captured by the Canadian Automated Meteor Observatory (CAMO), were analysed to determine the transverse motion of the fragments. CAMO is a two-station, automated, image-intensified video system [1]. Each station is comprised of a tracking narrow-field camera (~4.8 m per pixel at 150 km range), guided by a fixed wide-field camera (105 m per pixel at 150 km). Data from the narrow-field cameras were used to measure relative speeds of distinct fragments perpendicular to the meteor's direction of travel. A sample event capture is given in Fig. 1. Meteor height, velocity, and absolute magnitude were calculated with wide-field data.

Eight of the nine meteors, with photometric masses $\sim 10^{-4}-10^{-6}$ kg, displayed definite transverse motion of fragments, with speeds up to 117.3 m s^{-1}. Fragments showed constant transverse speed, with negligible acceleration. Observations are summarised in Table 1. The meteors were observed at heights between 104 and 75 km. Fragmentation and dispersion of the meteoroids is not explained by pressure gradients, unlike in the case for larger objects, as these small bodies encounter free molecular (or transition) flow in the rarified atmosphere. Instead, rotational fragmentation [2], as well as triboelectric charging, fragmentation, and electrostatic repulsion [3] of the resulting fragments are found to be plausible processes to explain the observations.

Understanding the fragmentation and subsequent dispersion for faint meteors is important in improving the accuracy of radar observations, as well as providing constraints for high-resolution models. Determining the strength and structure of these small meteoroids also provides insight into the fundamental physical makeup of their parent bodies.

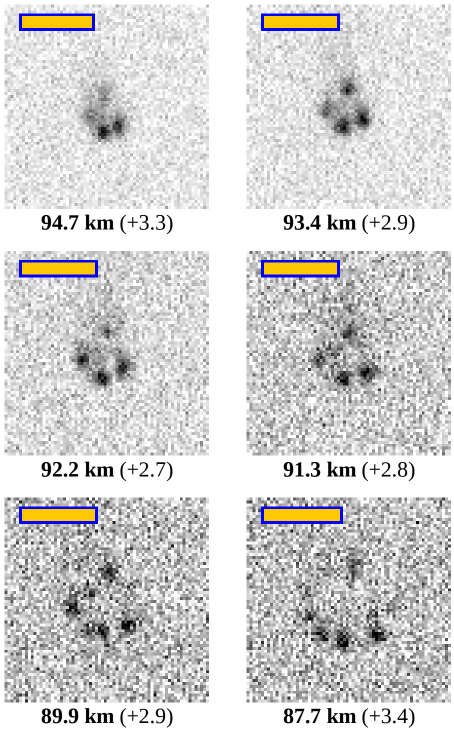

Figure 1: Six frames for event 20101013_064003 from the Elginfield tracking narrow-field cameras. The average velocity of the meteoroid was 26.0 km s^{-1}. The height of the meteor is given for each frame, as well as the absolute magnitude in brackets. Scale bars on each figure represent approximately 100 m. The colours have been inverted for visibility.

Table 1: Characteristics of meteors studied in this survey. h is the height range of observation, v is the average velocity throughout the observations, M_{peak} is the peak observed absolute magnitude, m is the photometric mass, v_{t} is the observed maximum transverse speed of the fragments, and N_{frag} is the number of fragments observed.

Name	h (km)	v (km s^{-1})	M_{peak}	m (kg)	v_{t} (m s^{-1})	N_{frag}
20100914_054515	98 - 84	29.6	$+1.9$	2.3×10^{-6}	85.2 ± 10.2	3
20101010_023500	100 - 87	30.6	$+1.6$	6.0×10^{-5}	117.3 ± 20.1	5
20101013_064003	98 - 77	26.0	$+2.5$	2.6×10^{-6}	94.3 ± 16.1	7
20101016_070052	86 - 75	17.9	-0.4	1.3×10^{-4}	79.3 ± 21.8	5
20110204_023725	95 - 77	15.4	$+1.2$	1.4×10^{-4}	21.1 ± 6.0	2
20110330_061029	95 - 81	25.1	$+0.4$	1.5×10^{-5}	46.0 ± 4.3	4
20110403_065305	104 - 96	67.3	$+1.2$	1.2×10^{-6}	79.8 ± 23.6	7
20120322_072602	101 - 85	42.4	$+1.5$	6.7×10^{-7}	11.4 ± 21.2	2
20110523_080013	95 - 84	28.5	$+1.7$	5.2×10^{-6}	99.9 ± 12.2	7

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High Resolution Video and Light Curve Analysis of Meteors

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Meteor light curves are often used to determine whether a meteoroid is fragmenting: for example, a classical shaped light curve is evidence of a single solid body, while a symmetrical light curve is evidence of a dustball structure. Using the Canadian Automated Meteor Observatory (CAMO), we collect optical data from both narrow field (with resolution of up to 3 m per pixel) and wide field cameras (26 by 19 degrees). We can extract the light curve of a meteor from the wide field camera and simultaneously observe the spread of fragments in the meteoroid in the narrow field camera, which tracks the meteor using a pair of mirrors.

In this work, we investigate the link between the high resolution narrow field videos of meteors, the shape of their wide field light curves, and their orbital properties. The orbital characteristics of the meteor allow us to infer characteristics of the parent body, including its origin (long period comets, Jupiter family comets, or asteroidal).

Since 2010 we have amassed almost 3000 two station tracked events with the high resolution narrow field camera, with the corresponding wide field observations. In this work, we present the classification schemes used for the wide and narrow field data, and preliminary correlations among them. Figure 1 shows the depth of detail we can acquire from the narrow field videos, specifically of a fragmenting meteor. The light curve of this meteor is shown in Figure 2.

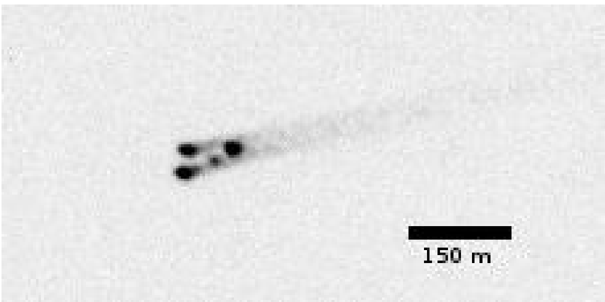

Figure 1: A fragmenting meteor as seen by the narrow field camera.

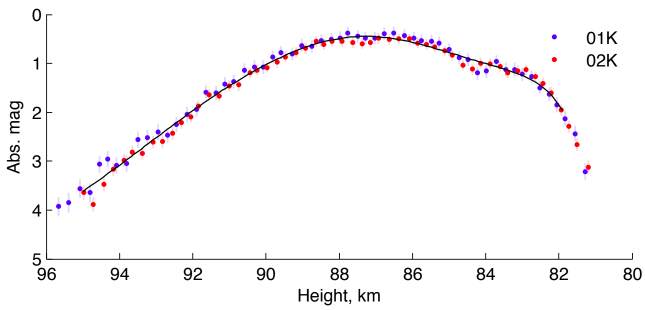

Figure 2: The light curve of the meteor shown in Figure 1.

Automatic Detection of Asteroid and Meteoroids – Wide Fields Survey

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Introduction

We propose a robotic low-cost optical survey for 1 – 300 m diameter interplanetary objects near the Earth with four state of the art telescopes with extremely wide field of views. The small Near-Earth Asteroids (NEA) represent potential risk but also accessible planetary materials from the early Solar system evolution for future robotic or human space missions or commercial activities. The survey system will be optimized for the recognition of fast moving trailed asteroids and meteoroids and will provide real-time alert notification. The expected cost of the project that includes 1-year development and 2-year operation is $1,000,000. The successful demonstration of the system will promote cost-effective ADAM-WFS systems to be built around the world.

Concept

ADAM-WFS will consist of 4 identical wide-field astrographs (Houghton-Terebizh D=300 mm, f/1.44) on a fast-track mount with accurate guiding (Fig. 1). Each telescope will be equipped with a large-scale single chip CCD camera (4096x4096 pix) providing a total FOV of almost 100 square degrees. The predicted limiting magnitude with the wide-band optical filter is +17.5 at S/N~5.0 with 30 sec exposures and a pixel scale of 4.36 arcsec/pix. This configuration is able to survey almost the entire available sky in 3 visits per night and rapid image processing will provide moving targets in almost a real-time. We will use the Moving Object Processing System (MOPS [1]) that has been utilized by the Pan-STARRS system. Stationary transients will be processed during the daytime. We propose to build the system at an existing observatory with existing infrastructure and dedicated 60-80 cm follow-up telescope.

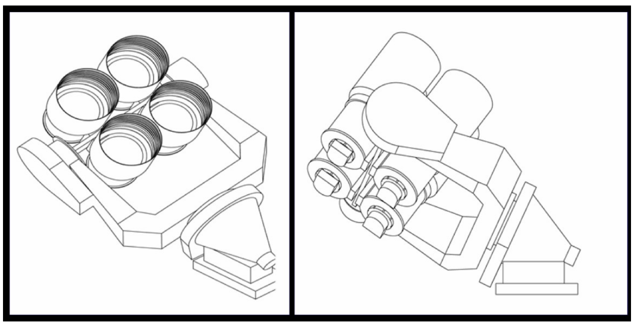

Fig 1: Concept of the mount and optical assembly of the ADAM-WFS.

Goals

• Discovery and characterization of small NEA and close-approaching populations [2].
• Search for potential Earth impactors [3] and bolide pre-entry detection.
• Discovery of active comets.
• Monitoring and characterization of space debris.
• Automated sparse light curve photometry of bright main belt asteroids.
• Stationary transient detection (variable stars, novae, supernovae, lensing events, gamma ray burst, etc.).

Why ADAM-WFS?

• Cost-effective
• All sky vs. deep survey. We will cover entire sky per night for the cost of the lower limiting magnitude.
• Do not reinvent the wheel. We will use existing methods, software pipelines and technology, avoiding years of development and testing. Off the shelf solutions.
• Compact team - Individuals with experience on existing and planned survey telescopes (Pan-STARRS, ATLAS, LSST) and external cooperation and consultations.
• Existing infrastructure – ADAM-WFS will be built on existing observatory and buildings. Future deployment of ADAM-WFS systems on existing observatories.
• Focused on asteroids - most surveys are multidisciplinary. ADAM-WFS is optimized towards asteroids.

Expected outcome

The results of ADAM-WFS simulations using MOPS, OpenOrb [4], the Pan-STARRS synthetic Solar System Model [5] for impactors and close-approaches with D<300m and SPACE-TRACK debris catalog were carried out. We expect to discover 30 – 120 NEO with D>10 m within 10 lunar distances per year, similar number for D<10 m and detect 350 – 550 space debris particles per night. We will obtain 650 light curves of bright main belt asteroids every year.

Acknowledgments

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Solid Hydrogen and Micrometeors of Interstellar Origin

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Abstract

The elemental composition of interstellar dust remains uncertain; it could be quite different to interplanetary dust. Recent work has given new life to an old idea - that solid H_2 could be a significant component of interstellar dust. That idea was discarded 40+ years ago because it was thought that small particles of solid hydrogen could not survive for more than a few months in interstellar space. However, that conclusion is based on the sublimation rate of the pure solid, whereas grains are expected to acquire surface charges and these lower the molecular sublimation rate. The unique electronic properties of solid H_2 lead to a double-layer charge configuration which is neutral overall, so that charging continues to high surface densities. Consequently hydrogen grains may survive indefinitely in interstellar space. Furthermore there is spectroscopic evidence for solid H_2 in interstellar dust. The molecular ion H_6^+ is known to form in condensed H_2, and only in condensed H_2. All seven of the expected vibrational transitions of this ion are coincident with strong mid-IR bands of absorption or emission from the ISM. I will describe these new developments and discuss the implications for observations of interstellar micrometeors.

Correction Effect to the Radiant Dispersion in case of Low Velocity Meteor Showers

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Introduction

We usually apply various corrections for determining apparent radiant point to the actual trajectories of shower meteors. In case of low velocity meteor showers, the velocity corrections should be carefully performed together with the error estimate. Here we show that such correction strongly affects the dispersion of radiant points especially in case of low geocentric velocity meteor showers.

Examination

The radiant is described by the synthetic vector between the velocity of meteoroids and the velocity of the Earth. We assumed the range of error in the estimate of velocity "d", and derived the corresponding radii of radiant points in various meteor showers. Figure 1 shows the result when "d" = 2 km/sec. We can easily recognize the correction effect of the error is larger with lower velocity meteor showers. While in the case of large velocity such as Leonids and Perseids, the derived dispersion of the radiants is small, it becomes quite large in the case of Draconids and Phoenicids.

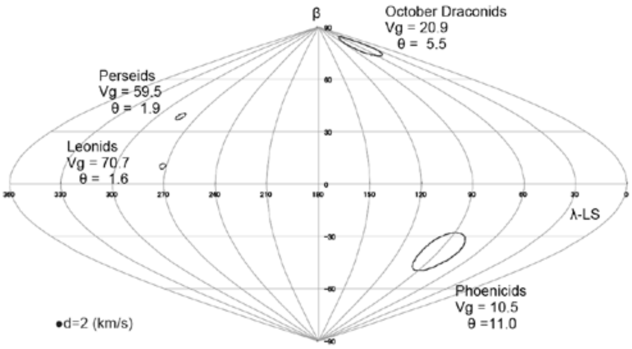

Fig. 1 Derived radii of radiant points corresponding to the error of 2 km/sec. "Vg" is the geocentric velocity of meteor showers.

Detection of meteor showers

We carried out careful inspection to the observed data for low velocity meteor showers by taking this correction effect into account, and found the existence of activities of Phoenicids in 2008 and December Piscids in 2012. Figures 2 and 3 show the result of the obtained radiants of uncorrected and corrected of this effect.

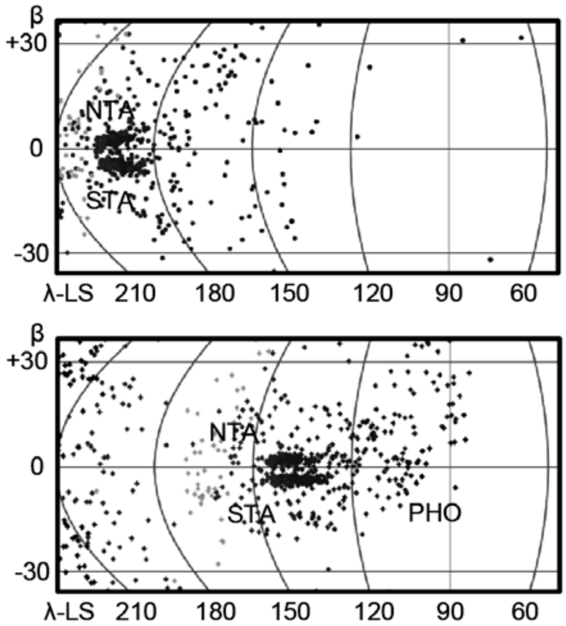

Fig.2 Distributions of radiants between October 20 and November 20 in 2008. Upper panel shows uncorrected radiants and lower panel shows corrected radiants. The radiant of Phoenicids (PHO) can be recognized only in corrected figure.

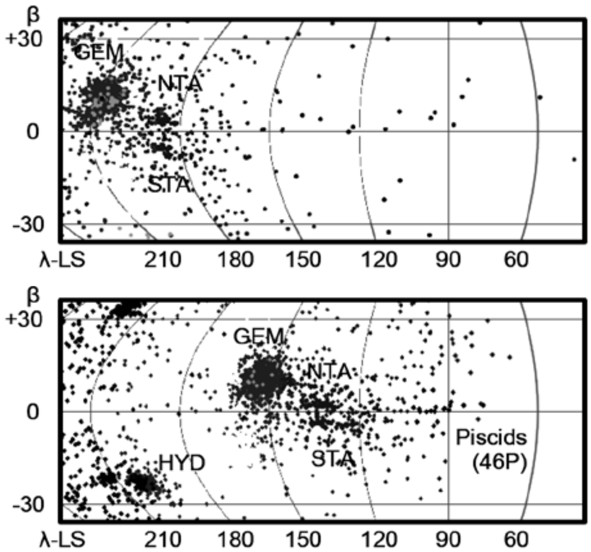

Fig.3 Distributions of radiants between December 1 and 21 in 2012. Upper panel shows uncorrected radiants and lower panel shows corrected radiants. The radiant of December Piscids can be recognized only in corrected figure.

On the standardization of photometric results of meteor registrations processing

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The traditional method for meteor brightness measurements claims that meteor brightness is equal to the stellar magnitude of a star that looks like meteor in the brightest point of its track. The obtained brightness has to be adjusted to “standard” distance 100 km for proper comparison of meteors that were observed at different distances. This rule was convenient for comparison of observations by different observers and for analysis of brightness distribution of meteors from observed showers. This “meteor brightness” is non-system unit, because it does not refer to the ground illumination by meteor as standard stellar magnitudes mean. The matter is that illumination time of each angular resolution element of light sensor is different for meteor and for referent star, so simple estimation of “point” brightness of meteor is not enough for measurement of instant meteor brightness. Besides that, the maximal meteor brightness cannot indicate total light flux from meteor that is necessary for calculation of meteoroid mass. The modern meteor science needs objective observational data that allow serious mathematical processing.

The ratio of input signals from meteor N_m and referent star N_* in a single resolution element of an optical sensor is:

$$\frac{N_m}{N_*} = \frac{I_m}{I_*} \times \frac{q}{\omega_m F \tau_*},$$

where $I_m(t)$ and I_* – are ground illuminations [photon/s·cm^2] of meteor and referent star respectively, ω_m – angular meteor velocity [radian/s], τ_* – time resolution of sensor [s], F – focal length of optic [cm], and q – linear dimension of the sensor resolution [cm]. When this ratio is 1, illumination from meteor is larger than from referent star by factor ($\omega_m F \tau_*$/q). Only in the case when meteor is slow enough to rest in resolution element during exposition τ_*, meteor and referent star will have equal brightness (mention that it is true for all-sky cameras).

Human eyes have nearly same properties, so visual observers estimate brightness of the same meteor equally. But photographic and TV-cameras are various, and direct application of traditional method for meteor brightness measurements will surely lead to unbearable errors.

Some part of kinetic energy of meteor is radiated in visible light. So energetic parameter of any meteor is its total light flux. It can be calculated from measurement of total registered light flux of the meteor if distance to the meteor is measured too. Thus double-station observations seem to be most valuable for measurements of this main physical parameter of meteors. High frame rate of TV cameras allows to add total light flux by its time dependence, that characterizes ablation processes of meteor in atmosphere.

Single-station observations allow correct measurement of instant illumination by meteor as well as time dependence of visible meteor brightness (if possible).

Our propositions are:

- meteor observers reports have to contain meteor brightness corrected for observation technique properties and for meteor angular velocity.
- If possible, light curve for each meteor is desirable.
- Double-station observations reports on track and orbital parameters have to be added with total light flux measurements and, if possible, with meteor luminosity time dependence.

The Chelyabinsk bolide as a prove of cometary nature of Earth orbit crossing bodies.

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The February 15, 2013 Chelyabinsk Bolide was registered by numerous TV-cameras with high-resolution parameters from different sites since its appearance up to its total disappearance. Coordinate processing of this data allows precise determination of spatial trajectory of the bolide and parameters of its orbit. This is the first super-bolide event registered carefully enough to reveal its nature.

As the bolide moved at narrow angle to horizon, we can propose that the pressure increased slowly, and moment of the main light flash coincides with moment when increased air pressure became enough to break the body. Observed behavior of brightness evolution of the bolide as well as its trail picture indicated that initially a unit body penetrated the Earth's atmosphere, and then split into two fragments, and they in their turn broke into numerous tiny particles. The final destruction took place at altitude about 22-23 km [1]. As a result of instant deceleration of large mass by airflow, its whole kinetic energy turns into heat energy like explosion, with light blast and shock wave.

Basing on estimation it is possible to calculate the total bolide mass. NASA made such estimations on the base of analysis data from infrasonic registrations and observations from satellites. They came to the explosion energy from 300 to 500 kiloton TNT [2]. It is equal to $12 \div 20 \cdot 10^{14}$ J. For the velocity $1.8 \cdot 10^4$ km/s it leads to the value of initial bolide body mass of $(7 \div 12) \cdot 10^6$ kg. This is ordinary level of mini-comets blast observed in the Earth atmosphere by intelligence satellites.

At the height of the bolide explosion we can assume atmosphere density dependence from height exponential and calculate the value of contrary flow pressure to the bolide body when it was dispersed. Preliminary calculations give 15 MPa, and more accurate calculations lead to 3.5 MPa. These data show that strength of the bolide body was some above strength of pure ice but definitely less than friable sandstone [3]. So we come to conclusion that the main body of the Chelyabinsk bolide was ice.

Gathered after the bolide event meteorites are referred to hondrides. As our results reveal that the main bolide body has to be ice composite one only, it means that all meteoritic material was initially inside bolide ice body. This conclusion is in total agreement with generally accepted idea on the origin of meteoroid streams as result of disaster parent comet nuclei.

The Chelyabinsk bolide seems to be just the sample of the second generation comet nuclei [4]. The bolide reveal itself as unit body consisted mainly of volatiles, though fallen to the Earth meteorites were of refractory material evidently being brought here as intrusions of the main body matrix. Arguments for this proposal can be obtained as age measurements of examined meteorites. The isotopic meteorite ages has to reveal time since last harden of its previously melted material. If it was in melted condition inside Phaeton, then the isotopic age will be about 4-4.5 billion years. In the same time "exposition" age of the same meteorites, that show duration of exposition of the meteorite surface by cosmic rays will be miserable, as all meteorites were protected from cosmic rays up to the moment of their fall. So meteorites from the Chelyabinsk bolide have to radically differ from any other meteorites that spend long time in the open space without such protection since the time of their parent comet total disaster. The care analysis of the Chelyabinsk meteorites ages would be a key to their real origin.

The Earth as a planet cleaned its orbit surroundings of short-period bodies ages ago. Only comets or their remnants can cross the Earth's orbit and collide it. The Chelyabinsk bolide is a sample of a second-generation comet nucleus disaster product collided with the Earth and observed in its atmosphere. There is no obstacle to claim that there is not larger body among meteoroids on the parent comet's orbits. So detection of such dangerous bodies seems to be most effective by inspection of meteor orbits population as the meteor orbits are true indicator of parent comets orbits.

This work was partially supported by the Program 22 for basic researches of the Presidium RAS "The Basic Problems of the Research and Development of the Solar System".

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[071]

Meteoroid stream flux profiles derived from the IMO Video Meteor Network

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Introduction

The video meteor network of the International Meteor Organisation (IMO) consists of 81 narrow-angle video cameras, which are capable of detecting meteors in visible light down to a mean limiting magnitude of $3.0{\pm}0.8^m$ (with reference stars detected down to $4.0{\pm}0.9^m$). All stations are operated using the METREC meteor detection software. The software initially focused on collecting astrometric and photometric measurements, but in 2011 METREC was extended to provide flux estimates. [1]

Results

In this poster we present an overview of the meteoroid stream flux profiles which have been obtained in the first two years of operation. The profiles were obtained using a web-based tool, called METREC FLUXVIEWER, which allows the activity curves to be generated in near real-time (e.g. Fig. 1). Moreover, we show that these video-based flux estimates are consistent with those derived from visual counts by human observers.

Conclusions

The IMO Video Meteor Network provides the much-needed capability to monitor the activity of meteoroid streams at ~faint optical magnitudes, down to a typical depth of 3rd to 4th magnitude.

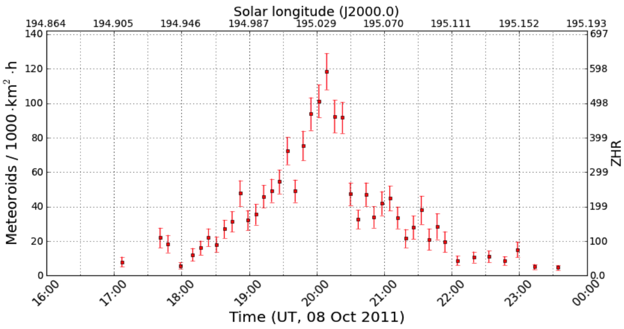

Fig. 1 MetRec-based flux profile of the 2011 Draconids. During the peak, this graph was updated every minute and made available online. [2]

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Chemistry of Benešov meteoroid

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Introduction

Benešov meteoroid penetrated into the Earth's atmosphere on May 7, 1991, its initial mass was about 4 000 kg [1]. Analysis of fragmentation of parent body was interpreted as an evidence of stony nature of this meteoroid; bands of diatomic molecules such as CaO, FeO, AlO, and MgO were detected in spectra of this superbolide [2]. Recently several pieces of Benešov meteorite (H5, LL3.5, and achondrite) were found [3].

Equilibrium composition of impact-produced cloud

Equilibrium approach and quenching theory were already applied to study the chemistry of impact-produced cloud formed by Benešov meteoroid [4]. However, in this paper it was assumed that Benešov bolide had the elemental composition similar to that of CI chondrite. We performed new calculations of the chemical composition of the impact-produced cloud for the case of impactor with much lower content of volatile elements H and C typical for LL chondrite [5], the largest Benešov meteorite [3]. Chemical time scales of main reactions with the participation of refractory elements were estimated based on NIST data base [6]. Quenching of chemical reactions occurs at 1500 – 2000 K for the case of pressure equal to 0.05 bar which is corresponding to the altitude of 20 km. Main compounds of refractory elements are SiO_2, AlO, FeO, and MgO. Difference between equilibrium chemical composition of the impact-produced fireballs formed after collisions of CI and LL chondrites is negligible because in both cases content of metal hydroxides is quite low.
Among impact-produced species of atmospheric origin is NO. NO molecules are produced in meteor tails at 1 500 – 4 000 K. Based on rate constants of main reactions of formation such as $O_2 + N = NO + O$ and $N_2 + O = NO + O$ [6] formation of NO molecules quenches at about 2 000 K at hydrodynamic time scale of about 1 s. At this temperature the NO equilibrium content is almost independent on the meteor altitude and equal to about 1 %. Assuming the air-to-meteoroid mass ratio in the impact-produced cloud equal to 30 [2] NO mass can be estimated as about 1 500 kg. Later impact-produced NO molecules react with O_3, it leads to local depletion of O_3 content at the place of the meteoroid impact [7].

Identification of molecular bands

Theoretical spectra of considered diatomic molecules were obtained with usage of PGOPHER program [8]. Molecular constants of AlO, MgO, and TiO molecules were taken from [9], [10], and [11], respectively. Molecular constants of FeO, CaO, NiO, and Al hydroxides are poorly known. For this reason we use for identification of molecular bands in Benešov spectra experimental spectra of FeO, CaO, NiO, and Al hydroxides taken from [12], [13], [14], and [15], respectively.

The most prominent broad bands in red region (at 560, 565, 590, and 620 nm) are identified as features of FeO orange system. Weaker CaO broad bands are identified at 553 and 615 nm. Due to significant difference between Benešov spectra and CaO and FeO experimental spectra additional identification of weaker molecular bands of other species at 550 – 650 nm range seems to be difficult.
Namely, weak features at 559, 617, and 620 nm may be identified with strongest transitions of TiO beta and gamma systems. NiO features are found at 488, 518, and 540 nm. However, absence of strongest NiO experimental band at 575 nm and presence of AlO features at 488 and 540 nm lead us to claim NiO detection as tentative. The most intensive unidentified band is located at 527 nm.
AlO bands are identified at 454, 468, 488, 513, and 542 nm. Agreement between Benešov spectrum and Al in air spectrum becomes better with adding of spectrum of Al in water vapor. Namely, HAlOH may be responsible for existence of 459 and 505 nm bands. The MgO green system is detected at 496 – 500 nm.
Theoretical intensities of AlO and MgO electronic-vibrational-rotational transitions were calculated with usage of approach [16]. Assuming optically thin emission, the AlO/MgO abundance ratio is estimated to be about 20. This value is higher than that obtained with usage of quenching theory by a factor of 50. However, emission of molecules in Benešov impact-produced cloud is optically thick and for this reason it is impossible to estimate the bulk chemical composition of the impact vapor from molecular spectra.

Conclusions

Based on quenching theory approach, formation of NO and metal oxides during meteor events is considered. Identification of FeO, CaO, AlO, and MgO bands is confirmed in Benešov spectra while Al hydroxides, NiO, and TiO are tentatively detected in meteor spectra for the first time.

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Reliability of the orbital clustering among the small bodies

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Introduction

The problem of the orbital clustering among the small bodies of the Solar System is a longstanding one. The presence of peaks in the distributions of dynamical parameters of meteoroids, suggested existence of particles of common origin — a meteoroid stream. On Figure 1 we see tactile presence of three showers. Their reality is accepted beyond the doubts. However in case of the near Earth asteroids (NEAs), see Figure 2, the presence of the groups among them is not obvious at all. However, as was shown in [1],[2] by quite rigorous cluster analysis, one can find amongst the NEAs several associations which consist of 10–50 members. Are these groups real? — not just the results of the orbital chance alignment? Some authors [3] are rather skeptical about the reliability of associations amongst the NEAs.

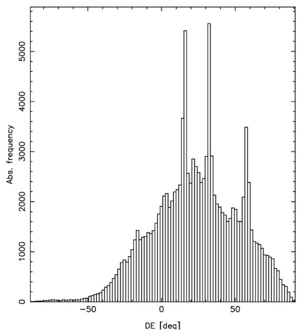

Figure 1: Histogram of the declinations of radiants of 117894 meteors observed by various techniques. The three peaks represent the Taurids, Geminids and Perseids, respectively.

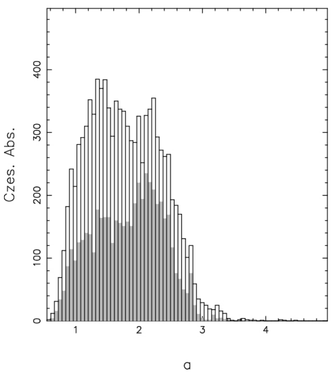

Figure 2: Histogram of the semi-major axes of 9949 NEAs. In contrary to the meteoroids, we do not see any clear presence of grouping

Present study

In our study we have touched these problem. In [4] the authors proposed a method for estimation of the probability of chance grouping for clusters of 2, 3, 4... members. In [5] the authors applied the geometric distribution (an alternation of a sequence of Bernoulli trials), and estimated the probability of finding a pair of similar objects in a given orbital sample.

In both approaches a central role is played by the orbital similarity function (D-criterion [6],[7],[8]), the similarity threshold, and the method by which the artificial orbital sample is generated. Estimation of the probability of chance alignment of the orbits depends on all these factors. The D-criteria available in the literature are not equivalent, the similarity thresholds are therefore related with given D-function. This was already known earlier, but the question which D-function is the best? — has no simple answer.

In case of the orbital D-criteria, the orbit of the meteoroid and the NEA is described as a point in 5-dimensional space. The observed orbital sample is biased by the selection effects. Therefore the generation of the artificial orbital samples, should take into account the multi-dimensionality of the orbits quasi-space, as well as the observational selection effects. It is not well known how the method of generation of the artificial samples influence the results of estimation of the probability of chance alignment of the orbits.

In this study we concentrate on these two aspects.

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[074]

Meteorites of Turkey

Özcan ÇALIŞKAN

Abstract
In this paper, firstly, an inventory of fallen meteorties of Turkey and doubdful meteorites of Turkey are provided together. This inventory contains information about variety of meteorites (mass, year, palce etc.). Then, images of a few fallen meteorite and images of meteorites which exhibited at Natural History Musuem are shown and indicated that belongs to which country. Finally, mineral compositions of a few meteorite are given.

[075]

Theoretical study of the ablation of Meteoroids in the upper atmospheres of Venus, Earth, Mars and Titan.

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Introduction

The Chemical Ablation Model (CABMOD) (Vondrak et al., 2008) includes sputtering by inelastic collisions with air molecules before a meteoroid melts, evaporation of atoms and oxides from the molten particle, and impact ionization of the ablated fragments. The thermodynamics are provided by the MAGMA model (Fegley et al, 1987).

One potential problem in CABMOD is that the thermodynamic data used by MAGMA corresponds to measurements made below 1700 K, which are then extrapolated to temperatures above 2000 K. The MELTS model (Ghiorso and Sack, 1994) has been developed for higher temperatures than MAGMA.

The insertion of MELTS into CABMOD could therefore provide better estimates of ablation rates. A second improvement to CABMOD involves the calculation of these rates. Langmuir evaporation provides an upper limit to the evaporation rate but, as Alexander (2001, 2002) has demonstrated, the evaporation coefficient can be less than the unity for elements such as Fe, Ca or Mg. This will significantly affect the height at which the ablation of the different elements occurs.

MELTS code

The process of evaporation of a chondritic melt is dominated by the loss of alkalis and FeO, resulting in melts which are dominated by CaO-MgO-Al_2O_3-SiO_2 (CMAS) (Hashimoto, 1983). In the process of condensation of liquid silicates, the first melts will be FeO-poor CMAS liquids. Berman (1983) designed a valid model for CMAS melts that can be applied to most of the type I chondrules, calcium-aluminum-rich inclusions (CAIs) and particles which contain little or no FeO. We are using MELTS and the Berman (1983) models to determine the activity coefficients and the evaporation coefficients for species in silicate melt solutions by a code developed by Alexander (2001, 2002).

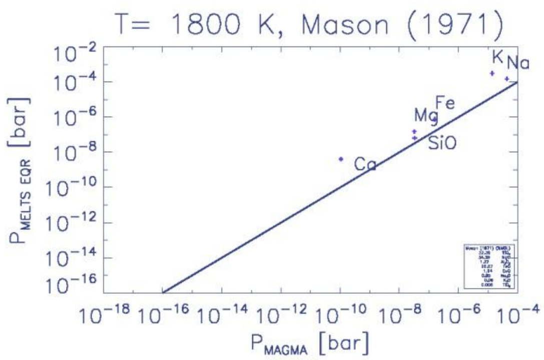
Preliminary results

Before assembling MELTS within CABMOD, various calculations have been carried out so as to compare the results obtained by MELTS with those offered by MAGMA. Equation [1] shows the way to calculate the vapour pressure of a metal M according to the reaction [R1] in a closed system:

$$\boldsymbol{M_xO_y \rightleftharpoons xM + yO} \qquad \text{[R1]}$$

$$P_M = \frac{x}{y}^{\,y} K f_M x_M^{\;\frac{1}{x+y}} \qquad [1]$$

where f_M is the Raoultian activity coefficient given by MAGMA or MELTS, x_M is the mole fraction of the considered oxide, K is the equilibrium constant and P_M is the vapour pressure of the metal. The figure below shows the vapour pressures of the major elements in a CI chondrite with a rich olivine composition (Mason, 1971) at a temperature of 1800 K. MELTS uses the *Equilibrium Reference Model* (EQR) which enables calculation of the closed system partial pressures of all the gases in equilibrium with the melt.



Conclusions

We have estimated the vapour pressures in equilibrium for eight oxides in the molten meteoroid: SiO_2, MgO, FeO, Al_2O_3, TiO_2, CaO, Na_2O and K_2O. Agreement between the MELTS and MAGMA is generally very good, although there are substantial differences for the less refractory elements Na, K and Fe. The next step is to assemble MELTS within CABMOD and to trace the ablation profiles for Mars, Venus and Titan.

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Polarimetric study of CB 56 and CB69 cloud

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Introduction

The study of projected magnetic field geometry and dust grain characteristics of the interstellar dust in relation with their other properties like structure and kinematics, can give great insight into the role played for the formation and evolution of dark clouds by the magnetic field in shaping the structure and dynamics of these objects. In this paper, we present the results obtained from polarimetric observations of two star forming clouds CB56 and CB 69 at V-filter. The observations were made from the 2-metre telescope at IUCAA Girawali Observatory (IGO), Pune, India on March 4, 2011. The CCD images obtained from the instrument (IFOSC) were analyzed to build the polarization map of two clouds.

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Three bright bolides in Kiev sky on 29 March 2013

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On March 29, 2013 during less 22 seconds the citizens of the capital of Ukraine Kiev were witnesses of three unique phenomenon of re-entry into the Earth's atmosphere of three meteoroids or possible of three fragments of one body of extraterrestrial origin; Kyiv local time sequential photographs are $16^h21^m56^s$, $16^h22^m04^s$, $16^h22^m16^s$ LT. The fourth panoramic picture referres to $16^h25^m32^s$ LT (Fig 1). Pictures were obtained by Egor Steklov – a pupil of the Lyceum "Logos". All three phenomena were accompanied by a noticeable increasing noise. Slow flowing traces across the sky does not exclude artificial origin of the samples.

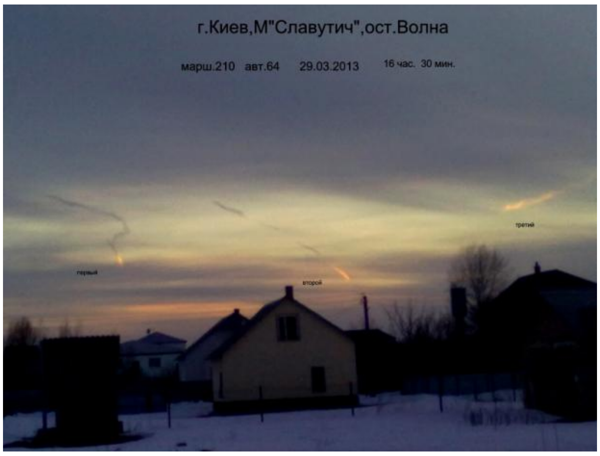

Fig.1. Three bolides on 29 March 2013 (Kiev, Ukraine)

Physics of the Chelyabinsk fireball

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Introduction

A bright fireball was observed on February 15, 2013 near Chelyabinsk city in the South Urals . The event occurred at coordinates 54.8 ° of North latitude and . 61.1 ° of East longitude at 03: 20: 33 UTC. Rough evaluation of weight and size with density 3.6 g/cm^3 were respectively about 10 000 tons and a diameter of about 18 meters. We think that values of these parameters of the Chelyabinsk fireball on 15 February 2013 are overestimated.

On a size and mass of the Chelyabinsk meteoroid and the real height of its explosion

Based on the theory of meteor phenomena [1] we obtained a formula for the maximum mass of a meteoroid:

$$m_{0\max} = 1.84 \cdot 10^{9} \left[\frac{AH^{*}}{\delta^{2/3} \cos Z_R} \right]^3 \quad (1)$$

Where A - the ratio of body shape, H * - the height of a homogeneous atmosphere, δ - the density of the meteoroid, Z_R - zenith distance of radiant. From equation (1) follows that the maximum mass of the meteoroid does not depend on the velocity, as determined by the shape factor, the value of the scale height, its density and $\cos Z_R$. Taking shape factor A = 1,21 ... 1,65; H* = (6,7 ... 7,3) · 10^5 cm; δ = 3 g/cm^3 and $\cos Z_R$ = 1.0 ... 0.5, we obtain m_{0max} = 1 1 · 10^8 ... 2,8 · 10^9 g, i.e. the maximum mass of the meteoroid that can achieve maximum braking height within the Earth's atmosphere is ≈ 3 · 10^9 g. The maximum diameter of the meteoroid imust be equal to ≈ 3 m instead of 100 m as it is considered in paper [2]. If to substitute to the formula (1) iron meteoroid density (7.8 g/cm^3) the maximum mass of the meteoroid will be 1,6 ·10^7 ... 4,1 · 10^8 g. Meteor bodies with mass exceeding 10^9 g will have maximal breaking height (formally) below the surface of the earth, that is they will not cause explosive outbursts in the atmosphere and in case of a fall of a body on the surface of a planet will form explosive craters.

Based on the above, estimation of the size of the Chelyabinsk meteoroid of the order of 15-20 m (the phenomenon of 02/15/2013), published in the press, significantly overestimated. False is also estimations of the height of its explosion. On the basis of the destruction that formed by shock wave the explosion of the meteoroid should not exceed 10-12 km, and its size should be of the order of 5-6 m. Mass of the meteoroid must be of the order ≈ 300 tons. At the size of 15-20 m of the meteoroid it would not have reached a height of maximum breaking within the Earth's atmosphere and exploded on the Earth's surface, creating a large explosive crater like of the Arizona one.

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On the chemical and mineral composition of the particles of the bright fireball EN171101 "Turyi Remety" in Transcarpathian

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Introduction

We presented results of searches of scientific expeditions from during 2007-2012 and mineralogical and geochemical studies of cosmic matter of the bright fireball EN171101 «Turyi Remety" which fall down in Perechyn region of Transcarpathian (near Uzhgorod city). Numerous magnetic beads and fused segments are fairly large quantities - up to 5 mm in diameter, which probably are fragments of the bolide, were founded by members of expeditions R.Belevtsev, S/Spivak, K.Churyumov and others .

X-ray spectral microanalysis of the meteoroid particles

X-ray spectral microanalysis (EPMA) of magnetic beads of the fireball at the Institute of Geological Sciences of Ukraine was made with the help of the microscope Jeol JSM-6490LV, EDS Oxford. Most of the analyzed small magnetic beads of the fireball (about 0.3 mm in diameter) have a composition close to FeO. Some pellets contain small inclusions of anorthite, hercynite, and fayalite, as well as a small admixture of Cr, Ni, C. Round cavities inside the pellets are probably formed during crystallization from the melt, or in the course of gas release.

Spectroscopy of the 2012 Geminids from AGM Marrakech observatory

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Abstract

An observation campaign of the Geminids was performed in December 2012 during two nights of observation at the AGM observatory in Morocco. At the night of Geminid maximum, we captured 27 spectra from $+2.1$ to -2.1 magnitude meteors. Here we present the results for the brightest meteor, which spectrum reveals the most features.

Introduction

The monitoring of meteor shower represents one of the many aspects of the current research developed at Oukaïmeden observatory (OUCA) and at the AGM observatory of Marrakech [1, 2]. A new meteor network was created to make a thorough study on this subject.

The Geminid meteor shower is one of the most active showers and occures between December 4 till 17. In 2012 the maximum was expected to occur on December 13 at 23h 30m UT, with ZHR = 120. We organized an observation campaign during which several meteors spectrum was captured in order to study their origin.

Observations

The observations presented in this paper were taken from AGM Marrakesh observatory. The station is situated on $31°37'8''$ North latitude, $7°59'35''$ East longitude, and at 485 m above the sea level. We performed video observations during the period from 20^h 30^m to 04^h 00^m UT on 12-14 December 2012. Our equipment for spectroscopic observations included Watec 902H2 camera with 12 mm/F1.2 lens (FOV $\sim$ $30° \times 20°$), and a 600 grooves/mm grating mounted in front of the lens. The GPS time inserters are used to stamp time on every video frame with a precision of 0.001 seconds. The camera detected 46 meteors, 27 of which showed spectra of variable quality.

Data reduction and Analysis

The meteor spectra data reduction and analysis were processed with IMCCE's program SPECIES[1]. The spectrum profile of the Geminid was extracted from each frame using the ImageJ program. The wavelength scale was determined by means of known lines in the calibration spectrum. For this purpose we used LED lights of known wavelengths (480 nm, 505 nm, 539 nm, 594 nm, 615 nm, 630 nm, 645 nm). Figure 1 shows the relative intensities of the sodium, magnesium, iron, and calcium. Comparing to the magnesium line, the other lines are faint. Magnesium, iron and calcium follow a profile similar to sodium.

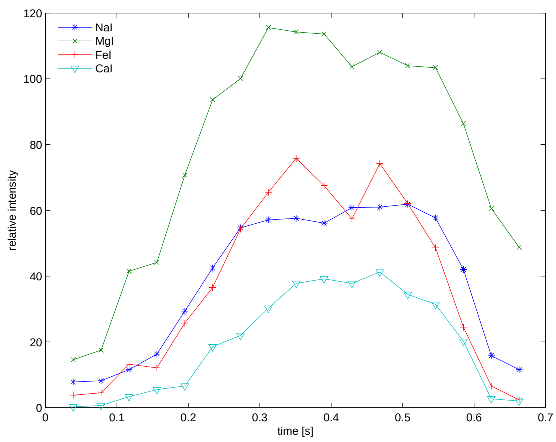

Figure 1: Relative intensities of sodium, magnesium, iron, and calcium of Geminid spectrum; corrected for spectral response of the instrument.

Conclusion

The analysis of one of our Geminid spectrum shows normal class spectrum, with higher sodium content, that would support a cometary origin for 3200 Phaethon pointed by Borovička [3].

Acknowledgement

We are grateful to the Mr. Hila Omar and it's company Atlas Golf Marrakech for putting at our disposal the means of their observatory to conduct the Geminids observation campaign.

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[1]SPECIES (SPECtra IdEntification Software) program written in MATLAB and developed by Rudawska.

Imaging Polarimetry of Comet C/2009 P1 Garradd

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ABSTRACT

In the present work, we report the preliminary results of imaging polarimetry of comet C/2009P1 Garradd at phase angles 28^o and 21.6^o. The polarimetric observations of the comet were carried out on 21st & 22nd of March, 2012 with the 2-m telescope of IUCAA Girawali Observatory, Pune, India & on 23rd of May, 2012 with the 1.04-m Sampurnanand Telescope of ARIES, Nainital, India. Both broadband and narrowband filters were used in the observation. Comet Garradd (C/2009 P1) is a dynamically new comet and it was discovered in 2009 and had a clear dust coma as far as 8.5 AU from the Sun. Cometary polarimetry in the continuum is a good technique to investigate the nature of cometary dust. The polarization is mainly based on the phase angle & wavelength. The study of the polarized light scattered by cometary dust provide useful information about the physical properties of the dust like shape, size distribution, morphology, porosity and the composition of the dust particles. In the March observation, a prominent jet extended up to 5000km was observed in the solar direction. The polarization value obtained from our analysis agrees well with the results retrieved by other authors for different comets at similar phase angles. Most importantly as expected a negative polarization value is obtained in the May observation at 21.6^o phase angle. A significant variation in the intensity profile of comet C/2009 P1 Garradd is obtained along the solar & anti-solar direction for the two period of observation. The polarization value obtained from our analysis at such phase angle is pointing towards the dusty nature of the comet.

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Two mechanisms of the ejection of meteoroids from comets

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May 27, 2013

Abstract

The mechanisms of the ejection of meteoroids from comets are reviewed. We focused on two questions. The first one is related to the dragging of dust-ice particles by molecules of gases which sublimate from a cometary nuclei. The second one is related to jets from cavities in nuclei of comets. The geysers-like phenomena in the form of strongly collimated jets of gas and dust are recently reported for a few comets. On September 21, 2001 the spacecraft Deep Space 1 approached the nucleus of Comet 19P/Borelly at a distance about 2170 km. The nucleus of this comet, coma and dust jets were pictured by onboard camera. A main jet which dominated in the near-nucleus coma was emitted from a broad central cavity and it had geyser-like form. On 2010 November 4 the Deep Impact spacecraft in the frame of the EPOXI mission visited the nucleus of Comet 103P/Hartley. On the excellent quality images performed by spacecraft camera, bright geyser-like jets emanated from the surface of 103P/H nucleus are visible. NASA's astronomers stated that this was the first time in history of cometary researches that comet activity dominated by sublimation of carbondioxide was observed so close to the Sun (1.06 AU). The nucleus of this comet was surrounded by clouds of large number of water ice relatively large particles which was ejected from nucleus by geyser-like jets of CO_2. Also long-standing observations of famous Comet 29P Schwassmann-Wachmann 1 revealed fact that the activity of this comet is probable associated with a number of jets produced by its nucleus. In the presented work maximal size of cometary particles which can be lifted from the cometary nuclei in different heliocentric distances by the jets of cometary geysers was examined.

Key words: *comets: general - meteoroids - dust*

Comets outbursts and the meteor showers

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The features of 116 comets, showing the outbursts of brightness, are considered in the paper. A hypothesis on the possibility to appearance the outburst's activity of comets as a result of their passing through meteoroid streams is studying. For this purpose the orbital elements of such comets relative to the planes of motion of 68 meteor showers [1] are analyzing. It was found that the number of the nearest and distant nodes of comet orbits relative to the planes of motion of four and nine meteor showers exceeds the average statistical background with confidence probability from 0.90 to 0.95, and more than 0.95, respectively. The *k*-Serpentids, δ-Draconids, Aurigids**,** σ-Hydrids, Coma Berenicids, Leonids, Leo Minorids, Perseids, and o-Draconids showers are the most effective for the matter of that, and strongly support this idea. As a whole, the results of calculation show that often, the comets outbursts may be conditioned alongside with the solar activity by collisions of comets with meteoroids under the passing through the meteoroids streams producing listed meteor showers.

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A Parent Body Search Across Several Video Meteor Data Bases

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Introduction

The ongoing collection of multi-station video meteor orbits has now reached a point of statistical significance, such that it was time to revisit the association of minor meteor streams to potetial new parent body candidates. Several such searches can be found in the existing literature emphasizing two main focus areas, near Earth object (NEO) and comet based searches, with examples in [1] and [2] respectively. Based on those and other previous successes, this work was initiated by utilizing the latest complete set of both comets and NEOs downloaded from the JPL small-body data base search engine [3]. Minor stream correlations were then made by data mining several published meteor orbit data bases to discover new associations between meteor streams that connected to either asteroidal or cometary bodies.

Meteor Data Bases and Methodology

Rather than search for clustering within a single given data base of meteor orbits, the method employed herein is to use all the known parent bodies with their individual orbital elements as the starting point, and find statistically significant associations across a variety of meteor data bases. Since 2007, two independent video meteor camera networks have been monitoring the skies over Japan and Croatia, the SonotaCo Meteor Network and Croatian Meteor Network (CMN) respectively. Between them their data base catalogues contain over one hundred thousand meteoroid orbits (114,280 SonotaCo 2007-2011; 19,372 CMN 2007-2010) that were obtained through multi-station trajectory and orbital parameter estimation. In addition, the IMO video meteor data base contains nearly one and a half million single station records (1993-2012) that were used to provide further statistical relevence to a given shower's existance. Combined, these data sets cover radiants down to declination -30°.

The processing approach employed an extensive search for meteor orbit relationships to potential parent bodies by applying several D-criteria restrictions with appropriate thresholds on shower membership. These were developed by Southworth-Hawkings [4], Drummond [5], and Jopek [6]. Each independent parent body was compared against every meteor orbit available. After an initial assessment, refinements were made to extend the association in time, and additional sweeps through the data bases were made. From that processing, a short list of parent bodies were obtained and the individual meteor orbits were analysed in greater depth to evaluate the significance of each result. A final search was also conducted using the single station IMO video data base for further statistical support.

Results

As would be expected, the major meteor showers such as the Geminids, Perseids, Leonids and several minor showers were connected to their known parent bodies. Of particular significance was that nearly a dozen new potential meteor streams were discovered through their similarity to orbits of known comets. One example shown in Fig. 1 is a plot of the meteor stream members connected to comet C/1853G1(Schweizer).

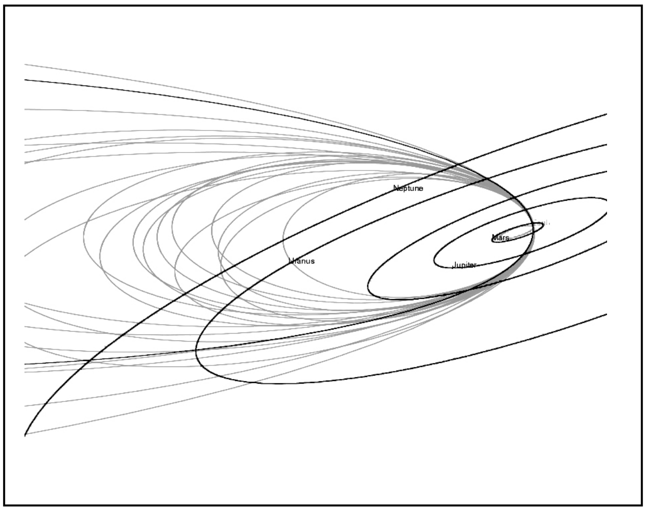

Fig.1 Meteoroid orbit plot for the new stream members associated with comet C/1853 (Schweizer). The comet's orbit is the black dashed line.

In addition, there were found a large number of potentially very low flux meteor showers connected to asteroids and comets, where additional sample support is needed for confirmation. It is hoped that in the near future with further multi-station meteor orbit data base growth and the publication of the CAMS [7] higher accuracy meteor orbits dating back to November 2010, these additional candidates can be verified. The current analysis has resulted in the confirmation of existing relations between known meteor showers and parent bodies, as well as many new findings of statistical significance in need of further study and dynamical modeling.

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The Geminids' orbital dispersion derived from the European video meteor network database

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Introduction

The distribution of meteor orbits within a meteor stream tells us about its structure, which is a result of the mechanism of its formation and evolution. The initial dispersion of meteoroids in a stream is influenced by a number of processes, such as planetary perturbations, collisions, solar radiation pressure and other non-gravitational forces, which appear during different stages of the stream evolution. Williams and Ryabova [1] have discussed the effects of both the initial formation processes and the subsequent gravitational perturbations on the structure of meteor streams, and concluded that the dominant one depends on the stream and thus, for the production of models for meteor streams, it is important to consider both effects.

However, studying the fine structure of meteor streams that are observed today, the fact that the original dispersion velocities are smeared by much larger observational and measurement errors also has to be considered. For the widely dispersed annual meteor showers, Kresák [2] showed that the real ejection velocities are comparable with the dispersion produced by planetary perturbations integrated over several revolutions, but that they are two or three orders of magnitude smaller than the measurement errors.

The orbits of the Geminid meteoroids, with aphelia far inside the orbit of Jupiter, indicate that the gravitational effects of the other outer planets are negligible. Therefore, the structure of the Geminid meteoroid stream is dominated by the initial spread of meteoroid orbits.

Data of meteor orbits used

For our analysis, a database of video meteor orbits EDMOND (European viDeo MeteOr Network Database), covering the years 2009 – 2012, was used. The database is the result of cooperation and data sharing among several national networks and the International Meteor Organization Video Meteor Database. Details can be found in the paper Kornoš et al. [3]. The current version consists of 79 402 higher quality orbits after a careful selection. Among them, 4644 were identified as meteoroids belonging to the Geminid meteor shower.

The dispersion of the semimajor axes

In this paper, we concentrate on the influence of velocity determination errors on the distribution of the meteor orbits within a stream. The accuracy and dispersion of the semimajor axes of the meteor orbits of Geminids are studied. Our task is to estimate the limits of possible errors and, hence, to determine the real dispersion of meteor orbits within the stream in the observed sample.

The dispersion of the semimajor axis within the meteor stream is described by the median absolute deviation Δ_M in terms of $1/a$, $\Delta_M(1/a) = |(1/a)_{1/2} - (1/a)_M|$, where $(1/a)_{1/2}$ are limiting values of the interval, which includes 50 percent of all orbits in the stream. The probable range of uncertainty is determined by $\pm n^{-1/2}\,\Delta_M(1/a)$, where n is the number of the meteor orbits used for the median determination $(1/a)_M$.

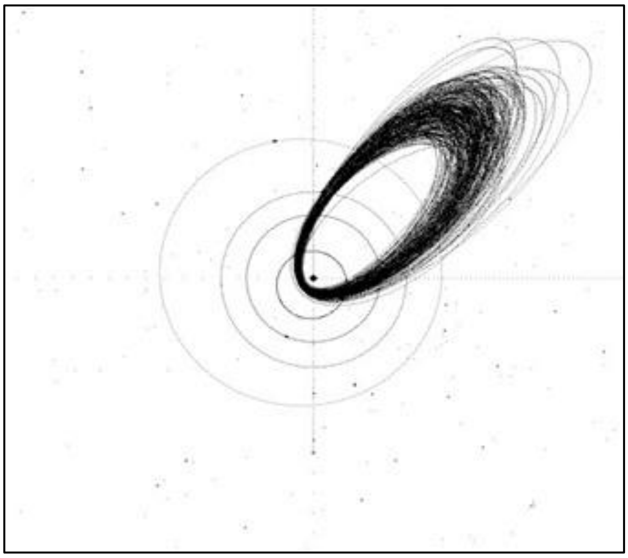

Fig. 1 Orbits of the Geminid meteoroids obtained from the European Video Meteor Network observations in 2009 - 2012.

It was shown earlier [4] that the medians of $(1/a)_M$ in several major meteor showers do not differ from those of their parent comets beyond the limits of statistical uncertainty. Thus, from our observations, the determination of the acceptable range of the observed median allowed us to find a corresponding upper limit of the dispersion of the Geminids, which was found to be several times smaller than indicated by the observations based on the European Video Meteor Network database.

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The distribution of the orbits within the meteor streams from the SonotaCo shower catalogue

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Introduction

The present work is based on an analysis of a large statistical sample of meteor orbits collected in the SonotaCo shower catalogue [1] of 114280 video observed meteors in the years 2007-2011. The shower meteor data have been selected and analysed with the aim of determining the orbits' distribution in major meteor streams with heliocentric velocities close to the parabolic limit, in which the errors in the velocity determination correspond to large differences in reciprocal semimajor axis $1/a$. The contribution of the real dispersion of the semimajor axes a is deduced from the high proportion of hyperbolic orbits in the analysed streams, where an excess over the parabolic value can be regarded as entirely due to measurement errors.

The distribution of meteor orbits within a meteoroid stream tells us about its structure, depending on its formation and evolution. An overview of the underlying principles of meteor stream formation and evolution, with consideration of its various stages, was given by Williams [2]. The initial distribution of meteoroids in a stream broadens under planetary perturbations after each encounter with a major planet. However, there are also compact structures in streams which can survive over long timescales. Emel'yanenko [3] pointed out the role of resonances in sustaining such structures in meteor streams in a study of the effects of planetary perturbation on the evolution of orbits with large eccentricities. In this study, we concentrate on the influence of measurement errors on the distribution of the meteor orbits within a stream, which seems to be a significant source of the observed orbital dispersion [4].

The dispersion of the semimajor axes in individual meteor streams

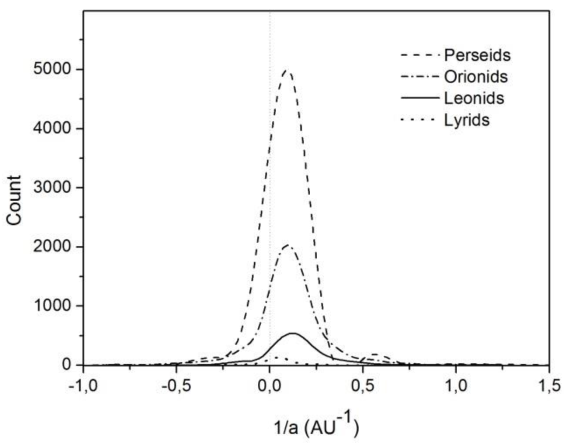

Fig. 1 The observed dispersion of semimajor axes within the 4 investigated meteor showers. The orbital distributions show a widely-observed dispersion within all four long-period meteor streams.

The distributions of the reciprocal semimajor axes show general deviations from the Gaussian distribution, sharp maxima, and excesses in the tails. All meteor streams seem to be diffused with an excess of particles on the short-period side.

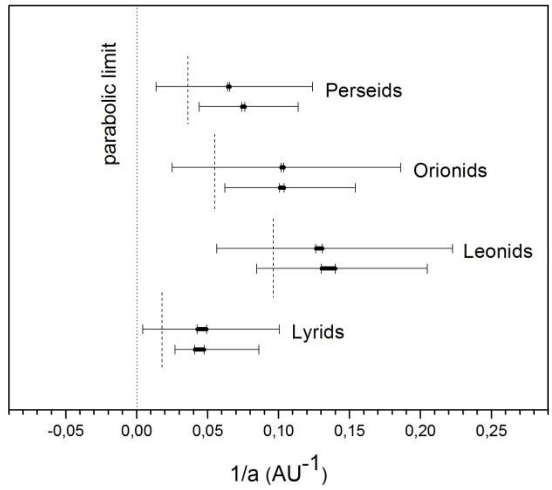

Fig. 1 Observed dispersion for each meteor stream (upper line is obtained from all orbits, and lower line - from the quality selection) described by absolute median deviation in terms of $1/a$. Thin line - interval between two limiting values of $(1/a)_{1/2}$, which includes 50 percent of all orbits. Bold line - interval between two limiting values of the uncertainty $(1/a)_L$ of the resulting values of median $(1/a)_M$. Dotted vertical line - parabolic limit. Dashed vertical lines - parent comets.

Conclusions

The observed differences in the semimajor axes within meteor streams were described by median absolute deviation in terms of $1/a$ and were compared with the orbital deviations determined from a selection of precisely-reduced orbits, in which the proportion of hyperbolic orbits is significantly smaller. The median deviations in terms of $1/a$ range in the data investigated from ±0.029 to ±0.083 AU^{-1}. Summarising the above data and numerical results, it can be concluded that the actual dispersions in the SonotaCo catalogue are, generally, about three times smaller than that indicated from the observations.

The median semimajor axes of meteor orbits in the SonotaCo catalogue are systematically biased in consequence of the method used for the orbit's determination, probably by absent correlations for atmospheric deceleration.

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Radar detectability studies of slow and small Zodiacal Cloud Dust Particles

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Introduction

The total amount of meteoric input in the upper atmosphere is a hotly debated quantity, which estimates vary by 2 orders of magnitude, depending on measuring techniques. The majority of the input is in the form of microgram size particles, which, in most cases, completely ablate injecting metals in the mesosphere. These metals are the primordial material for most of the layered phenomena (LP) occurring in the mesospause region (MR). Accurate knowledge of this quantity is crucial for the study of LPMR and in many cases it can contribute to the improvement of Whole Atmosphere Models (WAM) by constraining parameters such as vertical transport in the middle atmosphere. In an effort that ultimately aims to estimate this quantity, we utilize a new Zodiacal Dust Cloud (ZDC) model that follows the dynamical evolution of dust particles after ejection utilizing the orbital properties of comets and asteroids. One of the main results of this model is that it predicts that 85 - 95% of the dust in the inner solar system comes from Jupiter family comets (JFCs), with the remainder from the asteroid belt and Oort Cloud comets (OCCs). Furthermore, the modeled results show that most of the dust, which drifts down towards the inner solar system under the influence of Poynting-Robertson drag, has a mass in the range 1 - 10 μg at a near-prograde orbit with a mean speed of about 14 km/s, producing a global meteoric mass input around 41 t/d. The low average speed and the absence of significant orbital eccentricities, also a result of the model, do not accord with various types of meteor radar observations, which record average speeds closer to 30 km/s. One of the key problems with this model is that it is currently quantitatively only constrained by Infrared Astronomical Satellite (IRAS) observations of the ZDC and only qualitatively constrained with terrestrial observations using radars. Furthermore, the radars utilized do not have the sensitivity to observe the particle masses dominant in the ZDC model when they travel at low speed (i.e. low ionization production). In this paper we discuss a methodology to better constrain the ZDC physical model utilizing ground-based meteor radar observations of head echoes and modelling. For this, we integrate and employ existing comprehensive models of meteoroid ablation, ionization and radar detection and thus enable accurate interpretation of radar observations. This will address potential biases that could, in principle, prevent them to detect the large population of small slow particles predicted by the ZDC model.

An initial meteoroid stream survey in the southern hemisphere using the Southern Argentina Agile Meteor Radar (SAAMER)

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Introduction

We present in this manuscript a 4 year survey of meteor shower radiants utilizing the Southern Argentina Agile Meteor Radar (SAAMER) [1]. SAAMER, which operates at the southern most region of South America, is a new generation SKiYMET system designed with significant differences from typical meteor radars including high transmitted power and an 8-antenna transmitting array enabling large detected rates at low zenith angles. We applied the statistical methodology developed by [2] to the data collected each day and compiled the results into 1 composite representative year at 1 degree resolution in Solar Longitude. We then search for enhancements in the activity which last for at least 3 days and evolve temporally as is expected from a meteor shower. Using this methodology, we have identified in our data thirty two shower radiants, two of which were not part of the IAU commission 22 meteor shower working list. Recently, SAAMER's capabilities were enhanced by adding two remote stations to receive meteor forward scatter signals from meteor trails and thus enable the determination of meteoroid orbital parameters. SAAMER started recording orbits in January 2012 and future surveys will focus on the search for unknown meteor streams, in particular in the southern ecliptic sky.

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Orbital Evolution and Impact Hazard of Asteroids on Retrograde Orbits

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Introduction

We present the past evolutional scenarios of known group of asteroids on retrograde orbits. Applying the latest observational data, we determined their nominal and averaged orbital elements. Next, we studied the behavior of their orbital motion 1 My in the past taking into account the limitations of observational errors. It has been shown that the influence of outer planets perturbations in many cases can import small bodies on high inclination or retrograde orbits into the inner Solar System.

Dynamical past, possible reasons of 'orbit inversion'

Main aim of our work was the analysis of the orbital evolution of known asteroids on retrograde orbits in the past (time-span: 1 My). We also took into account the propagation of observational errors. We analyzed the reliability of initial observational data and the influence of observational data on the limitations of long numerical integration. We show possible scenarios of orbit inversion (if occured in the past) to current, retrograde motion.

Observational data and setup

Most of known asteroids on retrograde orbits have long observational arcs and well determined orbital elements. In some cases, observational arcs are relatively short (latest results) and connected to larger observational errors. Main source of observations was Minor Planet Center database, known as ECS (Extended Computer Service). To determine the orbital elements and to generate so-called clones we used Orbfit software ([5]). We computed clones of each asteroid with the multiple solution and with the ephemeris JPL DE405/406 (as the source of planetary perturbing forces). Next, the clones were propagated 10^6 years backwards by the numerical integration with the use of the Mercury software [1]. During the integration, we averaged orbital elements for all clones of the given asteroid by weighting each element, assuming the Gaussian distribution of observational errors. Most of our results we presented on diagrams according to the classification scheme proposed by Horner and Evans [2].

Results

Probably, part of known asteroids on retrograde orbits have similar dynamical past. They are from different taxonomic groups (Plutinos, Halley-like, SDO, Damocloids, Mars-Crossers, other inner and outer planet crossers). Only two numbered asteroids exist in this group, and most known is (20461) Dioretsa. Another interesting example is the Amor-type asteroid 2007 VA85. In the past, the eccentricity and semimajor axis of its orbit were greater. It is possible that 2007 VA85 changed the inclination significantly (from prograde with high inclination to retrograde motion). This scenario is confirmed by the evolution of nominal and averaged orbital elements [4]. It is also important to mention that impact predictions based on first 55 optical observations of 2007 VA85 estimated the probabilities of collision with the Earth from $2.7 \cdot 10^{-10}$ to $6.4 \cdot 10^{-10}$ in the 2082, 2083 and 2089 a.d. [4]. These results were excluded after the update of observational data. The second known example of retrograde NEA is Apollo-type object, 2009 HC82. For most retrograde objects, semimajor axis had greater values in the past and eccentricities were smaller. In some cases orbits changed directions from $i \sim 90°$ during last 1 My. In other cases it happened in the last 100 000 – 200 000 y due to planetary perturbations. The role of secular, nodal and apsidal resonances with Neptune is probably the most significant and can be possible cause of inclination changes [3].

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Micro-Raman spectroscopy of meteorite Kosice

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Introduction

The Raman microscope technique allows the analysis of micro-sized structures (3-5 μm) in the meteorite matrices. It is a non-destructive spectroscopic technique based on inelastic scattering of monochromatic light (Raman Effect), usually from a laser source. By Raman spectroscopy of meteoritic material it is possible to observe the presence of many minerals and amorphous carbon (e.g. [1, 2]). It is a sensitive tool for the study of structural properties of carbonaceous materials. In particular, it provides an indicator of the degree of crystallinity of sp^2 graphitic clusters, which is related with the methamorphic grade of meteorites [3].

Laboratory equipment and procedure

Several micro-Raman spectra of the interior part of meteorite Kosice sample were collected using a triplemate SPEX Raman spectrometer equipped with a 1200 groves/mm holographic grating. The spectrometer is coupled to a confocal DILOR xy illuminator equipped with an Olympus BX40 microscope with 10×, 50× and 100× magnification objectives, at Experimental Astrophysics Laboratory at Catania Astrophysical Observatory, Italy. The Raman spectrometer is equipped with a continuous Ar ion laser beam (514.5 nm) as exciting radiation and a CCD detector in the 0.4-1.0 μm spectral range. Details of the in situ Raman technique can be found in [4]. Using the microscope objectives (50×, 100×) to focalize the exciting laser beam we get the spot size of about 4 and 2 μm respectively.

Results

The Raman spectra of several different regions of the meteorite interior were taken. On the basis of characteristic frequencies of Raman modes the main types of minerals compound were identified. The common minerals found in the meteorite Kosice are silicates. Raman double-band (in a range 800-900 cm-1) indicates olivine (spectra no. 1-3 in Fig. 1) (e.g. [2]); a Raman "fingerprint" of pyroxene is identified in spectrum no. 4.

In the 800-2100 cm^{-1} Raman shift region, both D and G Raman bands were observed (Fig. 2). After a baseline correction, the Raman spectra were fitted by a two-Lorenzian band model [5, 6]. Consequently, the individual band parameters (center, intensity and FWHM of bands) were extracted. Considering meteorites, Raman spectra of metamorphized and thermally processed meteorites have D and G peaks quite narrow and well separated; on contrary, a primitive carbonaceous material has broad and blended D, G bands [7]. Taking into account width of the bands, the ratio of intensities, and supposing the stage 2 of the amorphization trajectory (between nanocrystalline graphite and amorphous carbon [5, 7]), the average size of graphite layer L_a ~14.6 Å was estimated.

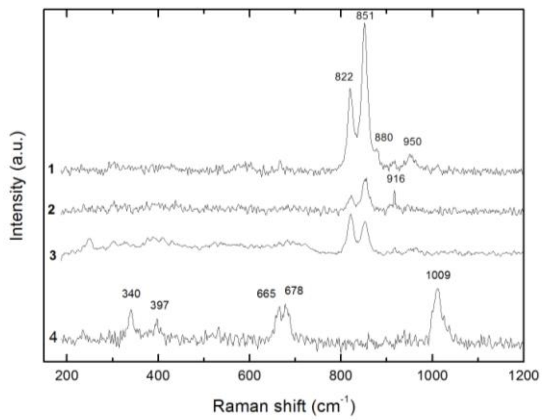

Fig. 1 Raman spectra of silicate grains in meteorite Kosice. Spectra were smoothed using 5 points in Svitzky-Golay procedure. Numbers 1-4 indicate different positions of laser spots at the sample.

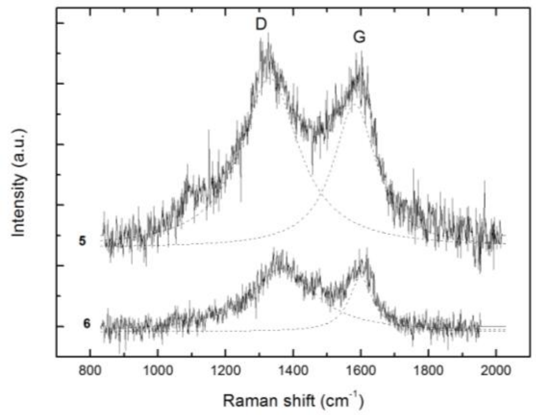

Fig. 2 Raman spectra of carbonaceous matter in Kosice. Numbers 5, 6 indicate different positions of laser spots at the sample.

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Chelyabinsk meteorite: eye witnesses interviews.

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Introduction

In the morning of February 15 2013 (3:20 UT) the large space body entered the Earth atmosphere in the Chelyabinsk region. The uniqueness of this event consists in the fact that entry of large (20 m in size body) was well documented. This event was observed by numerous eyewitnesses and by a number of registration systems including more than 400 photos and videos, satellite observations of the bolide light curve and subsequent dust trail, records of infrasound and seismic signals etc.

Eye witnesses interviews

Some information can only be collected by interviewing witnesses. Various smells, for example, were reported in a wide area around the fireball trajectory. To collect such data two approaches were taken. Some 1800 witness accounts were collected via a questionnaire on the internet, a great example of crowd sourcing. Unfortunately, the responses are mostly from highly populated areas centered on Chelyabinsk, Miass/Chebarkul, and the M36 road. Questions asked included information about the eye witness location, sound heard (yes, no, observer inside), temperature effects (observer became hot, felt some heat, did not feel heat, was inside, provide own description), smells (smell of burning, no smell, own description of smell), ashes (yes ashes, no ashes, didn't note), blast wave arrival (time difference estimated, yes, didn't hear, was inside), and it was asked whether there were any injuries.

To cover the smaller villages in the area as well, some 50 villages and towns were visited between 3 and 5 weeks after the event, during which time about 150 locals were questioned. The population is concentrated in villages and towns, with no houses in between, providing natural sampling points for information. The witnesses were asked whether the fireball was seen (blinding, pain in eye, was heat felt, sunburn?), how the impact of the shockwave was experienced (shaking, dust?), whether damages or injuries occurred (structural damage, flying glass?), whether unusual scents were smelled, and if meteorites were found locally. Several people in the each village were questioned, until reports of damage were confirmed.

Data obtained collected these interviews will be presented.

The MU radar meteor head echo database

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Abstract

A systematic set of monthly meteor head echo observations was conducted with the 1 MW, 46.5 MHz, interferometric, Shigaraki Middle and Upper atmosphere (MU) radar in Japan (34.85°N, 136.10°E) from June 2009 to December 2010 (>500 h), except for August 2009. The observation programme contains more than 100,000 events. It will in 2014 be released together with $\sim$ 20,000 events observed 2011-2012 in the form of an open database containing trajectory and orbit information. This presentation gives an overview of the data characteristics and the initial results [1], [2], [3], [4], [5].

A meteor head echo is caused by radio waves scattered from the dense region of plasma surrounding and co-moving with a meteoroid during atmospheric flight. The received signal's Doppler shift and targets range rate can therefore be used to accurately determine meteoroid velocity.

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Catalogue of meteoroid orbits with large eccentricities from the KhNURE database of radar observations in Kharkiv

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Introduction

Solar System models are built on the basis of observational data. At present stage studying meteoroids and small bodies of the Solar System both distant from the Sun and near it is topical. It is important to investigate the complex meteoroids observed near the Earth, orbits which have large values of eccentricities ($e \geq 0.9$). A part of the meteor orbits of this class may be associated with areas of deployment of the Kuiper belt objects, and the other part with the regions near the Sun. Some hyperbolic orbits ($e > 1$) of this sample ($e \geq 0.9$) can be traced back to the interstellar space. Ground-based radar methods for the determination of meteor orbits give the data that are the most statistically extensive. Today, the leaders in the number of determined individual orbits are meteor radar systems like: CMOR (Travistok, Canada) - more than three million orbits of meteors down to $+8^m$; AMOR (Christchurch, New Zealand) - about half of the meteor orbits down to $+13^m$; and MARS (Kharkiv, Ukraine) - more than a quarter million orbits of meteors down to $+12^m$. As observational data, most of this data is not published. Joining these three and other ground-based data about meteors with the data obtained "in situ" by spacecrafts is essential. At the same time an access to observational material in the form of catalogues is also important.

The catalogue

Publication of an extensive amount of meteor observational data in a form of one catalogue book is difficult. On the other hand, direct transmission of electronic data to all interested persons may violate someone's copyright. In addition, working with large data sets (even recorded in electronic form) is not always feasible and convenient. In such cases, it is sufficient that a specially selected portion of data will be extracted in the form of a catalogue. The Table shows the statistics of orbits redistricted by MARS system in Kharkiv (49.4^{0}N 36.9^{0}E). There are data from the Equatorial expedition to Mogadishu in the years 1968-1970. In column "Remarks" we can see Mogadishu site coordinates: 2^{0}N 45^{0}E. Some of the Kharkiv observational data have been published, for example we have the catalogue of 5317 orbits of individual meteors down to $+12^m$ [1], and the catalogue of 5160 streams and associations [2] ("streams and associations" indicated as "streams" in the Table). There are common classical requirements for the formation of data catalogues of the radar observations, taking into account the selectivity of the method and other features of the observations of meteors in the Earth atmosphere [1,2], which we will follow too. Here the authors solve two tasks: 1) extraction of meteoroid orbits with large eccentricities ($e \geq 0.9$) from available published and unpublished Kharkiv observational data to format the catalogue with its volume suitable for book publication; 2) representation of the results of own research for the chosen class of meteoroids on the basis of the Kharkiv radar data from the KhNURE (Kharkiv National University of Radio Electronics) database. In the Table there is a description of the KhNURE database of orbital observations performed in Kharkiv in the years 1959-1986. Statistics for all types of orbits are given (number of orbits N for any eccentricities e from 0 till 1 and higher). From all these data on orbits we selected orbits with $e \geq 0.9$. The Kharkiv data were obtained for the epoch and equinox 1950.0. Authors describe the transition to the J2000.0.

Table Some statistics of meteor observations in Kharkiv (Ukraine), where "Math" indicates that the streams were allocated mathematically

Type(all:e>0)	Obs. period	Orbits (N)	Remarks
Total	1959-1960	12500	$+8^m$
Sporadic	1959	360	$+8^m$
Geminids	1959	298	$+8^m$
195 streams	1959-1960	3500	$+8^m$/ Math
Total	1968-1970	5330	$+8^m$/2^{0}N 45^{0}E
Total	1968-1970	~ 90 000	$+12^m$
Total	1972-1978	~250 000	$+12^m$
Total	1975	5317	$+12^m$[1]
Sporadic	1972-1978	~160 000	$+12^m$
5160 streams	1972-1978	~100 000	$+12^m$/Math[2]
Eta Aquarids	1986	41	$+12^m$
Orionids	1985-1986	19	$+12^m$

Conclusions

Distribution of the orbital parameters of meteoroids belonging to a class with large eccentricities ($e \geq 0.9$) were presented and analyzed. Selected data on the orbits of meteoroids with large eccentricity values $e \geq 0.9$ together with the description of the used facility, observing conditions, processing techniques, and the ways to obtain given features and their statistics are all represented in the form of the catalogue. These data can be included in the international meteor database (the IAU Meteor Data Center).

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Theory and practice of low light TV meteors photometry: an empirical approach

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Introduction

Intensity of radiation of a low light meteor during time t of its flight along the trajectory L in atmosphere can be presented, in general, as function $I_1(L,t)$, where I is the energy of radiation per time and trajectory length units ($J \cdot s^{-1} \cdot m^{-1}$), (or per angular unit if the trajectory cannot be calculated: $J \cdot s^{-1} \cdot deg^{-1}$). For most of meteors to be observed with TV techniques the atmosphere ionized trail afterglow is of low intensity and becomes extinct fast, therefore we can consider simplified model of meteor radiation as the moving point object radiation. In that case the functional dependence $L = L(t)$ exists, and meteor light curve can be presented as function $I_0(t)$ or $I_0(L)$, where I_0 is the energy per time unit ($J \cdot s^{-1}$). Usually the light curve is plotted as function of meteor altitude. In case of nebulous or cloudy meteor structure [1], [2], [3] registered with observational systems with high spatial resolution we could introduce the surface radiation intensity as a function of azimuth A and zenith distance Z_R of a meteor: $I_2(A, Z_R, t)$, where I_2 is measured in $J \cdot s^{-1} \cdot deg^{-2}$. It is evident that values I_0, I_1 and I_2 are connected between themselves by single and double integration.

Reason of the approach

Observational TV systems to be used at Astronomical Observatory of Kyiv National Taras Shevchenko University are equipped with transmitting tubes of isocon type, which are very slowed in accumulation and readout of a signal which leads to long afterimage (sometimes tens frames dependently on intensity of the input signal). Besides, they have high non-linearity in formation of a response (amplitude) onto input video signal: $V \sim E^{0.75}$, where V is the measured digital volume of a star image, E is the luminosity of the star. For photometry of meteors registered with such systems we have to use only the radiation model I_0 [4].

Theory of photometry

Based on foregoing model of meteor radiation we have derived the formulae for calculation of meteor magnitude in own photometrical system established in accordance with spectral sensitivity curve of TV system. The calculation is done basing on the calibrating curve plotted over frame stars. Before calibration curve plotting we make correction of their catalogue magnitudes to own photometrical system with the help of energy distribution in spectra of stars of different spectral classes. It is noted that the formula for atmosphere absorption amendment will give a correct value only if we know the relative curve of energy distribution in the meteor spectrum. We propose to plot such averaged spectral energy distributions for shower meteors from existing spectral observations. After correction of atmosphere absorption the meteor magnitudes are reduced to their absolute values at 100 km.

Practice of photometry

For taking into account the effects of signal slowing and non-linearity of signal response formation we propose an empirical approach using results from tests with camera rotation [4]. Due to camera rotation the star images take the form of meteors, which gives a possibility to compare their photometrical measurements with meteor ones. Since the signal amplification factor in the systems of isocon type is adjusted each night one has to carry out the test every time before observations. In order to avoid this problem we have developed the model in which basing on only one test result the functional dependence is established between the measured values for star images in a range of their motion velocities over the frame from zero to maximal possible value. In this way we solve correctly the problem of photometrical measurements of a moving meteor over stationary stars around the meteor image from the same frame. Flat field correction is made as well [5].

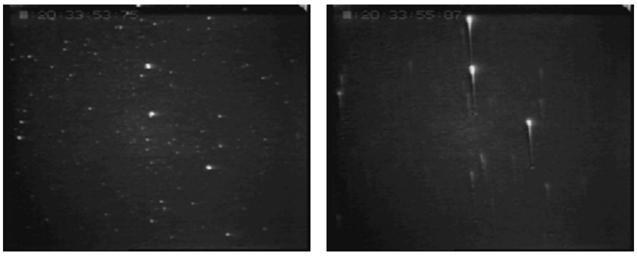

Fig. 1 Stable and moving star images in photometrical test (Ursa Major).

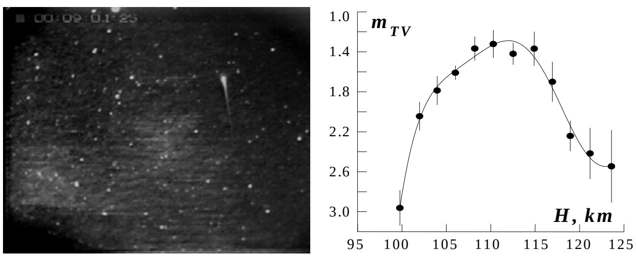

Fig. 2 A meteor for comparison with moving star images (left), and light curve of a Leonid storm 2002 meteor (right).

As an example of the photometry method we demonstrate light curves of meteors from Leonid storm in 2002 [6].

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The 2011 Draconids Airborne Observation Campaign: First results using the SPOSH camera

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Introduction

The Draconids is an annual meteor shower of early October, associated with the Jupiter-family comet 21P/Giacobini-Zinner. While meteor rates differ from year to year, simulations of meteoroid production and orbital evolutions predicted two outbursts around the time of the Draconid maximum on the 8^{th} of October 2011, with rates of several hundreds meteors per hour [2], [3] & [6].

Observations

An airborne campaign was organized in order to observe the predicted outbursts. Two aircraft type Falcon were flying at an altitude of 11 km, at a more or less constant distance, with aircraft positions given by GPS receivers, allowing double station observations. We used the data from two wide-angle cameras - the SPOSH Camera [4] and the AMOS camera [5] and an image intensifier S-VHS video camera to analyze the double-station data and determine meteor orbits.

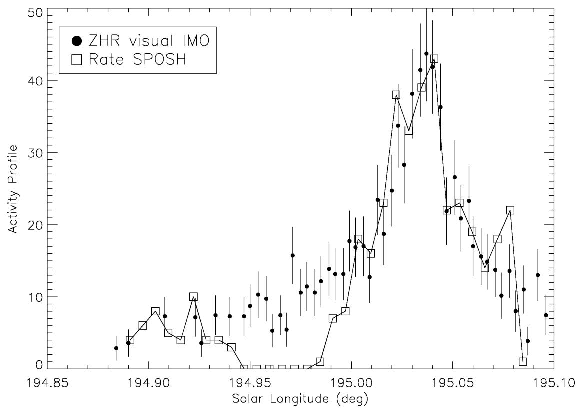

Figure 1: The rate of meteors captured by the SPOSH camera in 15 minutes bins between 16^h30^m and 21^h15^m (squares). The activity rate in terms of ZHR derived from visual observations (filled circles) scaled down to the meteor rate derived by the camera.

Data Reduction

The image data acquired by the SPOSH camera were reduced using custom-made software developed at the Technical University of Berlin and the German Aerospace Center (DLR). The software were slightly modified in order to meet the needs of the constantly moving camera placed in the aircraft. Stars in some images had to be depicted as point-like sources, in order to calibrate the camera and hence compute the meteor position with respect to the stars accurately. The astrometric data of the double-meteors captured by the AMOS and the video camera were derived using the UFO and the MILIG software packages respectively. A hybrid trajectory solution was desired after combining both astrometric data computed from the two camera systems using the standard line-plane intersection method [1].

Results

in total, 393 meteors were identified in the images acquired by the SPOSH camera. During the outburst two peaks were found, the first one occurring at 19^h51^m and the second one at 20^h18^m (Fig. 1). The trajectories and orbits of 34 Draconids captured between 19^h10^m and 21^h00^m were determined. The mean radiant of the shower is $\alpha = 262°.40 \pm 3°.55$, $\delta = 55°.30 \pm 2°.03$ being in a good agreement with the predicted radiant at $\alpha = 262°.2 \pm 0°.2$, $\delta = 55°.8 \pm 0°.2$ (Fig. 2).

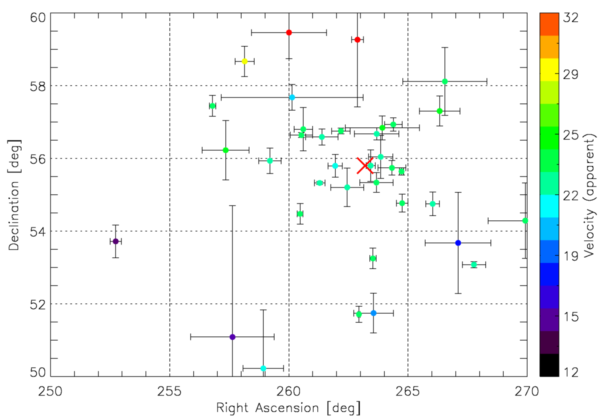

Figure 2: Radiant positions of the meteors around the predicted radiant position of the outburst (cross). The velocities of the meteors are color-coded.

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Video observations of the Geminids meteor shower in 2012 from Morocco

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Abstract

A video observation campaign of the Geminids was carried during its maximum activity peak in 2012. We detected over 131 meteors during two nights of observation at the AGM Marrakech observatory. Here we report analysis of the first meteor campaign in Morocco.

Introduction

The topic of small bodies is part of new research programs developed at Oukaïmeden observatory (OUCA) and at the AGM observatory of Marrakech [1, 2]. Deserts in southern Morocco are known of being one of the most important places in the world in meteorite recovery science. Studies of various meteorite falls in Morocco are led by H. Chennaoui [3]. In order to link meteorite falls with observations, the Oukaïmeden observatory set up first Moroccan meteor network.

Instruments

Our equipment included two Watec 902H2 cameras, a 12mm/F1.2 lens (FOV ~30°x20°), a 6 mm/F1.2 lens (FOV ~60°x40°), and a 600 grooves/mm grating, mounted in front of the 12 mm lens. The GPS time inserters are used to stamp time on every video frame with a precision of 0.001 seconds. The primary goal of the campaign was to make a double station observation (from Marrakech and Oukaïmeden observatories), but a technical problem has prevented us from achieving this goal. We report here all observations taken from AGM Marrakech. The AGM Marrakesh observatory is located 42.38 km south of the Oukaïmeden observatory. The station elevation is 485 m above the sea level; it is situated on 31°37’8” North latitude and 7°59’35” East longitude. The total number of effective hours of observation was 6h in the first night and 7h30min in the second one.

Analysis

The photometry of identified Geminids was performed with the UFOAnalyser. The magnitudes range between -2.1 and +2.1, where most magnitudes range between 0 and 1. Figure 1 reveals a correlation between the duration and the magnitudes. This distribution shows that brightest Geminids have longer duration than the fainter Geminids, with some exceptions. During the first night of observations, the maximum occurred between 23^h00^m and 00^h00^m UT, while on the second night it occurs between 02^h00^m and 04^h00^m UT. The ZHR was calculated assuming a population index of r=1.51. The ZHR profile shows Figure 2. We analysed Geminid spectrum for the brightest meteor. Its spectrum revealed the most features, showing a normal class spectrum, with high sodium content.

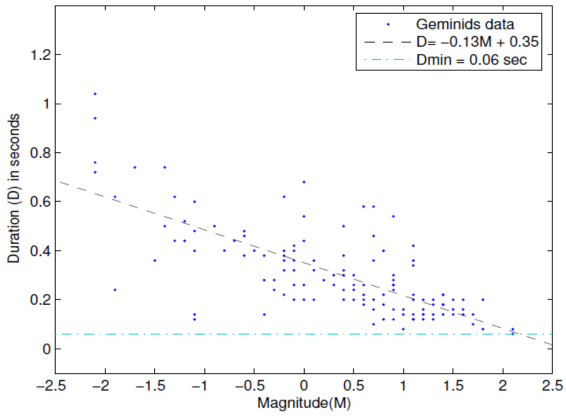

Fig. 1 Magnitude of 131 Geminids detected as a function of its duration.

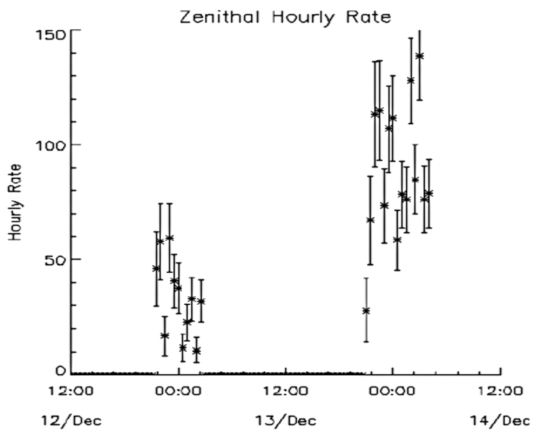

Fig. 2 ZHR profile based for the Geminids 2012.

Conclusion

Morocco is found to be an excellent place for meteor observations. The Geminid campaign gave us a great opportunity to test our equipment. Since then we are able to perform observations from two stations, monitoring meteor showers and detect the source of future meteorite falls.

Acknowledgement

The campaign was supported by Egide/PHC MA/11/257. We are grateful to the Mr. Hila Omar and its company Atlas Golf Marrakech for putting at our disposal the means of their observatory to conduct the Geminids observation campaign.

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Physical and kinematic characteristics of meteoroids producing bright radio meteors

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The physical characteristics of meteoroids, especially their masses and densities, on the row with radiant's and velocities are of great interest not only for meteor astronomy, but also cosmonautic and cosmogony of the solar system. They provide information about the nature of their parent bodies, the nuclei of comets and asteroids. One of the main methods of research of meteors is based on the results radar observations. Previously, based on radar observations of meteors in Kharkov, Harvard and Obninsk [1-3] several tens to several hundreds of meteor streams and associations were identified. However physical characteristics of meteoroids in small showers and associations are not studied.

Accumulated results of radar observations of meteors with 4 – 5 - station in Gisar Astronomical observatory (GisAO) Tajikistan in 1968-1980 can significantly supplement the data about meteor showers and associations. This is due to the fact that the data obtained in GisAO, is different from similar data from other stations in the following: 1) our data belong to meteors brighter +5 magnitudes, when at Harvard, Obninsk and Kharkov received information about of the weaker meteors (6.5 ÷ 13 magnitude); 2) radiant's and velocities of the meteors were determined by the bearing-time radio method. The bearing-time radio method [4] gives the gain in the number of measurement 3 times and the zenith angles of the radiant meteor is defined 25-50 times more accurately than the diffraction-time method; 3) this paper presents along with radiant's and velocities the physical parameters (the mass and density) of the meteoroid streams and associations.

This paper are contain data about radiant's, velocities, masses and densities of 214 meteor showers and associations identified by the results of radar observations of more than 6000 meteors observed in the GisAO in 1968 - 1969 gg. Certain meteor streams and associations were observed by the radar for the first time. On the results of radar observations of meteors, taking into account the factors influencing the shape of the ionization curves [5] the masses and densities of the meteoroids in meteor streams and associations are defined. The mean values of meteoroid masses in meteor showers and associations are in the interval $7.10^{-4} \div 0.3$ g, and their density in the range of $0.3 \div 7$ g/cm^3. The mean values of density of the meteoroids in 76% meteor showers and associations are concentrated between 1 and 4 g/cm3. 11% meteor showers and associations, have mean values of density of meteoroids in the limits from 4 up to 7 g/cm3, and the remaining 13% of meteor showers and associations have mean density smaller than 1 g/cm^3.

Analysis of the masses and densities of meteoroids in the meteor showers and associations show that, with an increase in the average masses of the particles, their average density decreases. It may be due to the structure of the particles. They can have a different porosity. Based on the results of radar observations studied, the density of the meteoroid streams twins and their porosity estimated. It is established that the density and structure of meteoroid streams with a common origin have similar values.

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Meteor detection in wide-field survey telescopes

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Introduction

Meteor observing requires huge field of view (FoV) as its appearance in the sky cannot be foreseen. In the new era of the time-domain astronomy many telescopes will cover the whole sky with a cadence of a few days. These requirements lead to fast large telescopes with wide FoVs, like the Schmidt cameras that were widely used for meteor observing in the past. We present here an estimation of the number of meteors detected as a byproduct of these surveys, with the detailed example of the Test-Bed Telescopes, an ESA project for NEO and space debris surveillance.

Telescopic meteors

Meteors have been widely observed with the use of telescopes [1], but in the vast majority of the cases these are serendipitous detections [2][3].

Due to their nature meteors within the hundredths of micron range are monitored using radar sensors. Most optical meteor surveys observe meteordown to magnitude 6 (millimeters range), however smaller meteoroids have similar luminous efficiencies and are able to produce meteorsas they suffer ablation down to 100 microns [4].

Therefore these meteors are observable in the optical range with the use of silicon devices (i.e., CCDs) and the aid of large collection area optical devices. The performance of this systems (meteor rate) is the product of the flux of meteoroids by the atmospheric area/volume A monitored by the telescope. The flux of meteoroids in the detection range of the telescope is the integral down to the limiting magnitude (ml) of the meteor luminosity function F(m).

$$meteor\ rate = A \times \int_{-\infty}^{ml} F(m)dm$$

Inputs for this study are the sporadic meteoroid fluxes detected in the visual range (down to magnitude +6) by IMONET[5] and in the radar range for fainter meteors [6].

Test-Bed Telescope (TBT) project

Within the Space Situational Awareness (SSA) programme of ESA, it is foreseen to deploy several robotic telescopes to provide surveillance and tracking services for man-made as well as natural near-Earth objects (NEOs). The Test-Bed Telescope (TBT) project will procure a validation platform for an autonomous optical observing system in a realistic scenario, consisting of two telescopes located in Spain and Australia, to collect representative test data for precursor SSA services.

These small telescopes are a clear example of this new astronomical survey era. They will be 60-cm telescope with a 2.3ºx2.3º FoV taking short exposure images during clear nights all year round.

The result of this study for the TBT telescopes with ~12 square degrees of FoV is the detection of meteors in the range of tenths per hour. Low-noise CCD read-out, short exposures and dark sky are essential to increase the SNR of meteors and the subsequent detection probability. Else the limiting magnitude is diminished rapidly due to the short time the meteor spends over a pixel compared to the constant sky background.

Meteor identification

Most meteor detection programs rely on movement detection thanks to the video rate imaging. However still images show streaks coming from several sources: planes, satellites and other fast-moving objects. In huge field of views meteors show characteristic lightcurves that allow unambiguous identifications.

Nevertheless identifications could be an issue in wide-field telescope images. Fortunately these telescopes usually have focal lengths long enough to show meteors (at 100km high) out of focus [2] [3]. Also low-earth orbit satellites are easily discarded taking images only when the Sun is not illuminating these orbits (usually within 2 hours after or before the twilight).

Conclusions

Meteor detection rates to be achieved with the future wide-field survey telescopes are similar to the ones forcurrent video networks. Therefore meteors detected as byproducts in these surveys will be a free source of meteoric data. For this purpose survey images should be analysed by meteors scientists using survey archives or even dedicated algorithm in their processing pipelines.

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Taurid Meteor Complex

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The structure of the autumnal part of the Taurid meteor complex based on photographic (IAU MDC database, [1]), radio (Harward Radio Meteor Project, [2]) and video (Japanese Network, [3]) meteor orbits is investigated and presented. Potential filaments or sub-streams to be associated with the complex were searched for utilizing the Southworth-Hawkins D-criterion. In order to get the cores of the streams a strict limiting value D of 0.10 (photo and video), 0.15 (radio) was applied. Altogether eighteen filaments or sub-streams associated with the complex were separated, with the length of the complex exceeding 100 degrees. Central part of the complex is formed by four the most dense filaments, the Northern and Southern Taurids, Southern Piscids and Omicron Orionids. Utilizing the D-criterion, also NEOs that might be associated with the filaments and streams of the complex were searched for following the orbital evolution of the mean orbits of the filaments and NEOs for 10 000 yrs. The most probable bodies genetically related to the complex besides 2P/Encke are 2005 UY6, 2005 TF50 and 2007 RU17.

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Photographic IAU MDC Meteor Database - Version 2013

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A new 2013 version of the IAU MDC photographic meteor orbits database which is an upgrade of the current 2003 version [1] is presented. To the 2003 version additional 282 orbits are added, thus the new version of the database consist of 4873 meteors with their geophysical and orbital parameters compiled in 41 catalogues (Table 1). For storing the data, a new format enabling a more simple treatment with the parameters, including the errors of their determination, is applied [2]. At present only the six newly added catalogues contain the parameters given with the errors of their determination. The errors, where these are available, will gradually be added to all parameters of the older catalogues included in the database. The database will be freely available in an electronic form on the IAU MDC web site ,,http://www.astro.sk/˜ne/IAUMDC/Ph2013/" and its dowloading will become possible immediately after the Meteoroids 2013 conference.

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Table 1: The statistics on the catalogues included in the new, Version 2013, IAU MDC Database of photographic meteor orbits. Abbreviations: IC – identification code of catalogue, N – the number of orbits in the catalogue.

IC	N	Investigator/Station
B1	359	Betlem, Dutch Meteor Society
B2	75	Betlem et al., Dutch Meteor Society
B3	47	– " –
C1	103	Ceplecha (small camera)
D1	73	Babadzhanov et al., Dushanbe (small camera)
D2	181	– " –
D3	72	– " –
D4	77	– " –
D5	15	– " –
D6	44	– " –
D7	20	– " –
D8	154	– " –
E1	189	Ceplecha and Spurný, European Network
E2	48	– " –
E3	98	Ceplecha, Spurný et al., European Network
E4	34	Spurný et al., European Network
F1	334	McCrosky, Prairie Network
G1	25	Gale Harvey, New Mexico State University
H1	313	Hawkins and Southworth (Super-Schmidt)
I1	136	Halliday et al., MORP Network
I2	123	– " –
J1	413	Jacchia (Super-Schmidt)
K1	100	Kiev (small camera)
K2	70	– " –
K3	36	– " –
N1	95	Koseki, Nippon Meteor Society
N2	164	– " –
O1	133	Shestaka et al., Odessa (small camera)
O2	22	– " –
O3	70	– " –
O4	122	– " –
O5	50	– " –
O6	62	– " –
P1	353	Posen and McCrosky (Super-Schmodt)
R1	32	Trigo-Rodríguez et al., Spanish Meteor Society
S1	314	McCrosky and Shao (Super-Schmodt)
T1	31	Ohtsuka, Tokyo Meteor Network
T2	48	Ohtsuka et al., Tokyo Meteor Network
T3	6	– " –
U1	66	Ochai et al., Nippon Meteor Society
W1	166	Whipple (small camera)

CMOR Observations of the 2011–2012 October Draconid Outbursts

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Here we present the observations obtained by the Canadian Meteor Orbit Radar (CMOR) during the 2011–2012 outbursts of the October Draconid meteor shower. The Draconid meteor shower is an annual meteor shower originated from Comet 21P/Giacobini-Zinner. The activity is typically very weak, except for a few years, most notably 1933 and 1946. A moderately strong outburst had been predicted for the year of 2011 [1]. CMOR recorded 61 multi-station echoes and 179 single-station overdense echoes between 16-20h UT on October 8, 2011. The mean radiant was determined to be $\alpha_g = 261.9° \pm 0.3°$, $\delta_g = +55.3° \pm 0.3°$ (J2000) in agreement with model predictions to $\sim 1°$. The average mass index using the amplitude distribution of underdense Draconid echoes was determined to be ~ 1.75, in general agreement with the value of ~ 1.72 found using the diffusion-limited durations of overdense Draconid echoes. The relative flux derived from overdense echo counts showed a similar variation to the meteor rate derived from visual observations. We also apply the ablation meteoroid model to the observation and find that Draconid meteoroids at radar sizes are consistent with a fixed grain number $n_{grain} = 100$ and a variable grain mass m_{grain} between 2×10^{-8} kg to 5×10^{-7} kg, with bulk and grain density of 300 $\mathrm{kg \cdot m^{-3}}$ and 3 000 $\mathrm{kg \cdot m^{-3}}$, respectively. There was no predictions for significant activies for the year of 2012, but an unexpectedly intense outburst was noted by CMOR [2]. CMOR recorded 516 multi-station echoes and 178 single-station overdense echoes between 15-19h UT on October 8, 2012. The mean radiant was determined to be $\alpha_g = 262.5° \pm 0.1°$, $\delta_g = +55.6° \pm 0.1°$ (J2000). A significant radiant shift ($0.4° \pm 0.2°$) was also noted between echoes recorded in the intervals of 15-16h UT and 16-17.5h UT. Numerical simulation of the 2012 outburst was conducted using the RADAU method. Initial results suggest that the outburst mostly originated from 1966 ejecta by the parent comet (21P/Giaconibi-Zinner), the simulated radiants agreeing with observations within uncertainty. Details of the radar analysis together with simulation results will be presented in this talk.

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Radio Polarisation Measurements of Meteor Trail Echoes with BRAMS

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Introduction

When using radio techniques to observe meteors, one way of gaining insights into the physical phenomena that produce the meteor echoes is by analysing the radio polarisation of meteor trail echoes [1-3]. For example, the time variation of the polarisation of meteor echoes can, in principle, provide information about electron densities in the meteor trail as shown in [4] and [5]. Furthermore, the physical phenomena that lead to specific signature of some echoes in the time-frequency domains, such as the multiple branch echoes are still not fully understood. The analysis of the polarisation of such echoes can be used to increase our knowledge in this field. In this study, the forward scattering technique is used to analyse the meteors. The transmitter is the dedicated beacon of the BRAMS (Belgian RAdio Meteor Stations) network [6]. The transmitting antenna emits towards the zenith a purely sinusoidal wave circularly polarised, at a frequency of 49.97 MHz and with a power of 150 watts. The receiving station includes a crossed 3 element Yagi antenna and therefore allows measurements of all polarisations.

Principle of polarisation measurement

The two receivers are synchronized with an external 10 MHz reference. Signals from the two receivers and the PPS from a GPS receiver are sampled simultaneously at 5512 Hz by an ADC and then stored on a PC.

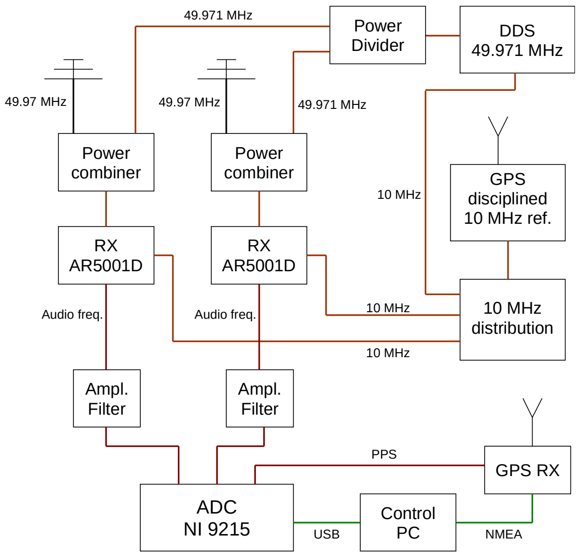

Fig. 1 Measurement setup.

Examples of meteor polarisation measurement

Below is an example of spectrograms (5 minutes) obtained for both polarisations. Stokes parameters U,Q,V + polarised signal Ip and profile I(t) are shown for an overdense echo (long echo produced by high ionisation meteor trails).

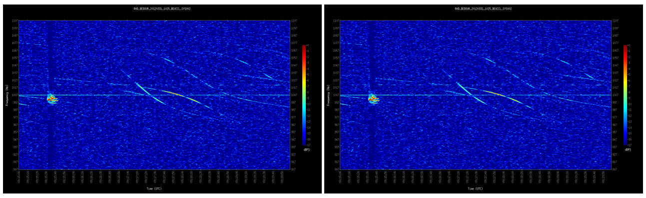

Fig. 2 Five minutes spectrograms for both polarisations.

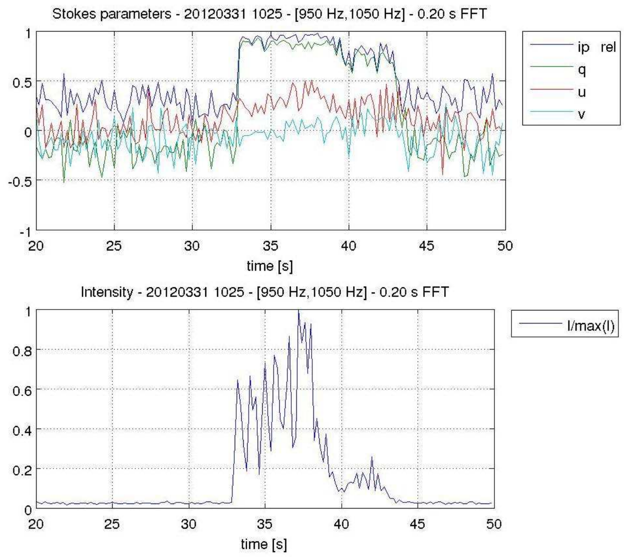

Fig. 3 Stokes parameters U,Q,V, polarised signal Ip and profile I(t).

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Evidence for a VLF propagation perturbation associated with a meteor

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Introduction

Evidence is given in this presentation that under some circumstances, a single meteor is capable, when entering the Earth atmosphere, of disturbing the propagation of VLF (Very Low Frequency) electromagnetic waves in the Earth-ionosphere waveguide.

VLF waves propagation

According to the ray tracing method commonly used to describe VLF radio propagation on short to moderate distances (<2000 km) [1], the amplitude of a VLF radio wave at a given observation location is the vectorial sum $\vec{A_O} = \vec{G} + \vec{S}$. Vector lengths of $\vec{G}$ and $\vec{S}$ represent respectively the amplitude of the ground wave propagating along the Earth surface, and of the sky wave reflected from the D region of the ionosphere. The angle between the two vectors represents the phase (delay) between the ground wave and the sky wave components.

The amplitude and the phase of the sky wave $\vec{S}$ at the observation location depend on the altitude and on the density of free electrons of the D layer of the ionosphere.

Various natural phenomenons such as solar flares, polar cap absorption events, X rays and γ rays radiated by distant stars, and lightning create long duration or short transient VLF propagation disturbances by modifying the ionospheric D layer parameters [2].

VLF phase [3] and amplitude [4] transient variations occurring during meteor showers were reported in the past, but these variations were observed only at large time scales (i.e. averaged values), and not directly linked to any discrete meteors.

Observation of a transient VLF amplitude disturbance induced by a single meteor

In the framework of a joint radio/video meteor observations campaign, VLF/VHF radio and video data were synchronously recorded at the Pic du Midi observatory during the 2010 Geminids meteor shower [5].

The radio set-up consisted mainly of an home-made e-field ELF/VLF broadband receiver (5 Hz to 24 kHz pass-band), a VHF commercial receiver dedicated to meteor pings detection and a digital hifi stereo recorder. Five military communications VLF transmitters (GBZ, DHO38, FTA, HWU and ICV) were monitored simultaneously 24 hours a day. Meteors were detected in VHF forward scatter mode, using the french military Graves (GRV) radar as targets illuminator (Fig. 1).

Short amplitude transients on the amplitude of the german VLF transmitter DHO38 and of the french VLF transmitter FTA were serendipitously observed when a large meteor entered the atmosphere on december 13 at $23^h13^m44^s$ UT. No visible transients were observed at the same time on the amplitudes of GBZ, HWU or ICV.

On Fig. 2, the upper trace shows successive meteor echoes detected in forward VHF scatter mode.

The middle trace shows a constructive interference between $\vec{S}$ and $\vec{G}$ detected on FTA, and the lower trace shows a destructive interference on DHO38.

The horizontal time scale on the figure is 10 s/div, and the vertical VLF amplitudes scale is 0.1 dB/div.

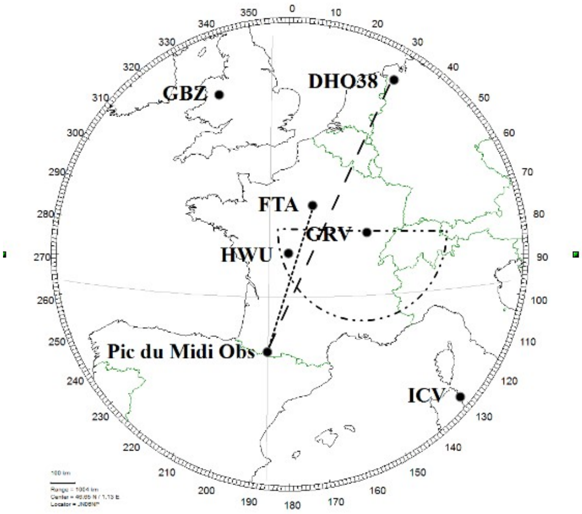

Fig. 1 Observatory and radio transmitters locations.

Such a "M-SID" (Meteor induced Sudden Ionospheric Disturbance) is supposed to be created by a sudden variation of density and/or altitude of the lower part of the ionosphere, this variation being due to the appearance of a large meteor overdense trail (presenting a free electrons line density greater than $2x10^{14}$ electrons/meter) .

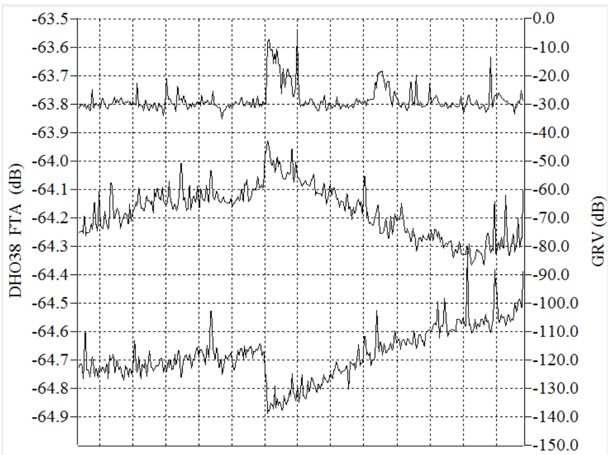

Fig. 2 Sudden ionospheric disturbances related to a single meteor

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THE NORWEGIAN METEOR NETWORK

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The Norwegian Meteor Network was founded on March 9, 2013, at a meeting held at the Natural History Museum, University of Oslo.

The aim of the network is to:

- Ensure that all Norwegian meteorites are handled open and available for scientific investigations.
- Ensure that new meteorites, or relevant fragments of them, are deposited and managed by a scientific institution, in Norway this shall be the Natural History Museum, University of Oslo, which today hosts all, except one, of the Norwegian meteorites.
- Spread information to the general public about meteorites and the information they can give about our planet and the outer space.
- Ensure that finders are rewarded.

Mode of operation:

- Collect and make available observations of fire balls.
- Establish a network for sky watching with "All Sky Cameras"
- Organize a qualified, standing team for meteorite searching at observed falls
- Strive to get meteorite aspects included in the Norwegian law for the diversity of nature (Naturmangfoldsloven), including ownership rights and finder's reward.
- Serve to the media correct and exact information regarding meteorites, fireballs and space issues.

A web site is in active operation: http://norskmeteornettverk.no

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New meteor showers identified in the CAMS and SonotaCo meteor databases

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In our talk, we will present new meteor showers identified in the Cameras for All-sky Meteor Surveillance (CAMS) and SonotaCo Network Japan databases, and talk about their possible parent bodies.

In our survey we used both CAMS and SonotaCo meteor databases. This includes video meteors collected during the first year of CAMS network operation [1], and meteor orbits detected by the SonotaCo network in 2007-2009 [2]. The meteor databases are examined using Southworth and Hawkins criterion [3]. The meteoroid stream identification method applied in our survey is based on single-linking method.

We identified 83 meteor showers. The list includes 43 already established streams and 40 newly identified streams (IAU#448-502). For each shower, we give radiant position, meteor shower velocity, the interval of activity, as well as their mean orbital elements. Additionally, we compared new streams indentified in this work with IMO video meteor network database. We found that the radiant position of 16 of our new showers is consistent with unassigned yet individual radiants detected in the IMO database. Moreover, for several of those newly identified streams we have identified possible parent bodies. However, the parent body links still needs to be firmly established by dynamical simulations (see later talk Rudawska & Vaubaillon).

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Spectroscopic airborne observations of the 2011 Draconids meteor shower outburst

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On the October 8^{th} 2011, meteors from comet 21P/Giacobini-Zinner were predicted to outburst with expected rates of several 100 meteors per hour [1]. Based on the expected conditions and the predicted location of the Draconid quadrant, airborne and ground-based meteor spectroscopic observations carried out.

Two Falcon aircraft (CNES/INSU/Meteo France-F-GBTM, DLR-DCMET) with mounted spectra cameras took off in Kiruna, Sweden, before the predicted double peak to apply 'double station' observations at an altitude of 11 km. The IMCCE camera captured spectra of five Draconid meteors, observed in the second peak of the predicted outburst. The spectra were taken with a WATEC 902H2 camera with a lens of focal length of 12mm, and FOV 30 x 40 deg, onboard the French Falcon. The camera was equipped with a 300 groves/mm. ESA provided a LCC1 camera with FOV 22 x 28 deg, and f = 50 mm lens, onboard the DLR Falcon, equipped with a spectral ZEISS grating with 600 grooves/mm. The LCC1 captured nine Draconid meteors.

This poster discusses the results obtained from the spectral observations and confirm the expected main constituents of the Draconid meteors, magnesium and sodium, with an early sodium release in the meteor event.

Acknowledgement

DLR Falcon flight was supported by EUFAR (FP7 EC funded project). French Falcon supported by INSU CSAA program.

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Observation of October Draconids 2011 in Maidanak Observatory and Study of its Peak time

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Introduction

October Draconids is one of the established meteor shower. The parent body is 21P/Gicacobini-Zinner discovered in 1900. In the past, several great meteor storms and outbursts were observed. For example, the estimated values of ZHR were about 10,000 both in 1933 and 1946, while they were between about 500 and 1,000 both in 1985 and 1998.

In 2011, the outburst of the October Draconids was forecasted on October 8. The main peak, we named “2nd peak”, was predicted at around 20h (UT) and the sub-peak, we named “1st peak”, was predicted at around 17h (UT) on October 8 [1][2][3][4]. The main peak was caused by a dust trail which was formed by meteoroids ejected from the parent body in 1900. The peak would be certainly expected because the dust trail which caused this peak was formed after the discovery of the parent comet. And the condition of its density of meteoroids was so favorable for a meteor outburst. On the other hand, the sub-peak was uncertain because the dust trail for this peak was formed before the discovery of the parent body. The meteoroids in this trail were ejected in 1883. However, if the sub-peak is detected, it shows the evidence of active ejection from the parent comet before its discovery. Hence, we set that a purpose was to detect the sub-peak and we decided to observe it in the area of Central Asia because a condition was favorable for observing the sub-peak. Moreover, we could observe the main peak, and a good weather was expected there.

Observation

We observed at Maidanak Observatory in Uzbekistan, where the longitude is 66d 54’ 0.5”E, the latitude is +38d 40’ 26.6”, and the 2600m above the sea level. We carried out a video observation by using high sensitivity monochrome cameras. We used WATEC Neptune100 with 6mm lens for the observation instrument.

We also performed a visual observation as a standard method for meteor observations as a complimentary method.

Result

The main peak (2nd peak) was obviously detected at around 20h (UT) both by a video observation and a visual observation. Its time was almost corresponding by the results collected by IMO [5]. On the other hand, the sub-peak (1st peak) was not clear because weather condition was not so good due to the scattered cloud. However, the appearance of the Draconids began at 15h (UT). Its time was before the expected sub-peak, and it was very early for the main peak. Moreover, the appearance continued until the expected time of the sub-peak. Hence, this activity was thought to be due to the sub-peak.

Discussion

The time of the main peak was predicted at 20h36m (UT) by Sato, one of authors [2]. The time difference between the predicted peak and the observed peak was about a half hour, it was slightly large. Then, the method of a prediction was examined again in detail. As a result, it became clear that the process of deriving the epoch with using orbital elements had an error. The corrected peak time was about 20h09m (UT) and it was almost matched the actual peak time of observations [6]. We also studied other peaks, it was found out that sub-peak was divided into two peaks which were formed by 1894 trail and 1887 trail.

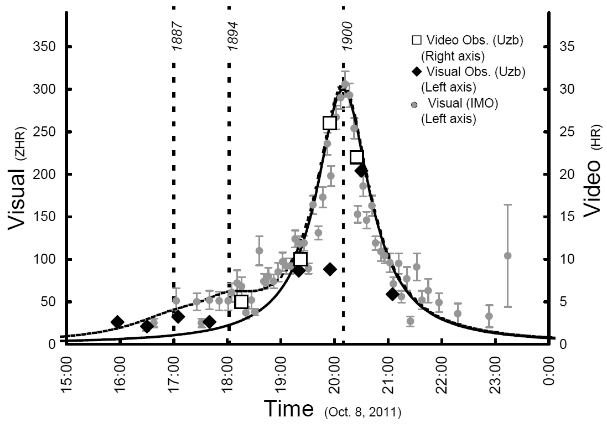

Fig. 1 Observation results and simulation curves

Fig.1 shows observation results and two simulation curves. The whole time variation of visual results was not fitted only by a simulation curve (solid) of the 1900 trail. Other simulation curve (dotted) which totaled three trails was mostly matched to the actual observation results. It may have been detected that the sub-peak caused by both the 1887 trail and the 1894 trail. Therefore, the parent body was thought to have been active before the discovery (in 1900).

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Present state of the MAARSY meteor head echo analysis

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MAARSY is a new high-power large aperture (HPLA) radar system with an operating frequency of 53.5 MHz, located at the North-Norwegian island Andøya $(69.30°N, 16.04°E)$. The 433 Yagi antennas arranged in a circular aperture with 90 m in diameter and a peak power up to 800 kW is able to detect meteor head echoes. Here we present the current state of our meteor head echo analysis, which includes a decoding algorithm and the combination of different receiver baseline length for an optimal trajectory calculation. An inter-pulse phase analysis leads to the determination of a time-dependant deceleration and first assumptions of the dynamical meteor masses. We derived for the Geminid meteor shower compaign in 2010 the dynamical meteor masses ranging from 10^{-3} to $10^{-13}kg$. Furthermore the radar cross section of the meteor head echo during its flight through the radar beam is calculated. In the future we plan to use these observed parameters for the modeling of the meteor flight through the atmosphere using a single body meteor ablation model. The evaporation pressures will be taken from the MAGMA equilibrium code, which combines dynamical and plasma characteristics with chemical constituents.

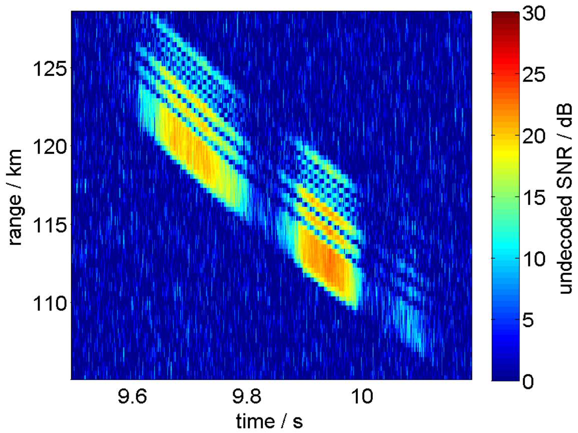

Figure 1: Undecoded Signal-to-Noise-Ratio of an oversampled meteor head echo.

Bright Perseid fireball with exceptional beginning height observed by different techniques

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Instrumental data

Regular all-sky observations of fireballs in the Czech Republic are carried out by Automated fireball observatories (AFO) [1] daily and by analog image-intensified video cameras from two stations with narrow (50 degrees) field of view during activity of selected meteor showers [2]. We report observation of a bright fireball belonging to the Perseid meteor shower which was recorded simultaneously by 11 all-sky photographic cameras on 12 August in 2012 at 22:29:46 UT and by chance it also flew very favorably in the field of view of video cameras on both stations. The fireball was also recorded by one high-resolution 360 mm photographic camera, three digital all-sky cameras, one wide-field digital camera, and one digital video camera. Evolution of persistent train of this fireball was detected by digital still cameras and analog video cameras for almost 15 minutes. The brightest part of the train was observed at heights 95-85 km. Moreover, one photographic spectral camera and one spectral video camera recorded spectrum of the fireball. Except direct photographic imaging each AFO is equipped with a fast photometer with a sampling rate of 5000 samples/s and -1 magnitude sensitivity limit. Therefore we have very detailed information about light curve of this fireball when it was brighter than this sensitivity limit. We have never recorded such bright fireball with so many different instruments, so it gave us unique opportunity to get complex and reliable results about this fireball and for the first time, we can also compare these results obtained independently from different kind of instruments for one meteor. Presented results are based on 5 best all-sky and 1 hi-res photographic images, 2 video records, and 3 digital pictures.

Atmospheric trajectory

The exceptionally long atmospheric trajectory (145 km) was determined with high accuracy. The standard deviation of any arbitrary point on the luminous trajectory is 28 meters. Terminal heights determined from different techniques are very close to each other: within 1 km in altitude. The photographic all-sky terminal height is 79.2 km, digital all-sky height is 79.4 km, and the terminal height from image-intensified video cameras is at 78.7 km. The fireball terminated suddenly and quickly which is in contrast to its beginning. The beginning heights strongly depend on the sensitivity of the detector (see Figure 1), which has been studied and demonstrated for other meteors in [3]. The image-intensified video cameras detected the Perseid at the height of 170.2 km as a meteor of +3 mag. This is the highest ever observed Perseid (160.7 km was the highest Perseid observed by our cameras so far) and one of the highest meteors ever observed by image-intensified cameras [4]. The highest ever observed meteors were Leonids in 1998 with the maximum observed height of 199 km [5]. The beginning heights from digital all-sky and photographic all-sky cameras are 135 and 116 km, respectively. The light of meteors produced above 130 km is accepted to be caused by atomic physical sputtering [6].

Physical properties and spectrum

We also studied physical properties of the fireball. According to the PE criterion [7], the Perseid consisted of soft cometary material (PE type IIIA) and did not differ from regular Perseid fireballs.

The spectrum shows atmospheric emissions (O, N_2) at the beginning. Later, the Na line appears, followed by other usual meteoric lines (Mg, Fe). At maximum, high temperature component lines (Ca+, Mg+) dominate. The early train was formed by the O I 557 nm line in the upper part and Mg and Na lines in the lower part. In general, the spectrum was not markedly different from other Perseids.

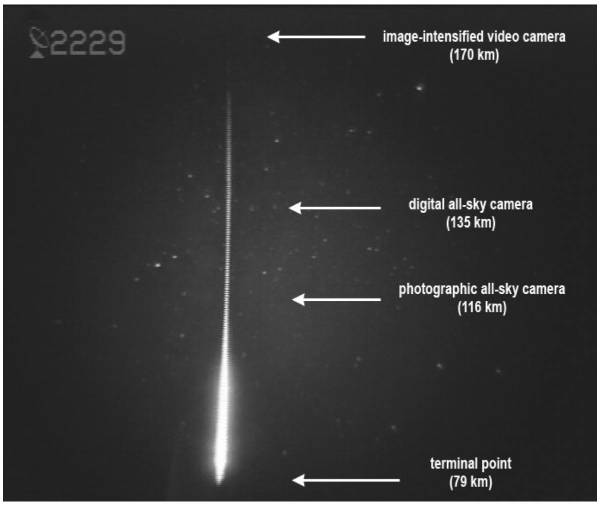

Fig. 1 Composition of the Perseid fireball from video record.

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Trajectory and orbit of the Maribo CM2 meteorite from optical, photoelectric and radar records

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Introduction

The very bright fireball illuminated sky over the Baltic Sea and neighboring countries on January 17th, 2009 at 19:08:29-33UT. It terminated as a meteorite fall and one 26g fragment, classified as a rare type of carbonaceous chondrite CM2, was found on the island Lolland in southern Denmark near the town Maribo, about two months later [1,2]. From the beginning it was clear that it will be very difficult to find enough useful instrumental records suitable to determine at least basic parameters of this extraordinary fireball, because of an almost complete cloud cover over northern and central Europe. In this study we present results of the complex analysis of all available instrumental records, which we were able to collect.

Instrumental observations

After extensive effort 3 kinds of instrumental records suitable for the trajectory analysis were found. This unique event was recorded optically, photoelectrically and by meteor radar. Optical records are represented by one video record taken by a surveillance camera in southern Sweden (from distances 172-197 km, and heights of 84-31km), the second optical record was taken by photographic all-sky camera in the Netherlands (distances 712-689km (!), heights 75-60km). Seven autonomous fireball stations in the Czech Republic equipped with fast photoelectric photometers recorded very detailed light curves (Fig. 1) and were used also for exact timing of the event [3]. Range of distances of the Czech cameras from the fireball was from 520 to 750 km which means that the brightest flare was already below local horizon on the most distant stations.

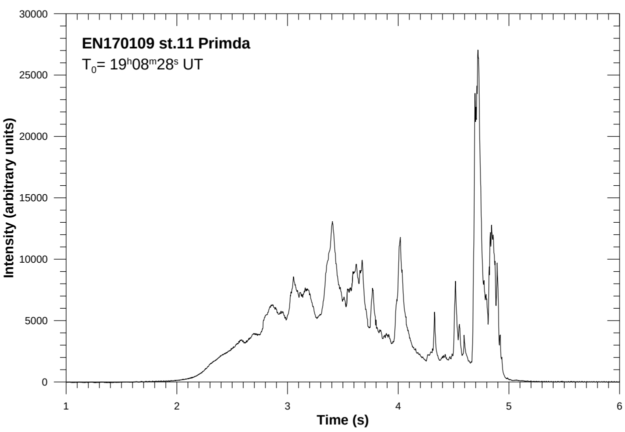

Fig. 1 Light curve of the Maribo bolide from the Czech station Primda.

The very beginning part of the fireball was recorded by meteor radar located practically below the trajectory at Juliusruh in Germany [4]. All of these records were used for the determination of the atmospheric trajectory of the Maribo bolide. Although the quality of the data is far from perfect we have been able to find reliable trajectory solution.

Results

Using our standard procedures [5] we reduced both video and photographic records. For this purpose the calibration images were used to set the coordinate system on each record and determine correct azimuths and zenith distances for each measured point on the fireball luminous trajectory. The difficulty of this task is well illustrated by the reduction of the all-sky photographic image – the fireball was recorded only 2.9 – 2.0 degrees above ideal local horizon. For the velocity determination we used different methods based on combination of optical and photoelectric data and radar data as well.
After complicated reduction work we used our rigorous methods [6] for determination of the atmospheric trajectory. The main result is that we were able to obtain consistent solution describing the atmospheric flight of the Maribo meteoroid, some of its physical characteristics, and the heliocentric orbit. These results will be the main part of our presentation.

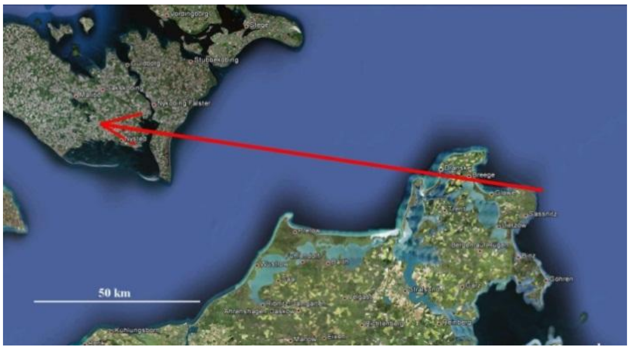

Fig. 2 Projection of the resulting atmospheric trajectory of the Maribo bolide

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Optical trail widths of faint meteors observed with the Canadian Automated Meteor Observatory

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The optical trail widths of 30 faint meteors were studied using the Canadian Automated Meteor Observatory (CAMO), located in Ontario, Canada. CAMO is an automated, two-station, image-intensified digital video system capable of detecting meteors as faint as magnitude +5. Each station is comprised of a narrow-field tracking camera guided by a wide-field camera, with resolutions of 6.6 and 145 arcsec per pixel, respectively. This gives spatial resolutions of 4.8 and 105 m per pixel at a range of 150 km. A sample sequence of frames for a meteor captured with both narrow-field stations is given in Fig. 1. Data from the narrow-field cameras were used to measure optical trail width, while data from the wide-field cameras were used to determine meteor range, velocity, and absolute magnitude. Image bloom was corrected by measuring the width of a star with equivalent brightness to a given meteor trail, and subtracting the star's width from the measured trail width.

Meteors captured over three nights, 2010 October 20, November 3, and November 6, were studied. Corrected trail widths up to 100 m at heights above 110 km were observed. 14 of the 30 events were observed with both stations and showed good agreement of trail widths after bloom correction, suggesting that the widths measured were true physical sizes, and not instrumental artefacts. The trail widths varied as the inverse of the atmosphere density, as shown in Fig. 2 for a sample event. Preliminary investigation suggests that collisional de-excitation of energetic atoms around the meteoroid is a plausible process for the formation of these wide trails.

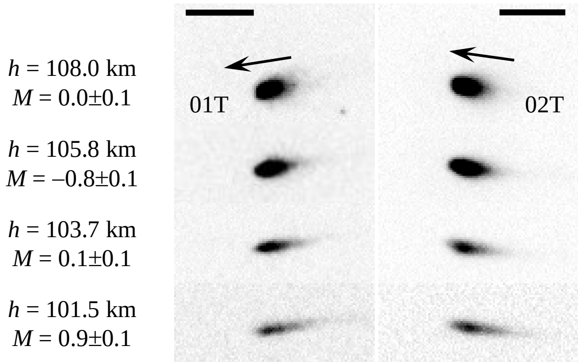

Figure 1: Four frames for event 20101020_095900 from Tavistock (01T) and Elginfield (02T) narrow-field cameras. Arrows indicate the direction of travel, while scale bars on each figure represent approximately 150 m. Height and absolute magnitude at the time of imaging is given on the left side. The velocity of the meteoroid was 66.9 km s^{-1}. The colours have been inverted for visibility.

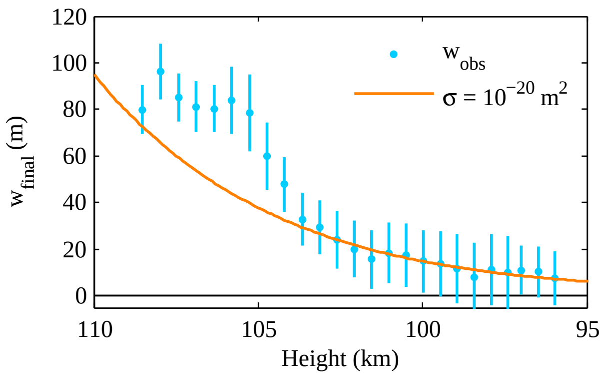

Figure 2: The peak observed, corrected trail widths for the meteor in Fig. 1. The atmospheric mean free path of an atom with collision cross-section $\sigma = 10^{-20}$ m is also plotted for comparison.

Taurids in the IAU MDC Database

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Introduction

The method of indices [1] was used to study the northern (NT) and southern branches (ST) of the autumn (night) part of the Taurid complex. The procedure based only on mathematical statistics was applied to select the Taurid meteor records from the IAU Meteor Data Center Database. There were selected 84 NT and 143 ST from IAU MDC Database [2].

Taurids associations

Using the method of indices we were searching for associations of meteoroid orbits (i.e. at least 3 meteors at similar orbits) in the datasets [3]. We found 11 associations of NT formed by 63 meteor orbits (what is 75% of 84) and 13 associations of ST formed by 114 orbits (80% of 143). The projection of the orbits of associations into the ecliptic plane is plotted in Fig. 1. Positions of radiants of associations are plotted in Fig. 2.

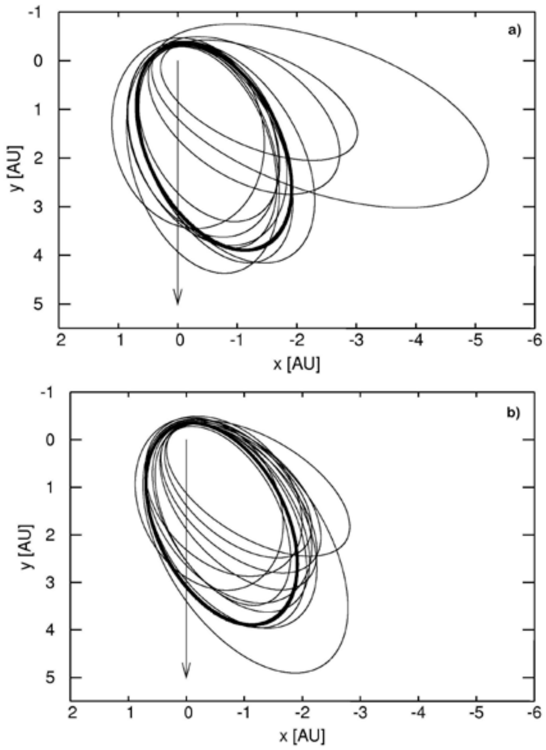

Fig. 1 A projection of the mean orbits of the selected associations of NT (a) and ST (b). A thick line is orbit of 2P/Encke.

Structure of the Taurids stream and minor autumn showers and associations

Characteristics of found associations were compared to that of known showers listed in several catalogues: A Working List of Meteor Streams [4], The list of meteor showers by Kronk [5], The list of meteor showers provided by IMO [6], Catalogues of Meteor Data Center [7], and Orbital parameters of 78 fireball streams [8].

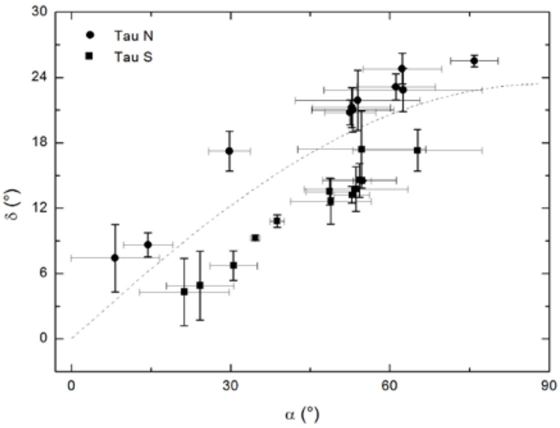

Fig. 2 The radiant motion of NT and ST is demonstrated by the radiant positions of selected associations. Dashed line is ecliptic.

We compared our findings also with the results of Porubcan and Kornos [9], who identified 15 filaments of the Taurids stream.

11 NT associations and 13 ST associations were identified with 11 known minor showers, north branch of Tau Arietids, which has not been detected yet, and 2 associations with the orbital characteristic of well known minor showers, but active before their known activity intervals. For the study of genetic relations between the orbits of associations and the orbit of accepted Taurids' parent comet 2P/Encke, we calculated the values of Southwort-Hawkins D-discriminants [10] of all possible pairs of orbits. Schemes of both the branches of Taurids were obtained.

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Prediction of meteor shower of comet 161P/2004 V2

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Introduction

Comet 161P/2004 V2 (Hartley-IRAS) is the Halley-type comet with orbital period of 21.5 years (Tisserand parameter with respect to Jupiter is 0.54). At the present, the orbit of 161P does not approach the Earth's orbit closer than ∼0.45 AU. Despite this fact, it appears that the comet can associate an Earth-observable meteor shower.

Modelling of the Stream Dynamics

The procedure of the modelling of the theoretical stream consists of the following steps.

1. The integration of motion of the parent body backward in time.
2. Modelling the theoretical stream in moment of parent perihelion passage reached at the previous step. Specifically, we generate orbits of 10,000 test particles.
3. Numerical integration of the stream particles from the moment of their assumed ejection (in step (2)) until the present.
4. The analysis of main evolutionary features of the theoretical stream.
5. The selection of the test particles in orbits passing around the orbit of the Earth in the distance shorter than 0.05 AU.
6. The analysis of the dynamical evolution of the Earth-orbit approaching part of the theoretical stream (EAPS) and, if there are enough particles, prediction of the characteristics of an eventual meteor shower associated with the studied parent body.
7. The identification of the EAPS with the actually observed meteors. We used 3, photographical IAU MDC ([1]), radar ([2], [3], [4]), and SonotaCo video ([5]) databeses.

The Predicted Stream

The stream associated with this comet is modelled for times of 200 and 500 P_o (where P_o is orbital period of the parent at the present), i.e. about 4,300 and 10,750 years before the present. The orbital as well as geophysical characteristics of seven particles of the EAPS appear to be too different from the mean characteristics of the EAPS, and, therefore, although they pass within 0.05 AU of the Earth's orbit, we do not regard them as members of the predicted shower. The EAPS consists of 729 particles in total.

The positions of radiants of the modelled particles are illustrated in Fig. 1. In this figure, the radiants of few not-shower particles are also shown (with squares). The radiant area of 161P shower associated with the stream modelled for time 200 P_o before the present is almost the same as that associated with the stream modelled for time 500 P_o before the present. The mean radiant is predicted in the direction α about 76° to 78°, δ about -23° to -22,5°. The geocentric velocity should be about 53 to 53,5 km.s^{-1}.

If the shower is relatively young, its period activity can be short, lasting only a few days. For the shower related to the stream modelled in 200 P_o before the present, the activity is pread around the mean ecliptical longitude of the Sun $<\lambda_\odot> = 181.48°$, and for the stream modelled in 500 P_o , $<\lambda_\odot> = 183.18°$.

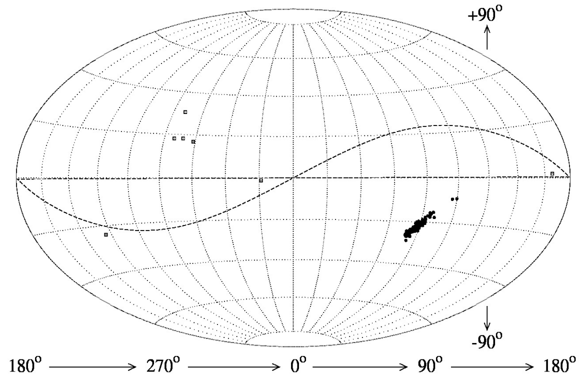

Fig. 1 Positions of radiants of the 161P-stream particles. The radiants are shown in the Hammer projection of the sky. The equatorial coordinate frame is used with right ascension indicated by meridional circles and declination indicated with the declination circles. The sinusoid-like curve illustrates the ecliptic.

Our identification of theoretical particles with the real meteors in used databases is not positive.

Conclusion

Comet 161P/2004 V2 could have associated an Earth-observable meteor shower, although no significant number of theoretical particles are identified with the real, photographic, video, or radar meteors at the moment. However, the radiants of the shower is predicted on southern sky (declination of mean radiant about -23°) where a relatively low number of real meteors has been detected and is therefore recorded in the used databases. The question on the existence of this predicted shower still remains opened.

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Slovak Video Meteor Network - AMOS Cameras - coverage, precision and results

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Introduction

Slovak Video Meteor Network (SVMN) is a project of Comenius University in Bratislava for continuous monitoring of meteor activity [1] over Slovakia and surrounding countries (Fig.1). The networks is based on AMOS (All-sky Meteor Orbit System) Cameras (Fig 3) [2], which astrometric precision was calibrated using several commonly observed fireballs within European Fireball Network [3]. The results of calibration as well as other observational results (Fig 2) will be presented.

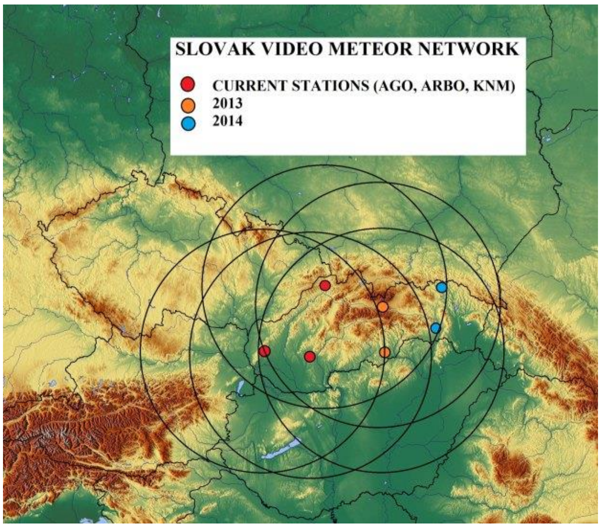

Fig. 1 Slovak Video Meteor Network, current stations and future plans.

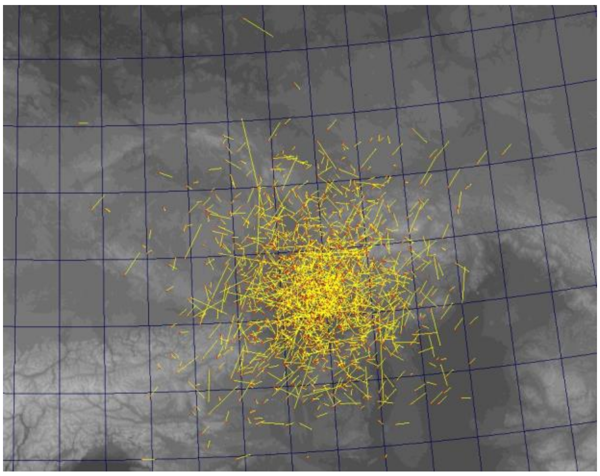

Fig. 2 Simultaneously detected meteors by SVMN in 2009-2012.

Fig. 3 View of the AMOS camera from ARBO station.

Observations

The commonly observed fireballs for calibration were selected. The dates of their appearances are following: 2013/05/07, 2013/04/16 and others. There were also possible meteorite dropping fireballs like "Komjatná" or "Kajárpéc", which were simultaneously observed from both networks.

The analyses of selected meteor streams (Geminids, Quadrantids, Lyrids, etc.) from SVMN data will be also presented.

Reductions

Astrometric transformation of all-sky video records was performed and compared with standard trasformation of all-sky photografic records as described in [4, 5]. The standard deviation of reference stars are in interval 0.03-0.05 deg. The internal precision of AMOS cameras is even better.

Acknowledgement
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Video observation of unexpected outburst of Draconids 2012

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Introduction

Draconid meteor shower surprised scientific community by an outburst of activity in Oct, 8, 2012 following the predicted outburst in 2011 [1, 2] which was covered by the airborne mission [4] and ground observations [5, 6]. But the 2012 outburst was unexpected and only partially recorded just after the sunset in Europe October 8, ~17 UT [7].

Observation and results

That critical night of Draconids 2012 outburst, there were several active stations of Slovak Video Meteor Network (SVMN), Central European Meteor Network (CEMeNt), Hungarian Meteor Network (HMN) as well as Polish Fireball Network (PFN), which are a part of new initiative to join the local observations to wider European network EDMONd. 36 simultaneously observed Draconids (e.g. Fig.1) were extracted from the data and an application of video orbit quality criteria, described in [8], resulted in 29 unique orbits of Draconids 2012 (Fig. 2).

Fig. 1 Composite all-sky image of Draconids 2012 from AMOS camera at the AGO Modra station of the SVMN.

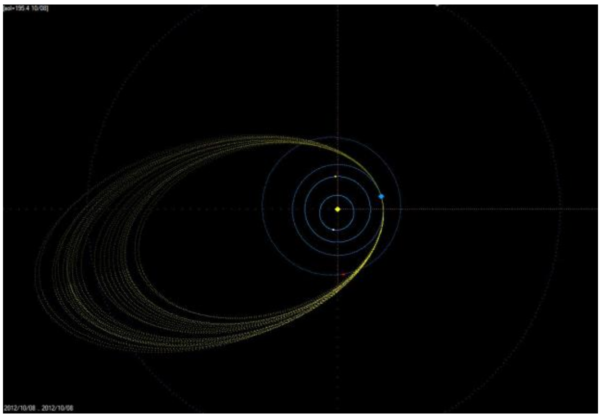

Fig. 2 Preliminary orbits of Draconids 2012.

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Compared their orbits with modeling ones by Maslov [9] showed a nice correlation. The results and discussion will be presented.

Acknowledgement

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Emission spectrum of a sporadic fireball afterglow

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Introduction

A mag. -11±1 fireball was imaged over the south of Spain on April 14, 2013 at 22h35m49.8±0.1s UTC. Its emission spectrum was also obtained. This event was assigned the SPMN code 140413 after the recording date. By the end of its atmospheric path it exhibited a very bright flare which resulted in a persistent train whose spectrum was recorded. Here we present a preliminary analysis of this event and focus special attention on the evolution of the main emission lines in the spectrum of the afterglow.

Fig 1. Composite image of the SPMN140413 fireball as imaged from El Arenosillo.

Instrumentation and methods

An array of low-lux CCD video devices (models 902H and 902H Ultimate from Watec Co.) operating from our stations at Sevilla and El Arenosillo was employed to record the SPMN140413 fireball (Fig. 1). The operation of these systems is explained in [1, 2]. Some of these are configured as spectrographs by attaching holographic diffraction gratings (1000 lines/mm) to the objective lens [3]. To calculate the atmospheric trajectory, radiant and orbit we have employed our AMALTHEA software, which follows the planes intersection method [4]. The spectrum was analyzed with our CHIMET application [5].

Table 1. Radiant and orbital data (J2000).

Radiant data			
	Observed	**Geocentric**	**Heliocentric**
R.A. (º)	186.79±0.03	186.30±0.03	-
Dec. (º)	-38.1±0.1	-41.6±0.1	-
V_∞ (km/s)	28.9±0.3	26.6±0.3	39.7±0.3
Orbital parameters			
a (AU)	4.6±0.4	**ω (º)**	71.1±0.1
e	0.85±0.01	**Ω (º)**	204.9556 ± 10^{-4}
q (AU)	0.690±0.001	**i (º)**	27.2±0.2

Data reduction and results

The parent meteoroid impacted the atmosphere with an initial velocity V_∞=28.9±0.3 km/s and the fireball began at a height of 104.4±0.5 km. The event ended at 80.7±0.5 km above the ground level, with the main fulguration taking place at 83±0.5 km under an aerodynamic pressure, calculated in the usual way, of $(7.4\pm0.6)\cdot10^4$ dyn/cm^2 [6, 7]. The radiant and orbital parameters are shown in Table I. These data confirm the sporadic nature of the bolide. The emission spectrum shows that the most important contributions correspond to the Na I-1 (588.9 nm) and Mg I-2 (517.2 nm) multiplets. In the ultraviolet, the contribution from the H and K lines from Ca was also identified. As usual in meteor spectra, most of the lines correspond to Fe I. The train spectrum was recorded during about 0.12 seconds. This provided the evolution with time of the intensity of the emission lines in this signal. The contributions from Mg I, Na I, Ca I, Fe I, Ca II and O I were identified in the afterglow, with the Na I-1 and Mg I-2 lines being the most important ones. The brightness of these lines decreased exponentially with time (Fig. 2).

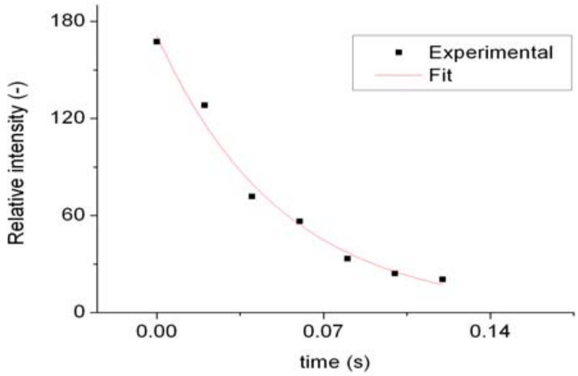

Fig. 2. Variation with time of the intensity of the Na I-1 line in the afterglow spectrum.

Conclusions

The preliminary atmospheric trajectory, orbit and radiant data derived from the analysis of a sporadic fireball recorded over Spain on April 14, 2013 have been presented. The contributions from Mg I, Na I, Ca I, Fe I, Ca II and O I were identified in the afterglow spectrum, with the Na I-1 (588.9 nm) and Mg I-2 (517.2 nm) lines being the most important ones. The brightness of these lines decreased exponentially with time.

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2014 CAMELOP Airborne campaign preparation

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Introduction

A meteor shower is expected from comet 209P/LINEAR on May 24th 2014. Though more investigation regarding the level of the shower are still being performed, we explore here how it will be possible to observe the event from an airborne platform, such as the Leonid MAC [1] or the recent 2011 Draconid campaign [2]. In this paper we aim at optimizing the flight plan in order to make the best of such an observation campaign.

Method

In order to optimize the flight plan, we consider the location of the Moon, the Sun and the radiant depending on the location and time on the surface of the Earth. The best location takes into account the local elevation of those 3 quantities.

Results

The results are summed up in Fig. 2 and 1. The location on Earth where the radiant is above 35° and the Sun below 18° is actually very narrow and concentrated in North-West United Sates. The summer season makes it hard to go further North.

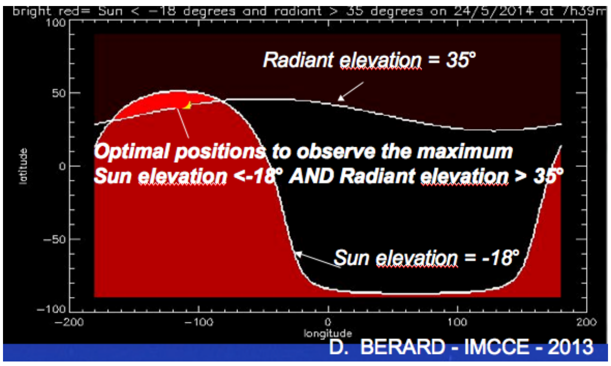

Figure 1: Location of the Sun and the radiant projected to the Earth surface. The best location is in North West United States.

The observation azimuth along the flight path is restricted by the location of the Moon and the radiant. Azimuth between 100 and 300° allow an optimum obervation strategy.

Conclusion

If funded, we will organize a double station airborne campaign, called "CAMELOP" and observe the event. In any case we will deploy in North-Western United States in order to keep in the shadow of the Earth and not too far form the radiant.

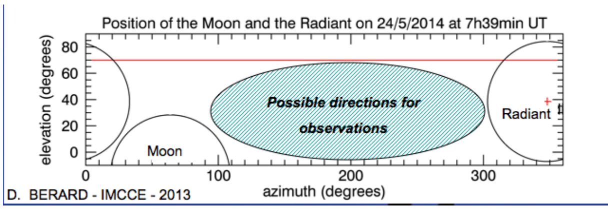

Figure 2: Location of the Moon and the radiant.

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Meteoroid 3D-trajectory determination using FFT from shuttered image.

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Introduction

In the framework of the Camera for BEtter Resolution NET work (CABERNET, [1, 2], the determination of the trajectory of a meteor is a key to derive an accurate orbit and to look for its parent body [3]. The cameras used in this French network are equipped with an electronic shutter, allowing to divide the path of a meteor into several different location in a regular way. So far the most used technique is to measure the photometry of each individual "blob" making the whole meteor. In this paper we explore the possibility of using Fourier Transform to best derive the location of each meteor blob in the image.

Method

The meteor profile is measured along its path. Fourier Transform is used to filter the signal and derive the period and therefore the location of the photometry maxima. An inverse FFT allows us to derive the location of the meteor.

Results

We expect to get a better accuracy on the measurement of each location of the meteor along its path, as well as to measure the deceleration. Thorough results will be presented.

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Impact probability calculations by the Hill sphere method

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Abstract

We present a method of impact probability estimations between a cometary population and terrestrial planets. In this method, the real target, i.e., its collisional sphere, is replaced by a much larger target (the Hill sphere). Knowing the ratio between areas of Hill sphere and collisional surface, the number of objects entering Hill sphere of the planet, the impact probability is estimated.

The poster presents the models and results for the two different approaches. The former uses the unperturbed Keplerian orbit of the projectile, while the second uses the elliptic restricted three-body problem (Sun-target-projectile). By comparing the two methods, we have checked if long-time perturbations have any important influence on the results.

The method can be applied to the modeling of small bodies dynamics during and after the LHB. It also should allow to conclude on water delivery, climate changes on Mars and effects on other terrestrial planets and Moon. Comparison to the Wetherill analytical method as well as the MOID method were also attached.

Faint Meteor Observation by Large-Format CMOS Sensor with 1.05-m Kiso Schmidt Telescope

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For observing faint meteors, we need a large telescope or similar optics, which does always give a restriction of the field of view. It is a kind of trade-off between the high sensitivity by using large telescope and narrower field of view. Reconciling these conditions, we need a large-format imaging detector.

The high-sensitivity CMOS sensor of 20cm by 20cm square was developed by Canon Inc., which is shown in figure 1. This is the world largest size as a one-chip CMOS sensor. The number of pixel is 1280 x 1248. We tried to use this large-format CMOS sensor attached to the prime focus of the 1.05-m (F3.1) Schmidt telescope at the Kiso Observatory, University of Tokyo, for faint meteor observation. The resulted field of view is 3.3 by 3.3 degrees.

A test observation was carried out during the peak time of Geminid meteor shower in 2012. The image of high time resolution can be obtained up to 60 frames per second. In this system, the limiting magnitude is estimated to be about 10 in our preliminary analysis. Assuming the height of faint meteors at 100 km, the derived flux of sporadic meteors is about $5 \cdot 10^{-4}$ km^{-2} sec^{-1} .

We describe the ability of the CMOS sensor for faint meteor observation together with the obtained result.

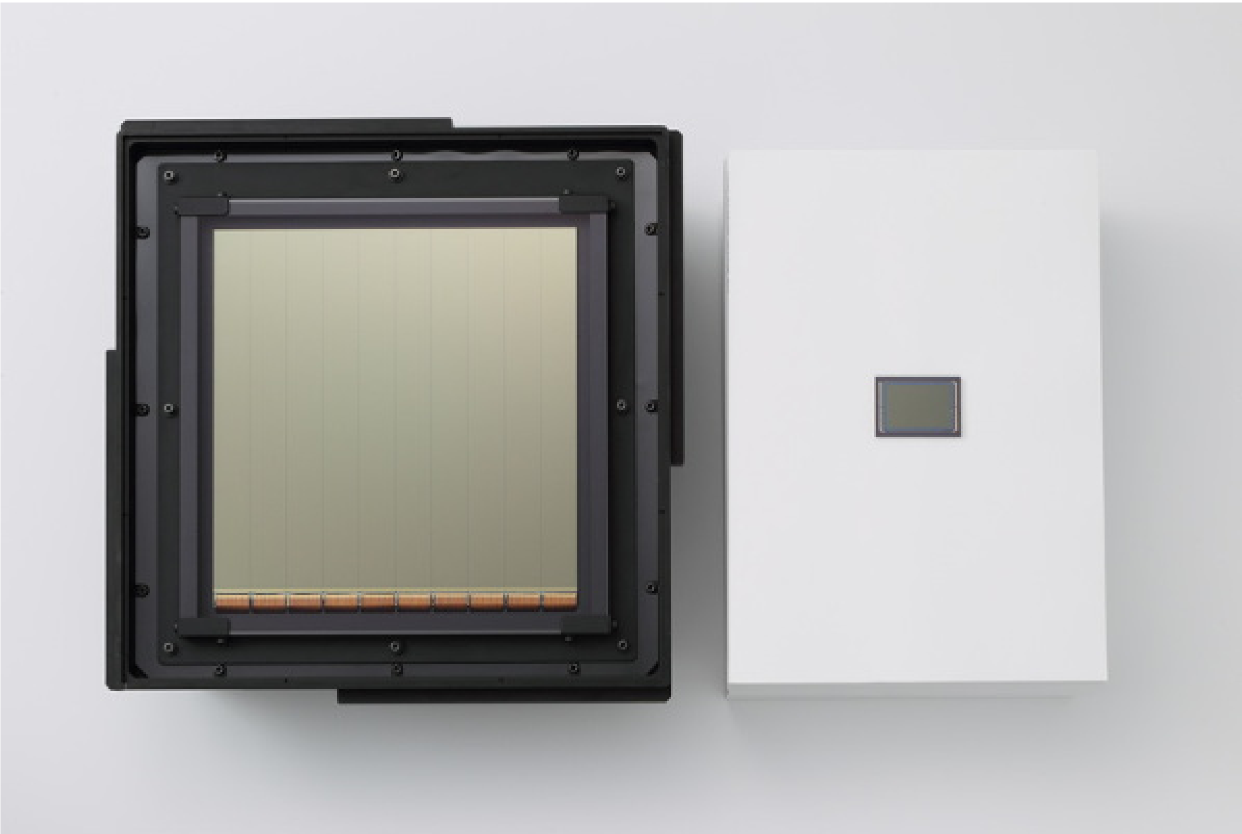

Fig. 1 A new large-format CMOS sensor (left) and a 35-mm full-frame CMOS sensor use in digital single-lens reflex camera product (right). Image was provided by Canon Inc.

Determining meteor trail radii using the Canadian Meteor Orbit Radar (CMOR)

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The radial distribution of electrons in a meteor trail affects the received echo power, which is used to determine the electron line density (q) needed to estimate meteoroid mass. Meteoroid mass and its distribution are essential physical properties which help to better understand the ejection mechanisms and orbital evolution of dust in the Solar System. The initial radii of meteor trails is also of fundamental importance in modelling the formation and development of meteor plasma [1].

In this work, we use the Canadian Meteor Orbit Radar [2] to constrain the initial radial electron distribution in meteor trails, and to estimate the radius of these trails. CMOR is a three-frequency, six-station backscatter radar used to detect particles $\geq 500\,\mu\mathrm{m}$ and to measure their heliocentric orbits.

While previous studies [3] determined the trail radii for underdense echoes, they were forced to assume a Gaussian trail distribution, a valid assumption if meteor trails form with negligible width then expand through ambipolar diffusion. Having a third frequency allows the functional form of the radial electron distribution to be constrained, confirming whether it is Gaussian in nature, or perhaps an inner core immersed in a more diffuse sheath [4]. As well, by using a full-wave scattering model [5], our analysis is extended into the transition-echo scattering regime ($q > 10^{14}\,\mathrm{e}^-/\mathrm{m}$). These estimates will be compared to recent video results [6], and can be used to improve estimates [7] of the luminous efficiency (τ_I) determined from simultaneous radar-video observations.

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PF191012 Myszyniec - highest Orionid meteor ever recorded

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Introduction

The television and photographic observations of the Leonid shower in 1995 and 1996 carried out by Fujiwara et al. [1] showed that the fastest meteors could start at heights of 130-160 km. Spurny et al. [2] divided the light curves of high-altitude meteors into three distinct phases: diffuse, intermediate and sharp. The sharp phase was connected with well known ablation process. The light emitted during the diffuse phase cannot be explained by standard ablation theory and a new type of radiation has to be taken into account. There was no single high altitude Orionid meteor recorded, which was surprising due to the fact that Orionids are characterized with high geocentric velocity.

Observations

The Polish Fireball Network (PFN) is the project whose main goal is regularly monitoring the sky over Poland in order to detect bright fireballs occurring over the whole territory of the country [3]. Presently, there are 18 video and 3 photographic fireball stations belonging to PFN which operate during each clear night.

On the night of Oct 18/19, 2012, at 00:23:12 UT, five video and one photographic stations of the PFN recorded bright, −14.7 magnitude fireball belonging to the Orionid shower. Fig. 1 shows image of the fireball captured by the photographic station in Siedlce.

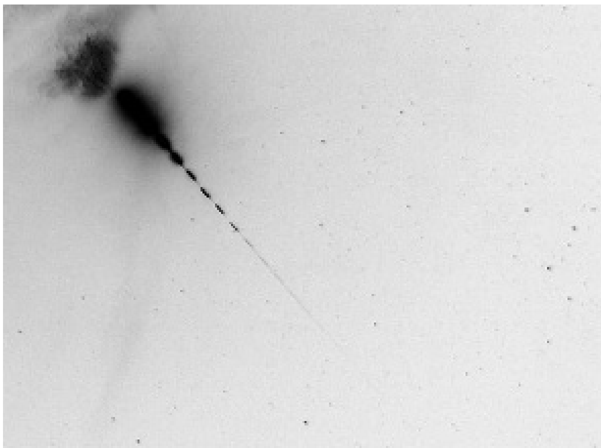

Fig. 1. The PF191012 Myszyniec fireball recorded at Siedlce PFN43

Calculations

The trajectory and orbit of the PF191012 Myszyniec fireball was computed using PyFN software written by P. Żołądek [4]. PyFN is written in Python with usage of SciPy module and CSPICE library. For trajectory and orbit computation it uses the plane intersection method described by Ceplecha [5].

Results

The trajectory and radiant parameters derived from the data collected in three PFN stations are summarized in Table 1.

Table 1 The basic trajectory and radiant data of the PF191013 fireball

	Beginning	Max. light	Terminal
Height [km]	168.4 ± 0.6	77.7 ± 1.0	69.4 ± 0.6
Long. [◦E]	22.336 ± 0.005	21.186 ± 0.020	21.040 ± 0.002
Lat. [◦N]	52.865 ± 0.004	53.385 ± 0.010	53.463 ± 0.007
Abs. mag	1.5 ± 1.0	−14.7 ± 1.0	−1.0 ± 0.5
Slope [◦]	42.4 ± 0.5	41.5 ± 0.5	41.4 ± 0.6

The meteoroid entered the atmosphere at a height of 168.4 ± 0.6 km which makes it the highest Orionid meteor ever observed. The initial velocity and absolute magnitude were 68.0±0.7 km/s and 1.5±1.0, respectively.

The first clear shutter break is detected at height of 128 km. At this point the color of the meteor changes from green to white-yellow. Below the height of 100 km color again changes and meteor starts to show white-blue hue.

The absolute magnitude of −14.7 ± 1.0 was observed at a height of 77.7 km.

Clear change of the slope of magnitude increase is evident at a height of around 115 km. At this point the ablation process becomes the dominant source of light.

Detailed inspection of the light curve shows some differences between the Orionid fireball light curve and these obtained for faster Leonids, which may suggest that the material of Leonids should be more fragile and have probably smaller bulk density.

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A New, Fast and Accurate MOID Calculation Method

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Abstract

We present a new, numerical and iterative method to compute Minimum Orbit Intersection Distances (MOIDs), suitable for any pairs of heliocentric orbits.

Initially we look for the MOID configuration by geometric scanning, where we use the meridional plane, which contains one of the objects and is perpendicular to the orbital plane of the other. Starting from the result of the scanning, an efficient parallel tuning technique is then used, in order to zoom in on the MOID configuration. We work with high accuracy and take special care to avoid the risk of missing the MOID, which is inherent to our type of approach.

Our method appears to be reliable, flexible and faster than other comparable methods. It is freely available and its source Fortran code will be downloadable via our web page.

Chelyabinsk Superbolide: a detailed analysis of the passage through the atmosphere and orbit determination

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Introduction

A detailed analysis of the passage through the atmosphere of a very bright meteor that exploded in the air near Chelyabinsk, Russia on February 15, 2013 is presented.

Method and results

A number of videos and photographs were examined thoroughly to determine the meteor trajectory beginning from the recorded atmospheric entry at the height of about 62.5 km above the ground until its disappearance at about 9.8 km. The calculated velocity changes with time revealed an unusual behavior: during the first 10 seconds the meteor velocity increased gradually from 14.4 km/s up to about 20.3 km/s in the main air burst at the altitude of 26.5 km and only afterwards it decreased rapidly. The light curves derived from videos enabled the total radiant energy and mass loss variations to be calculated and discussed here. The heliocentric orbit of the meteoroid was also computed and traced down to 10,000 years ago to find its close approaches to Venus, Earth, Mars, Jupiter and Moon. Results of these computations are presented in Fig.1.

In addition, similar computations were made for several asteroids suspected of being the parent body. Comparison with the orbits determined by other authors [1,2,3,4] is also presented.

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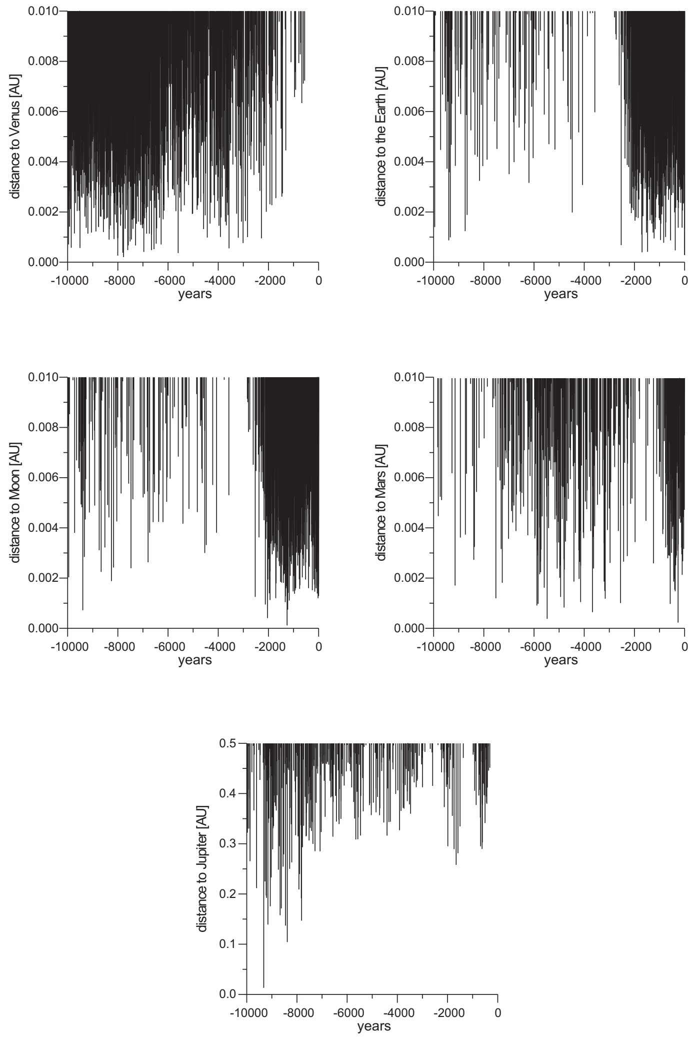

Figure 1: Possible past close approaches of the Chelyabinsk Superbolide to the planets and Moon.

The potentially dangerous asteroid (99942) Apophis

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Introduction

The asteroid (99942) Apophis was discovered on June 19, 2004 at the (IAU 695) Kitt Peak Observatory by F. Bernardi, D. J. Tholen, and R. A. Tucker. Asteroid (99942) Apohis belongs to the Aten group, comprising 779 members as of May 27, 2013) and is one of 9858 known Near-Earth Asteroids at this time [1]. Apophis belongs to one of 1401 Potentially Hazardous Asteroid (PHA) [2]. The JPL NASA Sentry Risk Table [3] lists, as of May 27, 2013, 438 Near Earth Asteroids which have potential future Earth impact events. Apophis has 10 years observational arc and is still in this Table from 2004 year. From 2004 there are published many papers with many listed possible impacts computed with different methods: [4], [5], [6] and many others.

Method and Results

The asteroid possible impact solutions are usually presented in a form such as that used by the NASA's Impact Risk Page [3] or by the NEODyS [7]. They list the name of each dangerous asteroid, the dates of its potential impacts, the probability of possible impact at each date and the impact energy. Generally, the OrbFit software searches for possible impacts and give these *standard* solutions. Table 1 lists these parameters for 2068.

Computations were made using the free OrbFit Software Package [8]. We are taking into account the JPL DE405, perturbations of additional 25 massive asteroids, different weighting methods and selection of observations, error model based on [9] and the Yarkovsky effects. Asteroid (99942) Apophis has 10 years observational arc so it is possible to compute da/dt with the method given by [10] for asteroid (101955) 1999 RQ36). The value of da/dt computed by us is placed in Table 1.

Our method of computing possible impact orbits [11] is based on the method of Milani included in the OrbFit software where the *cloning* is based on the line of variations (LOV) with the largest eigenvalue, where σ_LOV denotes the position of an asteroid on the orbit along the line of variations in σ space [12].

Our computations are based on 4022 optical observations and 7 radar observations of the asteroid (99942) Apophis from March 15.10789 UTC through March 28.089569 UTC, 2013.

The asteroid (99942) Apophis will be observable for many years so new optical and radar observations can refine the orbit of the asteroid and probably give more precise possible impacts solutions.

Table 1: Apophis. Possible impact solutions for the year 2068 using computed parameter $da/dt = -1.17 \times 10^{-4} AU/Myr$.

Impact probability	5.784E-9
Mass	2.10E+10 kg
Impact velocity	12.61 km/s
Energy	3.98E+2 MT
Date of impact	2068/10/15.325
σ_LOV	3.757

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[127]

Taiwan Elegant Meteor and TLE Network (TWEET)

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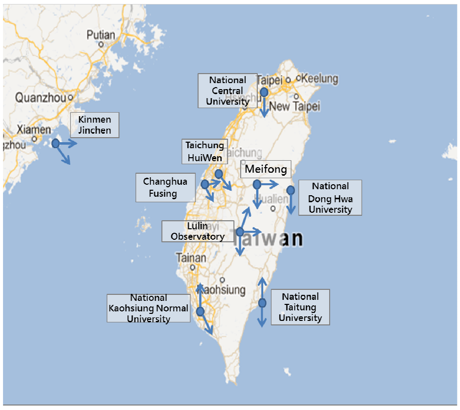
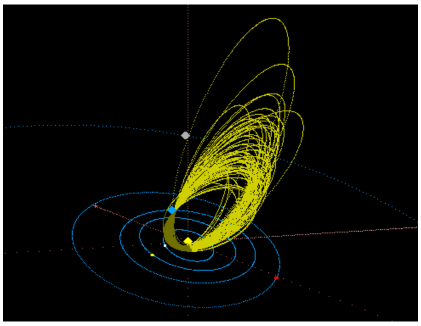
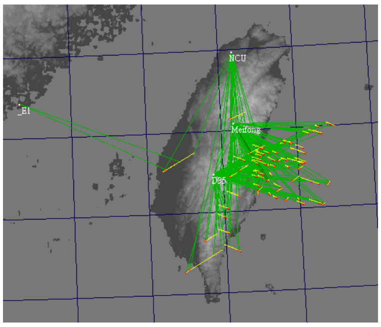
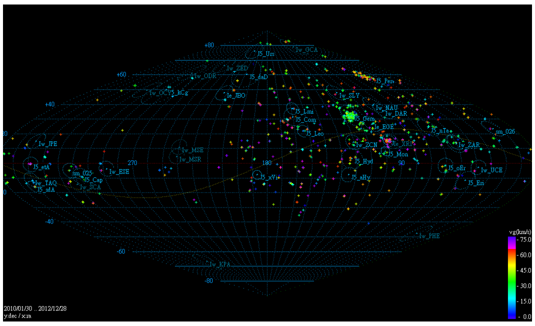
Lulin Meteor System (LMS) has started regular observation since December 2009 at Lulin observatory in Taiwan. Three cameras towards north, east, and south are carried out using high sensitive CCD-TV cameras (Watec and Mintron) with wide field of view CCTV lens, which are recorded in video rate controlled by the software UFOCapture. About twenty cameras have been installed at nine stations in Taiwan. The coordinate of Lulin observatory is 120.87˚E, 23.47˚N, h=2,862m so we have more chance to observe southern meteor showers from the northern hemisphere.

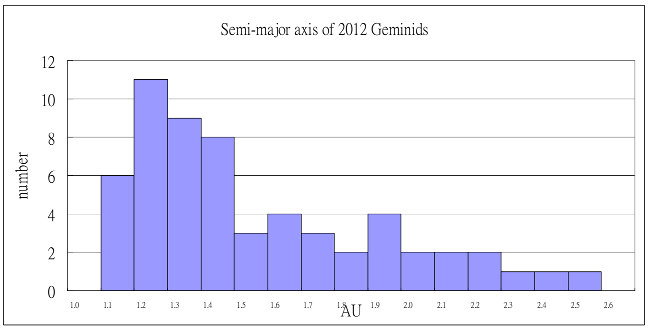


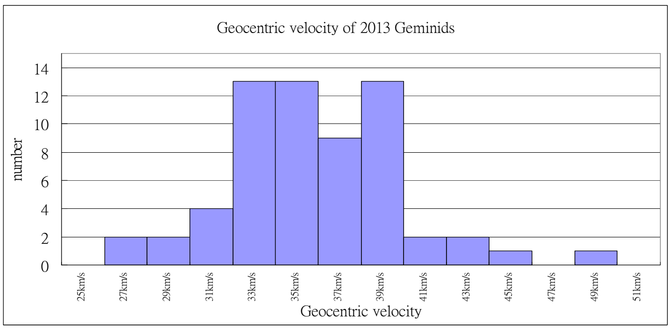
If we have more location to observe meteors, we can use triangulation method to analyze meteors. 655 Geminids meteors were detected by LMS in December 2012 in which 186 pairs were recorded from more than two stations. Astrometry was done by using the software UFOAnalyzer. Most of measured velocity and semi-major axis were 33-41 *km/s* and 1.2-1.5 *au* (average ~1.7 *au*), respectively. Note that Geminids' parent body, (3200) Phaethon, has its semi-major axis 1.271 *au*. The derived orbits were consistent with that of Phaethon.











The weather of Taiwan is Subtropical marine climate. It usually rains during the typhoon and plum rain season, May - October. Our meteor observing system also detected many Transient Luminous Events (TLEs) with triangulation data that provided better accuracy of the location of TLE events. Compared with VLF/ELF lightning detection network, each TLE event was identified.

In this year, we held several workshops to invite more high school students/teachers and amateur astronomer in Taiwan. We also have a forum on the web to discuss and exchange our data (http://astro.km.edu.tw/phpbb/). We will continue to establish more meteor observing stations and have some teaching material for high school students.