Czech Science Foundation - Part C
Project Description

Applicant: RNDr. David Čapek, Ph.D.

Name of the project: *Rotation of meteoroids*

1 Rotation of meteoroids - present state of the problem

The knowledge of the evolution of meteoroid rotation is important for understanding many facts in the physics of the small solar system bodies. For example, the rotational bursting is probably dominant mechanism of fragmentation of small meteoroids and dust particles. The spin rate and spin axis orientation affects Jarkovsky effect and possible destruction of meteoroids by the thermal stress. The knowledge of preatmospheric rotation of parent bodies of meteors and bolides may affects the explanation of some features of their luminous path through the atmosphere.

1.1 Initial rotation of meteoroids

The initial rotation state depends on process of meteoroid's birth. Asteroidal meteoroids originate as debris from collisions of asteroids in the Main Belt. Their formation was studied by catastrophic fragmentation experiments (e.g. Fujiwara et al. 1989; Martelli et al. 1994; Giblin et al. 1998). The majority of fragments which formed during these experiments with sizes of 1-10 cm had spin frequencies of several tens rotations per second (Giblin et al. 1998). Smaller bodies tend to rotate faster than larger ones, and most of them rotate without observable tumbling (Giblin & Farinella 1997).

Shower meteoroids can be released from parent cometary nucleus during its breakup or during regular activity of comet by gas drag (e.g. Jenniskens & Vaubaillon 2007). The gas drag mechanism is connected with sublimation of water ice at the surface of the nucleus and acceleration of embedded dust and pebbles by gas flow away from the comet.

If the meteoroid has irregular shape with some degree of windmill asymmetry, the gas may also accelerate its rotation - similarly as in simple experiment of Paddack (1969). Although many authors studied the ejection process and terminal velocity of meteoroids (e.g. Whipple 1951; Olsson-Steel 1987; Crifo 1995; Jones 1995; Crifo & Rodionov 1997), the rotation of meteoroids caused by gas drag have not been studied yet, except for recent study of Čapek (submitted)[1].

1.2 Meteoroid rotation in the space

1.2.1 Windmill effect - the reflected radiation

The "windmill effect" was proposed by Paddack (1969) to explain rotational bursting of tectites in the space. Up to now, it is assumed as most important mechanism affecting the rotation and consequently rotational bursting of meteoroids in the interplanetary space. This phenomenon causes acceleration of rotation due to action of reflected radiation on irregularly shaped body with an amount of windmill asymmetry. Paddack carried out a simple experiment, whereat crushed stones (2.5-5.9 cm) were dropped into swimming poll. According to their motion, the value of effective moment arm for those bodies was determined as 0.02 mm. This corresponds to asymmetry parameter value 0.0005, which is equal to effective moment arm over body size. (A new value of asymmetry parameter 0.02-0.2 was experimentally determined by Abbas et al. (2004) for laboratory-prepared SiC analogs of cosmic dust with sizes $\sim 0.5 - 8$ μm.) Finally he found that centimeter-sized tectites will reach bursting speed at 60 000 years.

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[1] Preprint available at David Čapek's personal page: `http://www.asu.cas.cz/~capek/`

The windmill effect and Paddack's value of asymmetry parameter have been widely used in literature as a basis for estimations of the rotation of meteoroids till today: Paddack & Rhee (1975) estimated that the rotation bursting lifetime of interplanetary dust particles is one order of magnitude shorter than that of Pointing-Robertson effect. Rotational bursting of the dust due to windmill effect, other spin-up mechanisms and formation of β-meteoroids was studied by Misconi (1993). Sekanina & Farrell (1980) and Sekanina & Pittichová (1997) assumed rotational bursting due to windmill effect as a main fragmentation mechanism of particles in cometary tail striae. Olsson-Steel (1987) studied the dispersal of Geminid stream by radiative forces and some attention paid to the spin rate of meteoroids, which was important for his calculations. He showed that windmill effect predominates over collisions with zodiacal dust or with other meteoroids and over the interaction with solar wind particles. He also found, that 1 mm meteoroid reaches rotation rate $\sim 10\,000$ rad/s within thousand years and 1 cm meteoroid reaches $\sim$ 100 rad/s within the same time interval. Beech & Brown (2000) studied fireball flickering (i.e. quasi-periodic changes in the light-curve) and found that windmill effect is inefficient for meteoroids larger than $\sim$ 10 cm and it is not able to explain higher spin rates for these bodies. They assumed that the rotation comes from collisional fragmentation of their parent bodies. Beech (2002) and Beech et al. (2003) used Geminid fireball flickering for determination of preatmospheric rotation rate of parent meteoroids. Assuming the spin rate acceleration due to windmill effect, the interval between meteoroid ejection from parent body and the atmospheric entry was determined. The age of the meteoroids nicely fall into the range determined by other techniques (e.g. Jones 1982; Gustafson 1989).

1.2.2 YORP effect - the thermal radiation

The non-reflective irregularly shaped bodies may be also spun-up, due to emission of thermal radiation from the surface. This phenomenon is known as Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect (Rubincam 2000). This phenomenon is important for long-scale evolution of small asteroids (e.g. Čapek & Vokrouhlický 2004). It grows with decreasing size D of the body as D^{-2}, but this dependency probably changes to D^{-1} for bodies of meteoroid sizes due to smaller temperature variations on their surface caused by lateral heat diffusion (Breiter et al. 2010). But the role of this mechanism for meteoroids is not fully understood since the model which takes into account 3D heat diffusion and non-principal axis rotation of meteoroids is still lacking.

1.2.3 Collisions with dust

Hawkes & Jones (1978) explained the radius of meteor trains by rapid rotation ($\sim$ 5000 rad/s) of parent meteoroid. They pointed out that such spin rates can be caused by erosive collisions in interplanetary space. They suggested that space erosion changes the shape of meteoroids and consequently the windmill effect (which is otherwise faster) will change the rotation in a random fashion with time.

Watanabe et al. (2003) observed short duration outbursts during Leonid activity in 1997 and 2001. The most probable explanation for these phenomena is breakup of parent meteoroid several days before encounter with Earth. The determination of relative velocity of meteoroids from each outburst was based on assumption that parent meteoroid rotates. The spin rate was deduced from energy distribution between rotational and translational energy from catastrophic fragmentation experiments (Fujiwara et al. 1989). The breakup event shortly before atmospheric entry was also assumed by Hapgood & Rothwell (1981) who observed group of three Perseids in 1.3 seconds.

1.3 Interaction of meteoroids with the atmosphere, flickering

If the meteoroid finally reaches the Earth, the rotation may affect the interaction with the atmosphere. The light-curves of some bright meteors show quasi-periodic brightness variations. This phenomenon, which is called " flickering", is sometimes interpreted as a result of rotation of non-symmetric meteoroid (e.g. Beech & Brown 2000; Spurný & Borovička 2001). The air flow encounters the changing cross-section of rotating body, which causes periodical changes in amount of ablated material and therefore brightness variations. The frequency of these variations can be used for meteoroid spin rate determination. Spurný & Borovička (2001) interpreted periodic variations in Vimperk fireball light

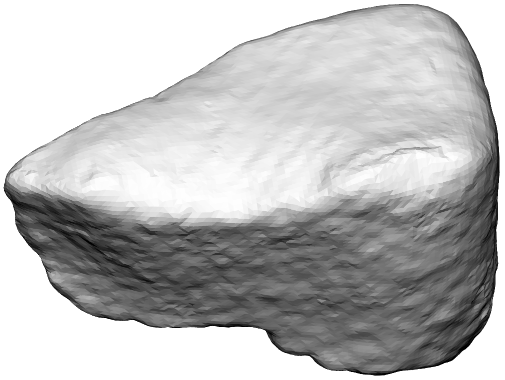

Figure 1: Example of the shape model, which was obtained by the 3D laser scanning by SolidVision, s.r.o. company. The picture shows the model of 5.7 g meteorite Bassikounou (H5) which consists from 42 450 surface triangular facets. Preatmospheric meteoroid shapes will be approximated by ∼300 digitized shapes of fractured terrestrial rocks with a similar spatial resolution.

curve as a result of rotation of two fragments with initial spin frequencies 3 Hz and 5.5 Hz. Beech (2002) reported the preatmospheric angular velocity of three Geminid meteoroids as 700 rad/s for 14 mm body, 520 rad/s for 13 mm body and 250 rad/s for 18 mm body. Beech et al. (2003) studied flickering of bright Geminid fireball and determined the rotation frequency 6 Hz and dimensions $\sim$ 10 cm.

Some authors doubted the explanation of flickering by meteoroid rotation and proposed other mechanisms. Babadzhanov & Konovalova (2004) studied flickering of three Geminid fireballs and pointed out that (i) the amplitude of brightness pulsations do not vary during penetration of meteoroids into the atmosphere and (ii) the pulsation occurred suddenly in the middle of the luminous trajectory. These phenomena do not correspond to theoretical predictions and the autofluctuation mechanism was suggested for explanation of flickering. Borovicka (2006) also tend to the opinion that the flickering is caused by autofluctuation mechanism. Spurný & Ceplecha (2008) proposed the triboelectric charging and uncharging as a main process leading to fast variations in the fireball light curves. Spurný et al. (2012) analyzed light curve of Bunburra Rockhole fireball and found, that the flickering frequency is higher than the rotational bursting limit according to relationships published by Paddack (1969) and Beech (2002).

2 Proposed project

We propose the solution of three main topics which have not been studied up to now, which need revision and which can be studied in more detail. The common approach to the solution of these problems will be polyhedral description of meteoroid shapes, numerical evaluation of the forces and moments acting on it (including numerical solution of the heat diffusion equation), numerical solution of the equation of motion and comparison of the results with observations. The project is divided into three tasks. The key quantity affecting the rotation - the shape of meteoroids - will be created during Task A. The evolution of the rotation of both cometary and asteroidal meteoroids in space will be studied in Task B. Task C will deal with the meteoroid fligth through the atmosphere and explanation of the fireball flickering.

The outcome of each task will be a publication of one or more papers in a scientific journal - Astronomy and Astrophysics, Icarus, etc. The results will be also presented on several international meetings each year.

Task A: "Realistic" shape models of fragments

Up to now, in the meteoritic sciences, the meteoroids were usually approximated by simple shapes like spheres, ellipsoids or wedges. Such simplification, however, is not applicable for studies of the meteoroid rotation, since the knowledge of precise shape is necessary for correct determination of the net torques caused by radiation or gas flow.

The first task of our project is therefore to obtain more realistic shape models of meteoroids. Because the real meteoroids are unavailable, their (unknown) shapes will be approximated by 3D laser scanning method of diverse alternative samples. First group of these samples will consist from fragments of terrestrial rocks with different origin and material properties. Some of them will be prepared by contact explosive charge technique (which simulates impact disruption of the meteoroid parent body in the Main belt) in collaboration with Institute of Energetic Materials, University of Pardubice. Next group will contain fresh whole stone meteorites from Košice fall, which will be loaned from Comenius University in Bratislava. The shape collection will be supplemented by several shapes of IDPs which were obtained by X-ray microtomography at University of Helsinki. The samples will be digitized by 3D laser scanning method. The shape of each sample will be represented by a polyhedron with many thousands of triangular surface facets stored in `stl` file format. Such description is very useful for numerical modelling. The 3D scanning will be performed by SolidVision, s.r.o. company (`http://www.solidvision.cz/`), which was chosen from three candidates (INNOMIA a.s., MCAE Systems, s.r.o., and SolidVision, s.r.o.) on the basis of the price (~ 300 CZK/sample if special holder of samples, developed by D.Č., is used), precision of scanning and scanning capacity. Almost 50 testing samples have been already digitized by the chosen company (see Fig. 1). We have also developed the methodology of the 3D scanning of small rock samples and basic codes processing the 3D models.

Expected results: The resulting database will contain large amount (~ 300) of very diverse shapes ranging from rounded ones to very sharp ones, those with bumpy or polish surface, etc. This shape collection will be used (i) for further modeling of the meteoroid rotation in the space and in the atmosphere, as well as for the shape evolution due to collisions with dust particles (Tasks B and C). (ii) The shape database will be available for professional public and it will be described by, at least, one paper. It will represent a unique dataset which can be used in many applications in the physics of small Solar system bodies. For example the shape models derived from rock fragments may be also compared with shape models of small asteroids and used for statistical study of the YORP effect on these bodies (e.g. Čapek & Vokrouhlický 2004). The proposed high accuracy of the shape models allows a theoretical study of the dependence of the YORP effect on surface roughness (e.g. Rozitis & Green 2012) and on small-scale topography changes (e.g. Statler 2009).

Task B: In-space dynamics: rotational and orbital evolution of fragments

The meteoroid rotation in space is determined by (i) initial conditions which correspond to the rotation after meteoroid release from the parent body and (ii) by various effects which act on the meteoroid during its stay in the interplanetary space. The most important is windmill effect, i.e. reflected radiation from the meteoroid surface, and YORP effect, the relative importance of which grows with increasing size of the body. There are also second-order effects, like collisions with dust (which is connected with meteoroid shape modification and size reduction) and several damping mechanisms. The acceleration of rotation can finally cause the rotational bursting of meteoroids. The rotation has also consequences for meteoroid transport via Jarkovsky effect and possible thermal bursting. We intend to study three fractional topics which will together represent comprehensive description of the meteoroid rotation in the space.

B1) Reflected radiation - windmill effect

The reflected radiation (i.e. windmill effect) represents the most important effect for meteoroid spin evolution. Up to now, the windmill effect has usually been described in terms of Paddack's (1969) asymmetry parameter, which was, however, determined for the interaction with a stream of water and for motion in the direction which is parallel to the shortest axis of inertia tensor. The asymmetry parameter may differ for interaction with the radiation, which, moreover, comes from various directions, according to the orientation of the spin axis.

Our mathematical approach will be similar to the case of YORP effect for asteroids with zero thermal inertia (e.g. Vokrouhlický & Čapek 2002). The meteoroids will be approximated by shape models resulting from Task A. The initial spin states will be adopted from Čapek (submitted) for cometary meteoroids or it will be estimated according to studies dealing with catastrophic fragmentation experiments for asteroidal meteoroids (e.g. Giblin et al. 1998). The spin evolution will be described either by torque averaging method on long-term time scales and by direct integration of equations of motion. The non-principal axis rotation a role of damping mechanisms, YORP effect and collisions with dust will be also taken into account.

B2) Thermal radiation - YORP effect

In order to address the evolution of rotation caused by the emission of thermal radiation, we have to solve a three-dimensional heat diffusion problem in irregular meteoroids and compute temperature distribution on the surface of the meteoroid. Since the problem is non-linear and the geometry is far from being spherical (as in Nesvorný & Vokrouhlický 2007), we prefer complete numerical solutions. A calculation of both the Yarkovsky and the YORP effects (i.e. accelerations and momenta) is then possible for a given scattering law.

We suggest to use a finite-element (FEM) discretization in space (suitable for irregular geometries) and an implicit Euler scheme in time (which is unconditionally stable). A weak formulation of the problem using the Galerkin method can be done according to **?**. In order to solve for the non-linearity we have to perform (a number of) iterations. It is possible to employ one of general FEM implementations, e.g. the `FreeFEM++` code (**?**) and the tt Tetgen program (**?**) for optimal triangulation of the volume. An implementation of the mutual shadowing and possibly also irradiation, reflection is necessary, of course.

We will compute and discuss the dependence of the YORP momenta - affecting spin rate and obliquity - on the (global) shape of the meteoroid and its thermal parameters. These results can be then used in models of asteroid/meteoroid transport, in a similar way as in Brož et al. (2011) for larger bodies.

Further applications are also possible, for example it is possible to discuss the role of topographic features, a topic address by Golubov & Krugly (2012), but using a much simpler 1-dimensional semi-analytical model and an idealised geometry. We can compute "individual" YORP momenta for realistic boulders, which were indeed seen on the surfaces of Itokawa (Mazrouei et al. 2014) or Eros (Cheng et al. 2002), or for small craters. Using the measured size distributions and/or information on surface roughness (Ostro et al. 2004) we can also estimate the total YORP momentum.

B3) Shape modifications and size reduction due to collisions with dust

Due to collisions with dust, erosion of meteoroids occurs (Hawkes & Jones 1978). Using Monte Carlo method, we will study the time dependence of size reduction and shape modification (rounding) for various meteorid streams and sporadic orbits. The effect for further ability of meteoroids to be spun up by windmill or YORP effect will be finally determined.

Expected results: Our work will represent the first study of meteoroid's rotation in the space based on realistic assumptions and on precise determining of the acting torques. The results will have strong consequences for determination of meteoroid life time due to rotational bursting, meteoroid's orbital drift, and the age determination of some meteoroid streams. It also allows to predict the preatmospheric spin rates of meteoroids, as well as corresponding frequencies and amplitudes of variations in the beginning part of meteor and fireball lightcurves caused by rotation (see Task C).

We expected one paper devoted to the role of windmill effect, one paper devoted to the YORP effect and one describing the erosion of meteoroids by collisions with dust.

Task C: Dynamics of an atmospheric entry constrained by flickering

The stations of the Czech part of the European Fireball Network are equipped with all-sky photoelectric radiometers (Spurný et al. 2007) which produce high resolution light curves with 500 measurements per second and recently (2009-2010) these fast photometers were upgraded for 10× time resolution, i.e. 5000 samples per second (see Fig.2). The growing amount of fireball light curves captured by these instruments shows fast brightness variations, which is called flickering. These variations is not sufficiently explained up to now. For solving this mystery, we intend to combine unique data from fast photometers, their phenomenological description and numerical modeling of meteoroid flight through the atmosphere.

Task C1: Observations and phenomenological description of flickering events

Up to now, approximately 30 periodic flickering cases are documented by Czech part of European Fireball Network with ∼5-10 new events per year. At first, phenomenological study of these events will be performed. We will focus on material, orbital, and atmospheric trajectory relationships and also on selection effects.

LUKÁŠ - upravit, doplnit: - nezpracovaná fotometrická měření a očekávaný počet periodických flikeringů mezi nimi - očekávané počty případů ročně

Task C2: Rotational hypothesis about origin of flickering

The rotational origin of the periodic flickering will be tested by comparison of observed lightcurves with synthetic ones resulting from numerical model. The model will assume irregular bodies represented by digitized meteoroid shape models (Task A), preatmospheric rotation consistent with results of Task B. The description of interaction of meteoroid with atmosphere will be simplified by assumption that the gas flow is not affected by moving meteoroid. (Such simplification is good approximation in free molecular flow regime, but it is usually used also for meteoroid motion in deeper layers of the atmosphere.) The role of ablation on size reduction and shape modification will be also taken into account. The comparison of synthetic lightcurves with real ones will allow not only testing the possibility, that the periodic flickering is a result of rotation of irregularly shaped meteoroid. It will also allow constraining the preatmospheric rotation and shape characteristics of the meteoroids, regardless of whether the flickering is caused by rotation or not.

Task C3: Autofluctuation mechanism hypothesis about the origin of flickering, hypersonic flow, shock waves, ablation.

As pointed out by Popova (2004), the modelling of meteoroid-atmosphere interaction is not complete yet. We propose to use an approach similar to Shuvalov & Artemieva (2002) or Artemieva & Pierazzo (2009) but applied to small meteoroids and, most importantly, we will use new observational constraints, namely the flickering observed for some fireball lightcurves.

One of the hydrodynamic codes suitable for gas-dynamics simulations is the `PLUTO` code (Mignone et al. 2007). It may include also a radiation-transfer module (**?**), assuming a flux-limited diffusion approximation (Levermore & Pomraning 1981) which is a different (better) approach than that of Shuvalov & Artemieva (2002). An adaptive-mesh-refinement (AMR) scheme is also available to properly capture shock waves in the flow.

For first tests, we will assume a simple/fixed geometry of the meteoroid (i.e. without ablation) and study instabilities arising in a hypersonic flow with suitable inflow/outflow boundary conditions. We expect that Rayleigh-Taylor and Kelvin-Helmholtz instabilities in the flow may drive variations of the radiation flux, which can be directly compared to observations acquired by our team (Task C1). In the second stage, we will use the results of gas-dynamics simulations and account for ablation of meteoroid material, e.g. using the `FreeFEM++ code`, this time with a free-surface condition (**?**).

Expected results: The flickering phenomenon will be statistically described on the basis of the detailed, accurate and extensive data including lightcurves, atmospheric path and orbital parameters. The two physical processes will be proposed as a possible explanation of the flickering: rotation of irregularly shaped meteoroid and hydrodynamical processes during its supersonic flight through the atmosphere (autofluctuating mechanism).

The comparison of synthetic lightcurves with real ones will allow constraining the preatmospheric rotation and shape characteristics of the meteoroids, and consequently the physical properties of meteoroids' parent bodies, ejection proceses and proceses affecting the rotation in the space, regardless of whether the flickering is caused by rotation or not.

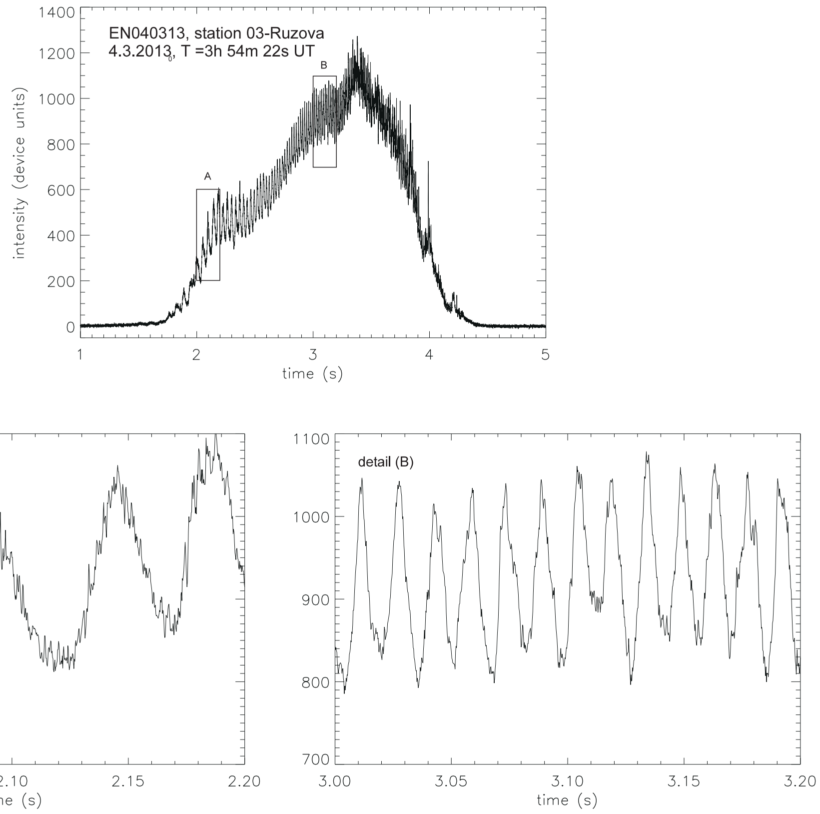

Figure 2: An example of the high resolution light curve of fireball obtained by the fast all-sky photometer (see Sec. 3). The flickering (fast periodic changes of the brightness) can be clearly seen. Is it possible to explain it by rotation of the irregularly shaped meteoroid? The project results should also answer this question.

We expected publication of one or two papers concerning the phenomenological description and rotational hypothesis of flickering and one or two papers focused on hydrodynmical modelling of the meteoroids flight through the atmosphere.

3 Instrumental equipment

Computing instruments The numerical codes will be written in `Fortran90/95` language. The numerical computations will be executed either on PC and on computer cluster `OCAS` consisting from 16 two-processor nodes (2× 64bit AMD Opteron 252 CPUs (2.6 GHz), 4GB DDR400 ECC reg. RAM), 4 four-processor nodes, and 4 eight-processor nodes.

Photometers Along with direct photographic recording each Automated Fireball Observatory (AFO) contains a fast linear photometer which records the total illumination of the sky with a rate of 5000 samples per second. The sensitivity of these photometers corresponds almost exactly to the photographic sensitivity of the imaging system. The original intention for the implementation of these instruments into automated observatories was to have an exact time for each photographed fireball. However these photometers have much wider utility. In addition to providing the exact time of the event we have a very precise and detailed light curve for each event which is bright enough to have a good s/n ratio. Thanks to these photometers we can record and study also fast variations on the light curves which is one of the main topics of the proposed project.

Meteor video cameras. There are two different systems of the video cameras which are currently operated at the Ondrejov observatory. The older one still analogue system is in operation since 1998, when the double station experiment started. The second station is located in Kunzak observatory at distance of 92 km. Such configuration with almost south to north orientation is excellent platform for the double station experiment (e.g. Koten et al. 2004).

Analogue cameras are equipped with 50mm lenses providing field-of-view of about 45 degrees in diameter. In connection with the second generation image intensifier they are able to record faint meteors up to +5.5 magnitude. The image rate is 25 frames per second.

Recently developed system MAIA (Meteor Automatic Imager and Analyser) is based on the digital cameras JAI and the same kind of the image intensifier (Koten et al. 2011). Its characteristics are significantly better in comparison with older system. MAIA is working in automatic regime, what allows us to cover more nights and record higher number of the meteors. Another advantage against the older system is the frame rate 60/s, what is important for this proposed project since such frame rate is promising for detection of the periodic variations of the light curve.

The double station data provides us with the atmospheric trajectories as well as the heliocentric orbits of the meteors. While the heliocentric orbit brings the information about the meteoroid origin, the atmospheric trajectory provides the key data for the modelling of the meteoroid interaction with the atmosphere. Using meteor light curve we can also determine the photometric mass of the meteoroid, what is another important entry parameter for any model.

Finally, we will also look for the cases of the meteors which occurred within very short time interval. Such pairs or groups of the meteors could be potential candidates for meteoroid pre-atmospheric break-up. We will investigate their trajectories and try to determine if such break-up could really occur.

4 Qualification of the team members

David Čapek (workload 70%) is PI of the project. He has research experience in determination of weak non-gravitational forces and torques acting on asteroids. It involves modelling of the shapes by polyhedrons with many triangular facets, numerical and analytical methods of solving the heat diffusion problem and the evaluation of forces and moments arising from interaction of radiation with asteroids. His major role in the project is the development of the theoretical models of the meteoroid rotation and, together with other team members, to compare the theoretical data with the observations.

Pavel Koten (workload 25%) will be responsible for the double station video data on the fainter meteors. His field of the scientific interest is in photometry of meteors, analysis of their light curves and atmospheric trajectories, computation of the heliocentric orbits, double station observations and image and data processing.

Within the proposed project he will check the recorded data and select interesting cases for the project study. He is maintaining data base of the meteor atmospheric trajectories and orbits, which will be major source of the data for this project. Data are based on the older analogue observational system as well as on the new digital MAIA system. In cooperation with other members of the team he will be comparing the results of the theoretical models with the real data.

Miroslav Brož (workload 20%)

Lukáš Shrbený (workload 15%) will be responsible for the data about light curves of fireballs with flickering. The main fields of his scientific interests are atmospheric penetration of fireballs which contains deceleration, mass loss, and radiation. Within the proposed project he will select those events which exhibit periodic variations on their light curves. For these particular fireballs he will measure the light curves and describes variations of observed frequencies, which are important for comparison with atmospheric and heliocentric parameters of the fireball.

Pavel Spurný (workload 10%) will be responsible for the data about larger meteoroids recorded during their interaction with the Earth's atmosphere by the European Fireball Network. His main field of interest is data acquisition and complex analysis of all fireballs recorded photographically (atmospheric trajectories and heliocentric orbits) and photoelectrically (detailed light curves) by Automated Fireball Observatories at all stations in the Czech Republic, Austria and Slovakia. Within the proposed project he will select those events which exhibit periodic variations on their light curves. For these particular fireballs he will compute atmospheric trajectories, heliocentric orbits and basic physical characteristics necessary for modelling of rotating meteoroid interacting with the atmosphere (task C of the proposed project).

5 Collaborators

Tomáš Kohout (Department of Physics, University of Helsinki) - shapes of IDPs from X-ray microtomography.

Jiří Pachmáň (Institute of Energetic Materials, University of Pardubice) - terrestrial rock samples preparation by contact explosive charge technique.

Jiří Petr (Solid Vision, s.r.o. company) - 3D laser scanning of the terrestrial rock samples.

Juraj Toth (Department of Astronomy, Physics of the Earth and Meteorology, Comenius University in Bratislava) - whole-stone samples of Košice meteorite

MSc. students: Kateřina Chrbolková, Pavel Ševeček

Ph.D. students: p. Chrenko

6 Timeframe of the project

The ongoing observation of meteors and fireballs by double station video cameras and by Automated Fireball Observatories and the flickering data acquisition will be performed continuously throughout the duration of the project 2015-2017.

2015 (i) Determination of the shape models of meteoroid analogues by 3D scanning, statistical analysis of the resulting shape characteristics and publication of the results (Task A). (ii) Selection of periodic flickering cases in European Fireball Network light curve database (Task C1), (iii) Code writing for Tasks B1-B2 concerning effects of reflected a thermal radiation on meteoroid's rotation, and (iv) completion of Task B3 (meteoroid shape modifications due to erosive collisions with dust).

2016 (i) Completion of Tasks B1 and B2, (ii) preliminary results of Task C1, code writing and preliminary results for Tasks C2 and C3 dealing with the physical proceses responsible for the flickering phenomena.

2017 Completion of Tasks C1 - C3, finishing the project.

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