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Modern problems of meteoric astronomy and possible ways of their solutions

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Abstract The article gives an overview of the most important problems of modern meteoric astronomy and briefly describes ways and methods of their solutions. Particular attention is paid to the construction and arrangement of meteoric video cameras intended for registration of the meteoric phenomena as the main method of obtaining reliable and objective observational data on the basis of which the solution of the described tasks is possible.

1. Introduction

Meteors as an astronomical phenomenon have been studied since the XVII century. Now we know that meteors ("shooting stars") are the light phenomena which appear during the invasion of cosmic particles of small size in the Earth's atmosphere. By now we have firmly established the existence of about 400 permanently operating meteoric streams and the same quantity of not confirmed streams. About half of the observed meteors cannot be attributed to the streams, and they are considered as sporadic.

Meteoric astronomy as a branch of observational astronomy studies the small-sized substances of the Solar System. This allows us to expand our understanding of its cosmogony. However, all the substances in meteoritic bodies completely evaporate in the atmosphere, so its physical properties are estimated on the nature of its destruction and the evaporation of particles. So far, the theory of movement of meteoric bodies with space speeds in the atmosphere is rather well worked only for large bodies (bolides). It is connected with the existence of reliable objective registration of the flight of such bodies in the Earth's atmosphere, recorded with a high frame rate that is explained by the high brightness of the bolides. Theory of combustion of bodies of small masses (meteors) is constrained by a lack of observational data of good quality. The task of meteoric observations is to obtain high quality registrations of meteoric phenomena necessary for the development of the theory.

2. Main tasks and problems of meteoric astronomy

Almost all of the main problems of meteoric astronomy, formulated in the last century, are still relevant. Among them the following issues are most important (http://www.

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astro.amu.edu.pl/˜jopek/MDC2007/Roje/roje_lista.php?corobic_roje = 0&sort_roje = 0):

- Origin of meteoric material and meteorites.
- Study of the evolution of meteor streams and the movement and distribution of meteoric material in the Solar System.
- Determination of physical and kinematic properties of meteor velocities and orbits of meteoroids.
- Study of meteor's "parent bodies" – comets and asteroids.
- Study of the possible meteoric activity in the Galaxy searching for "galactic" meteors.
- Study of cosmic dust on the Earth and the inflow of meteoric material to the Earth.
- Creation of the general theory based both on theoretical presuppositions and on objective observational data.

Since the time the meteoric astronomy emerged until now a large number of various results were received. These results expanded our understanding of the meteoric phenomena, meteoric material and its distribution in space. In particular, dynamic characteristics of meteors are received, their structure, sizes, density and masses to a certain degree is investigated, and some physical processes connected with the destruction of meteors in the atmosphere of Earth are studied. Besides, our understanding of the physical properties of the Earth's atmosphere is based exactly on the observations of meteors on heights of their fire (80–120 km). Direct observations of meteoroids proved its genetic linkage with comets. By means of basic observations a large number of orbits of individual meteors are calculated. On the basis of various methods of observing catalogs of the confirmed meteoric streams (http://www.astro.amu.edu.pl/˜jopek/MDC2007/Roje/roje_lista.php?corobic_roje = 0&sort_roje = 0) and of the "small" streams which still need an additional research (Terentyeva, 1966) are made.

However, despite a rather large volume of knowledge about meteors, many questions of meteoric astronomy are not fully resolved and remain relevant. These treat both questions of the physical theory of meteors and questions about meteoric streams and the distribution of matter in the Solar System.

2.1. The questions related with meteoric streams and distribution of meteoric material in the Solar System

- The observers of meteors have no rather clear idea of all meteoric streams now. Despite the existence of a large number of streams (Fig. 1) operating at different times with different intensities and coordinates of radiants, there is no catalog which would contain full information on them. More than a half of all meteors registered by observers cannot be correlated with any known existing stream. However the essential part of such non identified meteors is potentially belonging to certain streams of which the modern meteoric astronomy has no ideas (Astapovich, 1958). And it is the most important problem of modern meteoric astronomy. As streams show instability, it is necessary not only to investigate all operating streams, but also to carry out a search for new ones.
- Another important task which follows from the previous one – the identification of small meteoric streams with a small number of particles in the structure. This will allow to define the valid quantity of operating streams, and to clarify the proportion of sporadic meteors in the total mass of migrating bodies. In the future it will give an objective material to study the properties of orbits of meteoric streams and their evolution which is caused by the influence of sunlight, gravitational perturbations from planets, the Poynting–Robertson and Yarkovsky–Radzievskii effects and other factors.

This observational task can be solved by long-term monitoring of bright meteors on large areas of the Earth's atmosphere, preferably at different latitudes. The field of view of one meteoric set covers only a small part of the Earth's surface.

If a meteoric stream is weak, from it annually is registered a small number of meteors. It is necessary to accumulate several registrations of meteors from this stream with the help a large number of observational sets, or to conduct long range observations to measure its radiant.

- Research on the meteoric streams consisting only of faint meteors. The observation of such meteoric events provides an opportunity to determine the initial orbit of their parent streams. The calculation of the value of the drift of particles of different masses will determine the duration of the drift in the future and will allow to receive the parameters of an initial orbit of such a parental stream, not even observable from the Earth. The main requirement is to provide high accuracy registrations for the correct identification of non-gravitational effects.

The search for such streams can be carried out by monitoring of faint meteors by TV-cameras with large fields of view and sufficient penetrating force to observe these meteors.

- One of the tasks connected with the specification of already known characteristics of meteoric streams, consists in identification of the drift of the radiant of a meteoric stream depending on changes in longitude of the Sun. If a meteoric stream is quite young, but the differentiation of the particles of different masses has already began to appear, it is possible to reveal several radiants of such a stream. These radiants will be characterized by the existence of particles of different masses and, therefore, different brightness (Leonov, 2011).

For observation of such streams TV cameras with high penetrating power are necessary.

- The age of meteoric streams is extremely important both for studying of their evolution, and for studying of all substances of the Solar System. It is possible to determine their age by the size of radiants displacement of faint and bright meteors of the same stream. Under the influence of not gravitational effects the particles of different masses in this stream will have various orbits and radiants observed from the Earth.
- Identification of this effect can be carried out using the television cameras possessing a wide field of view and at the same time high penetrating power.
- One of the most difficult problems of meteoric astronomy is the studying of the inflow of meteoric substances to the

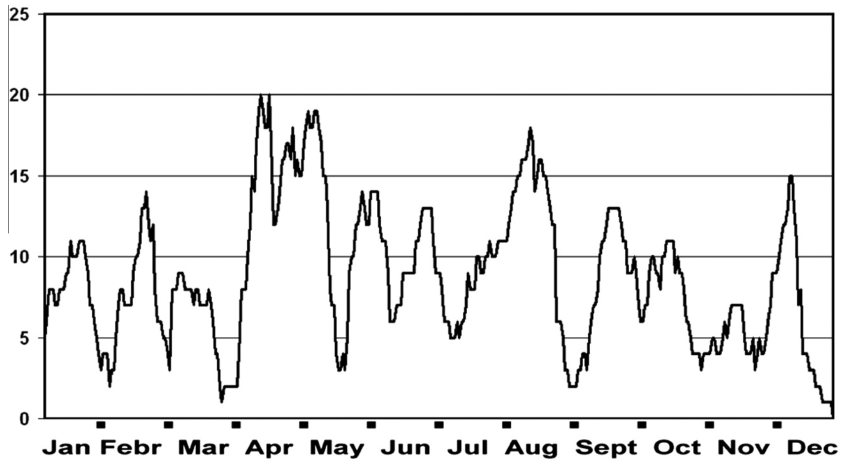

Figure 1 Annual distribution of meteoric streams. (Leonov, 2011).

Earth. Updating and specification of modern models of inflow of substances will confidently allow to estimate the level of meteoric danger to the man-made objects orbiting the Earth, and risk of collision with meteoric bodies.

There are two main methods for obtaining such evaluations – an astronomical and a cosmochemical one.

The last approach is based on calculation of the maintenance of cosmogenical elements in various depositions: in deep-sea sediments, glaciers and snow deposits.

This method has a rather low accuracy because estimates of inflow of substances according to astronomical data carried out by different researchers are on the basis of strongly different approaches (Bronshten et al., 1987). Therefore, they are all based on assumptions and reductions that require critical examination.

- The determination of the orbital parameters of individual meteors will give a clear idea about the composition of meteoric swarms, and on the processes occurring in them, of the movement of the bulk of meteoric matter in their orbits as well as to resolve the issue of the existence of meteors with hyperbolic velocities. It is also important to analyze the orbits of meteors, streams and comets in terms of their genetic match.

Data acquisition on parameters of orbits of individual meteors is only possible with the basic observation, one-sided monitoring for such studies is not acceptable.

2.2. Some questions of the physical theory of meteors

- The study of the physical properties of meteoric particles is based on research of their masses and densities. Determination of the mass of the particles is carried out in an indirect way – in their loss of kinetic energy at the flashing. However, the current reductions of the brightness of the meteors to their masses are still insufficiently proved, mainly due to the lack of high quality observational data. In this case, we assume that the particles belonging to the same meteoric stream should be homogeneous in their physical characteristics. But in literature different researchers give different indicators of the density of meteoric substances for particles of the same stream. Probably, they considered meteors from different meteoric streams. Therefore the question about the properties of particles even in strong streams with a large number of meteors remains open and demands detailed studying.

For such estimates, first of all, it is necessary to receive the values of photometric accuracies of measurements and to study in detail the atmospheric parameters in the areas of the movement of meteors. And as a possible indicator of the density of meteoric particles it is possible to consider the characteristics of their inhibition in the Earth's atmosphere, and density along a trajectory of the meteor is measured from other measurements.

- The evaluation of brightness of meteors is the most important parameter determined by their direct observations. The brightness of meteoric tracks gives useful information on which it is possible to estimate the total light energy emitted by a meteor, and further to estimate the mass. The majority of researchers carried out such an assessment, comparing the brightness of a meteor and brightness of the nearest stars in the frame. However this assessment is not certain.

However, this estimate is fairly uncertain, because it does not give the size of a full light stream – meteoric bodies can radiate constant light energy throughout all movement in the atmosphere, and to give the short-term flashes exceeding several times the glow of the track. The knowledge of the size of the total light energy emitted by a meteor will help to specify models of movement of particles in strongly rarefied environments.

It is possible to receive the size of a full light stream from a meteoric track by making a summation of a light signal from a meteor with a predetermined threshold in each pixel. Traditionally, as brightness of meteors is taken the brightness of the star making at the observer impression of equal brightness with a meteor at the time of its maximum brightness. But as meteors are observed at different distances from the observer, the concept of absolute brightness of a meteor (carried to the distance equal to 100 km) is entered. At the same time photometric value of brightness of stars consists in the illumination generated by a star on the surface of the Earth. In the observation of moving objects that meteors are, it is necessary to calculate the illumination created by a meteor.

2.3. The problem of registration of elements of space debris in Earth's atmosphere

The problem of space pollution of different near-earth space (NES) with elements of the space debris (SD) has emerged almost immediately after the launch of the first artificial satellites.

The question of ensuring trouble-free operation in an orbit of spacecrafts and protecting them from influences of SD is also actual, as well as a question of meteoric safety (Bagrov et al., 2009) for these devices.

The solution of this problem is based now on the use of computer models of pollution of NES by the SD elements (Nazarenko, 1997; Cherniavskyi and Nazarenko, 1995; GOST, 2005; ORDEM, 2000). These models reliably are confirmed only for the SD elements of the huge sizes observed by control services of NES. All small-sized parts of SD remain outside the availability of optical and radar observation equipment.

However, according to researches (MASTER, 2000), the particles of SD interacting with upper layers of the Earth's atmosphere eventually slowed down into the denser layers where they burn down as usual meteors.

It allows to make direct observations of burning of particles of KM in Earth's atmosphere by the methods of meteoric astronomy.

The process of burning of particles of SD is not very different from processes of the meteors combustion in the Earth's atmosphere; both processes will generate similar meteoric phenomena. The criterion for the selection of particles of SD from the general stream is their linear speed. Meteoric bodies of the Solar System have speeds of meeting with the atmosphere, exceeding 11.2 km/s, and the SD elements have a speed not higher than this value.

For measurement of the linear velocity of meteors it is most effective to make basic observations that allow to receive a full vector of meteor velocity.

However, under some assumptions and admissions it is possible to use one-sided observations of meteors, in which by a certain technique individual elongation of a meteor (Leonov and Bagrov, 2011), and then its velocity is calculated.

3. Equipment for meteoric observations and construction of optimal television system for registering meteors

The most effective way to conduct research of the meteoric phenomena at present is television observations. This type of observation has many advantages which other methods possess too. However it has its essential advantages. Among them may be mentioned a high sensitivity and shooting speed, the possibility of operating the received results in real time, compactness, mobility, low cost of the equipment and some others.

A choice of TV cameras for the registration of meteors must be based on the tasks which need to be solved with the help of these cameras. However the standard television system which we will consider below is suitable for the solution of the majority of problems of meteoric astronomy.

The most essential parameter of a video camera is the size of an element of resolution. A few years ago astronomers had the opportunity to use the TV cameras which were issued in large quantities for various systems of safety. They were inexpensive television cameras with the format of CCD-matrix 1/2″ and the size of pixel 8.6×8.3 microns. For systems of the passive (hidden) observation these cameras were completed with ultra-luminous lenses with the aperture ratio 1:0.8, specially developed for these purposes. These lenses with spherical components provided the resolution through all fields of view for the 1/2″ format matrices. These cameras, which were issued at the beginning of this century, had optimal technical specifications for meteoric observations, were inexpensive, and had a very high sensitivity. The majority of observers of meteors still use exactly these cameras. The television equipment evolves toward compact cameras now, and video surveillance systems switched to the 1/3″ and 1/6″ format matrices in which the size of the pixel decreased to 3 microns. These cameras are absolutely unsuitable for meteoric astronomy because with the small size of matrices it is impossible to provide a combination of a wide field of view and a large entrance aperture of a lens.

Nevertheless, some large producers of video equipment are still developing visual surveillance cameras with the format of matrix 1/2″ and the size of pixels 8.6×8.3 microns (it should be noted that producers of video equipment and tracking systems in the majority are not the producers of CCD and CMOS-matrices).

Nevertheless, some of the major manufacturers (it is worth noting that the producers of video equipment and tracking systems in the vast majority are not producers of CCD and CMOS matrices). Those producers are focused mainly on a wide range of consumers, including the scientific organizations and astronomers. The cost of such cameras fluctuates within 300–500 USD (Bagrov and Leonov, 2010), and cameras (Fig. 2) have some features which allow to expand the possibilities of observers.

In particular, they may have both digital and analog outputs, to be equipped with an electronic shutter with a wide range of exposures, the system automatically determining the type of lens, and also special casings for observation in any temperature condition, and having a high sensitivity (to 0.000005 lux).

At the same time producers of optical components do not produce ultra-luminous lenses for such cameras because to

Figure 2 Video camera based on a CCD matrix of 1/2″ Watec WAT-902H2 Ultimate with the sensitivity 0.0001 lux. (watec.net/english/bw_top.html)

work in darkness tracking systems are supplied now with infrared illuminators, so security systems do not need such ultra-luminous lenses.

The aperture of industrial lenses for tracking cameras rarely exceeds 1:1.2, and the use of photographic lenses becomes complicated by problems of their compatibility with cameras. Different systems of adapters and bayonets are often not compatible with each other. Thus, the photographic lenses produced in mass production have the aperture 1:1.4, meanwhile lenses with higher characteristics, usually produced in a small amounts, have rather high cost (1000–3000 USD).

An important parameter at a choice of lens is the size of the receiver, there the lens is established. For example, if the lens is designed to receiver 1/2″, it can be applied to receivers 1/3″ or less in size. That is, for matrices of 1/2″ format are required lenses designed for the matrices of the same size or greater (for example, 2/3″), which significantly narrows the choice.

In view of the above, we can conclude that the best choice of commercially available optical devices for video surveillance systems are lenses with an aperture of 1:1.2 and a focal length of 40–60 mm. Long focal lengths bring some restrictions that considerably narrows both a view of the camera, and a choice from lenses available on sale.

Lenses with such long focal lengths in generally are variable focus lenses having deliberately low luminosity, or zoom lenses. Their cost is much higher than that of usual lenses. For example, the lens Fujinon DV10 × 8SA with the aperture of 1:1.4 (Fig. 3), designed for use on cameras with receiver 1/2″, and the focal length of 8–80 mm (http://www.fujinon-cctv.ru/; http://www.cctv-catalog.ru/f0n227s0p40.ahtm), and also a zoom lens of the same company D8 × 78A with the aperture of 1:1.2 for the cameras with a receiver 1/2″ and focal lengths 8–63 mm (http://www.fujinon-cctv.ru/; http://www.cctv-catalog.ru/f0n228s0p80.ahtm). Do not forget that the sight of such lenses with a focal distance of 50 mm should be about 10° × 10°. It is necessary to remember that the field of vision with such lenses at focal length of 50 mm will be about 10° × 10°.

In this context it is necessary to mention the radiation receivers with large sizes of the pixel, developed directly for astronomical observations.

Figure 3 Lens Fujinon DV10 × 8SA with the aperture 1:1.4 and a focal length 8–80 mm, designed for use on cameras with a receiver 1/2″.

It is CCD and CMOS-matrices with sizes of pixel of 24 × 24 microns which occupy an essential segment in the market. However the cost of these products is comparable to the budgets of small research institutes.

Cameras with radiation detectors, occupying an intermediate segment, for example, with sizes of pixel of 12 × 12 microns, 14 × 14 microns, 16 × 16 microns, etc. have a lot of features useful for observing meteors. In particular, the camera X-PRI of AOS Technologies AG (http://www.aostechnologies.com/fr/) does not require a computer, can be powered by battery and record video at up to 1000 frames per second at full resolution (1280 × 1024 pixels). These cameras in the majority belong to the category of high-speed systems applied in various branches of science and technology. Registration of the meteoric phenomena by such cameras is possible with the use of software for automatic detection and recognition of meteors in the video stream data. The prices of such systems begin from 20,000 USD.

Thus, with respect to "performance/price" from products available on the market the most preferable and convenient for recording meteoric phenomena is 1/2″ format camera with a pixel size of 8.6 × 8.3 microns and lens aperture of 1:1.2.

However, the effectiveness of surveillance technology, including meteors, is characterized not only by the systems themselves, but also the software. In view of a large volume of obtained data and complexity of allocation of fragments with meteors their automatic selection is very necessary. The vast majority of researchers of meteors use for this purpose UFO Capture software package (http://sonotaco.com/). However, many manufacturers of video equipment and tracking systems develop and distribute a large number of software products which can be used for the allocation of moving objects from a video series.

4. Conclusions

During the last three centuries visual observations have been the sole method for the registration of meteors. Only in the XX century they were replaced at first by photographic, then radar, and in the last two decades – television methods. Despite the rapid development of the technology and facilities of photo and video recording, the volume of the obtained data needed to construct the modern picture of meteoric phenomena, and meteoric substance, is insufficient.

The majority of made observations belongs to the strong meteoric streams which are more convenient for observation. Faint and low-active streams generally are not studied. Besides, not all the streams listed in the majority of main catalogs, currently exist, and radiants of known existing streams are not always reliable. Without their studying it is impossible to investigate the evolution of meteoric substances of the Solar System. The productivity of direct studying of meteors is substantially connected with the development of observing techniques, the expansion of its capabilities, the acquisition of a large number of original observational data, and also with algorithms of processing of received data.

Of particular importance are the software tools for the identification of meteors from the general stream of information and recording software for processing received data. In the future the functionality of the software will allow to increase the productivity of research. Therefore, the accumulation of observational recordings of meteors (especially made with high frame rate recordings of meteors of low brightness), and also the development of algorithms and the software are the primary tasks for construction and verification of the theory of the meteoric phenomena.

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