CrossMark

Applied Mathematics and Nonlinear Sciences 2(2) (2017) 473–478

Applied Mathematics and Nonlinear Sciences

http://journals.up4sciences.org

Study the combustion processes of space debris in the Earth's atmosphere by meteoric TV camera

V.A. Leonov[1], A.V. Bagrov[1,2], G.F. Attia[3 †], A.M. Abdelaziz[3] and R. Ghoneim[3].

[1]Institute of Astronomy of Russian Academy of Sciences(INASAN), Moscow, Russia.

[2]Federal Enterprise "Lavochkin Association", Moscow region, Khimki, Russia.

[3]National Research Institute of Astronomy And Geophysics(NRIAG), Cairo,Egypt.

Submission Info

Communicated by Elbaz I. Abouelmagd
Received 5th July 2017
Accepted 15th November 2017
Available online 15th November 2017

Abstract

Space debris of millimeter dimensions is almost not detectable by normal methods of observation from Earth. However, particles of such sizes can cause damage to the spacecraft. and even eliminate it. Estimating the status of impurity of near-Earth space mainly based on mathematical models, which are confirmed only for large particles. The millimetric fractions of space debris elements remain unexplored.In case of invasion of debris particles into the planet's atmosphere, they burn down as well as meteoric particles of natural origin. In this work, the observation technique of separation of debris particles and particles of natural origin is described. Also, the results of the detection of particles from space debris received during the TV observations on the wide-angle camera patrol camera FAVOR (Russia, Northern Caucasus).

Keywords: Space debris, observation methods,TV observation.
AMS 2010 codes: 85A04, 70F15.

1 Introduction

The problem of space pollution, space debris, arose almost immediately after the launch of the first spacecraft into space. Extent of pollution of near earth space is growing with every new launch of spacecraft, and security work in the earth orbit satellites for different purposes, particularly man-made, raises serious concerns. Not all spacecraft after a period of active existence utilized. Many from long time turned into debris. At collisions of the large-size elements of space debris with natural bodies can form a large number of fragments of different sizes -

†Corresponding author.
Email address: wahba_gnkj@yahoo.com

down to the micron. The number of fragments and their trajectories after such collision are difficult to predicte. Recently, debris are of particular danger to small satellites. Their sizes and diminutiveness negatively affect their resistance to meteoritic bombing. Using various models of impurity of near-earth space allows us to get an idea of the distribution of debris fragments [1]- [5], including after the shock interactions. However, verification of these models can only take place in the field of large-debris observed by control services of the near-earth space. Shock interactions are modeled for velocity impactor and target up to 3 km/sec [6]. Small-sized part of the space debris is not registered for any optical or radar observation equipment. However, the results of some of our researches [7] allow to claim that combustion of space debris is also observed, as well as the usual meteor phenomena. This is due to the fact that, naturally occurring meteoroid in Pre-atmospheric solar system has a speed of 11.2 km/sec, and the space debris have a speed less than 11.2 km/sec. Therefore, the selection of the speed of meteors is a reliable method for isolating meteor events caused by the combustion of the space debris elements.

2 Method of Observing Debris Particles by the Meteoric TV Camera

Space debris elements interacting with the earth's thermosphere are slowing down, thereby falling to lower orbit. As a result, they enter the Earth's atmosphere and burn down in it. The process of combustion of space debris particles is absolutely an identical combustion of natural meteors. The latter meets with the atmosphere of speed exceeding 11.2 km/sec, and the elements have a speed not more than 11.2 km/sec. Selection of the velocity can reliably isolate events caused by the combustion of the elements of space debris. Obtaining a linear and orbital velocity characteristics are possible with meteor basis of observations. These observations may be conducted using two or more stations separated by a distance of a few tens of kilometers, depending on the optical characteristics and the radiation receiver [8] [9]. Single-station observations, despite the mass character, allow to receive the coordinates of radiant of meteor swarms, but don't provide any information about the space debris particles, as the latter do not form a swarms in the conventional understanding. However, in some cases, the linear velocity of the meteor assessment can be used as measurements of its angular velocity, provided that the angle between the direction of flight of the meteor and the direction of the radiant and the distance to the meteor's flight is known. Burning meteors usually occurs at altitudes of 80-120 km from the earth’s surface, and the approximate distance to the meteor can be estimated from the measurements of its distance and the zenith of the altitude range. The angular velocity of the meteor is obtained directly from these TV-observations. The difficult issue is to obtain an individual meteor elongation (the angle between the meteor and the direction of the radiant). Special geometrical method was proposed to calculate the elongation of the individual meteors on unilateral TV-registrations. It allows obtaining elongation meteor recorded for five or more TV-frames [10]. If a certain elongation of the meteor is close to 90°, then the meteor moves orthogonally to the line of sight, which gives the basis to estimate its linear velocity. If it is known to be less than the escape velocity, then the observed meteor is caused by combustion of space debris. This method is applicable for all the meteors, which lies in the field of view of the TV-camera, and the duration of the meteor phenomenon exceeds 0.7 seconds. In case of the standard frequency of a vertical sweep, it makes about 18 frames. This method does not consider braking of meteoric particles. Our studies of braking meteors [11] suggest that the first clear indication of braking occur not earlier than 700 milliseconds after the appearance of a meteor, and in most cases are present before its fading. Unlike photographic registrations, for weak meteors (+ 3m) are generally not recorded, TV-registration on FAVOR cameras [12] provide material mainly for weak meteors. They are characterized by movement in a more rarefied medium and smaller brake. Probably the recorded braking meteoric particles are poorly noted in photos, even less seen on television multiframe registrations of low-brightness meteors. It is important to note that this conclusion is reached regarding the meteors observed in the entire frame. Therefore, the geometric analysis of multiframe meteor registrations in unilateral observations will be effective only for cameras with large fields of view.At the same time, in the processing of meteoric strokes as reference points, it is necessary to consider only their ends. The experience of our meteors TV-observations shows that regardless of the brightness of the meteor track (up to + 8m inclusive) short trail can be seen behind him. The brightness of the trail is often not differ from the brightness of the meteor. Therefore, in successive television frames at the beginning of the track is often imposed glowing trail of a meteor, and finding the true position of the beginning of the track becomes quite difficult. End of the meteor track accurately indicates the position of the meteor particles in the end of the exposure. The considered method is designed in the form of a computer program, which is registered in the Patent Office of the Russian Federation and is available to the public use [11] [13].

3 Observational techniques used in INASAN and NRIAG

In INASAN since 1999 and from 2015 in NRIAG TV-observations of meteors are conducted [17]. TV technique is currently the main method of meteoric registration. For meteors recording, different TV-cameras are used: PatrolCa, MobilCa, SMAC and FAVOR. PatrolCa TV-cameras (their mobile versions - MobilCa) are used now in INASAN and NRIAG for basic observations. There are simple in the technical performance, but despite that, they allow sufficiently high performance achievements. Each of PatrolCa cameras include:

- Wide-angle lens Fujinon (F=8-80 mm relative aperture of 1:1.4) or Computer (F=6 mm, relative aperture of : 0.8).

- Black-and-white CCD camera Watec WAT-902H2 Ultimate.

Super high aperture lenses is no longer manufactured now, so a high-quality Fujinon varifocal lens can be considered rather acceptable option for configuration of patrol cameras. The brightness of the meteor depends on many parameters of the recording device, so we carried out the analysis of modern video surveillance systems with characteristics of which enable them to apply for meteors registration. On its basis recommendations for the design of optimal meteor camera are formulated. The most efficient in the ratio of "price / performance" are a standard video camera with CCD or CMOS image sensor size 1/2 inch (the sizes of a pixel 8.6×8.3 micron or more) and lens relative aperture of 1:1.2 (Fig. 1).

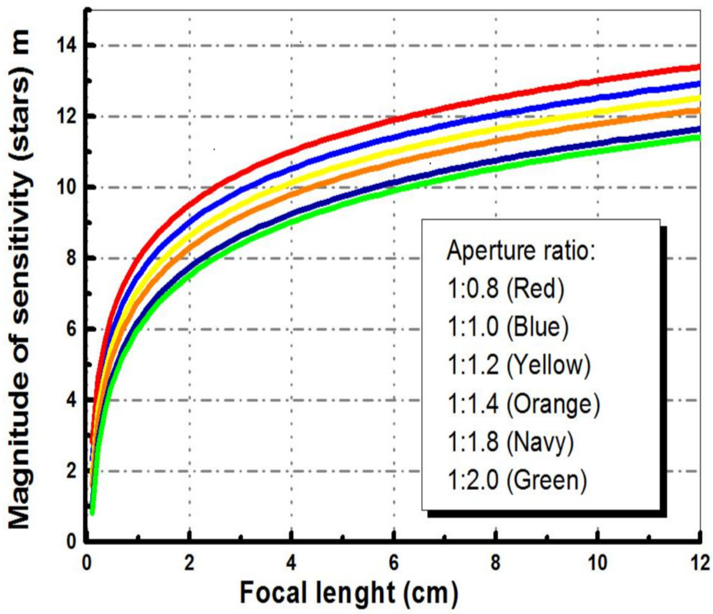

Fig. 1 The extreme sensitivity of the Watec CCD (stars) with afrequency 25 frame/sec and lenses with different characteristics.

The camera Watec WAT-902H2 - one of the most sensitive black-and-white video cameras with a 1/2 inch CCD receiver, equal to. One of the features of the WAT-902H2 is the presence of an additional stage with gain amount which can increase the contrast of the image in case of threshold illuminating intensity at an extremely high level of noise. It is one of the most popular CCD cameras among researchers worldwide. Cameras are placed in weatherproof boxes of factory manufactured supplied are factory-built, equipped with heating systems to prevent their misting when passing the dew point and freezing at low temperatures. The detection threshold of meteors on such cameras with a frame rate of 25 Hz (signal accumulation time 0.039 seconds per frame) does not exceed + 5m.The wide-angle FAVOR camera has been designed for the detection of sources of X-ray flares in the optical band, but for a long time, it is used to register the meteors [12]. When designing the camera, different decisions were implemented, such as accumulation mode, which allows to reach the maximum time resolution without loss of sensitivity. Furthermore, for matching the resolution of the recording device (CCD) and a maximum field of view of the camera used in FAVOR, intermediate luminance amplifier with internal scaling of 1:6.5 is used. As a result, the camera has a field of view 18° x 22°, which is recorded on a matrix format 1392×1040 pixels.Accumulation time of 0.129 seconds provides a sensitivity on stars +10m/11m, but it is less on meteors at 1m. Limiting cases of detecting meteors to +10m are found, but they register only in a single frame. It is not possible to determine the direction of their movement, and they have a short track length of a few pixels. Therefore, the threshold of detection of meteors on camera FAVOR is +8.5m. Complex software to work with the camera FAVOR also provides for automatic identification of the pattern of stellar performance in the frame and perform astrometric measurements of coordinates of points on the meteor track [14].Another type of cameras - SMAC is constructed in conjugate option for supporting of a double-stations and according to its ability, it is close to FAVOR camera. These cameras are designed for experimental studies of the capabilities of modern TV-technique and applied in INASAN for the dynamic characteristics of the meteors observations, and for studies of their physical properties, including Spectral. Using a sensitive Sony ICX-285 CCD detector with a size of the matrix 2/3 inch in Canon EF-85 lenses allows to correct the spherical aberration in case of completely open aperture, giving the field of vision 5.5° x 5.5°. This makes it possible to exclude an expensive image intensifier camera scheme to save, at the same time, the limit of sensitivity value, reaching +11m (on stars) at frame frequency of 25 Hz.

4 Analysis of the array of observations obtained by the Meteoric TV Cameras

For the experimental verification of these provisions, an array consisting of 4500 meteors had been recorded on the camera FAVOR in 2006-2007. These were isolated events, for which there was a possibility to determine an individual elongation of meteors. Further, all the events for which belonging to famous meteor shower were set, and also those which didn't meet the requirement for an elongation were excluded. From the remaining number of meteors, meteors which had the lowest angular velocity were selected. As a result, 7 meteors of an artificial origin were found. After bringing the linear velocity was evaluated Table 1. Thus, Concerning these

Table 1 Characteristics of meteors from space debris.

Case	Meteor	Elongation(Degrees)	angular velocity (deg/s)	Linear velocity (km/s)
1	2006-08-31=00h41m28s	86	2.1 (±0.35)	3.4
2	2006-09-13=22h00m46s	74	2.8 (±0.35)	4.7
3	2006-09-18=19h59m54s	78	2.7 (±0.35)	4.5
4	2006-10-14=22h24m04s	90	2.2 (±0.35)	3.5
5	2006-10-20=17h21m04s	89	1.9 (±0.35)	3.0
6	2007-10-12=20h08m06s	79	2.4 (±0.35)	3.9
7	2007-10-18=23h36m45s	70	2.0 (±0.35)	3.2

7 meteors, we can confidently claim that the facts of combustion of particles of space debris were observed (Fig. 2). The error in determining the linear velocity by the angular velocity measurement and evaluation of elongation in this case equal 0.6 km/sec approximately. This ensures that the observed particles have speed, certainly less than the second space, which is the main criterion for differentiating of artificial meteors from an array of natural meteors. Only meteors which have a direction of movements close to horizontal, have been considered. This means that in our analysis, we only consider space debris particles which move at a very low orbits - close to circular. Using these results of basic registrations will help to identify the meteors velocity and broaden our approach and elements of space debris, which are at higher elliptical orbits. For example, resulting from the destruction of the satellite as a result of collisions or explosions [15]. Observation of meteors caused by combustion such fragments will give another way of confirmation of disasters in the near-earth space and perhaps will allow to determine the nature of the destruction by counting the number of fragments, which have burned down in the atmosphere.

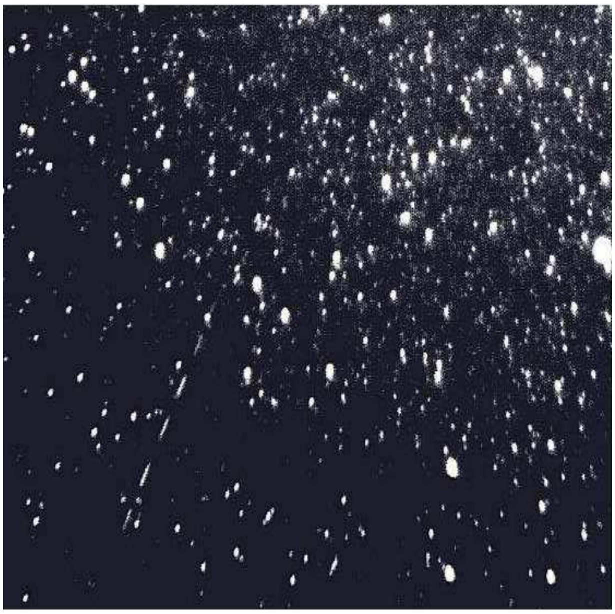

Fig. 2 Summarized meteor frame Date: 2006-08-31-00h41m28s From Space Debris average brightness 5.5m,elongation 86°,angular speed 2.1 deg/sec,linear speed 3.4 km/sec.

5 Self Cleaning Estimation of Near-Earth Space Debris

Assuming that the size of the camera's field of view at the height of meteor combustion is about 1000 km^2 ,taking into account the rate of emergence in this field to be 1 particle/ 40hours, It is possible to estimate the lower limit of daily space debris combustion rate in the atmosphere. According to our observations, it is 30,000particles/day. This assessment is directly related to the results of our observations. Therefore it is obvious that real rate of self-cleaning of near-earth space has to be a little higher. In this estimation, only meteors received from the one-station observations were investigated. This type of observation makes it possible to distinguish meteors from space debris, where the direction of movement was close to the horizontal, i.e, only space debris particles move in very low orbits close to circular. At double-station observations, such selection gives the chance to receive values of a vector speed meteors which will give further opportunity to extend this approach to the space debris elements which are in higher elliptic orbits. For example, which are resulting from destruction of the artificial satellite as a result of collisions or explosions. According to [16] for the model estimated in the near earth space, there are at least 1 million space debris particles at a size of a few millimeters. The total accumulated mass of man-made objects is about 6000 tons. The rate of increase in pollution in near earth space in case of continuing of launches is estimated at 120 tons/year (up to 20,000 particles in the size of a few millimeters a year. Our estimates self-cleaning show that, it does not practically compensate for the continued growth for near earth space contamination. This method of registration of space debris via meteor TV-cameras will provide an opportunity not only to estimate the rate of self-cleaning of the near earth space but also to conduct small-sized experimental specification of models of small substances which have an artificial origin.

6 Conclusions

The proposed method of separation of space debris and particles of natural origin is a new way of registration of space debris. Direct observations of meteors coming from space debris may clarify debris in the small-sized particles to control the rate of self-cleaning of the near earth space. And, it is essential to improve the prognosis of the danger of collisions of the spacecrafts with space debris elements.

References

[1] A.I. Nazarenko et al, (1997), Model of spatial and temporal distribution of flux density of man-made substances in the near-Earth space, Ensuring environmental safety of rocket and space technology, Moscow: Russian State Standard.
[2] G.M. Cherniavskyi and A.I. Nazarenko, (1995), Simulation of space debris in: Clashes in outer space (space debris),Moscow: Kosmosinform, pp. 104-130 in Russian.
[3] National Standard, (2005), Space environment (natural and artificial), Model of spatial and temporal distribution of flux density of man-made substances in outer space,Moscow: Standartinform in Russian.
[4] NASA,JSC,(2000), Engineering model of space debris (Orbital Debris Engineering Model ordem 2000 - v 1.0).
[5] ESA SD - CD03,(2000), Reference model meteoroids and space debris in near-Earth space (Meteoroid and Space Debris Terrestrial Environment Reference - Model Master 99).
[6] A.F. Klishin, D.V. Tulin and A.M. Nikitin. (2016), Small spacecrafts and technogenic danger, Abstr. book of the “Iosifiyan Readings 2016”, Istra: AO NIIEM, pp.83-84 in Russian.
[7] V.A. Leonov and A.V. Bagrov. (2011), Investigation of combustion elements of “space debris” in the Earth’s atmosphere by TV meteor monitoring, Astrophysical Bulletin, pp. 70-89 in Russian.
[8] A.V. Bagrov, S.F. Bondar, V.A. Leonov, A.V. Perkov and Vygon. (2004),Studying of the origin of meteoroids in INASAN ,Abstr. book of the 35thCOSPAR Scientific Assembly, p.618.
[9] A.P. Kartashova, A.V. Bagrov, G.T. Bolgova, S.V. Kruchkov, V.A. Leonov and V.A. Mazurov. (2013), Goals, technique and equipment of meteor study in Russia , Abstr. book of the European Planetary Science Congress,London: EPSC Abstracts, p.197.
[10] A.V. Bagrov and V.A. Leonov. (2010), The Calculation of Meteor Motion Parameters Based on the Data of One - Way Television Observations ,Solar System Research, pp. 327-333.
[11] V.A. Leonov ,(2011), Monitoring of meteor events by television method,DC Thesis Sankt-Petersburg in Russian.
[12] A.V. Bagrov, G.M. Beskin, A.V. Biryukov, S.F. Bondar, I.Y. Zolotukhin, S.V. Karpov, E.I. Ivanov and A.S. Pozanenko. (2003),The wide-angle high speed optical camera for detection of the flashing and moving objects, Proceedings of the Conf. Near-earth Astronomy, pp. 101-106 in Russian.
[13] V.A. Leonov. (2010), A method for determination of meteor stream membership based on the results of the single-station TV-observations used at INASAN ,Solar System Research, pp.122-125.
[14] Terentev D.A,(2014),The manual for work with the program FAVI,private message.
[15] L.V Rykhlova et al. (1997),Investigation of combustion elements of "space debris" in the Earth’s atmosphere by TV meteor monitoring,Astrophysical Bulletin, pp. 313 - 319.
[16] A.I Nazarenko. (2002), Modeling Technogeneous Contamination of the Near - Earth Space,Solar System Research, pp.513-521.
[17] G.F.Attia, A.M.Abdelaziz and I.A.Hassan. (2017),Video Observation of Perseids meteor shower 2016 from Egypt, Applied Mathematics and Nonlinear Sciences, pp.151-156. doi:10.21042/AMNS.2017.1.00012.

©UP4 Sciences. All rights reserved.