SUPERBOLIDES – DELIVERY TO THE EARTH THE SUBSTANCE OF SMALL BODIES OF SOLAR SYSTEM

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ABSTRACT. The existence of the cometary meteoroid streams containing m-sized, high-strength meteorite-producing meteoroids that open a pathway to deliver primitive materials to the Earth are considered. The light curve, mechanism of ablation and physical properties (mass, bulk densities, structural strength and terminal height) of meteoroid are very important information specifying under what circumstances it is possible to expect a meteorite landing. The multi-instrumental aspect of the collected observed data of an extremely bright slow-moving fireball of July 23, 2008 (Tajikistan) that has enabled us to study in detail the passage of this a m-sized cometary meteoroid through the Earth's atmosphere are used. The heliocentric orbit of the meteoroid was found to be similar to the mean orbit of the June Bootid meteor shower, whose parental comet is 7P/Pons-Winnecke. The conclusion that the July 23, 2008 event occurred over Tajikistan is a good candidate to recover of cometary meteorites are made.

Key words: superbolide, meteorite, meteoroid.

Introduction

Many cometary meteoroid streams were formed the continuous sublimation of the ice-rich regions in cometary nuclei. Other important mechanism to form the meteoroid stream connected with the comet is the catastrophic disruption of cometary nuclei and formation of m-sized fragments. The formed large fragments are potential candidates to produce meteorite-dropping meteoroids which cross the Earth and can survive during interaction with the Earth's atmosphere. Reliable observed data about bright fireball allow to calculate their atmospheric trajectory, pre-atmospheric velocity, heliocentric orbit, and to reveal the connection with their parental bodies - asteroids and comets. Till now the observed data received by various systems of observation, including optical, seismic, infrasonic and from orbital satellite which have provided definition of exact heliocentric orbits of meteorites are still small.

Now in the many museums of the world are stored not less than 500 tons of meteorites. It is considered, that for days falls to the Earth about 10 tons of meteoric substance among which there can be meteorites both asteroidal and cometary origins. The terrestrial collection of meteorites includes 4 % of iron meteorites, 85 % of ordinary chondrite (OC) and 9 % of carbonaceous chondrites (CI, CII, CM) which possibly are insufficiently presented because of the fragility and low density (Grady 2000). In Table 1 lists 11 meteorites - ordinary chondrites type H4-H6 were produced by fireballs with asteroidal orbits. Other two meteorites Tagish Lake and Maribo are carbonaceous chondrites CM2 type. Tagish Lake meteorite is related to the known μ-Orionid fireball stream. Moreover, the 60-Orionid meteor stream and asteroid (4183) Cuno can be connected with the μ-Orionid fireball stream and the Tagish Lake meteorite. (Unusually fast fireball, formed meteorite Maribo, is connected with cometary source – the complex Taurid of comet Enke (Haack 2010).

Table 1: List of recovered meteorites with known orbits.

Meteorite name	Meteorite type	Year of fall
Pribram	H5	1959
Lost City	H5	1970
Innisfree	L5	1977
Peekskill	H6	1992
Tagish Lake	CM2	2000
Moravka	H5-6	2000
Neuschwanstein	EL 6	2000
Park Forest	L5	2003
Villalbeto de la Pena	L6	2004
Bunburra	Achondrite	2007
Almahata Sitta	Ureilite	2008
Maribo	CM2	2009
Mason Gully	H5	2010

The observed data and results

The flight and destruction in the Earth's atmosphere of the large, m-sized bodies is accompanied by the formation of light, as well as acoustic-gravitational and infrasonic disturbances. Such disturbances having reached a surface of the Earth cause occurrence of a seismic waves. Use the data of seismic registration of bolides and superbolides in a combination with the data of optical and infrasonic registration is now the established practice of scientific research. As a result it is possible to receive of importance information on the interaction of large meteoroids with the Earth's atmosphere, as well as the atmospheric trajectory, radiant, the heliocentric orbit of the bolide and the position of the place of possible falling of a meteorite.

We have presented here the results of the analysis of complex optical and seismic registration of atmospheric passage and explosion of extremely bright slow-moving fireball and its spectacular dust trail observed over Tajikistan on July, 23rd, 2008 at 14:45:25 UT. The fireball had a -20.7 maximum absolute magnitude. Some eyewitnesses who were from about 25 km from the epicenter of event, heard a whistling sound from the sky, drawn their attention. They have seen flying in the sky object as a small sphere with a tail and of white-blue colour. Soon the explosion which has frightened them has thundered, and there was a white dust trail, which was perceptible for about 20 minutes and was later on distorted by atmospheric winds. Several distinguishable strong knots in this persistent trail, probably produced by successive meteoroid fragmentations, are similar with dust trails of other fireballs observed in a similar manner.

A spectacular long-persistence dust trail was witnessed by numerous casual witnesses in a widespread region of Tajikistan and recorded by video and photo cameras. The fireball was also recorded by two infrasound (Popova et al. 2011) and five seismic stations too. Some observers reported intense rambling sound, such as “thunder” which was audible for several seconds. Sonic boom was heard as far as 100 km away from the burst location and was very strong in the area of about 30 km around the ground projection of the burst location. The fireball was bright enough to be recorded by a visible-light satellite system which provided the irradiated energy for the brightest part of the fireball light curve. The total radiated energy was 2.1 x 10^{11} J, which is equivalent to a total released energy of about 0.05 kT (Brown, 2008).

Statistical observed data about a large bolides testifies, that already at the realised energy equivalent to ≥0.02÷0.03 kilotons THT, at the explosion of a large bolide the shock wave forms acoustic and seismic waves. For the last 20 years among the 30 fireballs, registered by using the various systems of the observation only for 15 fireballs have been received besides optical, also infrasonic and seismic data. Such data were essential addition and have been used for more detailed and full analysis with the aim of definition of the fireball's atmospheric trajectory.

Among the numerous photos received by casual eyewitnesses fortunately two witnesses separated by a distance of 11.3 km were alert enough to capture with photo cameras the dust trail immediately after the flight of the fireball. These two records were an exceptional opportunity to carry out a detailed study of the event, much better opportunity than if only visual sightings were available as the primary sources for determining the fireball trajectory.

The image of fireball’s trail in these photos has been slightly distorted by atmospheric wind so that has given the chance for the measurement of coordinates of its axial line. The subsequent astrometric calibration on stars according to standard procedure of processing of meteor pictures (Babadzhanov, Kramer, 1963) was made. Measuring the rectangular coordinates of the positional stars and any feature point (beginning, terminal, and all flares and depressions) on the fireball trail, such measurements were converted to equatorial coordinates by using the astrometric method of the METEOR software package developed by the Meteor department (Institute of Astrophysics, Tajikistan). As a result of the astrometric measurements we were able to determine the atmospheric trajectory of fireball, coordinate of radiant, velocity, and heliocentric orbit (Table 1-3).

The exact duration of the fireball was known from the data of a visible-light satellite system (Brown 2008). The fireball was first recorded at a height, H_b of 38.2 ± 0.5 km when the velocity, v_b was 14.3 ± 0.5 km/s. The fireball traveled a 19-km observed luminous trajectory and terminated its light at a low altitude H_e of 19.6 ± 0.5 km when the fireball decelerated to 5.8 ± 0.5 km/s. The slope of the trajectory was extremely steep - the zenith distance of the radiant was only of about 10° and the difference between the beginning and the terminal height was 18.6 km.

Table 2: Atmospheric trajectory data

	Beginning	Maximum	Terminal
V (km/s)	14.3 ± 0.5	13.1 ± 0.5	5.8 ± 0.5
H (km)	38.2 ± 0.5	35.0 ± 0.5	19.6 ± 0.5
Abs. mag.	-	- 20.7	-

Table 3: Radiant data

Radiant (J2000.0)	Observed	Geocentric	Helio-Centric
α_R (deg)	221.83 ± 2.1	219.52 ± 2.1	-
δ_R (deg)	+32.40 ± 2.1	+30.95 ± 2.1	-
v_∞ (km/s)	16.0	11.6	38.5

Table 4: Obital data

Orbit (J2000.0)	
Semimajor axis (AU)	3.32
Eccentricity	0.694
Perihelion distance (AU)	1.015
Aphelion distance (AU)	5.624
Argument of perihelion (deg)	176.76.
Ascending node (deg)	119.709
Inclination (deg)	11.95°

The brightest flare was near the beginning of the trajectory at the height H_{max} = 35.0 ± 0.5 km when the first break-up must have occurred under an aerodynamic pressure P_{dyn} of about 1.5 MPa. At the heights of other two small flares the aerodynamic pressure was 2.9 MPa and 3.1 MPa respectively. The apparent radiant was in Bootes, which suggests that the bolide belongs to the J.Bootid meteor shower.

On the seismogram of the analogue seismic station «Hissar», located on the distance about 45 km from the epicentre of event, the weak signal which has arrived in a time interval corresponding to event of fireball has been registered. On July, 23rd, 2008 one five more digital stations «Chujangaron», «Gesan», «Igron», «Garm» and «Shaartus» was operated (Table 5). On the seismogramms of four digital seismic stations «Chujangaron», «Gesan», «Igron» and «Garm» the registration of the seismic signals which are corresponding to the moment of the flight of fireball has been found out

(Konovalova et al. 2011). As a result of the processing of seismic data some types of waves the most visible at the stations which are located more closely to the trajectory of the fireball have been identified.

Table 5: List of seismic stations.

Station	Latitude (°N)	Longitude (°E)	Altitude (m)
Garm	39.00	70.3160	1 305
Gesan	39.2833	67.7155	1 485
Igron	38.2203	69.3266	1 284
Chujangaron	38.6569	69.1582	1 049

For each station the arrival time of various types of the waves generated by the explosion of bolide and distance to the projection of the fireball's trajectory to a terrestrial surface where there was an explosion is defined (Table 6).

Table 6. Arrival time of various types of the waves

Station	Arrival time of seismic wave, u. m. s.	Arrival time of acoustic wave, u. m. s.
Garm	14:46:37.2796	14:50:01.1137
Gesan	14:44:31.5979	14:48:58.8562
Igron	14:45:26.0877	14:48:53.5208
Chujangaron	14:44:12.1039	14:48:14.8369

Using the amplitude of the registered seismic signal has been defined that the seismic energy generated by the explosion of fireball corresponds to the energy of earthquake with a power class 8.5, that is magnitude M = 2.5 (without filter application).

Conclusion

In order to obtain an accurate orbit, it is necessary for the fireball to be observed from multiple stations. In spite of the presence of only two records of the 23 July, 2008 fireball, the resulting data have a good accuracy. On the basis of this data we can conclude that the superbolide of July 23, 2008 was sufficience large and exhibiting high enough tensile strength to be a good candidate to produce meteorites. The break-up of comet 7P/Pons-Winnecke has probably produced high-strength meteoroids capable to produce meteorites under determinate geometric circumstances.

As a result we can conclude that both the fireball and the meteor streams of cometary origin can include large, m-sized meteorite-dropping bodies. The detailed study of physical and structural properties of this component of interplanetary bodies yields very important information about the sources of meteorites – comets and asteroids, from which they have occurred.

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