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Swarm of fragments from the Tunguska event

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ABSTRACT

The Tunguska event took place on 1908 June 30. It was accompanied by an abnormal effect on the Earth's atmosphere, manifesting itself through 'white nights'. These nights were associated with a dispersion of cosmic matter and the formation of a field of noctilucent clouds with a uniquely large size of over 10 million km^2. However, overall, the cosmic matter was scattered over a territory of around 18 million km^2. The most likely cause of the Tunguska event was the flux of fragments from the broken-up cometary object. The destruction of the cosmic body over Siberia, according to local inhabitants, was marked by numerous sound phenomena. After analysing eyewitness accounts, we can conclude that there were at least two major objects at the Tunguska event. The largest object exploded over the Taiga and caused damage to the forest. In addition, there were several dozen fragments of around 10 m in size, as well as many fragments of a smaller size.

Key words: atmospheric effects – comets: general – comets: individual: Earth.

1 INTRODUCTION

The Tunguska event manifested itself primarily through a powerful influence on the Earth's atmosphere. The atmospheric anomalies were so impressive that they were noted by numerous Russian and European newspapers. Nearly a hundred articles about bright nights, unusually colourful sunsets, and a variety about solar haloes were published in 1908 alone. Catalogues describing the glow of 1908 are contained in the works (Shönrock 1908; Whipple 1934; Zotkin 1961; Vasiliev et al. 1965). As soon as the scientific world learned about a cosmic object that exploded on 1908 June 30 near the Podkamennaya Tunguska River, an assumption arose that these events were closely related (Apostolov 1926; Kulik 1926; Whipple 1934; Fesenkov 1968).

It was suggested that the glow was associated with dust in the atmosphere and the reflection of sun light from noctilucent clouds, a field of which formed over Europe as well as partly over Russia and had a size of 10 million km^2 (Shönrock 1908; Zotkin 1961; Fesenkov 1966; Romejko1991). Fesenkov suggested that a cloud of small fragments, that is to say the tail of a comet, entered the Earth's atmosphere simultaneously with a large object. Bronshten (1991) supported this hypothesis and calculated the movement of the small fragments entered into the atmosphere at small angles in relation to the Earth's surface. According to his model, dust particles are affected by attraction to the Earth and collisions with atmospheric components (molecules and atoms). As a result of these collisions, the dust fragments are broken up and heated. The transfer of dust particles across the rarefied upper atmosphere makes it possible to explain the spread of a dust cloud across large distances to the west from the entry point of the Tunguska cosmic body into the Earth's atmosphere.

After the collision of the Shoemaker–Levy 9 Comet with Jupiter in 1994, a new hypothesis arose explaining the anomalous state of the Earth's atmosphere after the Tunguska event. As a result of the explosion of the Shoemaker–Levy comet in Jupiter's atmosphere, a backward ejection of matter (plume) was observed from the depth of the explosion to the upper atmosphere. The light nights observed in Europe and Asia after the Tunguska catastrophe were, as part of this hypothesis, associated with the collapsing plume, which rose hundreds of kilometres up from the ground (Boslough & Crawford 1997).

Here, we show that the Tunguska event is most likely associated with a swarm of fragments.

2 SWARM OF FRAGMENTS

2.1 The basis for the hypothesis

It was hypothesized that the Tunguska event was a collision of an extinct fragment of the nucleus of the Encke Comet with the Earth (Zotkin 1969; Kresak 1978; Bronshten & Zotkin 1995). The Encke Comet is a comet of the Jupiter family with an orbital period of about 3.3 yr. It is assumed that the Encke Comet and the Taurids Meteor Shower are the remnants of a much larger comet, which broke up 20 000–30 000 yr ago. The Taurids Meteor Shower occurs between June 5 and July 18, with its peak on June 29. We recall that the Tunguska event occurred on 1908 June 30.

However, it is possible that the parent body of the Tunguska object had no relationship with the Encke Comet and the Taurids

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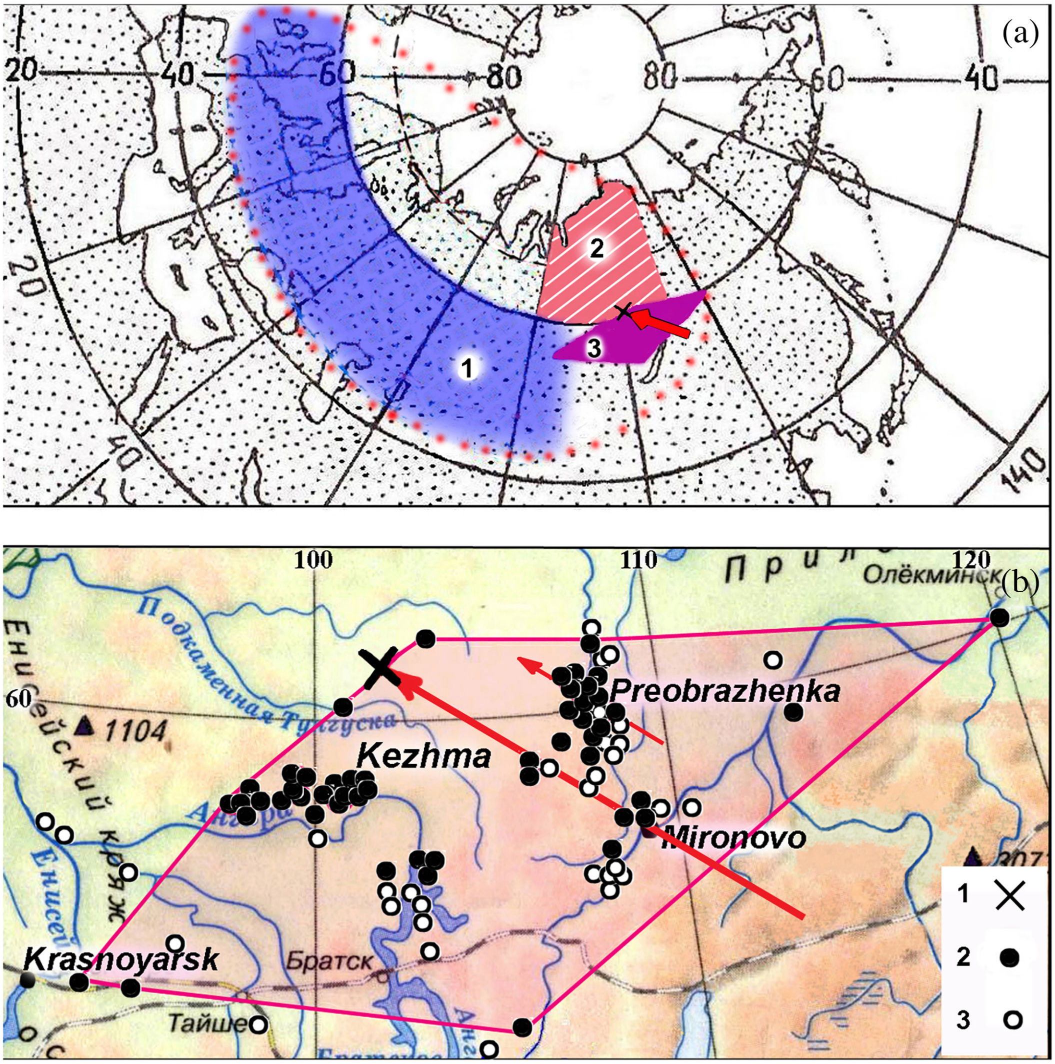

Figure 1. The territory, where the substance of the Tunguska cosmic object was dispersed. (a) X – the epicentre of the Tunguska disaster; arrow – the direction of the object's flight; the dotted line – the boundary of the territory where the substance was scattered; (1) zone with an anomalous glow in the atmosphere (field of noctilucent clouds); (2) zone of accelerated tree growth (Kasatkina & Shumilov 2007); (3) area which noted sound effects. (b) Area which noted sound effects. Arrows – trajectories of object's fragments with an azimuth of $A = 300°$; (1) epicentre; (2) settlements, residents of which noted that the flight of the object was accompanied by a sound; (3) places where eyewitnesses did not hear a sound.

Meteor Shower. Jopek et al. (2007) showed that at least a dozen comets moved in orbits close to the orbit of the Tunguska cosmic body.

2.2 The area over which the matter was scattered

The territory over which the substance of the Tunguska cosmic object was scattered (Fig. 1) can be determined from the following considerations. First, this territory includes an area of atmospheric anomalies. The area where light nights were observed stretched from the Siberian cities of Yeniseysk and Krasnoyarsk all the way to the United Kingdom. The northern border of this area merged with the border where the 'white nights' were observed ($\geq 59°$ N). The 'white nights' refer to a natural phenomenon over the northern latitudes, where darkness does not come at night and instead, dusk lasts from sunset to sunrise. The southern border reached Tashkent and the Black Sea, in some places as far south as $\sim 42°$ N (Whipple 1930; Zotkin 1961; Fesenkov 1968). In this case, the light night spanned a vast territory stretching from $-10°$ to $90°$ E and from $42–47°$ to $60–80°$ N. It should be noted that longitude $-10°$ E corresponds to the coast of the Atlantic Ocean, and it can be assumed that the boundary of light nights was further into the ocean.

Secondly, Kasatkina & Shumilov (2007) determined that the substance of the Tunguska cosmic body that fell on to the ground had an influence on the vegetation. A zone of accelerated tree growth extends to a distance of >1500 km north of the epicentre of the Tunguska disaster and has an area of about 2 million km^2.

Thirdly, there is a zone where strong acoustic phenomena were noted across a large distance between the Yenisei and Lena Rivers and Lake Baikal. This zone has an area of over 1 million km^2. Following the initial reports of the Tunguska disaster, the director of the Irkutsk Magnetic and Meteorological Observatory A.V. Voznesensky (1925) interviewed more than six dozen people who personally observed this phenomenon. He concluded: 'We are most likely dealing with a group of meteorites that were flying in the same direction and gradually exploded. But the very fact that there were tremors noted by the seismograph in Irkutsk and the barograph in Kierensk suggests that a very significant mass fell simultaneously to the ground.'

2.3 Sound effects of the Tunguska event

Kulik (1927) first noted peculiarities in the distribution of sound effects similar to thunder strikes or gunfire. According to him, local residents across a vast territory (with a radius of more than 600 km) were sure that the object fell somewhere nearby 'behind the grove, beyond the outskirts, in the forest outside the village.' Kulik decided that the illusion of a nearby impact was caused by the fact that the destruction of the large cosmic object was accompanied by powerful sound and light phenomena.

However, it is known that sound propagating through the air is transformed, and the human ear is able to separate a close thunderbolt or gun shot from distant peals, especially when we refer to distances of hundreds of kilometres. Sound propagation in the atmosphere has a number of features. The absorption of sound waves depends on the thermal conductivity, viscosity, pressure, and relative humidity of the air. Humidity is one of the largest sound absorbers. The higher the frequency of the sound, the stronger it is absorbed. As a result, sounds that are sharp in the vicinity of shots or explosions become deaf at large distances. Thus, it can be assumed that people heard sounds from many different close explosions. The catalogue by Vasiliev et al. (1981) contains 700 eyewitness accounts of the Tunguska disaster. These stories of Siberia inhabitants reflect different aspects of the Tunguska event. However, every 10th message claims that the flight of a cosmic body was accompanied by sound.

The most unusual in these observations was that more than three dozen eyewitnesses from those interviewed noted that the sound preceded the appearance of the object or came alongside it (see supplement). A flying object was sighted by inhabitants after they heard the sound. In a number of places, eyewitnesses ran out to the sound from enclosed spaces and noticed a flying object in the sky (Krinov 1949, 1966). It goes without saying that neither sound nor shock waves from an object flying at interplanetary speed at high altitude could form sounds near the Earth's surface. It can be assumed that these sounds were associated with explosions near the Earth's surface of other cometary fragments, which arrived before the main object.

It is important to note that the settlements in which sound was detected during the flight of the object are adjacent to places where no sound was heard (Fig. 1b). This is evidence of the locality of sound effects and does not contradict the fact that the sound was generated by explosions of individual fragments.

2.4 The multiplicity of objects

Another confirmation of the plurality of objects that entered into the dense layers of the atmosphere is the eyewitness stories. In a number of cases, residents observed the movement of several objects following one after another ('a broom flew, then a sheaf flew') or several flying bodies of different sizes ('as large as a house, and nearby – the size of a barrel'; Vasiliev et al. 1981).

The points at which the flying object crossed the Siberian Rivers of Lena and Nizhnyaya Tunguska were determined based on eyewitness surveys. These are the settlements of Mironovo (Epictetova 1976) and Preobrazhenka (Tsvetkov & Boyarkina 1966; Konenkin 1967), respectively. Konenkin calculated the azimuth of the object's movement over the Nizhnyaya Tunguska near the village of Preobrazhenka. This azimuth was equal to $A = 300°$. In turn, the azimuth $A = 300°$ connects the settlement of Mironovo with the epicentre of the explosion (Fig. 1b).

The trajectory of the Tunguska cosmic body could not have been rectilinear if we were dealing with one object. In the case of multiple objects, we have to conclude that two different fragments of the cosmic body flew over Preobrazhenka and Mironovo. It can be assumed that the object flying over Preobrazhenka was inferior in size to the main fragment, since its destruction did not have catastrophic consequences.

3 MODELLING

At this point, we will not consider the interaction of the main body with the atmosphere, it was done in Gladysheva (2020). We only calculate the movement of fragments. We can only speculate as to the size of the fragments that preceded the largest object. Therefore, let us consider that the cometary fragments of 3 and 10 m in radius interacted with the atmosphere.

3.1 Modelling the movement of fragments in the atmosphere

We used the basic equations for calculating the motion of cosmic bodies in the atmosphere (Bronshten 1983; Chyba et al. 1993; Lyne *et al.* 1998):

$$\frac{dM}{dt} = -\frac{1}{2}\frac{C_H \rho_a A V^3}{\varsigma},$$

$$\frac{dV}{dt} = -\frac{C_D \rho_a A V^2}{M} + g\,\sin\alpha,$$

$$\frac{dZ}{dt} = -V\,\sin\alpha,$$

where M, V, Z, and t are mass, speed, altitude, and time; C_H and C_D are dimensionless coefficients of heat transfer and aerodynamic resistance. The heat transfer coefficient is $C_H \approx 0.1$ (Bronshten 1983). $C_D = \text{const} \sim 1$ for an object with a spherical shape; ρ_a is the atmospheric density; $A = \pi \cdot R^2$ is the area of the object's mid-section, where R is its radius; $\boldsymbol{\zeta}$ is effective heat of destruction for the comet; g is acceleration of gravity; α is angle of flight path measured from the horizon.

The most probable trajectory of the Tunguska cosmic body is with having an inclination angle of $\alpha = 20°$ (Gladysheva & Skorodumov 2014). We can take the density of the object as 500 kg m^{-3}. We can also choose a speed of entry into the dense layers of the atmosphere of 20 and 30 km s^{-1}. The main object with a speed of 20 and 30 km s^{-1} will disintegrate at the altitude of ~10 km, if the effective heat of destruction of the comet's substance is $\boldsymbol{\zeta} = 1 \times 10^6$ J kg^{-1} and 2.5×10^6 J kg^{-1}, respectively (Gladysheva 2020).

3.2 The results of the calculations

Changes in the object's mass (M) with altitude, the distribution of ejected mass (ΔM) over the altitude and the change in the speed of the object (V) as a function of time are shown in Figs 2 and 3. It can be seen that in all cases the amount of ejected substance has a distinct maximum (Figs 2b and 3b). Fragments of 10 m in radius are almost completely destroyed at an altitude of 30 km, and those of 3 m in radius at an altitude of ~40 km. The value of speed at the time of object's destruction decreased by less than 16 per cent of the initial speed.

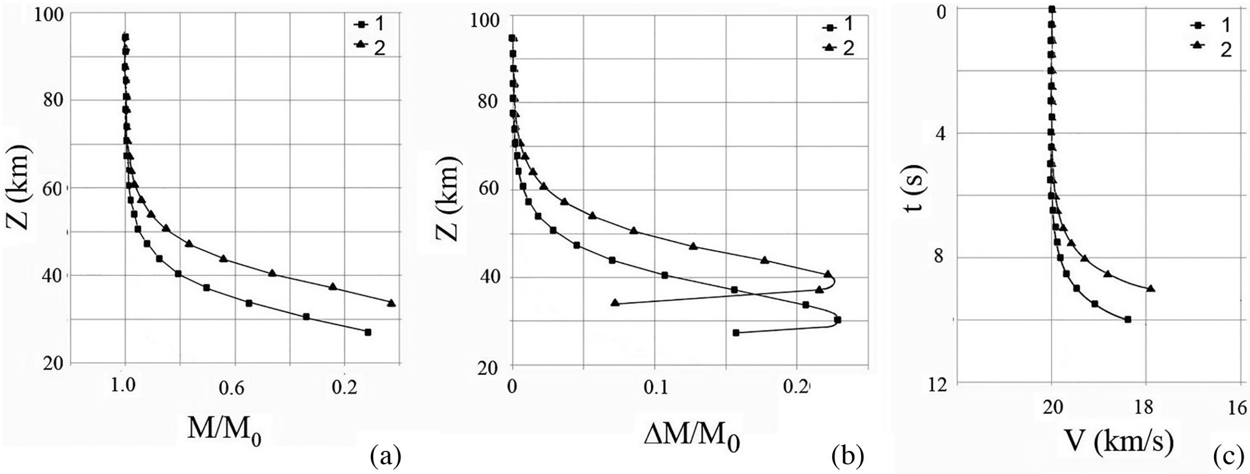

Figure 2. Interaction of cometary fragments with a radius of 10 m (1) and 3 m (2) at a density of 500 kg m^{-3} with the Earth's atmosphere. The entry speed is 20 km s^{-1}. The effective heat of destruction is $\zeta = 1 \times 10^6$ J kg^{-1}. (a) Change in the mass with altitude; (b) mass-loss depending on altitude; (c) a change in speed over time.

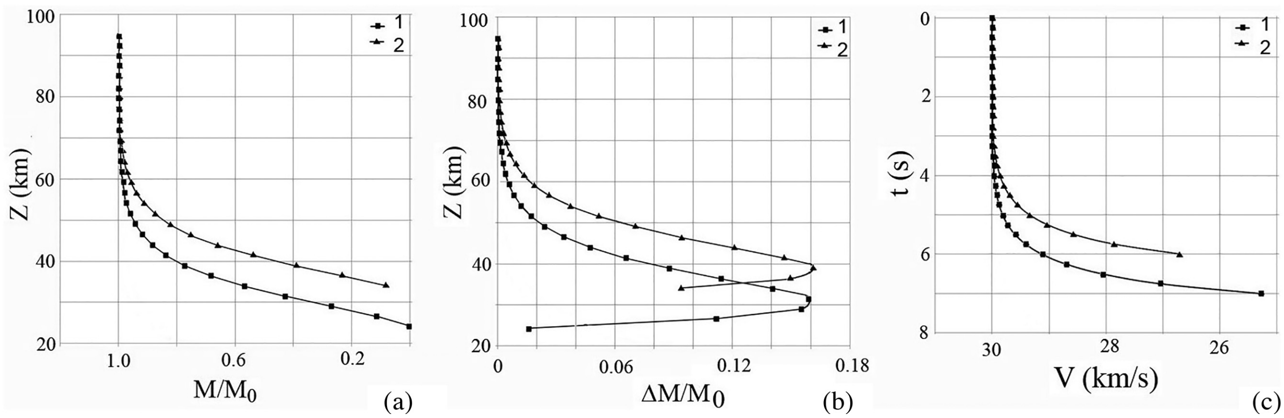

Figure 3. Interaction of cometary fragments with a radius of 10 m (1) and 3 m (2) at a density of 500 kg m^{-3} with the Earth's atmosphere. The entry speed is 30 km s^{-1}. The effective heat of destruction is $\zeta = 2.5 \times 10^6$ J kg^{-1}. (a) Change in the mass with altitude; (b) mass-loss depending on altitude; (c) a change in speed over time.

As shown above, fragments of 3–10 m in radius will disintegrate at an altitude of 30–40 km, where they will still have significant speed. Consequently, the destruction of these objects will be accompanied by sound effects similar to those observed during the explosion of the Chelyabinsk cosmic object, which disintegrated at an altitude of 30 km. It is known that the sound of explosions in the Earth's atmosphere at altitudes less than 50 km will reach ground level. This means that local residents will have heard these sounds and this fact can explain the variations in the eyewitness accounts shown in Fig. 1(b).

4 DISCUSSION

The Tunguska event was accompanied by specific sound effects noted by Voznesenky (1925) and Kulik (1927). Most likely, the Tunguska object approached the Earth's atmosphere surrounded by numerous fragments of different sizes. The smallest fragments slowed down at altitudes of 80–90 km (where meteors usually burn up) and formed a large field of noctilucent clouds. Large fragments of ≥10 m in size penetrated deep into the Earth's atmosphere, and local residents heard when they exploded. There is reason to believe that the Tunguska cosmic body can be attributed to comets, classified as split comets. This is consistent with the hypothesis that the Tunguska cosmic body had common origins with the Encke Comet, and that it belongs to the comets of the Jupiter family. The question of which object was moving from the Sun to the Earth remains open. It could be a swarm of fragments of different sizes or one extinct fragment from the nucleus of the Encke Comet, as Kresak (1978) claimed. In the latter case, the object exploded even before entering the Earth's atmosphere.

Sound effects noted by eyewitnesses allow us to assume that a significant part of the larger fragments approached the Earth's surface much earlier than the main object. The first thunder-like sounds, according to Naumenko (1941) (see supplement), were heard when the main object was projected in the Sun. The calculations show that, at this moment, the main object was visible at an altitude of approximately 80 km. Given the speed of the propagation of sound waves, it can be calculated that the destruction of fragments happened ahead of the destruction of the main object by at least 30–60 s.

We can assume that the main object was in the centre of the swarm of fragments. Taking into account the size of the region where the cosmic substance was dispersed (Fig. 1), we can see that the larger fragments were located at a distance of up to 1000 km from the main object. The small particles that led to the observation of 'white nights' were scattered across a zone ∼3000 km wide. The movement of smaller particles towards Europe fits into Bronshten's model (1991) in which particles are capable of moving over a long distance in a rarefied atmosphere.

The hypothesis put forward by Boslough & Crawford (1997) that the 'white nights' over Europe and Asia were associated with the plume of matter raises serious doubts. It does not explain how the substance ejected in a south-easterly direction moved ∼6000 km to the north-west inside a strip of up to 3000 km in width. The territory over which the cosmic matter was scattered is about 1.8×10^7 km^2 and only the entry of a swarm of comet fragments can satisfactorily explain the scattering of matter over such a large area.

5 CONCLUSION

Analysis of eyewitness observations near the epicentre suggests that the object which exploded over the Taiga was accompanied by many fragments of different sizes. The maximal object in the swarm of fragments was ∼100 m in size. Furthermore, there was at least one object a little inferior in size, with several tens of objects of 10 m in size and many smaller fragments.

It is most likely that this swarm of fragments was the result of the breaking up of a cometary object. The break-up of this object should have occurred much earlier than the entry of the cosmic body into the Earth's atmosphere. Thus, we can conclude that the Tunguska cosmic body was a split comet. It is highly likely that this object belonged to the comets of the Jupiter family and had the same properties as the Encke Comet.

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SUPPORTING INFORMATION

Supplementary data are available at *MNRAS* online.

Supplementary appendix.pdf

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