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A. V. ZOLOTOV

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Abstract

Full Text

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NEW DATA ON THE TUNGUSKA CATASTROPHE OF 1908

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This article presents some new data on the Tunguska catastrophe, obtained by us in the summer of 1959.

1. The most characteristic feature of the destruction in the taiga produced by the explosion of the Tunguska cosmic body on June 30, 1908, is the radial character of the forest fall, with a practically single center located in the region of the Southern Swamp. The area of continuous forest fall extends to a distance of up to 20–22 km from the epicenter of the explosion (*1, 2*). Comparison with experimental data on large explosions (*3, 4*) shows that such a forest fall can be produced by an explosion with a total energy of about $4 \cdot 10^{23}$ ergs, which corresponds to a TNT equivalent of about 10 million tons.

Fig. 1. Map of the region of the Tunguska catastrophe of 1908 (boundaries of the forest fall are shown according to K. P. Florensky). *1* —projection of the trajectory of the cosmic body (according to E. L. Krinov), *2* —front of the blast wave, *3* —front of the ballistic wave, *4* —tree with broken branches, *5, 6* —direction of photographing of the tree, *7* —zone of dry standing trees, *8* —boundary of continuous forest fall, *9* —boundary of appreciable forest fall, *10* —Kulik' s road.

2. One of the interesting facts of the Tunguska catastrophe is the presence of standing forest in the epicenter of the explosion, about 10 km in diameter (*1, 2*). The presence of standing forest, preserved on the root at a distance of up to 5 km from the epicenter of the explosion, indicates that the explosion of the cosmic body occurred in the air at a height of several kilometers (not less than 5 km) (*3, 4*).

3. In the case of an explosion in the air of a cosmic body, its velocity can be determined from several indications: 1) from the ratio of the amplitudes of the ballistic and blast waves at a given point in space relative to the

Fig. 2

Figure 2: Fig. 2

flight trajectory of this body; 2) from the brightness and temperature (before the explosion) of the flying fiery body—the bolide. Let us estimate the upper value of the velocity of the Tunguska cosmic body from these indications.

1) It proved possible to estimate the ratio of the amplitudes of the blast and ballistic waves from the character of the breaking-off of branches on trees that had remained standing at the boundary of the forest fall. For this purpose it proved convenient to choose points in directions from the epicenter close to the flight trajectory of the body (the south-east sector), since in these directions the ballistic wave should have manifested itself most strongly (Fig. 1). In contrast to po-

of a felled tree, on a tree that remained standing on its root after the catastrophe traces of the action of both waves have been preserved, regardless of the sequence of their action. As an example, Fig. 2 shows a tree standing at a distance of 21 km south of the epicenter of the explosion. This tree, 300–400 years old and 35–40 m high, is a witness to the interaction of both waves. In Fig. 2a the tree was photographed in the north-to-south direction, i.e., in the direction of motion of the blast wave. In Fig. 2b the same tree was photographed in the west-to-east direction, i.e., approximately along

Fig. 2

the direction of motion of the ballistic wave at this point. These photographs show quite clearly the direction of action of the wave at this place from north to south, i.e., in the direction of the blast wave, and the absence of any noticeable action of the ballistic wave. The blast wave broke off all the lateral boughs of the tree; only some boughs remained, directed forward and backward along the direction of motion of the wave, whereas the ballistic wave did not break off even thin lateral boughs (relative to the direction of its motion). It follows from this that at this place the amplitude of the ballistic wave is substantially smaller than the amplitude of the blast wave. The destruction at this place was produced essentially only by the blast wave.

From experimental data on large explosions it is known that the excess pressure at the front of the shock wave that fells trees is about 0.1 kg/cm^2 ([3,4]). To break off even thick branches of a tree, a shock wave with an excess pressure of no more than 0.03-0.5 kg/cm^2 is sufficient. Since the ballistic wave did not break off even very thin boughs (Fig. 2b), the excess pressure of the ballistic wave at this place, at a distance of about 20 km from the flight trajectory of the body, does not exceed 0.01-0.02 kg/cm^2. Having determined the pressure at the front of the ballistic wave for known distance and size of the body, one can also estimate the speed of the moving body. To determine the upper limit of the speed in our case, let us take the smallest assumed dimensions of the body, $r = 20$ m (5) (for simplicity of calculation we shall assume the body to have the shape of a sphere). Then, according to G. I. Pokrovskii' s formula,

$$\Delta p = 0.0114 \sqrt[3]{\frac{c_x}{2} \frac{\rho v^2 S}{R^2}}, \tag{1}$$

valid in the range of pressure variation: $0.01 \leq \Delta p \leq 0.1$ kg/cm^2 ($c_x = 4$ is the drag coefficient, $\rho = 0.127$ TEM/m^3 is the air density in technical units, S is the cross section of the body in m^2) the spee-

the velocity of the body v, at which at a distance $R = 20\,000$ m an excess pressure of the ballistic wave equal to 0.02 kg/cm^2 is produced, will be about 3 km/sec.

With these initial data the velocity of the body, calculated by Landau's formulas (6), has the same order of magnitude.

2) According to eyewitness testimony about the brightness of the bolide, the temperature of the Tunguska body during its flight was no more than 4000 –5000° (the fiery body was paler than the sun, and it was possible to look at it without pain in the eyes (2)). To determine the upper limit of the velocity, let us assume that the temperature of the bolide was equal to the temperature of the sun, 6000°K.

By the well-known equation of gas dynamics

$$\frac{c_v}{M} T_y = \frac{u_p^2}{2}, \tag{2}$$

where c_v is the heat capacity of the gaseous medium; M is the molecular weight of the gas; T_y is the temperature in the front of the shock wave forming ahead of the flying body; u_p is the velocity of the body; a bolide temperature equal to 6000°K corresponds to a body velocity of about 4 km/sec.

A comparison of the brightnesses of the Tunguska and Sikhote-Alin bolides (2,7,8) shows that the final velocity of the Tunguska cosmic body was less than the flight velocity of the Sikhote-Alin meteorite, i.e., less than 3 km/sec. Finally, the obtained velocity is also consistent with other observations of eyewitnesses who simultaneously heard sound shocks and saw the flying fiery body, which is possible only when the velocity of the body is comparable with the speed of sound; especially noteworthy is the testimony of eyewitnesses who heard a noise while indoors, then ran out into the street and only then saw the flying body (2).

Thus, it follows from these data that the final velocity of the Tunguska cosmic body did not exceed 3–4 km/sec. In this case an explosion of the Tunguska body in the air due to the conversion of its kinetic energy into heat is impossible, since even upon impact with the ground a body explodes only at a velocity of about 5 km/sec (8). Hence, apparently, it may be concluded that the Tunguska cosmic body exploded for another reason, i.e., at the expense of internal energy.

4. The magnitude of the energy of light radiation of the Tunguska explosion is an important parameter that will help clarify the nature of the explosion. From the fraction of light energy in the total energy of the explosion there is a fundamental possibility of determining the initial temperature of the explosion region and the thermal effect of the explosive transformation.

In our case the light energy of the Tunguska explosion E_c was determined from the magnitude of the light impulse I_c at the moment of the explosion:

$$E_c = \frac{I_c \cdot 4\pi R^2}{e^{-\mu(R-r)}}, \tag{3}$$

where R is the distance from the point of the explosion, r is the mean radius of the luminous region, μ is the coefficient of absorption of light in the atmosphere. Taking into account that on June 30, 1908, in the region of the Tunguska catastrophe it was a clear and cloudless day (2), and that the explosion occurred at a great height (not less than 5 km), which favors the propagation of light, in calculating E_c the limiting visibility range for real air was taken as about 120 km (3). At such a visibility range the coefficient of absorption of light in air will be $\mu = 0.033$ km^{-1} (3). Let us estimate the lower value of the light energy of the Tunguska explosion, based on three facts: 1) scorching of trees, $R = 17$ km; 2) eyewitness testimony of the explosion at the Vanavara trading post, $R = 65$ km; 3) eyewitness testimony of the explosion in the village of Kezhma, $R = 200$ km.

Estimate 1. At a distance of 15–16 km from the epicenter (17–18 km from the point of explosion), near the boundary of the scorch zone, we discovered scorching of trees.

with ignition. The ignition of a growing tree (fresh boards) occurs from a light impulse of 60-100 cal/cm^2 (4). Taking into account the dark color of the wood, we shall take the lower value of the impulse, i.e., 60 cal/cm^2. Then, according to formula (3), the light energy of the explosion will be equal to: $E_c = 1.5 \cdot 10^{23}$ erg.

Estimate 2. An eyewitness of the explosion at the Vanavara trading post, S. B. Semenov, related that at the moment of the explosion he became as hot as if his shirt had caught fire; he wanted to tear it off and throw it away (2). The eyewitness P. P. Kosolapov said that his ears were so badly burned that he grabbed them and sat down on the ground, thinking that the roof had caught fire (2). Although these testimonies also contain a psychological element, they can be converted into numerical data. It follows from them that the burn of human skin (in Vanavara) was close to a first-degree burn, which arises at a light impulse of 2-4 cal/cm^2 (4). According to literature data, slight pain is felt when the human body is exposed for one second to a light impulse of 0.3 cal/cm^2, which corresponds to a value of the total light impulse of the explosion of about 0.6 cal/cm^2, since more than 90% of the radiation of the glowing cloud of a large explosion is emitted within 2 sec. (^{4}). Thus, the value of the light impulse from the Tunguska explosion at the Vanavara trading post was no less than 0.6 cal/cm^2 and no more than 2 cal/cm^2. For the calculation we shall take the lower value of the light impulse, 0.6 cal/cm^2. Then the light energy of the explosion will be equal to: $E_c = 1.1 \cdot 10^{23}$ erg.

Estimate 3. Eyewitnesses of the explosion in the village of Kezhma, at a distance of about 200 km from the epicenter, note a strong light flash at the time of the explosion, which formed secondary shadows in rooms whose windows faced north (^{2}). It follows from this that in the village of Kezhma the illumination from the explosion was comparable with the illumination of daylight. At 7 o' clock in the morning in June at this latitude (60°), the daylight flux is about 0.0015 cal/cm^2 • sec. Evidently, the light impulse of the explosion must have been no less than 0.001 cal/cm^2 • sec for the reflection of the explosion to be noticeable in a room. Then the total light impulse of the explosion will be about 0.002 cal/cm^2. In this case the energy of the explosion will be equal to: $E_c = 2.8 \cdot 10^{23}$ erg.

Thus, all three independent estimates have yielded quite satisfactory agreement. Therefore we may consider that the energy of the light radiation of the Tunguska explosion is, in order of magnitude, equal to $(1.1—2.8) \cdot 10^{23}$ erg, which constitutes several tens of percent of the total energy of the explosion.

From this follows an interesting conclusion: the ratio of the light energy of the Tunguska explosion to its total energy is of the same order as in a nuclear explosion (i.e., about 30% (^{3}, ^{4})).

Volga-Ural Branch
of the All-Union Scientific Research Institute
of Geophysical Prospecting Methods
Oktyabrsky

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Note: Figure translations are in progress. See original paper for figures.

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