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Cometary nature of the 1908 Tunguska cosmic body

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Abstract. The cometary nature of the 1908 Tunguska cosmic body is compatible with the predictions of an analytical theory of the 1908 Tunguska explosion developed in 1976–1979. The theory takes into account the three simultaneously occurring processes, namely aerodynamic destruction of the cosmic body in the Earth's atmosphere, transversal expansion of the crushed mass under the action of pressure gradient on the frontal surface of the body, and an aerodynamic deceleration of crushed expanding mass. The use, for the mechanical parameters of the Tunguska cosmic body, of the characteristics of a cometary nuclei such as that of comet Halley 1986 III and comet Shoemaker – Levy 9 1994, gives parameters of the Tunguska explosion derived from observations of Tunguska event in the Siberian taiga in 1908.

Keywords. comets: general; flares: comet nuclei, planetary atmospheres, aerodynamic destruction, transversal expansion, Tunguska explosion

1. Introduction

The nature of the Tunguska explosion occurred in Siberian taiga, Russia, on June 30, 1908, that produced catastrophic destruction in the taiga, remained mysterious during many decades, and scientific investigations were carried out to accumulate data on the parameters of this event. The estimation of the initial mass of the exploded cosmic body M_o made on the basis of observations of reduction of solar radiation due to atmospheric opacity in California, USA, is of the order of 10^6 tons (Fesenkov 1949). From the analysis of crushing the taiga, the derived energy of explosion was of the order of $E_e = 4x10^{24}$ erg or 10 megatons in TNT equivalent, i.e., 1000 times the energy of the Hiroshima atomic explosion. The geocentric velocity of the bolide being considered as a fragment of comet Encke, is about 30 km/s, the inclination angle of his flight trajectory to the horizon is $\alpha = 30 - 45^o$, the altitude of explosion of the bolide above the Earth's surface is estimated as $h_e = 5 - 10$ km (Korobeinikov *et al.* 1991, and references therein).

2. Analytical theories of explosion of Tunguska cosmic body

The hypothesis of the Tunguska body as a cosmic body of anomaly small density (less than 0.01 g/cm^3), for which the generation of a strong shock wave above the Earth's surface becomes possible due to the sharp aerodynamic deceleration of the evaporating body and the fully dissipation of its large initial kinetic energy in the atmosphere, was theoretically considered in 1975. However, the theory was not applicable because of unacceptability of the starting hypothesis on the extremely low density of cosmic body (Petrov & Stulov 1975; Grigorian 1979; Surdin *et al.* 1982).

An analytical theory of the Tunguska explosion, taking into account an aerodynamic destruction of cosmic body, transverse expansion of the crushed mass under the action of pressure gradient on the frontal surface of the body and aerodynamic deceleration of the fragmented flattened expanding hypervelocity mass, was developed by Grigorian (1976, 1979).

The theory was used, applying numerical methods of integration and mathematical modeling, also for a quantitative estimation of events, occurring at the entry of fragments of the nucleus of comet Shoemaker-Levy 9 into the atmosphere of Jupiter on July 16-22, 1994 (Grigorian 1994; Fortov *et al.* 1996).

In 2008 we modified the theory of Grigorian (1979) to find the law of variation of the kinetic energy of the fragmented mass in the explosion zone in an explicit form, that is necessary for deriving the position of the point of maximal deceleration - maximal energy release, and solving thus the problem of analytically finding the altitude and other parameters of "explosion" of cosmic bodies like cometary nuclei, having usually small density and material strength, in the atmospheres of planets (Ibadov *et al.* 2008a).

The solution of the above problem is of interest also to investigate explosion of sungrazing comets in the atmosphere of the Sun and comet-like bodies, as well as stargrazers, in the atmospheres of young stars in order to study flare mechanisms of such stellar objects (Ibadov 2007; 2008b).

3. Nature of the Tunguska cosmic body

The basic parameter of the Tunguska event, the altitude of "explosion" of bolide in the Earth's atmosphere where the maximal energy release due to sharp aerodynamic deceleration of the crushed and transversally expanding mass occurs, is determined as

$$z_m = z_e = z_* - H \ln\left(1 + \frac{\sqrt{3C_x}C}{2b}\right) = H \ln\left(\frac{\rho_o V_o^2}{(1+\frac{\sqrt{3C_x}C}{2b})\sigma_*}\right) = H \ln\left(\frac{2b\rho_o V_o^2}{\sqrt{3C_x}C\sigma_*}\right), \tag{3.1}$$

where

$$z_* = H \ln\left[\left(\frac{\rho_o V_o^2}{\sigma_*}\right)\right], \quad b = \nu \exp\left(-\frac{z_*}{H}\right), \tag{3.2}$$

$$\nu = \frac{3C_x \rho_o H}{4\rho_b R_o \sin\alpha}, \quad C = \left(\frac{3C_x R_o \sin\alpha}{8H}\right)^{1/2}; \tag{3.3}$$

z_* is the altitude corresponding to the onset of the cosmic body aerodynamic destruction in the Earth's atmosphere, H is the height scale of the atmosphere, R_o is the body initial radius, V_o is the initial entry velocity of the body to the atmosphere, ρ_b and σ_* are the density and mechanical strength of the body material.

Assuming for the Tunguska cosmic body $M_o = 4x10^{12} g$ (Fesenkov 1949), $\rho_b = 1$ g/cm^3 (Marov 1994) and $R_o = 10^4$ cm, $V_o = 3x10^6$ cm/s, $\alpha = 30^0$, $\sigma_* = 10^7$ dynes/cm^2, $C_x = 1$, $\rho_o = 1.3x10^{-3}$ g/cm^3, $H = 7x10^5$ cm according to (1), (3.2) and (3.3) we obtain $\nu = 0.14$, $b = 1.2x10^{-4}$, $C = 5.1x10^{-2}$, $z_* = 48.3x10^5$ cm $= 48.3$ km, $z_m = 7.3x10^5$ cm $= 7.3$ km.

It should be noted that the theoretical values of "explosion" altitude of the cosmic body z_m, computed with (1) will correspond to the altitude of explosion h_e obtained from observations of the Tunguska phenomenon as well as to the mass and the radius of the cosmic body M_o and R_o of the order of 10^{12} g and 100 m, respectively, to the initial kinetic energy of the body E_o in the range of $10^{24} - 10^{25}$ erg in the case if the density of the body is $\rho_b = 0.5 - 1$ g/cm^3.

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The obtained density of the exploded Tunguska cosmic body is characteristic for the density of nuclei of comets (Reinhard 1986; Sagdeev 1986; Fortov *et al.* 1996).

4. Conclusions

The theory of aerodynamic destruction of cosmic bodies and transversal expansion of fragmented mass in the Earth's atmosphere can adequately explain the 1908 Tunguska explosion for mechanical parameters of the body like those for comet Halley 1986 III and comet Shoemaker – Levy 1994. It indicates, along with data of observations of the phenomena, that the 1908 Tunguska cosmic body had cometary nature.

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