Long–term dynamics of the Tunguska Cosmic Body

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Abstract

We performed a detailed analysis of the large amount of the literature on the Tunguska event in order to determine a useful sample of observed data. Then from a selected range of meaningful atmospheric trajectories, we computed a set of 886 possible TCB (Tunguska Cosmic Body) orbits, which were used to estimate the probabilities of the possible origin of the TCB. According to the obtained results, the probability of an asteroidal origin of the TCB is much higher i.e. 83% than the cometary one i.e. 17%.

1 Introduction

The origin of the body which caused the catastrophe in the Tunguska forest on 1908 June 30^{th} is still unknown. In fact it was only nineteen years later that the first scientific expedition arrived on the site. Though the forest was devastated over $\approx$ 2000 km^2, neither impact crater and nor macroremnant (fragment, splinter...) of the Tunguska cosmic body (TCB) were found. Despite the great number of articles which have been published by many scientists around the world (see the reviews by Krinov 1966, Trayner 1997, Vasilyev 1998, Bronshten 2000) the dilemma between a cometary origin and an asteroidal one of the TCB is yet unsolved.

In this paper we estimate the probabilities of possible origin of the TCB, using dynamical considerations. We first construct a sample of possible TCB orbits, and assume that the TCB might have been placed on any of such orbits. Then by means of the dynamical model elaborated by Bottke et al. (2001) we compute the most probable source for each orbit, thus giving the respective probabilities for an asteroidal or a cometary origin. Previously Andreev (1990) considering a sample of 300 orbits (using the intervals of initial data $95° \leq a_\infty \leq 175°$, $10° \leq h_\infty \leq 35°$,(where a_∞ and h_∞ define respectively the pre–atmospheric azimuth and inclination over the horizon) and the speed $V_\infty = 20 - 40$ km/s found that most of the calculated orbits correspond to Apollo asteroids. Bronshten (1999) performing a similar investigation obtained also a small set of orbits consistent with the cometary hypothesis, while all radiants for geocentric velocity smaller than 30 km/s correspond to Apollo–like asteroids.

However the main novelties of our paper with respect to Andreev's and Bronshten's works are (a) that our sample of orbits is much larger and more robust statistically and (b) by means of the dynamical model of Bottke et al.(2001) we are able to estimate the relative probabilities that the TCB came from an asteroidal or a cometary source, avoiding the use of an arbitrary threshold dicriminating between a cometary and an asteroidal origin.

Table 1: The dynamic parameters of the Tunguska body chosen for the analysis in this paper. In the first column the intervals of the apparent pre–atmospheric radiant coordinates and speed are given. The second column shows the geocentric values, i.e. corrected from the Earth's gravity and motion. Two groups of parameters are selected according to their speed and inclination over the horizon: the first set (I) refers to low inclination and low speed, while the second one (II) to high inclination and high speed.

Time (UTC)		1908 06 30, $00^h 14^m 28^s$	
Location		$60°53^{'}09";N$, $101°53^{'}40";E$	
(I)	azimuth [deg]	$a_\infty \in (97, 127)$	$a_G \in (97.1, 127.6)$
	inclination over the horizon [deg]	$h_\infty \in (3, 5)$	$h_G \in (-25.0, -12.8)$
	velocity [km/s]	$V_\infty \in (14, 16)$	$V_G \in (8.0, 11.2)$
(II)	azimuth [deg]	$a_\infty \in (97, 127)$	$a_G \in (97.1, 127.3)$
	inclination over the horizon (deg)	$h_\infty \in (15, 28)$	$h_G \in (11.8, 25.9)$
	velocity [km/s]	$V_\infty \in (30, 32)$	$V_G \in (27.6, 29.8)$

The remainder of this paper is organized as follows: in section 2 after a short explanation of our choice of the parameters which are needed to construct the sample of orbits, we compute the osculating elements of the possible TCB orbits. In section 3 we first recall briefly the dynamical model which allows us to identify the main sources of Near Earth Objects and then we caculate for a TCB particle placed on each orbit with the osculating elements (a, e, i) (i.e. semi major axis, eccentricity and inclination) the probabilities of its origin from the different sources. The conclusions are presented in section 4.

2 Computation of the initial osculating elements of the TCB orbits

In order to calculate the osculating elements of the possible TCB orbits, we need to know the following parameters of the event: (i) the time of the explosion and the geographic coordinates of the epicentre, (ii) the azimuth and the inclination of the trajectory of the bolide, and finally (iii) its velocity which is related to the height (closely related to the value of the released energy) of the explosion and the physical nature of the bolide. After a detailed analysis of the literature available on the Tunguska event taking into account both the objective data and the eyewitness testimonies, and taking into account the large uncertainties of the observed value of the TCB, we selected the parameters listed in Table I. Moreover we considered two interval values for the speed, covering the possibility that the TCB is either a cometary body or an asteroidal one. Thus, as indicated in Table I two sets of parameters have been selected. From previously well–used criterion based on some velocity threshold, set (I) would correspond to "asteroidal" origin of the TCB, while set (II) would correspond to "cometary " parameters. Before any orbital calculation the apparent pre-atmospheric radiant coordinates a_∞, h_∞, and the speed V_∞ must be corrected for the Earth rotation and gravity attraction (Ceplecha 1987), to obtain the values a_G, h_G, and V_G listed in the second column of Table I.

Using the two sets of data (I) and (II) we define a grid in azimuth, height, and velocity such that the steps are respectively 5°, 0.5°, and 0.5 km/s. In all cases we use the same state vector of the Earth's motion which was calculated using the JPL DE–405 Ephemerids (Standish et al.1997). For more details on the computation of the sample of the orbits, we refer to Farinella et al. (2001). We obtain a sample of

1090 orbits, among which 175 (16 %) have geocentric velocities in the range (14–16 km/s) while 915 (84 %) have geocentric velocities between 30 and 32 km/s, showing that our sample of orbits is in favor of the cometary hypothesis, if we assume that the velocity is a good indicator by itself.

3 Possible origin of the Tunguska Body

Until now in order to find the origin of the TCB an assumed impact velocity threshold has generally been used to distinguish a comet from an asteroid and has served to qualify the orbit.

Recently Bottke et al. (2000, 2001) have created a steady state model of the orbital distribution of the NEO population. To construct their model, the authors first performed numerical integrations of several thousands of test particles over millions of years, initially located in or/and near the main identified sources of NEOs, namely the $3:1$ mean motion resonance with Jupiter, the ν_6 secular resonance , the Mars –crosser asteroids (MC), the outer main belt (OB) and the Jupiter Family comets(JFC). Then the particles which enter the NEO region are tracked through a network of cells in the (a, e, i) space until their dynamical elimination, and the mean time spent in each cell (i.e. resident time) is computed. The resultant residence time distribution shows where the bodies from each source statistically spend their time. Thus in a steady state scenario the residence time distribution corresponds to the relative orbital distribution of NEOs that originated from the sources. Using the distribution of observed NEOs and accounting for observational biases allows to determine the unbiased orbital distribution of NEOs and the relative contribution of each source. With this model it is then possible to estimate the relative probability that a body on a given (a, e, i) orbit in the NEO region comes from a particular source, and consequently to estimate the asteroid and comet contributions to the NEO population defined respectively as Near–Earth Asteroids (NEAs) and Near–Earth Comets (NECs)

However as the authors themselves recognize, the method is not “perfect”, in particular in some regions where NEA and NEC pathways overlap. In this case it is difficult to distinguish between NEOs coming from the asteroid sources and those coming from the cometary source. This is specially the case for NEOs coming from the outer part of the main belt (with $a > 2.8$ AU) and NEOs coming from JFC. In the following, we will thus add the contributions of OB and JFC to define a unique cometary origin. Consequently our estimate will give a maximum weight to the cometary contribution.

In our work we have only considered 886 orbits since we have eliminated 204 bodies which have semimajor axes $a > 4.2$ AU, the target region of the bodies evolving from each source in the considered model being limited to $a \leq 4.2$ AU.

Then we estimate the relative probabilities $P_1 = P_{3:1}$, $P_2 = P_{\nu_6}$, $P_3 = P_{MC}$, $P_4 = P_{OB+JFC}$ that a particle on each of these orbits with orbital elements (a, e, i) comes from the associated sources $S_1 = S_{3:1}$, $S_2 = S_{\nu_6}$, $S_3 = S_{MC}$, $S_4 = S_{OB+JFC}$. We first consider (criterium 1) that a body comes from the source S_i if this source corresponds to the maximum value of the computed probabilities P_i i.e. **no overlapping** of the sources. We obtain that 739 (83 %) particles have the highest probability of originating from the asteroid belt (40 bodies come from S_1, 678 originate from S_2 and 21 from S_3) while for 147 (17 %) bodies the greatest probability P_4 indicates a cometary origin.

However since as underlined from Bottke et al. (2001) the intermediate sources may overlap, then our criterion 1 may be considered as a crude approximation. Thus for each considered orbit, we have also calculated all the differences $P_i - P_j$

and assumed that it is not possible to discriminate between two sources S_i and S_j whenever $P_i - P_j$ is smaller or equal to 0.1 (criterion 2).

Applying criterion 2, we found that the respective numbers of particles coming from an asteroidal source S_1, S_2, or S_3 are changed (see Farinella et al. 2001), since some bodies may originate equally from two or/and three asteroidal sources. However criterion 2 **does not change** the total number of orbits coming from the asteroid belt and consequently the total number of bodies of cometary origin.

Another distinction between NEA and NEC may be performed according to the Tisserand parameter (defined as $T = a_j/a + 2\sqrt{a/a_j(1-e^2)}\cos i$, where a_j is the semimajor axis of Jupiter's orbit) Bodies on orbits with $T < 3$ are classified as comets while NEOs with $T > 3$ are classified as asteroids. Following this criterion, in our sample of 886 bodies, we counted 201 (22.7 %) bodies on orbits with $T < 3$ and 685 (77.3 %) bodies on orbits with $T > 3$. Therefore this criterion also indicates that an asteroidal origin is more probable than a cometary one.

4 Conclusion

After a detailed analysis of the numerous data supplied by the literature, we delimitated a range of possible pre–atmospheric orbits of the Tunguska cosmic body (TCB). From these data we constructed a sample of 886 heliocentric orbits of the TCB.

Then using the model of Bottke et al. (2000, 2001) based on dynamical properties of NEOs, we were able to estimate the origin probabilities of the TCB. According to our results the TCB has a greater probability (83%) of coming from an asteroidal source than to be of cometary origin (17%). These results were compared with the classification obtained by using the Tisserand parameter T. This later classification also indicates that an asteroidal origin is more probable (77.3%) than a cometary one (22.7%), though the parameter choice was extremely in favor of the cometary hypothesis, based on the usual velocity criterion. Our results agree with those obtained by Andreew (1990) and Bronshten (1999) who also found a small set of orbits consistent with the cometary origin, but concluded that the stony hypothesis is not reliable because neither macroscopic remnants nor crater were found. However some C–type asteroids may have a very low bulk density like Mathilde ($\approx$ 1300 kg.m^{-3}, just higher than water), which suggests that they are porous bodies. They might thus be pulverised when impacting the Earth. As until now, despite the annual (since 1958) expeditions, no typical material has yet allowed to discriminate between an asteroidal or a cometary nature of the TCB, we are let with the conclusion that assuming that our sample of possible TCB orbits is statistically robust, our study based on purely dynamical considerations gives an asteroidal origin of the TCB with the greatest probability.

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