THE TUNGUSKA OBJECT: A FRAGMENT OF COMET ENCKE?

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Тунгусский объект — осколок кометы Энке?

Высказывается предположение, что Тунгусский объект был потухшим осколком отделившимся от ядра периодической кометы Энке. Приводятся свидетельства в пользу этого заключения.

It is suggested that the Tunguska object was an extinct fragment separated from the nucleus of the periodic comet Encke. Evidence in support of this conclusion is presented.

1. Introduction

Hundreds of articles written on the unique Tunguska event of June 30, 1908, offer a variety of competitive explanations. Apart from the obvious fictions and speculations lacking on scientific objectivity (alien spacecraft, nuclear explosion, antimatter, black hole), every known type of interplanetary body crossing the orbit of the Earth has been suggested as the impacting object. The candidates include a small asteroid – or unusually large meteorite – ranging in composition from meteoric iron (Yavnel', 1957) to pre-type I carbonaceous chondrite (F. L. Whipple, 1967), and a small comet, extinct or active, with a dust tail (F. J. W. Whipple, 1930; Fesenkov, 1961 and 1966).

A preference for a low-density object is based on the kind of destruction of the region of impact. While the estimated energy of the explosion (from 10^{14} J according to Krinov, 1949, to 4×10^{16} J according to Hunt et al., 1960) seems to have been comparable to that wasted in the formation of the 1200 m wide and 170 m deep Canyon Diablo Crater (Shoemaker, 1963), no sizeable crater could be found in the heavily damaged Tunguska area (Krinov, 1949).*) Furthermore, the location of the impact point on the front side of the Earth (local time of fall 7 : 05 a.m.) was at variance with typical orbits of meteorites intercepting the Earth from the rear side, and exhibiting a pronounced afternoon maximum (see Kresák, 1963, Fig. 5, or Wetherill, 1969, Fig. 2). Tentative calculations of the orbital elements (Fesenkov, 1964) pointed decidedly to a long-period comet in a retrograde, or at least high-inclination, orbit inconsistent with the asteroids and comets of the Jupiter family.

*) The suspected shallow dips, reported by earlier expeditions, have been explained by the persistent operation of freezing and melting ice-cover. Similar features can be found at other places of comparable topography and climate.

2. Dynamical Evidence

As a matter of fact, the only evidence concerning the orbit of the object before its entry into the atmosphere is the position of the apparent radiant. This was reconstructed from reports of several dozen eyewitnesses, mostly 200 to 700 km distant from the point of impact, supported by the topography of the razed and broken-down forest, and by the position of the epicentre of the shock wave relative to the direction of searing of the trees. The velocity data are only secondary, being derived from the radiant position under tentative assumptions about the semimajor axis of the orbit. The earliest estimate by Voznesenskij (1925), rediscussed and upheld by Astapovich (1933 and 1958) placed the radiant about 20° South of the apex. Such small apex elongations are only observed for long-period and intermediate-period comets – e.g., P/Tempel-Tuttle, the parent comet of the Leonids. Although Levin (1954) pointed out that small apex elongations pertain not only to head-on collisions with objects in retrograde orbits but also to objects in direct orbits overtaken by the Earth near their aphelia, this conjecture was not taken too seriously because objects of the type required were not known at that time. Until recently, two Apollo asteroids of $a < 1$ (1976 AA and 1976 UA) were discovered; also two new Apollo asteroids (1973 NA and 1975 YA) were found to have orbital inclinations exceeding 60°.

Even more essential for the problem is that later re-evaluation of the data (Krinov, 1949; Zotkin, 1966) placed the radiant much farther to the East. The situation is shown in Fig. 1. The last determination by Zotkin is apparently the most reliable one, owing to the greatest number of observations collected and analyzed. In a co-ordinate frame referred to the Sun and apex, it locates the apparent radiant just in the middle of the area from which a number of the Apollo asteroids (Icarus, Adonis, Geographos, 1976 UA) would approach the Earth. Unlike the range of possible orbits, determined by Fesenkov (1964), the orbits based on Zotkin's radiant are of low inclination. Hence, there is no longer dynamical evidence against the Tunguska object having been a small Apollo asteroid.

However, the Apollo asteroids are not the only objects matching the revised encounter geometry. An important fact which seems to have escaped attention as yet, is the striking resemblance to the major daytime meteor showers. The Tunguska fall occurred only twelve days after the end of the Daytime Arietid and ξ Perseid activity (as listed by Cook, 1973), from a radiant situated at distances of 20° and 15°, respectively, from the centers of their radiant areas. The best match of all is the β Taurid shower which peaks just at the time of the Tunguska event, with the mean radiant a mere 10° North-East. And the β Taurid shower is one of the two annual apparitions of the broad meteor stream associated with Comet Encke!

The solar longitude and the equatorial co-ordinates of the apparent radiant, as given by Zotkin (1966), compare with those of Comet Encke and the β Taurids as follows:

	⊙	α	β
Tunguska Object	98°	79°	+13°
Comet Encke	98°	85°	+13°
β Taurids	98°	87°	+19°

For Comet Encke the solar longitude refers to the point of closest approach of the Earth to the comet's orbit, and the radiant co-ordinates to the direction parallel to the tangent through the nearest point on the comet's orbit. For the β Taurids the Jodrell Bank data (Lovell, 1954), adopted by Cook (1973) in his Reference list of meteor showers, are used, the solar longitude being defined by the mean date of maximum shower activity.

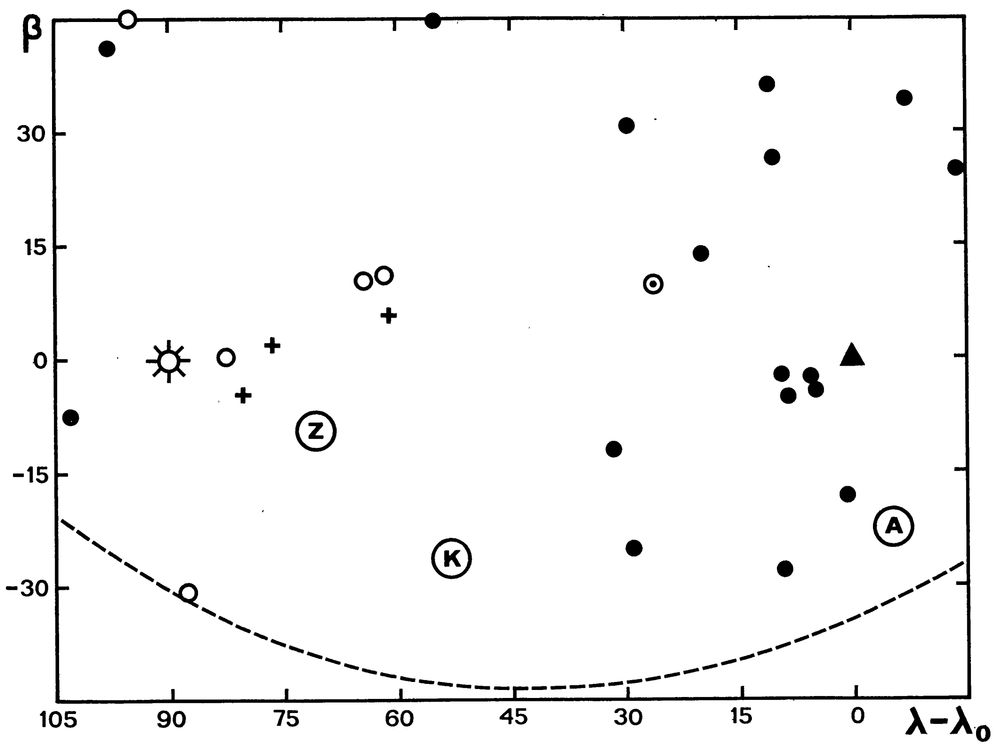

Fig. 1. Direction of the geocentric motion of the Tunguska body compared with those of the Earth-approaching long-period comets (solid circles), Comet Halley (open circle with a dot), and Earth-crossing asteroids (open circles, from the left: 1976 WA, 1620 Geographos in 1969, Adonis in 1936, 1976 UA, 1566 Icarus in 1968). Ecliptical co-ordinates reckoned from the position of the Earth's apex (triangle) at the time of each approach are used; scales are in degrees. The position of the Sun is marked on the left, the dashed curve shows the line of horizon at the time of the Tunguska fall. The radiants of the major daytime meteor showers are marked by crosses (from the left: β Taurids, ξ Perseids, Arietids). The Tunguska radiants are shown as determined by Astapovich (A), Krinov (K), and Zotkin (Z).

The solar longitudes agree absolutely. The orbit of Comet Encke can be brought into intersection with the Earth's orbit at the point of the Tunguska event by a mere rotation of the nodal line from $\Omega = 334°$ to $\Omega = 278°$. In respect of the low inclination and differential secular perturbations, this change appears plausible. It may be noted that the result is exactly the mean position of the nodes of the β Taurids and that the other, nighttime apparition of meteors associated with Comet Encke involve values of Ω widely dispersed from 0° to 60° (Southern Taurids), and from 180° to 240° (Northern Taurids). The distance from the point of the Tunguska encounter to the orbit of Comet Encke, 0·18 A.U., is not excessive, since the nighttime Taurids are anually observed up to distances twice as large. Remembering that the radiant position of the Tunguska object is uncertain to at least 10°, the agreement is essentially perfect.

If the association is true, a sharp estimate of the encounter velocity is possible:

$$V_\infty = 31 \pm 2 \text{ km s}^{-1}$$

including the gravitational acceleration by the Earth, provided that the revolution period of the body did not substantially differ from that of Comet Encke. On the other hand, an independent determination of the orbital elements is hardly feasible, since these are very sensitive to the errors in radiant position. Zotkin's radiant is shifted in the direction of smaller perihelion distances and higher inclinations, but the displacement is less than the mean error. Provided that the suggestion of the Tunguska object having been a fragment of Comet Encke is correct, its trajectory prior to the impact can be reconstructed as shown in Fig. 2.

It may be noted that Kulik et al. (1926) have suggested the association of the Tunguska object with another short-period comet, P/Pons-Winnecke. However, computations of the expected radiant by Guth (1931), as well as by the present author (Kresák 1978b), make this assumptions untenable. A body pursuing the orbit of Comet Pons-Winnecke should have impacted from the North, with the apparent radiant situated far outside the margin of Fig. 1.

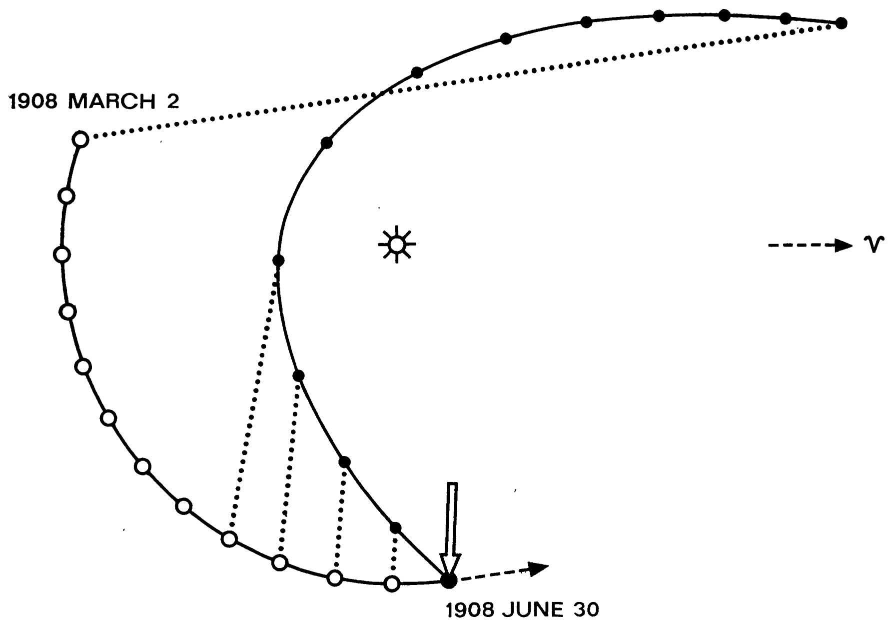

Fig. 2. Encounter geometry of the Earth (open circles) with the Tunguska object (solid dots) based on its association with Comet Encke. The view is perpendicular to the ecliptical plane from the North, with the point of vernal equinox on the right. Positions are marked in 10-day intervals starting 120 days before the collision; for the first and the last four ephemeris dates, the simultaneous positions are connected by dotted lines. The arrow pointing downwards indicates the geocentric direction of the fall, resulting from the vectorial composition with the motion of the Earth (dashed arrow) at the point of impact (solid circle).

3. Inference from Accompanying Phenomena

As already mentioned, important evidence in support of the cometary nature (or at least a very friable comet-like composition) is the kind of damage produced at the point of impact: tremendous explosion, shock wave and forest fire without appreciable cratering. Estimates of the explosion energy range from 10^{14} J (Krinov, 1949) to 4×10^{16} J (Hunt et al., 1960). The terminal mass is estimated at 2×10^7 kg (Bronshten, 1961; Tsikulin, 1961); with $E = 10^{15}$ J this would correspond to a terminal velocity of 10 km . . s^{-1}. On the other hand, subsequent optical phenomena – not seen on any other occasion – indicate much higher initial mass, 10^9 to 10^{10} kg according to Fesenkov (1955). The most recent analysis by Bronshten (1975) suggests an initial mass of 10^8 to 10^9 kg, and a terminal height of 5 to 7 km. While all these figures are necessarily uncertain, a high ablation rate and a violent fragmentation are clearly indicated. A rather conservative estimate of 5×10^8 kg for the pre-atmospheric mass, combined with a tentative density of 10^3 kg m^{-3}, yields an initial diameter of 100 m for the body which was completely destroyed in 10 seconds before reaching the ground. Petrov and Stulov (1975) set the density as low as 10 kg m^{-3} and the diameter at 600 m.

The implication – based on the recovery of metallic particles by the earliest field collections (Yavnel', 1957) – that the body was an iron meteorite like Sikhote-Alin, is no longer defendable. Later expeditions have collected both magnetite and silicate spherules (Kirova, 1961; Kirova and Zaslavskaya, 1966) which may well come from the non-volatile inclusions of a cometary conglomerate. This interpretation is indeed supported by the microprobe analyses (Glass, 1969; Dolgov et al., 1973) showing little resemblance to the silicate portion of any major meteorite group. Obviously, the recovered material can provide only limited information on the quantitative composition of the object, as it remains open to what fraction of the original body the samples refer.

Another possibility, proposed by Whipple (1968) is that the body was an asteroidal pre-type I carbonaceous chondrite of $\varrho = 1000$ kg m^{-3}. As regards the encounter geometry and the phenomena accompanying the fall, this assumption is nearly as reasonable as that of a cometary nature. However, linkage with the known Apollo asteroids presents some difficulties. One is the scarcity of similar asteroidal events, predicted at about one in 6000 years (Kresák 1978b). Moreover, recent spectrometric, radiometric and polarimetric data (Zellner and Bowell, 1977) classify all but one of the Apollo asteroids investigated as siliceous or ordinary-chondritic objects, apparently of high bulk density and strength. While observational selection works against dark carbonaceous objects, their abundance at the inner boundary of the asteroid belt seems to be very low anyway. There is only indirect evidence that the required type of material may be present at the outer boundary and, in particular, in the Trojan clouds. (If so, the rapid rotation of 624 Hector would not be at variance with its highly elongated shape: see Cook, 1971.) The hypothesis cannot be definitely rejected, but it appears distinctly inferior to that of a cometary nature.

The assumption that the body was an active long-period comet was most thoroughly elaborated by Fesenkov (1961, 1964, 1966). Fesenkov based his conclusion on orbit computations adopting the radiant positions by Voznesenskij, Astapovich and Krinov, which essentially ruled out a low-inclination orbit. As shown above, the re-evaluation of the data by Zotkin (1966) changes this situation fundamentally. Fesenkov also maintained that the anomalous optical phenomena observed over Europe on the nights following the fall had been caused by the encounter with a dust tail emanating from the Tunguska body on the side remote from the Sun. But, there are strong arguments against the object having been still active at that time.

An analysis of close approaches of comets to the Earth shows that a collision with an active comet is an exceedingly rare event occurring, on the average, once in 6×10^7 years, or once in 2×10^8 years over the mainland (Kresák, 1978a,b). Furthermore, there is a distinct cutoff in the absolute magnitude distribution of long-period comets at $H_{10} = 12$; it seems that active objects with a nuclear diameter of the order of 100 m do not exist at all. The encounter geometry determined by Zotkin's radiant compares better with a short-period comet or an Apollo asteroid than with a long-period comet (see Fig. 1). If an active comet were approaching the Earth from the region of the apex (radiant **A**), it should have been observable on several mornings preceding the encounter. With an apparent direction from the Sun (radiant **Z**) it would have been invisible during the last phase of approach, as already noted by Zotkin. But, in this case the perihelion distance would have had to be small. As a result of the different angular velocities of the Earth and the comet, the perihelion passage and, hence, also the period of maximum brightness, would have fallen outside the twilight zone. In the orbit drawn in Fig. 2, the object would have been observable in the evening sky, about 20° East of the Sun, for a few weeks around the perihelion passage (1908 May 16). As shown by Fig. 3 (Kresák, 1965) the apparitions of Comet Encke with the perihelion passage in May are rather favourable; in fact, this is one of the two opportunities when the comet can be observed at perihelion.

An identification of the Tunguska object with an active short-period comet is not impaired by the lack of absolutely faint comets, at least not so obviously as for long-period comets. On the other hand, no short-period comet of $q < 0{\cdot}5$ has been observed during the last 200 years from which dependable orbital data are available. Perihelion distances as small as that are not attained by a single perturbation unless the miss distance and encounter geometry is quite extraordinary (such a case has never been recorded); and the object must have had both nodes at $r \leqq 1$, which precludes a close approach to any outer planet unless the inclination is almost exactly zero. The assumption of the Tunguska object being an active short-period comet would have to face the problem, why it remained undetected during the preceding apparitions. The diameters of some known short-period comets are probably below 1 km (Roemer, 1966; Kresák, 1973; Whipple, 1978); yet 100 m appears too small, pointing to an extinct remnant rather than to an active cometary nucleus.

4. Association with Comet Encke

As shown in Section 2, the fall of the Tunguska object occurred at the time when the distance of the Earth from the orbit of Comet Encke was less than one half of the observed dispersion of its débris, and from a direction which coincided with their motion within the uncertainty of the radiant determination.

It must be emphasized that this is not simply one amongst a number of possible, *a priori* equivalent, coincidences with different objects. There is no object akin to Comet Encke as to the efficiency in producing interplanetary matter. There is also no other short-period comet freed from encounters with Jupiter, acting as a means of permanent depletion. Comet Encke is really a unique contributor to the maintenance of the whole meteor complex in the inner part of the solar system (Whipple, 1967).

The icy conglomerate model (Whipple, 1950 and 1951) predicts a lower size limit of the ejecta which can be released by the nucleus. However, this only applies to the continuous normal activity near the Sun, and not to catastrophic breakups. Splitting of cometary nuclei into separate large components, which may retain discrete activity for some time, is by no means rare (Whipple and Stefanik, 1966; Pittich, 1971). It appears probable that breakup into sizeable inactive fragments is the ultimate fate of many comets, and that these cometary boulders represent an overwhelming majority of interplanetary matter in the size range of 1 to 100 m (Kresák, 1978c).

In this connection, one point of the history of Comet Encke deserves attention. A study of the secular perturbations of the Taurid meteors led Whipple and Hamid (1952) to the conclusion that these meteors have had two parent bodies in similar orbits from which they were ejected 4700 and 1400 years ago. The companion of Comet Encke responsible for the other part of the stream must have been a product of an earlier breakup, akin to that required for the separation of the Tunguska object. Investigations on the same lines may perhaps check this hypothesis, and reveal additional associations and branching. One can even speculate whether some other short-period streams, in particular the daytime ξ Perseids and the nighttime Arietids, cannot be referred to the same original object. The progressive splitting of an exceptionally large comet may have helped the decelerated offspring, known as the present comet Encke, to escape the control of Jupiter, while accelerated fragments were ejected or intercepted by the planet. In this case the nongravitational jet effects alone would not have to reduce the aphelion distance. The peculiar orbit of Comet Encke would be the consequence of an abnormal size of its parent body, rather than a consequence of external effects and processes occurring in all short-period comets.

These comments on the possible history of Comet Encke are a matter of speculation, not supported by quantitative evidence. Whether or not they are correct, the identification of the Tunguska objects as an extinct cometary fragment appears to be the only plausible explanation of the event; and a common origin with Comet Encke appears very probable.

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Note added in proof: Commenting on the preprint of this paper, Dr. I. T. Zotkin drew my attention to his article "Anomalous twilight associated with the Tunguska meteorite" (1969, Meteoritika 29, 170), concluded by a short note on the origin of the object. While I find it difficult to agree with the reasoning that the nodal passage of Comet Encke in May 1908 was essential for the encounter with its larger fragments (such objects should have overtaken one another many times since their separation, presumably thousands of years ago), Zotkin was apparently the first to recognize the similarity of the two orbits and to suggest an association of the Tunguska object with Comet Encke on the basis of the encounter geometry.

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