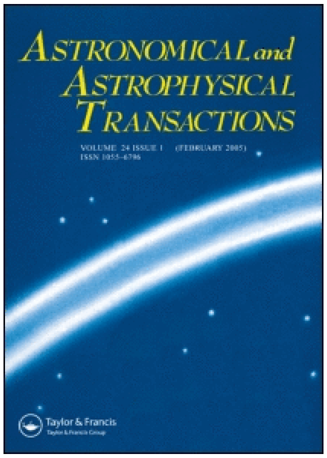

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Evolution of the meteoroid complex of comet Tempel-Tuttle from computer simulation

N. V. Kulikova [a]; V. M. Chepurova [b]
[a] Institute of Nuclear Power Engineering, Obninsk, Russia
[b] Moscow State University, Sternberg Astronomical Institute, Moscow, Russia

Online Publication Date: 01 October 2004
To cite this Article: Kulikova, N. V. and Chepurova, V. M. (2004) 'Evolution of the meteoroid complex of comet Tempel-Tuttle from computer simulation', Astronomical & Astrophysical Transactions, 23:5, 469 - 474
To link to this article: DOI: 10.1080/1055679042000272677
URL: http://dx.doi.org/10.1080/1055679042000272677

Astronomical and Astrophysical Transactions
2004, Vol. 23, No. 5, pp. 469–474

EVOLUTION OF THE METEOROID COMPLEX OF COMET TEMPEL–TUTTLE FROM COMPUTER SIMULATION

N. V. KULIKOVA[a]* and V. M. CHEPUROVA[b]

[a]*Institute of Nuclear Power Engineering, Obninsk, Russia*
[b]*Moscow State University, Sternberg Astronomical Institute, Moscow, Russia*

(Received 5 July 2004)

Computer simulation of the formation of meteoroid bodies formed in Tempel–Tuttle comet disintegration in all its known appearances is performed. Simulation results are analysed according to the retrospective review of observational data for this comet and the Leonids. Simulation was carried out by probability methods for any point of a cometary orbit.

KEYWORDS: meteoroid complex, comet Tempel–Tuttle, Leonids, computer simulation

Tempel on 19 December 1865 in Marseilles and Tuttle on 5 January 1866 in Washington independently of one another discovered a comet denoted as 1866 I and named comet Tempel–Tuttle. Historically there were four returns of this comet: in 1366, 1699, 1865–1866 and 1965. Chinese chronicles describe five observations from 25 to 30 October 1366 and indicate its position relative to stars (Newton, 1868). 118 positions of this comet have been determined in the period from 21 December 1865 to 9 February 1866. Four observations have been carried out in 1965: on 30 June (two cases), 1 July and 26 July (Schubart, 1866). Comets of 1366 and 1866 I were identified in 1933 (Kanda, 1933). Comet Tempel–Tuttle is thought not to have made close approaches to the major planets for 2000 years. It is a generally recognized parent comet of the Leonids which entailed the striking meteor showers in 1799 and 1832–1833. A pronounced periodicity had been observed of the meteor activity amplification coinciding with the comet's period estimated at about 33.25 h in 1863 (Newton, 1868; Belkovich *et al.*, 1996). The stream structure was extremely inhomogeneous; the age of some parts caused meteor showers in 1833, 1866 and 1966 and was assessed at about 100 years at the observation moment. The total age of this stream was estimated within 1000–2000 years (Newton, 1868; Kazimirchak-Polonskaya *et al.*, 1967; Astapovich, 1969, 1972). The Leonids belong to periodic streams but their activities are different in different years. The annual stream activity ranged from some meteors to tens of meteors an hour; however,

---

* Corresponding author. Email: kulikova@iate.obninsk.ru

ISSN 1055-6796 print; ISSN 1476-3540 online
DOI: 10.1080/1055679042000272677

in years preceding the perihelion passage and immediately after it the stream activity sharply increased and caused a striking meteor phenomenon in the form of ‘showers’. The typical stream duration did not exceed 4 days with a narrow peak in the period of maximum activity. So, the ‘shower’ in 1966 lasted for only 20 min; the maximum stream activity in 1965 was observed for approximately 36 h and many bright bolides have been registered (possibly large meteoroid fragments?). The stream in 1969 had a narrow peak of activity of about 1.3 h. In comparison with the previous decade, in the 1970s the Leonids were characterized by low activity and were hardly observable.

From 1994 the stream activity began to increase and researchers have associated it with the perihelion passage of comet Tempel–Tuttle in February 1998. It was noted that 5 years before the perihelion passage the stream activity had increased 8 times in comparison with that of previous years. It was observed that even 6 years after the next perihelion passage in 1966 the stream activity was rather high, that is about 250 meteors an hour with the ordinary mean activity equal to the sporadic background or even below. The Leonids storm in 1966 from radar and visual observations at $S = 2.0$ (a parameter characterizing mass particle distribution) had clearly revealed the Gaussian form of a stream and a maximum activity of 150 000 meteors an hour (Brown *et al.*, 1997). The densest part of a stream in 1966 had covered this distance in an hour. It was supposed (Yomanc, 1981) that most of the ejected dust had also followed the comet beyond its orbit (the presence of a thin stream structure in the form of a ‘layered pie’?).

In 1995 based on a large body of analysed observations it was concluded (Rao, 1995) that a reliable forecast of the maximum of the Leonids is impossible. Along the orbit of comet Tempel–Tuttle there are probably several daughter thread-like streams, each of which consisting of solid fragments ejected by this comet during its previous perihelion passages. On the other hand, the analysis of 58 known significant manifestations of the Leonids has shown (Mason, 1995) that 27 of 35 strong streams and all 23 meteoric storms were observed 750 days before (a little more than 2 years) and 1750 days (4.85 years) after the parent-comet passage of the descending node that confirmed the conclusions of other workers (Yomanc, 1981; Rao, 1995).

Observations of this storm in 1996, 1997 and 1998 have shown a clear maximum of activity with the pronounced large particle and bolide activity at moments close to comet passage of a descending node.

Thus, all the above does not allow one to come to a comprehensive conclusion about the origin of the Leonids, its structure, the mechanism of its formation, its relationship with comet Tempel–Tuttle, the fragment composition and the population density of a meteoroid complex causing the Leonids meteors observed from the Earth. It is quite clear, however, that the stream structure is inhomogeneous and already at the end of the nineteenth century this peculiarity had been noted by English astronomers (Stony and Downing, 1898–1899) who divided the stream into two unequal parts: Orto-Leonids (clusters near the comet) and Klino-Leonids (an orbit-stretched section governing the annual periodicity of a stream).

Based on a long history of studies and a large body of information it is a good practice to develop adequate mathematical models for new natural formations. Theoretical developments in combination with computer simulation and application of observational data give not only qualitative but also specific quantitative characteristics of the objects and phenomena studied. One of the present authors has used a previously developed stochastic–statistical algorithm (Kulikova, 1971, 1988) of nucleus disintegration at any point of a cometary orbit at different rates of substance eruption to comet Tempel–Tuttle. Disintegration is considered as an isotropic ejection of a solid nucleus component. To simulate this comet disintegration in all its known appearances, the orbital elements given by Yomanc (1981) and obtained by numerical integration of the equation of a comet motion with allowance for disturbances of eight planets (Mercury–Neptune) (Kondratjeva *et al.*, 1977) were taken as input parameters.

Simulation results allow one to establish the main tendencies to variations in orbital elements of ejected fragments, to develop a general pattern of the space region under consideration with disintegration products within a calculated time interval, to confirm possible identification of the Leonids with the meteoroid complex formed and to consider a fine structure of the meteoroid formation. Simulation results present also deviations of the Keplerian orbital elements of ejection products from the parent-body orbit. Compared with observations, these results clearly reveal that the meteoroid fragments observed from the Earth as bolides or meteors belong to the substance ejected by a comet at a given moment and at a given space point. So, comparison of simulation results and observational data at fixed moments with allowance for repeated ejection effects will provide approximate ideas of comet Tempel–Tuttle, its meteoroid complex and the Leonid stream to the actual situation in space.

Figure 1 presents deviations of the Keplerian orbital elements of fragments formed in simulating the nucleus disintegration of comet Tempel–Tuttle with the ejection rates of $25\,\mathrm{m\,s^{-1}}$ at the true anomaly points 0–180° for ten appearances of the comet.

Considering (Kulikova, 1988) that orbital element deviations vary by an order of magnitude as the ejection rates increase or decrease by the same factor, it can be concluded that the greatest variety of orbital fragment forms and dimensions is observed when substance is ejected near the perihelion but not farther than 80–90° of the true anomaly. In this case there are no abrupt variations in angular orbital elements of ejection fragments from the parent orbit at these ejection rates. It should be noted that the range of ejection rates always demonstrates a jet structure pattern of the meteoroid complex formed. If a substance is ejected at much greater rates, the densest part of a stream (Orto-Leonids) is formed by fragments ejected at the rates below $2.5\,\mathrm{m\,s^{-1}}$ and fragments ejected with higher rates form another part of the stream (Klino-Leonids). In this case within a certain number of rotations the high-rate ejection fragments of different years will increase the total amount of substances falling on the Earth. It is noted (Rao, 1995) that, for a storm to be observed, the Earth should interact with a dense but narrow jet of meteoroid substances (except for the main part of the Leonids) which could not be determined or followed prior to entry in the Earth's atmosphere. It is just this factor that can be established from deviations of the Keplerian orbits of different ejection fragments when comparing simulation results and observations.

Figure 2 gives variation ranges of the semimajor axis and the eccentricity of fragment orbits for the above conditions. The variation range of presented elements is stipulated by maximum and minimum deviations of orbital elements of ejection fragments from the parent-body elements at a given moment at prescribed ejection rates for a given orbital point. A space region is determined where meteoroid bodies generated by a given comet during the whole known period of its cycle could be found. Clearly seen are the fine structure of a simulated meteoroid complex specified by ejection rates, the ejection point position in a comet orbit and an ejection moment ('a layered pie' effect).

Figure 3 presents space distribution of a meteoroid complex of comet Tempel–Tuttle obtained in simulating disintegration at the substance ejection rates up to $50\,\mathrm{m\,s^{-1}}$ at the true anomaly of 0–180° for all ten appearances of the comet from 1533 to 1899. There are pronounced ranges of jet overlaps which enhance the population in some regions of the meteoroid stream. Figure 4 gives an enlarged representation of a section where the Earth's orbit intersects the meteoroid complex obtained in modelling the cometary nucleus disintegration at rates up to $100\,\mathrm{m\,s^{-1}}$ at the true anomaly points 0–180° in 1899. It is clear that the Earth would face only some part of a stream whereas inside as well as outside its orbit there is

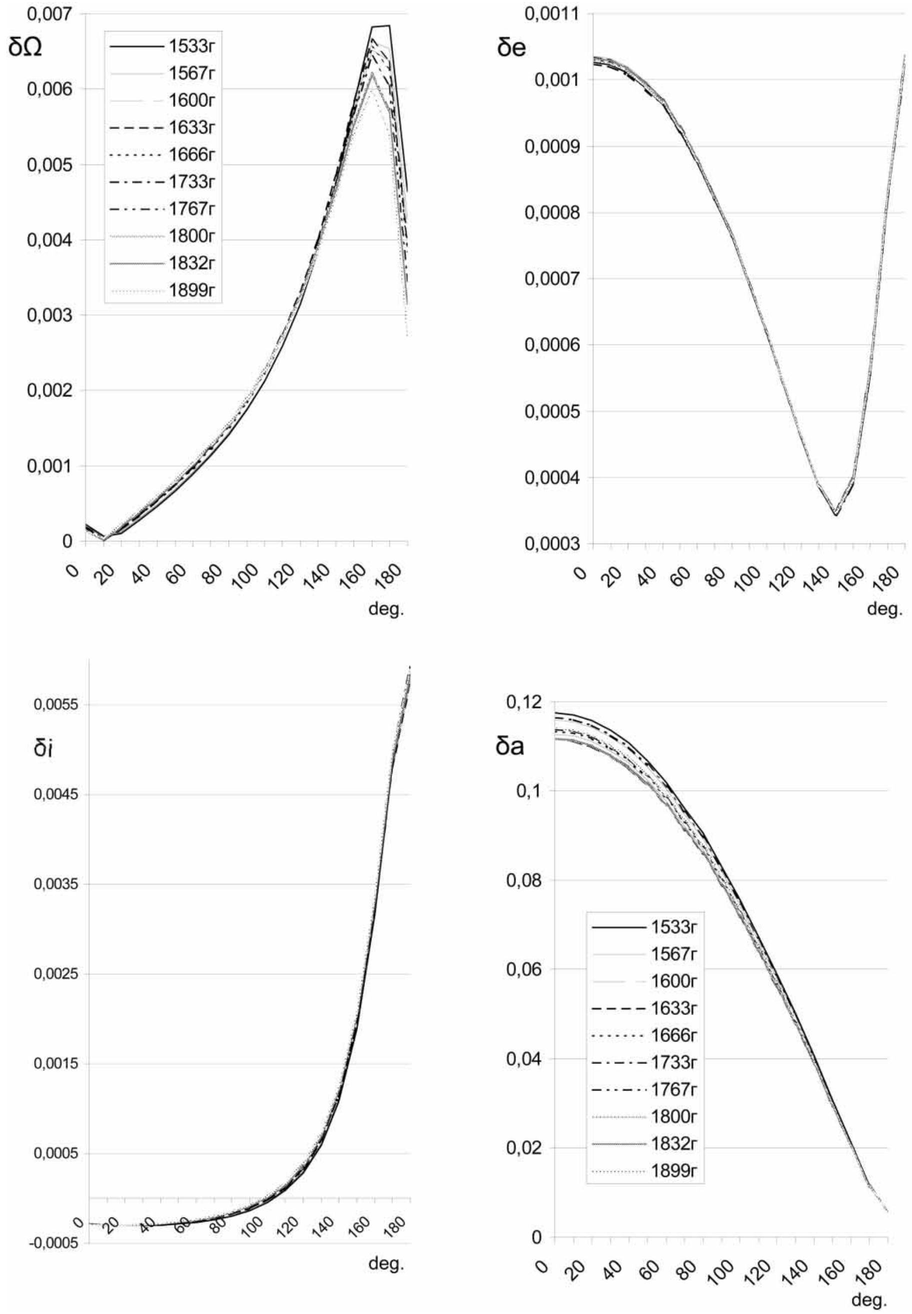

Figure 1. **Deviations in the Keplerian orbital elements of fragments at ejection rates of 25 m s^{-1} for ten appearances of comet Tempel–Tuttle II.**

another part of a meteoroid complex formed at different ejection rates. A similar proposal has been made in 1995 based on observations (Mason, 1995).

Thus, stochastic simulation, analysis and generalization of the obtained results and qualitative and quantitative comparison with observations expand our ideas of space population and enhance the possible forecast of a meteoroid situation near the Earth at a fixed moment.

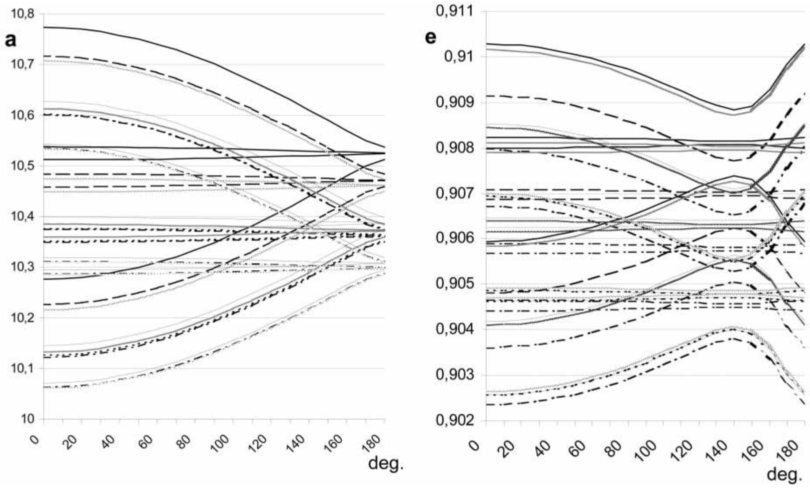

Figure 2. Variation ranges of the orbital semimajor axis and eccentricity of fragments ejected from the nucleus of comet Tempel–Tuttle in all its ten appearances.

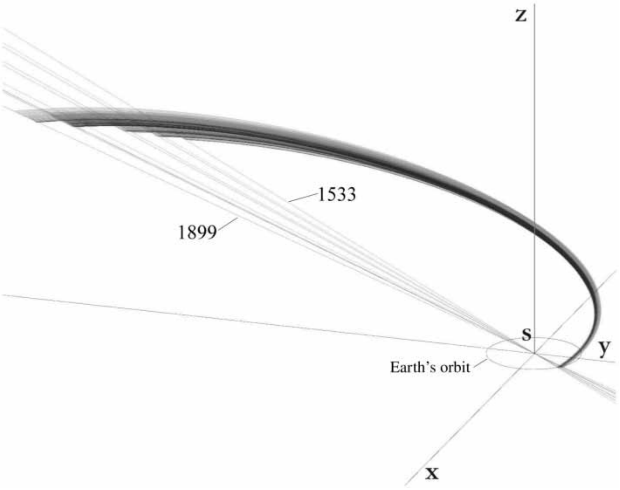

Figure 3. Expected meteoroid complex of comet Tempel–Tuttle in 1533–1899 (range of ejection rates, up to $50\,\mathrm{m\,s^{-1}}$, ejection points, from 0–180°).

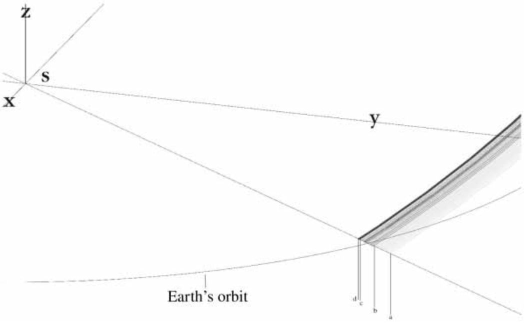

Figure 4. Enlarged presentation of a section where the Earth's orbit intersects the meteoroid complex formed in nucleus disintegration of comet Tempel–Tuttle in 1899 (showing various ejection rates: a–d, $100\,\mathrm{m\,s^{-1}}$; b–d, $50\,\mathrm{m\,s^{-1}}$; c–d, $5\,\mathrm{m\,s^{-1}}$).

Acknowledgements

The work is supported by a regional grant PFFI 05-02-97244 and a Minpromnauka grant.

References

Astapovich, I. S. (1969) *Astron. Circ.* No. 539, 2.
Astapovich, I. S. (1972) *Problems Space Phys.* **7**, 100.
Belkovich, O. I., Ishmukhametova, M., and Suleymanov, N. (1996) *Astron. Vest.* **30**, 377.
Brown, P., Simek, M., and Jones, J. (1997) *Astron. Astrophy.* **322**, 687.
Kanda, S. (1933) *Japan J. Astron. Geophys.* **10**, 3.
Kazimirchak-Polonskaya, E. I., Belyaev, N. A., Astapovich, I. S., and Terentjeva, A. K. (1967) *Astron. J.* **44**, 616.
Kondratjeva, E. D., Muravjeva, I. N., and Resnikov, E. L. (1977). *Astron. Vest.* **31**, 546.
Kulikova, N. V. (1971) *Astron. Vest.* **5**, 181.
Kulikova, N. V. (1988) Doctor's Thesis, Obninsk, 1988.
Mason, J. W. (1995) *J. Br. Astron. Assoc.* **105**, 219.
Newton, H. A. (1868) *Am. J. Sci. Astron. Ser. 2* **45**, 91.
Rao, J. (1995) *WGN, J. Int. Meteor Org.* **23**, 120.
Schubart, J. (1965) IAU Circ. No. 1907.
Stony, G. H., and Downing, A. M. W. (1898–1899) *Proc. R. Soc. Ser. A* **64**, 403.
Yomanc, D. K. (1981) *Icarus* **47**, 492.