TAURID METEOROIDS AND ASTEROID COMPLEX

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Abstract.
The orbital evolution of model meteoroids ejected from the comet Encke and from the asteroid Hephaistos was investigated. The particles abandoned the mother body with velocities 40, 150 and 600 ms^{-1} at their perihelia within the interval of 10,000 to 20,000 years, respectively. Their 10,000 to 20,000 years old osculating orbits were numerically integrated forward, using a dynamical model of the solar system consisting of all planets. Forces from solar electromagnetic and corpuscular radiation effecting the particles were considered, too. Orbital dispersions of the model meteoroids, ejected in different epochs, compared with those obtained from observations. It seems probable that the comet Encke and the asteroid Hephaistos are sufficient to produce the observed Taurid meteor complex.

1. Introduction

The long-term orbital evolution of model meteoroids of the comet Encke showed that the observed distribution of the longitude perihelion for the whole Taurid meteoroid complex cannot be explained by this comet alone. It is not possible even in the case when the solar radiation effects are taken into account (Klačka and Pittich, 1994, 1995). It is generally believed that the source of the Taurid meteor complex are both the Taurid asteroid com-

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plex and the comet Encke (Asher *et al*, 1993; see also Klačka, 1995). The meteoroids with the longitude of perihelion higher than 160° had to be ejected from an asteroid or asteroids belonging to the hypothetical Taurid asteroid complex. The aim of the present article is to study the possibility of the Taurid stream creation, to find an asteroid which can explain the observed distribution of the longitudes of perihelia higher than 160°, and to ascertain under which conditions this situation may occur.

2. Computational Model

We traced the 10,000 years orbital evolutions of the model particles ejected from the Encke comet perihelion using the numerical integration with the RA15 integrator (Everhart, 1985). Similar process was applied to the model particles ejected from the Hephaistos asteroid perihelion for a twice longer period. The input data for the integration, ecliptical rectangular coordinates and velocities, were calculated from the Encke comet orbital elements for the epoch 1987 July 24 (Marsden, 1989) and from the Hephaistos asteroid orbital elements for the epoch 1993 August 1 (Batrakov, 1992).

The adopted ejection velocity 40 $\mathrm{m\,s^{-1}}$ corresponds to the value determined by Sykes and Walker (1992) for the comet Encke, 150 $\mathrm{m\,s^{-1}}$ is the value calculated by Gajdošík and Klačka (1995) from the same data as used by the above mentioned authors. The value 600 $\mathrm{m\,s^{-1}}$ seems to be realistic for some comets and asteroids (Harris *et al*, 1995). The model particles were released from the Encke comet perihelion 10,000 years ago in three directions – tangential to the cometary motion, normal to the comet's orbital plane, and perpendicular to the preceding ones – and for two orientations in each direction. The same procedure was employed in the case of another parent body, the asteroid Hephaistos, except that the model particles were ejected from its perihelion 15,000 and 20,000 years ago. The motions of both the comet Encke and the asteroid Hephaistos were calculated, too.

We have made 10,000 years backward numerical integration of the Encke comet orbit, beginning from the epoch 1987 July 24, and 20,000 years backward numerical integration of the Hephaistos asteroid orbit beginning from the epoch 1993 August 1. Then, the forward numerical integration for the model dust particles – meteoroids – was performed, taking into account the gravitational perturbations of all planets as well as nongravitational effects – solar electromagnetic and corpuscular radiations – acting on the model meteoroids.

Particles with the ratio of the radiation force to the gravity force $\beta = 5.7 \times 10^{-5}/(\varrho\, s) = 4 \times 10^{-4}$ were taken into account; ϱ is the mass density measured in $\mathrm{g\,cm^{-3}}$ and s is the radius of the particle in cm. For dimensions of particles with such β see Table 1 in Klačka and Pittich (1994).

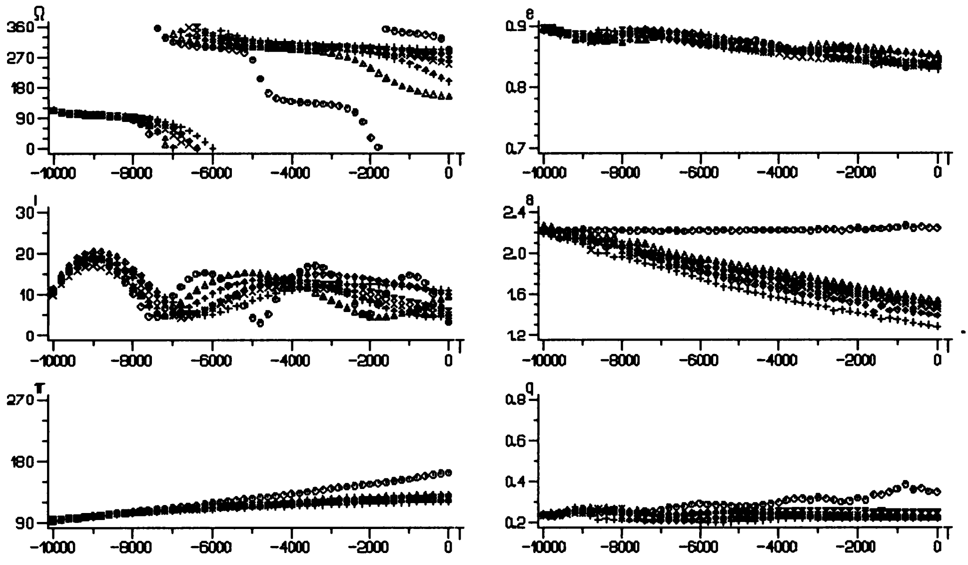

Figure 1. Time evolution of orbital elements of the comet Encke ○ — 0 m s^{-1} (ejection velocity), and of the model meteoroids ejected from the Encke comet perihelion 10,000 years ago. The meteoroids were disturbed by gravitational perturbations of planets and solar electromagnetic and corpuscular radiations. For the meteoroids $\beta = 4 \times 10^{-4}$. The particle parameters are: △ — +150 m s^{-1} in the direction of the cometary motion, + — −150 m s^{-1} in the direction of the cometary motion, × — +150 m s^{-1} in the direction normal to the comet's orbit, ◇ — −150 m s^{-1} in the direction normal to the comet's orbit, ↑ — +150 m s^{-1} in the direction perpendicular to the preceding directions, ⊼ — −150 m s^{-1} in the direction perpendicular to the preceding directions.

3. Results of Orbital Integrations

The results of the orbital integrations for the longitudes of perihelia are given in Table 1. For different cases, the evolution of the osculating elements is plotted on Figures 1–3. The symbols of the orbital elements are standard: ω – argument of perihelion, Ω – ascending node, i – inclination, π – longitude of perihelion, e – eccentricity, a – semi-major axis, q – perihelion distance, Q – aphelion distance. Fig. 1 shows the evolution of these elements for the model particles ejected from the Encke comet perihelion 10,000 years ago with the velocity 150 m s^{-1} in all selected directions. Figs. 2 and 3 show the evolution of the orbital elements of the same model particles ejected from the Hephaistos asteroid perihelion 15,000 and 20,000 years ago, respectively. In both cases the model particles were ejected with the velocity of 150 m s^{-1} in the selected directions.

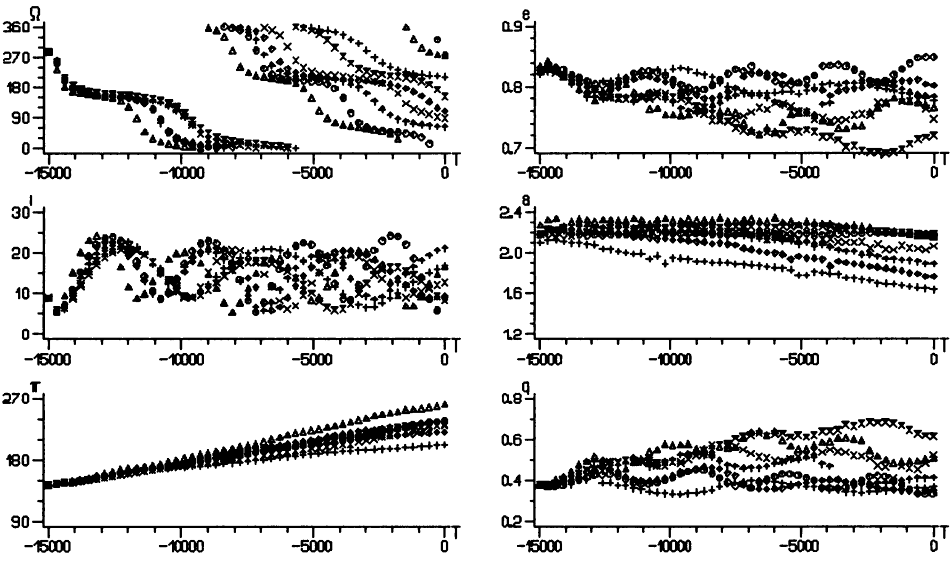

Figure 2. Time evolution of orbital elements of the asteroid Hephaistos ⊙ — 0 m s^{-1} (ejection velocity), and of the model meteoroids ejected from the Hephaistos asteroid perihelion 15,000 years ago. The meteoroids were disturbed by gravitational perturbations of planets and solar electromagnetic and corpuscular radiations. For the meteoroids $\beta = 4 \times 10^{-4}$. The particle parameters are: △ — +150 m s^{-1} in the direction of the asteroid motion, + — −150 m s^{-1} in the direction of the asteroid motion, × — +150 m s^{-1} in the direction normal to the asteroid's orbit, ◇ — −150 m s^{-1} in the direction normal to the asteroid's orbit, ↑ — +150 m s^{-1} in the direction perpendicular to the preceding directions, ⊼ — −150 m s^{-1} in the direction perpendicular to the preceding directions.

4. Discussion

The Taurid meteor stream is characterized by the longitude of perihelion $\pi \in (100^\circ, 200^\circ)$ determined from observations already described (Štohl and Porubčan, 1992). From Fig. 1 and Table 1 it can be seen that the observed distribution of the longitudes of perihelia for the Taurid meteoroid complex cannot be explained by the Encke comet alone, if other nongravitational forces, besides those taken into consideration, are neglected. Some other nongravitational forces effecting the distribution of the longitudes of perihelia of model particles heve been dealt with in our earlier paper (Pittich and Klačka, 1994). The evolution of the orbital elements of model particles ejected with smaller velocities from the Encke comet perihelion is described in our preceding papers (Klačka and Pittich, 1994, 1995).

In order to obtain also particles with $\pi > 160^\circ$ we have to take into account some other parent body, or bodies which at present, are probably dormant comets. Our calculations with such a body, the asteroid Hephaistos, show that simultaneous acting in the past both of the Encke comet

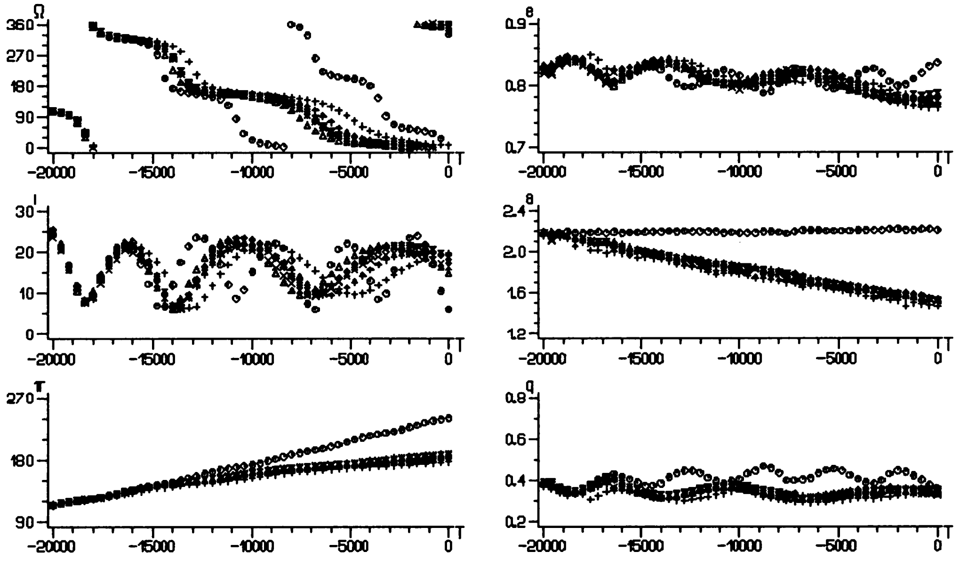

Figure 3. Time evolution of orbital elements of the asteroid Hephaistos ⊙ — 0 m s^{-1} (ejection velocity), and of the model meteoroids ejected from the Hephaistos asteroid perihelion 20,000 years ago. The meteoroids were disturbed by gravitational perturbations of planets and solar electromagnetic and corpuscular radiations. For the meteoroids $\beta = 4 \times 10^{-4}$. The particle parameters are: △ — +150 m s^{-1} in the direction of the asteroid motion, + — −150 m s^{-1} in the direction of the asteroid motion, × — +150 m s^{-1} in the direction normal to the asteroid's orbit, ◇ — −150 m s^{-1} in the direction normal to the asteroid's orbit, ↑ — +150 m s^{-1} in the direction perpendicular to the preceding directions, ⊼ — −150 m s^{-1} in the direction perpendicular to the preceding directions.

and this asteroid might explain the distribution of the longitudes of perihelia of the Taurid meteoroids derived from observations. If Hephaistos became a nonactive body 20,000 years ago, the maximum ejection velocity ,producing meteoroids with the present 200° longitude of perihelion, would have to be 600 m s^{-1}. The perihelion distance of the Hephaistos asteroid 15,000–20,000 years ago ($q \sim 0.35$ AU) was similar to the longitude of perihelion of the Encke comet at present. Thus, in the first approximation, we can assume similar ejection velocities for particles ejected from the comet Encke now and for those ejected from Hephaistos 15,000–20,000 years ago.

5. Conclusion

The model particles ejected from Hephaistos 20,000 year ago with the ejection velocity 600 m s^{-1} together with the particles of the comet Encke are sufficient, to cover the values of the longitudes of perihelia less than 200° derived from observations (Table 1). The consequence of this result is that

TABLE 1. Longitudes of perihelia of model particles for two parent bodies.

Ejection velocity	Encke 10,000 years ago	Encke now	Hephaistos 15,000 years ago	Hephaistos now	Hephaistos 20,000 years ago	Hephaistos now
$m\,s^{-1}$	°	°	°	°	°	°
40	94	125–132	143	213–248	114	184–191
150	94	121–131	143	202–262	114	177–189
600	94	111–152	143	195–349	114	165–198

Hephaistos had to be inactive during the last 20,000 years. All these conclusions hold if nongravitational effects different from solar radiations are negligible.

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