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NEAR-EARTH ASTEROIDS AND METEOR SHOWERS

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The term Near-Earth Asteroid (NEA) is taken to mean a mimor planet on an orbit which, as a consequence of secular perturbations, can intersect the orbit of the Earth. Known groups of NEAs include Aten asteroids (a¡1.0 AU, Q¡0.983 AU), Apollo asteroids (a¡1.0 AU, q≤1.017 AU) and Amor asteroids (a¿1.0 AU, 1.017¡q≤1.3 AU). Catalogue of minor planets with q¡1.5 AU discovered before March 1995 are Atens, 171 are Apollos, and 137 are Amors. Muinonen et al. (1991) estimated the total number of NEAs with diameter larger than 0.1 km as about 10^5. The largest NEA, 1036 Ganimed, has a diameter of 39 km, another two - 433 Eros and 3552 Don Quixote - about 20 km, all of the others less than 10 km, and 3/4 of them less than 3 km. The smallest NEA (1991 BA) is a 9-m asteroid of Apllo group(Lupishko and Belskaya, 1993).

According to available data among the Near-Earth asteroids may be both extinct comets (Opik, 1963) and former main belt asteroids (Rarinella et al. 1991). We propose that in order to distinguish between the two origins it is important to determine which asteroids have associated meteor showers.

Meteoroid streams are assumed to be formed by the process of the cometary decay. The ejection velocity ν of a meteoroid particle from a cometary nucleus on a distance r from the Sun may be written down as (Whipple 1951)

$$v = 6.6\sqrt{R_c/(\rho\delta r^{0.75})}\text{m/s} \qquad (1)$$

where R_c is the radius of a cometary nucleus in km, ρ and δ are particle's radius and density both in CGS units.

The maximum differences between orbital semi-major axis Δa and the eccentricity Δe of the ejected meteoroid from those of the comet will be (Plavec 1955):

$$\begin{aligned}\Delta a &= \pm 6.72\times 10^{-5} a_c^2 v\sqrt{2/r-1/a_c}\text{AU}\\ \Delta e &= \pm 6.72\times 10^{-5} r e_c v\sqrt{2/r-1/a_c} \qquad (2)\end{aligned}$$

where a_c and e_c are semi-major axis and the eccentricity of the comet's orbit respectively.

The other orbital elements of released particles differ only slightly from the cometary ones and, thus, these differences may be neglected.

Just after release from the comet nucleus, the meteoroids are exposed to the solar radiation pressure. This pressure leads to an increase in the orbital period and to variations in the eccentricity (Radzievsky 1951).

The initial dispersion of the orbit of ejected meteoroids arises therefore through the dispersion due to ejection velocities and light pressure. A further evolution of a meteoroids near the nucleus of a parent comet. Whenever the Earth pass through this cloud a meteor storm is observed (e.g. the Draconids in 1933 and 1946 yrs).

Dispersion of meteoroids semi-major axes determine the time during which the meteoroids will both lead and lag the comet and eventually form a complete loop. The minimum time T required to form a complete loop of meteoroids around the original comet orbit may be estimated according to formula (Hughes, 1985):

$$T = \frac{P_c}{2}\left(\frac{e_c}{\Delta P} - 1\right), \qquad (3)$$

where

$$P_c = a_c^{3/2},\ \Delta P = \frac{3}{2}P_c a_c^{-1}\Delta a,$$

and P_c - period of the comet's orbit. Results of the estimation of the time for meteoroids of different streams show that a complete meteoroid stream is formed in comparatively short time, which is much shorter than life time of the parent body.

In the initial stage of the formed complete meteoroid stream the orientation of meteoroids orbits (inclination, argument of perihelion ω, and longitude of ascending node Ω) differ only slightly from cometary ones, and thus in this stage a meteoroid stream is very flat, narrow at the perihelion and broad at the aphelion, because the ejection of particles is more intensive near the perihelion.

Due to the differences in the planetary perturbing action on the steram meteoroids of different semi-major axes and eccentricities the rate of variations in the orbital elements of various particles will be different. The angular elements (i, ω, Ω) of stream meteoroids, undergo especially major variations, This process can essentially increase the meteoroid stream in size and, first of all in its thickness. The stream may thicken and take such a shape as to cause the start of several discrete active showers at different solar longitudes. If the Earth's orbit assumed to be circular, then it may be intersected by those meteoroids which have a node at $r = 1$ AU, i.e. satisfy the expression:

$$\pm\cos\omega = \frac{a(1-e^2)-1}{e} \qquad (4)$$

A meteoroid stream may consist of meteoroids of every possible values of ω. As seen from condition (4) for a given a and e the Earth's orbit may be intersected at four possible values of ω. As a result, one meteoroid stream may produce four meteor showers: two at pre-perihelion intersection and two at post-perihelion intersection with Earth. At pre-perihelion intersection a meteoroid stream produce two night-time showers, and

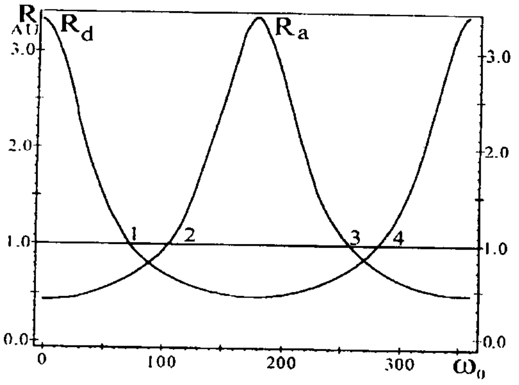

Fig. 1.— The dependence of radii-vectors to ascending R_a and descending R_d nodes of the asteroid 2101 Adonis on perihelion argument ω. The intersection (1) corresponds to Capricornids-Sagittariids, (2) χ-Sagittariids, (3) χ-Capricornids, (4) σ-Capricornids.

at post-perihelion intersection produece two day-time showers.

Calculation of meteor showers radiant is the first step for revealing of genetic relationship between given shower and its potential parent body. From the early eighties for determination of theoretical radiants we use new method which tqake into account the orbital evolution of orbital elements of stream meteoroids (Babadzhanov and Obrubov 1985, 1987)

Weismann et al.(1989) proposed that the asteroids 2101 Adonis, 2212 Hephaistos and some others with large probability have a cometary origin and their physical properties are in accord with this proposal. If so, and these asteroids have old meteoroid sterams then they could produce the meteor showers observable in the Earth.

Asteroid 2101 Adonis now has following orbital elements (Batrakov 1988):

$$\omega = 41^\circ.7, \quad \Omega = 350^\circ.58, \quad i = 1^\circ.36 \quad (1950.0)$$
$$a = 1.875\,\mathrm{AU}, \; e = 0.764, \quad q = 0.443, \mathrm{AU}.$$

Its diameter is equal to 1 km (Shoemaker et al. 1991).

Results of the calculations of secular perturbations of the Adonis' orbital elements by the Halphen-Goryachev method for the time interval of 14 millenia, Which embraces one cycle of variations of ω, shows that Adonis is an quadruple Earth-crosser and hence its possible meteoroid stream may produce 4 meteors showers (Fig. 1)

Theoretical (T) and observed (O) geocentric radiants (right ascension α and declination δ), velocities V_g (in km/sec), and solar longitudes $L^{o}_{\otimes}$, at which the Adonis meteor showers manifest they activity, are presented in Table 1. The D-criterion, which is a measure of similarity of two orbits (Southworth and Hawkins, 1963), given in the last cloumn of Table 1 show a good accordance between theoretical and observed data, i.e all 4 possible Adonis meteor showers are active today.

The asteroid Hephaistos has following orbital elements (Batrakov 1988):

$$\omega = 208^\circ.27, \quad \Omega = 27^\circ.89, \quad i = 11^\circ.8 \quad (1950.0)$$
$$a = 2.167\,\mathrm{AU}, \; e = 0.834, \quad q = 0.360, \mathrm{AU}.$$

Its diameter is estimated as 5 km (Shoemaker et al. 1991).

Variations of Hephaistos' orbital elements were calculated for the time interval of 6000 yrs. During one cycle of variation of ω the inclination i varies sufficiently, within the limits from 5 to 24. As for 2101 Adonis, the Hephaistos is an quadruple Earth-crosser and, hence, it might produce 4 meteor showers observable on the Earth.

Theoretical dates of activity (L_o) and geocentric radiants (α, δ) and velocities V_g of the Hephaistos' meteor showers are given in Table 2. They are named according to the position of their theoretical radiants.

In the published catalogues of meteor showers only for δ-Cancrids we find observed radiant among 275 streams detected by Sekanina (1976).

In order to obtain a confirmations of the asslociation of 2212 Hephaistos with this and other three showers we carried out a search of individual meteors, probably belonging to these showers, in the catalogues of the IAU Meteor Data Center (Lindblad 1987). We found 31 δ-Cancrid meteors, 31 χ-Cancrids (South branch of δ-Cancrids), 15 Daytime Northern September Leonids and 12 Daytime Southern September Leonids. The average geocentric radiants and velocities of observed showers meteors are presented in Table 2. The values of D-criterion given in the last column of Table show a good accordance between theoretical and observed data.

Results of foregoing investigations show that the predected and observed geocentric radiants and velocities of four meteor showers of asteroid Adonis and that of asteroid Hephaistos are in satisfactory agreement. The existence of meteor showers associated with these asteroids is indicative that 2101 Adonis and 2212 Hephaistos are of cometary origin.

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Table 1. Theoretical and observed geocentric radiant and velocities of the Adonis meteor showers

Showers	Theoretical				Observed				
	$L_{\otimes}^{0}$	α^{0}	δ^{0}	V_g	$L_{\otimes}^{0}$	α^{0}	δ^{0}	V_g	D
σ-Capriconrids(N)	105	295	-18	25	107	298	-19	25	0.01
χ-Sagittariids(N)	106	296	-22	25	100	290	-26	26	0.02
Capricornids-Sagittariids(D)	319	313	-17	25	309	299	-14	25	0.01
χ-Capricornids(D)	320	315	-21	25	324	314	-24	27	0.02

N-nighttime, D-daytime shower. V_g - in km/s.

Table 2. Theoretical and observed geocentric radiants and velocities of the Hephaistos meteor showers

Showers	Theoretical				Observed					
	$L_{\otimes}^{0}$	α^{0}	δ^{0}	V_g	$L_{\otimes}^{0}$	α^{0}	δ^{0}	V_g	N	D
δ-Cancrids(N)	304	139	21	28	300	138	20	29	31	0.20
χ-Cancrids(N)	303	135	9	29	300	135	9	29	31	0.14
N. Sept. Leonids(D)	169	162	15	28	174	162	16	30	15	0.30
S. Sept. Leonids(D)	169	159	3	28	173	160	4	29	12	0.12

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