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Streamlets within meteoroid streams on NEA orbits

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Resumen

Cinco corrientes de meteoroides de aparente naturaleza asteroidal se han identificado en la Base de Datos de Meteoros Fotográficos del IAU_MDC. Tres corrientes de meteoroides contienen subcorrientes, compuestas de dos o más meteoroides compartiendo prácticamente la misma órbita. La razón de impactos aleatorios en la población de NEAs por objetos de 1 m de longitud o mayores se estima que es de 4900 año^{-1}.

Palabras clave: NEAs, meteoroides, corrientes, subcorrientes.

Abstract

Five meteoroid streams of apparent asteroidal nature have been identified in the IAU_MDC Database of Photographic Meteors. Three streams contain streamlets, composed of two or more meteoroids sharing nearly the same orbit. The random impact rate on the NEA population by objects 1 m or larger is estimated to be 4900 yr^{-1}.

Key words: NEAs, meteoroids, streams, streamlets.

Introduction

Meteoroid streams are commonly associated with cometary paths. Though evidence of meteoroid streams on Near Earth Asteroid (NEA) orbits has been persistent since 1937 (Kostolansky, 1998). Impacts on the NEA population are naturally expected: the same mechanisms that scatter NEAs from the Main Belt (MB) to the near-Earth space, which are the mean motion and secular resonances, simultaneously scatter many times more smaller fragments together with the NEAs. Some of these smaller fragments eventually hit the asteroids of the NEA population, creating in the process new fragment swarms that will travel along the impacted NEA´s orbit as a stream. Moreover, since most NEAs have aphelia that lie within the MB, every time they move through it, they do it at the lowest possible speed of their orbits and crossing at the same time multiple quasi-circular orbits of Main Belt fragments of systematically higher speeds. This makes NEAs to become easy targets of these MB fragment population. Finally, the near-Earth space is crossed by about 135 Short Period Comet (SPC) orbits plus some Long Period Comet (LPC) ones, populated with fragments of diverse sizes. As many of these cometary orbits overlap the NEA space, eventually some NEAs will cross one or more of these fragment paths, increasing greatly the probability of being hit by one or more of them every time they return to the crossing point. Whatever the point of the orbit a Near Earth Asteroid is hit by an impactor, the resulting fragment swarm will travel along with the asteroid on about the same orbit. This will be detected at the Earth as an Asteroidal Meteoroid Stream.

Observations

We have performed a visual search for possible simultaneous clustering of the orbital parameter values of meteoroid groups in the IAU_MDC Database of Photographic Meteors (Lindblad *et al.*, 2003). The search was positive, giving as a result five probable asteroidal meteoroid streams (Table 1 and Fig. 1) with three of them, S1, S2, and S3 containing streamlets as part of their structure. Streams S2 and S3 contain, respectively, four and three streamlets but stream S1, coming from the innermost Asteroid Belt, contains nine such streamlets (Table 2 and Fig. 2), including the most populous one with six orbits. Streams are distinguished from each other due to a clear difference in their mean orbital parameters values (Table 1). This is not the case for streamlets within streams, since all of them have very similar orbital parameters values. It is only a slight but systematic difference in the aphelion values what distinguishes a streamlet from the rest; by times a slight difference in semi-major axis also helps isolate streamlets (Table 2). In the case of streamlet SS1d, besides a slight difference in q, the homogeneity of q and Ω values is what distinguishes it from SS1a.

Analysis

In agreement with Neukum *et al.* (2001), for the last Gy during which the impact rate on the Moon has been approximately constant, the cumulative crater size distribution is given by

$$\log N = a_0 + a_1 \log D + a_2(\log D)^2 + \ldots + a_{11}(\log D)^{11}, \quad (1)$$

Table 1

Mean coordinates of five meteoroid streams on NEA orbits.

Stream	*a*(*AU*)	*q*(*AU*)	*e*	*Q*(*AU*)	*i*(°)	*ω*(°)	*Ω*(°)
S1	1.350	0.141	0.895	2.56	23.17	324.30	261.89
S2	1.929	0.379	0.802	3.47	4.76	112.84	37.60
S3	2.230	0.363	0.835	4.09	2.982	292.83	231.46
S4	2.462	0.581	0.760	4.34	6.426	257.18	130.70
S5	2.793	0.980	0.648	4.60	71.92	173.01	283.3

where D is the crater size in km, N is the number of craters per km^2 with diameter $> D$, $a_0 = -3.0876$, $a_1 = -3.557528$, $a_2 = 0.781027$, $a_3 = 1.021521$, $a_4 = -0.156012$, $a_5 = -0.444058$, $a_6 = 0.019977$, $a_7 = 0.08685$, $a_8 = -0.005874$, $a_9 = -0.006809$, $a_{10} = 0.000825$, and $a_{11} = 0.0000554$. If D = 0.01 km, equation 1) implies that a lunar area 1 Gy old has a crater density of $N(D \geq 0.01\text{km}) = 3700/\text{km}^2$. For the case of the Moon (See Melosh, 1989), the relationship between a crater of diameter D made by an impactor of diameter d is given by

$$d = 9.77\rho_i^{-0.5356}\rho_m^{0.5952}v_i^{-0.666}D^{1.19} \text{ (mks)}, \qquad (2)$$

where $\rho_i = 2200$ kg/m^3 and $v_i = 10^4$ m/s are the mean density and mean impact velocity of NEAs on the Moon and $\rho_m = 2400$ kg/m^3, the mean density of the Moon (Jeffers *et al*., 2001). By replacing these values in 2) we find that

Table 2

Coordinates of streamlets SS1* associated with streams S1.

Stream	*Streamlet*	*a*(*AU*)	*q*(*AU*)	*e*	*Q*(*AU*)	*i*(O)	ω(O)	*Ω*(O)
S1	SS1a	1.337	0.139	0.896	2.55	23.6	324.7	261.4
		1.337	0.139	0.896	2.55	24.2	324.7	258.2
		1.34	0.138	0.897	2.55	23.1	324.8	261.8
		1.347	0.136	0.899	2.55	24	325.1	262
		1.337	0.139	0.896	2.55	23.6	324.7	262.1
	SS1b	1.308	0.14	0.893	2.47	23.3	325	261.6
		1.311	0.139	0.894	2.47	23.7	325.1	261.7
		1.301	0.134	0.897	2.47	23.2	325.8	263.2
	SS1c	1.312	0.143	0.891	2.48	23.7	324.5	261.9
		1.308	0.14	0.893	2.48	24	325	261.5
		1.315	0.142	0.892	2.48	25.8	324.6	261.8
	SS1d	1.343	0.141	0.895	2.55	23.4	324.4	261.8
		1.346	0.14	0.896	2.55	23.4	324.6	261.9
		1.346	0.14	0.896	2.55	22.3	324.6	261.7
		1.346	0.144	0.893	2.55	23	324.1	261.8
		1.343	0.141	0.895	2.55	23.1	324.4	262.4
		1.343	0.145	0.892	2.55	20.6	323.9	262.7
	SS1e	1.356	0.141	0.896	2.58	23.1	324.3	261.7
		1.356	0.141	0.896	2.58	22.9	324.3	261.8
		1.356	0.141	0.896	2.58	23.2	324.3	261.9
	SS1f	1.163	0.143	0.877	2.18	24.8	326	262.3
		1.163	0.15	0.871	2.18	21.2	325.1	262.3
	SS1g	1.241	0.144	0.884	2.35	23.7	324.9	262.1
		1.241	0.144	0.884	2.35	25.2	324.9	261.8
	SS1h	1.324	0.135	0.898	2.5	24.3	325.6	262.1
		1.324	0.135	0.898	2.5	24.7	325.5	262.9
	SS1i	1.352	0.142	0.895	2.57	22.9	324.2	262.8
		1.352	0.142	0.895	2.57	23.2	324.2	262.8

a = semi-major axis, q = perihelion distance, e = eccentricity, Q = aphelion distance, i = inclination, ω = argument of perihelion, Ω = ascending node

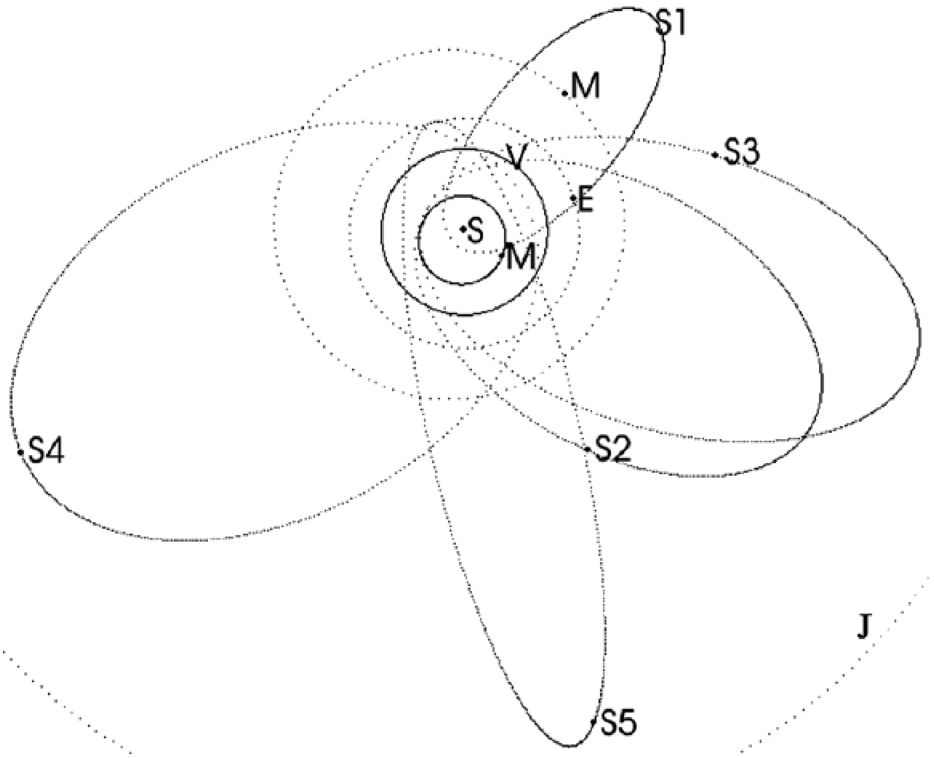

Fig. 1. Mean orbits of the five meteoroid streams on asteroidal orbits. The rest of the letters in the figure stand for the terrestrial planets, Jupiter and the Sun.

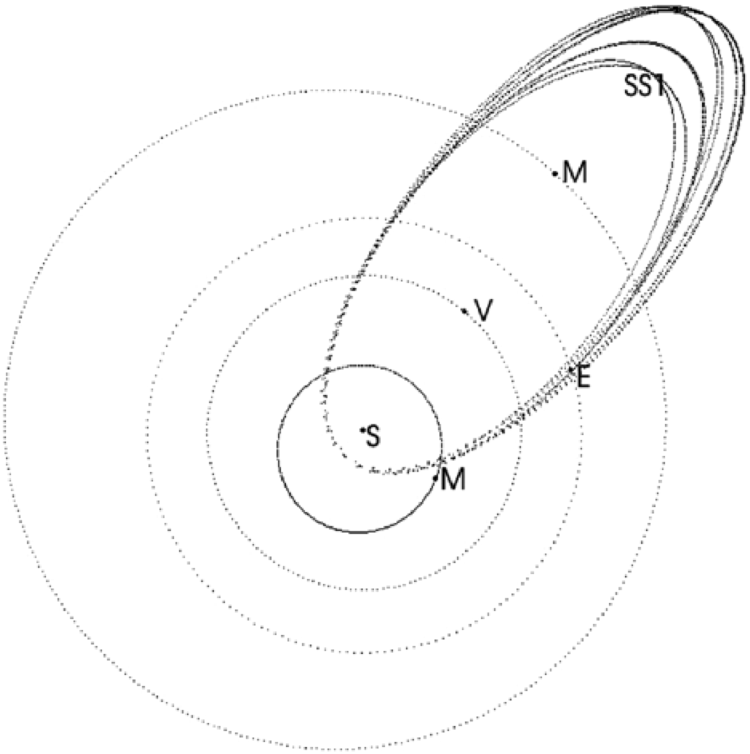

Fig. 2. Orbits of five out of nine meteoroid streamlets (SS1) within stream S1 of Table 2. It is highly unlikely these streamlets are cometary. See the closeness of each streamlet's orbits. The rest of the letters in the figure stand for the terrestrial planets and the Sun.

a crater of approximately 500 m in diameter is made by a typical 50 m impactor, what justifies the commonly used rule of thumb $d \approx 0.1D$. Thus the latter result implies that about the Earth's orbit the impactor flux with diameter ≥ d is given by $n_e = N(D \geq 0.01\text{km})/1$ Gy, or

$$n_e(d \geq 1\text{m}) = 3.7\text{x}10^{-6}\text{km}^{-2}\text{yr}^{-1}. \qquad (3)$$

On the other hand, since most NEAs move periodically into the impactor-populated Main Belt, the approximate impactor flux they are subject to while in the Belt is expected to be

$$n_m(d \geq 1\text{m}) = 7.336\text{x}10^{-6}\text{km}^{-2}\text{yr}^{-1}, \qquad (4)$$

as estimated for Gaspra by S. V. Jeffers and D. J. Asher (2003), given the orbital similarity of this asteroid with typical Apollo and Amor NEAs.

So, on the average, the Apollo and Amor population is expected to be subject to a mean impact flux

$$n(d \geq 1\text{m}) = [n_e(d \geq 1\text{m}) + n_m(d \geq 1\text{m})]/2, \text{ or} \qquad (5)$$

$$n(d \geq 1\text{m}) = 5.556\text{x}10^{-6}\text{km}^{-2}\text{yr}^{-1}. \qquad (6)$$

Now, since in agreement with Table 3 the total estimated area for the NEA population is 8.92x10^{8} km^{2}, the expected impact rate on the whole population by objects 1m or larger in diameter would be 4900 yr^{-1}. This high impact rate on the NEA population explains the observation of fragment streams about mean orbits in the NEA space.

Table 3

Number of NEAs per diameter range, mean diameter and area per range and total area of NEAs.

Diameter range (km)	N	D(km)	A(km^2)
0.001- 0.01	5.47x10^{10}	0.005	8.59x10^{8}
0.01 - 0.07	2.5x10^{8}	0.04	3.14x10^{7}
0.07 - 3.5	2.75x10^{5}	1.78^{5}	1.54x10^{6}
3.5 - 40	30		9.77x10^{3}
Total mean area of NEAs (km^2)			8.92x10^{8}

The area of the 30 largest NEAs has been calculated separately, as their dimensions are reasonably well known (Lupishko and Di Martino, 1998). For the rest of the asteroids, the data are from Jeffers *et al.* (2001).

Regarding the presence of several streamlets within streams, such as in Fig. 2 and Table 2, this fact implies that the parent NEA has been subject to an impact rate much higher than estimated by equation 6. A plausible interpretation for this observation is the parent NEAs have happened to cross periodically through densely populated debris paths, probably cometary, in such a way that for each impact received by a sizable cometary fragment, the creation of a streamlet is ensued.

Summary

Five streams of apparent asteroidal nature have been identified. Three streams contain streamlets as part of their structure. The probable sources of streams and streamlets are Near Earth Asteroids, as they follow typical NEA orbits. It is probable streamlets are asteroidal fragments resulting from recent collisions of a NEAs with cometary fragments, probably due to periodic encounters of the latter with a densely populated cometary debris path. Concerning the random impact rate on the NEA population by objects 1m or larger in diameter, it is estimated to be 4900 yr^{-1}.

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