Meteoroid streams and their parent bodies

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Computer studies (1)

- Southworth and Hawkins (1963) meteor streams, comets,
- Nilsson (1964) meteor streams,
- Lindblad (1971,...) meteor streams, comets,
- Sekanina (1973,1976): 20 NEAs with suggested meteor stream associations,
- Drummond (1982):
 - 8 NEAs associated with modern meteor streams,
 - 13 NEA associations with Prairie Network Fireballs,
 - 15 possible NEA associations with Medieval Fireball Radiants,
- Jopek (1986) streams, one stream and two parent comets,
- Ollson-Steel (1988): possible associations between 25 NEAs and the meteoroid streams,

Computer studies (2)

- Porubčan et al. (1991): 14 most probable associations of NEAs with meteors,
- Drummond (1991): 4 groups of NEAs only (asteroid streams),
- Jopek (1992, 1997, 1998, 1999, 2003, 2007) meteoroid streams,
- Drummond (2000): 21 asteroid streams (4-25 members).
- Kostolanský (1998): list of 29 NEAs associated with photographic meteoroids,
- Jenniskens (2008): 29 NEAs associated with meteoroid sreams,

Computer studies (3)

• A-C-M complexes:

Taurids:

Asher et al. (1993), Shestaka (1994), Babadzhanov (1999, 2001), Porubčan et al. (2006),

 κ Cygnids: Jones et al. (2006),

Geminids-Sextantids: Ohtsuka et al. (2005), Jenniskens (2008).

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Searching for parent bodies of meteoroid streams

Computer studies (4)

• evolutionary studies of the A-C-M relationships:

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Ryabova (2002),
Jenniskens (2004),
Porubčan et al. 2004,
Williams et al. (2004),
Porubčan and Kornoš (2005),
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 families of the meteoroid streams: generated by 3200 Phaeton, 2101 Adonis, 2329 Orthos, 1996 SK, 96PMachholtz 1 (Babadzhanov and Obrubov (1989),...).



Jopek, Valsecchi, Froeschle (1999)

Orbital data sources

- 4098 meteor orbits IAUMDC photographic orbits,
- 5518 NEAs orbits (NeoDys site, AD 2008),
- 579 cometary orbits with e < 1, single apparitions (M-W C.Catalogue, 2003).



All objects: 4098 M, O A, O C, Vg=36.7[km/s]

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All objects: 0 M, 0 A, 579 C, Vg= nan[km/s]

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e=1 0 a=3 AU Orbital energy -10-4 a=1 AU -2×10⁻⁴ a=0.7 AU -0.04 -0.020.02 0.04 0 hz - angular momentum

All objects: 4098 M, 5518 A, 579 C, Vg=36.7[km/s]

Serching method — meteoroid stream definition.

- D_{SH} and D_V distance functions,
- a single linkage cluster analysis algorithm,
- thresholds *D_c* statistical approach, reliability level 99%,
- individual D_c for groups of M = 2, 3, 4... members.

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Jopek, Rudawska, Bartczak 2007

$$D_{VE}^{2}(A,B) = w_{h1}(h_{A1} - h_{B1})^{2} + w_{h2}(h_{A2} - h_{B2})^{2} + 1.5 w_{h3}(h_{A3} - h_{B3})^{2} + w_{e1}(e_{A1} - e_{B1})^{2} + w_{e2}(e_{A2} - e_{B2})^{2} + w_{e3}(e_{A3} - e_{B3})^{2} + 2 w_{E}(E_{A} - E_{B})^{2},$$

where w_{hk} , w_{ek} , w_E — weighting factors.

$$\mathbf{h} = (h_1, h_2, h_3)^T = \mathbf{r} \times \dot{\mathbf{r}},$$
$$\mathbf{e} = (e_1, e_2, e_3)^T = \frac{1}{\mu} \dot{\mathbf{r}} \times \mathbf{h} - \frac{\mathbf{r}}{|\mathbf{r}|},$$
$$E = \frac{1}{2} \dot{\mathbf{r}}^2 - \frac{\mu}{|\mathbf{r}|},$$

where: $\mathbf{r} = (x, y, z), \dot{\mathbf{r}} = (\dot{x}, \dot{y}, \dot{z})$ — heliocentric position and velocity.

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Vectorial orbital elements

or alternatively:

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$$\mathbf{h} = \sqrt{1 - e^2} \begin{pmatrix} \sin i \sin \Omega \\ -\sin i \cos \Omega \\ \cos i \end{pmatrix}$$
$$= e \begin{pmatrix} \cos \omega \cos \Omega - \cos i \sin \omega \sin \Omega \\ \cos \omega \sin \Omega + \cos i \sin \omega \cos \Omega \\ \sin i \sin \omega \end{pmatrix}$$
$$E = -\frac{\mu}{2a},$$



where: a, e, i, Ω, ω — keplerian orbital elements, $\mu = k^2, k$ — Gauss gravitational constant.

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Southworth and Hawkins, 1963

$$D_{SH}^2 = (e_B - e_A)^2 + (q_B - q_A)^2 + \left(2\sinrac{l_{AB}}{2}
ight)^2 + \left(rac{e_B + e_A}{2}
ight)^2 \left(2\sinrac{\pi_{AB}}{2}
ight)^2$$

$$\begin{split} I_{AB} &= \arccos(\hat{\mathbf{h}}_{\mathbf{A}} \cdot \hat{\mathbf{h}}_{\mathbf{B}}) \\ \mathbf{N} &= \hat{\mathbf{h}}_{\mathbf{A}} \times \hat{\mathbf{h}}_{\mathbf{B}} \\ \pi_{AB} &= \arccos(\hat{\mathbf{N}} \cdot \hat{\mathbf{e}}_{\mathbf{A}}) - \arccos(\hat{\mathbf{N}} \cdot \hat{\mathbf{e}}_{\mathbf{B}}) \end{split}$$



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Results of two searches amongst 10195 orbits:

Table: Accepted groups of $M \ge 5$ members.			
	Number of	Percentage of	
	identified groups	orbits in groups	
D _{SH}	21	17.9 %	
D_V	23	25.4%	

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Present study: meteoroid streams and parent bodies

Name	Code	D _{SH}		D_V	
		N _M	N _{A/C}	N_M	N _{A/C}
Perseids	15	641	0/1	631	0/1
Orionids	116S	75	0/1	56	0/1
Monocerotids	88	13	0/1	12*	0/1
Leonids	93	28	0/1	3	0/0
	95V			15	0/1
Lyrids	2	13	0/1	2	0/1
				3	0/0
Geminids	68	381	1/0	371	1/0
Quadrantids	46	52	0/0	49	1/0
κ Cygnids	16	36	0/0	24	0/0
δ Aquariids (S)	365	41	0/0	16	0/0
δ Aquariids (N)	389	9	0/0	-	-

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Name	Code	D _{SH}		D _V		Notes
		N _M	N _{A/C}	N _M	N _{A/C}	
Taurids (N,S)	70	14	0/0	134	11/1	S7 (D)
	91	174	9/0			
α Capricornids	12V			136	647/2	A1,A2,A5,A7 (D)
	13S	40	2/0			S1,S3-4,S8 (D)
	43S	24	132/1			
	4133S	0	27/0			
η Taurids	177V			49	198/0	A4,A8-10,A13 (D)
	796S	11	25/0			
	1612S	3	12/0			
Piscids	107V			8	9/0	
Cyclids	495S	8	19/0			
	654V			6	27/0	

D- Drummond (2000)

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Present study: groups of NEAs and comets

Name	Code	D _{SH}		D _{SH} D _V		V_G
		N _M	N _{A/C}	N _M	N _{A/C}	[km/s]
Association 228	228V			5	33/0	7.2
Association 657	657V			5	25/0	4.6
Association 694	694V			6	34/0	7.4
Association 1821	1821V			1	38/0	9.4
Association 4266	4266V			0	20/0	-
Bielids	131			2*	0/8	
	540S	2	7/0	-	-	
Kreutz group	9634V	0	0/6	0	0/8	
Shoemaker-Levy	9855	0	0/19	0	0/19	

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Metroroid streams – on the $E-h_z$ plane



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Taurid complex on the $E-h_z$ plane



Taurids (N,S): 182 M, 13 A, 1 C, Vg=27.7[km/s]

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Name	Name	Name		
2201 (Oljato)	2002 MX	2003 WP21		
2003 UV11	2004 TG10	2005 NX39		
2005 TB15	2005 TF50	2005 UR		
2005 UY6	2006 SO198	2007 RU17		
2007 UL12	2P/Encke			

Identified by: D_{SH} function D_{VE} function D_{SH} and D_{VE} functions

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Capricornid complex on the $E-h_z$ plane



α Capricornids-2: 64 M, 161 A, 1 C, Vg=17.4[km/s] SH

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Capricornid complex on the $E-h_z$ plane



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η Taurids complex on the *E*-*h_z* plane



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B 1 4 B 1

Cyclids complex on the $E-h_z$ plane

Cyclids: 11 M, 35 A, 0 C, Vg= 3.5[km/s] 0 -5×10⁻⁵ a=3 AU Orbital energy 10-4 Cyclids -1.5×10⁻⁴ a=1 AU Meteoroids Asteroids Comets *_0.02 -0.01 0 0.01 0.02 0.03 0.04 hz - angular momentum

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Image: A matrix

E

Image: Second second

NEAs complex on the $E-h_z$ plane



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