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The Quadrantid meteor stream and 2003 EH1

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Abstract. The radiant and orbit of the Quadrantid meteoroid stream are studied on the basis of the updated version of the IAU MDC photographic meteor catalogue. The mean orbit, the shape, size and ephemeris of the radiant are derived. The radiant area of the central part of the stream is more concentrated and is of the size $4° \times 2°$. The origin of the stream is discussed and orbital evolution over 5000 years of five filaments found in the stream is compared with asteroid 2003 EH1, the recently proposed parent of the stream (Jenniskens, 2004). Two of the filaments follow the orbital evolution of 2003 EH1.

Key words: asteroid – meteor streams – parents

1. Introduction

The Quadrantids, active in the beginning of January, rank together with the Perseids and Geminids among the most pronounced meteor showers. The stream has a very narrow and sharp maximum between January 3-4. The first note about the stream is from Quetelet (1839). The observational history of the stream is briefly summarized by Kronk (1988).

More detailed knowledge of the Quadrantids was obtained from systematic radio observations carried out almost for two decades in Canada and Czechoslovakia (McIntosh, Šimek 1984). The data have revealed an asymmetric activity curve with a slower increase to maximum following by a steeper decrease after maximum and that the position of the maximum from year to year is changeable. Further there was observed a mass separation of meteoroids in the stream with the peak of smaller particles preceding the peak of larger particles (Hughes, Taylor 1977; Porubčan, Hajduková 1982).

The Quadrantids move in a short-period orbit with a period of revolution of about 5 years, at a high inclination of 70° and approach the orbit of Jupiter. The approaches cause considerable perturbations on the stream and a retrograde motion of the ascending node (Hamid, Youssef 1963; Hughes 1972). However, this inference was based on only a few precise photographic orbits.

The parent of the Quadrantids is not well known. Hasegawa (1979) has suggested comet C/1491 to be a likely Quadrantid parent. McIntosh (1990) by integrating the orbit of 96P/Machholz found an orbital similarity between the comet and Quadrantids. Williams and Collander-Brown (1998) discussed a possible connection of the asteroid 5496 (1973 NA) with the stream and recently Jenniskens (2003) has suggested that the parent of the Quadrantids is 2003 EH1 and concludes that the object is an intermittently active comet.

In this contribution a study of the orbital evolution of the Quadrantid stream based on precise photographic orbits from the IAU Meteor Data Center as well as of the orbit of 2003 EH1 is performed and a possible connection between the Quadrantid stream and 2003 EH1 is discussed.

2. The radiant and the mean orbit of the Quadrantids

The most precise orbital elements and geophysical parameters of meteors are derived from photographic observations. Though the Quadrantids are relatively reach for bright meteors, due to rather unfavourable weather conditions in January, only a rather low number of them is photographically recorded. Hamid and Youssef (1963) for their analysis of the stream orbital evolution had at their disposal only 6 orbits, Kresák and Porubčan (1970) for their study of the stream's radiant area had at their disposal 16 Quadrantids and the mean orbit presented by Kronk (1988) is based on 25 Quadrantids.

The present MDC catalogue of photographic orbits, version 2003, contains 4581 meteors (Lindblad *et al.* 2004). This provides a possibility to derive a more precise mean orbit of the stream, as well as the radiant position, its daily motion and verify the size and form of the radiant area. The Quadrantids were searched for by a stream search procedure applying the Southworth-Hawkins D criterion (Southworth, Hawkins 1963). For a limiting value of $D \leq 0.2$, 60 meteors belonging to the Quadrantids from the period January 2-8 were found in the catalogue. The orbits are compiled from a period of 40 years (1951-1991) and the obtained radiant ephemeris is

$$\begin{aligned} \alpha &= 230.4^\circ + 0.64\,(L_s - 283.3^\circ) \\ \delta &= \;\;49.1^\circ - 0.41\,(L_s - 283.3^\circ). \end{aligned}$$

The daily motion in right ascension and declination was found by the least squares solution where L_s is the solar longitude of the time of observation for equinox 2000.0 and 283.3° is the solar longitude of the maximum of activity.

The size of the radiant area correlates with the dispersion of orbital elements and so with the structure of a stream. To find the size and form of the stream radiant area, the radiants were reduced to a common solar longitude of the maximum of activity and they are plotted in Fig. 1a. The Quadrantid radiant area is an oval of the size of approximately $10^\circ \times 5^\circ$. Fig. 1b depicts the radiant area for meteors from a narrow period of the maximum of the length of 0.3° (solar longitude $283.2^\circ - 283.4^\circ$, 17 meteors). The radiant area in the central part of the stream is substantially more concentrated and reaches a size of $4^\circ \times 2^\circ$, while in the marginal regions the radiant is more diffuse. In the shower maximum the Earth passes the region where the orbits are strongly concentrated around the mean orbit of the stream.

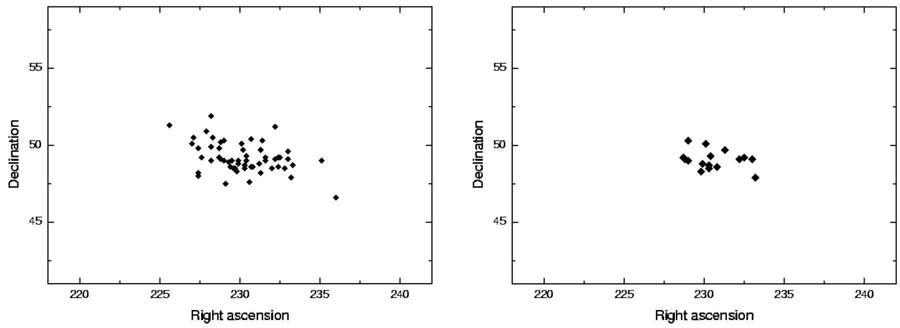

Figure 1. Photographic radiants (α, δ) of the Quadrantid meteor shower reduced to the common solar longitude (283°): a) from the whole period of activity (60 meteors), b) from the narrow peak of activity (17 meteors).

The mean orbit of the Quadrantids derived from 60 photographic orbits is listed in Table 1. For comparison the table lists also the orbits derived by Kresák and Porubčan (1970), Lindblad (1987), Kronk (1988). Further, the table lists the mean orbit of the stream derived for Quadrantid fireballs only by Porubčan and Gavajdová (1994) and also the mean orbit obtained from radar observations (Sekanina 1970). The radar orbits are less precise and more dispersed. These represent smaller particles than are photographic particles and they are more influenced by dispersion effects. The angular elements in Table 1 are referred to equinox 2000.0. The photographic orbits derived by various authors from samples of different sizes show only minor differences, which demonstrates that the Quadrantids are a rather strongly concentrated meteoroid stream.

Table 1. The mean Quadrantid orbit derived from photographic and radar observations.

author	a (AU)	q (AU)	e	i (°)	ω(°)	Ω(°)	number
Kresák *et al.* (1970)	3.0	0.979	0.674	72.9	171.2	283.4	16
Lindblad (1987)	3.037	0.981	0.677	71.9	171.1	283.1	14
Kronk (1988)	2.526	0.975	0.614	71.4	170.7	283.3	25
Porubčan *et al.* (1994)	2.383	0.977	0.589	68.6	169.3	286.0	6
Sekanina (1970)	3.064	0.974	0.682	70.3	168.1	283.0	57 radar
present analysis	2.925	0.977	0.665	71.6	170.7	283.3	60
	±.057	±.004	±.056	±1.6	±3.6	±.8	

3. Possible parent of the Quadrantids

The parent of the Quadrantids is still uncertain and several suggestions have been presented up to date. McIntosh (1990) has shown that the orbital evolution of comet 96P/Machholz is very similar to that of the Quadrantids. The comet librates in the period of 4000 years and its present orbit is similar to the Quadrantids orbit in the period about AD 0 till 500. Hasegawa (1979) has suggested for the Quadrantids as parent comet 1491 I. Williams and Wu (1993) have studied a long-term orbital evolution of the comet and found that its orbit was similar to the Quadrantids at about 1650, when Jupiter substantially influenced its orbit. A part of modeled particles get on the orbit similar to that of the Quadrantids, however, the dispersion of the modeled orbits was too large. Another approach to the problem have been made by Babadzhanov and Obrubov (1993) showing that as a result of the orbital evolution of 96P/Machholz up to eight meteoroid streams can be generated including the Quadrantids.

Williams and Collander-Brown (1998) concluded that more likely than both the comets a parent of the stream can be asteroid 5496 (1973 NA) and that even if 5496 is not the actual parent, it is either likely to be a fragment of the parent, or the dormant remains of the parent. Most recently with a similar suggestion came Jenniskens (2003 and 2004), who announced an identification of asteroid 2003 EH1 as a very strong candidate for the parent of the stream, or as a remnant of the parent. Following the orbital evolution of the asteroid he has concluded that the asteroid is now likely an extinct cometary nucleus that is a remnant of a larger object that broke up about 500 year ago.

For the present study we have chosen only precise orbits which are available from photographic observations summarized in the IAU MDC catalogue. Applying the stream search procedure utilizing the Southworth-Hawkins D-criterion to the whole set of 4581 orbits (2003 version of the catalogue - Lindblad *et al.*, 2004), for D=0.20 rejection level, 60 Quadrantids were separated from the database (mentioned above). A narrow and rather strong activity of the stream indicates that the stream is young. A relatively high and constant activity of the stream in consecutive years with a short period of revolution (P=5 years) demonstrates that several filaments have to be present and intermixed in the stream.

A detailed study of the set of Quadrantid orbits has shown that distinctly separated filaments of the stream can be recognized only for very small values of D=0.03. In this way five different filaments within the stream were separated. The orbital elements of the filaments together with the orbital elements of the asteroid 2003 EH1 are listed in Table 2. The D value between 2003 EH1 and the Quadrantid mean orbit (Table 1) is D=0.22.

In order to find a possible link between 2003 EH1 and Quadrantids, the orbital evolution of the asteroid and each of the five Quadrantid filaments over 5000 years back were studied. For the integration of the orbital evolution a DE multistep procedure of Adams-Bashforth-Moulton's type up to 12th order, with

Table 2. The Quadrantid filaments from photographic observations and 2003 EH1

filament	Q (AU)	q (AU)	a (AU)	e	i (°)	ω (°)	Ω (°)	π (°)	R.A. (°)	Dec. (°)	V_g ($\mathrm{km\,s^{-1}}$)
I.	4.75	0.982	2.867	0.657	72.0	176.8	282.7	99.5	227.2	50.6	41.2
II.	4.88	0.977	2.931	0.666	72.2	170.3	283.2	93.5	230.2	48.8	41.3
III.	4.49	0.980	2.735	0.641	70.8	173.3	283.3	96.7	229.8	49.7	40.7
IV.	5.38	0.974	3.176	0.693	70.9	168.0	283.3	91.4	232.6	48.9	41.0
V.	5.28	0.981	3.131	0.686	72.9	174.5	283.0	97.6	228.2	49.7	41.8
2003 EH1	5.06	1.192	3.128	0.619	70.8	171.4	282.9	94.3	229.9	49.6	40.2

a variable step-width, developed by Shampine and Gordon (1975), implemented into C++ language (Montenbruck, 2002), was applied. The positions of the perturbing major planets were obtained from the Planetary and Lunar Ephemerides DE406 prepared by the Jet Propulsion Laboratory (Standish, 1998).

Results of the integration are presented on plots in Figs. 2-7 depicting the orbital elements - a, e, i, ω, Ω and q. The plots of the filaments contain 18 modeled particles distributed equidistantly along the mean orbit of each filament according to the mean anomaly by 20°. These Figs. show that filaments 1 and 2 undergo the same orbital evolution as 2003 EH1 and so they are most likely associated with the asteroid. The stream is very narrow, concentrated and represents a typical cometary meteoroid stream. It can be inferred that 2003 EH1 is most likely a dormant or inactive comet at present and in agreement with Jenniskens the asteroid is probably only a remnant of the Quadrantid parent or one of several bodies forming a complex. Contrary to filaments 1 and 2, filament 3 behaves completely different from the asteroid and filaments 4 and 5 with aphelia just beyond Jupiter are on chaotic orbits and cannot be old and may represent ejecta from a so far unknown body of the complex.

4. Discussion and conclusions

By applying a computerized stream search procedure (utilizing the D-criterion) to photographic meteor orbits, 60 Quadrantid meteors were found in the IAU MDC catalogue. The mean orbit, as well as the shape, the size and ephemeris of the Quadrantid radiant, were derived (Table 1). The radiant area depicted from all Quadrantids (Fig. 1; period Jan. 2 - Jan. 8), reduced to a common solar longitude of 283.3°, is 10°×5°, while the radiant of the central part of the stream was found to be much more concentrated and is of the size of 4°×2°.

Applying a strict limit for the D criterion, D=0.03, five distinct filaments within the stream were found (Table 2) which may correspond to different ejection events of the stream formation. Filaments 1 and 2 follow the orbital evolution of 2003 EH1 which is more likely, and consistently with Jenniskens (2004) conclusion, a dormant or at present inactive cometary nucleus or it is a rem-

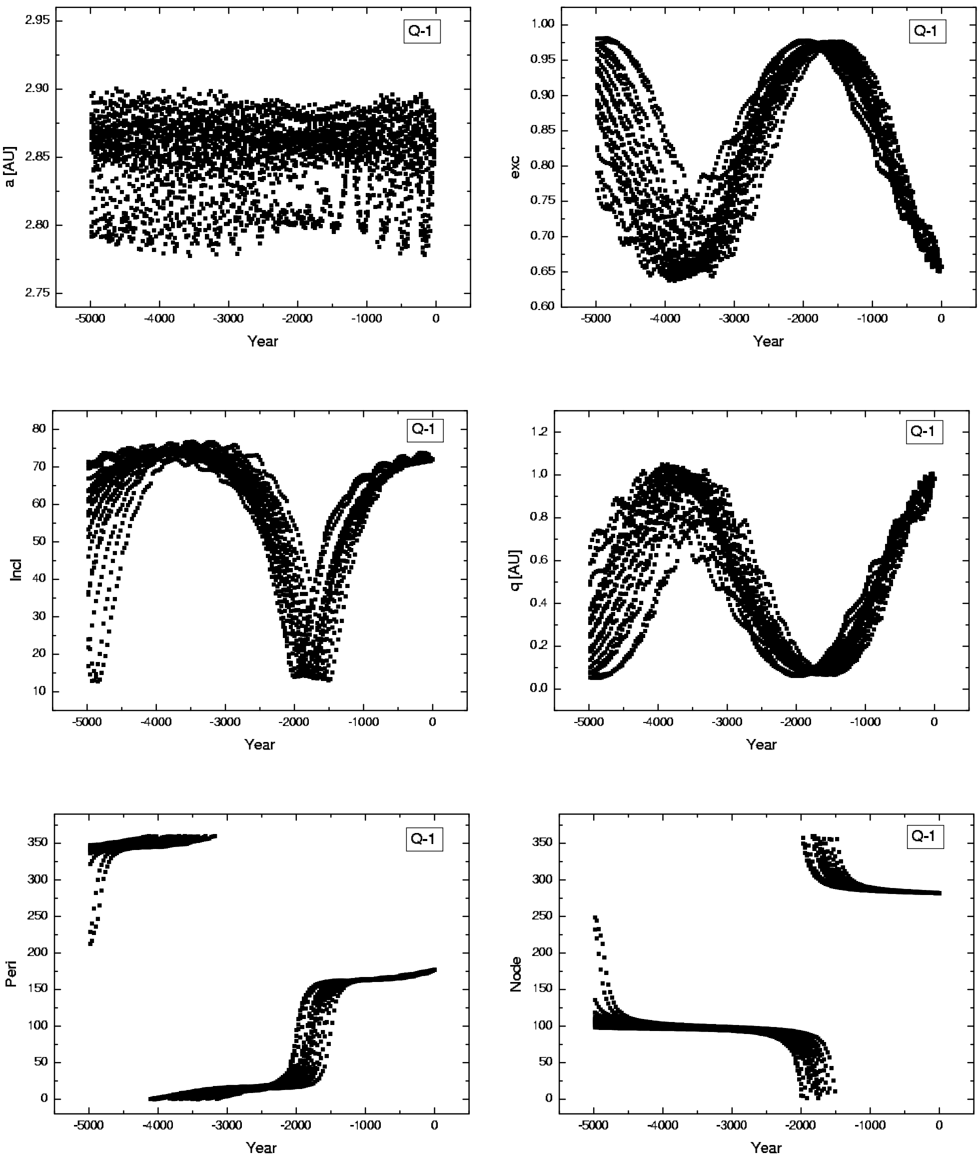

Figure 2. Quadrantids, the filament I.

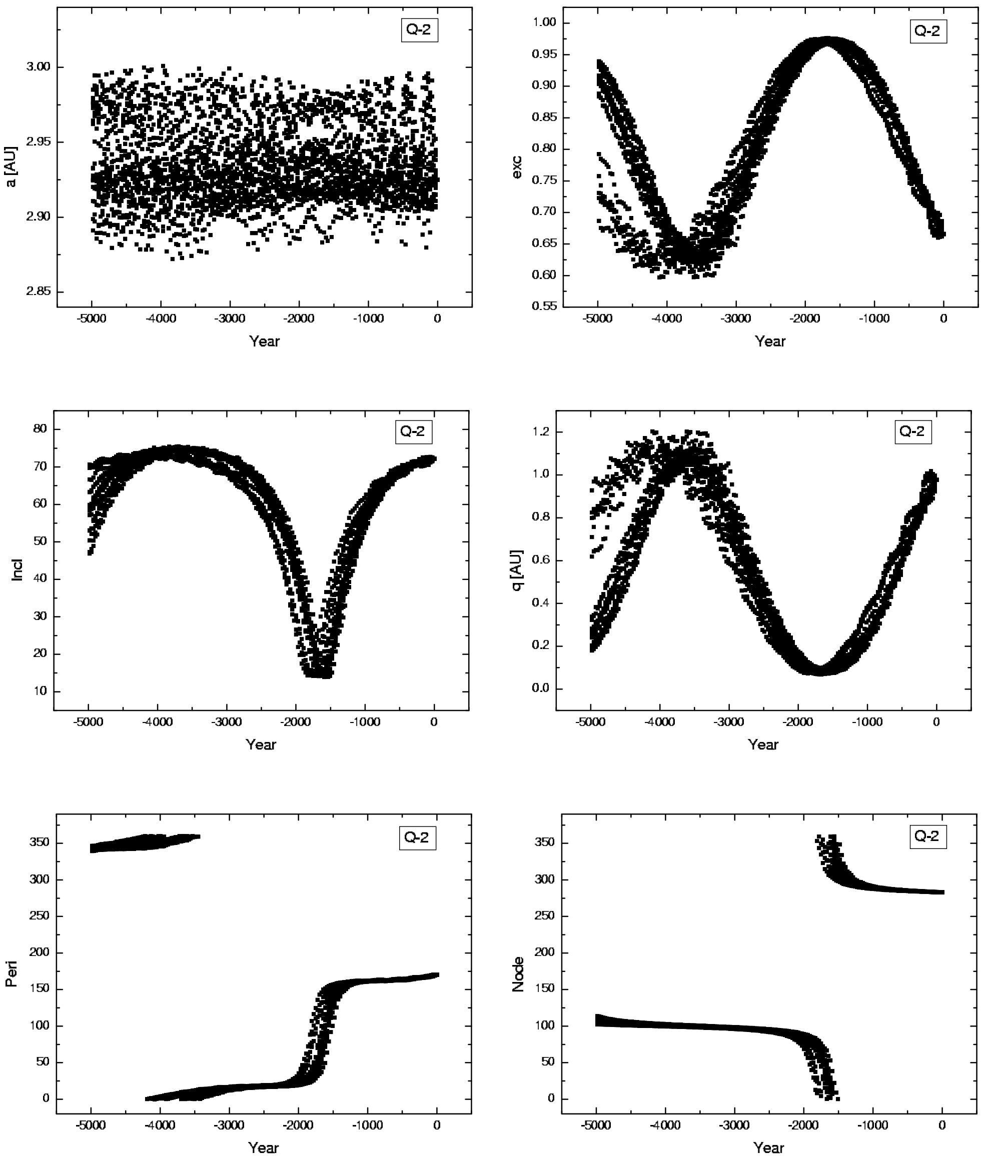

Figure 3. Quadrantids, the filament II.

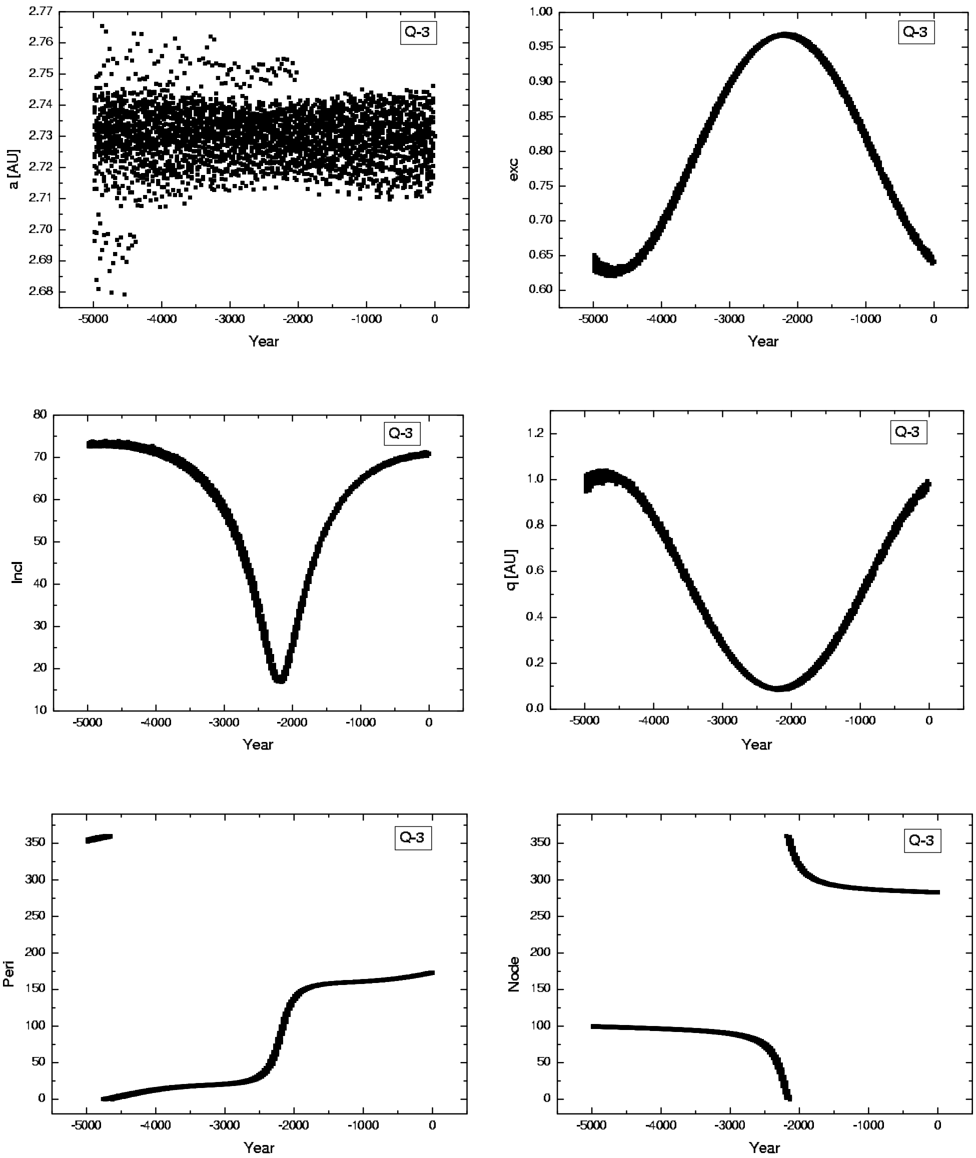

Figure 4. Quadrantids, the filament III.

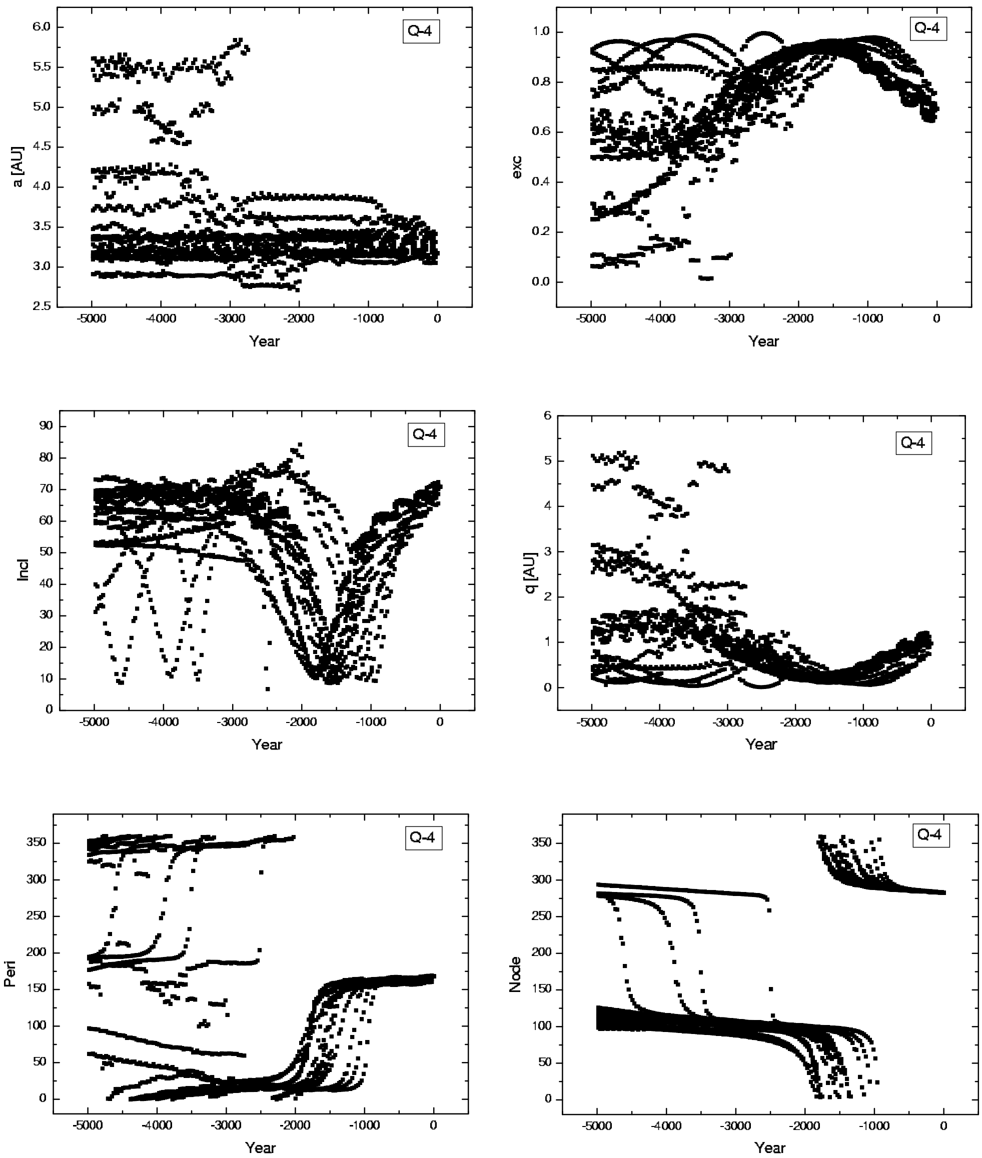

Figure 5. Quadrantids, the filament IV.

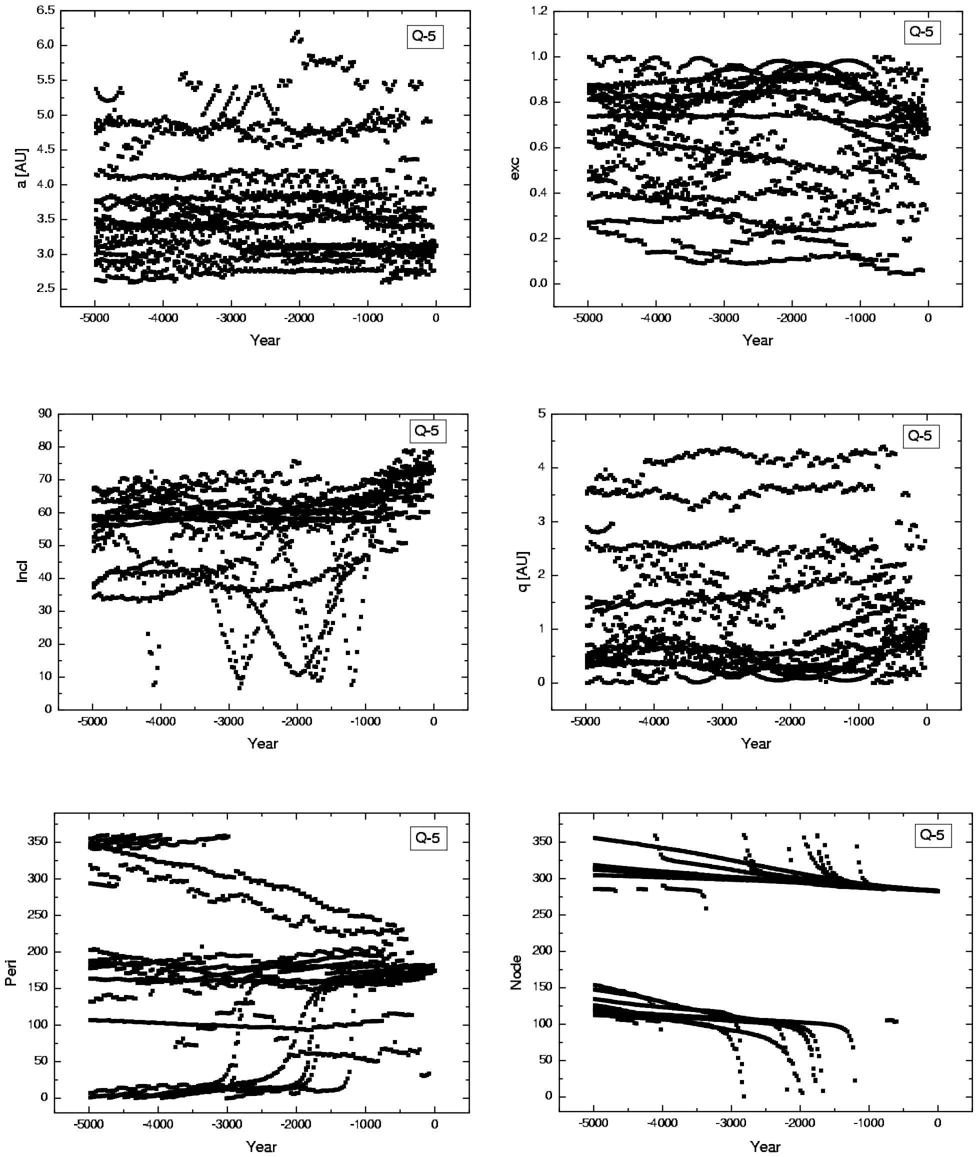

Figure 6. Quadrantids, the filament V.

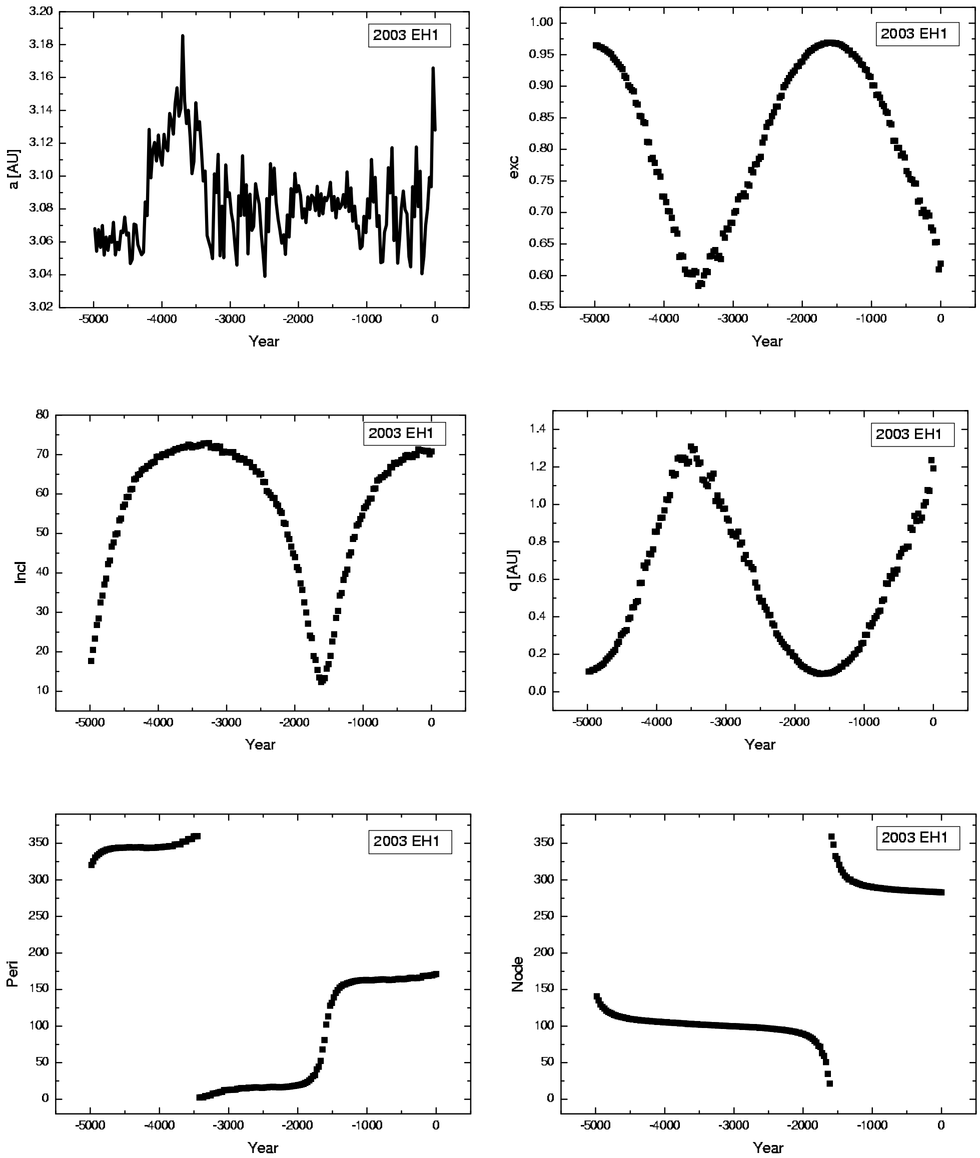

Figure 7. Asteroid 2003 EH1

nant of a larger parent body of the stream. Additional three filaments have their origin most likely in some other so far unknown bodies forming together with 2003 EH1 and probably with 5496 (1973 NA), comets 96P/Machholz and 1491 I a complex. A more conclusive solution asks for additional precise orbits of the Quadrantid meteors and a systematic monitoring of the stream activity.

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