Quadrantids

2003 EH$_1$ and the Quadrantid shower

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Photographic observations of the Quadrantid shower in 1995 by members of the Dutch Meteor Society showed little sign of the diffusion created by frequent close encounters with Jupiter. From this, I suspected that the parent was still among the meteoroids, difficult to observe because it may no longer be active. On March 6, the Lowell Observatory Near-Earth Object Survey first spotted this asteroid and since the orbit was refined significantly by other observers in the next 48 days, I now find it very close to that expected for the Quadrantid parent. The identification of a dust trail in the orbit of 2003 EH$_1$ (the Quadrantids) identifies this object as a (now likely extinct) comet nucleus that appears to be the remnant of a larger object that broke up about 500 years ago. Only a breakup can account for both the young age and the large amount of mass in the stream. Efforts to link the orbit of 2003 EH$_1$ to that of comet C/1490 Y1 await a better orbit for 2003 EH$_1$, but do not seem to exclude the possibility that this sighting was associated with that breakup.

Received 2003 December 23

1 Introduction

The Quadrantids (Sauval, 1997; Fisher, 1930) is our most intense shower with rates peaking at Zenith Hourly Rate = 130 meteors/hr. Until now, it has been the only major shower with no known parent body. It was long thought that the comet had moved away from the meteoroid stream. This idea came about when it was found (Hamid & Youssef, 1963; Williams et al., 1979; Hughes et al., 1979; Hughes et al., 1980) that the orbit rotates very rapidly due to numerous close encounters with Jupiter. About 1 500–4 000 years ago, the orbit was inclined by only 13° and the meteoroids approached the Sun to within 0.10 AU. Today, the orbits of Quadrantid meteoroids are at a steep angle of 71° and do not come closer than 0.78 AU to the Sun.

2 Locating the parent body

Based on this rapid evolution, Bruce McIntosh (1990) first suggested that the newly discovered comet 96P/Machholz (now with $q = 0.12$, $i = 60°$) has a sibling relationship with the Quadrantid shower. The comet was in an intermediate stage of this evolution and could be part of a larger complex of dust that includes the Daytime Arietid and southern Delta-Aquarid showers. It was later found that such a complex could be as old as about 5 400 years, or as young as 2 200 years (Jones & Jones, 1993). More recently, Iwan Williams and S.J. Collander-Brown (1998) concluded for the same reasons that asteroid 5496 (1973 NA) is a likely candidate (Table 1), more likely than 96P/Machholz and even more likely than comet C/1490 Y1 (see below).

The idea that the shower was evolved and old was based to a large extend on very poor observational data (mixed in with some much better results...). When observers of the Dutch Meteor Society, in a photographic campaign led by Hans Betlem and a multi-station video effort led by Marc de Lignie, finally had a clear night on January 3, a total of 36 were obtained that came out very similar, with a small dispersion in radiant positions and an interesting stratification in speed and position.

That was very surprising, because Jupiter is supposed to rapidly disperse such orbits in a more or less random manner. Each time Jupiter is near the aphelion of the shower, some meteoroids will be relatively severely affected. Over time, that results in a rapid broadening of the stream. Only if the age of the shower is very young may we expect to find the parent still among the meteoroids.

Based on the measured dispersions of meteoroid orbits, and compared with the dispersion found in the models by Iwan Williams and Zidian Wu (1993), I concluded that the stream was no older than about 500 years (Jenniskens et al., 1997). Because most of the meteoroids escaped being ejected altogether, I suspected that the comet would also survive those close encounters with Jupiter. I predicted that an asteroid-like object would be found among the meteoroids and provided an approximate orbit of this parent, assuming that the Quadrantids would trace its path (Table 1).

Unfortunately, I was not certain where along the orbit the comet was hiding (the guessed position, a return in 2002.7, based on high rates seen in the past turned out to be less than half a year off). The results were published (Jenniskens et al., 1997) and I periodically checked the orbits of newly discovered minor planets for a possible parent.

3 Asteroid 2003 EH$_1$

Patience paid off last March. Although this comet is on a very steep orbit and passes by the Earth very quickly because the perihelion is near the Earth's orbit (see Figure 1), the comet does on occasion cross the field of view of the many active automatic asteroid search programs. The return in 1997 was not very favorable, but the return of 2003 was better. It was the Lowell Observatory Near-Earth Object Survey — LONEOS telescope (Observer B.A. Skiff) that first detected the asteroid. The initially published orbit was very imprecise and unlike that of the Quadrantids, but other observers followed

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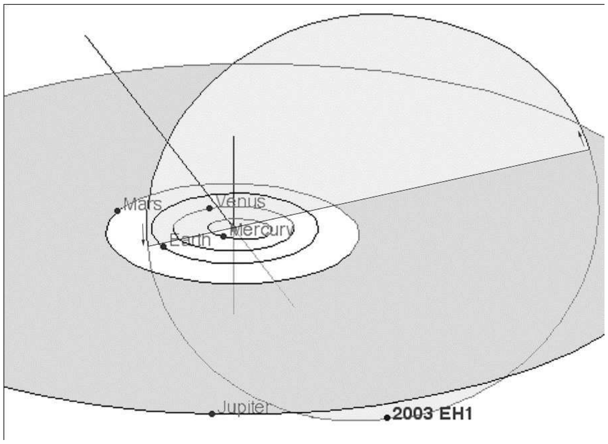

Figure 1 – Orbit and position of 2003 EH_1 in 2004 January 04.

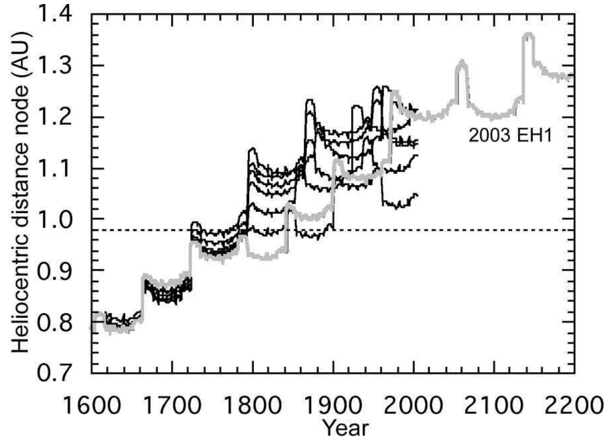

Figure 2 – Differential evolution of meteoroid orbits ejected from 2003 EH_1 in 1600 January relative to the evolution of the comet (gray line).

up and tracked the minor planet for 48 days (Marsden, 2003).

When I checked the asteroid database again recently, I found the updated orbit of minor planet 2003 EH_1 (meaning the 33rd object found during the period 2003 March 1-15) to be very close to the expected path of the Quadrantid parent body. Indeed, the theoretical radiant and speed for a shower from 2003 EH_1 (RA = 229.9°, DEC = +49°.6, Vg = 40.2 km/s at $\lambda_\odot$ = 282.9°; J2000) falls in the middle of those measured for the Quadrantids. The semi-major axis of 2003 EH_1 is exactly that measured for the Quadrantids, as are the inclination and argument of perihelion.

The node is a few tenths of a degree lower and the perihelion distance is significantly longer, now q = 1.19 AU while the Quadrantids have $q = 0.98$ AU. Indeed, the minimum distance between comet orbit and Earth (0.213 AU) is larger than typical for other annual showers (<0.04 AU).

To demonstrate that 2003 EH_1 is the Quadrantid parent, I calculated the orbit of the comet back in time, using the NASA/Horizons program, and found that the perihelion distance q changed the most rapidly and has moved outward in the last few hundred years. I tested only a few orbits, because the evolution has been studied in detail before, finding the same results (Hughes et al., 1981; Gonczi et al., 1992; Williams & Wu, 1993). The node has steadily declined at a gradual pace. A single perturbation of the parent body by Jupiter can move it significantly away from the stream center and that seems to have happened in a close encounter in 1972.

By ejecting particles with slightly wider orbits from the comet in 1600 (a random year, but set by the limit of the integration program used), I find that forward in time, the meteoroids spread in the expected manner relative to the position of the comet (Figure 2). The close encounters with Jupiter especially spread out the perihelion distances in a manner found before by Iwan Williams and Zidian Wu (1993).

The resulting shower is a ribbon, narrow in Earth's path, but wide in heliocentric direction. Based on the orbital evolution and the observed peak rates (McIntosh & Šimek, 1984; MacKenzie, 1980; Rendtel et al., 1993; Jenniskens, 1985), the spread in heliocentric direction can be measured. After taking that large dispersion into account, I find a total mass of about 1×10^{13} kg for grains in the range 10^{-9} kg to 1 kg (Jenniskens, 1994). That is about 300 times the amount of dust lost by comet 55P/Tempel-Tuttle in a single orbit. Hence, I suspect that the Quadrantid shower was created in a breakup of the parent comet about 500 years ago, from which 2003 EH_1 is a remnant (about 6×10^{12} kg in mass). More such remnants (presumably smaller) may be present among the Quadrantids (a potential impact danger).

4 C/1490 Y1

It is not necessary that this breakup was observed. When recent comet C/1999 S4 (LINEAR) broke apart into about 26 small fragments in 2000, it brightened only modestly. However, there happens to be a sighting of a comet C/1490 Y1 by Chinese, Korean and Japanese astronomers at about the right time for the proposed breakup 500 years ago. Ishiro Hasegawa (1979) first pointed out the similarity of the parabolic orbit calculated for C/1490 Y1 and the orbit of the Quadrantids. Iwan Williams and Zidian Wu (1993) investigated the case and found that a short period orbit would fit the observations as well. (They continued to propose that comet had a close encounter with Jupiter in 1650 and was ejected from the stream, and that the shower itself was 5 400 years old (Wu & Williams, 1992).)

Sadly, it turns out to be very difficult to tie the two objects together in a common orbit at this moment. 2003 EH_1 has too many close encounters in the backward integration. The calculations are very sensitive to even small changes in the initial orbit. Moreover, the initial orbit after the breakup could have been affected by the rocket effect of water vapor streaming away from the nucleus. Most solutions put the perihelion distance and inclination relatively low, which would cause the apparent orbit of the shower to shift lower in

Table 1 – Orbital elements of possible parent objects of the Quadrantid shower (J2000).

Object	T (UT)	q (AU)	e	a (AU)	ω (°)	Ω (°)	i (°)
Quadrantids (1) (2)		0.979	0.69	3.14	171.2	283.3	71.05+72.7 (3)
Variance		±0.002	±0.03	< 0.27	±2.1	±0.16	±1.0
2003 EH_1 (2)		1.1979	0.6176	3.1320	171.19	282.952	70.68
2003 EH_1 (2003)	2003 Feb 24.5	1.1924	0.6188	3.1277	171.368	282.938	70.798
Meteoroids ejected from 2003 EH_1 in 1600:							
(2)		1.157	0.628	3.114	173.38	283.08	71.24+72.4 (3)
Variance		±0.064	±0.020	±0.041	±1.20	±0.11	±0.56
Derived epoch of meteoroid ejection		-.-	~ 1400	-.-	~ 1300	~ 1420	~ 1290
C/1490 Y1 (4)	1491 Jan. 08.9	0.761	1.000	-.-	164.9	280.2	73.4
Not parents, but perhaps related:							
96P/Machholz	2002 Jan. 08.6	0.1241	0.9582	2.969	14.596	94.609	60.186
5496 (1973 NA)	2003 Sep. 28.0	0.8829	0.6373	2.435	118.124	101.109	68.003

Notes:
(1) See (Jenniskens et al., 1997).
(2) Epoch 1995 January 04.15, the moment the meteoroids would have been seen as meteors. These values are extrapolated.
(3) These double numbers represent two clusters of orbits that follow from the integrated orbits.
(4) See (Hasegawa, 1979).

the sky than suggested by the Chinese descriptions in 1491. One promising solution is shown in Figure 3. Indeed, several solutions were found that suggest there could be a common orbit. On request, Brian Marsden looked into this as well and confirmed that a common orbit might exist. A better result is expected when the orbit of 2003 EH_1 will be better known.

The identification of 2003 EH_1 as a remnant of the parent of the Quadrantid shower was announced on 2003 December 08 in an IAU Circular (Jenniskens, 2003) and a paper has been accepted for publication in the Astronomical Journal. All major showers now have a known parent body.

The identification of the Quadrantid parent is more than just a curiosity. NASA's Deep Impact mission is scheduled to visit comet 9P/Tempel 1 in July 2005 to probe the internal structure of that comet nucleus. The discovery of a cometary nucleus fragment in the orbit of a meteoroid stream makes it possible to investigate the mineralogical and morphological properties of cometary dust originating from much deeper inside a comet nucleus than is typically observed in meteor streams. Moreover, the identification of 2003 EH_1 as an extinct comet nucleus could provide a new target for future missions.

In the near future, the identification of the parent will lead to much improved meteoroid stream models and we expect to learn a lot about the breakup process by careful comparison with observations. For that reason, it is important to keep observing the Quadrantid shower in the years to come in order to measure if intensity variations and differences in the shower's peak time may be linked to perturbations by Jupiter.

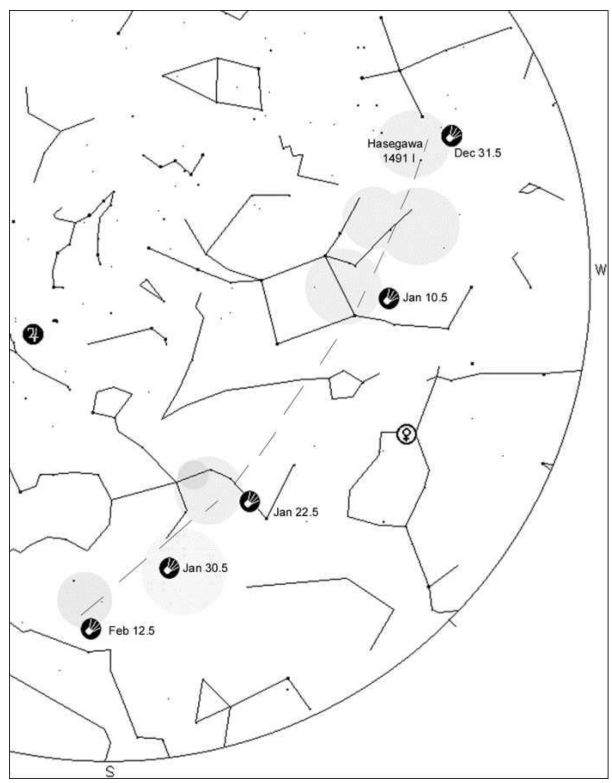

Figure 3 – Calculated position of the comet 1491 I for one possible common orbit with 2003 EH_1, compared to reported positions by Chinese, Korean and Japanese observers (gray circles, Kronk, 1999) and the best solution by Hasegawa (dashed line).

I thank Brian Marsden for his help in exploring the possibilities for a common orbit with C/1490 Y1, the Lowell Observatory Near-Earth Object Search for their successful program, and the observers of the Dutch Meteor Society for making an important contribution to this work. PJ is supported by NASA's Planetary Atmospheres and Planetary Astronomy programs.

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