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MINOR PLANET 2008 ED69 AND THE KAPPA CYGNID METEOR SHOWER

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ABSTRACT

Until recently, the kappa Cygnids (IAU#12) were considered an old shower, because the meteors were significantly dispersed in node, radiant, and speed, despite being 28–38° inclined. In 1993, an outburst of kappa Cygnids was observed, which implied that this meteoroid stream was relatively young, instead. At least some dust was still concentrated in dust trailets. Until now, no active comet parent body was known, however, and the wide 22° dispersion of nodes was difficult to explain. This work reports that a minor planet has been discovered that has the right orbital dynamics to account for the kappa Cygnids. Minor planet 2008 ED69 is intrinsically bright, with $H = 16.7 \pm 0.3$, and moves in a highly inclined orbit ($i = 36.3°$). With one node near Jupiter's orbit, the perihelion distance, longitude of perihelion, and node quickly change over time, but in a manner that keeps dust concentrated for a long period of time. The stream is more massive than the remaining body, and a form of fragmentation is implicated. A break-up, leaving a stream of meteoroids and at least the one remaining fragment 2008 ED69, can account for the observed dispersion of the kappa Cygnids in Earth's orbit, if the formation epoch is about 2–3 nutation cycles ago, dating to around 4000–1600 BC. Most of that debris now passes close to the orbit of Venus, making the kappa Cygnids a significant shower on Venus.

Key words: comets: individual (2008 ED69) – meteors, meteoroids – minor planets, asteroids

1. INTRODUCTION

The kappa Cygnids (IAU shower #12) is a weak shower with a peak Zenith Hourly Rate of no more than ZHR $= 2\ \mathrm{hr}^{-1}$ in most years, but which stands out in visual and photographic observations during the Perseid observing season because of common bright fireballs with multiple flares (Trigo-Rodriguez 1988; Arlt 1995; Jenniskens 1994, 2006). The shower was first mentioned by N. de Konkoly in 1874 and by W. F. Denning in 1877, when the meteors too were bright and irregular (Denning 1893; Kronk 1988).

The activity curve peaks at $\Omega = 145°$ and spreads over 22° (Jenniskens 1994; Arlt 1995). This diffuse nature of the stream was thought to imply an old shower age. The first orbital elements were published by Jacchia (1952), Letfus (1955), and Whipple (1954), who pointed out the large dispersion of nodes, which coupled to a 28–38° inclination and significant activity suggested that the debris was from a large comet.

In contrast, a young age was implicated when Jenniskens (2006) pointed out that the kappa Cygnids had an outburst in 1993, so that at least some of the matter was still concentrated in well-defined dust trailets. Since then, Triglav-Cekada (2006) has found that the kappa Cygnids were more active than usual in the period from 2002–2004, while Jenniskens et al. (2006) reported on high kappa Cygnid rates in 2007. All this suggests that the stream is relatively young and a parent body may still reside among the meteoroids.

The diffuse radiant and speed have caused some difficulty in defining the extent and mean orbit of the stream. Table 1 gives a summary of several such mean orbits. Lindblad (1995) split his group of candidate shower members (out of a sample of 3518 orbits) into four individual streams: the kappa Cygnids (9 members), the alpha Lyrids (11), the zeta Draconids (12), and the August Lyrids (6). His kappa Cygnid shower is listed in Table 1. Porubçan & Gavajdová (1994) assigned 13 photographic orbits to the kappa Cygnid stream and De Lignie & Jobse (1997) added 5 more orbits from intensified video observations, which are included in the analysis by Jenniskens (2006), from which dispersions were derived listed in Table 1

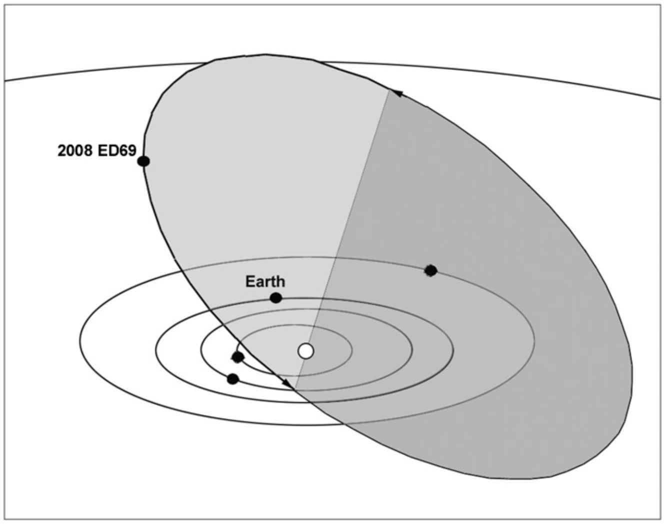

Figure 1. The orbit of minor planet 2008 ED69, and its position during discovery on 2008 March 11.

Jones et al. (2006) threw a wider net and studied the orbital evolution of 59 potential kappa Cygnid meteoroids. They found that most orbits evolved with a sinusoidal variation of the angular elements, perihelion distance, and eccentricity, with a period of about 2000 yr. A few orbits evolved differently, with a more rapid periodic variation of smaller amplitude, in our opinion, because the semimajor axis (a) of the measured orbit was close to the 2:1 mean-motion resonance with Jupiter ($a_J = 5.203$ AU). Jones et al. found two minor planets that followed this minority behavior: 2001 MG1 ($a = 2.504$ AU) and 2004 LA12 ($a = 2.511$ AU), but none that followed the large secular change typical of the bulk of kappa Cygnids.

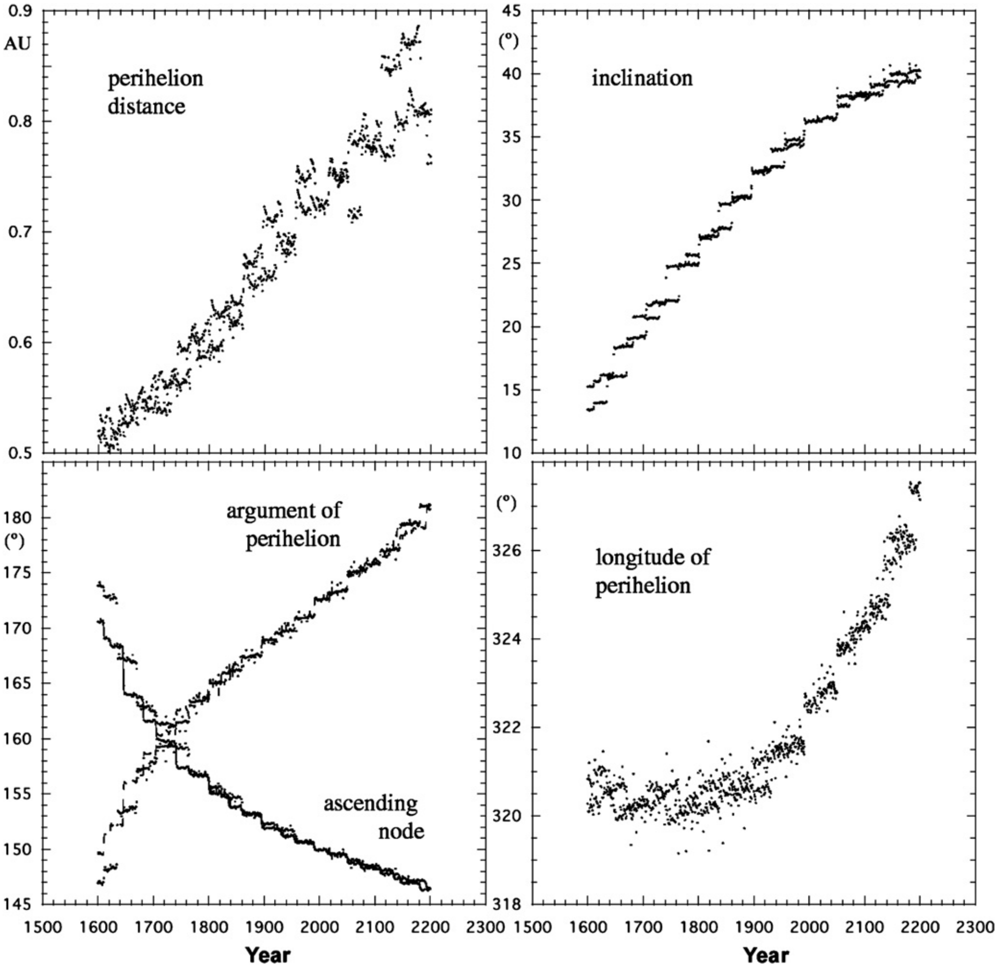

Figure 2. The orbital element evolution of 2008 ED69 over the period 1600–2200 AD. Two solutions are given, for the 8-day orbit (dark symbols) and for the 9-day orbit (gray).

Table 1
Orbital Elements of 2008 ED69 and the Kappa Cygnids

			2008 ED69			IAU Shower 12 (Kappa Cygnids)		
Ref.	MPEC 2008 F-11		Calculated		JPL 13	J	PG	L
#orbits	1				1	25	13	9
Epoch	2008–3-14.0	1600–08-21	2200–03-29	**∼2340**	2008–3-14.0	(1952–1989)		
$a =$	2.90 ± 0.05	2.93	2.90	**2.9**	2.884 ± 0.002	**3.0 ± 0.5**	3.513	3.724
$q =$	0.723 ± 0.004	0.516	0.810	**0.97**	0.7222 ± 0.0001	**0.97 ± 0.03**	0.991	0.983
$e =$	0.770 ± 0.003	0.824	0.721	**0.67**	0.7496 ± 0.0001	**0.75 ± 0.04**	0.718	0.731
$i =$	36.3 ± 0.16	13.45	40.2	**39.4**	36.276 ± 0.006	**33 ± 5**	33.0	36.8
$\omega =$	172.6 ± 0.6	147.0	181.1	**186.8**	172.70 ± 0.02	**192 ± 11**	197.7	200.5
Node =	149.9 ± 0.3	173.9	146.4	**145.9**	149.89 ± 0.01	**145 ± 10**	142.0	145.0
$\Pi =$	322.5 ± 0.7	320.9	327.5	**332.7**	322.59 ± 0.02	**337 ± 11**	339.7	345.5

This work reports that the newly discovered minor planet 2008 ED69 (Figure 1) does have the required large sinusoidal oscillation from a secular nutation cycle. The orbit of 2008 ED69 evolves toward an Earth-intersecting orbit, with orbital elements very similar to those of the kappa Cygnid shower.

2. ORBITAL DYNAMICS OF 2008 ED69

Minor planet 2008 ED69 was discovered on 2008 March 11 by the Catalina Sky Survey, which observed it at March 11.50–11.51 UT and at 12.46 UT. The discovery was confirmed by the Mt. Lemmon Survey at March 12.49–12.51 UT (Boattini et al. 2008). It was a faint +19.7 mag object at position R.A. = $16^{\mathrm{h}}14^{\mathrm{m}}34\overset{\mathrm{s}}{.}65$, decl. = $+25^{\circ}22'56\overset{''}{.}4$. At the time of writing, it was still approaching Earth and one purpose of this paper is to call attention to the gradually improving viewing conditions and upcoming return to perihelion, in the hopes of encouraging observations of taxonomy and the search for a possible cometary activity from this minor planet.

The very first published 1-day orbit, based on only 1-day of observations, had large uncertainties, with the semimajor axis $a \sim 3.36$ AU and the uncertainty in ω being 111°, for example. Even then, the inclination of the orbit and longitude of perihelion were already close to those of the kappa Cygnids. Subsequent observations established the orbit and it became clear that the ascending node of the orbit was close to Jupiter (Figure 1). The

4-day orbit had $a = 2.71 \pm 0.25$ AU, while the 9-day orbit now has $a = 2.883 \pm 0.041$ AU. This is sufficiently accurate to evaluate the secular evolution of the orbit over a period of a few hundred years. The meteoroid orbits are typically known with less accuracy.

The 8-day and 9-day orbits were integrated backwards and forwards respectively using the JPL/Horizons software (Figure 2). The secular evolution of the orbit is a rapid rotation of the nodal line relative to the line of apsides, a secular nutation cycle with a period of about 1800 yr. Since 1600, the node has changed over a large angle, from $\Omega = 172°$ in 1600 AD to $\Omega = 146°$ in 2200 AD.

In recent years, the orbital evolution is influenced by sudden changes caused by Jupiter's presence near the ascending node. The longitude of perihelion now changes significantly, and evolves from a low value of $\Pi = 321°$ toward the value typically found for the kappa Cygnids ($\Pi \sim 337°$).

Calculations show that in the next few hundred years, the orbit of 2008 ED69 will evolve into one approaching Earth's orbit (Figure 3). Presently, the descending node is at the orbit of Venus and 2008 ED69 is not listed as a potential hazardous object. When the perihelion distance reaches $q = 0.97$, the orbital elements (extrapolated from the sinusoidal variation found by Jones et al. 2006) compare well to those of the kappa Cygnid shower (Table 1).

At the same time, the evolution reaches a maximum in the heliocentric distance of the node, and intersecting orbits will occur for a range of nodes, reflecting different speeds of this secular evolution.

3. FORMATION EPOCH OF THE KAPPA CYGNID SHOWER

The speed of the orbital evolution along the nutation cycle depends critically on the semimajor axis. The 9-day orbit of 2008 ED69, with $a = 2.88$ AU, has a slightly slower evolution of q, for example, than the 8-day orbit with $a = 2.90$ AU, because the ascending node evolves slightly less close to Jupiter's orbit. This means that when meteoroids are ejected at perihelion, with a range in the semimajor axis, those with the values for the heliocentric distance of the node closer to Jupiter's orbit will evolve more rapidly into Earth-crossing orbits. The minor planet 2008 ED69 lags the evolution of the kappa Cygnid stream presently at Earth's orbit by only about 340 years.

Obrubov (1995) calculated that the long-term secular evolution of the mu Virginids (IAU#47, mean orbit by Lindblad 1971) could give rise to eight Earth-crossing orbits, possibly resulting in eight meteor showers. One of these showers was thought to be the kappa Cygnids. The time needed to form the necessary phase difference in the variation of longitude of perihelion and inclination was about 6000 years. Obrubov showed that the phase difference in the backwards integrated orbits of kappa Cygnids and mu Virginids was such that both orbits were in good agreement 6160 years ago, which amounts to about three nutation cycles.

3.1. A Model of Kappa Cygnid Stream Formation and Evolution

Following the initial report of this identification, described in the previous paragraphs, a meteoroid stream model was developed using the methods described in Vaubaillon (2004) and Vaubaillon et al. (2005). The 38-day orbit of 2008 ED69 (JPL 13 in Table 1, Column 6) was integrated backwards in time. The backward integration of the orbit is deemed reliable, because there were no major perturbations from close encounters with planets in the past 6000 years. Subsequently, a cloud of 30,000 meteoroids was ejected from the body when it arrived at perihelion, in three bins of particle size (0.1–1, 1–10, and 10–100 mm), and with an isotropic distribution of ejection speeds as described in Jenniskens & Vaubaillon (2007). The planetary perturbations on the orbit of each particle were calculated forward in time until the present epoch (AD 2008).

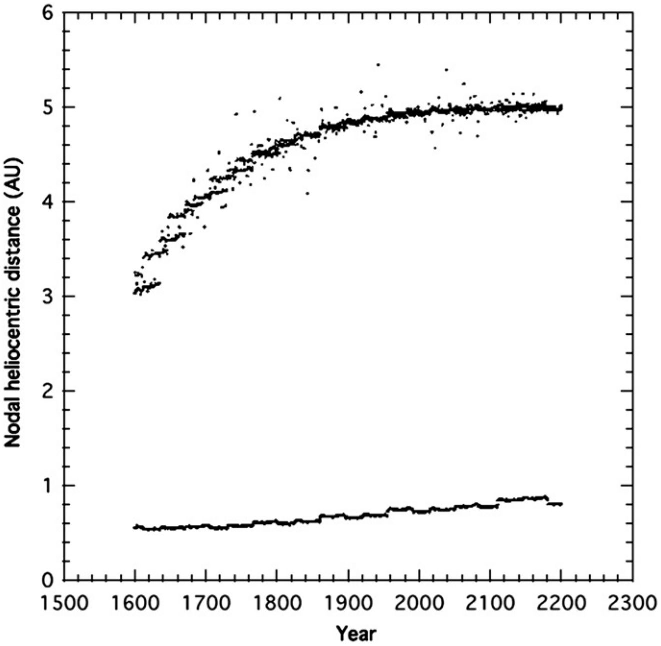

Figure 3. The heliocentric distance of the descending node (bottom) and ascending node (top) of the orbit of 2008 ED69 over the period 1600–2200 AD.

Figure 4 shows the distribution of nodes of all particles ejected in 4000 BC, 2000 BC, 1 AD, and 1001 AD, respectively, which correspond to about three nutation cycles ago, two cycles, one cycle, and half a cycle, respectively. The calculations show that ejection 1000 years ago would not have generated sufficient dispersion for the shower to be detected at Earth. On the other hand, ejection around 2000 years ago, or earlier, would have created sufficient dispersion to move particles in Earth's orbit.

Figure 5 compares the calculated dispersion of nodes to that of the observed distribution, derived from visual observations of kappa Cygnids in the period 1988–1991, summarized by Jenniskens (1994). Care was taken to derive the kappa Cygnid rates only from plotted meteors, so that contamination with sporadic meteors was minimized.

The calculated dispersion of nodes for a 2000 BC ejection peaks at the observed time of the kappa Cygnid shower, but so does the 4000 BC ejecta. In contrast, the 1 AD ejection peaks slightly later than observed. The calculated dispersion is in reasonable agreement with observations, with the ascending branch being perhaps slightly steeper and shallower than observed. However, this could easily be ascribed to uncertainty in the observations, or the initial conditions of fragmentation.

3.2. Mass of Shower and Remaining Fragment

The intrinsic brightness of 2008 ED69, $H_N = 16.75 \pm 0.29$ mag, implies a diameter of about $D = 2.92 \pm 0.04$ km, if the albedo is $\alpha = 0.04$ and Equation (10.1) in Jenniskens (2006, p. 137) applies. This is the same size as that of minor

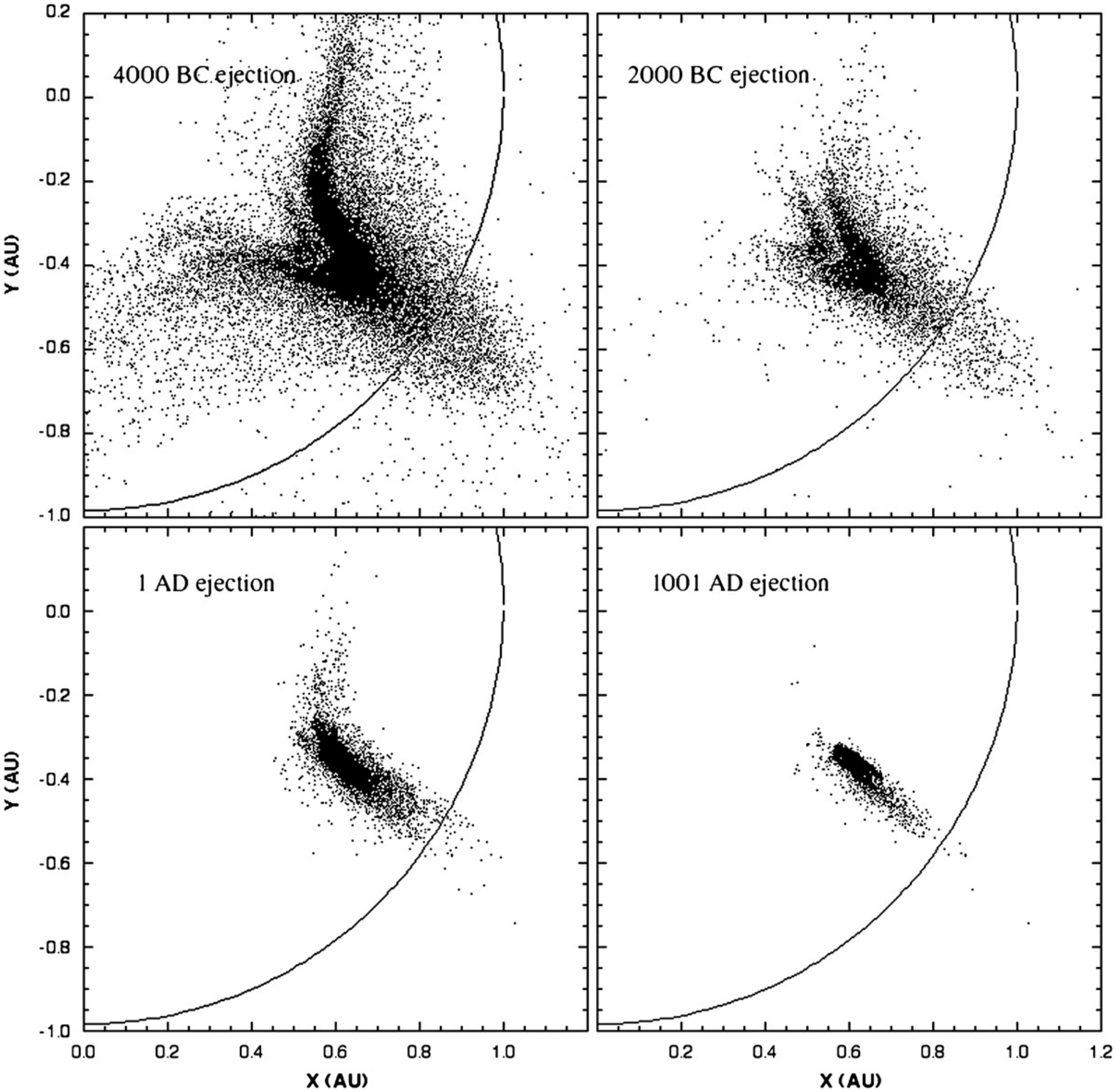

Figure 4. The position of the descending node in 2008, in ecliptic coordinates, of particles that were ejected from the backward integrated (38-day) orbit of 2008 ED69 in 4000 BC, 2000 BC, 1 AD, and 1001 AD, corresponding to three nutation cycles, two cycles, one cycle, and half a cycle from the present epoch.

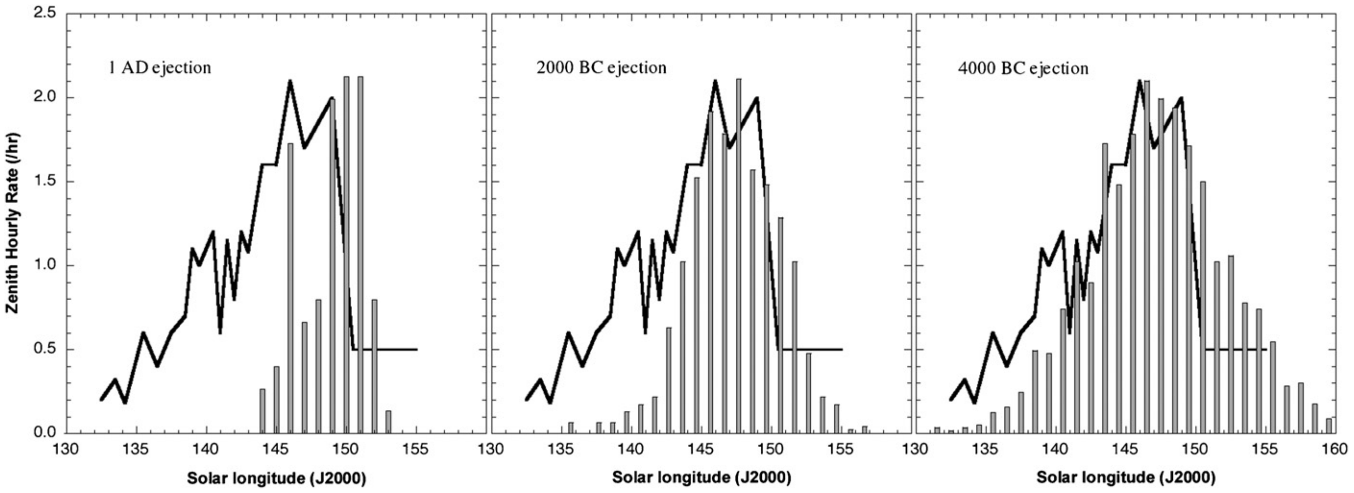

Figure 5. The distribution of nodes at Earth's orbit for particles ejected in 4000 BC, 2000 BC, and 1 AD, expressed in terms of the solar longitude of Earth arriving at the node. The model calculations are compared to the 1981–1991 averaged kappa Cygnid Zenith Hourly Rate activity curve derived by Jenniskens (1994).

Table 2

Mass Estimates of Meteoroid Streams and the Remaining Fragments of their Parent Bodies

Recovered fragment	Mass (10^{10} kg)	Meteor shower	Mass (10^{10} kg)	Formation eoch
2003 WY25	3	Phoenicids	10	~AD 1819
2003 EH1	1600	Quadrantids	1000	~AD 1490
Marsden-group	1000	Daytime Arietids	800	>AD 1059
Kracht-group	1000	Delta Aquariids	160	>AD 1059
3200 Phaethon	6900	Geminids	2800	~AD 1030
2005 UD	120	Sextantids	230	~AD 1000?
2004 TG10	360	Northern Taurids (part)	$\ll$10300	~AD 600?
2002 EX12	1700	Alpha Capricornids	520	~AD 10?
2008 ED69	1300	Kappa Cygnids	6600	~BC 1600–4000

planet 2003 EH1 ($H_N = 16.67$ mag), the remaining fragment in the Quadrantid stream (Jenniskens 2004). It is a common diameter for Jupiter-family comets. With a nuclear density of 1 g cm^{-3} (as used in our prior mass estimates, Jenniskens 2006), this would mean a mass of about 1.3×10^{13} kg. If the density is 0.5 g cm^{-3}, the mass would be half that value. If such a comet would have a normal cometary activity, the intrinsic brightness (at 1 AU from Earth and 1 AU from the Sun) would be $H_{10} = +7.5$ (Jenniskens 2006, p. 79, Equation (6.1)). In the case of a sudden break-up, the brightness could have been higher than that.

The mass of the kappa Cygnid stream can be evaluated based on the calculated distribution of dust in the model. Jenniskens (1994) derived a mass of $12.8 \pm 0.5 \times 10^{12}$ kg. It was assumed that dust had an orbital period of 9.5 yr, was evenly spread along the orbit, and the distribution perpendicular to Earth's orbit was 0.08 AU wide. For an even distribution with an orbital period of 4.9 yr, that of 2008 ED69, this would translate to $6.6 \pm 0.3 \times 10^{12}$ kg. The model shows that only one in ten particles ends up to a distance of ± 0.04 AU from Earth's orbit after 4000 years. Hence, the total mass in the kappa Cygnid stream is about 6.6×10^{13} kg.

4. IMPLICATIONS

If, indeed, the kappa Cygnid stream and 2008 ED69 originated from the same parent body, then the fragile properties of the kappa Cygnid meteoroids identify 2008 ED69 as a now dormant comet nucleus, rather than an asteroid from the outer belt. Verniani (1967) measured a low mean density of $\rho = 0.17$ g cm^{-3} for the kappa Cygnid meteoroids, as compared to $\rho = 0.32$ g cm^{-3} for the Perseids from comet 109P/Swift-Tuttle. Babadzhanov (1989) also found a lower mean density for the kappa Cygnids than for the Perseids. Jacchia et al. (1967) derived a higher progressive fragmentation index for these meteors, showing that the kappa Cygnids had their fragmentation frequency multiply more rapidly than the Perseids and were slowed down more efficiently than the Perseids when entering Earth's atmosphere. These results imply that the current annual kappa Cygnid meteoroids are more fragile than the cometary grains that were ejected by comet 109P/Swift-Tuttle about 5000 years ago, which is the approximate age of the core of the Perseid stream (Jenniskens 2006).

The identification that 2008 ED69 is the source of the kappa Cygnid shower is important, not only because the kappa Cygnids are known from common bright meteors in August, but also because here is another example of a massive meteoroid stream having been created in the recent past from a now (mostly) dormant parent body. The stream is more massive than the remaining minor planet. If 2008 ED69 would have been a regularly active Jupiter-family comet over the past 3600–6000 years, then the average dust production rate would have been between 5.4 and 9.0×10^{10} kg/orbit, which is implausibly high for a typical $H_{10} = +7.5$ Jupiter-family comet. A form of fragmentation is implicated that leaves a significant fraction of the parent object in dust, much like the break-up of 3D/Biela (Jenniskens & Vaubaillon 2007).

This paper is a continuation in a series to demonstrate that most of our meteor showers originated in this manner. Until very recently, this mechanism was dismissed (Williams 2004), in favor of a gradual release by water vapor drag as proposed by Whipple (1951) over a long period of time in the distant past, the active comet now having been lost or dormant.

In recent years, a number of asteroid-looking minor planets have been identified as the parent bodies of our meteor showers (Table 2). These included the Quadrantids (Jenniskens 2004), the Geminids (Whipple 1983) and the Sextantids (Ohtsuka et al. 2005), the Phoenicids (Jenniskens & Lyytinen 2005), the daytime Arietids and the delta Aquariids (Seargent 2002; Jenniskens 2006), and the alpha Capricornids (Wiegert et al. 2005; Jenniskens 2006). Other possible associations with less well-defined meteoroid streams are given in Jenniskens (2008). In light of this new evidence, Williams now supports the fragmentation hypothesis (e.g., Babadzhanov et al. 2008).

The kappa Cygnids now add a case that dates from slightly further back in time to about 3600–6000 years ago (Table 2). This may prove important for understanding the long-term physical evolution of meteoroids in interplanetary space.

In addition, most of the dust passes close to the orbit of Venus (Figure 4) and the kappa Cygnids are expected to be an important shower at Venus.

5. CONCLUSION

Minor planet 2008 ED69 has the right orbital dynamics to account for the kappa Cygnids. The object is as large as the body found in the Quadrantid meteoroid stream and is in a steeply inclined orbit ($i = 36.3°$), which makes it unlikely that the position of the minor planet among the meteoroid stream is a chance coincidence. The nodal line rotates rapidly relative to the line of apsides, with a period of about 1800 yr. At present, the orbit has one node close to Jupiter's orbit, temporarily causing a rapid change of the longitude of perihelion.

The stream was most likely created in a fragmentation event that lost an amount of matter similar to (or more than) that of the now recovered fragment. This is a common scenario for other identified shower and minor planet associations. The most likely formation epoch for the kappa Cygnid stream is 2–3 nutation cycles ago, about 3600–6000 years in the past.

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