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No Meteor Storms Expected from P/Machholz 2

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Abstract. P/1994 P1 Machholz 2 is the first Earth-crossing short-period comet to have been observed to have split since 3D/Biela about 150 years ago, and that fragmentation resulted in the Andromedid meteor storms of 1872 and 1885. Thus a pertinent question is whether meteor storms might result from P/Machholz 2 in the foreseeable future. Here we integrate its orbit to ascertain when the node might next occur near a heliocentric distance of 1 AU, and find that this is not anticipated for over 1000 yr, although some meteor activity in ~300 yr is possible. On such time-scales the recently-released debris will have dispersed, so that meteor storms are *not* expected from this comet.

1. Introduction

Comet 3D/Biela was discovered in 1826, recognized as being identical with objects seen in 1772 and 1805, and observed again in 1832. In 1846 and 1852 it was seen to have fragmented, presumably at some time during the 1830s (see Babadzhanov *et al.* 1991). In 1872 and 1885 spectacular meteor storms (the Andromedids) were observed as the Earth passed through the concentration of meteoroidal material liberated by the disintegration of 3D/Biela; there was another notable shower in 1892 (*e.g.*, Kresák 1993). Orbital precession/evolution and dispersal of the meteoroids has meant that no pronounced storms/showers have been seen since from this complex.

Clearly the discovery of another split short-period comet on an Earth-crossing orbit is of interest. The first such object to be discovered since 3D/Biela is P/Machholz 2 (P/1994 P1), which was discovered by Donald Machholz in 1994 August (*IAU Circulars 6053, 6059, 6108*). Within a few weeks of its discovery it was recognized by various observers that this comet had produced at least five well-separated fragments/nuclei (*IAU Circulars 6066, 6070, 6071, 6081, 6090*), denoted A to E. The separations are indicative of fragmentation events having occurred at low relative speeds ($\lesssim$ 1 m/sec) years to decades ago.

The comet and its observed fragments do not have nodes on the ecliptic near 1 AU in the present epoch, so that related meteor activity is not expected immediately. In order to discover whether a meteor storm produced by the debris from this cometary disintegration might be anticipated, we have numerically integrated the orbit of the main fragment (P/1994 P1–A) forwards in time over 2000 years, along with a number of other particle orbits meant to represent meteoroids ejected with different speeds from that nucleus. Since the possibility of historically-recorded meteor activity is also of interest, we have additionally integrated these particles *backwards* in time for 1000 years.

2. Method

The brightest fragment of this comet was observed from 1994 August through to December, when it became too faint for most telescopes. Using the 3.9 m Anglo-Australian Telescope we obtained astrometric positions for P/1994 P1–A in the last few days of 1995 March; P/1994 P1–D, which had been the brightest other fragment, was not identifiable in our images, although it should have appeared if it had faded quantitatively in the same way. The positions were found, by B.G. Marsden and S. Nakano, not to be fittable by a purely-gravitational orbit if positional uncertainties due purely to measurement errors are to be accommodated; that is, there seem to be significant non-gravitational forces acting on the comet. In view of this, any orbital integrations (such as those performed here) must be viewed with caution, and taken as referring only to hypothetical particles rather than the real orbital evolution of the object in question. However, from the present perspective (the prediction — or not — of meteor storms) such considerations are not of great significance.

We integrated an unpublished purely-gravitational orbital solution for fragment P/1994 P1–A, due to B.G. Marsden, derived from 141 astrometric positions obtained between 1994 August 17 and 1995 March 30; this orbit has elements as follows:

$$a=3.0131876\,\text{AU}; \qquad e=0.7502496; \qquad i=12.78720\,\text{deg};$$
$$\Omega=246.18154\,\text{deg}; \qquad \omega=149.25784\,\text{deg}; \qquad M=357.39914\,\text{deg};$$
$$\text{(Epoch 1994 September 05.0).}$$

All planets from Mercury to Neptune were included, using smoothed planetary elements (updated every 500 years) supplied to us by T. Quinn. This is accurate enough for our purposes as we are determining general patterns of orbital behavior, rather than attaching great importance to the evolution of single particles.

3. Results

The general orbital evolution of the comet we discuss in detail elsewhere (Asher and Steel 1996), but we note that its orbit appears to be remarkably stable over the time-scale of interest here (millennia) due to its persistence about the 9:4 mean motion resonance with Jupiter, this leading to random close approaches being avoided.

In Figure 1 we show the the variation between A.D. 1000 and 4000 of the heliocentric distance (R) to the ascending ('a') and descending ('d') nodes, based upon our integration of P/1994 P1–A. As can be seen, in the present epoch the descending node occurs at about 0.8 AU from the Sun, whilst the ascending node is at over 3 AU. Our integration shows that the nodal crossings would have been at close to 1 AU in about 1730–1750 (ascending), and about 1830–1850 (descending). Historical records of meteor showers associated with this comet are therefore not out of the question, although this would depend upon its history of meteoroid production. Looking into the future, nodal crossings close to 1 AU are not expected to recur until about A.D. 3100–3200 (descending) and 3200–3300 (ascending). These four points at which the node occurs at 1 AU make this a 'quadruple crosser' of the Earth's orbit; thus four distinct meteor showers could be produced, corresponding to the pairings of the ascending and descending nodes with the pre- and post-perihelion (nighttime and daytime) intersections (*e.g.*, see Babadzhanov and Obrubov 1992 [BO92]). However, in A.D. 1000–1200

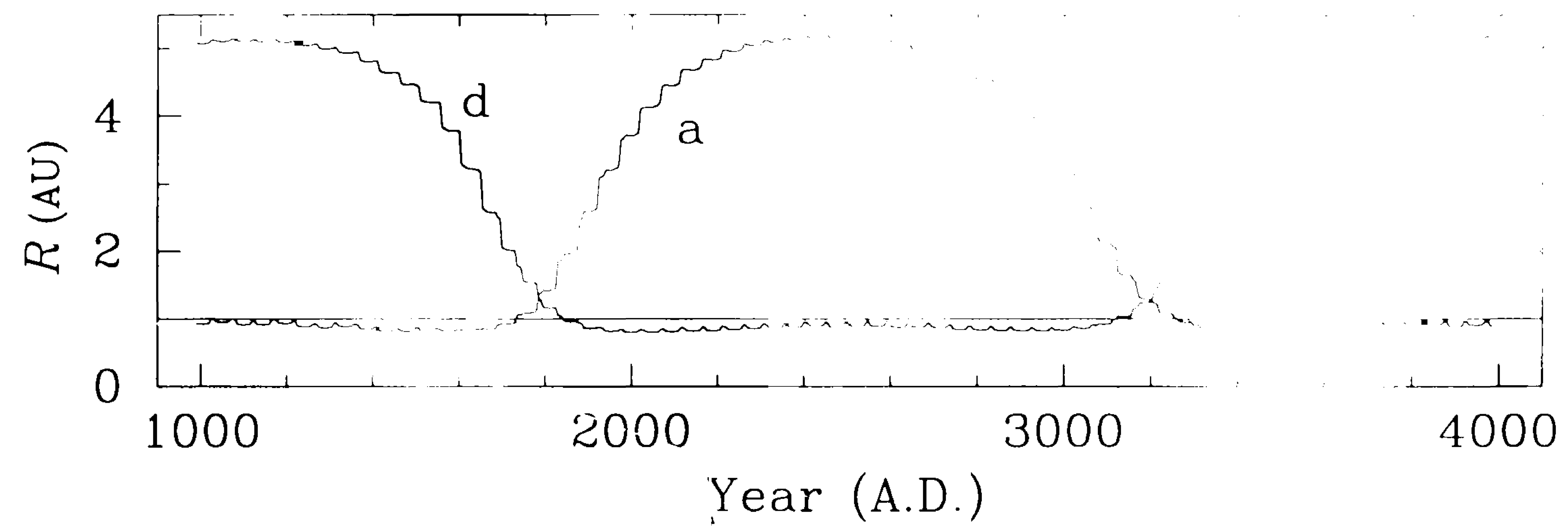

Figure 1. The variation of the heliocentric distance (R) to the ascending ('a') and descending ('d') nodes of P/Machholz 2 as a function of time. The horizontal line at 1 AU shows the approximate location of the terrestrial orbit (*i.e.*, assumed circular).

and 3800–4000 the ascending node occurs *just* inside the Earth's orbit, similar behavior being shown by the descending node in A.D. 2400–2600. A very small change in the heliocentric distance would make this orbit an 'octuple crosser' of the Earth (again, see BO92). By a remarkable coincidence, the best-established octuple crosser of the Earth is the other periodic comet discovered by Donald Machholz (96P/1986 J2 Machholz 1 = 1986 VIII). Eight meteor showers associated with 96P/1986 J2 are known — some of them being of high influx, such as the Quadrantids and the Delta Aquarids — and the orbital evolution of that comet has been studied by several authors (see BO92, and the various papers cited by Steel 1994); thus it is interesting to speculate whether P/Machholz 2, or some of its daughter fragments, might actually evolve in the same way and produce eight meteor showers.

In order to investigate the orbital evolution of meteoroids ejected by this comet, we integrated a total of 30 hypothetical particles. The first set of ten (Set A) had orbital elements identical to the comet, except that their semi-major axes (a) differed from that of the comet by values arranged in jumps of 0.0001 AU from −0.0005 to +0.0005 AU, with ejection near perihelion in the current epoch. The second set (Set B) had a varying by ten times as much (from −0.005 to +0.005 AU), and the third set (Set C) by another factor of ten (from −0.05 to +0.05 AU). For this orbit it turns out that the ejection speed in kilometers per second is roughly the same as the change in a in AU, so that these three sets correspond to ejection speeds of 0.5, 5 and 50 m/sec respectively.

For each particle we calculated, as a function of time, the minimum distance (D) between its elliptical orbit and the orbit of the Earth. In Figure 2 we plot the values of D for each of the above three sets. Clearly Set A, with low-speed ejection, does not have orbits sufficiently different from that of the parent comet to result in radically different orbital evolution over this time-scale (a few millennia). Set B (middle panel) shows some approaches to the Earth to within ~0.01 AU around A.D. 2500, but no Earth-crossing behavior until the fourth millennium. The effects of chaos (close approaches to a planet; the Earth in this case) are shown by the behavior of one wayward particle in Set B, at far right in Figure 2.

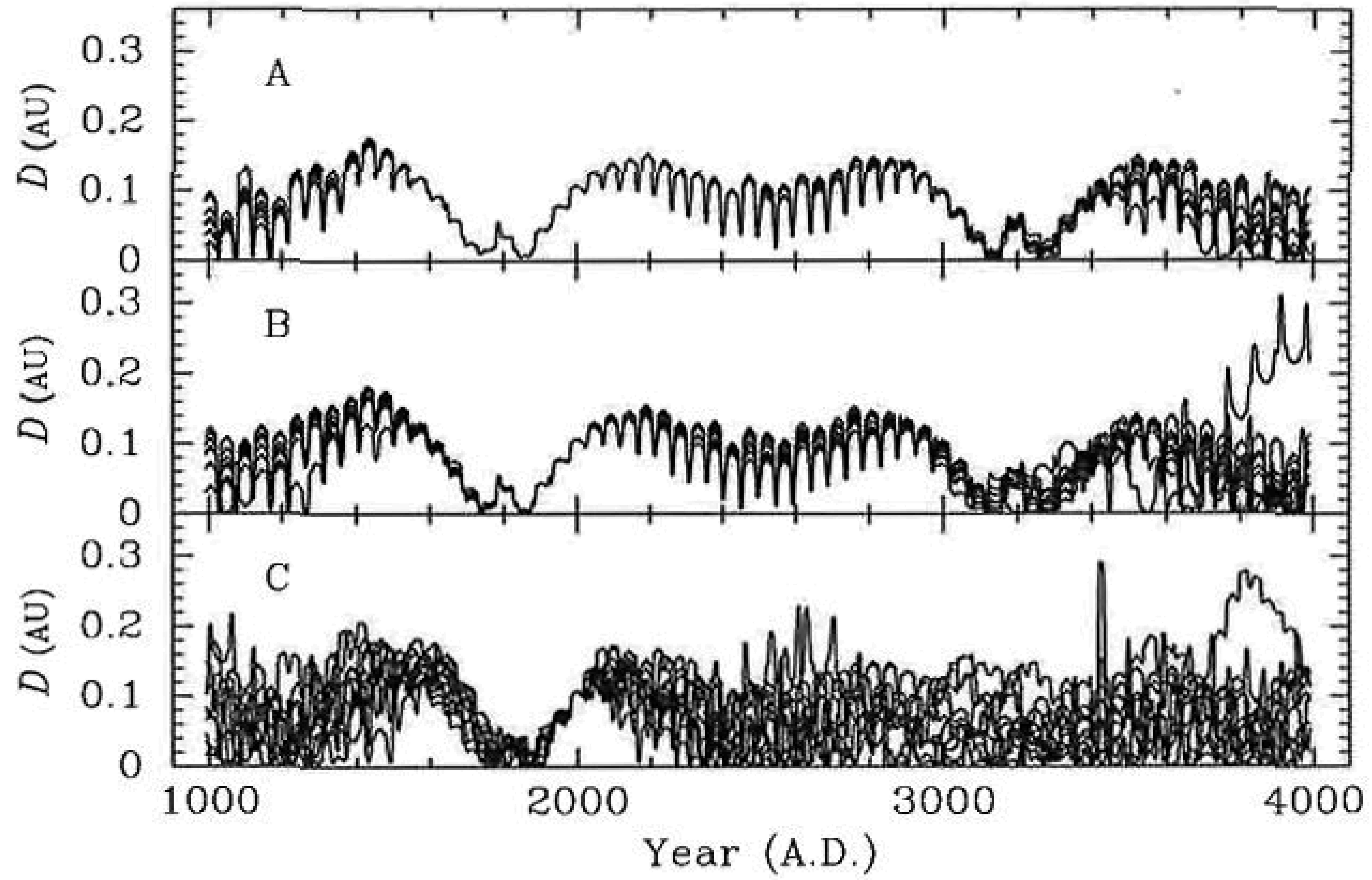

Figure 2. The distance D between the terrestrial orbit and the orbits of 30 test particles ejected from P/Machholz 2 at speeds of up to 0.5 m/sec (top panel, Set A), 5 m/sec (middle panel, Set B), and 50 m/sec (bottom panel, Set C).

It is Set C, with the larger ejection speeds, that show the greatest difference in behavior from their parent, as is to be expected. The bottom panel in Figure 2 indicates that such ejection speeds result in Earth-intersecting orbits within about 300 years of the present, with some particles from this set remaining on Earth-crossing orbits at all times after that. However, these particles will be widely dispersed from their parent, meaning that although a meteoroidal influx is to be expected, the dispersion argues against the occurrence of a meteor storm.

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