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DID EARTH-APPROACHING ASTEROIDS 3551, 3908, OR 4055 PRODUCE METEORITES?

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ABSTRACT

Orbital integrations show that Amor asteroid 3908 could have ejected one out of four plausible groups of meteorite producing fireballs during a collision in the asteroid belt. It has been suggested by others that such a collision may also have split asteroids 3551 and 3908. A member of this group of fireballs is listed as one of the better possibilities for recovery.

INTRODUCTION

Amor asteroids 3551 and 3908 approach the Earth on adjoining orbits and have nearly identical spectra (Cruikshank *et al.*, 1991). Their spectra also resemble those of nearby asteroid 4055 and main belt asteroid Vesta, even more intriguing is their similarity to laboratory spectra obtained from basaltic meteorites, i.e., Eucrites, Howardites, and Diogenites or HED meteorites. Drummond and Wisniewski (1990) suggest that 3551 and 3908 may be fragments of a common parent asteroid who's disruption created a stream of meteorite dropping basaltic meteoroids. Cruikshank *et al.* (1991) went one step further, suggesting that a Vesta-like asteroid is the parent or grandparent of all three Amor asteroids and the basaltic meteorites. Do meteorite dropping meteoroids move in orbits close to asteroids 3551 and 3908? Cruikshank *et al.* (1991) found no clear correlation between the present orientation of the asteroid orbits and occurrence of 41 HED meteorite falls. Drummond and Wisniewski (1990) claimed to find two meteor orbits in the Super-Schmidt photographic data by McCrosky and Posen (1961) and one Prairie Network fireball orbit by McCrosky *et al.* (1978) that satisfy both the D_{SH} and D' criteria commonly assumed to indicate stream membership (Drummond, 1981). A closer examination, using Southworth and Hawkins' (1963) exact formula for D_{SH} rather than the approximation that was also given by them, shows that no meteor orbits in these surveys satisfy both criteria. We examine meteorite producing fireball data from the Canadian Meteorite Observation and Recovery Project (MORP) listed by Halliday *et al.* (1989) and show, using orbital integrations, that a collision suffered by 3908 in the asteroid belt could have ejected one of the four tight groups proposed by Halliday *et al.* (1990) and that 3908 may have split from 3551 at that time.

METEORITE DROPPING FIREBALL ORBITS

Figure 1 shows orbital eccentricity versus reciprocal semimajor axis of meteorite dropping MORP fireball orbits listed by Halliday *et al.* (1989). Also shown are asteroids 3551, 3908, 4055, and Vesta with the region corresponding to the main asteroid belt. Earth-crossing orbits fall above the dashed line delineating perihelia at 1 AU (1/a < 1) and aphelia at 1 AU (1/a > 1). Meteorite dropping fireballs preferentially enter Earth's atmosphere near their perihelion with aphelia in the asteroid belt or beyond. Semimajor axes cluster near and inside the inner part of the asteroid belt. Meteoroids from the outer half of the belt are also abundant in the MORP data but are not listed as meteorite producing. This may be a

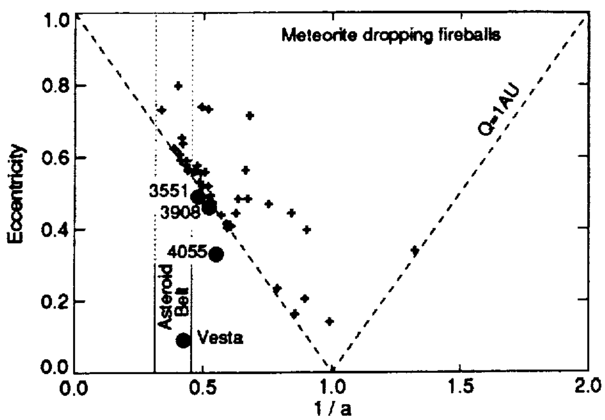

Figure 1. The shape and size of meteorite producing fireball orbits from the MORP survey, crosses, indicate that a large fraction could have been perturbed from the asteroid belt (solid lines) into Earth-crossing orbits (bracketed by the dashed lines). But there is an excess of less eccentric orbits with smaller major axes that may be related to the Amor asteroids 3551, 3908, and 4055.

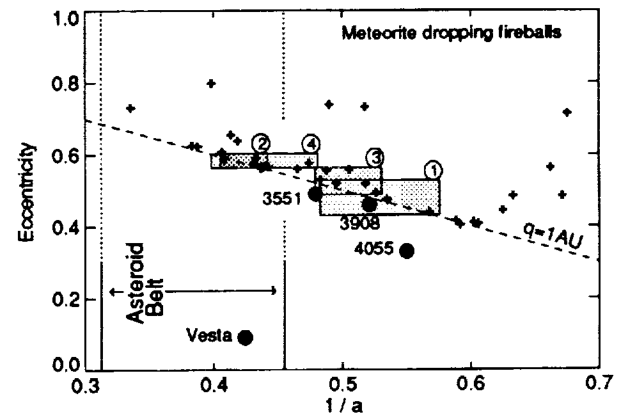

Figure 2. This detail of Figure 1 shows the extent of four groups of meteorite producing fireball orbits. Group 2 and 4 orbits may be perturbed directly from the inner edge of the asteroid belt while the orbits of group 1 and 3 are similar in size and shape to those of asteroids 3551 and 3908.

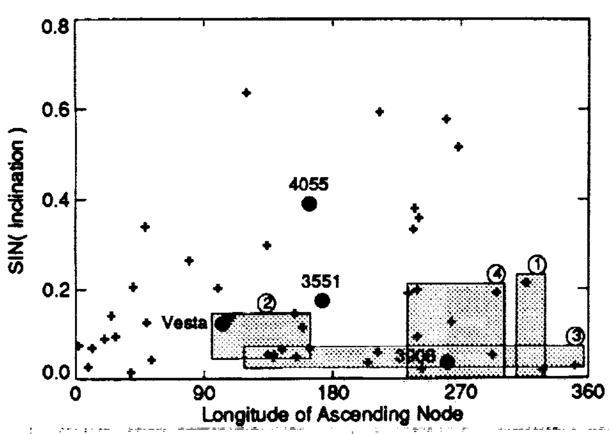

Figure 3. The orientation of group 3 orbital planes are consistent with low relative ejection velocities and differential precession. The other groups may have started out with higher relative velocities but are less affected by precession. Notice that the orientation of 3908's orbital plane is typical of group 3.

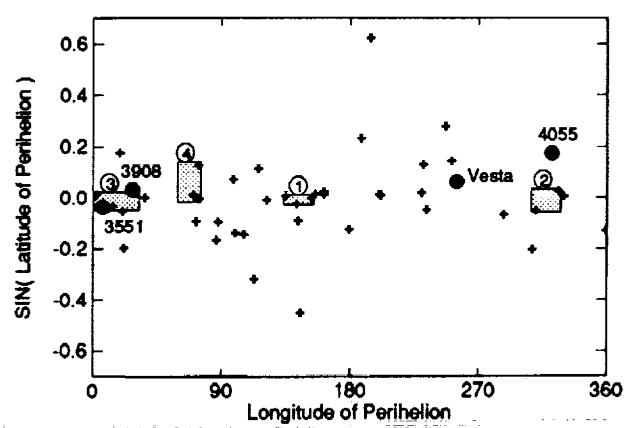

Figure 4. The major axis orientation of group 3 orbits is like those of asteroids 3551 and 3908. This orientation is relatively stable to planetary perturbations unlike the orientation of the orbital plane.

consequence of higher entry velocities or of morphology. Wetherill (1988) summarized the process by which main-belt asteroids and asteroidal meteoroids may be perturbed into Earth-crossing orbits. This article concentrates on the possible relation between the excess of orbits with semimajor axes just inside the asteroid belt and the set of Earth approaching asteroids proposed to be their parents. Figure 2 shows this region in more detail with the numbered zones corresponding to Halliday *et al.'s* (1990) groups of apparently related meteoritic orbits with the same numbers. The meteoroids in zones 2 and 4 may arrive more or less directly from the asteroid belt while zones 1 and 3 are close to or overlap asteroids 3551 and 3908 in this orbital parameter projection. The perihelion of 4055's orbit may be too distant for a tightly associated stream to intersect the Earth. Figure 3, shows that the primary difference between group 3 orbits is in the longitude of the ascending node, as is expected for an aging group of debris ejected at low relative velocity. The nodes of the low inclination orbits could spread about that of 3908 by differential precession. The orientation of the major axes is a relatively stable property of eccentric orbits and the tight association between 3908, 3551, and group 3 in Figure 4 is further evidence of their kinship to each other, at least between the meteoroids and 3908. A relation between 3551 or 3908 and group 4 could also be suspected.

ORBITAL EVOLUTION AND METEOROID EJECTION

Did orbits in zone 3 intersect the orbit of 3908 or 3551 in the past? If so, did this occur in the asteroid belt where chances for collisions is largest and could the relative velocities at the point of intersection be obtained by impact ejecta? Orbital integrations accounting for perturbations by the planets Mercury through Neptune show that the mean orbit of zone 3 meteoroids, as given by Halliday *et al.* (1990), intersected that of 3908 repeatedly over the last 10^4 years. Intersections last occurred approximately 4000 years ago, in the middle of the asteroid belt (2.75 AU) at relative velocities of approximately 100 m/s. Ejection velocities of that order are easily obtained in a collision.

Group 3 orbits also intersect the orbit of 3551 approximately 6000 years ago and then again 2500 years ago at relative velocities of the order of 500 m/s respectively more than 1 km/s. These are suspiciously high ejection velocities, especially that the low velocity dispersion required to form a stream as tight as the group 3 meteoroids would also have to be explained. The 6000 year old event would have taken place near 1.3 AU, a region between Earth and Mars where collisions are unlikely, but the more recent higher relative velocity intersection is in the asteroid belt near 2.8 AU. Both are unlikely ejection events.

Intersections with both asteroid orbits are primarily due to differential precession and repeat with approximately $2x10^4$ and $1x10^4$ year periods respectively, so that intersections occur again at the mentioned epoch and an integer times the period. Differential precession also makes the orbits of 3551 and 3908 intersect three times per 10^4 year period, approximately 9000, 3000, and 1000 years ago. The intersection 3000 years ago took place in the asteroid belt (near 2.8 AU). The other intersections occur near perihelion where chances for collisions are small.

In conclusion, it is possible that meteorite dropping fireballs were ejected from Amor asteroid 3908. If the narrow group of meteor orbits labeled No. 3 by Halliday *et al.* (1990) are related, they are likely ejecta from 3908. They would result from a collision in the asteroid belt, approximately $N(2x10^4)$ + 4000 years ago where N is an integer. One might speculate that this event coincided with a split between 3551 and 3908, approximately 3000 and an integer times 10^4 years ago considering that the periodicity is approximate. Drummond and Wisniewski (1990) and Cruikshank *et al.* (1991) suggested that asteroids 3551, 3908, and possibly 4055, may be related to each other and to meteorite dropping meteoroids based on spectral similarity and their present orbits. We have investigated the orbits and show that it is dynamically possible for one group of meteoroids to be ejecta from 3908. There is no evidence for recent ejecta from 3551 or 4055 but such ejecta may exist without being in Earth intersecting orbits.

That the group of meteorite producing fireballs may be ejecta from a collision in the asteroid belt is in contrast to the origin of another group of meteoroids thought to be related to an asteroid, the Geminids. Orbital integrations of 20 high precision meteoroid orbits showed that they were ejected from Phaethon near perihelion, probably during a cometary phase in the Parent's evolution (Gustafson, 1989).

According to *Halliday et al.* (1989) meteorites from group 3 members are probably ordinary chondrites but one, the Allan Sask event, also could be a carbonaceous chondrite. It fell on farmland of western Canada in October of 1979. Recovery and spectral classification of this meteorite would help test the link to the Amor asteroids. According to Halliday *et al.* (1989), another member fireball, the Middle Lake event of September 1975 remains one of the best possibilities for recovery

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