section of the Mars asteroids.* Families 5 and 30 predominate, accounting for 29 and 66% of the mass and 34 and 49% of the cross-section, respectively. This does not imply that they also contribute to the earthward flux of meteorites in these proportions. The relative importance of each of these groups depends not only on the masses but to an even greater degree on the orbital elements. These determine the life-time against planetary capture and the fraction of such captures effected by the Earth. Both can vary within nearly an order of magnitude (ÖPIK, 1963; ARNOLD, 1964). Nevertheless, it seems likely that these four families will dominate over the remainder of the Mars asteroids, some of which may in fact be stray members of these families.

For comparison, Figure 27 also includes the elements of the Apollo Group asteroids (triangles) and nine meteorites (squares). Both the Apollo asteroids and the Mars asteroids outside the asteroid belt proper ($a<2.1$ a.u.) have capture life-times short compared to the age of the solar system (ÖPIK, 1963). They must be replenished from some source, presumably the Mars asteroids in the region 2.2–2.8 a.u. In that case, they represent intermediate stages in the transfer of asteroidal material to terrestrial space. If the meteorites are derived from asteroids by the same process, their orbits should be similarly distributed. Of course, only the grossest similarity can be expected. ARNOLD (1964) has shown that the transition from Mars-crossing to Earth-crossing orbits causes major changes in the orbital elements, particularly a. In seven specific examples with initial a of 2.08–2.58 a.u., he obtained final a's some 0.5 to 1 a.u. smaller, with standard deviations of ± 0.4–0.6 a.u. The changes in e and $\sin i$ were less drastic, but still appreciable. To relate the observed orbits of meteorites and Apollo asteroids to their proposed source, it would be necessary to repeat Arnold's calculations with the starting elements of Families 5, 29, 30, and 31. Nevertheless, it is interesting that most meteorites in Figure 27 fall near an Apollo asteroid. This similarity of distributions shows up even more strongly in a diagram of e vs $\sin i$ (Figure 28).

4.223. *Contributions by Ring Asteroids*

Granted that the Mars asteroids are especially promising sources of meteorites, are they necessarily the only ones? They comprise less than 0.1% of the asteroid belt as a whole, and we must therefore make sure that their advantageous location is not more than offset by their small mass. In particular, we must try to assess the contribution of asteroids with perihelia lying barely outside the orbit of Mars. Even though they themselves do not cross the orbit of Mars, their debris will, if ejected with suitable velocities. This debris thus is a possible source of meteorites for injection into terrestrial space.

* The total mass of the known Mars asteroids is 3.8×10^{14} tons, for an assumed density of 3.6 g/cm^3. Although many undiscovered ones undoubtedly exist in the size range below $d \approx 20$ km (absolute magnitude $g > 12$), their contribution to the total mass is probably small. The true cumulative number N of the asteroids greater than diameter x is usually assumed to be given by the function $N = N_0 x^{-s}$, where s, the population index, has been estimated to be 1.6 (ÖPIK, 1960) or 2.0 (KUIPER, 1964, private communication). A correction for the undiscovered Mars asteroids might raise the total mass to 5 or 6×10^{14} tons at most. For comparison, the mass of the entire asteroid belt is estimated to be about 10^9 tons (Section 4.223).

A survey down to the 11th absolute magnitude ($d = 31$ km, assuming an albedo equal to that of Ceres or the Moon) reveals only four asteroids: 164 Eva ($d = 59$ km), 324 Bamberga ($d = 116$ km), 413 Edburga ($d = 31$ km) and 654 Zelinda ($d = 53$ km) with perihelia within 0.1 a.u. of Mars' aphelion (1.666 a.u.). Edburga and Zelinda

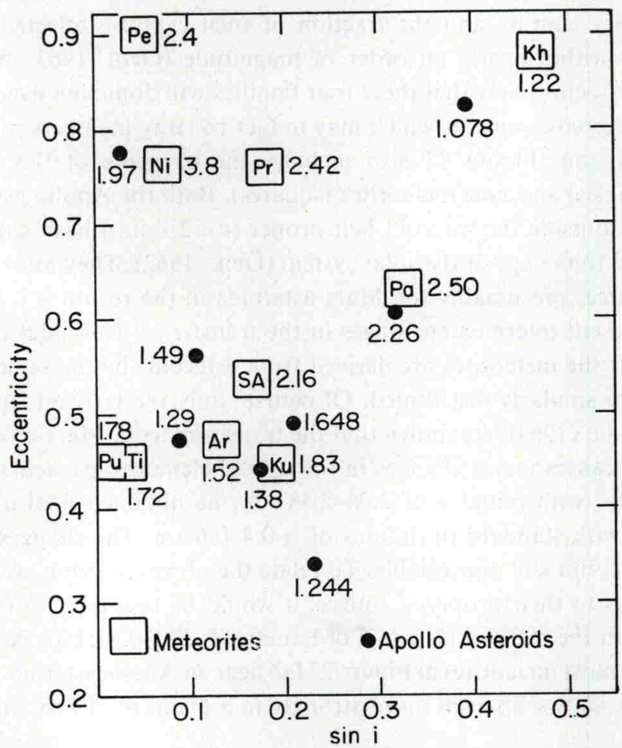

Fig. 28. Orbital elements of meteorites and Apollo asteroids. Similarity of distributions suggests that the meteorites, too, are stray members of the asteroid belt.

belong to families 29 and 5, respectively, and need not be considered here. Eva is possibly related to Family 30. Let us see, however, whether Bamberga can dispatch meteorites to the Earth.

To maximize the impact velocity let us suppose that Bamberga ($a = 2.6815$, $e = 0.340$) collides with an object on the inner fringes of the asteroid ring (e.g. $a = 2.20$, $e = 0$, $i = 0°$). From Öpik's (1951) formulae, the relative impact velocity is 7.5 km/sec, and the ejection velocities from Table 11 are therefore applicable. Bamberga's perihelion is 1.773 a.u.; if any of its debris is to reach the aphelion of Mars, it must be ejected with a negative velocity of at least -370 m/sec in the x-direction. But we see from Table 11 that even the material just outside the central funnel ($y = 25$) reaches velocities of only 351 m/sec. Ten projectile masses further outward ($y = 35$) the velocity has dropped to 251 m/sec. Moreover, only a small fraction of this material will have a large velocity component in the x-direction.