ORIGIN OF THE DOUBLE ASTEROID 90 ANTIOPE: A CONTINUING PUZZLE. S. J. Weidenschilling, F. Marzari*, D. R. Davis, and C. Neese, Planetary Science Institute, 620 N. 6th Avenue, Tucson AZ 85705 USA. (*permanent address, U. Padova).

At present, four main-beltasteroids are known to be binaries. Three have satellites much smaller than their primaries (45 Eugenia, 243 Ida, and 762 Pulcova). The fourth, 90 Antiope, is unique. At its 1996 opposition, Antiope displayed a classic eclipsing binary lightcurve with brightness varying by a factor of two [1]; at other orientations the amplitude is < 0.1 mag [2]. The lightcurve data are consistent with nearly spherical components separated by about twice their diameter. This model was confirmed by direct imaging with adaptive optics [3]. The equal mass ratio and large separation imply that this system has very high specific angular momentum, which makes it difficult to explain its origin.

The IRAS albedo and absolute magnitude of Antiope correspond to a single body of diameter 125 km; the binary components therefore each have diameter ~85 km, with distance ~170 km between their centers. Their orbital period of 16.5 hours implies a mass ~$4x10^{20}$ g for each, with density 1.3 g/cm^3. The total angular momentum is $6.9x10^{30}$ g cm^2 s^{-1}, of which about 90% is due to orbital motion, and 10% in spin of the components (assuming synchronous rotation). In natural units of $(GM^3/R)^{1/2}$ as defined by Chandrasekhar [4], the angular momentum has a value of 0.5, more than 4 times that of the Earth-Moon system, and well in excess of the rotational stability limit for a single self-gravitating body. Only the Pluto-Charon system, with smaller mass ratio but larger separation, approaches this value.

The nearest analogs to Antiope are the Trojan asteroid 624 Hektor, which may be a contact binary, and 216 Kleopatra, which is a bifurcated single body. Both have significantly lower angular momenta, and may be survivors from a primordial era of low-velocity accretion. Antiope is a member of the Themis family, so the binary cannot be primordial, but was formed during or after breakup of the parent body after high-velocity impacts came to dominate collisional evolution. We cannot rule out the possibility that two large fragments from the family-forming disruption event remained in mutual orbits as they escaped, but purely geometrical considerations make it unlikely that such large fragments could have sufficiently parallel velocity vectors to remain mutually bound while escaping the parent body's disruption [5]. Also, the nearly spherical shapes and low densities of the components strongly suggest that they are rubble piles, rather than competent fragments (the non-eclipsing lightcurves are consistent with equilibrium Darwin ellipsoids).

A single 100-km fragment from the Themis parent body might have experienced a later collision that shattered it and spun it up to fission. However, it appears to be impossible to do this by an impact at typical velocities for field asteroids. At 5 km/s, an impact with enough angular momentum would deliver enough energy to destroy the target body. A low-velocity impact of a relatively large projectile is necessary in order to supply enough angular momentum for binary fission without dispersing the fragments. We have computed impact disruption models, and find that the maximum allowed impact velocity and smallest projectile/target mass ratio are about 2 km/s and 0.01 (corresponding to a projectile diameter of ~25 km), respectively. For a mass ratio of 0.1, the allowed velocity range is about 0.2 - 1.0 km/s. Impacts in this range of velocity are extremely rare between non-family asteroids, which have mean relative velocities >5 km/s. However, Themis family members have low inclinations (typically 1-2 deg), and an atypical distribution of relative velocities between members that is nearly uniform between 1 and 5 km/s, with some higher and lower values. The Themis family contains 7 bodies of diameter ~ 100 km and ~100 bodies larger than 25 km. Usingthe collision probabilities of Bottke et al. [6], the probability of a low-velocity impact of such a projectile on a 100 km target is only of order 10^{-12}/y. Thus, an intra-family impact capable of forming a binary with Antiope's properties is unlikely, even if the Themis family is older than 10^9 y.

Another possibility for binary formation is the immediate aftermath of the disruption of the Themis parent body. There is some interval in which orbital elements are correlated, before jovian perturbations randomize the nodes and apsidal directions of the family members. We have integrated orbits of simulated members with the expected initial velocity dispersion of a few hundred m/s, and find that although full randomization takes ~10^5 y, impact velocities remain < 1 km/s for ~10^4 y. During this time, all intra-family collisions are in the velocity range that could produce the Antiope binary. However, the short time available makes such a collision unlikely. Using the algorithm of Dell'Oro and Paolicchi [7], we estimate that the probability of a collision between two bodies in the appropriate size range is of order 10^{-3} during this interval.

We conclude that the formation of a large binary is an intrinsically improbable event, even for the relatively favorable velocity environment within an asteroidal family. By this reasoning, Antiope should be unique. The discovery of another large binary with equal components in the main belt would be a serious challenge to our understanding of the collisional history of the asteroids.

References: [1] Hansen A. T. et al. (1997) *Minor Plan. Bull. 24*, 3. [2] Davis D. R. et al. (2001) in preparation. [3] Merline W. et al. (2000) *BAAS 32,* 1017. [4] Chandrasekhar S. (1969) *Ellipsoidal Figures of Equilibrium*, Yale Univ. Press. [5] Weidenschilling S. J. et al. (1989) in *Asteroids II.* [6] Bottke W. et al. (1994) *Icarus 107*, 255. [7] Dell'Oro and Paolicchi P. (2000) *Icarus*, submitted.