**Dynamical Evolution of the Hungaria Asteroids.** F. M. McEachern, M. Cuk, and S. T. Stewart. Department of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge MA 02138, USA. (fmmceach@fas.harvard.edu)

**Introduction:** The Hungarias are a population of asteroids with semi-major axes between 1.77 and 2.06 AU from the Sun. They typically have high inclinations (16°-34°), low eccentricities (<0.18), and include a range of taxonomic classes [1]. In addition to the S-type bodies common to the inner asteroid belt, there exists a high proportion of E-type asteroids, which are rare in all other populations. The region owes its name to the E-type asteroid (434) Hungaria, its largest specimen. (434) Hungaria has also been identified as the largest fragment of what is likely to be the region's sole asteroid family, created by a catastrophic collision 0.5 Gy ago [1]. A majority of the approximately 5000 Hungaria bodies are thought to be part of this family.

In this study we investigate some 30 of the largest Hungaria asteroids for which taxonomic classes have been assigned, specifically to shed light on their possible dynamical histories. Most Hungaria asteroid orbits are very stable, so it is natural to reason that they are primordial residents having formed in place or migrated there early on. However, this scenario is still an open question. They could have been there since the formation of the solar system, are interlopers, or a combination of both. It is the third possibility that interests us most.

**Method**: We integrated the orbits of 30 large asteroids and 8 planets using the symplectic integration package, HNBody [2]. We favoured large asteroids because they were more likely to be independent bodies, i.e. not members of the same family. Five 100 My simulations of the 38-body system were conducted, with identical initial conditions except for the asteroids' semi-major axes. The first simulation was run with initial conditions equal to present day ephemerides. A pair of simulations was run with initial semi-major axes equidistant from the true semi-major axes of the asteroids (one larger, the other smaller than present ephemerides values). Another pair of simulations was run having initial semi-major axes even further from the true values, again on either side.

These translations in semi-major axes account for past migrations the asteroids have likely experienced due to the Yarkovsky effect. The smaller translation assumes the Yarkovsky effect has been acting on the bodies continually for 0.5 Gy without a change in spin direction. The larger translation, meanwhile, assumes a Yarkovsky action time (uninterrupted by spin changes) of 1.0 Gy. Translation amounts were estimated from calculations of semi-major axis change rates vs. body diameter [3]. The long drift periods of 0.5 and 1.0 Gy were justifiable due to the sizes of the chosen asteroids. Larger bodies are more resistant to spin changes (whether caused by collisions or the YORP effect) that otherwise limit the timescale of steady, unidirectional Yarkovsky migration [3].

*The Yarkovsky Effect.* The Yarkovsky effect is a radiation-derived migration mechanism postulated over a century ago. Since then, two components of the Yarkovsky effect have been identified: one diurnal, the other seasonal, although both rely on the same physical principles. Light hits a body's surface, is stored as heat, and is later released in a different direction. This photon emission impels the body along or against its orbital motion (depending on the rotation direction or Yarkovsky component in question), which can cause significant secular changes in semi-major axis.

Prior to the 1990s, dynamicists explained the evolution of asteroids and meteoroids primarily with collisions and gravitational interactions with planets [4]. However, studies in the late 1990s [5][6][7] and early 2000s [8] highlighted a need for another process to accurately explain a confusing assortment of observations. For a lucid review of how important the Yarkovsky effect has proved to be for small body migration, see Bottke et. al. 2006 [3].

**Results**: The translations of the initial semi-major axes in our simulations represent the amount the asteroids may have drifted over the last 0.5 or 1.0 Gy to arrive at their current locations. Assuming the planets have not changed much in the last 0.5 to 1.0 Gy, these various starting positions also allowed us to effectively quintuple our sample size and better characterize the stability of the region. As expected, we find several narrow resonances with Mars affect the dynamical behaviour of the asteroids.

There are three categories of objects exhibited by our simulations: 1) Stable bodies away from resonances; 2) Bodies near resonances; and 3) Mars crossers. Although we filtered out all asteroids with eccentricities greater than 0.16 from this study (in order to avoid bodies whose perihelia reach within Mars' orbit), some Mars crossers inevitably pose as true Hungarias with eccentricities that are temporarily low enough to be included. Their erratic orbits are only revealed after integration.

The mean motion resonances with Mars can lead to heightened eccentricity, a subsequent close encounter with the planet, and ultimate loss from the region. However, because gravity is a conservative force, the reverse process can theoretically occur too. It is therefore possible that a non-Hungaria asteroid can have a close encounter with a planet and adopt a near-resonance semi-major axis between 1.77-2.06 AU. Our results show that while most Mars crossers visit the region transiently, some remain for many tens of millions of years. This moderate security is helped by the fact that Mars crossers in the Hungaria region have high inclinations and spend little time in the plane of Mars' orbit, where perturbations are stronger. The longer a visitor stays in the Hungaria region, the more likely it will be captured near a resonance. If so, its eccentricity can fluctuate– even decrease –thereby ending its Martian encounters. Given the relative strength of the Yarkovsky effect at this orbital distance, captured asteroids can be efficiently removed from a resonance, especially smaller ones.

There is hence a two way exchange between Mars crossers and proper Hungarias. Native asteroids can be injected into the inner solar system like main belt asteroids. Conversely, Mars crossing interlopers can achieve long term stability in the region, essentially becoming adopted Hungarias. The former will always be more prevalent than the latter, however, because "insiders" greatly exceed the number of "outsiders". From a statistical standpoint, the Hungarias have more individuals to cast off than Mars crossers have to repopulate the Hungarias. One objective for future work would be to devise a method of identifying stable "adoptees", what their characteristics are, and what percentage of the Hungarias they encompass in steady state.

*Work in Progress.* We are currently investigating the relationship between the taxonomic classes in the Hungarias. E types are extremely rare elsewhere in the solar system, so they are likely a native population in the Hungarias. By contrast, S types are common (especially in the inner main belt), and may comprise some interlopers. Examining whether their pattern of instabilitiy can be distinguished from the E types may offer clues to a potentially unique dynamical history. Warner et al.'s recent work [1] will allow identification of Hungaria family members among our sample. Knowing the center of the family and hence the direction family members have migrated, we then have a check on the actual dynamical histories of select asteroids. Similarly, further observational data on the direction of Hungaria group rotations will also indicate which asteroids have moved in what direction. These data may encourage a revision of our estimated Yarkovsky shifts over the last 0.5-1.0 Gy– in both amount and direction –allowing us to concentrate on simulations that more likely resemble past orbits. Analyzing the stability of these orbits alongside the classifications of the asteroids may reveal real discrepancies between the dynamical histories of E and S-type asteroids. These findings will give insight as to whether or not the Hungarias are indeed a repository for both primordial bodies and interlopers.

**References:** [1] Warner B. D. et al. Submitted to Icarus (Dec. 2008). [2] Rauch, K. P. and Hamilton, D. P. (2002) *DDA XXXIII Meeting,* Abstract #08.02. [3] Bottke W. F. Jr. et al. (2006) *Annu. Rev. Earth Planet. Sci*., 34:157-91. [4] Bottke et al. (2002) *Asteroids III.*, 395-408. [5] Farinella P. et al. (1994) *Nature,* 371, 315-16. [6] Gladman B. J. et al. (1997) *Science,* 277, 197-201. [7] Farinella P. et al. (1998) *Icarus,* 132, 378-387. [8] Zappala V. and Cellino A. (2002) *Icarus*, 157, 280-296.