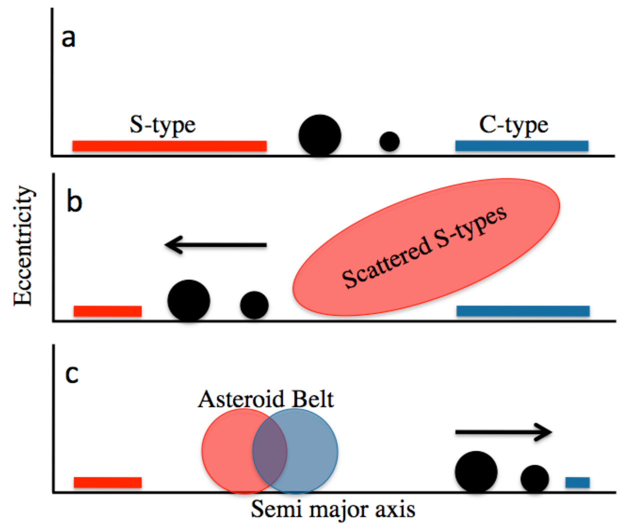
DEPLETION AND EXCITATION OF THE ASTEROID BELT BY MIGRATING PLANETS.

K. J. Walsh [1] A. Morbidelli [2] S. N. Raymond [3] D. P. O'Brien [4] and A. M. Madell [5], [1] Southwest Research Institute, Boulder, CO USA (kwalsh@boulder.swri.edu), [2] Obs. Cote d'Azur, Nice, France, [3] Lab. d'Astrophysique de Bordeaux, Floirac, France, [4] Planetary Science Institute, Tucson, AZ, USA, [5] NASA Goddard, Greenbelt, MD, USA

Abstract: We present a model of early inner Solar System evolution whereby the gas-driven migration of Jupiter and Saturn bring them to 1.5 AU, truncating the disk of planetesimals, before they migrate outward to their current locations. This model, dubbed "The Grand Tack", solves some outstanding problems for terrestrial planet formation, notably the small Mars/Earth size ratio. It also has vast implications for the excitation, depletion and origin of the asteroid belt. During Jupiter's two passages through the asteroid belt region it empties it of planetesimals. However, during Jupiter's outward migration it scatters some bodies onto stable orbits in the asteroid belt, leaving a depleted and dynamically excited population. We model the scattering with two asteroid source populations, one inside, and one outside the giant planets. This leads to an asteroid belt with overlapping populations from each of the two distinct source regions.

The Grand Tack: Giant planets in gaseous protoplanetary disks carve annular gaps in the disk and migrate inward in a process called type II migration. However, this evolution is very different for two planets in resonance. For Jupiter and Saturn, hydrodynamic simulations show that Saturn is eventually captured in the 2:3 mean motion resonance with Jupiter [1]. This configuration leads to a change in the net torques felt by the planets and a migration reversal, with both planets migrating outwards instead of inwards. This evolution persists while the planets remain in resonance until the disappearance of the gas disk. If Jupiter migrated in to 1.5 AU before reversing its migration, the inner disk of planetesimals and embryos would have been truncated at 1 AU, leading to initial conditions for terrestrial planet formation that reproduce all four terrestrial planets including Mars [2,3]. The question then becomes the fate of the asteroid belt after the planets migration.

Our simulations begin with two entirely separate parent populations of asteroids (Fig. 1a). First, there is the planetesimal disk interior to Jupiter, from ~0.7 AU out to 3.0 AU, determined by Jupiter's starting location - nominally set at 3.5 AU by estimates of the snow line location [4]. Between and beyond the giant planets is a second population of asteroids. We label the inner population "S-types" and the outer "C-types", however compositional variations within each population are expected.



During Jupiter's inward migration it scatters about ~15% of the planetesimals from the inner disk (the "S-types") onto orbits beyond 3 AU (Fig. 1b). When Jupiter and Saturn "tack" and begin their outward migration, they first encounter this scattered population of S-type material and only later begin encountering the "C-type" bodies that are initially located between and beyond the giant planets (Fig. 1c). We find that a fraction (0.5%) of the "S-type" material is scattered back inward, ending on stable orbits in the asteroid belt. A similar fraction of the "C-type" material also reaches stable orbits in the asteroid belt.

The final asteroid belt in our simulations is composed of material from both populations: we reproduce the observation that S-type material dominates the inner belt (interior to 2.8 AU) and that C-type material dominates the outer belt. Eccentricities are elevated among our final implanted asteroids, but are likely to be re-shuffled during the later events that occur during the Late Heavy Bombardment. The inclinations, which are less susceptible to later changes, cover a range of 0–20º, appropriate to match the asteroids' distribution when later Solar System evolution is accounted for [5].

References:

[1] Masset F. & Snellgrove M. (2001), MNRAS, 320, L55 [2] Hansen B. M. S. (2009), Astron. J., 703, 1131 [3] Walsh K. J. et al. (2011), Nature, 475, 206 [4] Ciesla F. J. & Cuzzi J. N. (2006) Icarus, 181, 178. [5] Morbidelli A. M. et al. (2010), Astron. J., 140, 1391.