Understanding the Formation Location and Evolution of Asteroids

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The asteroid belt is observed to be a mixture of objects with different compositions, with volatile-poor asteroids (mostly S-complex) dominant in the inner asteroid belt while volatile-rich (mostly C-complex) asteroids dominate the outer asteroid belt. While this general compositional stratification was originally thought to be an indicator of the primordial temperature gradient in the protoplanetary disk, the very distinct properties of these populations suggest that they must represent two completely decoupled reservoirs, not a simple gradient (e.g., Warren 2011). It is possible to create this general stratification (as well as the observed mixing) as the implantation of outer Solar System material into the asteroid belt by the early migration of the giant planets (e.g. the Grand Tack, Walsh et al. 2011). However, this presupposes that the inner and outer Solar System materials were still sorted in their primordial locations prior to any migration of the planets. The lack of a fully dynamically self-consistent model of giant planet core formation has prevented the study of how the core formation process itself may result in dynamical mixing in the early Solar System's history.

Recently, pebble accretion, the process by which planetesimals can grow to giant planet cores via the accretion of small, rapidly drifting sub-meter-sized bodies known as ``pebbles,'' (Lambrechts & Johansen 2012, Levison, Kretke & Duncan 2015) finally offers such a model. Here we show how the process of giant planet formation will impact the surrounding planetesimal population, possibly resulting in the observed compositional mixture of the asteroid belt, without requiring a dramatic migration of the giant planets. For example, preliminary runs suggest planetesimals from the Jupiter-formation zone can be implanted in the outer main belt via interactions with scattered Jupiter-zone protoplanets. This could potentially provide an alternative non-Grand Tack solution to the origin of many C-complex bodies, including Ceres. This may also explain many other properties of C-complex asteroids. For example, the presence of ammoniated phyllosilicates on Ceres, as identified by the DAWN mission, suggests it formed in a very cold location well beyond the current orbit of Jupiter (De Sanctis et al. 2015). Perhaps the carbonaceous chondrite samples returned by the OSIRIS-REx and Hayabusa 2 missions will also provide evidence that the parent bodies of Bennu and Ryugu formed in the giant planet region. What should we look for to prove/disprove this idea?