Using asteroid families to test planetesimal differentiation hypotheses

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There have been a series of papers (e.g., Weiss et al. 2008, 2010, 2012; Carporzen et al. 2011; Elkins-Tanton et al. 2011) suggesting that large planetesimals should have metamorphic grading within their crusts and possibly fully-differentiated interiors with mantles and cores. This is a very attractive hypothesis consistent with ideas that planetesimals form as large bodies (Johansen et al. 2007, Cuzzi et al. 2008, Morbidelli et al. 2009) and form early in Solar System history when radioactive heating is still important.

It is natural to look to the asteroid belt, our prime reservoir of terrestrial planet building blocks (i.e., left-over planetesimals), for confirmation of this idea. Asteroid families, long known to be the debris from catastrophic disruptions (Hirayama 1918, Michel et al. 2003) conveniently expose the interiors of these left-overs.

From simulations of the catastrophic disruption process, we know that not all material is ejected equally. Material near the surface is given higher expulsion velocities and divided into smaller pieces (Michel et al. 2004). Furthermore, while catastrophic disruptions appear to be a messy process, the largest remnants, including those formed by re-accumulation of smaller fragments, come from coherent sections of the progenitor body, although the extent and depth of these sections within the progenitor depend on its internal structure (Michel et al. 2014). This suggests that the ejected material should also maintain a coherent compositional structure (Michel et al., 2004). Therefore, compositional gradients within planetesimals should expose themselves within asteroid families.

While all asteroid families share a number of common features, there is a large diversity of membership numbers, progenitor masses, collision energy, formation times, and spectroscopic type and sub-type both between and within families (Zappala et al. 1995, Nesvorny 2012). This compositional diversity allows for a thorough exploration of the consequences of the hypothesized compositional radial gradients within the planetesimal population. The circumstantial diversity (membership number, progenitor mass, and collision energy) determines how exposed the interior of the planetesimal is.

Using estimates of the progenitor mass and the mass of the largest remnant (Tanga et al. 1999, Durda et al. 2007, Broz et al. 2013), we can assess the exposed nature of different asteroid families. Those with the lowest ratio of largest remnant to planetesimal mass are more exposed since more of their mass is within the asteroid family membership as opposed to being sequestered in the largest remnant. Furthermore, models of the planetesimal differentiation process are strongly size dependent since smaller bodies cool much more effectively. Therefore, progenitor mass is also a proxy for the expected degree of differentiation.

Using this set of proxies, we examine a diverse array of asteroid families to test the hypothesis of differentiation or metamorphic grading.