Planetesimal Growth through the Accretion of Pebbles. A. G. Hughes[1] and A. C. Boley[1], [1]University of British Columbia (ahughes@phas.ubc,ca, acboley@phas.ubc.ca).

The growth of planetesimals from small grains in protolanetary disks is fundamental to the process of planet building. However, this critical component of planet formation remains poorly understood. Planet formation models must explain the growth of small grains to planet sizes, but in all models of early growth there are several processes such as radial drift and particle bouncing that can inhibit mm-cm grains from reaching larger sizes. Observational data suggests that early growth must be rapid. If a small number of 100-km-sized planetesimals do manage to form in a disk, then these rare objects could rapidly accrete pebbles due to gravitational and hydrodynamical enhancement of the planetesimal's cross-section (Johansen et al. 2015). As grains flow past a large planetesimal, solids that have local gas-drag stopping distances comparable to the Bondi radius of the planetesimal are subject to inspiral and accrete onto the planetesimal from beyond even the gravitationally focused radius (see Figure 1). This enhanced accretion cross-section, paired with dense gas and high populations of small solids, enables a planet to grow at much faster rates for certain "intermediate" pebble sizes. For a range of likely disk conditions, the optimal particle size for this process of pebble accretion overlaps with chondrule sizes.

Relics from the planet formation epoch in our own solar system can provide evidence of the timescale of formation and growth of planets in general. Meteorite parent bodies that did not undergo any differentiation – chondrites - are minimally altered, contain information about the nature of solids and composition of the disk. Chondrites preserve pristine data on the primordial composition and formation process. Moreover, chondrites contain chondrules (0.1-1mm igneous spherules (Desch et al. 2012)) that remain largely unaltered since their incorporation into their parent bodies. Isotopic dating of chondrules can be used to infer formation timescales and the sequence of formation events. The chondrite Kaidun contains only millimeter-sized chondrules, indicating that it may have formed after chondrules were dominant but before the gas had dissipated and solids had grown to larger sizes. Kaidun suggests that young planetesimals can form entirely of chondrules, consistent with the formation of planetesimal seeds from grains entirely and subsequent growth through the accretion of pebble-sized objects. Low abundances of igneous rock in this and similar objects suggest that these bodies may have formed inwards of 2 au and migrated outwards later. Other data such as that of Schersten et al. (2006) suggest that some large planetesimals could have formed earlier than most chondrules, providing ample time for planetesimal growth via pebble accretion. If 100-km sized objects are able to form early on in the disk's history, growth by pebble accretion can build gas giant cores within the lifetime of gas in the disk. We run simulations of accretion rates at various distances in the disk, using a variety of pebble sizes to constrain when planetesimal growth is optimized. Our results indicate that growth is optimized inwards of 3 au, consistent with the results of Scott & Krott (2006).

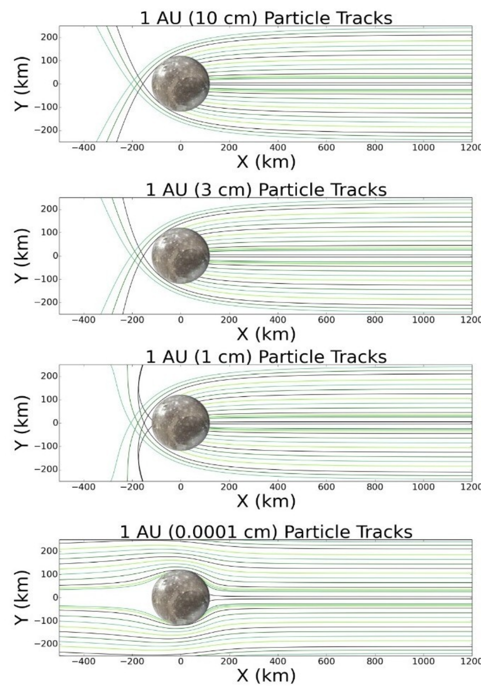

Figure 1: Tracks of traced particles streaming past the planetesimal at 1 au. Large particles (10 cm) are not slowed by gas drag and accrete from the gravitationally focused radius only. Very small particles become strongly coupled to the gas and mostly stream past the planetesimal. Chondrule-sized pebbles are accreted most efficiently - from beyond the gravitationally focused radius.

We present self-consistent hydrodynamic simulations with direct particle integration and gas-drag coupling to estimate the rate of planetesimal growth due to pebble accretion. We explore a range of particle sizes and disk conditions using a wind tunnel simulation. We also perform numerical analysis of planetesimal growth and drift rates for a range of stellocentric separations. The results of our models indicate that rapid growth of planetesimals is most efficient at very close stellar separations, and that at such distances centimeter-sized pebbles and larger are required for maximized accretion. At distances of a few au, the optimal particle size for accretion corresponds to about 0.3 mm.

References:

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