Collisional Winnowing of Planetary Materials

E ASPHAUG[1] AND A REUFER[1,2]

[1]School of Earth and Space Exploration, Arizona State University, Tempe AZ, USA
[2]University of Bern, Switzerland

The origin of planets is now appreciated as resulting from late and random giant collisions. Much of what happened in the first ~1-10 Ma is recorded in the isotopic geochemistry, but the bulk composition of planets – the presence or absence of a core, the volatile abundances – is determined by the last few giant impacts. So, perhaps, is final angular momentum. And so for instance, we believe that the Moon formed when something Mars-like crashed into Earth.

These last late collisions are stochastic, and as such are subject to two generalizations: (1) two most massive bodies (Venus and Earth) formed as amalgams of dozens of random collision, growing broadly similar in bulk composition; and (2) the final population of unselected outliers grew highly diverse. The first point is obvious, but the latter is less usual to think about, the attrition bias that applies to the unaccreted relics of planet formation.

Consider a few dozen pennies and a jar. Pick up a penny and flip it, and see if it comes up tails. If it does, put it in the jar; if not, mark it *h* and put it back on the table. Continue picking coins at random – previously flipped or otherwise – and flip them, and if they come up tails put them in the jar. Eventually the jar has all but a few of the coins. The ones left on the table are unusual, having been flipped 'heads' a few times in a row, on average.

In the context of planet formation, if there were once a few dozen planets that accreted to become the Earth and Venus, then we could consider Mars, Mercury and the Moon as the unaccreted (or partially accreted) leftovers, lucky pennies left on the table by the above analogy. These would be a highly diverse population according to an analogous statistical model. Some (e.g., Mercury, or Psyche) would have suffered two or more hit and run collisions, while others none, and others (e.g. Theia) shredded by partial mergers.

Mantle stripping occurs frequently during planet formation, leading to a systematic transfer or winnowing of composition. In pairwise encounters between planets of masses $M_1 > M_2$, material is stripped preferentially from M_2, and then accreted preferentially onto M_1 due to its larger gravitational cross section. If somehow M_2 manages not to be accreted by M_1, after one or more hit and runs, then it will have lost much of its mantle (and crust, and possibly ocean), materials that would find a permanent sink in M_1.