Mixing of Condensable Constituents with H/He During Formation of the Jupiter

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We present results of simulations of the growth of giant planets that incorporate the mixing of light gases with denser material that enters the planet as solids. We find that heavy compounds and gas begin to intimately mix when the planet is quite small, and substantial mixing occurs when the planet becomes roughly as massive as Earth, because even incoming silicates can then fully vaporize if they arrive in the form of planetesimals or smaller bodies. Nonetheless, most of the icy and rocky material accreted by a giant planet settles to a region in which vaporized ice and rock are well-mixed until the growing planet is several times as massive as Earth. Subsequently, planetesimals break up in a region that is too cool for all the silicates to vaporize, so the silicates continue to sink, but the water remains at higher altitudes. As the planet continues to grow, silicates vaporize farther out. Because the mean molecular weight decreases rapidly outward at many radii, some of the radially inhomogeneities in composition produced during the accretion era are able to survive for billions of years. After 4.57 Gyr, our model Jupiter retains compositional gradients; from the inside outwards one finds: (i) an inner core, dominantly composed of heavy elements; (ii) a density-gradient region, containing the majority of the planet's heavy elements, where H and He increase in abundance with height, reaching ~90% mass fraction at 30% of Jupiter's radius, with rocky materials enhanced relative to ices in the lower part of this gradient region and the composition transitioning to ices enhanced relative to rock at higher altitudes; (iv) a large, uniform-composition region (we do not account for He immiscibility), enriched relative to protosolar in heavy elements, especially ices, that contains the bulk of the planet's mass; and (v) an outer region where condensation of many constituents occurs. This radial compositional profile has heavy elements more broadly distributed within the planet than predicted by classical Jupiter-formation models. NASA's Juno spacecraft's measurements of Jupiter's gravity field also implies less concentration of heavy elements near the center of the planet than classical theoretical models. However, the preferred dilution of the core found in Juno-constrained gravity models is substantially larger than what is suggested by our accretion models, requiring some modification in the heavy element distribution. The compositional gradients in the region containing the bulk of the planet's heavy elements prevent convection, both in our models and the models that fit current gravity, probably resulting in a hot deep interior where much of the energy from the early stages of the planet's accretion remains trapped.