MIXING OF CONDENSABLE CONSTITUENTS WITH H AND HE DURING THE FORMATION AND EVOLUTION OF JUPITER.

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Introduction: Any attempt to explain the formation and evolution Jupiter should aspire to be compatible with the planet's current structure, the main features of which have been partially clarified by the *Juno* mission. Some aspects of that structure are still uncertain, but the key implication is the presence of perhaps twenty or thirty Earth masses of heavy elements (everything other than hydrogen and helium), with some tendency towards a central concentration of the heavy elements. Instead of the old well-defined core picture, Jupiter appears to have a "dilute" or "fuzzy" core, perhaps with a large region stabilized by mean molecular weight gradients. The substantial (factor of five or more) average enrichment in heavy elements over the solar composition must arise from some aspect of the formation process that we seek to understand, and the current radial distribution of heavies is presumably also affected by initial conditions (the origin story) as well as by any processes of redistribution after formation. The emphasis on the distribution of heavy elements is appropriate because most heavies are likely to arrive as condensed matter (pebbles and planetesimals) that is partially or totally decoupled from the gaseous nebula in which they form. A successful Jupiter model should also seek to explain the observed atmospheric abundances, the planetary heat flow and the magnetic field. We are particularly concerned with the first of these here, since it may be related to the assumed accretion story, or even to the delivery of material from deep down to near surface layers. However, our goal is not to compete with detailed models for the gravity and magnetic field, but to identify possible evolutionary scenarios leading to structures that are broadly compatible with what we see now.

Results: We present results of simulations of the growth of Jupiter that incorporate the mixing of light gases with denser material entering the planet as solids. We use the general methodology described in [1], but we now treat heavy compounds as arriving in planetesimals that are half silicate rock and half water ice by mass

Heavy compounds and gas begin to intimately mix when the planet is quite small, and substantial mixing of newly-accreted material occurs when the planet becomes roughly as massive as Earth, because even incoming silicate planetesimals can then fully vaporize. Nonetheless, until the growing planet is several times as massive as Earth, most accreted ice and rock remain in condensed form as they fall to a region where vaporized ice and rock are well-mixed. Subsequently, planetesimals break up where it 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 in much of the planet, 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 rock and water ice occurs.

This radial compositional profile has heavy elements more broadly distributed within the planet than predicted by classical Jupiter-formation models, but the core is less diluted than suggested by Juno-constrained gravity models. 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.

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Reference:

[1] Bodenheimer, P., Stevenson, D.J., Lissauer, J.J. and D'Angelo, G. 2018. *Astrophys. J. 868*, 138 (17pp).