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Formation, Evolution, and Future Exploration of the Giant Planets

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The giant planets are key to the mystery of the origin and evolution of the solar system and, by extension, extrasolar systems. Prevailing hypotheses of the giant planet formation include the core accretion model and the gravitational instability model, while the former is conventionally favored. At the heart of the classic core accretion model is the formation of a solid core of a critical mass of 10-15 Earth masses, followed by gravitational collapse of surrounding protoplanetary nebula that completes the formation of the planet. The core forms from agglomeration of grains of dust, refractory material, metals and ices and the volatiles they trap. The most volatile of the gases, hydrogen, helium and neon are captured last, gravitationally during the collapse phase. The atmosphere results from these gases and the volatiles initially trapped in and subsequently released from the core during accretional heating, and presumably mixed uniformly. The above formation scenario demonstrates that the core is critical to the formation of the giant planets, and that the well-mixed atmosphere is expected to reflect the composition of original elements. Since heavy elements (>4He) comprise much of the core mass, their determination is crucial to any model of the giant planet formation. The core accretion model predicts solar abundances of heavy elements, all relative to H. The Galileo probe measurements at Jupiter in 1995 changed all that. The probe revealed that the heavy noble gases, argon, krypton and xenon, were each enriched relative to solar by roughly a factor of two, whereas the enrichment factor was 4-6 for carbon and nitrogen and about 2.5 for sulfur. Thus, these heavy elements were found to be enriched relative to solar by a factor of 4(+/-2), and the enrichment factor is non-uniform. One missing element is oxygen, which is crucial since water ? the principal reservoir of oxygen in Jupiter ? was presumably the original carrier of the core-forming heavy elements and could make half of the core mass, or greater. The Galileo probe entered a five-micron hotspot ? the Sahara Desert of Jupiter ? where water vapor was severely depleted. O/H was measured to be 0.4x solar in this site. It is unknown whether water is depleted everywhere on Jupiter or enriched like the other heavy elements. The Juno microwave radiometers will measure and map water to deep tropospheric levels in Jupiter in July 2016. It is only then one could assess whether Jupiter is indeed carbon rich and oxygen poor like the exoplanet hot Jupiter WASP-12b, or not. Even after the inventory of key heavy elements has been completed for Jupiter, comparison with the other gas giant, Saturn, is essential. However, with the exception of carbon, no reliable data exist on other heavy elements for this planet or, for that matter, the icy giant planets, Uranus and Neptune. Considering the fundamental importance of this science, which only entry probes can deliver, the US NRC Planetary Decadal Survey (Visions and Voyages, NRC, 2011) has recommended a Saturn probe as one of four candidate missions in the New Frontiers class and a Uranus orbiter and probe as one of four candidate missions in the flagship class for the 2013-2023 decade. Relevant publications may be downloaded from www.umich.edu/˜atreya for personal use.

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