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Formation of Saturn and Jupiter and their Atmospheres

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The heavy elements ($>^4$He) in the well-mixed atmosphere are key to understanding the formation of Saturn and Jupiter and the origin and evolution of their atmospheres. The conventional model of the giant planet formation, known as the core accretion model, requires first the formation of a substantial core of 10-15 Earth masses, followed by gravitational capture of the most volatile of gases, hydrogen, helium and neon. The core is made from gradual agglomeration of grains of rock, metal, ice and the volatiles trapped in them. During accretionary heating, volatiles are released from the core and form the atmosphere together with hydrogen, helium and neon. The above formation scenario implies solar abundances of heavy elements, as does the gravitational instability model. However, the heavy elements (relative to H) in Jupiter's atmosphere were determined by the Galileo probe to be enriched by a factor of 4 ± 2 compared to the sun. Galileo is the only probe ever to enter a giant planet to make in situ composition measurements. Moreover, the inter-elemental ratios were uneven, hence non-solar. One key elemental ratio, O/H, could not be determined as the probe entered a meteorologically anomalous region that was exceptionally dry. The O/H ratio is a key missing piece of the formation puzzle, however, as water was presumably the original carrier of heavy elements that formed the core and could have made up more than half of the core mass. This situation will be rectified in 2016 when the Juno microwave radiometer (MWR) experiment measures and maps Jupiter's water abundance to pressure levels of several hundred bars, hence the O/H ratio.

Unlike Jupiter, the only reliable data presently available for Saturn are on C/H from methane, and P/H from phosphine in the upper troposphere/stratosphere by remote sensing. However, P/H in this region is not a good indicator of either the deep P/H or the enrichment of other heavy elements in Saturn, since phosphine is in thermochemical disequilibrium in the upper atmosphere. If Saturn's O/H is subsolar, a measurement of water even at shallow depths could allow its determination. CO could also provide a handle on O/H, but requires a knowledge of vertical mixing in Saturn's interior. The measurement of water and phosphine, respectively by the MWR and the Jovian InfraRed Auroral Mapper (JIRAM) on Juno, together with prior data on CO at Jupiter will provide a useful guide for determining convective mixing in Saturn as well. As in the case of Jupiter, an entry probe is essential for determining the bulk composition in Saturn's atmosphere, especially the elemental abundances of He, Ne, Ar, Kr, Xe, O, N and S and the critical isotopes, D/H, ^{3}He/^{4}He, ^{18}O/^{16}O, ^{13}C/^{12}C, ^{15}N/^{14}N, ^{34}S/^{32}S and the isotopes of the heavy noble gases. This would enable the type of comparative study of Saturn and Jupiter that is crucial to unraveling the mystery of the formation and evolution of the solar system and, by extension, extrasolar systems. [www.umich.edu/∼atreya to download pdf's of related publications]