EGU21-1403
https://doi.org/10.5194/egusphere-egu21-1403
EGU General Assembly 2021

Measurements by Probe and Orbiter Critical for Models of Formation and Evolution of Uranus and Neptune

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Core accretion is the conventional model of the formation of gas giants, Jupiter and Saturn. According to this model, a core of 10-15 Earth-mass forms in 1-5 Myr from non-gravitational collisions between submicron size grains of dust − ice, rock, metals, and trapped gases. Most volatile of the gases, hydrogen, helium, and neon, can then be gravitationally captured, completing the planetary formation. Unlike gas giants, formation timescale of the icy giant planets (IGPs), Uranus, and Neptune by core accretion at their present orbital distance exceed the typical lifetime of the protoplanetary nebula. Thus, there are two alternatives: IGPs begin their formation also in the neighborhood of Jupiter and Saturn (5-10 AU) and then migrate out to their present orbital distances (20 and 30 AU), or they form by a fast process, called the gravitational instability model that requires only 1000’s of years for to form them from clumps in massive protoplanetary disks at their present orbital distances. Core accretion followed by migration is still the favored scenario for the IGPs, considering the latter model does not satisfactorily explain the measured elemental abundances in the giant planets. Moreover, the exoplanet observations also support the core accretion theory. The heavy elements are key constraints to formation and migration models. Those found in the condensible, reactive, and disequilibrium species (C, N, S, O) require measurements in the deep well-mixed atmosphere, which is below kilobar levels at the IGPs, according to our thermochemical models. Extension of the models deeper shows formation of alkali metal and rock clouds at several kilobars and greater. These cloud aerosols provide extensive sites for adsorption of volatiles, irrespective of any volatile loss by sequestration or clustering in a purported water ocean or ionic-superionic ocean proposed previously [1]. Fortunately, abundances and isotopic ratios of the noble gases, He, Ne, Ar, Kr and Xe, will provide necessary constraints to the formation and evolution models of the IGPs [1,2], and entry probes deployed to only a few bars can measure them precisely. In addition, complementary measurements of gravity, magnetic field, stratospheric composition, and depth profiles of certain condensible gases from an orbiter are important to make [1,3]. Atmospheric temperature vs. pressure from exosphere to the probe depth of 5-10 bars is essential also for the interpretation of the measurements. An orbiter-probe mission that makes use of a Jupiter gravity-assisted trajectory to deliver affordable payload mass requires launch between 2030-2034 for Uranus and 2029-2031 to Neptune [1]. Such a mission requires no new technology. This presentation will discuss the new models mentioned above and possible mission scenarios. The US Astrobiology

and Planetary Science Decadal Survey committee is presently reviewing the White Papers submitted in support of a mission to the icy giants in the 2023-2032 decade [e.g., 4], and would make a recommendation of mission priorities for NASA in 2022. [1]Atreya et al. Space Sci. Rev. 216:18; [2]Mousis et al. Space Sci. Rev. 216:77, 2020; [3] Fletcher et al. Trans. R. Soc. A 378: 20190473, 2020; [4]Beddingfield et al. arXiv.2007.11063, 2020.