

# Scientific rationale for Uranus and Neptune in situ explorations

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# Motivation and Background

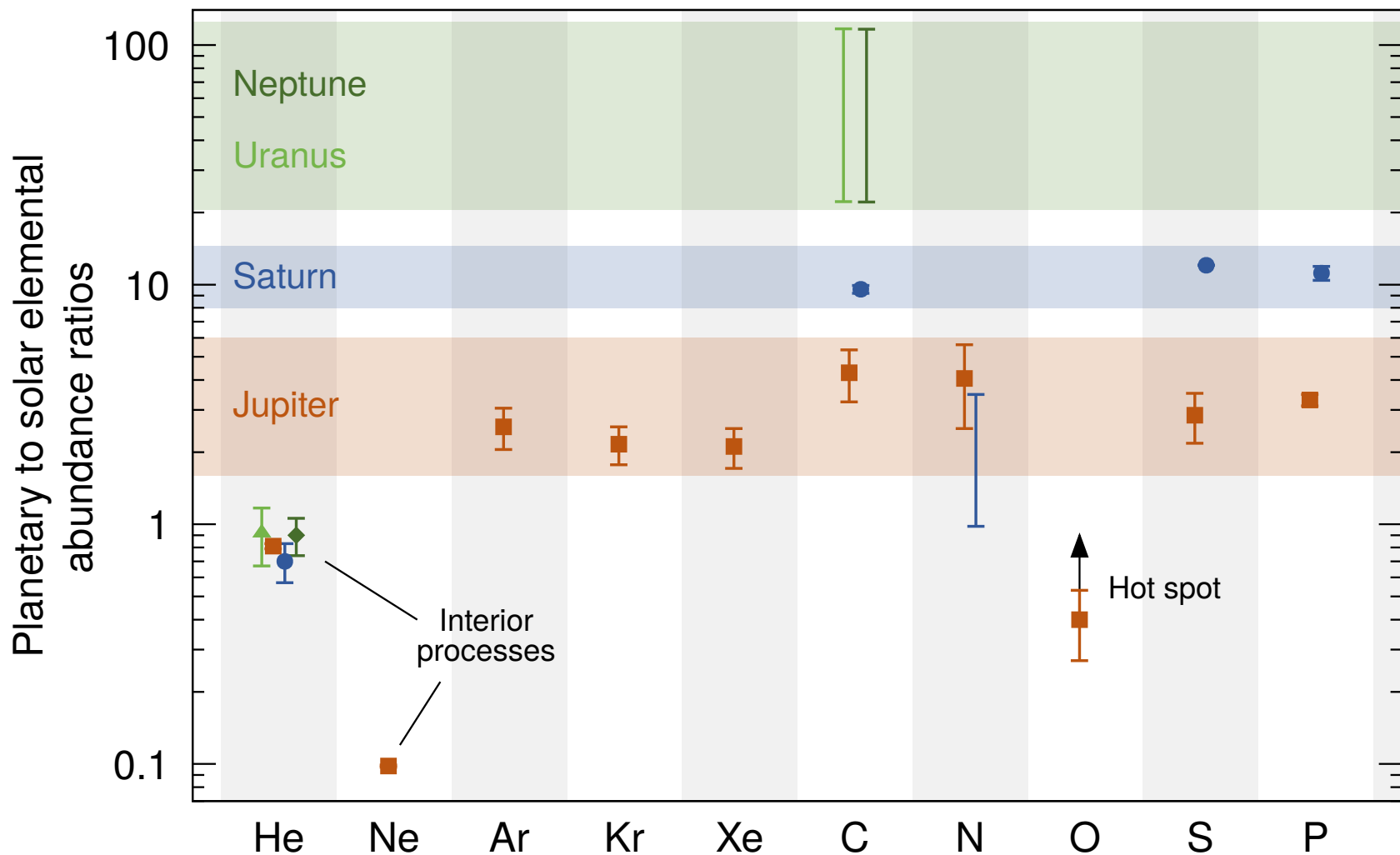
- Giant planets have played a significant role in shaping the architecture of the solar system, including the smaller, inner terrestrial planets.
- The efficiency of remote sensing observations has some limitations, especially to study the bulk atmospheric composition. In particular, the measurement of noble gas and helium abundances requires in situ measurements.
- The Galileo probe provided a giant step forward regarding our understanding of Jupiter.

However, it remains unknown whether these measurements are unique to Jupiter or are representative of all gas giants including Saturn, and how the composition, processes, and dynamics of the giant planets are similar and different from the ice giants.

## Key Measurements Needed

- **Bulk composition:** Elemental abundances including O, C, N, S, He, Ne, Ar, Kr, Xe
- **Isotopic ratios:** Noble gas isotopes, D/H,  $^{13}\text{C}/^{12}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N}$
- **He/H<sub>2</sub> ratio:** For planetary heat balance, interior processes, and thermal history
- **Ortho/Para H<sub>2</sub> ratio:** For thermal structure and deep dynamics

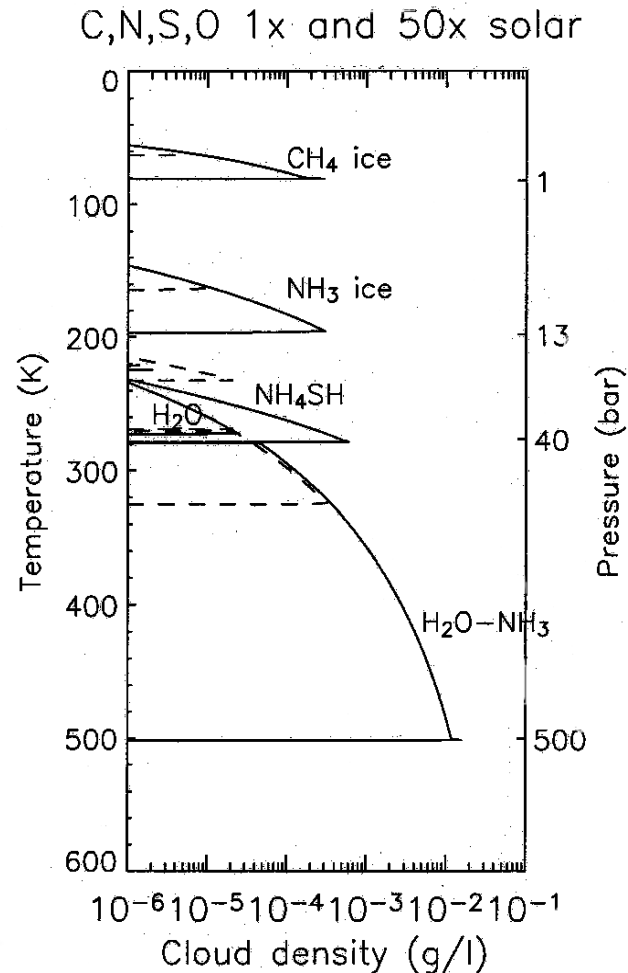
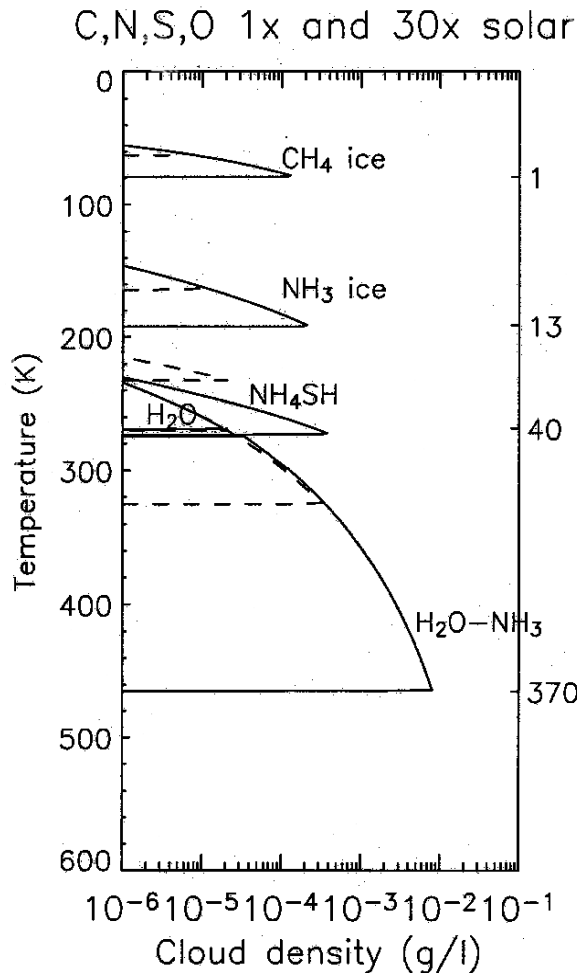
# Existing Measurements



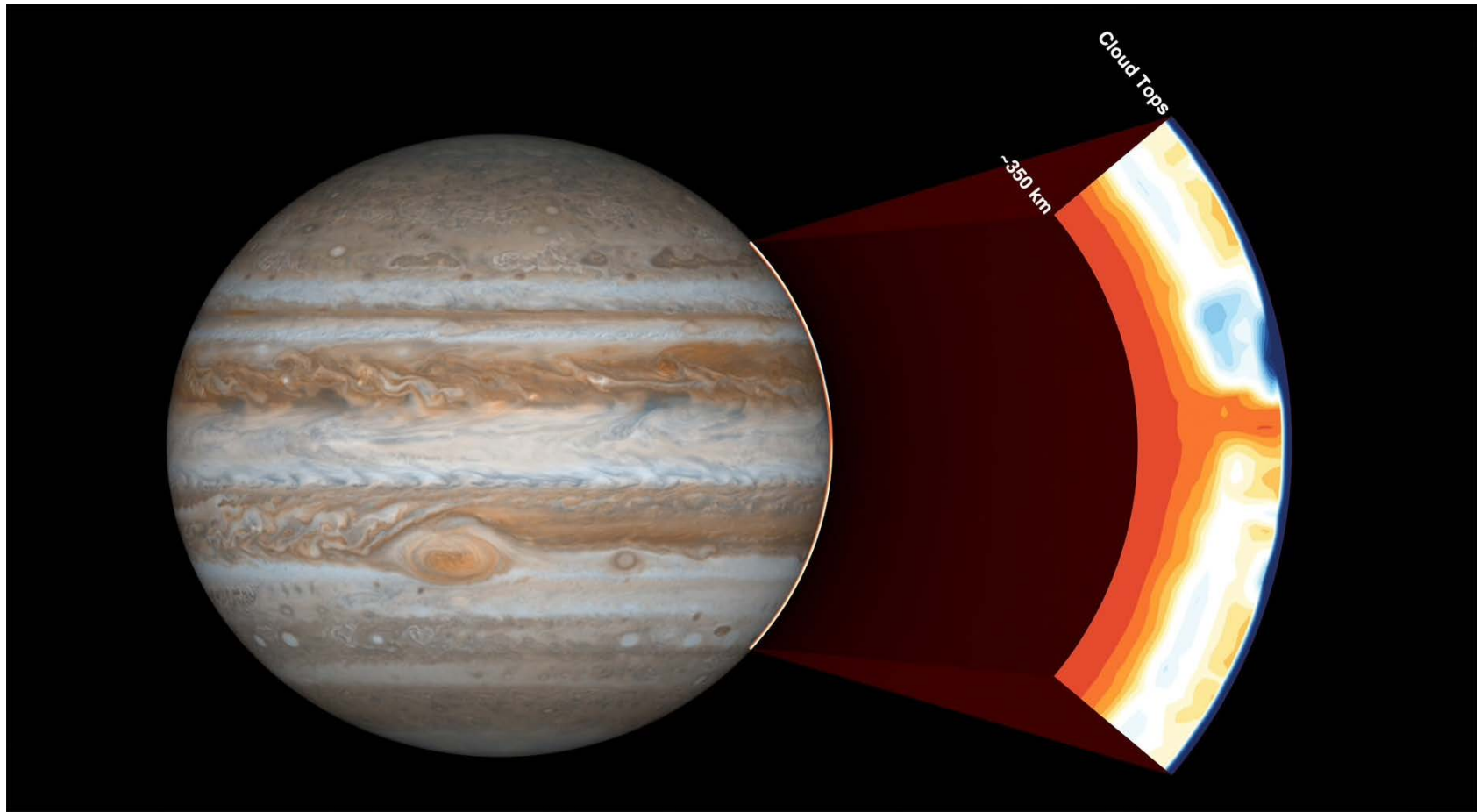
# Predicted Cloud Layers

## Neptune

Uranus water cloud at 500 bars; elements enriched by 30x and 50x solar



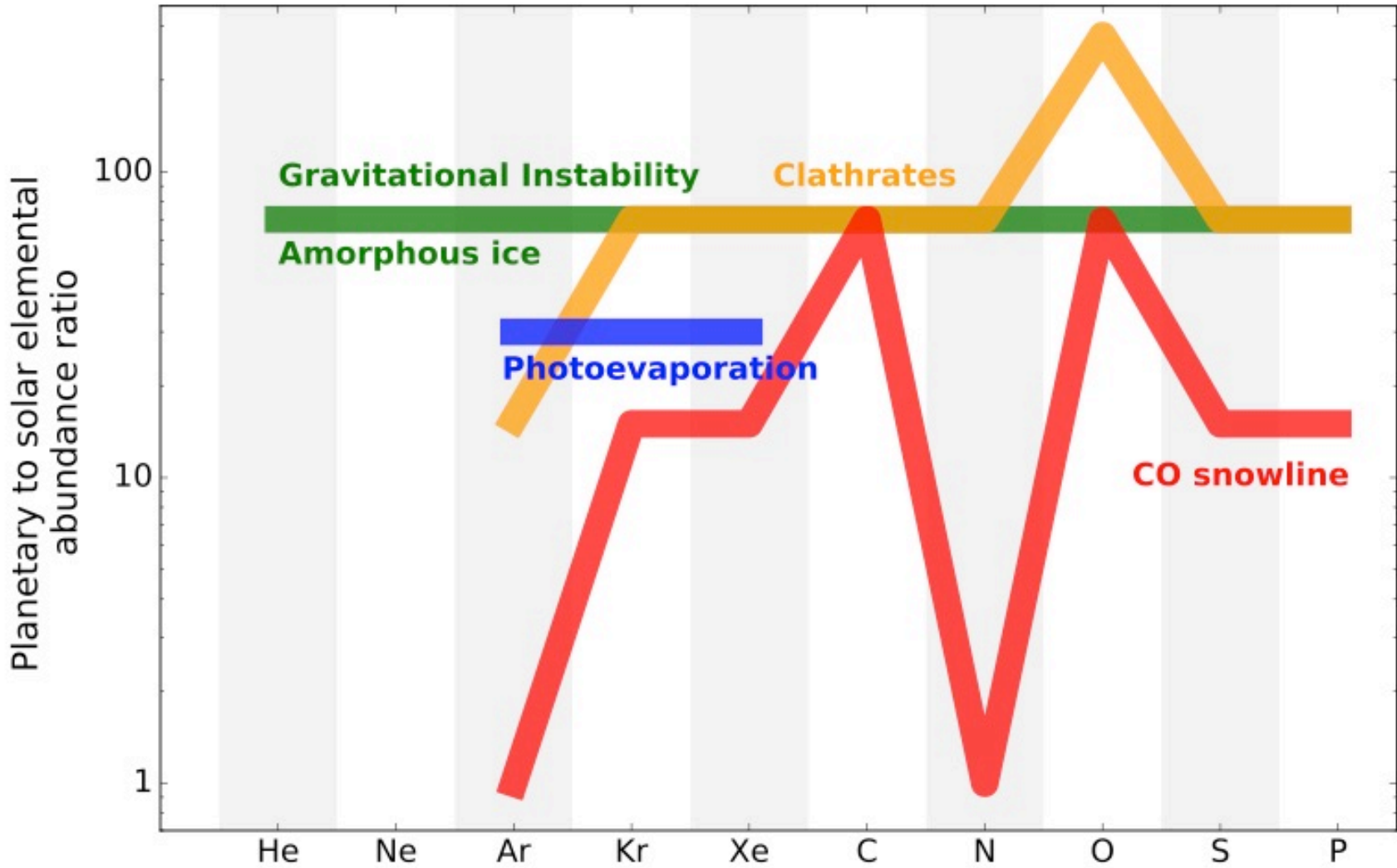
# Lessons From Juno



Jupiter thermochemical equilibrium models predict  $\text{NH}_3$  cloud base at  $\sim 700\text{mb}$ .

However Juno MWR data show a highly complex distribution of ammonia over Jupiter. **Near the equator, well-mixed ammonia is reached at atmospheric pressures  $\sim 100$  bars.** (Bolton et al. 2017; Ingersoll et al. 2017)

# Different Scenarios of Giant Planet Volatile Enrichment



# Strawman Science Payload

Instrument	Measurement
Mass Spectrometer	Elemental and chemical composition, especially noble gases and key isotopes
Atmospheric Structure Inst.	Pressure and Temperature → Thermal structure, density, stability Entry Accelerations → Density
Radio Science Experiment	Atmospheric dynamics: winds and waves; Atmospheric absorption → composition
Nephelometer	Cloud structure, microphysics, aerosol number densities & characteristics
Net Flux Radiometer	Net radiative fluxes: Thermal IR, solar visible
Helium Abundance Detector	Helium Abundance



# Core mission profile modeled after Galileo probe

NASA provided HEEET would enable significant mass savings over CP for range of EFPA's

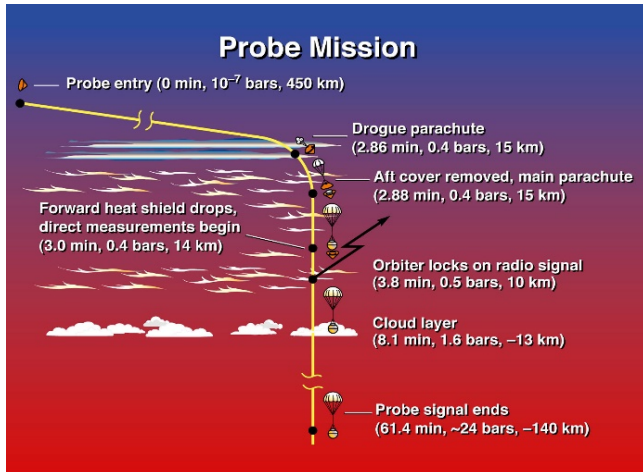


Table E.1 Entry System Mass Estimates

Entry Flight Path Angle (EFPA), degrees	-8		-19	
TPS Material	Mass, kg			
	HEEET	Carbon Phenolic	HEEET	Carbon Phenolic
<b>Entry System (total mass)</b>	215	255	199	223
<b>Deceleration module</b>	92.6	132.6	76.6	100.6
<b>Forebody TPS (HEEET)</b>	40	80	24	48
<b>Afterbody TPS</b>	10.5	10.5	10.5	10.5
<b>Structure</b>	18.3	18.3	18.3	18.3
<b>Parachute</b>	8.2	8.2	8.2	8.2
<b>Separate Hardware</b>	6.9	6.9	6.9	6.9
<b>Harness</b>	4.3	4.3	4.3	4.3
<b>Thermal Control</b>	4.4	4.4	4.4	4.4
<b>Descent Module</b>	122.7	122.7	122.7	122.7
<b>Communication</b>	13	13	13	13
<b>C&amp;DH Subsystem</b>	18.4	18.4	18.4	18.4
<b>Power Subsystem</b>	22 <sup>1</sup>	22 <sup>1</sup>	22 <sup>1</sup>	22 <sup>1</sup>
<b>Structure</b>	30	30	30	30
<b>Harness</b>	9.1	9.1	9.1	9.1
<b>Thermal Control</b>	4.3	4.3	4.3	4.3
<b>Science Instrument</b>	25	25	25	25
<b>Separate Hardware</b>	0.9	0.9	0.9	0.9

**Note.** Deceleration of (or Entry System) module 1m diameter aeroshell, 36 km/s inertial velocity, 10 deg latitude). The descent module mass estimate, except for the Science Instruments, are the same as that of Galileo Probe. Additional mass savings are likely when the descent system structure is adjusted for reduction in scale as well as entry g-load. Galileo design-to g-load was 350. Saturn probe entry g-load with 3-sigma excursions will be less than 150 g's.

# Next Stop: Ice Giants!



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**ABSTRACT**

The ice giants Uranus and Neptune are the most underexplored class of planets in our solar system but the most frequently observed type of exoplanets. Presumed to have a small rocky core, a deep interior comprising ~70% heavy elements surrounded by a more diffuse outer envelope of H<sub>2</sub> and He, Uranus and Neptune are fundamentally different from the better-explored gas giants Jupiter and Saturn. Because of the lack of dedicated exploration missions, our knowledge of the composition and atmospheric processes of these distant worlds is presently

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