2013-03-29 17:36:45

ID:	3
Submitted at:	2013-03-29 17:36:45
IP:	143.232.123.166
Browser:	Mozilla/5.0 (Macintosh; Intel Mac OS X 10_6_8) AppleWebKit/537.22 (KHTML, like Gecko) Chrome/25.0.1364.172 Safari/537.22
Submitter operating system:	mac
Data:	
Title:	Characterizing Uranus with an Ice giant Planetary Origins Probe (Ice-POP)
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Abstract (up to 5000 characters):	We now know from studies of planetary transits and microlensing that Neptune-mass planets are ubitquitous and may be the most common class of planets in the Galaxy. As such it is crucial that we understand the formation and evolution of the ice giant planets in our own solar system so that we can better understand planet formation throughout the galaxy. An entry probe mission to Uranus would help accomplish this goal. In fact the Planetary Decadal Survey recommended a Uranus orbiter with entry probe but did not explore in detail the specifications for the entry probe. NASA Ames is currently studying thermal protection system requirements for such a mission and this has led to questions regarding the minimum interesting science payload of such an entry probe. The single most important in-situ measurement for an ice giant entry probe is a measurement of atmospheric composition. For Uranus this would specifically include the methane and noble gas abundances. An in situ measurement of the methane abundance, from below the methane

cloud, would constrain the atmospheric carbon abundance, which is believed to be roughly 30 to 50 times solar. There are hints from the transiting planets that extrasolar ice giants show comparable or even greater enhancements of heavy elements compared to their primary stars. However the origin of this carbon enhancement is controversial. Is Uranus a “failed core” of a larger gas giant or was the atmosphere enhanced by accretion of icy planetesimals? Constraining atmospheric abundances of C and perhaps S or even N from below 5 bars would provide badly needed data to address such issues.

A measurement of the N abundance would provide clues on the origin of the planetesimals that formed Uranus. Low N-abundance indicates planetesimals from 'warmer' regions where N was mainly in form of NH_3, whereas a strong enrichment could indicate planetesimals / cometary material from the colder outer regions of the nebula. Furthermore CO and HCN have been detected in Neptune but not in Uranus. A measurement of the abundance of either would constrain the source mechanisms for these molecules (exogenic or internal).

A major surprise from the Galileo Entry Probe was that the heavier noble gases Ar, Kr, and Xe are enhanced in Jupiter’s atmosphere at a level comparable to what was seen for the chemically active volatiles N, C, and S. It had been generally expected that Ar, Kr, and Xe would be present in solar abundances, as all were expected to accrete with hydrogen during the gravitational capture of nebular gases. Enhanced abundances of Ar, Kr, and Xe is equivalent to saying that these noble gases have been separated from hydrogen. There are several mechanisms that could accomplish this but these hypotheses require further testing. Measurement of noble gas abundances in an ice giant would constrain the planetary formation and nebular mechanisms responsible for this enhancement.

Standard three-layer models of Uranus find that the outer, predominantly H/He layer of Uranus does not reach pressures high enough (~1 Mbar)

	for H2 to transition to liquid metallic hydrogen. However, valid models can also be constructed with a smaller intermediate water-rich layer, with hydrogen then reaching the metallic hydrogen phase. If this occurs, He should phase separate from the hydrogen and ``rain out," taking along a substantial abundance of Ne, as suggested for Jupiter (and likely also for Saturn). Hence He and Ne depletions could be probes of the planet's structure in the much deeper interior. A determination of Uranus' atmospheric abundances, particularly of the noble gasses, is thus critical to understanding the formation of Uranus, and giant planets in general. These measurements can only be performed with an entry probe. The second key measurement would be a temperature-pressure sounding to provide ground truth for remote measurements of atmospheric temperature and composition and to constrain the internal heat flow. This would also establish that the methane abundance measurements have indeed been made below any possible methane cloud. Finally an ultra stable oscillator would measure wind speeds and constrain atmospheric dynamics. In our presentation we will discuss the importance of all of these measurements and argue that an entry probe is a crucial component of any ice giant mission.
Presentation Preference:	oral
Preferred session:	Giant_Planets