Entry Probe Missions to the Giant Planets

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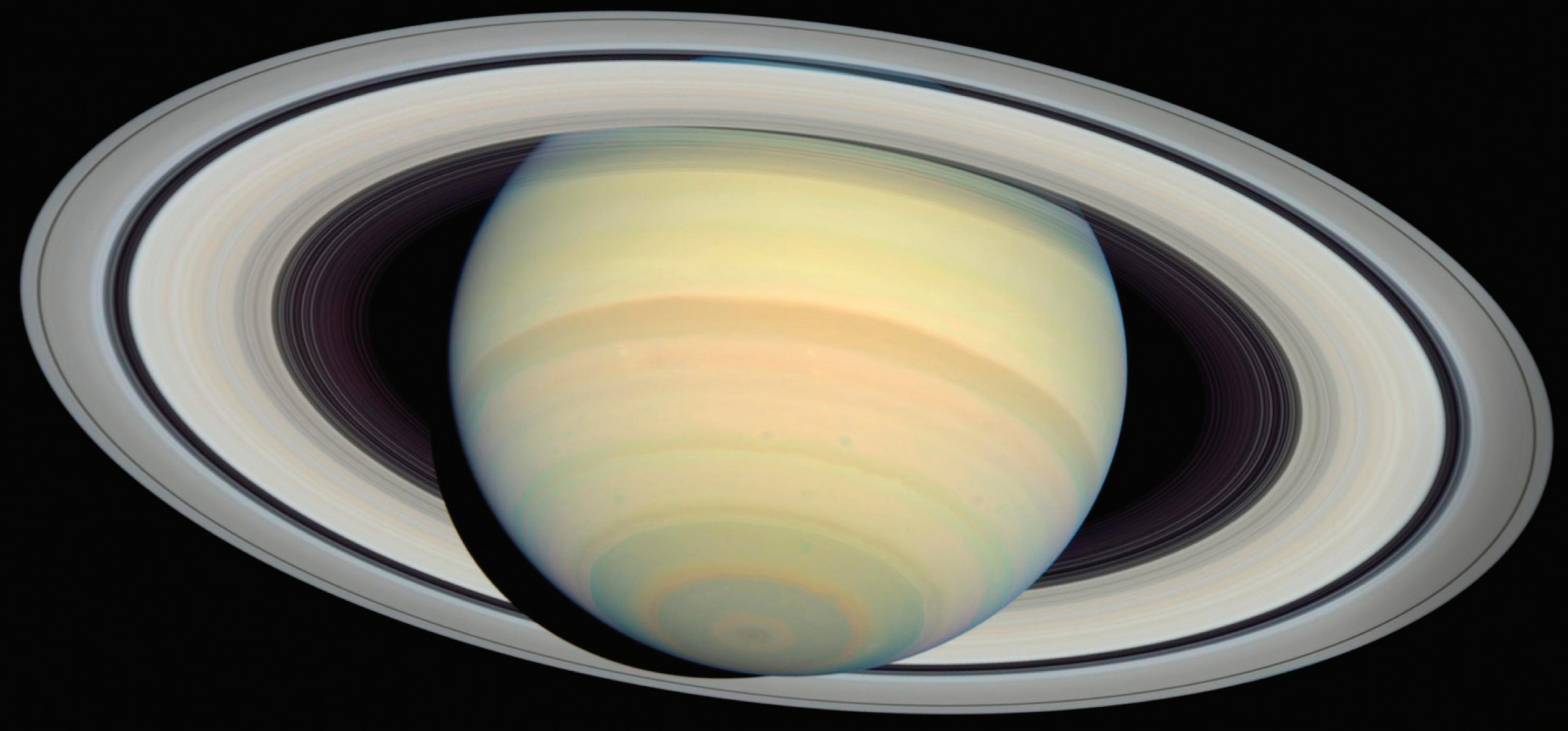


Background

The primary motivation for in situ probe missions to the outer planets derives from the need to constrain models of solar system formation and the origin and evolution of atmospheres, to provide a basis for comparative studies of the gas and ice giants, and to provide a valuable link to extrasolar planetary systems. As time capsules of the solar system, the gas and ice giants offer a laboratory to better understand the atmospheric chemistries, dynamics, and interiors of all the planets, including Earth. It is within the deep, well-mixed atmospheres and interiors of the giant planets that pristine material from the epoch of formation can be found, providing clues to the local chemical and physical conditions existing at the time and location at which each planet formed. Detailed explorations and comparative studies of the gas and ice giant planets will provide a foundation for understanding the integrated dynamic, physical, and chemical origins, formation, and evolution of the solar system. To provide a basis for significantly improved interpretations of the Galileo Jupiter probe measurements and to allow for comparative studies of gas giants Jupiter and Saturn, an entry probe mission to Saturn is needed. To provide a basis for comparative studies of the gas giants and the ice giants a probe mission to either Uranus or Neptune will be needed.

Key Science Questions

To unveil the processes of outer planet formation and solar system evolution, detailed studies of the composition, structure, and dynamics of giant planet interiors and atmospheres are necessary, and will require both in situ entry probe missions and remote sensing studies of the giant planets.

The key science questions to be addressed by giant planet entry probe missions are:

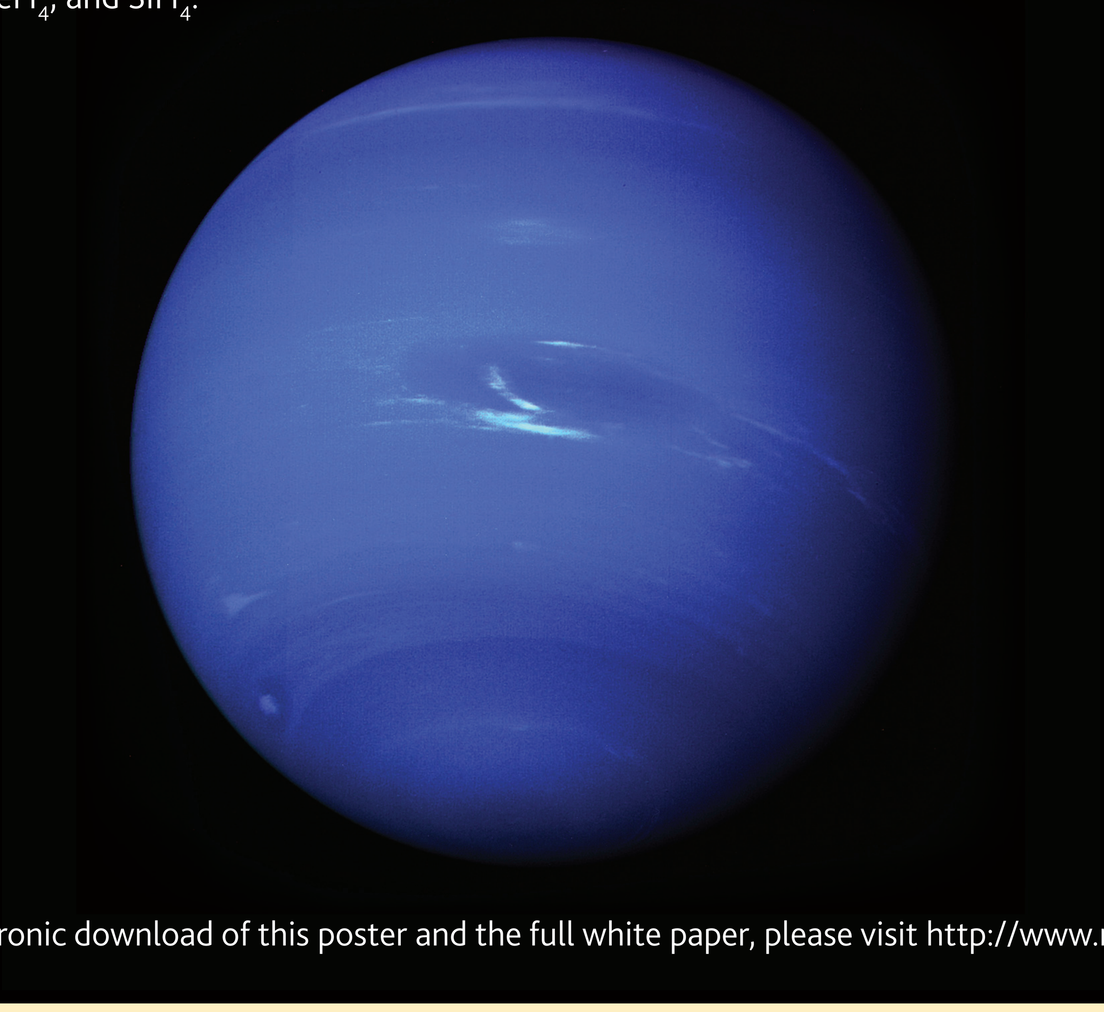
- **What was the time scale over which the giant planets formed, and how did the formation process of the ice giants differ from that of the gas giants?**
- **What is the history and distribution of water and other volatiles in the solar system?**
- **What are the processes that have and continue to shape the character of the outer planets, and how do they work?**
- **What can be learned about exoplanets by observing the giant planets of our solar system?**

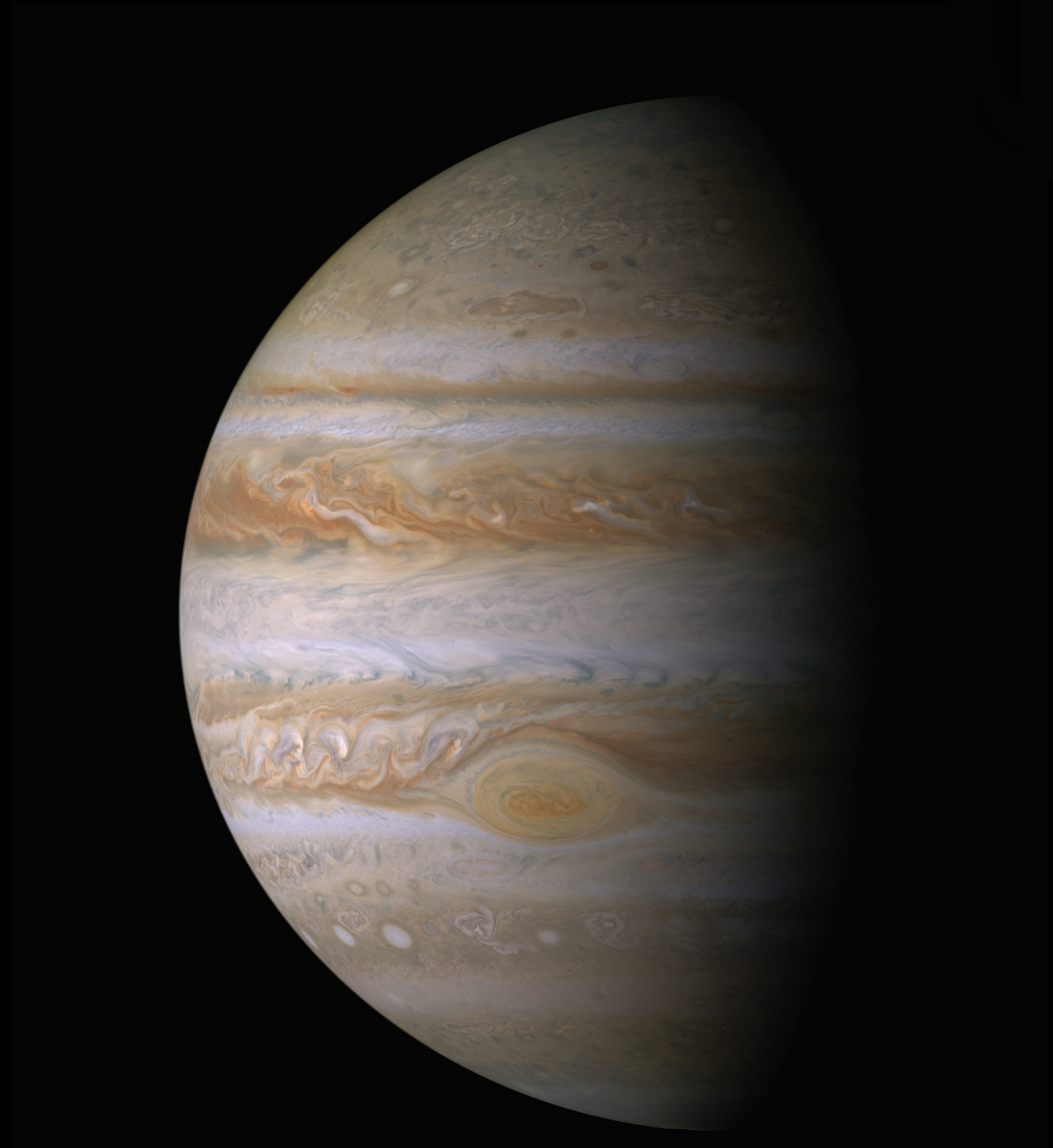
To address the key science questions, several specific direct measurements will be needed, including:

– abundances (relative to hydrogen) of heavy elements C, S, N, O, and noble gases He, Ne, Ar, Kr, Xe, key isotopic ratios (relative to solar) such as D/H, $^{3}He/^{4}He$, $^{14}N/^{15}N$, $^{12}C/^{13}C$, $^{16}O/^{18}O$, of Saturn relative to Jupiter, and of the ice giants relative to the gas giants;

– dynamical and thermal structure of the atmosphere beneath the cloud tops, including measurements of net local opacity and radiative divergence (heating), variations in net flux of radiant energy at different wavelengths as a function of depth, and

– measurements of local winds and waves; measurement of disequilibrium species such as PH_3, CO, AsH_3, GeH_4, and SiH_4.





Technology needs for future outer planet probe missions

Probes intended for Jupiter, Saturn, Uranus, and Neptune are designed to operate from carrier release through probe approach, atmospheric entry, and descent. During these phases, the probes must tolerate extreme environmental conditions such as entry heating, followed by both low and (for deep probes) high temperatures and pressures during descent. To safely enter and operate within the atmosphere of a giant planet, several critical technologies must be addressed, including

Thermal Protection Systems. Future giant planet entry probe missions must either utilize the very limited remaining stock of Heritage Carbon-Phenolic (HCP) or develop an alternative to HCP. Development of new TPS materials will require extensive technology maturation and ground testing, and it is recommended that the heritage carbon phenolic capability be re-established, and investment be made in the development of either a new batch of Carbon Phenolic or another type of highly dense ablator.

Extreme Environment Materials and Systems. To enable greater deep probe payload mass fraction for the same entry mass, technology development is needed for lighter pressure vessel and passive thermal insulation and control designs, and to develop components interfacing with the deep extreme environments.

Power Technologies. To meet the probe energy demands for long descent times into giant planet atmosphere without unacceptable increases in battery mass and to minimize power requirements from probe housekeeping, science, and communication operations, investment is needed in low power logic and power conditioning electronics, and in high energy density battery technologies.

Mission Recommendations

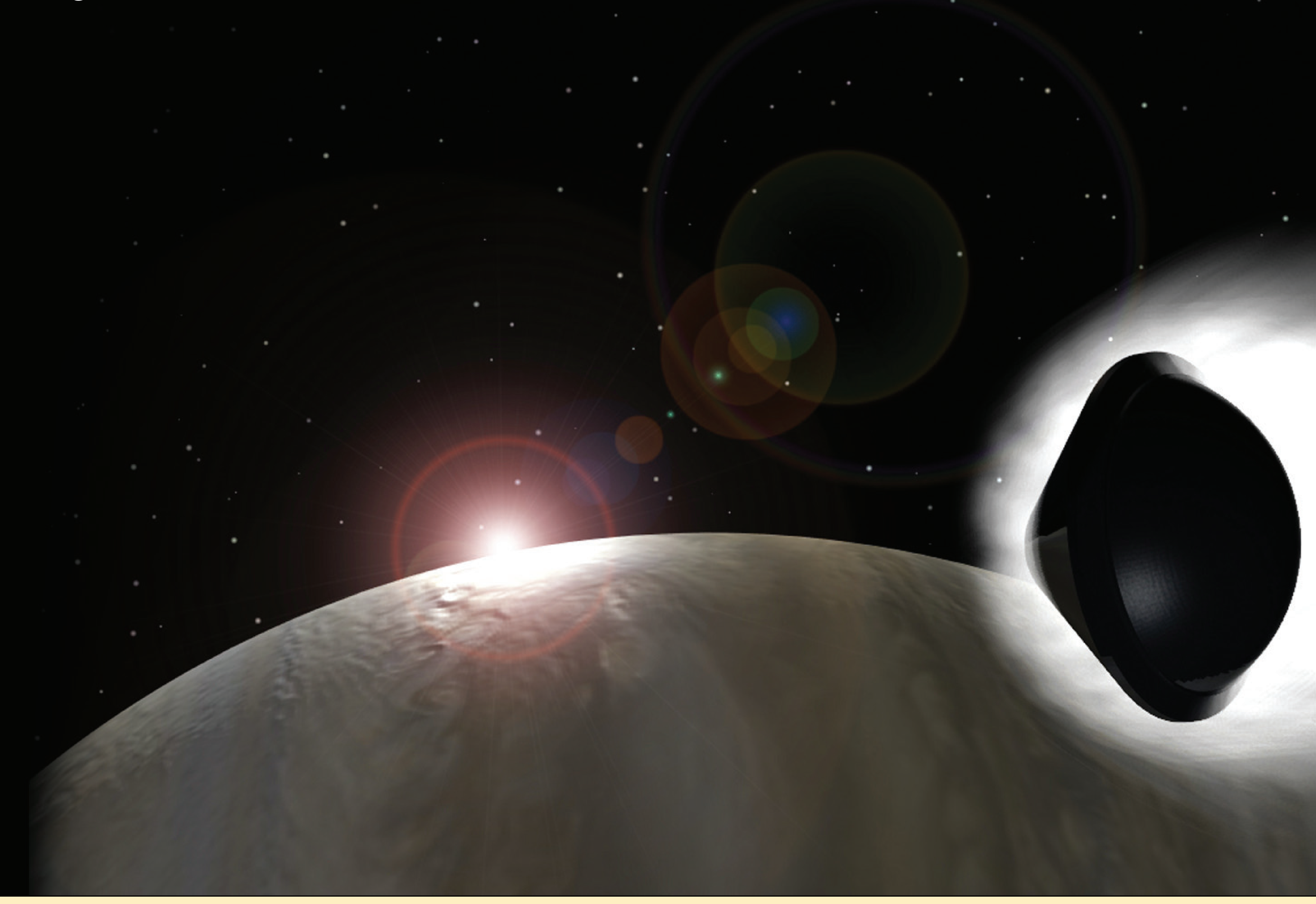
Jupiter is the only giant planet to have been studied in situ. To provide improved context in the results of the Galileo probe studies of Jupiter, and to provide for additional discrimination among theories of the formation and evolution of the gas giants and their atmospheres, it is essential that the Galileo Jupiter probe studies be complemented by similar studies at Saturn. For an understanding of the formation of the family of giant planets, both ice giants and gas giants, and by extension the entire solar system, probe missions to the ice giants Uranus and Neptune are also essential.

Saturn Probe. A Saturn in situ mission, a mission of exceptionally high scientific value, is recommended as the highest priority giant planet probe mission. The goals of Saturn probe science can be accomplished with either deep (20-100 bar) entry probes alone, or shallow (<20 bar) probes complemented by Juno-type remote sensing with microwave radiometers (MWR) from a flyby carrier or orbiter for determination of water vapor. For risk mitigation and to sample a diversity of environments, a dual-probe mission is most desirable. The key measurement of a Saturn probe mission is composition of the well-mixed atmosphere below the cloud layers, including the heavy elements O, C, N, and S, the noble gases He, Ne, Ar, Kr, Xe and their isotopes, isotope ratios $^{14}N/^{15}N$, $^{12}C/^{13}C$ and D/H, and disequilibrium species such as CO, PH_3, AsH_3, GeH_4 as tracers of internal processes.

With far fewer technology issues and relatively less expense than probe missions to other destinations, a Saturn Probe(s) mission with MWR on a flyby carrier is the highest priority and most feasible near-term mission.

Neptune and Uranus Probe. Shallow probes to Uranus and Neptune will retrieve abundances of most heavy elements other than oxygen and nitrogen, and will make atmospheric structure and dynamics measurements below the levels significantly influenced by sunlight. Ice giant shallow probes will measure noble gas and methane abundances and will help constrain the bulk oxygen, nitrogen, and sulfur abundances. An ice giant probe(s) mission is strongly recommended.

Return to Jupiter. A single or multiprobe return to Jupiter should be considered soon after water and ammonia data from Juno have been received and analyzed. Despite the measurements available from the Galileo probe and the expected measurements of water abundance from Juno microwave measurements, a probe mission to Jupiter is still needed since measurements of deep atmospheric composition, clouds, and dynamics are essential for unambiguous understanding of the formation of Jupiter and the origin of its atmosphere. Additionally, such measurements will also provide "ground truth" for microwave remote sensing.



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