EPSC Abstracts
Vol. 8, EPSC2013-745-2, 2013
European Planetary Science Congress 2013

Unveiling the evolution and formation of icy giants

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Abstract

The planet Uranus is one of two ice giants in the solar system, both of which have only been visited only once by the Voyager 2 spacecraft. Ice giants represent a fundamental class of planet, and in fact, many known exoplanets fall in this category. Therefore, a dedicated mission to an ice giant is crucial to deepen our understanding of the formation, evolution and current characteristics of such planetary and exoplanetary systems. Here we present the results of a detailed study of a mission to investigate the Uranus system as an archetype for ice giants. Our detailed trade-off study has resulted in a mission configuration consisting of an orbiter with a deep atmospheric probe and an extensive orbital tour of the main moons of the Uranus system

1. Introduction

Since no dedicated mission to an icy giant has flown so far, there is a pressing need for this type of mission to deepen our knowledge of the formation, evolution and current characteristics of such a planet and its system [1, 2]. Not only will the measurements performed by this kind of mission directly provide crucial science data, they will help to constrain the interpretation of ground-based observations. We conducted a detailed study for the design of a mission to fulfill the primary science goal, namely: to investigate Uranus and its system as an archetype for ice giants. We present the science objectives, instrument selection, architecture rationale and system design for a mission to the Uranian system.

2. Science objectives

The mission is a general exploratory mission, with a focus on exploring the formation and evolution of the icy giants and further constrain planetary system formation models. Furthermore, specific investigations of the Uranian system will be performed. The science objectives have been divided into the following categories:

- Atmosphere: What is the composition of the atmosphere? What are the drivers of atmospheric chemistry? What are the atmosphere dynamics?
- Interior: Why is the heat flux lower than expected? What are the implications for the interior and thermal evolution of the planet? Why does Uranus have such a strong intrinsic magnetic field? How do its characteristics constrain the interior? Is there a rocky silicate core?
- Uranian system: What is the origin and evolution of the Uranian moons? What is the internal structure, composition and current thermal state of the moons? How have the Uranian rings formed and evolved? What governs the dynamics of the Uranian rings?
- Magnetosphere: How is plasma produced and transported in the magnetosphere? What are the dynamics of the uniquely configured Uranian magnetosphere and its interaction with the Solar wind?

From these top-level questions, we derived specific science questions, required measurements and finally instrument requirements and suitable instruments. The primary science questions relate to investigating Uranus' deep interior and outer layers as these are most directly related to the primary science goal. Investigations of the moons, rings and the magnetosphere can then provide complementary observations on the Uranian system specifically and less on icy giants in general.

3. Trade-off & Selection

Several mission architectures, such as an orbiter with probe or a flyby mission, were traded off. In this process, the relative importance of the science questions, the capabilities of each concept to carry a certain payload and its capability to answer the science questions in the given architecture were traded off. Similarly, the feasibility of each concept from an engineering point-of-view was assessed, taking into account matters such as cost and risk. The results are presented as a function of relative engineering and science score weights, providing an envelope of optimal mission selections over a range of mission scopes and types. For our objectives and mission type, we determine that a Uranus orbiter with a single entry probe, including an extended moon tour, is the optimal selection. Other possibly competitive mission architectures include a flyby mission, for a concept with a high engineering weight or a multi-spacecraft mission, for concepts with extremely low engineering weights.

4. Mission Profile

The spacecraft is to launch in 2026 on an Ariane 5 ECA launcher and arrive at Uranus in 2044 using conventional high-thrust systems. Before Uranus orbit insertion, the probe is deployed, which is designed for a descent down to 100 bar [3]. The first two years of the mission are dedicated to close observations of Uranus itself, with a periapsis very close to the planet, for high resolution imaging and gravity science, and an apoapsis outside the bow shock, for magnetospheric studies. Subsequently, the periapsis is raised incrementally, allowing for a nominal nine flybys of each of the five main moons of Uranus. Possibilities exist for mission extension at the final orbit, which crosses the orbit of the moon Oberon, to extend even further the science return from this mission

5. Spacecraft systems

The dry mass in Uranus orbit, applying both system and subsystem margins, is determined to be 2052 kg, excluding the 350 kg probe. The spacecraft is to be powered by four Advanced Stirling Radioisotope Generators (ASRGs), which are currently under development. A set of batteries is included, capable of covering the loss of one ASRG through the peak power phase. The spacecraft will have 100 Gbit data storage capacity for optimizing the science return through careful selection of transmitted data. Data transmission is performed by a 3.5 m high gain antenna transmitting in X-band for communications and Ka-band for tracking. .

6. Conclusion

A dedicated mission to Uranus represents a unique opportunity to study an ice giant system and to gain new insights into the formation and evolution of icy giant systems. The knowledge gained from this investigation would provide crucial constraints to current models for planetary formation and evolution, and would further address a significant gap in the current understanding of Solar System formation. Our detailed trade-off study has resulted in a mission configuration consisting of an orbiter with a deep atmospheric probe and an extensive orbital tour of the main moons of the Uranus system.

Acknowledgements

The authors acknowledge support from ESA, FFG, ISSI, Austrospace and Europlanet for the Alpbach summer school and the following 1-week meeting in Graz, Austria. Also, we would like to thank all Alpbach lecturers and tutors for their valuable input and feedback. This study benefited from the work of 45 other students during the Alpbach summer school.

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