OCEANUS: A URANUS ORBITER CONCEPT STUDY FROM THE 2016 NASA/JPL PLANETARY SCIENCE SUMMER SCHOOL. A. M. Bramson[1], C. M. Elder[2], L. W. Blum[3], H. T. Chilton[4], A. Chopra[5], C. Chu[6], A. Das[7], A. Davis[8], A. Delgado[9], J. Fulton[8], L. Jozwiak[10], A. Khayat[3], M. E. Landis[1], J. L. Molaro[2], M. Slipski[8], S. Valencia[11], J. Watkins[12], C. L. Young[4], C. J. Budney[2], K. L. Mitchell[2], [1]University of Arizona (bramson@LPL.arizona.edu), [2]Jet Propulsion Laboratory, California Institute of Technology, [3]NASA/Goddard Space Flight Center, [4]Georgia Institute of Technology, [5]University of Washington, [6]University of Alaska Fairbanks, [7]Purdue University, [8]University of Colorado at Boulder, [9]University of Texas at El Paso, [10]Johns Hopkins University/Applied Physics Laboratory, [11]Washington University in St. Louis, [12]California Institute of Technology

Introduction: The ice giants (Uranus and Neptune) are the least understood class of planets in our solar system, with our understanding of these planets coming only from ground-based observations and the solitary fly-by of the Voyager 2 spacecraft in 1986 of Uranus [e.g. 1] and 1989 of Neptune [e.g. 2]. Much remains unknown about the formation and evolution of these planets and their moons, including their unique magnetic fields and why the two planets differ significantly in their internal heat flux and obliquity [3]. The discovery of thousands of exoplanets by the Kepler mission, of which ice giant-sized planets are the most numerous [4], makes an ice giant mission even more topical. While the 2011 Planetary Decadal Survey [5] calls out the ice giants for a Flagship mission, we have developed a New Frontiers-class mission concept that would be able to address a significant fraction of the open scientific questions for the ice giants. Here, we present the results of a concept study for a Uranian orbiter resulting from the 2016 NASA/JPL Planetary Science Summer School (PSSS).

Science Objectives: Our mission concept was designed to explore the origins and evolution of planetary systems by studying Uranus' interior structure, magnetosphere, and atmosphere. OCEANUS (Origins and Composition of the Exoplanet Analog Uranus System) would address the following science objectives:

1. What is the size of Uranus' rocky core, and is it consistent with core accreation formation models (core 3-6 M_E) [e.g. 6, 7] or gravitational instability models (core < 1 M_E) [e.g. 8, 9]?

2. How and where is the magnetic field at Uranus generated, and to what extent does the offset between the unusual tilt of the spin axis and magnetic field affect the structure and dynamics of the magnetosphere?

3. Is Uranus' composition consistent with formation in its current position or does it suggest planetary migration? Is its atmospheric profile more similar to that of Earth or the gas giants?

Instruments: Our simple instrument suite (Fig. 1) would enable OCEANUS to achieve the objectives listed above, as well as four of the Decadal Survey's science objectives for Uranus (including one of the two highest priority objectives):

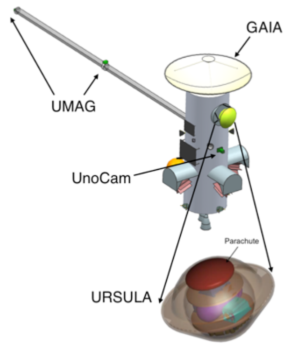

Fig. 1: OCEANUS spacecraft concept with magnetometer boom (UMAG), engineering camera (UnoCam), descent probe (URSULA) and high gain antenna with synchronous X and Ka band transmission for gravity measurements and atmospheric occulations (GAIA).

UMAG (Uranus Magnetometer) – Would measure the structure and dynamics of the magnetic field at Uranus to constrain models for dynamo generation as well as characterize the magnetosphere, magnetosheath, and bow shock under various solar wind conditions (Fig. 2).

GAIA (Gravity and Atmospheric Instrument Antenna) – Would utilize the on-board communications antenna, transmitting in both X and Ka band frequencies, for radio science. This would enable measurements of Uranus' global gravity field to a maximum of degree and order six, and would constrain models for the interior structure of Uranus. We would also use the instrument for atmospheric occulatations to retrieve the thermal structure of the atmosphere, especially of methane, ammonia and water clouds.

URSULA (Understanding Real Structure of the Uranian Laboratory of Atmosphere) – Would be a donated probe that would make the first in situ measurements of noble gas abundances, isotopic ratios, temperature and pressure profiles, vertical wind profiles and cloud composition, density and location via a mass spectrometer, atmospheric structure instrument, nephelometer and ultra-stable oscillator.

UnoCam (Uranus' Juno Cam) – Visible light, color camera to detect hazards; for example Uranus' ring system is poorly characterized. UnoCam would also be used to provide context for our scientific measurements and take images for public outreach and engagement, as power and data limitations allow.

Mission Design: OCEANUS would launch August 5, 2030 on an Atlas V 511 rocket. The current orbital configuration and distance between the ice giants and Earth present a major hurdle to achieving a mission to

Uranus or Neptune on a New Frontiers-class budget. In particular, opportunities for a Jupiter gravity assist to Uranus or Neptune are rare in the next two decades. OCEANUS would overcome this challenge through two Venus gravity assists (in November 2032 and August 2034) and one Earth gravity assist (October 2034) along with the use of Solar-Electric Propulsion (SEP) within 1.5 AU.

Uranus capture would occur 11 years after launch, in 2041, with the atmospheric probe dropped 30 days before orbital insertion. Our capture orbit would have a period of 120 days, and be reduced to a 30-day orbit in December 2041. We would complete 14 orbits, with periapsis of 1.1 R_U and apoapsis of 77 R_U (Fig. 2), in our primary mission phase.

Voyager 2 flew past Uranus in 1986, one year after southern solstice. The OCEANUS primary mission phase would span 2041-2043, a period close to Uranian equinox in 2049. This would provide important data relating to Uranus' seasonal variability (especially important due to the planet's high obliquity).

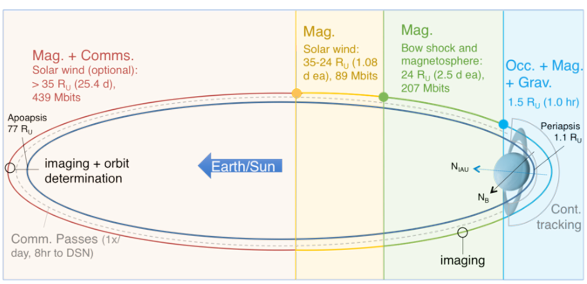

Fig. 2: Diagram showing when the instruments would take measurements during OCEANUS' orbits.

Systems: Our spacecraft would be powered by three Multi-Mission Radioisotope Thermoelectric Genertator (MMRTG) units with two enhacements to increase power by ~100%, providing 290 W of total power at EODL (end-of-design-life). We would employ an active thermal control system with two-phase pump heating (in development) to utilize eMMRTG waste heat while only requiring 5 W (vs. 25 W for a traditional single-phase pump system).

Our propulsion would be controlled by a two biprop engine system. From launch through atmospheric probe separation, the spacecraft would be three-axis stabilized. After dropping the probe, the spacecraft would be spin-stabilized with a pointing accuracy of 1 mrad. We would use conventional hardware to track and navigate the spacecrafts with a robust dual string design for redundancy in our X and Ka-Band telecom system.

Cost, Schedule and Risk: The guidelines of the 2016 PSSS specified a mission concept cost cap of $1B but this was increased to include a cost credit of $213.2M for eMMRTGs for a total mission budget of $1.2132B (FY 2015). The SEP stage would cost $142.8M, over 10% of our total mission budget. This additional cost reduced our instruments budget to $22.1M ($14.1M for the magnetometer and $8.0M for the camera).

We would utilize two new technologies which pose some risk to the mission: 1) the dual-phase thermal pump for the eMMRTGs is still in development, and 2) the dual biprop engine system has not been utilized in the outer solar system before. To mitigate the risk associated with these technologies, we allow time in phase B (Fig. 3) to test the new systems. There is also a slight risk of a Uranus rings collision, however, OCEANUS would pass 7000 km from the rings, which is 10x further than the gaps in Saturn's rings successfully navigated by Cassini. We would mitigate the risk of contamination of the Uranian icy moons by deorbiting the spacecraft into Uranus for our end-of-life plan.

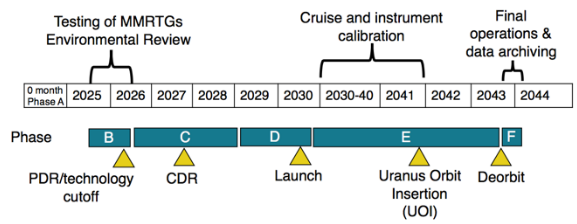

Fig. 3: OCEANUS mission schedule.

Conclusions/Lessons Learned: The need to explore the ice giants is imperative – they are the least-explored class of planet and are exoplanet analogs in our own solar system. Mission design, power, mass and cost constraints make achieving a New Frontiers-class mission to Uranus extremely difficult within the next several decades. The main challenges were appropriate launch vehicles (especially limited without Jupiter gravity assist) and power sources. To accomplish an ice giant orbiter launch before 2040 (within the lifetime of current planetary scientists, and to obtain new seasonal data for Uranus), cost allowances for radioisotope power systems and/or powerful launch vehicles will likely be necessary.

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