OCEANUS: A Uranus Orbiter Concept Study from the 2016 NASA/JPL Planetary Science Summer School

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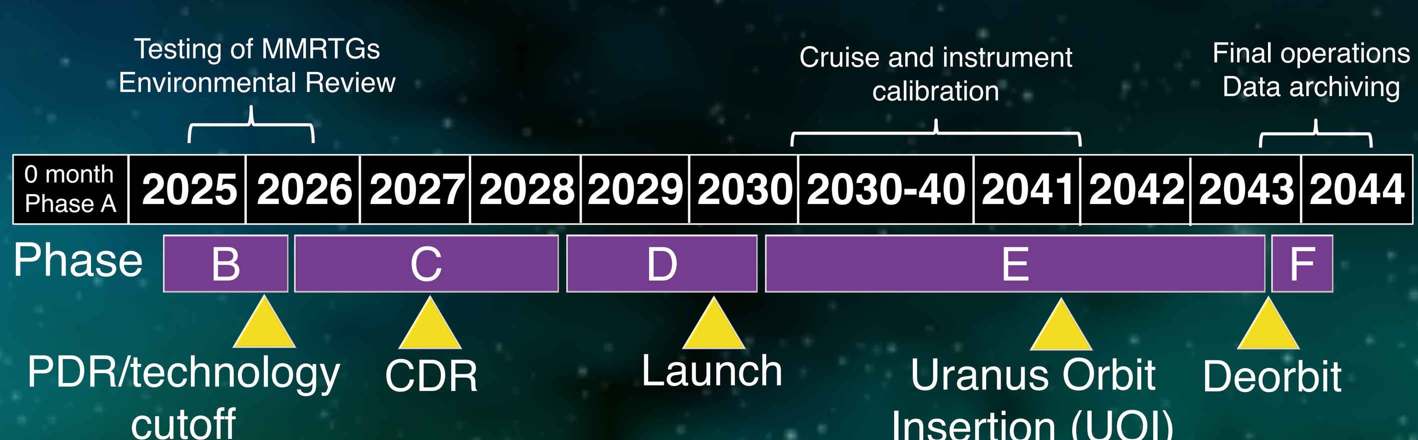
Why an Ice Giant Mission?

- The need to explore the ice giants is imperative – they are the least-explored class of planet. The structure and composition of these planets differ significantly from the gas giants. Current interior models disagree with models of solar system formation on the expected size of the core. The unique magnetic field orientations and dynamo generation have not been well characterized.
- Voyager 2 in the 1980s is the only spacecraft to have visited the ice giants. It visited Uranus close to southern summer solstice, which will occur again in 2070. To obtain new seasonal data (especially important due to Uranus' high obliquity), the next mission should arrive well before 2070.
- Ice giant-sized planets are the most numerous type of exoplanet discovered, making Uranus and Neptune the exoplanet analogs in our own solar system.

OCEANUS (Origins and Composition of the Exoplanet Analog Uranus System) was designed to explore the origins and evolution of planetary systems by studying Uranus' interior structure, magnetosphere, and atmosphere.

Notional Mission Schedule



Baseline System Summary

- 3 eMMRTGs producing 290 kW
- Two-phase thermal system technology development to utilize eMMRTG waste heat while only requiring 5 W (vs. 25 W for a traditional single-phase pump system)
- Propulsion controlled by two biprop engines for orbital insertion
- ACS Systems:
  - SEP phase: 3-axis reaction wheels
  - Cruise phase: RCS thrusters
  - Science phase: Axial spinning, pointing accuracy of 1 mrad

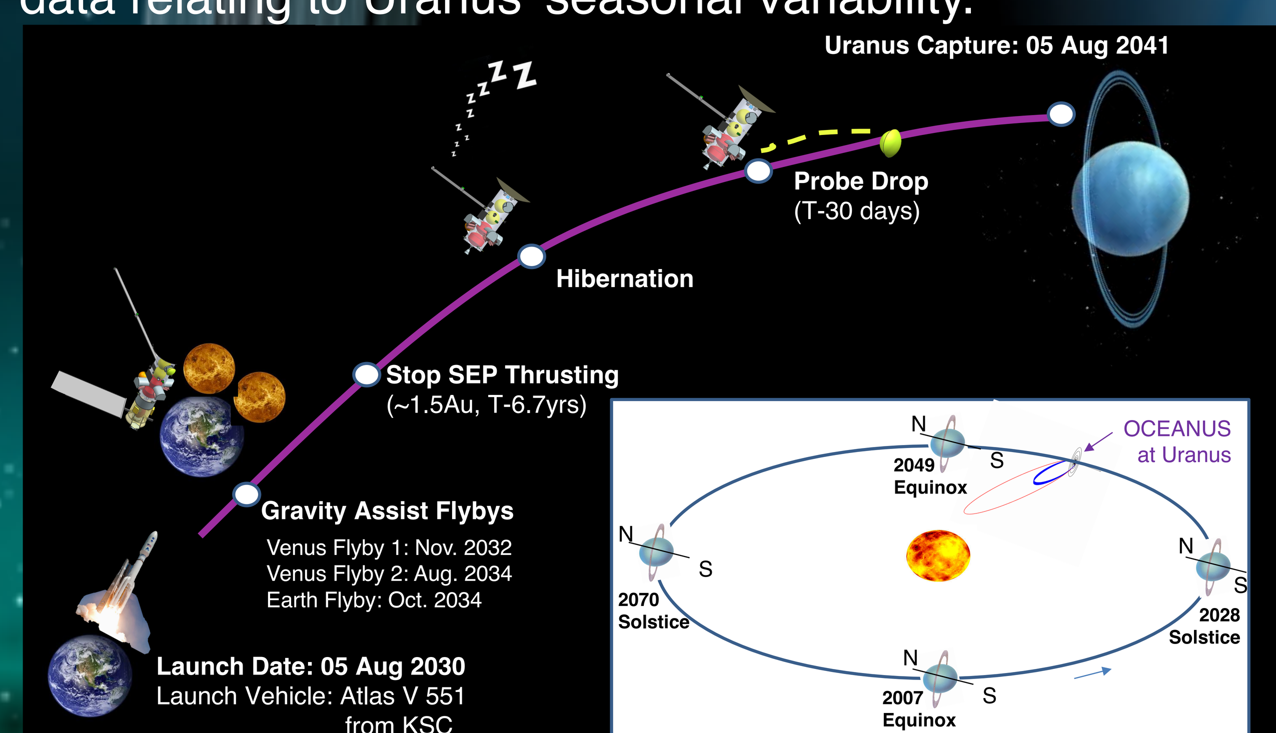
Mass, Power and Margins			Mass Fraction	Mass (kg)	Subsys Cont. %	CBE+ Cont. (kg)	Mode 1 Power (W) Safe	Mode 2 Power (W) Cruise	Mode 3 Power (W) Cruise + Telecom	Mode 4 Power (W) UOI	Mode 5 Power (W) Orbital Science	Mode 6 Power (W) Orbital Science + Comm	Mode 7 Power (W) Approach Science	Mode 8 Power (W) Recharge	Mode 9 Power (W) Gravity Science
Power Mode Duration (hours)							24	24	8	2	16	8	8	1	1
Payload on this Element															
Instruments			1%	12.5	2%	12.8	2	1	1	1	12	13	12	12	14
Additional Elements Carried by this Element															
Probe			11%	127.0	0%	127.0	2	2	2	0	0	0	2	0	0
Spacecraft Bus					do not edit formulas below this line, use the calcualtions and override tables instead -->										
Attitude Control			3%	37.0	8%	40.1	35	43	43	45	45	45	45	45	45
Command & Data			2%	25.8	25%	32.1	37	37	37	37	42	42	42	37	37
Power			16%	180.4	26%	227.8	29	35	37	37	36	37	35	35	38
Propulsion1	FALSE		18%	203.5	5%	214.7	0	1	1	31	0	0	0	0	0
Structures & Mechanisms			33%	369.6	30%	480.5	0	0	0	0	0	0	0	0	0
Cabling			6%	67.1	30%	87.2									
Telecom			5%	56.2	20%	67.5	86	15	86	86	20	91	0	0	141
Thermal			3%	31.3	25%	39.3	5	5	5	5	5	5	5	5	0
Bus Total				971.0	22%	1189.2	192	136	208	242	148	220	127	122	261
Spacecraft Total (Dry): CBE & MEV				**1110.5**	20%	**1329.0**	196	139	211	243	160	233	141	134	275
Subsystem Heritage Contingency		20%		218.5	SEP Con	10%	0	0	0	0	0	0	0	0	0
System Contingency		18%		204.4			83	59	90	104	69	100	60	58	118
Total Contingency		**38%**		422.9											
Spacecraft with Contingency:				**1533**	of total	/o addl p	**279**	**197**	**301**	**347**	**228**	**333**	**201**	**192**	**393**
Propellant & Pressurant with residuals1			61%	2405.4	For S/C mass =		3998.9		Delta-V, Sys 1	2784.3	m/s	siduals =	58.4	kg	
Launch Mass				**3939**	ss for Prop Sizing		1533		EOL Power:	285.2	W				
							Launch C3	0							
Launch Vehicle Margin				**60.1**	on Unique LV Contingency			0%		1640					
							Fairing dia., m	0							
JPL Design Principles Margin				**483.0**	**30%**										
NASA Margin				**264.5**	**20%**							264.5			

Science Objectives

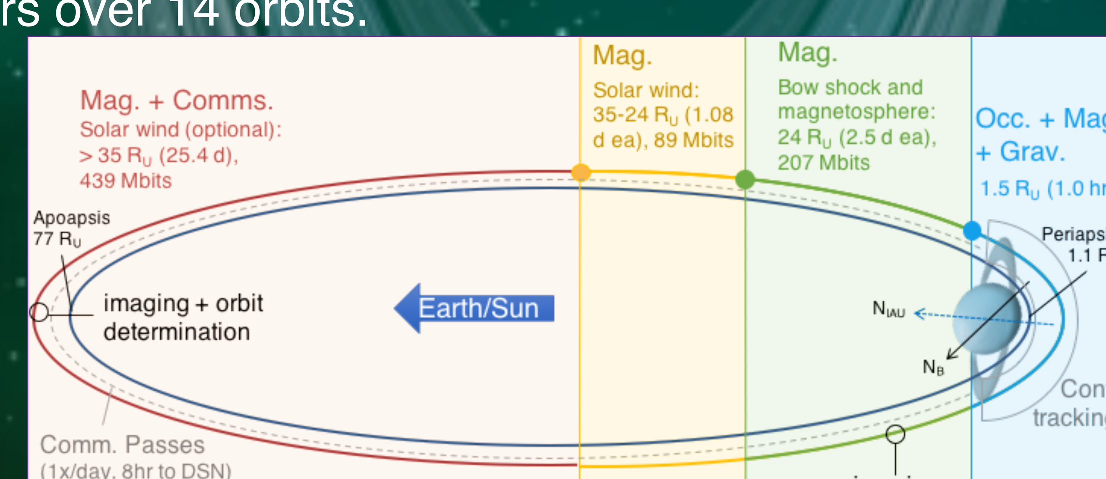
1. What is the size of Uranus' rocky core, and is it consistent with core accretion formation models (core 3-6 ME) [e.g. Pollack et al. 1996; Rice & Armitage 2003] or gravitational instability models (core < 1 ME) [e.g. Boss 1997; 2000]?
2. How and where is the magnetic field at Uranus generated, and 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? And is its atmospheric profile more similar to that of Earth or the gas giants?

Baseline Mission Design

A 2030 launch to orbit insertion in 2041 would involve two Venus gravity assists and one Earth gravity assist. Solar Electric Propulsion (SEP) would be required within 1.5 AU if a Jupiter gravity assist is unavailable. OCEANUS would be at Uranus close to equinox in 2049, providing important new data relating to Uranus' seasonal variability.



Our 30 day science orbit has a periapsis at 1.1 R_U and apoapsis at 77 R_U. Magnetometer observations to be taken at any time including magnetopause and bow shock crossings. Continuous tracking for gravity measurements would occur when $r < 1.5R_U$. Nominal mission length is 1.5 years over 14 orbits.



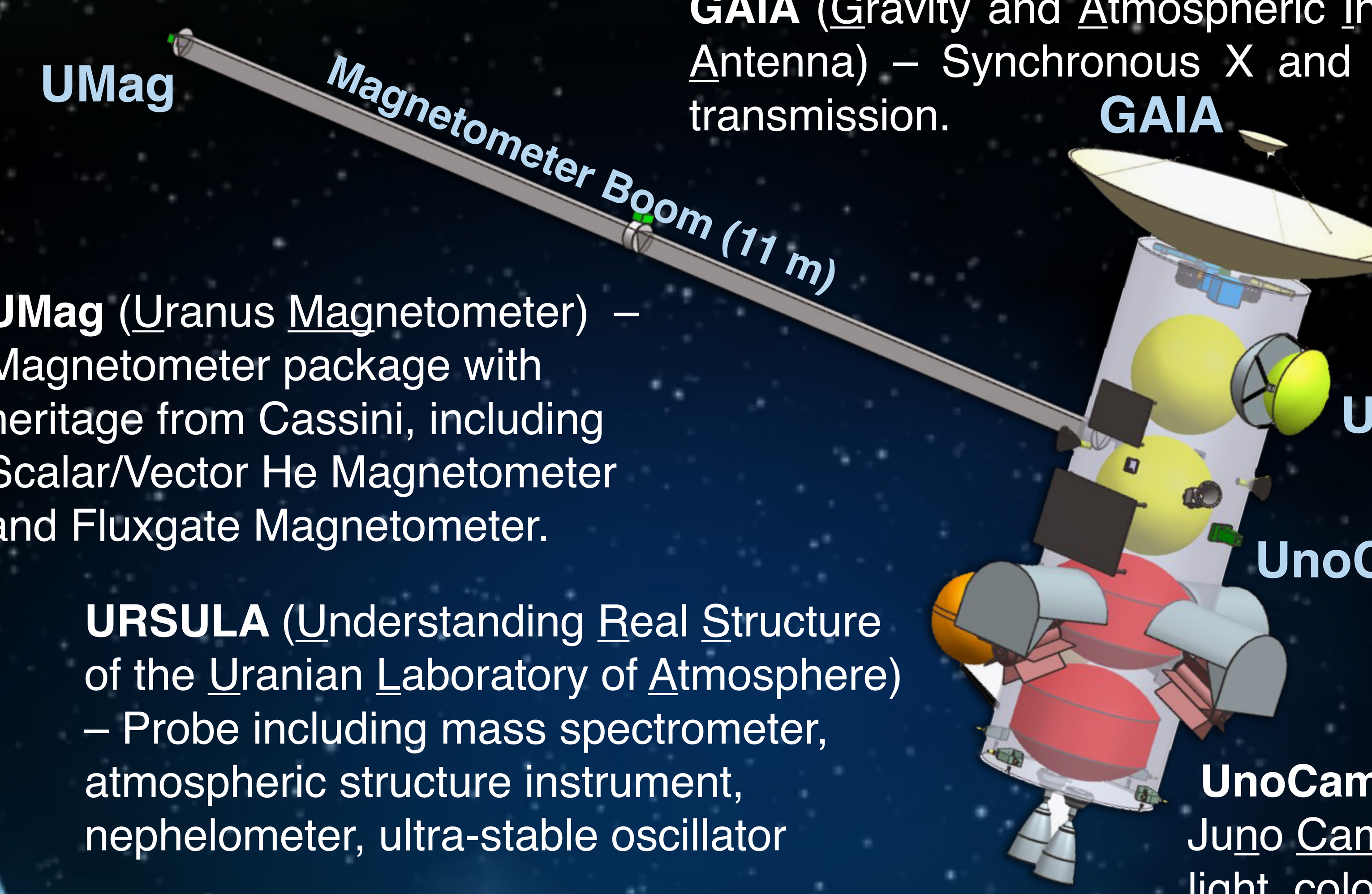
Projected Cost

Total budget $1213.2M (FY2015) **Our cost: $1180.8 M**

- Mission cost cap of $1B, with cost credit of $213.2M for eMMRTGs.
- SEP stage cost: $142.8M (over 10% of OCEANUS' budget)
- OCEANUS features a low-cost instrument suite: $14.1M for the magnetometer and $8.0M for the engineering and navigation camera.

Baseline Instruments

GAIA (Gravity and Atmospheric Instrument Antenna) – Synchronous X and Ka band transmission.



UMag (Uranus Magnetometer) – Magnetometer package with heritage from Cassini, including Scalar/Vector He Magnetometer and Fluxgate Magnetometer.

URSULA (Understanding Real Structure of the Uranian Laboratory of Atmosphere) – Probe including mass spectrometer, atmospheric structure instrument, nephelometer, ultra-stable oscillator

UnoCam (Uranus' Juno Cam) – Visible light, color camera

Key Trades

Mission Type:

Orbiter ✓	Flyby	
2000 kg constrained	500 kg delivered	More compelling science at lower cost
Single reliable instrument	Low TRL Instrument	
$13.5 million instrument cost	$70 million instrument cost	

Power Source:

Solar Power	Radioisotope Power ✓	
$334 thousand cost	$165 million cost	Solar power is not feasible due to mass and surface area, cannot deliver spacecraft
4.03 W/m² at Uranus	290 W at Uranus	
361 m² solar arrays	120m² solar arrays (SEP)	
692 kg	135 kg	

Spacecraft:

3-Axis	Spinner ✓	
Cheaper orientation sensor	Expensive sensors	Sacrifice cost for manageable mass and power
Higher mass/power	Lower mass/power	

Probe Deployment:

Articulating Antenna	Spin-up After Probe Separation ✓	
1 ACS method	2 ACS methods	Avoid risk and limit articulation
Higher risk	Lower risk	

Conclusions/Lessons Learned

- An ice giant mission is of high priority.
- In the event a flagship-class mission to an ice giant in the next decade is unavailable, we considered a medium-class Uranus orbiter concept of focused scientific scope that would accomplish 3 of the 9 objectives outlined by NASA's Decadal Survey on a total budget of $1.2B (FY2015).
- Mission design, power, mass and cost constraints make achieving such a mission to Uranus with a New Frontiers budget difficult.
- To accomplish an ice giant orbiter launch before 2040 (for arrival 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 may be necessary for a mission of limited budget.