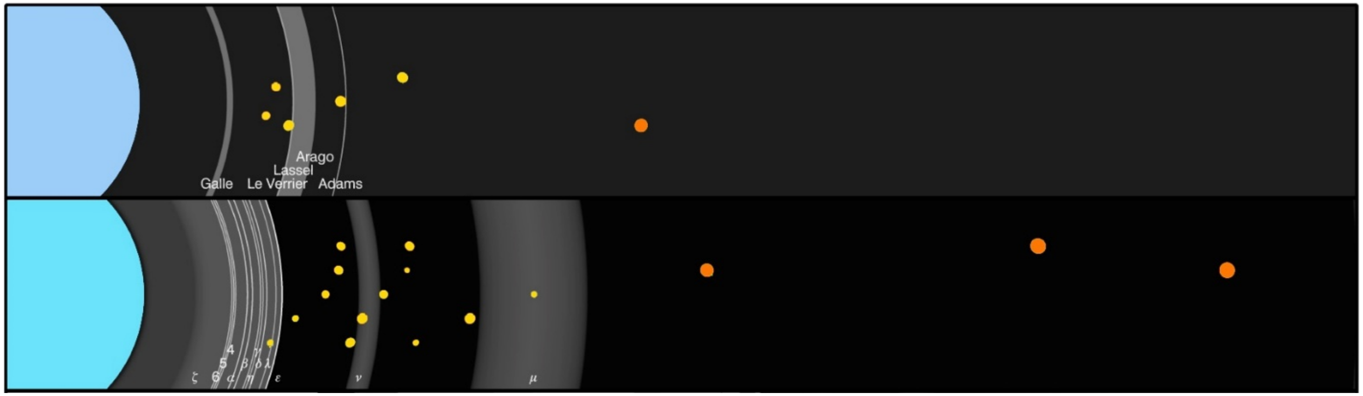
Ice Giants

Pre-Decadal Study Summary

OPAG, 22 February 2017

Mark Hofstadter, for the Ice Giant Study Team



Science Definition Team

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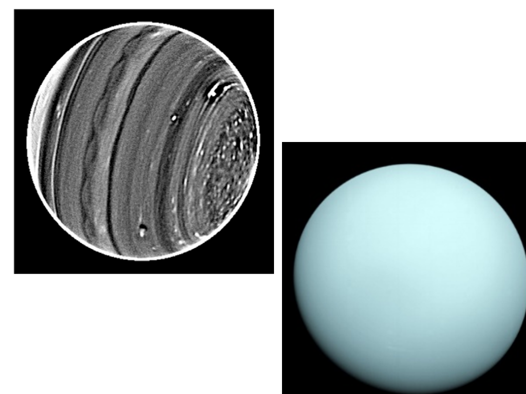
Why Uranus and Neptune?

- These relatively unexplored systems are fundamentally different from the gas giants (Jupiter and Saturn) and the terrestrial planets
  - Uranus and Neptune are ~65% water by mass (plus some methane, ammonia and other so-called "ices"). Terrestrial planets are 100% rock; Jupiter and Saturn are ~85% H_2 and He

- Ice giants appear to be very common in our galaxy; most planets known today are ice giants

- They challenge our understanding of planetary formation, evolution, and physics
  - Models suggest ice giants have a narrow time window for formation. If correct, why are they so common in other planetary systems?
  - Why is Uranus not releasing significant amounts of internal heat? Does its output vary seasonally?
  - Why are the ice giant magnetic fields so complex? How do the unusual geometries affect interactions with the solar wind?



Uranus in 2012 (Sromovsky et al. 2015) and 1986 (right, Voyager)

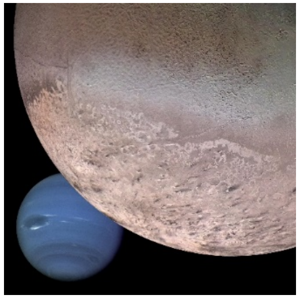
12 Key Science Objectives

Highest Priority

- Interior structure of the planet
- Bulk composition of the planet (including isotopes and noble gases)

Planetary Interior/ Atmosphere

- Planetary dynamo
- Atmospheric heat balance
- Tropospheric 3-D flow

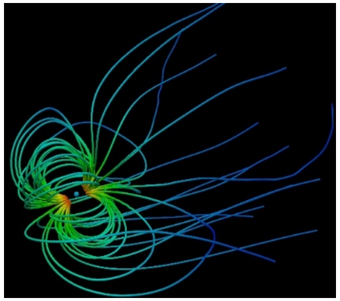


Rings/Satellites

- Internal structure of satellites
- Inventory of small moons, including those in rings
- Ring and satellite surface composition
- Ring structures and temporal variability
- Shape and surface geology of satellites
- Triton's atmosphere: origin, evolution, and dynamics

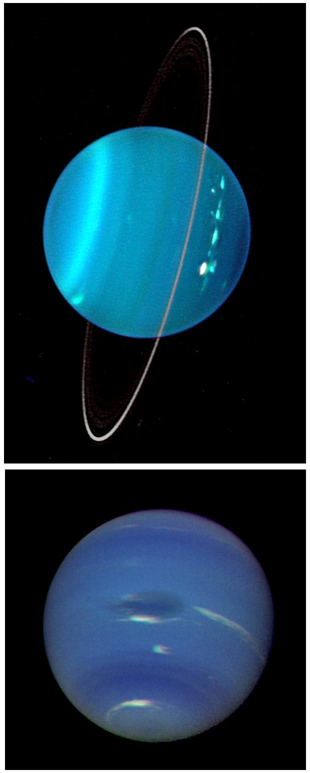
Magnetosphere

- Solar wind-magnetosphere-ionosphere interactions and plasma transport



Uranus or Neptune?

- Uranus and Neptune systems are equally important
- A Flagship mission to either is scientifically compelling
- It is important to recognize, however, that Uranus and Neptune are not equivalent. Each has things to teach us the other cannot. For example
  - Native ice-giant satellites (Uranus) vs. captured Kuiper Belt object (Neptune)
  - The smallest (Uranus) and largest (Neptune) releases of internal heat, relative to input solar, of any giant planet
  - Dynamics of thin, dense rings and densely packed satellites (Uranus) vs. clumpy rings (Neptune)



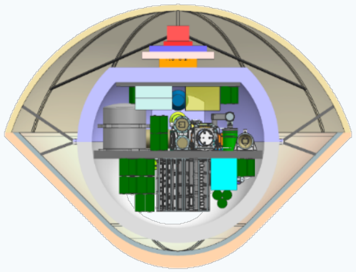
Uranus (top, Sromovsky et al. 2007) and Neptune (bottom, Voyager)

Model Payloads

Chosen to maximize science return. Similar for Uranus and Neptune, and whether flyby or orbiter.

Model payload for probe:

- Mass spectrometer
- ASI (density, pressure and temperature profile)
- Hydrogen ortho-para instrument
- Nephelometer



Model payload for orbiter

50 kg orbiter payload addresses minimum acceptable science

- NAC,
- Doppler Imager,
- Magnetometer.

90 kg orbiter payload partially addresses each science objective. Add to 50 kg case:

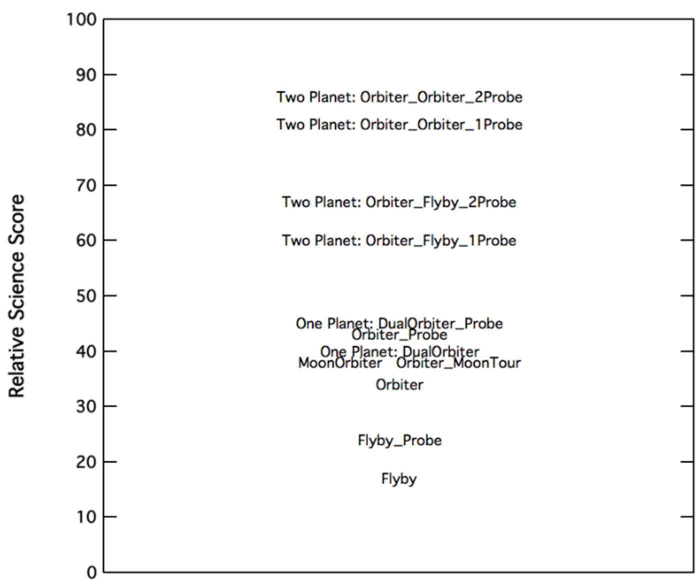
- Vis/NIR imaging spect.,
- Radio and Plasma suite,
- Thermal IR,
- Mid-IR or UV spect.

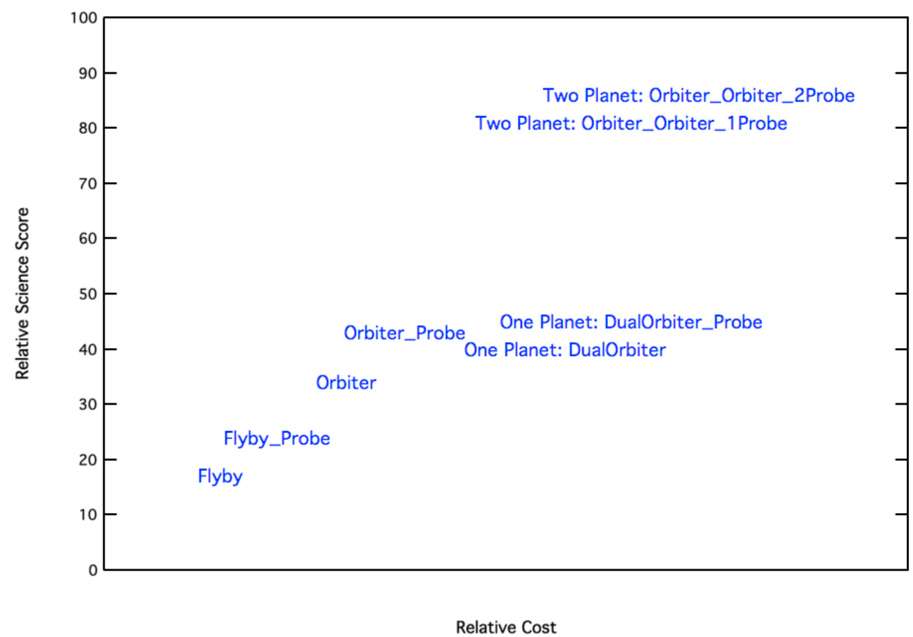
150 kg orbiter payload comprehensively addresses all science objectives. Add to 90 kg case:

- WAC,
- USO,
- Energetic Neutral Atoms,
- Dust detector,
- Langmuir probe,
- Radio sounder/Mass spec.

Mission Architectures

- Wide range of architectures assessed; ranked scientifically and costed
- An orbiter with probe meets the science requirements and study cost target
- Adding a second spacecraft to the other ice giant significantly enhances the science return at a proportionally higher cost

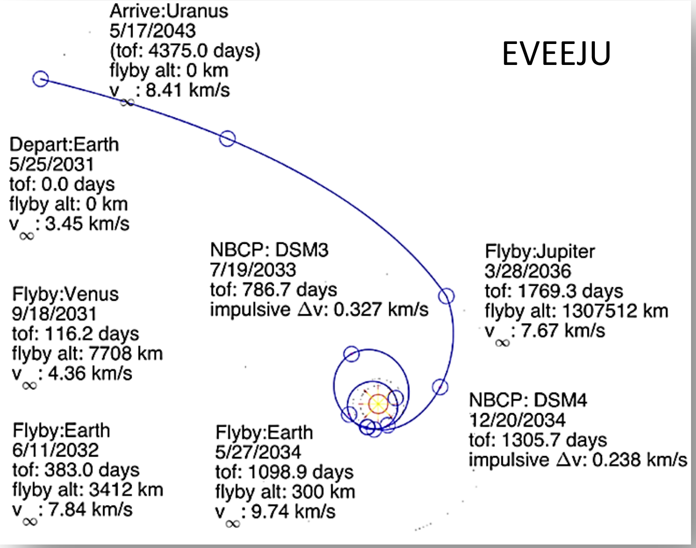




Mission Design Takeaways

- Launches are possible any year studied (2024-2037)
  - Optimal launch opportunities are in 2029-2032, using Jupiter gravity assist
  - Missions to Uranus via Saturn are possible through mid-2028
  - No Neptune via Saturn trajectories in the study time-range

- Chemical trajectories deliver a flagship class orbiter (>1500 kg dry mass) to Uranus in < 12 years using Atlas V
  - Delta-IV Heavy can reduce interplanetary flight time by 1.5 years



- No chemical trajectories exist for delivering a flagship class orbiter to Neptune in < 13 years using Atlas V or Delta-IV Heavy launch vehicles. SLS or Longer flight times would be needed.

- SEP Enables a flagship orbiter to Neptune in 12-13 years
  - Implemented as separable stage to minimize propellant required for insertion

Benefits of SLS

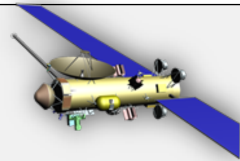
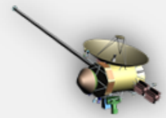
All single planet missions studied are achievable with existing ELVs

SLS can provide enhancing benefits:

- Increases deliverable mass and lowers flight time by 3 to 4 years
- Enables chemical Neptune mission in 11.5 yr.
- Enables two spacecraft missions with a single launch
- Increases launch opportunities

When combined with aerocapture capability, enables very low flight times for both Uranus (< 5 yr.) and Neptune (< 7 yr.)

Cost Summary, Key Architectures

				
Description	Neptune Orbiter with probe and 50 kg science payload (requires SEP stage)	Uranus Flyby spacecraft with probe and 50 kg science payload	Uranus Orbiter with probe and 50 kg science payload	Uranus Orbiter without a probe, and 150 kg science payload
Team X Cost Estimates ($k, FY15)				
Total Mission Cost*	1971	1493	1700	1985
Aerospace ICE ($k, FY15)				
Total Mission Cost*	2280	1643	1993	2321

**Includes cost of eMMRTGs, NEPA/LA, and standard operations. LV cost not included.*

- Neptune missions cost ~$300M more than Uranus for comparable science return (driven by SEP)
- The Uranus orbiter with probe mission is estimated to be in the range of $1.7 to $2.6B depending on the orbiter payload (50-150 kg range) and reserve posture

Technology Considerations

- In Space Transportation
  - Aerocapture
  - LOX-LH2 chemical propulsion
  - Radioisotope Electric Propulsion (REP)
- Optical Communications (Beyond 3AU)
- Small satellites in mass range 100 to 400 kg, CubeSats
- Advanced Radioisotope Power
  - eMMRTG
  - Segmented Modular Radioisotope Thermoelectric Generator (SMRTG)
  - High Power Stirling Radioisotope Generator (HPSRG)
- HEEET thermal protection system

- Ice Giants concepts can be implemented with eMMRTG and HEEET technology currently in development

International Partnerships

- A broad option space exists for international partnerships
  - Scientists
  - Instruments
  - Probes
  - Spacecraft or spacecraft subsystems
  - Ground stations
  - Possible second spacecraft on either a shared or separate launch vehicle
- ESA received a briefing on 31 January
  - They will propose a mechanism for their participation in an Ice Giant Flagship

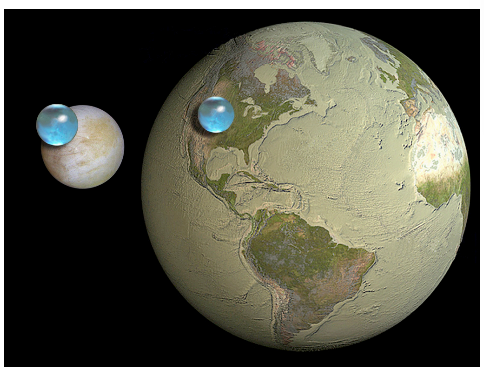
Study Recommendations

- An orbiter with probe be flown to Uranus, launching near 2030
- A Uranus or Neptune orbiter should carry a payload between 90 and 150 kg
- Two-planet, two-spacecraft mission options should be explored
- The development of eMMRTGs is enabling and should be completed as planned
- There should be continued investments in ground-based research (theoretical and observational) and instrumentation. Important areas include upper-atmospheric properties, ring-particle impact hazard, and giant-planet seismology
- International collaborations should be leveraged to maximize the science return while minimizing the cost to each partner
- An additional mission study should be performed that uses refined programmatic ground-rules to better target the mission likely to fly

An Ice Giant Mission in 2030

Why should we be excited about this possibility?

- This mission engages all disciplines in the planetary science community, as well as heliophysics and exoplanet scientists
- Later launches lose the opportunity to map the Northern Hemispheres of the Uranian satellites, and sample unique solar wind geometries
- The mission requires no new technology, and is low-risk



- The funding profile fits with Mars 2020 and Europa MFM
- Partners, especially ESA, interested in cost-sharing