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UCL

Missions to Uranus

Exploring the Origins and Evolution of Ice Giant Planets

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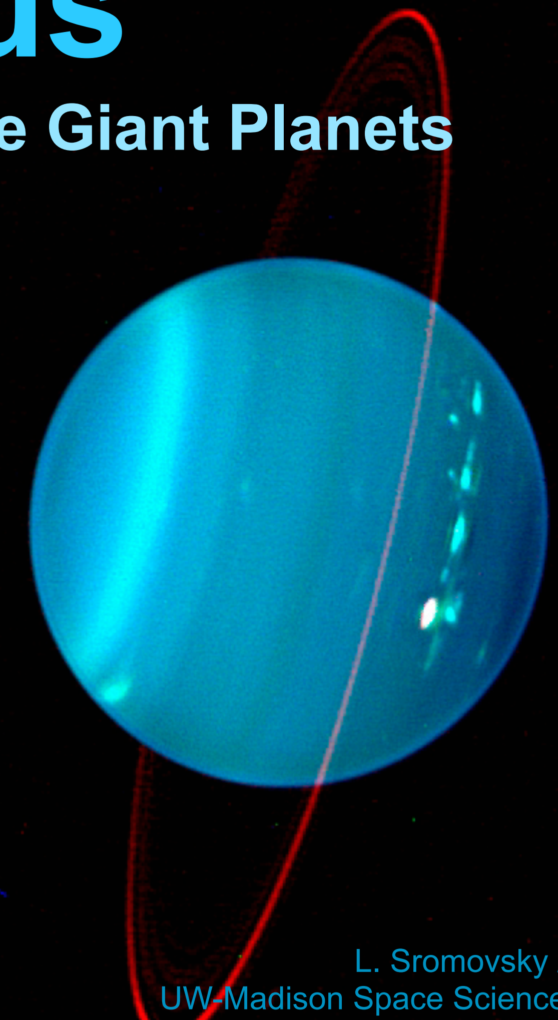
2. The Centre for Planetary Sciences at UCL/Birkbeck, UK.
3. CNRS, Institut de Recherche en Astrophysique et Planétologie, France.

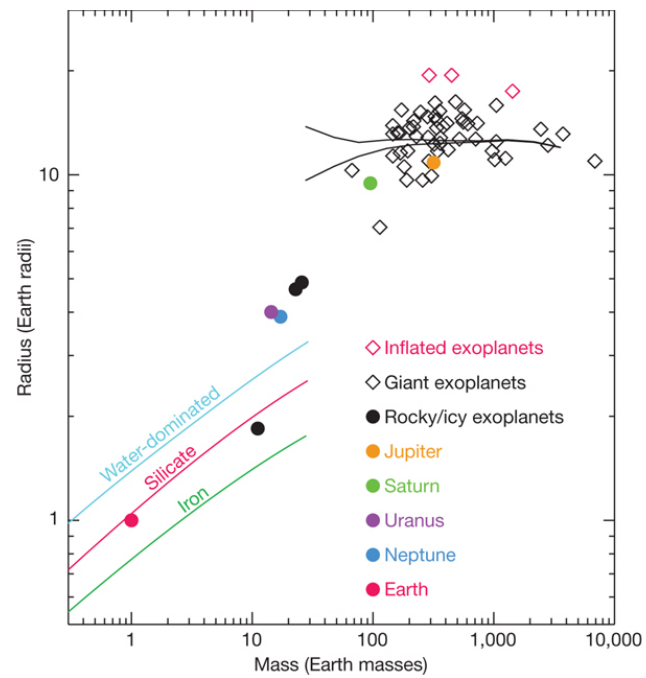
Also thanks to SEA Ltd. (Chris Chaloner, Andrew Bacon, Michael Guest) and EADS Astrium (Lisa Peacocke, Stephen Kemble, Steve Eckersley) for industrial support.



L. Sromovsky / UW-Madison Space Science and Engineering Centre / Keck

Introduction

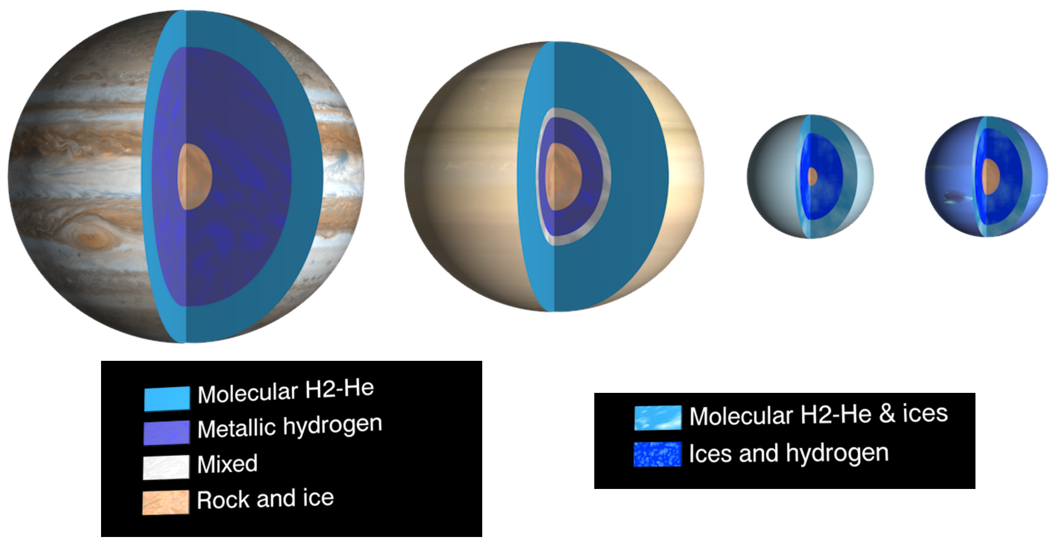
- Giant planets account for more than 99% of the solar system.
- Ice giants (U/N) are fundamentally different from gas giants (J/S).
- U/N-mass exoplanets have been observed – remove observer bias from exoplanet distributions ⇒ U/N exoplanets are common.
- The ice giants also have fascinating and unique planetary environments.
- Voyager 2 remains the only spacecraft to have returned data from Uranus – 26 years have elapsed since that flyby.
- Need new in situ observations to constrain models, obtain ground-truth for exoplanet observations, and understand solar system formation.

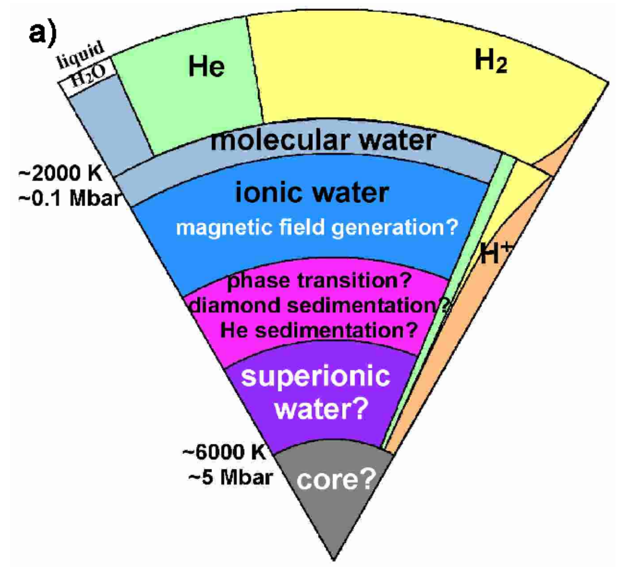


Deming & Seager (2009)

Uranus as an Ice Giant Planet

UP Consortium





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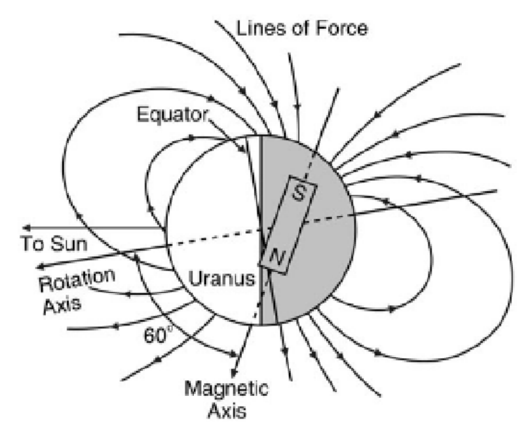
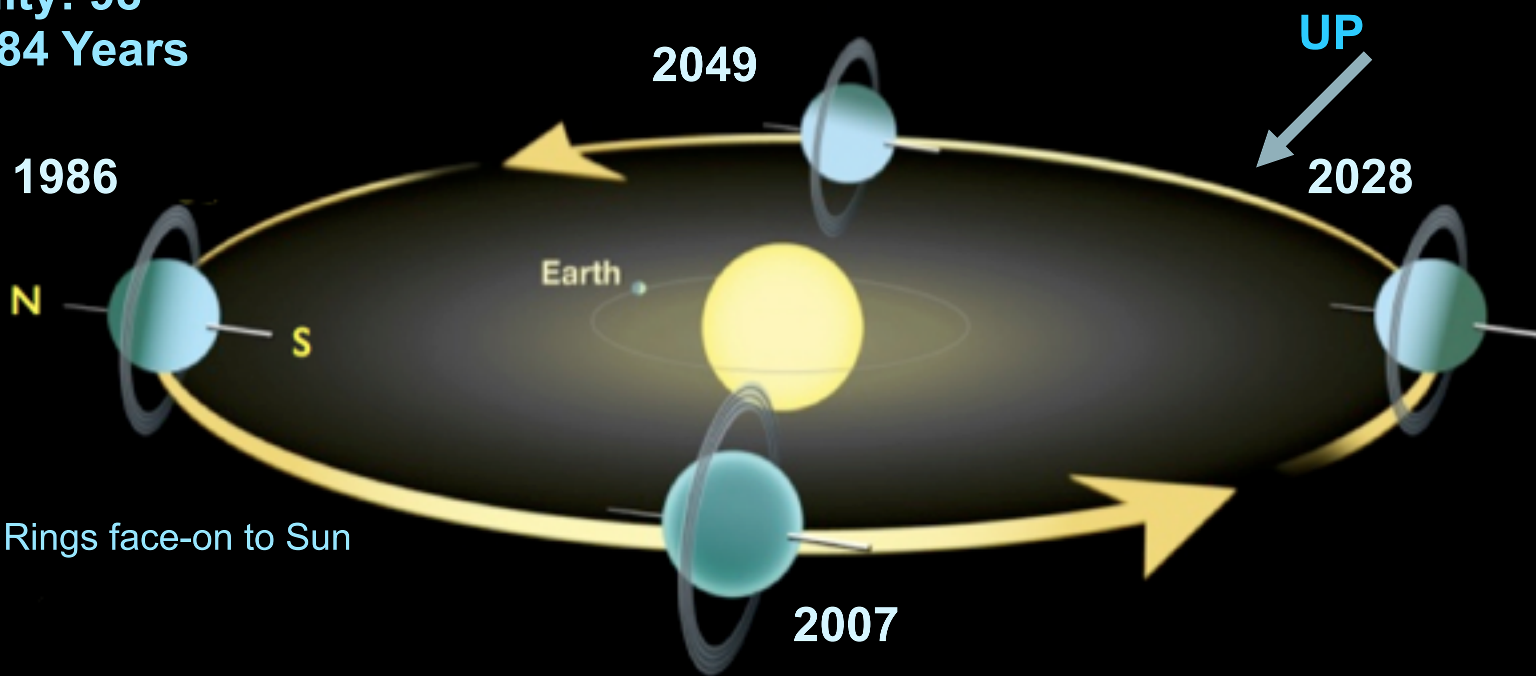


- Ice giant: envelope rich in "ices" (H_2O, CH_4, NH_3).
- No interior model that is consistent with all constraints (gravity field, magnetic field, heat flux, composition, temperature).

(a) N. Nettelmann; (b) Connerney et al. (1987)

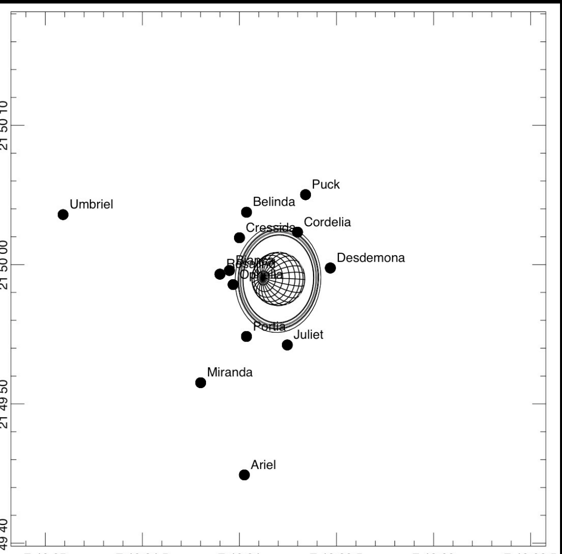
Seasonal variations

Obliquity: 98º
Orbit: 84 Years

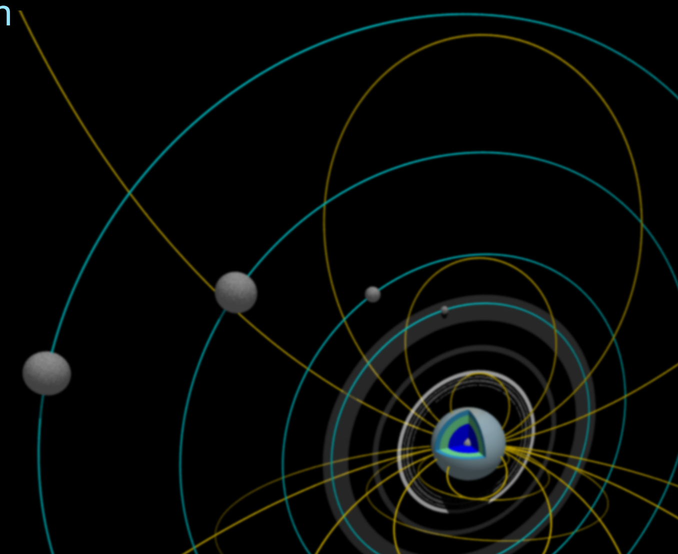


Solstice: Rings face-on to Sun

Equinox: Rings edge-on to Sun



PDS Rings Node Tools

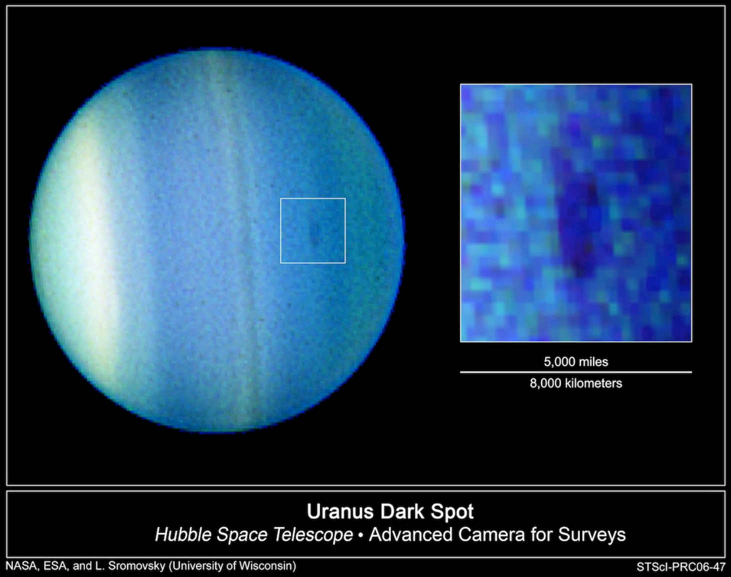


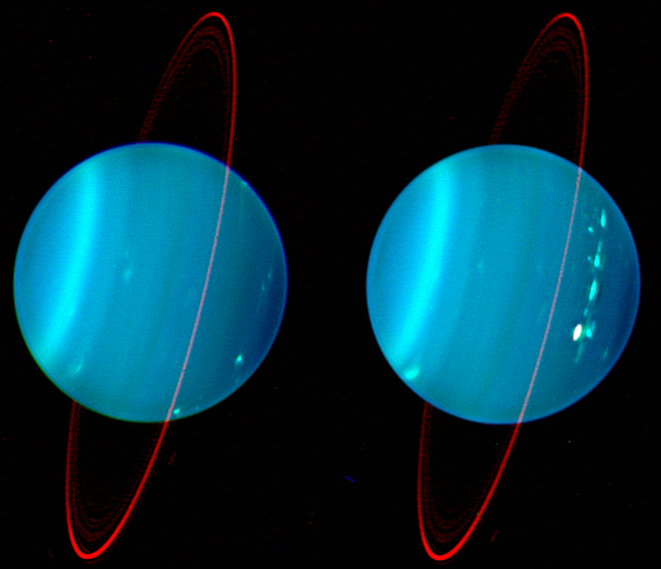
UP Consortium

Based on artwork by M. Showalter and M. Gordon, SETI Institute

Seasonal driving of the atmosphere

Voyager 2 / NASA JPL

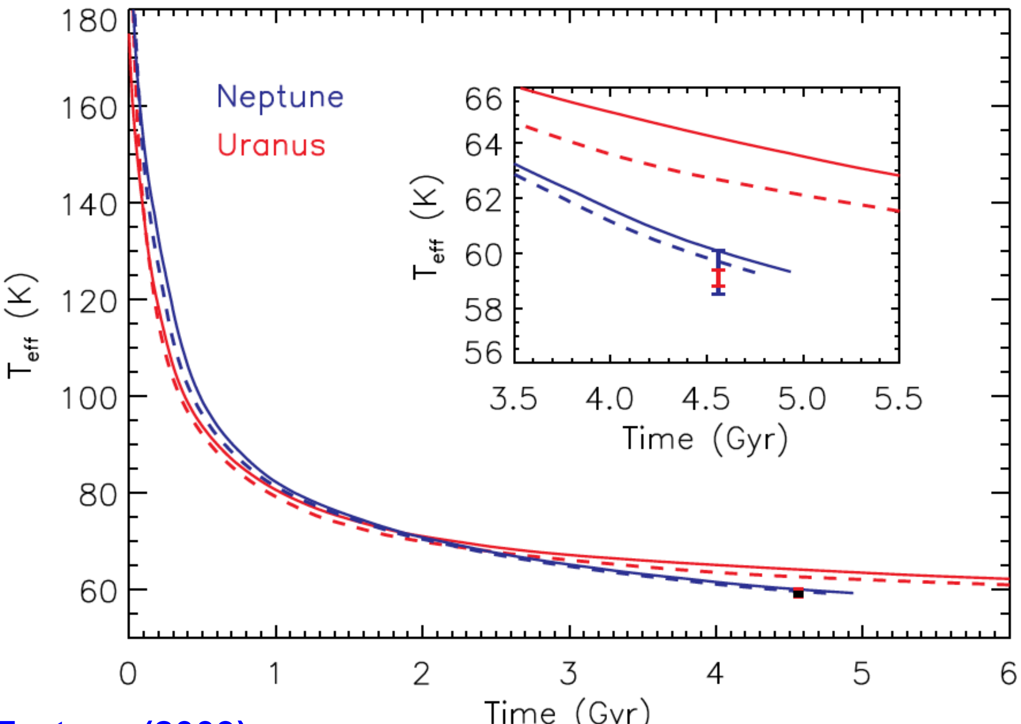




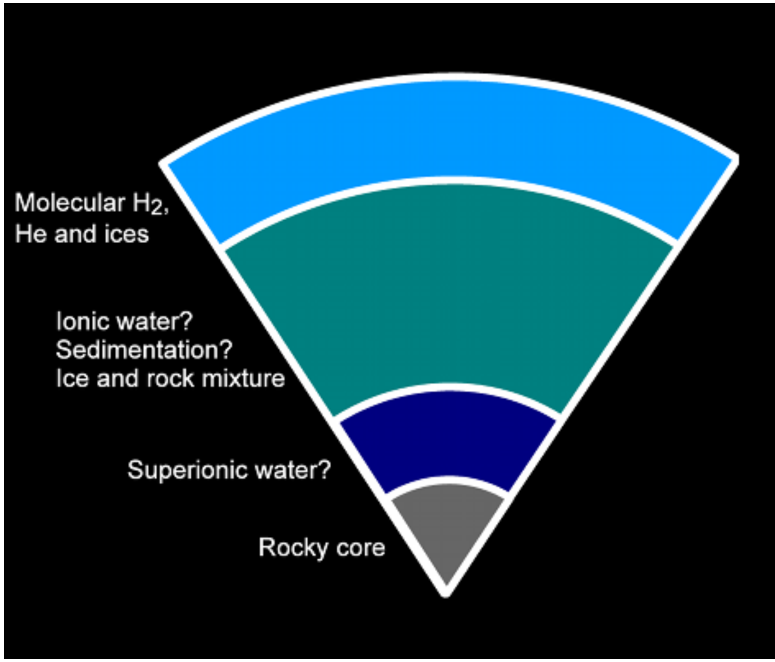
L. Sromovsky / UW-Madison Space Science and Engineering Centre / Keck

Self-luminosity and temperature

- Uranus is cold and has a small self-luminosity.
- Possibly related to a collision early in the life of Uranus – dramatic loss of primordial heat.
- Could also be a seasonal effect – Uranus' atmosphere appears to be more active at equinox (inhibiting convection near solstice).

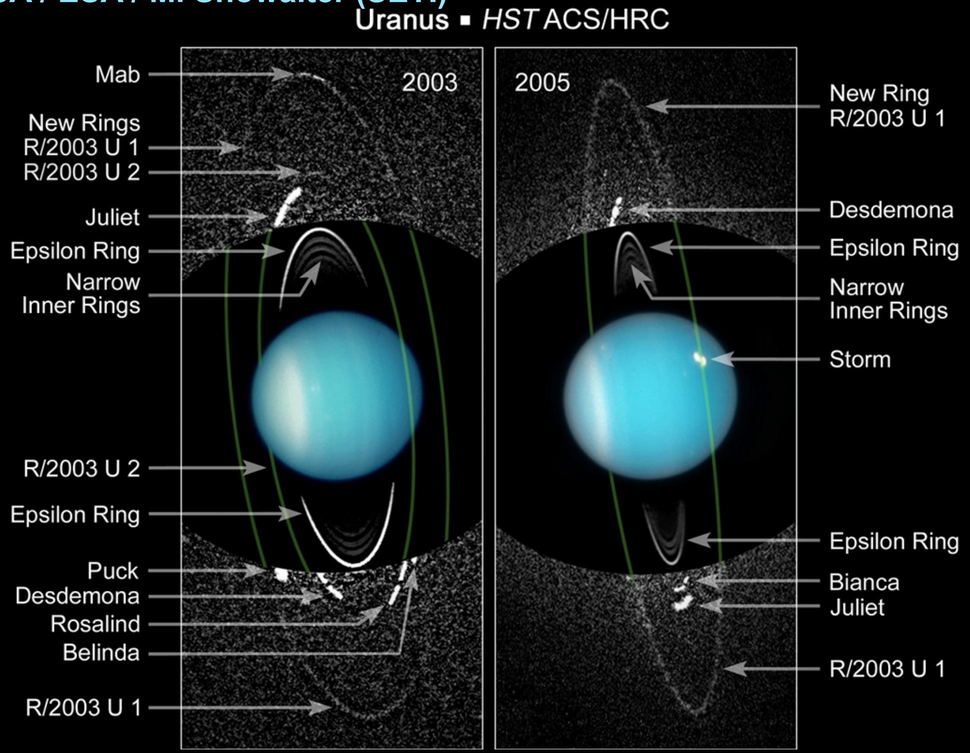


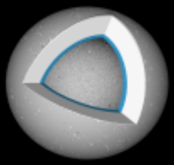
Fortney (2009)



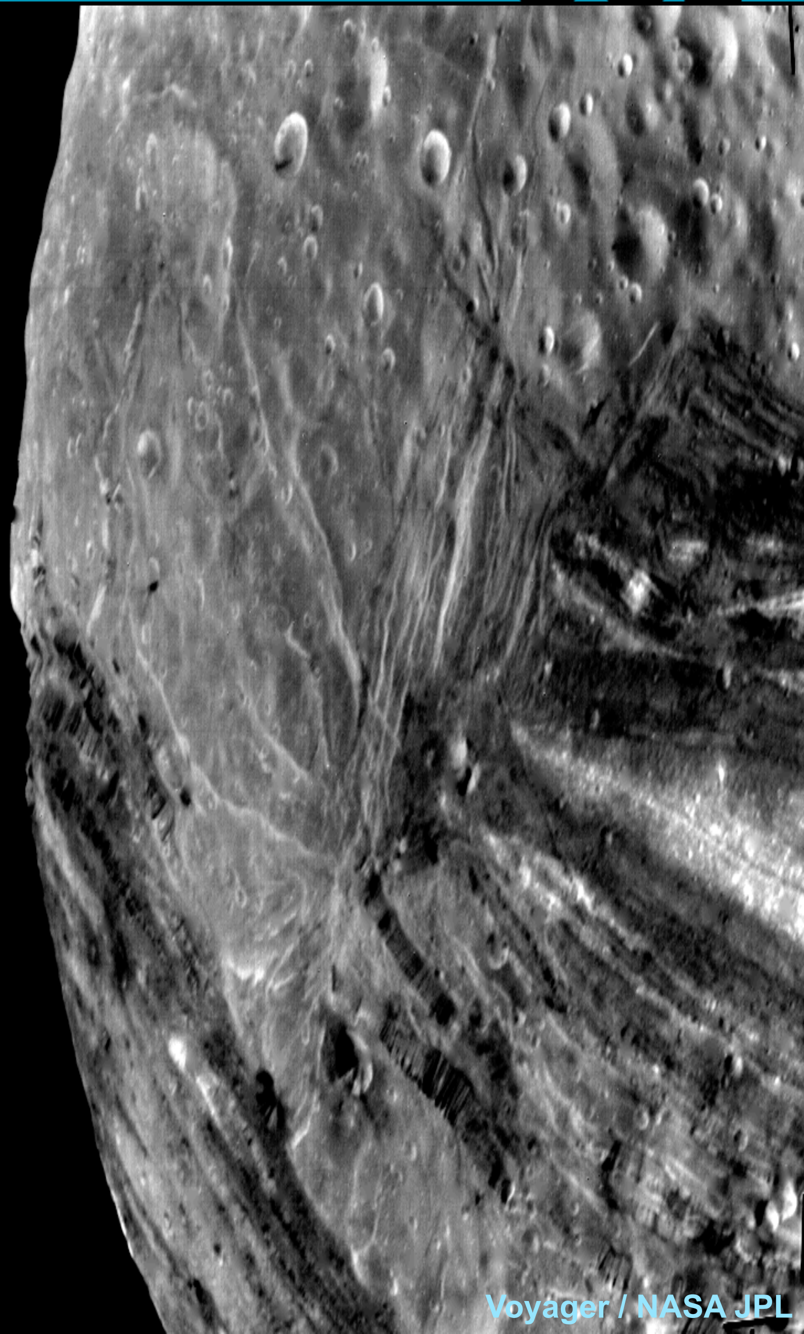
Rings and natural satellites

NASA / ESA / M. Showalter (SETI)





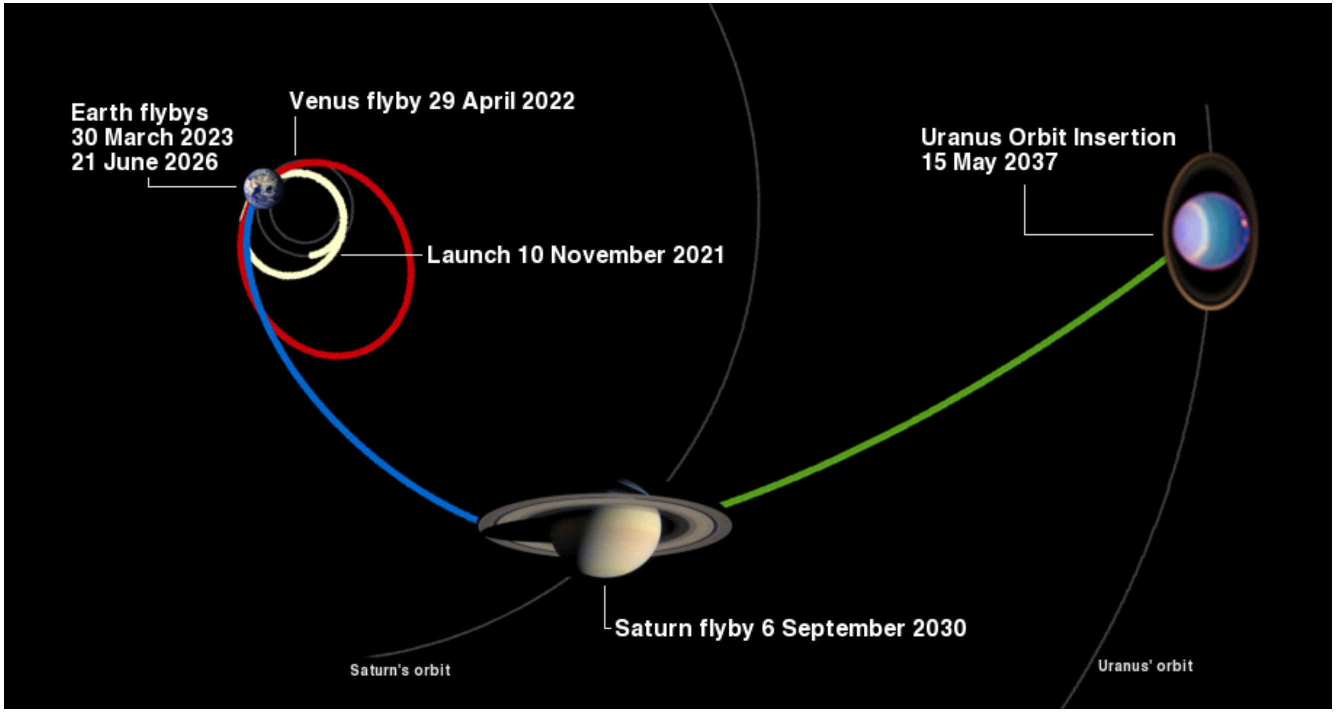
Paul Schenk



Voyager / NASA JPL

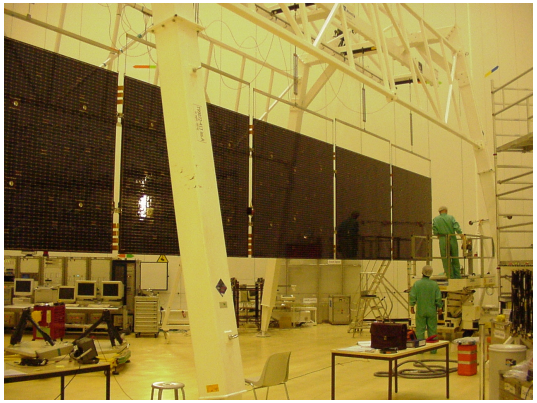
Uranus Pathfinder: Mission profile

- Submitted to ESA M3 call in 2010 – highly rated (last eight) but not selected.
- Launch and transfer:
  - Soyuz launch (Kourou) in 2021, arrive in 2037 with a variety of available transfers
  - Transfer not more expensive than mission to Saturn but taking 15.5 years.
  - Assumed chemical propulsion – SEP not studied.
  - Inject to GTO then separate propulsion module used to achieve v_{inf}.
  - Poorly known ring plane hazards limit orbital insertion periapsis => limit injected orbit.
  - Aerocapture not considered (low TRL).
- Near polar science orbit: great for interior/magnetic field studies.

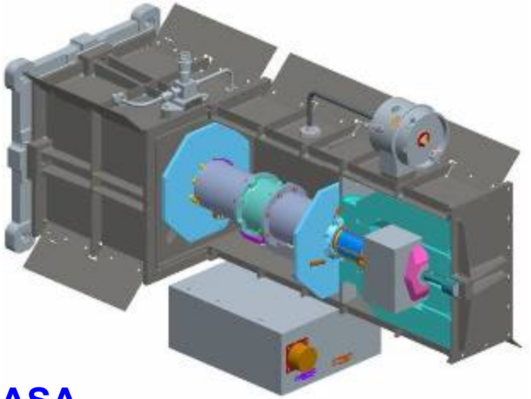


Electrical power

ESA



Wikipedia

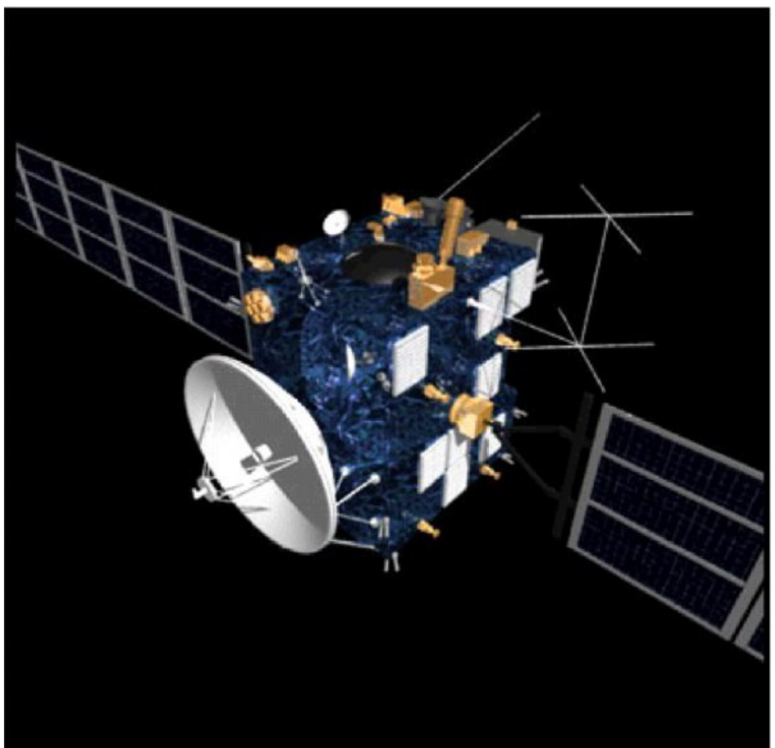


NASA

- Solar energy flux ~3.5 W m^{-2} at Uranus requiring >400 m^2 solar arrays c.f. 64 m^2 arrays on Rosetta.
- Not viable with present technology.
- Use radioisotope power sources employing ^{241}Am rather than ^{238}Pu:
  - Longer half-life than ^{238}Pu.
  - $W_{th}(^{241}Am)$=0.11 W/kg, $W_{th}(^{238}Pu)$=0.57 W/kg
  - Lower Wth ⇒more fuel is required.
  - Also managed at a system level using more efficient Stirling engine (c.f., ASRG).
- ^{241}Am is obtained from Am_2O_3 in spent fuel rods.
  - ^{241}Am is decay product of ^{241}Pu with $t_{1/2}$ of 14.4 years.
  - No complex reprocessing technology – chemical separation.
- Low TRL devices.

Uranus Pathfinder orbiter configuration

- Reuse Mars Express/Rosetta heritage platform.
- Spin (during hibernation) and three-axis stabilised (tour) – reaction wheels and thrusters.
- Hibernate during cruise to reduce cruise phase costs.
- ORS instruments on one face of the spacecraft and similarly bore-sighted.



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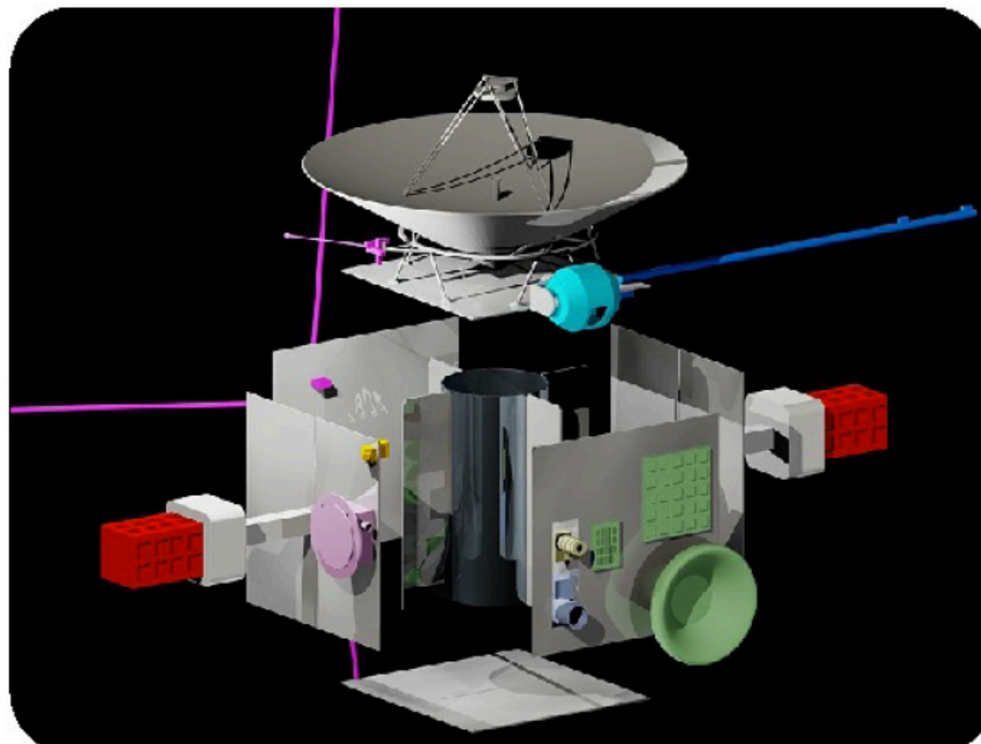


P. Dunn / C.S. Arridge / UCL

Scientific payload

- Focused set of high TRL instruments with strong European heritage.

- Particles and plasma, gravitational and magnetic fields, and optical remote sensing.

- Mass: 53.8 kg (CBE) [62.6 kg with DMM].

- Power: 88 W [with DMM].

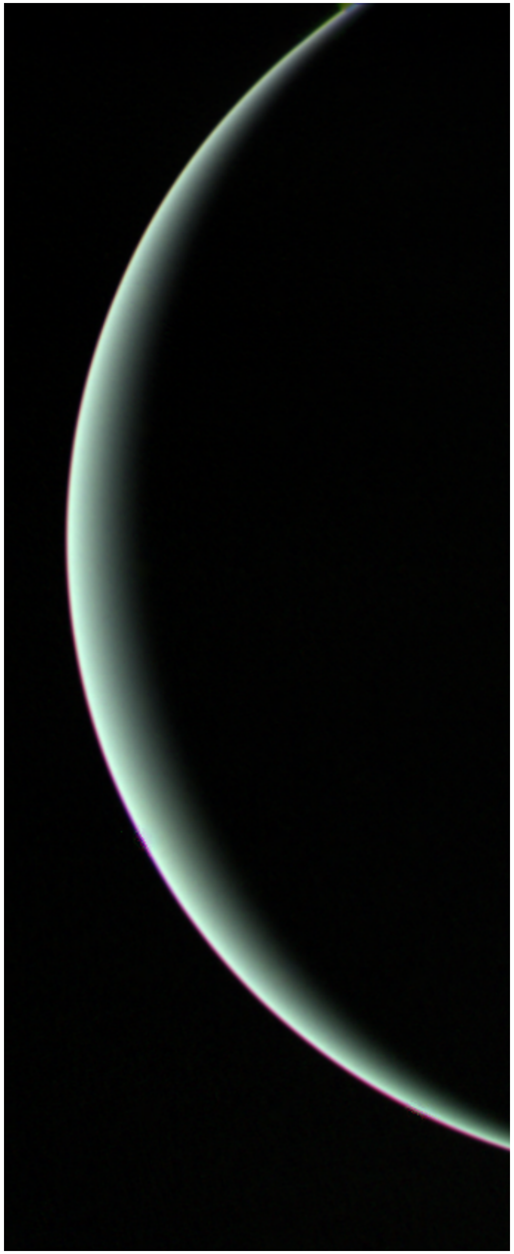
- Telemetry: 4.2 Gbit per orbit (75 Mbit per downlink in Ka band).

- Limited electrical power ⇒ observing plans need to be carefully constructed.

Instrument	TRL
Magnetometer (MAG)	9
Plasma and Particle Science (PPS)	8 / 9
Radio and Plasma Wave Experiment (RPW)	8 / 9
Microwave radiometer (MWR)	7 / 8
Thermal Infrared Bolometer (UTIRM)	5
Visual and Near-Infrared Mapping Spectrometer (NIR/MSIC)	>5
Ultraviolet Imaging Spectrometer (UVIS)	>5
Narrow Angle Camera (NAC)	>5
Radio Science Experiment (RSE)	9

Public engagement and Uranus

- **European** mission to a distant and poorly understood world like Uranus provides a unique public engagement opportunity.
- Planetary missions continue to capture the public's imagination and attract school children/students to science and engineering.
- Uranus' moons named after literary characters – opportunity to engage with literature/arts.
- Exploity new media – many of the UP consortium already engage with the public on Twitter.
- Leverage public engagement opportunities: British Science Festival (UK) & Highlights of Physics (DE).
- Special campaigns to maintain momentum during long interplanetary transfer.



Voyager 2 / NASA JPL

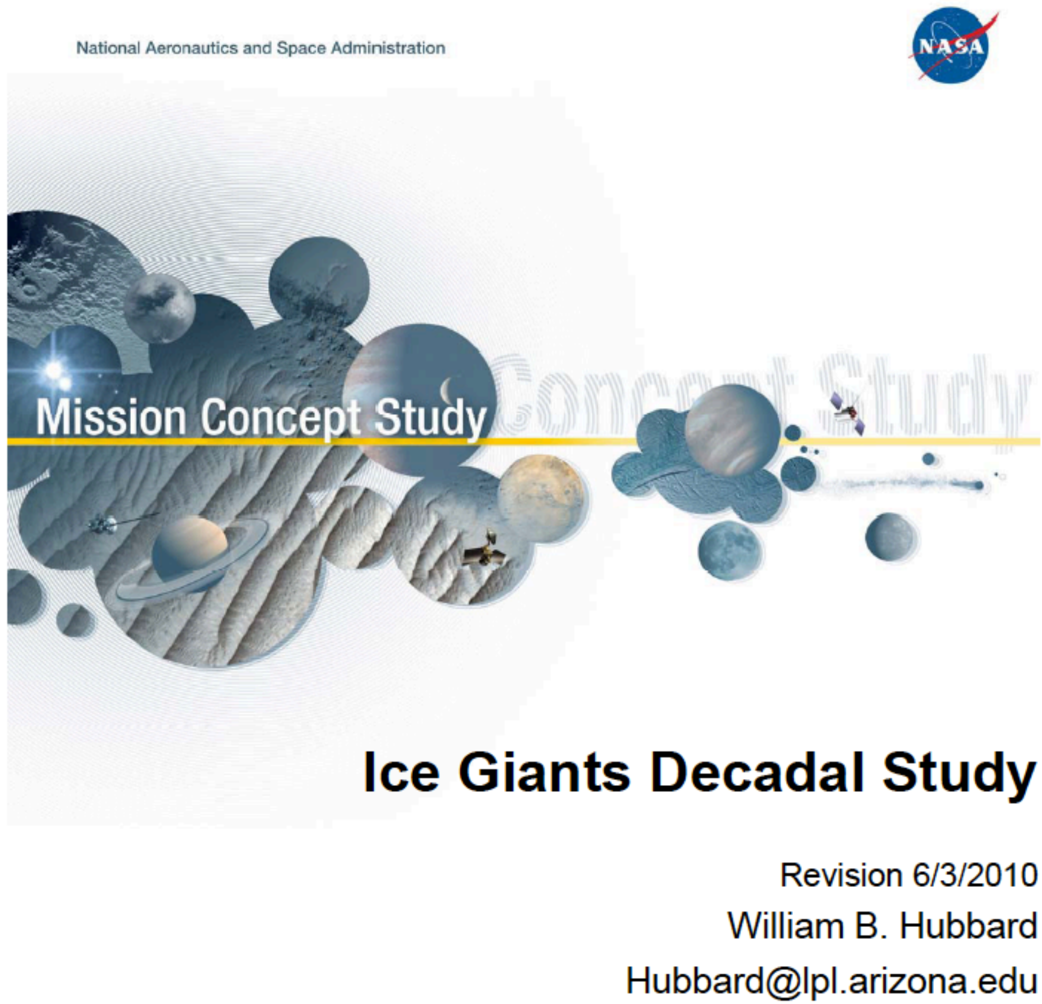
Probe science goals

- Most crucial measurement: heavy element/noble gas abundances/key isotope ratios – constraints on models of planet formation.
  - Isotope ratios H, C, N, even S, O.
  - Key measurement of noble gas and isotopic ratios only require a **shallow probe** (to ~1 bar).
  - **Deep probes** (to ~>5 bar) permit determination of bulk CH_4 and H_2S abundances as well as whether S/N ratio is enriched relative to solar.
  - Can only be made in situ – provides crucial ground truth for orbiter/ground-based observations and measurements.
  - Determine if gas giant and ice giant formation mechanisms are fundamentally different.

- Theoretical models have difficulties generating the strong winds found in the upper atmospheres (~600 km/h at J, 1500 km/h on S/N).
  - Energy distribution, depth of zonal wind structure, effect of solar energy and internal heat flux high priorities.
  - Nephalometer and accelerometer/USO will allow the measurement of key atmospheric properties and profiles along the probe trajectory.

NRC Planetary Decadal Survey

- Rapid mission study for the NRC Planetary Decadal Survey 2013-2023 in response to Uranus community white paper led by Mark Hofstader (JPL).



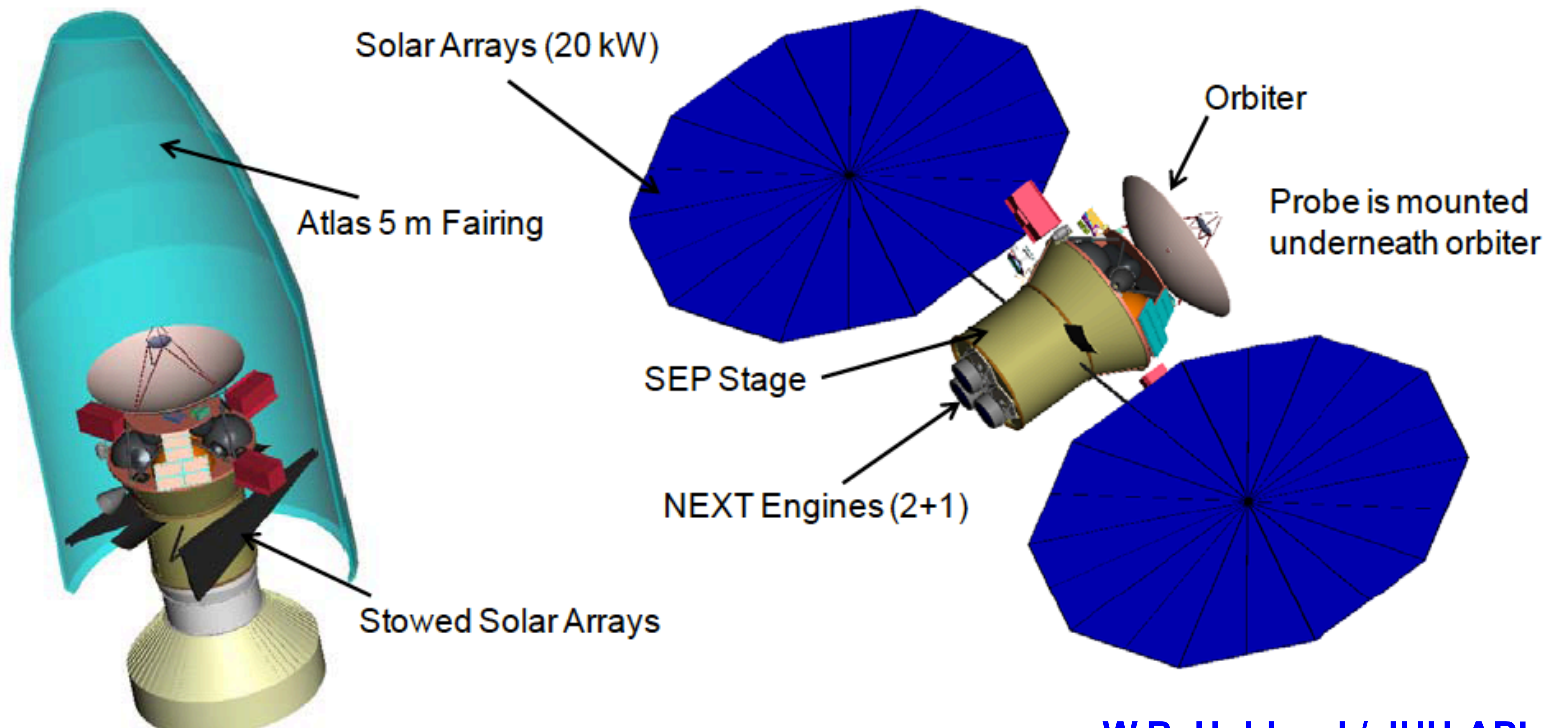
- Rapid mission study for the NRC Planetary Decadal Survey 2013-2023 in response to Uranus community white paper led by Mark Hofstader (JPL).

- Main design centre was APL/JHU with support from NASA Glenn & Langley.

- $1.5B – 1.9B mission (sub-flagship) in FY15.

Decadal study mission profile

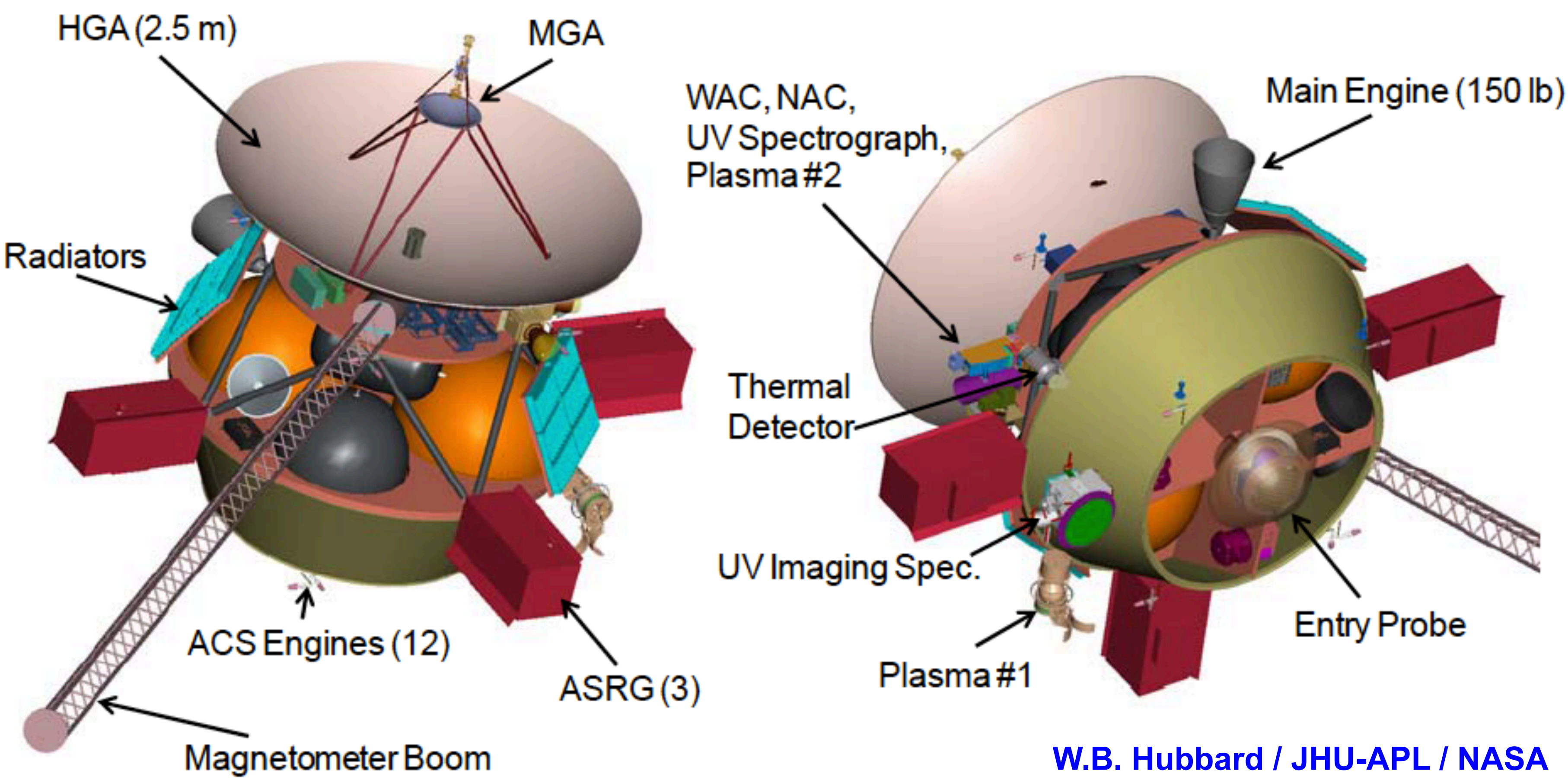
- Launch on an Atlas V with an interplanetary cruise time of 13 years.
- Five-year SEP stage using solar arrays, with a single Earth GA.
- Jettison SEP stage to leave ASRG-powered orbiter for Uranus entry and orbital tour.
- Atmospheric entry probe prior to UOI.
- Satellite tour.



W.B. Hubbard / JHU-APL / NASA

Decadal survey orbiter

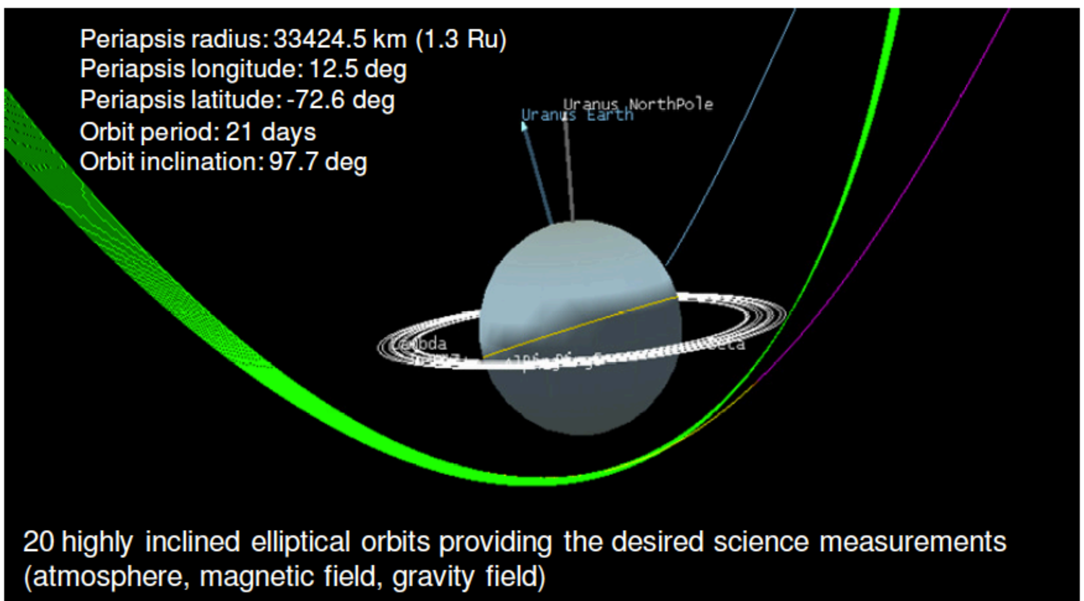
- Three-axis stabilised during orbital tour / spin stabilised during hibernation/probe release.
- Reaction wheels/thrusters for AOCS.
- Powered by 3 ASRGs providing 438 W (367.5 W) BOL (EOL).



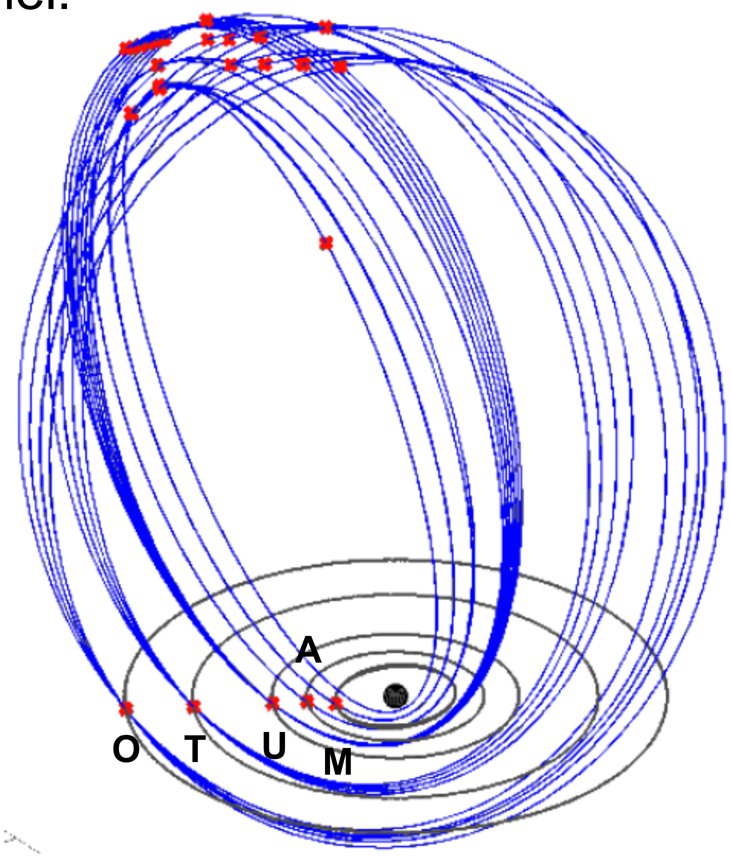
W.B. Hubbard / JHU-APL / NASA

Decadal survey planetary tour

- **Orbit:** P=21 days, r_p=1.3 R_U, r_a=51.3 R_U, i=97.7º
- Encounter five major natural satellites twice: Miranda, Ariel, Umbriel, Titania, and Oberon.
- Additionally four untargetted flybys of Umbriel.



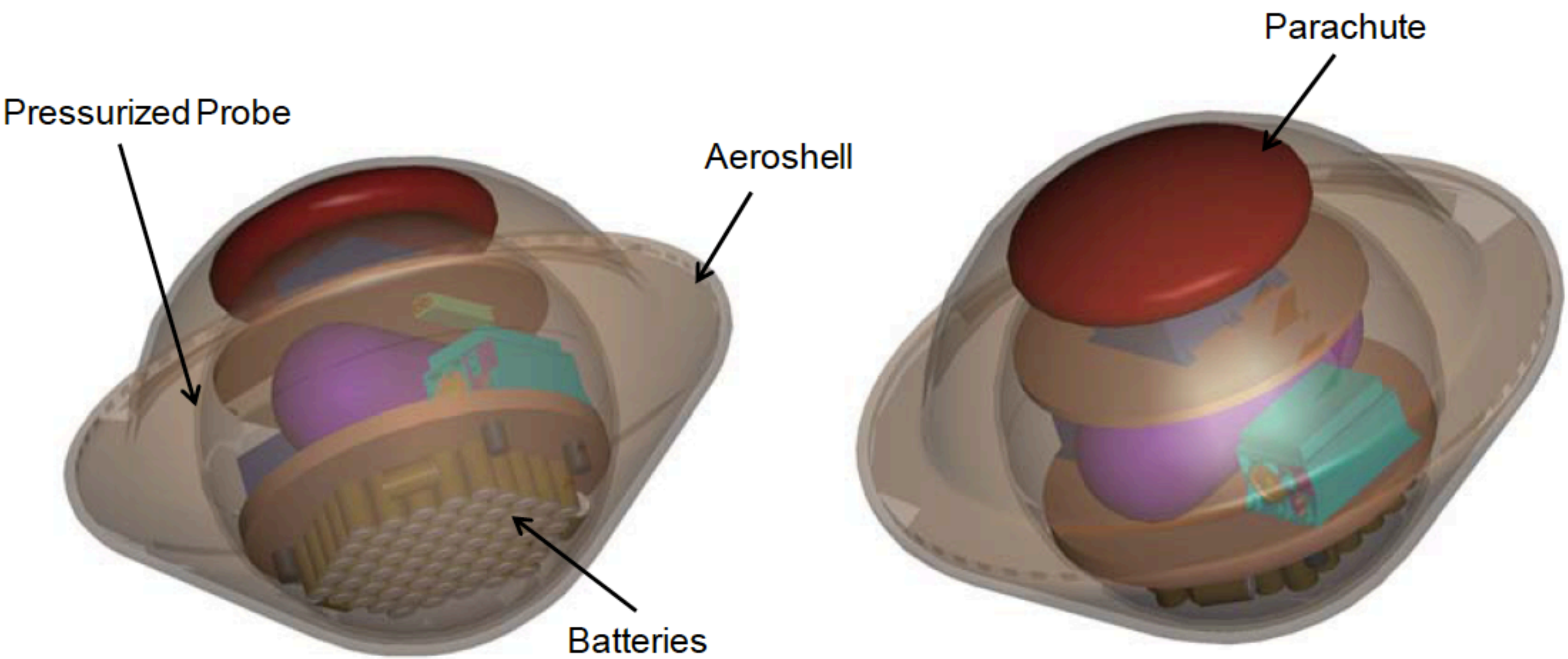
20 highly inclined elliptical orbits providing the desired science measurements (atmosphere, magnetic field, gravity field)



W.B. Hubbard / JHU-APL / NASA

Probe design

- Thermal: 4 RHUs (free flight) / foam insulation (after aeroshell deployed).
- Materials: Al aeroshell – Ti pressure vessel.
- Stabilisation: spin-stabilised in free flight, aerodynamically stabilised during descent by 3.25 m diameter parachute.
- Data: 200 kbps.
- Power: 69 W from a 49 Ah battery.
- Payload: Mass spec, Atmospheric structure, Nephalometer, USO.



W.B. Hubbard / JHU-APL / NASA

Entry timeline

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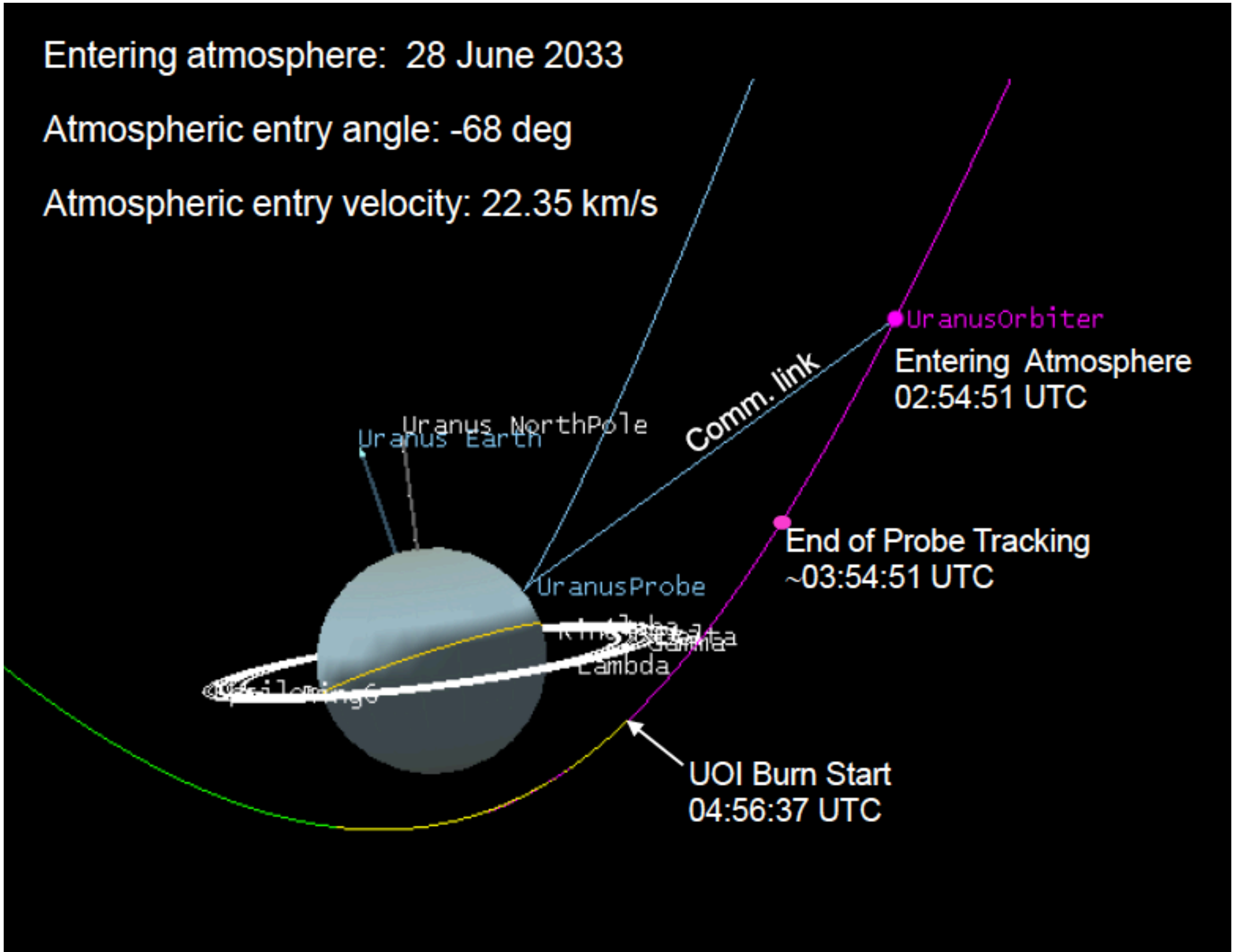
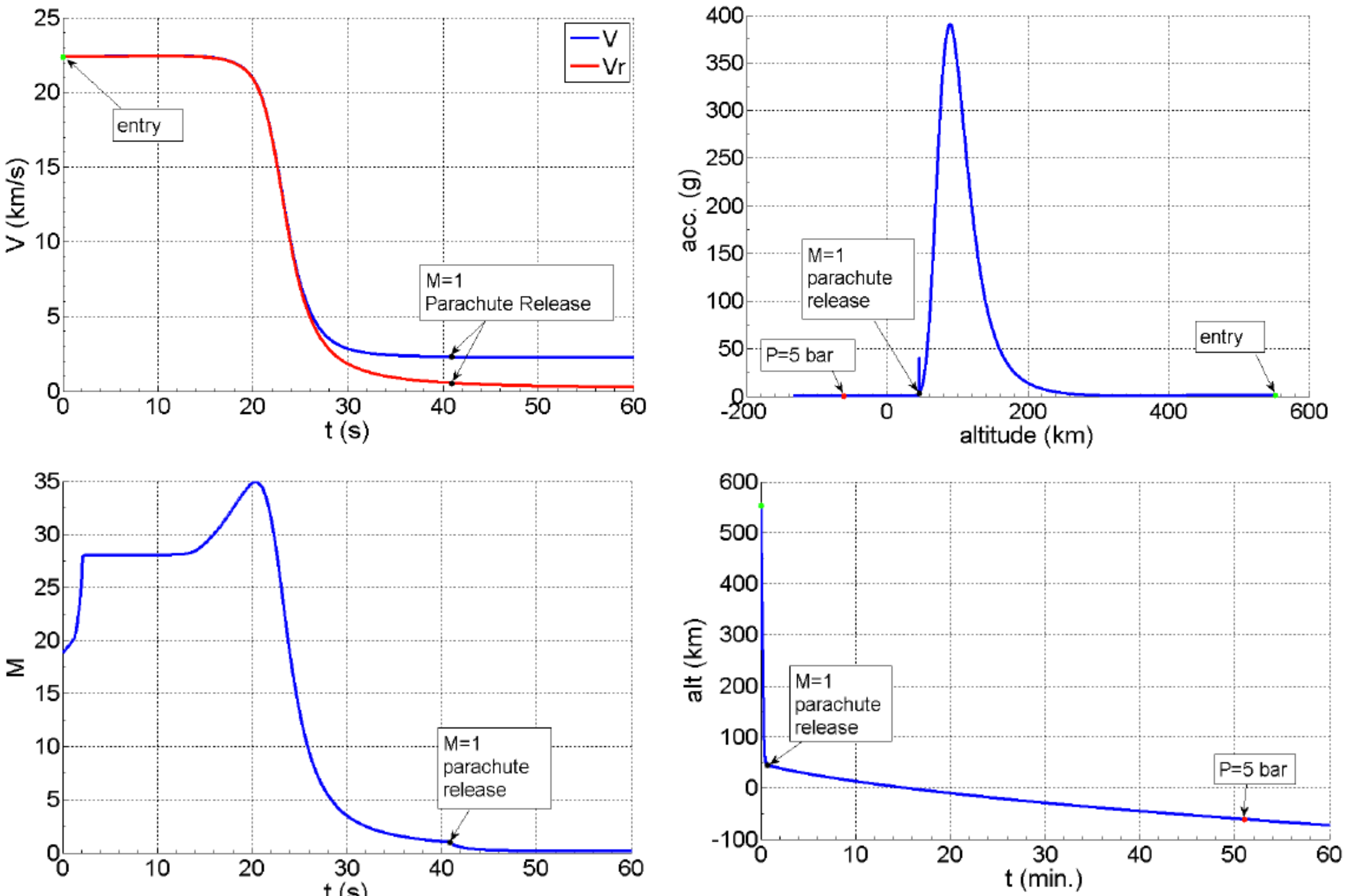
- Spin-stablised in free-flight – spin imparted by orbiter rolling.
- Probe separates from orbiter 29 days before UOI.
- Probe visible to Earth and probe.



W.B. Hubbard / JHU-APL / NASA

Probe entry profile



W.B. Hubbard / JHU-APL / NASA

Bilateral opportunities

- Share costs between space agencies – probe/orbiter provided by different agencies similar to Cassini-Huygens.

- Uranus mission: ESA probe attached to NASA orbiter, or vice-versa?

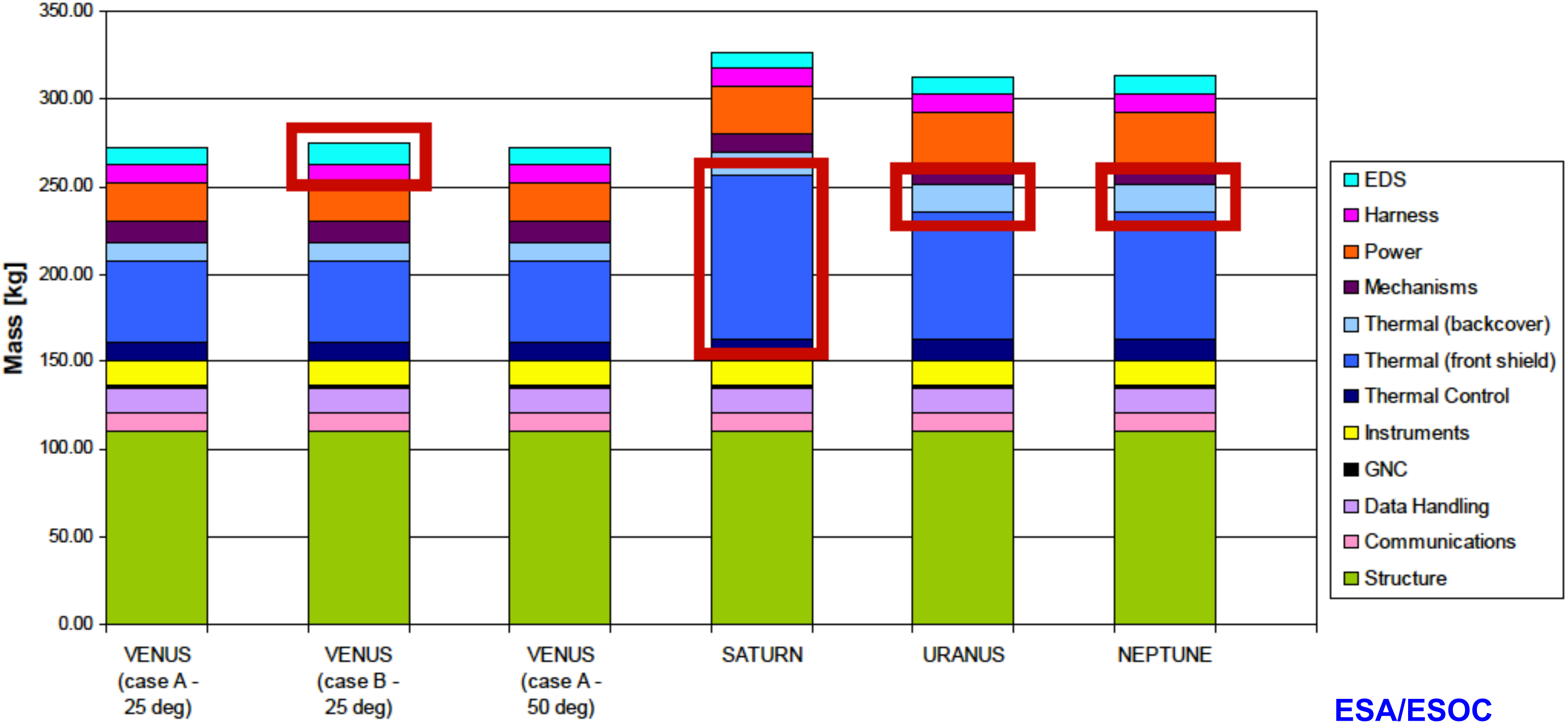
- Alternative model: Probe & limited delivery platform / separate orbiter.
  - Defer risk.
  - Delivery platform as a flyby vehicle or an orbiter?

- Orbiting delivery platform could carry minimal payload (e.g., magnetometer and radio science) and perform two-point sampling of the uranian system.

- Or deliver multiple probes to sample two locations.

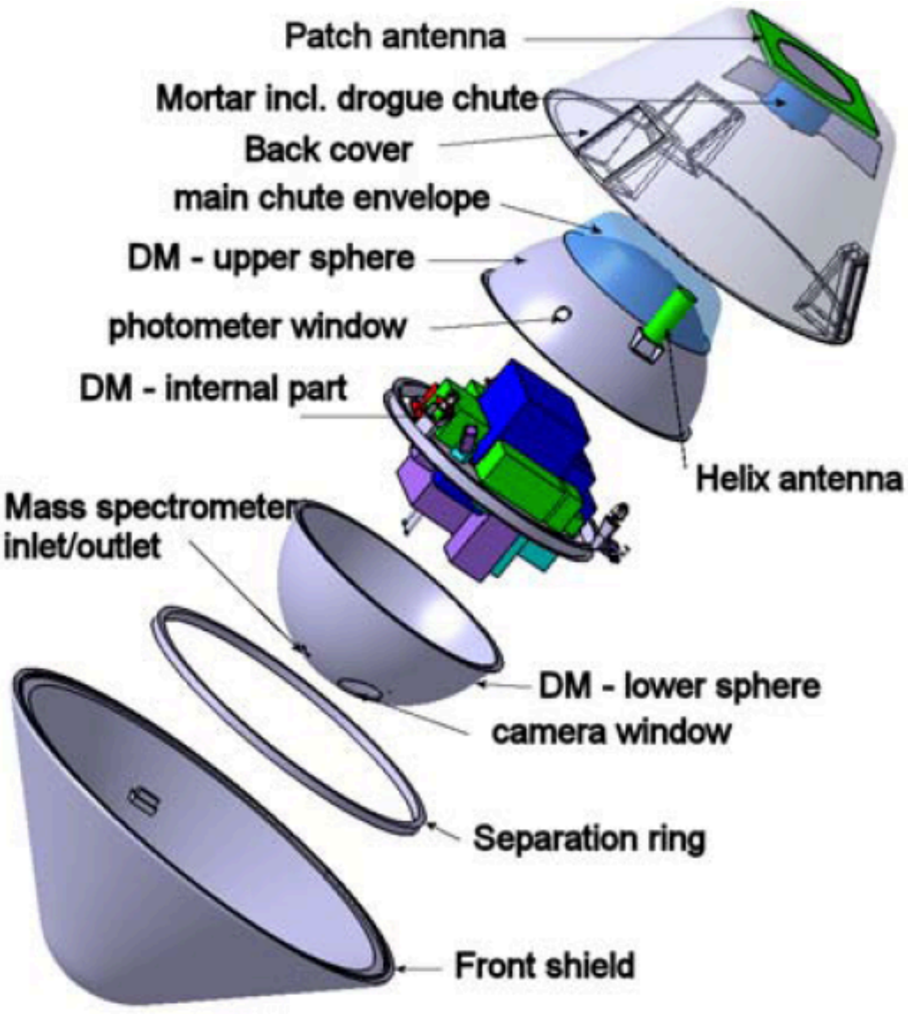
ESA CDF Probe Studies

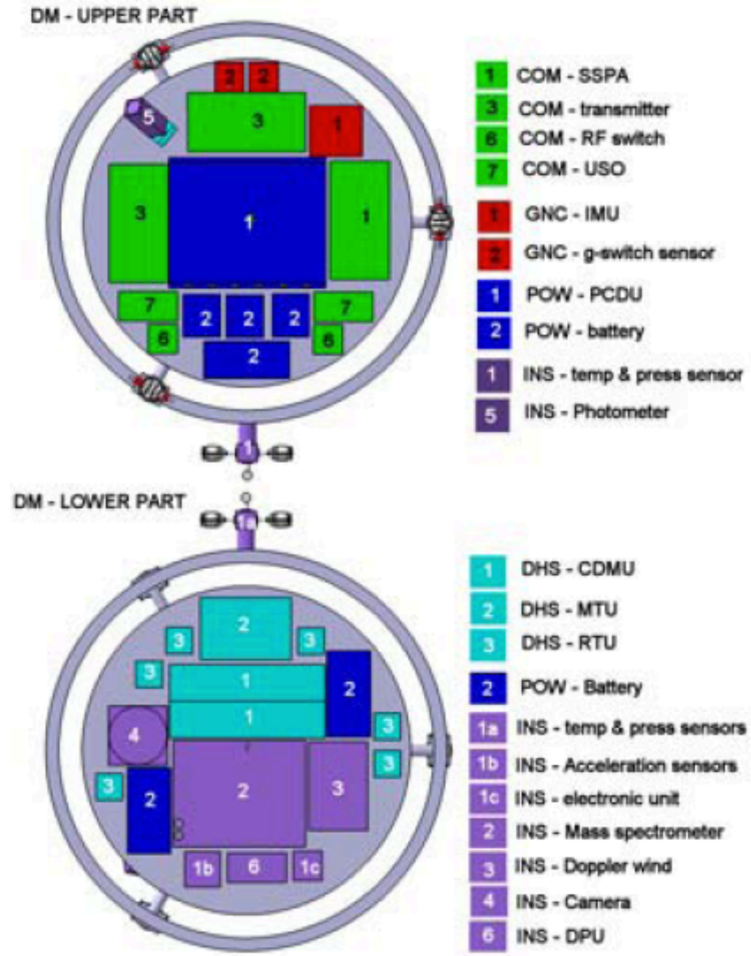
- CDF probe studies aimed at supporting upcoming CV calls.
- Based on Pioneer Venus probe heritage.
- Very little change in probe characteristics from Venus to outer planets.
- 313 kg Uranus probe.



ESA/ESOC

Probe configuration





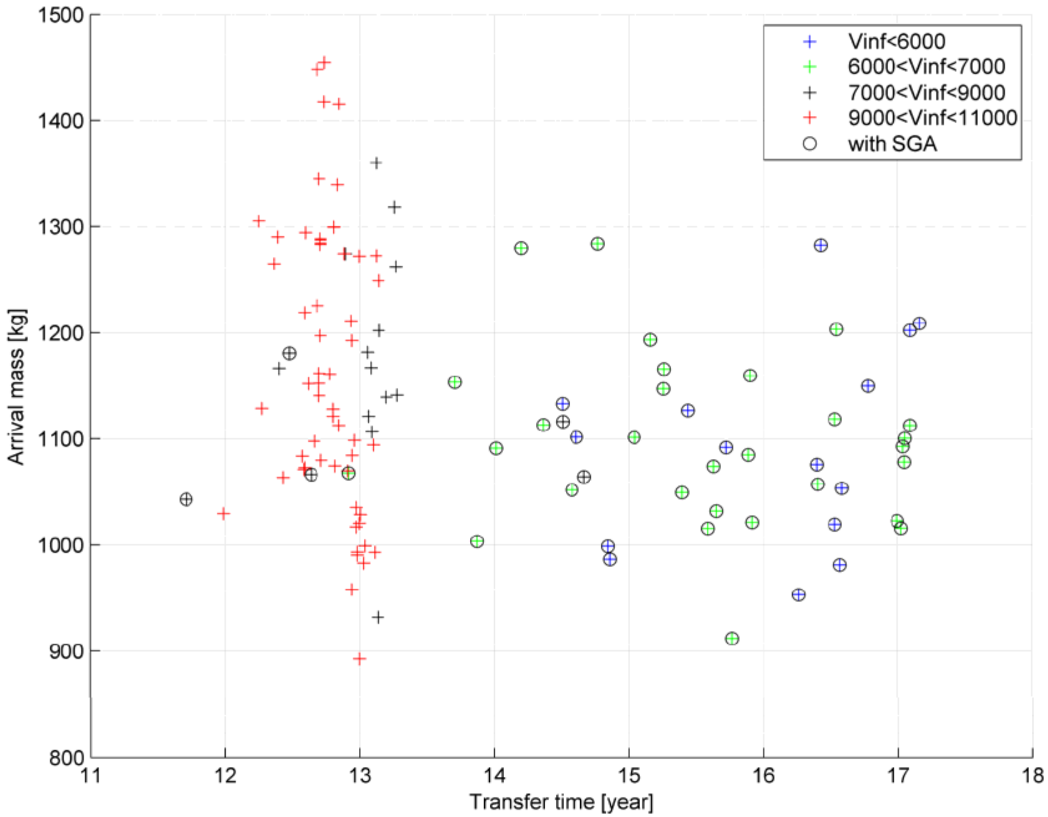
ESA/ESOC

Interplanetary transfers

- Considered delivery platforms in the 2025-2035 timeframe.
- Launch vehicles: investigated Soyuz (three marginal solutions) and Ariane 5 (three good solutions).
- Assumed 300 kg probe.

- **Soyuz**
  - Transfer time 12.7 – 15.8 years.
  - V_{inf} = 6.5 – 10.9 km/s
  - No dual probe solution.

- **Ariane 5**
  - Transfer time ~ 13 years (comparable with decadal study profile).
  - V_{inf} = 4.2 – 6.8 km/s
  - Permits dual probes.



ESA/ESOC

Summary

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- Probe missions to Uranus provide the only way to resolve some issues on the origin and evolution of ice giants – but solely probe-based missions miss out on the wealth of science to be harvest by an orbiter.
- Despite funding crises in the US and deep cuts to planetary exploration, a Uranus mission has remained high priority.
- NASA's Outer Planets Assessment Group established Uranus WG.
- Uranus Pathfinder
  - Continuing to develop mission concept.
  - Platform studies ongoing.
  - Looking towards resubmission for M4 or L2 in 2013/14.
  - Consortium continues to grow – **please participate to the development of science case / payload definition / platform / mission profile**.

Arridge et al. (2012) Exp. Astron. 33(2) pp. 753-792 (*M3 special issue*)
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