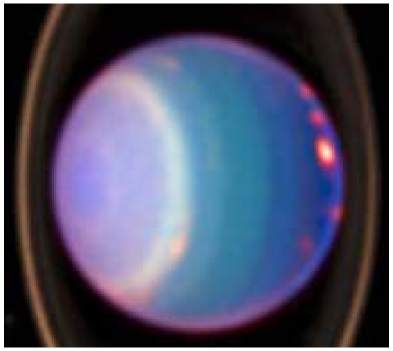
Ice Giant Science:
The Case for a Uranus Orbiter

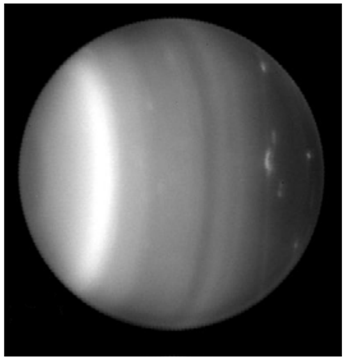
Mark Hofstadter
Jet Propulsion Laboratory/California Institute of Technology

Report to the Decadal Survey Giant Planets Panel, 24 August 2009

Voyager 1986



Hubble 1998
(Karkoschka)



Keck 2003
(Hammel et al.)

JPL Contributors

This talk is based on an internal JPL study of missions to Uranus. Co-authors are listed below.

A White Paper, "The Case for a Uranus Orbiter," is currently being circulated.

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This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Outline of Today's Talk

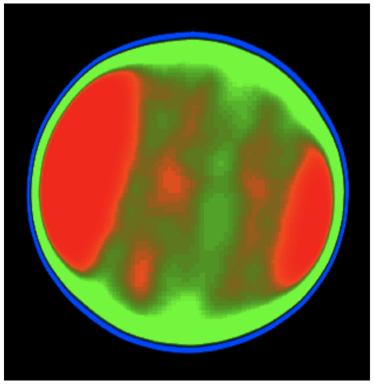
I) Introduction

II) The scientific importance of ice giants

III) General results from our study of Uranus missions

IV) Specifics of a New Frontiers-class Uranus Interior Mission

V) Conclusions



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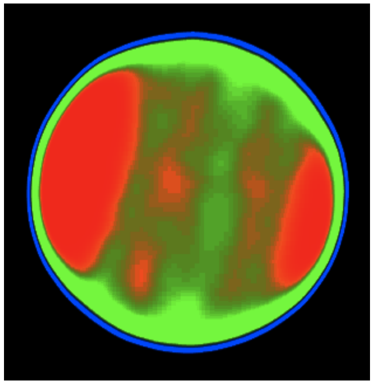
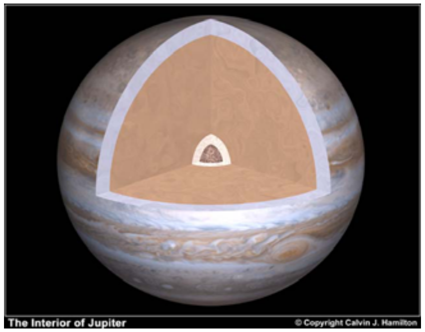


Ice Giant Science Questions (Page 1 of 4)

What is the bulk composition and interior structure of the ice giants?

This is the most important question to address, as it defines what an ice giant is. It influences our understanding of

- The proto-planetary nebula (composition and dynamics),
- Planetary formation (how and where planets form),
- Thermal and chemical evolution of planets (heat flow, interior convection),
- Extra-solar planets.



Images © C.J. Hamilton

Ice Giant Science Questions (Page 2 of 4)

Where and how is the magnetic field generated?

The magnetic field is important for understanding

- Upper atmospheric composition and energy balance,
- The interior structure (conductive and convective regions),
- The dynamo generation process.

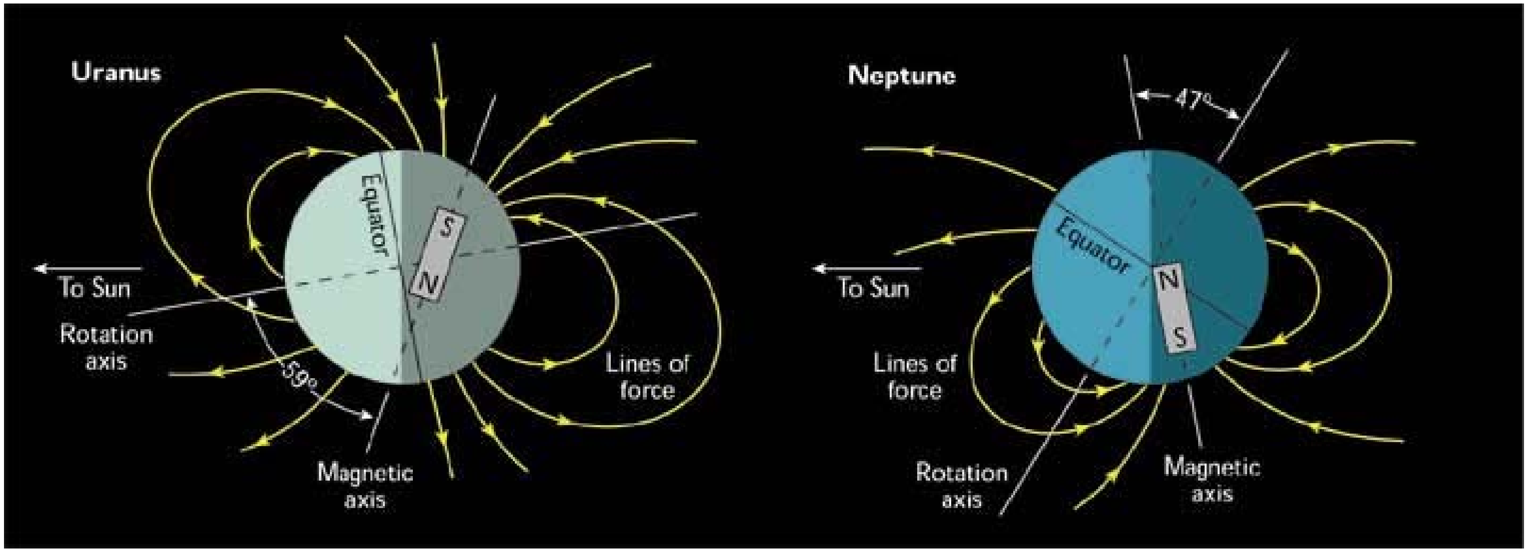


Image courtesy F. Bagenal

Ice Giant Science Questions (Page 3 of 4)

What is the nature of internal heat transport within Uranus?

Uranus is emitting essentially no internal heat, perhaps due to density variations inhibiting convection. This impacts Uranus'

- Evolution,
- Interior structure and circulation,
- Atmospheric dynamics and composition,
- The dynamo generation process.

Internal Heat	Jupiter	Saturn	Uranus	Neptune
W / m^2 x 10^{11}	5440 ± 430	2010 ± 140	42 ± 47	433 ± 46
W / kg x 10^{10}	1.7	1.5	0.04	0.32
Internal / Absorbed Solar	0.7	0.8	0.08	1.6

Based on Guillot 2005

Ice Giant Science Questions (Page 4 of 4)

What is the nature of everything else about the ice giants?

- The magnetosphere and its special solar wind geometry.

  The inclined dipole field maximizes the coupling between the solar wind and the magnetosphere. This is particularly true at Uranus near equinox.

- The atmosphere

  There are aspects of composition, temperature, chemistry, circulation, and variability only seen in the ice giants. Uranus' extreme seasonal forcing is an example, or Neptune's Dark Spots.

- The satellites

  The size distribution and perhaps composition of native ice giant satellites is different than gas-giants.

- The rings

  The particle size distribution and morphology of ice-giant rings is different than the gas giant's.

Why a Mission to an Ice Giant?

In the parameter space of “all possible planets,” Uranus and Neptune occupy a region we know very little about. They have an important story to tell about planetary formation and evolution. Learning about them is particularly important if we are to understand extra-solar planetary systems.

Either ice giant can serve as a model for this poorly-understood class of planet, and both have unique features worthy of study.

All major categories of objects in our solar system have a dedicated mission currently flying, except for the ice giants.

A mid-sized mission launched to an ice giant in the next decade is the only way to dramatically advance our understanding of these objects in our professional lifetimes.

Why Uranus Instead of Neptune?

- Uranus’ interior structure and internal heat flow are most challenging to our understanding of planetary formation and evolution, and better constrain our models.

- Uranus is closer, allowing for
  Shorter flight times (reduced cost and greater reliability),
  More sunlight (for imaging and power),
  Better ground-based supporting observations.

- Its atmosphere and satellites experience extreme seasonal forcing due to the systems 98° axial tilt.

- The uranian satellite system may be our solar system’s only surviving example of an ice giant system.

- It allows a scientifically compelling mission in our lifetimes.

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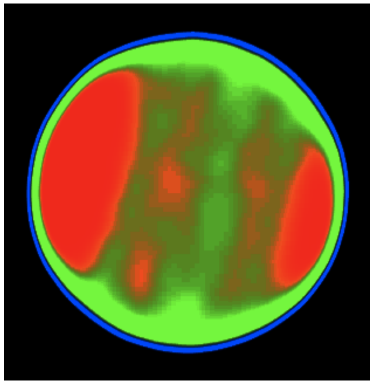
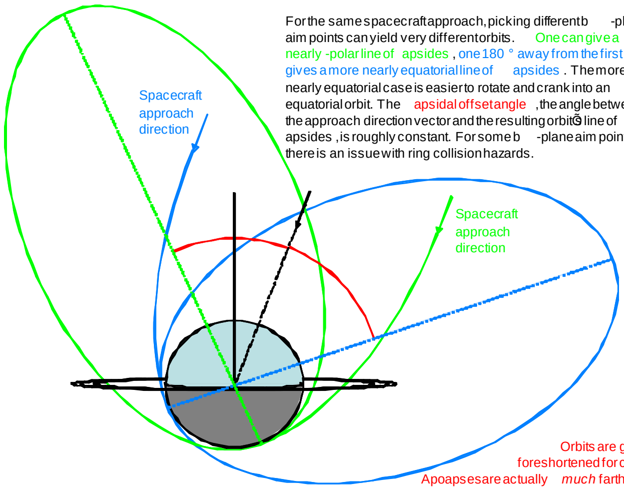


The JPL Study

Late last summer, we undertook a small study to explore the feasibility of a solar powered mission to Uranus. Most results are relevant to nuclear powered missions as well.

Our primary focus was on New Frontiers, but we also considered higher-cost options.

We engaged JPL’s “Rapid Mission Architecture” (RMA) process, which compliments the more familiar Team-X studies. RMA allows a much broader range of missions and architectures to be explored, but with less cost fidelity.



For the same spacecraft approach, picking different b -plane aim points can yield very different orbits. One can give a nearly -polar line of apsides , one 180 ° away from the first gives a more nearly equatorial line of apsides . The more nearly equatorial case is easier to rotate and crank into an equatorial orbit. The apsidal offset angle , the angle between the approach direction vector and the resulting orbitÕs line of apsides , is roughly constant. For some b -plane aim points there is an issue with ring collision hazards.

Orbits are greatly foreshortened for clarity. Apoapses are actually *much* farther out.

Study Assumptions

Do not use nuclear power sources (but allow radioactive heating units).

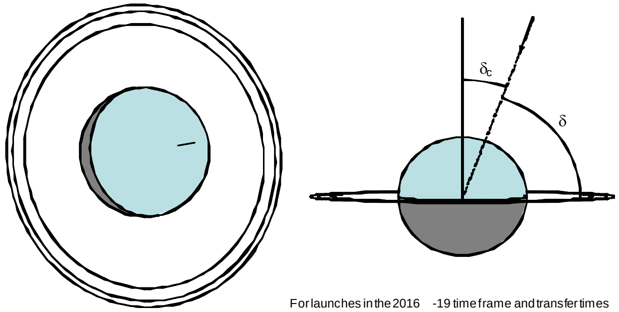
Keep approach velocities under 15 km/s (faster speeds make flyby encounters too brief, and orbiter missions difficult to slow down).

For hardware reliability, keep mission length under 15 years.

Use current technologies (e.g. aero-capture is not an option).

Consider launches between 2015 and 2023.

Orbital and flyby geometries must match the chosen instrument suite and mission objectives.



As seen from approaching spacecraft

As seen from (roughly) ecliptic north

For launches in the 2016-19 time frame and transfer times of 11-12 years, δ is ~70°, decreasing with time such that for 2023 launches it is <60°. δ this high precludes encountering multiple satellites with a single flyby spacecraft.

Architectures Explored in the RMA Study

A: Minimum cost (Voyager-class) flyby.

B: Upgraded flyby (includes 1-μrad imager, VIMS-type instrument).

C: Minimum cost flyby with a probe.

D: Minimum cost flyby with 3 probes.

E: Minimum cost flyby with 10 free-flying magnetometers.

F: Minimum polar orbiter (Ka-band radio, simple magnetometer)

G: New Frontiers orbiter (dual-band radio, enhanced magnetometer).

H: Moderate orbiter (Option G with SWIR and microwave sounder).

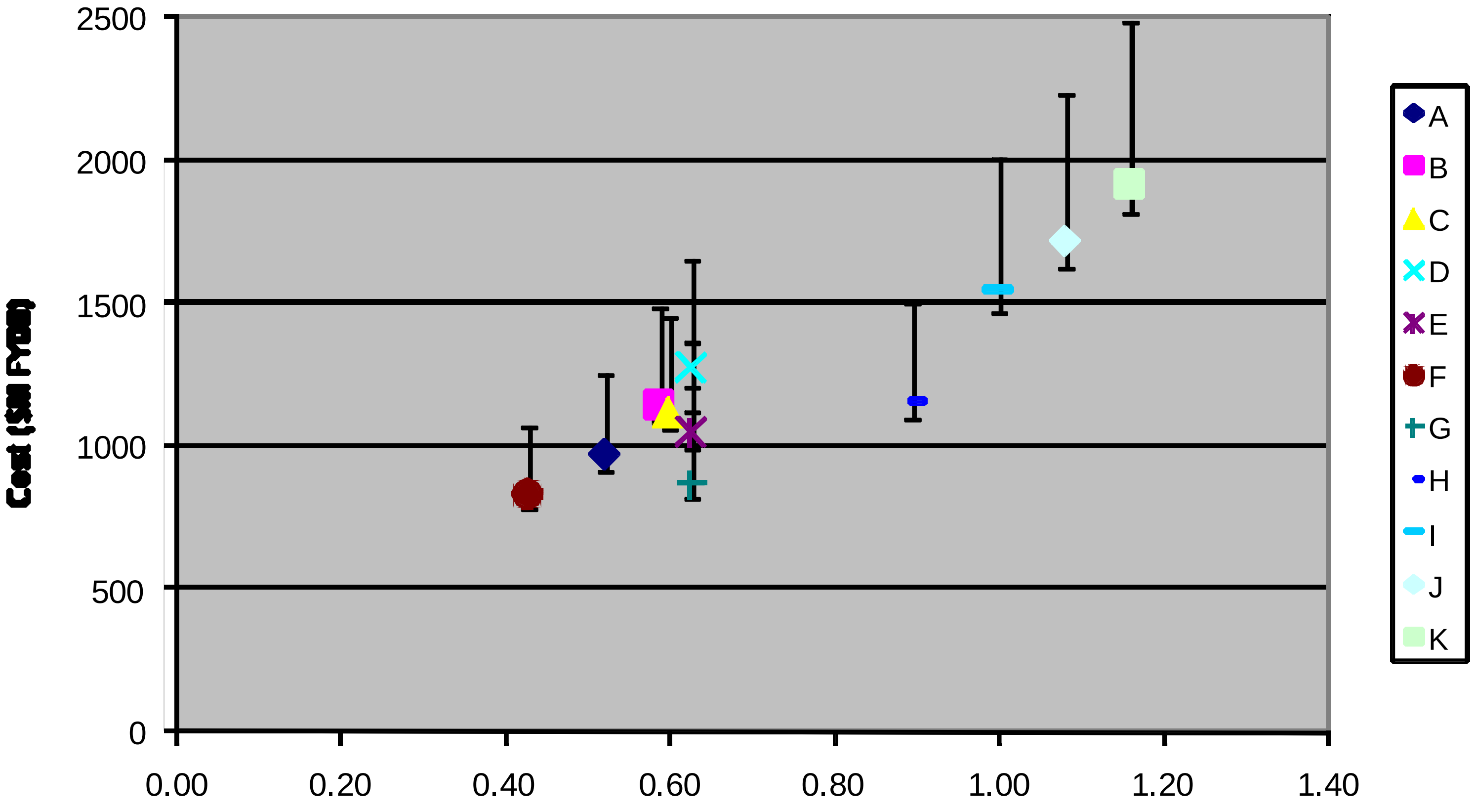
I: Cassini-class orbiter (instruments and range of orbit inclinations).

J: Cassini-class orbiter with probe.

K: Dual orbiter mission, one polar one equatorial.

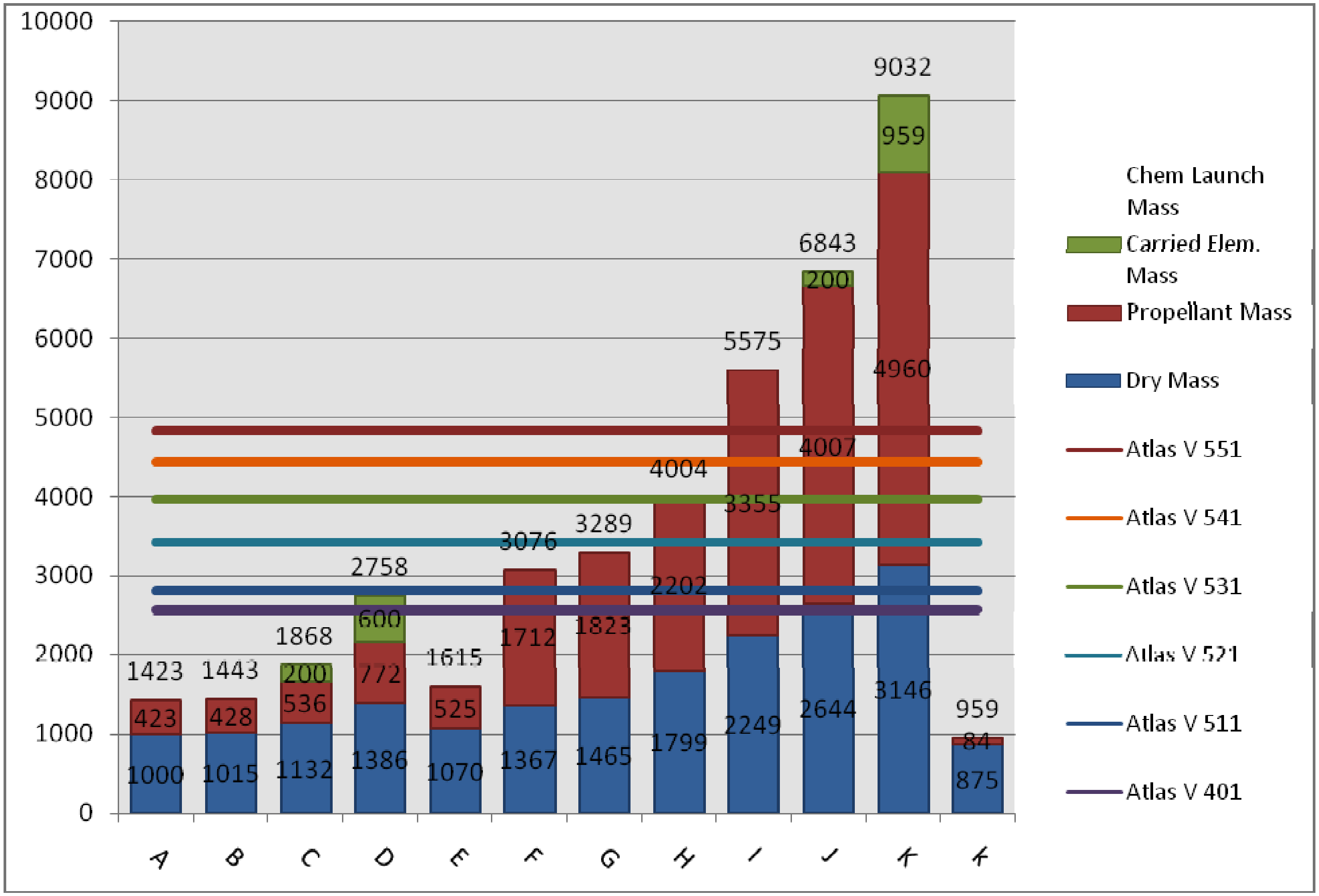
Study Results: Cost vs. Science Value

Each architecture was judged against its ability to meet science goals related to the interior, atmosphere, magnetosphere, satellites, and rings.



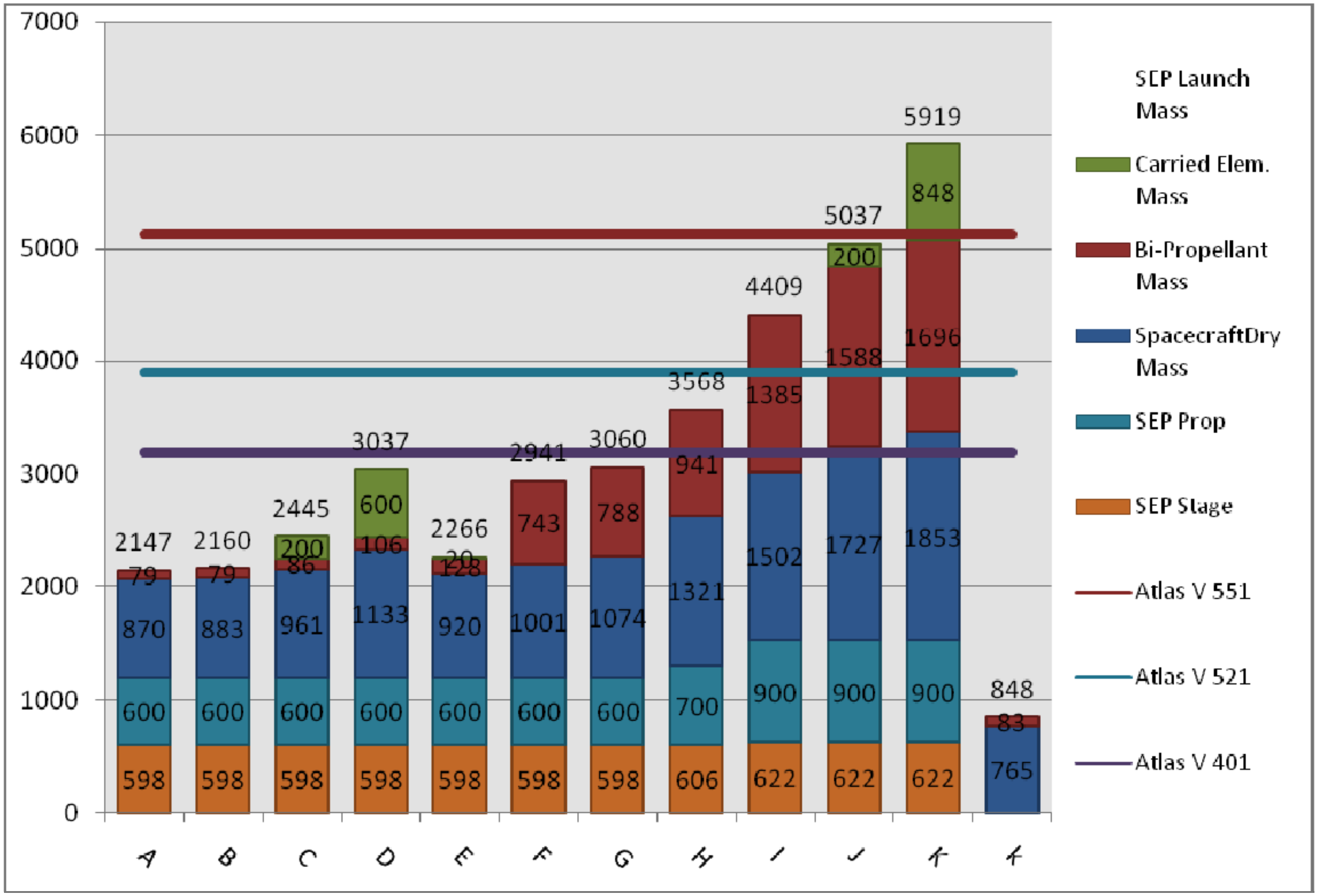
Option “G” is the NF Orbiter, “H” is the Moderate Orbiter.

Study Results: Launch Masses for Chemical Propulsion



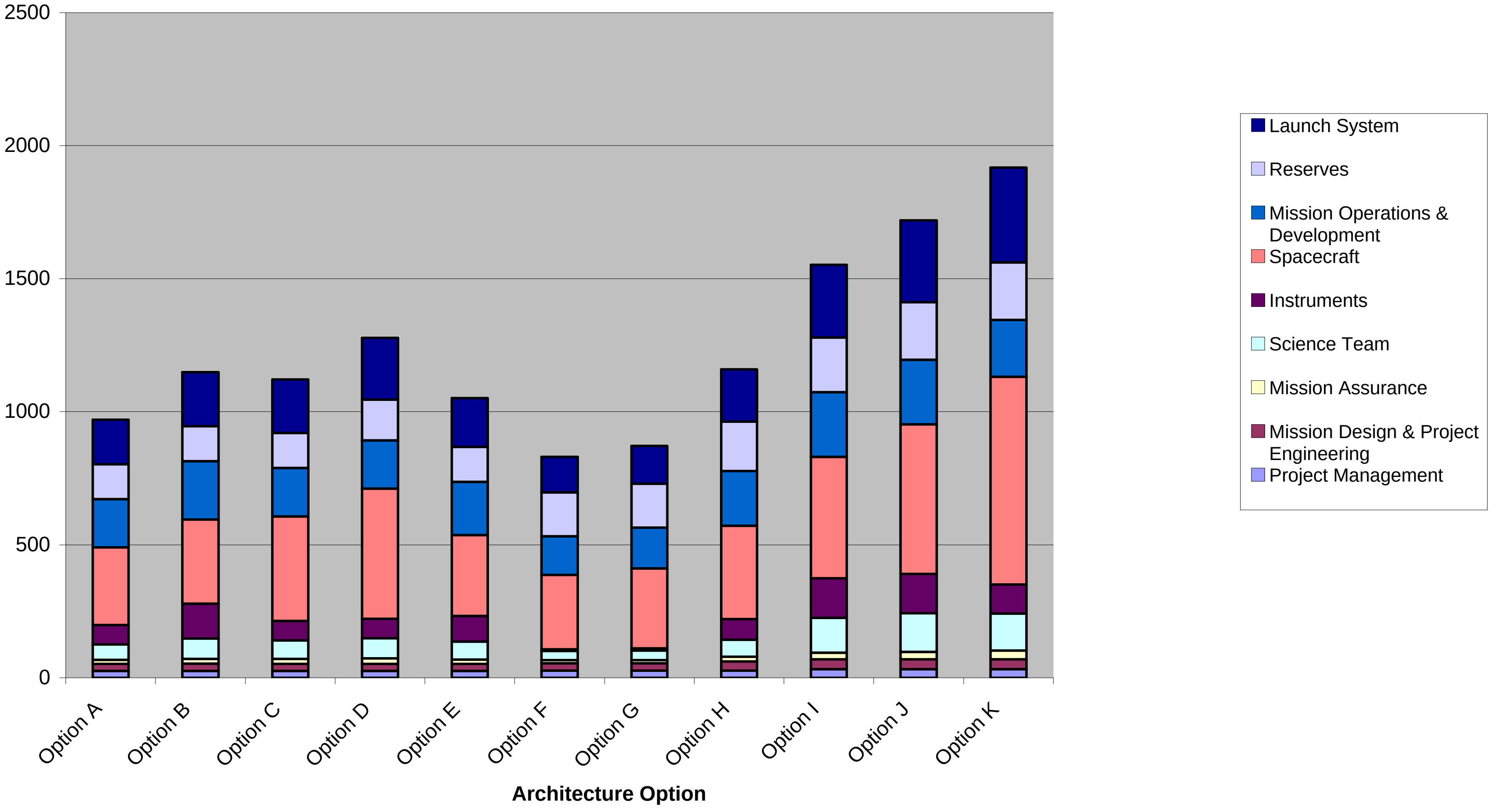
Option “G” is the NF Orbiter.

Study Results: Launch Masses for Solar Electric Propulsion



Option “G” is the NF Orbiter.

Study Results: Cost Estimates (Uncertainty +30%, -5%)

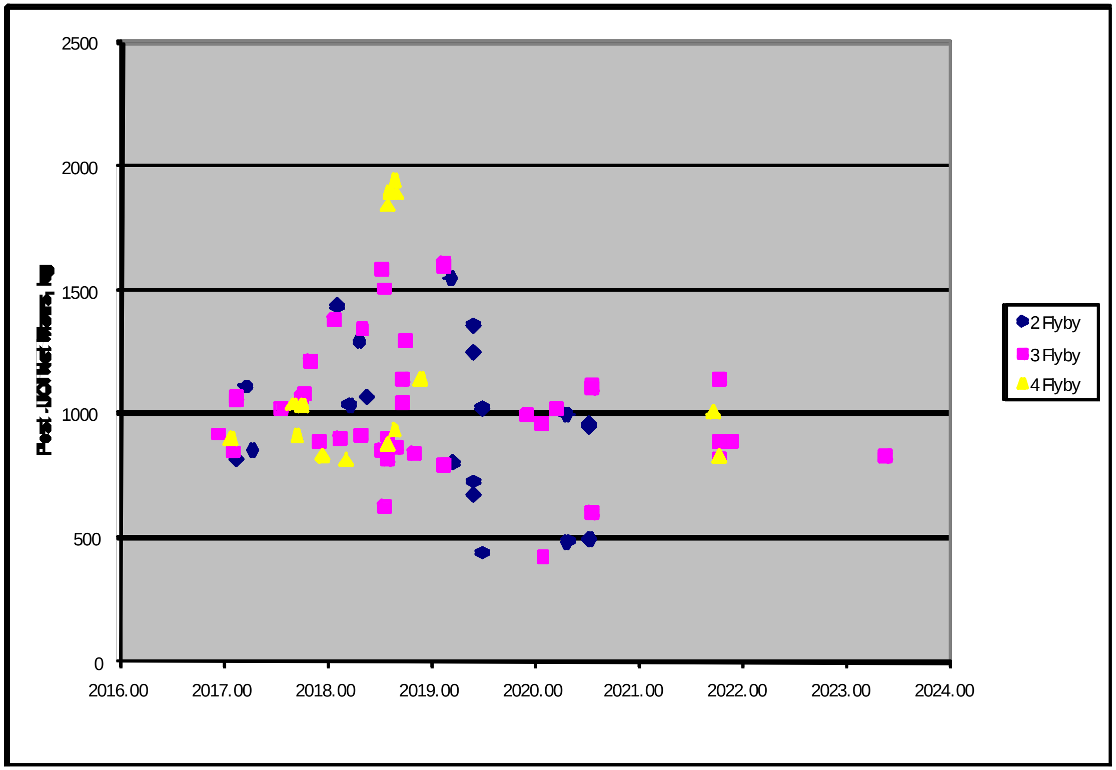


Option “G” is the NF Orbiter.

Study Results: Launch Year vs. Inserted Mass

For Solar-Electric Propulsion (SEP), all years have similar performance, and there is a trade off to be made among flight time (8-12 years), delivered mass (800 to 2000 kg), and launch vehicle.

For chemical propulsion, the launch-year is more important, with 2018 providing a particularly good geometry for a Jupiter gravity assist.



Study Results: General Conclusions

- Large masses can be placed into orbit around Uranus.

  For example, using an Atlas 521 and only chemical propulsion, a **dry mass** in excess of 1500 kg (~100 kg for science instruments) can be inserted after a 12-year flight.

  There are many trade-offs possible among cost, flight time, and delivered mass. Electric propulsion may be an attractive option.

- Uranus will be encountered near northern Solstice. This samples the same atmospheric season as Voyager did, but allows for imaging the unseen hemispheres of the satellites.

- Solar powered missions are feasible. Power is a significant constraint, but batteries, radioisotope heating units, and phasing of instrument on/off times allow the needed science return with solar panels producing only 100 W.

- Missions **may** be possible under the current New Frontiers (NF) cost cap.

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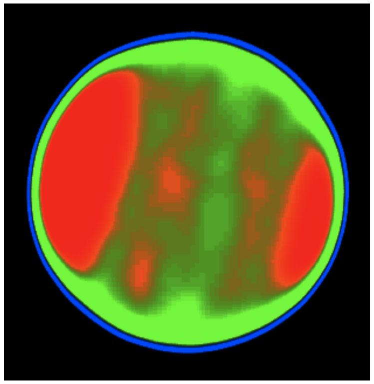


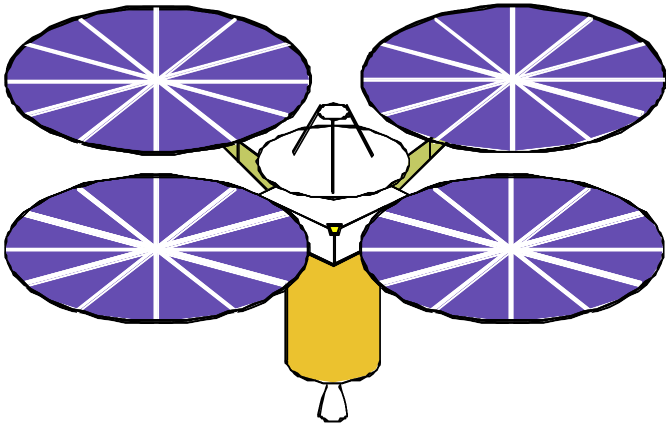
A Possible New Frontiers Mission (1 of 2)

- We found the most cost-effective, scientifically compelling mission to be an orbiter for high resolution mapping of the gravity and magnetic fields as a probe of interior structure.

- Our rough cost estimate (±30%), including all reserves, is 10% over the current NF guideline ($650 million not counting the launch vehicle).

- Mass is not a limiting factor, so foreign contributions of instruments or a probe can be a way to increase science return while minimizing cost.

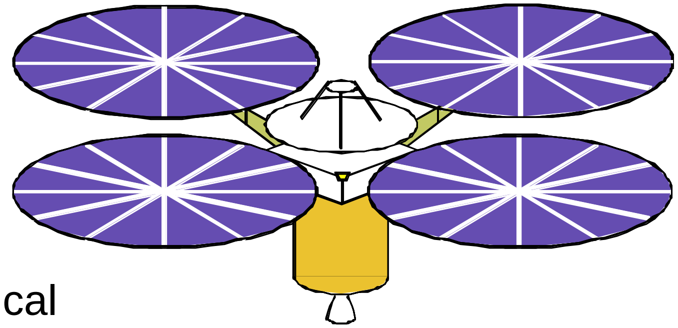
- Mission is possible with no new technology, though we need to optimize Ultraflex arrays for low light and temperatures.



- Advances in low-power electronics, improved downlink rates, low-temperature propellants, or aero-capture significantly improve capabilities.

A Possible New Frontiers Mission (2 of 2)

We found this mission scenario to be a good starting point for future studies:



- Launch September 2018 on an Atlas 521.
- Flybys of Venus (2), Earth, and Jupiter.
- Arrival at Uranus in September 2030.
- Insertion into a polar orbit (~70° inclination).
- 1.2 year mission consisting of 10, 44-day elliptical orbits. Periapse 1.1 Uranus radii, apoapse 100 radii.

Science floor instrument package consists of

- X/Ka radio transmitters (Doppler tracking used for mapping the gravity field).
- Scalar and vector magnetometers (plus boom with star tracker).
- PEPPSI-type instrument for particle measurements.

Total science mass ~22 kg, not counting radio transmitters. 12 Gb of data generated during Uranus operations.

Subject to power and data volume constraints, ~100 kg of additional science payload can be accommodated.

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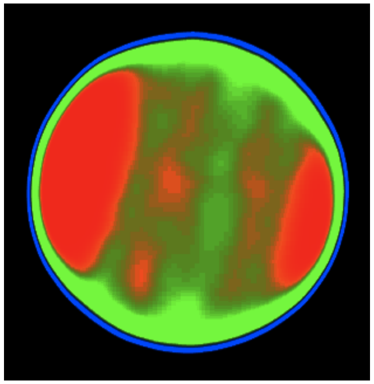
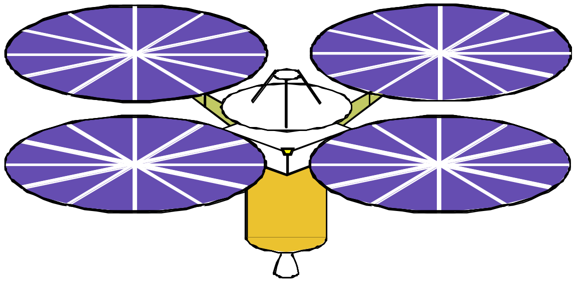


What do we Ask of the Decadal Survey?

- Recommend that a mid-sized mission to Uranus or Neptune be launched in the next decade. This is crucial for understanding the diversity of planets and their formation and evolution.

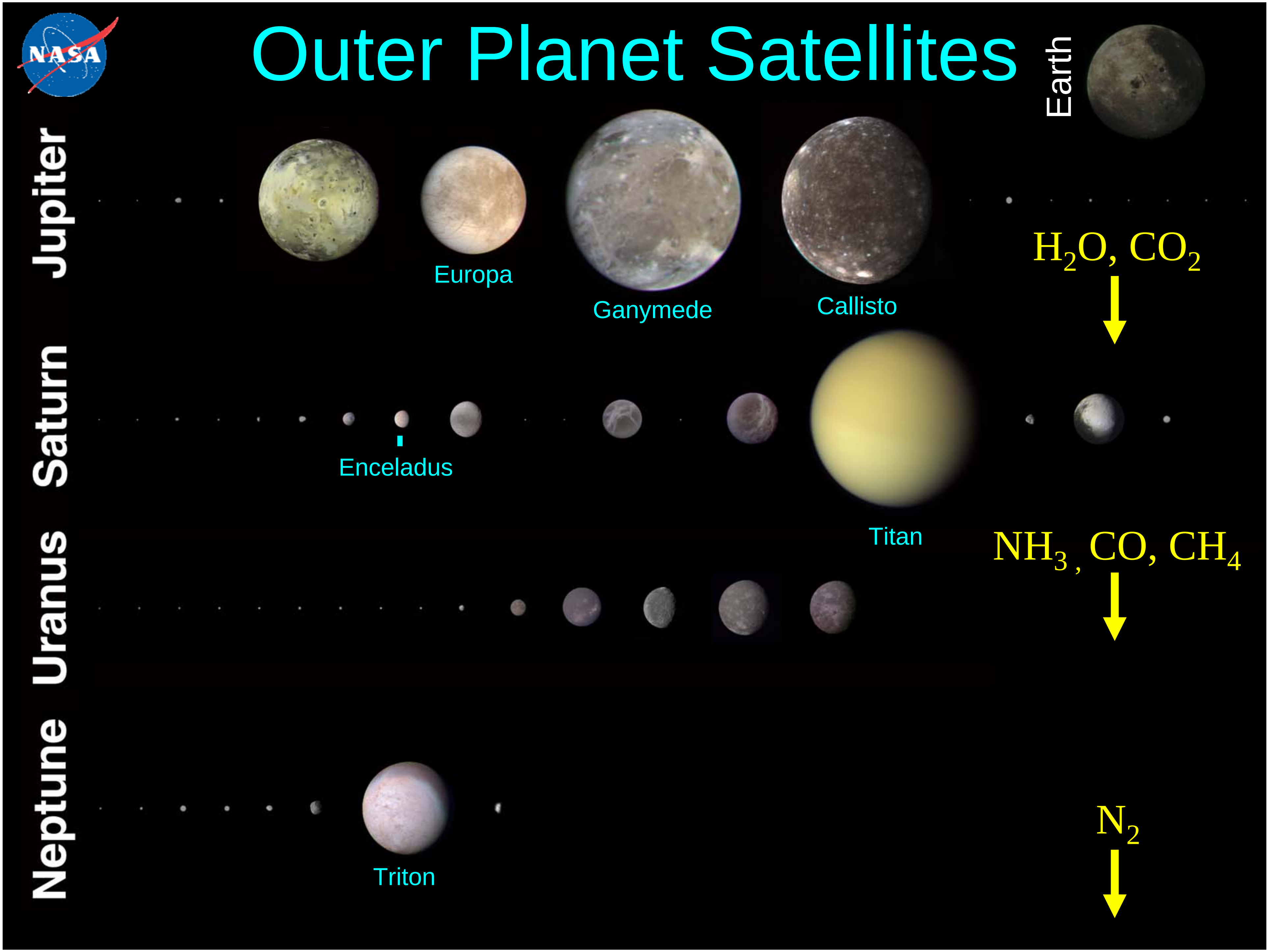
- Conduct a more detailed mission study of the science capabilities and cost of a Uranus orbiter, including the option of using solar power.

- Assess our team’s conclusion that a Uranus orbiter, focused on studies of the gravity and magnetic fields, is the most cost-effective, scientifically compelling mid-sized mission.



Backup Slides

Outer Planet Satellites

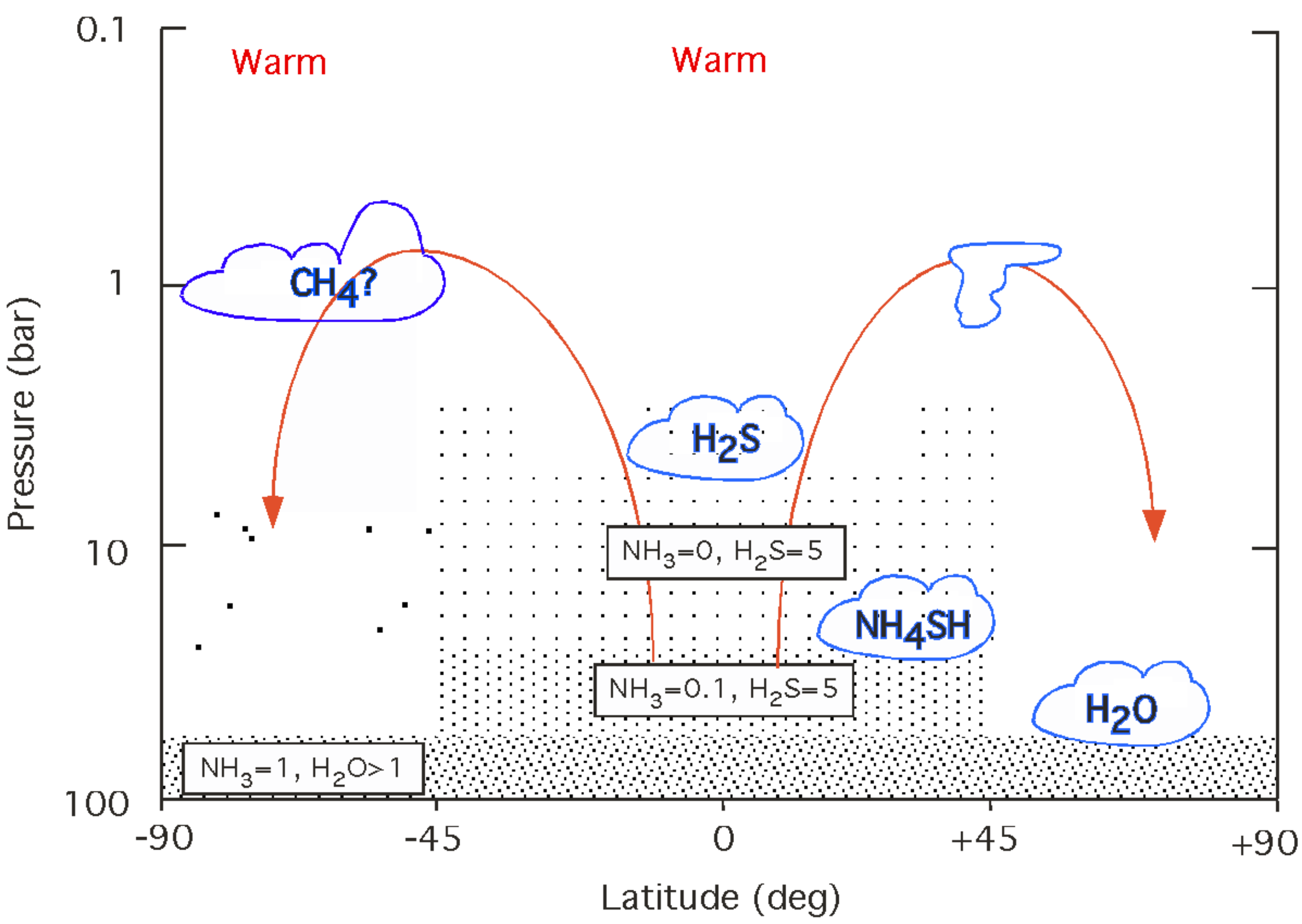


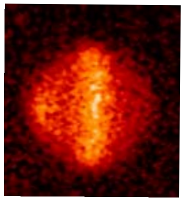
H_2O, CO_2 ↓

NH_3, CO, CH_4 ↓

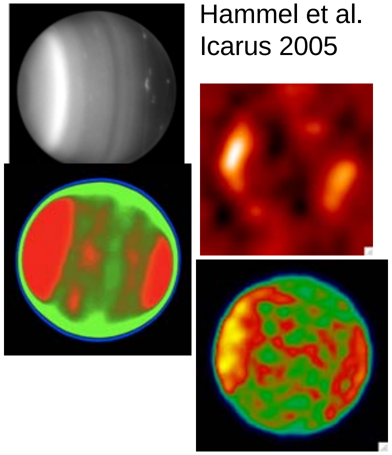
N_2 ↓

Uranus: The Big Picture





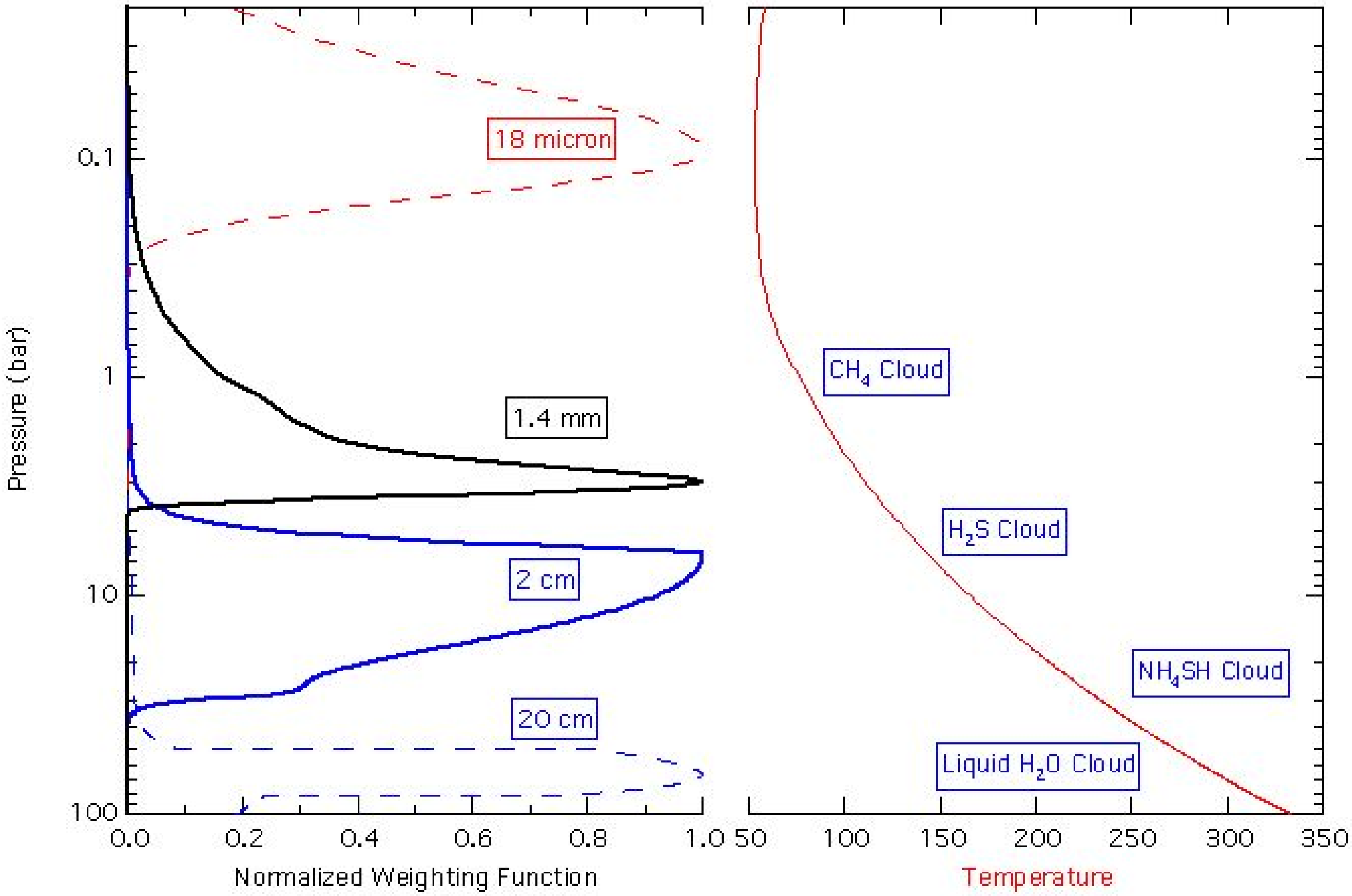
Orton et al.



Hammel et al.
Icarus 2005

Hofstadter: Uranus Orbiter

Weighting Functions and Atmospheric Profile



Hofstadter: Uranus Orbiter