# Ice Giant Mission Study Status

## Briefing to OPAG

12 August 2016

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Ice Giant Science Definition Team and JPL Ice Giant Study Team
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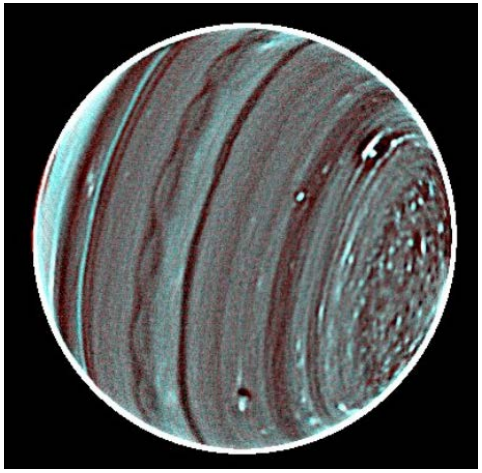
Neptune and Triton
from Voyager

Ground-Based Image of
Uranus. Sromovsky et al.
2012



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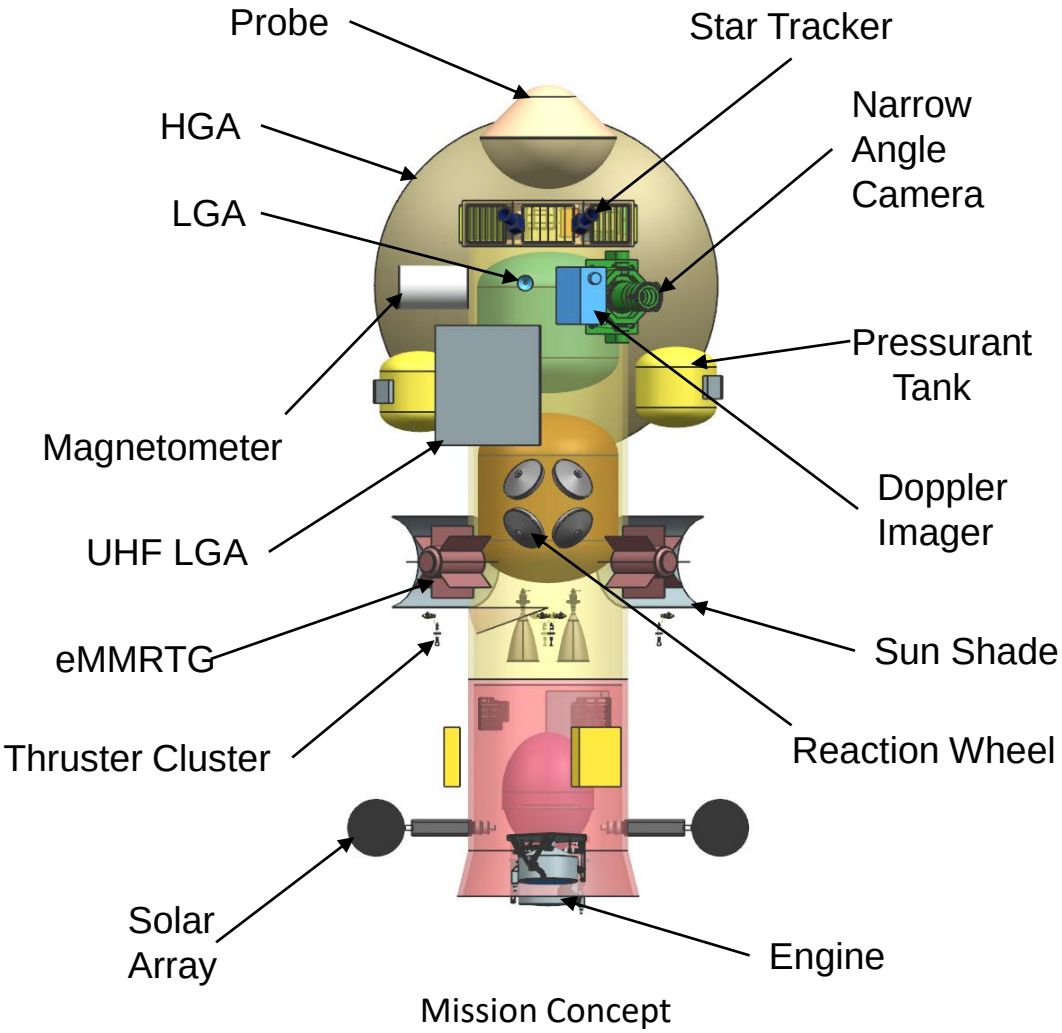
# Outline

- Overview
- Personnel
- Status
  - Science
  - Instruments
  - Architectures
  - Trajectories
  - Technology

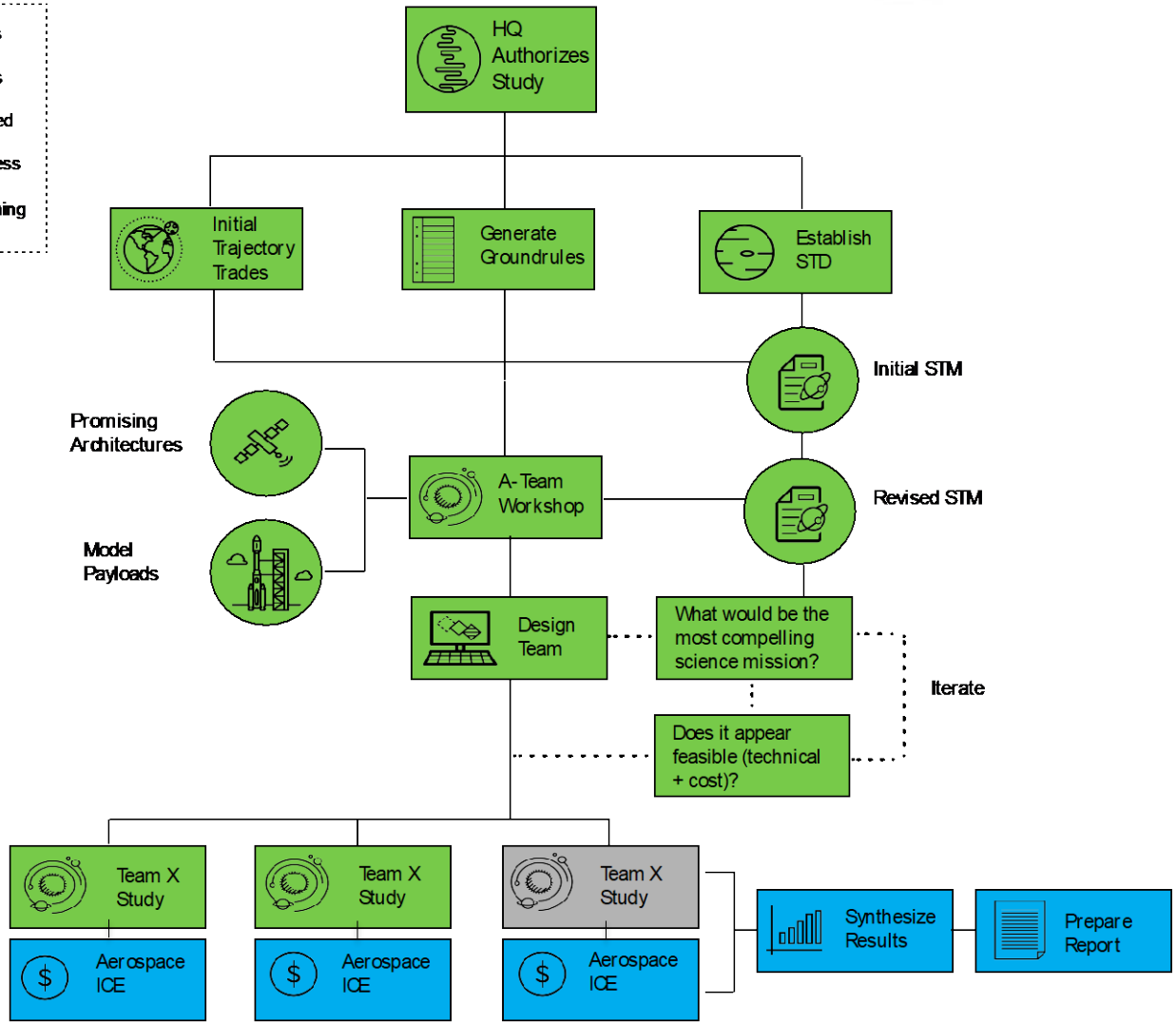



Mission Concept

# Statement of Task

- Goal: Assess science priorities and affordable mission concepts & options in preparation for the next Decadal Survey
- Objectives:
  - Identify mission concepts that can address science priorities based on what has been learned since the 2013-2022 Decadal
  - Identify potential concepts across a spectrum of price points
  - Identify enabling/enhancing technologies
  - Assess capabilities afforded by SLS
  - Identify opportunities for international collaboration

# Study Plan




## Next Steps

- Schedule additional Team-X session.
- Aerospace Corporation executes ICE.
- Continue community meetings (DPS, AGU).
- Coordinate with OPAG's Roadmap to Ocean Worlds (ROW) effort.

# Mission Study Team

**NASA Interface:** Curt Niebur
**Study Lead:** John Elliott

**ESA Interface:** Luigi Colangeli
**JPL Program Office:** Kim Reh

**Mission Design**

David Atkinson (probes)
Nitin Arora (trajectory)
Chester Borden (system eng.)
Jim Cutts (technology)
Minh Le (documentation)
Young Lee (RPS)
Anastassios Petropoulos (trajectory)
Tom Spilker (science, system eng.)
David Woerner (RPS)

**Science Definition Team**

Co-Chairs: M. Hofstadter/A. Simon
Members: See next slide

**Other Organizations**

Langley Research Center (TPS)
Ames Research Center (TPS)
Purdue University (mission design)
Aerospace Corp. (ICE)

# SDT Members

**Chairs:** Mark Hofstadter (JPL), Amy Simon (Goddard)

Sushil Atreya (Univ. Mich.)
Donald Banfield (Cornell)
Jonathan Fortney (UCSC)
Alexander Hayes (Cornell)
Matthew Hedman (Univ. Idaho)
George Hospodarsky (Univ. Iowa)
Kathleen Mandt (SwRI)
Mark Showalter (SETI Inst.)
Krista Soderlund (Univ. Texas)
Elizabeth Turtle (APL)

**ESA Members:**
Adam Masters (Imp. College)
Diego Turrini (INAF-IAPS)

# Status: Science (1/2)

Science Traceability Matrix

- All elements of the Ice Giant systems (interior, atmosphere, rings, satellites, magnetosphere) have important science objectives.
- Determining the interior structure and bulk composition of the ice giants is identified as the highest-payoff science.
  - Has the greatest impact on our understanding of ice giants and exoplanets.
  - Scientific and technological advances, and improved trajectories, give these measurements higher priority than they had in the Decadal Survey.
- Identified 12 key science investigations that potentially drive mission architectures (next slide).
- Identified >50 lower-priority science investigations.
- All science objectives consistent with and traceable to the decadal survey.

# STM Top 12 Science Investigations

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

Remaining 10 in alphabetical order:

- Atmospheric heat balance.
- Internal structure of satellites.
- Inventory of small moons, including those in rings.
- Planetary dynamo.
- Planet's tropospheric 3-D flow.
- Ring and satellite surface composition.
- Structures and temporal variability in rings.
- Shape and surface geology of satellites.
- Solar wind-magnetosphere-ionosphere interactions and plasma transport.
- Triton's atmosphere: origin, evolution, and dynamics.

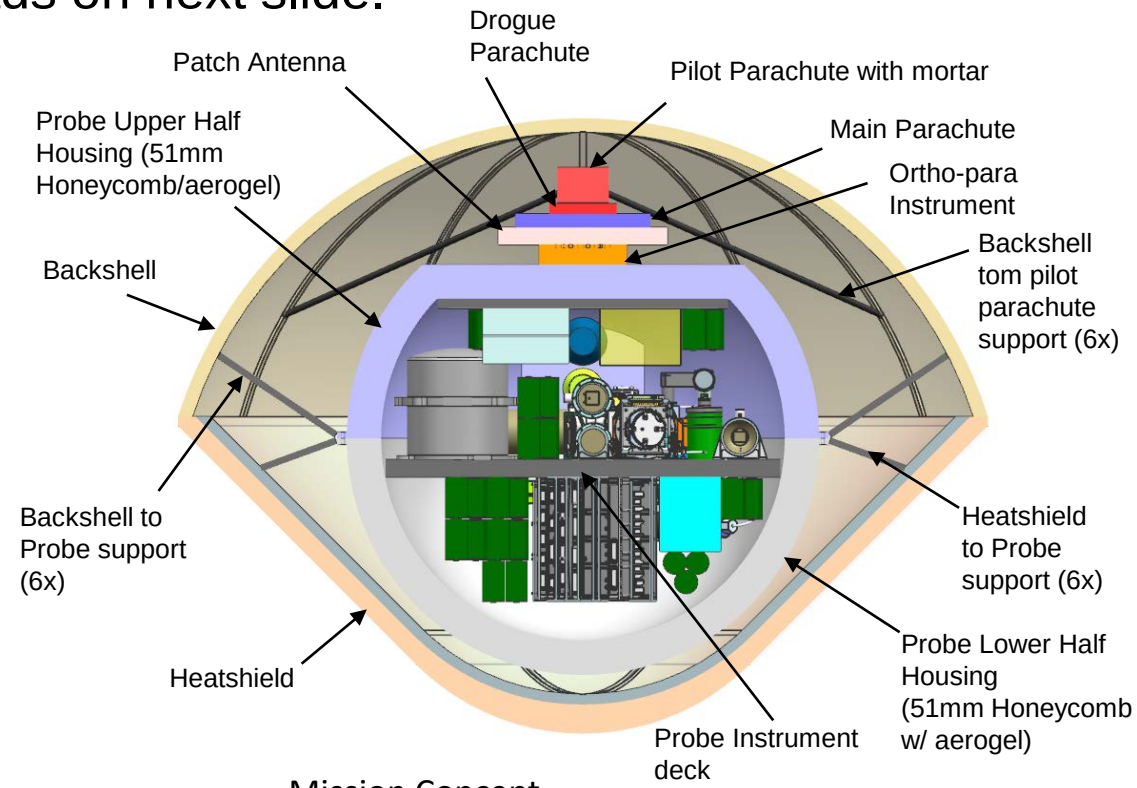
# Status: Model Instruments (1/2)

Identified 18 relevant instruments (counting an atmospheric probe as an instrument) to address top science objectives.

- Listed in back-up slides.
- Model orbiter payloads on next slide.

Model payload for the probe:

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




Mission Concept

# Status: Model Instruments (2/2)

Minimum orbiter payload to achieve significant science is 50 kg.

- NAC,
- Doppler Imager,
- Magnetometer.

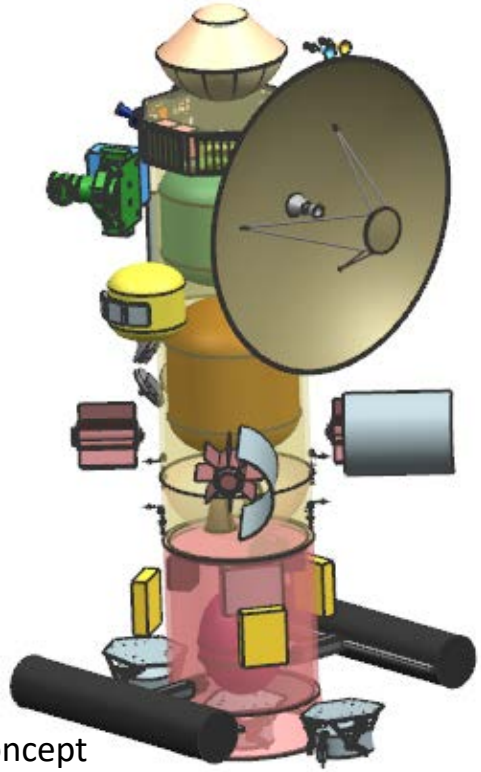
If Doppler measurement deemed too risky, replace with Vis/NIR imaging spec.

A 90 kg orbiter payload addresses all priority science. Add

- Vis/NIR imaging spectrometer,
- Radio and Plasma suite,
- Thermal IR,
- Mid-IR (Uranus) or UV (Neptune) spectrometer.

A 150 kg orbiter payload addresses all science goals. Add

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



Mission Concept

# Status: Architectures (1/4)

A-Team Study and Science Meeting held 29-31 March 2016

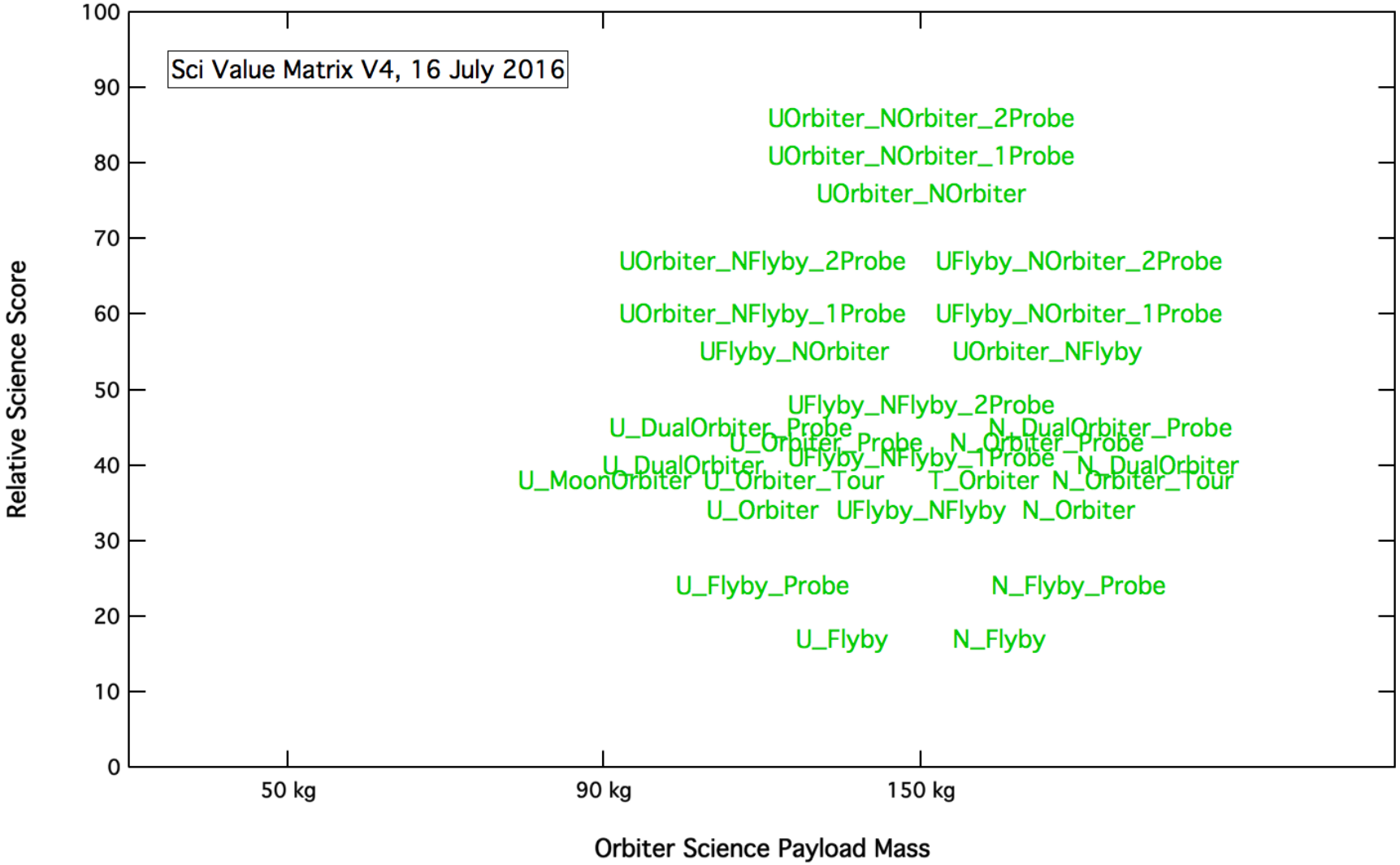
- A-Team studies are more than a back-of-the-envelope calculation, but not a detailed point design.
- Dozens of mission architectures considered (see backup slides). Preliminary estimates were made of the science potential of each, and preliminary cost estimates made for 18 of them.

Follow-on SDT work refined the “science value” estimates for 32 mission candidates of interest (see next slide).

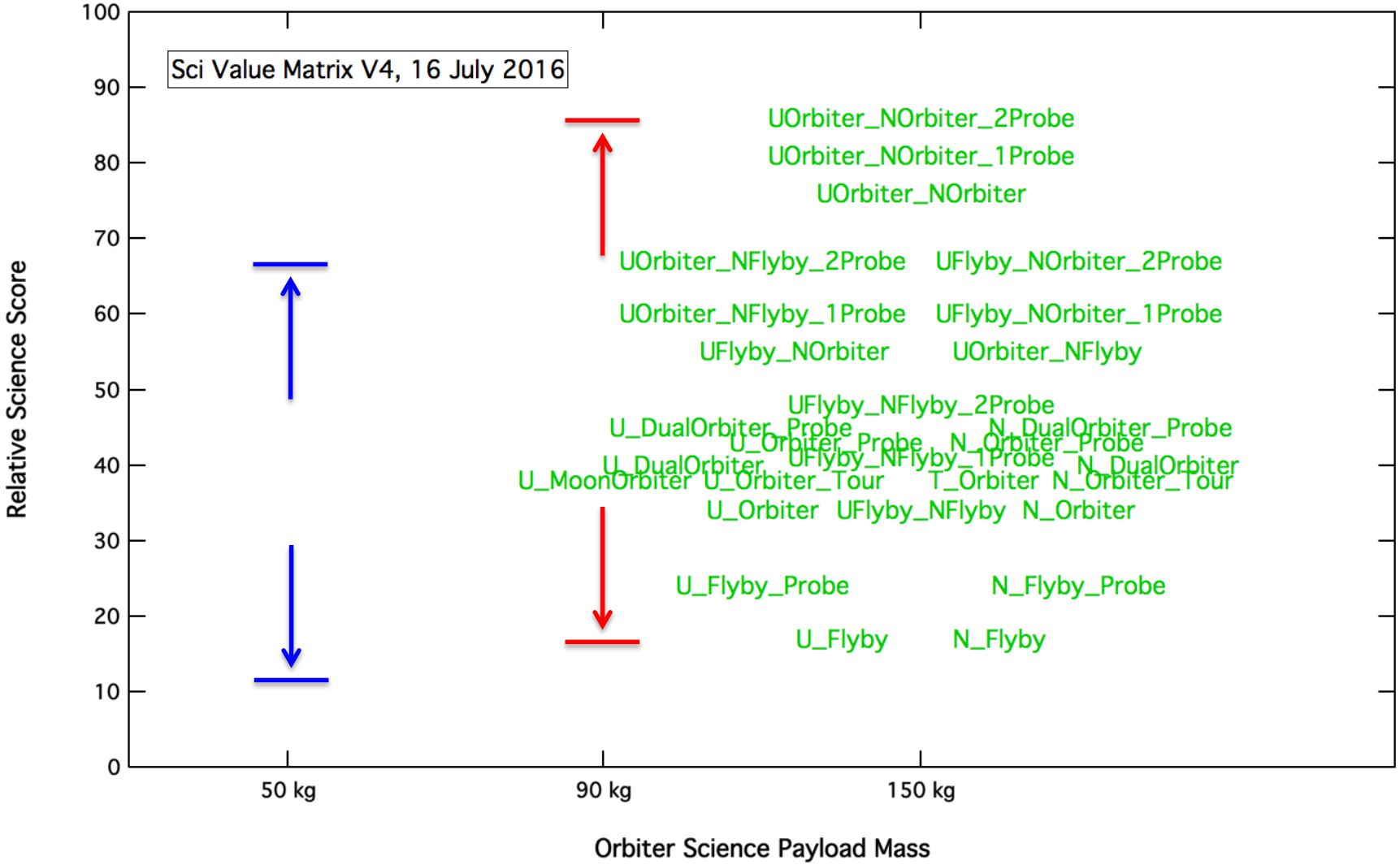
Nine mission architectures chosen for further consideration.

- Uranus flyby with probe.
- Uranus orbiter (with and w/o probe).
- Neptune orbiter (with and w/o probe).
- Triton orbiter.
- Uranus and Neptune flybys (two s/c) with at least 1 probe.
- Uranus orbiter and Neptune flyby (two s/c).
- Uranus and Neptune orbiters (two s/c) with at least 1 probe.

# Status: Architecture and Sci. Value



# Status: Architecture and Sci. Value



# Status: Architectures (3/4)

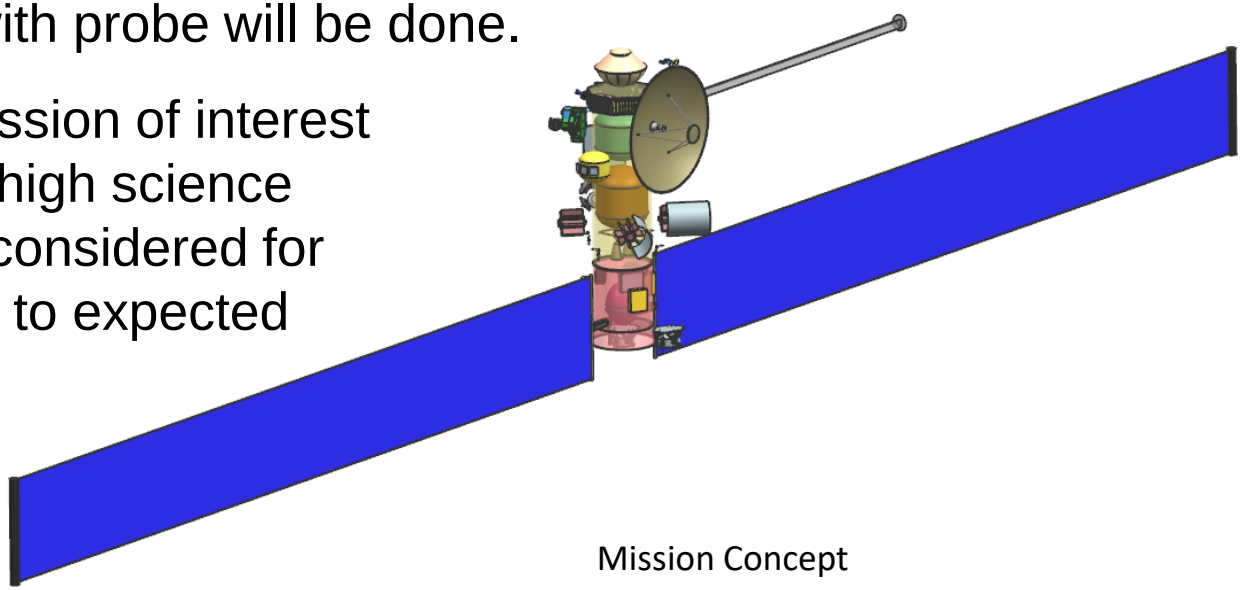
Three Team-X (higher fidelity) studies chosen.

- Can use them to refine A-Team results for other missions.
- Uranus orbiter concept with 50 kg science payload plus probe
  - Solar Electric Propulsion.
  - Launch in 2030, 11-year cruise to Uranus.
  - 4 years of operation at Uranus.
  - Probe release 60 days prior to orbit insertion.
  - Probe relay down to 10 bars.
  - Long orbital tour allows s/c to enter ring-plane with 10 satellite flybys.
- Neptune orbiter concept with 50 kg science payload plus probe
  - Solar Electric Propulsion.
  - Launch in 2030, 13-year cruise to Neptune.
  - 2 years of operation at Neptune.
  - Probe release 60 days prior to orbit insertion.
  - Probe relay down to 10 bars.
  - One flyby of Nereid, ~5 of Triton.
- Uranus orbiter concept with 150 kg science payload (no probe)
  - Same trajectory as 50 kg case.

# Status: Architectures (4/4)

All three studies appear to be towards the top of our target cost range. Will perform at least one more Team-X study this summer.

- Uranus orbiter with probe, but using chemical propulsion may be done.
  - Modest savings and easier conditions for probe relay.
  - Increase cruise time to Uranus ~1 year, with a reduction in time in orbit.
- Uranus flyby with probe will be done.
- Dual-planet mission of interest because of its high science value, but not considered for next study due to expected high cost.

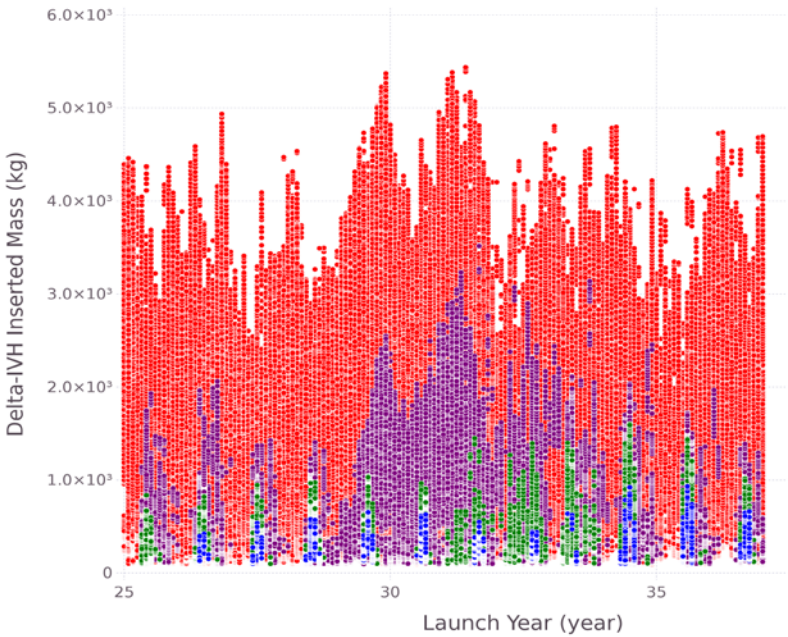


Mission Concept

# Status: Trajectories

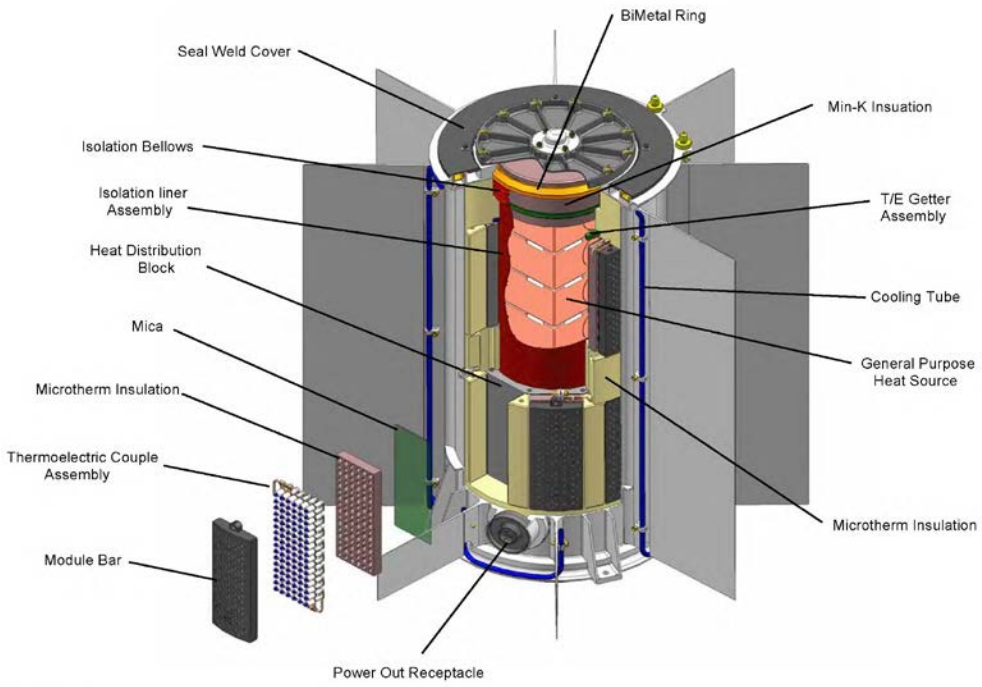
Launches possible every year

- Studied chemical and SEP missions; details in backup slides.
- Optimal launches in 2027-2033 time frame.
- Uranus flight times 10-11 years, possible with Atlas V or larger.
- Neptune flight times 12-13 years, prefer Delta-IVH or larger.
- SLS reduces flight times by ~2 years (highly variable), and allows much larger s/c.



# Status: Technology

- eMMRTG's would be enabling.
- Aerocapture is at least an enhancing technology. Work being done at Purdue to assess performance.
- Atmospheric entry systems being assessed by Ames.
- Small satellites and CubeSats are potentially useful, but are not enabling.



# Summary

Study is proceeding well. We have a science traceability matrix, have identified model payloads, and a wide range of mission architectures to consider. Three point designs are completed.

Costing exercise is not yet complete. Preliminary indications are:

- It is challenging to have a mission near $1 billion (FY15 dollars).
- A range of options are near the $2 billion point.
- Significantly higher science return for missions costing more than $2 billion.

It is part of our charter to identify opportunities for international collaboration. That work has not been done yet.

esa European Space Agency

Imperial College London

Public website (hosted by LPI) to share information with the broader community:

http://www.lpi.usra.edu/icegiants/mission_study/

Full report to NASA and ESA expected in the Fall. Community updates at DPS and AGU.

# Backup Slides

# Ground-Rules Highlights (1/2)

- Science objectives based on 2013-2022 Decadal Survey, revised for developments in science and technology.
- Study to address both Uranus and Neptune systems.
- Identify missions at a range of costs up to $2B (FY15$).
- Perform an independent cost assessment *and reconciliation.*
- Identify model payload for each candidate mission. Also identify instruments not in the payload that address science objectives.

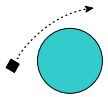
# Ground-Rules Highlights (2/2)

- Identify clean-interface roles for international partnerships.
- Launch dates from 2024 to 2037.
- Evaluate use of realistic emerging enabling technologies.
- Identify benefits/cost savings if SLS were available.

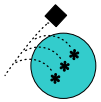
# Architectures in A-Team Study (1/2)

## Uranus Architectures

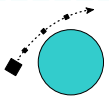
**Uranus Flyby**



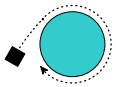
Flyby w/ Probe(s)



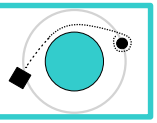
Flyby w/ Sub S/C



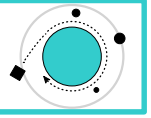
**Uranus Orbiter**



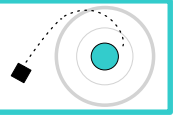
Moon Orbiter



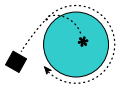
Orbiter w/ Moon Tour



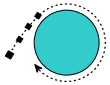
Ring Hover



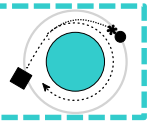
Orbiter w/ Probe(s)



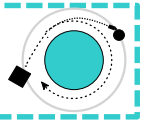
Orbiter w/ Sub S/C



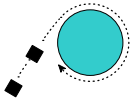
Orbiter w/ Moon Lander



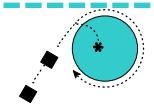
Orbiter w/ Icy Moon Penetrator



**Uranus Dual Orbiter**



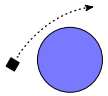
Dual Orbiter w/ Probe



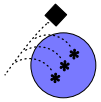
# Architectures in A-Team Study (2/2)

## Neptune Architectures

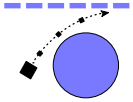
**Neptune Flyby**



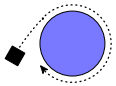
Flyby w/ Probe(s)



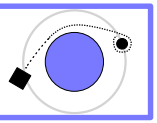
Flyby w/ Sub S/C



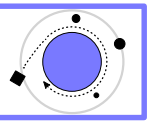
**Neptune Orbiter**



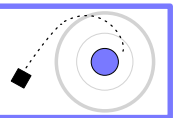
**Triton** Orbiter



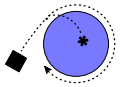
Orbiter w/ Moon Tour



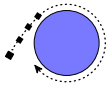
Ring Hover



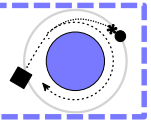
Orbiter w/ Probe(s)



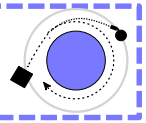
Orbiter w/ Sub S/C



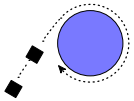
Orbiter w/ **Triton** Lander



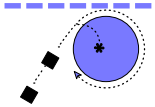
Orbiter w/ **Triton** Penetrator



**Neptune Dual Orbiter**



Dual Orbiter w/ Probe

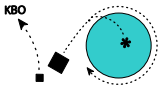


## Hybrid Architectures

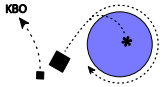
**Multiple Bodies**

Note: Flyby S/C can be instrumented SEP stage

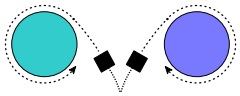
Uranus Orbiter, KBO Flyby



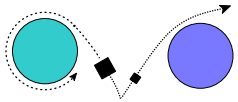

Neptune Orbiter, KBO Flyby



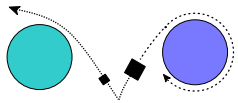

Neptune and Uranus Orbiters



Uranus Orbiter, Neptune Flyby



Neptune Orbiter, Uranus Flyby



# Instruments

The Science Traceability Matrix for the top-12 science objectives identified 18 instruments.

- Mass spectrometer on orbiter,
- Vis/NIR imaging spectroscopy,
- Thermal-IR bolometer/Vis photometer (can replace bolometer with imager) ,
- Narrow angle camera,
- Plasma waves,
- Plasma low-energy particles,
- Plasma high-energy particles,
- Magnetometer (with boom) ,
- Doppler imager,
- UV imaging spectrometer,
- Energetic neutral atoms detector,
- Dust detector,
- Ground penetrating radar,
- Langmuir probe,
- USO (for radio science),
- Microwave sounder,
- IR imaging spectrometer,
- Probe.

Top 4 instruments for maximizing # of science objectives addressed: NAC, Magnetometer, Vis/NIR imaging spectrometer, UV spectrometer.

Top 4 instruments for addressing highest priority science: Doppler imager, magnetometer, USO, probe.