Ice Giant Mission Study Status

Briefing to OPAG

12 August 2016

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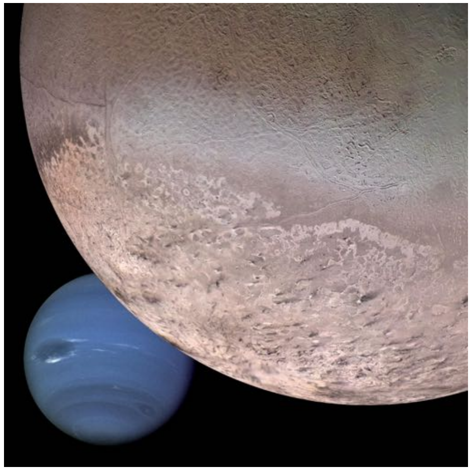
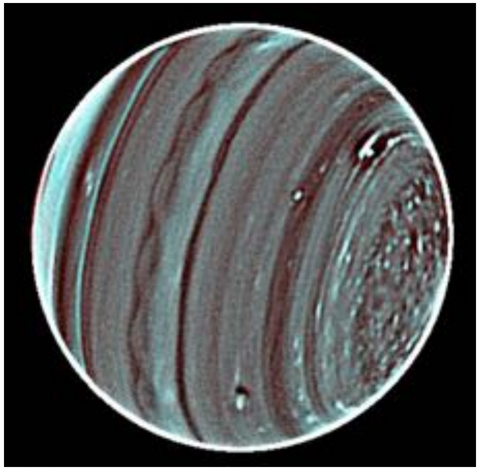


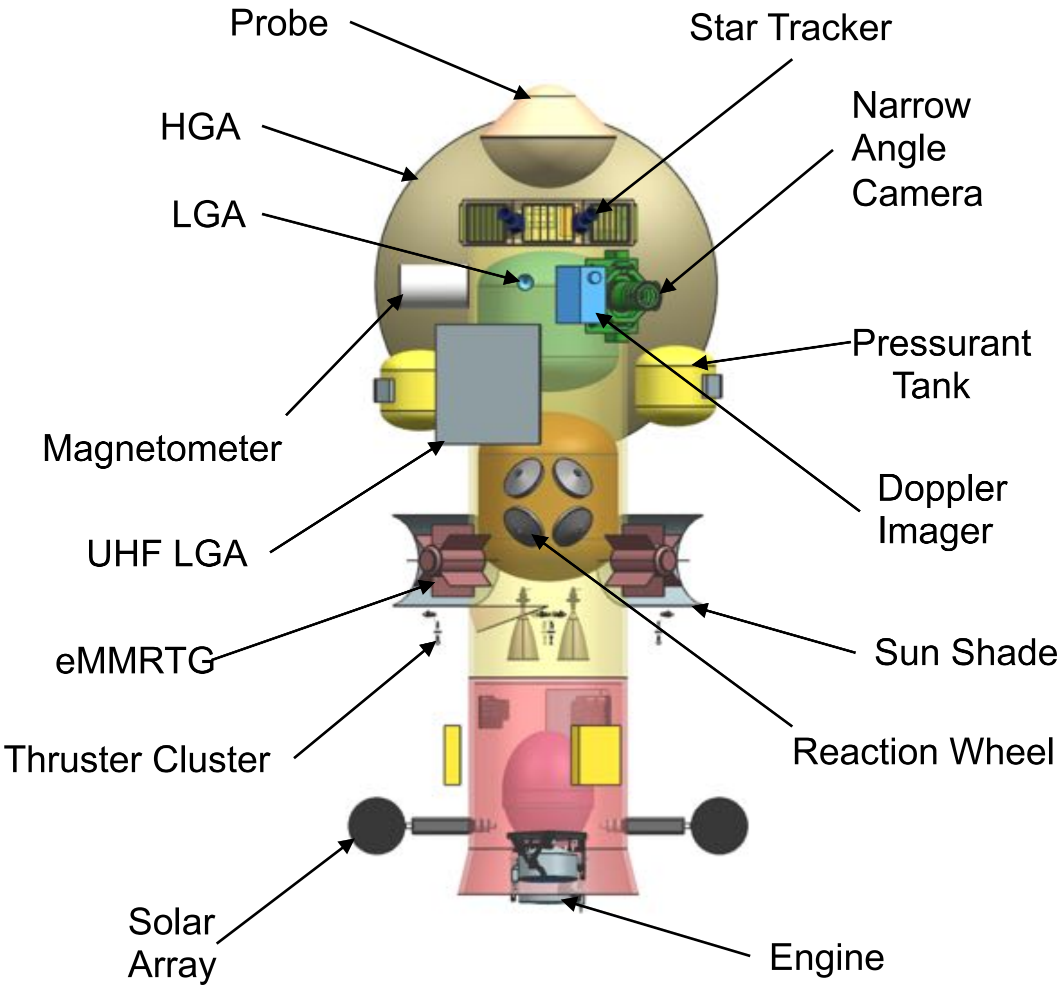
Neptune and Triton from Voyager



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

Outline

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



Mission Concept

Statement of Task

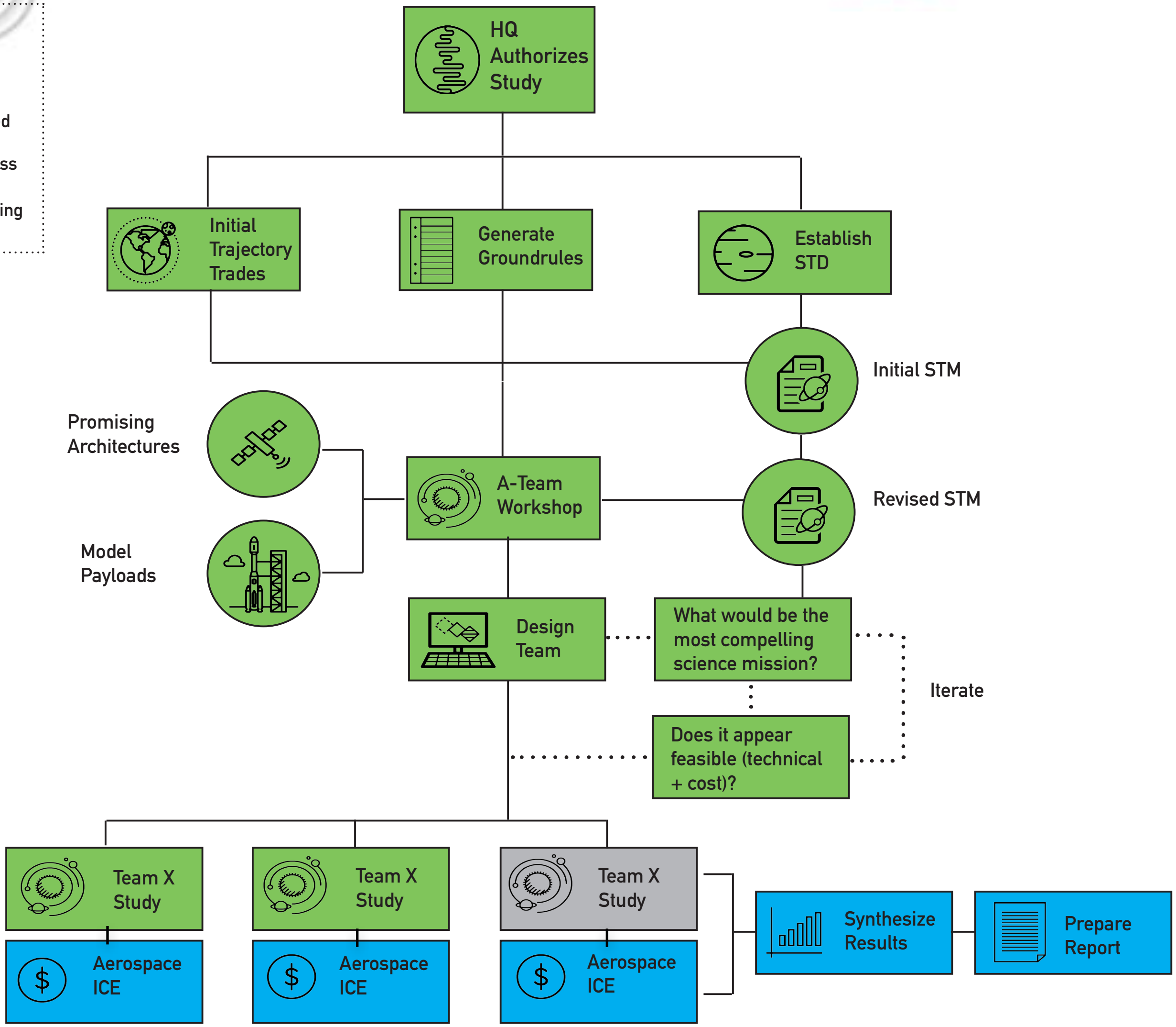
- Goal: Assess science priorities and affordable mission concepts & options in preparation for the next Decadal Survey
- Objectives:
  - Identify mission concepts that can address science priorities based on what has been learned since the 2013-2022 Decadal
  - Identify potential concepts across a spectrum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

Study Plan

☐ activities
○ products
🟩 completed
▨ in progress
🟦 forthcoming

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.



HQ Authorizes Study

Initial Trajectory Trades

Generate Groundrules

Establish STD

Initial STM

Promising Architectures

Model Payloads

A-Team Workshop

Revised STM

Design Team

What would be the most compelling science mission?

Does it appear feasible (technical + cost)?

Iterate

Team X Study

Aerospace ICE

Team X Study

Aerospace ICE

Team X Study

Aerospace ICE

Synthesize Results

Prepare Report

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.

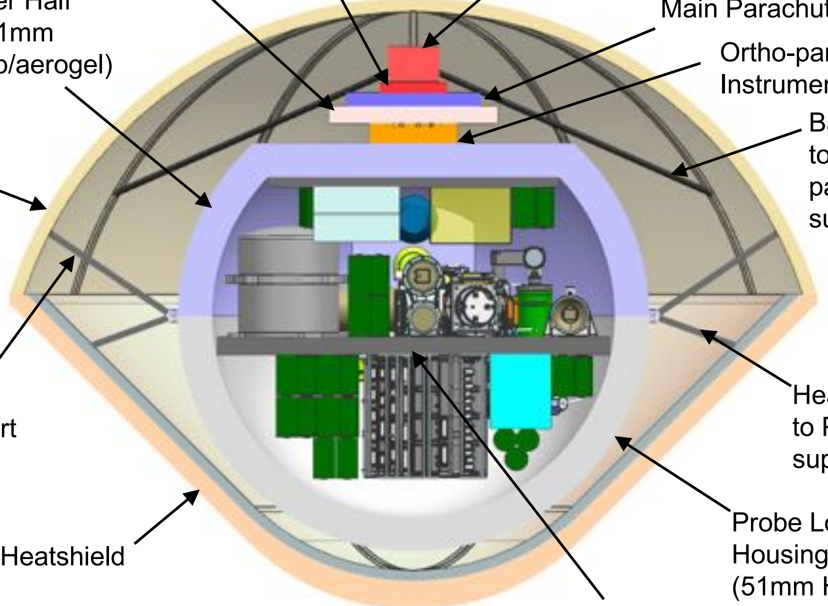
Status: Model Instruments (1/2)

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.



Drogue Parachute

Patch Antenna

Pilot Parachute with mortar

Probe Upper Half Housing (51mm Honeycomb/aerogel)

Main Parachute

Ortho-para Instrument

Backshell

Backshell tom pilot parachute support (6x)

Backshell to Probe support (6x)

Heatshield to Probe support (6x)

Heatshield

Probe Lower Half Housing (51mm Honeycomb w/ aerogel)

Probe Instrument deck

Mission Concept

Status: Model Instruments (2/2)

Minimum orbiter payload to achieve significant science is 50 kg.

- NAC,
- Doppler Imager,
- Magnetometer.

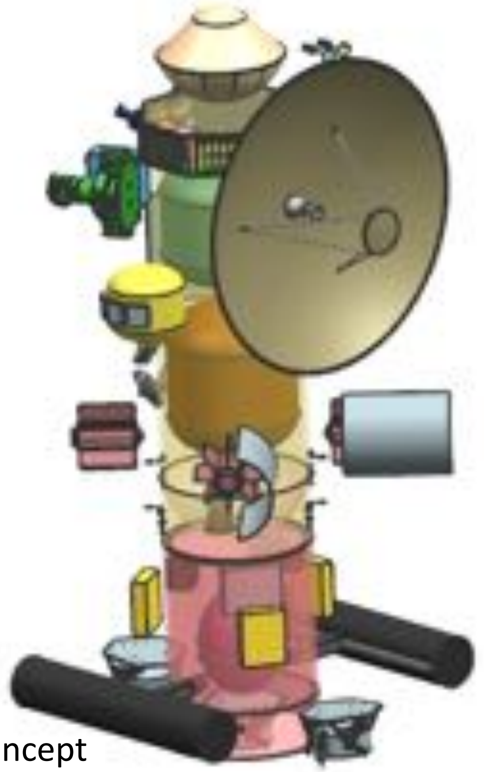
If Doppler measurement deemed too risky, replace with Vis/NIR imaging spec.

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

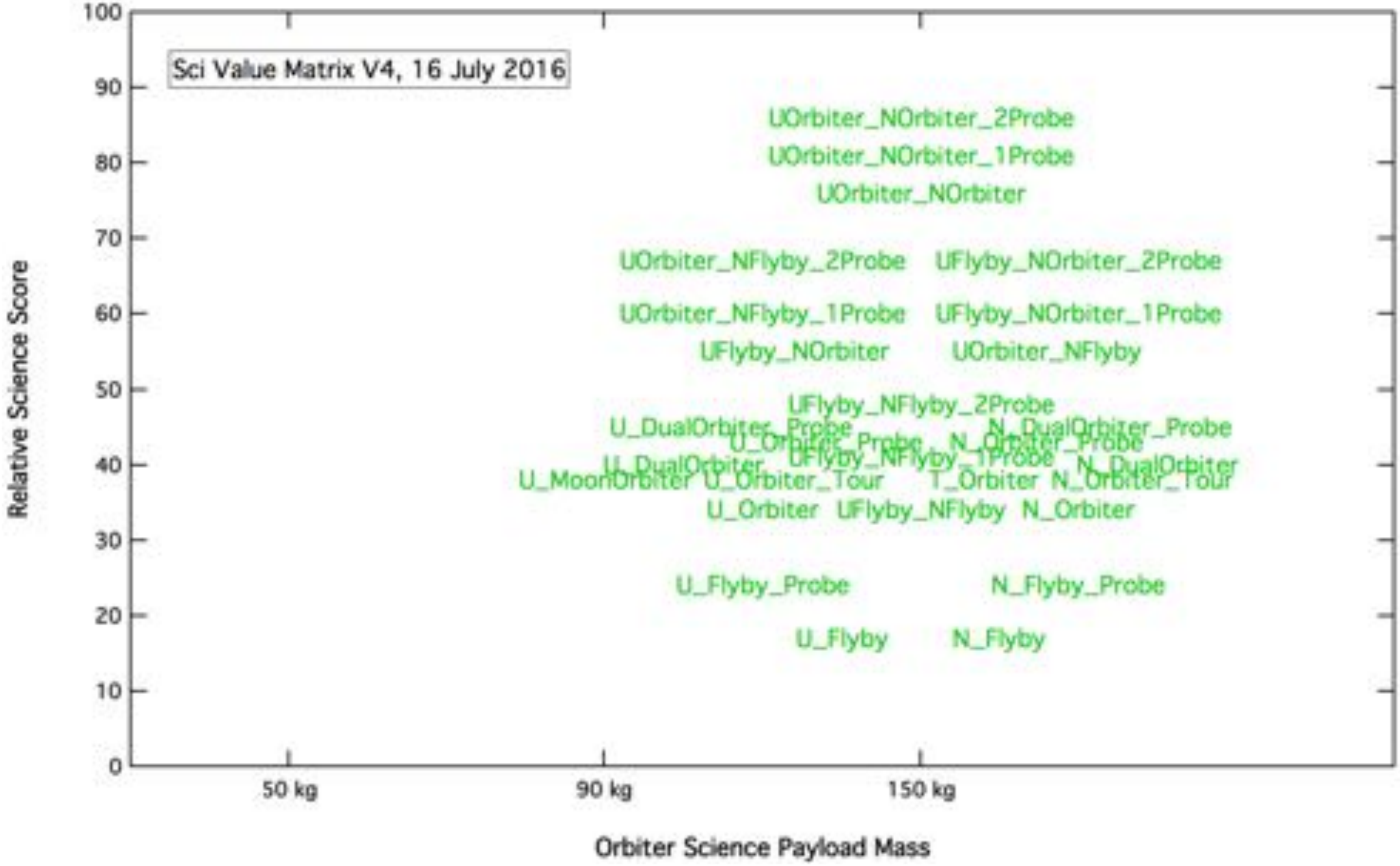
- A-Team studies are more than a back-of-the-envelope calculation, but not a detailed point design.
- Dozens of mission architectures considered (see backup slides). Preliminary estimates were made of the science potential of each, and preliminary cost estimates made for 18 of them.

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

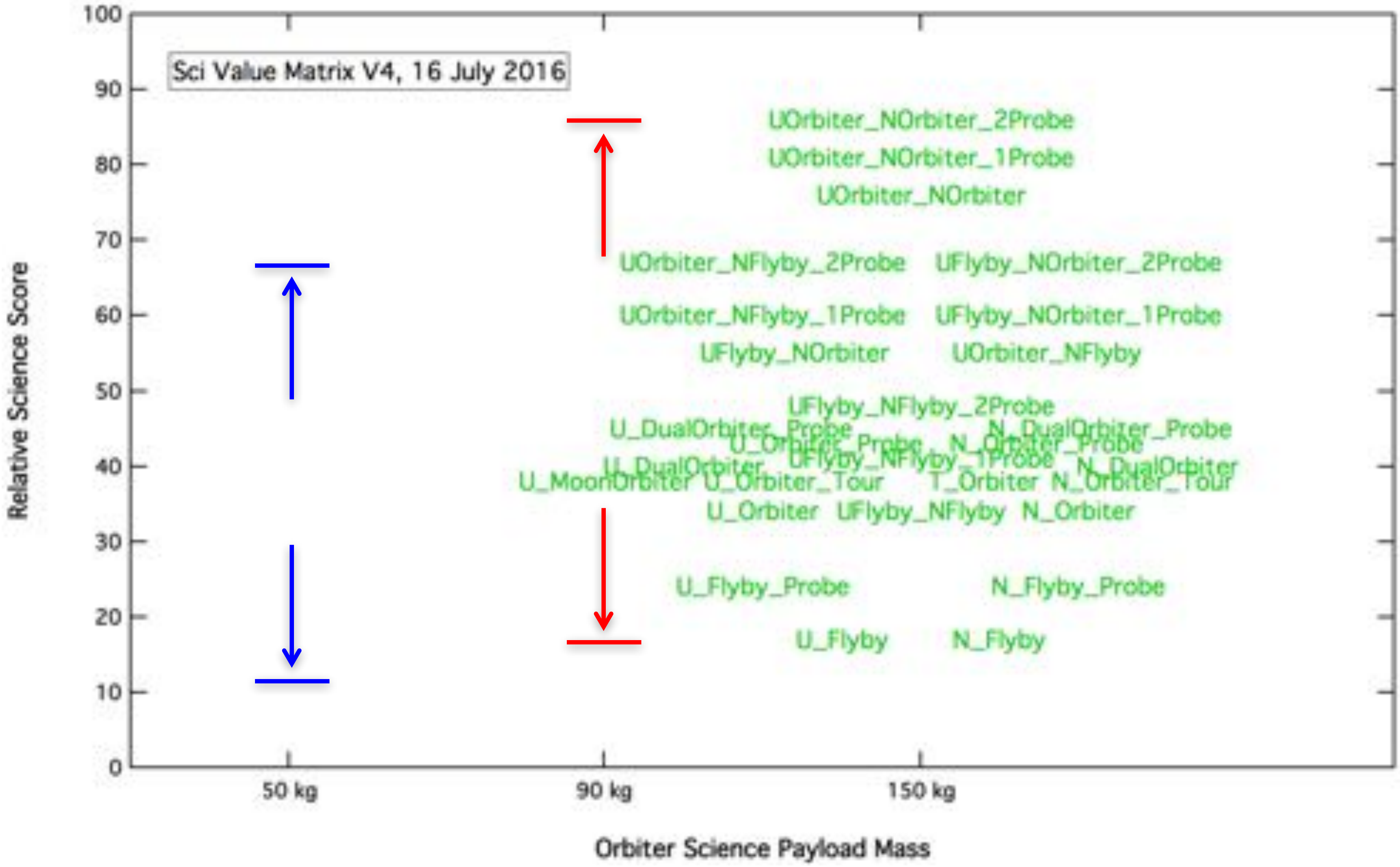
Nine mission architectures chosen for further consideration.

- 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)

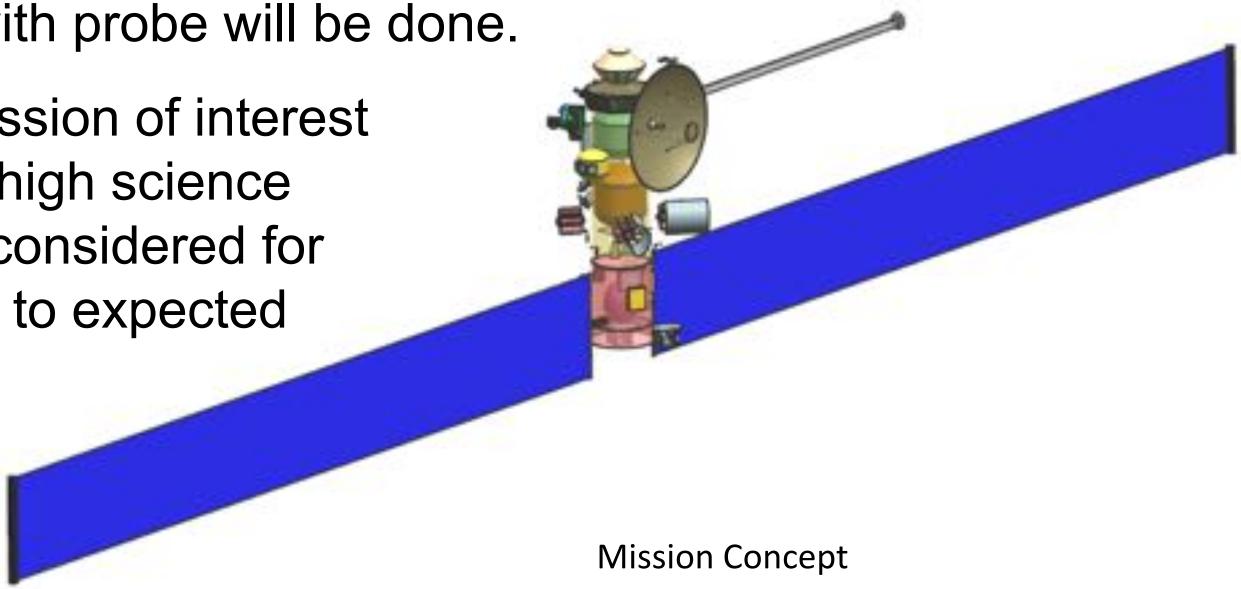
Three Team-X (higher fidelity) studies chosen.

- 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.

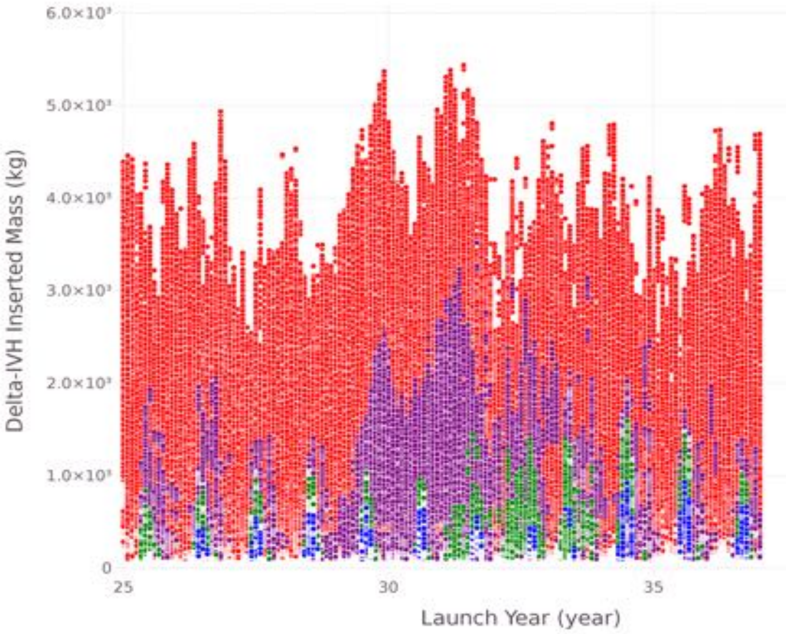


Mission Concept

Status: Trajectories

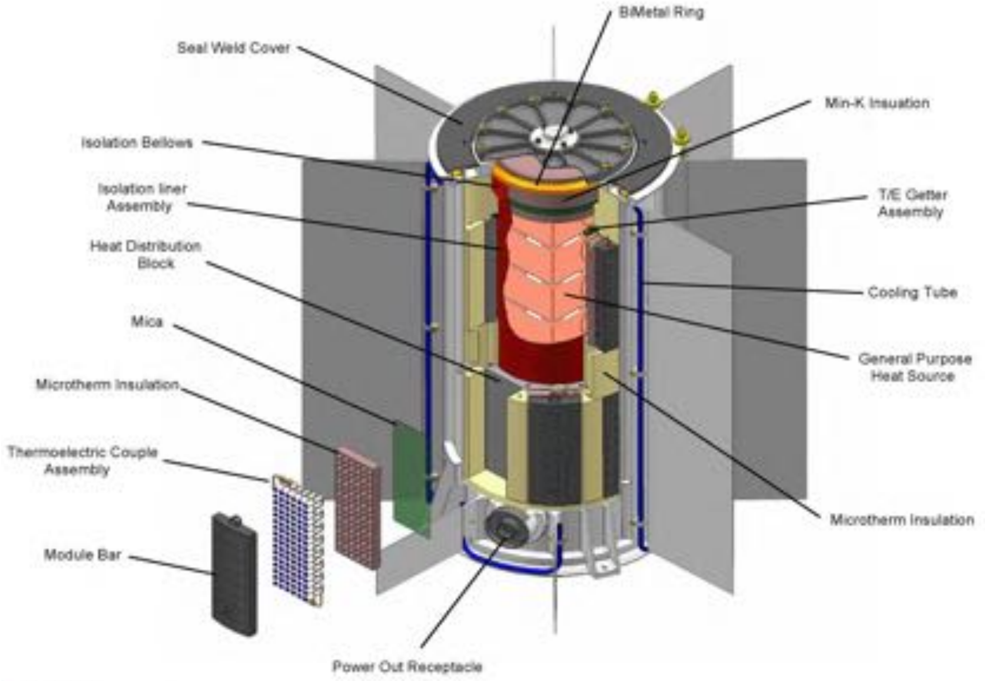
Launches possible every year

- Studied chemical and SEP missions.
- 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

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
ISTITUTO DI ASTROFISICA E PLANETOLOGIA SPAZIALI DI ROMA

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)

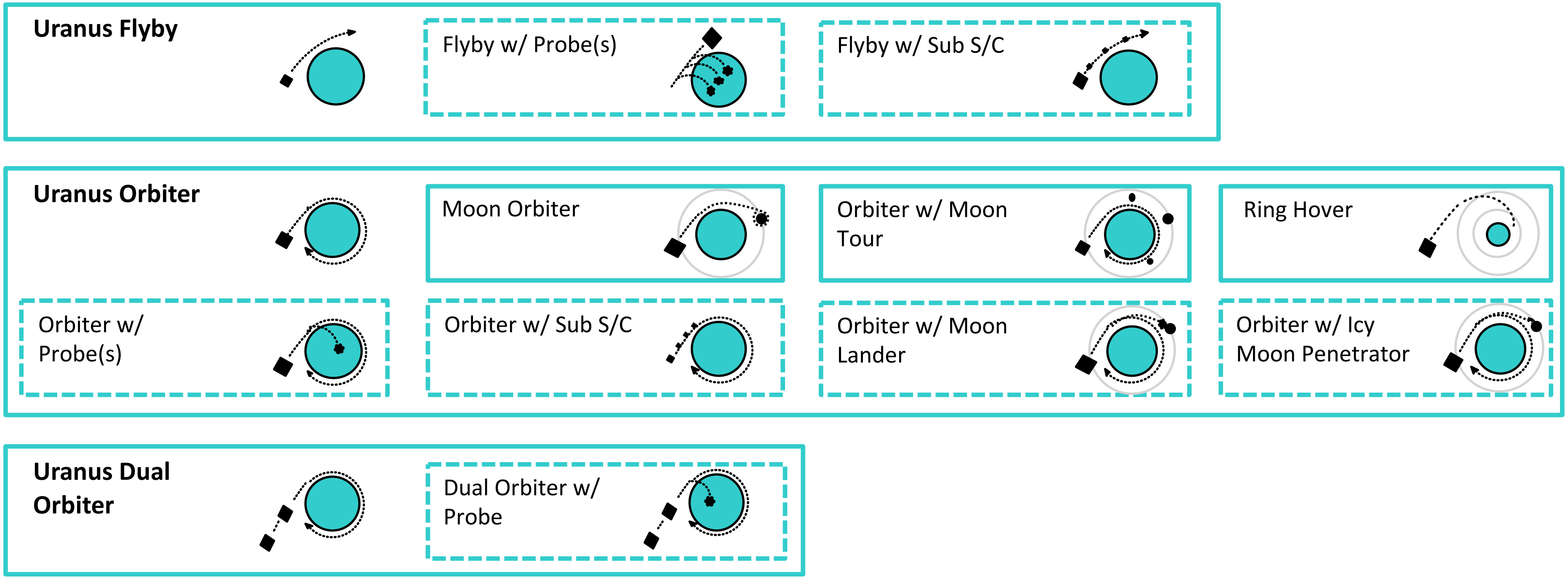
- Science objectives based on 2013-2022 Decadal Survey, revised for developments in science and technology.
- Study to address both Uranus and Neptune systems.
- Identify missions at a range of costs up to $2B (FY15$).
- Perform an independent cost assessment *and reconciliation.*
- Identify model payload 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

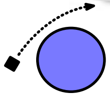
Uranus Dual Orbiter

Dual Orbiter w/ Probe

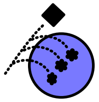
Architectures in A-Team Study (2/2)

Neptune Architectures

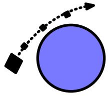
Neptune Flyby



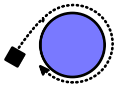
Flyby w/ Probe(s)



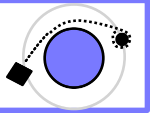
Flyby w/ Sub S/C



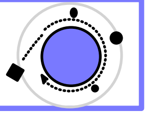
Neptune Orbiter



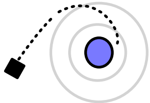
Triton Orbiter



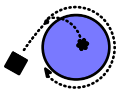
Orbiter w/ Moon Tour



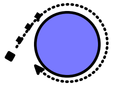
Ring Hover



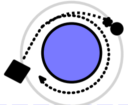
Orbiter w/ Probe(s)



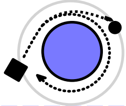
Orbiter w/ Sub S/C



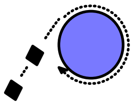
Orbiter w/ **Triton** Lander



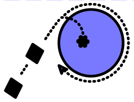
Orbiter w/ **Triton** Penetrator



Neptune Dual Orbiter



Dual Orbiter w/ Probe

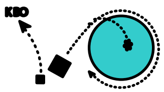


Hybrid Architectures

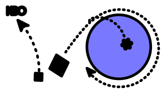
Multiple Bodies

Note: Flyby S/C can be instrumented SEP stage

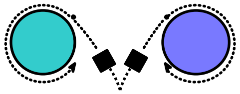
Uranus Orbiter, KBO Flyby



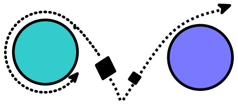
Neptune Orbiter, KBO Flyby



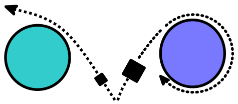
Neptune and Uranus Orbiters



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,
- Radio and 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.

STM Top 12 Science Investigations

- Constrain the structure and characteristics of the planet's interior, including layering, locations of convective and stable regions, internal dynamics.
- Determine the planet's bulk composition, including abundances and isotopes of heavy elements, He and heavier noble gases.

Remaining 10 in pseudo-alphabetical order:

- Determine the planet's atmospheric heat balance.
- Determine the density, mass distribution, internal structure of major satellites and, where possible, small inner satellites and irregular satellites.
- Obtain a complete inventory of small moons, including embedded source bodies in dusty rings and moons that could sculpt and shepherd dense rings.
- Improve knowledge of the planetary dynamo.
- Measure planet's tropospheric 3-D flow (zonal, meridional, vertical) including winds, waves, storms and their lifecycles, and deep convective activity.
- Determine surface composition of rings and moons, including organics; search for variations among moons, past and current modification, and evidence of long-term mass exchange / volatile transport.
- Characterize the structures and temporal changes in the rings.
- Map the shape and surface geology of major and minor satellites.
- Investigate solar wind-magnetosphere-ionosphere interactions and constrain plasma transport in the magnetosphere.
- Determine the composition, density, structure, source, spatial and temporal variability, and dynamics of Triton's atmosphere.