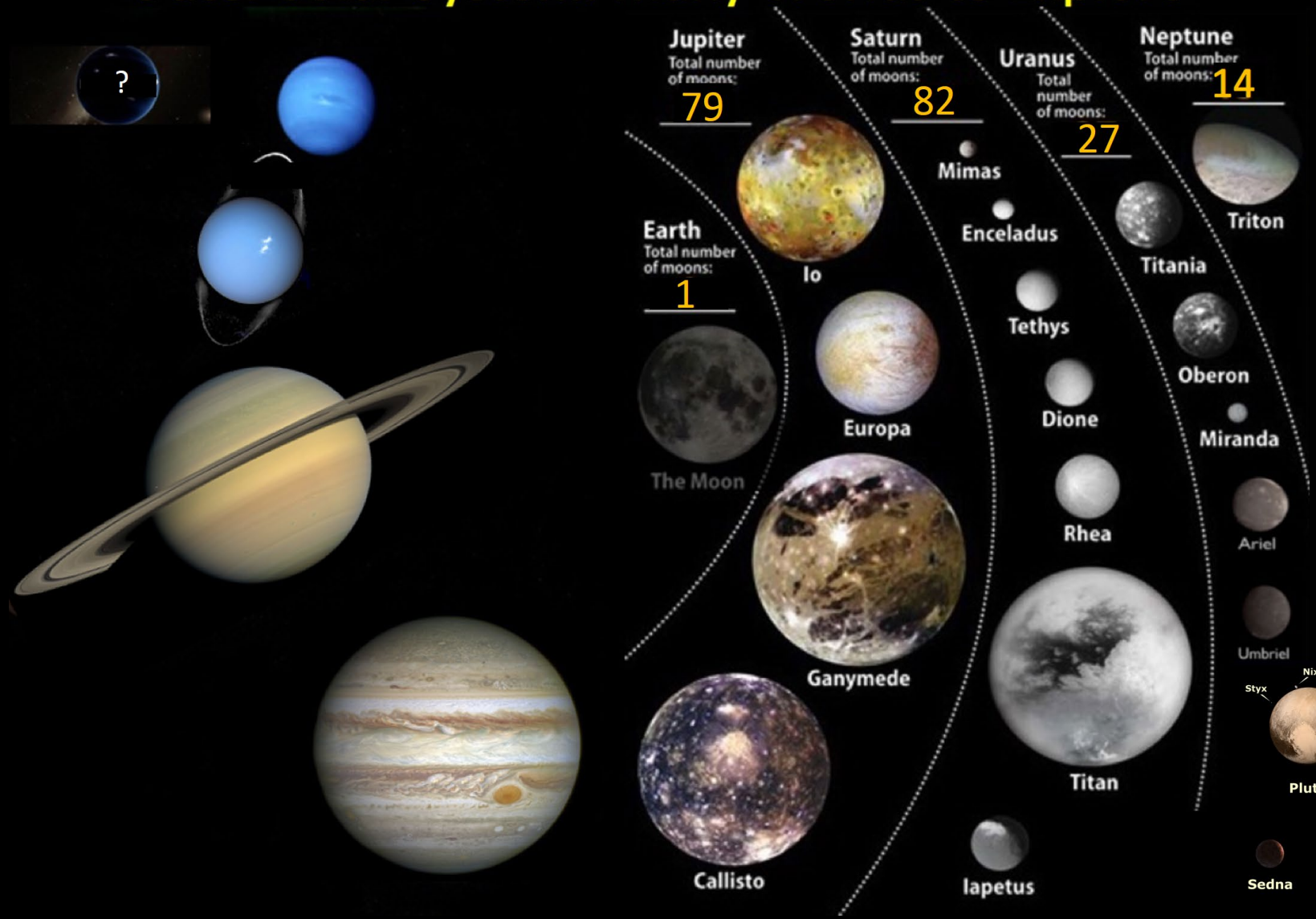
OPAG Presentation to Giant Planet Systems Panel for NAS Planetary Science and Astrobiology Decadal Survey

Linda Spilker and Jeff Moore, OPAG Co-Chairs, 10 May 2021



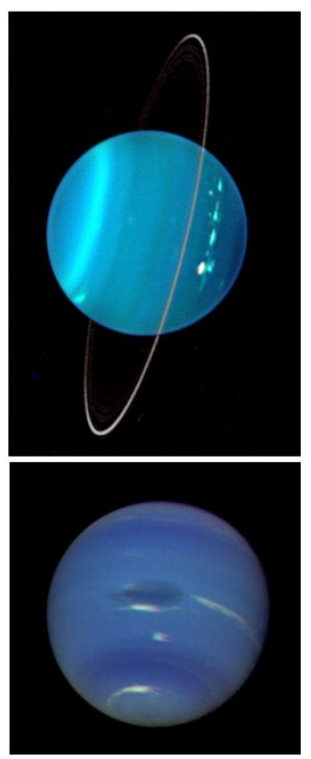
OPAG *is* the Comparative Planetology AG

Large KBOs:

Outer Planets Assessment Group (OPAG) Charter

https://www.lpi.usra.edu/opag/

- NASA's community-based forum to provide science input for planning and prioritizing outer planet exploration activities for the next several decades
- Evaluates outer solar system exploration goals, objectives, investigations and required measurements on the basis of the widest possible community outreach
- Meets twice per year, spring and fall
  - Most recent meeting (virtual): 9-11 February 2021
- OPAG documents are inputs to the Decadal Surveys
- OPAG and Small Bodies Assessment Group (SBAG) have Joint custody of Pluto system and other planets among Kuiper Belt Objects



KBO planets

OPAG Committee White Paper

- **Organized around Big Questions**
  - What is the distribution and history of life in the solar system?
  - What is the origin, evolution, and structure of planetary systems?
  - What present-day processes shape planetary systems, and how do these processes create diverse outcomes within and across different worlds?

  With a fourth Cross-Divisional theme: How can solar system bodies inform our understanding of bodies in exoplanetary systems?
- **Strategic Approach**
  - Research and Analysis (R&A), International Partnership
- **Technology and Supporting Strategic Investment** (including)
  - Orbital vs. *In situ* in Exploration, Aerocapture, Earth-based Astronomy, Laboratory Measurements
- **Diversity Statement**
  - Foster an interdisciplinary, diverse, equitable, inclusive, and accessible community with improved representation of underrepresented people

Three Big Questions
OPAG issues to consider in Decadal Survey Statement

Big Question #1: What is the distribution and history of life in the solar system (see backup)? (Ocean Worlds and Dwarf Planets Panel)

Big Question #2: What is the origin, evolution, and structure of planetary systems?

Big Question #3: What present-day processes shape planetary systems, and how do these processes create diverse outcomes within and across different worlds?

Big Question #2: What is the origin, evolution, and structure of planetary systems?

- What was the initial chemical profile of the protoplanetary disk as informed by noble gas content in the giant planets, and how did this profile impact the overall formation and evolution of our solar system?
- What are the possible architectures of planetary systems, and how do these different configurations affect planet formation and evolution (e.g., giant planet migration, tidal evolution, etc.)?
- What controls the formation, evolution and internal structures of gas giants (Jupiter, Saturn), ice giants (Uranus, Neptune), planetary satellites (particularly ocean worlds), rings, and small bodies in the outer solar system?
- How do planetary crusts/cryospheres, oceans, atmospheres, and magnetospheres form and evolve in the outer solar system, and how do they influence the evolution of bodies in those systems?

Big Question #3: What present-day processes shape planetary systems, and how do these processes create diverse outcomes within and across different worlds?

- How do the chemical and physical processes in the solar system scale with planet size and location within the solar system?
- What is the dynamic relationship between the planets, rings, and moons of giant planet systems, and how do these relationships influence their constituent members?
- How do the magnetospheres of gas and ice giants influence the dynamics, composition and structure of the atmospheres, rings, and moon surfaces?
- How do the aurorae and induced magnetic fields of ocean worlds characterize the coupling between planets, moons, and magnetospheres?

Big Question #3: (continued)

- What are the mechanisms, drivers, and rates for transporting heat and materials within, and ejecting them from, (cryo-)volcanically active worlds?
- How does coupled orbital evolution and tidal heating affect the interior structures and activity of satellites, and how does the interior evolution of the primaries affect this evolution (e.g., resonance locking)?
- What drives the transport of energy and materials within the deep interior of the giant planets?
- How do the atmospheric dynamics, cloud microphysics, radiative transfer, and chemistry interact to form stable and transient features observed in outer planet and satellite atmospheres?
- How do the ice giant magnetospheres and atmospheres respond to the impulsive solar wind forcing created by their unusual geometries, and what effect does solar insolation play on weather and upper atmospheric structure?

Cross-Divisional Theme: How can knowledge of the solar system advance our understanding of Earth, Sun, and Exoplanets?

- How does knowledge gleaned from studying the outer solar system make us better stewards of our own planet?
- How does the study of our planet inform our understanding of the outer planets and their moons?
- How do studies of the diverse present-day oceans in the solar system advance biological, chemical and physical oceanography? (OW & DP panel)
- How does the study of the solar wind interaction at bodies in the outer solar system improve our understanding of the Sun and the propagation and evolution of its dynamic atmosphere?
- How can solar system bodies inform our understanding of bodies in exoplanetary systems?

OPAG Committee White Paper Conclusions
Large Directed Missions

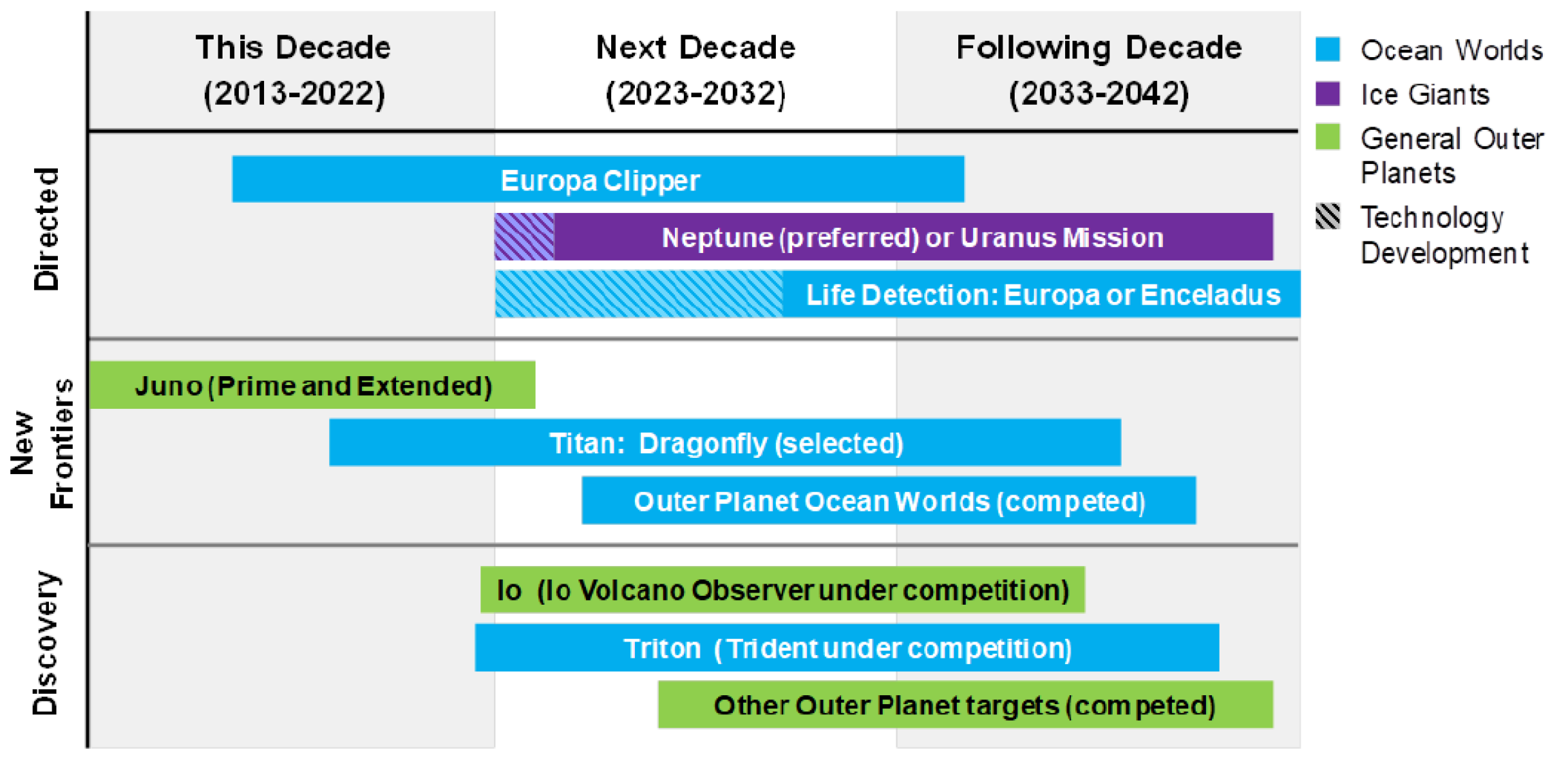
- **Complete Europa Clipper**
- **New start for an Ice Giant Systems mission**
  - Neptune is preferred since Triton is a higher-priority Ocean Worlds target
  - Re-affirms importance given to such a mission in previous Decadal Survey
  - No new technology efforts needed for this mission to proceed
- **New start for Ocean Worlds mission** in second half of decade
  - Search for life or biosignatures on an ocean world, most likely Europa or Enceladus
  - Life detection technology development could prove essential to either mission
  - Strongly support continuing ongoing technology development efforts
  - Recommend that current Decadal Survey include a Priority Question about life or biosignature detection rather than just the study of habitability

OPAG Committee White Paper Conclusions
New Frontiers Missions

- OPAG encourages making the New Frontiers programs open to all outer planet targets that address Decadal priorities
  - Outer solar system has a great abundance of interesting worlds to explore
  - Mission restrictions are a particularly onerous for future exploration

- Support inclusion of:
  - Enceladus and Titan ocean worlds missions
  - Io Observer (if IVO not selected for Discovery mission)
  - Saturn probes

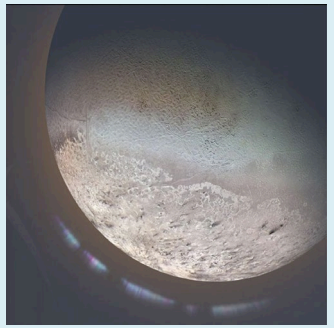
Timeline for a robust Outer Planets Program spanning three decades

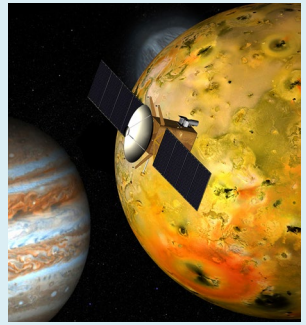


Mission Proposals to Outer Planets in Discovery

- **At least 6 OP Discovery missions proposed but declined in Step-1**
- **3 missions selected for Phase A:**
  - **TiME**
  - **Trident**
  - **Io Volcano Observer**
- LUCY will go to 5 AU but does not get close to high-radiation Jupiter, does not need propulsion for orbit insertion, and can return data when closer to Earth.
- Outer Planets exploration is challenging via Discovery
  - Mission/instrument lifetime requirements
  - High radiation environment at Jupiter
  - Cold environments (plus hot during Earth/Venus gravity assists)
  - Challenging for power at >5 AU
  - Need large propulsion system to be captured into orbit or to land
  - Need large telecom system to return significant amounts of data
- **Outer Solar System Discovery missions are getting closer to a successful selection in Step-2**

OPAG supports Discovery and smallsat missions





Smallsats for Outer Planet Exploration

- Challenges in applying SmallSats to the outer Solar System:
  - Integrating Propulsion Systems (propellant mass fraction is often >50%, + propulsion hardware)
  - Satisfying Telecom Needs (need High Gain Antenna and high power to return significant data)
  - Radiation Tolerance at Jupiter (Juno Radiation vault = 200 kg)
  - Power – requires large solar panels (Juno has 340 kg panels) or radioisotope power (a single MMRTG = 45 kg)
  - Long mission duration requires redundancies, increasing mass
  - Thermal management requires mass and/or power
- **Benefits of Smallsat developments to Outer Planets Exploration:**
  - Miniaturization of all subsystems is highly beneficial
  - Secondary Payloads on large missions, rely on host mission for delta-V and telecom
    - Example: Huygens probe on Cassini, 320 kg

Huygens probe

Urgent: Hubble Space Telescope Follow-on is Needed

Past NASEM Studies recommended examining value of space telescopes dedicated to solar system science (See backup slide)

- Such a study was not executed before the current decadal survey

HST has made critical contributions to Solar System Science

- Examples: Captured High-resolution UV-Visible Snapshots and Short Movies; Europa plume searches/discovery; Ganymede & Io auroral studies…

Next Transformational Advances Require a Space Telescope dedicated to solar system observations (not just for giant planets!)

- Not all science can be done with target-specific visiting missions!
- Study Temporally Dynamic Phenomena

e.g. Plumes/Volcanoes on satellites, Transient Atmos. Events, Aurora, Comets…

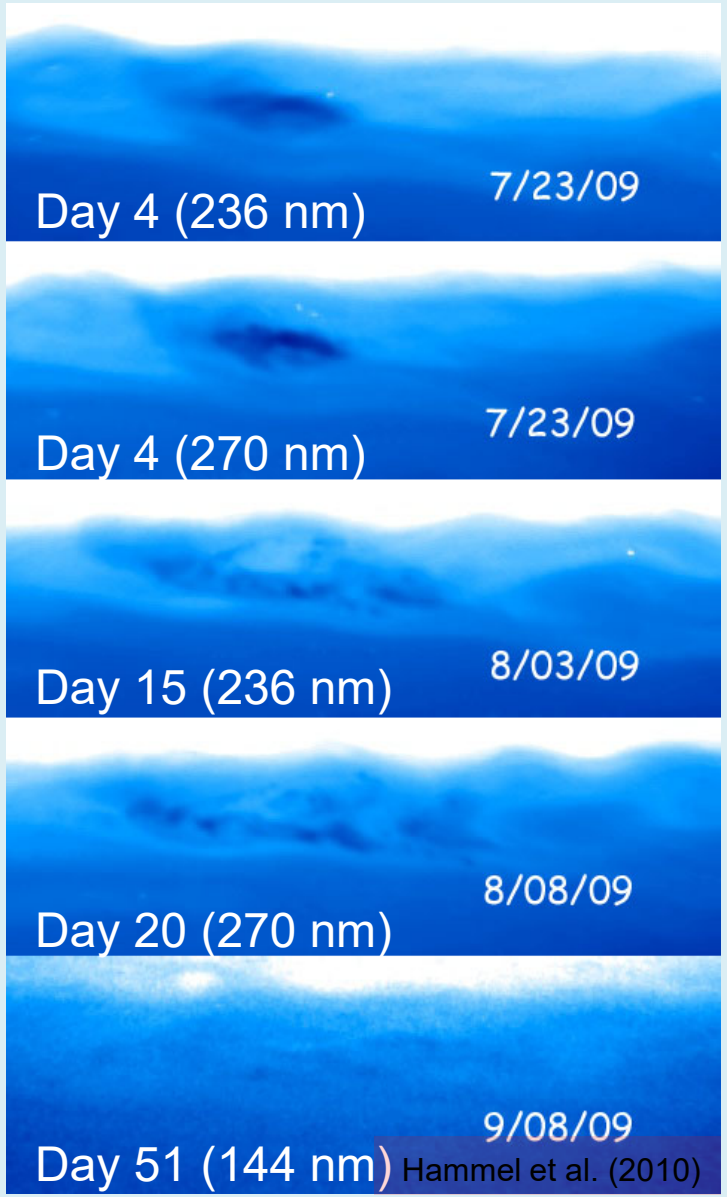
→ Need high-frequency, long-duration campaigns

- Survey of Small-Body Surface Composition

→ Need HST-class sensitivity for many targets

Solar System Science needs a UV-Visible Follow-on to HST

Impact Scar on Jupiter (HST UV Images



Hammel et al. (2010)

Highlights of Recent OPAG Findings

3. Implementation of Inclusion, Diversity, Equity, and Accessibility (IDEA) principles across all missions

- Planetary science as a discipline is woefully underrepresented even when compared to the National Civilian Labor Force (see Decadal white paper by Rivera-Valentin et al., 2020). Many of the noted concerns with increasing diversity within the planetary science community have been centered on the lack of access to missions for diverse populations.
- OPAG would like to see NASA encourage all missions to follow Dragonfly's example of tangible action in implementing Inclusion, Diversity, Equity, and Accessibility (IDEA) as a fundamental principle of the mission design and execution. The Dragonfly Student & Early Career Investigator Program is a groundbreaking program that will take concrete steps to broadening participation in NASA missions.

Highlights of Recent OPAG Findings

1. Dragonfly Mission Launch Delays

- … further delays of the Dragonfly launch could have cascading impacts on the next New Frontiers mission (NF-5)… *(and beyond)*

2. Collecting and reporting on demographic data for NASA proposals

- Continue to collect demographic data in NSPIRES, posed in a way that allows multiracial and non-binary members of our community to provide responses.

4. Radioisotope Thermoelectric Generators: Planning for future outer planet mission needs (Full finding in backup)

- OPAG is concerned that the single unit of NextGen RTG included in the NASA-DoE "2020 Mission Set" is not sufficient to power a Flagship mission… …ensure that the plutonium production is planned accordingly to fuel two units on a schedule consistent with a potential Flagship mission to an Ice Giant planet to be launched in the early 2030s.

RTG Needs to Sustain Outer Planets Exploration

NASA's current plan to Fabricate *and* Fuel RTGs:

- x2 MMRTGs for Discovery in 2025 (Needed only if Trident is selected)
- x1 MMRTG for Dragonfly in 2026
- x1 DRPS (2-GPHS modules) for CLPS in 2025
- x1 NextGen RTG (16-GPHS modules) for TBD mission in 2030

NASA plans to fabricate (not yet committed to fueling):

- x1 additional NextGen RTG (16-GPHS modules) ready to be fueled in 2026

Future Ice Giant Flagship will require at least two NextGen RTG units

NASA needs to commit to fueling the second NextGen RTG unit to enable an Ice Giant Flagship to be launched in the 2030s

Back up slides

Prospect of Jupiter System Science with Europa Clipper

Long-running discussion topic at OPAG meetings over the years

- Should be considered only after launch to avoid impacting development
- Until launch, it is premature for OPAG to issue a finding on the topic to avoid impacting the cost in any form

Giant Planets System Panel should assess the scientific value and cost of adding Jupiter System Science to the scope of Europa Clipper after launch

Whitepapers that discuss Jupiter System Science Objectives:

- Nenon et al. “Open science questions and missing measurements in the radiation belts of Jupiter”
- Smith et al. “Callisto: A Guide to the Origin of the Jupiter System”
- Sayanagi et al. “Priority Questions for Jupiter System Science in the 2020s and Opportunities for Europa Clipper”
- Crary et al. “The Magnetosphere of Jupiter: Moving from Discoveries Towards Understanding”
- Wong et al. “Gas Giant and Ice Giant Atmospheres: Focused Questions for 2023-2032”
- Kim et al,. “Composition and Dynamical Processes of Ions in Giant Magnetospheres: The Importance of In Situ Measurements for Advancing the Current Knowledge”
- Hsu et al. “Jupiter System Observatory at Sun-Jupiter Lagrangian Point One”

‘The PSD R&A program is critically underfunded to the detriment of NASA’s strategic objectives.’ Castillo et al., White Paper 2020

- “Budget analysis [Sykes 2017] suggests that NASA PSD was not compliant with the second Decadal’s recommendation regarding R&A funding levels and their priority in the context of overall insufficient funds available to the Division….The selection rates in the Planetary Science Division remain the lowest across all of NASA SMD’s divisions…” Castillo et al. WP2020
- “Boldly Increase the Planetary Science Research & Analysis Budget by 50% Immediately” Retherford et al. WP2020
- See also Bottke et al WP2020 “Tenets of an effective and efficient research and analysis program for NASA”

Recommendations by Recent National Academies Reports on a Space Telescope Dedicated to Solar System Science

Getting Ready for the Next Planetary Science Decadal Survey (2017):

https://www.nap.edu/catalog/24843/report-series-committee-on-astrobiology-and-planetary-science-getting-ready

"Synoptic observations of solar system bodies are limited by two factors, the availability of telescope time and resolution. First, while current (e.g., Hubble Space Telescope and Spitzer Space Telescope) and future (e.g., James Webb Space Telescope and Wide-Field Infrared Space Telescope) space observatories are available to the planetary astronomy community and are not resolution constrained, such assets are in great demand for other astronomical studies. Therefore, the availability of telescope time for long-term monitoring of, for example, Titan, Europa, and Io or for surveys is highly limited. Second, the resolution of such observations is primarily dictated by telescope aperture (the larger the aperture the greater the cost of the mission). Hence, *studies to determine the potential scientific return of a space telescope dedicated to the monitoring and studies of solar system bodies that can be achieved within the scope of either the Discovery or the New Frontiers programs would benefit the next planetary science decadal survey.*

Visions into Voyages for Planetary Sciences in the Decade 2013-2022: A Midterm Review (2018):

https://www.nap.edu/catalog/25186/visions-into-voyages-for-planetary-science-in-the-decade-2013-2022

NASA should conduct an assessment of the role and value of space-based astronomy, including newly emerging facilities, for planetary science. This assessment should be finished before the next decadal survey is significantly under way.

NASA Response to the Midterm Review Recommendation:

https://www.lpi.usra.edu/NASA-academies-resources/PSD-Response-Decadal-Mid-Term.pdf

NASA agrees that it is important to continue to explore the role that space-based astronomy plays in planetary science and *will seek community input for an assessment through a mechanism such as a community workshop or study, the planning for which will begin in 2019.* Further, NASA recognizes that space-based astronomy has already proven its value for planetary science such as observing the Comet F2 D/1993 Shoemaker-Levy 9 impacts with Jupiter using the HST; discovering approximately fifty of the potentially hazardous asteroids with NEOWISE and characterizing many more with NEOWISE and Spitzer; discovering the New Horizons follow-on target 2014 MU69 in the Kuiper Belt with HST; and assessing the potential hazard to the Mars orbiters posed by Comet C/2013 A1 (Siding Spring) using HST, NEOWISE, Spitzer and Swift.

Three Big Questions
OPAG issues to consider in Decadal Survey Statement of Tasks

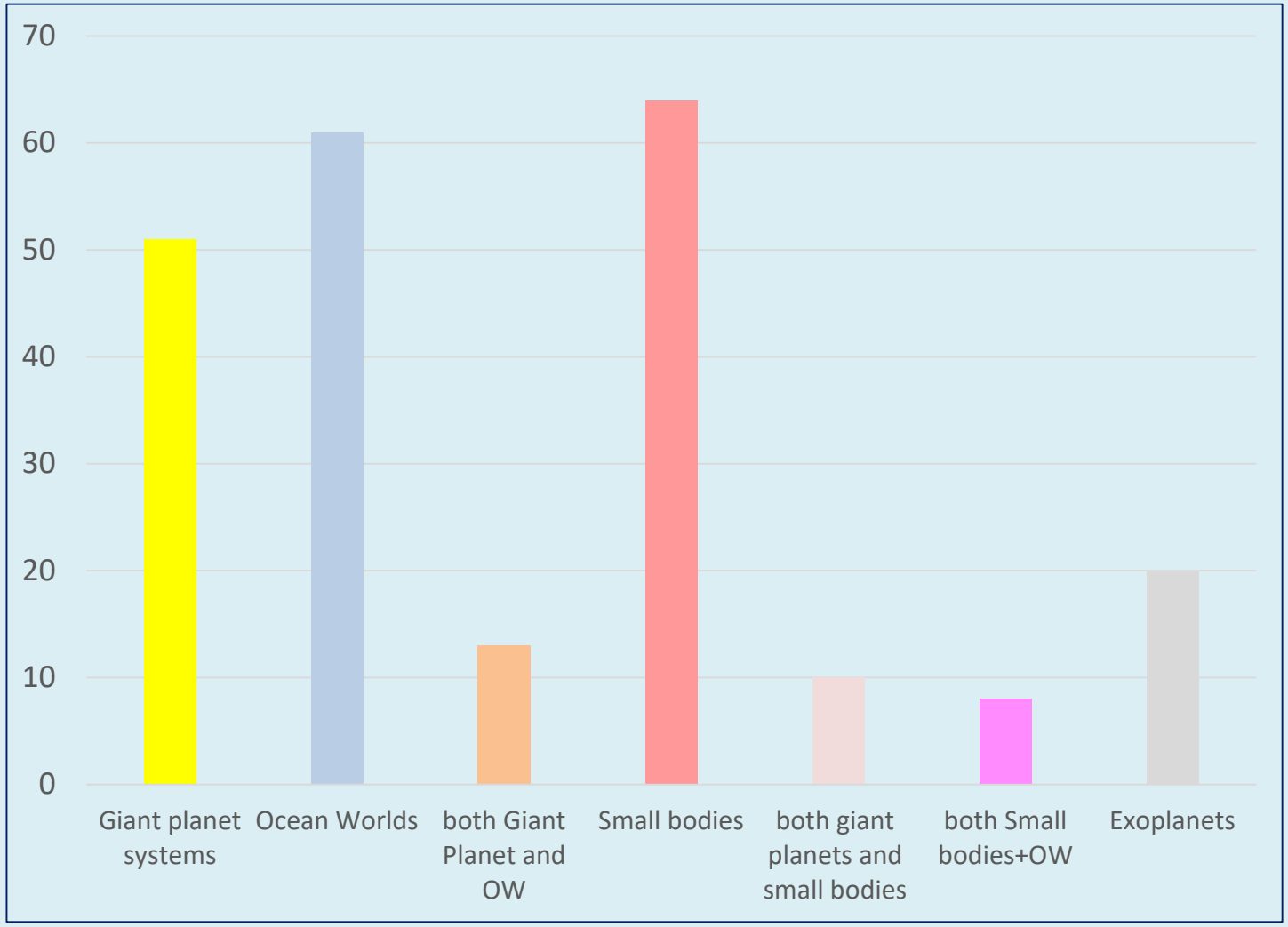
Three "Big Questions" are listed below along with example bulleted, high-level, OPAG-specific sub-questions:

Big Question #1: What is the distribution and history of life in the solar system?

- Does life or do habitable conditions exist beyond the Earth?
- What controls the habitability of ocean worlds?
- Do ocean worlds host life now, or did they in the past?
- What is the potential for prebiotic chemistry in ocean worlds, and how far towards life has this progressed?
- What role did the giant planets play in the emergence of life on Earth or elsewhere in the solar system?

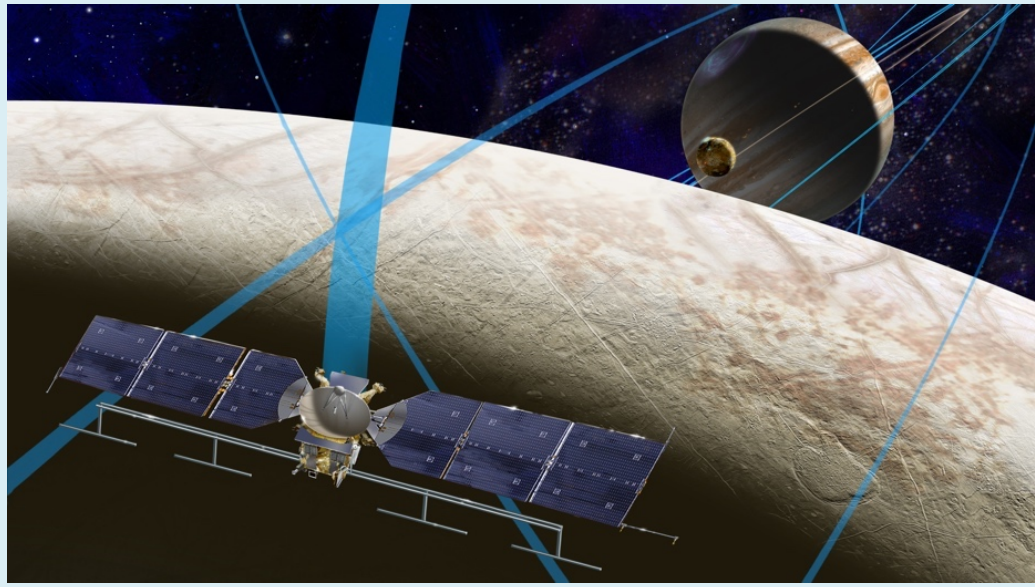
Preliminary OPAG-Relevant White Paper Statistics

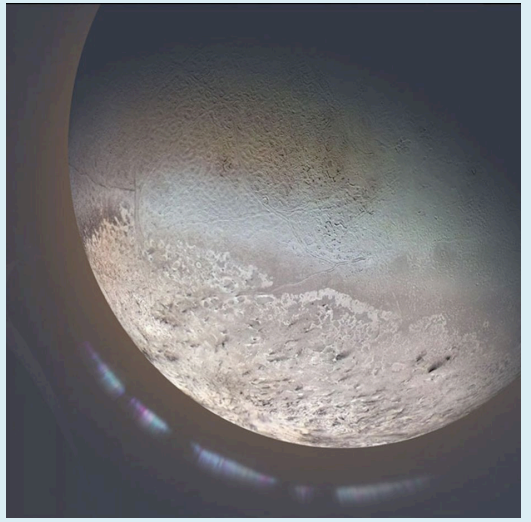
Number of White Papers (of 381 submitting as of 13 August 2020)	
Giant planet systems	51
Ocean Worlds	61
both Giant Planet and OW	13
Small bodies	64
both giant planets and small bodies	10
both Small bodies+OW	8
Exoplanets	20

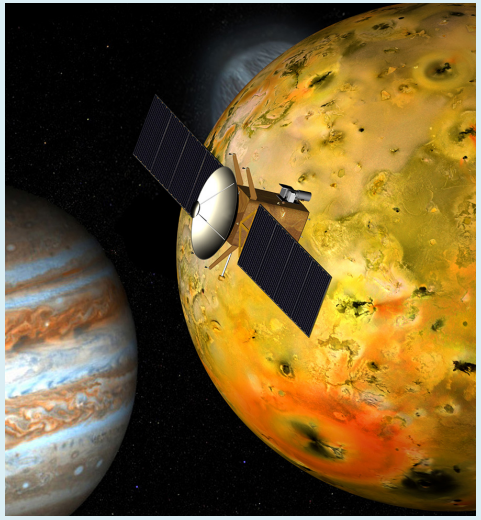


Some Recent Key Activities

- Io Volcano Observer (IVO) selected for further Discovery Mission study. Alfred McEwen (PI)
- TRIDENT selected for further Discovery Mission study. Louise Prockter (PI)
- Juno Probe Completed 34th Orbit of Jupiter
- Update: Europa Clipper progressing well
- JUICE progressing towards 2022 launch
- 3 Outer Planet mission studies for the Decadal Survey: final reports submitted
- **OPAG Committee White Paper posted**







New Frontiers has been good for exploration of Outer Planets

- Missions from the 1st Decadal survey:
  - New Horizons
  - Juno
- Approved candidate missions in 2nd Decadal (V&V) to outer solar system:
  - Saturn Probe
  - Ocean Worlds: Enceladus and Titan
  - Dragonfly to Titan selected for NF-4
- OPAG supports keeping Io Observer and Ocean Worlds in NF-5, along with Saturn Probe
- If IVO is selected for Discovery, then there might be no Io Observer proposals submitted to NF-5, similar to what happened with the Trojan mission after Lucy was selected.
- **Though Dragonfly was selected for NF-4, OPAG supports CAPS recommendation for keeping Enceladus as an NF-5 option**

Recent and Upcoming OPAG-related Meetings

- **OPAG Meeting** (February 9-11, 2020) Virtual

Upcoming Meetings:

- **OPAG Meeting** (Aug. 30 – Sept. 1, 2021) (Virtual)
  - Focus on upcoming Planetary Science and Astrobiology Decadal Survey
  - 6 Findings from February meeting that will be addressed in NASA HQ briefing