Decadal Perspective on New Frontiers

Presentation to Committee on Astrobiology and Planetary Sciences, 2-20-24

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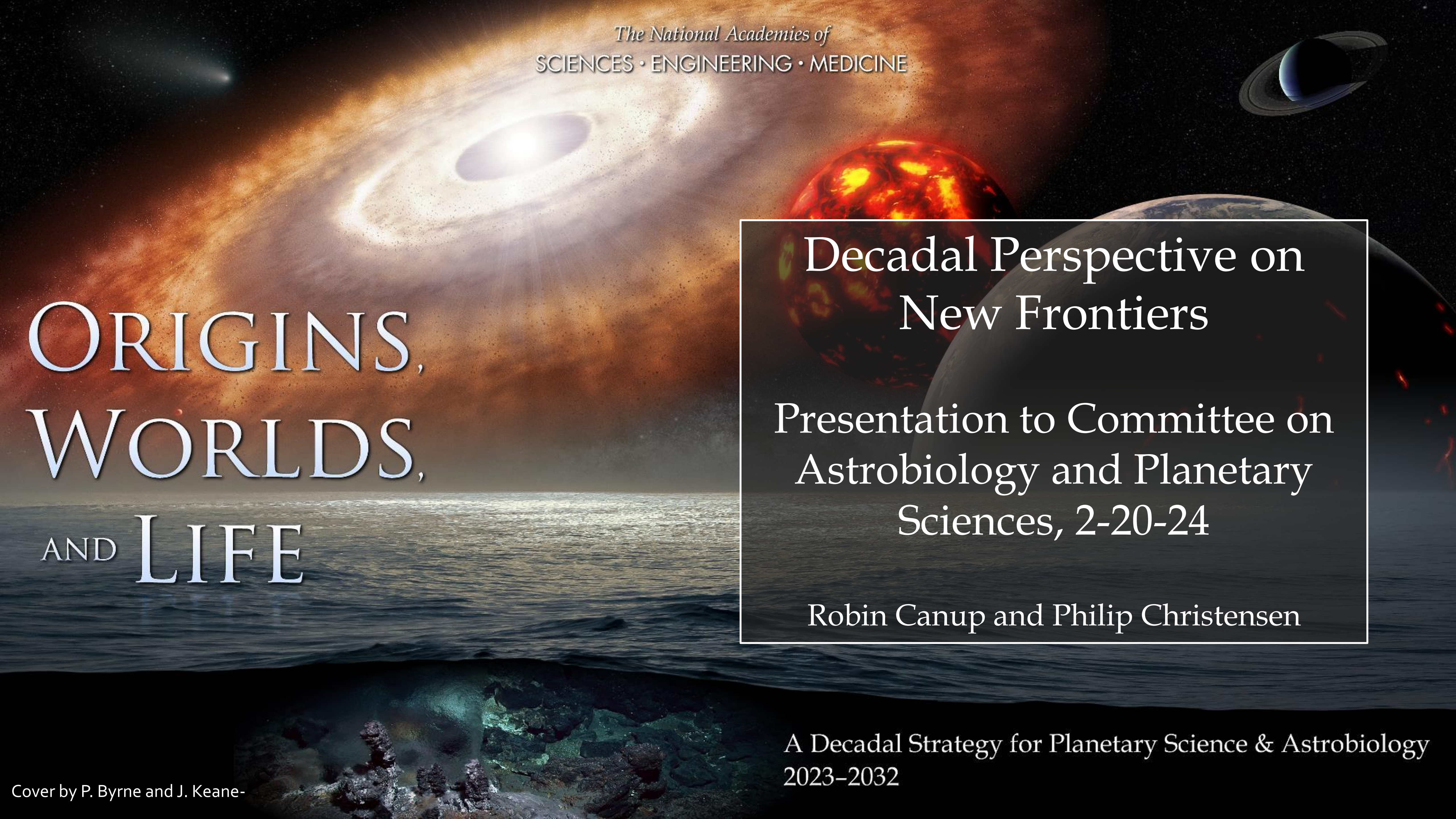
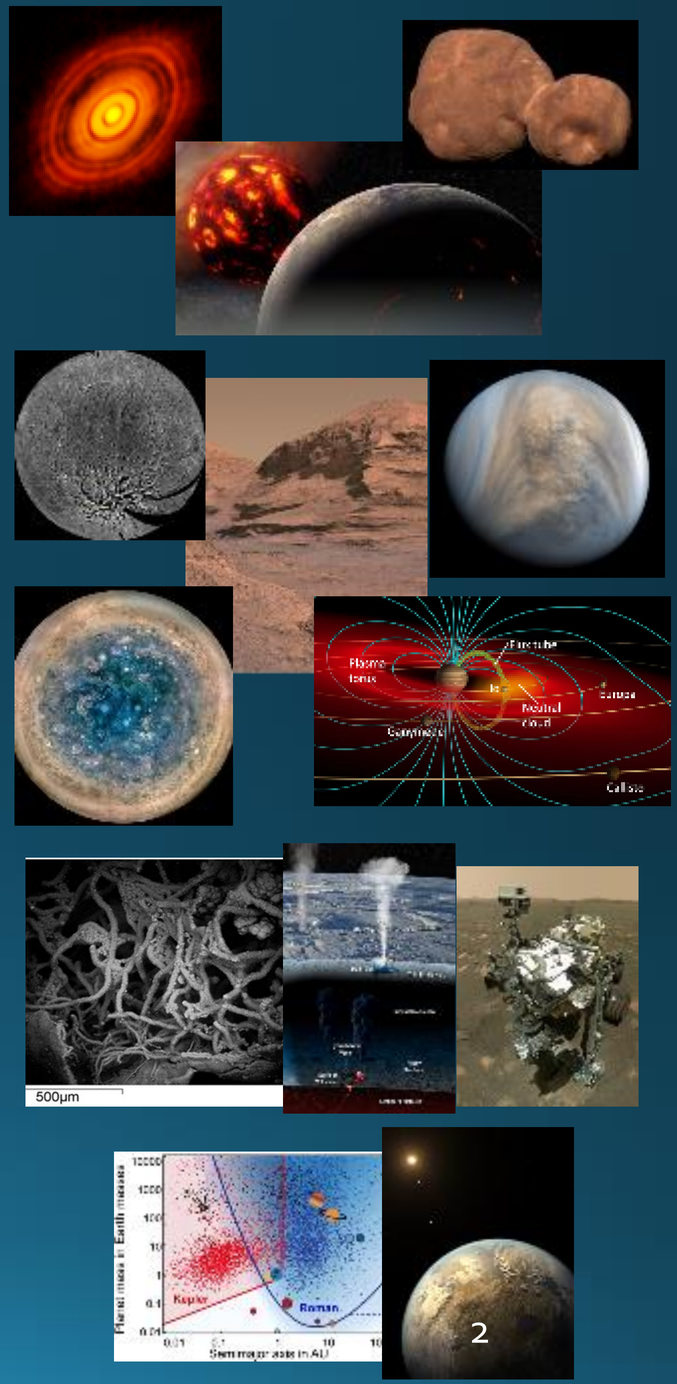


Cover by P. Byrne and J. Keane-

Themes	Priority Science Question Topic and Scope
A) Origins	**Q1. Evolution of the protoplanetary disk** What were the initial conditions in the Solar System? What processes led to the production of planetary building blocks, and what was the nature and evolution of these materials?
	Q2. Accretion in the outer solar system How and when did the giant planets and their satellite systems originate, and did their orbits migrate early in their history? How and when did dwarf planets and cometary bodies orbiting beyond the giant planets form, and how were they affected by the early evolution of the solar system?
	Q3. Origin of Earth and inner solar system bodies How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer Solar System materials incorporated?
B) Worlds & Processes	**Q4. Impacts and dynamics** How has the population of Solar System bodies changed through time, and how has bombardment varied across the Solar System? How have collisions affected the evolution of planetary bodies?
	Q5. Solid body interiors and surfaces How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?
	Q7. Giant planet structure and evolution What processes influence the structure, evolution, and dynamics of giant planet interiors, atmospheres, and magnetospheres?
	Q8. Circumplanetary systems What processes and interactions establish the diverse properties of satellite and ring systems, and how do these systems interact with the host planet and the external environment?
C) Life & Habitability	**Q9. Insights from Terrestrial Life** What conditions and processes led to the emergence and evolution of life on Earth, what is the range of possible metabolisms in the surface, subsurface and/or atmosphere, and how can this inform our understanding of the likelihood of life elsewhere?
	Q10. Dynamic Habitability Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?
	Q11. Search for life elsewhere Is there evidence of past or present life in the solar system beyond Earth and how do we detect it?
All Themes	**Q12. Exoplanets** What does our planetary system and its circumplanetary systems of satellites and rings reveal about exoplanetary systems, and what can circumstellar disks and exoplanetary systems teach us about the solar system?



Science Question Chapters: Key Takeaways

- Crucial role of sample return and in situ analyses
- Dearth of knowledge of the ice giant systems
- Importance of primordial processes to compositional reservoirs, planetary building blocks and primitive bodies, and early solar system dynamical evolution
- Complex interplay of internal and external processes that affect planetary bodies
- Varied evolutionary paths of the terrestrial planets
- Central question of how life on Earth emerged and evolved, and the compelling rationale to study habitable environments at Mars and icy ocean worlds
- Desire to make substantive progress this decade in understanding whether life existed (or exists) elsewhere in the solar system

New Frontiers Program

<u>Cost structure</u>:

- NF-4 had Phase A-D cap of $850M (FY15 $), equivalent to $1.1B in FY25 $
  - Cap excluded Phase E and LV
- NF-5 Draft AO had Phase A-D cap of $900M (FY22 $), equivalent to $980M in FY25 $, PLUS additional $300M for Phase E-F → total cap of ~$1.3B in FY25 $ (not inc. LV)
- Committee carefully deliberated on future NF cost structure, considering:
    - Crucial importance of breakthrough science and access to outer solar system at the potential expense of launch cadence
    - Realistic cost estimates for highly-ranked NF concepts
    - Desire to more clearly anticipate full mission Life Cycle Cost (LCC), both for community awareness and NASA budgetary planning
    - Effects of inflation (*as they were understood at the end of 2021*)

New Frontiers Program Recommendations

- Phase E costs should be included in the cost cap, which should be substantially increased
- To enable access to all targets in the solar system, as well as long trajectories associated with sample return, cap should include an allocation based on the length of the quiet cruise phase

Recommendation:

- **The NF Phase A-F cost cap, exclusive of quiet cruise and launch vehicle costs, should be increased to $1.65 billion in FY25 dollars**
- **A quiet cruise allocation of $30 million per year should be added to this cap, with quiet cruise to include normal cruise instrument checkout and simple flyby measurements, outbound and inbound trajectories for sample return missions, and long transit times between objects for multiple-target missions**

New Frontiers Mission Themes

- Committee considered 13 (potentially) medium class missions it prioritized for TRACE + 6 other missions that underwent independent cost and technical evaluation as part of *Vision & Voyages* (prior Decadal Survey)

- Committee considered number of NF mission themes per call:
  - "Because preparation and evaluation of NF proposals places a substantial burden on the community and NASA, it is important to restrict each NF solicitation to a manageable number of candidate missions" *Vision & Voyages*
  - Only 3 centers can manage NF missions and proposals (APL, GSFC, JPL)
  - NF-4 and draft NF-5 AO had 6 themes each
  - However, strong desire to include new themes prioritized in OWL report

- Prioritized 8 mission themes for NF-6 + 1 additional theme for NF-7

NF-6 Mission Themes* (alphabetical):

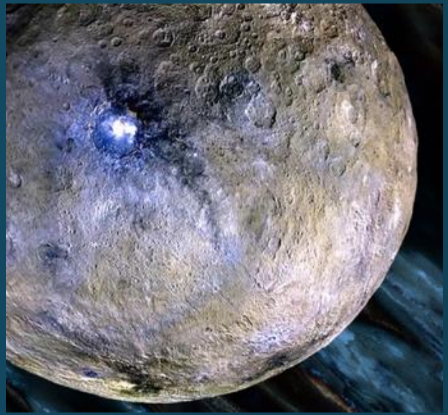
- **Centaur Orbiter and Lander**
- **Ceres sample return**
- Comet surface sample return
- Enceladus multiple flyby
- Lunar Geophysical Network
- Saturn probe
- **Titan orbiter**
- Venus In Situ Explorer

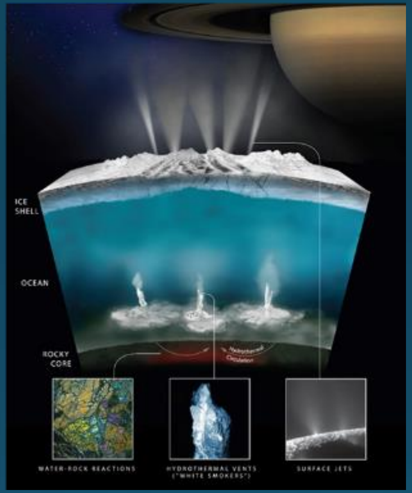
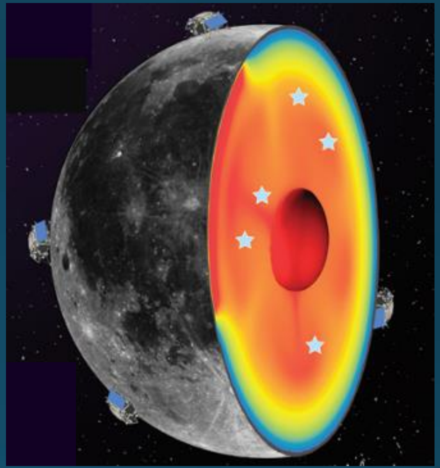
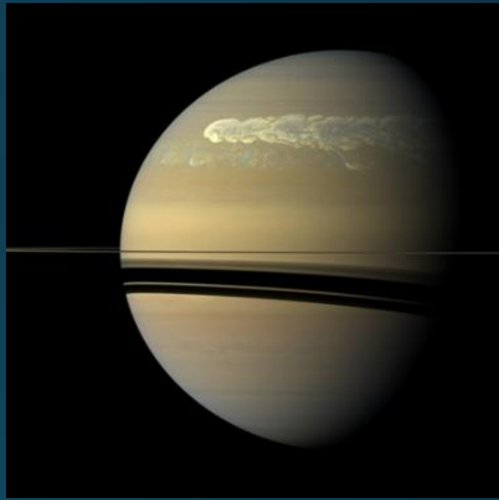
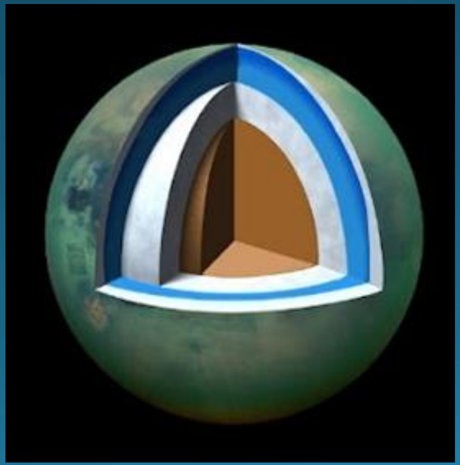
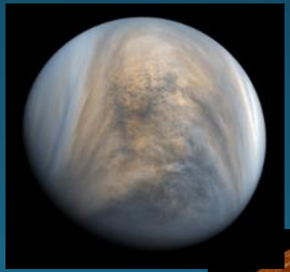
NF-7: All non-selected from NF-6 plus

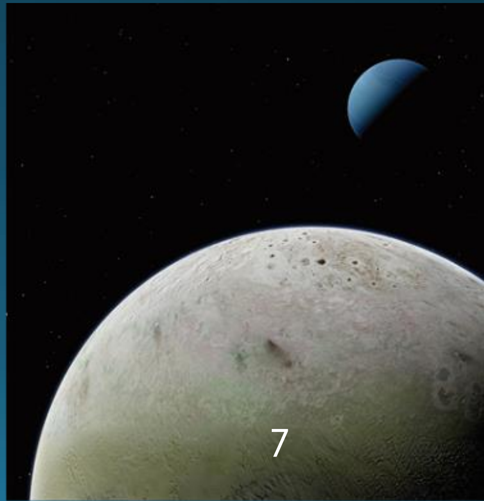
- **Triton Ocean World Surveyor**

Yellow: new mission themes in OWL

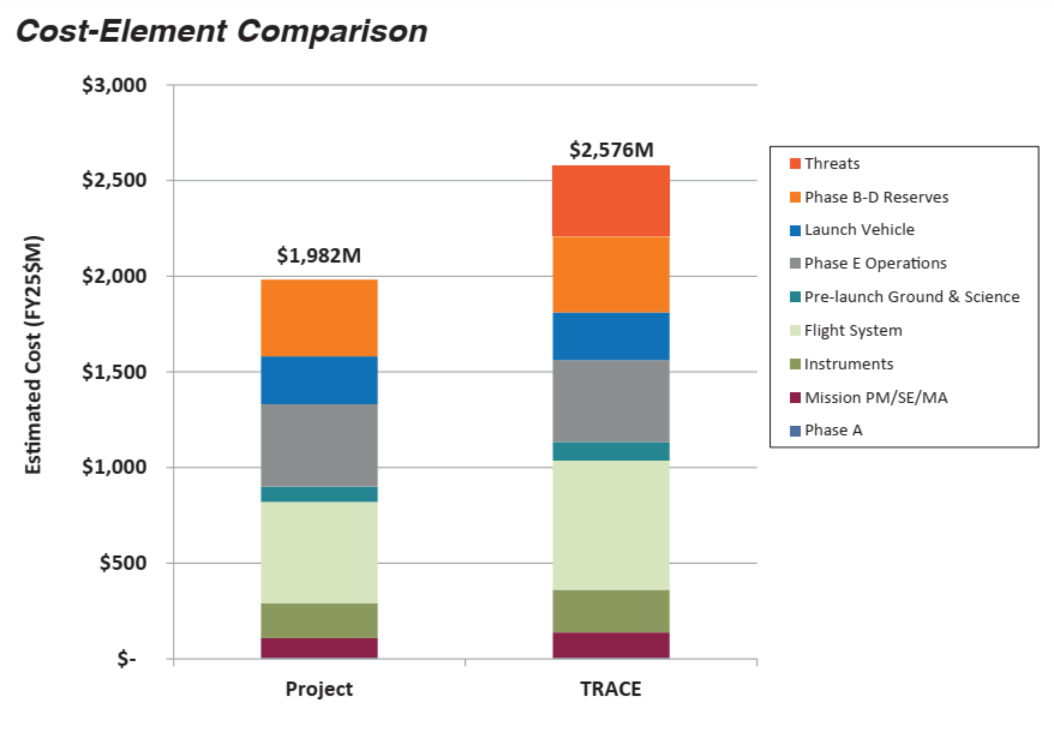
***Theme descriptions found in backup slides & in Chapter 22 of OWL Report**



Centaur Orbiter & Lander (CORAL)

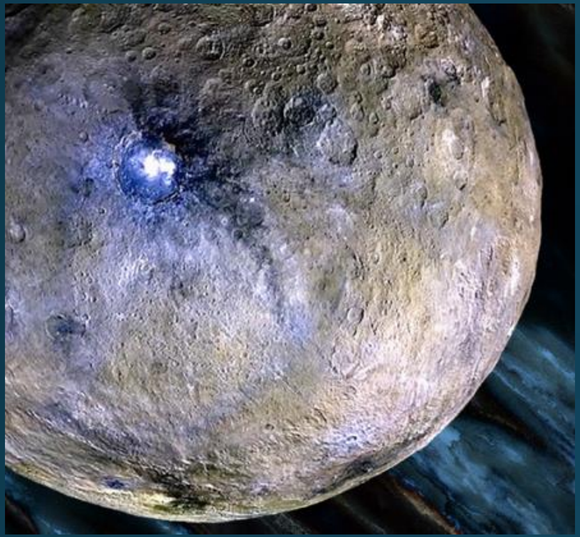


Investigate physical + chemical properties of a Centaur from orbit and in situ, exploring one of a population of dynamically evolved but compositionally primitive small icy bodies from the Kuiper Belt that currently reside between Jupiter and Neptune. Constrain the nature of ice-rich planetesimals and compositional reservoirs in the protoplanetary disk.

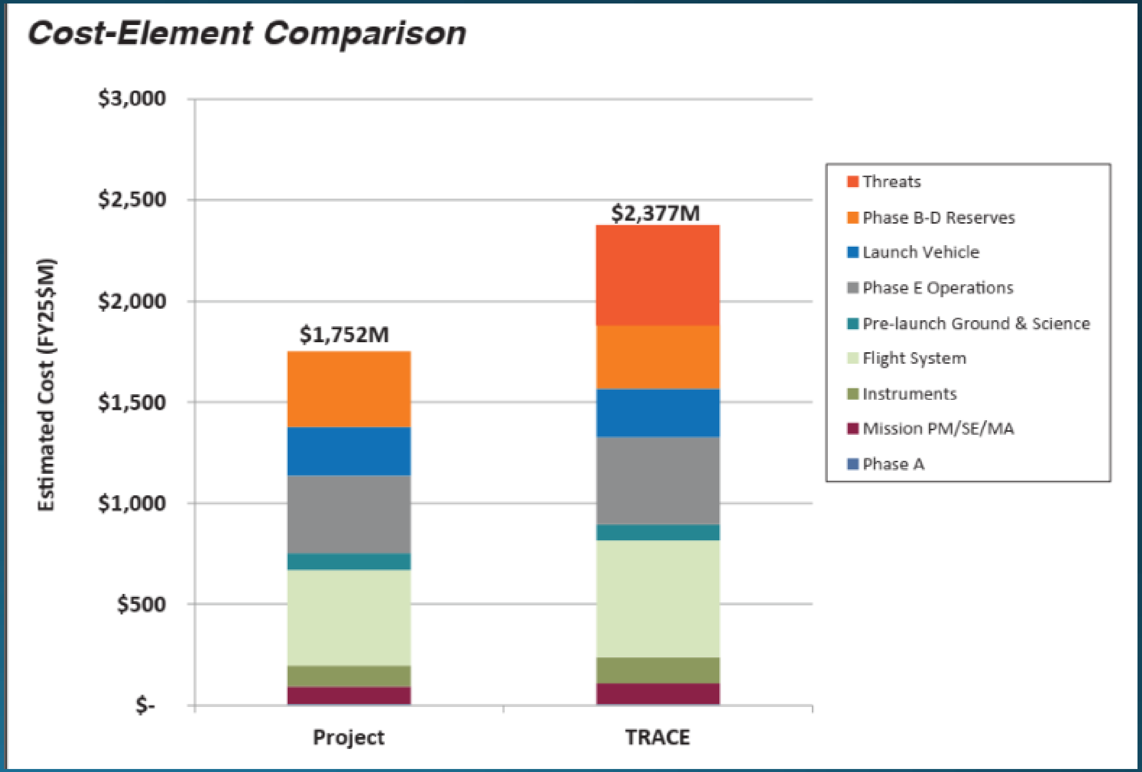
Highest TRACE cost of prioritized NF missions

Ceres Sample Return

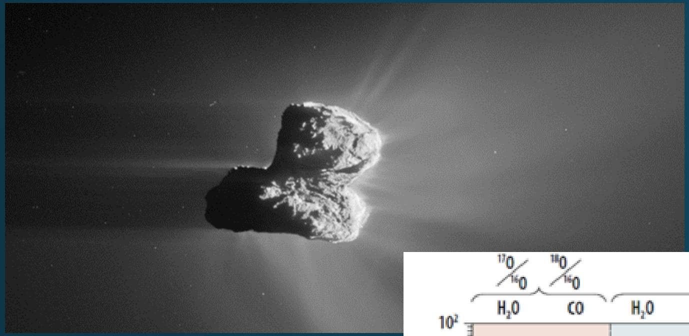
- Received a “Medium” risk rating from TRACE (all other prioritized themes received a “Medium-Low” rating)
- Second highest TRACE cost

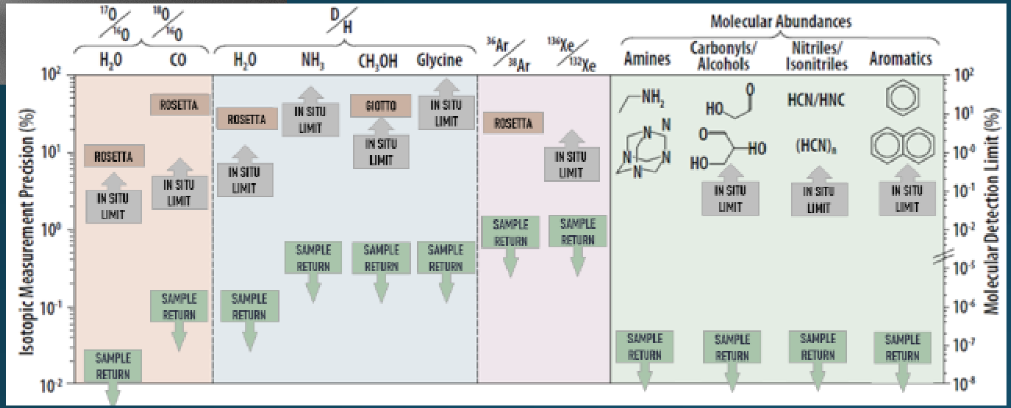


Quantify accretional conditions and habitability of a dwarf planet and the most ice-rich body in the inner solar system through orbital, in situ, and sample return investigations. Samples to include young carbonate salt deposits (e.g., from Occator crater) and some of Ceres’ typical dark materials.



Comet Surface Sample Return (CSSR)

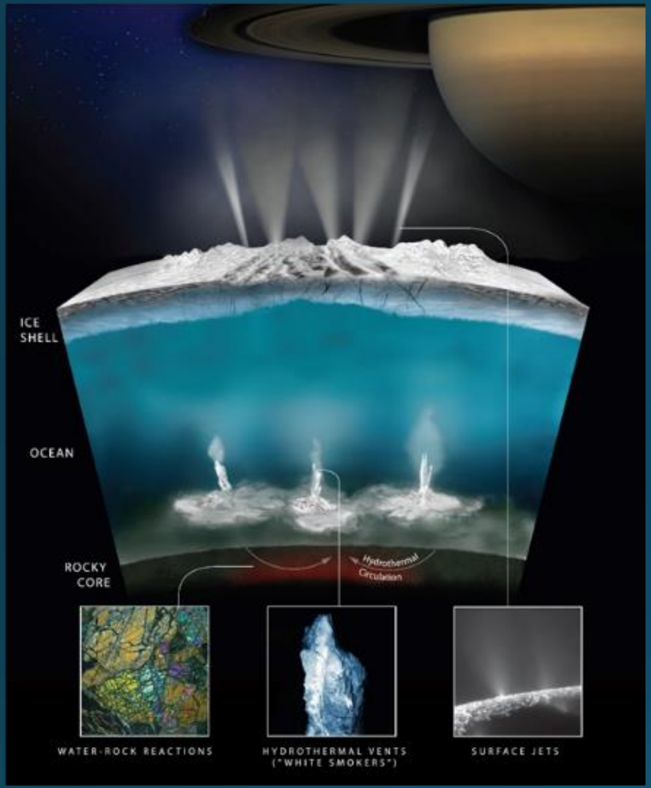




Map comet nucleus and return sample to Earth for detailed analyses to understand comet formation and activity, primordial mixing in solar nebula, and role of comets in delivery of water and organics to Earth. Will include volatile characterization and sample processing to preserve organics and prevent aqueous alteration.

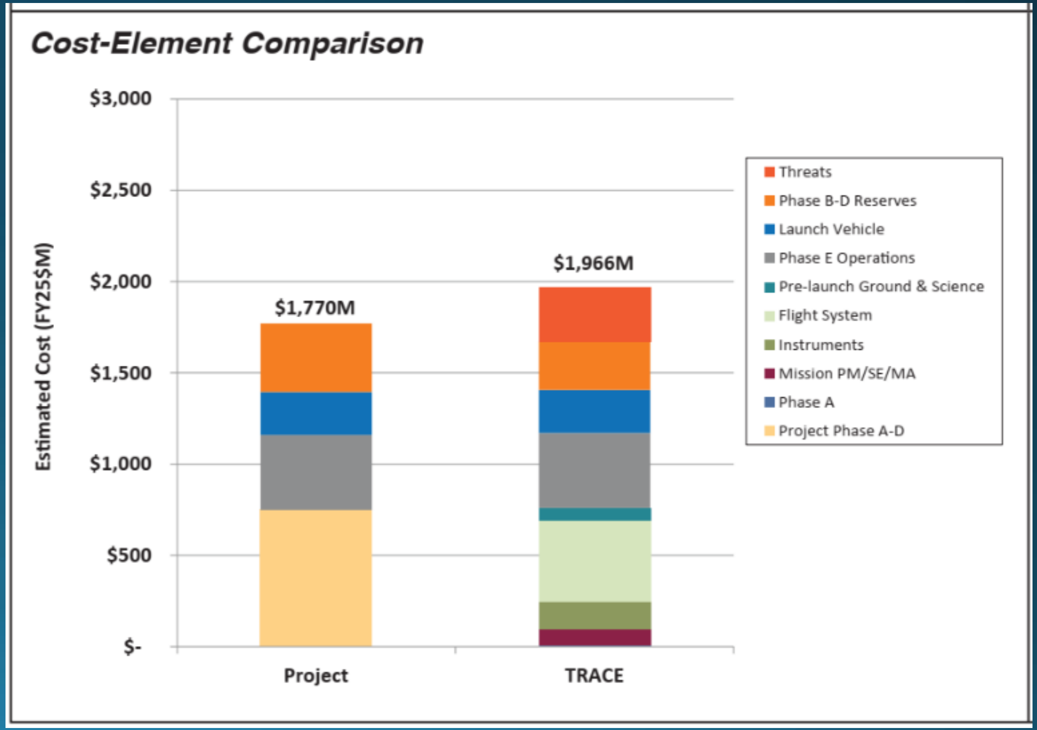
- Competed in NF-4 (and reached Phase A) and was to be in NF-5
- Cost assessed by prior Decadal, so no new TRACE conducted as part of OWL Report

Enceladus Multiple Flyby

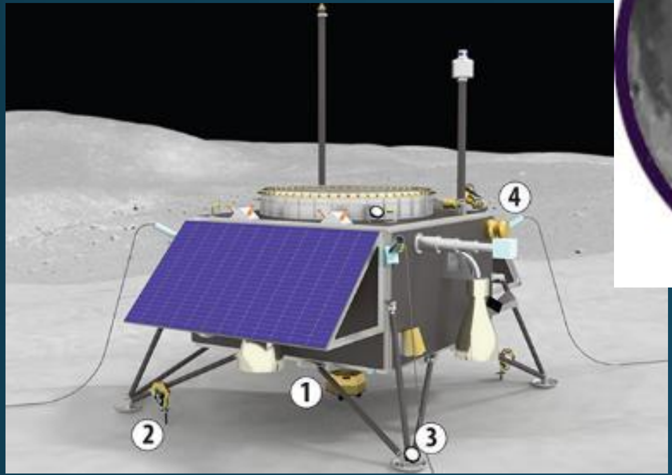


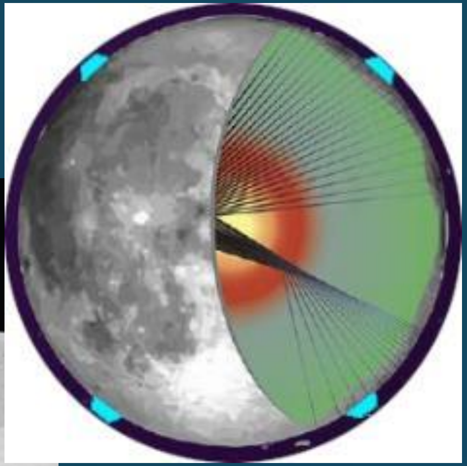
Characterize habitability and look for evidence of life via analysis of fresh plume material sampled at low velocity (< 4 km/s) to preserve large organic molecules and with sample volume > 1 μl.

- Oceans Worlds theme in NF-4 (Dragonfly selected); Ocean Worlds—Enceladus theme was to be in NF-5
- Was added mid-decade by CAPS, and so TRACE performed as part of OWL Decadal



Lunar Geophysical Network

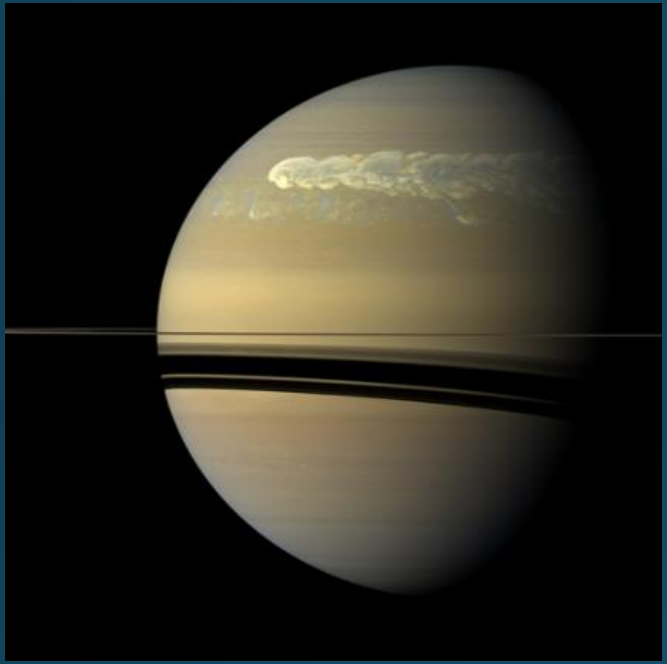




- Was not on NF-4 list; per V&V, was to be added to NF-5 list
- Cost assessed by prior Decadal, and so no new TRACE conducted as part of OWL report

Examine Moon with a global, long-lived (≥ 6 yr) network of geophysical instruments on surface to constrain geological processes, bulk composition, distribution of heat-producing elements, and Moon's interior state and thermal evolution.

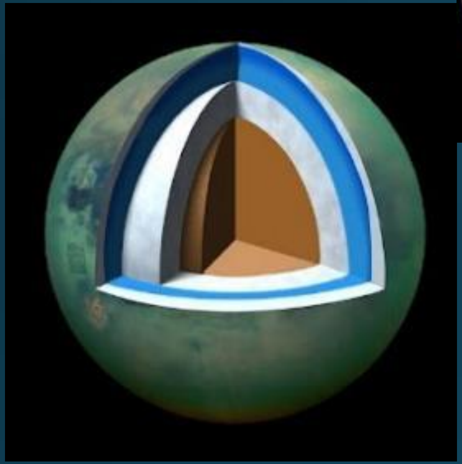
Saturn Probe

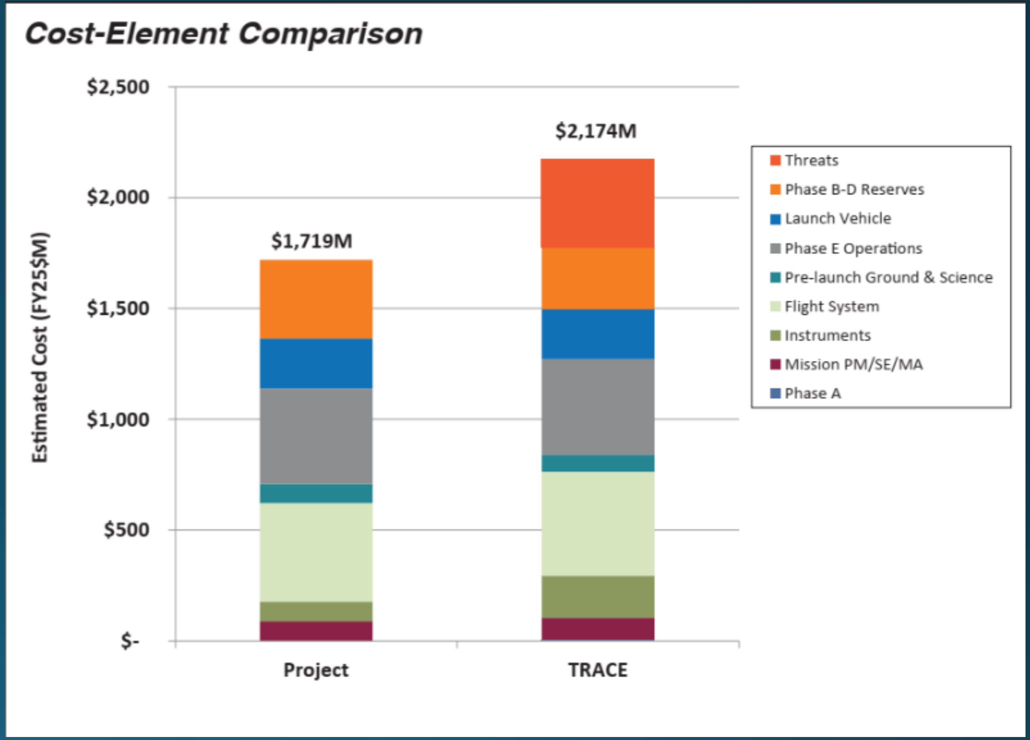


Obtain in situ measurements of Saturn's atmosphere from an entry probe to understand conditions in the protosolar nebula, constrain giant planet formation mechanisms including when and where Saturn formed, and study what governs the diversity of giant planet climates, circulations, and meteorology.

- Same theme competed in NF-4 and was to be in NF-5
- Cost assessed by prior Decadal Survey, so no new TRACE conducted as part of recent Decadal Survey

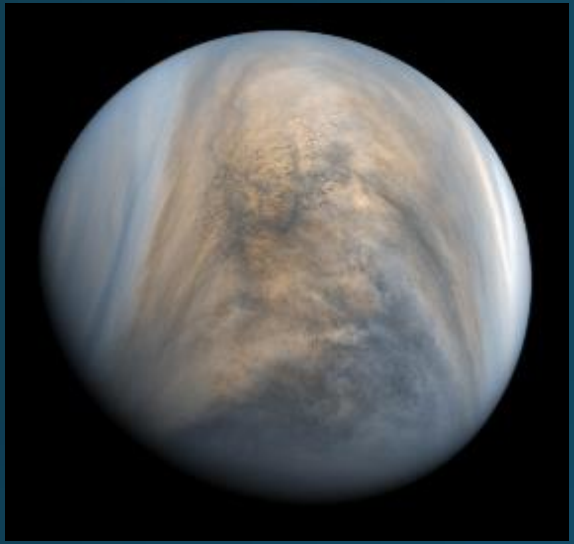
Titan Orbiter





Characterize Titan's internal structure (including its ice shell and subsurface ocean), dense N_2 atmosphere, and methane hydrological cycle and seas to assess its potential habitability and prebiotic chemistry relevant to the early Earth. Global-scale studies are complementary to several 100s of km to be explored by Dragonfly.

Venus In Situ Explorer

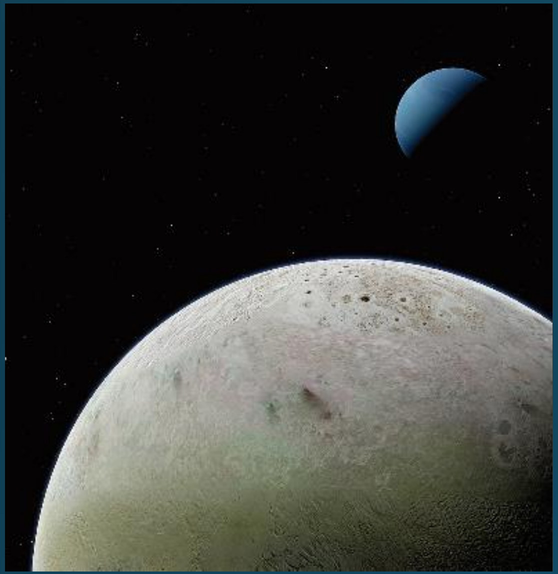


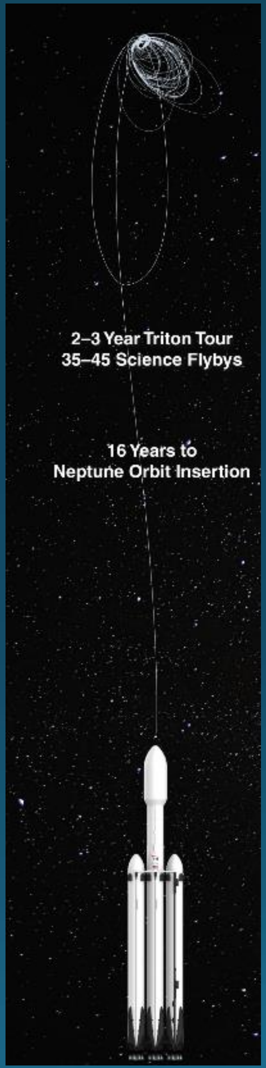
- VISE Competed in NF-4, was removed from NF-5 list after selection of Davinci & Veritas
- Cost assessed by prior Decadal, so no new TRACE conducted as part of OWL report

Investigate processes and properties that cannot be characterized from orbit or from a single descent profile – e.g., global, complex atmospheric cycles, surface-atmosphere interactions, and surface properties – to provide breakthrough understanding on the origin and evolution of terrestrial planets.

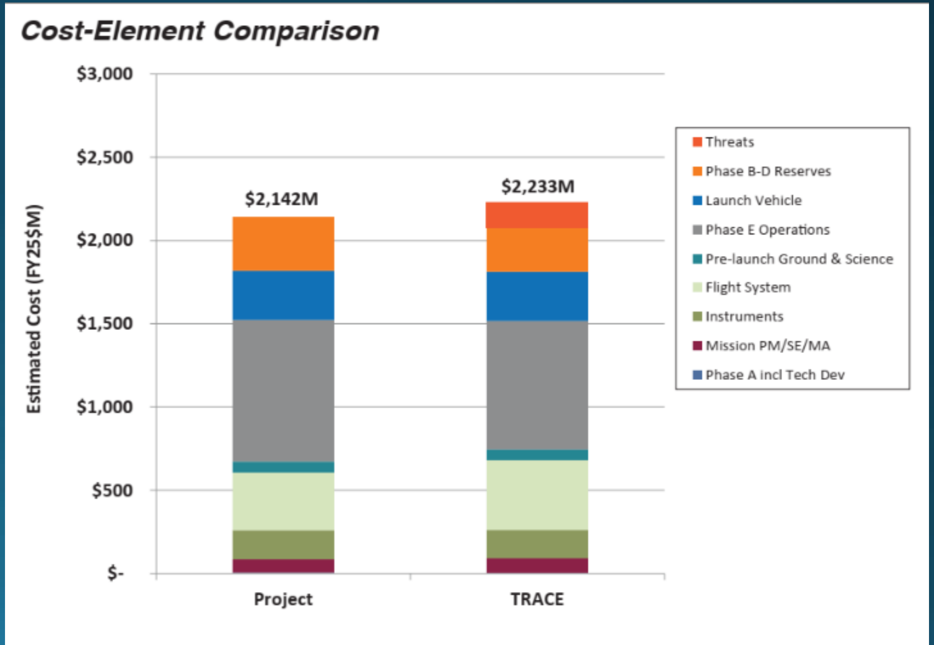
Triton Ocean World Surveyor

- Feasible on Falcon Heavy by focusing on Triton and streamlined payload
- Launch date in early 2040s for JGA → NF-7 designation





Utilize a Neptune-orbiter to complete numerous flybys of Triton, a captured Kuiper Belt Object that has a geologically young surface and active geysers, and is a potential ocean world. Characterize internal structure, geology and composition, moon-magnetospheric interactions, and atmospheric properties and variability.



Cost estimates for new mission themes

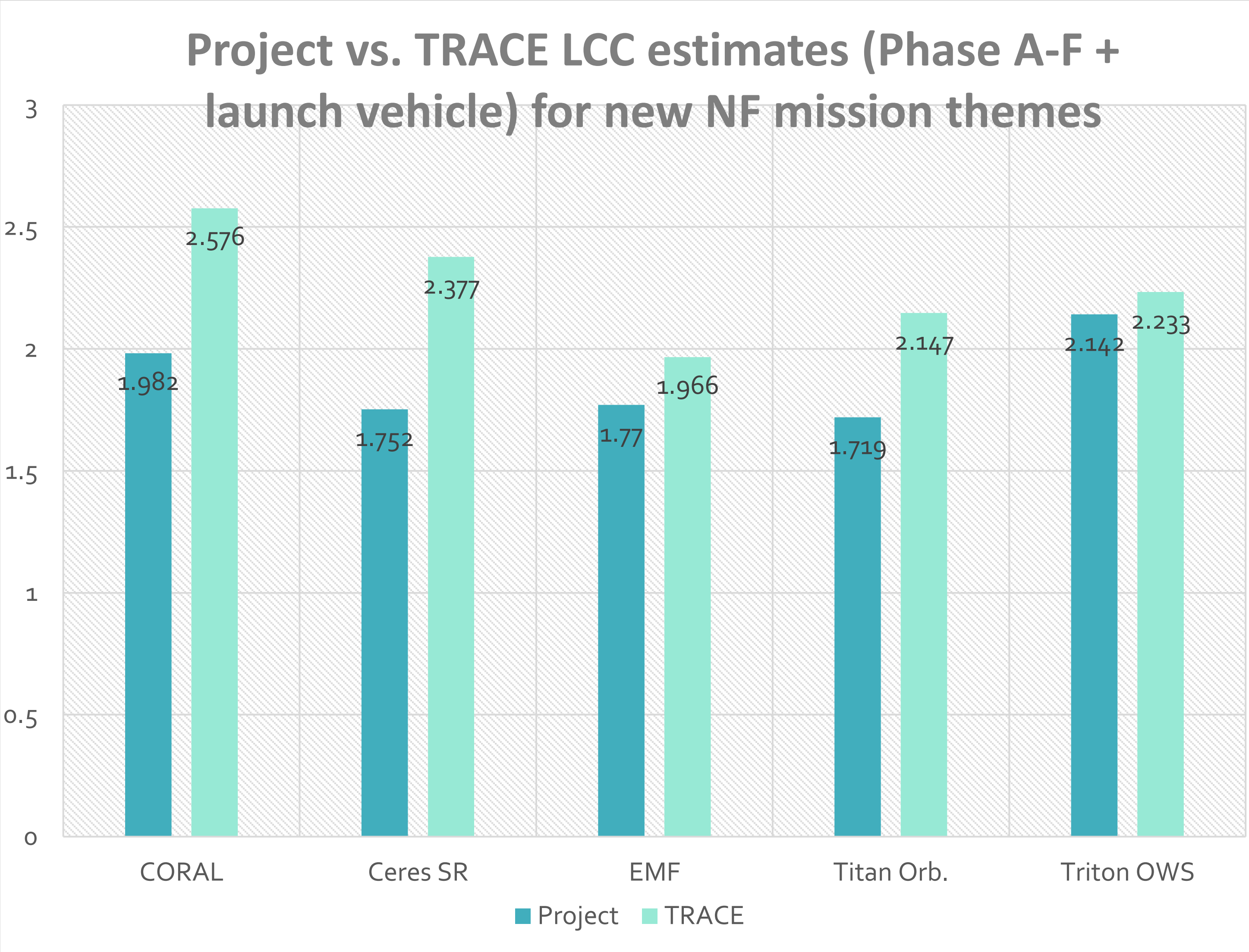
- OWL Report considered both project advocate and TRACE results in establishing recommendations for NF-6 cost cap
- Considered that clever teams could develop ways to optimize mission and reduce costs relative to TRACE estimates
- But recognized that TRACE-type estimates historically better predict final life cycle costs (LCC) than original advocate estimates

OWL Rec. Cost Cap:

- $1.65B cost cap, A-F
- + $30M/yr quiet cruise

Example mission with this cap:

- $1.65 A-F
- $250M LV
- 5 yr quiet cruise = $150 M
- LCC = $2.05B



LCC = Life Cycle Cost = Total mission cost including Phases A – F and launch vehicle (LV)

OWL discussion of NF-5 themes removed from NF-6 list

1) South Pole Aitken sample return

- Competed (unsuccessfully) in NF-2, NF-3, and NF-4
- Challenging to guarantee transformative science would be accomplished by samples found in only one landing location
- Endurance-A farside sample return campaign seen as scientifically superior approach for similar mission cost to SMD
    - Prioritized by OWL Report as strategic LDEP-led mission to be implemented as a collaborative effort between SMD and Artemis program

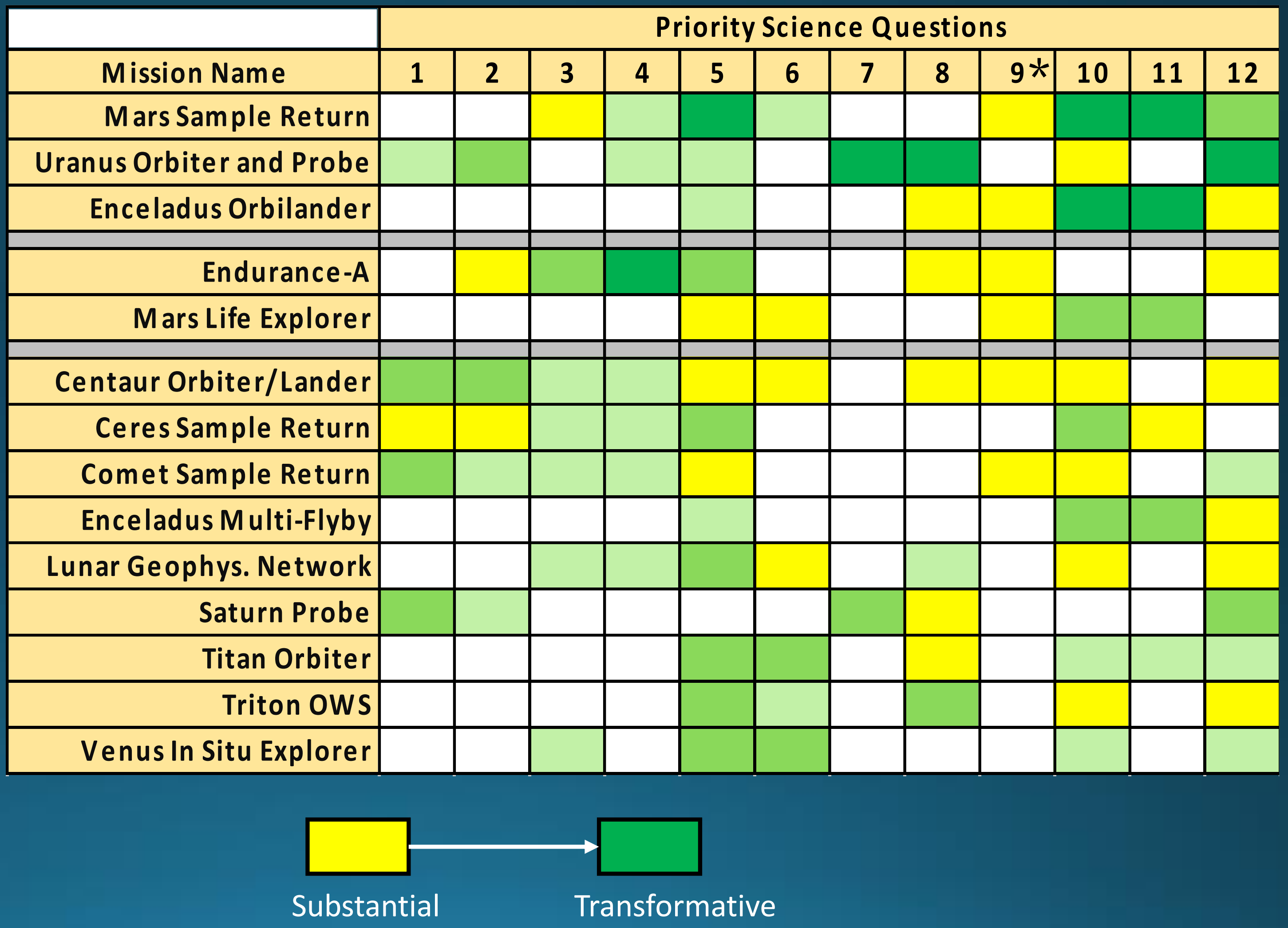
OWL discussion of NF-5 themes removed from NF-6 list

1) **South Pole Aitken sample return**

2) **Io Observer**
   - Committee reaffirmed importance of Io as a unique body for understanding active volcanic, tectonic, and plasma processes, and for providing analog to exoplanets and young terrestrial planets
   - Phase A selection of IVO showed feasibility of accomplishing fundamental Io science in Discovery. This caused it to be judged a lower priority than missions that clearly require NF.
   - CAPS 2020 report: If IVO was selected, inclusion of Io Observer in NF-5 would be redundant and "merit reconsideration"
   - IVO was not selected, and OWL committee anticipated that it would have opportunity to compete in NF-5

Traceability of recommended missions to science objectives

Themes	Priority Science Question Topic
A) Origins	Q1. Evolution of the protoplanetary disk Q2. Accretion in the outer solar system Q3. Origin of Earth and inner solar system bodies
B) Worlds & Processes	Q4. Impacts and dynamics Q5. Solid body interiors and surfaces Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution Q7. Giant planet structure and evolution Q8. Circumplanetary systems
C) Life & Habitability	Q9. Insights from Terrestrial Life Q10. Dynamic Habitability Q11. Search for life elsewhere
All Themes	Q12. Exoplanets



Backup

Theme Description from OWL Report

CORAL investigates a Centaur from orbit and in situ, exploring one of a population of dynamically evolved but compositionally primitive small icy bodies from the Kuiper belt that currently reside between Jupiter and Neptune. The proximity of Centaurs provides an opportunity to conduct a comprehensive study of the geochemical and physical properties of primordial ice-rich planetesimals, which trace the composition of nebular volatiles such as H_2O, CO_2, CO, and NH_3, revealing the nature of early solar system compositional reservoirs. The mission will map the surface and measure the ices and organics in situ.[15]

Science Objectives:

- Determine the chemical and physical properties of a Centaur to understand the nature of primitive planetesimals.
- Perform in situ elemental, isotopic, and organic analyses of a Centaur to develop a comprehensive understanding of the composition and initial conditions of the protoplanetary disk.
- Determine the shape, topography, geological landforms, and density of a Centaur to understand the evolutionary history of this population of objects.
- Determine degree of aqueous alteration on a Centaur to investigate the biologic potential of icy planetesimals and potential brine reservoirs.

The mission shall address all four objectives.

Theme Description from OWL Report

Ceres Sample Return focuses on quantifying Ceres's current habitability potential and its origin, which is important for understanding habitability of mid-sized planetary bodies. Habitability is addressed through orbital and in situ investigation of the surface and subsurface environment around a hypothesized brine extrusion zone and via detailed compositional investigations in Earth labs of a returned samples. These samples will be collected from young carbonate salt deposits, typified by those identified by the Dawn mission at Occator crater, as well as some of Ceres's typical dark materials. A sample of adequate mass to achieve the science objectives, acquired in pristine condition and returned at a temperature of lower than −20°C to prevent alteration, would allow investigations of the origin and evolution of Ceres's organic matter, its brine chemistry and sources, and its accretional environment.

Science Objectives:

- Characterize the depth and extent of potential deep brine layer(s) to determine whether liquid exists beneath Ceres today near hypothesized brine extrusion zones.
- Characterize the nature of Ceres's brines from salt deposits to determine the chemistry of waters and their potential habitability.
- Determine the composition, structure, and isotopic composition of Ceres's organics to understand processes of abiotic organic synthesis and evolution.
- Determine the elemental abundances and isotopic ratios of Ceres's materials via measurements on returned samples to determine its accretional environment.

The mission shall address all four objectives.

The **Comet Surface Sample Return** mission theme is focused on acquiring and returning to Earth a macroscopic sample from the surface of a comet nucleus using a sampling technique that preserves organic material in the sample. The mission theme would also use additional instrumentation on the spacecraft to determine the geologic and geomorphologic context of the sampled region. Because of the increasingly blurred distinction between comets and the most primitive asteroids, many important objectives of an asteroid sample return mission could also be accomplished by this mission. The science objectives (listed without priority) of this mission theme are:

- Acquire and return to Earth for laboratory analysis a macroscopic comet nucleus surface sample;
- Characterize the surface region sampled; and
- Preserve sample complex organics.

Prior: NF-5 Draft AO

New: OWL Report

Comet Surface Sample Return seeks to understand the nature of cometary formation and mixing of materials in the protosolar nebula; compositional reservoirs present in the early solar system; the role of comets in the delivery of water and organic molecules to the early Earth, terrestrial planets and satellites; and evolutionary processes spanning from the protoplanetary disk to current cometary activity. The mission will map the nucleus of a Jupiter family comet, select an optimal sampling site, and acquire a sample from the surface for return to Earth for laboratory analysis. The sample will be acquired and transported in a manner that preserves organics and prevents aqueous alteration of the sample. Volatile material will be characterized via onboard analysis and/or by capture and return at noncryogenic temperatures.

Science Objectives:

- Determine the elemental, isotopic, and structural composition of the organic and inorganic components of a comet nucleus to understand early compositional reservoirs.
- Sample, preserve, and analyze cometary organic material to determine how complex organic molecules form and evolve in interstellar, nebular, and planetary environments.
- Determine the isotopic composition of cometary water to address the role of comets in delivering volatiles to Earth's atmosphere and interior.
- Determine if cometary organic matter contributed significantly to prebiotic chemistry and homochirality of life on Earth.

The mission shall address all four objectives.

OWL Report specifies study of volatiles & isotopic composition of water with onboard analysis and/or by return at noncryogenic temperatures

Prior: From NF-5 Draft AO

The **Ocean Worlds** mission theme is focused on the search for signs of extant life and/or characterizing the potential habitability of Enceladus. For Enceladus, the science objectives (listed without priority) of this mission theme are:

- Assess the habitability of Enceladus' ocean; and
- Search for signs of biosignatures and/or evidence of extant life.

New: From OWL Report

Enceladus Multiple Flyby seeks to characterize Enceladus's habitability and look for evidence of life via multiple flybys and analysis of plume material. Enceladus, an active icy moon with a subsurface ocean in a relatively benign radiation environment, provides the best opportunity to directly sample a potential habitable subsurface ocean. Prior Cassini observations demonstrate the presence of alkali and carbonate salts and complex organic molecules in plume icy grains; gas-phase nitrogen- and oxygen-bearing as well as aliphatic and aromatic organic molecules; redox couples (e.g., H_2 and CO_2), habitable temperature, salinity, and pH; alkaline hydrothermal activity; and water–rock reactions. However, Cassini flyby velocities were high, leading to fragmentation of large compounds, and ambiguity as to the precise identity of the parent organic molecules.[16]

Science Objectives:

- Search for and identify complex organic molecules in Enceladus plume materials, with velocities <4 km/s and sample volume >1 µl with appropriate contamination control to enable life-detection investigations.
- Determine the composition, energy sources, and physicochemical conditions of Enceladus's ocean to assess its habitability.
- Characterize Enceladus's cryovolcanic activity to determine spatial and compositional variations in plume activity and the processes causing ocean material ejection and modification.

The mission shall address all three objectives.

- OWL Report has increased emphasis on life detection
- Specifies fly-through velocity and minimum sample mass

Prior: NF-5 Draft AO

The **Lunar Geophysical Network** mission theme has an overarching goal to enhance knowledge of the lunar interior derived from detailed study of lunar seismic activity and internal structure. The science objectives (listed without priority) of this mission theme are:

- Determine the lateral variations, the structure, mineralogy, composition, and temperature of the lunar crust and upper mantle, the nature of the lower mantle, and the size, state, and composition of a lunar core to understand the formation of both primary and secondary crusts on terrestrial planets;
- Determine the distribution and origin of lunar seismic activity. Understanding the distribution and origin of both shallow and deep moonquakes will provide insights into the current dynamics of the lunar interior and its interplay with external phenomena (e.g., tidal interactions with Earth);
- Determine the global heat-flow budget for the Moon and the distribution of heat-producing elements in the crust and mantle in order to better constrain the thermal evolution of our only natural satellite;
- Determine the size of structural components (e.g., crust, mantle, and core) making up the interior of the Moon, including their composition and compositional variations to estimate bulk lunar composition and how they relate to that of Earth and other terrestrial planets, how the Earth-Moon system was formed, and how planetary compositions are related to nebular condensation and accretion processes; and
- Determine the nature and the origin of the lunar crustal magnetic field to probe the thermal evolution of the lunar crust, mantle, and core, as well as the physics of magnetization and demagnetization processes in large basin-forming impacts.

New: OWL Report

Lunar Geophysical Network examines the physical properties of the present-day Moon by deploying a global, long-lived (≥6 years) network of geophysical instruments on its surface. Although all large terrestrial bodies are thought to form cores, mantles, and primordial crusts through solidification of magma oceans, the Moon retains the most faithful record of the nature of this process. LGN will reveal the nature and evolution of the lunar interior and facilitate understanding of the initial solidification and primordial geologic processes that have shaped all terrestrial bodies. These measurements (e.g., seismic, heat flow, laser ranging, and magnetic-field/electromagnetic sounding) will allow the bulk composition of the Moon to be calculated, elucidate the dynamical processes that are active during the early history of terrestrial planets, provide new constraints on the collision process that generated our unique Earth-Moon system, and illuminate processes currently active on the Moon.

Science objectives:

- Determine the internal structure and size of the crust, mantle, and core to constrain the composition, mineralogy, and lithologic variability of the Moon.
- Determine the distribution and origin of lunar seismic activity in order to better understand the origin of moonquakes and provide insights into the current dynamics of the lunar interior and the interplay with external phenomena such as tidal interactions with Earth.
- Determine the global heat-flow budget for the Moon in order to constrain more precisely the distribution of heat-producing elements in the crust and mantle, the origin and nature of the Moon's asymmetry, its thermal evolution, and the extent it was initially melted.

The mission shall address all three objectives.

- OWL report recognized prospects for individual, short-lived geophysical packages via CLPS/PRISM
- New LGN theme emphasizes need for multiple, long-lived packages (\ge 6 yr) operating simultaneously
- OWL Report expressed support for CLPS program, and noted that that successful delivery to lunar surface had yet to be demonstrated

Prior: NF-5 Draft AO

The **Saturn Probe** mission theme is intended to deploy one or more probes into Saturn's atmosphere to directly determine the structure of the atmosphere as well as noble gas abundances and isotopic ratios of hydrogen, carbon, nitrogen, and oxygen. The science objectives (listed without priority) of this mission theme are:

- Determine noble gas abundances and isotopic ratios of hydrogen, carbon, nitrogen, and oxygen in Saturn's atmosphere; and
- Determine the atmospheric structure at the probe descent location.

New: OWL Report

Saturn Probe obtains in situ measurements of the atmosphere from an entry probe. Understanding the initial conditions in the protosolar nebula requires measurements of each of the giant planets' elemental and isotopic compositions. Constraining giant planet formation mechanisms is particularly dependent on knowing when and where Saturn formed, over how long, and if its orbit has migrated over time to stop Jupiter's inward movement. Noble gas abundances are also crucial for determining if helium rain has prolonged Saturn's thermal evolution. Additionally, comparisons of what governs the diversity of giant planet climates, circulation, and meteorology require constraints on the vertical temperature and wind profiles, as well as vertical circulation. Although some measurements may be obtained via remote sensing, many of the science objectives require in situ sampling.

Science Objectives:

- Determine the in situ noble gas, elemental, and isotopic abundances to understand conditions in the protosolar nebula, as well as constrain Saturn's formation, evolution, and migration.
- Determine the in situ tropospheric temperature-pressure profile to quantify Saturn's heat transport and convective stability.
- Determine the in situ vertical wind shear to characterize Saturn's tropospheric circulation and meteorology.
- Constrain vertical mixing in Saturn's troposphere to bound transport from the deeper interior

The mission shall address all four objectives.

Broadly similar theme language, with some science updates and additional details

Theme Description from OWL Report

Titan Orbiter globally characterizes Titan's dense N_2 atmosphere that harbors prebiotic molecules, its Earth-like methane hydrological cycle and seas, and its subsurface liquid water ocean, including how they evolve over time, in order to assess Titan's potential habitability. Cassini flybys revealed complex organic chemistry, methane-ethane lakes and seas, and meteorology on Titan; however, these processes could not be thoroughly studied owing to instrumentation and flyby coverage limitations. Titan orbiter will investigate how the organic chemical factory on Titan works, both in the atmosphere and on the surface, providing important context for data from Dragonfly and complementary global measurements.[17]

Science Objectives:

- Determine Titan's internal structure, the depth and thickness of the ice shell and subsurface ocean, and whether the former is convecting; and determine rates of interior-surface solid or gas interchange.
- Characterize Titan's global geology and its landscape-shaping processes.
- Characterize Titan's global methane hydrological and sedimentological system, including surface transport/flow rates and cloud distributions.
- Quantify the production, transport and fate of organic molecules in Titan's upper atmosphere and atmospheric and climate evolution in general.

The mission shall address all four objectives.

- OWL report cited CAPS 2020 report: "With the selection of Dragonfly in the NF-4 competition…reconsideration by NASA of including a Titan mission in the NF-5 call … is warranted on programmatic grounds and removing Titan from the list… would be appropriate."
- OWL committee evaluated this and concluded that Titan Orbiter provides important and complementary science to Dragonfly and prioritized it for the NF-6 list
- Assumed that Titan would not be included in NF-5 list in making this prioritization

Theme Description from OWL Report

Venus In Situ Explorer (VISE) investigates the processes and properties of Venus that cannot be characterized from orbit or from a single descent profile. These include (1) complex atmospheric cycles (e.g., radiative balance; chemical cycles, atmospheric dynamics, variations of trace gases, light stable isotopes, and noble gas isotopes, and the couplings between these processes); (2) surface–atmosphere interactions (e.g., physical and chemical weathering at the surface, near-surface atmospheric dynamics, and effects upon the atmosphere by any ongoing geological activity); and (3) surface properties (e.g., elemental and mineralogical composition of surface materials, heat flow, seismic activity, and any magnetization). VISE will provide breakthrough information on the origin of the terrestrial planets, the evolution of their interiors and surfaces, atmospheric evolution and climate, and critical insights into the nature and habitability of exoplanets.

Science objectives:

- Characterize past or present large-scale spatial and temporal (global, longitudinal and/or diurnal) processes within Venus's atmosphere.
- Investigate past or present surface–atmosphere interactions at Venus.
- Establish past or present physical and chemical properties of the Venus surface and/or interior.

The mission shall address at least two of these three objectives.

- OWL Report recognized recent selections of Davinci, Veritas, and EnVision.
- VISE theme emphasizes complementary science involving surface/near-surface and global processes
- Committee assumed VISE would not compete in NF-5 in making this prioritization

Theme Description from OWL Report

Triton Ocean World Surveyor orbits Neptune and performs multiple flybys of its largest and retrograde orbiting satellite, Triton. Triton is likely a captured KBO and a candidate ocean world with a geologically young surface and active geysers. It has a hazy atmosphere like Pluto's and a uniquely strong ionosphere.

Proposed Science Objectives:

- Determine whether Triton is an ocean world, ascertain its interior structure, and decide whether Triton's ice shell is in hydrostatic equilibrium and decoupled from the interior.
- Characterize Triton's surface composition and geology, and look for changes, including plumes and their composition.
- Determine the nature of the moon–magnetosphere interaction at Triton.
- Determine the composition, density, temperature, pressure, and spatial/temporal variability of Triton's atmosphere.

The mission shall address all four objectives.

The recommendation that Triton Ocean World Surveyor be delayed until NF-7 took into consideration launch trajectories, which benefit from a Jupiter gravity assist likely available in the NF-7 timeframe.

Getting to Triton at NF level requires JGA for current launch vehicles; next feasible date for JGA is ~ 2041