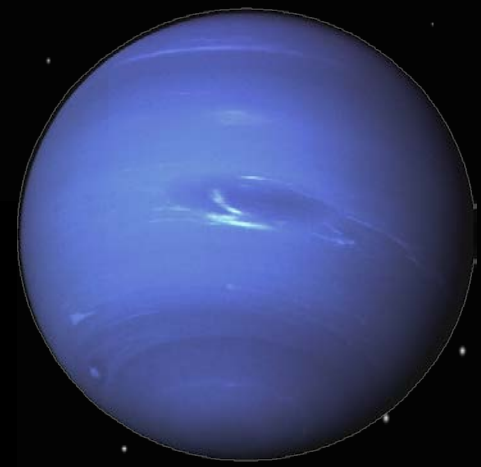
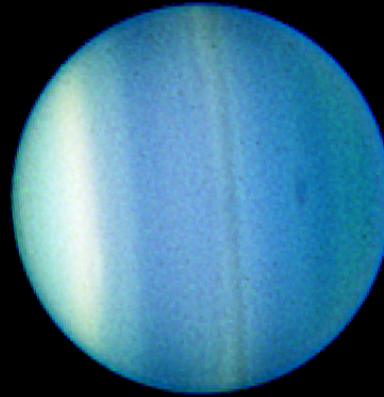
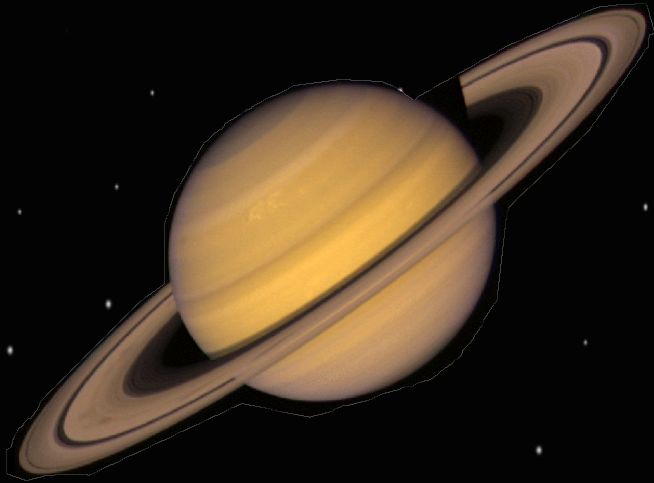


Outer Solar System Exploration

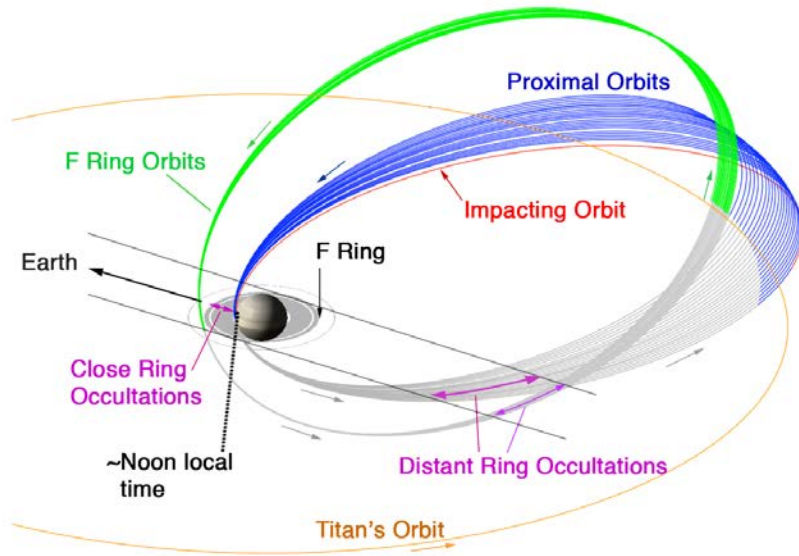


Outer Planets
Assessment Group
(OPAG) Report
September 2014

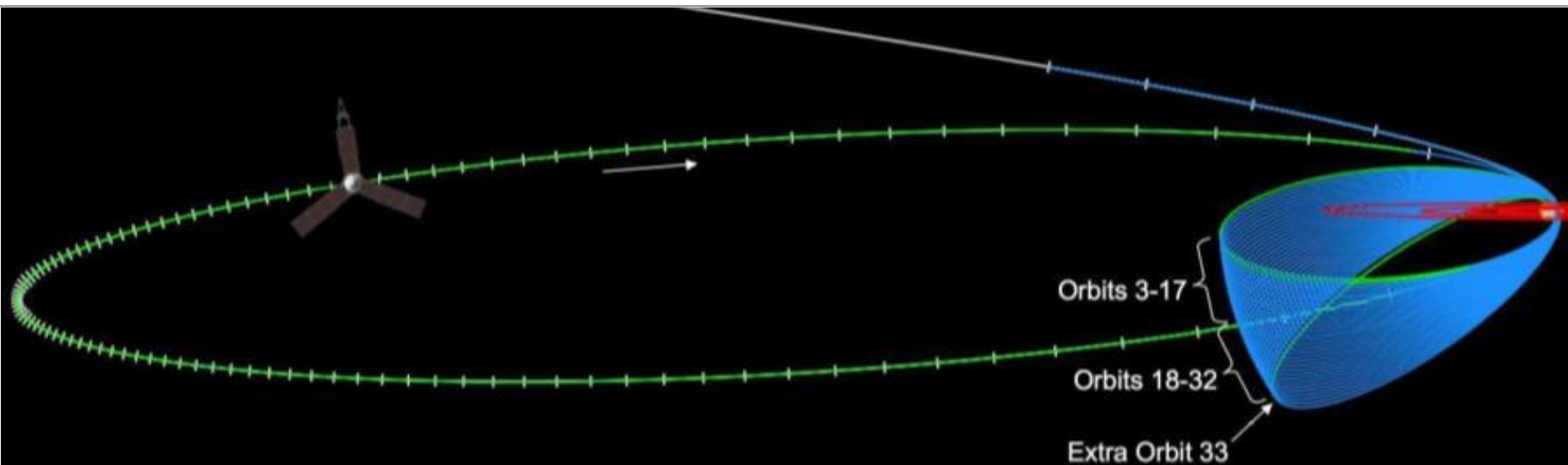
OPAG Assessment: Looming Gap

- OPAG regularly evaluates outer solar system exploration goals, objectives, investigations and required measurements on the basis of the widest possible community outreach. The group assembles twice per year to assess the current state of outer solar system exploration, goals for future exploration, and technology development needed to achieve those goals.
 - Most recent OPAG meeting was 23-24 July 2014 in Bethesda, MD
- ***Our biggest concern remains the looming gap in missions to the outer solar system***
- The near-term future is bright
 - Juno at Jupiter
 - Cassini at Saturn
 - New Horizons flyby of Pluto
- After that outer solar system exploration consists of only
 - Limited participation in JUICE
 - Possible New Horizons flyby of a KBO

Juno and the final stages of the Cassini mission

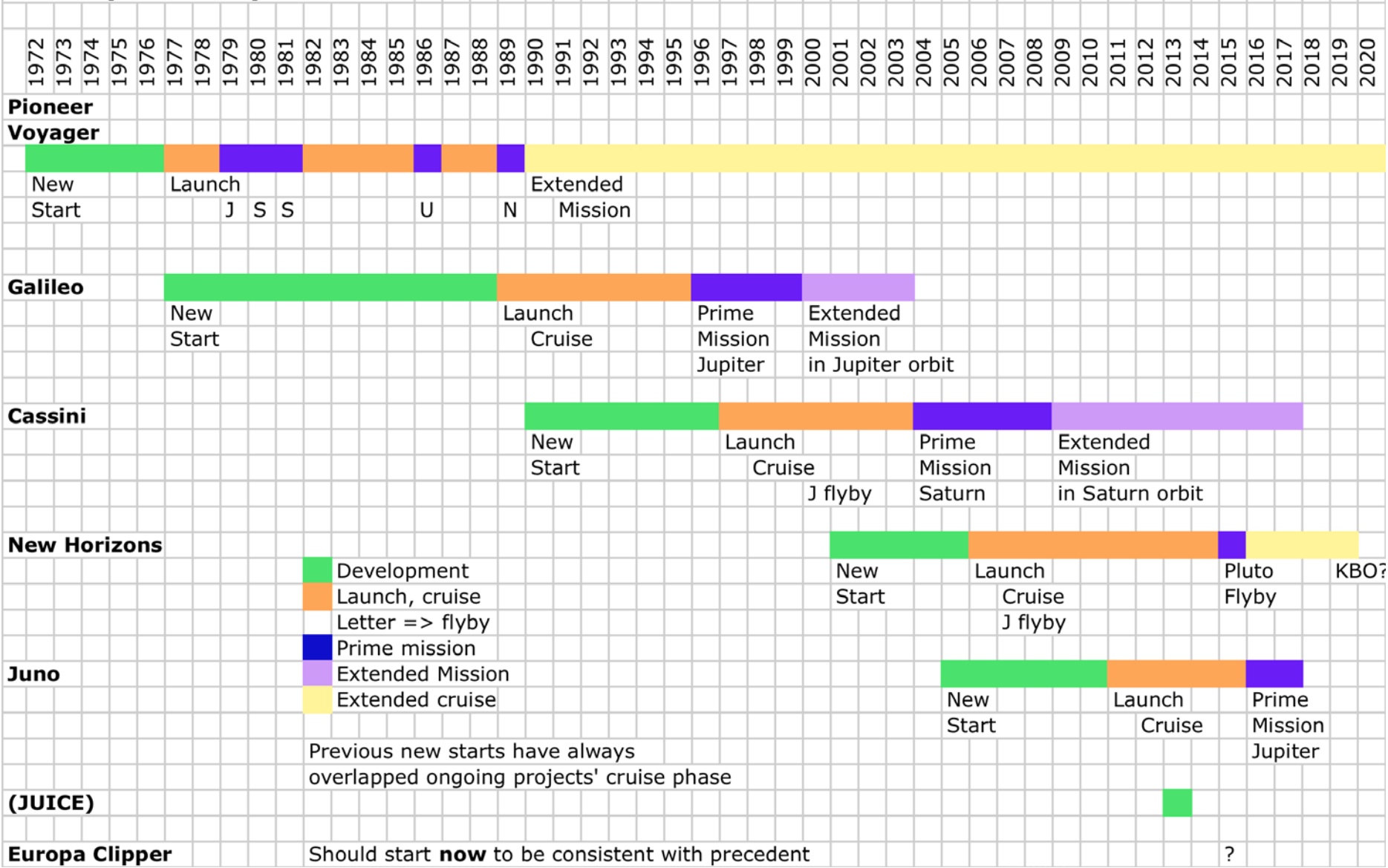


- After a long successful mission at Saturn the Cassini End-of-Mission is planned for Sept. 2017 when the spacecraft runs out of fuel
- Juno End-of-Mission at Jupiter is predicted as October 2017 with expected radiation damage
- Similar orbits offer comparable science objectives – giant planet interior structure, gravity field, auroral studies, magnetospheric physics





Outer planet exploration



Exploration ends in 2018 with no new US-led missions in development



Why should we explore the Outer Solar System?

Why not just focus on Mars? (Mars is *a fascinating* planet, certainly worthy of exploration, but...)

- Understanding *atmospheric circulation* – the giant outer planets have entirely different atmospheres than the terrestrial planets – understanding them means developing advanced fluid dynamics models (that have been applied for example to ocean currents)
- *Weather* more akin to earth: Earth is at the mercy of processes today that are taken to extremes on Saturn's moon Titan: a thick greenhouse atmosphere with violent rainstorms, desertification, and seas with coastline erosion and climate impact.
- *Atmospheric chemistry and astrobiology* - The reducing atmospheres in the outer solar system are home to a vigorous organic chemistry that does not occur in the inner solar system in the present day, providing an opportunity to study natural production of biological building blocks.
- *Magnetospheres* – the variety of the outer solar system tests our models and understanding of how our own magnetosphere is structured
- *Materials' behavior* in extreme pressures and temperatures not natural on earth – for example ice behaves like rock at outer solar system temperatures, but interior to many moons may be liquid
- *Exoplanets* – most of the new planets discovered around other stars are similar to Uranus and Neptune – we have a very limited understanding of our own ice giants

What do we need to do

How do we get outer solar system exploration back on track?

OPAG Findings address the need to:

1. Maintain current mission support (Cassini!)
2. Get a new start for a Decadal-Survey-responsive Europa mission
3. Make sure that outer solar system missions have a home in Discovery and New Frontiers
4. Invest in power sources appropriate for the outer solar system

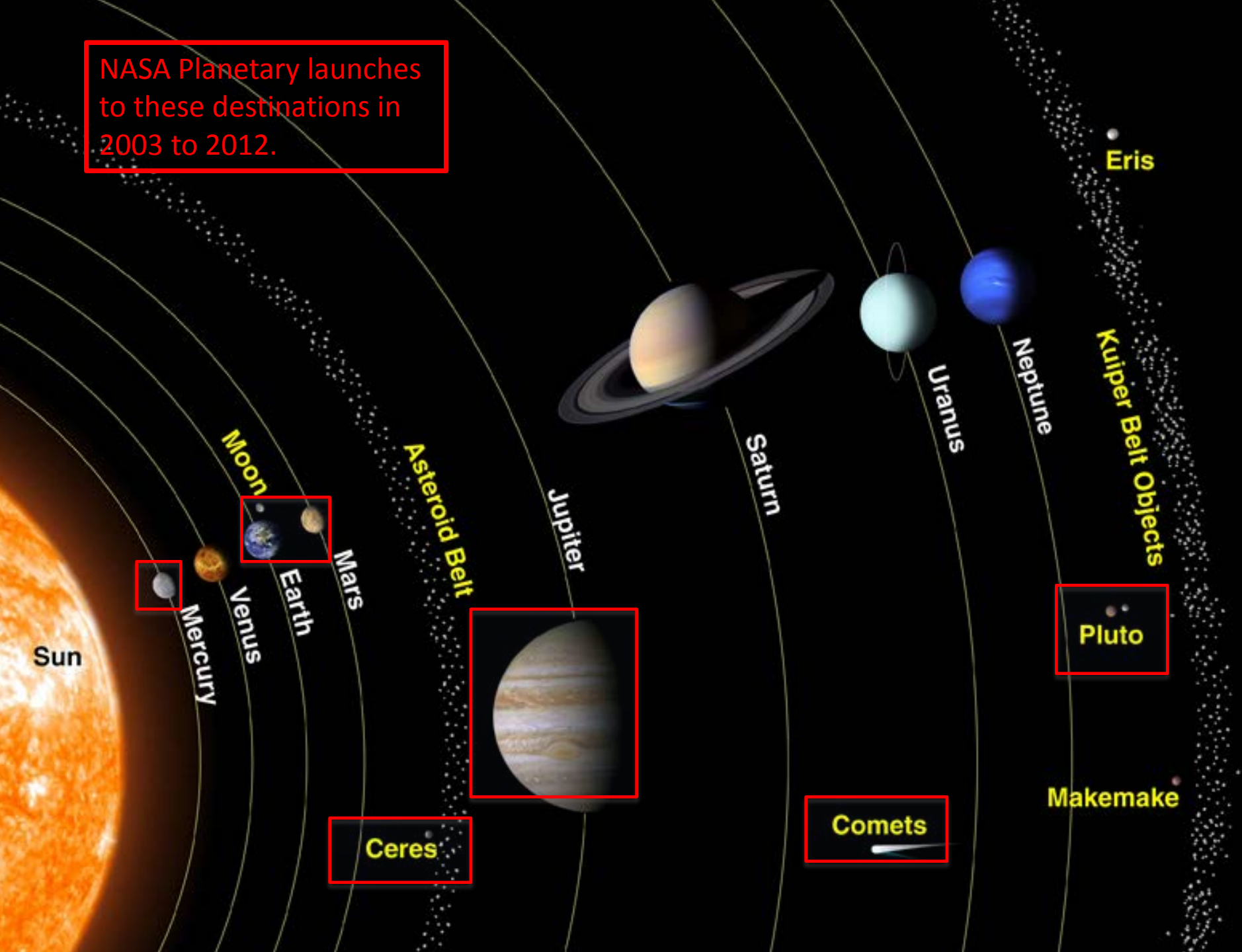


1. Maintain Current Mission Support

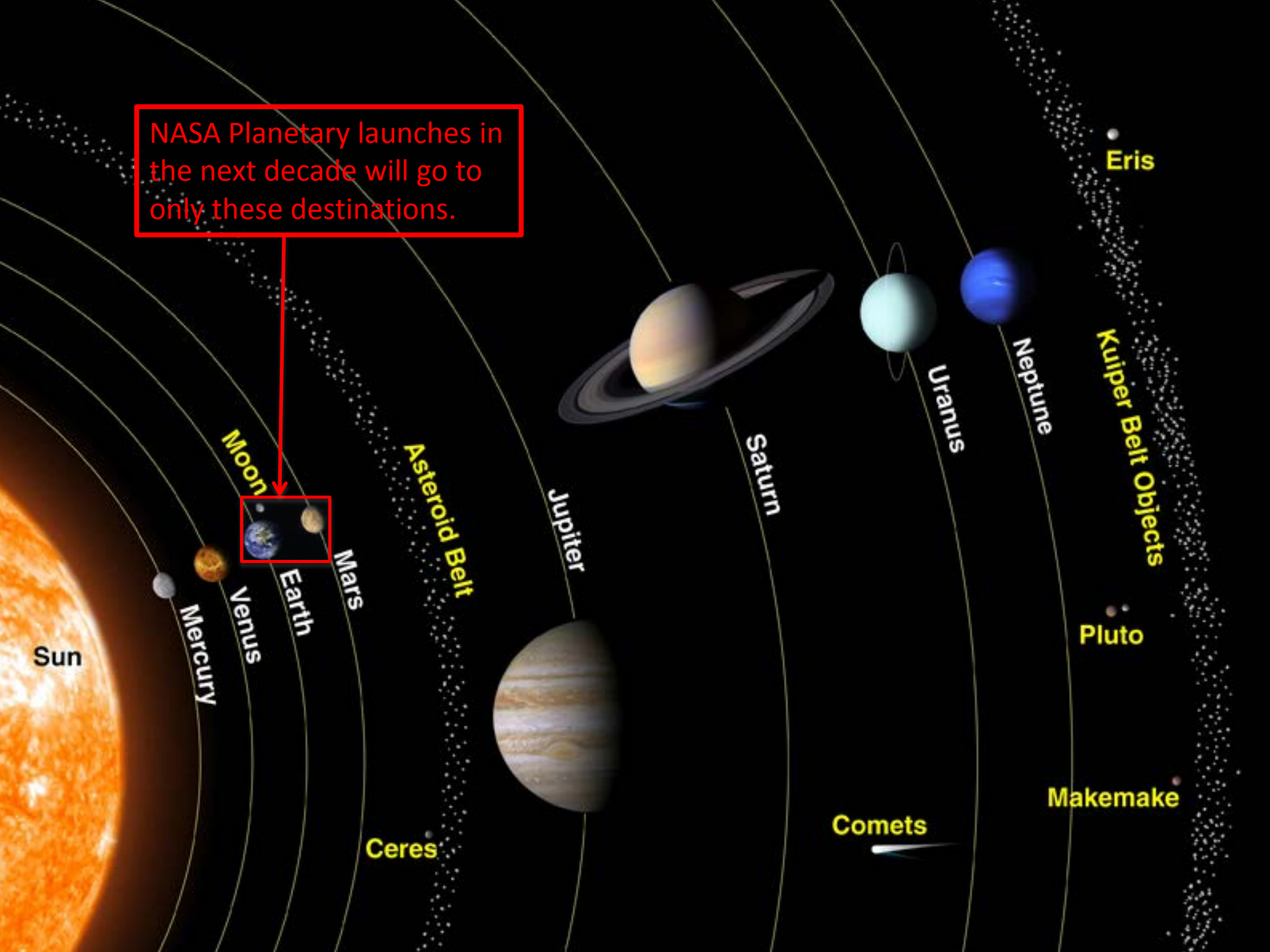
Threat to Cassini's final years has passed

- *Cassini is NASA's premier flagship mission.* Cassini's data return from the Saturn system continues to inspire, challenge and enchant us. The final 3 years of the Cassini Solstice Mission (2015, 2016, and 2017) offer opportunities to study seasonal changes in Titan's weather, seas and surface, dynamic interactions of small moons with Saturn's rings, and the investigation of Enceladus' enigmatic plume.
- For a time NASA's notional budget for the outyears did not include funding for Cassini in the outer planets line
- Now Cassini has passed the senior review milestone, and funding seems secure
- ***OPAG finding: OPAG wholeheartedly endorses continuation of Cassini, through the Proximal mission ending in 2017, in recognition of the exceptional scientific value and dramatic cost effectiveness of the extended mission, and the new scientific results it will produce, as was supported by the Planetary Decadal Survey***

NASA Planetary launches
to these destinations in
2003 to 2012.



NASA Planetary launches in the next decade will go to only these destinations.

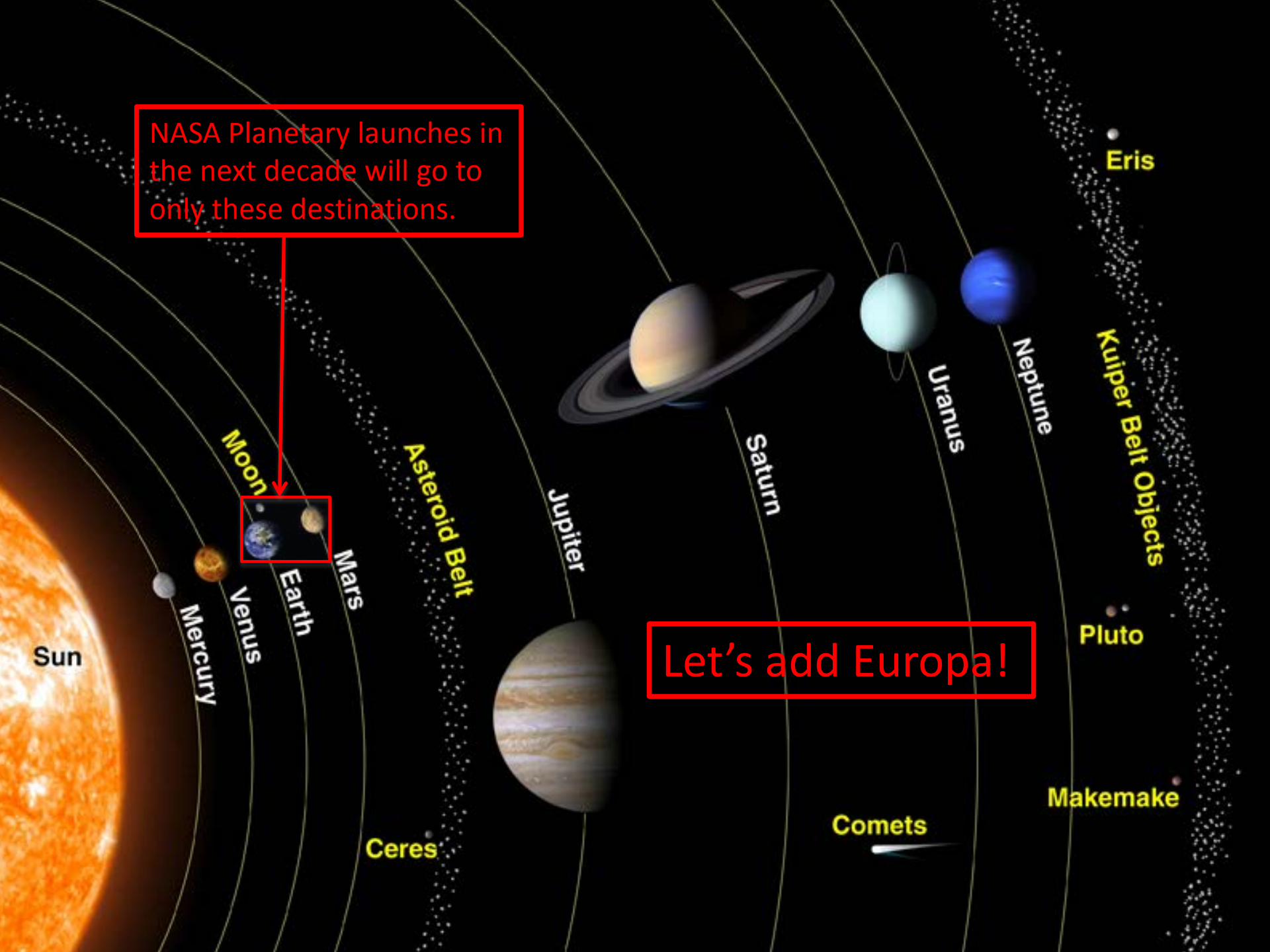




2. Get a mission to Europa started

- **Europa** remains the highest priority mission destination for the outer planets community. The next Europa mission *should address a majority of the goals for Europa science outlined in Vision and Voyages (V&V)*. *We continue to strongly support the **Europa Clipper** as a scientifically compelling, technologically feasible and fiscally responsible approach to exploration of Europa.* (OPAG has not yet seen the concepts submitted in response to the 2014 RFI for \$1B Europa mission concepts, thus cannot assess if these meet a majority of the V&V goals.)
- ***OPAG finding: OPAG commends NASA for the significant progress that has been made on Europa exploration opportunities, especially releasing the PEA for Europa Instrument Investigations. We were also pleased to see funding for a Europa mission study specifically called out in the FY15 budget, albeit at a modest level.***
- ***However, we are concerned about the longer term funding of these projects and the implementation of a Europa mission. OPAG would like clarification on the strategy that PSD has in mind for the out years. We request that the next report to OPAG include a notional schedule (perhaps expressed in relative time) for moving the Europa mission from a study to the launchpad.***

NASA Planetary launches in the next decade will go to only these destinations.



Let's add Europa!



3. A home for outer solar system missions in Discovery and New Frontiers

- **Discovery AO** changes – letter sent to Dr. Michael New on March 2, 2014
 - Pleased that Phase E costs are now excluded from the cost cap. Proposals with outer solar system destinations may now be evaluated equitably alongside those to more easily accessible objects
 - Disappointed that the schedule for fueling the RPSs will prohibit their use for this round of Discovery mission proposals
- **New Frontiers** has been an important and very successful component of NASA's program for solar system exploration. One might expect that as the funding required for OSIRIS-Rex winds down, a wedge of funding would be available to start the next New Frontiers mission. However, there is no plan for a new start for a New Frontiers Mission, and New Frontiers does not appear in the out years of the PSD budget.
- ***OPAG finding: OPAG recognizes the funding challenges PSD has faced for the past few years, and the fact that the \$1.5B is not achieved in future years. However, we register our support for the New Frontiers program, and encourage PSD to restore this critical program as soon as practical.***

Outer Solar System Challenges

- ***Travel time*** – OPAG is intrigued by the potential for use of the SLS, which could considerably shorten the time required to get to outer solar system destinations; however a cost model must be developed that fits within normal PSD expenditures for launch vehicles
- ***Power*** – solar power has now been shown to be viable as far out as Jupiter, but with current technology to go beyond Jupiter (or to places with inherently little sunlight such as polar regions) Radio-isotope Power Systems (RPS) are still required. Getting domestic production of Pu238 restarted was an important milestone reached this year.
 - Near-term there must be a focus on getting all the steps in the RTG production line working to provide pellets to fuel the current generation of RTGs
 - OPAG supports important technology developments are underway for the next generation of RTGs
 - Advanced solar arrays – will they ever provide enough power to conduct a mission at Neptune?



4. Invest in power sources needed for outer solar system exploration

- There are many potential planetary missions that require use of Radio-isotope Power Systems (RPS), including all that would venture beyond Jupiter. To build on the demonstrated reliability of MMRTG technology (and therefore mission success), increase efficiency of Pu238 usage, and boost end-of-life mission power, the OPAG advocates the Planetary Science Division's continuous upgrade development path for radioisotope thermoelectric generators.
- ***OPAG finding: The re-start of domestic production of Pu238 is a significant achievement and enables our continued exploration of the outer solar system. We are disappointed that other challenges have arisen (specifically the status of the pellet-making equipment) with the result that RPS power will not be available for this Discovery mission call. It is important to invest in future technologies thus OPAG also endorses PSD's evaluation of other potential nuclear power system developments (Nuclear Power Assessment Study) to meet future mission needs and would like to be briefed on the outcome of that study as soon as practical. OPAG does not advocate fission power technology for planetary missions at this time because science mission need for multi-kilowatt power (which comes with significant mass, cost and complexity penalties) has not been demonstrated.***

OTHER OPAG FINDINGS

Earth-based observations for missions

- Earth-based, telescopic observations of planetary objects being studied by spacecraft enable greater science return than the mission itself can provide by giving **context** to the spacecraft data, and by observing the object for a **longer time** or with **different instruments**. The Galileo, Cassini, and New Horizons missions have already benefitted from earth-based observations that yielded contextual information on Io's volcanoes and Jupiter's clouds, for example. Future Juno-related science in particular can benefit from use of ground-based assets to find hotspots and to predict the location of major atmospheric features to facilitate targeting of Juno's JunoCam and JIRAM instruments.
- ***OPAG finding: OPAG encourages NASA to support earth-based observations in general that leverage greater science return from active missions.***

Research & Analysis programs

- R&A is an essential part of maximizing science return from NASA's missions. OPAG responded to a request for feedback on the re-organization being carried out this year with a set of concerns provided to HQ last fall. Most concerns had to do with the implementation, rather than the fact that the R&A program was being re-organized. OPAG remains concerned about the logistics of handling ~500 proposals in Solar System Workings (which absorbed the Outer Planets Research program).
- ***OPAG finding: Once the proposals have been selected we request a description of funding breakdown on program level. In SSW OPAG would like to see how many proposals and how much funding was allocated to outer planets' investigations along with historic comparisons to OPR***

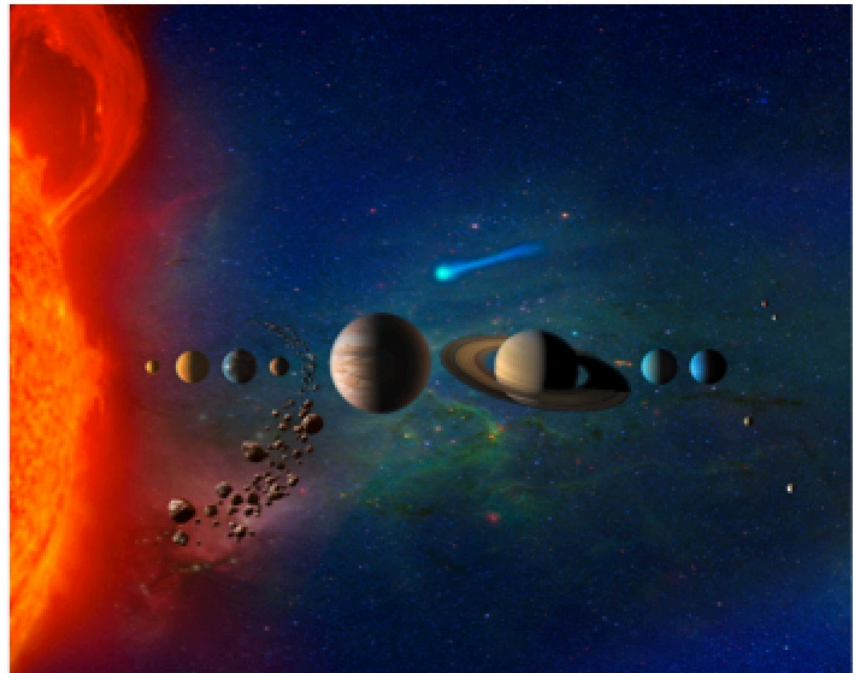
OTHER OPAG BUSINESS

NEW SCIENCE GOALS DOCUMENT

New OPAG Science Goals Document

Scientific Goals for Exploration of the Outer Solar System

*How did the outer planets mold the solar
system and create habitable worlds?*



OPAG Report

DRAFT

14 August 2014

Science Goals articulated by OPAG

- Last full document was in 2006
 - “Scientific Goals and Pathways for Exploration of the Outer Solar System”: A Report of the Outer Planets Assessment Group (OPAG) 2006
 - Plus the Decadal Survey white paper 2009
 - Plus the Technology Recommendations 2009
- Vision & Voyages is written and that effort is complete
- Going forward, we decided it was time to update the OPAG Scientific Goals and Pathways report
- Following that we will update the technology plan

OPAG's New Science Goals Document

Motivation

The “Vision and Voyages” writers are done – OPAG is the voice of the outer planets community until the next decadal survey – this needs to be a living document

- React to new discoveries
- Focus on science rather than missions
- Because*
 - A new possibility for Discovery missions to the outer solar system (such as IVO, TIME)
 - Need to constructively confront new budget realities
 - Europa Clipper is responsive to the new reality
- Identify *questions* that can be addressed with New Frontiers and Discovery size missions
 - Like Juno – Juno addresses an important set of questions identified in the 2003 decadal survey with a mission approach completely unlike the mission described in the 2003 DS
- *Prepare* for the next decadal survey
 - What to do about our target-rich dilemma?

New OPAG Science Goals Document

Approach

- Identify broad scientific goals (start with science, not missions)
- Use existing content from previous work done by the community, for example:
 - TSSM flagship study
 - EJSM flagship study
 - Decadal survey white papers
- Currently target-body-based, but we'll compare and contrast, and place within context of our over-arching science theme
- (Draft) Over-arching theme: ***How did the outer planets mold the solar system and create habitable worlds?***
- *Want to get to the point that we specify a science question, then say what destination addresses that question*
- Use Vision and Voyages initially for the high level themes

New OPAG Science Goals Document

Status

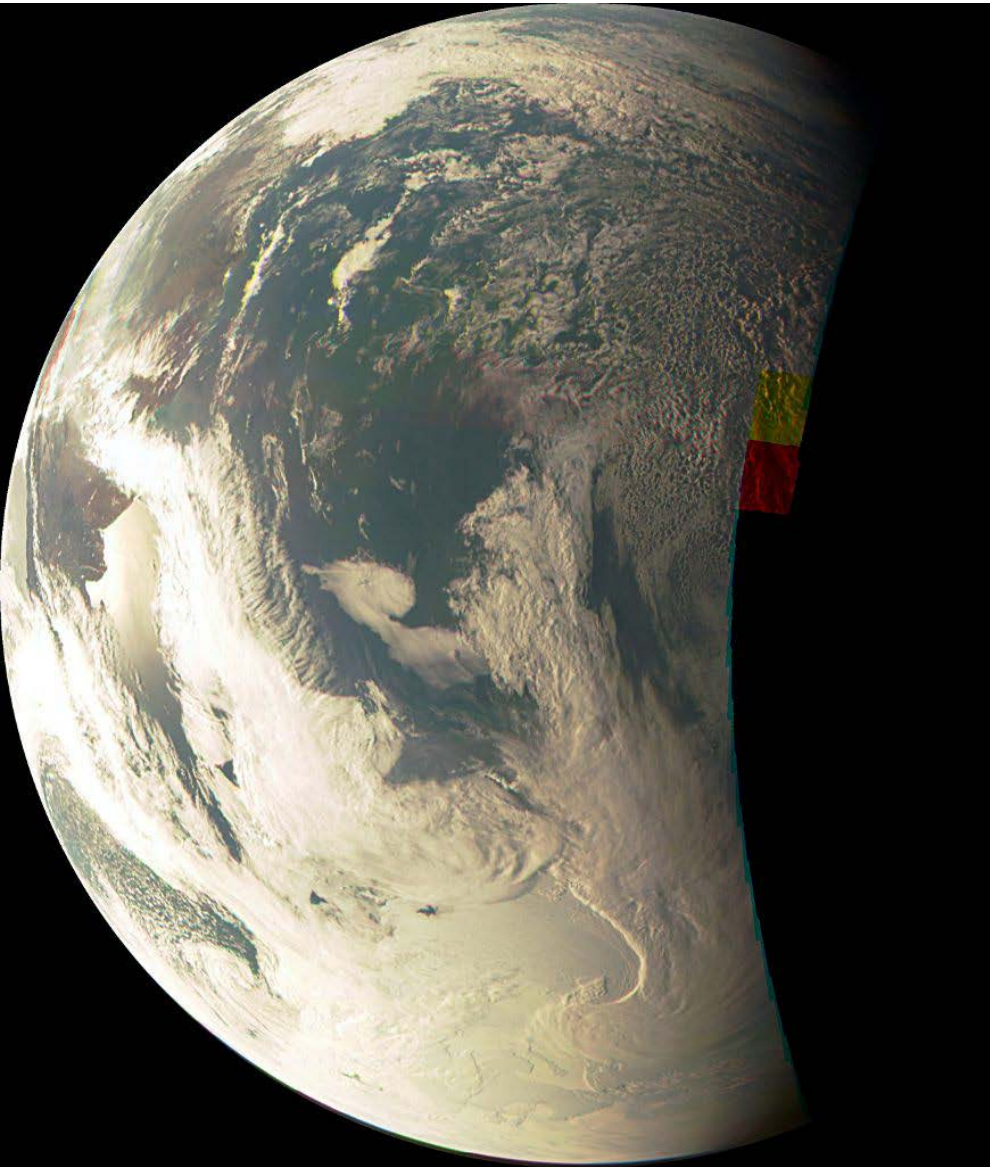
- Initial draft has been written by OPAG Steering Committee
 - Organized by targets
 - Top 5 – 6 goals, not a lengthy laundry list
- We have distributed this draft and invited the community to give us feedback and provide more content
 - Draft is posted on the OPAG website
 - Townhall being scheduled at DPS to solicit feedback
- Concurrently we'll look at unifying science objectives
 - Threads: Origins and Habitability
- Incorporate community feedback between now and the February 2015 OPAG meeting
- Will “publish” on our website, but will continually update in response to new discoveries as needed
 - E.g. Europa's Plumes

RECENT EVENTS



Juno's flyby of Earth

9 October 2013



1,470,000 views on youtube of the approach movie with the earth and moon, set to original music by Vangelis

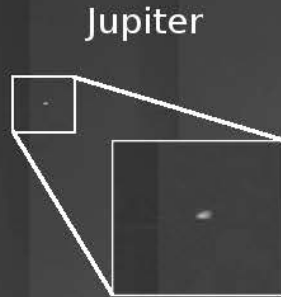
HI Juno ham radio operator video: amateur radio operators sent a message in Morse Code to say “hi” to Juno

www.nasa.gov/mission_pages/juno/multimedia

This JunoCam image views the Argentinean coastline with specular highlights off the Rio Negro north of Golfo San Matias, as well as cloud formations over the continent of Antarctica.



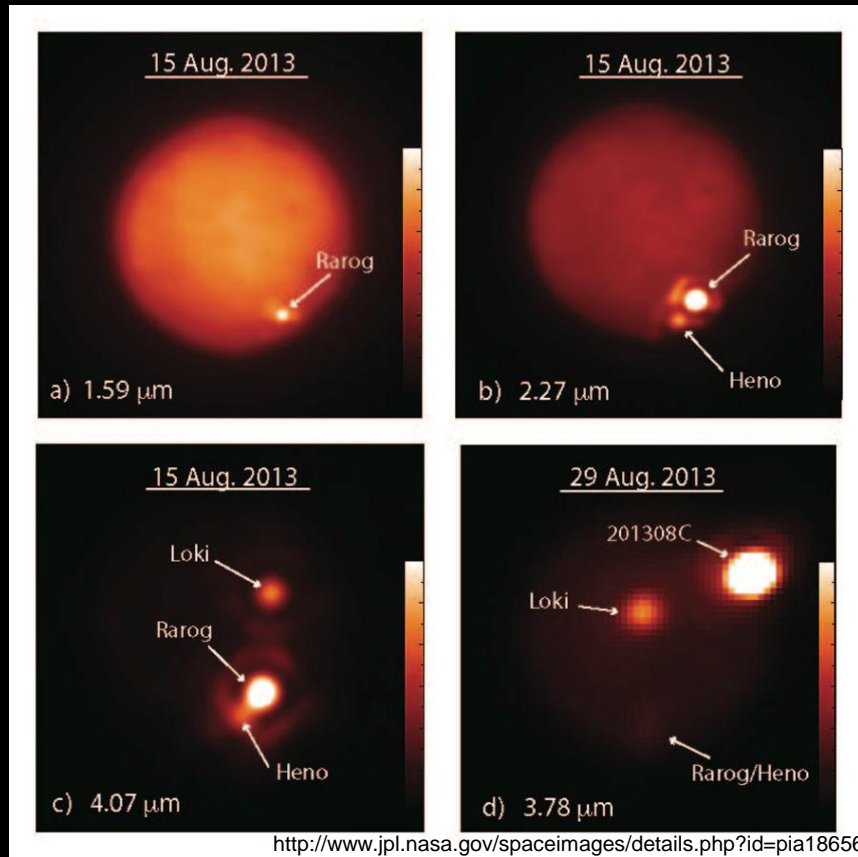
Jupiter: Juno's Ultimate Destination



This single-filter image was acquired on October 9, 2013 at 18:51:30 UT. The glow at the bottom is scattered light coming from the earth, just outside the camera field of view.

NUGGETS

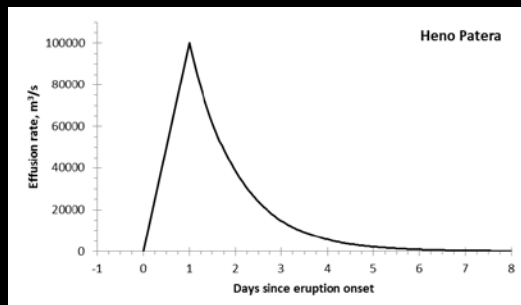
Massive lava flows on Io reveal how it was done on ancient Earth, Mars, Venus...



Massive flood basalt lava flows helped shape the surfaces of the terrestrial planets but how fast the lava was erupted and how long the eruptions lasted is unknown... until now. Such eruptions have been seen and quantified on Io.

Data obtained in August 2013 using the Keck, Gemini and IRTF telescopes showed three immensely powerful, high-volume, high-temperature, short-duration eruptions that created lava flows that rapidly spread across Io's surface.

At the peak of the eruption at Heno Patera, lava erupted at about $10^5 \text{ m}^3/\text{s}$. This is 100 times greater than the peak eruption rate of Mauna Loa, Hawai'i, in 1984, one of Earth's greatest effusive eruptions of recent times.



Heno Patera 312° W ,
 -57°
Size: 62 km x 72 km

Image: Galileo SSI

We now have a better understanding on how these important eruptions behaved. This, once again, shows how Io is a laboratory for understanding volcanic activity on a massive scale, and a key to the hidden history of Earth.

de Pater et al. (2014) *Icarus*, in press, DOI: 10.1016/j.icarus.2014.06.016.

de Kleer et al. (2014) *Icarus*, in press, DOI: 10.1016/j.icarus.2014.06.006.

Cassini: A Decade at Saturn and Counting

On June 30, 2014, Cassini marks 10 years of exploring the Saturn system.



Saturn's F Ring: A Calm Core in the Midst of Chaos

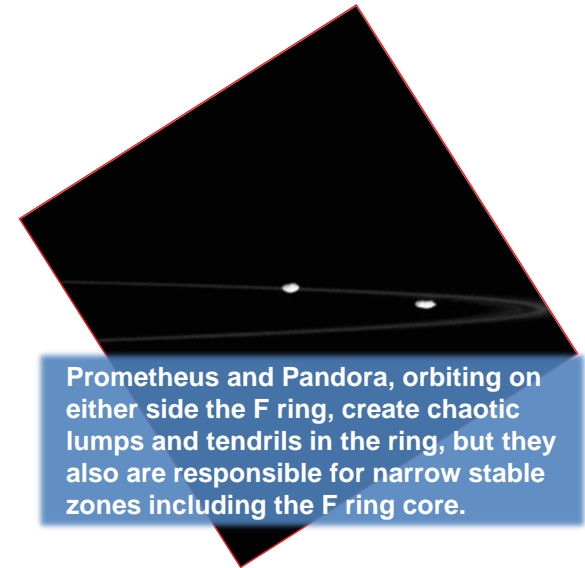
Long-term stability of the narrow F ring core (**center right**) has been difficult to understand. Instead of acting as “the shepherd moons”, Prometheus and Pandora together stir the region into a chaotic state where the orbits of particles and moonlets sporadically change in unpredictable ways.

In new research*, Cassini scientists present numerical integrations of tens of thousands of test particles over tens of thousands of Prometheus and Pandora orbits. The findings show that the two shepherds, while creating confusion in the F ring, also maintain its peaceful core.

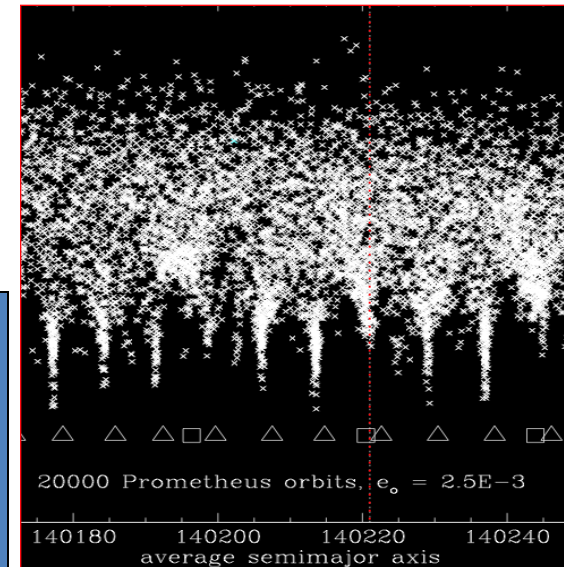
At select, very narrow locations, orbits of particles can remain essentially constant for long periods of time due to the perturbations of Prometheus at one encounter being promptly cancelled at the next encounter. The long-lived F ring core lies precisely at one of these locations. This work has implications for understanding how shepherd moons shape the ring systems that they are embedded in.



Computer simulations (**right**) reveal the presence of narrow, stable zones (the icicle-like clusters of points) which are associated with gravitational resonances of Prometheus and Pandora (triangle and square symbols). F ring material could be stable in any of these zones. The **red dotted** line shows the observed location of the F ring core, lying in one of the theoretically stable zones.



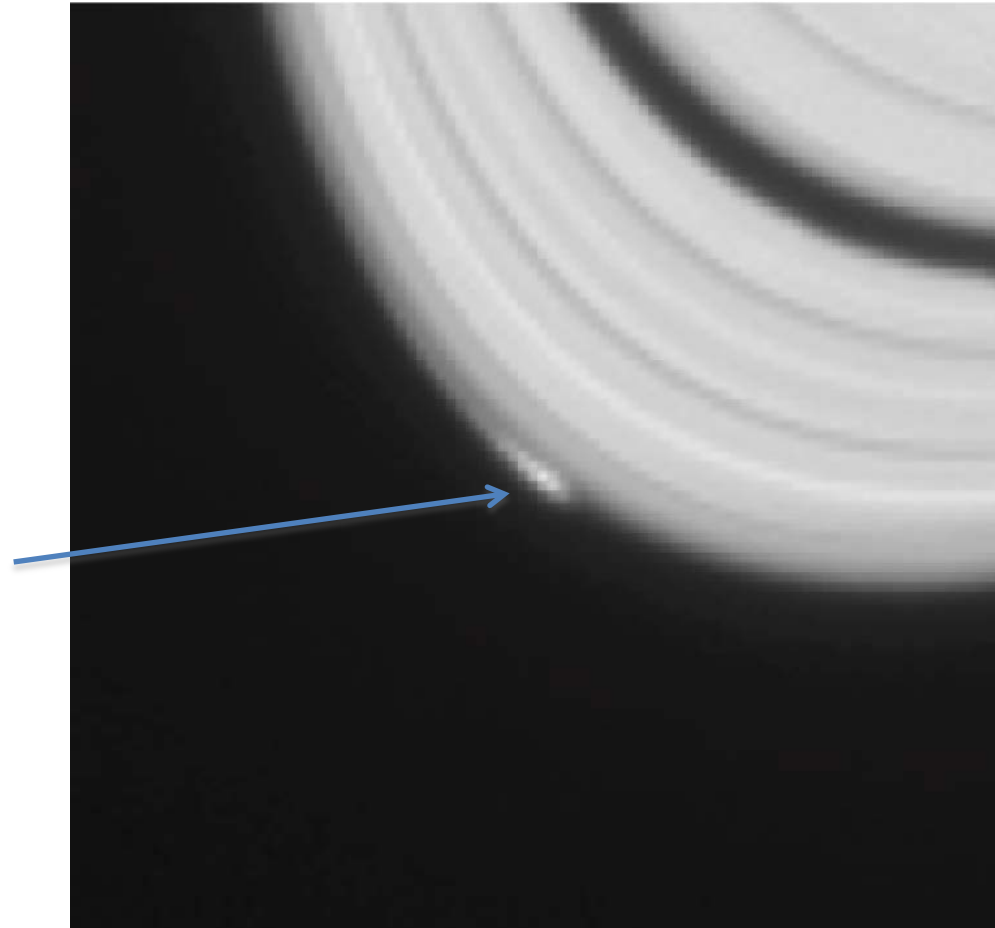
Prometheus and Pandora, orbiting on either side the F ring, create chaotic lumps and tendrils in the ring, but they also are responsible for narrow stable zones including the F ring core.



A New Moon is Born???

A commotion at the very edge of Saturn's outer bright ring appears to be associated with the birth of a small, icy infant moon.

- NASA's Cassini spacecraft has been documenting the birth process, which may demonstrate how many of Saturn's other moons formed.
- The object, nicknamed "Peggy," appears to be disturbing nearby ring particles as it moves to exit the rings. In time, it may assume a place in orbit among Saturn's 62 other known moons.
- "Peggy" appears to be about the size of three soccer fields. It has gathered an entourage of particles that stick together in a bright arc about 750 miles (1,200 kilometers) long and about 6 miles (10 miles) wide.
- Scientists have long theorized that our solar system's planets formed in a similar fashion from a ring-like disk around our early sun.



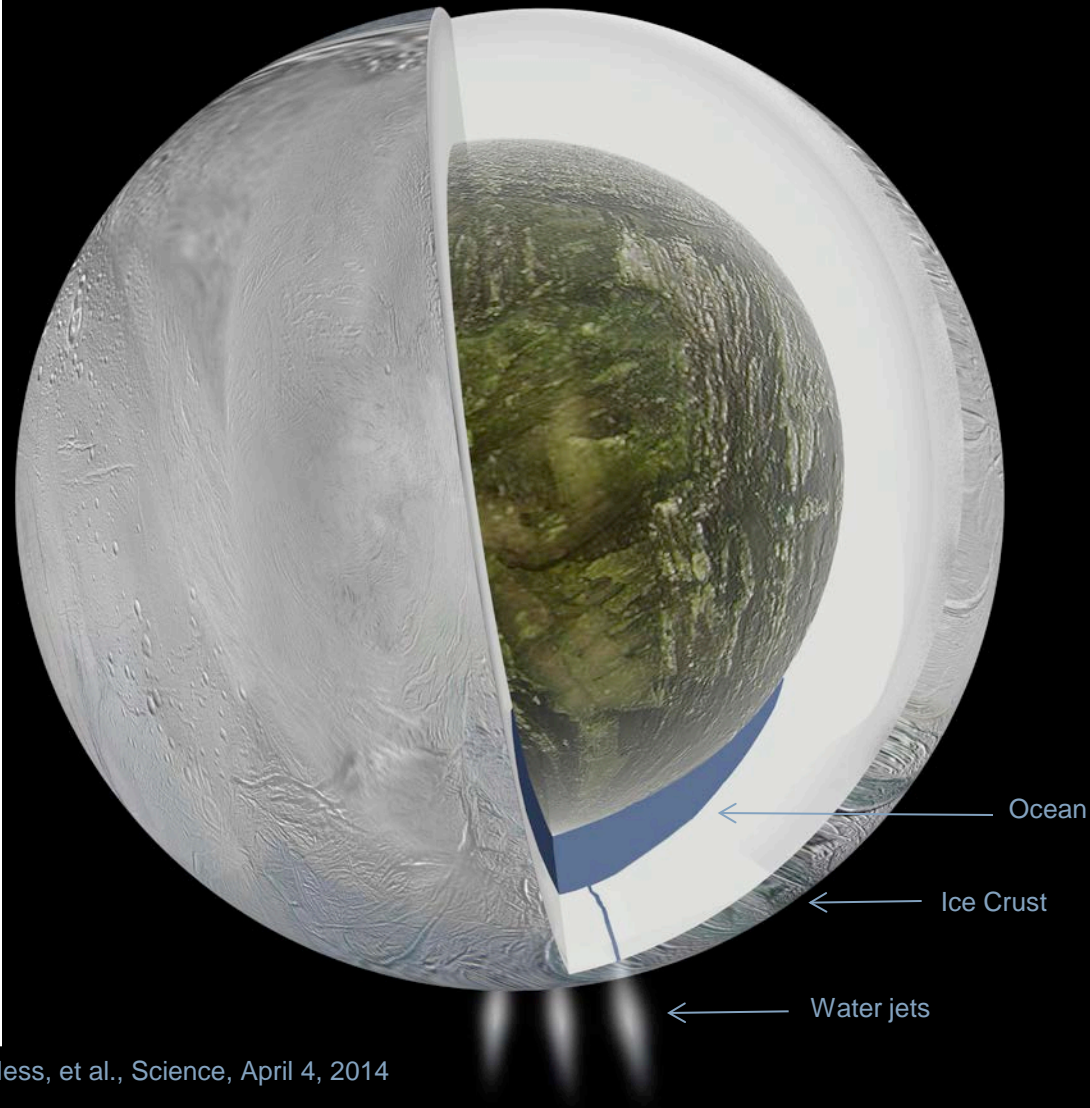
"The discovery and dynamical evolution of an object at the outer edge of Saturn's A ring," Murray, C.D., Cooper, N.J., Williams, G.A., Attree, N.O., Boyer, J.S., Icarus (2014), doi: <http://dx.doi.org/10.1016/j.icarus.2014.03.024>

Cassini Detects Enceladus Ocean: A Habitable World?

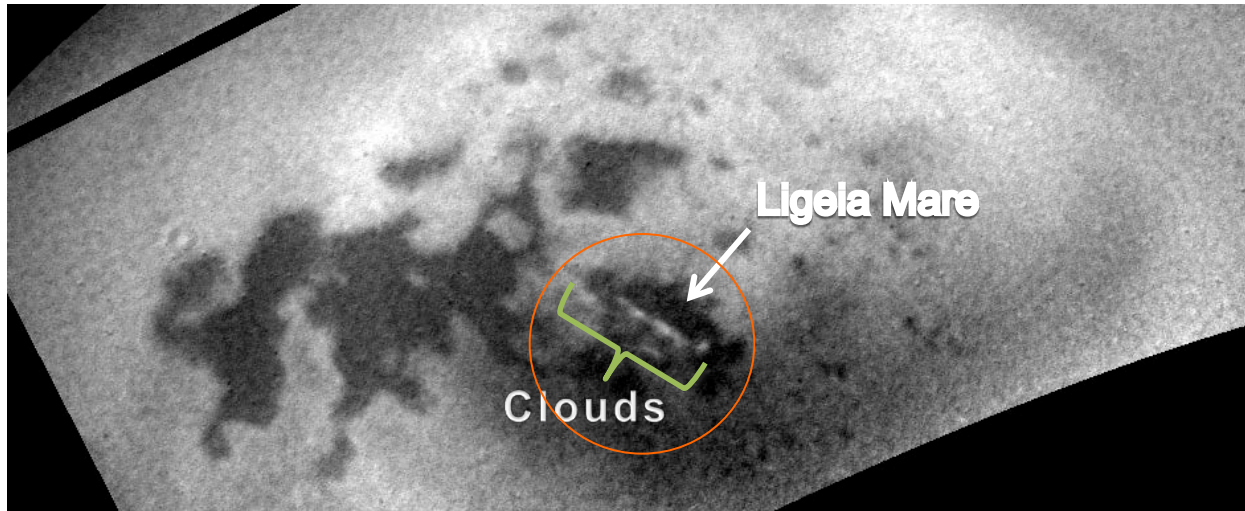
Saturn's moon Enceladus harbors a large, 6-mile deep underground ocean of liquid water, indicated by gravity measurements by the Cassini spacecraft and Deep Space Communications network.

- Radio measurements of Enceladus' gravity indicate an interior reservoir of liquid water, which may be connected to water jets gushing from fractures near the small moon's south pole.

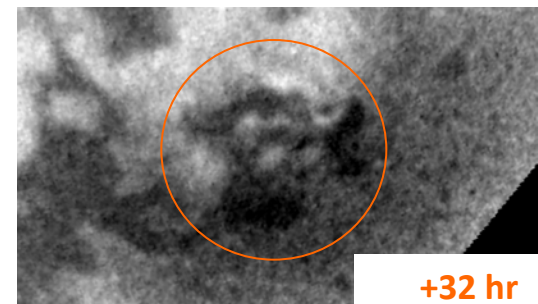
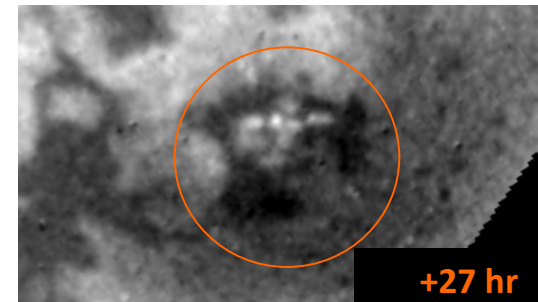
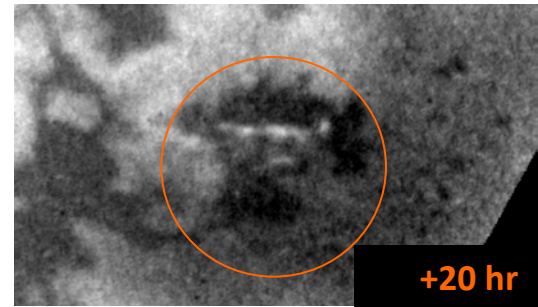
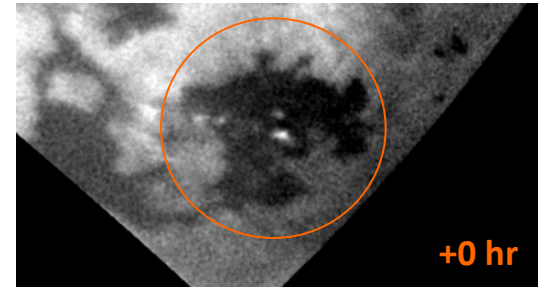
- The newly reported finding validates the inclusion of Enceladus among the most likely places in our solar system to potentially host life.



Titan Storm Watch!



- Cassini scientists are finally seeing spring clouds that were predicted to start appearing in Titan's northern hemisphere several years ago. Significant cloud activity had not been seen anywhere on Titan since 2010.
- Cloud activity was tracked over the Great Lake-sized sea, Ligia Mare, during a July 2014 flyby. The weather system was observed for about two days as it developed and dissipated. Wind speeds were measured at about 3 to 4.5 meters per second (7 to 10 miles per hour).
- Cassini will continue to look for further signs of the anticipated spring storms during several upcoming flybys.
- Movie: <http://go.nasa.gov/1AbiPBA>



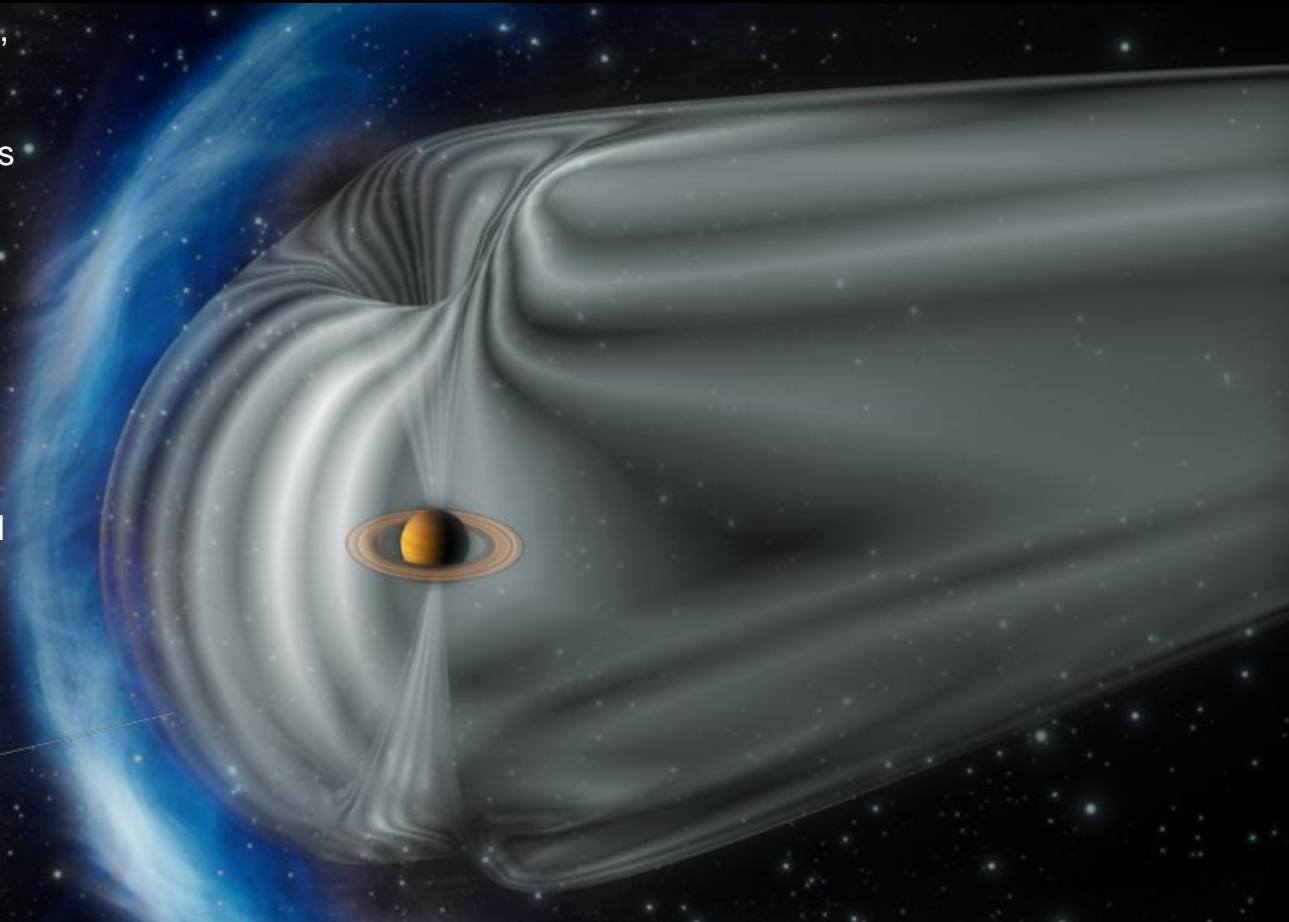
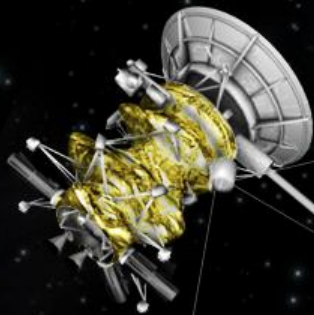
“Supernova” Science At Saturn

The next best thing to a spacecraft orbiting a supernova is Cassini being present for the first ever observation of near-relativistic electrons accelerated within Saturn's bowshock (represented by blue region in the graphic below).

Electrons were accelerated to ultra-high, relativistic energies when an unusually strong blast of solar wind compressed the bowshock, the region where Saturn's magnetosphere meets the solar wind.

This event is similar to shock-acceleration of particles taking place around supernovas and may be the dominant source of high-energy cosmic rays that pervade our galaxy.

Cassini data is providing unprecedented insights into how energetic particles are generated at supernova boundaries.



This artist's concept illustrates Saturn's invisible magnetic field lines (gray) and the invisible bowshock (blue) where Saturn's magnetic field is compressed by the incoming super-sonic solar wind.

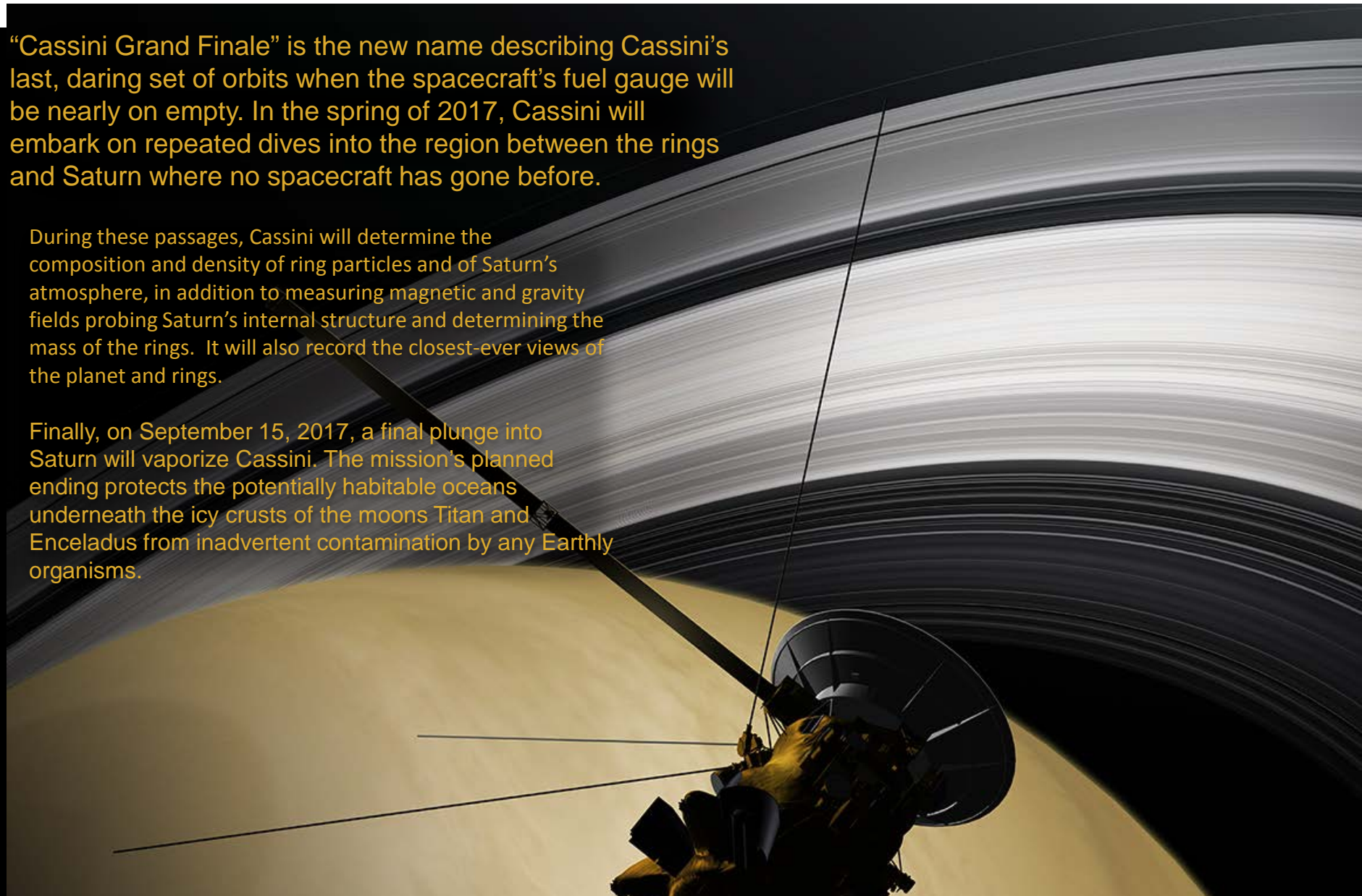


The Best for Last: “Cassini Grand Finale”

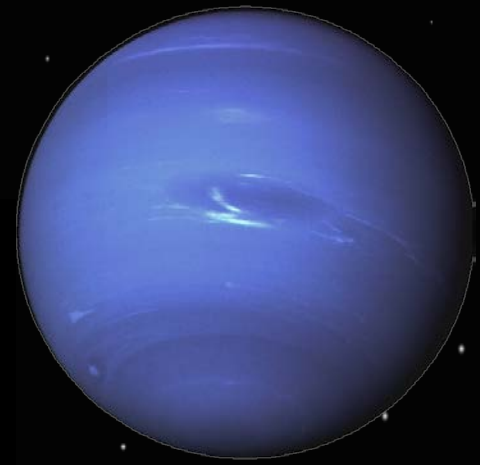
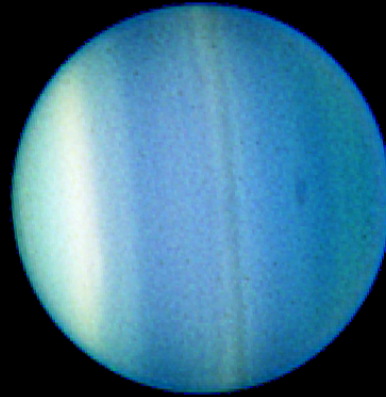
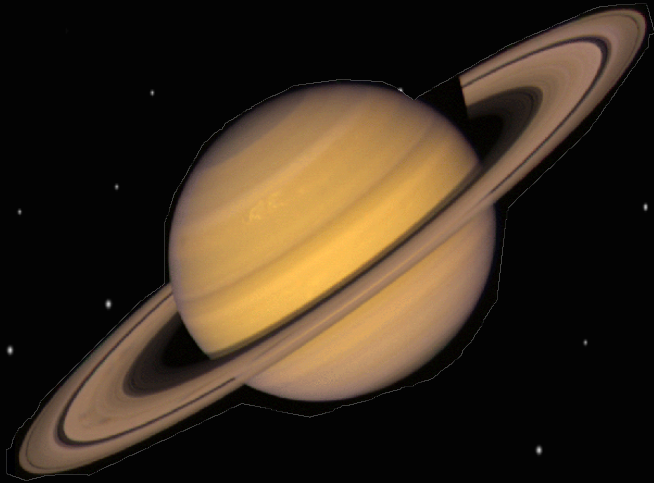
“Cassini Grand Finale” is the new name describing Cassini’s last, daring set of orbits when the spacecraft’s fuel gauge will be nearly on empty. In the spring of 2017, Cassini will embark on repeated dives into the region between the rings and Saturn where no spacecraft has gone before.

During these passages, Cassini will determine the composition and density of ring particles and of Saturn’s atmosphere, in addition to measuring magnetic and gravity fields probing Saturn’s internal structure and determining the mass of the rings. It will also record the closest-ever views of the planet and rings.

Finally, on September 15, 2017, a final plunge into Saturn will vaporize Cassini. The mission’s planned ending protects the potentially habitable oceans underneath the icy crusts of the moons Titan and Enceladus from inadvertent contamination by any Earthly organisms.



Outer Solar System Exploration



Worth the journey

BACKUP CHARTS

Decline in NASA Planetary Launches

- 2003-2012:

- MESSENGER – Mercury
- GRAIL -- Moon
- Lunar Reconnaissance Orbiter
- MER-Opportunity
- MER-Spirit
- Mars Reconnaissance Orbiter
- Phoenix – Mars lander
- Mars Science Laboratory
- Dawn – Vesta and Ceres
- Juno – Jupiter
- Deep Impact – comets
- New Horizons – Pluto
- **Total: 12 missions, from Mercury to Pluto, all successful**

- 2013-2022:

- LADEE – Moon
- MAVEN – Mars orbiter
- InSight – Mars Lander
- OSIRIS-Rex – near-Earth asteroid sample return
- 2020 Mars rover
- New Discovery mission
- **Total: 5 or 6 missions**
- **It is already too late to increase the number of launches over the next decade, except for one Discovery mission if the planetary budget is restored soon.**

Treasures in the Outer Solar System

- *The outer solar system is target-rich.* We'd like to learn more about volcanoes on Io, storms on Titan, the rings around Uranus and whether Ariel is a frozen version of Enceladus. We'd like to study geysers on Triton, the plumes of Enceladus, and the magnetosphere of Neptune. And of course the highest priority of all is to learn more about Europa, a moon that could conceivably have life today in a subsurface ocean.
- We send our robotic emissaries to places too dangerous for humans – that doesn't make those places less worthy of exploration
- Destinations recommended in the Decadal Survey "Vision and Voyages" for the upcoming decade:
 - [Europa](#), to learn more about the subsurface ocean and how to access it in the future
 - [Uranus](#) orbiter, to study an ice giant in our own solar system analogous to many exoplanets being discovered
 - [Saturn](#) probe, to study the layers under the cloudtops
 - [Io](#) volcano observer, to learn the secrets of the most volcanically active place in the solar system