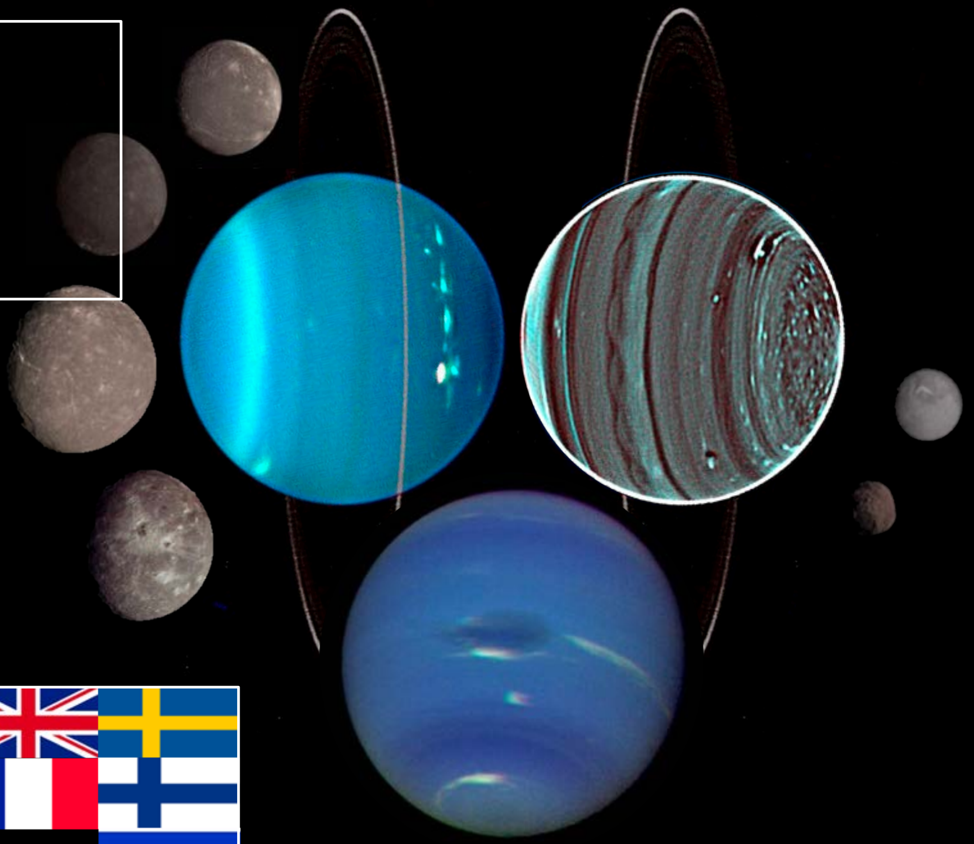
Ice Giant Systems:

Scientific Potential of Missions to Uranus and Neptune



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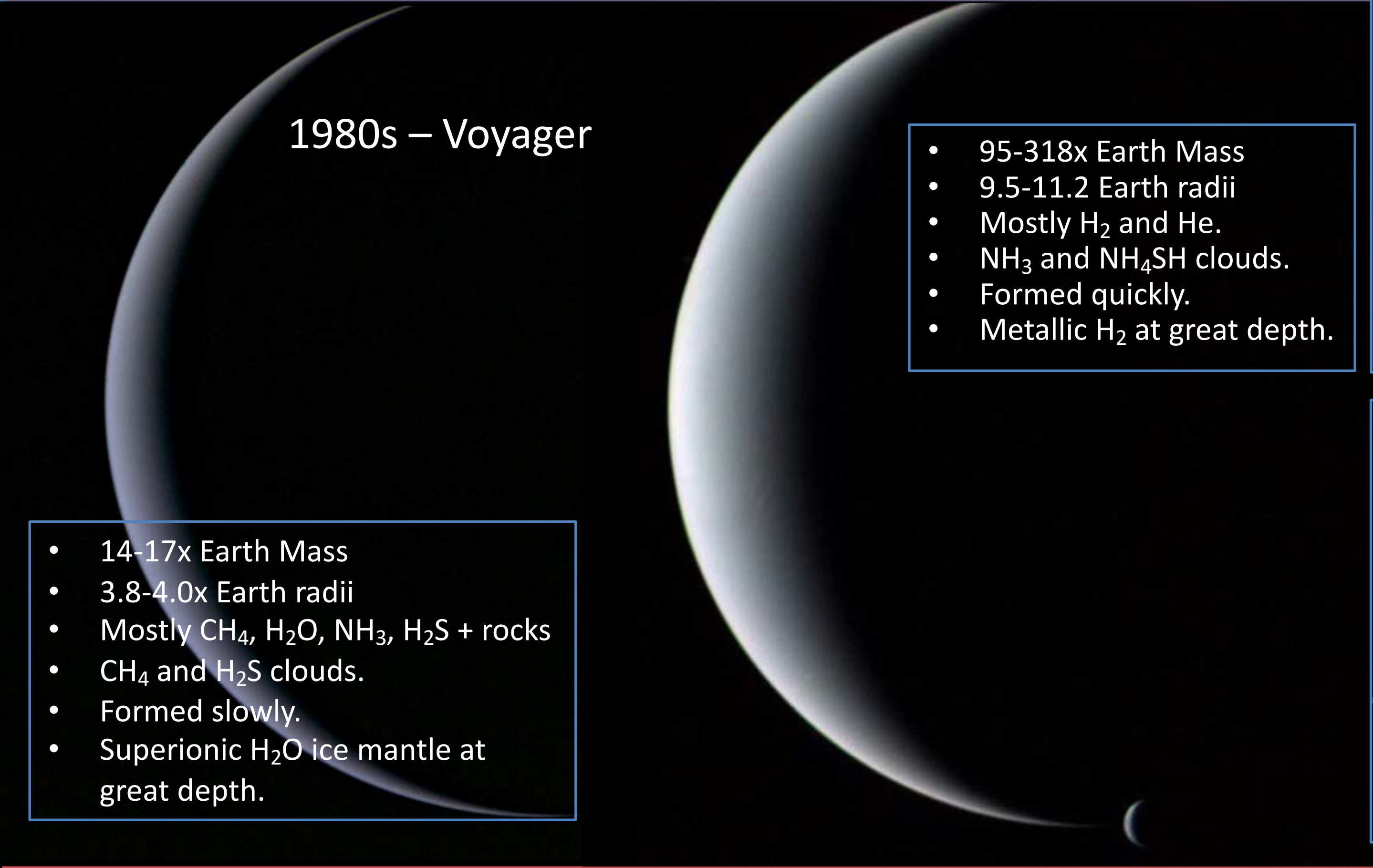
arXiv:1907.02963

UNIVERSITY OF LEICESTER

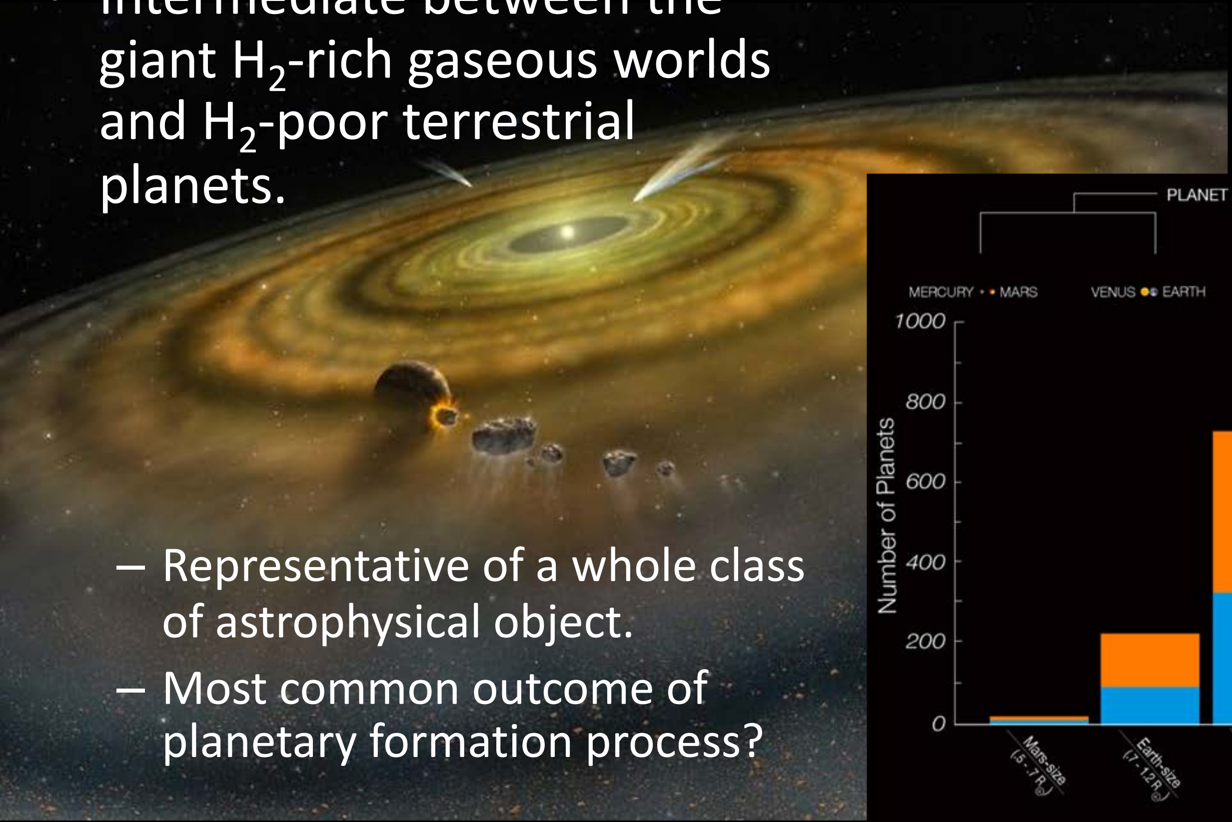
The Next Step in our Exploration



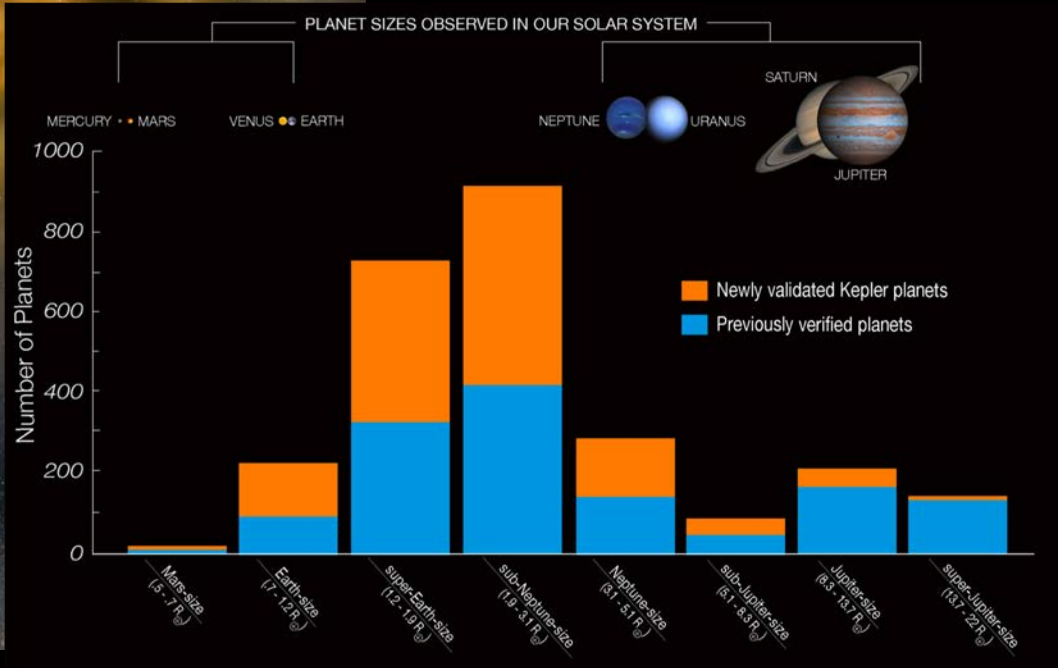
- 14-17x Earth Mass
- 3.8-4.0x Earth radii
- Mostly CH_4, H_2O, NH_3, H_2S + rocks
- CH_4 and H_2S clouds.
- Formed slowly.
- Superionic H_2O ice mantle at great depth.

- 95-318x Earth Mass
- 9.5-11.2 Earth radii
- Mostly H_2 and He.
- NH_3 and NH_4SH clouds.
- Formed quickly.
- Metallic H_2 at great depth.

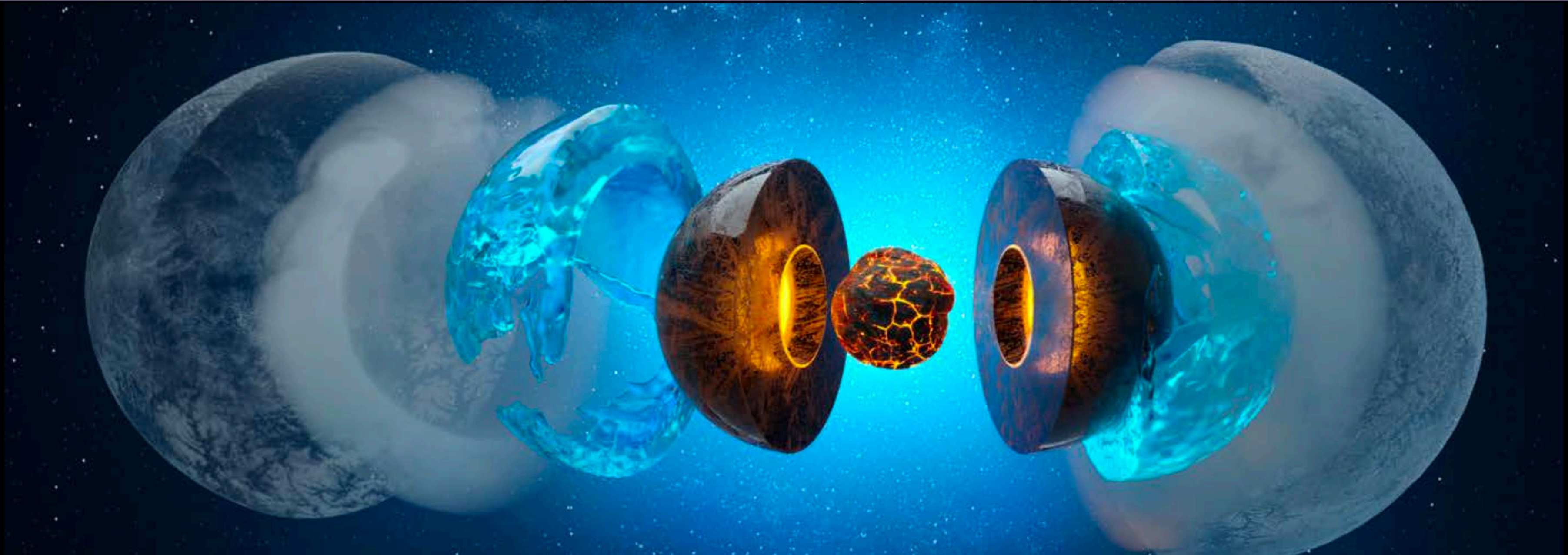
The Missing Link: Exoplanets in Our Back Yard



- Intermediate between the giant H_2-rich gaseous worlds and H_2-poor terrestrial planets.
  - Representative of a whole class of astrophysical object.
  - Most common outcome of planetary formation process?



Exotic Interiors



- Millions of bars, thousands of degrees.
- Magnetic fields formed in partially ionized conducting layers.
- Superionic ices recently created in laboratories – deep icy mantle?

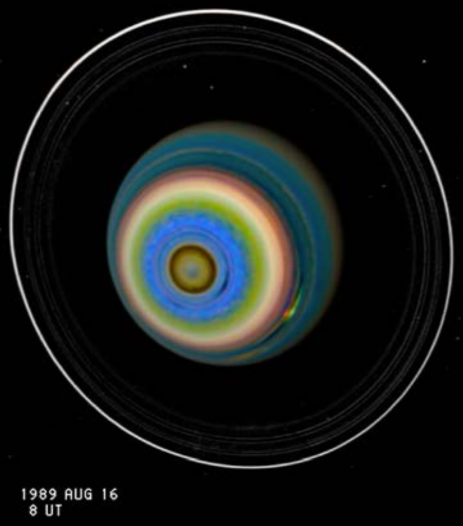
Example of Divergent Evolution

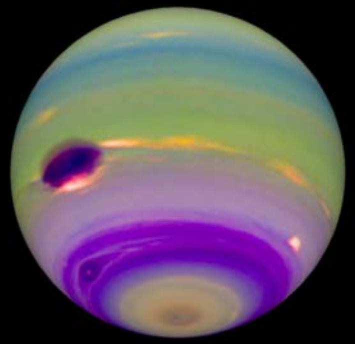
- Different evolutionary paths despite their shared origins.

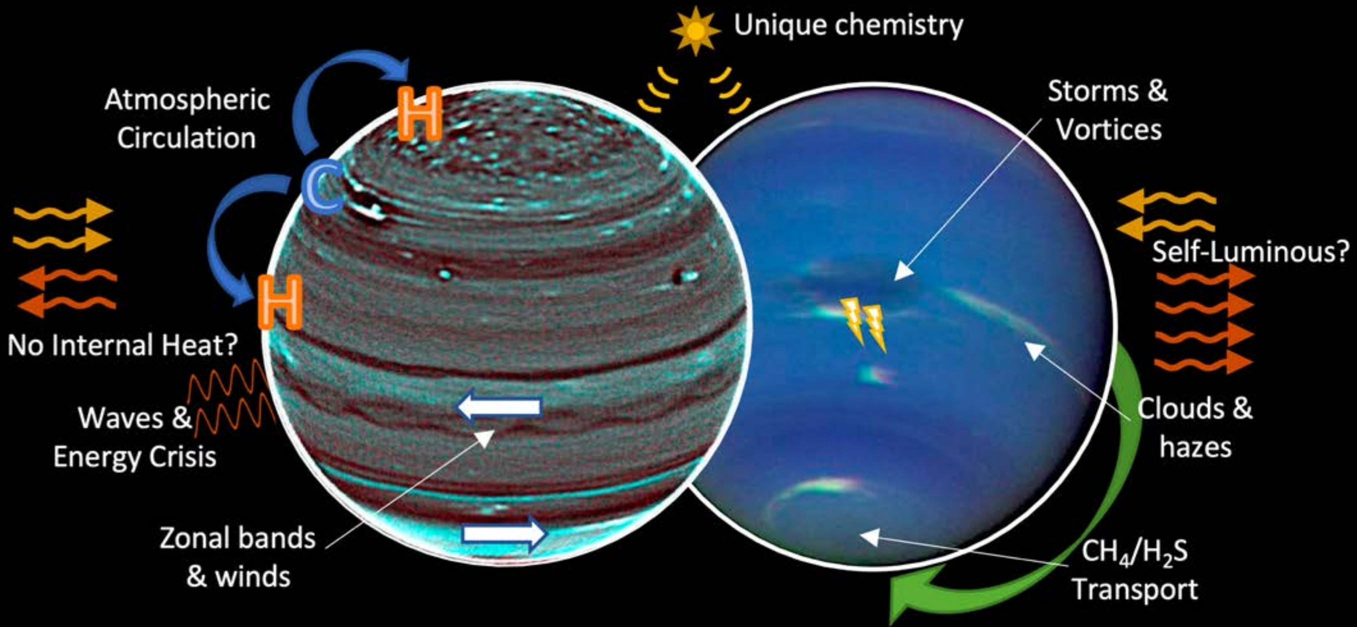
URANUS:
- Extreme axial tilt.
- Negligible internal heat.
- Sluggish atmosphere.
- Many small satellites.
- *A unique ice giant?*

NEPTUNE:
- Earth-like axial tilt.
- Enormous internal heat.
- Active atmosphere.
- Large captured satellite.
- *A typical ice giant?*

Dynamic Atmospheres

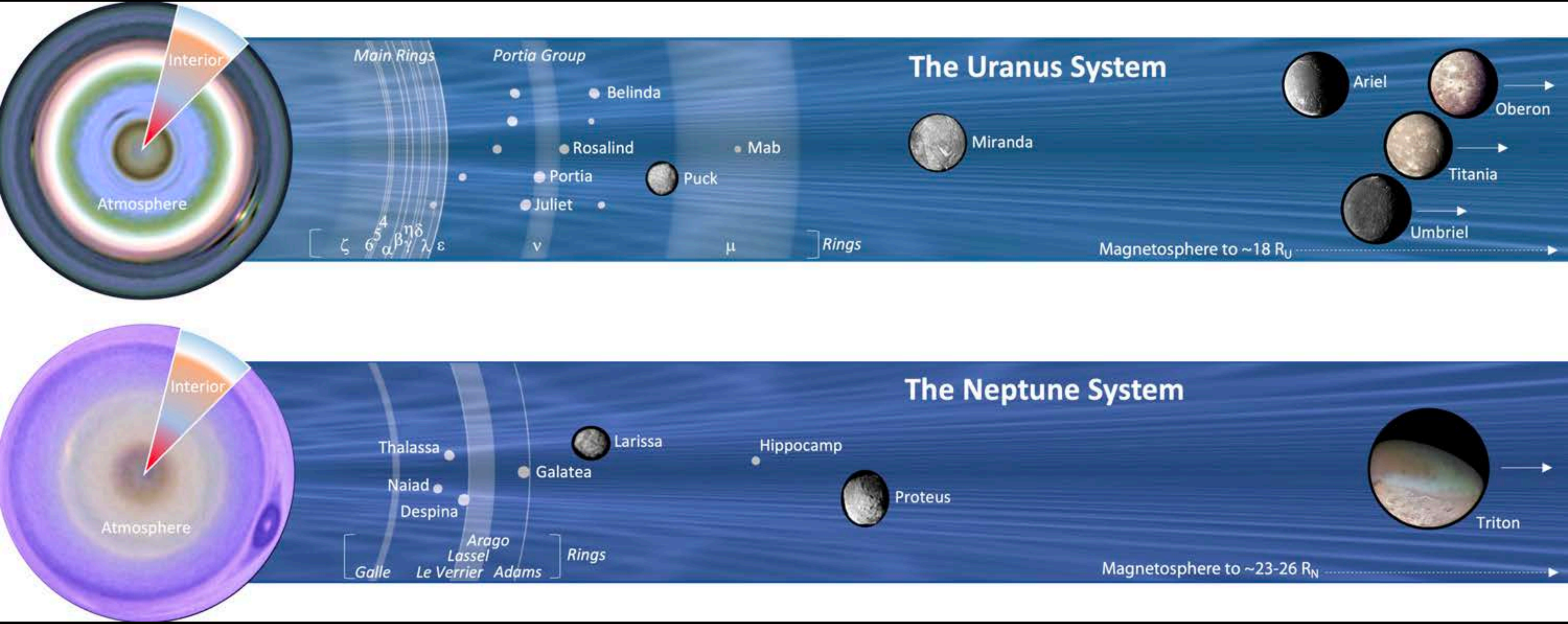




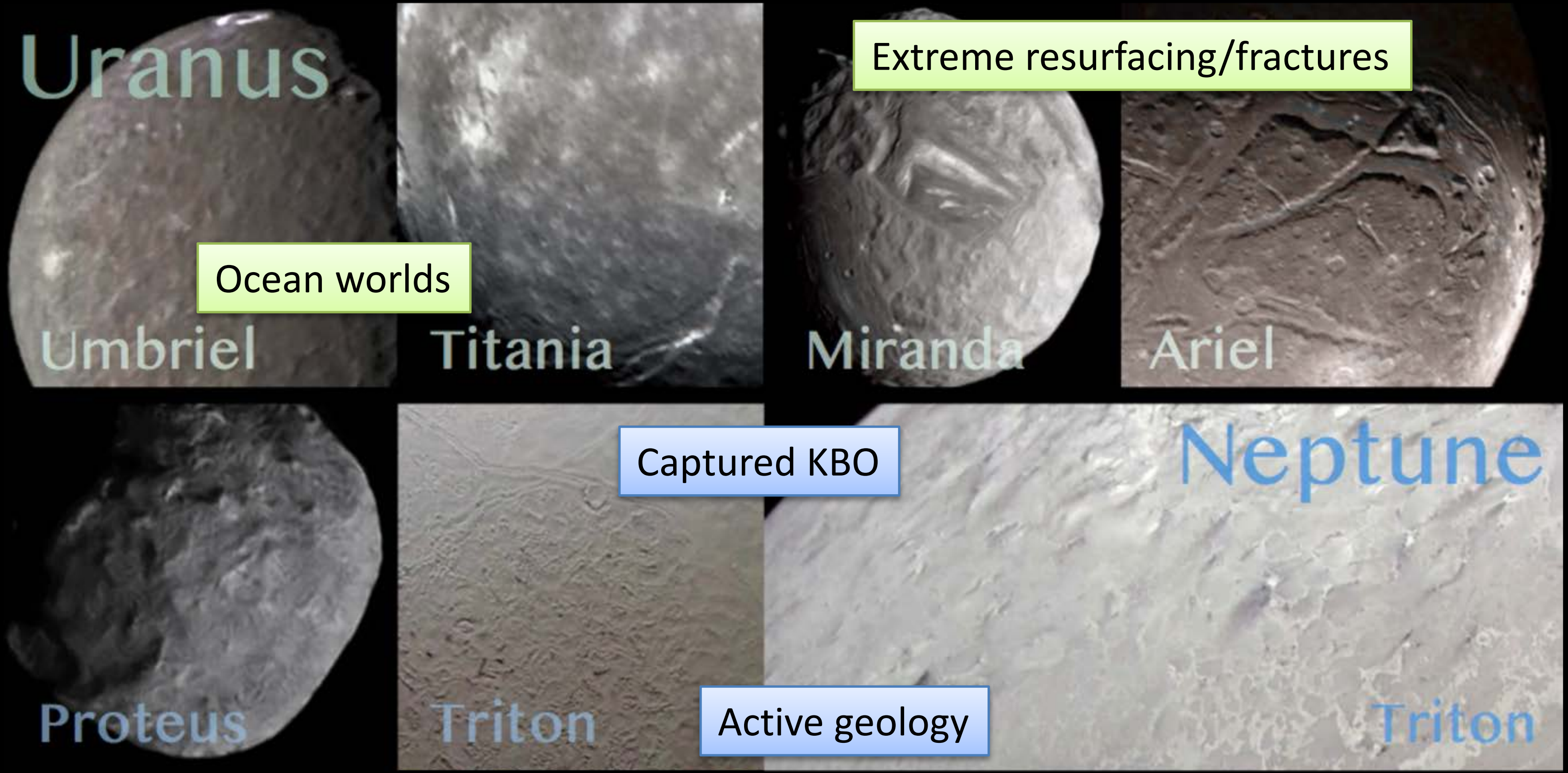


- Extreme seasons of Uranus; dramatic storms of Neptune.
- Slower rotation & smaller size = different dynamical regime to Jupiter/Saturn.

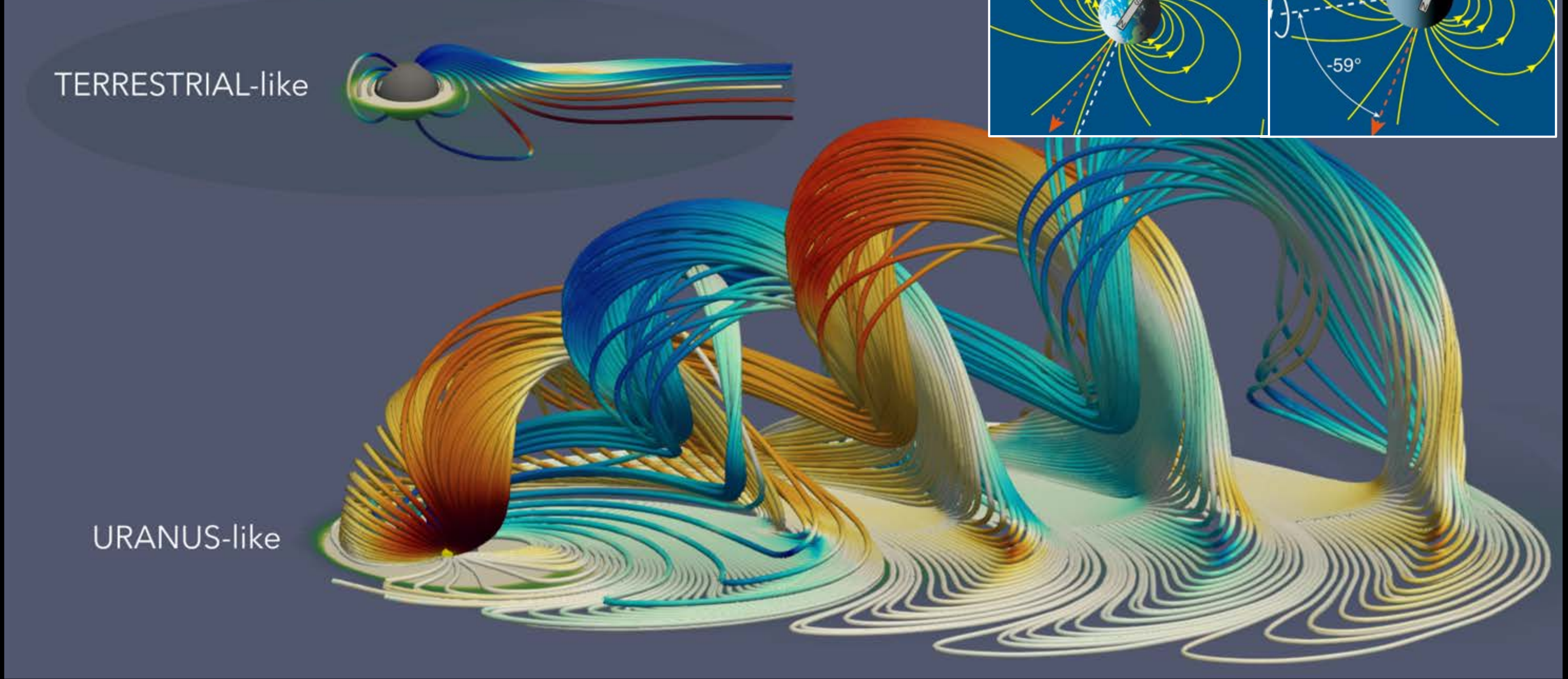
Ice Giant Systems – Rings & Satellites

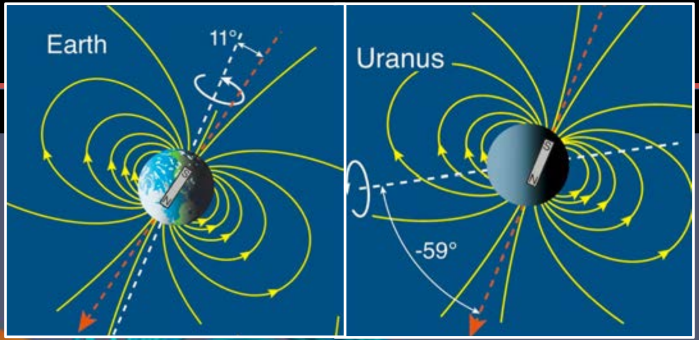


Unique and Active Icy Satellites – Distant Ocean Worlds

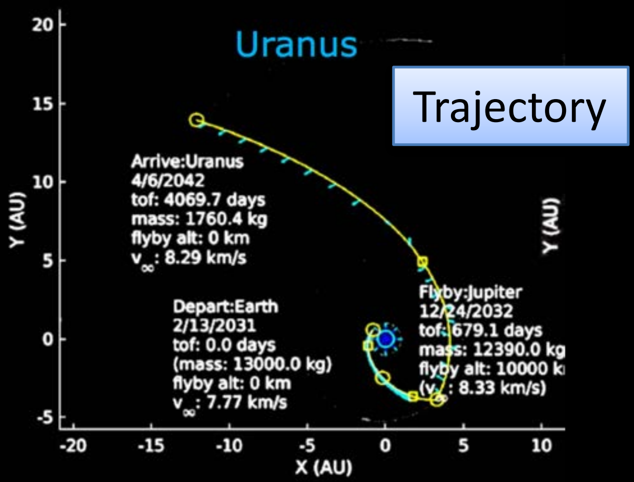


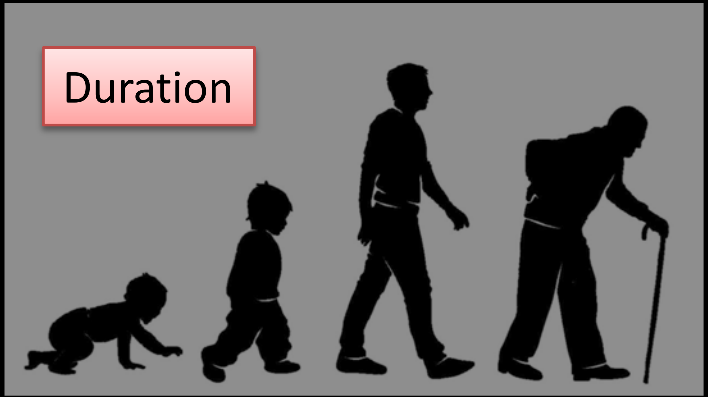
Extreme Magnetospheres

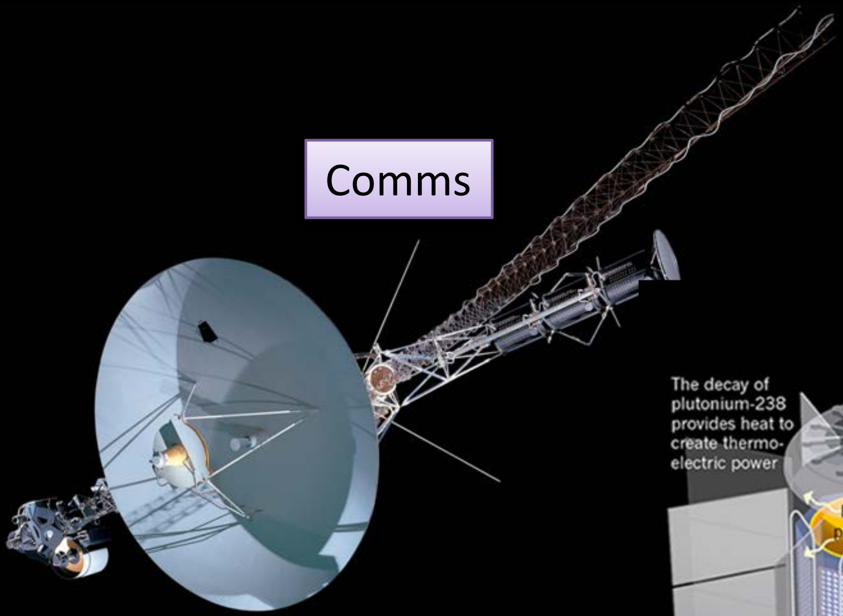


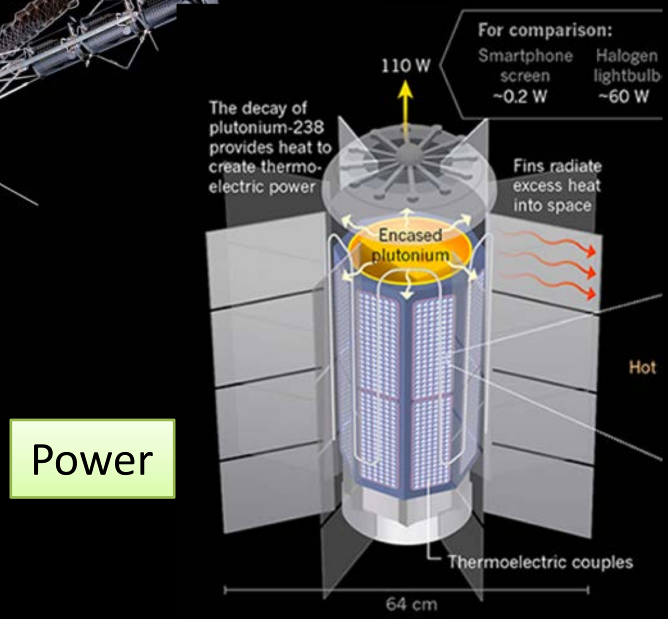


Challenges of Ice Giant Missions

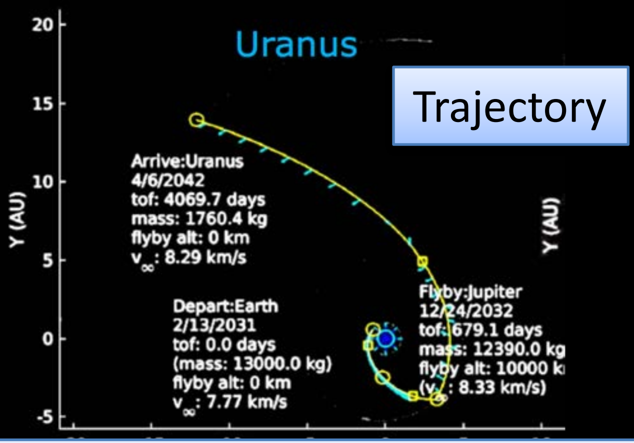


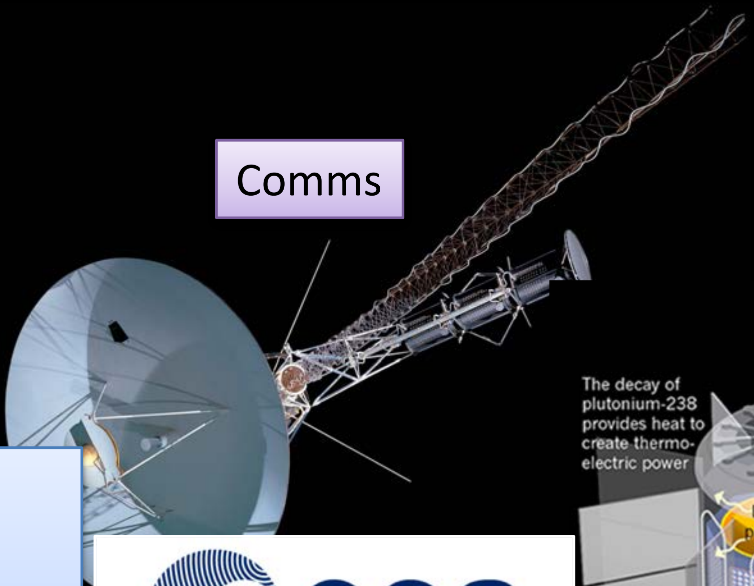


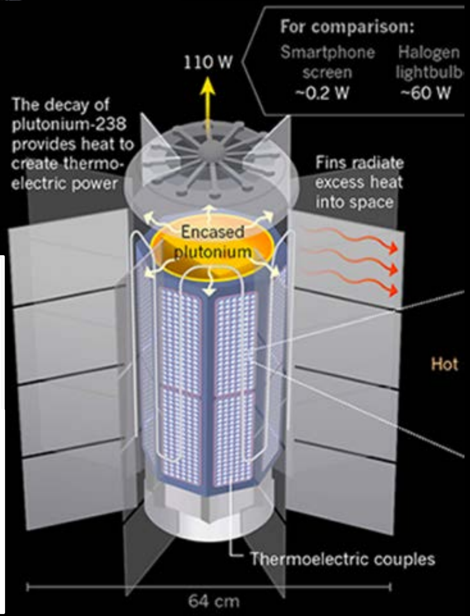




Challenges of Ice Giant Missions





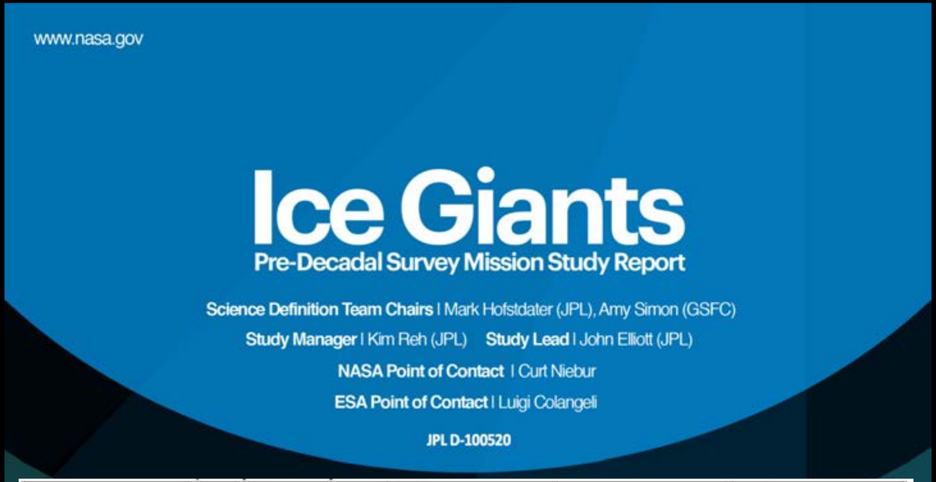


ESA Senior Survey Committee (2013) recommendation:

"Study of the icy giants to be a theme of very high science quality and perfectly fitting the criteria for an L-class mission"

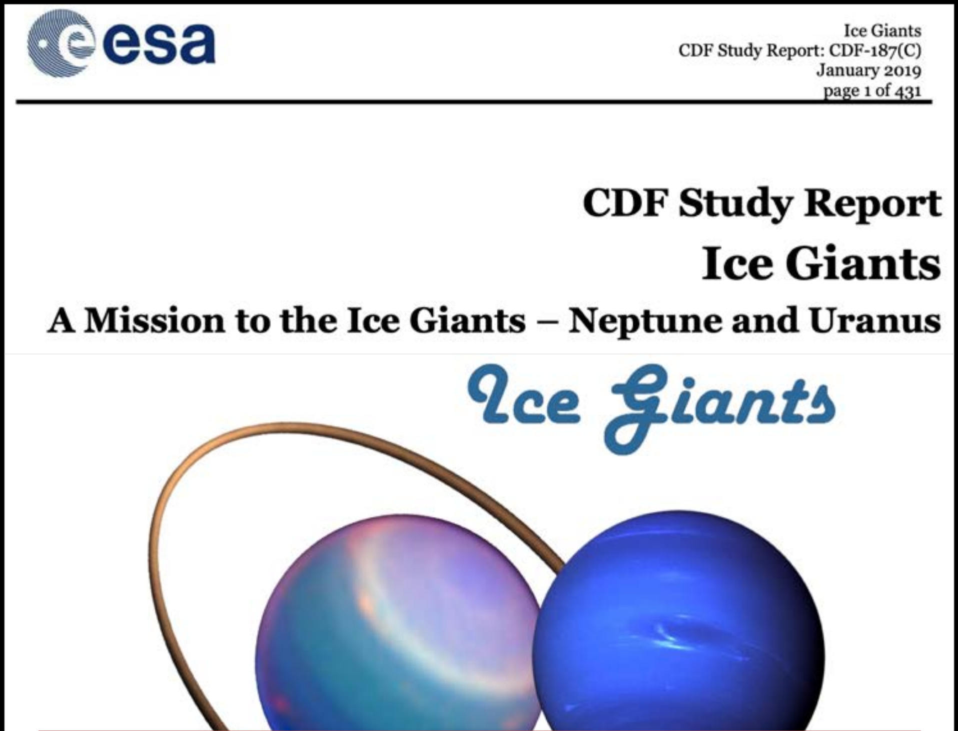
"…recommends that every effort is made to pursue this theme through other means, such as cooperation on missions led by partner agencies."

Maturation of Concepts through Joint Studies



Case Description	Neptune Orbiter with probe and ~50 kg science payload. Includes SEP stage for inner solar system thrusting.	Uranus Flyby with probe and ~50 kg science payload. Chemical only mission.	Uranus Orbiter with probe and ~50 kg science payload. Chemical only mission.	Uranus Orbiter without a probe, but with ~150 kg science payload. Chemical only mission.

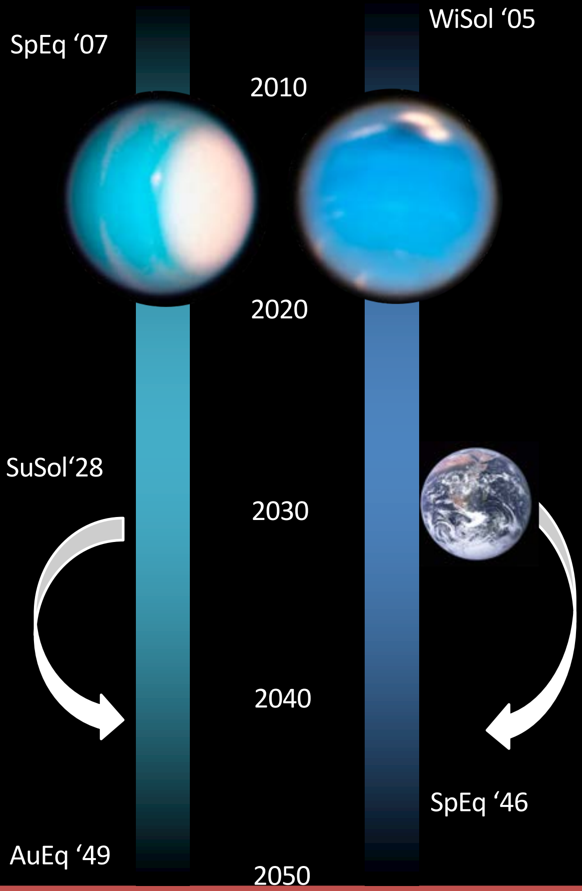
- US Decadal Survey 2021-22
- Pre-Decadal Studies – Neptune Odyssey



- Space19+ M* Mission Opportunity
- Voyage 2050 Process

Key Conclusion: Best Opportunities 2029-2034

- **Active science during 2030s and 40s.**
- Mission feasible with chemical propulsion:
  - Jupiter GA windows every 12-13 years.
  - **2030-34 for Uranus** (northern solstice ‘28; equinox ‘49) – a 2040s launch would capture the same hemispheres as Voyager 2.
  - **2029-30 for Neptune** (southern solstice ‘05; equinox ‘46) – a 2040s launch could miss Triton’s high-latitude plumes.
- Characterise a Centaur en route?
- Extend characterization of heliosphere/solar wind propagation out to 20-30AU during cruise.



Onwards to the Ice Giants

Our 20th Century Views of the Ice Giants → **Science Themes for the 21st Century**

ORIGIN & INTERIOR	What does the origin, interior, and divergent evolution of the Ice Giants reveal about the formation of planetary systems?
ATMOSPHERE	What processes shape the atmospheres of intermediate-sized worlds, and why do atmospheric phenomena differ between Uranus and Neptune?
MAGNETOSPHERE	What can we learn about astrophysical plasma processes by studying the highly-asymmetric, fast-rotating Ice Giant magnetospheres?
OCEAN WORLDS	What can Uranus' natural satellites and the captured "Ocean World" Triton reveal about the drivers of active geology and habitability in the outer Solar System?
RINGS	What processes shape the narrow, dusty rings of Ice Giants, and why do they differ from the extensive rings of Saturn?
HELIOPHYSICS	How does the solar wind affect planetary environments in the realm of the Ice Giants?
EXOPLANETS	What can the interiors, atmospheres and magnetospheres of Uranus and Neptune teach us about the most common class of exoplanets?

Future exploration of the ice giants

Scientific discussion meeting

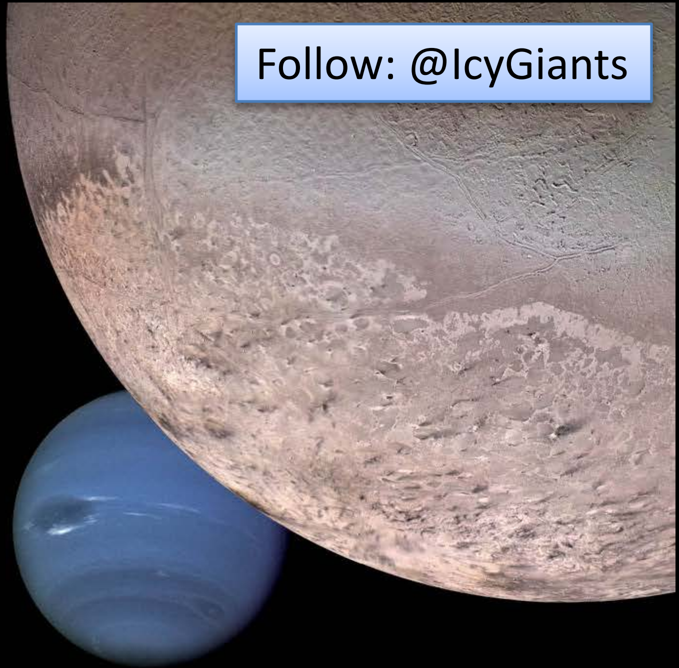
20 – 22 January 2020

Part of the Royal Society scientific programme

#IceGiants2020 @IcyGiants

THE ROYAL SOCIETY

Image: NASA/JPL/USGS.



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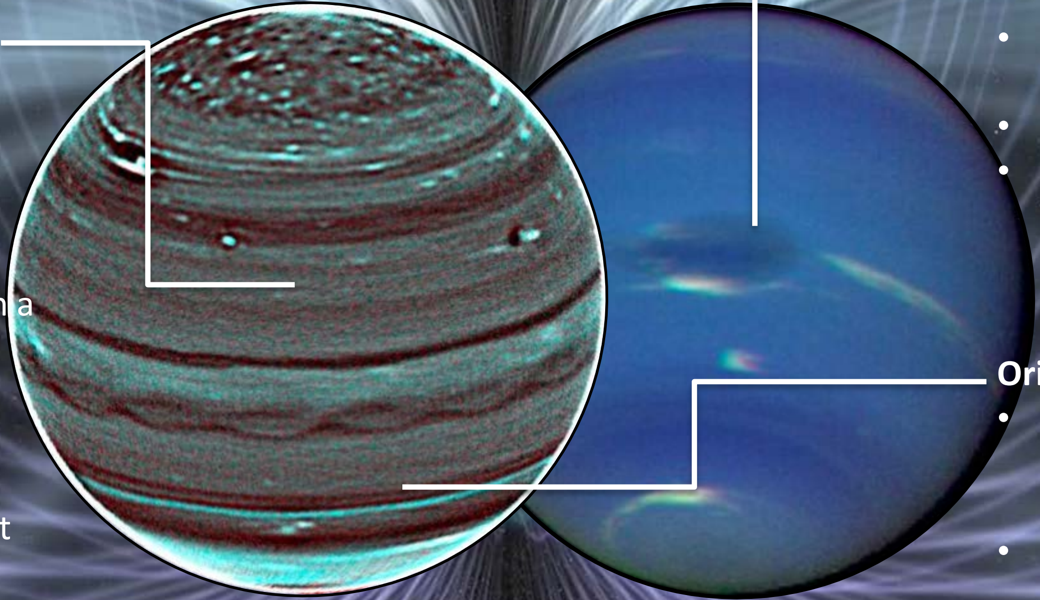
Plenary Talks: Monday-Tuesday 20/21 January 2020 – Royal Society
Poster Session: Monday 20 January 2020
Splinter Sessions: Wednesday January 22 – Burlington House, London.
Full details: https://ice-giants.github.io/
Registration and Abstract Deadline: December 10th 2019

Backup Slides

Exoplanets in Our Backyard

Same planetary radius ≠ same planetary type!

Magnetospheric Insights:
- Eccentric and complex orbit/rotation is commonplace.
- Radio emission, magnetospheric transport resulting from a complex orientation .
- Stability/strength of radiation belts.
- Dynamo mechanism – predictions of exoplanet mag field.



Atmospheric Insights:
- Size/rotation determines dynamical regime.
- Chemistry in ice-rich atmospheres.
- Clouds at low-T.
- Composition from atmosphere to interior.

Origins Insights:
- Solve "fine-tuning" problem to understand core accretion.
- Interior composition reflecting formation mechanism.