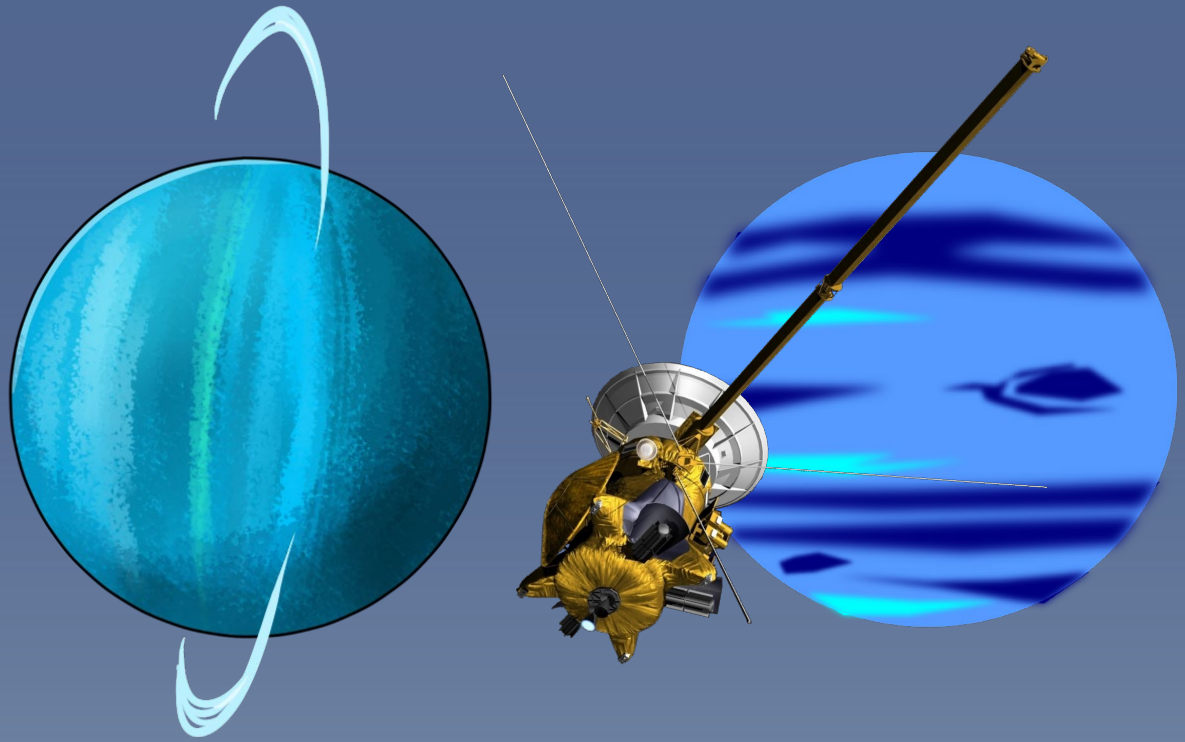
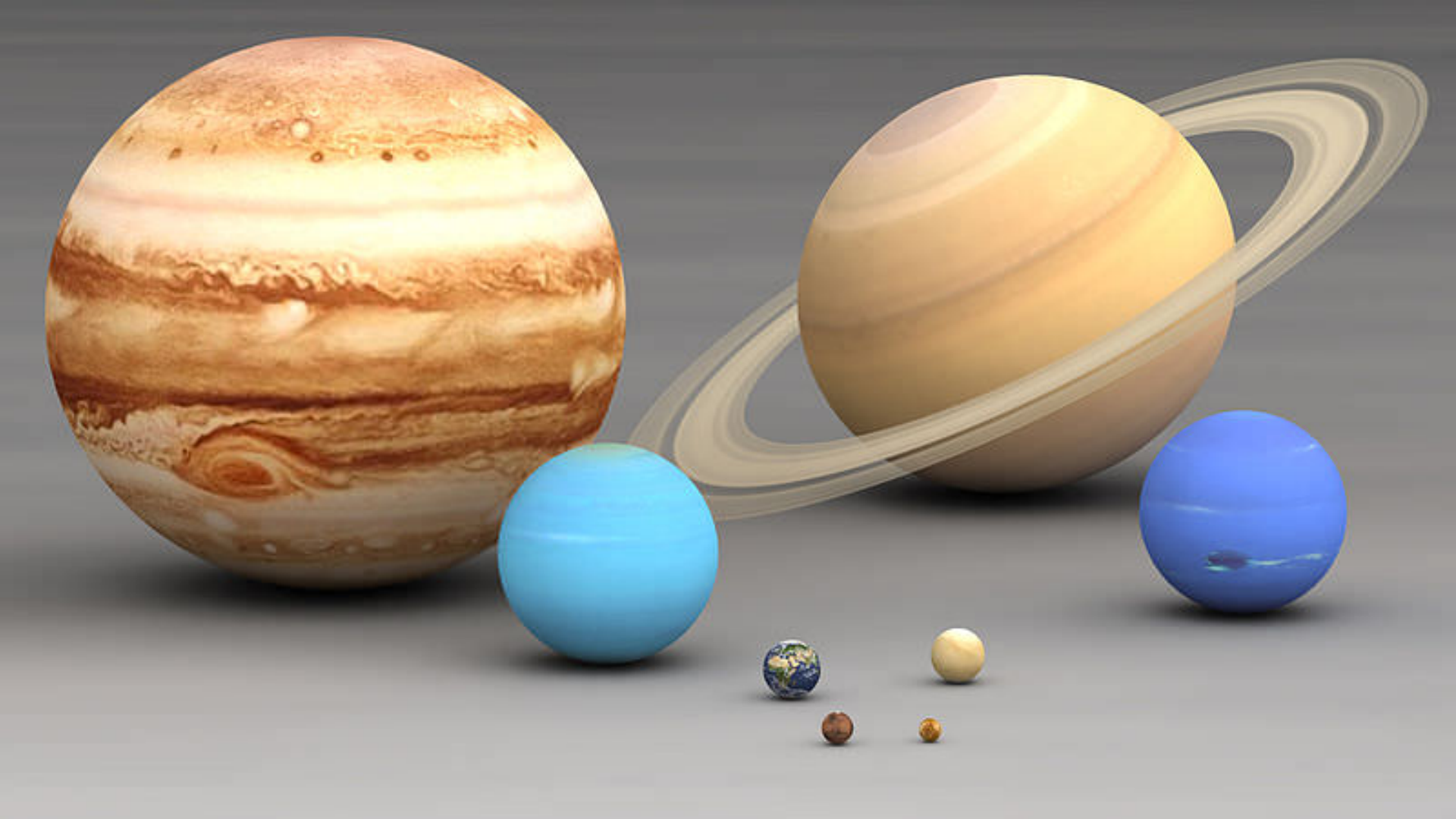
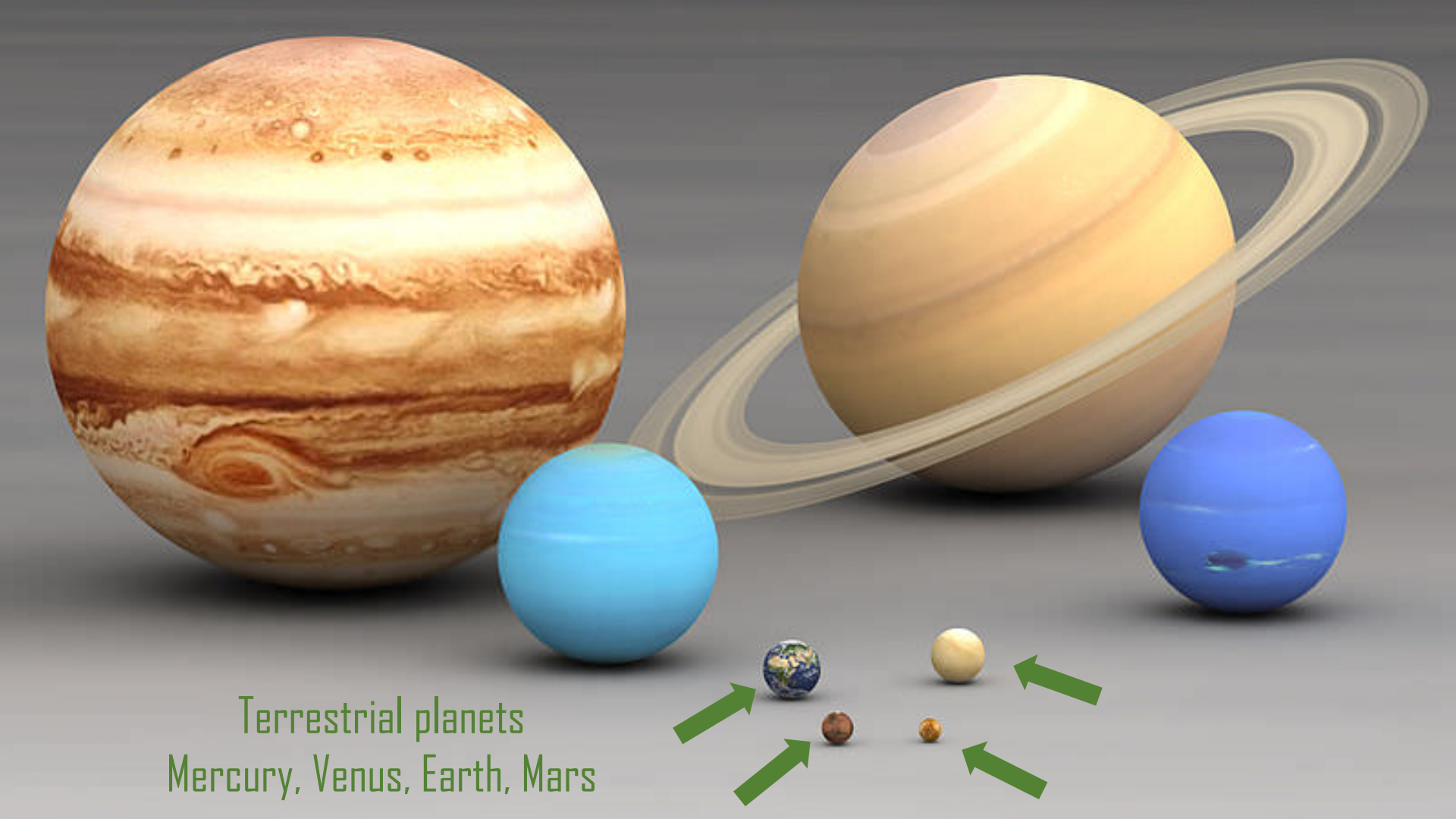


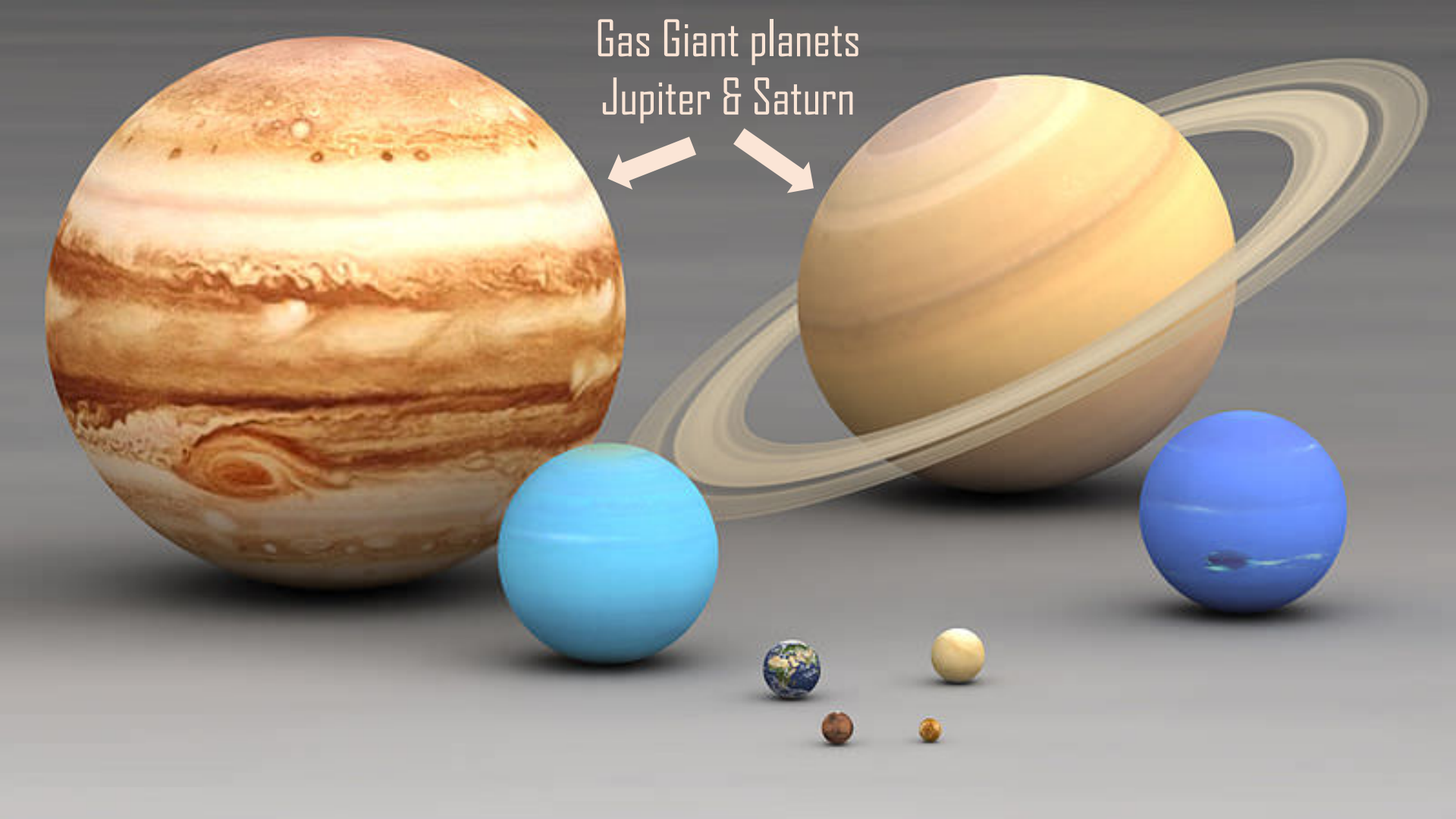
Heidi B. Hammel
AURA
Washington, DC, USA

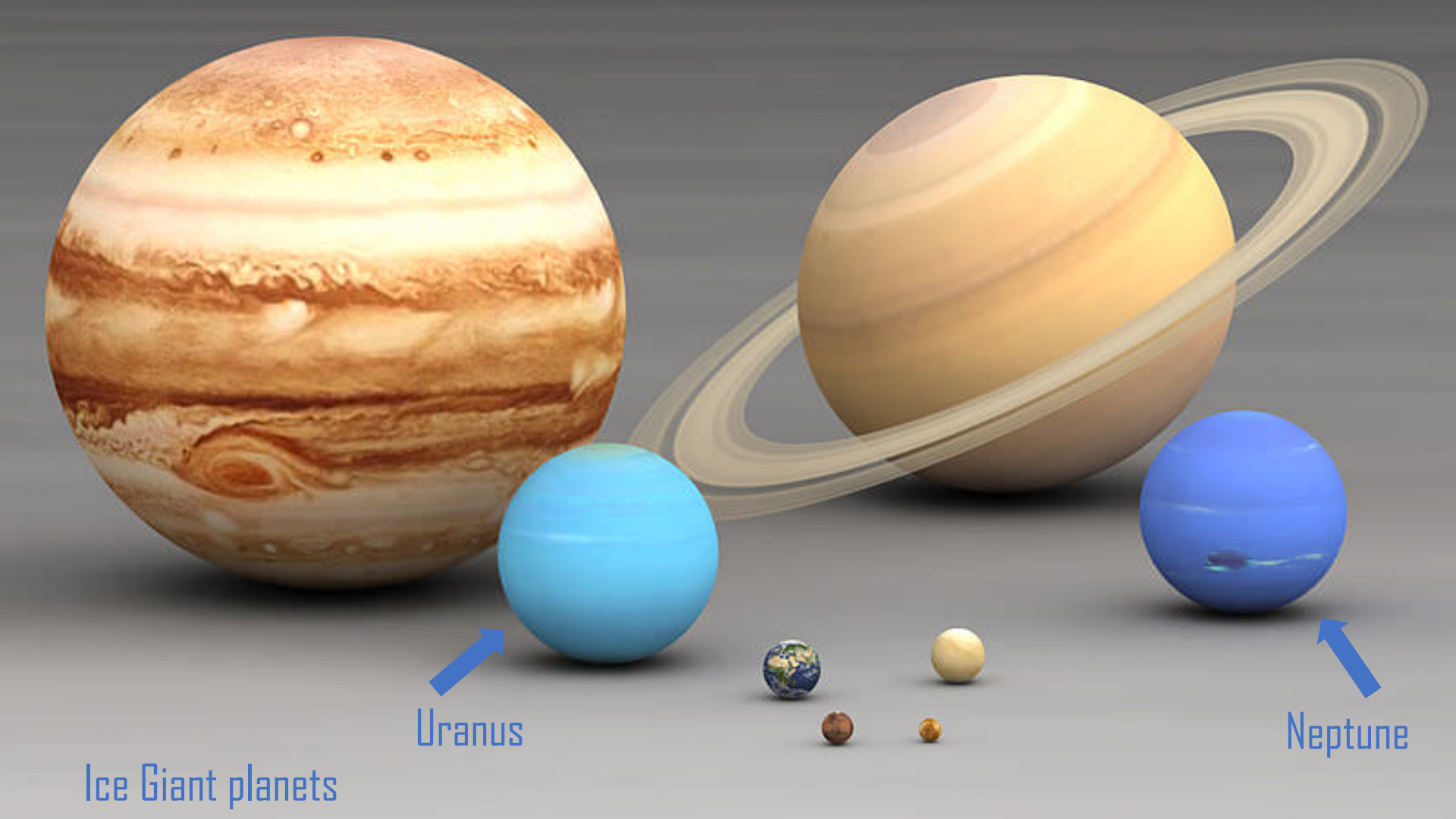
Exploration of the Ice Giants

16th Appleton Space Conference



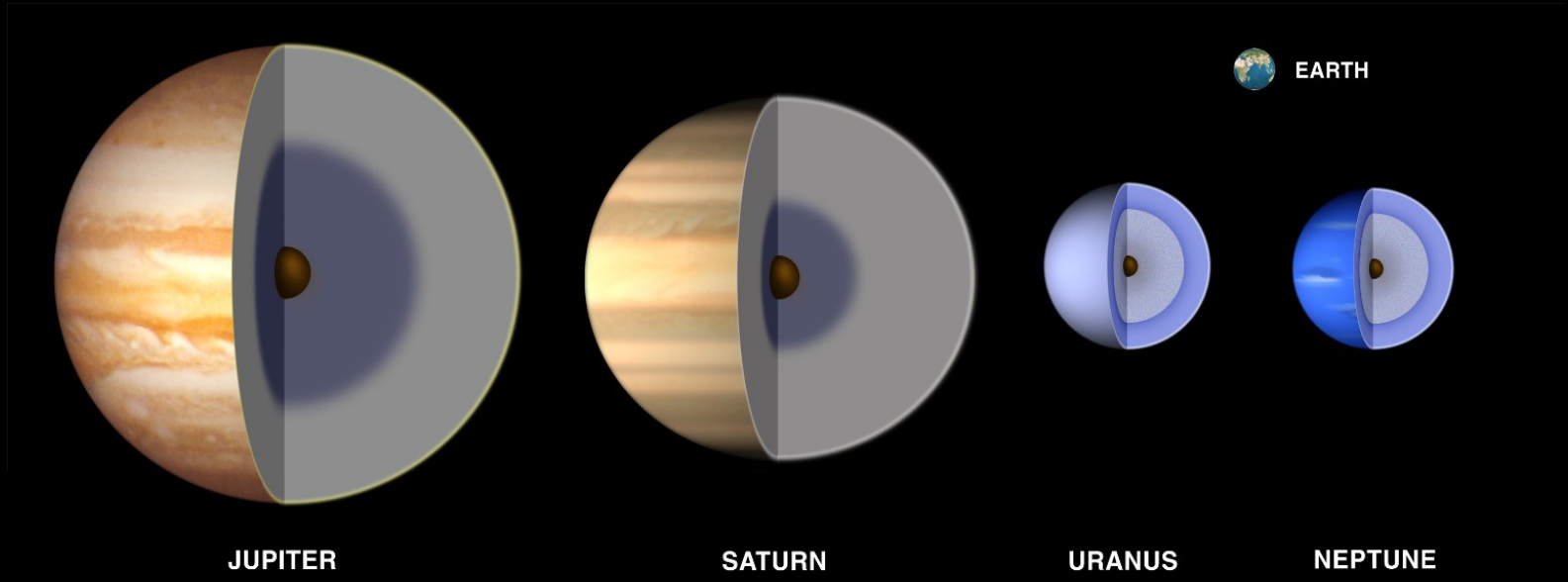

Terrestrial planets
Mercury, Venus, Earth, Mars

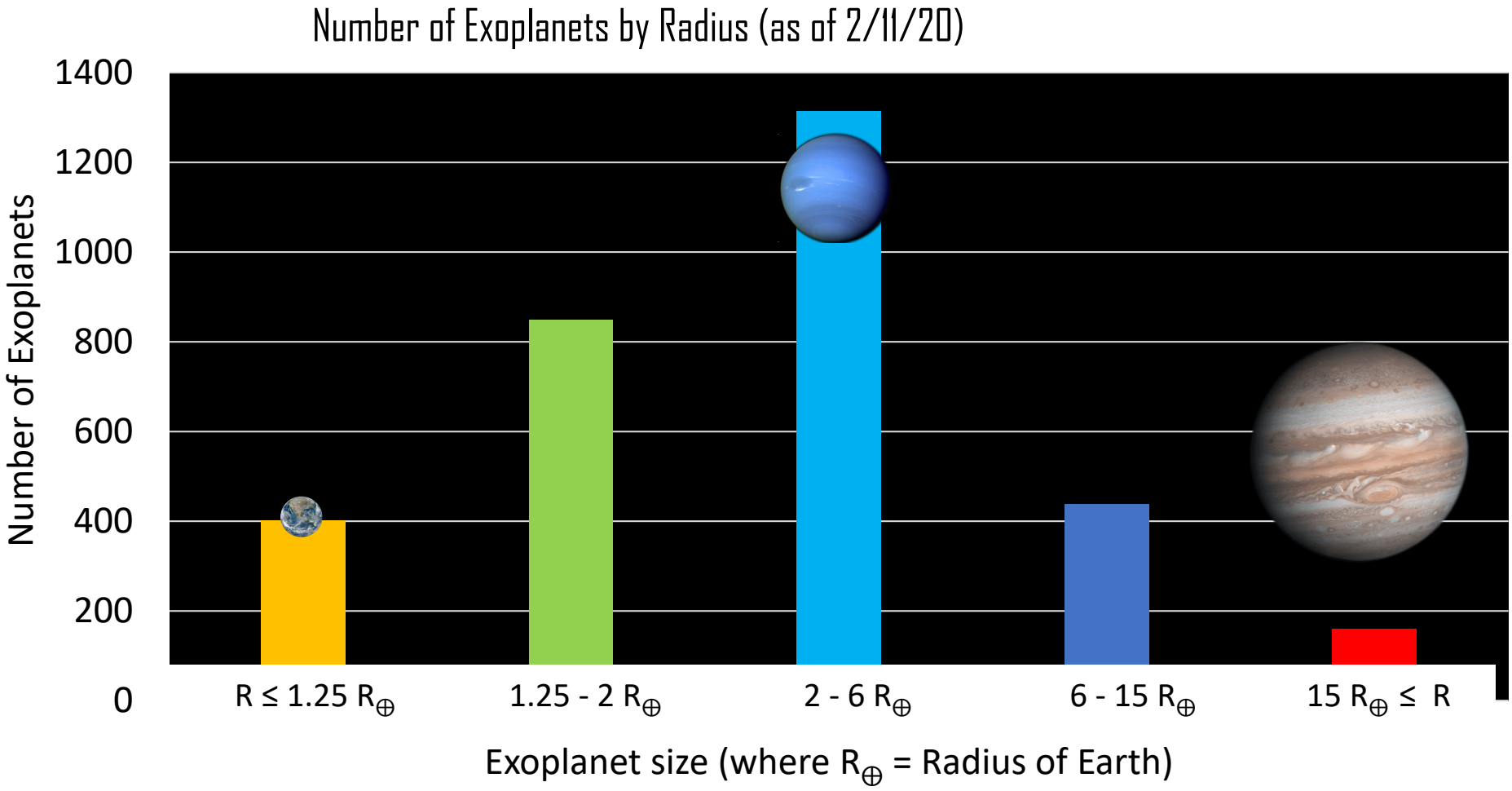

Gas Giant planets
Jupiter & Saturn



Ice Giant planets

What are ICE GIANTS?




Number of Exoplanets by Radius (as of 2/11/20)
1400
1200
1000
800
600
400
200
0
Number of Exoplanets
R ≤ 1.25 R⊕
1.25 - 2 R⊕
2 - 6 R⊕
6 - 15 R⊕
15 R⊕ ≤ R
Exoplanet size (where R⊕ = Radius of Earth)


THE SUN
MERCURY
VENUS
EARTH
THE MOON
MARS
PHOBOS
1 CERES
JUPITER
SATURN
URANUS
NEPTUNE
PLUTO
CHARON
2685 MASURSKY
5535 ANNEFRANK
243 IDA
951 GASPRA
67P/C-G
433 EROS
4 VESTA
19P/BORRELLY
253 MATHILDE
81P/WILD
132524 APL
2867 ŠTEINS
21 LUTETIA
103P/HARTLEY
9P/TEMPEL
9969 BRAILLE
4179 TOUTATIS
26P/GRIGG-SKJELLERUP
1P/HALLEY
25143 ITOKAWA
21P/GIACOBINI-ZINNER
GANYMEDE
CALLISTO
IO
EUROPA
AMALTHEA
PROMETHEUS
EPIMETHEUS
TELESTO
HELENE
CALYPSO
JANUS
PALLENE
IAPETUS
METHONE
RHEA
DIONE
HYPERION
TETHYS
POLYDEUCES
MIMAS
ENCELADUS
TITAN
PHOEBE
1 Venus
2 Venus
3 The Moon
4 The Moon
5 The Moon
6 Mars
7 Mars
8 The Sun
9 Jupiter
10 The Sun
11 Untargeted
12 Untargeted
13 The Sun
14 19/Halley
15 25143 Itokawa
16 The Sun
17 Mercury
18 4 Vesta, 1 Ceres
19 433 Eros
20 81P/Wild, 9P/Tempel
21 Pluto
22 67P/C-G
23 The Moon
24 The Sun
25 19/Halley
26 19/Halley
27 Venus, Mercury
28 Jupiter, Saturn
29 Jupiter, Saturn, Titan
30 Jupiter, Saturn, Uranus, Neptune
31 Venus, 19/Halley
32 Phobos


THE SUN
MERCURY
VENUS
EARTH
THE MOON
MARS
PHOBOS
1 CERES
JUPITER
GANYMEDE
CALLISTO
IO
EUROPA
AMALTHEA
SATURN
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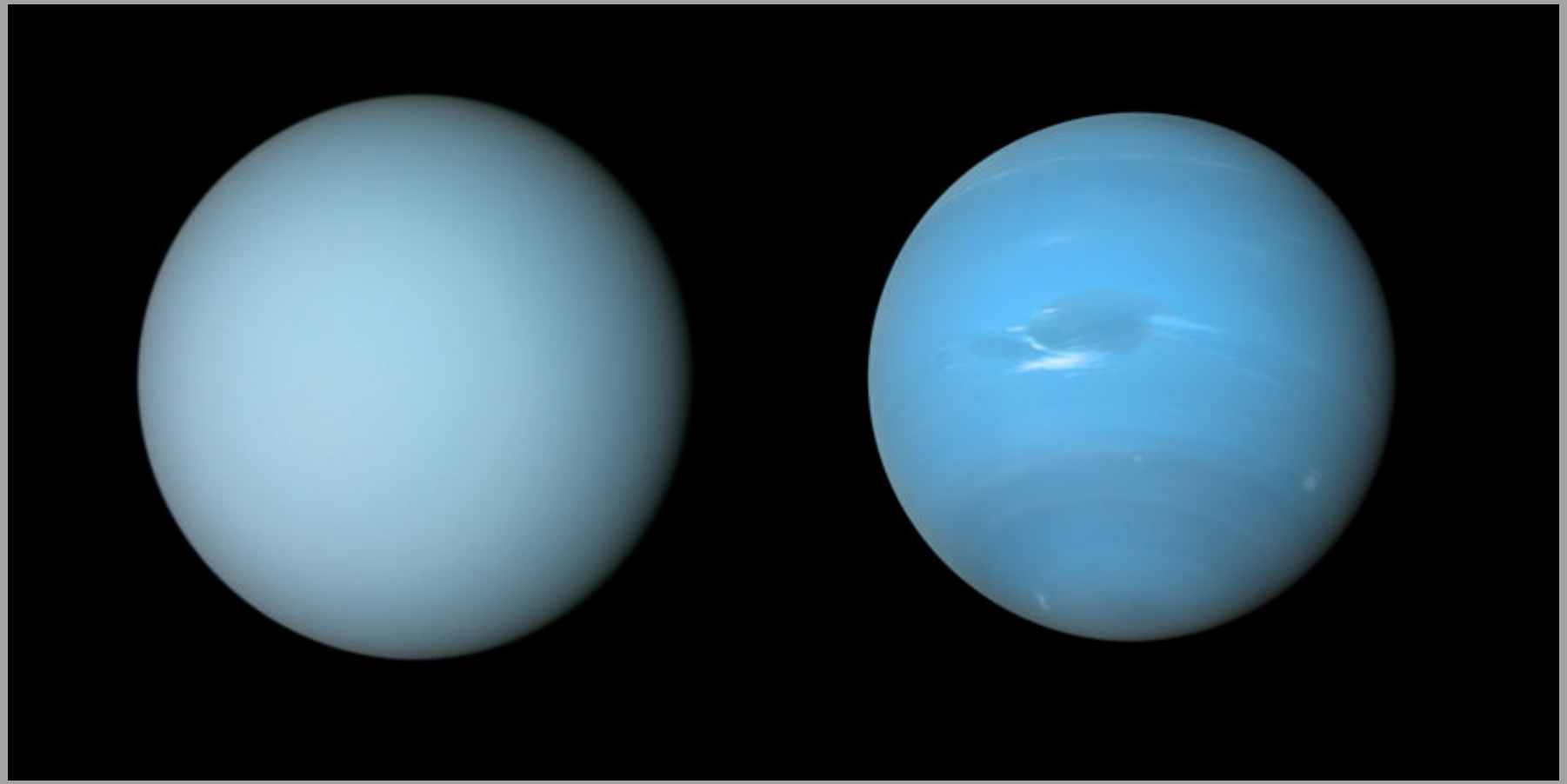
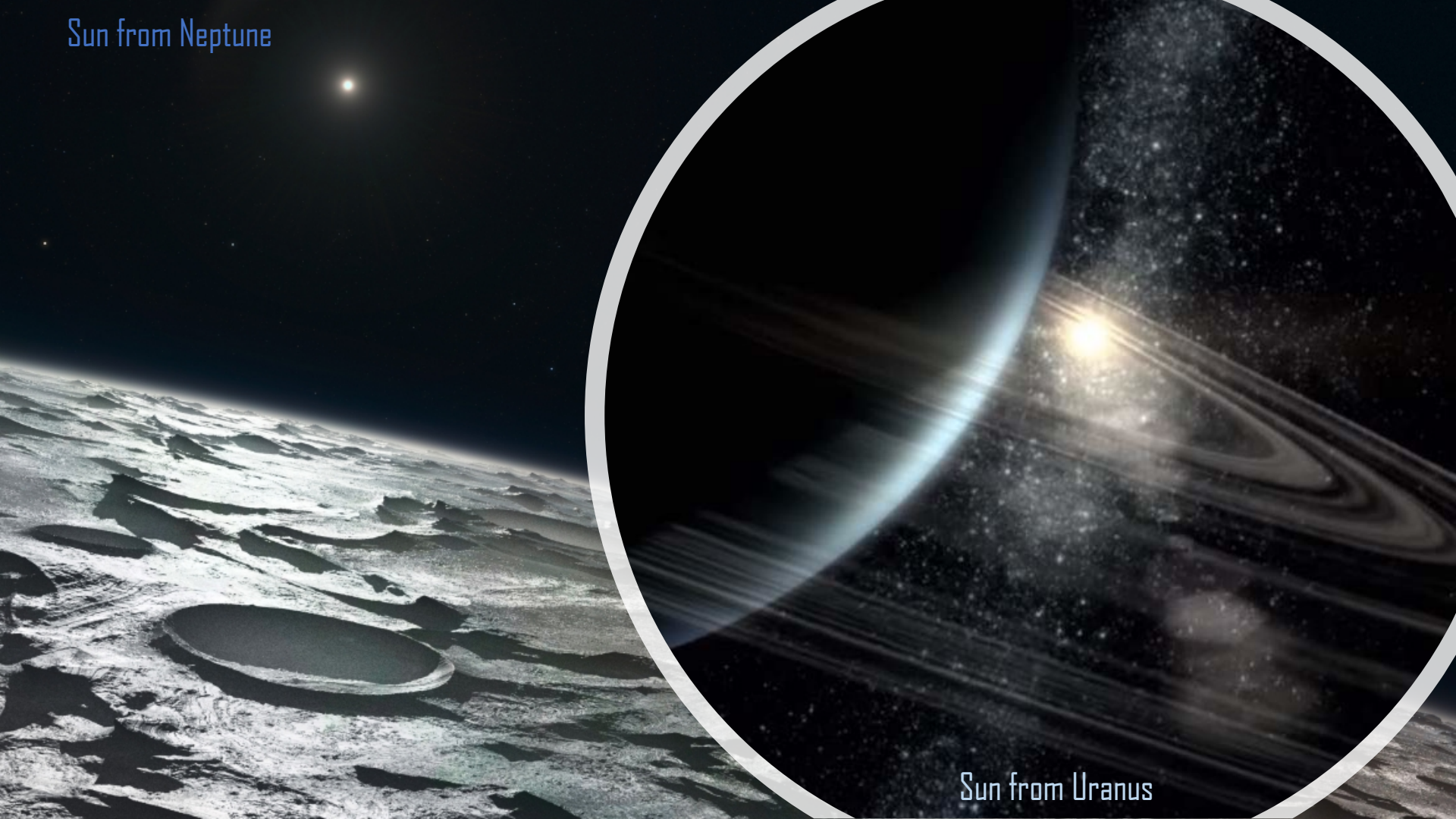
103P/HARTLEY
9P/TEMPEL
9969 BRAILLE
4179 TOUTATIS
Voyager 2
Launched 1977
Uranus flyby 1986
Neptune flyby 1989

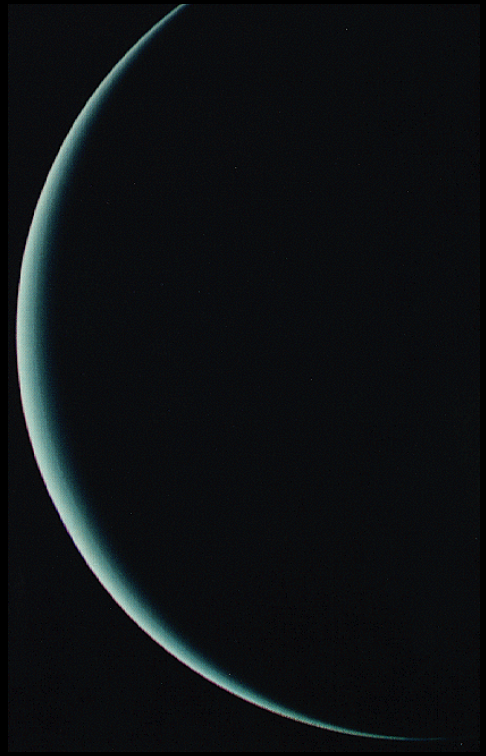


NASA / JPL-Caltech / Björn Jónsson


Sun from Neptune
Sun from Uranus

ICE GIANT ATMOSPHERES

Voyager Uranus in 1986



Smith et al. 1986

Voyager Uranus in 1986

3.8"

Smith et al. 1986

adaptive optics

power of adaptive optics

keck 10-m

mauna kea

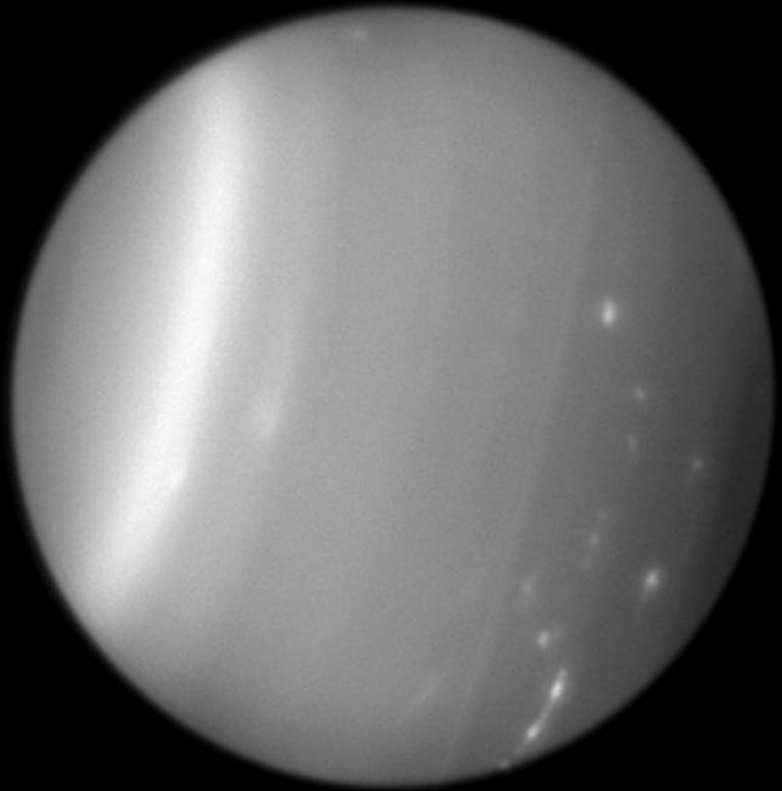
9 july 2004

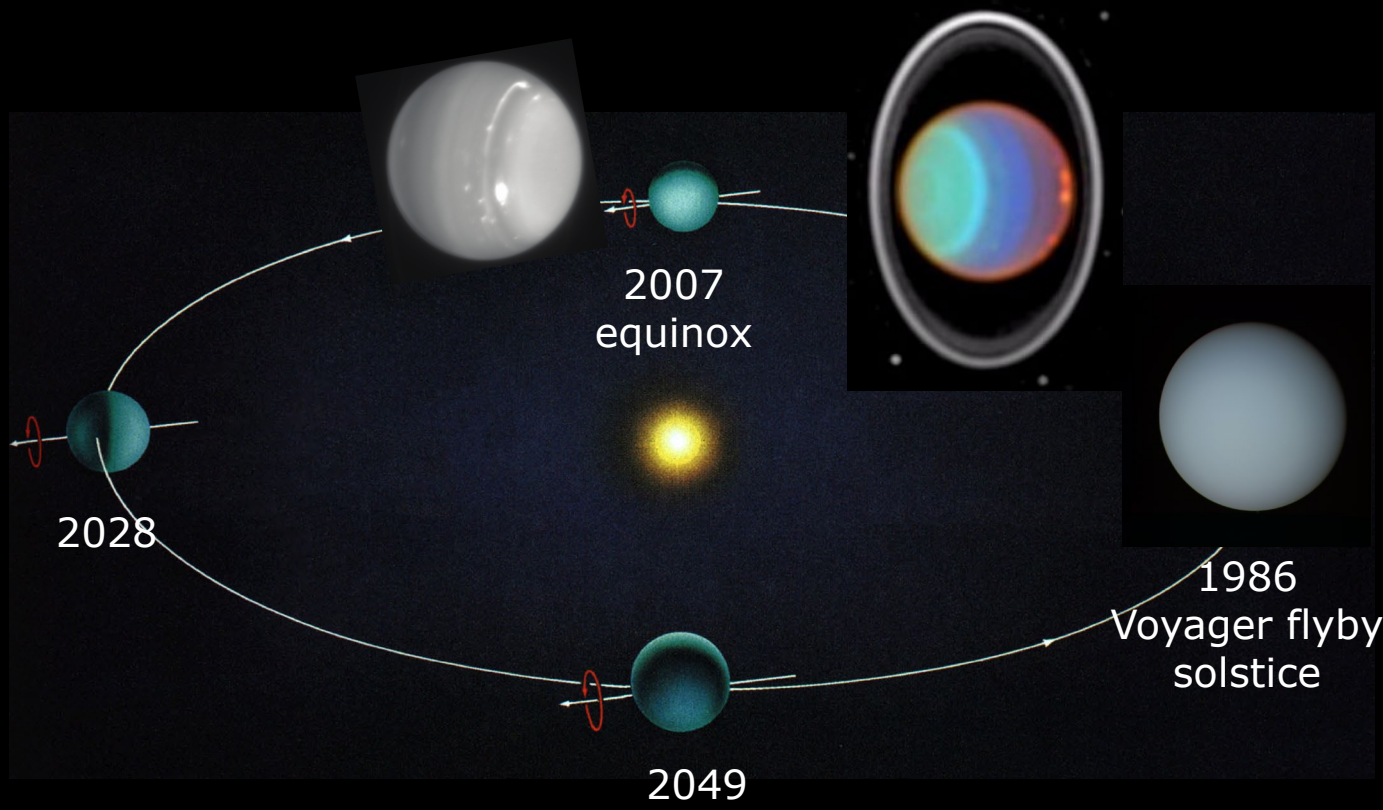
Hammel & de Pater

H (1.6 μm)

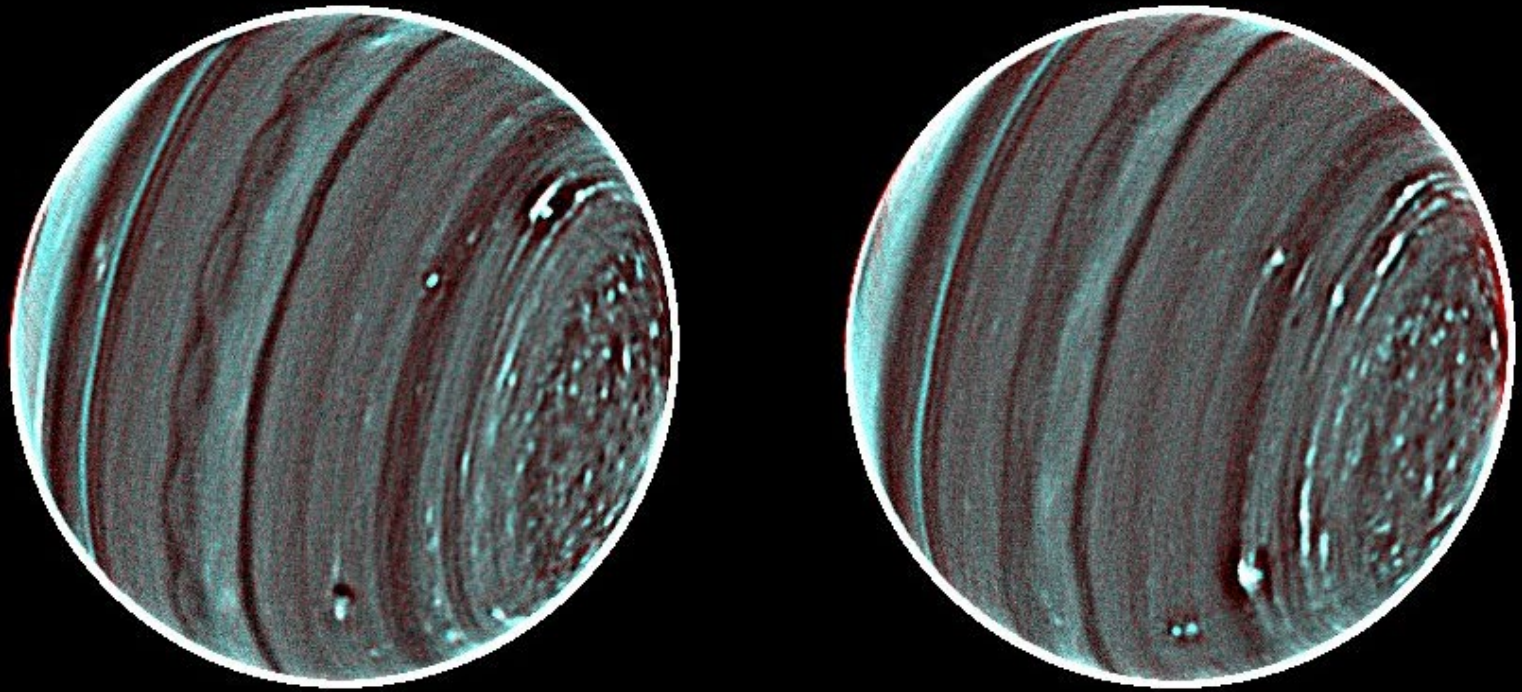
adaptive optics

ON



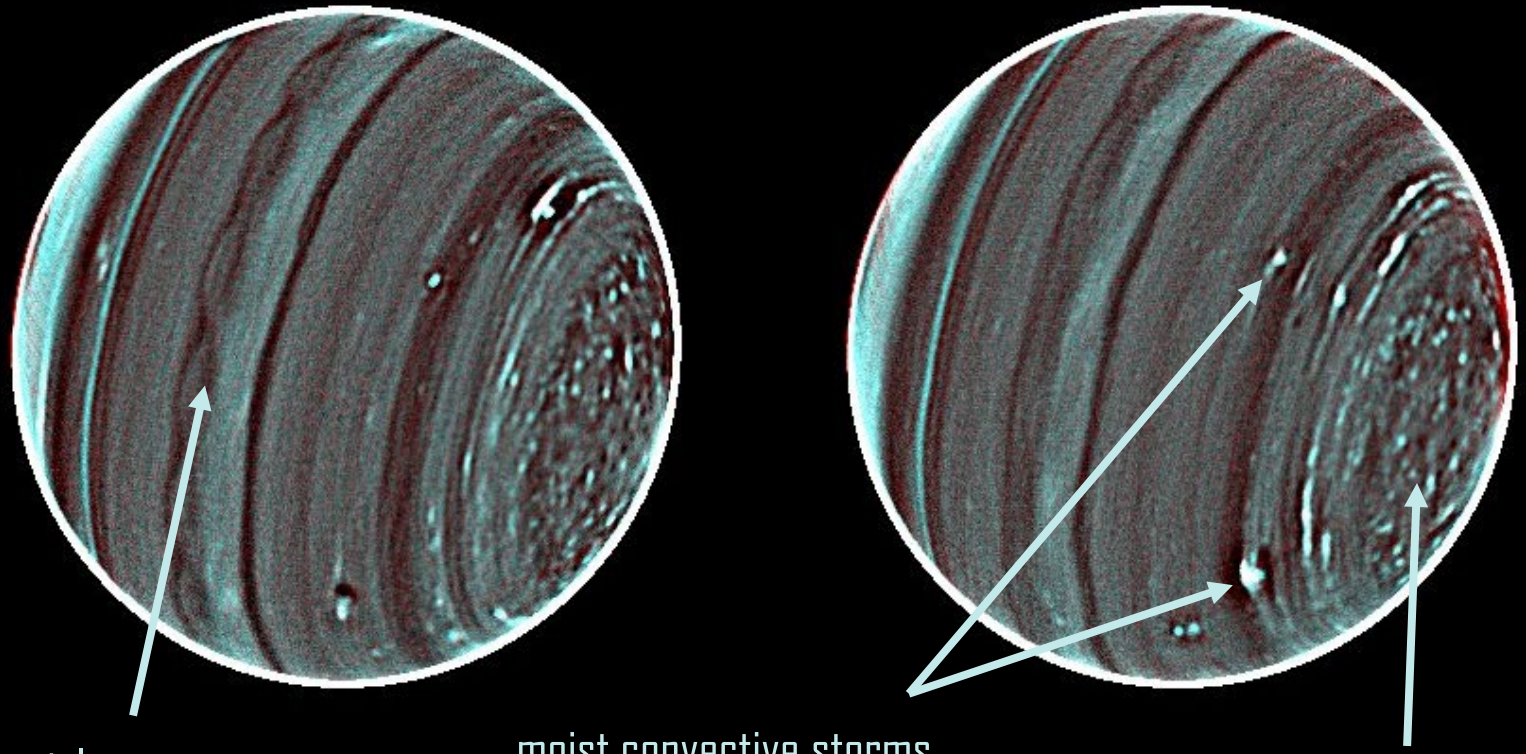

2007
equinox
2028
1986
Voyager flyby
solstice
2049

Keck in 2012 - best maps of Uranus **EVER**

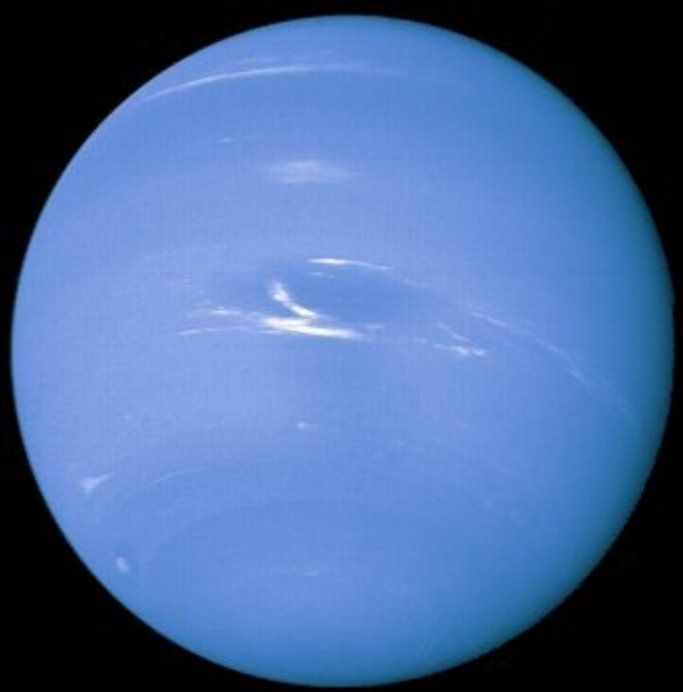


Larry Sromovsky, Pat Fry, Heidi Hammel, Imke de Pater:
Keck Observatory, H band (1.6 microns), July 2012

Keck in 2012 - best maps of Uranus **EVER**

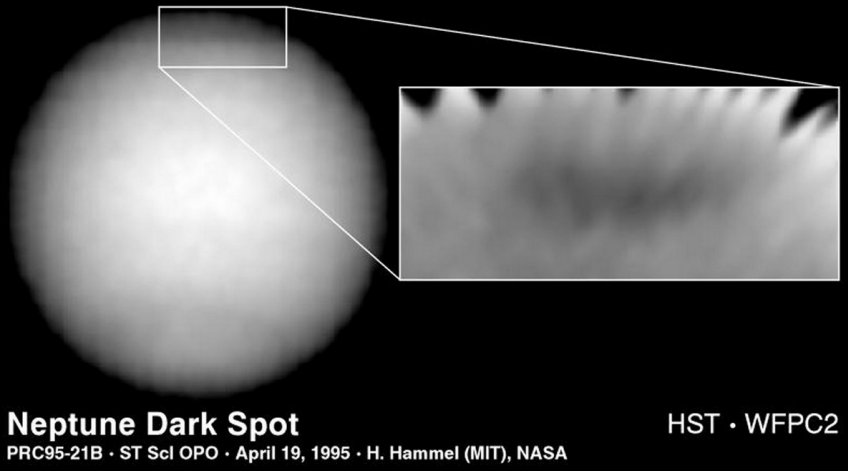


Voyager Neptune in 1989

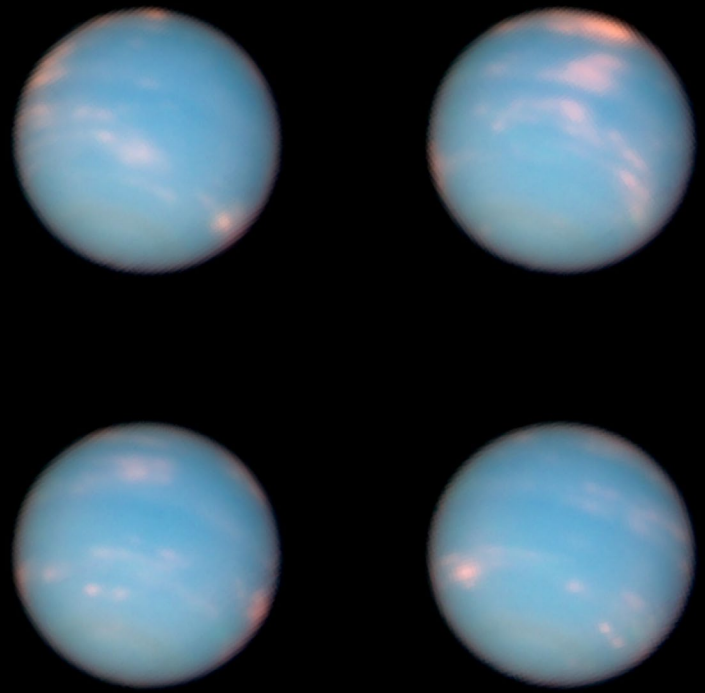


Smith et al. 1989

Neptune with Hubble – remarkably variable atmosphere

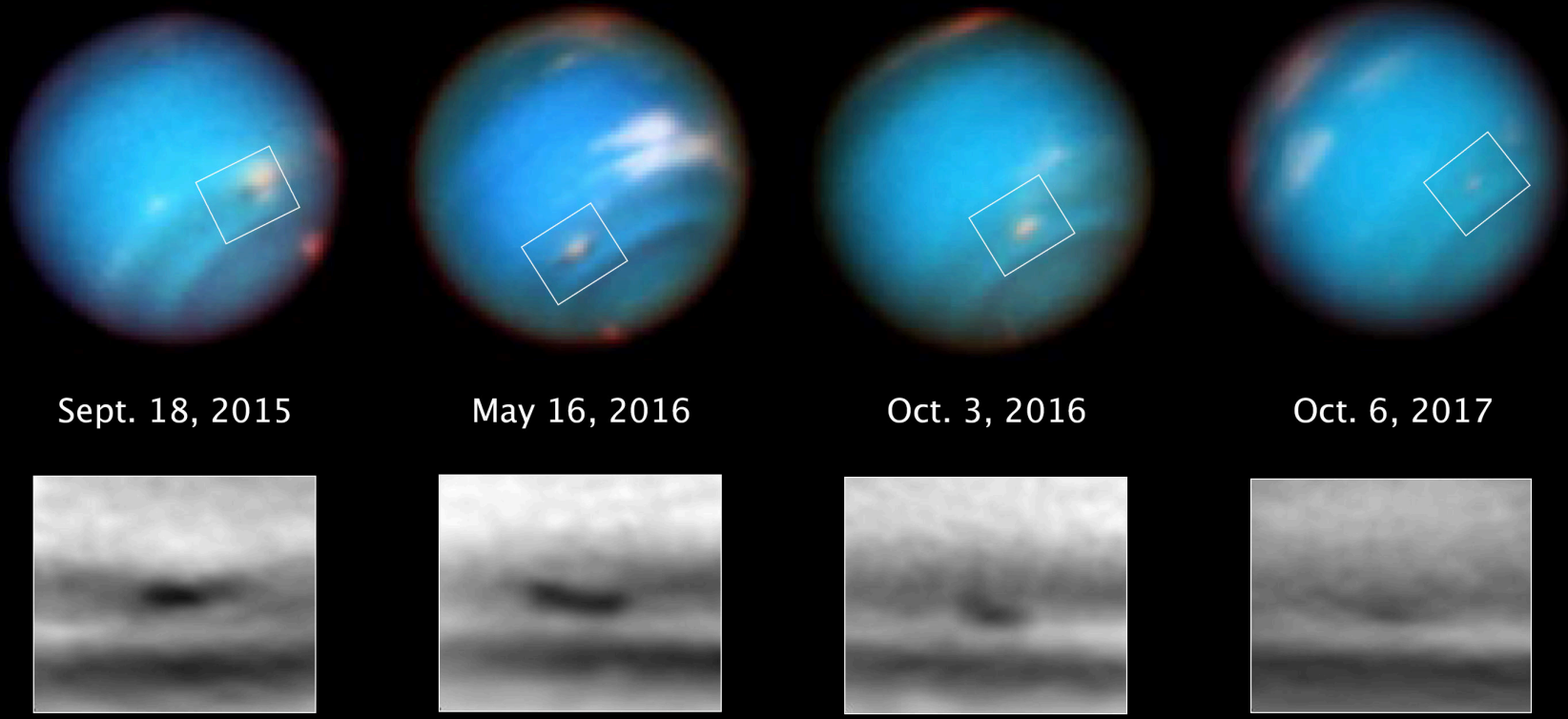


Hubble's first look at Neptune after Voyager in 1994 - the Great Dark Spot gone! A NEW Great Dark Spot seen in northern hemisphere



Neptune anniversary in 2011: in the same location in the sky where it was discovered nearly 165 years earlier (and no Great Dark Spot)

Neptune with Hubble – remarkably variable atmosphere



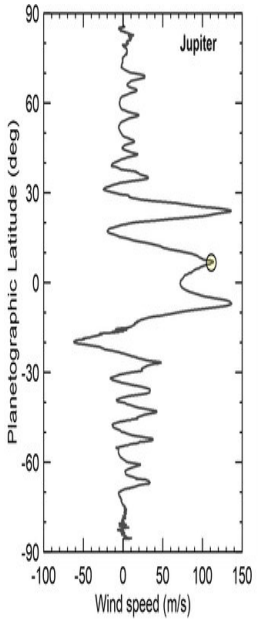
2015-2017: Hubble watches the evolution of a Neptune variable Great Dark Spot

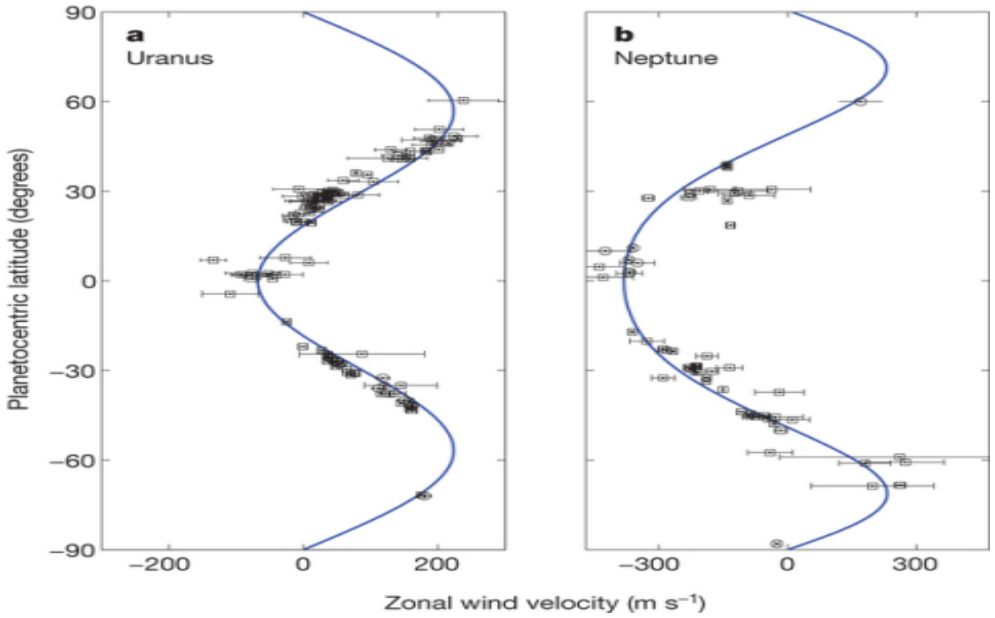
Wild winds on Ice Giants

Neptune: fastest winds in the solar system! What drives them?!?

relative speeds of almost 600 m/s (2,200 km/h = 1,300 mph) - nearly reaching *supersonic* flow

Also note: Uranus* and Neptune very similar *asymmetry





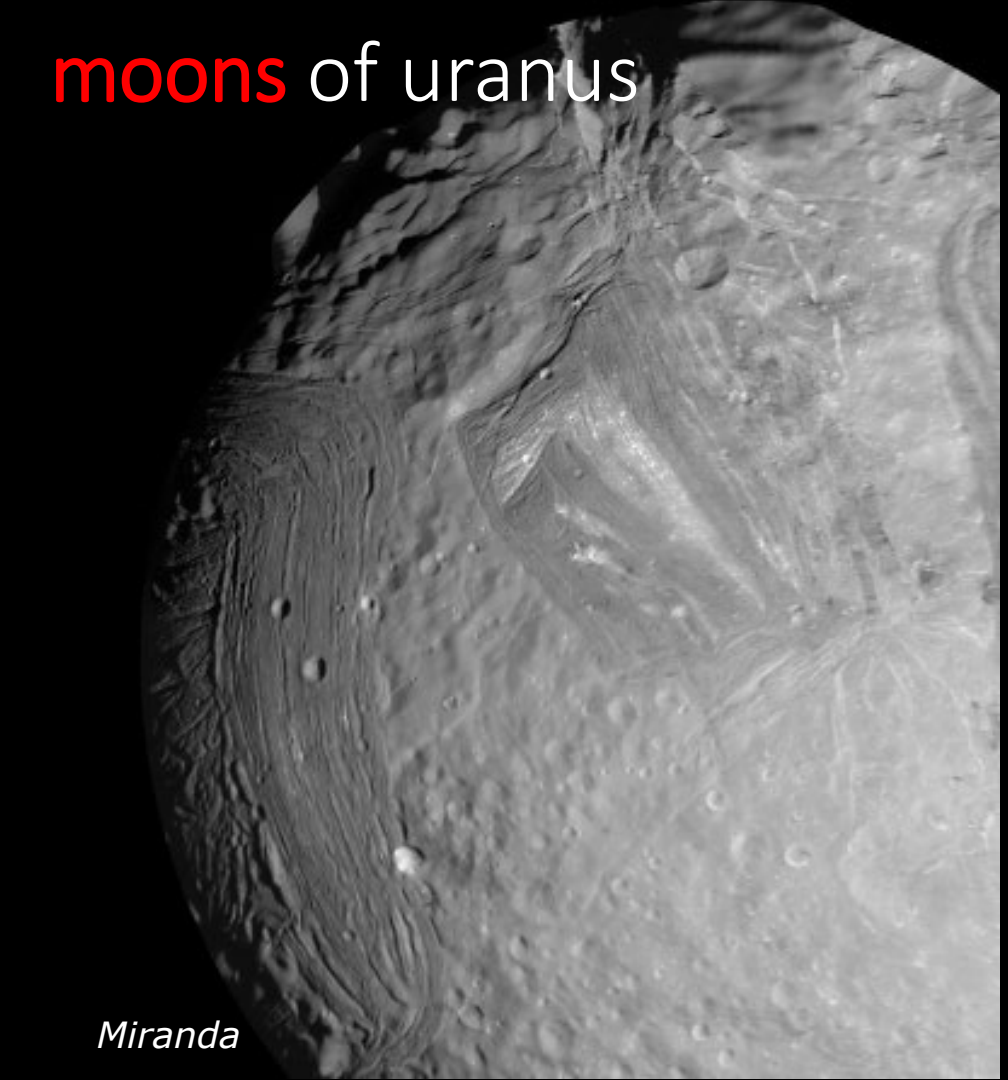
prograde
midlatitude jetstream

retrograde
equatorial jetstream

prograde
midlatitude jetstream

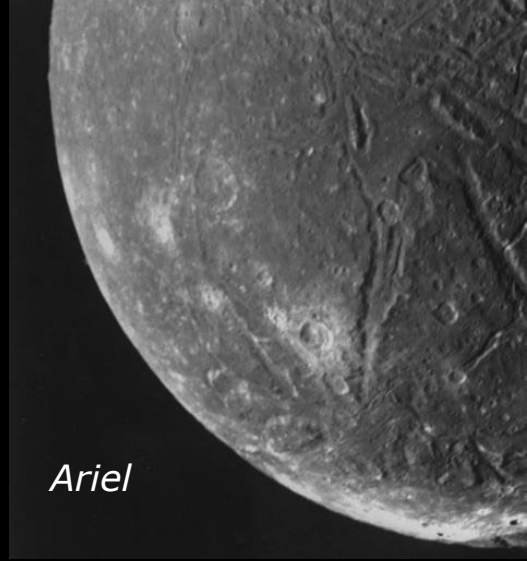
MOONS

moons of uranus



Miranda

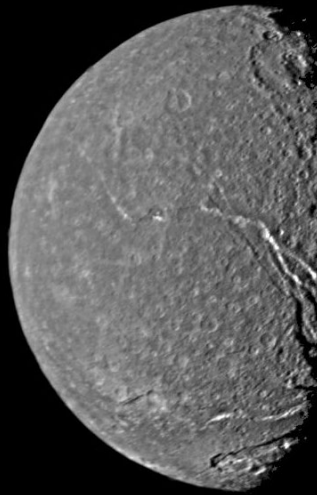
Umbriel



Ariel

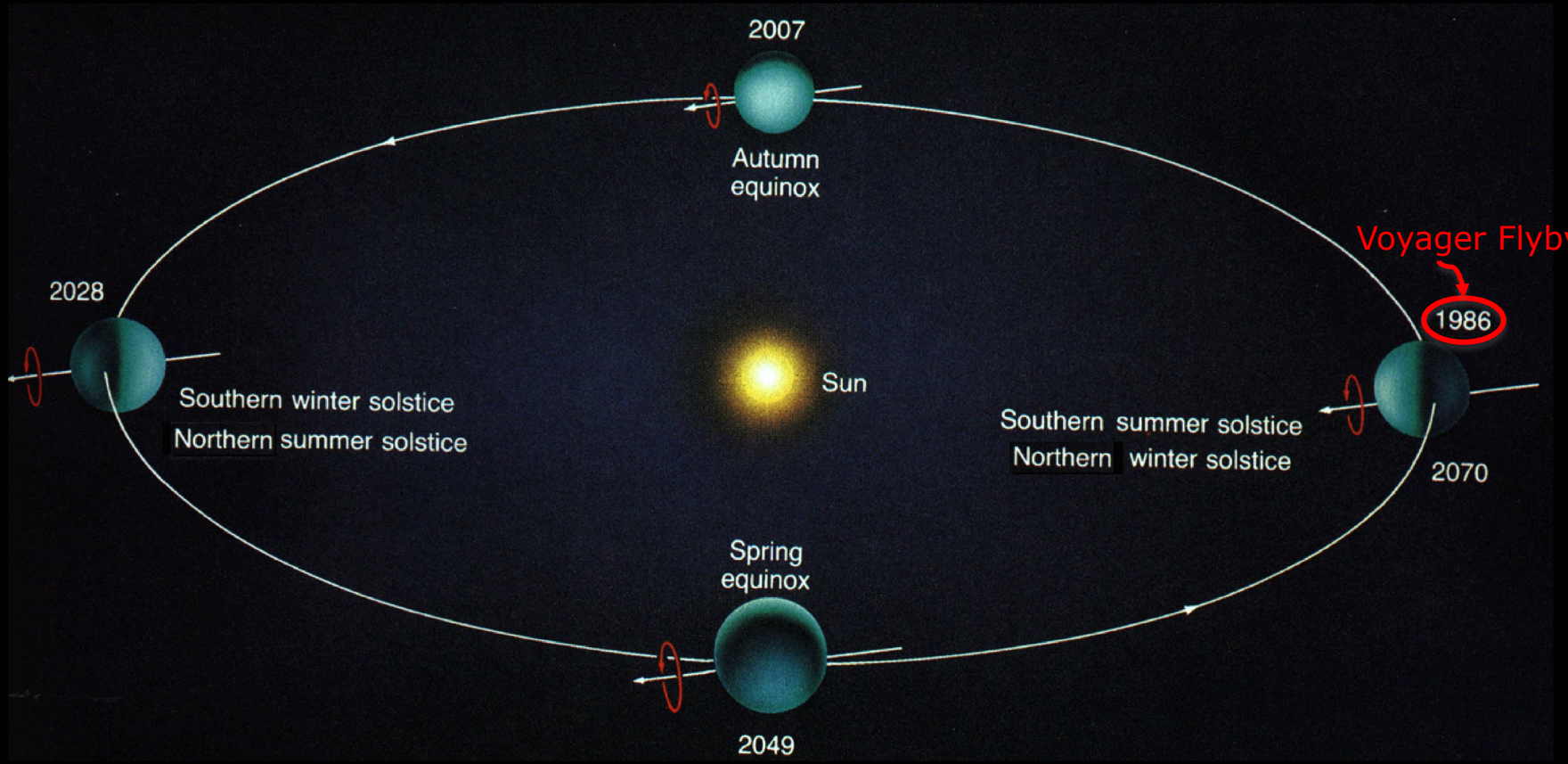
Oberon

Puck

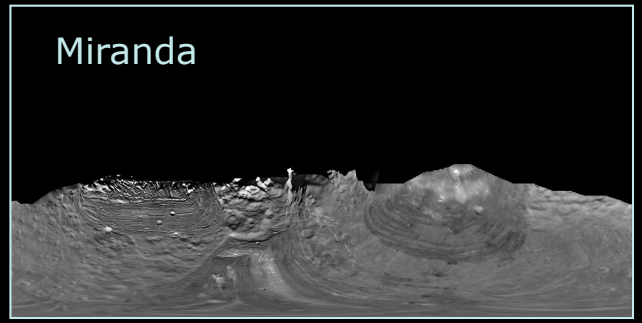


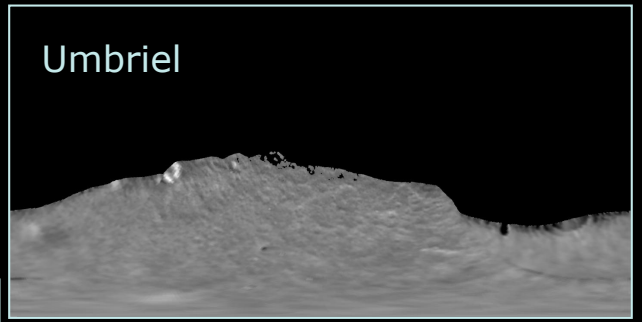
Titania

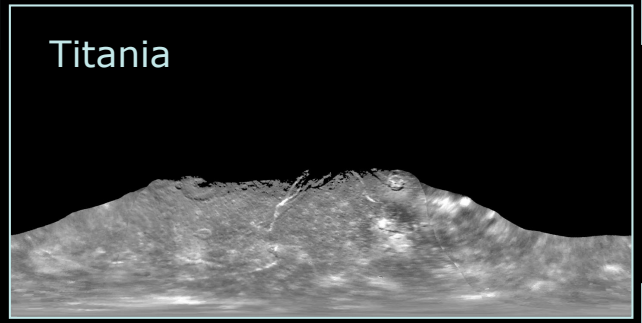
The half-seen Uranus satellites

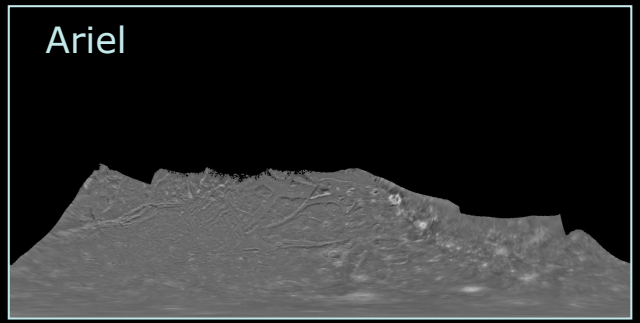


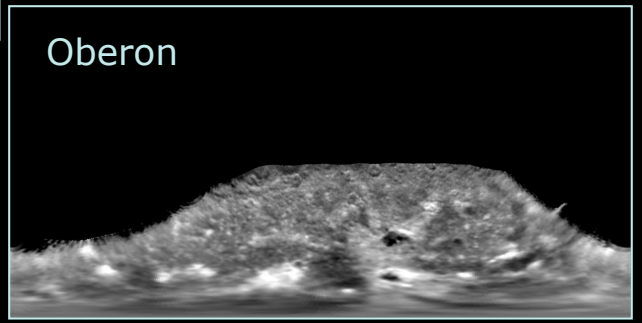
The half-seen Uranus satellites





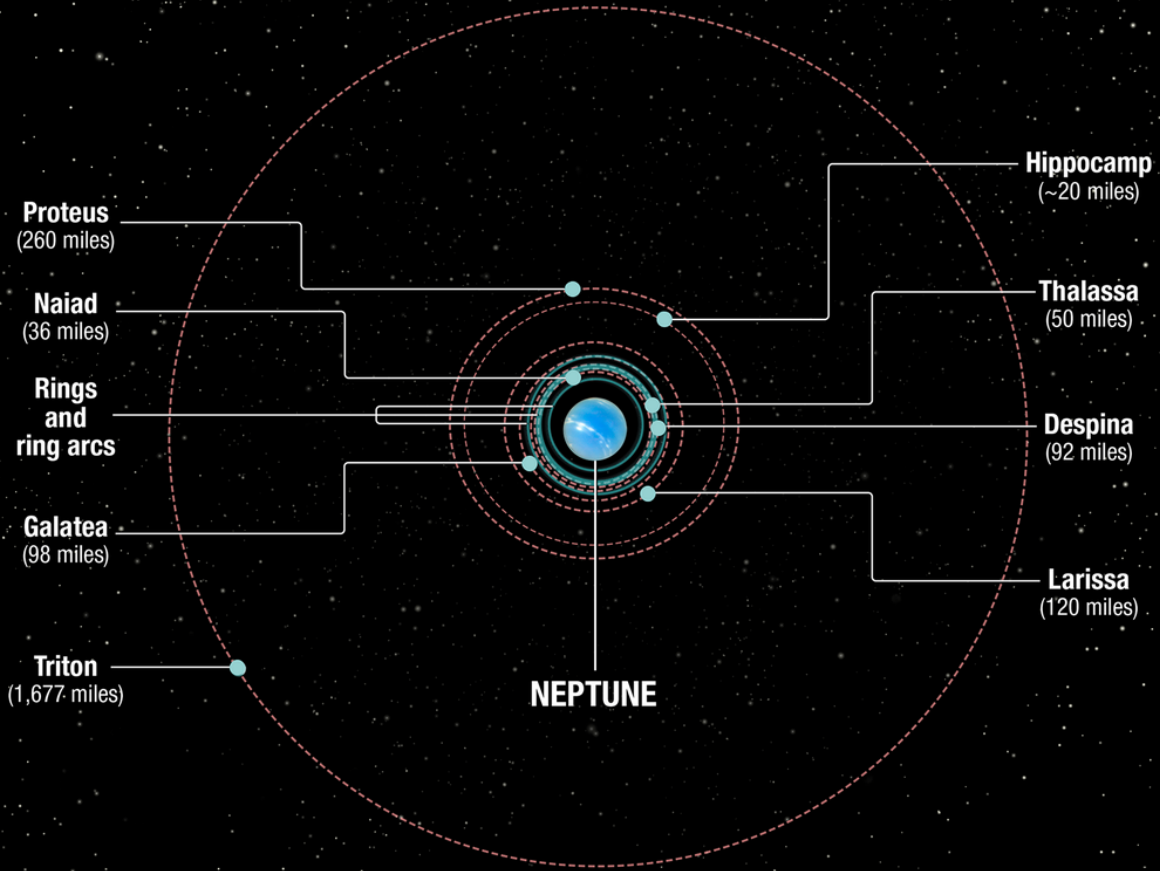






Voyager only saw half of each Uranian moon

Neptune's Inner Moons and Their Diameters



Voyager saw cryovolcanoes erupting on Neptune's moon Triton!

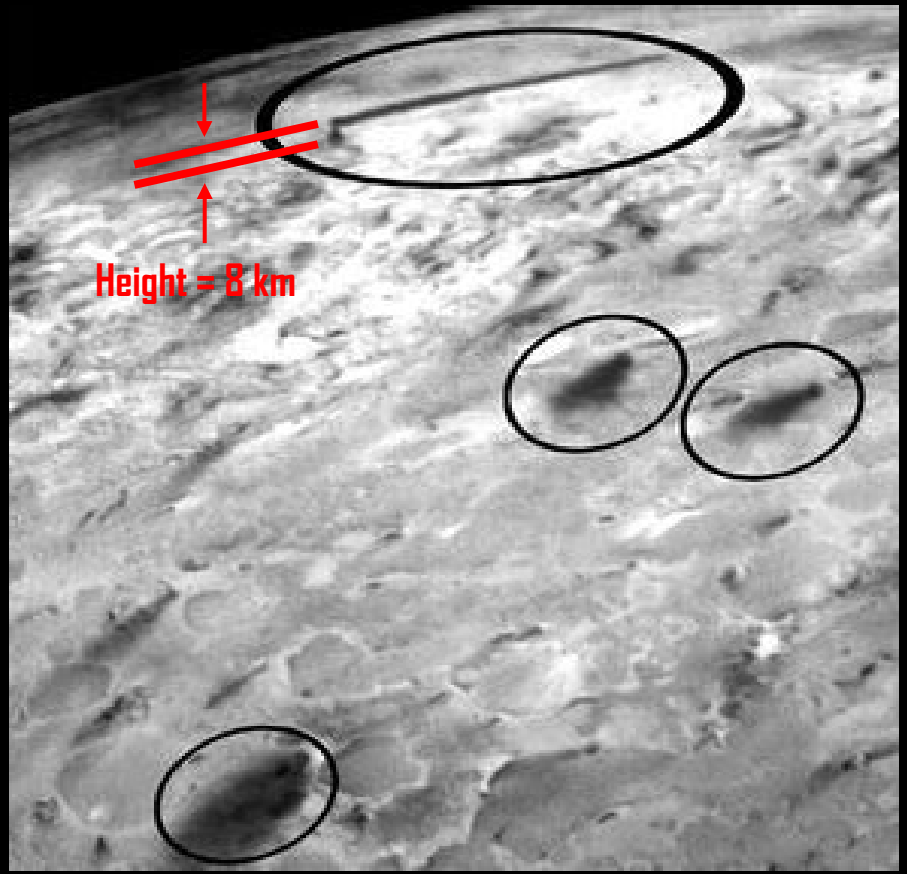
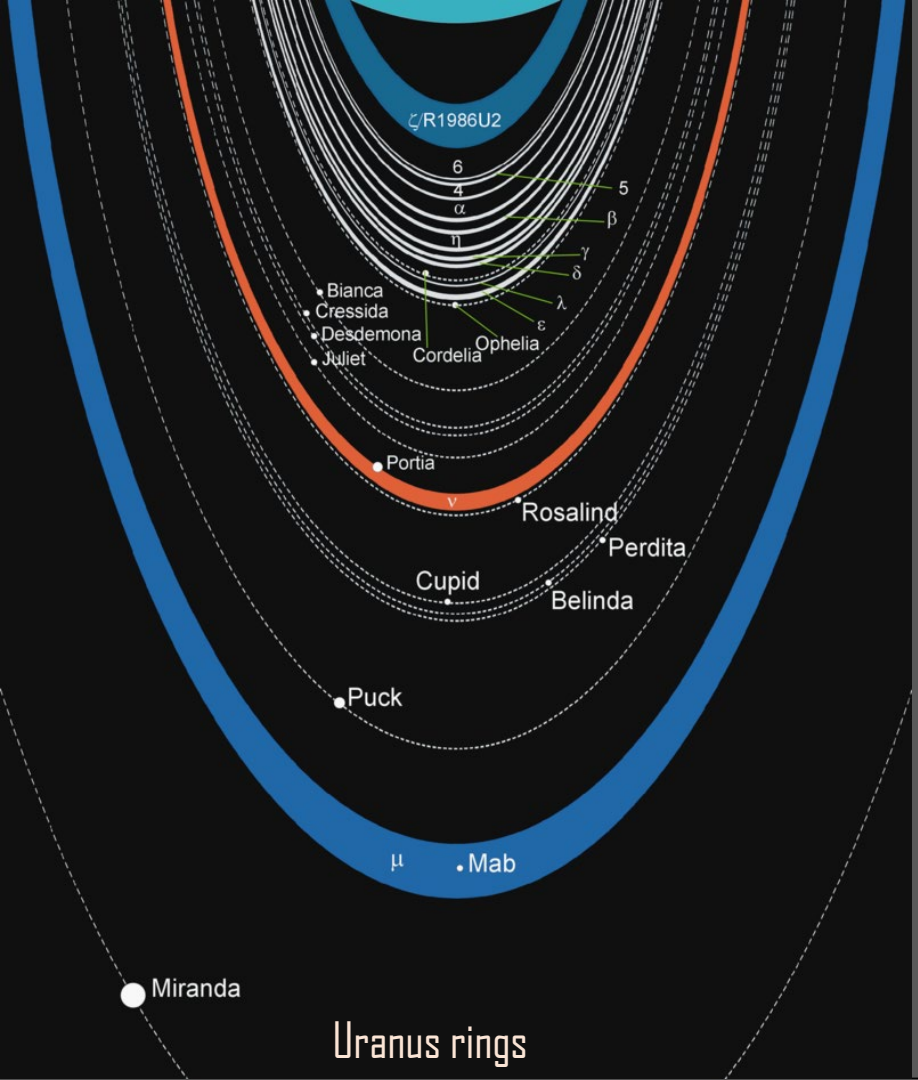
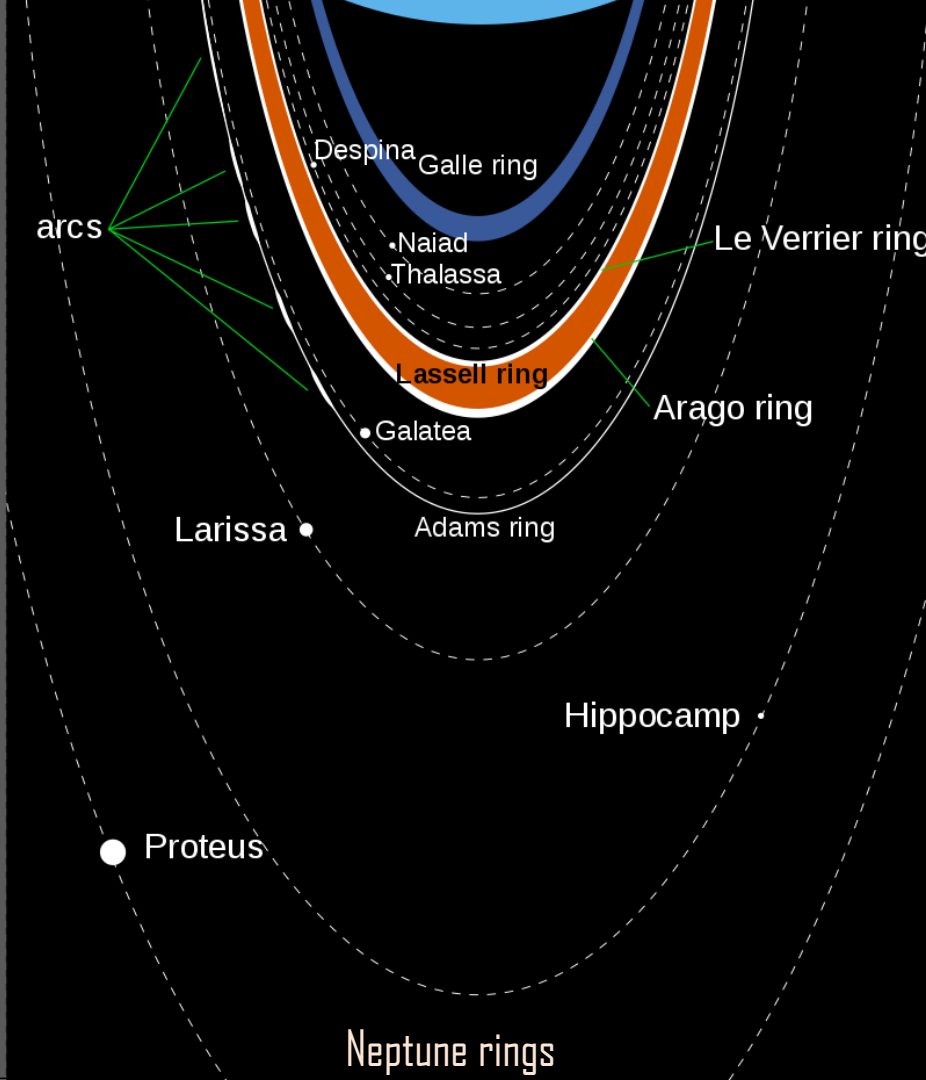


Image credit: NASA/JPL

RINGS

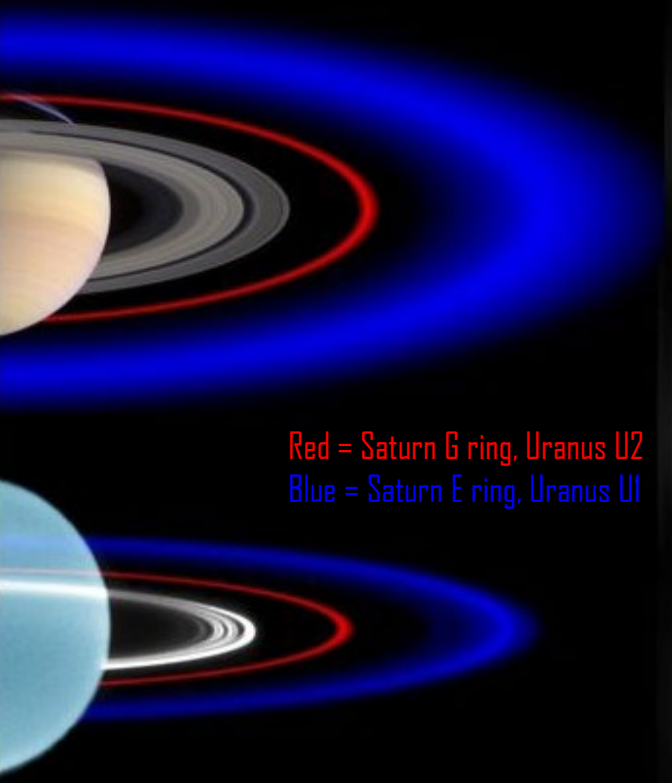


Uranus rings



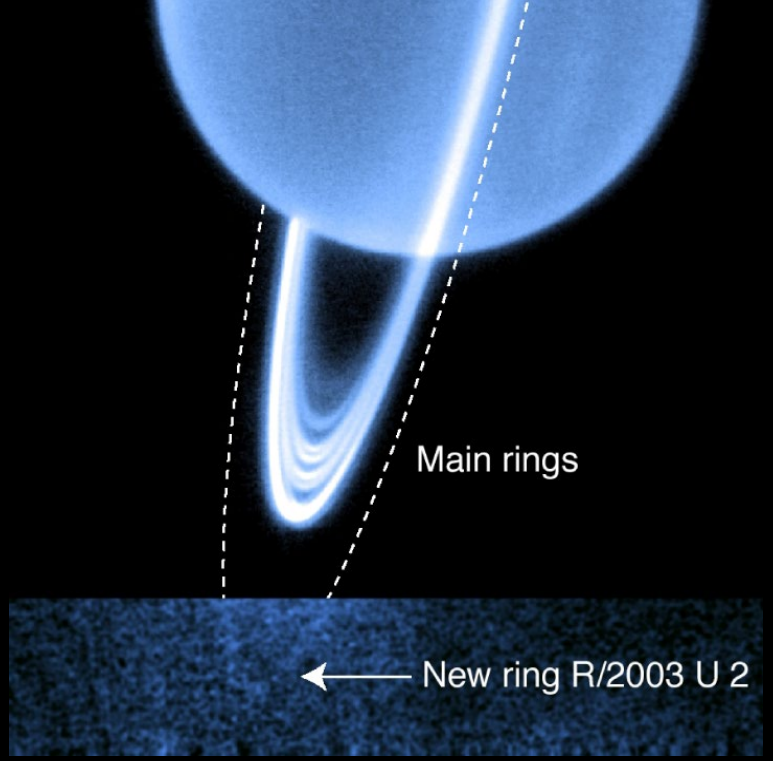
Neptune rings

Uranus rings



Red = Saturn G ring, Uranus U2
Blue = Saturn E ring, Uranus U1

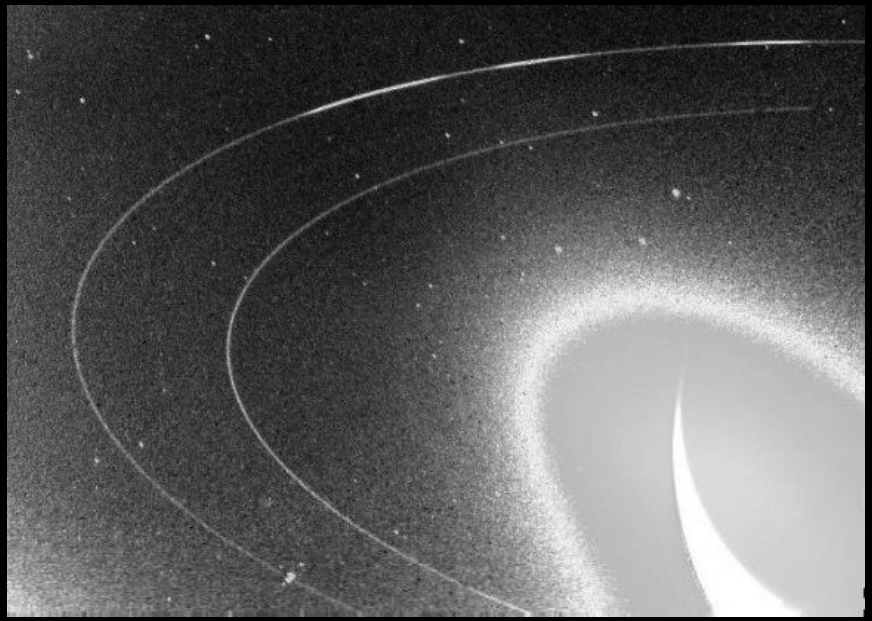
ring colors determined in 2006 with Keck



new rings discovered in 2005 with Hubble

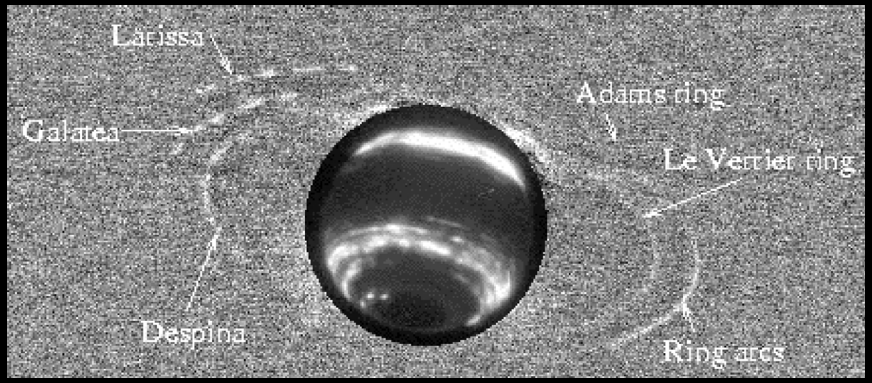
de Pater et al. 2006

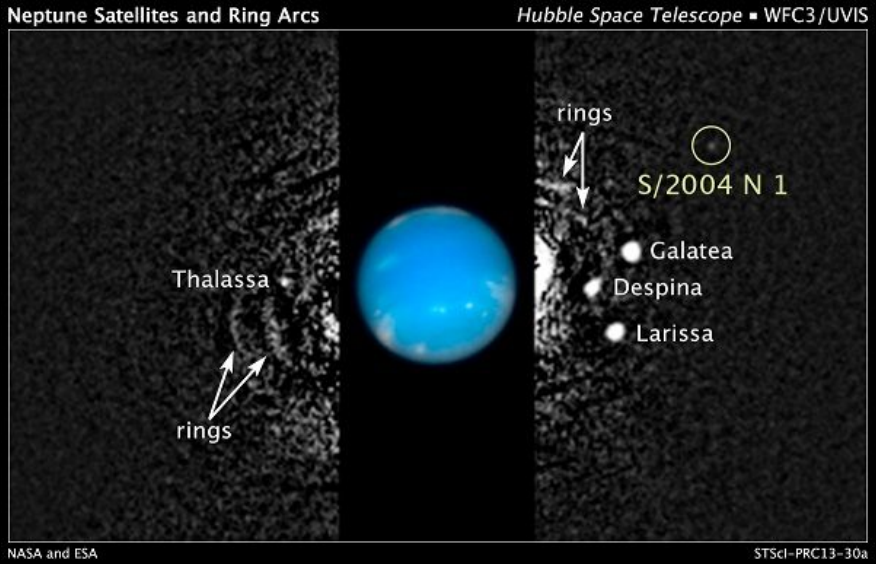
Neptune rings



Voyager 2 in 1989

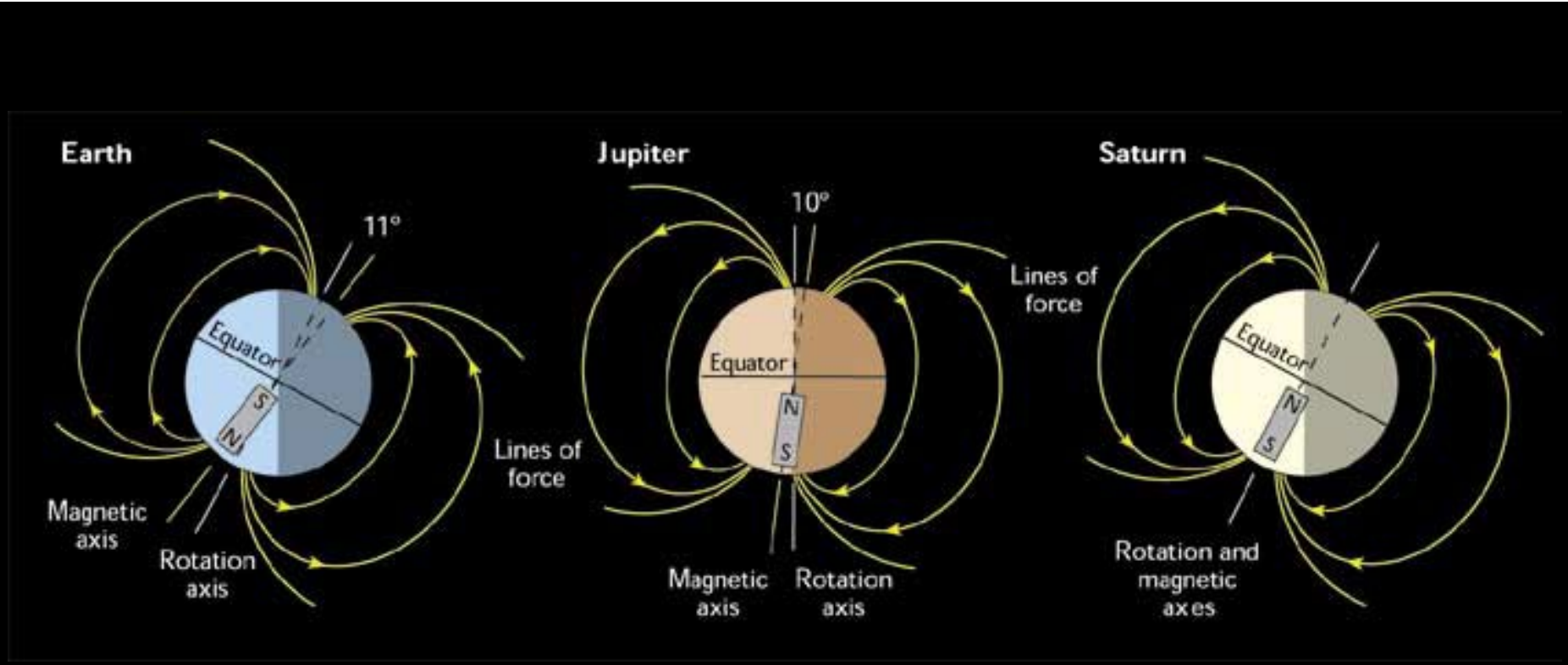
de Pater et al. 2005



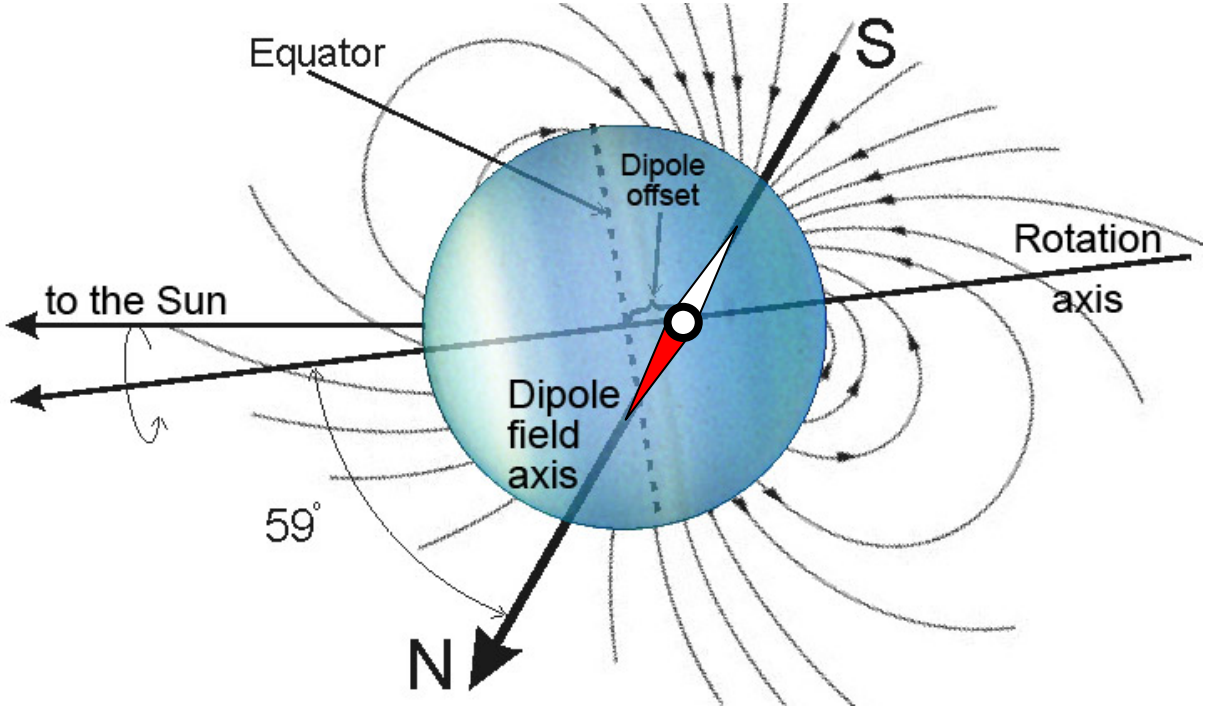


MAGNETIC FIELD

Planetary Magnetic Fields



Unusual magnetic field of Uranus

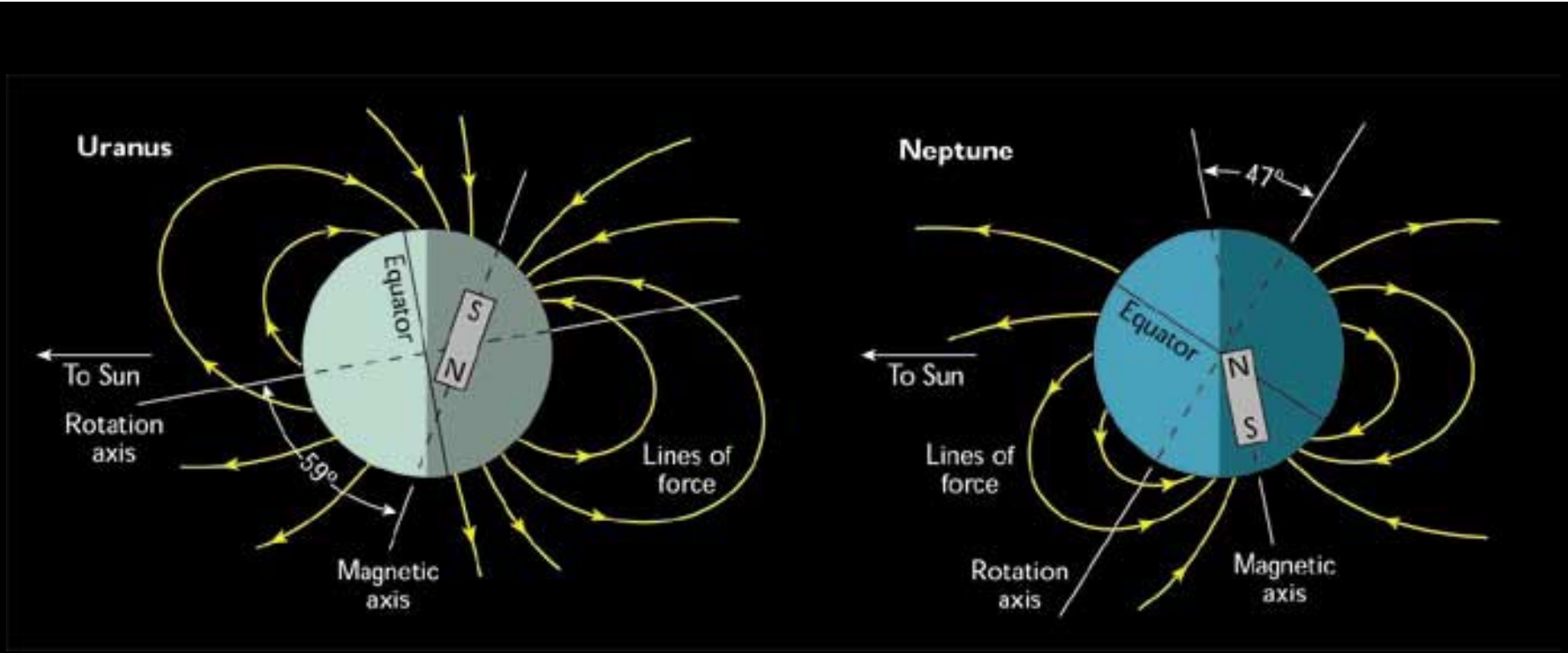


Dipole tilted 59° from the planet's rotation axis

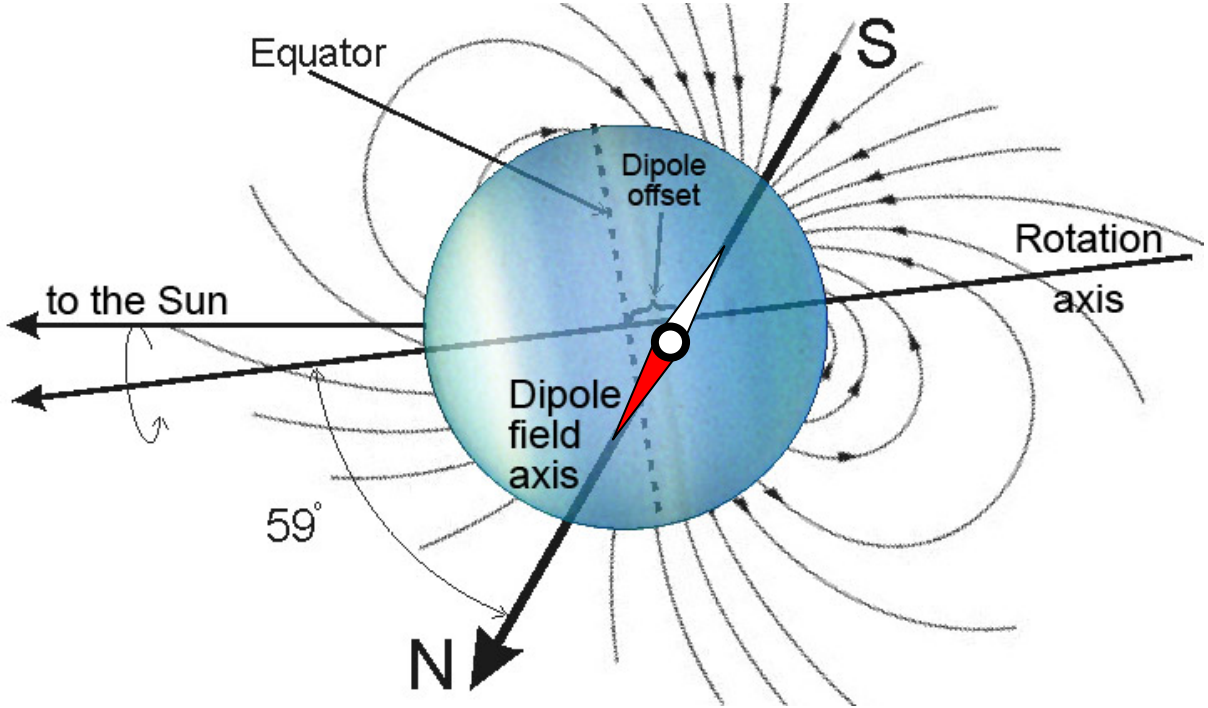
Dipole offset from the planet's center by about 1/3 of Uranus

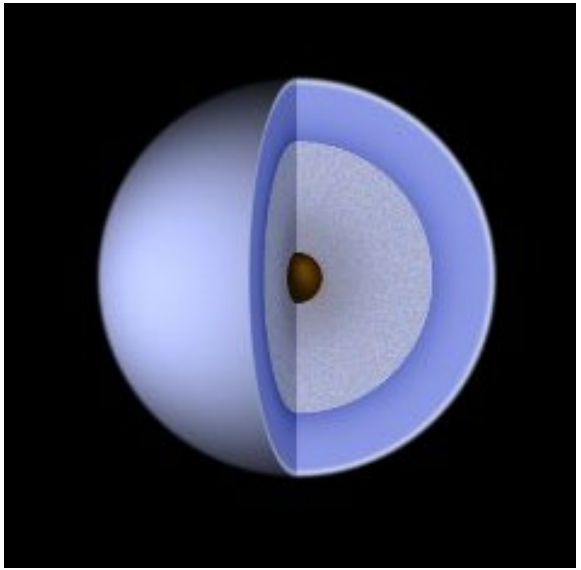
Uranus image from the Hubble Space Telescope

Neptune's field just as strange as that of Uranus



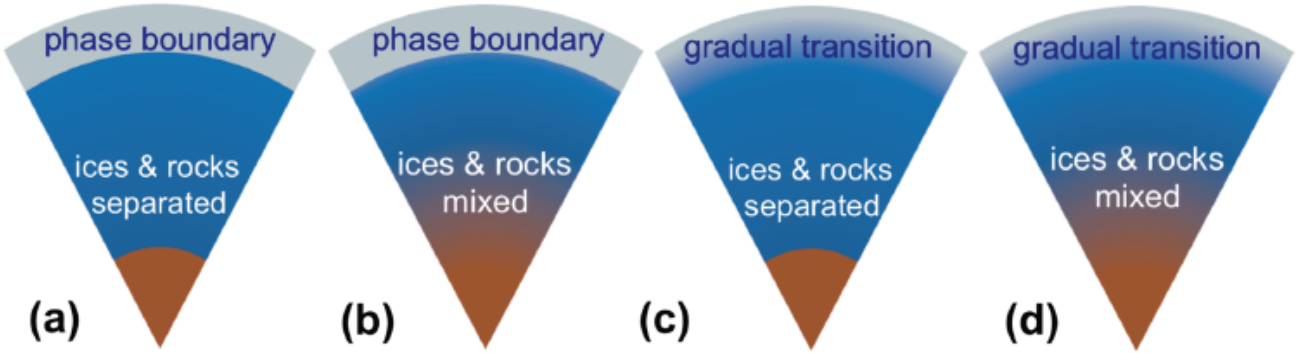
Ice Giant magnetic fields linked to interior structure





ICE GIANT INTERIORS

Composition and Interior



IMPORTANT: Uranus and Neptune are unique planets – they are different from the terrestrial planets and the gas giants.
We still not have a good modeling approach!

e.g., Stevenson, 1985
Lozovsky, Helled et al., 2017
Helled & Stevenson, 2017

We need to lock down the distribution of mass as a function of radius. But how?

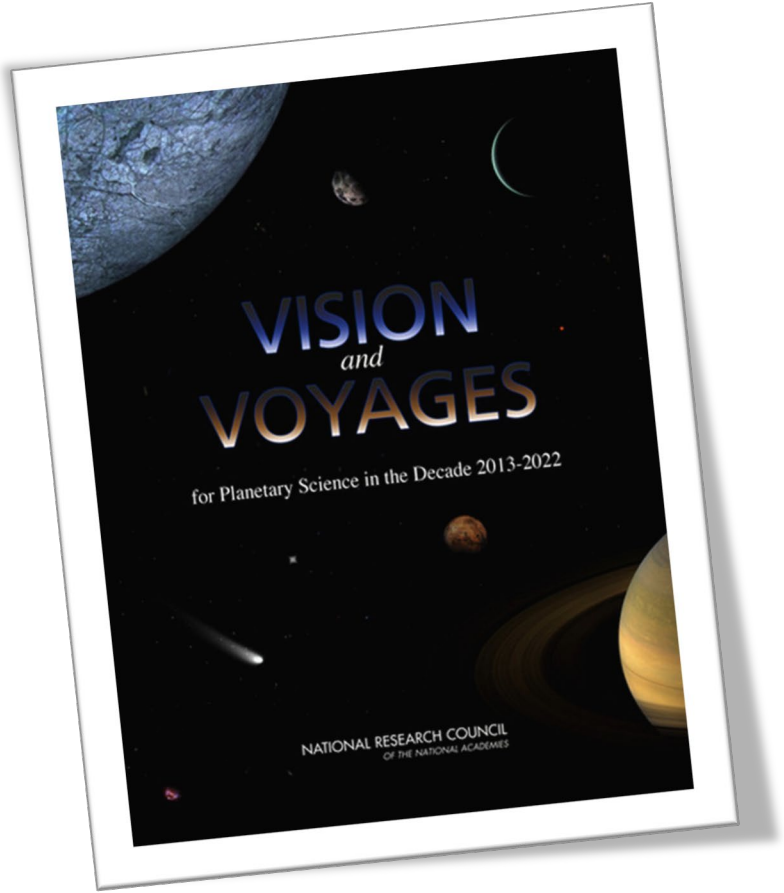
Measure the gravity field → **An orbiting spacecraft is required!**

We've done this with Jupiter and Saturn

PLANS FOR FUTURE MISSIONS

US Planetary Decadal Survey 2013-2022

After Mars and Europa, the "third highest priority flagship mission is the Uranus* Orbiter and Probe mission" * Both ice giants studied: Uranus chosen because the decade was 2013-2022



New US Planetary Decadal Survey happening now

Many white papers about Ice Giants

Ice Giant exploration is international

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Future exploration of the ice giants

← What's on

Discussion meeting

Starts: January 20 2020 09:00

Ends: January 21 2020 17:00

Location

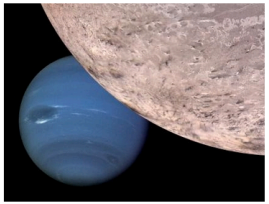
The Royal Society, London, 6-9 Carlton House Terrace, London, SW1Y 5AG

View map | Venue information

Overview

Scientific discussion meeting organised by Dr Leigh Fletcher, Dr Adam Masters, Dr Athena Coustenis, Dr Kathleen Mandt, Dr Ian Cohen, Dr Christopher Arridge and Dr Amy Simon.

Uranus and Neptune are our closest representatives of a class of planet that may be commonplace in our universe, and yet our exploration and understanding of these icy worlds is in its infancy. This meeting aimed to shape the key questions, motivations, and concepts for future collaborative missions to these tantalising destinations.



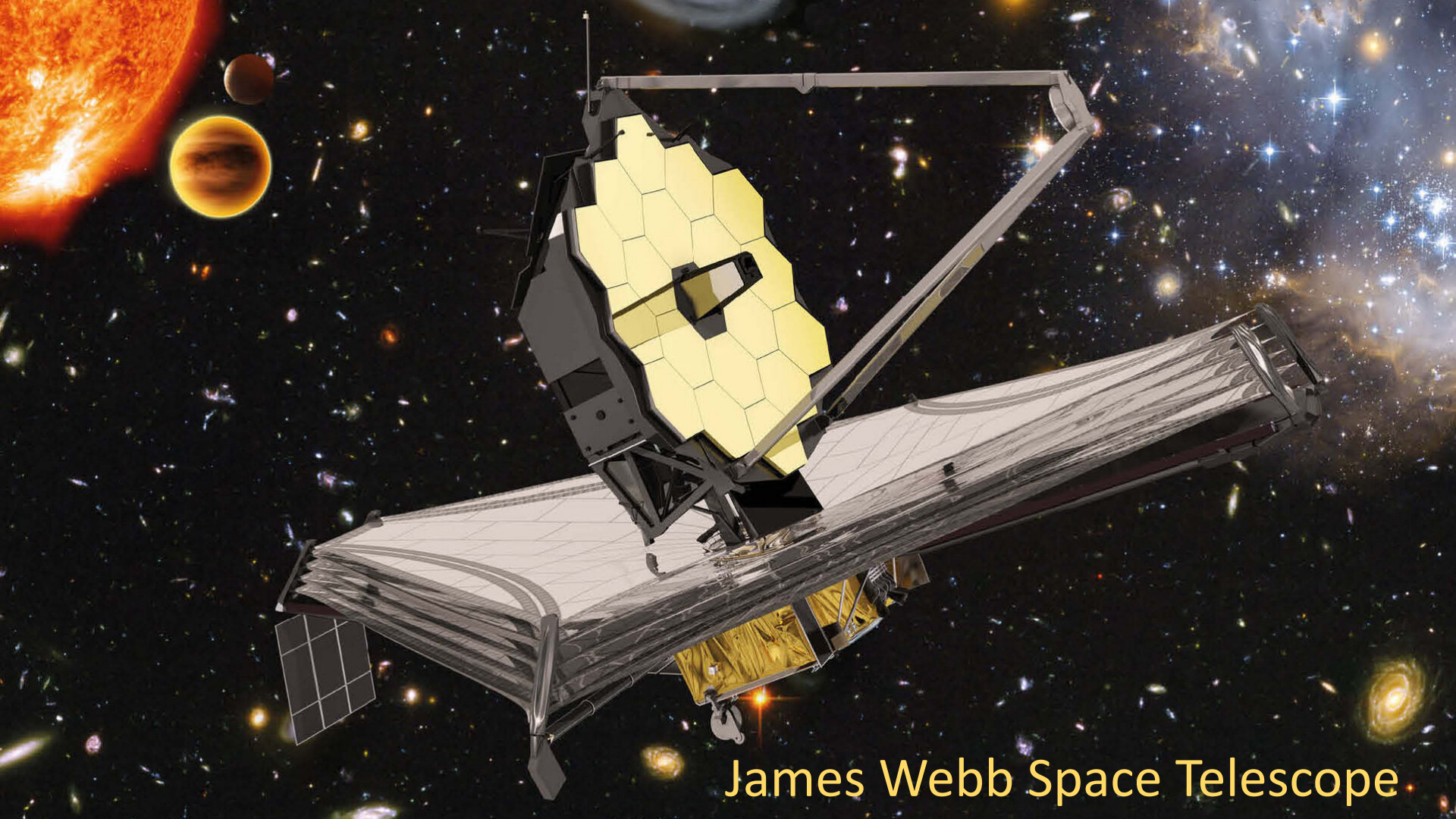
Neptune viewed from beyond the orbit of its largest moon, Triton

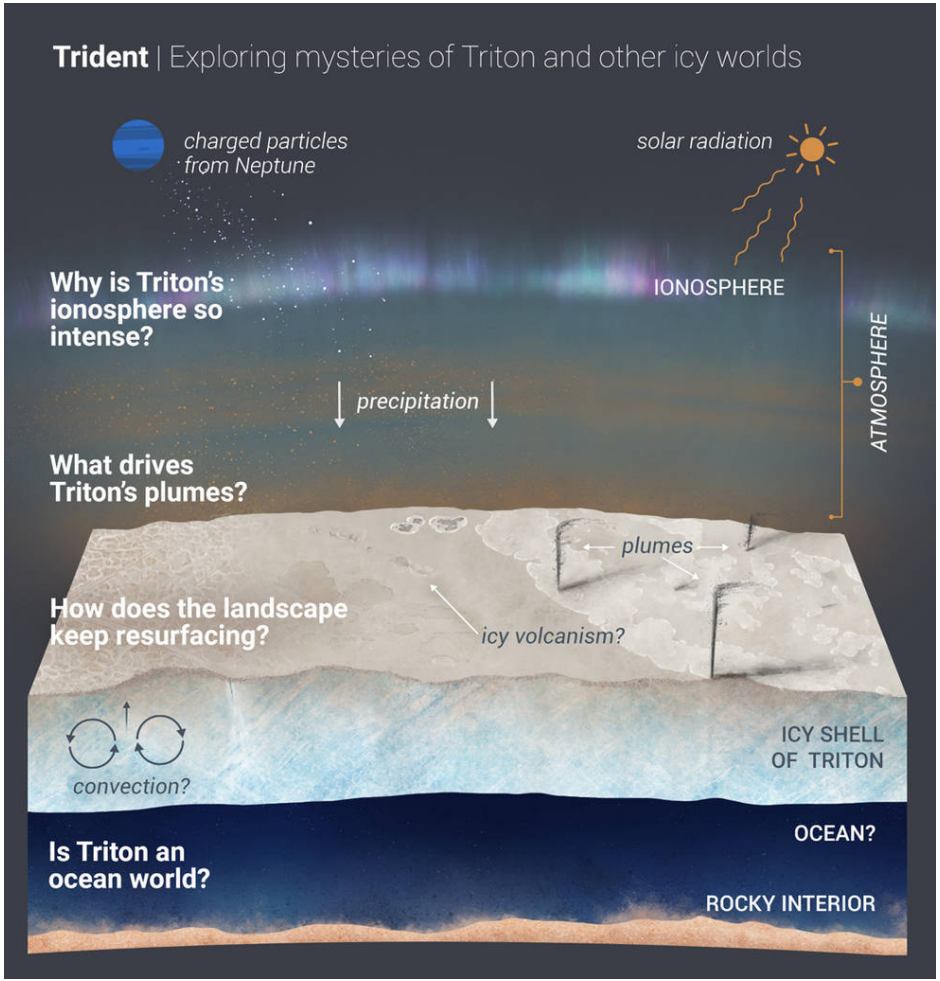
Speaker biographies and abstracts are available below. Recorded audio of the presentations is also available below. An accompanying journal issue was published in *Philosophical Transactions of the Royal Society A*.

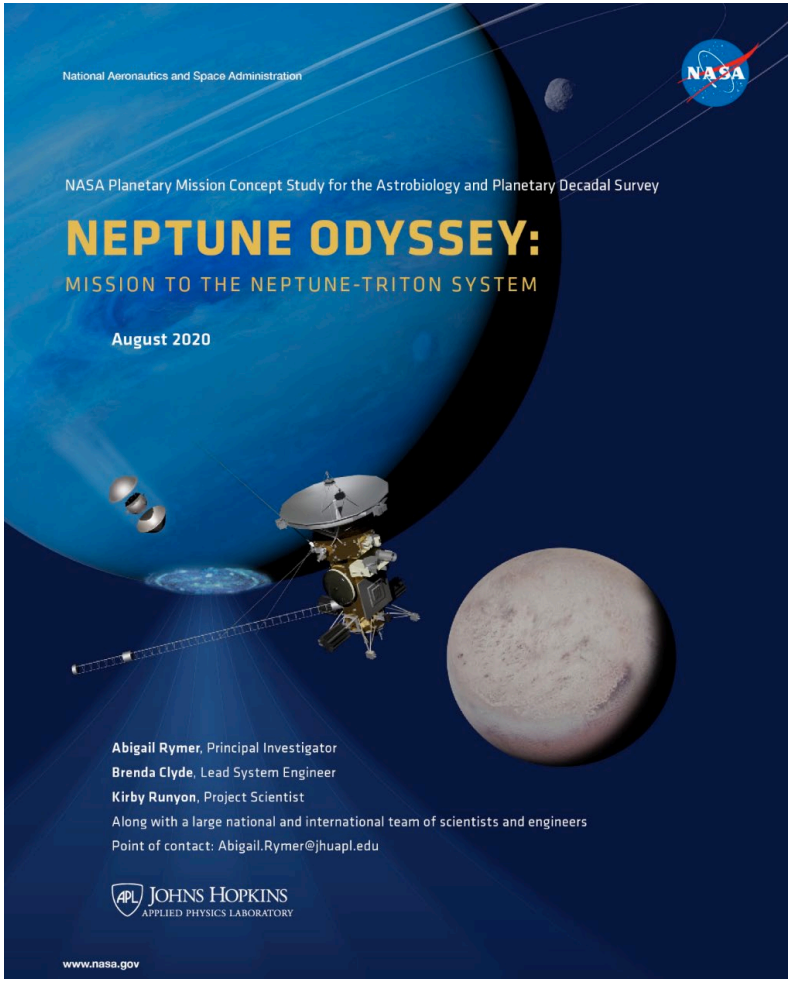
Enquiries: contact the Scientific Programmes team

Splinter meeting

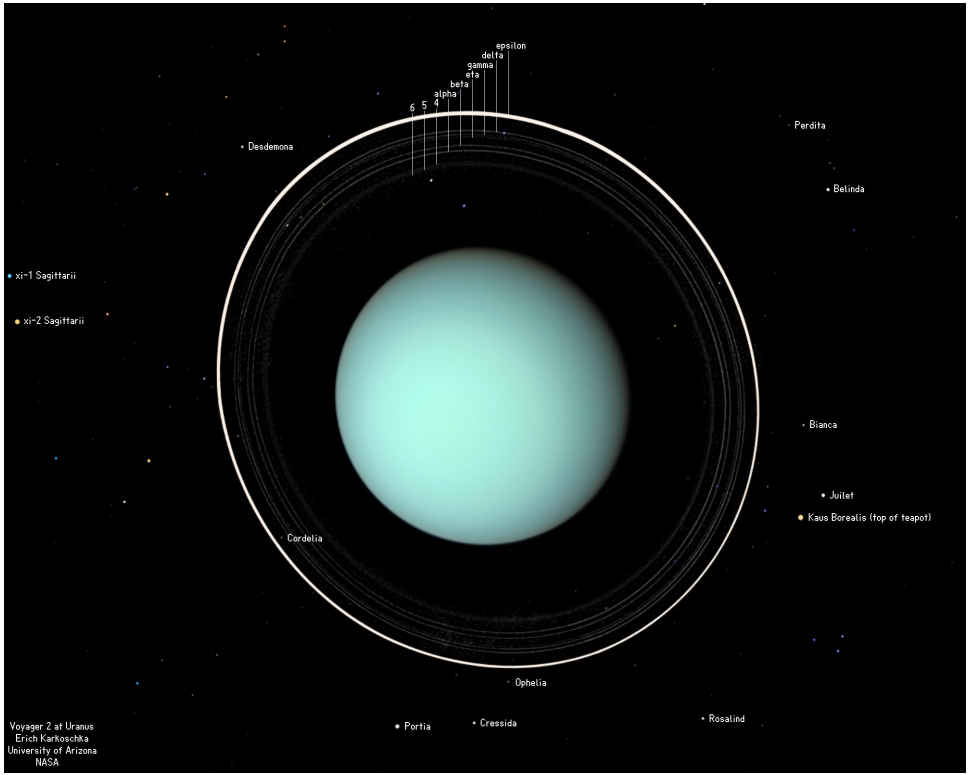
A splinter meeting was held following this meeting, details of which can be found on the organisers' website.


James Webb Space Telescope


Trident | Exploring mysteries of Triton and other icy worlds
charged particles from Neptune
solar radiation
IONOSPHERE
ATMOSPHERE
Why is Triton's ionosphere so intense?
precipitation
What drives Triton's plumes?
plumes
How does the landscape keep resurfacing?
icy volcanism?
convection?
ICY SHELL OF TRITON
OCEAN?
Is Triton an ocean world?
ROCKY INTERIOR


National Aeronautics and Space Administration
NASA
NASA Planetary Mission Concept Study for the Astrobiology and Planetary Decadal Survey
NEPTUNE ODYSSEY:
MISSION TO THE NEPTUNE-TRITON SYSTEM
August 2020
Abigail Rymer, Principal Investigator
Brenda Clyde, Lead System Engineer
Kirby Runyon, Project Scientist
Along with a large national and international team of scientists and engineers
Point of contact: Abigail.Rymer@jhuapl.edu
APL JOHNS HOPKINS APPLIED PHYSICS LABORATORY
www.nasa.gov

Why go to Neptune and Uranus again?



Voyager 2 Launched in 1977

More than **30 years later…**

2020 iMac Pro

2020 Playstation 5

besides...

everything we can detect in these systems

has changed

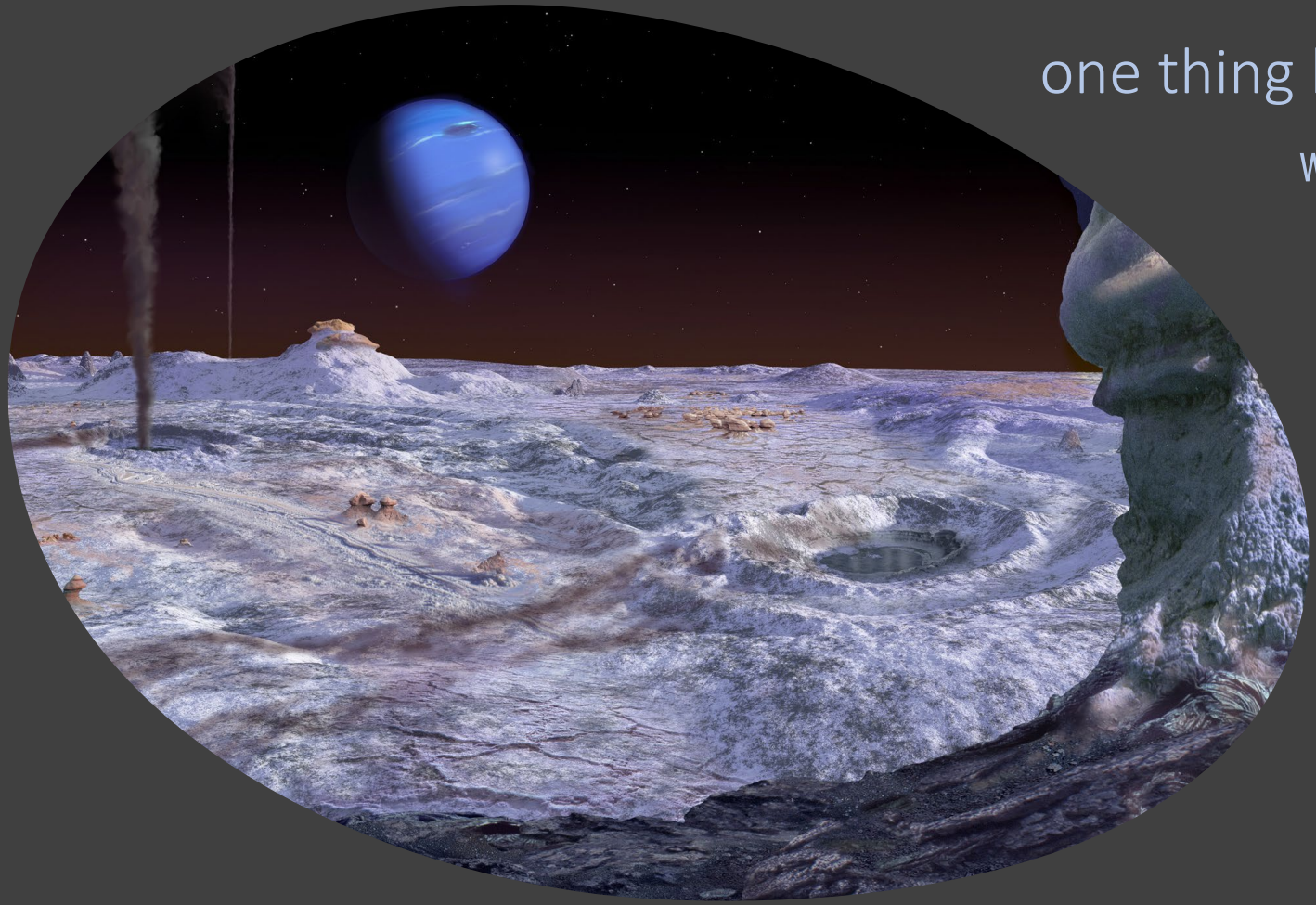
Ice giant cloud distribution

Ring system structure

Satellite spectra

Why?

WE DON'T KNOW! WE CAN'T SEE ANY DETAILS!



one thing hasn't changed

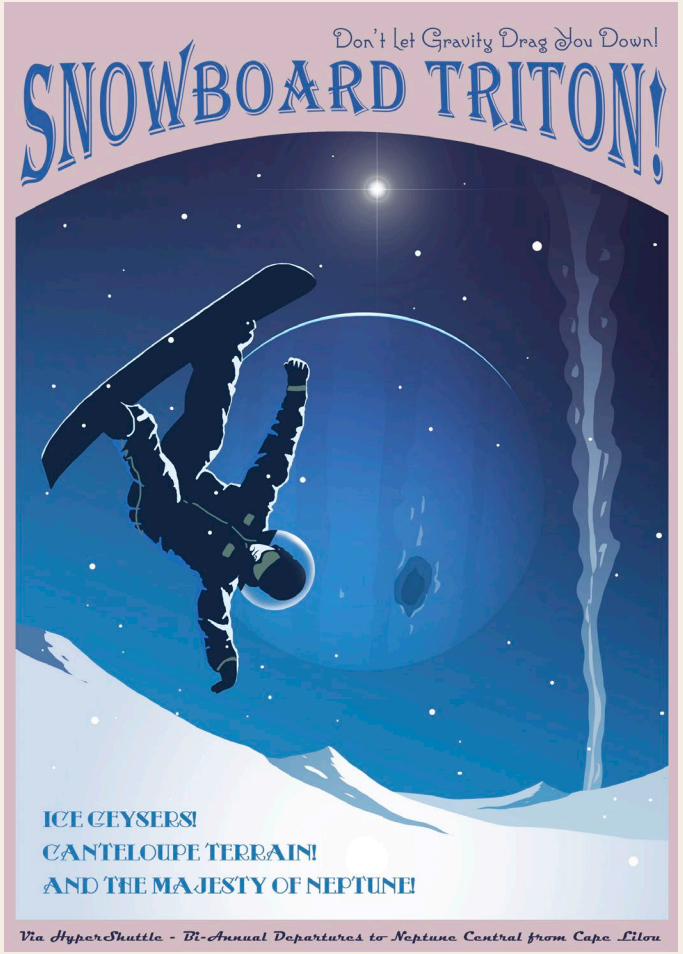
we seek to explore

#ItsTime

#UranusAndNeptuneLetsGoBack

Art by Michael Carroll


STARLIGHT CRUISELINES
With Regular departures to Uranus


Don't Let Gravity Drag You Down!
SNOWBOARD TRITON!
ICE GEYSERS!
CANTELOUPE TERRAIN!
AND THE MAJESTY OF NEPTUNE!
Via HyperShuttle - Bi-Annual Departures to Neptune Central from Cape Lilou