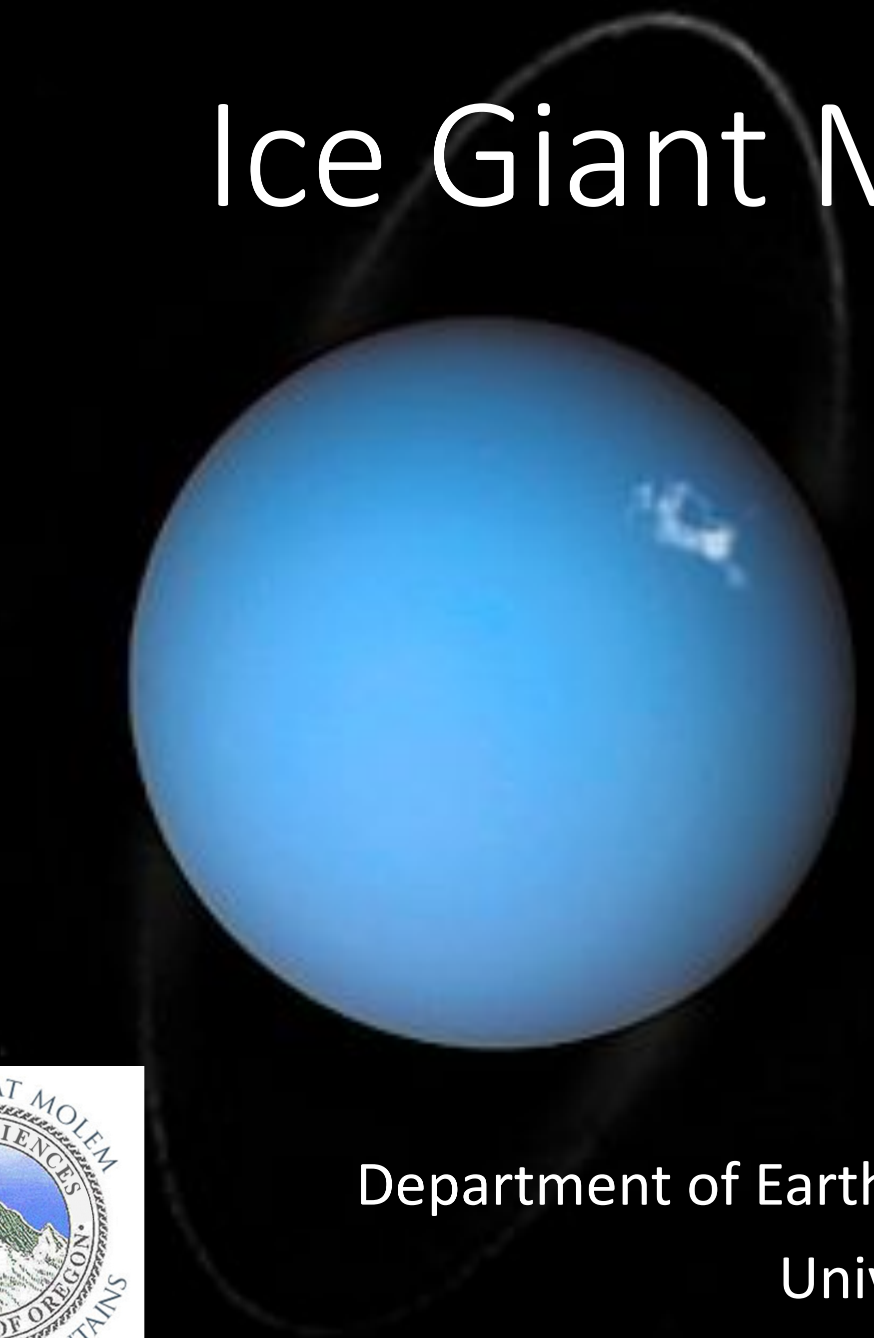
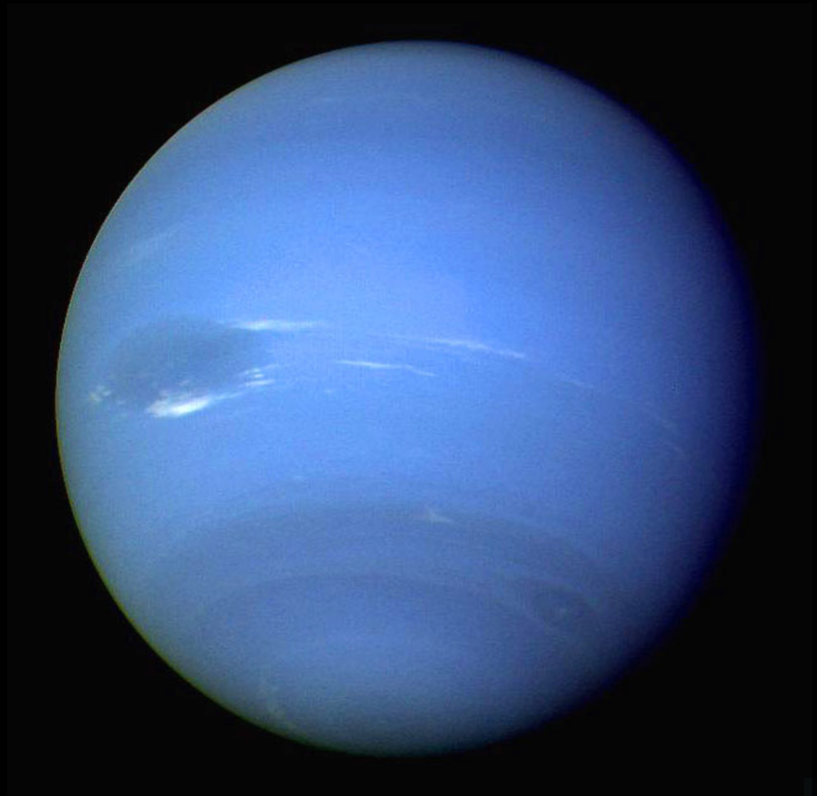
Ice Giant Magnetospheres



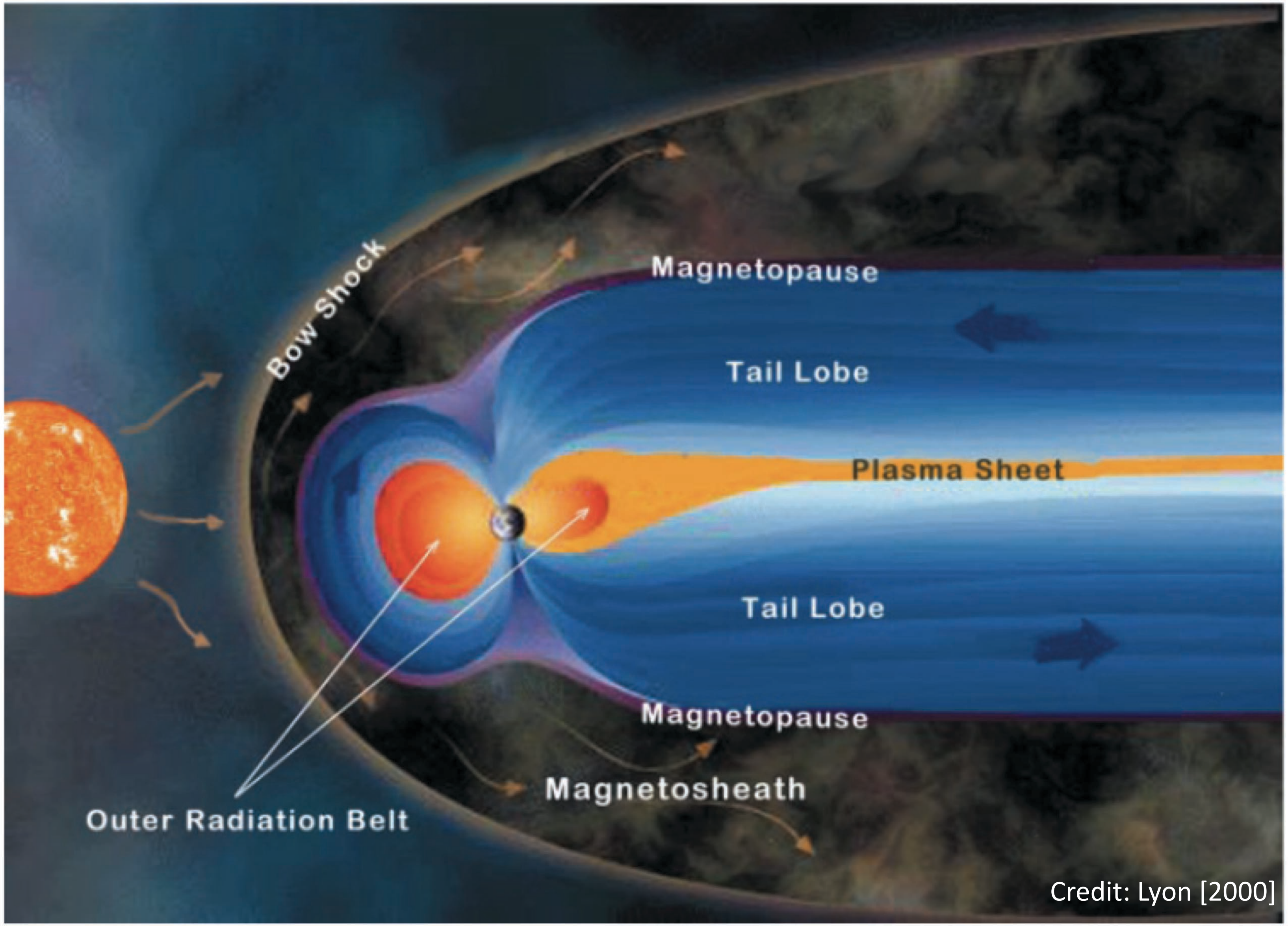


Carol Paty

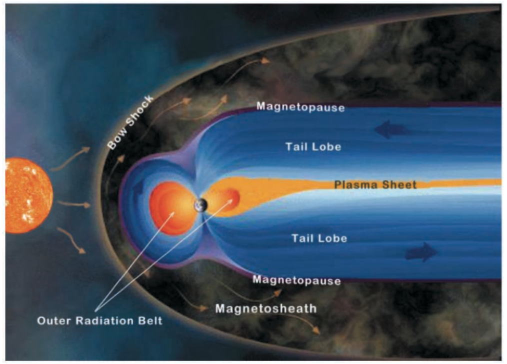
Department of Earth Sciences & Clark Honors College

University of Oregon

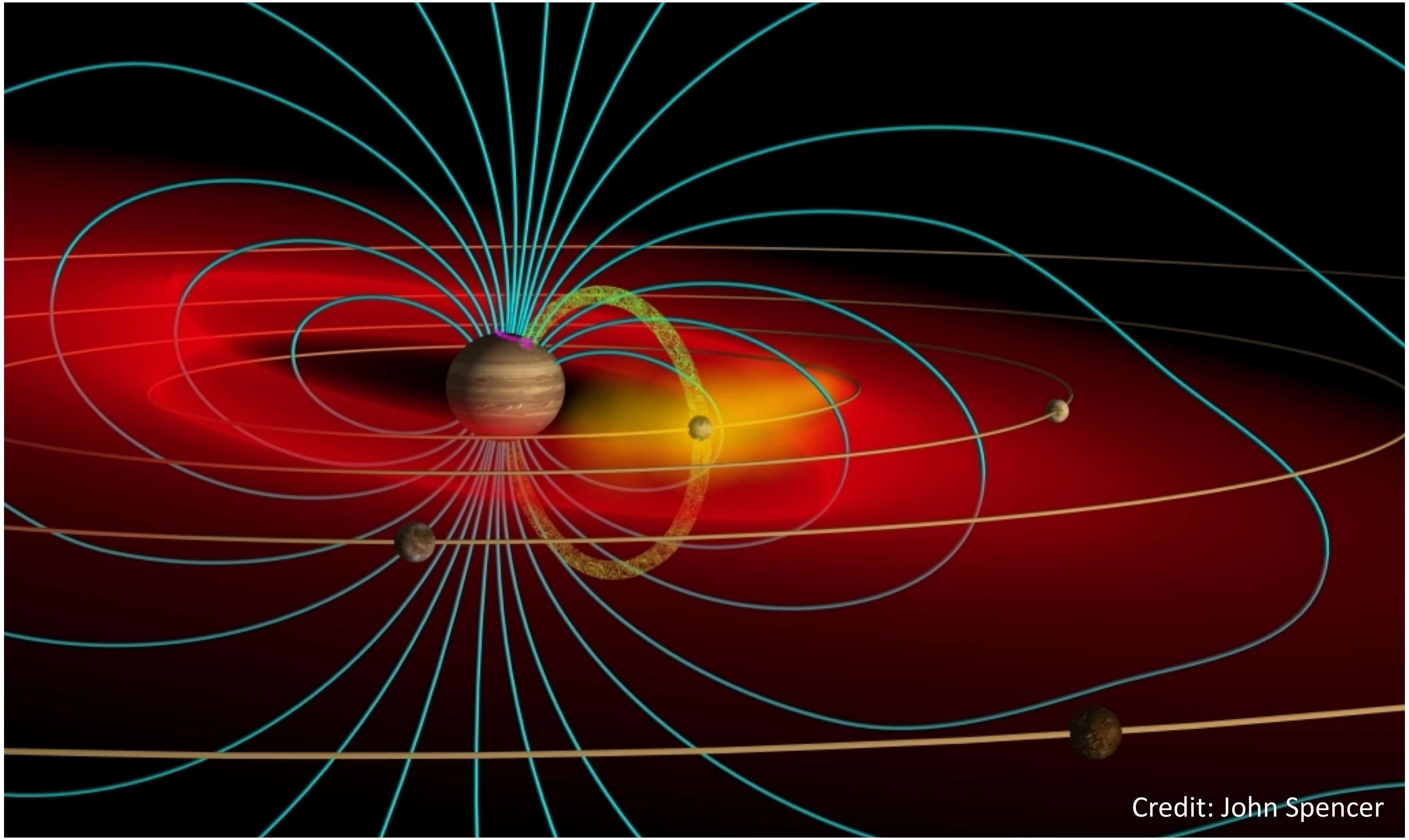
The Magnetosphere: A Natural Plasma Laboratory



Credit: Lyon [2000]

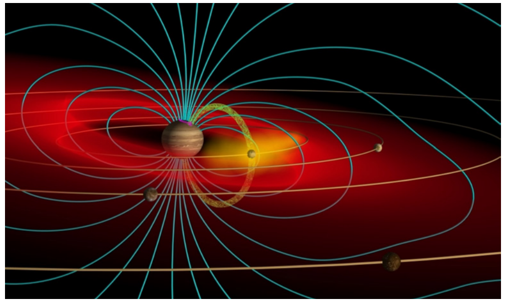


Asymmetric Magnetospheres: Tilted

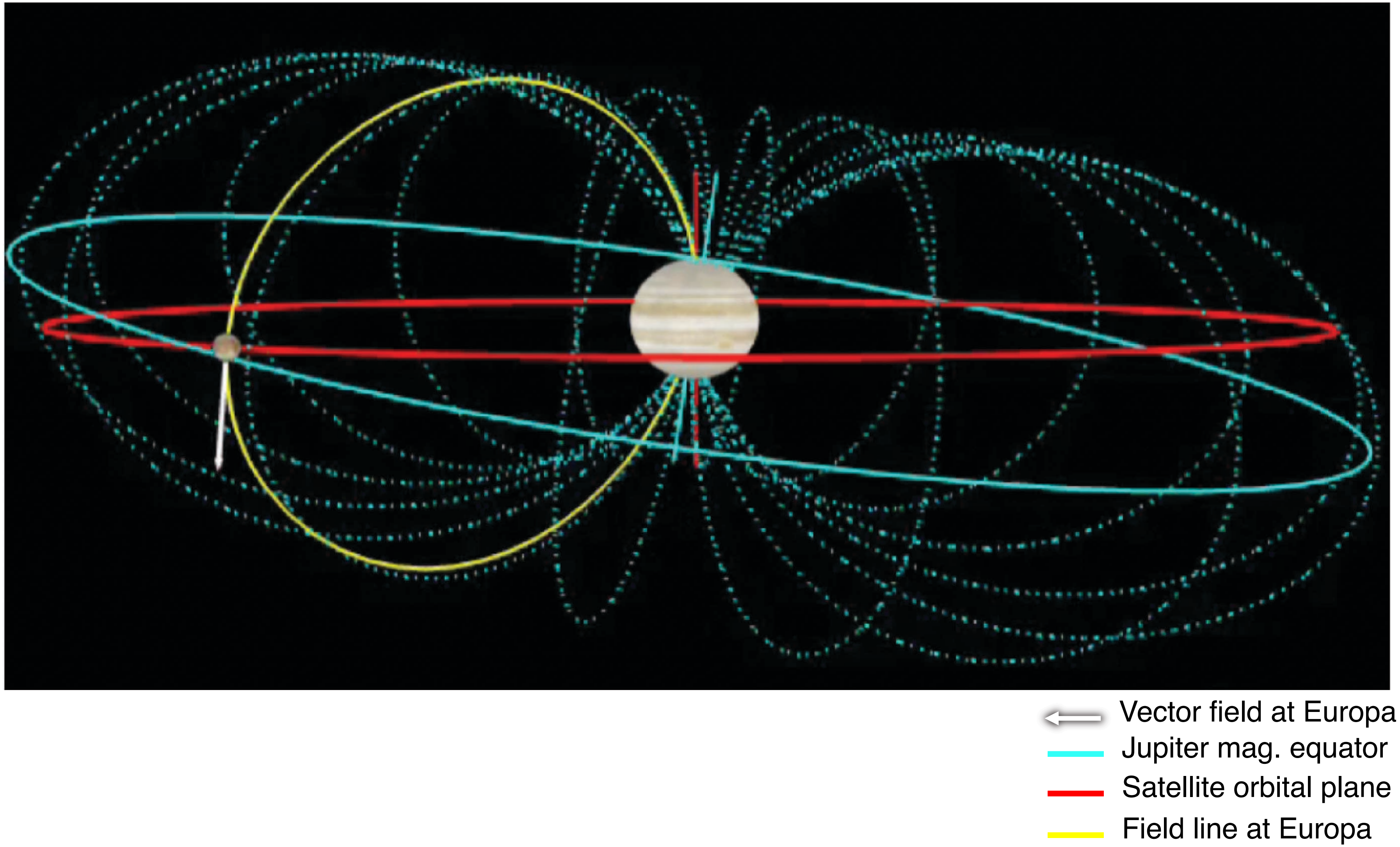


<u>Dipole Tilt</u>

Jupiter: 10°



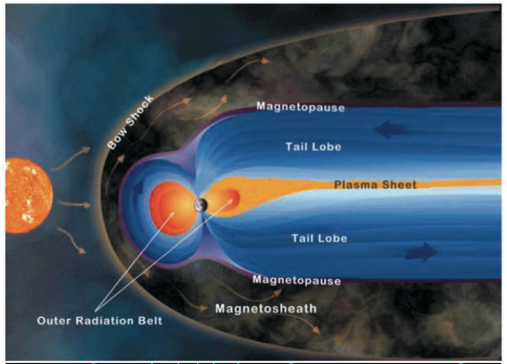
Tilted Magnetic Axis

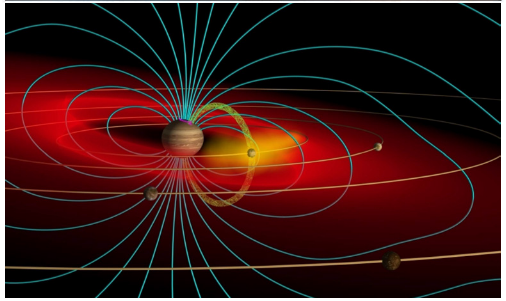


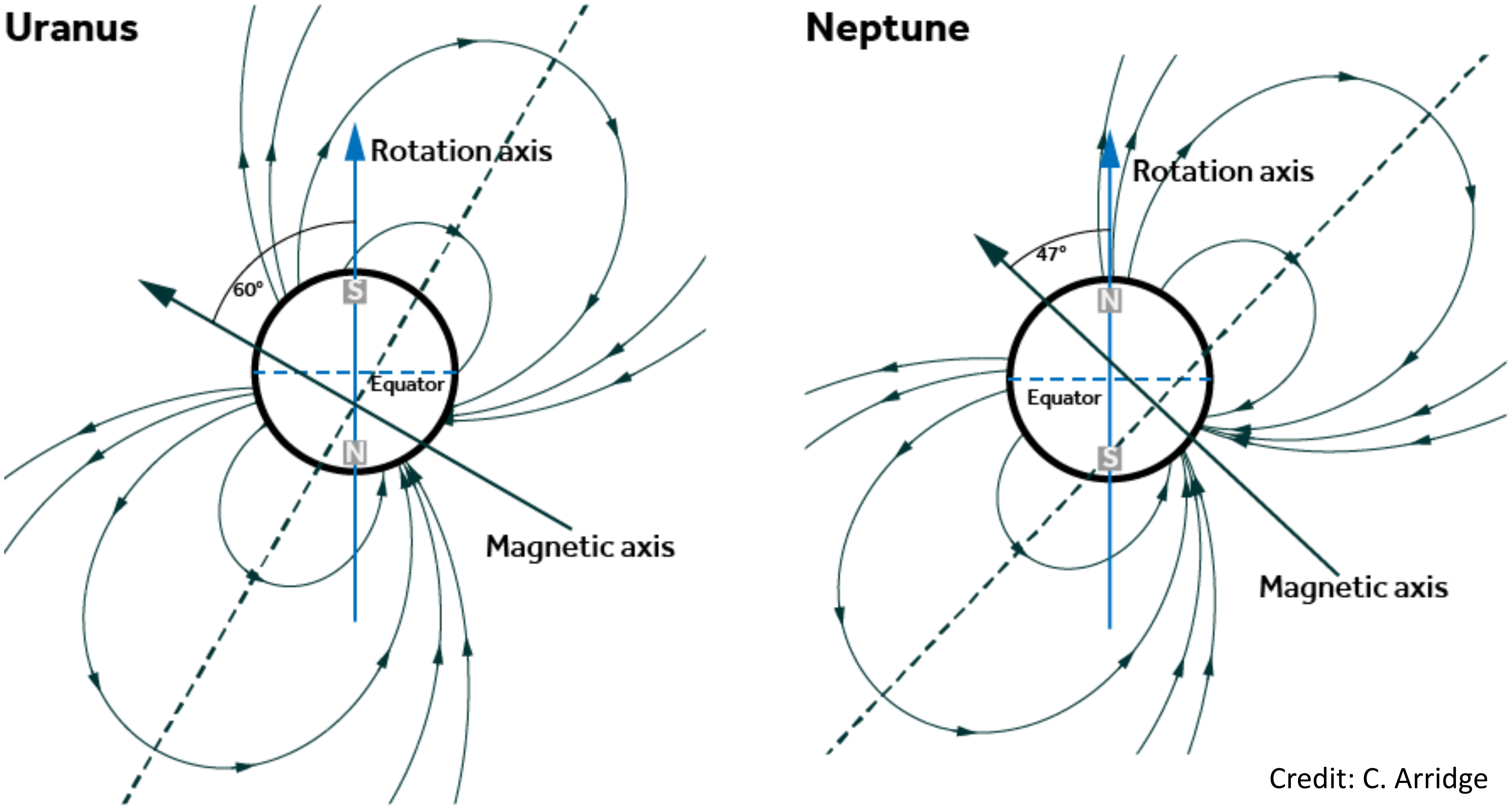
<u>Dipole Tilt</u>

Results in the precession of the magnetic axis about the axis of rotation, creating a periodic flapping of the currentsheet about the rotational equator

Asymmetric Magnetospheres: Tilt + Offset







Credit: C. Arridge

<u>Dipole Tilt</u>

Uranus: 59°

Neptune: 47°

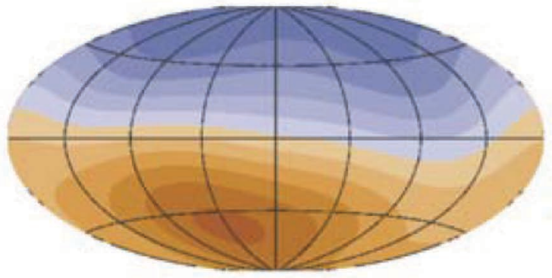
<u>Offset</u>

Uranus: .33 R_U

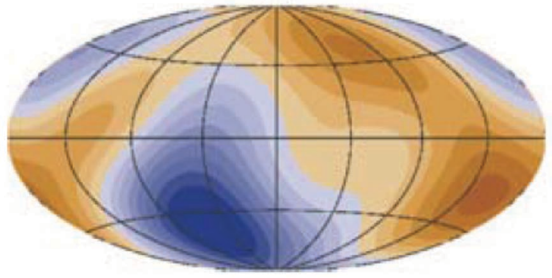
Neptune: .55 R_N

Asymmetric Magnetospheres: Tilt + Offset

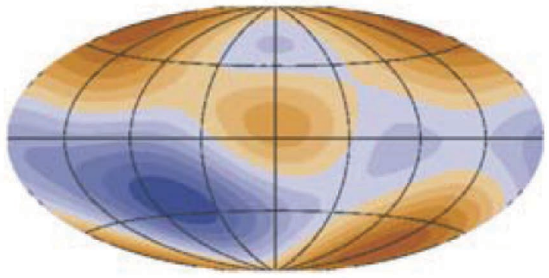
Earth



Uranus



Neptune



Modified from: Stanley & Bloxham, 2006

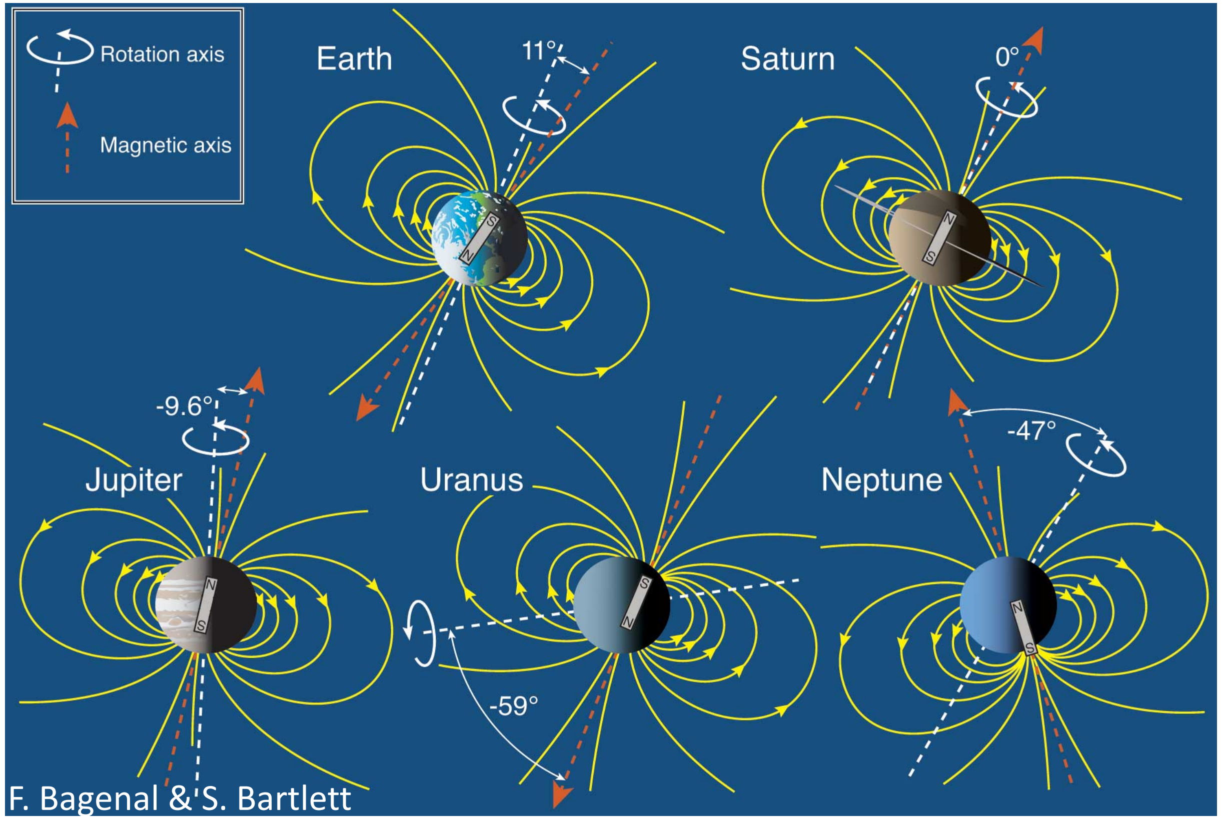
- These highly asymmetric fields can be represented with an offset tilted dipole, or equivalently, with the addition of a quadrupole to the dipole (Lowes, 1994).
- Lead to large differences in polar radial field strength and those effects can structure the interaction of the global magnetic field with the solar wind:

  1. Varying the standoff distance of the magnetopause
  2. Varying the strength/depth of the cusps
  3. Determining the shape/curvature of the plasma sheet in the magnetotail (Hammond et al., 1990)

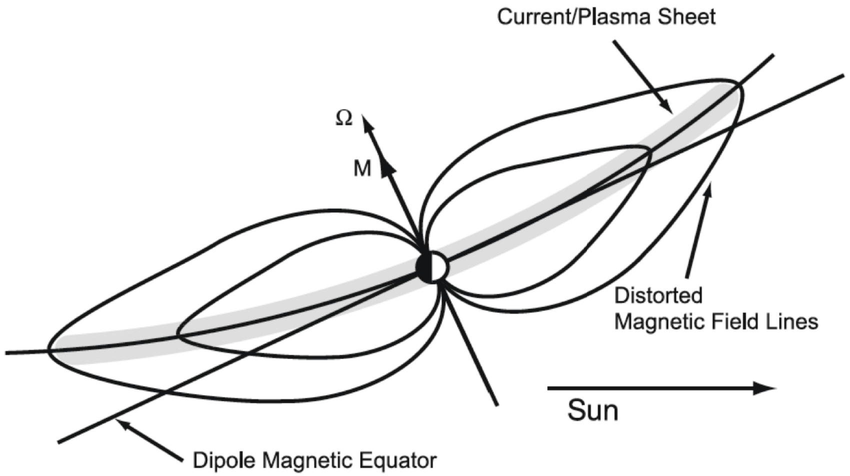
Obliquity & Season Variability

Obliquity

Earth: 23.4°
Saturn: 26.7°
Jupiter: 3.1°
Uranus: 97.8°
Neptune: 28.3°

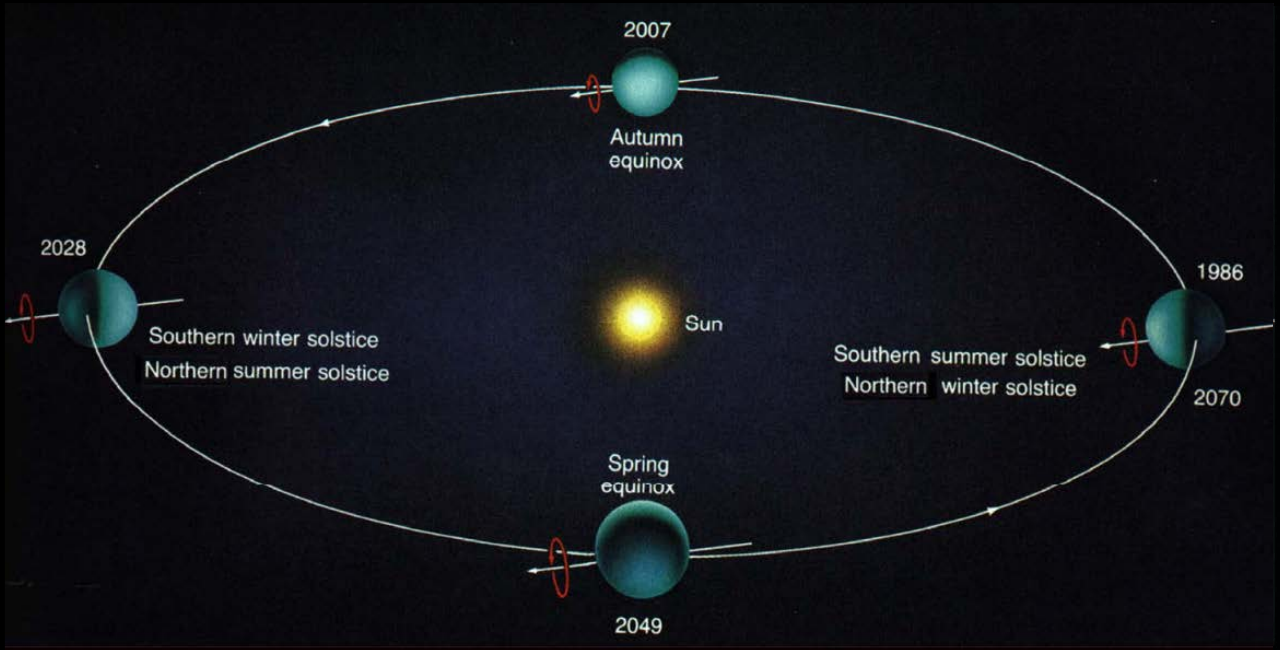


- For Saturn, the obliquity is directly linked to warping of the magnetotail and plasma sheet (Arridge et al., 2008; Sergis et al., 2011)



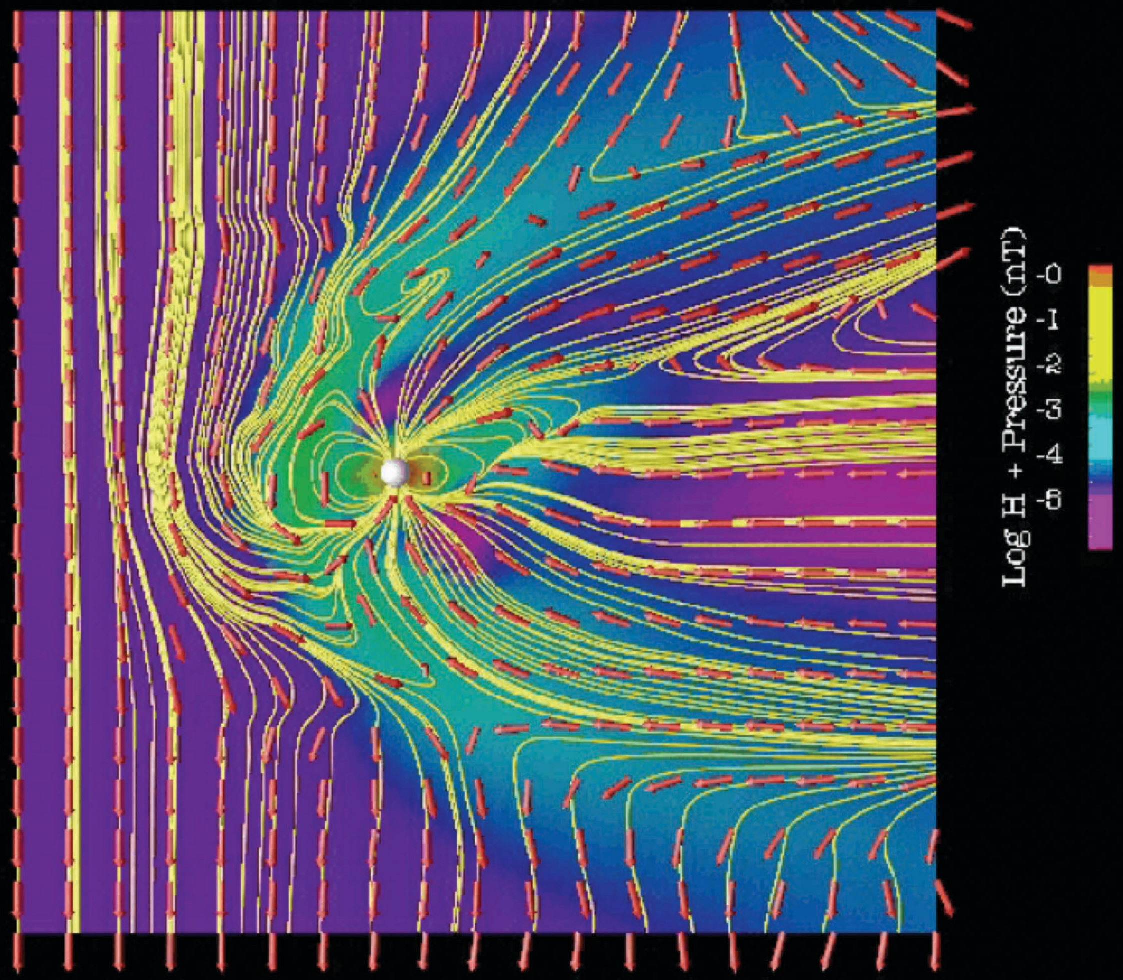
- It is also linked to the variation in magnetospheric periodicities (*)

Obliquity & Season Variability



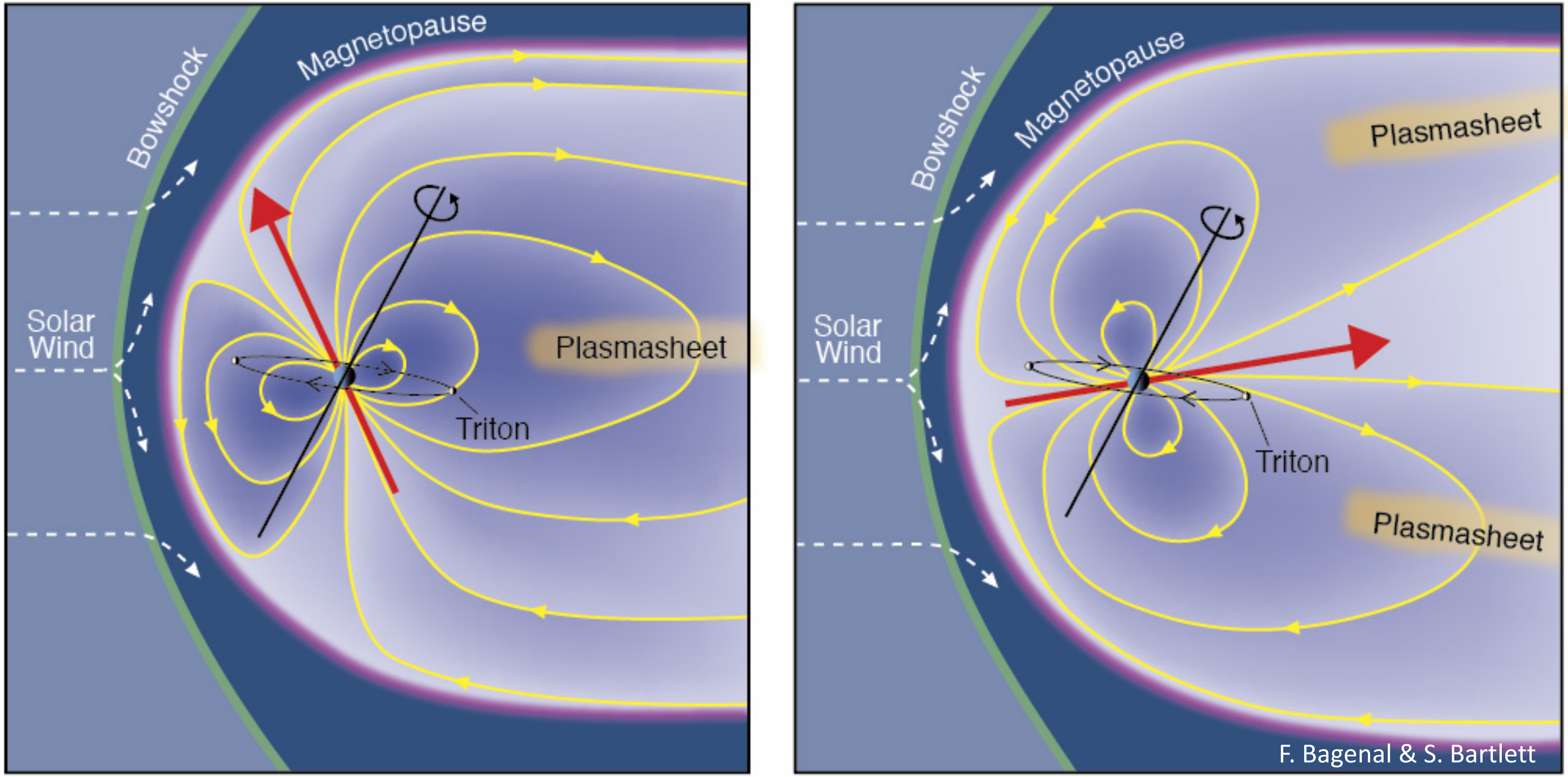
Credit: H. Hammel, 2006 (OPAG report)

For **Uranus**, the obliquity is so large, that the difference between equinox and solstice is dramatic in terms of the magnetosphere – solar wind interaction geometry, causing a daily reconnection cycle (Cao & Paty, 2017)

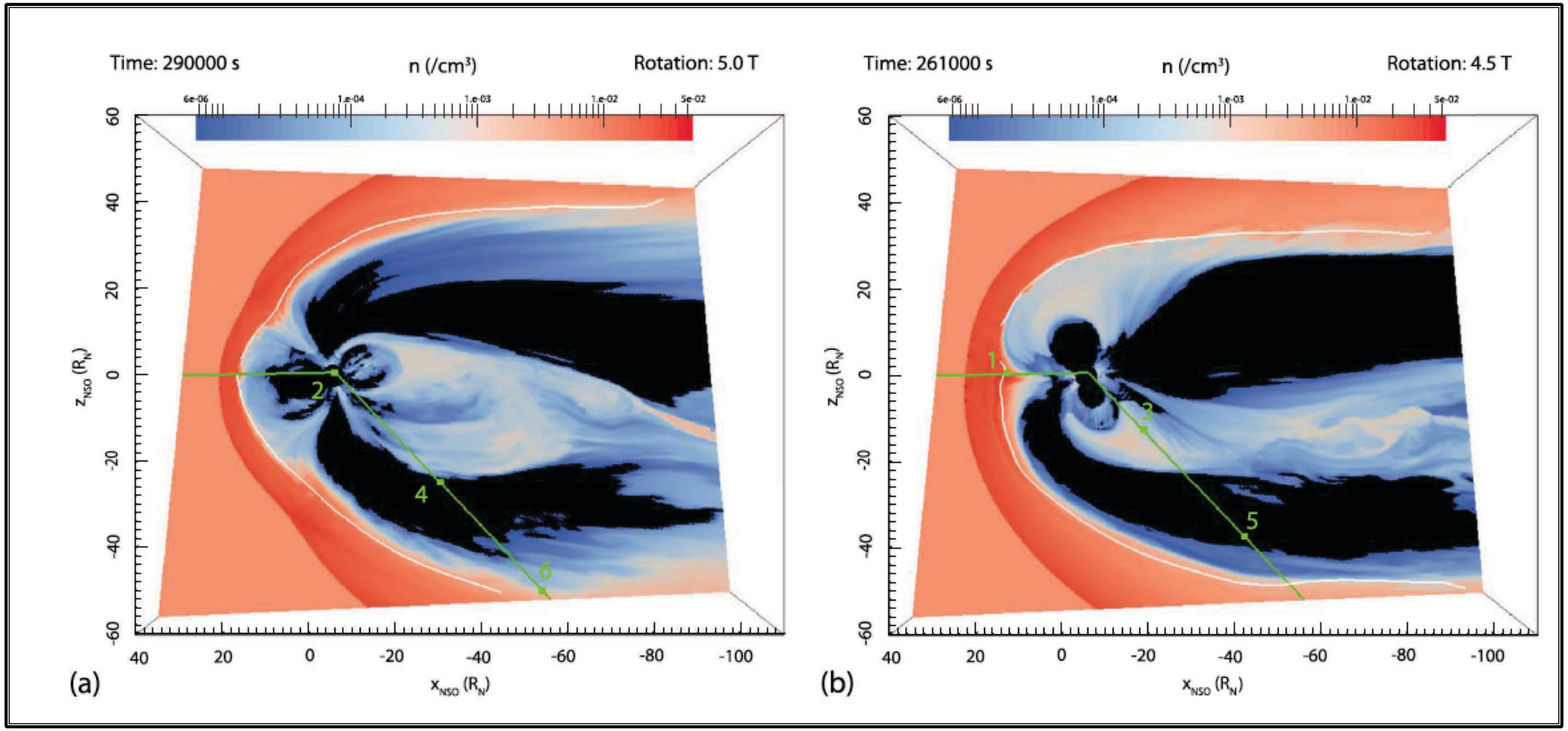


Diurnal variation of plasma pressure & magnetic field at Equinox

Obliquity & Asymmetric Magnetic Fields

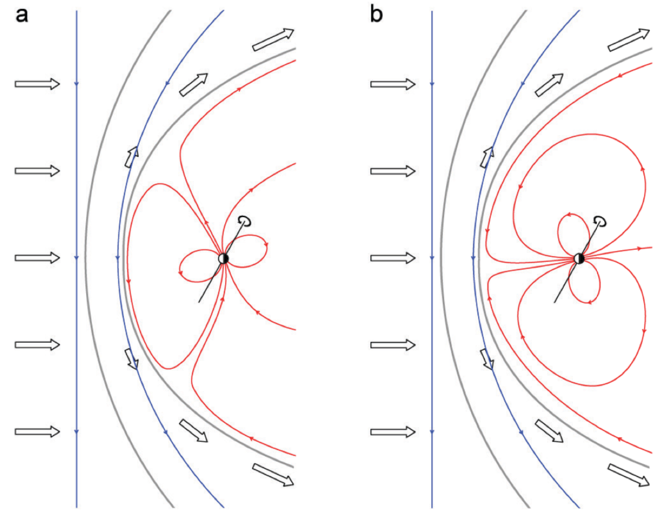


Obliquity & Asymmetric Magnetic Fields



For **Neptune**, (Mejnertsen et al., 2016) found that there was large-scale reconfiguration of the magnetosphere as the rotation moved through a 'pole-on' orientation. This changed the magnetopause stand-off and enabled reconnection on a daily cycle.

Solar Wind Interaction



Masters, 2015

Due to the evolution of the SW with distance from the sun, Uranus and Neptune are embedded in very high Mach # flows

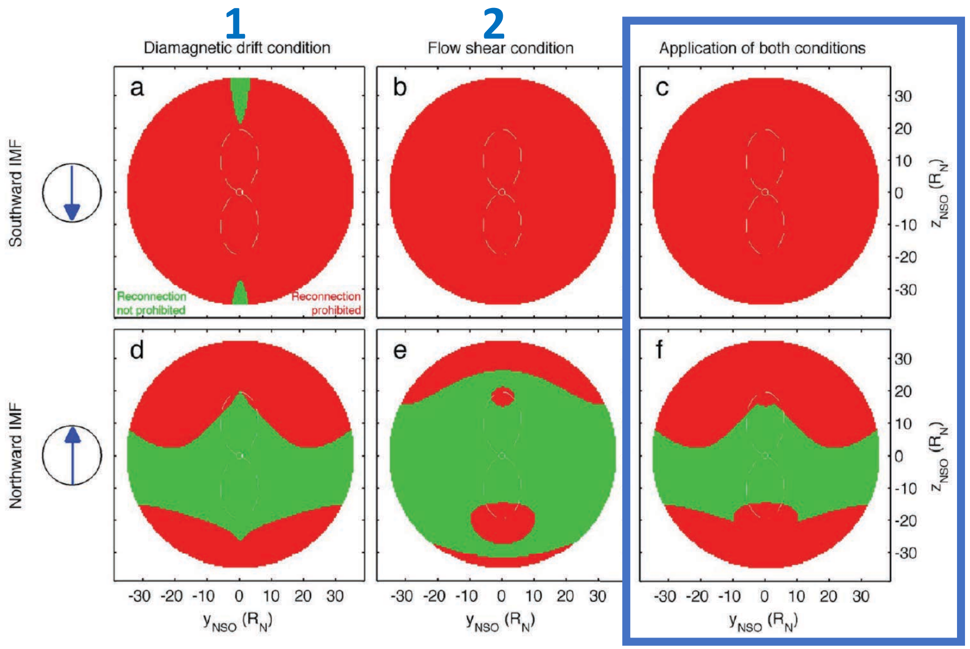
<u>Uranus:</u>	$M_S = 27$	$M_A = 23$
<u>Neptune:</u>	$M_S = 28$	$M_A = 24$

Yielding stronger shocks and higher plasma $\boldsymbol{\beta}$ in the magnetosheath than in the inner solar system.

To assess the likelihood of reconnection at the magnetopause, Masters (2014, 2015) analytically examined two criteria at Uranus and Neptune:

1 - Diamagnetic Drift Onset (Swisdak et al., 2003)
2 - Flow Shear Onset (Cassak and Otto, 2011)

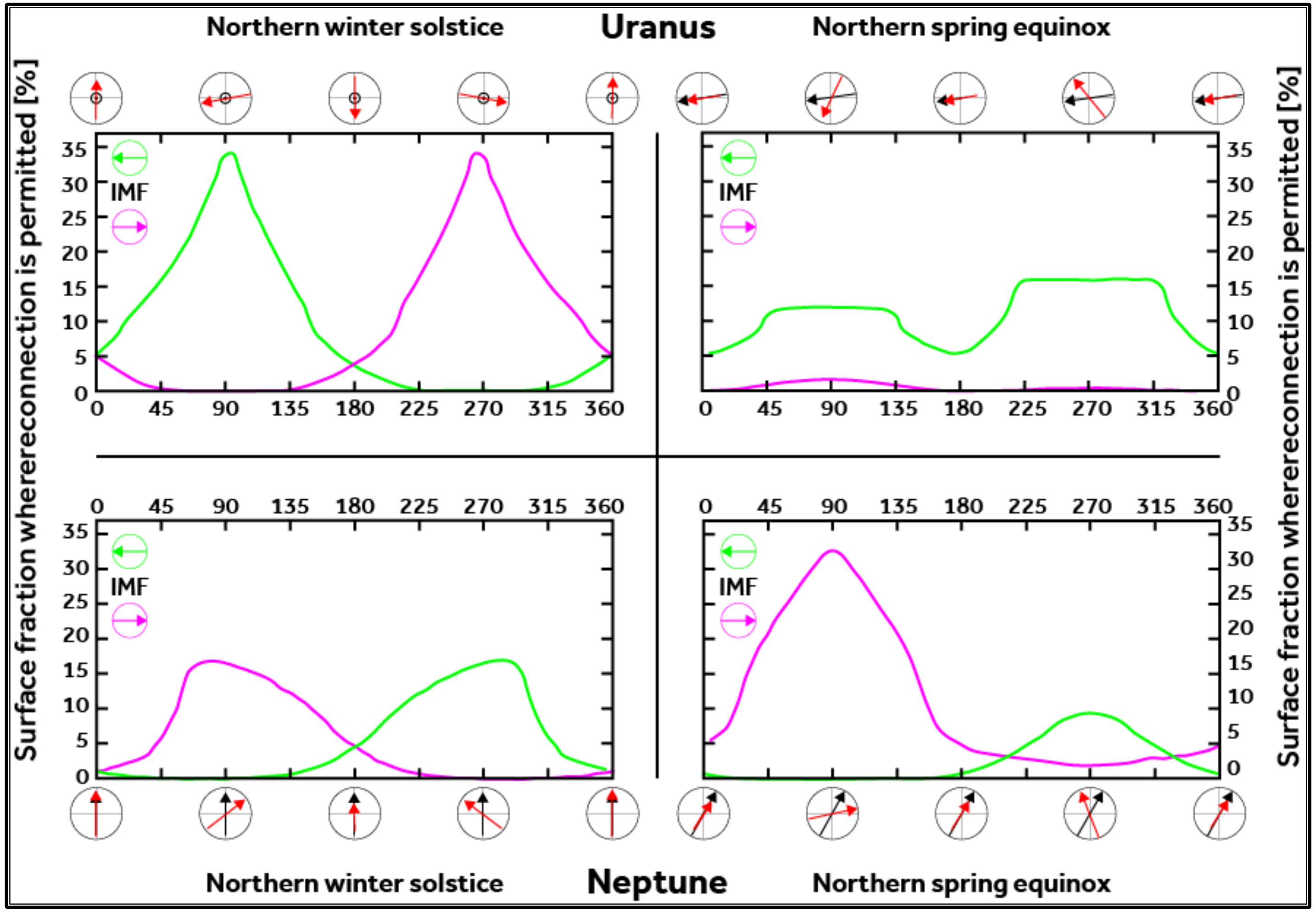
Without *both* reconnection should be suppressed.



Solar Wind Interaction

Taking the stability exercise and running it for different seasonal configurations, rotation phases, and IMF orientation is challenging!

Results for Uranus and Neptune at Solstice and Equinox given in a fraction of the magnetopause where reconnection is permitted throughout a rotation.



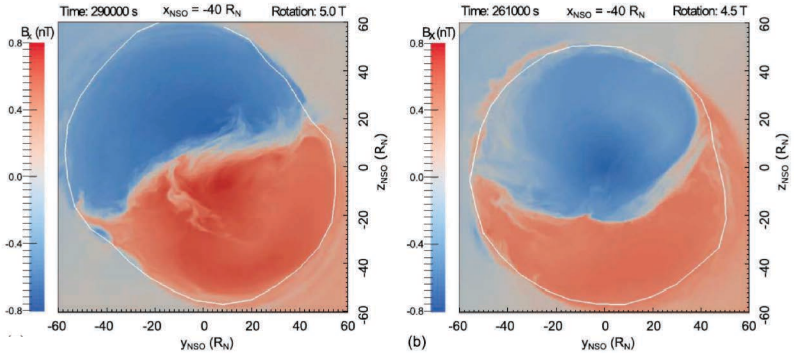
Adopted from Masters, 2014; 2015

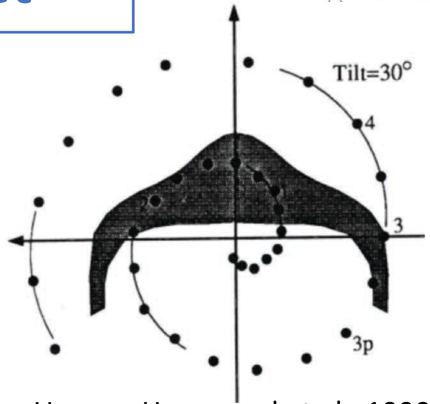
The Magnetotail

Due to the encounter geometry, some characteristics of the magnetotails of Uranus and Neptune were observed, and have be explored analytically and through modeling to develop a 3-D context to place the observations.

Curved, rotating plasma sheet

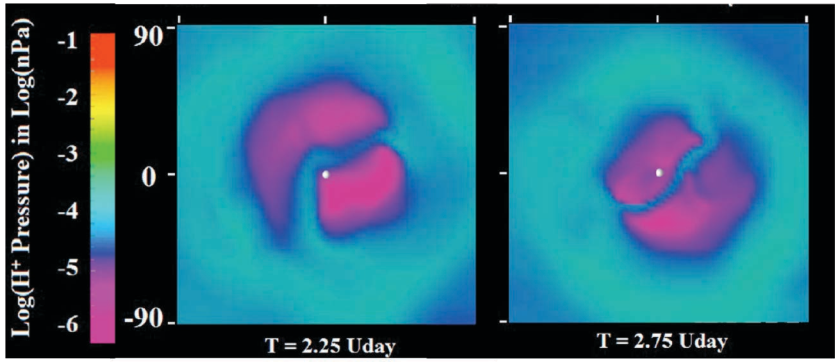
Neptune: Mejnertsen et al., 2016





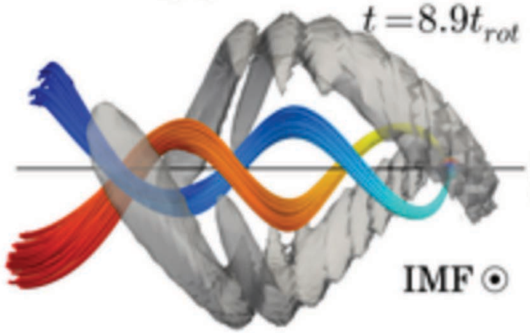
Uranus: Hammond et al., 1990

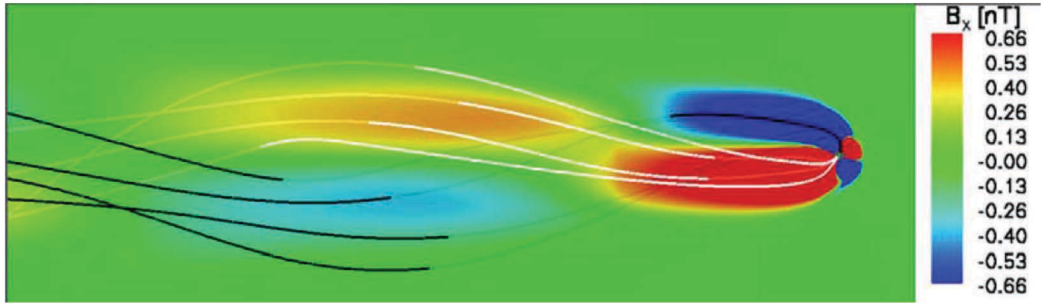
Uranus: Cao & Paty, 2017



Helical tail structure, coupled to IMF

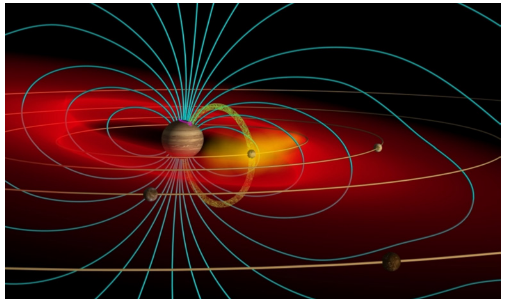
Rapid rotator/Uranus-like: Griton et al., 2018

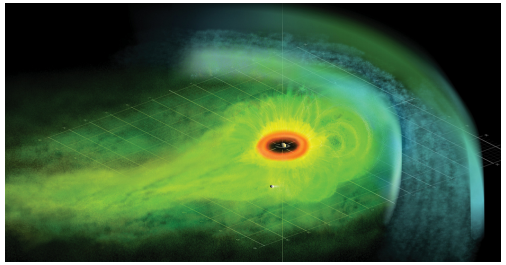




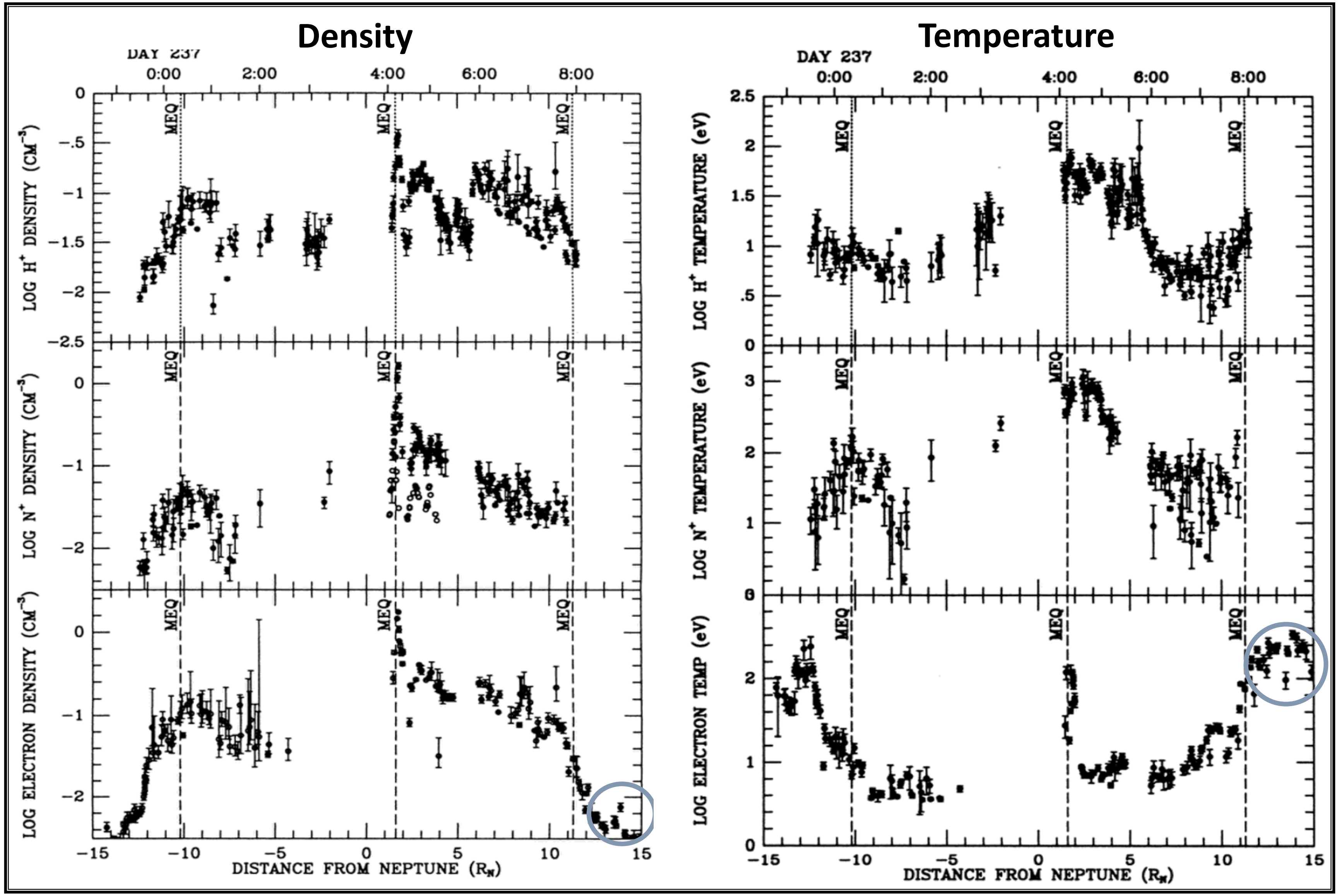
Uranus: Toth et al., 2004

Magnetospheric Plasma Sources

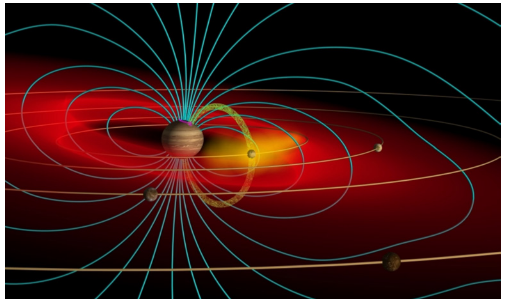


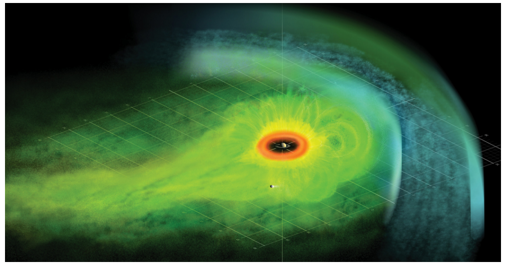


<u>Jupiter:</u>
Io Plasma Torus
<u>Saturn:</u>
Enceladus Neutral Cloud
<u>Uranus: </u>??
<u>Neptune:</u>
Triton Neutral Cloud



Neptune and Triton, ed. D. P. Cruikshank





Magnetospheric Plasma Sources

<u>Jupiter:</u>

Io Plasma Torus

<u>Saturn:</u>

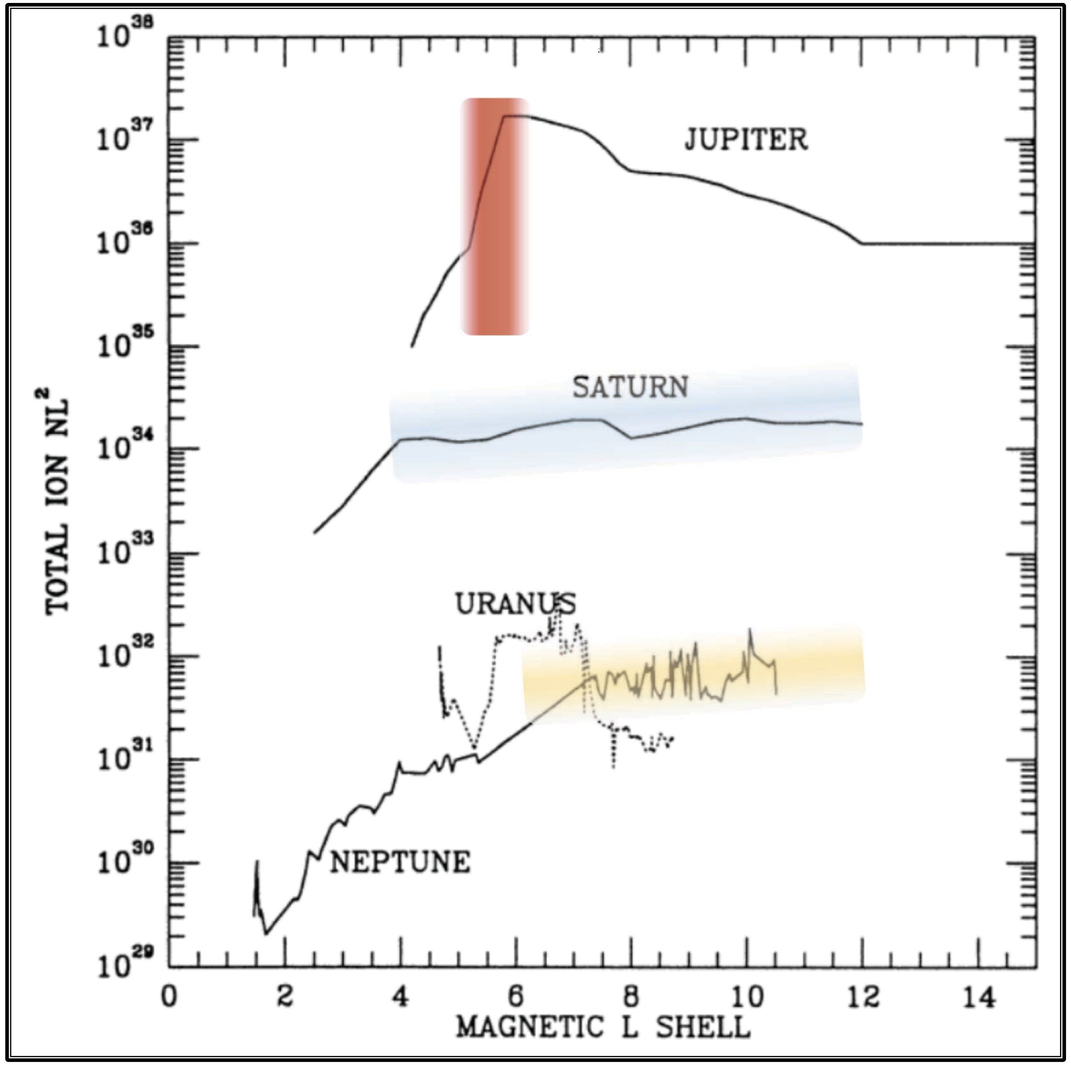
Enceladus Neutral Cloud

<u>Uranus:</u> ??

<u>Neptune:</u>

Triton Neutral Cloud

More instructive than simply seeing the low plasma densities in the Ice Giant magnetosphere is exploring the sources via the plasma flux tube content.



Neptune and Triton, ed. D. P. Cruikshank

Plasma ~~Longevity~~ Stability

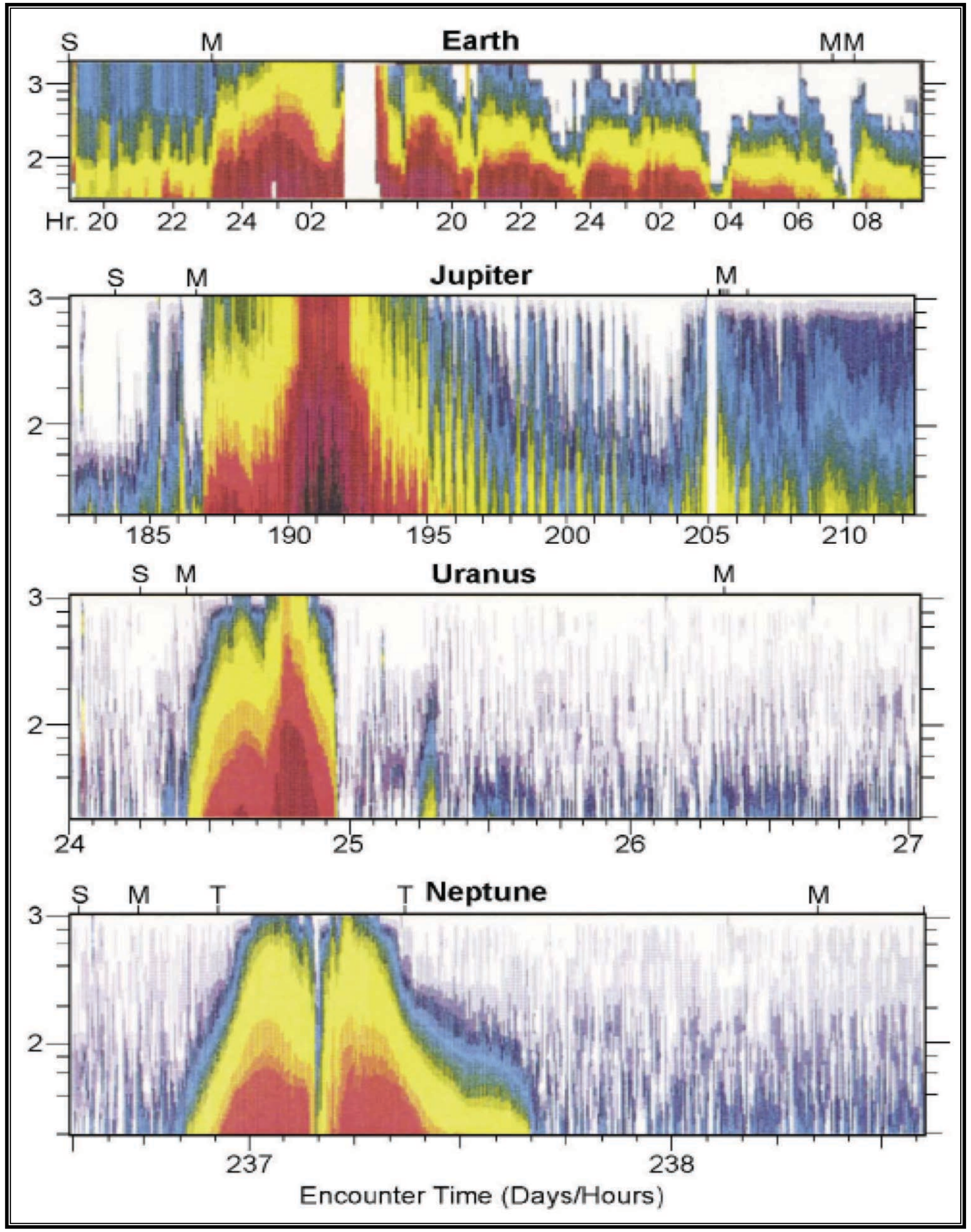
But why are the Ice Giant magnetospheres so devoid of plasma?

Eviatar & Richardon (1986) determined that Uranus' magnetosphere should enable the formation of a stable plasma torus sourced from Uranus' larger icy moons.

Similarly, it was thought that Triton should supply Neptune with a torus of N+ and H+ (Cheng, 1990; Delitsky et al., 1989). Due to the long self-collision time of this putative and diffuse torus, it should have a lifetime orders of magnitude longer than plasma generated in the Io torus (Marconi, 2003).

Both magnetospheres generally lack stable magnetospheric convection as their polar caps are completely changing orientation relative to the solar wind every rotation

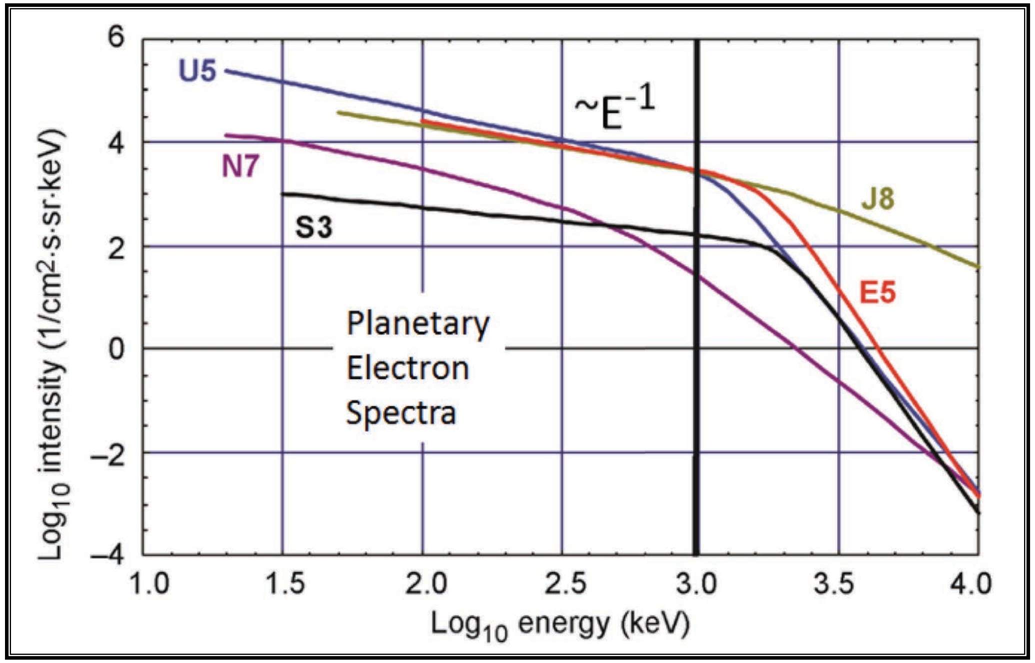
Radiation Belts



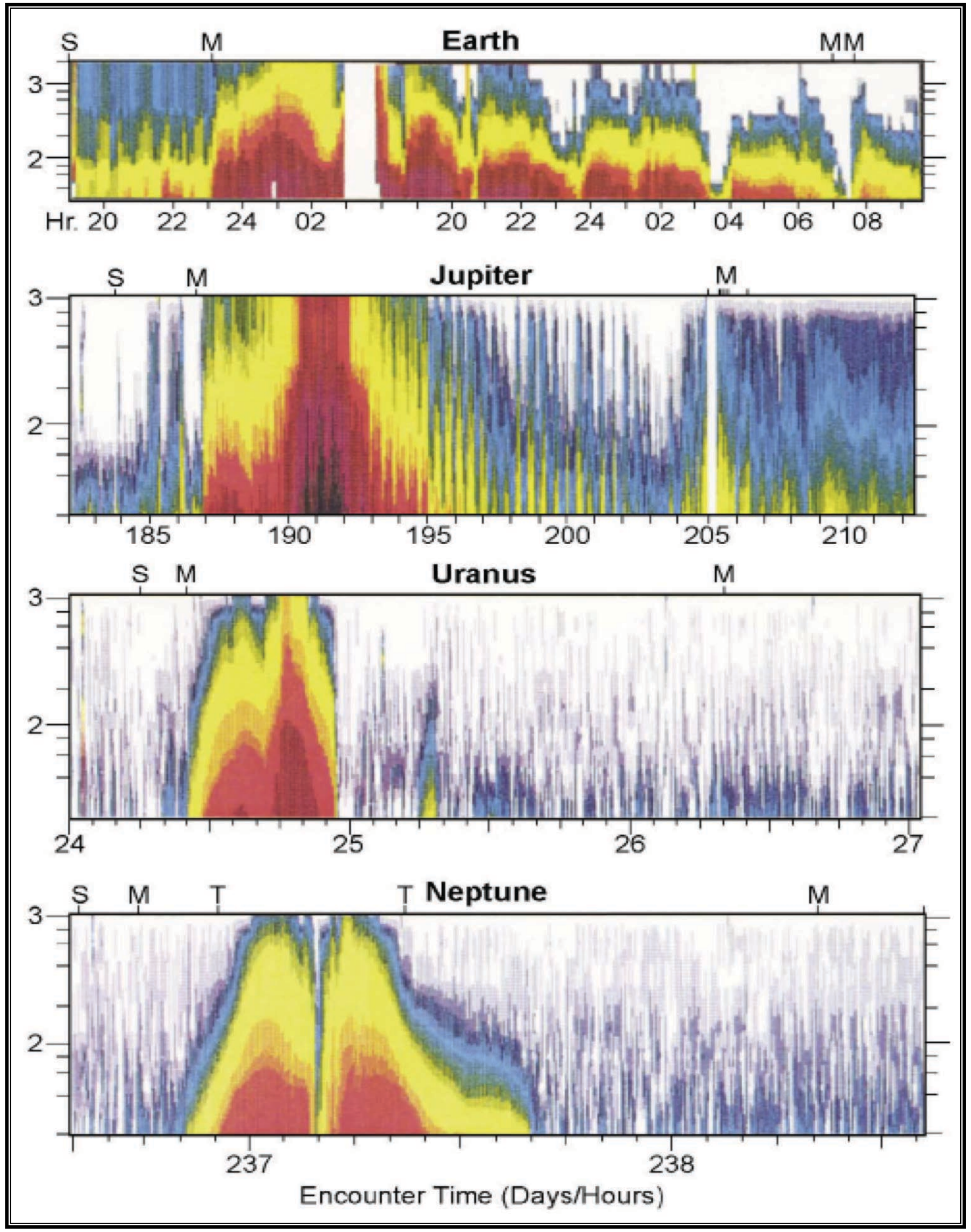
Mauk & Fox, JGR, 2010

While both Neptune and Uranus are nearly devoid of plasma, both possess radiation belts, and Uranus has particularly intense ones!

But with one observation, is this even 'normal'?



Radiation Belts



Mauk & Fox, JGR, 2010

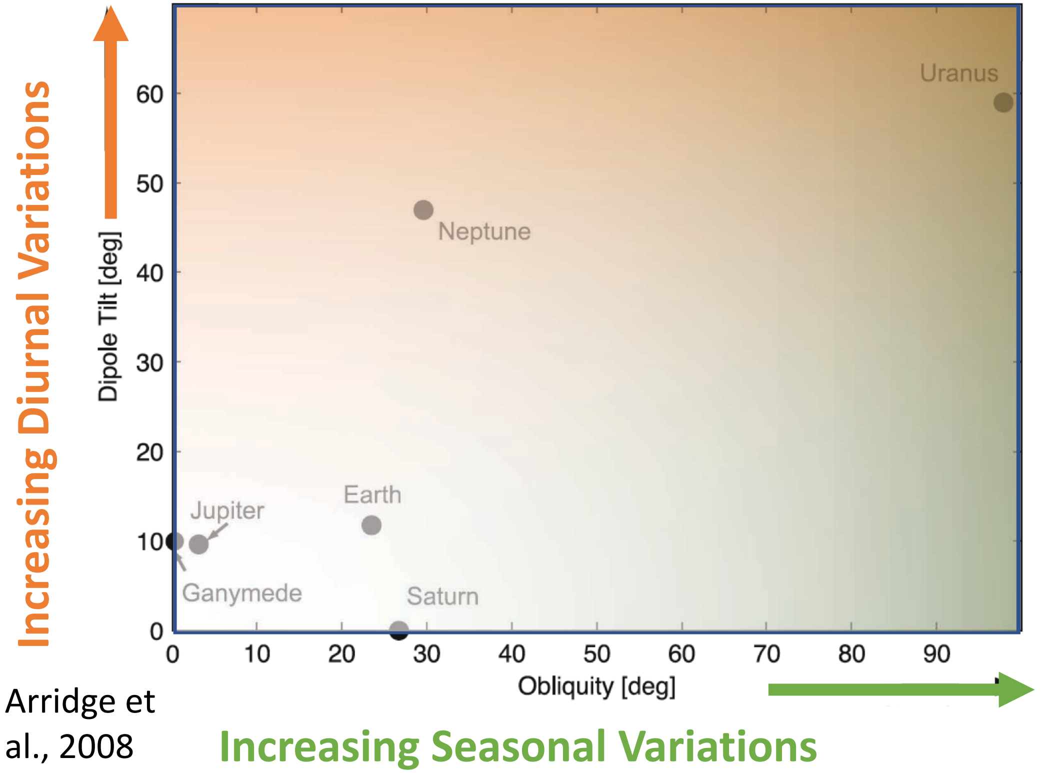
At Earth, the Van Allen Probes have found that chorus waves are driven by energetic particle injections – these wave energize seed populations to supply the energetic electrons to the outer radiation belt (Jaynes et al., 2015).

At Uranus, strong whistler waves and injections were observed!

Neptune, none. But did we just miss them?

Conclusions

Uranus and Neptune provide an expansion of our 'Natural Laboratory' enabling us to explore an even wider range of magnetospheric dynamics than the Gas Giants.

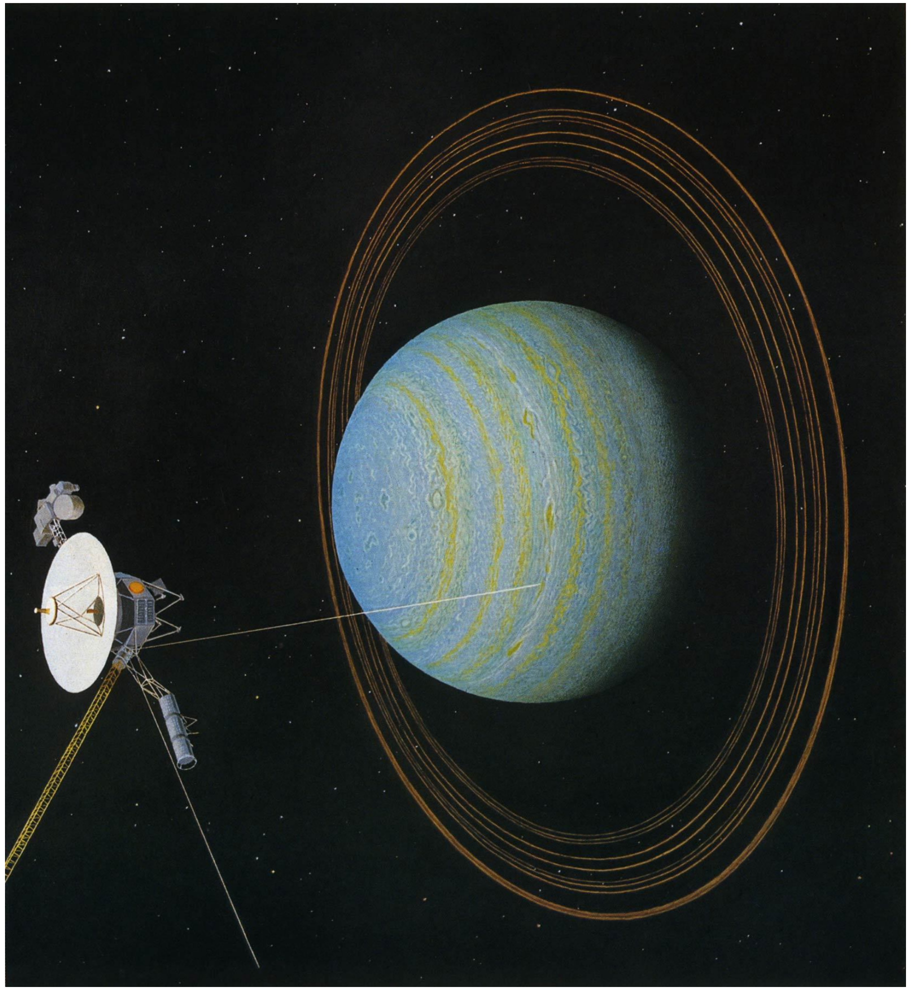


Arridge et al., 2008

<u>Some Questions:</u>

- How do the Ice Giant magnetospheres evolve dynamically? Differences?
- Is there an equilibrium state for either of the Ice Giant magnetospheres?
- What role do moons (esp. Triton) and rings play in supplying the Ice Giant magnetospheres with plasma?
- Why does Uranus have such intense radiation belts, and what processes generate them?
- How prominent is the the season response of these magnetospheres?

Conclusions



NASA/JPL

Complex geometries of the magnetospheres of Uranus & Neptune were advantageous for exploring much of the magnetosphere, enabling a single flyby of each planet to sample the bow shock, magnetopause, radiation belts, the plasma sheet, lobes, and helical tail structure… but it was still essentially a snapshot in time for highly variable system.

Imagine if we had an orbiter?
Imagine if we had time to watch any of these properties evolve?

Let’s Explore