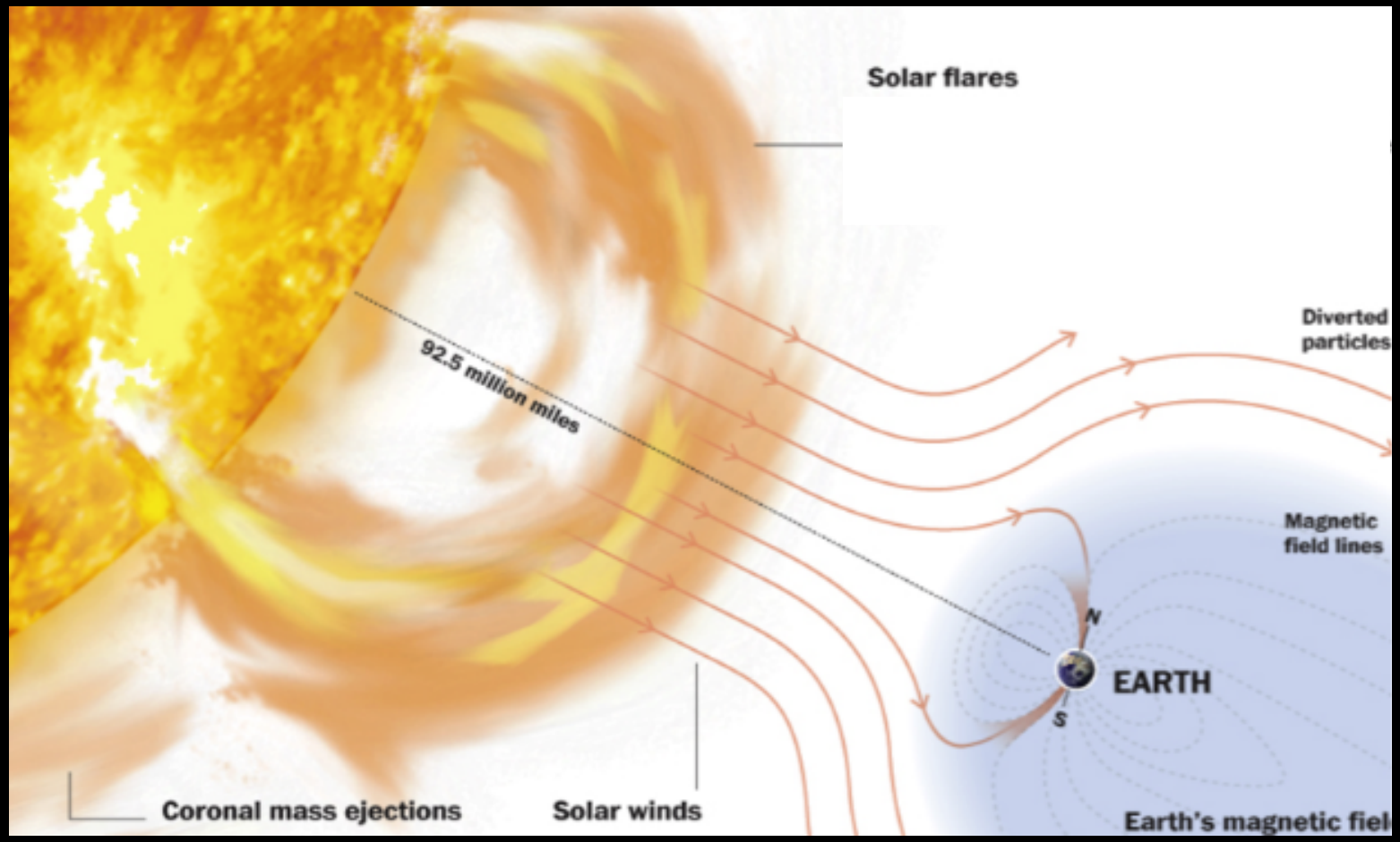
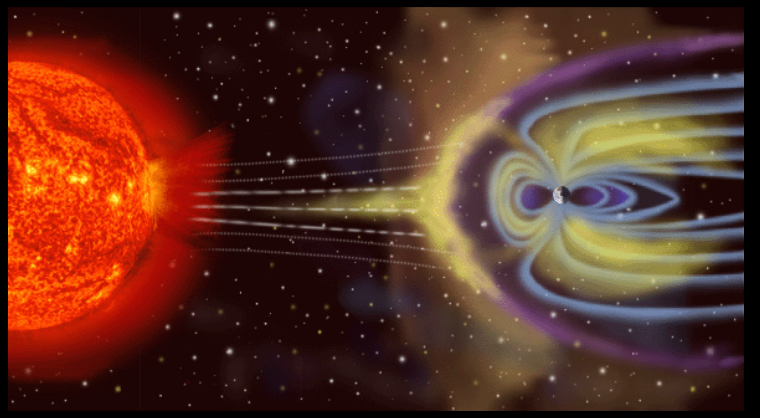
Understanding magnetospheric interactions in the solar system



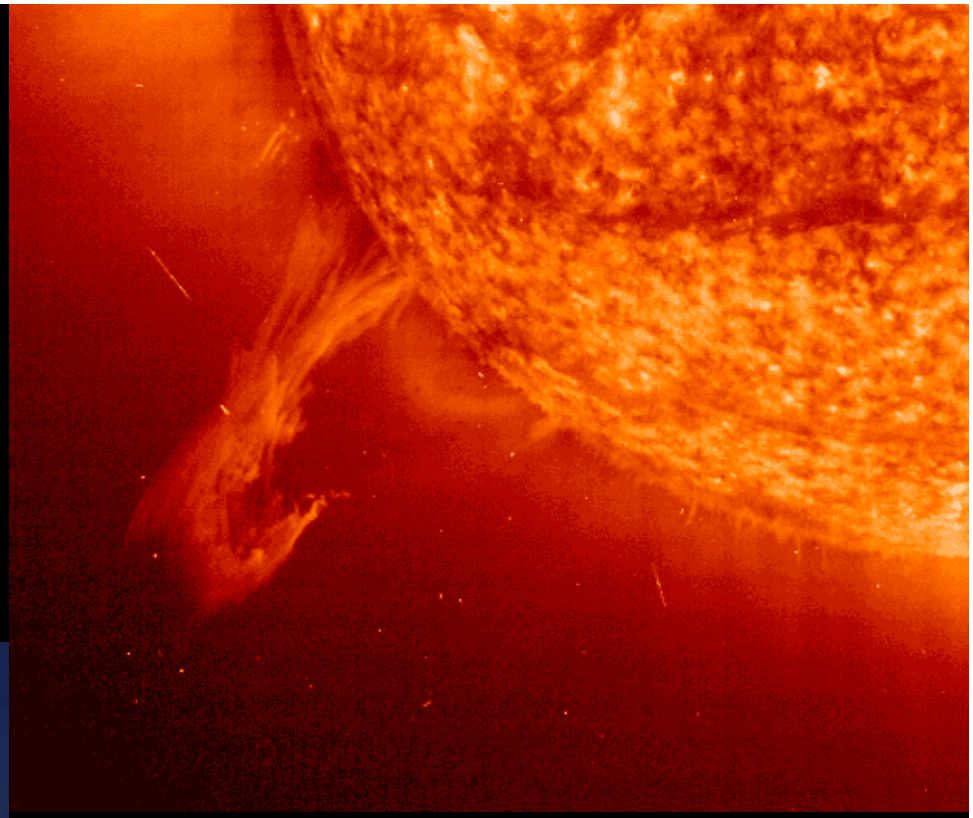
Outline

- Space Physics Overview
  - Solar Wind
  - Earth's Magnetosphere
  - Space Weather
  - Space Plasma
- Studying Magnetospheres
- Magnetospheres Around the Solar System
  - Saturn & Enceladus
  - Mars
  - Jupiter & the Galilean Moons



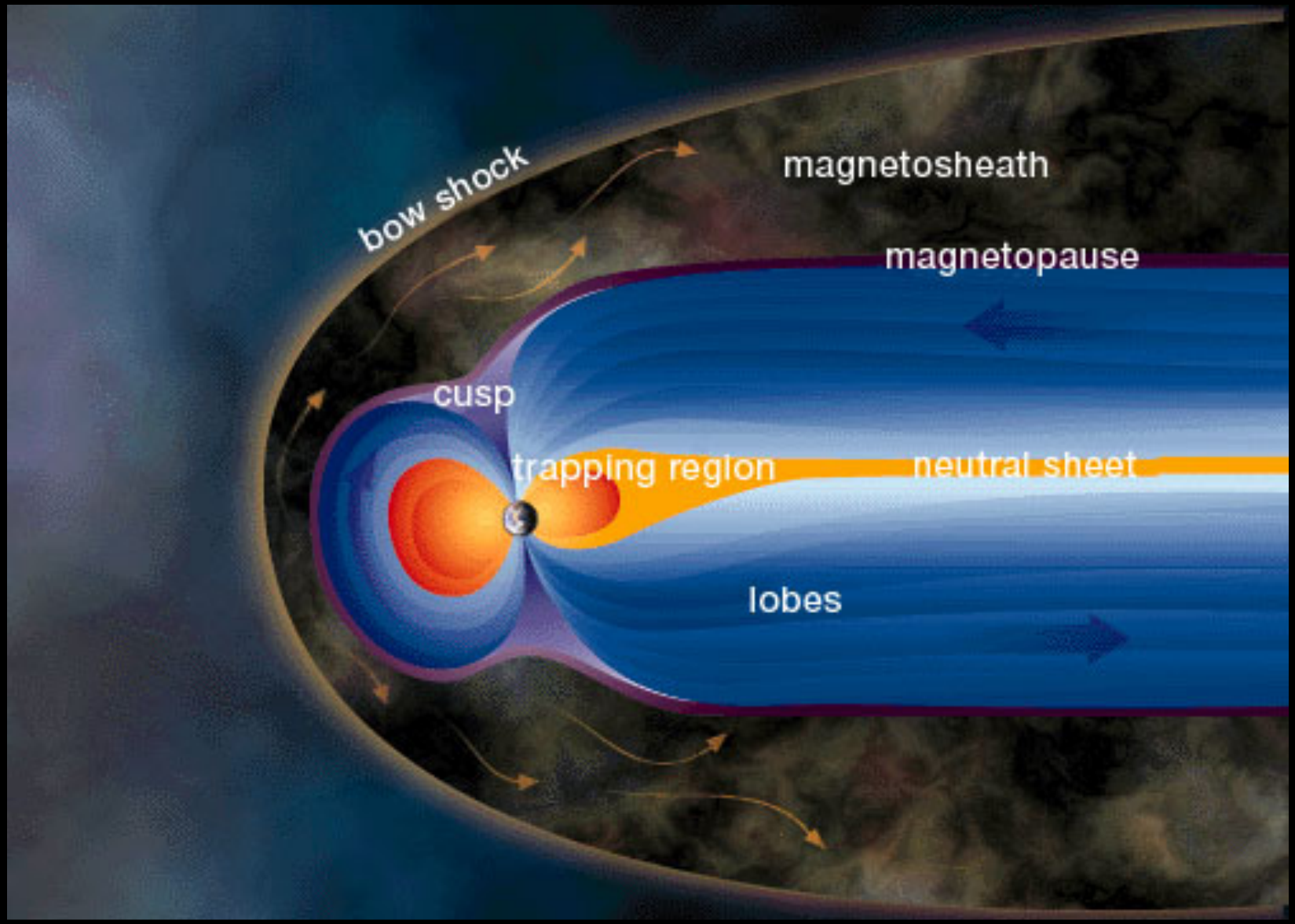
Solar Wind

Density ~ 10 cm^{-3}
Speed ~ 300 km/s
Magnetic field ~ 10 nT

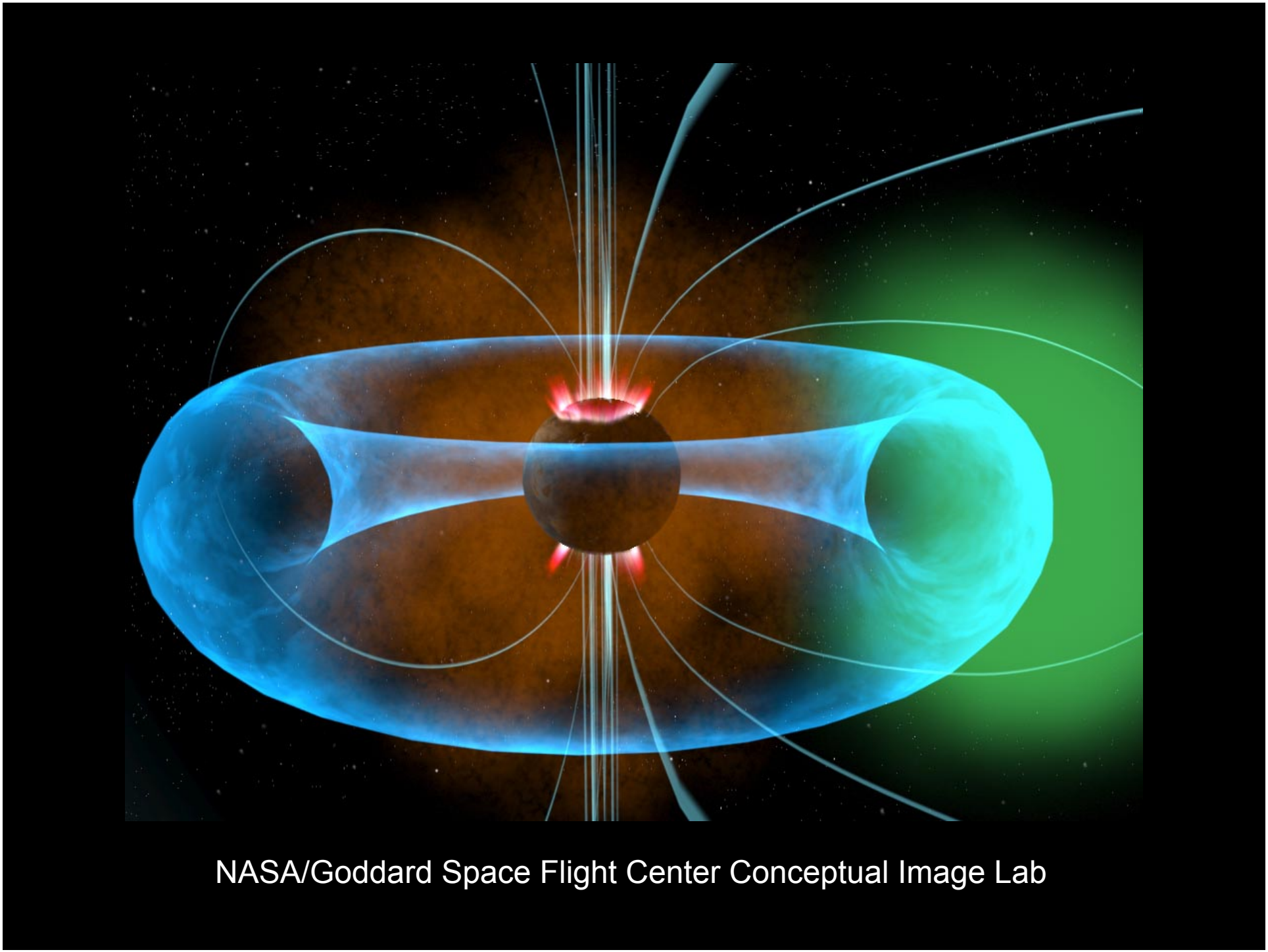


Temperature ~ 10^5 K
Sonic Mach ~ 10
Alfvén Mach ~ 4

Planetary Magnetic Fields



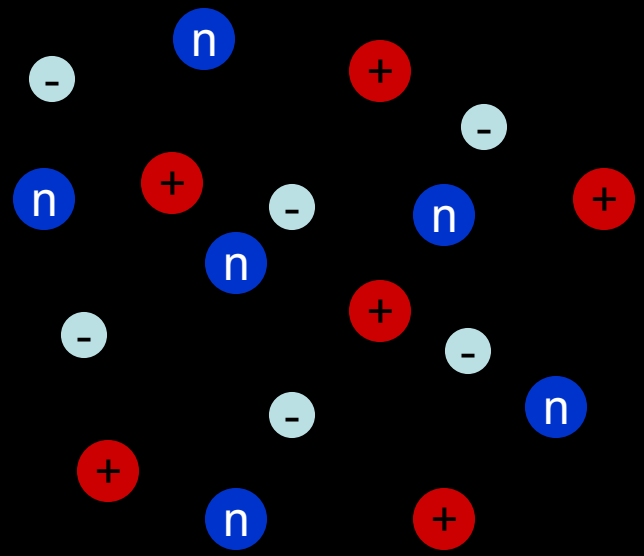
NASA/Goddard Space Flight Center Conceptual Image Lab



NASA/Goddard Space Flight Center Conceptual Image Lab

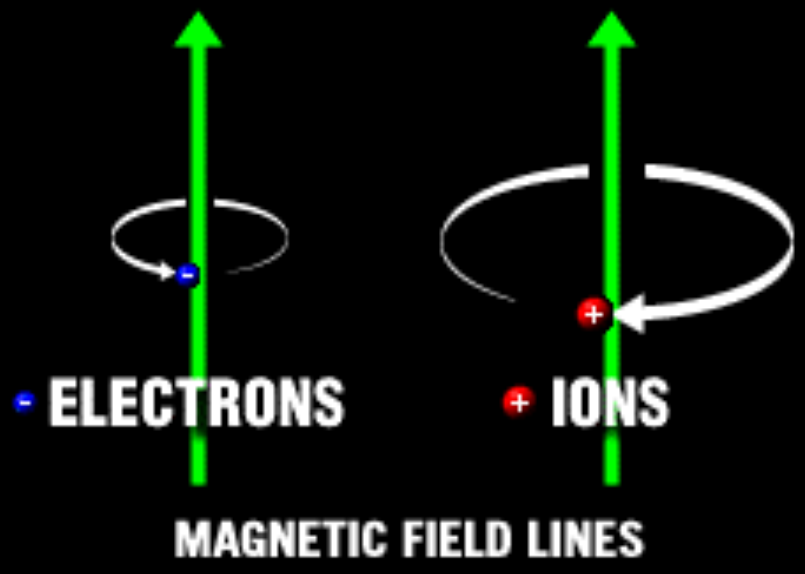
Space Plasma

- 4th State of Matter
- High Temperature
- Quasi Neutral
- Collisionless
- Interacts with Electric and Magnetic Fields



Ion & Electron Motion

In space, charged particles tend to become attached to magnetic field lines they encounter, spiraling around them in a helical motion.



This motion is governed by the *Lorentz Force Law*

Charged Particle Motion

- Lorentz Force Law

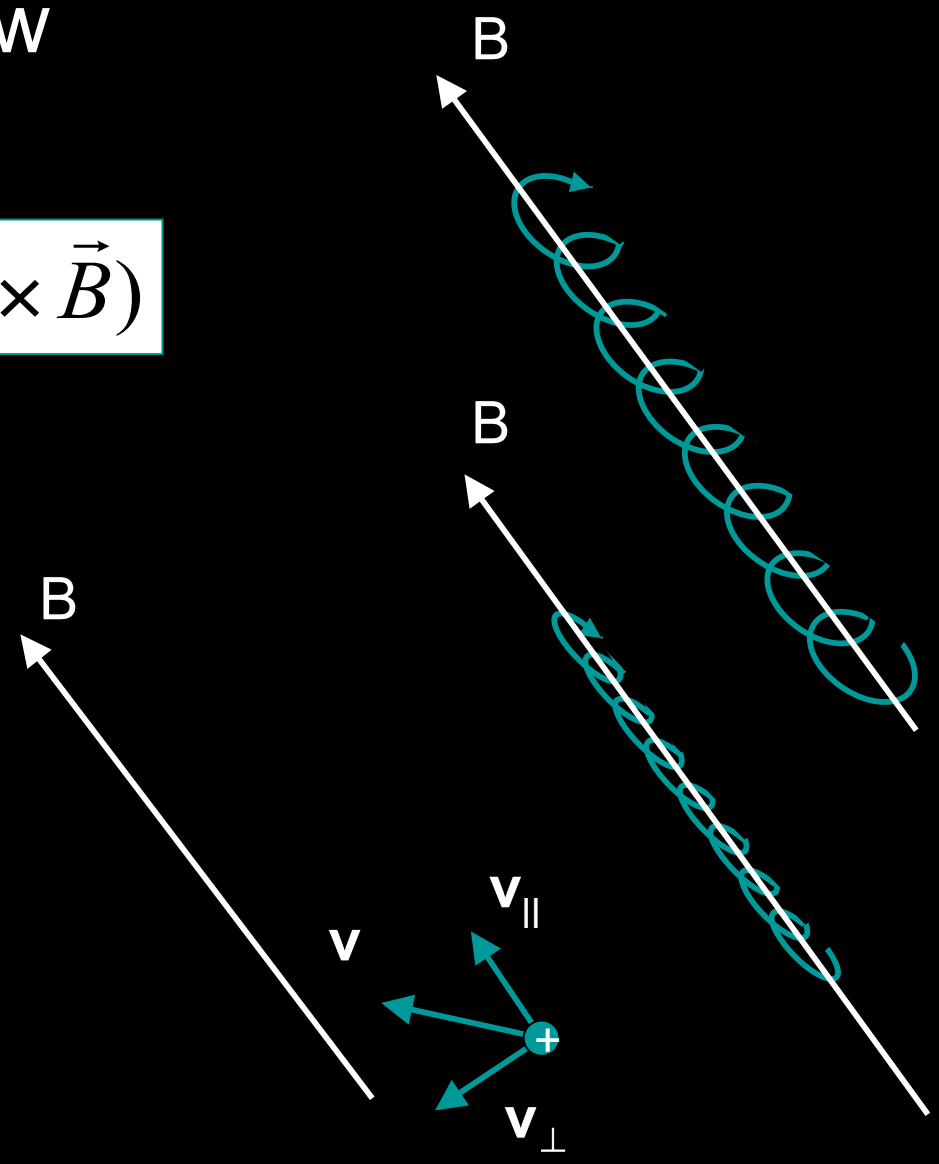
$$\vec{F} = m\vec{a} = q(\vec{E} + \vec{v} \times \vec{B})$$

- Gyroradiaus

$$r_{gyro} = mv_{\perp} / qB$$

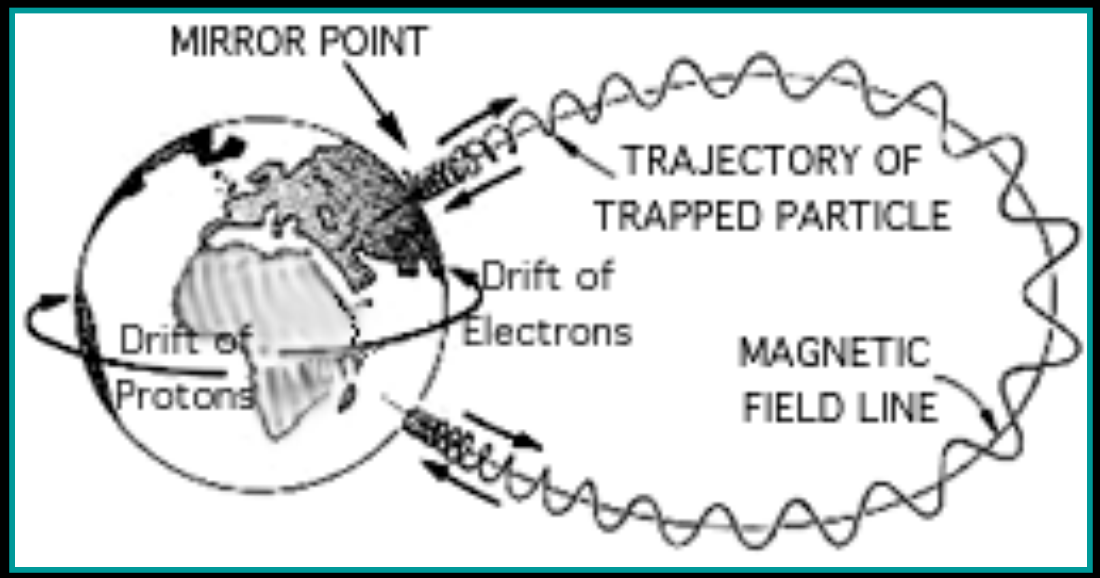
- Gyrofrequency

$$\omega_c = qB / m$$



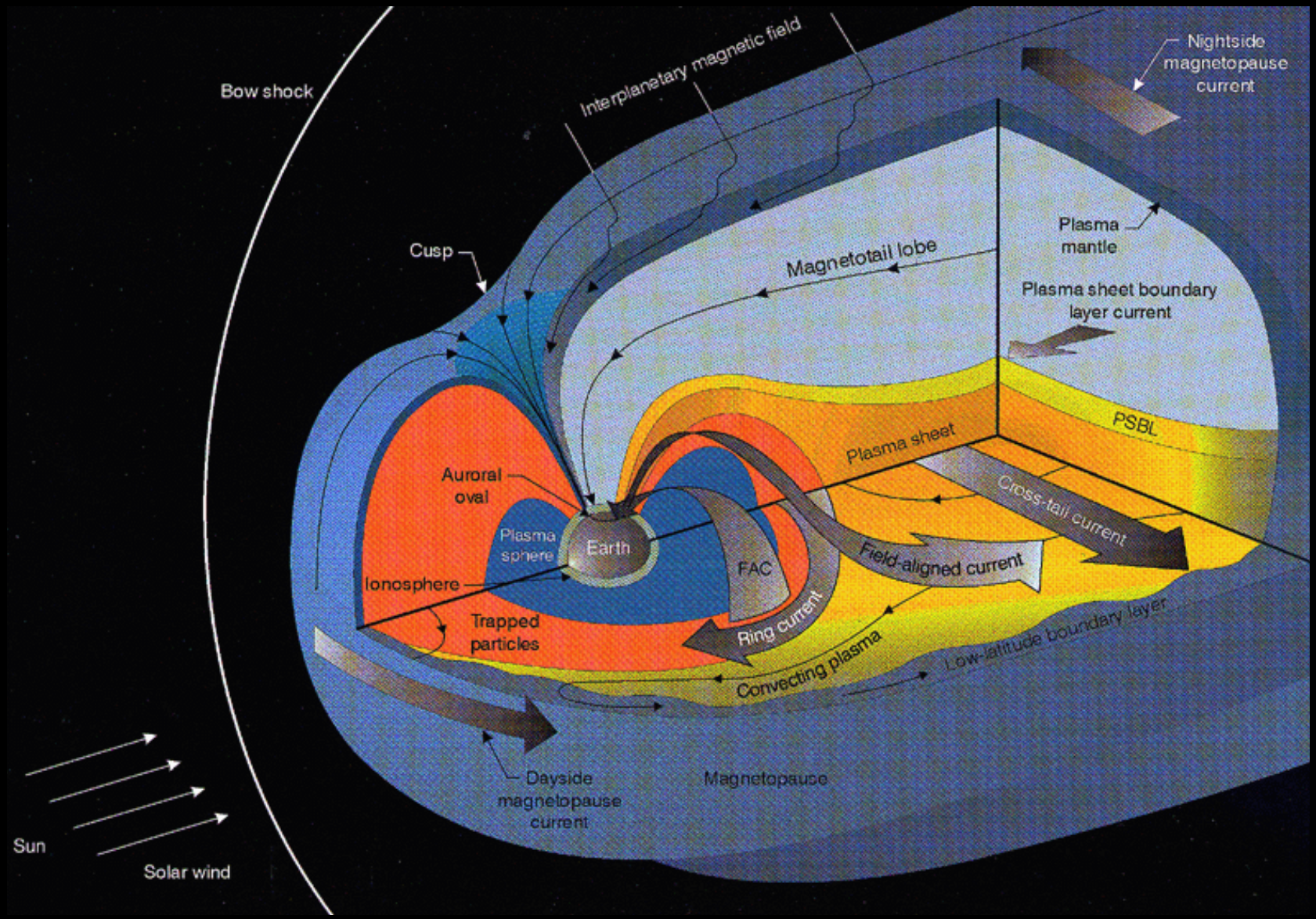
Particle Motion: Trapped Particles

As they spiral into a region of strong field, charged particles are reflected back along the magnetic field line.

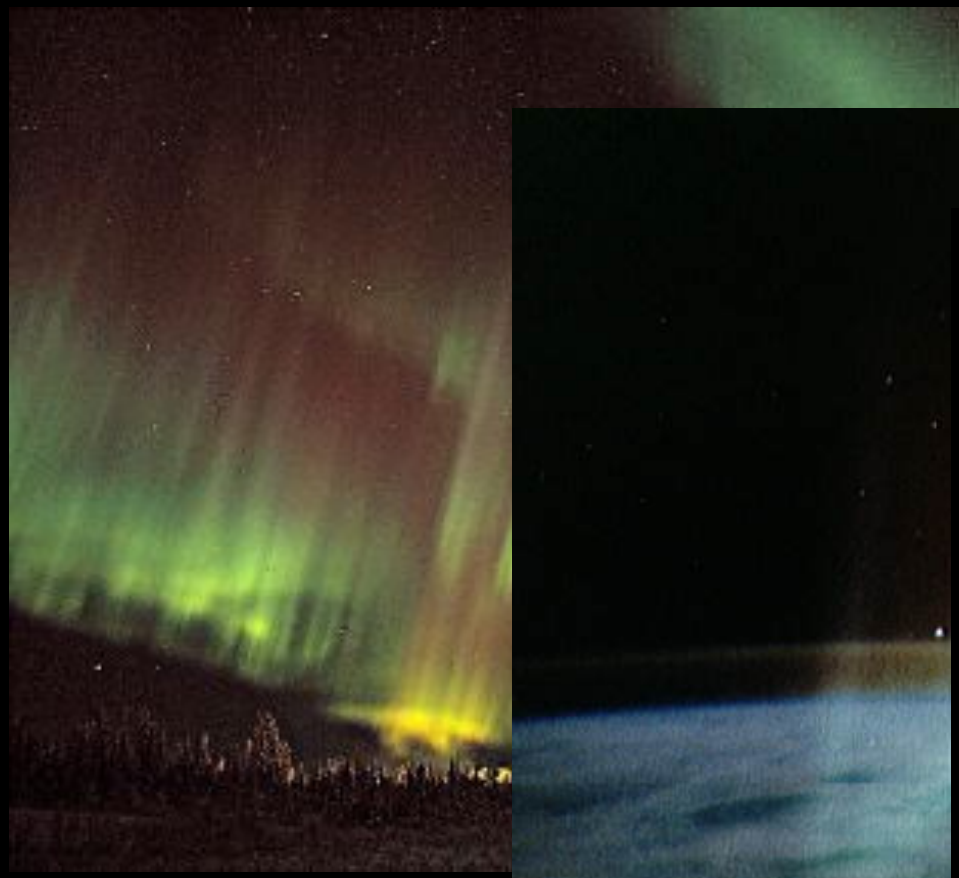


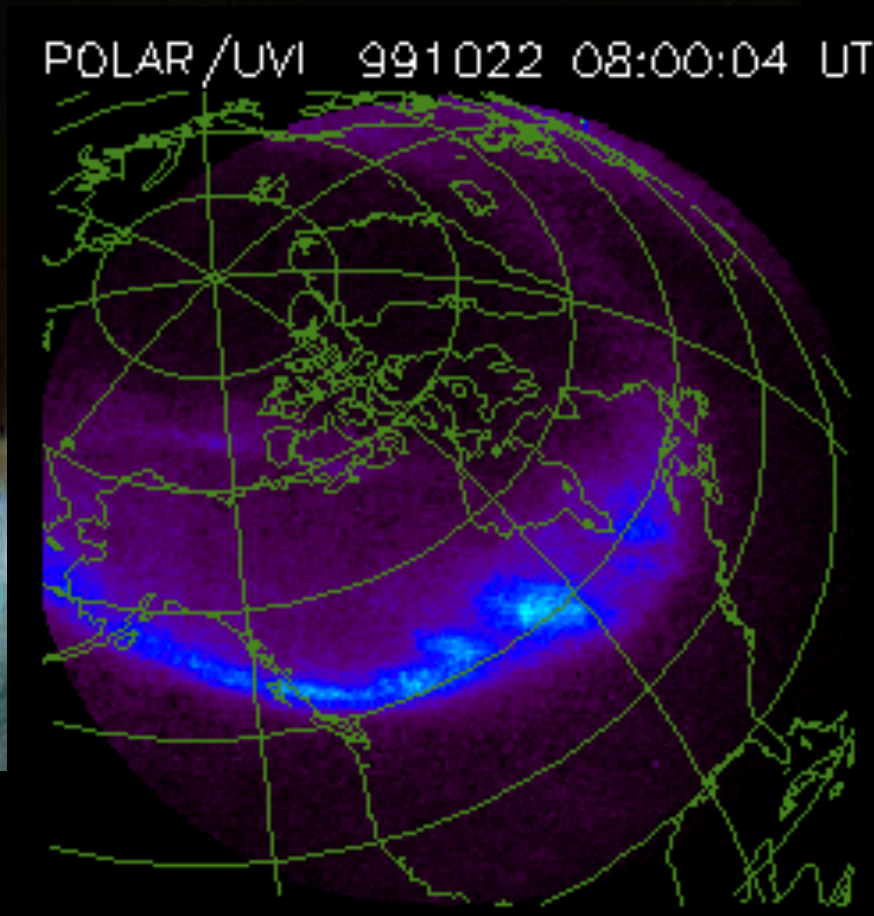
Such particles are thus “trapped” and bounce back and forth between opposite hemispheres.

Currents in the Magnetosphere



Earth’s Aurora

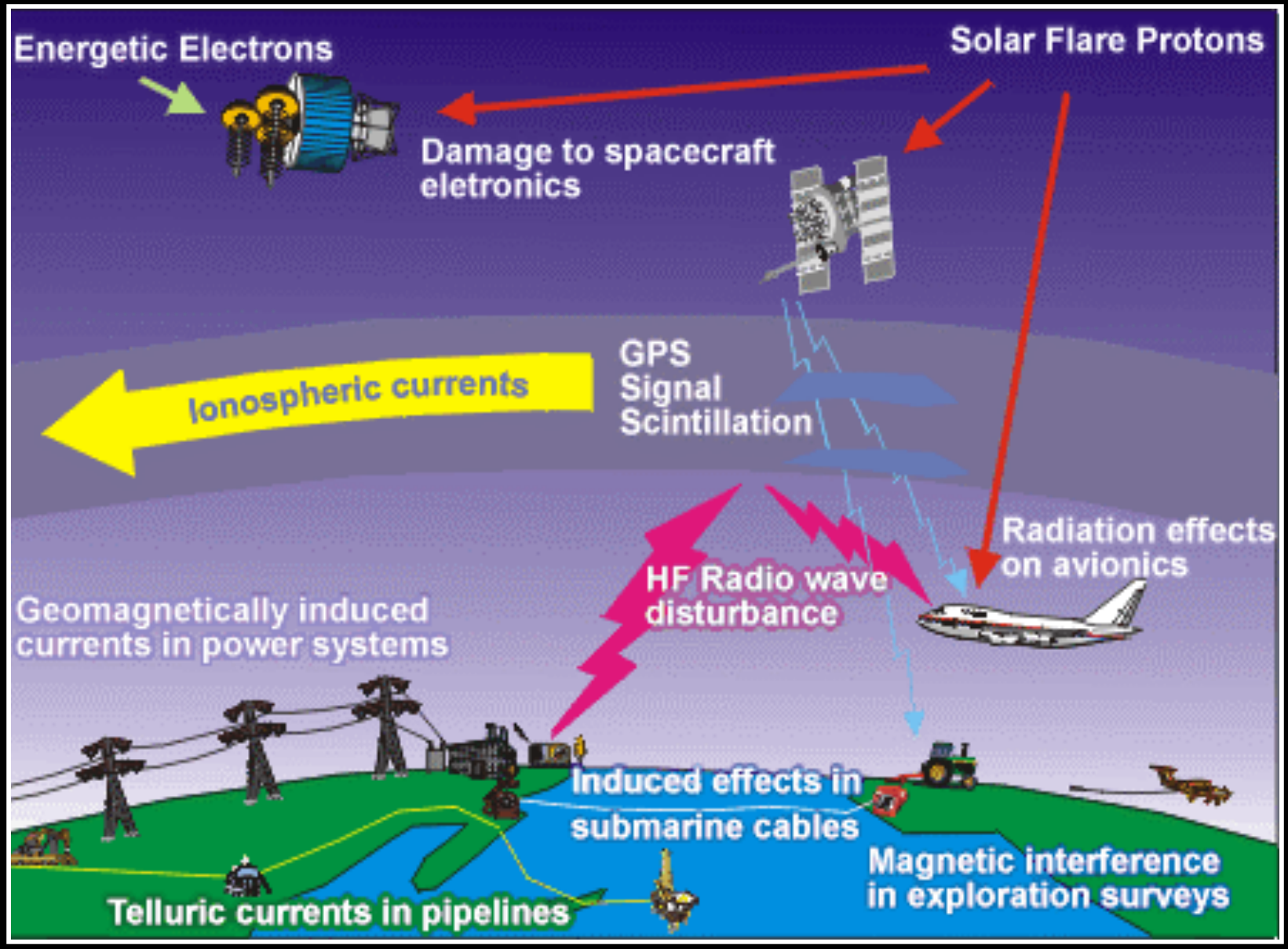




What is Space Weather?

- “Conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."

Space Weather & Us



Questions in Space Physics

- Magnetosphere Interaction and Response
- Predictability
  - Magnetic Reconnection
  - Local Plasma Acceleration
  - Propagation
  - Coupling of the Magnetosphere and Ionosphere
  - Ionosphere/Atmosphere Loss

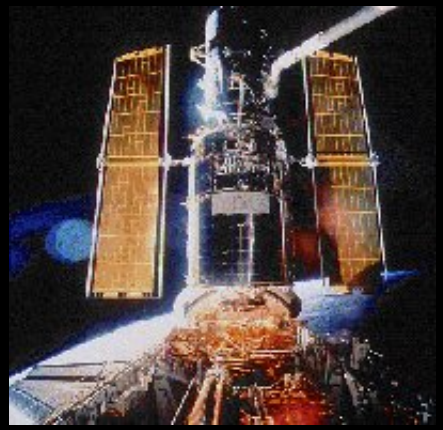
How do we study magnetospheres?

Observations:

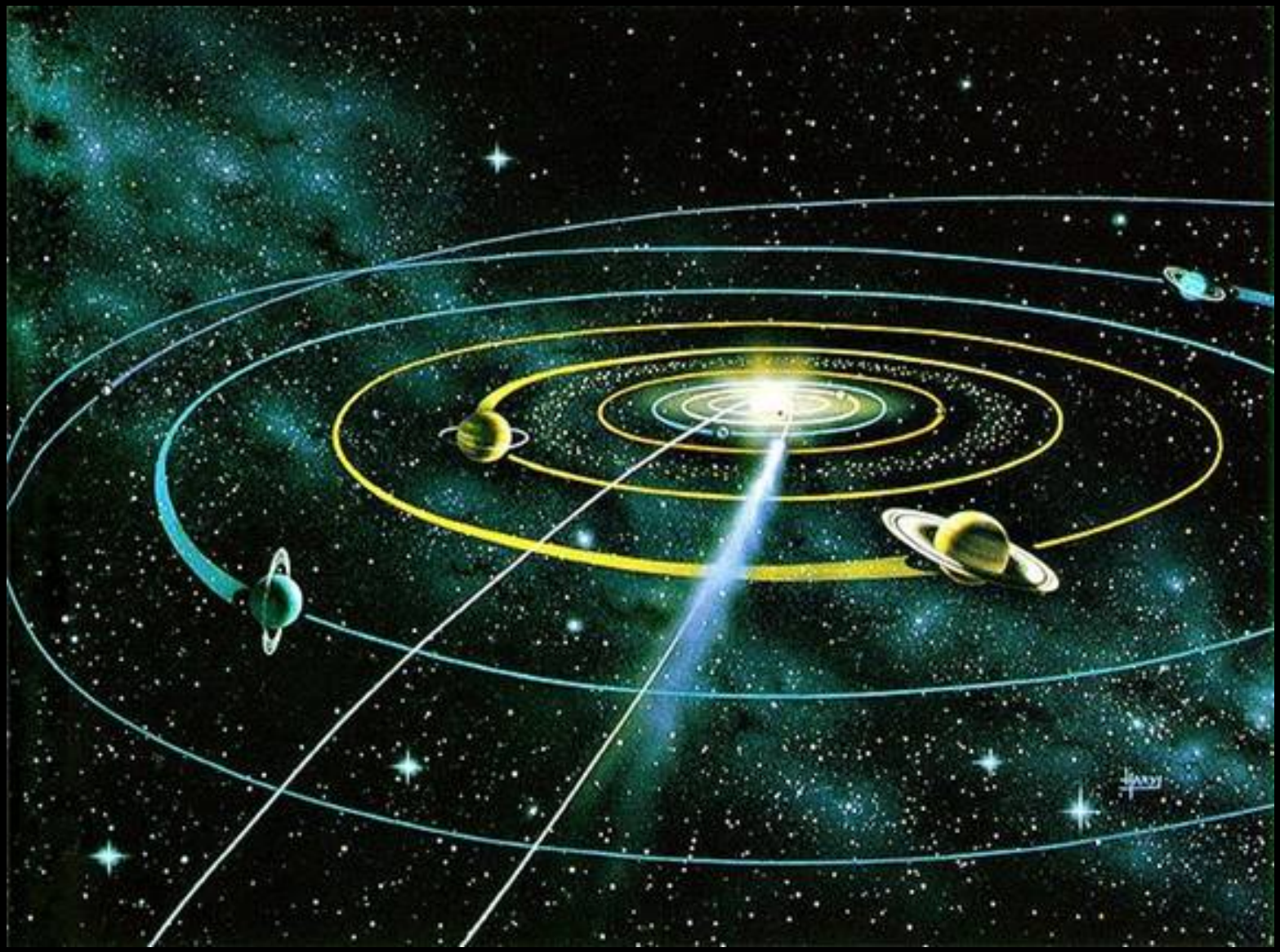
- Orbiting Spacecraft
- Rockets & High Altitude Balloons
- Remotely Using Telescopes

Theory:

- Computer Simulations



Earth: One of Many

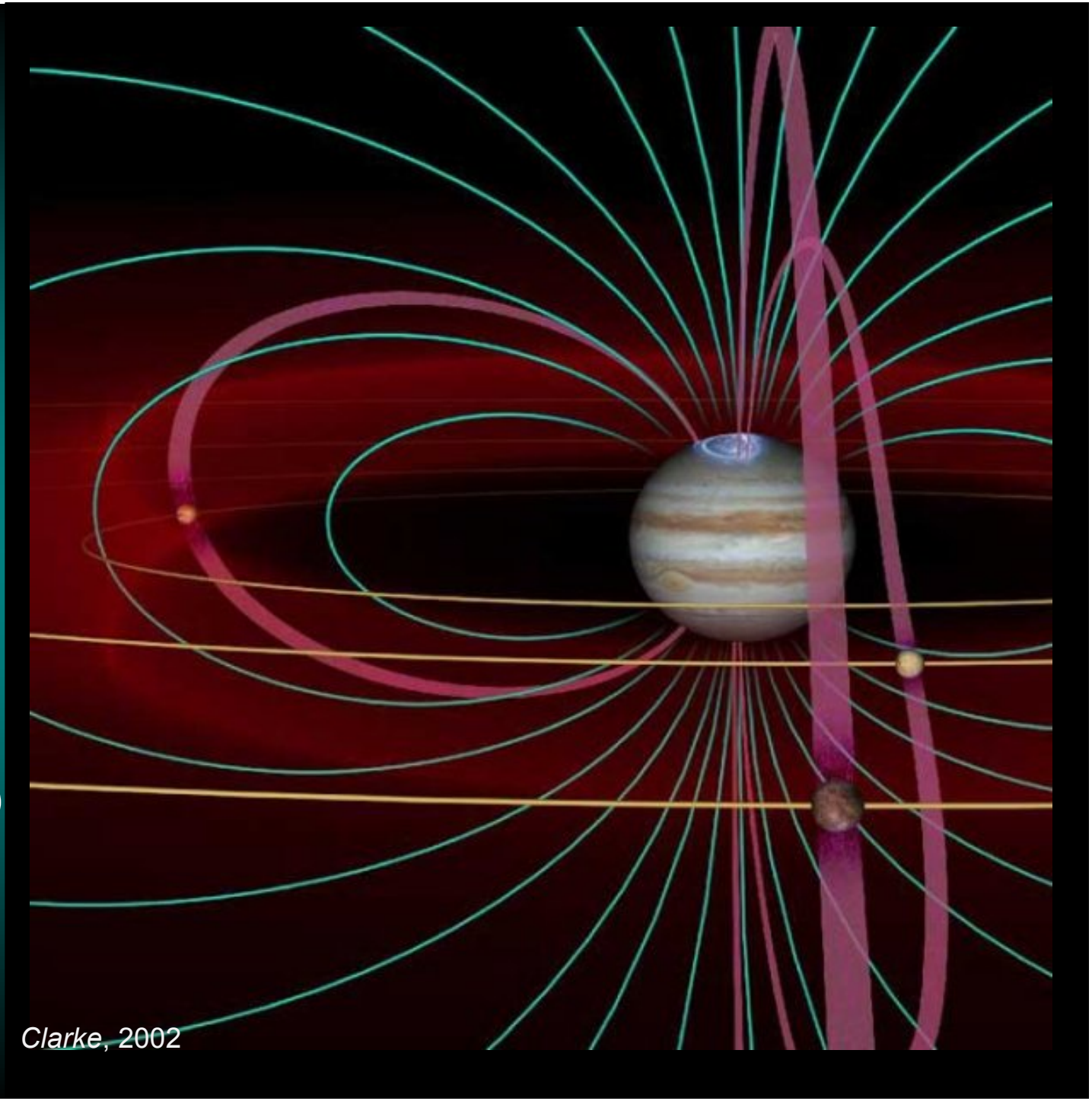


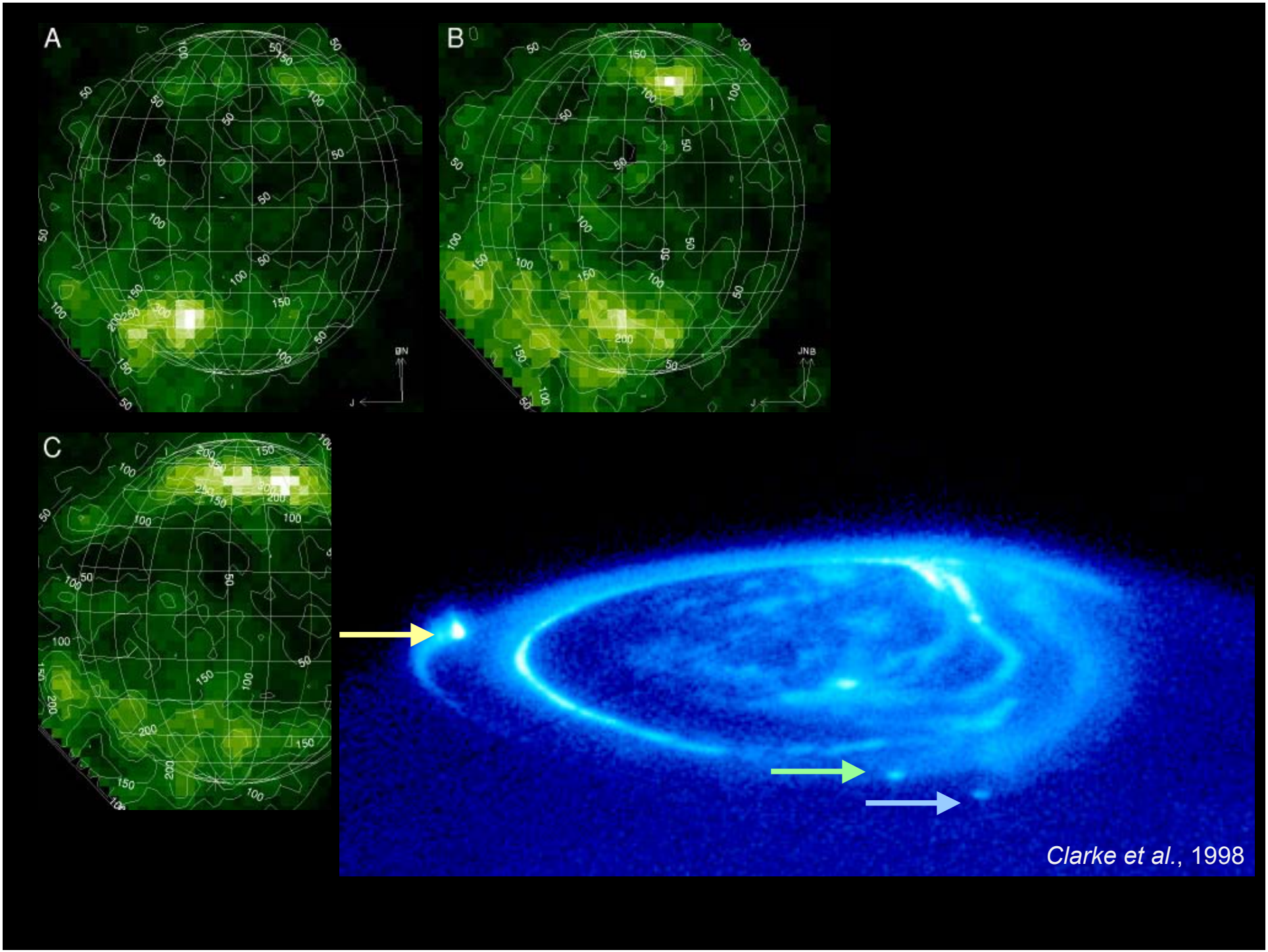
Jovian System

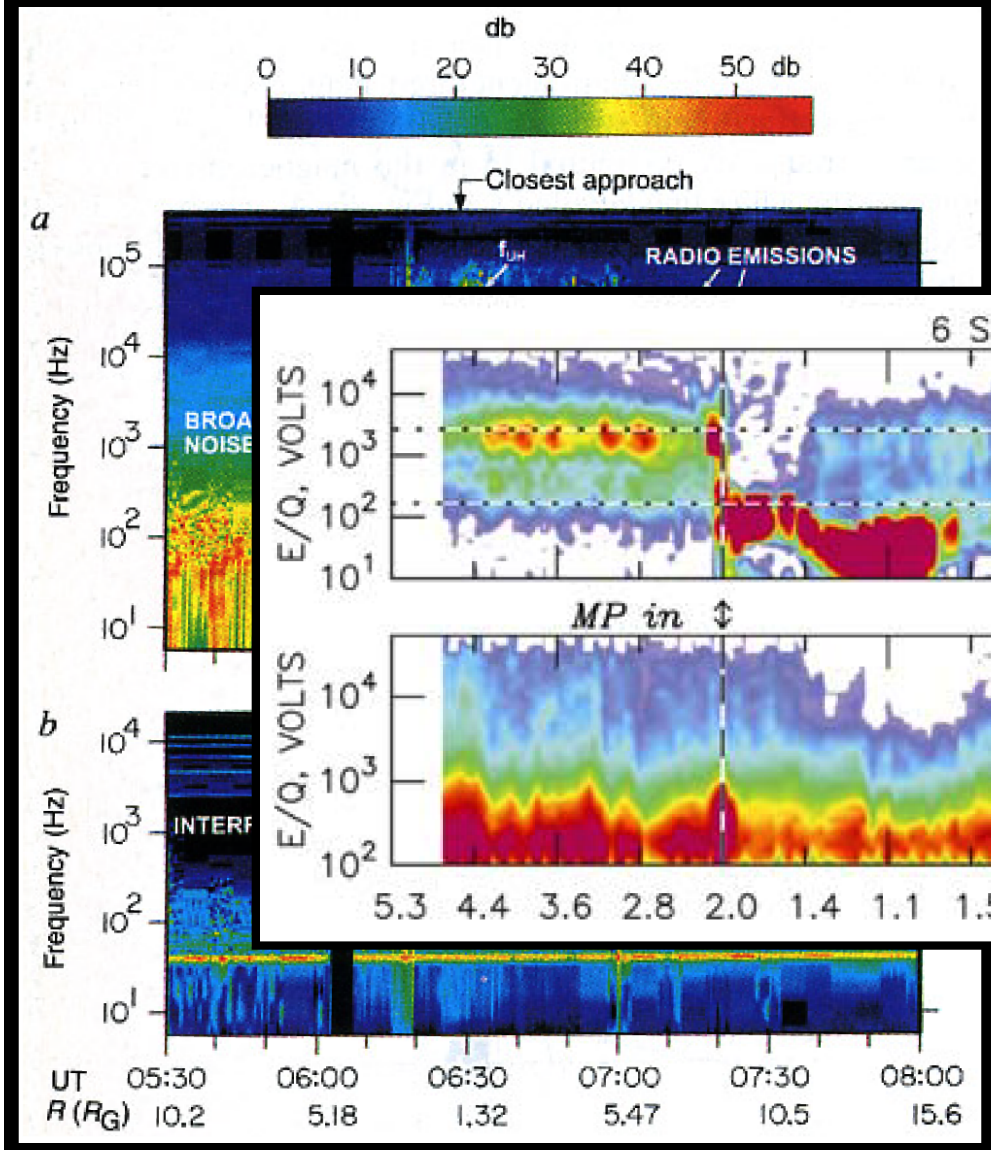
Io (6 R_J)

Europa (10 R_J)

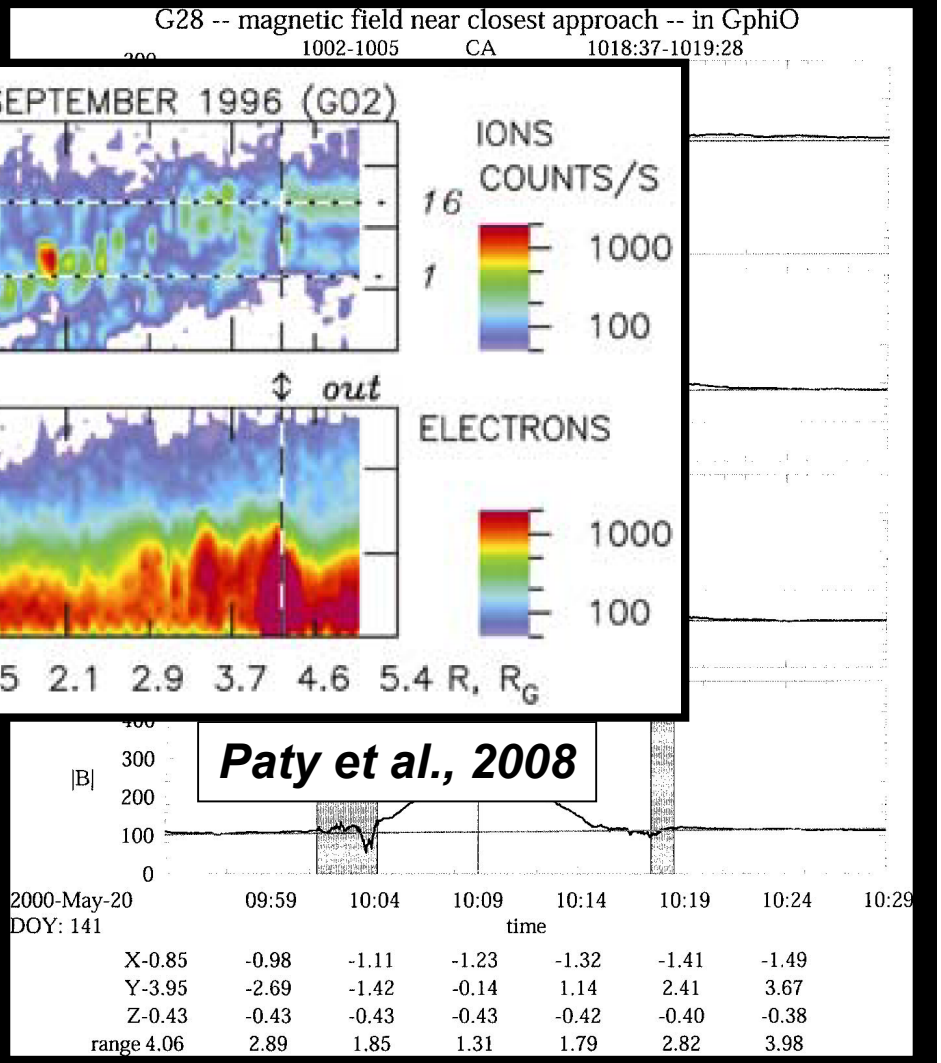
Ganymede (15 R_J)




A
B
C
Clarke et al., 1998



Gurnett et al., 1996



Paty et al., 2008

Kivelson et al., 2002

Questions raised by Ganymede:

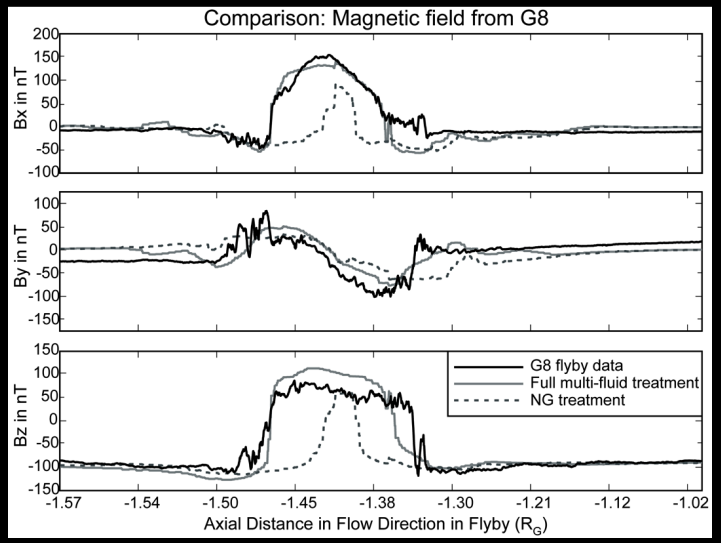
- How does it have a magnetosphere?
- How does it couple to the Jovian magnetosphere?
  - Local Plasma Acceleration
  - Propagation
  - Coupling of the Magnetosphere and Ionosphere (-- Aurora)
  - Ionosphere/Atmosphere Loss

From Point Measurements to a 3D Dynamic System

- Combine observational data

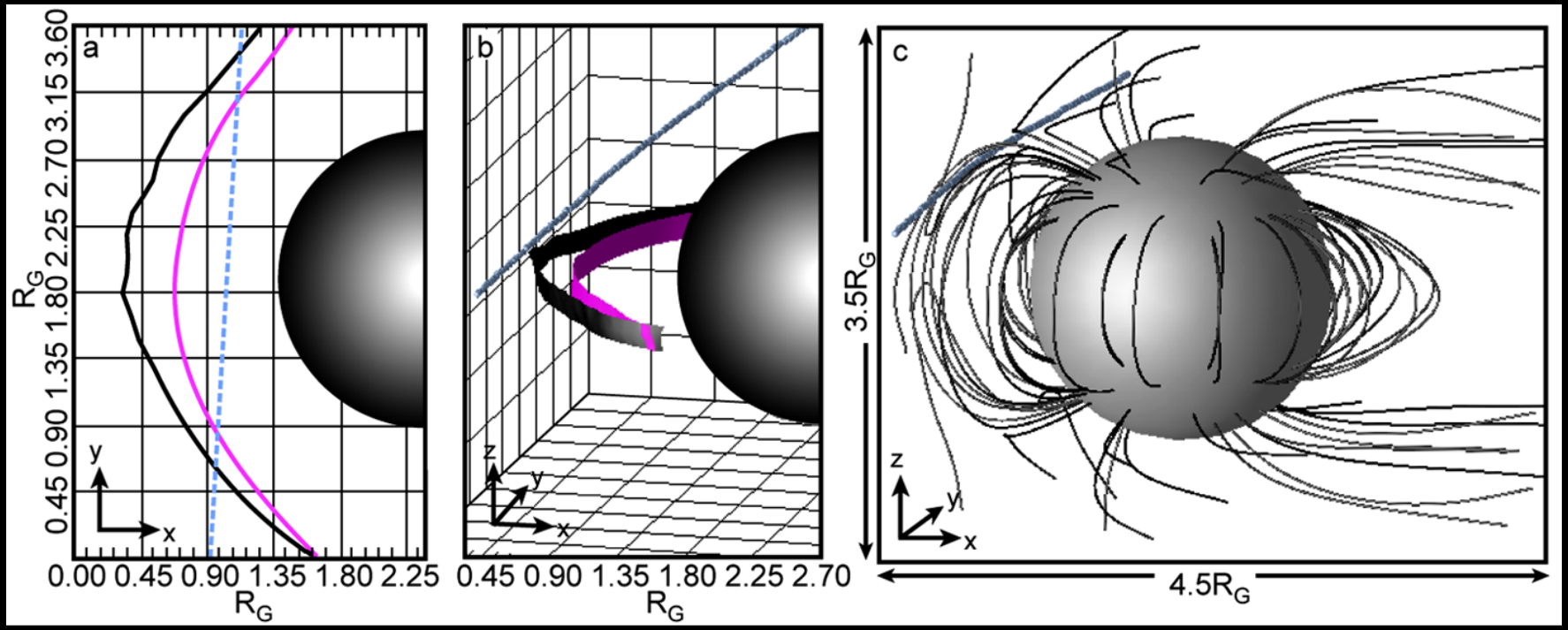
  ➡ Can be difficult!

- 3D Dynamic Model
  - Multiple ion sources
    - Ion transport and loss
      - Comparable to multiple data sets

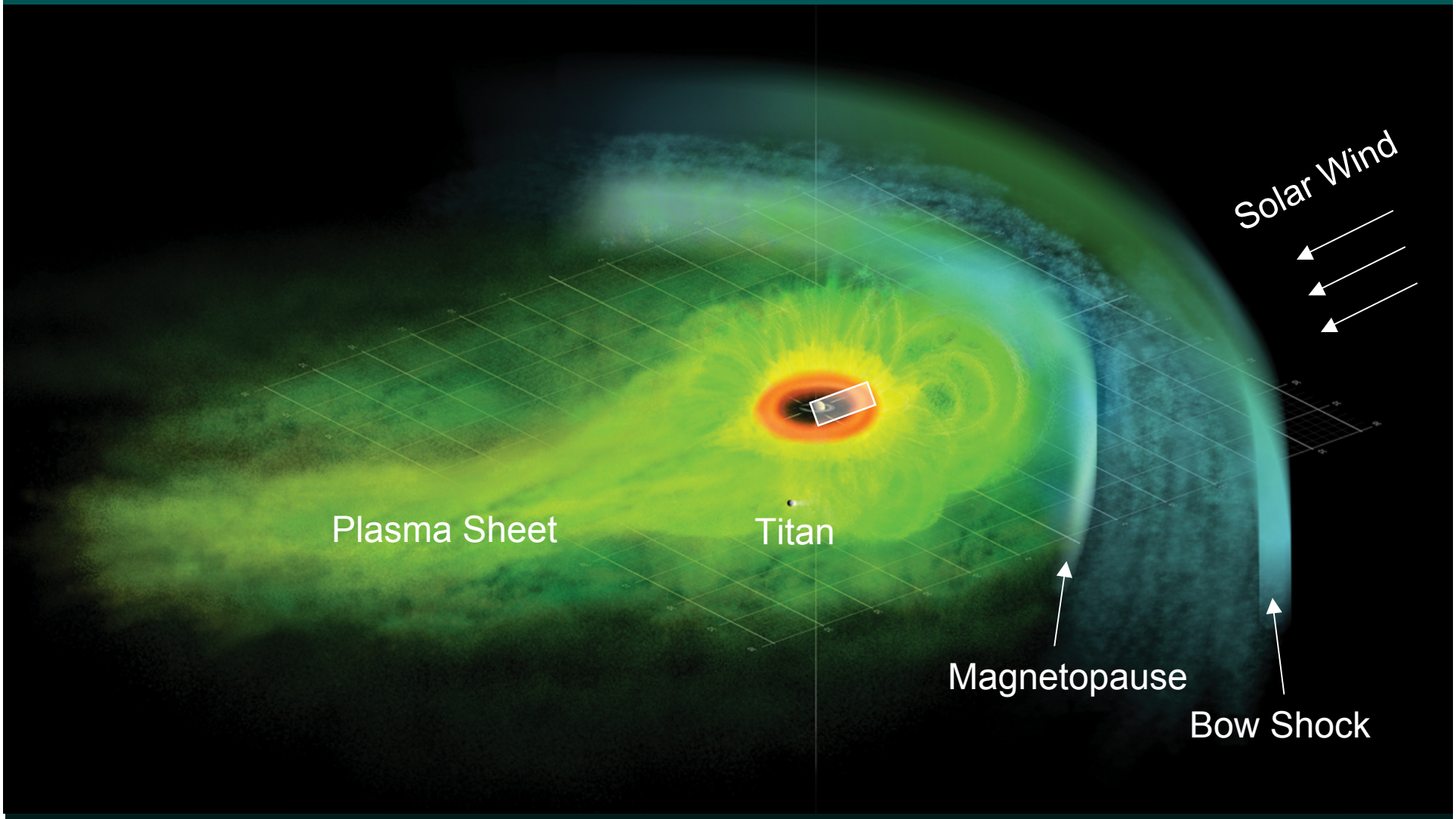


- 1D flyby comparison
- 3D morphology

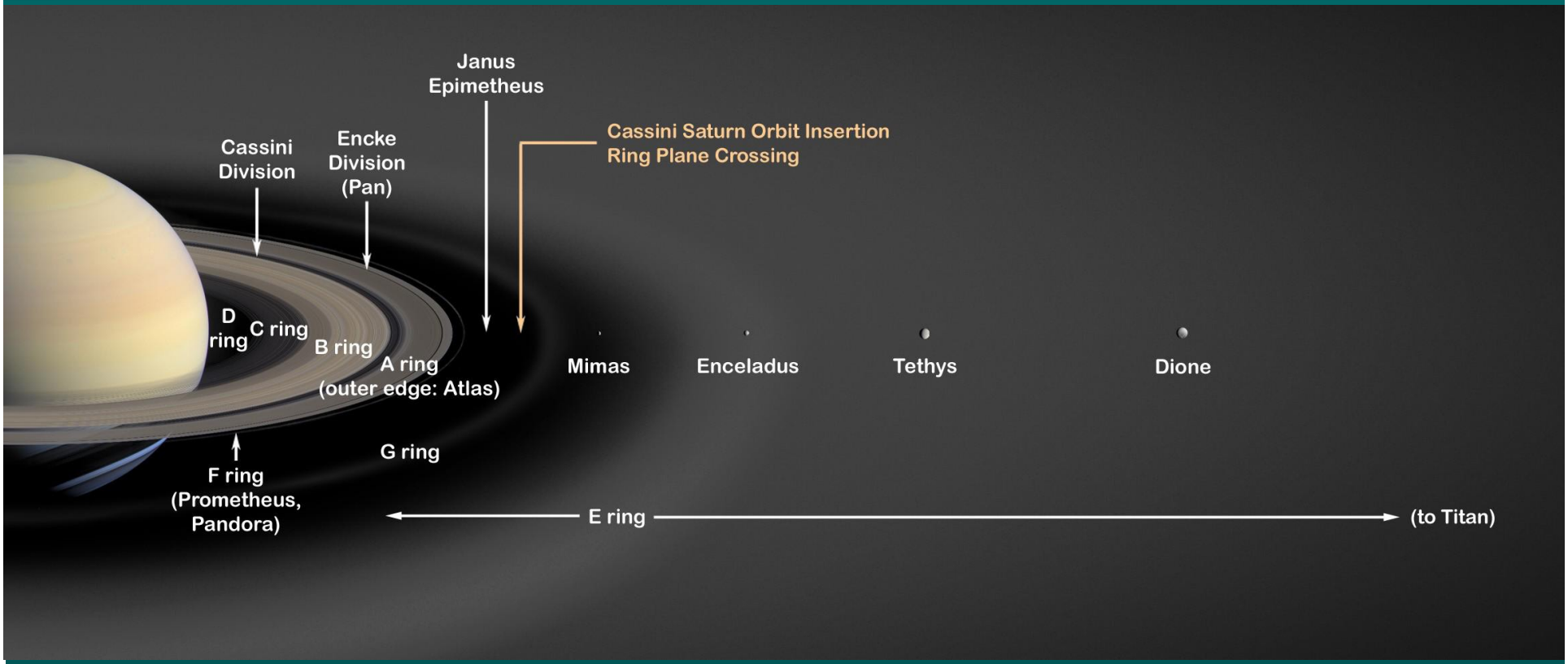
Paty & Winglee, 2006



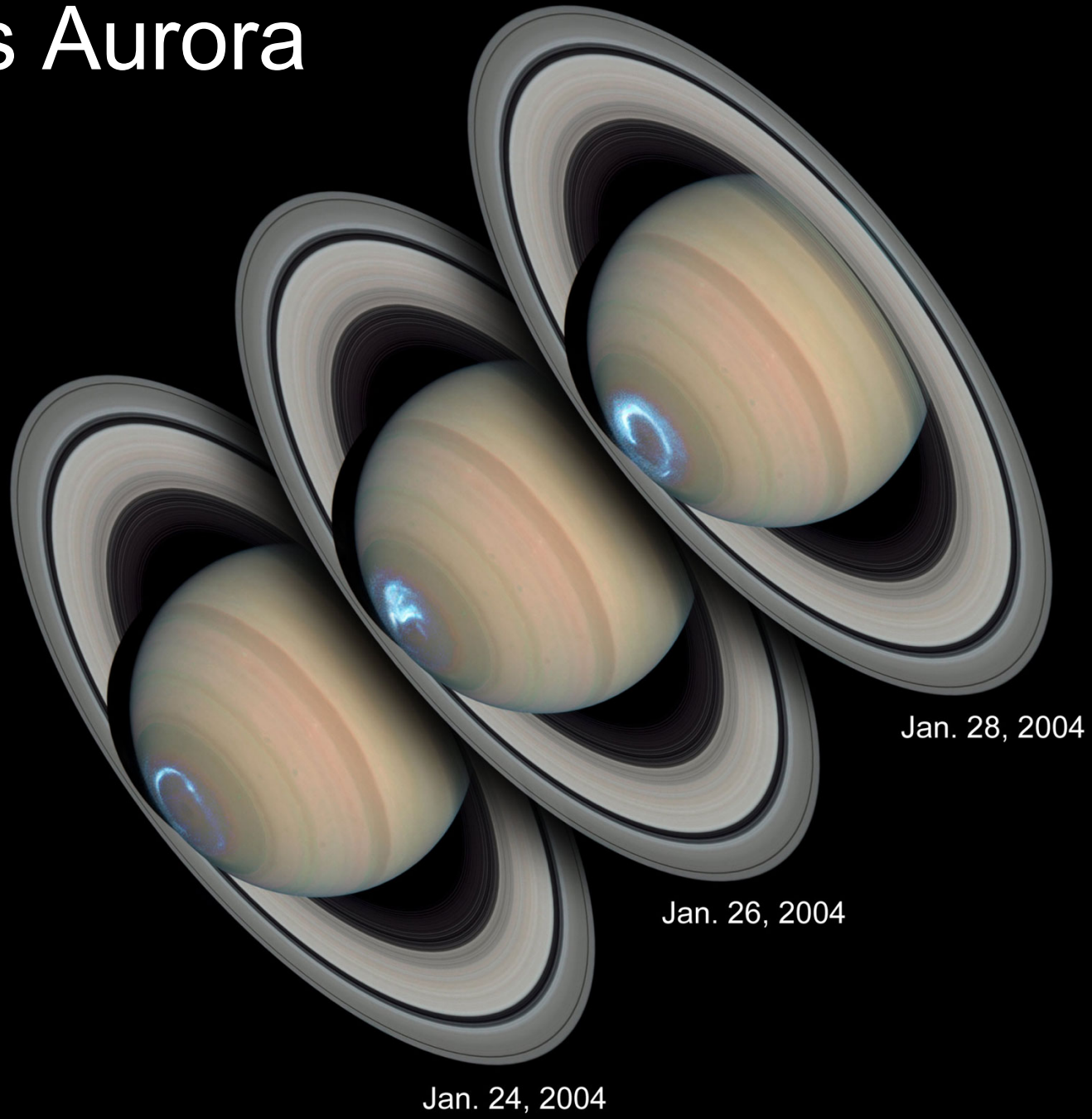
Saturn's Magnetosphere



Saturn's Magnetosphere

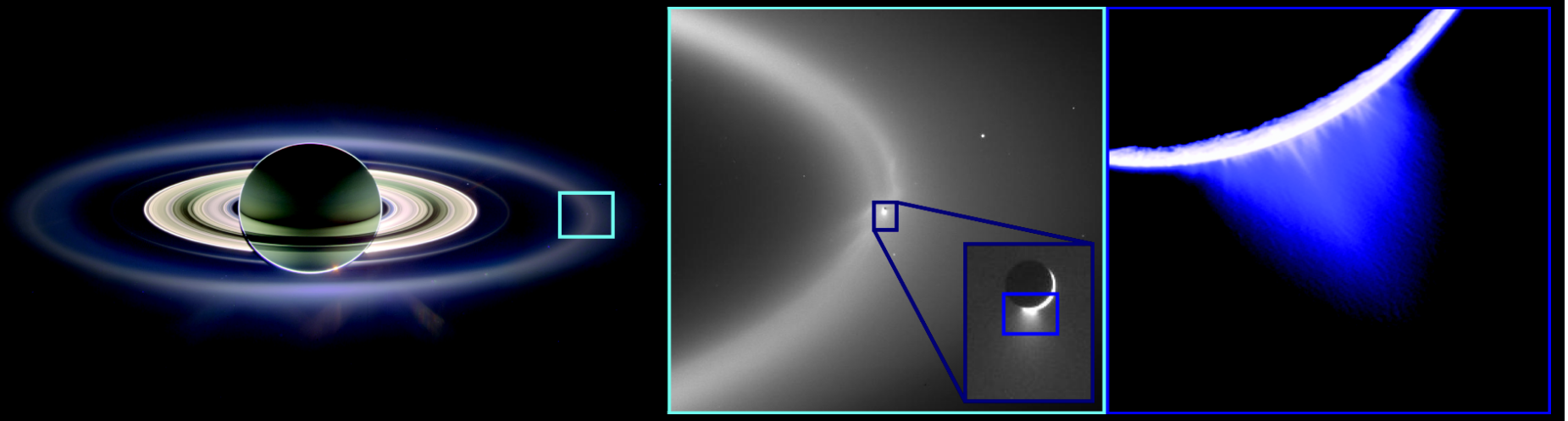


Saturn's Aurora



Credit NASA

Motivation through Observations



In situ (Cassini)

Plasma Spectrometer

Magnetometer

Neutral Mass Spectrometer

Remote Sensing (HST/Cassini)

Neutral Cloud -- OH line emission

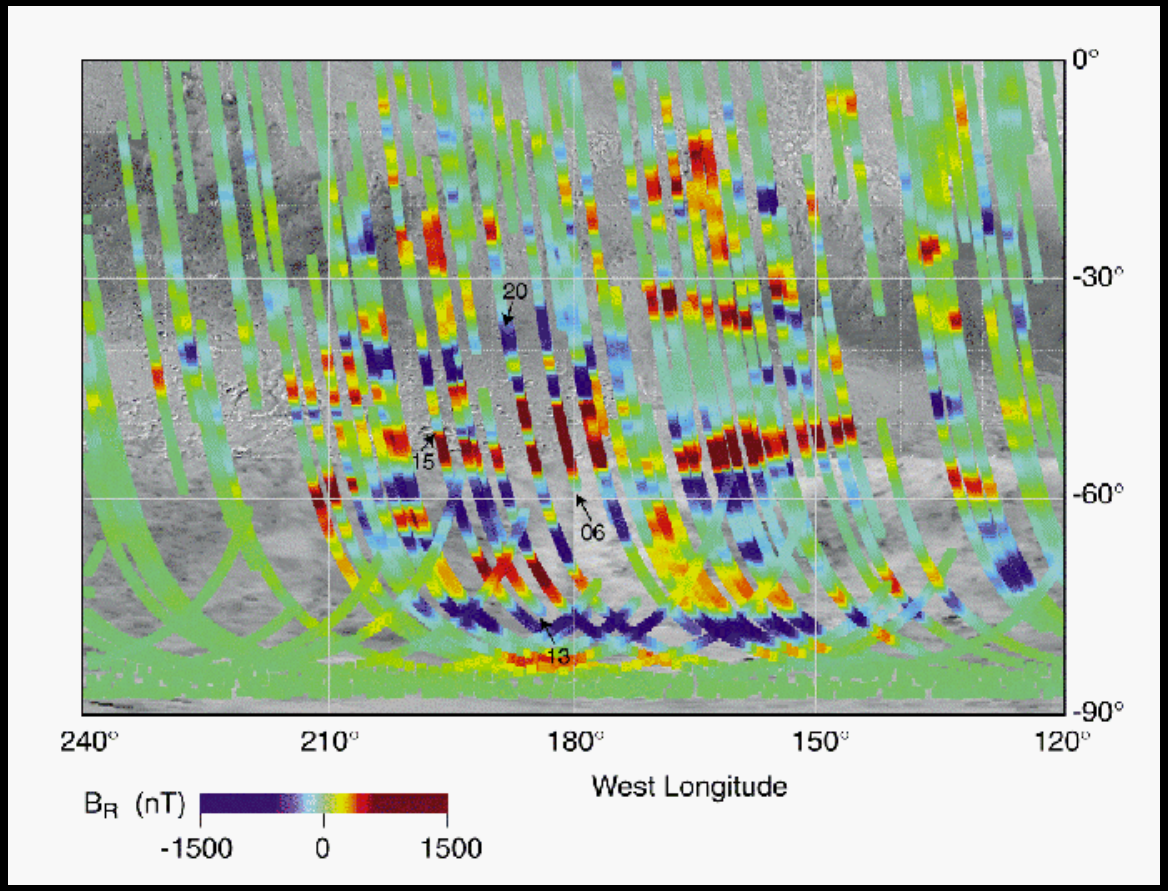
Energetic Neutrals

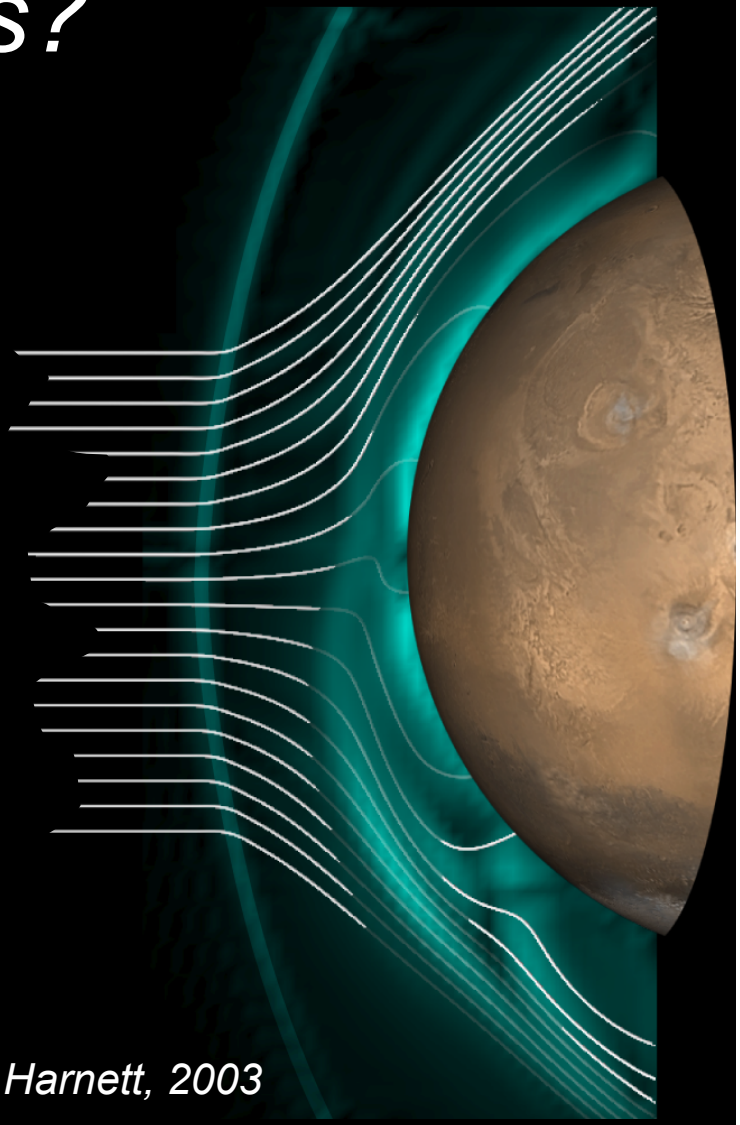
Questions raised by Enceladus:

- What is causing the plume?
- What are the magnetospheric responses to the dense neutral cloud or neutrals in general?
  - Local Plasma Acceleration
  - Propagation
  - Coupling of the Magnetosphere and Ionosphere
  - Ionosphere/Atmosphere Loss

Mars: A Lack of Magnetosphere

Implications?

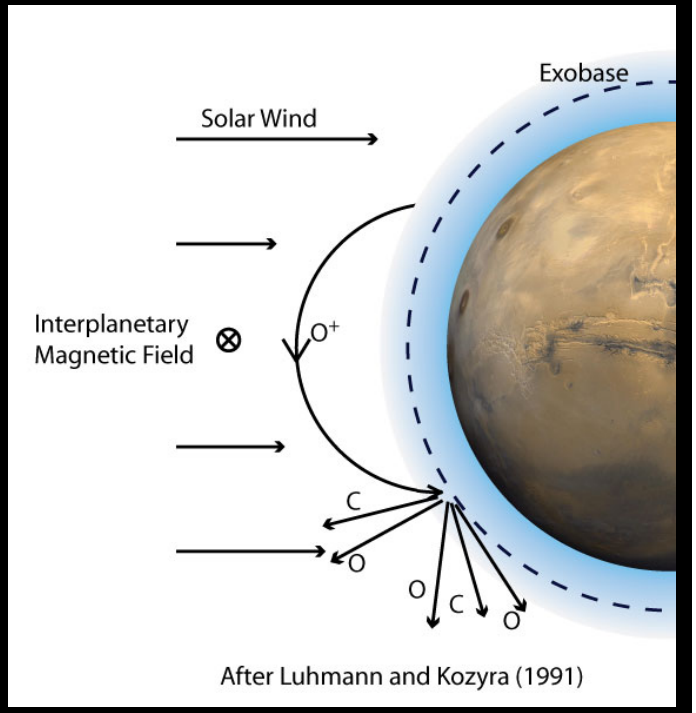




Harnett, 2003

Questions raised by Mars:

- Why is there no magnetosphere?
- How were the magnetic anomalies formed?
- What are the implications for the atmosphere and its evolution over geologic time scales?



Interested in Space Physics?

Spring 2013:
Introduction to Space Physics &
Space Instrumentation