Saturn's Magnetosphere: Five Times a CHARM

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2000 Watts
by Michael Jackson
(Invincible album)

Chorus:

2000 Watts,

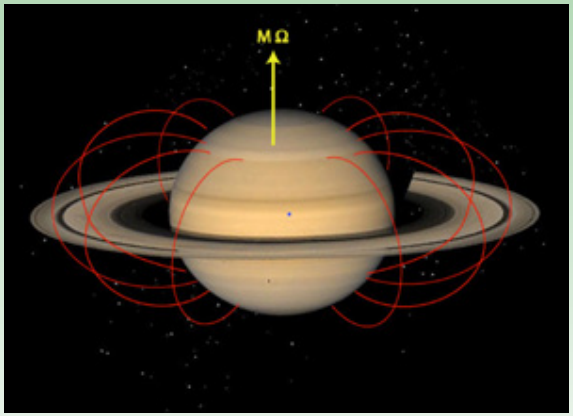
8 ohms, 200 volts, real strong

Too much of that, fuse blown

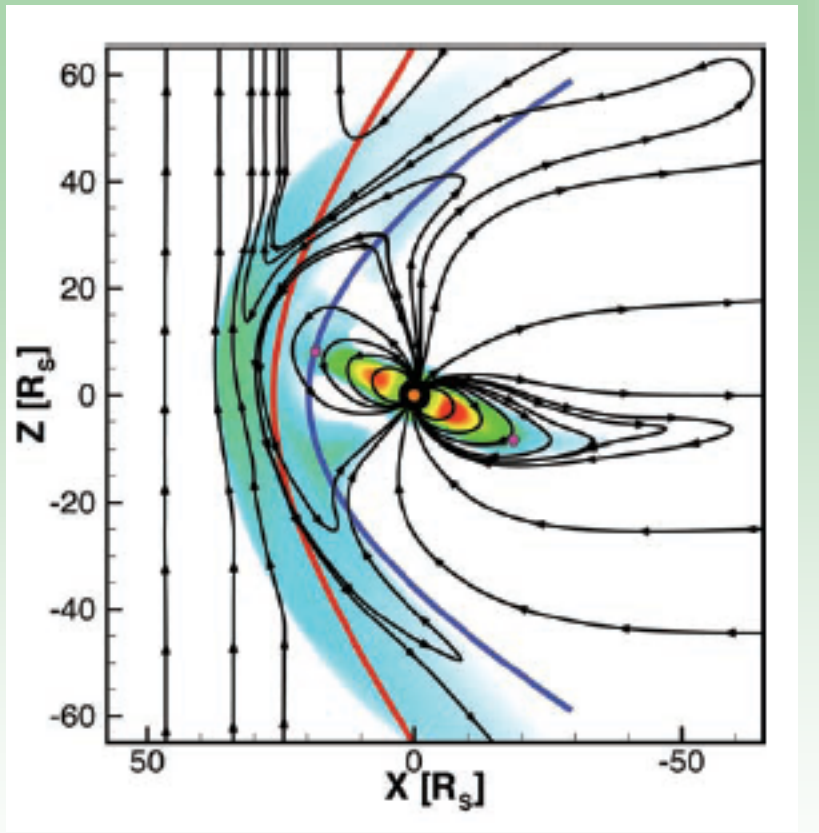
Be careful what you say, don’t overload

Global Morphology

(size and shape for magnetospheric 'waterballoon')

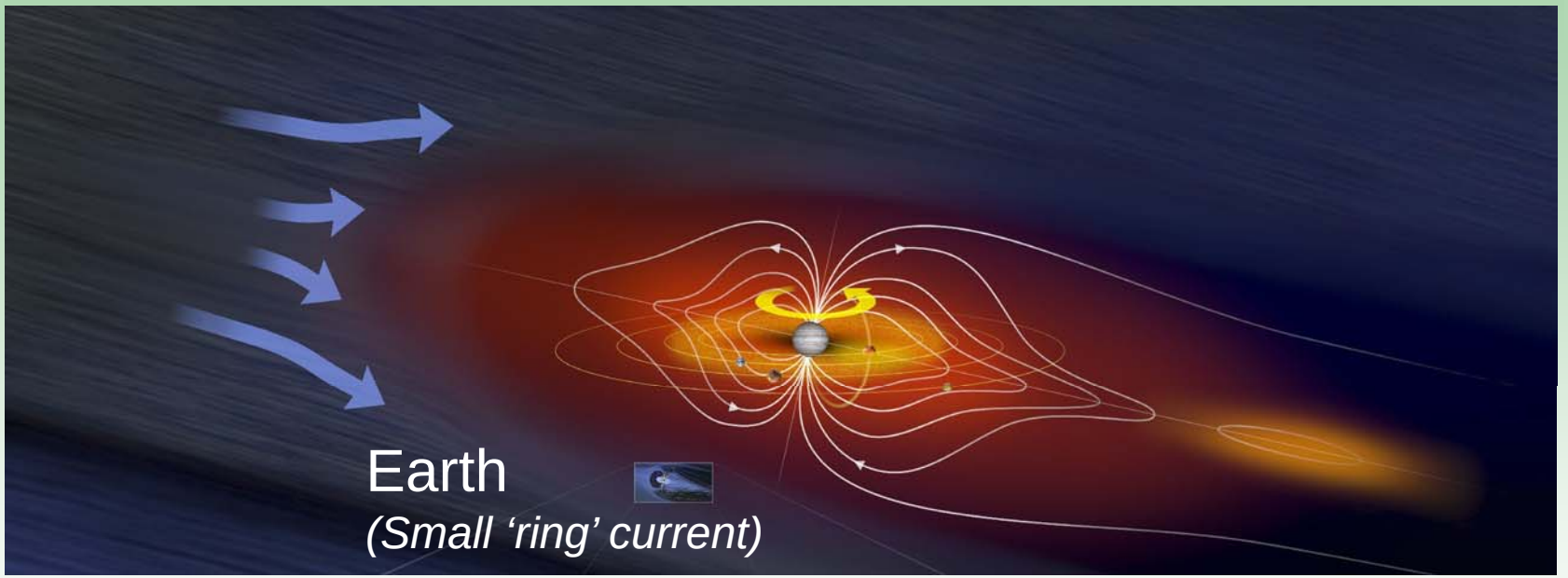


Very simple illustration. Saturn with a dipole field construction superimposed. The magnetic axis is aligned with The rotational axis.



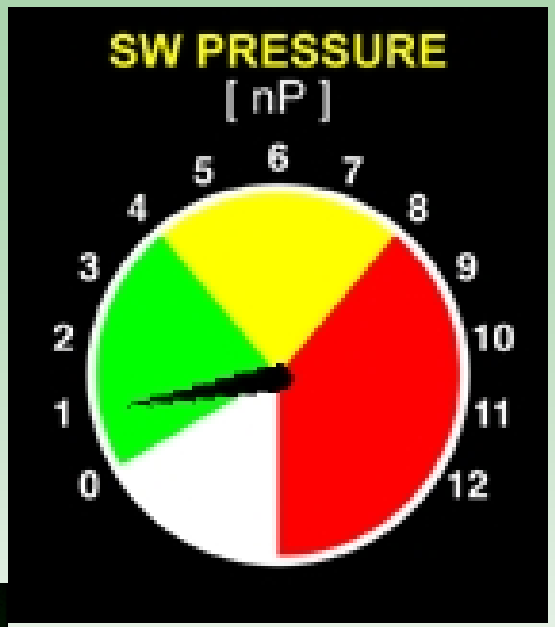
A post-Cassini representation of the magnetosphere. A decided tilt has been discovered.

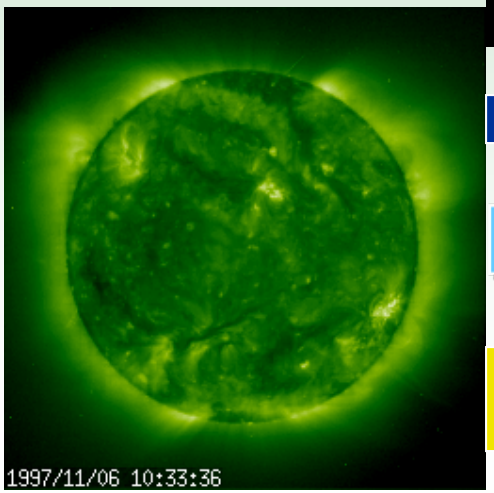
Comparison of the Scale of the Magnetospheres of Outer Planet (Jupiter) and Earth

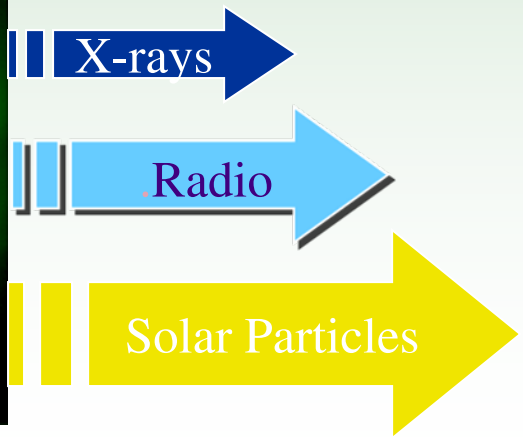


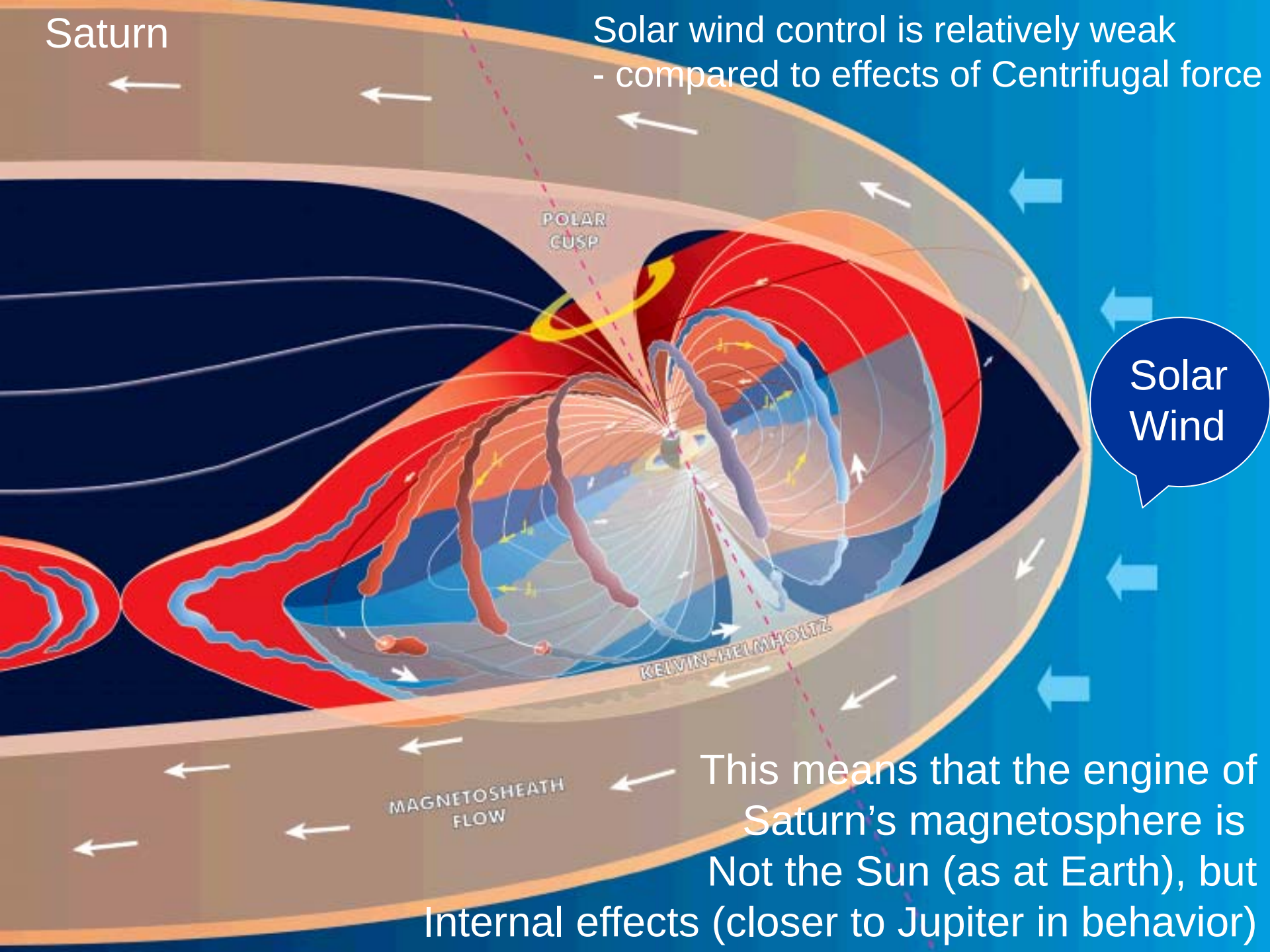
Magnetosphere; Space Weather; and The Sun

- **The magnetospheric 'bubble' responds to the presence of the solar wind – called 'space weather'**
- **'Signal light' (right) reflects the general level of space weather (solar wind) disturbance (measured near Earth.)**

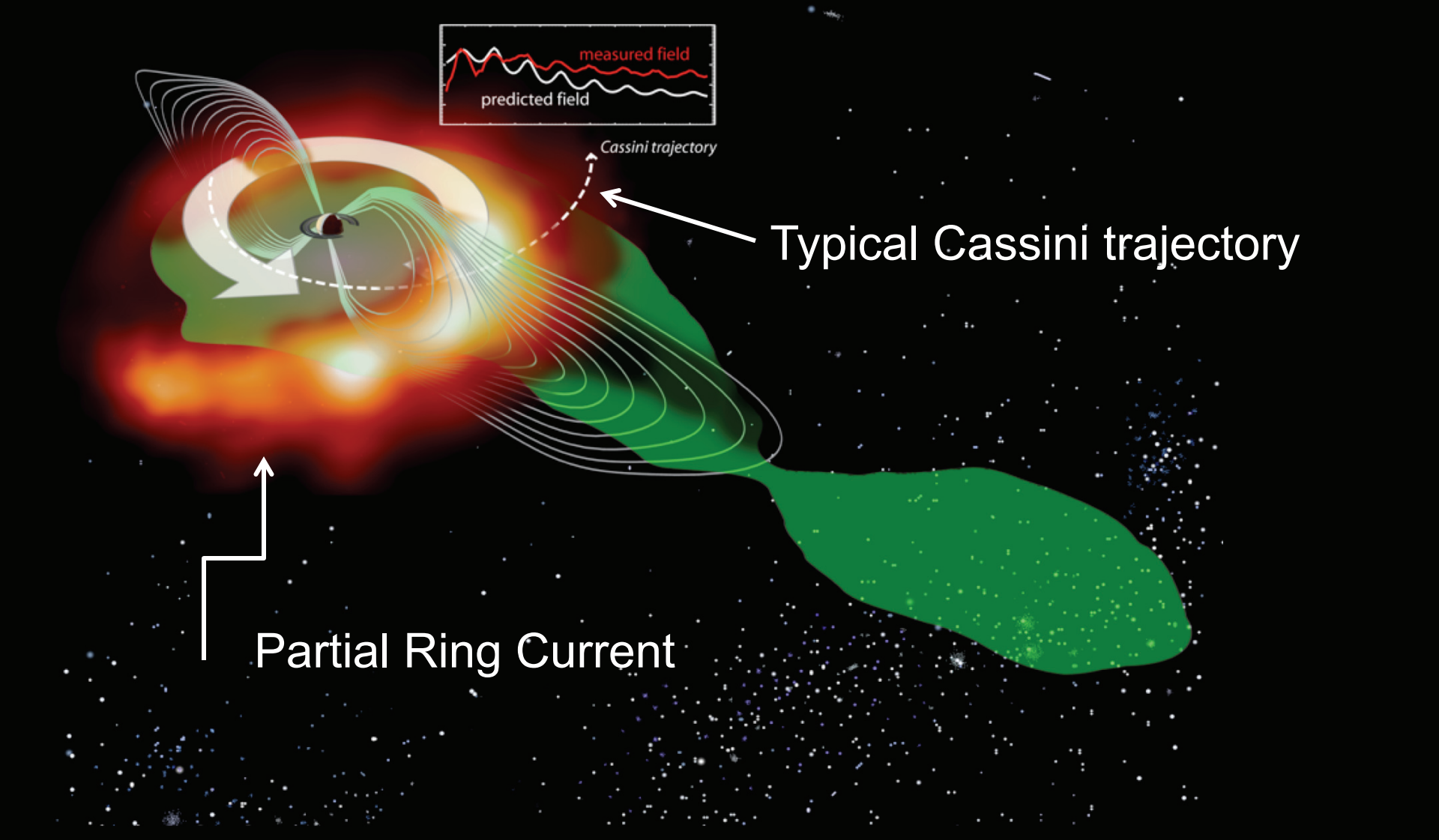







Saturn
Solar wind control is relatively weak
- compared to effects of Centrifugal force
POLAR
CUSP
Solar
Wind
KELVIN-HELMHOLTZ
MAGNETOSHEATH
FLOW
This means that the engine of
Saturn's magnetosphere is
Not the Sun (as at Earth), but
Internal effects (closer to Jupiter in behavior)

Another view of Saturn's Magnetosphere: field, current disc (orange) , and plasma sheet



Power in the Magnetosphere

Earth:

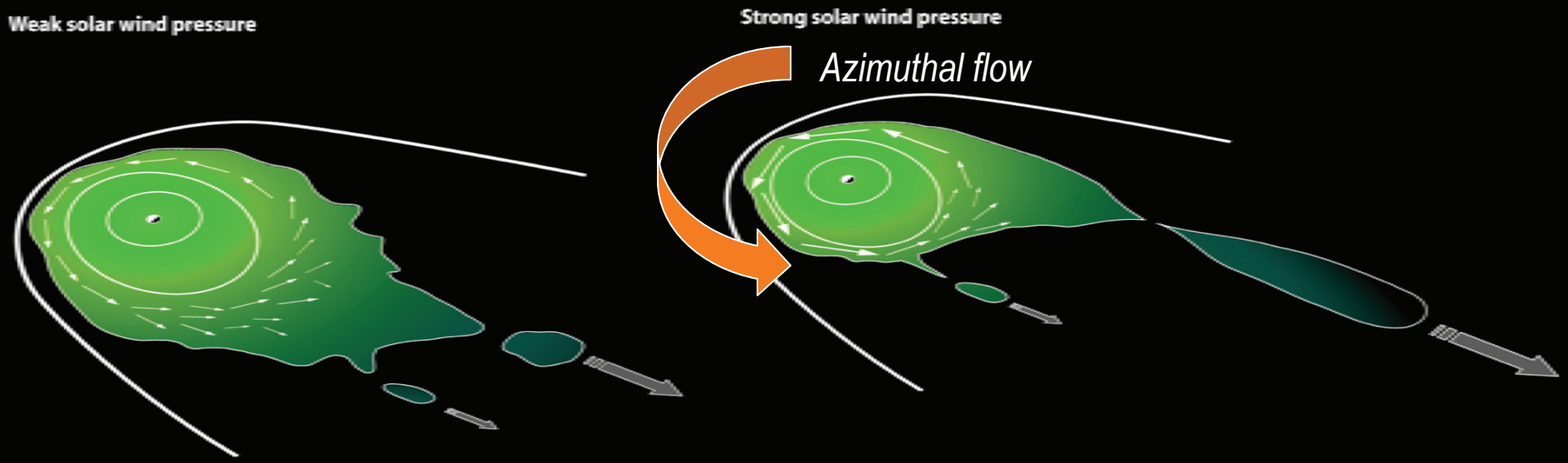
- Typical Geo-magnetic sub-storm, on Earth, = 150 Gigawatts
- Los Angeles municipal burden* = 280 Megawatts
  - So, a substorm is roughly the equivalent of 1000 large cities
    - Assuming the municipal 'burden' is 10% of the total population
- London, England: electrical spike when 40% turned on their lights at the same time = 1400 Megawatts
  - Equivalent to a half-million tea kettles boiling at once**

Saturn:

- Estimated power in the Kronian ring current = 10(s) Terawatts
  - Equivalent to 1,000,000 cities the size of Los Angeles!

**Los Angeles Times; **Strokes of Genius, L Jon Wertheim, Houghton Mifflin*

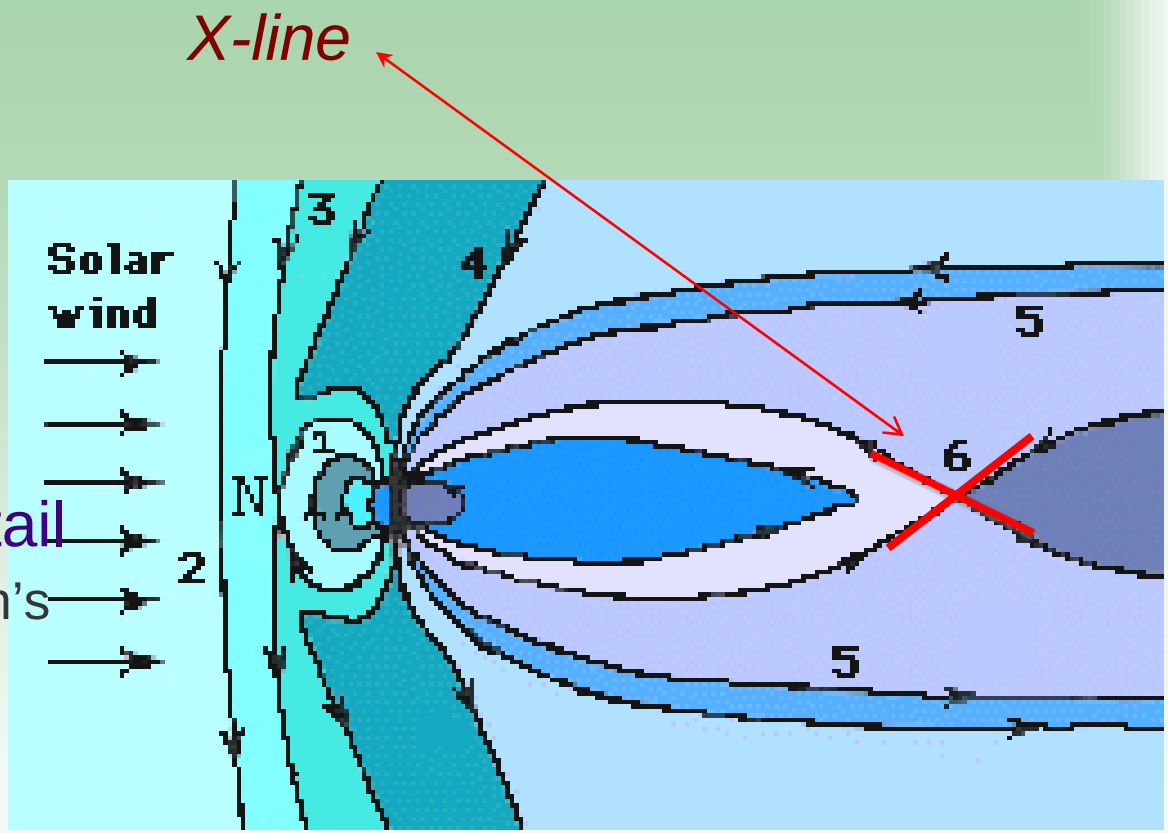
How Does the Solar Wind Affect Magnetospheric Storms?



When solar wind dynamic pressure increases, the dayside magnetosphere compresses. Conservation of angular momentum leads to increased azimuthal flow speed of cold plasma on the dayside, which in turn leads to stronger centrifugal forces acting on the corotating cold plasma. Since plasma is free to expand on the night side there is a sharper increase of centrifugal force in the post-midnight sector during enhanced SWP. This leads to stronger and larger plasmoid releases.

Earth tail formation driven by: Sun/Earth interaction

- This is the 'Dungey' model of the Earth's magnetosphere
- In which the magnetotail stretches out and an 'X'-line is formed deep into the tail
  - [range = 50 R_E?]; Earth's moon is at 60 R_E
- The X-line moves in response to the solar wind pressure on any given day.



The so-called 'Dungey' model

Does Saturn have a Magnetotail? (what are its dynamics?)

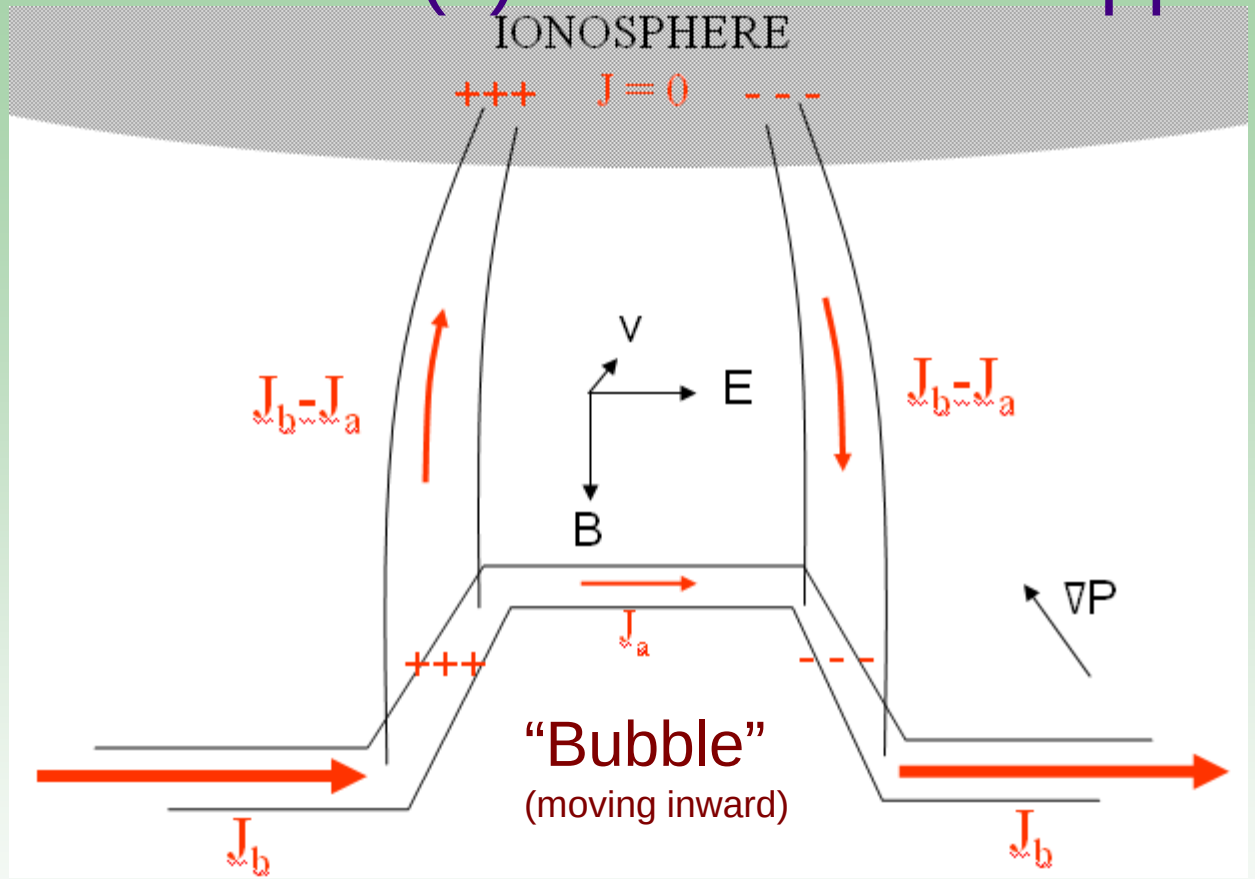
- An ‘asymmetrical cavity’ is not a magnetotail.
  - A magnetotail carries a current in the middle
  - Earth: formed via solar wind interaction (Dungey-style circulation)
  - Jupiter: formed via planetary wind
- ‘Dipolarizations’ – in which the X-line moves toward the planet, creating field lines of a more ‘dipolar’ shape.
  - Cassini has noticed a few at Saturn (three)
  - Indicates some sort of ‘Dungey’ cycle at work.
- *Cassini’s orbit did not reach the magnetotail reconnection region nor the neutral sheet.*

50 ‘things you should know …’

A popular book series published in England (similar to the ‘For Dummies’ books) relates the following (paraphrased):

- Electricity: Charge can pile up (creating static electricity), or charge can flow (creating a current).
- Ohm’s Law: The flow of current follows Ohm’s Law: $\mathbf{J}=\sigma\mathbf{E}+\sigma\mathbf{v}\times\mathbf{B}$ *(current density **J** in a resistive material is a product of the conductivity and the electric field **E**, plus a component that accounts for the movement **v** of plasma against the magnetic field **B**)*

Radial Transport in the Magnetosphere:
the currents (J) that make it happen

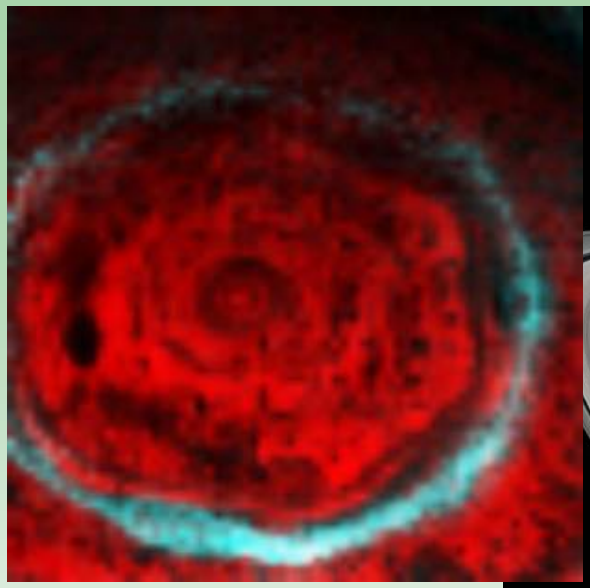


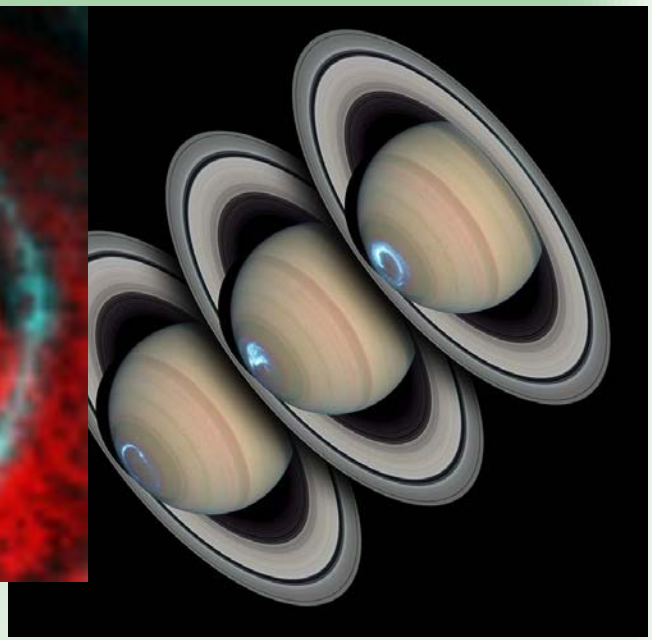
Work in progress

This figure shows the "pressure driven" current system linking a small inward perturbation (bubble) and the ionosphere. An analogous system exists for "centrifugally driven" current and it is the balance of these that determines the direction and magnitude of radial transport at Saturn.

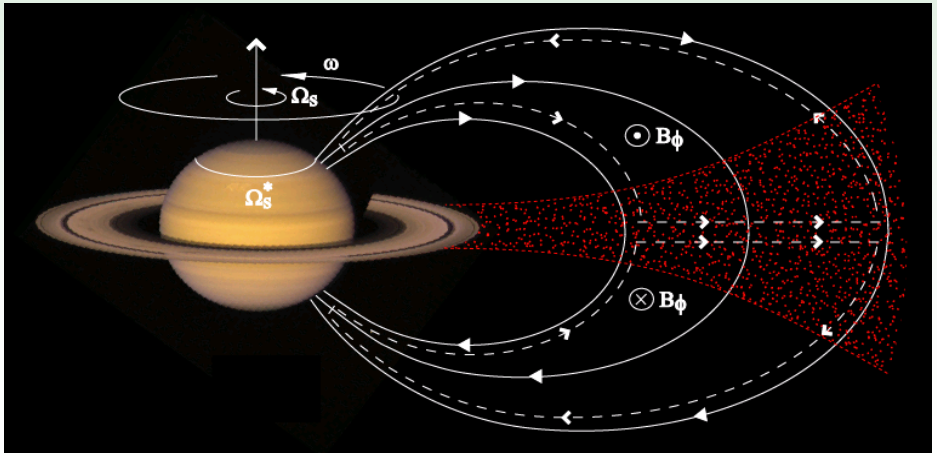
Aurora

Superposition of hexagon and aurora observed in infrared. *Clarke et al.*





- Field-aligned currents are associated with precipitating particle fluxes are responsible for the aurora (in general).
- Predicted that magnetosphere-ionosphere coupling currents are not sufficient to produce kronian aurora (Cowley and Bunce, 2003)
- Instruments that explore the magnetosphere did find evidence for precipitating beams.



Summary of Discoveries

- Saturn's magnetosphere is very tilted
  - A surprise because the rotation and magnetic axis are nearly aligned
- Solar wind influence is mild
  - Magnetosphere responds more to internal forces
- The magnetosphere is filled with neutrals, and the influence of the neutral cloud is great.
- Progress:
  - Understanding the roles of currents in moving plasma around the magnetosphere
  - Understanding the aurora
  - Understanding the magnetotail dynamics
    - Role of 'Dungey' cycle

More to Do in Equinox and Solstice Missions …

– Magnetosphere Objectives:

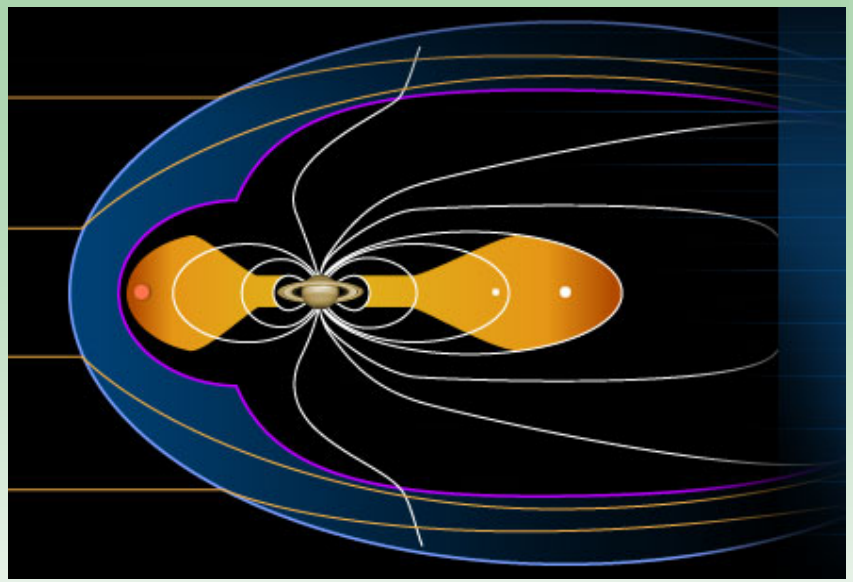
1. Cassini's orbit did not reach the magnetotail reconnection region and the neutral sheet during prime mission.
2. Cassini's orbit allowed *in-situ* observation of the auroral zones only late in the prime mission. To be covered further during the Equinox Mission.
3. Temporal variations for 4 years.
4. To accurately determine the planetary magnetic field of Saturn, complete spatial coverage at a wide range of latitudes and longitudes and close distances is required.
5. Cassini's orbit allowed only very limited observations in the 3-5 R_S region
6. The 4 year prime mission did not allow enough time to distinguish between competing theories of why the rotation period varies.
7. Internal rotation period is still not determined.

Appendix

Saturn’s Magnetosphere: Five Times a CHARM

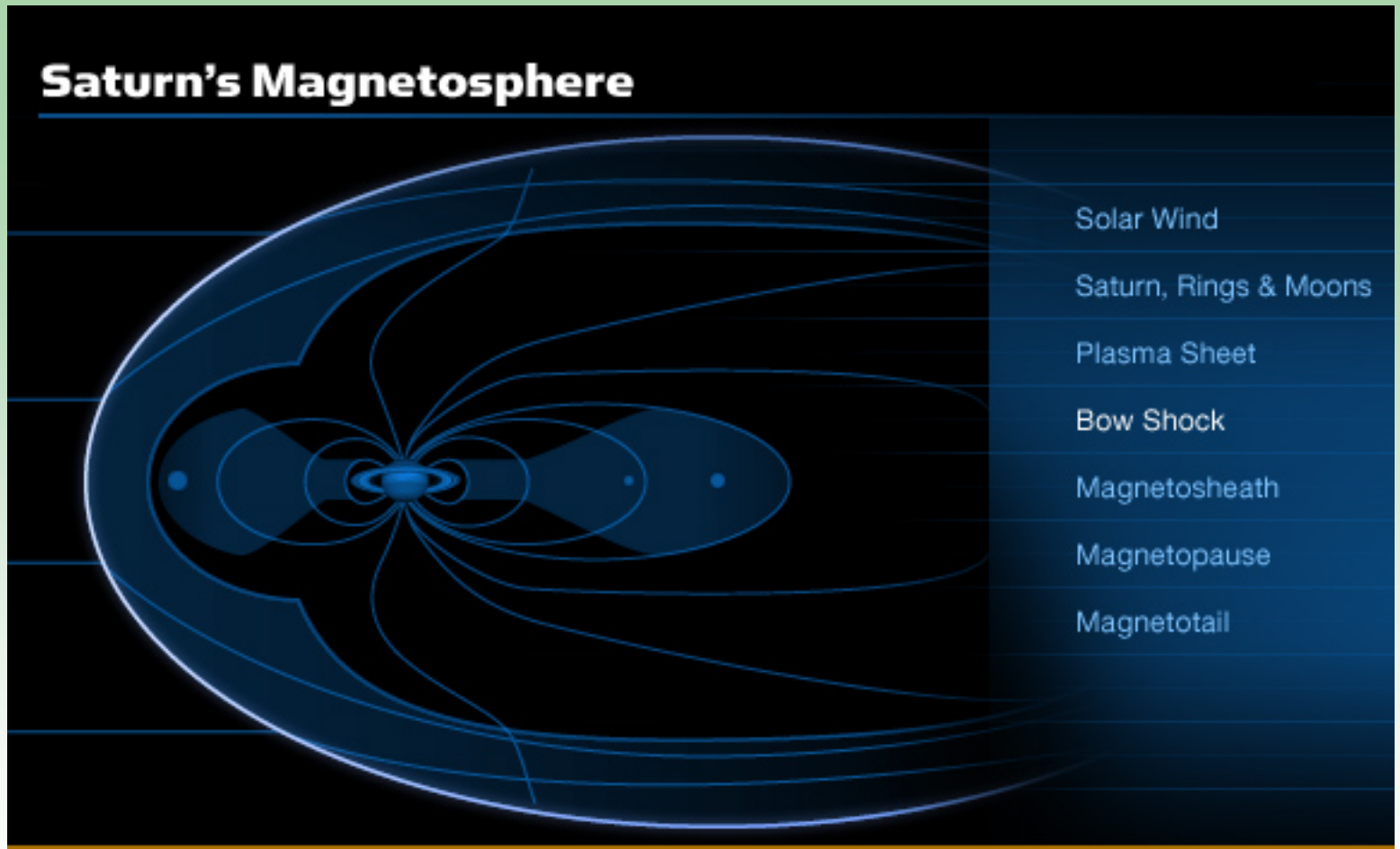
Basic Elements of the Magnetosphere

- Bow Shock
- Magnetosheath
- Magnetopause
- Moons & Rings
- Plasma Sheet/ magneto-disc
- Neutral Cloud
- Magnetotail



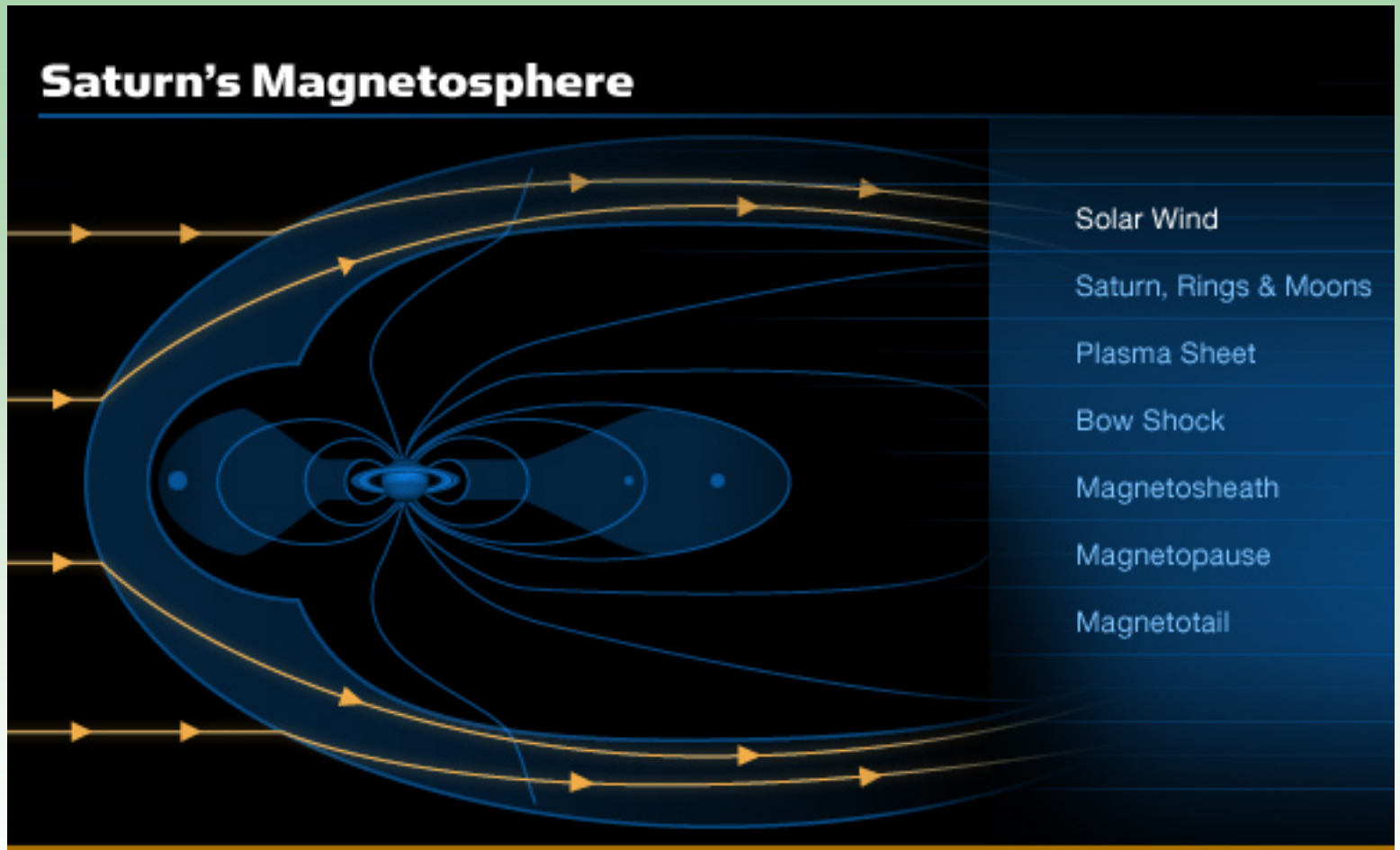
All of these parts ARE IN MOTION!

Bow Shock



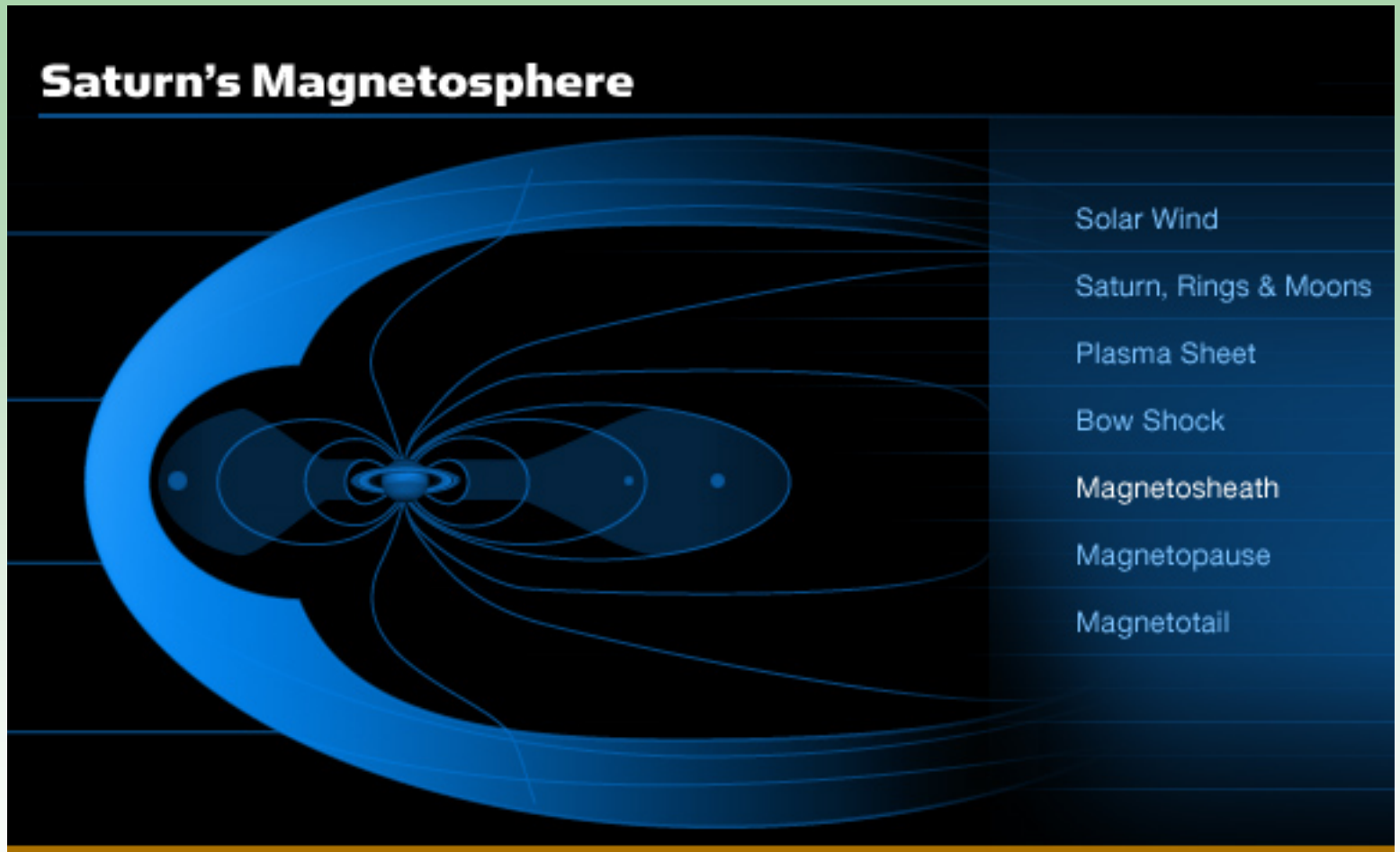
A supersonic shock wave that is formed as the solar wind interacts with the outermost layer of Saturn´s magnetosphere.

Solar Wind



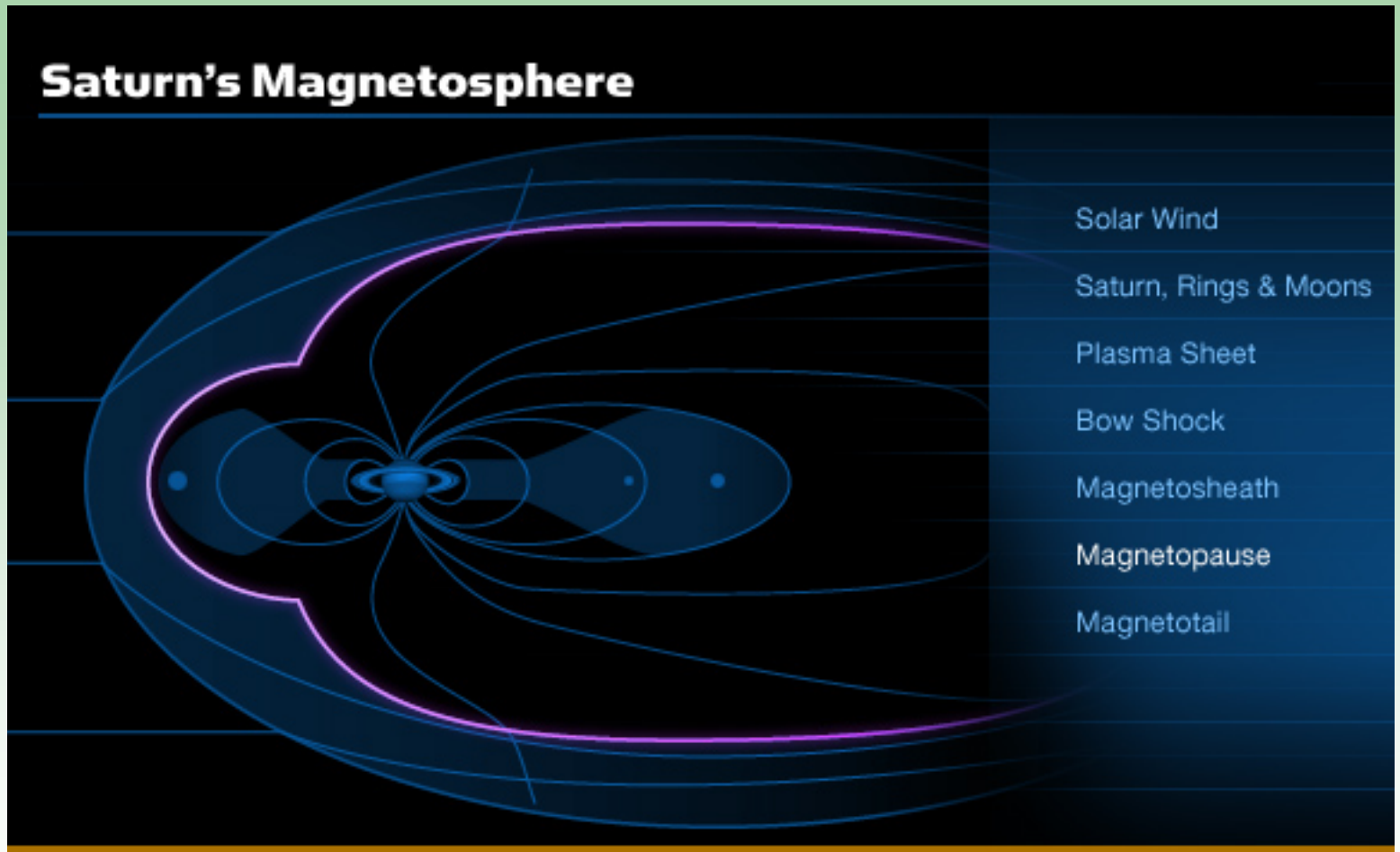
An outward flow of high-speed charged particles from the Sun´s corona. The particles are mostly positively charged Hydrogen and Helium ions.

Magnetosheath



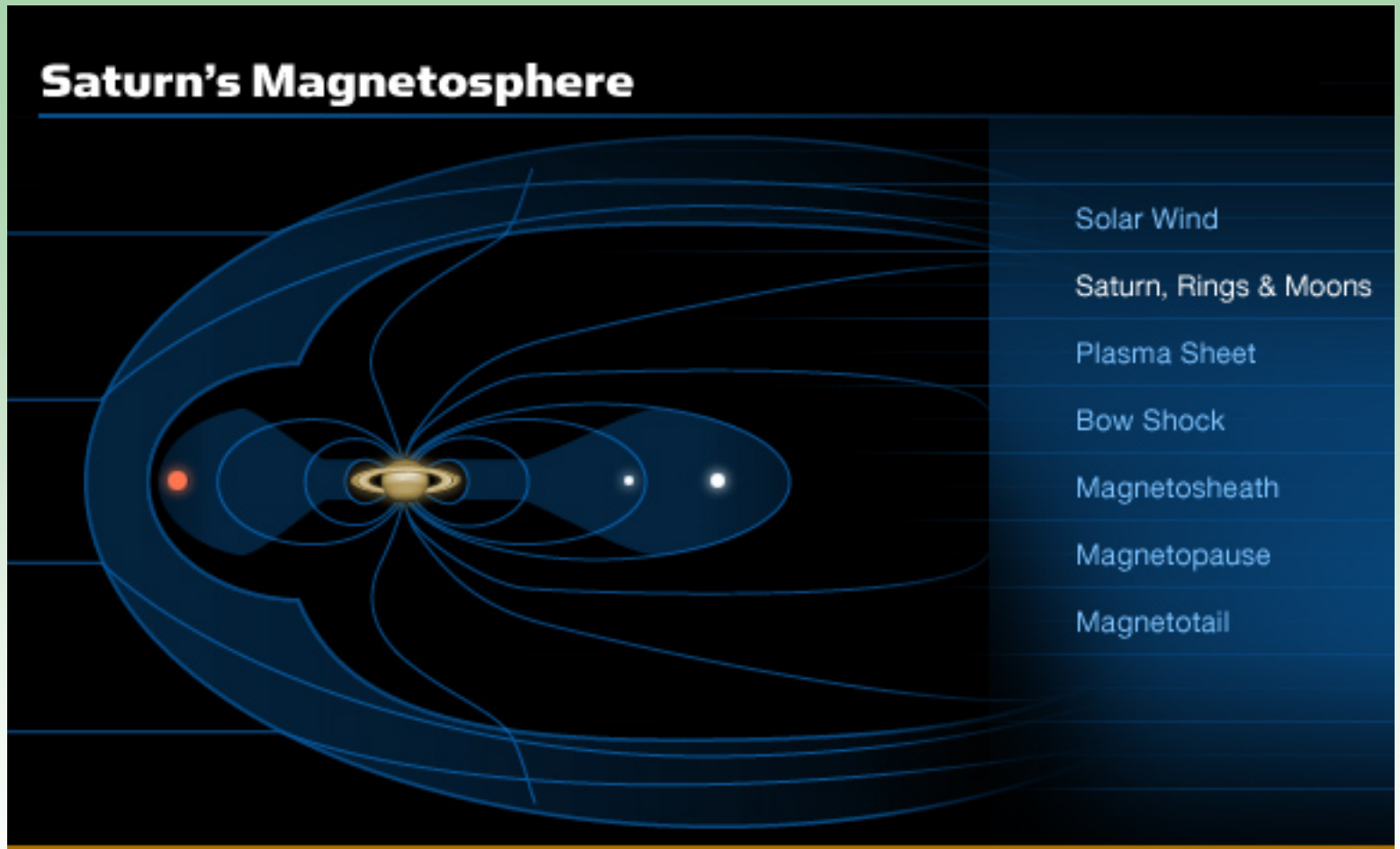
The very turbulent plasma region between the bow shock and the magnetopause.

Magnetopause



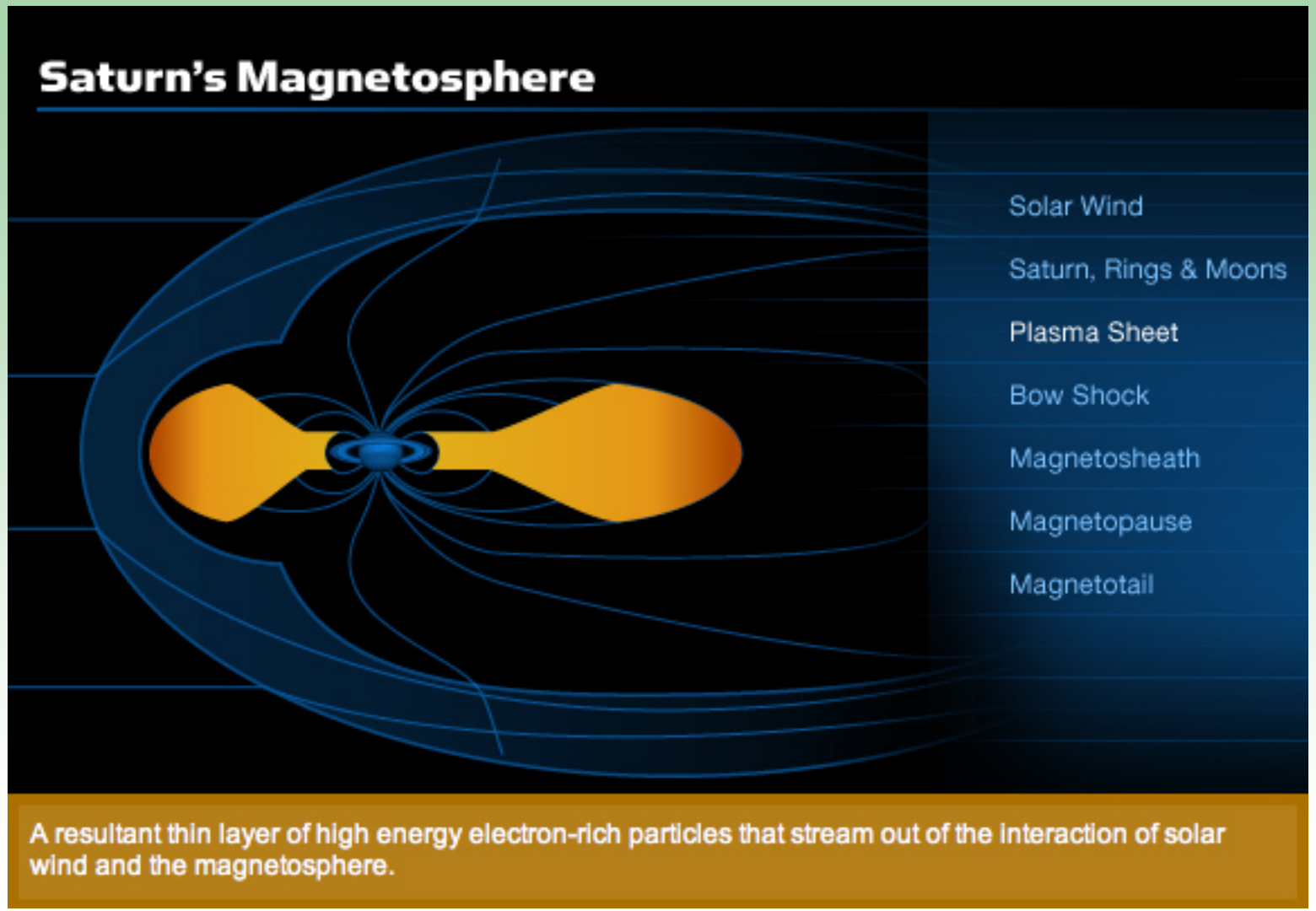
The outer boundary of the magnetosphere where the solar wind and magnetosphere interact.

Rings & Moons

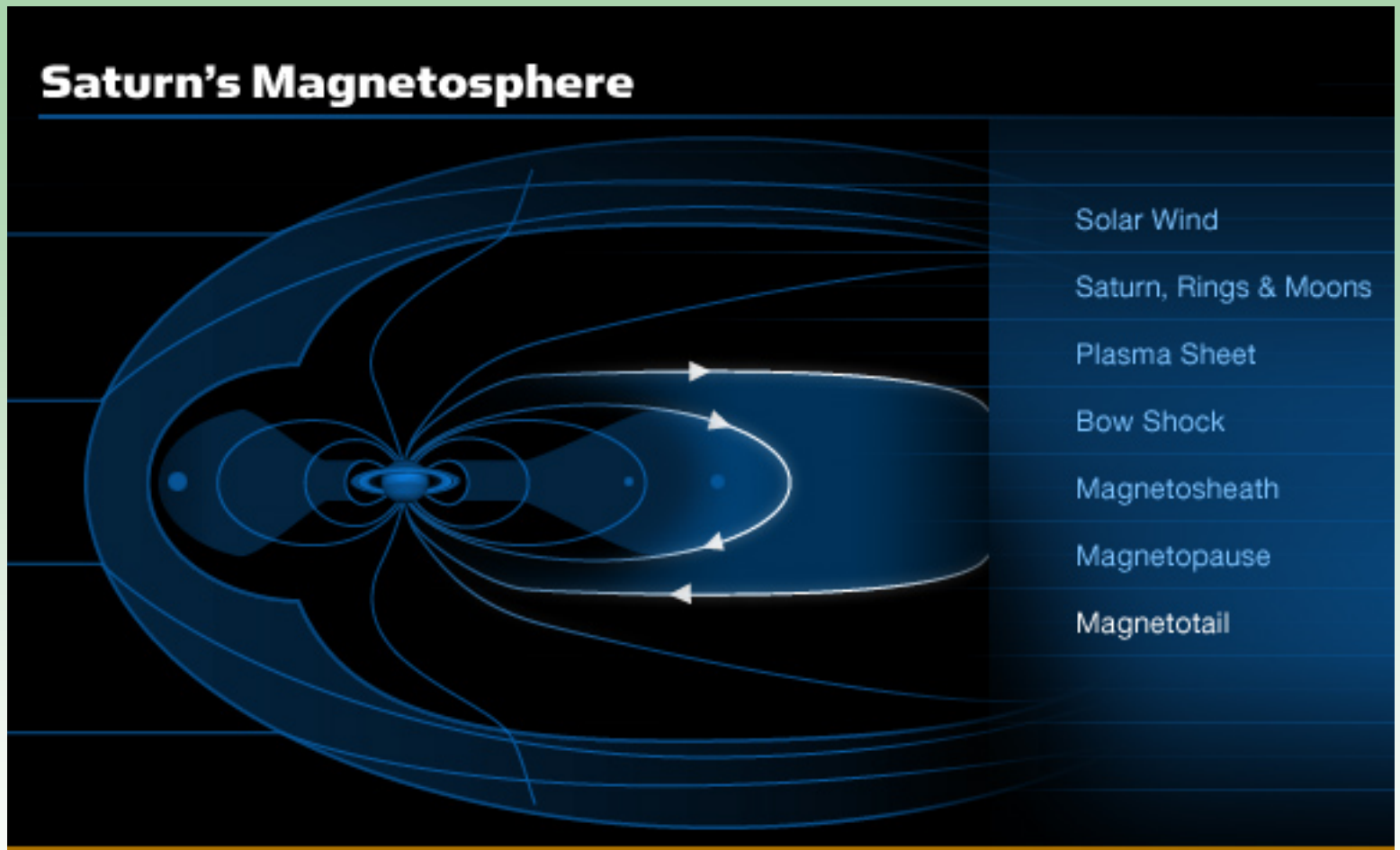


Saturn´s metallic-rocky core creates a magnetosphere that forces the charged particles to stream around Saturn, its rings and most of the moons.

Plasma Sheet, Magnetodisc,& Neutral Cloud



Magnetotail



The long, trailing limb of Saturn´s magnetosphere on the side facing away from the sun composed of trapped ionized particles.

MAPS-Focused Instruments

- CAPS
  - Ion Mass Spectrometer
  - Ion Beam Spectrometer
  - Electron Spectrometer
- MAG
- MIMI
  - LEMMS: Suprathermal particles
  - CHEMS: Ion charge-state
  - INCA: Ion and Neutral Camera
- RPWS
  - Wave Electric Field Sensors
  - Wave Magnetic Field Sensors
  - Langmuir Probe
  - 1 Hz – 16 MHz receivers, including waveform capabilities

Multiple-Purpose Instruments

- INMS
  - Measures ion and neutral composition
    - in the upper atmosphere of Titan,
    - during ring plane crossings and
    - at icy satellites.
- CDA
  - Investigates dust as a source/sink of charged particles.
- RSS
  - Observes ion and neutral density profiles in the upper atmospheres of Saturn and Titan.
  - Measures the exospheres of icy satellites.
- ISS
  - Investigates lightning, aurora and airglow.
- UVIS
  - Observes the aurora and neutral tori.

Basic units for Fields and Particles

- *V: potential difference; measured in units of volts*
- *I: current; in units of amperes*
- *R: resistance; in units of ohms*
- *J: current per unit area; amps/m^2*
- *E: electric field vector; amps/m*
- *P: power; units of Watts ($P=IV$ or $P=V^2/R$)*