The effects of the solar wind on Saturn's space environment

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On behalf of the Cassini science community

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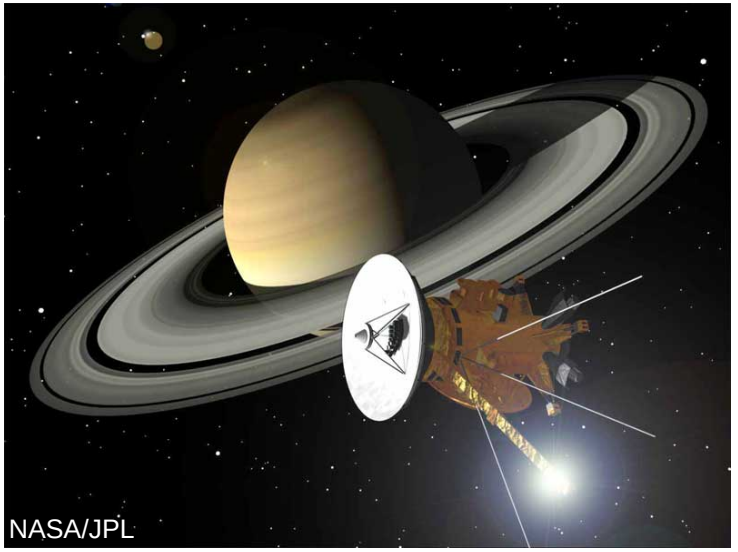
Outline



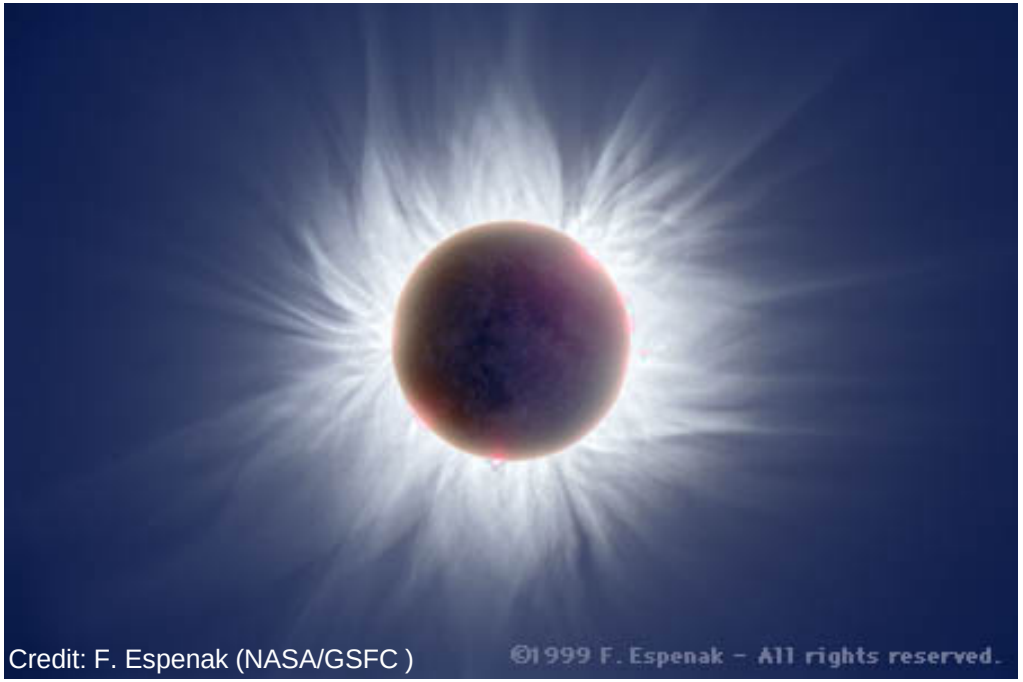
- The solar wind – a space plasma
- Saturn's magnetosphere
- Cassini's exploration of the magnetosphere
- How the solar wind affects the magnetosphere:

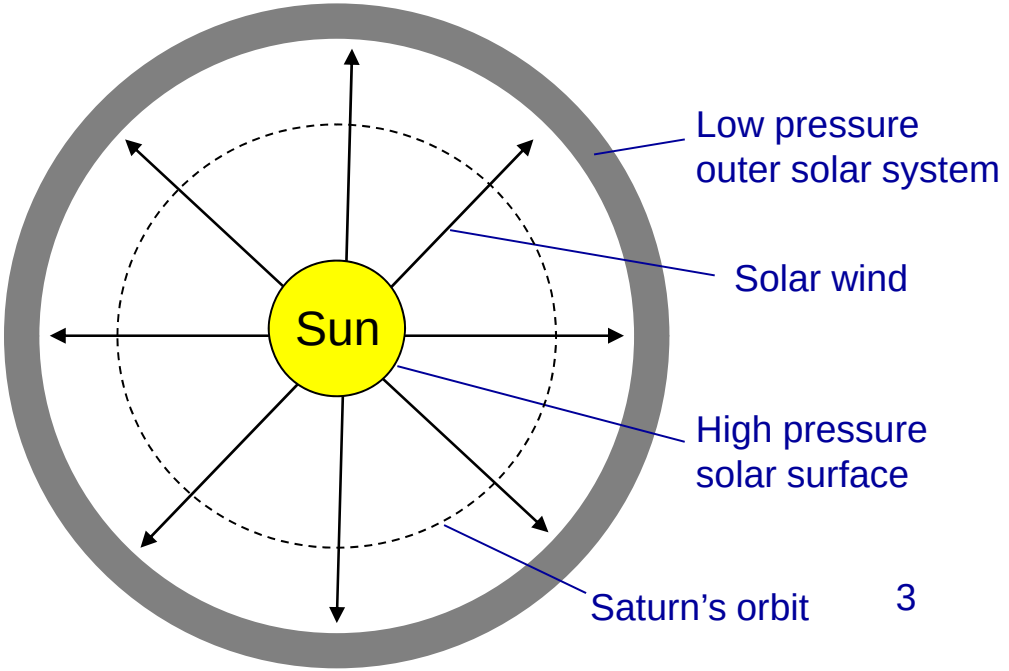
  - Size of the magnetosphere
  - Auroral emissions
  - Reconnection
  - Waves in the outer magnetosphere

- Summary

The solar wind

- The Sun is made of partially ionized gas – a plasma (charged particles not bound together as atoms or molecules)
- There is a large pressure difference between the surface of the Sun and the outer solar system
- As a result the particles of the solar surface flow away from the Sun
- All the planets are immersed in this solar wind, like pebbles in a stream





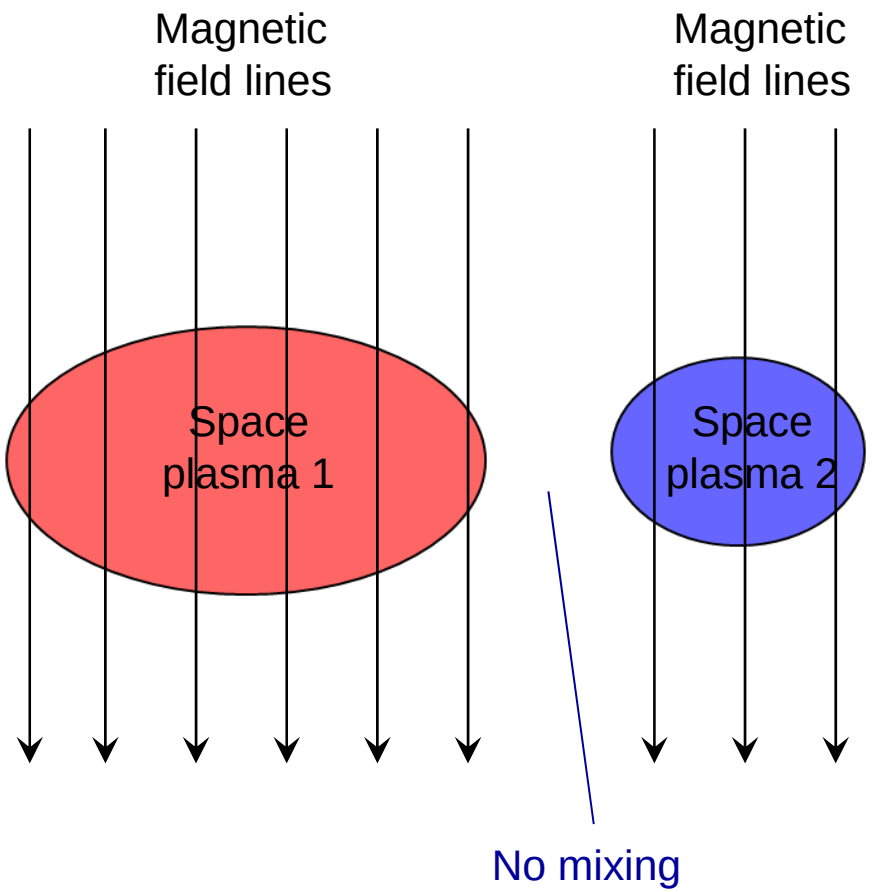
What is special about space plasmas?

- Space plasmas (like the solar wind) are very low density, a better vacuum than we can make in a laboratory

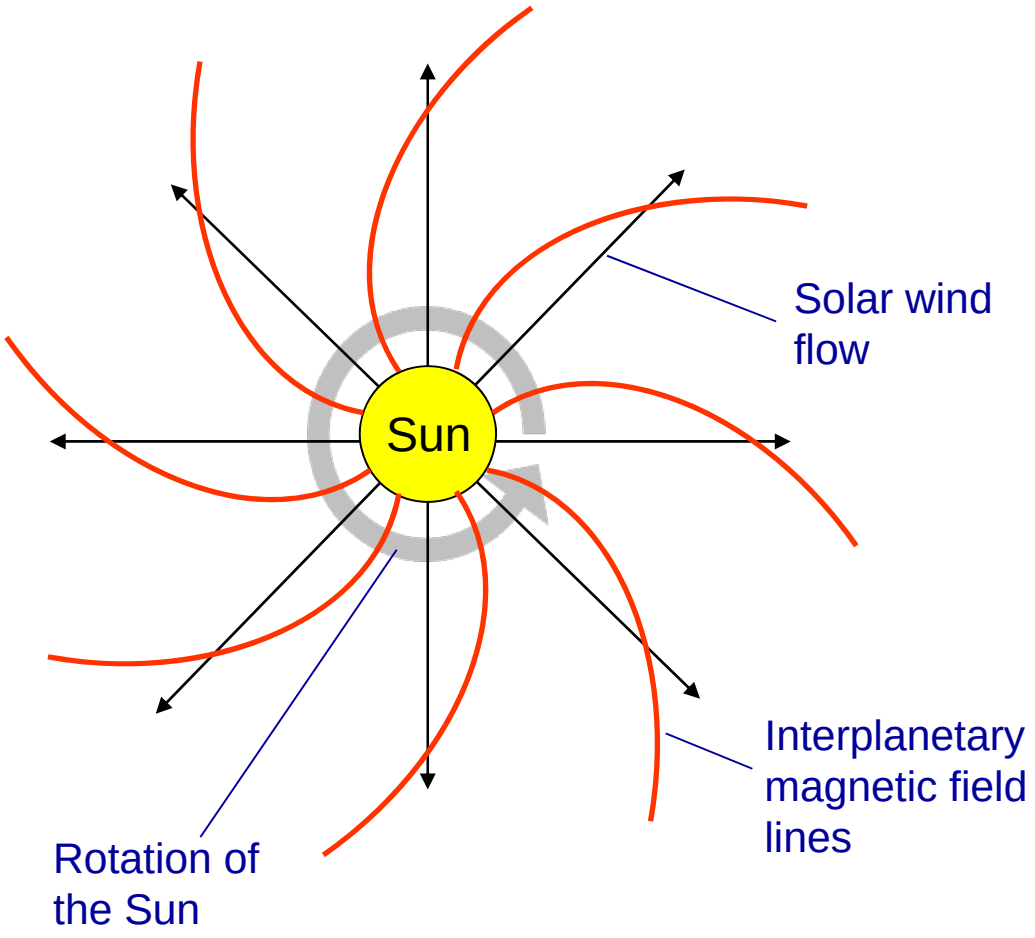
- Because of their low density, magnetic field lines threading a space plasma are ‘frozen-in’

  → Wherever the plasma goes the magnetic field lines have to go too

  → Two different space plasmas with different frozen-in magnetic fields cannot mix



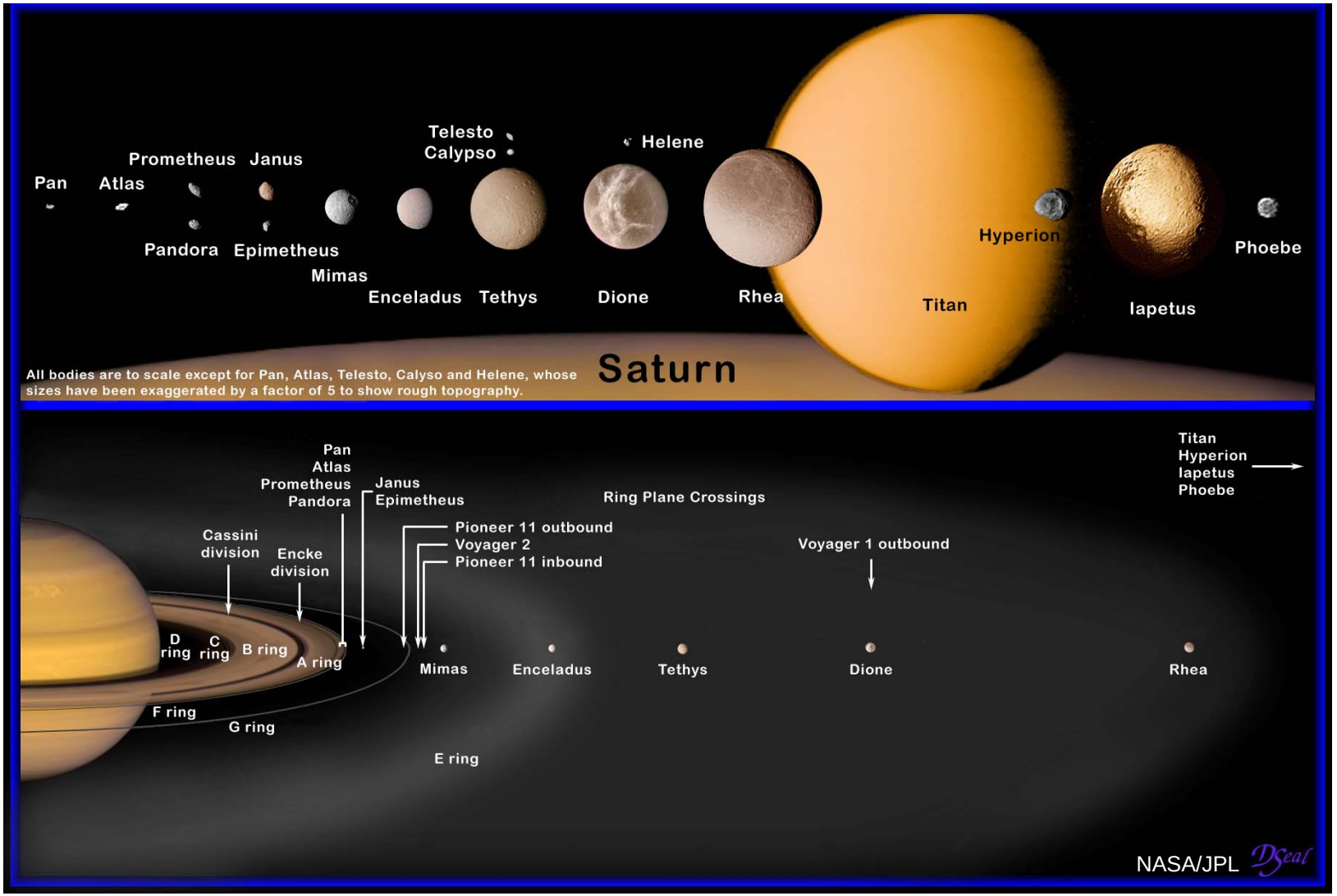
What does the solar wind do to the Sun's magnetic field?



- The Sun generates its own magnetic field
- As the solar wind flows away from the Sun it carries this magnetic field out into the solar system
- This solar wind magnetic field is called the interplanetary magnetic field (IMF)
- Due to the Sun's rotation, the IMF field lines extending out into the solar system form a spiral pattern

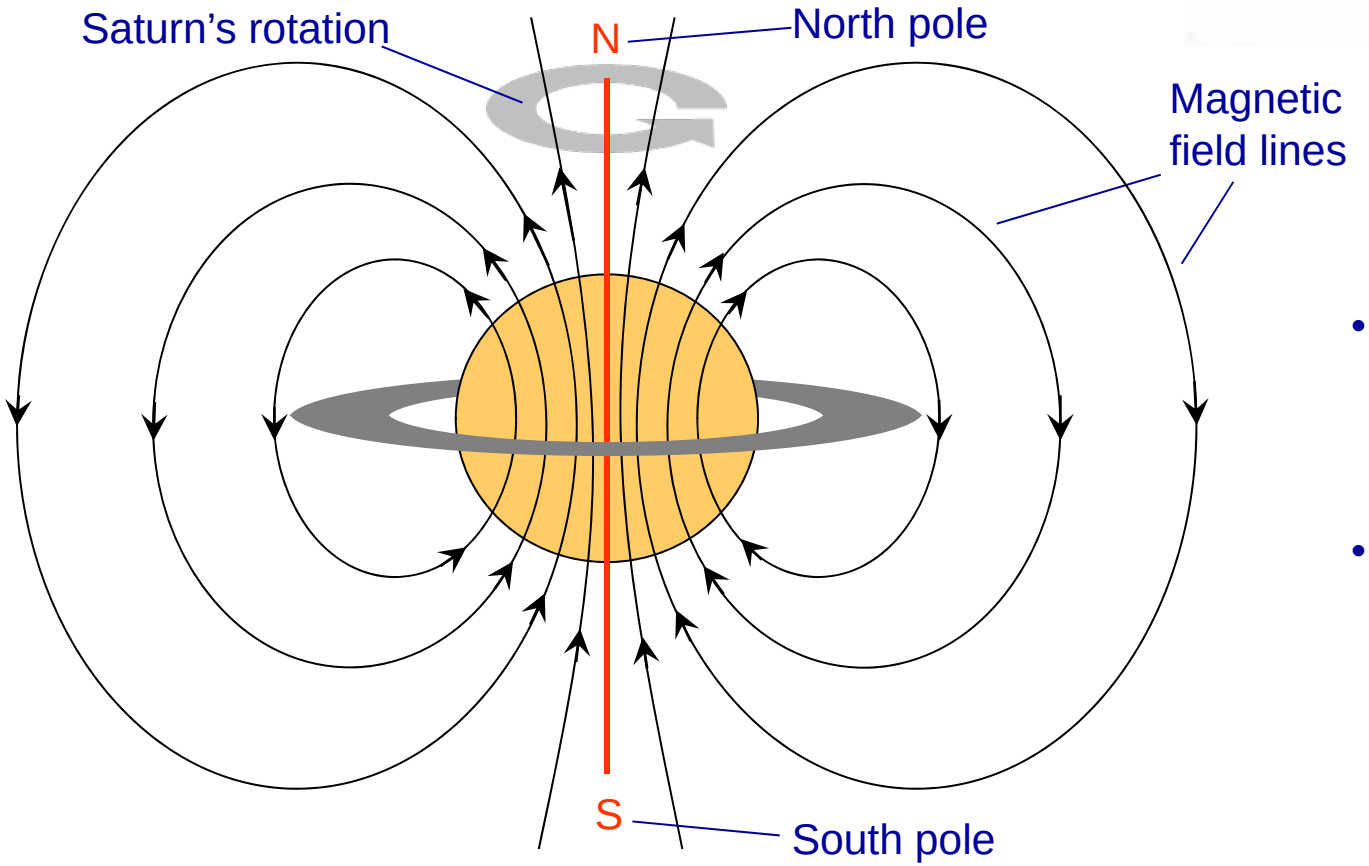
  – The famous Parker spiral

The Saturn system



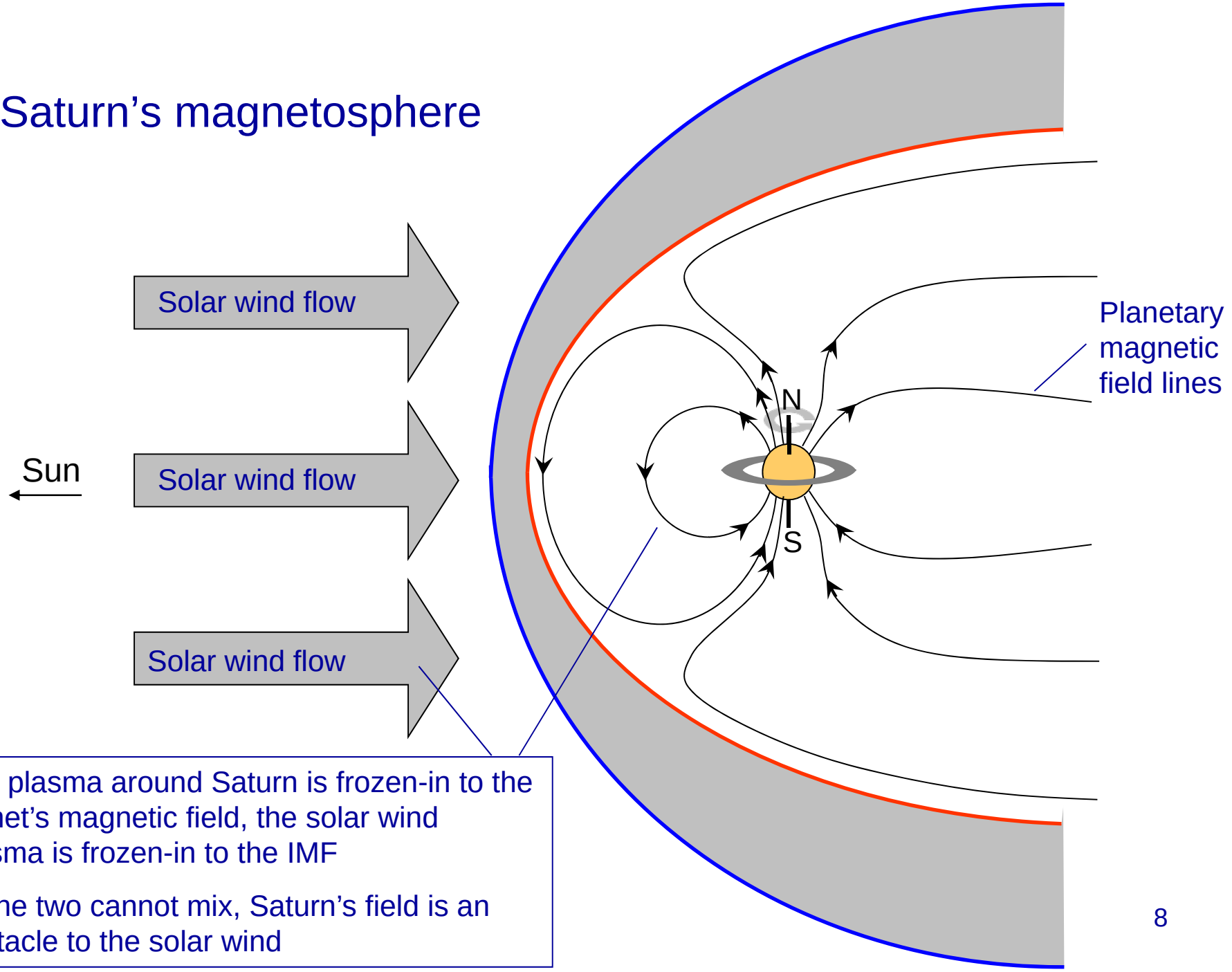
Saturn's magnetic field

- Saturn generates a magnetic field (like the Earth) due to processes operating in the planet's interior



- The field is dipolar – like the field of a bar magnet
- Saturn's magnetic axis and spin axis are closely aligned

Saturn's magnetosphere



The plasma around Saturn is frozen-in to the planet's magnetic field, the solar wind plasma is frozen-in to the IMF

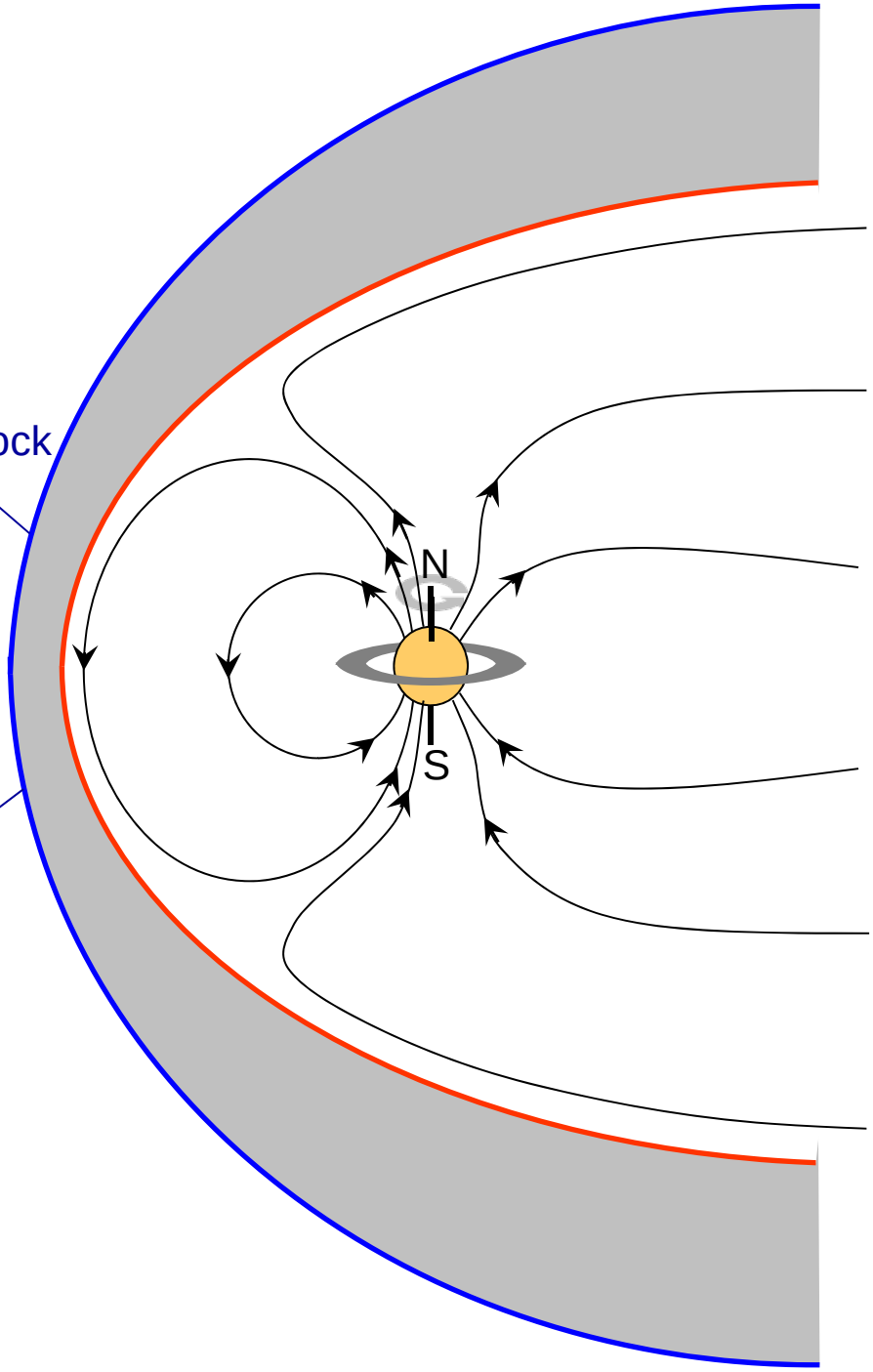
→ the two cannot mix, Saturn's field is an obstacle to the solar wind

Saturn's magnetosphere

The solar wind flows at ~500 km/s

This high speed means that the only way to slow the solar wind down so it can flow around Saturn's magnetic field is via a shock wave, called the bow shock

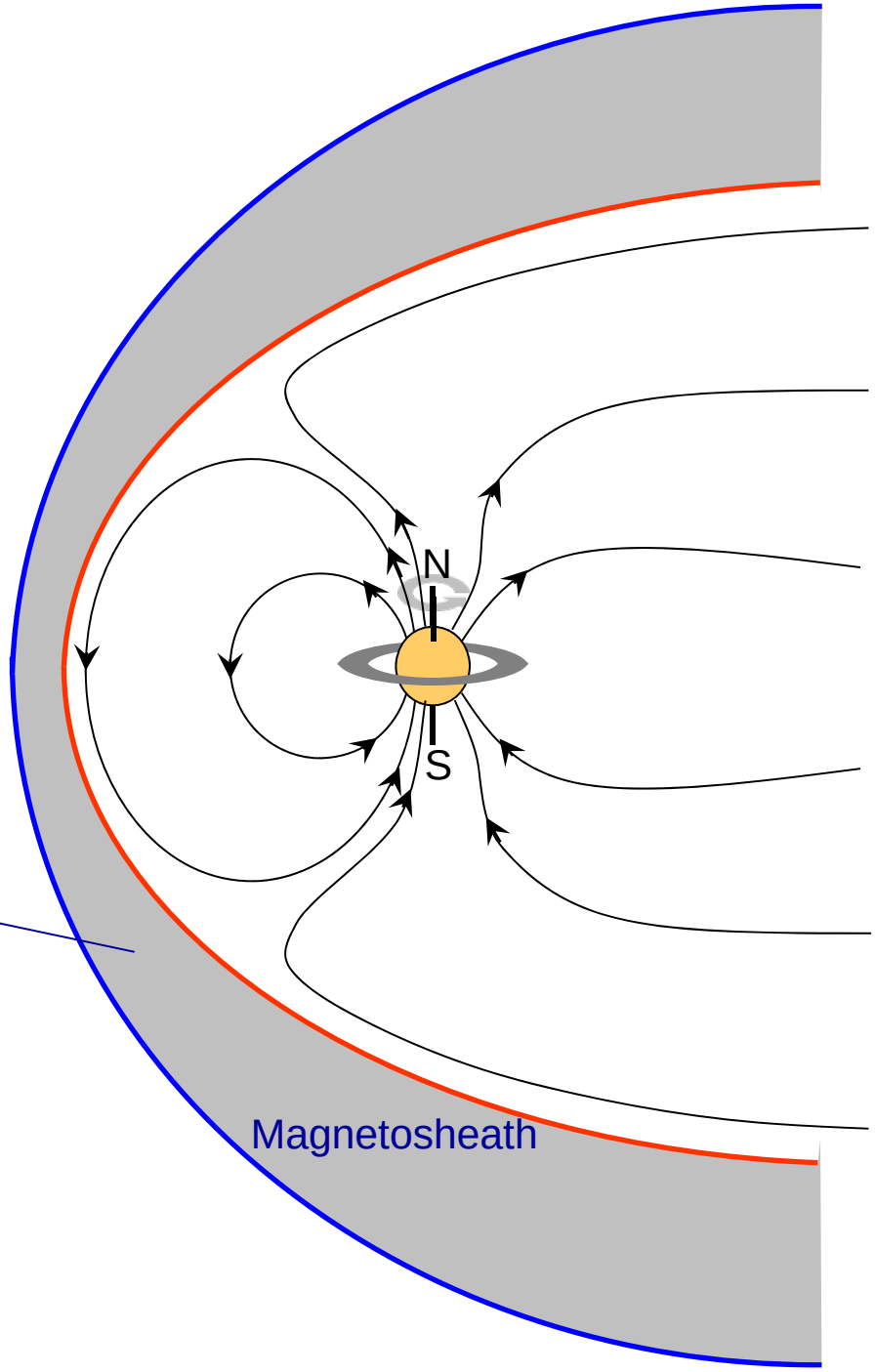
(analogous to the shock waves seen in front of supersonic aircraft)



Saturn’s magnetosphere

Downstream of the bow shock the solar wind is slower, hotter, and denser, and the plasma flows around the planetary field obstacle

This region is called the magnetosheath

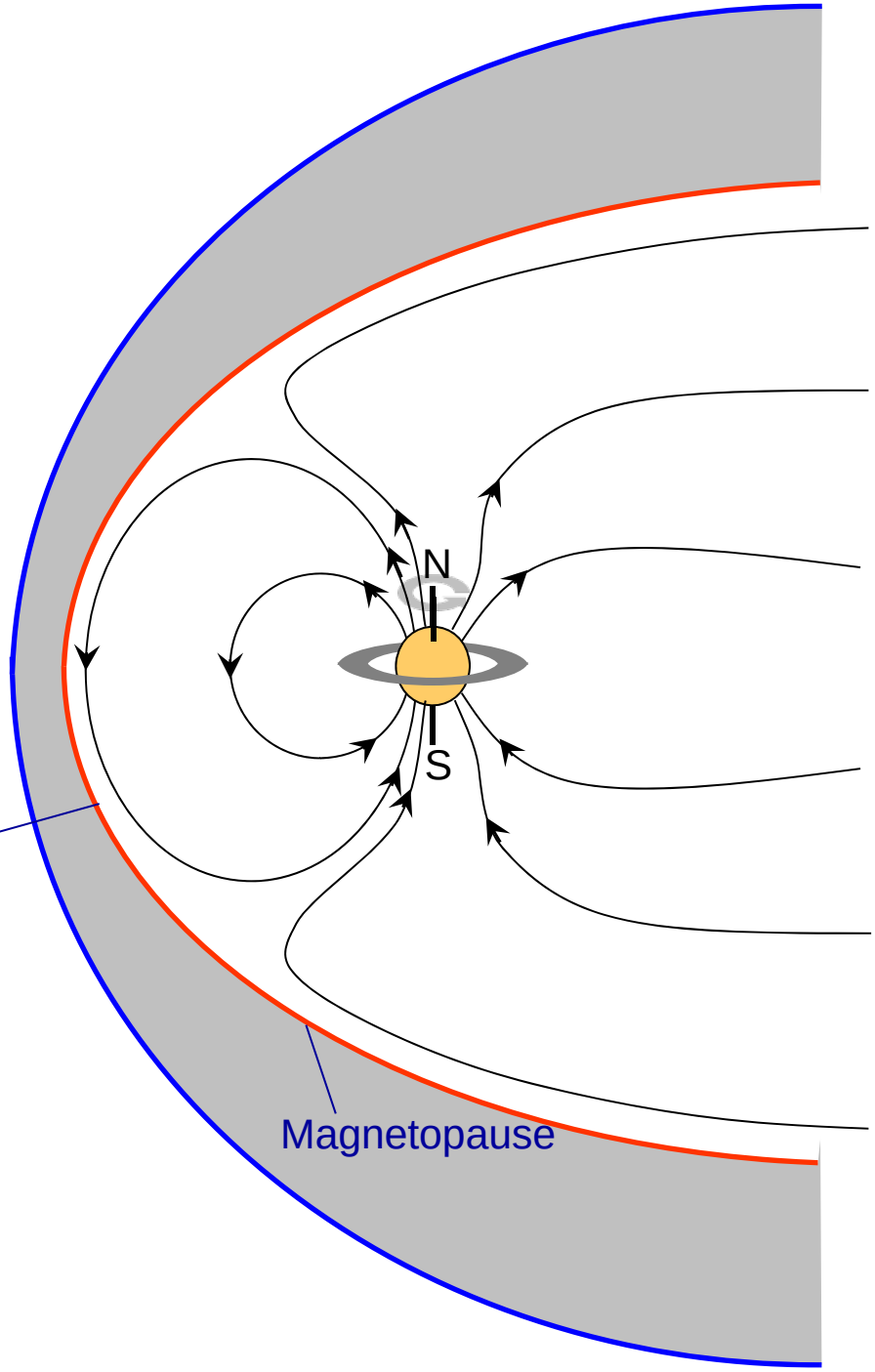


Saturn’s magnetosphere

The boundary of the planetary field obstacle is called the magnetopause

Generally, solar wind plasma cannot flow across this surface

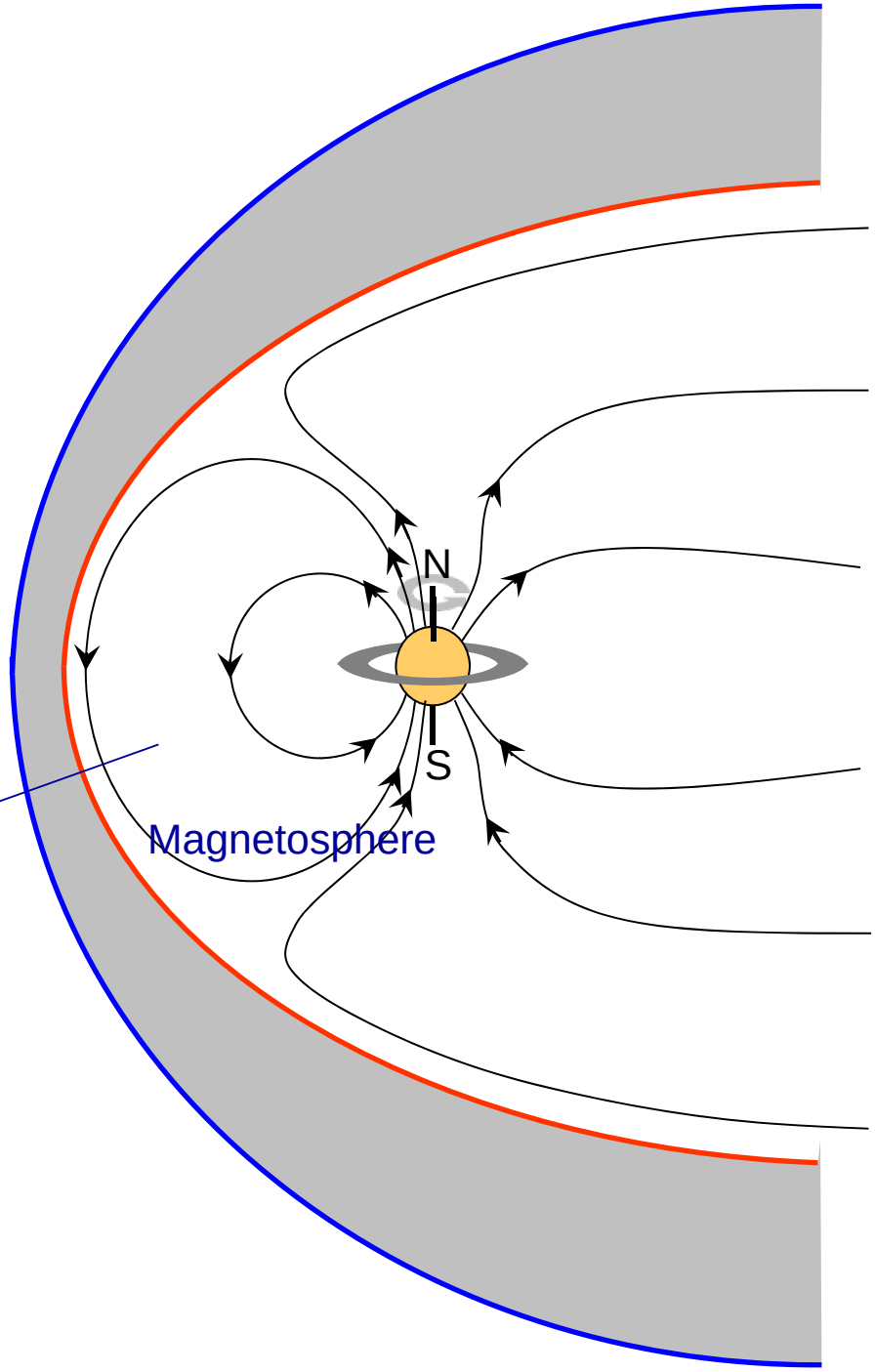
The position of the magnetopause corresponds to pressure balance between the solar wind and the planetary field



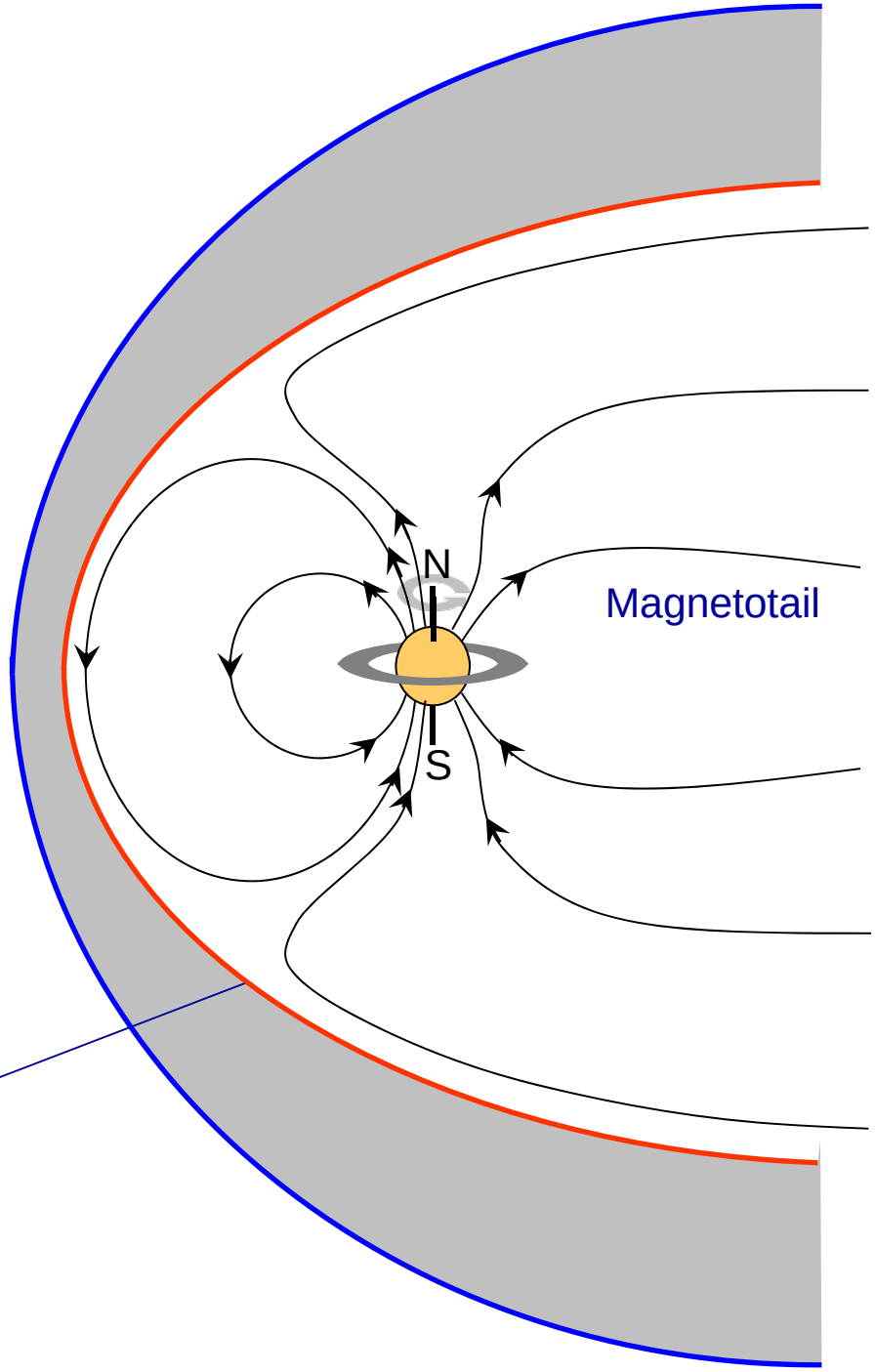
Saturn’s magnetosphere

The region where the Saturn’s magnetic field is experienced is called the magnetosphere

On the planet’s sunward side the field is compressed



Saturn’s magnetosphere



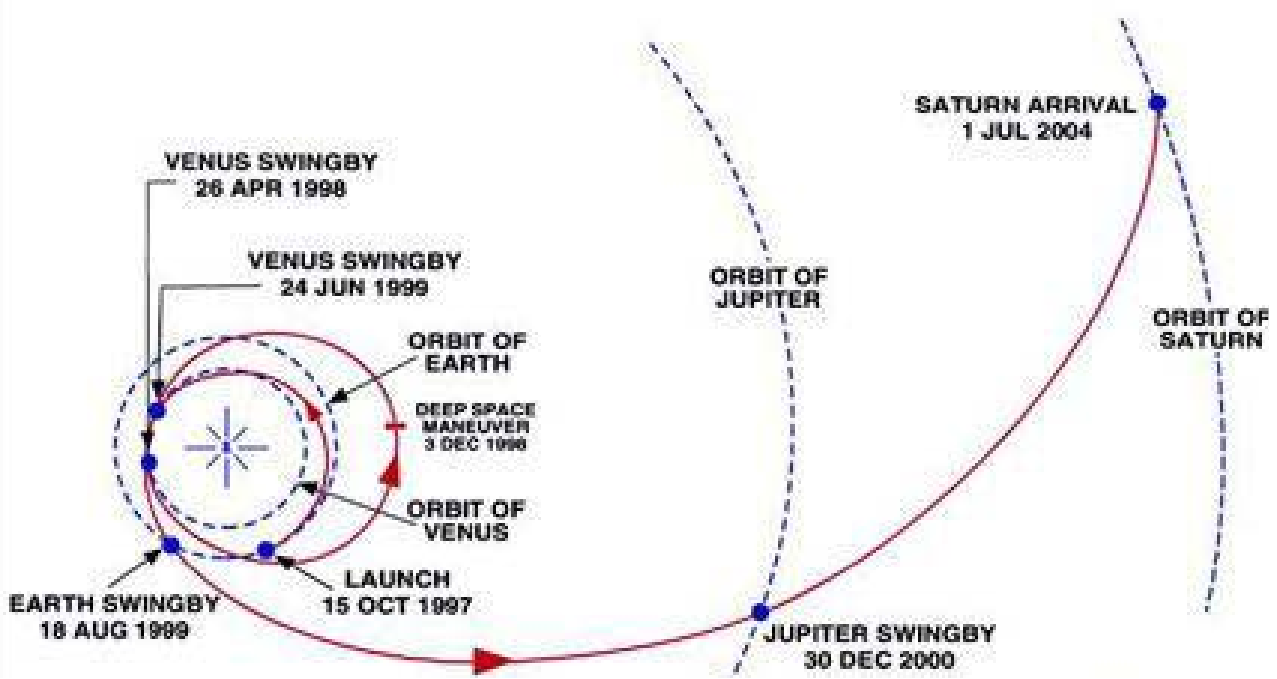
On the antisunward side of the planet, the field lines extend to form a long magnetotail

The solar wind-magnetosphere interaction: why study it?

- As we will see in the following slides, the solar wind can profoundly affect Saturn's magnetosphere
- To better understand the physics of Saturn's magnetosphere it is essential that we study the solar wind-magnetosphere interaction
- Compared to the equivalent interaction at Earth and at Jupiter, the Saturn interaction is different in many respects
- By examining the interaction at Saturn we may learn something new about how the solar wind interacts with other planets

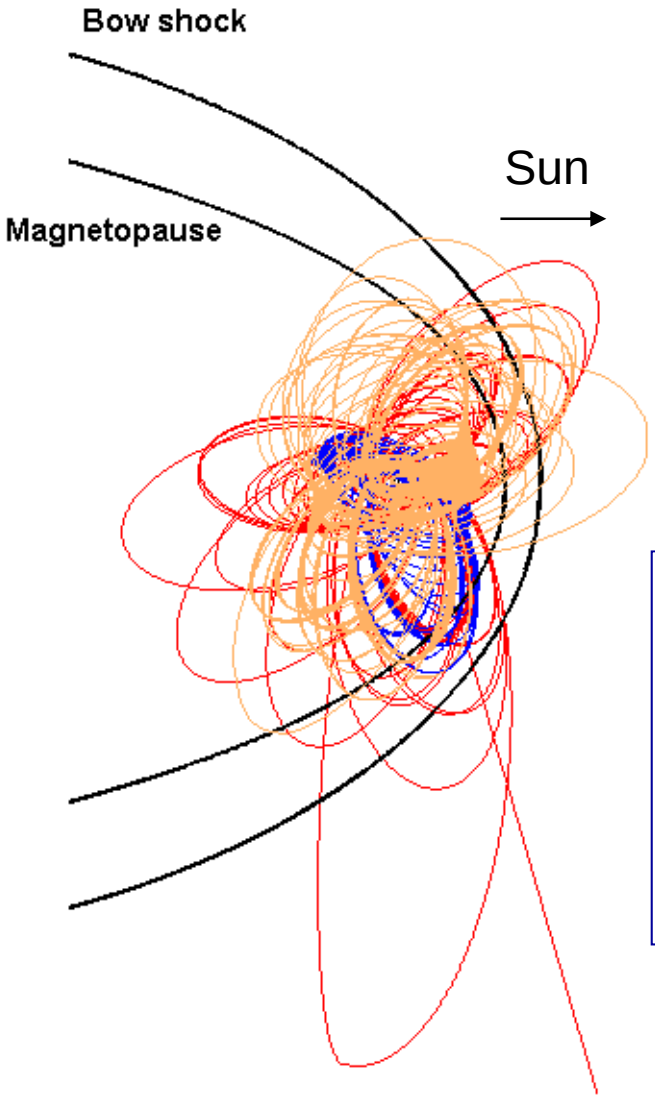
Cassini's approach to the Saturn

- During Cassini's approach to Saturn we were able to observe many of the properties of the solar wind 10 times further from the Sun than the Earth
- Hubble Space Telescope images of the planet allowed us to study the effect of changing solar wind conditions

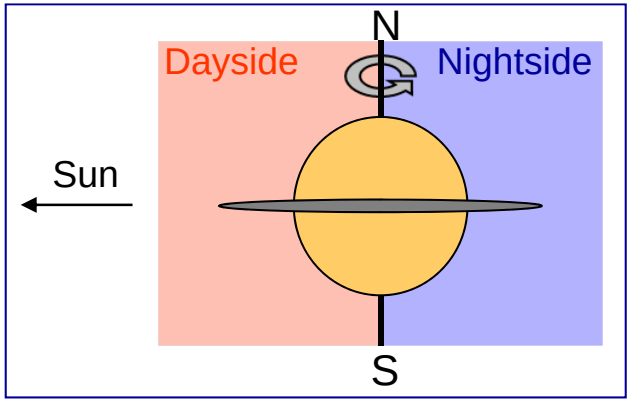


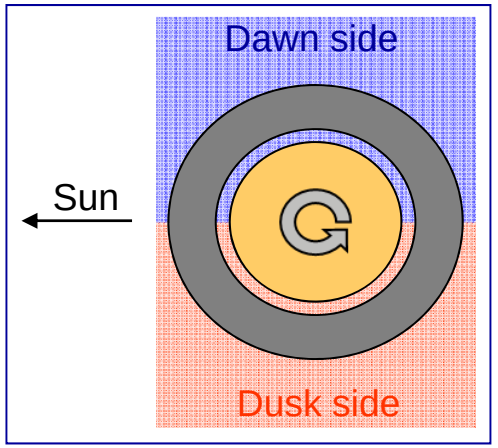
Taken from *Matson et al.* [2002]

Cassini's exploration of the magnetosphere



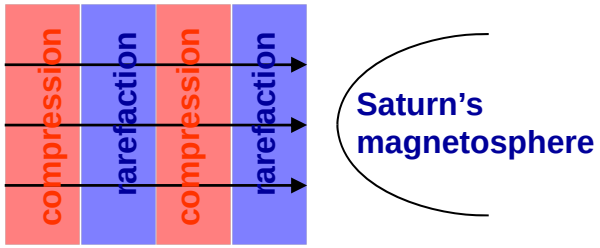
- Since arriving at Saturn in July 2004 Cassini has spent a significant amount of time within the planet's magnetosphere
- By the end of the mission the spacecraft will have comprehensively explored Saturn's space environment

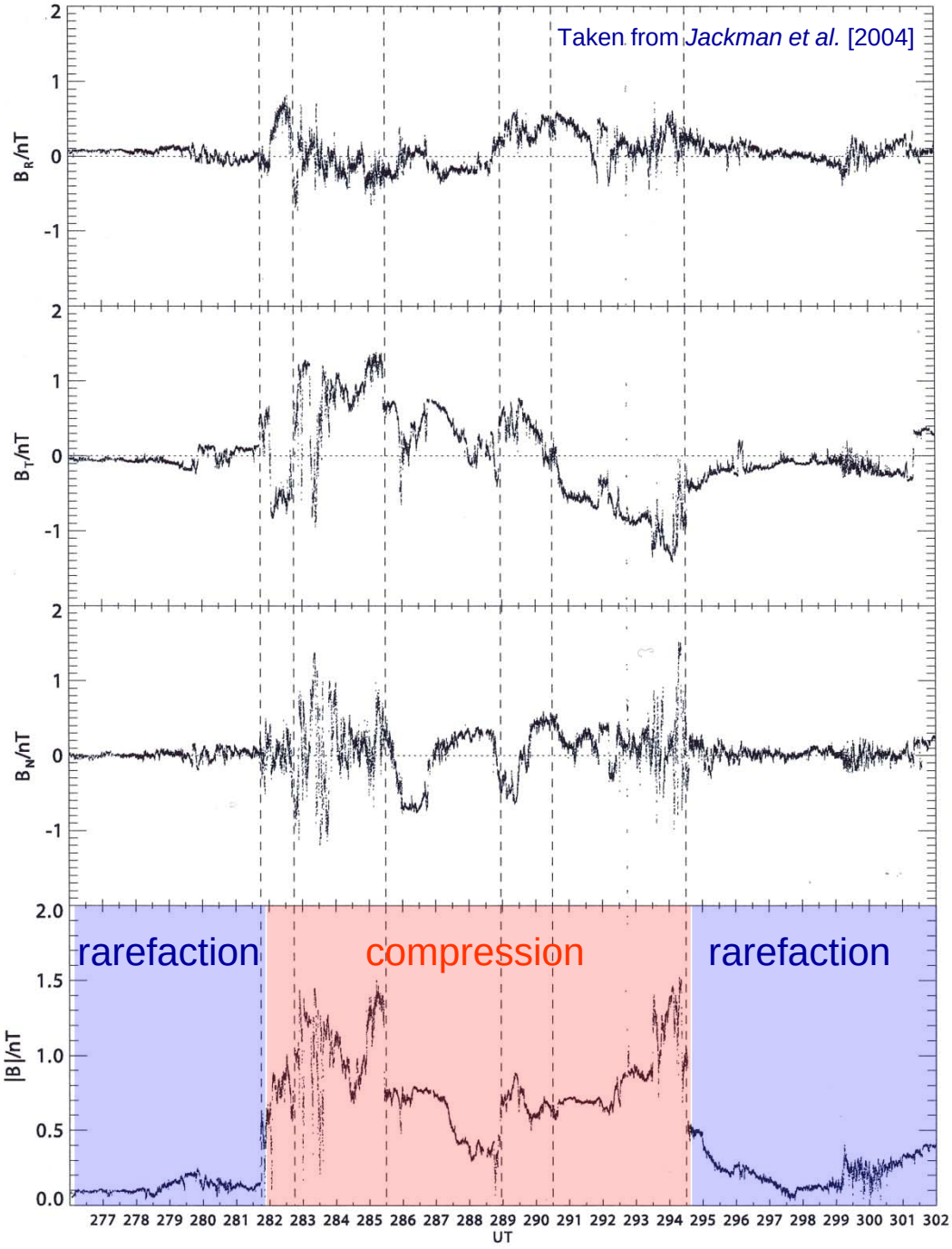




Solar wind at Saturn orbit

- Cassini observations made during the spacecraft's approach to Saturn revealed that the solar wind consisted of alternating regions of compression (higher density) and rarefaction (lower density)





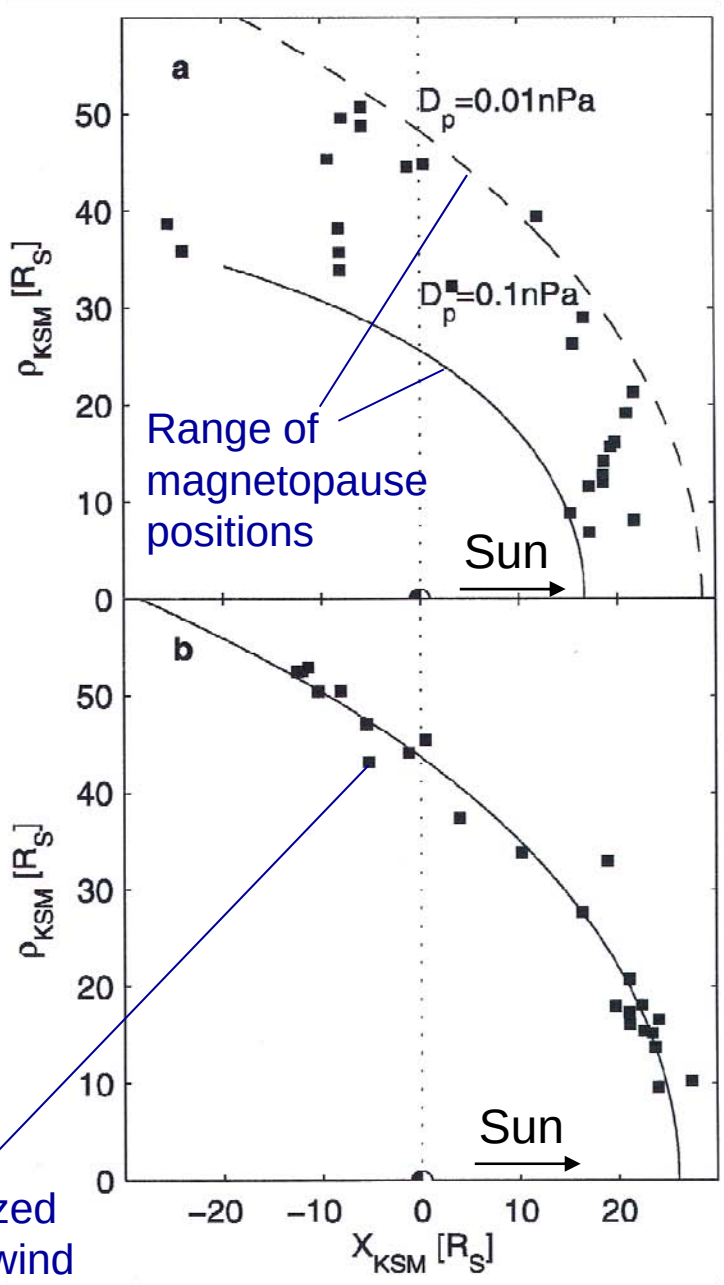
Size of the magnetosphere

- These compressions and rarefactions resulted in changes in the total pressure exerted by the solar wind on the magnetosphere

  → Motion of the magnetopause to maintain pressure balance

- Due to such solar wind variations the magnetosphere can dramatically expand/contract

- This has a clear effect on other magnetospheric phenomena

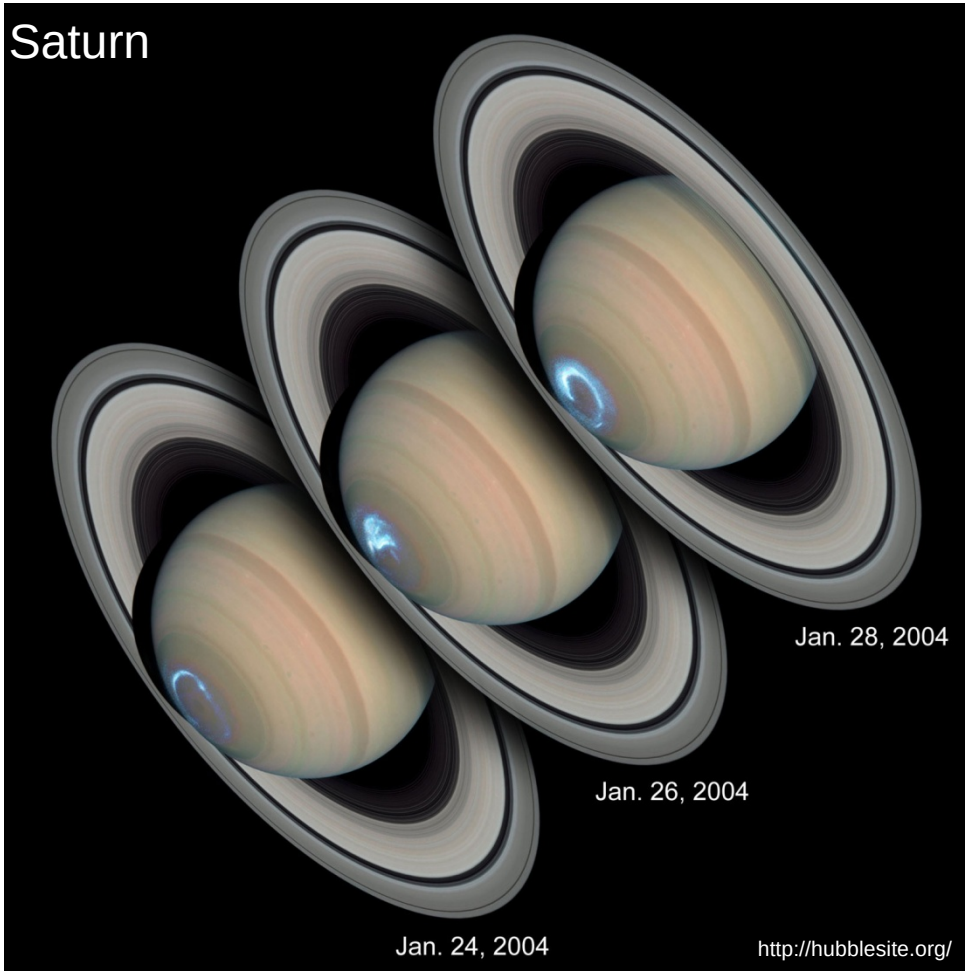


Crossings normalized to the same solar wind pressure

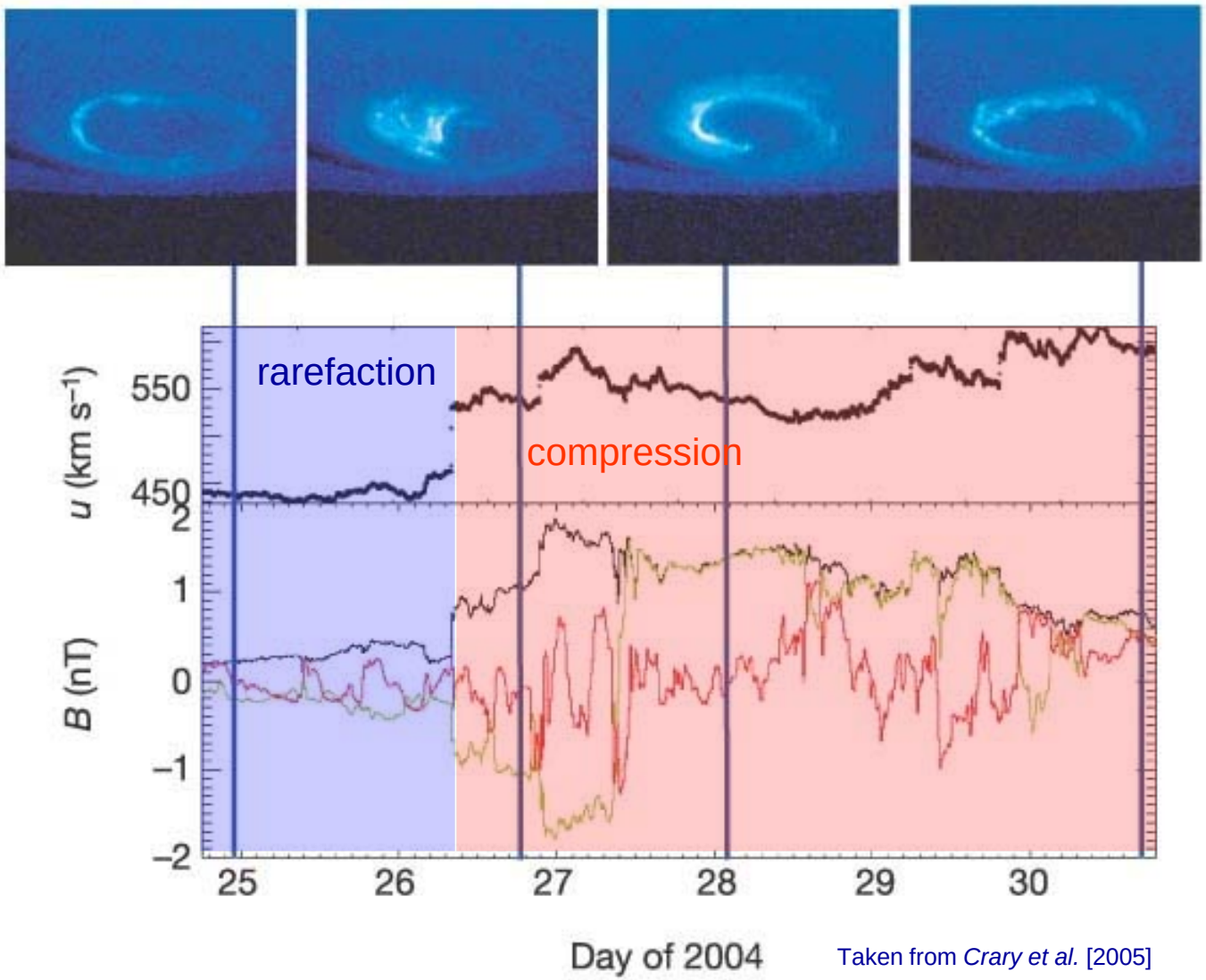
Taken from *Arridge et al.* [2006]

Solar wind influence on auroral emissions

- Like Earth, Saturn has aurorae
- These emissions are caused by charged particles that travel along magnetic field lines and hit the planet's upper atmosphere



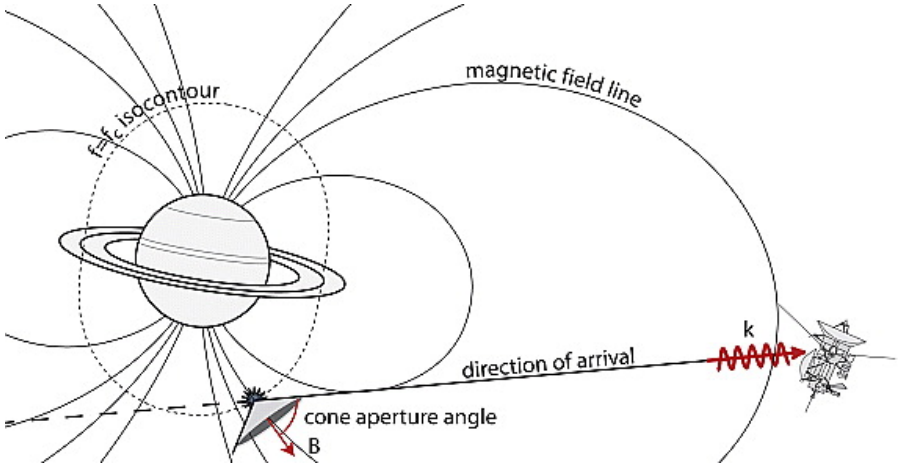
The ultraviolet aurorae



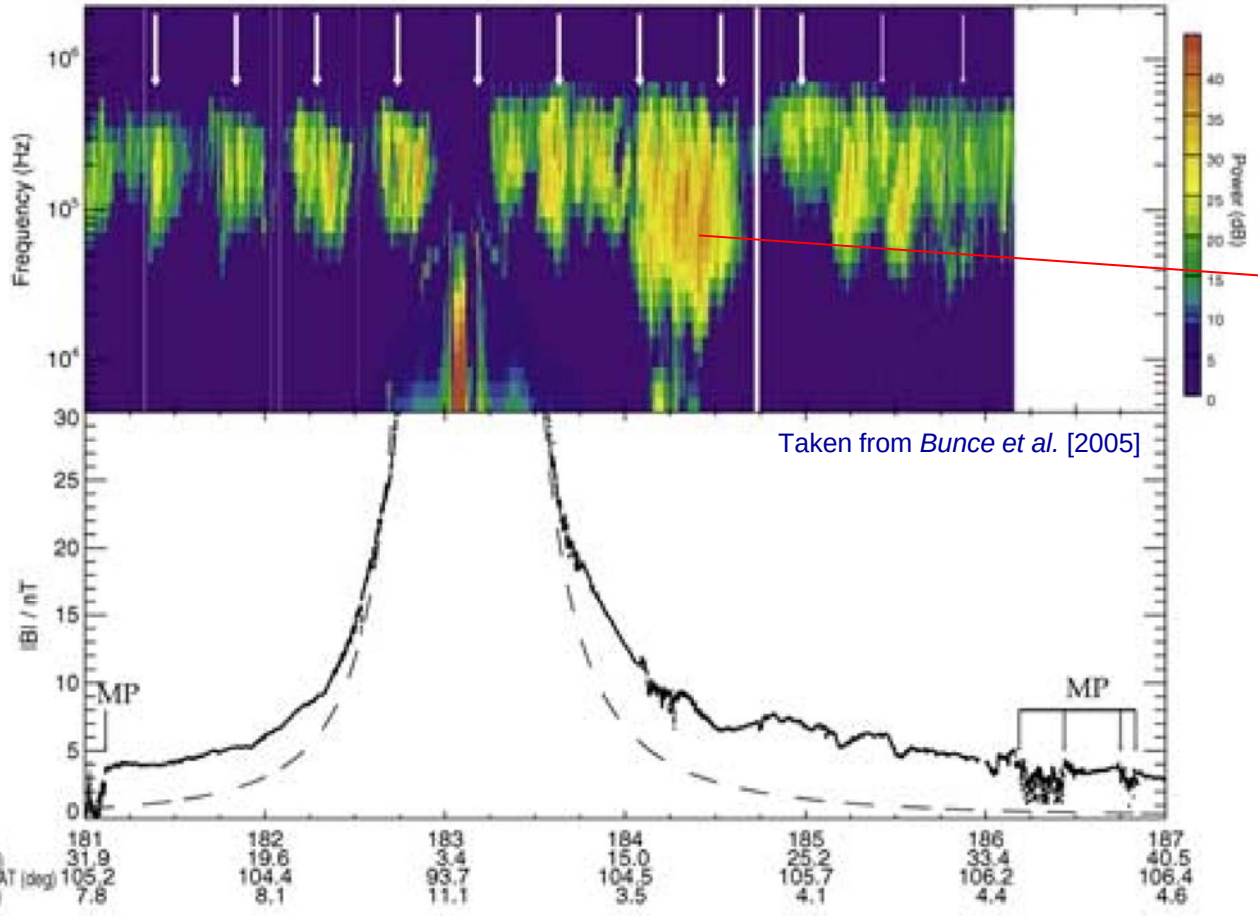
Taken from *Crary et al.* [2005]

Saturn kilometric radiation

- Saturn's mysterious auroral radio emission is called Saturn kilometric radiation (SKR)



Taken from *Cecconi et al.* [2009]



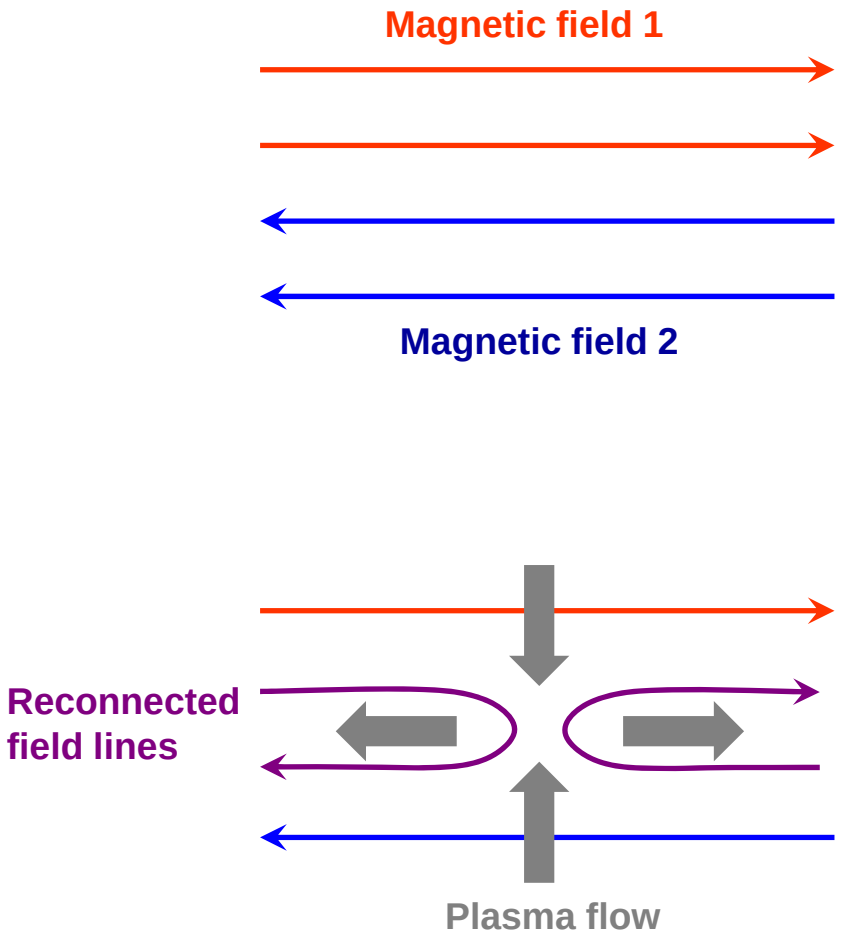
Taken from *Bunce et al.* [2005]

Intense SKR associated with a compression of the magnetosphere

- The SKR power varies with a variable period close to the rotation rate of the planet – the solar wind also affects this modulation period

Reconnection

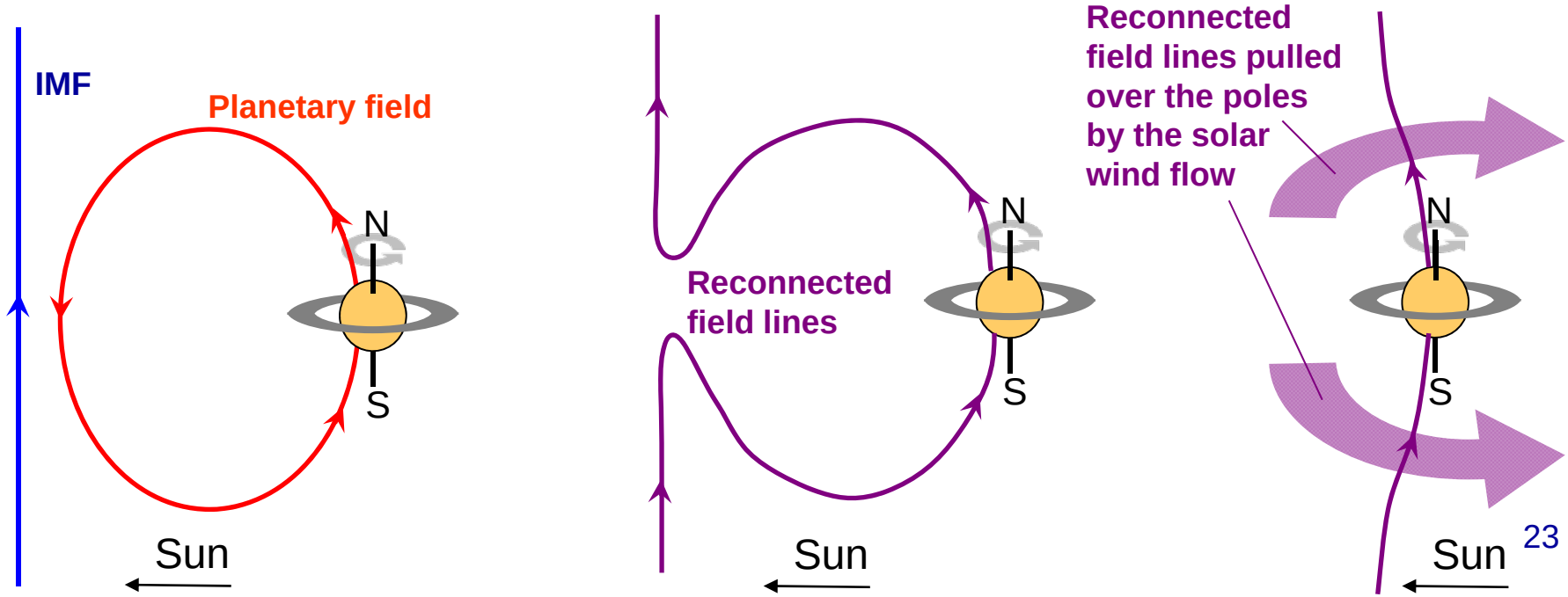
- Magnetic reconnection is a particularly important process that can operate in space plasmas
- Simple picture: Anti-parallel field lines break, and reconnect
- The process energizes the plasma and is important for our understanding of planetary magnetospheres



Dayside reconnection

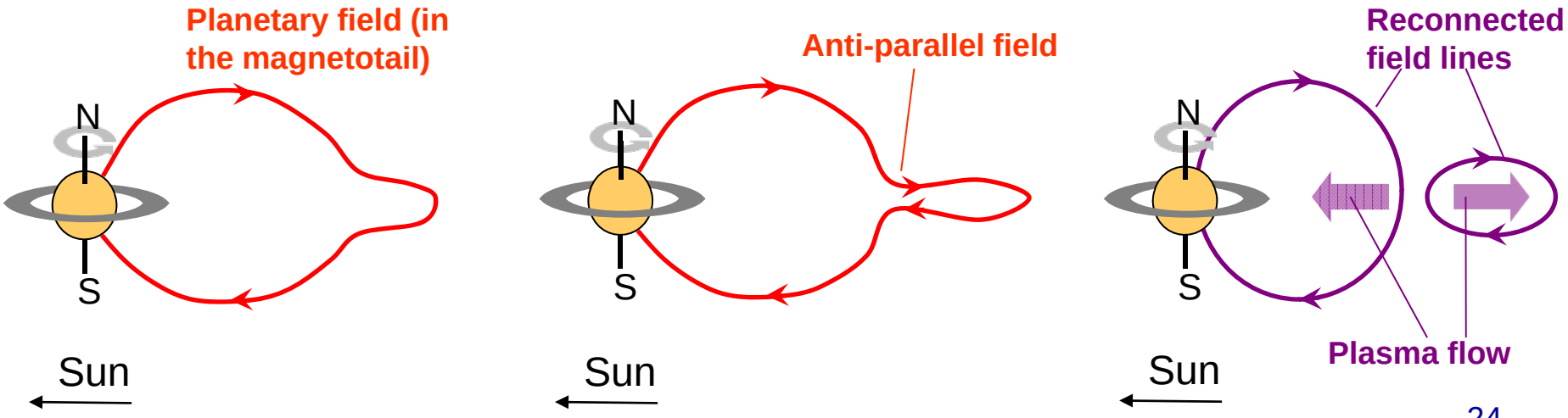
- The IMF field lines carried by the solar wind can reconnect with Saturn's magnetic field lines, particularly when the IMF points North → entry of solar wind plasma into the magnetosphere

- Cassini has found evidence of reconnection at the magnetopause; however the nature of dayside reconnection at Saturn appears to be different to that at Earth and Jupiter



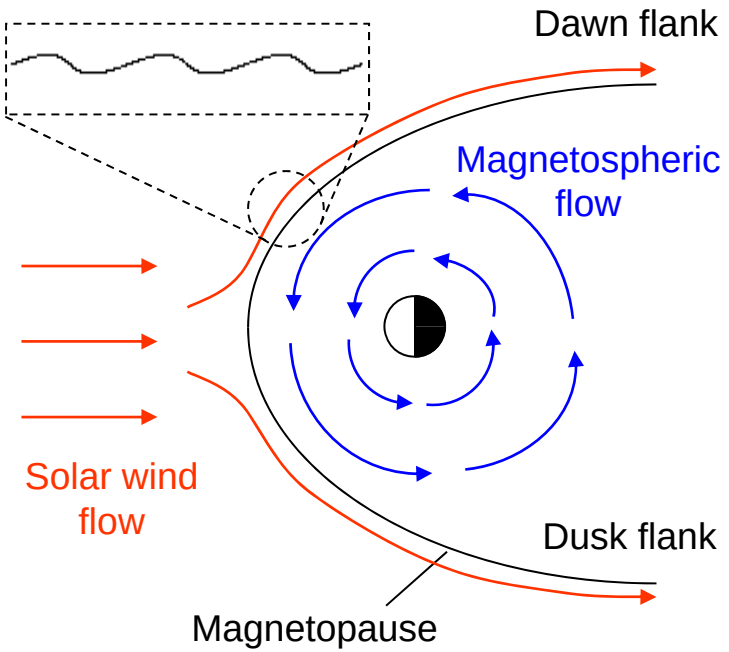
Magnetotail reconnection

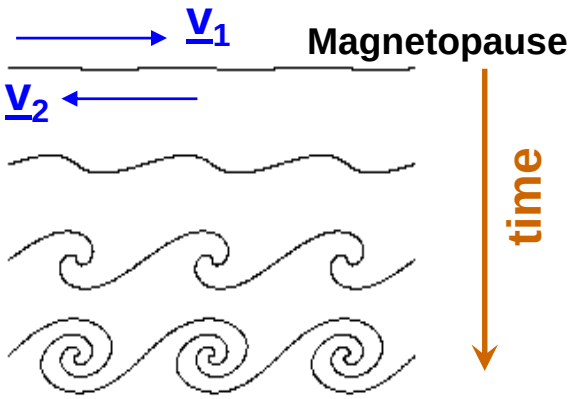
- Evidence for reconnection in the magnetotail has been found by Cassini and is linked to intense auroral emissions and the generation of energetic neutrals
- It has been suggested that rapid bursts of tail reconnection are triggered by solar wind-induced compression of the magnetosphere
- Do Earth-like substorms occur at Saturn?



Waves on the magnetopause

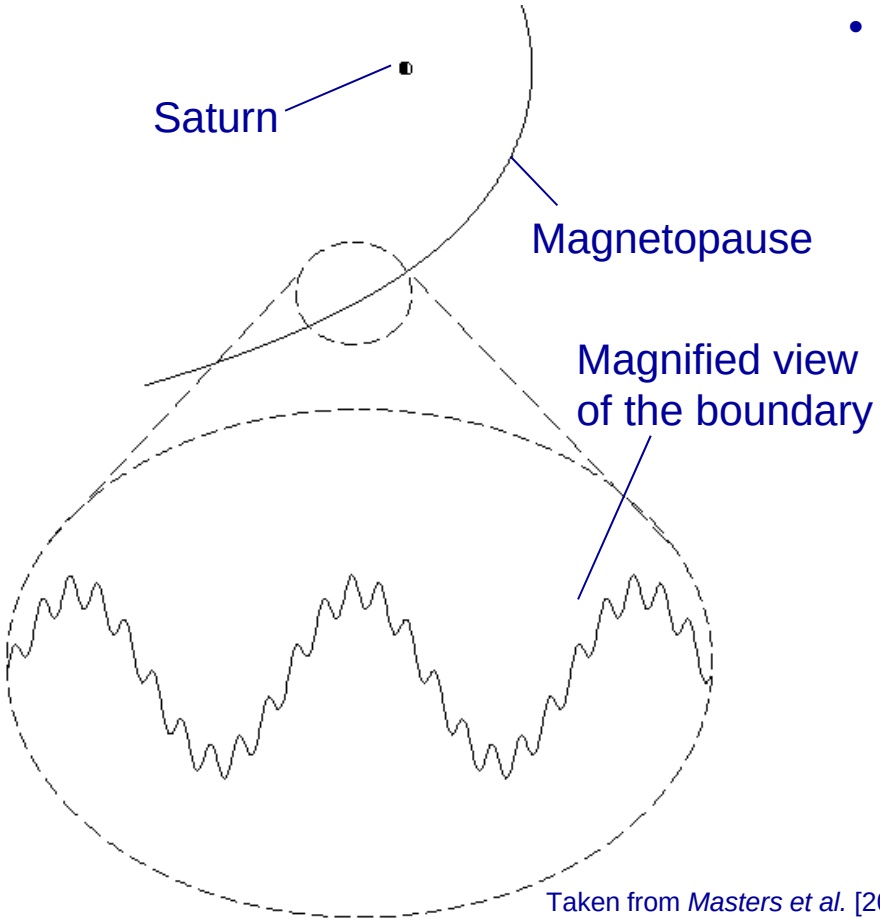
- Solar wind pressure fluctuations can produce waves on the magnetopause surface
- When the plasma flows either side of the boundary are very different, waves can also be generated due to the growth of the Kelvin-Helmholtz (K-H) instability
- This is analogous to waves on the sea caused by wind blowing across the surface





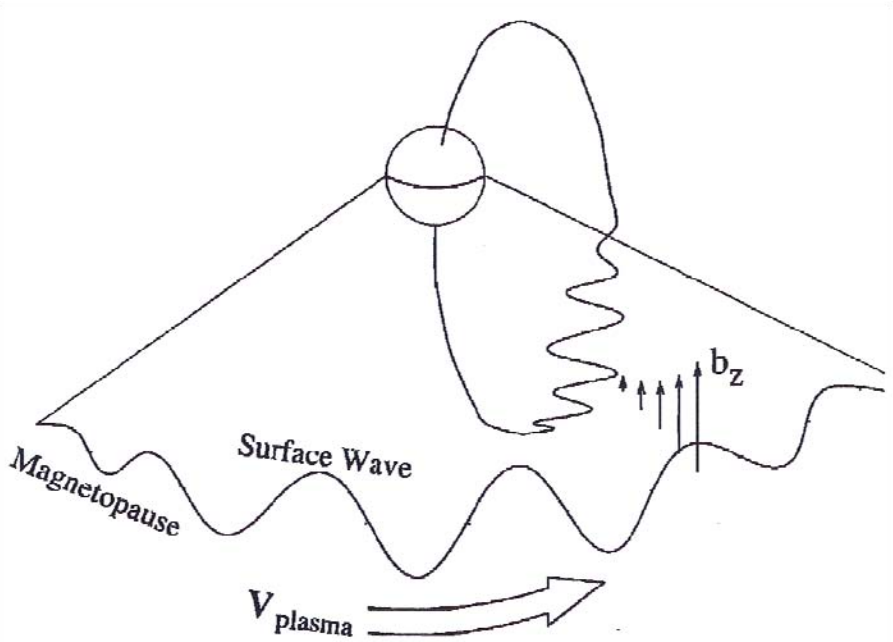
Waves on the magnetopause

- Cassini has found evidence of complicated wave structures on the magnetopause surface, likely driven by the K-H instability



Taken from *Masters et al.* [2009]

- These waves are expected to launch more waves into the magnetosphere itself, leading to energy transport



Taken from *Cramm et al.* [1998]

Summary

- The interaction between the solar wind and Saturn's magnetic field produces a cavity around the planet – the magnetosphere
- This space environment is complex and can be significantly affected by changes in the solar wind
- In many ways, this interaction at Saturn is different from the interaction at the other planets of the solar system
- Cassini's ongoing exploration of near-Saturn space should further improve our understanding of the environment