Nature's light show: Saturn's aurora

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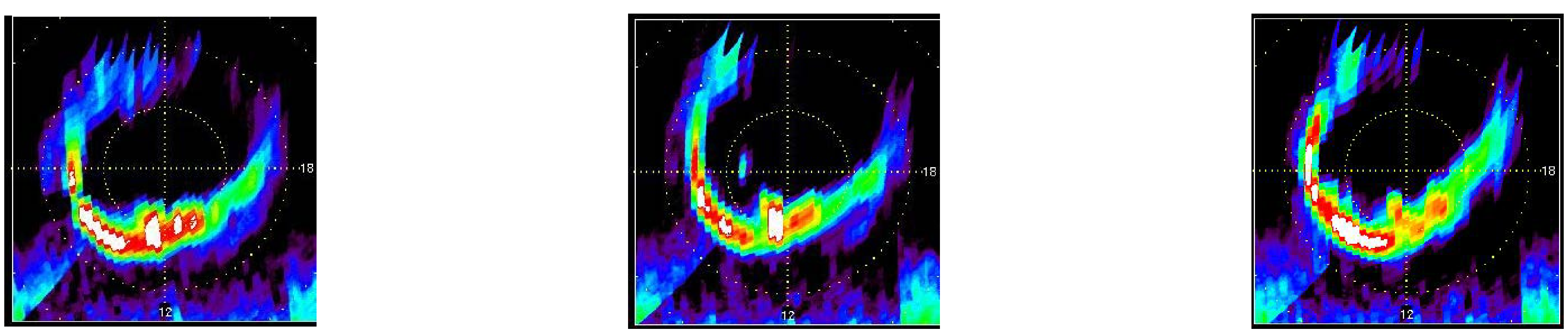
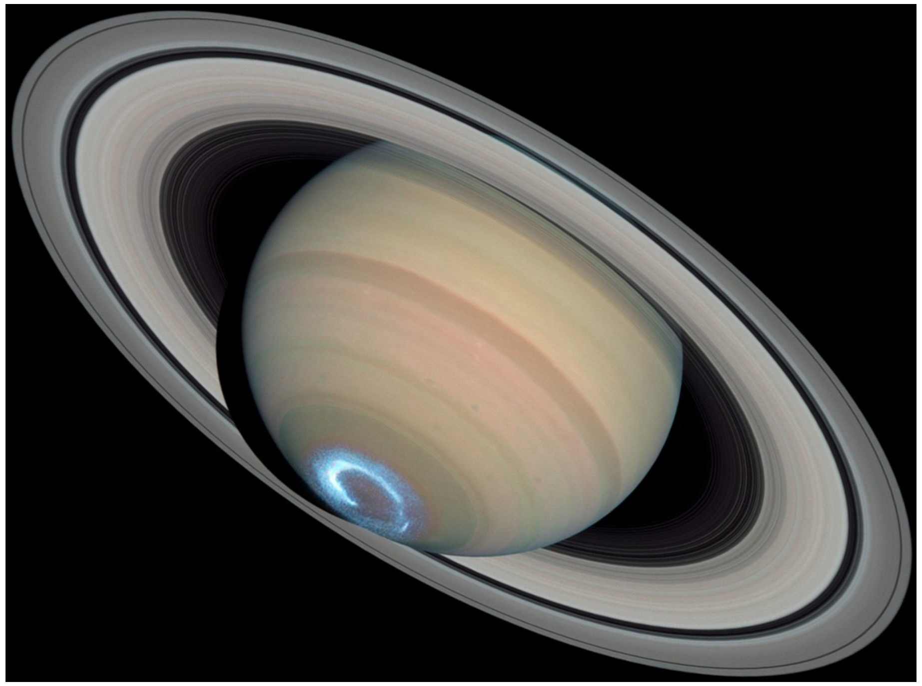


Cassini/UVIS images of Saturn's northern aurora (Badman et al., 2013)

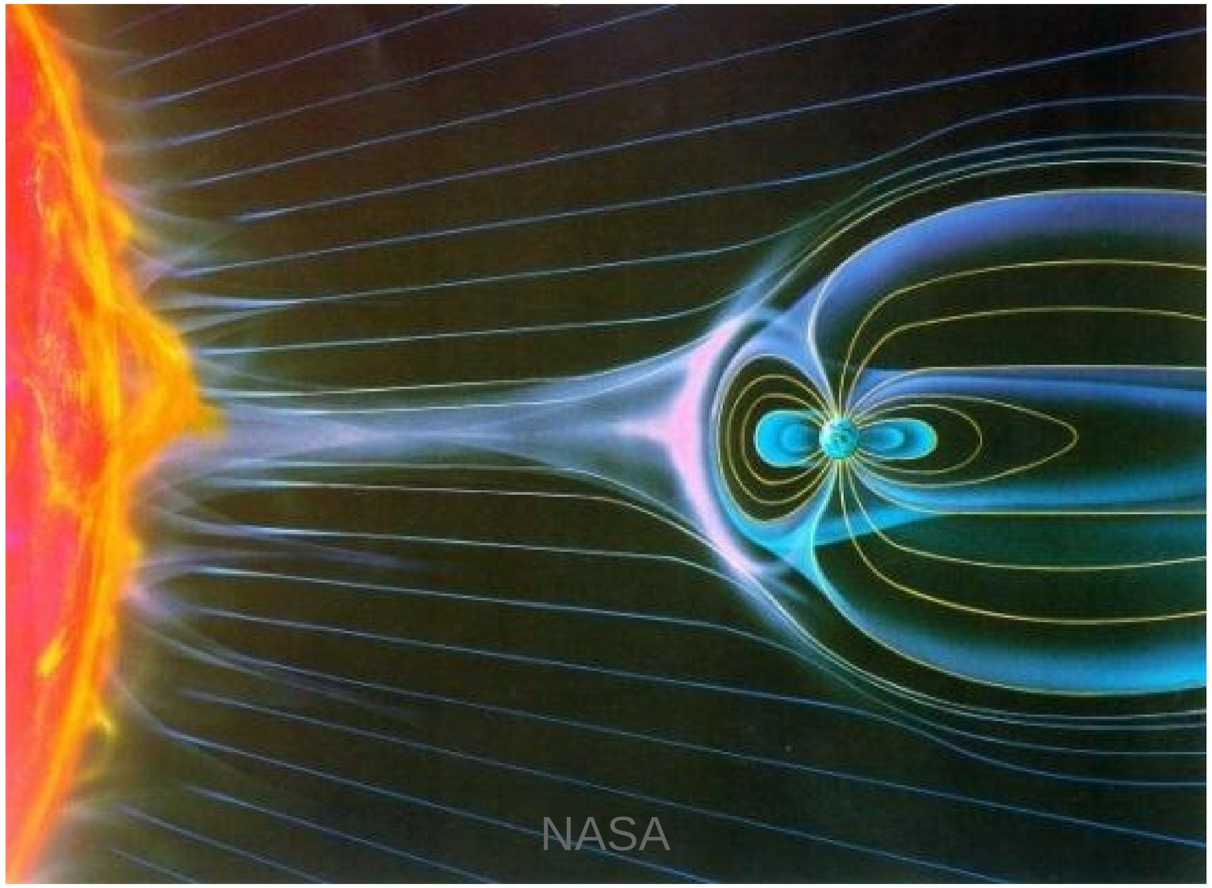
Outline

- How the solar wind affects Saturn’s magnetosphere
  - Why do we care?
- Saturn’s aurora: a global view
- Recent Cassini auroral discoveries
- What are we looking for next?
  - The 2013 and 2014 auroral campaigns
- Summary



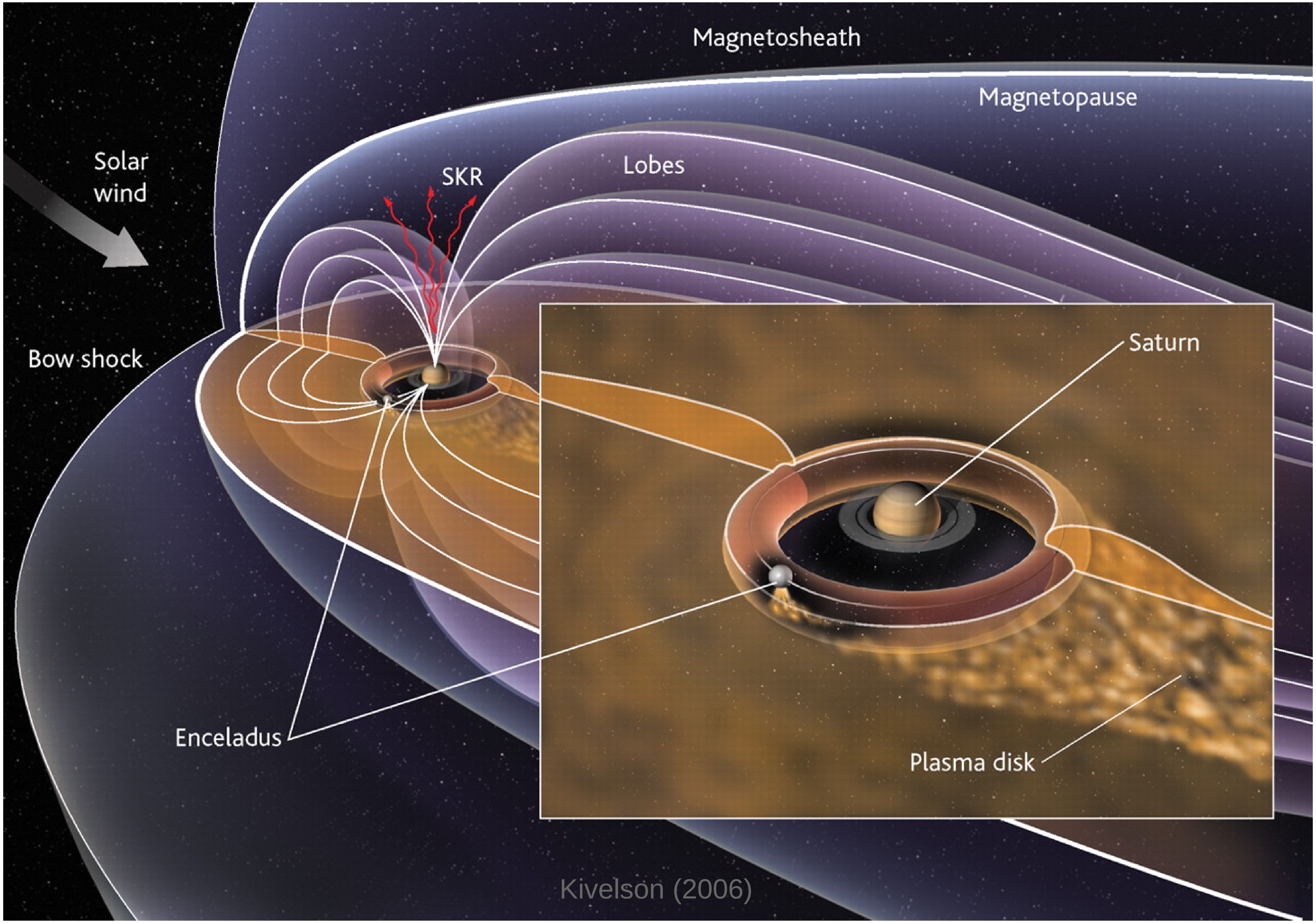
Science Objective

- 'To characterise the structure of the magnetosphere and its interactions with the solar wind, Saturn's moons and rings.'



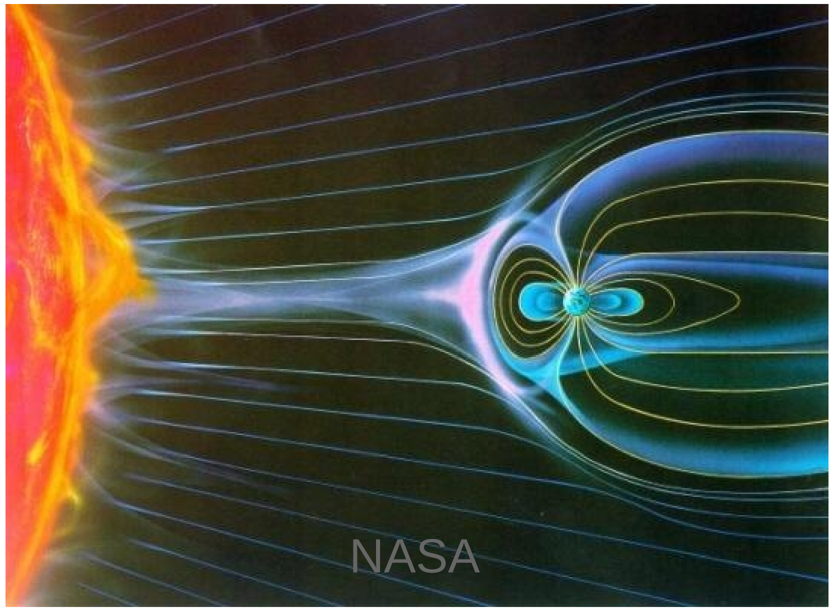
- We are studying how the energy from the Sun spreads through the solar system, and how it affects the local environment of the planets.

Saturn’s magnetosphere

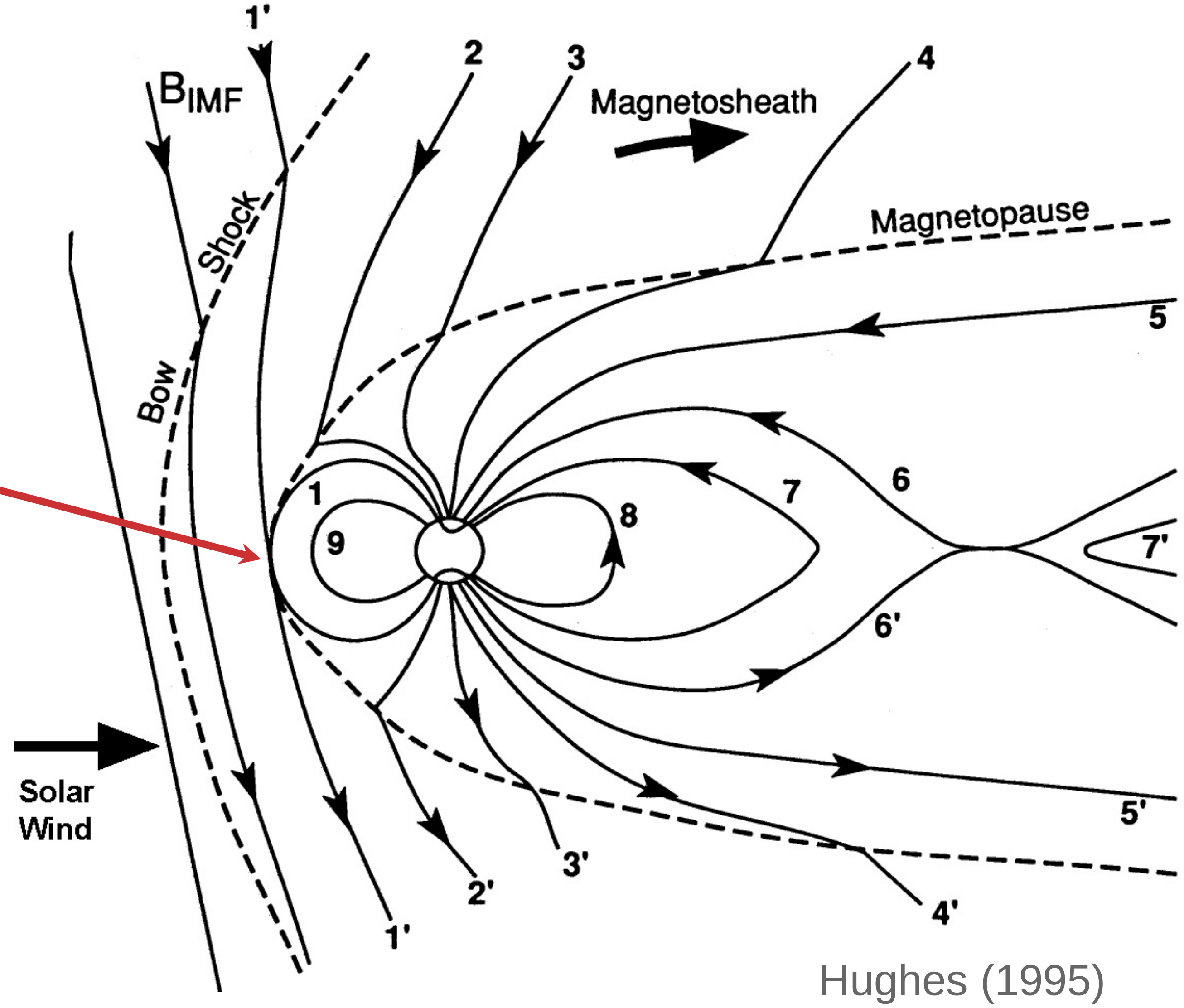


Kivelson (2006)

The solar wind interaction



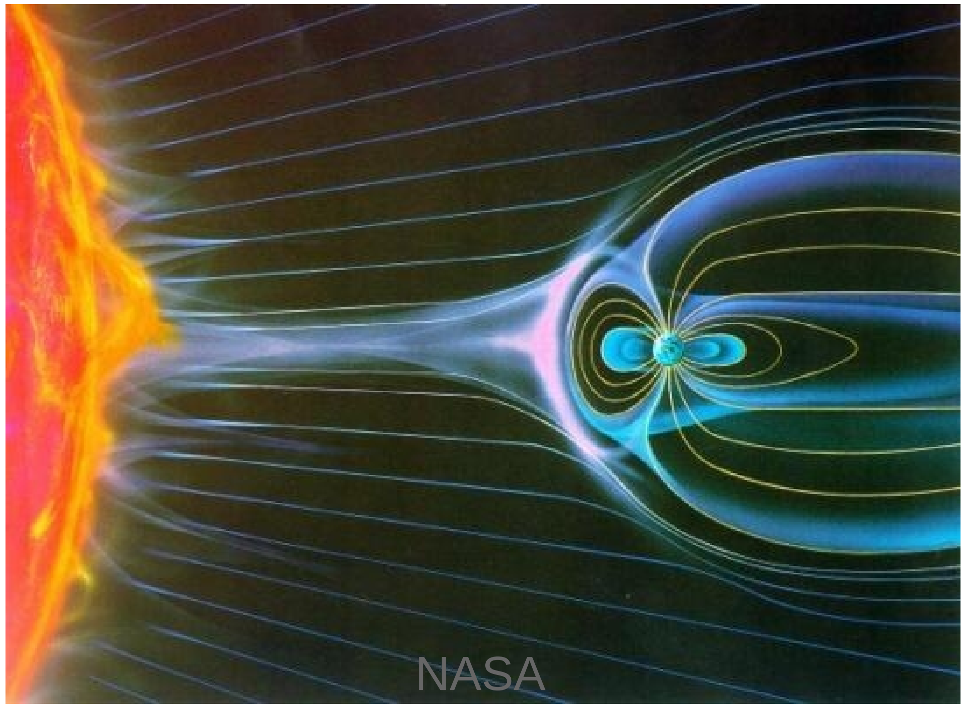
At the magnetopause the planet's magnetic field lines 'break' open and connect with the interplanetary field carried by the solar wind => 'open' field lines



Hughes (1995)

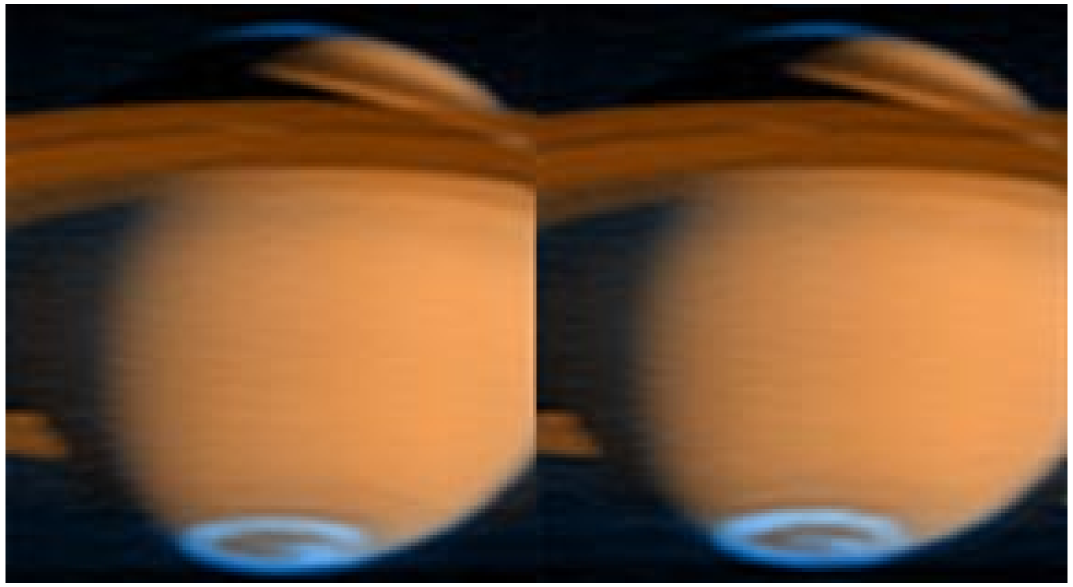
- The solar wind stirs the planetary plasma and magnetic field.

The solar wind interaction

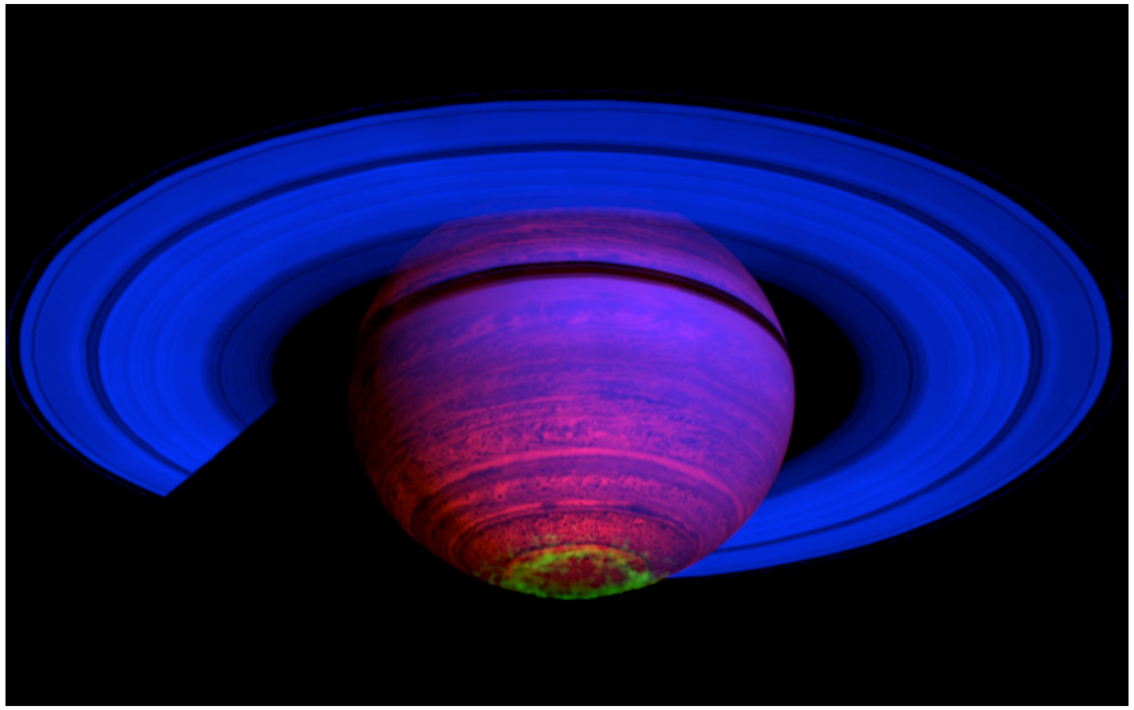


- The solar wind interaction allows particles and energy to be exchanged between the magnetosphere and surrounding space.
- If the solar wind conditions change (speed, pressure, field orientation) then the interaction with the magnetosphere will change.
- How can we see it?

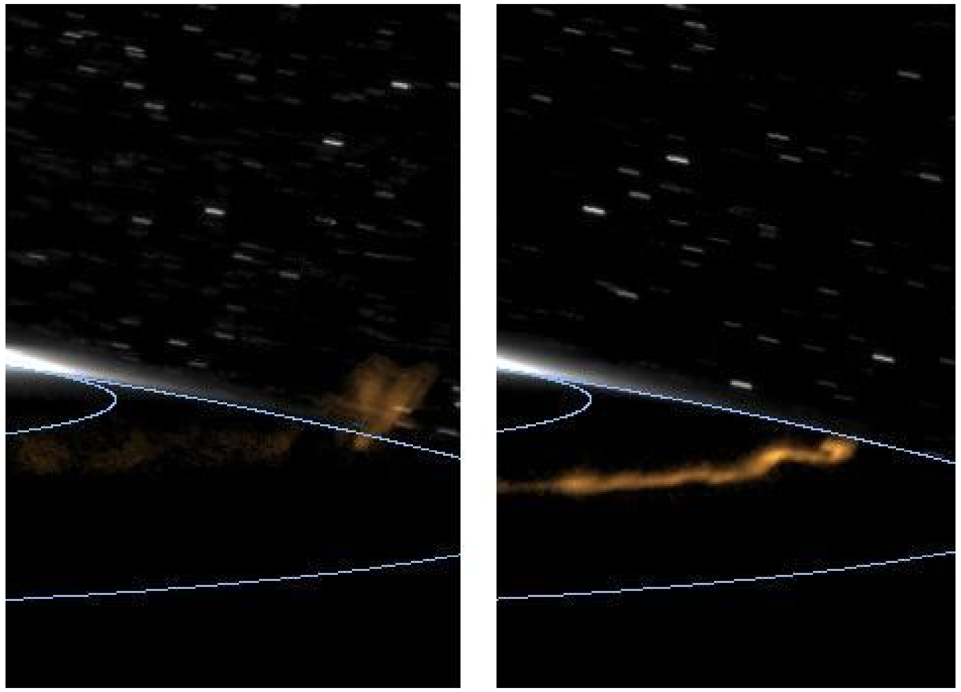
Saturn's aurora



- ←Saturn's ultraviolet aurora seen by Cassini/UVIS



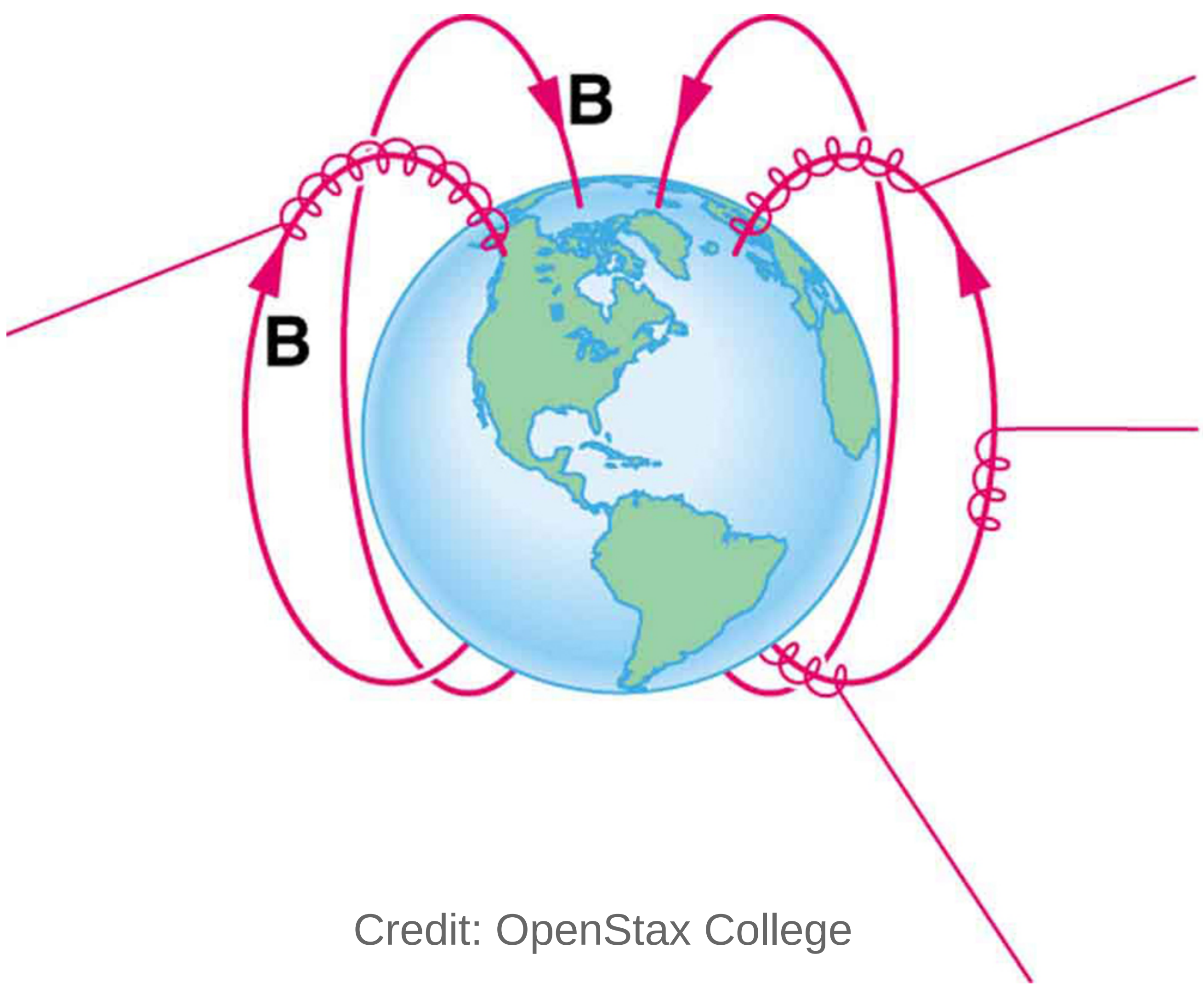
Saturn's infrared aurora seen by Cassini/VIMS→



←Saturn's visible aurora seen by Cassini/ISS

Saturn’s aurora

- The aurorae are generated when particles crash into the planet’s atmosphere and cause it to glow.
- The particles travel down magnetic field lines, so the aurorae show us the footprint of the magnetic field in the ionosphere.



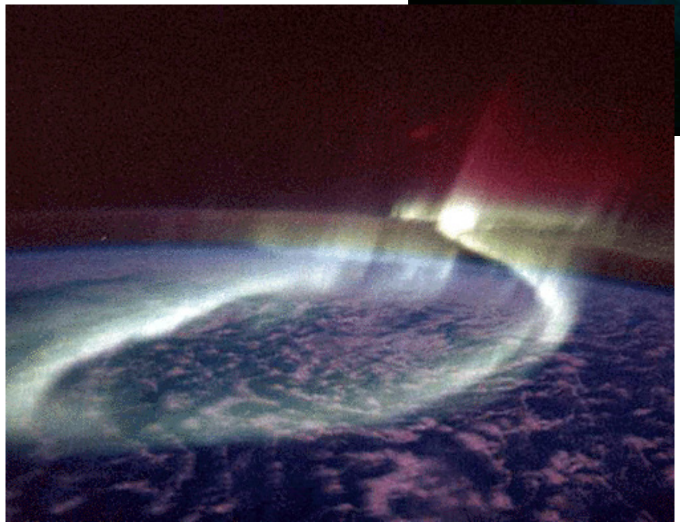
Credit: OpenStax College

What are the aurorae?

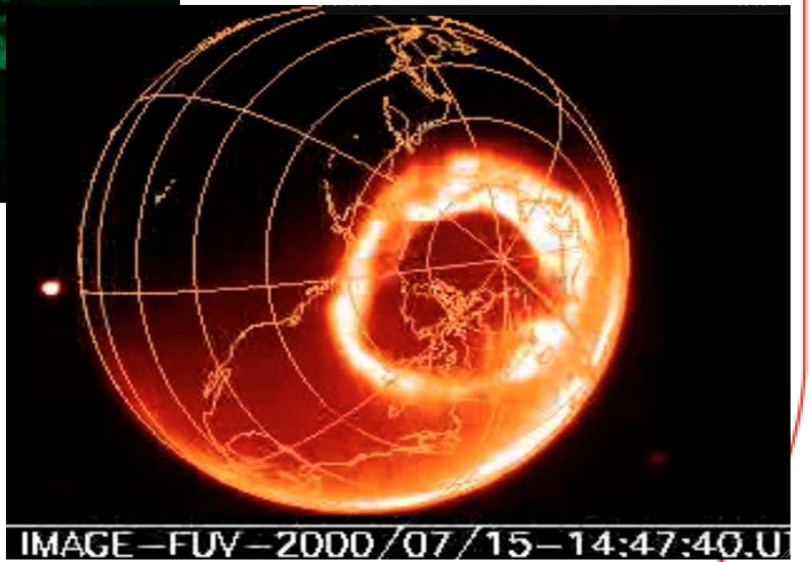
- Particles crash into a planet's atmosphere causing it to glow.
- Aurorae have been observed at the Earth, Jupiter, Saturn, Uranus, Neptune and Ganymede.
- They occur in the polar regions at the footprints of magnetic field lines and usually form an oval around the pole.

Aurora seen from the IMAGE satellite. N_2 / O / H. (NASA) ↓

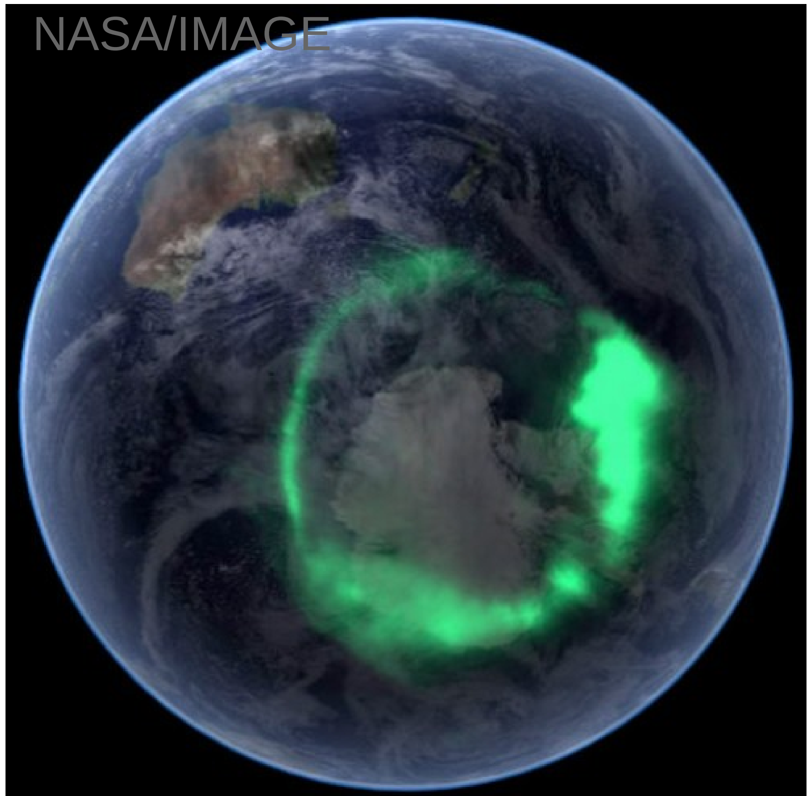
Aurora seen from the ISS (NASA)↓

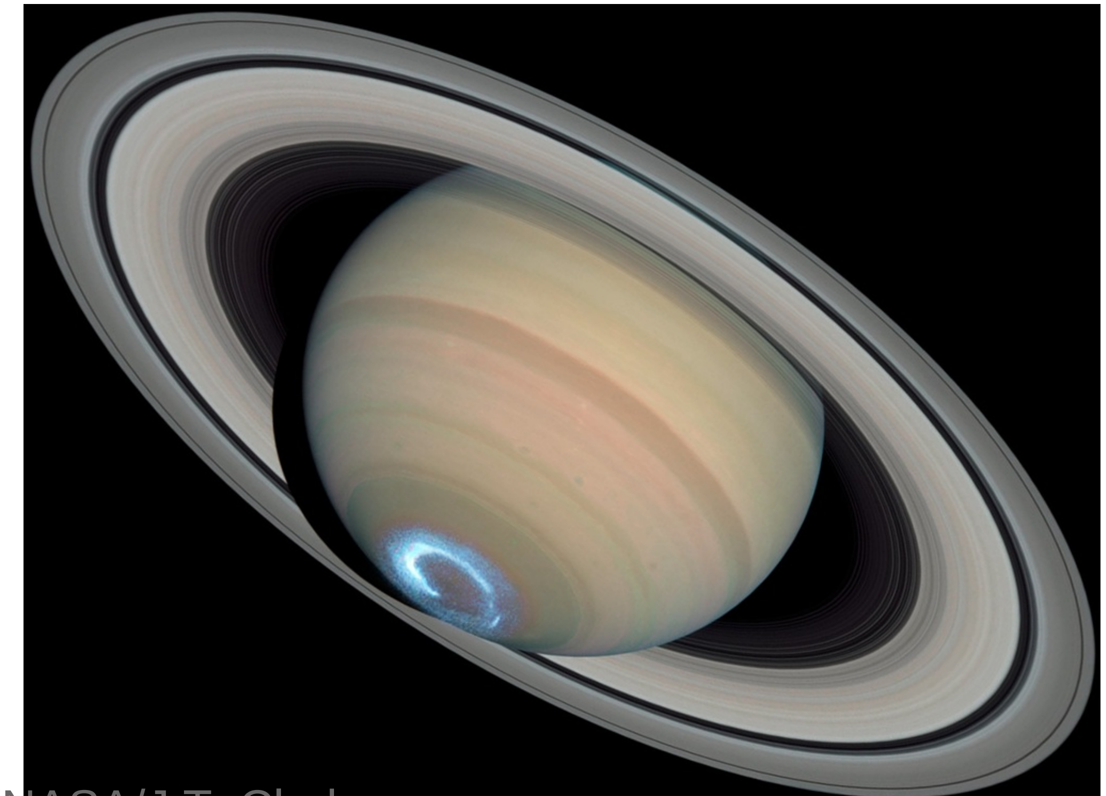


↑Aurora seen from the ground in Alaska. O 558 nm. (Credit: Bud Kuenzli)

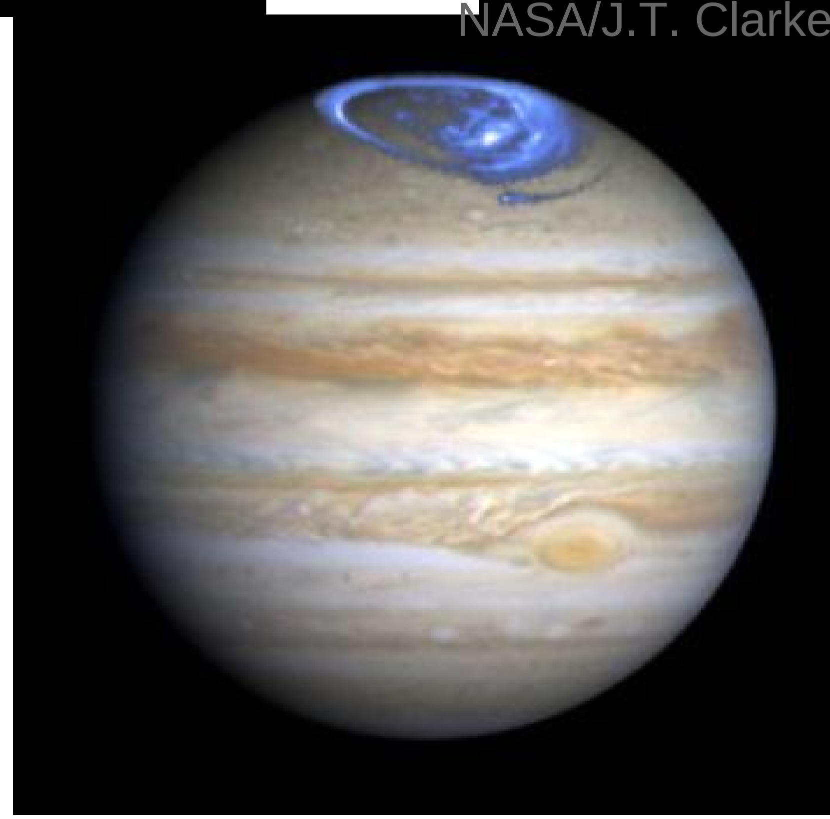


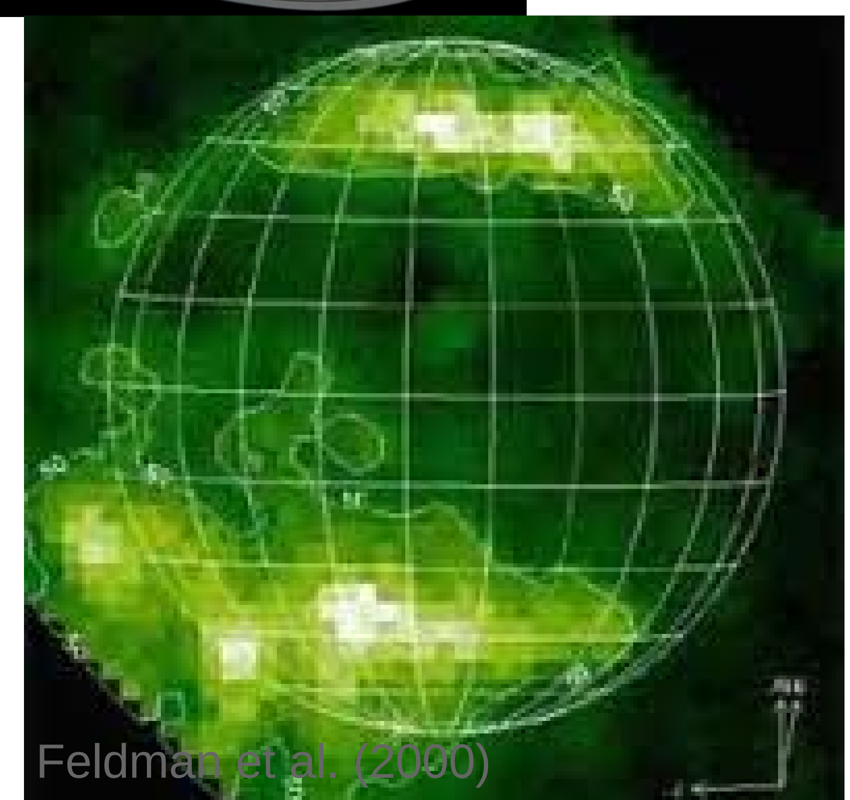
Aurorae through the solar system


NASA/IMAGE



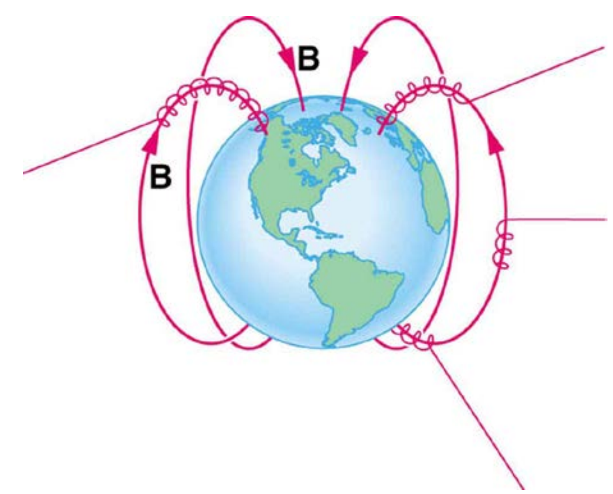
NASA/J.T. Clarke




Feldman et al. (2000)

Saturn's aurora

- The aurorae are generated when particles crash into the planet's atmosphere and cause it to glow.
- The particles travel down magnetic field lines, so the aurorae show us the footprint of the magnetic field in the ionosphere
- Saturn's aurora has different components:

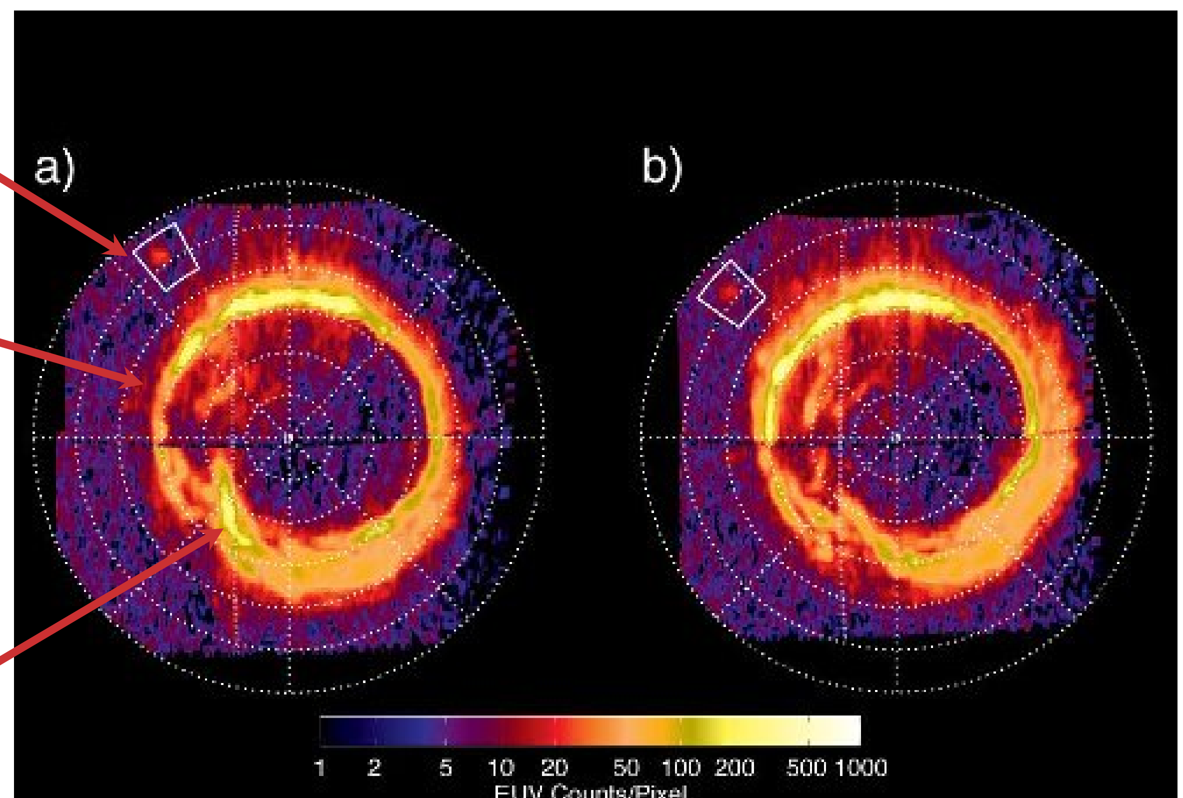


Enceladus spot

Main oval

To the Sun

Poleward arcs
or 'bifurcations'



Pryor et al. (2011)

←Two views from Cassini/UVIS looking down on the northern pole with the Sun to the left.

Saturn's aurora

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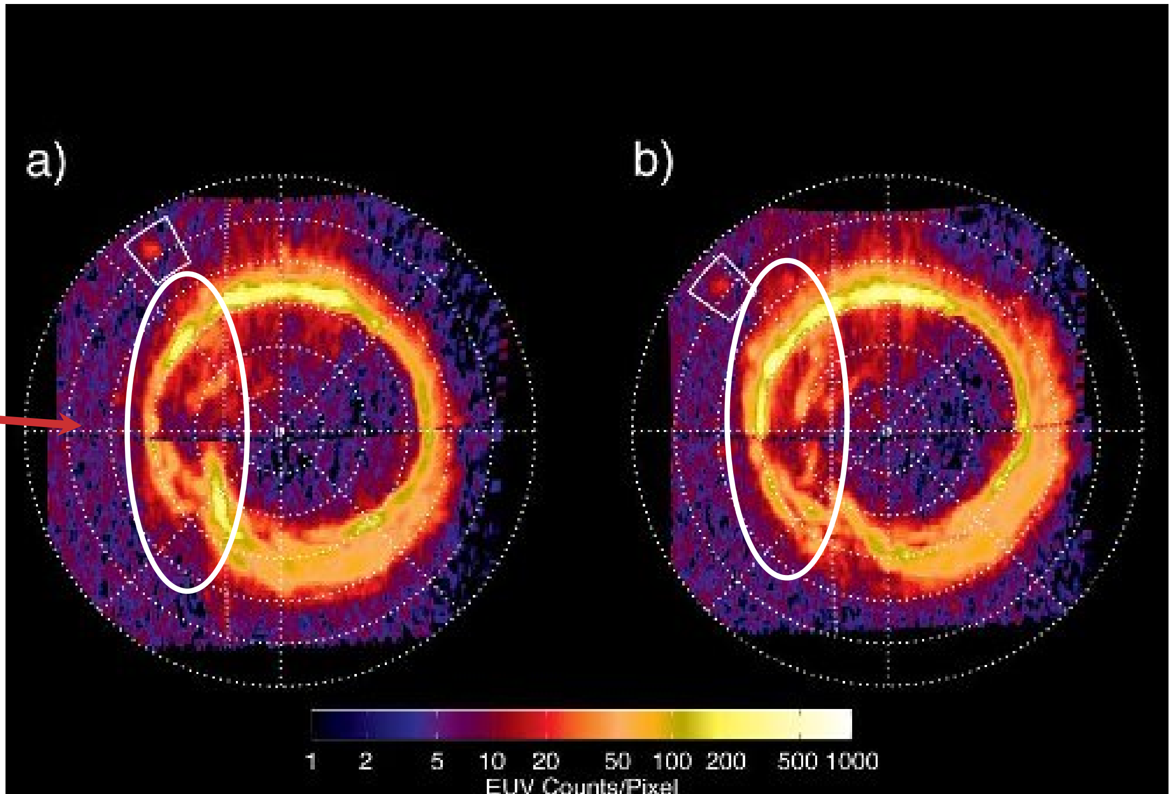
- Saturn's aurora has different components:

This 'dayside' region represents the field lines at the front of the magnetosphere, i.e. where the solar wind is impacting.



Pryor et al. (2011)

Two views from Cassini/UVIS looking down on the northern pole with the Sun to the left.

Saturn's aurora

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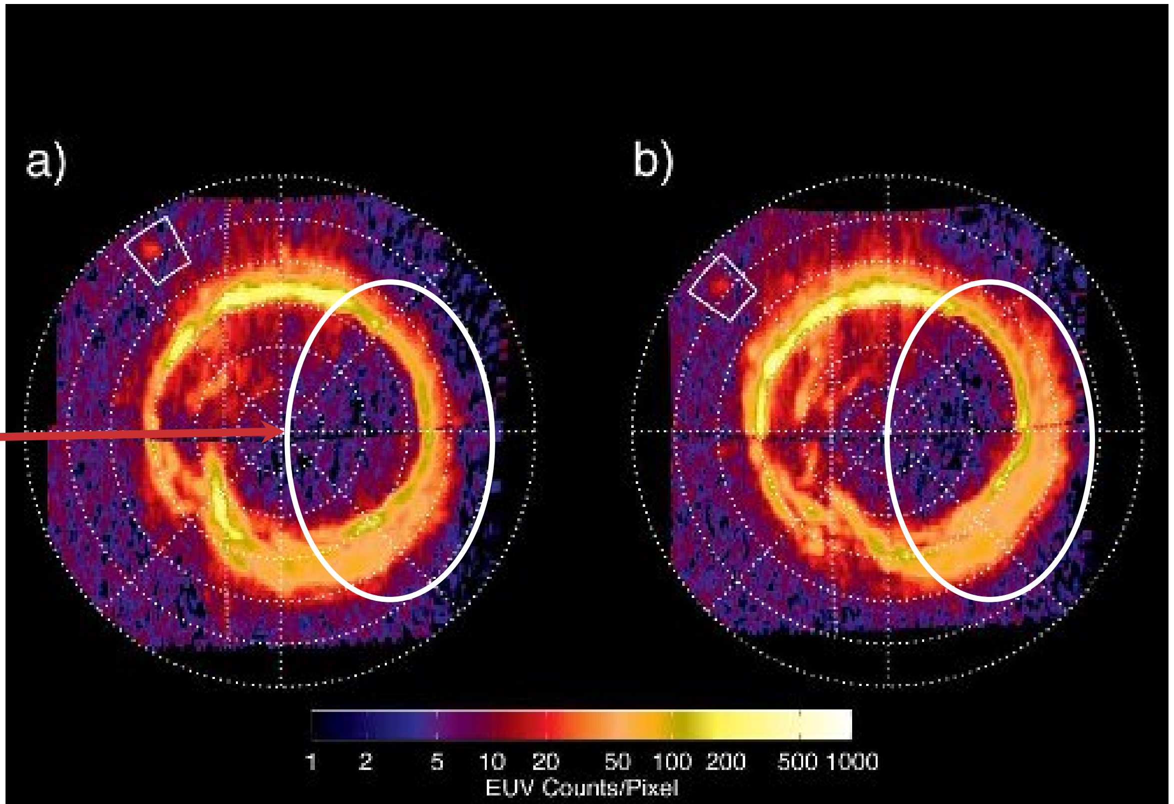
- Saturn's aurora has different components:

The nightside region represents the field lines in the magnetotail: where mass is released downtail and field lines start to move back towards the planet.



Pryor et al. (2011)

Two views from Cassini/UVIS looking down on the northern pole with the Sun to the left.

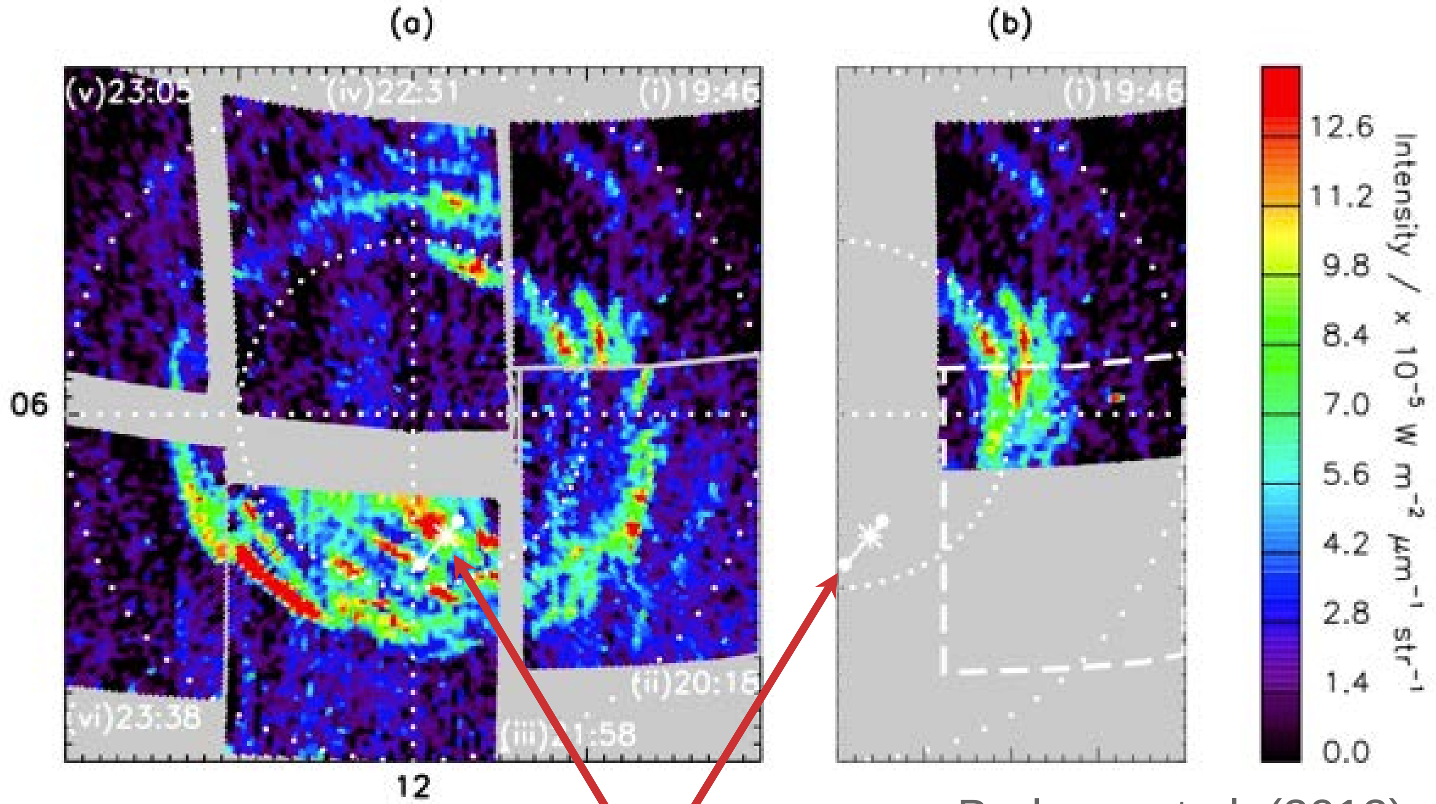
Unique science opportunities

- Cassini's suite of instruments include those which measure the local environment (e.g. particle detectors and magnetometer) as well as those which remote sense the more distant environment (e.g. imagers).

- This means that Cassini can tell us what's happening locally and, simultaneously, how that fits in with what's happening globally.
- A great example of this is auroral imaging with simultaneous in situ fields and particles measurements.
- Cassini's long orbital tour also allows us to study long-term trends in the aurora and its response to solar wind activity.

1: Aurora and energetic particles

15 Nov 2008



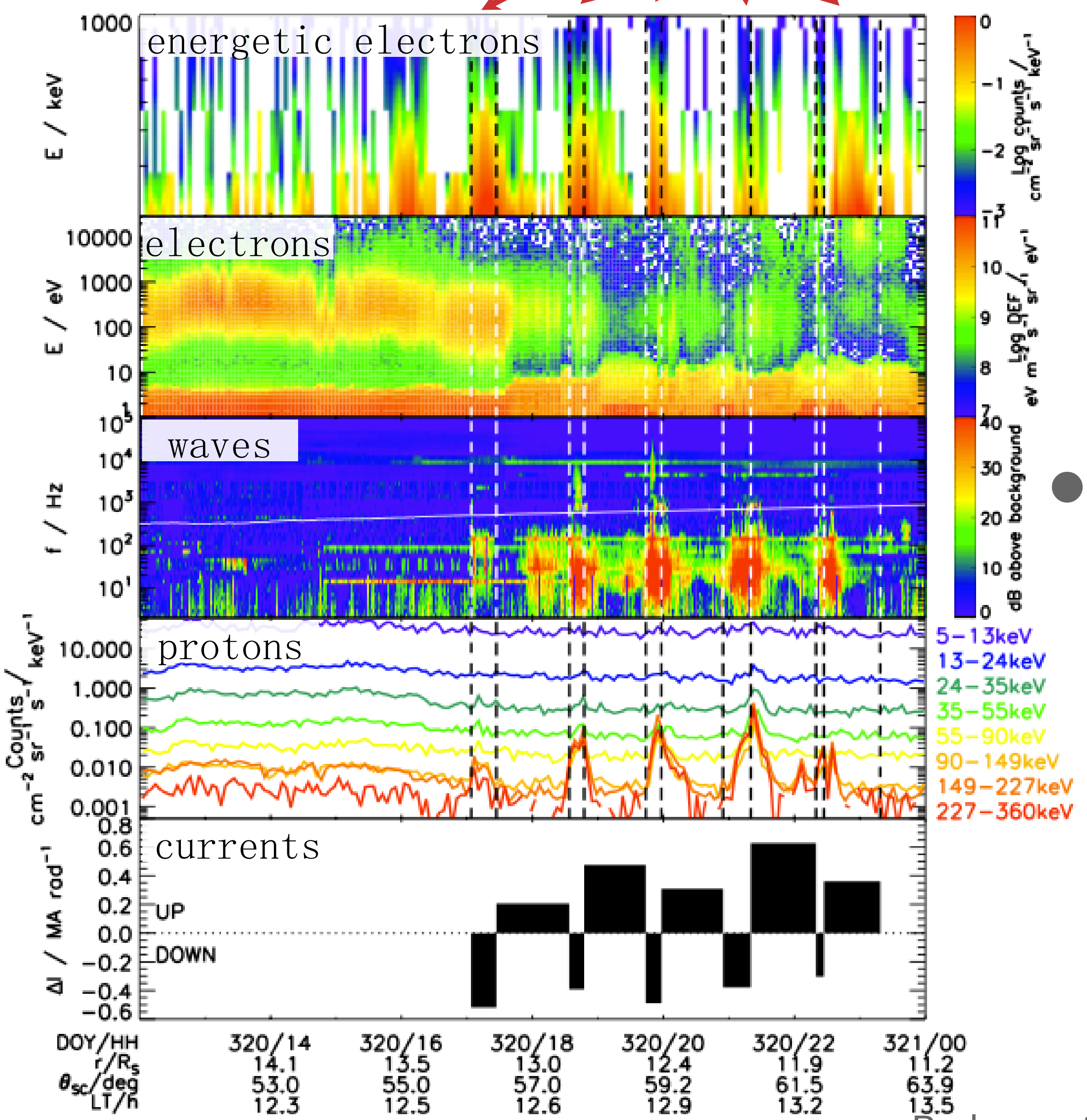
Badman et al. (2012)

Cassini's footprint in the ionosphere

- Cassini/VIMS took a mosaic of the northern infrared aurora.
- At the same time it was travelling across magnetic field lines mapping down to the bright arcs observed.

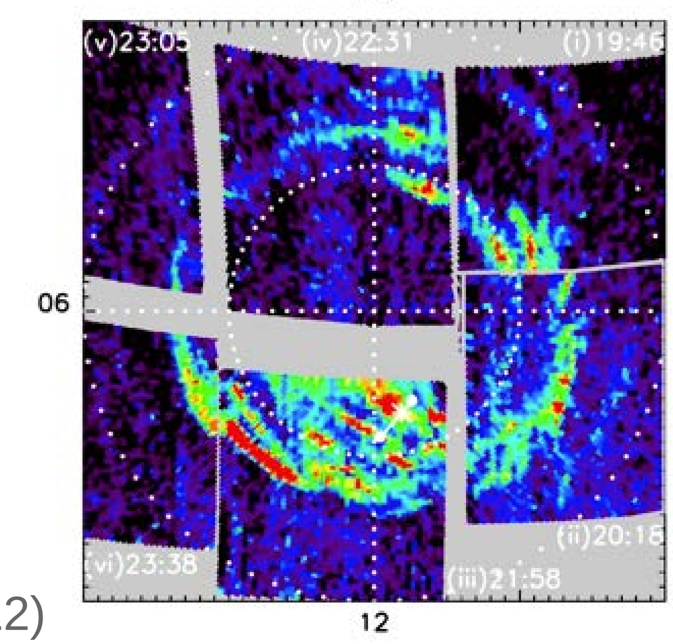
1: Aurora and energetic particles

15 Nov 2008 Bursts!



- While the auroral arcs are related to electrons travelling down into the atmosphere, here we see bursts of energetic particles travelling up away from the atmosphere.
- Related to the dark regions between the auroral arcs?

(a)

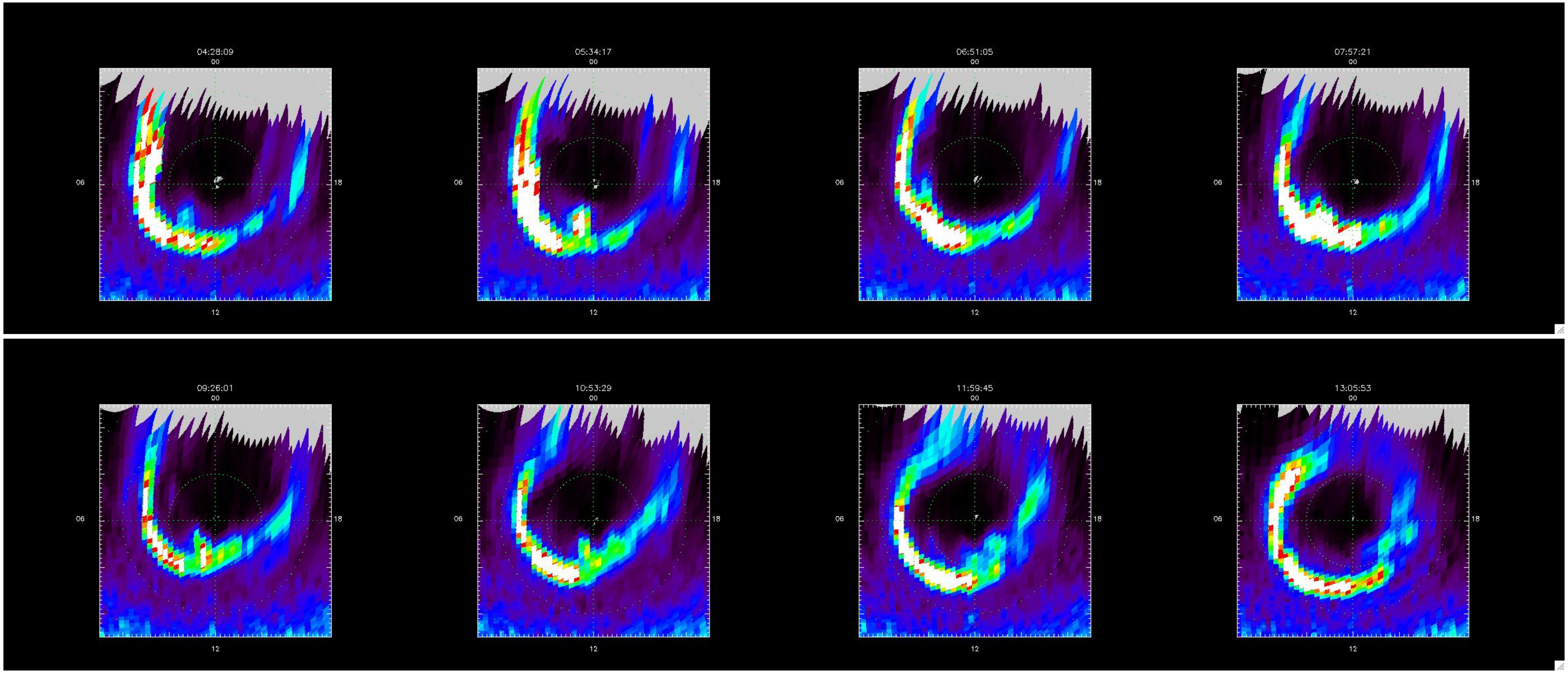


Badman et al. (2012)

2: Time-development of the aurora

19 July 2008

03:00 - 13:00 UT

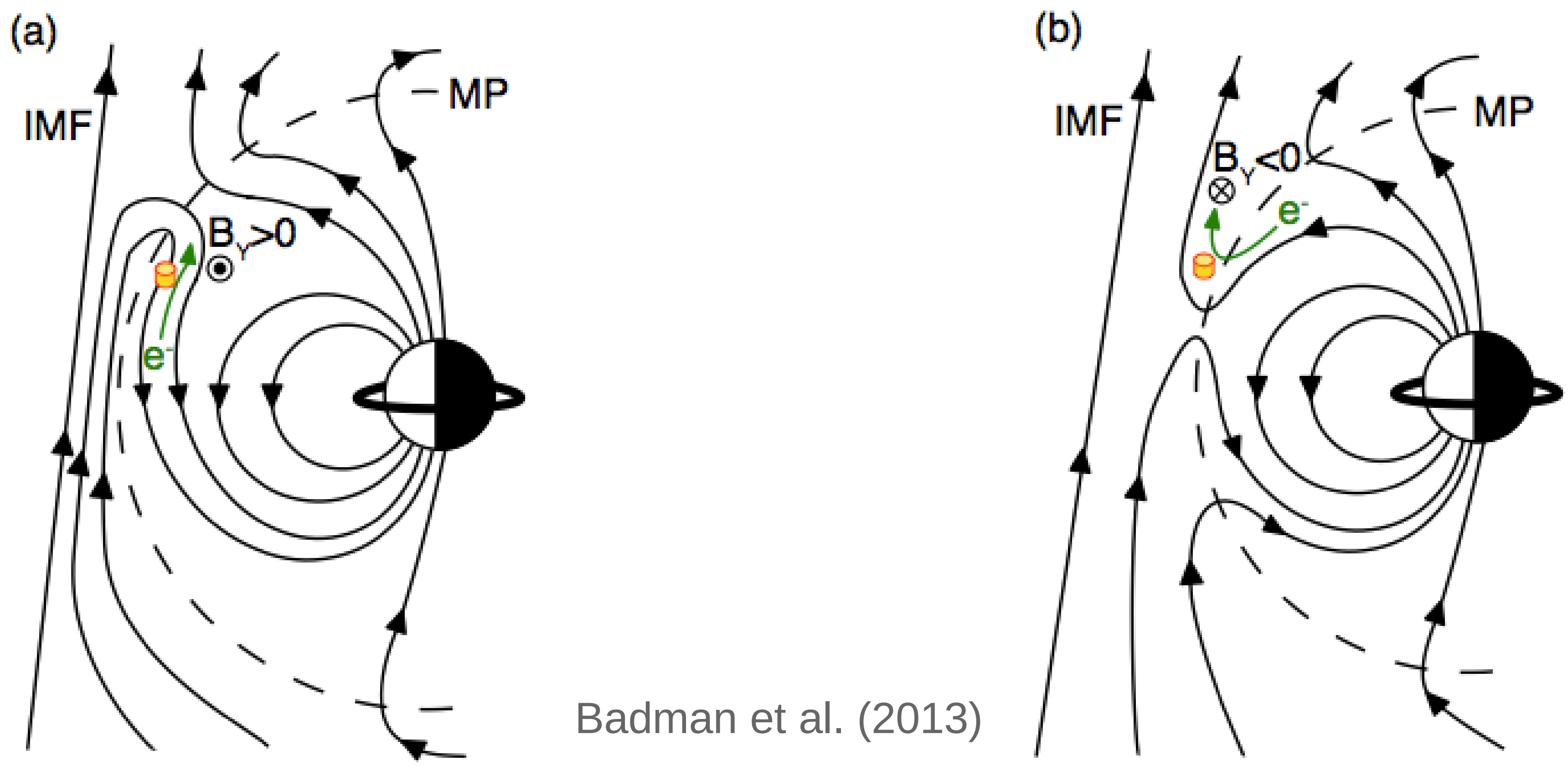


Badman et al. (2013)

- Sequence of UVIS observations of the northern aurora.

2: Time-development of the aurora

19 July 2008



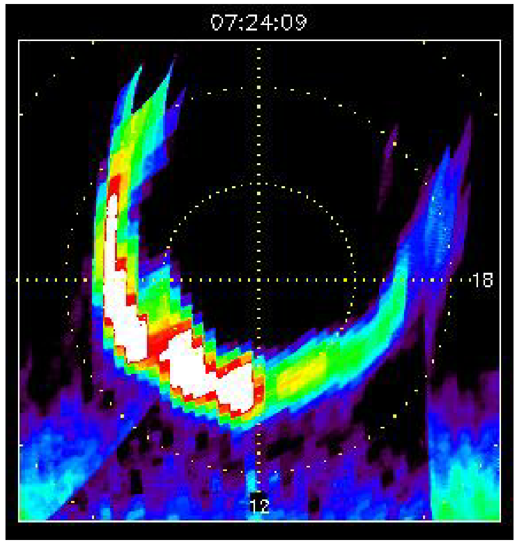
Badman et al. (2013)

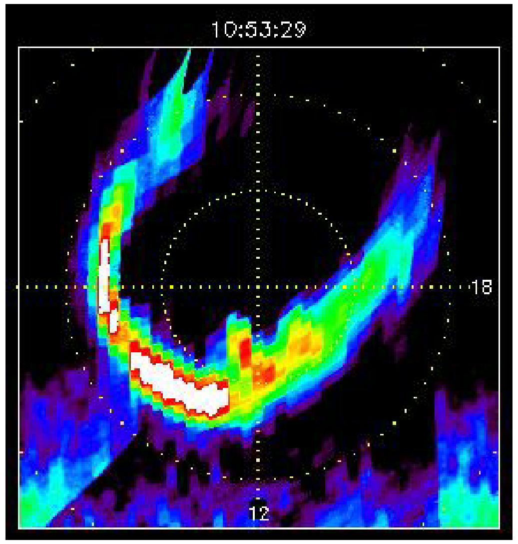
- 07 UT: Cassini was inside the magnetopause (MP) and detected electrons escaping from Saturn's magnetosphere.
- 10 UT: Cassini was now outside the magnetopause (MP) and again detected electrons escaping from Saturn's magnetosphere.
- This suggests the field lines were 'open' to the solar wind.

2: Time-development of the aurora

19 July 2008

- What auroral features were seen at the footprint of the magnetic field lines?

(a) 

(b) 

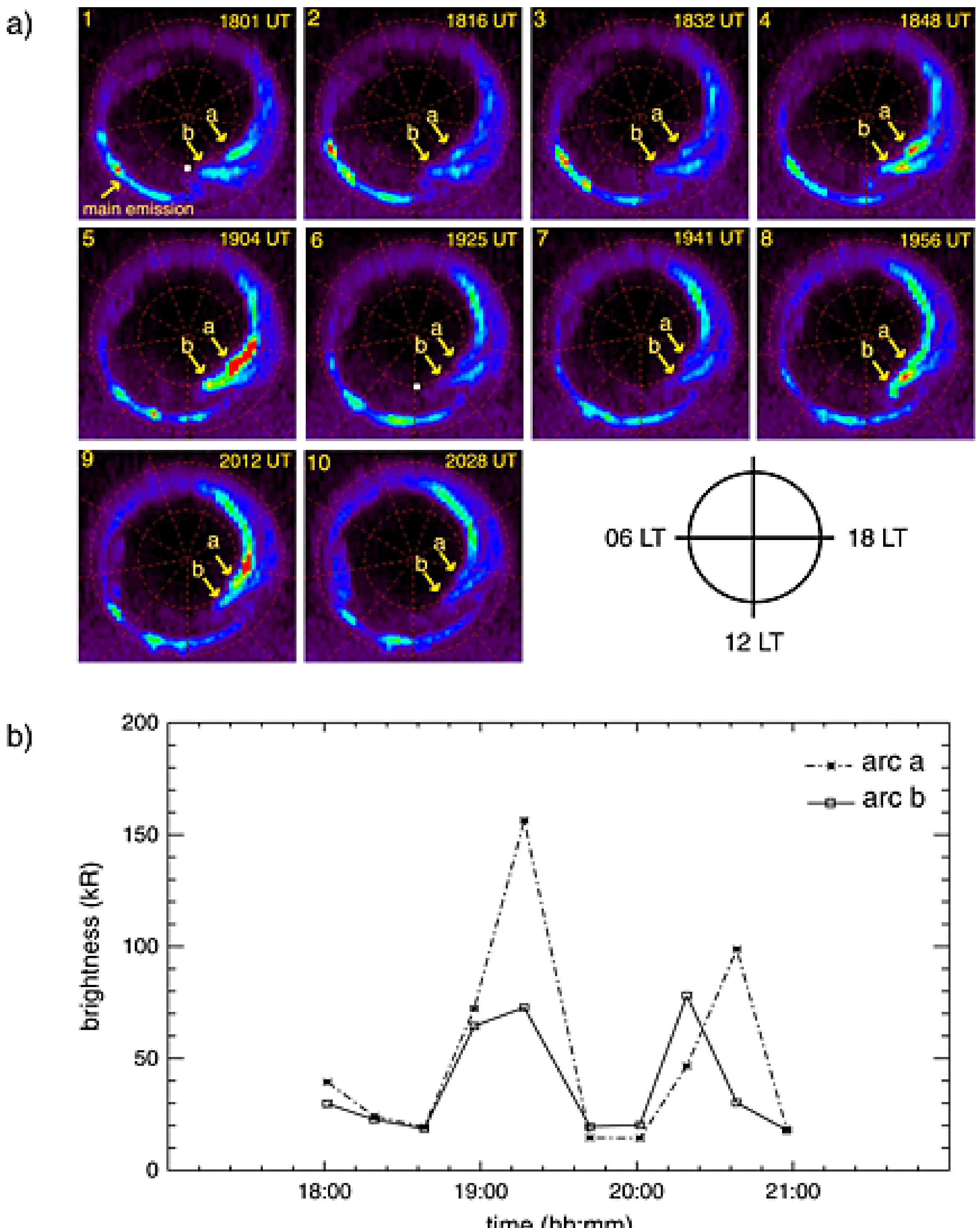
Badman et al. (2013)

- Intensification of the dayside auroral arc: signature of coupling between the solar wind and the magnetosphere.
- Bifurcated arcs move poleward: signature of bursts of field line reconnection and their subsequent poleward motion.

- The solar wind interaction changes with time.

3: Flashing of auroral arcs

21 Jan 2009



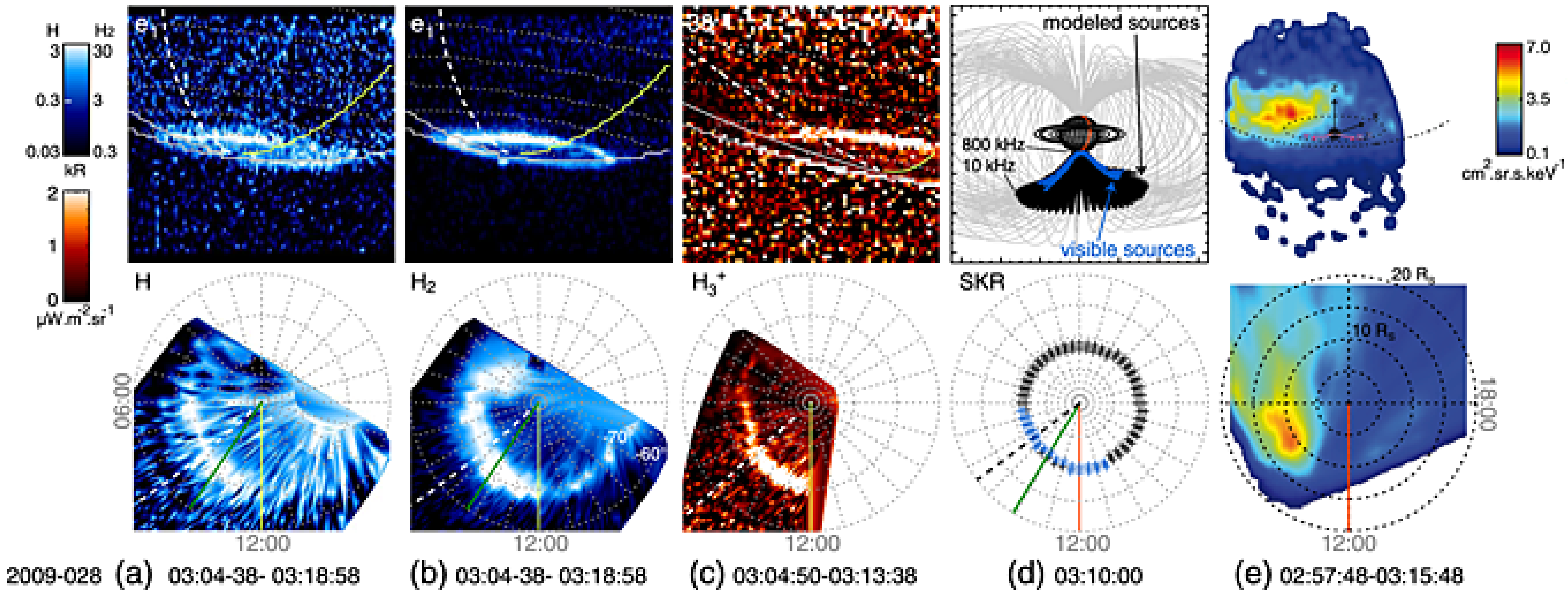
Radioti et al. (2013)

- These UVIS images show some dayside auroral arcs.
- Arcs a and b brighten and then dim twice while Cassini was watching.
- This is related to repeated ‘breaking’ of the planetary field lines, producing a flash each time.
- The solar wind keeps interacting with the same field lines.

4: Aurora across the spectrum

28 Jan 2009

Lamy et al. (2013)



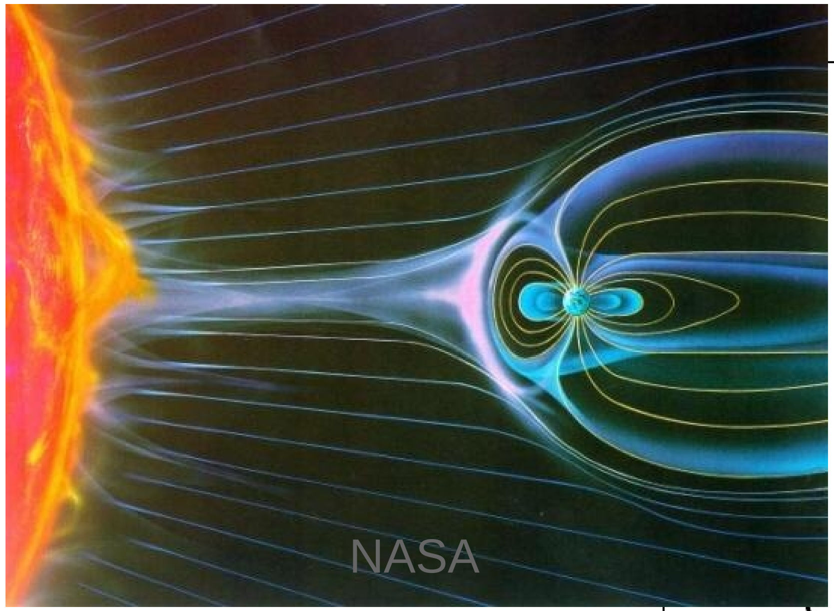
- All Cassini's remote sensing instruments were observing together and saw blobs rotating around:

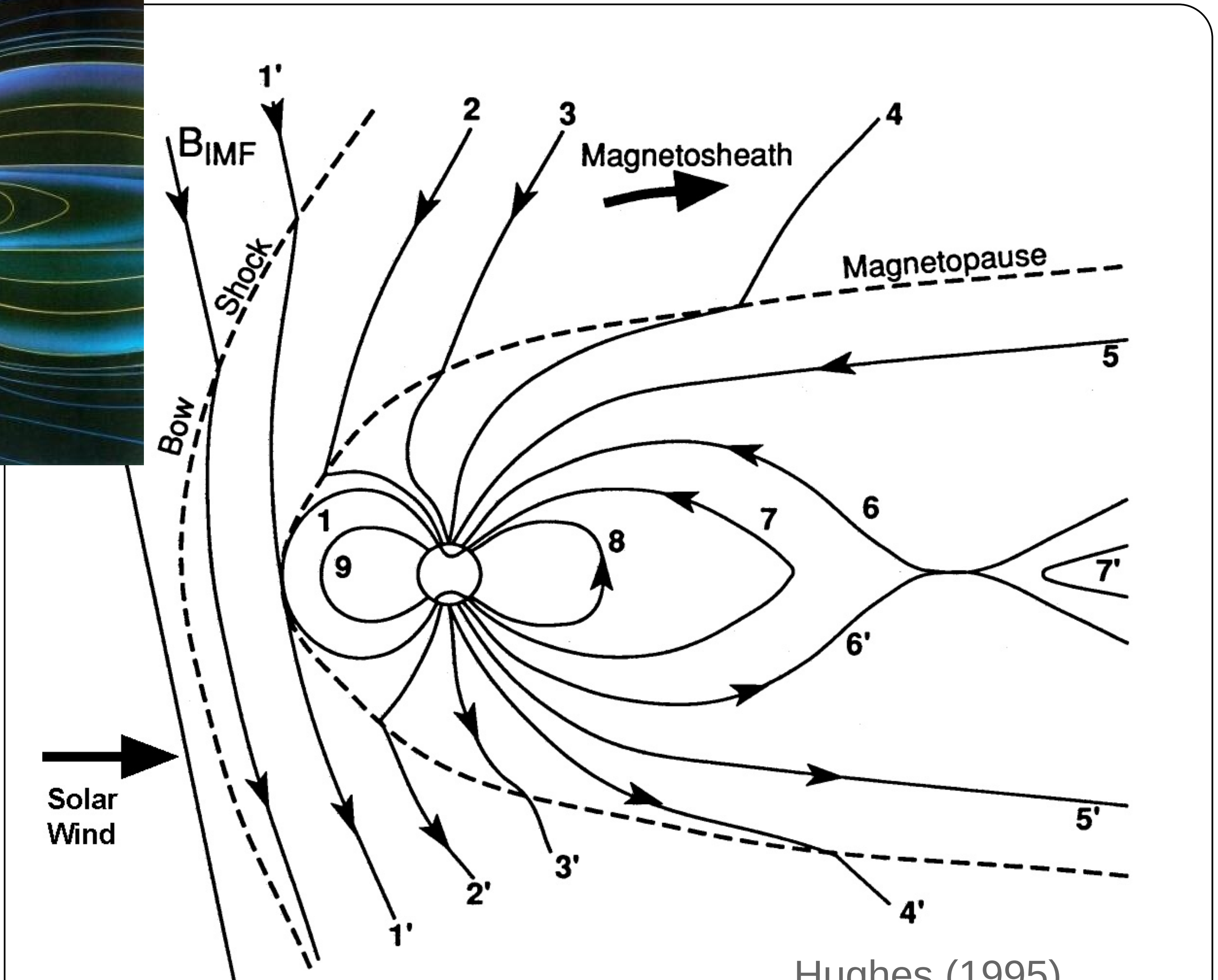
(a) (b) (c) Auroral arcs at infrared and ultraviolet wavelengths.

(d) Radio emission coming from the same place.

(e) Energetic plasma moving through the corresponding region of the magnetosphere.

The role of the Sun

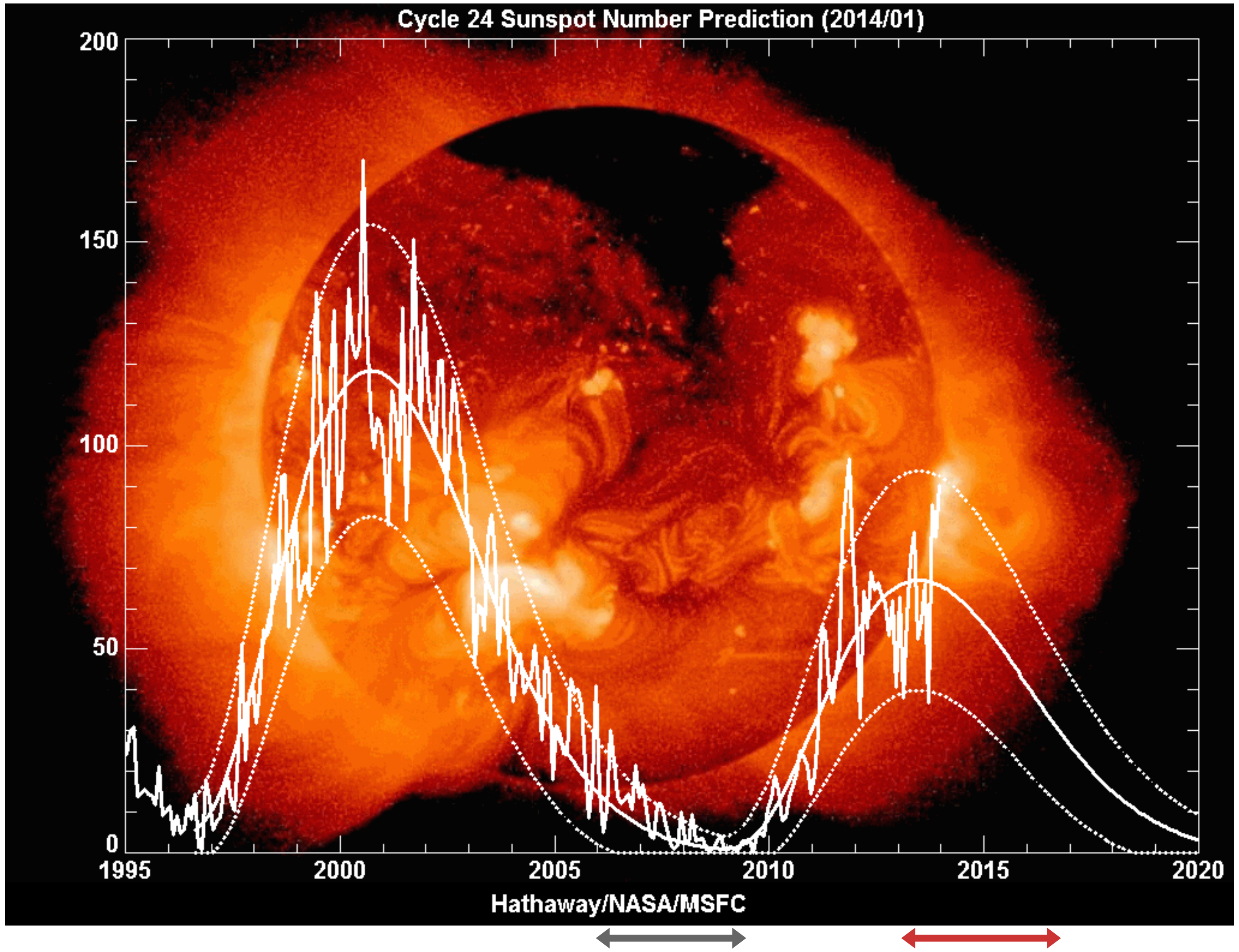




Hughes (1995)

- All these observations show the influence of the Sun on Saturn’s magnetosphere and atmosphere.
- What happens if the Sun’s activity increases?

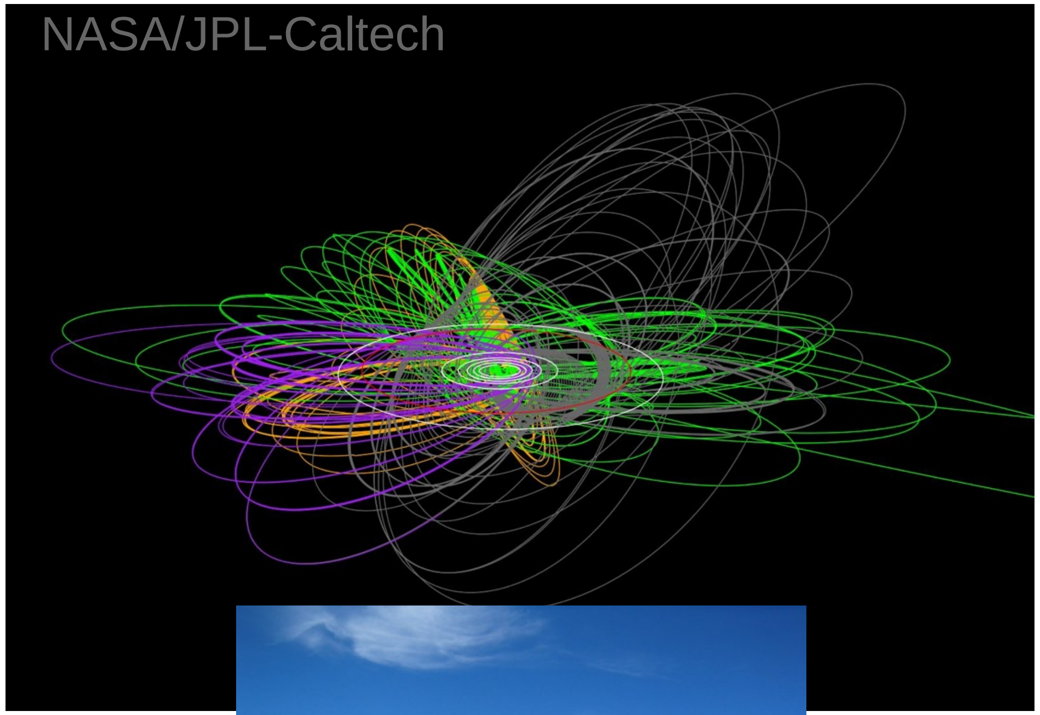
Has the solar activity changed?

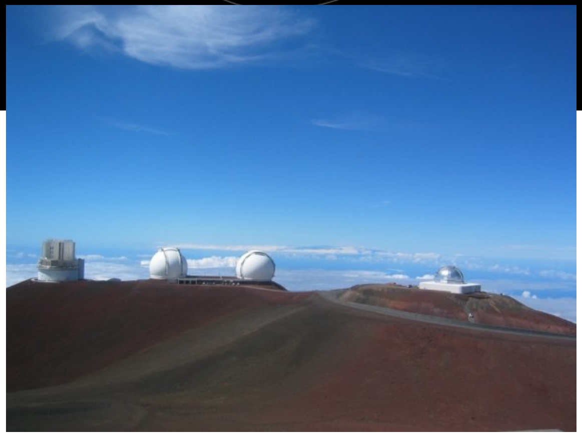


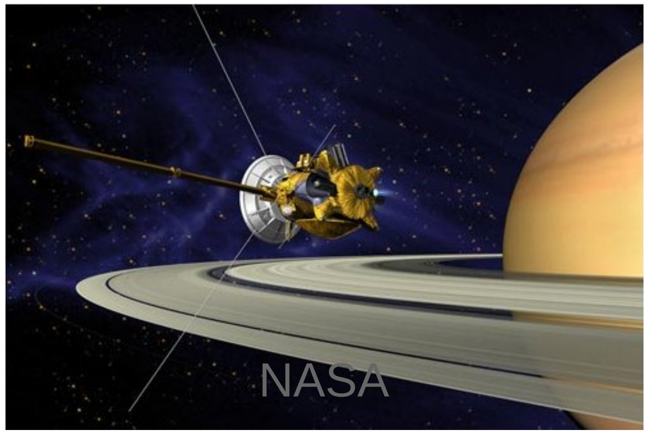
- The observations just shown occurred when solar activity was a minimum in its 11 year cycle, as indicated in this plot of sunspot number.
- Now we are at solar maximum and the Sun is much more active (although still quiet compared to 11 years ago).

So what's next?

- In early 2013, Cassini again moved into an inclined orbit.
- This allows the best view of the aurora since before equinox in 2009.







- In spring 2013 there was a large auroral campaign: monitoring Saturn's aurora using Cassini, the Hubble Space Telescope, and ground-based infrared telescopes e.g. NASA IRTF.

Aims of the auroral campaign

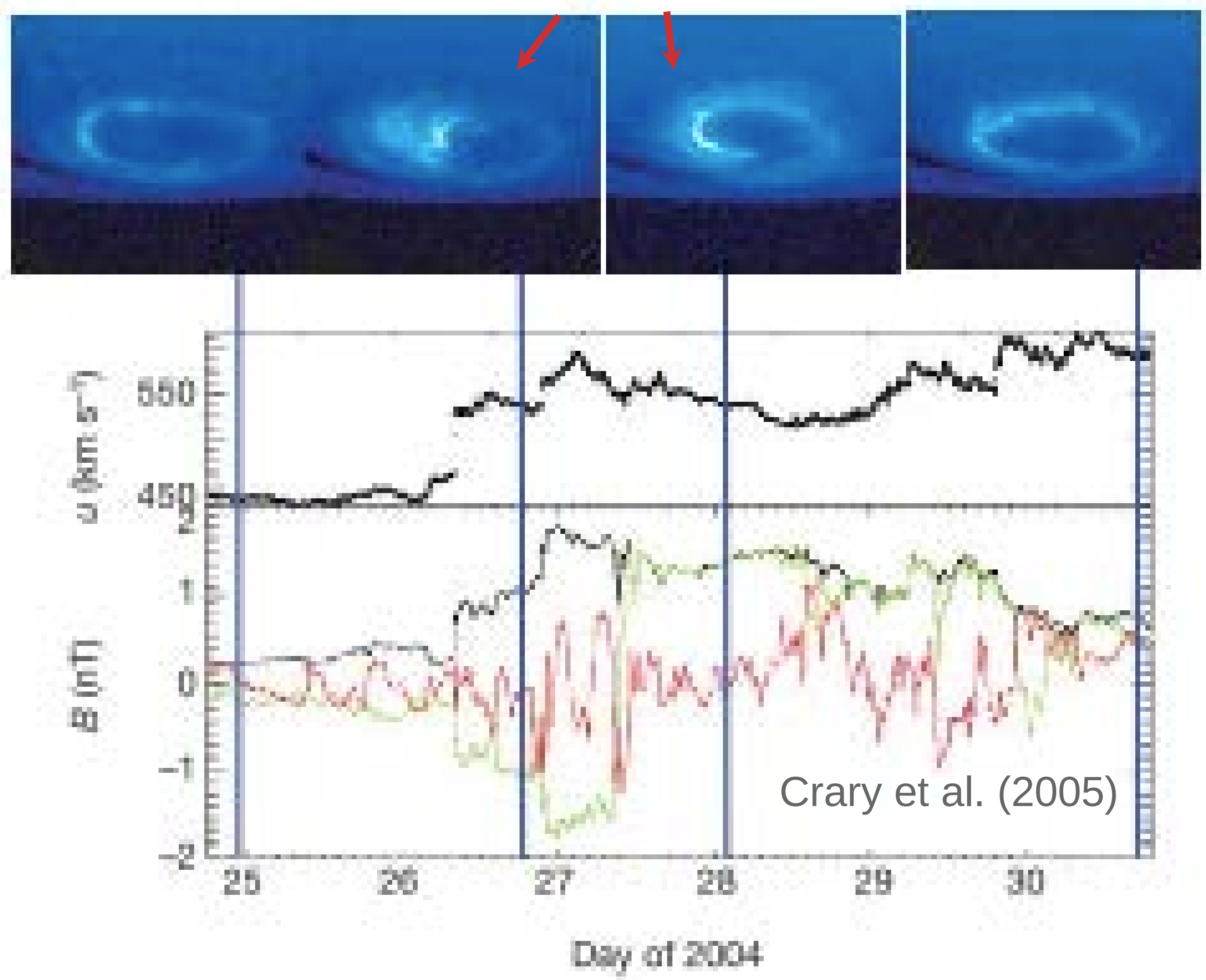
- Discover how the solar wind drives Saturn's magnetosphere and aurora when the solar activity is high.

Storm!

Saturn's southern aurora→

Solar wind speed→

Interplanetary magnetic field strength (carried in the solar wind)→



- Auroral 'storms' have been observed when high pressure regions of the solar wind crash into Saturn.

Aims of the auroral campaign

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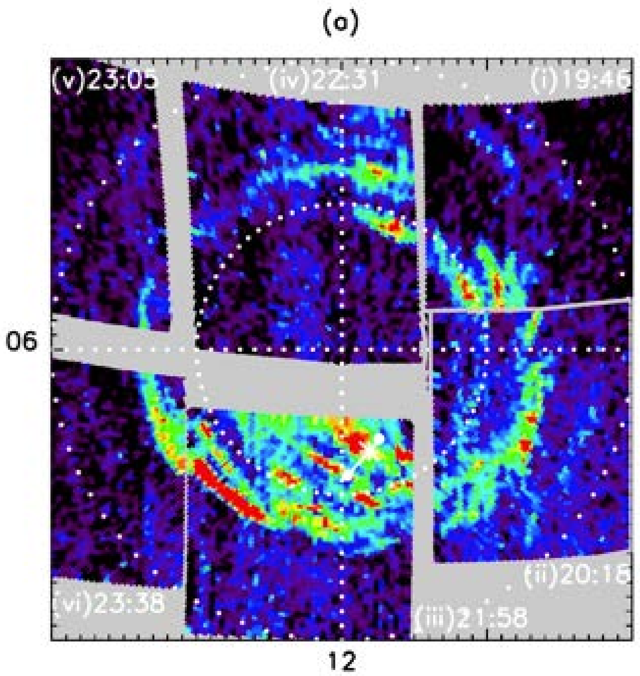
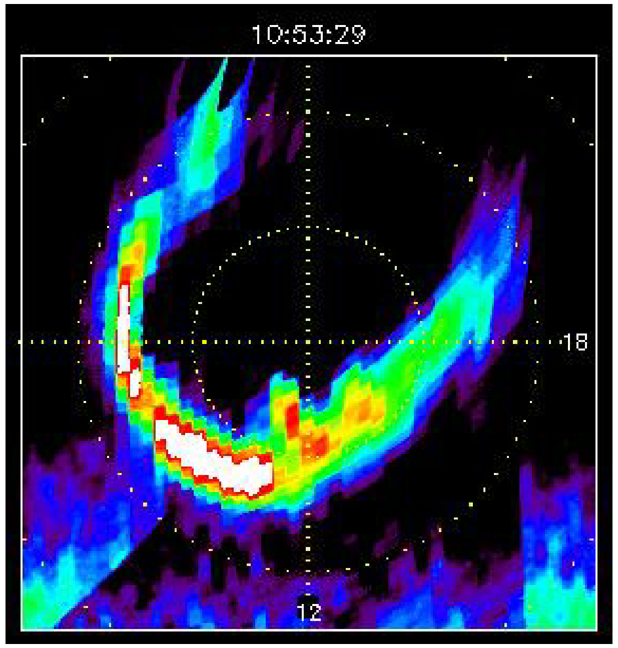
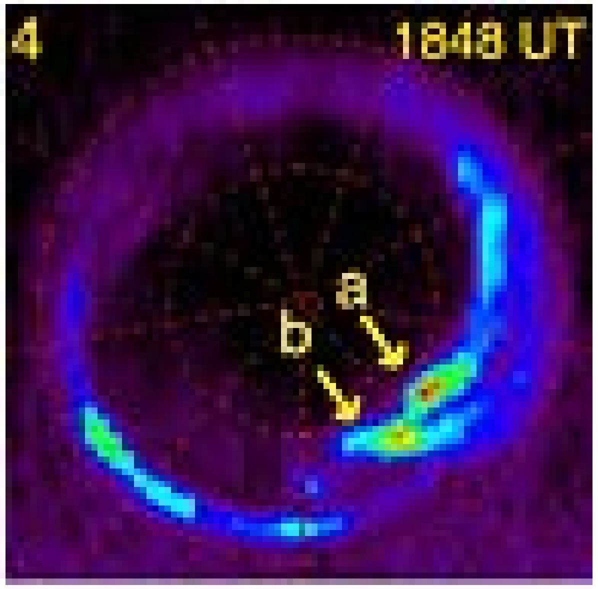


Badman et al. (2012)



Badman et al. (2013)

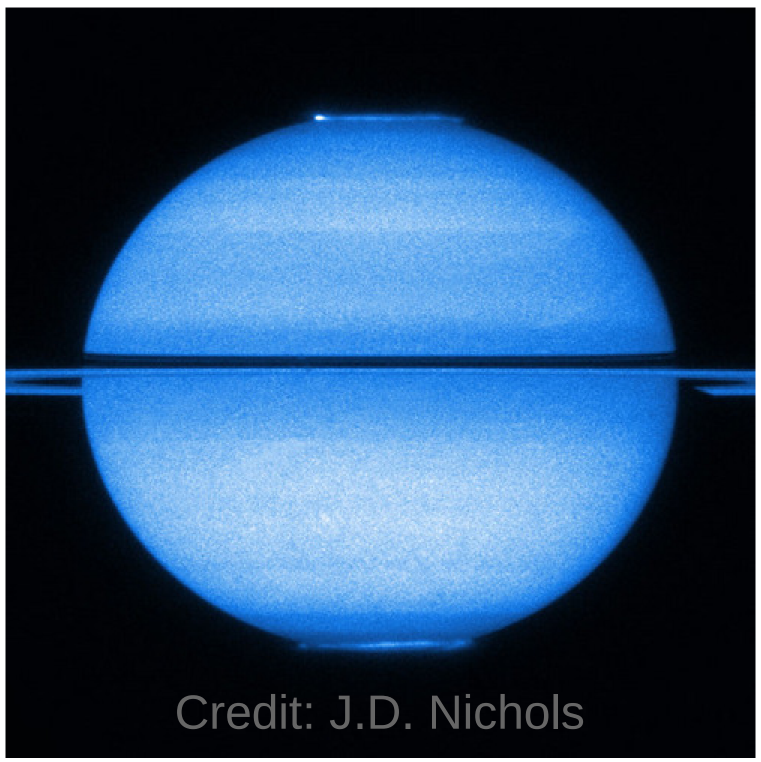


Radioti et al. (2013)

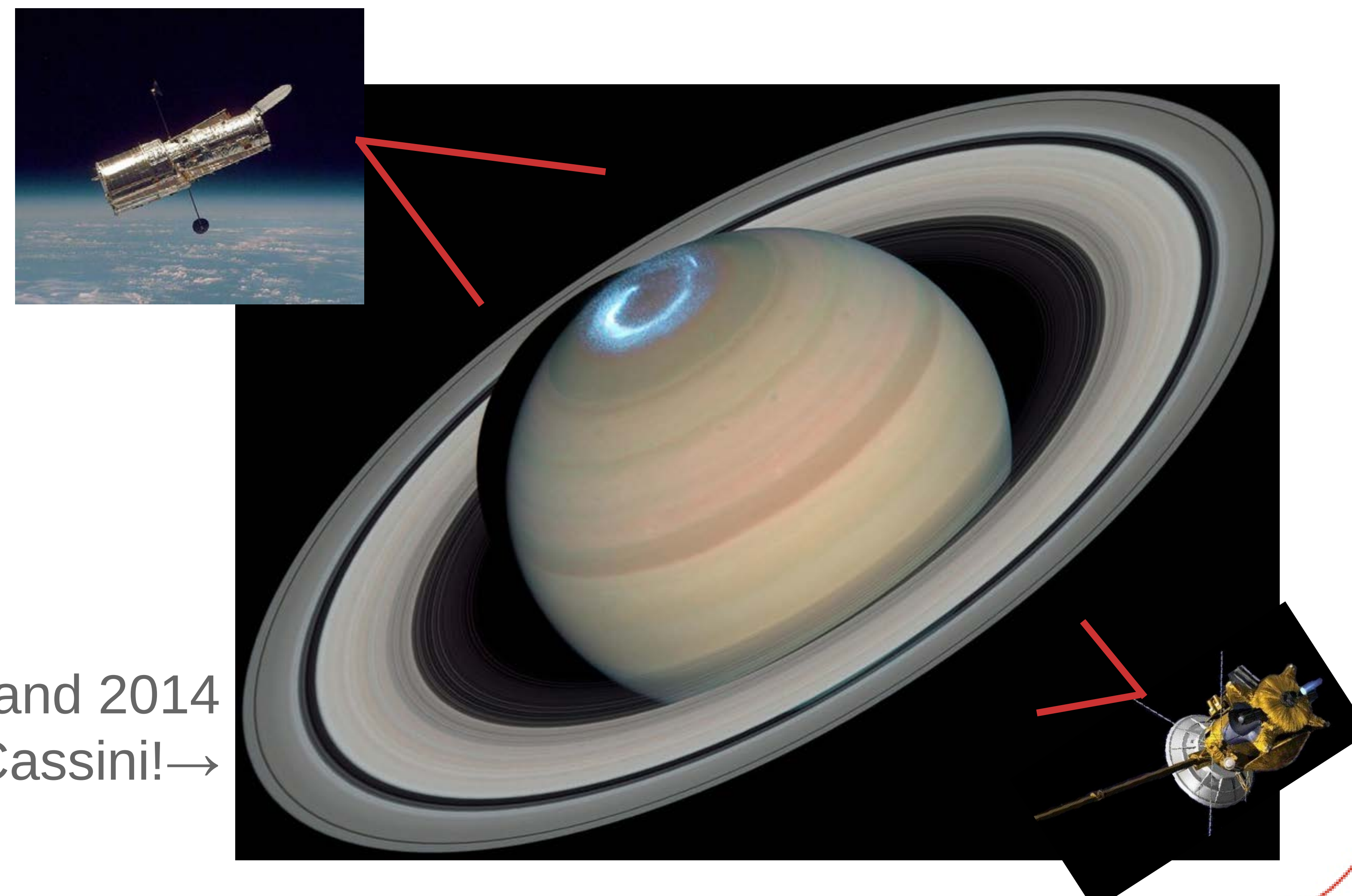
- What signatures of the solar wind interaction will we see in the dayside aurora? Bigger, brighter, more often, or something different?

Aims of the auroral campaign

- Compare the northern and southern aurora using the Hubble Space Telescope looking at the north, and Cassini looking at the south.



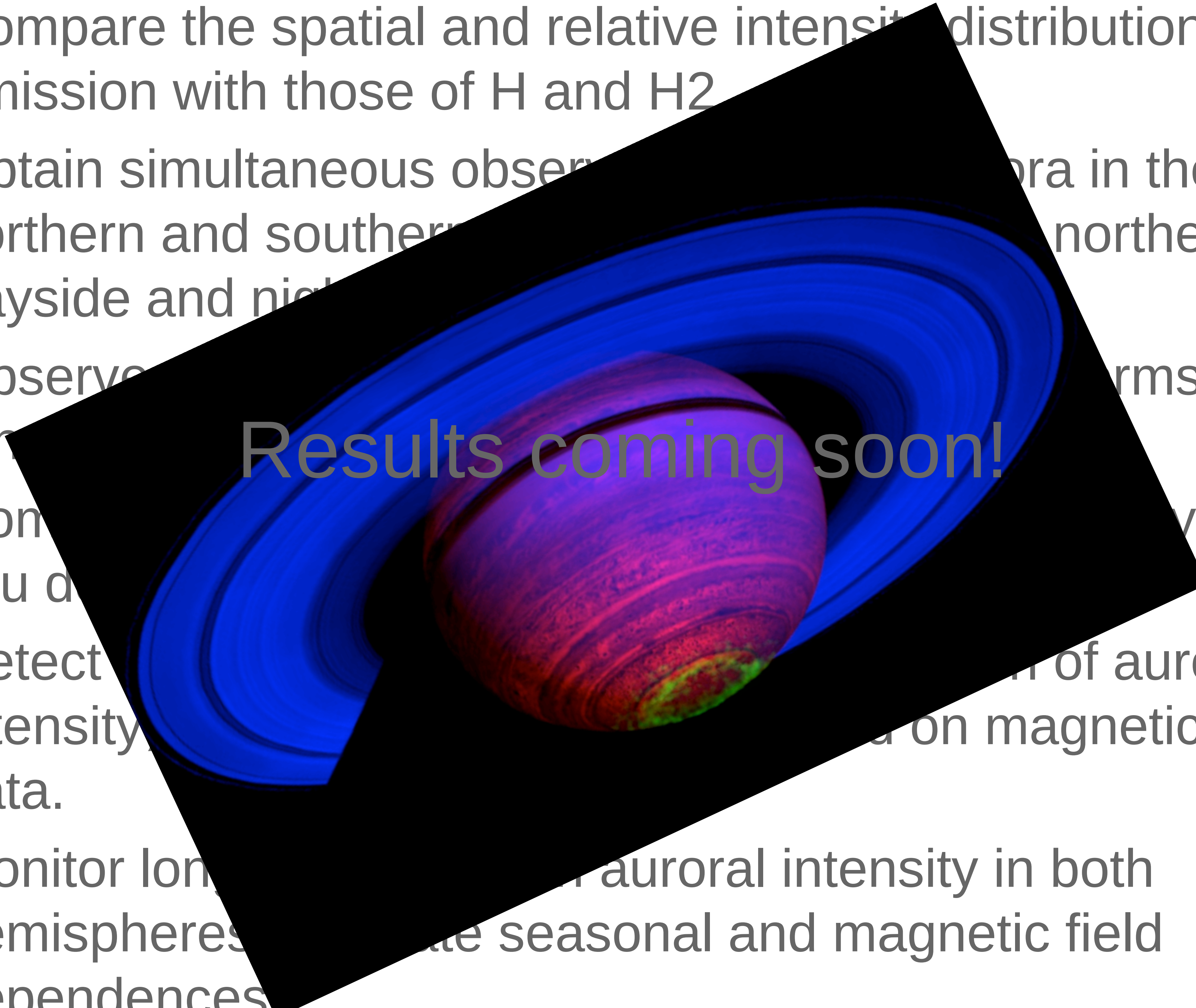
←The best simultaneous view of both hemispheres we’ve had so far, taken by Hubble in 2009.



The view in 2013 and 2014 using Hubble and Cassini!→

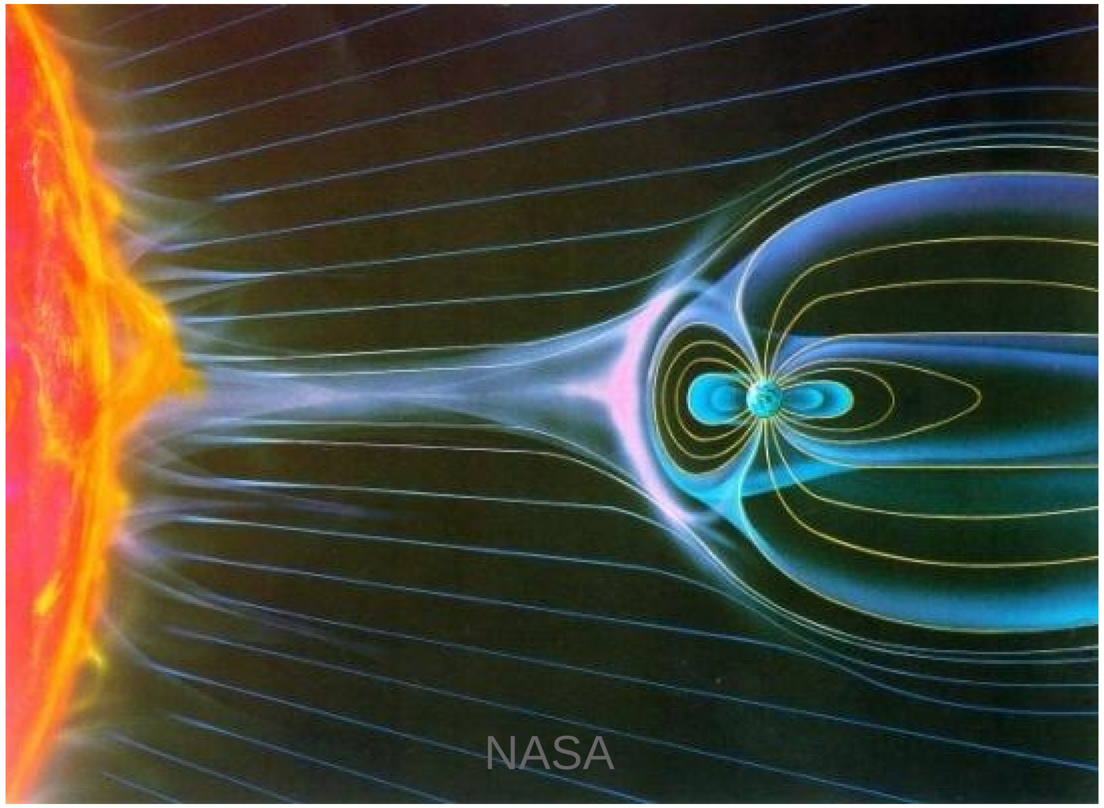
Aims of the auroral campaign

- Compare the spatial and relative intensi distributions of H_3^+ emission with those of H and H_2
- Obtain simultaneous obser ora in the northern and souther northern dayside and ni
- Observ rms and oth
- Com y with in situ d
- Detect n of auroral intensity on magnetic field data.
- Monitor lon auroral intensity in both hemispheres te seasonal and magnetic field dependences.



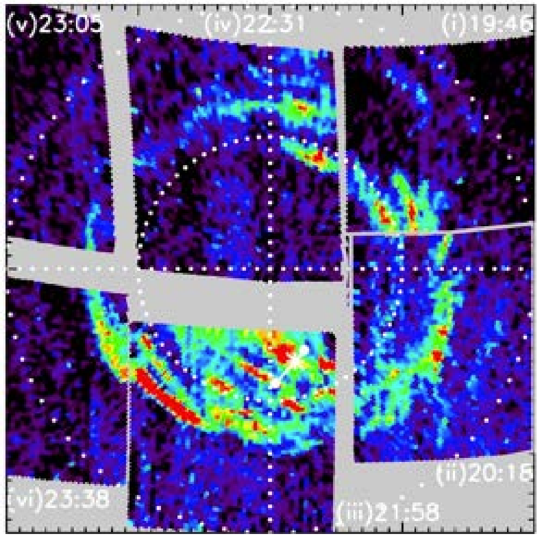
Summary

- The interaction between the solar wind and Saturn's magnetosphere is important for the exchange of mass and momentum.
- It's difficult to measure this interaction using single point measurements from one spacecraft in the huge magnetosphere.
- We can use auroral images to show us the global picture.

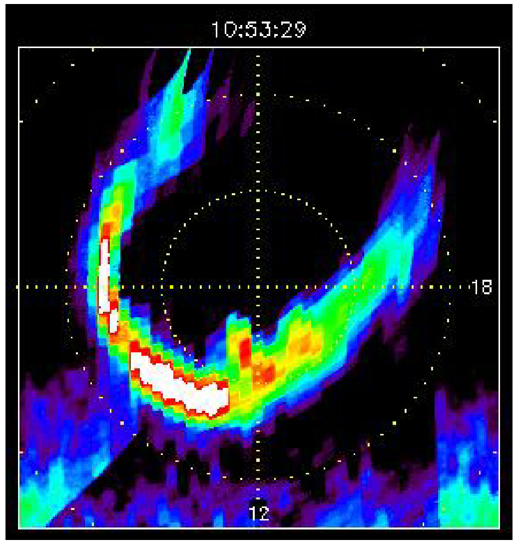


Summary

- We have shown examples of how Saturn's aurorae reveal a variable interaction with the solar wind:



- auroral arcs with energetic ions and electrons
- time evolution of auroral arcs
- flashing of auroral arcs
- moving blobs



- How will the aurorae look at solar maximum? Will we see more bright polar events?
- Auroral campaign results coming soon...