

A composite image of Saturn and its rings. The planet is shown in the center, with its rings extending outwards. The planet's surface is illuminated with a mix of purple, red, and green colors, suggesting auroral activity. The rings are a deep blue color. The background is black.

Saturn's aurorae

Tom Stallard



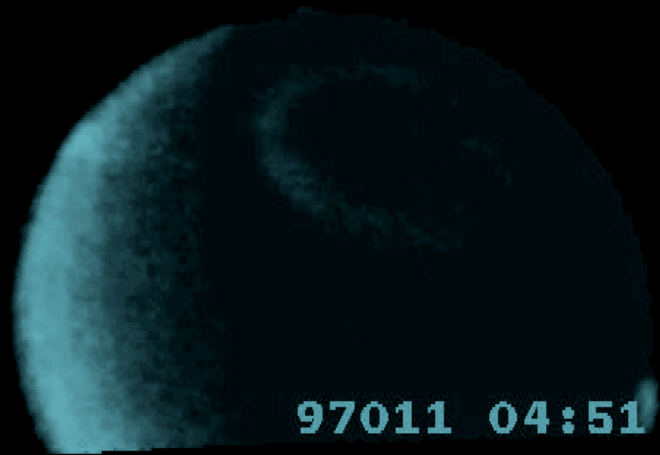
Sarah Badman, University of Lancaster

Ulyana Dyudina, Caltech

Denis Grodent, University of Liege

Laurent Lamy, l'Observatoire de Paris

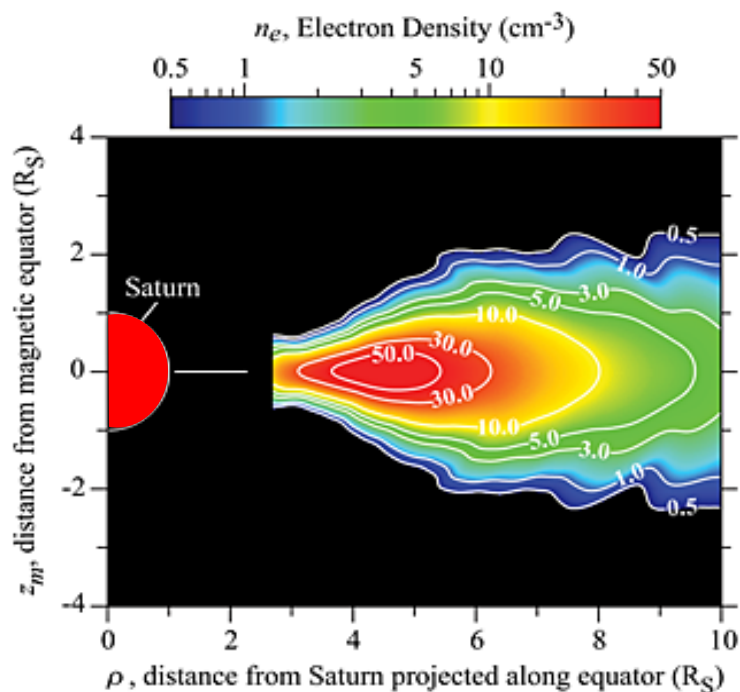
Earth



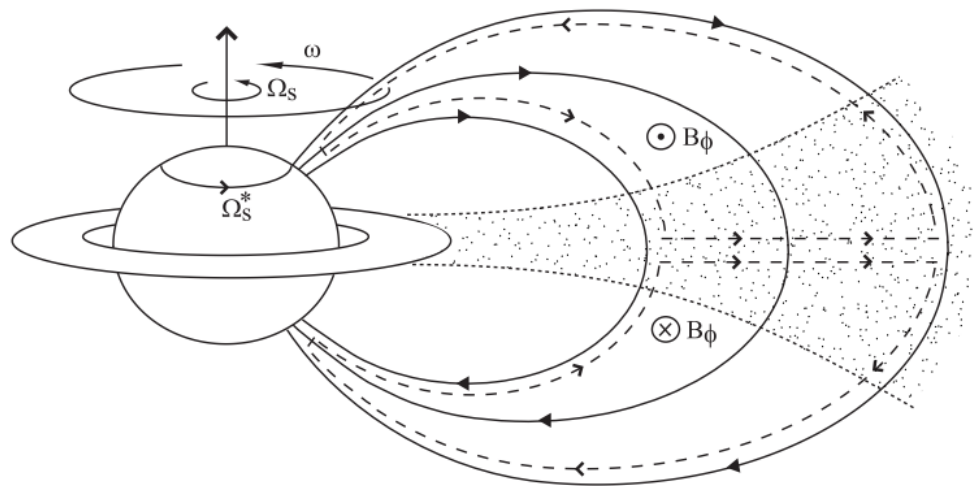
Jupiter



What drives auroral emission?



Persoon et al [2013]



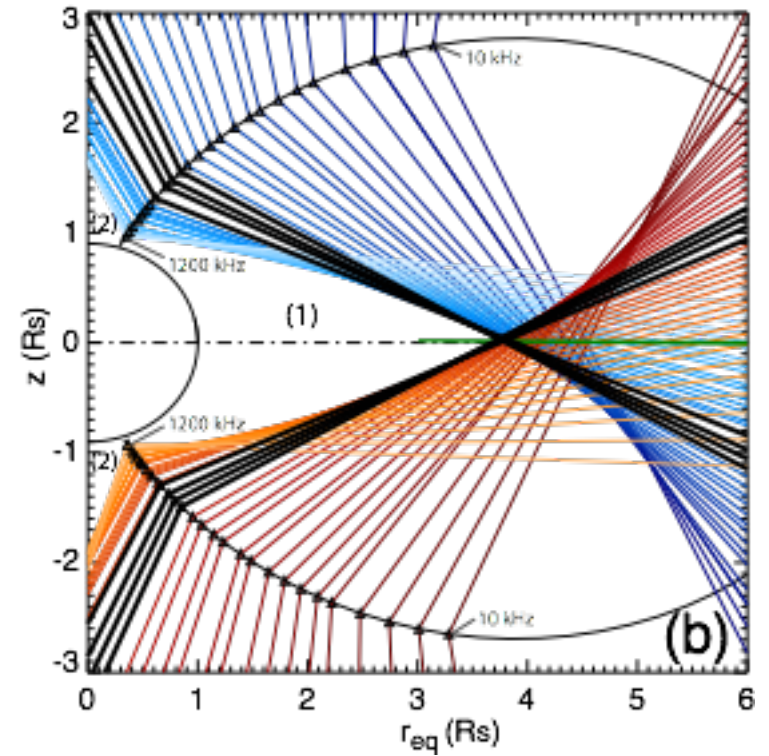
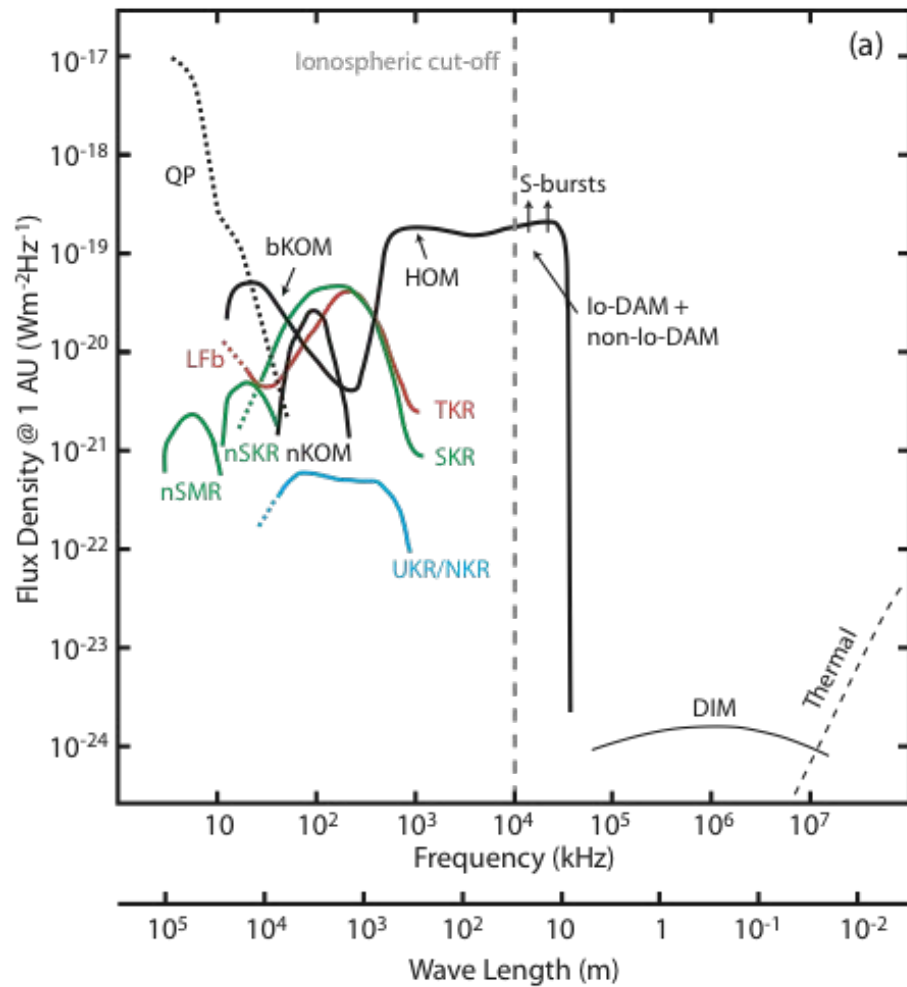
Bunce et al [2003]

Radio aurora

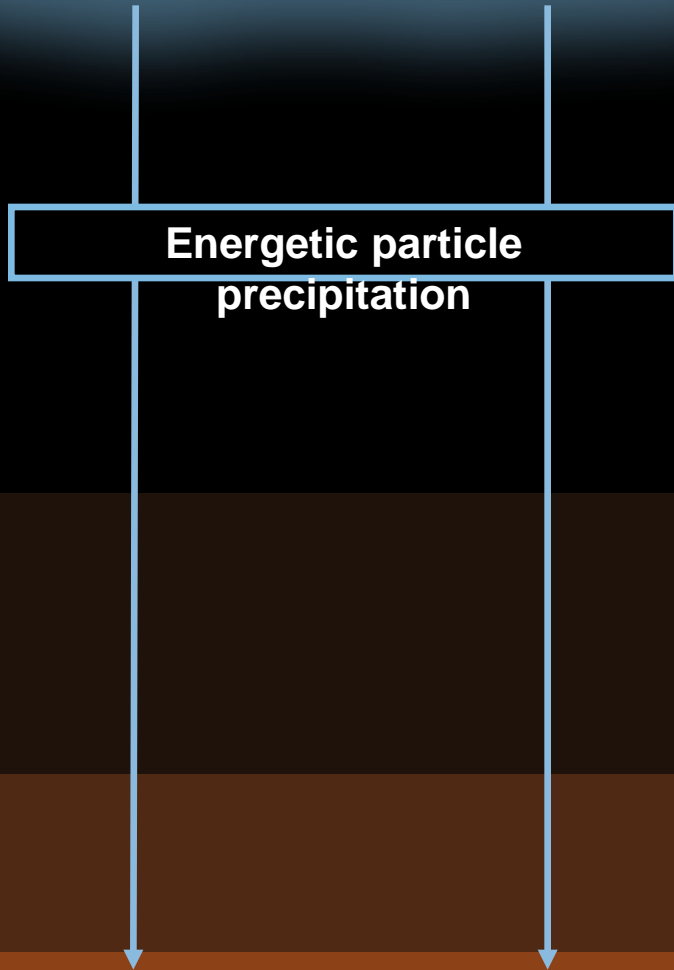


Lamy et al., 2009

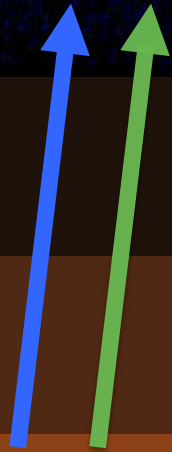
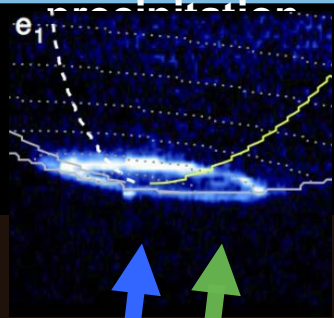
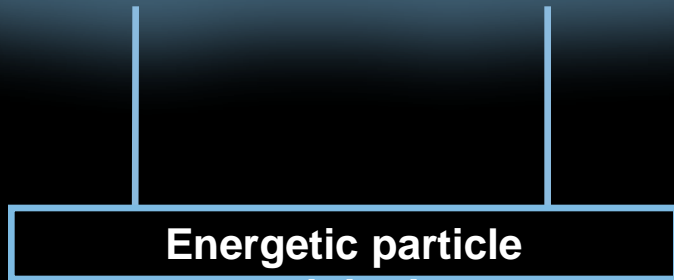
[No auroral X-ray emission]



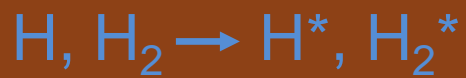
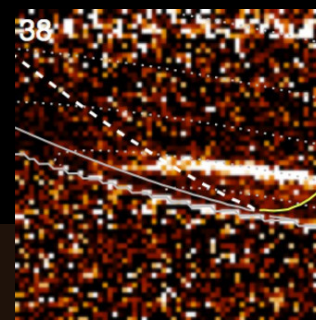
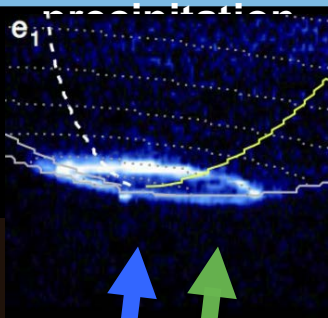
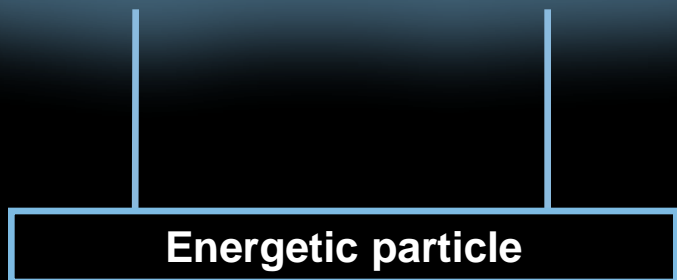
Magnetosphere



Magnetosphere



Magnetosphere

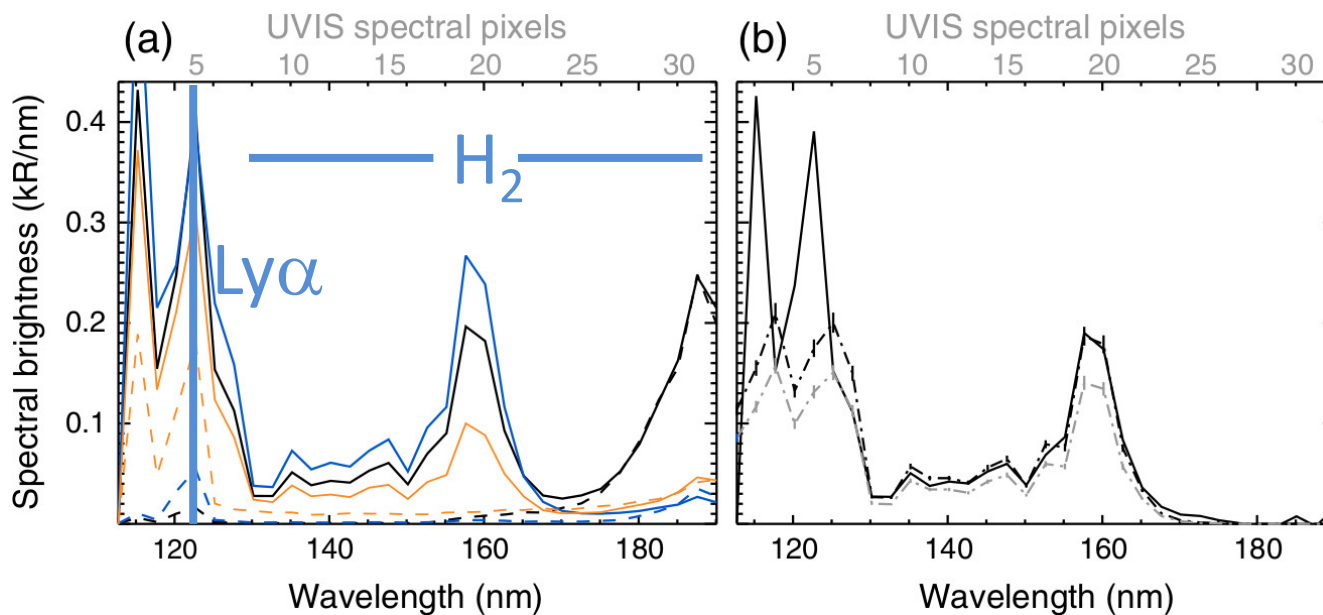
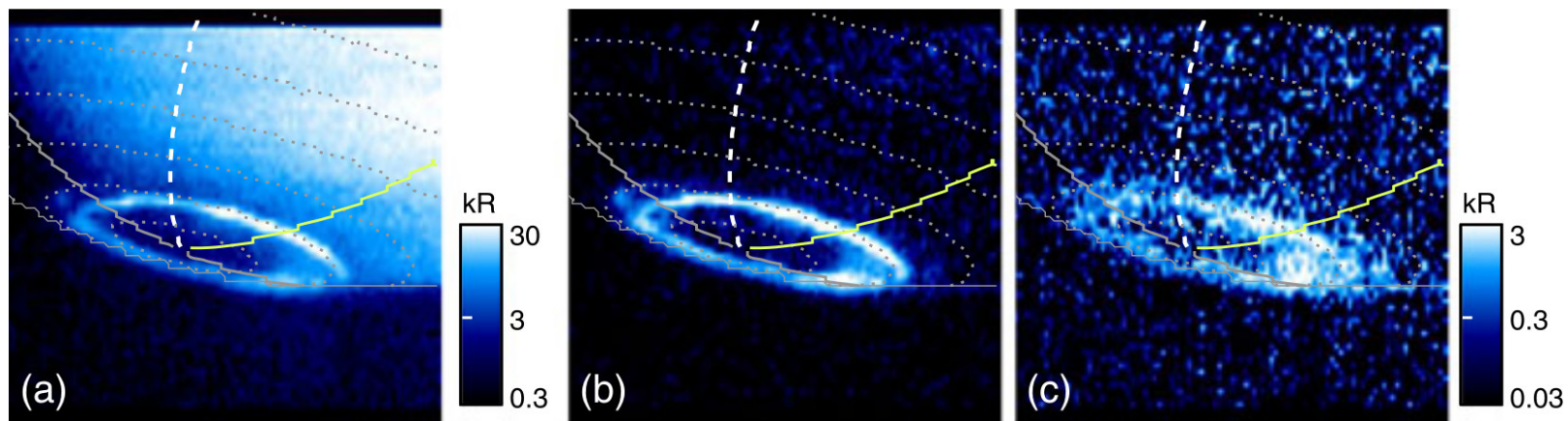


1

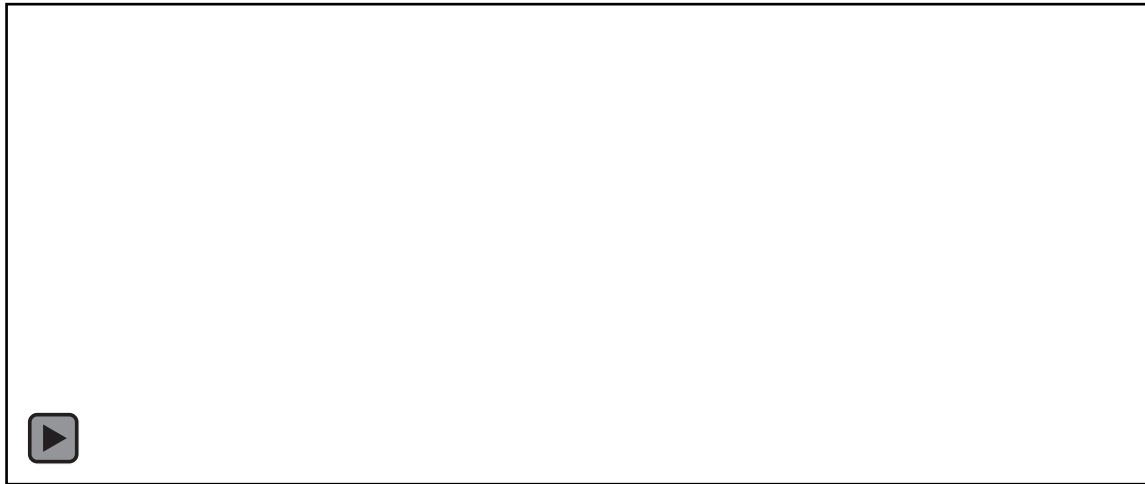
2

3

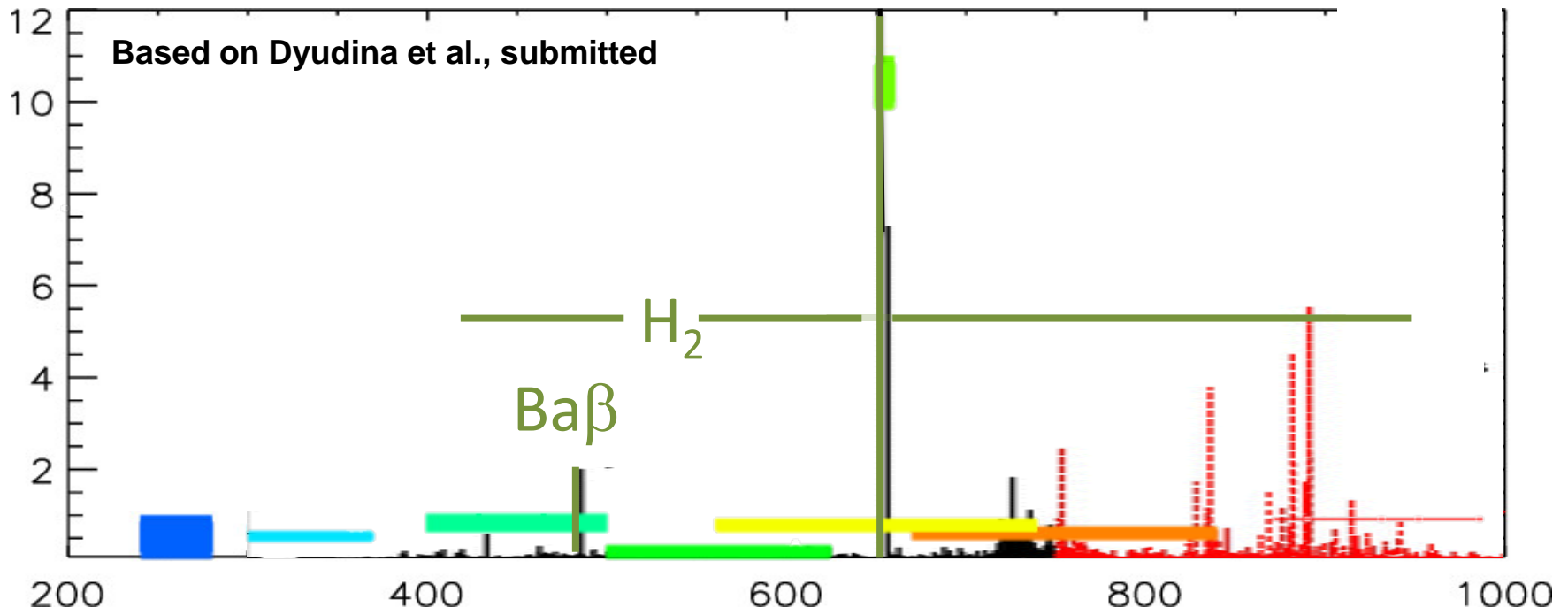
UV aurora



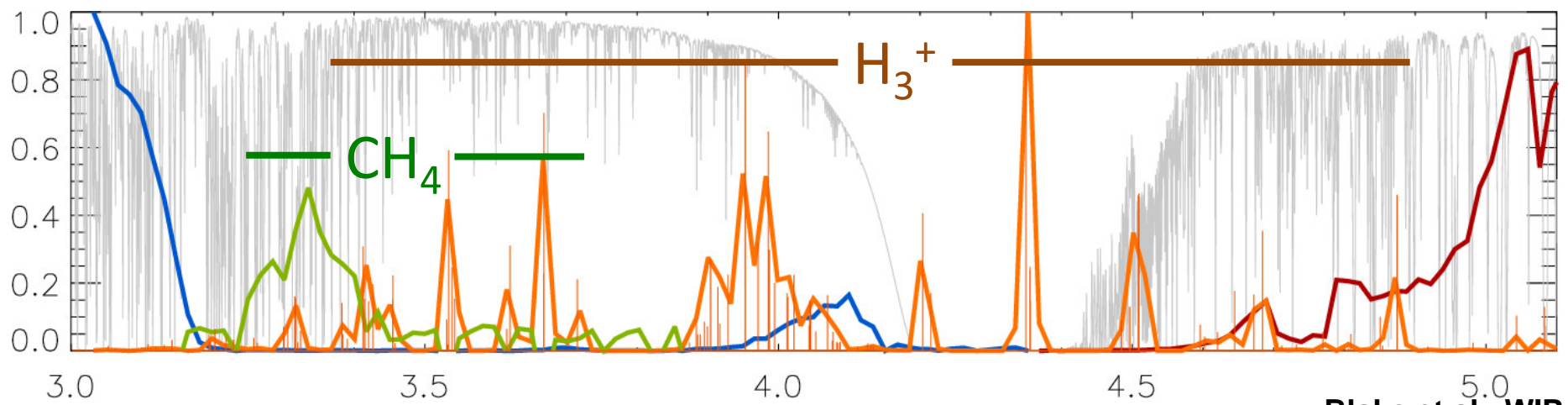
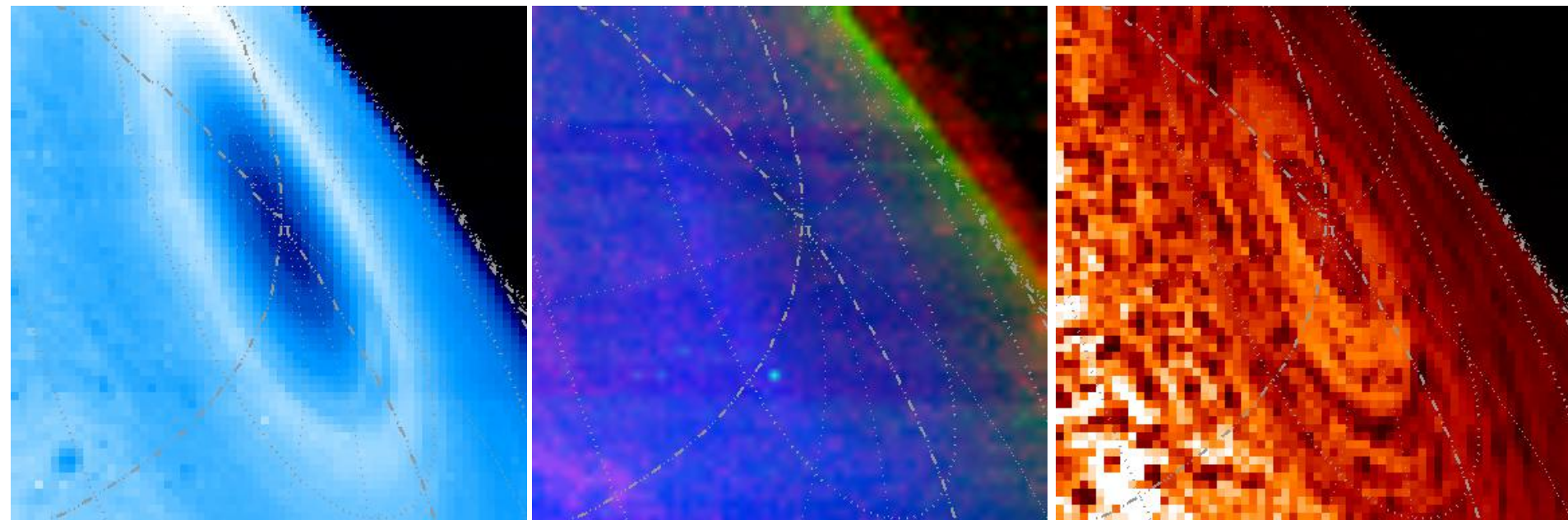
Visible aurora



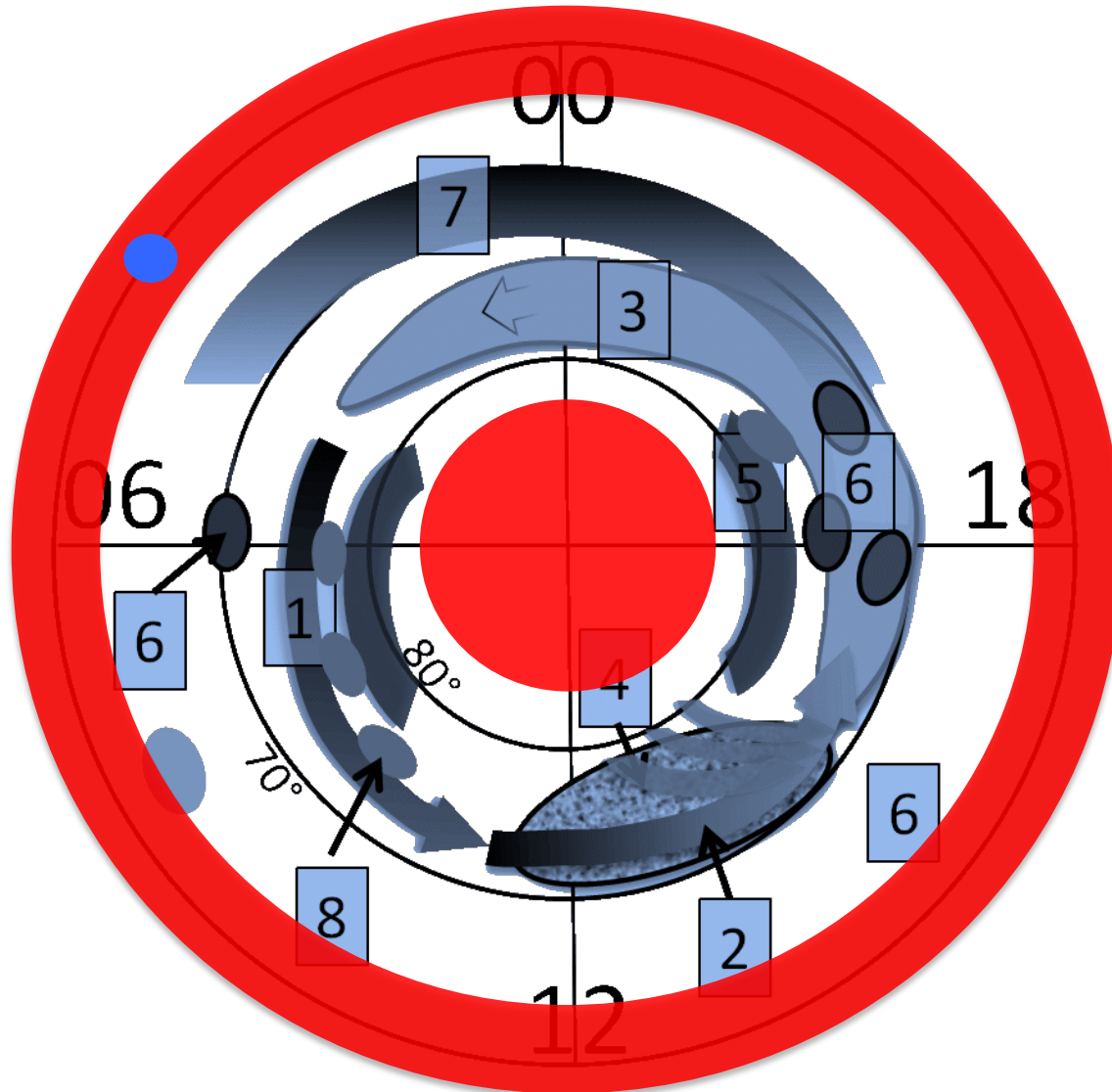
Dyudina et al.



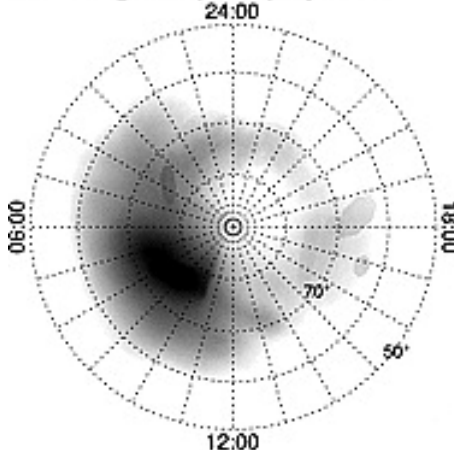
Infrared aurora



Morphology of the aurora



a Magnetic polar projection

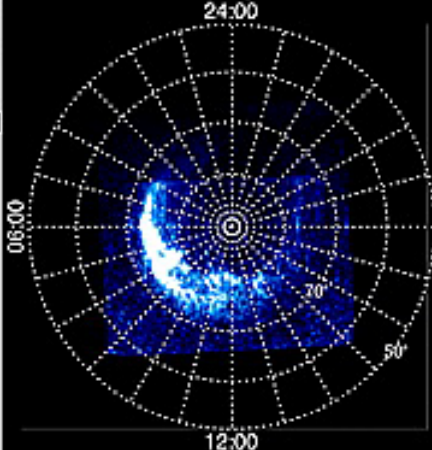


Data selection:

$|\bar{\lambda}_{\text{obs}}| (^{\circ}) = [10, 40]$
 $r_{\text{obs}} (R_{\odot}) \leq 15$
 $f_{\text{min}} (\text{kHz}) = 100$
 $f_{\text{max}} (\text{kHz}) = 1000$
 $V = [0.80, 1.10]$
 $\text{SN}_{\text{Lr}} (\text{dB}) \geq 40$
 $\beta (^{\circ}) \geq 20$



b Polar projection



Data:

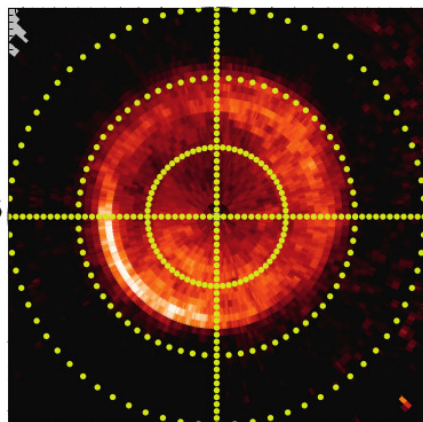
HST-STIS 2004
 13 days (34 images)
 1 filter
 HST-ACS 2007
 14 days (349 images)
 3 filters



Lamy et al., 2009

North

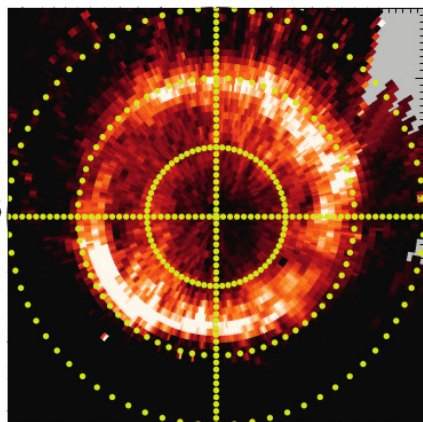
00



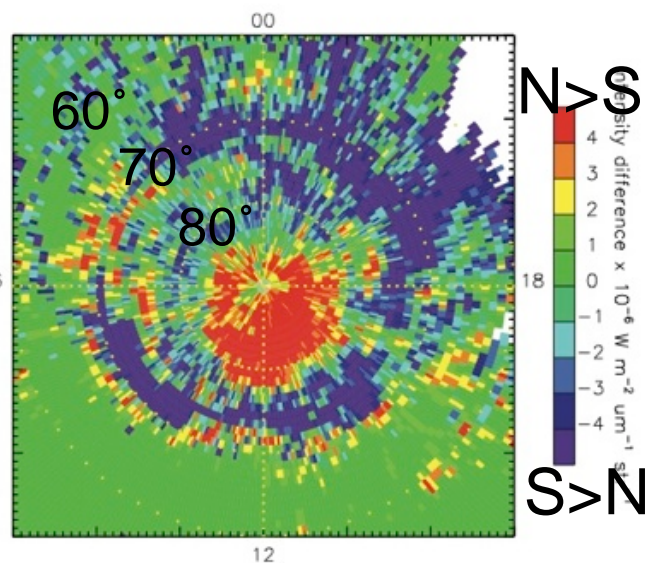
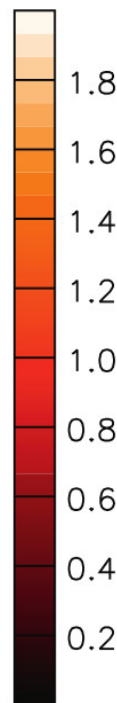
12

South

00



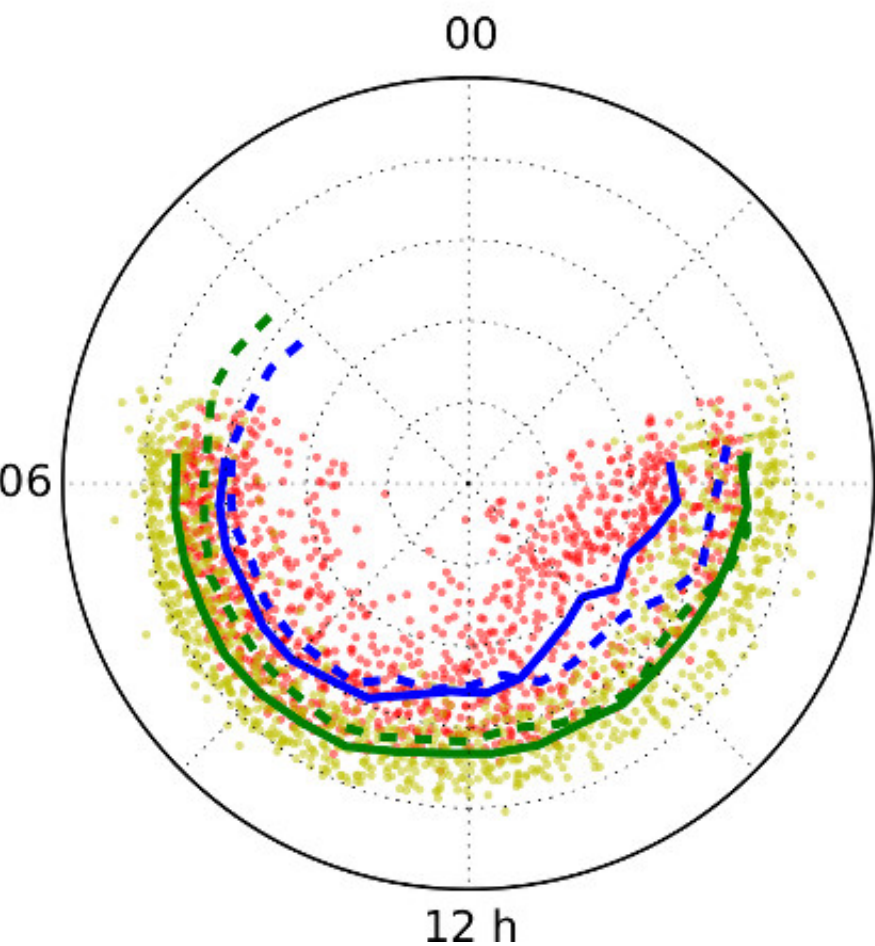
12



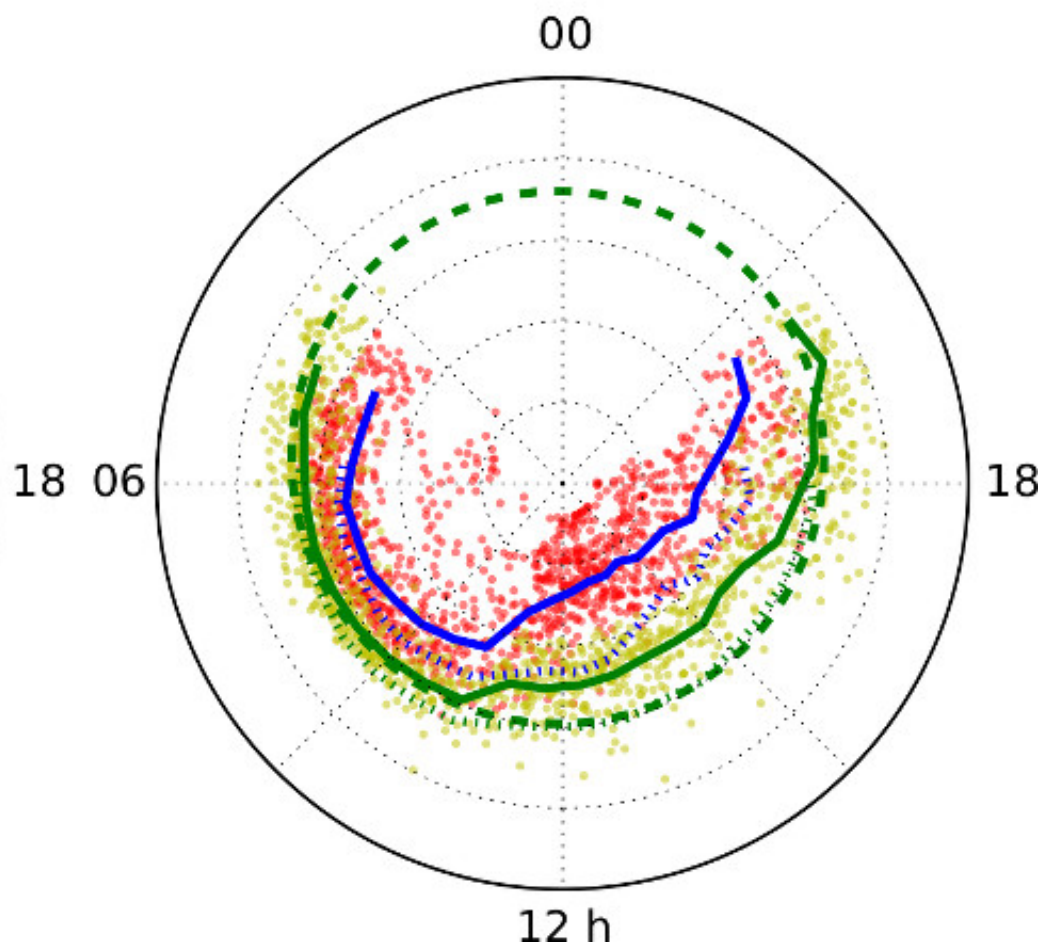
Badman et al., 2011

Location of the main emission

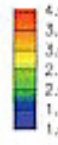
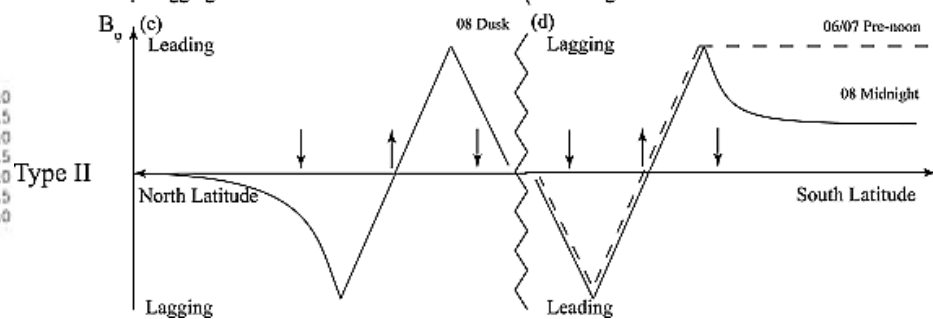
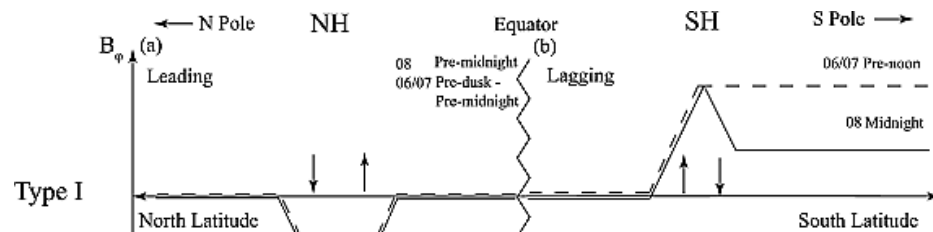
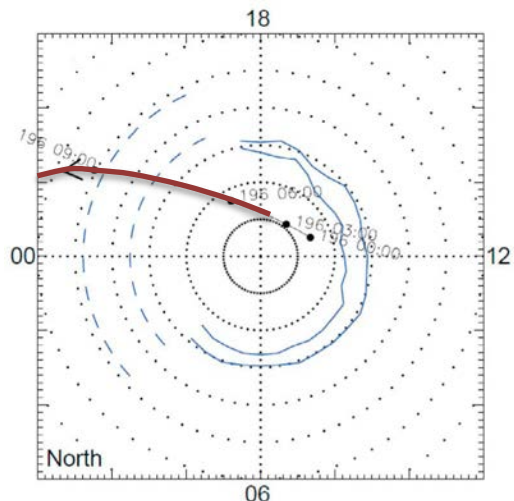
(a) South 2007-2008



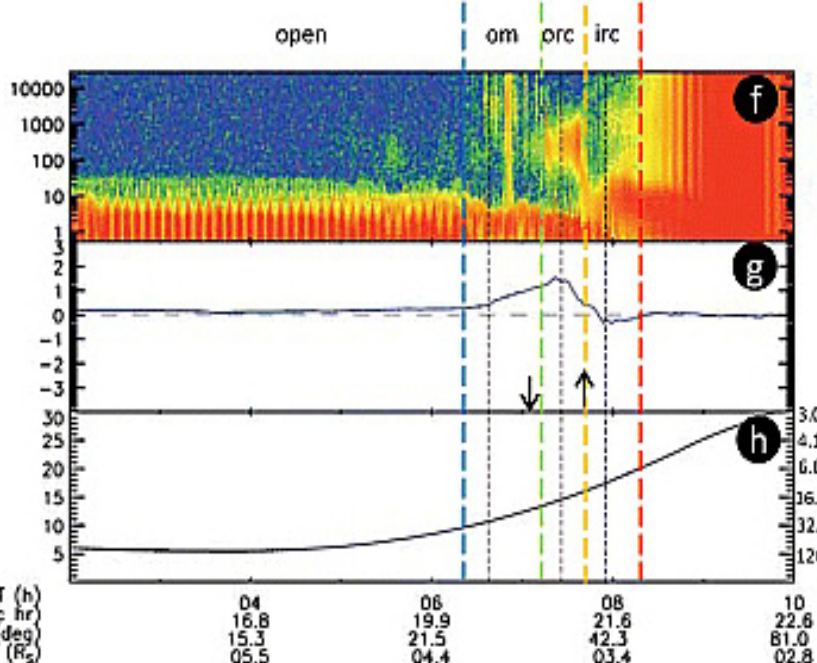
(b) North 2011-2013



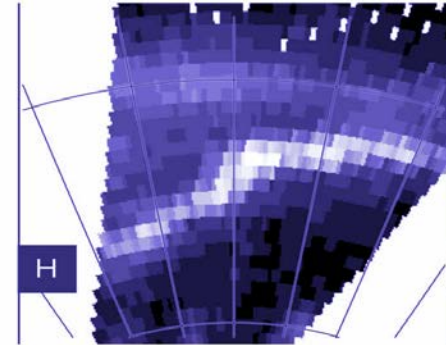
Main emission currents



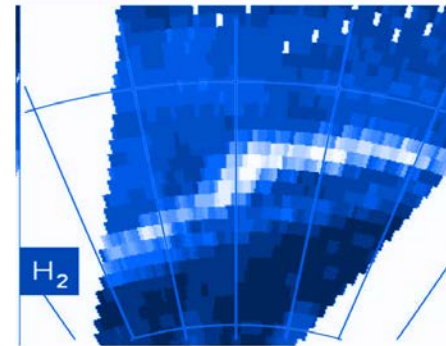
r_B / r_p



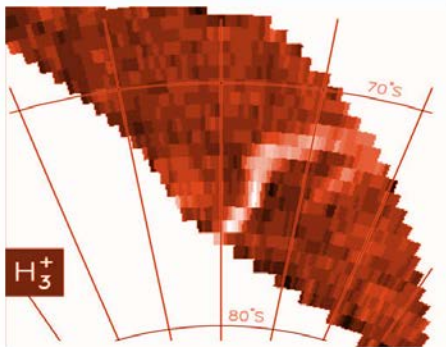
Simultaneous observations



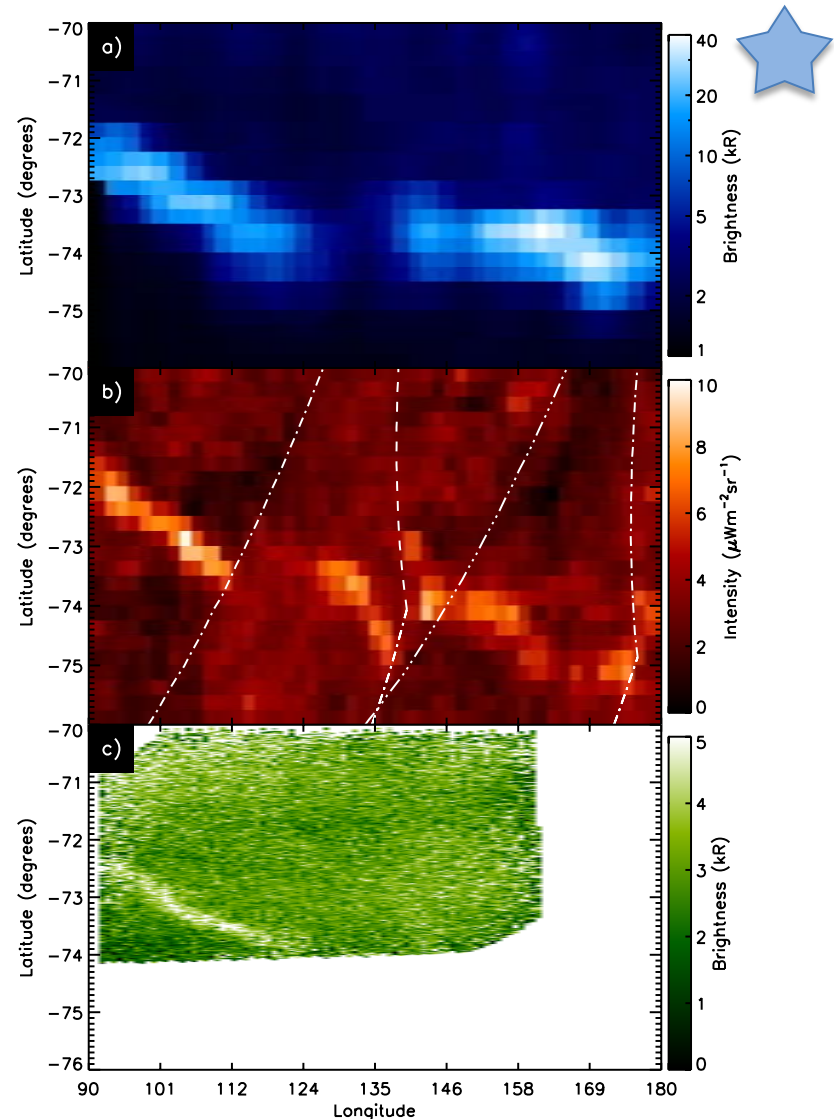
UVIS



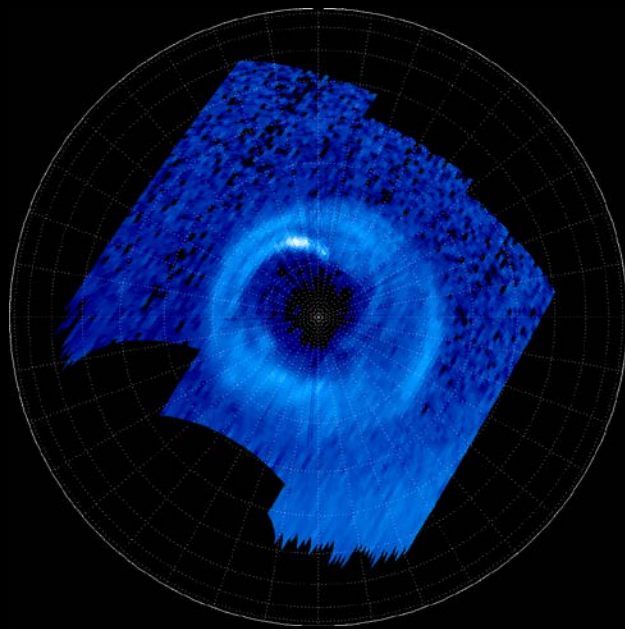
VIMS



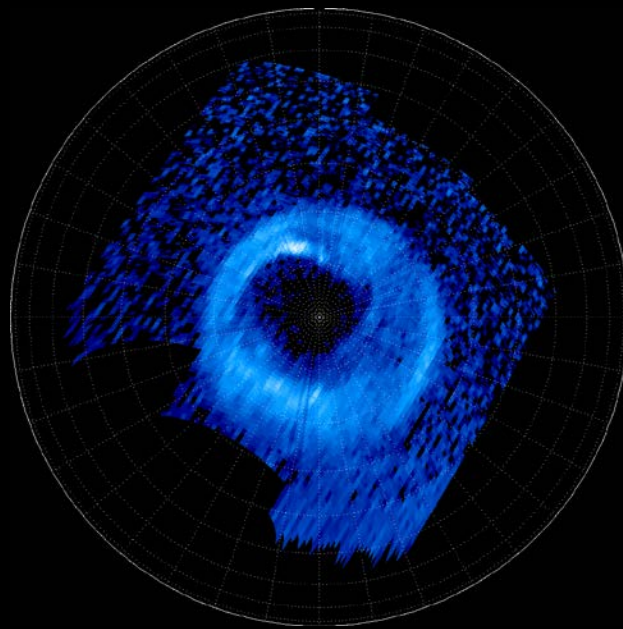
ISS



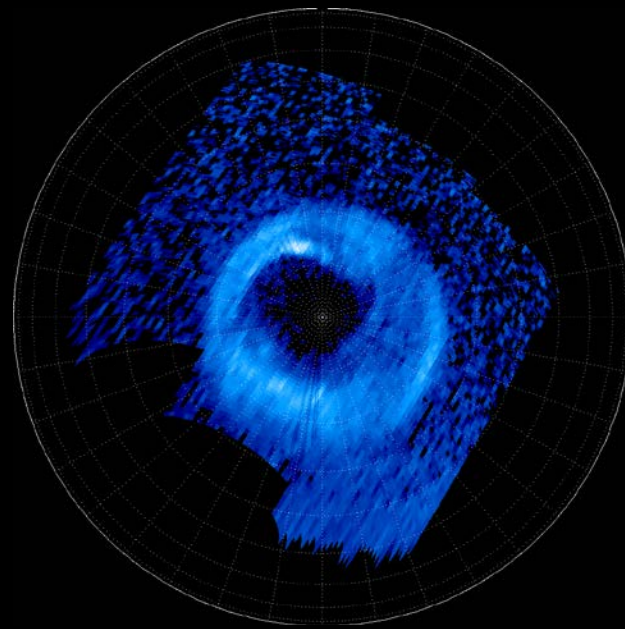
FUV



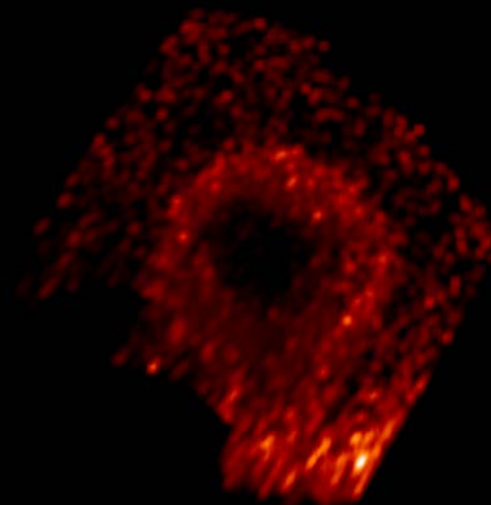
EUV



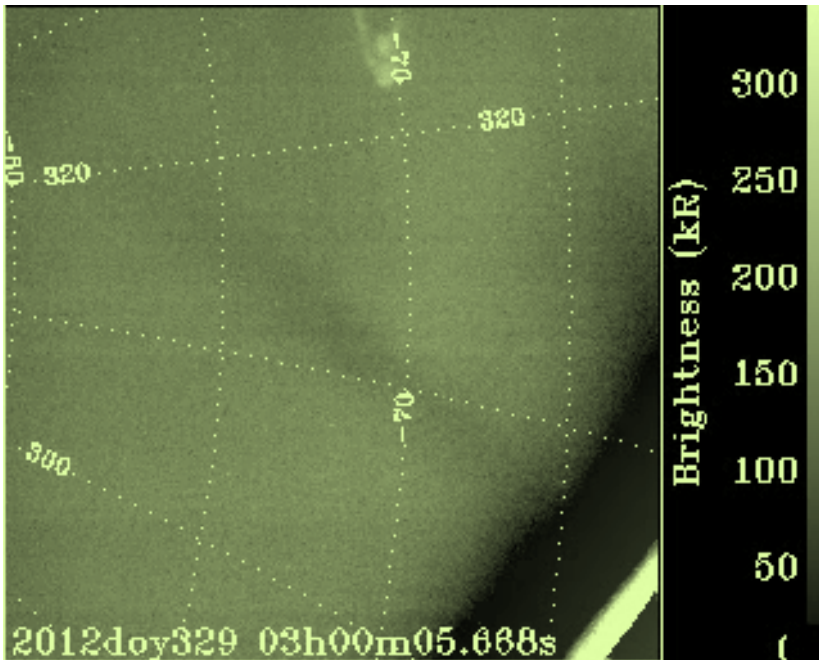
FUV+EUV



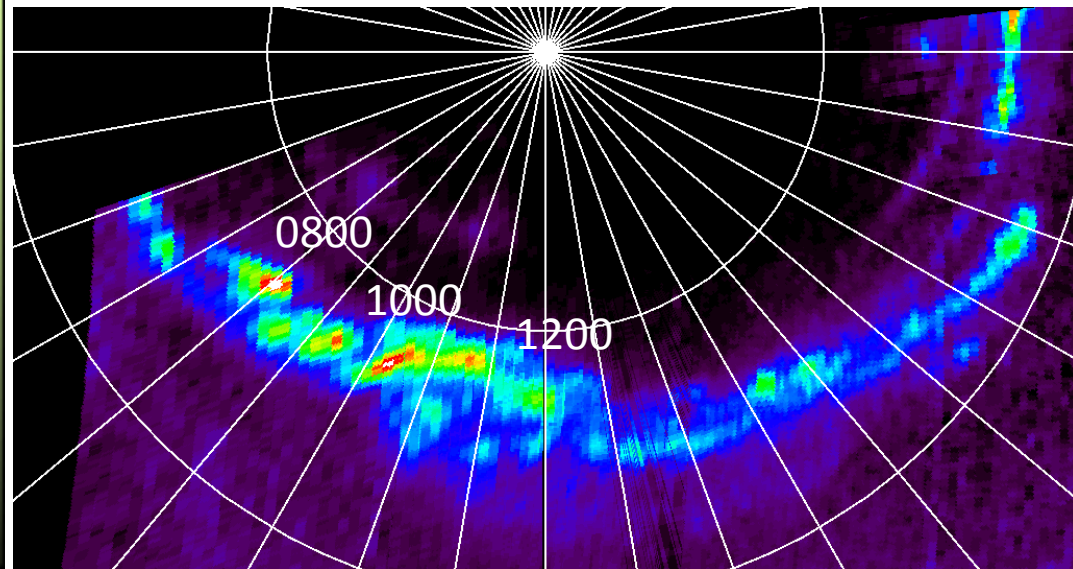
H₂ color ratio



High resolution observations



Spatial resolution ~200 km

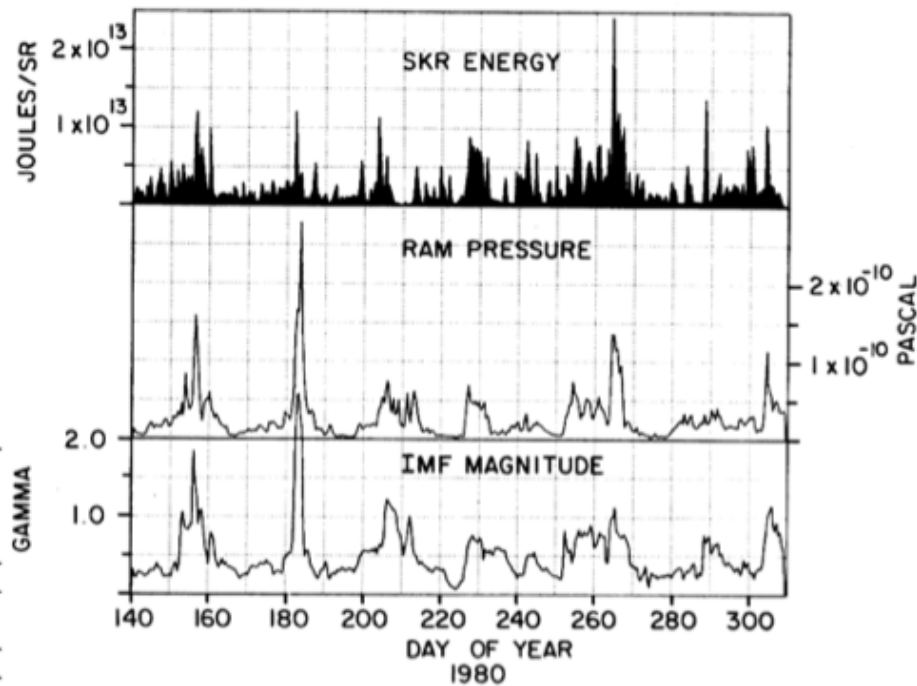


Dyudina et al., submitted; Grodent et al., WIP

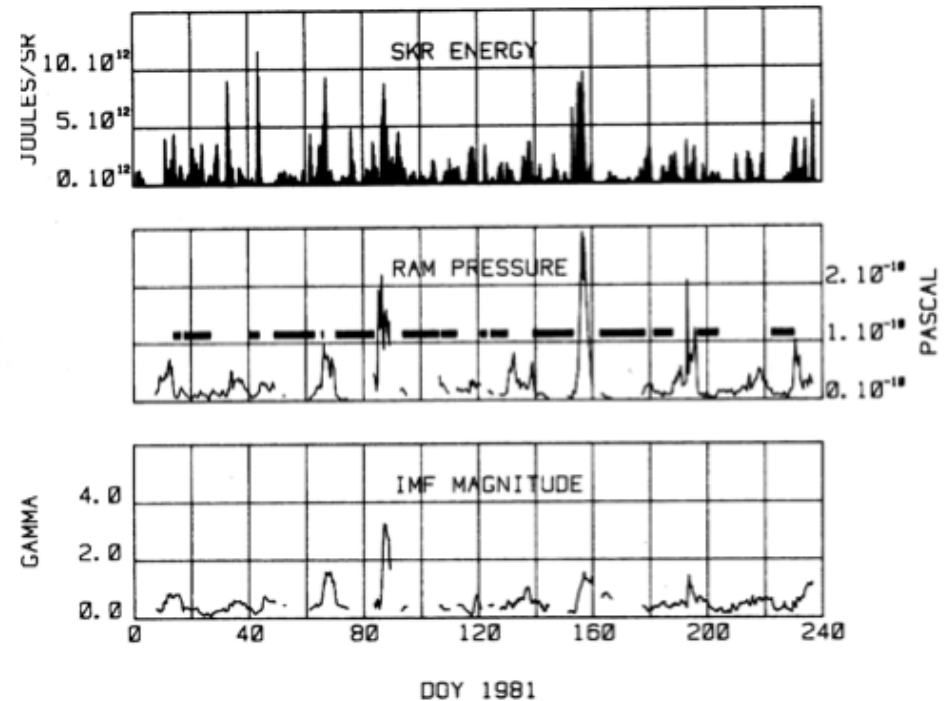
Solar wind
interaction

Radio emission power

(Desch et al. 83a, 83b)

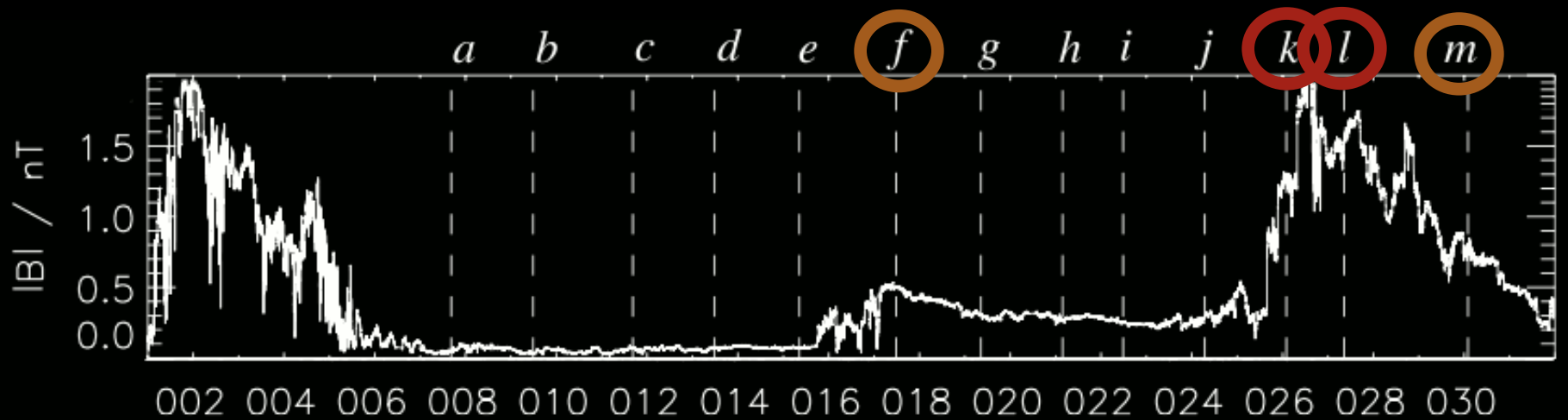
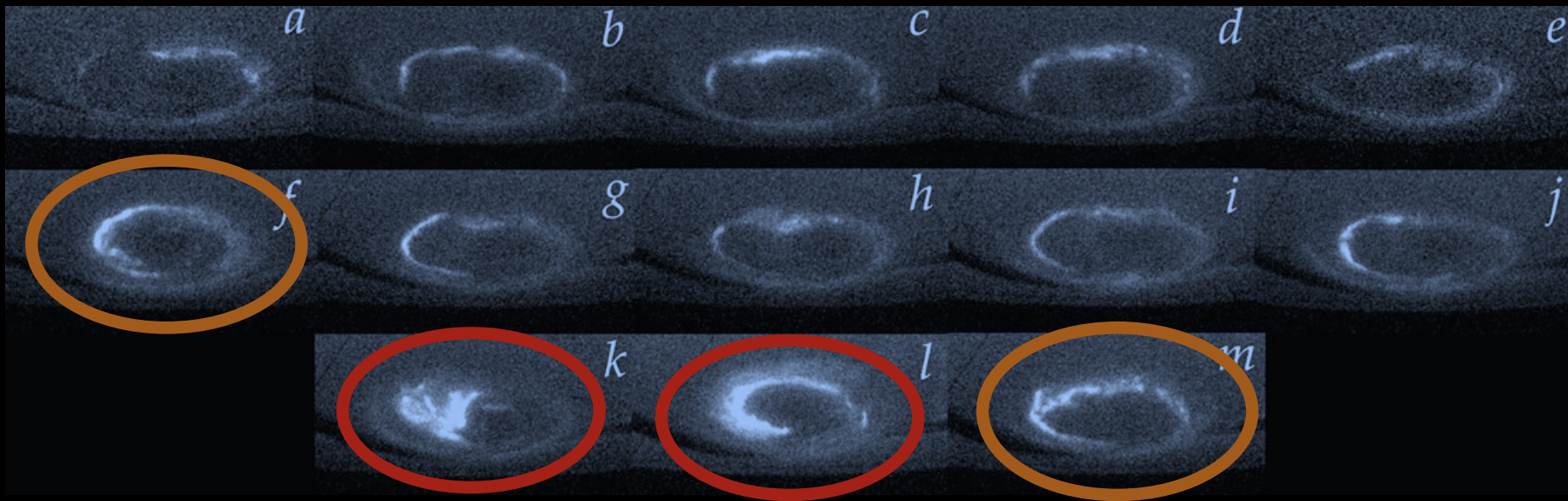


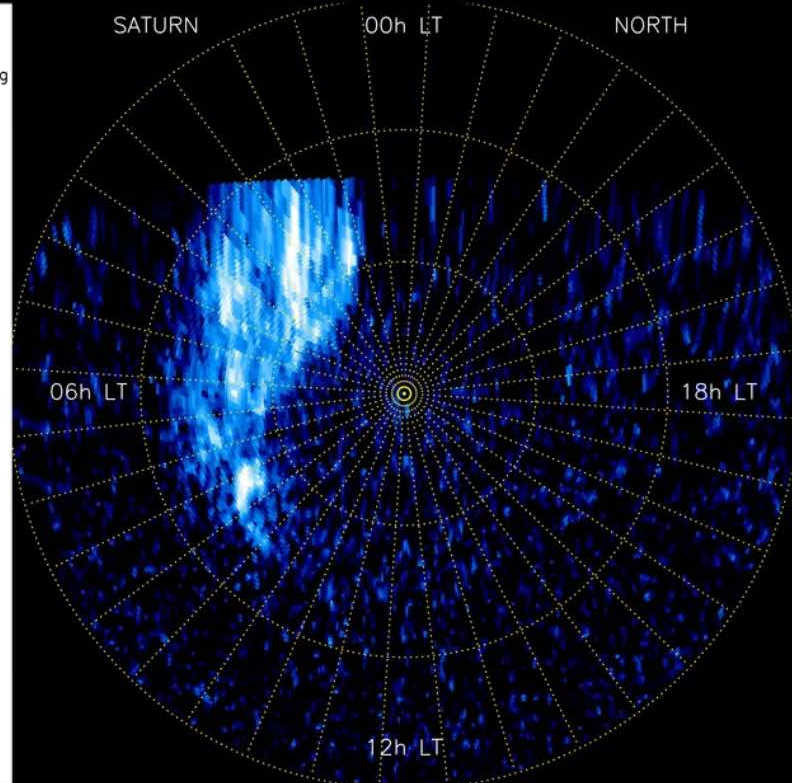
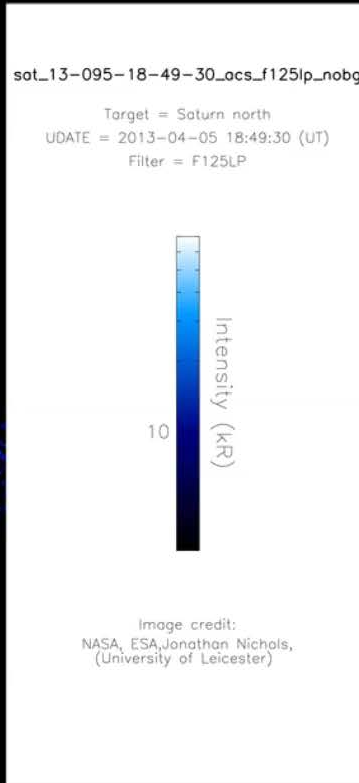
Voyager 1



Voyager 2

- SKR power correlated with SW dynamic pressure
- SW essential to the usual SKR activity level which dramatically drop out by several orders of magnitude when SW is cut off (Saturn immersed in Jupiter's tail)





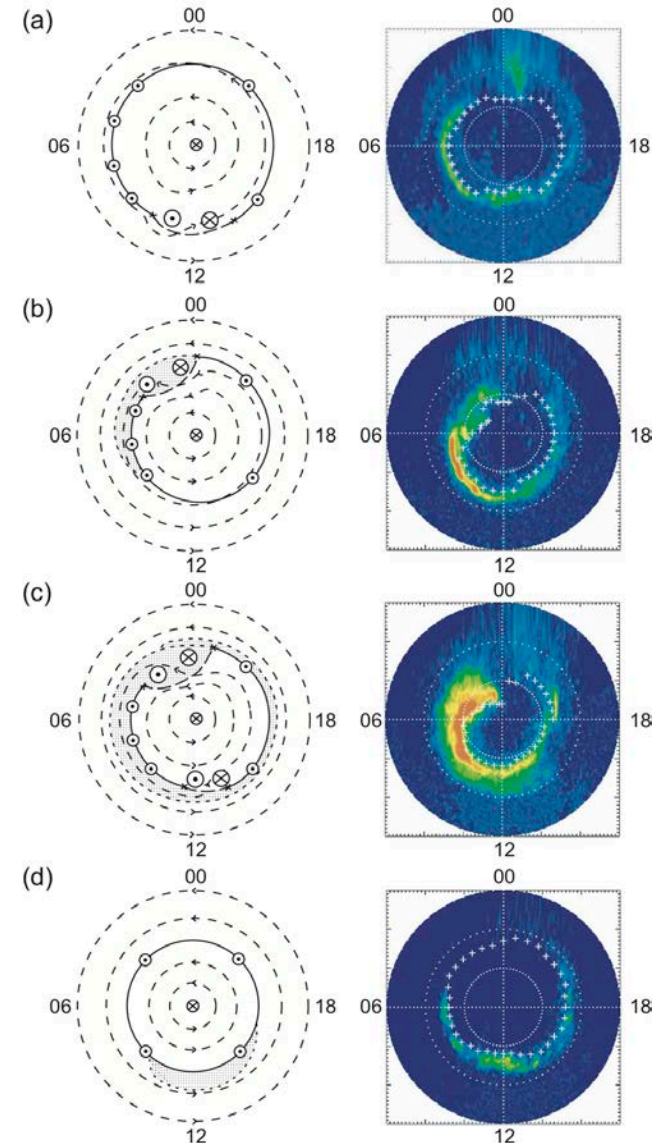
Tail reconnection

(a) Dayside reconnection

(a) Tail reconnection

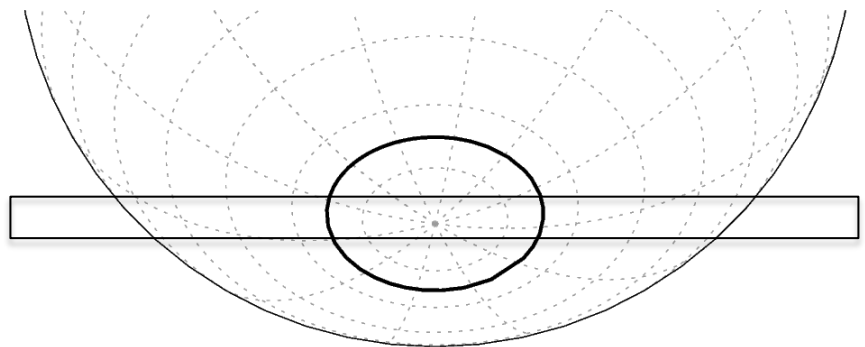
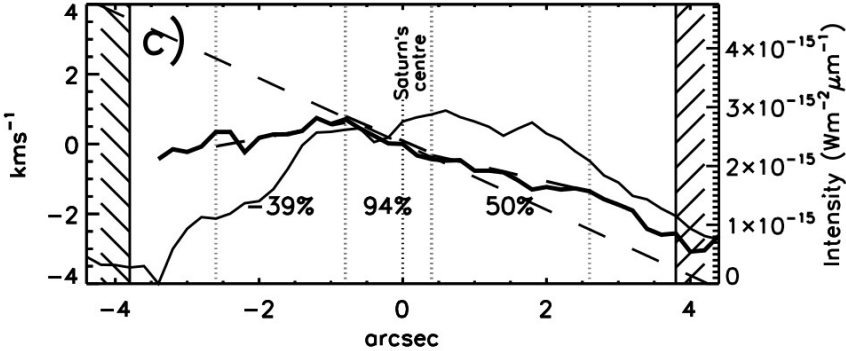
(a) Unbalanced tail and dayside reconnection e.g. large compression-induced tail reconnection

(b) Rotating diffuse blob produced by tail reconnection

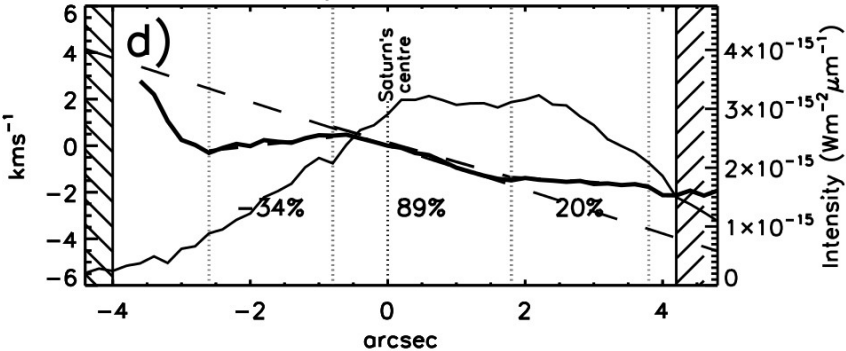


After Badman et al. (2005), Cowley et al. (2005)

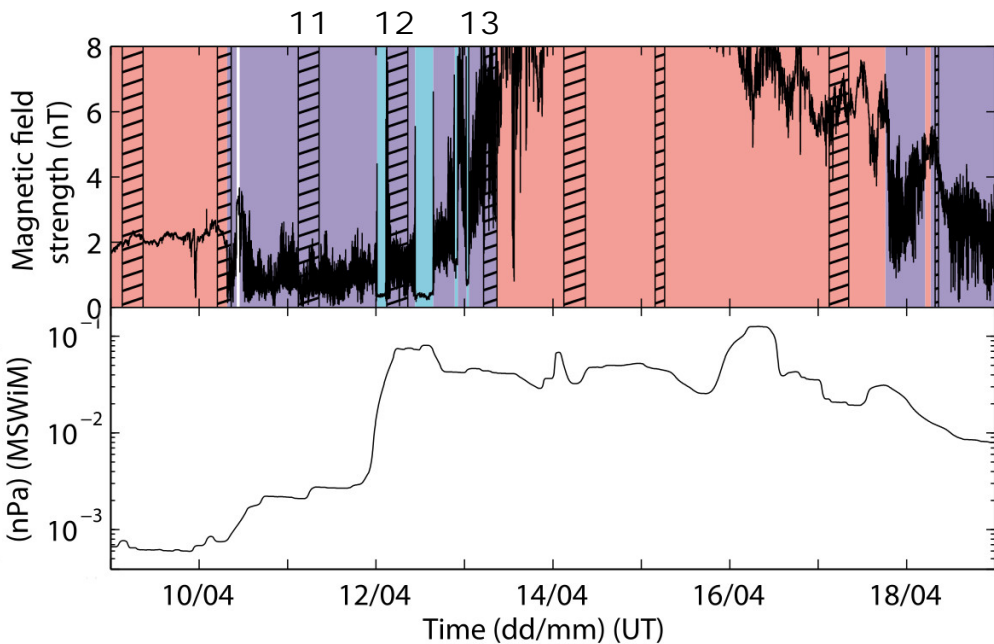
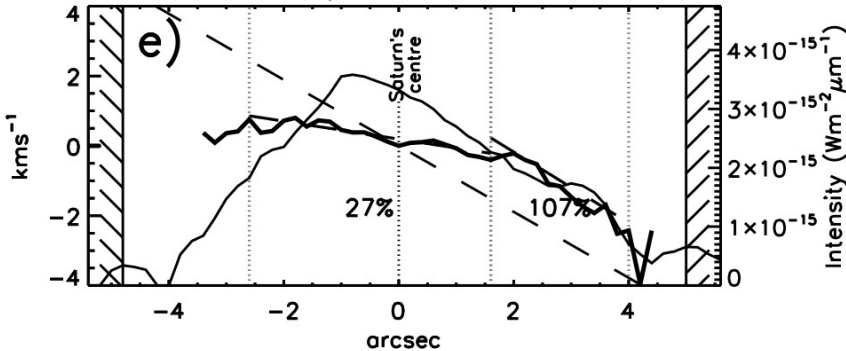
11 April - DOY 101

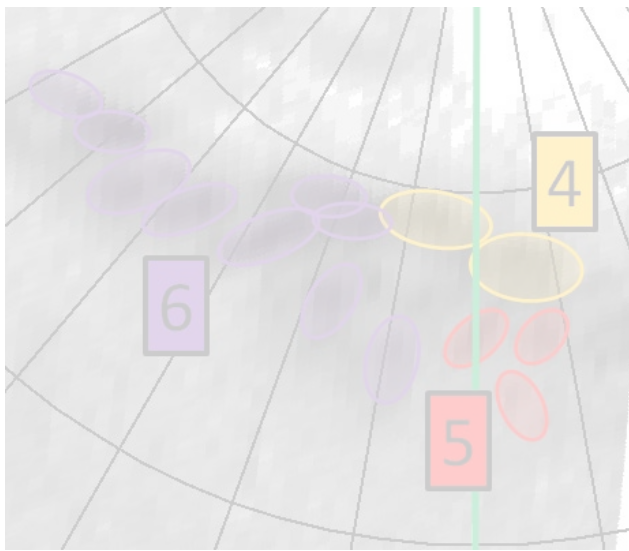


12 April - DOY 102

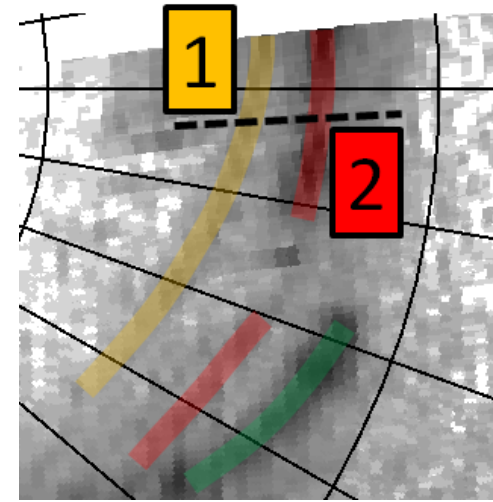


13 April - DOY 103



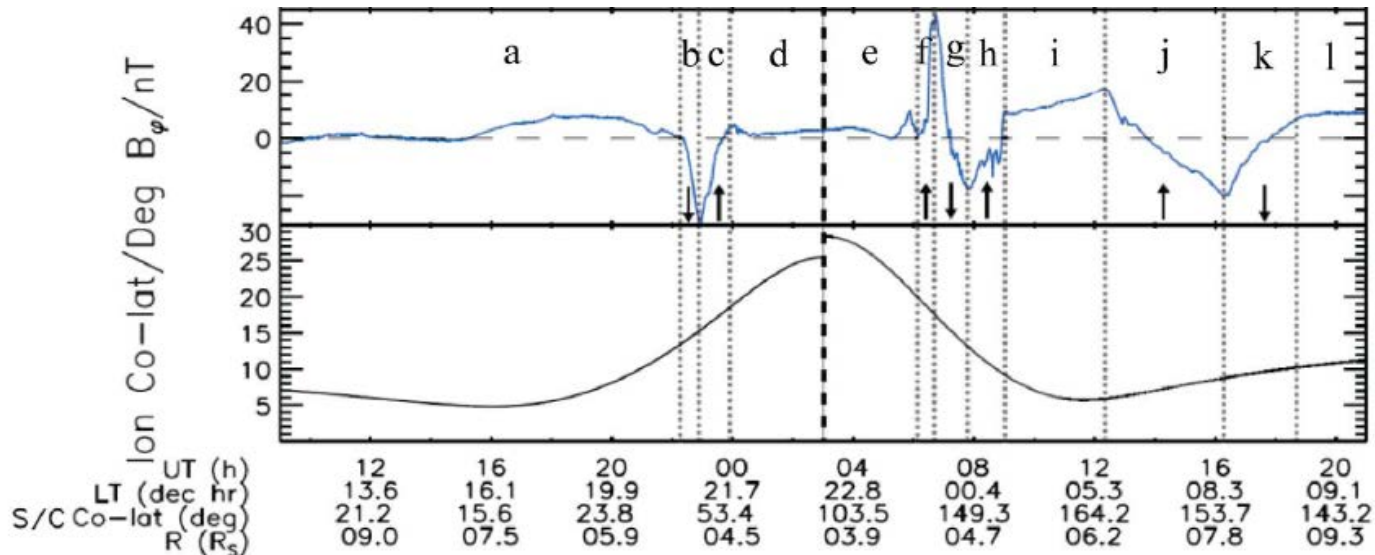


Origin of these small scale auroral features?



Complex Field-Aligned Current (FAC) structures

Bunce et al. [2010], Talboys et al. [2009,2011]



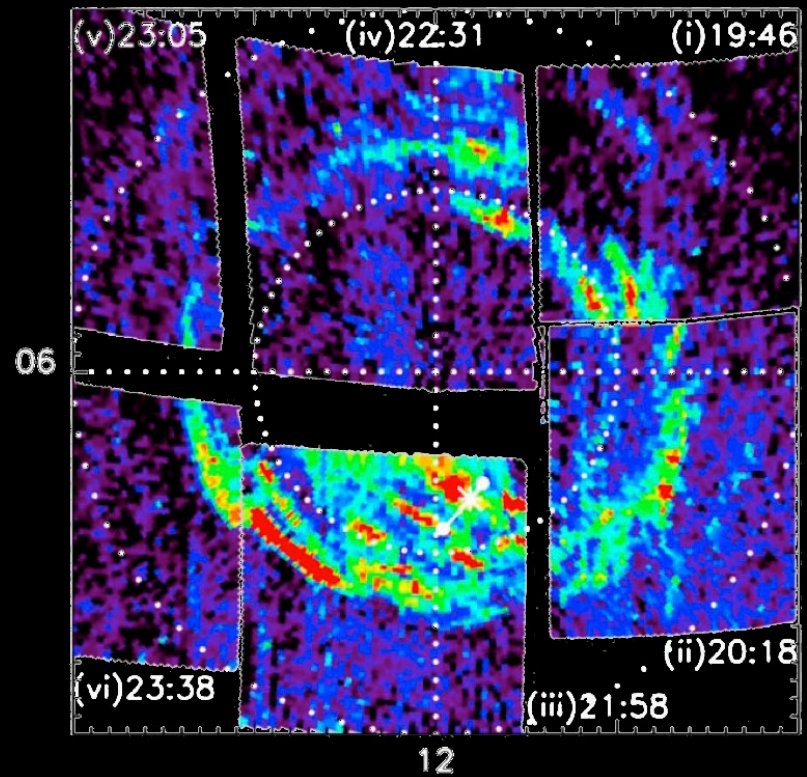
1-2° (lat) wide FAC structures

Poleward bifurcations

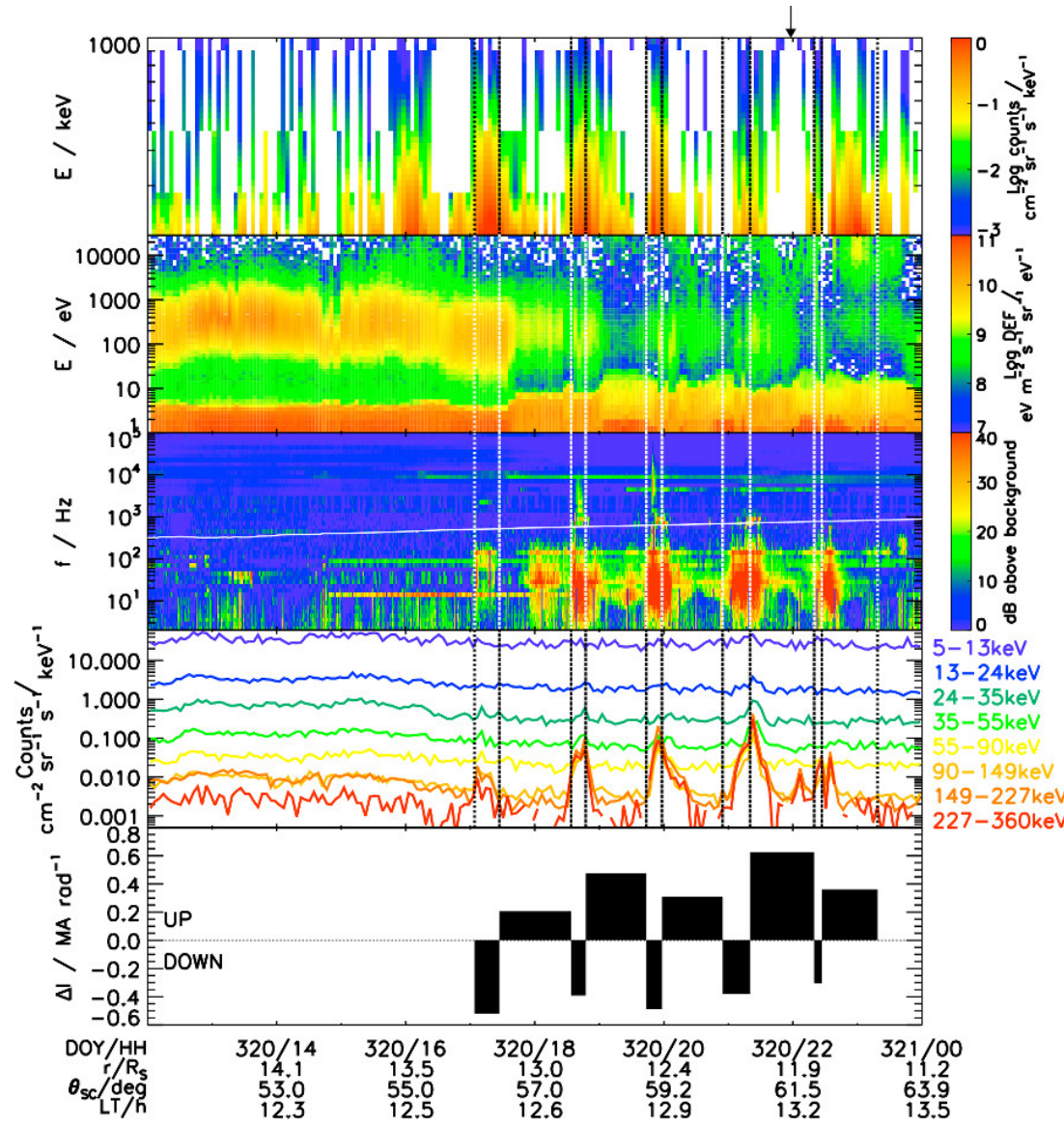
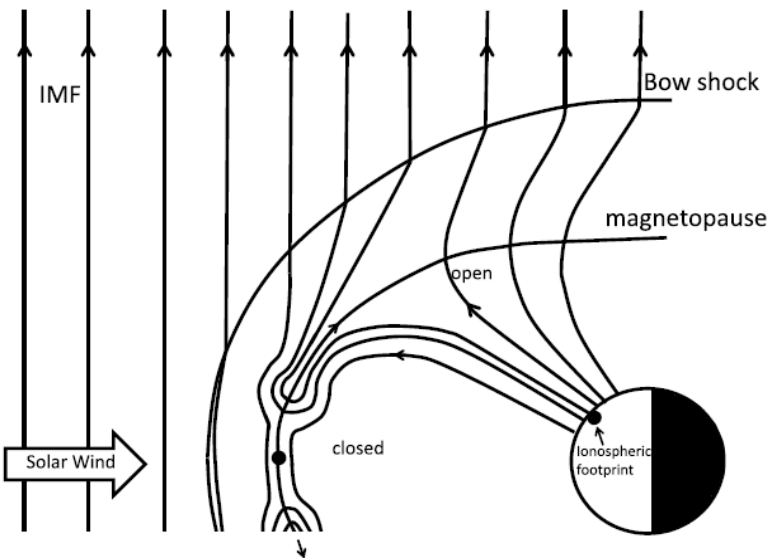
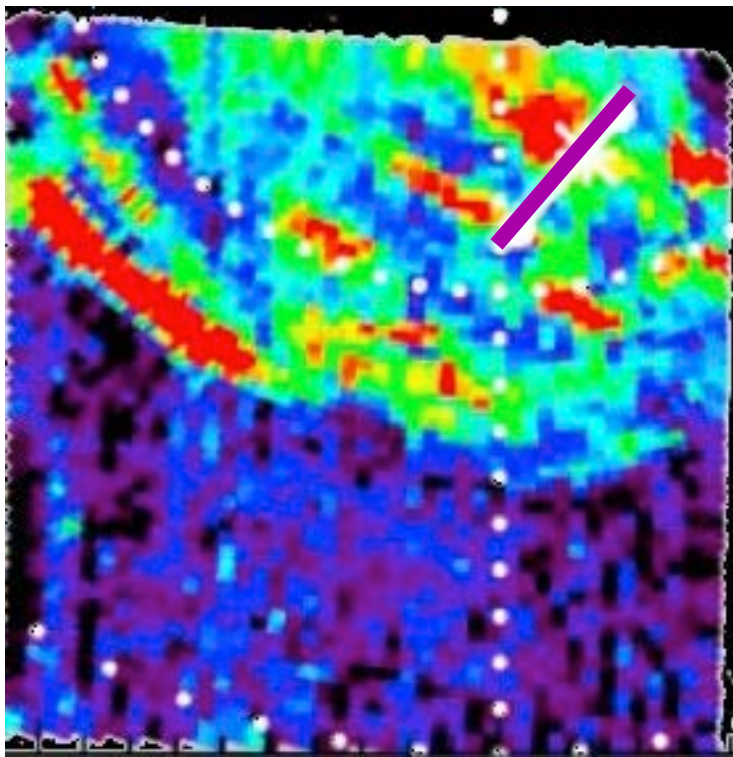


2008 JUL 19 03:21:34.816 to 2008 JUL 19 03:31:10.816

Pryor, priv. comm.



Badman et al., 2012

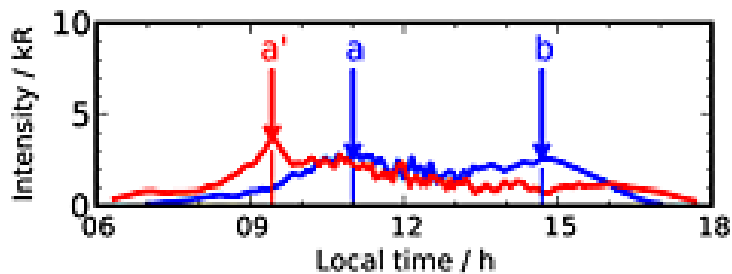
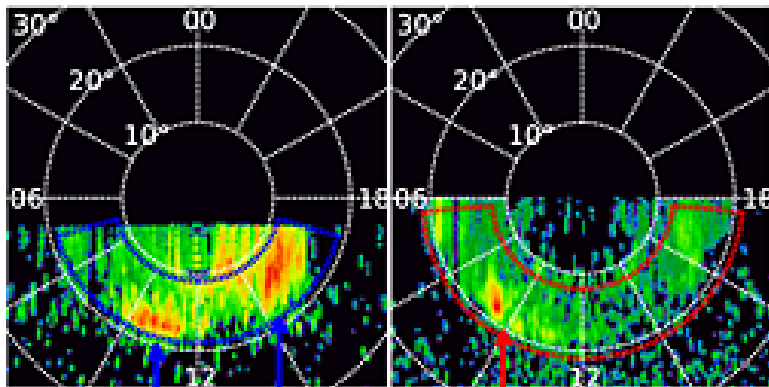
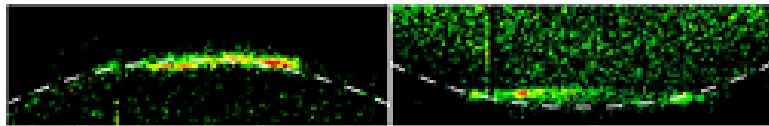


Dusk spots non-conjugate

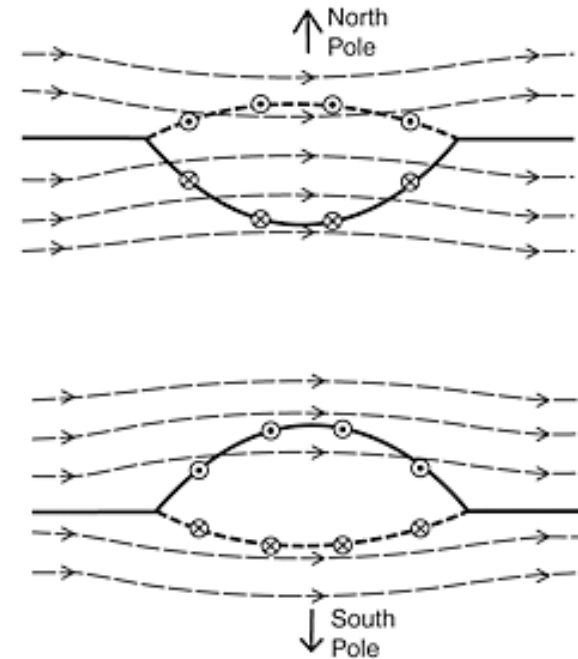
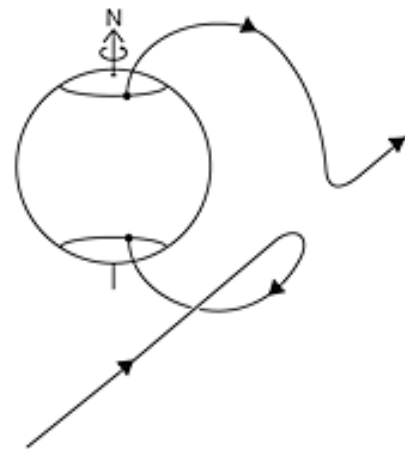
C4 - Image 9 2009-02-17 09:25:53

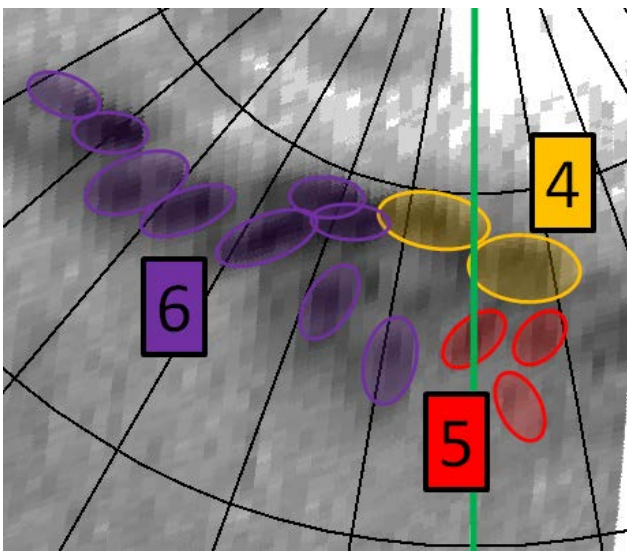
North

South



(a) IMF $B_y > 0$



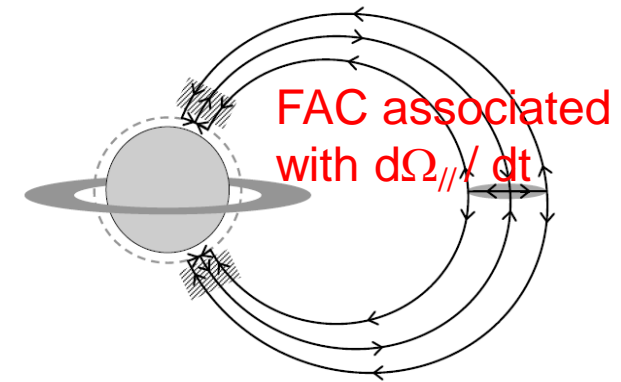
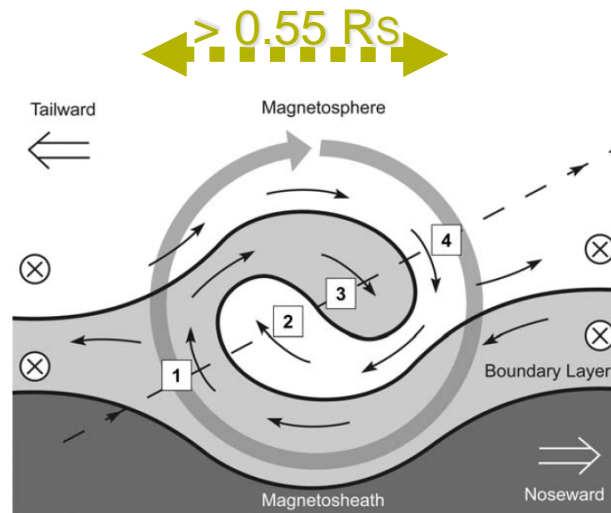
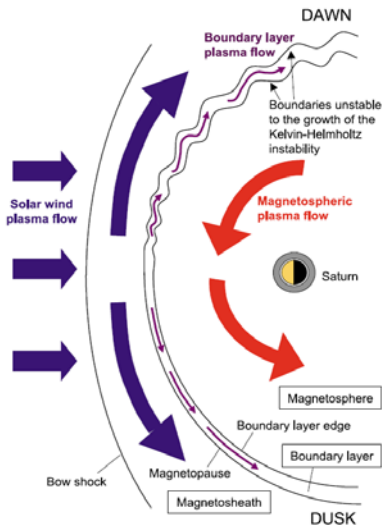


Origin of these small scale auroral features?



Vortices triggered by K-H instabilities

Masters et al. [2010], Fukazawa et al. [2009], Walker et al. [2011], Delamere et al. [2011]



Wilson et al. [2012]:
4 (?) vortices

Dawn spots offset

D3 - Image 5

2009-02-18 07:39:00

D3 - Image 9

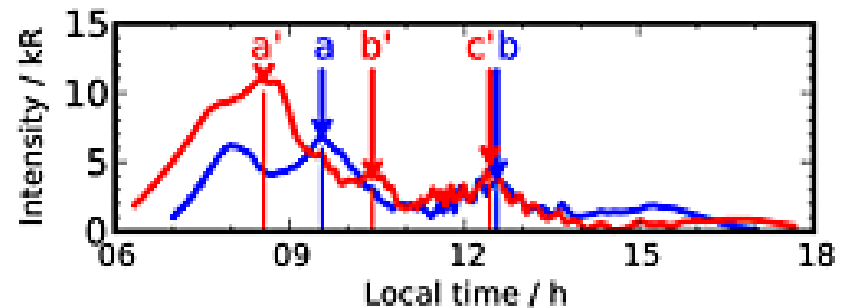
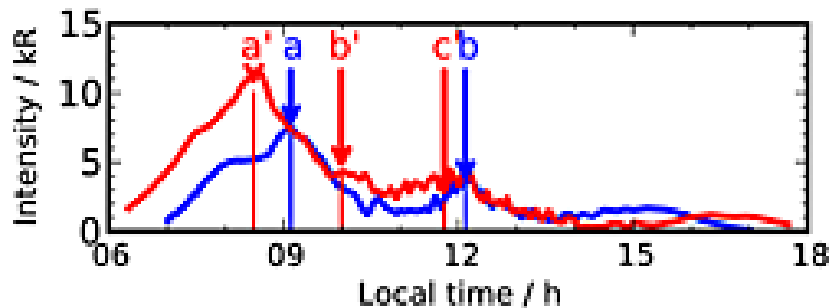
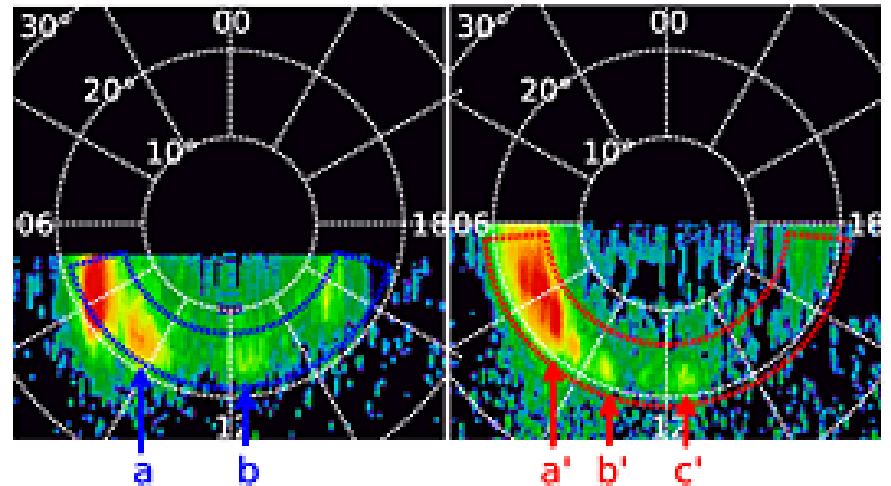
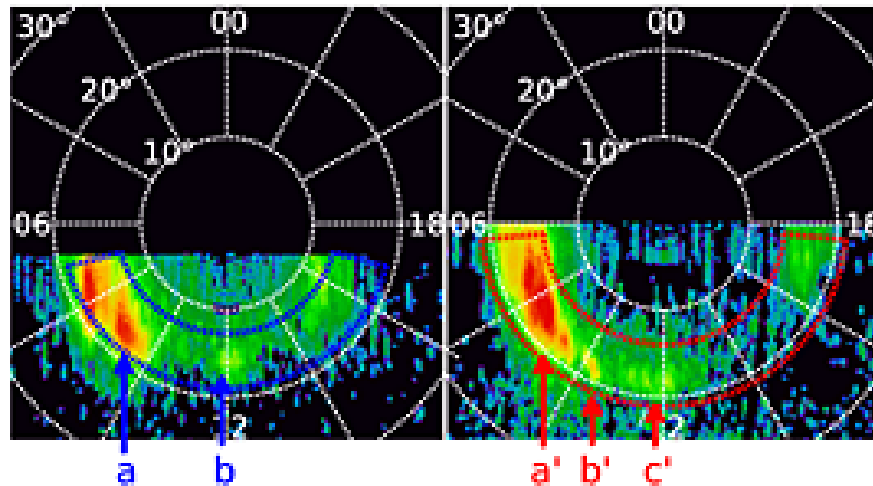
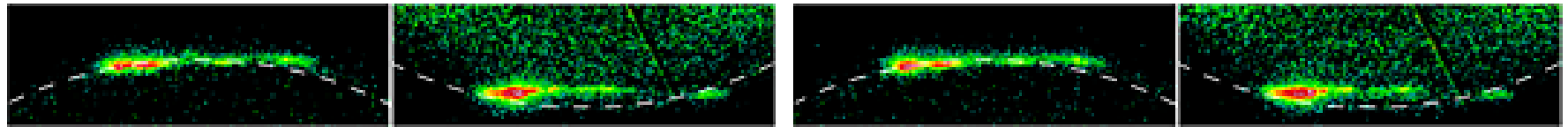
2009-02-18 07:48:20

North

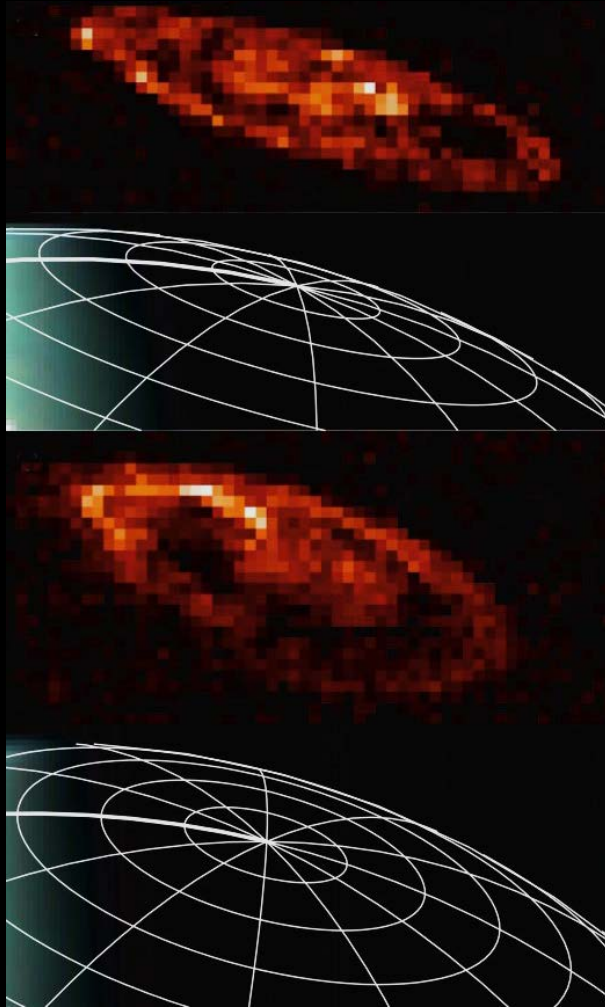
South

North

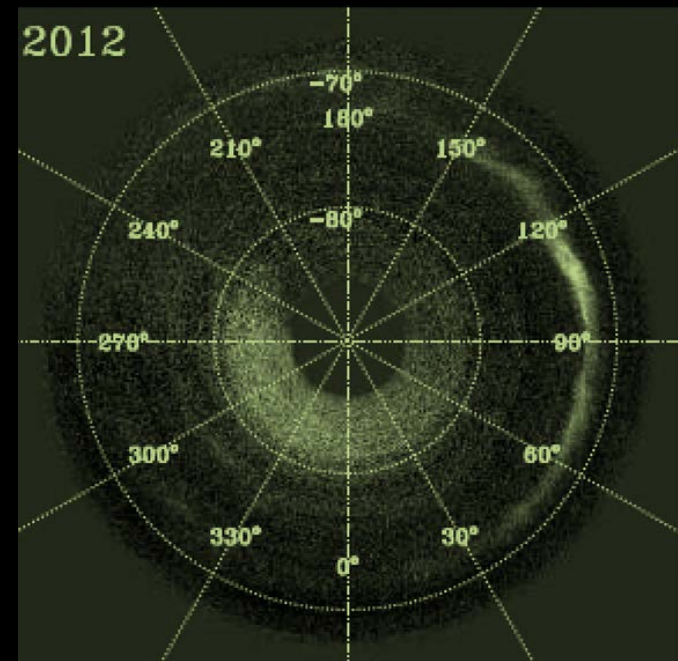
South



Polar cap aurora



Stallard et al., 2008

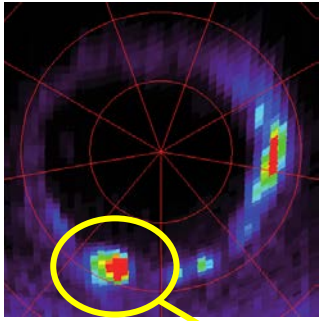


Dyudina et al., submitted

Magnetospheric
plasma
interactions

Energetic plasma interactions





Cassini/UVIS

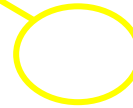
UV aurora related to **electrons** injections

1) pitch angle diffusion + electron scattering

and

2) FACs driven by ∇p along boundaries of hot plasma cloud (ENA)

Cassini/INCA

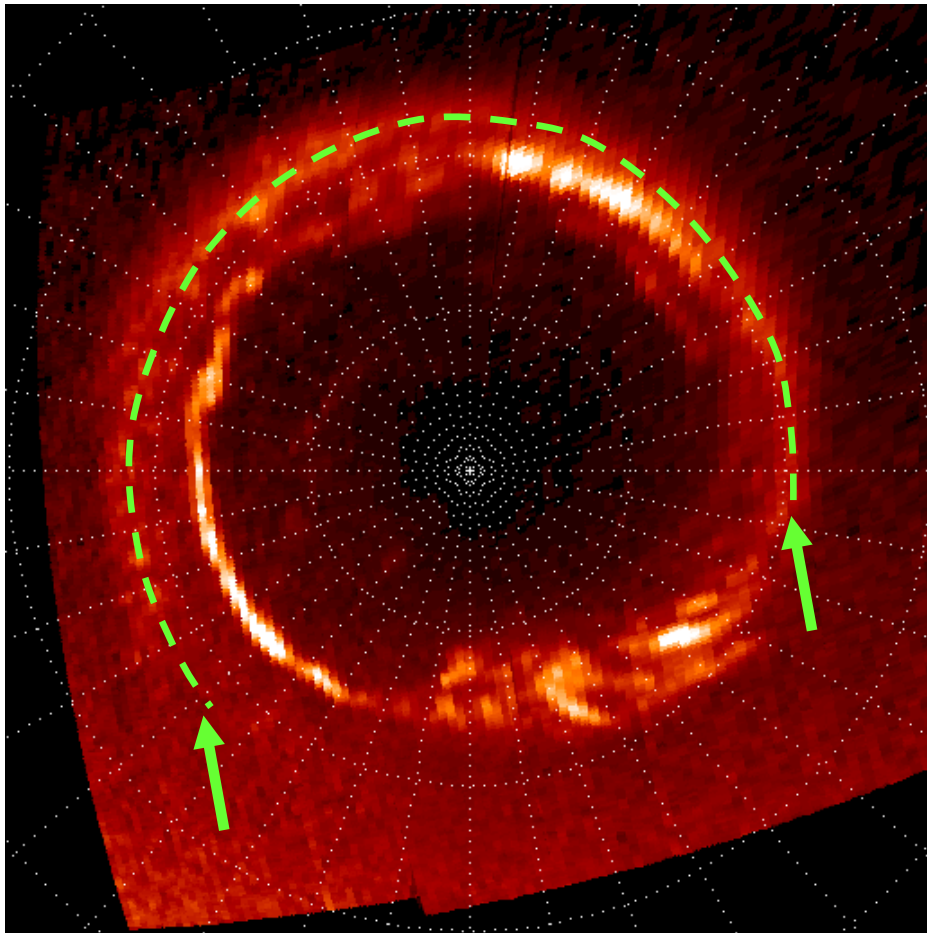


Older feature (disappeared in UV)

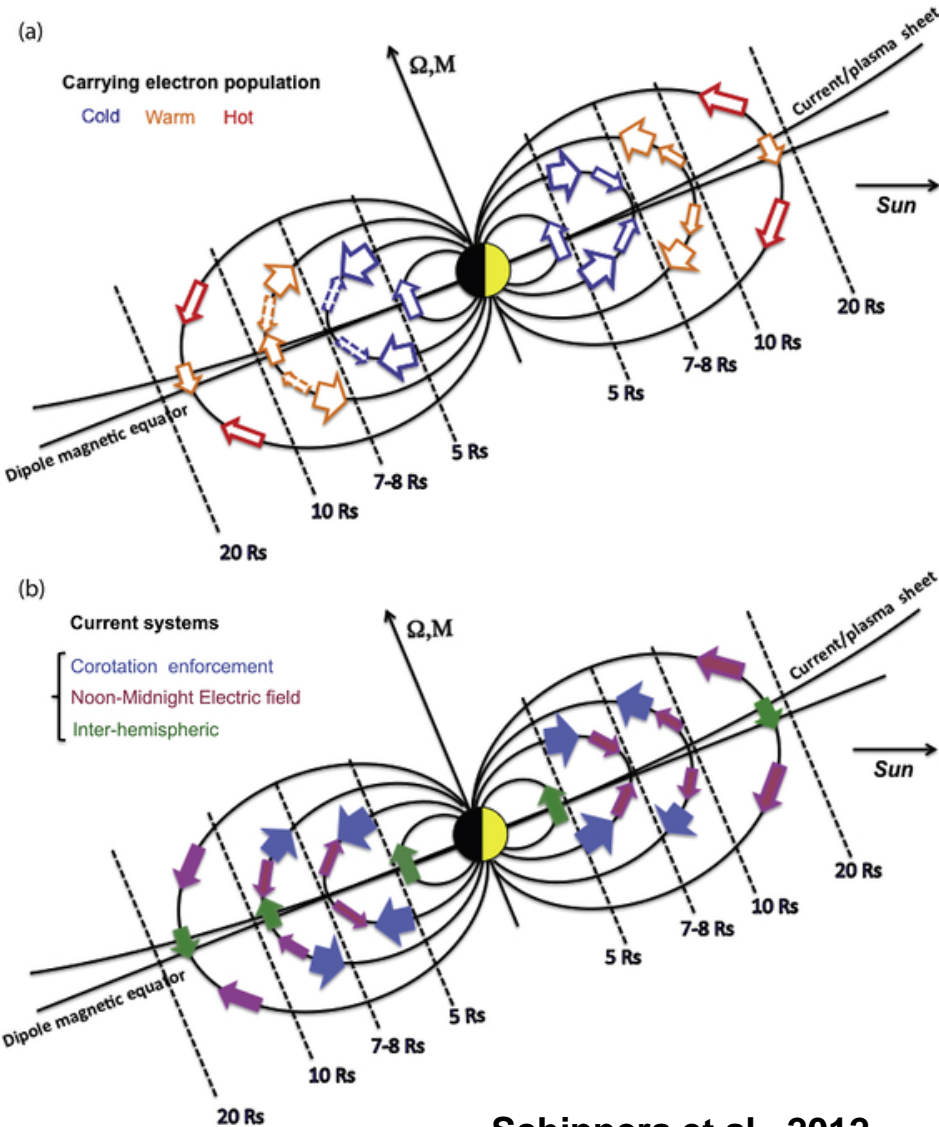
variable color scale

'Outer' aurora

Cassini/UVIS 2008_240_05_46 South Pole

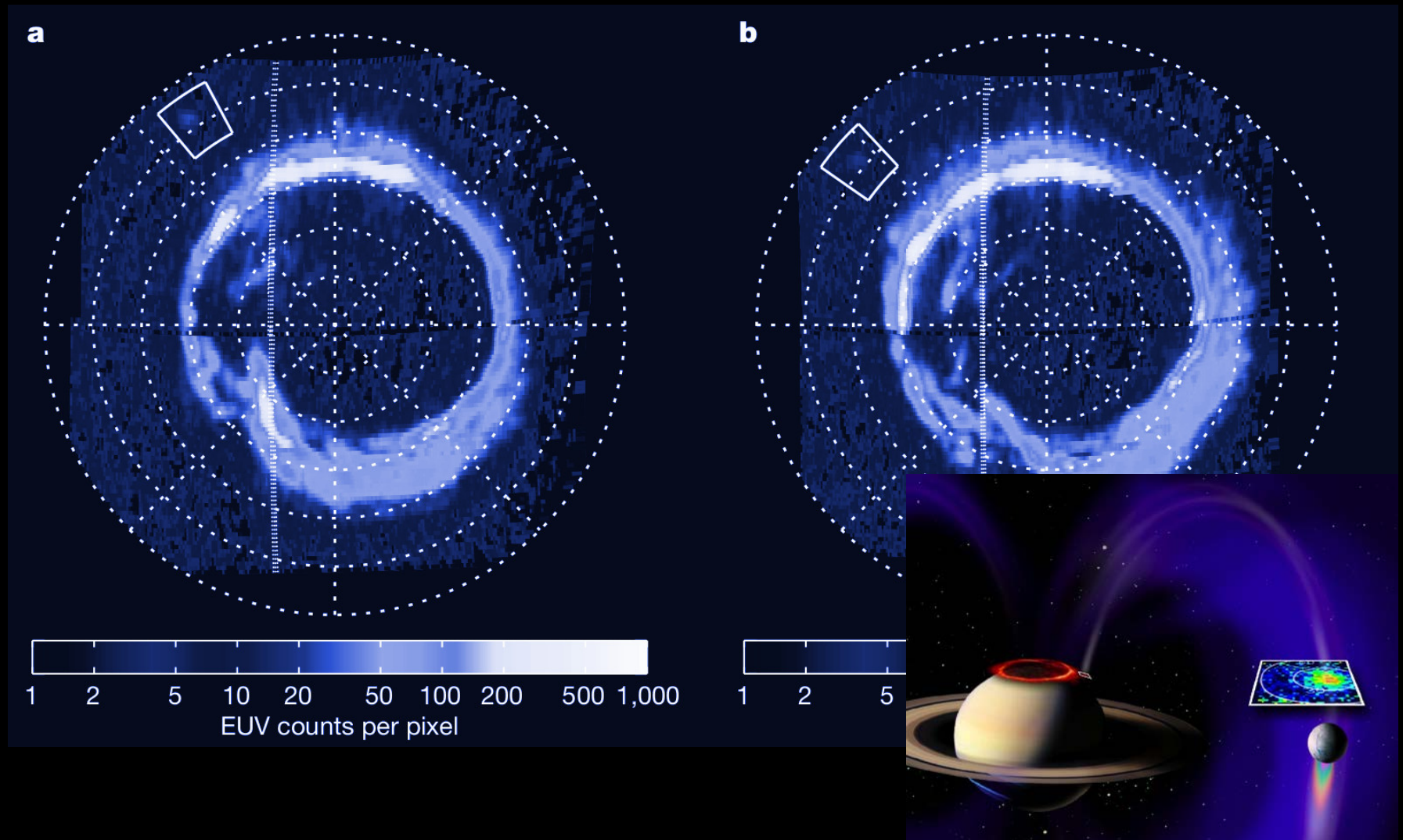


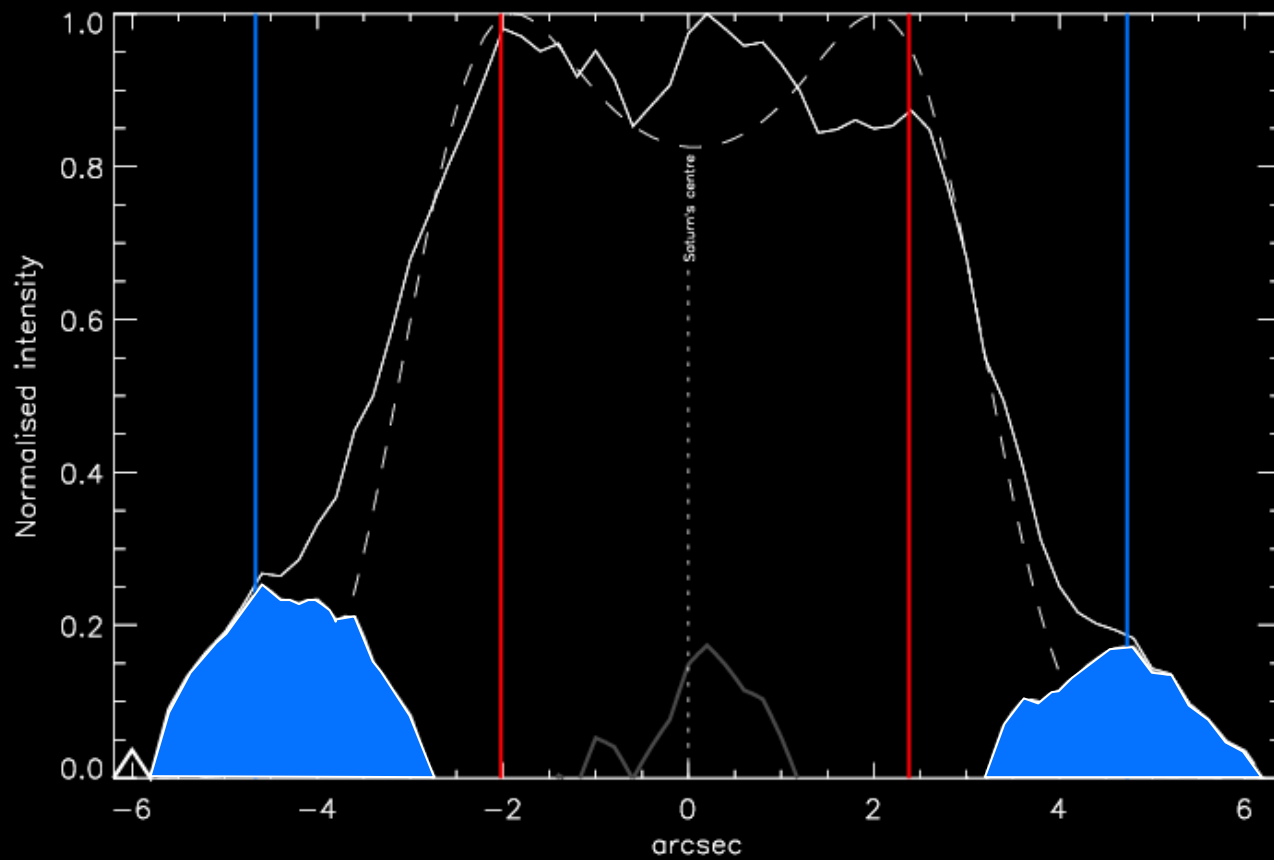
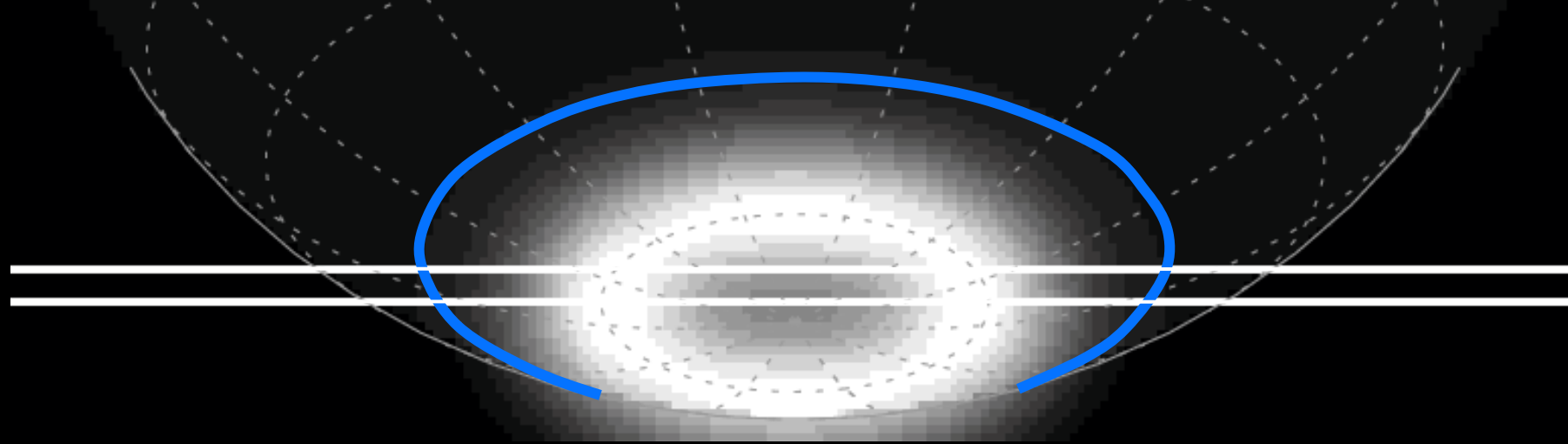
Grodent et al. WIP



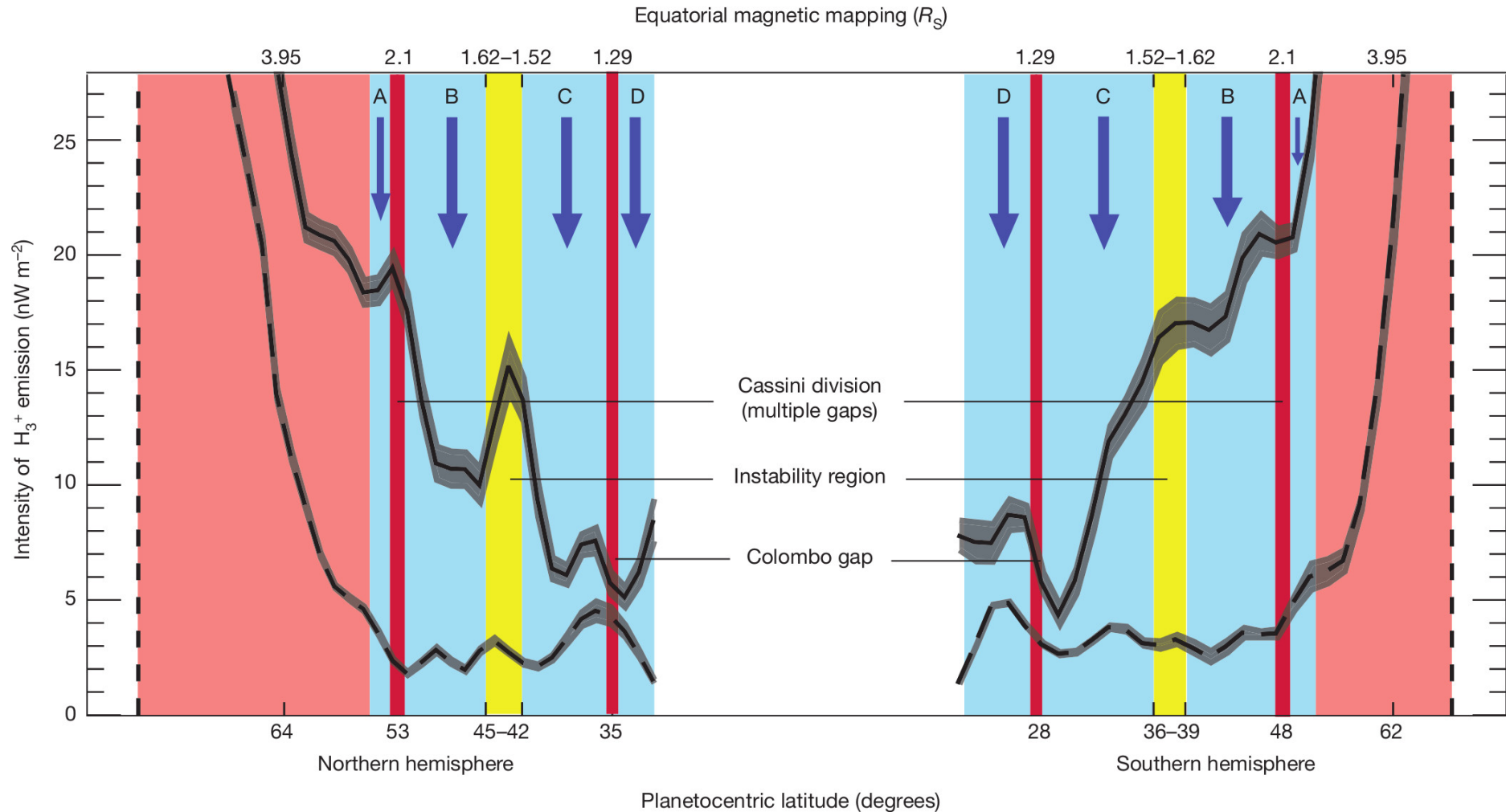
Schippers et al., 2012

Enceladus interactions





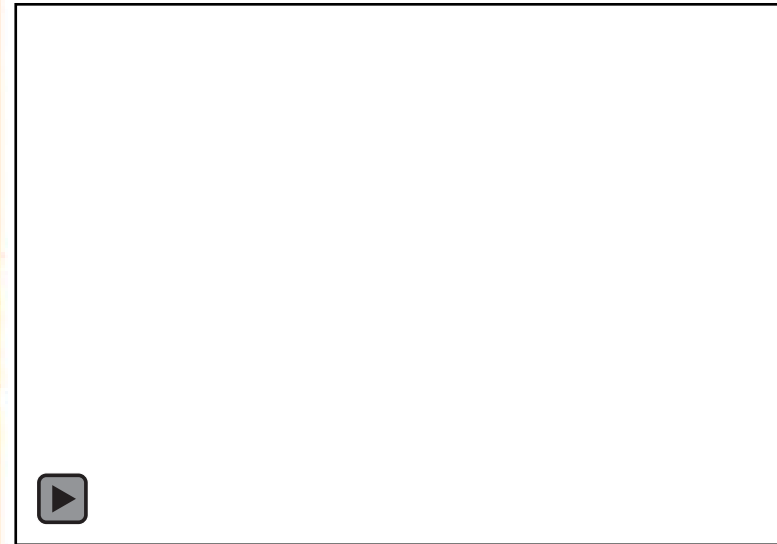
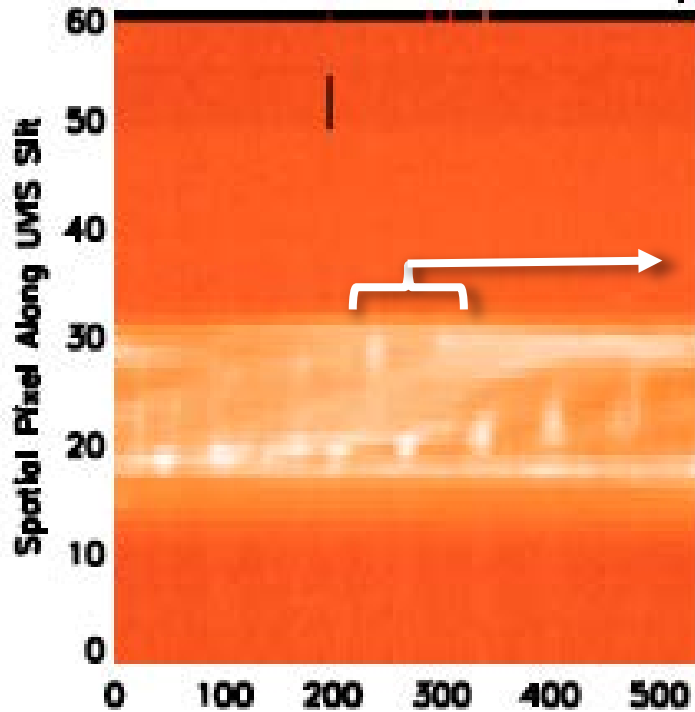
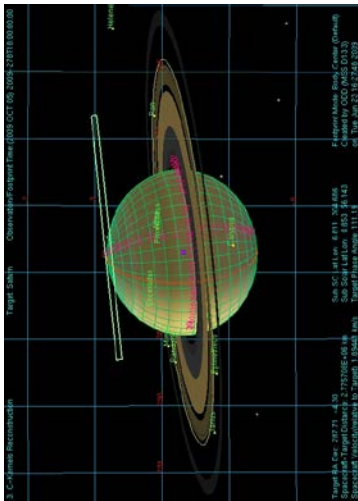
'Ring rain' - aurora?



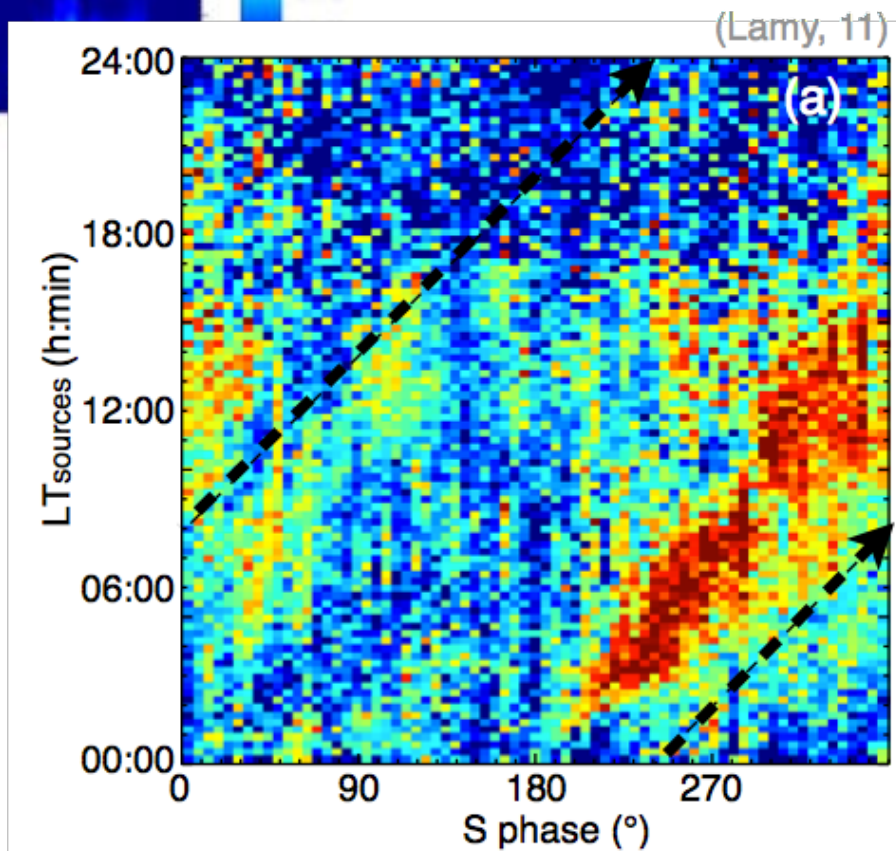
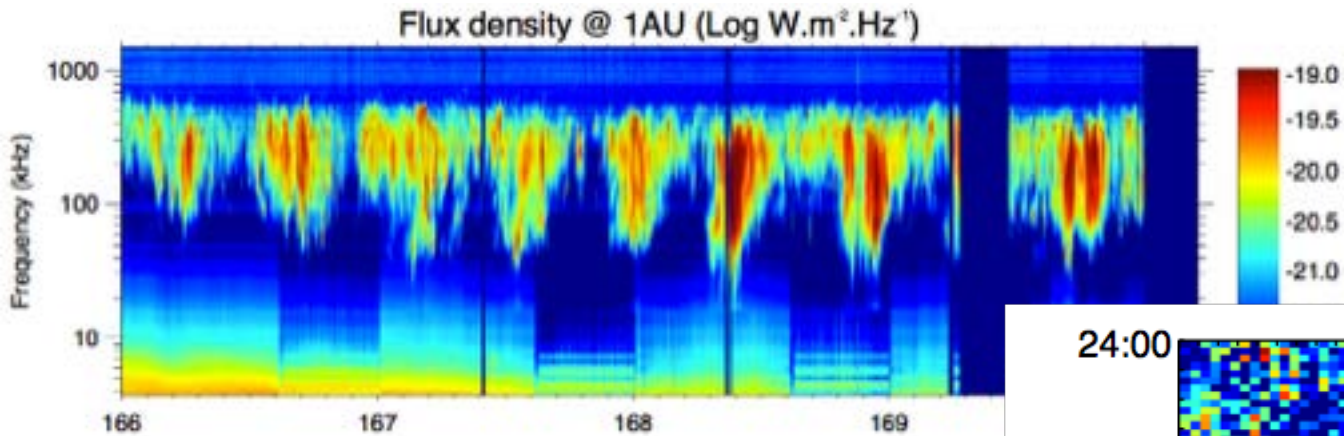
O'Donoghue et al., 2013

Periodic oscillations

One-hour period oscillations



Planetary period oscillations





Saturn North

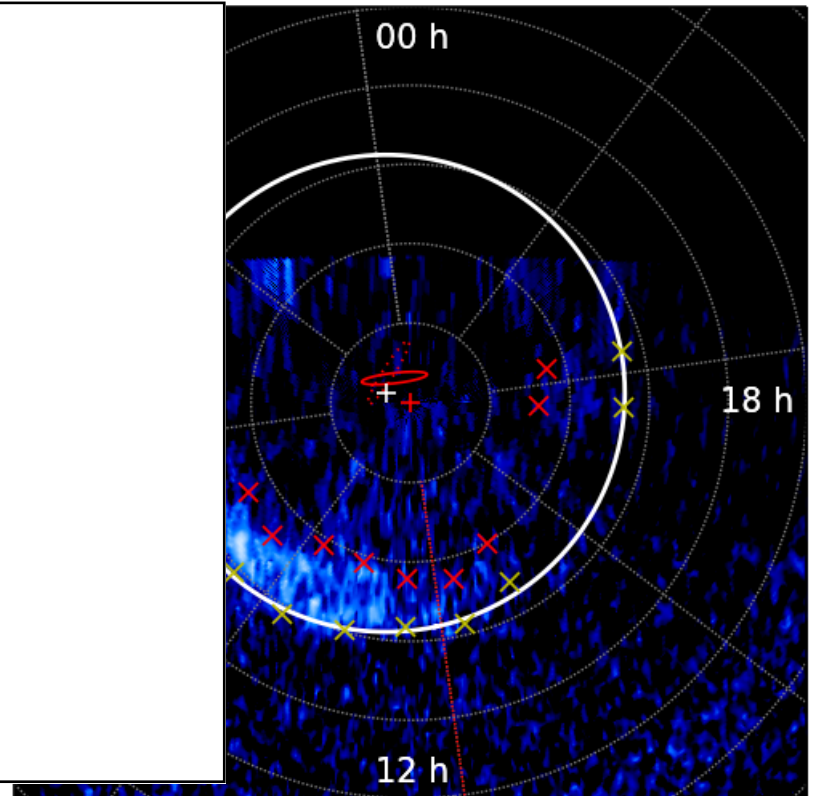
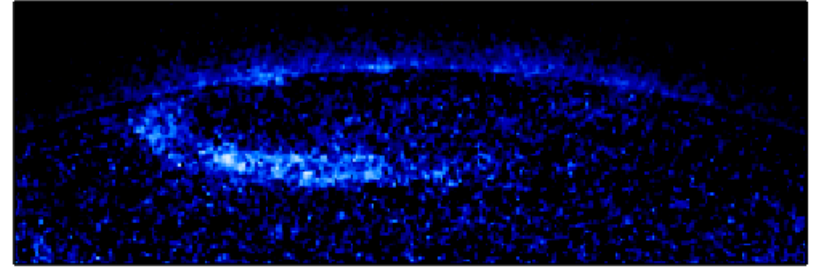
2012-04-03 (DoY 94)

10:24:31 (Earth), 09:11:48 (Saturn)

Visit = I7.001

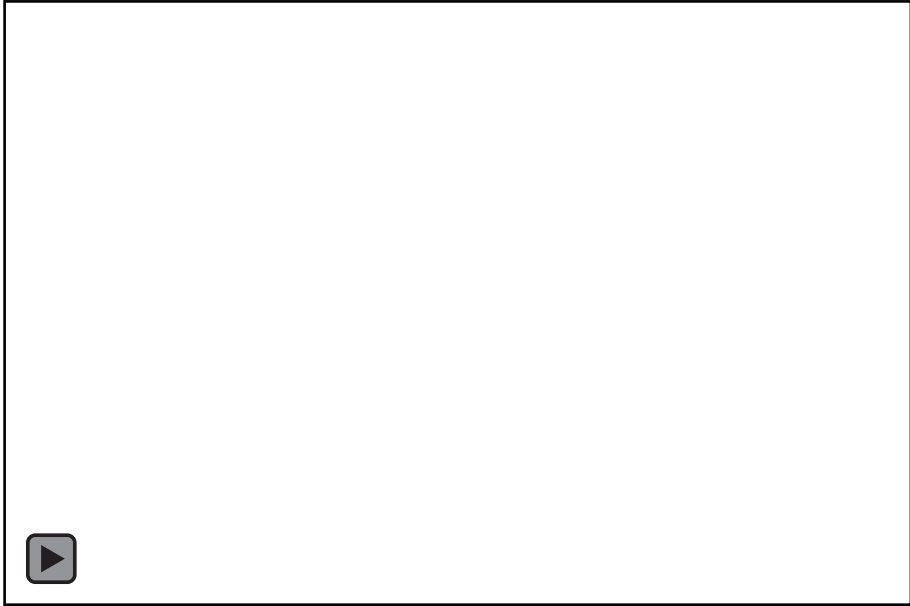
Filter = F125LP

$\varphi_{mag N} = 8^\circ$

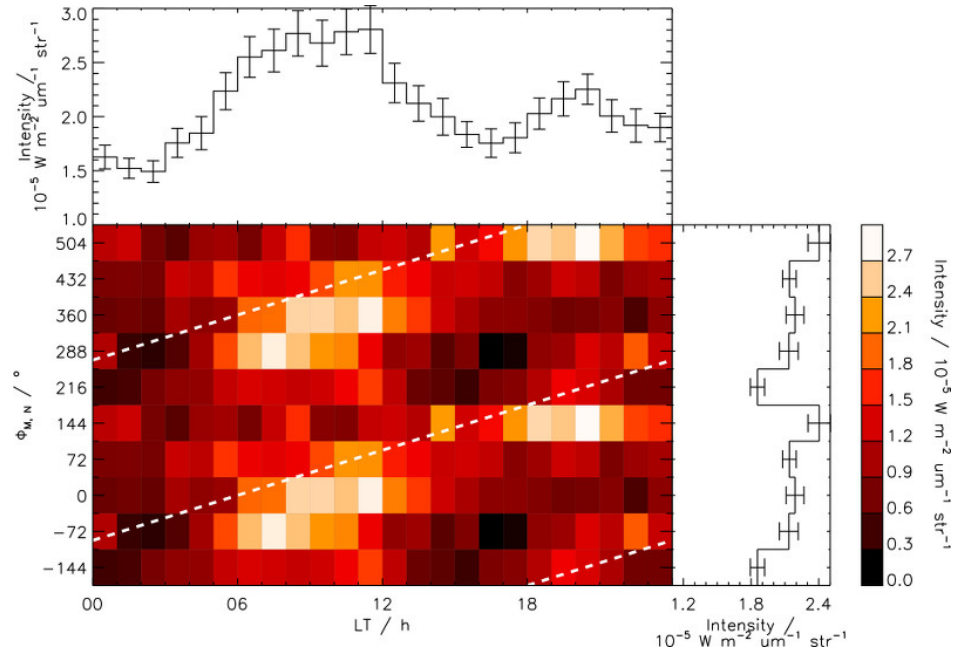


Nichols et al., 2010

Nichols et al., submitted



Stallard



Badman et al., 2012

Auroral currents in PPO phase

59 60 61 62 63 64 65

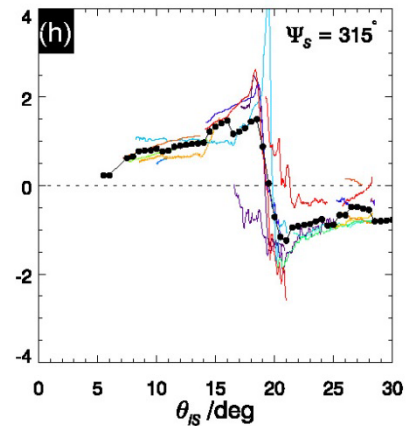
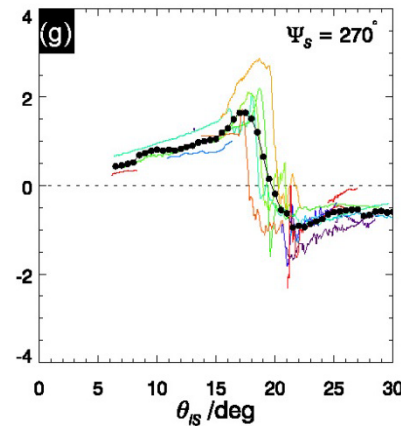
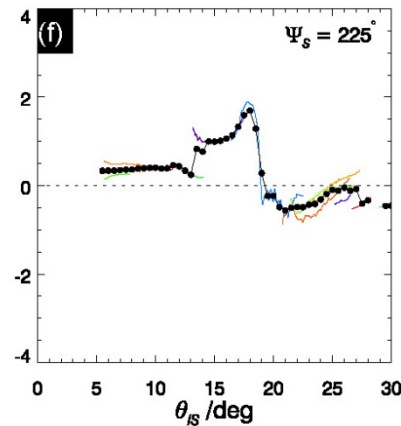
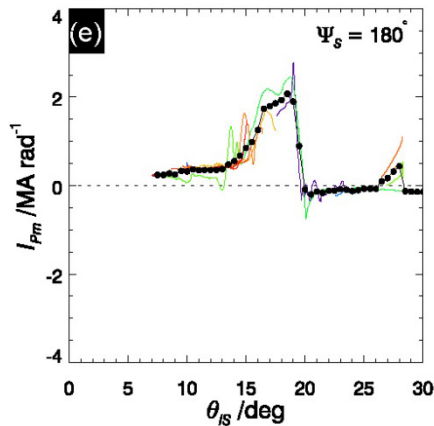
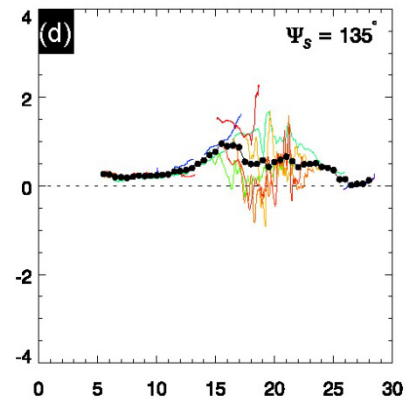
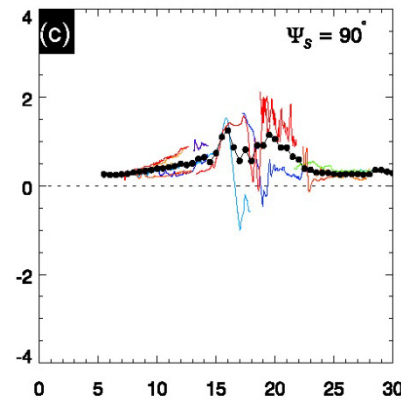
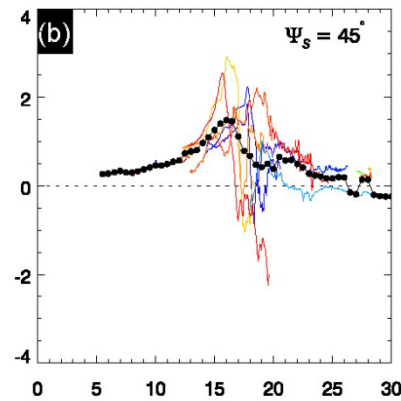
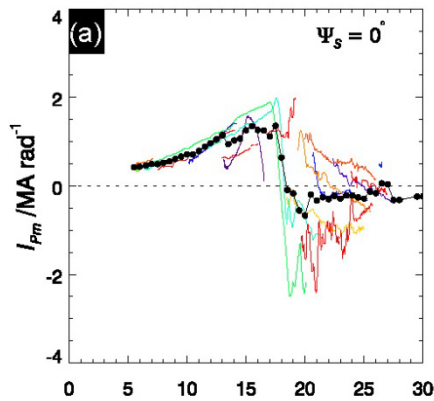
67 68 69

72 73 74 75 76

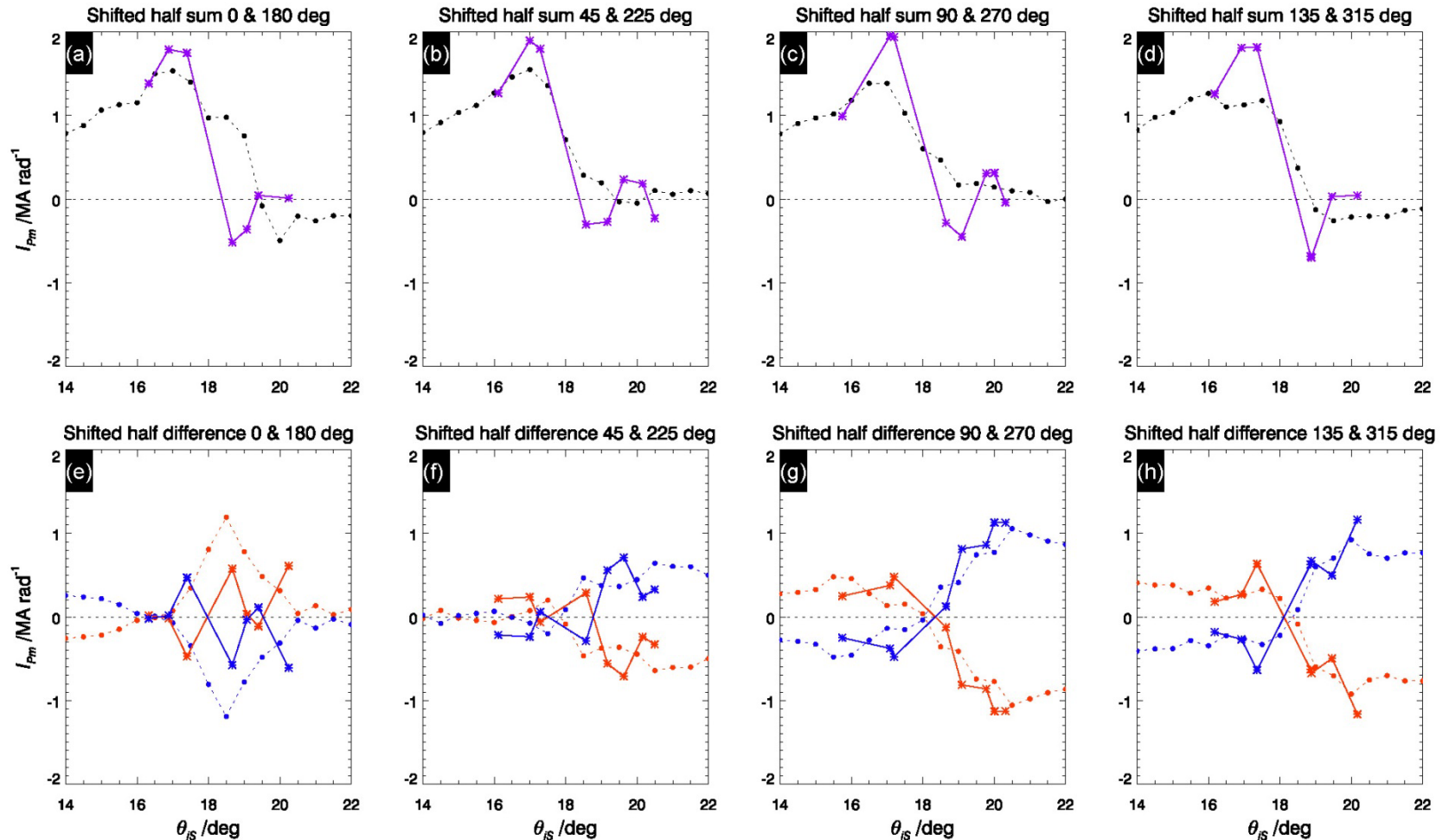
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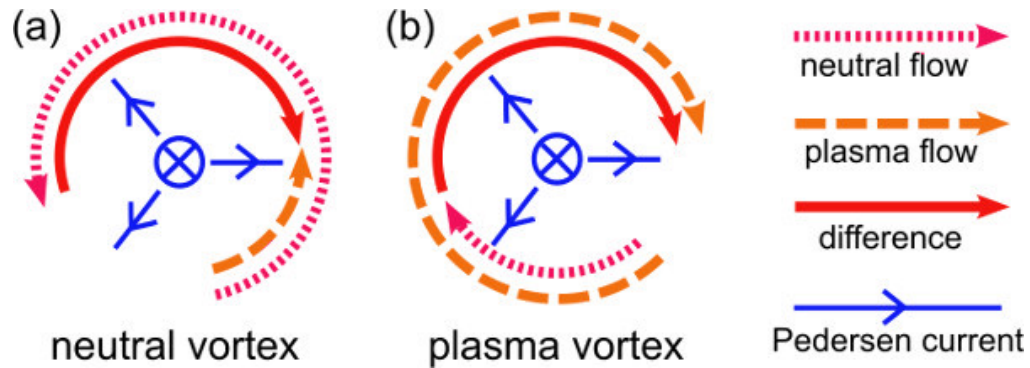
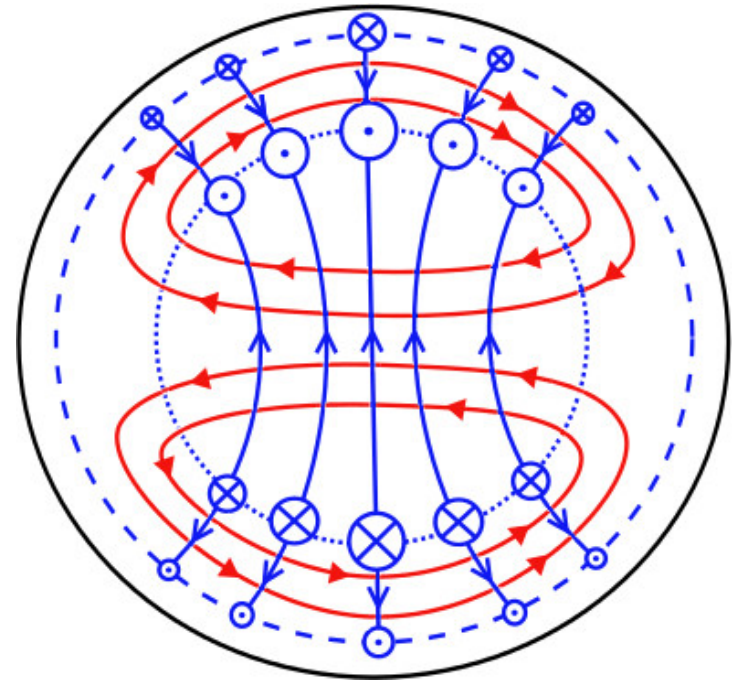
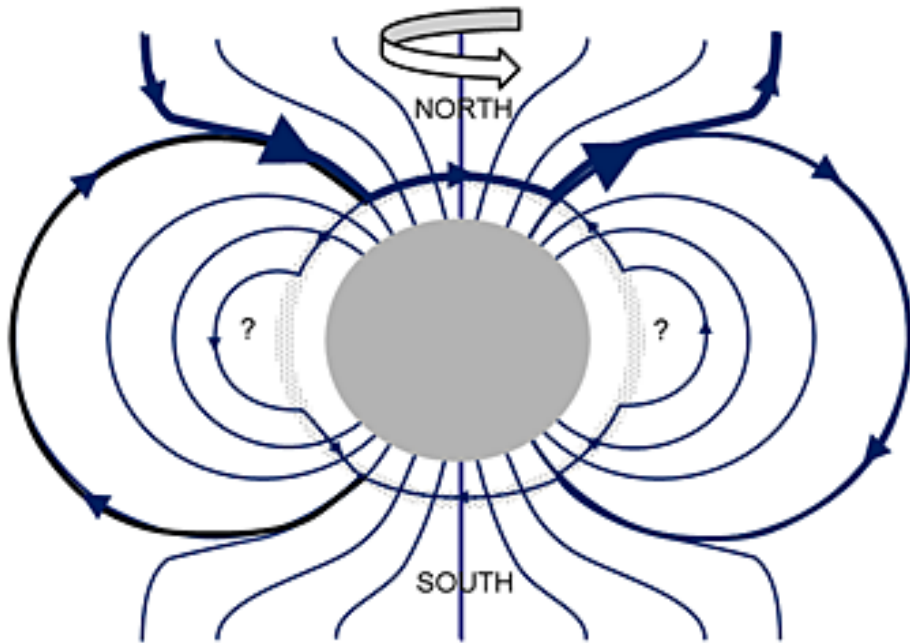
90 91 92 93

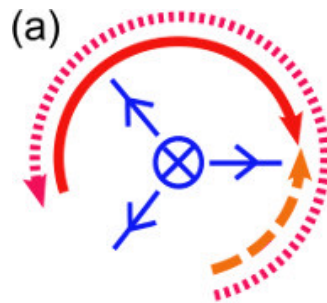
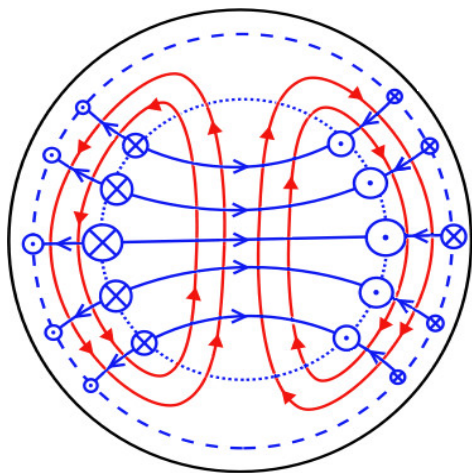
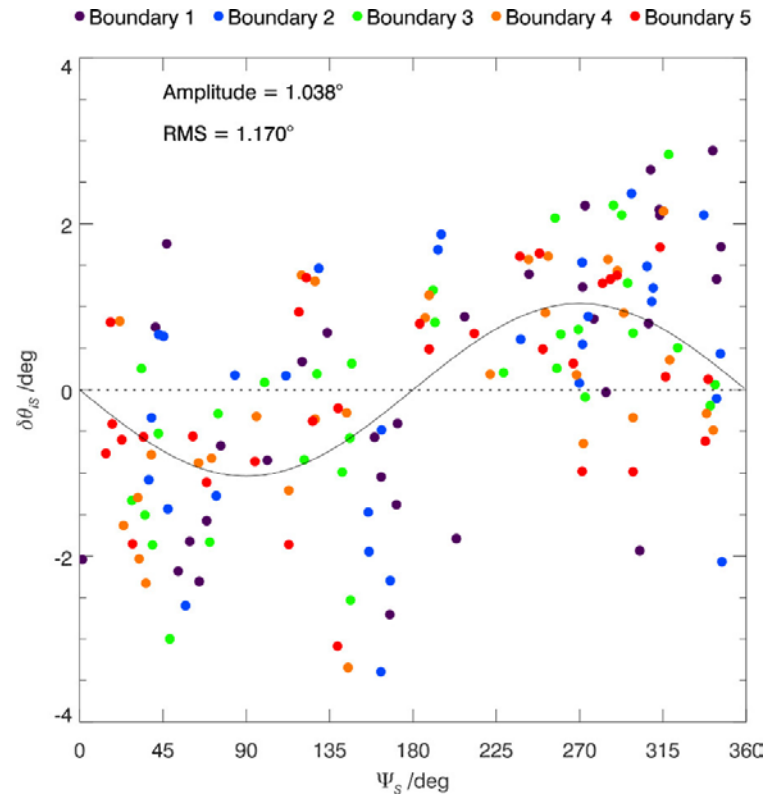
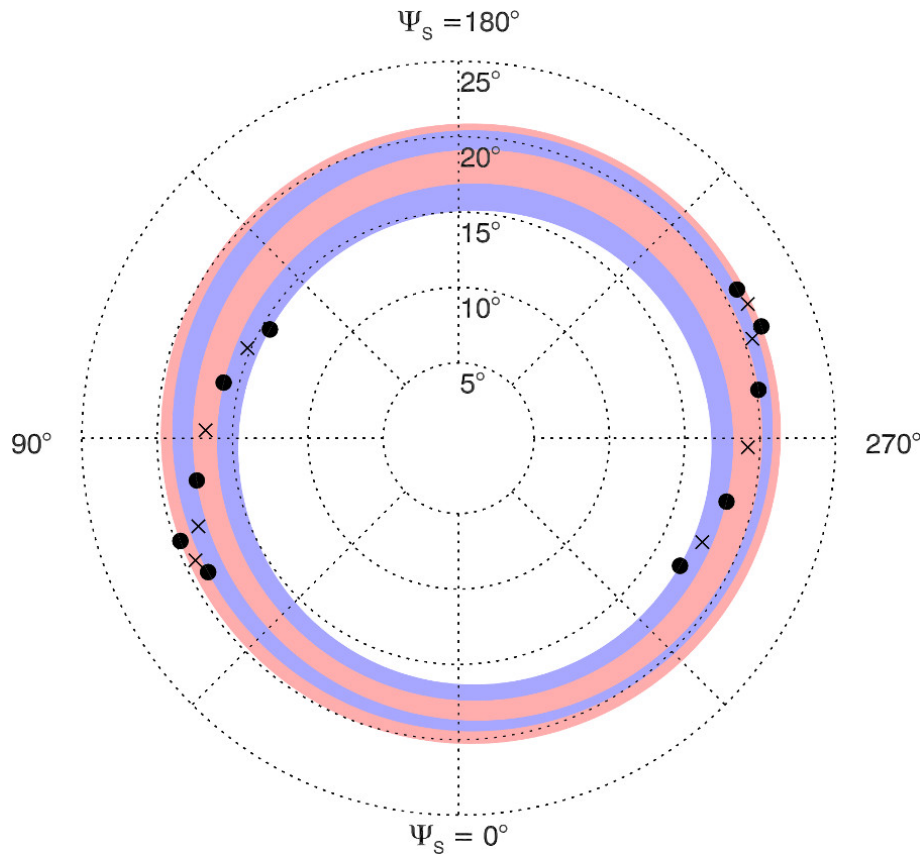
95



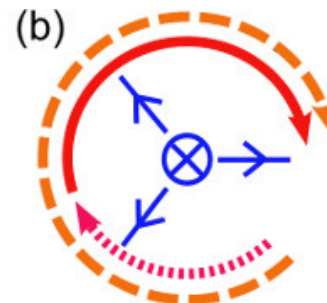
Opposite sum and difference profiles



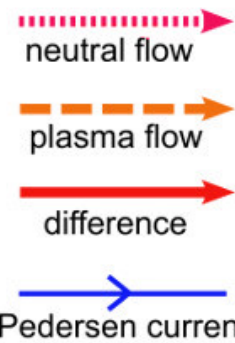




neutral vortex



plasma vortex



Summary

Drivers of aurora

- Solar wind interactions (*Earth-like*)
- Internal plasma interactions (*Jupiter-like*)
- Neutral atmosphere interactions(?)
- Highlights the need for multi-instrument observations

Ongoing research

- ★ 2013 Campaign Icarus Special Issue
 - Continued simultaneous observations in 2014-2015
 - Proximal orbit campaign
 - Need to observe mesosphere-ionosphere-aurora interactions
 - Seasonal variability