Proton Aurora

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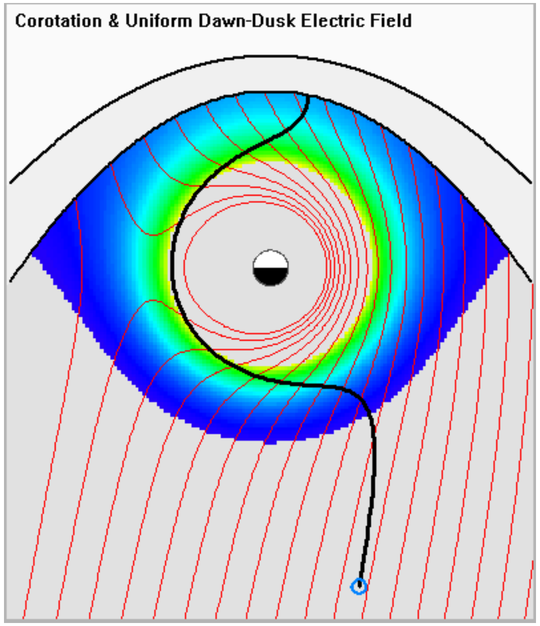

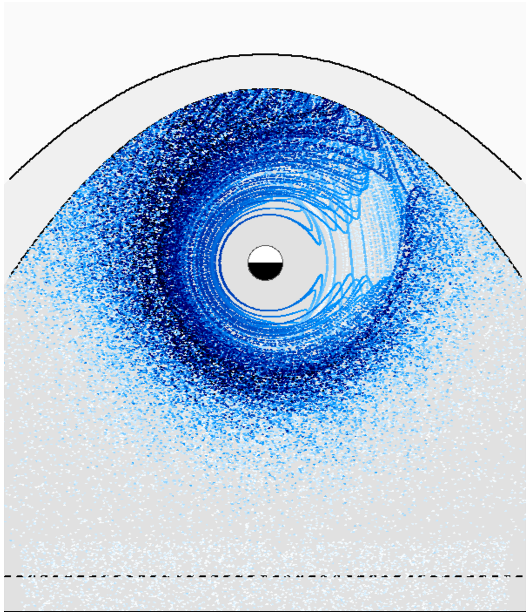

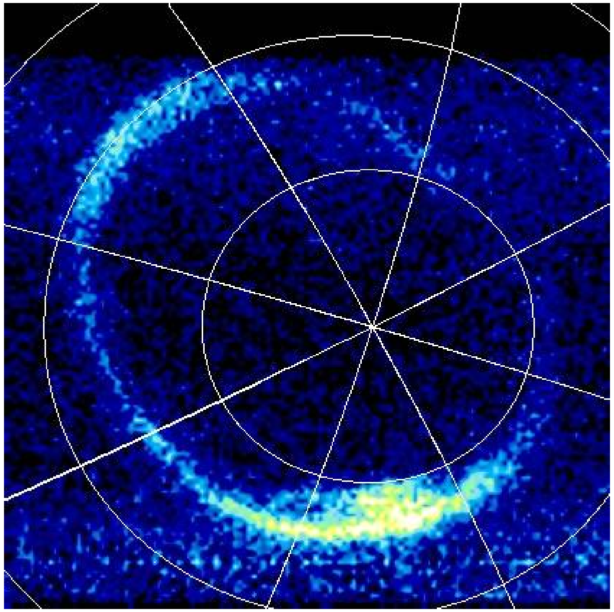

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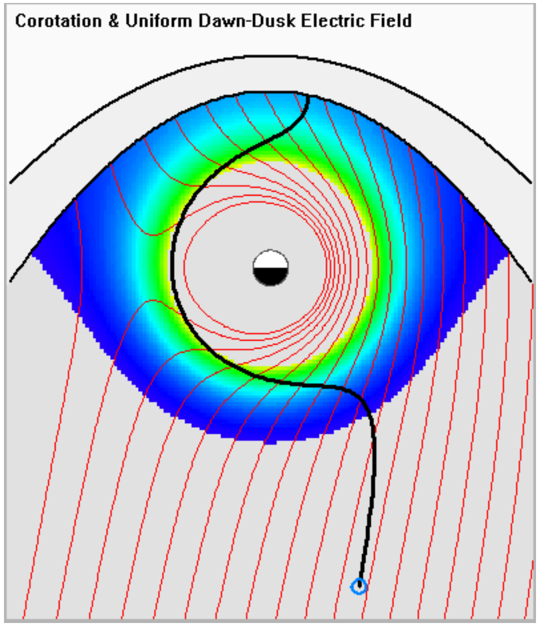
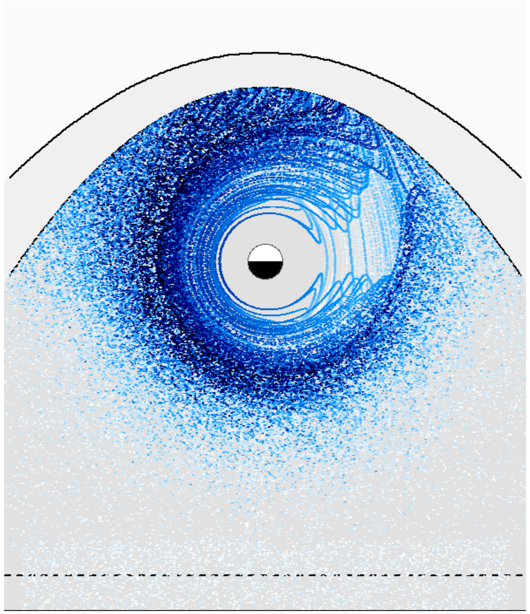
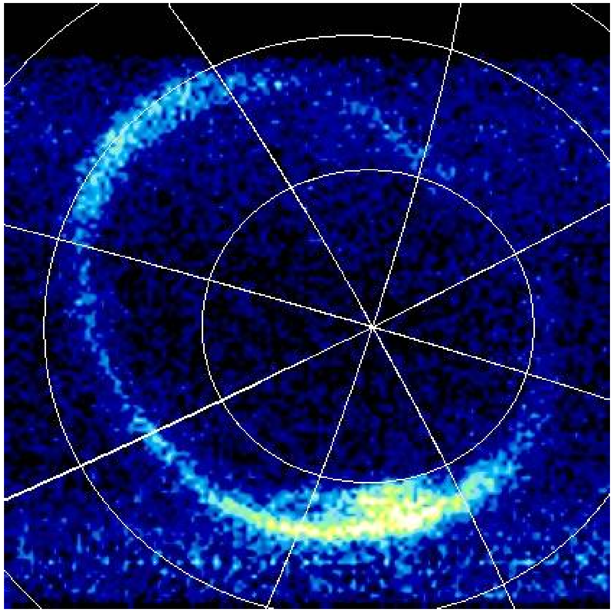
Proton Aurora

Some History







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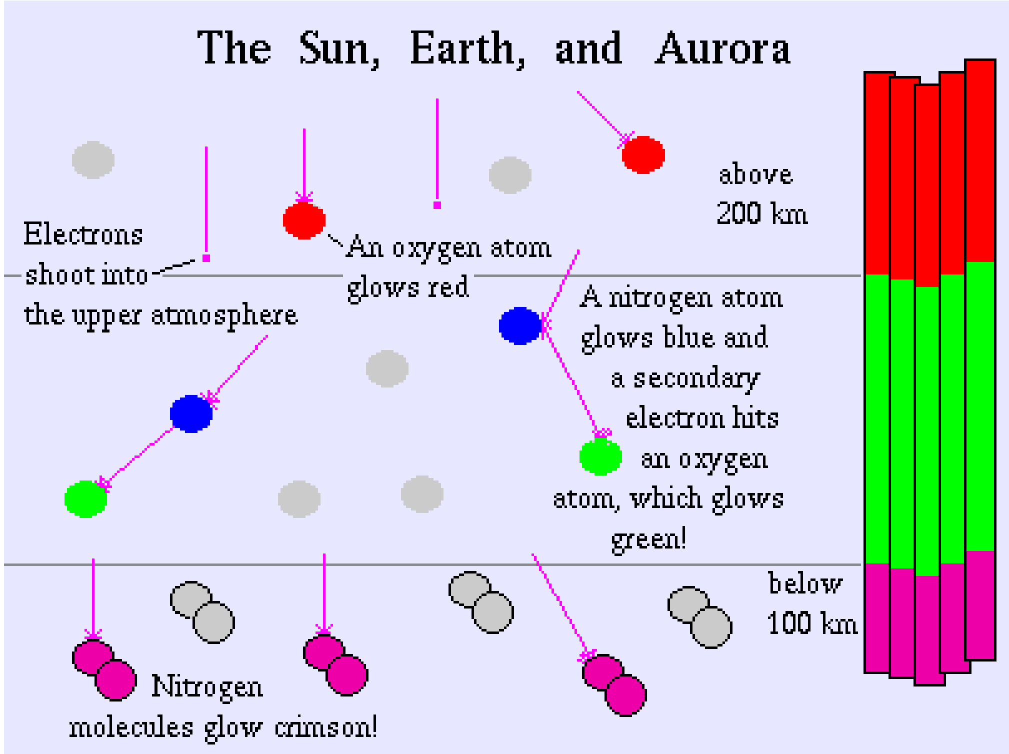


Christina Shaw, UAF

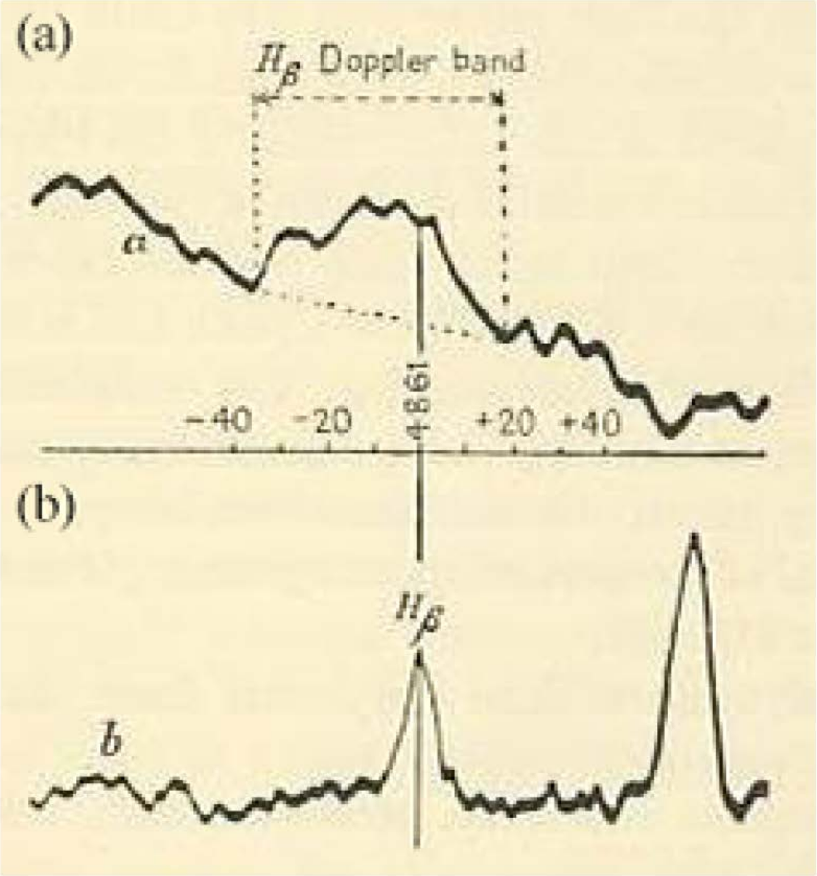


Figure 3. Example of H_β line Doppler-shifted towards the violet **(a)** in comparison with the unshifted line **(b)** observed in Vegard's laboratory.

Vegard, 1939; Egeland and Burke, 2019

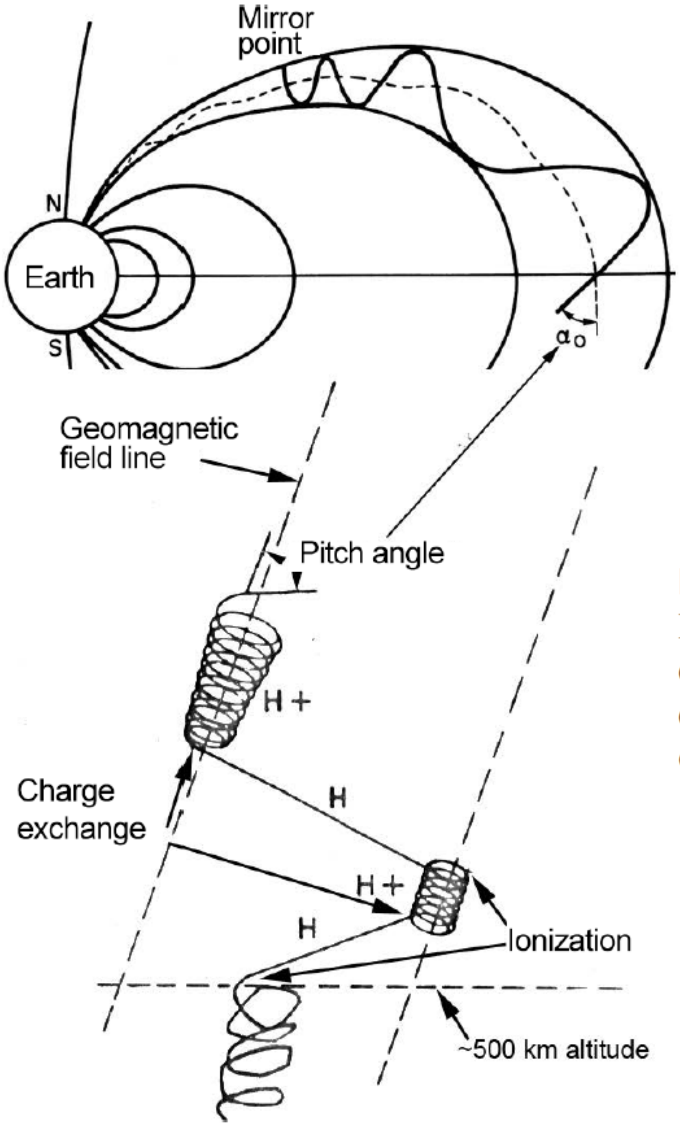
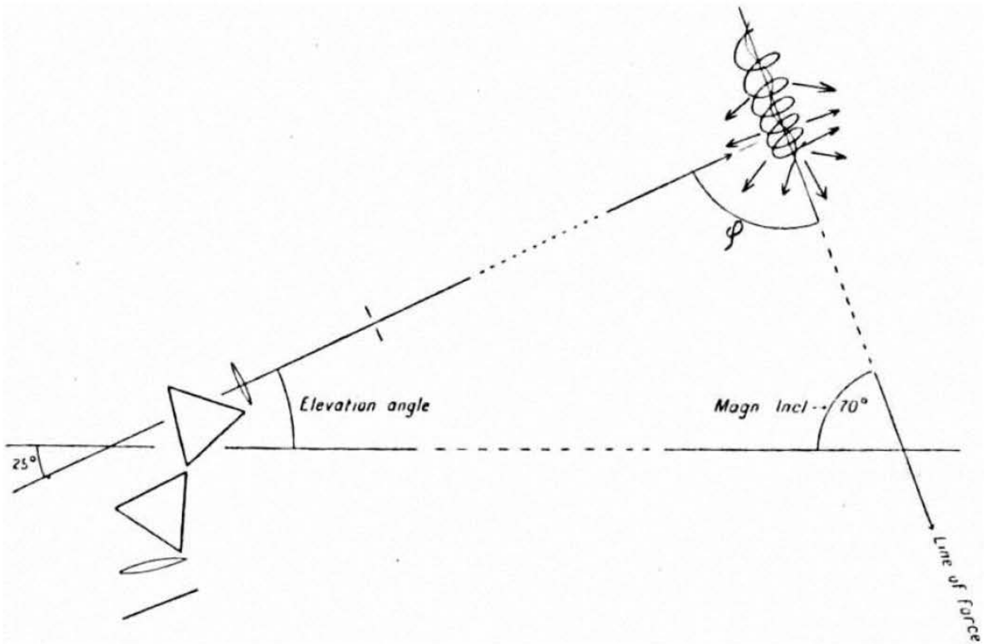


Figure 10. A cartoon representation where protons bombard the Earth's atmosphere; multiple charge exchanges occur resulting in excited hydrogen atoms (H*) emissions followed by hydrogen emissions, new ionizations and charge exchanges. The production of hydrogen emissions mainly occurs below 200 km.

Davidson, 1965; Egeland and Burke, 2019

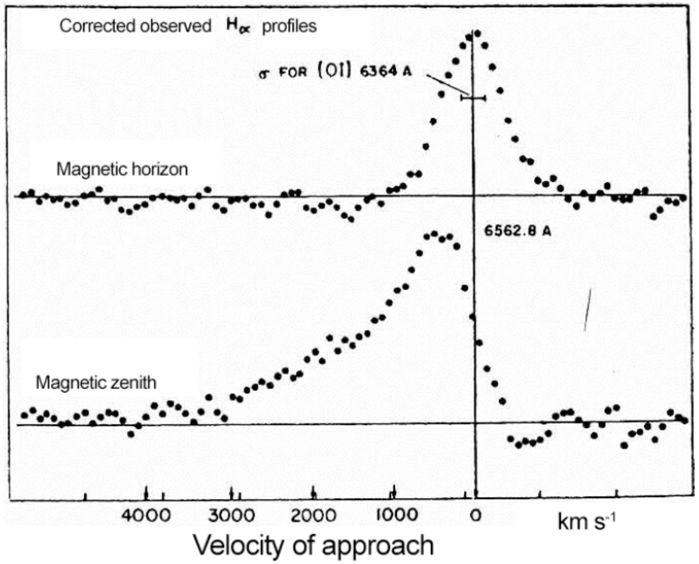


Egeland and Burke, 2019

Figure 4. Schematic illustrating spectral results seen by two observers looking at the same H_β emission source, parallel and perpendicular to the Earth's magnetic field.

Figure 5. A Doppler shift of the H_β line towards the violet measured in kilometers per second during an intense aurora on 19 August 1950. According to Meinel (1950), the observed shift of more than 7 nm corresponds to a proton velocity of 3200 km s^{-1}.

Egeland and Burke, 2019



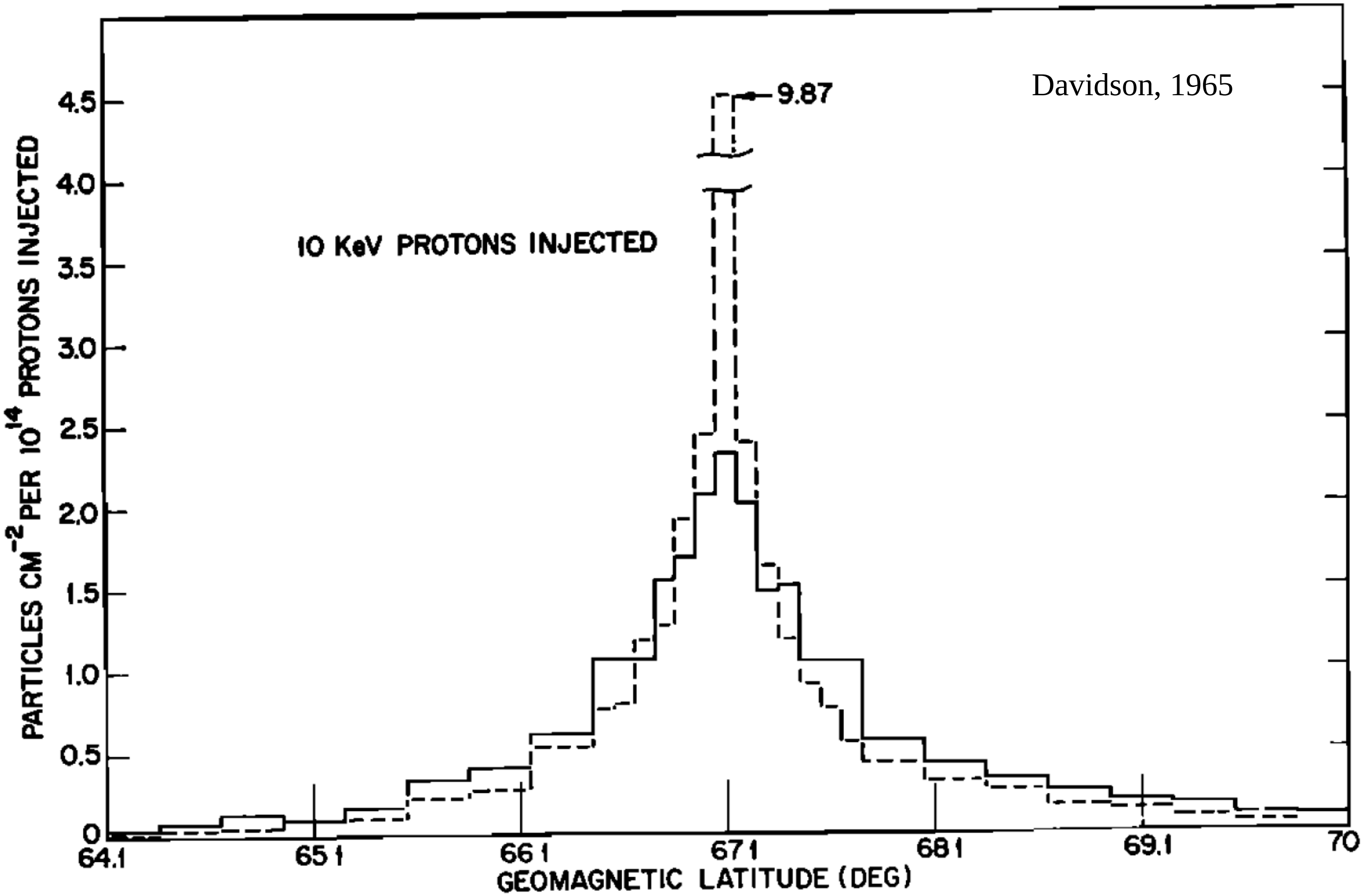
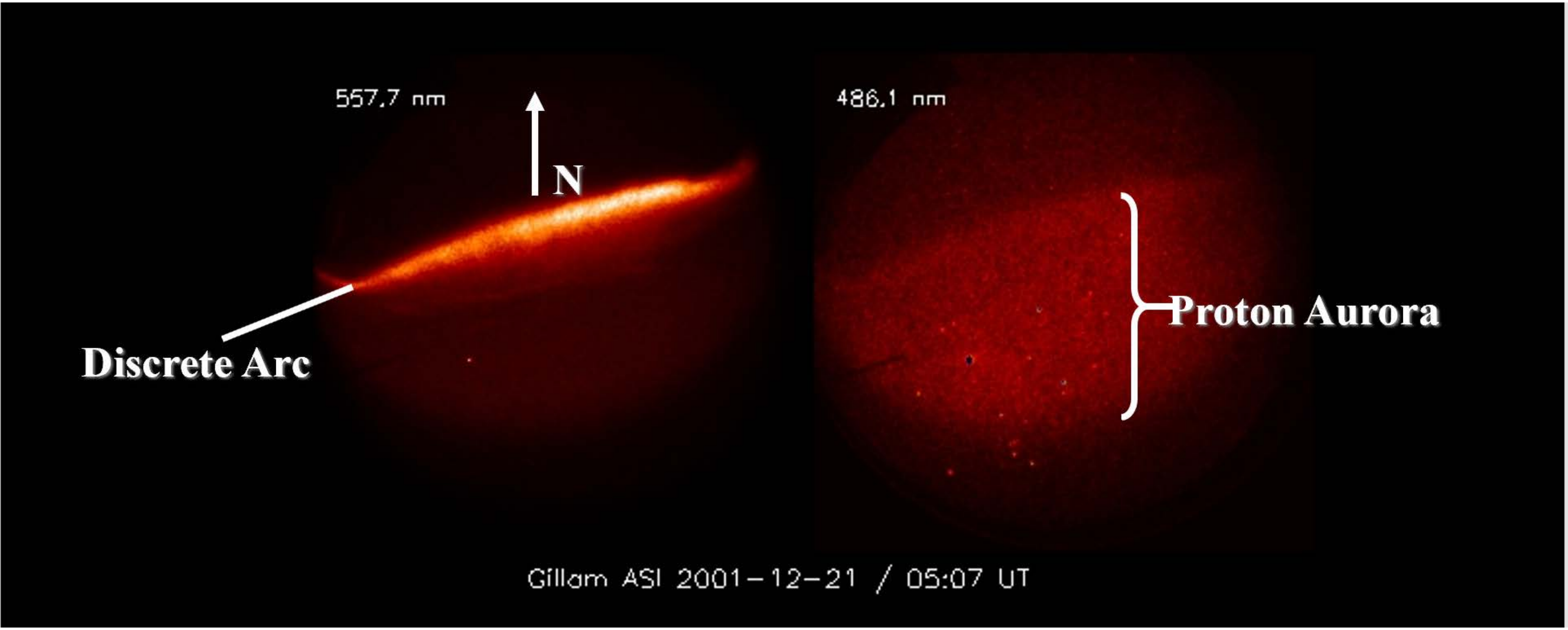
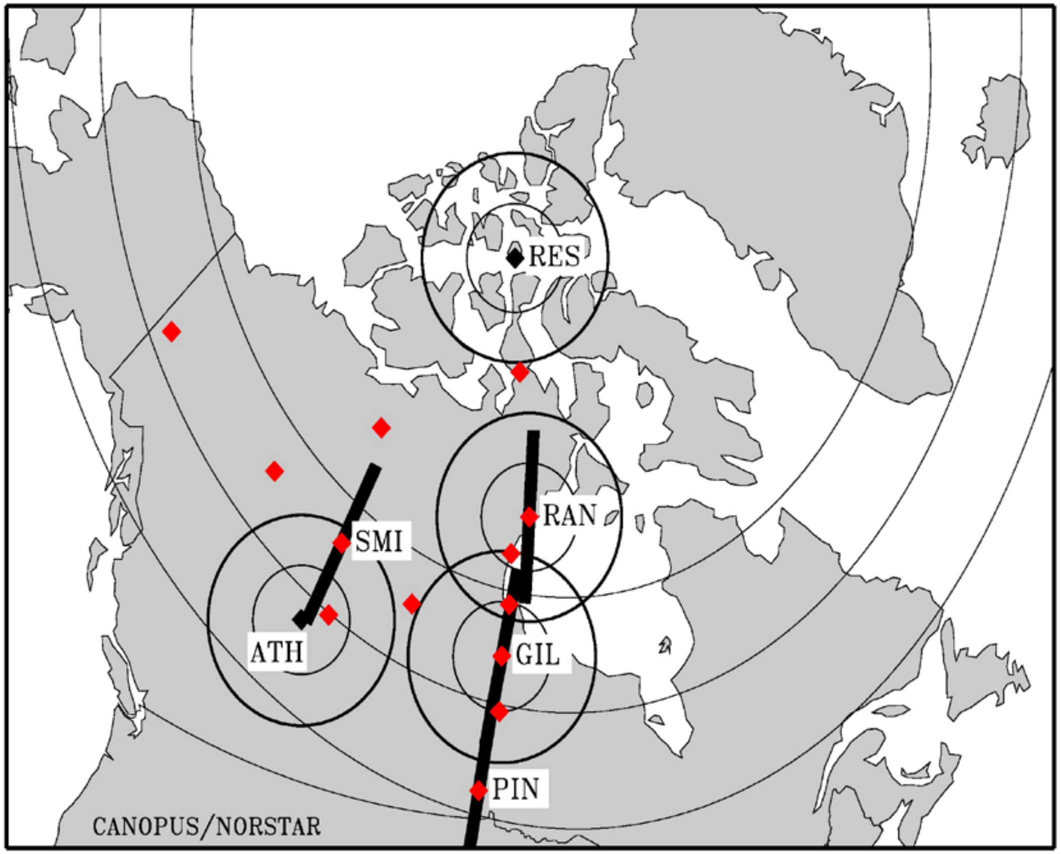
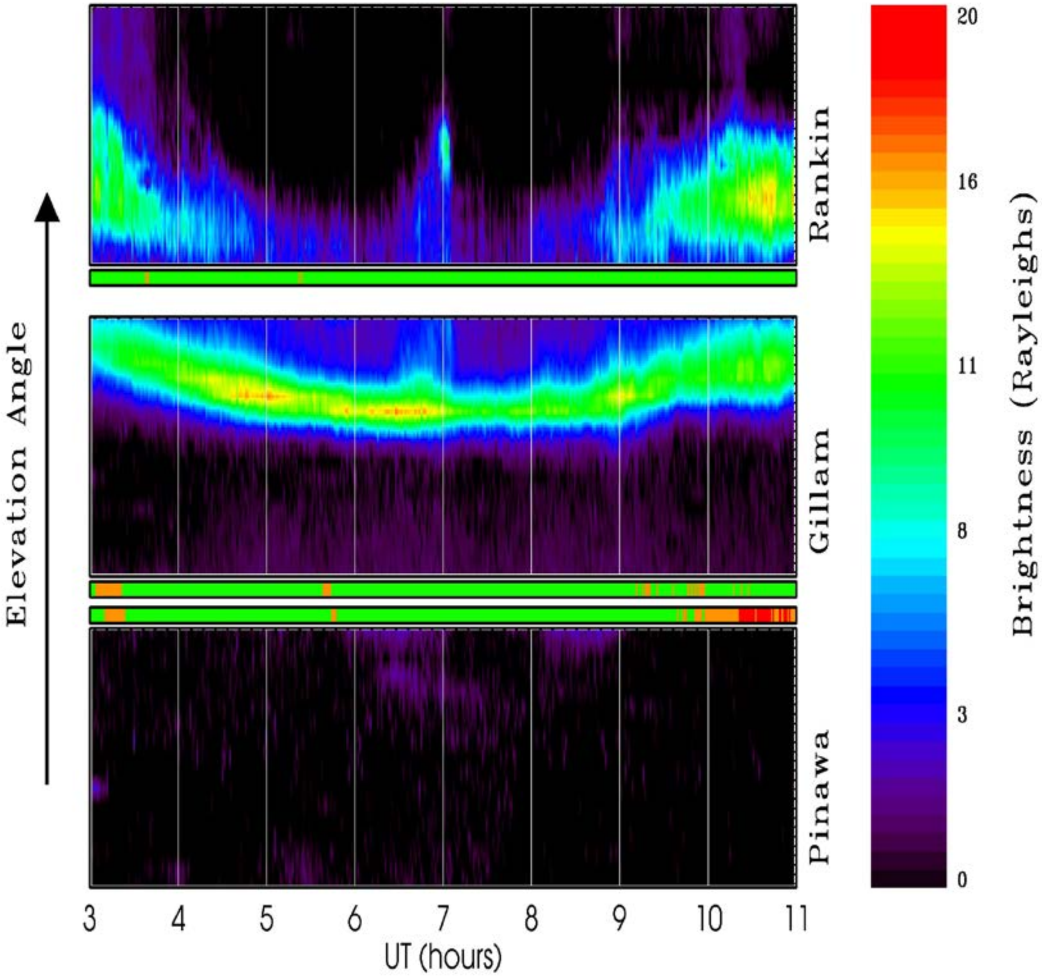


Fig. 5. The numbers of protons and hydrogen atoms per square centimeter crossing the altitudes of 306.7 km (dashed line) and 200.6 km (solid line). An isotropic injection pitch angle distribution was assumed. The proton injection energy is 10 kev; nearly identical results were obtained for 5 and 20 kev. Figures 5 and 7 are centered about the field line that intersects the earth's surface at a geomagnetic latitude of 67.1°.

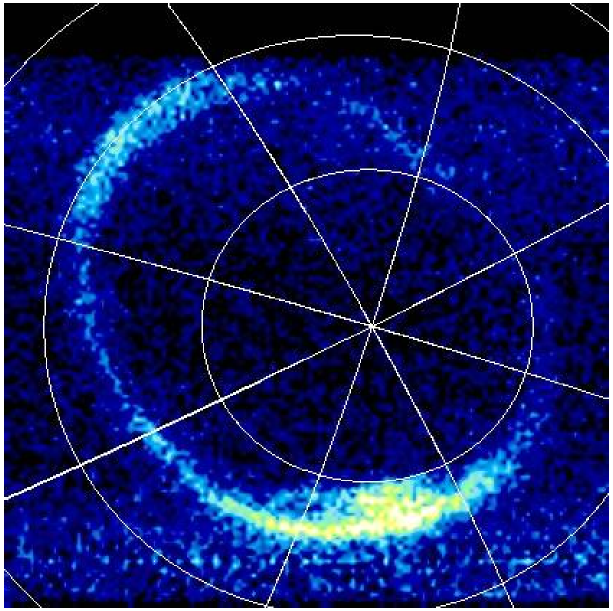


NORSTAR-CANOPUS Camera

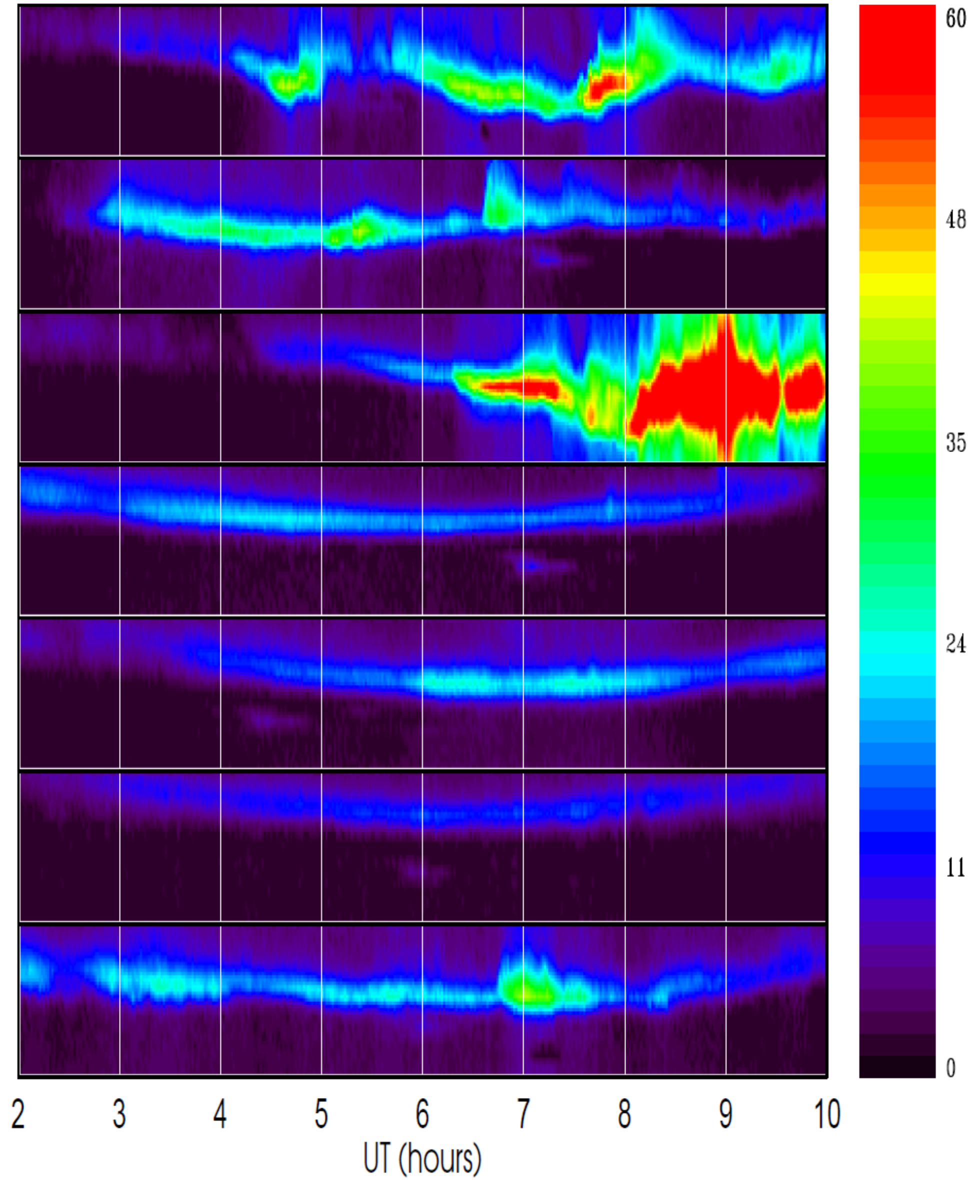

RES
RAN
SMI
ATH
GIL
PIN
CANOPUS/NORSTAR



CANOPUS Meridian Scanning Photometers

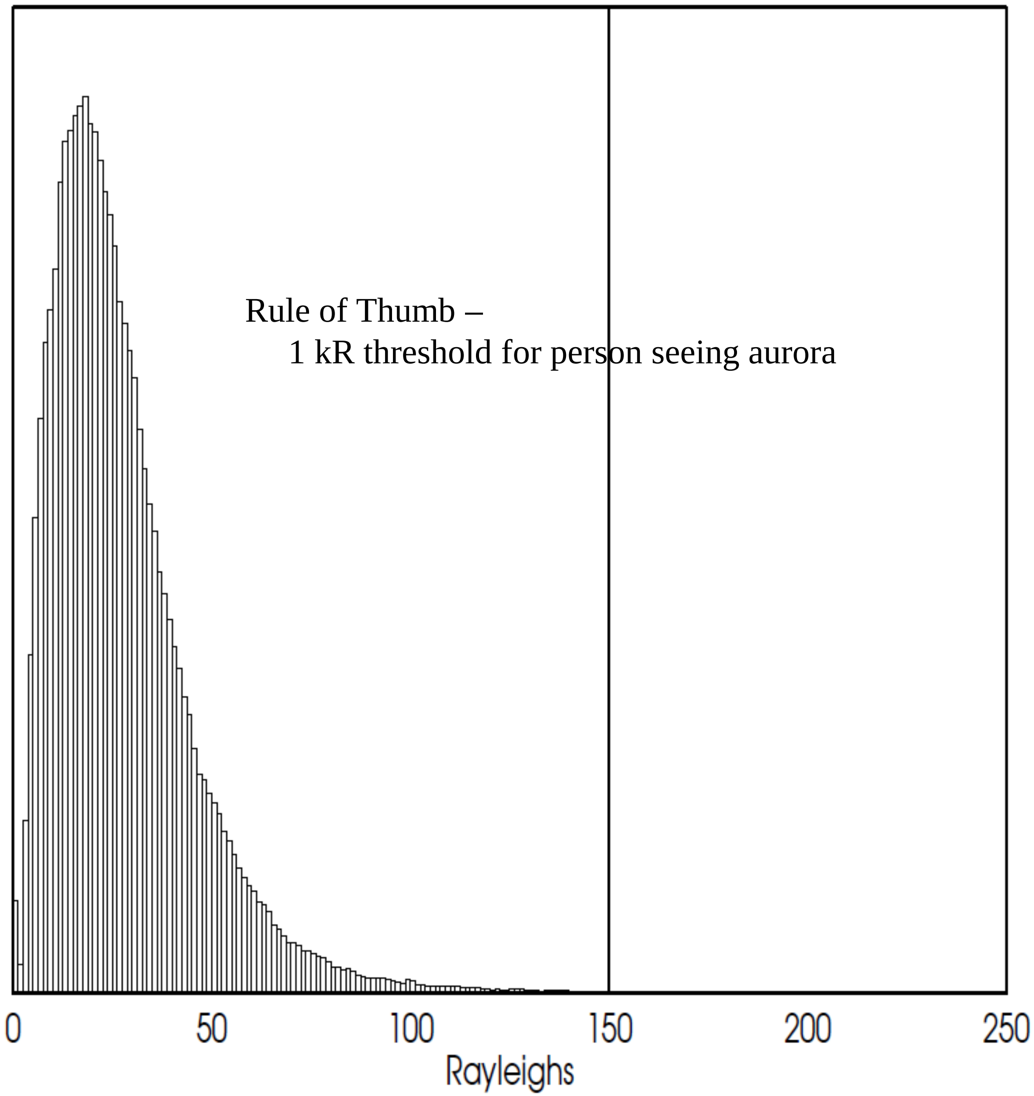


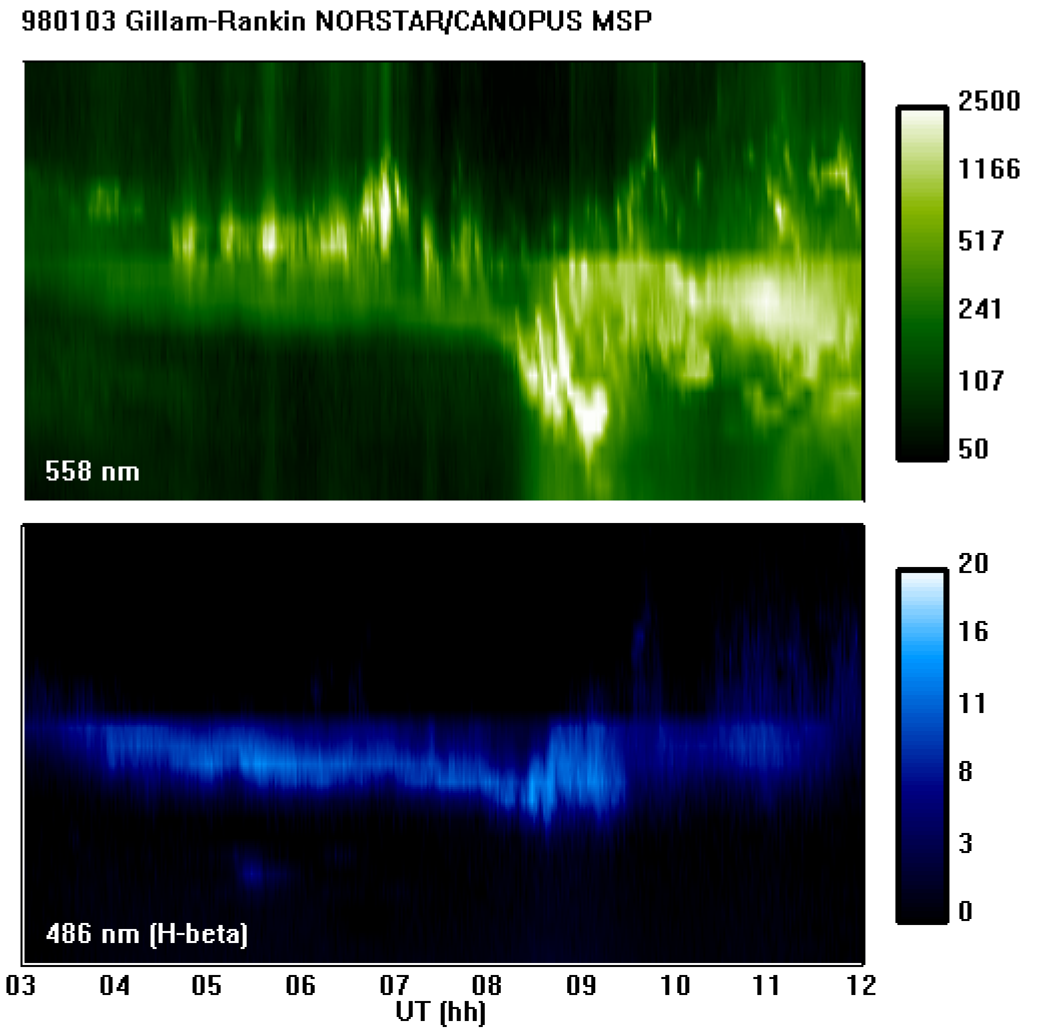
NASA IMAGE SI-12 [*Frey et al.*, 2003]

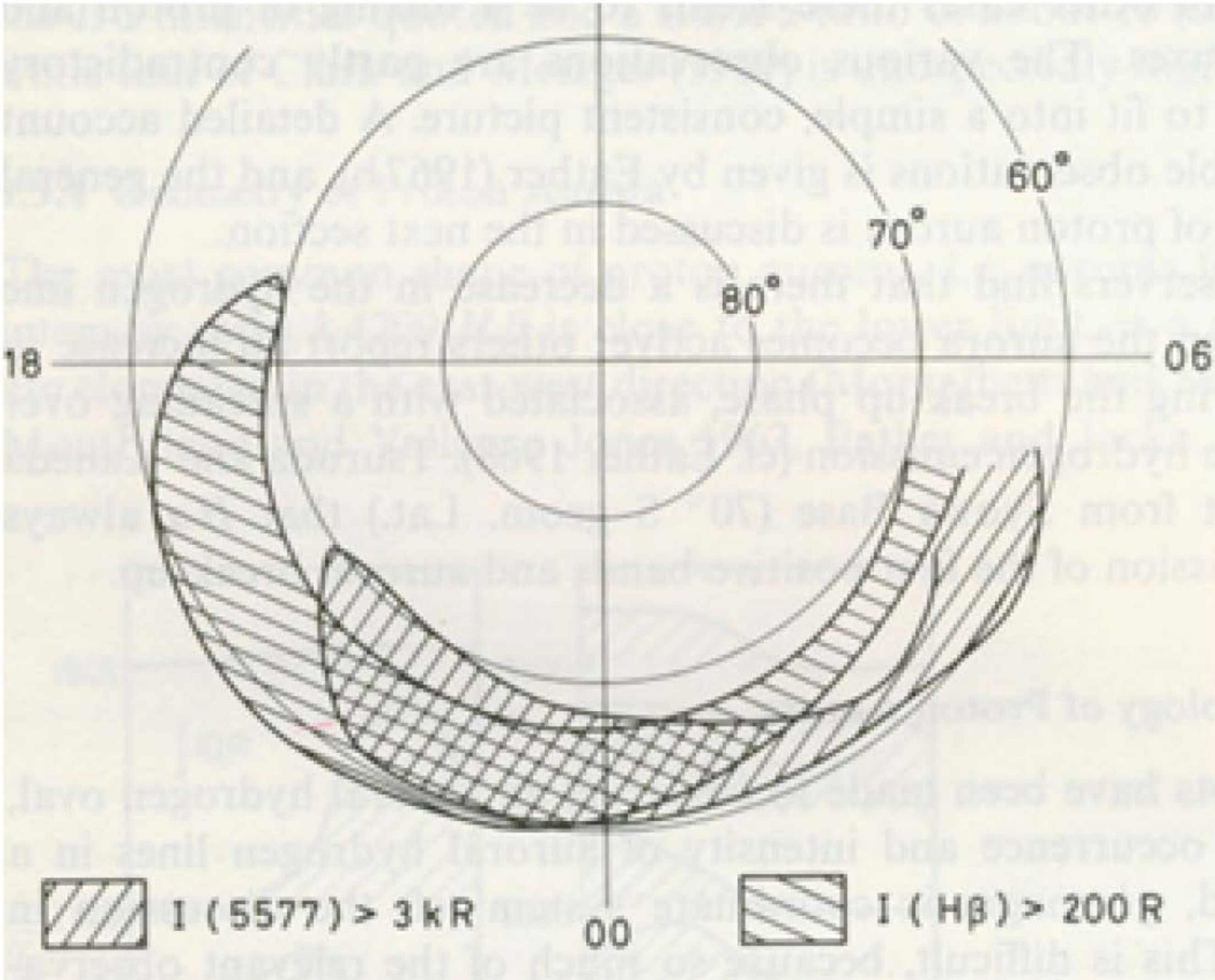


CANOPUS Gillam MSP

Distribution of Peak Hβ Intensities
270,000 Gillam MSP Scans (1991-1999)



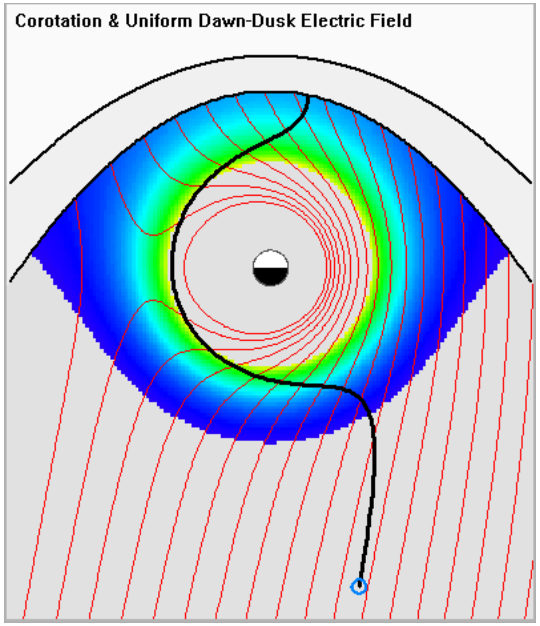

980103 Gillam-Rankin NORSTAR/CANOPUS MSP
558 nm
2500
1166
517
241
107
50
486 nm (H-beta)
20
16
11
8
3
0
03
04
05
06
07
08
09
10
11
12
UT (hh)

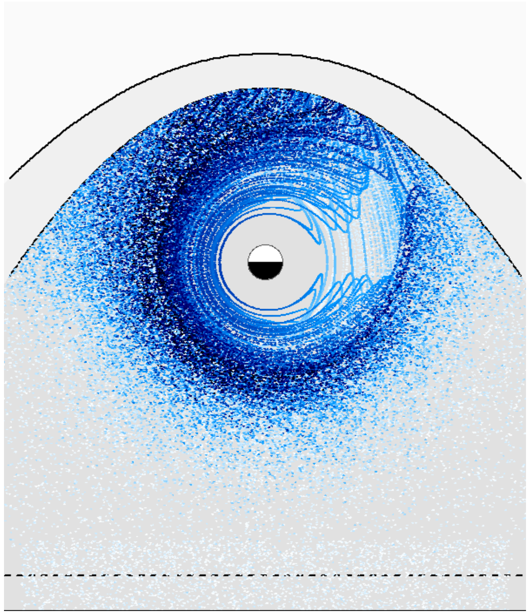


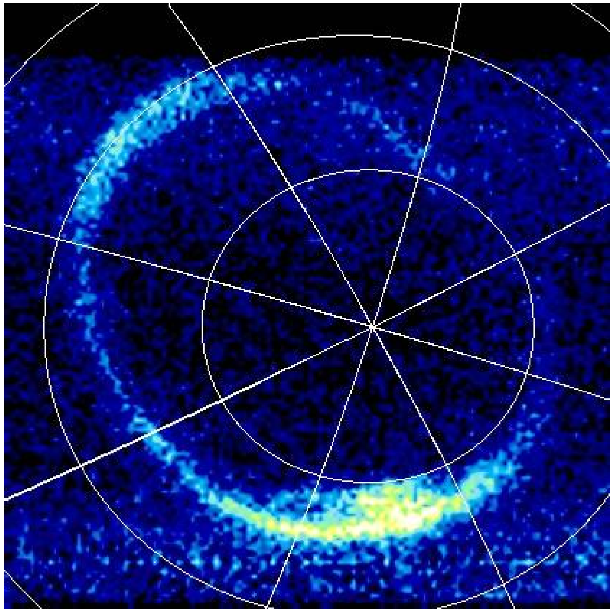
Omholt, 1971; Creutzberg et al., 1987.

Proton Aurora

Where is the Preciptation Originating?







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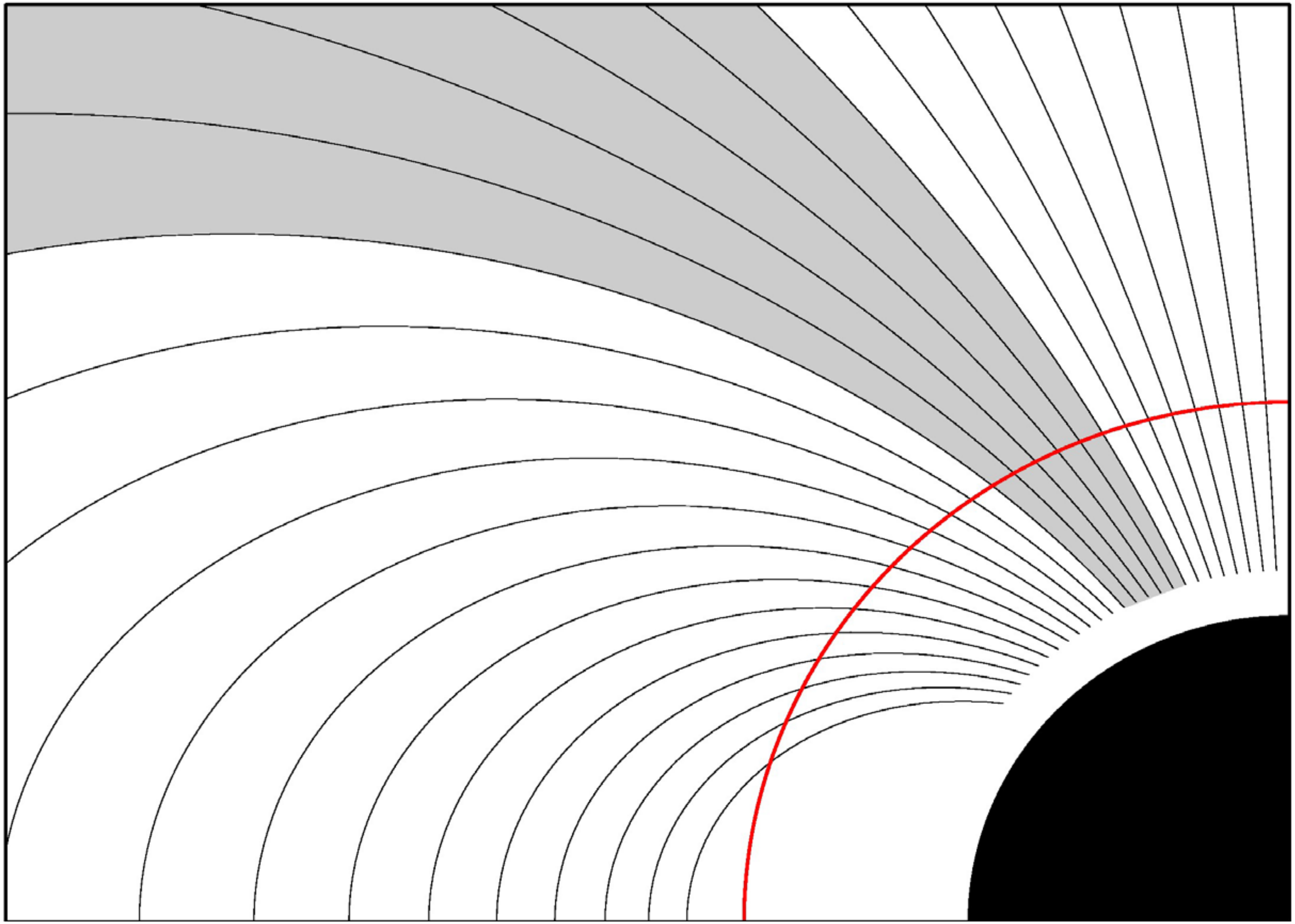
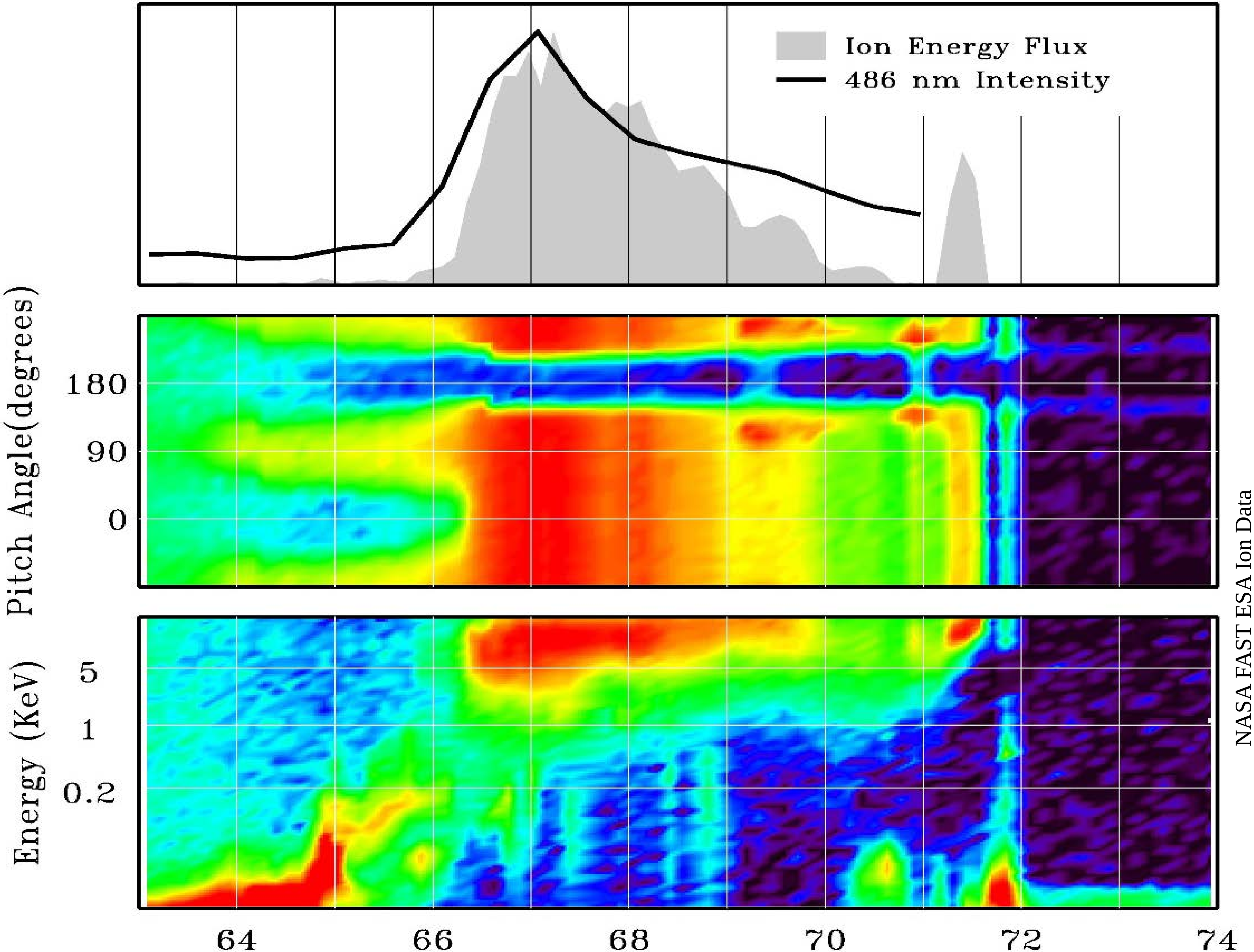
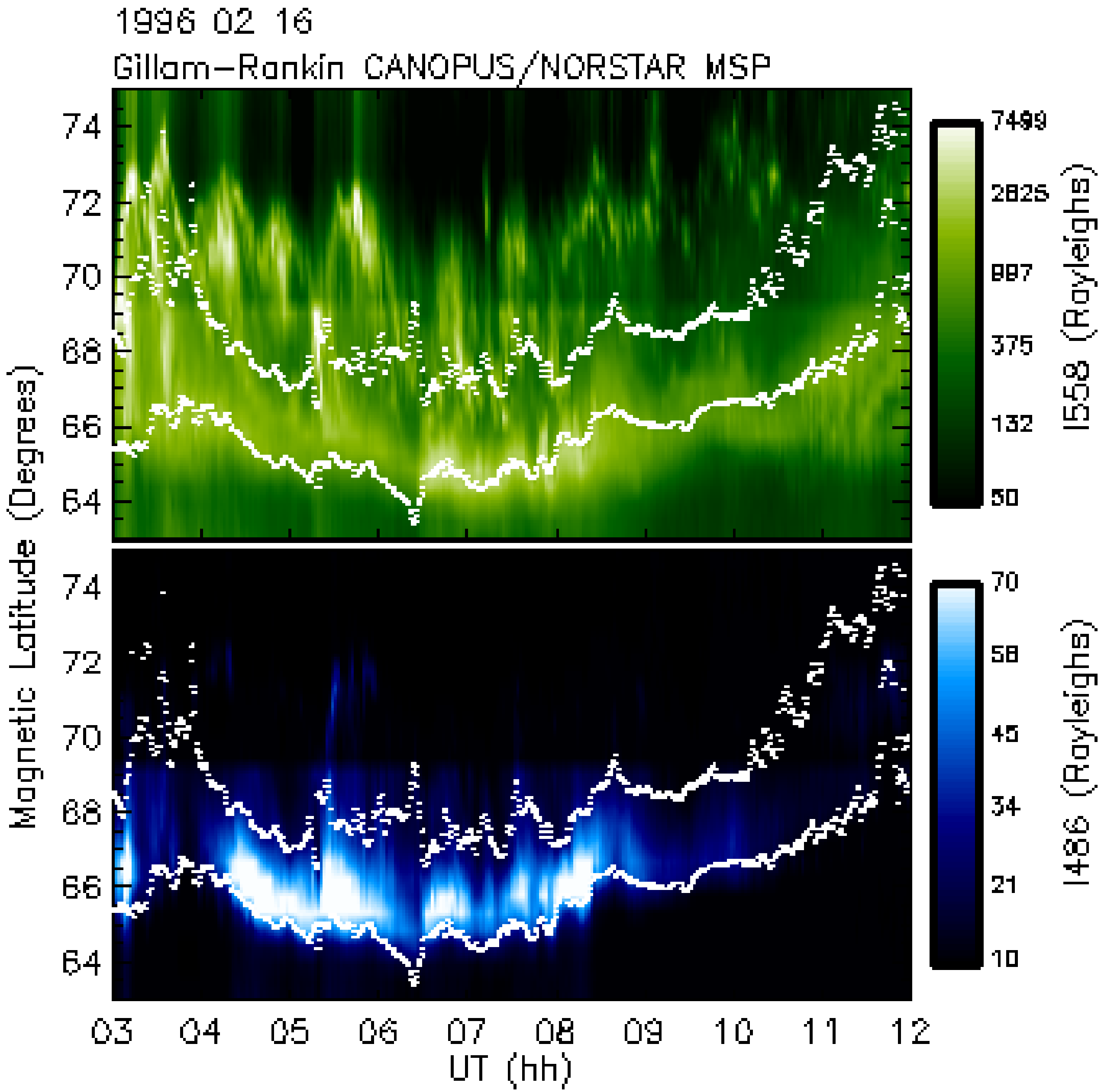
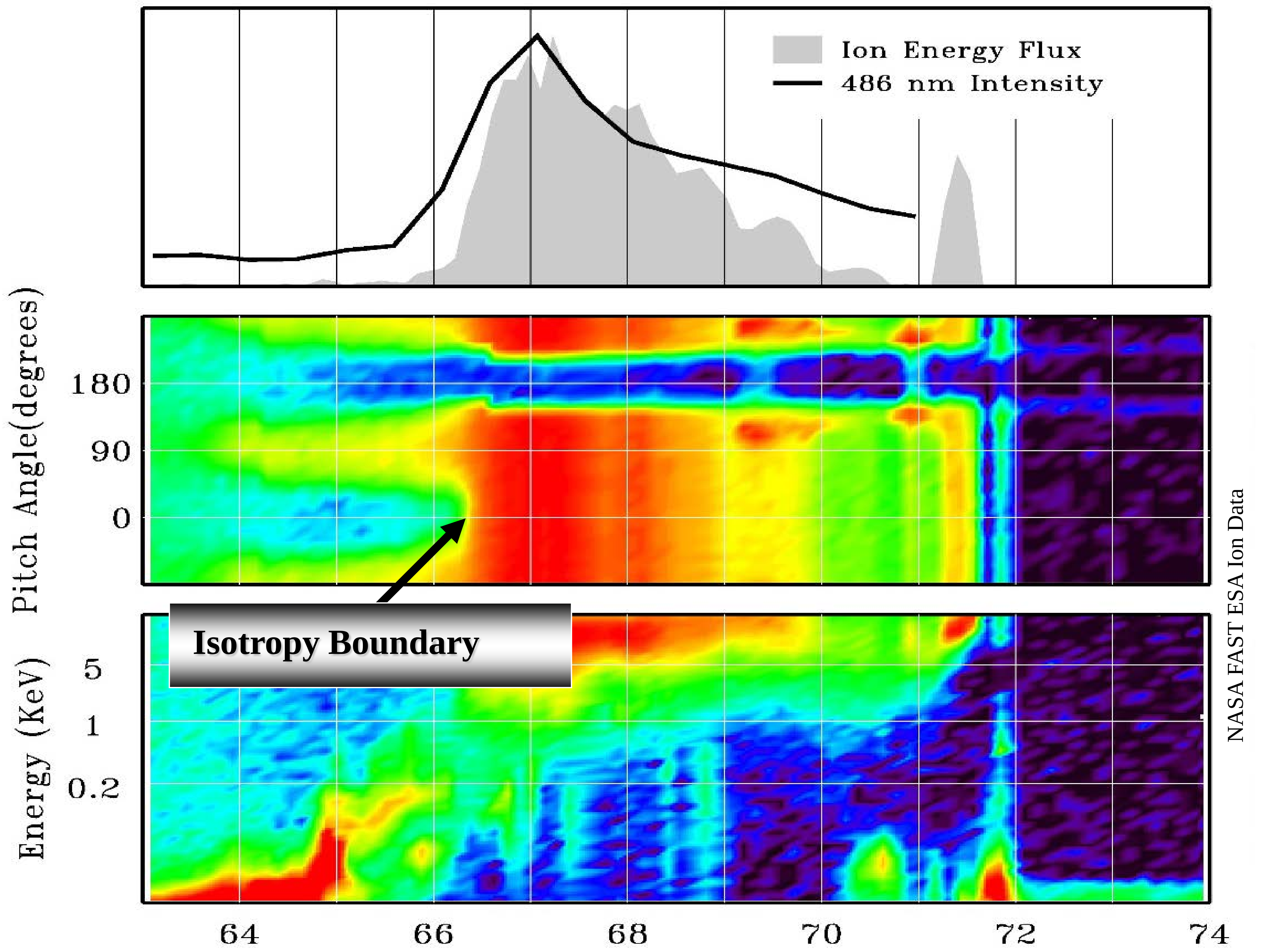




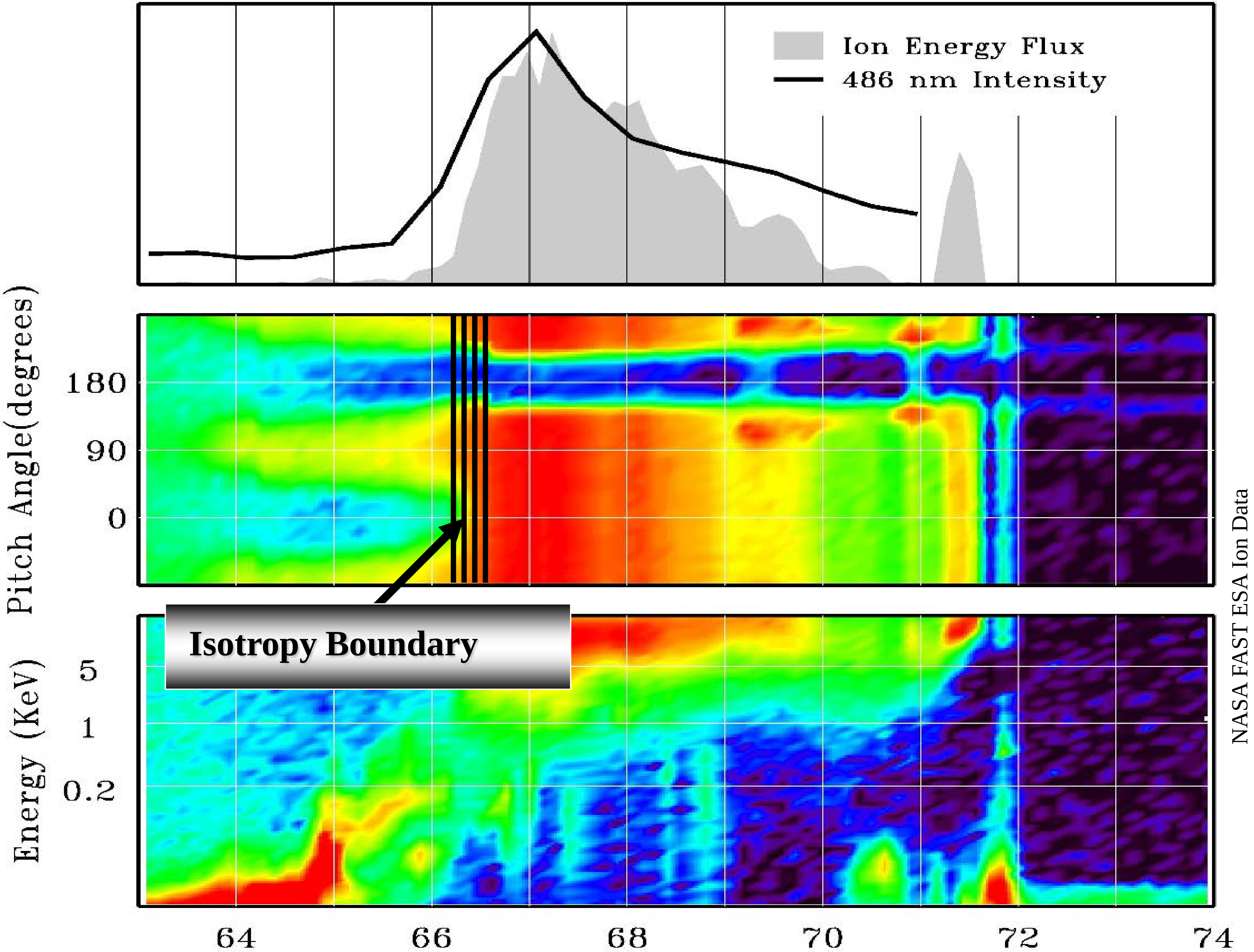
Ion Energy Flux
486 nm Intensity
Pitch Angle(degrees)
180
90
0
Energy (KeV)
5
1
0.2
64
66
68
70
72
74
NASA FAST ESA Ion Data



1996 02 16
Gillam–Rankin CANOPUS/NORSTAR MSP
Magnetic Latitude (Degrees)
74
72
70
68
66
64
7499
2825
887
375
132
50
I558 (Rayleighs)
70
58
45
34
21
10
I486 (Rayleighs)
03
04
05
06
07
08
09
10
11
12
UT (hh)

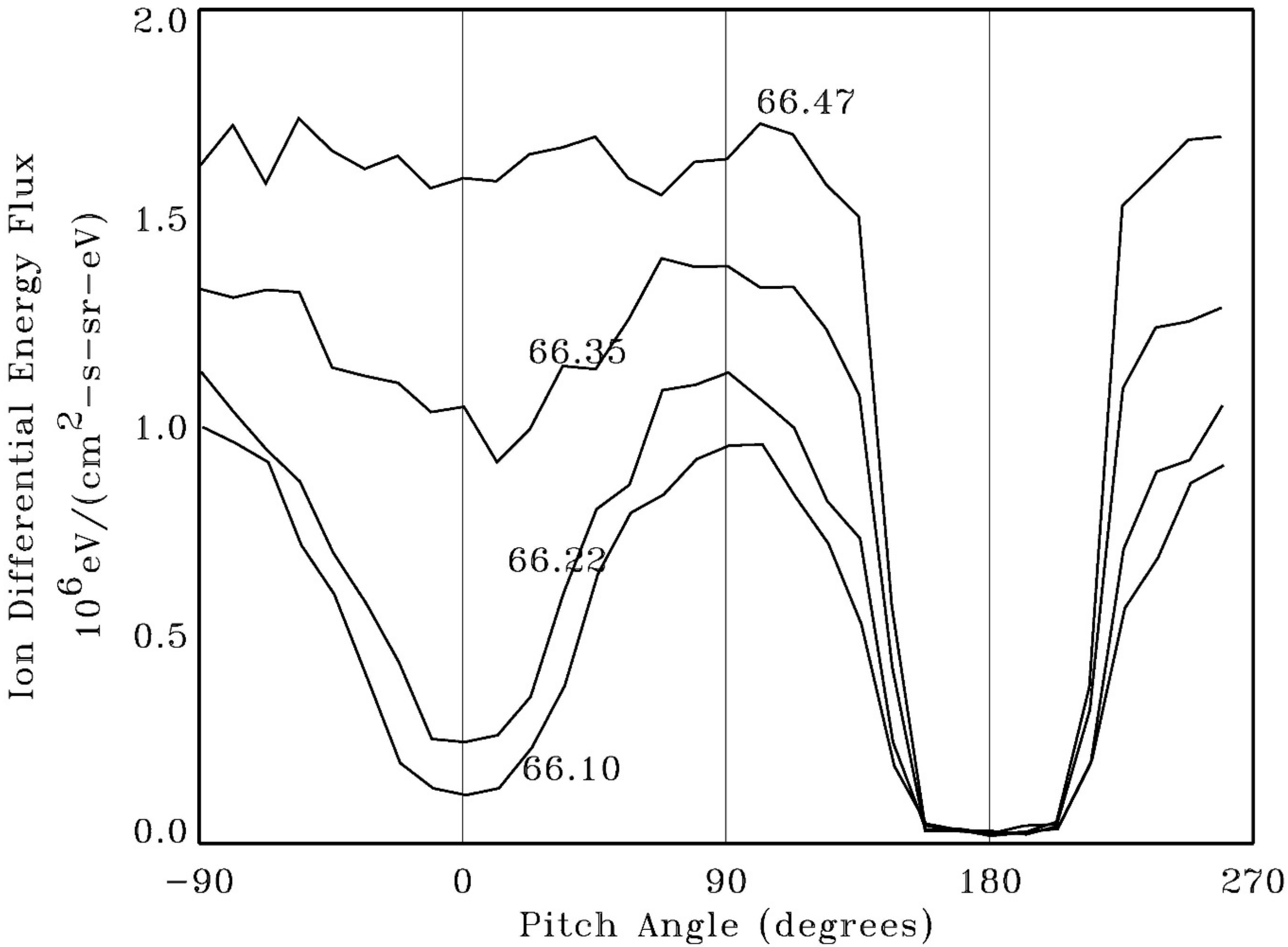


Ion Energy Flux
486 nm Intensity
Pitch Angle(degrees)
180
90
0
Isotropy Boundary
Energy (KeV)
5
1
0.2
64
66
68
70
72
74
NASA FAST ESA Ion Data



Ion Energy Flux
486 nm Intensity
Pitch Angle(degrees)
180
90
0
Isotropy Boundary
Energy (KeV)
5
1
0.2
64
66
68
70
72
74
NASA FAST ESA Ion Data

Isotropy Boundary or IB

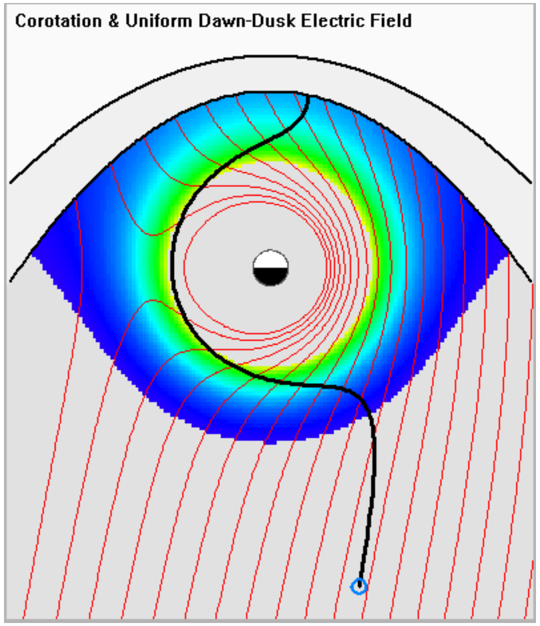


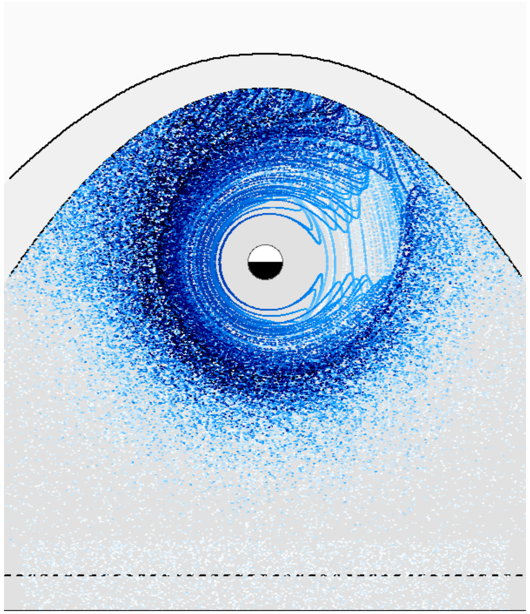
NASA FAST ESA Ion Data

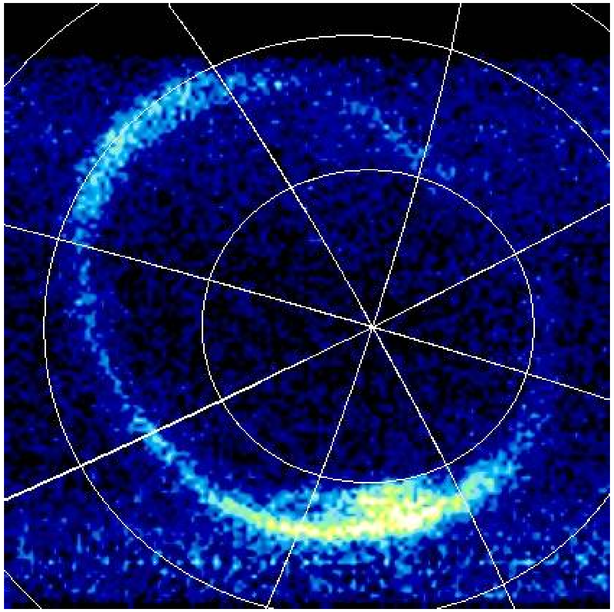
See Sergeev and Gvozdevsky, 1995 (MT-Index) and references therein.
Newell et al., 1996 (equated DMSP inferred b2i with IB)

Proton Aurora

What's filling the loss cone?







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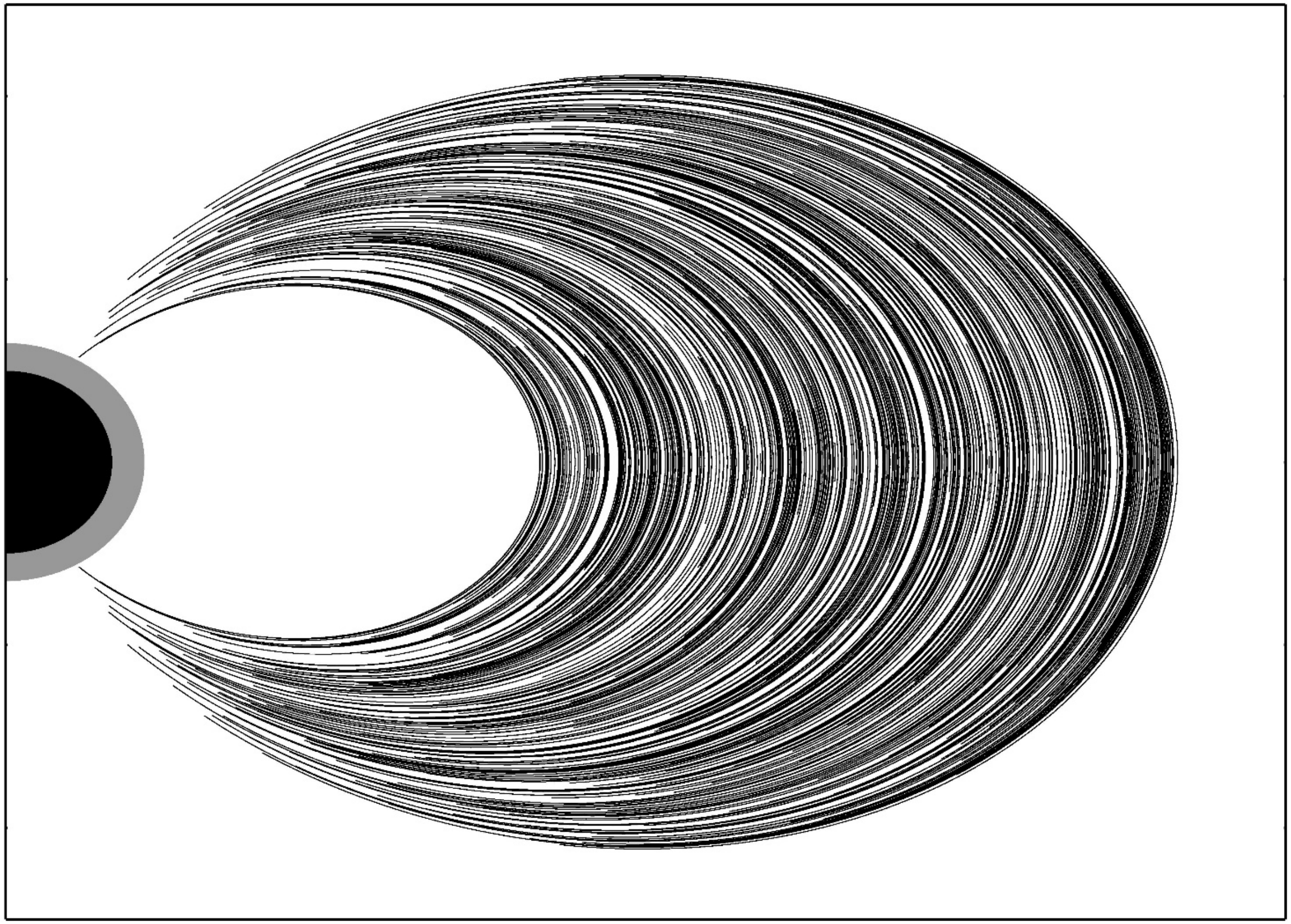
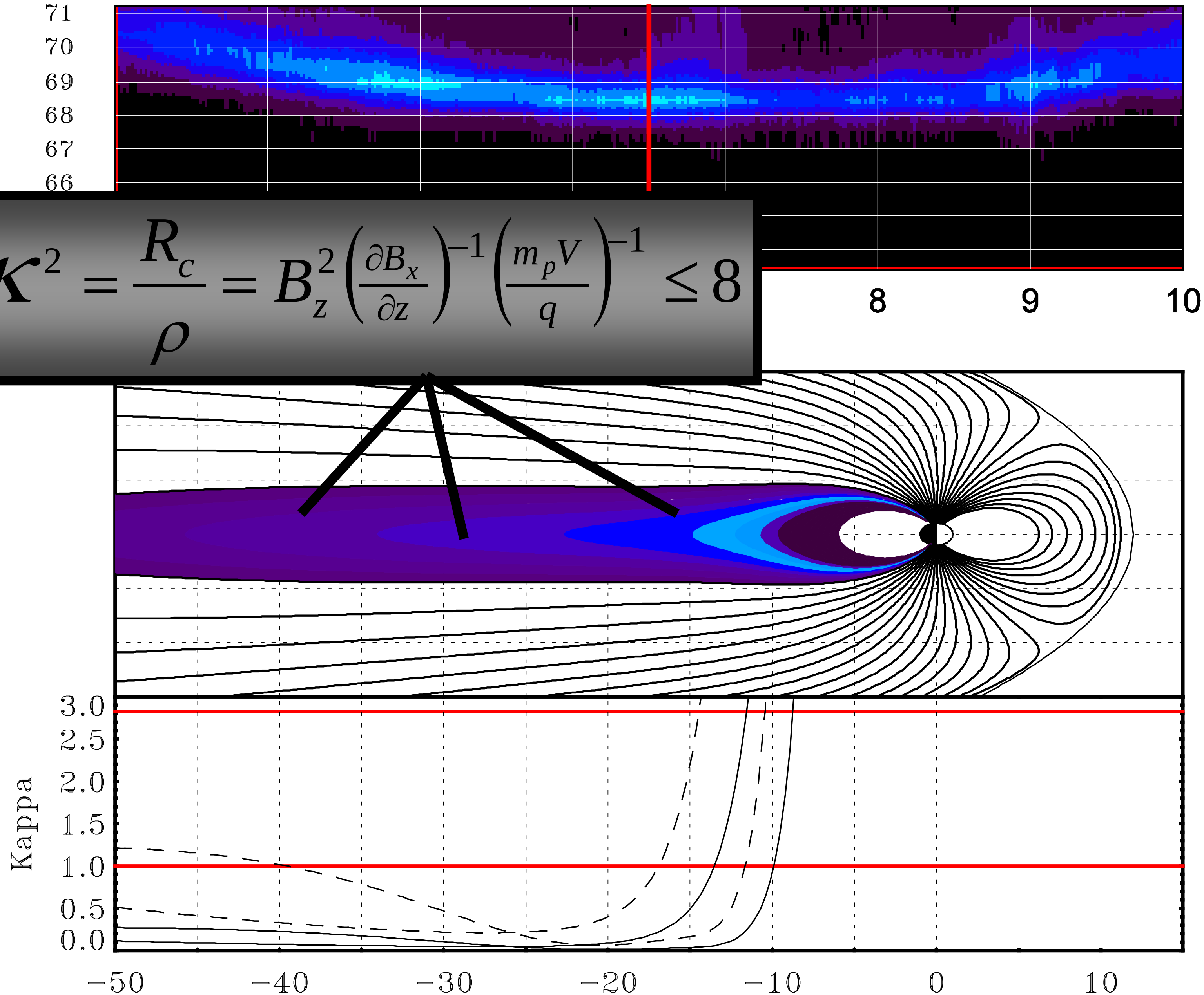


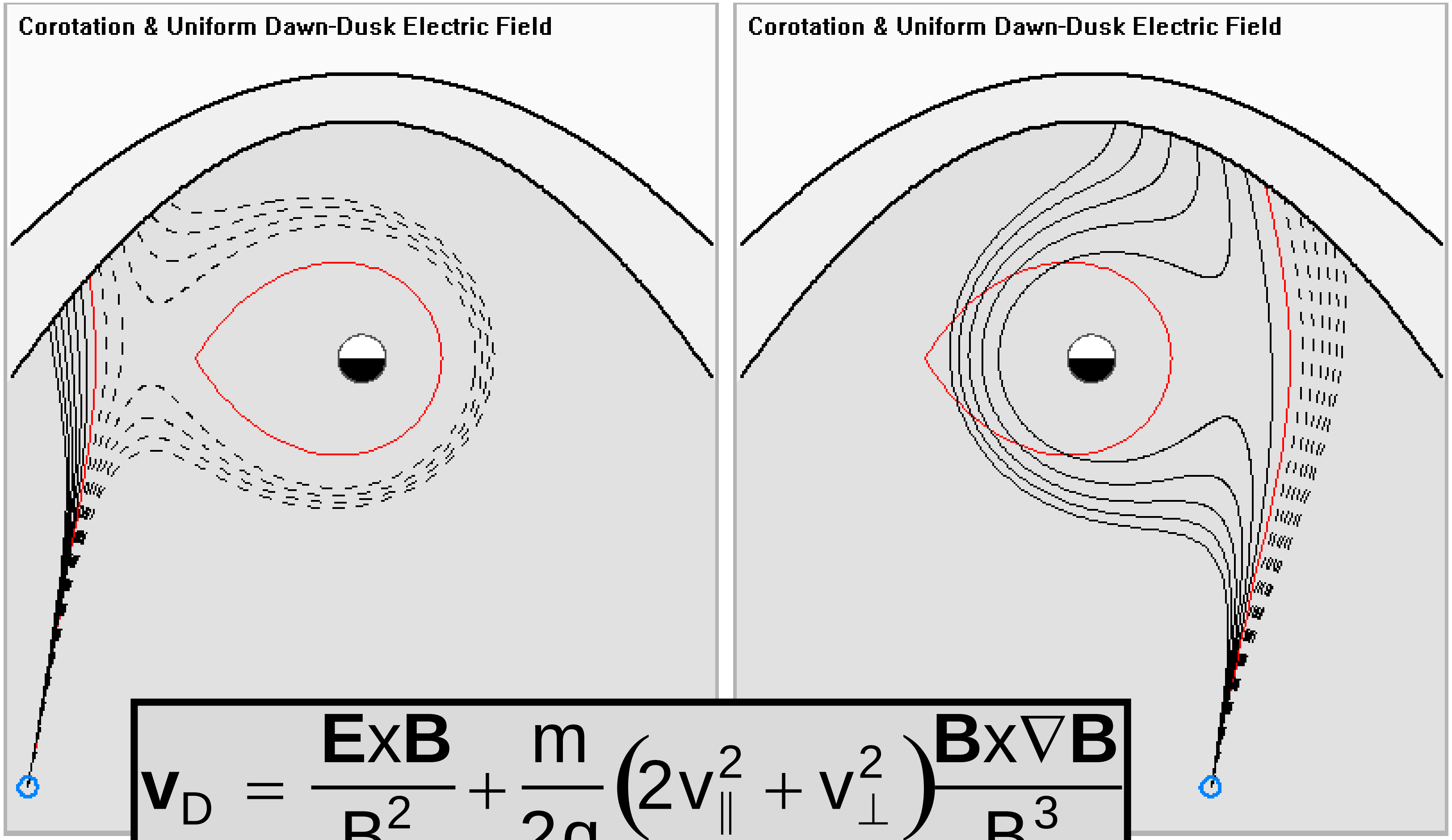
All aurora involves the continuous though variable changing pitch angles from outside the losscone to inside the loss cone… when this is due to parallel electric fields we call the aurora discrete, when do to changing the pitch angle without (much) change to the particle energy (caused by some stochastic process) we call the aurora diffuse.

Dave Klumpar (private communication) says that he saw some evidence for ion inverted-V precipitation with FAST ESA, but the *bright proton aurora* which we see in e.g., SI-12 and the MSP data is properly thought of as diffuse aurora. *What causes the precipitation?*

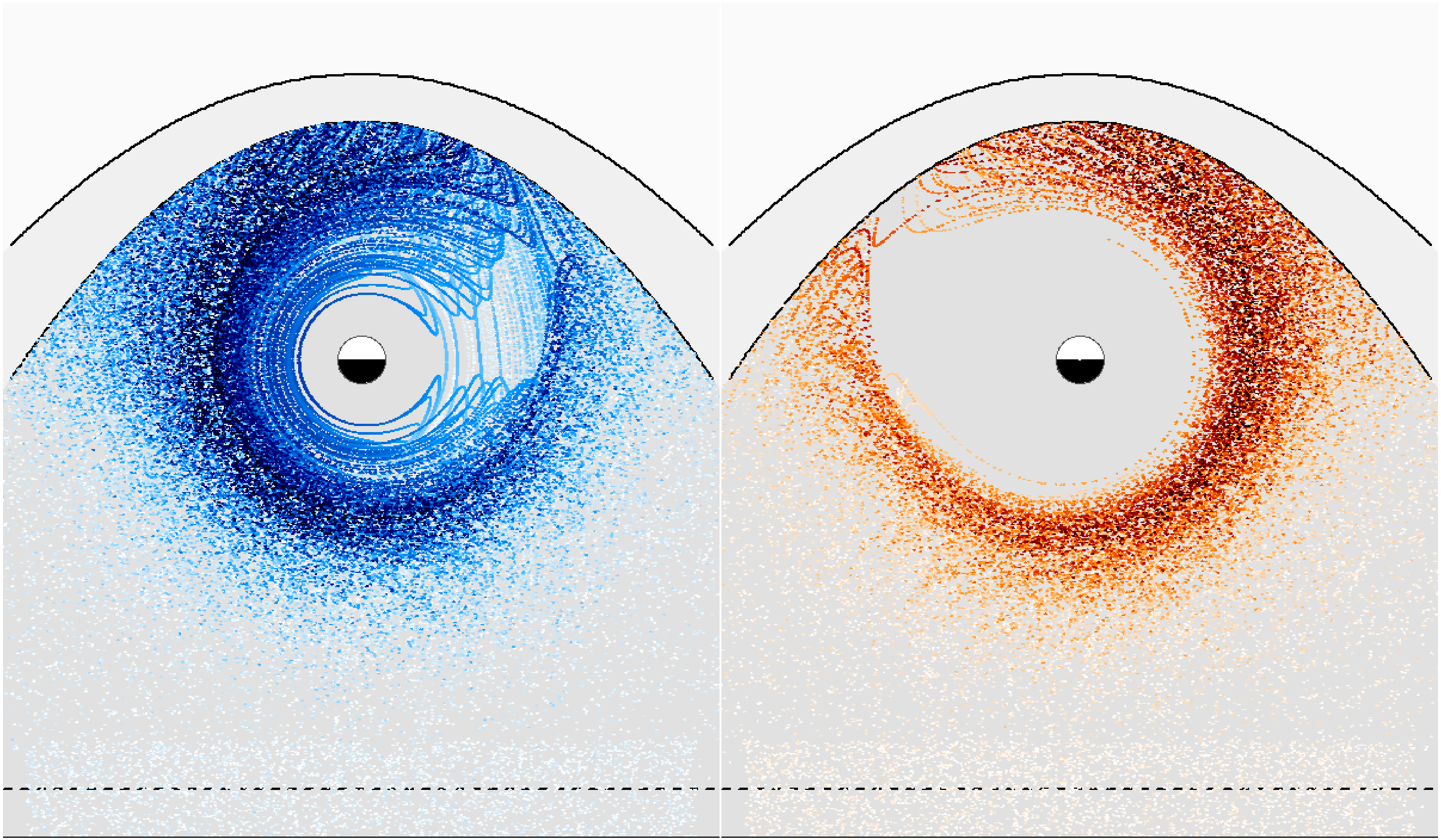


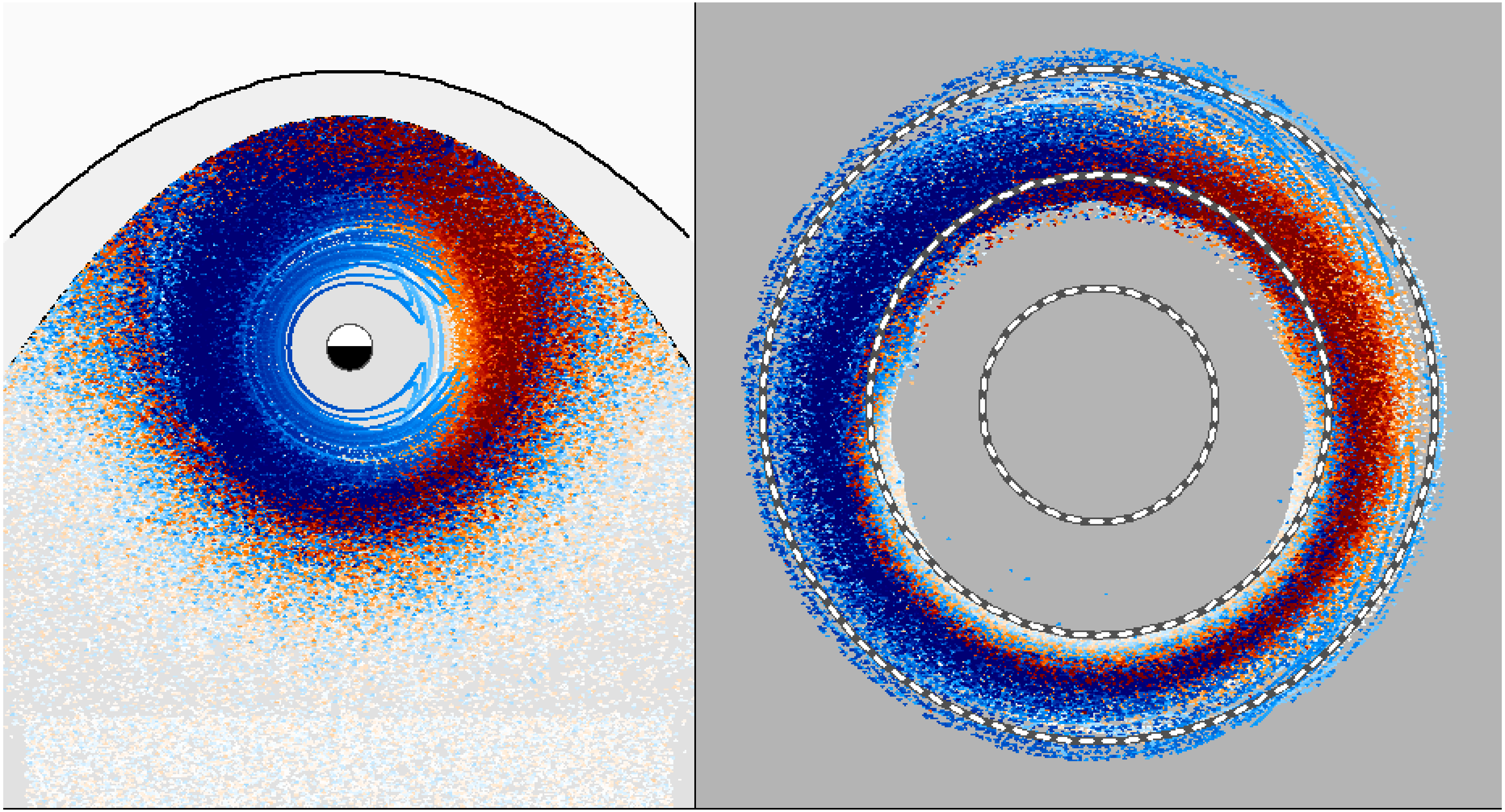
$$\kappa^2 = \frac{R_c}{\rho} = B_z^2 \left(\frac{\partial B_x}{\partial z}\right)^{-1} \left(\frac{m_p V}{q}\right)^{-1} \leq 8$$

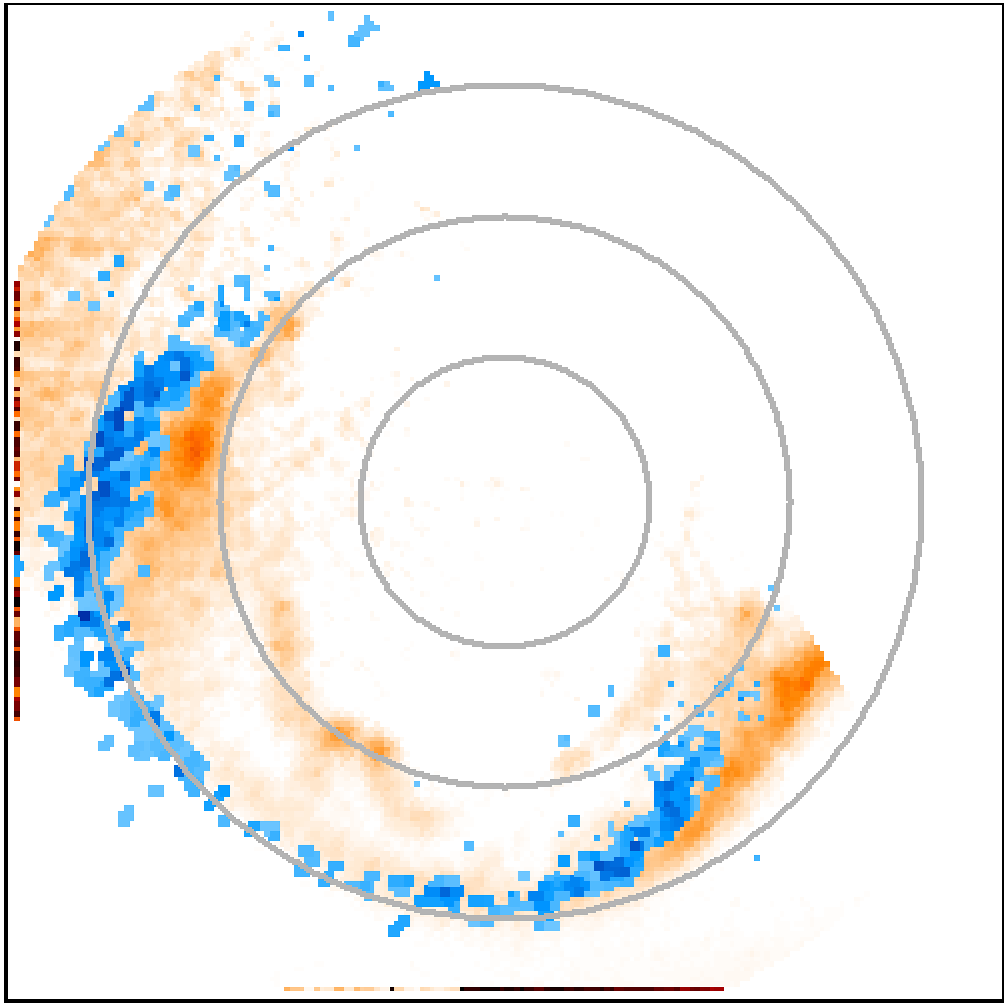
See Sergeev and Tsyganeko, 1982



$$\mathbf{v}_D = \frac{\mathbf{E}\mathrm{x}\mathbf{B}}{B^2} + \frac{m}{2q}\left(2v_{\parallel}^2 + v_{\perp}^2\right)\frac{\mathbf{B}\mathrm{x}\nabla\mathbf{B}}{B^3}$$

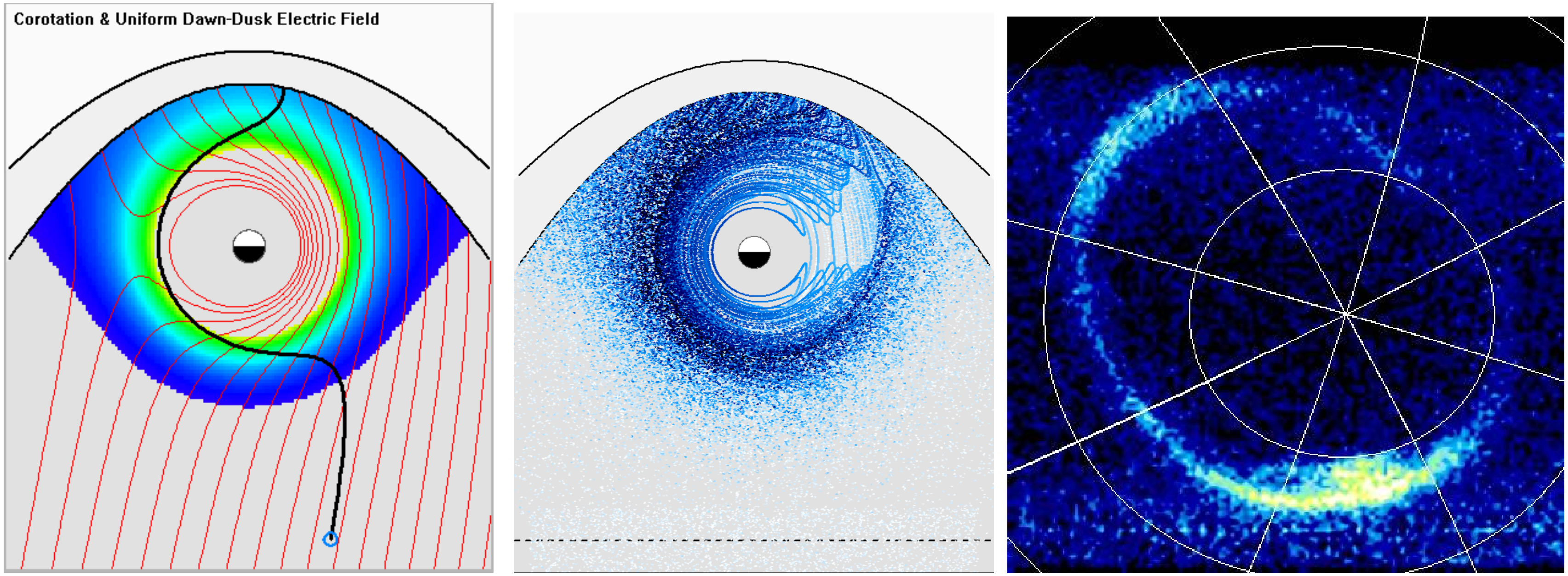


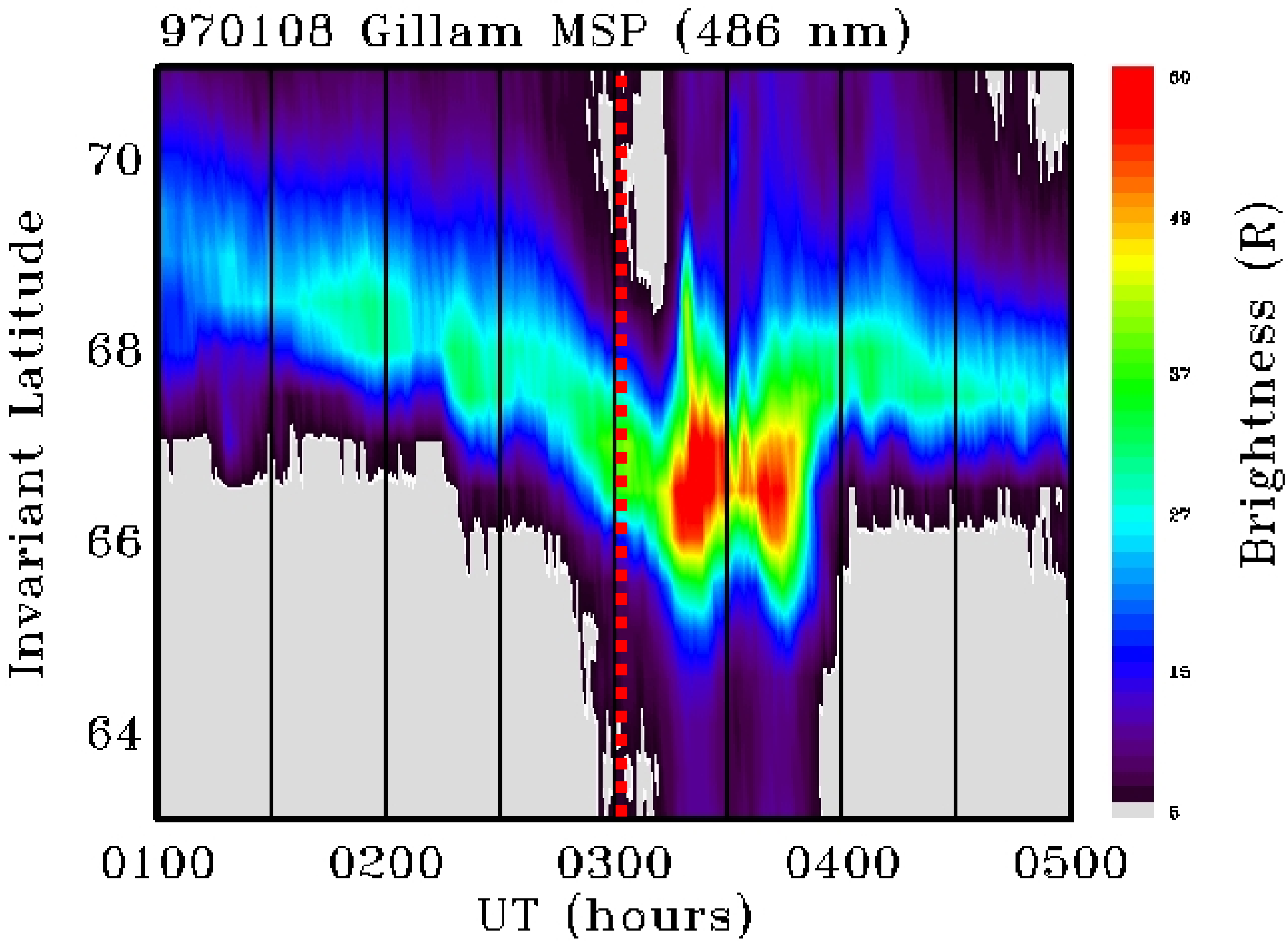




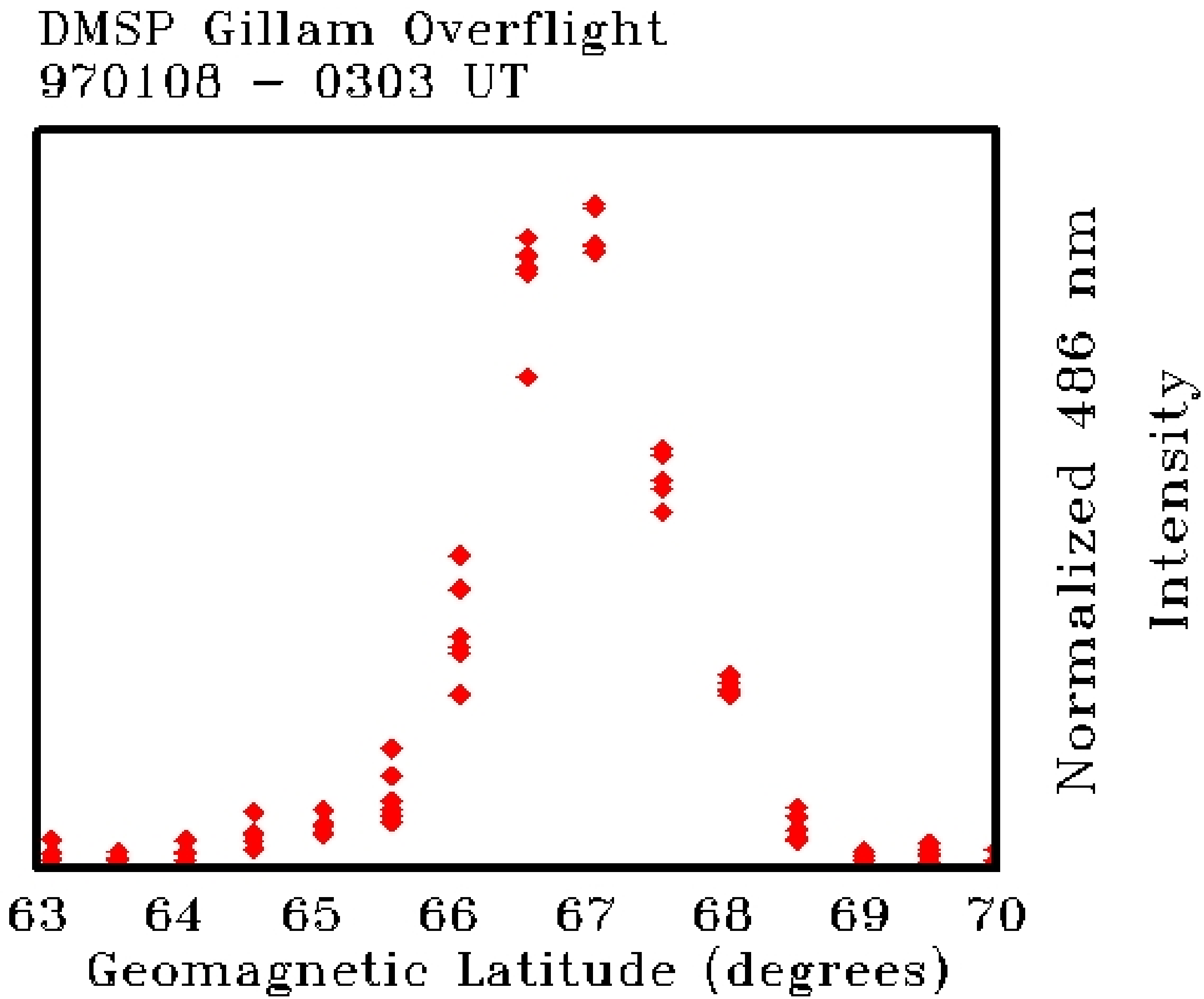
Proton Aurora

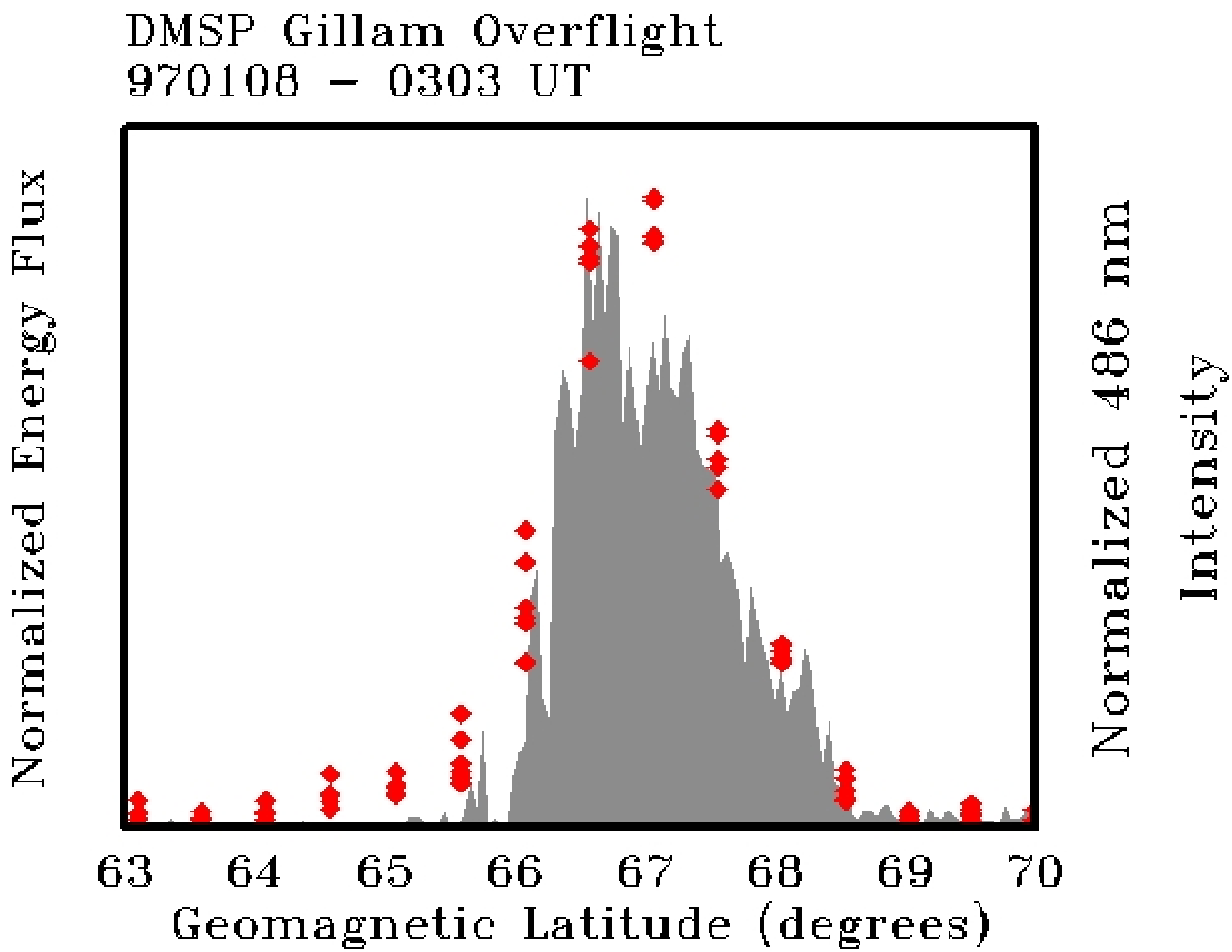
Remote Sensing the (inner CPS) Magnetosphere

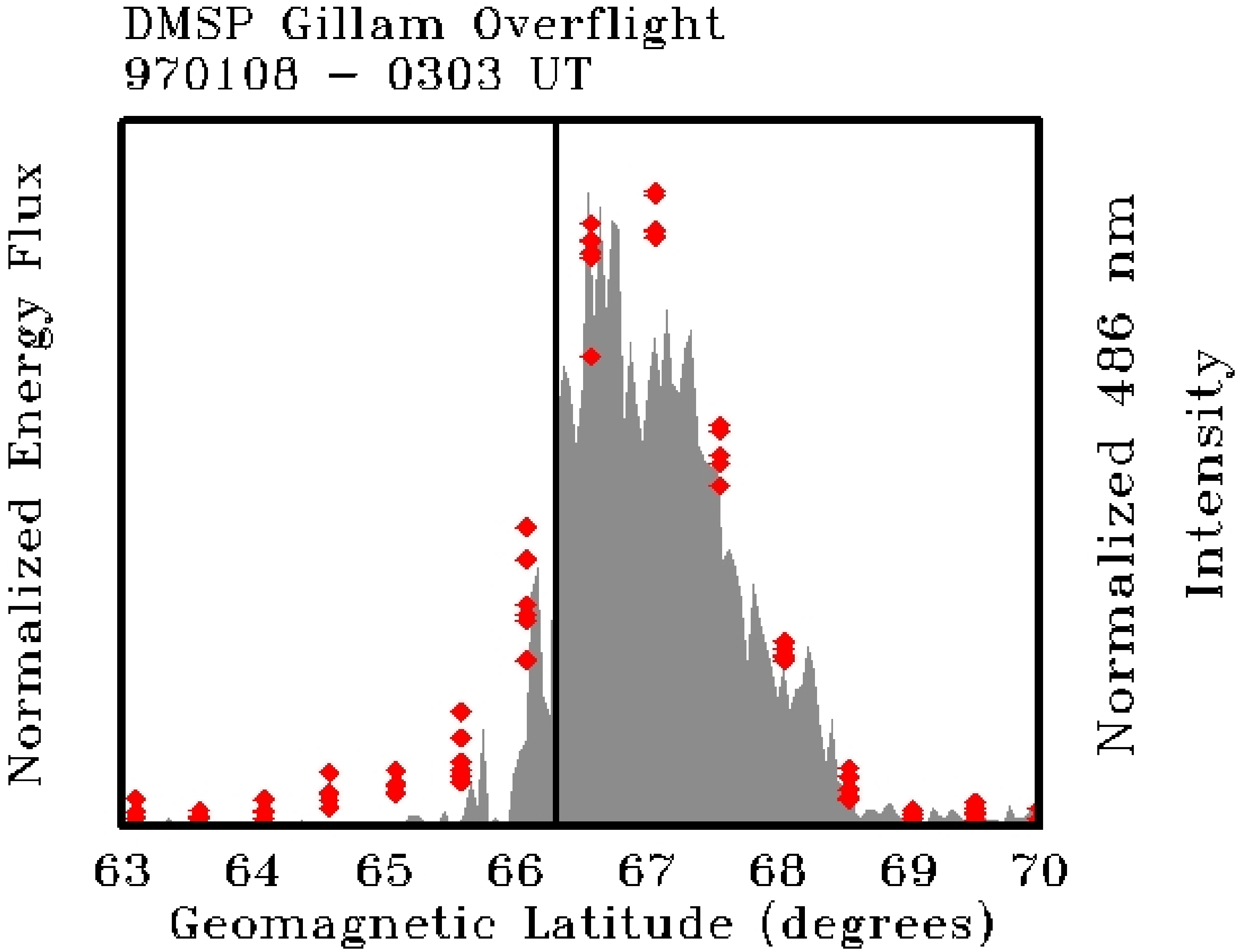




970108 Gillam MSP (486 nm)
Invariant Latitude
70
68
66
64
0100
0200
0300
0400
0500
UT (hours)
Brightness (R)
60
49
37
27
15
5


DMSP Gillam Overflight
970108 – 0303 UT
63
64
65
66
67
68
69
70
Geomagnetic Latitude (degrees)
Normalized 486 nm
Intensity


DMSP Gillam Overflight
970108 – 0303 UT
Normalized Energy Flux
Normalized 486 nm
Intensity
63
64
65
66
67
68
69
70
Geomagnetic Latitude (degrees)


DMSP Gillam Overflight
970108 - 0303 UT
Normalized Energy Flux
Normalized 486 nm
Intensity
63
64
65
66
67
68
69
70
Geomagnetic Latitude (degrees)

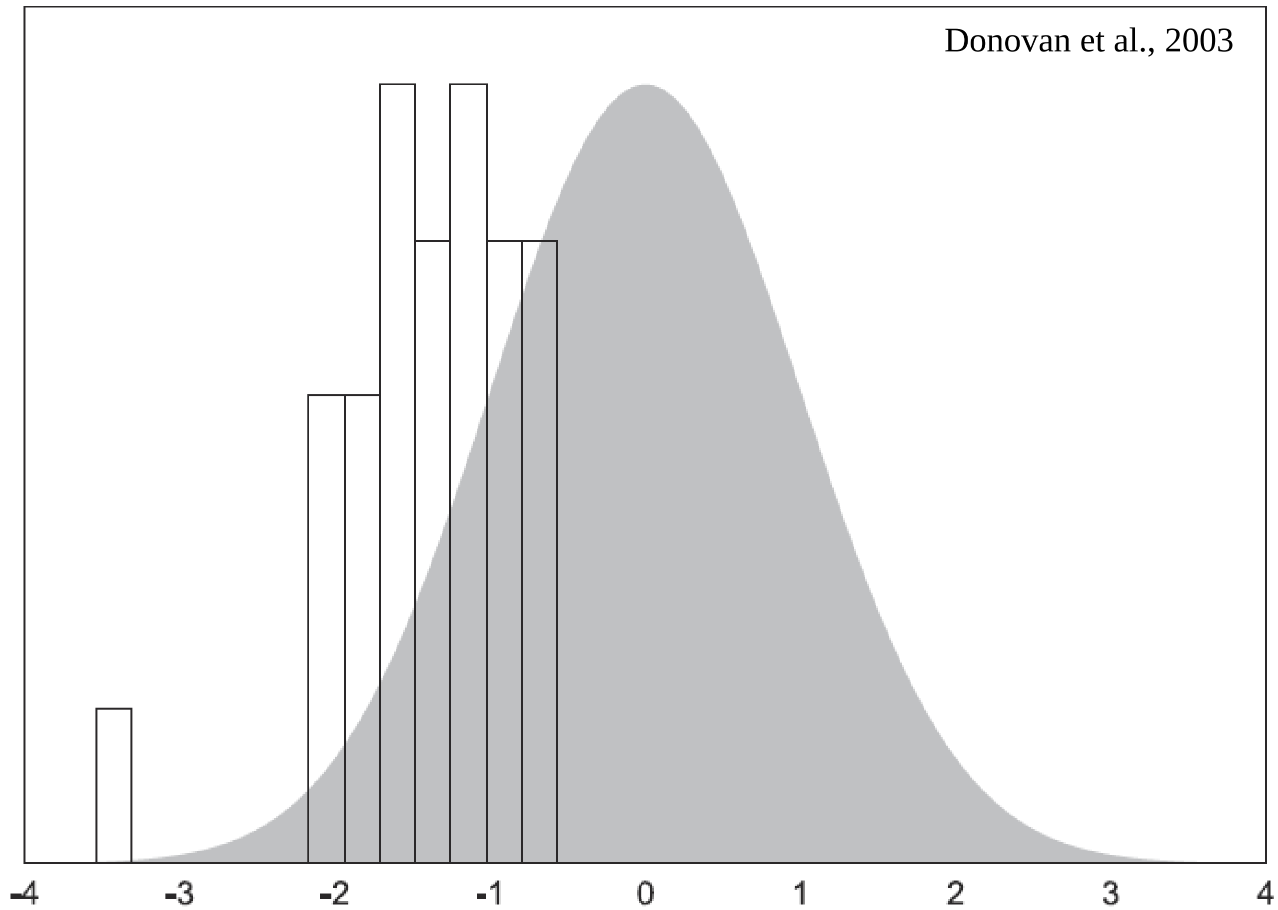
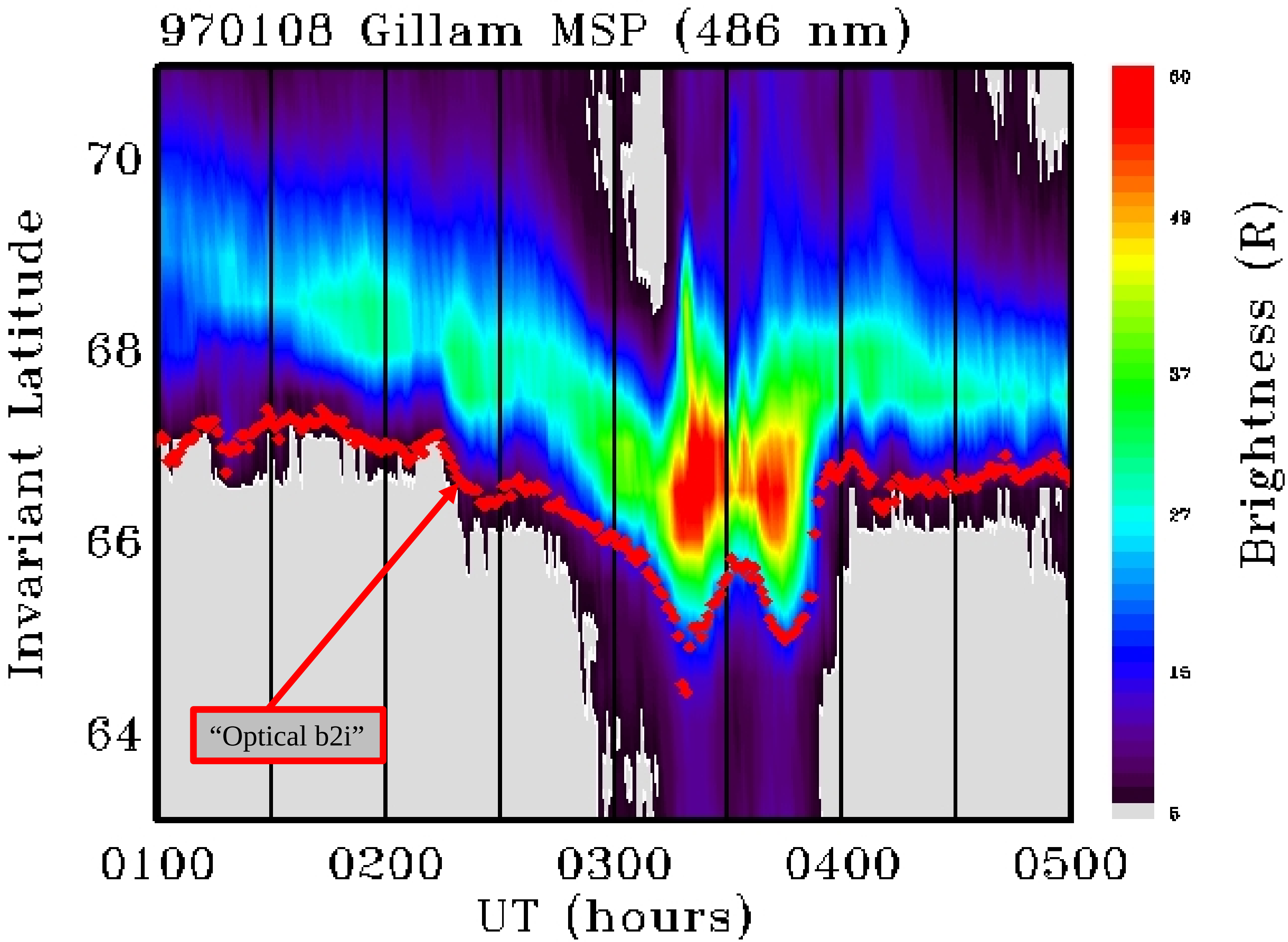
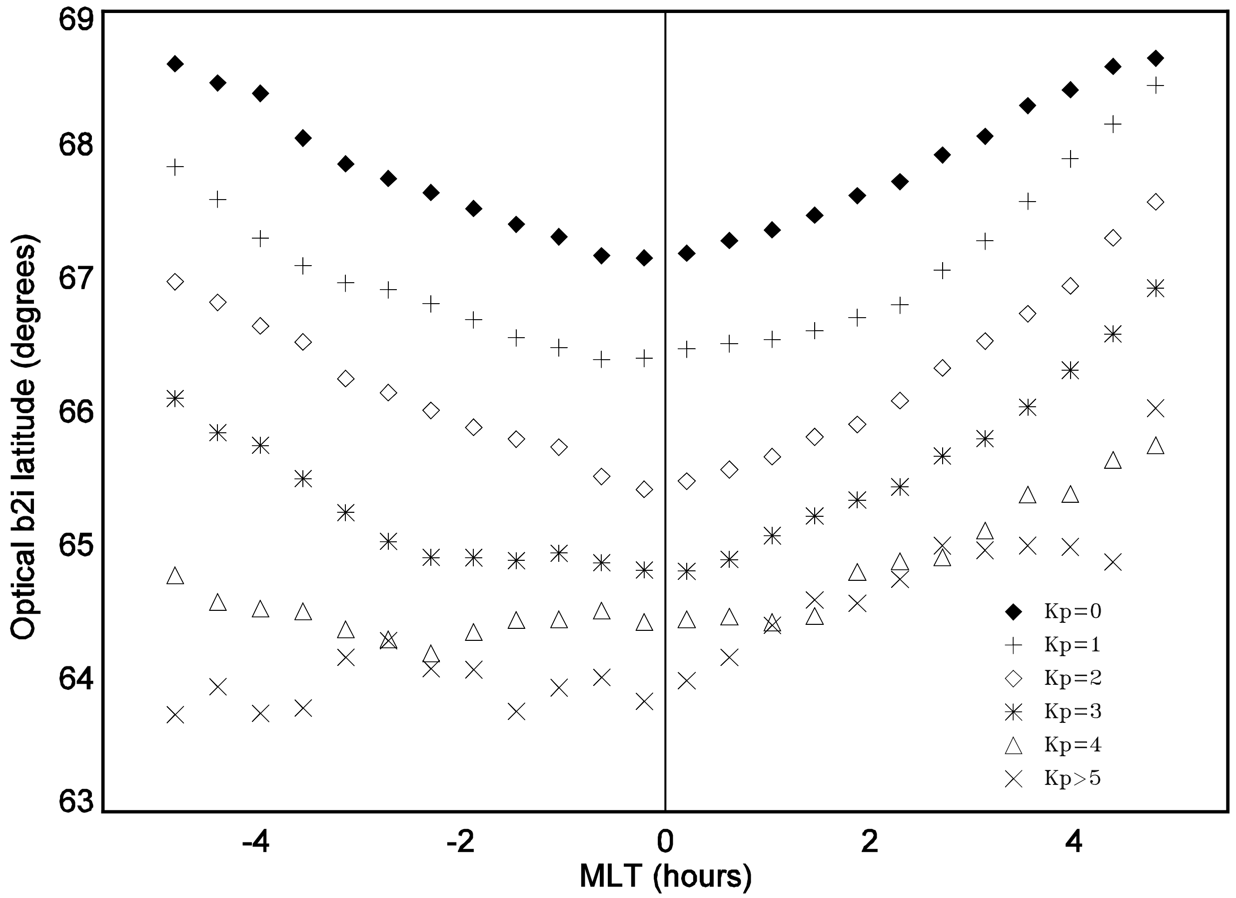


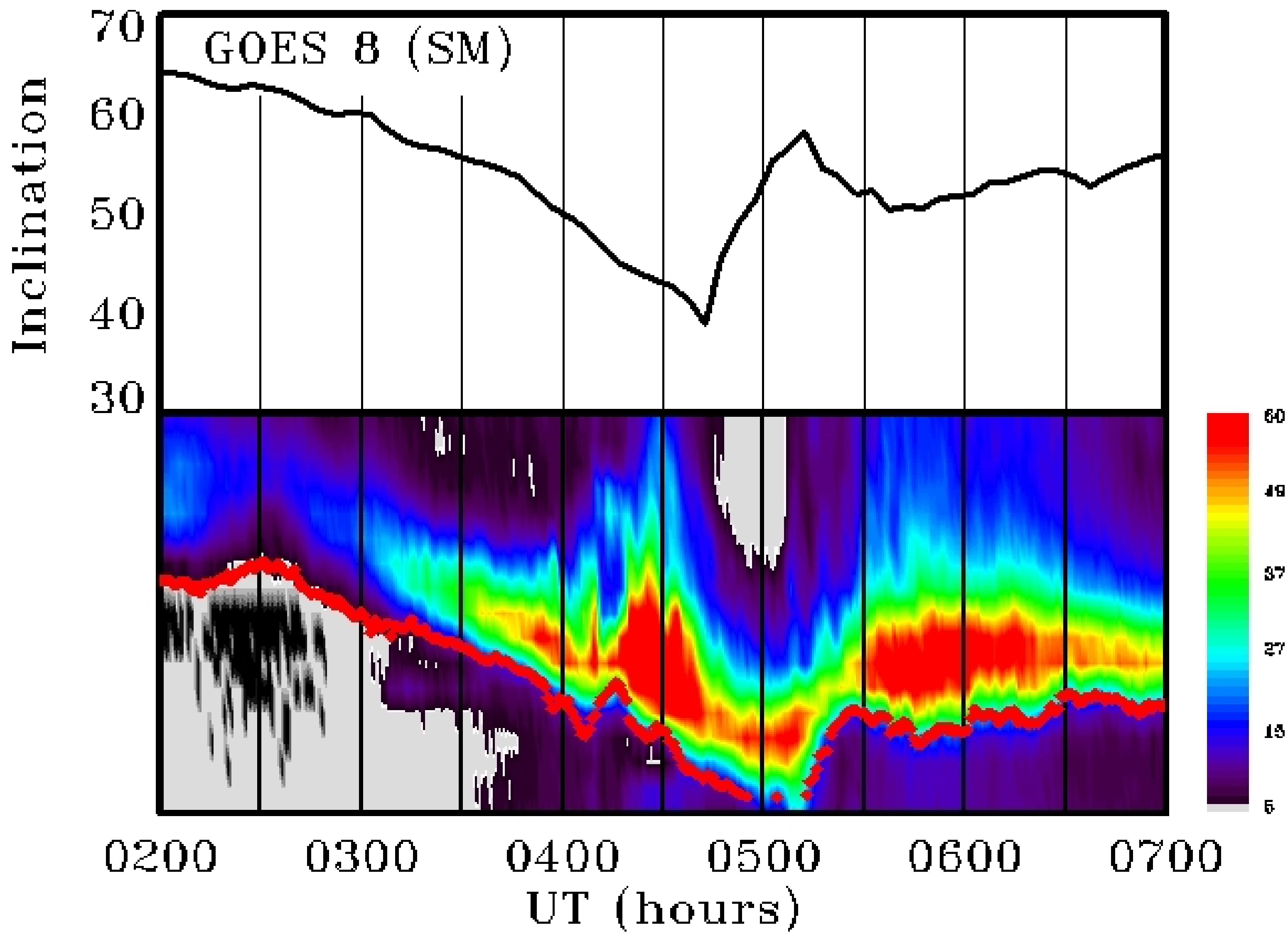
Figure 3. Distribution of b2i boundary locations, relative to the peak in H_β intensity for 29 DMSP overflights of Gillam (see text). The histogram shows the distribution of the 29 b2i locations with a shaded Gaussian included for reference. Negative values indicate locations equatorward of the peak in brightness.



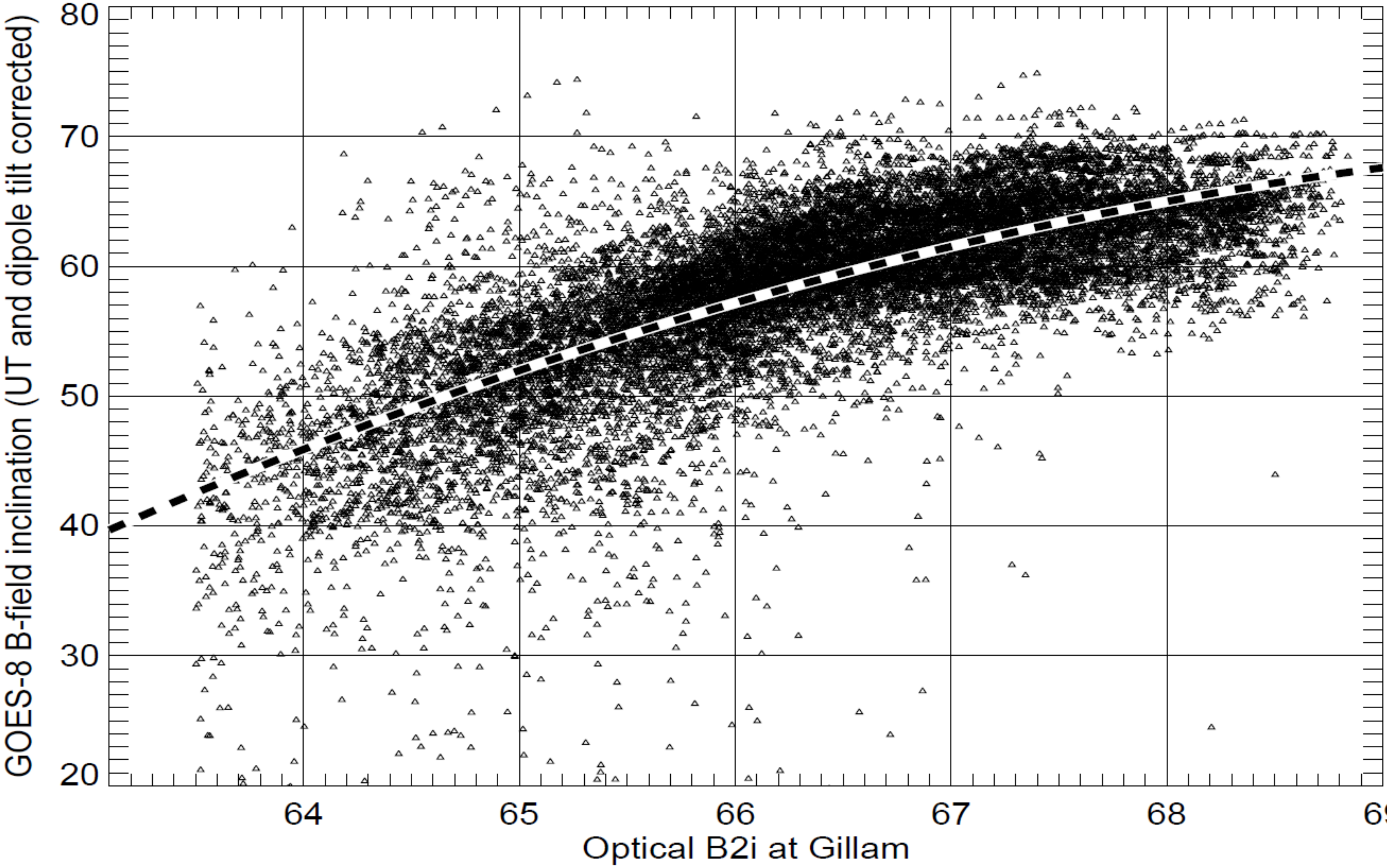
970108 Gillam MSP (486 nm)
Invariant Latitude
70
68
66
64
"Optical b2i"
0100
0200
0300
0400
0500
UT (hours)
Brightness (R)
60
37
27
15

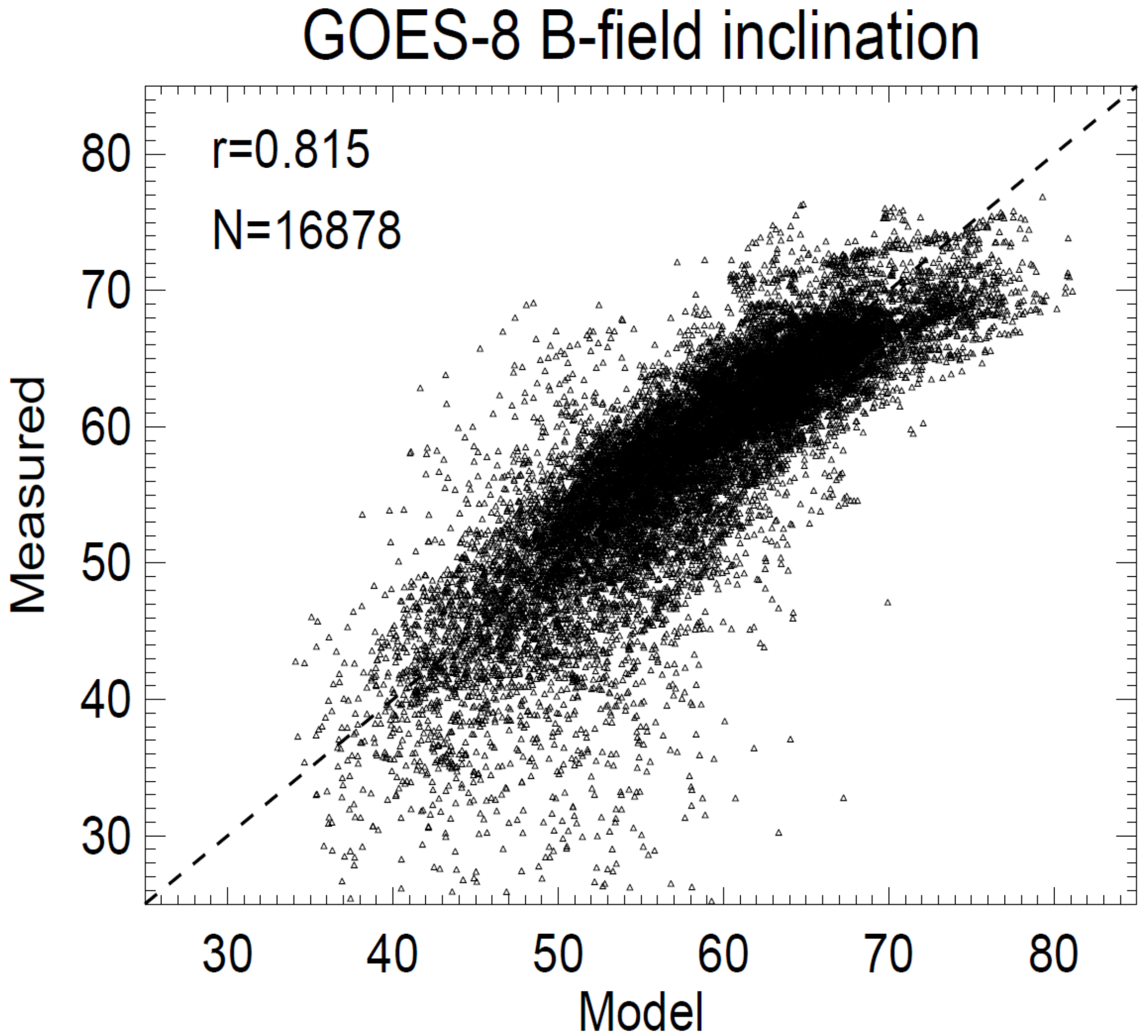


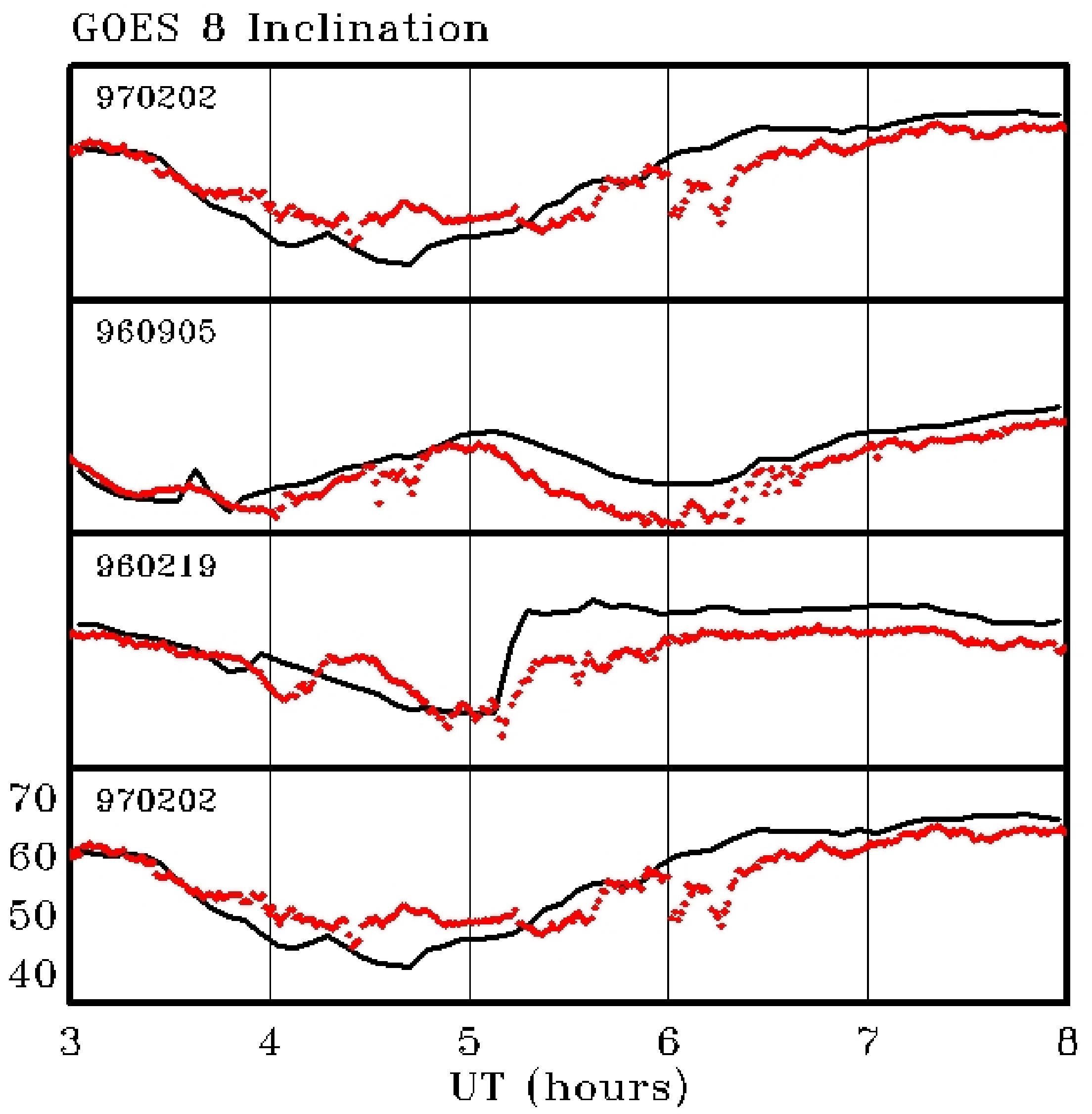
Optical b2i latitude (degrees)
69
68
67
66
65
64
63
-4
-2
0
2
4
MLT (hours)
Kp=0
Kp=1
Kp=2
Kp=3
Kp=4
Kp>5



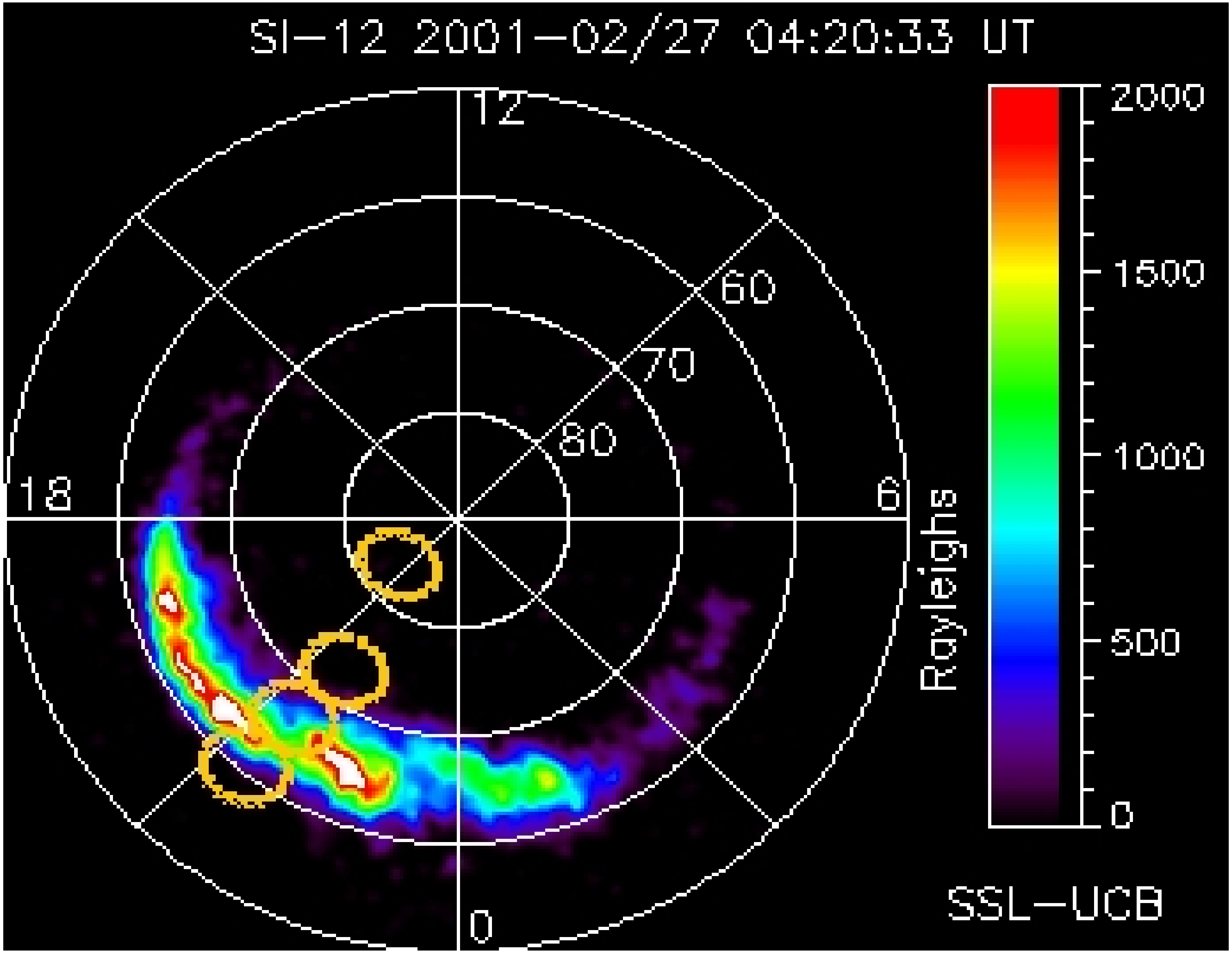
GOES 8 (SM)
Inclination
70
60
50
40
30
60
49
37
27
15
5
0200
0300
0400
0500
0600
0700
UT (hours)


GOES-8 B-field inclination (UT and dipole tilt corrected)
80
70
60
50
40
30
20
64
65
66
67
68
69
Optical B2i at Gillam

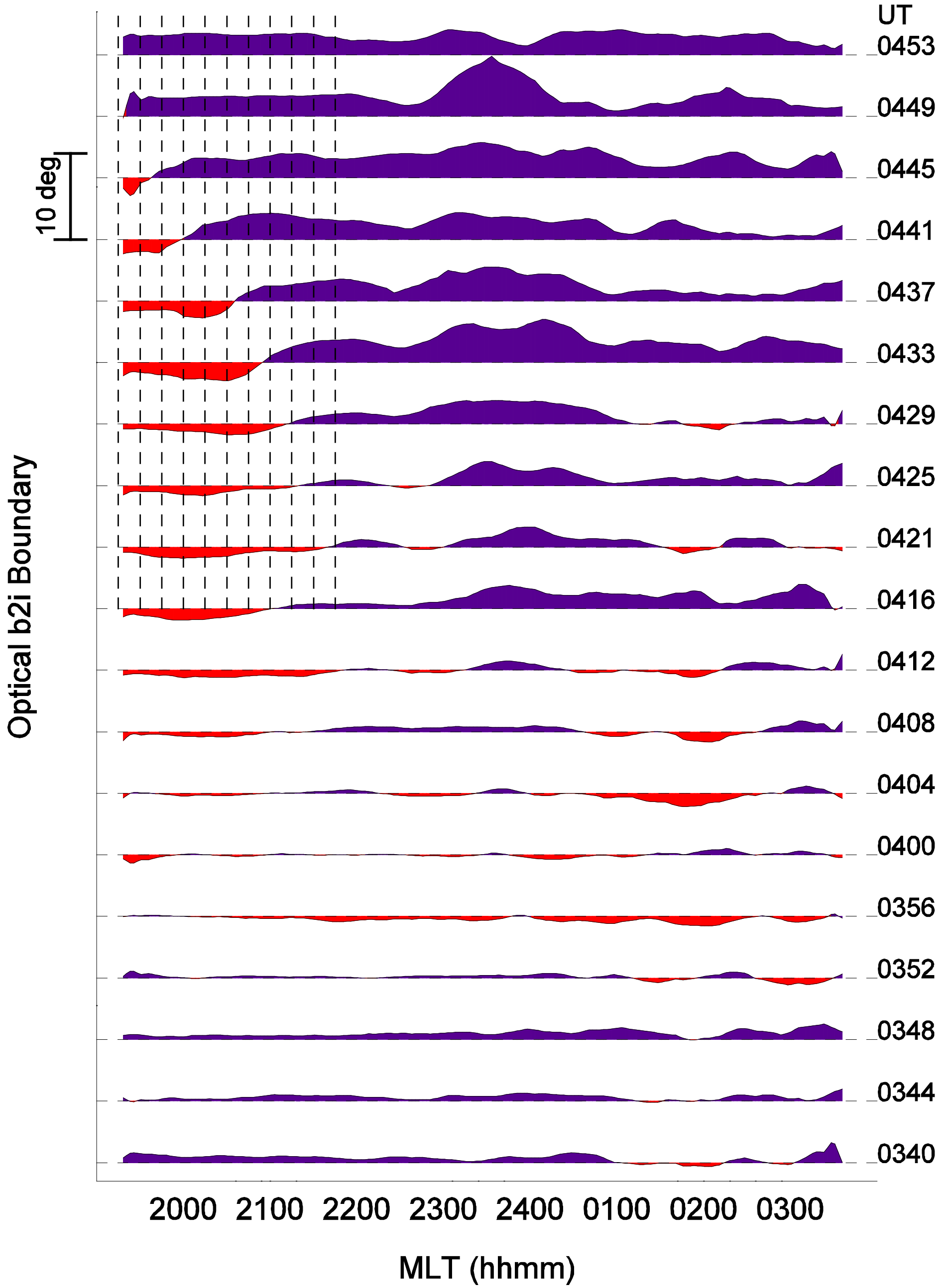

GOES-8 B-field inclination
r=0.815
N=16878
Measured
Model
80
70
60
50
40
30
30
40
50
60
70
80

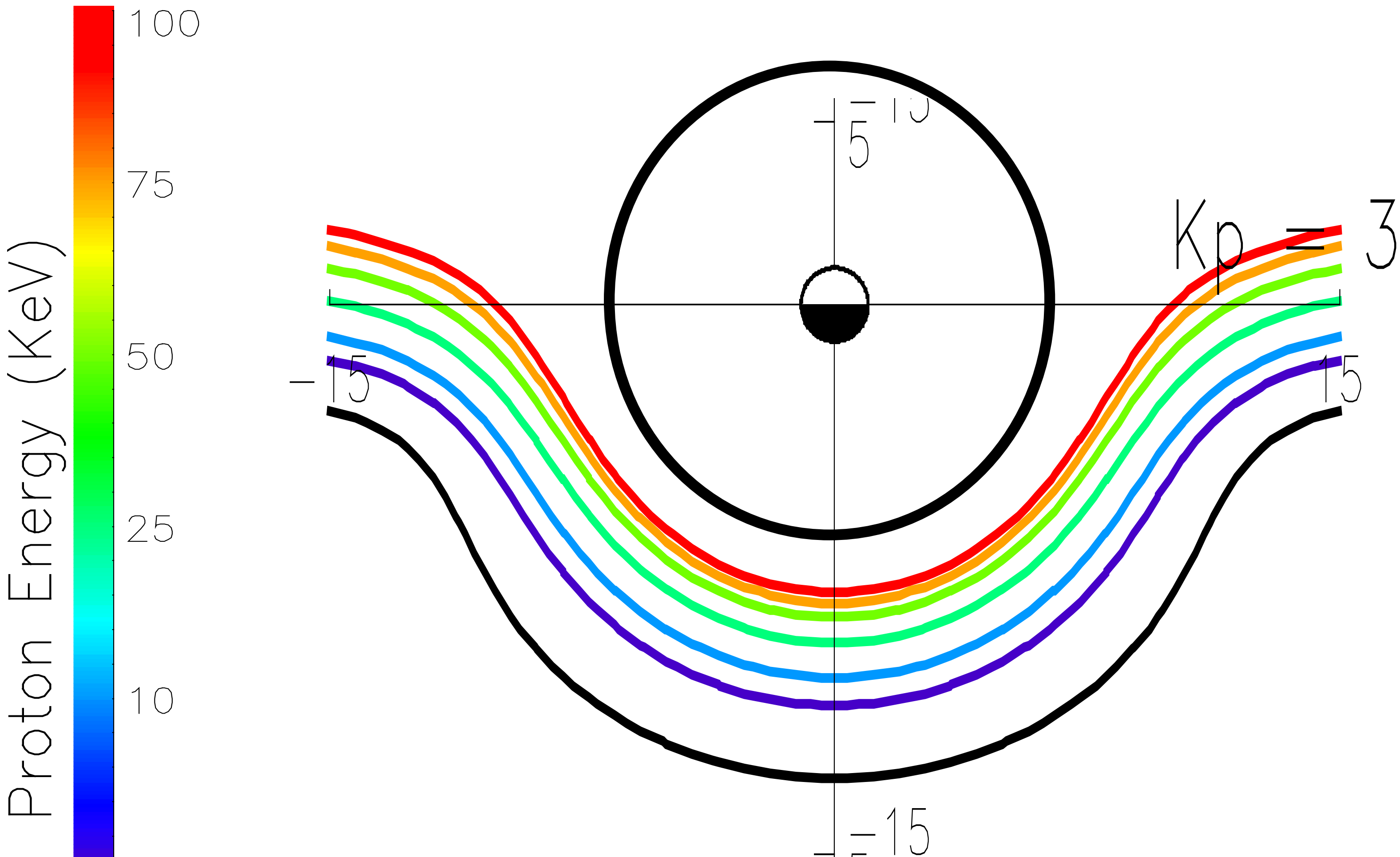


GOES 8 Inclination (measured, inferred from Optical b2i from Gillam MSP)

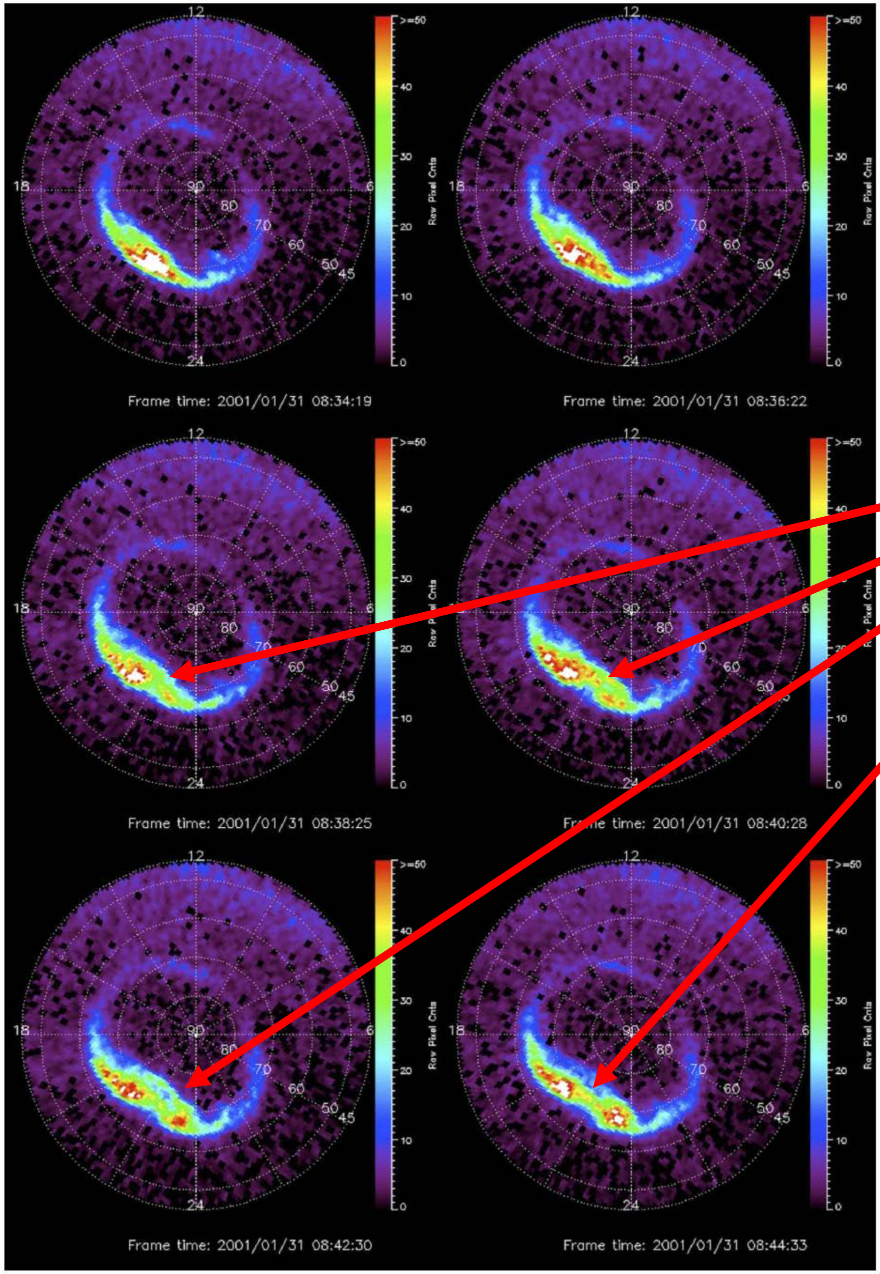

SI-12 2001-02/27 04:20:33 UT
12
18
6
0
60
70
80
2000
1500
1000
500
0
Rayleighs
SSL-UCB

Optical b2i inferred from SI-12 images: Shows westward propagating (evolving?) depolarization at geosynchronous orbit. It also shows continued stretching outside of what I would argue is the evolving SCW.





$$\kappa^2 = \frac{R_c}{\rho} = B_z^2 \left(\frac{\partial B_x}{\partial z}\right)^{-1} \left(\frac{m_p V}{q}\right)^{-1} = 9$$



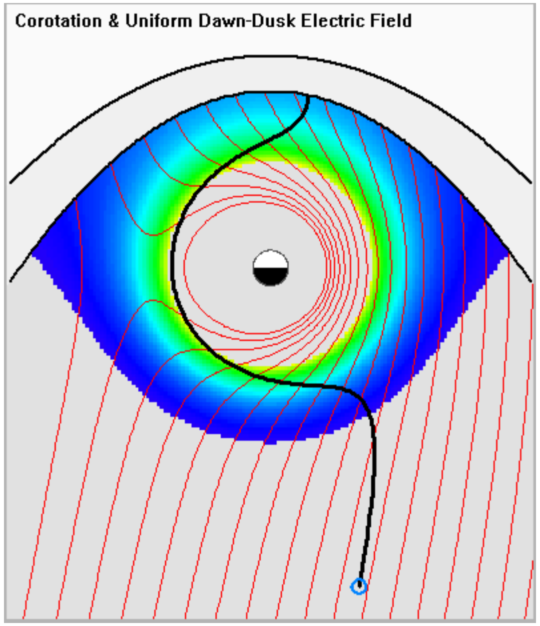
‘Split’ in proton auroral oval (forms in about half of substorms according to SI-12 data): Corresponds to SCW and changes in convection in expansion phase of substorm.

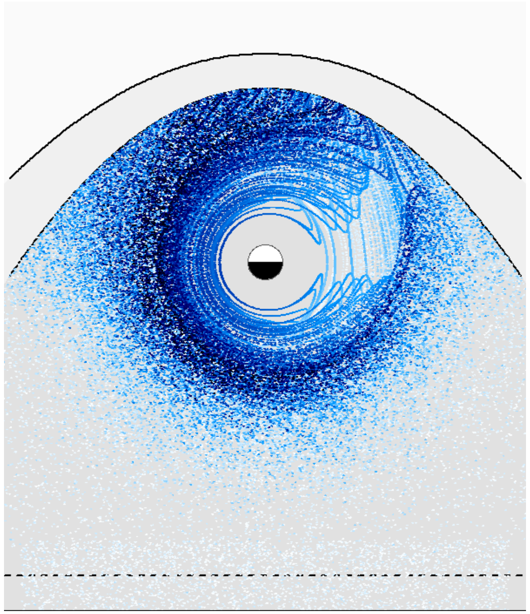
Figure 1. Splitting of the proton aurora during a substorm on 31 January 2001 as seen by the IMAGE SI-12 instrument: From left to right and top to bottom are smooth (visual) IB_λ (first panel), slight increase in the IB_λ near 21:00 (second panel), split precipitation maximum centered around 22:00 (third panel), and further development of the split region (fourth, fifth, and sixth panels). White pixels represent counts greater than 50.

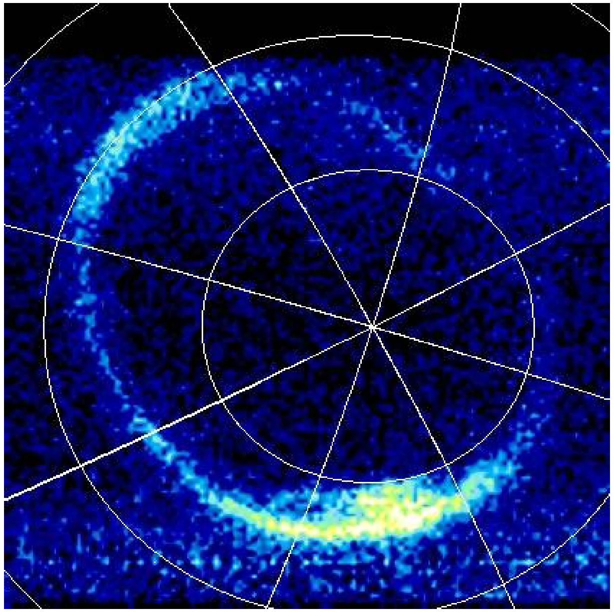
Gilson et al., 2011

Proton Aurora

Watching the IB 'wash' over THEMIS-A and THEMIS-E

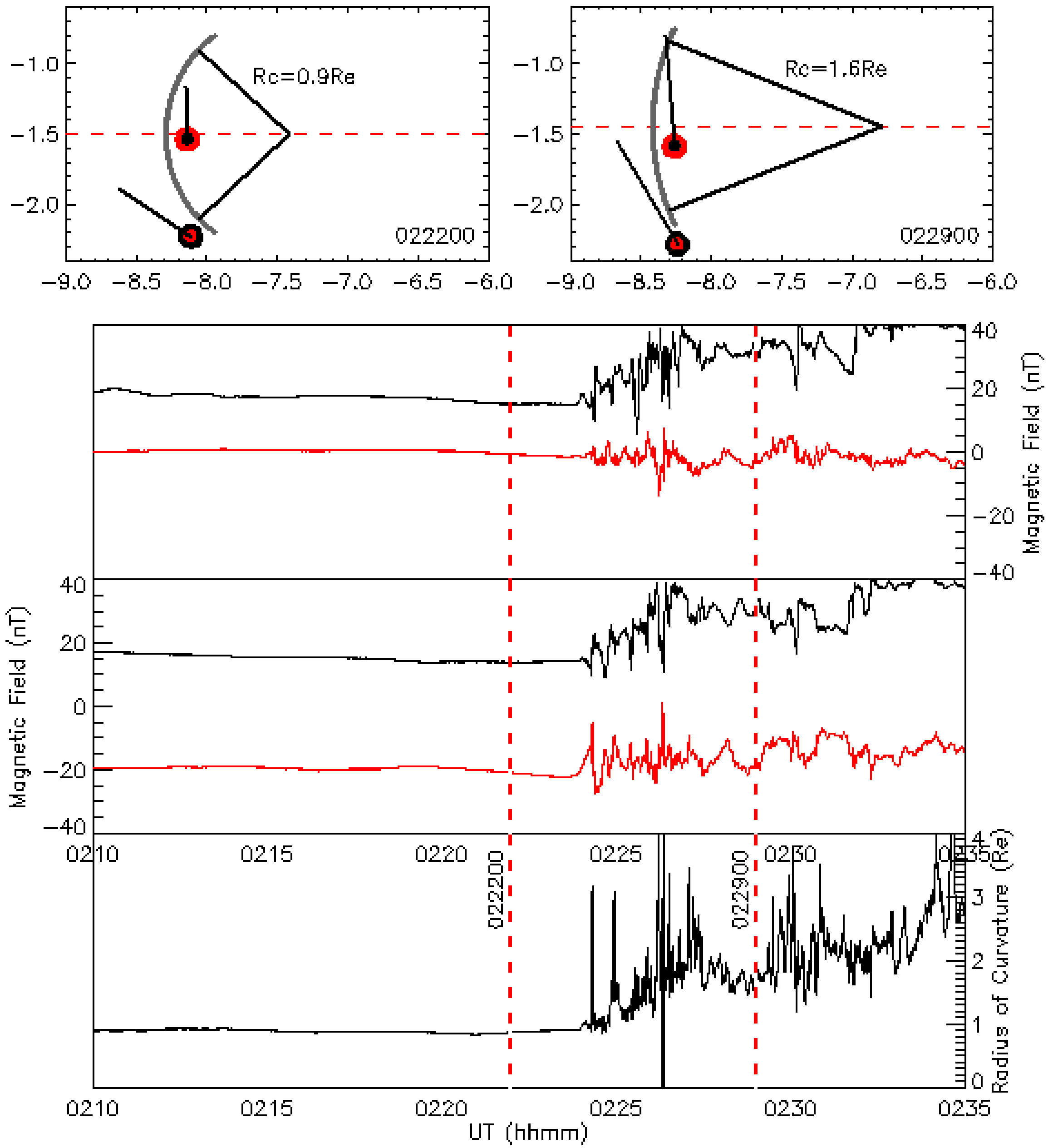






This presentation is being recorded.

Substorm onset that occurred when THEMIS-A and –E were separated in Z by <1Re and very close in X and Y. This allowed a time series of estimated radius of curvature. This enables one to create a time series of the energy for which K=3. By superposing this ‘critical energy’ on ESA/SST data, we can cearly see the passage of the b2i (IB) across the satellites (from inside of their location to tailward of it).



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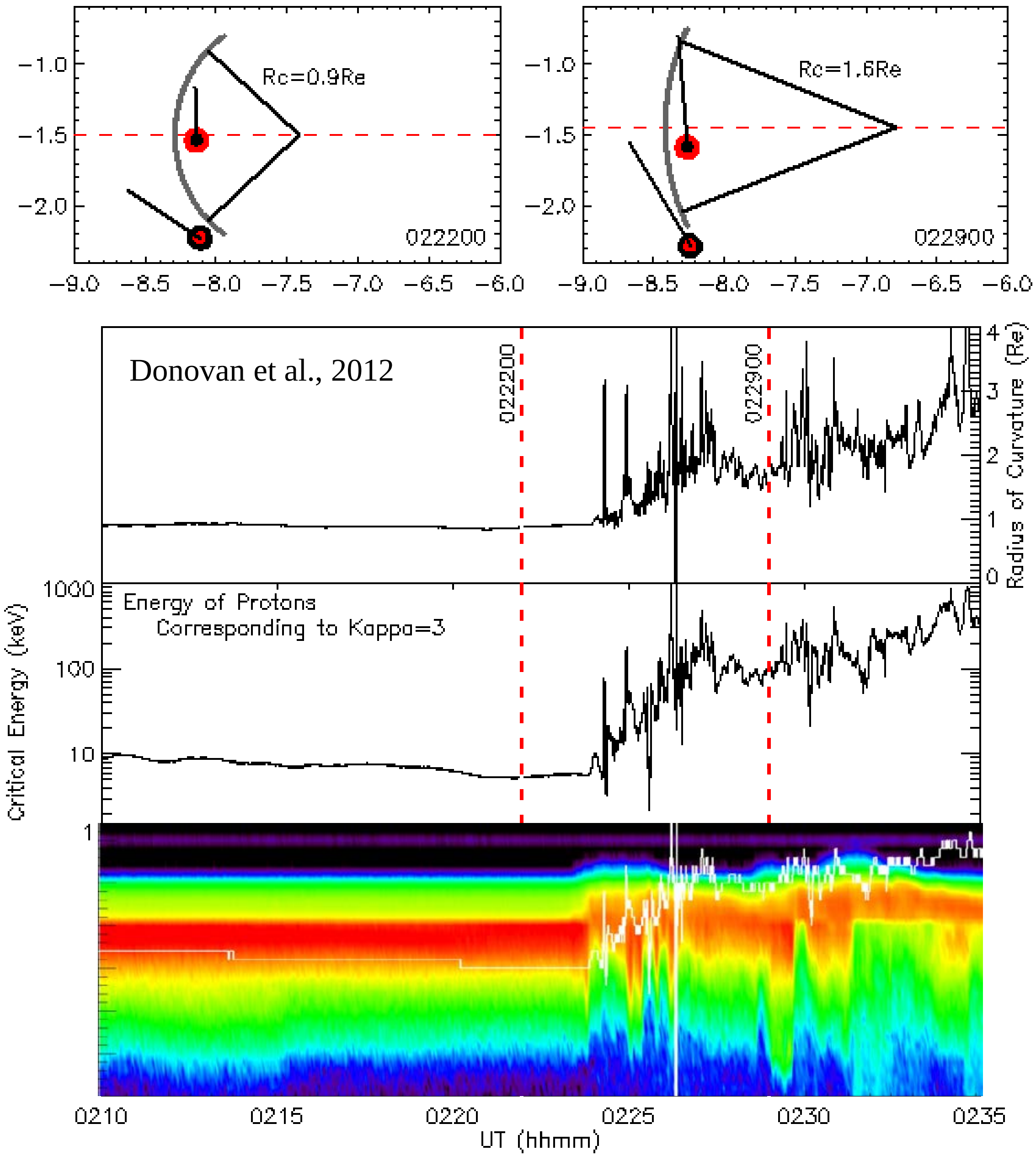
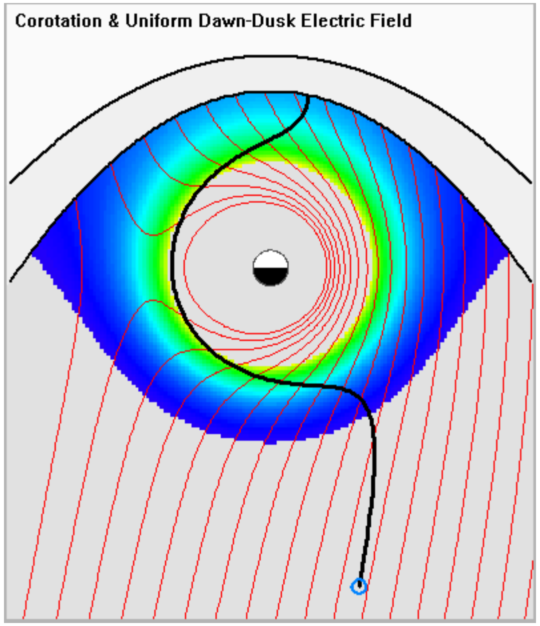
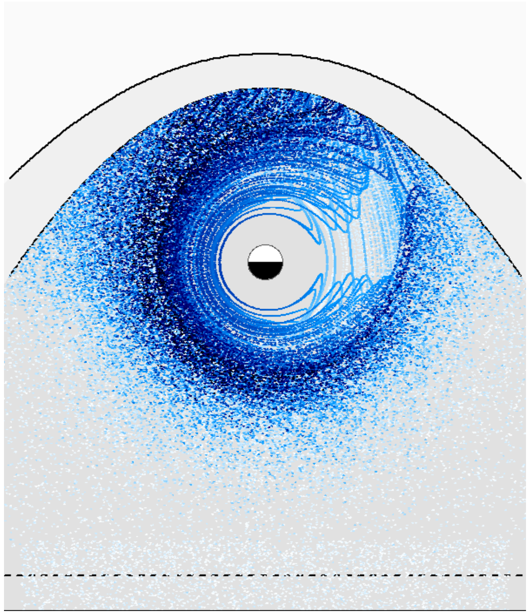
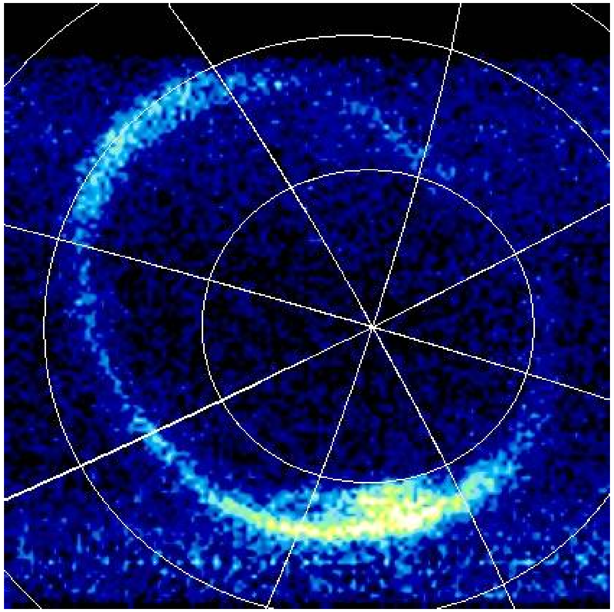


Proton Aurora

Where in the magnetotail does the bright proton aurora originate?







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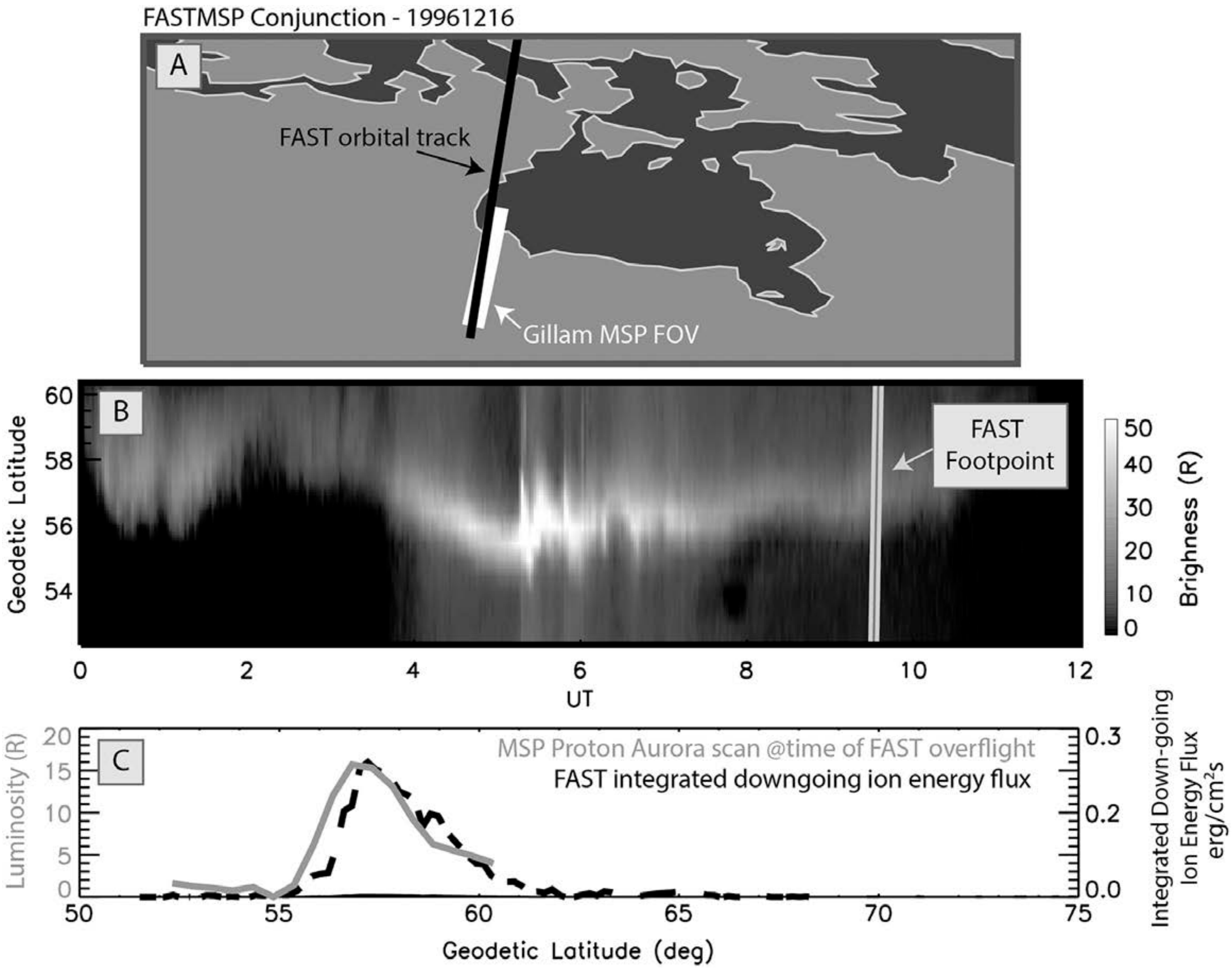
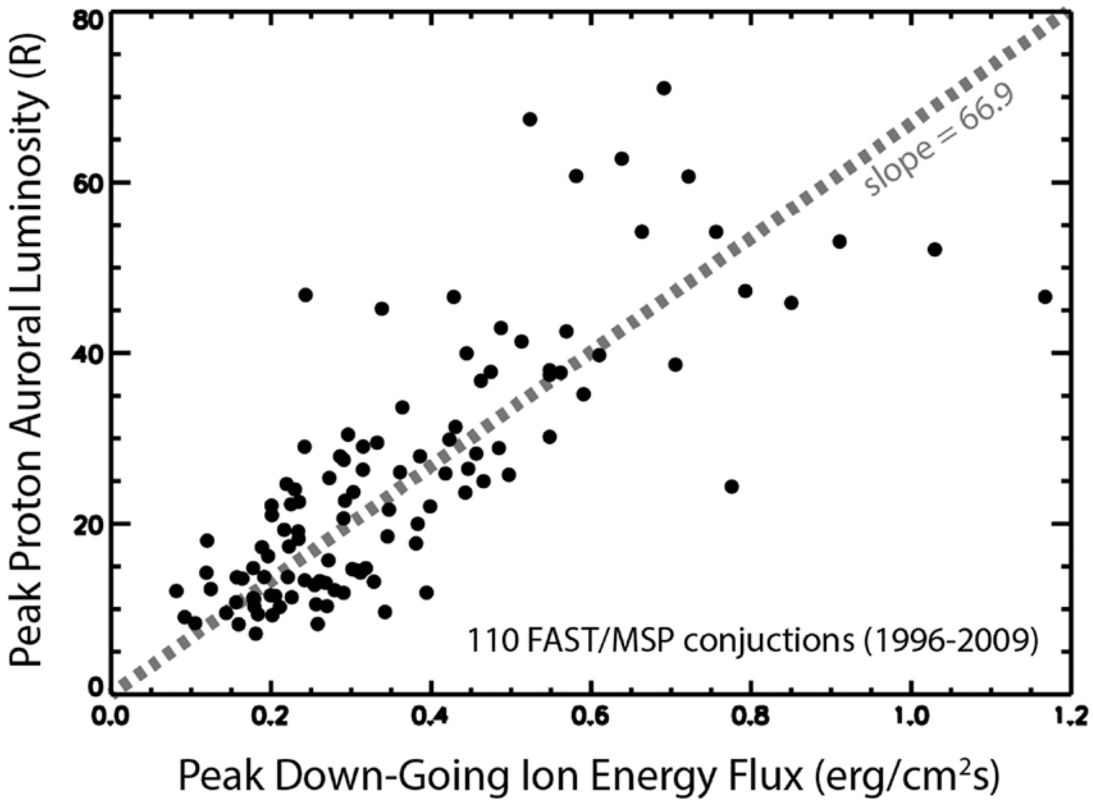


Spanswick et al., 2018



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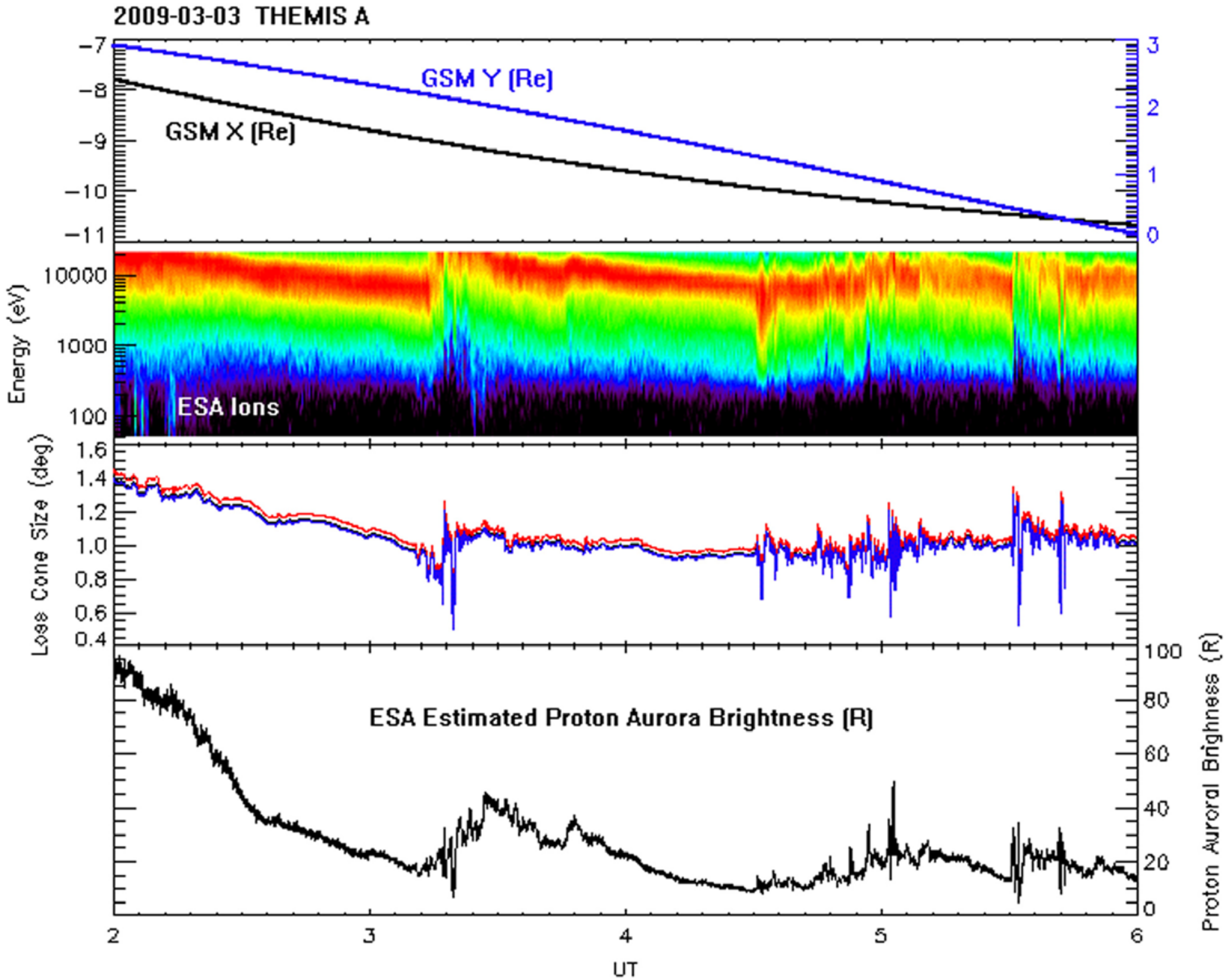

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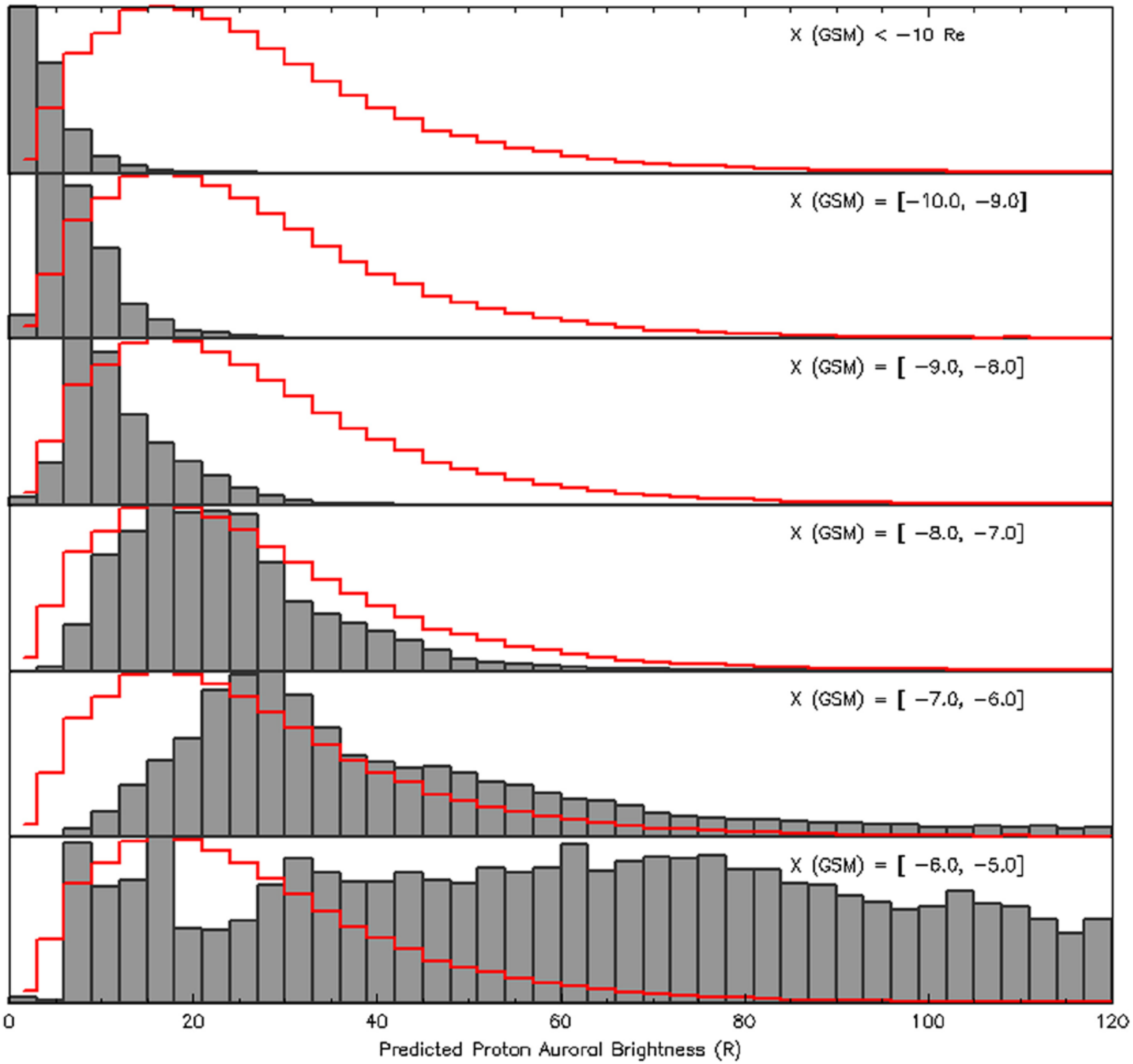

Spanswick et al., 2018

Some closing thoughts…

We know (BPA=Bright Proton Aurora)…

- pulsating aurora occur within or equatorward of the BP (Grono, 2019)
- all arcs occur poleward of the peak in the BPA (Lyons, ?; Conjecture?)
- arc that brightens is on poleward shoulder of BPA (Lui, 1975; Samson, 1992)
- BPA fades in the minutes before onset (Liu, 2007)
- near midnight, the BPA originates from the 7-11 Re region (Spanswick, 2017)
- proton aurora provides us a means of remote sensing stretching (Donovan, 2003)

There is a lot I glossed over or simplified…

- a key thing is that if the pitch angle diffusion is accomplished via curvature, then IB dependence on energy should be such that the IB is at lower latitude for higher energies… that is the case almost always in the evening sector but often the ordering is reversed in the morning sector….
- are there proton auroral ‘arcs’ or is all proton aurora diffuse?
- I didn’t talk about the role of EMIC waves in causing localized proton aurora

We don’t have great proton auroral measurements now…

- Shiokawa camera and Connors MSP at Athabasca
- Hampton Meridian Imaging Spectrograph(s?) at PFRR
- Two TREx Meridian Imaging Spectrographs in Saskatchewan
- GDC?