THE IMPACT OF SUDDEN STORM COMMENCEMENT ON MAGNETOSPHERIC ION DISTRIBUTIONS

Vahé Peroomian and Mostafa El-Alaoui

UCLA Institute of Geophysics and Planetary Physics

Outline

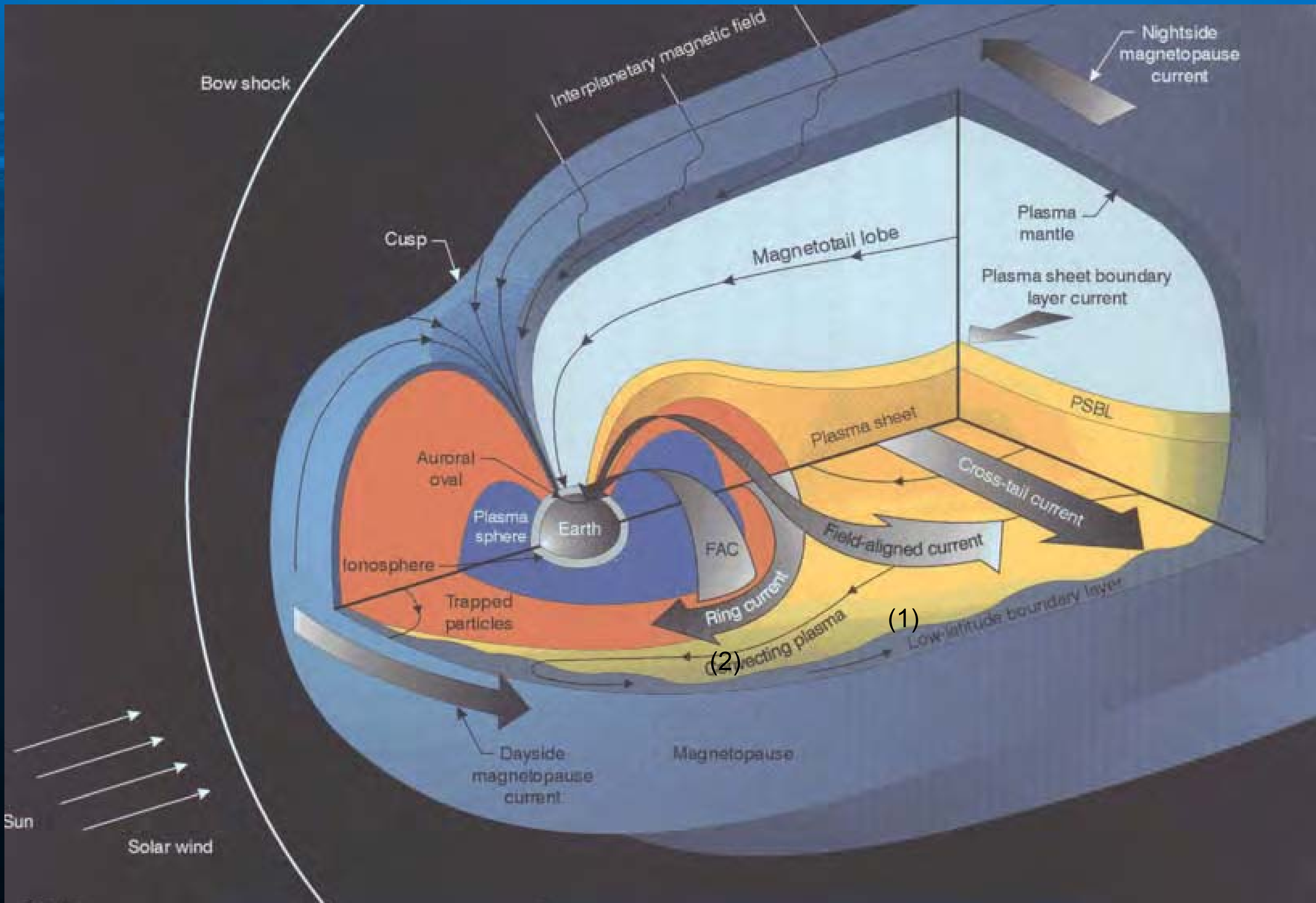
- Introduction
  - Motivation
  - Approach
- The 28 October 2001 Storm
  - Observations
  - Large-Scale Kinetic Results
    - Physics of ion population
    - Physics of ion injection
    - Physics of ion acceleration
- Comparison with the 17 April 2002 and 24-25 September 1998 Storms

Motivating Question

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

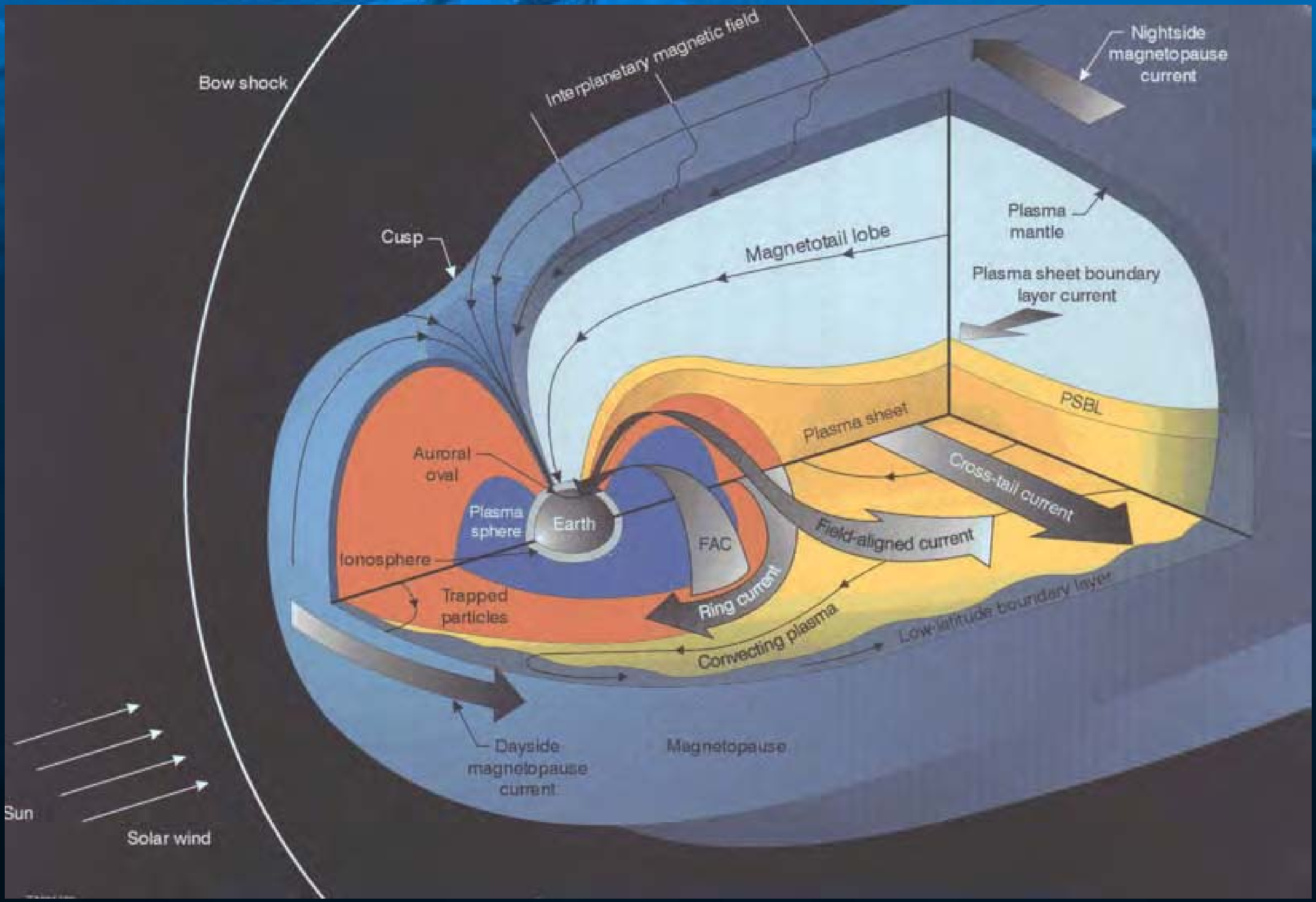
- Impact of CME with Earth’s magnetosphere is the most violent component of a geomagnetic storm.

How does Sudden Storm Commencement affect the ion distributions in the inner magnetosphere: how are ions energized and injected?



The magnetosphere is defined by its current systems and by its plasma regimes.

Population of the Magnetosphere



- Two sources: Solar wind (Mostly H^+, some He^{++}) and ionosphere (H^+, He^+, O^+, …)

Approach

- Run global magnetohydrodynamic (MHD) simulation of each storm event using upstream data from solar wind monitor spacecraft.
- Follow orbits of millions of ions in time-dependent electric and magnetic fields from MHD simulation using full Lorentz force equation.
- Launch H^+ ions in the solar wind; launch O^+ ions from the ionosphere throughout each storm.

The Large-Scale Kinetic (LSK) Modeling Technique

- Follow the orbits of a large number of particles in specified global electric and magnetic fields.
- Use Lorentz Force Equation to integrate particle orbits:

$$m\frac{d\vec{v}}{dt} = q\left(\vec{E} + \frac{\vec{v}\times\vec{B}}{c}\right)$$

Include kinetic physics on global scales

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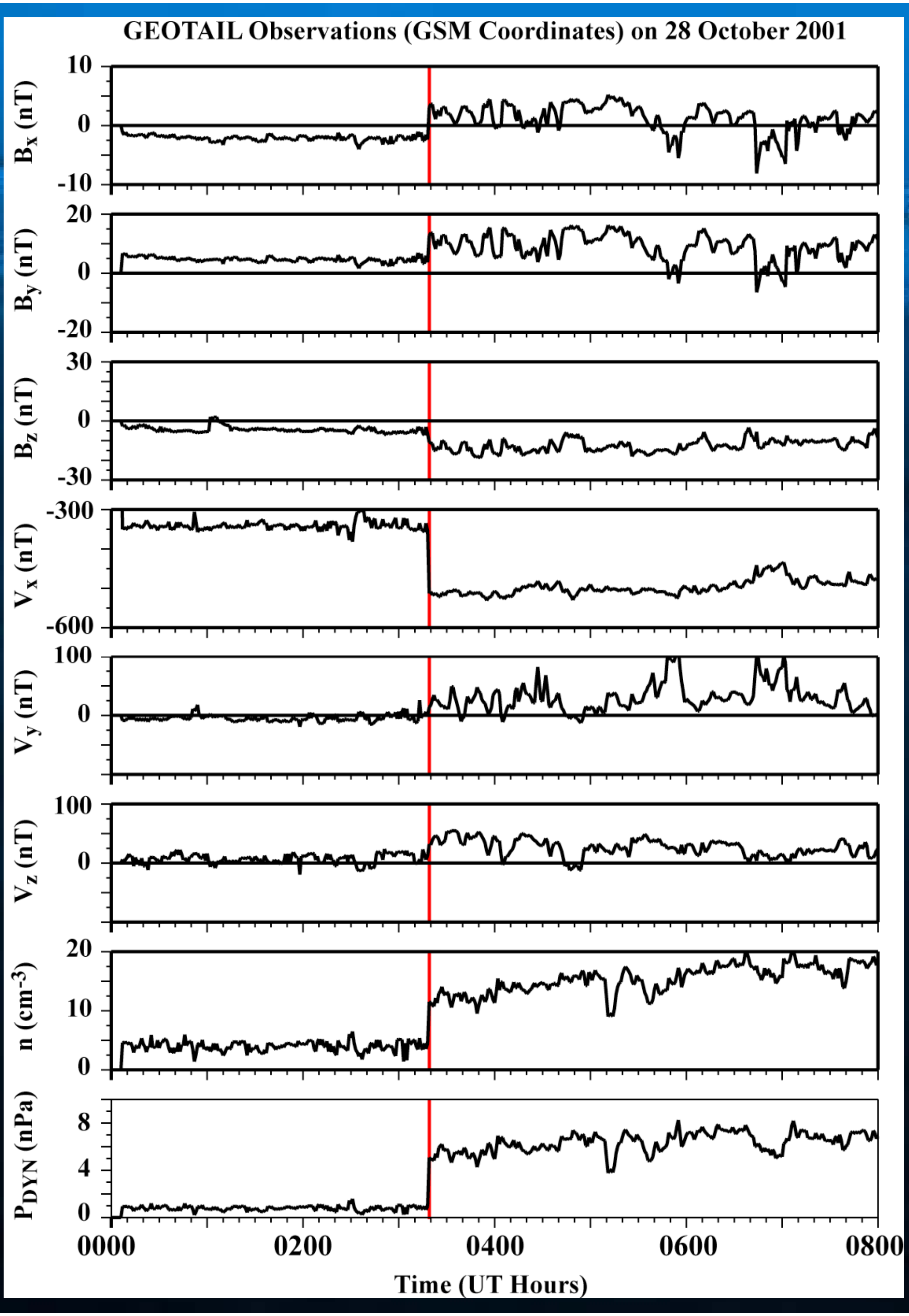
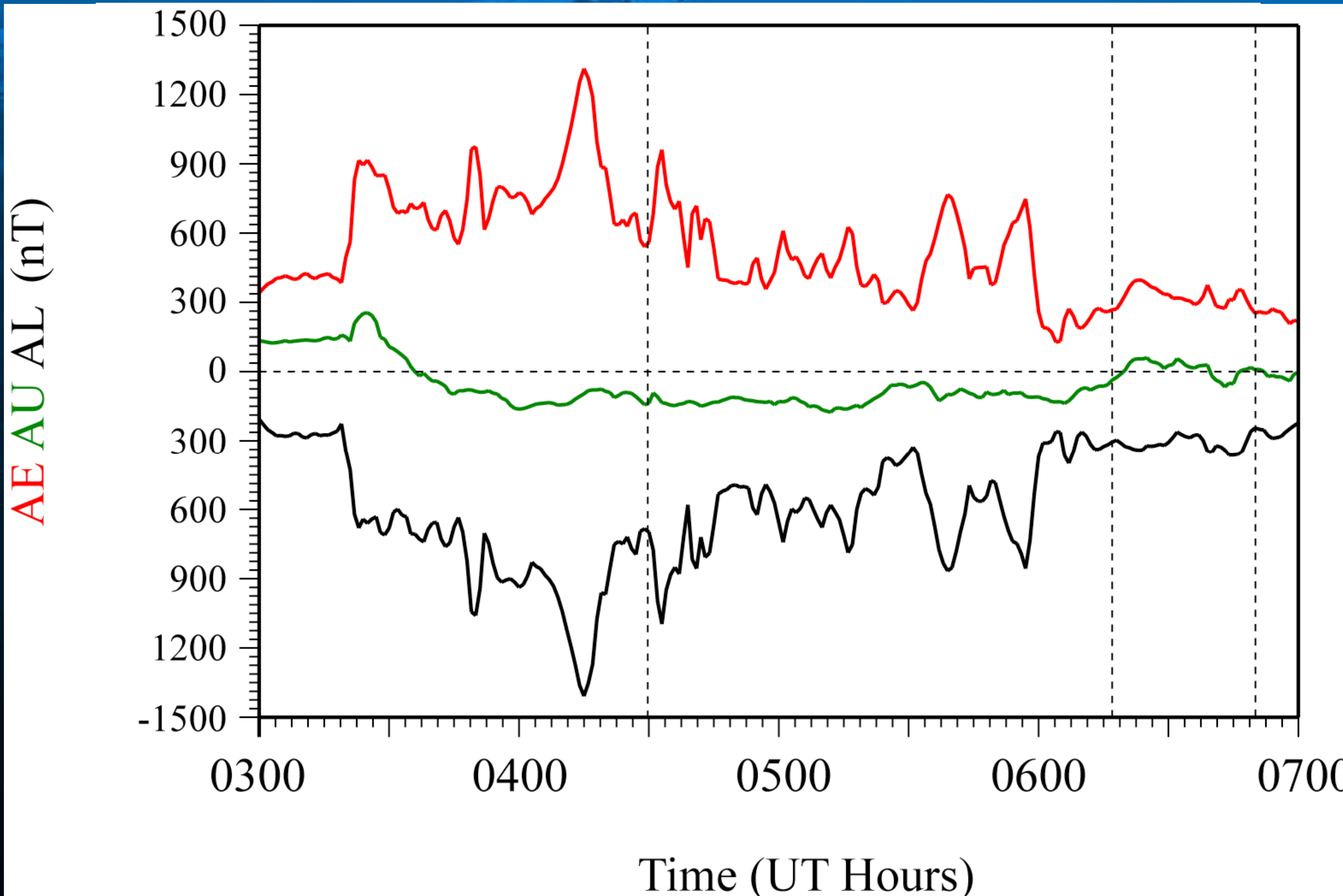
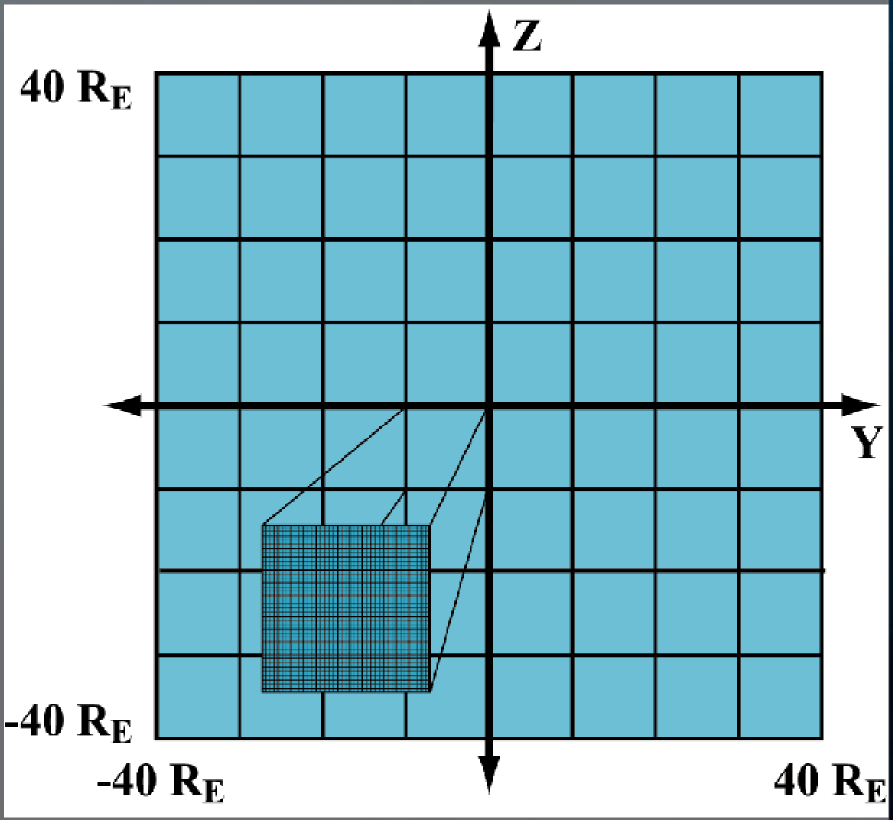

GEOTAIL Observations (GSM Coordinates) on 28 October 2001
B_x (nT)
10
0
-10
B_y (nT)
20
0
-20
B_z (nT)
30
0
-30
V_x (nT)
-300
-600
V_y (nT)
100
0
V_z (nT)
100
0
n (cm^{-3})
20
10
0
P_{DYN} (nPa)
8
4
0
0000
0200
0400
0600
0800
Time (UT Hours)

Global Indices for 28 October 2001



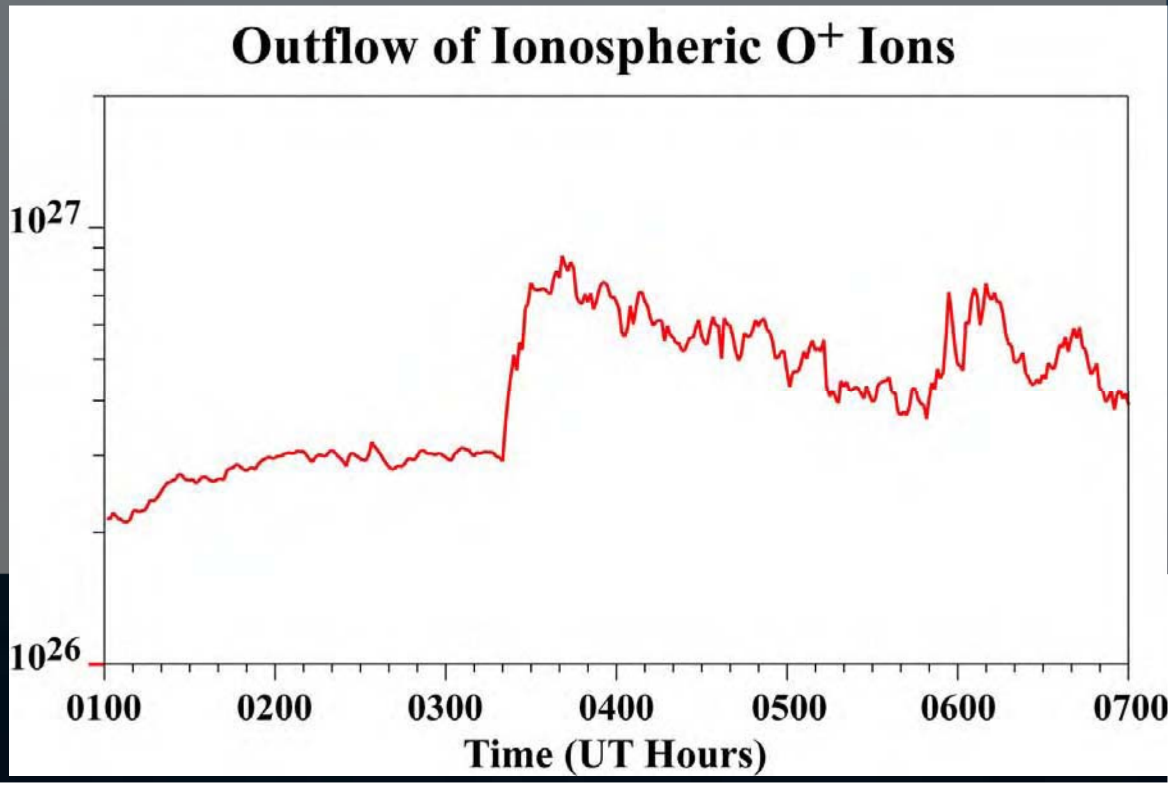
Solar wind H^+ Ion Launch Scheme

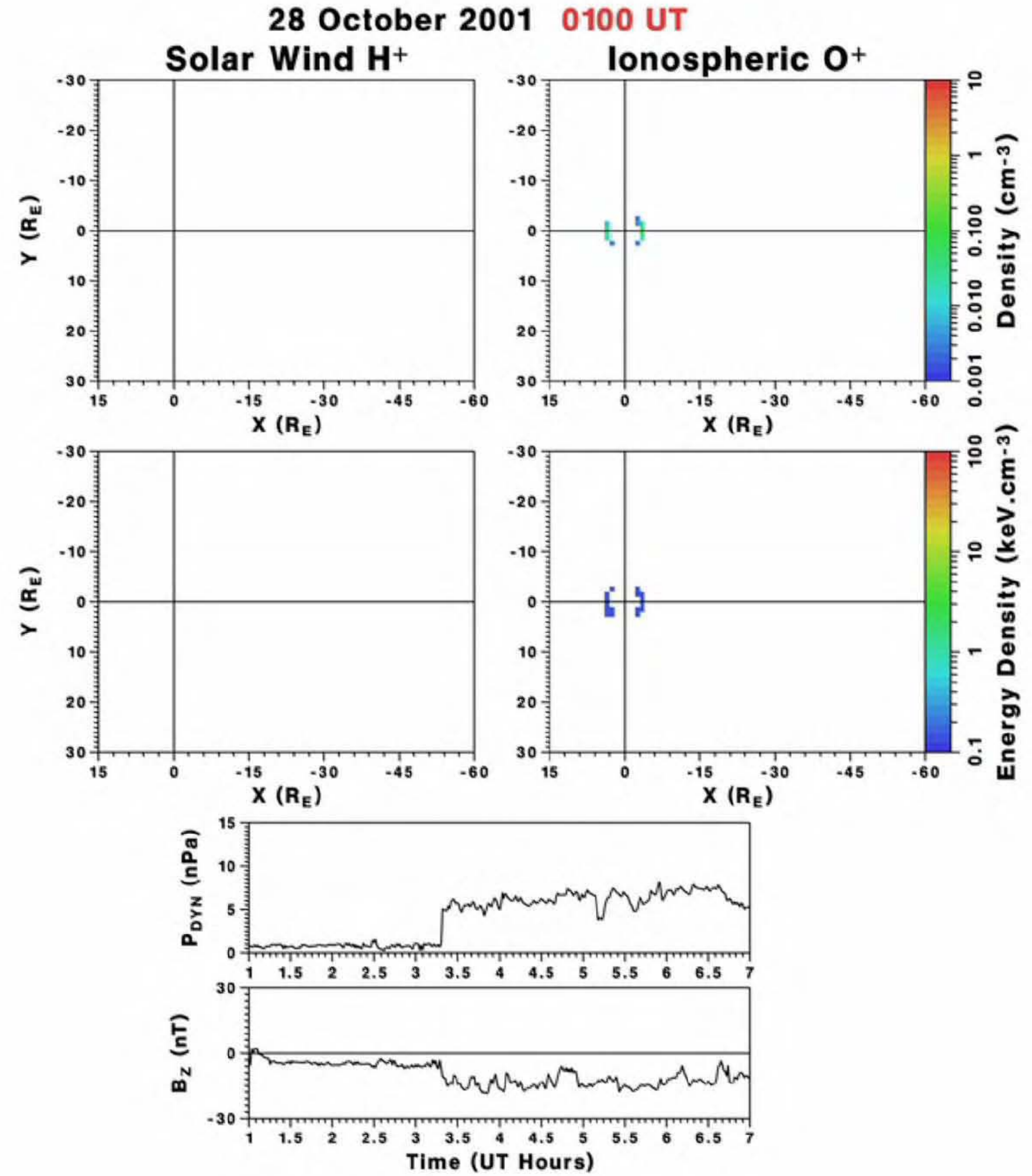
- Ions launched at $X = 17\ R_E$, upstream of bow shock at 1-minute intervals beginning ~140 min prior to the SSC.
- Grid spacing $0.5\ R_E \times 0.5\ R_E$ (Y-Z).
- 100 ions per grid point. ($>2 \times 10^7$ ions per launch)
- Ions launched as a drifting Maxwellian with V_{SW} and T_{SW}.
- Flux of launched ions normalized to solar wind flux through upstream boundary.

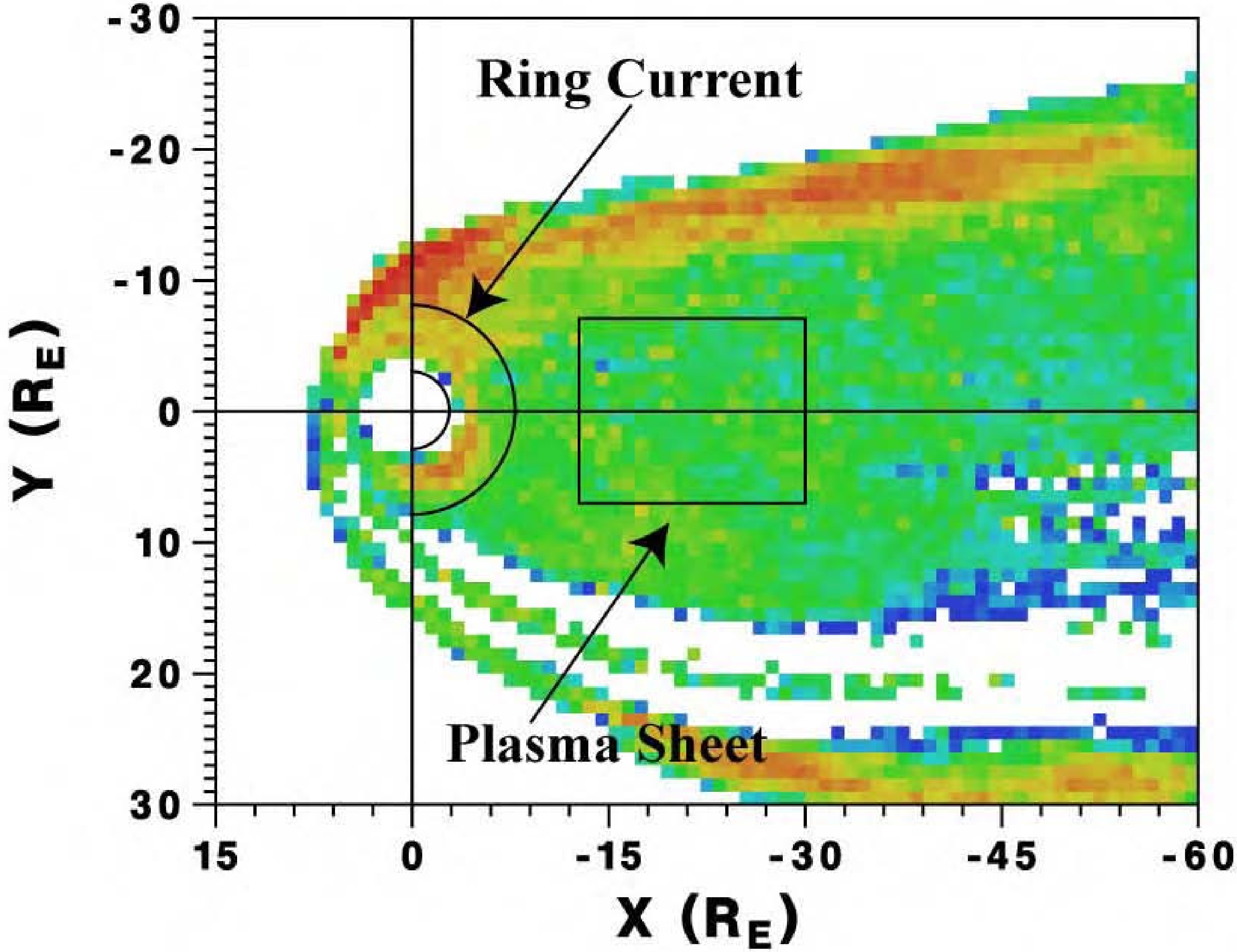


Ionospheric O^+ Ion Launch Scheme

- Ions launched every minute using *Strangeway et al*. [2005] formula relating upflow to precipitating density obtained from MHD simulation.
- Spatial Distribution (SM coordinates): $\lambda = \pm(60^\circ - 85^\circ)$ All MLTs
- Altitude: 2.2 R_E
- Temperature: 30 eV
- Streaming Energy: 50 eV
- Total of $> 2 \times 10^7$ ions launched.

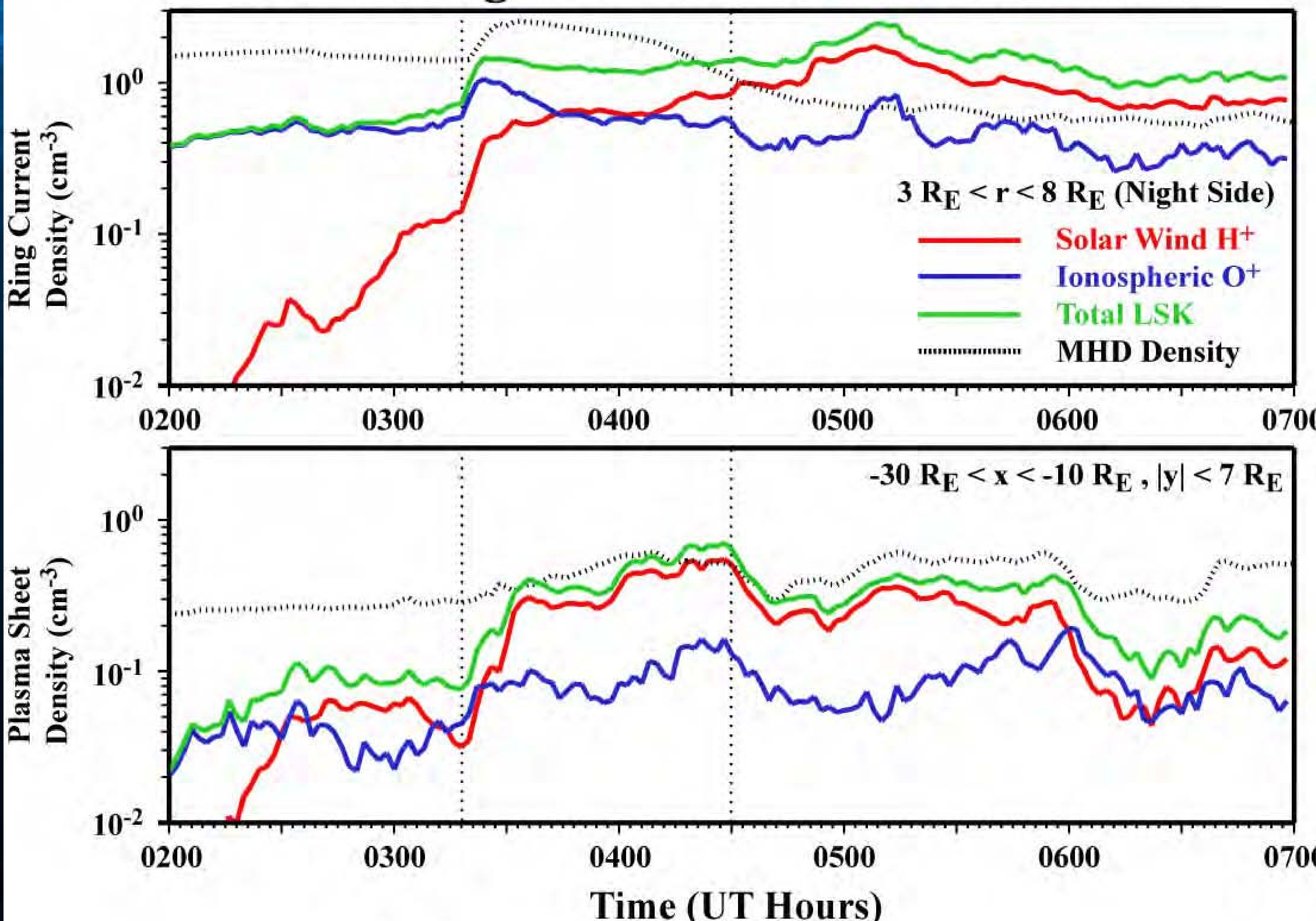


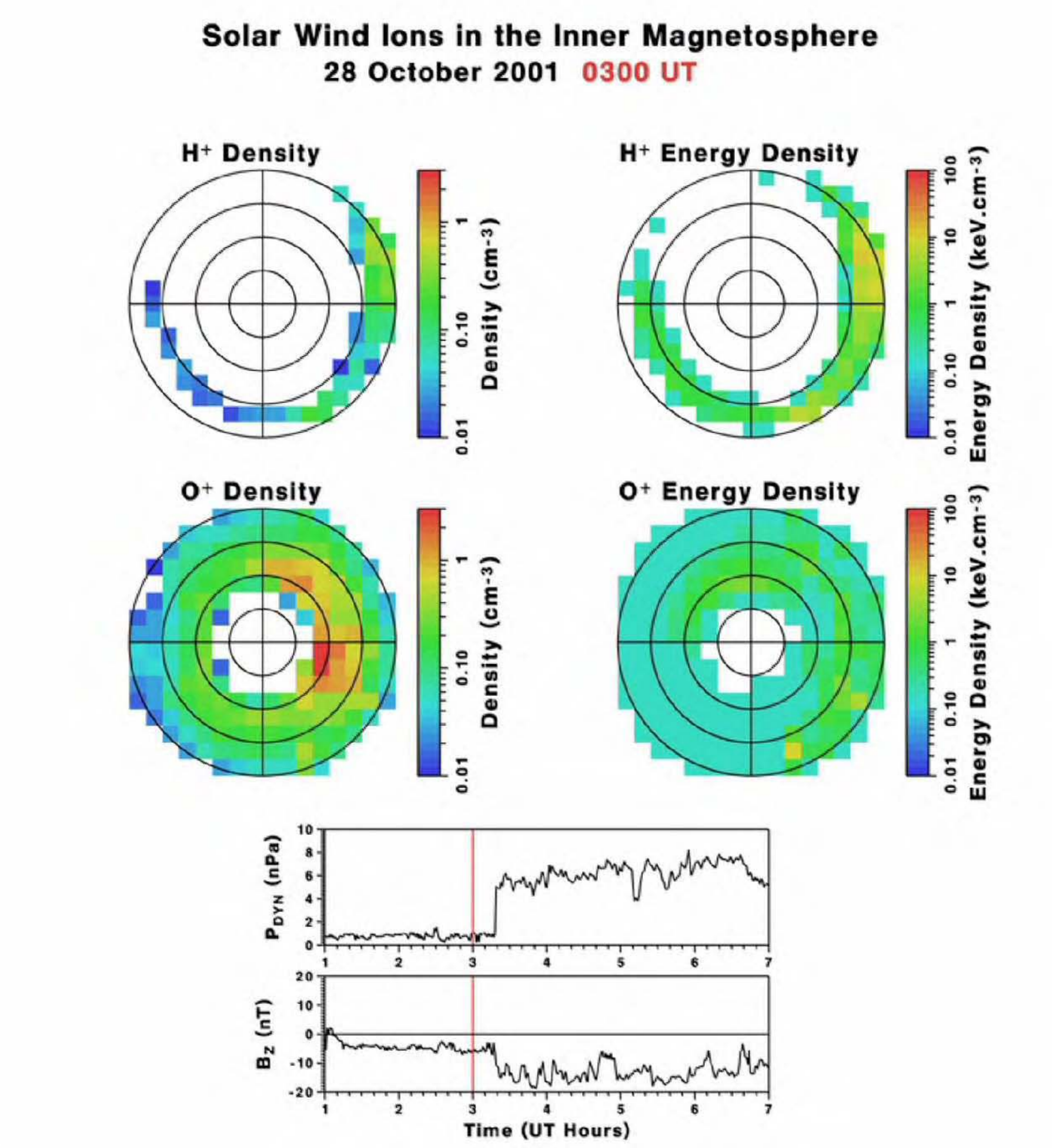

28 October 2001 0100 UT
Solar Wind H+
Ionospheric O+
Y (RE)
X (RE)
Density (cm-3)
Energy Density (keV.cm-3)
PDYN (nPa)
BZ (nT)
Time (UT Hours)



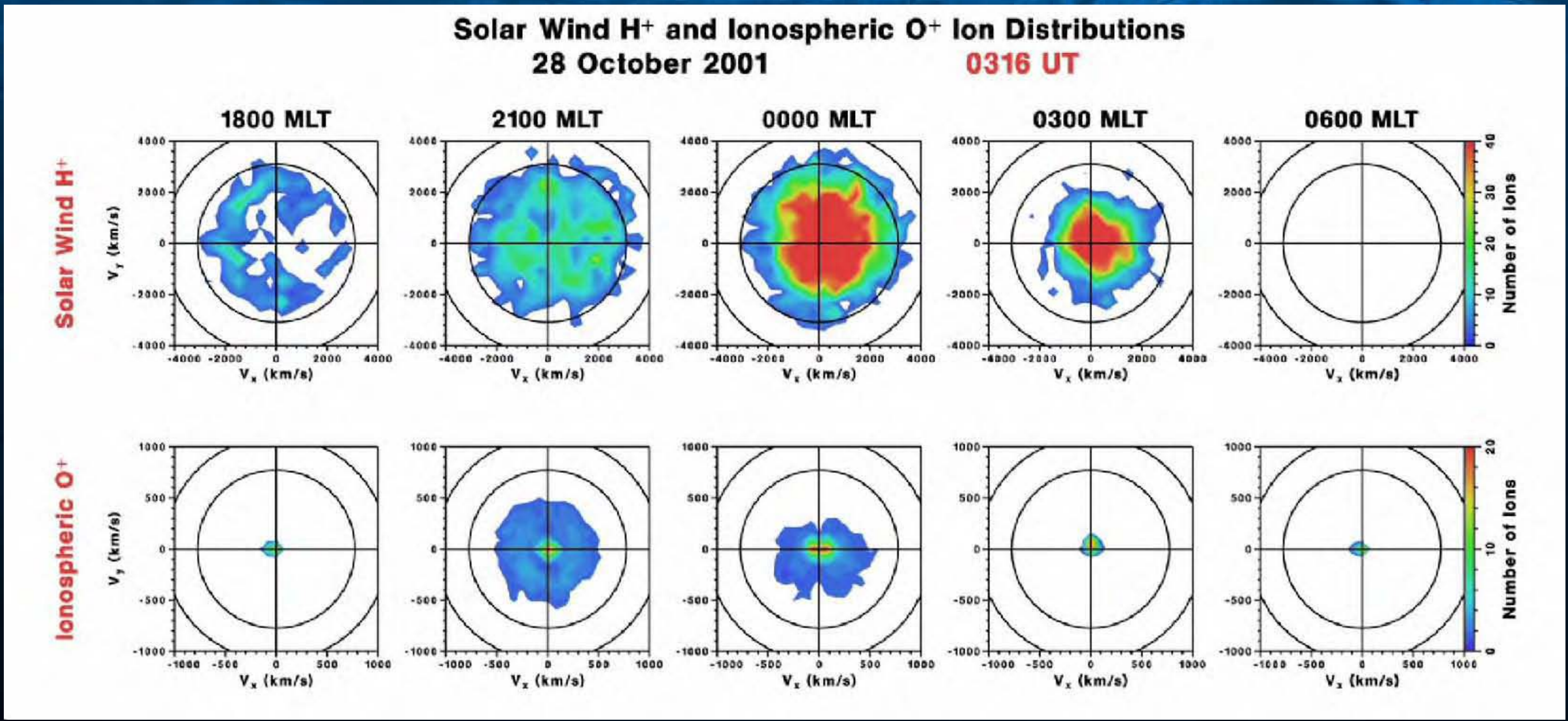
Ring Current
Plasma Sheet
-30
-20
-10
0
10
20
30
Y (R_E)
15
0
-15
-30
-45
-60
X (R_E)

Densities of Ions in the Ring Current and Plasma Sheet





Solar Wind Ions in the Inner Magnetosphere
28 October 2001 0300 UT
H+ Density
H+ Energy Density
O+ Density
O+ Energy Density
Density (cm-3)
Energy Density (keV.cm-3)
0.01
0.10
1
10
100
PDYN (nPa)
BZ (nT)
Time (UT Hours)


Solar Wind H+ and Ionospheric O+ Ion Distributions
28 October 2001
0316 UT
1800 MLT
2100 MLT
0000 MLT
0300 MLT
0600 MLT
Solar Wind H+
Ionospheric O+
Vy (km/s)
Vx (km/s)
Number of Ions

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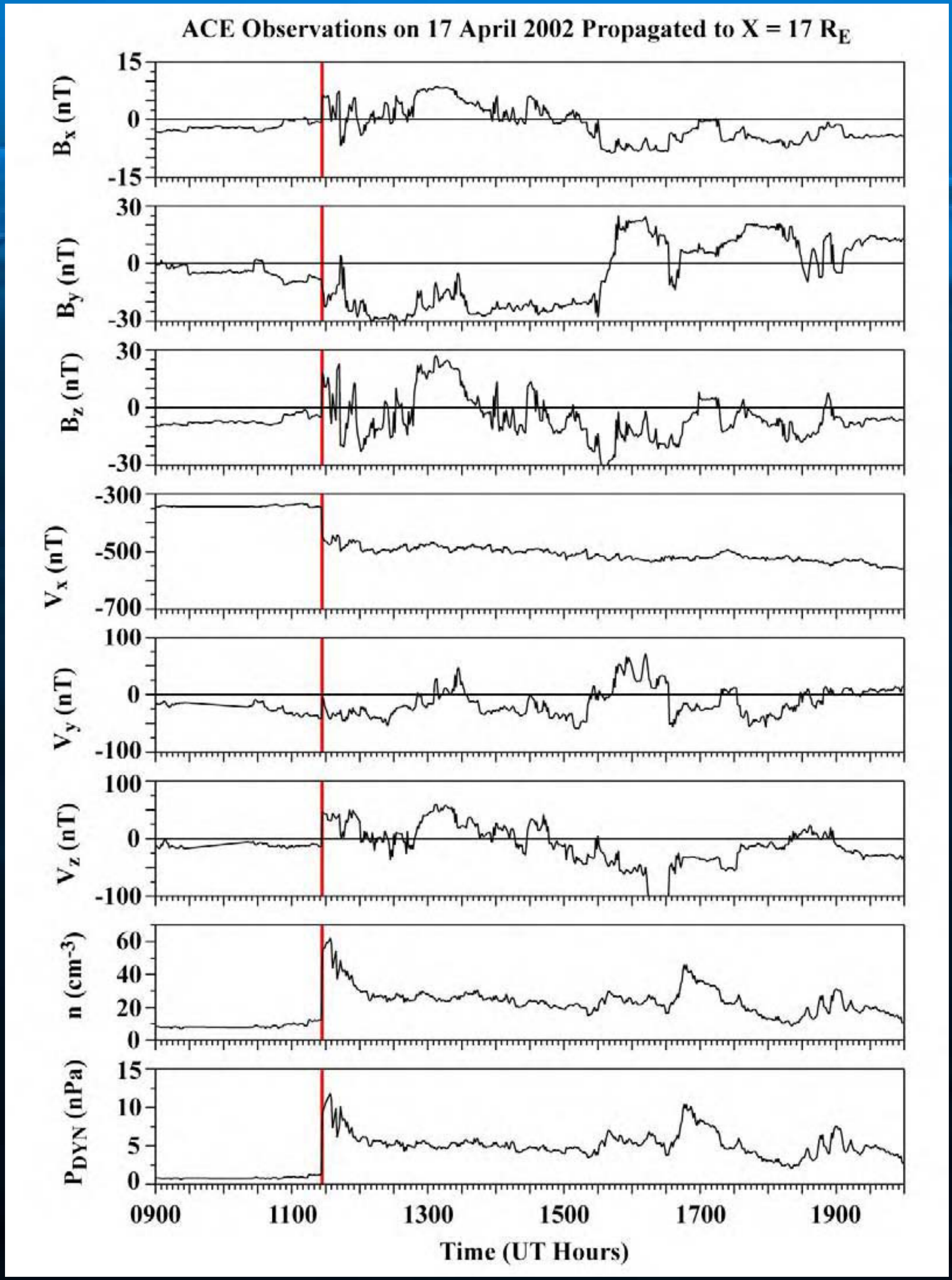
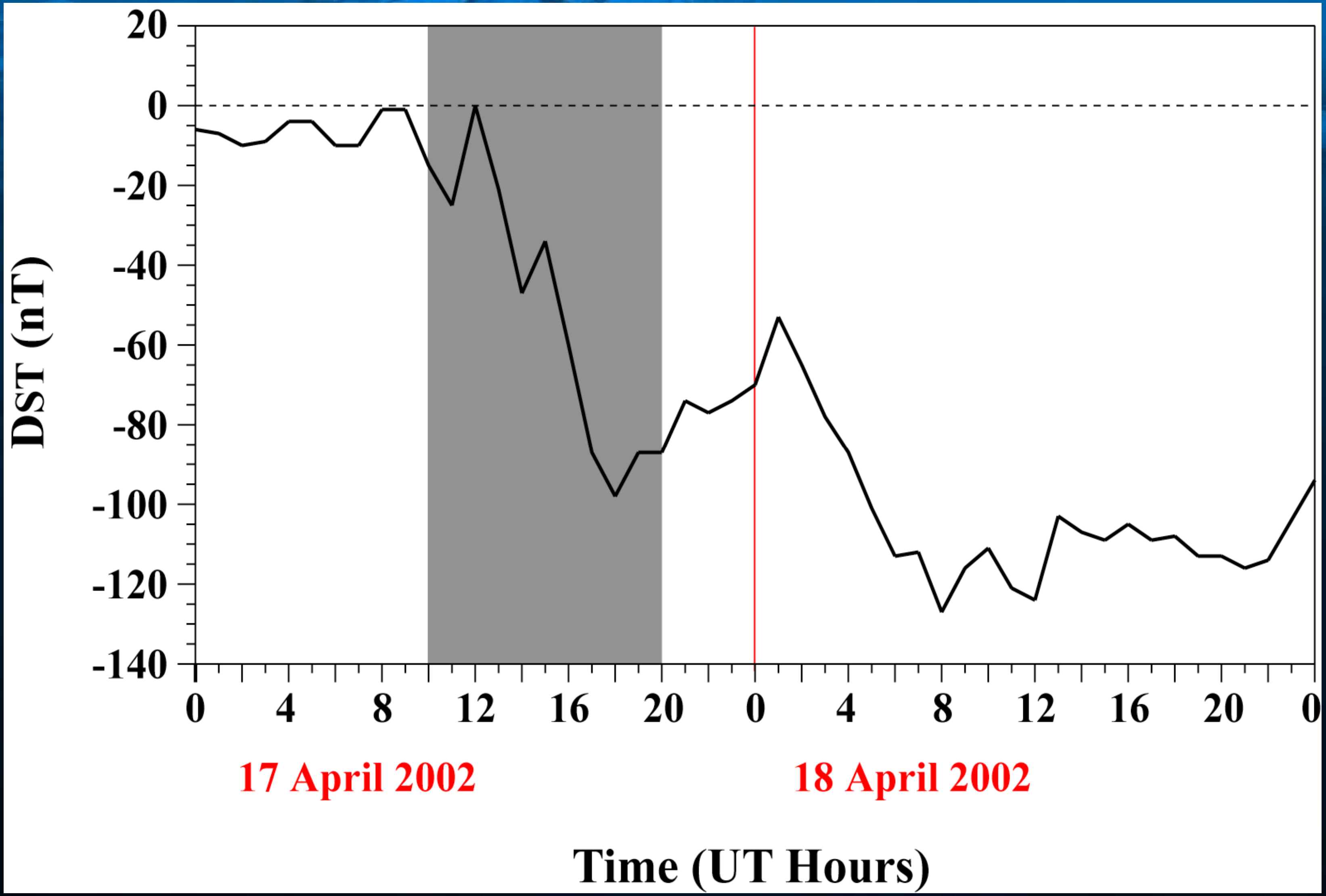
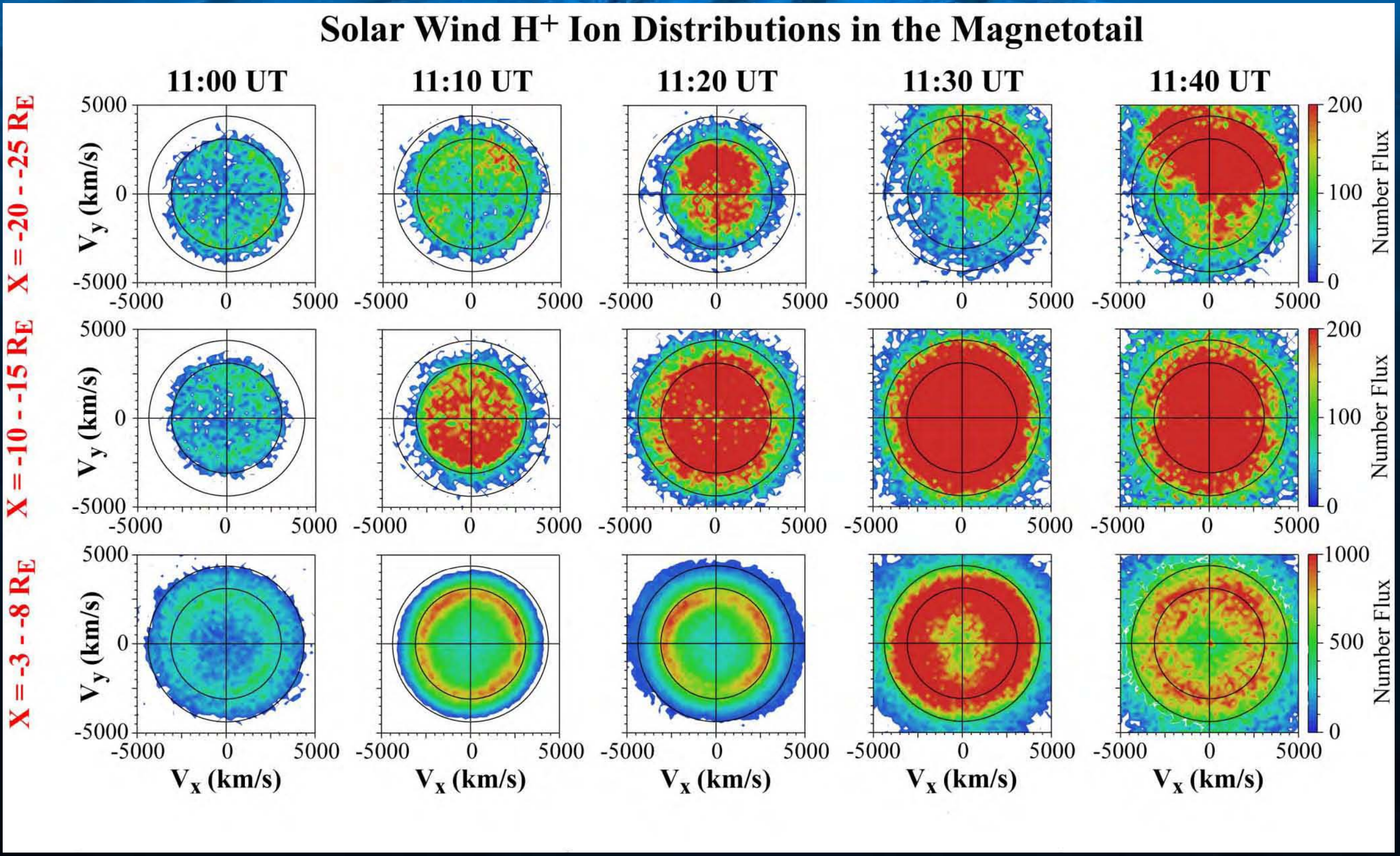

ACE Observations on 17 April 2002 Propagated to X = 17 R_E
B_x (nT)
15
0
-15
B_y (nT)
30
0
-30
B_z (nT)
30
0
-30
V_x (nT)
-300
-500
-700
V_y (nT)
100
0
-100
V_z (nT)
100
0
-100
n (cm-3)
60
40
20
0
P_DYN (nPa)
15
10
5
0
0900
1100
1300
1500
1700
1900
Time (UT Hours)



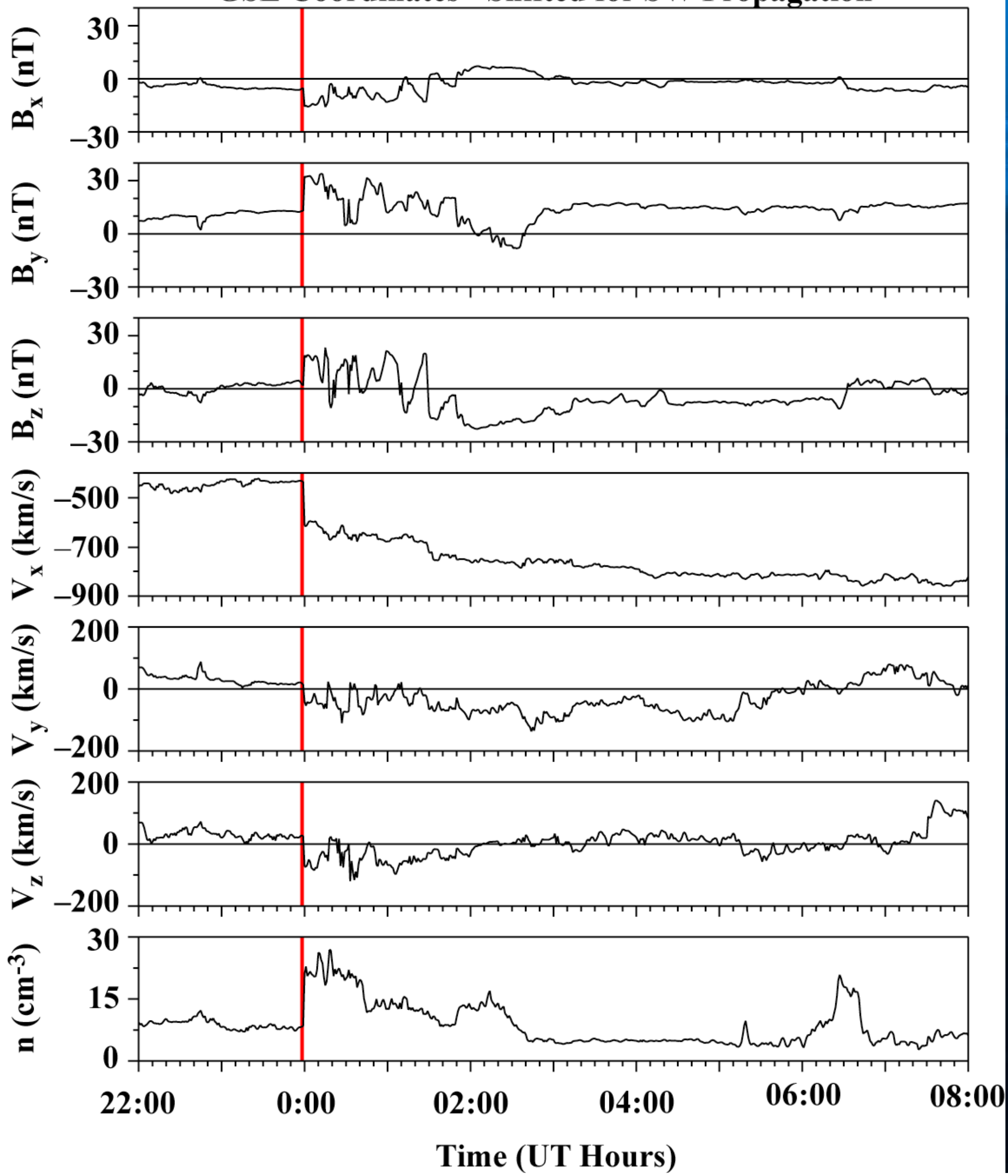
20
0
-20
-40
-60
-80
-100
-120
-140
DST (nT)
0 4 8 12 16 20 0 4 8 12 16 20 0
17 April 2002
18 April 2002
Time (UT Hours)

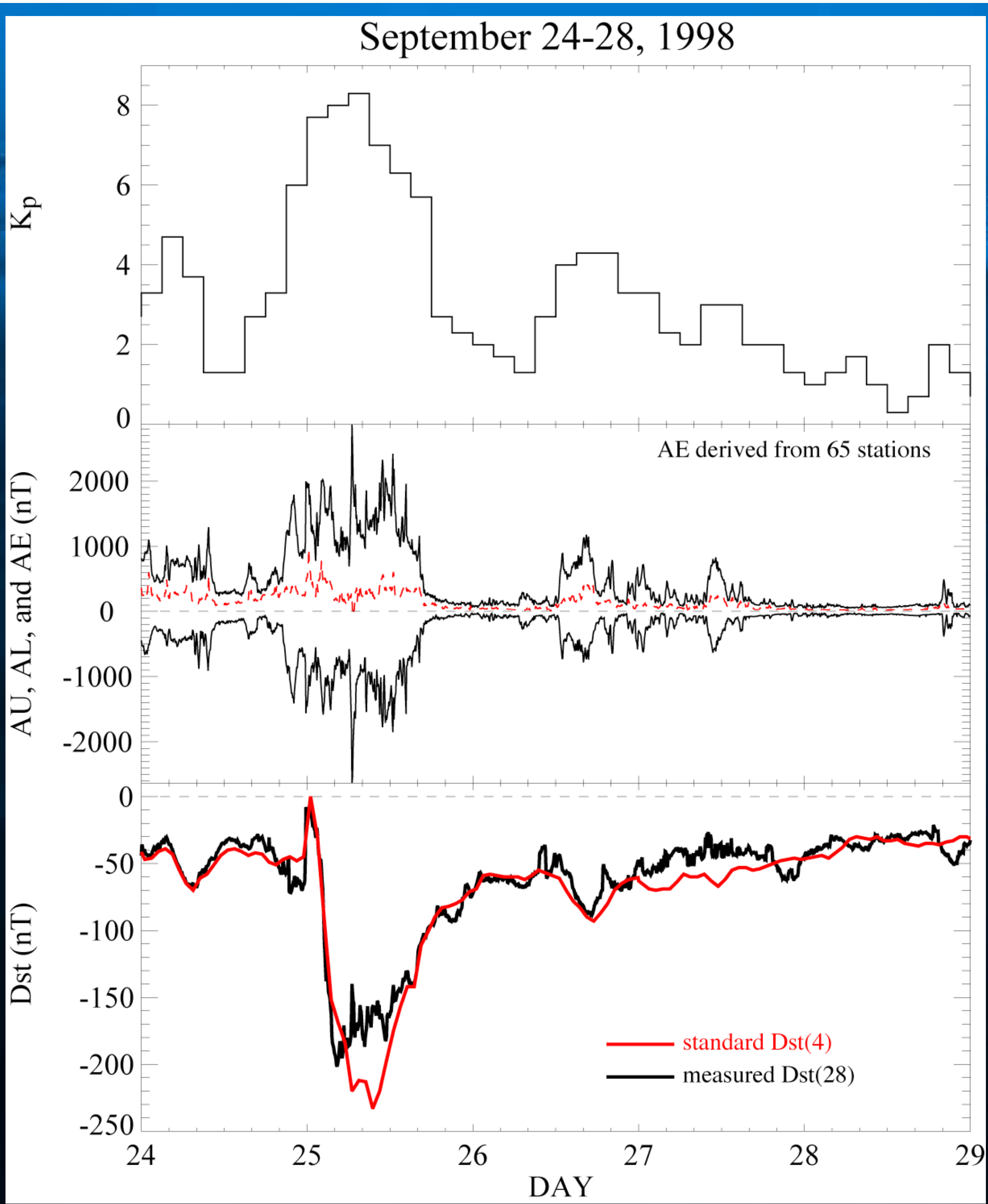
17 April 2002 Magnetic Storm

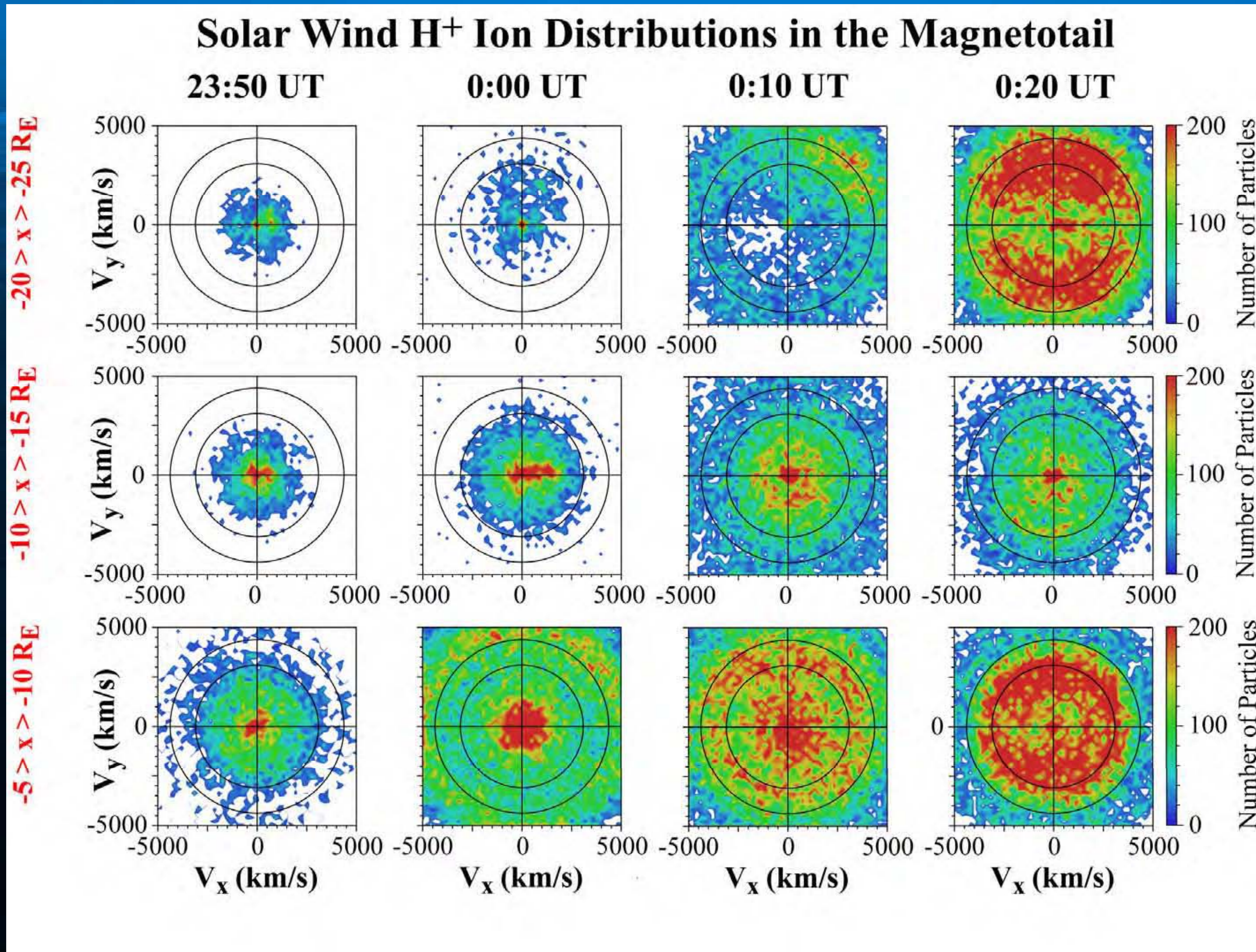


Wind Observations on September 24 - 25, 1998

GSE Coordinates - Shifted for SW Propagation

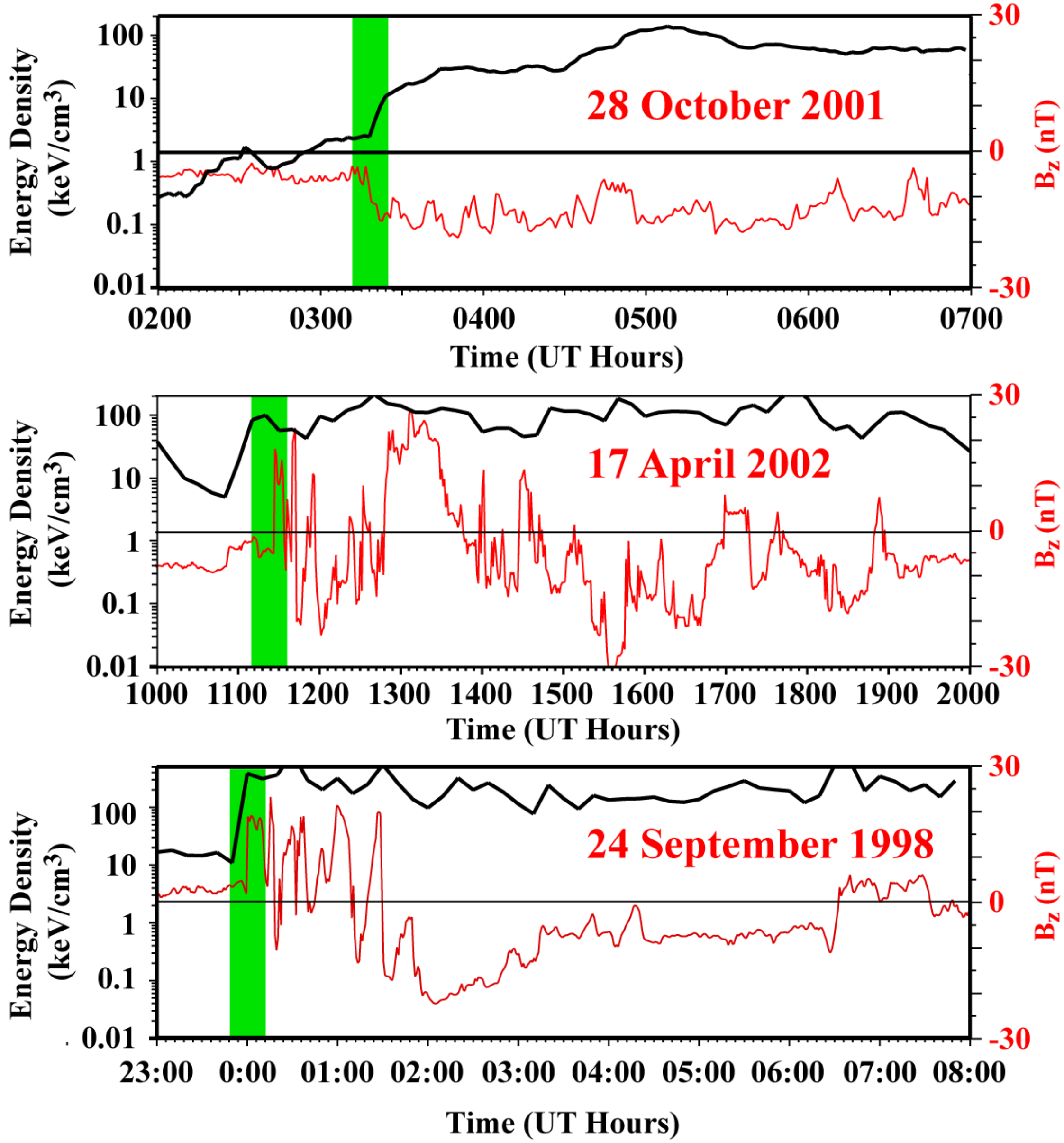



September 24-28, 1998
Kp
AE derived from 65 stations
AU, AL, and AE (nT)
Dst (nT)
standard Dst(4)
measured Dst(28)
DAY
24
25
26
27
28
29



Solar Wind H+ Ion Distributions in the Magnetotail
23:50 UT
0:00 UT
0:10 UT
0:20 UT
-20 > x > -25 RE
-10 > x > -15 RE
-5 > x > -10 RE
Vy (km/s)
Vx (km/s)
Number of Particles
5000
0
-5000
200
100

Solar Wind H^+ Energy Densities in the Ring Current



Summary

Plasma Population:

- Plasma sheet fills in with solar wind H^+ ions gradually from dawn and dusk, with dominant entry occurring on dawn flank throughout the interval.
- O^+ ions fill plasma sheet gradually, are 10% - 20% of density throughout storm.

Summary

<u>Plasma Injection</u>

- SSC results in ion injection into inner magnetosphere at all local times for both H^+ and O^+.
- 0430 Substorm onset shows strong injection at dawn, gradual increase in density at midnight and dusk for H^+ ions, very little change for O^+ ions.

Summary

Plasma Acceleration:

- 28 October 2001 Ion velocity distribution functions show energization spreading from midnight to dusk and entry of solar wind ions from the dawn flank.
- Energization for both 24 September 1998 and 17 April 2002 storms more dramatic:
  - Stronger dynamic pressure
  - Highly variable IMF during the SSC.

A Word About Forecasting

- "Geoeffectiveness" of magnetic storms in accelerating ions cannot be characterized by Dst alone:
  - Solar wind dynamic pressure and IMF B_y and B_z fluctuations more important.
- Any remote sensing of a magnetic cloud must be able to tell us about the characteristics of the IMF within the cloud, especially along its leading edge.