Ionospheric Input to the Magnetotail During Storm-time Substorms

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Outline

- Introduction
- Superposed Epoch Study of Storm vs. Non-storm substorms - results from expanded study
- MLT dependence of substorm dynamics
  - When do the changes in the plasma sheet occur at different MLTs
  - When and Where us O+ observed during a substorm

Heavy Ions - Why do we care?

- Sources
  - » Direct ionospheric ions (cold)
  - » Accelerated ionospheric ions (aurora, cusp)
  - » Solar Wind
- Physical Processes
  - » Reconnection
    - – Increases mean gyroradius
    - – Increases mean ion inertial length
    - – Decreases Alfven speed
  - » Instabilities
    - – Decreases velocity threshold for Kelvin Helmholz instabilitiy
    - – Decreases threshold for Tearing Mode instability

Why storm-time vs non-storm-time?

- It has been well established that in the inner magnetosphere, storm-times are associated with an increase in ionospheric plasma, particularly O+.
- It is also well established that storm-times are associated with enhanced auroral activity, and ion outflow.
- Thus it is likely that storm-time substorms would have a higher O+ content in the plasma sheet, as well.
- Comparing storm-time with non-storm-time substorms allows us to compare “high O+” with “low O+” substorms to look for effects from the increased ionospheric component.

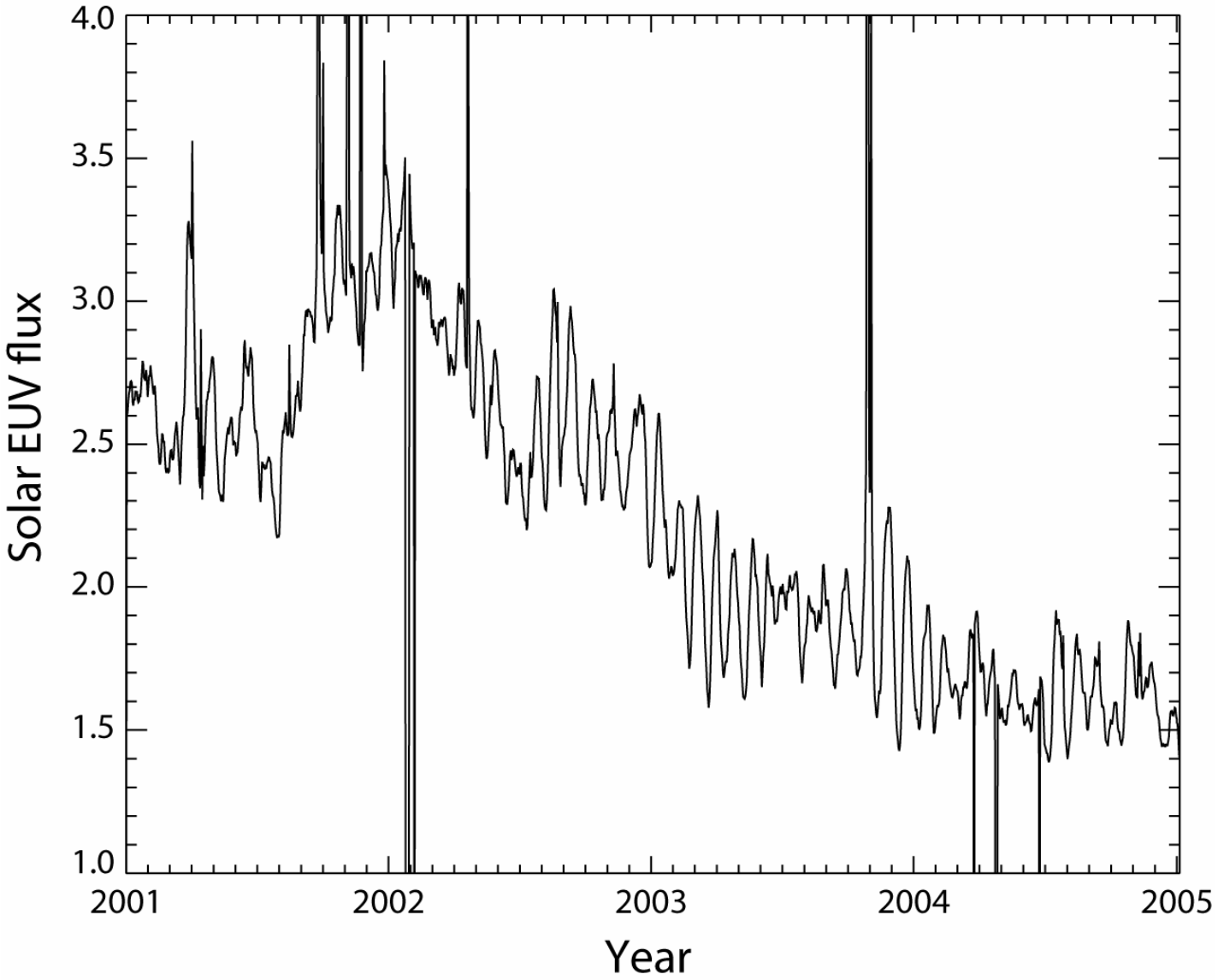
Statistical Study of Storm vs Non-Storm Substorms

- Procedure - Original Study:
  - » Identified all substorms during the 2001 and 2002 CLUSTER tail seasons, using IMAGE and LANL data
  - » Divided substorms into “Storm-time” and “non-storm-time”, and further subdivided the storm-time into
    - – “Main phase” - After SSC, and from -10 to +2 hours around the min Dst
    - – “Recovery Phase - from +2 hours from min Dst to end of recovery.
  - » When restricted to events with central plasma sheet data (beta>1) this gave
    - – 59 non-storm substorms
    - – 11 main-phase substorm
    - – 21 recovery-phase substorms
  - » However, the beta criteria is applied to every 1-min data point. So there were some times (e.g. right after substorm onset) when only a few events contributed to the CPS storm-time data

Statistical Study of Storm vs Non-Storm Substorms

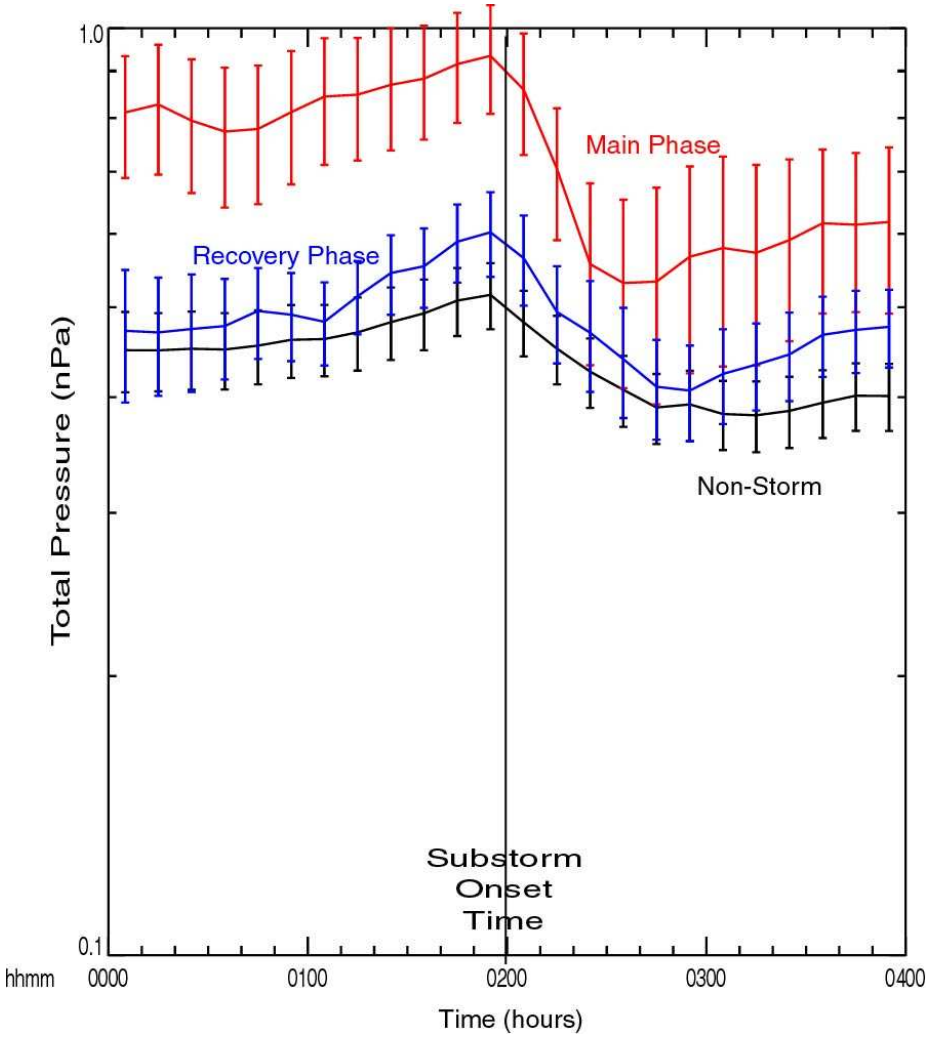
- New Study:
  - » Added 2 more years of CLUSTER tail data: Full range 2001-2004.
  - » This increased the data set to
    - – 130 non-storm substorms
    - – 27 main-phase substorm
    - – 33 recovery-phase substorms
  - » This significantly improves our confidence in our storm-time results, and gives us enough data to look at local dependencies.

EUV 2001-2004

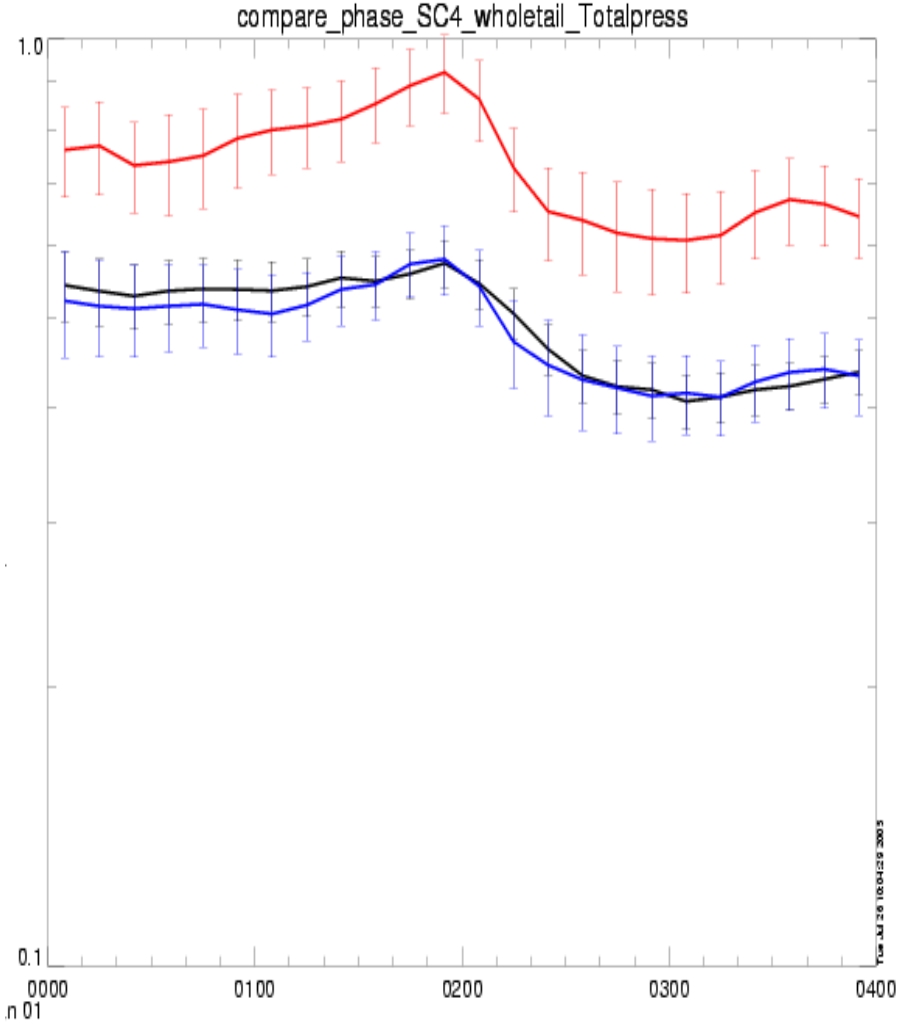


Comparison of Total Pressure (Magnetic+Plasma)

Total Pressure - 2001-2002

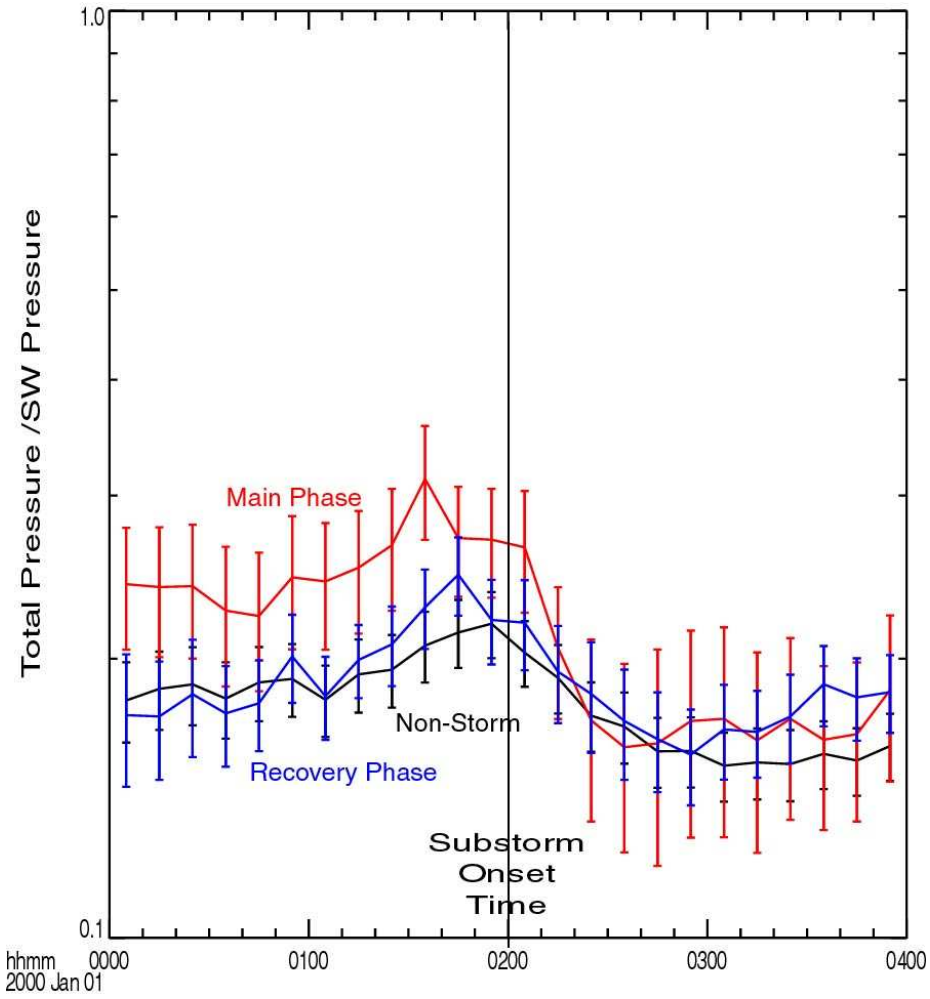


Total Pressure -2001-2004

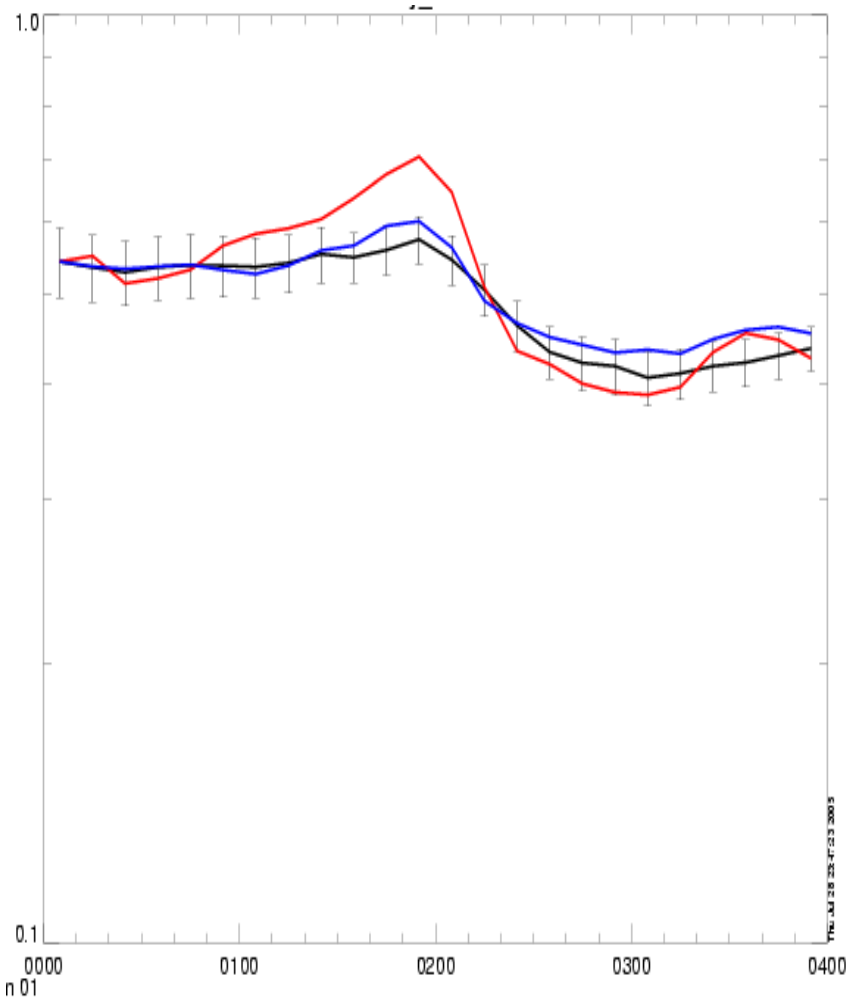


Comparison of Total Pressure (Magnetic+Plasma)

Normalized Total Pressure 2001-2002

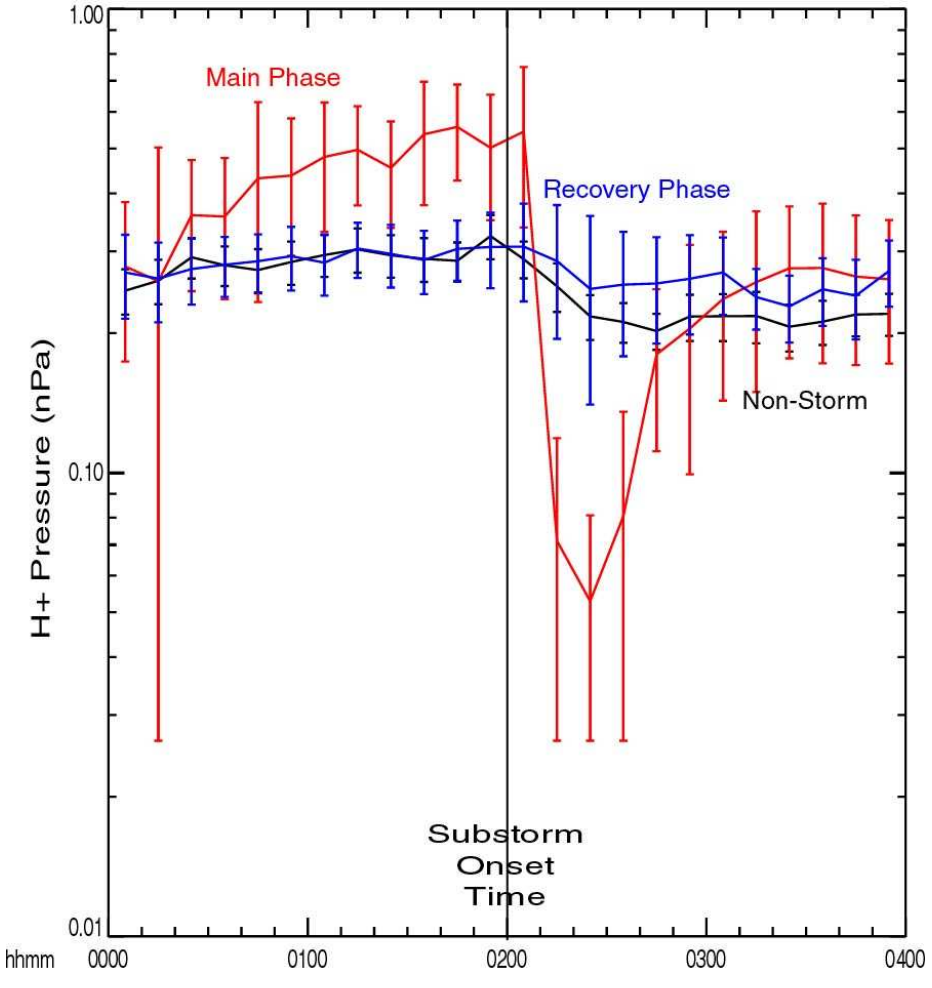


Normalized Total Pressure 2001-2004

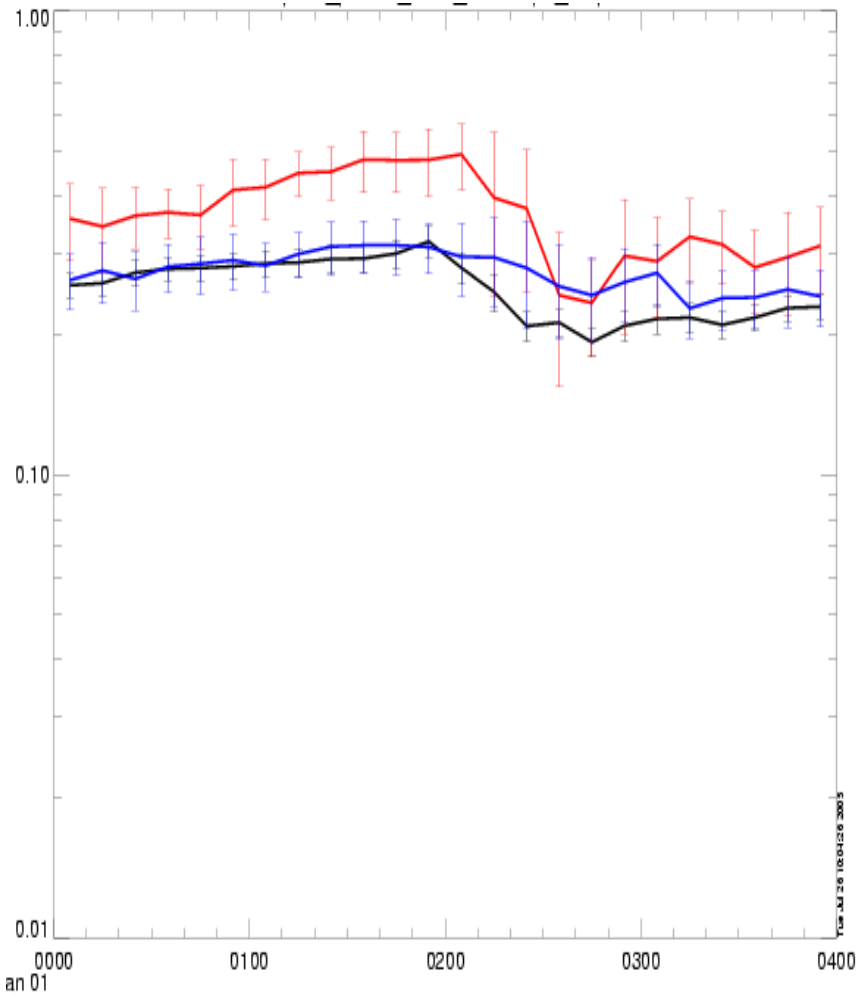


Comparison of Central Plasma Sheet H+ Pressure

2001-2002

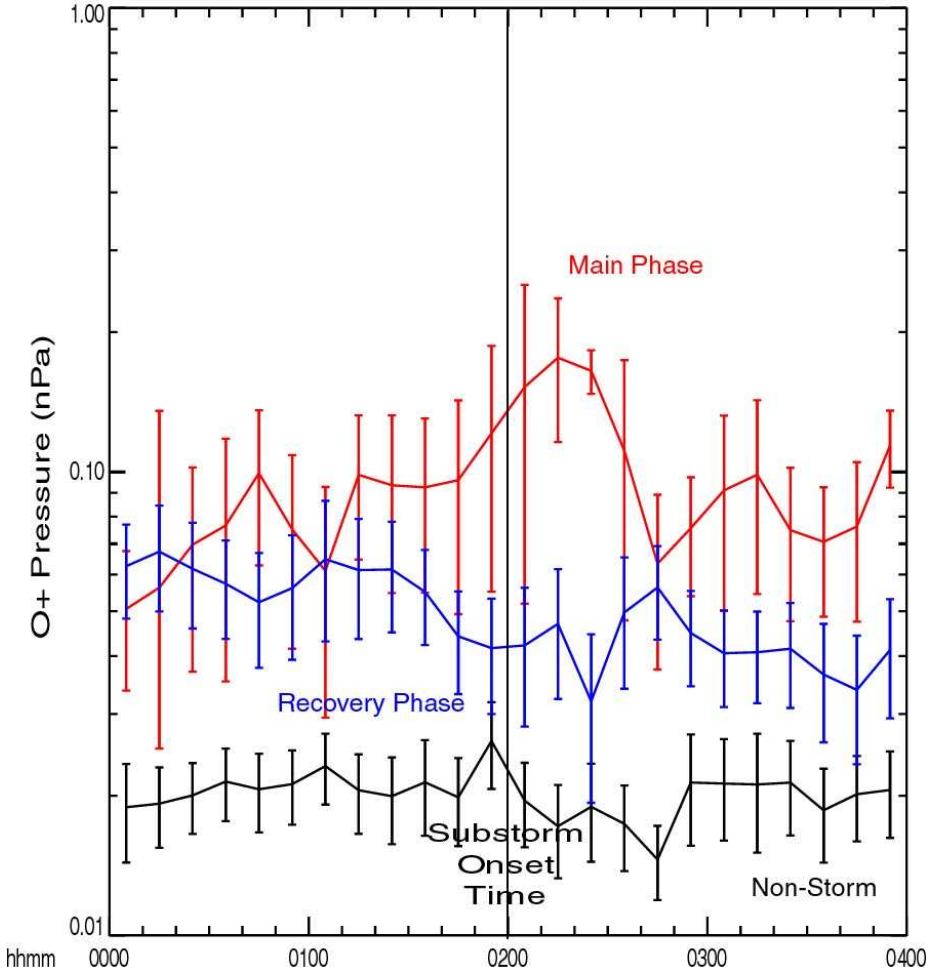


2001-2004

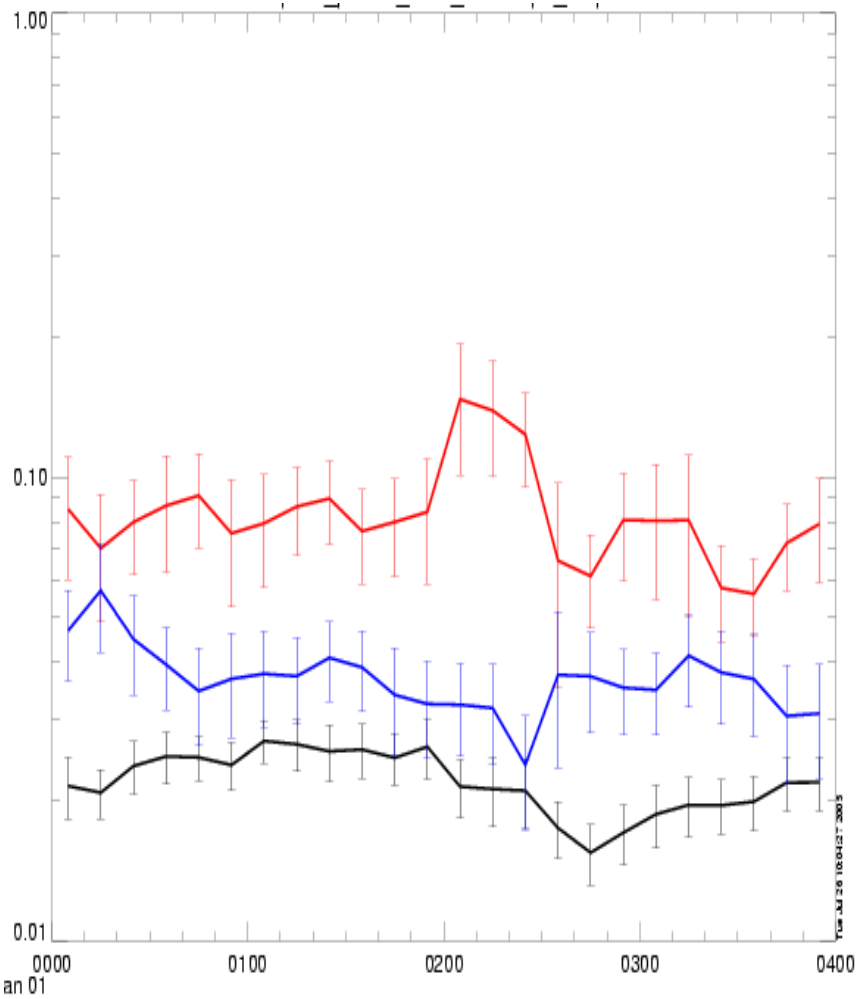


Comparison of Central Plasma Sheet O+ Pressure

2001-2002



2001-2004



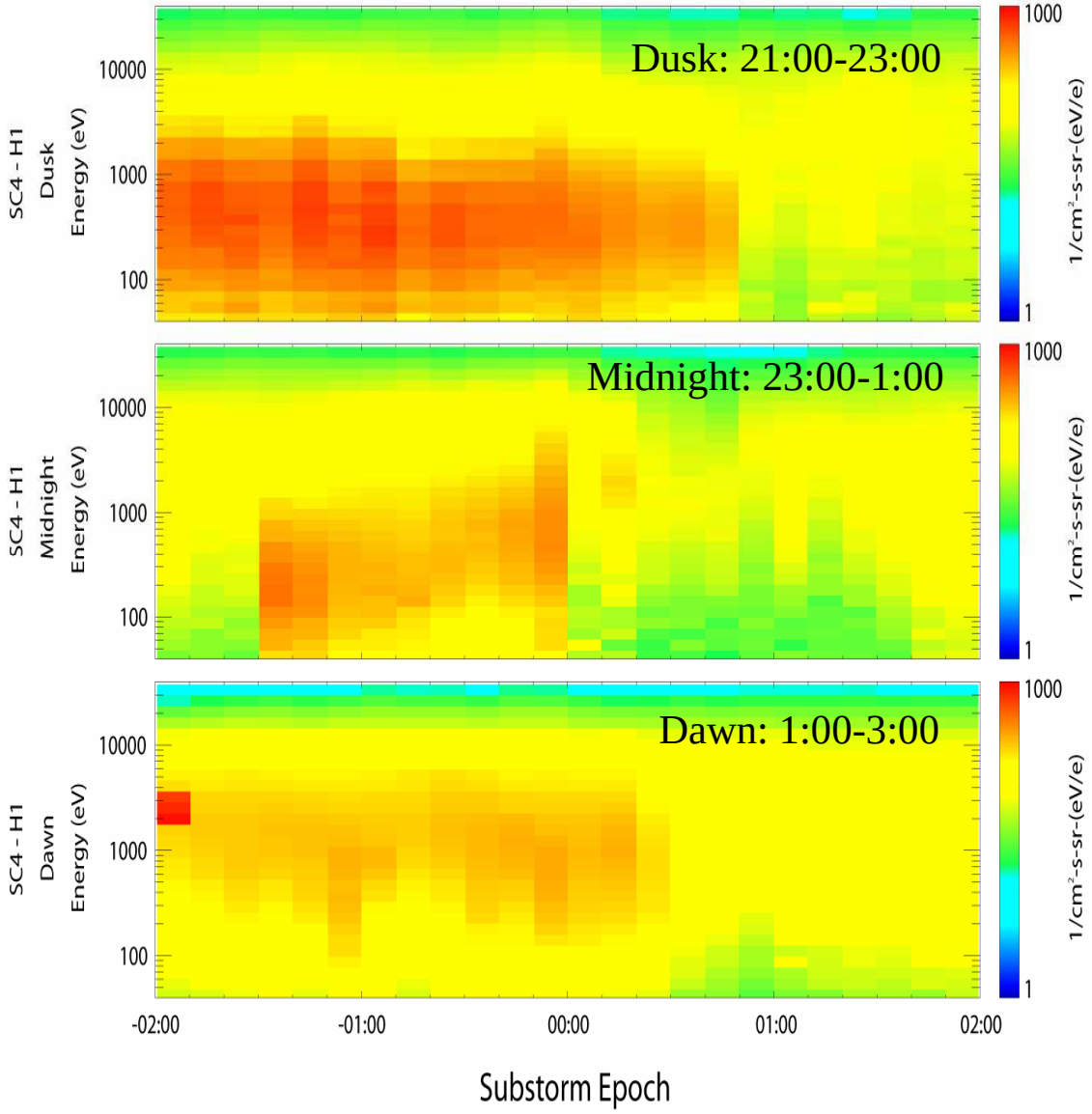
Summary of Old vs New Results

- The main results from our smaller study still hold:
  - The main differences in conditions between storm-time and non-storm-time substorms are
    - The solar wind pressure, and therefore the tail pressure, is substantially higher during main phase substorms
    - There is more O+ in the plasma sheet during these substorms.
  - There is a larger pressure increase (more loading) and a faster pressure decrease during storm-time substorms than non-storm-time substorms.
  - For storm-time substorms, the H+ pressure decreases and O+ increases at substorm onset. However, the H+ decrease is not as dramatic at onset as the smaller dataset showed.

MLT Studies

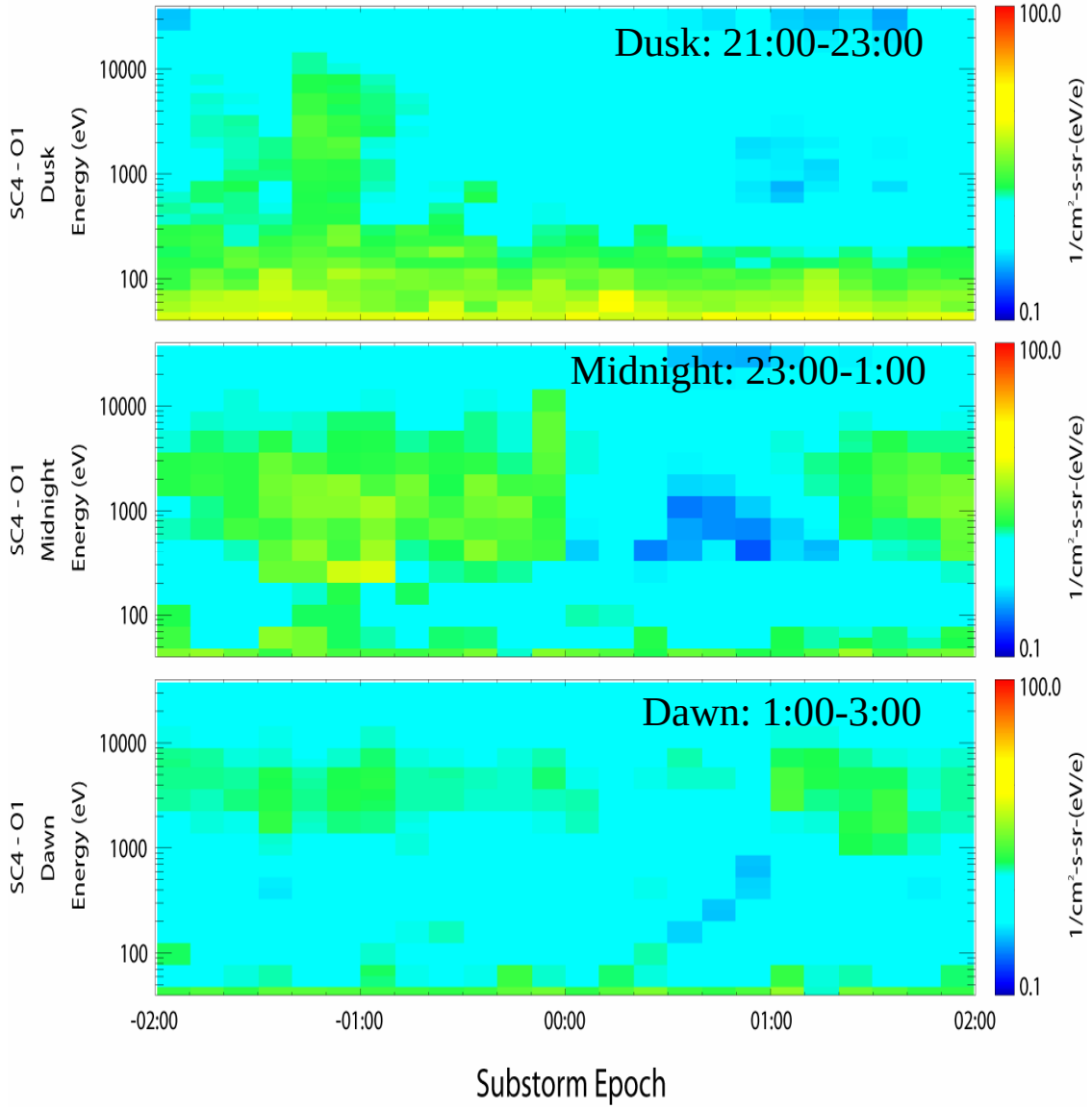
- To understand ion transport into the tail during substorms, and any effects that heavy ions might have, we would like to know:
  - Where the O+ enters the plasma sheet
  - When it enters, relative to substorm onset time
  - How this differs in storm and non-storm times
- To understand substorm development across the tail, we would like to observe the timing of substorm features at different magnetic local times.
- To do this, we have divided the dataset into 3 local time ranges (only 2 for storm-time), and we do a superposed epoch analysis of the energy spectra vs. time relative to substorm onset.
- All data is from ~ CLUSTER apogee of ~19 Re.

Non-storm time H+ Diff. Flux



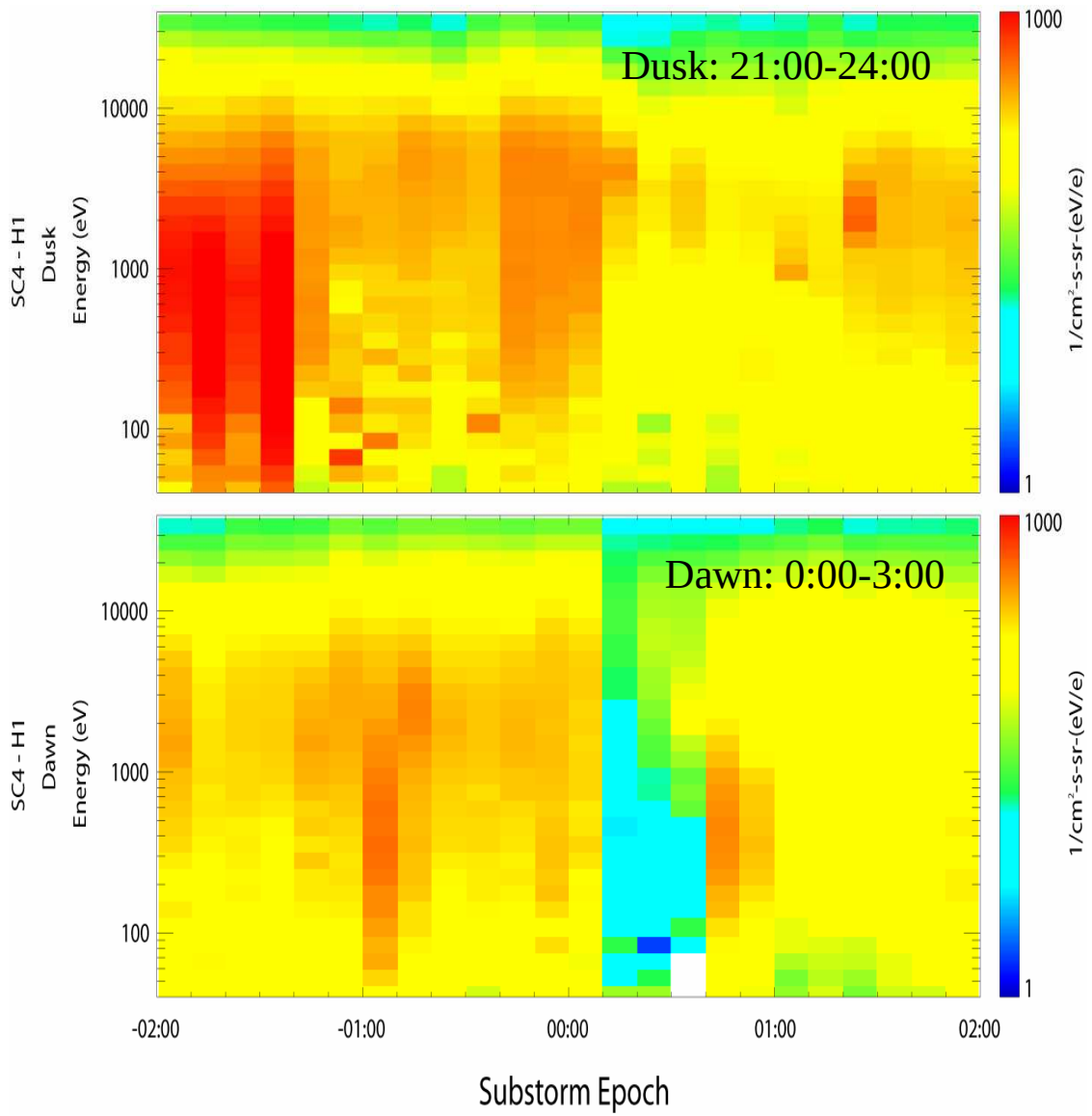
- This “Differential Flux” representation emphasizes the low energy populations.
- A clear change in the energy spectrum is observed exactly at substorm onset time in the midnight region.
- The changes at dawn and dusk are both delayed.
- The dusk-side has a more intense low energy population than the dawn side.

Non-storm time O+ Diff. Flux



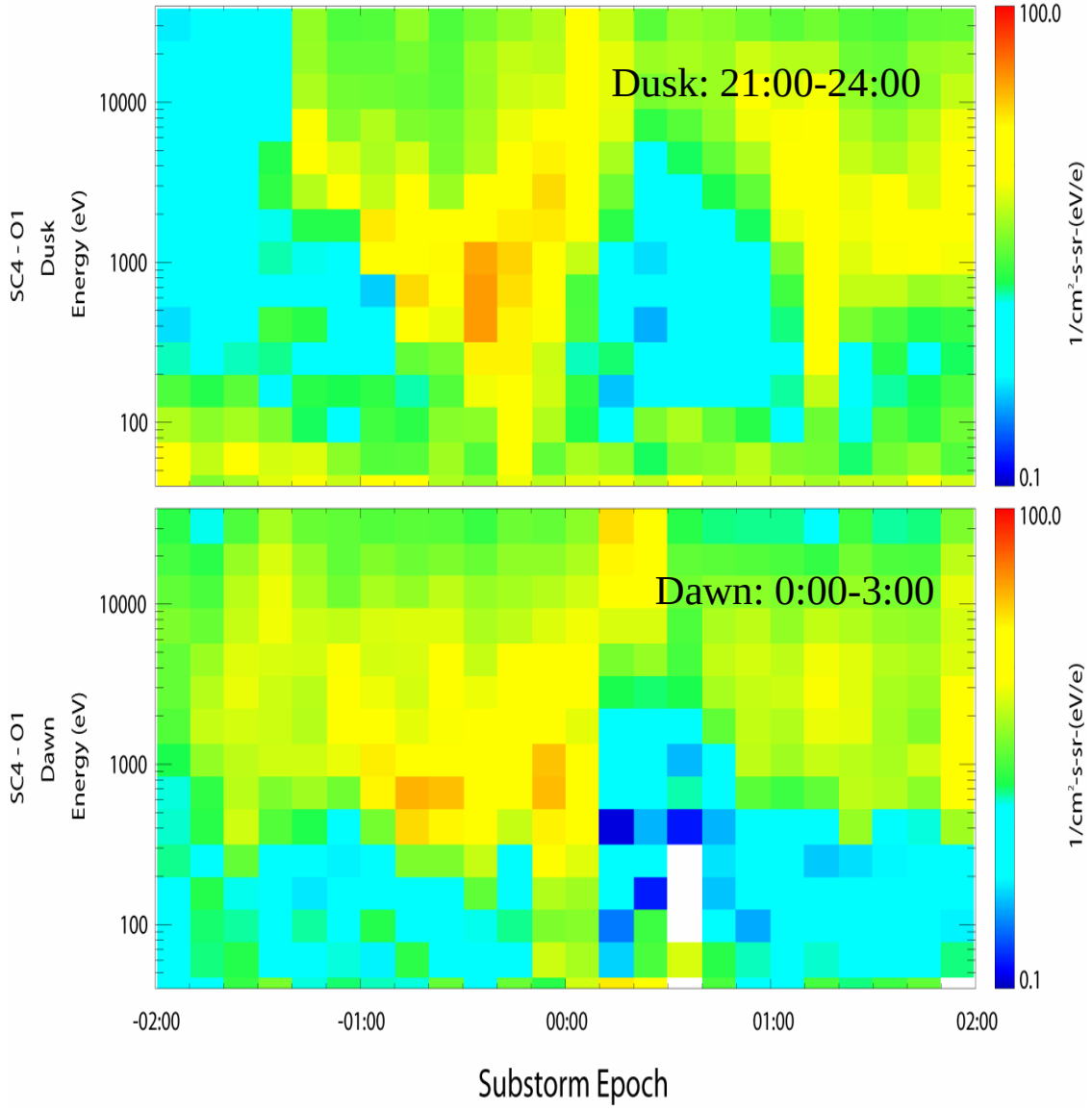
- This “Differential Flux” representation emphasizes the low energy populations.
- At midnight, an increase in the O+ is evident prior to substorm onset. This population has a predominantly tailward anisotropy, and is not evident dawnward or duskward.
- The dusk-side has a low energy O+ population which is not seen at midnight or dawn.

Storm time H+ Diff. Flux



- In storm-time, there is no significant difference between dawn and dusk in the timing - both show change at substorm onset.
- The H+ decrease at onset is more pronounced at dawn than at dusk.

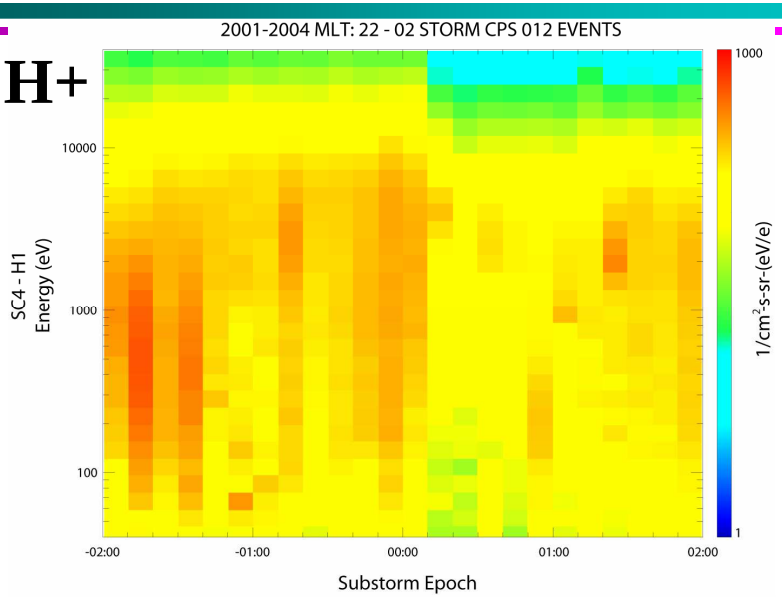
Storm time O+ Diff. Flux

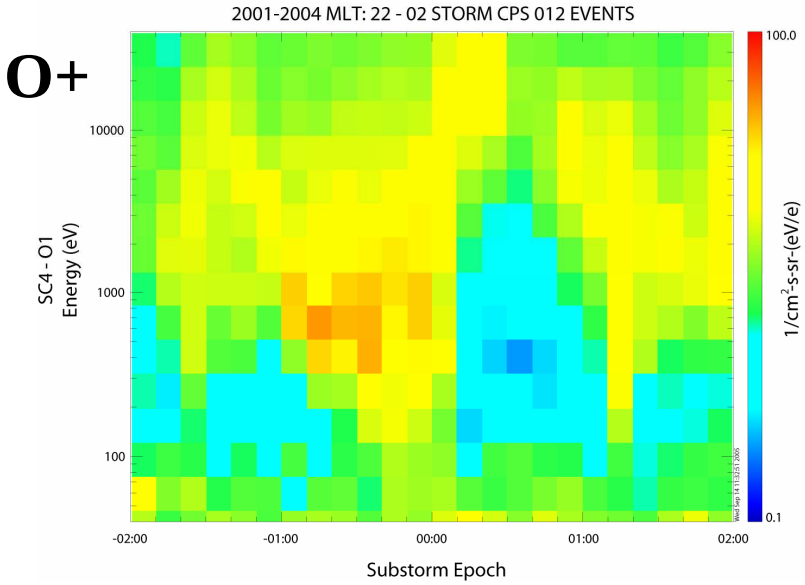


- The O+ spectra also show no significant local time dependence.
- At all local times, the ~1 keV O+ increases in the hour prior to substorm onset.
- The drop-out at low energies and increase at high energies at onset is clear.

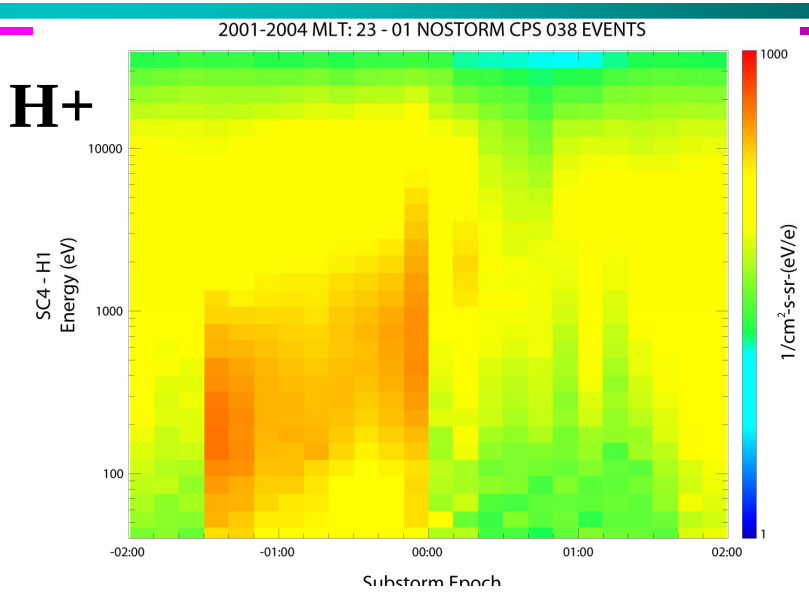
Midnight - Diff Flux

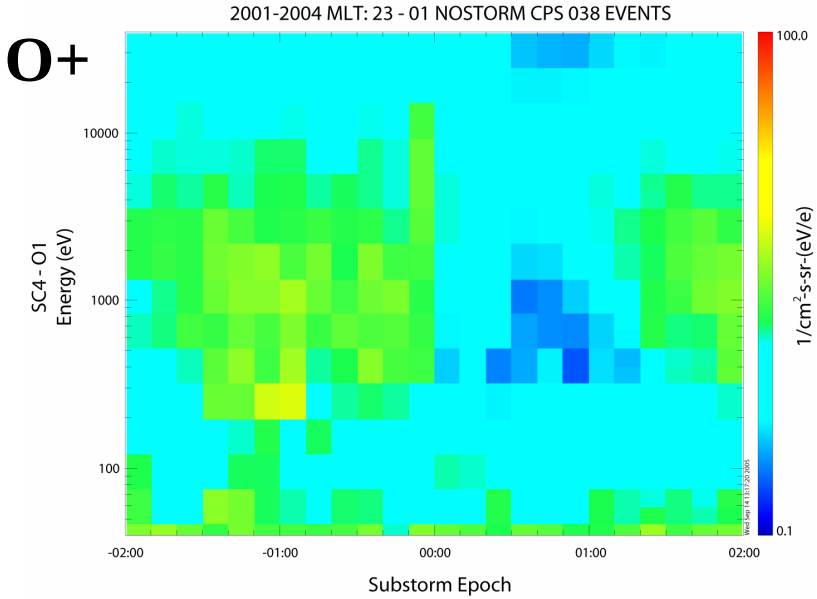
Storm





Non-Storm

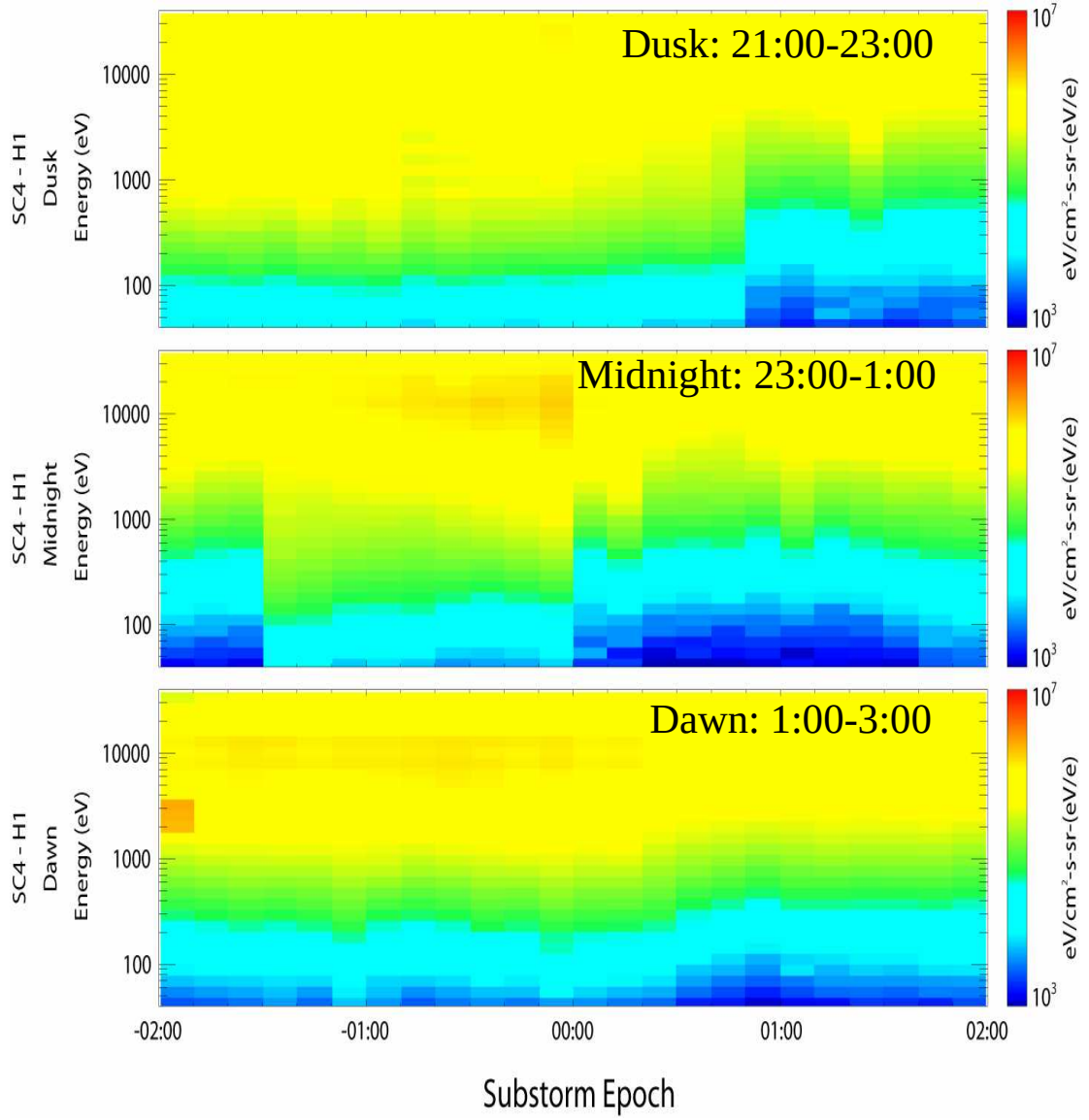




Conclusions

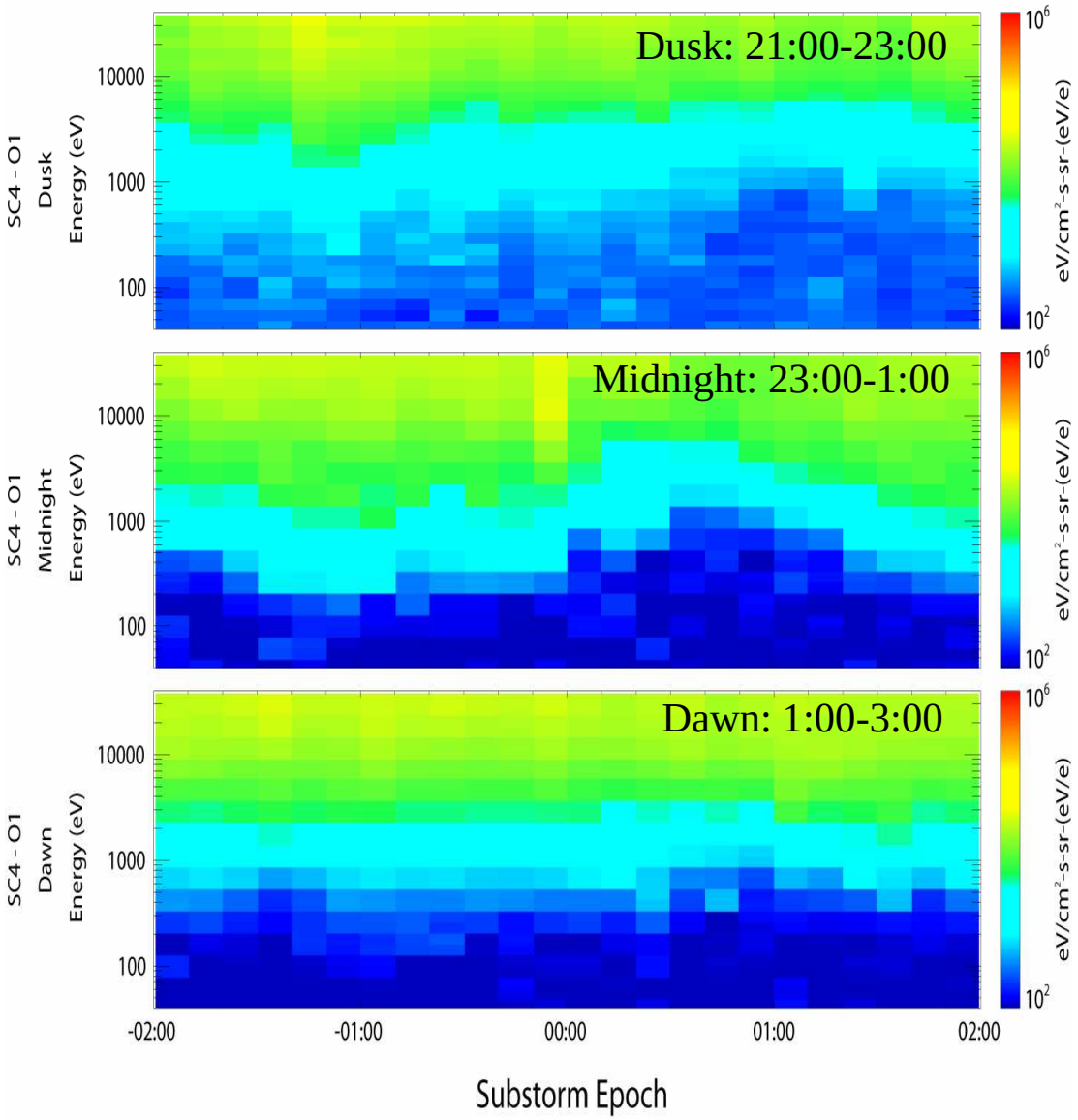
- Storm-time substorms appear to be a more global event
  - » Tailward streaming ~ 1 keV O+ is observed across the tail
  - » Sharp spectral changes occur at all local times at substorm onset
- Non-storm-time substorms show more local features.
  - » The ~1 keV O+ is observed predominantly at midnight.
  - » The sharp spectral changes are observed at midnight at substorm onset, and later at dawn and dusk.
- Is the onset location controlled in any way by the O+? This is hard to say, but these observations are consistent with onset occurring where the energetic (1 keV) O+ is present.

Non-storm time H+ En. Flux



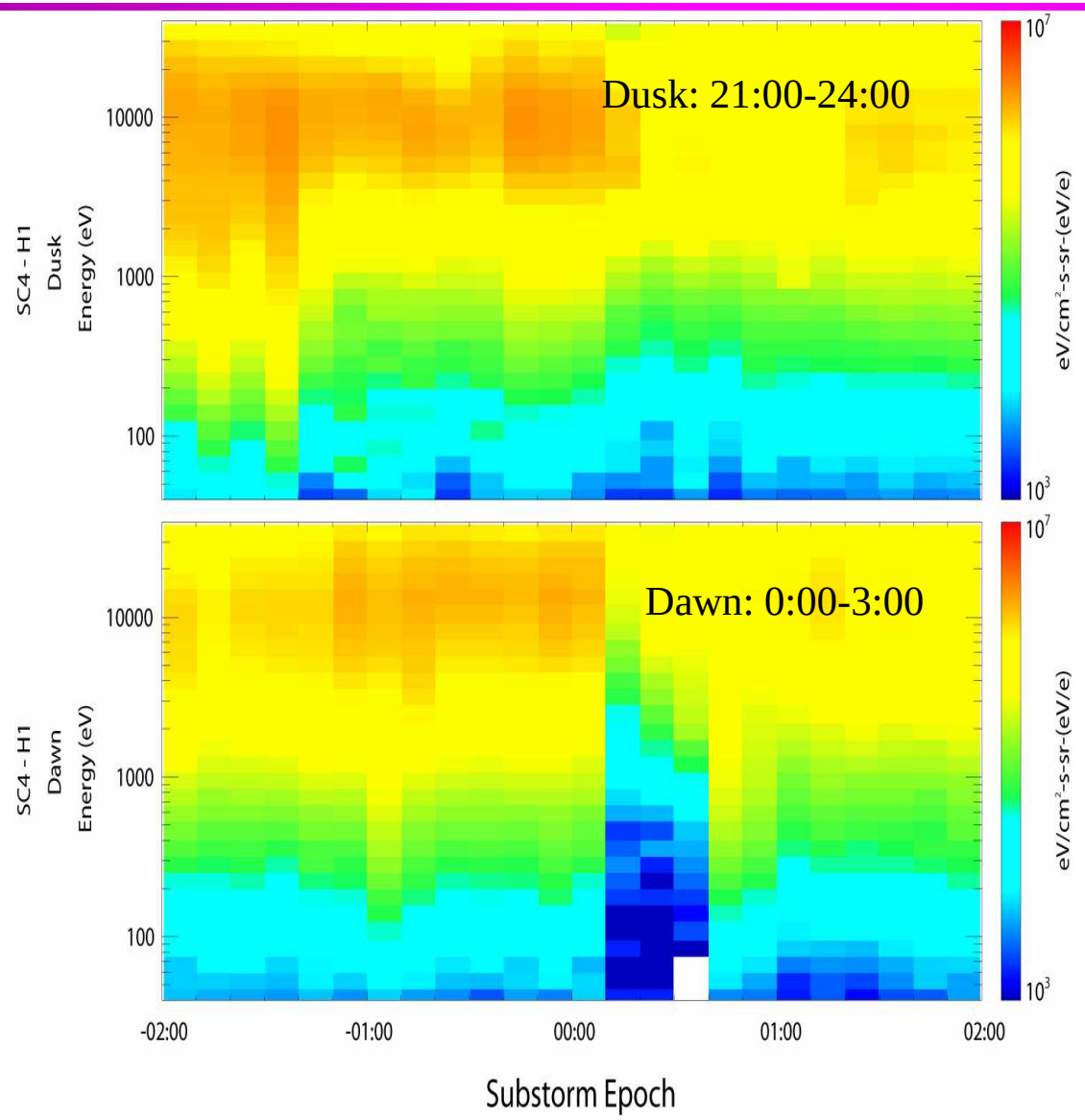
- The “Energy Flux” representation emphasizes the high energy population, which tends to be more isotropic, or peaked at 90 degree PA.
- The same timing in the spectral changes, are observed in this pictures.

Non-storm time O+ En. Flux



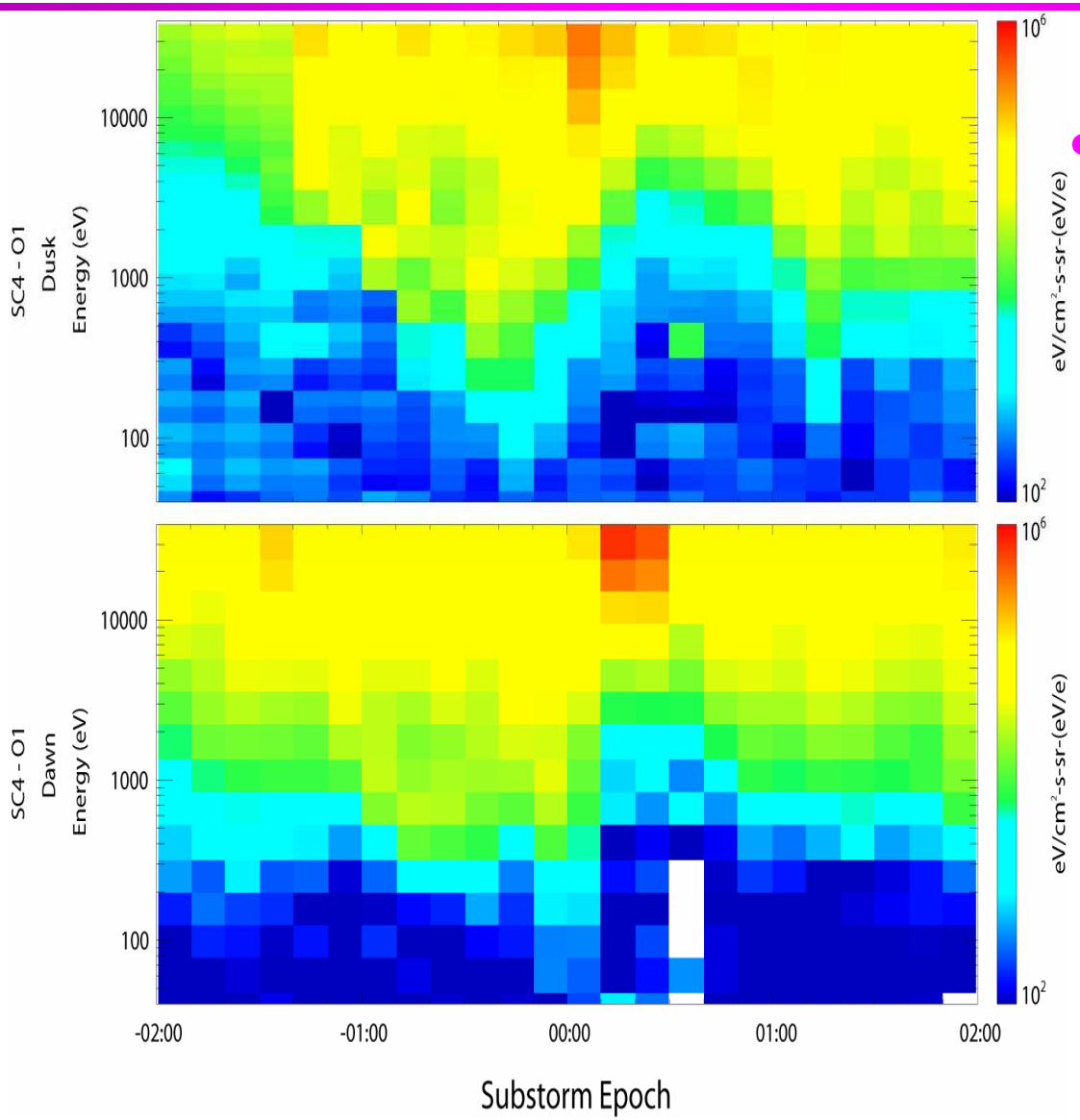
- This “Energy Flux” representation emphasizes the high energy populations.
- There is no significant local time difference in the high energy O+.

Storm time H+ En. Flux



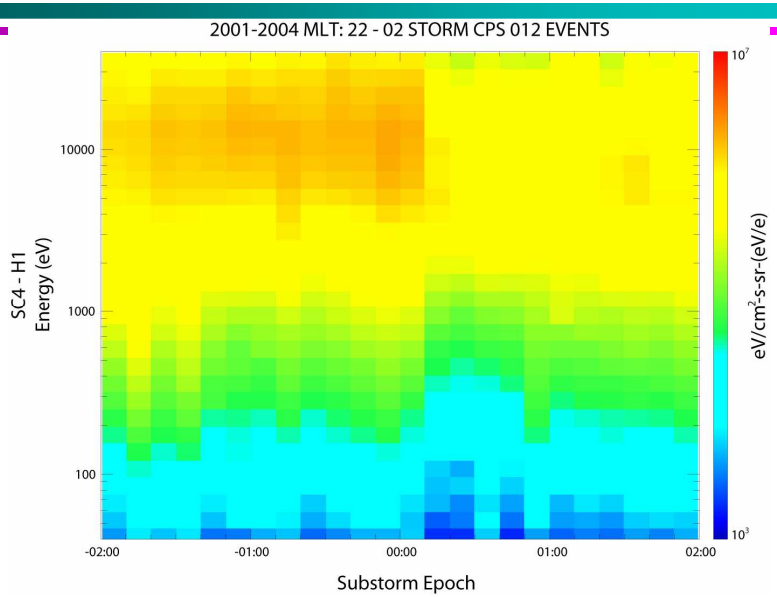
- Similarly, the high energies also show a sharp spectral change at substorm onset at both dawn and dusk.

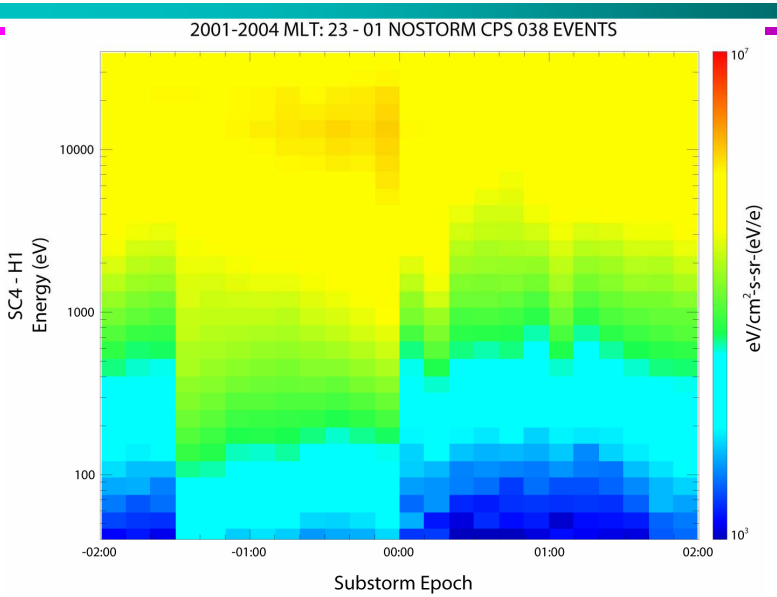
Storm time O+ En. Flux

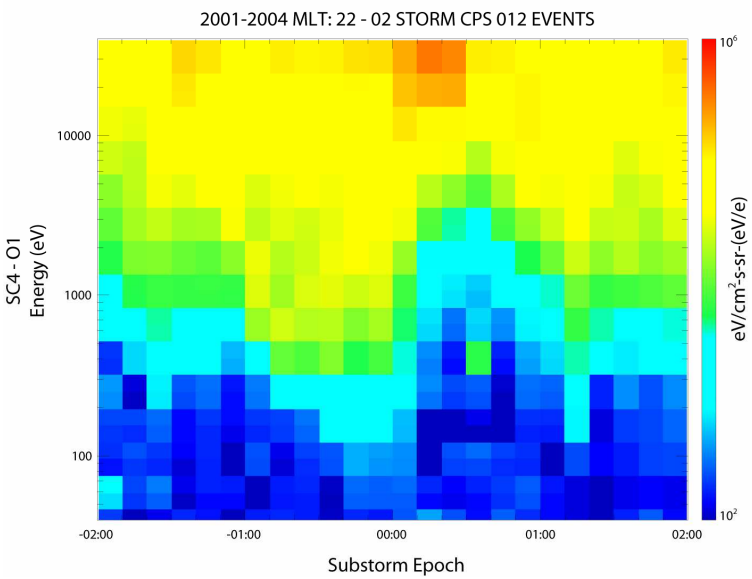


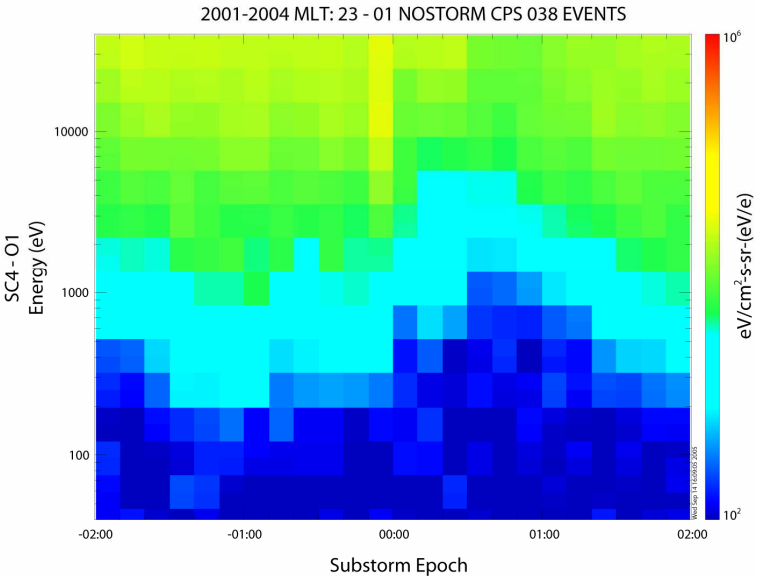
- The high energies also show similar features.

Midnight - EP
Storm vs. Non-Storm

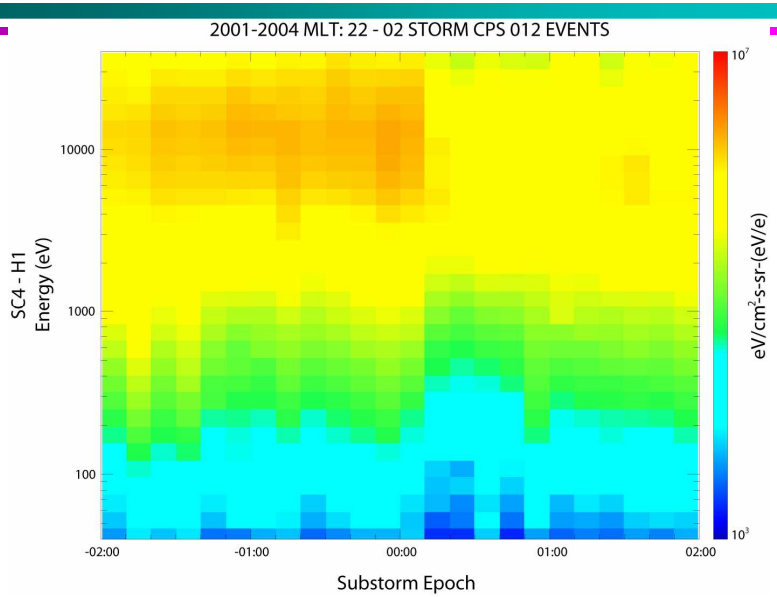


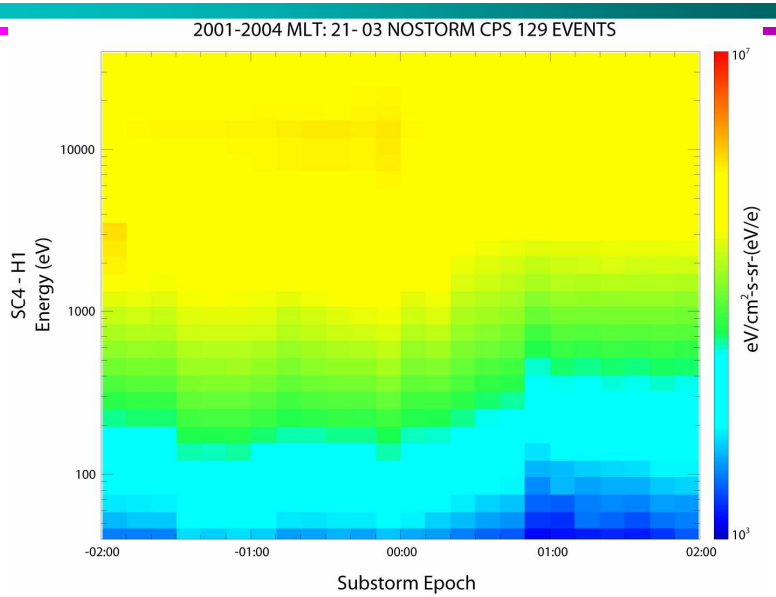


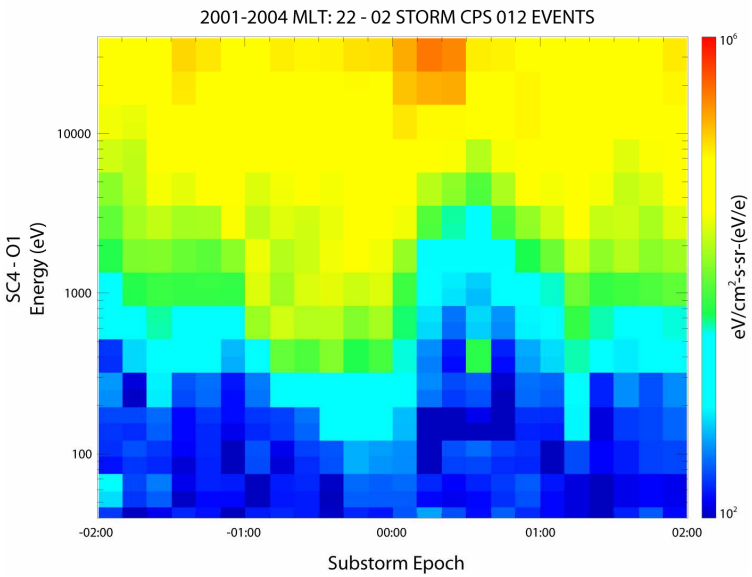


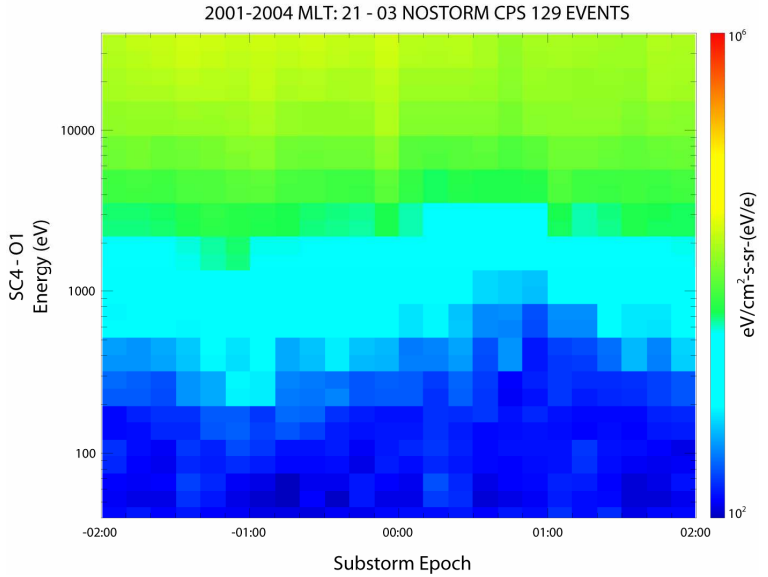


Midnight - ET
Storm vs. Non-Storm

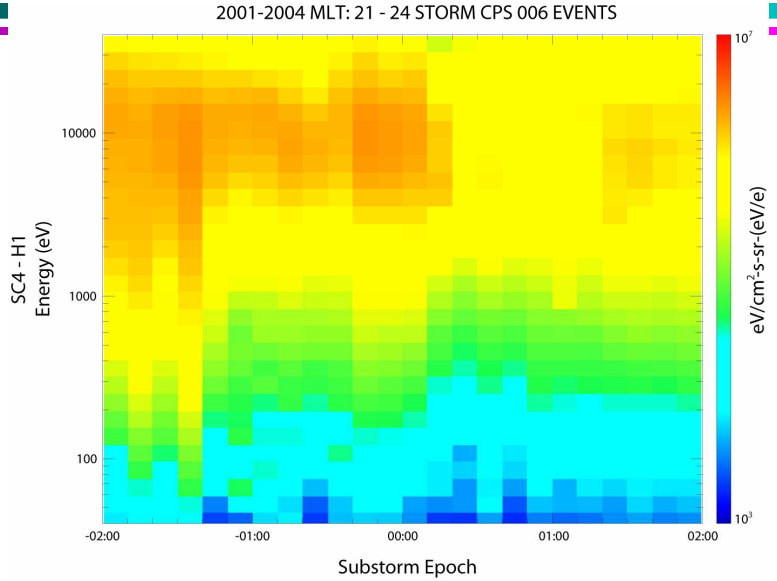


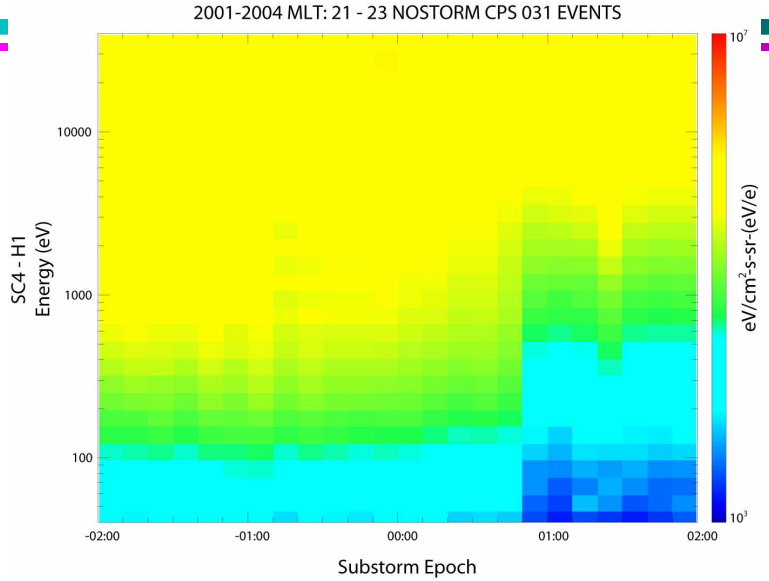


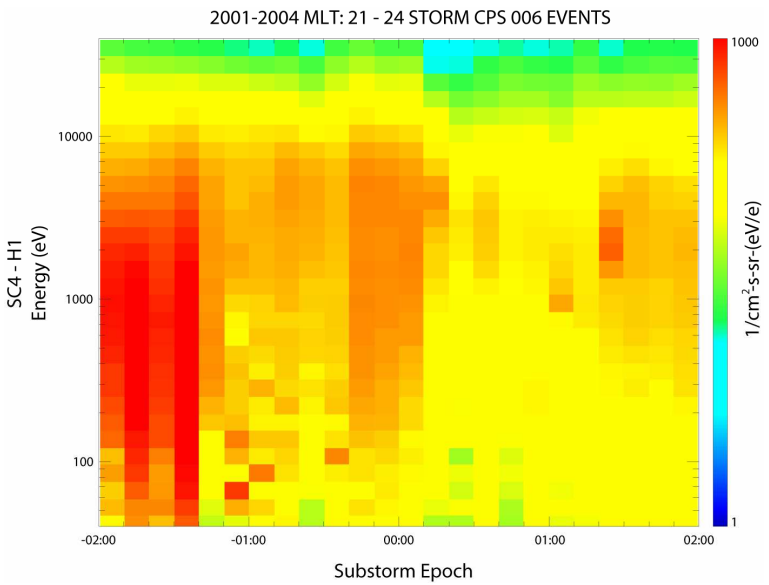


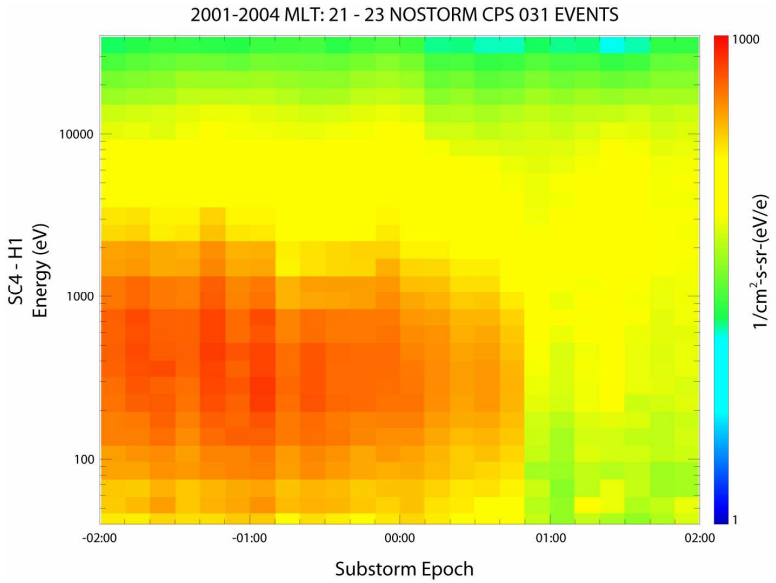


11+ Dusk
Storm vs. Non-Storm

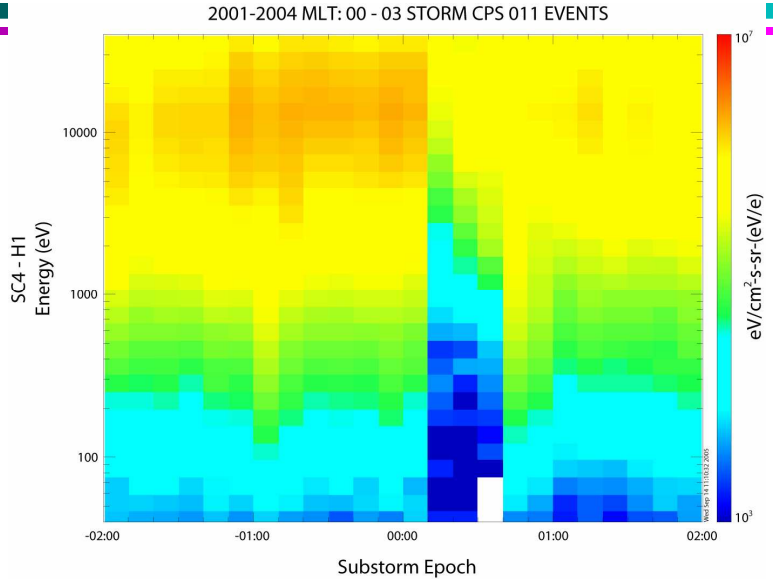


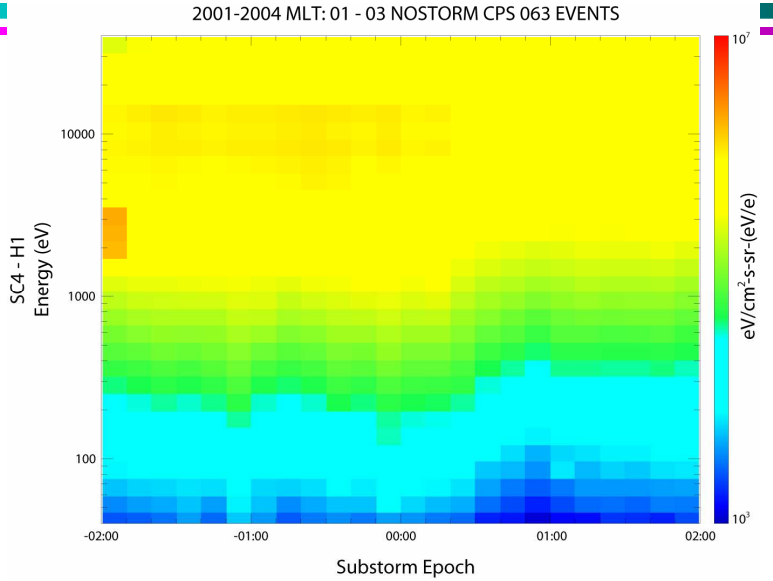


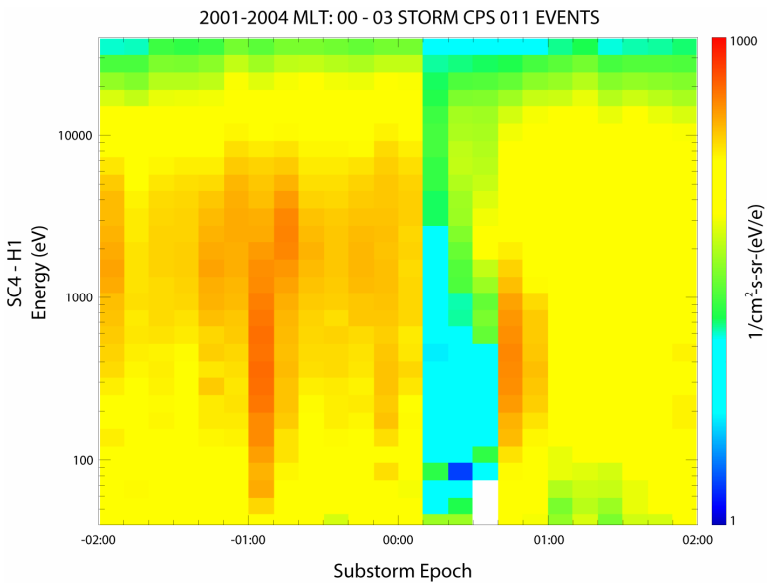


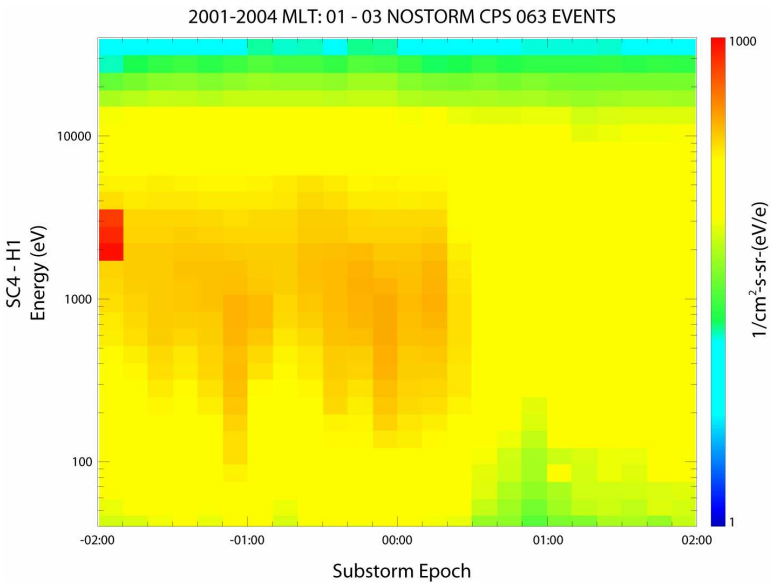


11+ Dawn
Storm vs. Non-Storm

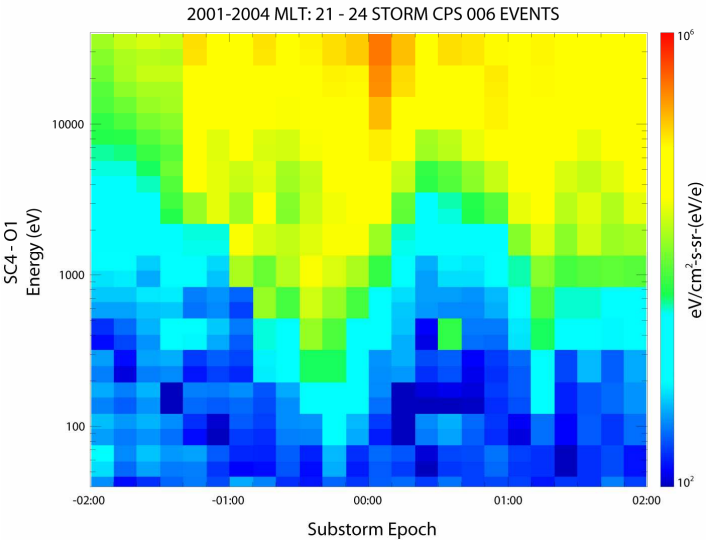


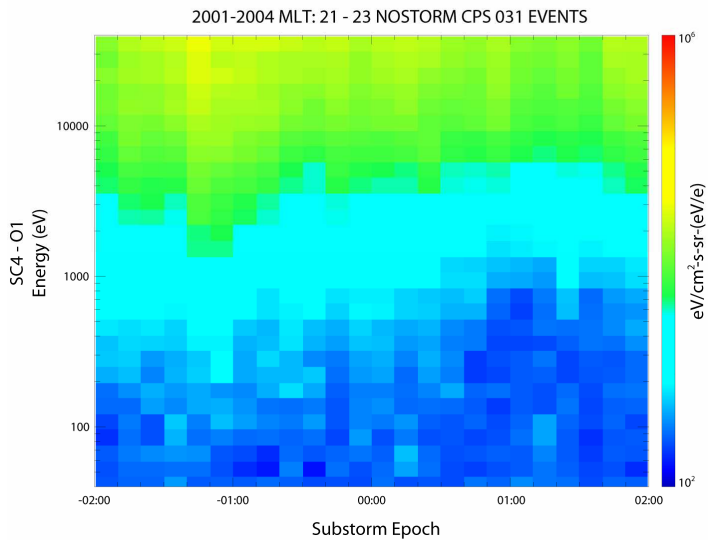


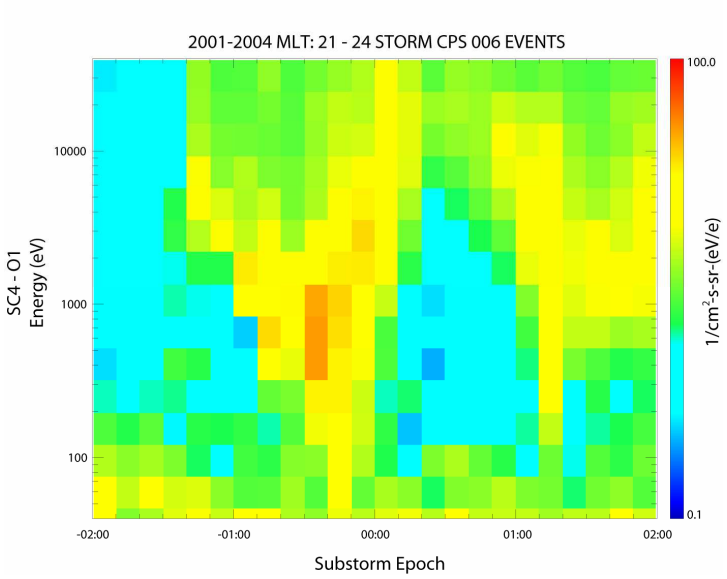


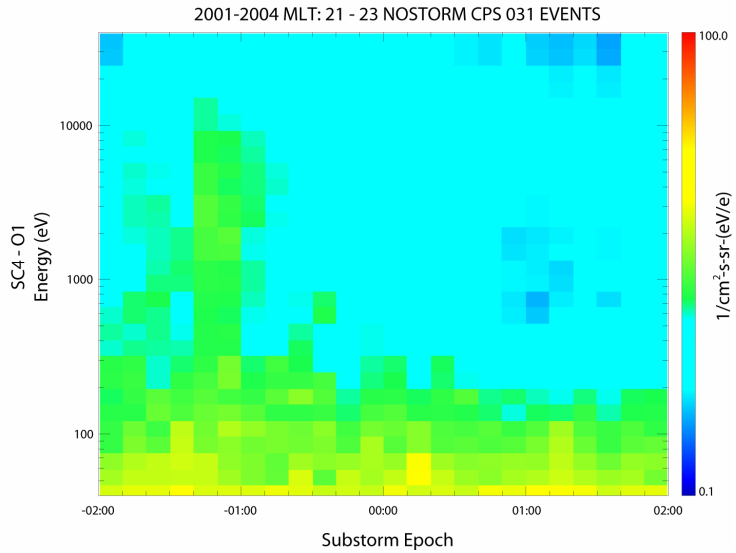


O+ Dusk
Storm vs. Non-Storm

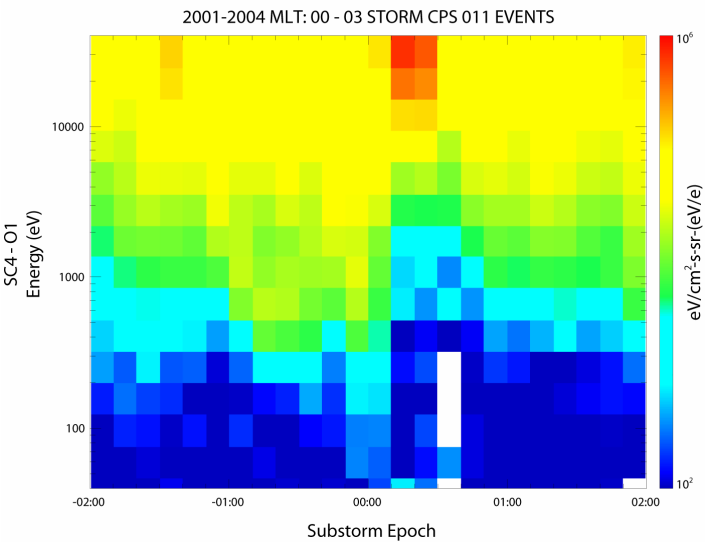


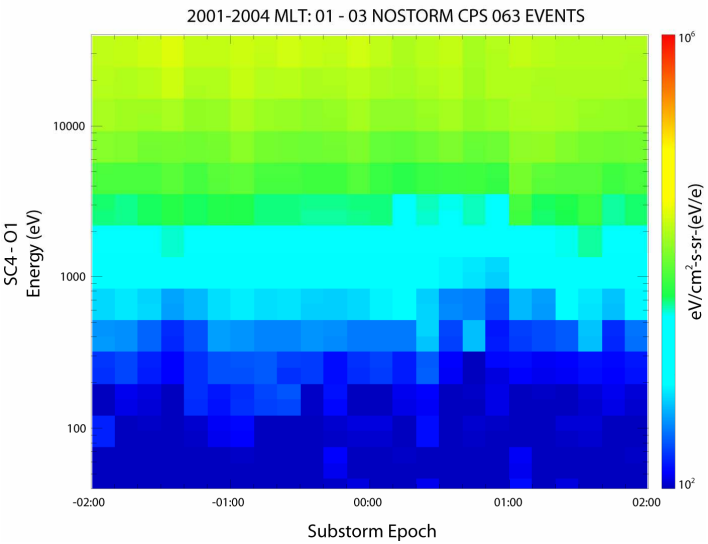


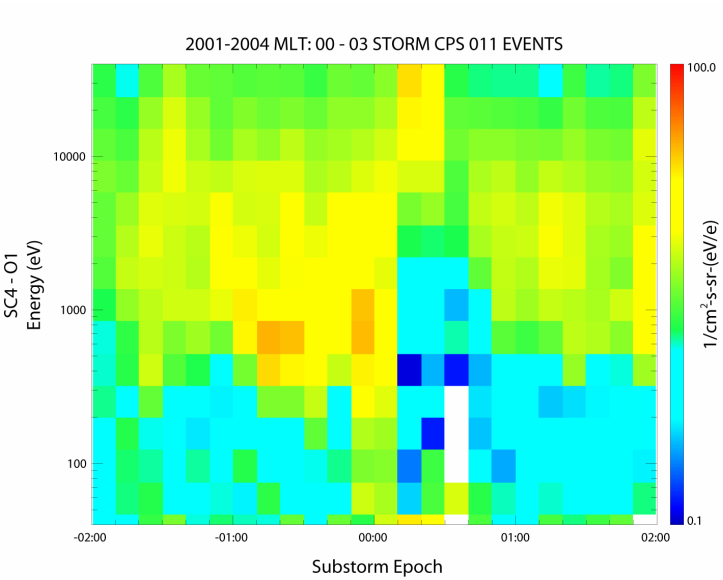


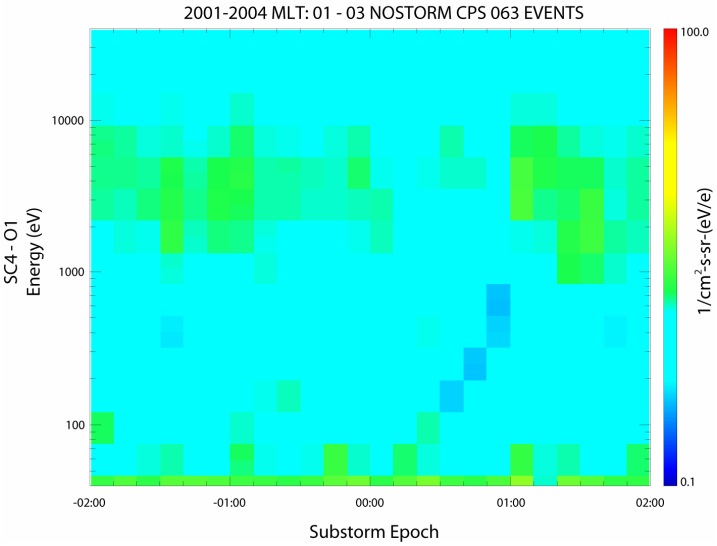


O+ Dawn
Storm vs. Non-Storm

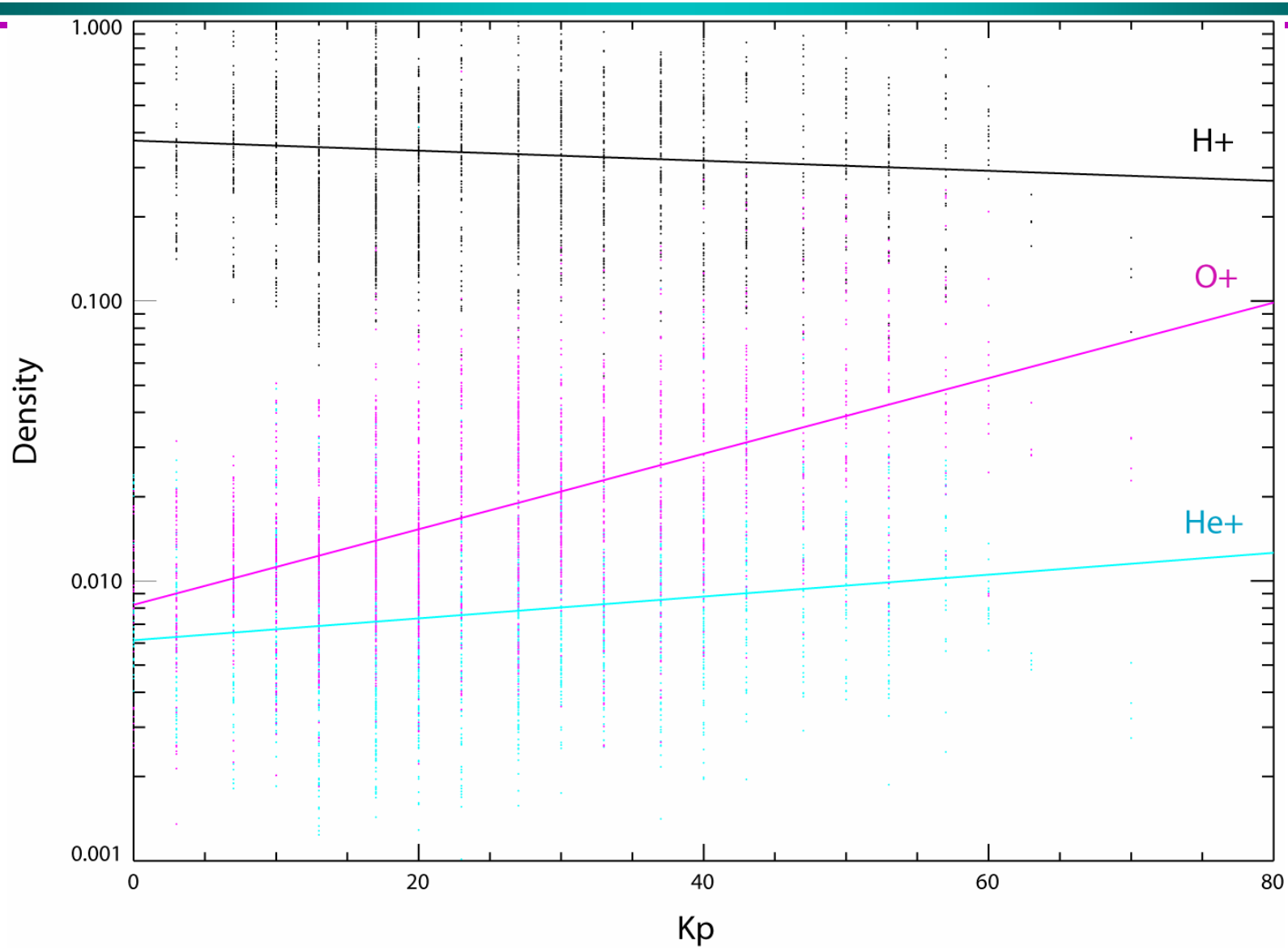




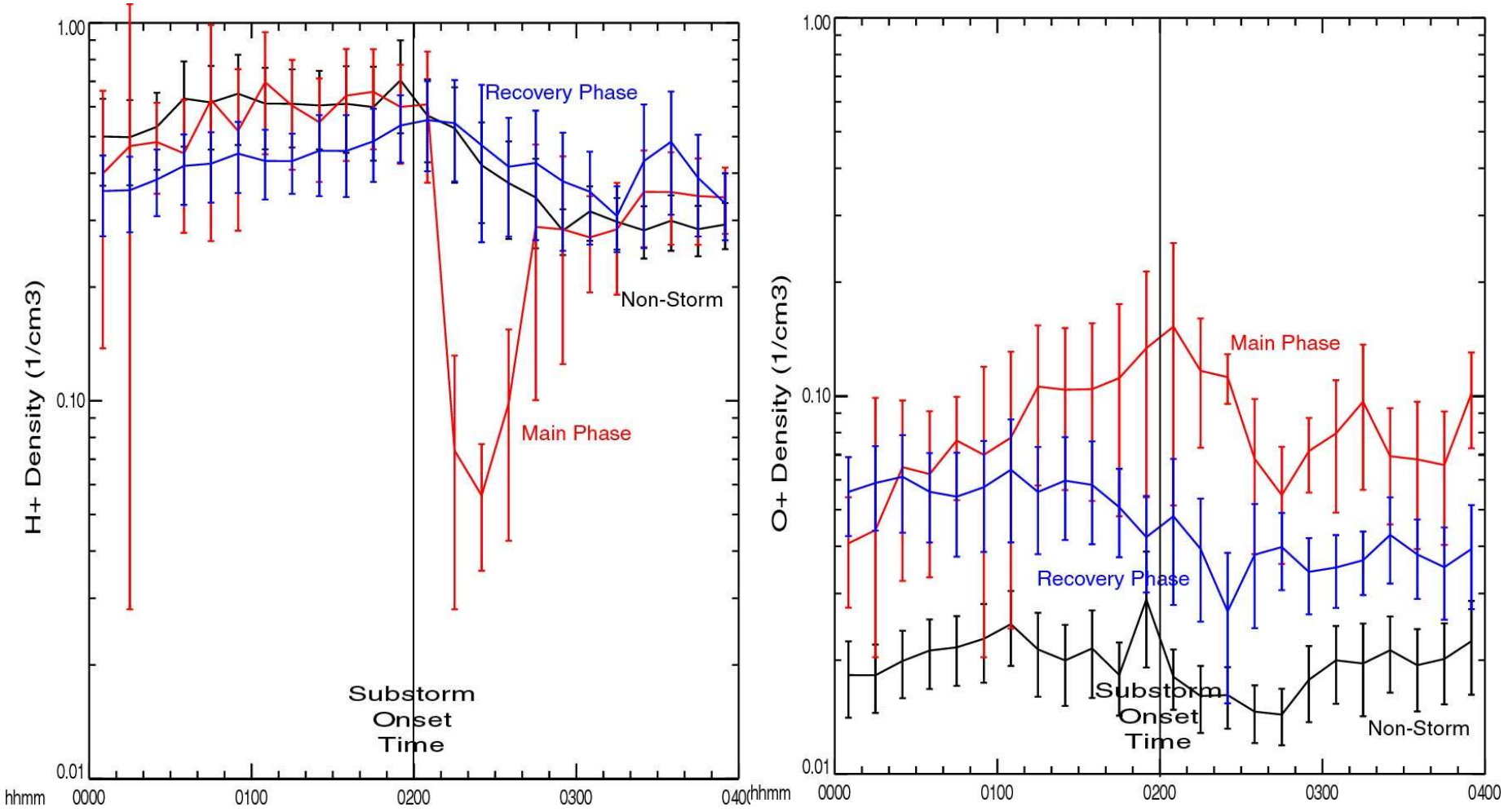




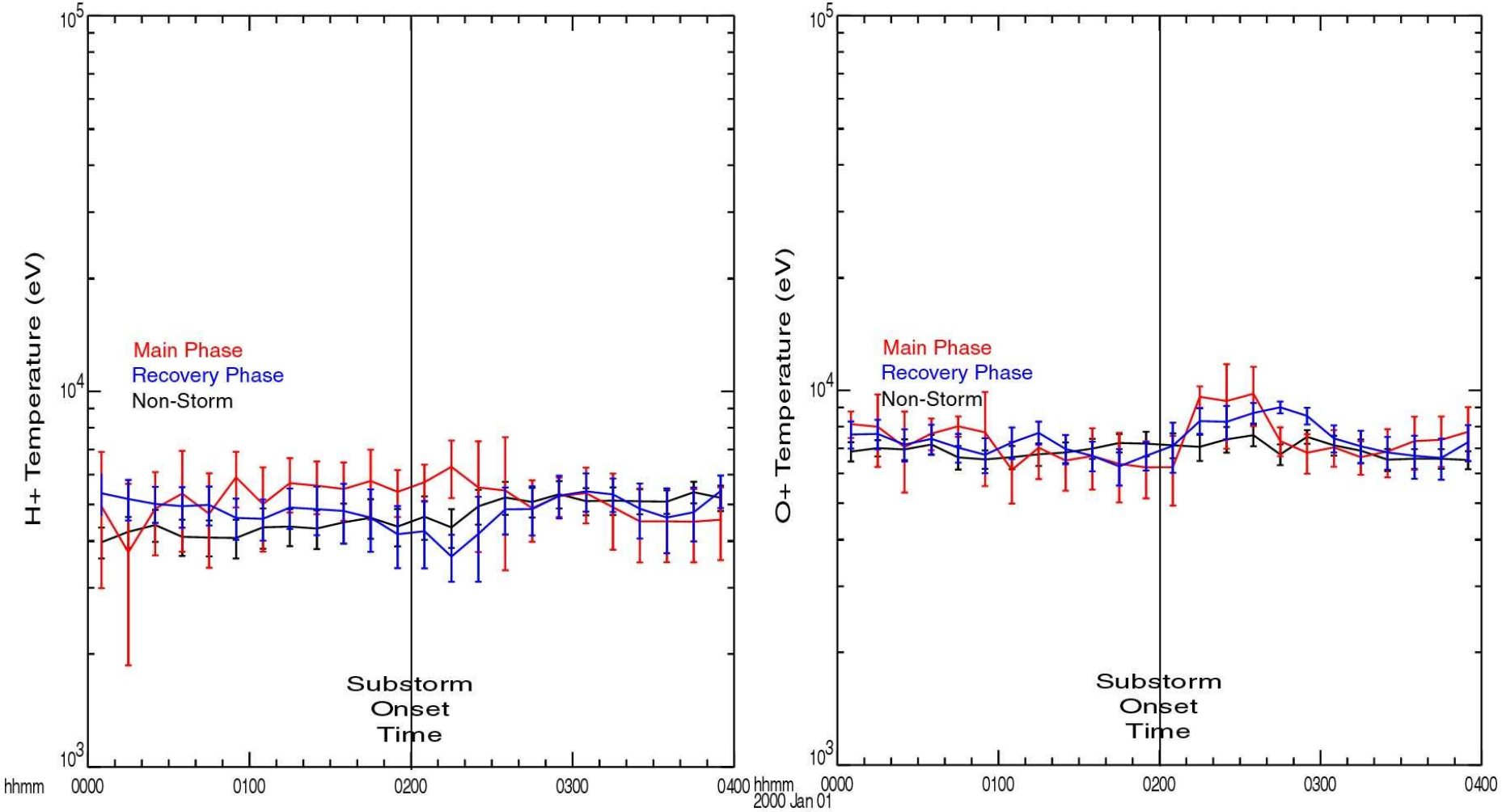
Density vs. Kp



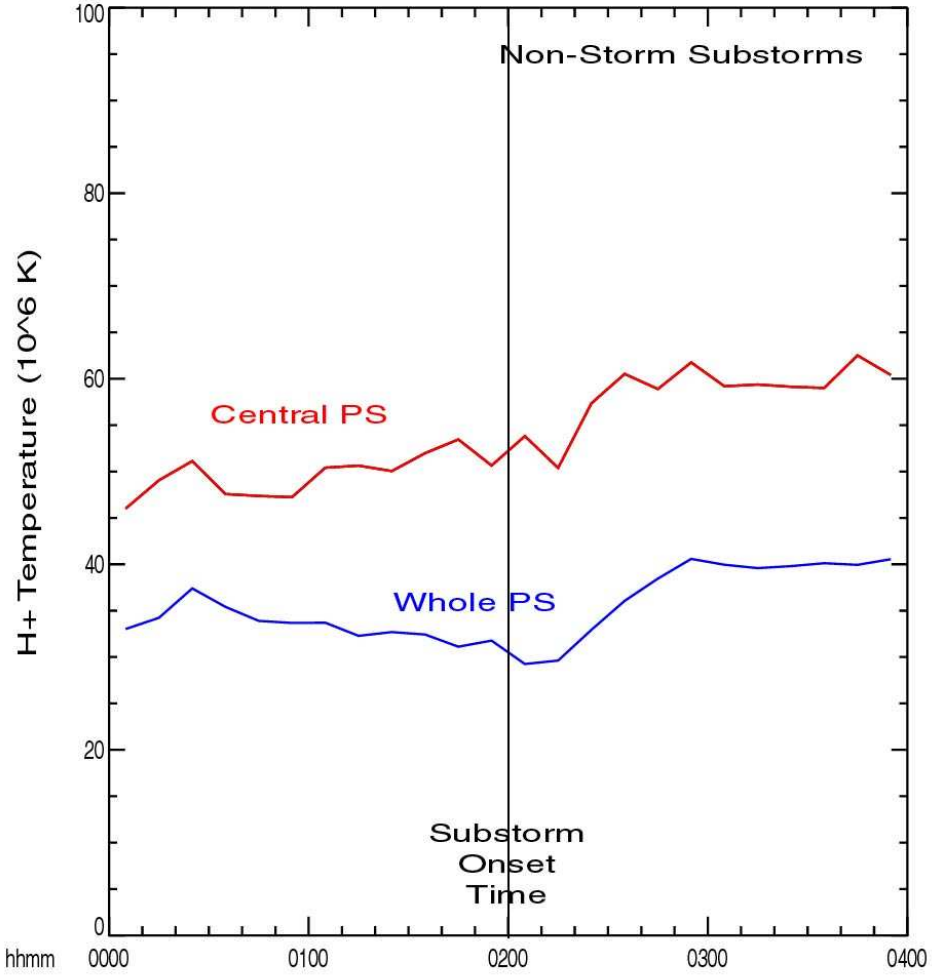
Comparison of Central Plasma Sheet H+ and O+ Density

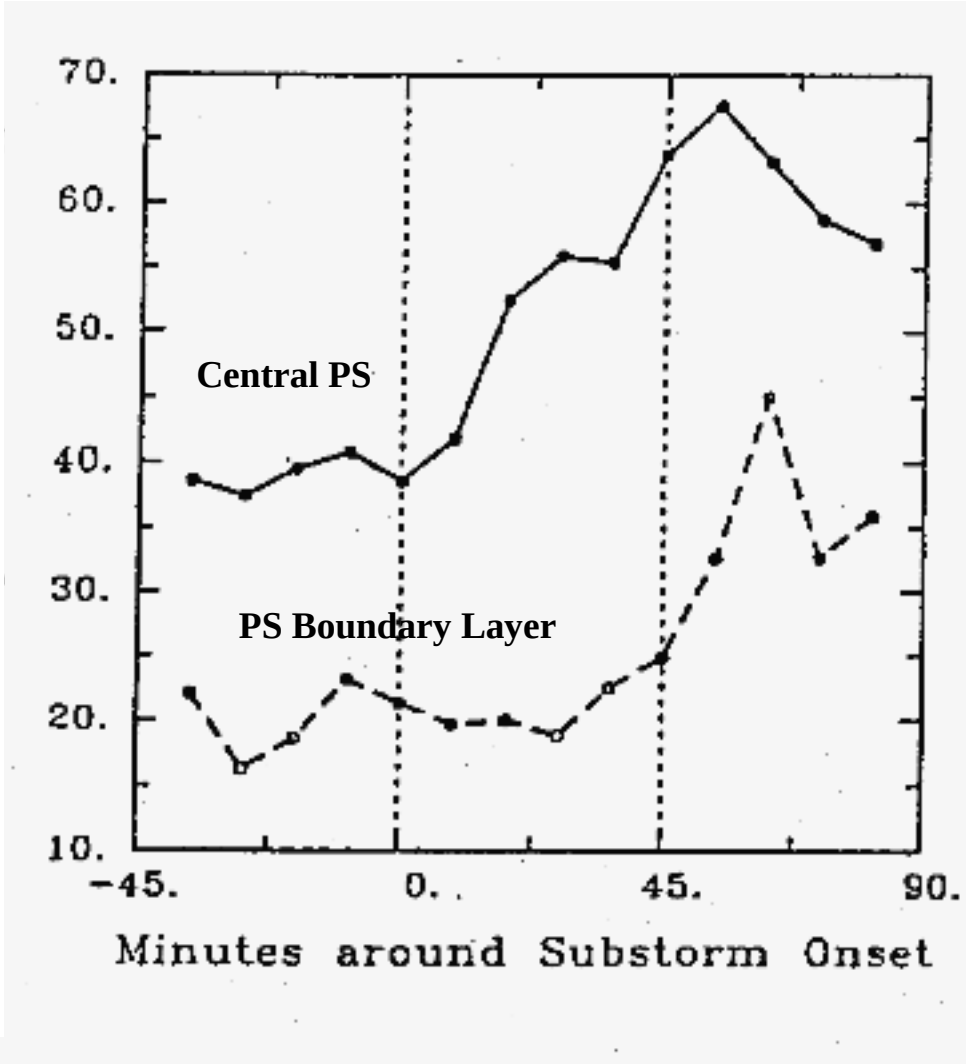


Comparison of Central Plasma Sheet H+ and O+ Temperature



Comparison of Central Plasma Sheet H+ Temperature with AMPTE/IRM results





Non-storm time O+ Diff Flux