FIRST RESULTS OF DRIFT SIMULATIONS OF 'MULTI-BAND' STRUCTURES IN SPACECRAFT OBSERVATIONS OF INNER MAGNETOSPHERE PLASMA ELECTRONS AND IONS

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What are ‘Bands’?

BANDS IN DOUBLE STAR TC-1 DATA

Bands: Features in particle energy-time spectra between 100 eV – 10’s keV. Multi-bands refer to 2 or more bands.

Noses (yellow box): Ends of Bands.

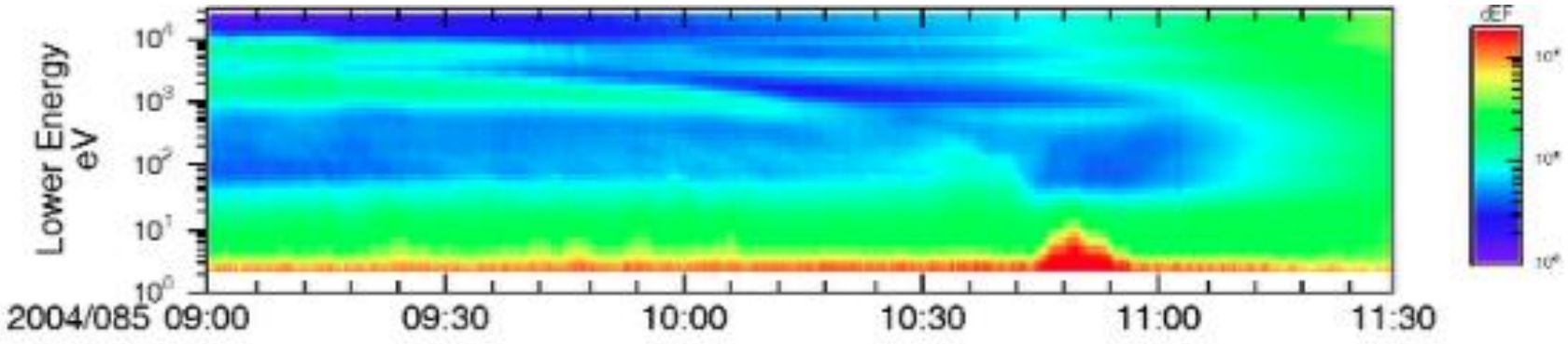


Fig. DS TC-1 PEACE Electron energy-time spectra for 25th March 2004 showing **multi-bands**.

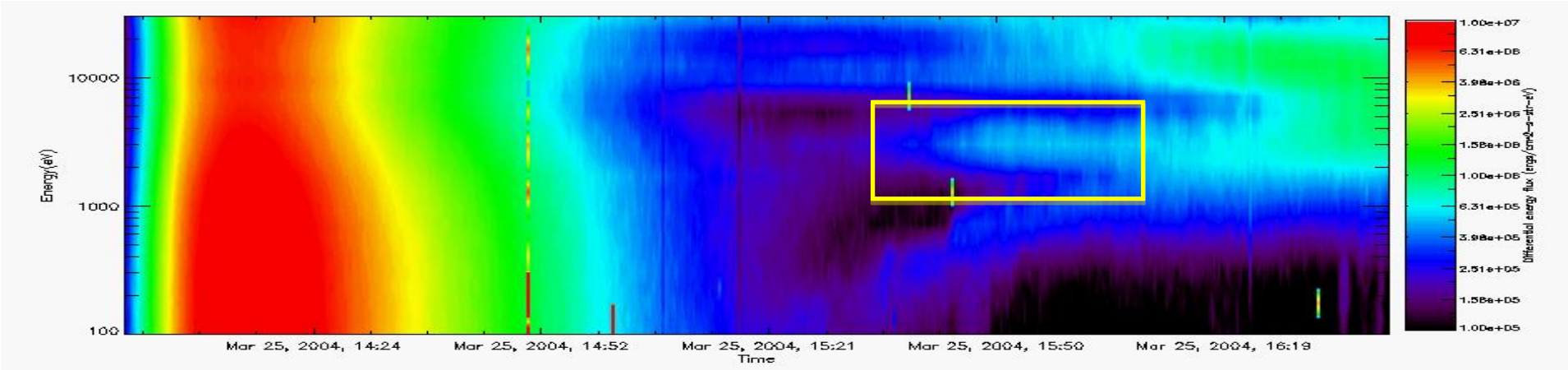


Fig. DS TC-1 HIA Ion energy-time spectra for 25th March 2004 showing **multi-banded structures**.

BANDS – A CONSEQUENCE OF DRIFTS?

UCL

Total Drift Velocity:

$$v_d = \underbrace{\frac{((\vec{R}\times\vec{\Omega})\times\vec{B})\times\vec{B}}{B^2}}_{\text{Corotation}} + \underbrace{\frac{\vec{E}\times\vec{B}}{B^2}}_{\text{Convection}} + \underbrace{\frac{W_\perp \vec{B}\times\nabla B}{qB^3}}_{\nabla B}$$

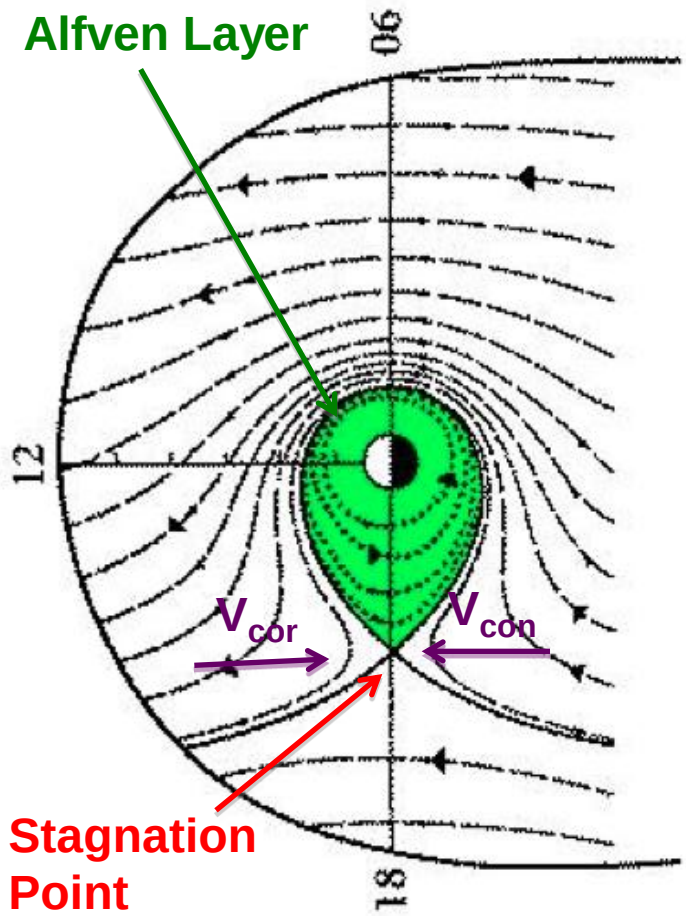


Image Courtesy : Kavanagh et al., 1968

DRIFT PATHS OF PARTICLES

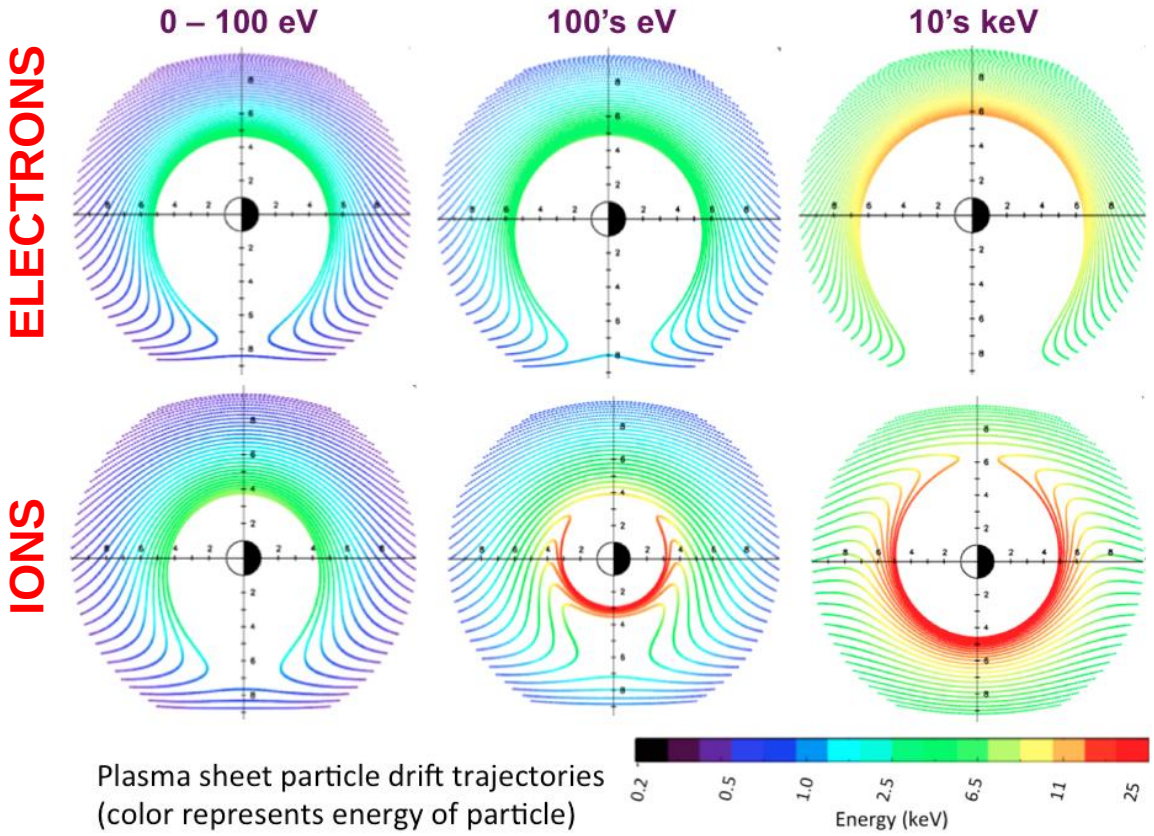


Fig: Drift trajectories in a simple dipole magnetic field and Volland-Stern Electric field model.

SIMULATING NOSE STRUCTURES

Simulate QUIET STEADY STATE magnetosphere.

Input Parameters - Particles: Pitch angle = 90, Energy 0.1 – 30 keV
- Geomagnetic Activity: Kp = 0
- Position of particle input: L = 10, MLT = 20-4

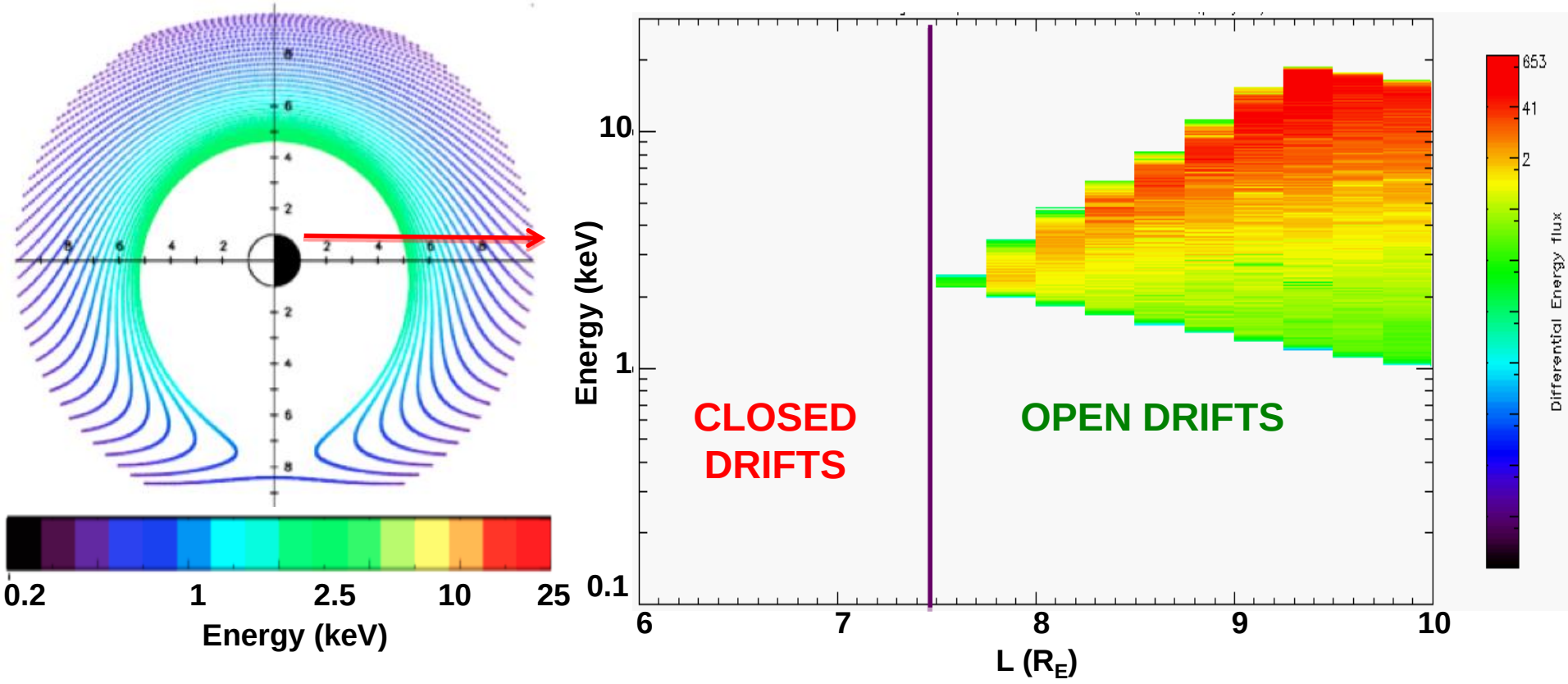


Fig. Energy-L spectra showing a single nose structure formed as a consequence of particle drifts. **This is similar to what we see for all MLT cuts in both ions and electrons.**

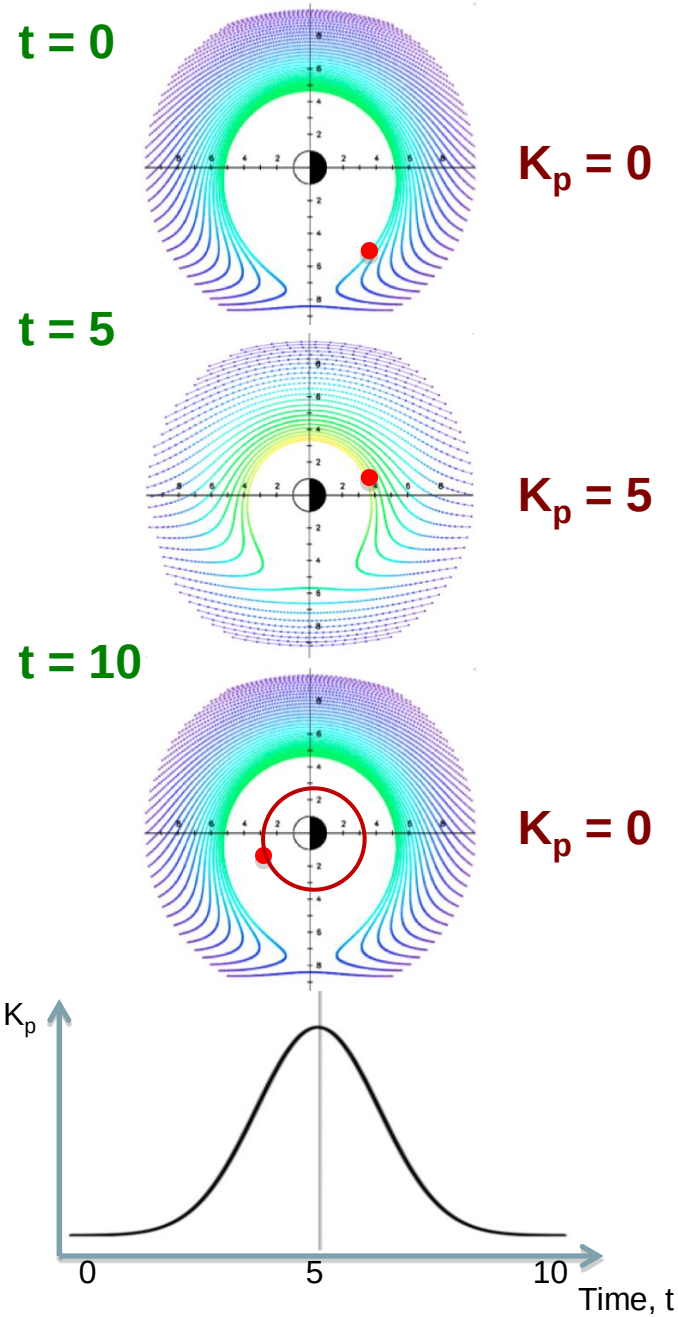
How are Multi-banded Structures formed?

OTHER EXPLANATIONS - BANDS
ELECTRONS AND IONS

(Burke et al., 1995; Liemohn et al., 1998; Ejiri et al., 1980)

1. Low Kp: Alfven layer further away from Earth
2. As Kp increases i.e. during a substorm, Alfven layer moves inwards and particle penetrates closer toward Earth.
3. After the substorm, as the K_p index decreases, the particle becomes trapped within the Alfven layer and follows closed drift path.

Bands – particles on closed drift paths seen as the spacecraft passes through the region



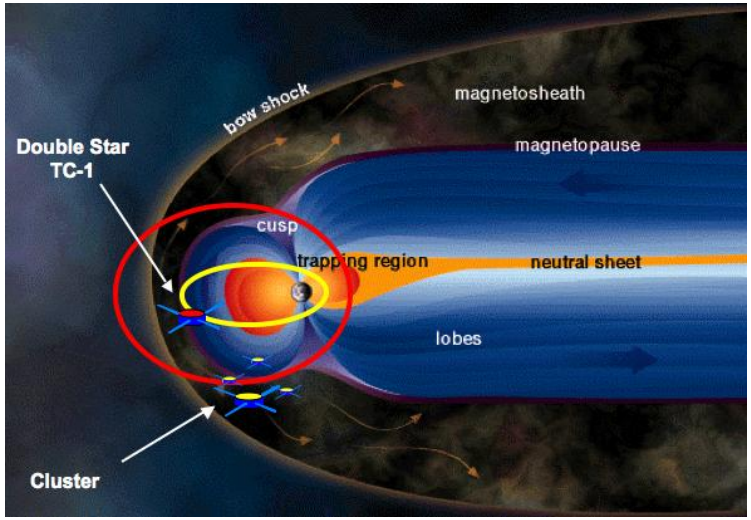
EXPLANATIONS FOR MULTI-BANDS

1.Superposition of old/new bands: **ELECTRONS** and **IONS**
2.Multiple injections
3.Nose/band structure split into 2 or more by spectral gaps due to loss of particles through:
- Charge Exchange : **IONS** *(Vallat et al., 2007)*
- Wave – particle interactions : **ELECTRONS** and **IONS**

DOUBLE STAR TC-1 STATISTICAL SURVEY

DOUBLE STAR TC-1
Collaboration between China and ESA

Equatorial orbit - 570 × 78 970 km with inclination 28.5° to the equator.
Orbits over 2004-2007 - all MLT covered.



CODE to pick out banded features in Double Star Tan Ce-1 HIA ion and PEACE electron energy-time data summed over all pitch angles:

1.Peaks in 5-min averaged flux data
2.Flux of peak has to be at least 105% of background flux of the 5 min interval
3.BAND = consecutive peaks at Energies ± 1 energy channel for at least 30 MINUTES.

NOTE: Times of bad quality data were excluded from the survey.

(Presented in previous workshops/conferences)

26 JANUARY 2004 – 1/2 bands

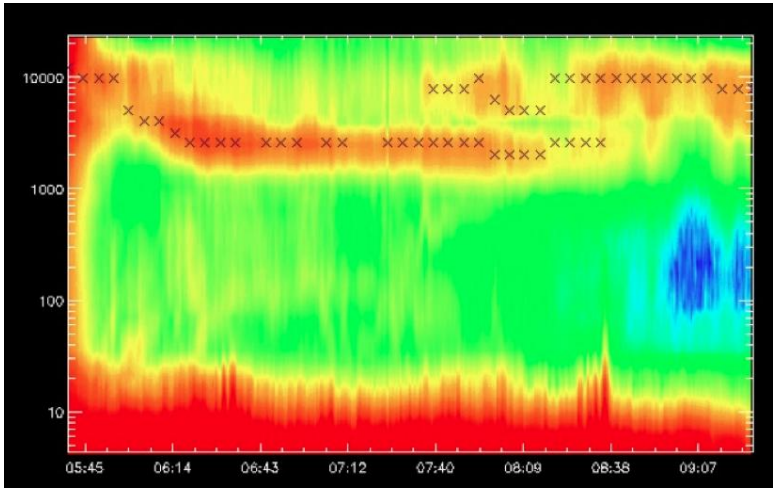


Fig. DS TC-1 Observations of banded structures. The black crosses denote where CODE picks up banded structure.

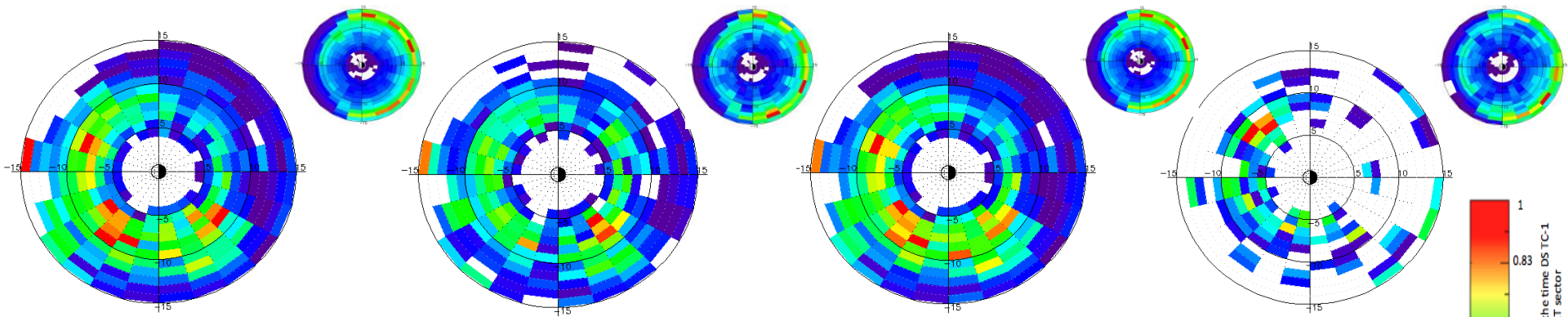
STATISTICS OF MULTI-BANDS

UCL

Kp = 0 - 7 **Kp = 0 - 1** **Kp = 0 - 3** **Kp = 3 - 5**

ELECTRONS

SUN



Total = 800.6 hrs Total = 435.3 hrs Total = 749.6 hrs Total = 51 hrs

IONS

Total = 1329.5 hrs Total = 503.5 hrs Total = 1101.9 hrs Total = 206.75 hrs

Fig. Self-normalized distribution of multi-banded structures as a function of L and MLT. Data under L < 4 is not shown. **The sun is to the left**.

STATS - ENERGY OF BANDS

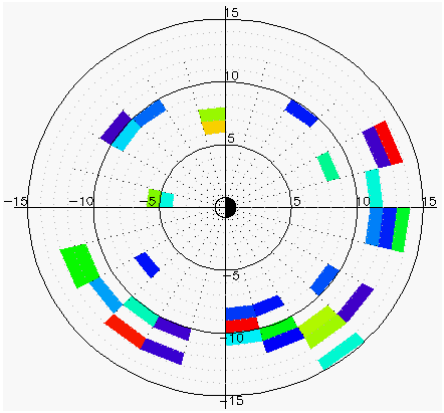
Are band structures solely due to particles on closed paths?

Kp = 0 – 1; AE = 0 – 50 nT

SUN

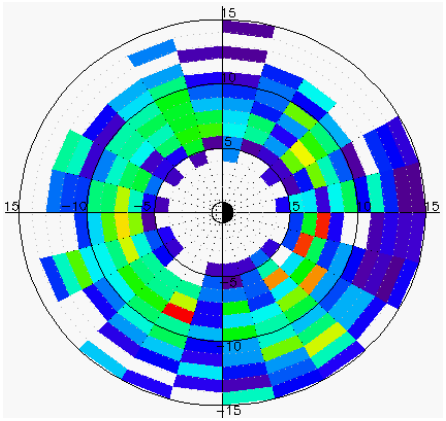
ELECTRONS

120 – 344 eV



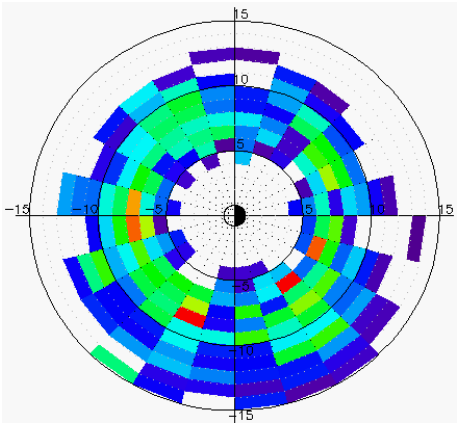
Total = 30.75, R = 0.09

430 – 4974 eV

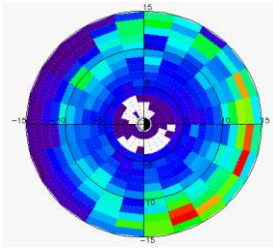


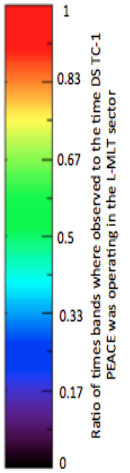
Total = 454.5, R = 0.63

6204 – 23748 eV



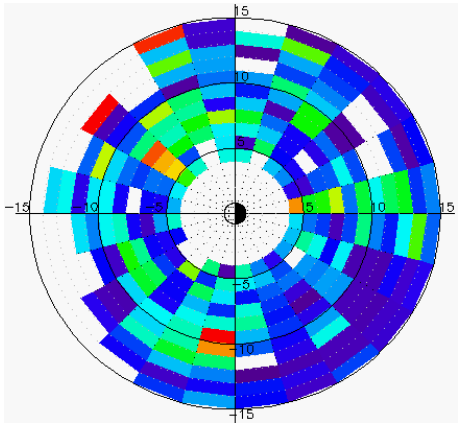
Total = 385.3, R = 0.53





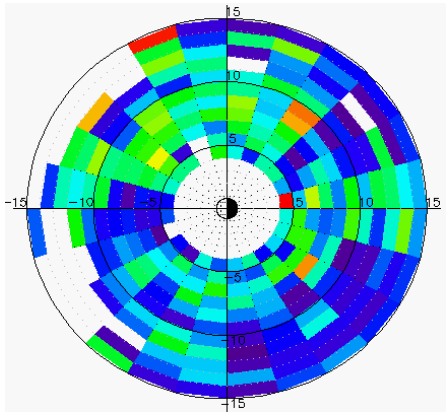
IONS

127 – 712 eV



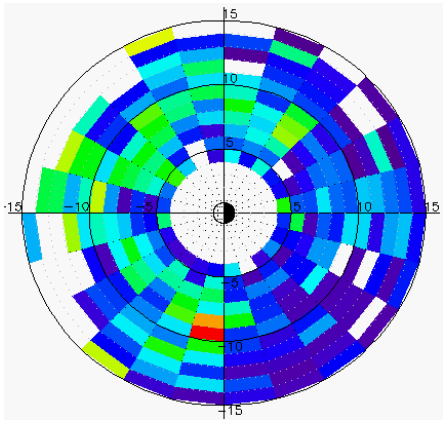
Total = 196.0, R = 0.36

402 – 9266 eV

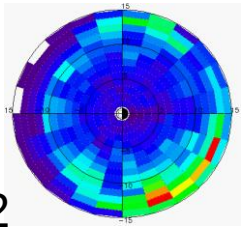


Total = 543, R = 0.62

12322 – 28990 eV



Total = 234.9, R = 0.92



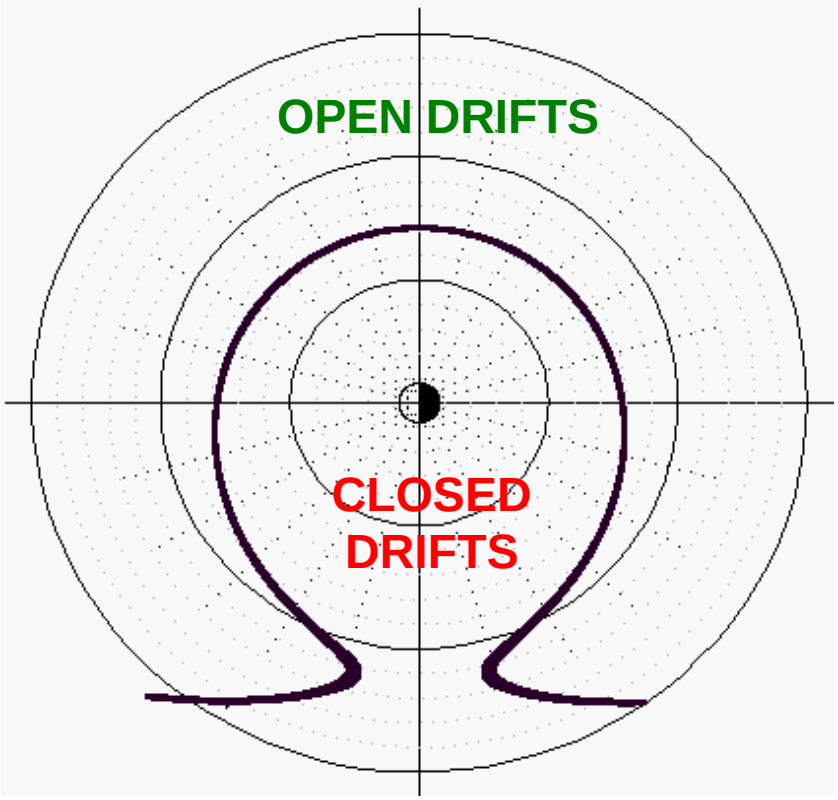
STATS - ENERGY OF BANDS

Closest open drift path to the Alfven layer is plotted on top of the statistics to show open and closed drift regimes.

Kp = 0 – 1; AE = 0 – 50 nT

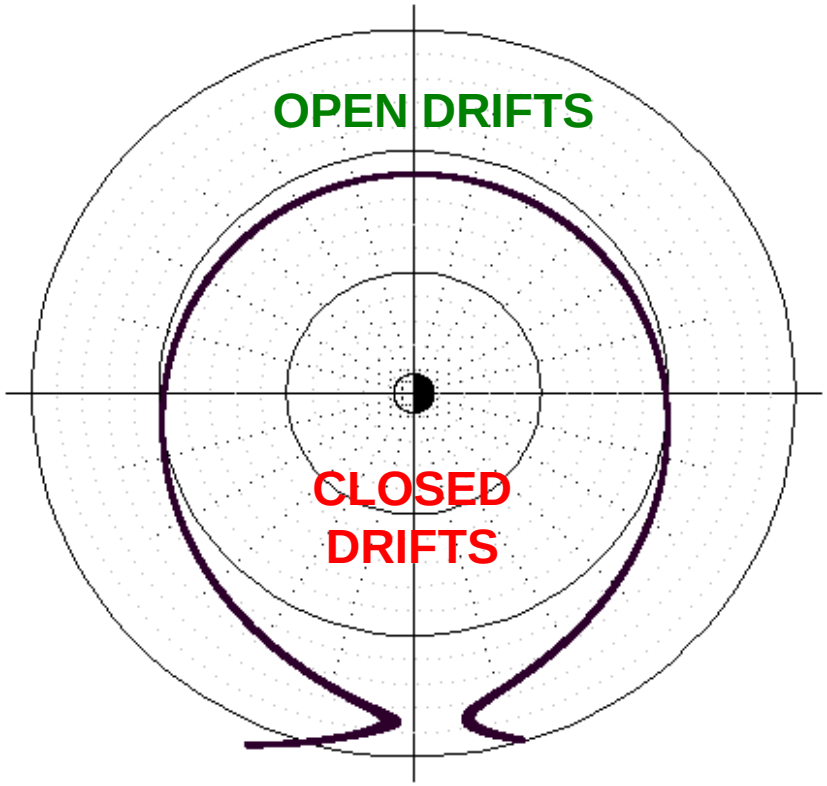
Energy : 430 – 4974 eV

Kp = 1, E = 430 eV



CLOSEST OPEN DRIFT PATH

Kp = 0, E = 4974 eV



FURTHEST OPEN DRIFT PATH

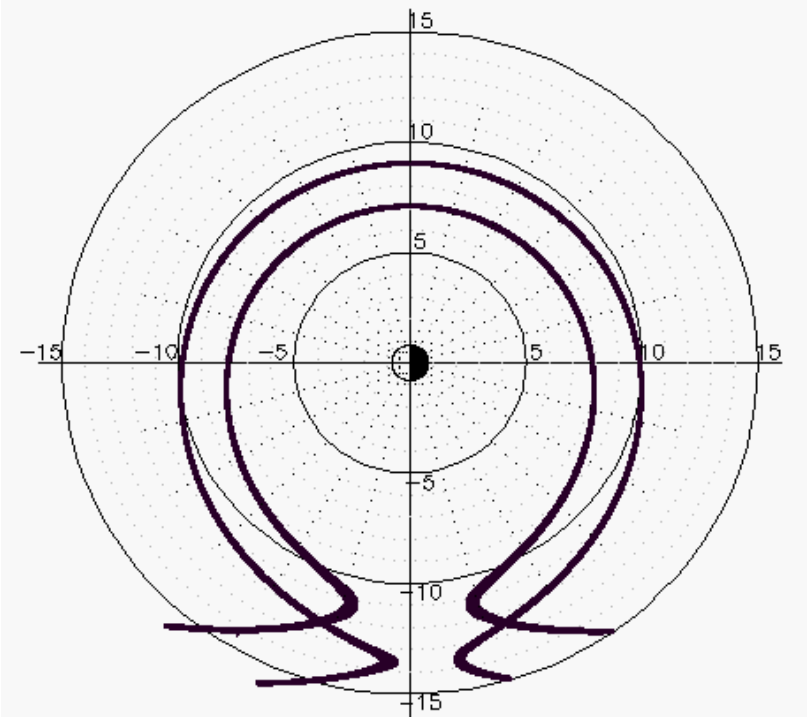
STATS - ENERGY OF BANDS

Closest open drift path to the Alfven layer is plotted on top of the statistics to show open and closed drift regimes.

Kp = 0 – 1; AE = 0 – 50 nT

Energy : 430 – 4974 eV

Kp = 1, E = 430 eV + Kp = 0, E = 4974 eV



CLOSEST OPEN DRIFT PATH SUPERPOSED ON FURTHEST OPEN DRIFT PATH

STATS - ENERGY OF BANDS

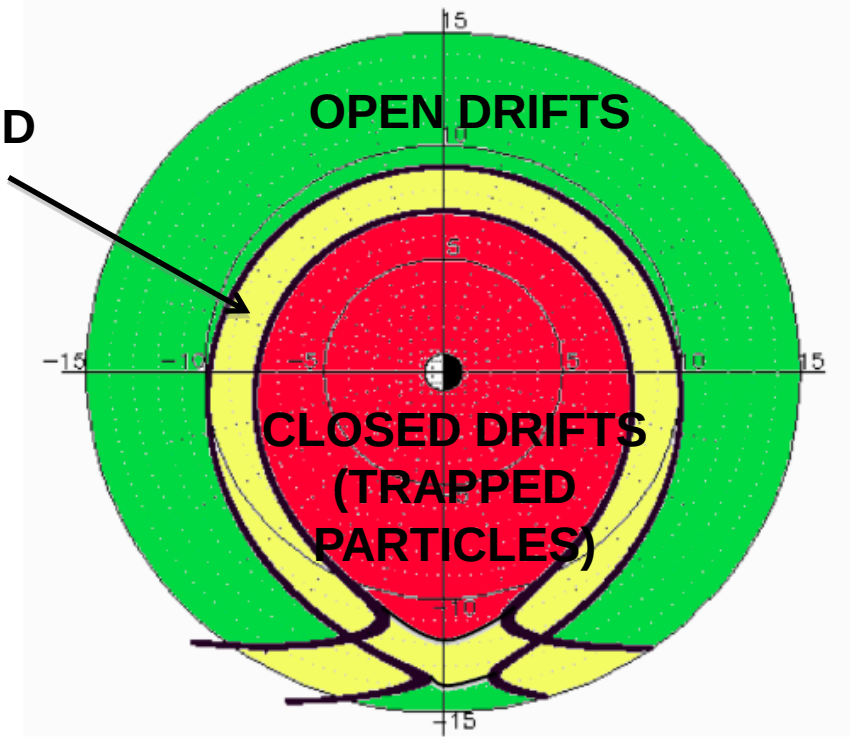
Closest open drift path to the Alfven layer is plotted on top of the statistics to show open and closed drift regimes.

Kp = 0 – 1; AE = 0 – 50 nT

Energy : 430 – 4974 eV

Kp = 1, E = 430 eV + Kp = 0, E = 4974 eV

OPEN OR CLOSED DRIFT PATHS



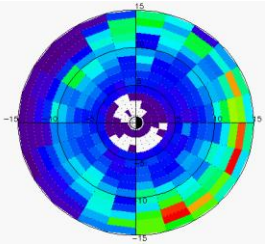
CLOSEST OPEN DRIFT PATH SUPERPOSED ON FURTHEST OPEN DRIFT PATH

STATS - ENERGY OF BANDS

Are band structures solely due to particles on closed paths?

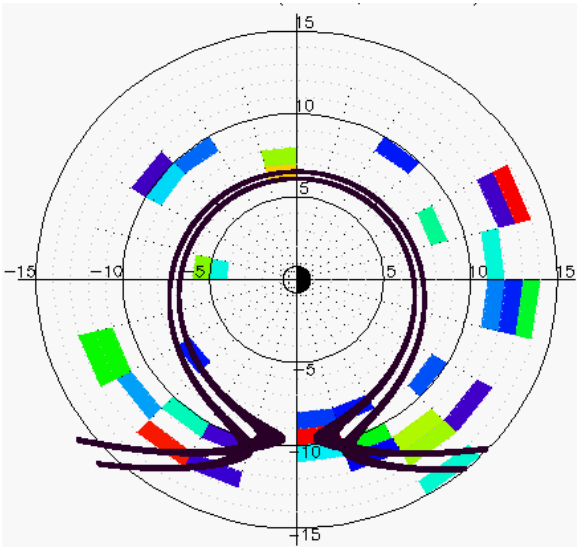
Kp = 0 – 1; AE = 0 – 50 nT

SUN ←



ELECTRONS

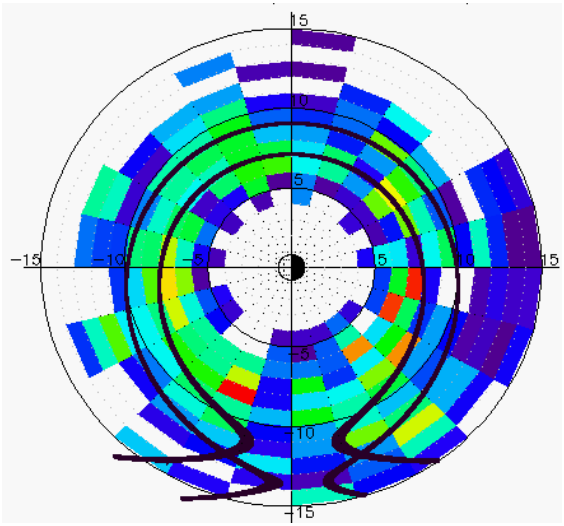
120 – 344 eV



Total = 30.75, SNR = 0.09

BANDS ON OPEN DRIFT PATHS

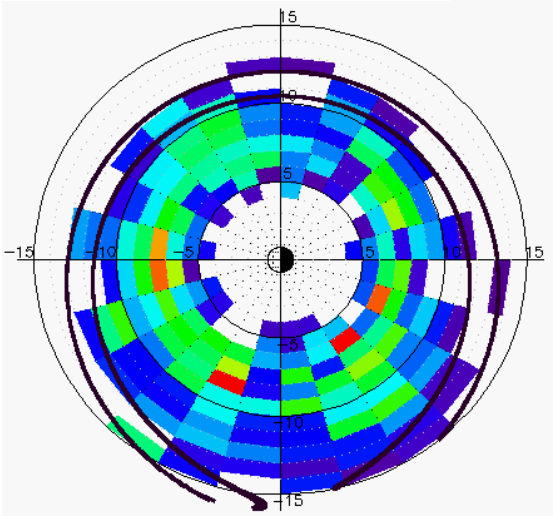
430 – 4974 eV



Total = 454.5, SNR = 0.63

BANDS ON OPEN AND CLOSED DRIFT PATHS

6204 – 23748 eV



Total = 285.3, SNR = 0.53

BANDS ON CLOSED DRIFT PATHS

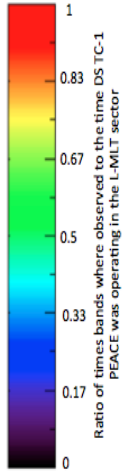


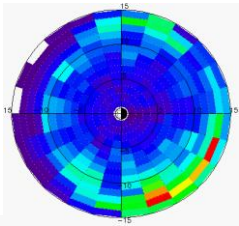
Fig. Self-normalized distribution of electron multi-banded structures as a function of L and MLT and energy of the bands.

STATS - ENERGY OF BANDS

Are band structures solely due to particles on closed paths?

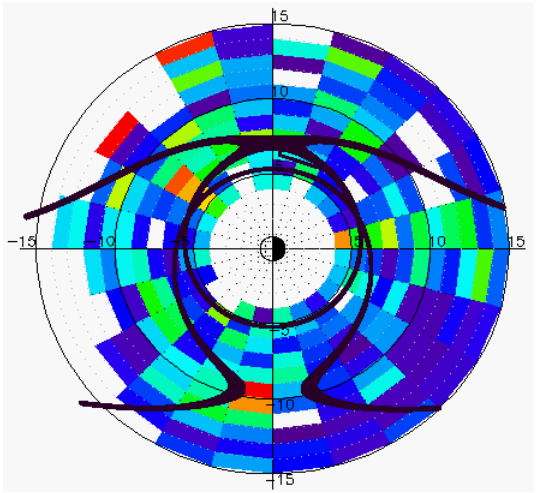
Kp = 0 – 1; AE = 0 – 50 nT

SUN



IONS

127 – 712 eV

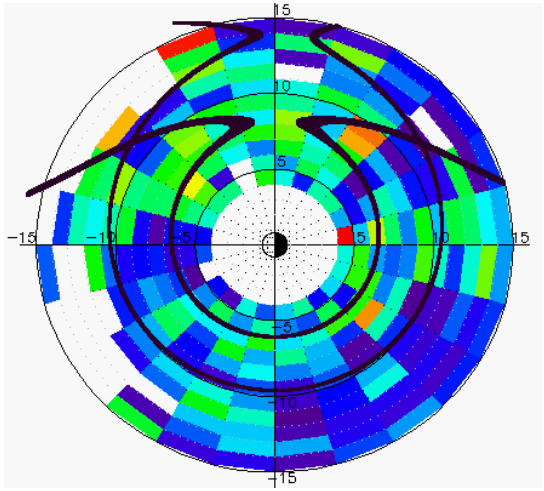


Total = 196.0, SNR = 0.36

BANDS ON OPEN DRIFT PATHS

NOTE: SOME CLOSED ON BANANA ORBITS

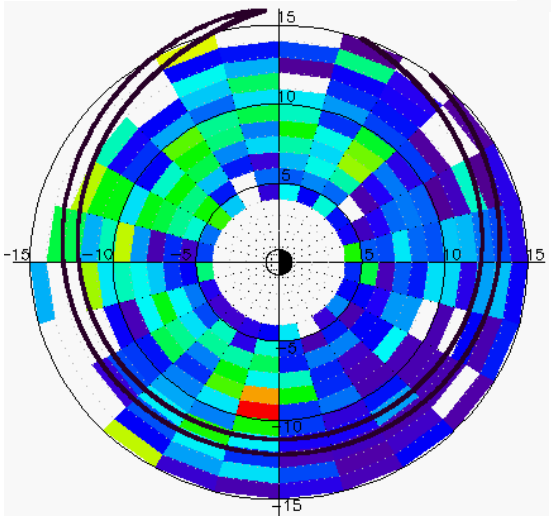
946 – 9266 eV

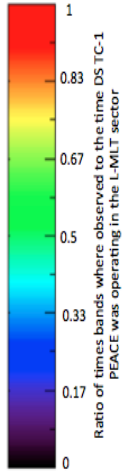


Total = 543.5, SNR = 0.62

BANDS ON OPEN AND CLOSED DRIFT PATHS

12322 – 28990 eV





Total = 234.9, SNR = 0.92

BANDS ON CLOSED DRIFT PATHS

CONCLUSIONS

1.Statistical analysis on DoubleStar TC-1 HIA and PEACE ion and electron data – Bands are most often observed in quiet times.
2.Statistics for energy of multi-bands with comparison to model Alfven layers:

- Multi-bands are largely found on closed paths or very slow open paths (Previously suggested).
- At Energy > ~6 keV (electrons) and ~12 keV (ions): Multi-bands are due to particles on closed drift paths.
- There are some cases at lower energies where multi-bands are clearly seen on open drift paths (Not highlighted previously).

FURTHER STUDY

- Investigate individual cases of low energy multi-bands on open paths; can we explain their origin – multiple injections of low energy particles??
- Seek to further confirm global picture of drifting particles in different energy bands on closed paths using case studies with Cluster, TC-1 and TC2

SIMULATION PARAMETERS

UCL

Simulate QUIET STEADY STATE magnetosphere.

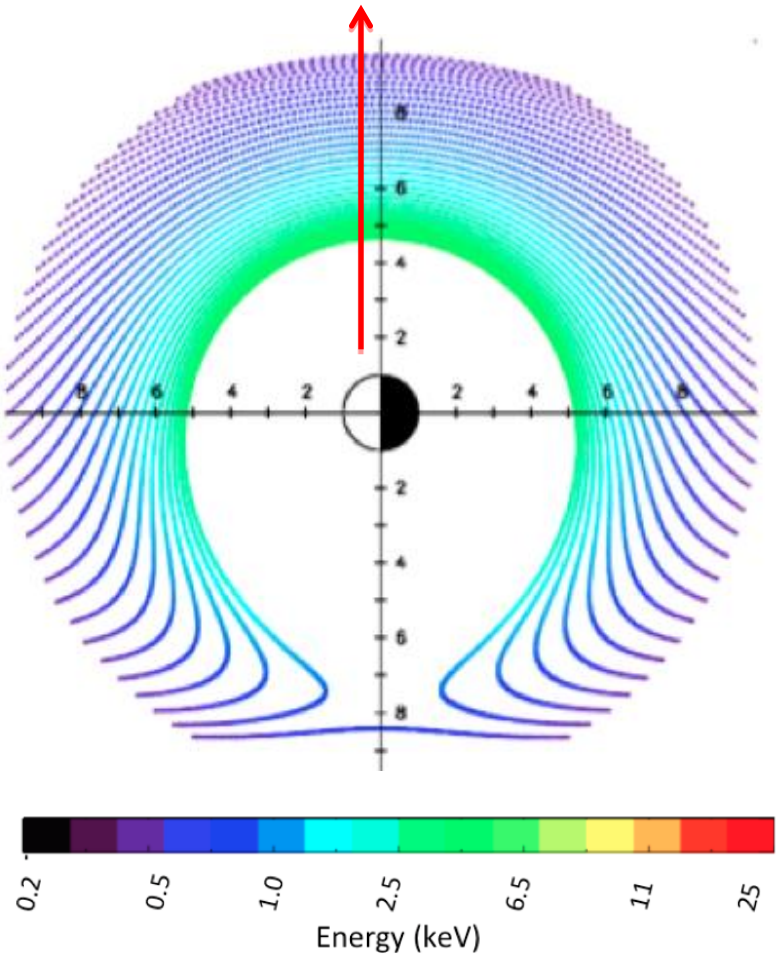
Simple drift trajectory model:

- Volland Stern Electric Field
- Dipole Magnetic Field

Input Parameters:

- L = 10 Re
- MLT = 20 – 4 in steps of 0.1
- Kp = 0
- Pitch Angle = 90
- Energies = 0.01 – 30 keV

Flux Grid to calculate fluxes

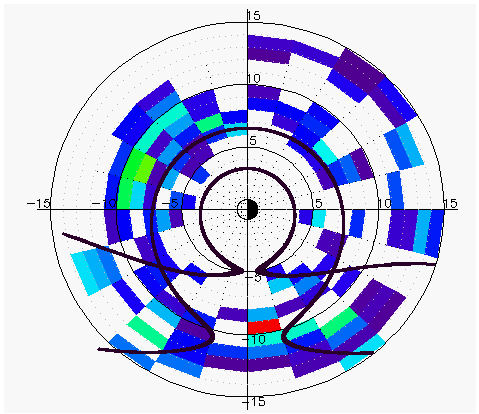
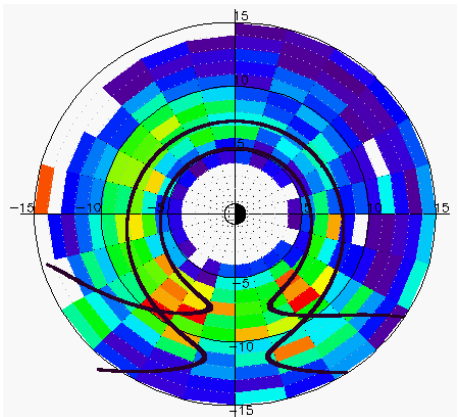
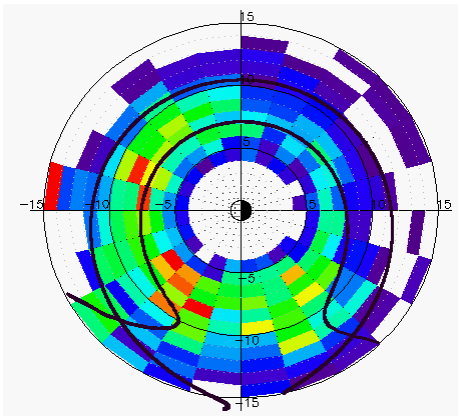
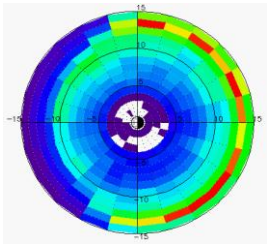


STATS - ELECTRONS: ENERGY OF BANDS

Are band structures solely due to particles on closed paths?

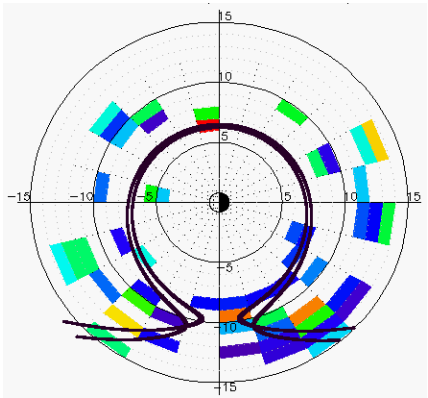
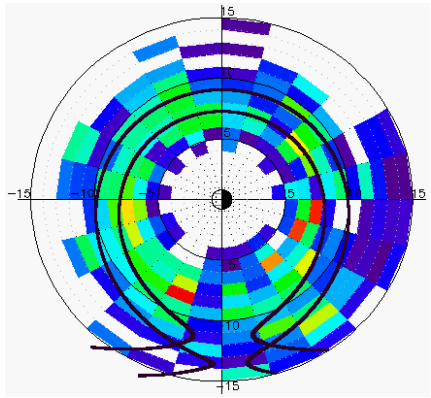
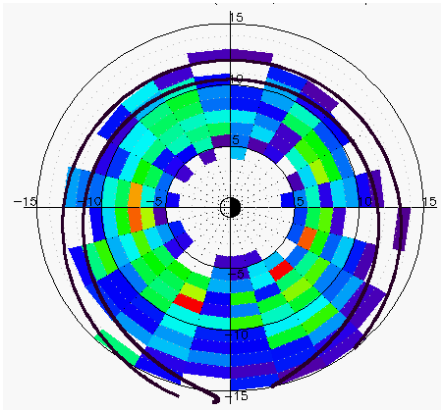
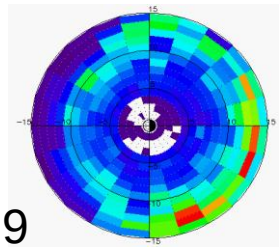
120 – 344 eV **430 – 4974 eV** **6204 – 23748 eV**

Kp = 0 – 7; AE = 0 – 3000 nT

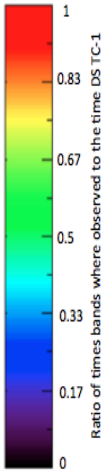





Total = 58 , R = 0.21 Total = 814.3, R = 0.42 Total = 639.5, R = 0.90

Kp = 0 – 1; AE = 0 – 50 nT

Total = 22.3, R = 0.12 Total = 340.2, R = 0.59 Total = 245.3, R = 0.99

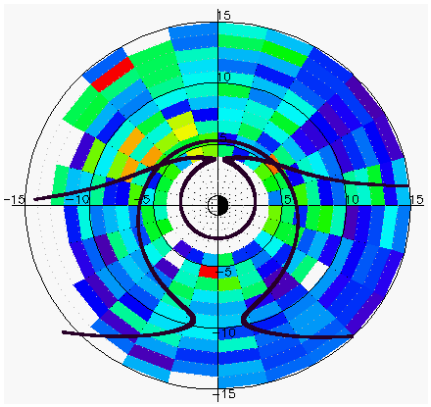


STATS - IONS: ENERGY OF BANDS

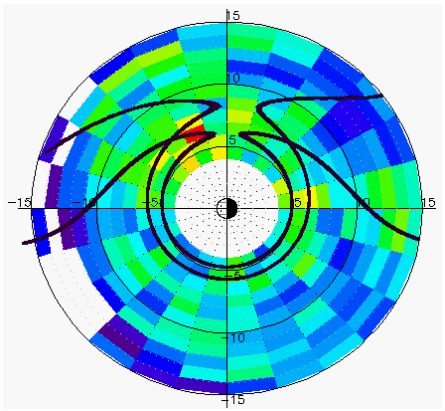
Are band structures solely due to particles on closed paths?

127 – 302 eV **402 – 9266 eV** **12322 – 28990 eV**

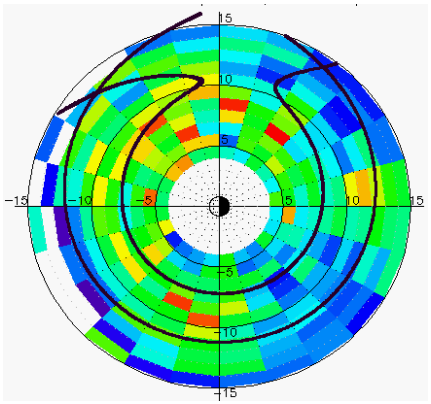
Kp = 0 – 7; AE = 0 – 3000 nT



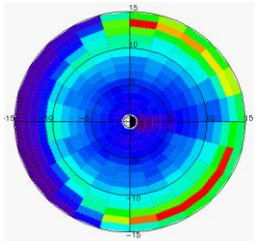
Total = 163 , R = 0.15

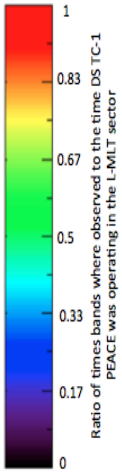


Total = 1942.1, R = 0.08

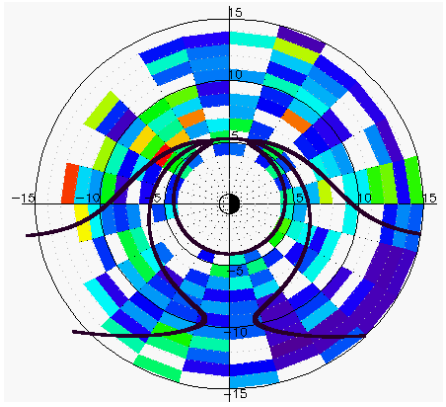


Total = 827.6, R = 0.78

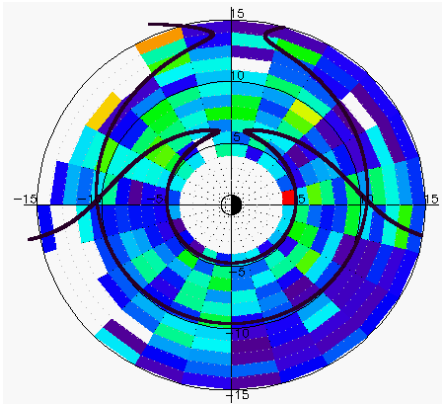




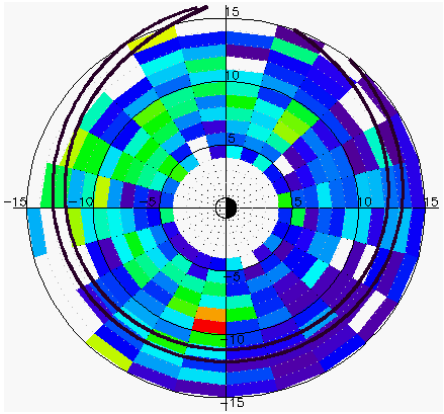
Kp = 0 – 1; AE = 0 – 50 nT



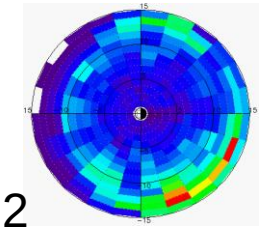
Total = 46.7, R = 0.11



Total = 543, R = 0.62



Total = 234.9, R = 0.92



SIMULATION PARAMETERS

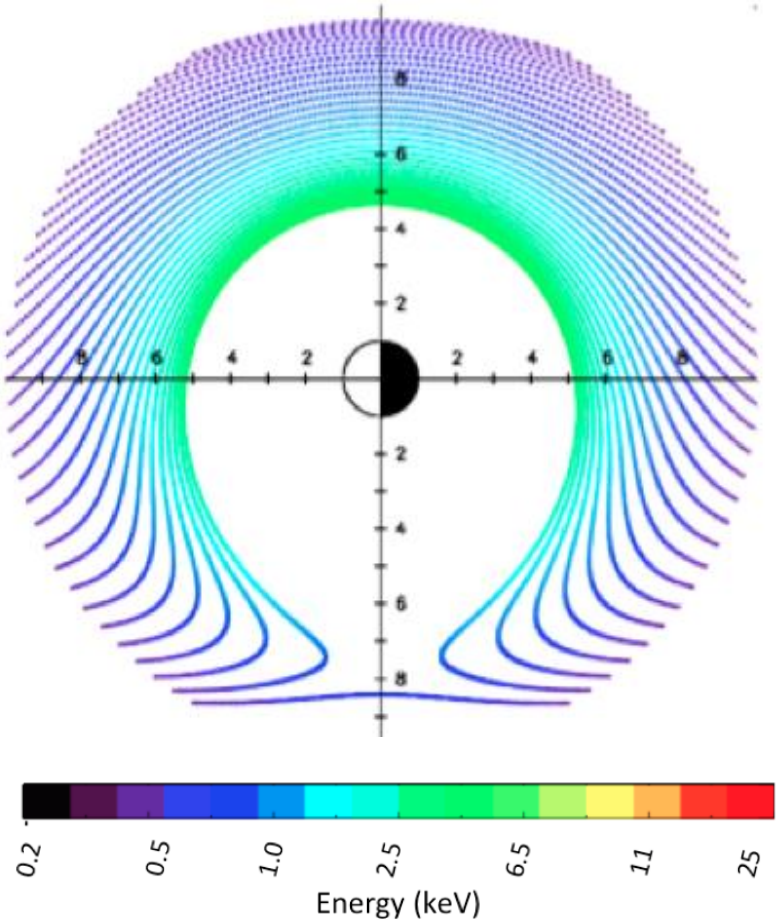
Simulate QUIET STEADY STATE magnetosphere.

Simple drift trajectory model:

- Volland Stern Electric Field
- Dipole Magnetic Field

Input Parameters:

- L = 10 Re
- MLT = 20 – 4 in steps of 0.1
- Kp = 0
- Pitch Angle = 90
- Energies = 0.01 – 30 keV



SIMULATION PARAMETERS

Simulate QUIET STEADY STATE magnetosphere.

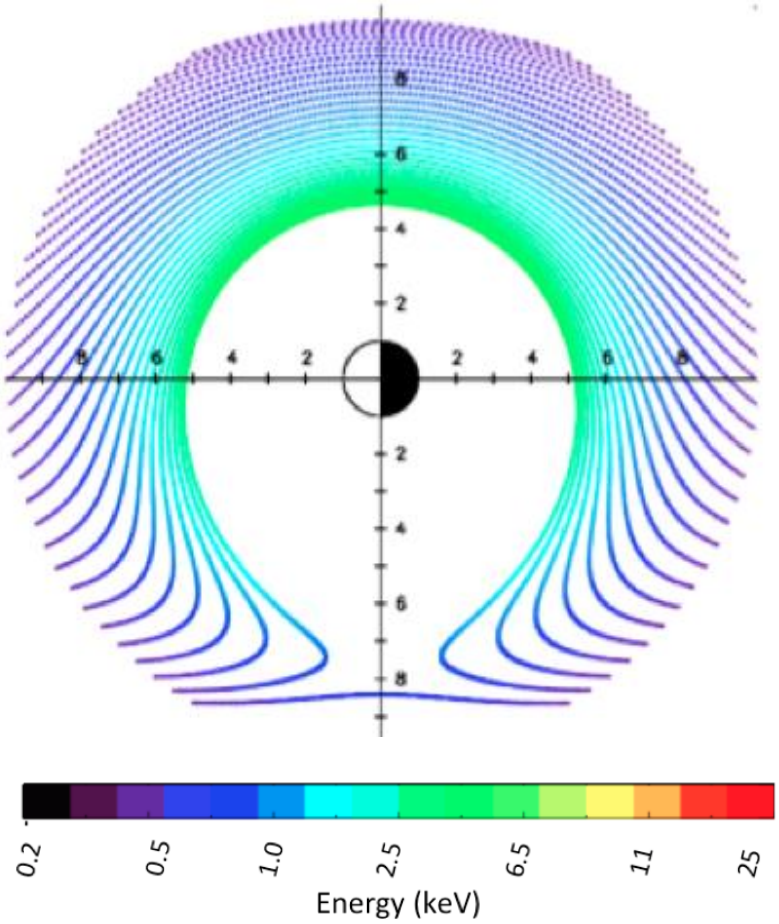
Simple drift trajectory model:

- Volland Stern Electric Field
- Dipole Magnetic Field

Input Parameters:

- L = 10 Re
- MLT = 20 – 4 in steps of 0.1
- Kp = 0
- Pitch Angle = 90
- Energies = 0.01 – 30 keV

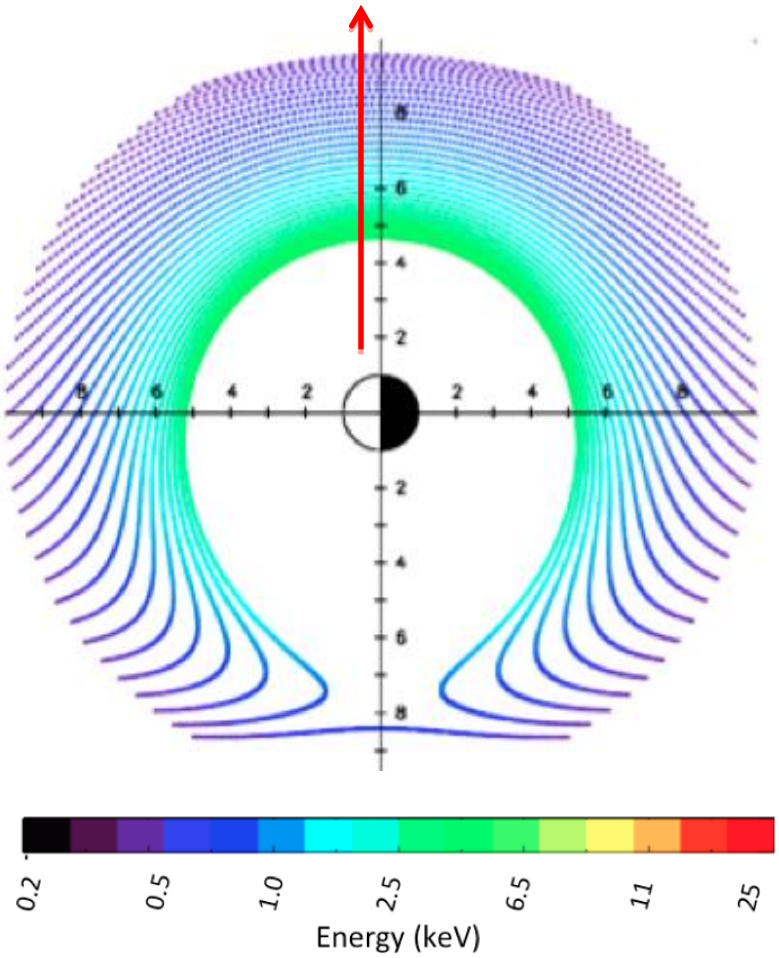
Flux Grid to calculate fluxes



SIMULATION PARAMETERS

Simulate QUIET STEADY STATE magnetosphere.

- Simple drift trajectory model:
  - Volland Stern Electric Field
  - Dipole Magnetic Field
- Input Parameters:
  - L = 10 Re
  - MLT = 20 – 4 in steps of 0.1
  - Kp = 0
  - Pitch Angle = 90
  - Energies = 0.01 – 30 keV
- Flux Grid to calculate fluxes
- MLT cut – Do we see a nose?

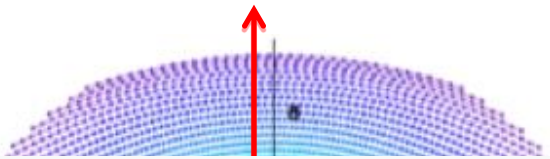


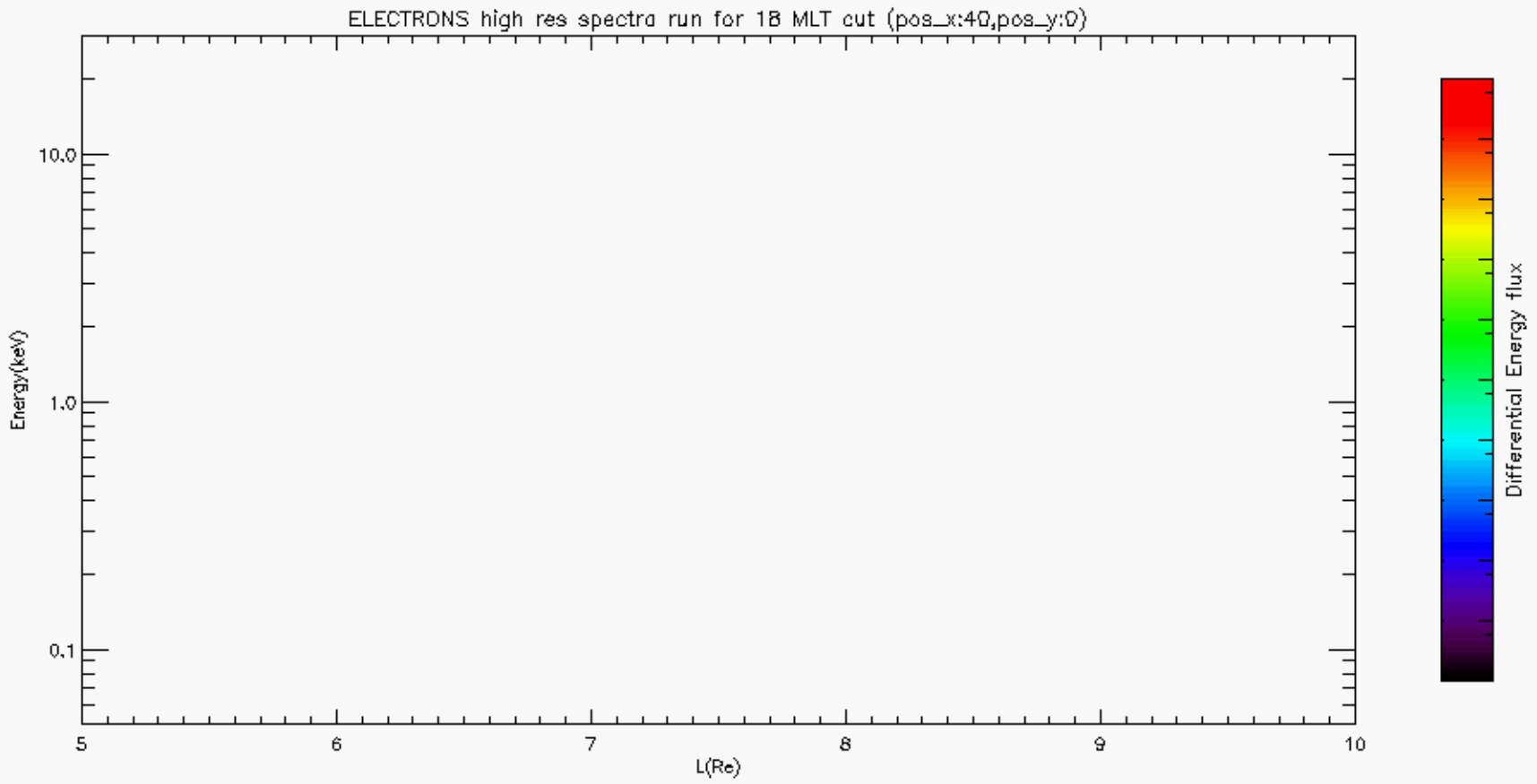
SIMULATION PARAMETERS

Simulate QUIET STEADY STATE magnetosphere.

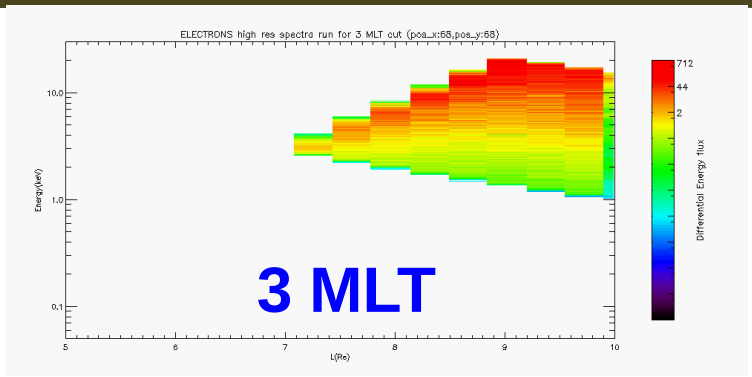
Simple drift trajectory model:

- Volland Stern Electric Field



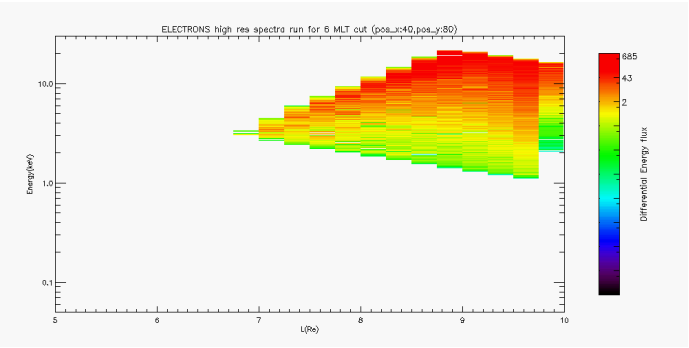


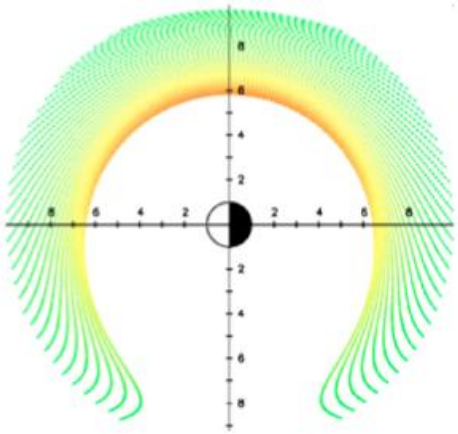
SIMULATIONS – WE SEE A NOSE!



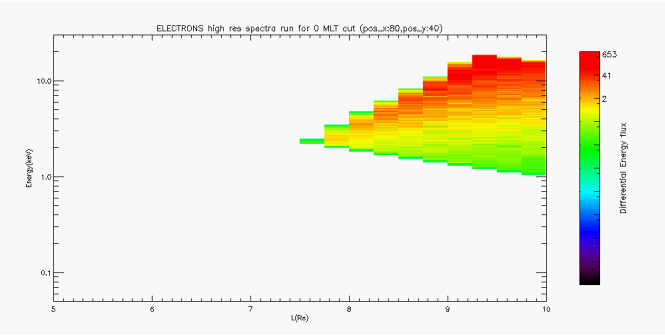
3 MLT

6 MLT

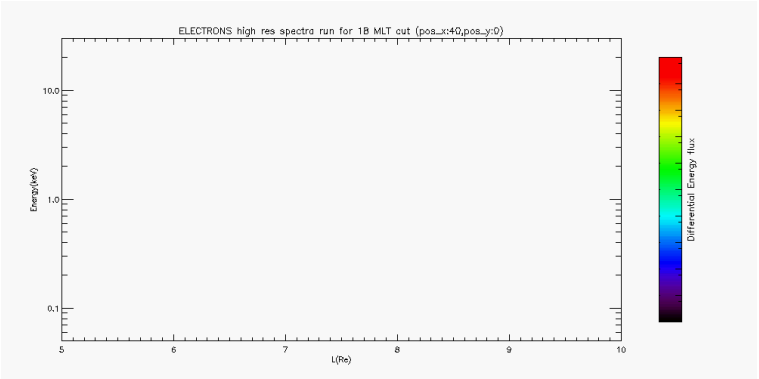




0 MLT



18 MLT



21 MLT

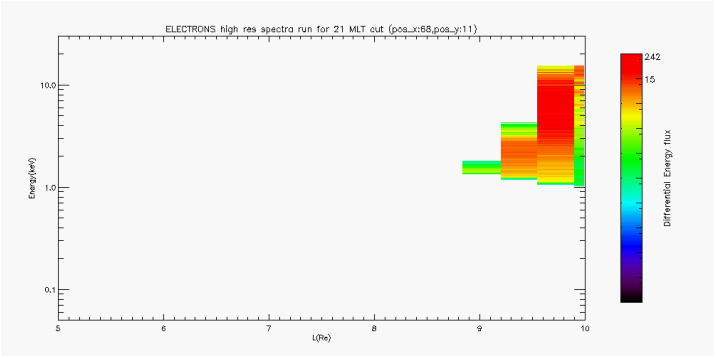
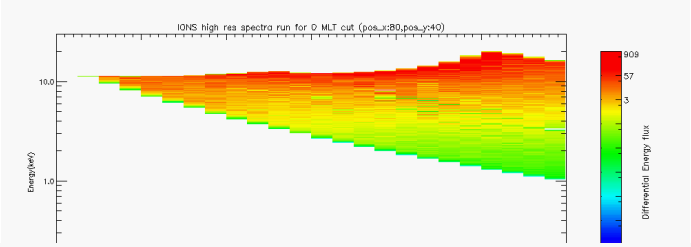
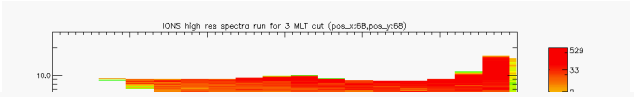
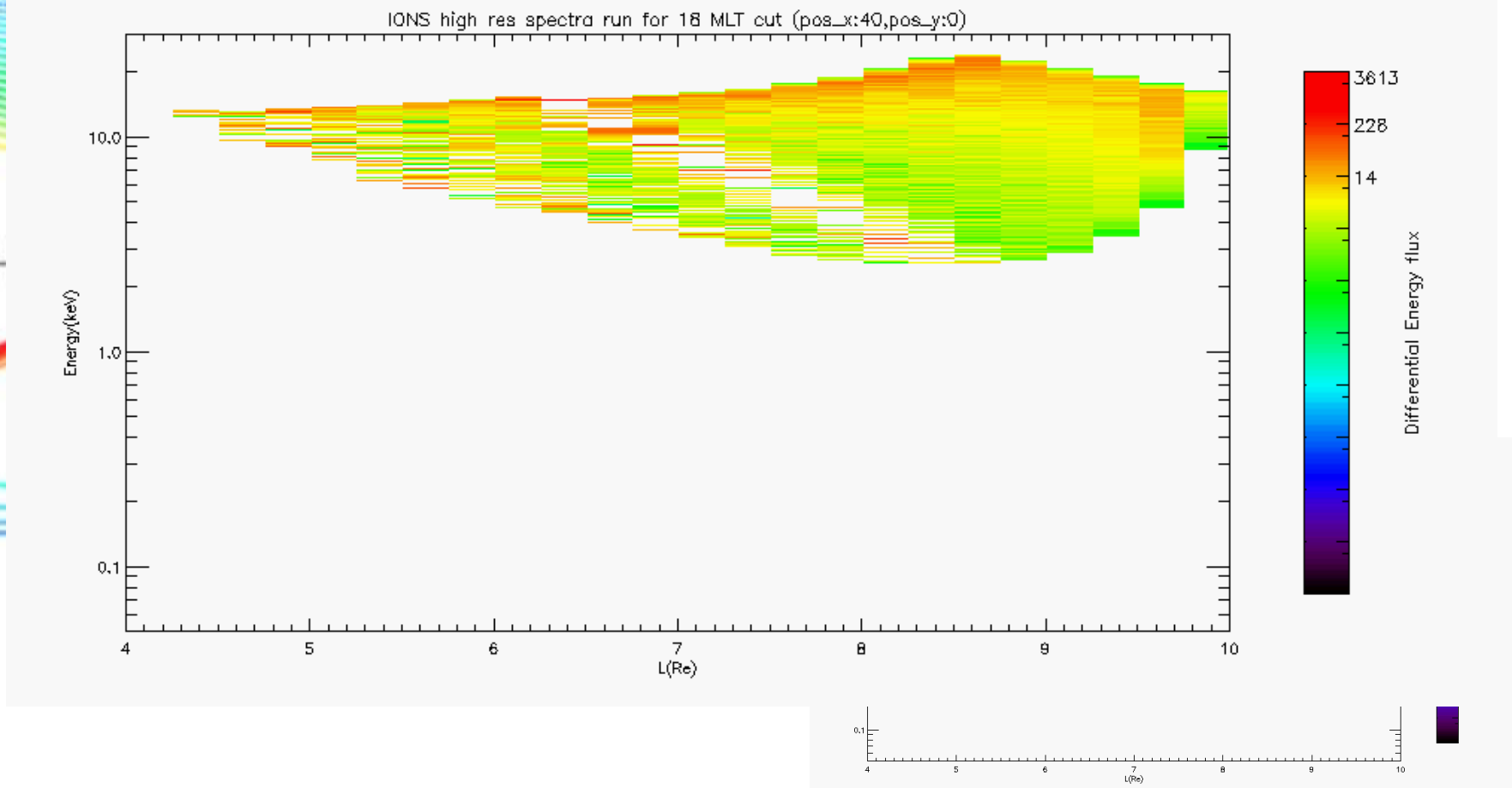


Fig. Simulated electron energy-L spectra showing single nose structures.
We see similar results in the case of the ions.

SIMULATIONS – IONS: WHAT DO WE EXPECT TO SEE?







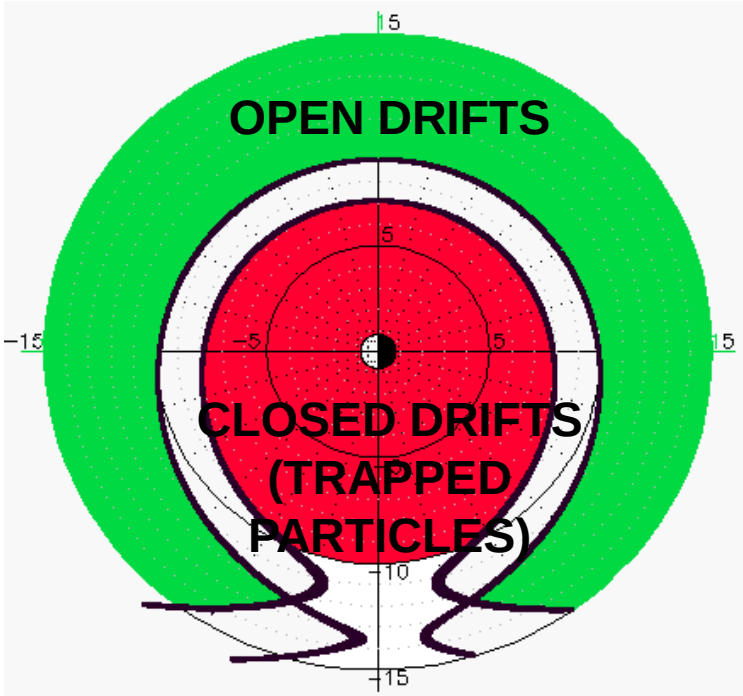
STATS - ENERGY OF BANDS

Closest open drift path to the Alfven layer is plotted on top of the statistics to show open and closed drift regimes.

Kp = 0 – 1; AE = 0 – 50 nT

Energy : 430 – 4974 eV

Kp = 7, E = 430 eV + Kp = 0, E = 4974 eV



CLOSEST OPEN DRIFT PATH SUPERPOSED ON FURTHEST OPEN DRIFT PATH