

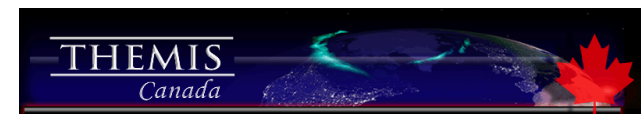


# Auroral Beads Associated with a Field Line Resonance

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**Frances Fenrich, Robert Rankin**  
*Department of Physics, University of Alberta*

**2024 DASP Workshop**  
*Thursday, February 22*



# Some Background on Auroral Beads

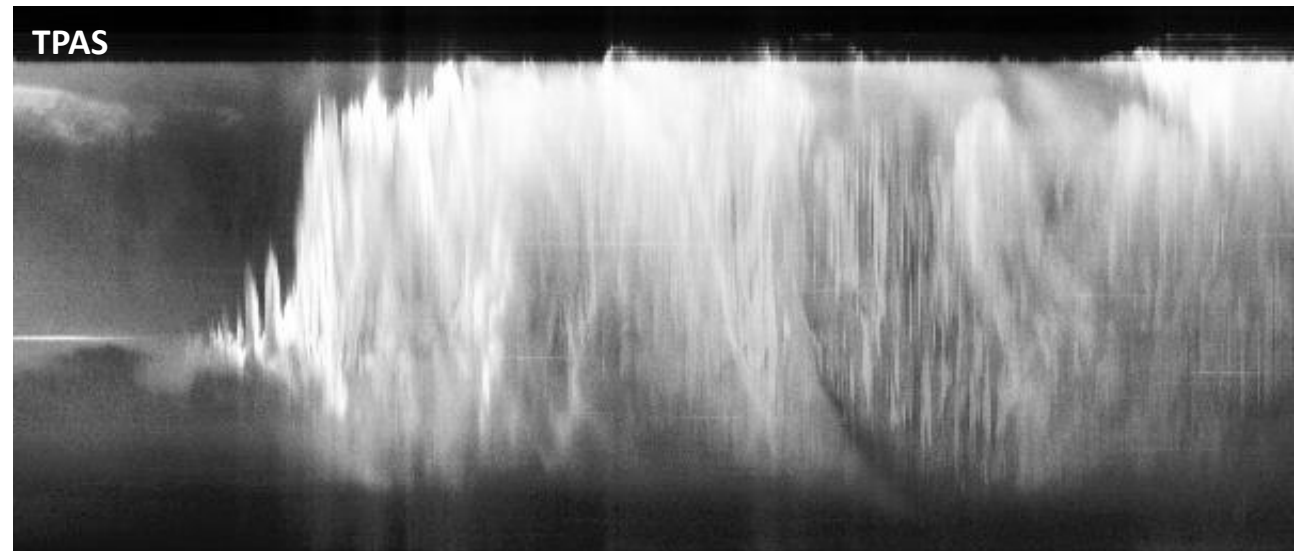
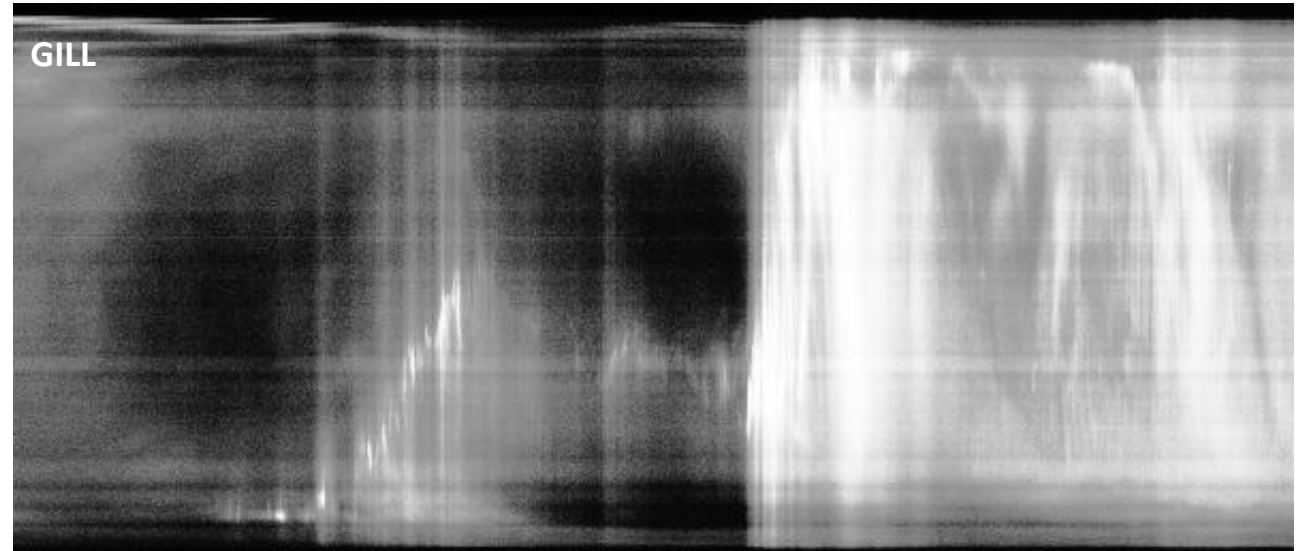
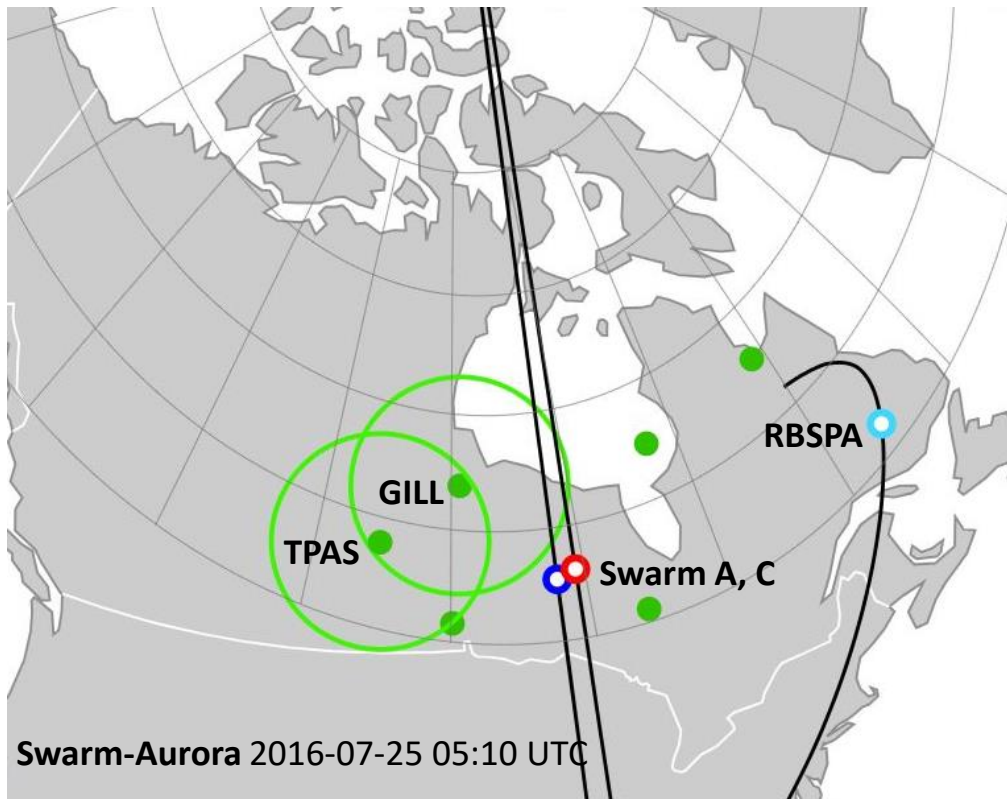
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- Auroral Beads are azimuthally periodic enhancements in auroral emissions along a pre-existing arc that develop into periodic spirals/vortices followed by auroral breakup.
- They are observed prior to >90% of substorm onsets (Nishimura et al., 2016). and are therefore a key mechanism in substorm triggering. Both eastward and westward propagation beads are observed with eastward propagation more common.
- Many studies have shown an association between Pi1-2 (10-100 mHz) ULF waves and auroral beads/substorm onset (Elphinestone et al., 1995; Smith et al., 2020; Lessard et al., 2011; Rae et al., 2010, 2014)
- Tian et al. (2022) presented Van Allen Probe (RBSP) observations showing auroral bead emissions are due to electron acceleration via Kinetic Alfvén Waves (KAW) in the equatorial inner magnetosphere. These KAW were accompanied by a 15 mHz Alfvén wave.



# Auroral Beading and Intensification Event

Observed by the THEMIS TPAS ASI on July 25, 2016 at ~ 05:10 UT

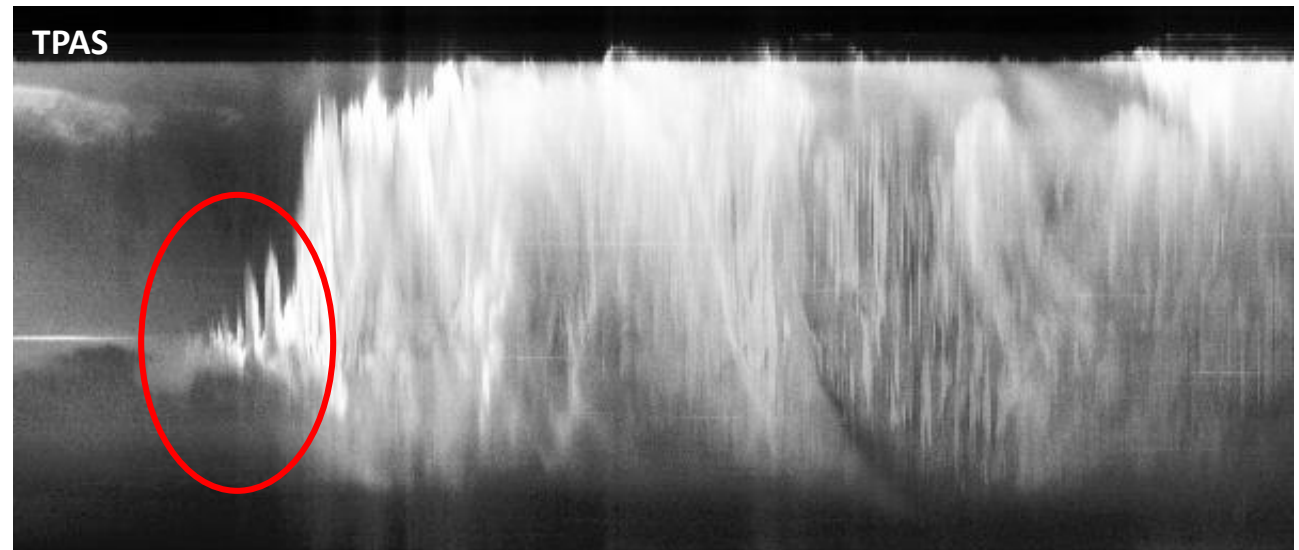
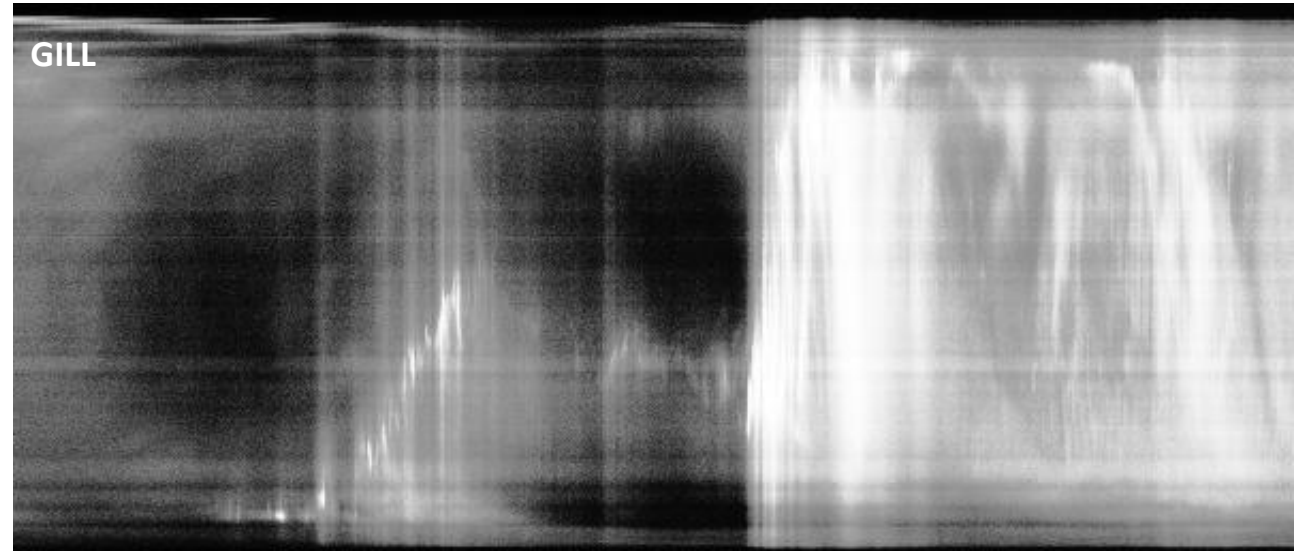
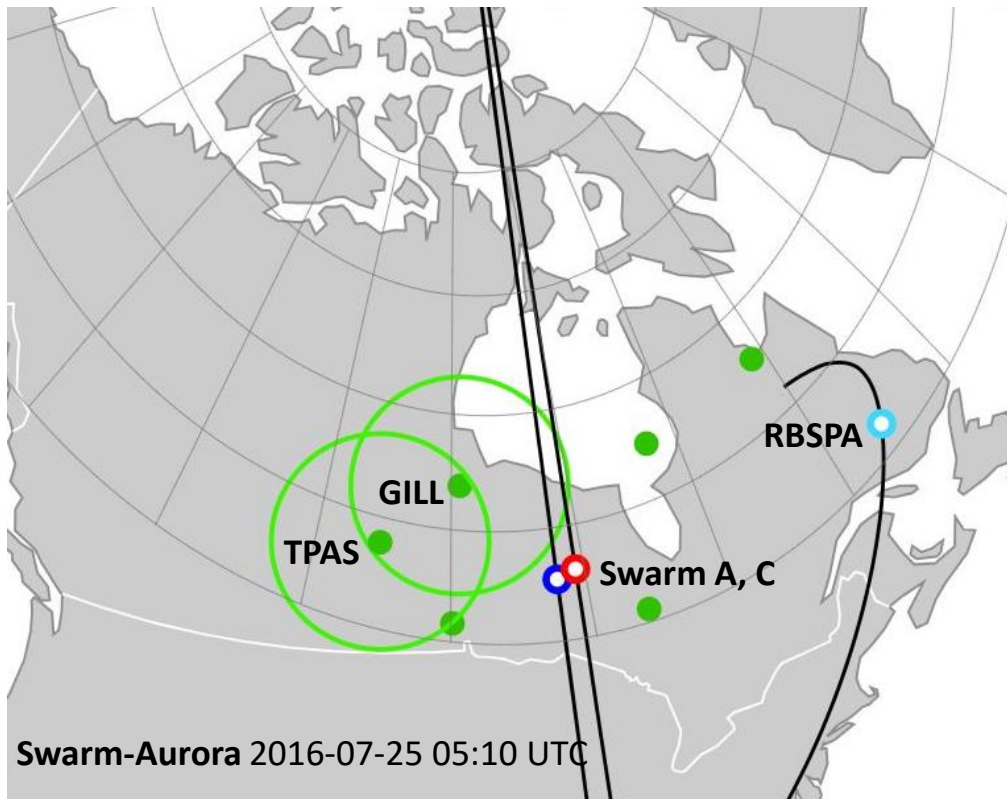


05:00

06:00

# Auroral Beading and Intensification Event

Observed by the THEMIS TPAS ASI on July 25, 2016 at ~ 05:10 UT



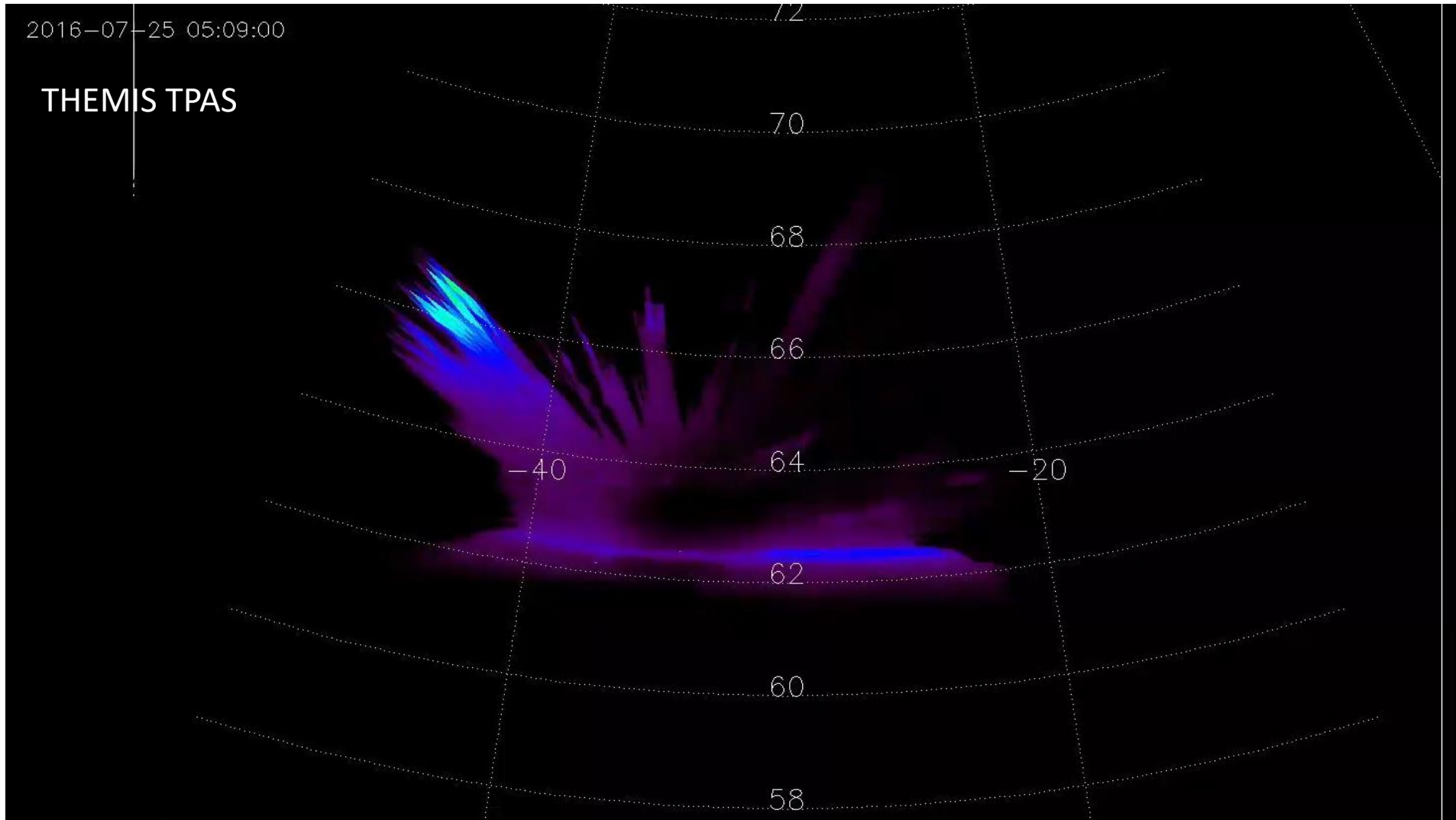
05:00

06:00

# Auroral Intensification

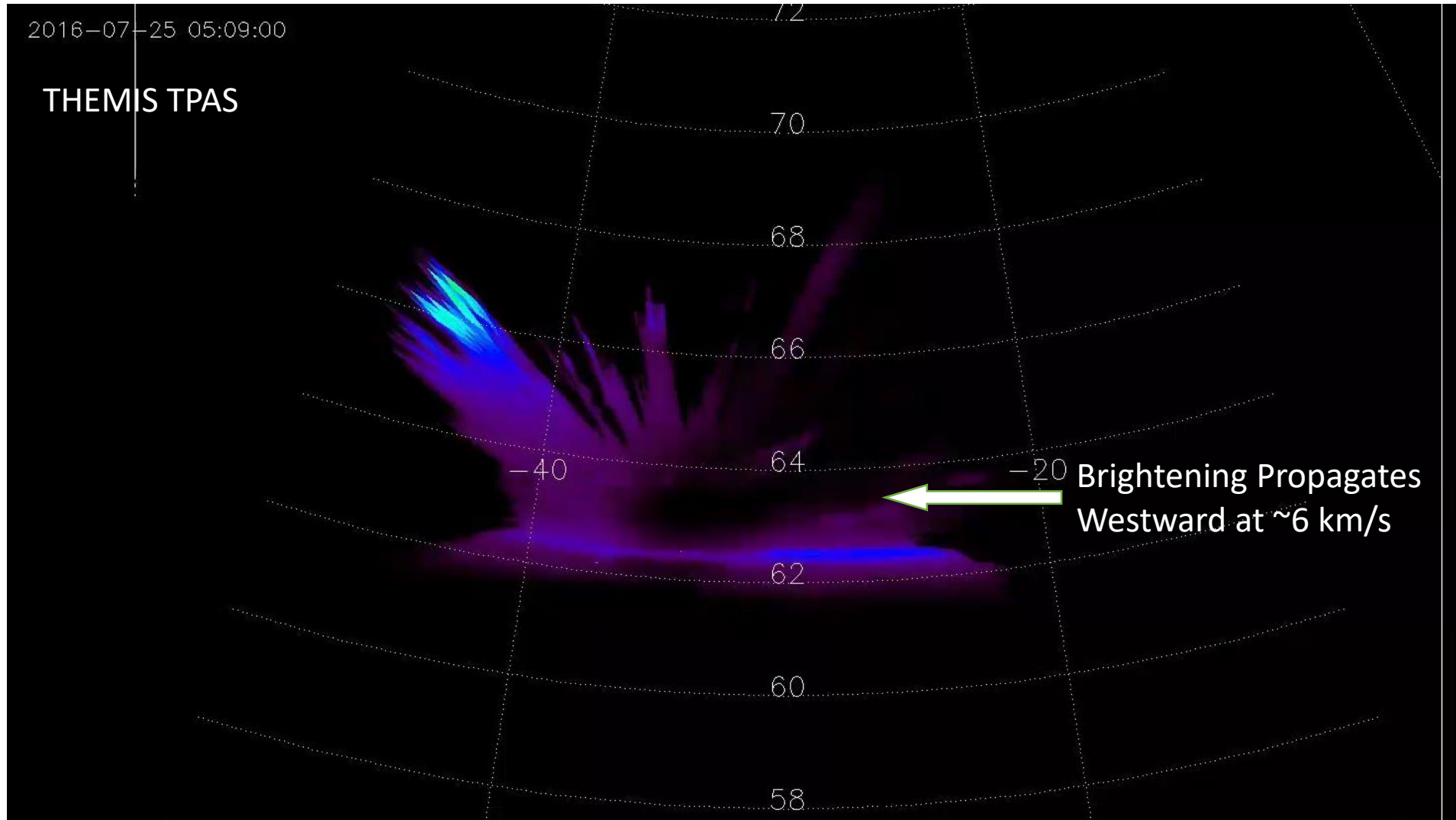
Observed by the THEMIS TPAS ASI on July 25, 2016 at 05:10 UT

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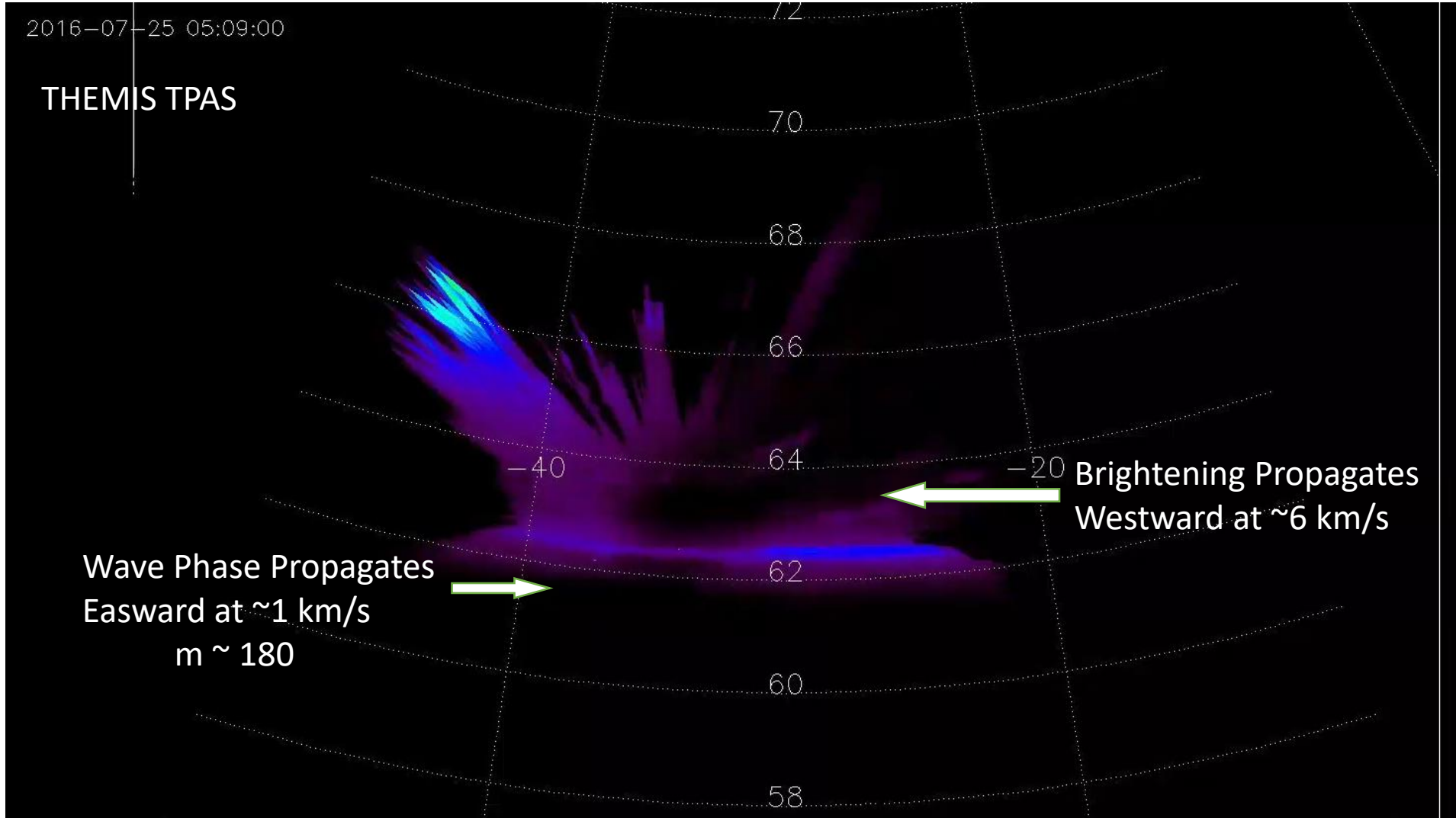
# Auroral Intensification

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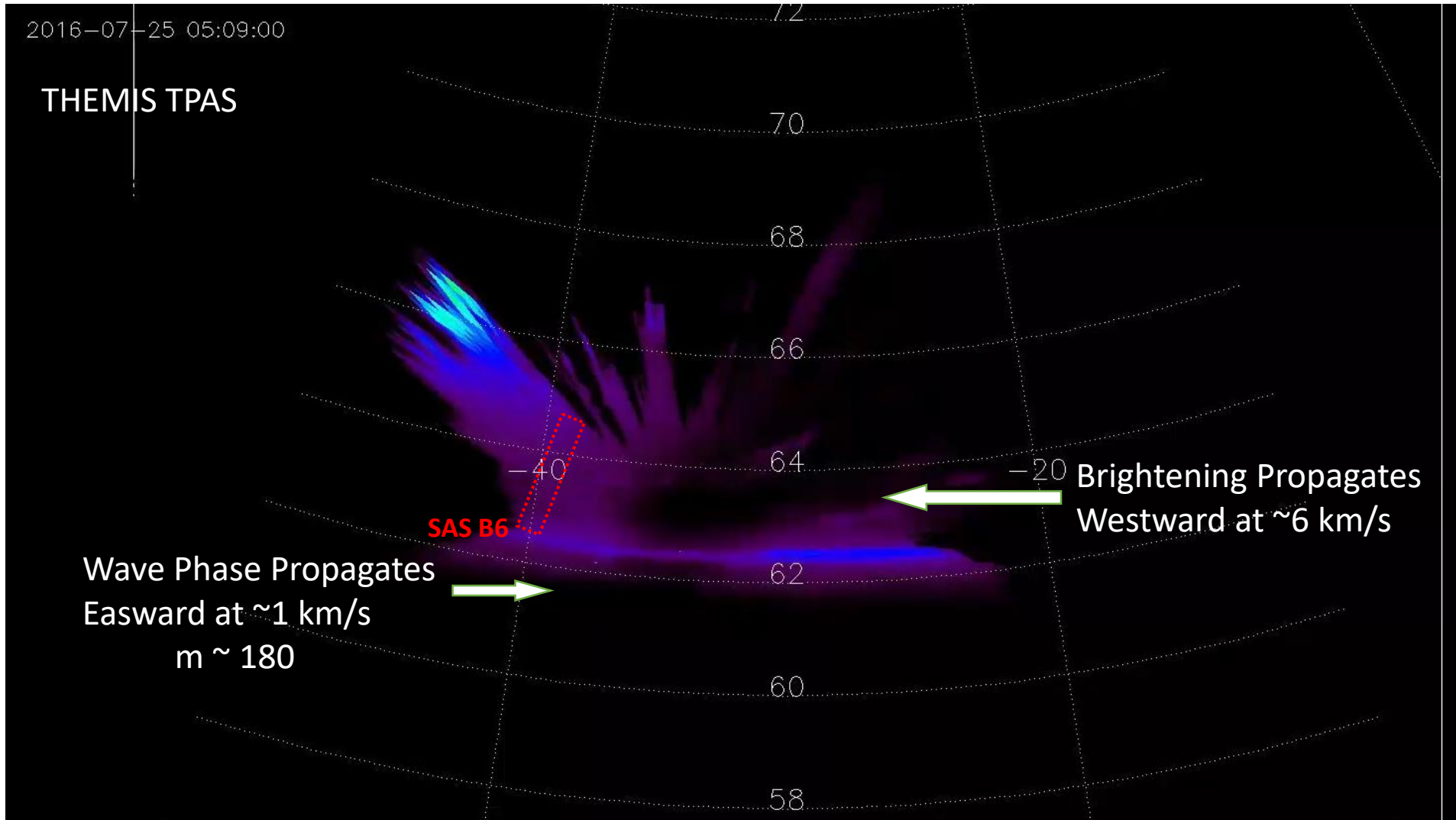
# Auroral Intensification

Observed by the THEMIS TPAS ASI on July 25, 2016 at 05:10 UT



# Auroral Intensification

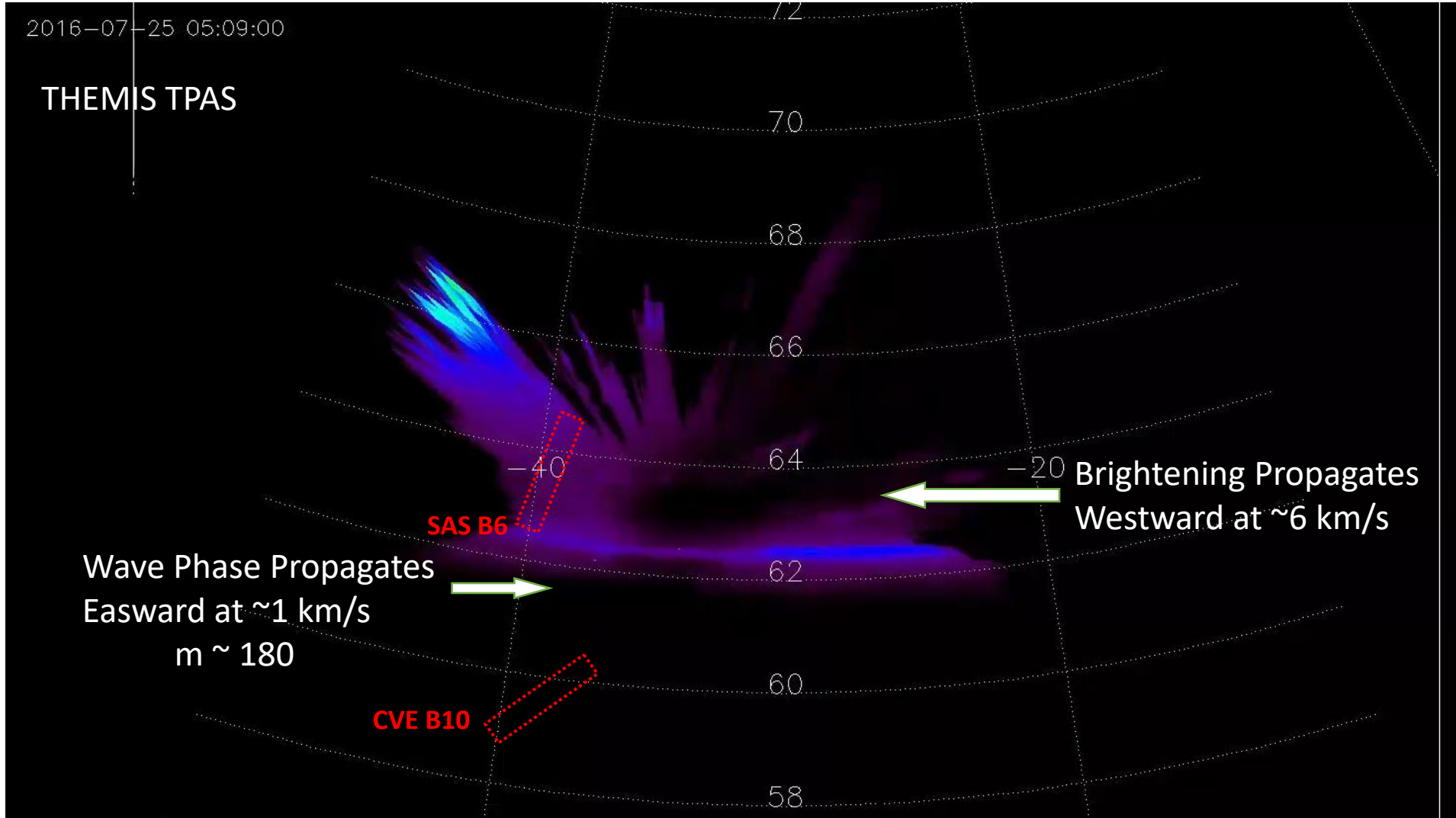
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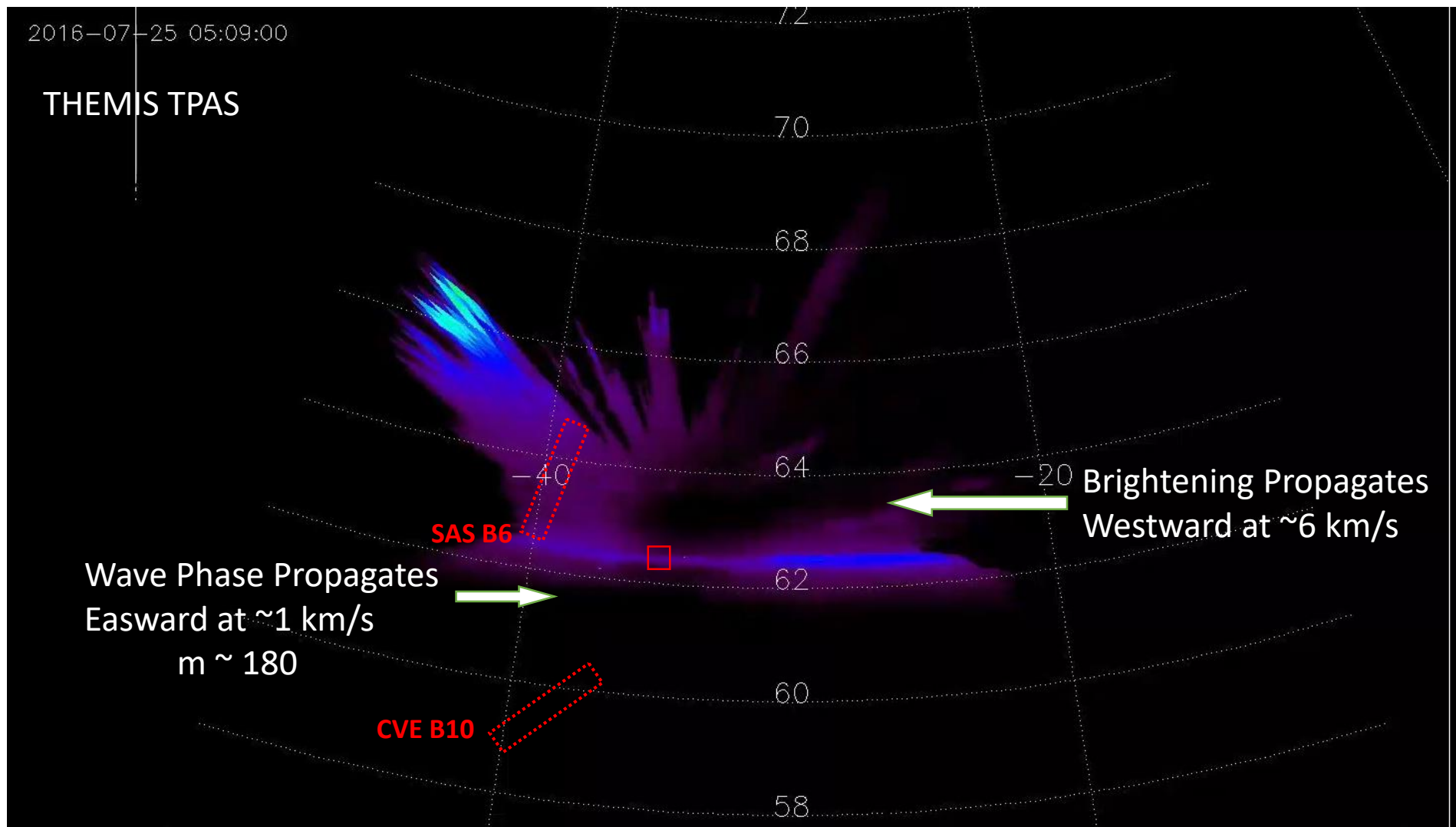
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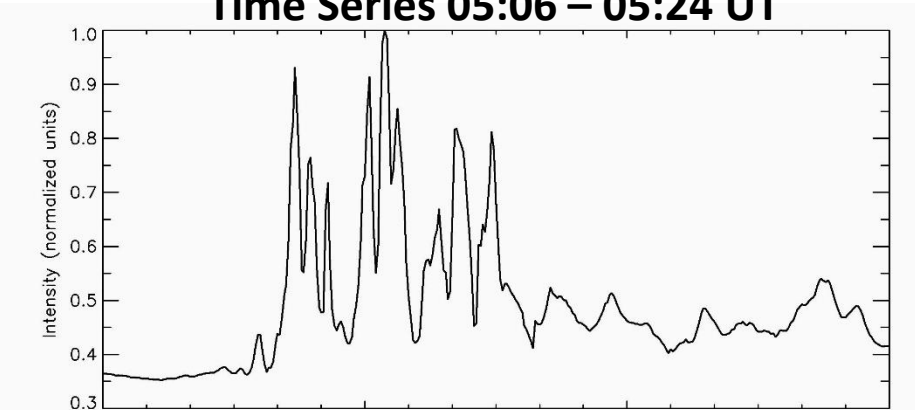
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Observed by the THEMIS TPAS ASI on July 25, 2016 at 05:10 UT

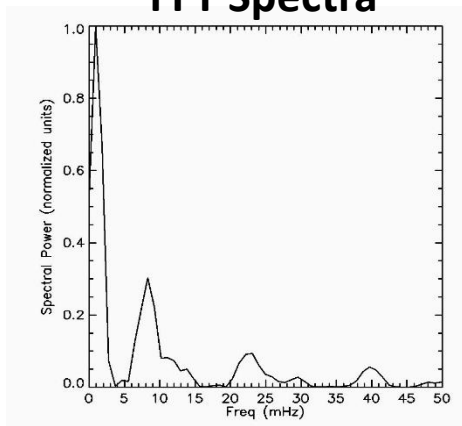


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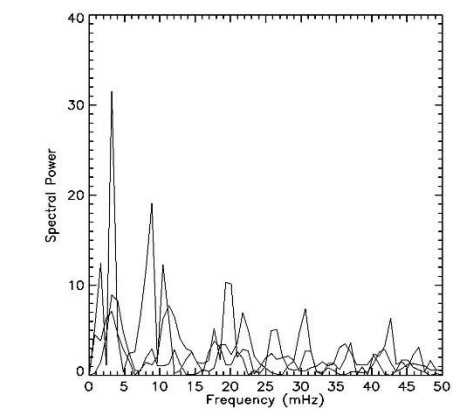
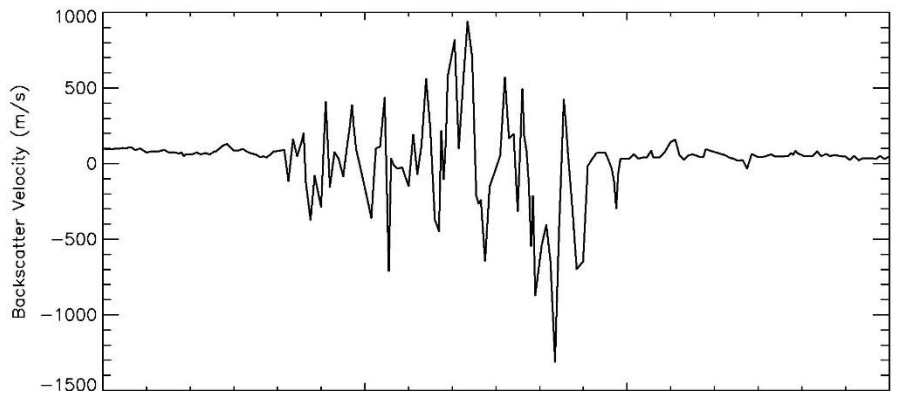
**TPAS Intensity**  
-35° mlon, 62.5° mlat



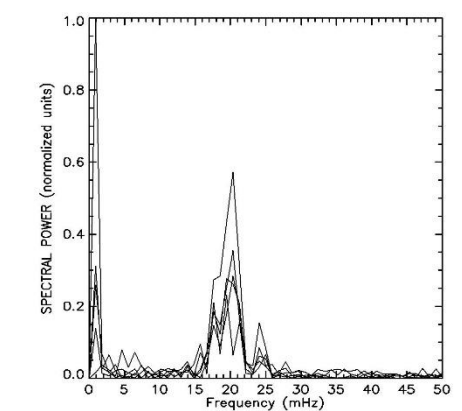
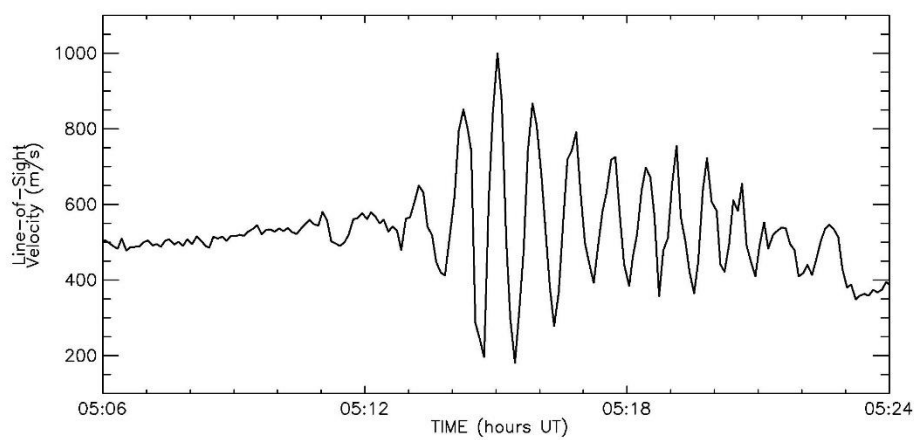
### FFT Spectra



**SAS LOS Velocity**  
Beam 6, Gate 4  
-39.8° mlon, 63.5° mlat

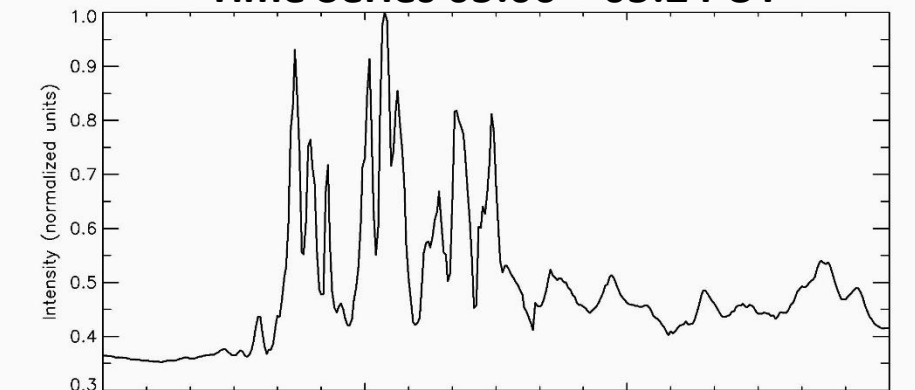


**CVE LOS Velocity**  
Beam 10, Gate 27  
-39.5° mlon, 59.4° mlat

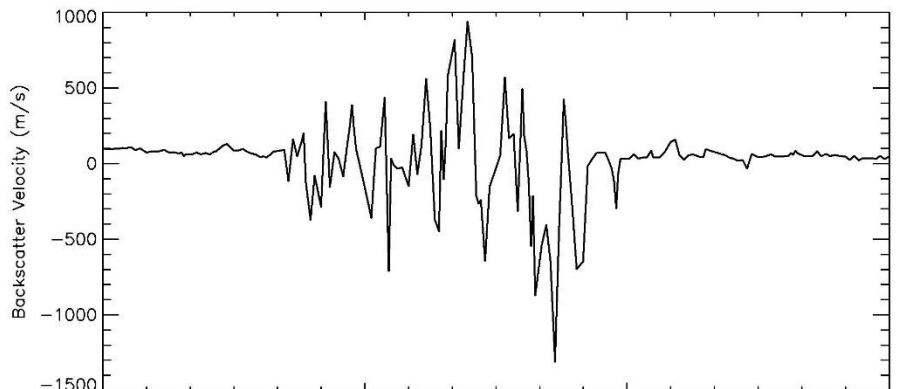


### Time Series 05:06 – 05:24 UT

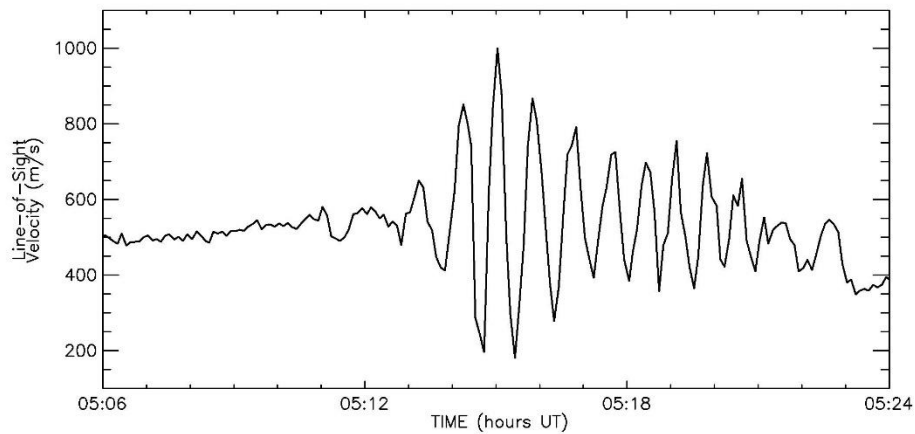
**TPAS Intensity**  
-35° mlon, 62.5° mlat



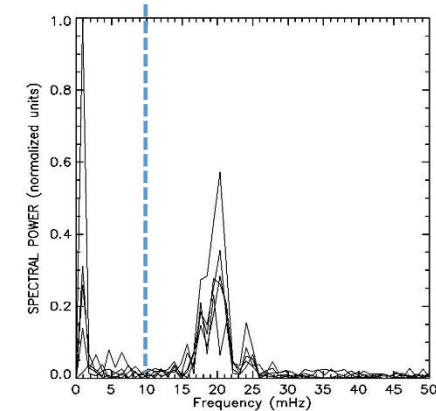
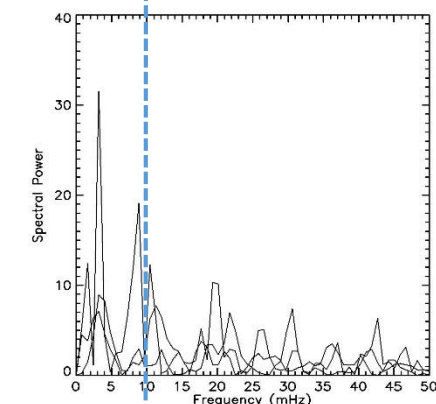
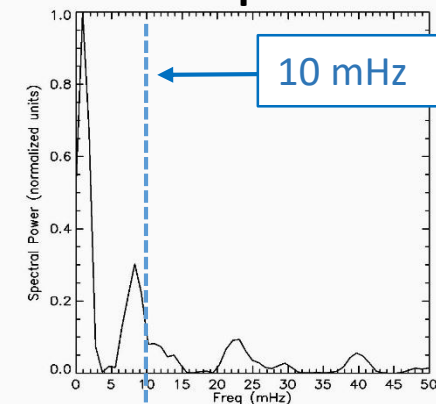
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Beam 10, Gate 27  
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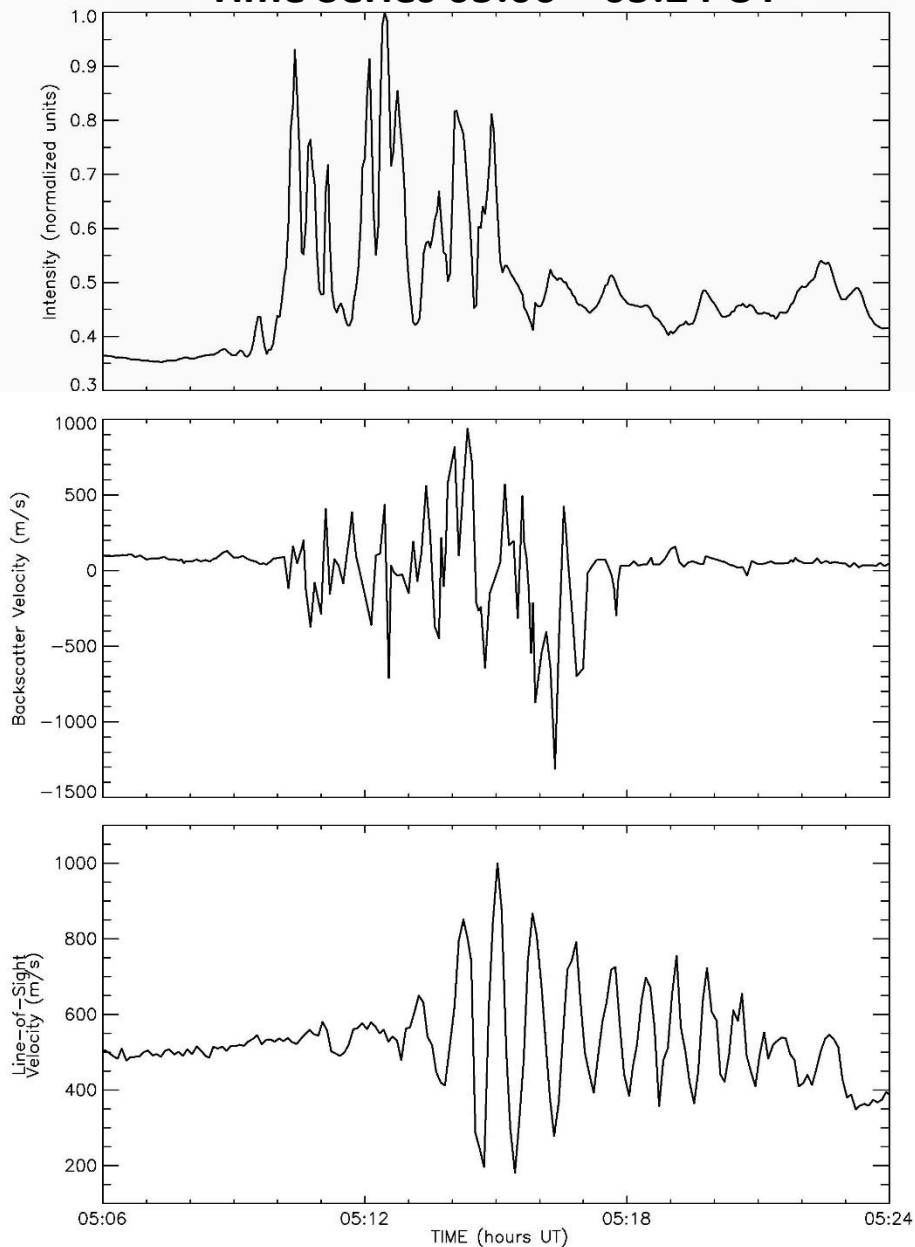


### FFT Spectra

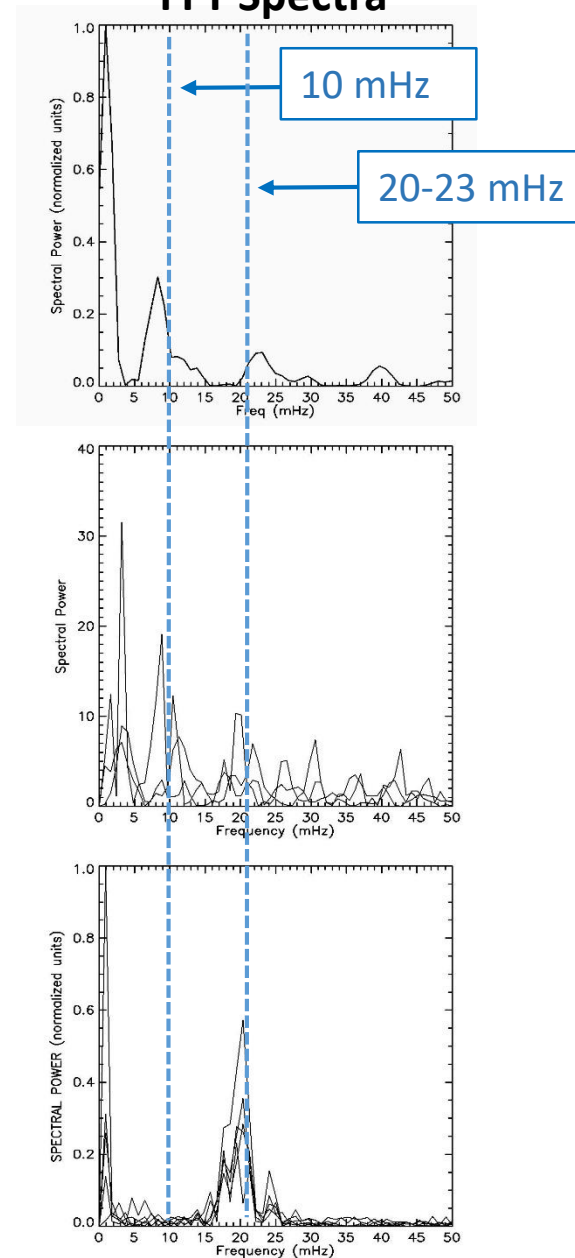


### Time Series 05:06 – 05:24 UT

**TPAS Intensity**  
-35° mlon, 62.5° mlat

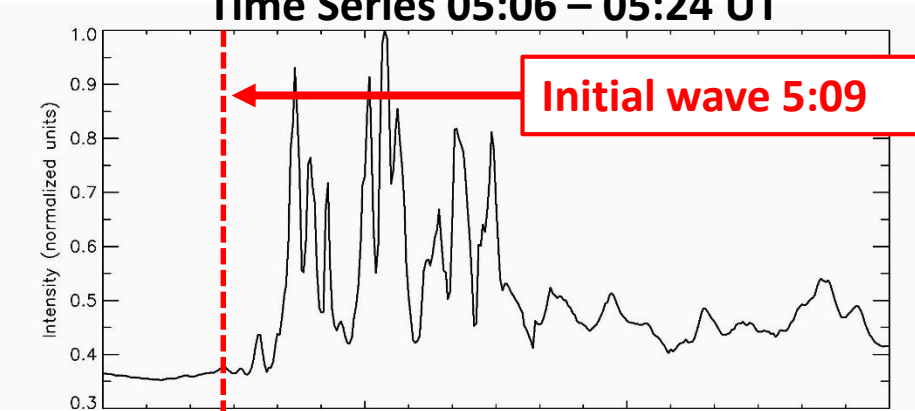


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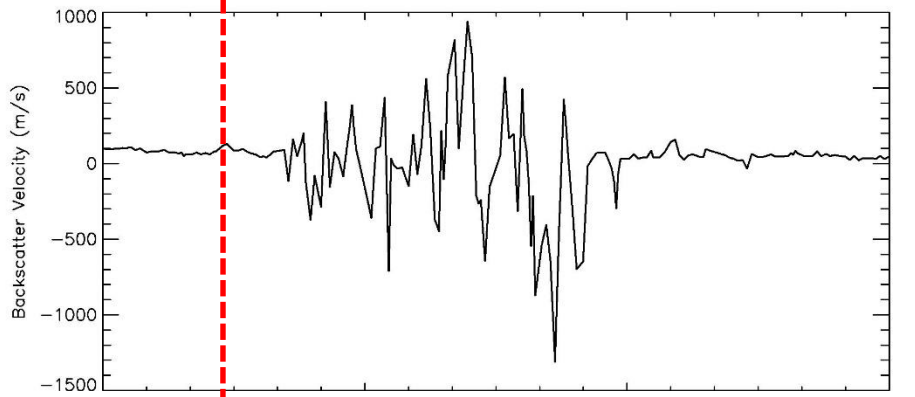


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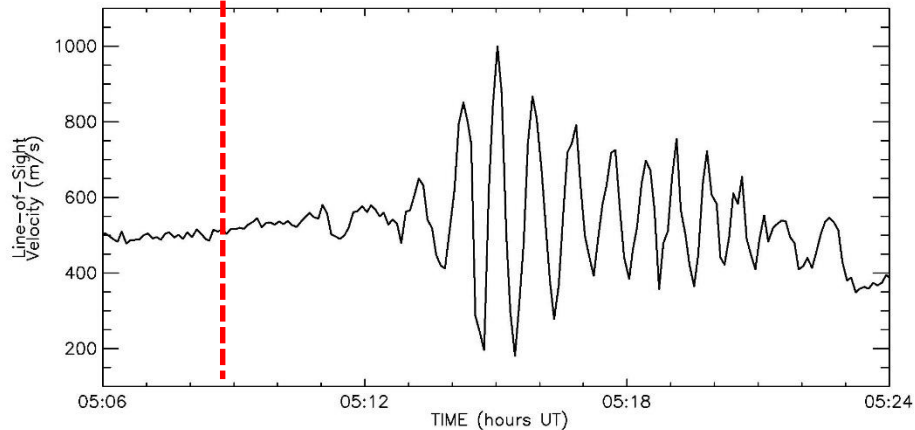
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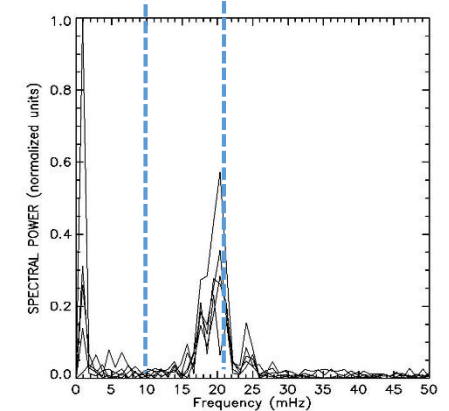
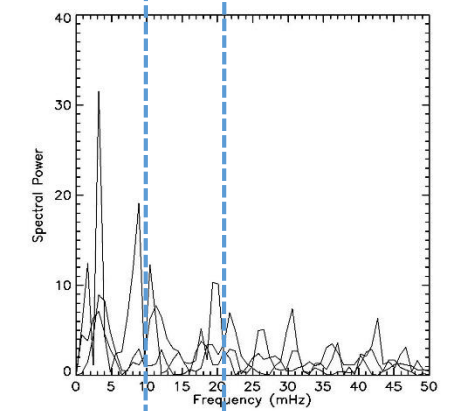
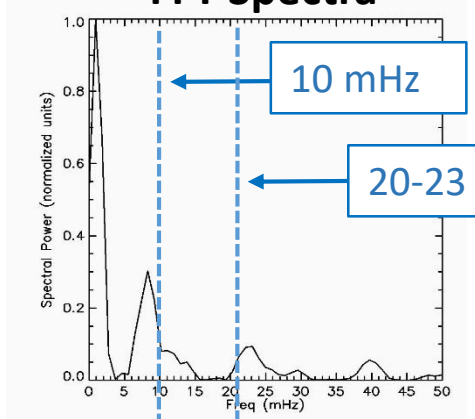
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Beam 10, Gate 27  
-39.5° mlon, 59.4° mlat

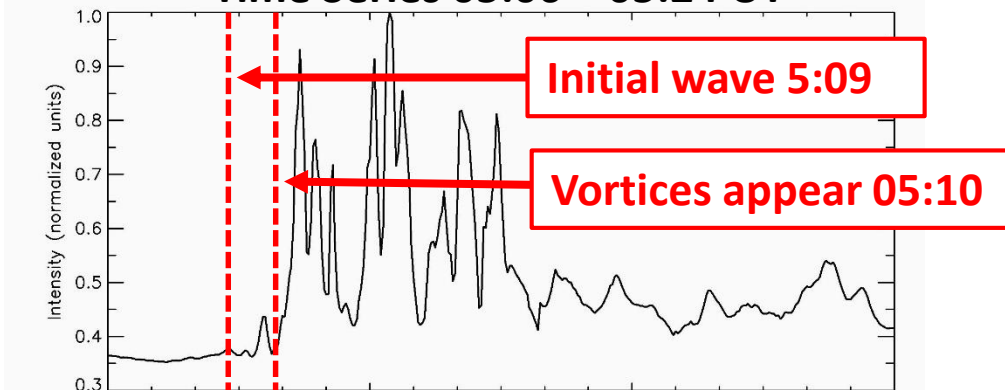


### FFT Spectra

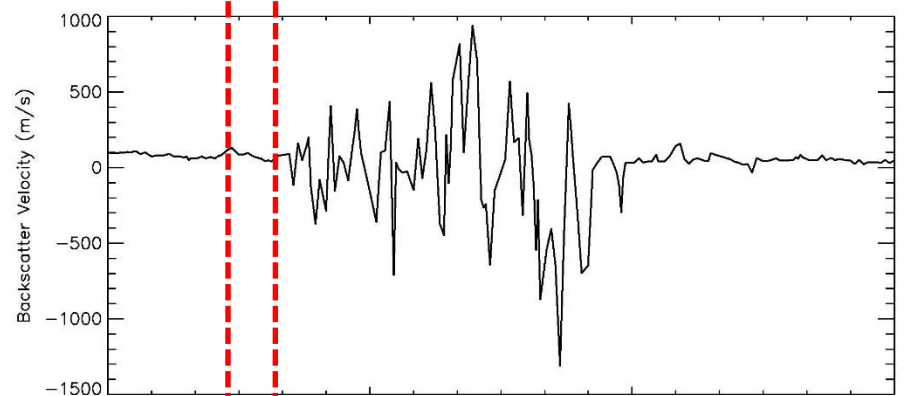


### Time Series 05:06 – 05:24 UT

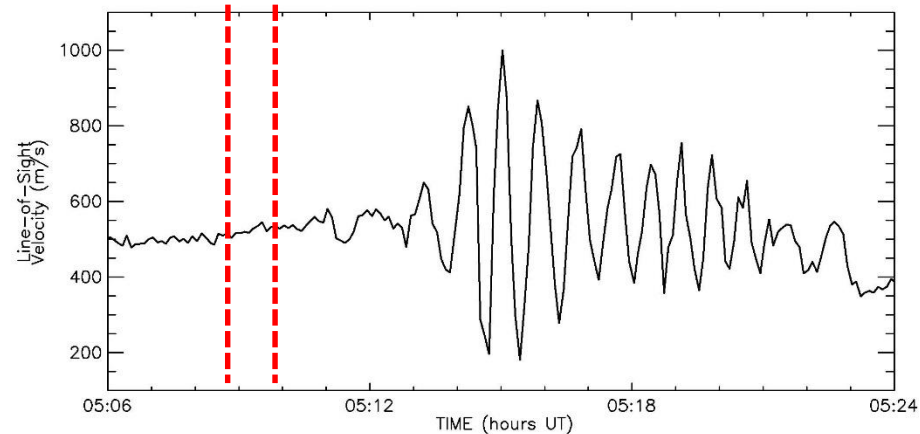
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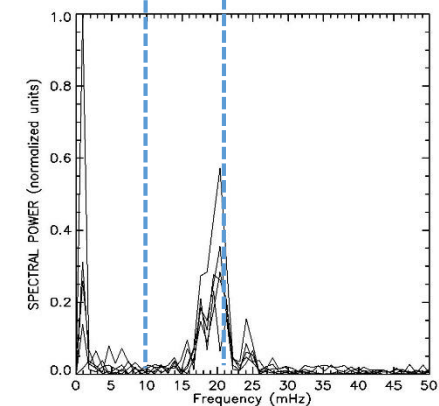
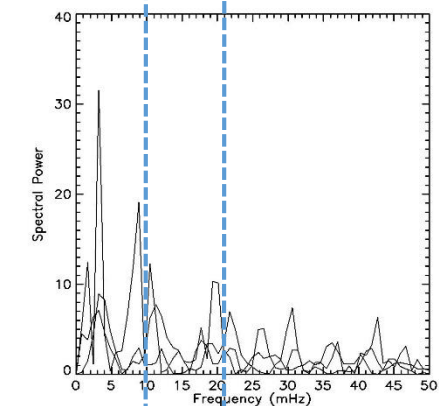
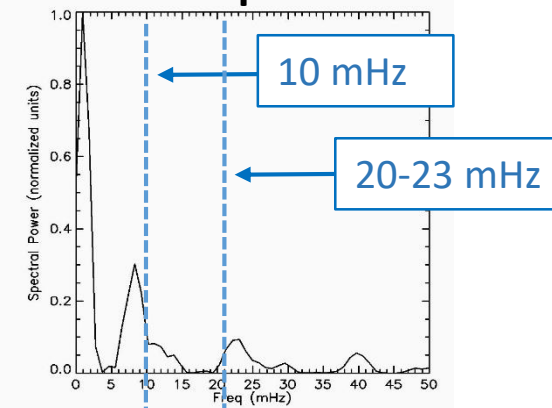
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Beam 10, Gate 27  
-39.5° mlon, 59.4° mlat

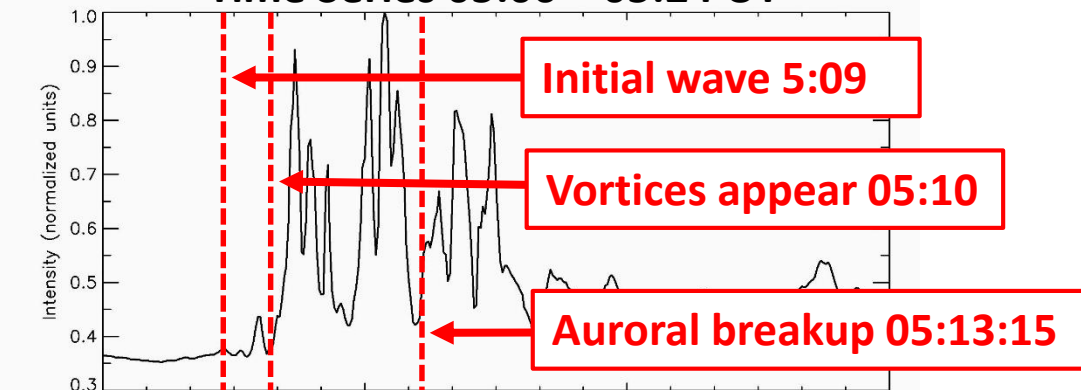


### FFT Spectra

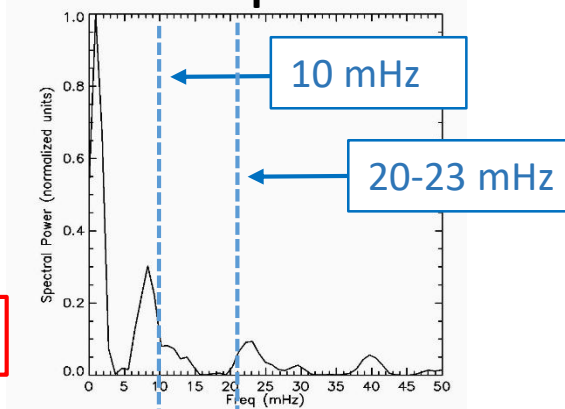


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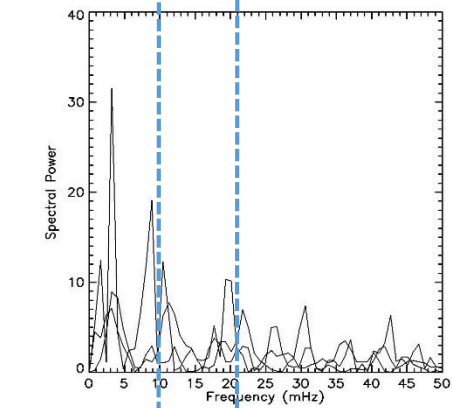
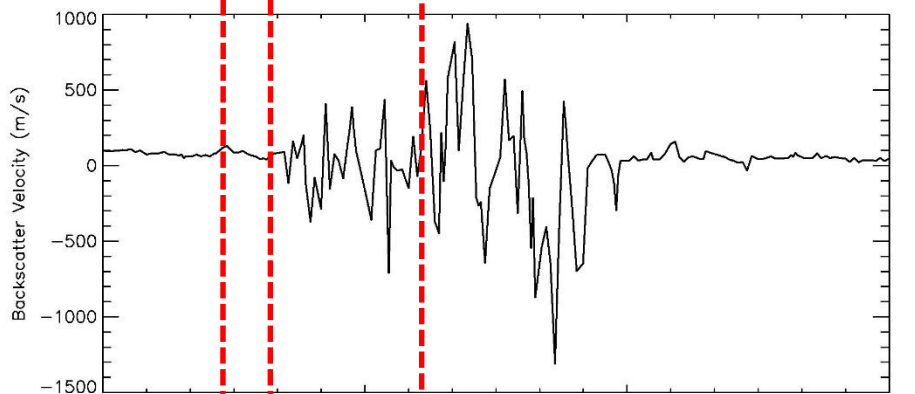
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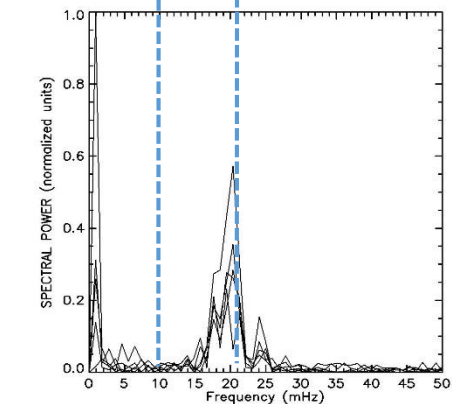
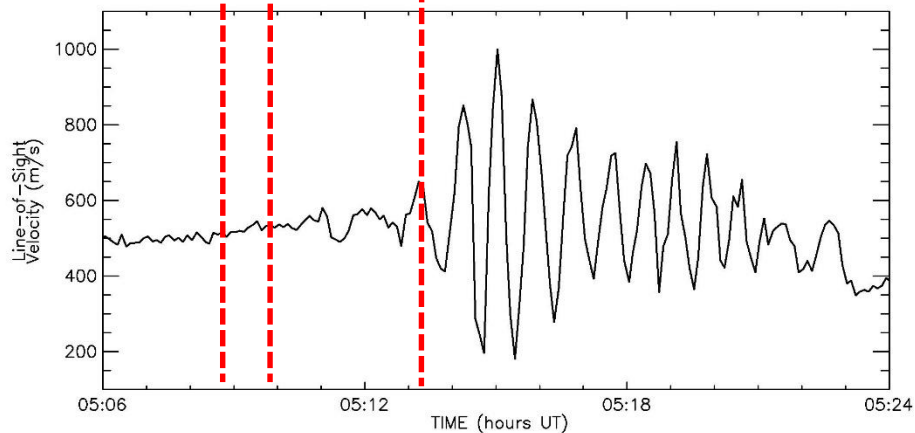
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Beam 10, Gate 27  
-39.5° mlon, 59.4° mlat





# FLR Analysis

## Spectral Power and Phase Profiles vs Latitude at 10 mHz and 20 mHz

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Localized Power and  $\sim 180^\circ$  Phase Variation Versus Latitude  $\rightarrow$  FLR

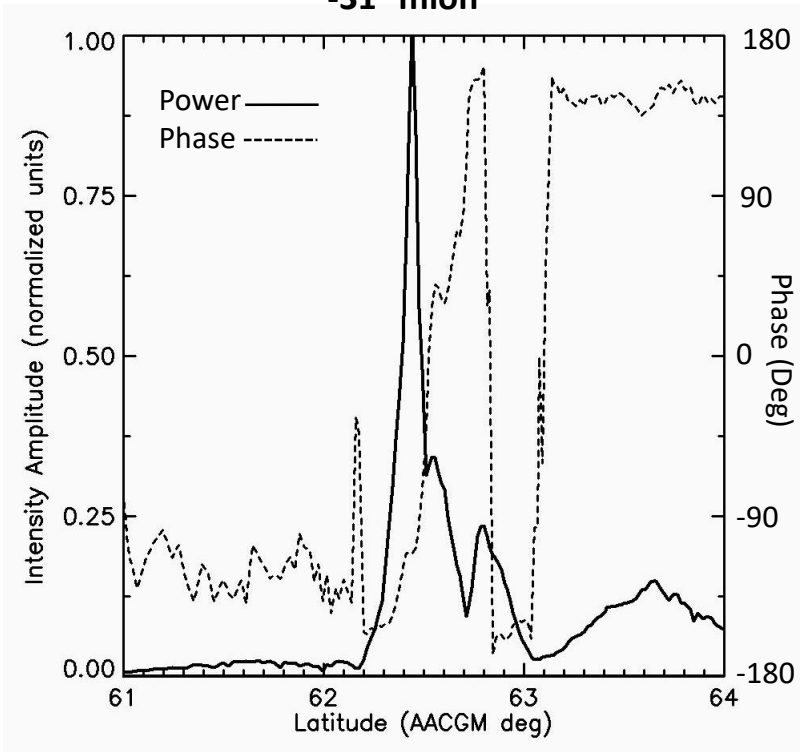
# FLR Analysis

## Spectral Power and Phase Profiles vs Latitude at 10 mHz and 20 mHz

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Localized Power and ~180 Phase Variation Versus Latitude ➡ FLR

TPAS at 6-12 mHz  
-31° mlon

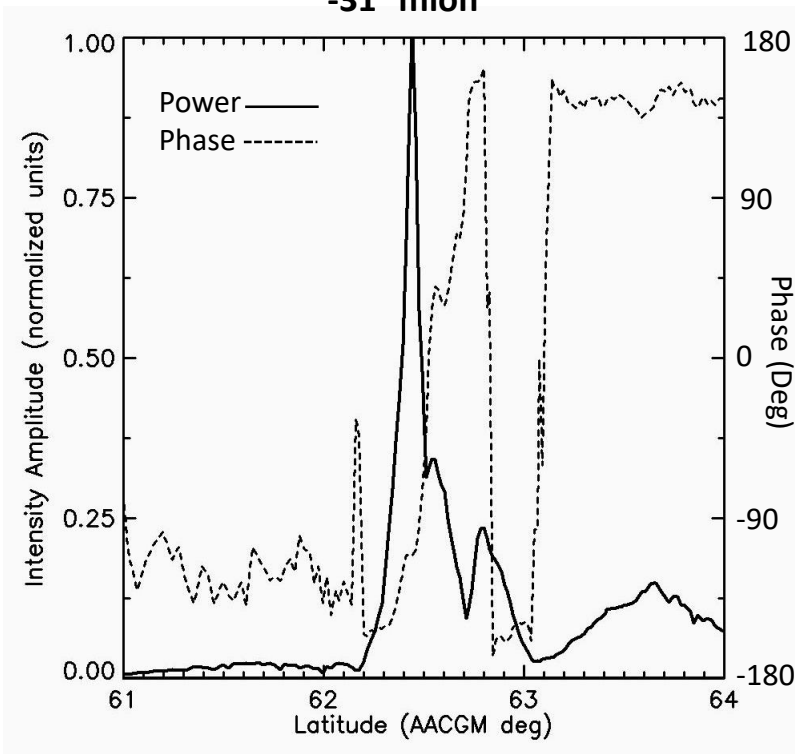


# FLR Analysis

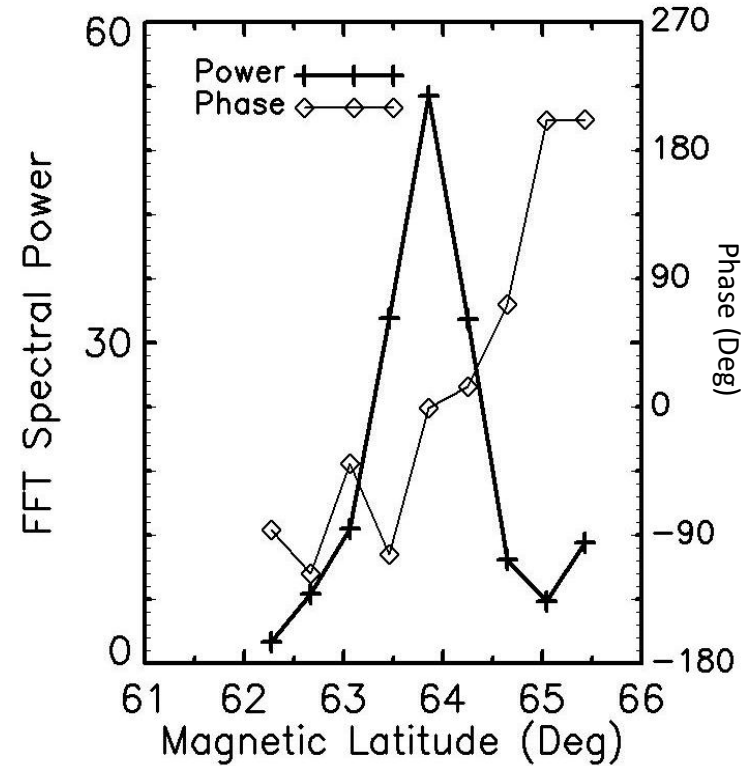
## Spectral Power and Phase Profiles vs Latitude at 10 mHz and 20 mHz

Localized Power and ~180 Phase Variation Versus Latitude  $\longrightarrow$  FLR

TPAS at 6-12 mHz  
-31° mlon



SAS Beam 6 at 10 mHz

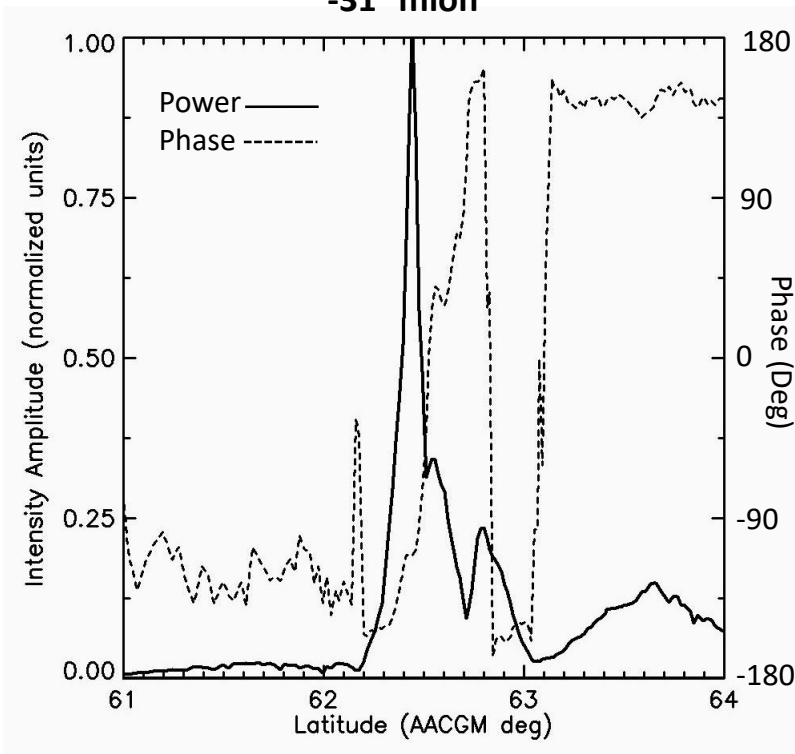


# FLR Analysis

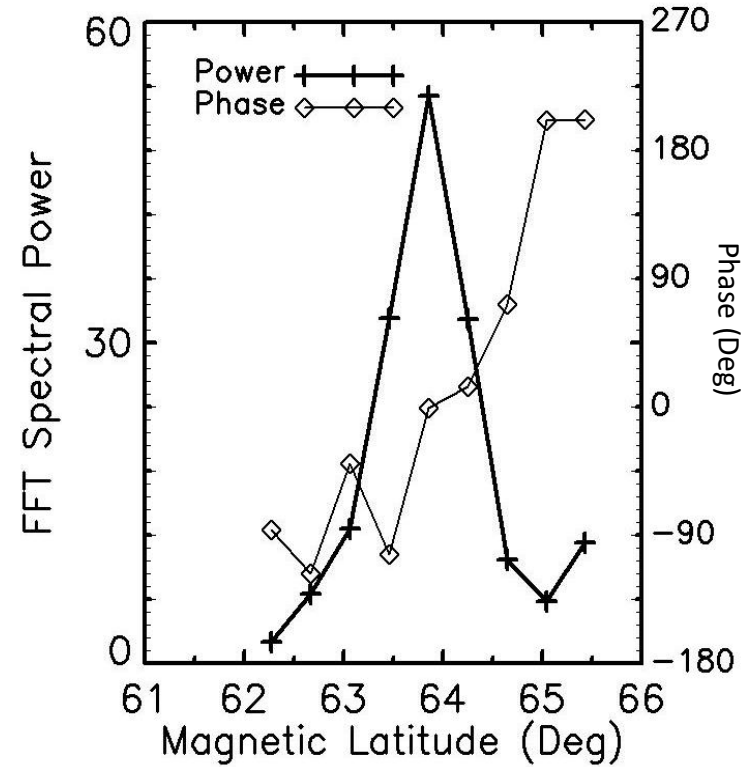
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Localized Power and ~180 Phase Variation Versus Latitude  $\rightarrow$  FLR

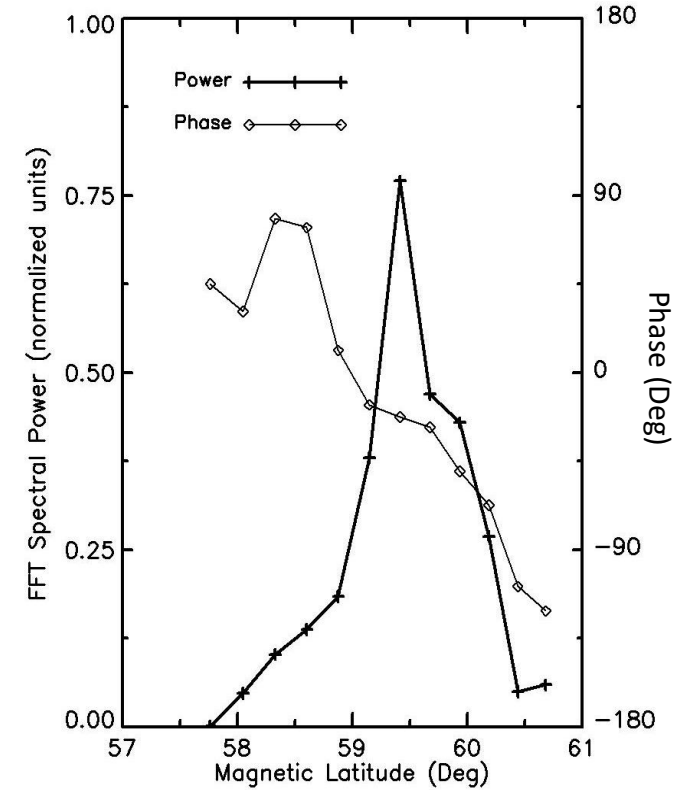
TPAS at 6-12 mHz  
-31° mlon



SAS Beam 6 at 10 mHz



CVE Beam 10 at 20 mHz

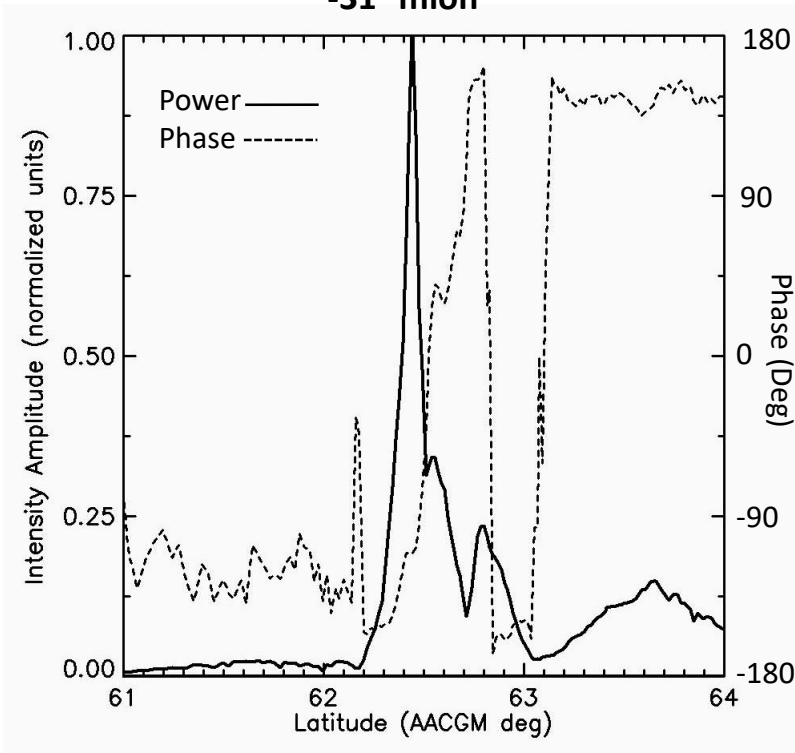


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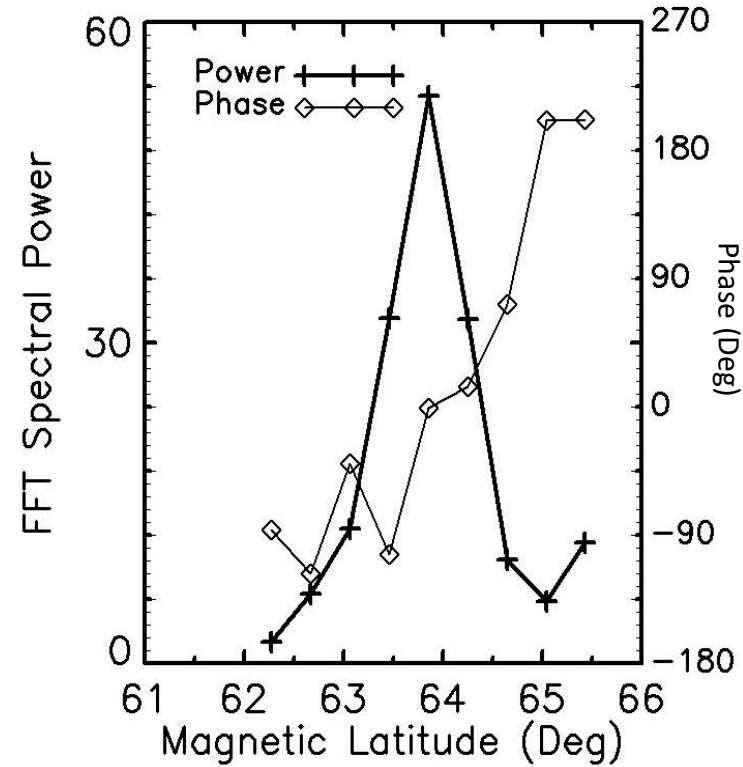
## Spectral Power and Phase Profiles vs Latitude at 10 mHz and 20 mHz

Localized Power and ~180 Phase Variation Versus Latitude  $\rightarrow$  FLR

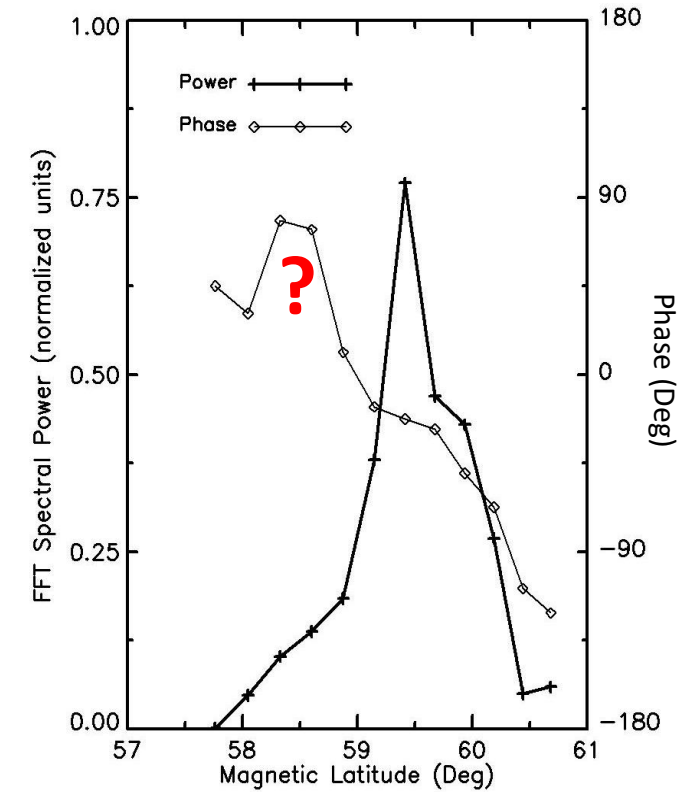
TPAS at 6-12 mHz  
-31° mlon



SAS Beam 6 at 10 mHz



CVE Beam 10 at 20 mHz

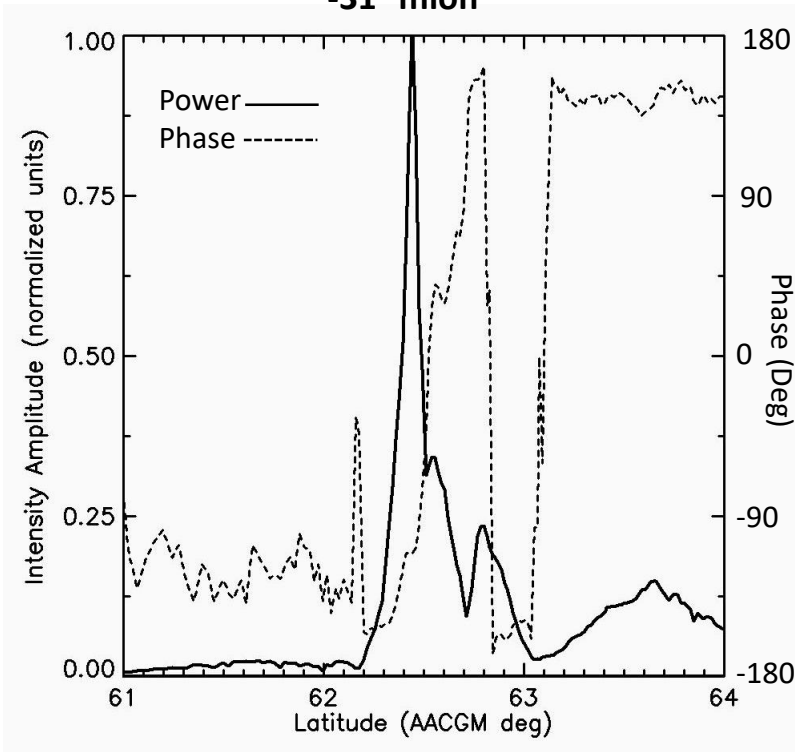


# FLR Analysis

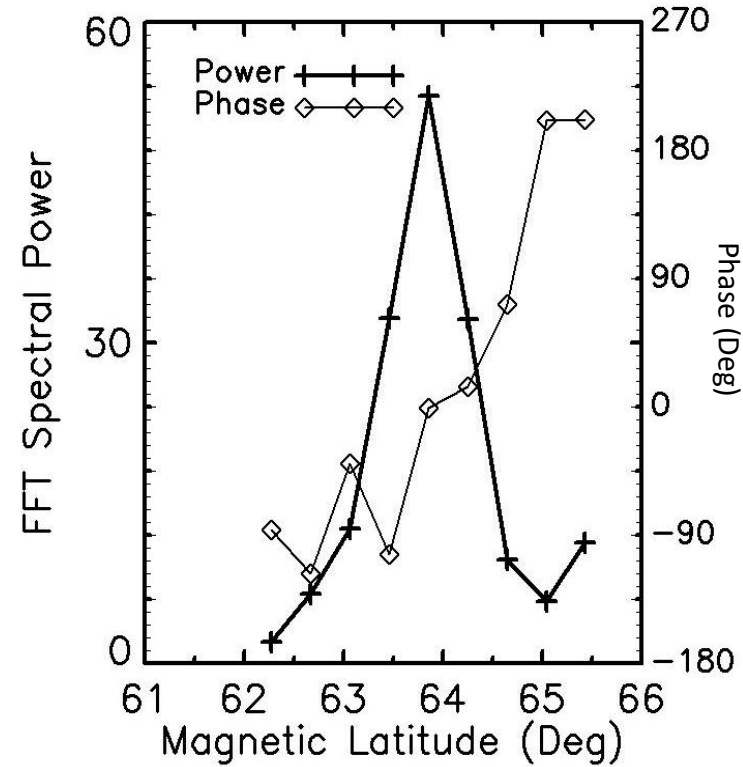
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Localized Power and ~180 Phase Variation Versus Latitude  $\rightarrow$  FLR

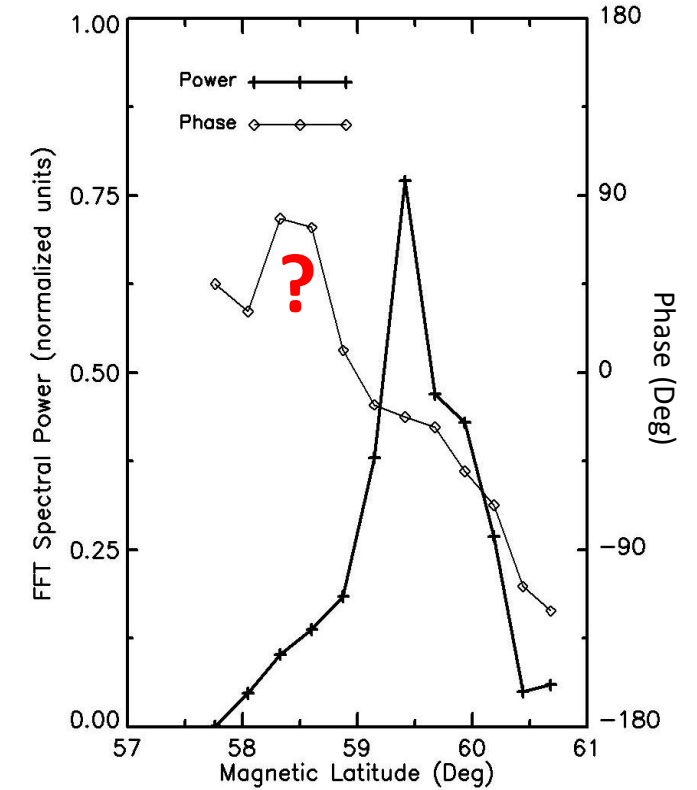
TPAS at 6-12 mHz  
-31° mlon



SAS Beam 6 at 10 mHz



CVE Beam 10 at 20 mHz

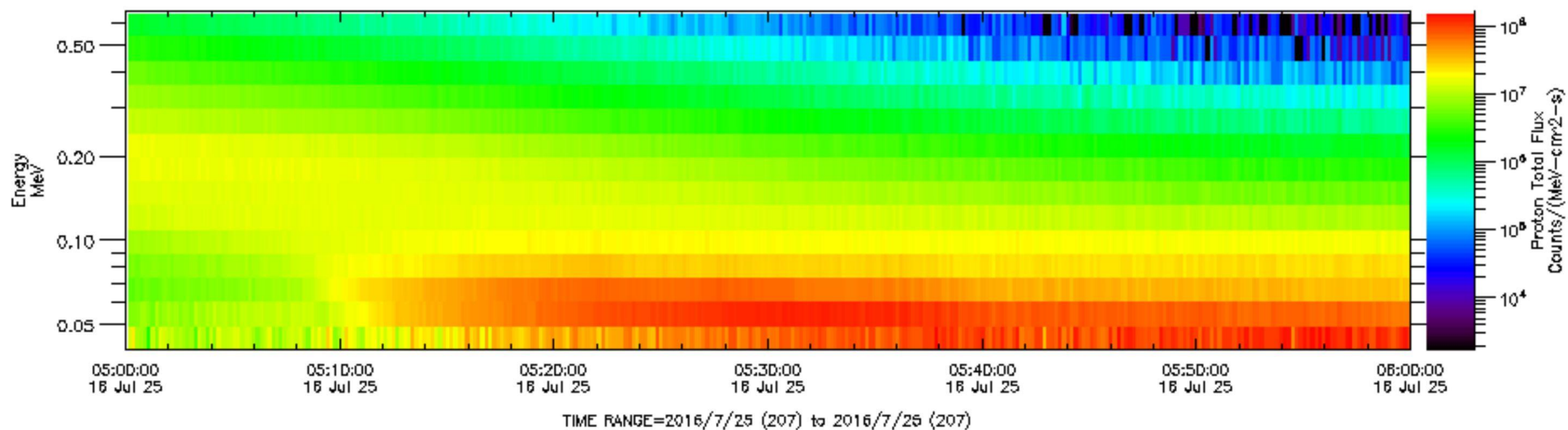


High- $m$  Poloidal FLRs  $\rightarrow$  Wave-Particle Coupling

# RBSPA Observations

## RBSP-A-RBSPICE\_LEV-3-PAP\_TOFXEH

RBSP-A Lev-3-PAP>Level 3 by Pitch Angle and Pressure TOFXEH>Time of Flight vs Energy of Hydrogen

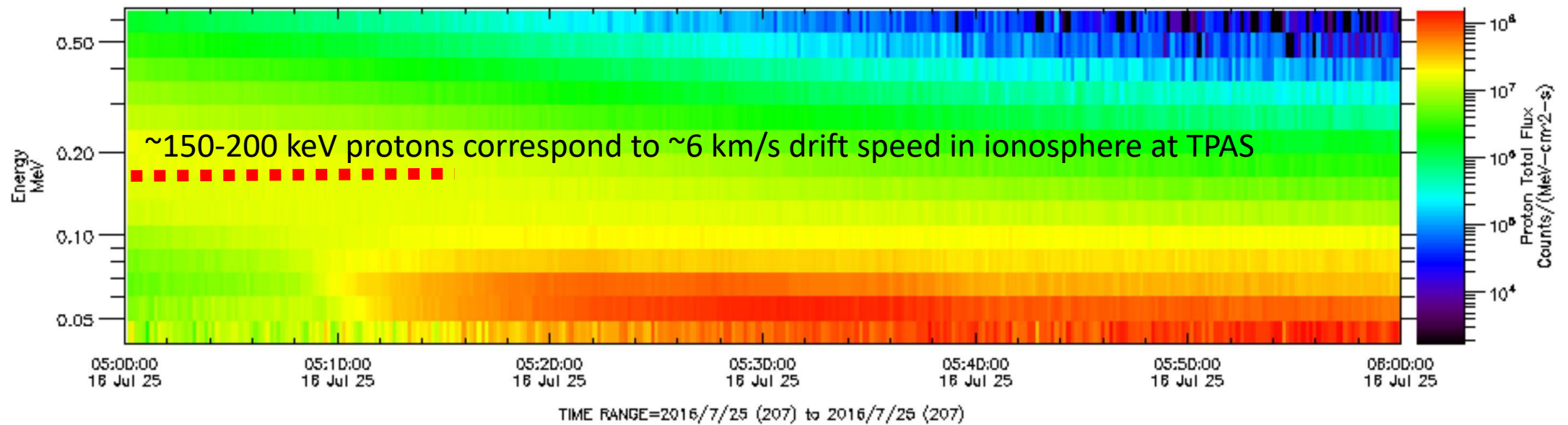


Please acknowledge PI, Lou Lanzerotti  
at New Jersey Institute of Technology and CDAWeb when using these data.  
Generated by CDAWeb on Mon Feb 12 17:58:56 2024

# RBSPA Observations

## RBSP-A-RBSPICE\_LEV-3-PAP\_TOFXEH

RBSP-A Lev-3-PAP>Level 3 by Pitch Angle and Pressure TOFXEH>Time of Flight vs Energy of Hydrogen



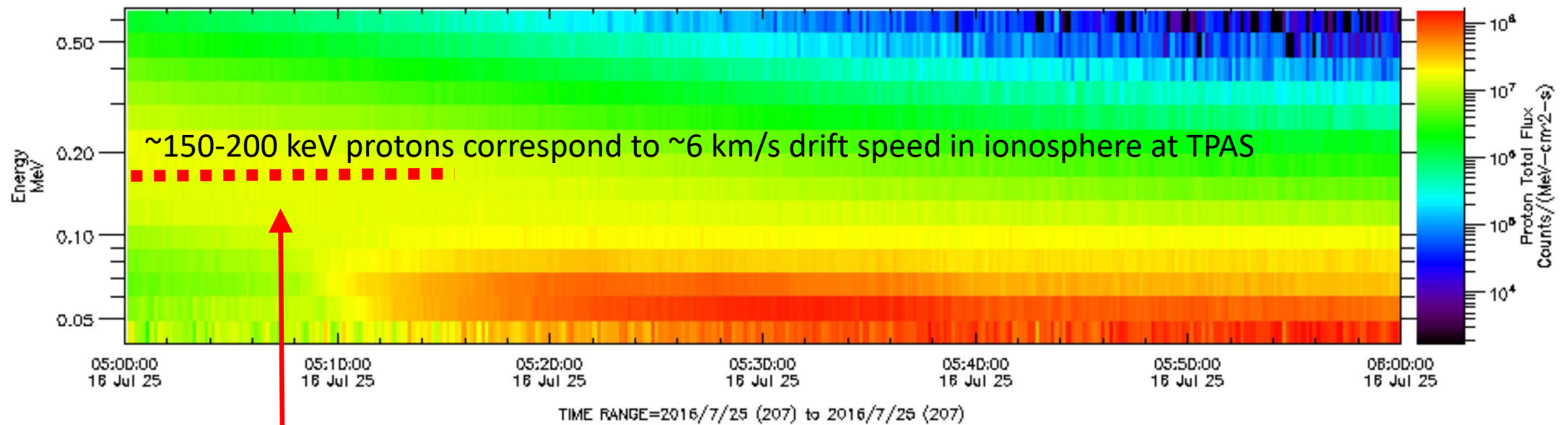
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# RBSPA Observations

## RBSP-A-RBSPICE\_LEV-3-PAP\_TOFXEH

RBSP-A Lev-3-PAP>Level 3 by Pitch Angle and Pressure TOFXEH>Time of Flight vs Energy of Hydrogen



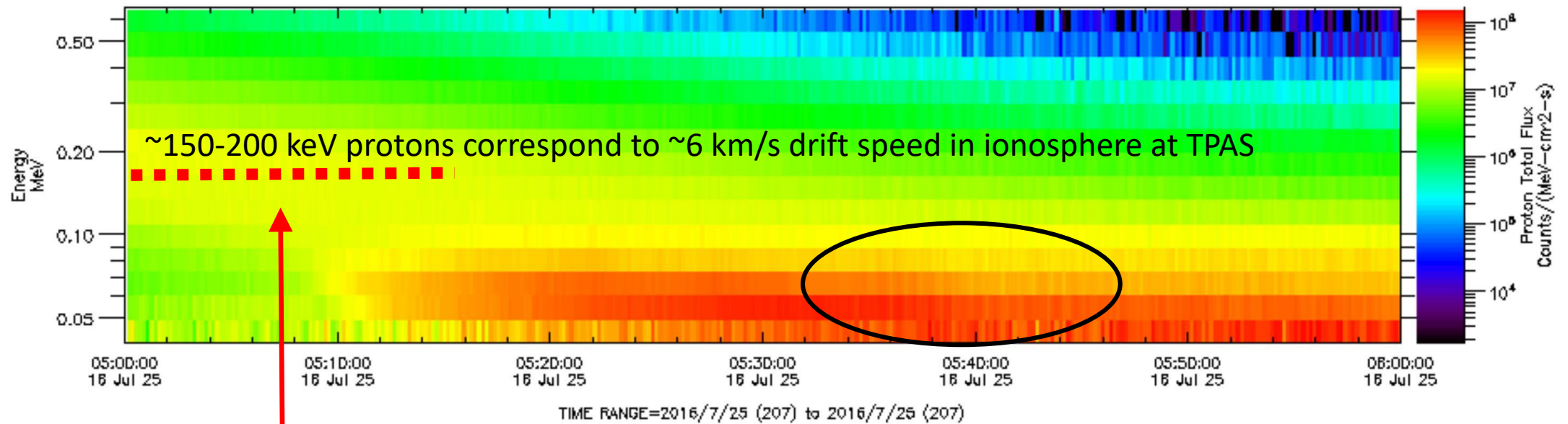
**This supports a wave-particle drift resonance driving initial bead growth at ~10 mHz.**

Knowledge PI, Lou Lanzerotti  
Technology and CDAWeb when using these data.  
on Mon Feb 12 17:58:56 2024

# RBSPA Observations

## RBSP-A-RBSPICE\_LEV-3-PAP\_TOFXEH

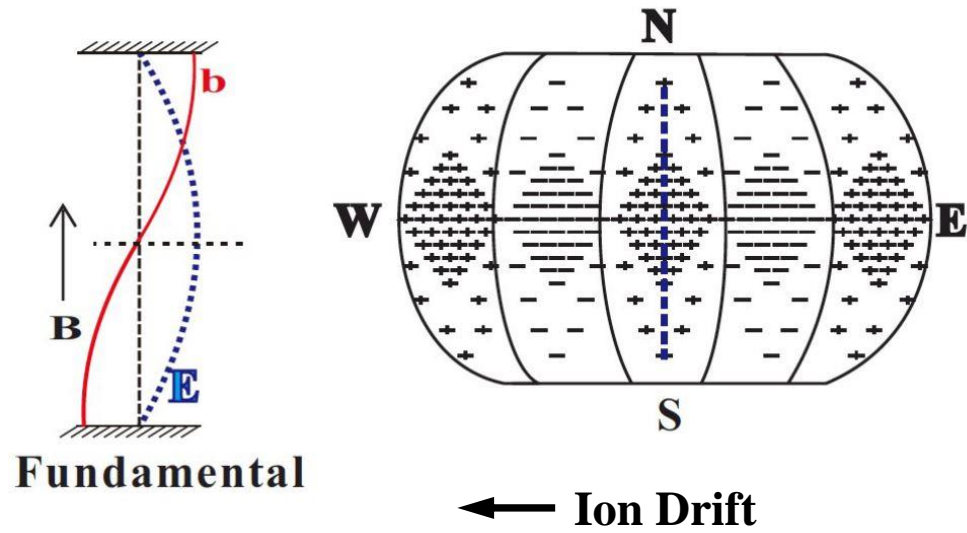
RBSP-A Lev-3-PAP>Level 3 by Pitch Angle and Pressure TOFXEH>Time of Flight vs Energy of Hydrogen



**This supports a wave-particle drift resonance driving initial bead growth at ~10 mHz.**

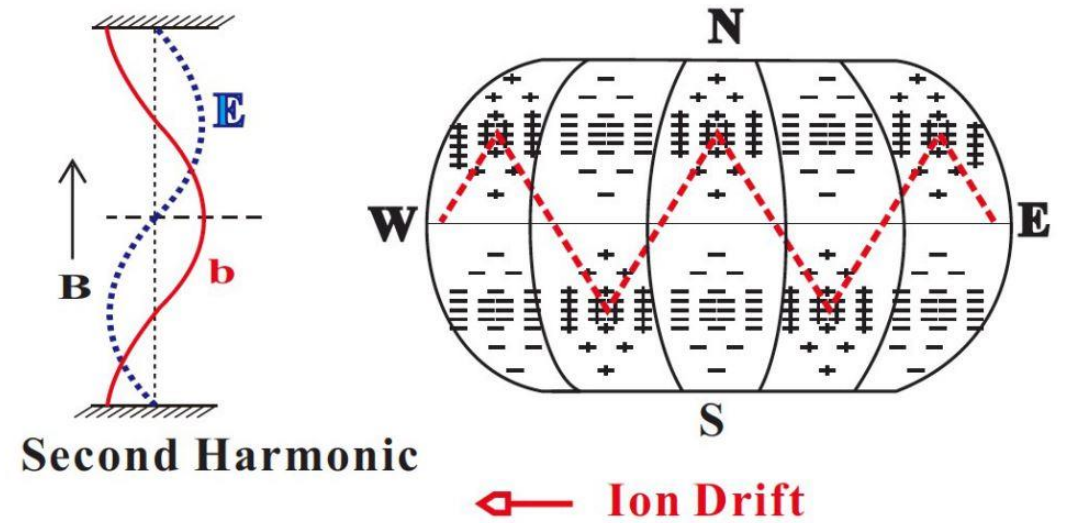
Knowledge PI, Lou Lanzerotti  
Technology and CDAWeb when using these data.  
on Mon Feb 12 17:58:56 2024

## Drift Resonance



$\delta E$  and  $\delta J$  will be in phase

## Drift-Bounce Resonance

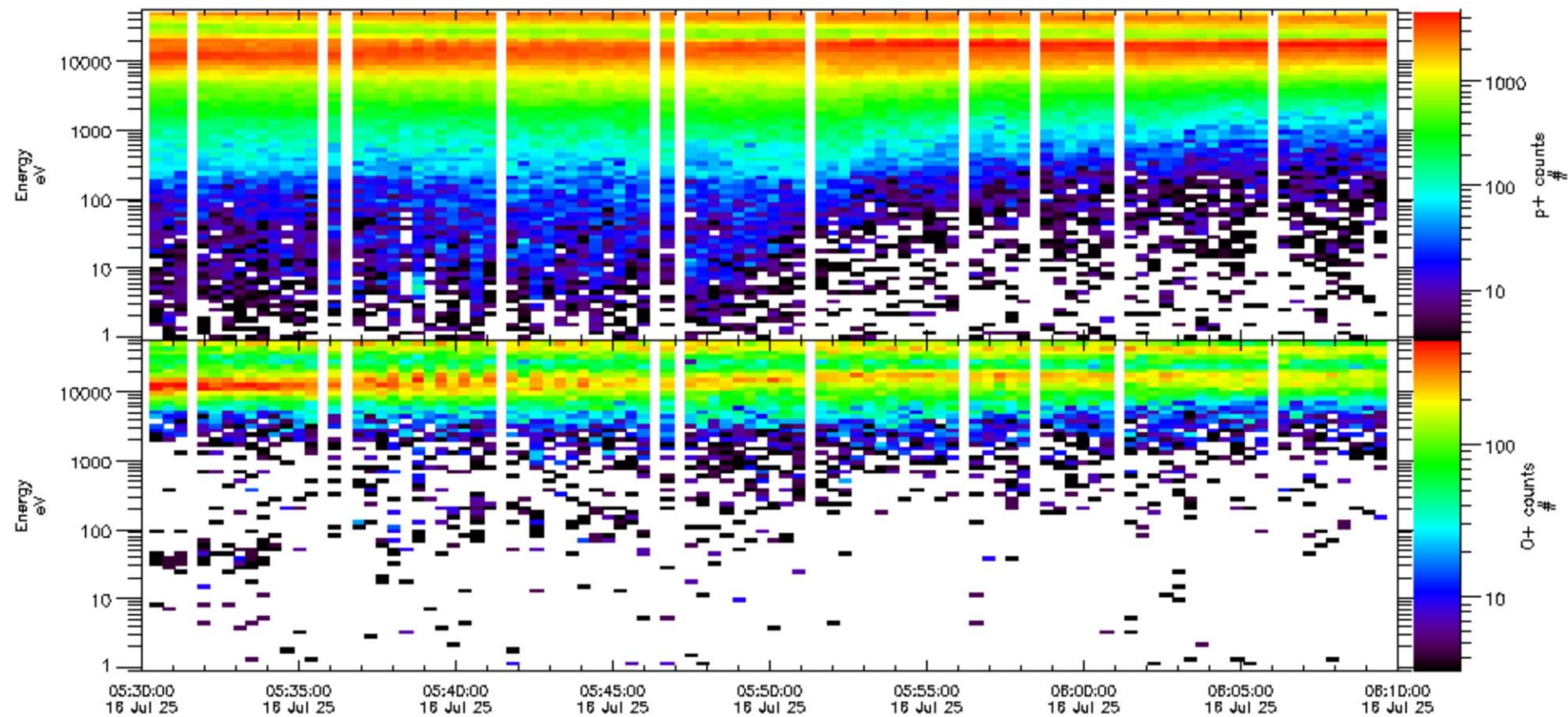


$\delta E$  and  $\delta J$  will have a  $90^\circ$  phase difference

# RBSPA Observations

RBSPA\_REL04\_ECT-HOPE-PA-L3

RBSP-A ECT-HOPE-PA-L3>ECT Helium Oxygen Proton Electron Plasma Analyzer Fluxes by Pitch Angle Level 3 rel04>Release 04



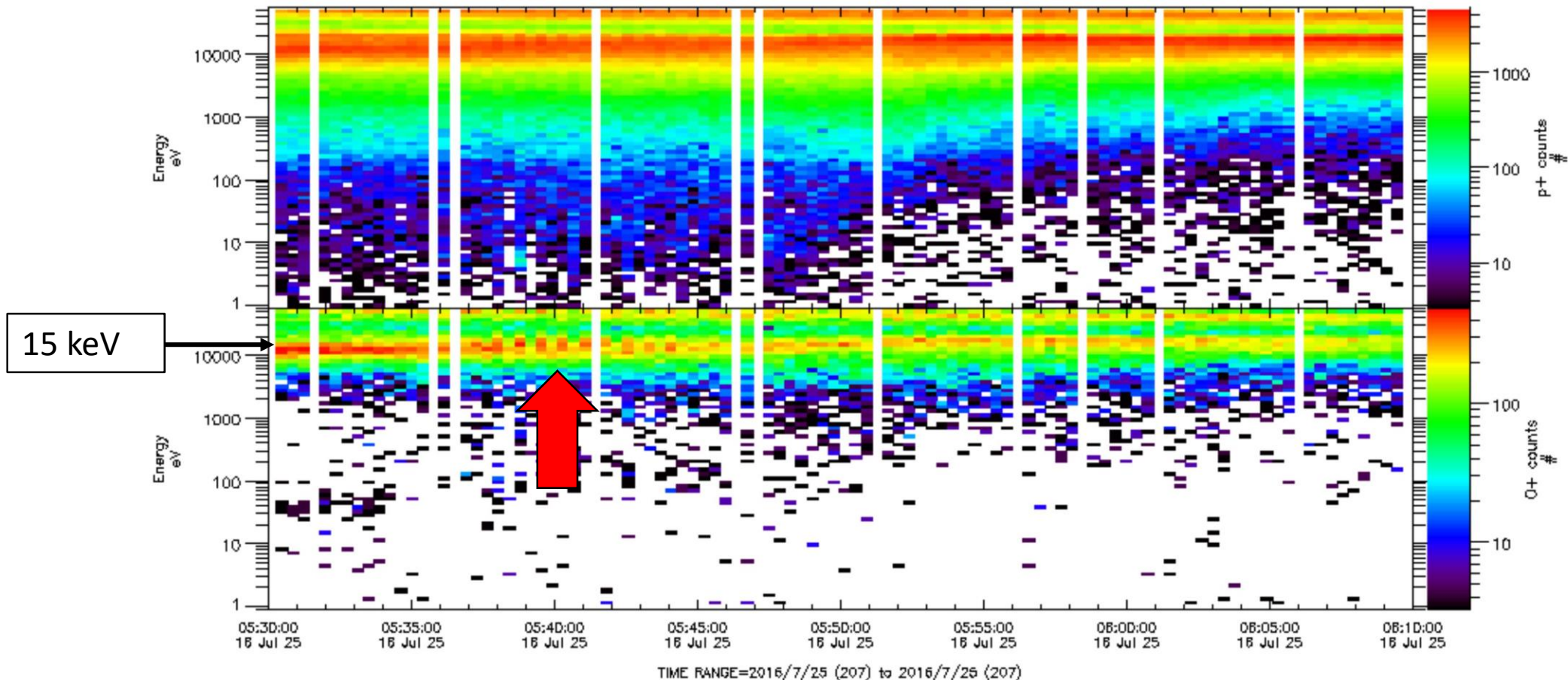
TIME RANGE=2016/7/25 (207) to 2016/7/25 (207)

Please acknowledge PI, Herbert Funsten  
at Los Alamos National Laboratory and CDAWeb when using these data.  
Generated by CDAWeb on Wed Feb 21 21:52:04 2024

# RBSPA Observations

RBSPA\_REL04\_ECT-HOPE-PA-L3

RBSP-A ECT-HOPE-PA-L3>ECT Helium Oxygen Proton Electron Plasma Analyzer Fluxes by Pitch Angle Level 3 rel04>Release 04

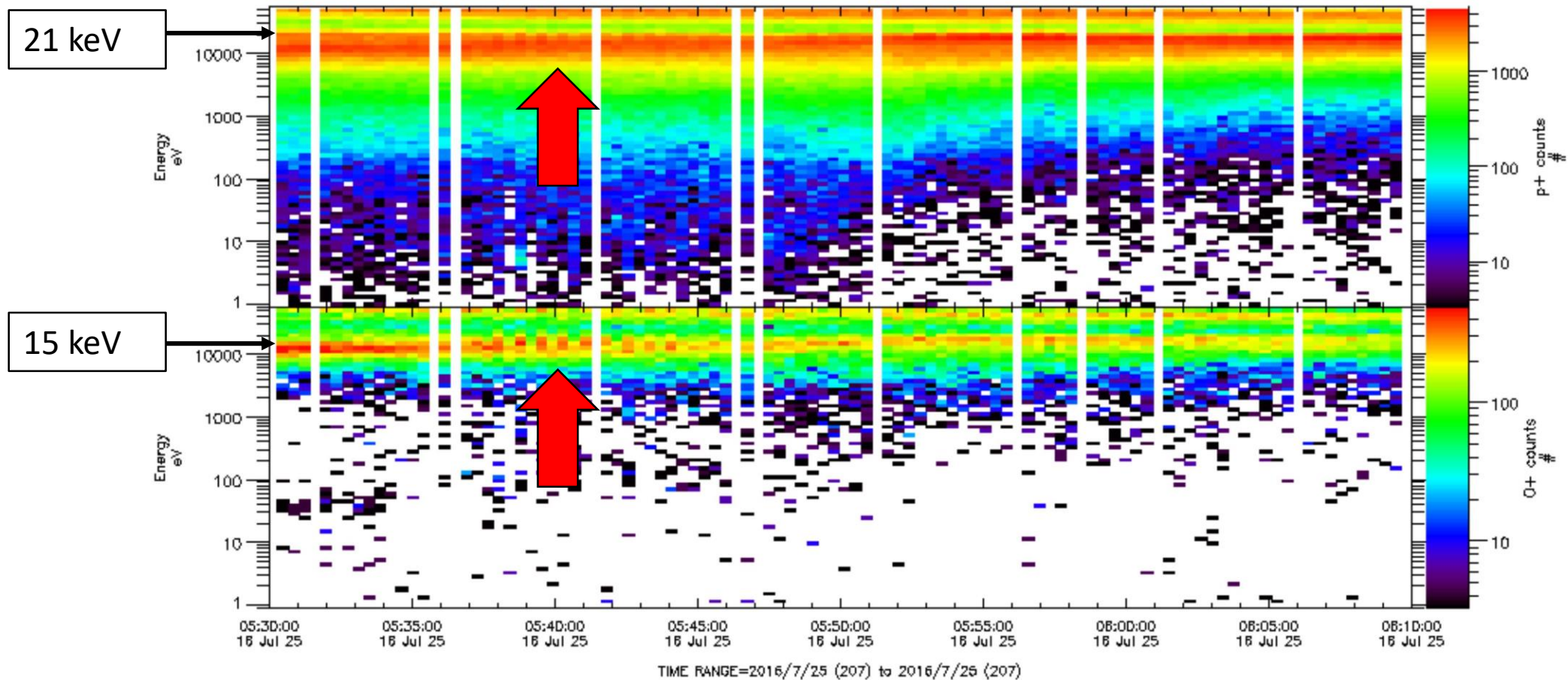


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Generated by CDAWeb on Wed Feb 21 21:52:04 2024

# RBSPA Observations

RBSPA\_REL04\_ECT-HOPE-PA-L3

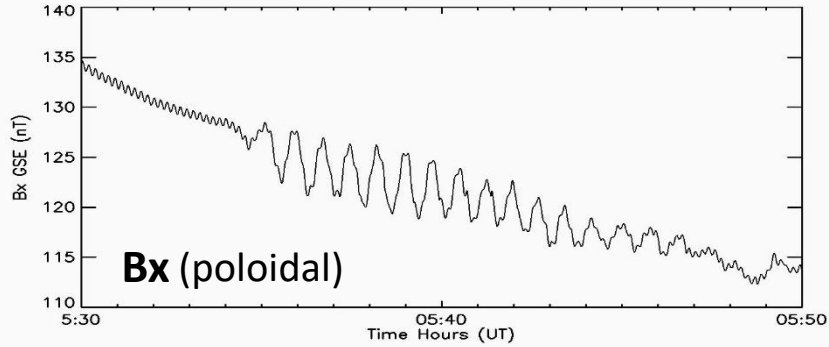
RBSP-A ECT-HOPE-PA-L3>ECT Helium Oxygen Proton Electron Plasma Analyzer Fluxes by Pitch Angle Level 3 rel04>Release 04



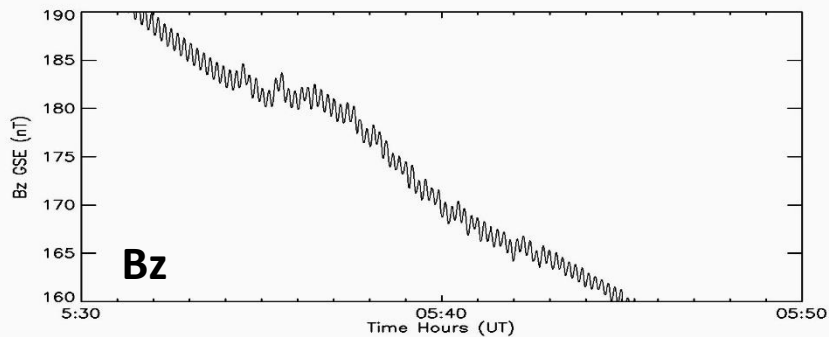
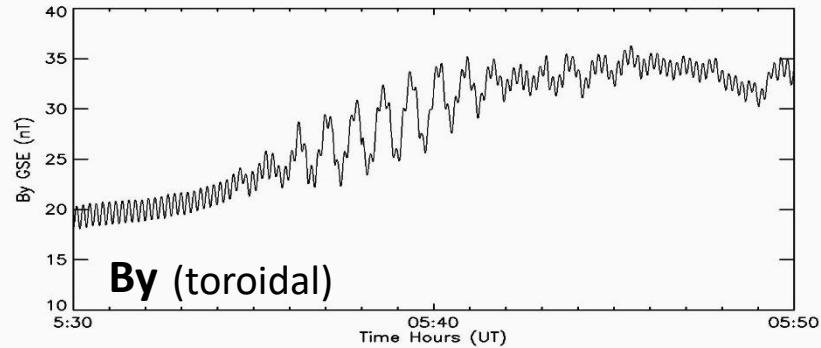
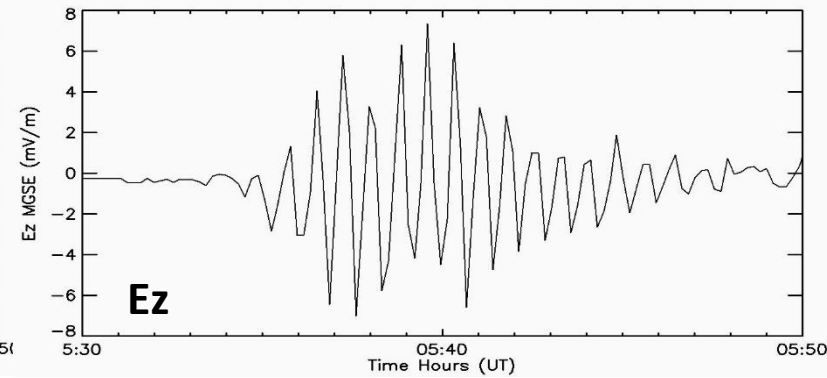
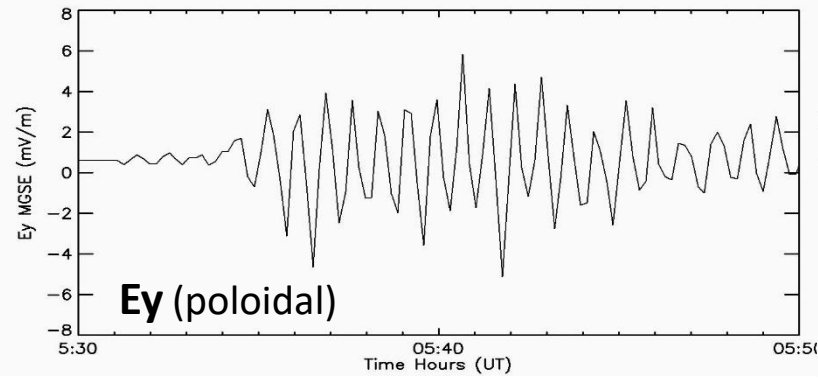
Please acknowledge PI, Herbert Funsten  
at Los Alamos National Laboratory and CDAWeb when using these data.  
Generated by CDAWeb on Wed Feb 21 21:52:04 2024

# RBSPA Observations of a mixed polarization 22 mHz wave

EMFISIS L3 Data

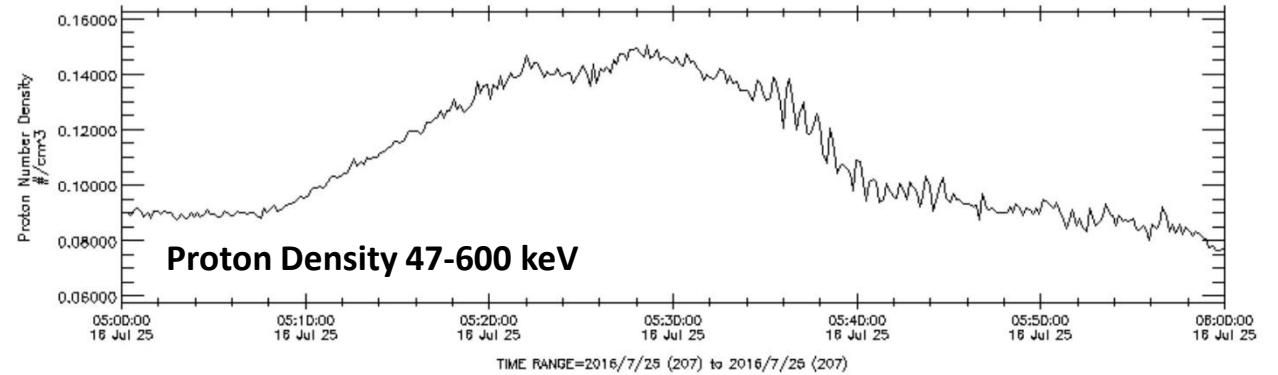


Electric Field and Waves L2 Data



RBSP-A-RBSPICE\_LEV-3-PAP\_TOFxEH

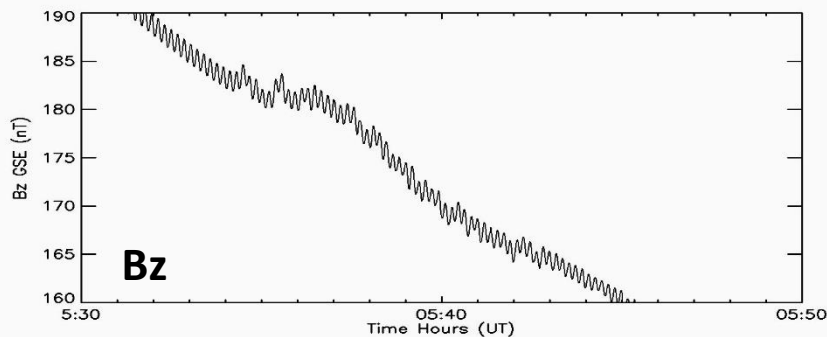
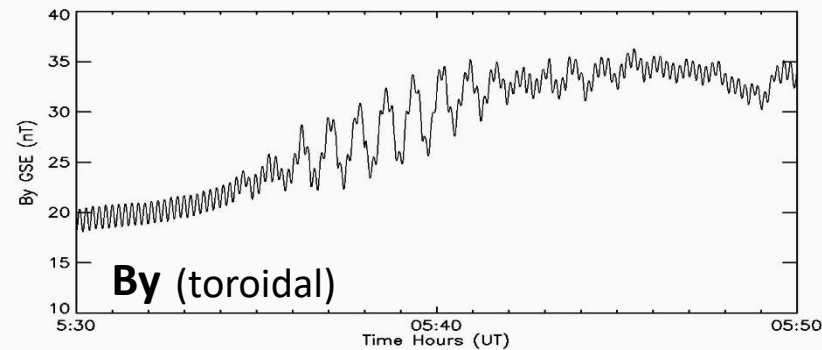
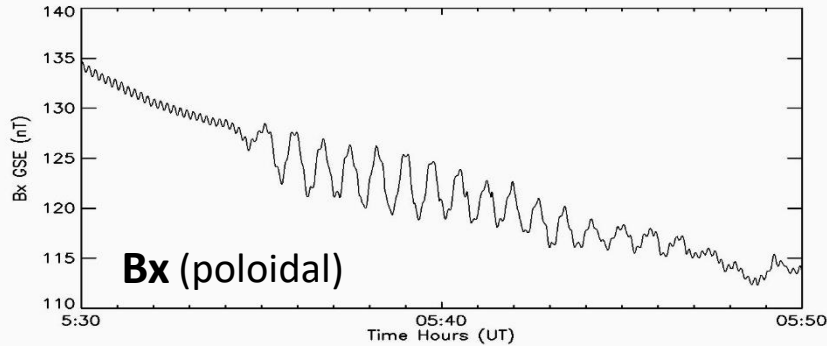
RBSP-A Lev-3-PAP>Level 3 by Pitch Angle and Pressure TOFxEH>Time of Flight vs Energy of Hydrogen



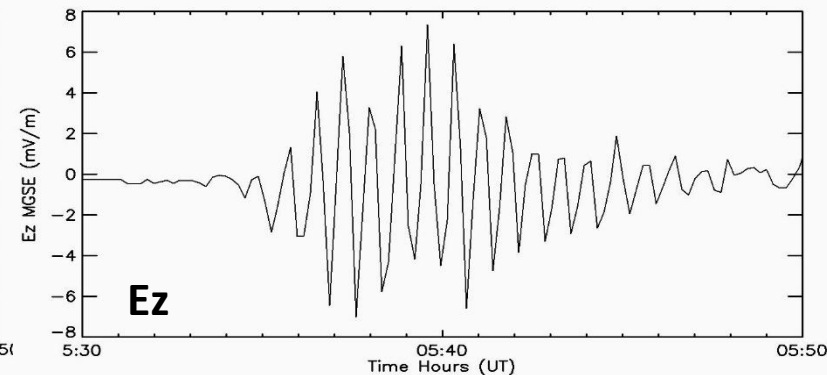
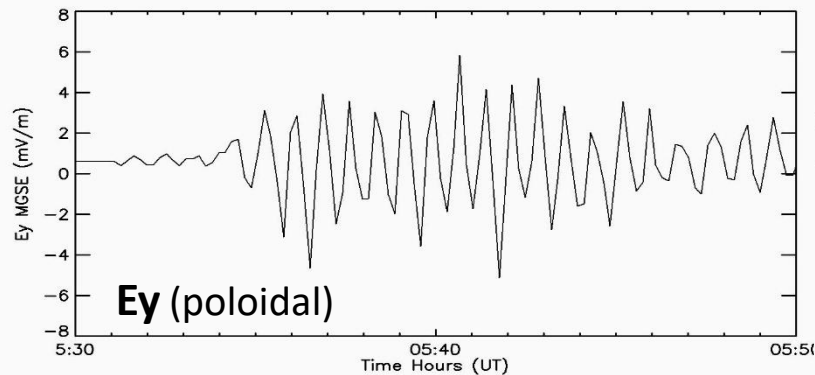
Please acknowledge PI, Lou Lanzerotti  
at New Jersey Institute of Technology and CDAWeb when using these data.  
Generated by CDAWeb on Sun Feb 11 22:30:21 2024

# RBSPA Observations of a mixed polarization 22 mHz wave

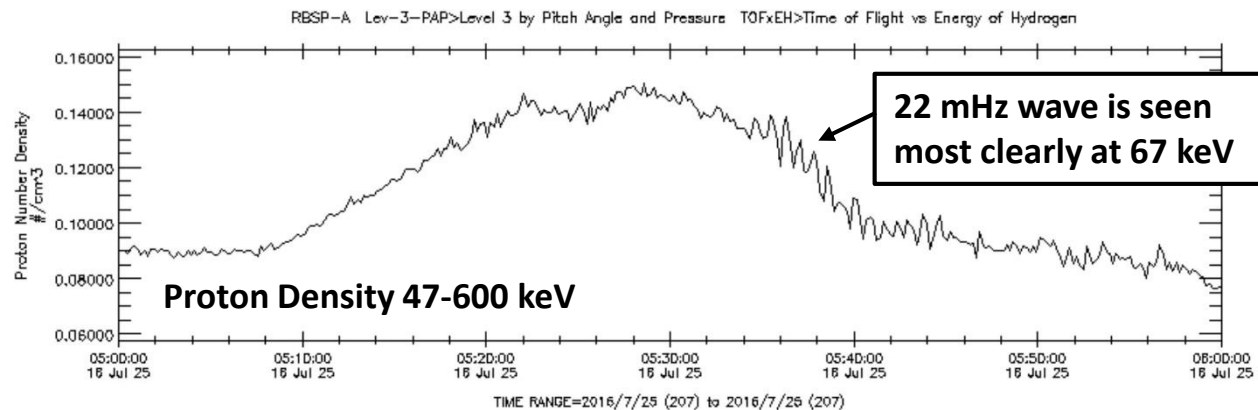
### EMFISIS L3 Data



### Electric Field and Waves L2 Data



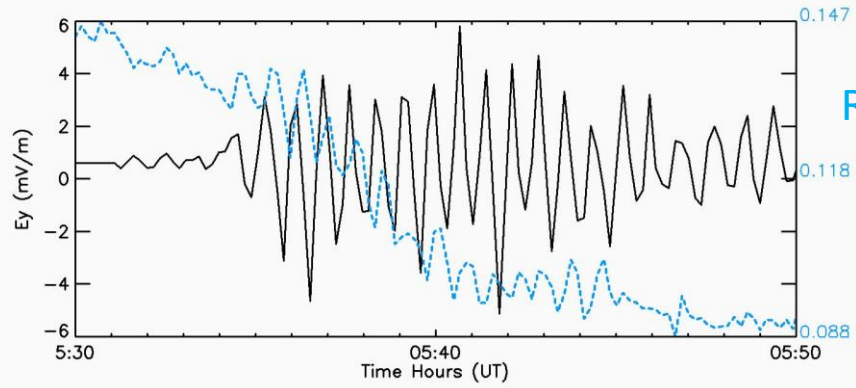
### RBSP-A-RBSPICE\_LEV-3-PAP\_TOFxEH



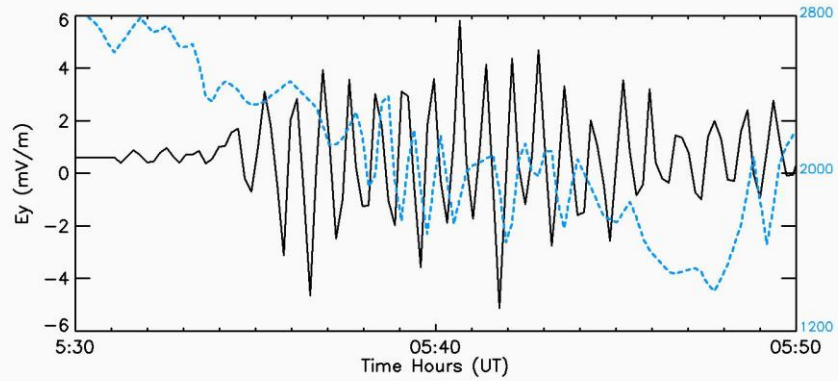
Please acknowledge PI, Lou Lanzerotti  
at New Jersey Institute of Technology and CDAWeb when using these data.  
Generated by CDAWeb on Sun Feb 11 22:30:21 2024



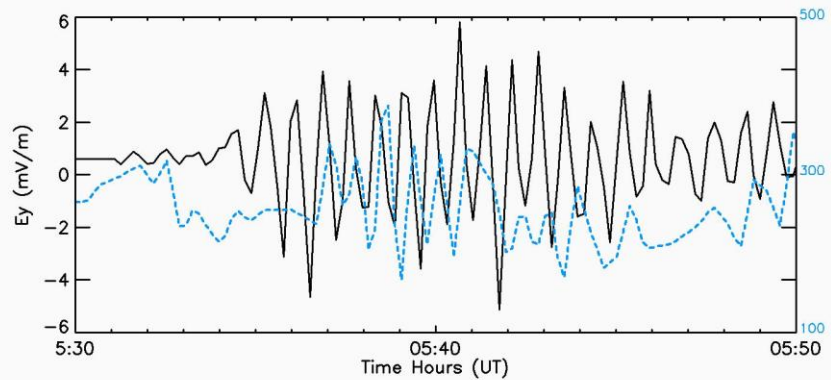
# Overlays of RBSPA Ion Data with the Poloidal Component, $E_y$



RBSPICE Proton  
Density  
47-600 keV

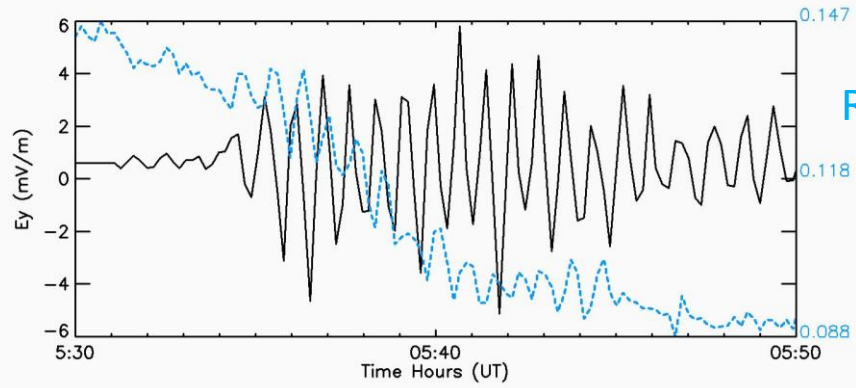


HOPE Proton  
Counts  
21 keV

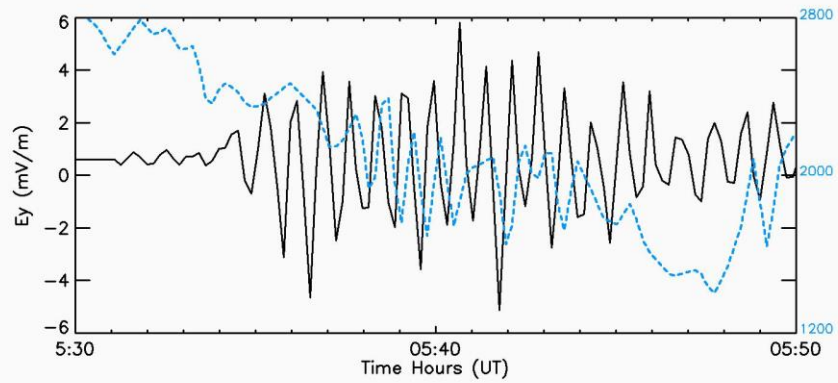


HOPE Oxygen  
Ion Counts  
15 keV

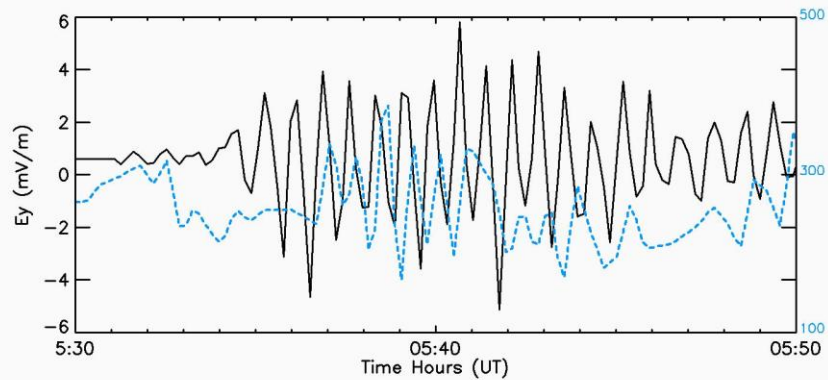
## Overlays of RBSPA Ion Data with the Poloidal Component, $E_y$



RBSPICE Proton  
Density  
47-600 keV

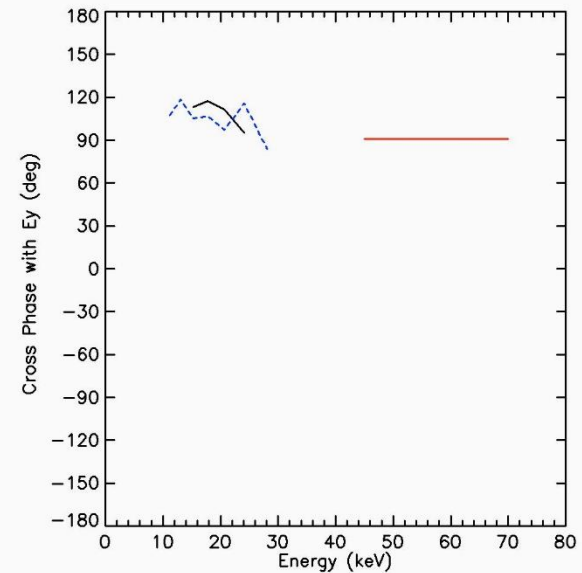
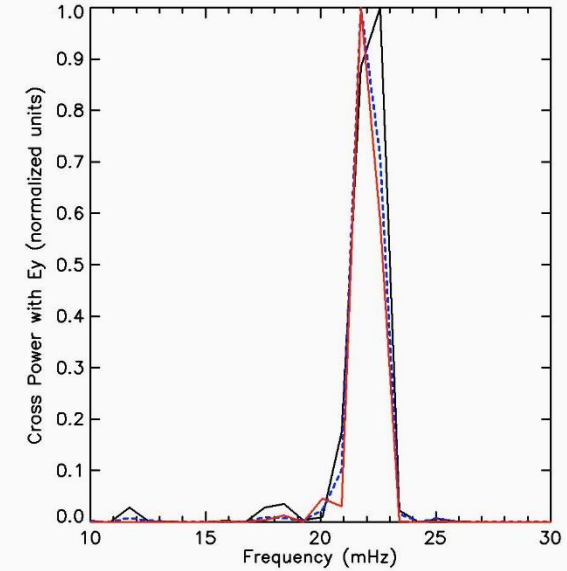


HOPE Proton  
Counts  
21 keV

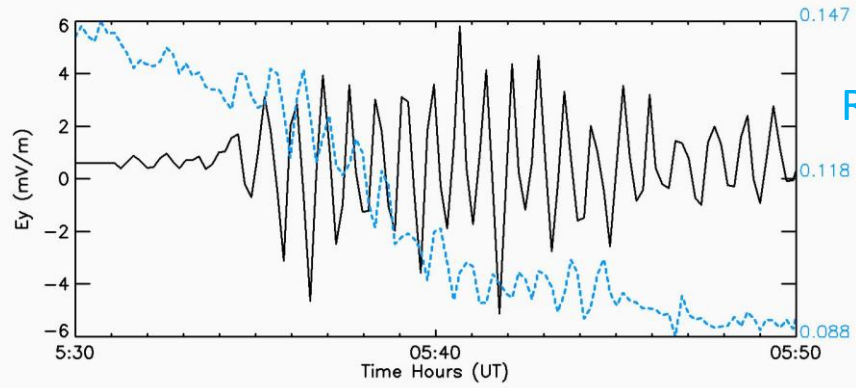


HOPE Oxygen  
Ion Counts  
15 keV

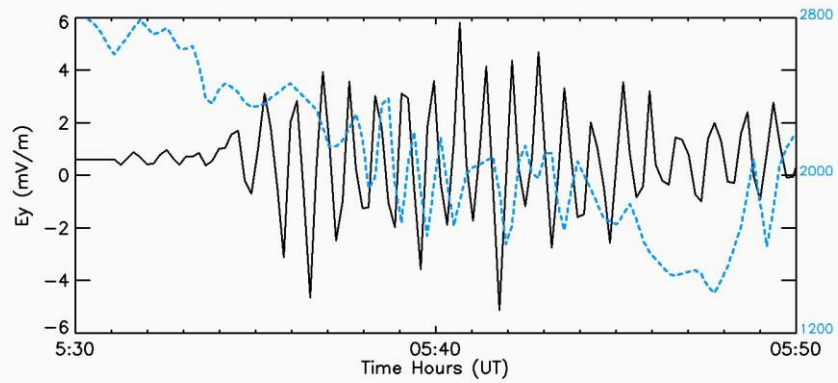
## Cross Power and Cross Phase



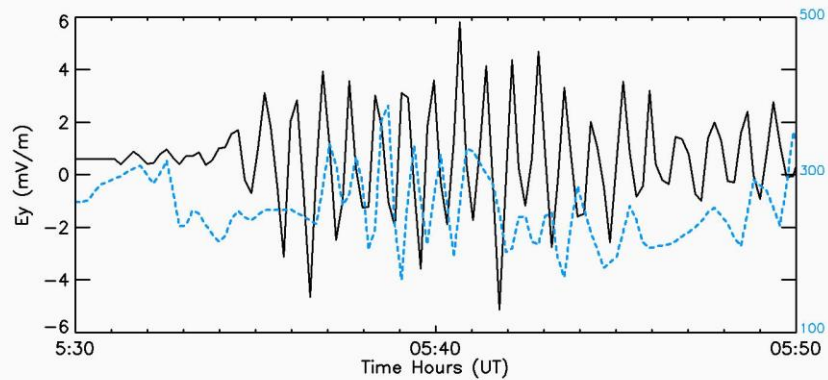
## Overlays of RBSPA Ion Data with the Poloidal Component, $E_y$



RBSPICE Proton  
Density  
47-600 keV

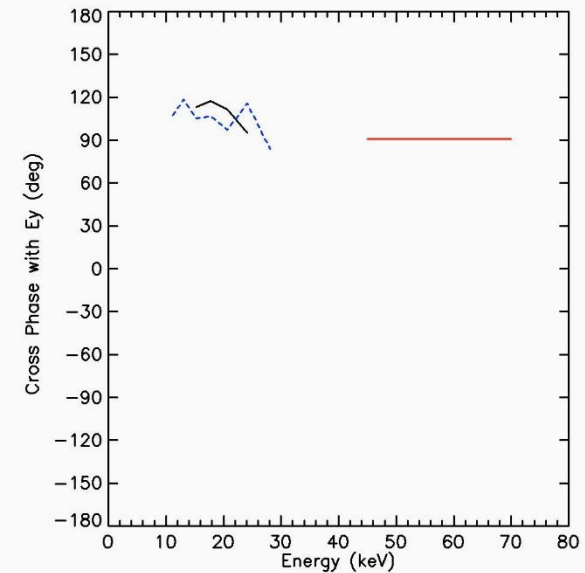
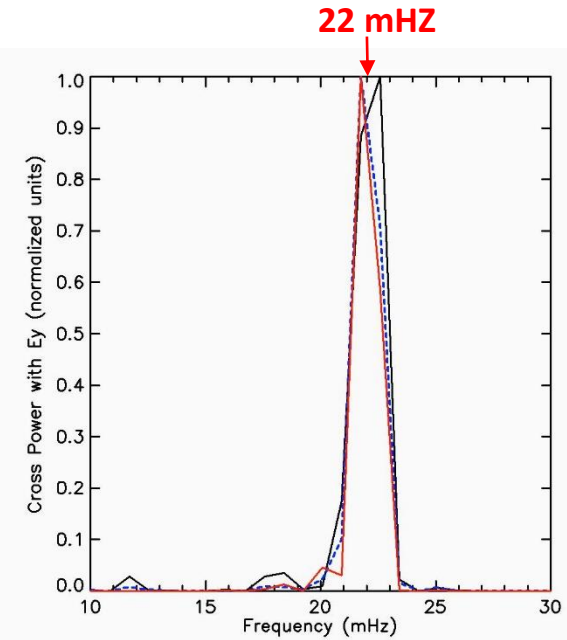


HOPE Proton  
Counts  
21 keV

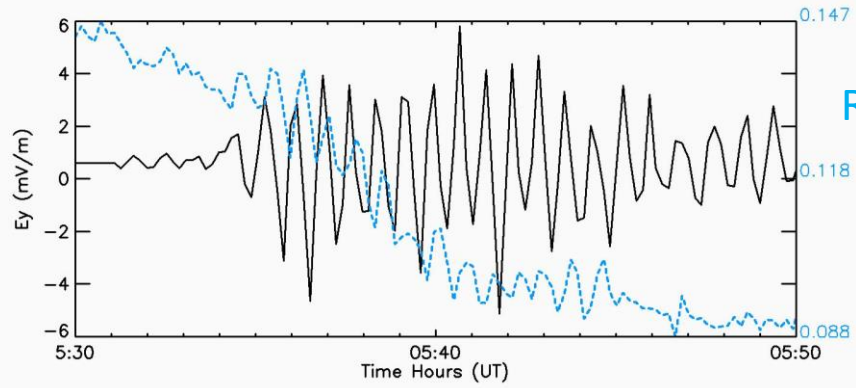


HOPE Oxygen  
Ion Counts  
15 keV

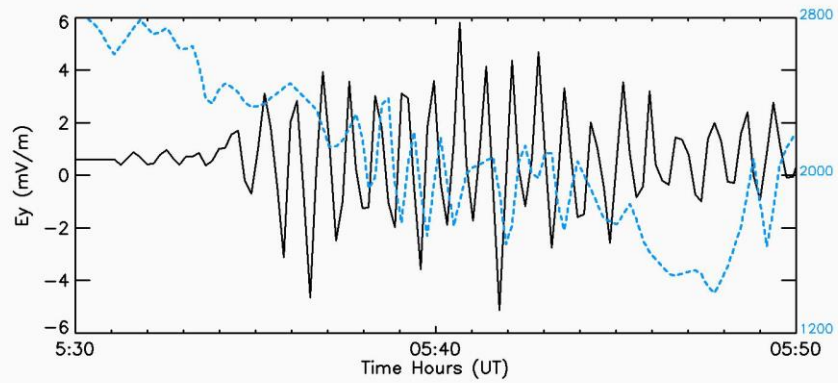
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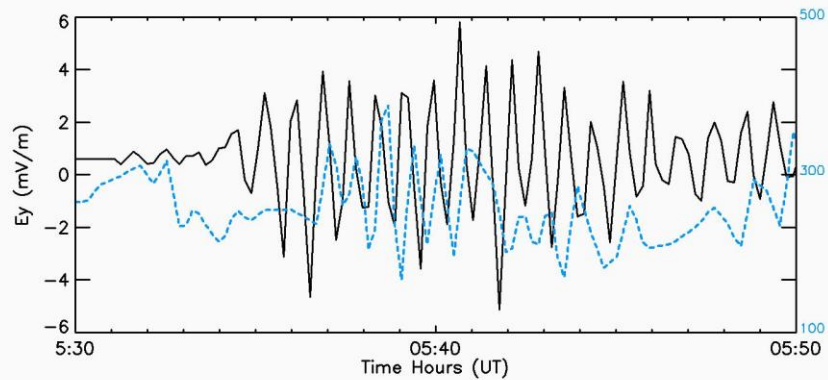
## Overlays of RBSPA Ion Data with the Poloidal Component, $E_y$



RBSPICE Proton  
Density  
47-600 keV

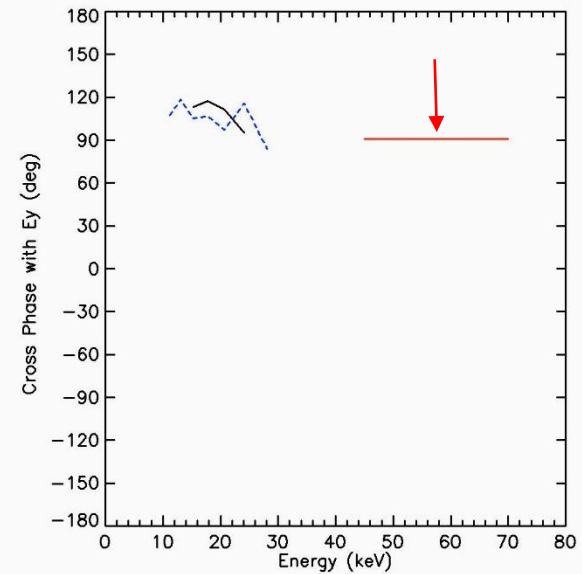
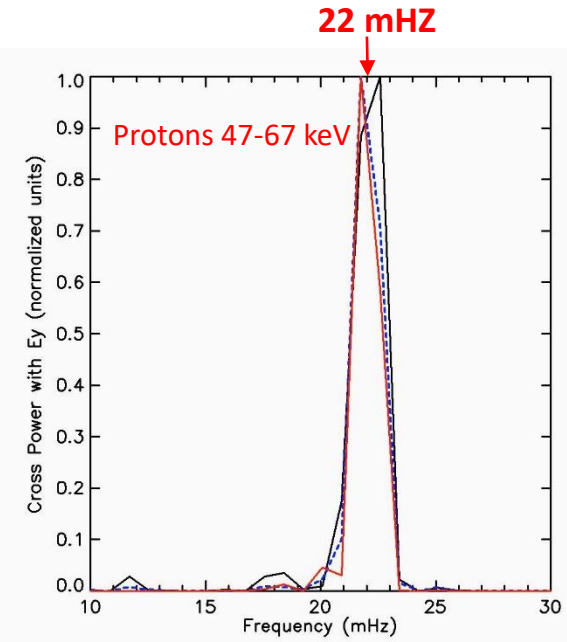


HOPE Proton  
Counts  
21 keV

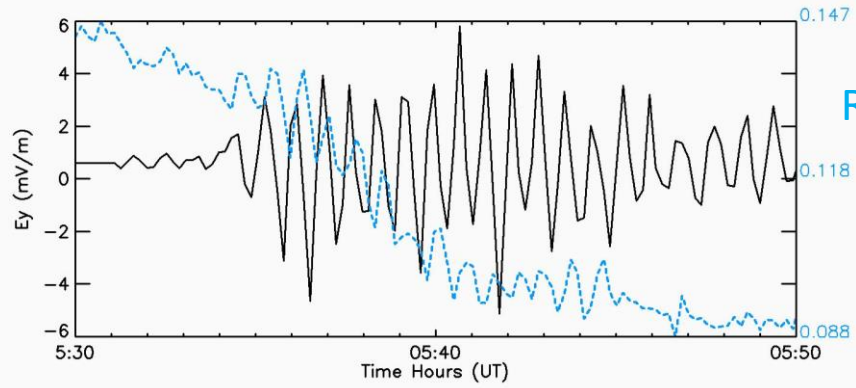


HOPE Oxygen  
Ion Counts  
15 keV

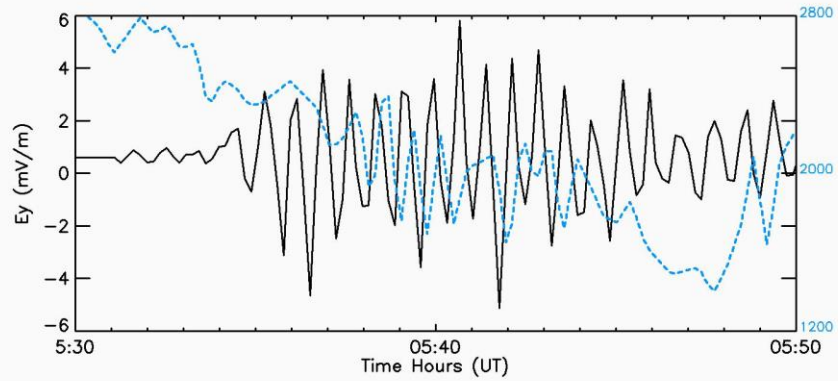
## Cross Power and Cross Phase



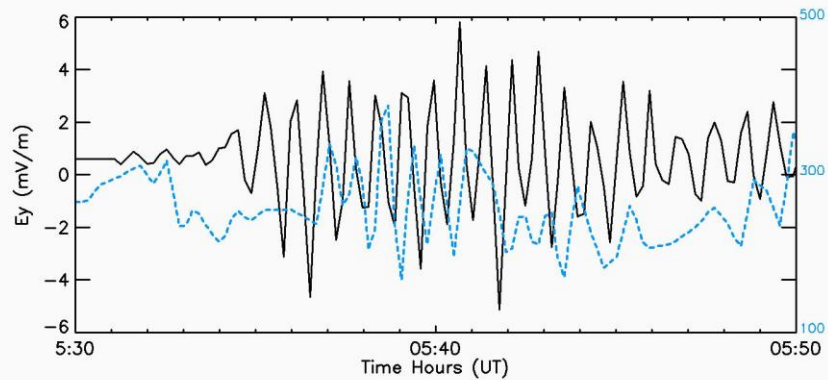
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RBSPICE Proton  
Density  
47-600 keV

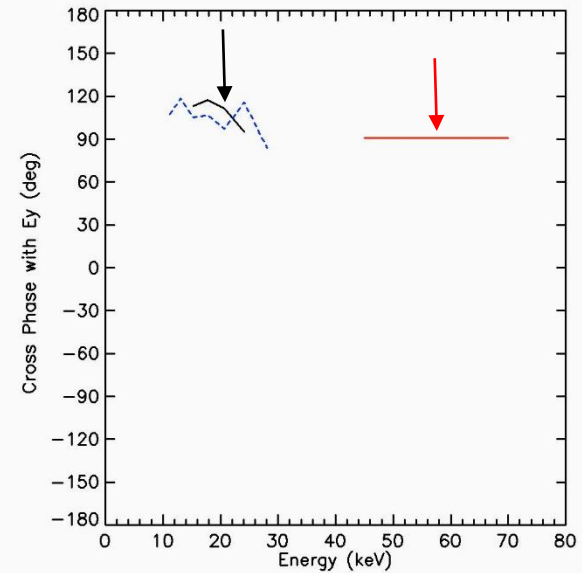
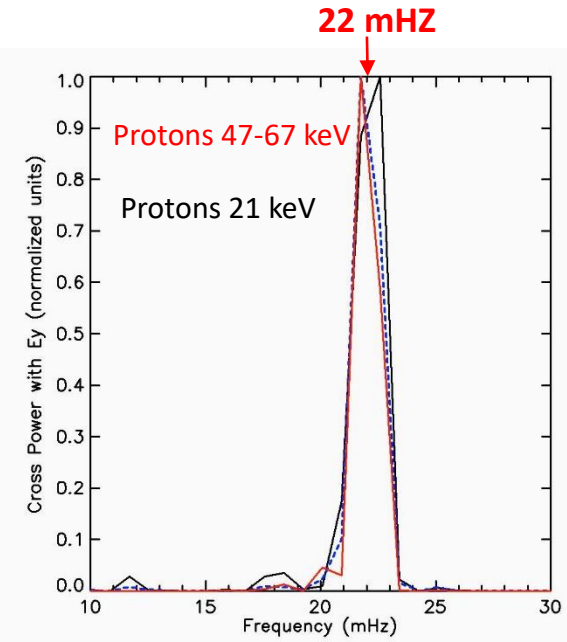


HOPE Proton  
Counts  
21 keV

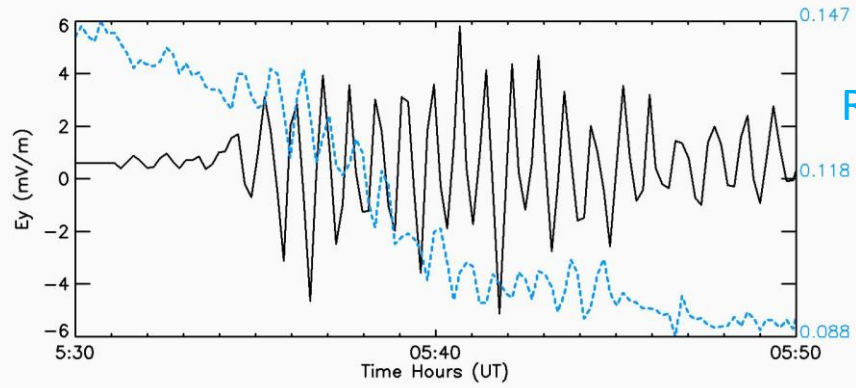


HOPE Oxygen  
Ion Counts  
15 keV

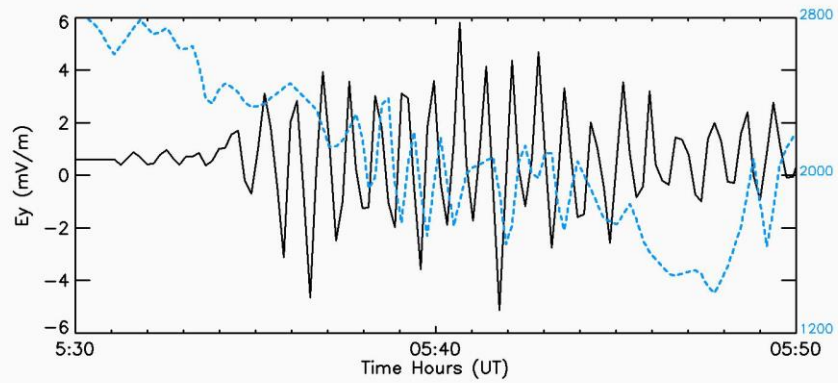
## Cross Power and Cross Phase



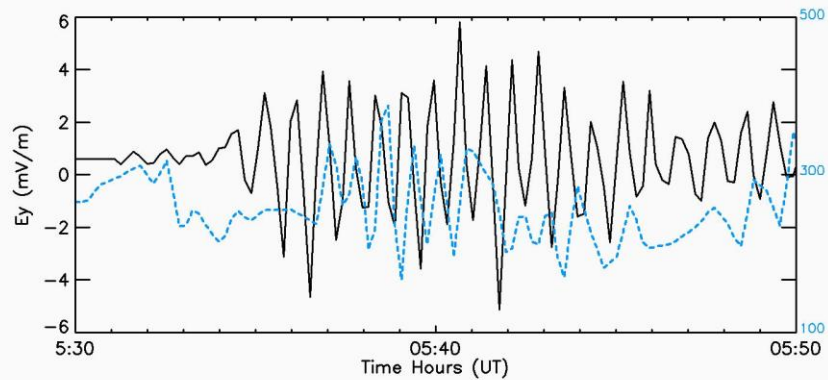
## Overlays of RBSPA Ion Data with the Poloidal Component, $E_y$



RBSPICE Proton  
Density  
47-600 keV

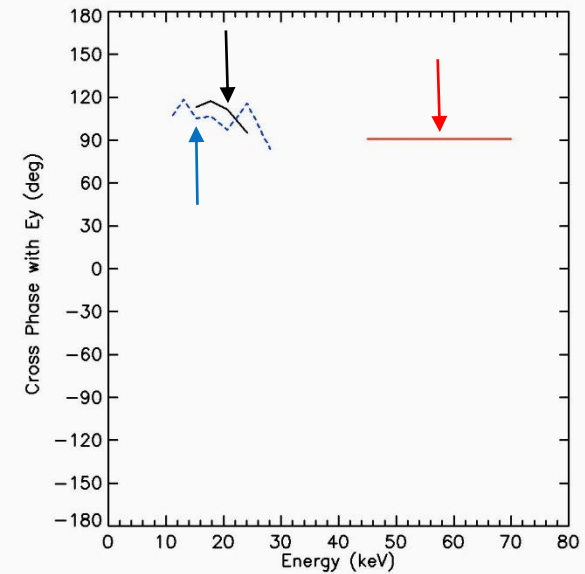
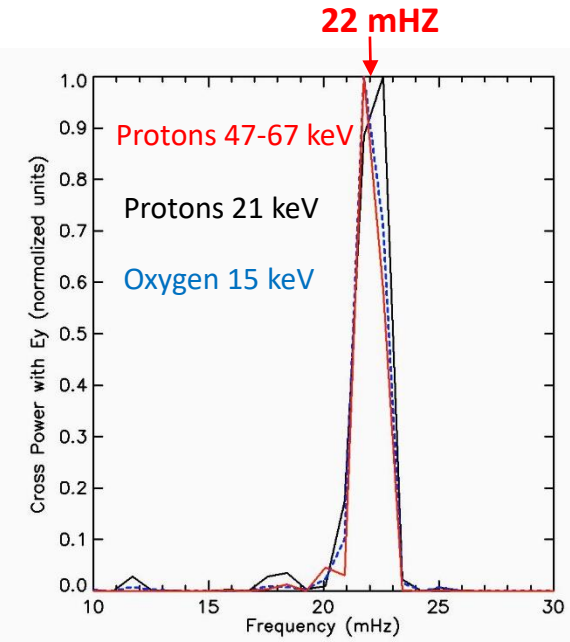


HOPE Proton  
Counts  
21 keV

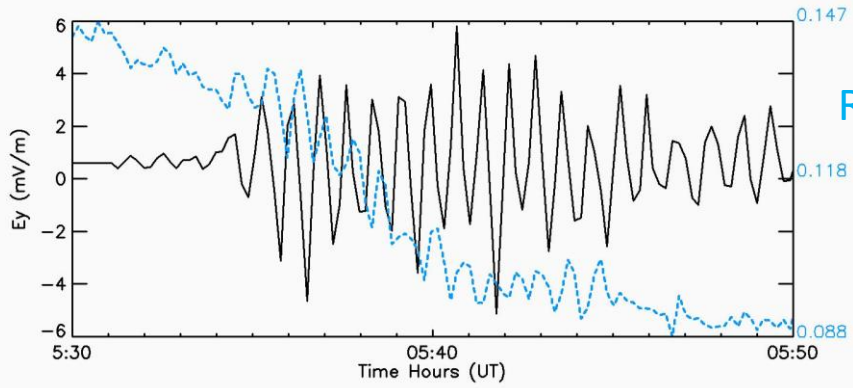


HOPE Oxygen  
Ion Counts  
15 keV

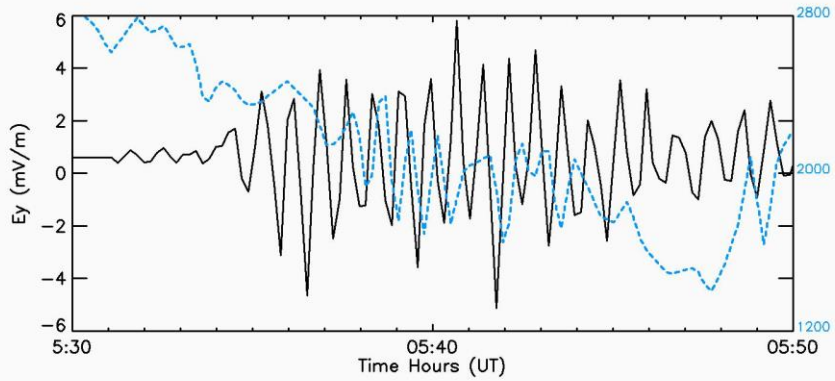
## Cross Power and Cross Phase



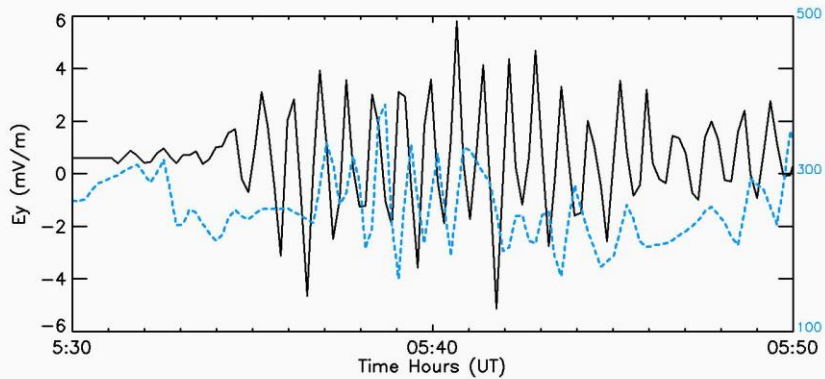
# Overlays of RBSPA Ion Data with the Poloidal Component, $E_y$



RBSPICE Proton Density  
47-600 keV

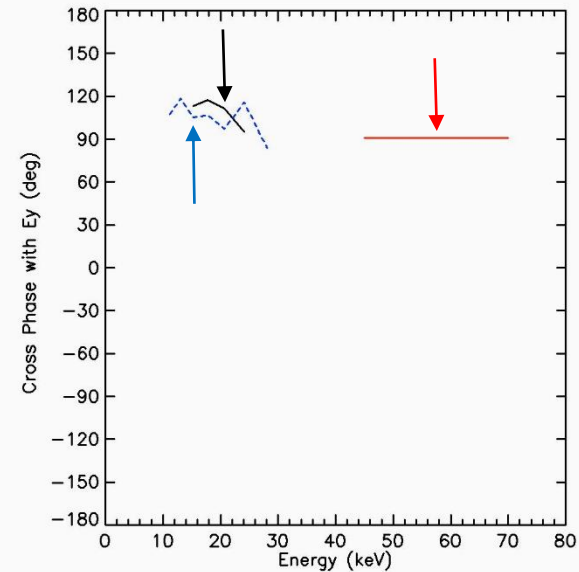
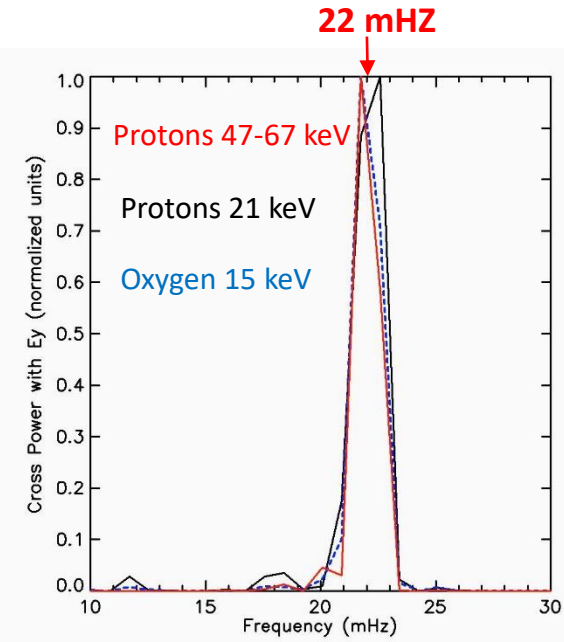


HOPE Proton Counts  
21 keV



HOPE Oxygen Ion Counts  
15 keV

# Cross Power and Cross Phase

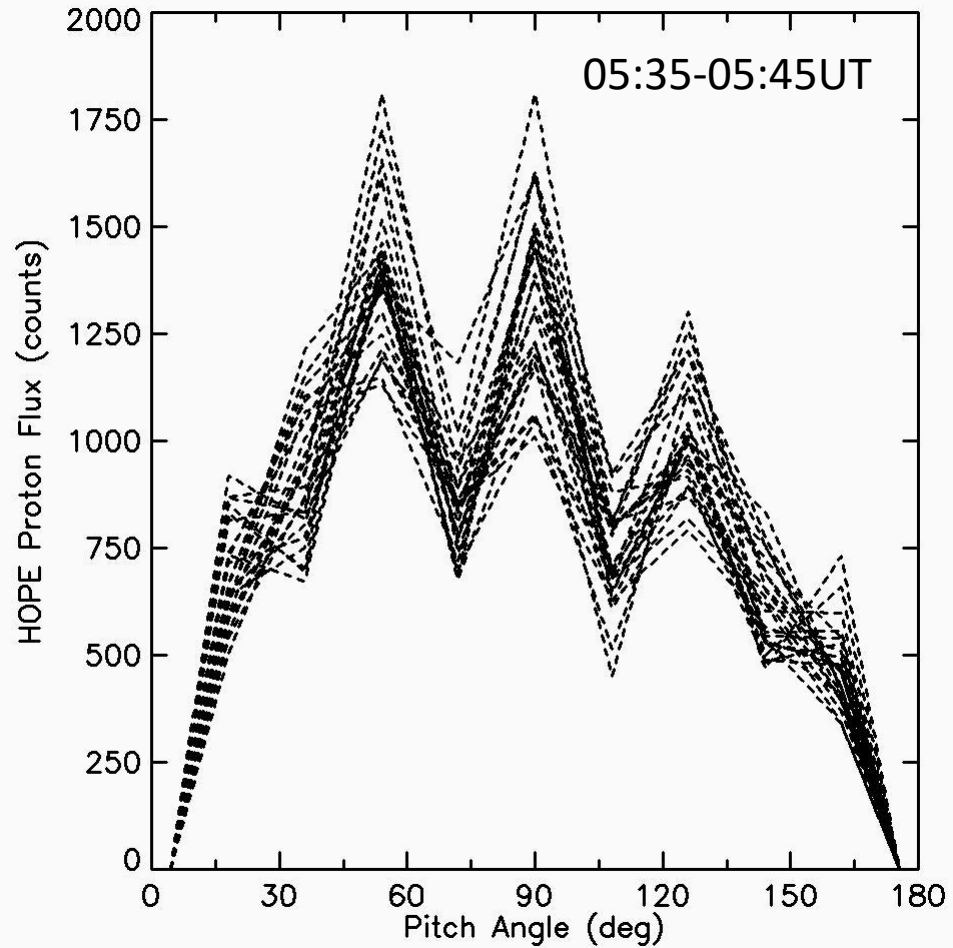


90° Phase Difference

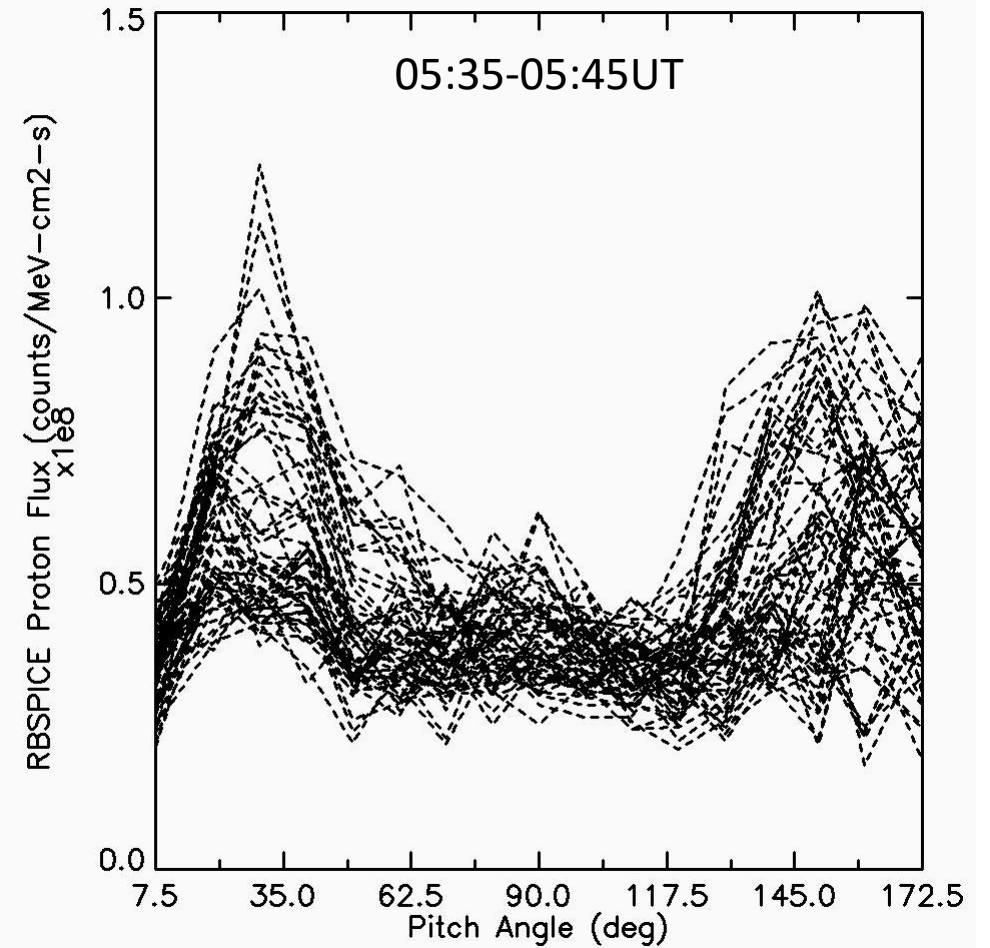
Drift Bounce Resonance Driving the 22 mHz Wave.

# Pitch Angle Distributions

HOPE 15-21 keV Protons



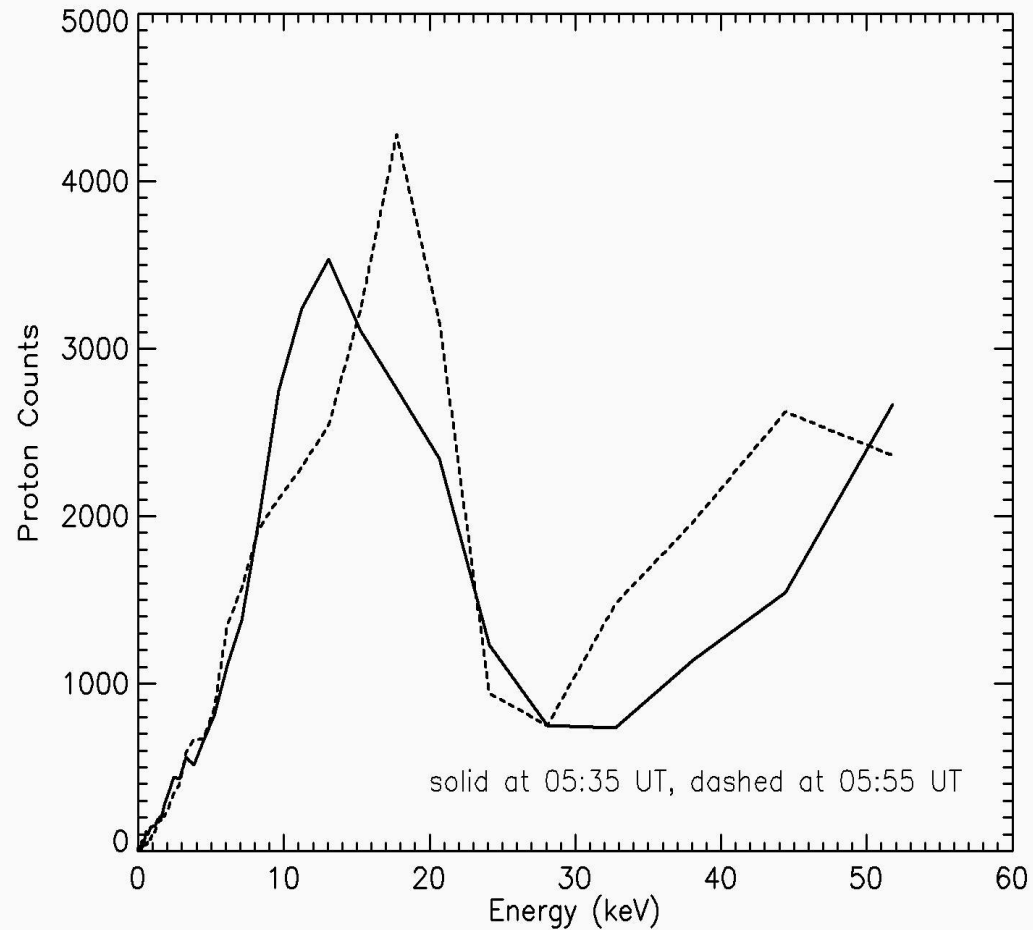
RBSPICE 67 keV Protons



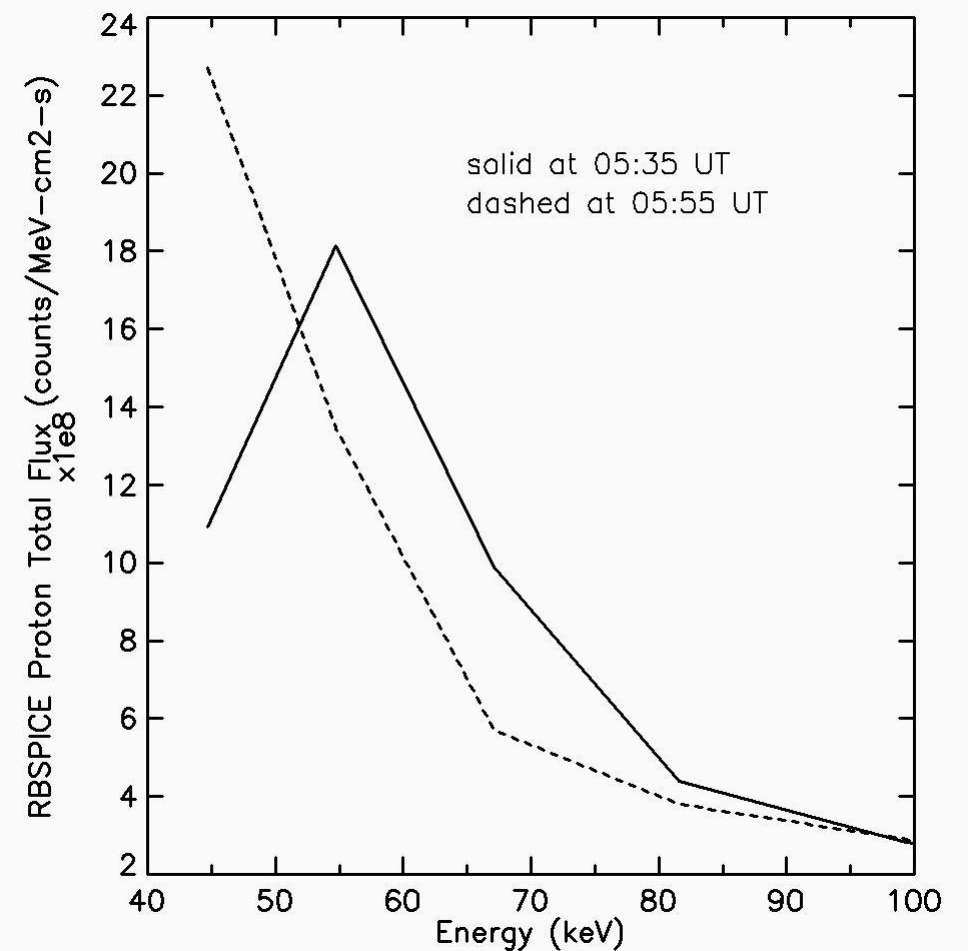


# Energy Distributions Before (solid) and After (dashed) the 22 mHz Wave

## HOPE 1-59 keV Protons

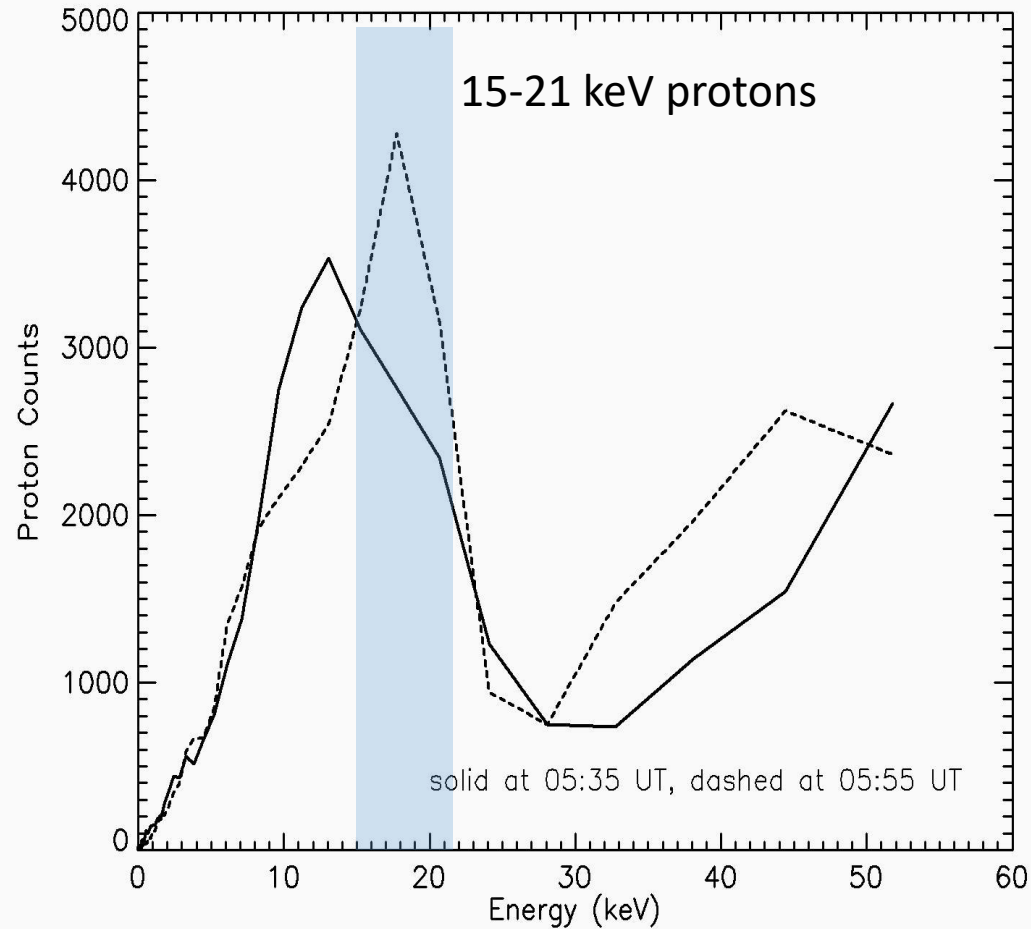


## RBSPICE 47-100 keV Protons

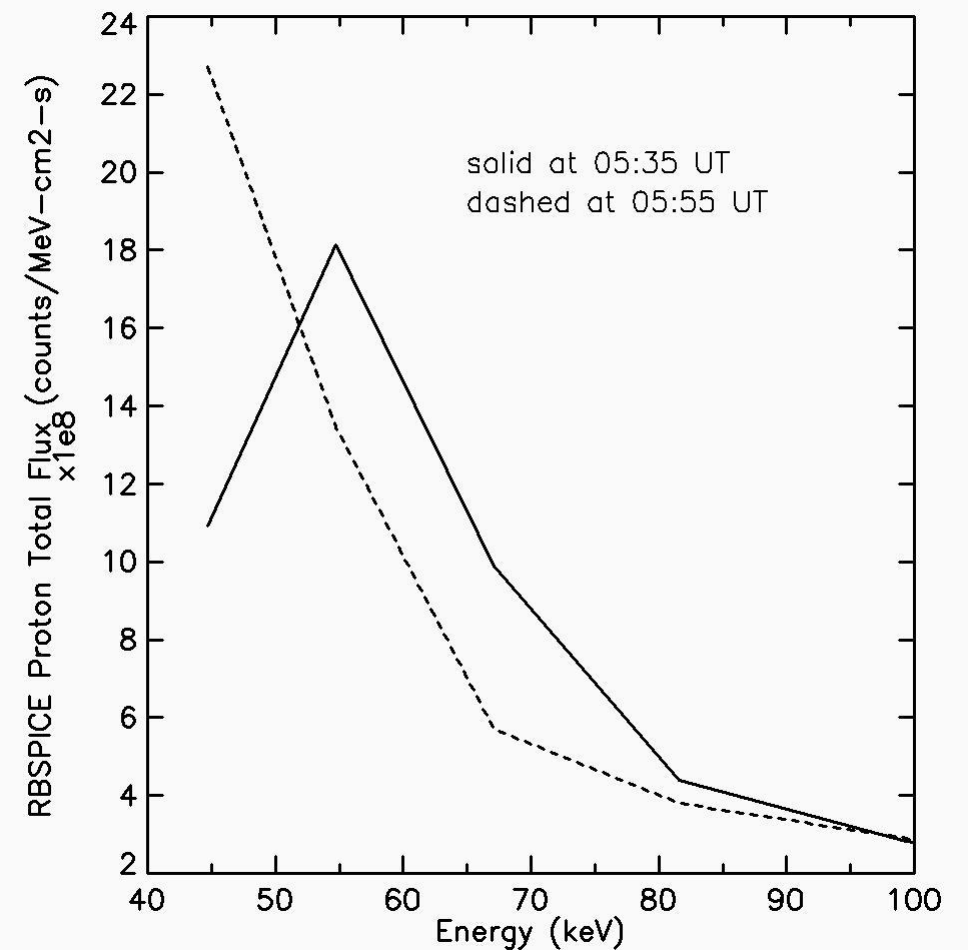


# Energy Distributions Before (solid) and After (dashed) the 22 mHz Wave

## HOPE 1-59 keV Protons

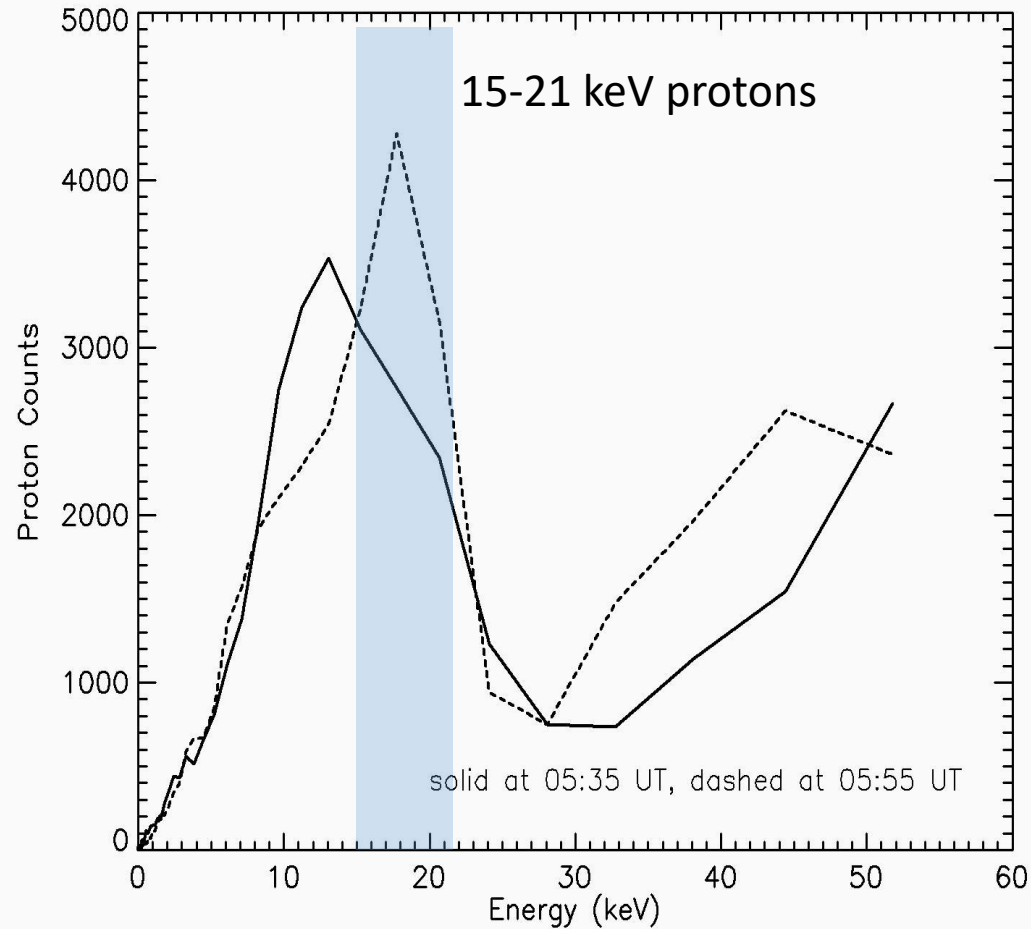


## RBSPICE 47-100 keV Protons

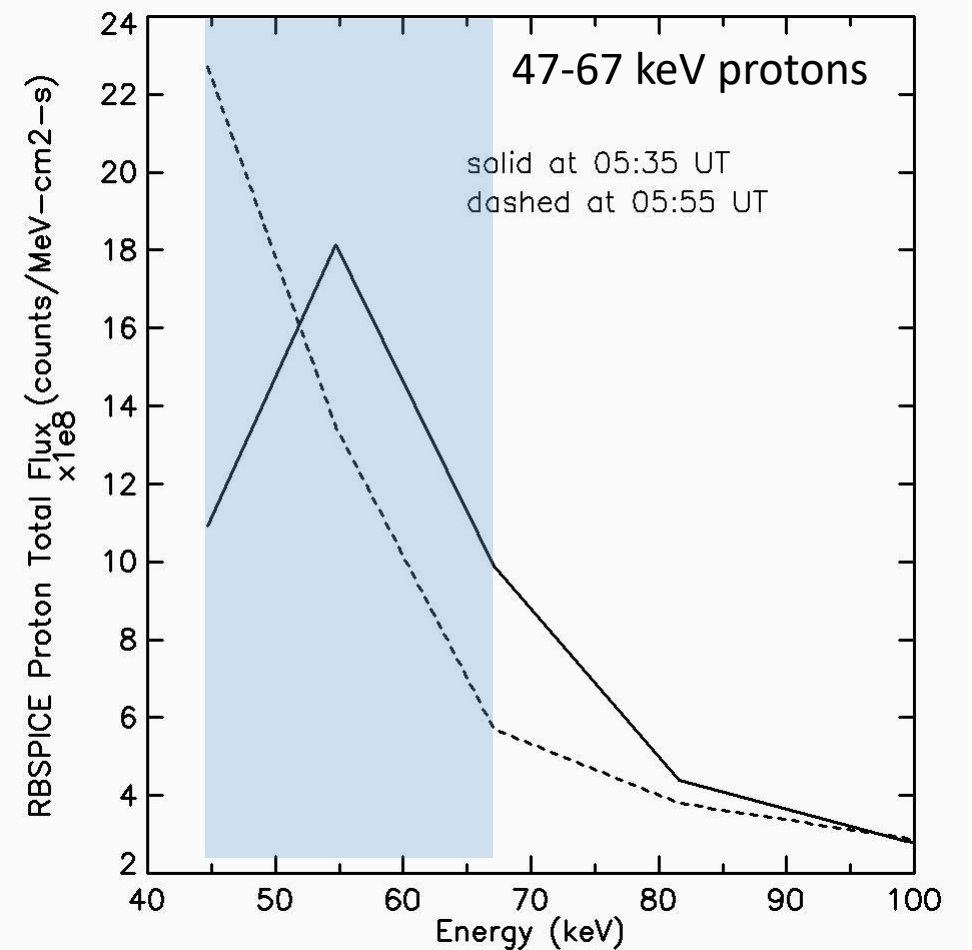


# Energy Distributions Before (solid) and After (dashed) the 22 mHz Wave

## HOPE 1-59 keV Protons



## RBSPICE 47-100 keV Protons



# Summary

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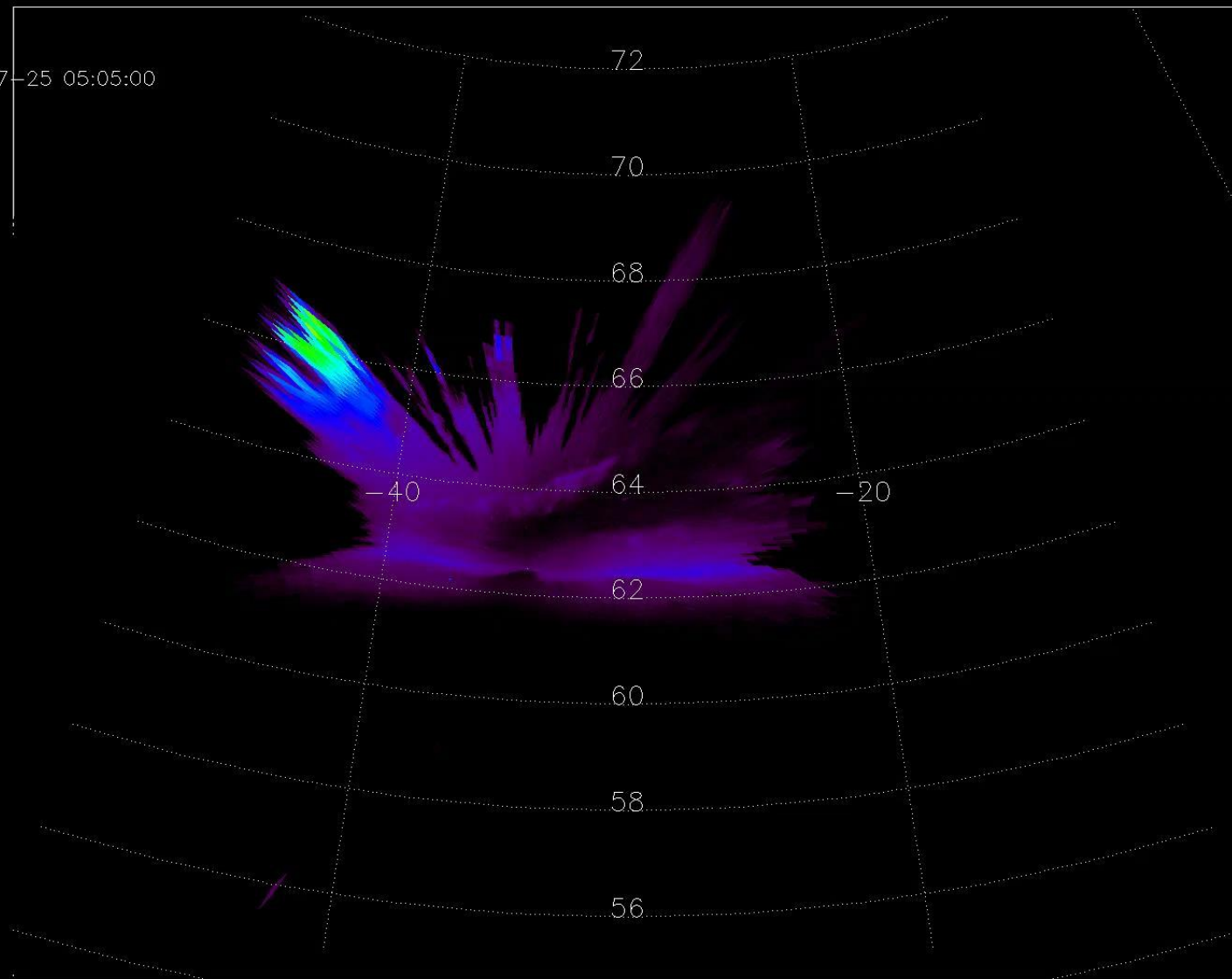
- ❑ Auroral Beads are high-m FLRs at frequencies ranging from 7-25 mHz driven by wave-particle drift and drift-bounce mode instabilities.
- ❑ Associated with the standing Alfvén FLRs are kinetic Alfvén waves that accelerate the auroral electrons producing the auroral bead emissions. ( Tian et al., GRL 2022)
- ❑ The high-m FLRs have strong shear flow which results in the spiral bead formations and possibly a shear flow instability which may be the trigger for auroral breakup and substorm onset.

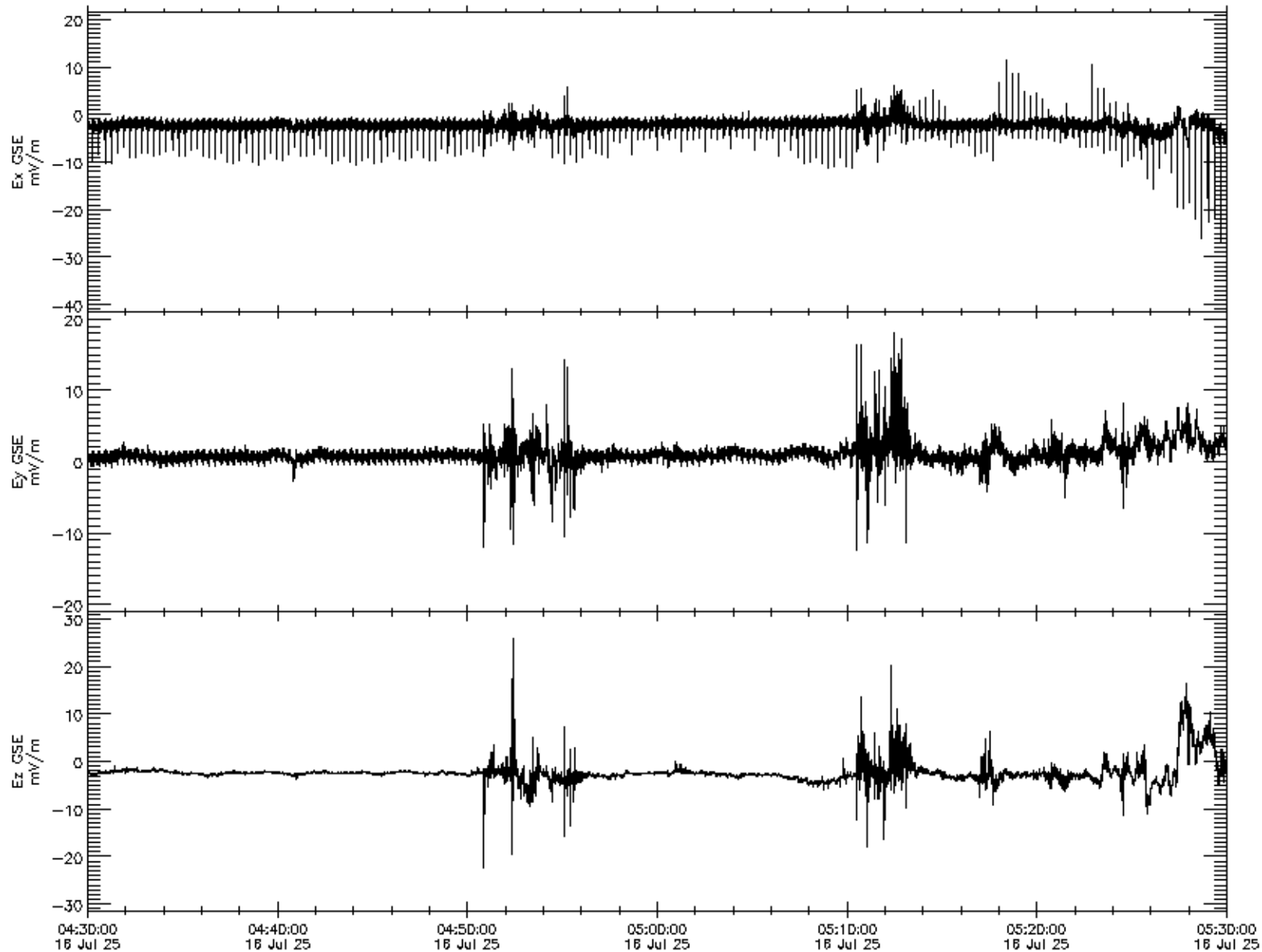
# Acknowledgements

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- SuperDARN is a collection of radars funded by national scientific funding agencies of Australia, Canada, China, France, Japan, South Africa, United Kingdom and United States of America. Raw data is available at <http://superdarn.ca>. We thank Principal Investigator, Kathryn McWilliams, and the Saskatoon SuperDARN Team for providing the SuperDARN data.
- We thank Eric Donovan, Emma Spanswick, and Darren Chaddock for the THEMIS ASI data, TReX data and Swarm-Aurora . The data presented in this talk is available at [https://data.phys.ucalgary.ca/sort\\_by\\_project/THEMIS/asi/stream0](https://data.phys.ucalgary.ca/sort_by_project/THEMIS/asi/stream0)
- The Van Allen Probe (RBSP) A data was obtained from CDAWeb. We acknowledge Principal Investigators J. R. Wygant for the EFW Electric Field data; Craig Kletzing for the EMFISIS Magnetic field data; Herbert Funsten for the Helium Oxygen Proton Electron (HOPE) Plasma Analyser data; Lou Lanzerotti for the RBSPICE high energy proton intensities. <http://rbspgway.jhuapl.edu/>
- Research funding is provided by the Canadian Space Agency.

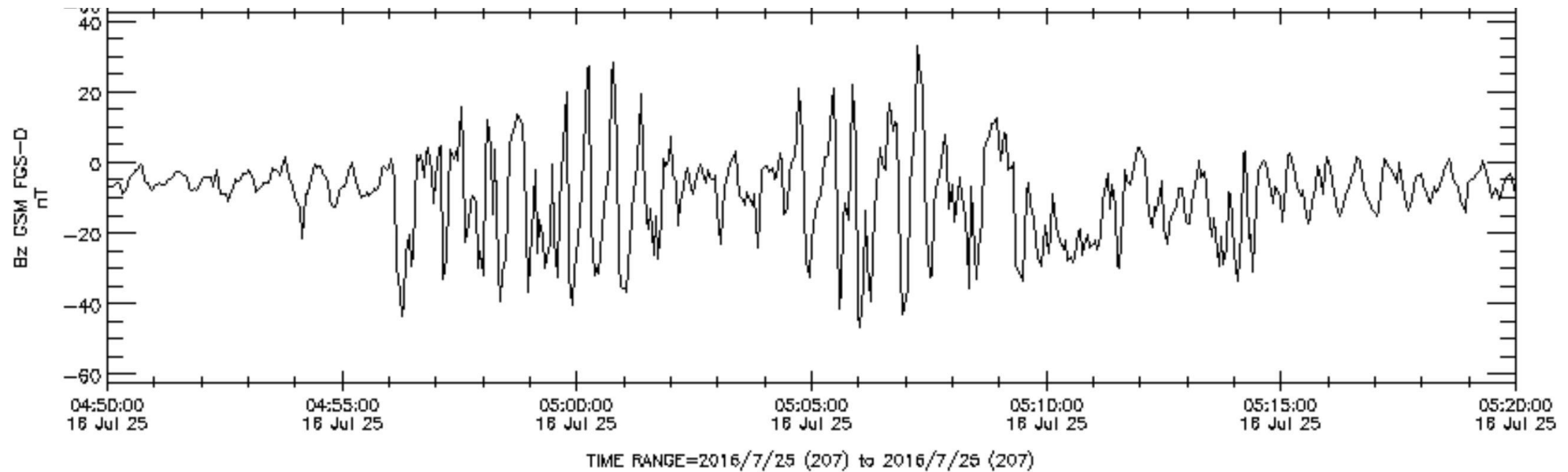
2016-07-25 05:05:00





TIME RANGE=2015/7/25 (207) to 2015/7/25 (207)

### Bz Measured by Themis D in the Magnetosheath

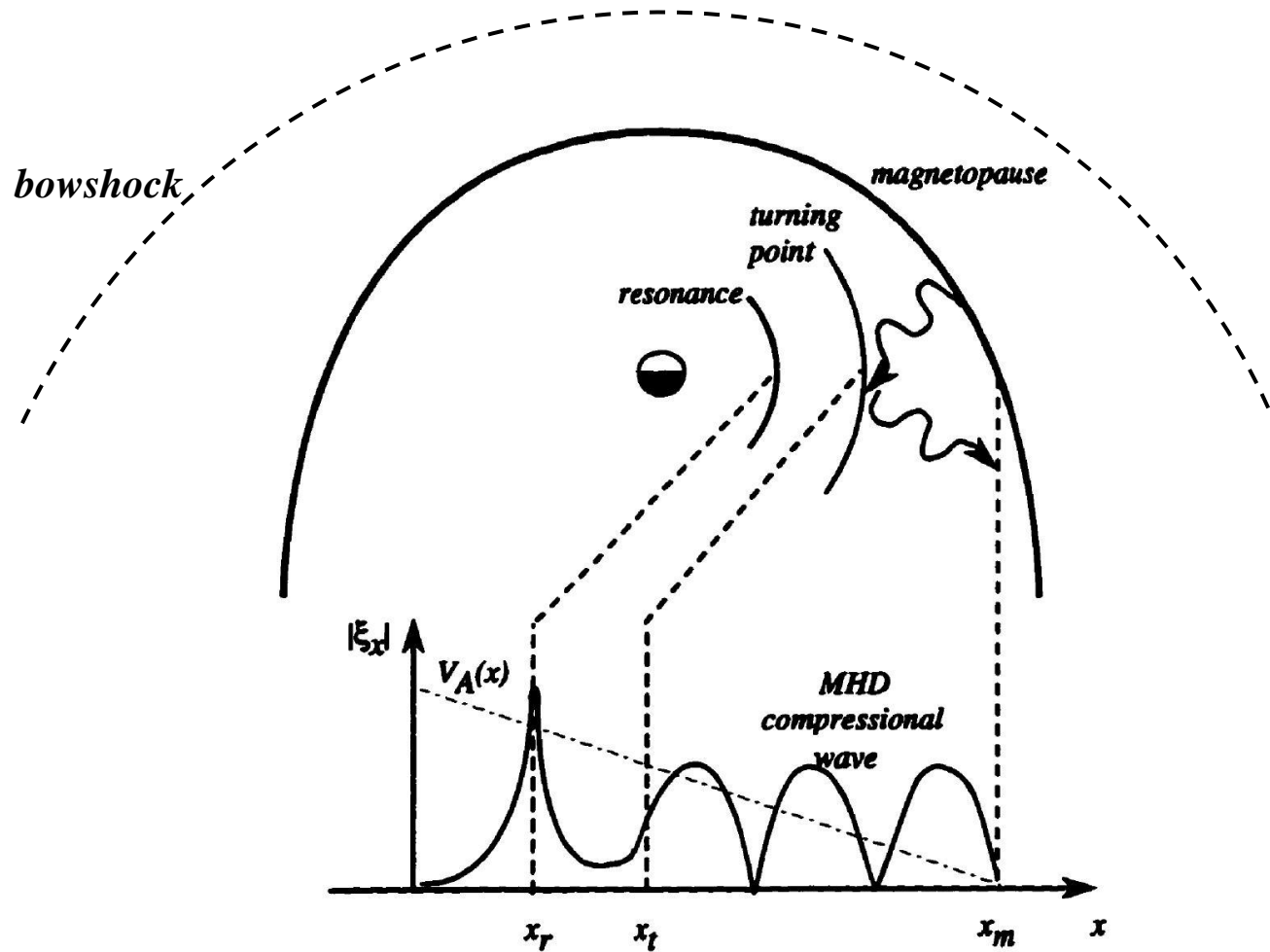


Please acknowledge PI, V. Angelopoulos at UCB, NASA NASS-02099 and CDAWeb when using these data.  
Generated by CDAWeb on Mon Feb 19 23:05:44 2024



# Are the ~10-20 mHz Waves Generating the Auroral Beads Purely Wave-Particle Driven?

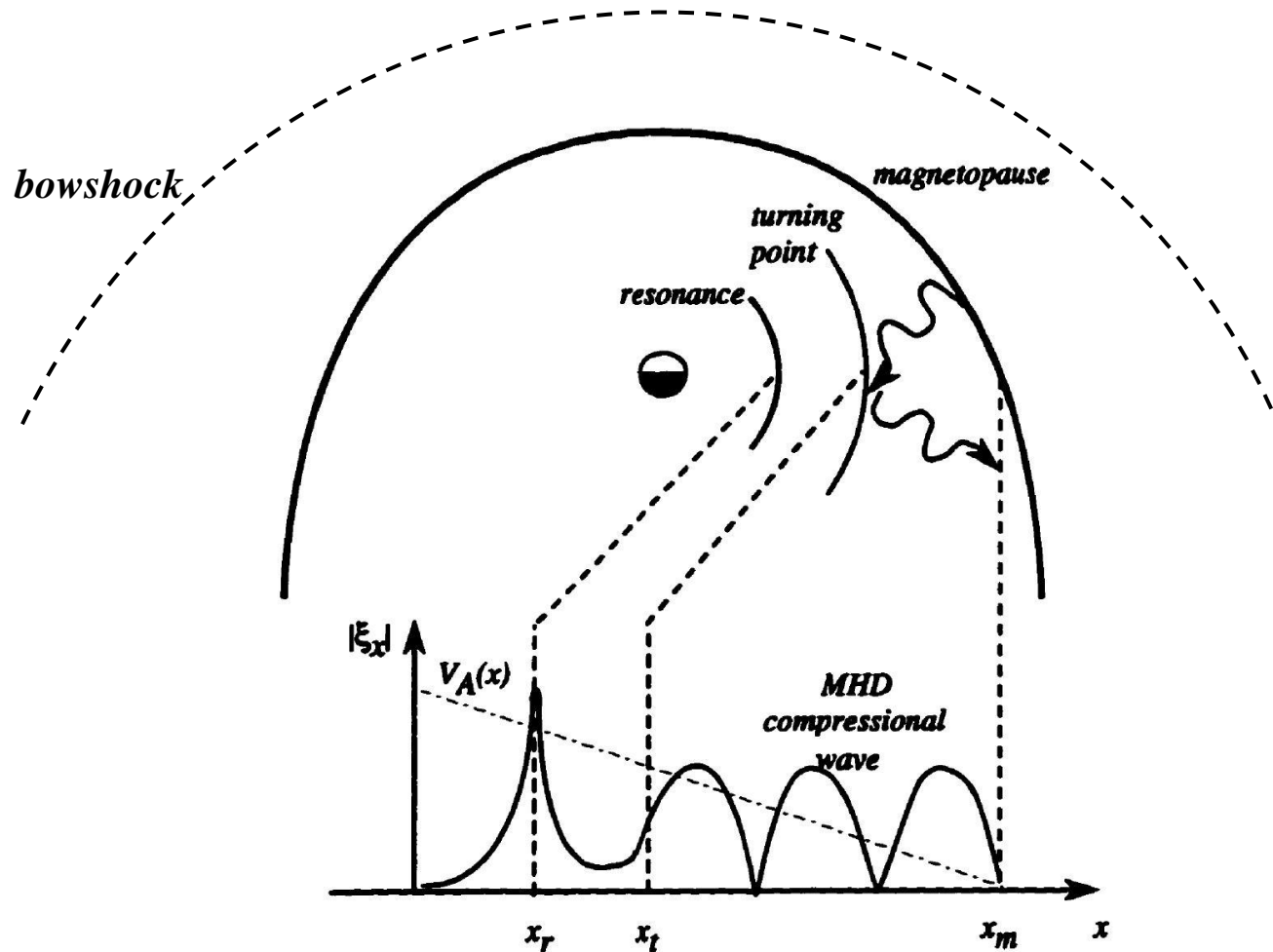
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# Are the ~10-20 mHz Waves Generating the Auroral Beads Purely Wave-Particle Driven?

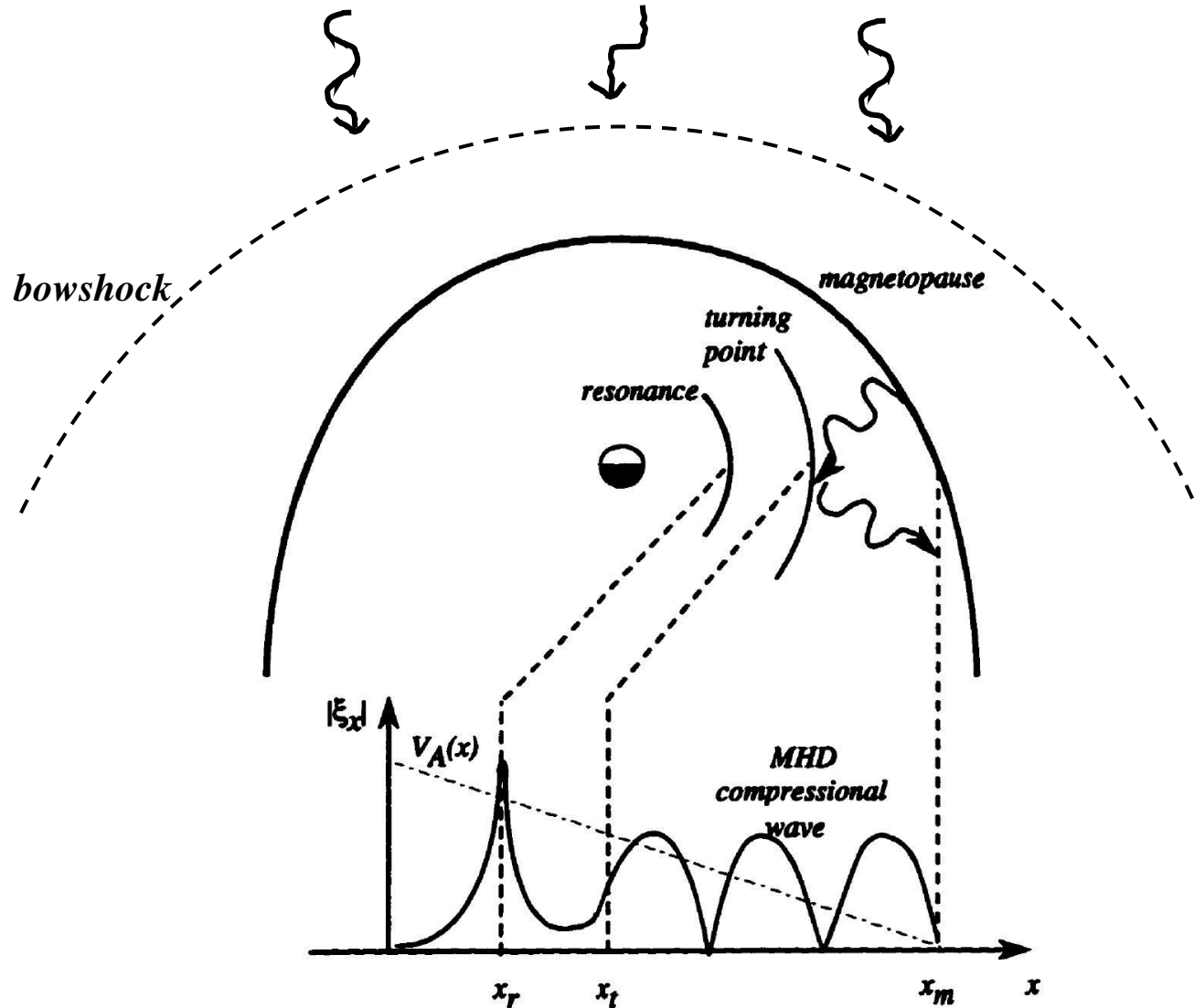
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## Wave Sources Driving ULF FLRs:



# Are the ~10-20 mHz Waves Generating the Auroral Beads Purely Wave-Particle Driven?

---

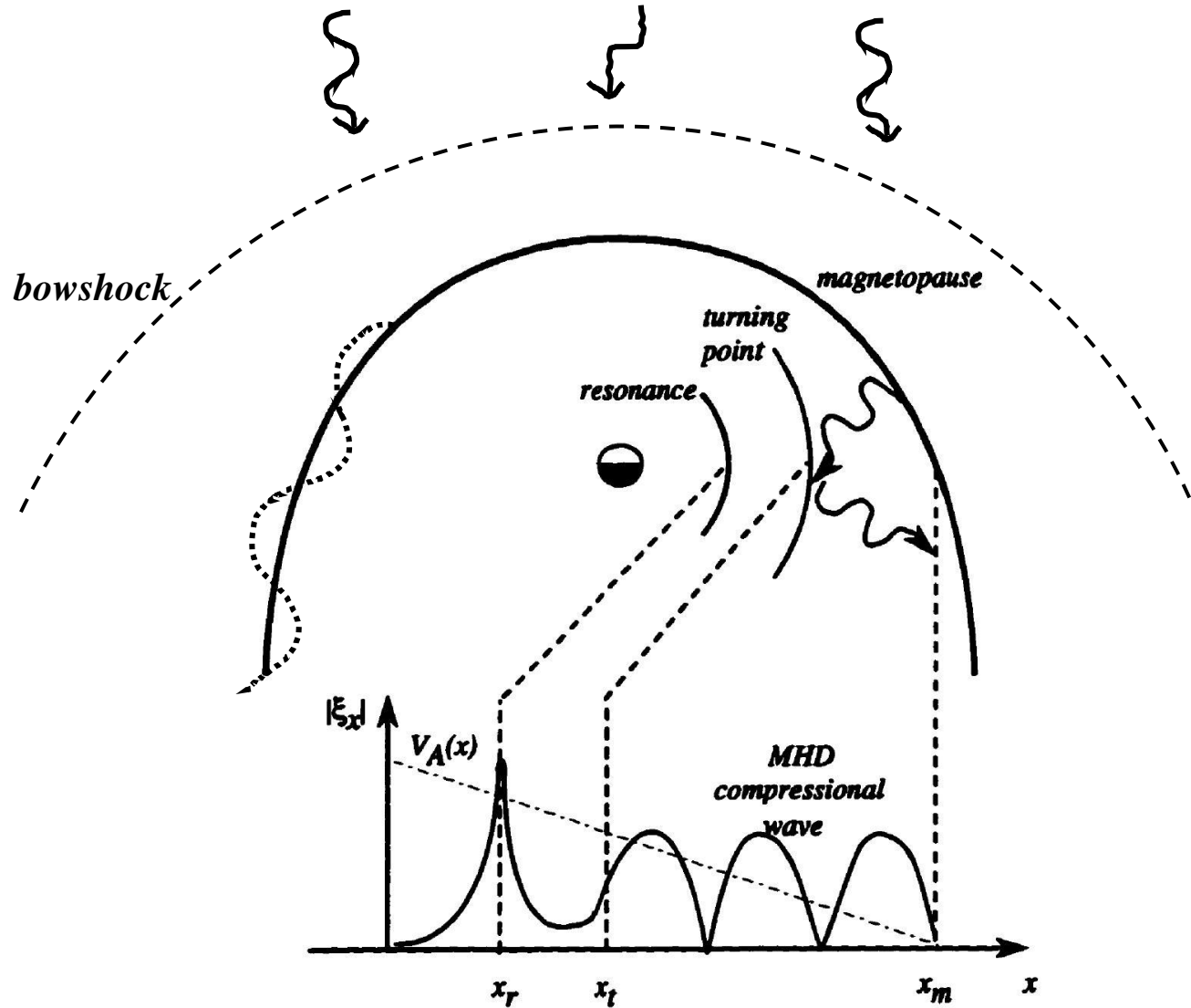


## Wave Sources Driving ULF FLRs:

- Solar Wind Structures and Alfvén waves

# Are the ~10-20 mHz Waves Generating the Auroral Beads Purely Wave-Particle Driven?

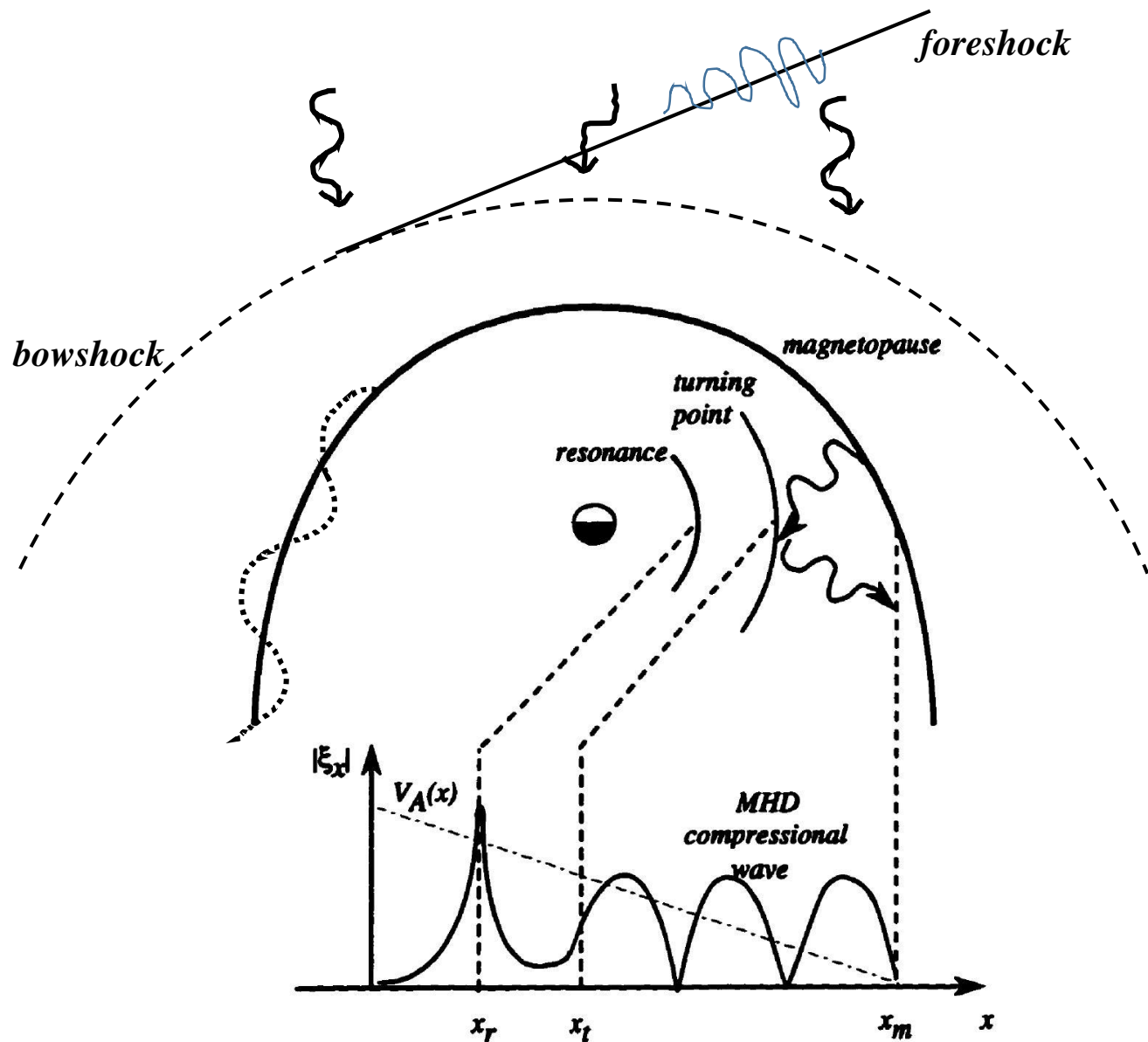
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## Wave Sources Driving ULF FLRs:

- Solar Wind Structures and Alfvén waves
- Kelvin-Helmholtz waves on Magnetopause

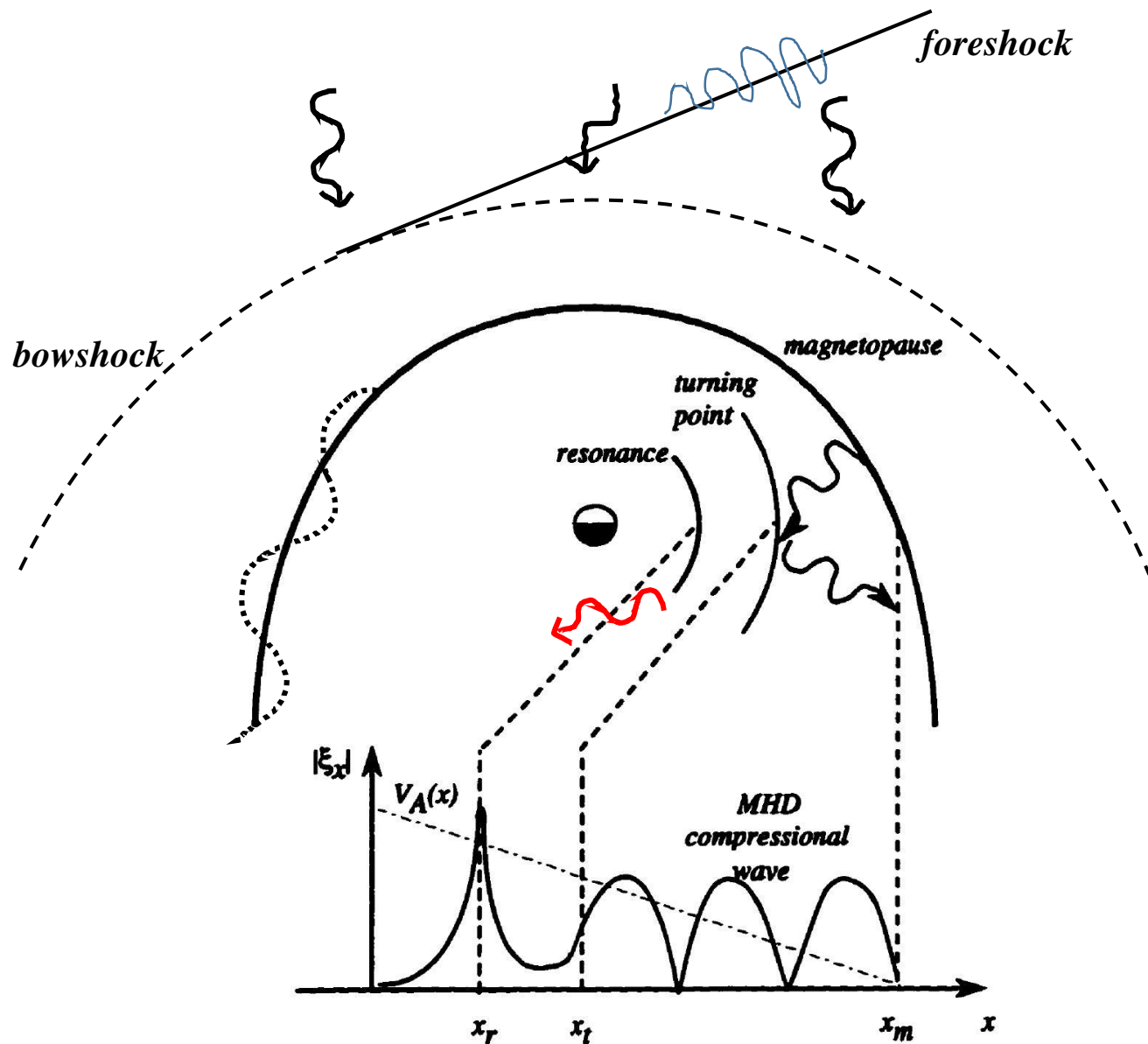
# Are the ~10-20 mHz Waves Generating the Auroral Beads Purely Wave-Particle Driven?



## Wave Sources Driving ULF FLRs:

- Solar Wind Structures and Alfvén waves
- Kelvin-Helmholtz waves on Magnetopause
- Solar Wind Particle Interaction with Foreshock

# Are the ~10-20 mHz Waves Generating the Auroral Beads Purely Wave-Particle Driven?



## Wave Sources Driving ULF FLRs:

- Solar Wind Structures and Alfvén waves
- Kelvin-Helmholtz waves on Magnetopause
- Solar Wind Particle Interaction with Foreshock
- Wave-Particle Driven modes