UNDERSTANDING THE ROLE OF EMIC WAVES IN RADIATION BELT DYNAMICS: RECENT ADVANCES

M. E. Usanova, I. R. Mann, A. Drozdov, K. Orlova, Y. Shprits, D. L. Turner, D. K. Milling, A. Kale, D. N. Baker, S. A. Thaller, G. D. Reeves, H. E. Spence, C. Kletzing, and J. Wygant

LASP, UC Boulder, USA

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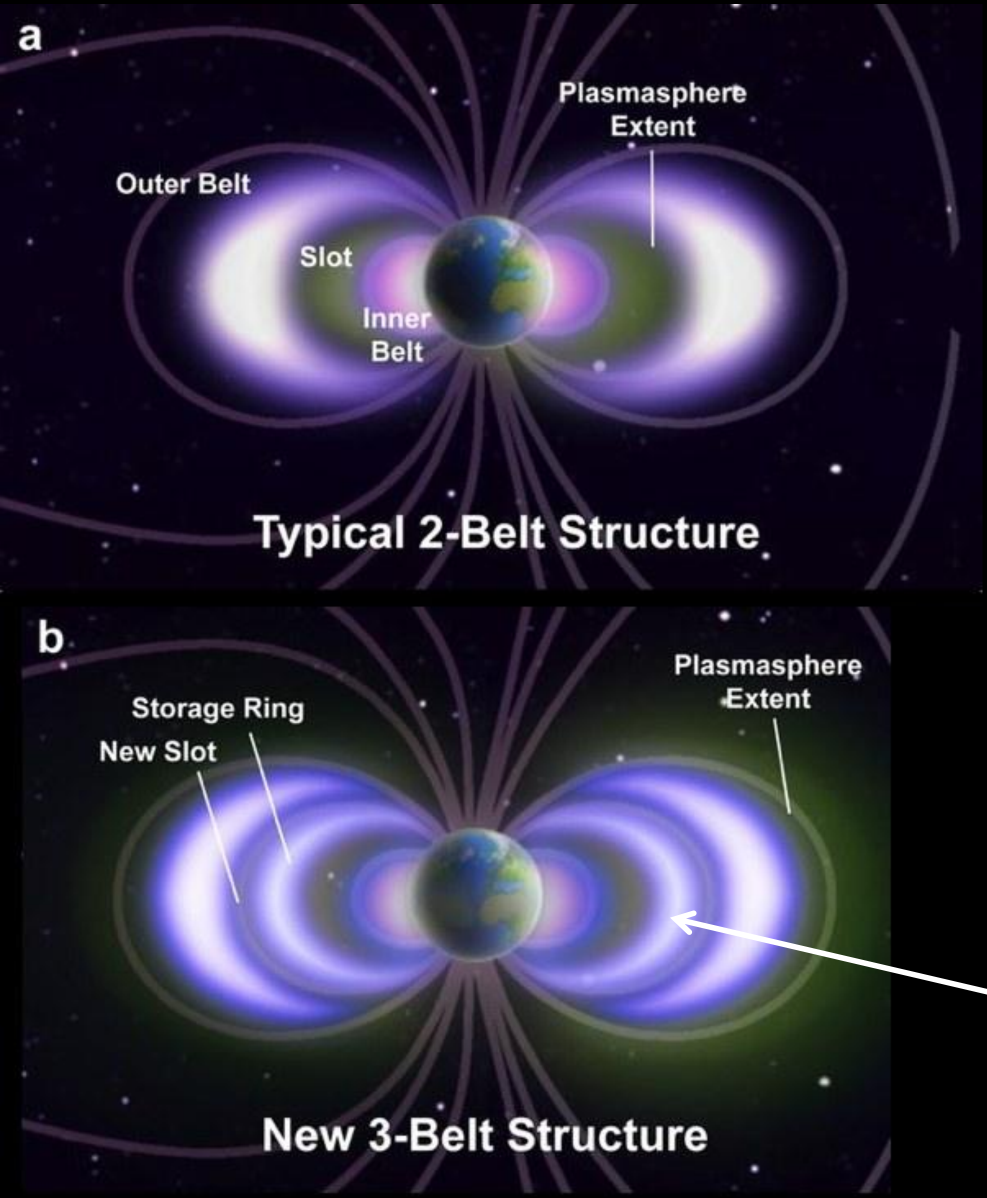
SEVENTH FRAMEWORK PROGRAMME

Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

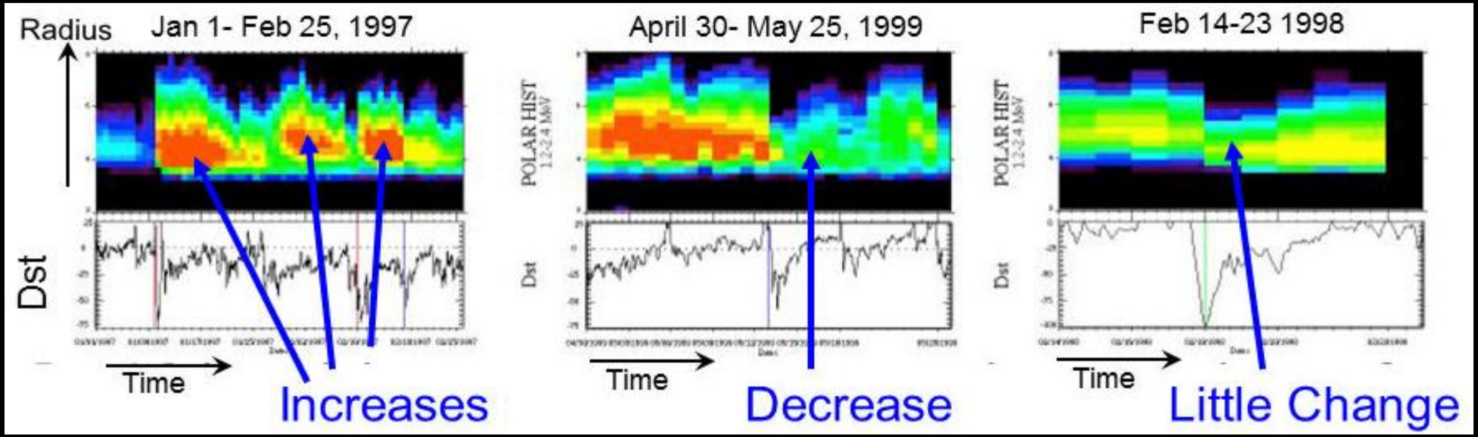
Third Radiation Belt



A very narrow third belt consisting of ultra-relativistic electrons with energy > 2 MeV can be formed and exist for over a month [Baker et al., 2013]

Ultra-relativistic (>2 MeV) belt

Why Wave-particle Interactions?

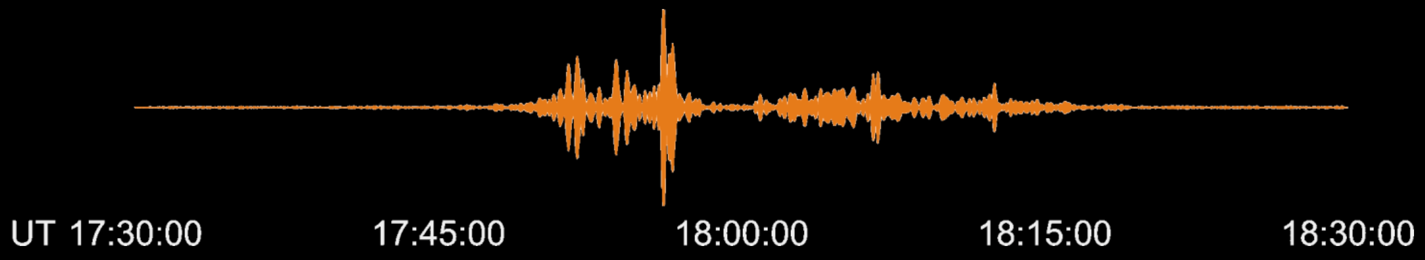


Reeves et al., 2003

Wave-particle interactions with different mode waves are required to explain relativistic (and ultra-relativistic) electron flux variability during different magnetic storms.

Background: Electromagnetic Ion Cyclotron (EMIC) Waves

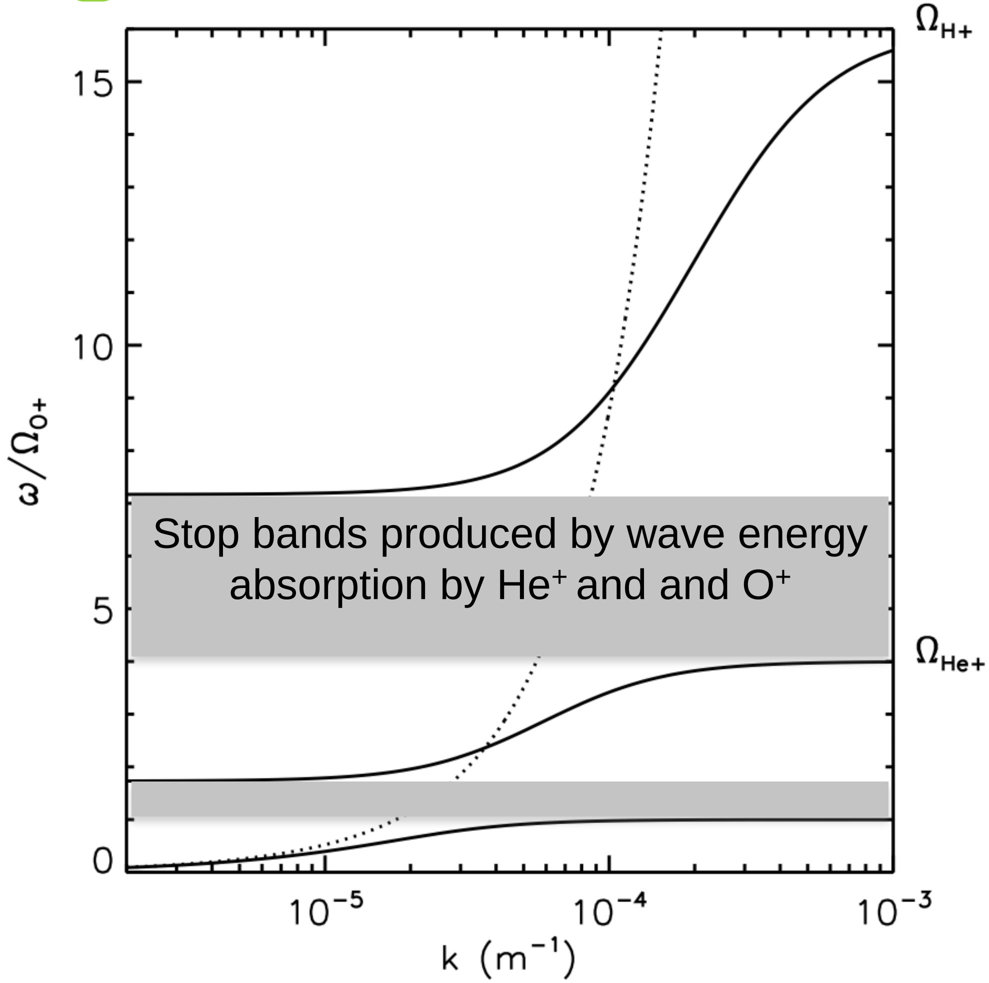
- Transverse plasma waves generated by wave-particle interaction (ion cyclotron instability)
- Energy source: 10 - 100 keV protons with $T_{perp} > T_{para}$
- Typical amplitudes in space:
  ~1 - 10 nT in B, ~1 mV/m in E
- Typical frequencies: 0.1 - 5 Hz (Pc 1 range)
- He^+ and O^+ may introduce additional stop bands and split the wave spectrum into three branches



EMIC Wave Dispersion Relation

EMIC wave dispersion relation for parallel propagation in a plasma composed of 70% H^+, 20% He^+, and 10% O^+ species. The solid curves show the three left-hand polarized modes below the H^+, He^+, and O^+ cyclotron frequencies, respectively.

The dashed curve denotes the right-hand polarized mode which becomes important for oblique propagation.



Adapted from Thorne et al., 2006

EMIC Cyclotron Resonance

EMIC waves can interact resonantly with energetic ions and relativistic MeV electrons if Doppler-shifted wave frequency (in the frame of reference of the particle) matches the particle cyclotron frequency:

$$\omega - k_{||} v_{||} = \frac{\Omega}{\gamma},$$

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

$k_{||}$ is the the wave number and $v_{||}$ is the particle velocity parallel to the background magnetic field.

Resonant particles may exchange energy and momentum with the waves and be accelerated along the background magnetic field and precipitate into the atmosphere while non-resonant particles sustain the wave oscillatory motion.

Localization in the magnetosphere

Kennel & Petschek, 1966: high plasma density lowers the instability threshold

$E_r = B^2/8\pi N/(A^2_c\,(1+A_c))$.

Summers et al., 1998: EMIC waves along the duskside plasmapause due to continuous convective injection of anisotropic ions

Olsen & Lee, 1983: generation of EMIC waves during sudden solar wind impulses due to adiabatic heating

Anderson & Hamilton 1993: EMIC waves close to the magnetopause during modest magnetospheric compressions

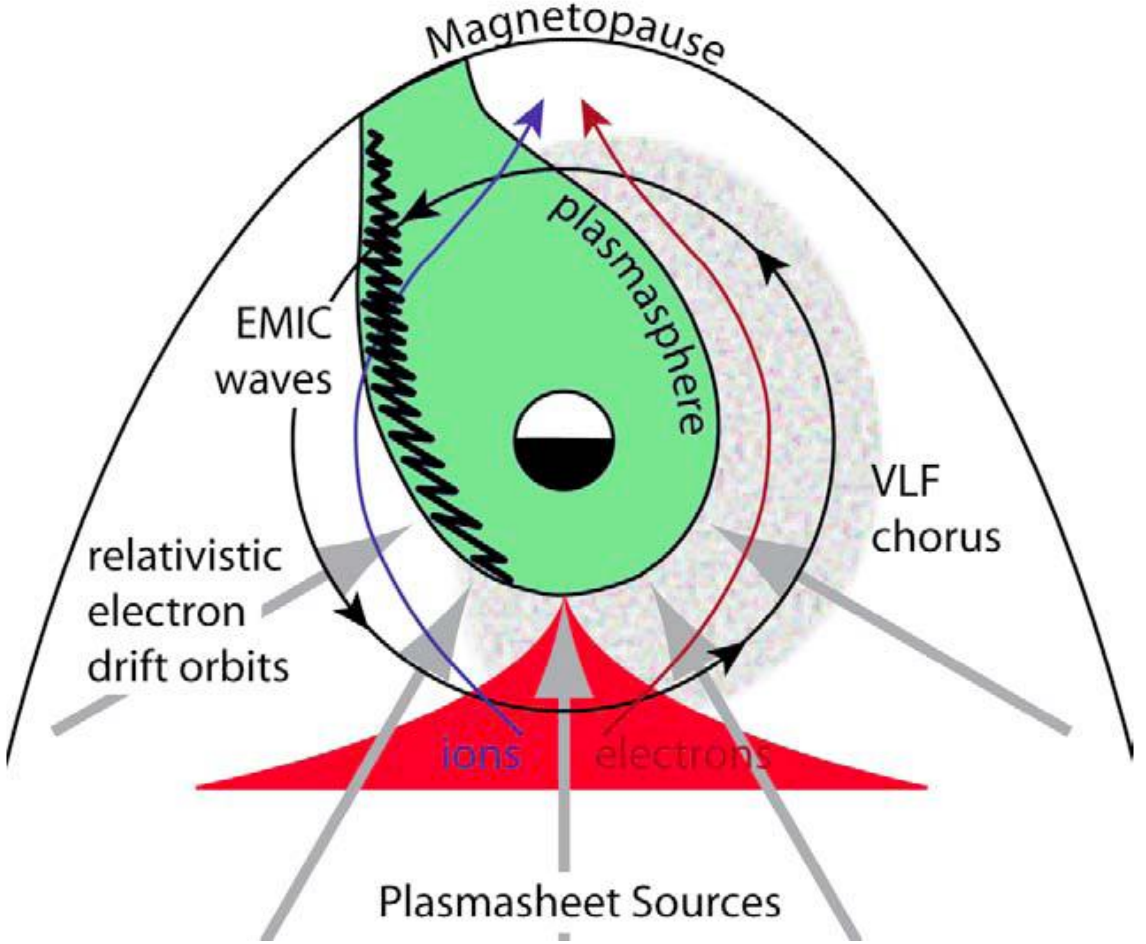
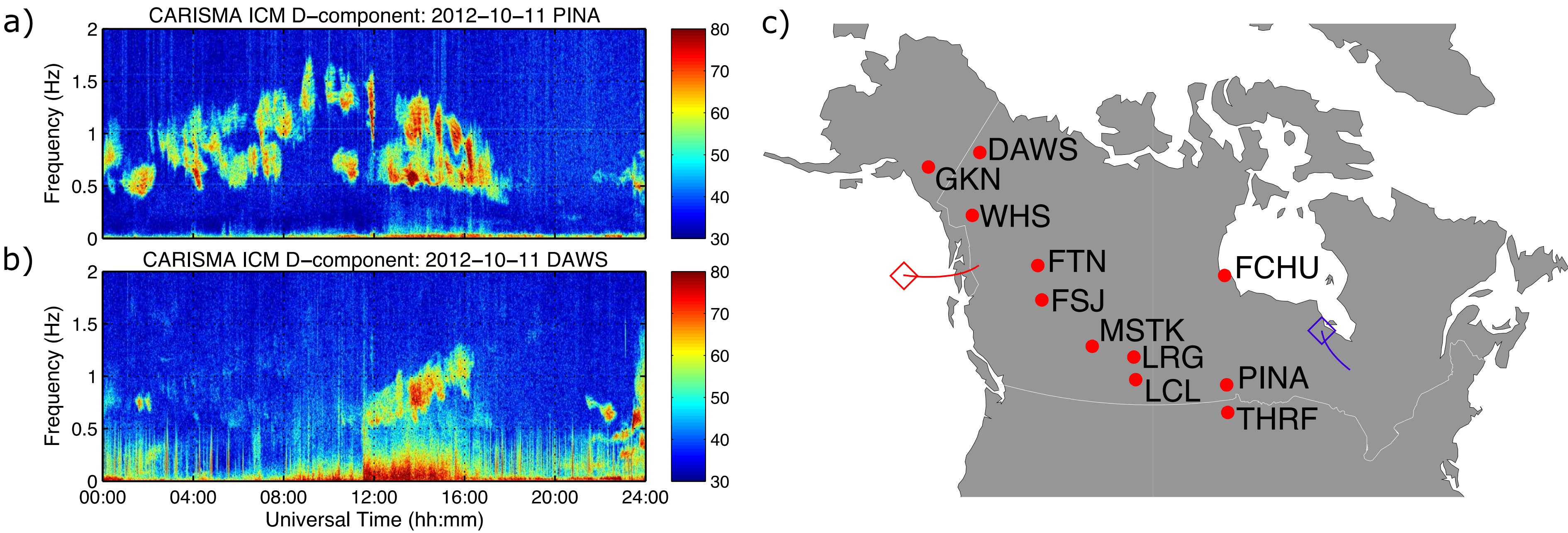


Figure by *G. Reeves* adapted from *Summers et al., 1998*

Long-lasting EMIC Event from October 11, 2012

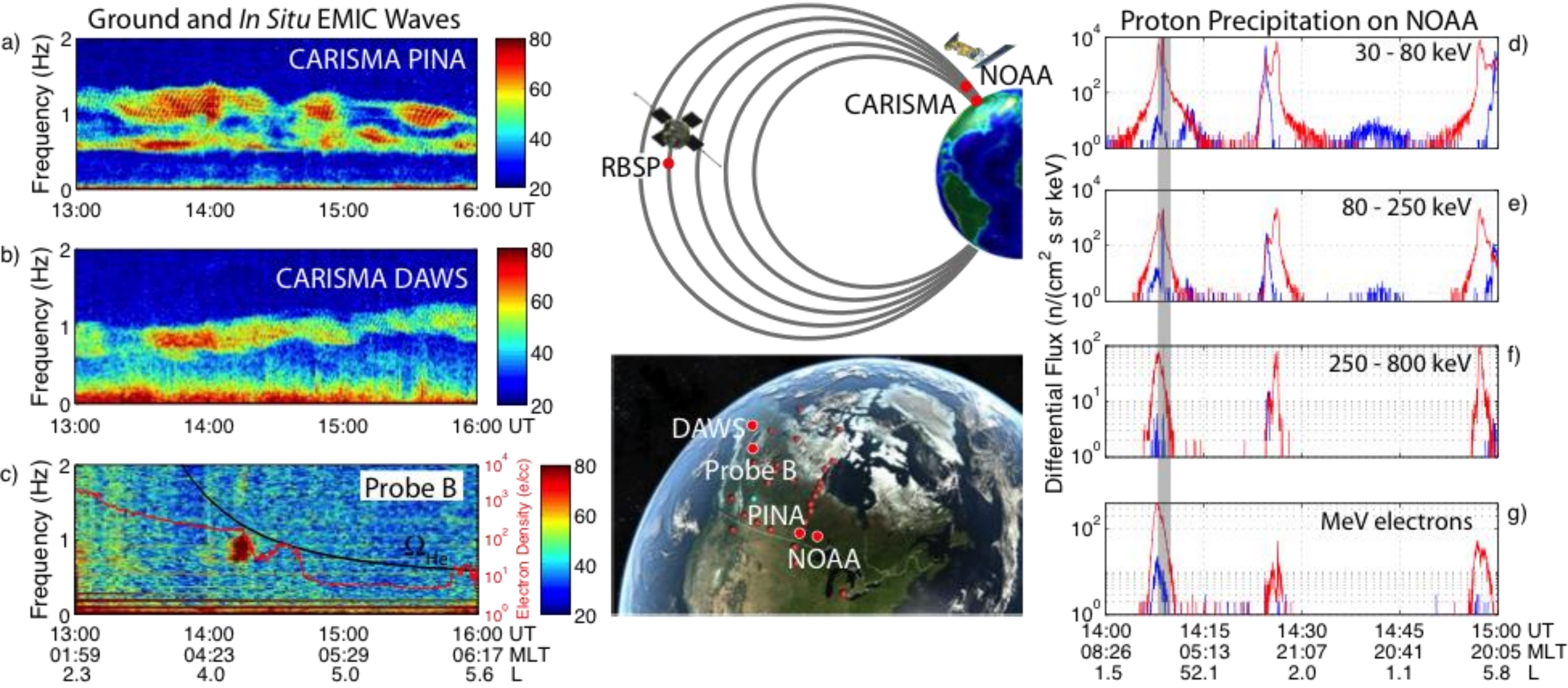
(Mann et al. and Usanova et al., special issue GRL's 2014)



(left) Magnetic field spectrogram from the CARISMA Pinawa station (L~4) and Dawson (L~6) on October 11, 2012.

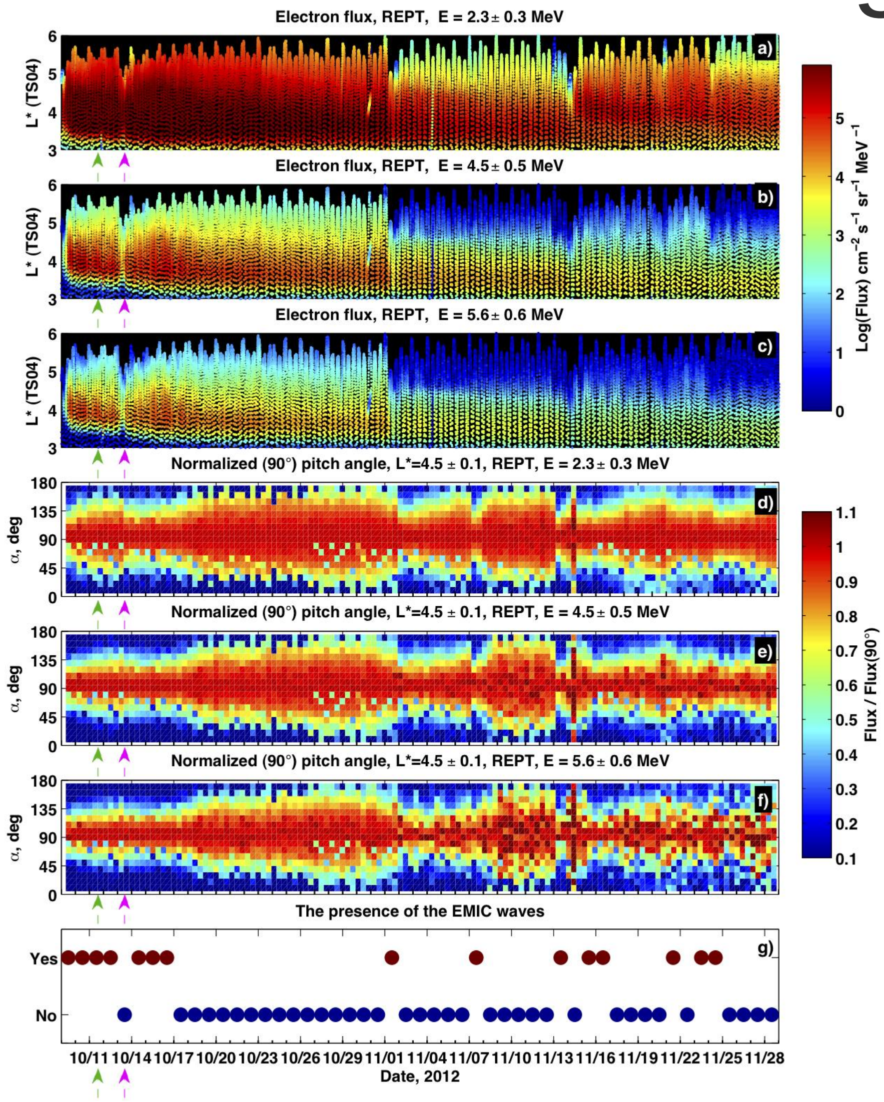
(right) Map showing CARISMA stations and Van Allen Probes ground footprints

Ground and Van Allen Probes EMICs and Proton Precipitation at LEO



Conjugate EMIC wave observations from the CARISMA magnetometers and the Van Allen Probes together with proton loss on the LEO-orbit NOAA POES satellite on October 11, 2012.

Electron Pitch-Angle Scattering



Differential electron flux as a function of L* (a-c), and differential flux as a function of PA, normalized by the 90-degree PA flux, at L*=4.5 (d-f) in the 2.3, 4.5, and 5.6 MeV energy channels,, and EMIC wave occurrence from L~4-4.5 on the ground (g)
between October 9 – November 29, 2012.
The green arrow: time of this EMIC event.
The purple arrow: the time of the minimum Dst in the consequent storm at 11 UT on October 13, 2012.

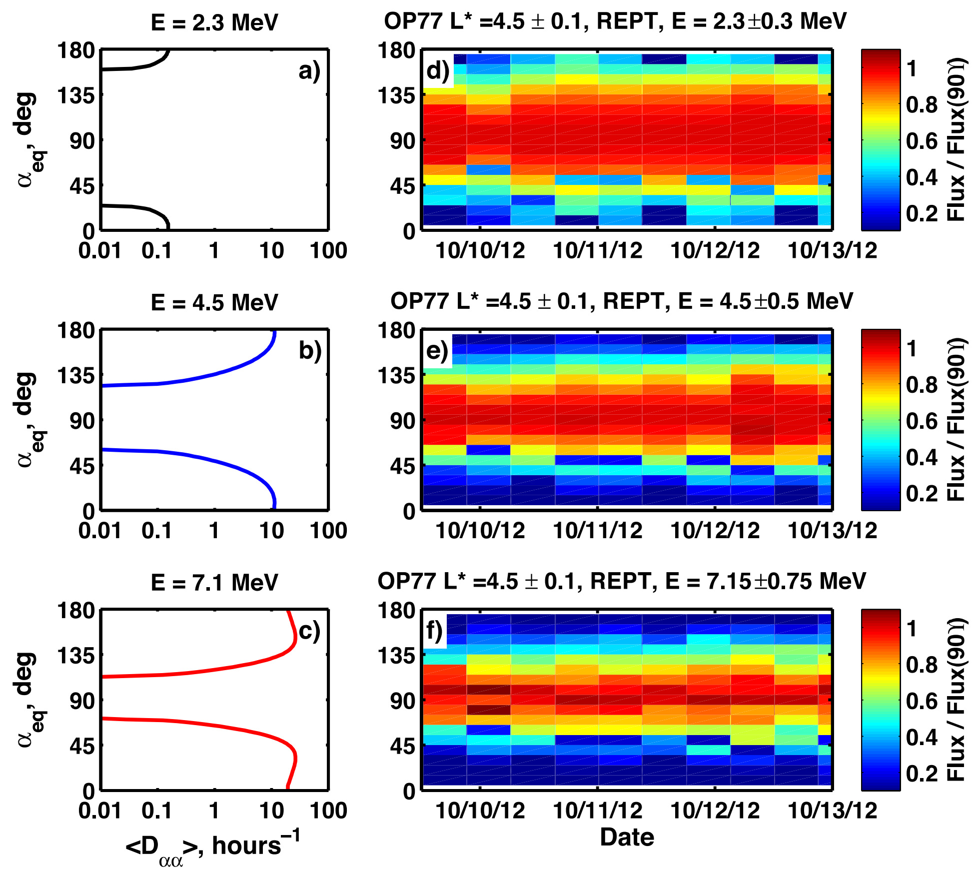
Computed Electron Pitch-Angle Diffusion

Parameters for the electron pitch-angle diffusion estimate:
B=330 nT; n_e=150 cm^{-3};
B_{EMIC}=2 nT; f_{EMIC}=0.7-1.1 Hz - RBSP

MLT extent: 25% of drift orbit

Ion composition:
70% H^+; 20% He^+; 10% O^+ } *assumption*

Computed pitch-angle diffusion coefficients (a-c) and observed normalized electron flux as a function of pitch-angle (d-f) in the 2.3, 4.5, and 7.15 MeV for October 9-13, 2012.



Summary

- We are interested in role of EMIC waves in radiation belt depletion.
- We identified a long lasting event during the Van Allen Probes era.
- We did not observe precipitation of >0.7 MeV electrons on POES satellites, nor did we observe any significant decreases of spin-averaged ultra-relativistic electron fluxes on the Van Allen Probes.
- We presented the first observation that EMIC waves affect low-pitch angle particles and do not affect the core RB distribution
- Future modeling and observations are required to address relativistic and ultra-relativistic electron response to EMIC waves, and to examine the dependence on various wave and plasma parameters in controlling the dynamics of the energetic electron population.