A Critical Test of Electron Acceleration in the Van Allen Radiation Belts

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CLUSTER, ESTEC , 22nd September, 2005

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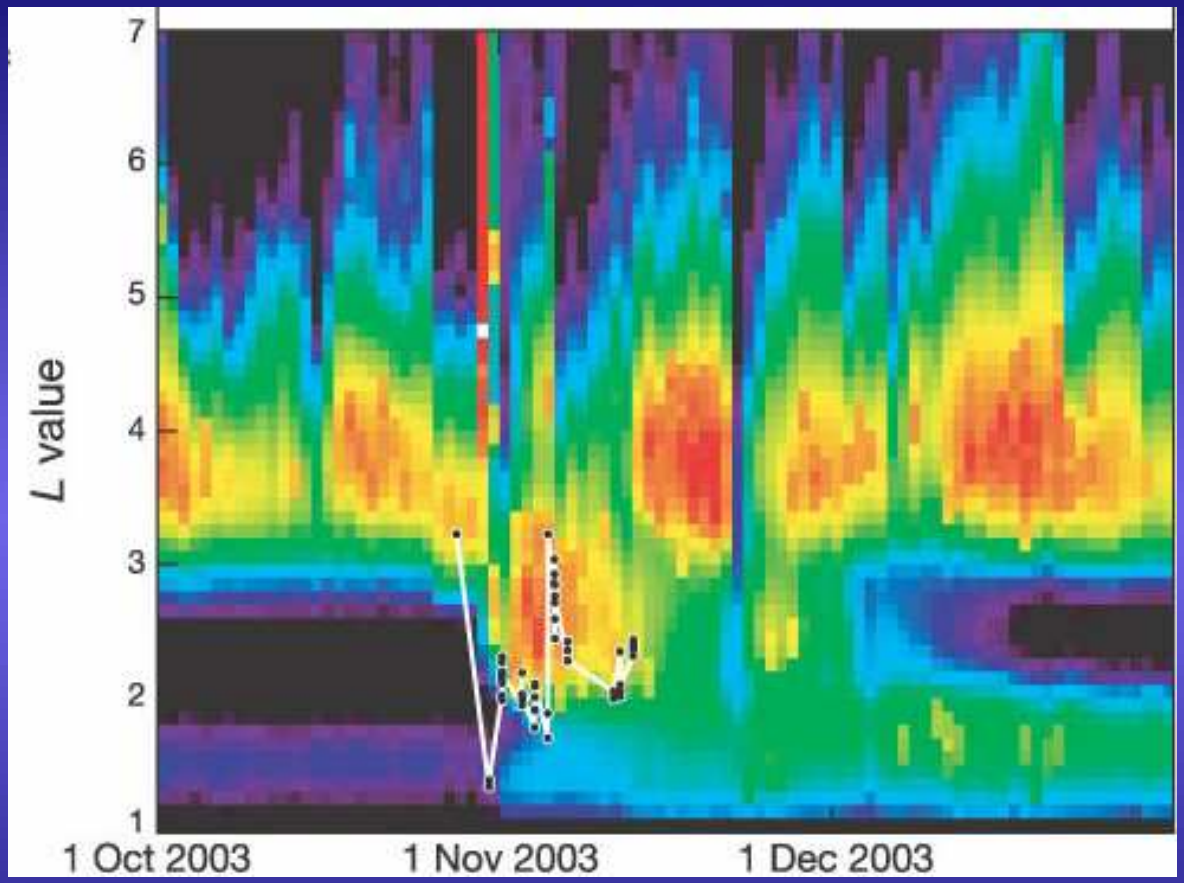
Haloween 2003 Magnetic Storm



- ~MeV electron flux increase in slot region
- Plasmapause L < 2.5
- Use to test electron acceleration theories

Baker et al. Nature [2004]

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Brautigam and Albert [2000]

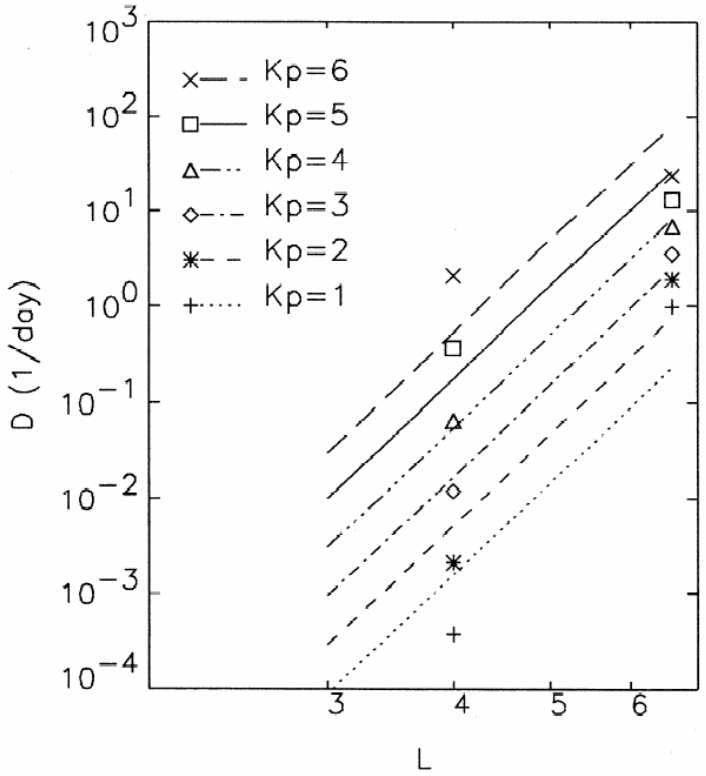

Figure 5. D^{M}_{LL} as a function of L, for Kp=1 to 6. Discrete values of D^{M}_{LL} at L=4.0 are adapted from *Lanzerotti and Morgan* [1973]; those at L=6.6, from *Lanzerotti et al.* [1978]. Continuous curves of D^{M}_{LL} are proportional to L^{10} (equation (6)) and were determined to maximize agreement with the discrete values. The legend associates a symbol (discrete D^{M}_{LL}) with its corresponding linestyle (continuous D^{M}_{LL}) for a given Kp.

- Radial diffusion most effective at large L
- Diffusion rate scaled by Kp
- Underestimates MeV flux near L=4

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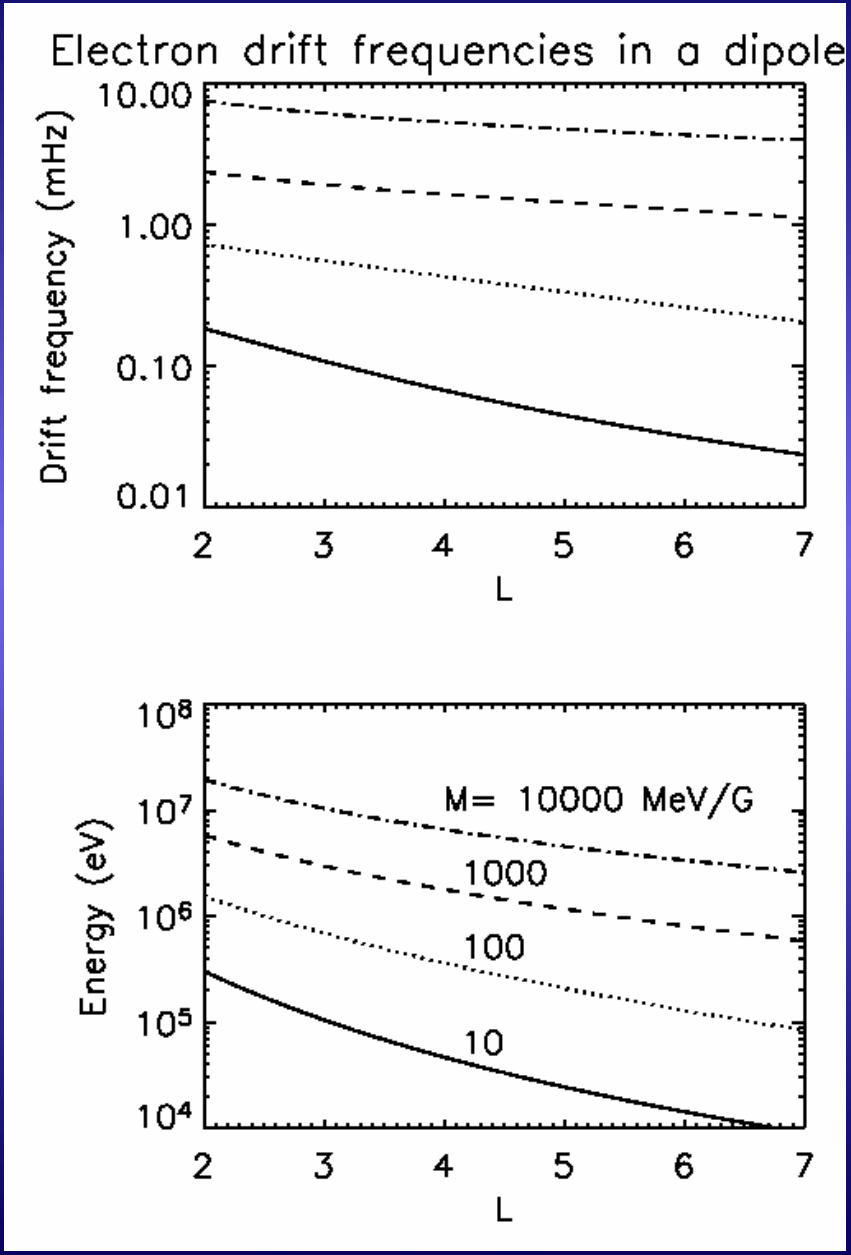
Radial Diffusion



- ULF waves drive radial transport when wave frequency matches the particle drift frequency
- For L ~ 2.5 – 3.3 and E~ 1 - 5 MeV
  - M ~ 100 – 1000 MeV/G
- Need waves at ~ 0.5 – 2 mHz

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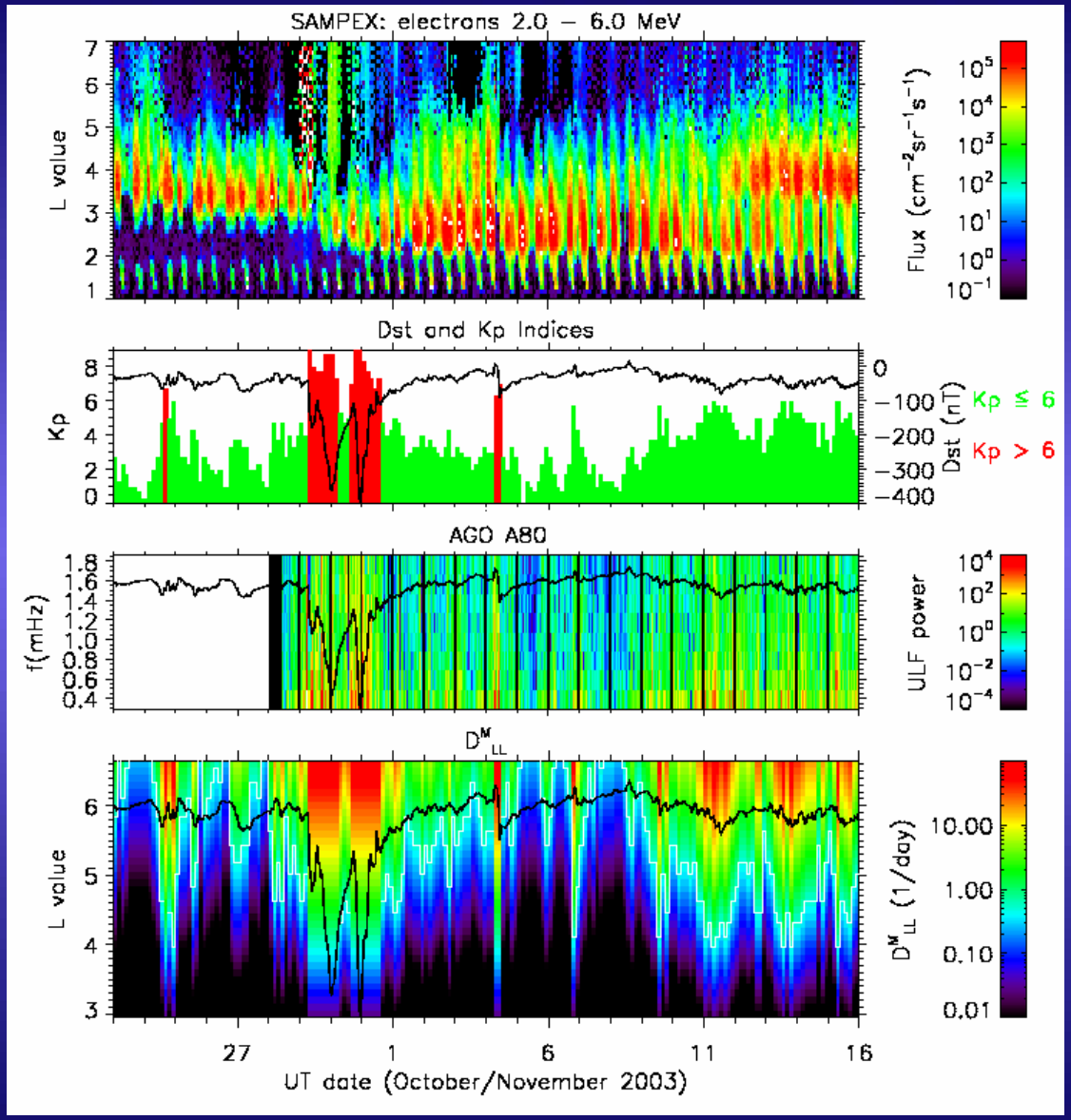
Halloween Storms



- 29 Oct, outer belt decays, new belt forms near L~ 2.
- Kp and ULF wave power is large
- 1 Nov onwards; flux increases by factor ~10, *when ULF wave power drops*
- Radial diffusion rate (DLL) decreases
  - comparable to before storm
- *Suggests another acceleration mechanism*

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Wave Acceleration

- Accelerate radiation belt electrons by whistler mode chorus waves
  - [Horne and Thorne, 1998; Summers et al. 1998]
- Waves generated by 10 – 100 keV electrons
  - Substorms and radial diffusion
- Electrons at small pitch angles lost into atmosphere
  - Wave growth – pitch angle diffusion
- But
- Electrons at large pitch angles accelerated to high energies ~ MeV
  - Trapped – energy diffusion
- Energy transfer

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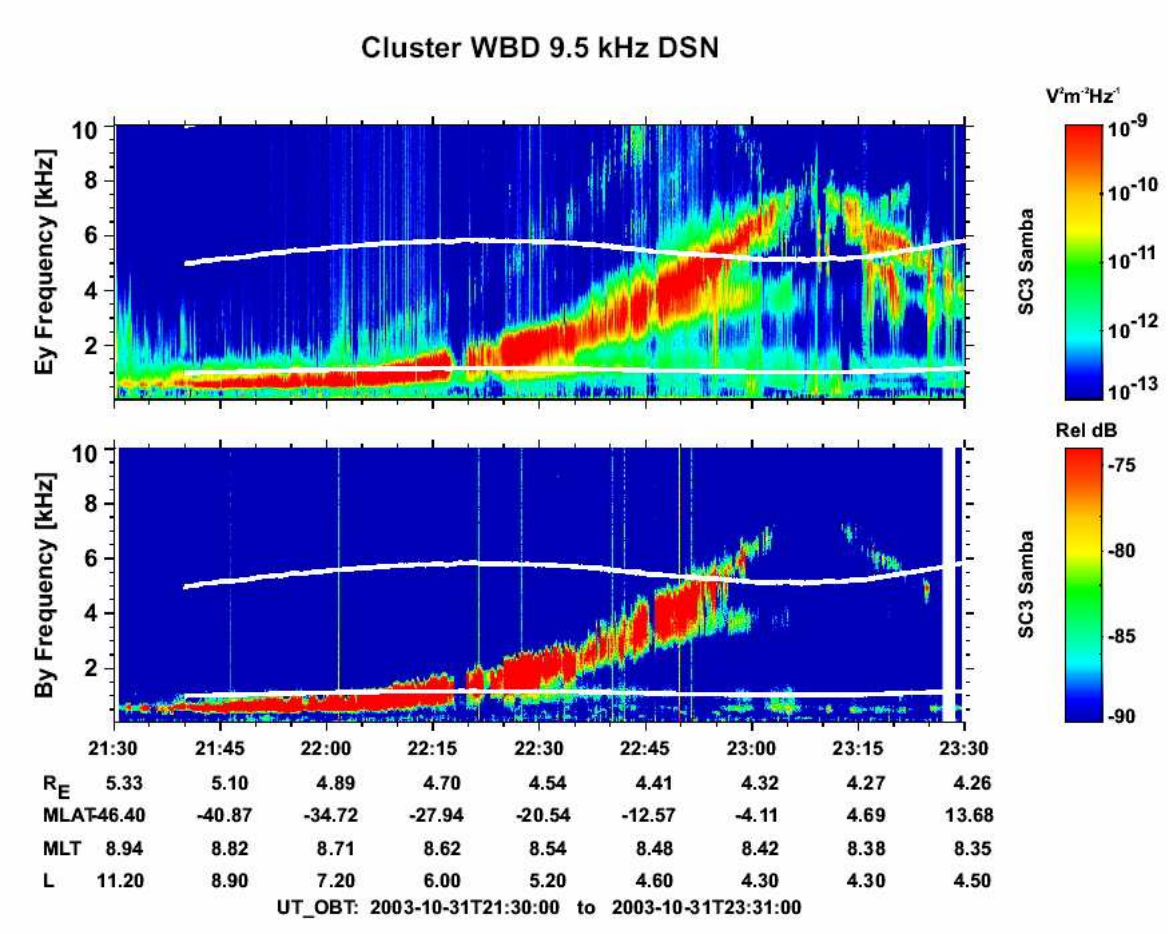
CLUSTER Wideband Wave data



- 31 Oct 2003
- Strong chorus waves
- Power spectral density ~ 6 x 10^{-6} nT^2 Hz^{-1}
- L ~ 4.3 at equator

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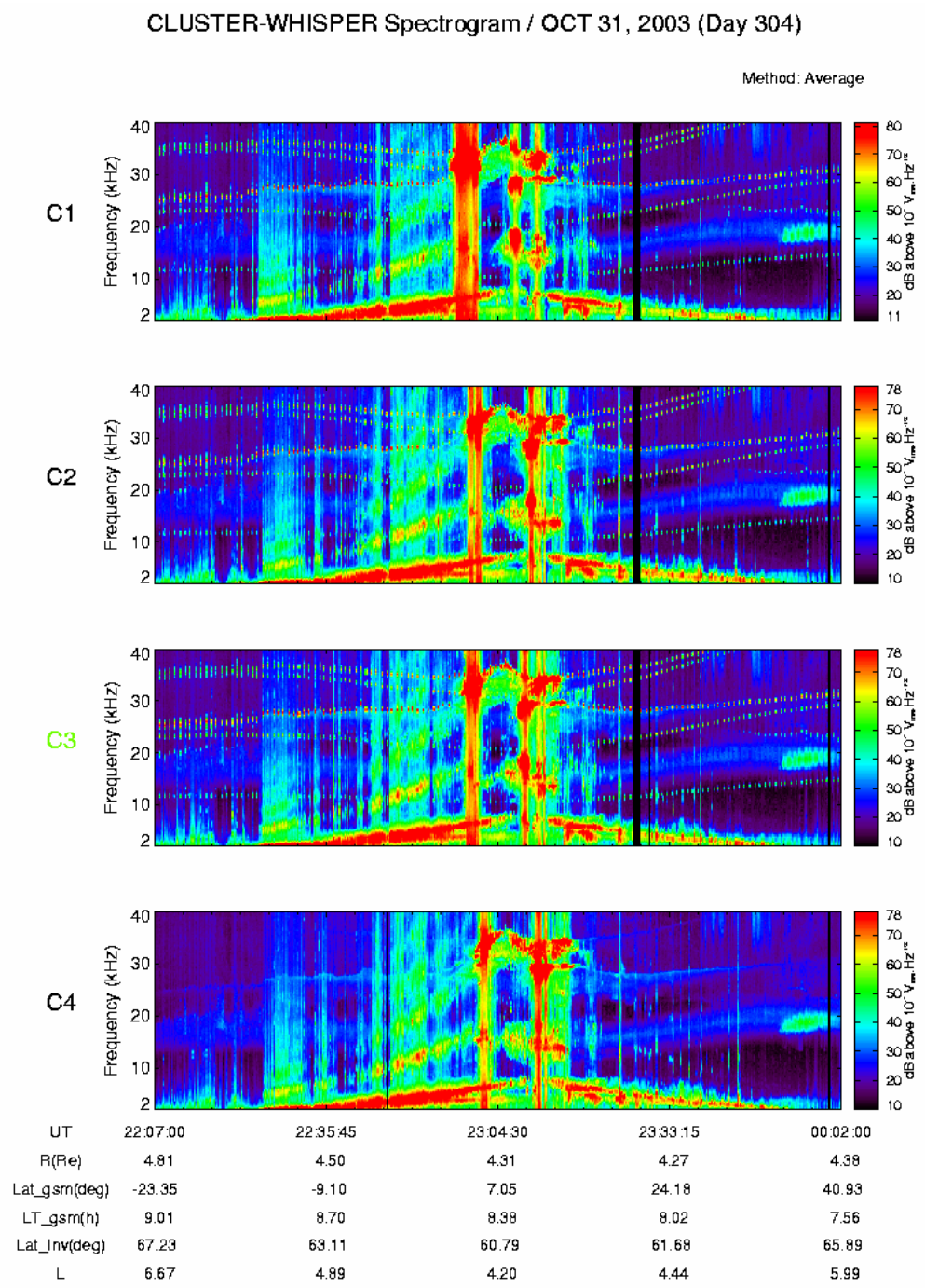

Cluster Whisper Data

- Evidence for whistler mode chorus waves on 31 Oct 2003
- Use the sounder to obtain fpe and fce
- At equator, L~ 4.3,
  - fce ~ 10 kHz
  - fpe ~ 35 kHz
  - fpe/fce ~ 3.5

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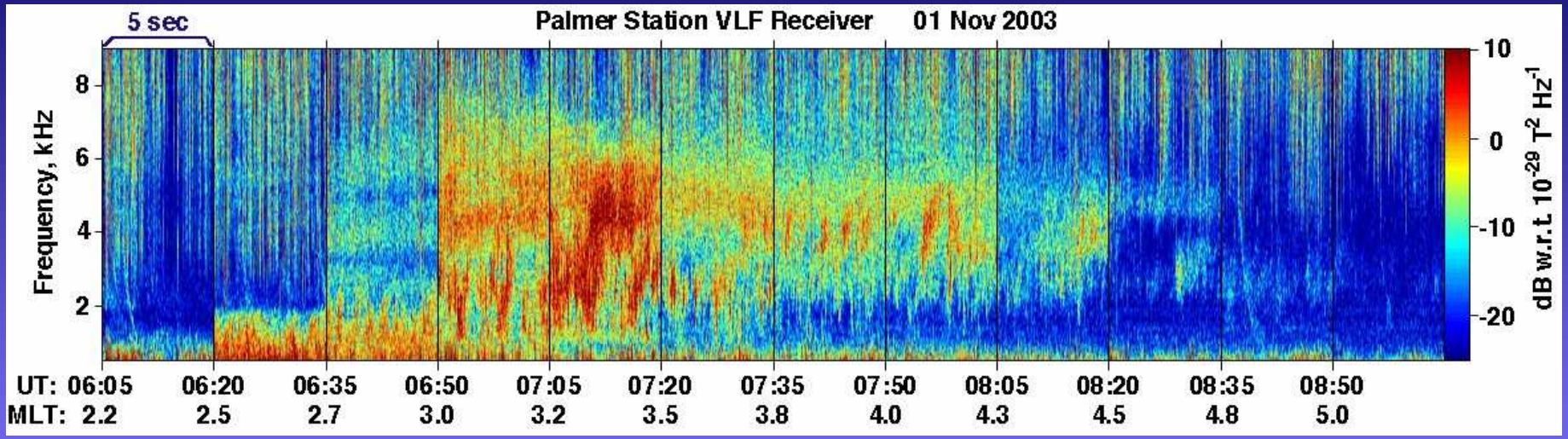
Palmer, Antarctica, L=2.6



- Unusually high frequency chorus ~ 6 kHz
- Station in daylight
  - strong attenuation
- At equator fce ~ 50 kHz
- Guiding of whistler waves by the magnetic field suggests waves near L ~ 2.6 in space

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Calculate Increase in Flux

- Calculate increase in flux using 1d Fokker Planck eqn.

$$\left\langle \frac{\partial F}{\partial t} \right\rangle = \frac{\partial}{\partial E}\left[A(E)\langle D_{EE}\rangle \frac{\partial}{\partial E}\left(\frac{F}{A(E)}\right)\right] - \frac{F}{\tau_L},$$

- Calculate energy diffusion coefficients from PADIE code [Glauert and Horne, 2005]

$$A = (E + E_0)(E + 2E_0)^{\frac{1}{2}}E^{\frac{1}{2}},$$

- For initial conditions
  - use average flux observed by CRRES at L=4.5 and 2.5
- Assume waves exist for 6 hrs MLT outside plasmapause at L=2.5 [IMAGE data]

- 1st term = energy diffusion due to chorus waves
- 2nd term = losses due to pitch angle scattering
- F = distribution function
- DEE = energy diffusion coefficients

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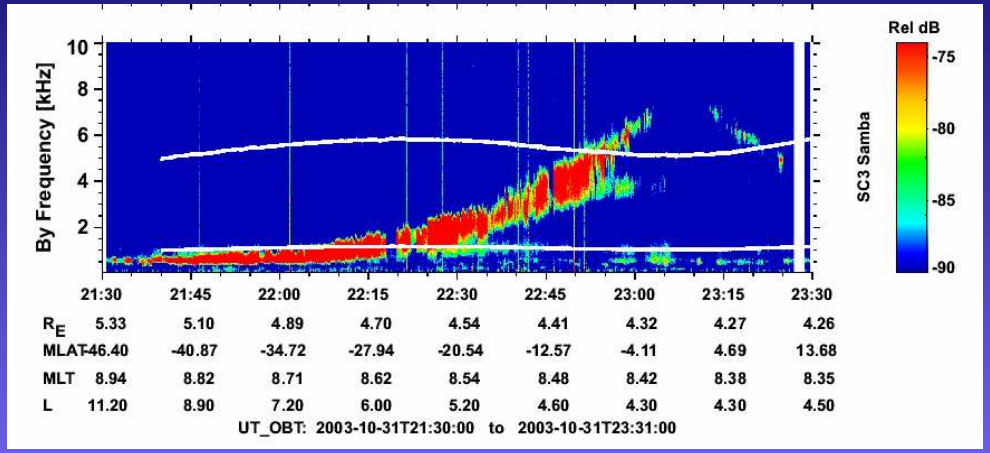
Calculate Energy Diffusion Coefficients

- Wave power (CLUSTER)
  - 6 x 10^{-6} nT^2 Hz^{-1} at L=4.5 and 2.5
- Assume Gaussian distribution
  - Peak frequency at 0.35fce
  - Bandwidth of 0.15 fce
- Angular spread:
  - Gaussian in X = tan(Y)
  - Peak along B0, X=0
  - Angular width, Xw = tan(30^0)
- Bounce average along B field
  - Assume fpe = constant, B=dipole
- Wave power < 15^0 latitude



- Use PADIE code
- Calculate all resonant wave-particle interactions for n = -5,....0,....5 harmonics

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Increase in Flux due to Wave Acceleration

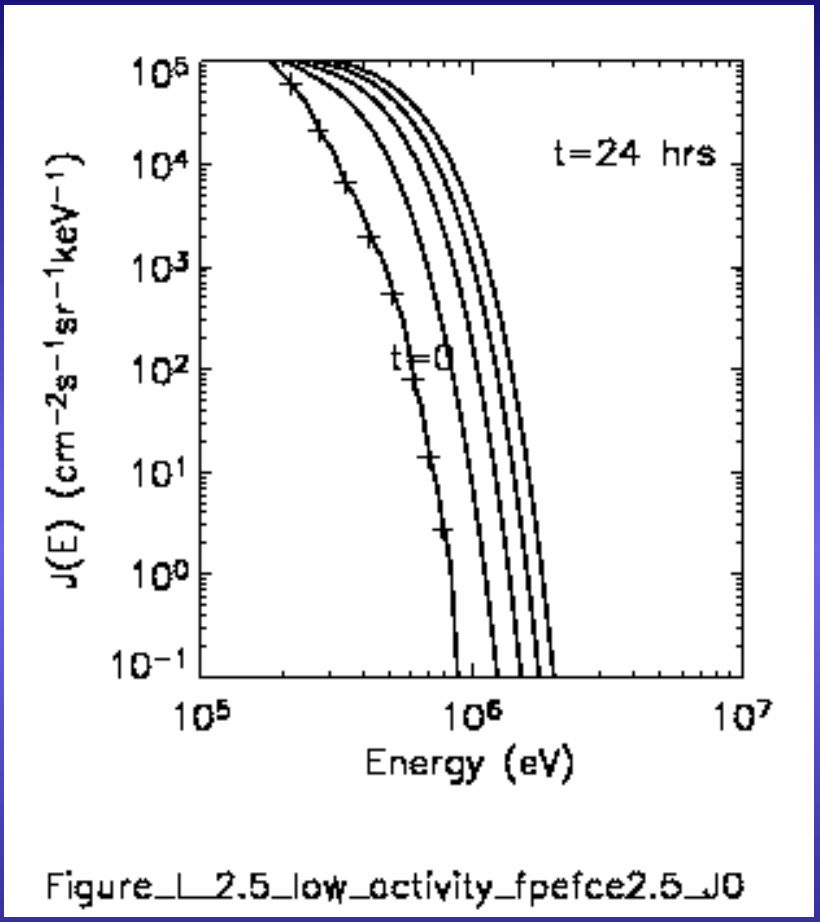

Figure_1_2.5_low_activity_fpefce2.5_J0

- L=2.5, fpe/fce = 2.5

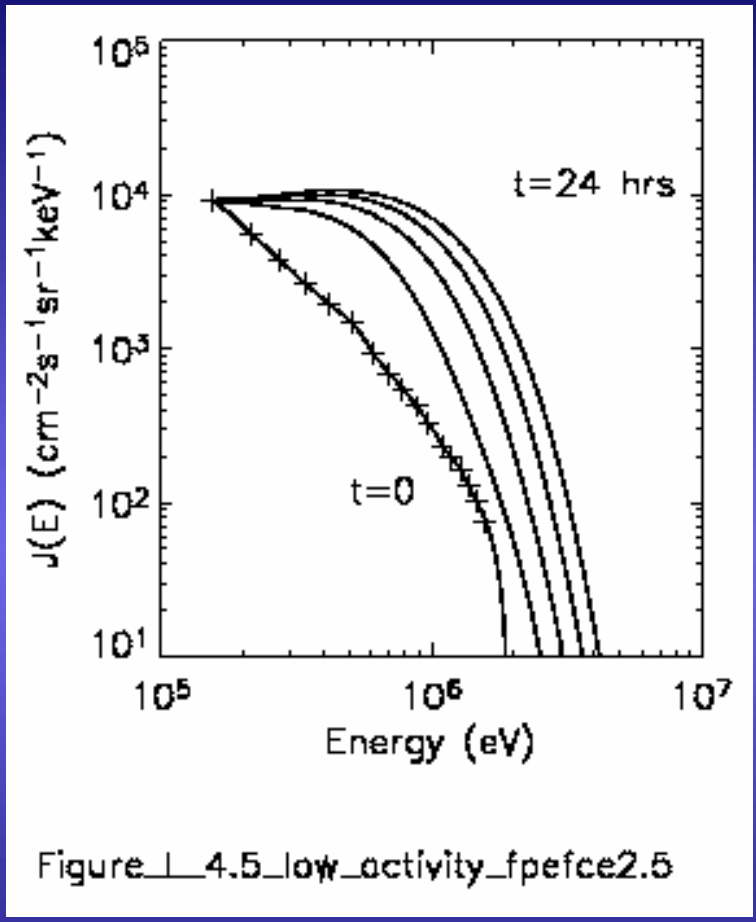

Figure_1_4.5_low_activity_fpefce2.5

- L=4.5, fpe/fce = 2.5

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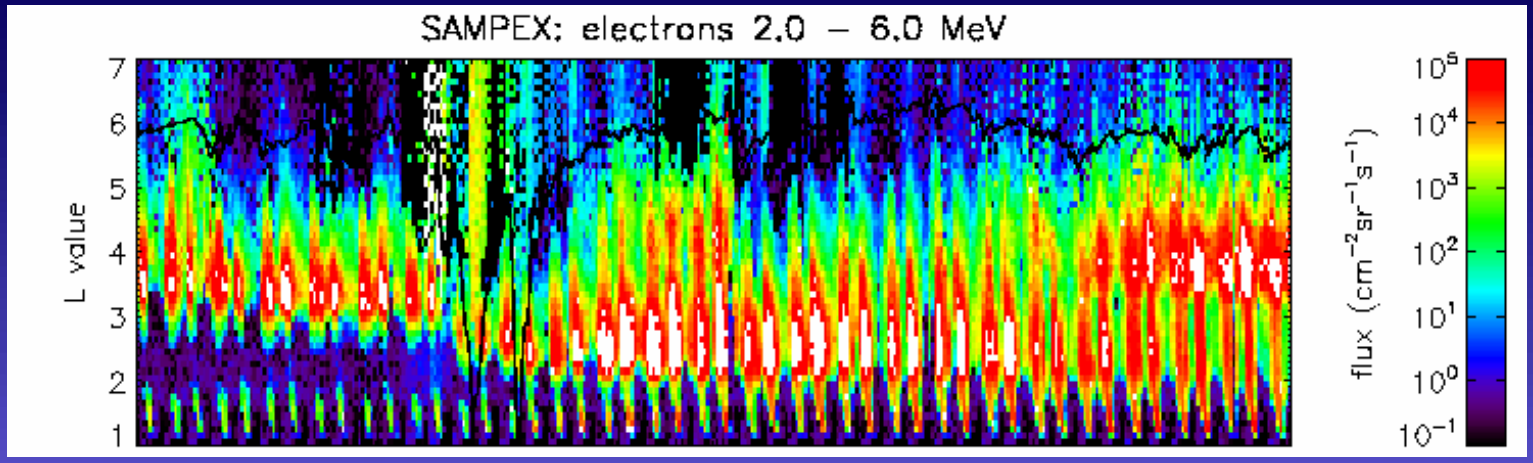

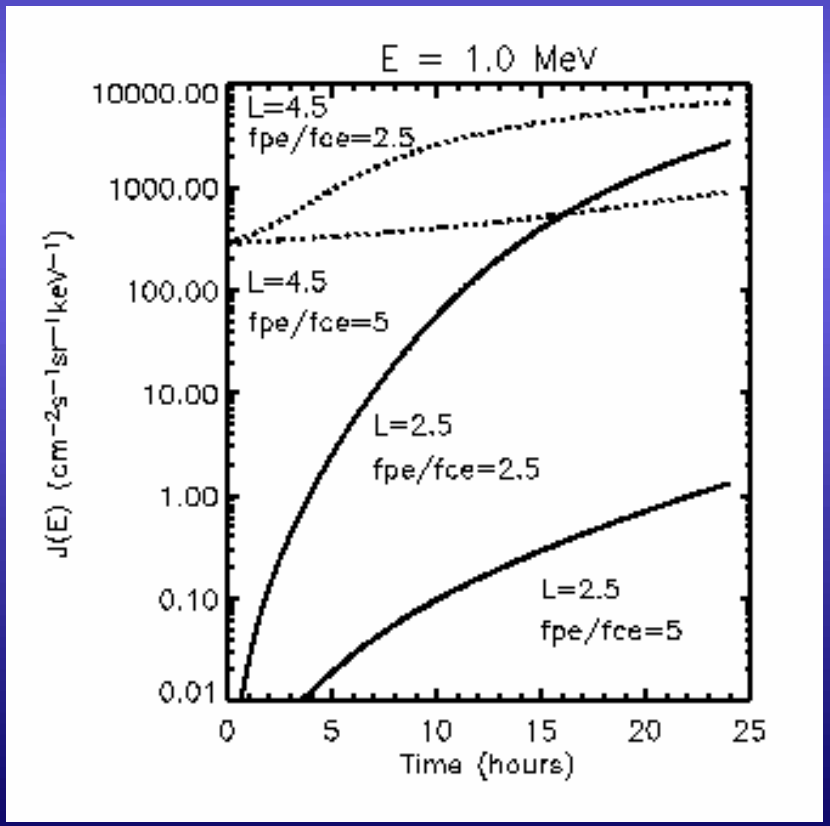

- Largest flux increase is for L=2.5 and low fpe/fce = 2.5
- At L=4.5 flux increase is smaller
- Wave acceleration can account for increase in new radiation belt

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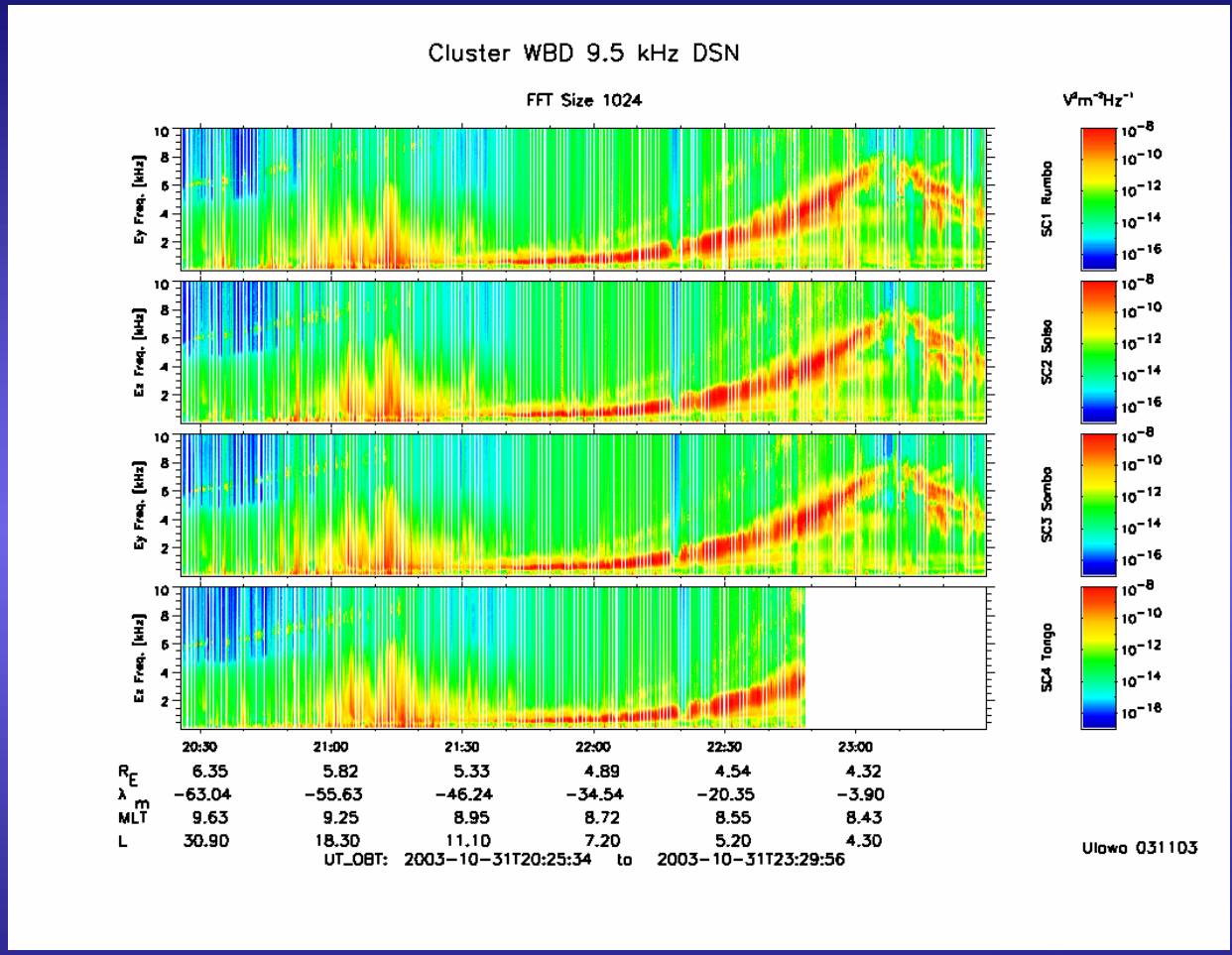
Summary and Conclusions

- Injection of MeV electrons into slot region (L ~ 2.5) observed during 2003 Haloween storm
- Major flux increase at L~2.5 occurred when ULF wave power decreased
  - Suggests local acceleration process – not just radial diffusion
- Strong whistler mode chorus observed
  - by CLUSTER at L ~ 4.3 with low fpe/fce ~ 2.8
  - At Palmer Antarctica, L~ 2.6
- Chorus wave power sufficient to increase flux to observed levels at L=4.5 and L=2.5 within 24 hours – for range of observed fpe/fce
- Suggest wave acceleration responsible for > 2 MeV flux increase in the new radiation belt

Cluster Wideband Wave Data L~ 4.3



- 31 Oct 2003, ~ 09:45 MLT
- Strong chorus waves
- Chorus strong for 45º >lat > 5º

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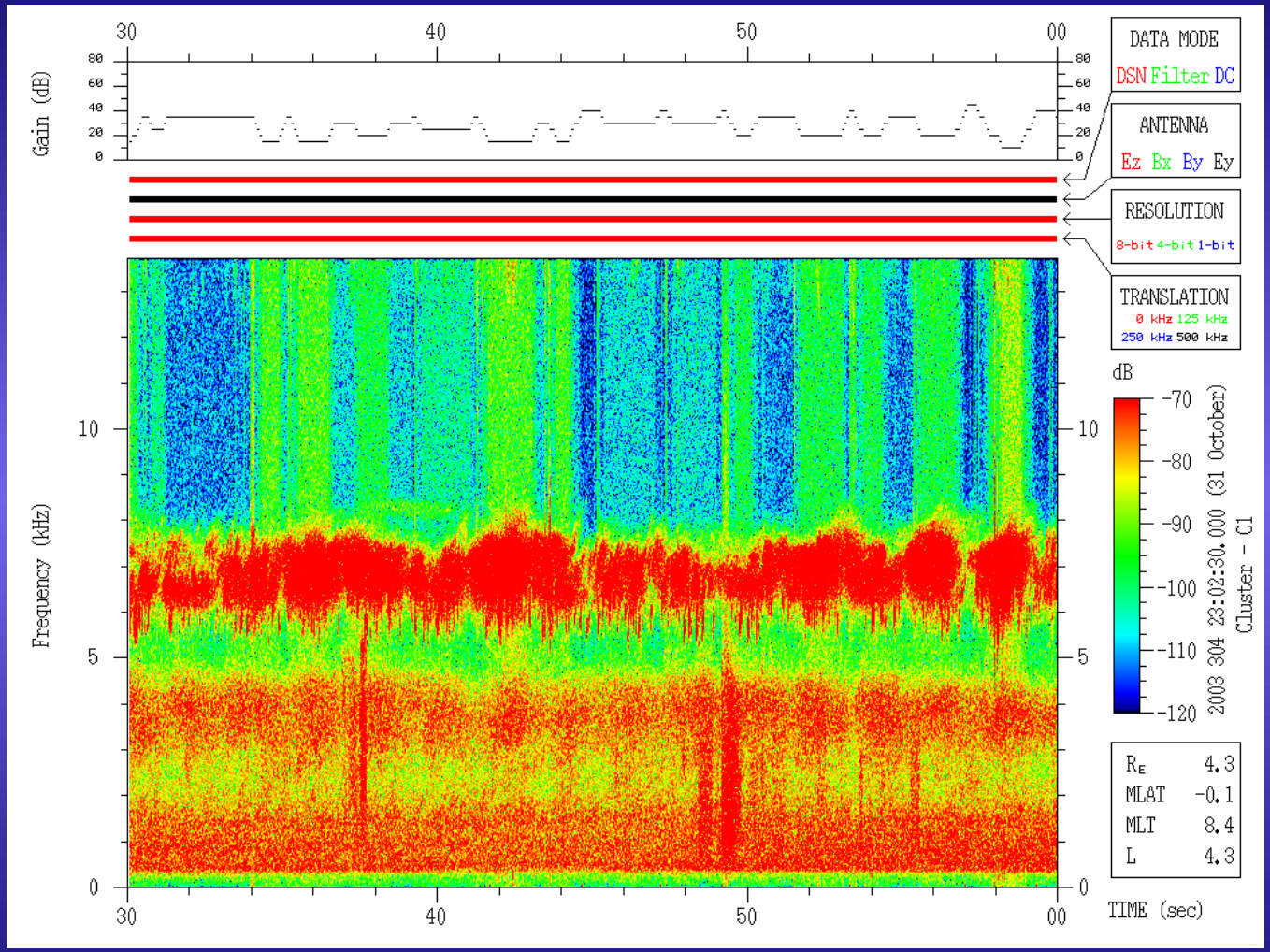
Cluster 1 Wideband Data



Lat = 0.1°

fce = 10 kHz

Bw ~ 63 pT

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