Van Allen Probes observations of wave-particle interactions in the Earth's radiation belts

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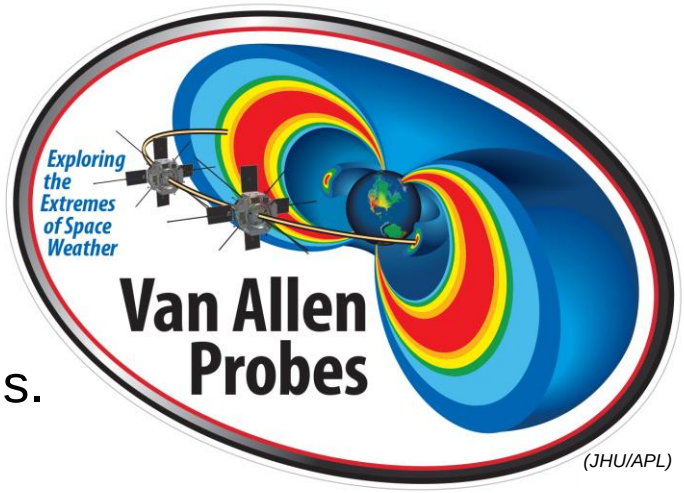
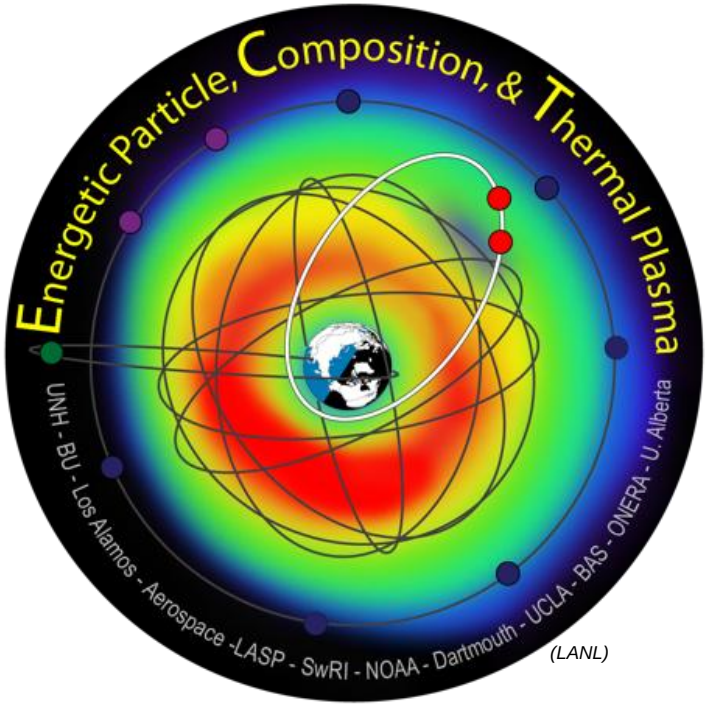
Geospace Revisited
2014/09/15
seth@aero.org

Outline



(JHU/APL)

- ECT/MagEIS instrument description and status.
- Drift-resonance observations.
- Background corrected electron flux.



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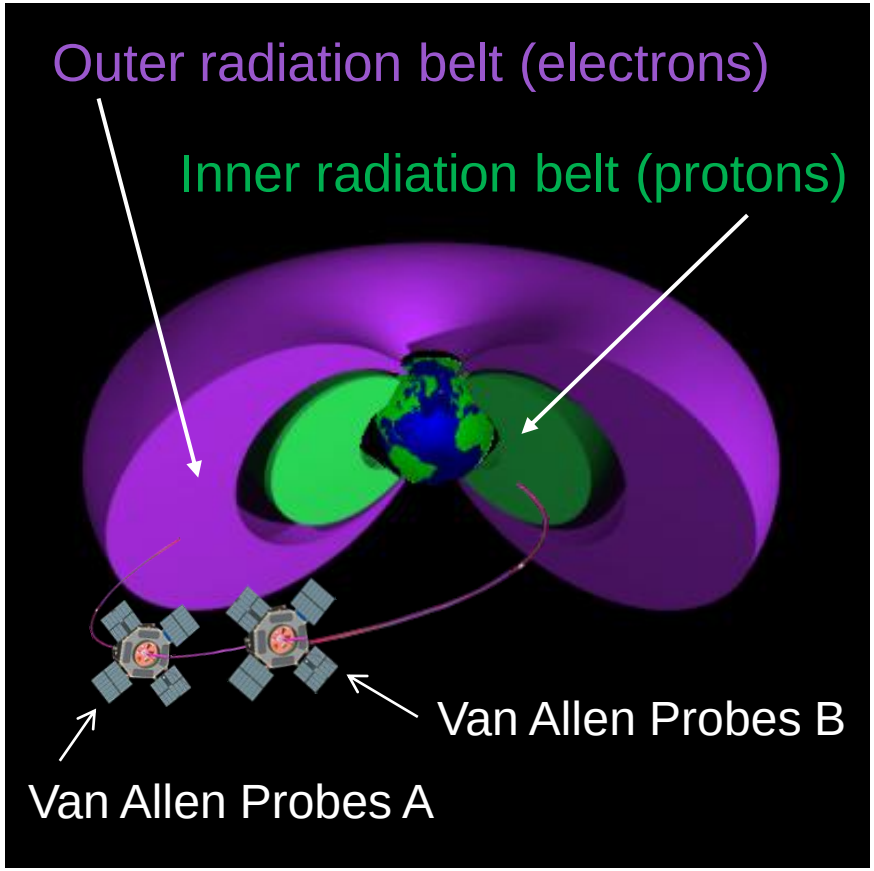
NASA Van Allen Probes Mission

Radiation Belt Storm Probes Mission (RBSP)

(JHU/APL)



- Launch on August 30th, 2012.
- Geotransfer orbit (GTO):

  perigee ~ 700 km

  apogee ~ 36000 km (~5.8 R_E).
- Orbital period ~9 hours. Spacecraft lapping rate ~70 days.

Package	Measurement
ECT	electrons and ions (particles)
RPS	protons (particles)
RBSPICE	electrons and ions (particles)
EFW	electric and magnetic fields (waves)
EMFISIS	electric and magnetic fields (waves)

ECT = HOPE + MagEIS + REPT

[1 eV-50 keV] ***[20 keV-4 MeV]*** ***[2 MeV-20 MeV]***

(electron energy)

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ECT MagEIS Instrument

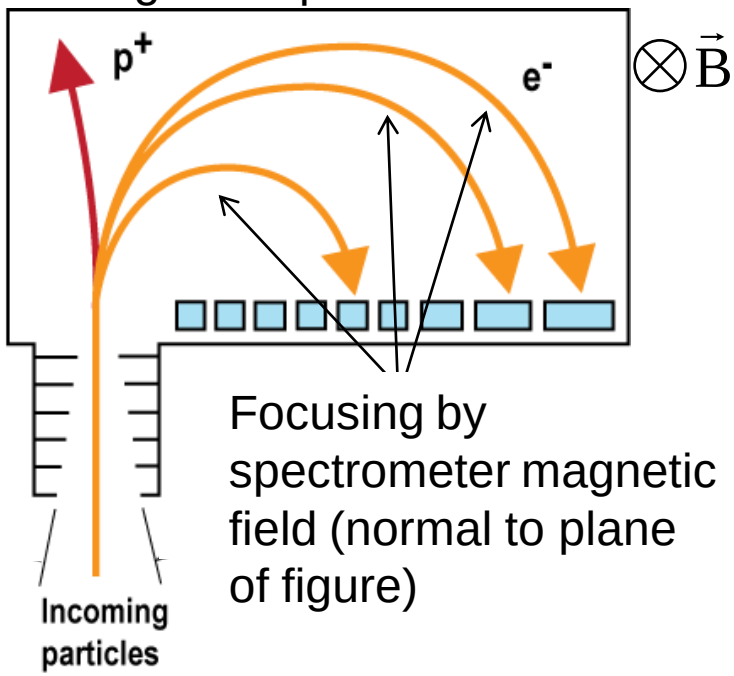
***Mag**netic **E**lectron **I**on **S**pectrometer*

Mass	34.1* kg
Power	53* W
Average Telemetry Rate	9.5* kbps
Energy Range	20-4300 keV (electrons) 60-20000 keV (protons**)
Energy Resolution	<30% (electrons) <16% (protons)
Geometric Factor	1.7×10^{-3} – 1.0×10^{-2} cm^2 sr (electrons) 4.1×10^{-4} – 2.4×10^{-3} cm^2 sr (protons)
Field-of-View	10^o x 20^o (electrons) 15^o FW conical (protons)

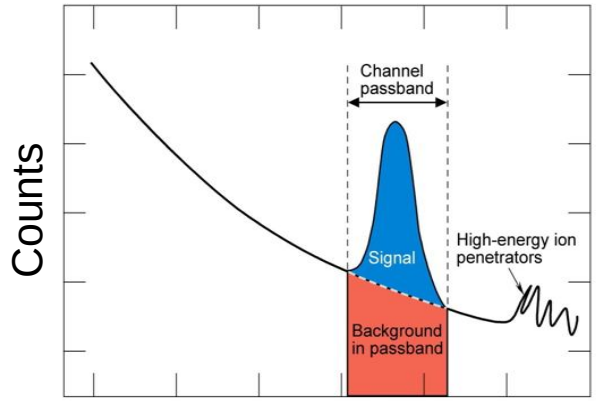
*Total. MagEIS consists of 4 separate electron spectrometers per spacecraft (LOW, M35, M75, HIGH).

**The HIGH unit also has a proton telescope.

Magnetic spectrometer



Focusing by spectrometer magnetic field (normal to plane of figure)



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ECT MagEIS Instrument Status

- All 4 instruments on each spacecraft returning quality electron data over required energy range from 30 keV to 4 MeV.

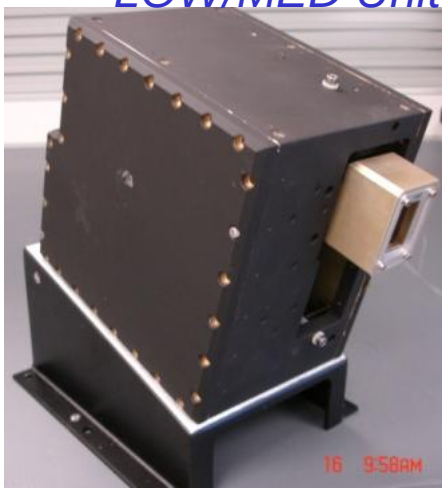
- Proton telescope response degraded below 100 keV due to noise.
  - Increased leakage current from ion implant.
  - Began around 2013 March.
  - Will eventually move into higher energy proton channels.

- HIGH-A detector failure on 2013 Oct 02.
  - ~900 keV electron channel. MED units provide overlap/redundancy.
  - Evidence of gradual increase in noise over many months in detector likely caused by increase in reverse-bias leakage current.
  - Consequence is minimal.

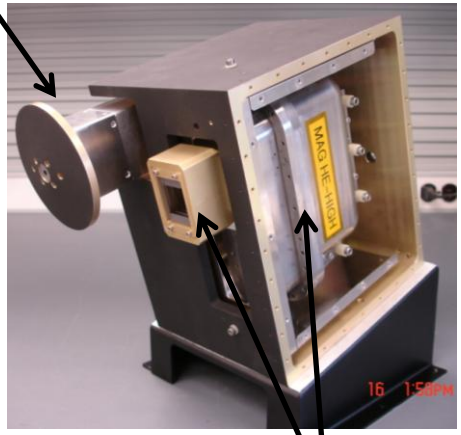
<u>Current operations:</u>

- Operating LOW-A instrument in high rate mode every orbit (*L*=4 to apogee to *L*=4).
- Increased sectoring -> better pitch-angle resolution.
- Decreased the histogram accumulation time -> increased temporal resolution for background corrections .

LOW/MED Unit



proton telescope



HIGH Unit

electron spectrometer

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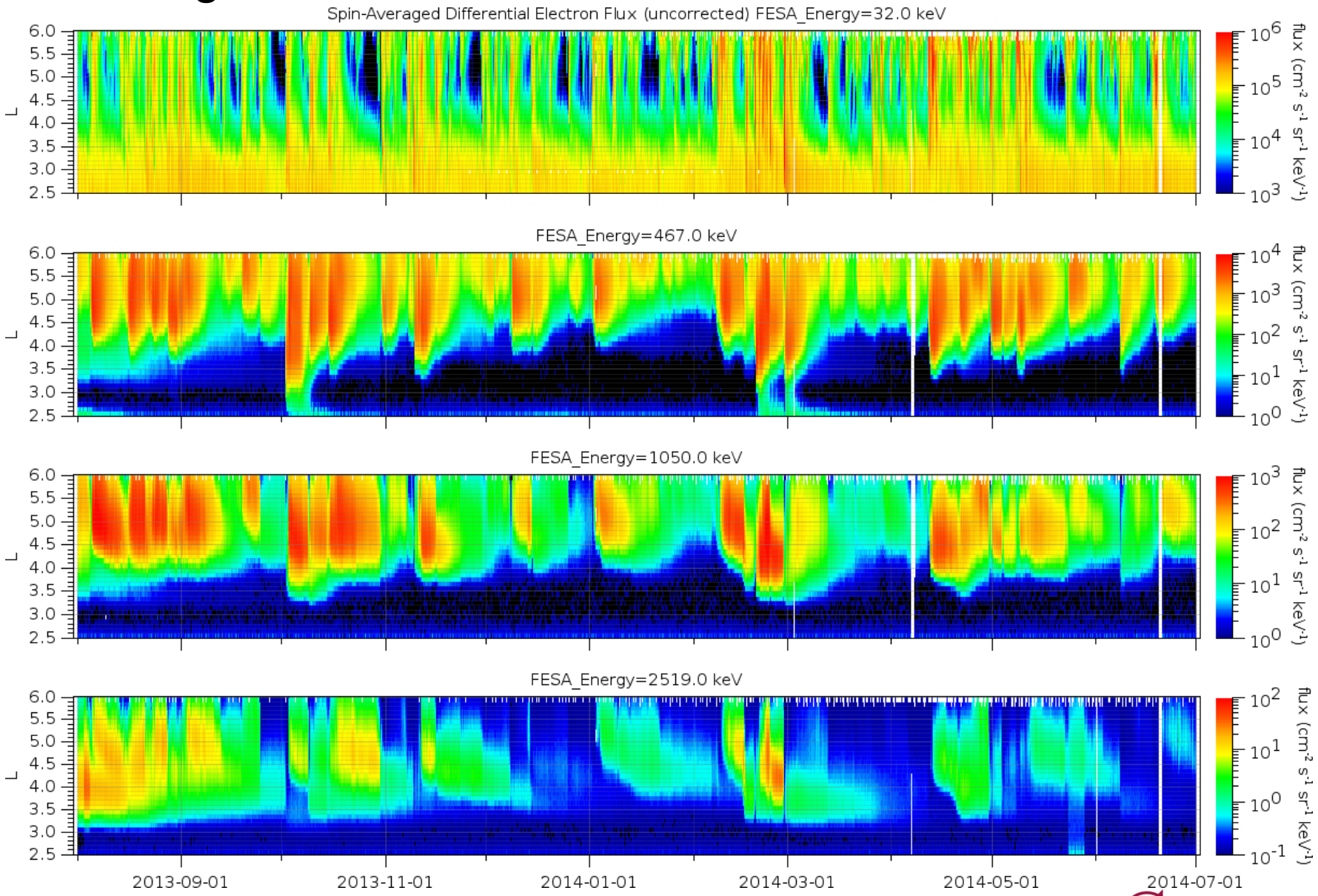
ECT MagEIS Instrument Status



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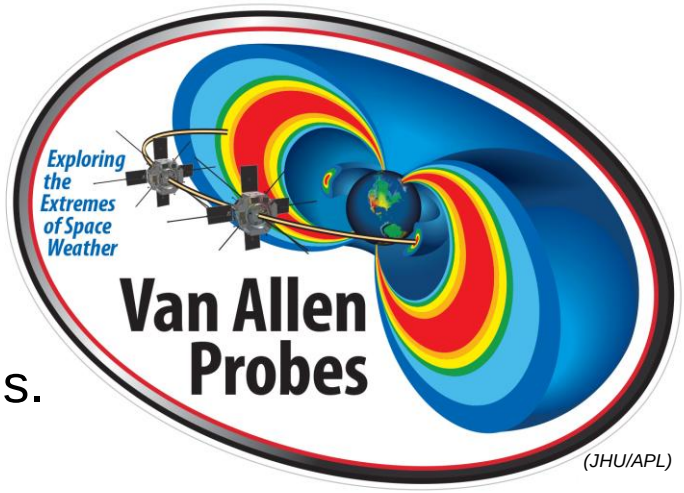

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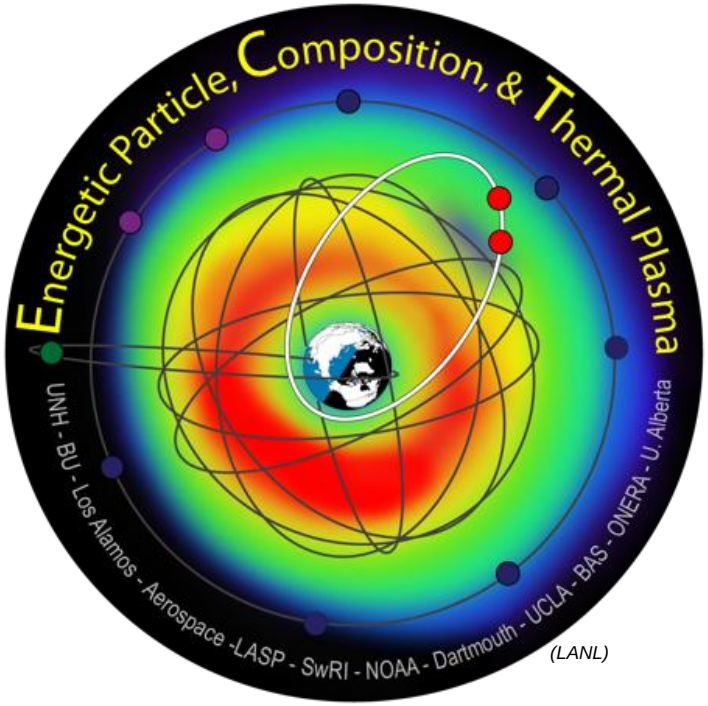

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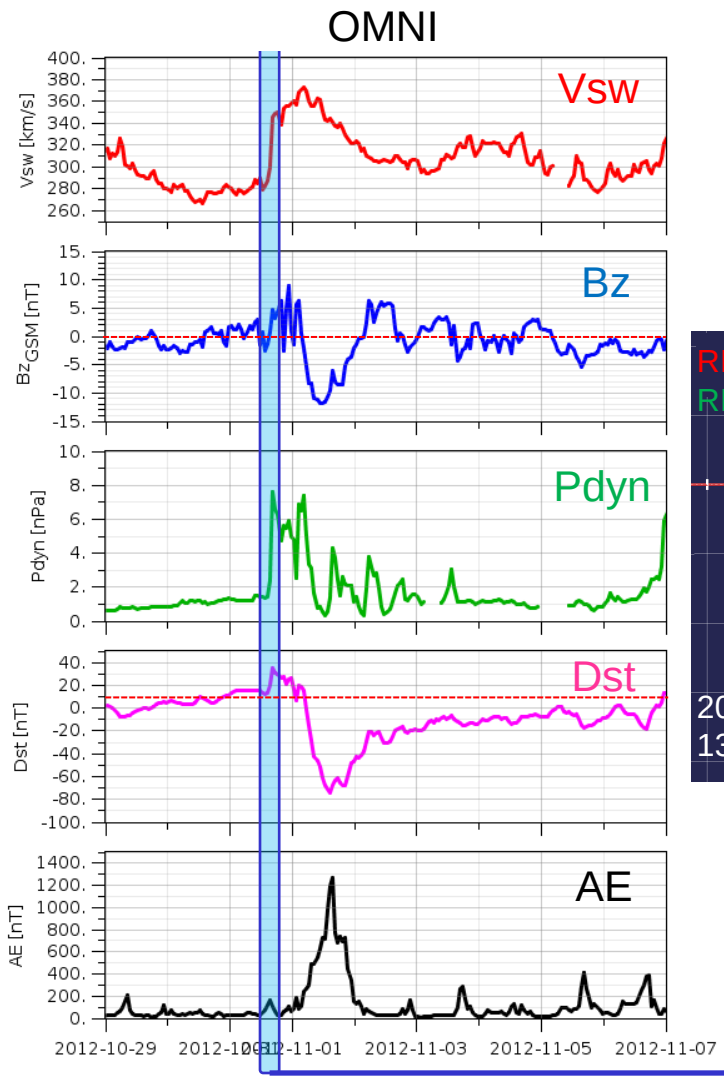
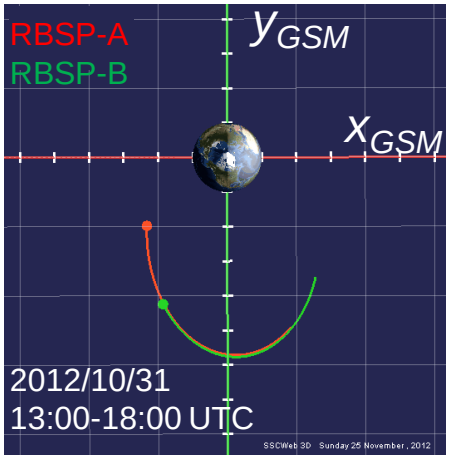
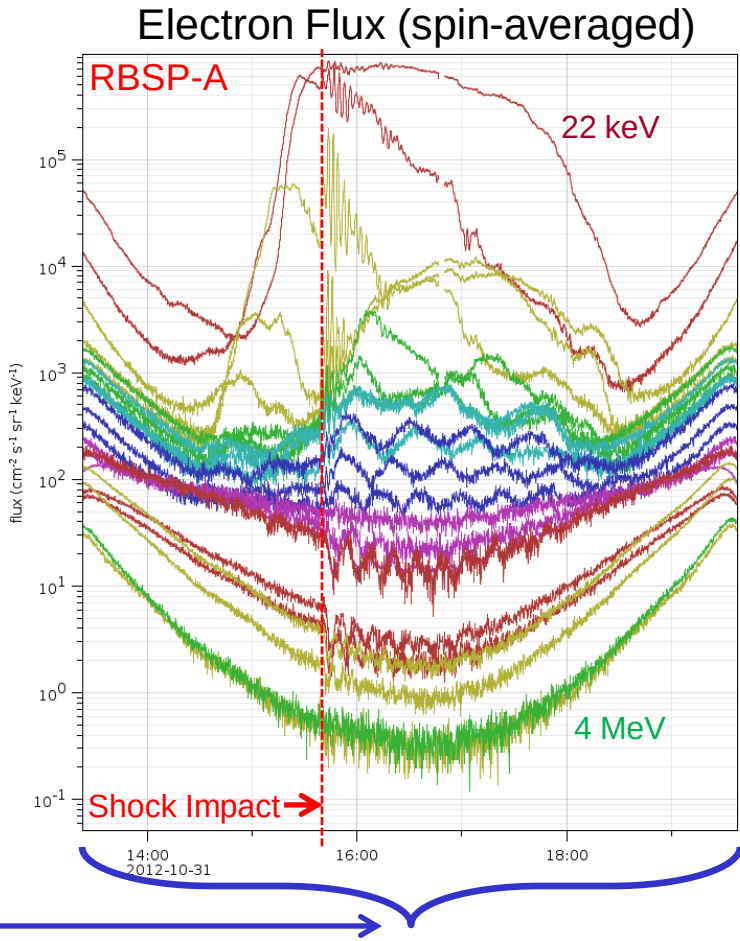
Event Overview: 2012/10/31 Interplanetary Shock







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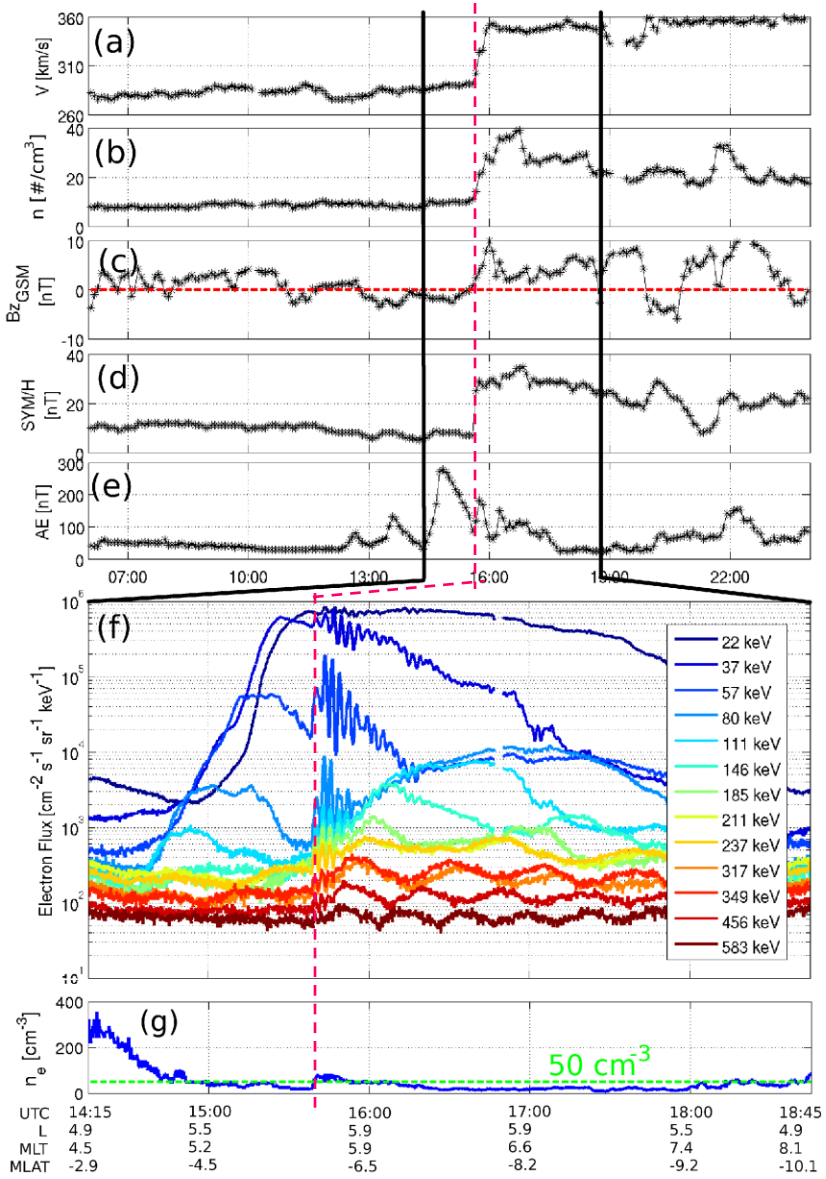
Periodic Electron Flux Oscillations

- Interplanetary shock impacted the magnetosphere at ~15:40 UTC on 2012/10/31.
- MagEIS subsequently observed monochromatic oscillations in electron flux:
  - *Frequency ~ 5 mHz (T=3 mins).*
  - *Energy range ~ 20-400 keV.*
  - *Duration ~ 20 mins (~6 wave cycles).*



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Periodic Electron Flux Oscillations

Drift-resonance

- Residual flux oscillations clearly show:
  1. *Oscillation amplitude peak at ~60 keV.*
  2. *180 degree phase change across the amplitude peak.*

- This is the hallmark signature of a drift-resonant interaction between the electrons and magnetospheric ULF waves.

- The ULF wave is identified as the fundamental poloidal mode.

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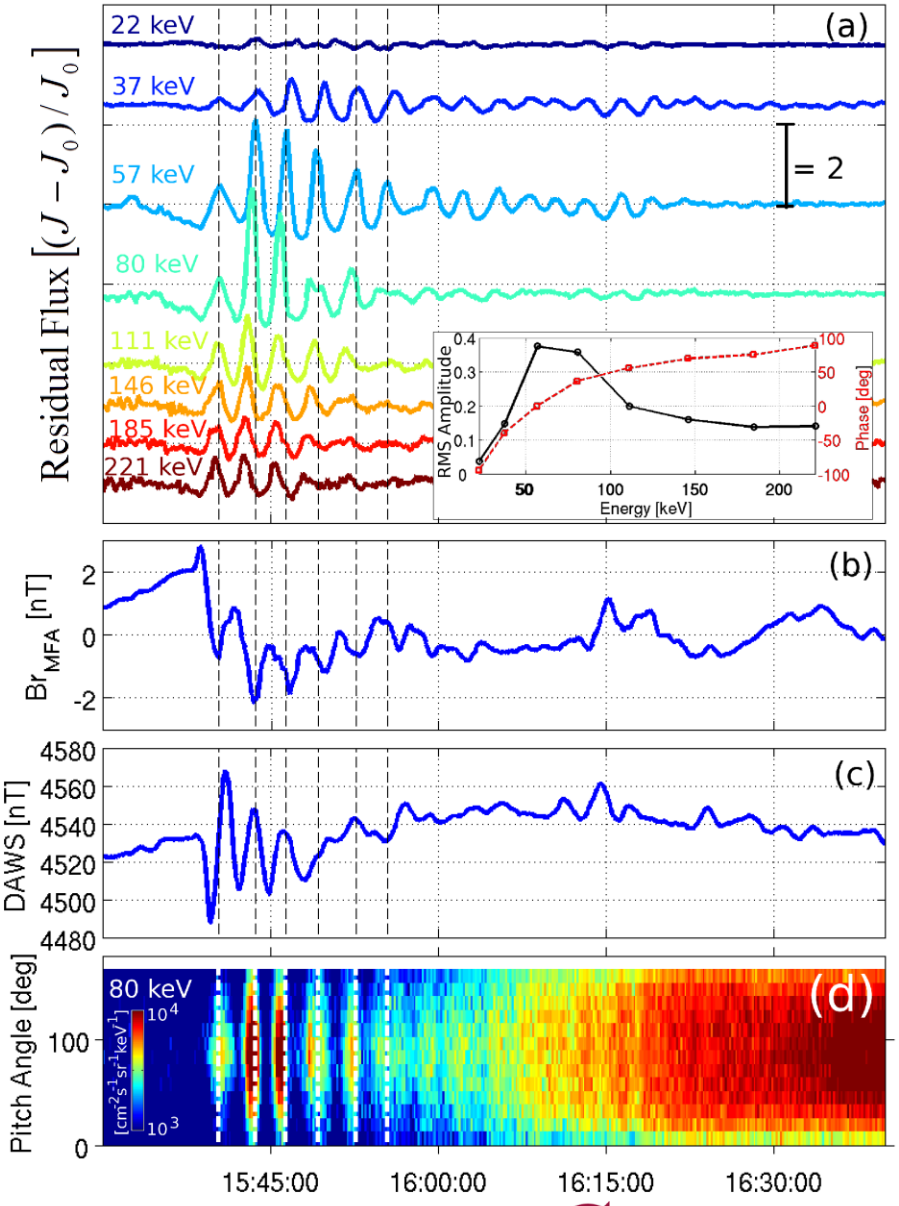

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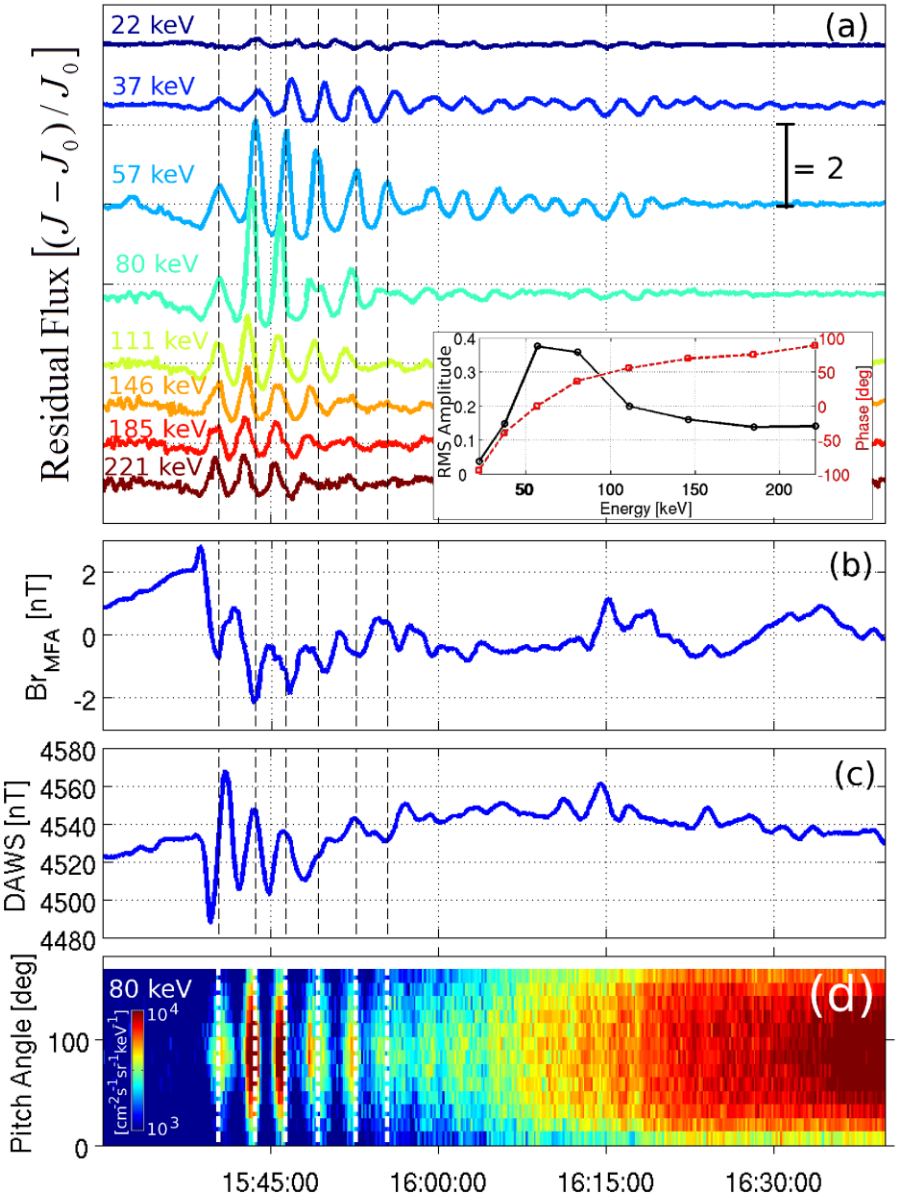
Periodic Electron Flux Oscillations

Drift-resonance

- The drift period of a 60 keV, 90^0 pitch-angle electron at L = 5.8 is T_D = 133 mins (f_D = 0.125 mHz).

- Thus, under the assumed drift-resonance:

$$\omega = m\omega_D$$
$$\text{with } f = 5.5\,\text{mHz}$$
$$\text{and } f_D = 0.125\ \text{mHz}$$
$$\Rightarrow m = 44$$



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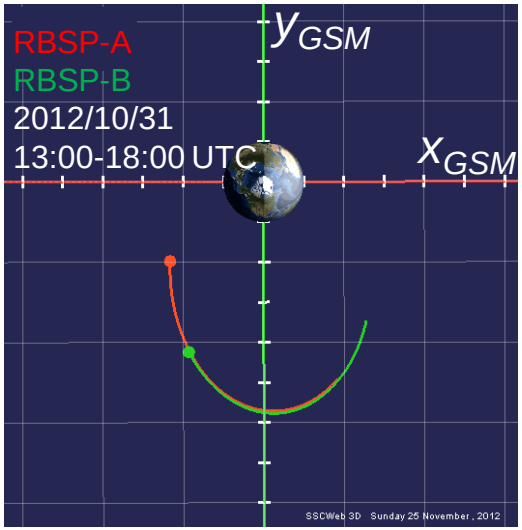
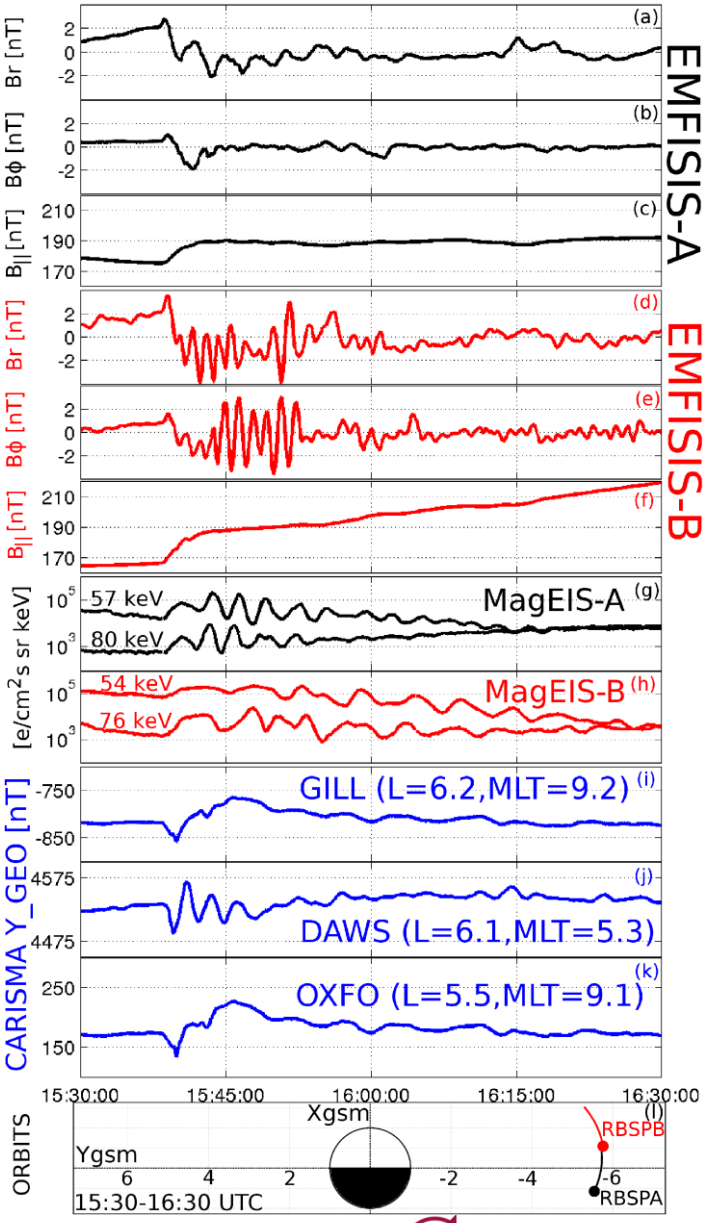
Periodic Electron Flux Oscillations

Drift-resonance

- The two Van Allen Probes spacecraft are quite close to one another.
- Yet, they observe strikingly different environments, in terms of ULF waves and electron flux oscillations.
- This suggests that the drift-resonant interaction is highly localized in space.





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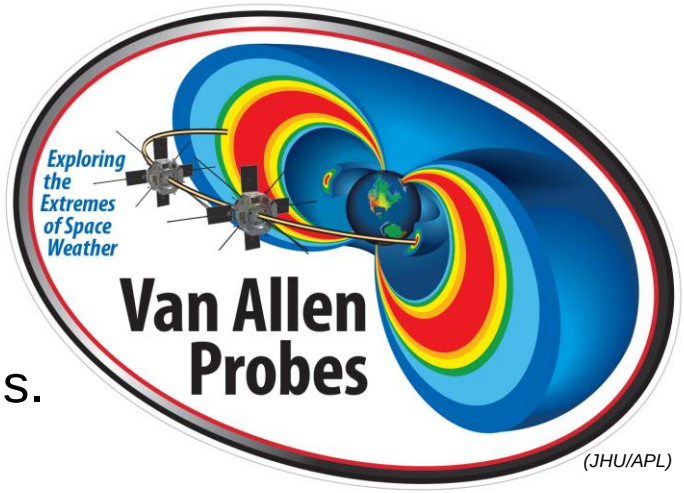

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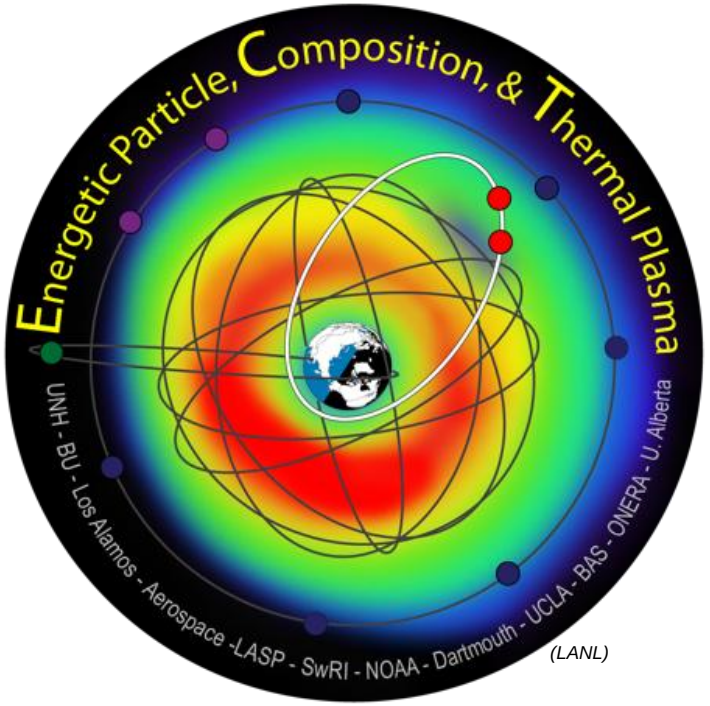

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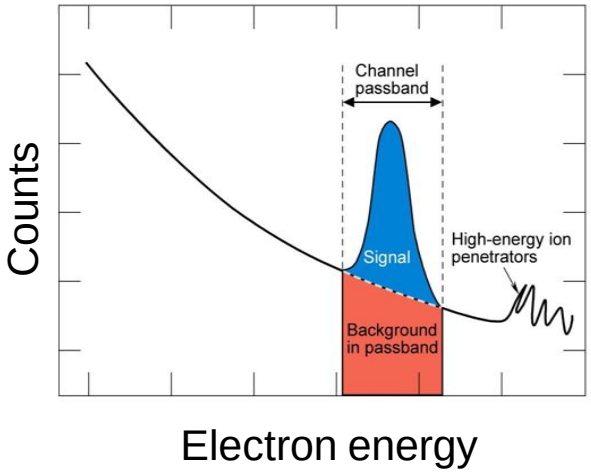
Background Corrected ECT/MagEIS Data

Sources of background that we can correct for in the MagEIS electron data:

(1) Inner Belt Protons

- Contamination from ~300 MeV protons.
- L = ~1.0 to ~2.5.
- Produce background in all MagEIS electron channels.
- ~30-600 keV: Signal is measurable above the background.
- ~800-4000 keV: No signal. All background.



(2) Bremsstrahlung

- Contamination from ~5 MeV electrons.
- L = wherever there are ~5 MeV electrons.
- Produces background in low and medium energy MagEIS channels (30-900 keV).
- Signal is at times completely dominated by background.

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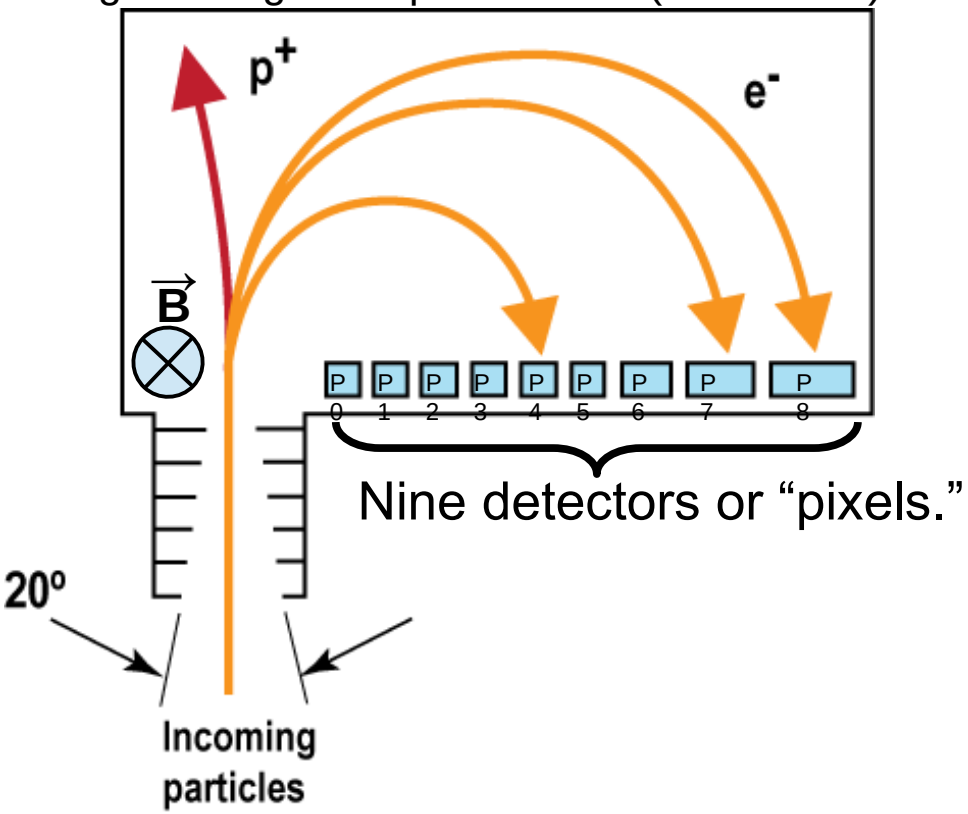
Background Corrections: “Histogram” Data

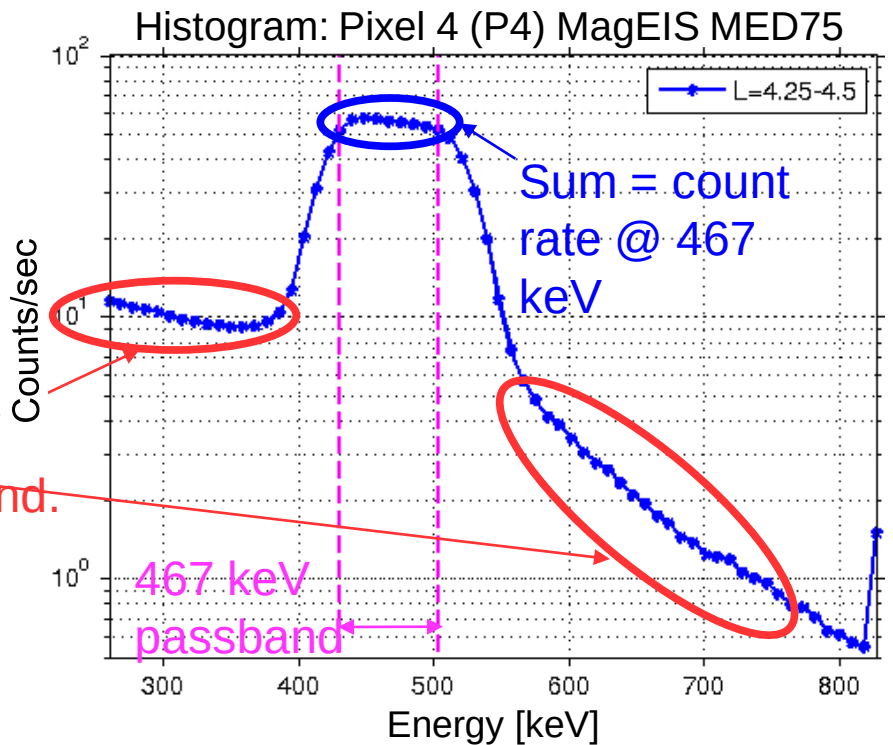
MagEIS magnetic spectrometer (LOW/MED)



Two Parameter Measurement:

(1) **Momentum selection** by the magnetic field within the instrument ensures that only electrons within the energy passband of a given pixel strike that pixel.

(2) On every pixel, each particle detection is also **pulse-height analyzed** (PHA) to produce the count rate as a function of PHA channel (e.g. energy):



Particle detections outside of 467 keV passband.

These particles constitute the “background.”

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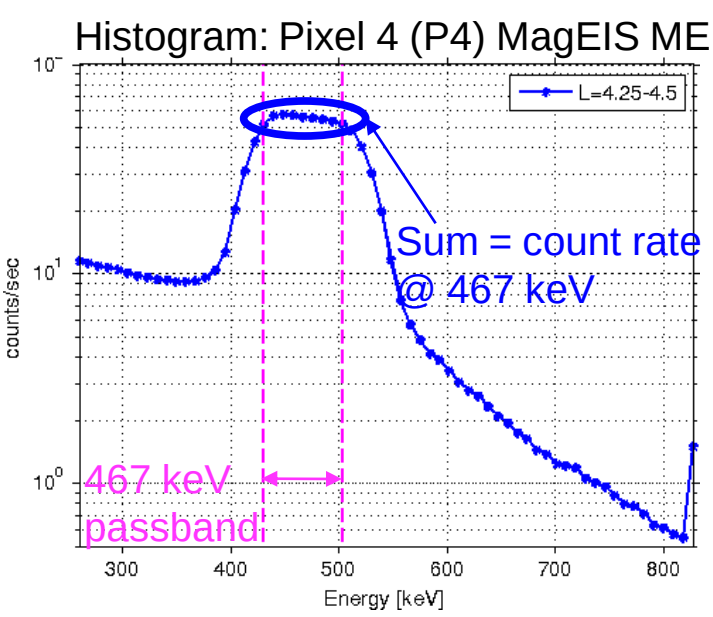
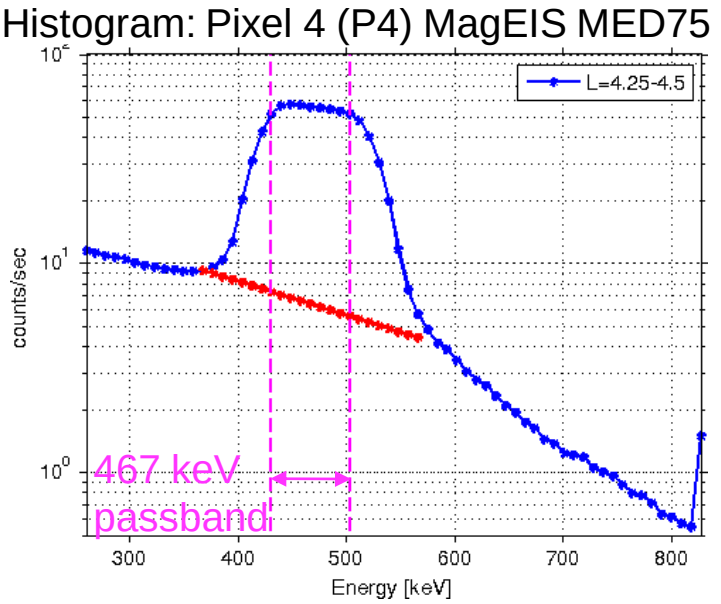
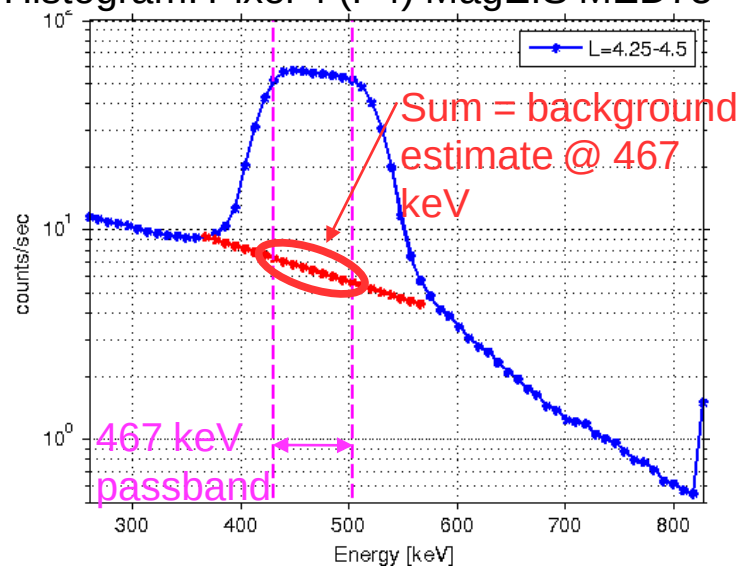
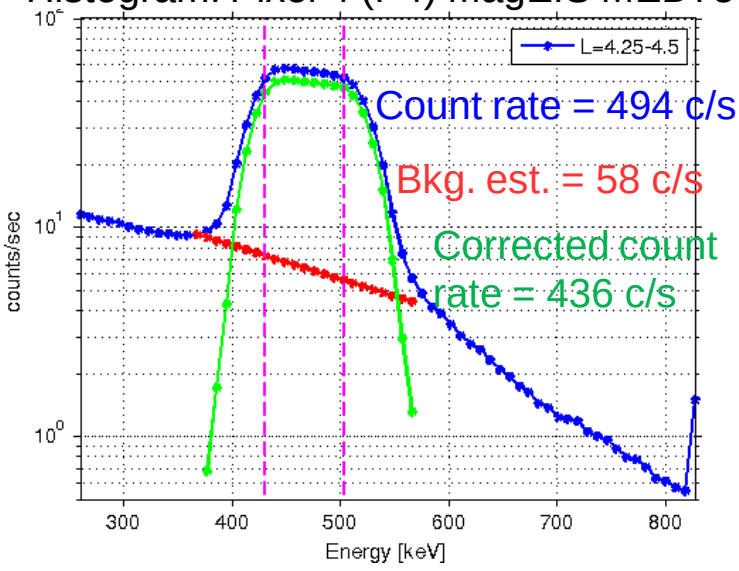
Estimate Background at L=4.5, E=467 keV

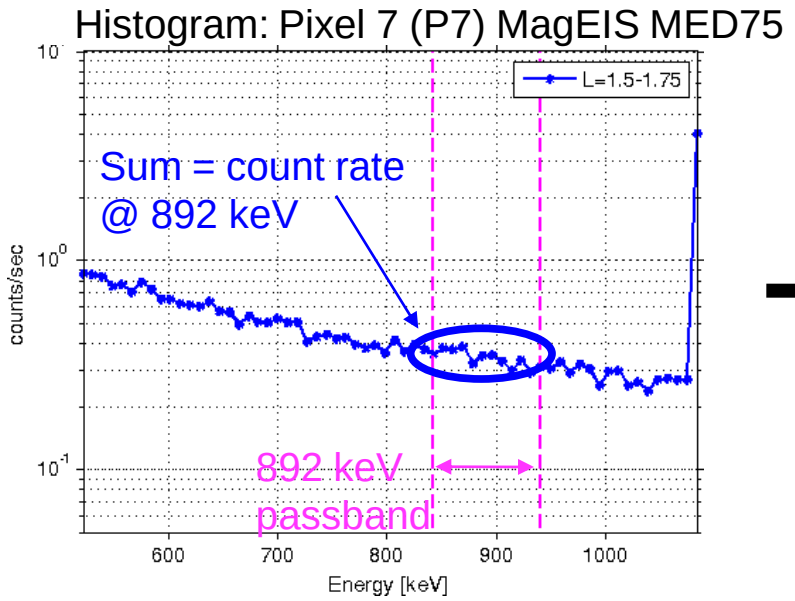


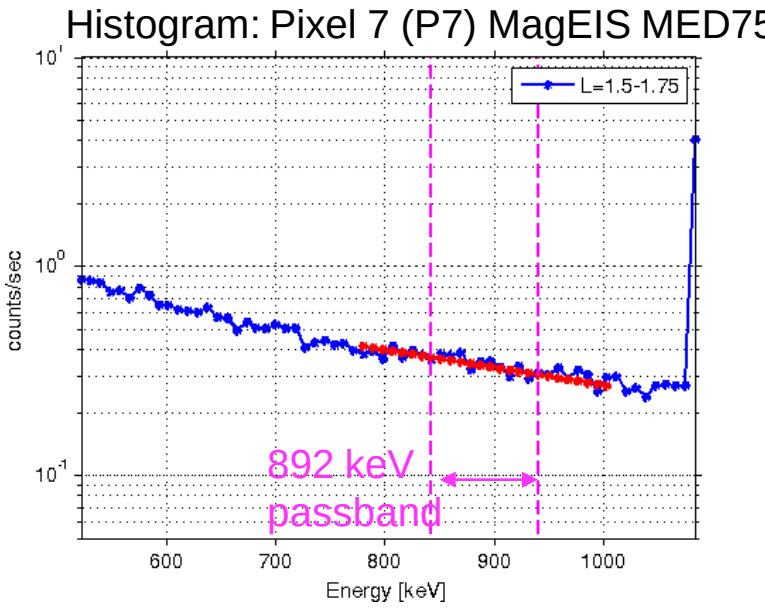


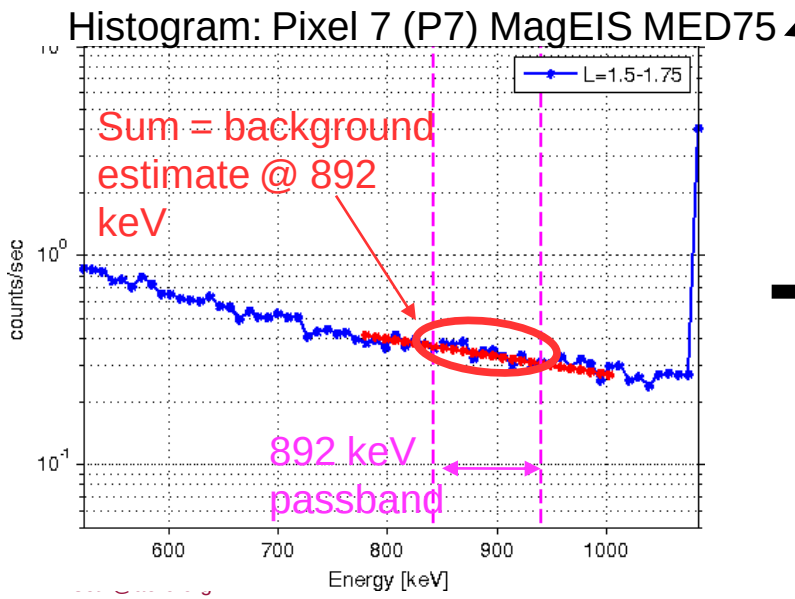


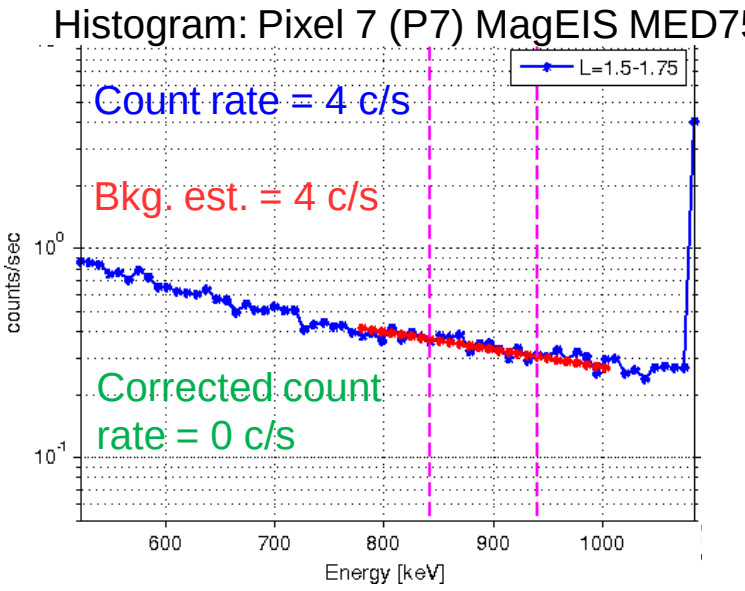


Estimate Background at L=1.5, E=892 keV





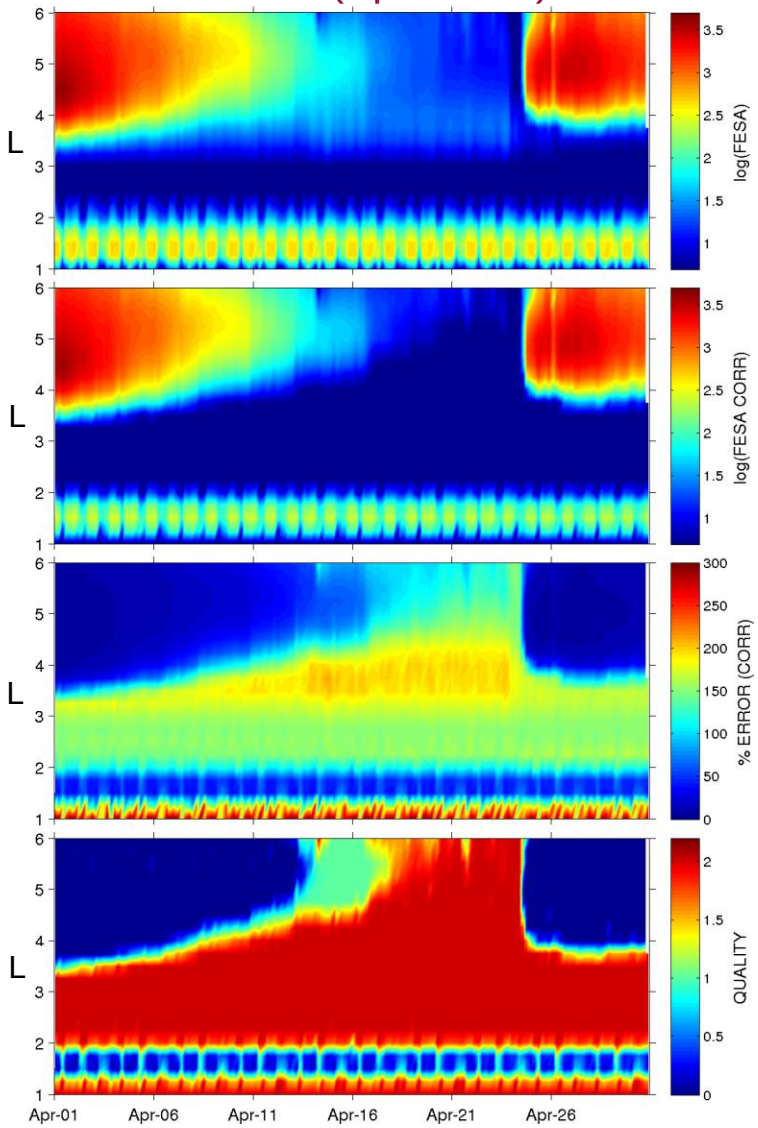




Background Corrected ECT/MagEIS Data

Data will be available soon.

600 keV (April 2013)



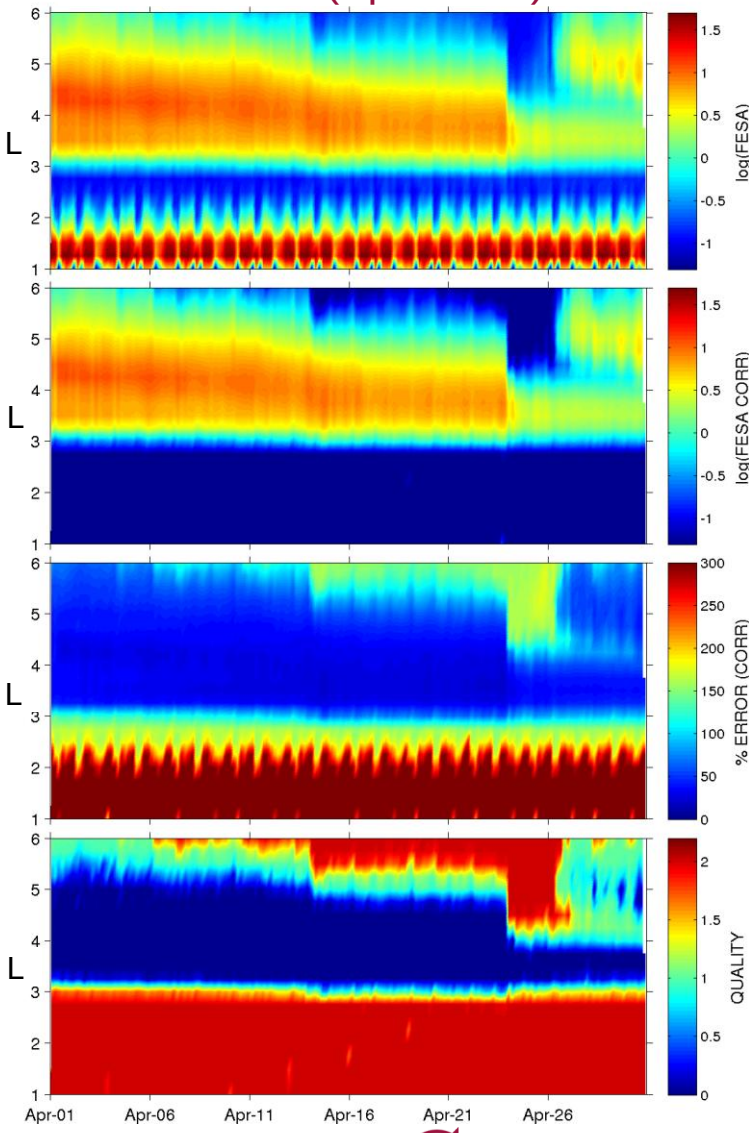
Electron Flux (uncorrected)

Electron Flux (corrected)

Percent Error

Quality Flag

2.6 MeV (April 2013)



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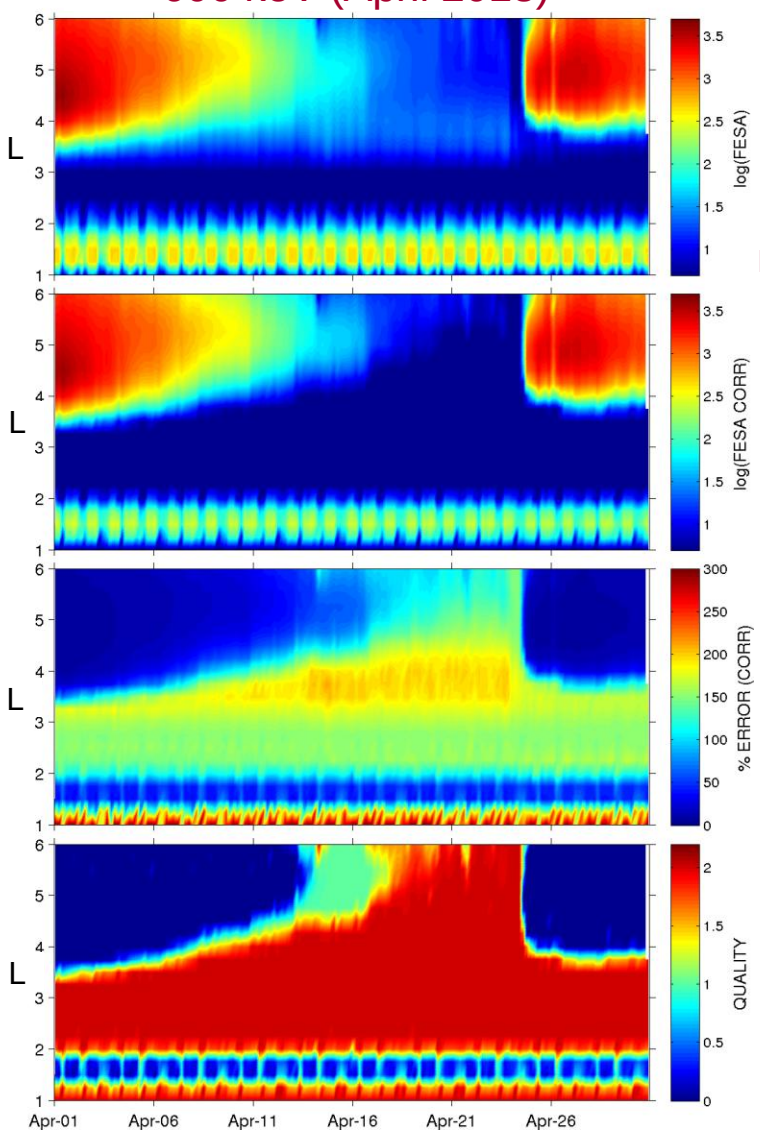


Electron Flux (uncorrected)

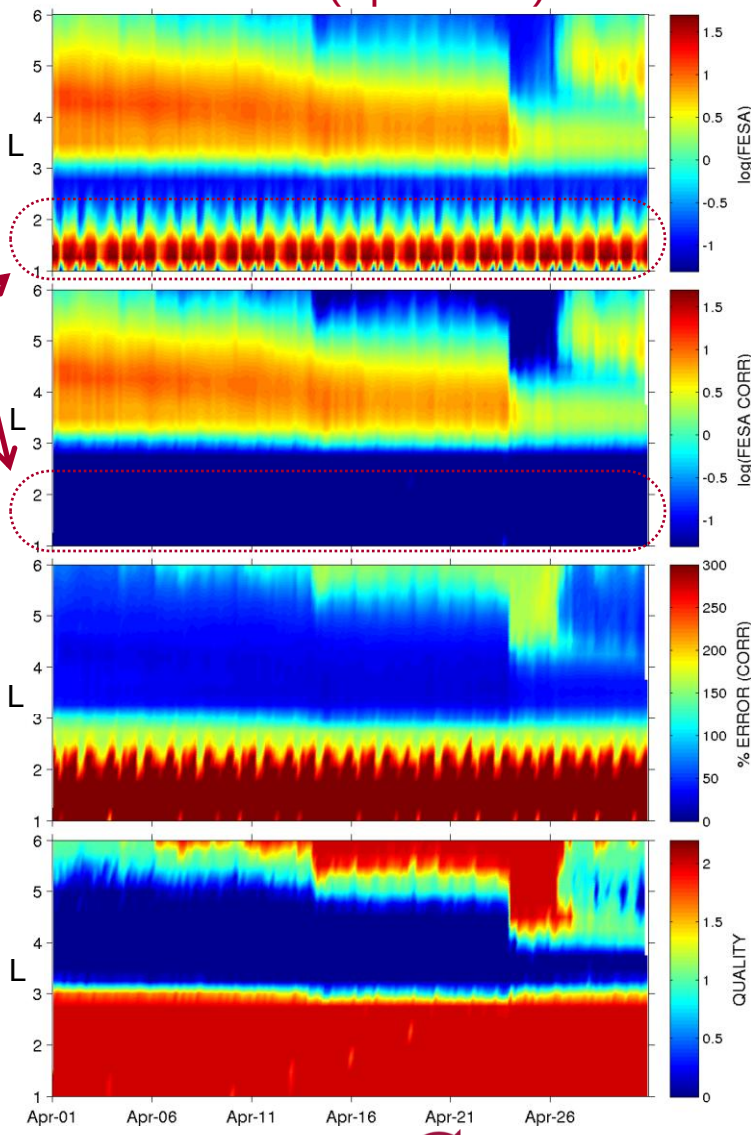
Inner zone contamination (from ~100 MeV protons)

Electron Flux (corrected)

Percent Error

Quality Flag

2.6 MeV (April 2013)



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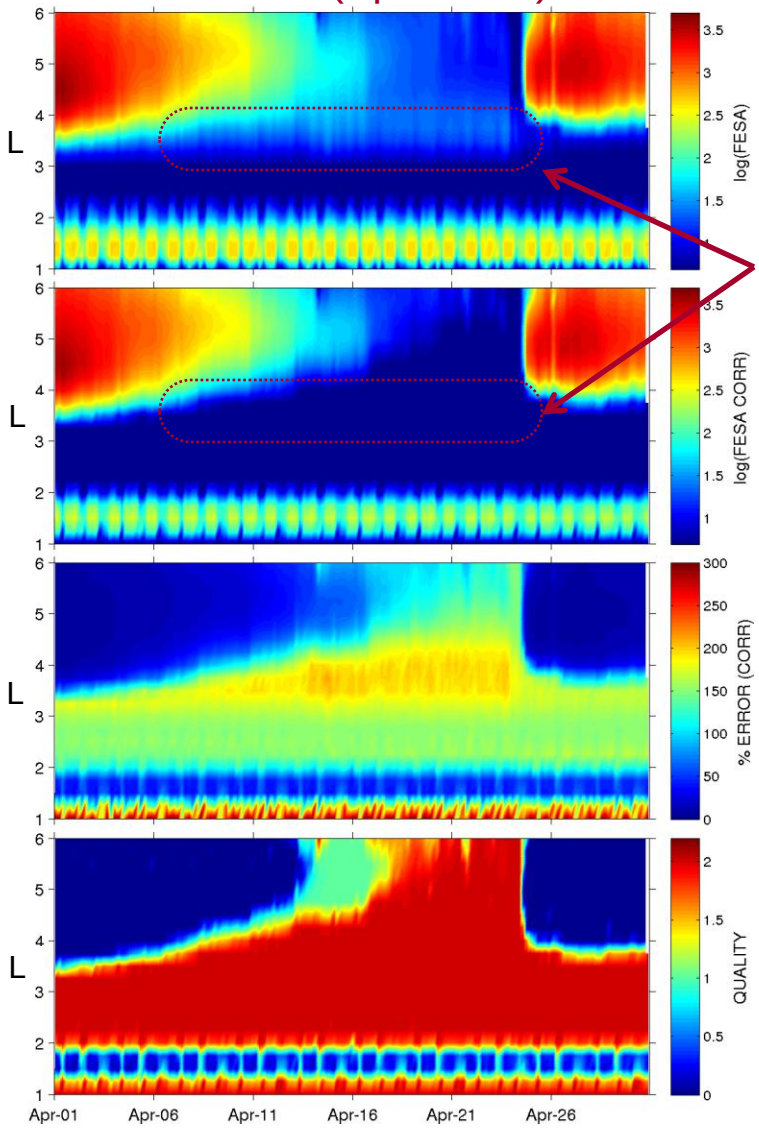


Electron Flux (uncorrected)

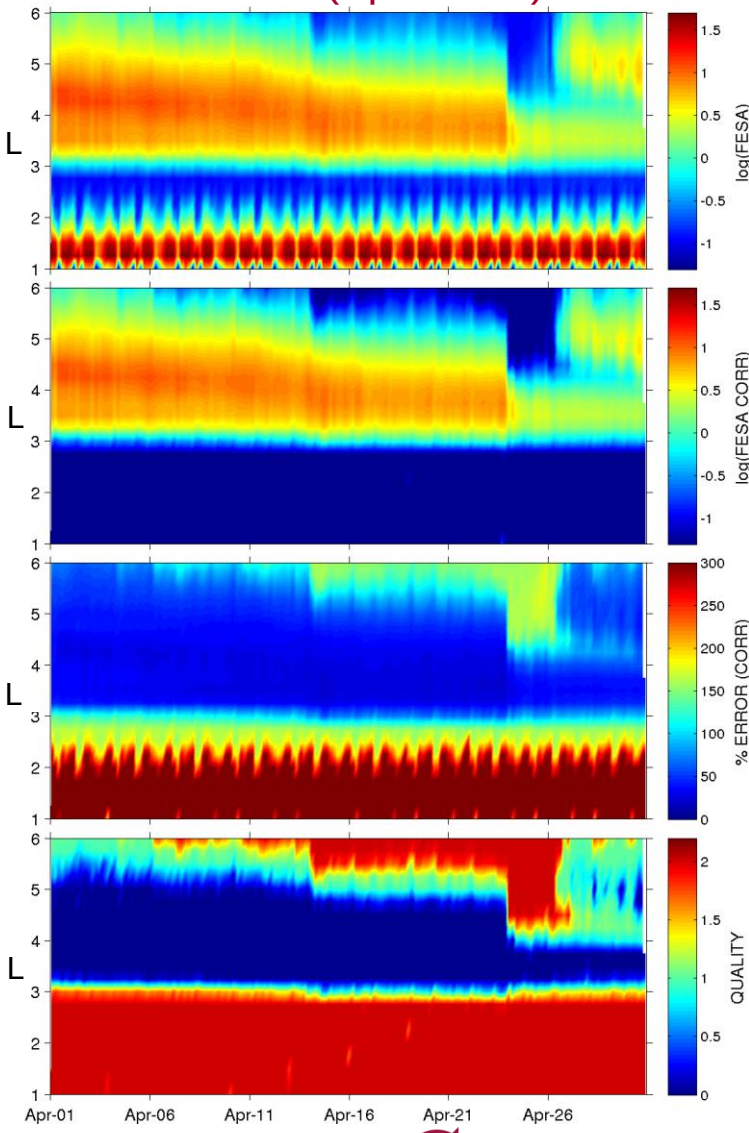
Outer zone contamination (from ~5 MeV electrons)

Electron Flux (corrected)

Percent Error

Quality Flag

2.6 MeV (April 2013)



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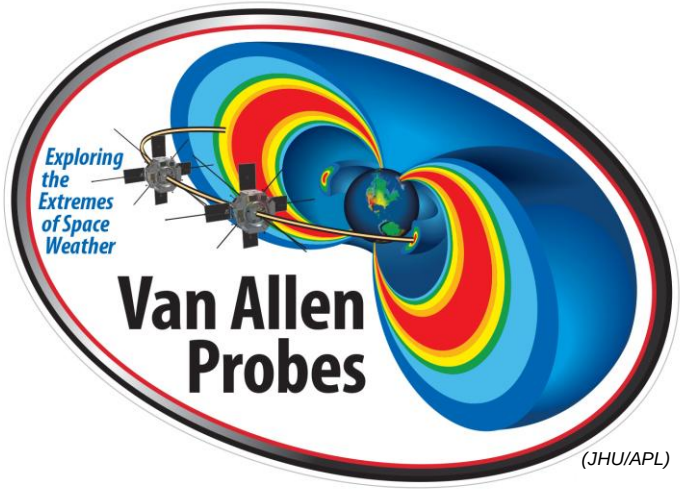
Conclusions

- MagEIS is returning clean electron measurements throughout the inner and outer zone.
- Electron flux fluctuation events (drift-resonance, drift-echoes, flux-bursts) are commonplace in the MagEIS data set.
- Background corrected fluxes will be available soon.
- MagEIS/REPT electron intercalibration work is nearing completion.



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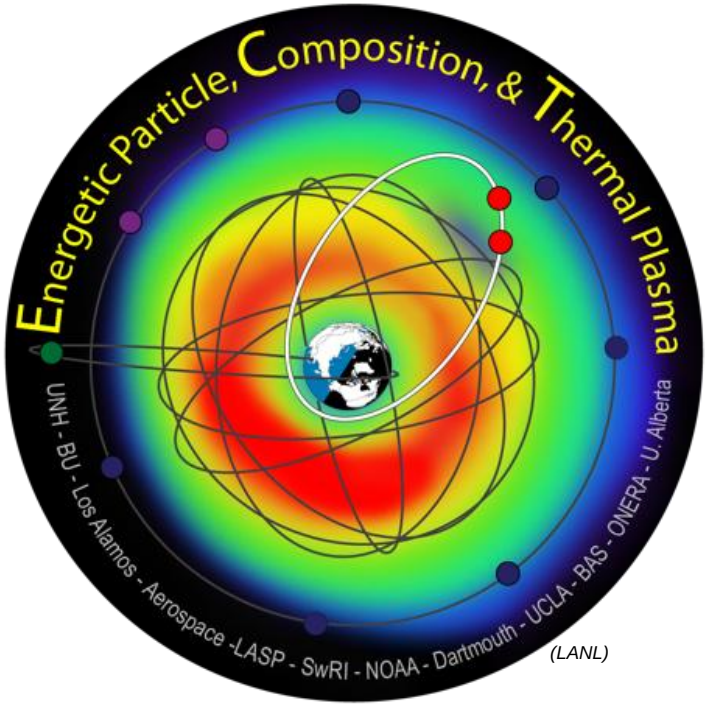

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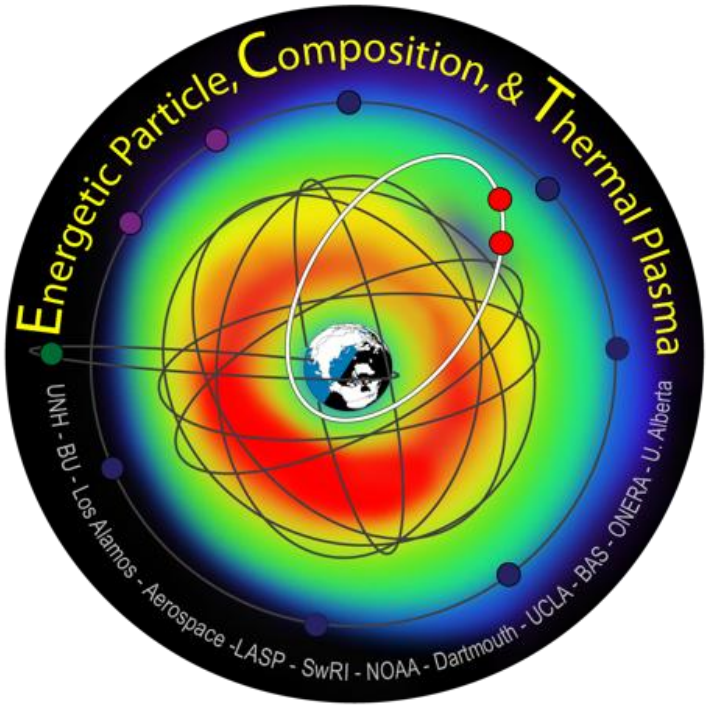
We acknowledge the RBSP-ECT Science Team:



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Special thanks to Jeremy Faden (autoplot.org).

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Backup

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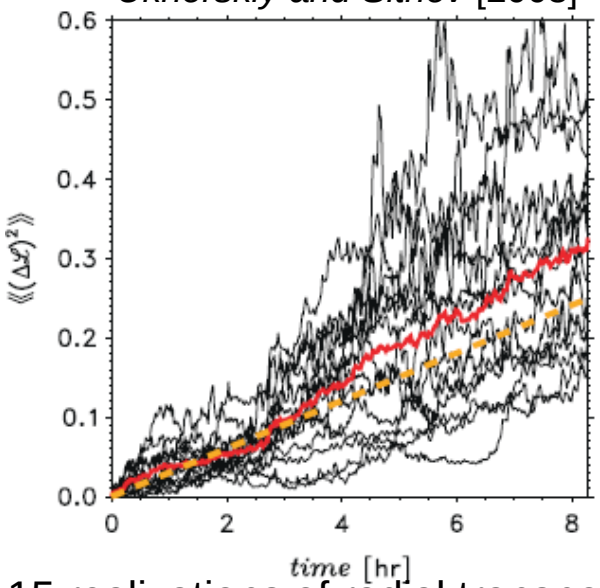
Radial Transport in the Radiation Belts

Why does radial diffusion work?

1) Radial diffusion (incoherent scattering in *L*).
2) Impulsive events (nightside dipolarizations/injections; dayside compressions/pressure pulses).
3) **Drift-resonance with monochromatic ULF waves.**

Ukhorskiy and Sitnov [2008]



15 realizations of radial transport.

Average over all 15 realizations.

Prediction from pure diffusion.

How do we represent radial transport in models?

- Radial diffusion models have consistently proven to be a good description of electron belts.
- Recent test-particle simulations have shown that this is true only when averaged over long times (e.g. multiple storms).
- **Superposition of many instances of 2) and/or 3) could produce radial diffusion for individual storms/events.**

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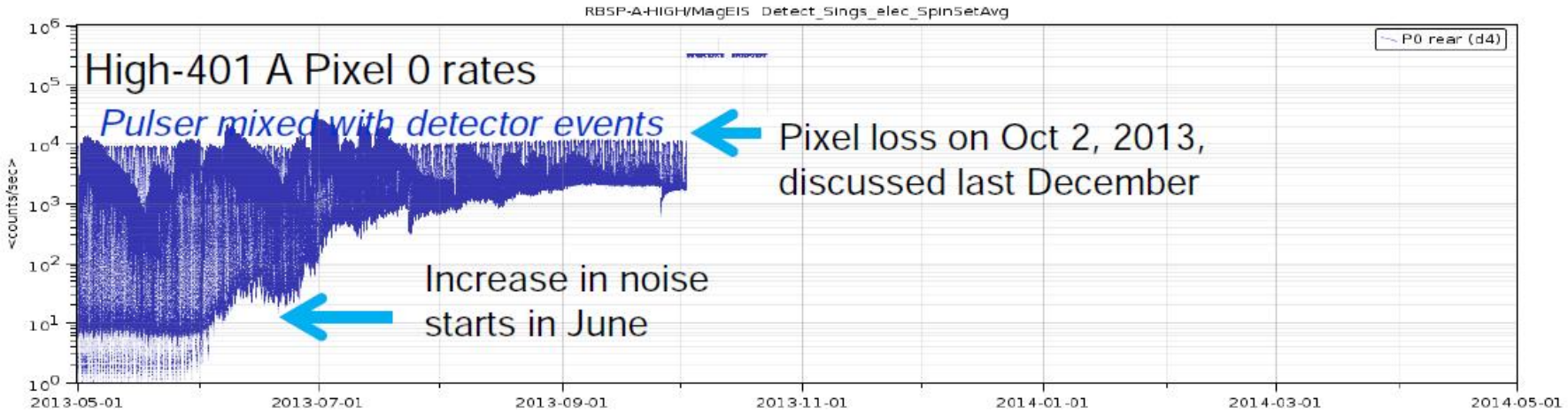
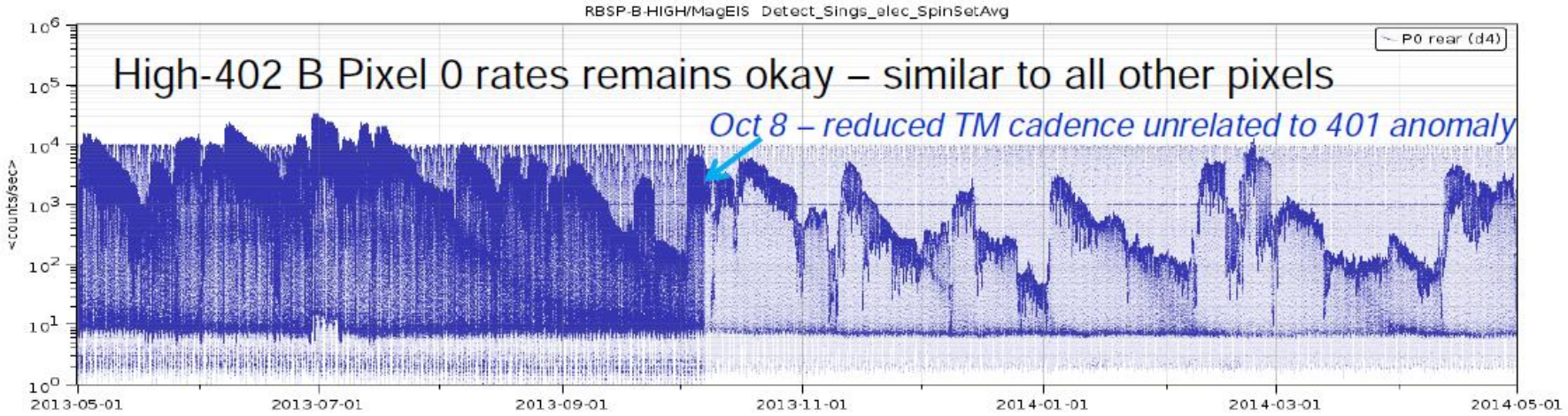
AEROSPACE

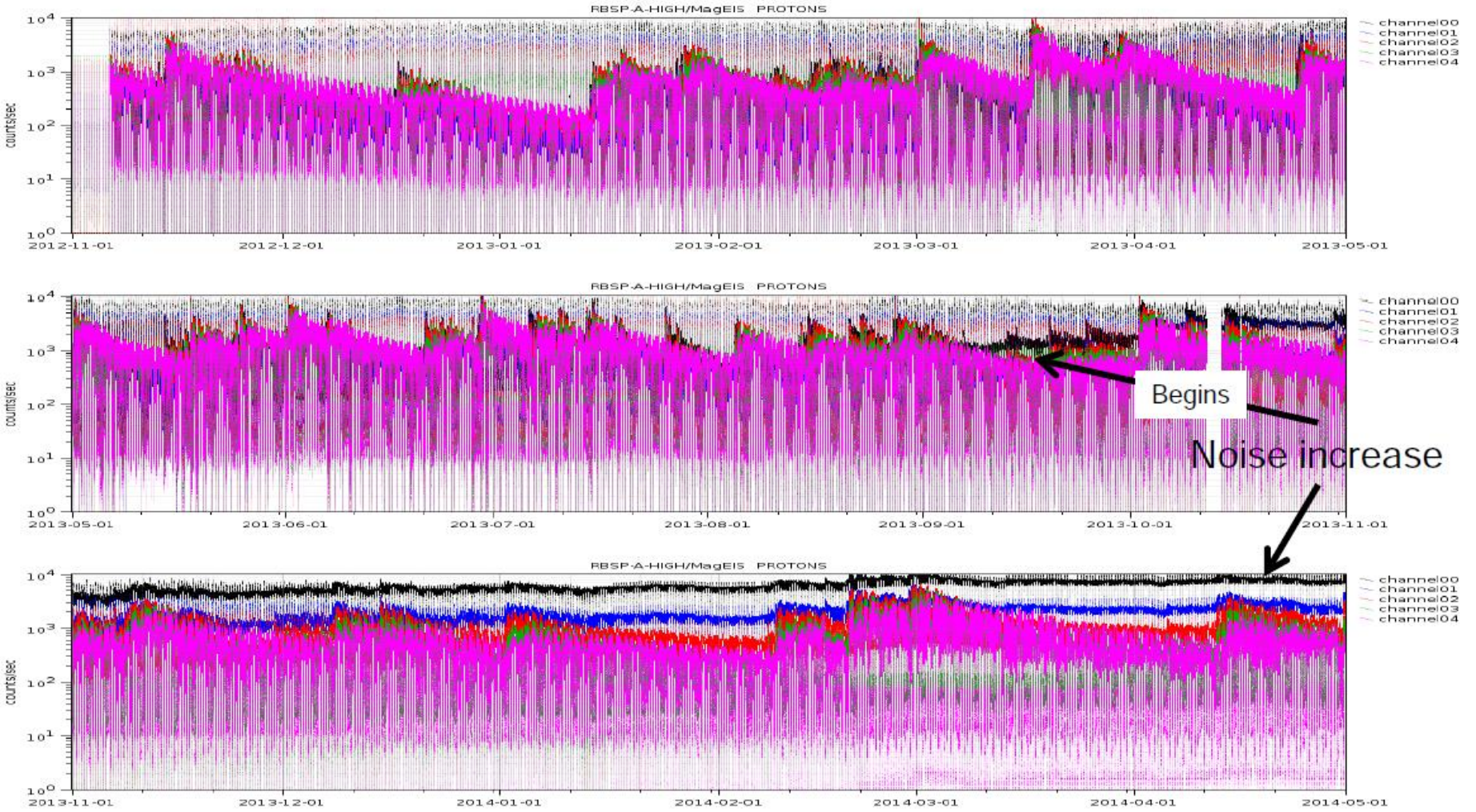
MagEIS Anomaly Status
Electron pixel rates nominal





MagEIS instruments have shown no increase in baseline count rates

MagEIS Anomaly Status
Proton telescope front detector noise



Front proton detector in both S/C A and B High has degraded with time