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# Multipoint Measurements

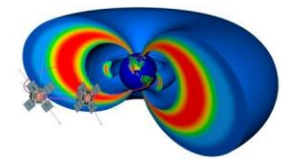
## how do we use multiple satellites ?

Shri Kanekal  
NASA GSFC

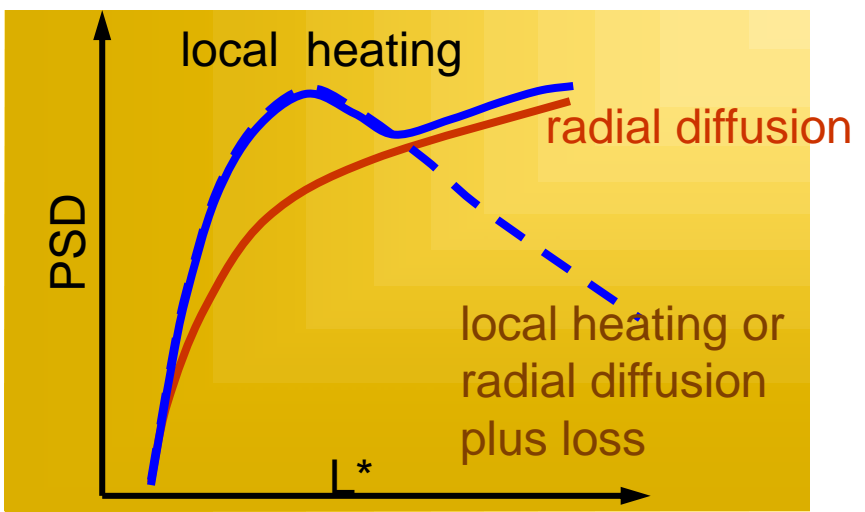
Mainly from the perspective of  
energetic particle  
measurements



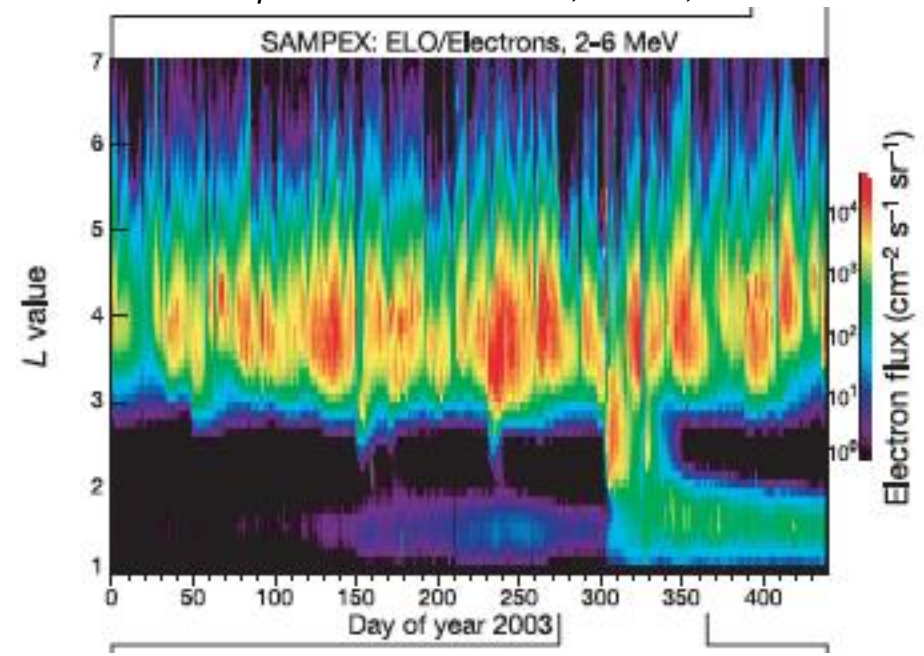
# Multipoint measurements : RBSP



- **Spatial separation**
  - ◆ Radial gradient of phase space density
  - ◆ Formation of new belts
  - ◆ Spatial extent of loss regions
  - ◆ Local time spectral variations

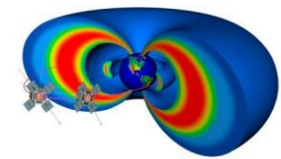


Adapted from Baker et. al., Nature, 2004





# Multipoint measurements : RBSP



- **Temporal separation**
  - ◆ in-situ evolution of spectra [absolute flux variations]
  - ◆ small s/c separation > rapid energization

PET/SAMPEX electron spectra before and after min. Dst

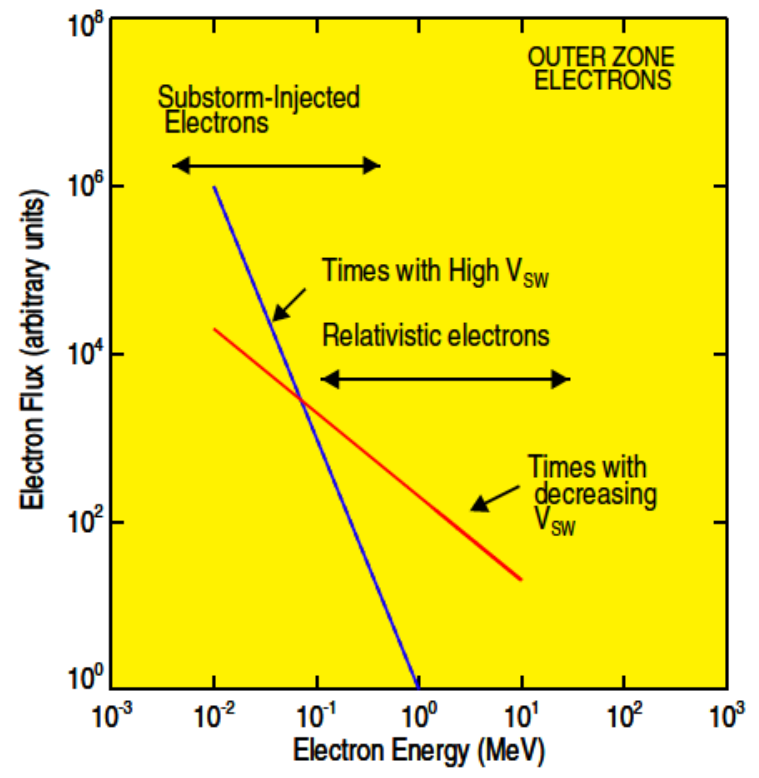
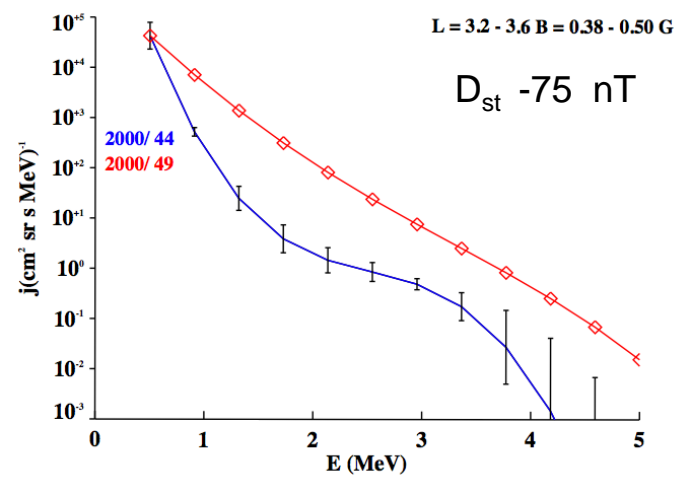
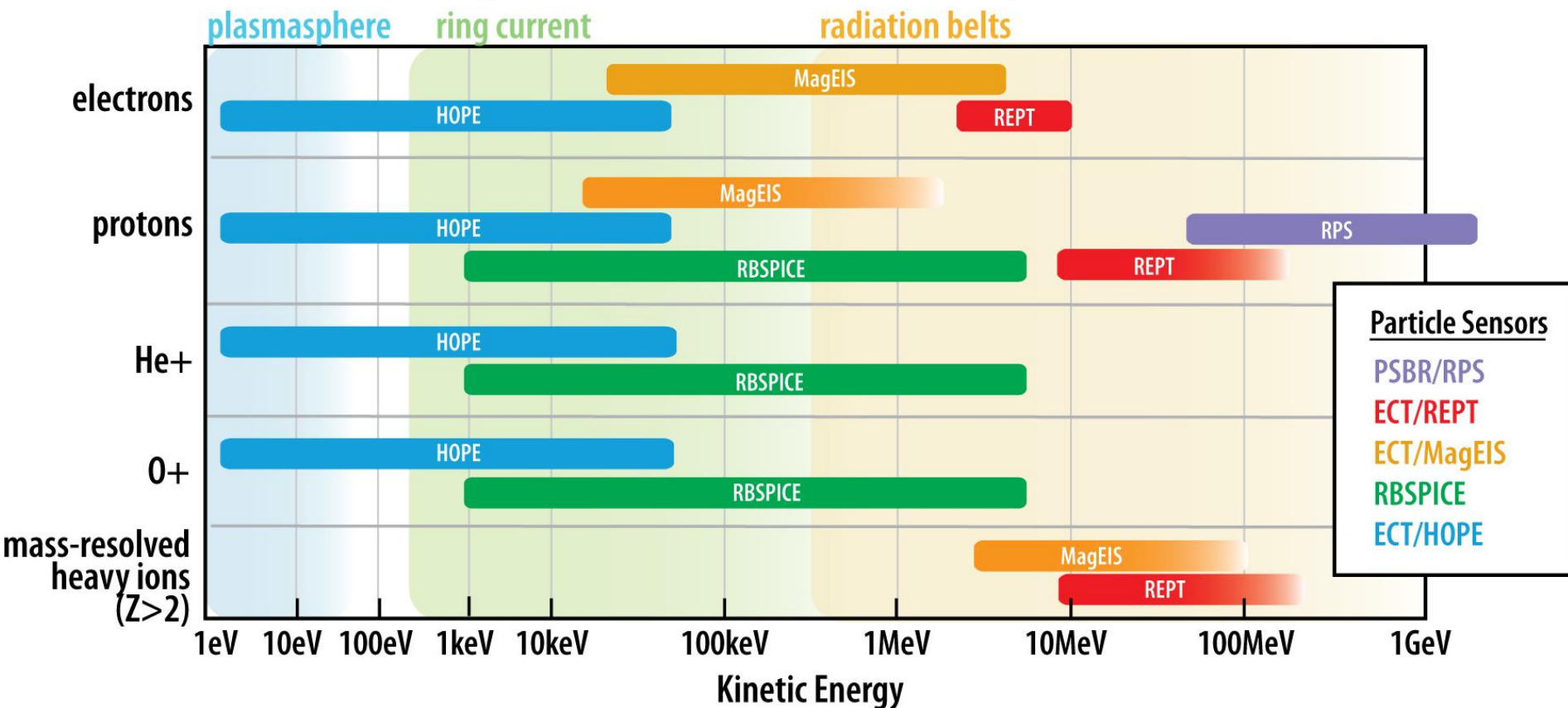
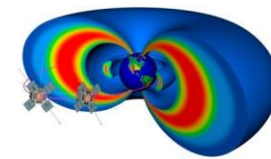
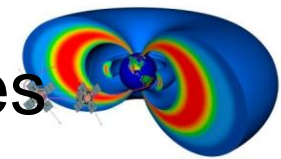


Figure 1: Acceleration of substorm seed population to relativistic energies (adapted from Baker et al., [1998a]).



# RBSP ECT : Energy ranges

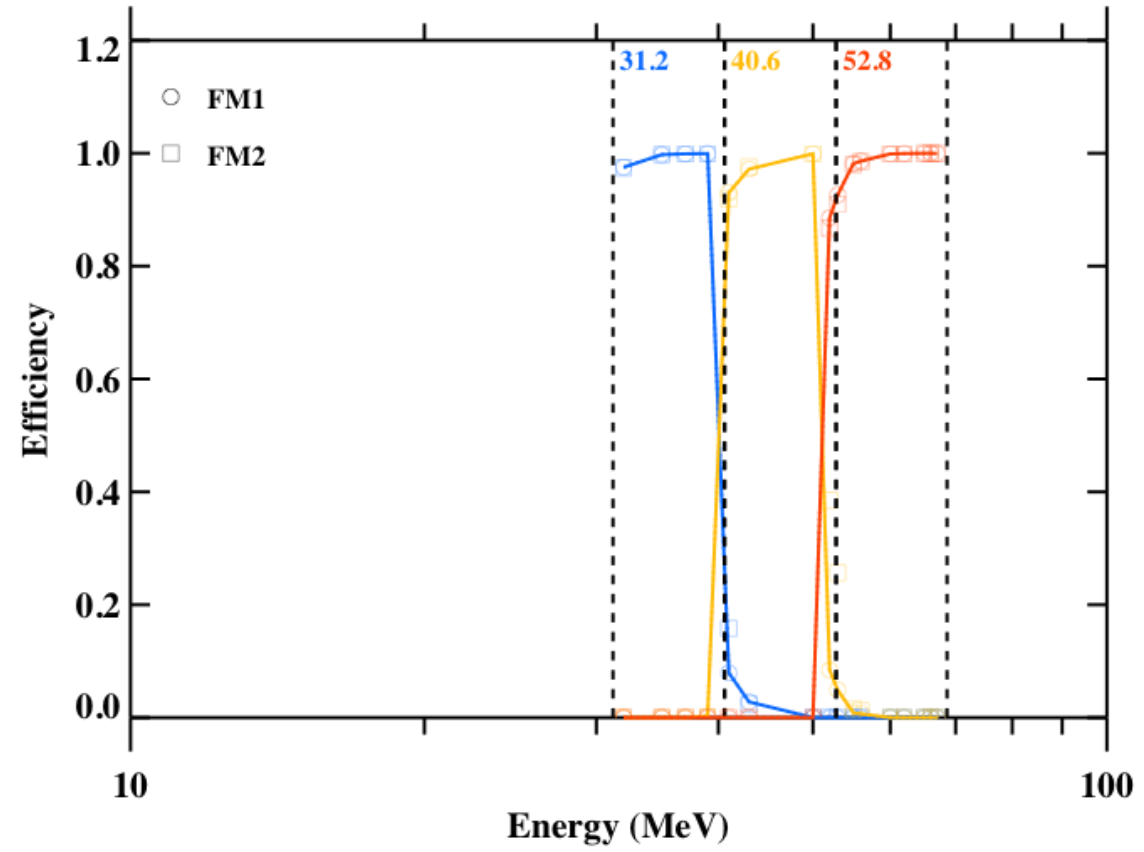
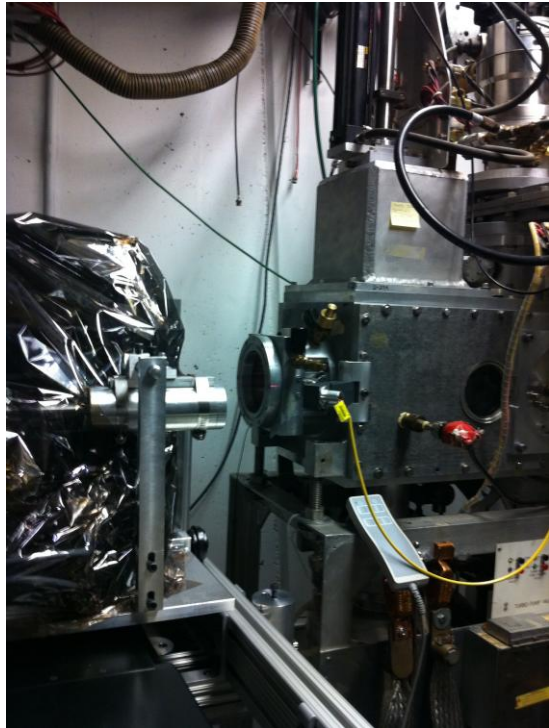
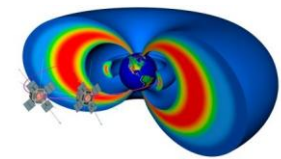




# Multipoint measurements: Energetic particles

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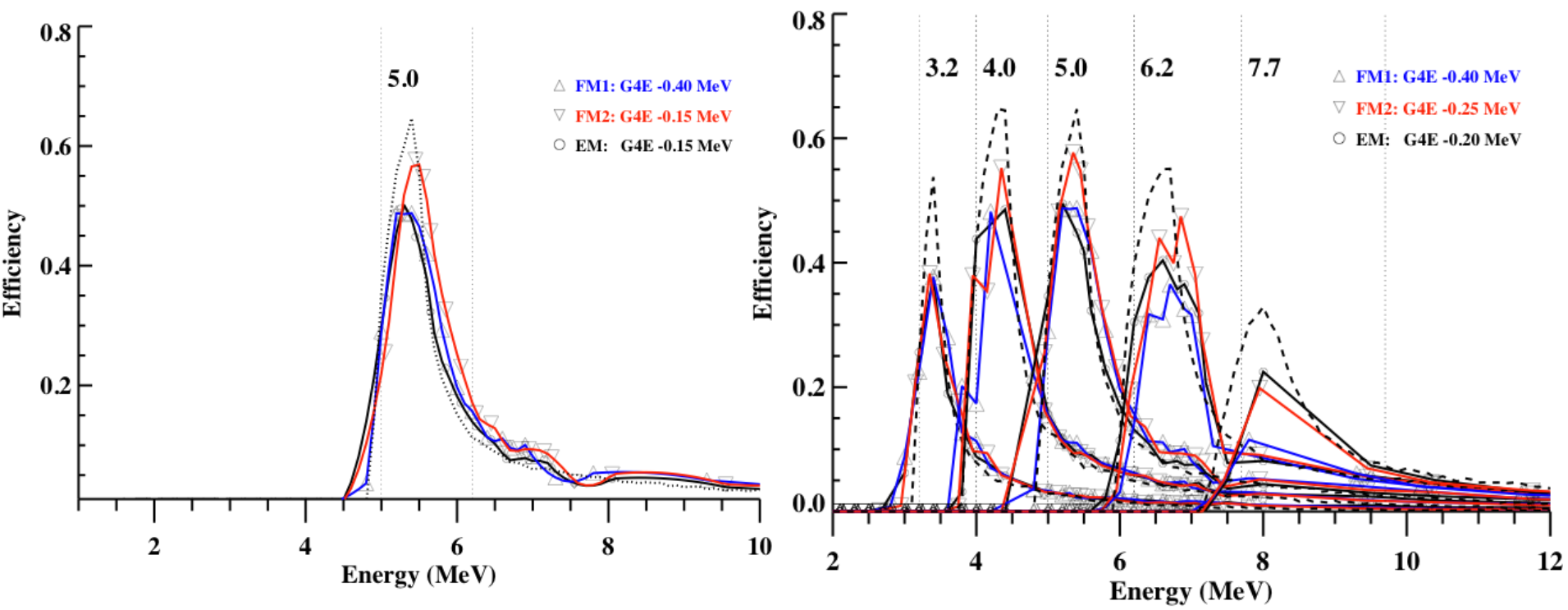
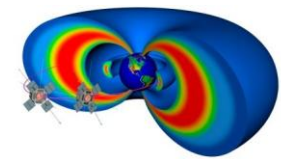
- Calibration is paramount
  - ◆ between instrument copies
    - recent results and lessons learned from REPT beam tests
  - ◆ between different instruments
    - ECT : HOPE, MagEIS, PSBR, and REPT overlapping energy bands
  - ◆ absolute[1] and relative[2] measurements
    - [1] radial gradients of phase space density
    - [2] temporal evolution of spectra during energization and loss



➤ spectra and absolute flux measurements directly comparable



# Calibration: REPT electrons



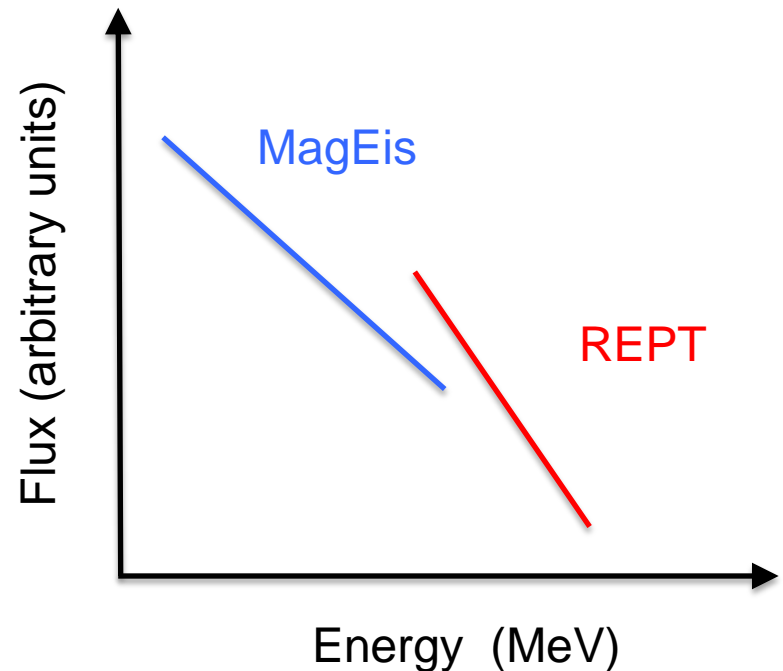
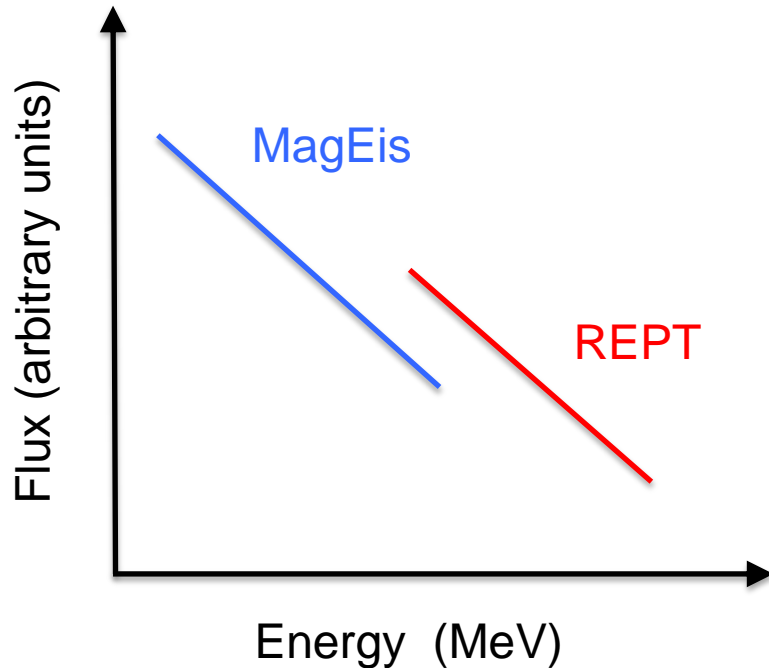
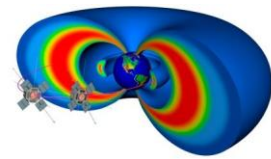
## ➤ Gain adjustment

- ◆ FM1 relative to FM2 of ~ 4%
- ◆ Software upload-able
- ◆ Use EM to cross calibrate with MagEIS





# Instrument cross calibration: beam tests



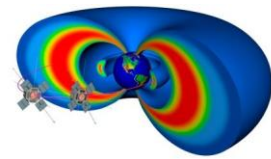
## ➤ Aerospace $\beta$ -spectrometer

- ◆ REPT MagEIS cross calibration
- ◆ Similar considerations – HOPE/MagEis
- ◆ Crucial for radial gradient studies



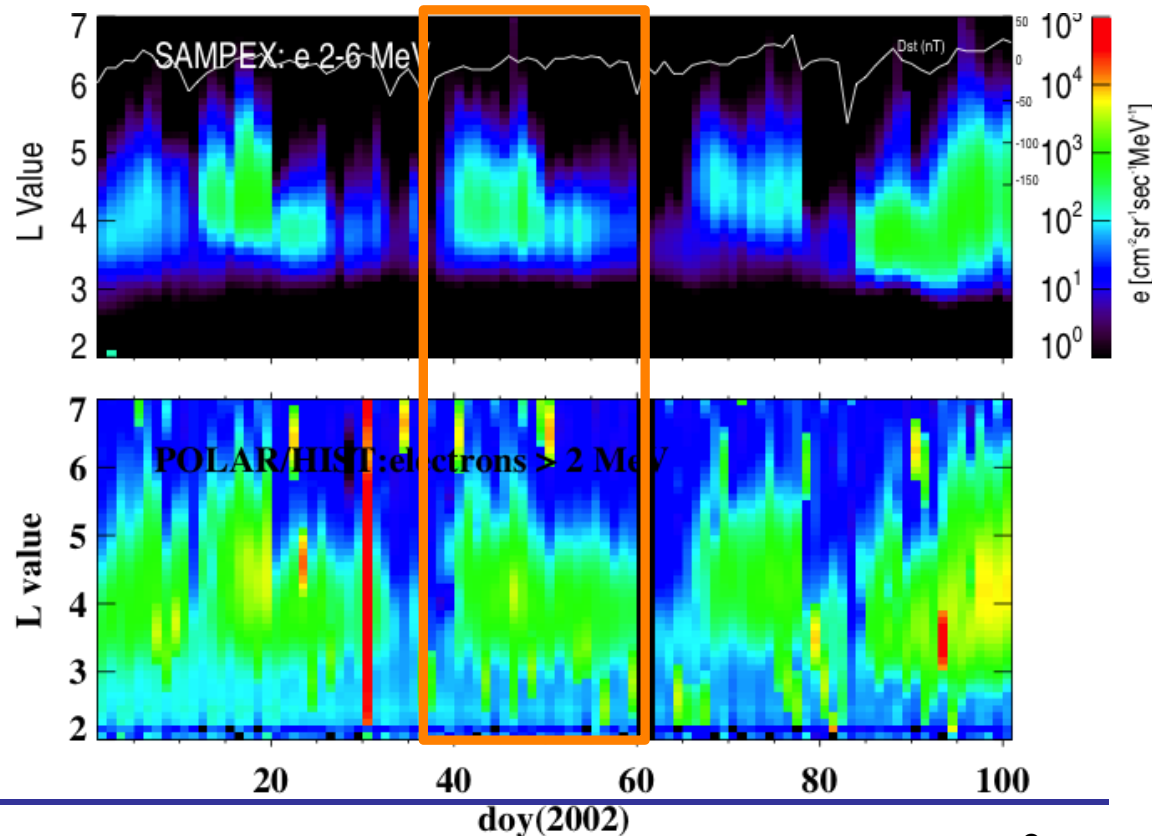


# Instrument cross calibration: on orbit



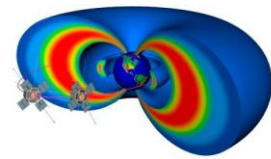
- spectral comparisons
  - ◆ Quiet times
    - heart of the outer zone
    - s/c not widely separated

- ◆ Absolute calibration within 5%... 10% ...?





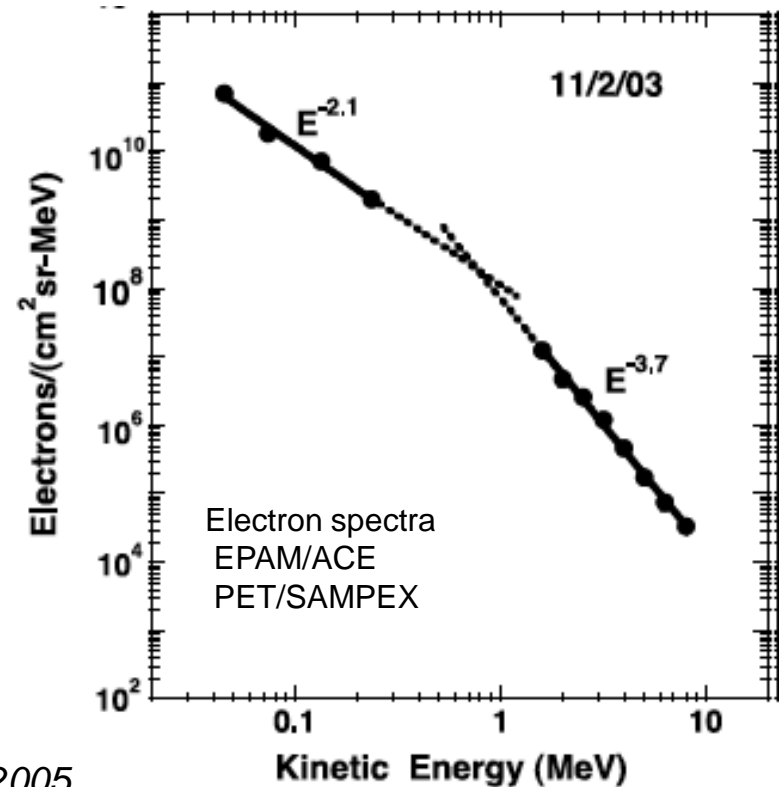
# Instrument cross calibration: on orbit



- spectral comparisons
  - ◆ Strong SEP events  
both electrons and protons

Impulsive events  
spectrum “constant”

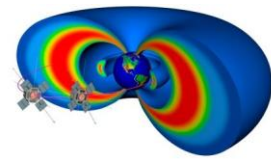
Gradual events  
choose peak flux time



*Adapted from Mewaldt et. al., JGR 2005*

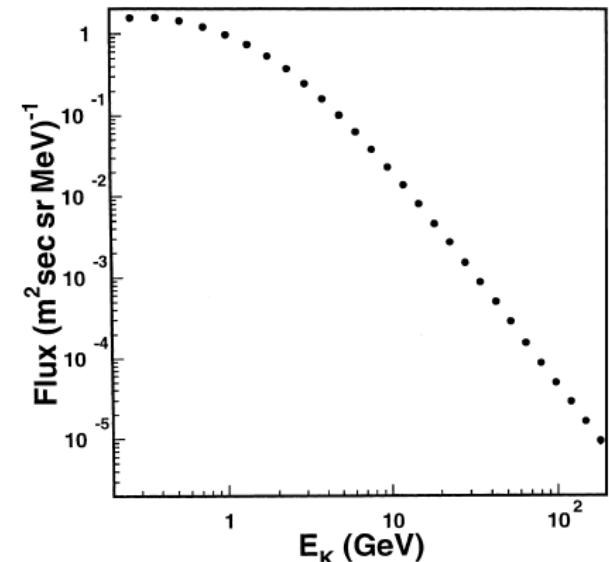


# Instrument cross calibration: on orbit



- spectral comparisons
  - ◆ Inner belt protons stable, expect reasonable cross calibration accuracy
  - ◆ GCRs inter calibrate REPT 1 & 2 using PSBR fluxes
  - ◆ Recent measurements from AMS are available for inner belt as well

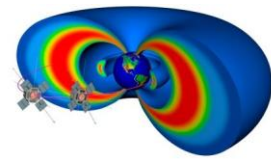
Primary cosmic ray protons



Adapted from Alcaraz et. al., *Phys. Lett. B* 2000

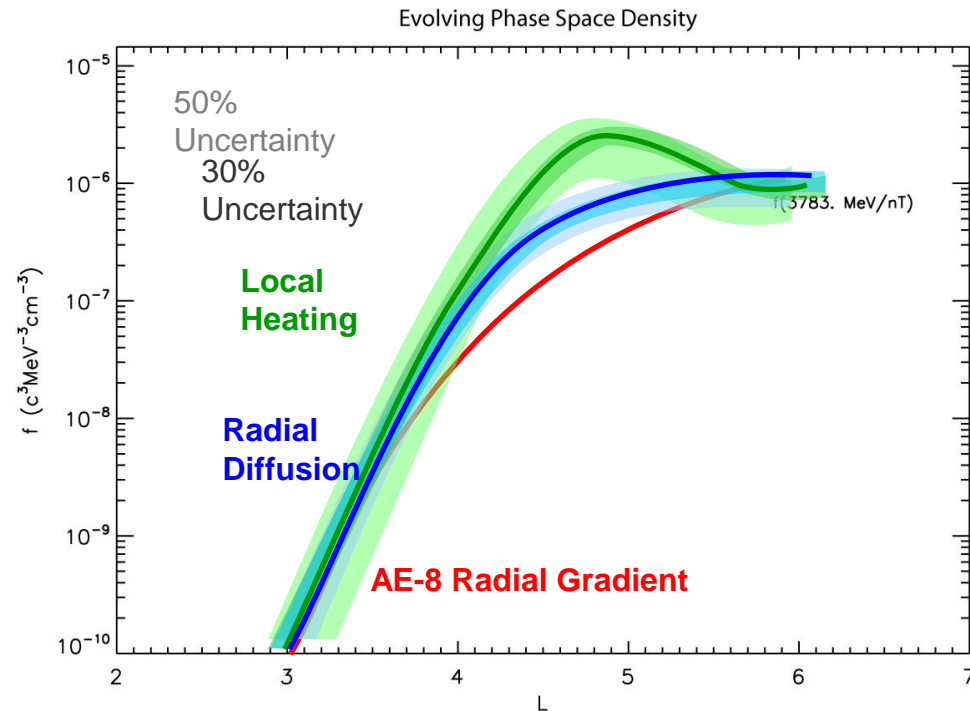


# Radial PSD gradients



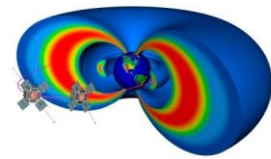
➤ Energy and pitch angle coverage  
: absolute calibration across s/c and instruments

- ♦ energy range  
~ 20 KeV to 10 MeV  
differential channels
- ♦ full pitch angle coverage
- ♦ measurement errors



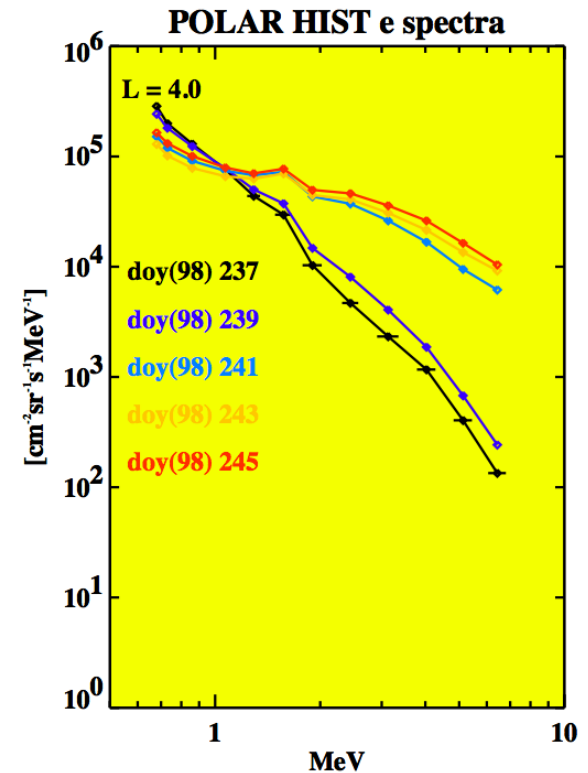


# In-situ Spectral evolution



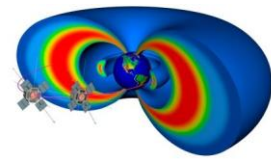
➤ Energy and pitch angle coverage  
: relative calibration

- ◆ time scales probed dependent upon s/c separation
- ◆ rapid local energization close s/c separation





# Wave-particle interactions



## ➤ Energy and pitch angle coverage

: relative calibration

- ◆ global coherence
- association with energization
- ◆ temporal evolution of pitch angle distributions

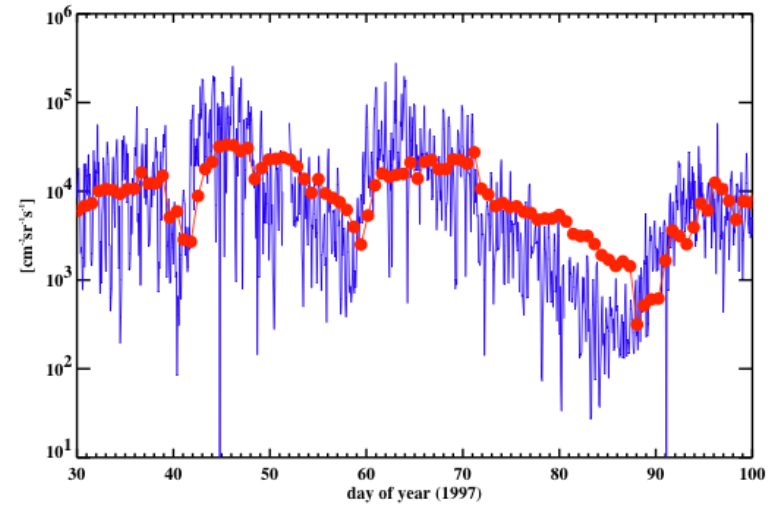
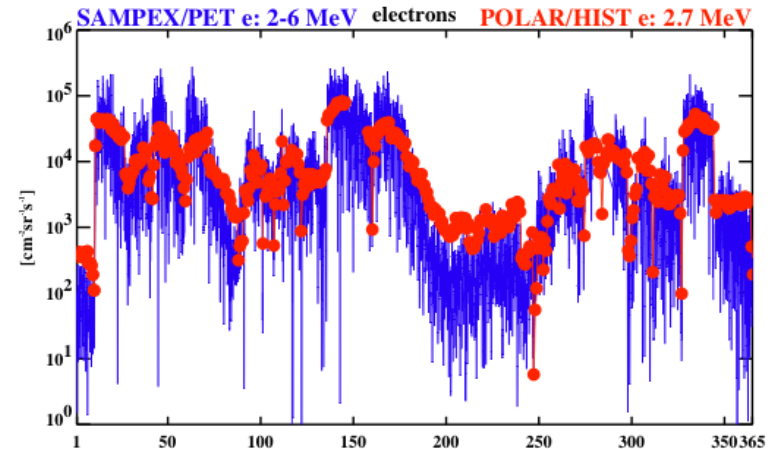
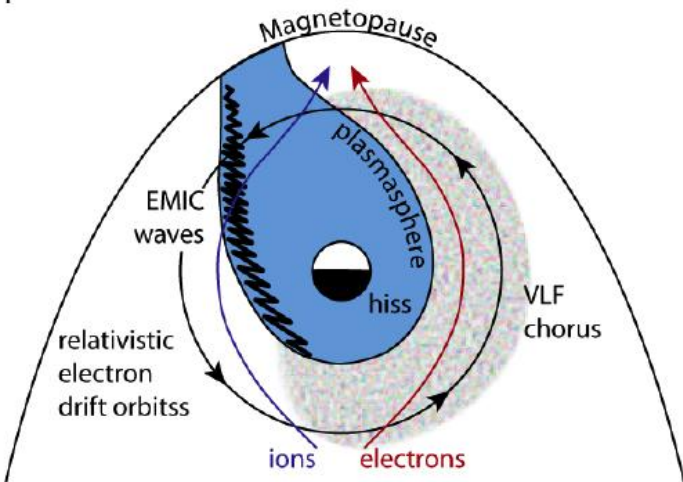


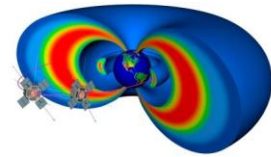
Figure 2



Adapted from Summers et al., 1998



# Conclusion

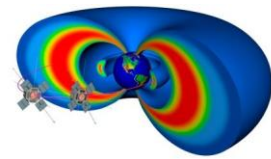


- Absolute calibration of instruments is crucial for RBSP multipoint studies such as radial gradients of PSD, radial transport...
- Relative calibration will suffice in studies involving differential changes, e.g., spectral hardening
- Good knowledge of systematic errors essential for characterization of various processes





# In-Person SWG 23-24 May(1)

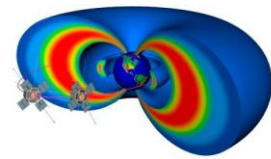


- Monday:
  - 8.30 Welcome
  - 8.35 Multipoint Measurements – how do we use multiple satellites? – Spence, Takahashi, Kanekal, O'Brien, Reeves
  - 11.30 SWARM Mission brief and M-I discussion – Knudsen/Purucker
  - 12.30 Lunch
  - 1.30 Data analysis and organization – are the adiabatic invariants the right frame to use for analysis? – Schulz, Ukhorskiy, O'Brien
  - 2.45 Break
  - 3.00 Active Experiments – Demekhov, DSX Representative, Lanzerotti, Papadopoulos, Ganguli
  - 4:45 Viewing the Spacecraft
  - 5.30 End of day 1
  - SWG Dinner

*Continued next Slide*



# In-Person SWG 23-24 May(2)



- Tuesday: Focus on 3 “Grass Roots” Working Groups
  - 8.30 THEMIS-RBSP Workshop (Sibeck (Ukhorskiy) and Bonnell)
  - 10.30 Break
  - 10.45 BARREL-RBSP Workshop (Millan and O’Brien)
  - 12.00 Lunch
  - 1.00 BARREL-RBSP cont.
  - 2.00 RBSP E/PO Program
  - 2.30 SuperDARN-RBSP (Yeoman and Ukhorskiy)
  - 4.15 Break
- 4.30 Wrap-up and action items