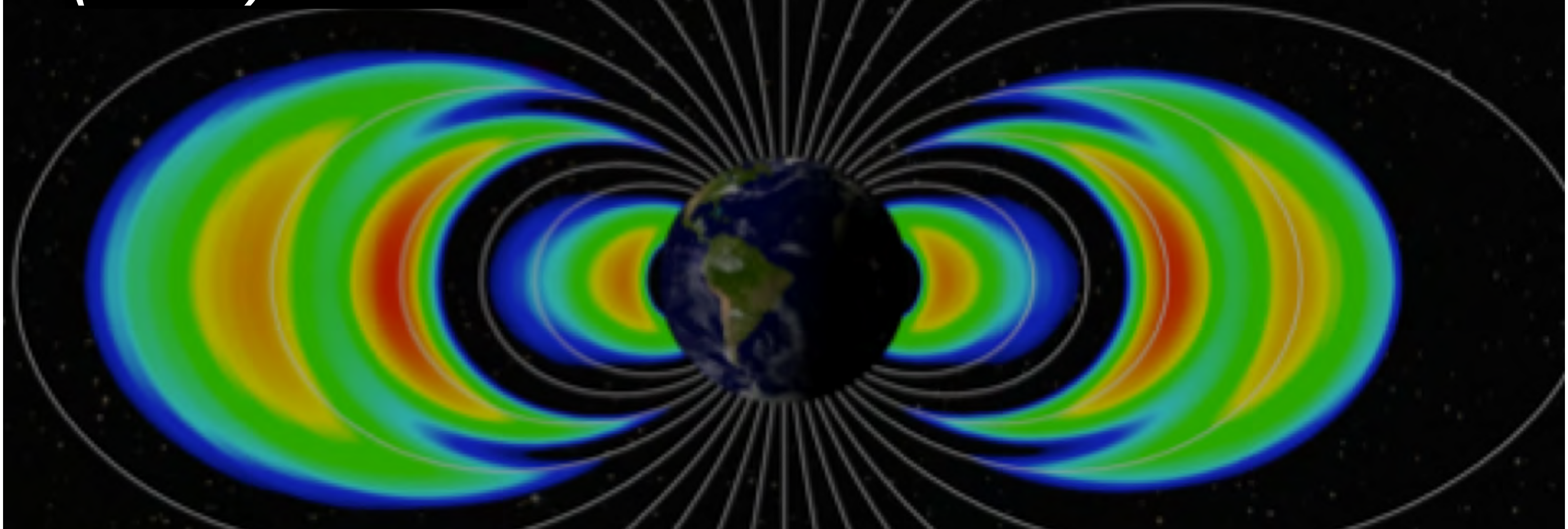
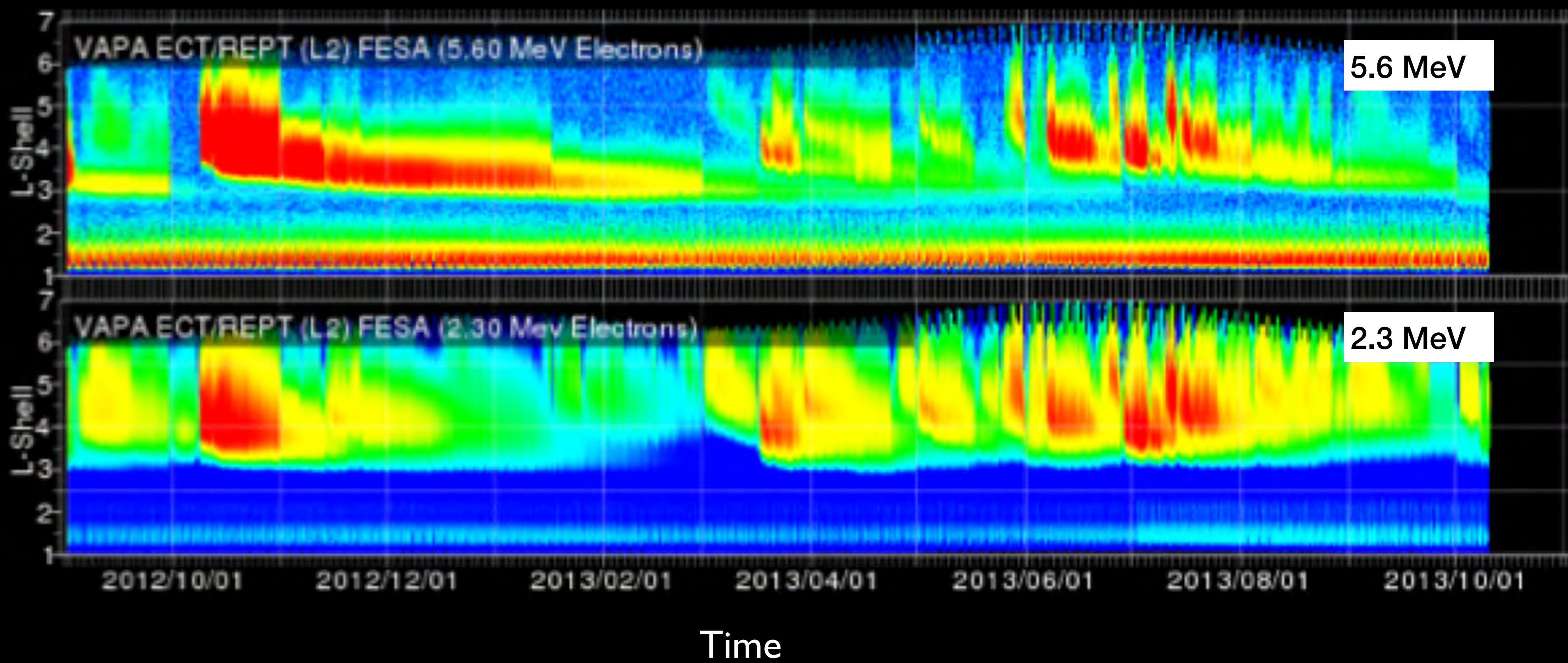
The Relativistic Electron Atmospheric Loss (REAL) CubeSat



T. Sotirelis, R. M. Millan, J. G. Sample, L. A. Woodger, Wen Li, A. Y. Ukhorskiy, Arlo Johnson, Romina Nikoukar, Mykhaylo Shumko, Luisa Capannolo, Brady Griffith

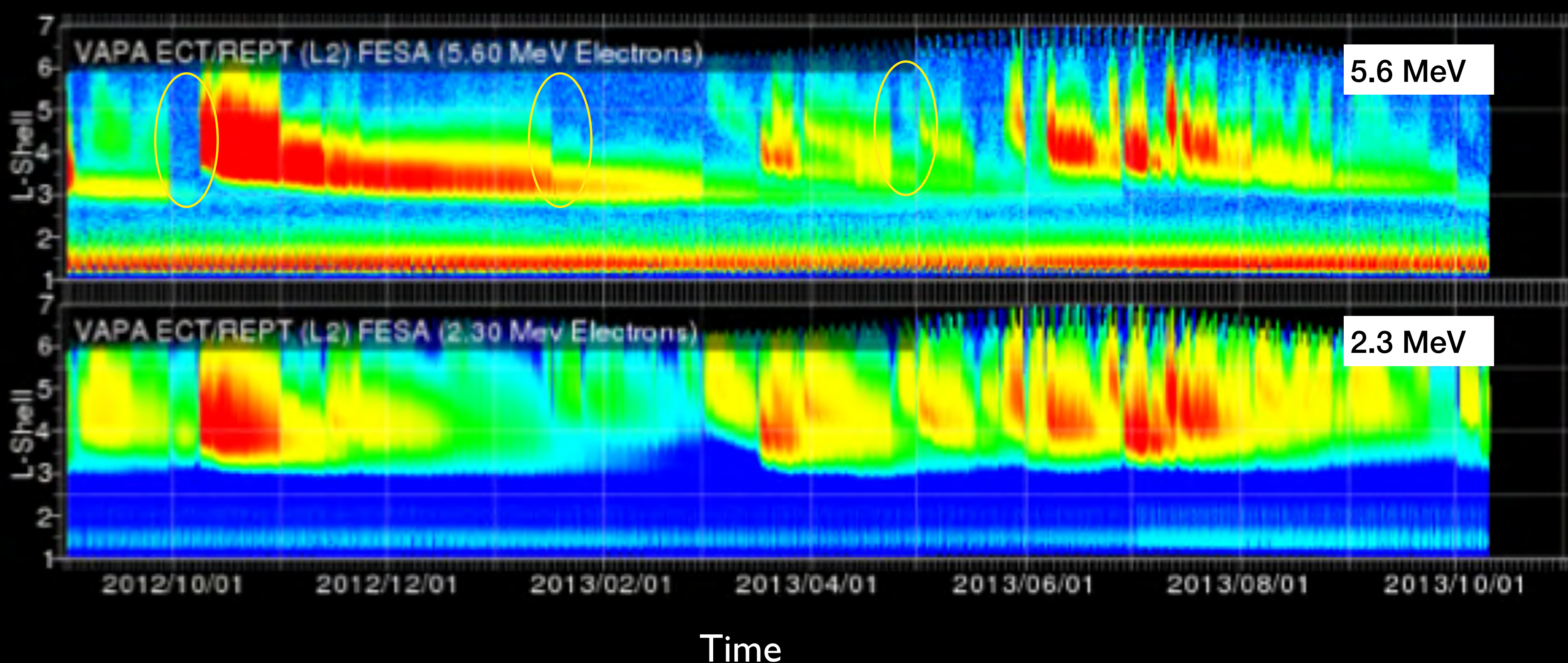
Radiation Belt Variability

- The intensity of high-energy particles in Earth's radiation belts varies by orders of magnitude on timescales from minutes to days.



Radiation Belt Loss

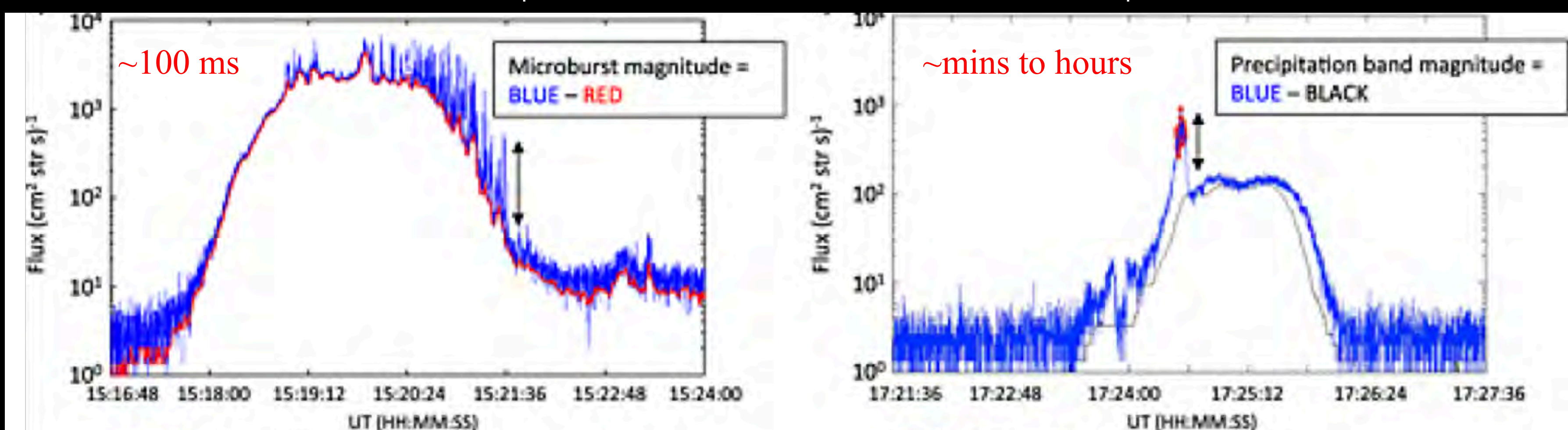
- Catastrophic depletions of radiation belt electrons are commonly observed.
- Electrons can be lost to the magnetopause or precipitate into Earth's atmosphere.



Atmospheric Precipitation Loss

- At least two types of precipitation have been identified:
  - microbursts: ~100ms bursts observed on the dawnside, associated with chorus
  - precipitation bands: very hard spectrum, last minutes to hours, possibly caused by EMIC waves
- REAL will measure both, revealing their relative importance for radiation belt dynamics.

Microburst Precipitation Precipitation Bands



[Blum et al., 2015]

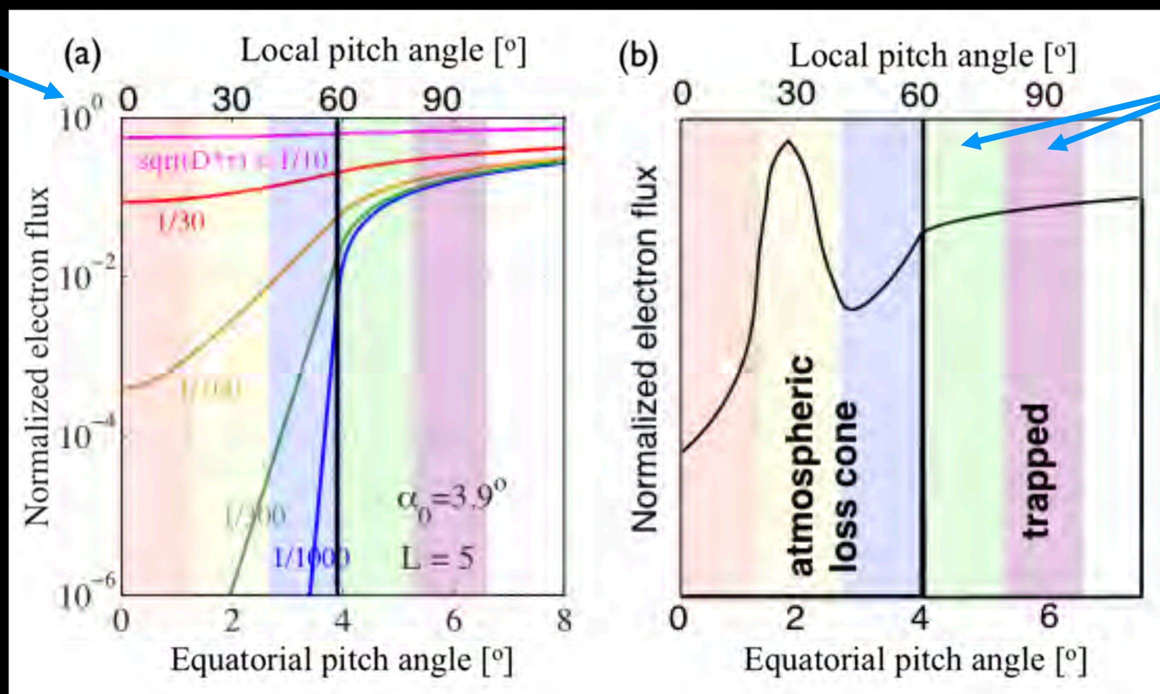
Modes of Atmospheric Loss

- The plasma waves that drive atmospheric precipitation are well known *[e.g.,Thorne, 2010*]
- However, physical "modes" in which these act is not well specified:
  - electrons may be scattered slowly through a diffusive process *[e.g., Shprits et al., 2008]*
  - or rapidly through nonlinear processes [e.g., Albert, 2000; Bortnik et al., 2008, Omura et al., 2015]
- The physical mode determines the scattering rate and thus the impact on the radiation belts.

  - The REAL CubeSat mission will characterize different modes of atmospheric loss by making high time resolution measurements of the electron pitch angle and energy distributions, in low Earth orbit (LEO), over a wide energy range, from keV to MeV

- The physics of the scattering process is imprinted on the pitch angle distribution.
  - Slow, diffusive processes create a smooth distribution across the loss cone
  - Non-linear wave particle interactions create a non-monotonic distribution

Distribution assuming different pitch angle diffusion coefficients from Li et al., (2013)

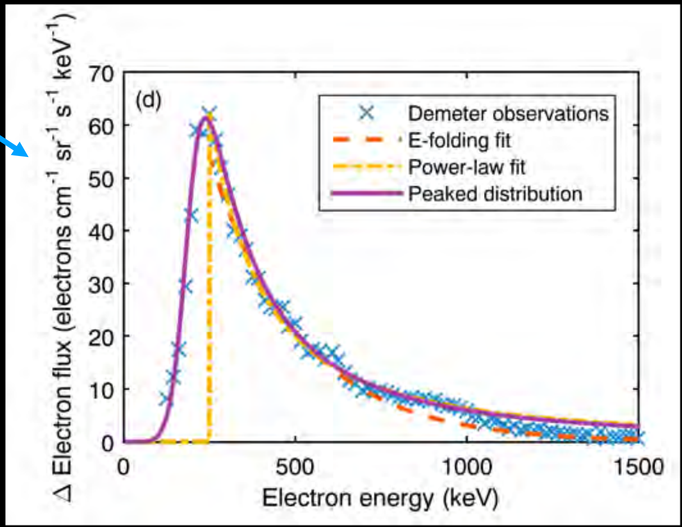


Non-monotonic distribution

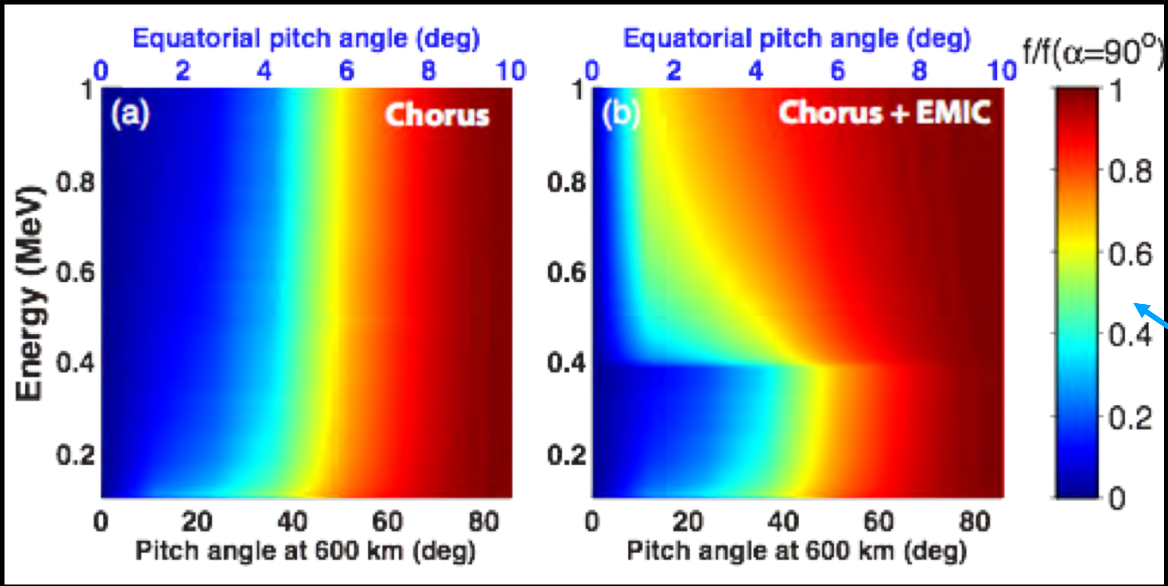
REAL look directions superposed

Energy Spectrum of Precipitation

- The energy spectrum also reveals key information about the scattering process.
  - EMIC wave scattering: low energy cutoff near 1 MeV is predicted
  - But, one Demeter event study found precipitation down to 250 keV



[Hendry et al., 2016]



Energy and pitch angle distributions depend on scattering mechanism

[Li et al., 2007]

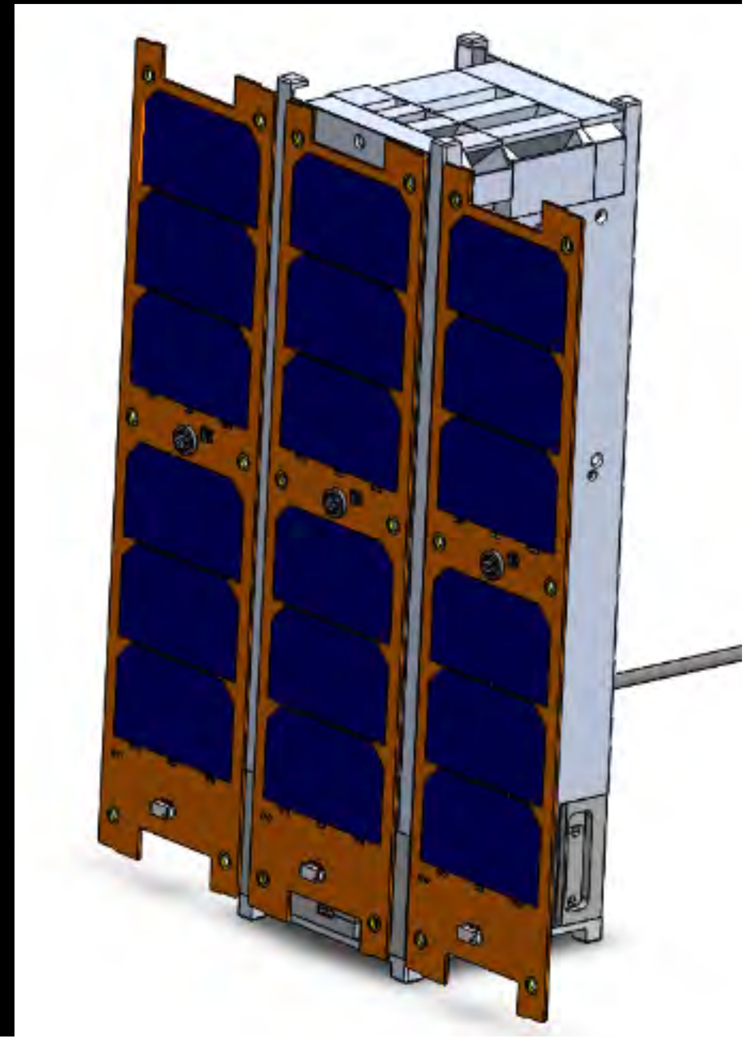
REAL Science Objectives

- REAL will improve our understanding of the physical mechanisms responsible for scattering relativistic electrons into the atmosphere.

  1. When and where do different precipitation loss modes (diffusion, strong diffusion, and nonlinear scattering) occur?
  2. How do electron precipitation loss modes depend on energy?
  3. What is the relative impact of different loss modes on the radiation belts?

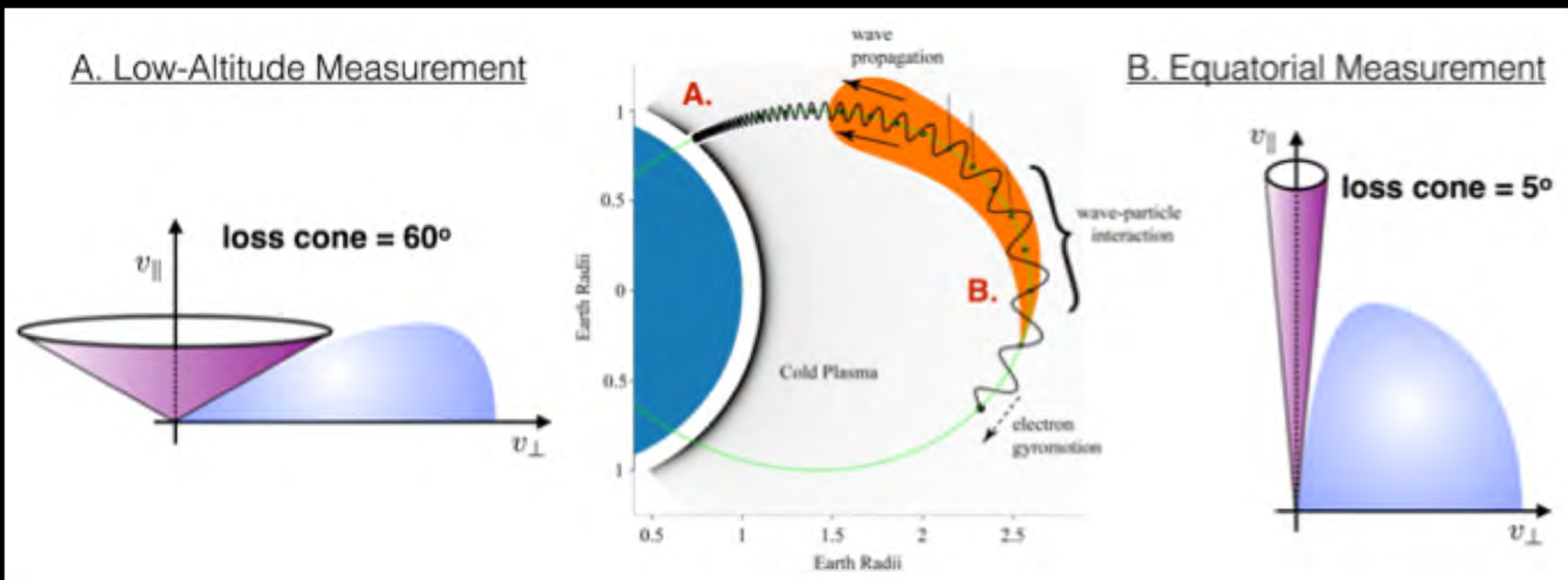
REAL Spacecraft

- 3U CubeSat, 3-axis stabilized, aligned with local B-field
- 3 sensors measure electrons from 100 eV - 2 MeV
- Field of view: 120^ox40^o comprised of 5 look directions
- First comprehensive measurements of pitch angle distribution at microburst timescales (~40ms)
- S-band for science data



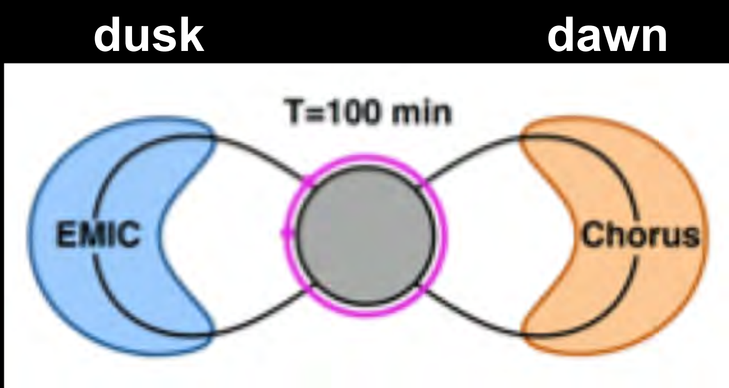
Low Altitude Measurements

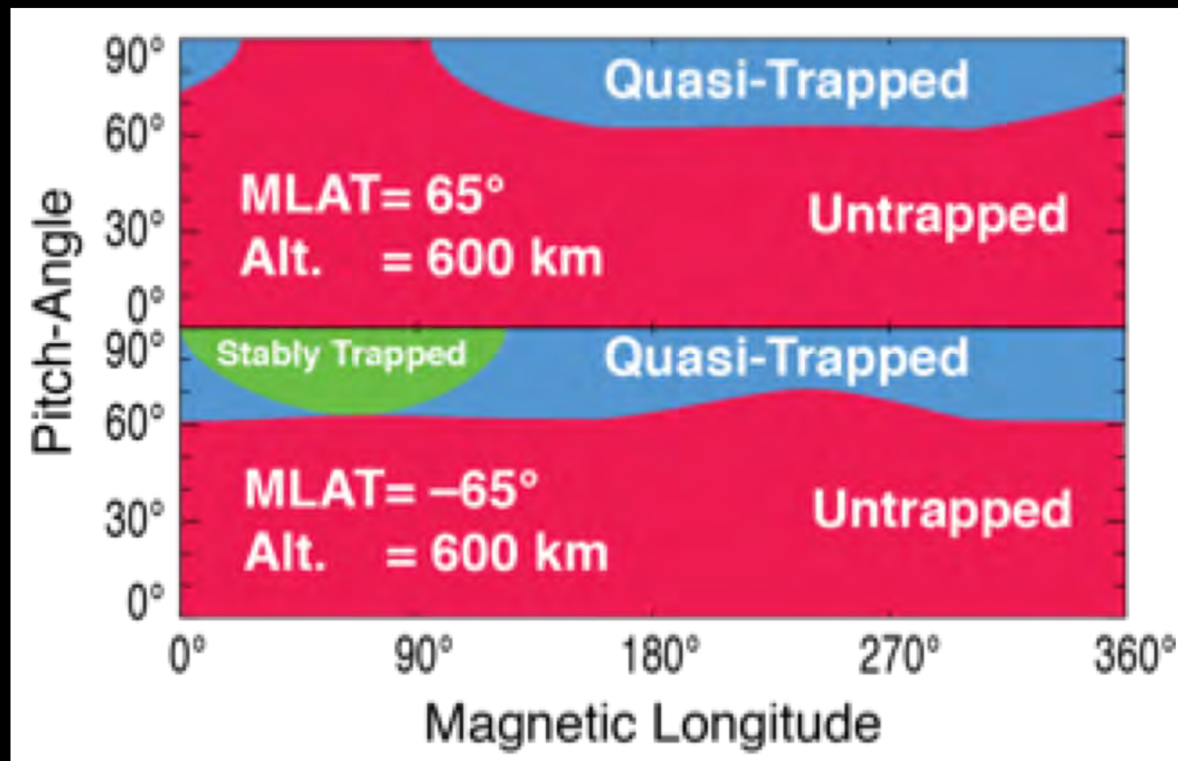
- Low altitude spacecraft are ideal for measuring atmospheric loss
- The equatorial loss cone (~5°) is smaller than the angular resolution of most particle detectors (≳15°) making it difficult for an equatorial spacecraft to make this measurement
- Wave-particle interaction extends over a broad range of latitudes (~30°) = rapid coverage across L-shells is essential



Mission Design

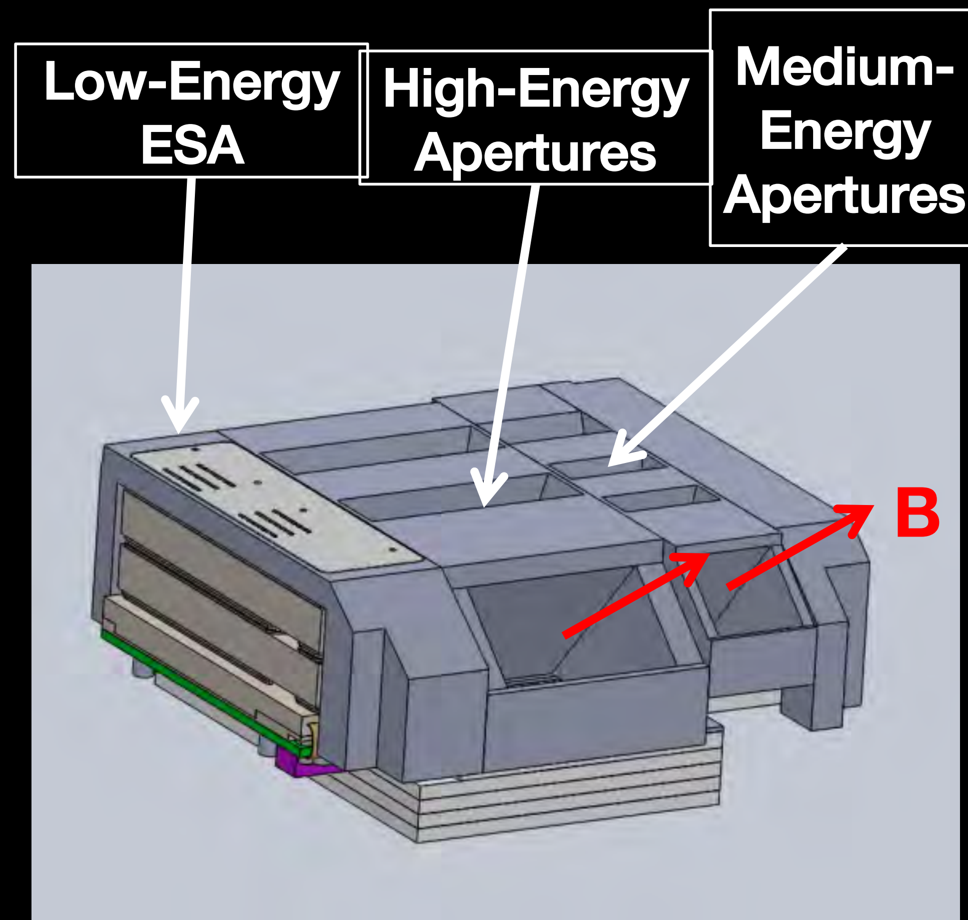
- Ideal orbit: dawn-dusk sunsynchronous polar LEO orbit similar to FIREBIRD II
- Measure precipitating and quasi-trapped populations at all relevant locations



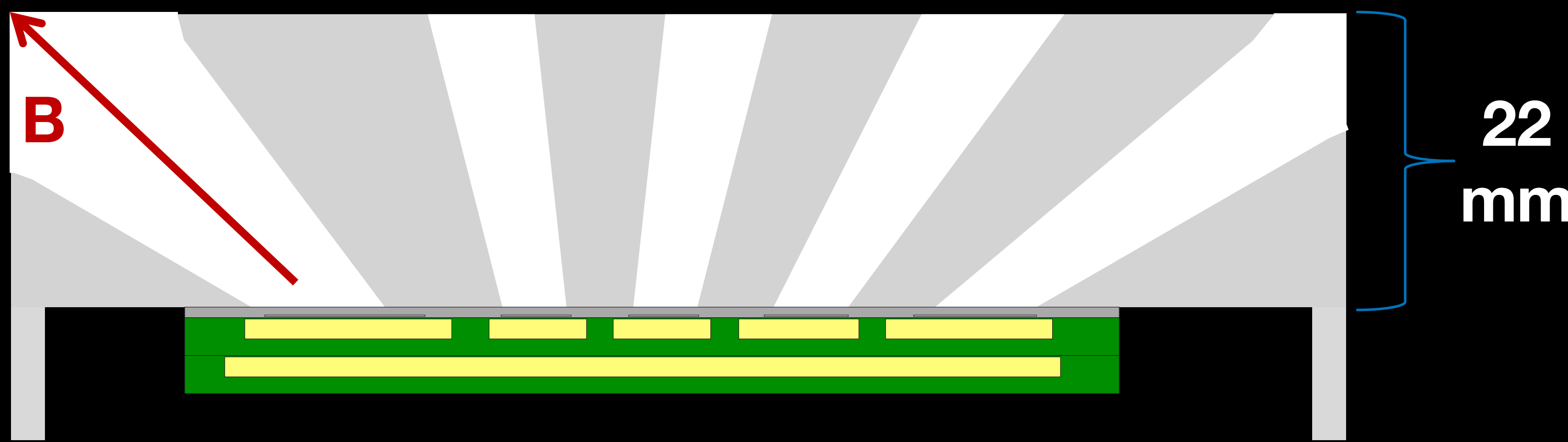


REAL Instrument

- The REAL instrument will constitute the top 1.4 U of the 3U REAL spacecraft
- Each of the medium- & high-energy apertures resolves a 20° range of electron pitch angles.
- The first Look-Direction (LD) will be centered on the magnetic field, so it has a 40° Field-of-View (FoV)



Medium Energy Head

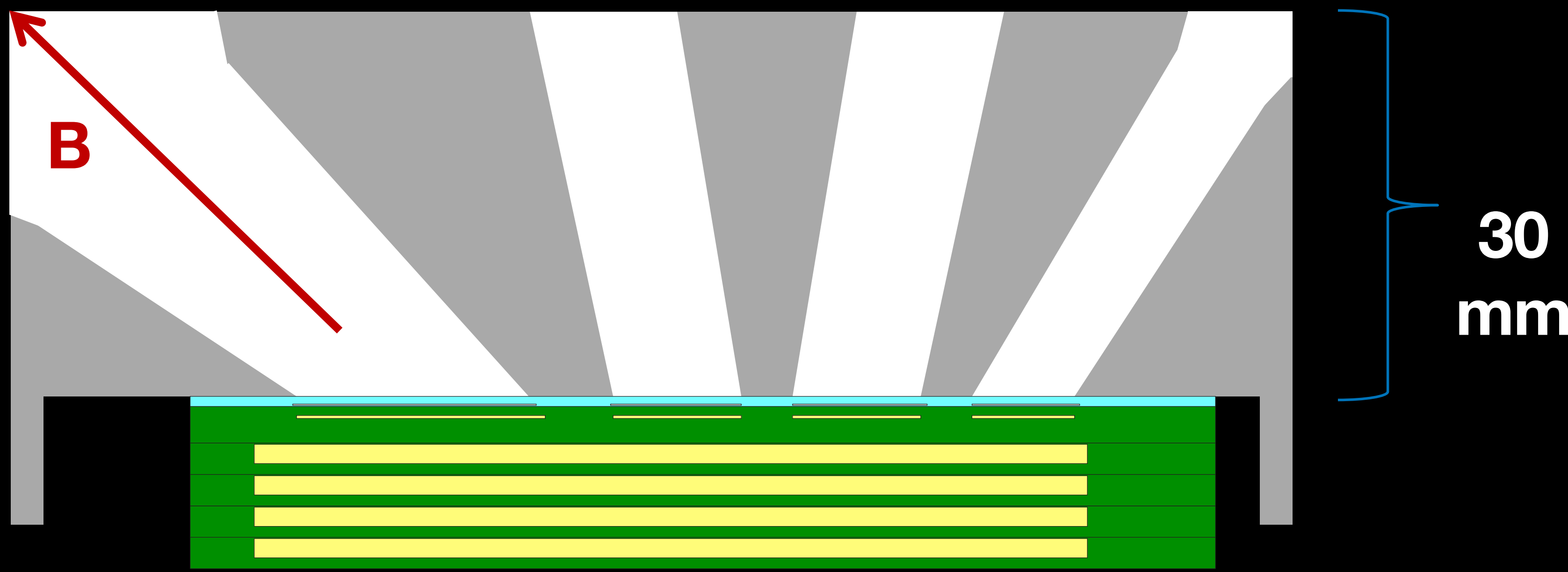


Yellow = Active areas

- 50 keV to 375 keV
- 22 mm thick Al collimator
- Five apertures, each spanning 20° of pitch-angle
- 1.5 mm thick Solid State Detectors (SSD)
- Five separate active areas
- Total energy measurement, with veto
- Al absorber to exclude protons E < 500 keV (~ 6 μm Al)

Aperture	# 0	# 1-4
G [cm^2 sr]	0.4	0.1

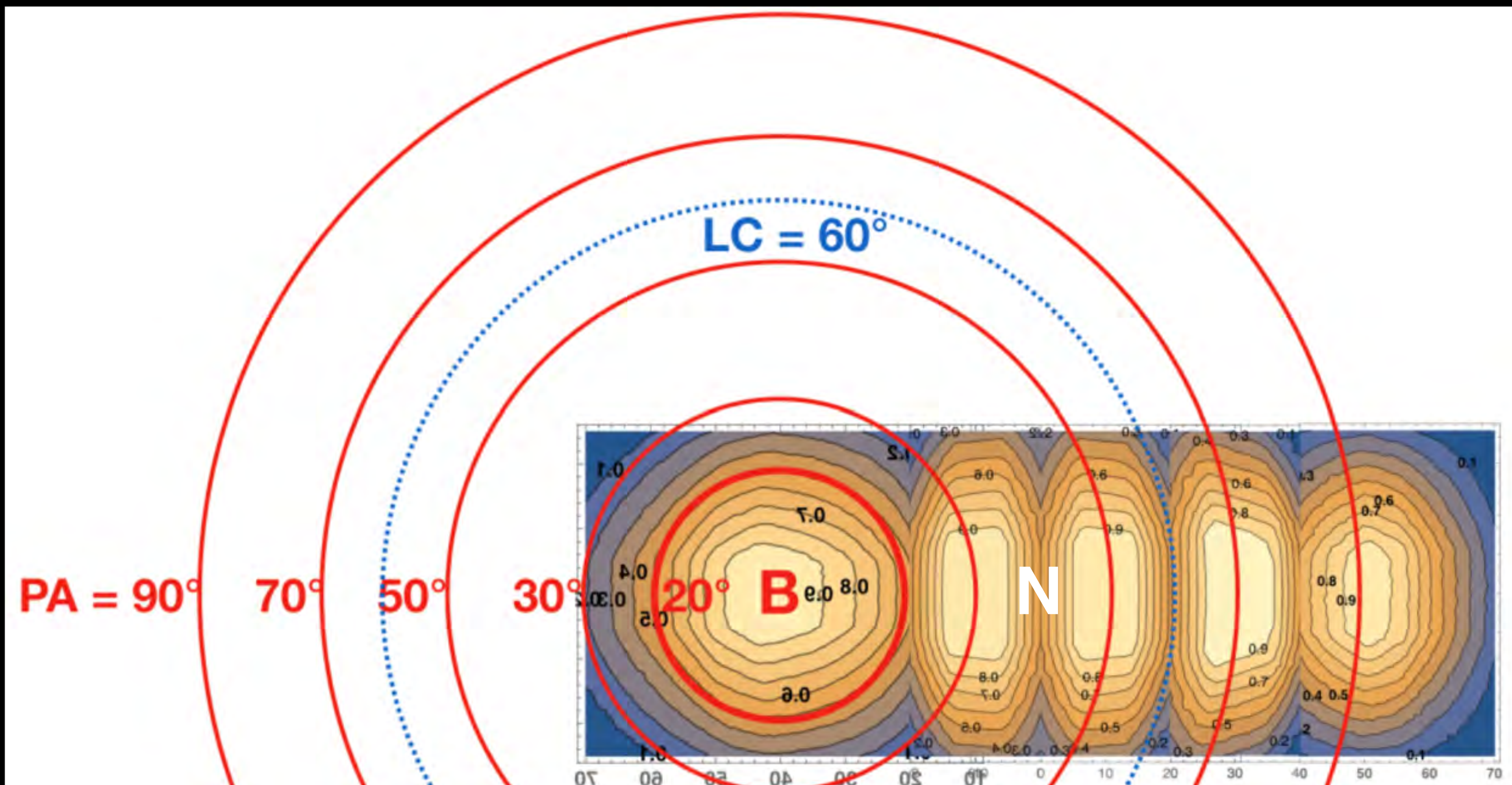
High Energy Head



- 375 keV to 2 MeV
- 30 mm thick Al collimator
- Four apertures, each spanning 20° of pitch-angle
- Al absorber to exclude lower energy electrons (~ 100 µm Al)
- 100 µm thin segmented front SSD with four active areas
- Four 1.5 mm thick SSDs, one active area each
- dE by E coincidence measurement

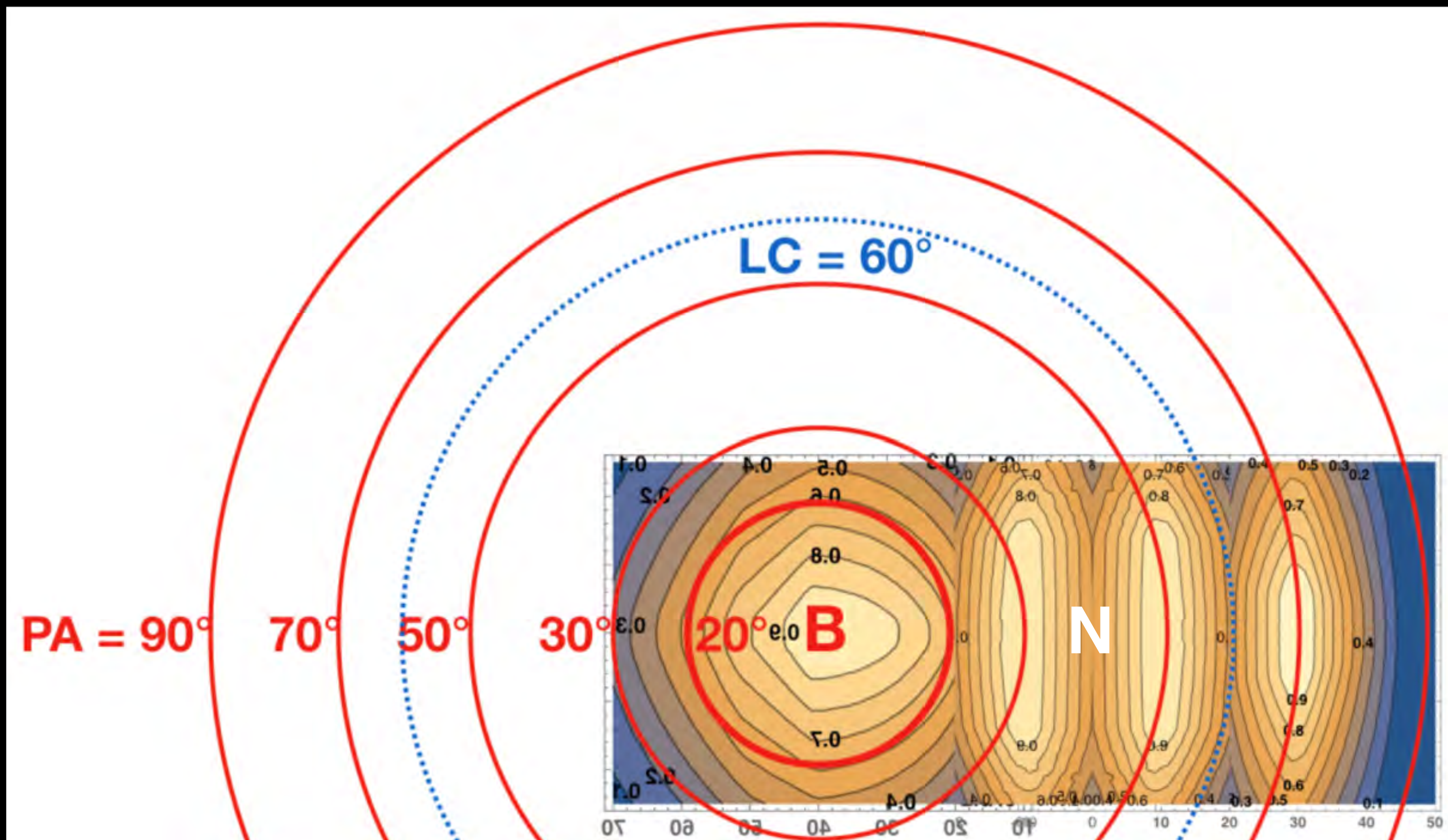
Aperture	# 0	# 1	# 2	# 3
G [cm^2 sr]	2.0	0.8	0.8	0.4

Medium-Energy Head: FoVs vs Pitch-Angle



N = Normal to collimator surface

High-Energy Head: FoVs vs Pitch-Angle



N = Normal to collimator surface

Conclusions

- REAL will make observations of energetic electrons in LEO with unprecedented energy and pitch-angle resolution.
- REAL will answer fundamental questions about the wave–particle interactions responsible for atmospheric losses
- PDR was earlier in May, Targeting 2021 launch