Radiation Belts

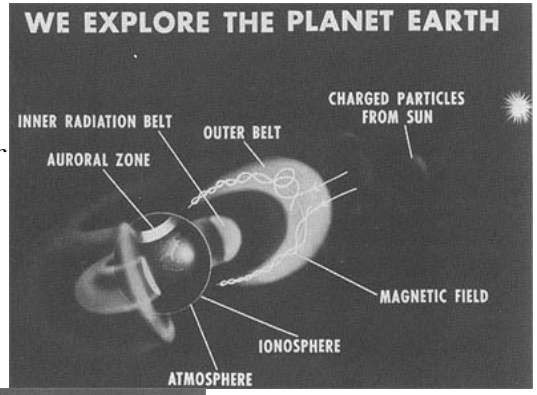
Alex Glocer

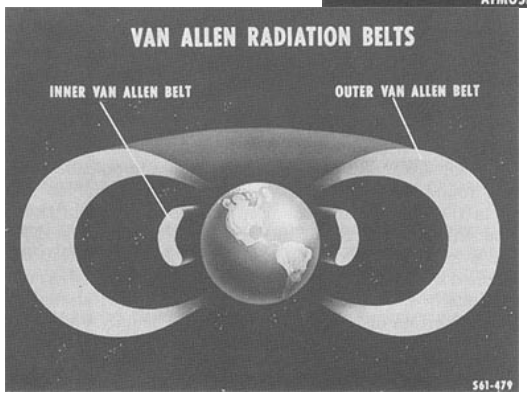
(With Thanks to David Sibeck, RBSP SWG, Colin Komar, and many others)

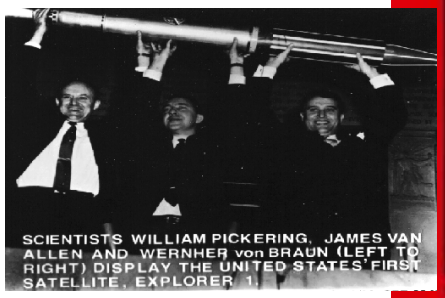
Van Allen's Discovery of Radiation Belts

- Put space physics in the news…

Artistic images of Van Allen belts, NASA/Langley, circa 1961

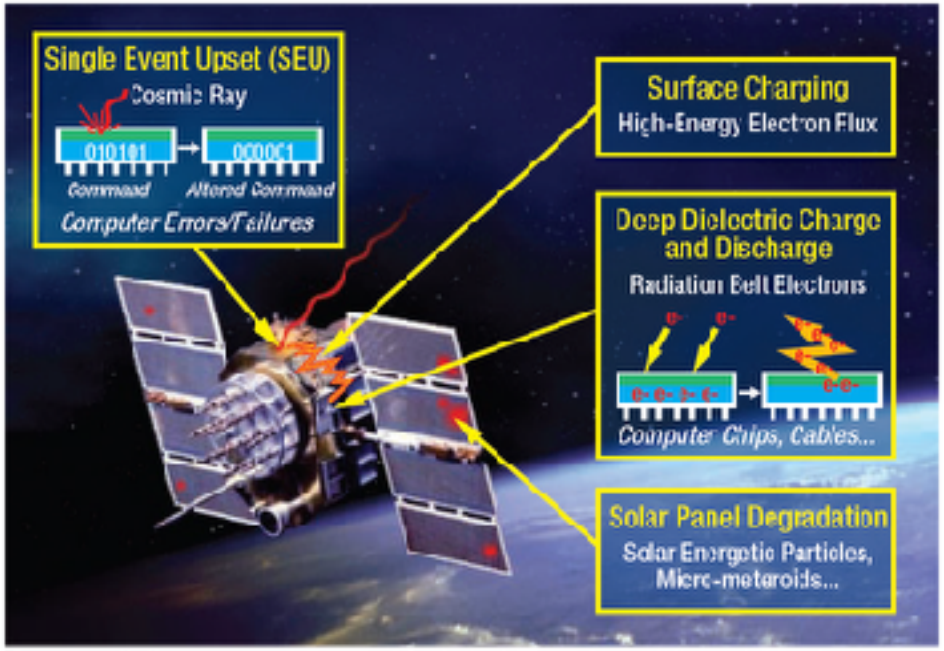




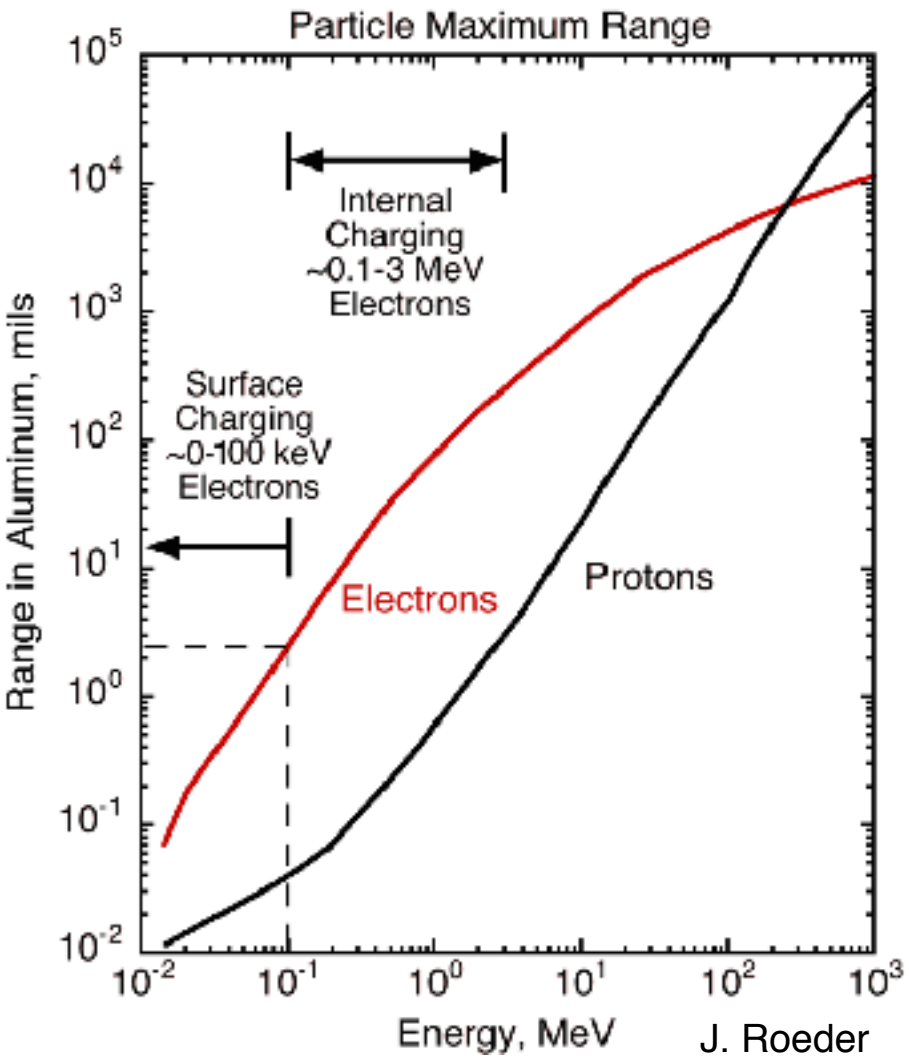


Cover of TIME in '59 and '64

Space Weather Impacts



(after Onsager et al.)



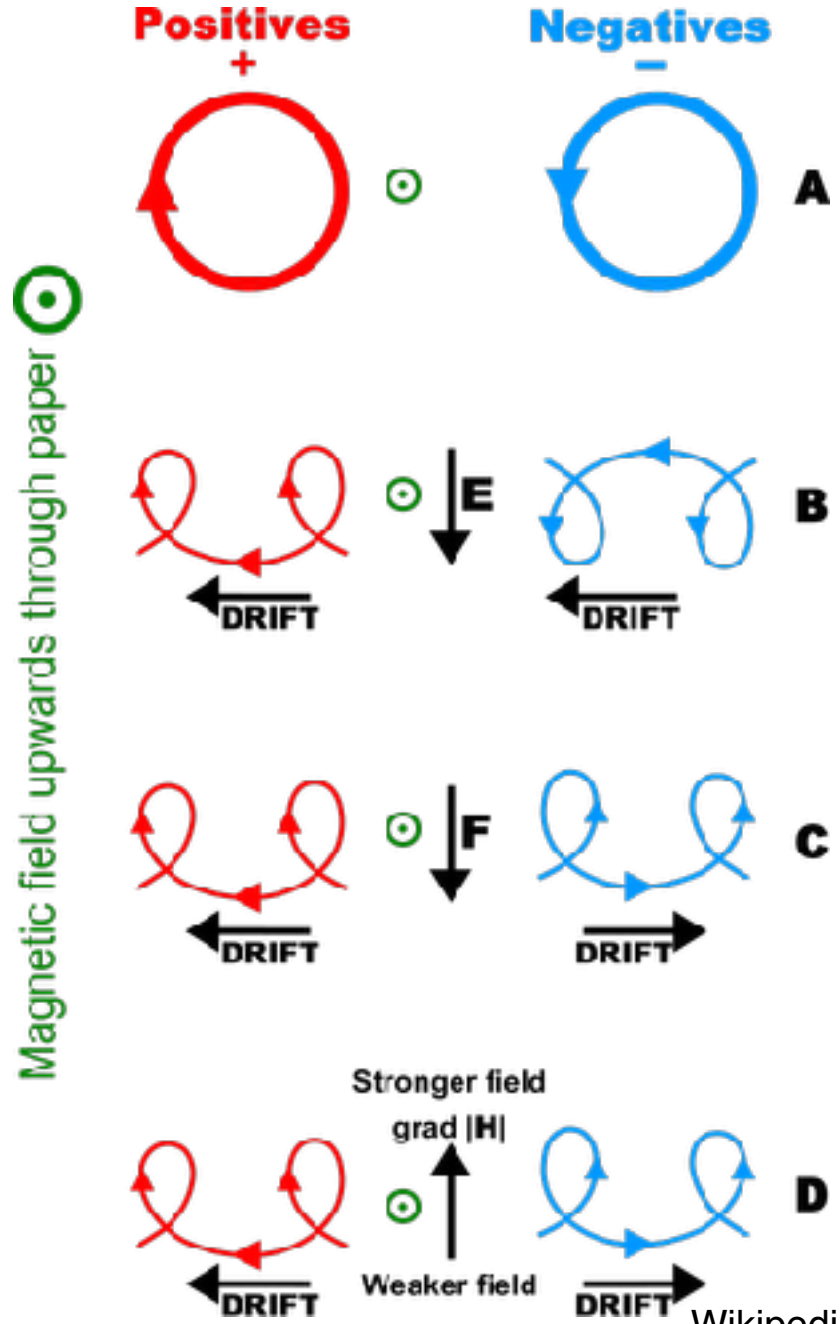
J. Roeder

Particle Drifts

$$\vec{v}_E = \frac{\vec{E} \times \vec{B}}{B^2}$$

$$\vec{v}_f = \frac{1}{q}\frac{\vec{F} \times \vec{B}}{B^2}.$$

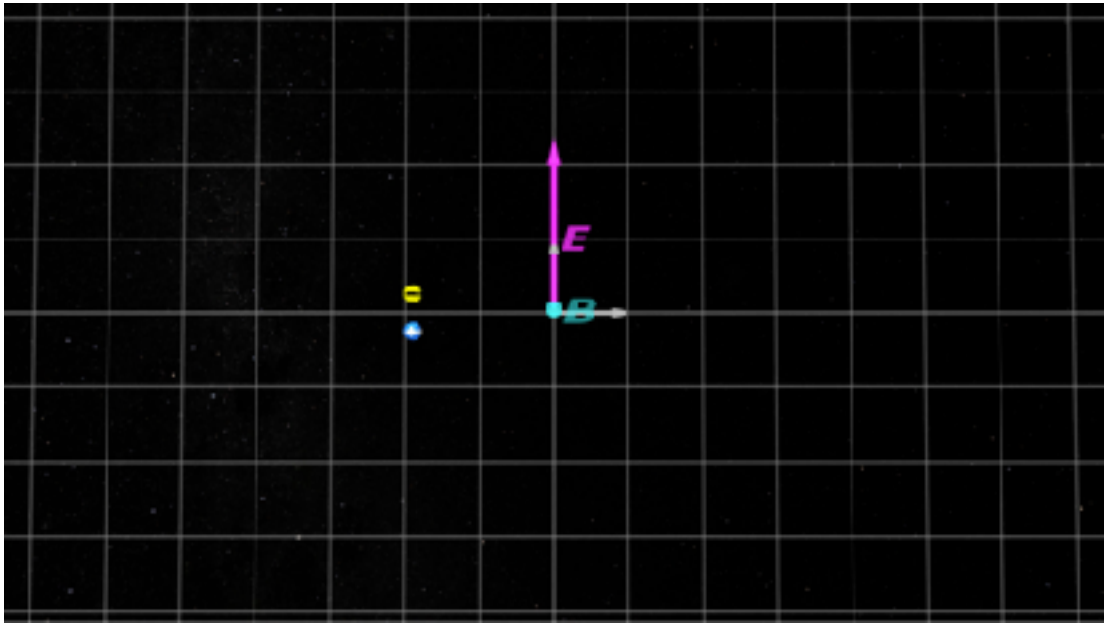
$$\mathbf{v}_B = \frac{m}{2qB}(v_\perp^2 + 2v_\parallel^2)\frac{\mathbf{B} \times \nabla B}{B^2}.$$



Wikipedia

Particle Drifts

$$\vec{v}_E = \frac{\vec{E} \times \vec{B}}{B^2}$$



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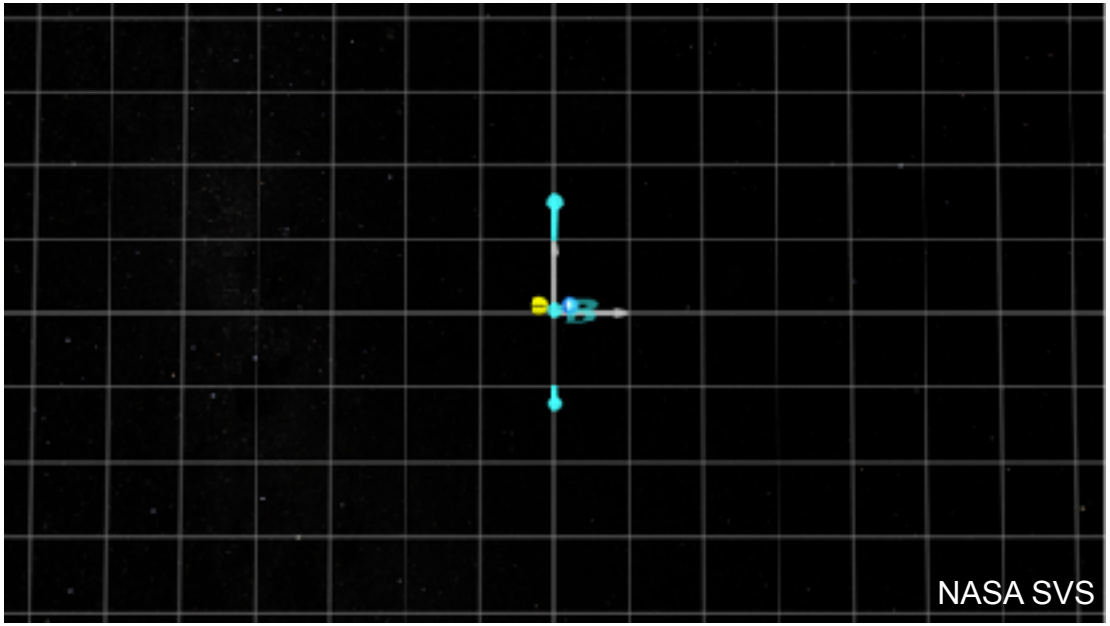
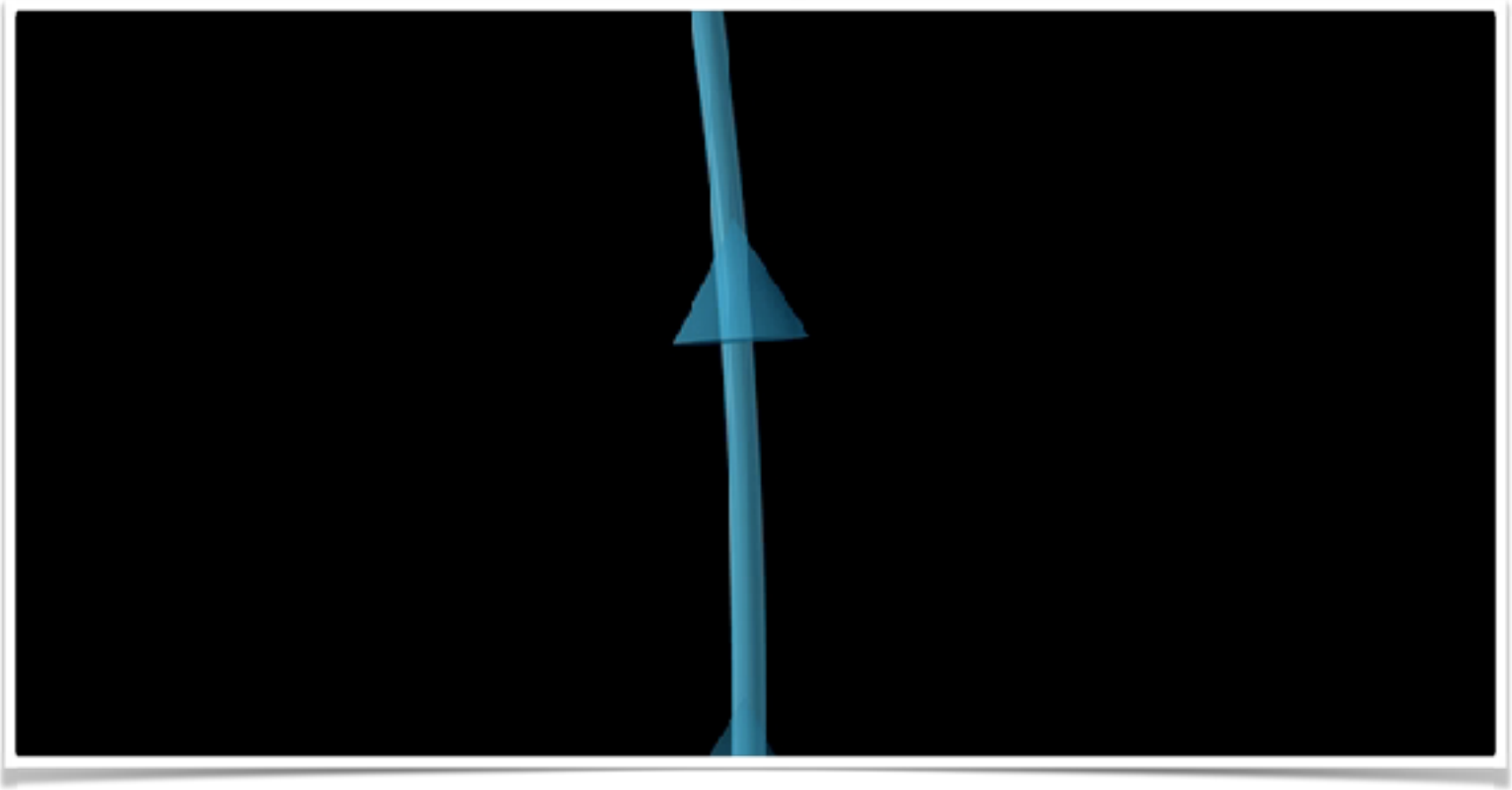


NASA SVS

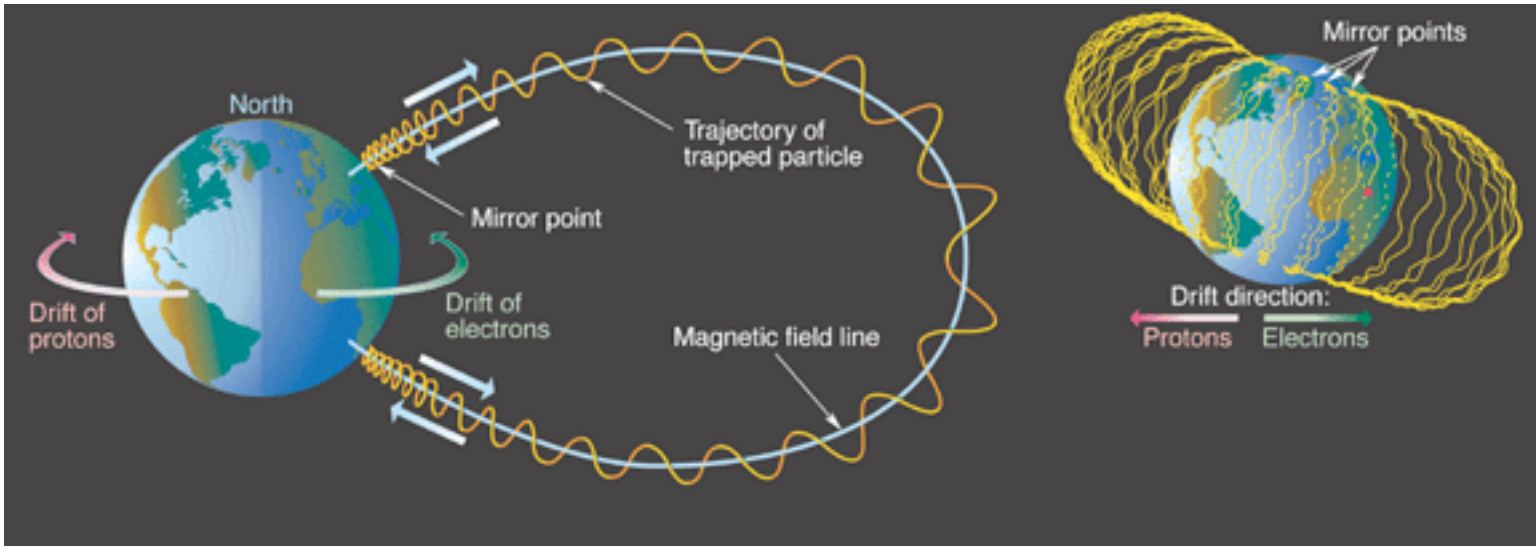


For 1 MeV electron at 6.6 R_E: Gyro ~10^{-3} s, Bounce ~ 10^{0} s, Drift ~ 10^{3} s

e^- Motion in the Radiation Belts

These motions are stable ad infinitum with no electron energization so long as no electromagnetic changes to Earth's magnetic field occur

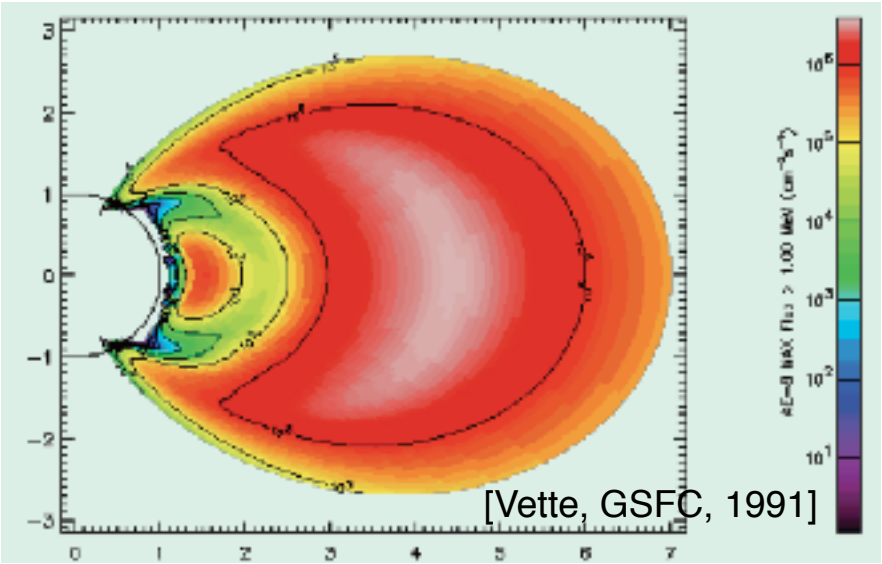
Overview of Trapped Radiation



Radiation Belts: Model vs Reality

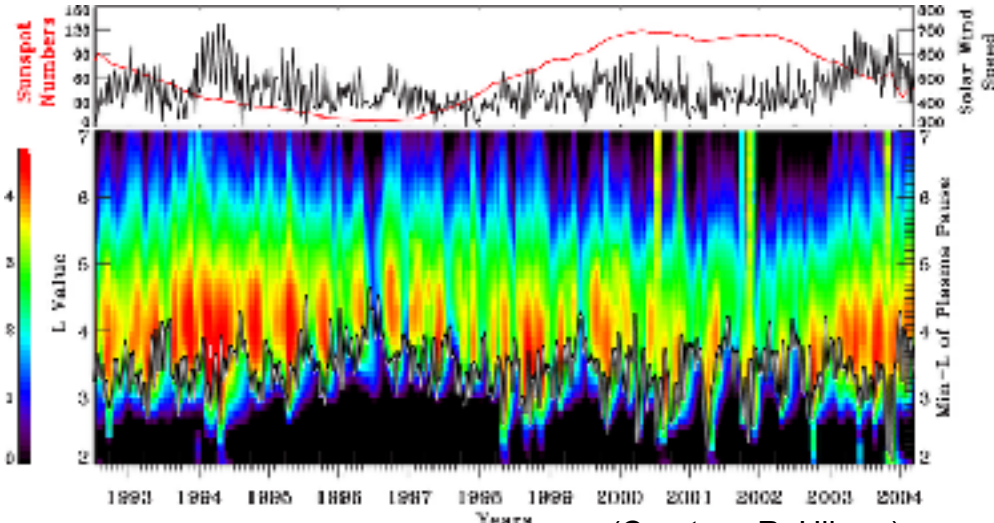
STATIC Empirical Model

AE-8 MAX E>1MeV



Dynamic Reality

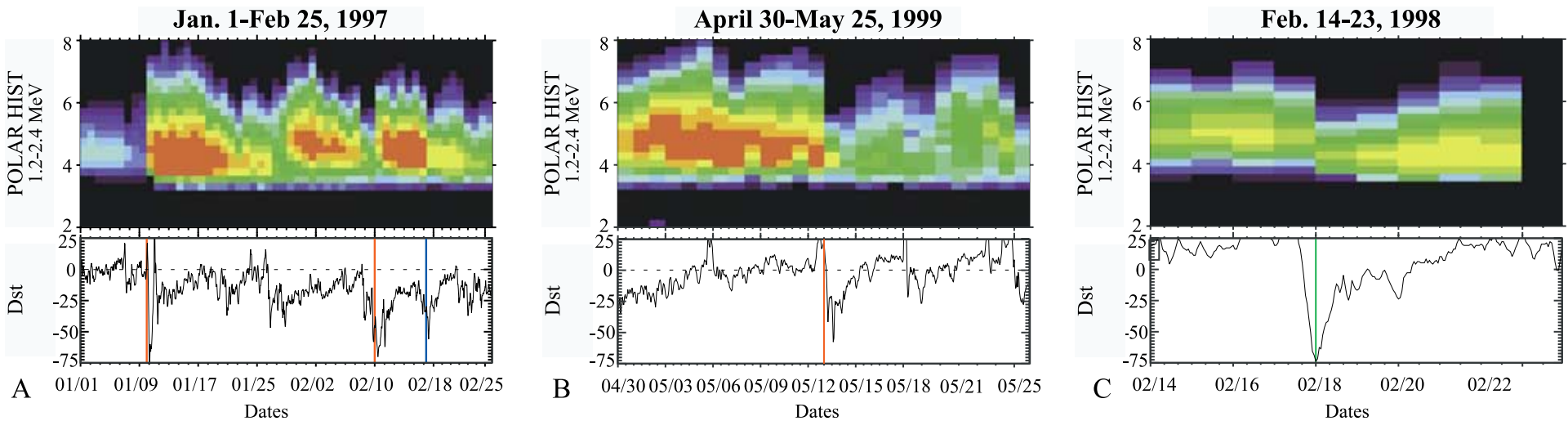
SAMPEX



(Courtesy R. Hilmer)

- Long lived but variable on many timescales

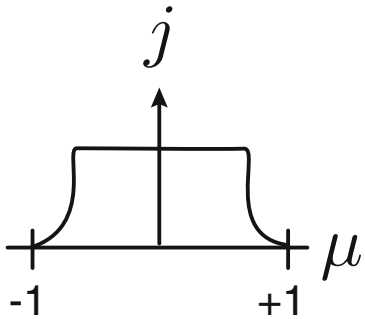
Radiation Belt Response is Hard to Predict



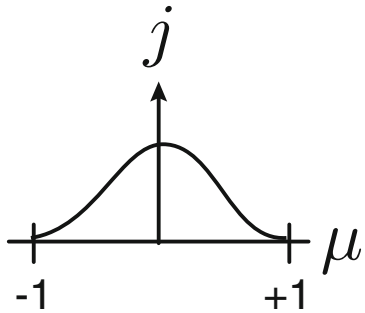
Reeves et al, [2003]

We do not understand the fundamental physics: the response of acceleration and loss mechanisms to solar-induced geomagnetic storms

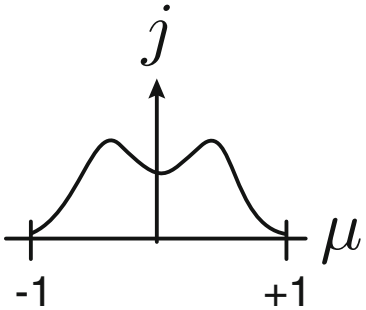
Exotic Particle Distributions



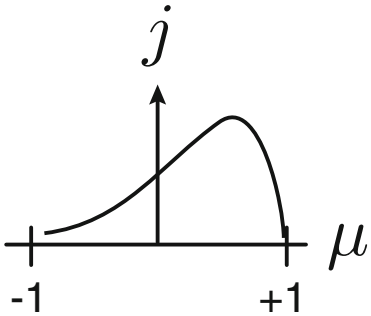
Isotropic with loss cone



Pancake (peaked at 90°)



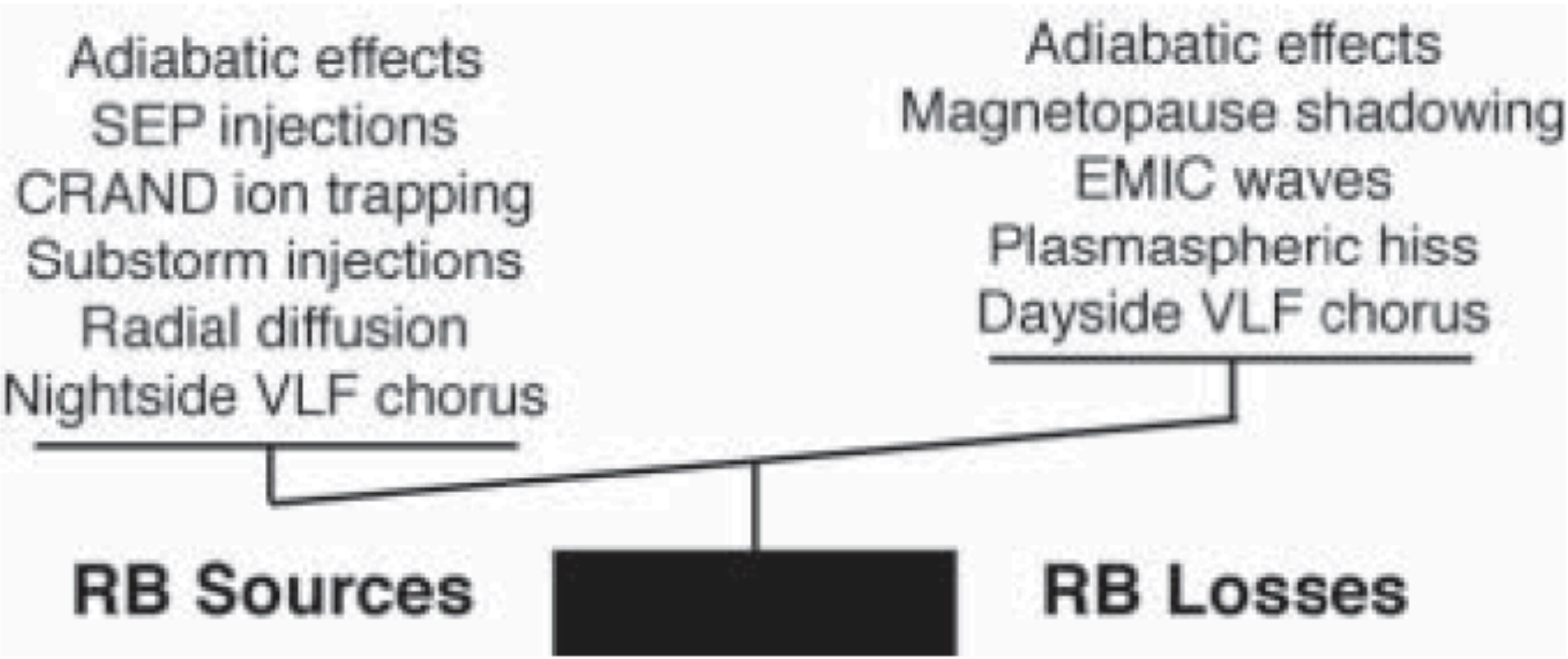
Butterfly



Streaming along B

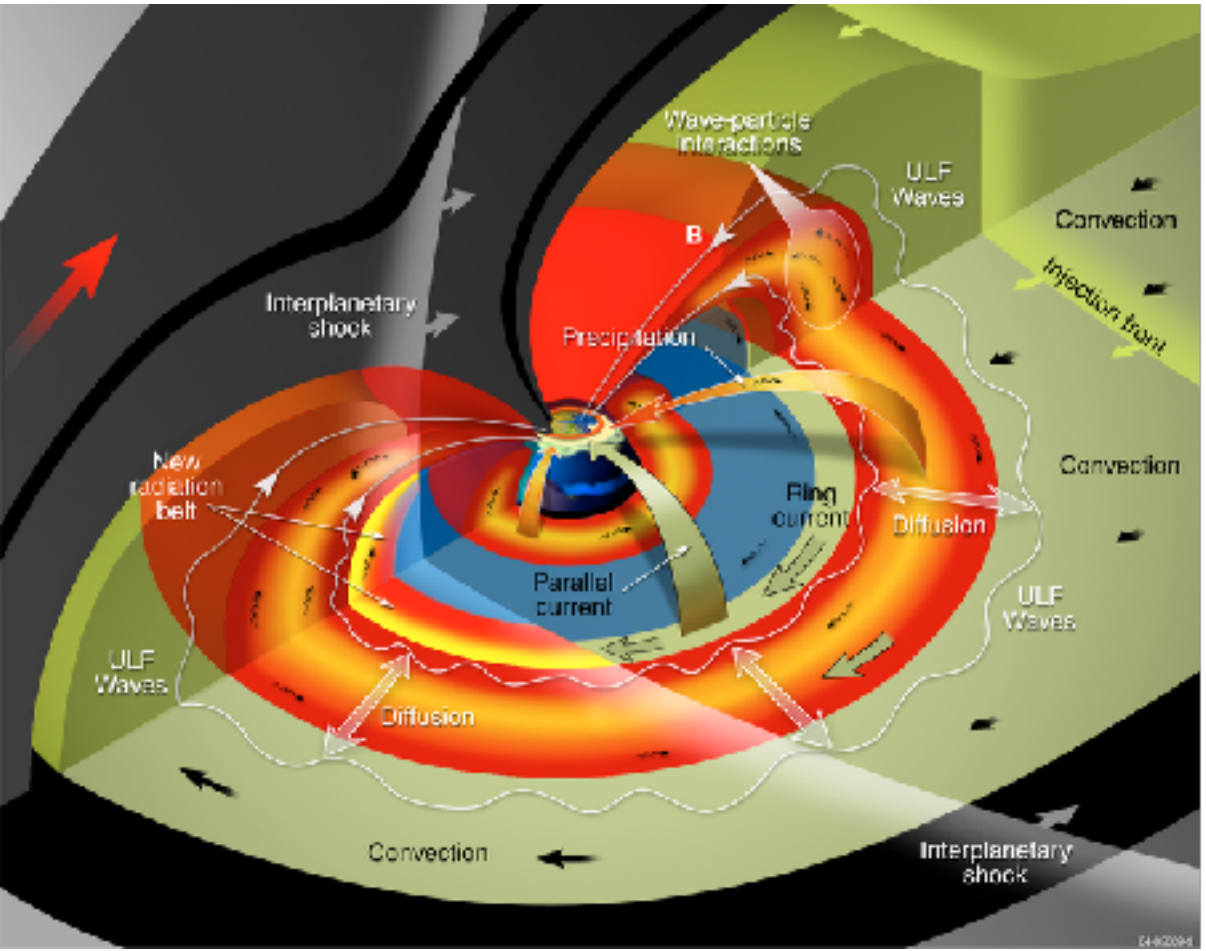
Roeder & Zhang, [2014]

Balance of Sources and Losses

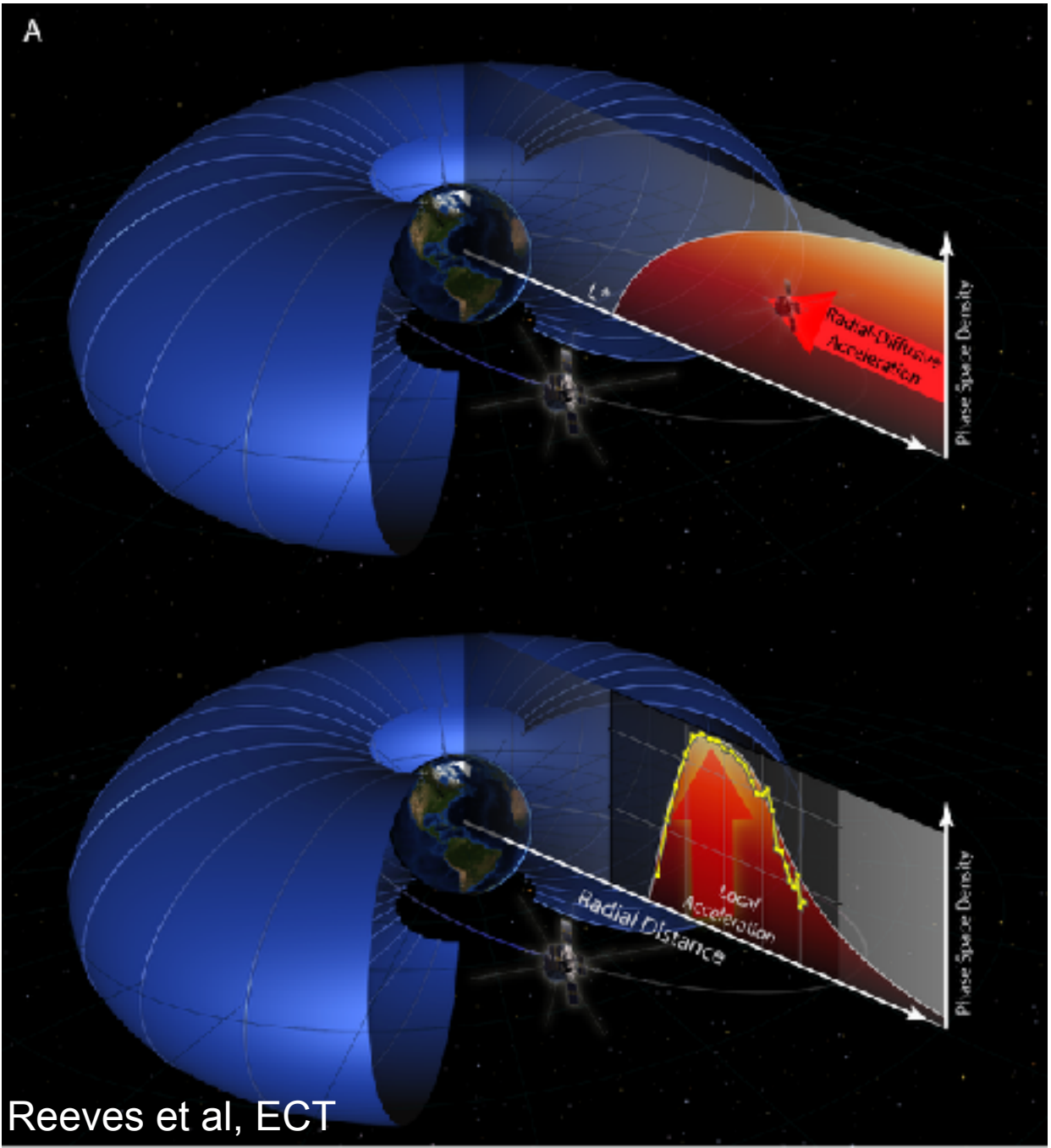


Liemohn [2007]

RB Sources and Losses



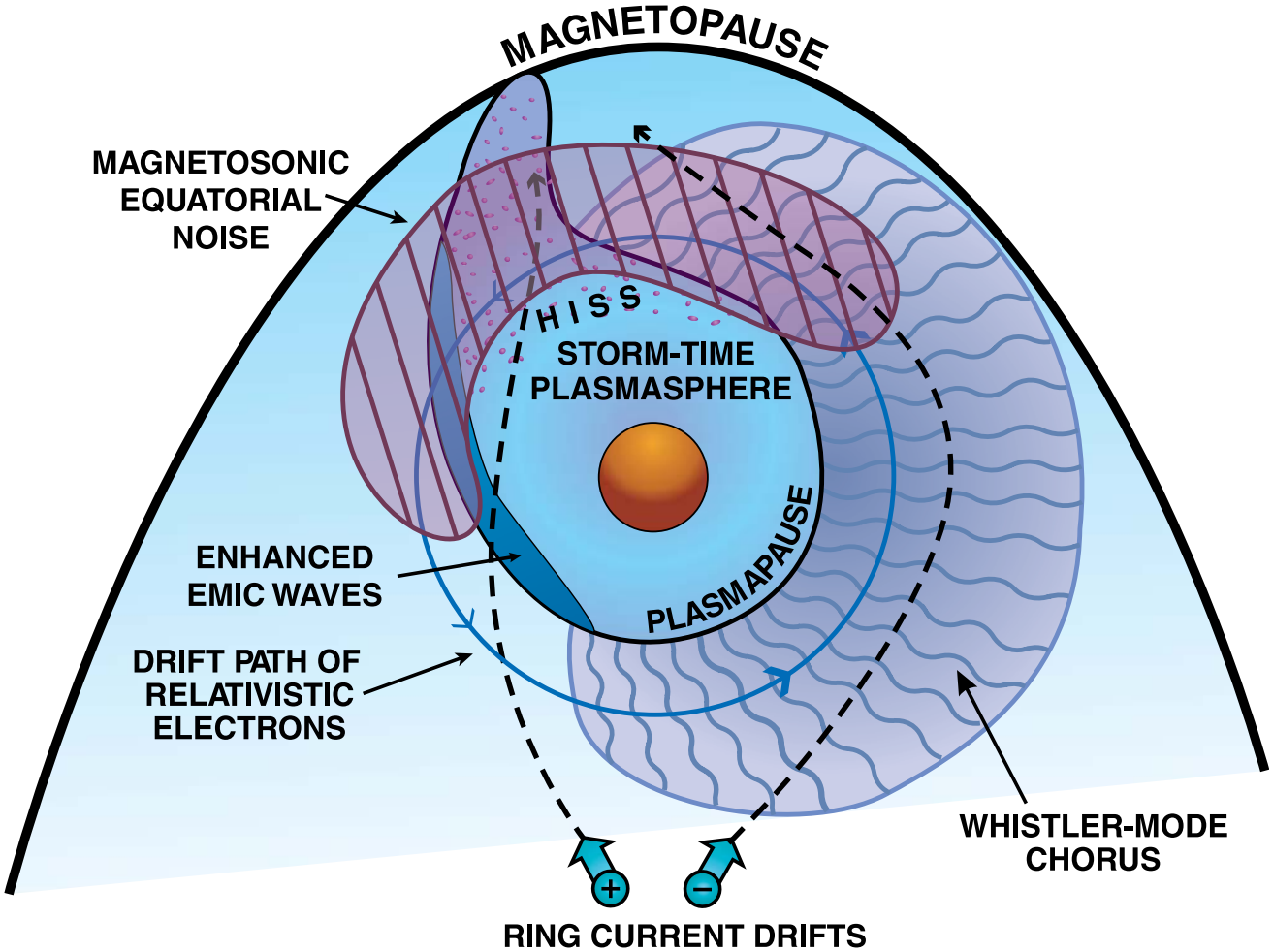
- Sources:
  - VLF waves
  - ULF waves
  - Radial transport
  - Prompt acceleration
- Losses
  - Shadowing
  - Loss to atmosphere



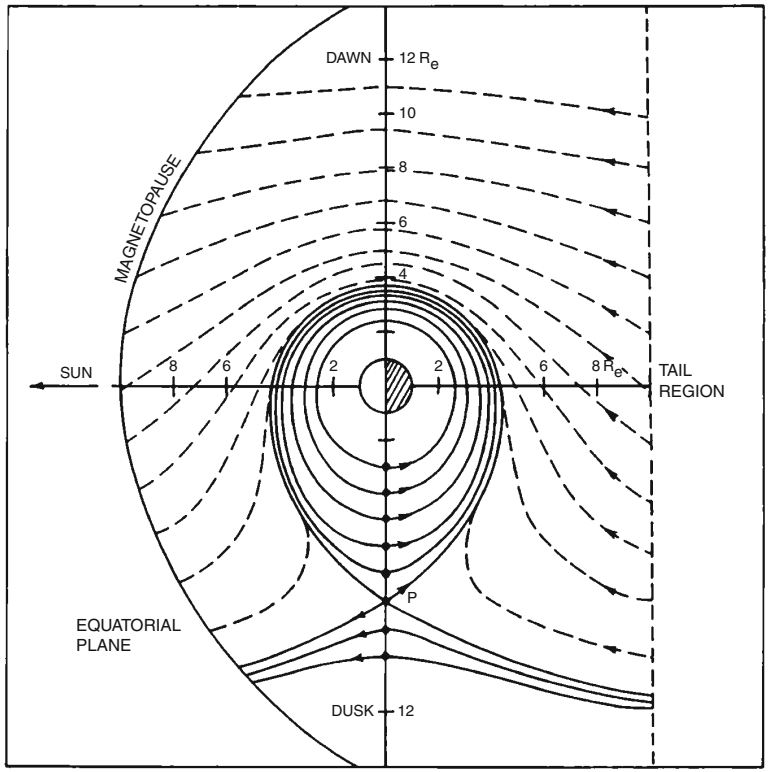
Reeves et al, ECT

Local acceleration
or
Radial Diffusion?

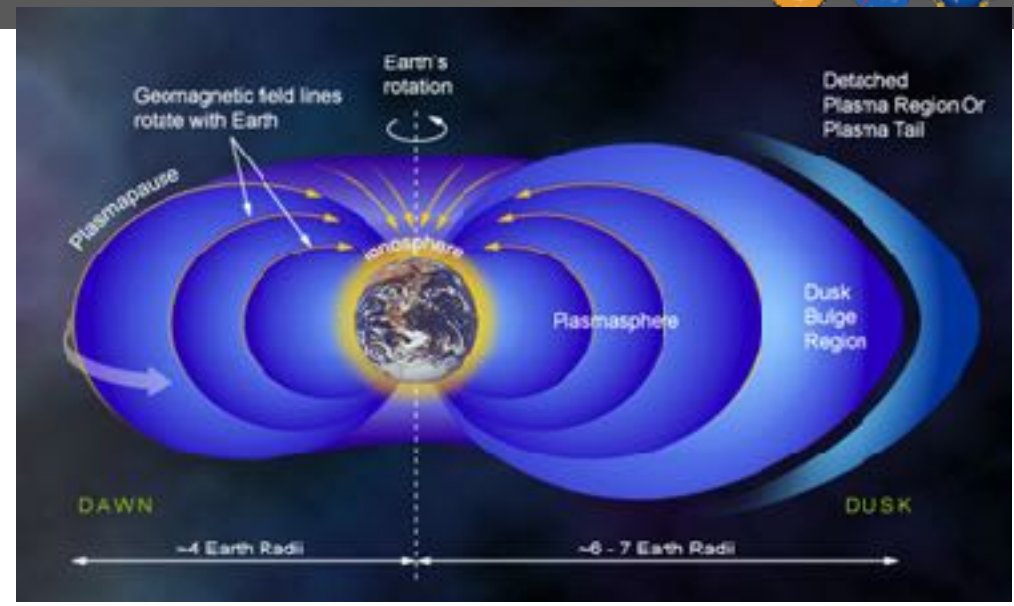
Wave Environment for Particle Acceleration

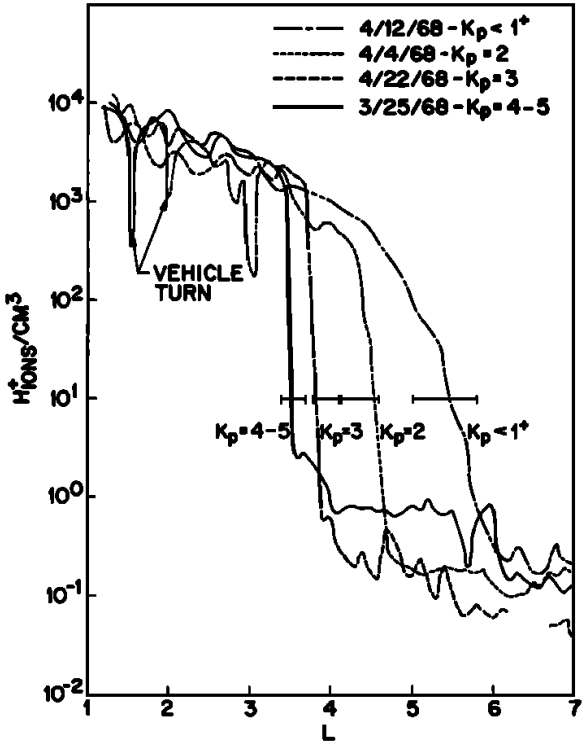


The Earth's Plasmasphere



Roeder & Zhang, [2014]



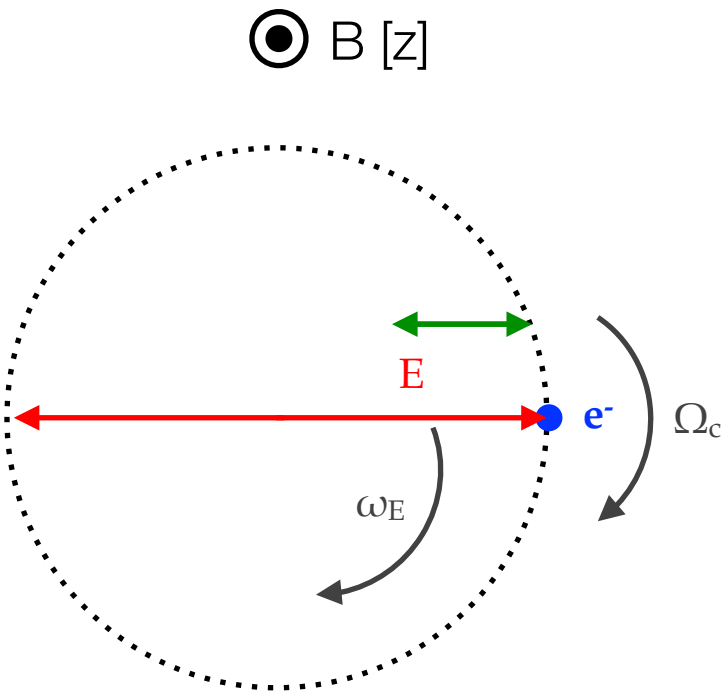


(Top) Schematic of Plasmasphere. Image courtesy of "Windows to the Universe " [windows2universe.org]

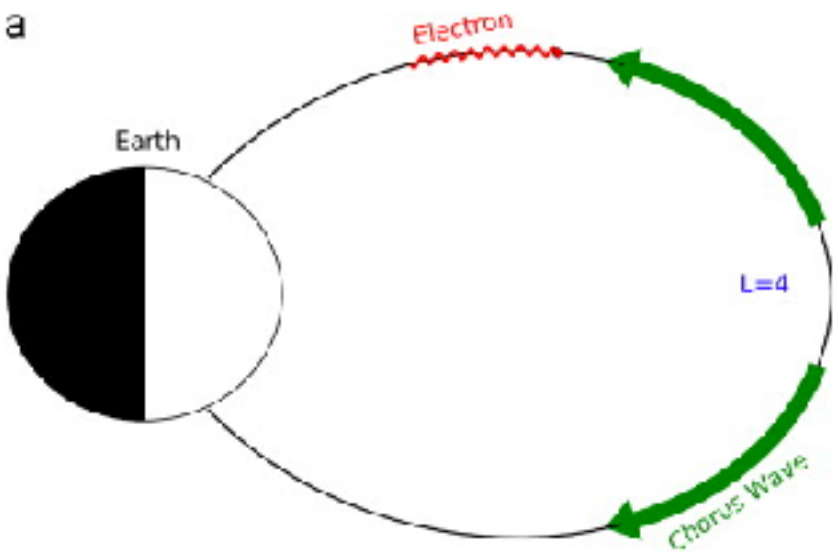
(Left) Plot of plasmasphere density as a function of radial distance. [Chappell, JGR, 1972]

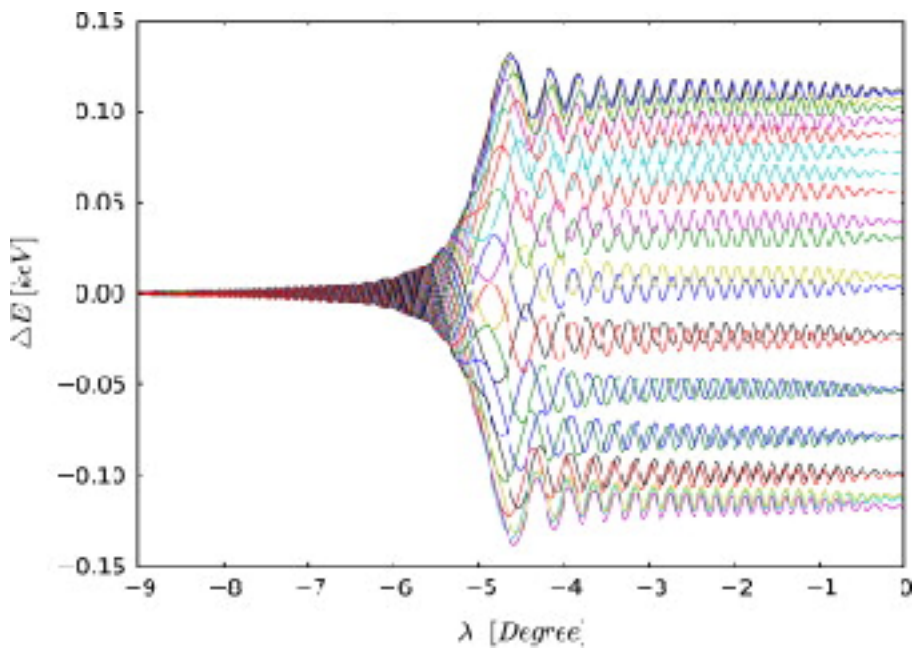
Chorus Waves

- Chorus waves occur OUTSIDE plasmasphere and **accelerate** particles via cyclotron resonance
  - Chorus waves are a circularly polarized electromagnetic wave
    - **Electric field** with frequency ω_E rotating around the magnetic field B
  - An **electron** has gyrofrequency (cyclotron) Ω_c
  - When $\Omega_c = \omega_E$, the electron sees same electric field and is **accelerated**
    - Direction of acceleration depends on phase of the electric field



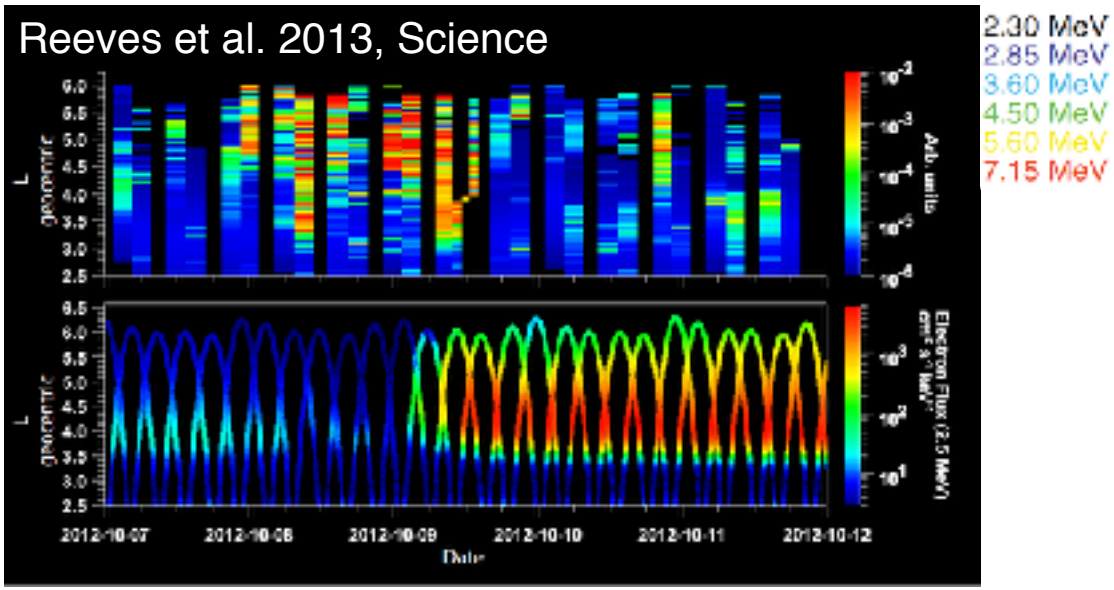
Chorus Wave-Particle Interaction: E and PA Diffusion

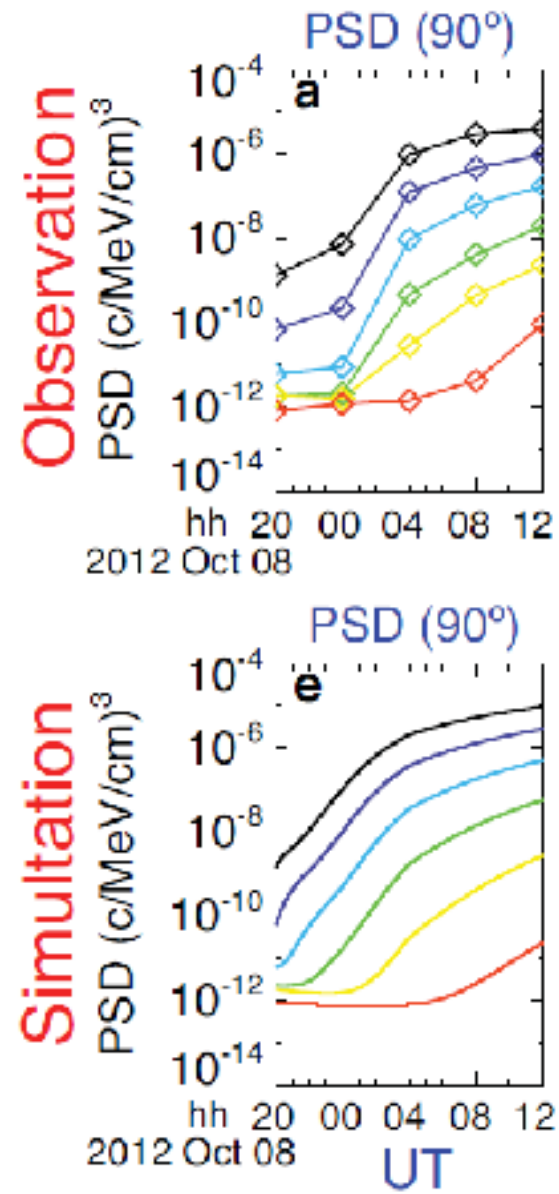




Zheng et al., [2012]

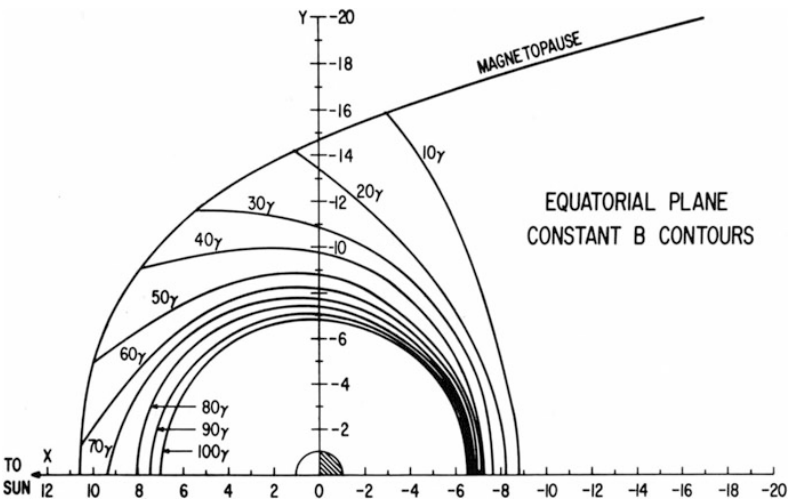
Observations of Chorus Wave Heating



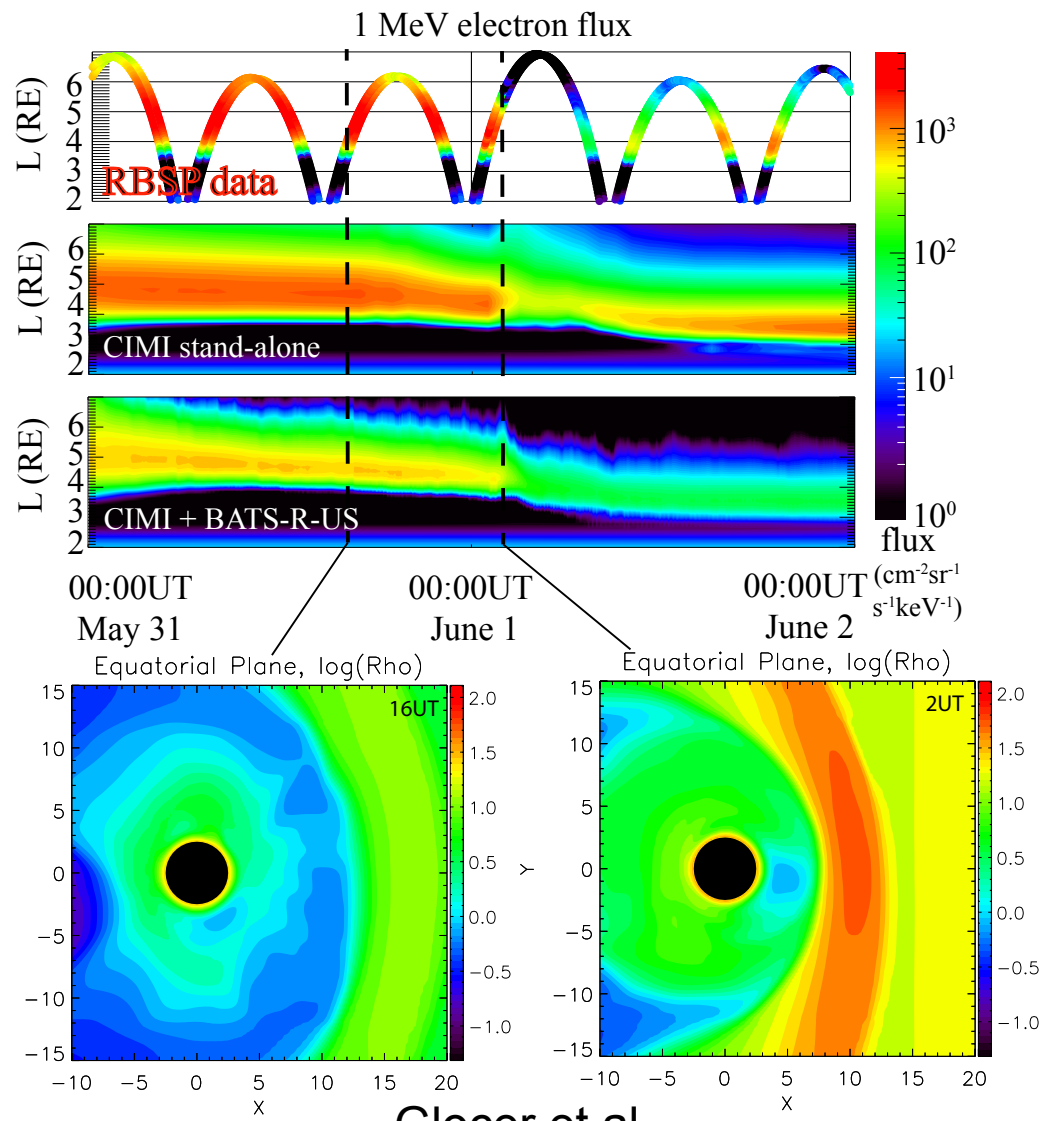


Thorne et al. 2013; Nature

Magnetopause Shadowing

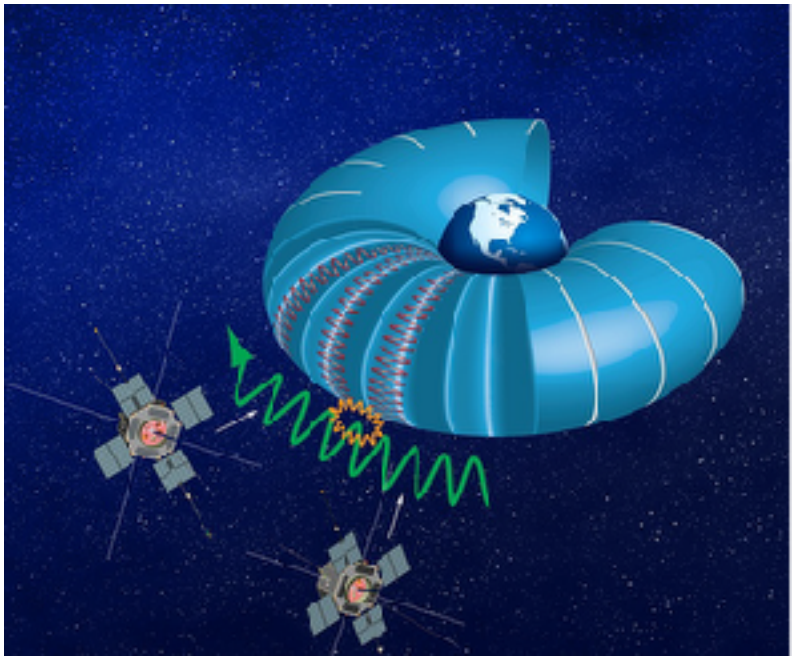


Roeder & Zhang, [2014]

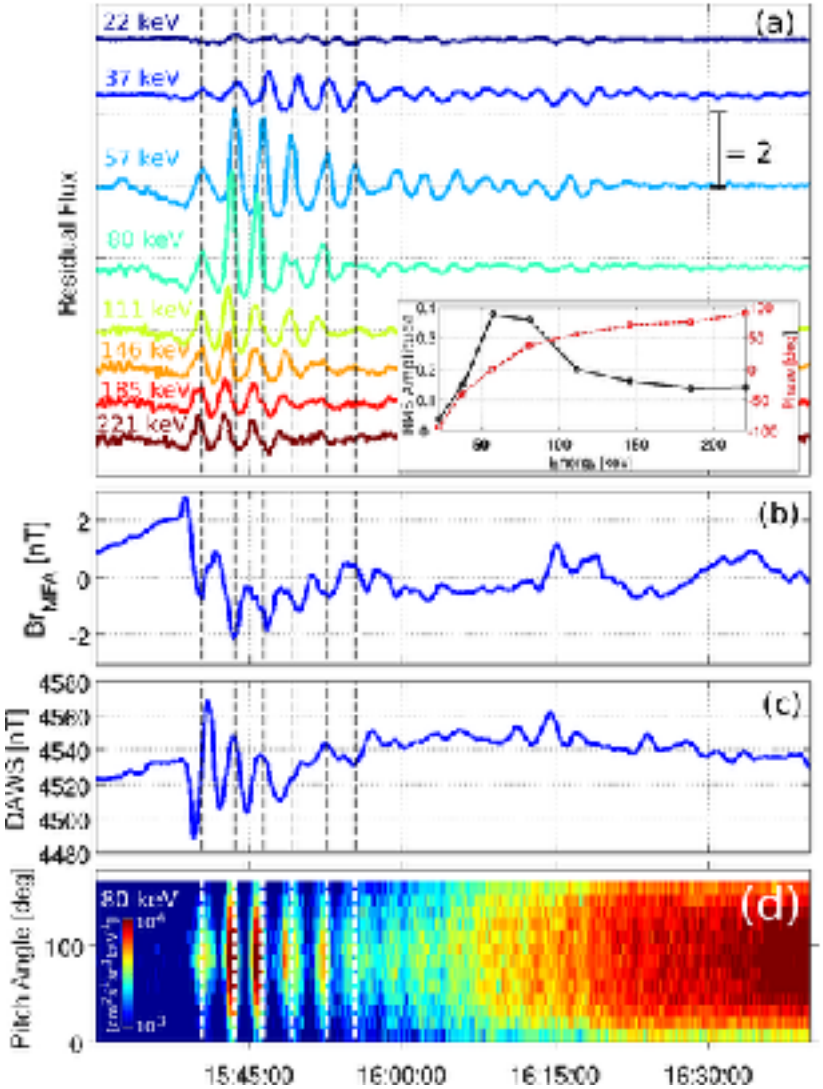


Glocer et al

ULF Waves: Drift Resonant Interaction



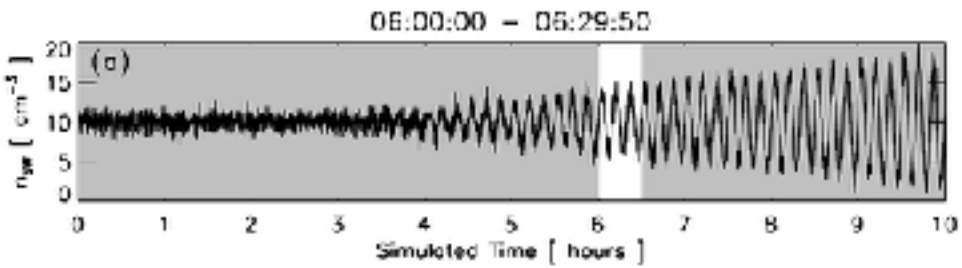
Dai et al., 2013, GRL



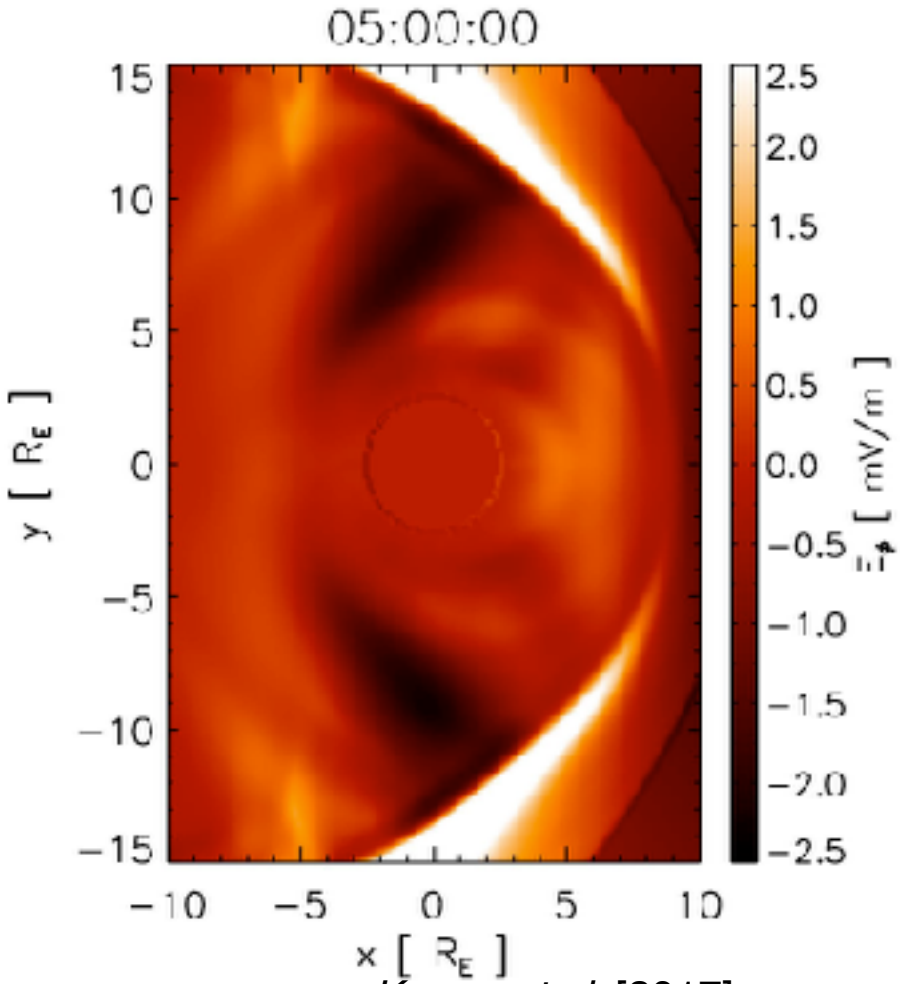
Claudepierre et al., 2013, GRL

ULF Waves: Drift Resonant Interactions

Solar Wind Input



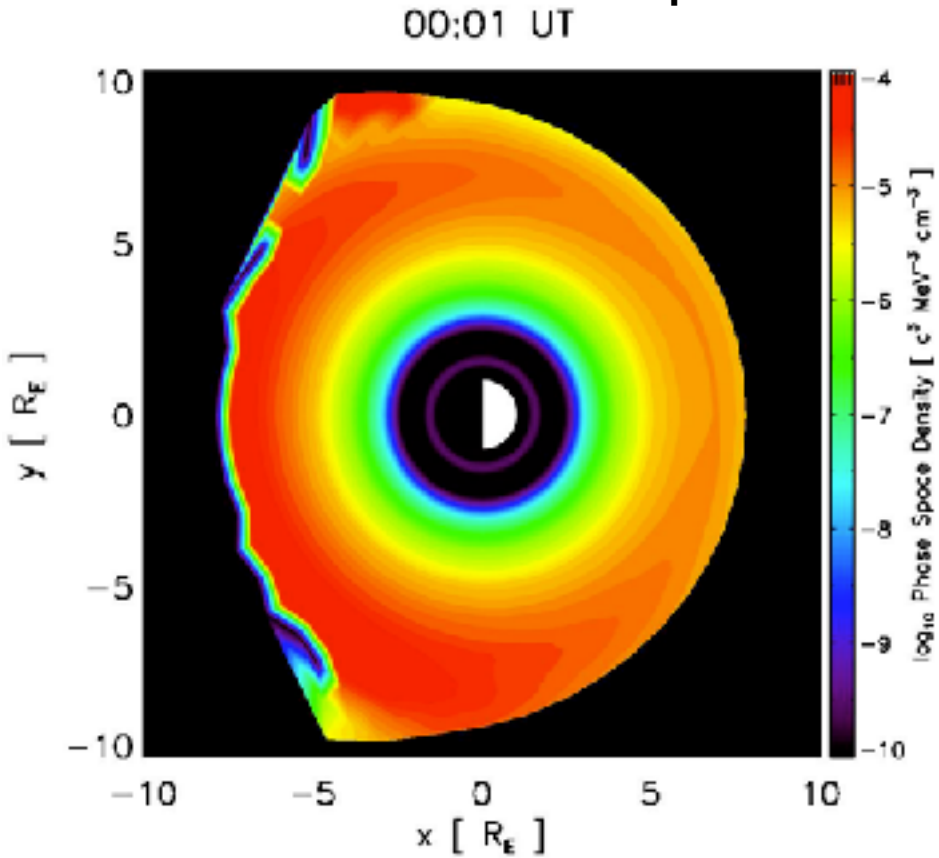
ULF Wave Response



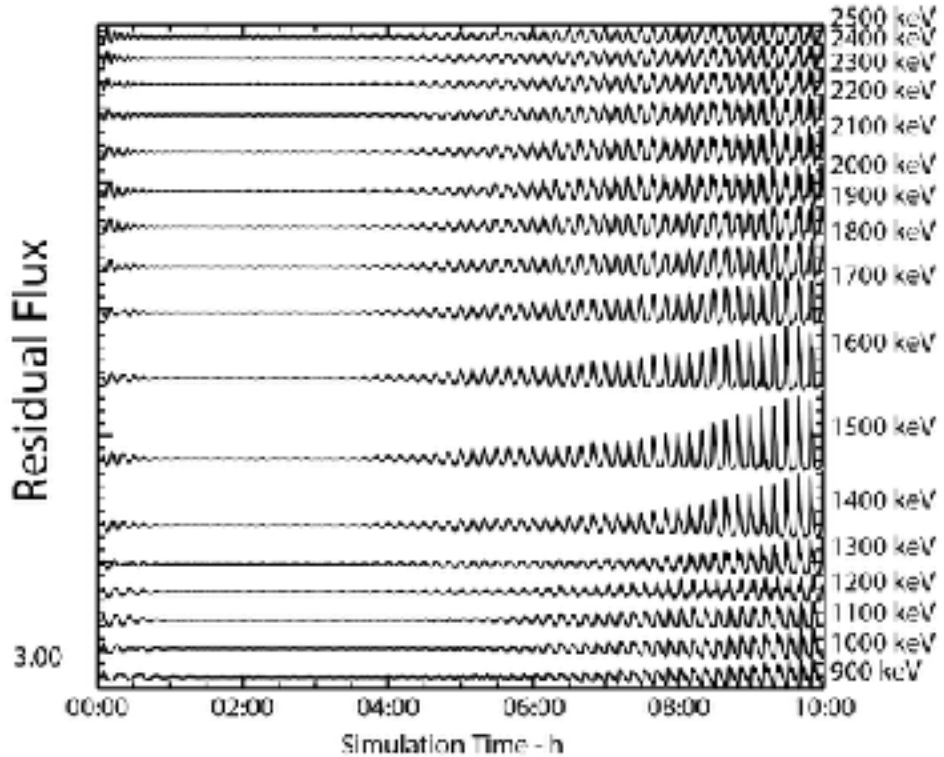
Komar et al. [2017]

ULF Waves: Drift Resonant Interactions

Effect on Particle Transport

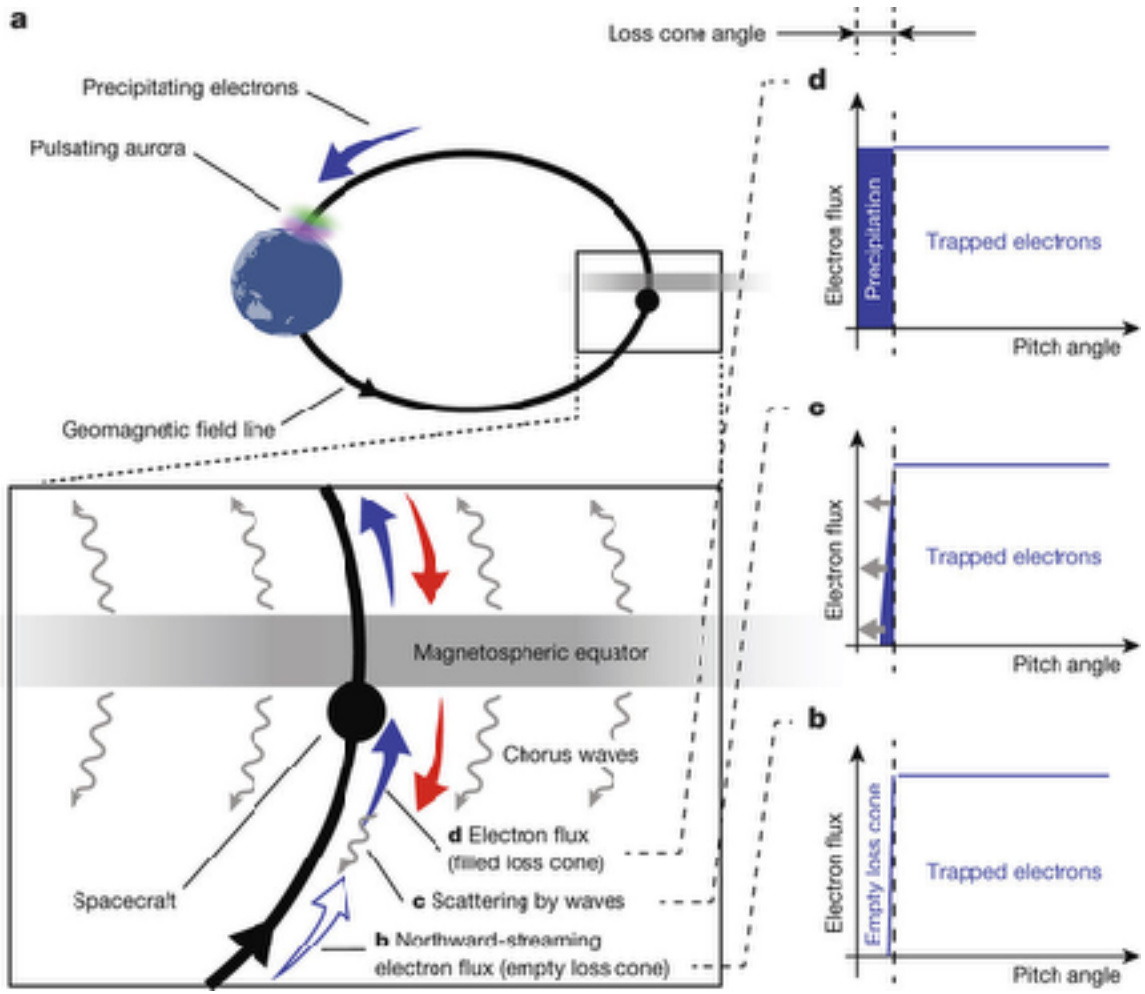


Residual Flux

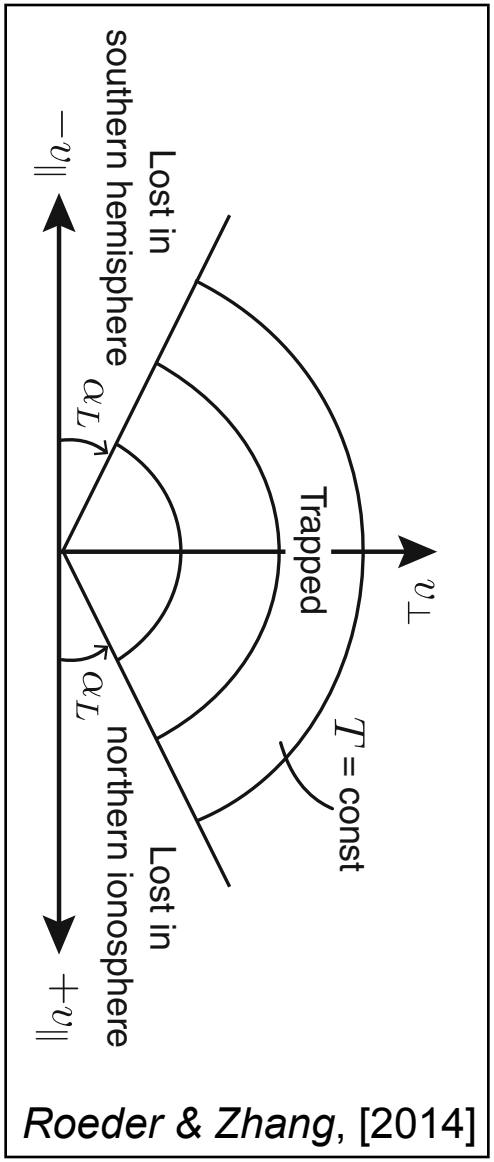


Komar et al. [2017]

Trapped Radiation Loss to Atmosphere

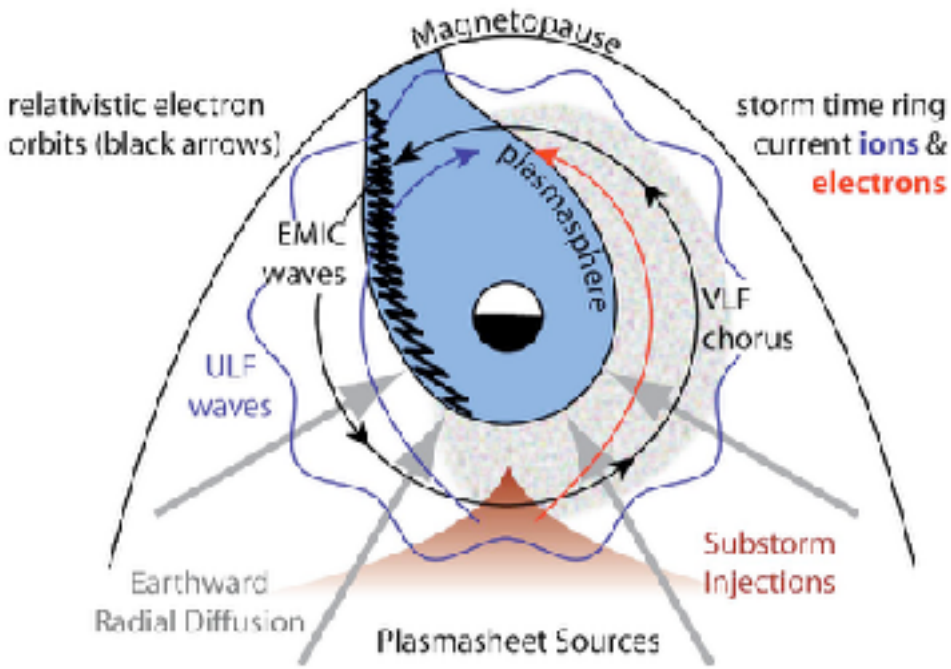


Kasahara et al. [2018]



Roeder & Zhang, [2014]

Summary



Reeves, 2007

- Trapped radiation is influenced by many factors.
- Particle drifts, dynamic fields, waves, and cold plasma mediation.
- While many mechanisms are understood, the balance for any particular event remains a mystery.