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Title: LANL LDRD-funded project: Test particle simulations of energetic ions in natural and artificial radiation belts

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LANL LDRD-funded project: Test particle simulations of energetic ions in natural and artificial radiation belts

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Abstract

- We summarize the scientific problem and work plan for the LANL LDRD-funded project to use a test particle code to study the sudden de-trapping of inner belt protons and possible cross-L transport of debris ions after a high altitude nuclear explosion (HANE). We also discuss future application of the code for other HANE-related problems.

Scientific problem: Natural radiation belts

- Recent observations show that energetic protons (E > tens of MeV) in the natural inner proton belt (L <~ 4) can be suddenly de-trapped on timescales of minutes during geomagnetic storms
- This rapid loss is not typical of physical processes associated with the radiation belts and is not well understood
- It is hypothesized that sudden changes in the trajectories of the particles due to the magnetic field perturbations during magnetic storms cause these large gyroradii particles to become suddenly de-trapped (e.g. Young et al. 2008, Selesnick et al. 2010)

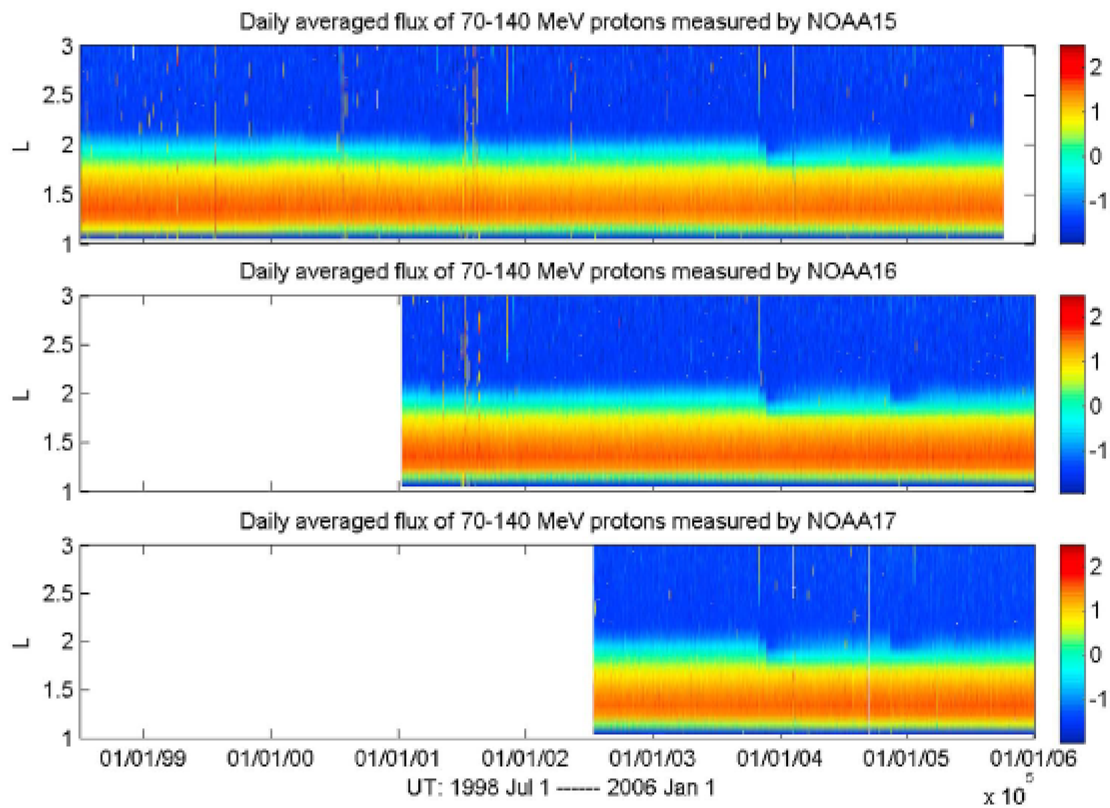

Figure shows the energetic proton flux ($p^+/cm^2/s$) measured by three NOAA satellites in the inner radiation belt. Sudden losses near L~2 seen in late 2003 and late 2004 are associated with geomagnetic storms (not shown). From Zou et al. (2011).

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Scientific problem: Artificial radiation belts

- Observations of the Starfish artificial radiation belt indicated the presence of β-decay electrons at L much higher than L_{det}
- The processes which allowed the debris ions and/or the betas to move outward across magnetic field lines on short timescales is not understood
- Since the debris ions have large gyroradii (like the energetic protons in the natural belt), is it possible that sudden perturbations in the magnetic field structure due to the burst could have altered the trajectories of the debris ions allowing them to move outward?

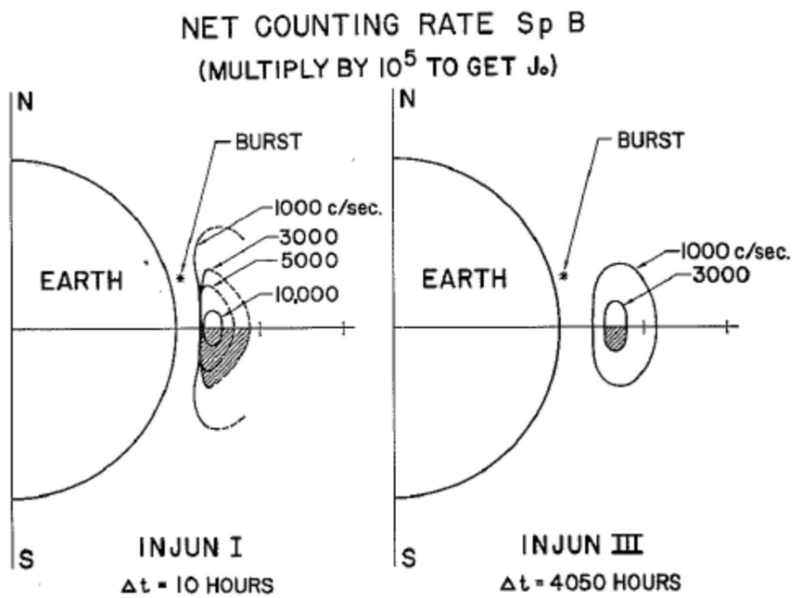
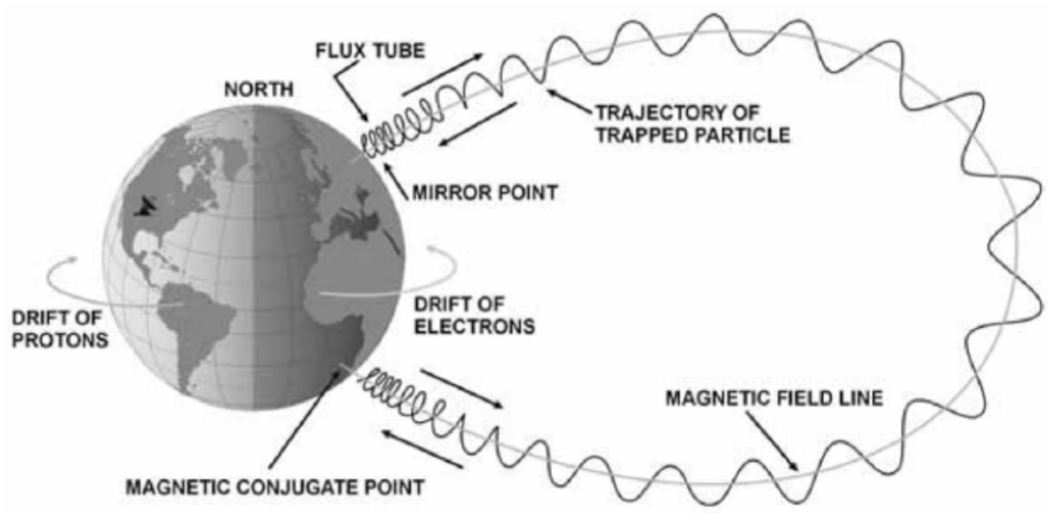


Figure shows the beta electron counts/s measured by Injun I at +10 hours (left) and +4060 h (right). The betas were detected well above the burst point. Fluxes near the burst point would have been lost to SAA by this time. From Van Allen (1966) article in “Radiation Trapped in the Earth’s Magnetic Field”, McCormac (ed.).

Magnetic field line curvature (FLC) scattering

- Figure (top) shows the typical motion of a trapped charged particles in the Earth's magnetic field. The particles gyrate around the magnetic field lines and "bounce" back and forth between magnetic mirror points above the atmosphere in the northern and southern hemispheres. This motion is governed by constants of motion called the "adiabatic invariants".



- HOWEVER, if the particle's gyroradius is large compared to the radius of curvature of the magnetic field line, then the magnetic field experienced by the particle changes significantly during one gyro-orbit and constants of motion cannot be determined (e.g. breaking the "adiabatic invariants").
  - The particles then exhibit chaotic behavior and will not be trapped but can instead travel across field lines. This process is called magnetic field line curvature (FLC) scattering, or μ-scattering (where μ is the first adiabatic invariant).

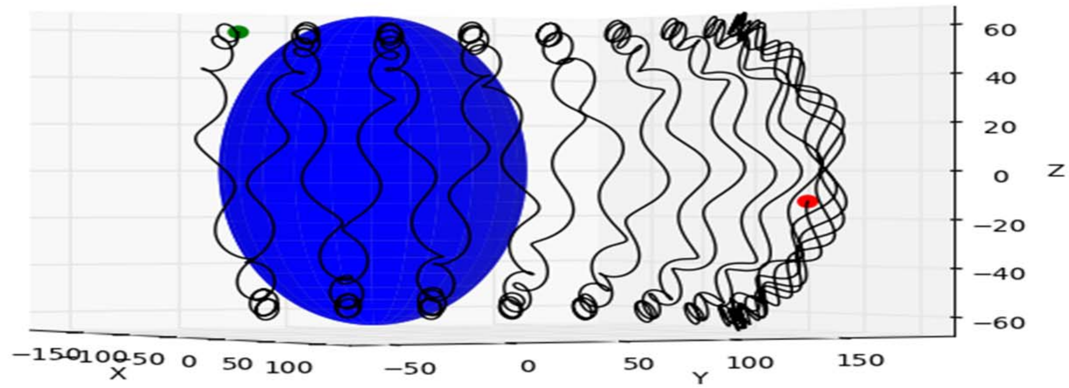
Test particle simulations

- To study FLC scattering, we use test particle simulations which follow the motion of energetic ions in the magnetic fields (electric fields are neglected)

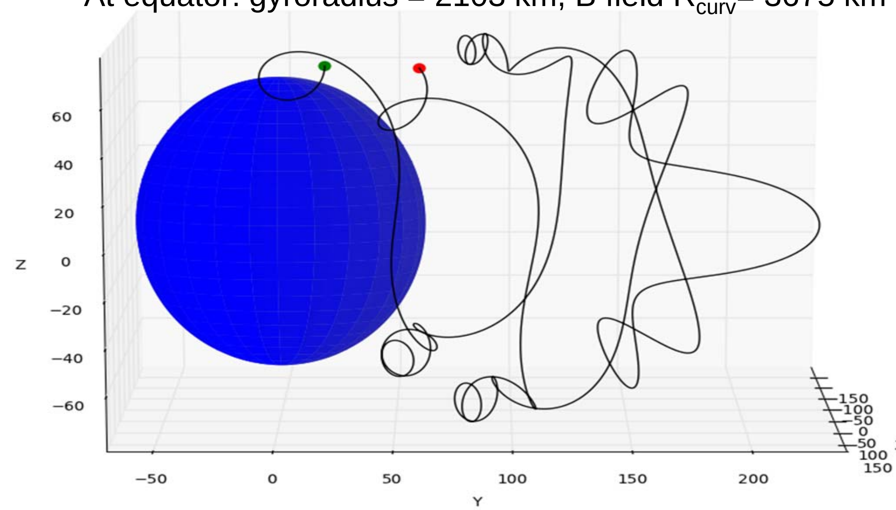
- Figures show examples of the trajectories of a 50 MeV and 500 MeV proton in a modeled moderate storm-time magnetic field
  - (top) 50 MeV proton exhibits the predicted bounce and drift motion
  - (bottom) 500 MeV particle exhibits unpredictable motion

- For the artificial belts, it is possible that the debris ions could FLC scatter to higher L than predicted where they would then β-decay.

50 MeV proton α = 45° at L = 3
At equator: gyroradius = 599 km , B field R_{curv} = 3675 km



500 MeV proton α = 45° at L = 3
At equator: gyroradius = 2103 km, B field R_{curv}= 3675 km



Work plan

- Two year project: April FY12 to March FY14
- Year 1: Natural radiation belts
  - Understand how the FLC scattering process depends on the proton and magnetic field properties
  - Simulate cases studies and compare to observations
- Year 2: Artificial radiation belts
  - Test if FLC scattering could have occurred in HANE-perturbed magnetic field near burst region
  - Test if FLC scattering could have occurred near the cusp in magnetic cavity created by the HANE pressure-pulse (Brecht suggests this could be important; in natural environment this is observed due to solar wind pressure pulses e.g. Fritz et al. 2003, Nykyri et al. 2011)
  - If viable mechanism, carry out sensitivity study and compare to observations
- Beyond this, the code could be adapted to study other HANE-related problems:
  - Effects of charge exchange of debris ions and atmospheric neutrals in the burst region (LLNL simulations suggest this could be important)
  - Effects of atmospheric scattering and energy loss on the debris ions and betas (as in Chris Cross' model)
  - Effects of neutral fission fragments (as Chris had hoped to do but didn't have time)

References

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