1 CIRES, University of Colorado at Boulder
2 Department of Physics, Auburn University
3 Applied Physics Laboratory, Johns Hopkins University
4 Fundamental Technologies, LLC
5 School of Physics and Astronomy, University of Minnesota

Multi-event Study on the Connection between Subauroral Polarization Streams and Deep Energetic Particle Injections in the Inner Magnetosphere

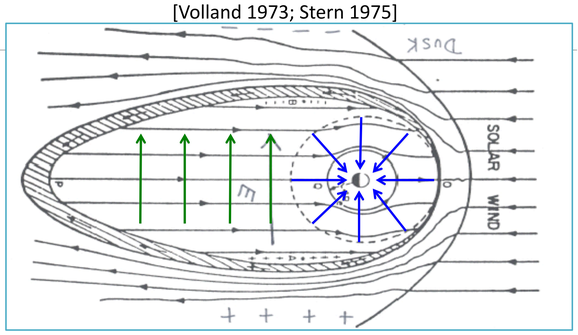
S. Califf[1], H. Zhao[2], M. Gkioulidou[3], J. W. Manweiler[4], D. G. Mitchell[3], and S. Tian[5]

Abstract

Energetic electron flux enhancements for 100s keV energies are often observed at low L shells (L < 4) in the inner magnetosphere during geomagnetic storms. However, protons with similar energies do not penetrate as deeply as electrons. Radial electric fields from subauroral polarization streams (SAPS) have been proposed as a mechanism to explain the difference between the 100s keV electron and proton behavior by altering the particles' drift paths and allowing electrons to access lower L shells than protons. We examine three events where SAPS were observed by the Van Allen Probes at the same time and L shell range as 100s keV electron enhancements deep within the inner magnetosphere. The observations demonstrate that 100s keV electrons were progressively transported radially inward and trapped at low L shells that were consistent with the spatial extent of the SAPS electric fields. Proton flux enhancements were limited to <100 keV energies and were only observed temporarily in the SAPS region, indicating that these particles were on open drift paths. The particle observations are consistent with the differential drift paths for electrons and protons predicted by a simple SAPS electric field model, suggesting that SAPS play an important role in 100s keV particle dynamics at low L shells in the inner magnetosphere.

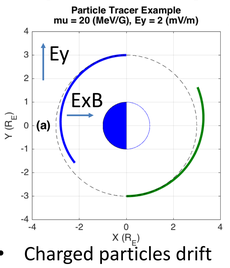
Inner Magnetospheric Electric Field and SAPS

[Volland 1973; Stern 1975]

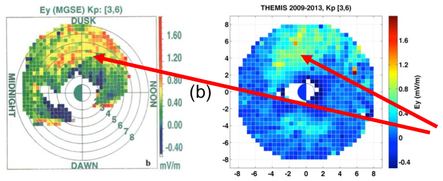


- Convection: dawn-dusk (+Ey GSM) driven by the solar wind
  - Shielding by the ring current reduces strength of convection near Earth
- Co-rotation: radially inward inside plasmasphere

[Califf et al., 2017]



- Charged particles drift around the Earth (electrons eastward, protons westward)
- Electric fields alter drift trajectory perpendicular to the electric and magnetic fields: ExB
- L shell = radial distance

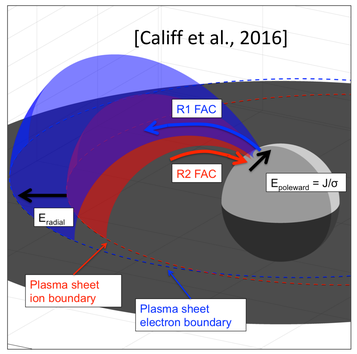


[Rowland and Wygant, 1998]

(b)

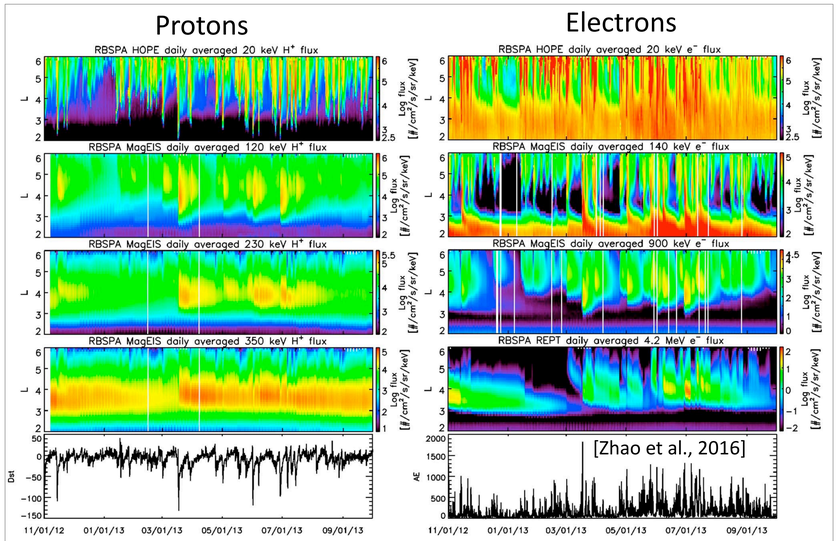
[Califf et al., 2014]

[Califf et al., 2016]



- Observations show strong dawn-dusk electric fields in the post-dusk sector during geomagnetically active times
- Subauroral polarization streams (SAPS) significantly alter the electric field, which affects the energetic particle trajectories in the inner magnetosphere
- SAPS are caused by coupling between the magnetosphere and ionosphere

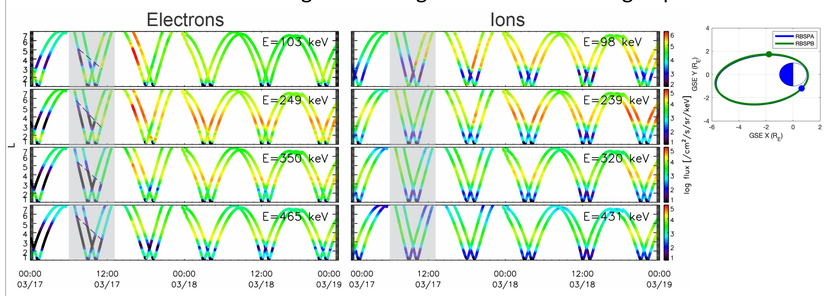
100s keV Charged Particles in the Inner Magnetosphere



- During geomagnetic storms, electrons systematically move closer to Earth than protons with similar energies
- This is inconsistent with a uniform dawn-dusk convection electric field (electrons and protons would be affected similarly)
- SAPS modify the electric field, and are frequently observed during the energetic particle injection events
- Is there a causal connection between SAPS and the differential response between 100s keV electrons and protons?

Multi-event Study of SAPS and Energetic Particle Injections

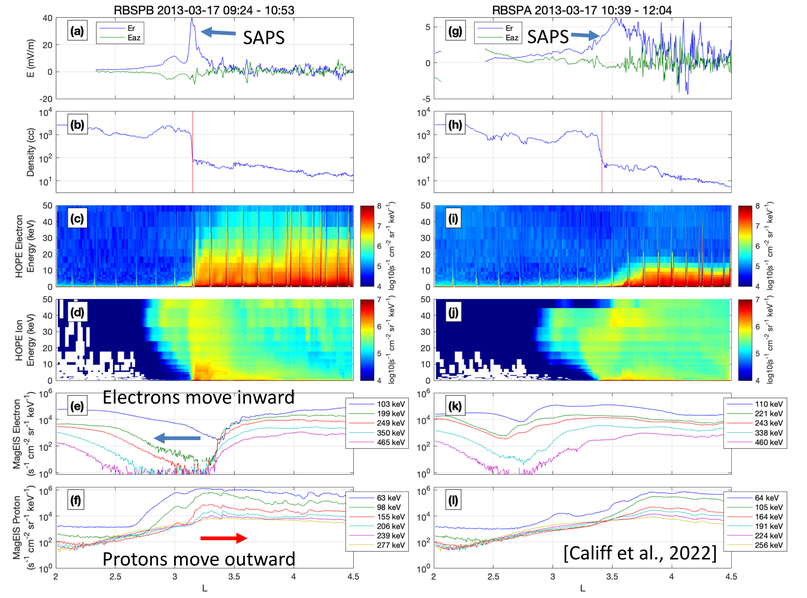
- Surveyed entire Van Allen Probes Mission for events where 100s keV particles were injected below L = 4 and SAPS electric fields were observed
- Spacecraft must be in the right place at the right time to observe SAPS
- Focused on 3 events with favorable orbital geometry and timing
- Van Allen Probes: 2 spacecraft in trailing geotransfer orbits, comprehensive instrument suite measuring electromagnetic fields and charged particles



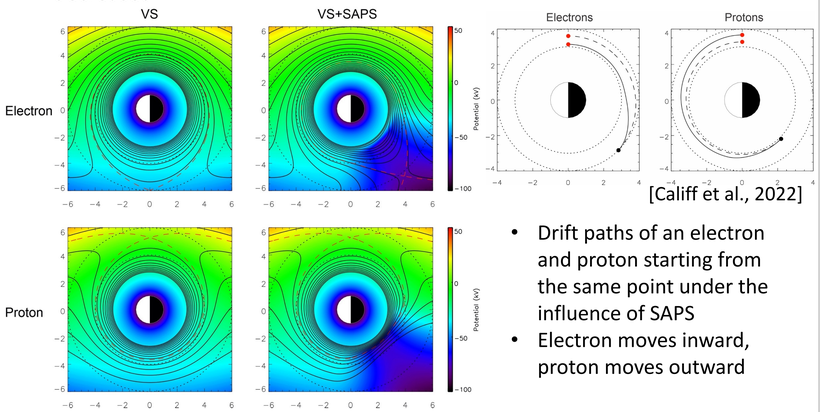
- SAPS were observed by both spacecraft inside L = 3 separated by 1.5 hr
- On the same passes, strong electron enhancements were observed at low L shells, while protons showed an opposite response

Califf, S., Zhao, H., Gkioulidou, M., Manweiler, J. W., Mitchell, D. G., & Tian, S. (2022). Multi-event study on the connection between subauroral polarization streams and deep energetic particle injections in the inner magnetosphere. Journal of Geophysical Research: Space Physics, 127, e2021JA029895. https://doi.org/10.1029/2021JA029895.

Observations, Modeling and Results



- Strong SAPS electric fields (1-2 mV/m is typical) were observed by both spacecraft 1.5 hr apart
- 100s keV electrons reached low L shells, similar to the SAPS location
- 100s keV proton fluxes remained stable, and lower-energy proton fluxes decreased



- Drift paths of an electron and proton starting from the same point under the influence of SAPS
- Electron moves inward, proton moves outward

- Observed differential response between electrons and protons is consistent with predictions from a simple SAPS electric field model
- Electrons tend to be pushed earthward by SAPS on the eastern portion of SAPS and then drift eastward and become trapped at low L shells
- Protons tend to be pushed away from Earth on the westward edge of the SAPS, and then drift westward out of the SAPS region
- Cumulative effect of many impulsive interactions results in electron enhancements at lower L shells than protons
- The inner magnetosphere is dynamic, varying on timescales (10s minutes) shorter than the orbit period (9 hrs), requiring a combination of direct observations, statistical characterization and physical modeling