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Localized Magnetic Field Perturbations in Planetary Magnetospheres and Their Trapping Mechanism for Energetic Particles

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Localized magnetic field depressions in Earth's inner magnetosphere, known as magnetic dips, are generated by the diamagnetic motion of energetic ions injected during substorm activities. When the magnetic dips are sufficiently deep, they can produce a local minimum in the radial profile of the field strength, resulting in a reversed magnetic gradient at the outer portion of the dip. This reversal can significantly alter particle drift motion, enabling magnetic dips to act as pitch-angle filters that trap the equatorially mirroring energetic protons while allowing bouncing protons to overtake [1,2]. This mechanism explains the concomitant energy-dispersionless injection signals observed far from the injection boundary. The resulting high proton temperature anisotropy within the dip structure in turn facilitates the localized EMIC wave excitation, making the magnetic dip a propagating hotspot of EMIC wave activity and a drifting origin of precipitation for energetic ions and relativistic electrons [2,3].

This trapping mechanism can also apply to other localized magnetic field perturbations in planetary magnetospheres, one of which is the injection flux tubes of Saturn's magnetosphere. These flux tubes are characterized as localized structures with sharply enhanced equatorial magnetic fields and hot plasma populations, which carry the magnetic fluxes radially inward to compensate for their outward convection. The sharp magnetic gradient at the edge of flux tubes, similar to the magnetic gradient reversal caused by the magnetic dip, can also significantly modify the drift trajectories of perpendicular-moving particles to enable their trapping motion within the flux tubes [4]. This trapping motion leads to the unexpected occurrence of energy-dispersionless signatures for perpendicularly moving particles in Cassini observations. The bouncing particles are less affected by the gradient, and therefore, still display the characteristic energy-dispersive signatures. Moreover, the particle-trapping flux tubes correspond to more energetic electrons therein, leading to the excitation of higher-intensity ECH waves with higher-order harmonics compared to the non-trapping counterparts. These results underscore the critical role of these spontaneously formed localized magnetic field perturbation structures in shaping particle dynamics within planetary magnetospheres.

References

[1] Yin et al., *GRL*, 48, e2021GL092567 (2021)
[2] Yin et al., *JGR: Space Physics*, 127, e2022JA030531 (2022)
[3] Yin et al., *JGR: Space Physics*, 129, e2023JA032317 (2024)
[4] Yin et al., *GRL*, 50, e2023GL105687 (2023)

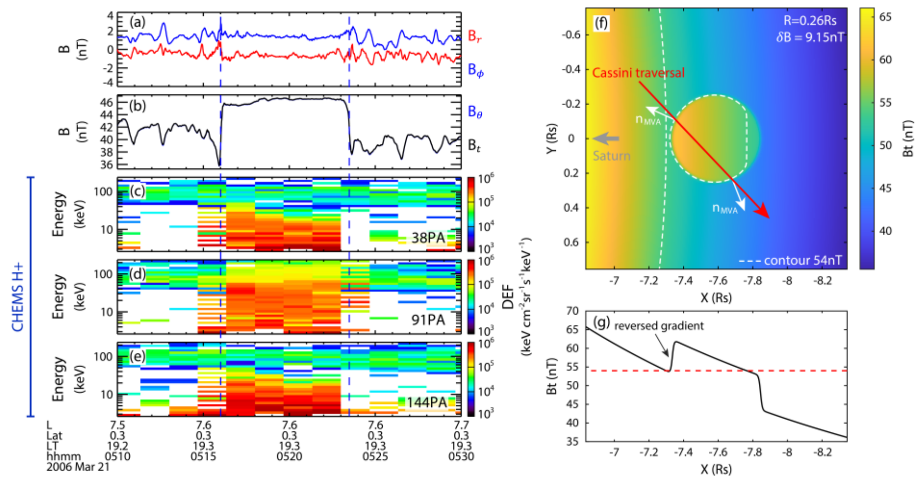

Figure 1. Cassini observations of injection flux tubes on 21 March 2006 (left) and the estimated spacecraft trajectory in the flux-tube rest frame (right). The observations include: (a) radial (red) and azimuthal (blue) components of the magnetic field; (b) polar component (blue) and the strength (black) of the magnetic field (nearly overlapped); (c)–(e) energy-time spectrograms of differential energy fluxes (DEF) for energetic protons measured by three CHEMS telescopes, corresponding to different pitch angles. Right panels are (f) Equatorial distribution of the field strength (background color), with the red arrow marking the spacecraft trajectory; (g) Radial profile of field strength at $y = 0$.