Observation of flux ropes in dayside magnetosphere at Saturn

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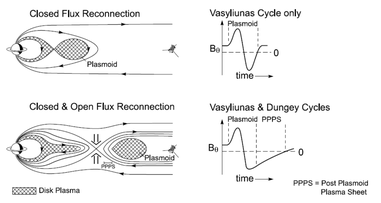
Abstract: Flux rope, often known as plasmoid when the guide field is small, is an important structure to transfer magnetic flux and plasmas in the magnetosphere of terrestrial and planetary magnetosphere. At Saturn, the flux rope can be generated by both 'Dungey cycle' and 'Vasyliūnas cycle'. Where and how a flux rope is formed and its evolution at Saturn is pivotal in understanding the energy and mass transportation in the magnetosphere. In this work, we present the observations of flux rope-like structures at pre-noon sector of Saturnian magnetosphere, which proves that the internally driven reconnection site can exist at dayside magnetosphere. We determine that the magnetic variations when crossing the 'flux rope' is caused by planetary rotation, not the traditional "reconnection retreat".

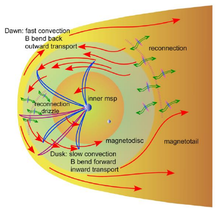
Introduction

Flux ropes formed by both Dungey cycle and Vasyliūnas cycle have bipolar B_θ observational signatures in Saturn's magnetotail [*e.g., Jackman et al., 2011*]. The bipolar signature is often explained as a tailward retreating of the flux rope, when it is formed pre-night and is carried to post-night sector by the rotating magnetosphere. For Vasyliūnas cycle, the flux ropes are formed in closed field line. It's an open question that how the flux ropes in Vasyliūnas cycle evolve and where they eventually go.

Statistical analyses have shown flux-conserving reconnection can occur in the subsolar and dusk sector [*Delamere et al., 2015*]. How are these "drizzle-reconnection" sites formed and evolved?

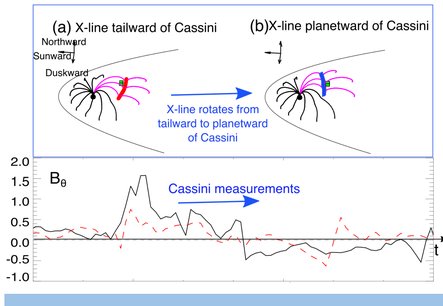


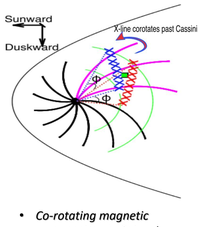
- *Observational signatures of flux rope in Saturn's magnetotail, selected from [Jackman et al., 2011]*



- *Reconnection drizzle on dayside, selected from [Delamere et al., 2015]*

Recently, *Yao et al.* [2017., under review] proposed a 3D co-rotating reconnection picture based on analysis of *in-situ* data from the Cassini spacecraft in Saturn's magnetosphere. They explain the bipolar B_θ signature as a result of azimuthal cross of the structure, rather than the traditional radial cross of a structure, based on the fact that the crossing can occur again after one rotating period when X-line rotates back to the spacecraft. This model implies that the X-line and the associated flux rope could drift to noon sector to affect dynamics on dayside magnetosphere.



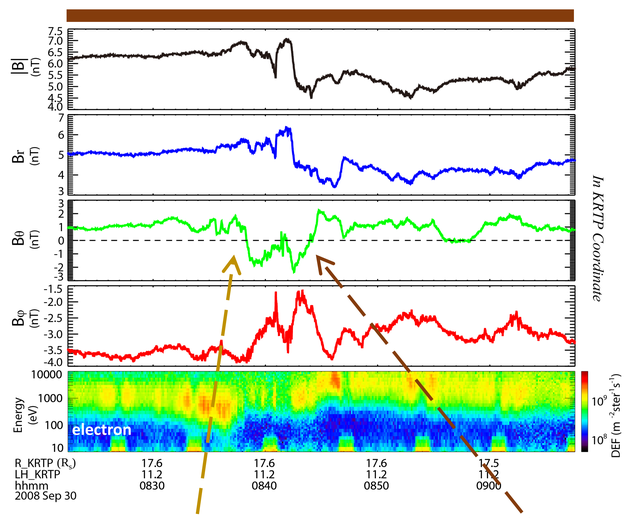


- *Co-rotating magnetic reconnection in Saturn's magnetosphere, selected from [Yao et al., Nat. Commun., under review]*

Motivation

- ☐ Does X-line & flux rope exist on dayside magnetosphere?
- ☐ What's the observational feature of flux rope at dayside?

'Flux Rope' on Dayside of Saturn's M'sphere



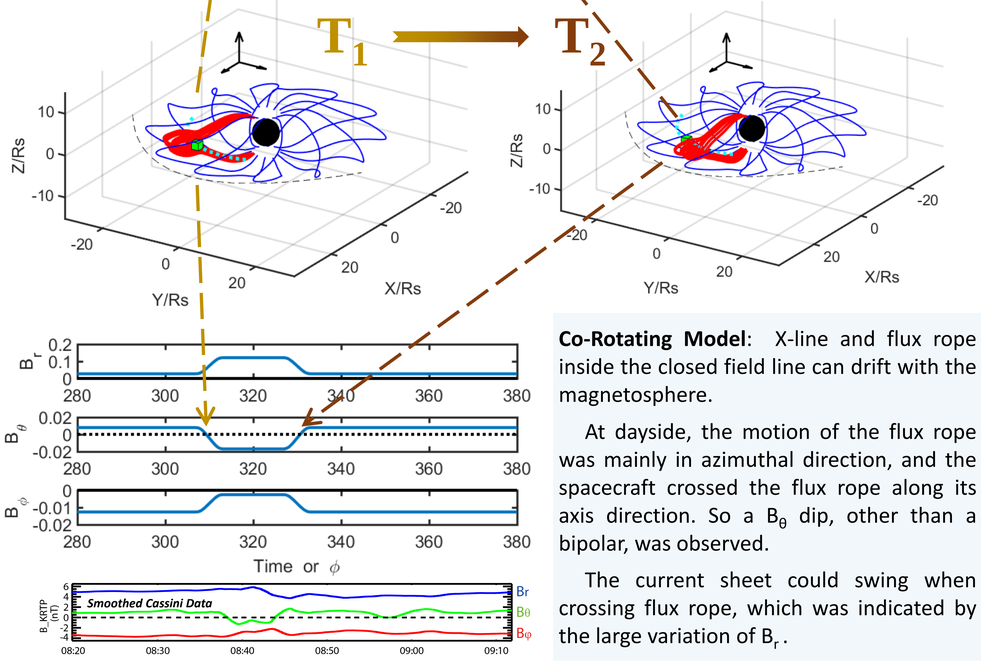
A magnetic reconnection related structure was detected by Cassini near the noon sector of the Saturn's magnetosphere.

- Location:
  - R: 17.6R_s (*$1R_s$=60,268km*)
  - Local Hour: 11.2
  - In Northern hemisphere: Br > 0
- Duration: ~6min

◆ Flux-rope-like features:
$B_\theta < 0$ & $|B_\varphi|$ decreasing

☐ No identifiable B_θ bipolar signal.

☐ How to cross the 'Flux Rope'?

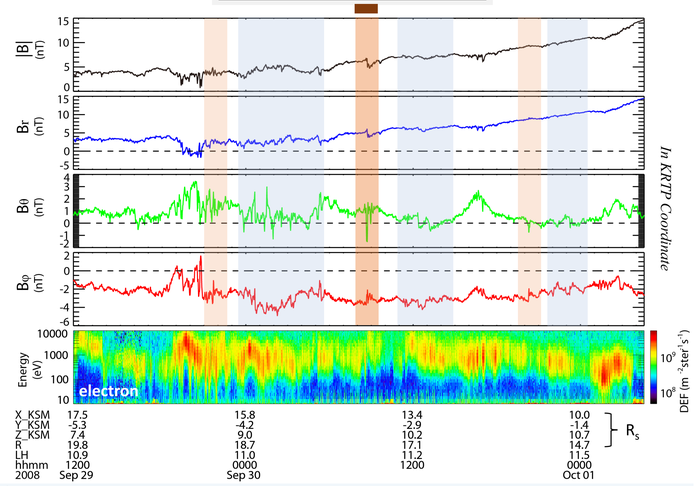


Co-Rotating Model: X-line and flux rope inside the closed field line can drift with the magnetosphere.

At dayside, the motion of the flux rope was mainly in azimuthal direction, and the spacecraft crossed the flux rope along its axis direction. So a B_θ dip, other than a bipolar, was observed.

The current sheet could swing when crossing flux rope, which was indicated by the large variation of B_r.

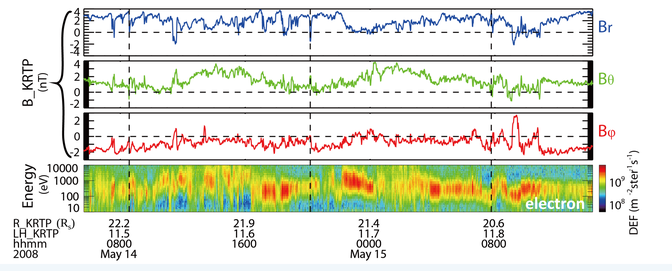
The Overview



◆ A series of B_θ dips were observed at pre-noon sector in the magnetosphere within 20R_s.

☐ There were three B_θ dips (in light brown colors) could display the same structure which rotated around Saturn three times: three B_θ dips were all accompanied with $|B_\varphi|$ decreasing and the period was ~11h.

Additional Co-Rotating Event



◆ Near noon, signatures of B_θ dip accompanied with B_φ increasing were recorded repeatedly with a period of ~ 11.6h.

Conclusion

- ✓ Flux-rope-like features are identified in dayside of Saturn's magnetosphere, which directly proves that the internally driven reconnection exist at dayside magnetosphere.
- ✓ Flux-rope/X-line could co-rotate with Saturn's magnetosphere several times, which is a strong support to the co-rotating reconnection picture proposed by *Yao et al.* [2017, under review].

Numerical model for the illustration: $\mathbf{B} = \mathbf{B}_{dipole} + \mathbf{B}_{RC} + \mathbf{B}_{drag} + \mathbf{B}_{X\text{-}line}$. $\mathbf{B}_{dipole}$ is the dipole field. $\mathbf{B}_{RC}$ is the field generated by ring current, $\mathbf{B}_{RC,r} = j_{\varphi 0}\tanh(z/L_{half\_width})$. $\mathbf{B}_{drag}$ is a constant value, $\mathbf{B}_{drag,\varphi} = B_{\varphi 0}$. $\mathbf{B}_{X\text{-}line}$ is an X-type magnetic structure; in the local X-line coordinate, $B_{x'} = B_{r',0}\cdot\sin(\theta')$, $B_{y'} = B_{r',0}\cos(\theta')$, where $\tan(\theta') = y'/x'$.

References: Delamere, P. A., A. Otto, X. Ma, F. Bagenal, and R. J. Wilson (2015), Magnetic flux circulation in the rotationally driven giant magnetospheres, *J. Geophys. Res. Space Physics*, *120*, 4229–4245, doi:10.1002/2015JA021036. | Jackman, C. M., J. A. Slavin, and S. W. H. Cowley (2011), Cassini observations of plasmoid structure and dynamics: Implications for the role of magnetic reconnection in magnetospheric circulation at Saturn, *J. Geophys. Res.*, 116, A10212, doi:10.1029/2011JA016682. | Yao et al., Discovery of co-rotating magnetic reconnection in Saturn's magnetosphere, *Nat. Commun.*, (under review).