8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Three-dimensional magnetic reconnection in planetary magnetospheres

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Magnetic reconnection triggers explosive phenomena in various plasma environments, such as the solar atmosphere, planetary magnetosphere, and laboratory. The plasma and magnetic field lines are decoupled at the reconnection site, where the magnetic topology changes and the particles are energized. The magnetic reconnection process is generally studied under a quasi-two-dimensional configuration. The dynamics inside the ion and electron diffusion regions are thoroughly analyzed and discussed. However, the reconnection region is three-dimensional (3D) and connected to the three-dimensional environment.

A critical characteristic in 3D is the presence of magnetic nulls, which is essential when the magnetic field topology changes [1]. Applying the fitting-reconstruction method to Cluster data, magnetic null pairs or multiple magnetic nulls linked by separators or helically wrapped spines [2] (Figure 1) are found in the reconnection diffusion region and turbulent outflow region [3]. The reconstructed magnetic structures show that the 2D features are parts of local approximations of the 3D geometries. The 2D regimes of antiparallel and component reconnection can simultaneously occur in 3D separator reconnection [4]. The flux ropes are formed along the spine line or in a region enclosed by wrapped fan surfaces in the presence of spiral null points.

We also showed that the reconnection sites are discretely distributed around the giant planetary magnetosphere (Figure 2), indicating that the reconnection line can only extended with a finite length in 3D space [5]. The formation of multiple magnetic reconnection sites is suggested to contribute to the rotating field-aligned currents and rotating aurorae in giant planets [6]. The linkage between the finite reconnection site, the magnetic null points, and the entire magnetosphere is still under investigation.

References
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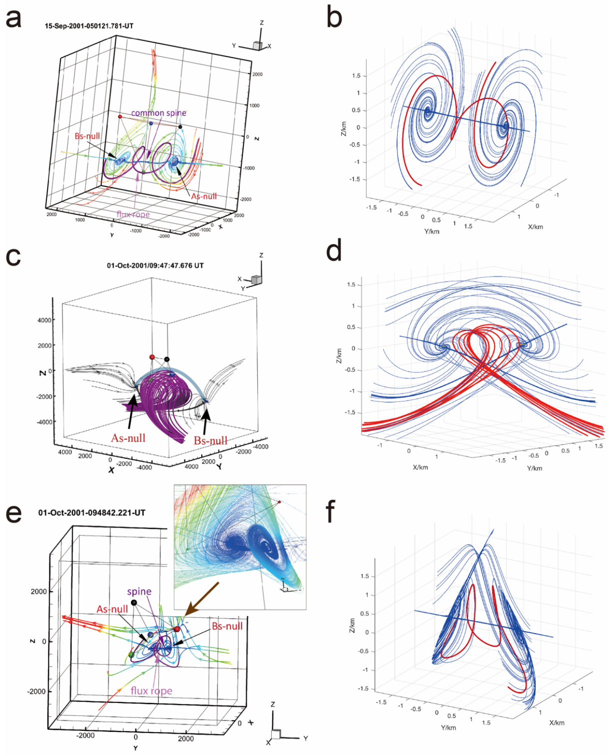

Figure 1. The magnetic reconnection region and flux ropes consist of 3D null points. (Guo et al., 2022)

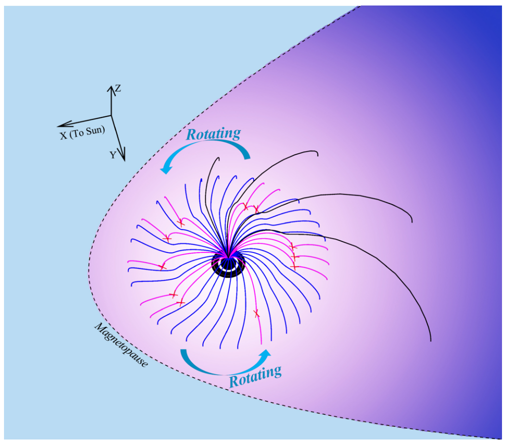

Figure 2. 3D global configuration of the reconnection sites in giant planets. (Guo et al., 2019)