A new method for finding magnetic nulls in space

Magnetic reconnection is a fundamental plasma process converting magnetic energy into particles' kinetic and thermal energy, and has been widely accepted as a mechanism responsible for many explosive phenomenon in the universe such as stellar flares, coronal mass ejection (CME), Gamma-ray bursts, substorms, strong emissions at the Galactic center, and also the disruptions in fusion experiments. In a three-dimensional (3D) regime, such reconnection often occurs at magnetic nulls, where the magnetic strength becomes zero and the particles get unmagnetized. Investigating the properties and topology of magnetic nulls, therefore, can help us to understand the energy conversion during reconnection process.

In theory and simulations, the properties and topology of magnetic nulls have been well studied. In spacecraft (SC) measurements, however, the properties and topology of magnetic nulls have not been well understood, because the measurements of magnetic field have been available only at single or a few points. To find a magnetic null in space, previous studies have used a method named "Poincare index" (PI). This method is based on four-point measurements; it gives PI=±1 when a null is enclosed by the SC tetrahedron but PI=0 when the null is outside the tetrahedron. This method has the following limitations: (1) it can give false positive or negative PI, hence leading to the misinterpretation of null types; (2) it is significantly determined by the data resolution—with high-resolution magnetic field data, a null is easily found, while with low-resolution data, a null is rarely detected; (3) it is strongly affected by the instrument uncertainty such as Bz offset—a slight change in Bz (0.1 nT) could lead to quite different results; (4) it is significantly dependent on interspacecraft separation—a large tetrahedron can always find magnetic null, while a small tetrahedron rarely finds the null; and also (5) it cannot find a null outside the tetrahedron and resolve the null position accurately.

Because of the limitations listed above as well as the fact that the PI method cannot reconstruct the magnetic field topology around a null, the research team led by Huishan Fu developed a new method—named FOTE. This method can (1) avoid limitations of the PI method such as data resolution, instrument uncertainty (Bz offset), and SC separation; (2) identify 3D null types and determine whether these types can degenerate into 2D; (3) reconstruct the magnetic field topology. The research team quantitively tests the accuracy of FOTE in positioning magnetic nulls and reconstructing field topology, by using the data from 3D kinetic simulations. The influences of SC separation and null-SC distance on the accuracy are both considered. They find that: (1) for an isolated null, the method is accurate when the SC separation is smaller than 1 d_i, and the null-SC distance is smaller than 0.25~0.5 d_i; (2) for a null pair, the accuracy is same as in the isolated-null situation, except at the separator line, where the field is nonlinear. They define a parameter to quantify the quality of the FOTE method—the smaller this parameter the better the results. Using the new method, they reconstruct the magnetic field topology around a radial-type null (see Fig. 1) and a spiral-type null (see Fig. 2), and find that the topologies are well consistent with those predicted in theory.

These results have been published in *Journal of Geophysical Research* (JGR)—a famous journal in space physics field—as the cover paper. They will significantly benefit the NASA MMS mission, which was launched this year for studying the electron-scale magnetic reconnection.

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Reference

[1]Fu, H. S., et al. (2015), How to find magnetic nulls and reconstruct field topology with MMS data?. *J. Geophys. Res. Space Physics*, 120, 3758–3782. doi: 10.1002/2015JA021082.

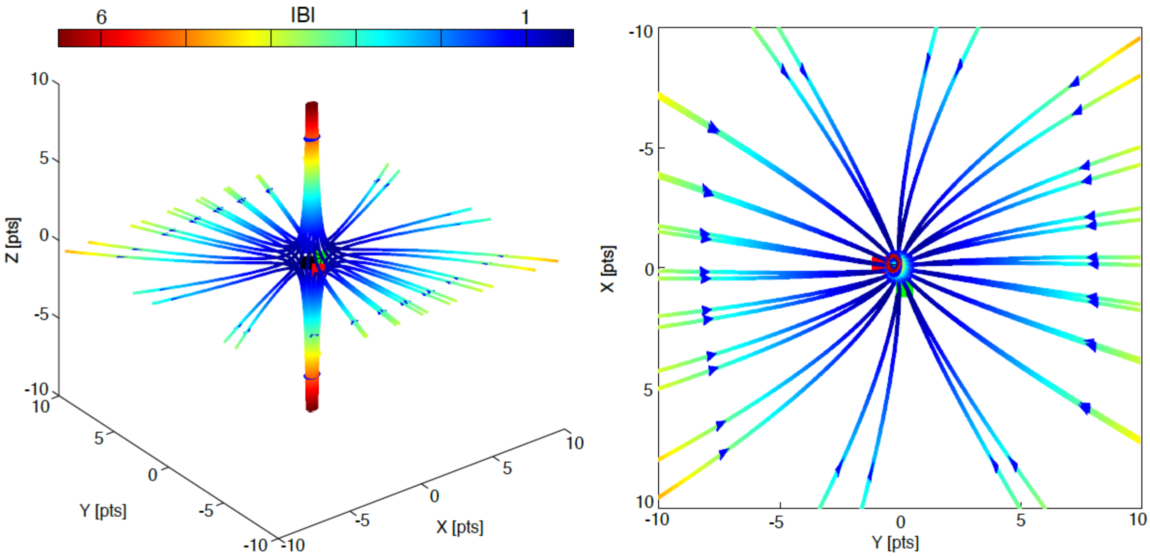

Figure 1: 3-D (left) and 2-D (right) view of a radial-type null, reconstructed using the FOTE method.

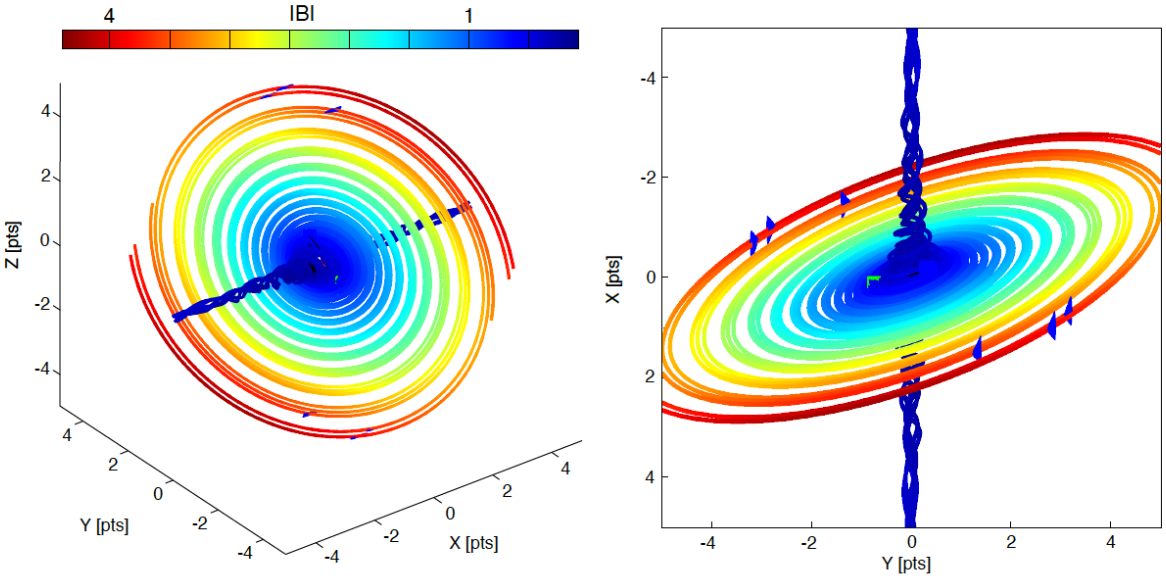

Figure 2: Topology of a spiral-type null in the same format as in Fig 1