Random Walk and Trapping of Interplanetary Magnetic Field Lines: Global Simulation, Magnetic Connectivity, and Implications for Solar Energetic Particles

การเดินสุ่มและกักตัวของเส้นสนามแม่เหล็กระหว่างดาวเคราะห์: การจำลองมหาภาค สภาพการเชื่อมทางแม่เหล็ก และผลที่ตามมาสำหรับอนุภาคพลังงานสูงจากดวงอาทิตย์

(R. Chhiber, **D. Ruffolo*,** W. H. Matthaeus, A. V. Usmanov, P. Tooprakai, P. Chuychai, and M. L. Goldstein 2021, Random Walk and Trapping of Interplanetary Magnetic Field Lines: Global Simulation, Magnetic Connectivity, and Implications for Solar Energetic Particles, Astrophys. J., 908, 174)
https://doi.org/10.3847/1538-4357/abd7f0

The random walk of magnetic field lines is an important ingredient in understanding how the connectivity of the magnetic field affects the spatial transport and diffusion of charged particles. As solar energetic particles propagate away from near-solar sources, they interact with the fluctuating magnetic field, which modifies their distributions. We develop a formalism in which the differential equation describing the field line random walk contains both effects due to localized magnetic displacements and a non-stochastic contribution from the large-scale expansion. We use this formalism together with a global magnetohydrodynamic simulation of the inner-heliospheric solar wind, which includes a turbulence transport model, to estimate the diffusive spreading of magnetic field lines that originate in different regions of the solar atmosphere. We first use this model to quantify field line spreading at Earth orbit, starting from a localized solar source region, and find rms angular spreads of about 20°–60°. In the second instance, we use the model to estimate the size of the source regions from which field lines observed at 1 au may have originated, thus quantifying the uncertainty in calculations of magnetic connectivity; the angular uncertainty is estimated to be about 20°. Finally, we estimate the filamentation distance, i.e., the heliocentric distance up to which field lines originating in magnetic islands can remain strongly trapped in filamentary structures.

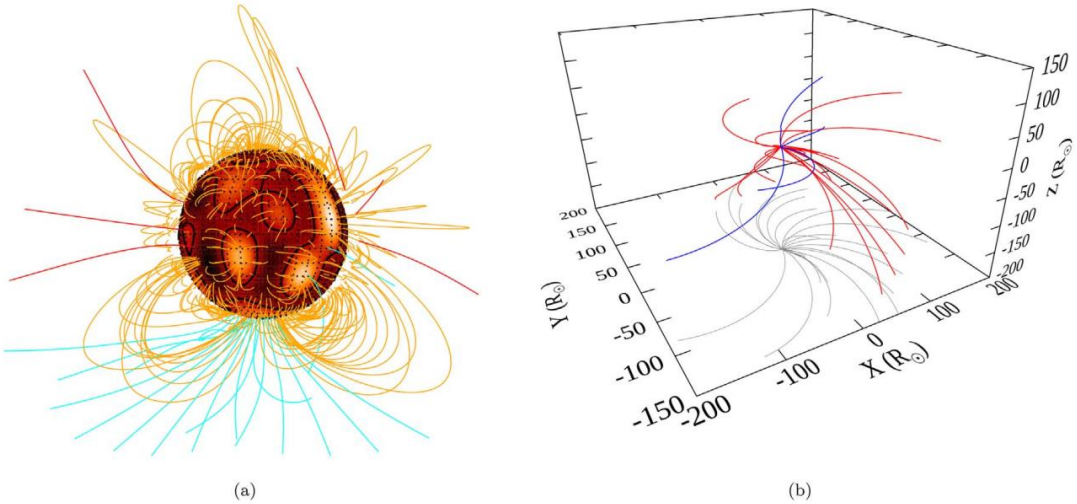

Figure: Left and right panels show two views of magnetic field lines based on a solar magnetogram. (a) A close-up view of the coronal base, with the center at 0° heliolatitude and 116° heliolongitude in heliographic coordinates. Contours of radial magnetic field are shown at the coronal base. Yellow curves represent closed field lines. (b) Open field lines traced out to Earth orbit. Projections of field lines on the X–Y plane are shown in gray. In both panels blue and red curves represent open field lines with positive and negative polarity, respectively.