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Seeking the origin of magnetic switchbacks and the acceleration mechanism of the solar wind

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The solar wind, the supersonic outflow from the Sun, plays several important roles in astronomy and geophysics, including the angular momentum extraction from the Sun and the source of disturbance in the geomagnetism. To better understand them, we need to know how the solar wind is heated and accelerated against the cooling by thermal conduction and gravitational deceleration. This solar wind acceleration problem has been studied as one of the most important problems in astronomy, from both observational and theoretical points of view.

Recently, research on the solar wind has made great progress. From observational point of view, Parker Solar Probe[1] (PSP), a spacecraft to reach the unexplored wind acceleration region, was launched in 2018 and is gradually approaching the Sun. Though not getting to the closest point, PSP has already provided a number of unexpected results. While from theoretical point of view, a 3D direct numerical simulation of the solar wind acceleration was achieved in 2019[2]. Given the current situation, it is the ideal time to make a quantitative comparison between direct numerical simulations and PSP observations.

To test the solar wind model with PSP observations, we have performed a three-dimensional direct numerical simulation of the solar wind acceleration with an unprecedented resolution. The simulation domain extends to 40 solar radii, including all the PSP perihelions. By taking the lower boundary at the coronal base, the boundary condition is constrained by the solar coronal observations. We specifically aim to investigate 1. whether the magnetic switchbacks are reproduced by the simulation and 2. whether the simulation data looks similar to the observed data. Figure 1 shows the simulation results. Left panels show the snapshots of the simulation and clearly show the existence of a locally-reversed radial magnetic field, that is, magnetic switchback. The magnetic switchback is associated with locally enhanced wind speed, which is consistent with observation. Right panel of Figure 1 compares the time-series data of the PSP observations (left and middle) and simulation (right). The simulation data looks similar to the middle panel but qualitatively different from the left panel. These agreement and disagreement mean that a part of the solar wind is well explained by the current solar wind model, while additional physics should be considered to explain the whole PSP observation.

References
[1] Fox, N. J. et al., Space Science Reviews, 204, 1131 (2016)
[2] Shoda, M. et al., The Astrophysical Journal, 880, L2 (2019)

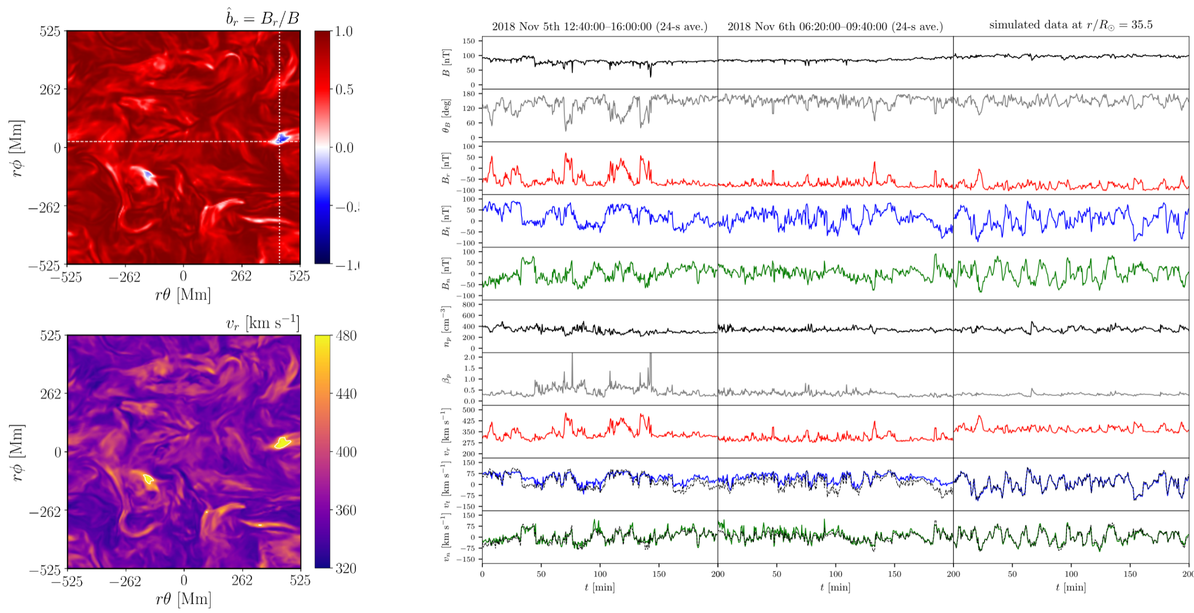

Figure 1. Left: Simulation snapshots on the $\theta\phi$ plane $(r = 35R_\odot)$. Top and bottom panels show the normalized radial magnetic field and radial velocity, respectively. The blue patch in the left-top panel corresponds to the magnetic switchback. Right: Comparison of PSP observations with the simulation data. Left and middle panels correspond to the PSP observations in the first encounter and right panel shows the simulation data.