Revealing the magnitude and magnetohydrodynamic to ion-kinetic scale structure of the heliospheric current sheet with IMAP and the L1 Constellation

Drew Turner[1], Savvas Raptis[1], Tim Horbury[2], Manuel Cuesta[3], Hameed Farooki[3], Jamie Rankin[3], Maher Dayeh[4], Dimitris Vassiliadis[5], Roy Torbert[6], Rob Ebert[4], Lynn Wilson[7], Adam Szabo[7], K Sankarsubramanian[8], Dibyendu Chakrabarty[9], Christina Cohen[10], Matina Gkioulidou[1], Eric Christian[7], Nathan Schwadron[11], David McComas[3]

[1]Johns Hopkins Applied Physics Laboratory, Laurel, United States, [2]Imperial College London, London, United Kingdom, [3]Princeton University, Princeton, United States, [4]Southwest Research Institute, San Antonio, United States, [5]NOAA/NESDIS/SWO, United States, [6]University of New Hampshire, Durham, United States, [7]NASA Goddard Space Flight Center, Greenbelt, United States, [8]U R Rao Satellite Center (URSC), Bengaluru, India, [9]Physical Research Laboratory, Ahmedabad, India, [10]California Institute of Technology, Pasadena, United States, [11]Los Alamos National Laboratory, Los Alamos, United States

The heliospheric current sheet (HCS) is the global, physical boundary between interplanetary magnetic field (IMF) oriented outward away from the Sun and inward toward the Sun. The HCS is an important boundary in both fundamental Heliophysics and space weather. With the exception of the Cluster and MMS missions, each consisting of four observatories separated at ion-kinetic or electron-kinetic scales, respectively, most prior studies of the HCS and its nature were conducted with single-point observatories, and these studies have revealed estimates of the structure of the HCS and magnitude of its current layer. Studies all agree that the HCS is structured, with a finite layer (or layers), embedded within a broader plasma sheet, with a peak intensity current on the order of $1 - 10e - 4\mu A/m^2$. In this study, we employ novel observations from the newly established L1 Constellation of six observatories around the Sun-Earth L1 point. NASA's IMAP and NOAA's SOLAR-1 missions launched in September 2025 and joined the Wind, ACE, DSCOVR, and Aditya-L1 missions already in operations around L1. Altogether, the six observatories span a range of separations from ~ 5 Earth radii (3.2e4 km) to 200 Earth radii (1.3e6 km) separated mostly transverse to the solar wind flow around L1. From this new L1 Constellation, we study heliospheric current sheets in full spatiotemporal detail, and for the first time (to our knowledge), the curlometer technique is applied at magnetohydrodynamic scales to derive the magnitude and components of the current density vector throughout the HCS. Our results reveal the bifurcated nature of the HCS, a structure that is not at all consistent with a Harris-type current sheet model and that demonstrates distinct embedded substructure that is stable over the 10s of minutes and millions of kilometers between the observatories in the L1 Constellation. As in previous studies, we find the HCS is embedded within a broader, $\sim$ 98 Earth radii (6.2e5 km) plasma sheet. The HCS itself is bifurcated, with two intense current sheets each $12 \sim 14$ Earth radii in scale embedded within a ~ 50 Earth radii central structure. Also consistent with previous studies, we show that the current density peaks at $\sim 5e - 4\mu A/m^2$, but the vector data available from the curlometer reveal new details consistent with a bifurcated, bipolar current sheet model. Intriguingly, the spatiotemporal nature of the HCS appears to be localized and dynamic in this case as well, with IMAP observing clear signatures of active reconnection, which are not observed at Wind, approximately $20 \sim 30$ Earth radii downstream.