Flux tubes and energetic particles in Parker Solar Probe: The magnetic helicity-PVI method and ISoIS observations

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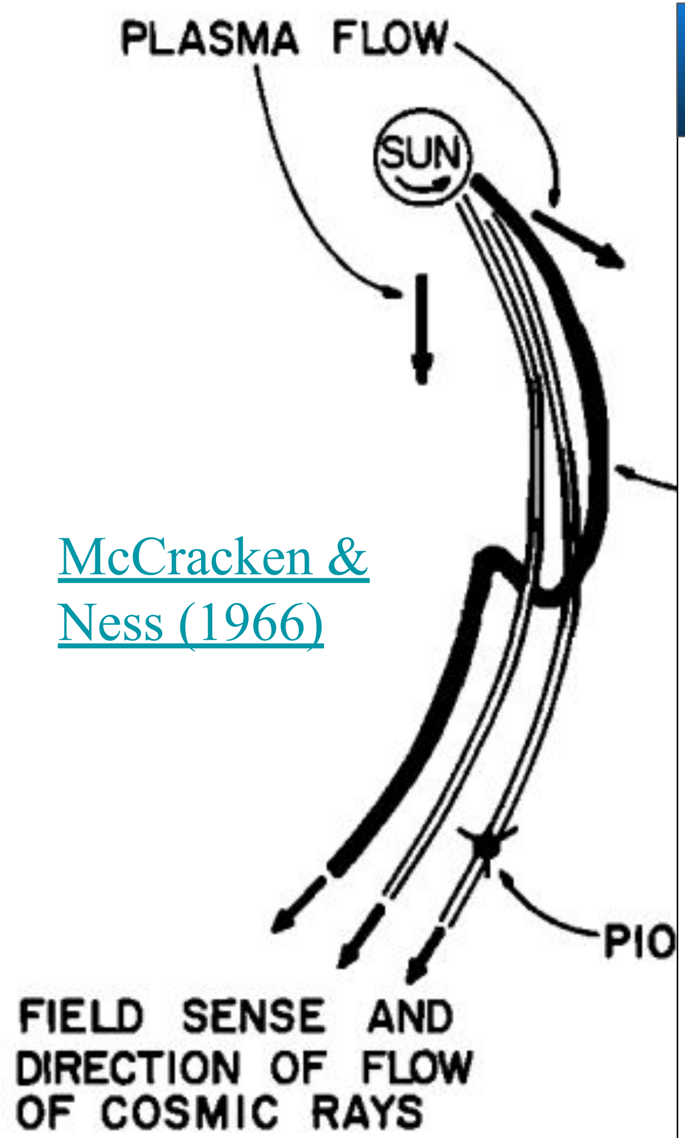


McCracken & Ness (1966)

INTRODUCTION

Plasma turbulence can be viewed as a magnetic landscape of large- and small-scale structures, such as magnetic flux tubes and their boundaries.

We present a synergistic use of the magnetic helicity-partial variance of increments (PVI) method paired with ISoIS observations of energetic particles (EPs). Magnetic helicity detects large-scale helical flux tubes, while PVI identifies their boundaries. We find that helical flux tubes act as hard boundaries that guide EP transport either confining populations within the helical field, or excluding them from entering it.

IDENTIFICATION IN SIMULATIONS

The method is applied to MHD simulations (black lines are vector potential contour). Islands' cores (cyan regions) and reconnection events (orange shaded) have been identified via an independent method based on topological properties Servidio+(2010). A virtual spacecraft (blue trajectories) spans the domain to mimic the 1D information that spacecraft collect in the interplanetary space. Along such trajectory, PVI and Hm are calculated, and their extrema reported over the 2D map. The accuracy of the method is evidenced by the positioning of Hm and PVI extrema that are respectively located within the cores and at the boundaries of magnetic islands.

IDENTIFICATION IN PSP DATA

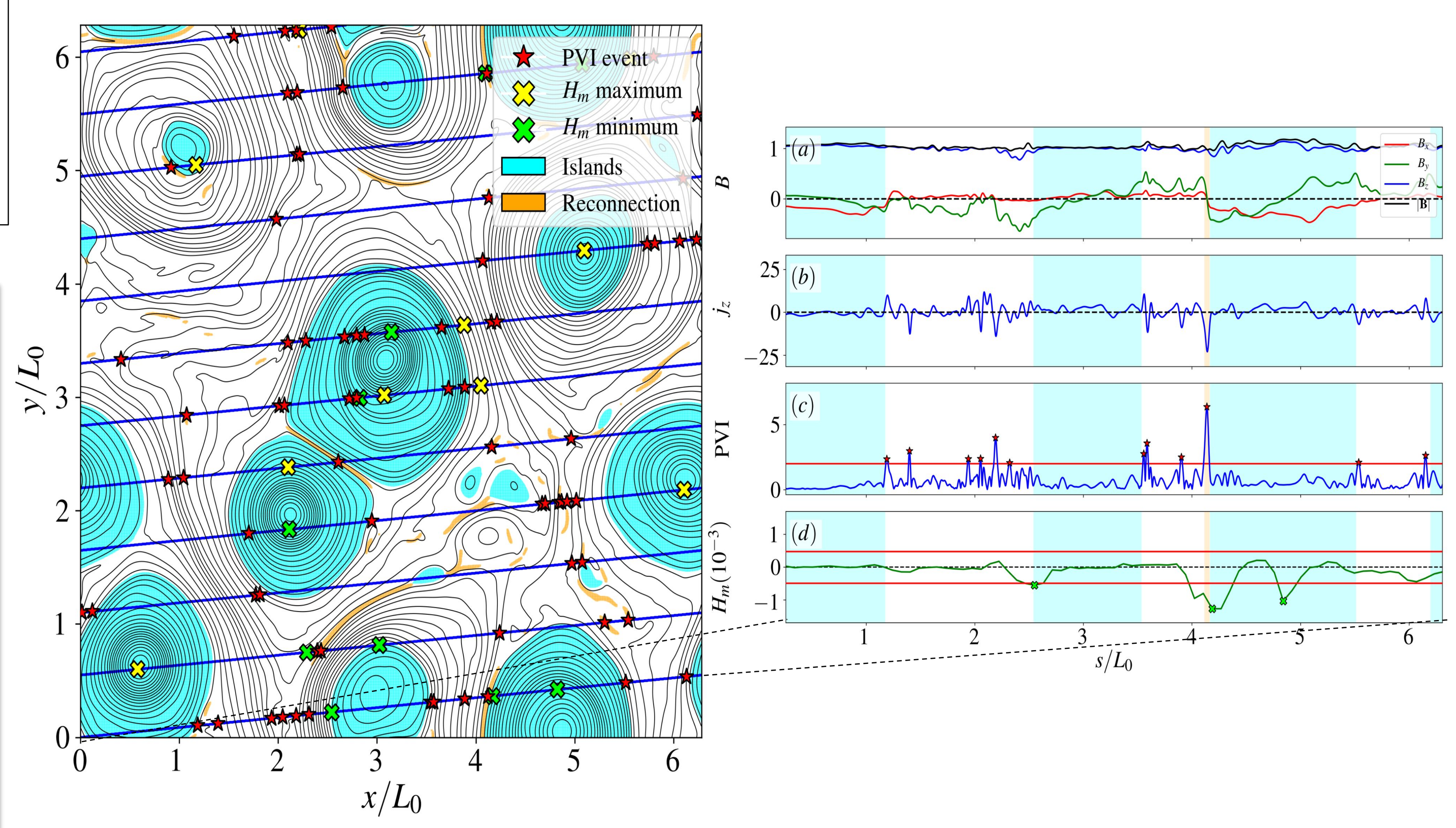
In PSP measurements, we found, Pecora+(2020), that helical structures are present, and they are bounded by strong PVI events. The figure reports the magnetic field (a), (f); the PVI signal (b), (g); and the magnetic helicity evaluated at 1 (c), (h); 1/2 (d), (i); and 1/3 of the correlation time (e), (j). Hm shape depends on the chosen window, suggesting a multi-scale nature of helical structures. The two structures, shown in left panels, show fragmentation of the structure at scales smaller than one correlation time. Right panels, instead, show a structure that has no internal features.

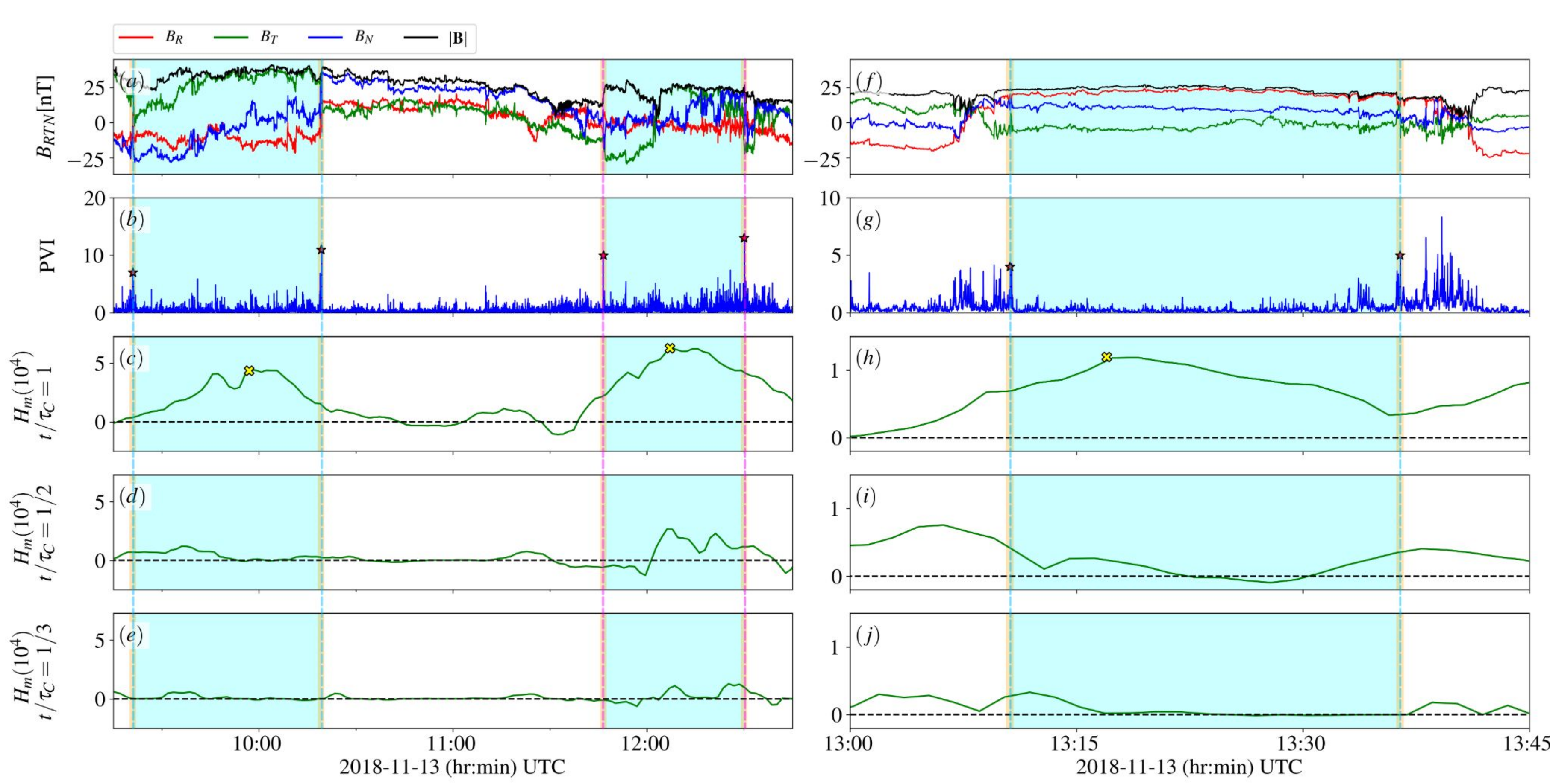
THE Hm-PVI METHOD

Magnetic helicity $H_m = \langle \mathbf{a} \cdot \mathbf{b} \rangle$, can be estimated by single-spacecraft 1D measurements, following Matthaeus+(1982) as described in Pecora+(2020), as

$$H_m = \int_{\ell}^{0} ds\ \hat{e}_i \epsilon_{ijk} R_{jk}(s)$$

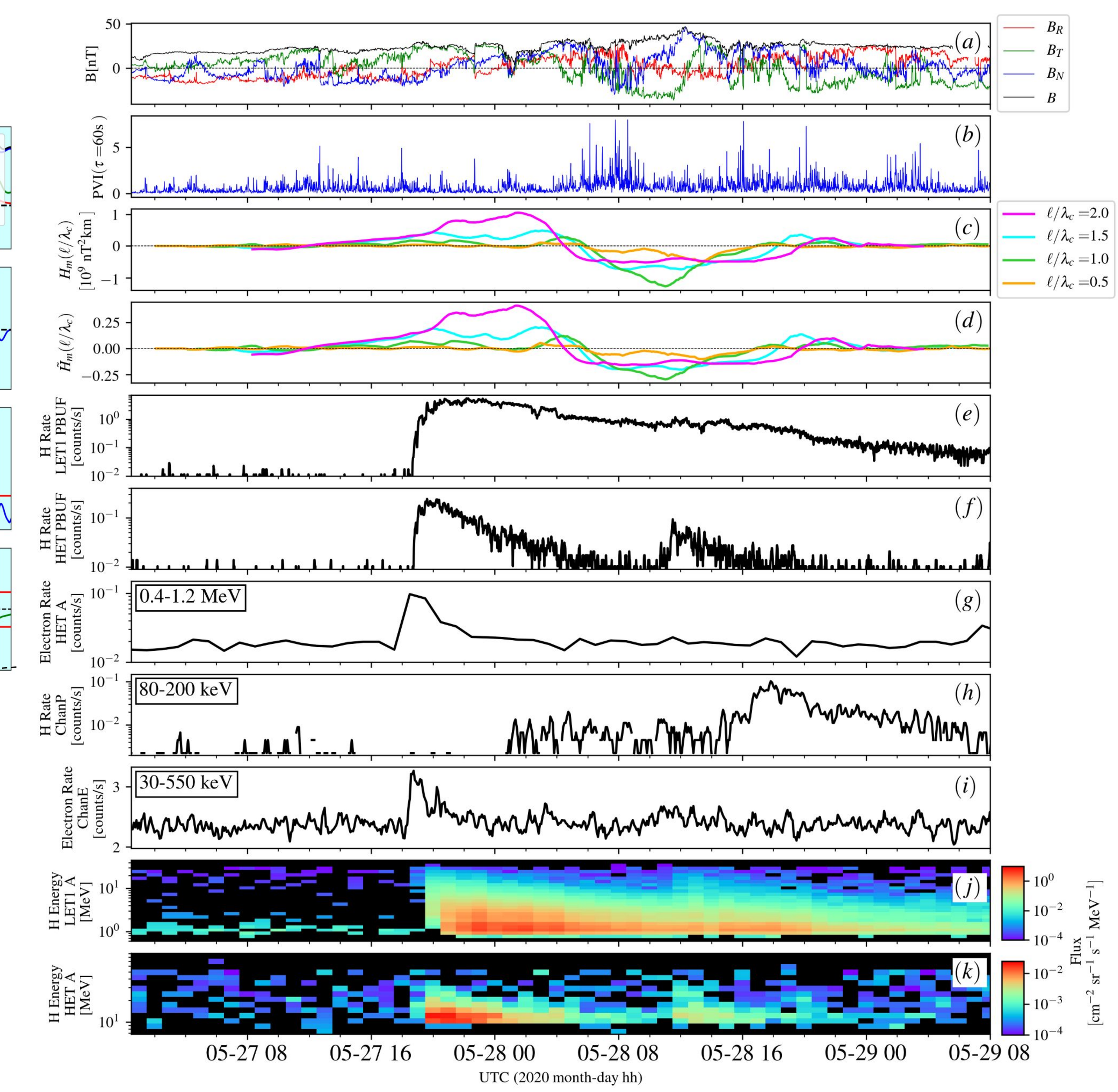
where $R_{jk}(s) = \langle B_j(r) B_k(r+s) \rangle$ is the correlation tensor evaluated at spatial lag s along the measuring direction $\hat{e}_i$. The integral retains contribution to magnetic helicity from structures at scales smaller than ℓ. We chose ℓ to be a fraction of the correlation length, as this is the typical scale of helical structures.

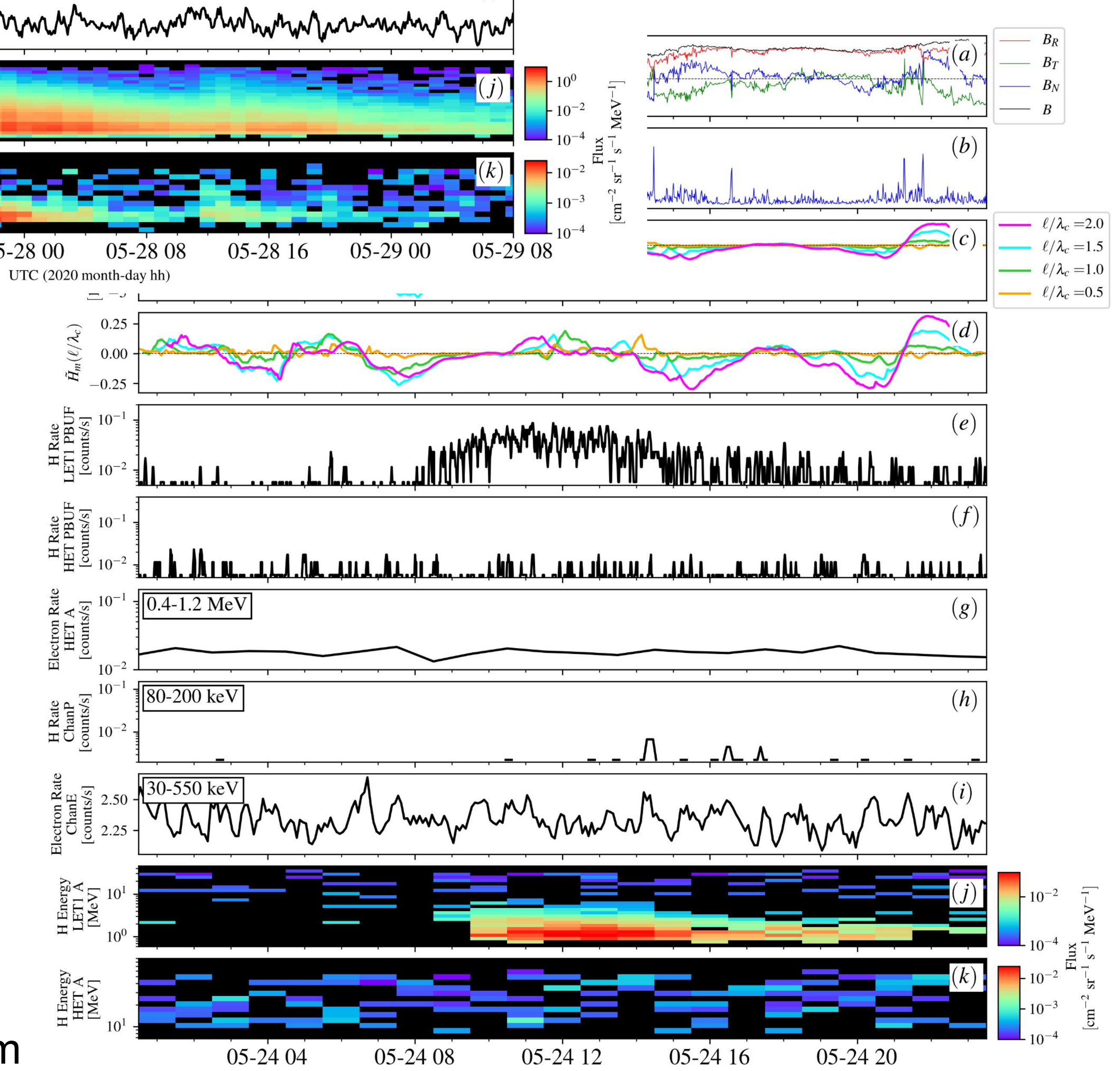




FLUX TUBES AND ENERGETIC PARTICLES

We have extended the use of the Hm-PVI technique to selected intervals in which energetic particles are observed by the ISoIS instruments on PSP. In particular, in the period 2020 May 24 to June 2, at least five SEP events are recorded Cohen+(2020). We focused on two sub-intervals in this period -- one in which energetic particles appear to be confined in the region *between* two helical flux ropes, and another in which the particles are confined *within* adjacent (and possibly interacting) flux ropes. The combined use of PVI and helicity measurements add detail to this characterization, the basic properties of which were previously reported using ACE data and the PVI alone.





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