Coronal Origins of the Alfvénic Slow Solar Wind

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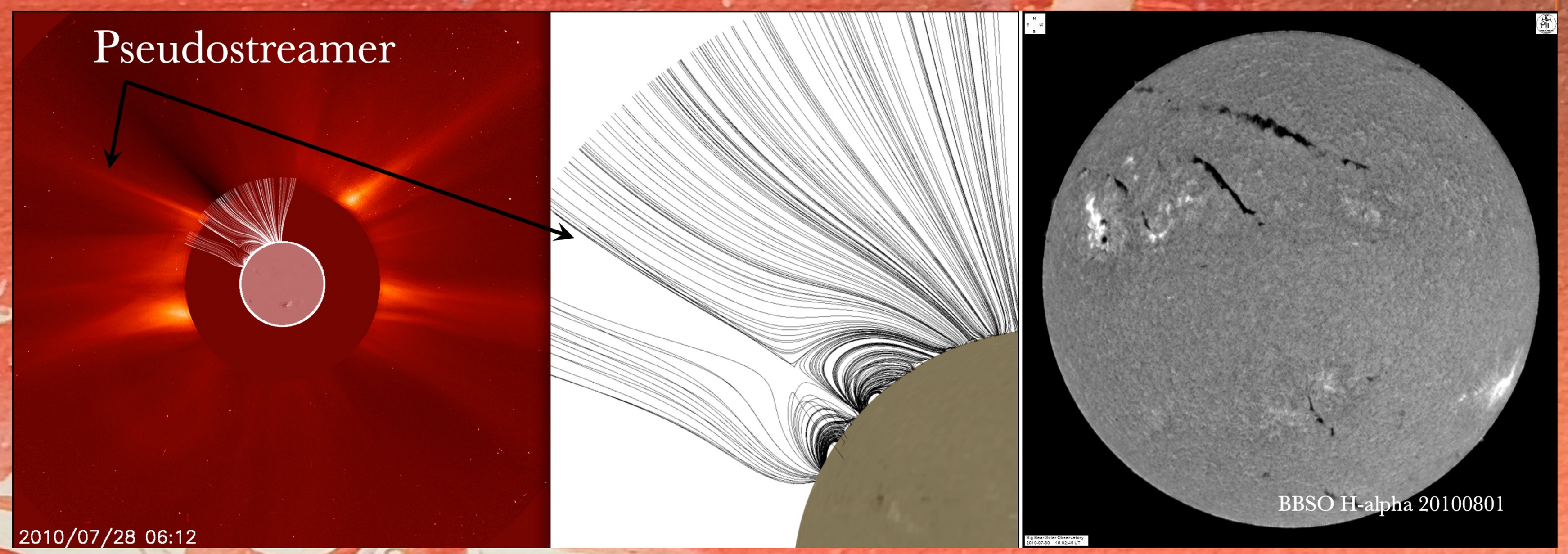
ABSTRACT

As demonstrated by the Ulysses mission the filling factor of the slow wind in the heliosphere is too large to arise only from the helmet streamer cusps, so magnetic field and plasma transport and instabilities involving processes at coronal hole boundaries and quiet sun must be at work. Outwardly propagating Alfvénic fluctuations are usually hosted by fast solar wind streams, however a number of slow solar wind periods have been identified where the turbulence is also dominated by outward Alfvénic modes. 80% of the wind at Helios was shown to be Alfvénic and ~ 37% Alfvenic slow. Is the difference between Alfvénic slow wind and standard slow wind associated with different dynamics, or is the coronal topology at the source completely different, as initial indications seem to show?

Here we discuss magnetic topology and properties of the coronal sources for the peculiar Alfvénic slow solar wind. We illustrate the specific role played by different coronal hole types (polar CHs, equatorial extensions of polar CHs, isolated CHs both at high latitude and close to the equator), as well as by solar filaments and active regions at coronal hole boundaries, that strongly influence the magnetic topology of the lower corona and solar wind properties. Pseudostreamers (PSs) are multipolar features, which develop into open fields that are unipolar at greater heights requiring the presence of two or more nearby coronal holes of the same polarity. MHD solar wind models along magnetic field lines show that the properties of the solar wind emanating from CHs with pseudostreamers are different from regular CHs. Here we explain the coronal conditions required for the development of Alfvénic slow solar wind.



East limb appearance of a pseudostreamer with twin filaments in its base.

The presence of multiple coronal holes of the same polarity then leads preferentially to the formation of multiple filament channels underneath pseudostreamers in the region between the holes. Such magnetic configurations survive in a quasi-stable manner until magnetic reconnection, either within the configuration itself or between the region and outside fields begins to disrupt the original magnetic connectivity pattern. Pseudostreamers harbor polarity inversion lines, typically two or more, within their closed, dome-like regions: when the polarity inversion lines below pseudostreamers coincide with filament channels, it is often the case that at least one filament channel, containing filament, is present. When two filaments are present, they have the same chirality, and they called twin filaments nested under the same pseudostreamer [1].

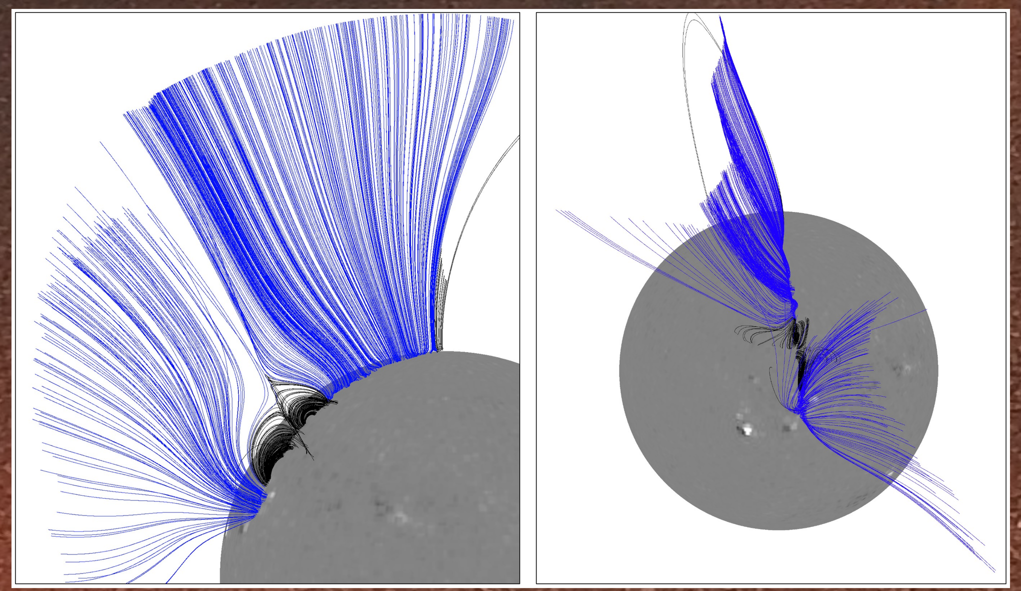
REFERENCES

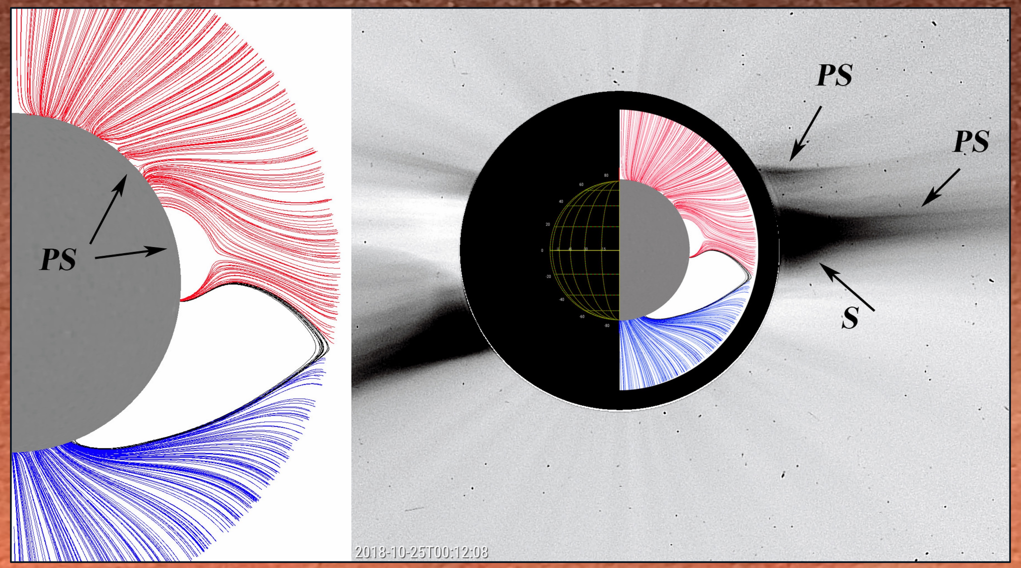
[1] Panasenco and Velli, 2013 *AIPC* **1539** 50

[2] Panasenco et al. 2019 *ApJ* **873** 25

[3] Panasenco et al. 2020 *ApJS* **246** 54

PFSS extrapolation (SDO/HMI) of the pseudostreamer magnetic field above two dextral filament channels on 2010 July 30: limb view (left), top view (right). The strong shear associated with twin filaments leads to separation of field lines on opposite sides of the pseudostreamer separatrix-skeleton. The null-point is located at ~ 300 Mm. The topology of pseudostreamers with one or two twin filaments create conditions for a strong divergence of the open magnetic field lines and that is a variations of a strong non-monotonic expansion [1], [2].





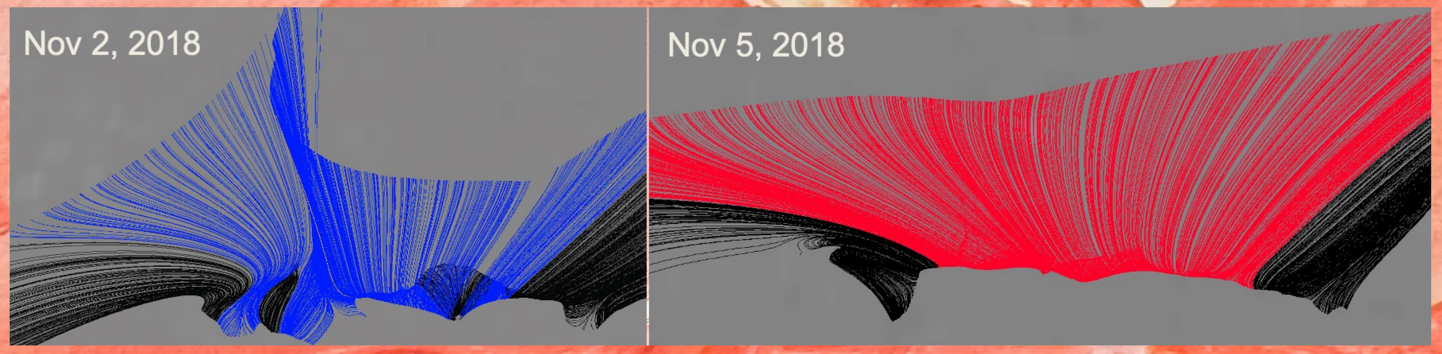
Using the best fit for Rss we traced back to the Sun the short Alfvenic slow wind streams observed at 1 AU, found their source regions and created the 3D PFSS models for the coronal field in these regions. These models reveled the peculiar topology in both cases - coronal pseudostreamers: large and smaller scales. We found that only small regions of wind remained Alfvénic out to 1AU, one of which corresponded to the fast-expanding open region at the PSP perihelion. [3]

CONCLUSIONS

Alfven waves may be an important part of most of the nascent solar wind, with the Alfvenicity degrading rapidly with distance from the sun, and surviving out to greater distances only in the fast wind from dominant polar coronal holes or in the slow wind from

- rapidly expanding small open regions that we have called coronal funnels
- "corrugated" open field lines at complex boundaries of large CHs.

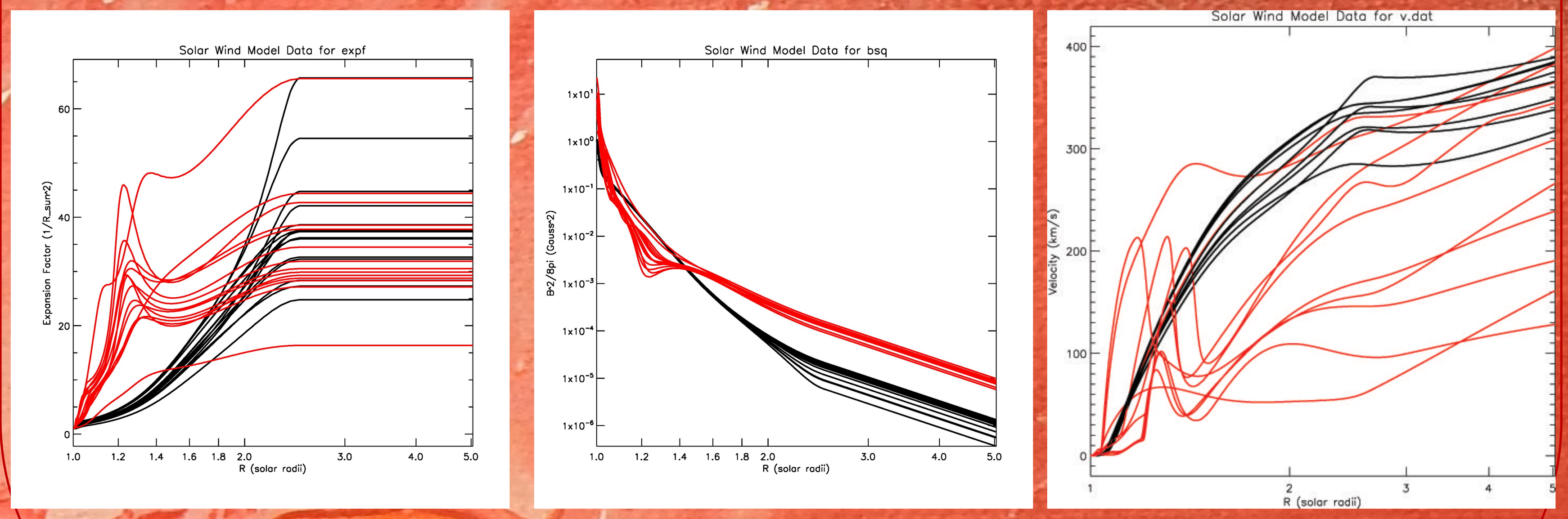
Further research will show whether these regions, often presenting multipolar pseudostreamer configurations at their base, may be identified by other tracers, including compositional differences, in the solar wind. To this end, joint observations with the upcoming PUNCH mission, together with Parker Solar Probe, Solar Orbiter, Proba-3 will help to shed light on the generation and acceleration of different solar wind stream types.



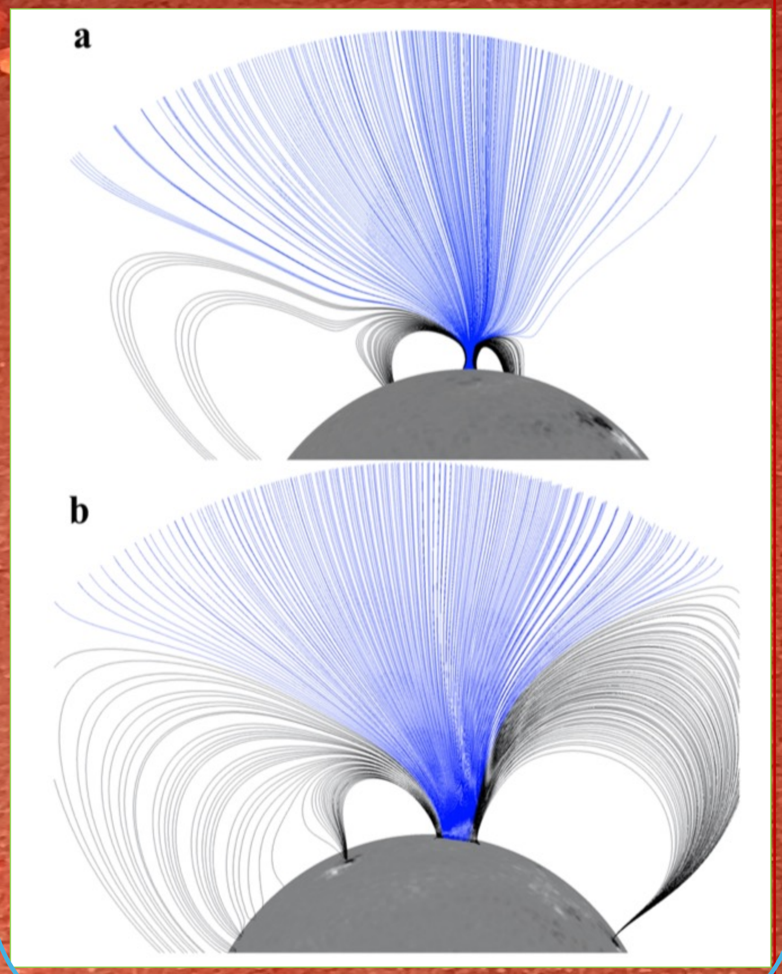
from [3]

A "non-monotonic expansion factor" in the solar corona magnetic field refers to a situation where the magnetic field lines do not expand smoothly and consistently outward from the Sun, but instead exhibit variations in their expansion rate, sometimes expanding rapidly and then slowing down or even contracting slightly as they move further away, creating a non-uniform pattern in the field line expansion. The non-monotonic expansion factor can significantly influence the behavior of the solar wind, as the speed and density of the plasma flowing outward from the Sun can be affected by the varying magnetic field geometry.

Contrast between configurations with and without a magnetic funnel is shown via a solar wind field-aligned model calculated using field lines from both the funnel structure before (red lines) and the regular coronal hole that developed later (black). Left panel: magnetic funnel field line expansion factors were calculated for 35 open field lines derived from the SDO/HMI magnetogram. The local extremum is at ~1.2–1.3 Rs. This is the exact height where the coronal cloud prominences begin to form inside this funnel. Middle panel: the magnetic pressure is a rapidly increasing function toward the solar surface, and in fact for the bulk of the funnel field lines has a minimum corresponding to the maximum expansion rate of the funnel, in the neighborhood of 0.25 Rs above the solar surface. Beyond the source surfaces a spherical expansion is assumed. Right panel: solar wind speed profile along the chosen field lines. Note how the rapid funnel expansion causes the solar wind to slow down in the neighborhood of expansion factor peaks. [2]



Comparison between funnel-like (a) and regular (b) open magnetic fields. The funnel open field evolved into a regular coronal hole one rotation later. The magnetic field lines for a regular coronal hole show monotonic expansion – no rapid funnel-like expansion. The topology evolved from the situation when magnetic field lines pinches dramatically to a configuration which YES narrows to the photosphere but in a very smooth and monotonic way. To contrast these two configurations next figure shows a solar wind model calculated for both. [2]



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