# Small-scale Current Sheets and Magnetic Reconnection in the Turbulent Solar Wind


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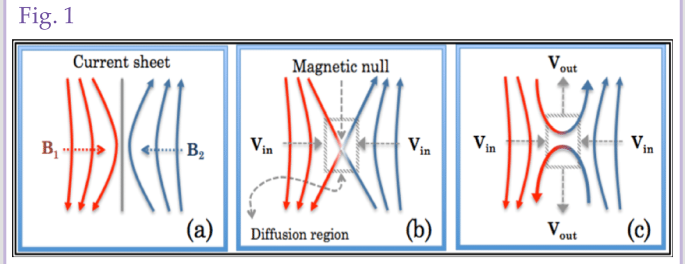
## 1 Motivation

- At small scales the solar wind is turbulent, with fluctuations of magnetic field that can make current sheets spontaneously arise.

Fig. 1




(1) Genestreti, et al. (2012)

- These current sheets can reconnect, accelerating the plasma particles that enter the ion diffusion region. Thus, the energy contained in the magnetic fields can turn into kinetic energy of the ions and be dissipated.
- The slope of the turbulent spectrum of magnetic fluctuations (an expression of the rate at which energy is transferred between scales) steepens for fluctuations of the order of magnitude of the ion inertial length, $\lambda i$, and smaller.
- It has been proposed that magnetic reconnection, as a magnetic energy dissipating process, may play a role in the explaining this behavior.

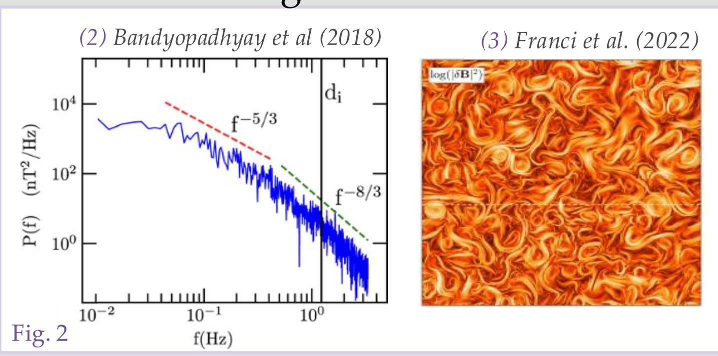



Fig. 2

## 2 Data set

- Our study focuses on ionic scales, searching for current sheets no thicker than 100 $d_i$.
- High cadence magnetic field and ion data has been taken from Solar Orbiter between 07-July-2020 and 11-Sept-2022.
- In our survey Solar Orbiter PAS will operate in one of it high cadence mode, snapshot or burst, for 54.75h and 48.25h, respectively.

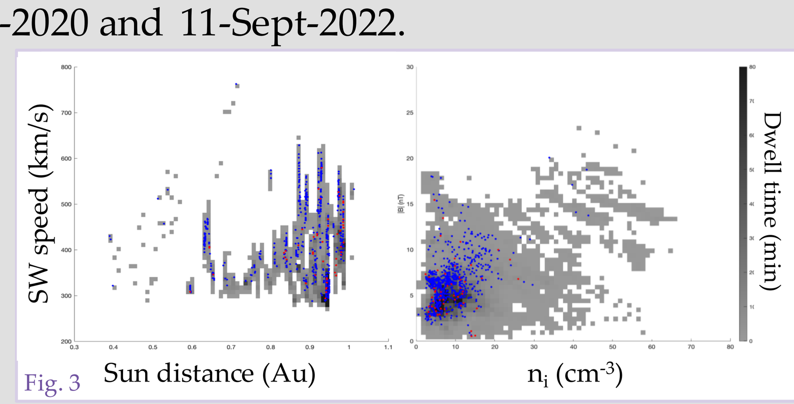



Fig. 3

Blue and red dots represent where alfvénic or reconnecting CSs have been found

## 8 Bibliography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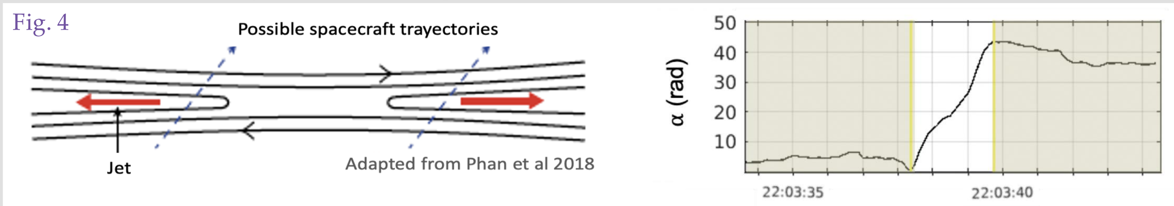
## 3 Methodology

1. Current sheets are looked for on the basis of large enough rotations of the magnetic field through a lapse of time that can have any duration in the range from the separation between two PAS data points and the time that corresponds to 100$d_i$ at its particular SW conditions.
2. All this time lapses are evaluated in search for a rotation of the magnetic field that is larger than $\alpha \geq 2\arcsin\left(\frac{\sqrt{nm_i\mu_0}}{|\vec{B}|}\right)\Delta v_{PAS}$ *(4)* and that is continually increasing.

Fig. 4




3. Overlapping current sheets found through this method are filtered out selecting a unique current sheet of maximal magnetic field rotation per each cluster.
4. These current sheets are evaluated for magnetic reconnection by implementing hybrid-MVA *(5)* and checking the correlation between variations of the L direction velocity and magnetic field, and whether the sign of the correlation changes from the leading to the trailing halves of the current sheets.

## 4 Current sheet catalog

We obtain a catalog of **974 CS**. Of them, **53 are reconnecting**, 838 are alfvénic, and 83 are undefined. We find that, in total, Solar Orbiter expends 4390 s inside a Cs and 290s inside a reconnecting CS.

An example of alfvenic and reconnecting CSs found is shown here

Fig. 5

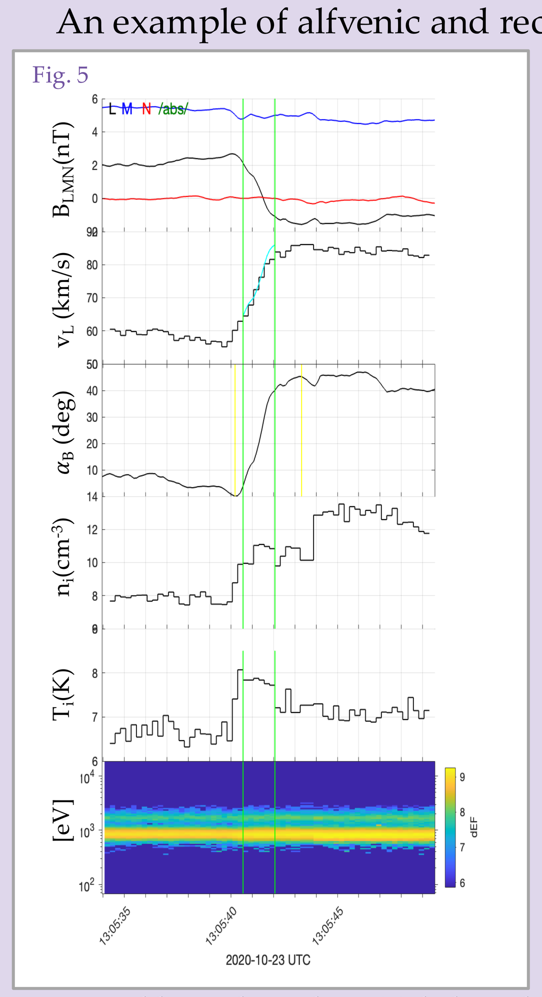
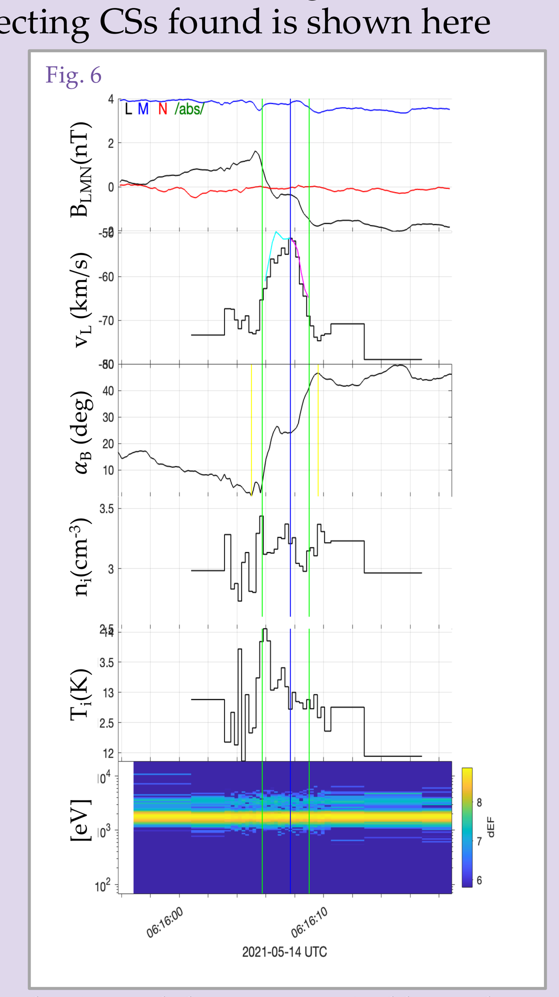


Fig. 6



Yellow vertical lines show the initial algorithm CS selection, while green vertical lines show the central 76% of the given CS where reconnection is assessed and other CS properties are computed. Cyan and magenta lines show the variations in Alfvén speed, with magenta/cyan showing correlation/anticorrelation between ion velocity and magnetic field.

## 5 State of the art

The results of previous studies searching for magnetic reconnection in the solar wind are summarized below for comparison with the findings of this study (purple shading).

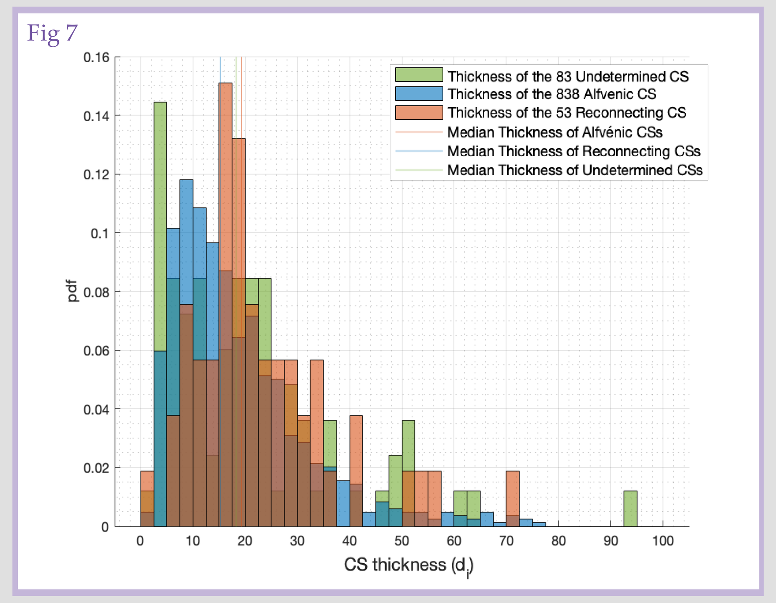
| | Method | Mission | Observation time | Sun distance | CS per unit time | Exhausts per unit time | CS thickness |
|---|---|---|---|---|---|---|---|
| Fargette + 2023 *(6)* | Bayesian statistical analysis | SolO | 20.7 day | 0.7 AU | - | **0.3/h** | **~ 40 - 1500 $\lambda_i$** |
| Eriksson + 2022 *(7)* | $\lvert\Delta B_L\rvert \geq 1nT + B_L$ sign change + Walén test | WIND | 10 years | 1 AU | - | **0.02/h** * | **~ 5 - 100$\lambda_i$** |
| Lotekar+ 2022 *(8)* | PVI + bifurcation check | PSP | 10 days | 0.2 AU | 46.7/h | **5.3/h** | **0.1 - 10$\lambda_i$** |
| Vasko+ 2021 *(9)* Vasko+ 2022 *(10)* | PVI + bifurcation check | WIND | 124 days | 1 AU | 6.3/h | **0.6/h** | **0.1 - 10$\lambda_i$** |
| Albert+ | B field rotation + Correlation | SolO | 103 h | 0.4-1AU | 9.5/h | **0.5/h** | **0.15 - 100$\lambda_i$** |

The present study searches for current sheets on the basis of magnetic field rotation and then assesses reconnection in each CS through the correlation change between magnetic field and velocity. In contrast, other studies, look for reconnection independently of presence of CS, base the search for CS in different signatures, or evaluate reconnection through different methods.

* Non exhaustive study

## 6A Results: Current sheet abundance and properties

Fig 7




- (Fig 7) Alfvenic CSs are thinner than reconnecting CSs, with a median thickness of 15.25$d_i$ for alfvenic and 19.2$d_i$ reconnecting.
- (Fig 8) We compare the alfvénicity of alfvénic CSs to the jet size of reconnecting CSs.

$$(v_{jet_{th}})^2 = \frac{B_{L1}B_{L2}}{\mu_0}\frac{B_{L1}+B_{L2}}{\rho_1 B_{L2}+\rho_2 B_{L1}}$$

- Jet size distribution is in agreement with findings by *(Eriksson et al., 2022 (5))*.
- (Fig 9) Flow shear is significantly higher for alfvénic than for reconnecting CSs. Reconnecting CSs flow shear is always smaller than 0.5 which is consistent with *(11) Cassak & Otto (2011)*, where strong flow shears are shown to suppress magnetic reconnection rate.

Fig 8

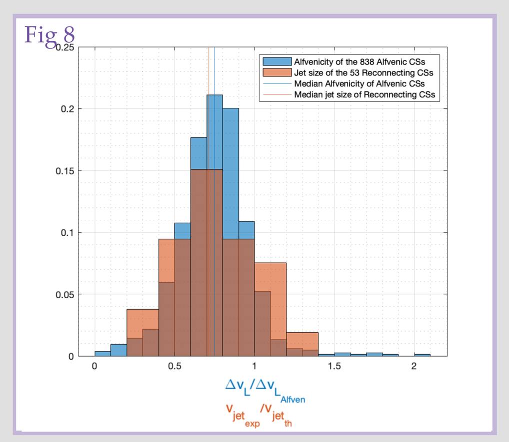
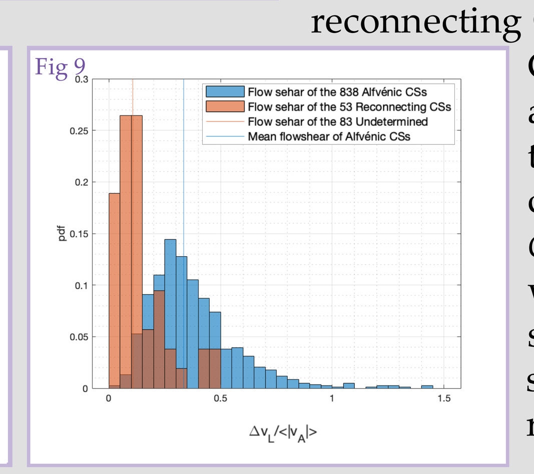


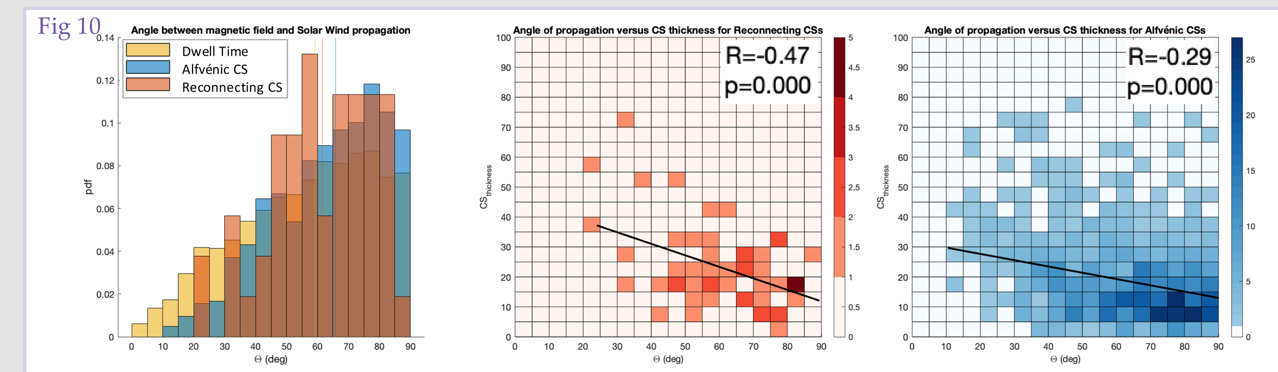
Fig 9



## 6B Results: Current sheet size and SW propagation

(Fig 10) Current sheets are more abundant the larger Θ (angle between magnetic field and plasma velocity) is. This behavior is more extreme for reconnecting Current Sheets. Furthermore, for larger values of Θ the detected Current Sheets are thinner, with the correlation index between Θ and CS thickness being -0.47 and -0.29 for reconnecting and alfvénic CSs, respectively. This seems to suggest that perpendicular propagation of the Solar Wind is more conducive to the formation of thin Current Sheets.

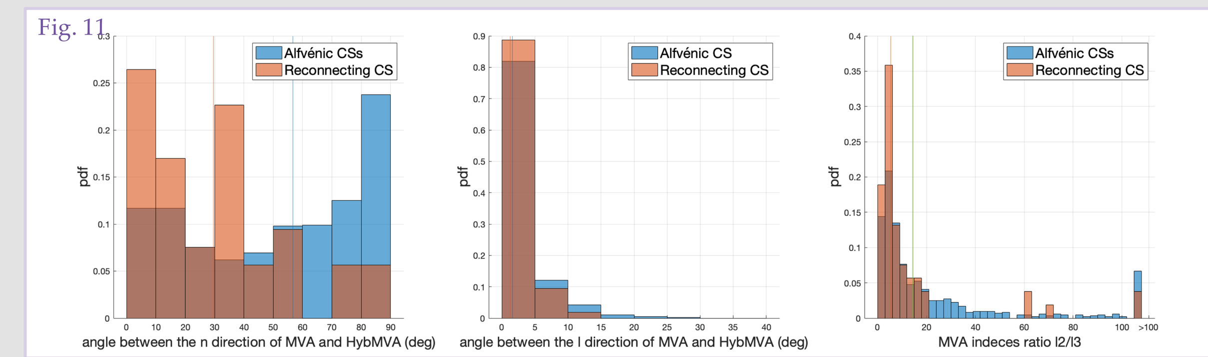
Fig 10




## 6C Results: Current sheet planarity

(Fig 11) The Angle between the N direction provided by classic and hybrid MVA is smaller for reconnecting than for alfvénic Current Sheets. The eigenvalue ratio $\lambda_2/\lambda_3$ is slightly smaller for reconnecting than alfvénic CSs. This puts into question whether Current Sheets are actually flat 2D structures or not. The interpretation of these results is complex, but signals towards the possibility of magnetic reconnection happening in non-flat 3D structures.

Fig 11




## 7 Conclusion

- Solar Orbiter allows us to measure solar wind properties at scales near the proton inertial length.
- We found 9.5 Current Sheets and 0.5 Reconnecting Current Sheets thinner than 100$d_i$ per hour of observation
- On average, the reconnection jet velocity is 0.7±0.1 times the theoretical prediction.
- Flow shear in reconnecting Current Sheets is smaller than 0.5 $v_A$, which is in agreement with high flow shears suppressing reconnection
- Both reconnecting and alfvénic Current Sheets are more abundant and thinner with increasing angle between the solar wind magnetic field and velocity
- The selected events are not flat, showing that magnetic reconnection can happen in more complex 3D structures.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