Magnetic reconnection and the scale-variability of alfvénicity in the solar wind

Rasser, Corentin[1]; Génot, Vincent[1]; Lavraud, Benoit[2]; Fargette, Naïs[1]; Réville, Victor[1]; Louarn, Philippe[1]; Vergé, Tristan[1]; Rungployphan, Kieokaew[1]; Fedorov, Andrey[1]; Rouillard, Alexis[1,3]; Penou, Emmanuel[1]; Barthe, Alain[4]; Owen, Christopher[5]

1. IRAP, Toulouse, France 2. LAB, Bordeaux, France 3. AIP, Potsdam, Germany
4. AKKODIS, Toulouse, France 5. MSSL, Holmbury St. Mary, U.K.

Introduction

Compressive structures in the solar wind are related to deviations from alfvénicity. However, the link between the solar wind alfvénicity and magnetic reconnection has not been explored extensively until now. Using the new detection algorithm of reconnection events devised by Fargette *et al.* (2023), we examine here this correlation for the events observed by Solar Orbiter between the 14^{th} of July and the 13^{th} of August 2020.

I - The magnetic reconnection detection algorithm

- Detection method developed by Fargette *et al.* (2023), based on in situ magnetic field and velocity correlations, following a Walén test (Figure 1).
- Bayesian model of magnetic reconnection events, with reconnection occurrence probability based on Solar Orbiter observations of Lavraud *et al.* (2021).
- Data exctracted from AMDA and processed by Speasy.

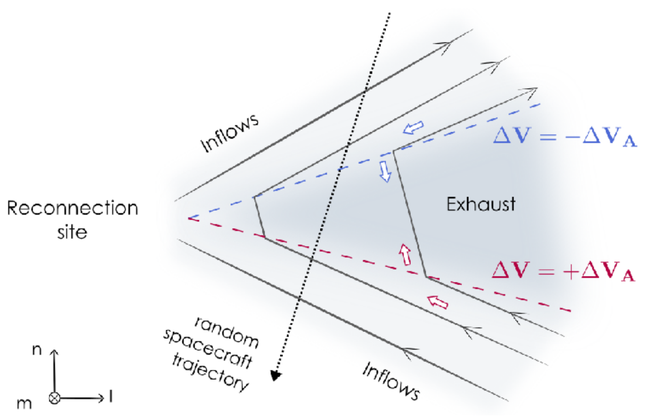

Figure 1: Scheme of fluctuations correlation in reconnection events, credits to Fargette *et al.* (2023).

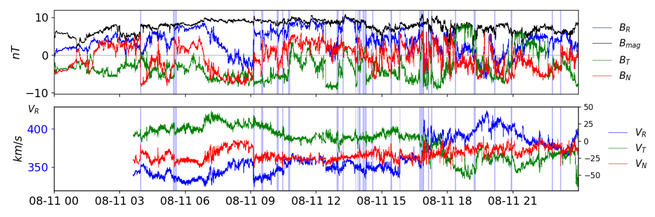

Figure 2: Example algorithm output for the 8^{th} of August 2020 (detections are blue lines).

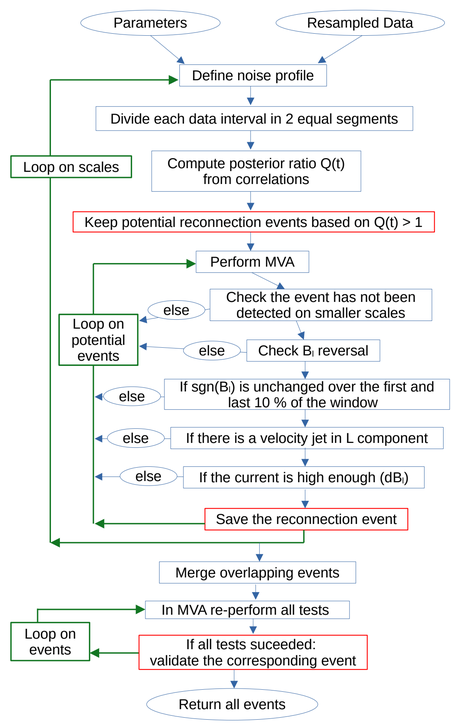

Figure 3: Flow chart of the detection algorithm

II - The alfvénicity markers

Alfvénicity quantities are evaluated using Elsässer variables $\mathbf{z}^{\pm}$ (1950). We consider the cross-helicity σ_c and residual energy σ_r as:

$$\boldsymbol{\delta z}^{\pm} = \boldsymbol{\delta U} \pm \boldsymbol{\delta b} \qquad \sigma_c = \frac{\langle(\boldsymbol{\delta z}^{+})^2\rangle - \langle(\boldsymbol{\delta z}^{-})^2\rangle}{\langle(\boldsymbol{\delta z}^{+})^2\rangle + \langle(\boldsymbol{\delta z}^{-})^2\rangle} = \frac{2\langle \boldsymbol{\delta U}\cdot\boldsymbol{\delta b}\rangle}{\langle|\boldsymbol{\delta U}|^2\rangle + \langle|\boldsymbol{\delta b}|^2\rangle}$$

$$\sigma_r = \frac{\langle \boldsymbol{\delta z}^{+}\cdot\boldsymbol{\delta z}^{-}\rangle}{\langle(\boldsymbol{\delta z}^{+})^2\rangle + \langle(\boldsymbol{\delta z}^{-})^2\rangle} = \frac{\langle|\boldsymbol{\delta U}|^2\rangle - \langle|\boldsymbol{\delta b}|^2\rangle}{\langle|\boldsymbol{\delta U}|^2\rangle + \langle|\boldsymbol{\delta b}|^2\rangle}$$

We proceed to a double sliding average, using the same window size, to evaluate the means (in δ) and to calculate the alfvénicity-related quantities. A 20-minute sliding average is used for the timeseries shown.
While the correlation time of the solar wind is one hour (Klein, 2023), small averaging window size, remain to be explored.

III - Characterising the fluctuations

To classify fluctuations, we calculate magnetic field compressibility C_b and density fluctuations C_n similarly to Bruno and Bavassano (1991):

$$C_b = \frac{\mathrm{Var}(|\mathbf{B}|)}{\mathrm{Tr}(\mathbf{Var(B)})} \qquad C_n = \frac{\sqrt{\langle \delta n^2\rangle}}{\langle n\rangle}$$

IV - A statistical view

- Reconnection is the source of high magnetic compressibility.

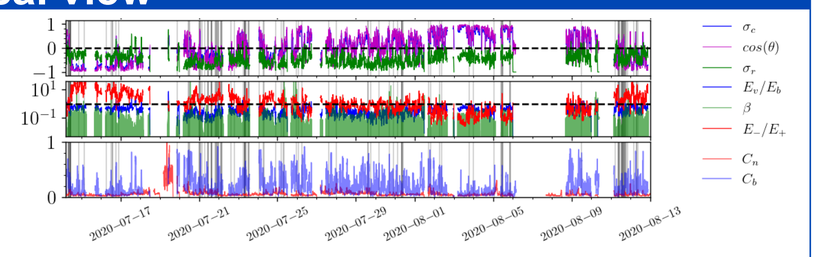

Figure 5: Interval from 14^{th} of July to 13^{th} of August 2020 with all reconnection events detected (grey shaded).

V - Reconnection and compressive structures

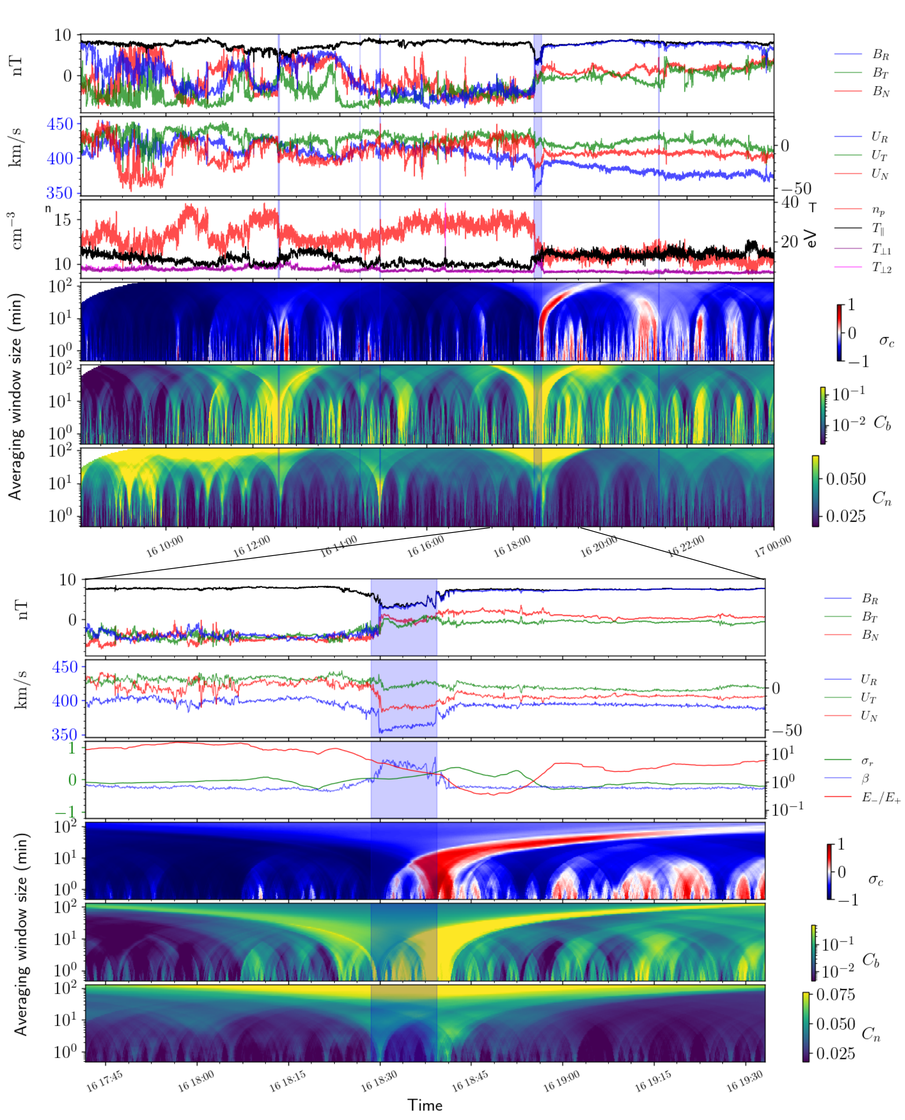

Figure 4: Solar wind properties on the 16^{th} of July and reconnection event occurring at 18:40 (below).

- Alfvénicity deviations and reconnection exhaust boundaries coincide with magnetic compressible structures.
- Compressible phenomena are ubiquitous, and of varying sizes.
- Density fluctuations enhanced at current sheets.
- Reconnection exhaust boundaries oppositely correlated: consistent with Walén relation.
- In the exhaust:
  ⇒ Thermal energy dominates magnetic energy
  ⇒ Kinetic energy dominates magnetic energy at the fluctuation scale
- Alfvénicity quantities calculated with 20-minute sliding averages.

VI - Investigation of low alfvénicity structures

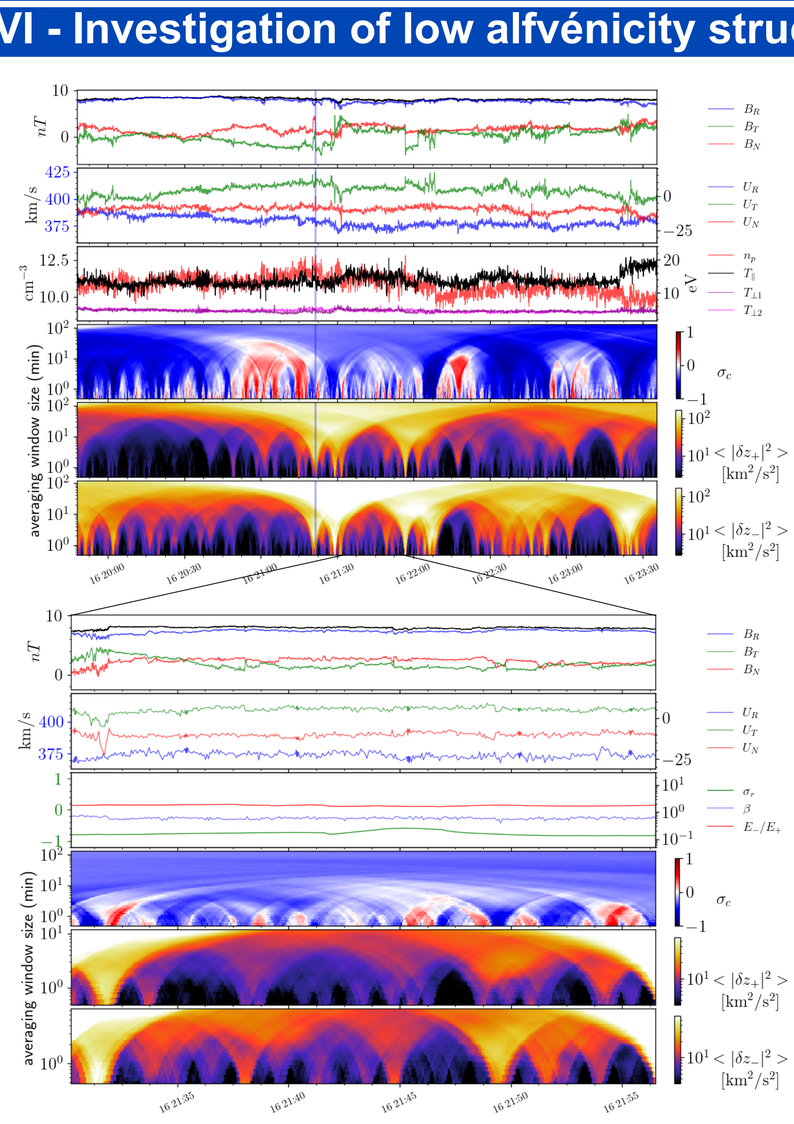

Figure 6: Low alfvénicity events occuring on the evening of the 16^{th} of July 2020 and zoom between 21:30 and 22:00 (below).

- Alfvénicity reverseals happen on different timescales and most of them are small scale.
- Alternating solar wind correlations and steady magnetic field suggests the presence of flux tubes (20:00 to 23:00).
- Low alfvénicity events present an Elsässer mode superposition.
- At the same time a high compressibility indicates non-alfvénic processes are also occuring.

Conclusion

- In agreement with Walén relation, **reconnection** events present the two Elsässer modes but also generate **compressive fluctuations**.
- The **low alfvénicity structures** can be explained by the **superposition** of both **Elsässer modes**, although non-alfvénic phenomena can also occur.

Open questions:

- What are the **different mechanisms behind** the **compressive structures** and how do they influence the **local energy content** of the solar wind ?

References

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- Bruno and Bavassano, 1991, JGR, Vol. 96, A5
- Lavraud *et al.*, 2021, A&A, Vol. 656, A37
- Elsässer, 1950, Phys. Rev., Vol.79, 1
- Klein, 2023, Space Science Reviews, Vol. 219, 8
- AMDA database: https://amda.irap.omp.eu/
- Speasy: https://github.com/SciQLop/speasy

corentin.rasser@utoulouse.fr

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