ON THE VALIDATION OF THE ROTATION PROCEDURE FROM HEE TO MFA REFERENCE FRAME IN





PRESENCE OF ALFVÉN WAVES IN THE INTERPLANETARY MEDIUM

AFFILIATION (1) University of L'Aquila, Dept. of Physical and Chemical Sciences, L'Aquila, Italy (2) Istituto Nazionale di Geofisica e Vulcanologia, L'Aquila, Italy

G. Carnevale (1, 2) - M. Regi (2) - P. Francia (1) - S. Lepidi (2)





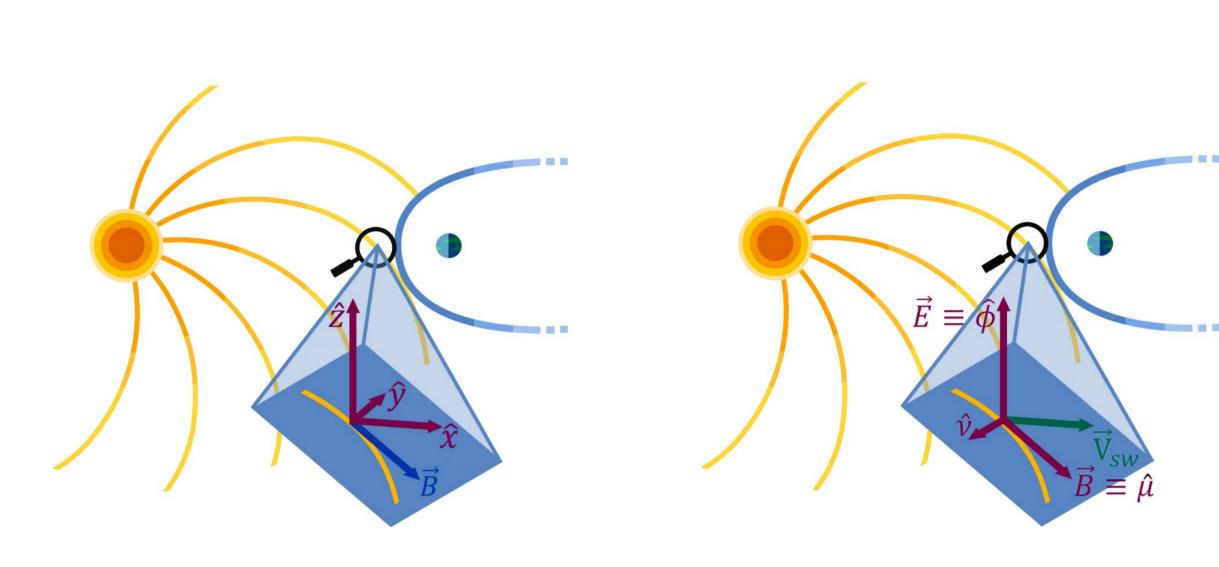




The **HEE reference** frame has x axis towards the Earth and its **z** axis perpendicular to the Ecliptic plane (positive North). Y axis completes the

orthogonal right

handed frame.



The **MEMFA reference frame** has μ axis aligned to the main ambient magnetic field, the ϕ axis aligned to main Electric field and the ν axis tha completes the orthogonal right handed frame.

INTRODUCTION

0.45

Alfvén waves play an important role in the stability, heating, and transport of magnetized plasmas. They are found to be ubiquitous in the solar wind (SW), mainly propagating outward from the Sun, especially in high-speed streams emanating from coronal holes. When high-speed streams impinge on the Earth's magnetosphere, the impact of Alfvénic fluctuations can cause magnetic reconnection between the intermittent southward Interplanetary Magnetic Field (IMF) and the Geomagnetic field, leading to energy injection from SW into the Earth's magnetosphere. In this work, we tested a rotation procedure from the Heliocentric Earth Ecliptic (HEE) to the Mean-Field Aligned (MFA) reference frame, identified by means of the Empirical Mode Decomposition (EMD), of both SW velocity and IMF at 1 AU. We define a new revised MFA reference frame: the MEMFA (Mean ElectroMagnetic Field Aligned) reference frame.

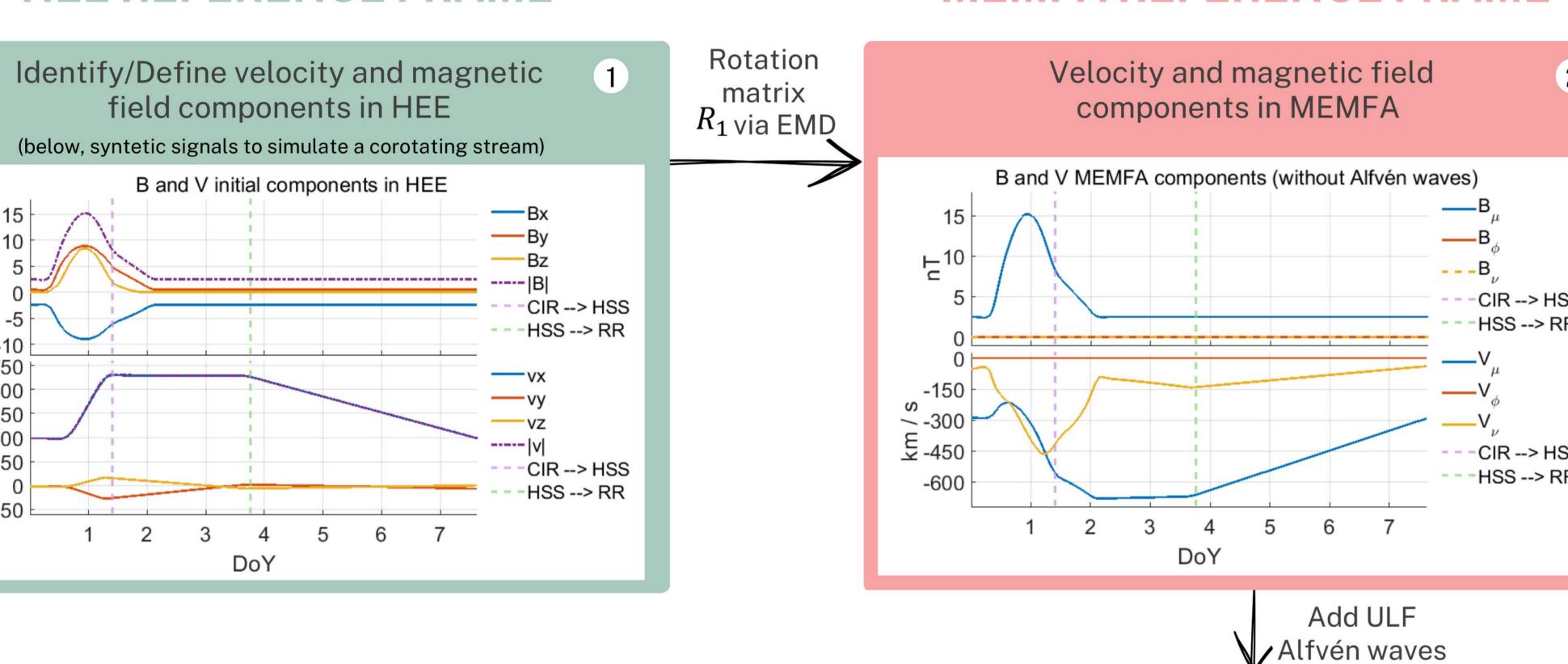
Our aim is to check the reliability of the method and its limitations in identifying Alfvénic fluctuations through the spectral analysis of time series in the MEMFA reference frame. With this procedure, we studied the fluctuations in the main-field-aligned direction and those in the orthogonal plane to the main field. The direction of the MEMFA reference frame aligned to the main Electric field direction proximity of the magnetosphere gives the most geoeffective component involved during space weather events.

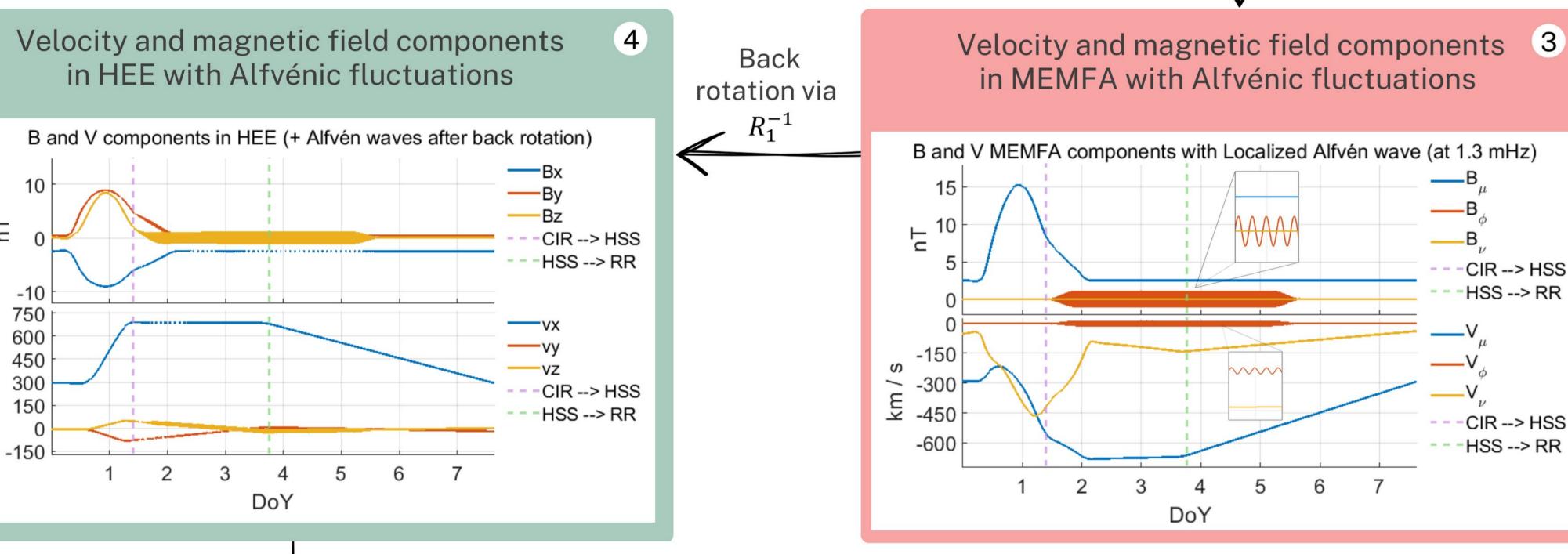
To highlight the peculiarities of each case of study and be able to better identify Alfvén waves when applying this procedure to real data, we reproduced the magnetic and velocity fields of a typical corotating high-speed stream (as shown in sec.1 fig.1). We tested the procedure in several cases, by adding the presence of Alfvén waves and noise. We performed the spectral analysis of the MEMFA component of both magnetic and velocity fields to define the power related to the two main directions: the one aligned to the ambient magnetic field and the one orthogonal to it. The efficiency of the procedure and the result's reliability are supported by Monte Carlo tests. The method is as well applied to a real case represented by a selected corotating solar wind stream. The results are also compared with those obtained by using the Elsässer variables to analyze the Alfvénicity of fluctuations via the cross-helicity, which is related to the degree of correlation between the solar wind velocity and the magnetic field fluctuations. On this regard, our method can be used as additional diagnostic tool, able to increase the reliability of alfvenicity found through classical metodologies.

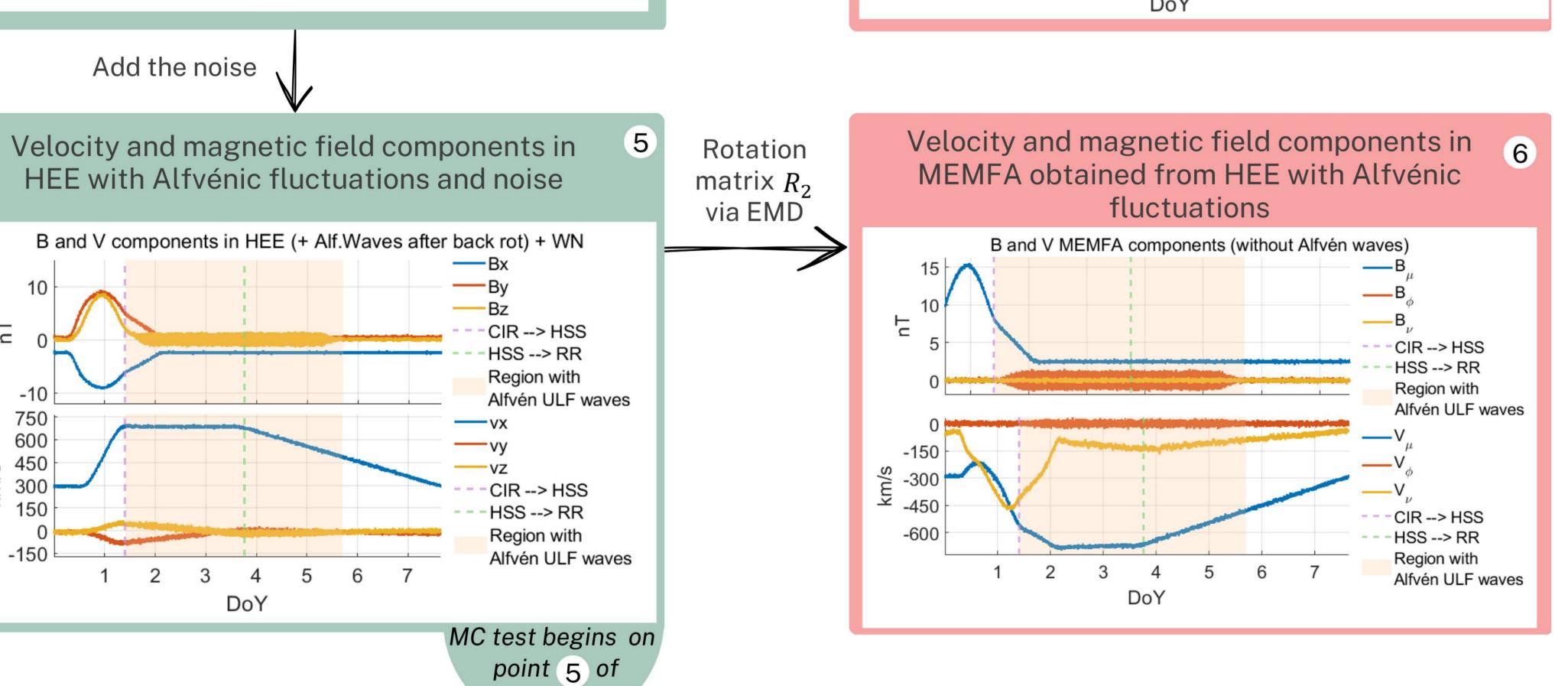
. FLOWCHART - TEST PROCEDURE

HEE REFERENCE FRAME

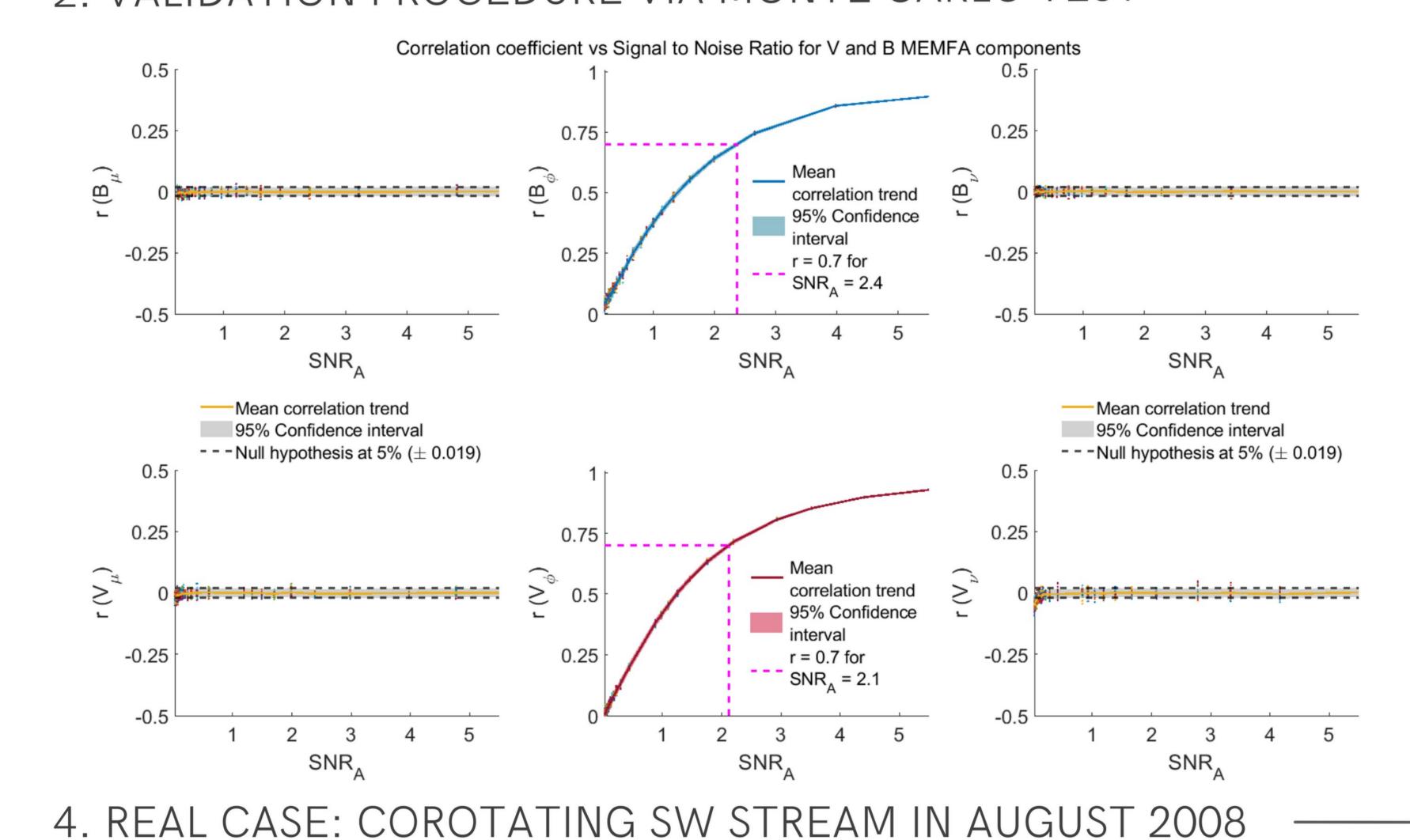
MEMFA REFERENCE FRAME







2. VALIDATION PROCEDURE VIA MONTE CARLO TEST



 $\sigma_{\rm c(sm)}$ - $P_{\perp}/P_{\rm Tot}(\rm sm)$

Moving correlation

between σ_{a} and

between σ_{z} and

Moving corr

Here we show the results (smoothed over 36 hours) obtained

with the procedure applied to a real case study. In the top panel

are plotted the normalised cross helicity (in blue) and the

normalized SW power (in yellow) orthogonal to the main field. In

the middle panel are plotted the normalised residual energy (in

green) changed in sign and the normalized SW power (in red)

aligned to the main field. In the bottom panel we show the

moving correlations (over 48 hours) between the two quantities

plotted in the top panel (in yellow) and between the two

quantities plotted in the middle panel (in red). The correlation

gives us an idea on how well the two procedures are in

From the beginning of DoY 223 to the end of DoY 225 we observe

both correlations have quite high values (except for a quick

suggesting a good accordance between the two methods used.

After DoY 226 the correlations decrease, suggesting that the

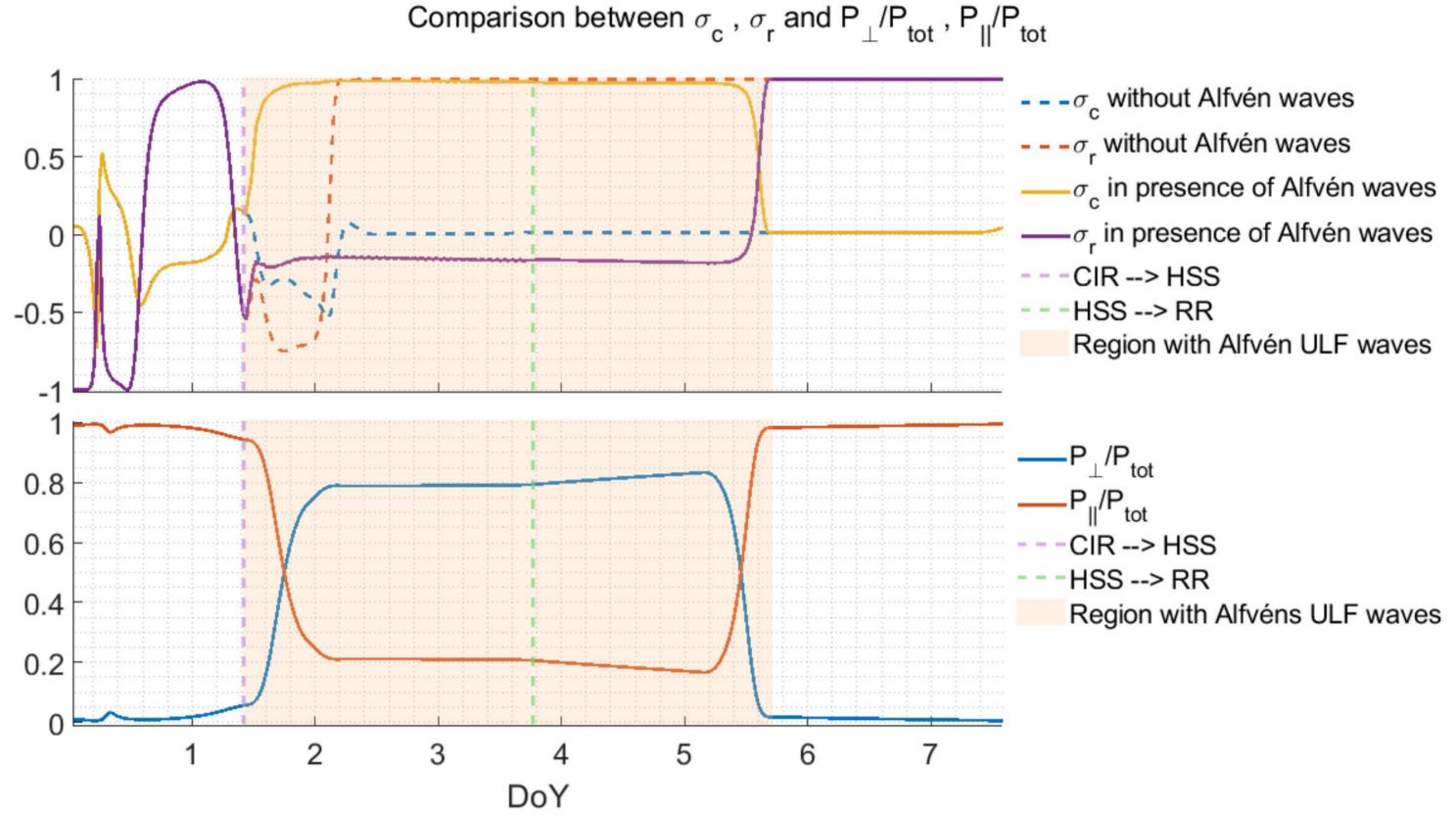
both correlations have similar trends

two methods give different information.

decrease at the beginnign of DoY 224)

5 of chartflow correlation the coefficient (r) between the MEMFA components with Alfvénic localised waves in absence of noise and the MEMFA components in presence of both Alfvénic waves and noise (with variable amplitude to vary the SNR_{\slash} : Signal to Noise Ratio evaluated with the Amplitudes of signals and noise). Here \mathbf{r} vs $\mathrm{SNR}_{\mathcal{A}}$ is shown . The procedure is able to recognize the Alfvénic fluctuations in presence of noise (middle column panels where the correlation coefficient is well above the significance level).

3. ALFVÉNICITY CHECK



cross helicity σ_c and the normalised residual energy σ_r computed in absence of Alfvén waves (dashed lines) and the same quatities computed in presence of Alfvén waves (solid line). Their behaviour in presence of Alfvén waves (shaded region) is the one expected (see

The top panel shows the normalised

The <u>bottom panel</u> shows the normalized power $P_{\parallel}/P_{\rm Tot}$ aligned to the main magnetic field and the one orthogonal to it P_{\perp}/P_{Tot} (where $P = P_{\mathbf{V}} + P_{B|_{\mathbf{V}}}).$

Reminder - for a pure Alfvén wave: $\sigma_r o 0 \quad \sigma_c o \pm 1 \quad \frac{P_\perp}{r} o 1$

CONCLUSIONS

We described a new method that allows us to define an inertial rotated reference frame aligned to both the main magnetic and electric field, where we can easily identify Alfvén waves, also in presence of noise. This method is easily adaptable to a general context. Here we reproduce an analitic corotating SW high speed stream profile to test the procedure and its reliability with a Monte Carlo test. The method is able to efficiently identify pure Alfvén waves embedded in **V** and **B**, for $SNR_A > 0.019$ (null hypothesis threshold at 5%).

Based on MC test results, we notice a high correlation (r > 0.7) for $SNR_A > 2.4$ for the magnetic component and for $SNR_A > 2.1$ for the velocity component; it means that the signal (total signal - noise), in terms of amplitude, is greater than 2/3 (~ 66%) of the total signal (signal + noise).

We show the well-founded correspondence between σ_c and $P_{\perp}/P_{\rm Tot}$ and between σ_r and $P_{\parallel}/P_{\rm Tot}$, both in the simulated case ($r(\sigma_c, P_\perp) = 0.95$ and $r(\sigma_c, P_\parallel) = 0.88$ related to HSS+RR) and in a real case study, carefully estimated by moving

In the real case study, a global correlation between the quantities derived from the classical and the new method reach values of ~0.9 related to the long term variation. The classical diagnostic method, based on the normalised crosshelicity and normalised residual energy can be well supported by the new proposed procedure, making more clear the identification of Alfvén waves in the experimental dataset.

The MEMFA reference frame can allow us to collect information not only in the main field direction but also in the main Electric field direction, that in proximity of the magnetosphere is the most geoeffective component. This means that this procedure could be used in space weather applications.

ACRONYM LIST CIR: Corotating Interaction Region • HSS: High-Speed Stream

SW: Solar Wind

 HEE: Heliocentric Earth Ecliptic MFA: Mean-Field Aligned MEMFA: Mean ElectroMagneti RR: Rarefaction Region Field Aligned

 WN: White Noise SNR: Signal to Noise Ratio IMF: Interplanetay Magnetic Field EMD : Empirical Mode Decomposition
DoY: Day of Year

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When there is accordance betweeen the two methods and σ_c and $P_{\perp}/P_{\rm Tot}$ reach high values, we are confident that there are Alfvén waves. When there is still accordance betweeen the two methods and σ_c and $P_\perp/P_{\rm Tot}$ values are low, we are confident that there are not Alfvén waves. When the two methods are not in agreement, there could be the presence of isotropic waves also in the orthogonal direction. A further test will be done for this case.

agreement.