EGU General Assembly 2020

D2739 | EGU2020-12171

Nature of Elsässer Variables in the Slow Solar Wind Turbulence

—— Fluctuation Amplitudes of Magnetic Field Directional Turnings and Magnetic-Velocity Alignment Structures

Xin Wang[1,2,3], Chuanyi Tu[2], Jiansen He[2]

[1] School of Space and Environment, Beihang University, Beijing, China
wangxinpku0209@gmail.com

[2] School of Earth and Space Sciences, Peking University, Beijing, China

[3] Key Laboratory of Space Environment monitoring and Information Processing of MIIT

OUTLINE

CONTENTS

1 Background

- Debate on the nature of $\mathbf{z}^{\pm}$

2 Observations

- Highly Alfvénic Fast Wind
  - Time series, CF, power spectra
- Slow Wind
  - $z^{\pm}$ in C_{vb}-σ_r plane

3 Conclusion

- Fast Wind : $z^{-} \rightarrow$ Noise
- Slow Wind: $z^{\pm} \rightarrow$ Combination of MFDT and MVAS

1. Background

Alfvén waves propagating paralle/anti-parallel to $\mathbf{B_0}$:

$$v_1 = \frac{b_1}{\sqrt{4\pi\rho}}$$

$$v_2 = -\frac{b_2}{\sqrt{4\pi\rho}}$$

Velocity and field fluctuations:

$$v = v_1 + v_2$$

$$b = b_1 + b_2$$

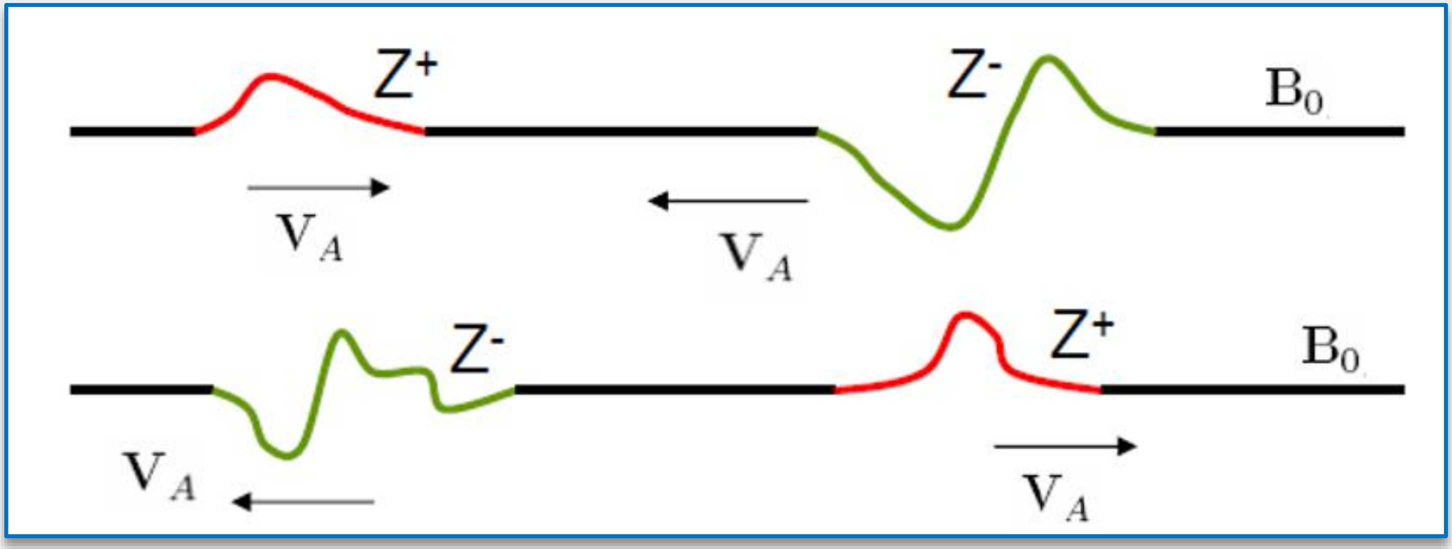
Elsässer variables $\mathbf{z}^{\pm}$:

$$z^+ = v + \frac{b}{\sqrt{4\pi\rho}} = v_1 + v_2 + \frac{b_1}{\sqrt{4\pi\rho}} + \frac{b_2}{\sqrt{4\pi\rho}} = v_1 + \frac{b_1}{\sqrt{4\pi\rho}}$$

$$z^- = v - \frac{b}{\sqrt{4\pi\rho}} = v_1 + v_2 - \frac{b_1}{\sqrt{4\pi\rho}} - \frac{b_2}{\sqrt{4\pi\rho}} = v_2 - \frac{b_2}{\sqrt{4\pi\rho}}$$

1. Background

Theoretically: counter-propagating Alfvén waves



(Tu and Marsch, 1995; Goldstein et al., 1995; Bruno and Carbone, 2013)

- Elsässer variables ($\mathbf{z}^{\pm}$) are widely used to describe the solar wind turbulence.
- They are believed to represent outward and inward propagating Alfvén waves, and the nonlinear interactions between them then produce the energy cascade.

1. Background

Observationally: several components of the fluctuations in the solar wind

$$d\mathbf{V} = d\mathbf{V}_w$$
$$d\mathbf{B} = d\mathbf{B}_w$$
$$\downarrow$$
$$\mathbf{z}^+ = d\mathbf{V}_w + d\mathbf{B}_w$$
$$\mathbf{z}^- = 0$$

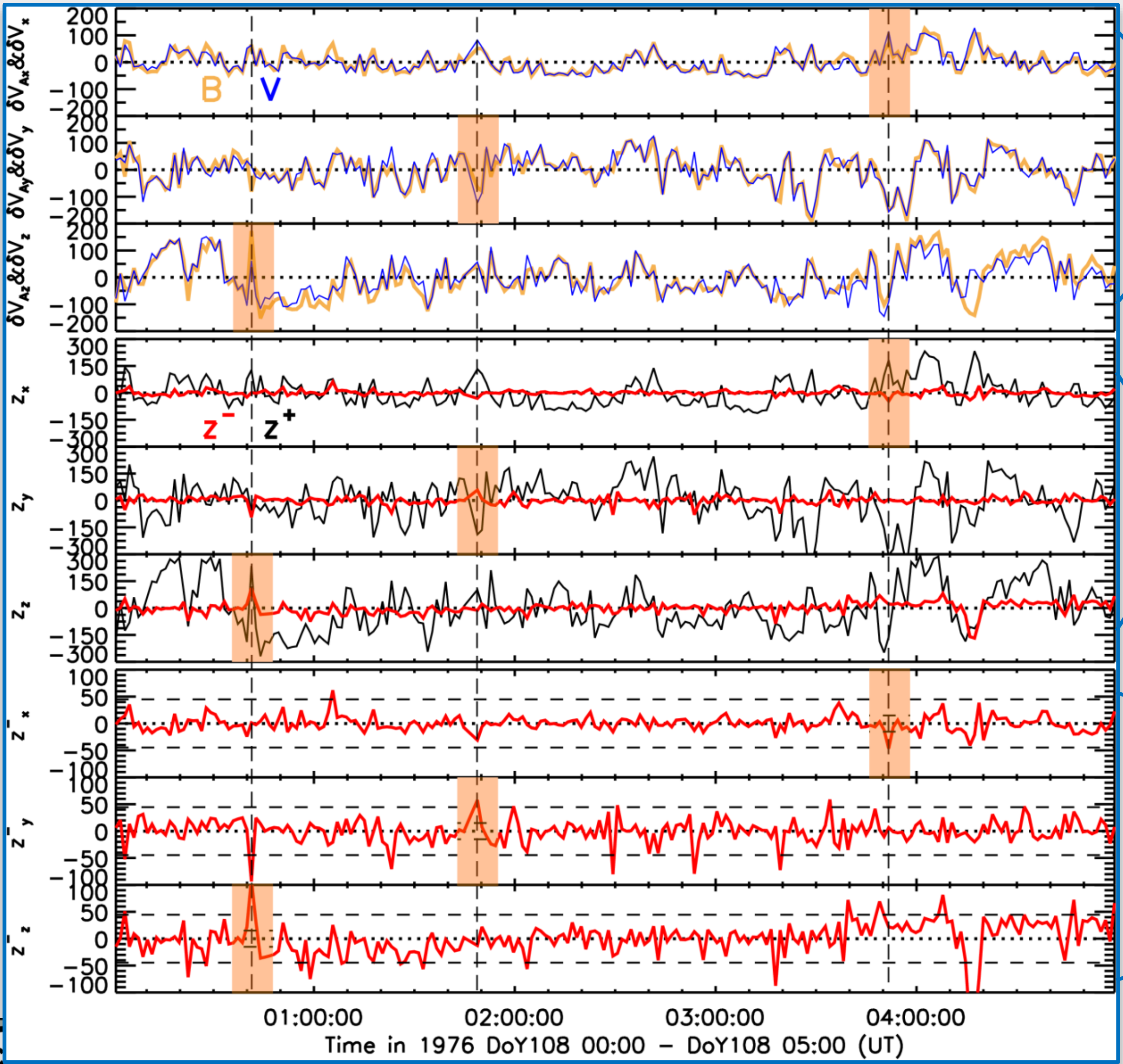
$$d\mathbf{V} = d\mathbf{V}_w$$
$$d\mathbf{B} = d\mathbf{B}_w + d\mathbf{B}_s$$
$$\downarrow$$
$$\mathbf{z}^+ = d\mathbf{V}_w + d\mathbf{B}_w + d\mathbf{B}_s$$
$$\mathbf{z}^- = -d\mathbf{B}_s$$

(Tu and Marsch, 1991)

- From in situ observations, the fluctuations could be considered as a superposition of several components. Different combinations of these components may result in different natures of $\mathbf{z}^-$.

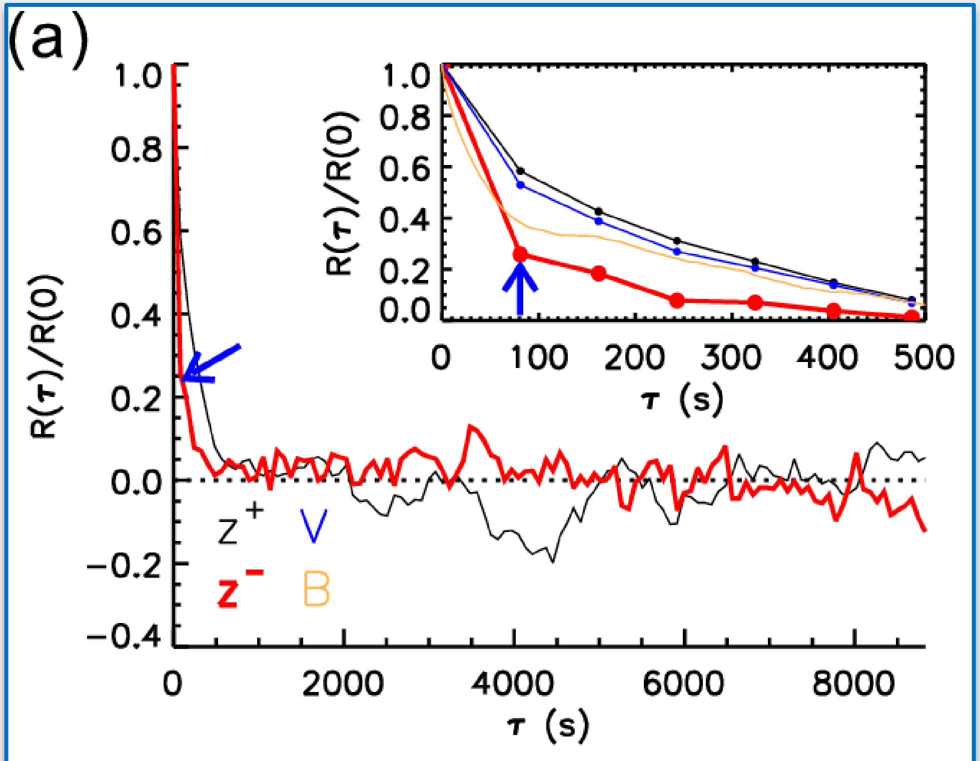
2. Observational study

Helios 2 at 0.3 AU



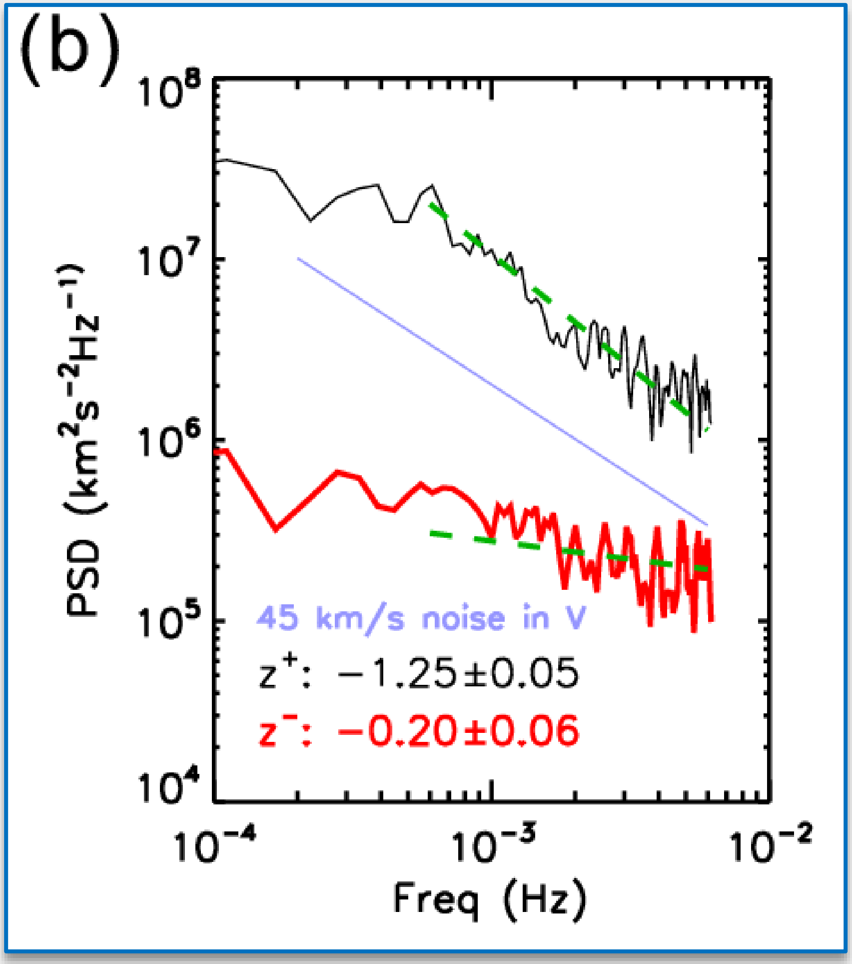
- High Alfvénicity $\sigma_c = 0.91$, $\gamma_A = 0.90$
- Amplitude of $z^+ >> z^-$
- Mostly amplitude of z^- < noise level
- Some spikes at shaded area (pseudo structures)

2. Observational study



- At $\tau \approx 1000$ s, both ACFs approach 0
- ACF of $\mathbf{z}^-$ **decreases significantly faster** than $\mathbf{z}^+$
- **Large drop** at $\tau = \Delta = 81$ s for $\mathbf{z}^-$
- The value of $\mathbf{z}^-$ at a time instant is **weakly related** to its adjacent data points, similar to white noise signal

2. Observational study



- PSD of $\mathbf{z}^{-}$ is lower than that of $\mathbf{z}^{+}$ by more than 1 order.
- $\mathbf{z}^{-}$ spectrum is as **shallow** as $f^{-0.20}$, like white noise.
- Power level of $\mathbf{z}^{-}$ is **lower than noise.**

2. Observational study

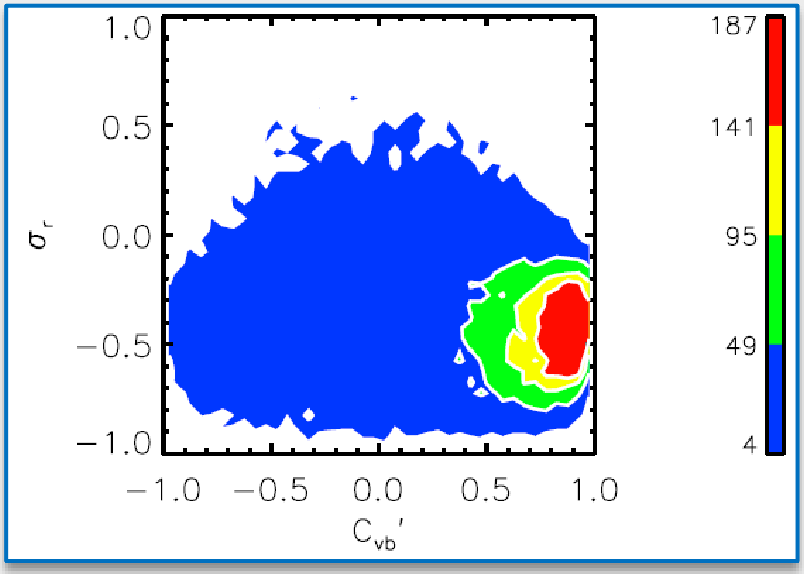
Correlation coefficient:
$$C'_{vb} = \frac{\langle \mathbf{v} \cdot \mathbf{v_A} \rangle}{\sqrt{\langle \mathbf{v}^2 \rangle \langle \mathbf{v_A}^2 \rangle}} \cdot \frac{B_{0x}}{|B_{0x}|}$$

Normalized cross helicity:
$$\sigma_r = \frac{\langle \mathbf{v}^2 \rangle - \langle \mathbf{v_A}^2 \rangle}{\langle \mathbf{v}^2 \rangle + \langle \mathbf{v_A}^2 \rangle}$$

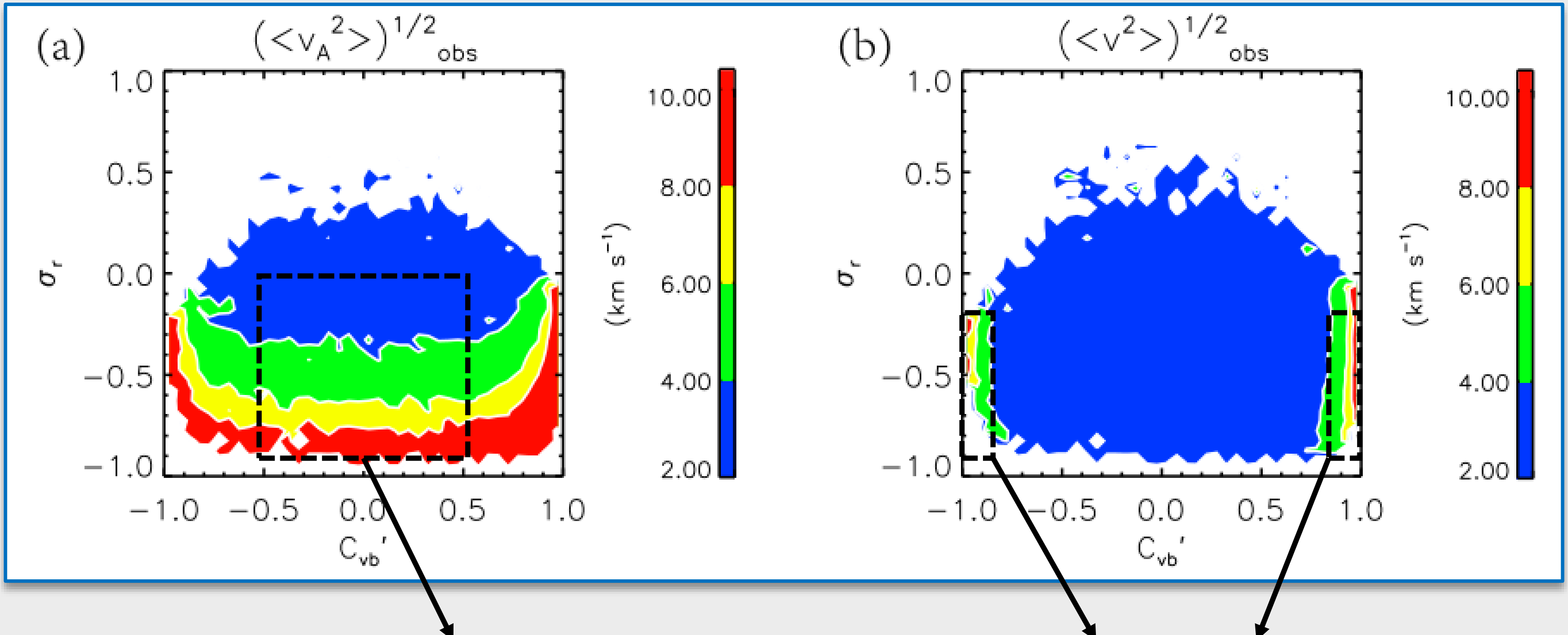
Here, $\mathbf{v}$ and $\mathbf{v_A}$ are velocity and magnetic field fluctuations in Alfvén unit, respectively.

- WIND MFI&3DP data
- 3-s resolution
- During 2005-2009
- Each interval lasts 6min

Number distribution in C'_{vb}- σ_r plane in slow wind



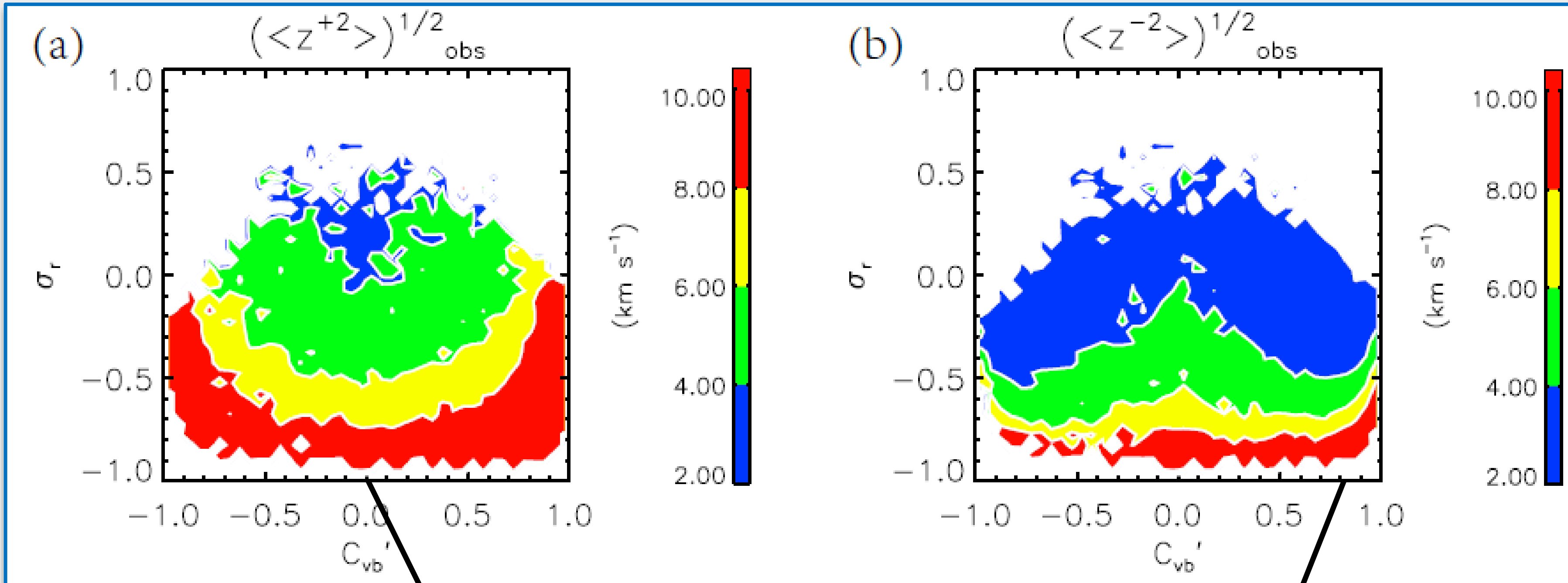
Fluctuation amplitudes of $\mathbf{v}_A$ and $\mathbf{v}$ in C'_{vb}- σ_r plane in slow wind



Magnetic Field Directional Turnings (MFDT)
v_A amplitude: horizontal stripe

Magnetic-Velocity Alignment Structures (MVAS)
v amplitude: vertical stripe

Fluctuation amplitudes of $\mathbf{z}^{\pm}$ in C'_{vb}- σ_r plane in slow wind



z$^+$ amplitude: "U" shape

z$^-$ amplitude: "W" shape

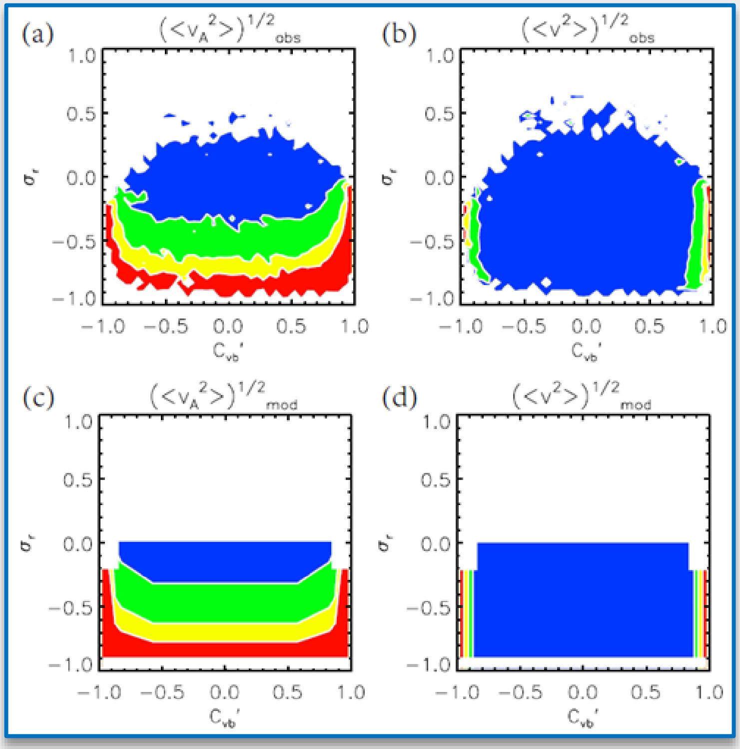
- Combination of MFDT and MVAS → Different features of $z^{\pm}$ amplitudes

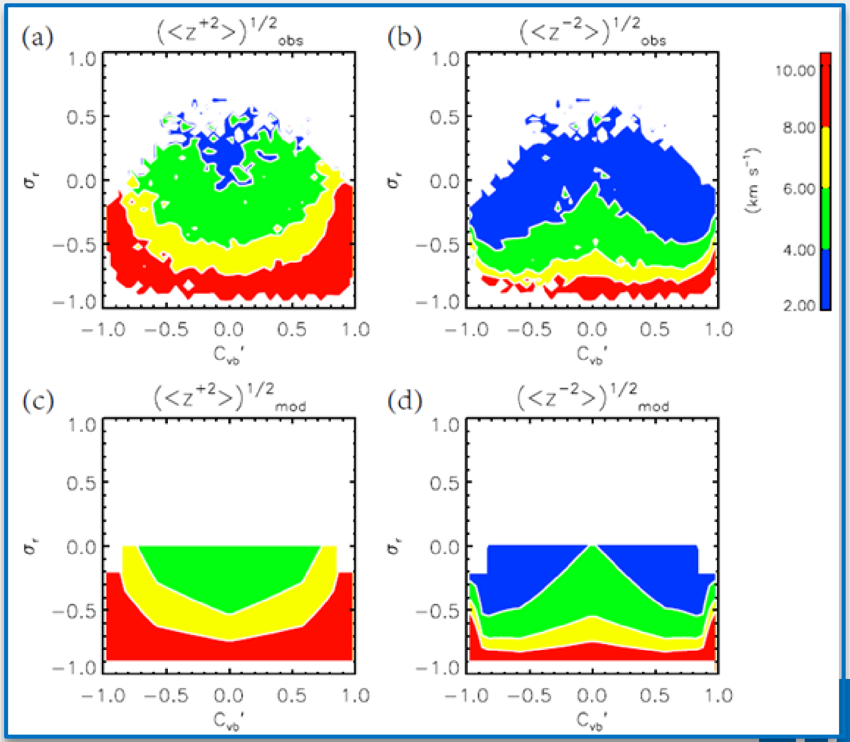
2. Observational study

An experimental model for the relation between fluctuation amplitude of **v** (A_v) and C'_{vb}:

$$A_v = \begin{cases} 58.6|C'_{vb}| - 47.5, & \text{For MVAS } (|C'_{vb}| > 0.85 \text{ and } -0.9 < \sigma_r < -0.2) \\ 2.9, & \text{For MFDT } (|C'_{vb}| < 0.55 \text{ and } -0.9 < \sigma_r < 0) \\ 2.2|C'_{vb}| + 1.6, & \text{For others } (0.55 \le |C'_{vb}| \le 0.85 \text{ and } -0.9 < \sigma_r < 0) \end{cases}$$

- Observation:
- Model:





3. Conclusions

- In the fast wind with highly Alfvénic fluctuations, $\mathbf{z}^-$ is suggested to be composed of high-frequency white noise and low-frequency pseudo structures in the studied cases.
- In the slow wind, the different features of the level contours of the $z^{\pm}$ amplitudes could be interpreted as being attributed to the combination of MFDT and MVAS.

Thanks!

Xin Wang
wangxinpku0209@gmail.com

Wang, X., Tu, C.-Y., He, J.-S., Wang, L.-H., Yao, S., & Zhang, L. (2018). Possible noise nature of Elsässer variable $\mathbf{z}^-$ in highly Alfvénic solar wind fluctuations. *Journal of Geophysical Research: Space Physics, 123*. https://doi.org/10.1002/2017JA024743
Wang, X., Tu, C.-Y., & He, J.-S. (2020). Fluctuation Amplitudes of Magnetic Field Directional Turnings and Magnetic-Velocity Alignment Structures in the Solar Wind. Submitted