Alfvénicity of Velocity and Magnetic Field Increments Observed by Parker Solar Probe

EGU General Assembly, May 26, 2022

Panisara Thepthong[1], Peera Pongkitiwanichakul[1] , David Ruffolo[2], Riddhi Bandyopadhyay[3] and William H. Matthaeus[4]

[1] Department of Physics, Faculty of Science, Kasetsart University, Bangkok 10900, Thailand
[2] Department of Physics, Faculty of Science, Mahidol University, Bangkok 10400, Thailand
[3]Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, USA
[4]Bartol Research Institute and Department of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA

Abstract
QR code

Sharing is encouraged

This presentation participates in OSPP

EGU

Outstanding Student & PhD candidate Presentation contest

Introduction

- Alfvénicity is the correlation of velocity fluctuations and magnetic fluctuations

$$\boldsymbol{v} = \pm\boldsymbol{b}$$

where magnetic fluctuation $\boldsymbol{b}$ is measured in Alfvén speed units

- We want to study the physics of Alfvénicity and how Alfvénicity depends on other variables using data from Parker Solar Probe (PSP) when the solar wind was super-Alfvenic or sub-Alfvenic.

Alfvénicity of increments

Magnetic and velocity fluctuations are defined as follows with τ as a time increment

$$\Delta\boldsymbol{v} = \boldsymbol{v}(t+\ \tau) - \boldsymbol{v}(t)$$

$$\Delta\boldsymbol{b} = \boldsymbol{b}(t+\ \tau) - \boldsymbol{b}(t)$$

Measures to quantify Alfvénicity (Parashar et al. 2020)

- **Normalized cross helicity** (σ_c)

$$\sigma_c = \frac{2\langle\Delta\boldsymbol{v}\ \cdot\ \Delta\boldsymbol{b}\rangle}{\langle|\Delta\boldsymbol{v}|^2\rangle\ +\ \langle|\Delta\boldsymbol{b}|^2\rangle}$$

- **Normalized residual energy** (σ_r)

$$\sigma_r = \frac{\langle|\Delta\boldsymbol{v}|^2\rangle\ -\ \langle|\Delta\boldsymbol{b}|^2\rangle}{\langle|\Delta\boldsymbol{v}|^2\rangle\ +\ \langle|\Delta\boldsymbol{b}|^2\rangle}$$

- **Alfvén ratio** (r_A)

$$r_A = \frac{\langle|\Delta\boldsymbol{v}|^2\rangle}{\langle|\Delta\boldsymbol{b}|^2\rangle}$$

- **Cosine of the alignment angle between v and b** $(\cos\theta_{vb})$

$$\cos\theta_{vb} = \frac{\langle\Delta\boldsymbol{v}\cdot\ \Delta\boldsymbol{b}\rangle}{\sqrt{\langle|\Delta\boldsymbol{v}|^2\rangle\ +\ \langle|\Delta\boldsymbol{b}|^2\rangle}}$$

Frequency in Fourier spectra

To match the frequency that contributes the most to $\Delta\boldsymbol{b}$ or $\Delta\boldsymbol{v}$, we assume that $\boldsymbol{b}$ and $\boldsymbol{v}$ have Kolmogorov spectra and assume the continuous equation for $\boldsymbol{b}$ (or $\boldsymbol{v}$)

$$\boldsymbol{b}(t) = \int \boldsymbol{b}(\omega)e^{i\omega(t)}d\omega$$

Let $\Delta\boldsymbol{b} = \boldsymbol{b}(t+\tau) - \boldsymbol{b}(t)$ and

$$G(\omega_0) = \frac{8\pi}{T}\int_0^{\omega_0} \boldsymbol{b}(\omega)\boldsymbol{b}(-\omega)\left(1-e^{-i\omega\tau}\right)d\omega \qquad \text{for very large } T$$

$$\langle\Delta\boldsymbol{b}^2\rangle = G(\infty)$$

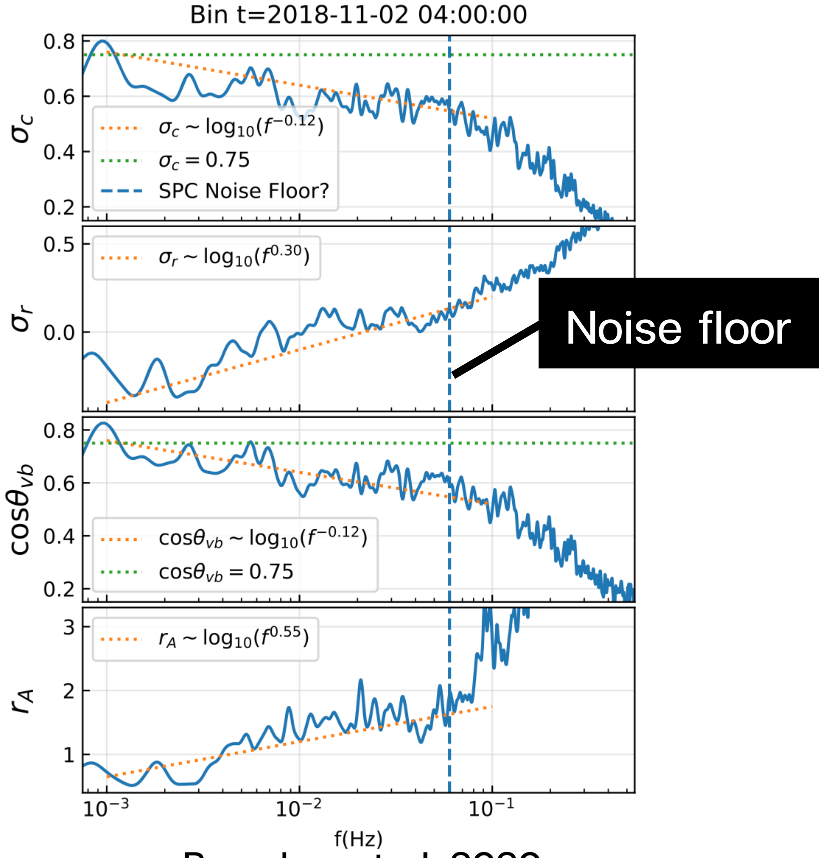
Consider the contribution to $\langle\Delta\boldsymbol{b}^2\rangle$ per logarithm of ω:

$$\frac{dG}{d\ln\omega} = \omega\frac{dG}{d\omega} \propto G(2\omega_0) - G(\omega_0/2) \sim \boldsymbol{b}(\omega)\boldsymbol{b}(-\omega)\left(1-e^{-i\omega\tau}\right)\omega$$

This contribution is maximized for

$$\omega \approx \frac{2.65}{\tau}$$

Noise subtraction

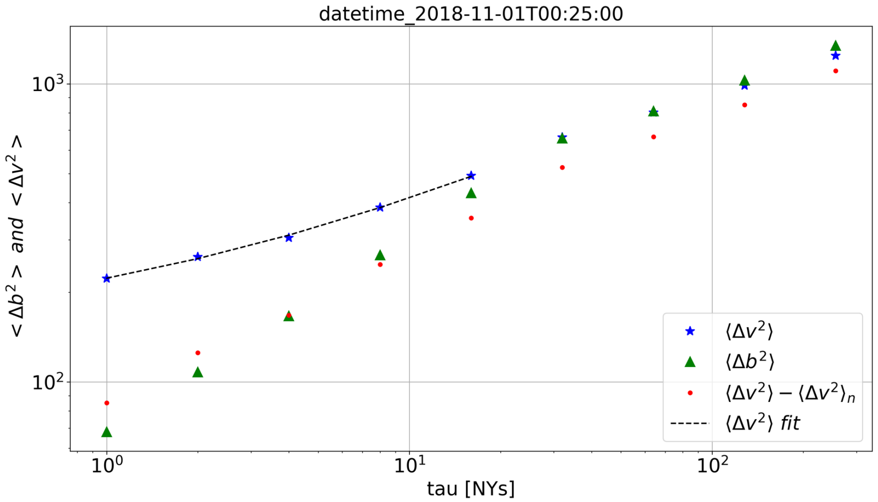


Parashar et al. 2020

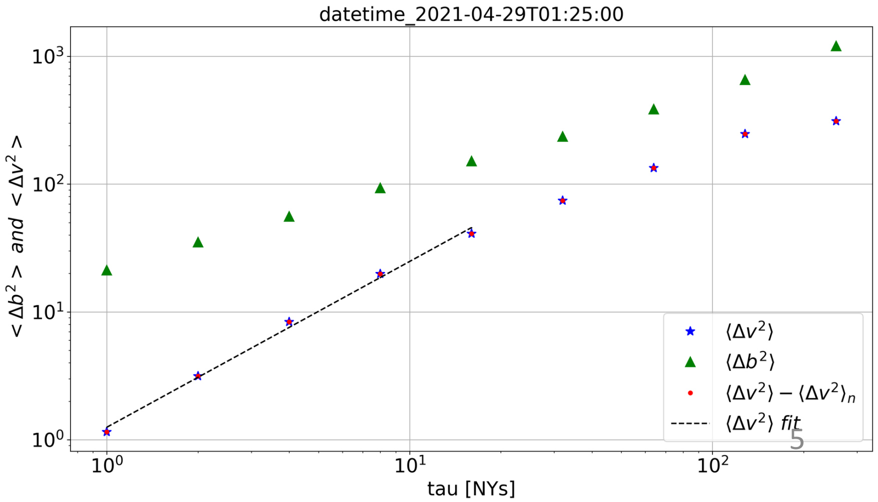
In previous work, we can observe noise at high frequencies. Without the noise, we can estimate Alfvénicity at small scales or high frequencies.

- We can eliminate the noise by assuming that the power spectrum of the $\langle|\Delta \boldsymbol{v}|^2\rangle$ is power-law in the inertial range without noise.

Example 10-min time period with strong noise

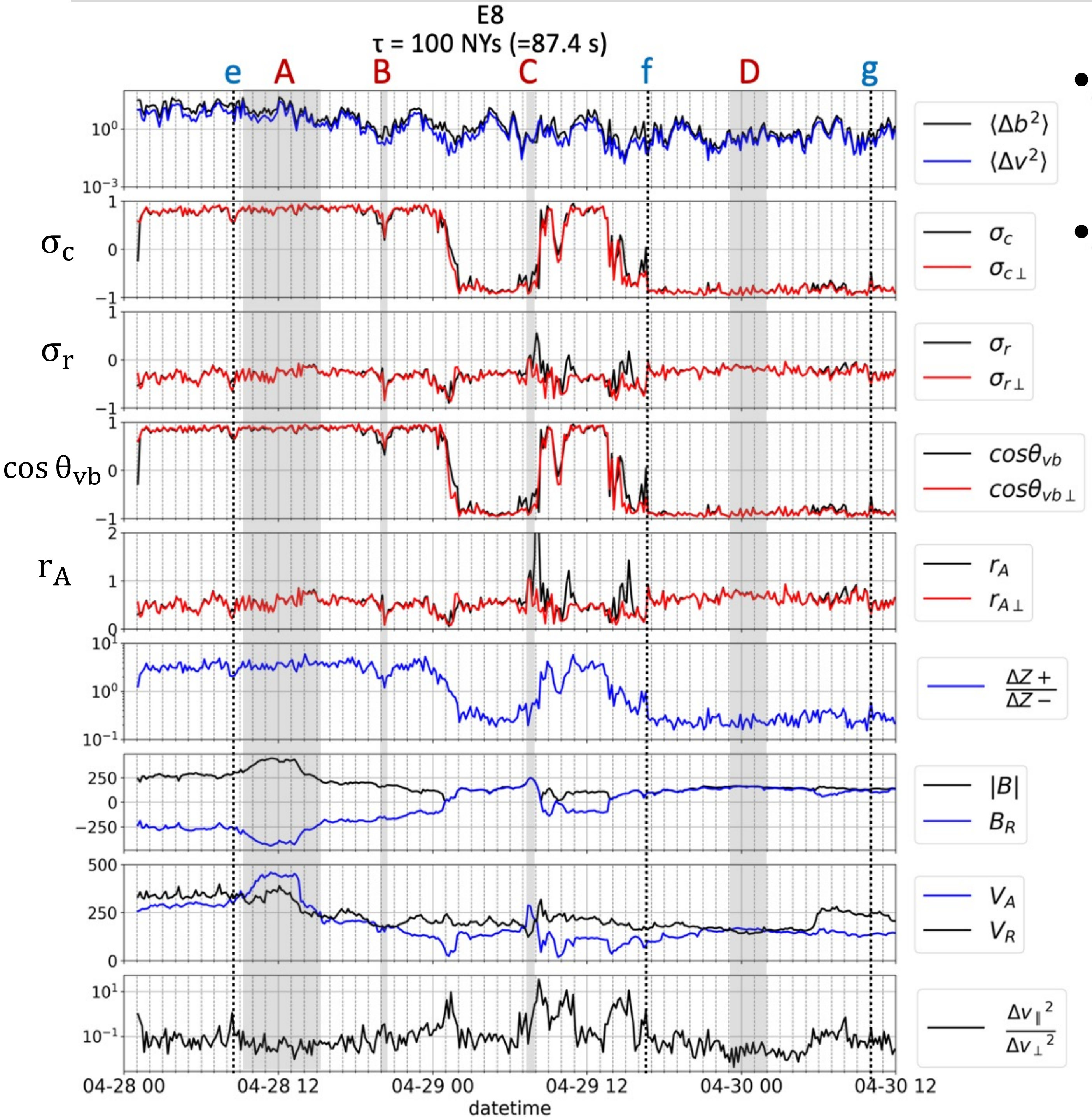


Example 10-min time period with no noticeable noise



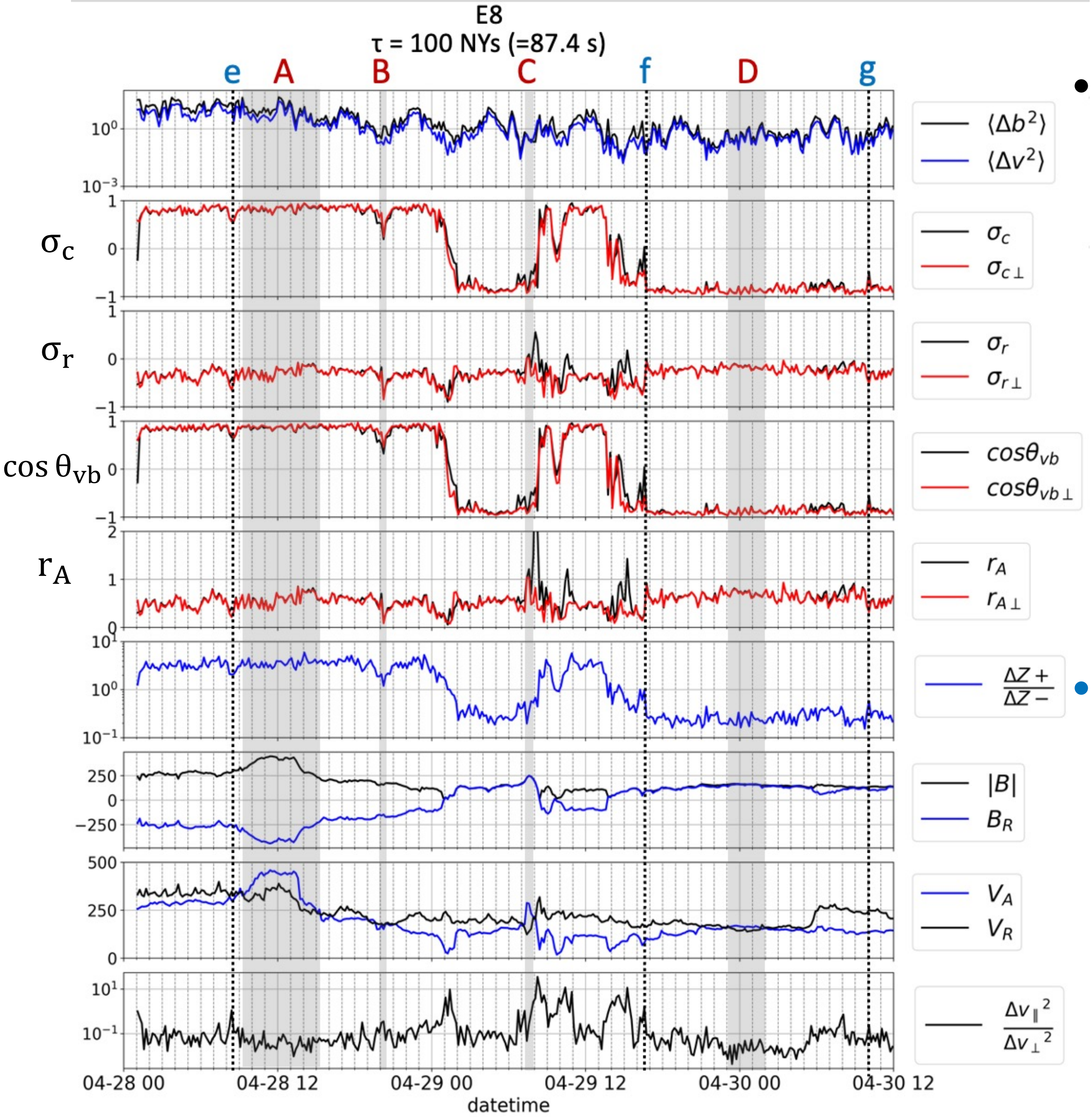
Time dependence of Alfvénicity near 8th perihelion

(10-min averages)



- Regions A, B, C and D are sub-Alfvenic.
- Regions A and D have typical high Alfvénicity for $\tau \sim 14.7 - 87.4$ s, but the region B has low Alfvénicity with low velocity fluctuation as the spacecraft possibly passes a twisted magnetic field inside a flux rope.

Time dependence of Alfvénicity near 8th perihelion
(10-min averages)



- Region C has "ideal Alfvénicity " with $r_A \approx 1$ and $\sigma_r \approx 0$ for balanced magnetic and velocity fluctuations for $\tau \sim 14.7 - 87.4$ s, unlike typical solar wind.
- e, f and g observed sudden drop of Alfvénicity at the high ratio of parallel to perpendicular velocity increments.