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Outstanding Student & PhD candidate Presentation contest

Analysis of Turbulence Energy Transfer at an Interplanetary Shock Observed by MMS

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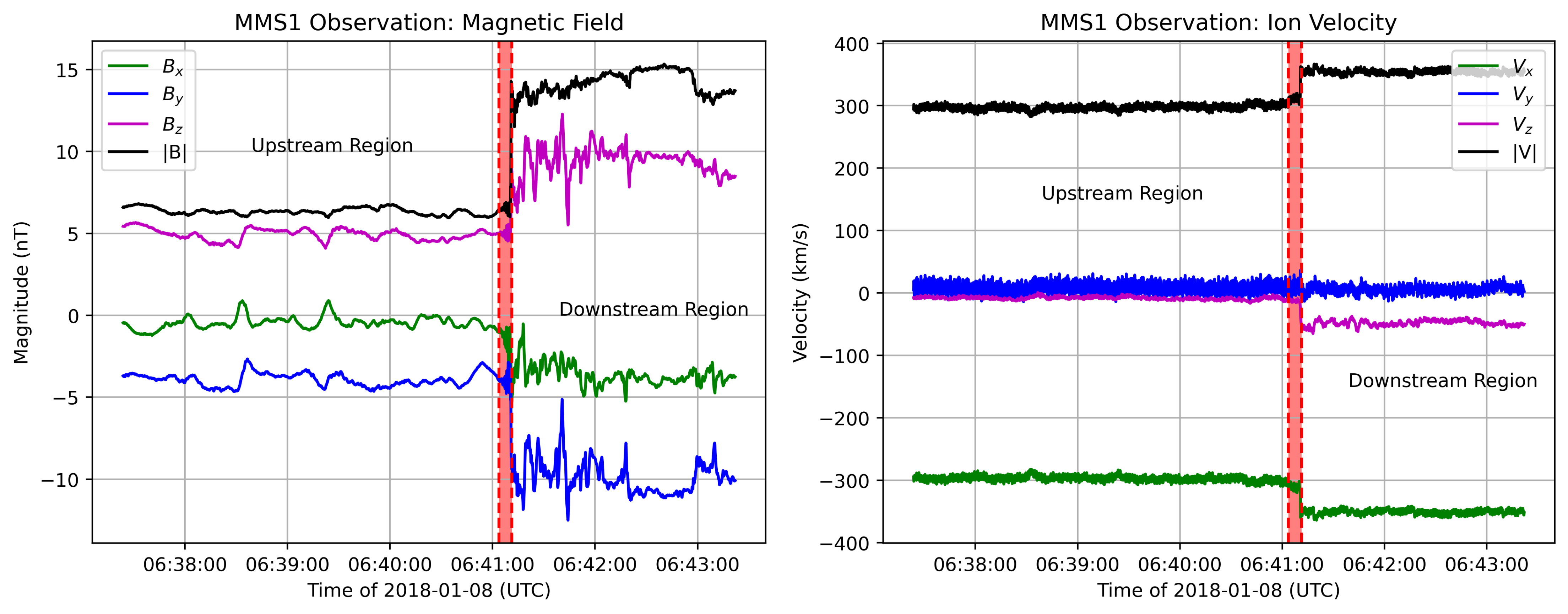
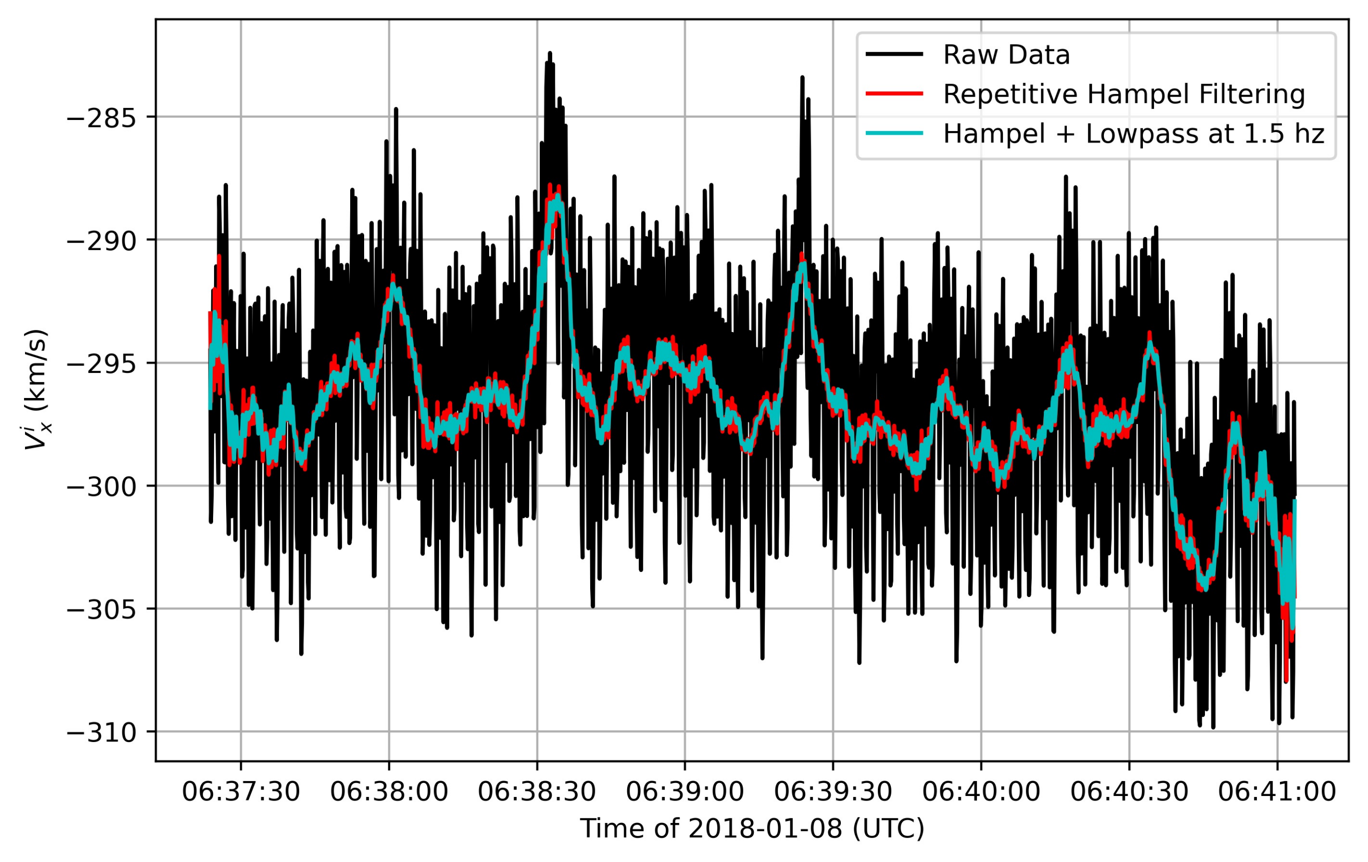
Introduction

On 2018/01/08 MMS observed an interplanetary shock driven by a corotating interaction region (CIR) on 06.41 UTC



Cleaning up FPI measurements of Solar Wind

- Issues of FPI (Fast plasma investigator): It is not designed for solar wind measurement
  - Periodic noise corresponds to spin tone period: $\approx 19.67\ s$ and its harmonics
  - Large amplitude fluctuations
- Apply Hampel Filtering-Based Technique to remove artificial noise
  - Based on Bandyopadhyay et al. 2018



Energy Transfer Rate ($\boldsymbol{\epsilon}$) calculation

- Assuming Taylor's frozen in condition
- Inertial Scale : Kolmogorov-Yaglom Law (Third-Order Law)

$$Y^{\pm}(\tau) = -\frac{4}{3}\epsilon^{\pm}\langle V_{SW}\rangle\tau$$

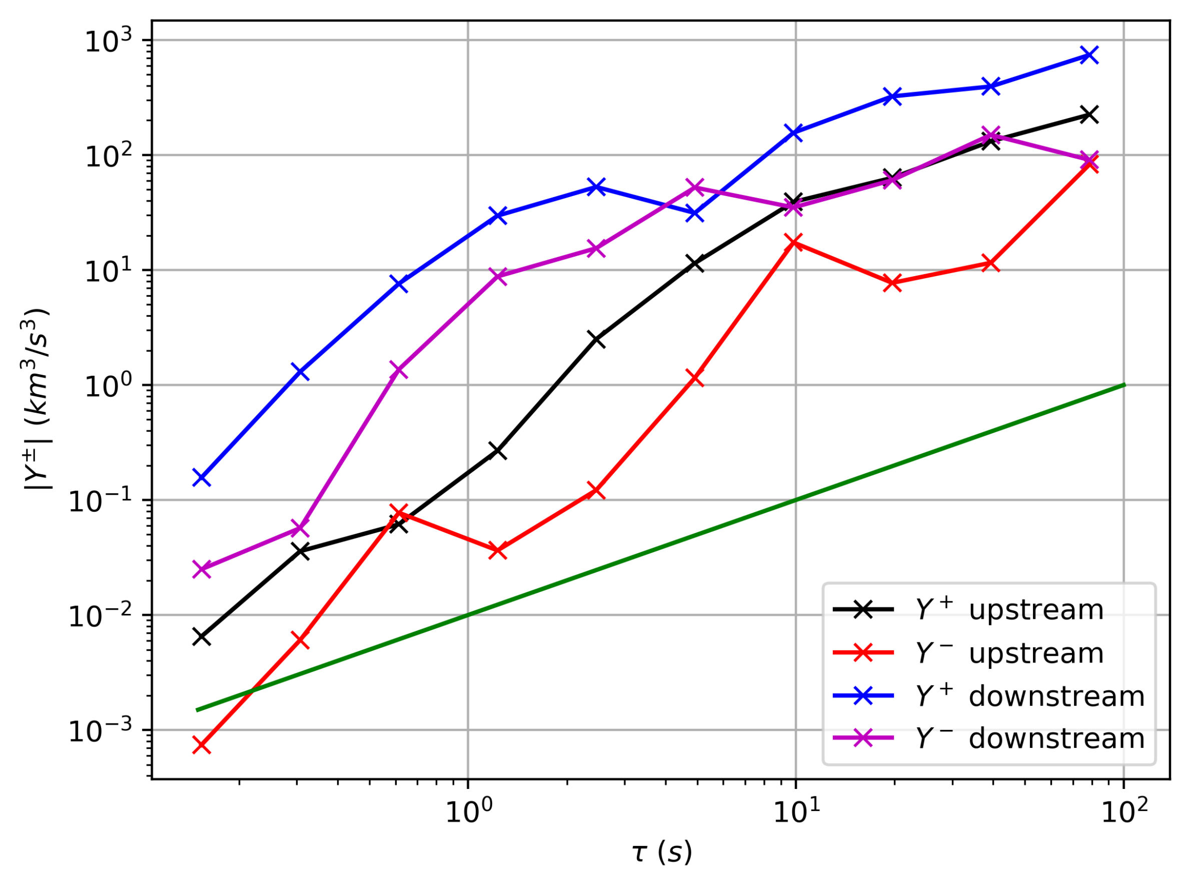
$$Y^{\pm}(\tau) = \left\langle \left|\boldsymbol{\Delta Z}^{\pm}(\tau;t)\right|^{2} \Delta Z_{R}^{\mp}(\tau;t) \right\rangle, \qquad \boldsymbol{Z}^{\pm} = \boldsymbol{v_i} \pm \boldsymbol{b}$$

- Energy containing scale: Von Kármán Analysis

$$\epsilon^{\pm} = -\frac{d(Z^{\pm})^2}{dt} = \alpha_{\pm}\frac{(Z^{\pm})^2 Z^{\mp}}{L_{\pm}}$$

- Mean energy transfer rate: $\epsilon = \frac{\epsilon^{+}+\epsilon^{-}}{2}$

Energy Transfer Rate: Inertial scale



	ϵ (kJ kg^{-1} s^{-1})	
	Upstream	Downstream
MMS1	4.9 ± 0.3	12 ± 1
MMS2	4.7 ± 0.3	14 ± 1
MMS3	5.0 ± 0.3	13.7 ± 0.9
MMS4	4.6 ± 0.3	12 ± 1

Table 1. Turbulence energy transfer rate in inertial scale at upstream and downstream region of a shock. The values estimated from third-order law

Energy Transfer Rate: Energy containing scale

- Using Von Kármán – Howarth decay law
- $\alpha_+ \cong \alpha_- = 0.055$, due to high Reynolds number

	ϵ (kJ kg^{-1} s^{-1})	
	Upstream	Downstream
MMS1	2.8 ± 0.5	20 ± 1
MMS2	3.0 ± 0.6	20 ± 3
MMS3	2.9 ± 0.6	21 ± 3
MMS4	2.8 ± 0.5	19 ± 3

Table 2. Turbulence energy transfer rate at upstream and downstream region of a shock. The values estimated from Von Kármán analysis

Discussion
Conclusion

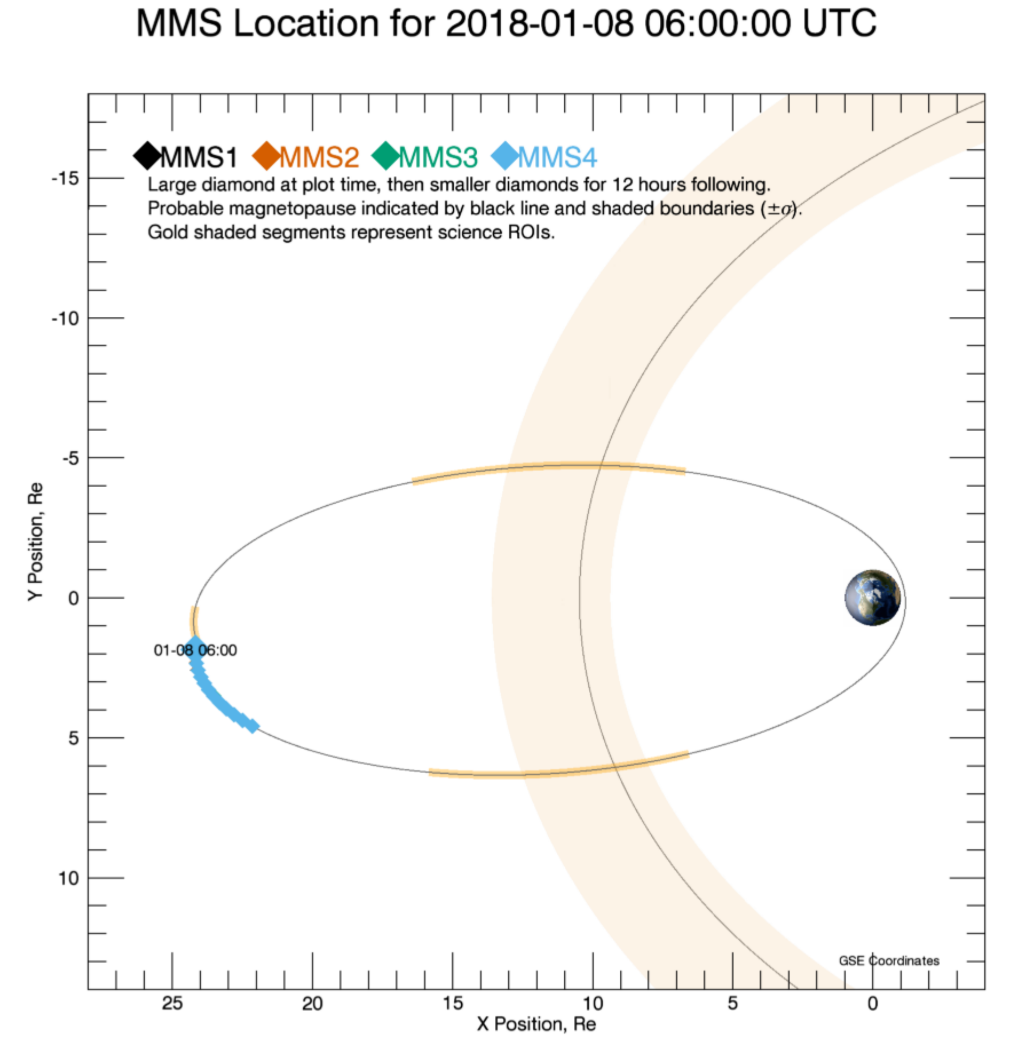
- In this work, we analyzed the energy dissipation rate of turbulence in the regions upstream and downstream of the interplanetary shock (IP) observed by the MMS on 8 January 2018.
- The turbulent energy transfer rate is calculated from both the third-order law (for the inertial range) and von Karman decay law (for the energy-containing range)
- **The analysis shows that the downstream region has a higher transfer rate, and the turbulence has developed to smaller scales compared to the upstream region.**
- Potentially further research should examine different IP shocks with a longer duration of burst mode data from MMS or other missions.

Sharing not permitted

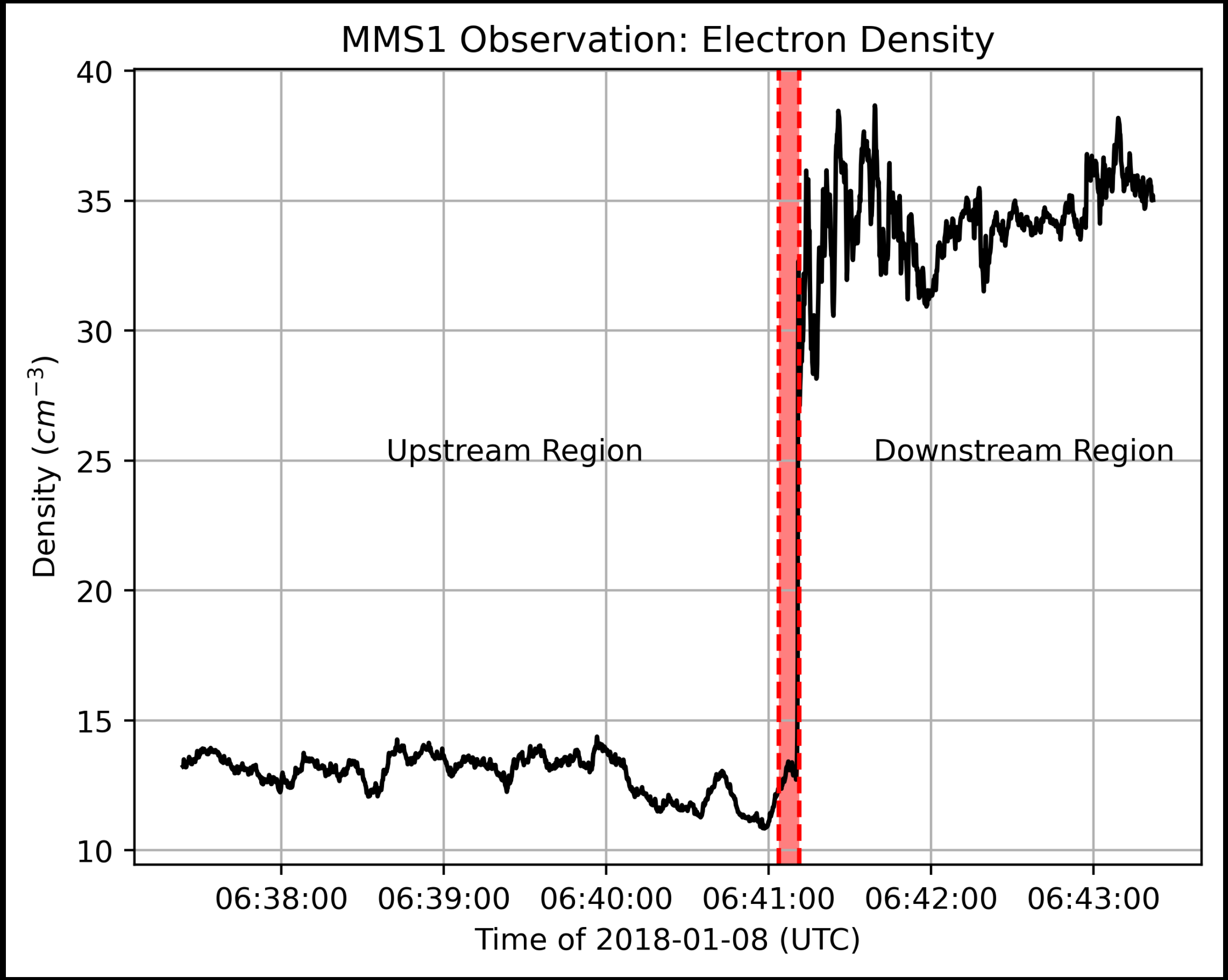
Appendix

*Not encouraged to take photo or share results after this slide

MMS position during the IP shock



Density profile at the IP shock

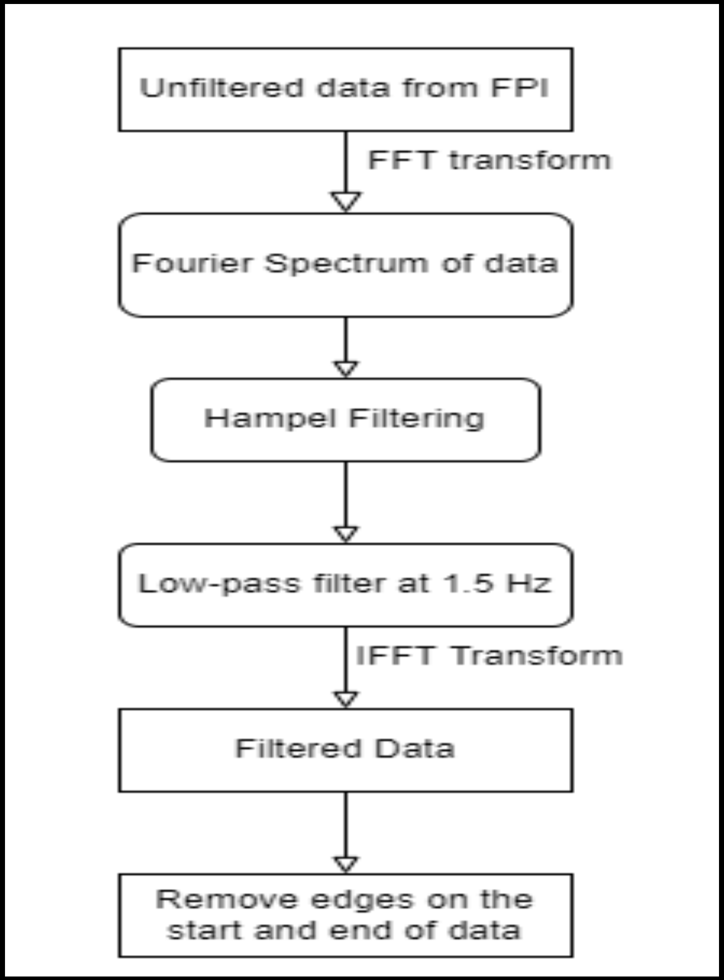


SW angle

- Angle between Solar wind velocity and X_GSE (Radial): $\theta_x = \frac{V_{i,x}}{|V_i|}$
- MMS1
  - θ_x upsteam = 177.08 deg, θ_x downstream = 172.03 deg
- MMS2
  - θ_x upstream = 177.16 deg, θ_x downstream = 172.04 deg
- MMS3
  - θ_x upstream = 177.26 deg, θ_x downstream = 172.11 deg
- MMS4
  - θ_x upstream = 177.28 deg, θ_x downstream = 172.09 deg

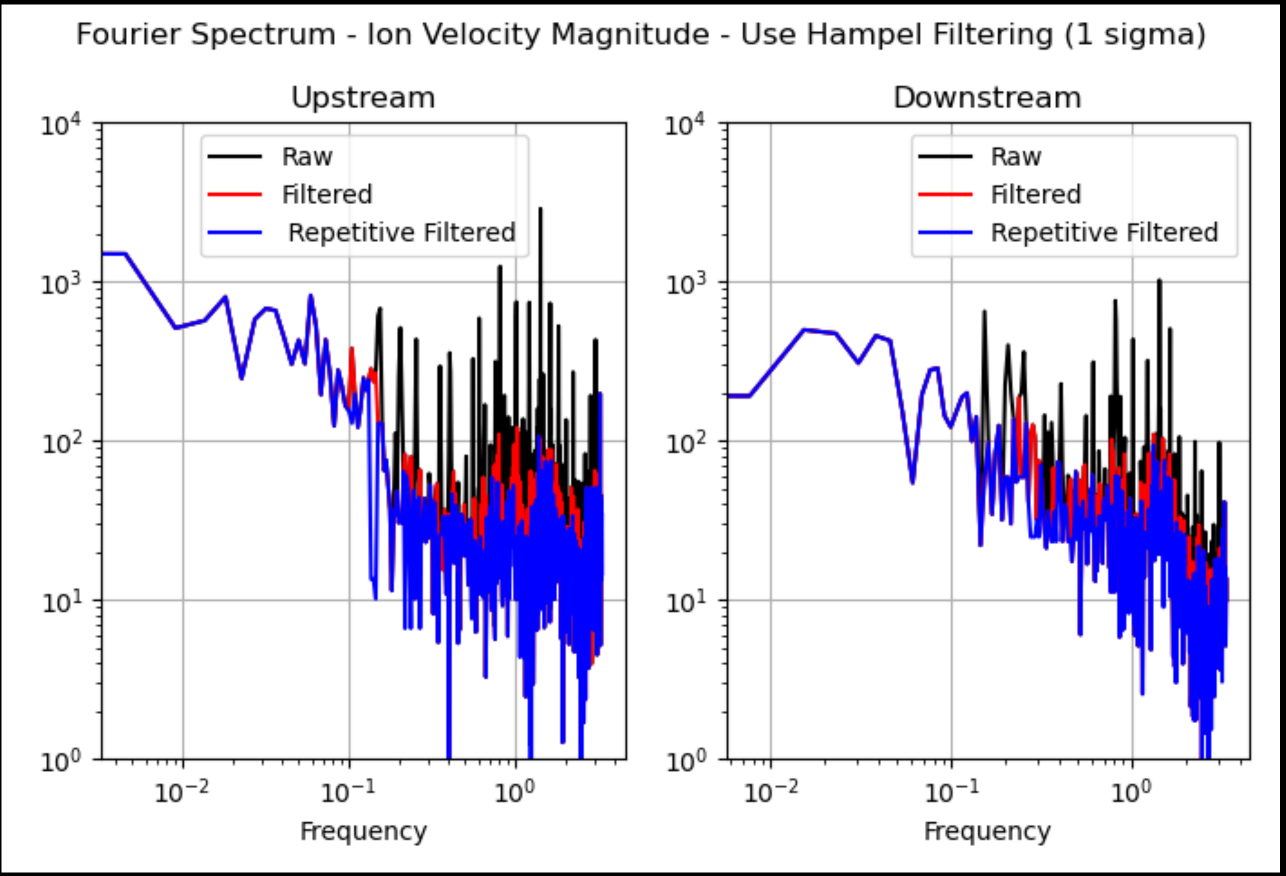
Cleaning up ion velocity data

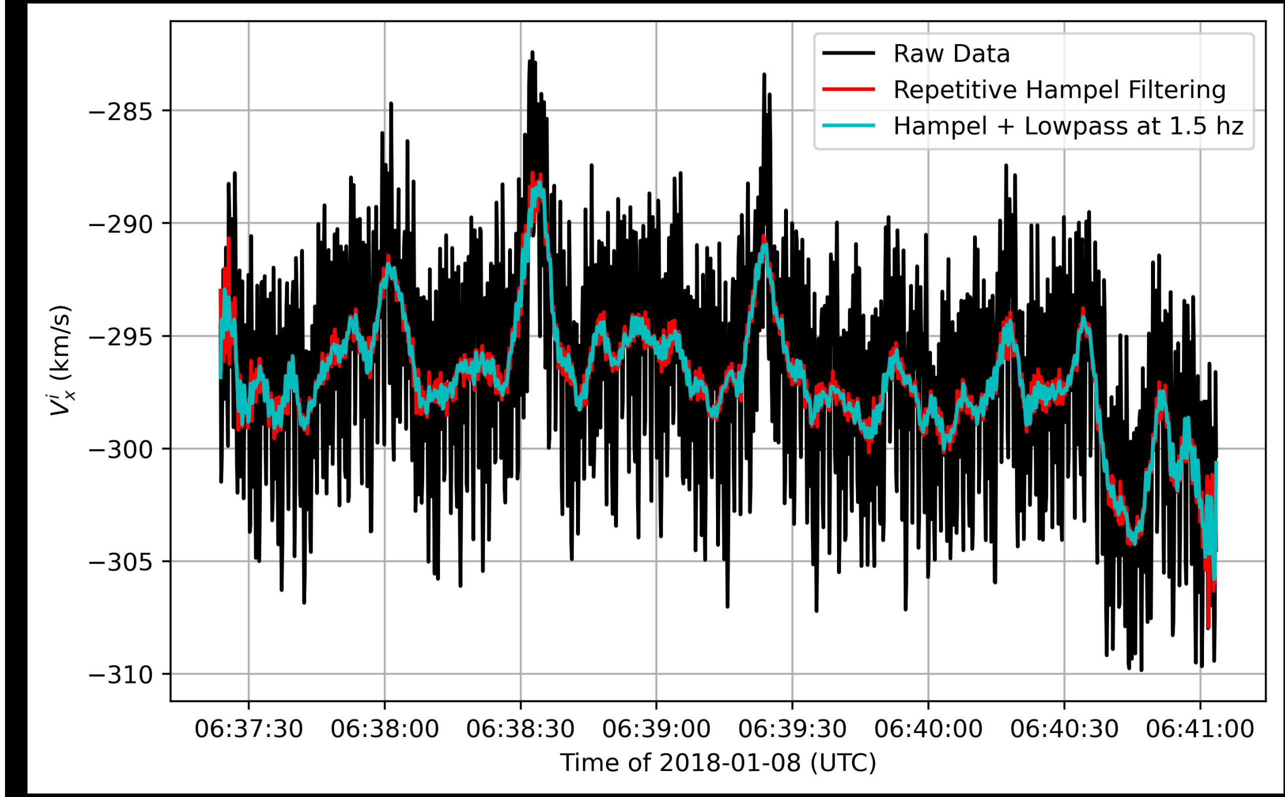
$$y_i = \begin{cases} x_i & \text{if } |x_i - m_i| \leqslant n_\sigma S_i, \\ m_i & \text{if } |x_i - m_i| > n_\sigma S_i, \end{cases}$$



- Apply Hampel Filtering - Based Technique (Bandyopadhyay et al. 2018)
  - Using Moving Window Length = 20 s
  - n-sigma = 1
  - Apply Hampel filtering two times in same data set
  - Low pass filter at 1.5 Hz
  - Remove 40 data points at edge
- Based on Bandyopadhyay et al. 2018

Effectiveness of Hampel Filtering





Elsasser Increment Calculation

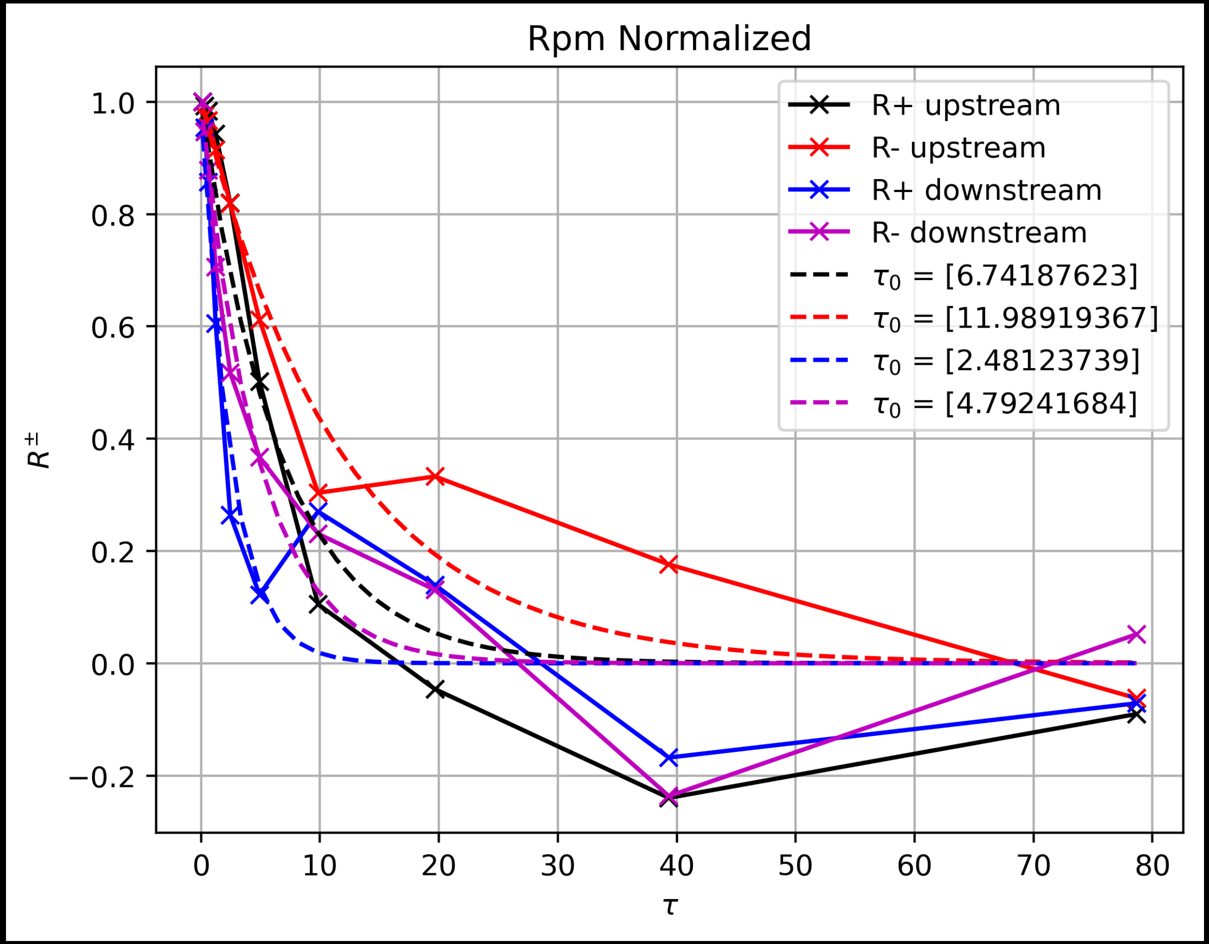
- Find $\Delta \boldsymbol{Z}^{\pm} = \boldsymbol{Z}^{\pm}(t+\tau) - \boldsymbol{Z}^{\pm}(t)$
- $\boldsymbol{Z}^{\pm} = \boldsymbol{v_i} \pm \boldsymbol{b}\,; \boldsymbol{v_i} = \boldsymbol{V_i} - \langle \boldsymbol{V_i} \rangle, \boldsymbol{b} = \boldsymbol{B} - \langle \boldsymbol{B} \rangle$ (in Alfven unit)
- τ choice: $\tau = 2^n * T_{spin}/32$
  - n = (-2, -1, …, 6, 7)
  - T_{spin} (spin period of S/C) = 19.67
  - Reduced more spin tone effect.

Correlation Function

$$R^{\pm}(\tau) = \langle \mathbf{Z}^{\pm}(t) \cdot \mathbf{Z}^{\pm}(t+\tau) \rangle_T .$$

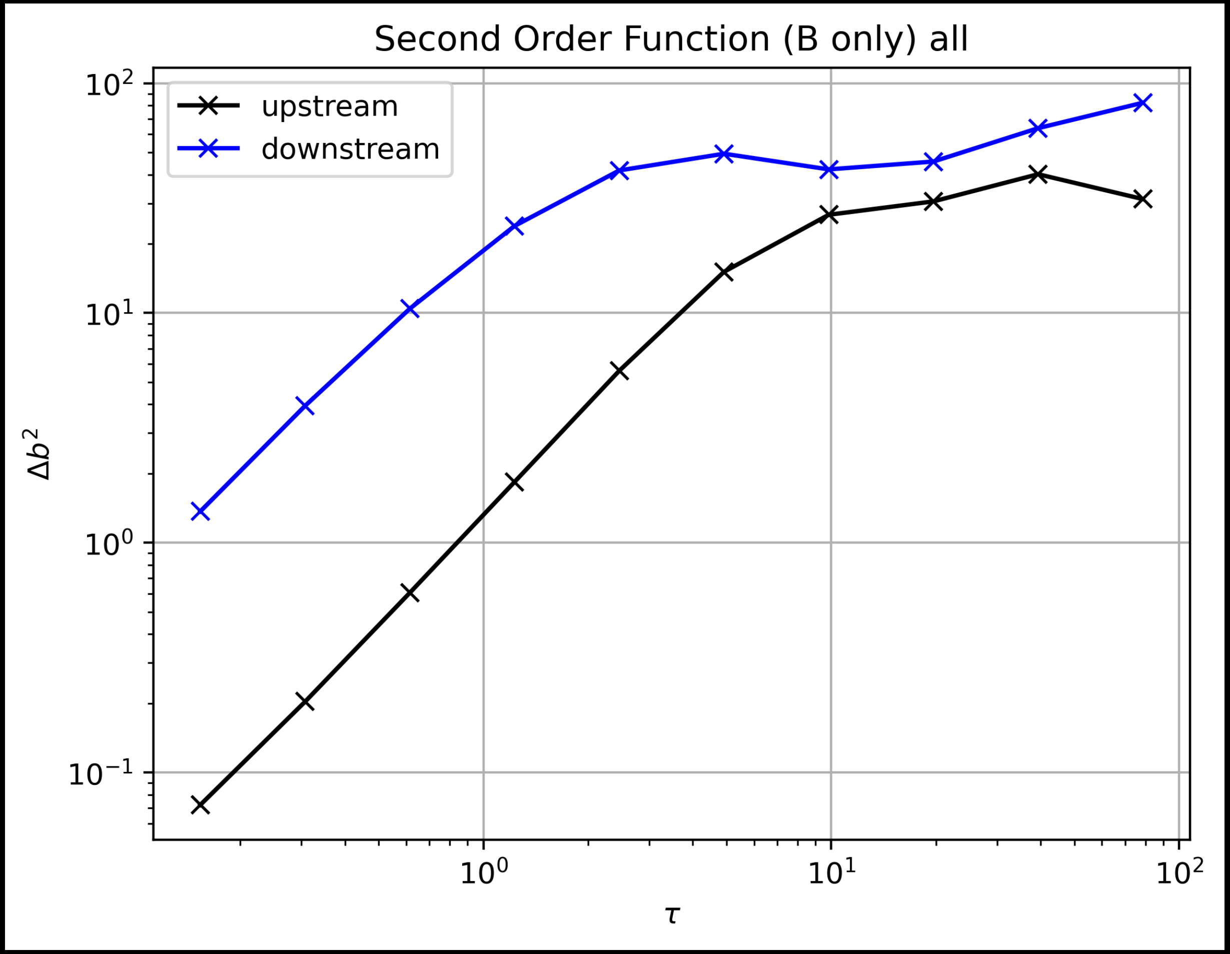
$$R^{\pm}(\tau^{\pm}) = \frac{1}{e},$$

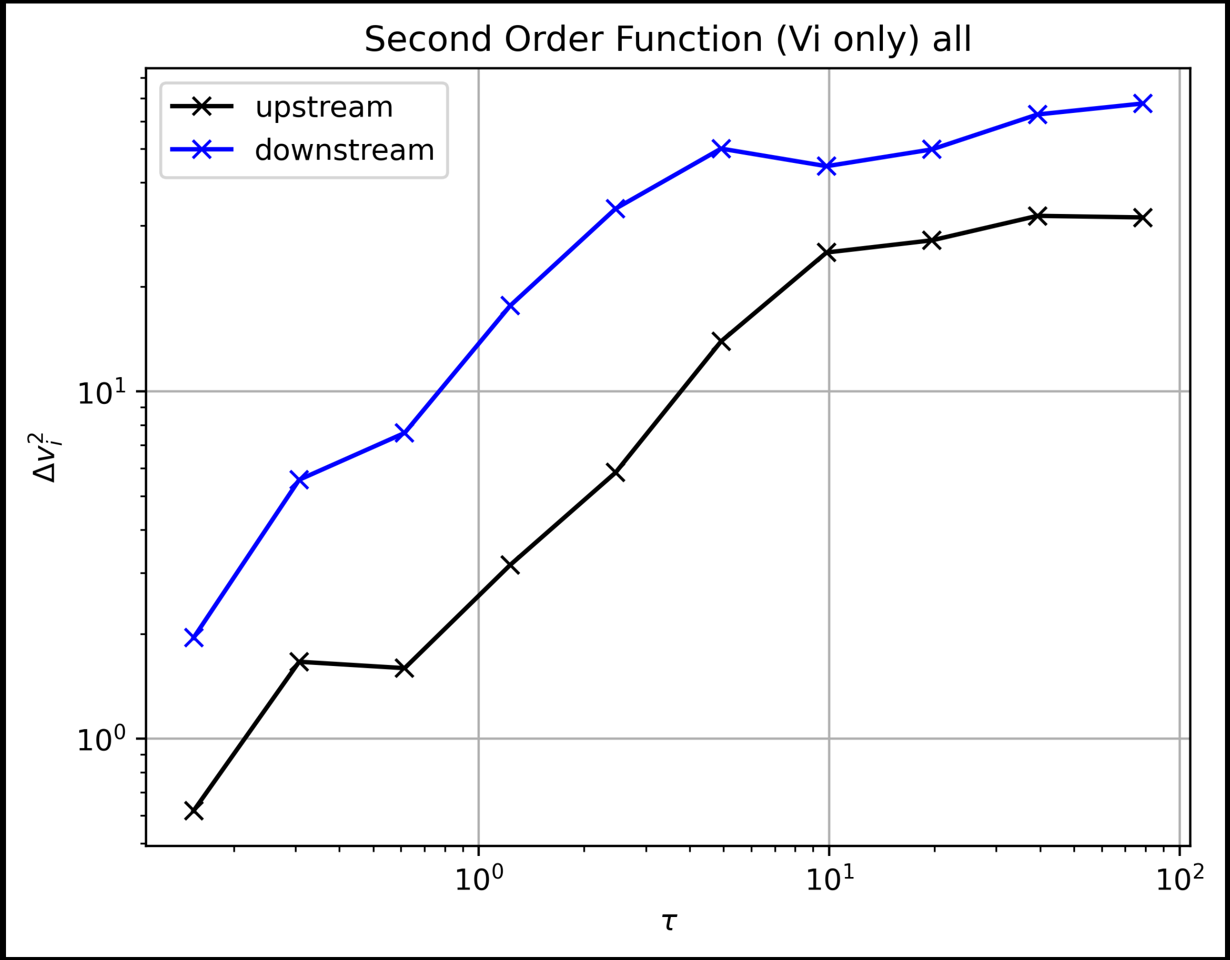
$$L_{\pm} = |\langle V \rangle| \tau^{\pm},$$



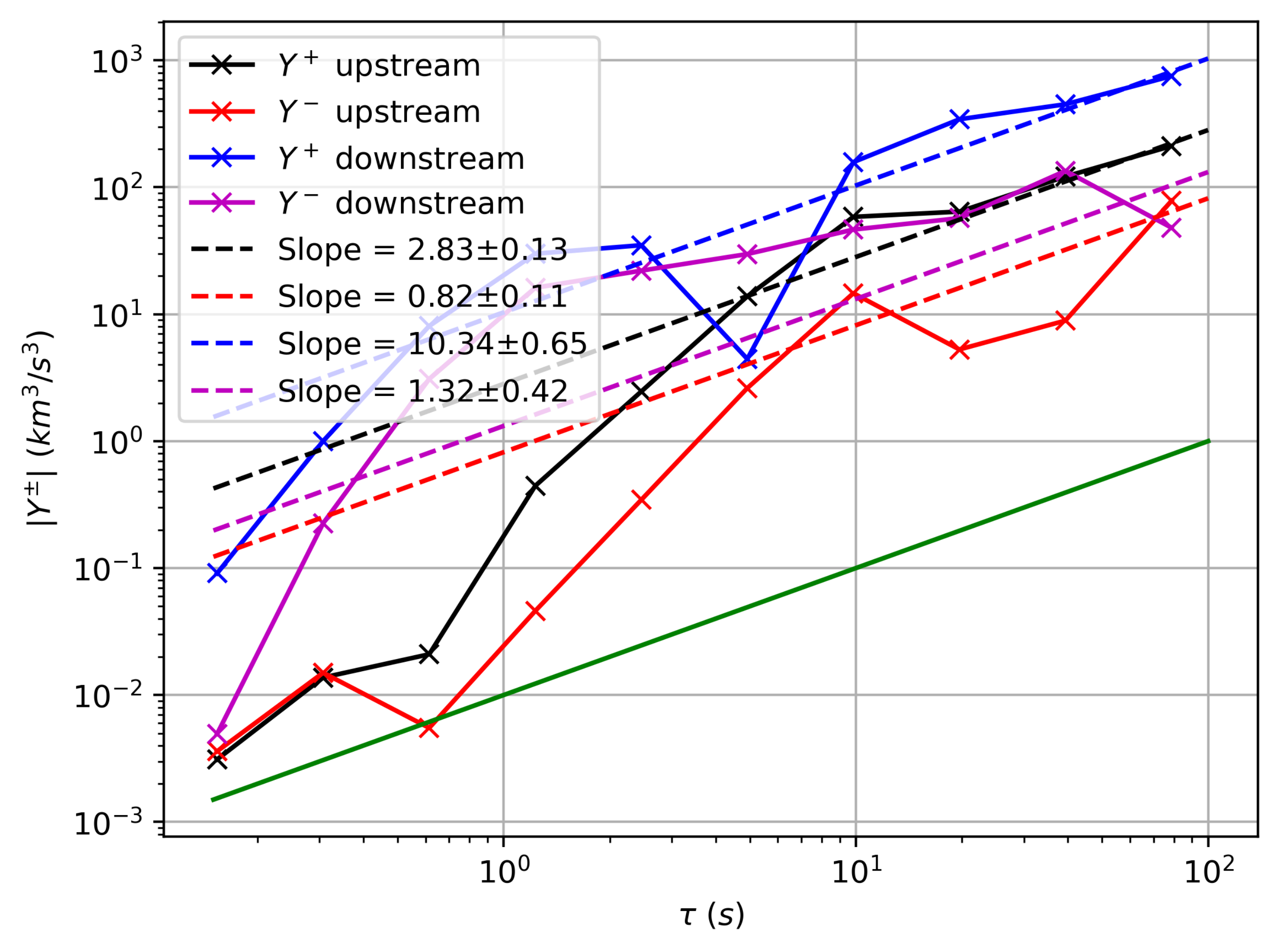
- Plot of normalized correlation function with fitted 1/e function
- Correlation scale τ_0
  - From 1/e method
  - τ_0 range from 2 – 12 second
  - Due to availability of data, maybe correlation scale is shorter than it should be for pristine SW.

Second Order Function: B and V_i



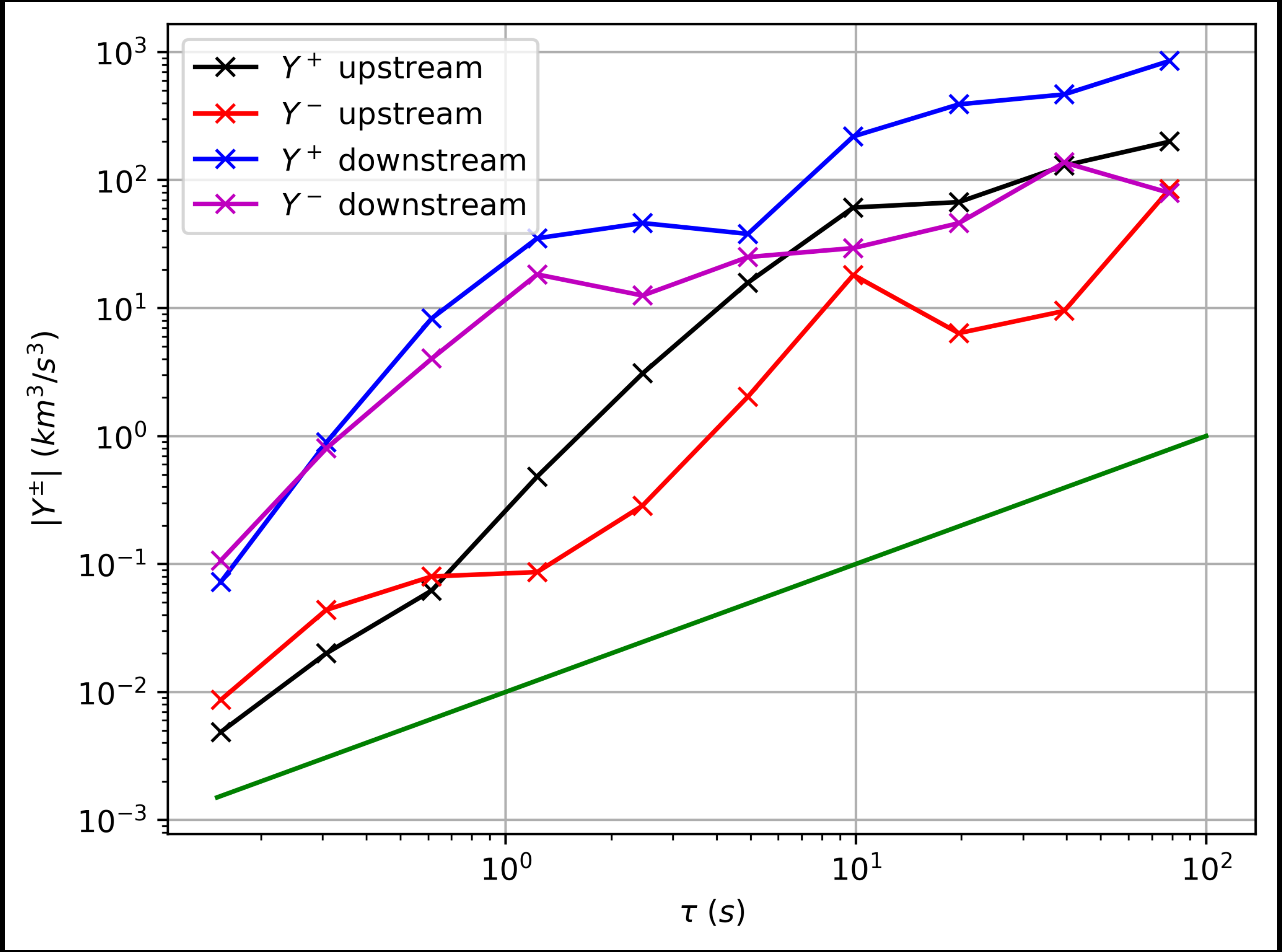


MMS1 – Third Order Law



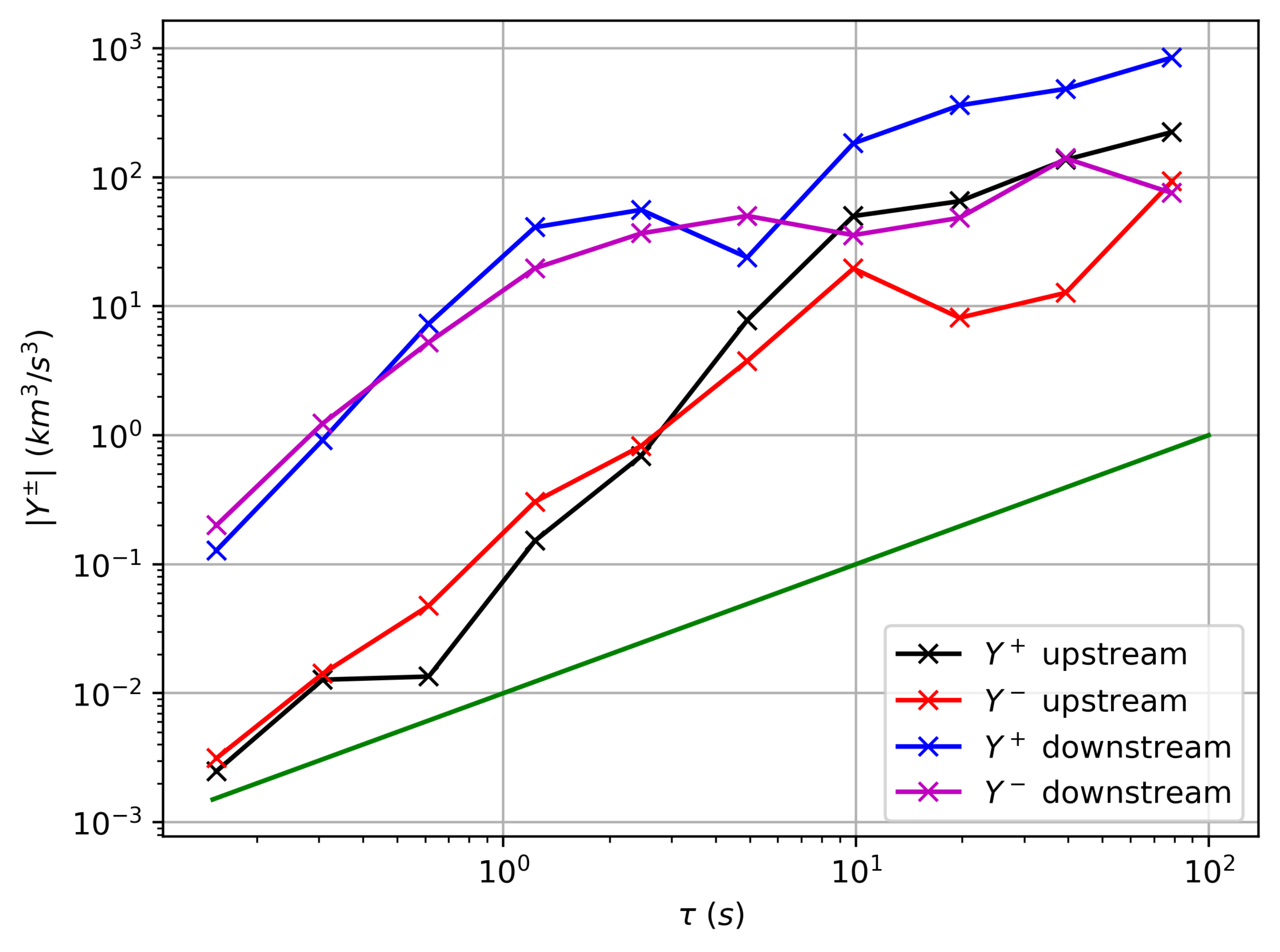
- ϵ^+ upstream = $7.5 \pm 0.2\ kJ\ kg^{-1}\ s^{-1}$
- ϵ^- upstream = $2.2 \pm 0.3\ kJ\ kg^{-1}\ s^{-1}$
- ϵ^+ downstream = $21 \pm 1\ kJ\ kg^{-1}\ s^{-1}$
- ϵ^- downstream = $3.9 \pm 0.9\ \mathrm{k}J\ kg^{-1}\ s^{-1}$

MMS2 - Third Order Law



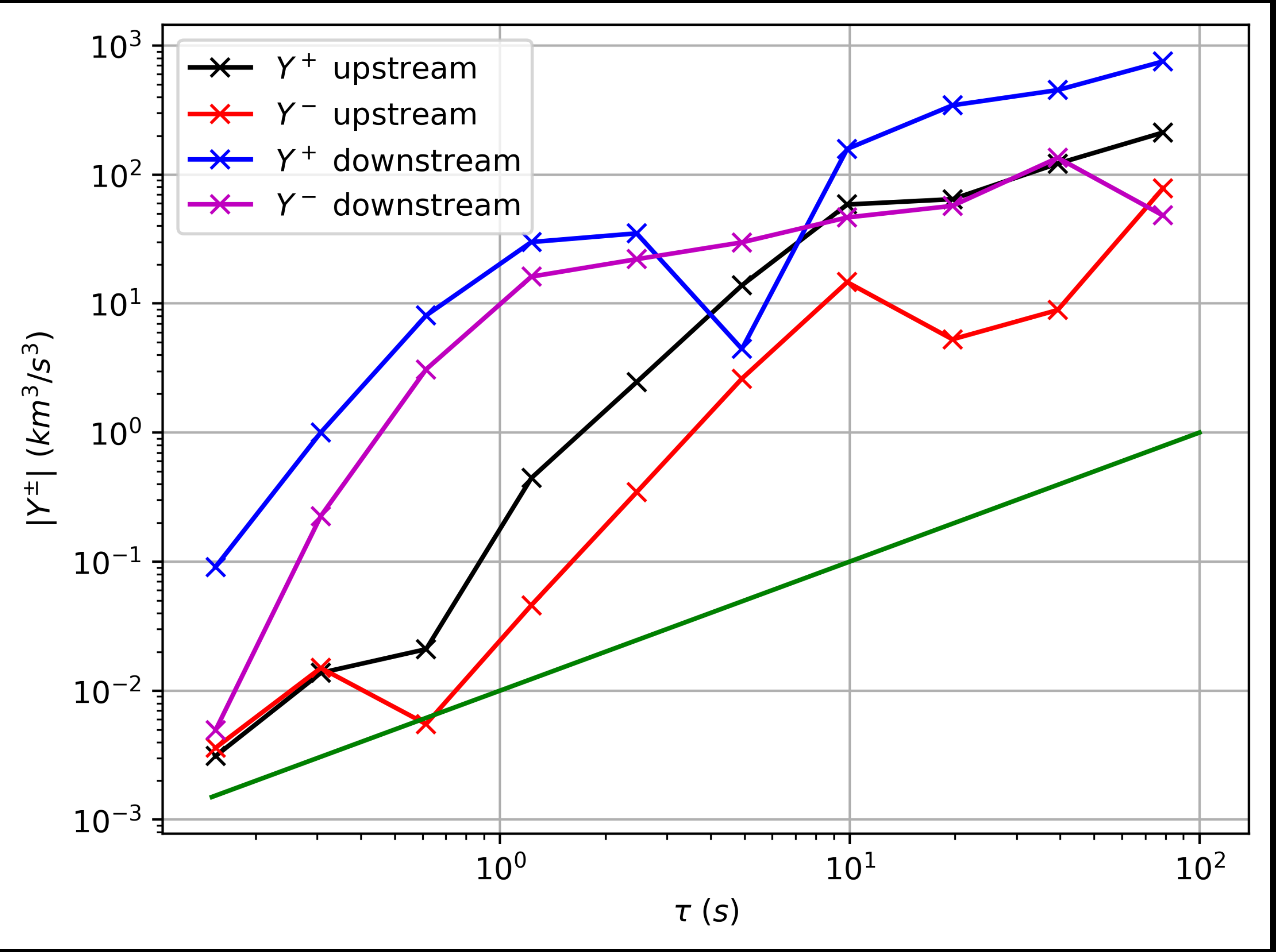
- ϵ^+ upstream = $7.0 \pm 0.4\, kJ\, kg^{-1}\, s^{-1}$
- ϵ^- upstream = $2.3 \pm 0.3\, kJ\, kg^{-1}\, s^{-1}$
- ϵ^+ downstream = $25 \pm 2\, kJ\, kg^{-1}\, s^{-1}$
- ϵ^- downstream = $3.3 \pm 0.7\, kJ\, kg^{-1}\, s^{-1}$

MMS3 - Third Order Law



- ϵ^+ upstream = $7.6 \pm 0.3\ kJ\ kg^{-1}\ s^{-1}$
- ϵ^- upstream = $2.5 \pm 0.3\ kJ\ kg^{-1}\ s^{-1}$
- ϵ^+ downstream = $24 \pm 1\ kJ\ kg^{-1}\ s^{-1}$
- ϵ^- downstream = $3.4 \pm 0.8\ kJ\ kg^{-1}\ s^{-1}$

MMS4 - Third Order Law



- ϵ^+ upstream = $7.1 \pm 0.3\ kJ\ kg^{-1}\ s^{-1}$
- ϵ^- upstream = $2.1 \pm 0.2\ kJ\ kg^{-1}\ s^{-1}$

ϵ^+ downstream = $22 \pm 1\ kJ\ kg^{-1}\ s^{-1}$

- ϵ^- downstream = $2.8 \pm 0.9\ kJ\ kg^{-1}\ s^{-1}$

Von Karman Analysis – MMS1 & 2

- MMS3
  - ϵ^+ upstream =4.6 $\pm$ 0.9 $kJ\ kg^{-1}\ s^{-1}$
  - ϵ^- upstream = $1.1 \pm 0.1\ kJ\ kg^{-1}\ s^{-1}$
  - ϵ^+ downstream = $29 \pm 5\ kJ\ kg^{-1}\ s^{-1}$
  - ϵ^- downstream = $10 \pm 1\ kJ\ kg^{-1}\ s^{-1}$
- MMS4
  - ϵ^+ upstream = 4.6 $\pm$ 0.9 $kJ\ kg^{-1}\ s^{-1}$
  - ϵ^- upstream = 1.3 $\pm$ 0.3 $kJ\ kg^{-1}\ s^{-1}$
  - ϵ^+ downstream = 31 $\pm$ 5 $kJ\ kg^{-1}\ s^{-1}$
  - ϵ^- downstream = 8.8 $\pm$ 0.2 $kJ\ kg^{-1}\ s^{-1}$

Von Karman Analysis – MMS3 & 4

- MMS3
  - ϵ^+ upstream = $4.5 \pm 0.9\ kJ\ kg^{-1}\ s^{-1}$
  - ϵ^- upstream =$1.2 \pm 0.2\ kJ\ kg^{-1}\ s^{-1}$
  - ϵ^+ downstream =$32 \pm 5\ kJ\ kg^{-1}\ s^{-1}$
  - ϵ^- downstream =$10 \pm 2\ kJ\ kg^{-1}\ s^{-1}$
- MMS4
  - ϵ^+ upstream = $4.4 \pm 0.8\ kJ\ kg^{-1}\ s^{-1}$
  - ϵ^- upstream = $1.2 \pm 0.2\ kJ\ kg^{-1}\ s^{-1}$
  - ϵ^+ downstream = $29 \pm 4\ kJ\ kg^{-1}\ s^{-1}$
  - ϵ^- downstream = $9.8 \pm 2\ kJ\ kg^{-1}\ s^{-1}$