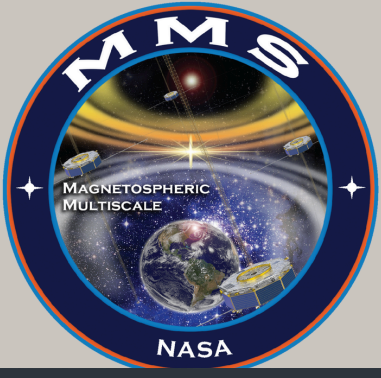




University of  
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# Investigating Anisotropies in Small-Scale Solar Wind Turbulence at 1 AU

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This MMS-EPD work supported by MMS Prime Contract NASA499879Q

Manuscript is currently under review at the *Journal of Geophysical Research: Space Physics*



## Correlation Analysis

$$A_{\text{norm},L} = \frac{\sum_{n=1}^{N-L} X_n \cdot X_{n+L}}{\sum_{n=1}^N X_n^2}$$

$$S_{\text{norm}}^{(2)} = \frac{\langle (X(x+L) - X(x))^2 \rangle}{\langle X(x)^2 \rangle}$$

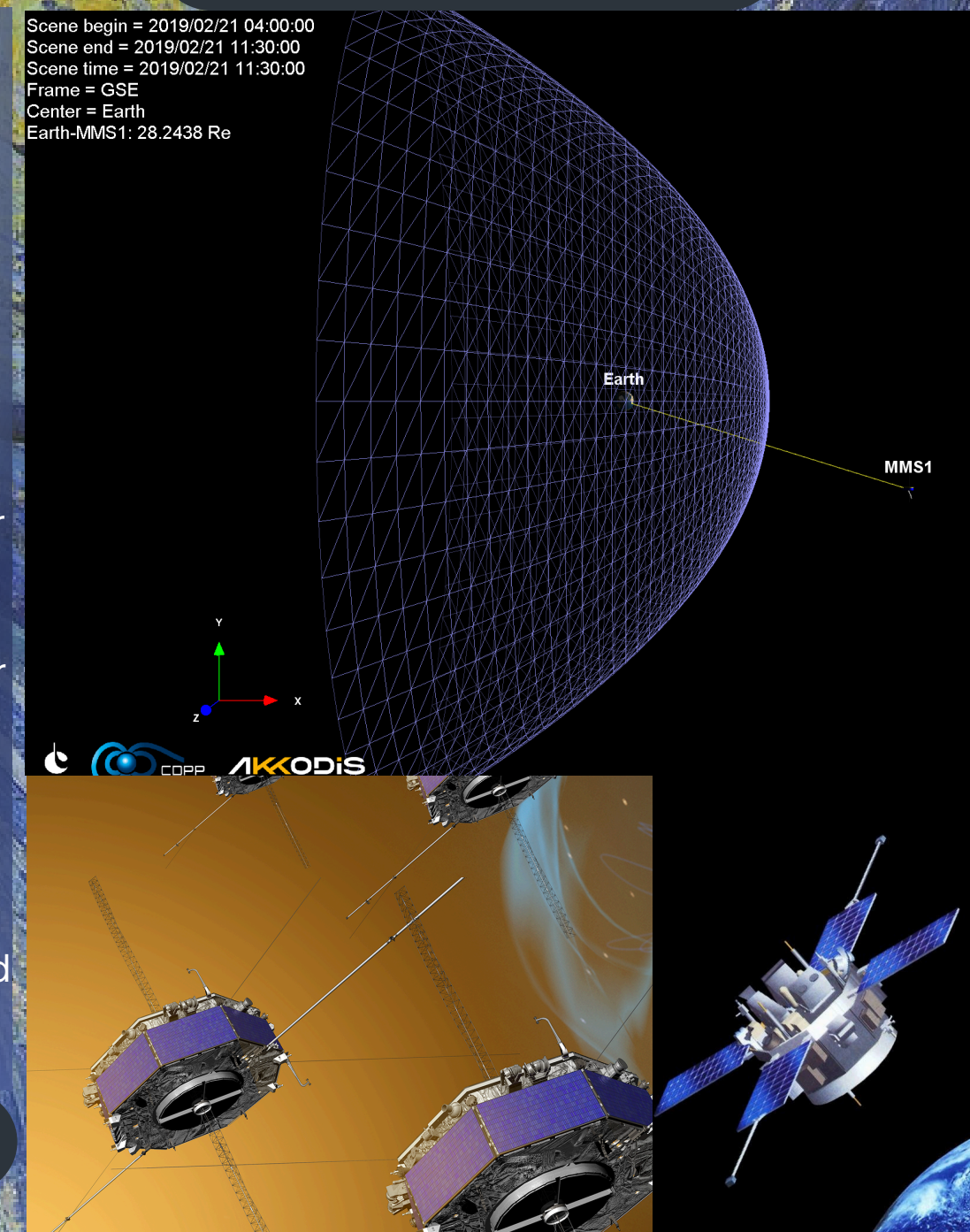
$$A_{\text{norm},L} = 1 - \frac{S^{(2)}(L)}{2}$$

Autocorrelation functions (ACF) and second order structure functions (SF) offer complimentary insights into turbulent behaviors. The ACF measures how correlated a signal is with itself at different lags, making it a direct probe of spatial or temporal coherence—it can be sensitive to noise, especially at longer lags. The SF quantifies the mean squared difference between the values at different lags, making it more robust to noise and better suited to capturing small-scale variability. By deriving the ACF from the SF we are able to produce a more stable and physically interpretable correlation result. We utilize Taylor's hypothesis to convert temporal lags into spatial ones using solar wind speeds.

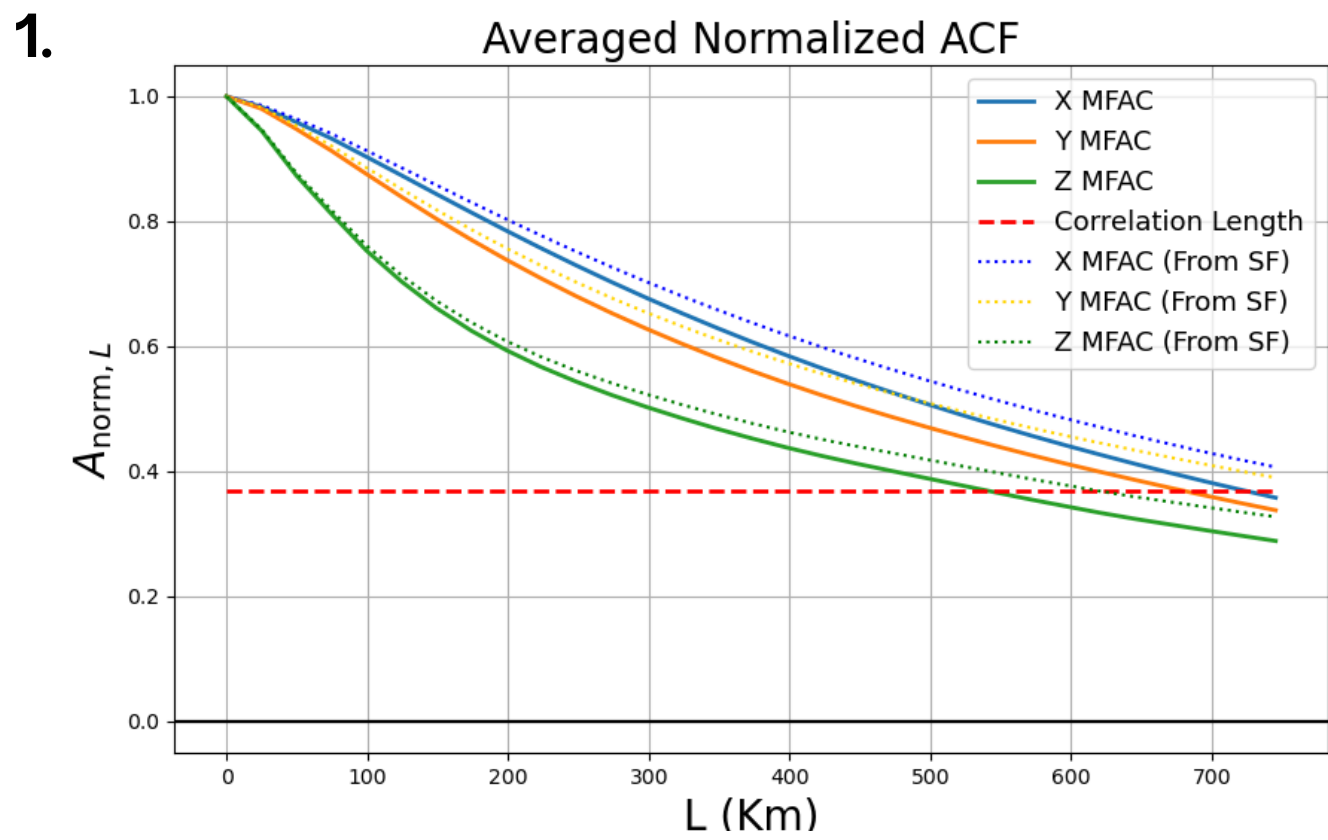
## Abstract

This study investigates energy dissipation in small-scale solar wind turbulence using a novel approach to autocorrelation function analysis leveraging high resolution data from the Magnetospheric Multiscale Mission (MMS). We analyze magnetic field fluctuations at ion dissipation scales, focusing on short 20-second intervals to isolate dissipation-scale dynamics. Using MMS's fluxgate magnetometer, fast plasma investigation, and energetic particle detector, we compute normalized correlation functions as functions of solar wind parameters, including interplanetary magnetic field cone angle and solar wind speed. Our results show that turbulence at these scales decorrelate over short spatial scales (~100–1000 km), with faster decorrelation in the compressional component compared to the transverse components. We find that the transverse correlation lengths differ most when the interplanetary magnetic field is nearly perpendicular to the solar wind flow and that they vary approximately as the inverse sine of the cone angle. The characteristics of the correlation length suggest that the turbulence observed is primarily two-dimensional. These findings highlight the anisotropic nature of dissipation-scale turbulence and its dependence on solar wind conditions, providing insights into energy transfer in space plasmas.

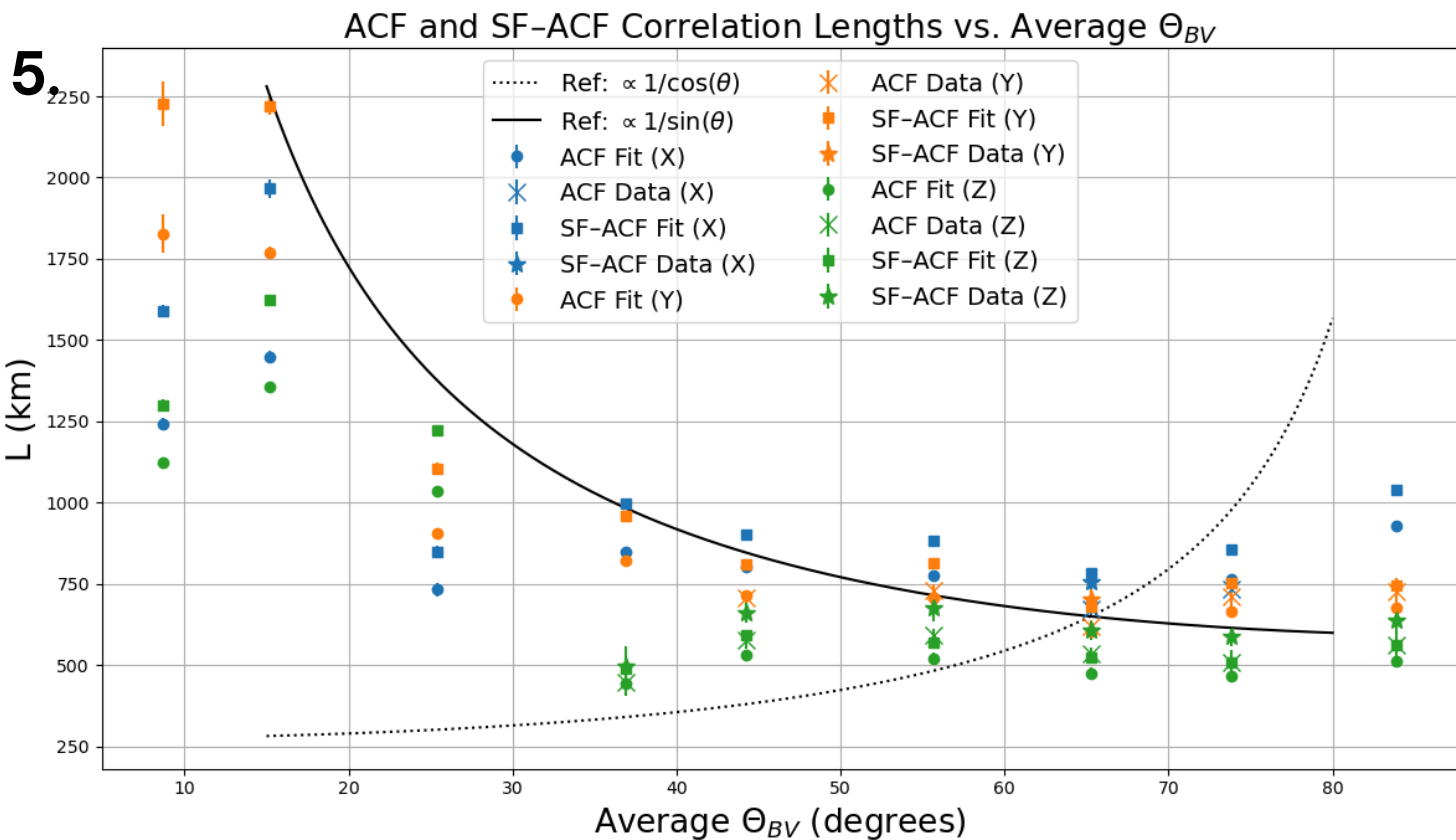
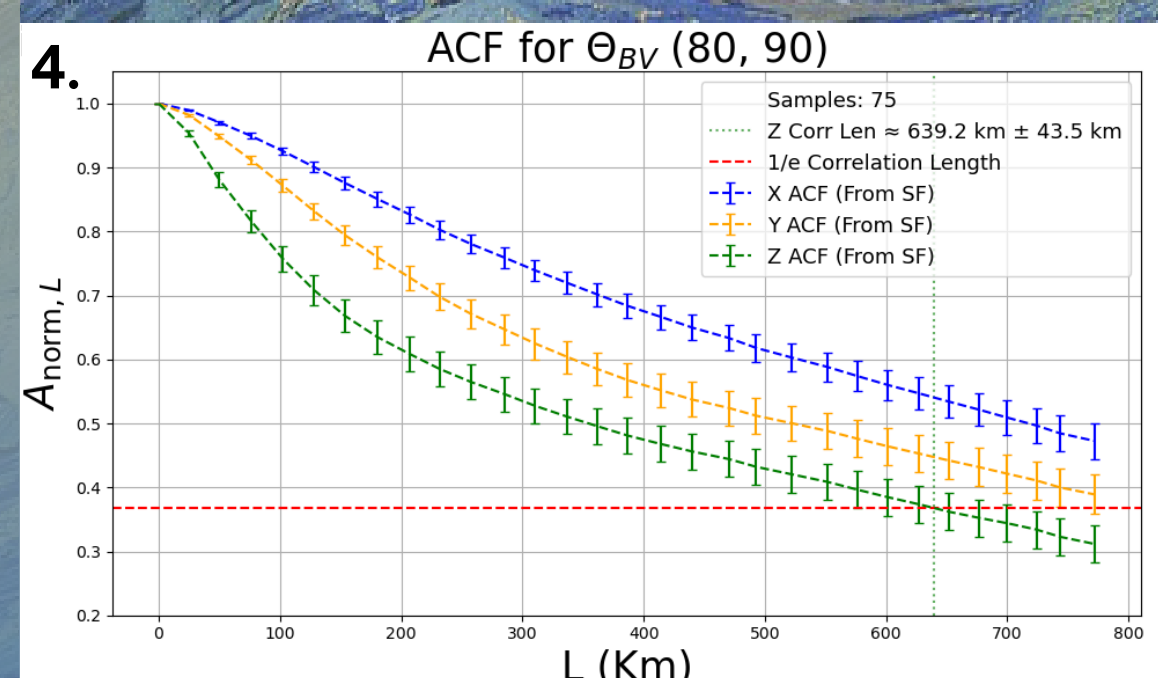
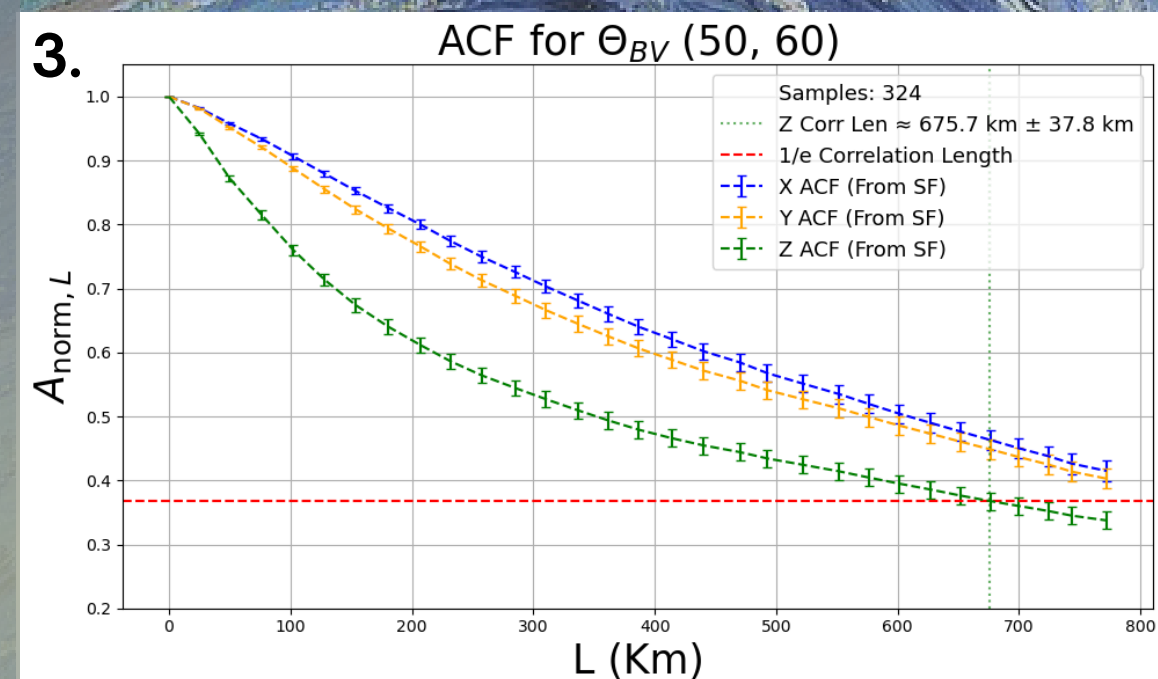
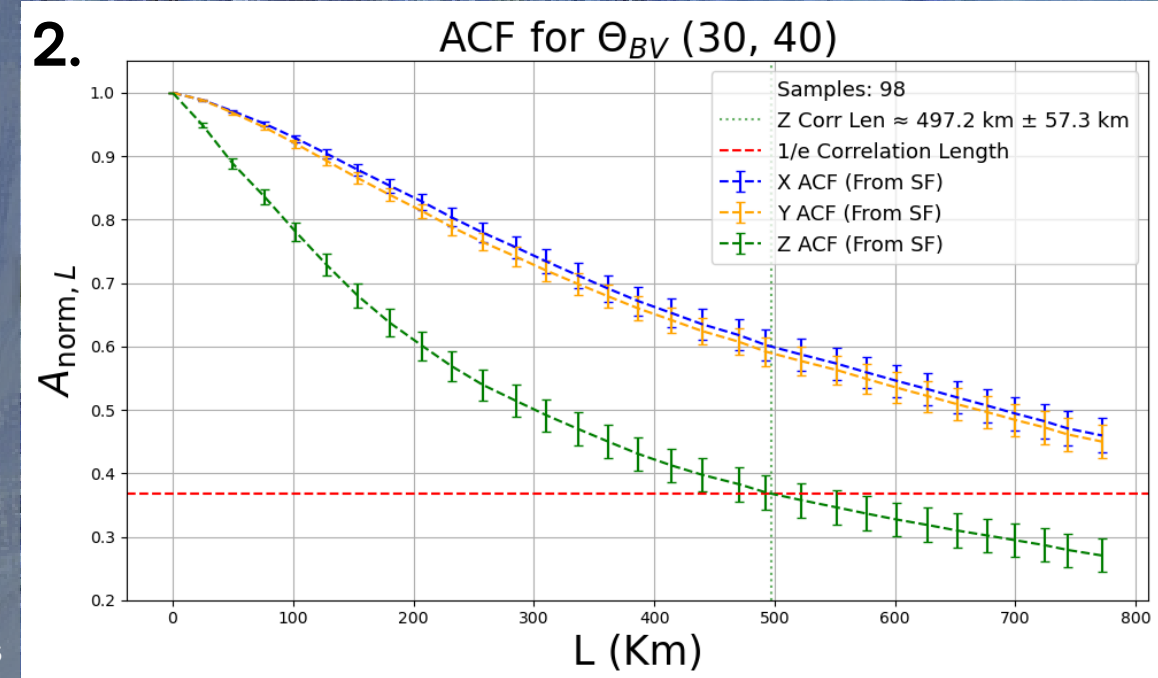
## Instruments



## Analysis and Results



We took 7.5 hours of ambient solar wind magnetic field and ion velocity data from MMS and divided it into 1350 non-overlapping, 20-second intervals. After converting them into a mean field coordinate system (MFAC), we calculated the ACF and SF-derived ACF for each interval and averaged them. Figure 1 depicts the normalized average ACF alongside the SF-reconstructed ACF in dotted lines. We see that each component has a lag value ~100's of km which place us in the ion-dissipation range. Additionally, the compressional (Z) component has the shortest correlation length compared to the two transverse components which suggests the presence of enhanced dissipation processes. We then decomposed the intervals into their respective cone angles; the angle between interplanetary magnetic field (along Z MFAC) and the solar wind direction. We found that the compressional component consistently exhibited a shorter correlation than the transverse components (with the exception of small angles 0–30 degrees). Additionally, the transverse components themselves exhibited anisotropy, with correlation lengths in Y exceeding those in X with the difference between the two components increasing between 30 and 90 degrees. Figures 2, 3, and 4 depict the SF-reconstructed ACF's for various angles. Figure 5 shows correlation lengths derived from both the raw ACF and the SF-reconstructed ACF plotted against the average cone angle. It distinguishes between data and model fits. In addition an inverse sine (representing pure 2D turbulence) and an inverse cosine (representing pure slab turbulence) are plotted. The curves are positioned so as to intersect each other at a lag of 650 km in the 60–70 degree bin. The correlation functions tend to follow the inverse sine line which suggests the dominance of 2D turbulence.



## Future Work

While this study provided valuable insights into solar wind turbulence at dissipation scales, its reliance on single-spacecraft data imposed significant limitations, particularly in resolving fluctuations at small angles relative to the mean magnetic field. We hypothesize that applying this modified correlation function analysis in conjunction with multi-spacecraft observations (i.e. MMS 2, 3, and 4), would address these limitations by enabling the sampling of the full 3D turbulent structure—without resorting to times of radial magnetic field when the data is contaminated by waves excited by upstream particles. Such an approach would provide a more complete characterization of the turbulent anisotropy and nature of wave-particle interactions in the solar wind.