Observational Signatures Of Fluctuating Moments Associated With Ion-Cyclotron Waves In The Solar Wind

Ramiz A Qudsi[1†], Bennett A. Maruca[1], D. Verscharen[2], Michael L. Stevens[3], Benjamin L. Alterman[4]

[1]Department of Physics and Astronomy, University of Delaware — [2]University College, London — [3]Harvard-Smithsonian Center for Astrophysics, Cambridge, MA — †ahmadr@udel.edu

[4]Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI

Abstract

Presence of magnetic field in solar wind gives rise to velocity distribution functions (VDF) with several interesting properties.

Time-averaged magnetic fields are used to process these distributions.

This technique works well during periods of nearly constant magnetic fields.

This does not represent a complete picture of solar-wind ion VDFs specially during periods of strong magnetic fluctuations.

In our analysis we let the magnetic field vary over for each datum in ion VDF.

We applied this technique to process Wind-spacecraft observations of a strong ion-cyclotron-wave storm. We found that, over the course of each ion distribution, the proton bulk-velocity fluctuated out of phase with the magnetic field, which is consistent with the theoretical predictions of Verscharen and Marsch (2011).

This represents one of the first quantitative measurements of ion fluctuations on timescales shorted than the ion measurements.

Introduction

The ion-VDF of solar wind for an anisotropic distribution can be approximated by a bi-Maxwellian distribution for each species, which has the following form:

$$\sim \exp\left(-\frac{\left|\vec{v}_{\perp}-\vec{V}_{w\perp}\right|^2}{v_{th\perp}^2}-\frac{\left(v_{\parallel}-V_{w\parallel}\right)^2}{v_{th\parallel}^2}\right)$$

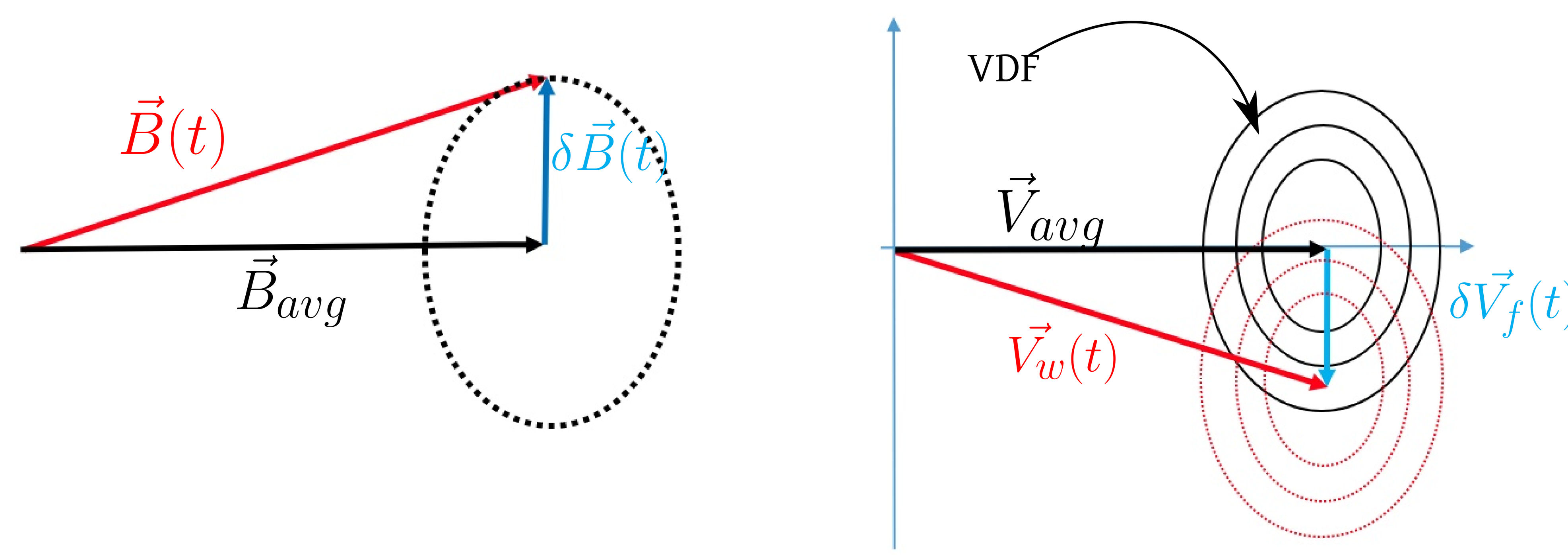
$V_{w\parallel}$ and $\vec{V}_{w\perp}$ are the bulk velocity of plasma which are conventionally set as constant.

The constancy of the bulk velocity assumes a fixed value of magnetic field during observation, which is, in general, certainly is not true.

If the magnetic field is fluctuating at a certain rate, because of frozen in condition, it would lead to fluctuation in bulk velocity as well.

Theoretical Background

The figure below represents qualitatively the behavior of VDF in a fluctuating magnetic field.



The entire VDF is expected to "slosh" around with magnetic field, so we implemented a modified form of bi-Maxwellian distribution, where we let the bulk velocity fluctuate with time.

For the case of an electromagnetic ion-cyclotron wave (EMIC) the fluctuations produced in the bulk velocity can be approximated as :

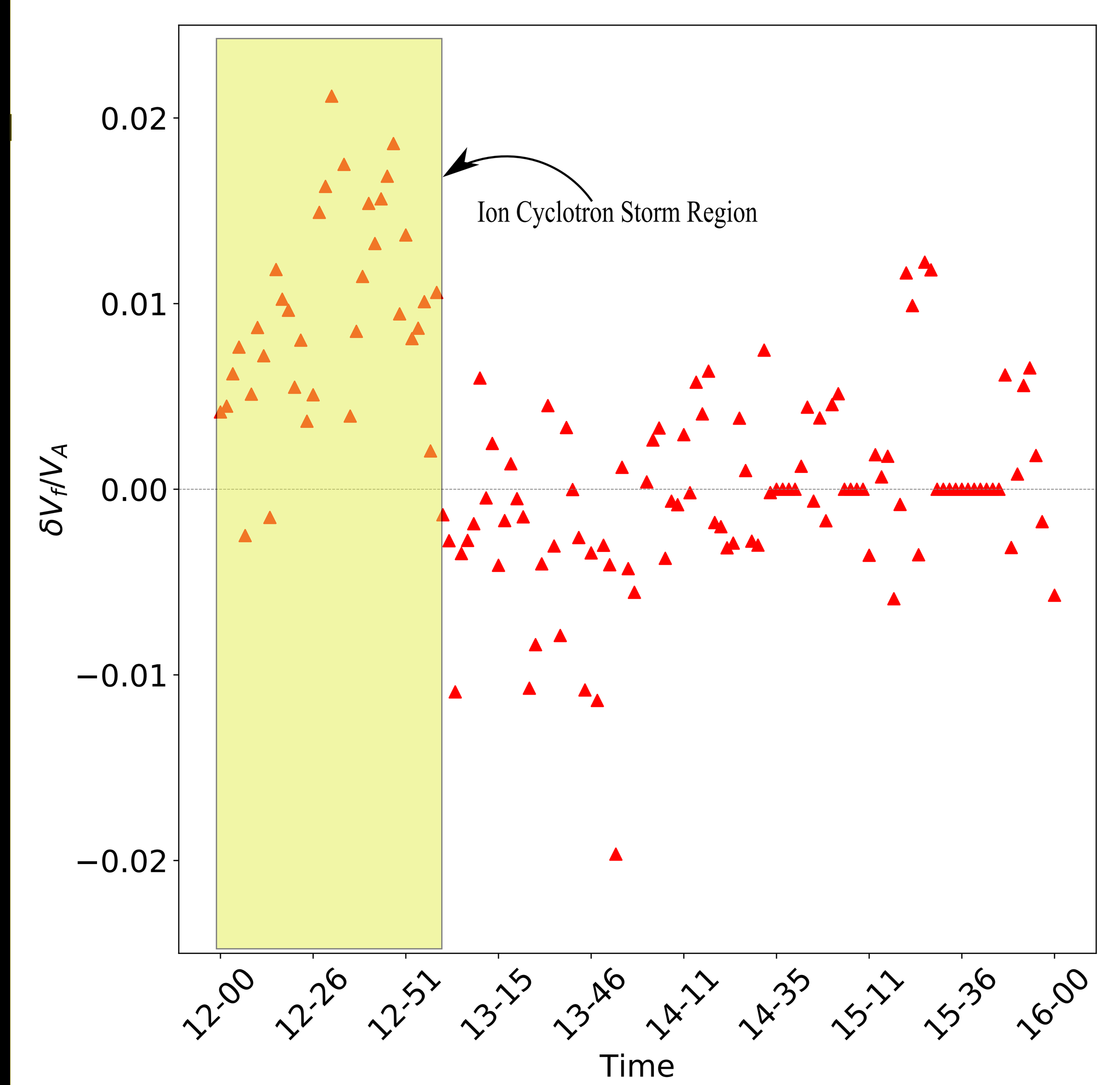
$$\vec{V}_w(t) = \vec{V}_{avg} - \delta V_f \, \delta\hat{B}(t) \quad \text{where} \quad \delta V_f = -\frac{\delta B}{|\vec{B}_0|}\frac{\omega/k}{1-\omega/\Omega_p}\left(1-\frac{k_{\parallel}\Delta V}{\omega}\right)$$

is the drift velocity of the speci with respect to the bulk velocity of proton core.

Data, Analysis and Results

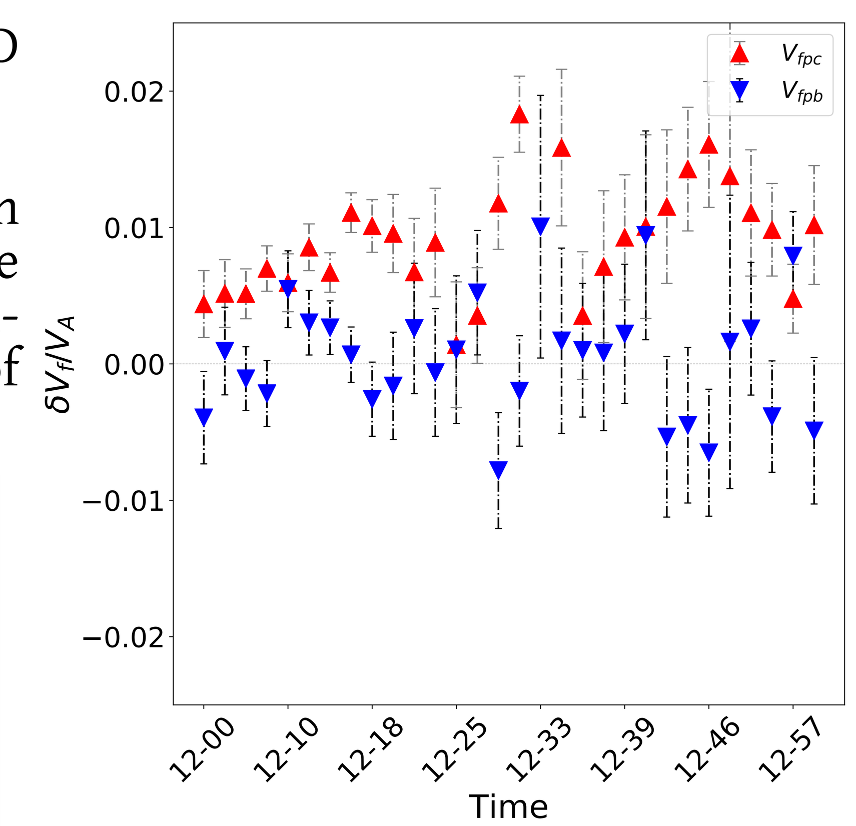
Data: From Faraday Cup aboard WIND Spacecraft.

We analyzed the period when fluctuations in magnetic field were perpendicular to the background field and were quasi-monochromatic, thus indicating the presence of an EMIC storm.



We assigned the field to each datum in the spectra and used the Levenberg–Marquardt algorithm (LVM) to fit the data.

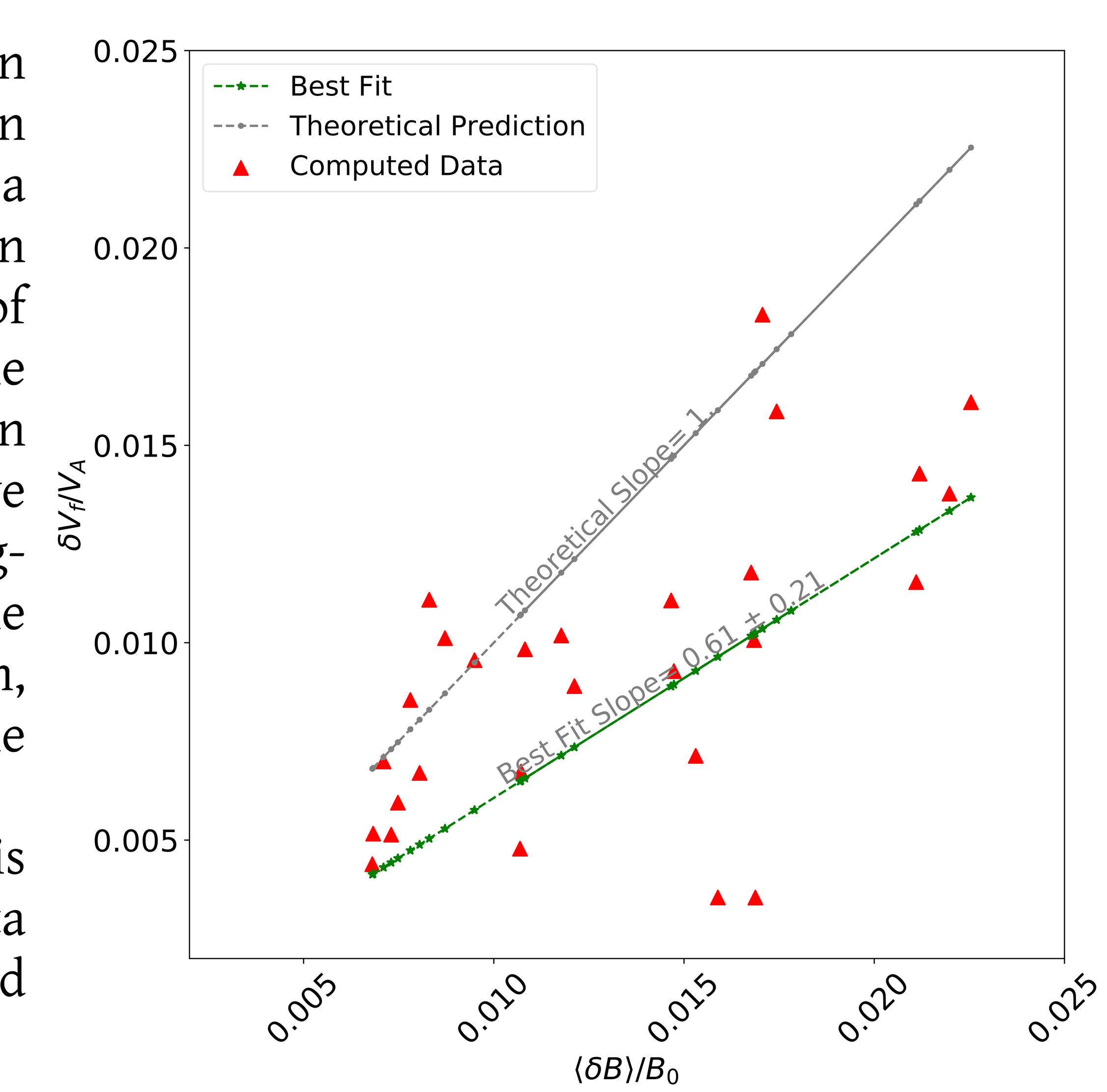
The values of measured fluctuation velocity was significantly higher during the EMIC storm (from 1200 Hr to 1300 Hr), which is what we expected.



The value of velocity fluctuation in the core is higher than that of beam. and is significantly above the zero line. For the beam, the values fluctuate around the zero line, with much higher error-bar (almost a magnitude higher), and statistically have zero value.

This is as expected, since the beam drifts at roughly the Alfven speed and is thus expected to have zero fluctuation in an Electromagnetic Ion Cyclotron storm.

For the fluctuations in core velocity, based on the theory we expect a linear trend between the amplitudes of magnetic field and the velocity fluctuations. In the figure on left, we plotted the two magnitudes. Gray line is the theoretical prediction, red points are the measured/calculated data and green line is the best fit for the data with a slope of 0.61 and error of about 0.21.



Conclusion and Discussion

All the values are positive and we do not see any perceptible offset in the best fit line, which is as the theory predicts.

We observe that the slope of the best fit line is lower than the expected value of 1. We suspect that this is due to the fact that field fluctuations are not monochromatic (as the theory assumed). Also, we approximated ω/k to V_A, though the value of ω/k is slightly higher than the V_A.

Future Work

Explore other periods with EMIC storms:
- (a) Check how the relation between δV and δB varies for different periods.
- (b) Explore how the angle between velocity and magnetic field affect the analysis.

Compare measures of goodness of fit:
- (a) Look at χ^2 and σ.
- (b) Temporal fluctuation in parameter.

Generalize the analysis for arbitrary fluctuations:
- (a) Turbulent fluctuations of various types.
- (b) Explore the limits of algorithm sensitivity.

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