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

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## 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 techniques 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:

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

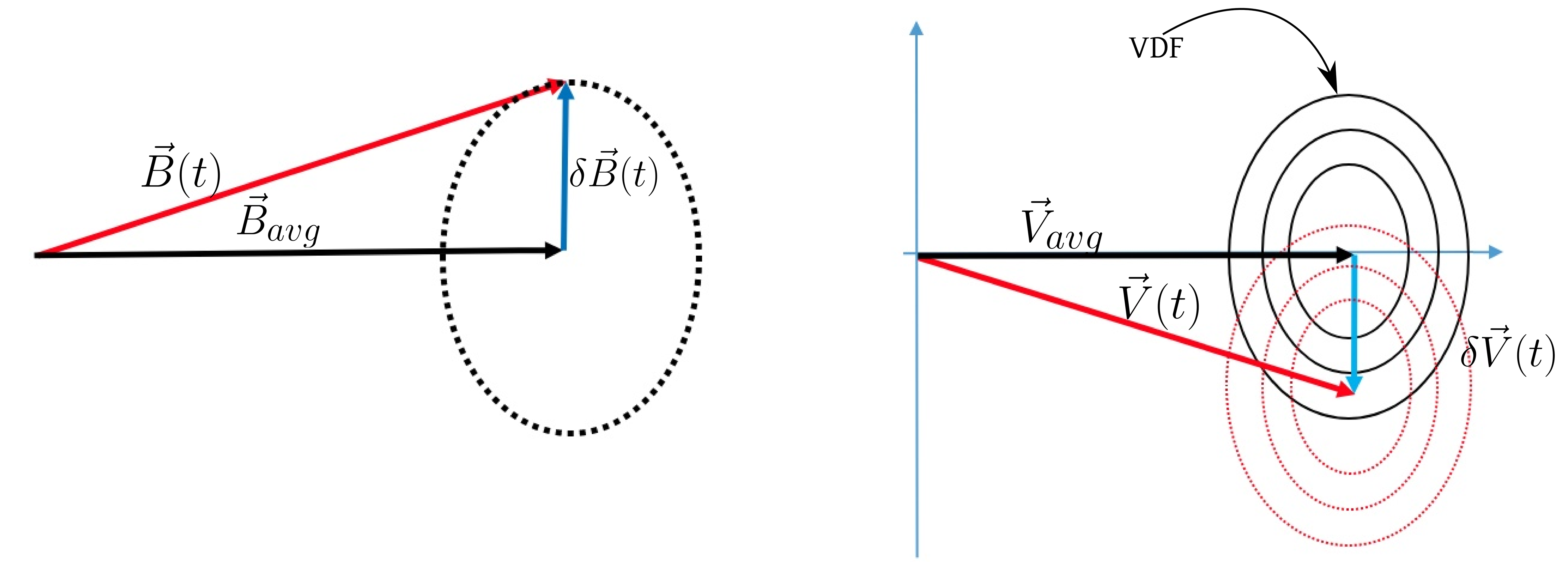
$\vec{V}_{w\parallel}$ and $\vec{V}_{w\perp}$ are the bulk velocity of plasma which are conventionally set as constant.

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

If the magnetic field is fluctuating at a certain rate, this could lead to a fluctuation in the bulk velocity as well.

## Theoretical Background

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

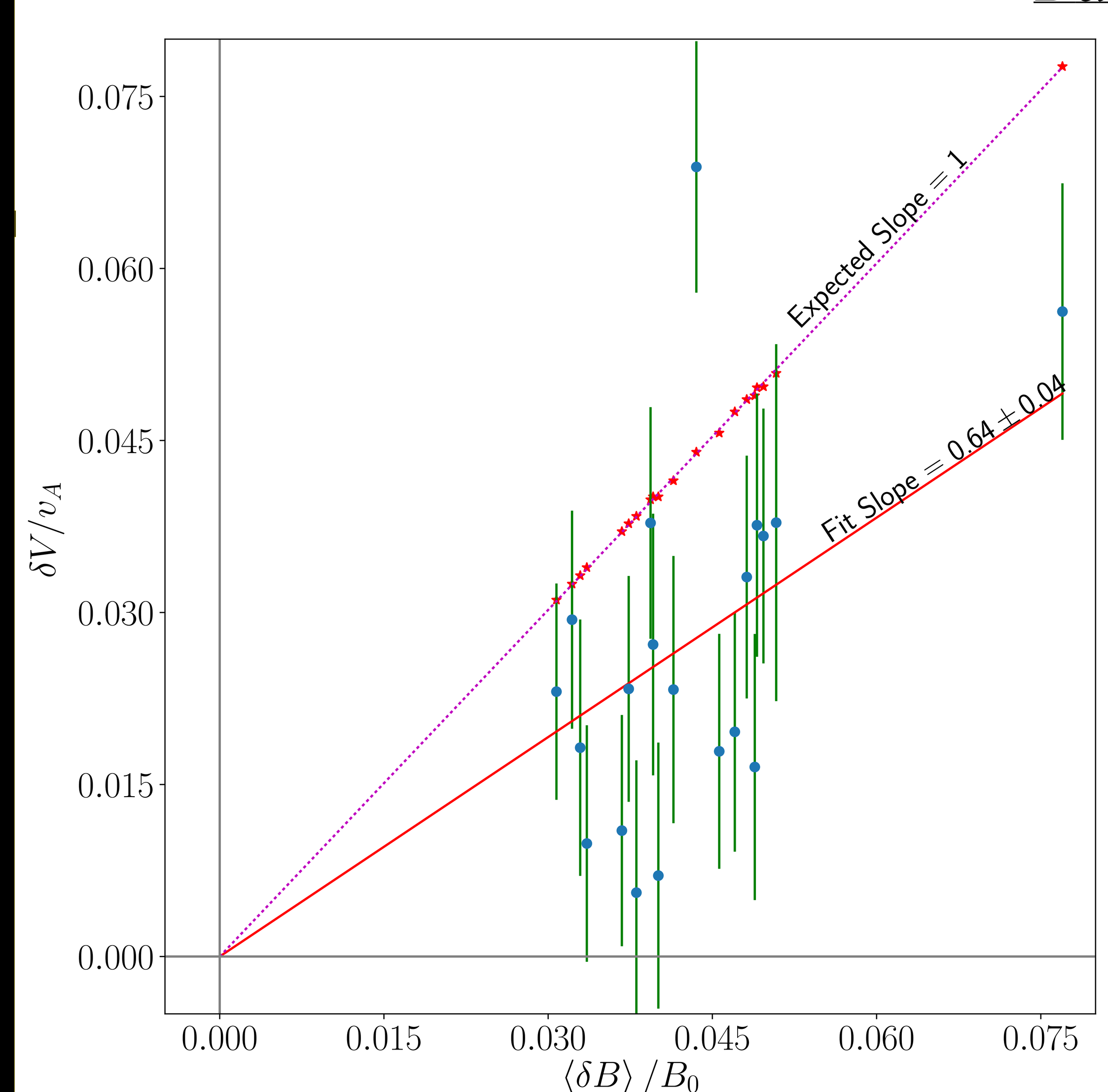



The entire VDF is expected to "slosh" around with magnetic field, so we implemented a modified form of bi-Maxwellian distribution, where we let the bulk velocity fluctuate with time.

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

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

## Data, Analysis and Results




Data: From Faraday Cup aboard WIND Spacecraft.

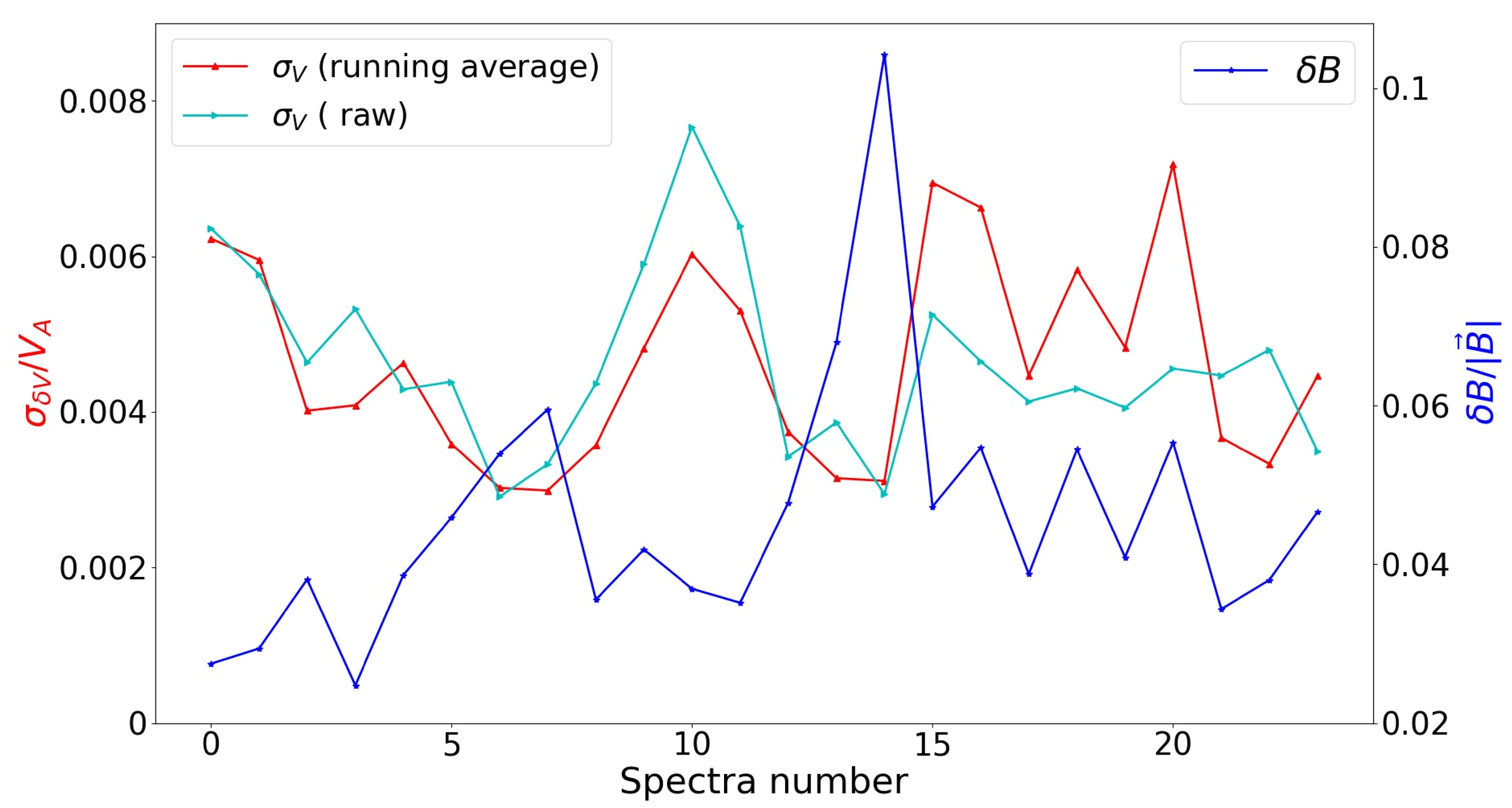
We analyzed the period when fluctuations in magnetic field were perpendicular to the background field and were quasi-monochromatic, thus indicating the presence of an EMIC.

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

We expected a linear trend between the amplitudes of magnetic field and velocity fluctuations which is what we observe. Red asterix are the theoretical predictions, blue dots are observed points and green vertical lines are the error in measurement.

We also used several different methods of estimating the background field, and analyzed the error produced by them.

The figure presented below shows the error magnitude for different spectra and two different background estimation techniques.




## Conclusion and Discussion

All the values are positive and we do not see any perceptible offset in the best fit line, which is what 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 field fluctuations not being purely monochromatic ( as assumed in theory ).

Measurements tend to be more accurate and closer to theoretical prediction when δB is greater than 5% as is evident from the second figure.

For two different background field, the value of $\sigma_V$ is slightly higher when compared with the time running average.

## Future Work

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

Compare measures of goodness of fit:
- (a) Look at $\chi^2$ 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.

## References and Acknowledgements

Verscharen and Marsch, Ann. Geophys., 2011, 29
Wicks, R. T., et al., ApJ, 819, 6
Stix, Waves in Plasmas, 1992, AIP Press
Jian et al., APJL, 2009, 701, L105-L109
Accunia et al., SSRv, 1995, Vol 71
Lepping et al., SSRv, 1995, Vol 71
Ogilvie et al., SSRv, 1995, Vol 71

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