Statistics of Total Pressure in Kinetic Plasma Turbulence

S. Adhikari[1,2*], T. N. Parashar[2,3], W. H. Matthaeus[2], M. A. Shay[2], P. A. Cassak[1]

1. Department of Physics and Astronomy, West Virginia University, Morgantown, West Virginia 26506, USA
2. Department of Physics and Astronomy, University of Delaware, Newark, Delaware 19716, USA
3. School of Chemical and Physical Sciences Victoria University of Wellington, Wellington 6140, NZ

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I. Introduction

- Pressure plays a vital role in turbulent plasmas.
- For example: energy transfer through the Pressure strain interaction, or routine interval of pressure balance in the solar wind.
- Density, as a linear response to pressure fluctuations, has beenexplored in the nearly incompressible (NI) MHD framework[1, 2, 3].
- However, mechanical and total pressure statistics in Vlasov-Maxwell plasmas have not been extensively studied.

II. Simulation

- Kinetic particle-in-cell (PIC) simulation of turbulence in a 2.5D setup with initial Fourier modes k ϵ [2,4] (See 4,5)
- Details: background density (n_b), mass (m) of ions (i)/electrons(e), temperature (T), plasma beta ($\boldsymbol{\beta}$), particles per grid (ppg)

$L_x=L_y$	n_b	m_i/m_e	$T_i=T_e$	$\boldsymbol{\beta}_i=\boldsymbol{\beta}_e$	ppg
149.6 d_i	1.0	25	0.3	0.6	3200

III. Results

- As turbulence evolves, volume averaged total pressure remains constant (Fig. 1). The thermal and magnetic pressure compensate for each other (Figs. 2 and 3)
- In the inertial range, while magnetic and thermal pressures have similar spectral slopes comparable to -5/3, the total pressure spectrum exhibits a slope of -7/3 (Fig. 4)
- Probability distribution functions of the increment of different forms of pressure show the departure from gaussianity. For two increments d_i and d_e, the total pressure pdf is close to a gaussian for d_i (Fig. 5, and 6)

* subash.adhikari@mail.wvu.edu

A. Pressure balance

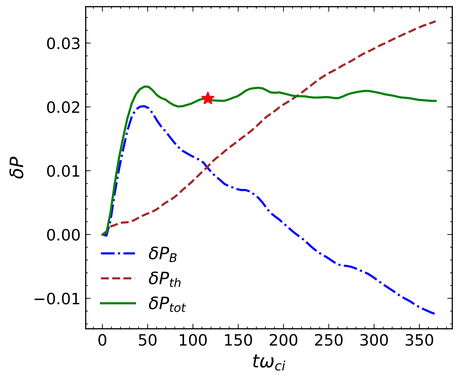

Figure 1: Time evolution of the change in thermal (δP_{th}), magnetic (δP_B), and total pressure (δP_{tot}). Red star represents the time of analysis (tw_{ci} = 116.5).

B. Pressure spectrum

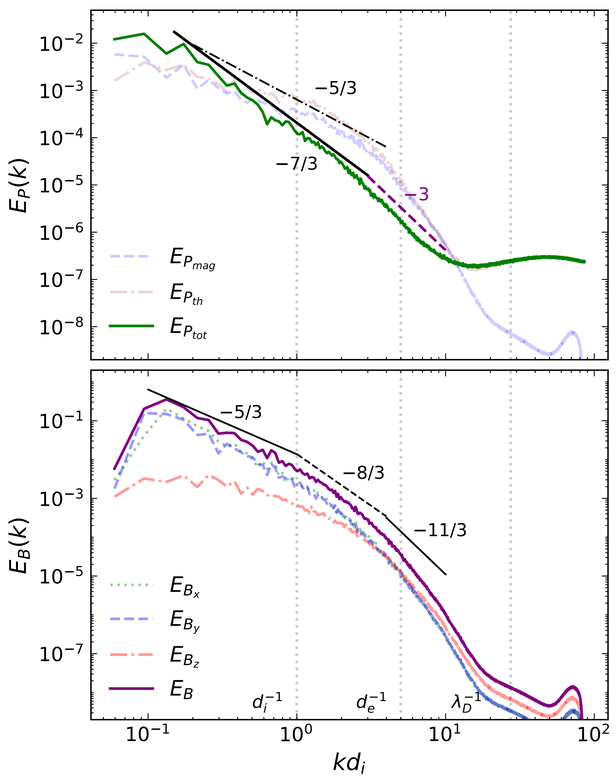

Figure 4: (Top) Pressure spectra for all types of pressure as a function of wavenumber. Black and purple lines with slopes -7/3, -5/3, and -3 are drawn for reference. (Bottom) Magnetic energy spectra at the same time of analysis. Lines of slope -5/3, -8/3, and -11/3 are drawn for reference.

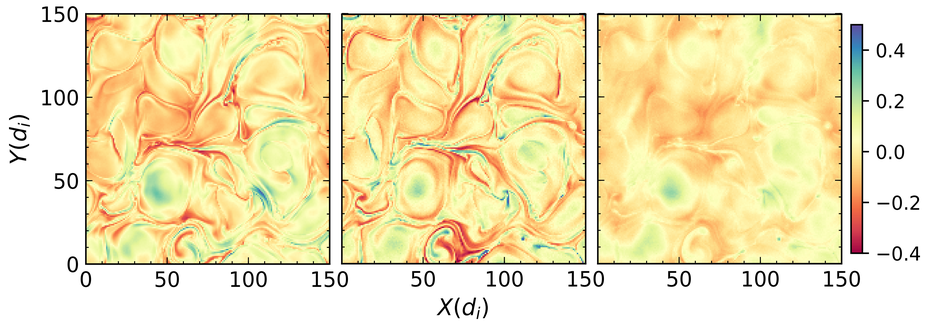

Figure 2: Two-dimensional image of the change in magnetic, thermal and total pressure normalized to the corresponding mean value at tw_{ci} = 116.5.

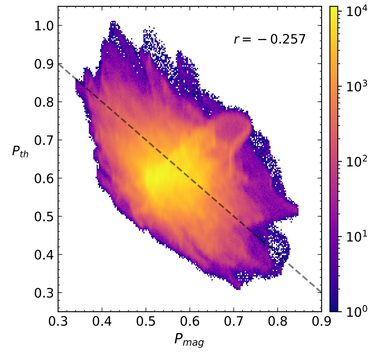

Figure 3: Joint probability distribution of the thermal and magnetic pressure at tw_{ci} = 116.5, where r is the correlation coefficient. A dashed line of slope -1 is drawn for reference.

C. Pressure pdf

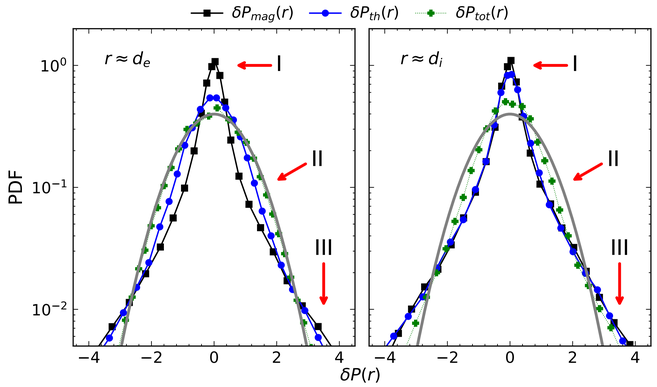

Figure 5: Probability distribution function of the increment of pressure dP at r=1d_e=0.2d_i (left) and r=1d_i (right) at tw_{ci} = 116.5. The gray curve represents the normal distribution for reference. Regions I, II and III are defined based on the pdf's intersection with the normal one.

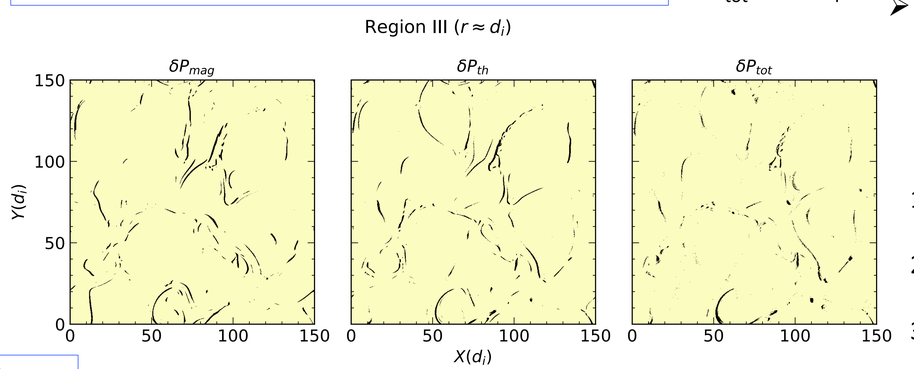

Figure 6: Structures in individual pressure terms contributing to the tails observed in Region III of Fig. 5 (right).

IV. Discussion

- The change in thermal pressure is opposite to the change in magnetic pressure keeping the total pressure approximately constant.
- The anti-correlation between P_{mag} and P_{th} is supported by the joint pdf and a –ve correlation coefficient.
- The omnidirectional spectrum for P_{tot} shows a -7/3 slope over k, steeper than P_{mag} and P_{th}. This behavior is similar to hydrodynamic turbulence.
- Intermittency is observed in the pdfs of pressure increments, with elongated tails in P_{tot} for r~d_i.
- How these extrapolate to 3D and anisotropy is left for a future study.

Acknowledgments

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References:

1. Montgomery D. et al., JGR: Space Physics, 92.A1 (1987).
2. Matthaeus W.H, Brown M.R., Phys. Fluids, 31, 3634 (1988)
3. Matthaeus W.H. et al., JGR: Space Physics, 96.A4 (1991).
4. Parashar T.N. et al., The ApJ Letters, 864, L21, (2018).
5. Adhikari S. et al., Physical Review E, 104, 065206 (2021).