A Statistical Comparison Between Proton Microinstabilities and Nonlinear Effects in Space Plasmas

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Abstract

Using Particle-In-Cell (PIC) simulations and observational data from Magnetospheric MultiScale (MMS) Mission and WIND, we calculate and compare proton-temperature-anisotropy driven linear-instability growth rate and non-linear time scale for every available pointwise sample.
The linear growth rates are computed using a linear Vlasov solver. The non-linear time scales are evaluated from increments with spatial lag of the proton-inertial length. We observe that both linear and non-linear time scales are distributed intermittently in space, with enhanced values near current sheets. However, for the micro-instabilities to have any dynamically significant effect, it is essential for the instabilities to grow sufficiently faster than the local non-linear processes. For only a small fraction of the available samples, linear time scales become faster than the computed non-linear time scales. These results imply that proton-micro-instabilities, when present, probably do not modify the large-scale dynamics in the evolution of a turbulent plasma.

Introduction

Temperature Anisotropy: Ratio of perpendicular to parallel components of temperature

$$R_p = \frac{T_{\perp p}}{T_{\parallel p}}$$

Parallel beta: Ratio of parallel thermal energy density to magnetic energy density

$$\beta_{\parallel p} = \frac{n k_B T_{\parallel p}}{{B_0}^2/2\mu_0}$$

Linear growth rate: Imaginary part of the solutions to the linear dispersion relation derived using Vlasov equation

$$\gamma_{\max} \equiv \max_{\mathbf{k}} \Im(\omega)$$

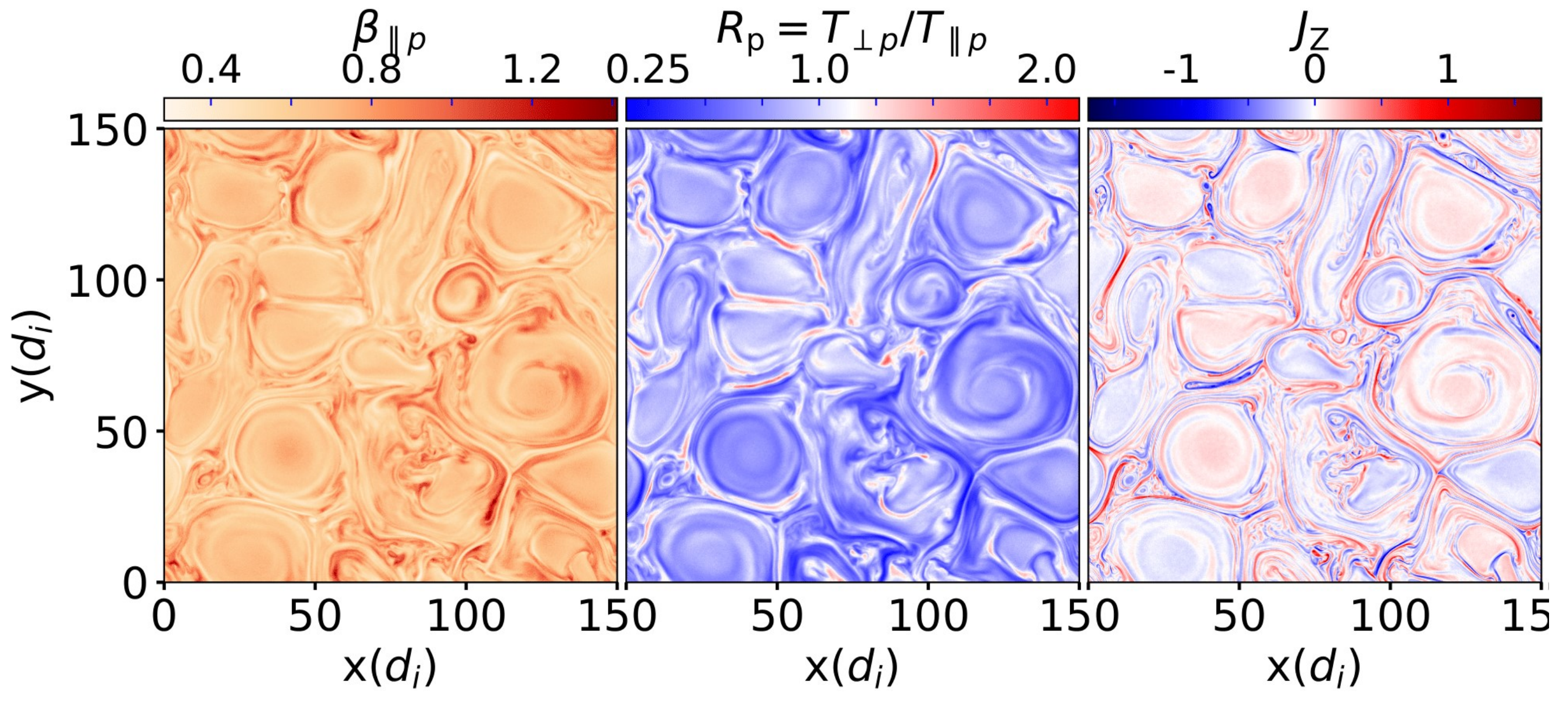
Non-linear growth rate: $\tau_{\rm nl}(\mathbf{r}) \sim \ell/\delta b_\ell$

where $\delta b_\ell = |\hat{\boldsymbol{\ell}} \cdot [\mathbf{b}(\mathbf{r}+\boldsymbol{\ell}) - \mathbf{b}(\mathbf{r})]|$

Results from 2.5D PIC simulations

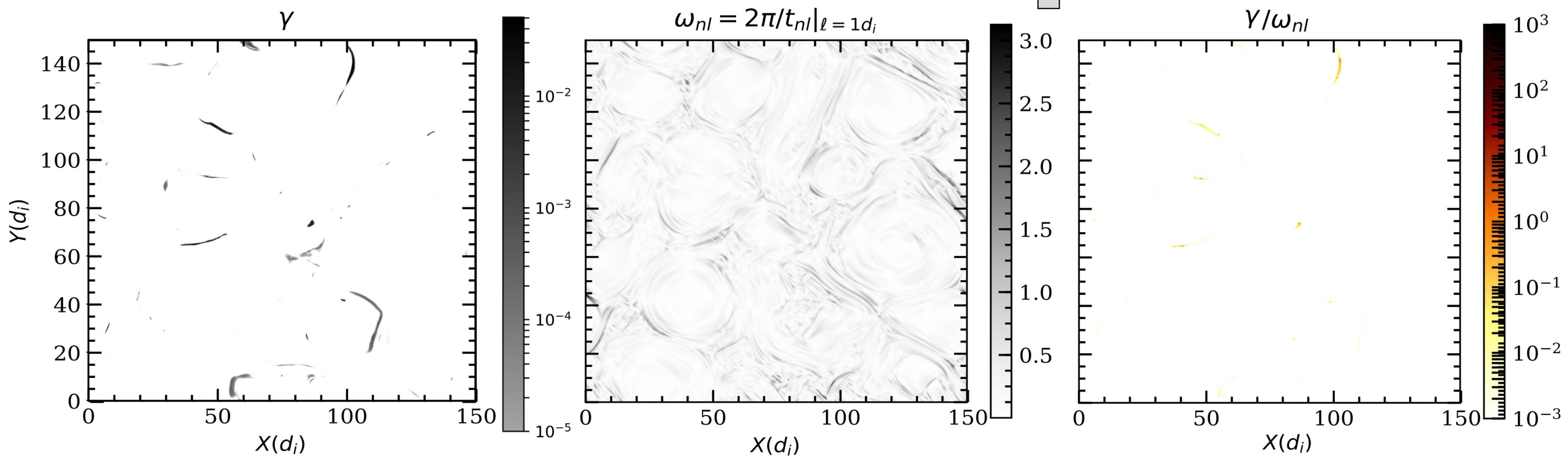
Initial conditions: $\beta_p = \beta_e = 0.6, T_p = T_e\, R_p = 1, \mathrm{N_x} = \mathrm{N_y} = 4096, \mathrm{n} = 3200/\mathrm{cell}, \delta b = 0.5 B_0, \delta v = 0.5 V_0$

Colorplot of various palasma parameters from a fully kinetic 2.5D PIC simulation.

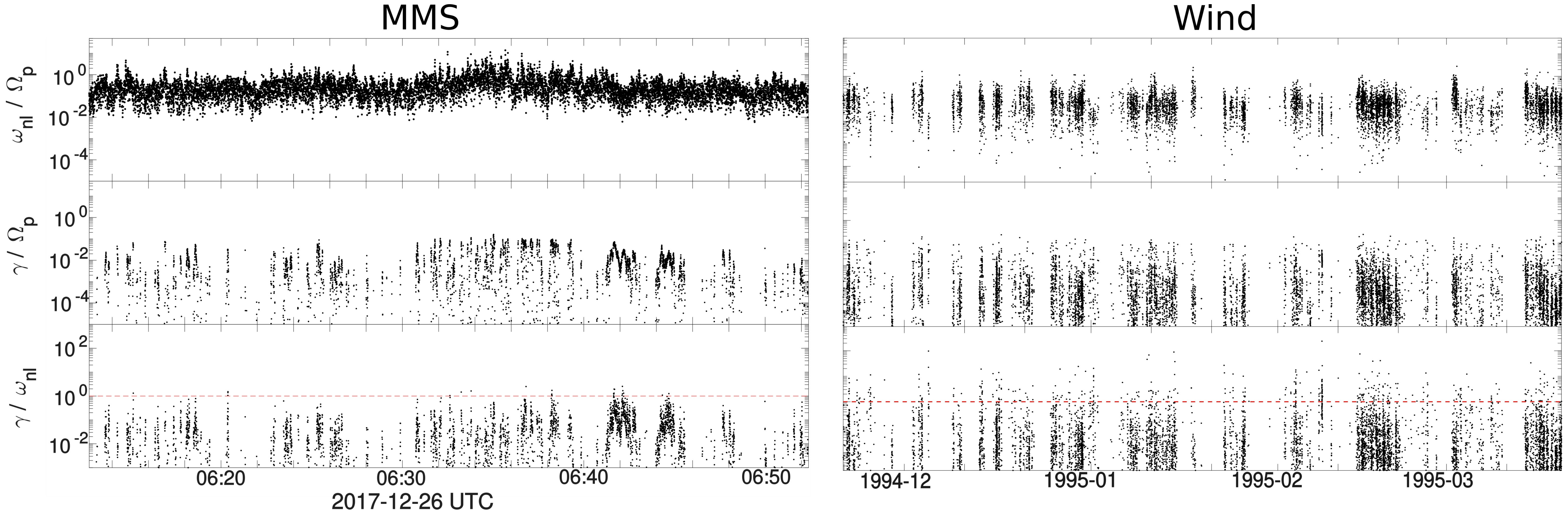


- $\beta_{\parallel p}$ and R_p values are very intermittently distributed.
- Current sheets occur in the regions where anisotropy is high/low.

- Extreme values of growth rates occur in the regions close to current sheets, though not exactly on top of it.
- Significantly larger value of non-linear time scale compared to the linear time scales.
- Very few points where linear time scales are faster than the non-linear times



Results from MMS and WIND



- Similar number of parallel and oblique instability growth rates above threshold for both magnetosheath and solar wind observations.
- Significatly higher number of growth rates above threshold observed for both MMS and Wind spacecraft compared to PIC simulation results. This, in part, could be attributed to higher value of in space plasma.
- Intermittent structure is observed for both MMS and Wind, implying similar driving mechanism in space plasma as PIC simulation.
- Very few points where linear time scales dominate compared to non-linear scales. (< 1%)
- Distribution of $\gamma_{\max}$ in two observations in time are very similar supporting the scale independence of turbulent structures and potentially fractal nature.

Conclusion and Discussion

- In all cases, simulation as well data from MMS and Wind, we find that the microinstabilities occur intermittently in the plasma.
- Simulation shows indications that the instabilities preferentially occur near current sheets.
- This suggests that, though microinstabilities affect the plasma globally, they act locally and develop in response to extreme temperature anisotropies generated by turbulent structure.
- For the most part, non-linear time scale dominates over linear time scale.
- Distribution of growth rates in both the spacecraft measurements supports the scale independence of turbulence.

Future Work

- Study the correlation between and J_z, by using the propinquity method.
- Study the distribution of the width of growth rates from both simulation as well as MMS data.
- Take into account other ion species with more sophisticated treatment of the VDFs
- Consider the wavelengths obtained from the linear Vlasov solver and compare them to the relevant lengthscales in real space

References and Acknowledgements

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