SH25A-2068 Interplay Between Linear and Nonlinear Processes in Simulation and Space Plasmas

Ramiz A Qudsi[1], Riddhi Bandyopadhyay[2], A. Maruca[3,4] and William H. Matthaeus[3,4]

[1]Center for Space Physics, Boston University, MA, [2]Department of Astrophysical Sciences, Princeton University, NJ, [3]University of Delaware, [4]Bartol Research Institute, Univ of Delaware, DE

Abstract

Over the last few decades, two different theoretical frameworks have been developed to study formation and evolution of space plasmas such as the solar wind and terrestrial magnetosheath. One uses linear Vlasov theory to explore micro-scale phenomena: the effects of waves and the constraints imposed by microinstabilities on the plasmas. The other includes the larger mesoscales and focuses on non-linear processes such as turbulence and the coherent structures it generates.

These two processes occur simultaneously in both space and time and are entangled together at different scales. Consequently, there is an implied competition between the two processes to determine which one dominates given a set of conditions in the space plasmas. We look at the two processes simultaneously, using the associated time scales in six different datasets (3 fully kinetic PIC simulations and 3 spacecraft observations) to see the result of this competition as well as the dynamics between the two. We compare the time scales of two processes to see which one dominates and report our results. We also explore why linear theory seems to work in space plasmas as well as it does.

Introduction

Ion VDFs of space plasmas exhibit temperature anisotropy which leads to microinstabilities fueled by the free energy in the system. These instabilities act to make the system more isotropic. Turbulence is another process by which the opposite affect can be achieved. Thus at any point these two processes are either feeding off of each other or are competing in the system. However, since these two processes compete with each another to influence the plasma, it remain unclear as of now which one dominates and drive the large scale phenomenon. We present a study of the time scales at which the two processes work and compare them in different types of plasmas.

Methodology and Results

For this study we considered 6 different datasets. Three datasets are fully kinetic PIC simulations (two 2-D and one 3-D) and three others are spacecraft observations (magnetosheath data from MMS and solar wind data from PSP and Wind).

For each dataset we compute the maximum of linear growth rate, Γ_{max}, as:

$$\Gamma_{\text{max}} = \max\left(\gamma_{\text{max,cyclotron}}, \gamma_{\text{max,mirror}}, \gamma_{\text{max},\|\text{firehose}}, \gamma_{\text{max},\nparallel\text{firehose}}\right)$$

The non-linear growth rate is computed as:

$$\omega_{\text{nl}} \sim \delta b_l / \ell$$

where δb_l is the change in the longitudinal magnetic field and is given by:

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

Where b is the total magnetic field expresses in local Alfven speed units.

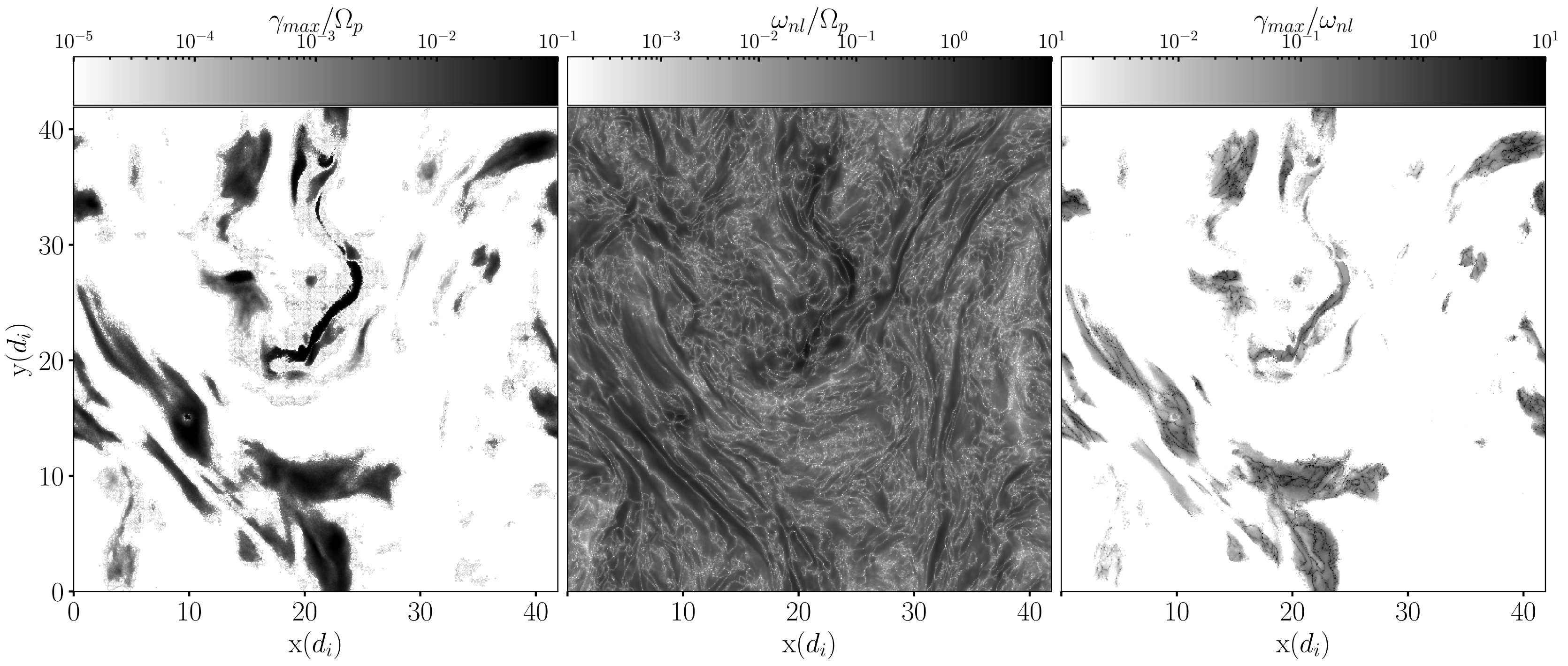

Figure 1: Comparison between linear and non-linear frequencies for 3-D dataset

Figure 1 shows a comparison between linear and non-linear growth rates on a cross section of the xy-planes of the full 3-D box. Linear growth rates are located intermittently, whereas non-linear growth rate is spread over the whole box and on average appears to be a lot more stronger than their linear counterpart.

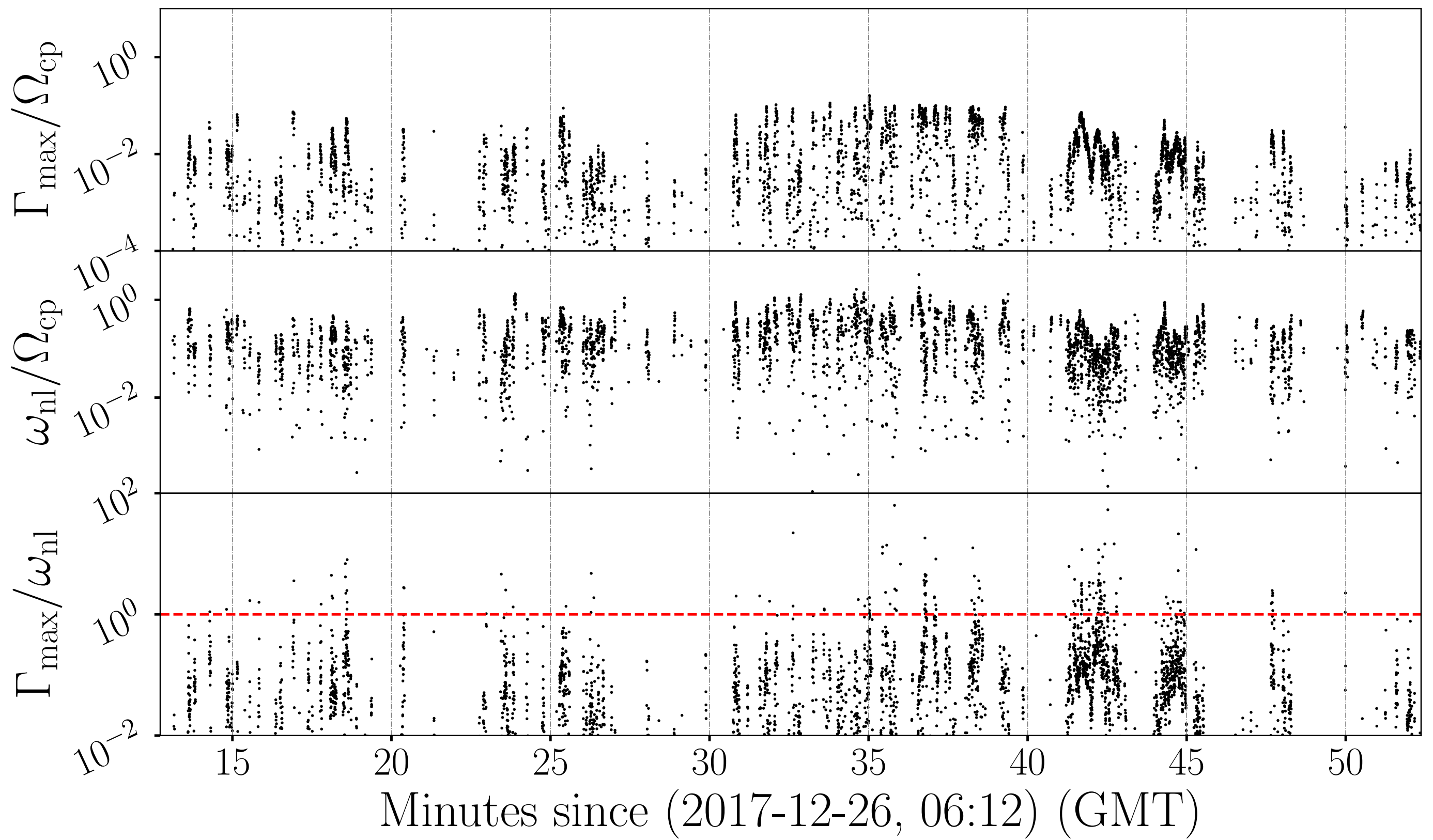

Figure 2: Time series comparison of linear and non-linear frequencies of MMS

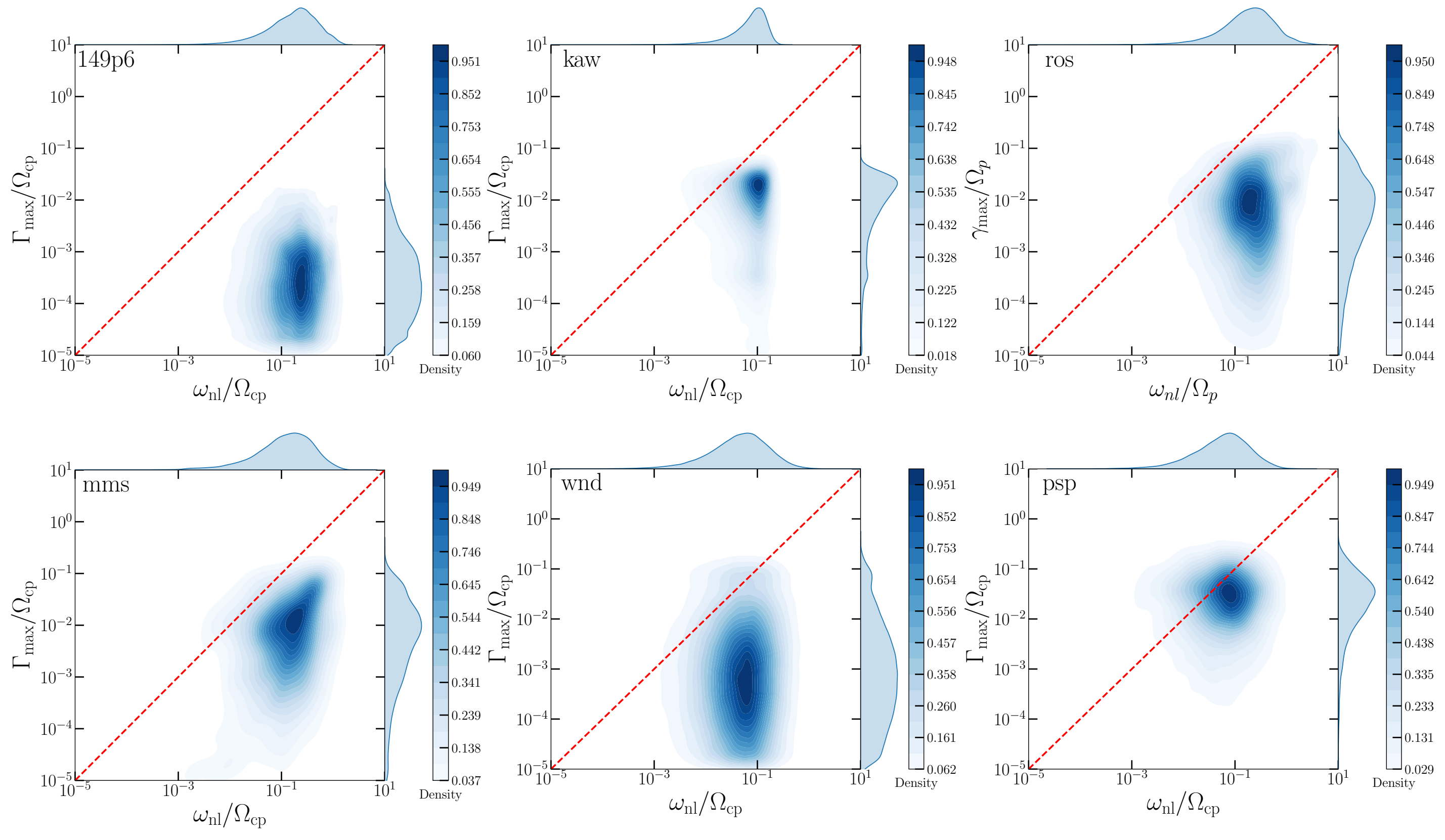

Figure 3: KDE plot of different datasets.

Figure 2 shows a similar comparison for time series data from MMS observation in the magnetosheath. For this case we show non-linear growth rate only at points where linear growth rates are greater than the set threshold of 10^{-5} Ω_p, where Ω_p is the proton gyrofrequency. For this case too we see (bottom most panel in Figure 2), that the non-linear growth rate is far more dominant than the linear ones. Consequently one would assume that they play dominant role.

However, the dynamics is not governed by just the number of points with higher non-linear frequencies, but also is a matter of where they occur in the R_p,$\beta_{\|p}$ plane. Figure 4 shows a Brazil-plot for solar wind data from Wind spacecraft for total number of observations, linear and non-linear growth rates and their ratios. We observe that along the edges linear growth rate dominates.

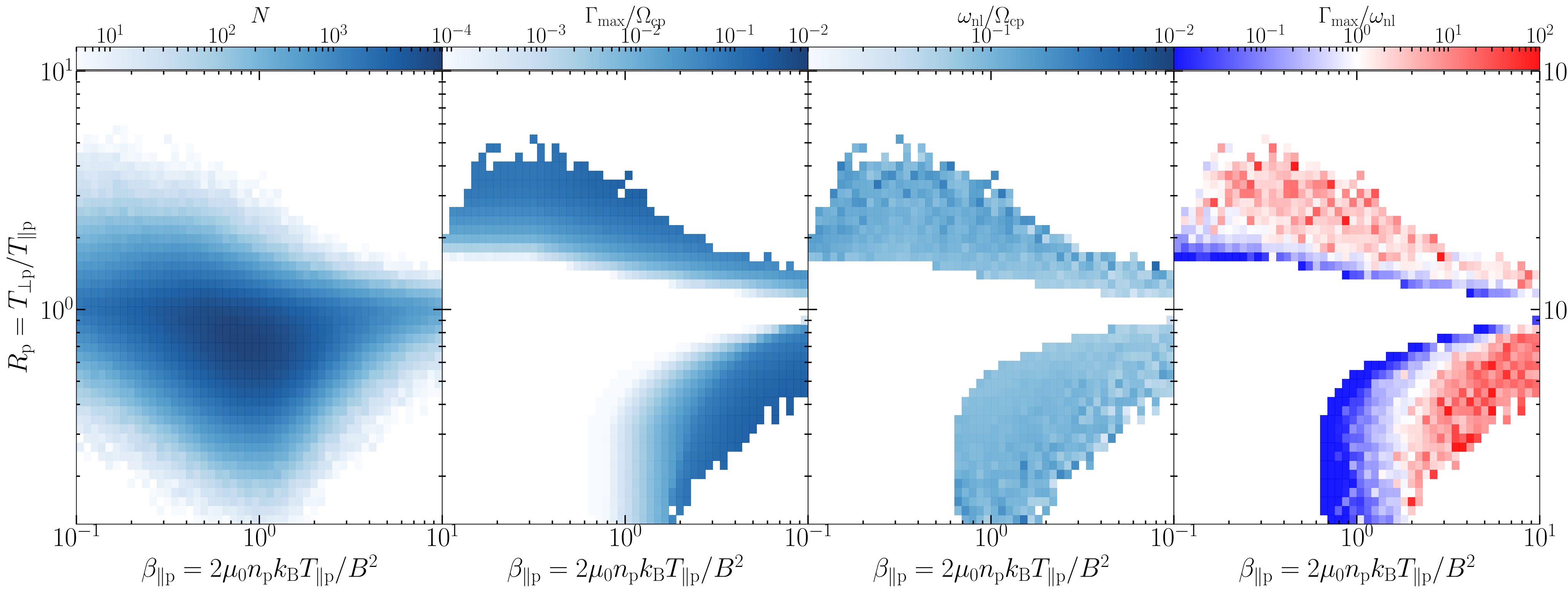

Figure 4: Brazil plot comparison of linear and nonlinear frequencies for Wind dataset

Conclusion and Discussion

- We compare the linear and non-linear growth rates of six different datasets. Figure 3 displays the kernel density plot for all the datasets and shows that for all six cases for an overwhelming number of points the value of non-linear growth rate is larger than the linear ones.
- Consequently, we would expect non-linear processes to dominate the dynamics of space plasmas. However, observations made over last three decades have presented empirical evidence of agreement between the observations and theoretical predictions of linear theory.
- Location of growth rates on a Brazil-plot shed some light on why despite the apparent dominance of turbulence, linear theory continues to work as well as it does. Simply put, in regions where linear instabilities must work for the observations to agree with predictions, they are strong enough to be faster than non-linear growth rates and thus control the dynamics of the space plasmas.

References

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