Kinetic Regulation of turbulence in the Earth's magnetic environment

Pablo S. Moya[1]
[1] Departmento de Física, Facultad de Ciencias, Universidad de Chile, Santiago, Chile
e-mail (speaker): pablo.moya@uchile.cl

Velocity distribution functions in space plasmas exhibit a variety of non-thermal features that deviate from thermal equilibrium. These deviations from equilibrium provide a local source for electromagnetic fluctuation emissions, including the commonly observed electron whistler-cyclotron and firehose instabilities (at electron scales), and ion-cyclotron or firehose instabilities (at ion scales). Among the fundamental and most challenging problems of laboratory, space, and astrophysical plasma physics is to understand the relaxation processes of nearly collisionless plasmas toward quasi-stationary states and the resultant states of electromagnetic plasma turbulence.

Recently, it has been argued that solar wind plasma β and temperature anisotropy observations may be regulated by kinetic instabilities such as the ion cyclotron, mirror, electron cyclotron, and firehose instabilities[1,2]; and it has been argued that magnetic fluctuation observations are consistent with the predictions of the fluctuation–dissipation theorem[3], even far below the kinetic instability thresholds. Indeed, using data obtained with the Wind spacecraft, for ions and electrons, it has been clearly shown that the temperature anisotropy threshold of the cyclotron anisotropic instability bounds solar wind plasma measurements[1,2]. Thus, collisionless wave–particle interactions seem to play an important role in the regulation of the plasma. In addition, collisions—while infrequent—also play a role, leading the plasma to isotropization, particularly in the slow solar wind. Here, using in situ magnetic field and plasma measurements by the THEMIS and Wind missions, we show that such regulation seems to occur also in the Earth's magnetotail[4] plasma sheet and magnetosheath[5], at the ion and electron scales.

In the case of the magnetospheric tail we have shown that temperature anisotropy at the kinetic level can regulate turbulence in the plasma sheet of the geomagnetic tail. Furthermore, our results also suggest that physics at the kinetic level may be a relevant contributor to the magnetic fluctuations observed in these plasmas. We demonstrated that the resonant Alfvén and whistler instabilities may regulate the observed anisotropies for values above unity. Electron anisotropies seem to be constrained by the nonresonant firehose instability, while for ion anisotropies this statement is still not clear. The ion and electron cyclotron instabilities seem to operate on timescales comparable to the scales of protons or electrons. This does not seem to be the case for the firehose instabilities. Thus, more work and precise measurements are needed to understand these results[4].

Our results also indicate that inside the magnetosheath the plasma is efficiently regulated by the whistler-cyclotron and electron firehose instabilities, consistent with previous results in different regions of space. The magnetic fluctuation level increases with the plasma beta value and as the state of the plasma approaches the instability thresholds. Finally, compared to the case of the solar wind, we can conclude that the magnetosheath plasma behaves very similarly to the slow solar wind during the same time interval. However, differences do exist, particularly at magnetic compressibility distributions, considerably larger than in the slow solar wind near the whistler-cyclotron instability threshold[5].

In summary, regardless of the clear differences between the solar wind, magnetotail, and magnetosheath environments, our results indicate that spontaneous fluctuations and their collisionless regulation are fundamental features of space and astrophysical plasmas, thereby suggesting the process is universal.

References

[1] S. D. Bale *et al*, Phys. Rev. Lett. **103**, 211101 (2009)
[2] M. L. Adrian *et al*, Astrophys. J. **833**, 49 (2016)
[3] R. E. Navarro *et al*, Phys. Rev. Lett. **112**, 245001 (2014)
[4] C. M. Espinoza *et al*, Astrophys. J. **924**, 8 (2022)
[5] P. S. Moya *et al*, in preparation (2022)