A new Cosmic-ray driven instability

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July 15, 2021

In this talk, I discuss the linear instabilities driven by CRs with a gyrotropically cold momentum distribution. Linear regime solutions show that CRs with a finite pitch angle drive a dominant intermediate-scale instability between the ion and electron gyroradii, if the CRs drifting velocity $v_{\rm dr} < v_A^e/2$, where v_A^e is the Alfvén speed of electrons.

The intermediate-scale instability excites ion-cyclotron wavemodes co-moving with the CRs that drive them (along the background magnetic field). Their growth rate is typically more than an order of magnitude faster than that at the gyroscale of CR ions, and it is artificially suppressed in the solution of the dispersion relation of gyrotropically cold CRs when the popular assumption $\omega \ll \Omega_i$ is adopted. This suggests that by considering the contribution of CRs with a power-law momentum distribution without such an assumption, a similar instability would arise.

Using an ab inito kinetic (full PIC) simulation, we demonstrate the growth of the dominant intermediate-scale instability and study the non-linear saturation in the simulation. We show with analytic arguments, which are confirmed by our simulation, that during the initial growth phase, the electromagnetic (ion-cyclotron) wavemodes exert only work in the parallel direction so that the CR distribution is primarily spread along the Background magnetic field.

In [1], we identify a number of major areas of research in which the intermediate-scale instability should play a decisive role. In this contribution we discuss 2 of these areas. First, We show using analytical argument, that depending on the nonlinear saturation of the instability, it could greatly enhance CR-induced pressure gradients and thus have important implications on both stellar and galactic scales. Moreover, since this instability is typically not damping via ion-neutral damping (friction), it could provide an efficient way of coupling MeV CRs to partially-ionized molecular clouds. Second, We show using a PIC simulation how Intermediate-scale instability plays an important role in setting the downstream electron temperature, and subsequently solving the electron-injection problem in magnetizied electron-ions non-relativistic shocks.

References

[1] Shalaby, M., Thomas, T., & Pfrommer, C. 2021, ApJ, 908, 206