PIC simulations of the magnetorotational instability (MRI) in stratified, collisionless accretion disks

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Abstract

The magnetorotational instability (MRI [1,2]) is an MHD instability that generates turbulence and produces outward angular momentum transport in various astrophysical accretion disks. For this reason, for many years the MRI has been recognized as of paramount importance in astrophysics for making the gas accretion process efficient. In low-luminosity accretion disks around black holes, the accreting gas is essentially a fully ionized plasma where particle-particle Coulomb collisions occur very infrequently, which makes these disks effectively “collisionless”. These collisionless accretion disks around black holes are very common at the center of nearby galaxies (including Sgr A*, at the center of our own Milky Way), and for that reason they have become the target of cutting edge observational efforts like the Event Horizon Telescope (EHT [3]) and GRAVITY [4], which are aimed to understand in detail the physics of plasmas and gravity under the most extreme conditions. The fact that these disks are collisionless makes the interpretation of the observations challenging, essentially because local thermodynamic equilibrium can not be assumed. This characteristic gives rise to several kinetic plasma physics effects that could modify the MRI evolution and generate important observational effects.

We present results of 2D and 3D fully kinetic, particle-in-cell (PIC) plasma simulations of the collisionless MRI. Our simulations are local and stratified, which means that we use the local, shearing box approximation and self-consistently include the vertical structure of the disk. We concentrate on the sub-relativistic plasma regime, relevant at tens of gravitational radii from the central black hole, and quantify the ability of the MRI turbulence to transport angular momentum and to accelerate non-thermal particles (or “cosmic rays”). We find that both angular momentum transport as well as particle acceleration in our stratified simulations are, on average, significantly more efficient than in the case where disk stratification is not included.

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References

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