PPI suppression by the MRI in relativistic accretion disks

M. Bugli[1,2], J. Guilet[2], E. Müller[1,2],
L. Del Zanna[3,4,5], N. Bucciantini[4,5], P. Montero[1]

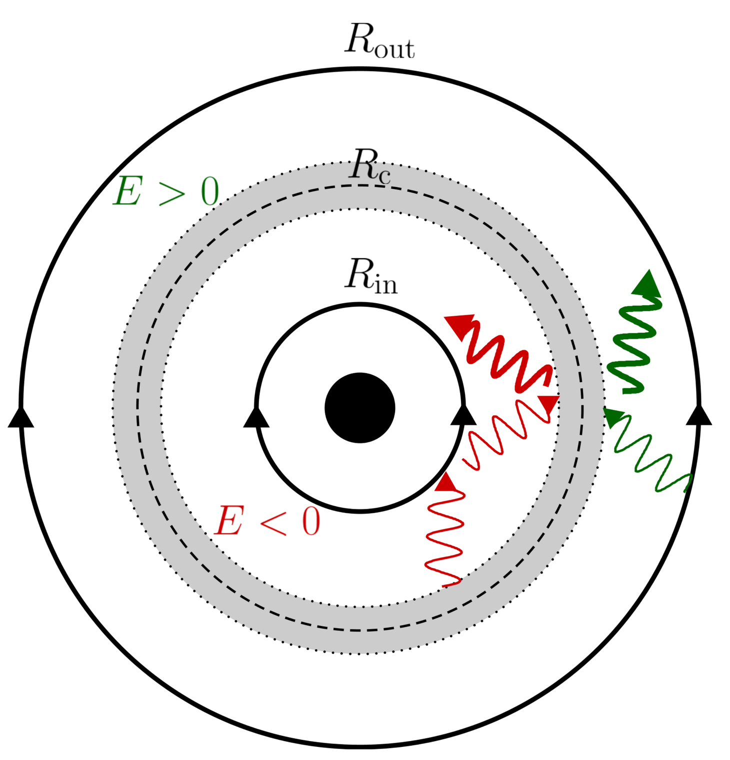
[1]Max Planck Institut für Astrophysik, Garching bei München;[2] CEA-Saclay, France;
[3]Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze; [4]INAF, Osservatorio Astrofisico di Arcetri, Firenze; [5]INFN, Sezione di Firenze

Abstract

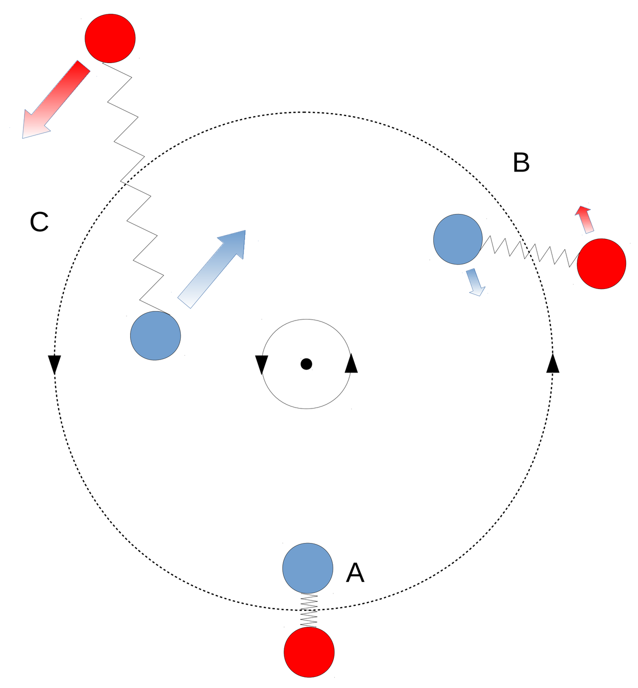
Geometrically thick tori with constant specific angular momentum have been widely used in the last decades to construct numerical models of accretion flows onto black holes. Such disks are prone to develop a global non-axisymmetric hydrodynamic instability, known as Papaloizou-Pringle instability (PPI), which can redistribute angular momentum and also lead to gravitational waves emission. It is, however, not completely understood how the linear development of the PPI is affected by the presence of a magnetic field and by the concurrent growth of the magnetorotational instability (MRI). Using three-dimensional GRMHD simulations we studied the interplay between the PPI and the MRI considering, for the first time, an analytical magnetized equilibrium solution as initial condition. In the purely hydrodynamic case, the PPI selects the large-scale $m = 1$ azimuthal mode as the fastest growing and non-linearly dominant mode. However, when the torus is threaded by a weak toroidal magnetic field, the development of the MRI leads to the suppression of large-scale modes and redistributes power across smaller scales, even if the system starts with a significantly excited $m = 1$ mode. Furthermore, the damping of large-scale non-axisymmetric modes occurs rather independently from the initial magnetization or perturbation spectrum.

Papaloizou-Pringle instability

- Thick disks with sub-keplerian angular momentum are most susceptible to PPI
- Global non-axisymmetric hydrodynamic instability
- Positive- and negative-energy waves couple through the resonance at the corotation radius
- Transport of angular momentum outwards and formation of long-lasting large-scale structures
- Significant emission of gravitational waves (Kiuchi et al. 2011)



Magnetorotational instability



- Disks are locally hydrodynamically stable by the *Rayleigh criterion*:

$$\frac{d(R^4\Omega^2)}{dR} > 0$$

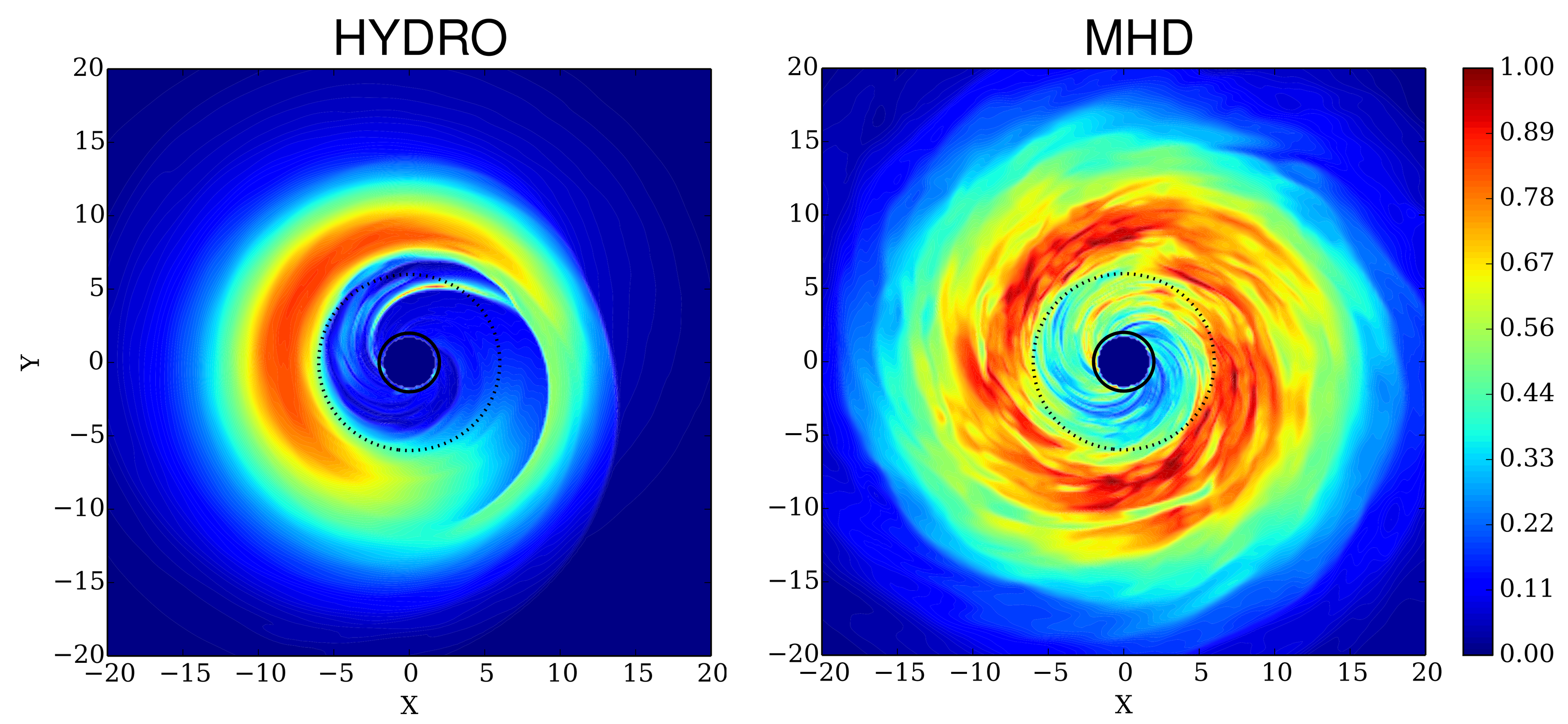
- But they are MHD unstable:

$$\frac{d(\Omega^2)}{dR} < 0$$

- Local instability
- Independent of field strength and orientation
- Growth on dynamical time scales (Balbus&Hawley 1998)

Global structure

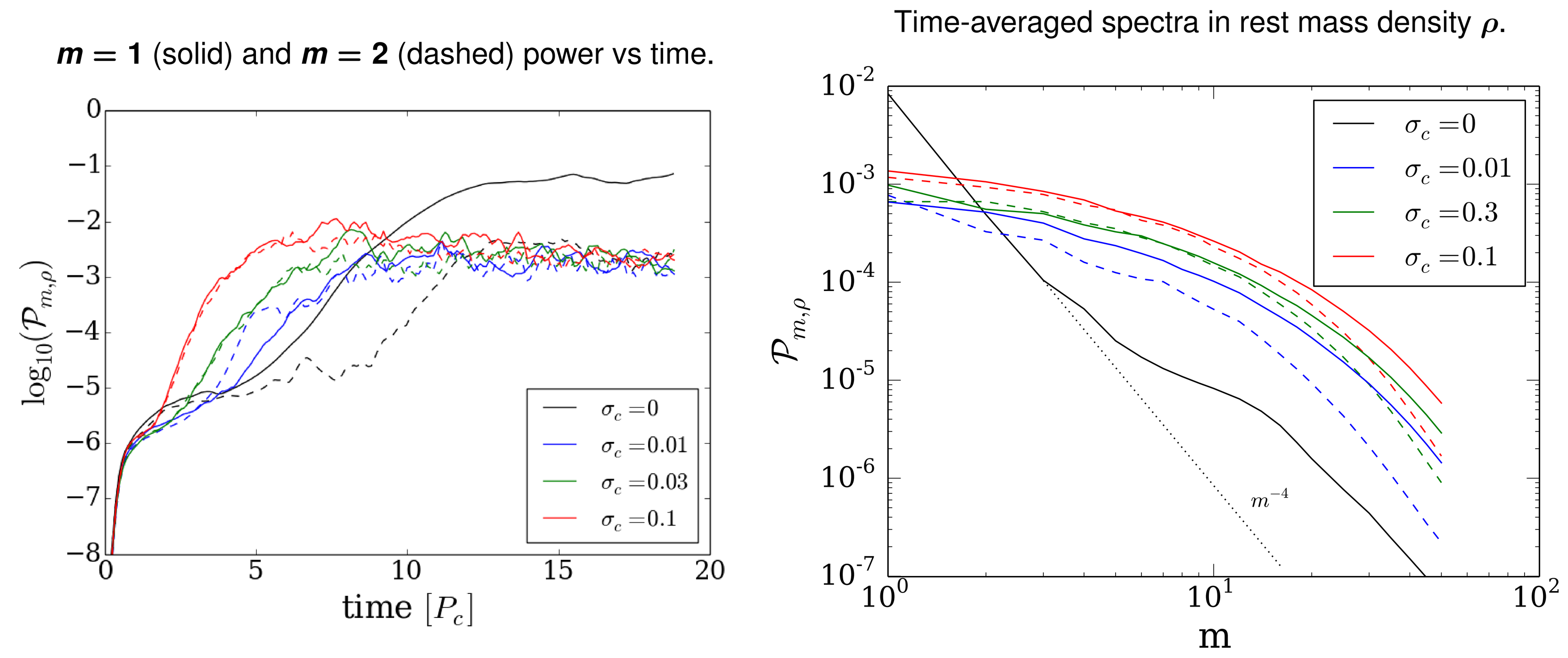
- Purely toroidal magnetic field in equilibrium with the gas (Komissarov 2006)
- No transient during the linear development of both instabilities



- Large-scale $m = 1$ mode selected by PPI
- Smooth flow, limited accretion

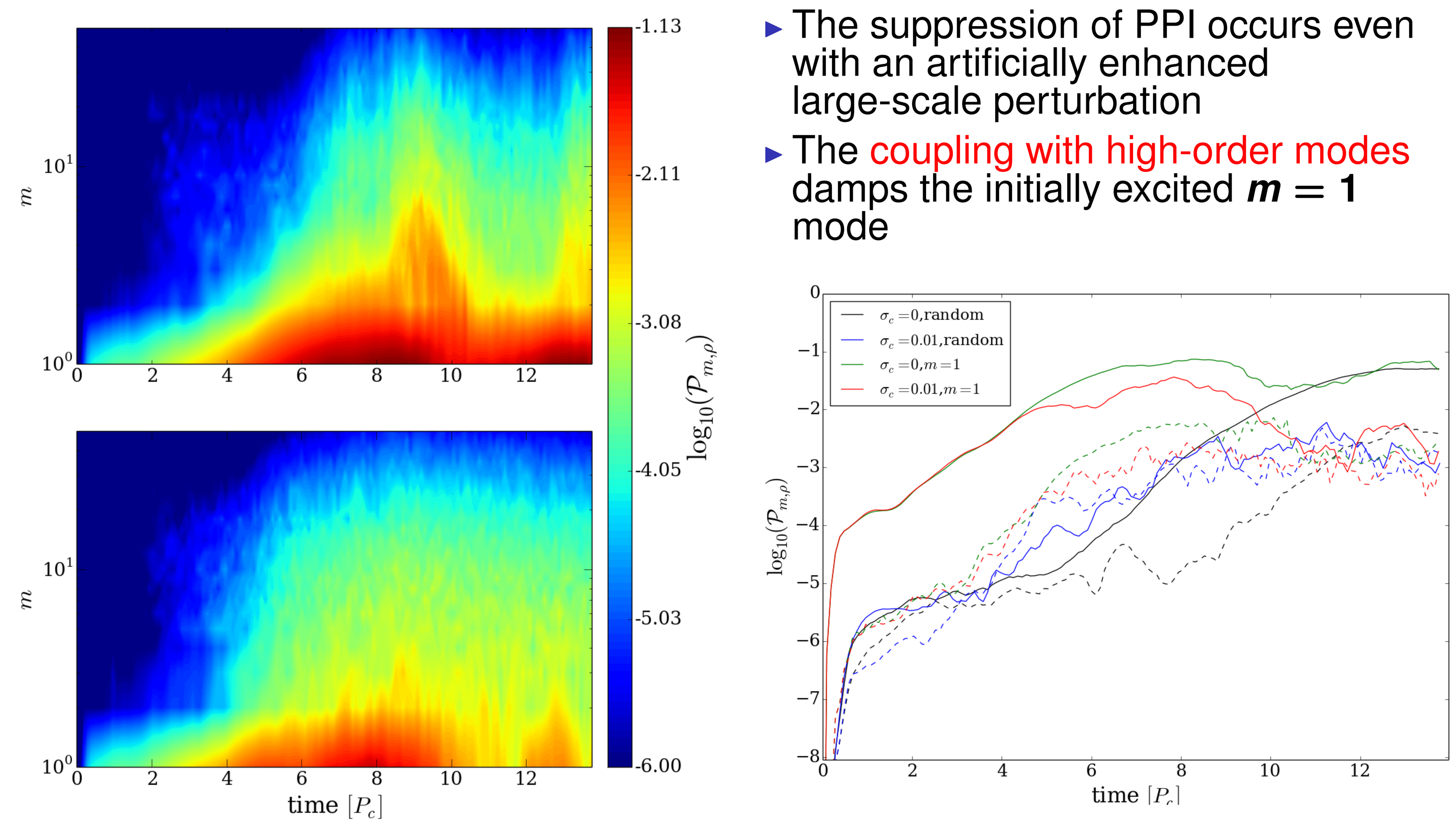
- Small-scale MHD turbulence
- No clear low m mode excited
- Higher stresses and accretion

Modes power and spectra



- Suppression of the $m = 1$ mode, regardless of the magnetic field strength
- Excitation of high-order modes by the MRI, faster for stronger magnetic fields
- Unresolved MHD turbulence (dashed spectra) can produce power excess on large-scales at the expense of small-scale modes

Initial perturbations

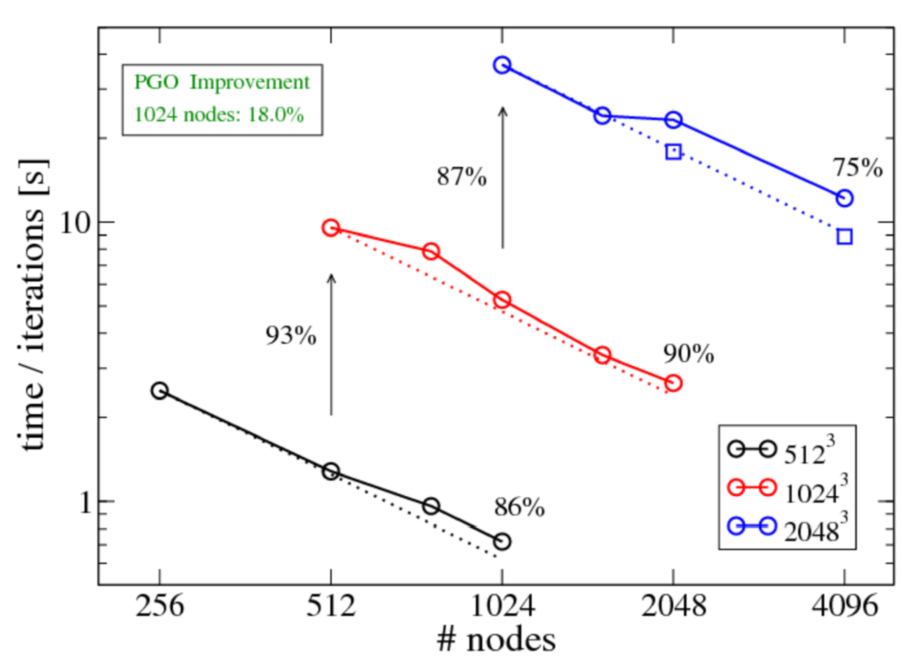


- The suppression of PPI occurs even with an artificially enhanced large-scale perturbation
- The coupling with high-order modes damps the initially excited $m = 1$ mode

Code and parallelization

Improved version of the GRMHD code `ECHO` (Del Zanna et al. 2007):

- `MPI` multidimensional domain-decomposition
- Parallel `MPI-HDF5` I/O management
- Strong and weak scalability up 2048^3 grid-points
- Simulations launched on SuperMUC @ LRZ, Garching



Results and perspectives

- General suppression of the $m = 1$ azimuthal mode selected by PPI and excitation of high-order modes by the MRI development
- Distribution of power among different length-scales independent of magnetic field strenght and initial perturbations
- Numerical dissipation can quench the MRI growth and lead to some excess of power on large-scales

Current developments and improvements:

- Effects of turbulent magnetic resistivity on the MRI quenching and PPI revival
- Role of the disk's self-gravity in the excitation of the $m = 1$ mode and effects of a kick velocity in the black hole

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