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Variability of magnetically-dominated jets in blazars and gamma ray bursts

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Abstract. The fastly variable accretion flows are found in a number of different types of astrophysical black hole sources. At largest scales, they are present in the cores of active galaxies. In the radio-loud objects, such as blazars, the variability of the inflow can be transmitted to the outflow properties. In these sources, the relativistic jets are pointing to our line of sight. In addition, many similarities are found between the jet physics in blazars and in gamma ray bursts. The latter are observed from extragalactic distances, but operate at smaller scales, within the stellar-mass accreting black holes and in collapsing star's environment. Observational studies have shown an anti-correlation between minimum variability time scale and Lorentz factor of the emitted jet. Motivated by those observational properties of black hole sources, we investigate the accretion inflow and outflow properties, by means of numerical GR MHD simulations.

Keywords. accretion, accretion disks, black hole physics, magnetic fields, hydrodynamics, MHD, gamma rays: bursts, galaxies: jets

1. Introduction

Blazars and gamma ray bursts share the properties of their jets, despite different Lorentz factors and accreting black hole masses (Wu et al. 2015). Launching and collimation mechanisms are common: thick disk or corona, pressure gradient in surrounding wall, external (matter dominated) jet, or toroidal magnetic field. Acceleration of jets occurs due to both magnetic field action field and accretion disk rotation (see Fragile 2008 for a review). The blazar jets are Poynting-dominated, and powered by the Blandford-Znajek mechanism which can extract energy from a rotating black hole. This mechanism is now well known and tested in the purpose of a jet launching, but observations are showing variability in the jet emission. Multiple shocks that collide in the jet, can lead to multiple emission episodes and can account for the fluctuating light curve. A reasonable interpretation of this effect is that the variability observed in the jets can directly reflect the central engine variability. The latter is tightly related to the action of magnetic fields in the center of the galaxy.

We present here the two-dimensional magneto-hydrodynamical models computed in full General Relativity (GR MHD). The numerical scheme is our implementation of the code HARM (Gammie et al. 2003, Janiuk et al. 2013). The properties of magnetic fields and their role in evolution in the flows are studied in detail. Our intial condition assumes the existence of a pressure equilibrium torus, embedded in the poloidal magnetic field which lines follow the isocontours of constant density (Fig. 1 left and middle panel). The Kerr black hole accretes matter from the torus, and the rotation affects the magnetic field evolution. The models are parameterized with the black hole spin, and the initial magnetization of the matter. Code works in GR framework, so dimensionless units are adopted, with $G = c = M = 1$. Hence, geometrical time is given as $t = GM/c^3$, where

M is the black hole mass. In this way, we are able to model the launching and variability of jets in both supermassive black hole environment, and in gamma ray bursts.

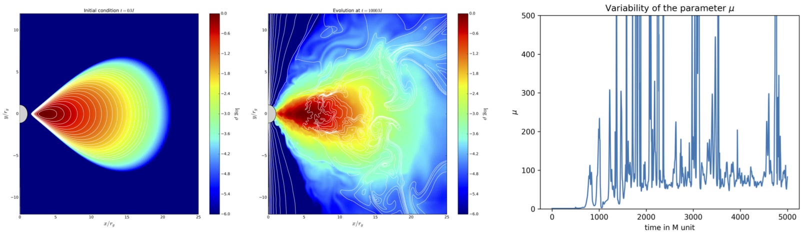

Figure 1. Left: initial configuration of the simulation (logarithm of density, in the code units). Middle: evolved state, after 1000 geometrical time units. Right: Variability of the μ parameter in time.

2. Variability of the jet

Energetic parameter. Variable energy output reflects the MRI instability timescale, which is well resolved through the adequate number of grid cells per MRI wavelength. The total plasma energy flux is given by parameter $\mu = -T^r_t/\rho u^r$. If the Poynting and thermal energy are fully transformed to bulk kinetic, the parameter μ can be interpreted as the Lorentz factor at infinity (Vlahakis & Koenigl 2003). Its value depends on location in the jet.

Correlation between Lorentz factor and minimum variability time scale. The minimum variability timescale, MTS, can be anti-correlated with the bulk Lorentz factor in the jet, if the magnetically arrested (MAD) flow is considered (Lloyd-Ronning et al. 2018). However, in the MAD mode, the flux accumulated at the BH horizon, and the interchange instability rather than MRI governs the minimum timescale of variability. In our simulation the accretion is not in a MAD state, and the Lorentz factor at infinity is given by the μ parameter. Its variability correlates with MRI timescale, interpreted in our model as the origin of the variability in the jet (Fig. 1 right panel).

3. Conclusions

The variable energy output from the central engine implies the varying jet Lorentz factor, which may lead to occurrence of internal shocks, and affect both GRBs and blazars observed variability. Unification of the models accross the black hole mass scale, from GRBs to blazars, is not straightforward though. The most uncertain aspect is whether the MAD state drives the jets in both type of sources, or rather halts the GRB emission.

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