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Exploring the feedback of asymmetric jets on the orbital motions in protoplanetary disks

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Abstract. Protoplanetary disks are often associated with powerful bipolar jets. In most cases the two jet lobes carry a different amount of linear momentum. We investigate the dynamical feedback of such an asymmetric jet on its launch region in the disk. We adopt a Hamiltonian formulation and solve for the departures from the initial Keplerian orbits with a symplectic integrator. The back-reaction effect produces a shift in the position of the orbits toward the weaker jet lobe, deforming the shape of the inner disk. The loci of the orbits oscillate quasi-periodically, alternating radial and vertical displacements. The amplitude is a small fraction of the disk thickness, and is proportional to the momentum imbalance. Such motions can contribute to the onset of turbulence, and to the mixing of molecular material.

1. Introduction

The evolution of protoplanetary disks is widely studied, as it leads to the accretion of mass onto the central star and to the formation of planets. There are still however many unsolved issues, as the mechanism of formation of large agglomerates (Birnstiel et al. 2016) or the assembly and release of complex molecules. These processes may require the presence of large scale motions, whose origin, however, is still debated (Turner et al. 2014). In this context, we have explored the feedback of bipolar jets (Frank et al. 2014) on the disk structure. The jet physical asymmetries lead to an imbalance in the flux of linear momentum carried by the ejected material of a factor 1.5 - 2 (e.g. Podio et al. 2011). Such imbalance generates a reaction force on the inner disk region, where the jet is launched, that pushes the disk toward the weaker jet lobe. Our aim is to explore how the orbits of the gas particles in the disk are modified by such effect.

2. Method

We consider a gaseous disk, with asymmetric jets accelerated from the inner disk region ($r < 5$ au) in the form of a magneto-centrifugal Disk-Wind (e.g. Ferreira et al. 2006). The disk, schematized in Fig. 1, has a mass density as in Eqs. 6-7 of Sheikhnezami (2012), and is subject to a perpendicular back-reaction force, that leads to a constant pressure on the inner launch region. Dissipative effects are neglected in this first study. Mathematically, the inner disk is

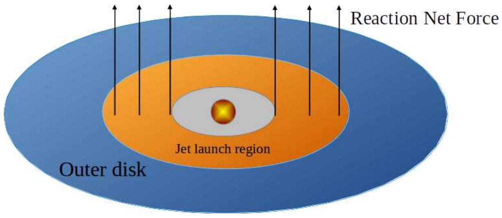

Fig. 1. Scheme of the disk subject to the back-reaction force generated by the linear momentum flux imbalance between the asymmetric jet lobes.

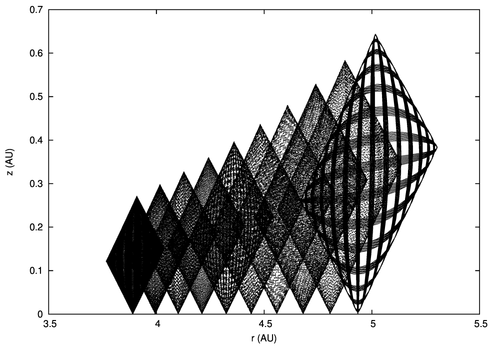

Fig. 2. Variation in 500 yrs of the position of the orbital disk rings in the (r, z) meridian plane caused by the jet back-reaction. Here only 10 rings of the 150 ring disk model are shown. The orbital loci, originally at $z = 0$, oscillate around new average positions z_{eq} located on the side of the weaker jet lobe.

represented as a series of concentric N rings, each with mass and distance from the star calculated as to keep the disk dynamical structure (Locatelli et al. *in prep.*). We seek for the variation with time of the originally Keplerian orbits in such rings, induced by the jet momentum imbalance and mediated by the mutual gravitational interactions. We describe the system with a Hamiltonian formulation, and solve for the motion of each ring in space with semi-analytical and numerical computations, adopting the symplectic methods as in Laskar & Robutel (2001). A similar approach has been followed in the past by Namouni (2007). We explored real systems with stellar mass ranging from 0.08 to 2.9 $M_{\odot}$, with the highest level of jet asymmetry presented by the Herbig AeBe star LkHα 233 (Melnikov et al. 2008).

3. Results

The system is globally accelerated by the jet momentum asymmetry, but the velocity acquired over the outflow phase is 100 times smaller than the average radial velocity of stars in our galaxy. The real interest of the model, however, is in the relative motions of the different components of the system. The back-reaction force causes the rings of matter to oscillate vertically and horizontally on a temporal scale of about the pristine Keplerian period. The loci of the positions of the rings describe with time lozenges in the meridian plane (r, z), as illustrated in Fig 2. Each lozenge is centred on a new average position $z_{eq}(r)$ located on the side of the weaker jet lobe, whose quota is larger for larger momentum imbalance and for smaller disk and stellar masses (Locatelli et al. *in prep.*). With the adopted disk density law, it turns out that $z_{eq}(r) \propto r^{7/2}$, which gives to the inner disk a characteristic curved shape. The maximum amplitude of the oscillations is equal to the displacement itself and in most cases is limited to a few percent of the disk thickness (Locatelli et al. *in prep.*), except in LkHα 233, for which the oscillation covers the whole disk thickness, due to the high momentum imbalance. Despite limited, the observed departure from Keplerian kinematics can be a contribution to the onset of turbulence, and to vertical and radial mixing of the disk material. This process can thus have an effect on the formation of complex molecules in the disk and on the spatial distribution of dust grains.

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