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The role of viscosity in AGN jet formation

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Abstract. Adopting the Smoothed Particle Hydrodynamics (SPH) numerical method we perform a time evolving model of a viscous accretion disc. We find a correlation between viscosity and outflows and a range of values in the Shakura-Sunyaev viscosity parameter α producing periodic outflows. These results give an explanation for the origin of jets and refuelling in Active Galactic Nuclei (AGN). Moreover, we are able to estimate the central supermassive black hole (SMBH) mass by comparison of model variability periods with observed periods in radio light curves of AGN.

Key words. AGN - accretion disc - jet

1. Introduction

Collimated structures of outflowing plasma (jets) are observed in many classes of astrophysical objects: young stellar objects Reipurth & Bertout (1997), X-ray binaries Mirabel et al. (1999), planetary nebula nuclei Lopez (1997), AGN Bragg et al. (2000). In particular, in AGN, jets frequently show non-continuous structures characterized by "blobs" of emission. Moreover, direct observations show that an accretion disc is a common feature for all jet-producing systems. According to some hydromagnetic mechanisms (Blandford & Payne 1982; Li et al. 1992; Tout & Pringle 1996), magnetic fields provide a mechanical connection between jets and discs, in order to explain jet production, confinement and collimation. But fundamental questions remain unresolved about the origin of magnetic fields and their geometry. We present a model where outflows and jets formation is intimately related to the role of viscosity in the accretion disc.

2. The simulations

By using the SPH method Monaghan (1992), we carried out an accretion disc model around a SMBH ($M_{SMBH} = 10^6 - 10^9$ solar masses) Lanzafame et al. (1998). We set the radial velocity v_r and specific angular momentum λ values of injected SPH particles in order to obtain an accretion rate between $1 - 100$ solar masses/year. By modeling viscous discs with the Shakura-Sunyaev viscosity parameter $1.5 \cdot 10^{-3} \leq \alpha \leq 3 \cdot 10^{-3}$, we found that outflows are correlated to the viscosity. In fig.1 the distribution of SPH particles is shown for the $\alpha = 2 \cdot 10^{-3}$, $v_r = 0.1c$ and $\lambda = 1.6$ (expressed in units of $2GM_{SMBH}/c$ with G universal gravitational constant and c velocity of electromagnetic waves in vacuum) model at four different times. Periodical shock fronts develop, drive away from the SMBH and then

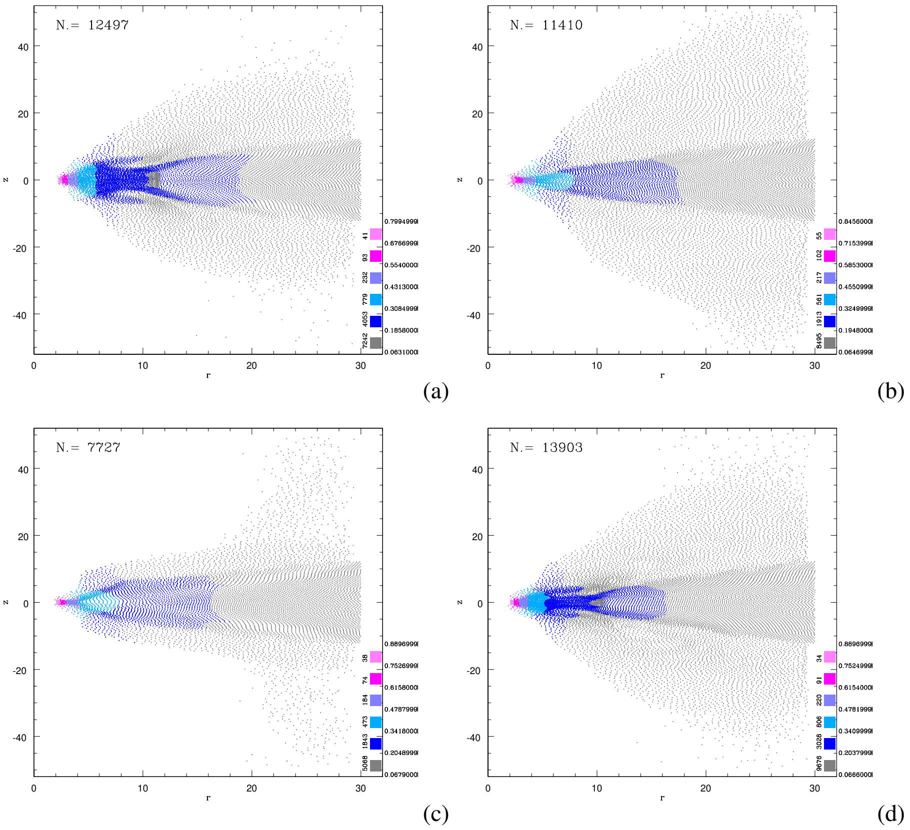

Fig. 1. Location of SPH particles for $\alpha = 2 \cdot 10^{-3}$ and $\lambda = 1.6$ at four different times (r=radial distance from the SMBH; z=height from the disc equatorial plane; N=number of disc particles). Particles with velocity in the same range are showed with the same colour.

Table 1. Outflow periods and SMBH masses.

Name	Outflow period [s]	M_{SMBH} [solar masses] for $\alpha = 2 \cdot 10^{-3}$	M_{SMBH} [solar masses] for $\alpha = 2.5 \cdot 10^{-3}$
0048-097	$4.4 \cdot 10^7 \pm 1.9 \cdot 10^7$	$1.4 \cdot 10^9 \pm 0.6 \cdot 10^9$	$9.8 \cdot 10^8 \pm 4.3 \cdot 10^8$
0235+164	$1.8 \cdot 10^8 \pm 0.3 \cdot 10^8$	$5.6 \cdot 10^9 \pm 1.3 \cdot 10^9$	$4.0 \cdot 10^9 \pm 0.8 \cdot 10^9$
1101+384	$5.6 \cdot 10^7 \pm 2.2 \cdot 10^7$	$1.7 \cdot 10^9 \pm 0.7 \cdot 10^9$	$1.2 \cdot 10^9 \pm 0.5 \cdot 10^9$
1418+546	$4.6 \cdot 10^7 \pm 1.9 \cdot 10^7$	$1.4 \cdot 10^9 \pm 0.6 \cdot 10^9$	$1.0 \cdot 10^9 \pm 0.4 \cdot 10^9$
1803+784	$4.3 \cdot 10^7 \pm 1.6 \cdot 10^7$	$1.3 \cdot 10^9 \pm 0.5 \cdot 10^9$	$9.7 \cdot 10^8 \pm 3.8 \cdot 10^8$
1807+698	$4.0 \cdot 10^7 \pm 2.2 \cdot 10^7$	$1.2 \cdot 10^9 \pm 0.7 \cdot 10^9$	$8.9 \cdot 10^8 \pm 5.0 \cdot 10^8$
2007+777	$4.2 \cdot 10^7 \pm 2.2 \cdot 10^7$	$1.3 \cdot 10^9 \pm 0.7 \cdot 10^9$	$9.3 \cdot 10^8 \pm 4.9 \cdot 10^8$

smooth out. A similar behaviour is obtained for $1.5 \cdot 10^{-3} < \alpha < 3 \cdot 10^{-3}$. From fig.1(a) we can point out that mass loss from the disc takes place in two "channels" above and below the disc mean plane. Indeed, these belts are the regions where the two outflows originate. As a consequence, Fig.1(b) shows the smoothing out of the particle accumulation region and the increase of the number of particles in the outflows. Of course, the number of particles in the disc decreases. In fig.1(c) the shock front previously observed starts again. During such phases we observe a step-like behaviour, corresponding to stages with outflows alternated with stages without outflows. The outflow period is $T_{mod} \simeq (1.60 \cdot 10^{-32} \pm 0.25 \cdot 10^{-32}) \cdot M_{SMBH}\ sec$ for $\alpha = 2 \cdot 10^{-3}$, while it is $T_{mod} \simeq (2.25 \cdot 10^{-32} \pm 0.25 \cdot 10^{-32}) \cdot M_{SMBH}\ sec$ for $\alpha = 2.5 \cdot 10^{-3}$. Therefore, the more massive are the objects, the longer is the period, and for larger values of the α Shakura-Sunyaev viscosity parameter this happens even if the dependence on the viscosity is weak.

3. Discussion

Therefore, from our preliminary results we confirm our hypothesis that the viscosity is connected to the outflows in accretion discs around SMBH. In particular we find that periodic outflows occur for $2 \cdot 10^{-3} \lesssim \alpha \lesssim 2.5 \cdot 10^{-3}$ and non-periodic ones for $\alpha \simeq 3 \cdot 10^{-3}$. The mass loss per unit time reaches its maximum value $\dot{M} \simeq 5 \cdot 10^{-6}$ solar masses·sec^{-1} for $\alpha \simeq 2 \cdot 10^{-3}$ and $\dot{M} \simeq 2 \cdot 10^{-5}$ solar masses·sec^{-1} for $\alpha \simeq 2.5 \cdot 10^{-3}$. Therefore, the mass loss is an increasing function of α. Instead, we observe a continuous mass loss for $\alpha \simeq 3 \cdot 10^{-3}$. In this context, comparing model predictions with observations explains the presence of blobs in jets. No continuous phase of ejection of particles from the disc is observed. So the jet is refuelled periodically. Since these particles are available for synchrotron energy loss, the periodic variations of light curves are also explained. From these simulations we are able to estimate the outflow periodicity T_{mod} for different values of the viscosity and SMBH mass: $T_{mod} \simeq \tau M_{SMBH}\ sec$ (where $\tau = 1.60 \cdot 10^{-32} \pm 0.25 \cdot 10^{-32}$ for $\alpha = 2 \cdot 10^{-3}$, $\tau = 2.25 \cdot 10^{-32} \pm 0.25 \cdot 10^{-32}$ for $\alpha = 2.5 \cdot 10^{-3}$). Therefore, by extrapolating the variability periods T_{obs} from the observed light curves of some X and γ-loud blazars that exhibit a periodicity (Venturi et al. 2001; Raiteri et al. 2001), we can estimate the central SMBH mass: $M_{SMBH} \simeq T_{obs}/\tau$. The values obtained for $\alpha = 2 \cdot 10^{-3}$ are in the second column of Tab.1; for $\alpha = 2.5 \cdot 10^{-3}$ in the third one. Mass values for $\alpha = 2.5 \cdot 10^{-3}$ agree with the estimates given by other methods (Kotilainen et al. 2002; Cao 2003). Hence this model seems to be promising in explaining the formation and refuelling of jets and outflows from accretion discs around SMBH in AGN, and in particular to provide an explanation for the quasi-periodic oscillations that are observed in some AGN. Moreover, the model allows us to estimate reasonably the central SMBH mass.

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