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Analytical modelling of AGN outflows

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Abstract. We study AGN jet formation by means of exact solutions of the relativistic magnetohydrodynamic equations. This is an original extension in Schwarzchild's metric of previous meridionally self-similar models. The outflow is mainly thermally driven to high asymptotic speeds from the central region where the escape speed is also high. The jet solutions are magnetically collimated on the sub-parsec scale.

1. Introduction

Almost all AGNs are associated with outflows. These phenomena of high energy affect the evolution of the central object and its surrounding medium. In fact, observations show that jets are launched very close to the black hole where the thermal and magnetic energies are sufficiently high such that the plasma escapes from the gravitational potential. Many analytical and numerical works have been developed to examine the mechanisms of acceleration and collimation of jets, few of them though in the frame of general relativity. Jet formation seems to be strictly related to the presence of large-scale magnetic fields and the existence of gaseous disks (Königl & Pudritz 2000). The origin can be the Keplerian disk or the spherical corona surrounding the central part of the AGN or the microquasar as discussed by several authors. All MHD models sustain the idea that the gravitational energy of the central object is transferred to the accreted matter and eventually the jet. This energy is carried by the flow along the magnetic field lines anchored in the corona of the rotating disk. The hot ionized fluid close to the axis where the rotation is weak may escape from the corona thermally in the form of a wind and forced to follow the field lines. Then rotation combined to the magnetic field collimates the flow beyond the Alfvénic surface. In this contribution we present a model for such thermally driven and magnetically confined outflows from a spherical hot corona. The terminal velocity is, as expected, of the order of the escape speed at the footpoints.

2. Results

We assume steadiness and axisymmetry. Using a 3+1 splitting of space time we construct a generalization of the classical θ-self similar models (see Meliani et al. 2003 and references therein), including both special relativistic effects and Schwarschild's metric. In order to get an exact generalization of the classical model, we assume that the fluid rotation never becomes relativistic as the central black hole is not rotating. This is equivalent to assume that the light cylinder is never attained along a given streamline in the region where the model is valid. This is of course quite different from the classical Blandford & Znajek mechanism (Blandford & Znajek 1977).

We plot one specific solution in Fig. (1a) for an outflow which reaches an asymptotic speed of $0.7c$ in the recollimation region at a distance of $2\,10^{-3}\,pc$ from the massive black

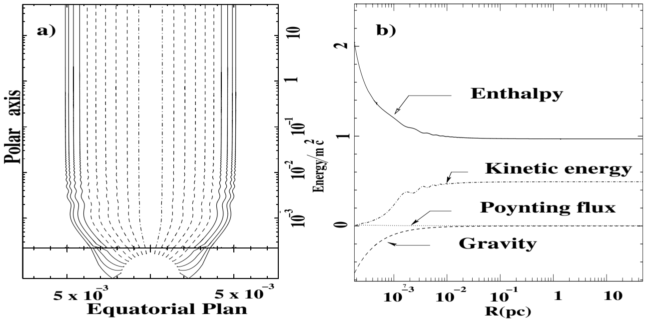

Figure 1. a) The morphology of the outflow. b) the energy contribution

hole of $10^9\,M_\odot$. Other solutions with higher Lorentz factor have been obtained too and where presented in previous contributions (Meliani et al. 2003). All the acceleration of the fluid occurs in the expansion region of the jet close the central black hole where the outflow is still a non collimated wind. In this region, the escape speed is $0.5c$ which is of the order of the asymptotic velocity. This is consistent with the idea of extraction of gravitational energy from the central engine (see Livio, 2002). As shown in Fig. (1b), the acceleration of the flow is thermal. The enthalpy of the fluid at the footpoints exceeds the gravitational potential and the excess is transformed into kinetic energy. The Poynting flux in this solution has a weak contribution to the total energy of the flow as we assume that the rotation of the streamlines is weak close to the jet axis. In the asymptotic region, most of the energy remains in the form of thermal content. In Fig.(1b), we see that the enthalpy represents asymptotically still 70% of the total energy, whereas the kinetic energy represents only 30%. This weak efficiency of the transfer of thermal energy into kinetic energy is related to the shape of the outflow of this particular solution. It is characterized by the weak expansion factor occurring only in a small region close to the central object of a few schwarschild radii, where a flow of positron/electron pairs or proton/electron is accelerated because of the high temperature . However this efficiency depends strongly on the parameters of the model. The mass loss rate achieved in this jet solution is $1.41\ 10^{-6} M_\odot/yr$ with an opening of the jet in asymptotic region of 7 schwarschild radii. It remains weak by comparison with the observational mass loss rate of $1 - 10 M_\odot/yr$ given by Chartas et al (2004). However, as in the classical case, the model reproduces only the inner part of the outflow close to the black hole axis or so-called spine jet. The density increases away from the axis, thus the larger part of the mass loss rate comes from the external disk wind. In the present solution the collimation of the outflow which is originally of magnetic origin is sustained asymptotically by the pressure of the external medium of the AGN jet. By choosing a lower initial pressure the solution would be magnetically confined even asymptotically and the jet morphology would be very similar because the magnetic rotator is efficient for this set of parameters.

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