Chin. J. Astron. Astrophys. Vol. 5 (2005), **Suppl.**, 263–268
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

Applying Magnetized Accretion-Ejection Models to Microquasars: a preliminary step

P. O. Petrucci ⋆, J. Ferreira, S. Tricot, G. Pelletier, C. Cabanac and G. Henri

Laboratoire d'Astrophysique de l'Observatoire de Grenoble, 414 rue de la Piscine, 38041 Grenoble Cedex 9, FRANCE

Abstract We present in this proceeding some aspects of a model that should explain the spectral state changes observed in microquasars. In this model, ejection is assumed to take place only in the innermost disc region where a large scale magnetic field is anchored. Then, in opposite to conventional ADAF models, the accretion energy can be efficiently converted in ejection and not advected inside the horizon. We propose that changes of the disc physical state (e.g. transition from optically thick to optically thin states) can strongly modify the magnetic accretion-ejection structure resulting in the spectral variability. After a short description of our scenario, we give some details concerning the dynamically self-consistent magnetized accretion-ejection model (Ferreira 1997; Casse & Ferreira 2000) used in our computation. We also present some preliminary results of spectral energy distribution.

Key words: magnetohydrodynamics: MHD; radiation mechanisms: general; X-rays: binaries

1 INTRODUCTION

Microquasars are X-ray binaries that present clear signatures of transient or persistent jets. These objects exhibit also different spectral states in X-ray. It is important to note that each state is actually a stationary state in terms of dynamical time scales. Indeed, they last about 10^6 times longer. Thus any variation and sudden transitions we observe can only be understood as slow (secular) variations. The mechanism of these transitions has still to be found.

As a preliminary step of a more detailed work presently in progress, we describe here the main characteristics of the model that we propose to explain the spectral state changes observed in microquasars. This model suppose the existence of a magnetized accretion-ejection structure (hereafter MAES) that is developed in our group. These MAES well explain the jet formation mechanism (e.g Ferreira 1997) but up to now the emission processes were not included in the computation. We believe that changes in the MAES (for example transition from optically thick to optically thin accretion disc) could explain the spectral state changes observed in galactic black holes and we present here the first sketch of the radiative transfer treatment in such structures.

⋆ E-mail: `petrucci@obs.ujf-grenoble.fr`

We present our scenario in Sect. 2. In Sect. 3 we give some details of the main characteristics of MAES used in our computations. In Sect. 4, we show preliminary disc SEDs in order to exemplify the effect of jet production on the disc emission.

2 OUR SCENARIO

Jets from microquasars share the property of an extreme collimation with AGN jets. Such a collimation cannot be achieved by the outer pressure and requires therefore self-generation. Only large scale magnetic fields that are carried along with the jet have been proved to provide such a self-collimation. We assume therefore that a magnetic field is anchored onto the accretion disk around the compact object giving birth to a MAES.

We aim to explain the two main microquasars spectral states, i.e. the low/hard and high/soft states, in the MAES framework. Simple cartoons of our model are shown in Fig. 1. In both states we suppose the existence of a MAES but the part of the accretion disc that ejects is much smaller in the high/soft compared to the low/hard state. In this case, the disc emission is strong and close to the standard one as observed in this state. Inversely, in the low/hard state the disc emission is weak due to a strong jet emission (cf. next Sect.). The jet basis is expected to be relatively hot and could explain the thermal Comptonized component observed in this state. The strong jet also explain the strong radio emission associated with this state. As we can see, one of the main parameter of the model is the radial extension of the ejection region in the disc. We believe that it is controlled by some disc instabilities, and for instance part of it may transit from optically thick to optically thin states.

In this model, we also assume the presence of a relativistic jet produced inside the MHD one (the two-flow model, Pelletier 2004 and reference therein) and energized by plasma-MHD waves interaction. This is the two-flow (outside MHD jet and inside relativistic one) model developed in our team (Pelletier 2004 and references therein). A zoom of the central region of the jet is also shown in Fig. 1. The two-flow model has been already applied with success to explain the SEDs of AGNs with jets (e.g. Marcowith et al. 1998). In the case of microquasars, the relativistic jet could explain the superluminal motions that can be observed in some cases. It could also explain the presence of the high energy tail generally observed in both states (e.g. Ling & Wheaton 2003), and which is not easily explained in the standard view.

We present below the general picture for handing the radiative transfer problem in MAES.

3 MAGNETIZED ACCRETION-EJECTION STRUCTURES

In a series of papers (e.g. Ferreira & Pelletier 1995; Ferreira 1997; Casse & Ferreira 2000) it has been shown that, in MAES, the poloidal magnetic field must be close to equipartition with the plasma thermal pressure in order to allow for steady ejection. Indeed, in any other situation, the magnetic field would produce an overwhelming vertical compression and the plasma pressure would not be strong enough to push out disk material and load the field lines with matter.

The presence of such an equipartition field has severe consequences on the disk dynamics since it is very difficult to get rid of the poloidal magnetic flux. If this assumption is correct, then every spectral state of microquasars should provide an observational evidence of its presence.

Two major characteristics of MAES are:

– **Jet torque:** Magnetically driven jets produce a torque on the underlying accretion disc such that $\Lambda = \dfrac{\text{jet torque}}{\text{viscous torque}} \sim \dfrac{r}{h} > 1$. As a consequence, **for the same accretion rate, discs driving jets are always less dense than standard/ADAF discs**.

– **Energy budget:** The released accretion energy is shared between the jet power and the disc emission, i.e $\mathcal{P}_{acc} = 2\mathcal{P}_{jet} + 2\mathcal{P}_{disc}$ with $\frac{2\mathcal{P}_{jet}}{\mathcal{P}_{acc}} = \frac{\Lambda}{1+\Lambda} \simeq 1$. Thus, **jets carry away most of the accretion power and discs producing jets are weakly dissipative (Ferreira & Pelletier 1995)**. This is a key point in our scenario (cf. Sect. 2) since it gives an alternative to conventional ADAF models, the accretion energy can be efficiently converted in ejection and not advected inside the horizon. Thus no (or weak) disc emission does not necessarily mean disc disappearance but more likely matter ejection! Such result can only be catched by solving the complete set of MHD equation of the disc-jet configuration.

A vertical cross-section of a MAES is shown in Fig. 2. The main parameters in the equations controlling the MAES are $\epsilon = h/r$ where h is the disc half-height, $\mu = B^2/\mu_0 P_{tot}$ and $m_{acc} = M_{acc}/M_{Edd} \propto r^{\xi}$ where the ejection efficiency ξ can vary between 0.01 up to 0.4. These values are not guessed (like in the ADIOS model) but were obtained by solving the full set of MHD

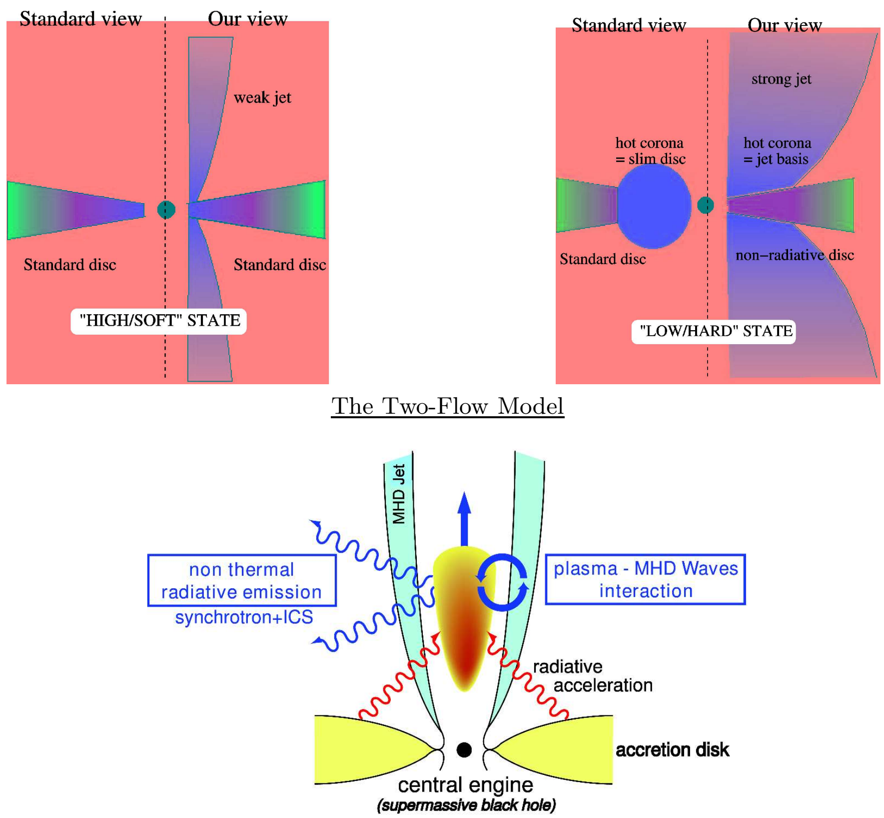

Fig. 1 Upper left: the high/soft state is characterized by a weak jet (weak radio emission) and strong disc emission. Upper right: the low/hard state is characterized by a strong jet (strong radio emission) and thus weak disc emission. In both state we also suppose the existence of a relativistic jet, produced inside the MHD one (the two-flow model, lower left. cf. Pelletier 2004 and reference therein for more details) and energized by it trough plasma-MHD waves interaction. This relativistic jets would produce, first the superluminal motion observed in some conditions in microquasars, and second it would produces the high energy power law tail observed in these states (Ling & Wheaton 2003).

equations and scanning the parameter space (Casse & Ferreira 2000). For example, as already noted above, a stationary disc + jet solution corresponds to $\mu \simeq 1$ i.e. equipartition between magnetic field and plasma pressure. As a result, we obtain the self-consistent spatial distribution of the main physical quantities. An example of such distributions along the line field is plotted in Fig. 3.

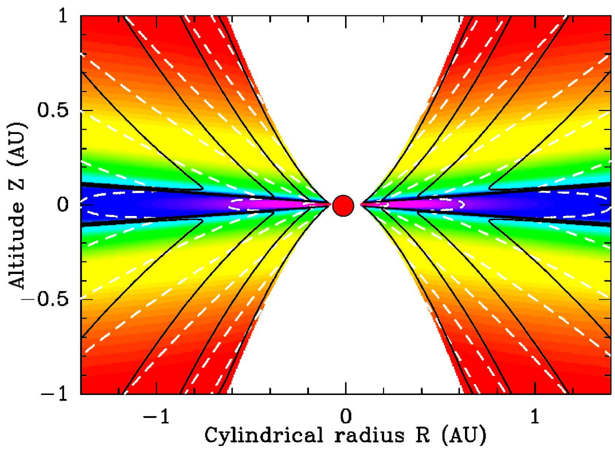

Fig. 2 Cross-section of an accretion disk driving cold jets (Ferreira 1997). Colors are density contours, streamlines are black solid lines, while white dashed lines show isocontours of total velocity.

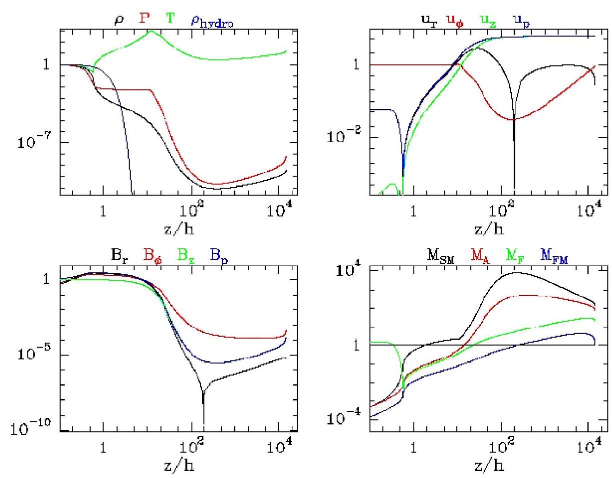

Fig. 3 Quantities along a field line for a Self-Similar solution that crosses all three critical points SM, Alfven and FM (Ferreira & Casse 2004). Density, pressure, temperature and magnetic fields are normalized to their values at the disk mid plane, velocity to the Keplerian speed at the anchoring radius. This solution recollimates at $z \sim 200h$, where h is the disc half-height. Our theory of steady jet formation from Keplerian accretion disks has been confirmed by numerical MHD simulations (Casse & Keppens 2004).

4 SEDS: PRELIMINARY RESULTS

As already said, we aim to develop a code that computes the total SEDs emitted by the disc+jet structure. Thus we need to combine the stationary solutions obtained for MAES (as shown in the previous section) with the energy equations followed by electrons and protons. This is a work in progress and at the moment, we compute only the SED produced by the disc alone, with or without jet emission, for different sets of parameter values i.e. the energy equation systems is still not solved self consistently.

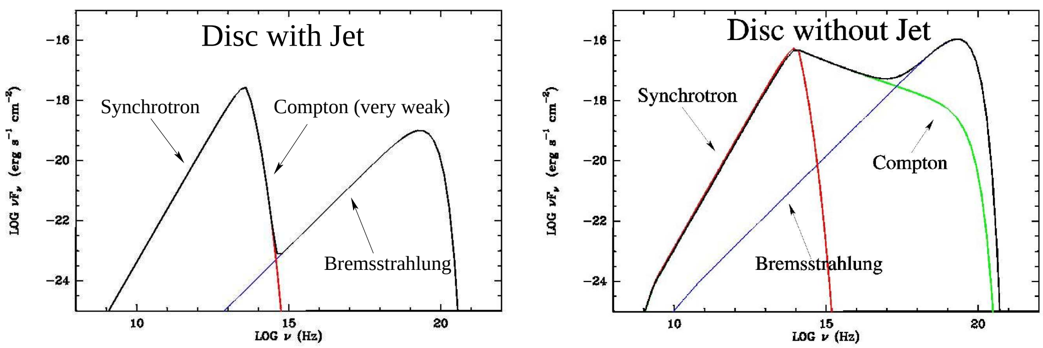

Fig. 4 Two examples of disc SEDs produced by our model with (right) and without (left) jet. When there is a jet, the disc density strongly decreases (cf. Sect. 3). Consequently, and since in this example we assume a fixed electron temperature, the global disc flux weakens with a strong decrease of the bremsstrahlung and Compton emissivity. The parameters are reported in the text. Red: synchrotron, blue: bremsstrahlung, green: Compton. Black: total

We take into account the main radiative processes for the electron i.e synchrotron, bremsstrahlung (including self-absorption) and Compton effects. The disc is divided in a large number of rings and the different emissivities are computed at each ring, using for the electron density and magnetic filed the expression consistent with a stationary MAES. We then sum over the disc surface to obtain the total emissivity. The figure below shows two examples of SEDs for an electron temperature $T_e = 10^9\,\mathrm{K}$, $\epsilon = h/r = 0.3$, $m_{\rm acc} = 0.01$, $M = 10\,M_\odot$ located at 10 kpc. For these parameter values, the disc is optically thin. We note that, when the energy equations for electrons and protons will be solved self-consistently, the values of T_e and ϵ will be naturally fixed.

The left plot corresponds to the case with jet and the right plot to the case without jet. Clearly, the presence of a jet strongly modified the disc SED! Indeed, when there is a jet the disc density strongly decreases (cf. Sect. 3). Consequently, and since we assume a fixed electron temperature, the global disc flux weakens with a strong decrease of the bremsstrahlung and Compton emissivity.

We note that we only want here to exemplify the impact of jet emission on the disc SED without trying to reproduce the observed microquasar spectral states. This will be of course the next step of this study. However, from this simple example, we can extrapolate that if we had assumed a constant total luminosity instead of a constant temperature, the case "disc-with-jet", would have had a higher electronic temperature, i.e. a hotter corona, to compensate the smaller density. This is in agreement with the presence of a hot thermal plasma commonly assumed in microquasars to explain the X-ray spectra in the low/hard state.

5 CONCLUSION AND PERSPECTIVES

We present here only some details of the model we are developing to explain the spectral changes in microquasars. We believe that the changes are mainly due to physical changes in the disc itself, and for instance part of it may be transiting from optically thin to optically thick states. This would strongly influence the disc-jet structure resulting in important changes of the global SED.

Work is in progress to develop a complete self-consistent solution of MAES with realistic radiative transfer in the disc and in the jet.

References

Ferreira J., Casse F., 2004, ApJ, 601, L139

Casse F., Keppens R., 2004, ApJ, 601, 90

Casse F., Ferreira J., 2000, A&A, 361, 1178

Ferreira J., 1997, A&A, 319, 340

Ferreira J., Pelletier G., 1995, A&A, 295, 807

Ling J. C., Wheaton W. A., 2003, ApJ, 584, 399

Marcowith A., Henri G., Renaud, N., 1998, A&A, 331, L57

Pelletier G., 2004, In: M. Lyutikov, ed., Dynamics and dissipation in electromagnetically dominated media, Hauppauge: Nova Science Publisher, preprint (astro-ph/0405113),