SF2A 2006
D. Barret, F. Casoli, T. Contini, G. Lagache, A. Lecavelier, and L. Pagani (eds)

RADIATION HYDRODYNAMICS SIMULATIONS OF JETS - ISM INTERACTIONS

M. González[1, 2], E. Audit[1,2] and T. Lery[3]

Abstract. We present simulations, carried out with the radiation hydrodynamics code HERACLES, of the interaction between a molecular jet and the interstellar medium (ISM). We first briefly describe the academic configuration used. We then present a first series of simulations of a molecular jet percuting the ISM. We discuss the influence of the different mechanisms: hydrodynamics, cooling and radiative effects. We show that the treatment of radiative transfer and feedback has great consequences over the jet propagation.

1 Introduction

During its formation, a star accretes matter in such a way that it creates an accretion disc and by magneto-centrifugal mechanism jets are launched perpendicular to this disc. These jets then propagate into the surrounding interstellar medium. Whereas the magnetic field surely plays an important role in the launching and collimation phases, its influence is much more reduced when the jet has reached a regime in which the kinetic energy dominates. We are interested in such a situation so that we neglect the magnetic field in our simulations. On the contrary, we will take into account radiative transfer which, as we will see, can have a great influence over the jet propagation.

2 Modelling

The observations show that jets are involved in a lot of different situations and that their characteristics can vary a lot (Reipurth & Raga 1999, Reipurth & Bally 2001, Cabrit 2002, de Gouveia dal Pino 2005). However, spectroscopy and Doppler shifts show that the temperatures and velocities involved are about 10^4 K and 100-500 km/s.

We have done several simulations of jet-ISM interactions varying the physical parameters of both the jet and the ISM. In this short paper, we present the results obtained in a particular series of simulations keeping the physical conditions constant and changing only the physics involved in order to illustrate the importance of radiative transfer.

The density of the ambient molecular cloud is set constant equal to 10^6 cm^{-3} which corresponds to the density observed at approximately 1 000 AU of the center of the cloud (Ciolek & Mouschovias 1994, André et al. 2000) and at a temperature of 15 K. The jet already collimated is then launched to impact this cloud. Its characteristics are: a radius of 5 10^{15} cm, a density of 500 cm^{-3}, a velocity of 500 km/s and a temperature of 100 K. Moreover, this jet is pulsed: its impulsion varies by a 25% factor upon a 60 years period. This pulsation is commonly used in the models to reproduce the knots along the jet seen in the observations.

To include radiative effects, we have to look at the opacities in such environments. We chose the interstellar dust opacities of Draine 2003 (cf. Figure 1). We then have to compare the photon mean free path λ with the typical simulation box size L. The opacity for which these two lengths are equal is defined by:

$$\kappa_{\lambda=L} = 4.3\,10^4 \left(\frac{10^3\ \mathrm{cm}^{-3}}{n}\right)\left(\frac{10^{16}\ \mathrm{cm}}{L}\right)\ \mathrm{cm}^2\,\mathrm{g}^{-1} \tag{2.1}$$

[1] CEA-Saclay, DSM/DAPNIA/Service d'Astrophysique, F91191 Gif-sur-Yvette Cedex, France
[2] AIM - Unité Mixte de Recherche CEA - CNRS - Université Paris VII - UMR n° 7158
[3] DIAS, Dublin, Ireland

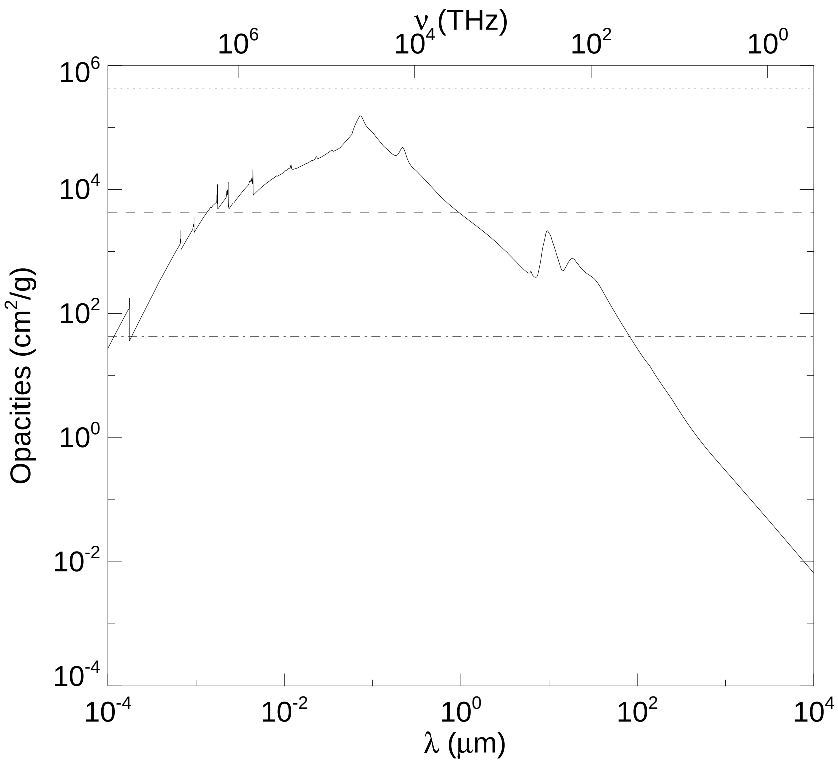

Fig. 1. Interstellar dust spectral opacities. The horizontal lines correspond to the opacity for which the photon mean free path is equal to the typical box simulation size (10^{16} cm) for a density of 10^2 cm^{-3} (dotted line), 10^4 cm^{-3} (dashed line) and 10^6 cm^{-3} (dashed-dotted line).

If the opacity is greater than this value, the photons are reabsorbed and if it is smaller, they freely cross and escape from the simulation box. In Figure 1, we display this opacity for a box size of $L = 10^{16}$ cm and for three densities. We can see that there are roughly two categories of photons depending on their wavelength. The photons with high wavelengths are not reabsorbed because their mean free path is greater than the width of the simulation box. They can then be treated by a cooling source term in the equation of evolution of the gas energy. On the other hand, the photons around 10^{-1} μm have a lower mean free path which means that they are reabsorbed in the medium. Furthermore, the energy transported by these photons is not at all negligible since for a temperature of 10^4 K (which approximately corresponds to the jets temperatures observed), they transport about 54% of the bolometric energy. For these reasons, it is necessary to treat these photons using radiative transfer method to take into account properly their dynamical effect.

3 Results

All the simulations were performed using the 3D radiation hydrodynamics code HERACLES (González & Audit 2005; González et al. 2006). Instead of considering a grey model as in these papers, we extend it to a pseudo-multigroup case. Only the group of photons centered over the 10^{-1} μm wavelength is treated using radiative transfer while the other group is only treated as a cooling function. The 2D axisymmetric simulation box used is sampled over 100x200 cells and covers a domain whose dimensions are 2.5 10^{16} cm x 5 10^{16} cm.

We performed three simulations involving different physical mechanisms. First of all, we compute a purely hydrodynamical simulation without any source term. Then, we add a cooling function and finally, we consider a radiation-hydrodynamics simulation. Figure 2 displays the density logarithm in these three simulations for two different output times.

In the first case, the cylindrical shock tends to adopt a bow shock form after a few hundreds of years and its radial width extends rapidly. A low density region is located around the initial jet width and the over pressure in front of this region tends to narrow the jet. Then, a conical structure develops after 2 500 years and gives a privileged direction to the bow shock.

When a cooling function is taken into account, the jet propagation is completely different. The jet width remains almost constant during all the simulation. Furthermore, the jet head which impacts the molecular cloud seems to be unstable. The jet creates in the ambient cloud a channel whose width is equal to the one of the initial jet.

In the last case, the radial extension of the jet changes completely during the simulation. Its conical structure clearly seen after 1 500 years is exclusively due to radiative transfer because it doesn't appear in the two other cases. Thanks to unidimensional simulations, we shed into light the mechanism involved in the jet narrowing. When the radiative transfer is taken into account, a hot isothermal region develops ahead the shock. In this preheated region, the pressure increases drastically and compresses the jet which narrows itself. A second aspect characterizing the simulation with radiative transfer is the development of a secondary jet. Actually, the two overdense regions ahead the shock tend to go closer to the symmetry axis. After about 1 500 years, they merge on the axis and accelerate to create another faster jet. This jet is narrower and denser than the primary one but slower : its density is 3.4 10^7 cm^{-3}, its radius 10^{15} cm. Furthermore, the pulsation of the primary jet are transmitted to the secondary which presents small density knots.

4 Conclusion

In this preliminary study, we show that taking into account the radiative effects in jet-ISM interactions can have a great influence over the propagation of the jet. In particular, the photons emitted by the shock are reabsorbed and preheat the surrounding ISM creating a high density region around the jet. This increase in pressure tends to compress and pinch the shock creating a secondary jet which is much narrower and denser than the primary one. This study needs to be extended for several jet/ISM parameters and quantitatively compared with observations.

References

André, P., Ward-Thompson, D. & Barsony, M. 2000, Protostars and Protoplanets IV, 59

Cabrit, S. 2002, EAS Publications Series, 147

Ciolek, G. E. & Mouschovias, T. C. 1994, ApJ, 425:142

Draine, B. T. 2003, ARA&A, 41, 241

González, M., & Audit, E. 2005, ApSS, 298, 357

González, M., Audit, E. & Huynh, P. 2006, submitted to A&A

de Gouveia dal Pino, E. M. 2005, Advances in Space Research, 35:908

Reipurth, B. & Bally, J. 2001, ARA&A, 39:403

Reipurth, B. & Raga, A. C. 1999, The Origin of Stars and Planetary Systems, 267

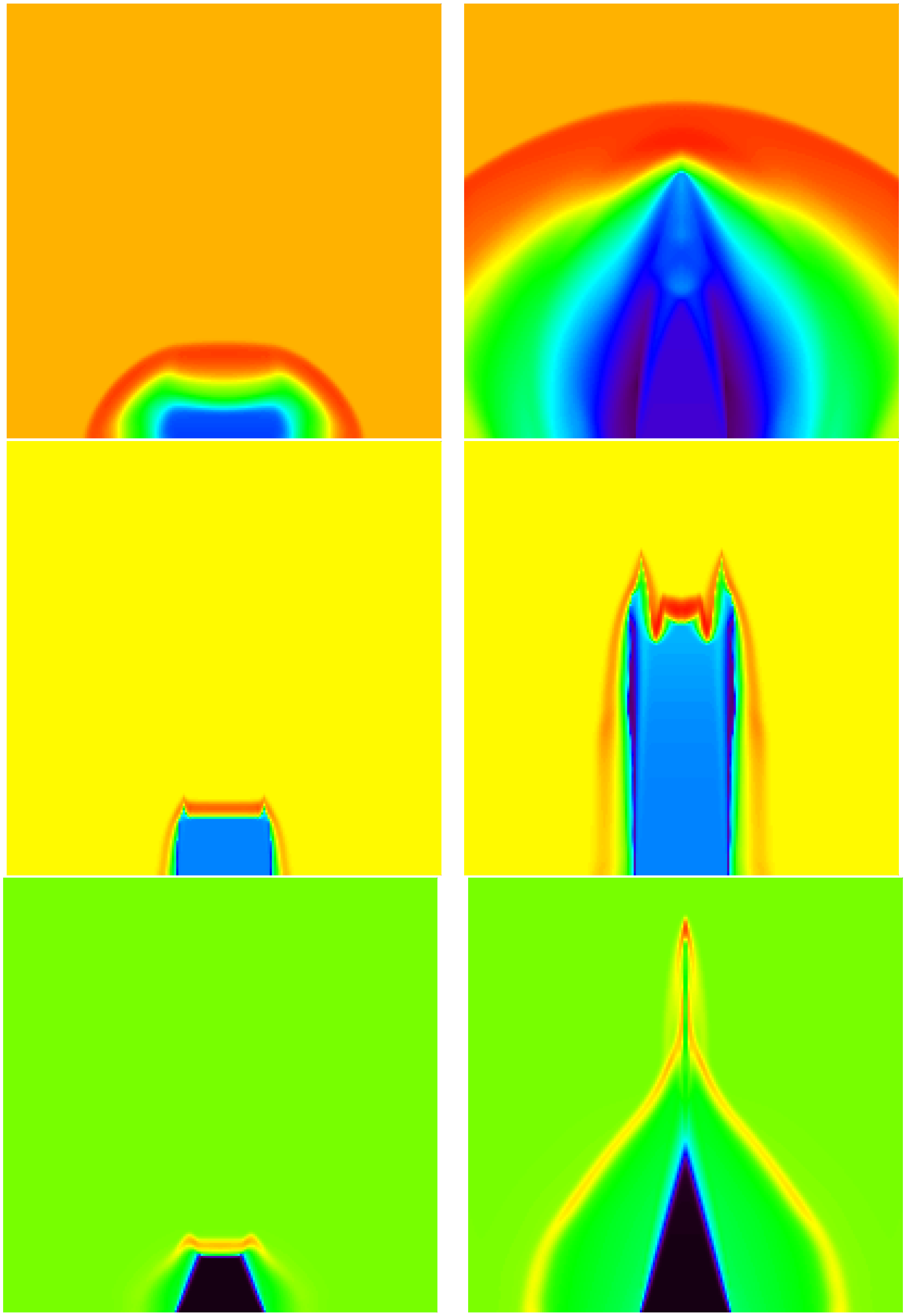

Fig. 2. 2D maps of the density logarithm in three different jet simulations. The left column corresponds to an evolution over 480 years and the right column to a 1 920 years evolution. The upper row (resp. central, lower) corresponds to a hydrodynamical (resp. hydro + cooling, hydro-radiative) simulation.