Highlights of Astronomy, Volume 15
XXVIIth IAU General Assembly, August 2009
Ian F. Corbett, ed.

doi:10.1017/S1743921310010458

Development of jets, outflows and HH objects

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1. Introduction

The entrainment of molecular material through a mixing layer along the walls of a HH jet beam has been modeled analytically (Cantó & Raga 1991; Stahler 1994) and numerically (Taylor & Raga 1995; Lim *et al.* 1999). However, when full radiative jet simulations are carried out, the molecular, environmental material remains within a dense shell which follows the shape of the leading bow shock. Because of this, no molecular material reaches the outer boundary of the jet beam, and therefore no “side-entrainment” of molecular gas into the fast jet beam takes place.

Therefore, if one wants to model objects in which a central, well collimated, fast molecular jet is observed (e.g., the spectacular HH 212, see Correia *et al.* 2009 and references therein), it is necessary to either assume that the jet flow is initially partially molecular (Völker *et al.* 1999) or to choose parameters such that molecules are formed within the jet beam (Raga *et al.* 2005).

2. Jet in a side-wind

In this paper, we propose the following possibility. Let us assume that an outflow source has a velocity of a few km s^{-1} relative to the surrounding environment (a velocity which would be consistent with the random velocity of T Tauri stars). This will produce a streaming motion of the environment relative to the jet beam, which for appropriate parameters will be able to push the far bow shock wing into contact with the jet beam. In this situation, the dense shell of environmental material (which follows the bow shock wings) will touch the body of the jet beam, therefore allowing side-entrainment of molecular material to take place.

Figure 1 shows the results obtained from a 3D simulation. In this simulation, a jet with a top-hat initial cross section with a velocity $v_j = 150$ km s^{-1}, density $n_j = 10^3$ cm^{-3}, temperature $T_j = 10^3$ K and radius $r_j = 10^{15}$ cm moves into a homogeneous environment of density $n_{env} = 200$ cm^{-3} and temperature $T_{env} = 10$ K. The environment streams past the jet source (in a direction perpendicular to the outflow axis) at a velocity $v_{env} = 5$ km s^{-1}. Both the jet and the environment are initially neutral (except for singly-ionized carbon), and a parametrized radiative energy loss is included. The ionization of hydrogen is explicitly followed.

The mid-plane density stratification of fig. 1 shows that the dense, post-bow-shock shell is indeed swept into direct contact with the jet beam. Through this shell/jet beam interface, direct entrainment of molecular gas into the jet beam can take place.

3. Conclusions

In this short paper we discuss the possibility of side-entrainment of molecular material into a HH jet as a result of a motion of the jet source through the surrounding, molecular environment. This model will be described in more detailed in a future paper.

Acknowledgements

This work was supported by the CONACyT grants 61547, 101356 and 101975.

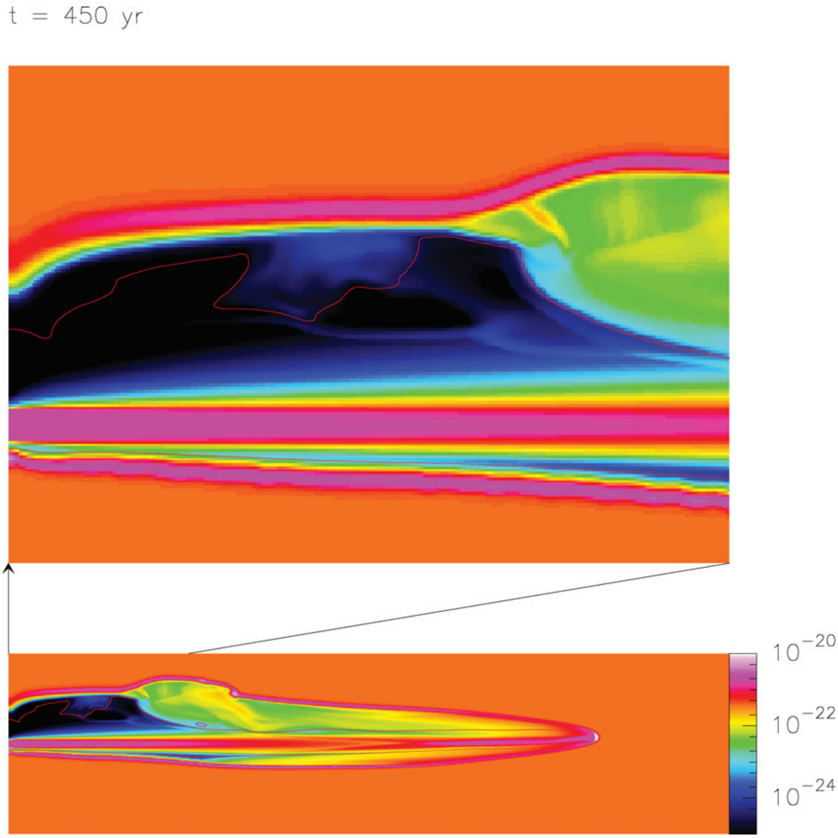

Figure 1. The density stratification (on the plain including the jet axis and the direction of incidence of the streaming environment) obtained from the numerical simulation described in the text after a 450 yr time-integration. The bottom frame has an axial extent of 2×10^{17} cm. The density (in g cm^{-3}) is shown with the look-up-table given by the bottom right bar. The single, black/grey solid line (red respectively in the online material) indicates the interface between the jet and the environmental material.

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