HERBIG-HARO OBJECTS: MODEL PREDICTIONS AND COMPARISON WITH X-RAY AND OPTICAL OBSERVATIONS.

R. Bonito, *DSFA-Universita' di Palermo; INAF-Osservatorio Astronomico di Palermo, COMETA, (sbonito@astropa.unipa.it)*, F. Favata, M. Fridlund, *ESA*, G. Micela, S. Orlando, *INAF-Osservatorio Astronomico di Palermo*, G. Peres, *DSFA-Universita' di Palermo; INAF-Osservatorio Astronomico di Palermo*, R. Rosner, *Center for Astrophysical Thermonuclear Flashes*, S. Sciortino, *INAF-Osservatorio Astronomico di Palermo*.

Our work is focused on the investigation of the physical mechanisms leading to the optical and X-ray knotty structures observed in the nearest protostellar jet, HH 154. At odds with the other X-ray emitting HH objects, discovered with XMM-Newton and Chandra satellites, the HH 154 jet shows an unexpected complex X-ray morphology. The X-ray source associated with HH 154 and observed with Chandra, in fact, consists of two well separated components: a bright, stationary, point-like source and a tail, consistent with the scenario of plasma propagating outward with respect to L1551 IRS5, the protostar from which the HH 154 jet originates.

The L1551 star-forming region is located in the Taurus molecular complex and, thus, is one of the closest (about 150 pc) to us. An optical jet, with Herbig - Haro characteristics (HH 154), originates from each of the components of the IRS5 binary system; the jets come from behind the about 150 magnitudes of visual extinction that surrounds the binary, the first optical knot being at about 0.5" from the star. Of course the proximity of HH 154 makes the associated protostellar jet probably the best laboratory to study the evolution of the complex X-ray morphology in HH objects.

We analyzed the joint optical (HST) and X-ray (Chandra) observations of HH 154 collected in 2005. By comparing our proprietary data with archive data, we are now able to derive the proper motion, the morphological changes, and the fluxes variations of each knot within the jet.

Fig. 1 (Bonito et al. 2007a in preparation) shows HST observations of HH 154 in 1996 (left panels), 1998 (middle panels) and 2005 (right panels) in the two filters Ha (upper panels) and [SII] (lower panels). The naming of the knots within the jet is according to Fig. 1 of Fridlund et al. (2005). The green cross superimposed on each panel of Fig. 1 corresponds to the same position on the sky.

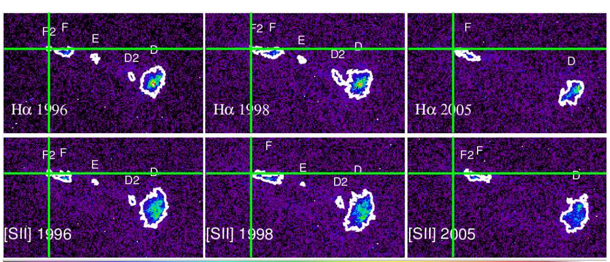

Figure 1: Multi-epoch image of the HH 154 jet in 1996 (left panels), 1998 (middle panels) and 2005 (right panels) in H_α (upper panels) and [SII] (lower panels). The green cross superimposed to each panel marks the same position in each image (Bonito et al., 2007a in preparation).

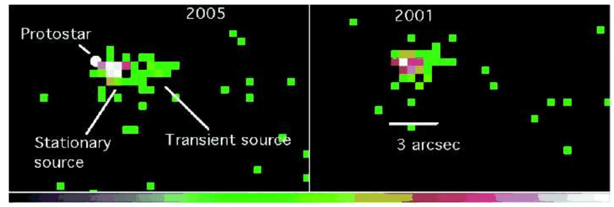

Figure 2: The X-ray source associated with the HH 154 jet observed with Chandra in 2001 (right panel) and in 2005 (left panel) (adapted from Favata et al. 2006)

The comparison of multi-epochs HST data of HH 154 allows us to analyze the morphological changes within the jet or even within each knot, occurring over few years.

The location of the X-ray emitters coincides with the position of the first knot at the base of the jet, where optical spectroscopy and HST imaging finds a nebular knot with true velocity of 500 km/s. A detailed comparison (Fig. 2) between our 2005 deep Chandra observation (Favata et al. 2006) and the 2001 Chandra archival data shows that the X-ray source consists of both an unresolved, point-like component, without detectable proper motion over 4 yr, and an elongated component whose expansion is in agreement with a shock (or some other phenomenon) moving away from the parent star at about 460 km/s.

Prompted by discovery of this X-ray emission, we developed a hydrodynamic model of a continuous supersonic jet traveling through a homogeneous ambient medium. We performed an extensive exploration of the parameter space of the model and synthesized several observable quantities as X-ray source emission, its morphology and proper motion (Bonito et al. 2004, 2007). We found that the X-ray emission originates at the head of the jet in the moving shock at the jet/ambient interaction front.

Albeit the moving shock model of Bonito et al. (2004, 2007) answers many of the previous questions, it appears that a more complex scenario of the star, shock and surrounding medium is required: the varying circumstellar absorption (Fridlund et al. 2005) shows that the ambient medium is highly inhomogeneous.

We present preliminary results on the modeling of an interaction between a supersonic protostellar jet and a circumstellar inhomogeneity described as a spherical dense cloud. The left panels in Fig. 3 shows the bi-dimensional density and temperature distributions after 6, 8 and 10 years since the beginning of the jet-ambient interaction. The relevant initial physical parameters of the jet/cloud system modeled are: jet density, $n_j = 500\ \mathrm{cm}^{-3}$; jet temperature, $T_j = 10^4$ K; jet Mach number, $M = 30$ (corresponding to an initial jet velocity, $v_j =$

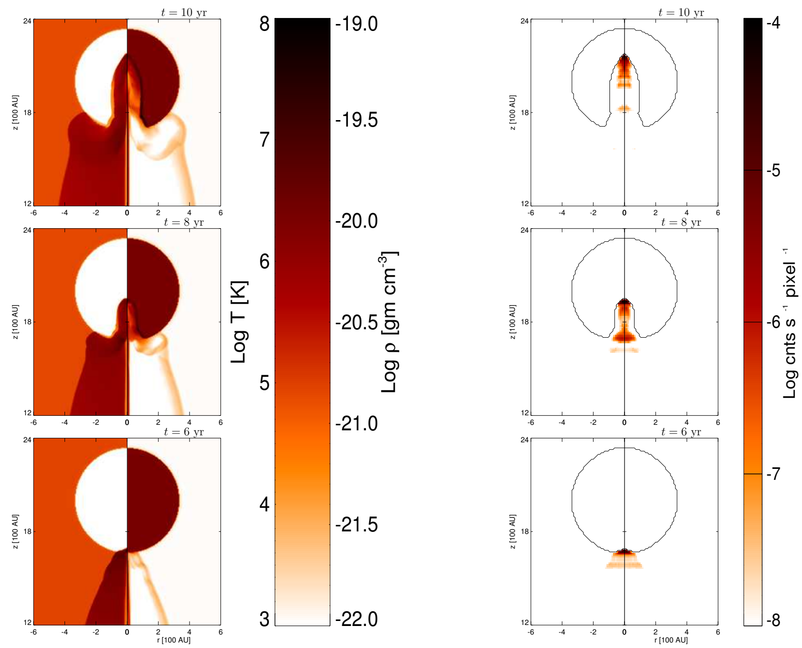

Figure 3: *Left panels*: Bi-dimensional density (on the right) and temperature (on the left) distributions 6, 8, and 10 years after the beginning of the jet-ambient interaction (Bonito et al. 2007b, in preparation). *Right panels*: X-ray emission as would be observed with Chandra/ACIS-I, synthesized from our numerical model of the jet/cloud interaction (Bonito et al. 2007b, in preparation)

1400 km/s); ambient-to-jet density ratio, $\nu_a = n_a/n_j = 0.1$; cloud-to-jet density ratio, $\nu_c = n_c/n_j = 10$.

Comparing the X-ray emission synthesized from our model (right panels in Fig. 3) with observations (Fig. 2), we conclude that the scenario of a jet/cloud interaction is very promising and could reproduce the complex (maybe transient over a few tens of years) morphology observed in the X-ray source of HH 154, with an almost stationary source at the base of the jet/cloud system and a faster component at the head of the jet with velocity of about 500 km/s (computed from our numerical model, Bonito et al. 2004, 2007), consistent with observations of HH 154 (Favata et al. 2006).

References

Bonito, R., Orlando, S., Peres, G., Favata, F., & Rosner, R. 2004, A&A, 424, L1

Bonito, R., Orlando, S., Peres, G., Favata, F., & Rosner, R. 2007, A&A, 462, 645

Favata, F., Bonito, R., Micela, G., et al. 2006, A&A, 450, L17

Fridlund, C. V. M., Liseau, R., Djupvik, A. A., et al. 2005, A&A, 436, 983