X-ray emission from protostellar jet HH 154: first evidence of a diamond shock?

R. Bonito[1], S. Orlando[1], M. Miceli[1, 2], G. Peres[1, 2], G. Micela[1], F. Favata[3]

[1] INAF–Osservatorio Astronomico di Palermo [2] DSFA-Universita' di Palermo [3] ESA-Paris

X-RAY EMISSION FROM HH 154

In the last decade X-ray emission from about ten protostellar jets has been discovered and now it appears as a common feature of the most energetic jets. In particular, almost all the protostellar jets from low-mass stars show X-ray emission from the base of the jet (see Bonito et al., 2010b for a brief review of the main properties of all the X-ray emitting protostellar jets discovered so far). This is also the case of one of the best investigated X-ray emitting protostellar jet, HH 154 (Fig. 1; see also Bonito et al. 2008).

We analyzed the multi-epoch Chandra observations of HH 154 (2001, 2005, 2009) which provide a time base of 8 years of the X-ray source from this jet. The X-ray source consists of a stationary bright knot at the base of the jet, with a hint of elongation away from the driving source (Fig. 2).

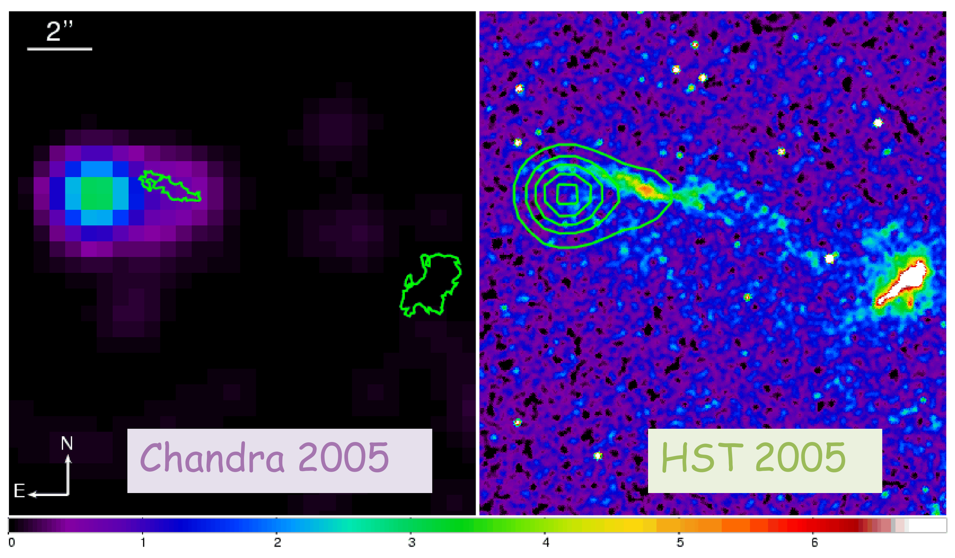

FIGURE 1
Chandra/ACIS-I with optical contours superimposed (left panel) and HST with X-ray contours superimposed (right panel) image of HH 154 in 2005. See details in Bonito et al. (2008).

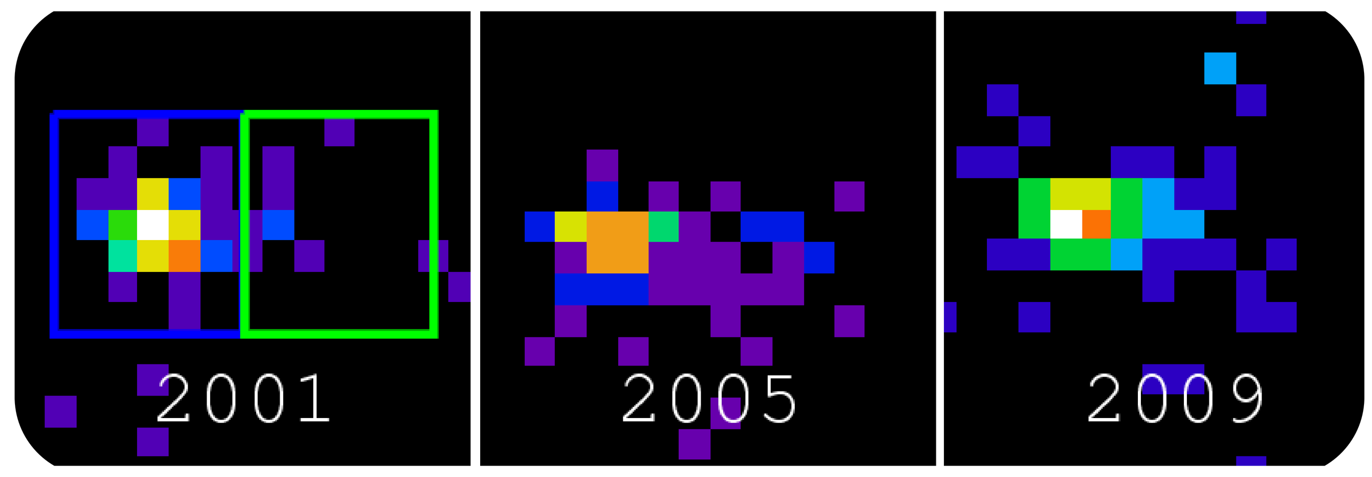

FIGURE 2
X-ray images in 2001, 2005, and 2009 at native ACIS pixel size, 0.5'' (Bonito et al. 2011).

THE MODEL: A DIAMOND SHOCK FROM A NOZZLE

Bonito et al. (2010b) suggested that the most likely mechanism leading to a stationary X-ray source at the base of a protostellar jet is a diamond shock forming near the launching/collimation site of the jet. The Chandra multi-epoch observations of HH 154 show the formation of a stationary X-ray source at the base of the jet, therefore we interpret the Chandra observations as the first evidence of a diamond shock. To investigate this scenario, we developed a model of a supersonic jet originating from a nozzle through which it is launched into the unperturbed ambient medium. The model solves the hydrodynamic equations (see also Bonito et al. 2004, 2007 for details) and takes into account the thermal conduction and the radiative losses, with calculations performed using the FLASH code (Fryxell et al. 2000). We have explored a wide parameters space, the best-fit model being characterized by $n_j = 300$ cm^{-3}, $u_j = 1500$ km/s, $T_j = 10^4$ K, with an initial ambient-to-jet density contrast ν = 10.

FIGURE 3

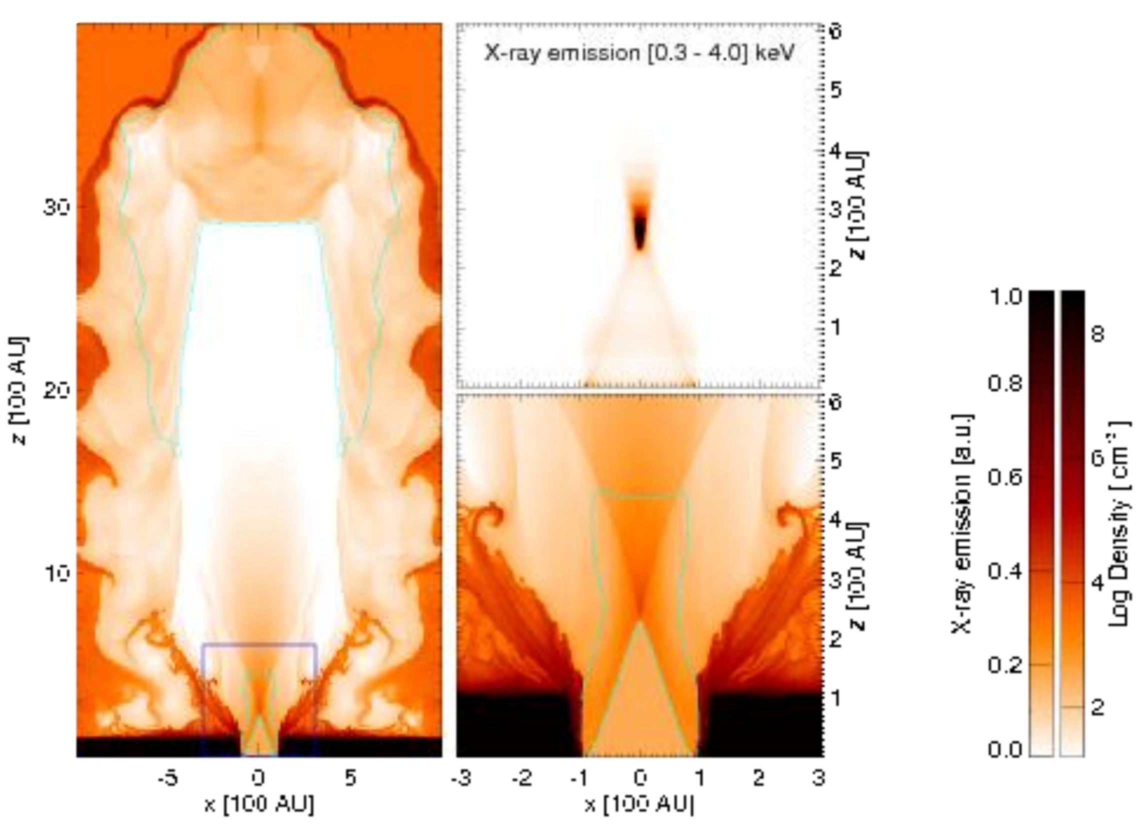

TABLE 1
BEST-FIT VALUES DERIVED FROM THE THREE DATA-SETS SIMULTANEOUSLY FITTED.

T (K)	EM (cm^{-3})	F_X (erg cm^{-2} s^{-1})	L_X (erg s^{-1})	N_H (cm^{-2})
$7^{+8}_{-2} \times 10^6$	$5^{+4}_{-3} \times 10^{51}$	$5^{+4}_{-3} \times 10^{-14}$	$1.3^{+0.8}_{-0.9} \times 10^{29}$	$1.2 \pm 0.2 \times 10^{22}$

Fig. 3 shows the density map (left and lower right panels) and the X-ray source synthesized from the model (upper right panel).

The diamond shock formed in the model is stationary, the thermal conduction being crucial in stabilizing its structure against the hydrodynamic instabilities. The brightest diamond shock is surrounded by a diffuse elongated region with lower temperature (Bonito et al. 2011).

FIGURE 4

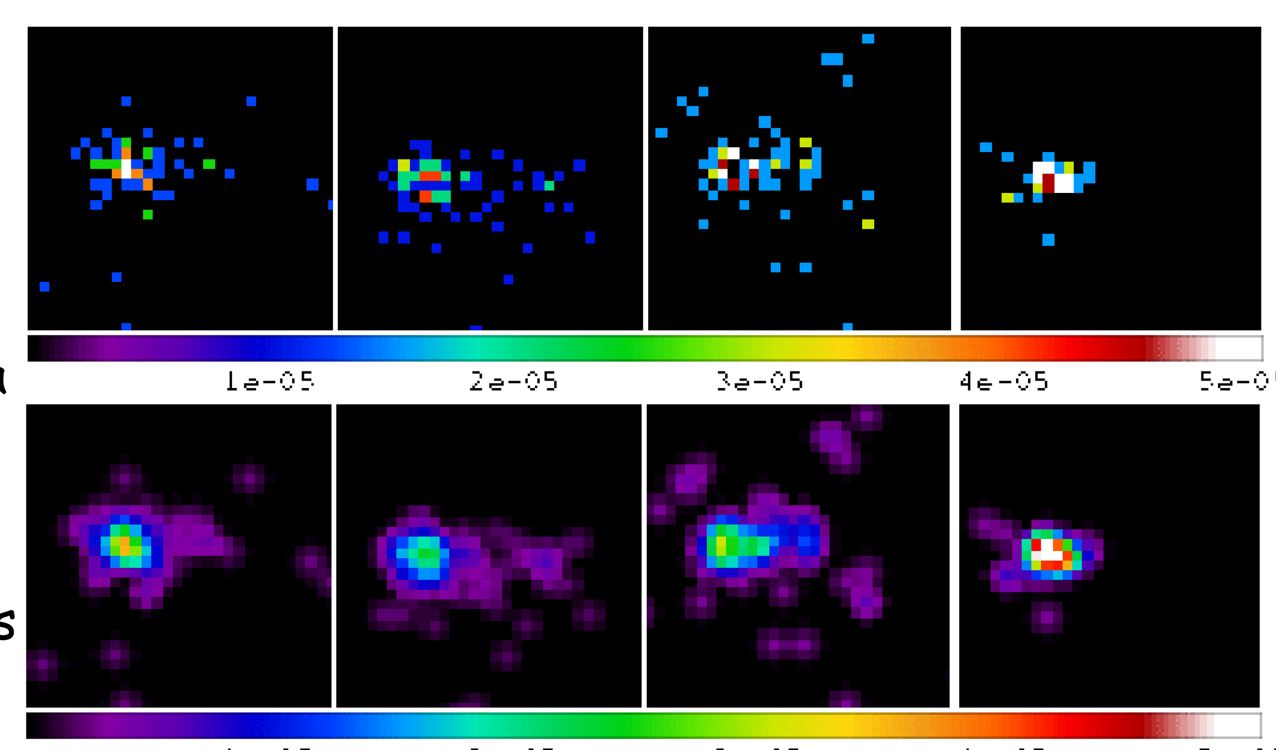

Fig.4 shows the X-ray images in 2001, 2005, and 2009 (first to third columns) and synthesized from the model (last column) at a pixel size one half of the native ACIS, i.e. at 0.25'' obtained using the EDSER technique (in lower panels we applied a Gaussian smoothing to the images; see also Bonito et al. 2011).

The model well reproduces the X-ray source observed at the jet base, the morphology consisting of a bright point-like component surrounded by a faint and elongated structure away from the driving source, as well as the spectral properties of the X-ray source with almost constant best-fit temperature, emission measure, and luminosity (Table 1).

DISCUSSIONS AND CONCLUSIONS

The model predicts X-ray emission from the diamond shock which cools down at larger distances from the driving source, as also inferred from the observations. From the Chandra data we found that the median photon energy decreases away from the driving source. This result can be due to the effect of both the variation of the N_H and the distribution of the plasma temperature, as predicted by the model.

From the multi-epoch Chandra observations of HH 154 we also find a hint of elongation away from the driving source, with a knot in 2009 closer to the stationary source than in 2005 observations, suggesting a newly formed knot as in the scenario of a pulsed jet model described by Bonito et al. (2010a, b.)

In conclusion, the jet/nozzle system accounts for the generation of a steady shock at the jet base. The origin of the nozzle could be related to the protostellar magnetic field which can be constrained by our model: assuming $\beta = p/(B^2/8\pi) = 1$, we derive from the model B = 6 mG, in good agreement with values inferred by Bally et al. (2003), Hartigan et al. (2007), and Schneider et al. (2011). Therefore the comparison between the model predictions and the observations may provide a diagnostic tool to probe the launching/collimation site near the driving source, a region that in general is very difficult to be directly observed in systems so deeply embedded.

REFERENCES AND ACKNOWLEDGEMENTS

Bally et al. 2003, ApJ, 584, 843R
Bonito et al. 2004, A&A, 424, L1
Bonito et al. 2007, A&A, 462, 645
Bonito et al. 2008, A&A, 484, 389
Bonito et al. 2010a, A&A, 511, 42
Bonito et al. 2010b, A&A, 517, 68
Bonito et al. 2011, ApJ, in press
Fryxell et al. 2000, ApJS, 131, 273
Hartigan et al. 2007 ApJ, 661, 910
Schneider et al. 2011, A&A, 530, 123

We acknowledge support in part by Agenzia Spaziale Italiana under contract No. ASI-INAF (I/009/10/0).
The software used in this work was in part developed by the DOE-supported ASC/Alliances Center for Astrophysical Thermonuclear Flashes at the University of Chicago.
The calculations were performed on the cluster at the SCAN HPC facility of the INAF – Osservatorio Astronomico di Palermo.