The X-ray Universe 2011

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X-rays from protostellar jets

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Protostars often drive very powerful bipolar mass outflows that remove angular momentum from the protostellar system. They are therefore essential for the star formation process and are observed during all stages of early stellar evolution. X-rays originating within these outflows have been observed only from about a dozen of Herbig-Haro (HH) objects. Assuming shock-heating, shock velocities of about 500 km/s are required. These shock velocities have not been observed at other wavelengths so that X-ray observations trace the highest velocities within protostellar jets inaccessible to other observations. Thus, the X-ray emission gives hints about the innermost and most energetic region of the jet acceleration.
We present *Chandra* X-ray data of HH 154 and HH 168 and discuss their X-ray properties. We focus on similarities and differences between these prototypical objects.

L1551 IRS 5 jet (HH 154)

The jet is located in the Taurus star-forming region (d=140 pc) and presents one of the most well studied protostellar X-ray jets. It is driven by a young low-mass binary system (see Fig. 1).

- The X-ray emission region is spatially resolved.
- Constant X-ray luminosity ($L_X = 9\times10^{28}$ erg/s) over one decade, including spatially unresolved XMM-Newton observations.
- The majority of the X-ray emission originates very close (70 – 280 AU) to the driving source in all observations (green box).
- Near-infrared observations ([Fe II], see Fig. 2) indicate the same pattern in low temperature plasma.

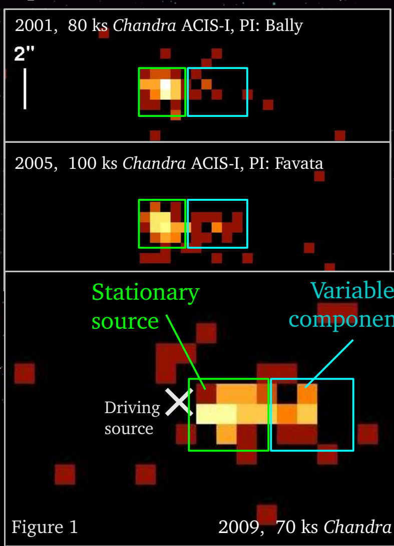

Figure 1

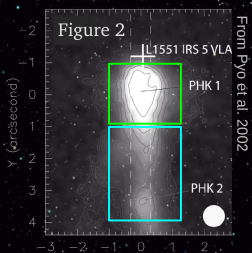

Figure 2

HH 168

This jet is located in the high-mass star-forming region Cepheus A (d=730 pc). Its driving source is currently unknown but might be the central high-mass protostar HW 2 (see Fig. 3).

- Diffuse X-ray emission close to Hα emission with individual condensations at optical knots. Additional large scale diffuse X-ray emission filling the region between the knots.
- X-ray emission displaced with respect to the optical emission by a few 10^3 AU and by 0.2 pc from the assumed driving source.
- The X-ray luminosity of HH 168 exceeds that of HH 154 by at least one order of magnitude ($L_X = 2\times10^{30}$ erg/s).
- The X-ray emission fills a 107 times larger volume than the X-ray emission of HH 154.

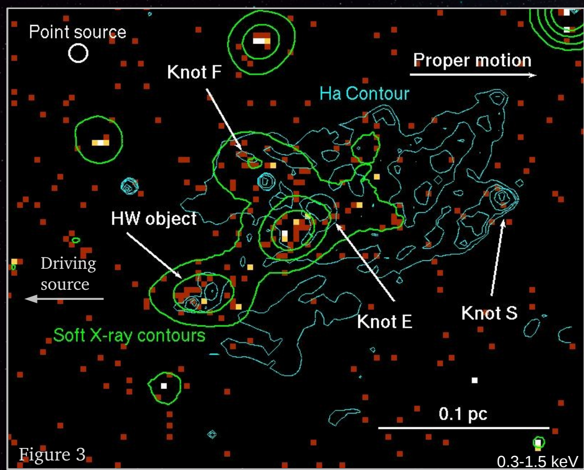

Figure 3

Conclusion

X-ray emission is associated with HH objects on very different scales. While the X-ray plasma temperatures of HH 154 and HH 168 (kT~0.5 keV) coincide, their spatial appearances differ greatly.
The X-ray emission of HH 154 is relatively compact, stationary and close to its driving source. On the other hand, HH 168 fills a much larger volume at a 400 times larger distance to its driving source. These big differences argue for different excitation mechanisms:
HH 154 can be explained by constant heating of the outflowing plasma close to the driving sources and suggests that this heating is related to a standing shock, e.g., related to the flow geometry (Schneider et al. 2011). In contrast, the X-ray emission of HH 168 is likely explained by small but frequent (every $\sim10^{1-2}$ years) shocks within the outflow. These shocks can explain the offset between X-ray and the Hα emission and its diffuse appearance (Schneider et al. 2009).

References: **Bally** et al. 2003, ApJ, 584, 843, **Favata** et al. 2006, A&A, 450L, 17, **Pyo** et al. 2002, ApJ, 570, 724, **Schneider** et al. 2009, A&A, 508, 717, **Schneider** et al. 2011, A&A, 530A, 123