LAUNCHING MECHANISMS FOR PRECESSING JETS.

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A significant proportion of protostellar jets exhibit S-shaped symmetry or corkscrew structure. Observations and modelling of these lead to constraints on the possible jet-launching mechanisms.

An example of S-shaped outflow symmetry powered by a Class 0 object is found in the Spitzer IRAC image and the 2.12μm shocked H_2 emission morphology associated with the outflow of IRAS 16253−2429 (Barsony et al. 2007, in prep.; Haisch et al. 2007, in prep.) IRAS 16253−2429 is a newly discovered protostar in the nearby (d=125 pc) ρ Oph cloud (Khanzadyan et al. 2004, Stanke et al. 2006), that does not suffer the source confusion found in the vicinity of its more famous neighbor, the binary VLA1623 outflows (*e.g.,* Dent et al. 1995).

The detailed appearance of the IRAS 16253−2429 flow, in both the 2.12 μm H_2 emission line and in the millimeter CO (3-2) line, can be reproduced by a modified 3-D hydrodynamic code that incorporates limited chemistry and sophisticated cooling functions (e.g., Rosen & Smith 2004, Smith & Rosen 2005).

Good qualitative agreement with the data for IRAS 16253−2429 is produced by a jet model that assumes a 400 yr precession period (compared to the jet evolution time of $\sim$ 500 yr) at a time t=212 yr in the simulation. The precession opening angle is 10°. The initial jet density is 10^5 cm^{-3} moving into an ambient constant density medium of n = 10^4 cm^{-3}. The initial jet temperature is 100K and the ratio of the jet to ambient thermal pressure is 100.

The simulation is meant to model a typical, precessing Class 0 flow. A fast (50 yr precession period) precessing flow would produce a ring appearance in H_2, which would quickly fragment, instead of the sinuous, S-shaped structure, which more closely fits the observations.

An example of a precessing flow driven by a Class I protostar has recently been demonstrated for the case of Elias 29 (Ybarra et al. 2006). At an estimated $L_{bol} = 26L_{\odot}$, Elias 29 is the most luminous object of its class in the ρ Oph clouds (Bontemps et al. 2001), with an estimated accretion luminosity of 15−18 $L_{\odot}$ (Muzzerolle et al. 1998).

Figure 1 shows a close-up of the pure 2.12 μm, shock-excited H_2 emission in the vicinity of the central protostar. Pure molecular hydrogen emission-line features 1, 2a, and 2b are labelled (nomenclature from Ybarra et al. 2006). These H_2 features are distributed in an S-shaped pattern about the position of the central young stellar object, consistent with the presence of a precessing jet. The bright continuum emission from the inner regions of Elias 29 obviated proper subtraction of the individual narrowband unpolarized images, leading to the 5″-radius circular image artifact in the center.

The inset of Figure 1 shows the AO-assisted, K-band, polarimetric image of the inner 3″ obtained with the VLT (Huélamo et al. 2005). The remarkable corkscrew structure may represent the cavity evacuated by the precessing jet on these small scales. The two small, white features, perpendicular to the jet axis, show the disk in absorption. This disk is clearly edge-on.

There are several observational constraints for jet launching mechanisms to be gleaned from the data for IRAS 16253−2429 and Elias 29. First, the presence of pulsed, as opposed to continuous, jets is suggested. This conclusion is arrived at from the regularity of the bow shock spacings seen in the pure H_2 line images for both objects, as well as from the symmetry of the shock features on either side of the central driving engine in each case. Second, slow precession seems to be operative. This conclusion is arrived at from comparison of synthetic molecular line images (CO and H_2) generated by a 3-D hydrodynamic code (combined with a simplified chemistry code and sophisticated cooling function calculations) with actual molecular line data. The slow precession case (as defined by Smith & Rosen 2005) best reproduces the observed S-shaped symmetry.

Possible models to account for the observed precession may be the presence of binaries (e.g., Terquem et al. 1999). In this context, it may be noted that Elias 29 has no known companions for separations $\geq$ 7 AU (Simon et al. 1995), although a much tighter binary cannot be ruled out. Another, more speculative possibility may be disk warping induced by a magnetically-driven outflow (e.g., Lai 2003). However, the physics of the latter suggestion requires further investigation– specifically, the effect needs to be calculated over the entire disk, to verify whether or not this process can actually occur.

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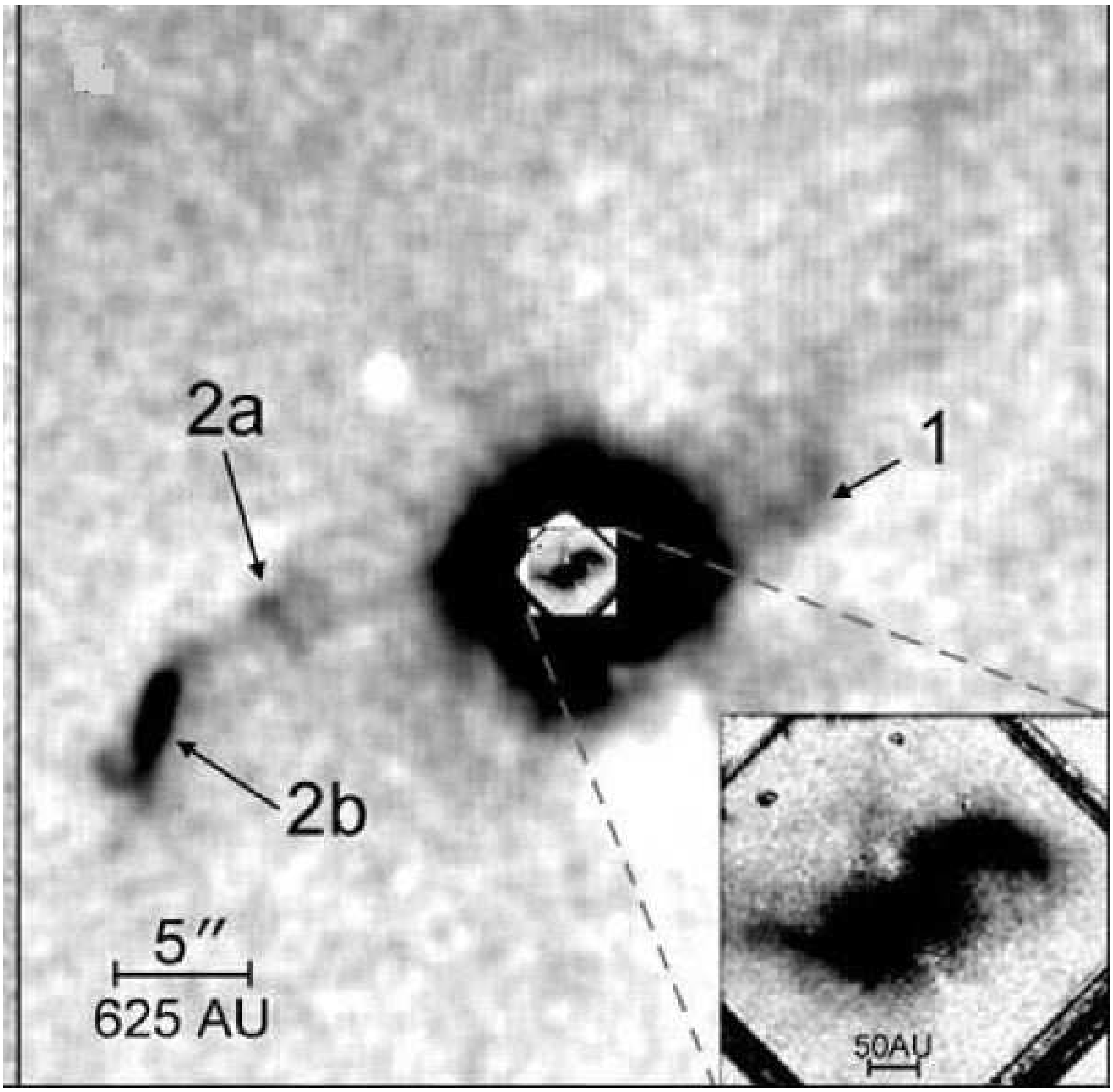

Figure 1: The inner $37'' \times 37''$ continuum-subtracted, pure H_2 emission-line image of Elias 29 (Ybarra et al. 2006), with the K-band polarized intensity image of the inner $3'' \times 3''$ in the inset (Huélamo et al. 2005). Figure produced by J. Ybarra (Univ. of Florida).