HERBIG-HARO PHENOMENA ASSOCIATED WITH T TAURI: EVIDENCE FOR A PRECESSING JET?

RICHARD D. SCHWARTZ
Department of Physics
University of Missouri - St. Louis
8001 Natural Bridge Road
St. Louis, Missouri 63121
U.S.A.

ABSTRACT. A [S II] emission-line image of T Tauri and its surrounding nebulosity suggests the presence of a precessing jet in the system.

1. INTRODUCTION

The early observations of Burnham and later work by Herbig established the presence of an extended emission nebula associated with T Tau (see Schwartz 1974 and references therein). Schwartz (1975) demonstrated that Burnham's Nebula had a spectrum characteristic of Herbig-Haro (HH) objects, and reported the discovery of faint HH emission about 30" west and 4" south of T Tau near the inner edge of Hind's reflection nebula (NGC 1555). Burke et al.(1986), with CCD imaging and long-slit spectra, discovered faint high-velocity (-40 to -150 km s^{-1}) gas between T Tau and a relatively bright knot of emission (HH 1555) located 32" west of T Tau. Dyck et al.(1982) discovered an infrared (IR) companion about 0.6" south of T Tau. Subsequent work (see Schwartz et al. 1986) has demonstrated that the IR companion is the source of significant IR and radio continuum, suggesting that it may possess a substantial stellar wind. This paper reports the discovery of additional HH nebulosity around T Tau, and the presence of morphological structure which may result from a precessing jet in the system.

2. OBSERVATIONS AND DATA ANALYSIS

Direct CCD observations of the T Tau system with a [S II] λ6730 filter were obtained with the Kitt Peak National Observatory 2.1-m telescope on 23 Nov 1987. To avoid image saturation, five successive 100 sec exposures of T Tau were coadded. A nearby reference star (SAO 93887) was imaged in similar fashion (five 35 sec exposures) to provide a stellar point spread function normalized to the central intensity of the T Tau image. With T Tau placed 3" outside of the CCD frame, a 2000 sec [S II] exposure of the emission and reflection nebulosity west of T Tau was obtained. A 500 sec I-band exposure was obtained at the same position to provide a continuum image of the region.

Following image registration, the continuum image of the reference

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star was subtracted from the image of T Tau. Likewise, after normalization of the I-band continuum in Hind's nebula to the continuum observed at the same location with the [S II] filter, the I-band image was subtracted from the [S II] image. The resultant frames, showing basically the [S II] emission around T Tau, were then joined to provide the single image shown in the contour picture of Fig. 1. Burnham's Nebula extending southward from the star is seen to exhibit what appears to be a hint of spiral shape. A new HH knot (A) is located on a continuation of the spiral about 17" SSW of the star.

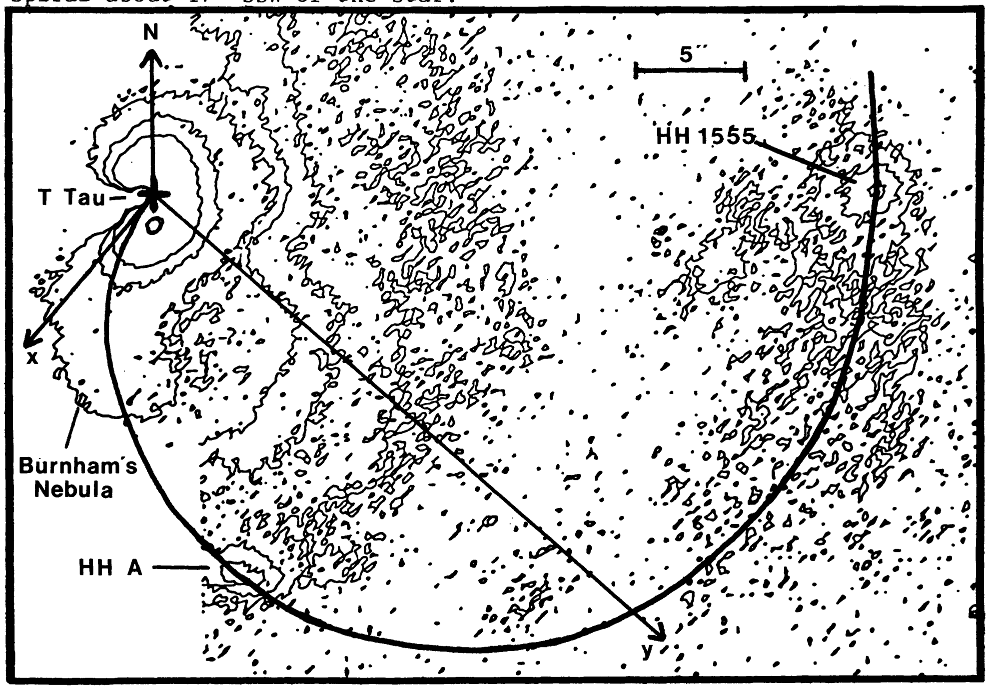

Fig. 1. An intensity contour plot of [S II] emission around T Tau. The x-y system is inclined from an x'-y' system by angles α,β (see text).

3. INTERPRETATION

The radial velocity measurements of Solf et al. (1988) indicate the presence of a bipolar flow from the T Tau system with a jump of more than 100 km s^{-1} from negative values 1.5" south of the star to positive values 1.5" north of the star. If one assumes that a collimated constant velocity flow emanates from a precessing source, a spiral pattern will be traced by the flow according to the relations:

$$x(\phi') = (Pv\phi'/360)[\cos\phi'\sin\psi\cos\alpha + \sin\alpha]$$

$$y(\phi') = (Pv\phi'/360)[\sin\phi'\sin\psi\cos\beta + \sin\beta]$$

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where ϕ' is the phase angle of the flow at a given point on the spiral measured from the x'-axis which is in position angle 220°(the present position angle of the flow), P is the period of precession, v the velocity of the flow, ψ is the opening half-angle of the precession cone, α is the inclination of the central axis of the precession cone in the x'-z' plane, and β is the inclination of the central axis of the cone in the y'-z' plane. Without independent estimates of the product Pv or the angle ψ, it is not possible to obtain a unique fit for a curve passing through Burnham's Nebula, HH A, and HH 1555. However, assuming a value $\psi = 20°$ and carrying out a variation of the parameters α and β yields the fit seen in Fig. 1 where $\alpha = \beta = 5°$. For a distance of 140 pc, the fit gives $Pv = 6.2 \times 10^{12}$ km. Therefore jet velocities in the range 50-200 km s^{-1} would yield precession periods in the range 1000-4000 yrs. For smaller values of ψ, the product Pv increases linearly. The small inclination ($\cong 7°$) of the present jet axis implied by the fit agrees with the T Tau rotation axis inclination ($\cong 10°$) found by Herbst et al. (1986), and if the flow originates from the IR companion, one could conclude that the two objects have comparable inclinations.

Fukue and Yokoo (1986) consider several scenarios in which precessing jets can arise from a young stellar object. Models which invoke torques between T Tau and the IR companion generally yield precession periods $>10^6$ yrs because of their relatively great separation ($\cong$84 A.U.). A more likely source of precession considered by these authors is that of a rapidly rotating, oblate central star which drives the precession of an orbiting torus (disk) misaligned with the equatorial plane of the star. Fukue and Yokoo find $P < 10^4$ yrs for toroids with $r < 1$ A.U. Such a source would probably require a relatively massive accretion disk with matter effectively weighted toward the inner disk, and if identified with the IR companion it would imply that the disk is optically thick even as viewed from the polar direction since no optical component is seen. It is not evident, however, if this is consistent with the presence of a jet which might be expected to have cleared matter from the polar zone. An additional observational feature is the prominent nebular emission immediately west (within a few arcsec) of the star and which may not fit into the bipolar jet model. To assess further the viability of the precessing jet model, it would be useful to obtain high spatial resolution images (<1") of the nebulosity around the star, and to map the velocity field of all material along the putative jet. This work was supported by NSF grant AST 8813917.

4. REFERENCES

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MONTMERLE: Is there any other example of a "precessing jet"? Would the S-shaped feature discovered by S. Strom a few years ago belong to the same category?

SCHWARTZ: I am unaware of any similar spiral jets observed in other young stars. Such jets are seen in some ejections from active galactic nuclei, and of course in the galactic source SS 433. Strom's "twisted filament" near HH 12 appears to be more like a "helix" instead of an opening spiral pattern. Some investigators have suggested that magnetic fields could give rise to helical motion.