ON THE NATURE OF THE EXTENDED RADIO EMISSION SURROUNDING T TAURI SOUTH

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ABSTRACT

At centimeter wavelengths, the young stellar system T Tauri is known to be composed of two sources, the northern one associated with the optical star T Tau itself, and the southern one related to the infrared companion T Tau S. Here we reexamine the origin of the radio emission from these two components using archival 2 cm, 3.6 cm, and 6 cm VLA observations. The emission from the northern member is confirmed to be largely dominated by free-free radiation from an ionized wind, while the southern radio source is confirmed to consist of a compact component of magnetic origin, surrounded by an extended halo. Only moderately variable, the extended structure associated with the southern source is most likely the result of free-free radiation related to stellar winds. However, its flat spectral energy distribution, its extent, and the lack of variation of its size with the frequency of observation are incompatible with the classical picture of a fully ionized wind with constant velocity and mass-loss rate leading to an electron density distribution of $n_e(r) \propto r^{-2}$. Instead, we propose a model in which the ionization results from the impact of a supersonic wind driven by T Tau Sb onto dense surrounding material, possibly associated with the circumbinary disk recently identified around the T Tau Sa/T Tau Sb pair. The timescales for cooling and recombination in such a situation are in good agreement with the observed morphological changes undergone by the extended structure as its driving source moves through the environment.

Subject headings: binaries: general — ISM: jets and outflows — radiation mechanisms: general — radio continuum: stars — stars: formation

1. INTRODUCTION

1.1. Optical and Infrared Observations

Ever since it was first identified as the prototype of a new class of variable stars (Joy 1945), T Tauri has been the subject of intense scrutiny. It is now known to be a $2 M_\odot$ pre–main-sequence star of spectral type K1, with a bolometric luminosity of $8 L_\odot$ (Koresko et al. 1997). T Tau appears to be surrounded by a $4 \times 10^{-3} M_\odot$ accretion disk whose plane is apparently inclined by $20^\circ$–$40^\circ$ with respect to the plane of the sky (Akeson et al. 2002), and it appears to suffer about 1.5 mag of visual extinction (Koresko et al. 1997) caused by material along the line of sight. High-resolution near-infrared observations (Dyck et al. 1982) revealed early that it had a companion (hereafter T Tau S) located $0.7^\prime$ to its south, whose nature remains somewhat mysterious. T Tau S has about twice the bolometric luminosity of the optical star T Tau (which we will refer to as T Tau N in the rest of the paper) and is very significantly more obscured (e.g., Koresko et al. 1997; Stapelfeldt et al. 1998); indeed, its spectral energy distribution peaks around 3 $\mu$m (Ghez et al. 1991). The relative motion between T Tau N and T Tau S (Ghez et al. 1991; Roddier et al. 2000; Duchêne et al. 2002, 2005) strongly suggests that they are physically bound to each other. In addition, the comparison between the transverse ($\sim 5$ km s$^{-1}$; Beck et al. 2004) and radial ($\sim 2.5$ km s$^{-1}$; Duchêne et al. 2005) components of the relative orbital motion shows that the orbit is close to being in the plane of the sky ($i \leq 30^\circ$) and is, therefore, very likely to be roughly coplanar with the circumstellar disk surrounding T Tau N.

Recently, T Tau S was itself found to be composed of two infrared sources (T Tau Sa and T Tau Sb; Koresko 2000; Köhler et al. 2000) in rapid relative motion (Duchêne et al. 2002). Here too, the comparison between the transverse and radial components of the relative motion strongly suggests that the orbit is nearly in the plane of the sky (Duchêne et al. 2006 and references therein). Infrared observations have shown that T Tau Sb has the infrared spectrum of a normal but very obscured ($A_V \sim 15$) pre–main-sequence M1 star, whereas the spectrum of T Tau Sa is generally featureless, with the exception of Br$\gamma$ in emission (Duchêne et al. 2002, 2005). On the basis of a detailed analysis of near- and mid-infrared observations and of orbital motions, Duchêne et al. (2005, 2006) convincingly argued that T Tau Sa is an intermediate-mass ($2.5$–$3 M_\odot$) young star surrounded by a small nearly edge-on disk (see also Schaefer et al. 2006). In addition to this circumstellar disk, T Tau Sa and T Tau Sb are apparently surrounded by an edge-on circumstellar torus seen as an absorption ultraviolet feature (Walter et al. 2003), which is responsible for the large extinction toward T Tau S. The exact size of this structure is still poorly constrained, but it is likely on the order of $1'' \times 0.5''$ (Walter et al. 2003; Duchêne et al. 2005). To be stable against the orbital motion of the Sa/Sb system, the inner radius of this structure must be larger than about $0.35''$ (Duchêne et al. 2005).

Two outflows have been identified around T Tau (Solf et al. 1988; Böhm & Solf 1994; Solf & Böhm 1999). One is oriented roughly east-west (P.A. $\sim 65^\circ$) and points almost exactly to the observer ($i \sim 80^\circ$), while the other is approximately north-south (P.A. $\sim -15^\circ$) and almost exactly in the plane of the sky ($i \leq 10^\circ$). The western side is the most prominent part of the east-west jet; it terminates as a series of Herbig-Haro objects (known as HH 155) in NGC 1555 (Hind’s Nebula), about 35$''$ west of T Tau. The north-south jet also defines a series of HH knots, including Burnham’s Nebula, 8$''$ south of T Tau, which is generically known as HH 255, and that apparently connects at larger scale with the giant flow HH 355 (Reipurth et al. 1997). Solf & Böhm (1999) showed that each side of these two flows produces well-defined spatiokinematical structures, and they...