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DUSTY DISKS IN THE MULTIPLE SYSTEMS UZ TAURI AND GG TAURI

M. SIMON[1] AND S. GUILLOTEAU[2]
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ABSTRACT

Interferometric observations of the 2.6 mm dust thermal emission around the T Tauri triple system UZ Tau show that most of it is equally divided between UZ Tau W (the close binary) and UZ Tau E. The emission is at least partially optically thick at 2.6 mm which implies an origin in disks of size of size ~13 AU and mass ~0.024 $M_\odot$. The 2.6 mm emission of the GG Tau system, a hierarchical quadrupole, is partially resolved. Strong emission extended over ~3″ × 5″ is associated with the close binary GG Tau. Weak emission is detected at GG Tau/c, also a close binary. Evidently extensive dusty disks can survive in the environment of close binaries for at least ~10^5 yr, and their structure can vary markedly from system to system.

Subject headings: binaries: general — stars: formation — stars: pre–main-sequence

1. INTRODUCTION

Near-infrared high angular resolution surveys of the young stars in the Taurus star-forming region (SFR) are revealing that many of the stars previously regarded as unresolved single stars are in fact binaries (Simon et al. 1992; Ghez et al. 1992; Leinert et al. 1992). Given the sensitivity and angular resolution limits of the surveys, it seems certain that most, and possibly nearly all, of the young stars in the Taurus SFR are in binary systems. Thus, star formation in Taurus produces mostly multiples.

Since the star–plus–circumstellar disk paradigm has proved so enormously successful in accounting for the observed properties of young stars considered as single stars (e.g., Lada 1991), it is very important to determine the effects of the binary environment on the properties and evolution of disks. The observations suggest a distinction between inner and outer circumstellar disks. The inner disks, extending to a few photospheric radii, are responsible for boundary layer emission phenomena and near-IR excess emission (Basri & Bouvier 1989). The dusty outer disks are identified by their continuum thermal emission at IR and mm wavelengths and may extend to ~100 AU (Adams, Lada, & Shu 1987; Beckwith et al. 1990). At the ~150 pc adopted distance to the Taurus SFR, 100 AU subtends 0″.7, and because of this small size, only one determination of the disk radius has been possible so far, in L1551 IRS 5 (Keene & Masson 1990). Young stars that have companions and those that do not are indistinguishable in their Hα equivalent width, indicating that active inner disks are found in both groups. The multiple systems are in general weaker 1.3 mm continuum emitters than the single stars, indicating that their extensive dusty disks are less massive (Simon et al. 1992). There are however prominent exceptions.

Of the multiples identified by Simon et al. (1992), the UZ Tau triple system is the strongest 1.3 mm source (Beckwith et al. 1990). UZ Tau W is a close binary (apparent separation 0″.34, so actual separation ≥49 AU) with the third member of the triple, UZ Tau E, 4″ away. UZ Tau E and W, each considered as single stars, are classic (emission-line) T Tauri stars (cTTs; Herbig & Bell 1988). The GG Tau system, the second strongest 1.3 mm source in Beckwith et al.'s survey, is a hierarchical quadrupole. It contains a pair of binaries: GG Tau (separation 0″.26), and at ~10″ distance, GG Tau/c (separation 1″.4 Leinert et al. 1991). GG Tau, considered as a single star, is also a cTT (Herbig & Bell 1988).

Tidal effects are expected to disrupt extensive disks in binaries whose separations are comparable to the disk size. This suggests that UZ Tau E, the single member of the UZ Tau system, might have a more extensive and longer lived disk than the UZ Tau W binary. Physical intuition, however, offers no guidance to the situation in the GG Tau system. To study the evolution of disks in these systems, it is necessary first to determine the location and structure of their dust emission. The IRAM interferometer has sufficient angular resolution and sensitivity to image these objects at 2.6 mm wavelength. We report IRAM observations of the UZ Tau and GG Tau systems in this *Letter*.

2. THE OBSERVATIONS AND RESULTS

2.1. *The Observations*

The observations were carried out with the IRAM Plateau de Bure Interferometer (Guilloteau et al. 1992) on 1992 January 3 and 28. Two configurations were used: a compact one (W05-W08-N03), with baselines between 24 and 65 m, and an extended one (W05-E18-N20), with baselines between 150 m and 240 m. The observing frequency was 109.8 GHz in the lower sideband, and 122.8 GHz in the upper sideband. Typical single-sideband system temperatures were 250–400 K in the LSB and 450–600 K in the USB. UZ Tau and GG Tau were observed alternately with the same configurations, resulting in a sparse coverage in the *u-v* plane. No emission from the $C^{18}O$ $J = 1–0$ line was detected in the lower sideband, and USB and LSB data were averaged to improve sensitivity and UV coverage through bandwidth synthesis. 3C 84 (6.1 Jy) and 3C 120 (1.4 Jy) were observed for phase and flux calibration. Excellent weather conditions produced rms phase noise between 5° and 15° on even the longest baselines. The flux density scale is accurate to better than 10%. The data were reduced using the GILDAS software package. The images were CLEANed using a restoring beam of ~2″.4 × 1″.8 at PA 50°. The flux densities were derived by integrating over the source area in the restored image and were checked for agreement with the total cleaned flux.

[1] Astronomy Program, State University of New York, Stony Brook, NY 11794.

[2] Institut de Radio Astronomie Millimétrique, 300 Rue de la Piscine, F-38406 Saint Martin d'Hères, France.

2.2. *The UZ Tau Triple System*

The UZ Tau image at 2.6 mm wavelength (Fig. 1) shows two point sources of nearly equal flux densities, 13 ± 1 mJy. Because the two point sources dominate the image, the CLEANed deconvolution is stable. We measure a total flux density of 37 ± 3 mJy from the region so extended emission must also be present, but its spatial distribution is uncertain because of the limited *u-v* plane coverage.

The astrometric position and proper motion of UZ Tau (Jones & Herbig 1979) refer to the photocenter of the E and W components (Herbig & Bell 1988). The point radio sources are coincident with UZ Tau E and W. Nearly identical flux densities are measured when generating an image with only the longest baselines (resolution 1″.5), showing that UZ Tau E and W are unresolved at these resolutions.

2.3. *The GG Tau Quadrupole System*

A resolved structure elongated north-south dominates the 2.6 mm image of GG Tau (Fig. 2); its peak flux density is 26 mJy beam^{-1}. This value is well determined but the flux density of the weak source $\sim 10''$ to the south, ~ 8 mJy, is not because of the sparse *u-v* plane coverage and the difficulty of CLEANing an extended image (e.g., Cornwell 1986). The flux density of the southern component is in the range 2–8 mJy. The total flux density of the extended structure is 90 ± 9 mJy. This value depends on the size of the CLEANing box but agrees well with the flux density 80 ± 5 mJy at 2.7 mm reported by Beckwith et al. (1990).

The 26 mJy beam^{-1} beam radio peak in Figure 2 lies within 0″.5 of the high-precision position of GG Tau given in the *HST* Guide Star Catalog. Proper motion alone (presently unknown) could account for this discrepancy. There is little doubt therefore that the radio peak coincides with the GG Tau binary. Moreover, comparing the radio image with Zinnecker & Reipurth's (1992) CCD image shows that if the radio peak is aligned with GG Tau, then the weak southern radio peak coincides with the optically brighter member of the GG Tau/c binary.

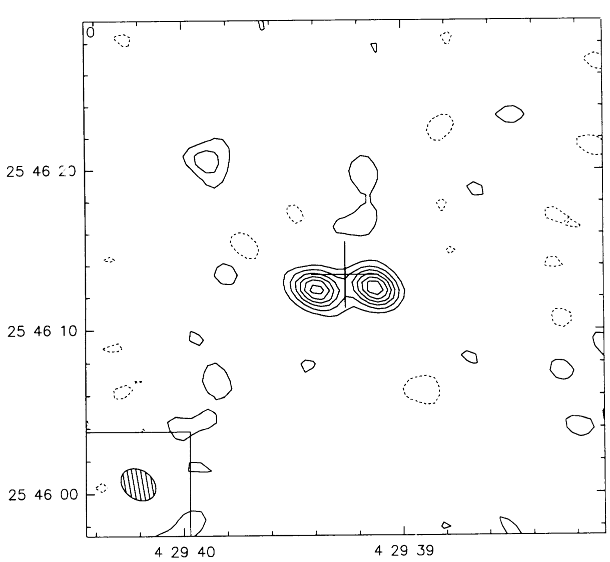

FIG. 1.—A CLEANed image of the UZ Tau triple system obtained with the IRAM interferometer operating at 2.6 mm wavelength. The inset shows the half-power size and orientation of the synthesized beam. The two compact radio sources are coincident with UZ Tau W (the 0″.34 apparent separation binary) and UZ Tau E. The contour spacing is 2 mJy per beam, negative contours are dashed, and the zero level has been omitted.

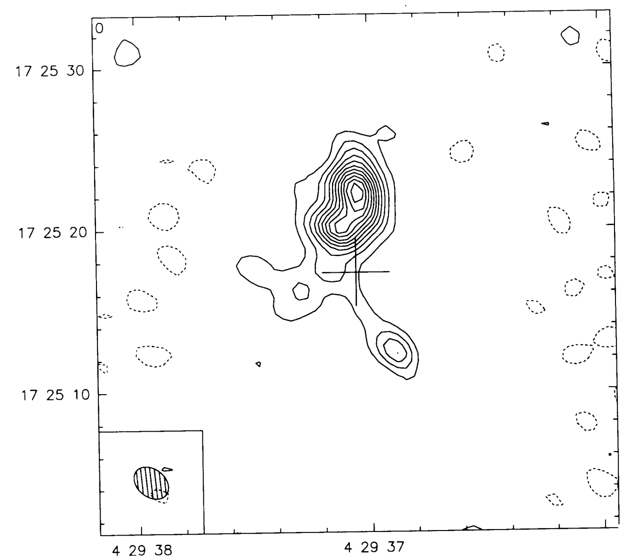

FIG. 2.—Same as Fig. 1 but for the hierarchical quadrupole system GG Tau. The peak of the strong resolved emission is coincident with the GG Tau binary (0″.26 apparent separation) and the weak peak $\sim 10''$ to the south is coincident with the optically brighter member of the GG Tau/c binary (1″.4 apparent separation). The contour spacing is 2 mJy per beam, negative contours are dashed, and the zero level has been omitted.

3. DISCUSSION

The total flux density of the UZ Tau system at 1.3 mm is 172 ± 15 mJy (Beckwith et al. 1990) so that with a total flux density of 37 ± 3 mJy at 2.6 mm, the spectral index strongly suggests that the 2.6 mm emission of the compact sources associated with UZ Tau E and W is optically thick and that the extended flux measured at 2.6 mm is optically thin. To estimate the size and mass of the disks in the UZ Tau system, we follow the approach of Beckwith et al. (1990). The mass absorption coefficient adopted by Beckwith et al., scaled to 2.6 mm, is $k_\nu(2.6 \text{ mm}) = 0.01 \text{ cm}^2 \text{ g}^{-1}$ (per gram of material, not just dust). We assume that the dust temperature and material surface density radial dependence are $T(r) = T_1(1 \text{ AU}/r)^q$ and $\Sigma(r) = \Sigma_1(1 \text{ AU}/r)^p$ and use Beckwith et al.'s values for UZ Tau, $p = 1.5$, $q = 0.63$, and $T_1 = 173$ K. We assume that the disks are seen face-on. Then, for a disk radiating 13 mJy, the size at which its 2.6 mm optical depth is unity is 13 AU and the mass interior to 13 AU is 0.024 $M_\odot$. Allowing for the mass in the optically thin extended component, the total mass of the two compact sources, $\sim 0.048\ M_\odot$, is in excellent agreement with Beckwith et al.'s estimate of 0.054 $M_\odot$ for the entire UZ Tau system. While these estimates are obviously imprecise, it seems firm that the disks of UZ Tau E and W are small and have relatively low mass. The one or two disks that UZ Tau W binary harbors have a smaller radius than the separation of its stars and thus are truly circumstellar.

The 2.6 mm emission of GG Tau is remarkable for its large $\sim 3'' \times 5''$ extent which is far greater than the 0″.26 apparent separation of its binary. The spectral index of the total flux of GG Tau between 2.6 and 1.3 mm is 2.90 ± 0.25, more or less typical of other disks (Beckwith et al. 1990), indicating optically thin emission. The measured deconvolved size, 130 × 350 AU at half-power, allows a more precise determination of disk mass than Beckwith et al.'s estimate, where an outer radius of

100 AU was assumed. With the surface density profile $\Sigma(r) \propto r^{-p}$ as above, the disk mass is

$$M_d = \frac{2\pi R_{\rm out}^2}{(2-p)k_\nu}\left(\frac{R_{\rm thick}}{R_{\rm out}}\right)^p ,$$

where $R_{\rm thick}$ is the radius at which the disk becomes optically thick, here, at 2.6 mm wavelength, and $R_{\rm out}$ is the outer radius of the disk. This expression follows from the flux density contributed by the optically thick part of the disk, $S_{\rm thick}$, which must be lower than the peak flux density we observed, 26 mJy beam^{-1}. Using the parameters adopted by Beckwith et al. for GG Tau, $q = 0.55$, $T_1 = 180$ K, $p = 1.5$, a consistent solution is found for $S_{\rm thick} \sim 14$ mJy, $R_{\rm thick} \sim 14$ AU, yielding $M_d \simeq 0.13\ M_\odot$.

The observed intensity distribution is however inconsistent with this simple disk model because it is not even centrosymmetric. Moreover, the assumed $T(r) \propto r^{-0.55}$ distribution implies unreasonably low temperatures in the outer regions of the disk, for example, 7 K at 350 AU. If instead we simply assume the total measured flux of 90 mJy is optically thin emission from a uniform dust disk at a constant temperature of 15 K (reached at $R = 100$ AU in the distribution above), we obtain a disk mass $M_d \simeq 0.15\ M_\odot$.

Our two estimates of GG Tau's disk mass are consistent with each other but are about half the value derived by Beckwith et al. The difference lies in the 100 AU outer radius they assumed, which forced them to derive a much larger optically thick radius (45 AU at their observing frequency, 22 AU at 2.6 mm), and consequently to infer a large hidden mass in the inner disk. Our measurements show that the outer radius is larger, and the dust optically thin, so that none of the mass we derived here is hidden.

It is interesting that the masses we estimate for the disks within UZ Tau and GG Tau systems are comparable to the "minimum mass" models of the solar system's protoplanetary disks (Lissauer 1987). The structure of the disks in the two systems is however very different; circumstellar in UZ Tau, and, at least in part, circumbinary in GG Tau. The Hayashi track ages of UZ Tau and GG Tau are $\sim 5 \times 10^4$ and $\sim 3 \times 10^5$ yr respectively (Beckwith et al. 1990). Our results thus show that dusty disks can survive $O(10^5)$ yr in the environments multiple systems. On the other hand, by $O(10^7)$ yr, most disks are not detectable at 10 μm wavelength (Skrutskie et al. 1990). Whether the structural differences that we observe are a consequence of the different ages of the systems or of different circumstances of their formation is impossible to determine at present. Measurement of the kinematics and gas content of these structures will advance our understanding of their evolution.

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