L1551NE—DISCOVERY OF A BINARY COMPANION

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ABSTRACT

L1551NE is a very young (class 0 or I) low-mass protostar located close to the well-studied L1551 IRS 5. Here we present evidence, from 1.3 mm continuum interferometric observations at ~1” resolution, for a binary companion to L1551NE. The companion, whose 1.3 mm flux density is ~1/3 that of the primary component, is located 1°43 (~230 AU at 160 pc) to the southeast. The millimeter-wave emission from the primary component may have been just barely resolved, with a deconvolved size of ~0.82’’ × 0.70’’ (~131 × 112 AU). The companion emission was unresolved (<100 AU). The pair is embedded within a flattened circumstellar envelope of size ~5’4 × 2’3 (~860 × 370 AU). The masses of the three components (i.e., from the circumstellar material of the primary star and its companion and the envelope) are approximately 0.044, 0.014, and 0.023 $M_\odot$, respectively.

Subject headings: binaries: general — ISM: individual (L1551NE) — stars: formation

1. INTRODUCTION

Young T Tauri stars in Taurus have been found to have a high incidence of multiplicity, with the fraction of close (<100 AU) companions found to be 0.40 ± 0.08 (Ghez, Neugebauer, & Matthews 1993; Leinert et al. 1993; Simon et al. 1995; Patience et al. 1998), using speckle and occultation techniques. Similar surveys of the Hyades cluster have found a smaller fraction of 0.30 ± 0.06 and a still lower fraction of 0.14 ± 0.03 for G dwarfs in the solar neighborhood (Patience et al. 1998), suggesting an evolutionary effect and/or environmental effects during formation. Deeply embedded class I and class 0 protostars cannot be surveyed using similar techniques since they are not visible at optical wavelengths and are generally too deeply embedded, even at infrared wavelengths. Millimeter/submillimeter-wavelength interferometry at subarcsecond resolution can resolve close companions if they have circumstellar disks. For example, L1551 IRS 5 was recently shown to be a binary based on 7 mm interferometric observations at the VLA (Rodríguez et al. 1998). Here we present evidence that L1551NE also has a binary companion.

L1551NE ($\alpha = 4^h 28^m 50^s.55$, $\delta = +18^\circ 02' 10''$ [B1950; Draper, Warren-Smith, & Scarrott 1985]) is a young stellar object in the L1551 molecular cloud, at a distance of 160 pc (Snell 1981). Discovered by Emerson et al. (1984) from IRAS data, it is the second brightest embedded source in the Taurus complex after L1551 IRS 5, with $L_{bol} \sim 6 \ L_\odot$. It has a molecular outflow (Moriarty-Schieven, Butner, & Wannier 1995). The radial density distribution of L1551NE has been modeled by Barsomy & Chandler (1993) from 800 $\mu$m images and by Butner et al. (1995) from 100 and 200 $\mu$m observations. Both found that the density distribution implied by the radial intensity profile was much shallower than the $n(r) \sim r^{-1.5}$ predicted by the “inside-out” collapse model of Terebey, Shu, & Cassen (1984). Moriarty-Schieven et al. (1995) have suggested that L1551NE may be a class 0 source.

2. OBSERVATIONS

The observations were taken with the Owens Valley Radio Observatory millimeter-wave array on 1994 November 12 and 1997 January 17, at a wavelength of 1.3 mm (230.65 GHz). The 1994 observations were taken with the array (consisting of the time of six 10 m antennae) in the compact “l”-configuration (with a maximum baseline of 115 m and a minimum baseline of 30 m), and in 1997, the data were taken using the extended “h”-configuration (maximum baseline 241.7 m, minimum baseline 35 m). The effective resolution of the synthesized beam was ~2” and 1” for the two configurations.

The observations were made in “snapshot” mode, with a series of 10 minute integrations interspersed with observations of other sources and the phase calibrators (0528+134 and 3C 84), to yield a total integration time of ~1 hr in the l-configuration and ~2 hr in the h-configuration. The system temperatures were ~1200 and ~1600 K, respectively. Neptune was used as the primary flux calibrator. The continuum bandwidth is 1 GHz.

The data were reduced using the standard reduction package MMA and then exported to the Astronomical Image Processing System (AIPS), which was used to generate and clean images (using the IMAGR task and uniform weighting). The clean box included only a small area covering the main source and the apparent binary companion. The angular resolution of the cleaned image was 1’29’’ × 1’07’’ at position angle (P.A.) of −74°.

3. DATA

Figure 1 presents a contour image of L1551NE. The primary source (hereafter source A) at (B1950) $\alpha = 04^h 28^m 50^s.552$, $\delta = +18^\circ 02' 09''$85 and another weaker source at 1°43 to the southeast (source B) are clearly seen. Emission also appears to extend to the north and to the east of the primary source, and it surrounds source B.

To verify that we are seeing real sources and not phase instabilities, we generated images using the same techniques of another source, IRAS 04169+2702, which was observed...
The rms noise of the image is 0.023 Jy beam$^{-1}$ and is shown in a box in the lower right-hand corner of the image. The negative contours are at 0.049 and 0.07 Jy beam$^{-1}$ and incrementally increase at intervals of 0.035 Jy beam$^{-1}$. The negative contours are $−0.049$ and $−0.07$ Jy beam$^{-1}$. The synthesized beam (FWHM) is shown in a box in the lower right-hand corner of the image.

during the same 2 days and interspersed with L1551NE. Phase errors would be manifested as “anomalous” sources or structures. No such anomalous sources are seen in the image of IRAS 04169+2702. In addition, we cleaned the l-configuration data separately from the h-configuration data. The high-resolution data clearly had two peaks, while the low-resolution data showed an extended dislikle structure with a long axis through the line joining the two sources. Thus, we believe that the structure seen here in L1551NE is real.

In Table 1, we present the positions, sizes, and flux densities of the sources. The single-dish flux density at 1.35 mm is also shown.

4. DISCUSSION

There are three distinct components apparent in the image shown in Figure 1: (1) a brighter, possibly extended source at the field center (source A), (2) a weaker, probably pointlike source (B) 1.43 southeast of A, and (3) diffuse, low-level emission that appears to surround both sources and extend $\sim$2° to the northwest and east of A.

Sources A and B were fitted with elliptical Gaussians using the AIPS task JMFT. The primary source A was found to have a size of $1.53 \times 1.28$ (i.e., it may have been slightly resolved with a size $\sim$2 $\sigma$ larger than the beam size), a peak intensity of $\sim$0.33 Jy, and an integrated intensity of $\sim$0.47 Jy (i.e., $\sim$40% $\sim$3 $\sigma$ larger than the peak intensity). It is slightly resolved (with a deconvolved size of $\sim$0.82 $\times$ 0.70), then its size is $\sim$131 $\times$ 112 AU at a distance of 160 pc. Source B is located 1.43 (229 AU at 160 pc) southeast of A, and its size and intensity are consistent with it being unresolved (i.e., $\leq$100 AU). We estimate the mass within each source using $M_p = [S_D^2/B(T)] (4/3) (\alpha_p Q_p)$, and we display these in Table 1. We used the integrated flux densities, assumed a distance of 160 pc (Snell 1981), used a dust temperature of 42 K (Moriarty-Schieven et al. 1994) and the dust emissivities from Hildebrand (1983), $(4/3) (\alpha_p Q_p) = 0.1(\lambda/250)^{\beta}$ g cm$^{-2}$, assuming $\beta = 1$ (Moriarty-Schieven et al. 1994), and have assumed a gas-to-dust mass ratio of 100. The derived masses are approximately 0.044 and 0.014 $M_\odot$ for the emission from source A and source B, respectively, and 0.022 $M_\odot$ for the envelope. The total mass for the two sources plus the envelope is $\sim$0.078 $M_\odot$.

Rodríguez, Anglada, & Raga (1995) imaged the L1551NE region at 3.5 cm and found a continuum source located within 1.5 $\sigma$ of our source A. Rodríguez et al. (1995) attribute the 3.5 cm emission to shocks associated with the outflow (Moriarty-Schieven et al. 1995). Thus, source A is the likely origin of the L1551NE outflow. Rodríguez et al. (1995) found a possible second source located $\sim$0.6 east of A, which is not coincident with our source B, for which no 3.5 cm emission was detected. If their source 0.6 east of A is real, this would suggest that L1551NE is at least a triple-star system. However, another protostar capable of generating an outflow jet should have had a circumstellar disk large enough to be detected by our observations. The eastern 3.5 cm source is possibly the result of a jet from source A, or is a background object.

The single-dish flux density (H. M. Butner, G. H. Moriarty-Schieven, & P. G. Wannier, in preparation) that was found by using the 14 m James Clerk Maxwell Telescope (JCMT; FWHM = 20") is not significantly different from the total intensity found in our image of L1551NE (primary beam FWHM = 28"). Thus, only a small amount, if any, of the single-dish flux can have been resolved out by the interferometer. However, considerable extended emission was seen at $\sim$850 $\mu$m by Barsony & Chandler (1993) and G. H. Moriarty-Schieven, H. M. Butner, N. Ohashi, & P. G. Wannier (2000, in preparation) and at 200 $\mu$m by Butner et al. (1995). Barsony

| Source Parameters |
|-------------------|
| Source A          |
| Peak intensity    | $0.333 \pm 0.022$ Jy beam$^{-1}$ |
| Integrated intensity | $0.473 \pm 0.049$ Jy |
| Position (B1950)  | $\alpha = 04^h28^m50.59^s, \delta = 18^o02^\prime09^\prime91^" (\pm 01^\prime)$ |
| Size              | $1.53 \times 1.28 (\pm 01^\prime), P.A. 104^\circ \pm 15^\circ$ |
| Deconvolved size  | $0.082 \times 0.70 (131 \times 112$ AU at $160$ pc) |
| Mass$^a$          | $0.044 M_\odot$ |
| Source B          |
| Peak intensity    | $0.146 \pm 0.022$ Jy beam$^{-1}$ |
| Integrated intensity | $0.197 \pm 0.048$ Jy |
| Position (B1950)  | $\alpha = 04^h28^m50.60^s, \delta = 18^o02^\prime08^\prime64^" (\pm 01^\prime)$ |
| Mass$^a$          | $0.014 M_\odot$ |
| Circumbinary Disk |
| Integrated intensity | $0.233 \pm 0.048$ Jy |
| Size              | $5.51 \times 2.59 (\pm 0.22), P.A. 2° (\pm 14°)$ |
| Deconvolved size  | $5.54 \times 2.23 (\pm 0.22), P.A. 2° (\pm 10°)$ |
| Mass$^a$          | $0.022 M_\odot$ |
| Total Integrated Intensity |
| Integrated intensity | $0.851 \pm 0.084$ Jy |
| Mass$^a$          | $0.079 M_\odot$ |
| Single-Dish Intensity$^b$ |
| 19" FWHM beam     | $0.83 \pm 0.03$ Jy |
| Mass$^a$          | $0.078 M_\odot$ |

$^a$ Assuming $T_d = 42$ K, $M_p/M_\odot = 100$, and $D = 160$ pc.

$^b$ From H. M. Butner, G. H. Moriarty-Schieven, & P. G. Wannier (2000, in preparation), obtained with the 14 m JCMT (20" FWHM).
& Chandler (1993) and Butner et al. (1995) modeled this extended emission as an envelope whose radial density distribution decreases very slowly with distance from the protostar. Weak, low-level emission can be seen extending \( \sim 1'' - 2'' \) to the north and east of source A and perhaps encompassing source B. This extended structure has a disklike appearance of dimension \( \sim 5'' \times 2'' \) \((\sim 800 \times 300 \text{ pc})\) with long axis at a position angle of \( \sim -12\degree \). This is roughly perpendicular to the axis of the conical reflection nebula emanating from L1551NE (Draper et al. 1985; Hodapp 1994) and hence of the molecular outflow (Moriarty-Schieven et al. 1995). This disklike structure may represent a circumbinary disk.

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