INTERACTIONS BETWEEN A BRIGHT YOUNG STELLAR OBJECT AND THE MIDCOURSE SPACE EXPERIMENT INFRARED-DARK CLOUD G79.3+0.3: AN EARLY STAGE OF TRIGGERED STAR FORMATION?

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Received 2002 April 19; accepted 2002 December 4

ABSTRACT

Millimeter and mid-infrared observations have been made of the dense clumps of dust and gas and of young stellar objects (YSOs) associated with the bright, compact submillimeter source G79.3+0.3 P1 in the relatively nearby MSX infrared-dark cloud G79.3+0.3. The Gemini mid-infrared observations reported here indicate the presence of three YSOs within the cloud. BIMA 3 mm continuum observations show that the brightest of the YSOs is likely to be a Herbig Ae/Be star. High angular resolution molecular line observations suggest that a wind from this star may be triggering collapse in the adjacent molecular cloud. The submillimeter source G79.3+0.3 P1 itself does not contain infrared sources and may represent an earlier stage of star formation.

Subject headings: dust, extinction — ISM: clouds — stars: formation — stars: pre–main-sequence

1. INTRODUCTION

Egan et al. (1998) have identified a large population of cold dust clouds in images of the Galactic plane made with the Midcourse Space Experiment (MSX) satellite (Price et al. 2001). These clouds appear as dark patches of absorbing material against a background of mid-infrared emission bands and emission from warm, small dust grains. Egan et al. defined the infrared-dark clouds (IRDCs) as having one to several magnitudes of extinction at 8 μm and no obvious emission in any of the 8–25 μm bands observed by the MSX satellite. They concluded that the IRDCs possess hundreds of magnitudes of visual extinction and contain large column densities of cold dust. Observations of a selection of these clouds in H2CO by Carey et al. (1998) revealed that much of the gas inside the IRDCs has TK ≈ 10–20 K and n(H2) ≳ 106 cm–3, with H2 column densities ranging up to 1023 cm–2. These results were confirmed by our subsequent observation of strong 850 μm emission from high column densities of cold dust in a selection of IRDCs (Carey et al. 2000). Most of these objects are quite distant, with kinematic distances between 1 and 8.5 kpc.

The IRDCs appear to be a very interesting population of molecular clouds. On theoretical grounds, we expect that molecular clouds on the verge of star formation will contain extremely cold and dense condensations, which will show up as IRDCs if they are favorably located in front of a region of extended mid-IR emission. The selection criteria for the MSX IRDCs (Carey et al. 1998) ensure that they do not yet contain high-mass main-sequence stars and H ii regions.

Trying to relate the physical properties of this selection of dust clouds to those of better-studied nearby molecular clouds, such as those in the Orion-Taurus region, is problematic. Most of the best-studied clouds lie in the outer Galaxy, where there is insufficient background emission for IRDCs to be identifiable. By contrast, the large distances of many MSX IRDCs make them difficult to detect at visible and near-IR wavelengths and difficult to pick out from the surrounding clutter of lower density clouds in molecular line surveys.

A notable exception is the cloud G79.3+0.3, located in the Cygnus Rift at an estimated distance of 800 pc (Miller 1937; Ikhsanov 1961; Wendker, Higgs, & Landecker 1991), close enough to the Sun that it can be seen at visible wavelengths (Redman et al. 2000). Figures 1 and 2 show our JCMT SCUBA 850 μm image of the G79.3+0.3 IRDC and the MSX 8 μm image of the same region, respectively. Unlike the other IRDCs we have observed, this cloud exhibits a variety of indicators of star formation. Most prominently, the H ii region DR 15 (G79.307+0.277) lies behind and slightly south of the IRDC, between P4 and P5 in the figures. It is not immediately obvious whether the IRDC is part of a larger complex including DR 15 or is an unrelated foreground cloud. In visible and near-IR images of the region (Redman et al. 2000), there is an association of stars (to the west of DR 15) whose northern boundary is defined by the southern edge of the IRDC. If DR 15 is related to this association, it suggests that both DR 15 and the association lie beyond the IRDC. In the 8 μm MSX image (Fig. 2), the dark filament of the IRDC (whose dust content is traced by the SCUBA 850 μm emission in Fig. 1) is interrupted between P1 and P3 by a bright patch of warm dust emission, which is suggestive of deeply embedded hot stars. Because of this, the eastern and western parts of the IRDC were initially assigned different designations in the MSX catalog (G79.34+0.33 and G79.27+0.38, labeled G79.34 and G79.27 in Fig. 1), although the figure clearly shows them to comprise a single, connected filament. A Herbig-Haro jet that appears to be driven by a YSO at R.A. = 20h31m45s.5, decl. = +40°18′44″
Fig. 1.—JCMT SCUBA 850 µm image of the MSX IRDC G79.3+0.3. The peak intensity is 1.7 Jy beam$^{-1}$.

Fig. 2.—MSX 8 µm image of G79.3+0.3 covering the same area as in Fig. 1. The intensities in the image have been transformed using an inverse sinh function, which results in a nearly linear scale for the faint structures that define the IRDC but compresses the bright features in DR 15 logarithmically. The gray contour represents the 0.15 Jy beam$^{-1}$ level from the SCUBA 850 µm map and delineates the filamentary region containing high column densities of dust. The box shows the area around G79.3+0.3 P1 imaged in Figs. 3 and 4. The locations of the Herbig-Haro jet and YSO mentioned in the text are shown by the short line and circle, respectively, to the west of G79.3+0.3 P3.
(J2000.0) (see Fig. 2) has been discovered in front of the IRDC at visible wavelengths (Redman et al. 2000).

In this paper, we focus our attention on the star-forming activity in the vicinity of its most prominent condensation, G79.3+0.3 P1. This region was selected for closer study because comparison of the MSX and SCUBA images discussed below showed the presence of a faint, pointlike 8 \( \mu \)m emission source, MSX5C G707.3398+00.3415, that was nearly coincident with the brightest compact source of emission at 850 and 450 \( \mu \)m. This suggested the presence of a deeply embedded star interacting with the cold dust cloud, but the relatively coarse resolution of both the MSX and SCUBA images hampered a more detailed interpretation. To address these issues, we combined JCMT observations at 450 \( \mu \)m, interferometry at 3 mm taken with the Berkeley-Illinois-Maryland Association (BIMA) array, and Gemini North imaging at 10.75 \( \mu \)m, together with archival data from the MSX satellite and the 2MASS survey.

2. OBSERVATIONS

2.1. JCMT Observations

JCMT SCUBA observations were obtained at 850 and 450 \( \mu \)m, at which the resolution is 14" and 8", respectively. “Scan mapping” was employed to produce Nyquist-sampled images. Sky subtraction was provided by chopping to a nearby location. We used the Emerson II scan-mapping procedure (Emerson 1995) as adapted for SCUBA (Jenness et al. 2000a) with offsets of 20", 30", and 65" at position angles of 0° and 90°. The data reduction process for scan maps attempts to correct for the chopping, so that sources appear only once, as positive features. However, structures larger than the chop throw may not be reproduced correctly. The zero level is uncertain unless the maps are large enough to include some blank sky in the image. Descriptions of SCUBA and its observing modes may be found in Holland et al. (1999) and Jenness et al. (2000b).

The SCUBA observations were taken under fair weather conditions (750 = 0.24–0.30) in 1999 April. The data were processed using the standard routines provided by the SURF package (Jenness & Lightfoot 1998) for flat-fielding, extinction correction, and sky subtraction. Uranus was used as a flux density calibrator, using the calculated flux densities of Uranus produced by the FLUXES program, which makes use of the measurements reported by Griffin & Orton (1993). Our measured flux densities are good to ±15%. Pointing was performed on Uranus and G34.3 and should be better than 2".

Observations of the HCO+ (3–2) transition were made using RxA3 in a raster-scanning mode. The grid of sample points had a spacing of 10" × 10", centered at R.A. = 20°32m03s4, decl. = +40°19'20" in J2000.0 coordinates and oriented with the Y-axis of the grid at a position angle -94°4 to follow the overall orientation of the G79.3+0.3 IRDC. The nominal beam size of the JCMT at this wavelength is 1874, so the grid of samples is approximately Nyquist-spaced. With the raster-mapping technique, the beam is smeared somewhat by the motion of the telescope during each sample, giving an effective beam size of 20°5 × 18°74, with the long axis aligned north-south. In this paper we report on a subset of the whole data set, a square region 160" × 160" with a position angle for the vertical axis of 0°, centered at R.A. = 20°32m22s24, decl. = +40°19'53" (J2000.0), covering the same area as the BIMA HCO+ (1–0) observations discussed below.

The HCO+ (3–2) observations were taken on the night of 2001 June 26 (UT) under weather conditions that are fairly poor for the JCMT but still quite usable at 267 GHz. The zenith opacity at 225 GHz ranged from 0.14 to 0.20, and the seeing was greater than 1". The Starlink program SPECX was used to process the observations into a data cube.

2.2. BIMA Observations

The BIMA interferometer (Welch et al. 1996), was used in its B, C, and D configurations to observe G79.3+0.3 P1 at 3 mm (90 GHz) for a total of five tracks between 1999 September and 2000 May. The lower and upper sideband signals were combined to obtain a total continuum band-width of 0.9 GHz. Additionally, two tracks in C configuration were obtained in 1999 September at 245 GHz by observing a seven-point mosaic to cover the 3 mm primary beam. The correlator setup included the HCO+ (1–0) line at 89.188 GHz and the CS (5–4) line at 244.935 GHz. MWC 349 and J2025+337 were observed as phase calibrators every 15–25 minutes. MWC 349 (assuming fluxes of 1 and 1.75 Jy at 90 and 245 GHz, respectively) was used to check the flux density calibration derived from observations on Uranus. The errors in the flux density scale are ±20% (30%) at 3 mm (1.2 mm). Calibration and image deconvolution was carried out using the MIRIAD package (Sault, Teuben, & Wright 1995). The 3 mm continuum and CS (5–4) images were deconvolved using a clean algorithm (MIRIAD tasks “clean” and “mosdf”), while the HCO+ (1–0) image was deconvolved with the MIRIAD task “maxen.” Beam sizes of 5°3 × 5°9, 4°5 × 4°2, and 3°3 × 2°7 were obtained for the images at 3 mm continuum, HCO+ (1–0), and CS (5–4), respectively. The rms noise in the 3 mm continuum image and the line-averaged HCO+ (1–0) and CS (5–4) emission images is 0.8, 56, and 500 mJy beam⁻¹, respectively.

2.3. Gemini Observations

Observations were carried out at the Gemini North Telescope on 2000 December 7 and 2001 July 10 using OSCIR, the University of Florida mid-IR imager/spectrometer. OSCIR employs a Si:As blocked impurity band (BIB) detector array with 128 × 128 pixels, optimized for a wavelength coverage from 8 to 25 \( \mu \)m. On Gemini its plate scale is 0°089 pixel⁻¹, which gives a field of view of 11°4 × 11°4. All observations were made using the standard chop/nod technique to remove the sky and telescope background emission and employing a chop frequency of 3 Hz and a throw of 25". Images were obtained in the N band (\( \lambda_0 = 10.75 \mu m \), \( \Delta \lambda = 5.23 \mu m \)), with 60 s of on-source integration time per field. A 3 × 3 mosaic was obtained by combining five fields acquired in December (mainly the southeastern part of the mosaic), with six acquired in July.

The standard stars \( \beta \) Peg and Vega were used to provide flux calibration. Their flux densities were taken to be 352.13 and 37.77 Jy, respectively, through the OSCIR N-band filter (Fisher 2001). Our 2001 July run was plagued by light cirrus and higher humidity; hence, the flux of 2MASSI 2032220+402017, observed the previous December, was used to estimate the fluxes of the fainter sources detected in the July fields.

All data were taken with the telescope active optics in open-loop mode, using an elevation-dependent lookup.
table and with fast guiding provided by the secondary mirror “tip-tilt” corrections under control of the Peripheral Wave Front Sensor (PWFS) locked on a nearby guide star. Hence, some residual astigmatism was present in the point-spread function (PSF). The detected sources should be considered unresolved, since their measured FWHMs (at best 0\textquoteleft 047; the diffraction limit in the N band for Gemini is 0\textquoteleft 028) are similar to those measured for the imaged standard stars. There is a discrepancy of the order of 2\textquoteleft in the coordinates of the detected source between the December and the July data. The adopted coordinates are those derived in July, since a guide star with better position accuracy was used (error < 0\textquoteleft 2). However, the accuracy of the model of the PWFS arm 2 for the distance between the OSCIR center and the PWFS is unknown. There is a 1\textquoteleft 5 offset between the position of 2MASSI 2032220+402017, with a nominal accuracy of 0\textquoteleft 2, and the apparent position of the OSCIR source. We do not believe that this difference is real, because of the possible systematic error mentioned above, so in this paper we assume that these two sources are the same.

3. RESULTS

3.1. YSOs and Infrared Stars

The original motivation for the N-band Gemini observations reported here was to determine whether the MSX $8\mu$m source was composed of a single star, a cluster of fainter stars, or a diffuse emission patch, and to determine what relationship, if any, it had to the P1 source in the SCUBA images. In fact, most of the mid-IR emission comes from a single pointlike source coincident with the star 2MASSI 2032220+402017 (see Fig. 3a).

In addition, two fainter sources are also found in the field, but far enough from the central source that they are unlikely to be directly associated with it. Figure 3b shows the locations of the three stars superimposed on a contour map of the SCUBA 450 $\mu$m emission. The angular resolution of the 450 $\mu$m map is 8\textquoteleft, sufficient to demonstrate that 2MASSI 2032220+402017 lies a full beamwidth away from the peak of the 450 $\mu$m emission. In fact, none of the three N-band sources lie within the top contours of the 450 $\mu$m emission from the P1 source. If YSOs are forming within the dust clumps constituting the P1 source, they are too faint and/or too deeply embedded to be detectable in these images.

From the N-band images it is impossible to rule out the presence of a significant component of extended emission around the 2MASS star. As mentioned above, the PSF had an FWHM of 0\textquoteleft 047, with roughly 60% of the signal contained in a circle of diameter 0\textquoteleft 8 centered on the star. An additional 40% of the signal comes from a region extending out as far as 2\textquoteleft 7 from the star. Because we were unable to take observations of a reliable PSF calibration star, it is possible that as much as 40% of the emission could be extended on a scale larger than 0\textquoteleft 8. Alternatively, the apparent extended emission could simply be due to the wings of the PSF.

The photometric properties of all three N-band sources are summarized in Table 1. The two fainter sources have been calibrated relative to 2MASSI 2032220+402017. In Table 1, the uncertainty in the flux density estimates has been divided into internal errors (which indicate the significance of the detection) and systematic errors due largely to the unknown degree of possible extended emission around the 2MASS star. The flux density of 2MASSI 2032220+402017 was determined using a large aperture, to capture all of the signal. The photometry of the weaker sources was measured in two ways. First, assuming that the apparent extended emission is due to the wings of the PSF, the photometry was done by convolving the images with a PSF derived from the bright source, effectively using a small aperture to maximize the signal-to-noise ratio. Second, assuming that the apparent emission is genuinely extended, the photometry was done using a 2\textquoteleft 7 aperture comparable to that used to calibrate the 2MASS star. The reported fluxes in Table 1 are the average of the two measured values.

On probabilistic grounds we can determine that the two weak N-band sources are YSOs, most likely associated with the IRDC, and are not simply background field stars seen through the cloud. The $(N-K_s)$ colors of unreddened stars are quite small, so we can estimate the surface density of N-band stars by using the 2MASS survey to measure the brightness distribution at $K_s$ in nearby fields with low extinction. The two N-band stars have $N$ magnitudes of 7.5 and 8.4. If the stars were merely background stars, the corresponding $K_s$ magnitudes would be similar, hundreds of times brighter than we would expect to find in the small area of sky we observed.

It is interesting that there appears to be a population of heavily reddened stars visible in the 2MASS $K_s$-band image of G79.3+0.3 P1 (that sometimes are not even visible at $H$ or $J$). We conclude that all three N-band sources are part of a much larger cluster of embedded and highly reddened young stars that has formed in the general area around G79.3+0.3 P1.

With the available data we can only place a lower limit on the reddening toward 2MASSI 2032220+402017. It is normal for the near- and mid-IR emission from YSOs to be dominated by their circumstellar disks. The intrinsic $H-K_s$ colors of these objects are larger than those of stars (see, e.g., Malfait, Bogaert, & Waelkens 1998), but are still small compared to the apparent reddening of 2MASSI.

| Designation | R.A. (J2000.0) | Decl. (J2000.0) | Flux Density$^a$ (mJy) |
|-------------|---------------|----------------|------------------------|
| 2MASSI 2032220+402017..... | 20 32 21.94 | +40 20 17.5 | 1130 ± 115 |
| Northeast........................................ | 20 32 22.79 | +40 20 21.7 | 40.0 ± 3.5 ± 5.3 |
| Southwest........................................ | 20 32 20.96 | +40 20 01.3 | 17.4 ± 2.5 ± 1.5 |

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

$^a$ Errors quoted are ± internal error ± systematic error.
Since the 2MASS star is close to the most heavily extincted part of the IRDC, we assume that most of the reddening is interstellar. 2MASSI 2032220+402017 has an apparent brightness at $K_s$ from the 2MASS Point Source Catalog of $K_s = 12.0$, but it is not detected in the $H$ band ($H > 17.3$). From these measurements we can estimate $A_K > 8$ mag using the extinction law from Martin & Whittet (1990), assuming that the intrinsic $H-K$ color of 2MASSI 2032220+402017 is small. With this estimate for $A_K$, the unreddened apparent magnitude $K_s < 4$ mag.

At an assumed distance of 800 pc, the absolute magnitude of 2MASSI 2032220+402017 at $K_s$ would be brighter than $-5.5$ mag. Although this ostensibly is the absolute magnitude of an early O star, the absence of a prominent H ii region indicates that the star must be considerably fainter and cooler, with a large IR excess. This object must be an
extremely luminous pre–main-sequence star with the energy output of an early B star. It thus seems likely that 2MASSI 2032220+402017 is a Herbig Ae/Be star with a large IR excess (Malfait et al. 1998) due to a circumstellar disk and/or dust in a strong, ionized wind.

As discussed by Fuente et al. (2002), pre–main-sequence stars that will ultimately have spectral types earlier than B5 pass through a stage lasting several hundred thousand years during which they are surrounded by a massive circumstellar disk but are still too cool to produce a significant UV flux. In this stage, a stellar wind from the pre–main-sequence star will be the primary mechanism dispersing the surrounding cloud.

3.2. Continuum Emission Sources Containing Dust and Hot Gas

To investigate further the nature of 2MASSI 2032220+402017, BIMA observations with an angular resolution of 5″ were made of the 3 mm continuum emission. At this resolution, the source breaks up into three components, as shown in Figure 3c. The observed properties of the three components measured from the BIMA 3 mm image are given in Table 2. Two components, labeled “A” and “B,” accord well with the morphology of our SCUBA 450 μm map. Their measured flux densities are consistent with the emission arising from dust, as discussed below. The third 3 mm component, labeled “C,” coincides within the accuracy of the astrometry with 2MASSI 2032220+402017, but is not evident in the 450 μm SCUBA image. It must have a significantly smaller spectral index, consistent with the 3 mm emission being dominated by thermal bremsstrahlung from the ionized wind of a Herbig Ae/Be star (Skinner, Brown, & Stewart 1993).

We estimated the dust temperatures and total masses of components A and B, following Hildebrand (1983). Assuming that the dust opacity per unit total mass column density (dust and gas) varies as \( \kappa_d = \kappa_0 (\nu/\nu_0)^s \), the dust temperatures were estimated as functions of \( \beta \) from the ratios of the flux densities at 450 μm and 3 mm. The masses were calculated using

\[
M_{\text{tot}} = D^2 F_\nu / \kappa_d B\nu(T) ,
\]

where \( M_{\text{tot}} \) is the total mass, \( D \) is the distance, and \( B\nu(T) \) is the Planck function for a dust temperature \( T \). We adopted the value of \( \kappa_0 = 0.005 \text{ cm}^2 \text{ g}^{-1} \) at 1.3 mm from Motte, André, & Neri (1998 and references therein) as an appropriate value for prestellar dense cores and clumps. Table 3 gives the derived dust temperatures and total masses as functions of \( \beta \) for the two sources.

If the flux densities for components A and B had been measured separately at a third frequency, it would be possible to estimate \( \beta \) for each component. Unfortunately, the beam size of the JCMT at 850 μm is so large that components A, B, and C all blend together, and the contribution to the combined flux density from component C is unknown. Nevertheless, we can still derive bounds on the allowed range of \( \beta \). The estimated temperatures in both components become unphysically large as \( \beta \) drops below 1.5. Also, if we assume that \( \beta \) is the same in components A and B, we can invert equation (1) to predict their combined flux density at 850 μm as a function of \( \beta \). For \( \beta > 2.0 \), the predicted value of the combined flux density becomes greater than 2.0 Jy, the observed flux density of the whole source at 850 μm. Thus, \( \beta \) is bounded in the range 1.5 ≤ \( \beta \) ≤ 2.0.

Other observers have measured values for \( \beta \) in similar clouds with temperatures below 20 K that are larger than 1.5, ranging up to 2.5 (see, e.g., Ristorcelli 2002 and references therein). On this basis, we believe that the combined mass of components A and B is likely to be about 15 \( M_\odot \), although it may be as low as 6 \( M_\odot \) or as high as 30 \( M_\odot \).

3.3. Molecular Gas in Relation to the YSOs

The integrated BIMA HCO+ (1–0) emission in a 1.5 km s\(^{-1}\) velocity range centered on −0.8 km s\(^{-1}\) is shown in Figure 3d. The bulk of the small-scale emission detected by the BIMA interferometer is confined to a roughly circular blob south and east of the 2MASS star. The star itself appears to lie in a small “bay” devoid of emission. The morphology of the emission resembles that of the \(^{13}\)CO (1–0) emission mapped by Fuente et al. (2002) around Herbig Ae/Be stars that are just beginning to disperse their placental clouds.

A comparison of HCO+ (1–0) spectra from the BIMA interferometer data with single-dish spectra of HCO+ (3–2) in Figure 4 illustrates the relative virtues of interferometric and single-dish observations. Figure 4a directly compares the integrated emission in the blue wing, where both data sets show prominent emission. The similarity of the maps is clear, but the much higher resolution of the BIMA data allows us to distinguish the A and B components of the G79.3+0.3 P1 from the larger blob of emission to the southeast. Figure 4b makes a similar comparison, but with the HCO+ (3–2) in the velocity range [−0.25, 2.25] km s\(^{-1}\). This range contains most of the HCO+ (3–2) emission from the cloud in the single-dish data but is almost devoid of HCO+ (1–0) emission in the interferometer data.

Figures 4c and 4d show spectra from the two HCO+ data sets at the point where the integrated emission peaks in the blue wing (labeled “W” in Fig. 4a) and in the main part of the line (labeled “M” in Fig. 4b). The upper spectra show the single-dish data from the JCMT, showing the presence of significant emission in the velocity range [−0.25, 2.25] km s\(^{-1}\). The lower spectra show the BIMA HCO+ (1–0) data and were constructed by convolving the high angular

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**TABLE 3**

| Component | R.A. (J2000.0) | Decl. (J2000.0) | \( F_{3\text{mm}} \) (mJy) | \( F_{450\text{mm}} \) (Jy) |
|-----------|---------------|---------------|----------------|----------------|
| A........... | 20 32 21.40   | 40 20 14.0    | 7.7            | 6.9            |
| B........... | 20 32 22.05   | 40 20 09.9    | 9.6            | 5.7            |
| C........... | 20 32 22.07   | 40 20 16.5    | 7.3            | . . .           |

Note—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
resolution BIMA data cube with a Gaussian, so that the effective beam size was comparable to the JCMT beam size. Both of these spectra exhibit the absence of detected emission in this velocity range in the BIMA data. Presumably, the emission is sufficiently smooth on small angular scales that it was resolved out by the interferometer.

On a larger scale, the JCMT observations show that there is significant emission in the blue wing, i.e., the velocity range $-1.75$ to $-0.25$ km s$^{-1}$, only from the small region near G79.3+0.3 P1 that is shown in Figure 4a. The BIMA data are therefore tracing the structure within a small parcel of gas with anomalous velocities.

We note that the absence of a counterpart to 2MASSI 2032220+402017 in the 2MASS J and H images suggests that it lies in or beyond the IRDC. Moreover, if the star were embedded in the IRDC, we would expect the wind from the star to excite red and blue wings of roughly comparable strength. Although there is also a small amount of emission at velocities near $+2.0$ km s$^{-1}$ that seems to be associated with the blob, the dominance of the blue wing indicates that the blob is a parcel of gas being driven into the far side of the IRDC. The red wing of the line in the BIMA data peaks at the same location as the blue wing, indicating that it arises in the same parcel of gas and that the

![Fig. 4a](image1.png)

![Fig. 4b](image2.png)

Fig. 4 — Comparison of the BIMA HCO$^+$ (1–0) interferometer data with the JCMT HCO$^+$ (3–2) single-dish data for the G79.3+0.3 P1 region. The images in (a) and (b) cover the same $90^\circ \times 90^\circ$ area as in Fig. 3. For reference, the locations of the three $N$-band sources are marked with asterisks, and the black contours show the integrated emission of the BIMA HCO$^+$ (1–0) line, as in Fig. 3d. (a) JCMT HCO$^+$ (3–2) (white contours) in the velocity range $[-1.75, -0.25]$ km s$^{-1}$ containing the blue wing of the line. The units for the white contours are K km s$^{-1}$. The location of the spectra shown in (c) is indicated by “W.” (b) JCMT HCO$^+$ (3–2) (white contours) in the velocity range $[-0.25, 2.25]$ km s$^{-1}$ containing the bulk of the HCO$^+$ emission from the cloud. The units for the white contours are K km s$^{-1}$. The location of the spectra shown in (d) is indicated by “M.” (c) Spectra of HCO$^+$ (3–2) taken with the JCMT and of HCO$^+$ (1–0) taken with BIMA near the peak of emission in the blue wing. (d) Spectra of HCO$^+$ (3–2) and HCO$^+$ (1–0) near the peak of emission in the line center. In (c) and (d), the vertical lines mark the velocity range $[-0.25, 2.25]$ km s$^{-1}$ containing the bulk of the HCO$^+$ emission.
velocity dispersion in this parcel of gas is appreciably larger than in the rest of the cloud. Alternatively, the red wing might arise from an unrelated weak outflow.

There is some HCO$^+$ (1–0) emission associated with the A and B components of the 3 mm emission. In fact, the B component appears to sit on the edge of the brightest part of the HCO$^+$ blob. Even in these high-density cores, the emission is largely in the blue wing and not in the velocity range that contains most of the mass in the cloud. The presence of emission in the blue line wing indicates that the same energy source that has disturbed the back side of the IRDC to the southeast of G79.3+0.3 P1 is also affecting the back sides of both the A and B components. Unfortunately, the weakness of the emission in the A and B components precludes the detection of extended line wings that might be taken as evidence of collapse and/or outflow.

Follow-up BIMA observations of CS (5–4), another high-density tracer, show a compact region of enhanced emission on the rim of the HCO$^+$ cloud closest to the 2MASS star (see the white contours in Fig. 3d). The absence of short spacings in the CS (5–4) observations, compared to the HCO$^+$ (1–0) observations, makes them even less sensitive to the large-scale structure of the emission. They have, however, higher angular resolution than the HCO$^+$ (1–0) observations and are useful for picking out fine-scale structure. We note that the B component of the 3 mm emission lies within the region of CS emission.

4. CONCLUSIONS

Our Gemini $N$-band observations demonstrate that the MSX 8 µm source MSX5C G079.3398+00.3415 associated with G79.3+0.3 P1 is dominated by a single compact object that we identify with the star 2MASSI 2032220+402017. This object is a luminous YSO with a strong IR excess that will likely become an early B star when it reaches the main sequence. Two nearby, fainter YSOs were discovered in our $N$-band images, and a cluster of faint, heavily reddened stars is visible in the 2MASS $K$-band images of the region. This concentration of stars and YSOs indicates that the IRDC is actively forming low-mass stars, with the 2MASS star as the most massive star that has formed from it to date.

There are a variety of unusual features in the region around G79.3+0.3 P1 that suggest that 2MASSI 2032220+402017 is interacting with the foreground IRDC. Most directly, the BIMA HCO$^+$ (1–0) line has a strongly enhanced blue wing in the velocity range $-1.5$ to $0$ km s$^{-1}$, as well as a slight enhancement on the red wing, in a region immediately to the southeast of the 2MASS star. The emission in the blue wing shows considerable structure on small angular scales. The unusual nature of this structure is highlighted by the fact that the rest of the cloud shows little emission in the blue wing and very modest small-scale structure in the velocity range $[-0.25, +2.25]$ km s$^{-1}$ that traces most of the mass of the cloud. The presence of small-scale structure close to the 2MASS star is confirmed by CS (5–4) observations with even higher angular resolution.

The simplest interpretation of these data is that the 2MASS star is a Herbig Ae/Be star that is forming on the far side of the IRDC. This star must have a warm disk that is the source of the $N$-band emission, but the disk cannot produce the observed reddening at $K$. Hence, the star must lie behind a lot of extinction from the IRDC. The strong wind that would be expected from such a star is probably impacting the back of the IRDC, exciting the blue wing of the HCO$^+$ line. Although it appears to be massive, the 2MASS star is still too young to have disrupted the IRDC. We speculate that in another million years or so this region may resemble a smaller version of DR 15 to the south, appearing as an H II region partially obscured by foreground dust left over from the IRDC.

It is, at the very least, a striking coincidence that the two condensations of dust and gas that comprise the G79.3+0.3 P1 SCUBA source (the A and B components in the BIMA data) lie immediately adjacent in the plane of the sky to the most massive YSO in the cloud and are apparently being affected by the same wind that is exciting the blue wing in the HCO$^+$ (1–0) line in the rest of the IRDC. The combined masses of the two components are comparable to the mass of the Herbig Ae/Be star. These two objects are the obvious candidates for the next generation of stars to form in the vicinity of the 2MASS star. Further observations may reveal whether the wind from the 2MASS star has played a role in forming the A and B components, or is just now impacting these two preexisting clumps, possibly driving them into collapse.

We thank H. J. Wendker for assistance with the distance to the Cygnus Rift. We would also like to thank the anonymous referee for a careful review that helped us to clarify the presentation in the paper. The JCMT is operated by the JAC on behalf of the Particle Physics and Astronomy Research Council of the UK, the Netherlands Organization for Scientific Research, and the National Research Council of Canada. This paper is based partly on observations obtained at the Gemini Observatory, which is operated by AURA, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the NSF (USA), PPARC (UK), the NRC (Canada), CONICYT (Chile), the ARC (Australia), CNPq (Brazil), and CONICET (Argentina). The Gemini observations were made with OSCIR, developed by the University of Florida with support from NASA, and operated jointly by Gemini and the University of Florida Infrared Astrophysics Group. The Berkeley-Illinois-Maryland Association (BIMA) is a consortium, consisting of the Radio Astronomy Laboratory at the University of California (Berkeley), the Laboratory for Astronomical Imaging at the University of Illinois (Urbana), and the Laboratory for Millimeter-Wave Astronomy at the University Maryland (College Park), that operates a millimeter-wave radio interferometer at Hat Creek, California. The BIMA array is operated with support from the National Science Foundation under grants AST 99-81308, AST 99-81363, and AST 99-81289. F. W. was supported by the NSF (USA) under grant 96-13716. S. J. C. received support from NASA under grant NAG 5-10824. This research made use of data products from the Midcourse Space Experiment. Processing of the data was funded by the Ballistic Missile Defense Organization, with additional support from NASA Office of Space Science. This research has also made use of the NASA/IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.
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