THE ASTROPHYSICAL JOURNAL, 398:L99–L102, 1992 October 20

MULTIPLE JETS FROM THE YOUNG STAR IRAS 21334+5039

HOWARD A. SMITH[1]
Laboratory for Astrophysics, MS-321, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560
AND
JACQUELINE FISCHER[1]
Center for Advanced Space Sensing, Code 4213.8, Naval Research Laboratory, Washington, DC 20375
Received 1992 June 29; accepted 1992 August 5

ABSTRACT

The source IRAS 21334+5039, a young stellar object (YSO) with broad CO outflow velocity profiles, was imaged in the 1–2 μm region with broad-band *J*, *H*, and *K* filters, and with a Fabry-Perot set to the molecular hydrogen $v = 1\text{–}0$ *S*(1) line, the hydrogen Brγ recombination line, and the neighboring continua. At 2 μm the source has an elongated continuum emission structure centered on the star. The structure has very blue tips, with a weak VLA 6 cm continuum source coincident with one of them. Strong molecular hydrogen emission appears as bow-shaped arcs oriented along an axis perpendicular to the continuum emission, and as a weaker structure aligned with it. Both the continuum and the molecular hydrogen emission are most likely produced by jets, possibly emanating in multiple directions from the central source at large angles to each other. While jets are a common feature of young stars, this source provides solid evidence for multiple jet structures.

Subject headings: circumstellar matter — infrared: stars — ISM: jets and outflows — stars: imaging — stars: individual (IRAS 21334+5039)

1. INTRODUCTION

The point source IRAS 21334+5039 lies in the direction of the dark cloud L1048 in Cepheus, at $l = 94^\circ.57$, $b = -1^\circ.45$, about 45′ NW of the H II region S124. The *IRAS* sky flux images show an elliptically shaped loop of about 10 objects with the H II region S124 being one of these sources; IRAS 21334+5039 lies near the center of this elliptical structure. Schwartz, Mozurkewich, & Odenwald (1992), in a survey of *IRAS* sources suspected of being young pre–main-sequence stars, observed the source in ^{12}CO 2–1. Their measurements showed velocities present of ΔV(FWZI) = 23 km s^{-1}, and their nine-point map indicates little separation between the observed red and blue wings. They found an LSR velocity ≈ -44 km s^{-1}, placing the source far beyond the L1048 cloud kinematic distance of 2.9 kpc ($V_{\rm LSR} = 15.9$ km s^{-1}), at an estimated distance of 5.9 kpc (Wouterloot & Brand 1989). S124, with a comparable LSR velocity of ≈ -48 km s^{-1}, has been located at a nominal distance of 4.4 kpc (kinematic distance estimate of Crampton, Georgelin, & Georgelin 1978) or 3.6 kpc (spectroscopic parallax distance estimate of Chini & Wink 1984). Given the uncertainties, we adopt a nominal distance to IRAS 21334 of 5.0 kpc. McCutcheon et al. (1991) have also observed the source in CO, with the VLA, and with near-IR photometry.

2. OBSERVATIONS AND ANALYSIS

2.1. *Continuum Results*

We have taken the *IRAS* Point Source Catalog flux values for IRAS 21334+5039 and color-corrected them with a two-temperature model blackbody fit. See Table 1. The dust can be fitted with a cool component of 60 K and a hot component of 152 K. These temperatures are similar to those seen in other dark clouds with very active star formation, a further indication that the region is young. The optical depth of the dust at 100 μm averaged over the *IRAS* beam, assuming a $\tau \propto v^1$, is $\approx 1 \times 10^{-3}$. The total luminosity of the source from the *IRAS* fluxes is $L_T \approx 2.5 \times 10^4 \, L_\odot$ based on a distance of 5 kpc, consistent with that from a B0 ZAMS star.

We used the NOAO Infrared Imager (IRIM) at the Kitt Peak 1.3 m telescope to examine IRAS 21334 in *J* (1.25 μm), *H* (1.6 μm), and *K* (2.2 μm) bands, with a pixel size of 1″.33. Figure 1*a* (Plate L4) displays the *K*-band image in color, with *J*-band contours superposed. The *K*-band nebulosity peaks at the *IRAS* position and shows an extended and highly collimated emission nebula, about 22″ in total length by 5″ in width. The *J*-band image is dramatically different: instead of an elongated structure, the image has two bright and somewhat resolved sources each coincident with an outer tip of the *K*-band nebulosity. The *H*-band image (Fig. 1*b*) shows structure that is qualitatively intermediate between the *J*- and *K*-band images. Also seen in these images are several field stars. The extent of the nebulosity is ≈0.5 pc at 5 kpc. Table 2 lists the fluxes in the source, both overall, and divided approximately into a central source and two outer parts. The fluxes in the outer regions can be approximately fitted to a color temperature of $T = 1200$ K, with an uncertainty of several hundred degrees. The total luminosity from the near-IR part of the spectrum is 20 $L_\odot$, or about 0.1% of the total FIR luminosity. The very red IR colors of the central 6″ × 6″ region, ($[J] - [K]) \approx +4.0$, suggest substantial extinction is present, but, if we have correctly identified the spectral type and distance, the IR magnitudes also imply there is an additional warm component. Indeed, the *K*-band image of this region reveals a complex shape and suggests the likely presence of some hot dust, scattering, and/or even other stars, precluding a simple interpretation from these data.

We obtained a snapshot of the source using the VLA in the

[1] Visiting Astronomer, Kitt Peak National Observatory, part of National Optical Astronomy Observatories, operated by Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.

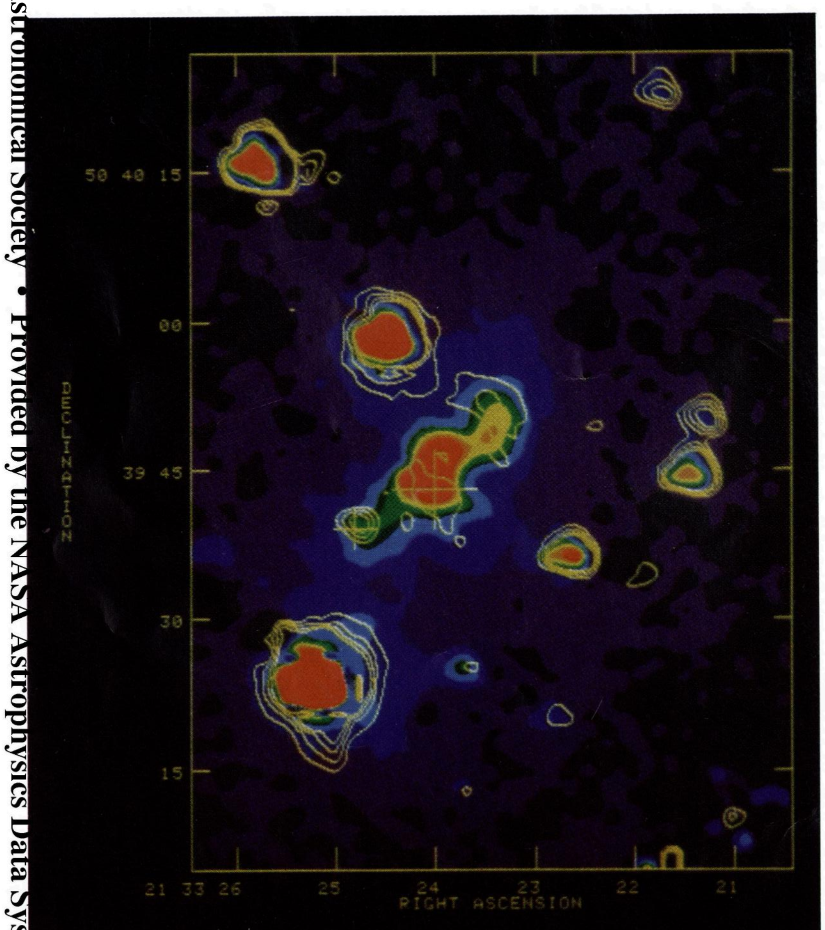

FIG. 1*a*

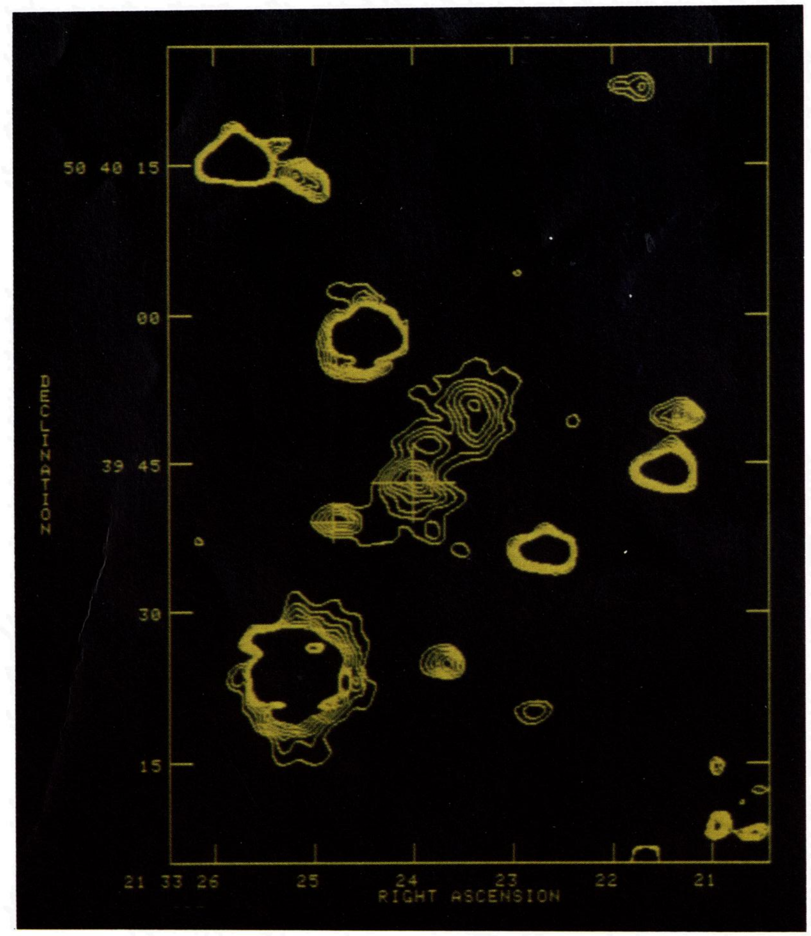

FIG. 1*b*

FIG. 1.—(*a*) The continuum emission of IRAS 21334+5039 at *K* band (color levels) and *J* band (contours) taken with the KPNO IR 62 × 58 InSb Imager (IRIM) on the 1.3 m telescope with 1".3 pixel^{-1} resolution and presented here interpolated by a factor of 8. Note that the *J*-band image is dominated by two bright peaks coincident with the lobes of the *K*-band image. The large cross marks the position of the *IRAS* point source. The small cross marks the position of the faint VLA source. The map coordinates were obtained from the positions of the field stars seen, calibrated with the *HST* finding star catalog, and are accurate to a precision of about 1". The *J*-band contour levels are 0.07, 0.10, 0.14, and 0.17 mJy arcsec^{-2}. (*b*) Contours of the continuum emission at *H* band as above. The contour levels shown are 0.072, 0.095, 0.12, 0.14, 0.17, 0.19, and 0.21 mJy arcsec^{-2}.

SMITH & FISCHER (see 398, L99)

TABLE 1

IRAS 21334+5039: $\alpha = 21^h33^m24^s.0$, $\delta = 50°39'43''$ (1950.0)

Wavelength (μm)	*IRAS* Fluxes (Jy)	
	Intrinsic	Color-corrected[a]
12..........	5.2	6.2
25..........	55	57
60..........	373	413
100..........	440	435

[a] $T_L \approx 60$ K; $T_H \approx 152$ K; $\tau(100\ \mu m) \approx 10^{-3}$. The total luminosity of the source is $2.4 \times 10^4\ L_\odot$ at a distance of 5.0 kpc.

A-configuration on 1988 December 5. A 4.5 GHz source of flux about 0.9 ± 0.2 mJy was detected coincident with the southern J-band lobe, but nothing was seen coincident with the *IRAS* source/2 μm continuum star. Our limit at the *IRAS* position, while about 100 times weaker than that expected from an optically thin H II region around a B0 ZAMS star, is consistent with emission from such a star with an optically thick wind at 4.5 GHz, as has been commonly observed (e.g., the case of BN, Moran et al. 1983; Smith et al. 1987a). Using the VLA in the C-configuration at 6 cm, McCutcheon et al. (1991) found an extended ($1'' \times 3''$) source of 4.5 GHz emission at the *IRAS* position with an integrated flux of 0.73 ± 0.1 mJy. They assume optically thin emission and infer from the weakness of the extended emission that the source is a pre–main-sequence B0 star, in contrast to our interpretation. Although we did not detect any emission at the *IRAS* position, our upper limit in the A-configuration is consistent with their detection of extended emission in the C-configuration. However, the fact that they did not detect emission at the southern lobe is an apparent inconsistency which needs further observations to be resolved.

2.2. *Spectroscopic Images in the* H_2 1–0 $S(1)$ *Line*

We used the NRL Imaging Fabry-Perot spectrometer to obtain images of the source in the 1–0 $S(1)$ line of H_2 and the Brγ line of atomic hydrogen. The data were obtained at the 1.3 m telescope at KPNO in 1989 September by mating the Fabry-Perot to IRIM equipped with a set of cold, spectral order-sorting filters; the plate scale was 1".33 per pixel. The spectrometer is described more fully elsewhere (Fischer, Smith, & Whitis 1992). The resolving power of the system was 350 for these observations, or about 6.0×10^{-3} μm at the $S(1)$ line. The variable wavelength transmission of the Fabry-Perot made it possible for us to image in the adjacent continuum on both sides of the line and to produce continuum-subtracted line images that are corrected for small continuum slopes that would be indistinguishable from line emission in a broader or fixed bandpass filter system. As a result we estimate our fluxes are accurate to $\pm 10\%$. Flux calibration was determined using the bright star BS 8252 (G8 III).

Figure 2*a* (Plate L5) shows the $S(1)$ line image, with the 2 μm narrow-band continuum shown as contours. Most striking are the two lobes of line emission in the NE and SW, suggestive either of a double bow–type shock morphology or perhaps the edges of a large disk or ring of material seen tilted at about 20°. Also evident is a clump of emission to the NW of, and fairly well aligned with, the smaller continuum structure. The total integrated flux in the 1–0 $S(1)$ line from this source is $9.8 \pm 2.0 \times 10^{-20}$ W cm^{-2}. This intensity corresponds to a luminosity of 0.8 $L_\odot$ at 5 kpc. If we assume the excitation is by shocks similar to those seen in Orion, the total luminosity in H_2 is about 10 times this, or 8 $L_\odot$, before taking extinction into account. Since the total FIR luminosity of the source is $2.5 \times 10^4\ L_\odot$, the ratio of luminosity in H_2 to total luminosity is about 3×10^{-4}, as compared, for example, with the efficiency in the Orion BN/KL region of about 2.5×10^{-3}. No Brγ emission was detected, with a 3 σ upper limit of 1.5×10^{-22} W cm^{-2} pixel^{-1}. Strong Brγ is expected from winds in B0 stars and typically would be around 10^{-18} W cm^{-2} for IRAS 21334 (Smith et al. 1987b). If the stellar image were smeared over 3×3 pixels, our Brγ limit would imply an $A_v \approx 50$ mag. Such highly obscured Brγ emission is seen elsewhere, e.g., in NGC 2071 IRS 1 (Walther, Geballe, & Robson 1991). Our limit to the 6 cm flux from the star is also consistent with an optically thick wind. The limit to the Brγ emission at our VLA position in the SE lobe is consistent with the radio flux seen there if the excitation is produced by a shocked zone (Smith et al. 1987a), where the resulting Brγ flux would be about 6×10^{-22} W cm^{-2} through 30 mag of extinction, and thus would go undetected when spread over several pixels. We note that the 2 μm narrow-band emission is consistent with the K-band emission, indicating that the latter is indeed dominated by continuum emission.

TABLE 2

IRIM Fluxes (mJy)

Band	NW Lobe	Central Area	SE Lobe	Total
J	2.86	1.88	1.38	16.4
H	5.61	5.63	2.09	24.2
K	15.4	30.5	7.11	94.5
$[J-K]$ mag	2.8	4.0	2.7	...
$[H-K]$ mag	1.5	2.2	1.7	...

3. DISCUSSION

The appearances and relative orientations of the infrared continuum and line morphologies suggest they result from disks or rings around the source, but we believe that a consideration of the possible excitation mechanisms rejects these models in favor of a multiple jet structure.

3.1. H_2 *Arcs*

The bright H_2 arcs are morphologically very similar to those excited by conventional wind-driven J-type complex shocks seen in many other YSOs (e.g., Garden et al. 1991; Lane 1989; Mundt 1988). The emission is rich with small-scale structures resembling the knots seen in shocked HH flows (Reipurth 1991), reflecting varying conditions in the ISM along the shock. In fact, this excited material has a double bow shape extending ≈ 1.5 pc from peak to peak as is typical (Mundt 1988), and strikingly similar in appearance to the double bow shock seen in the optical [S II] line material in HH 34 (Mundt 1988), which in addition shows a bright and collinear jet. However, because we do not yet have data on the line shapes of the 1–0 $S(1)$ line or measurements of any of the other H_2 lines, we are unable to model the excitation more exactly. We considered whether the shape of the arcs might not indicate the limb-brightened edges of a large ring with thermally excited H_2 (e.g., the interpretation by Gatley, DePoy, & Fowler 1988 of the secondary H_2 emission peaks at the waist of the proto–planetary nebula CRL 2688). A normally accreting disk is

1992ApJ...398L..99S

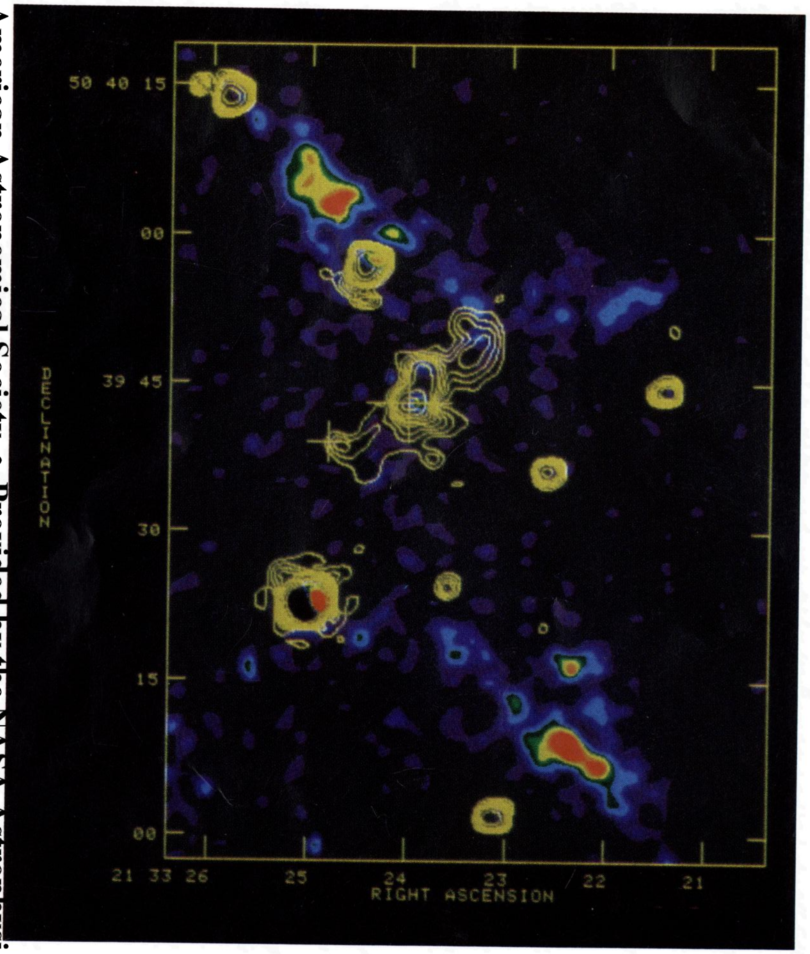

FIG. 2*a*

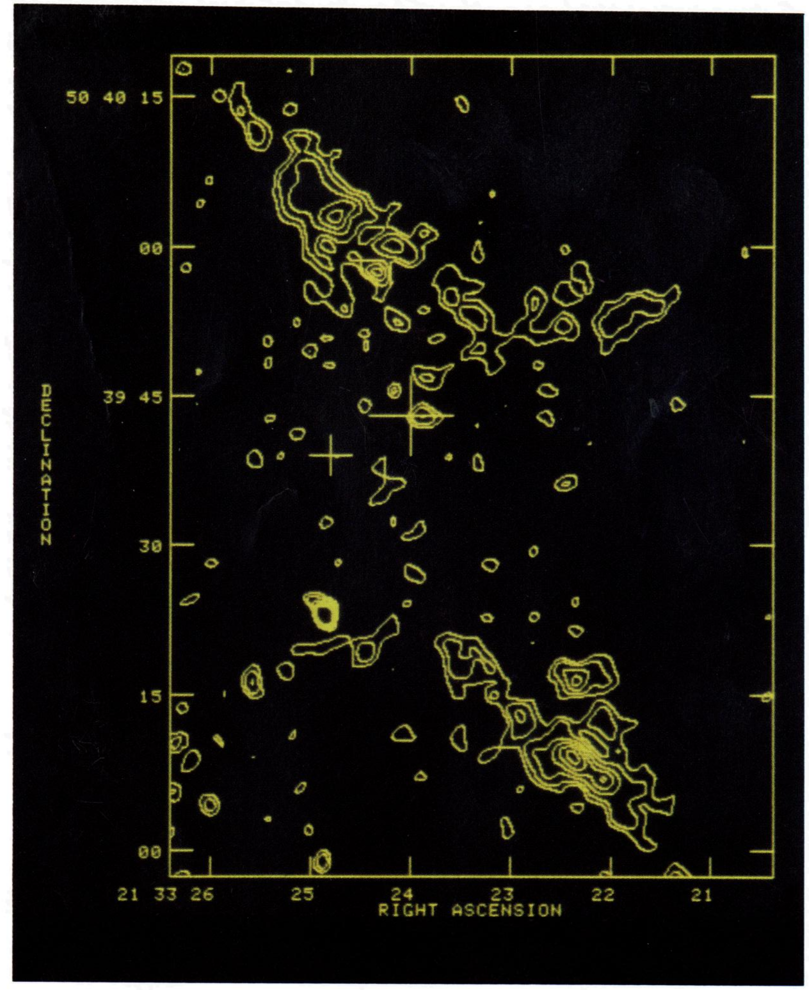

FIG. 2*b*

FIG. 2.—(*a*) Color map of the emission around IRAS 21334+5039 from shocked H_2 in the $v = 1–0$ $S(1)$ line at 2.12 μm, taken with the NRL Fabry-Perot and IRIM, and presented here interpolated by a factor of 8. The contours show the narrow-band 2 μm continuum, taken from the image of the continuum adjacent to the $S(1)$ line. Contour levels are 0.16, 0.24, 0.32, 0.40, 0.48, 0.57, 0.73, 1.0, and 1.7 mJy arcsec^{-2}. Note that in addition to the bright arcs of emission approximately perpendicular to the continuum emission, there is also substantial H_2 emission in the NW aligned with the continuum. The crosses and positions are as in Fig. 1. Slight seeing and pointing differences between the on- and off-line images caused imperfect cancellation of the continuum from the bright field star located about 16″ south of the VLA cross. (*b*) A contour map of the shocked H_2 emission seen in (*a*). The contour levels are 2.3, 2.7, 3.2, 3.7, 4.2, and 4.8 × 10^{-15} ergs s^{-1} cm^{-2} arcsec^{-2}.

SMITH & FISCHER (see 398, L100)

not able to produce the thermal excitation at such a large radius however, because gravity, the source of accretion heating, gives a maximum velocity $V(\max) = (GM/r)^{1/2} \approx 0.1$ km s^{-1} (r being the distance from the source to the disk), at least two orders of magnitude too small to excite or power the emission (cf. Adams, Lada, & Shu 1987).

3.2. 2 *Micron Continuum*

Since the linear 2 μm continuum structure appears nearly perpendicular to the axis of the excited H_2 arc structure, it is natural to suspect that it arises from a disk, imaged edge-on, which collimates the flow exciting these arcs, and which is either radiating itself or uniformly scattering the infrared starlight. There are at least four reasons that this appears unlikely.

1. The *J*-band lobes are bright, with fluxes comparable to that in the central source, and their peak color temperature T_c is high, about 1200 K, while any foreground extinction would tend to make the intrinsic colors even hotter. A uniformly scattering disk would not appear to have bright, blue tips. Lefevre, Daniel, & Bergeat (1983) have modeled radiative transfer in ellipsoidal dust shells. Whitney & Hartmann have calculated more pertinent scenarios to our case: the near-infrared appearance of scattered light from a circumstellar disk (Whitney & Hartmann 1992a). The morphology of all the models is quite different from what we observe, and, when detectable above the strong stellar contribution, the disk radiation lies in a flattened or fan-shaped structure. None of the models predict bright lobes. (While disk emission itself does not explain our image, an associated bipolar flow can produce a nebular structure seen along the flow direction which we consider in more detail below.) The *H*- and *K*-band images of the flat circumstellar envelope around L1551 obtained by Moneti et al. (1988) show hot dust ($T_{[H]-[K]} \approx 1000$ K) with emission peaking centrally in each band, and with no evidence of bright lobes, in much closer in agreement with these models than our image of IRAS 21334.

2. While the strongest case that we are not imaging the disk comes from the modeling of Whitney & Hartmann (1992a), the infrared colors also argue against it. While the lobe tips are blue as compared to the rest of the nebulosity, ($[J] - [K]) = +2.8$ vs. 4.0 for the central source, they are much redder than a B0 star ($[J] - [K]) \approx 0$, not bluer as they would be if simply scattering light (as, for example, in the "Frosty Leo" bipolar nebula; Rouan et al. 1988). We considered the effect of a small (unresolved) circumstellar shell adding about 20–30 mag of extinction between the star and a scattering *ring*, rather than a disk. The shell could preredden the light and also prevent the star and its Brγ from being directly observed, while the ring, if optically thin, might exhibit limb-brightening effects seen as the bright *J*-band tips. In order to allow for the jet that excites the H_2 arcs, the shell would have to have a channel along its polar axis; that is, the source would effectively have a thick small disk inside of, and roughly aligned with, the large outer ring seen in the continuum emission. However, we would also expect limb-brightening effects to be apparent in the *K* band, would expect a uniform T_c across the nebula, and finally would expect the scattered light from the tips to be fainter than that of the central source by a ratio of solid angles, about a factor of 5, whereas the tips are comparable in brightness to the central star ($[J] = 15$). The twisted curvature seen at the ends of the *K*-band continuum structure is also difficult to explain with a disk or ring, but similar features have been seen in jets (Mundt et al. 1990).

3. There is H_2 emission in the NW directly aligned with this continuum nebulosity, and possibly a faint VLA continuum source at the tip of the southern lobe, as would arise if the gas were shocked by jets flowing along the nebular region (as for example occurs in the optical case of HH 34).

4. If the hypothetical disk were not scattering, but were heated by accretion to circumvent some of the scattering model predictons, the process could not be a normal accretion process, which is unable to produce either the radio emission at the tip or the hot 2 μm continuum emission for the same reasons noted above—the dimensions are much too large; furthermore, over 1 $M_\odot$ yr^{-1} of accretion would be needed to sustain the 20 $L_\odot$ of near-IR emission seen.

While we have shown that scattering in a disk or ring is unlikely to make the disk itself appear imaged as the structure we see, scattering by dust in elongated bipolar nebulae is commonly seen in YSOs. These nebulae are thought to be produced by collimated winds and are oriented perpendicular to (hypothesized) disk structures (e.g., Tamura et al. 1991). The weak compact radio continuum source we detect at one of the 2 μm continuum lobes (opposite to the side with the H_2 clumps) suggests shock excitation by such a wind. Radio hot spots have been seen from jets in other outflow sources (e.g., Garden, Russell, & Burton 1990; Rodríguez et al. 1986), and an early B star can easily power a jet capable of producing such free-free emission as it impacts material; the same jet which produces the bipolar nebula could be responsible.

As a result of all these arguments we are persuaded that the linear 2 μm continuum structure comes from an elongated, probably wind-induced structure. Pendleton, Tielens, & Werner (1990) have modeled dust grain properties in IR reflection nebulae formed by collimated winds and find that a mixture of graphite and silicate grains of varying sizes scattering hot source radiation, even with additional foreground extinction, can produce a reflected spectrum with an effective temperature of 800 K or more. Their particular models applied to IRAS 21334 require an additional foreground extinction of ≥ 20 mag over the full dimensions of the nebula (consistent with the Brγ limits). Whitney & Hartmann (1992b) have calculated the near-infrared appearance of scattered light from an infalling dusty envelope with (and without) cavities created by a bipolar flow, and their models are also consistent with our *JHK*-band observations. In both sets of scenarios, the axis of any disk (and very likely of the YSO itself) is aligned with the direction of the jets which produce the bipolar reflection nebulae.

A possible alternative explanation to reflection or scattering in a bipolar nebula is heating of dust in the wind-blown tube by stellar UV photons or directly by the wind. A B0 ZAMS star emits about $10^{47.4}$ ionizing photons s^{-1}. Dwek (1986) has calculated the temperatures and spectral shape of UV-heated dust. If the efficiency by which small grains (PAHs?) converted UV to IR were only 10%, as is possible, this would be adequate to produce the observed IR luminosity and temperature in the lobes (Dwek 1986). Finally we considered if the 2 μm continuum emission might be generated by collisional heating of dust in a flow tube by material in the wind. Some heating has already been attributed to jets in other YSOs like L1551 (Edwards et al. 1986) and the complex DR 21 (Garden et al. 1991). If powered by winds of velocities of 20 km s^{-1} or more, such jets typically contain a substantial fraction of the total luminosity in the source (e.g., Mozurkewich, Schwartz, & Smith 1986), while the 2 μm luminosity in the heated dust is less than 0.1% of the total. Direct heating of *dust* by shocks, however, does not easily produce the high temperatures we see. Fast-moving protons ($V \geq 100$ km s^{-1}) in a strong wind might in principle be able to deposit enough energy to heat small grains ($a \approx 0.001$ μm) to high temperatures or even to evaporation (e.g., Dwek 1986), but this requires an extreme set of assumptions. Additional observations are needed to evaluate these various scenarios further, but in any case all of them imply the 2 μm continuum is a linear structure, not a disk, produced and/or perhaps excited by the jet that also produced the H_2 emission aligned with it in the NW.

4. CONCLUSIONS

We are thus led to the conclusion that jets are involved in producing emission over a wide angular distribution. The radiative cooling times of the H_2 and dust continuum emission are short (e.g., Kwan 1977; Dwek 1986), so our images provide a snapshot of such jet activity. A single jet, with periodic flaring and/or precession, might be responsible; precession has been considered for other flows (Mizuno et al. 1990), and models of relativistic precessing jets in radio galaxies have been used to explain how a jet can appear to have multiple axes (Gower et al. 1982). Another suggestion is that jets are emitted in several directions, perhaps simultaneously. The nature of the mechanism that produces and collimates jets in YSOs is poorly understood, and the mechanism for driving the multiple jets here is not known. One possible explanation is that IRAS 21334 is a multiple young star system whose polar axes are not aligned. A multiple central cluster is consistent with the small-scale structure visible in the central region of the 2 μm continuum emission image, and a system of multiple stars of type later than B0 could offer an attractive alternative explanation for the IR colors, extinction, and the weakness of the reported extended 6 cm continuum emission at the star. But this idea of nonaligned jets runs counter to conventional expectations. Mundt et al. (1990), for example, find that four out of five jets seen across the HL Tau/HH 30 region are aligned with each other to within a cone angle of about 40° (but not aligned with the cloud's magnetic field). Nevertheless there is increasing evidence that similar activity over wide angles has been spotted in other places. HH 7–11 (Edwards et al. 1986), L1551 (Moriarty & Wannier 1991), and NGC 2071 (Walther et al. 1991) are all objects with structures not aligned with the main jets; Mundt et al. (1990) as well report a linear Hα feature at a position angle $\approx 90°$ to the other four jets. At millimeter wavelengths some dramatic sources, like IRAS 16293 (Walker et al. 1988), show complex structures which might perhaps result from multiple jets. IRAS 21334+5039, however, is the clearest example of possible multiple jet activity from a single source.

We thank P. R. Schwartz for initially suggesting this object for study, and for assistance with the VLA measurements, and Mark Whitis for his assistance with the Fabry-Perot instrument development and his participation in the observations. We also acknowledge valuable help in the data analysis by Francesco Strafella and Jane Russell, and discussions with Eli Dwek. We thank B. Whitney for an early preprint of her paper on scattering in YSO envelopes. H. A. S. acknowledges with thanks the hospitality of the Wise Observatory, Tel-Aviv University, where he did much of the analysis for this study during a visit. This work was supported in part by NASA grant NAGW-1711 and the Office of Naval Research.

REFERENCES

Adams, F. C., Lada, C. J., and Shu, F. H. 1987, ApJ, 312, 788
Chini, R., & Wink, J. E. 1984, A&A, 139, L5
Crampton, D., Georgelin, Y. M., & Georgelin, Y. P. 1978, A&A, 66, 1
Dwek, E. 1986, 302, 363
Edwards, S., Strom, S. E., Snell, R. L., Jarrett, T. H., Beichman, C. A., & Strom, K. M. 1986, ApJ, 307, L65
Fischer, J., Smith, H. A., & Whitis, M. 1992, in preparation
Garden, R. P., Geballe, T. R., Gatley, I., & Nadeau, D. 1991, ApJ, 366, 474
Garden, R. P., Russell, A. P., & Burton, M. G. 1990, ApJ, 354, 232
Gatley, I., DePoy, D. L., & Fowler, A. M. 1988, Science, 242, 1264
Gower, A. C., Gregory, P. C., Hutchings, J. B., & Unruh, W. G. 1982, ApJ, 262, 478
Kwan, J. 1977, ApJ, 216, 713
Lane, A., 1989, in Low Mass Star Formation and Pre-Main Sequence Objects, ed. B. Reipurth (Garching: ESO), 331
Lefevre, J., Daniel, J.-Y., & Bergeat, J. 1983, A&A, 121, 51
McCutcheon, W. H., Dewdney, P. E., Purton, C. R., & Sato, T. 1991, AJ, 101, 1435
Mizuno, A., Fukui, Y., Iwata, T., Nozawa, S., & Takano, T. 1990, ApJ, 356, 184
Moneti, A., Forrest, W. J., Pipher, J. L., & Woodward, C. E. 1988, ApJ, 327, 870
Moran, J. M., Garay, G., Reid, M. J., Genzel, R., Wright, M. C. H., & Plambeck, R. L. 1983, ApJ, 271, L32
Moriarty, G. H., & Wannier, P. G. 1991, ApJ, 373, L23
Mozurkewich, D., Schwartz, P. R., & Smith, H. A. 1986, ApJ, 311, 371
Mundt, R. 1988, in Mass Outflows from Stars and Galactic Nuclei, ed. L. Bianchi & R. Gilmozzi (Dordrecht: Kluwer), 147
Mundt, R., Ray, T. P., Buhrke, T. Raga, A. C., & Solf, J. 1990, A&A, 232, 37
Pendleton, Y. J., Tielens, A. G. G. M., & Werner, M. W. 1990, ApJ, 349, 107
Reipurth, B. 1991, in Physics of Star Formation and Early Stellar Evolution (NATO Advanced Study Institute), ed. C. Lada (Dordrecht: Kluwer)
Rodríguez, L. F., Cantó, J., Torrelles, J. M., and Ho, P. T. P. 1986, ApJ, 301, L25
Rouan, D., Omont, A., Lacombe, F., & Forveille, T. 1988, A&A, 189, L3
Schwartz, P. R., Mozurkewich, D., & Odenwald, S. F. 1992, preprint
Smith, H. A., Fischer, J. Geballe, T. R., & Schwartz, P. R. 1987a, ApJ, 316, 265
Smith, H. A., Fischer, J., Mozurkewich, D., Schwartz, P. R., & Geballe, T. R. 1987b, in Star Formation Regions, ed. M. Peimbert & J. Jugaku (Dordrecht: Reidel), 343
Tamura, M., Gatley, I., Joyce, R. R., Ueno, M., Suto, H., & Sekiguchi, M. 1991, ApJ, 378, 611
Walker, C. K., Lada, C. J., Young, E. T., & Margulis, M. 1988, ApJ, 332, 335
Walther, D. M., Geballe, T. R., & Robson, E. I. 1991, ApJ, 377, 246
Whitney, B. A., & Hartmann, L. 1992, ApJ, 395, 529
———. 1992b, ApJ, submitted
Wouterloot, J. G. A., & Brand, J. 1989, A&AS, 80, 149