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NEAR-INFRARED POLARIMETRY OF THE STAR-FORMING REGION RE 50N

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RESUMEN

Hemos obtenido imágenes polarimétricas en el cercano infrarrojo (CIR) a 1.65 y 2.2 μm, de alta resolución angular (1.″2), de la fuente infrarroja Re 50N. Usamos los datos polarimétricos para analizar la distribución de los granos de polvo que dispersan la radiación en regiones cercanas a este objeto. En base a la distribución de la intensidad de la radiación polarizada, derivamos un gradiente de densidad dentro de un radio r $\leq 6''$ (0.01 pc) de la fuente embebida (IRS 1). Este gradiente de densidad es de baja pendiente, n(r) $\propto r^{\alpha}$, con $-0.3 < \alpha < 0.0$. Reportamos la primera detección de luz polarizada en el CIR, hacia el noroeste y el oeste de IRS 1, sugiriendo la presencia de un segundo lóbulo de reflexión y asociado con el lóbulo corrido al rojo del flujo molecular (CO) que se observa en esta región.

ABSTRACT

We have obtained high angular resolution (1.″2) near-infrared (NIR) polarimetric images at 1.65 and 2.2 μm of the infrared source Re 50N. We have used the polarimetry data to analyze the distribution of the scattering dust in the immediate environment of this object. From the distribution of the polarized intensity at K band, we derived a shallow dust density gradient within a radius of r $\leq 6''$ (0.01 pc) from the embedded luminosity source (IRS 1), n(r) $\propto r^{\alpha}$, with $-0.3 < \alpha < 0.0$. We report the first detection of polarized light at NIR wavelengths to the northwest and to the west of IRS 1, suggesting the presence of a second reflection lobe reflection and associated with the redshifted lobe of the CO outflow in this region.

Key words: **ISM: DUST, EXTINCTION — INFRARED: INDIVIDUAL: RE 50N — POLARIZATION — STARS: PRE-MAIN SEQUENCE**

1. INTRODUCTION

The reflection nebulosity Re 50N is coincident with a bright far-infrared (FIR) source designated *IRAS* 05380−0728 (L1641-S). It exhibits all the characteristics common to young stellar objects (Class I), namely a bright infrared source with no optical counterpart, a molecular outflow, Herbig-Haro objects, reflection nebulosities, the FU Ori phenomenon (Reipurth & Bally 1986; Strom & Strom 1993, and references therein) and radio continuum emission (Morgan, Snell, & Strom 1990). Re 50N is one of the most luminous objects in the L1641 molecular cloud, with an estimated total luminosity of 250 $L_{\odot}$ (Reipurth & Bally 1986). This luminosity is considerably less than that of massive embedded stars, but much higher than the average value for low-mass pre-main sequence stars. The infrared source IRS 1 is located at the western edge of Re 50N. The latter has been previously shown to be highly polarized at optical (Scarrott & Wolstencroft 1988) and at NIR wavelengths (Casali 1991). There is a second reflection nebulosity (Re 50S) $\sim$ 1.′5 to the south of Re 50N. Both objects are variable at optical and NIR wavelengths. The high degree of polarization and centrosymmetric pattern of the polarization position angles indicate that the emission from the nebulae is dominated by scattering. The overall orientation of the polarization vectors is consistent with IRS 1 illuminating both Re 50N and Re 50S. IRS 1 appears as the only point source at 3.6 μm (Casali 1991). Within Re 50N there is a second source, IRS 2, which is located a few arcseconds southeast of IRS 1. The former is not a point source even at K band, it is not as red as IRS 1, and it is most likely a density and scattering enhancement in the nebula.

2. BACKGROUND

One of the main goals of our current work in infrared sources has been to determine density gradients in selected galactic star-forming regions. By comparing these density gradients to those predicted by star formation theories we hope to gain more insight into the process(es) of star formation. In particular, we hope to establish differences in the physical characteristics of the infalling envelopes of pre-main sequence objects of very different masses. The overall density gradient in cloud cores associated with young embedded objects is derived by modeling both their spectral energy distributions (SEDs) and their intensity profiles at a wavelength at which most of their luminosity is re-radiated by dust grains, namely at $\lambda = 100$ μm. We combine FIR photometry with NIR polarimetry to increase the range of the distance scale over which dust density gradients can be determined. In this paper we present only the NIR polarimetry of one of the objects of our current study. The FIR observations and the radiative transfer modeling of the source have been presented elsewhere (Colomé, Di Francesco, & Harvey 1994).

3. OBSERVATIONS AND DATA REDUCTION

We observed Re 50N at 1.65 μm (H) and 2.2 μm (K). The observations were made on 9 December 1993 at the 2.7-m telescope at McDonald Observatory. The polarimetric imaging was performed with the infrared camera (IRC2) of the University of Texas which employs a 256×256 HgCdTe NICMOS III array and provides a plate scale of 0.″4 per pixel. A set of short exposures was taken at 4 separate positions (0° 22.5°, 45°, and 67.5°) of the half-wave plate. After sky-subtraction, bad-pixel interpolation, and flat-fielding, the images of each set were cross-correlated, and shifted-and-added. Averages of all the resulting images of the same position angle were constructed. The Stokes parameters were then calculated in the standard way. For a more detailed description of the camera, polarimeter, data acquisition, and reduction techniques (see Colomé & Harvey 1993). The bipolar nebula OH 231.8+4.2 was observed in the same fashion and used to calibrate the zero position angle of the instrumental system. Flux calibration was performed from the photometry of the stars HD 3029 and HD 40335 (Elias et al. 1982) and a set of unpolarized stars was also observed for instrumental polarization corrections.

4. THE NEBULAR SHAPE AND COLORS

The distribution of the total and polarized intensities at NIR wavelengths of Re 50N extends $\sim 25''$ predominantly to the east and southeast of IRS 1. At the tail of the reflection nebulosity the geometry bends to the southeast. The bent shape of the nebula becomes more pronounced with decreasing wavelength. Reipurth & Bally (1986) suggested that this peculiar shape might represent the illumination of the walls of a tunnel-like cavity, perhaps evacuated by the outflow. The reflection nebula is coincident with the blue lobe of the low-velocity CO outflow detected by Reipurth & Bally (1986). The nebula has relatively uniform colors, $H-K \sim$ 1.0, indicating very little extinction between the illuminating source and the scattering region. It reaches a relative maximum at the position of IRS 1 ($H-K \sim$ 2.0) and a minimum at the end of the southeastern tail ($H-K\sim$ 0.5).

5. NIR POLARIZATION: THE DISTRIBUTION OF THE SCATTERING DUST WITHIN RE 50N

For both wavelengths we constructed images of the *Polarized Intensity* (I_p). This is just p × I_T, where p is the polarization ($0 \le p \le 1$) and I_T is the total intensity. Knowing nothing about the geometry of the scattering region(s), the phase function of the scatterers, nor their density distribution, the quantity I_p has no unique meaning, but to a first order approximation it can be treated as a *Global Polarization Efficiency*. If we assume that the geometry of the reflection nebula surrounding IRS 1 can be approximated by a section of a sphere and that the distribution of the scattering dust can be represented by a power law of the form $n(r)=n_0(r/r_0)^{-c}$, with the dust grains scattering isotropically, we can then use the relationship between the intensity of the polarized radiation and the impact parameter or projected distance to the central source (see Weintraub et al. 1992, and references therein) to deduce the exponent of the dust density law "c". For particular directions on the plane of the sky we derived $\log(I_p) = A_0 + A_1 \log(r)$, where "r" is the distance between IRS 1 and the volume element in the nebula. We fit the data by the least-squares method and derived the coefficients A_0 and A_1. The latter is related to the coefficient "c" of the assumed power law of the density gradient of the scattering dust, namely $A_1 = -(c+1)$. Selecting the data with the highest signal-to-noise ratio, we chose the line joining IRS 1 to IRS 2 ($r \le 6''$). Applying this method to the observed polarized intensity in that particular direction we find that c=0.3; i.e., a very flat density distribution of the scattering dust. For other radial distances from IRS 1 the coefficient "c" is even smaller, in the 0.1 to 0.0 range.

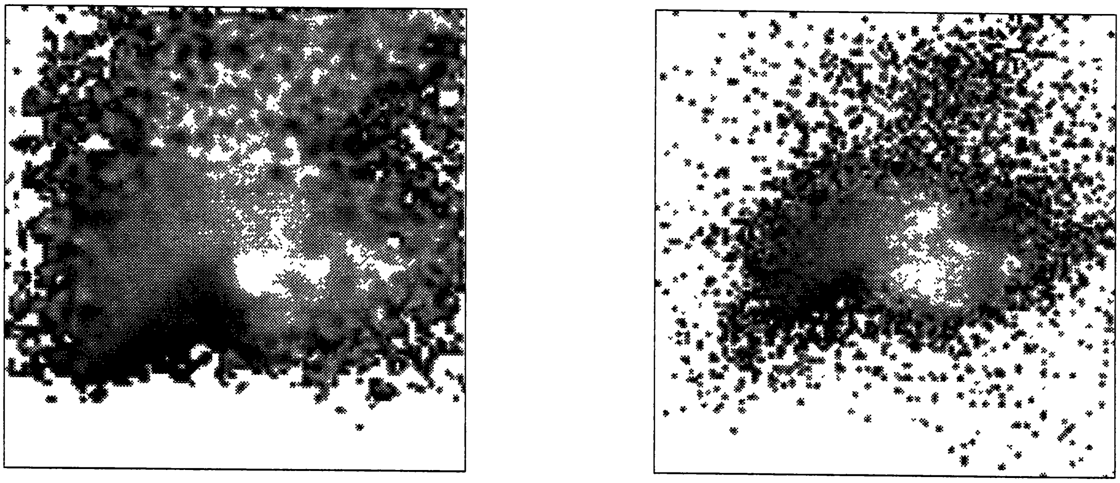

Fig. 1. *Left:* Polarization of Re 50N at *H* band. White and light grays correspond to $0.0 \leq p \leq 0.20$, while medium and dark grays represent $0.20 < p \leq 0.40$, and $0.40 < p \leq 0.70$, respectively. *Right:* Same as before but at *K* band. The area enclosed by each box corresponds to $40'' \times 40''$ on the plane of the sky.

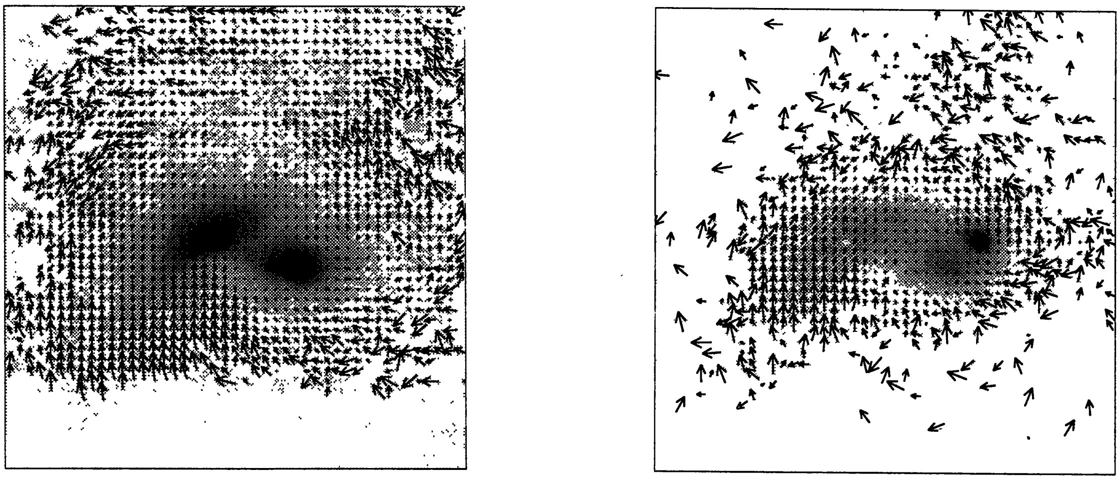

Fig. 2. *Left:* Position angle distribution of the polarized light at *H* band overlaid on the total intensity frame. The latter is shown in inverted gray scale. *Right:* Same as before but at *K* band.

6. DISCUSSION

Notice the large areas (light gray) of relatively low polarization (p) in Figures 1a and 1b. These correspond to $0 \leq p \leq 0.20$ compared to $0.20 < p \leq 0.50$ in the eastern and western regions of Re 50N. Figures 2a and 2b show the distribution of the position angles of the polarization vectors. Another feature of the polarization maps is that IRS 1 is not located in a position of a minimum of the polarization but rather is located at the edge of rapid variations of p. It is also worth noting that there is considerable polarization towards the northwest and west of IRS 1. This part of the nebulosity is very faint. The regions of low flux but considerable polarization of Re 50N might represent the "second lobe" of the true bipolar nature of Re 50N; they are located in the redshifted lobe of the outflow seen in CO emission (Reipurth & Bally 1986). These extensions of low flux but polarized light are parallel to the elongated structures observed at optical wavelengths by Scarrott & Wolstencroft (1988) and might delineate the walls of a cavity associated with the redshifted lobe of the CO outflow.

Re 50N has been resolved at far-infrared wavelengths, and the high angular resolution map of this object at 100 μm indicates that its intensity decreases more rapidly to the west and northwest than to the south or southeast of IRS 1 (Colomé et al. 1994). This is consistent with the fact that there seems to be higher density material in the western portion of the molecular core as observed in ^{13}CO (Reipurth & Bally 1986). This is also consistent with the elongation of the reflection nebula, although at different scales, towards the east and bending to the southeast of the IR peak. Photons escaping from IRS 1 can travel further into regions of lower density, i.e., there is a shallower dust temperature gradient in that direction.

7. SUMMARY

We have observed Re 50N (IRAS 05380−0728) at NIR wavelengths with high spatial resolution ($1\rlap{.}''2$). The NIR polarization observations indicate an anisotropic distribution of the scattering dust near the infrared source IRS 1 which is believed to be the sole young stellar object in the region. From a simple model for the distribution of the polarized intensity at K band we derived a density gradient for $r \leq 6''$ (0.01 pc) from IRS 1, namely $n(r) \propto r^{\alpha}$, with $-0.3 < \alpha < 0.0$. We report the first detection of polarized light at NIR wavelengths to the northwest and west of IRS 1, suggesting the presence of a second reflection lobe associated with the redshifted lobe of the CO outflow in this region.

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