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Near Infrared Polarimetric Imaging of the Giant H II region NGC 3576

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Abstract. NGC 3576 is one of the brightest H II regions in the infrared harboring a group of massive stars with infrared excess indicative of their youth. We present the near-infrared JHKs polarization images taken by SIRPOL, an infrared polarimeter camera mounted on the IRSF (Infra-Red Survey Facility) telescope in Sutherland, South Africa. An overall scattering pattern is seen centrally symmetric around the luminous stellar group, indicating their dominant role in illuminating the nebulosity. Organized scattering patterns also reveal special dust distribution around embedded infrared sources, e.g., a dust ridge which may be associated with IRS−1 #60. We find no systematic polarization of background stars, which may indicate an entangled magnetic field structure in a turbulent environment of massive star formation.

1. Introduction

Polarization in optical or near-infrared (NIR) wavelengths shows two kinds of diagnostic patterns. First, there is the scattering case, in which an embedded source illuminates surrounding nebulosity, giving rise to a polarization pattern centrally symmetric with respect to the embedded source. The spatial distribution of circumstellar dust can be inferred, see e.g., Tamura et al. (2006). The other is the transmission polarization. Because a paramagnetic grain tends to spin about its shortest axis in an external magnetic field, background starlight, unpolarized otherwise, would become polarized when passing through a foreground dust cloud, as a result of dichroic extinction (Davis & Greenstein 1951). The polarized electric field in this case is parallel to the direction of the magnetic field permeating the cloud. Polarization of background starlight hence provides a way to delineate the magnetic field structure in a molecular cloud, see e.g., Tamura, et al. (2007).

Magnetic field influences star formation on various scales. Close to a newborn star collapsed out of a dense molecular core, the field is expected — and indeed observed in many cases (e.g., Girart et al. (2006)) — to be roughly perpendicular to the accretion disk as the result of ampipolar diffusion (Vallée et al. 2002). On Galactic scales, the magnetic field is seen along the disk (Mathewson et al. 1970). On intermediate scales, such as the scales of molecular clouds, however, the field-cloud geometry remains elusive. The field could be either parallel or perpendicular to the extension of a cloud (Goodman et al. 1991). It was noted (Stahler & Palla 2004) that the field seems well aligned with the elongation of the filamentary clouds where star formation is relatively quiescent, but less organized where active star formation is taking place; that is, strong stellar winds, photoevaporation or supernova shocks from massive stars might disturb the field structure. Here we present the polarization study of such a violent environment in NGC 3576.

NGC 3576 (RA=11:11:55, DEC=−61:18:26, J2000), at a distance of 2.4 kpc (Persi et al. 1994), is part of the RCW 57 complex and one of the most luminous H II regions in the Milky Way Galaxy, The region hosts numerous massive stars (Persi et al. 1994), some still enshrouded in their natal cocoons (Figuerêdo et al. 2002), and a significant fraction of stars with infrared excess (>50%; Maercker et al. (2006), both signifying extreme youth. Promiment bow shocks in the region indicate turbulent environments (Fig. 1). NGC 3576 hence provides a good target to study the interplay between massive stars, molecular clouds and low-mass star formation.

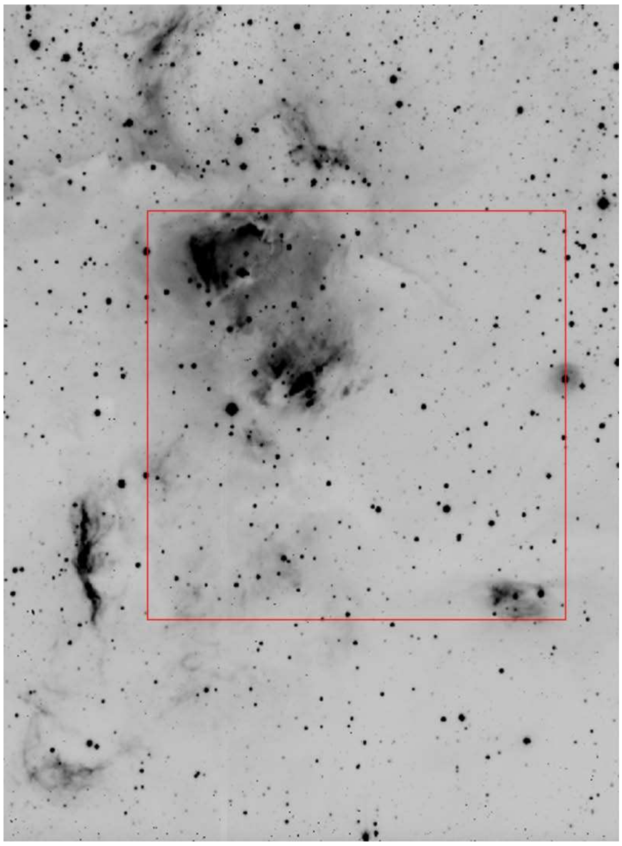

Figure 1. The [S II] image around NGC 3576 taken with the CTIO 0.9 m in Feburary 2008. The field is about 9.7' times 12.6', with north to the top and east to the left. The thin box marks the SIRPOL imaging area.

2. Observations and Results

Polarimetric imaging of NGC 3576 was obtained by the Simultaneous Infra-Red POLarimeter (SIRPOL) mounted on the IRSF (Infra-Red Survey Facility) 1.4-m telescope located in Sutherland, South Africa (Kandori et al. 2006), and operated by Nagoya University. The SIRPOL takes JHKs images simultaneously through a half-wave plate polarizer, with a field of view of $7.'7$ squared, and a 5-σ sensitivity of J=19.2, H=18.6 and Ks=17.3 mag, in one hour integration[1]. SIRPOL data of NGC 3576 were taken on 2006 May 7, at 4 polarization angles ($12.^\circ5$, $22.^\circ5$, 45°, and $67.^\circ5$), each with 4 set of 10 dithering positions. Each exposure was 10 s. The images were processed with an in-house package developed for SIRPOL based on the IRAF. The processed images at different polarization angles then were used to derive the Stokes parameters (I, Q, U) at each wavelength (Tamura, et al. 2007), $Q = I_0 - I_{45}$, $U = I_{22.5} - I_{67.5}$, $I = (I_0 + I_{45} + I_{22.5} + I_{67.5})/2$. We inferred the scattering and the transmission cases of polarization with two separate analysis pipelines.

2.1. Scattering Polarization by Nebulosity

To estimate the polarization by scattering within nebulosity, the polarization percentage (P) and position angle (θ) at each pixel are derived, $P = \sqrt{Q^2 + U^2}/I$, and $\theta = (1/2)\arctan(U/Q)$. Fig. 2 shows the polarization map at J band, superimposed on the total intensity images. For display clarity, each image was binned by 12 by 12 pixels, and only polarization greater than 40-σ above background is shown. As can be seen, polarization coincides well spatially with the reflection nebula. In general, the J-band emission is more polarized than those at H- or K-band, as expected in a scattering process. The maximum polarization are $P_{\rm J}^{\rm max} = 17.0\%$, $P_{\rm H}^{\rm max} = 14.7\%$, and $P_{\rm K}^{\rm max} = 11.3\%$, respectively. The centrally symmetric polarization pattern seen in Fig. 2 suggests a dominant role of the group of massive stars in illuminating the nebulosity.

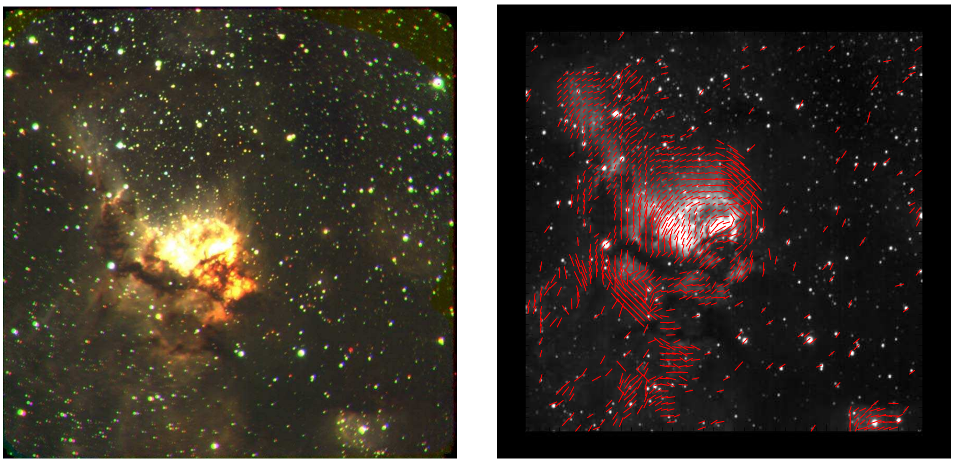

Figure 2. (*Left*) JHKs tri-color composite image of NGC 3576. (*Right*) Polarization map superimposed on the J-band total intensity image.

Embedded sources can be scrutinized in polarization observations. For example, IRS−1 has been resolved into a small group of objects, some of which (e.g., #50) are brighter toward longer wavelength (Barbosa et al. 2003). Our observations detected a source in the neighborhood of #48 (dubbed "A" here),

[1] See http://optik2.mtk.nao.ac.jp/ kandori/SIRPOL.html

which appears progressively stronger toward shorter wavelength, and becomes brighter than #48 at J band. Polarimetric imaging (see Fig. 3) also reveals a conspicuous pattern coincident with the diffuse source #60. It is likely a scattering dust ridge, but we are not certain of its nature or relation to source #60 at the moment.

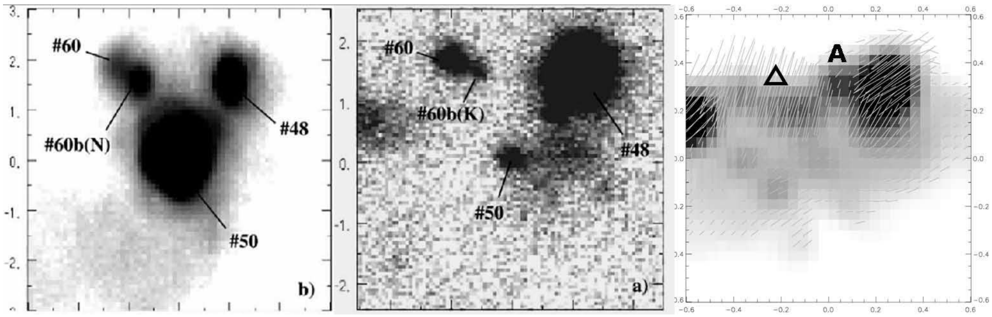

Figure 3. The NGC 3576 IRS−1 at infrared N (*left*) and K band (*middle*), taken from Barbosa et al. (2003), and our SIRPOL result at K band.

2.2. Polarization of Background Stars

The transmission polarization through a dark cloud is diagnosed by polarization of background stars, chosen as point sources with NIR colors consistent with being giant stars. For each such a background star, aperture photometry was performed to estimate the I, Q, and U parameters, which were in term used to derive the polarization percentage and position angle. The polarization of background stars in the NGC 3576 region is shown in Fig. 4. Because no molecular cloud data were available to us, we performed a 2MASS star count to reveal a concentration of dark cloud to the south-east of the region. This is to be compared with the inference of a star-formation sequence from the NE to the SW in the region (Persi et al. 1994; Damineli et al. 2002). As seen in Fig. 4, there is no systematic direction of polarization, including the densest part of the cloud to the south-east. NGC 3576 therefore appears to be a manifestation of a turbulent star-formation region for which shocks might have distorted the magnetic field (Loren 1989).

3. Summary and conclusions

Our near-infrared polarimetric imaging of NGC 3567 shows an overall scattering pattern centrally symmetric around the luminous stellar group, indicating their dominant role in illuminating the nebulosity. Organized scattering patterns also reveal special dust distribution on small scales around embedded infrared sources, e.g., a dust ridge which may be associated with IRS−1 #60. No systematic polarization of background stars is found, which may suggest an entangled magnetic field structure in a turbulent environment of massive star formation.

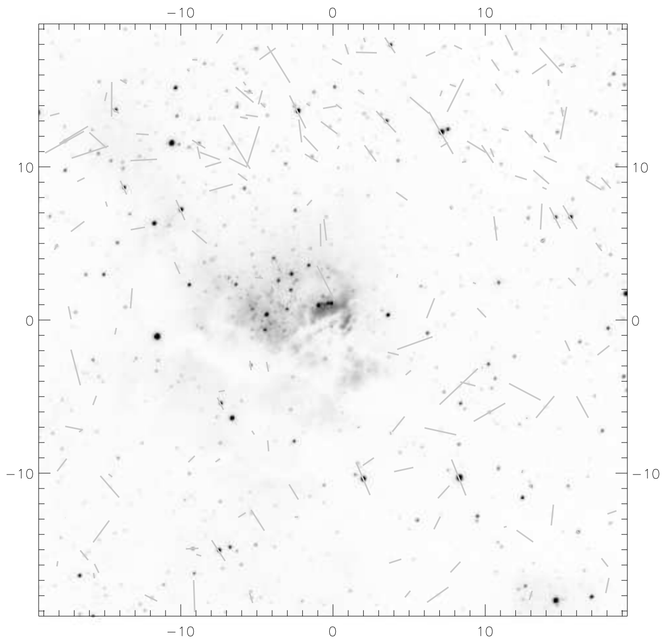

Figure 4. Polarization in the H band of background stars in the NGC 3576 region. The degree polarization and position angle of the polarization of each background star is marked by a line. The H-band total intensity image is shown.

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