巨型氫離子區 NGC 3576 之近紅外偏極化觀測

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摘要

NGC 3576是銀河系當中最明亮的氫離子區之一，包括成群大質量恆星，它們具有紅外超量輻射，顯示這些恆星仍然非常年輕。我們利用配掛在位於南非 IRSF (Infra-Red Survey Telescope) 望遠鏡上的SIRPOL近紅外相機，取得此區域之JHKs偏極影像。我們的資料顯示整體偏極呈現以明亮恆星群爲中心的對稱圖像，表示這些大質量恆星爲照亮雲氣的主來光源。在某些深埋在雲氣中的星球附近，例如IRS-1 #69以及 #85，有規律的塵埃空間分佈所造成的散射圖樣。對於背景恆星，我們沒有發現系統性偏極現象，這可能因爲大質量恆星形成所造成的劇烈環境使得磁場結構受到扭曲的結果。

Near Infrared Polarimetric Imaging of the Giant HII region NGC 3576

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Abstract

NGC 3576 is one of the brightest HII regions in 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 associated with IRS−1 #69 and perhaps also with #85. We find no systematic polarization of background stars, which may be the consequence of an entangled magnetic field structure in a turbulent environment of massive star formation.

關鍵字（Keywords）：恆星形成(star formation)；紅外線觀測(infrared)；偏極化觀測(polarimetry)；星際物質(interstellar medium)

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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 (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., by 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, photo-evaporation 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 RCW57 complex and one of the most luminous HII 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

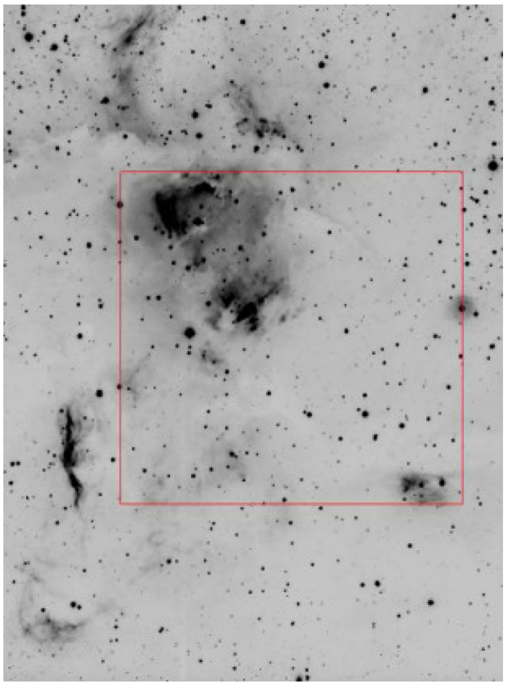

Fig. 1: The [S II] image around NGC 3576 taken with the CTIO 0.9 m in Feburary 2008. The field is about 9.7' times 12.6', with north to the top and east to the left. The thin box marks the SIRPOL imaging area.

(>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.

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 and a 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 (0º, 22.5º, 45º, and 67.5º), 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 θ = (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,

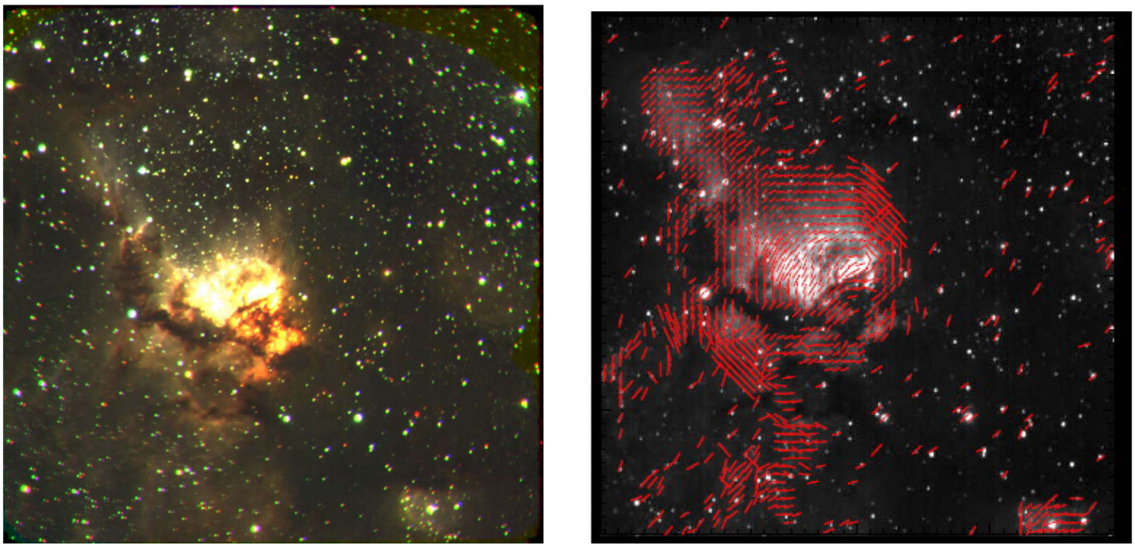

Fig. 2: (Left) JHKs tri-color composite image of NGC 3576. (Right) Polarization map superimposed on the J-band total intensity image.

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

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 $P_J^{\max} = 17.0\%$, $P_H^{\max} = 14.7\%$, and $P_K^{\max} = 11.3\%$, respectively. The centrally symmetric polarization pattern seen in Fig. 2 suggests a dominant role of the group of massive stars in illuminating the nebulosity.

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, naming from Figuerêdo et al. 2002) are much brighter toward longer wavelength (see Barbosa et al. 2003). Our observations reveal (Fig. 3) a conspicuous polarization pattern coincident with the diffuse source #69, perhaps extending to #85. The near-infrared spectrum of #69 shows a featureless continuum with a weak H2 emission (Figuerêdo et al. 2002), likely arising from shock excitation. It is probably a scattering dust ridge, but its nature requires further studies. Note the difference in polarization of this feature from those toward #48, 50, and 95, and the relatively weak polarization in #60.

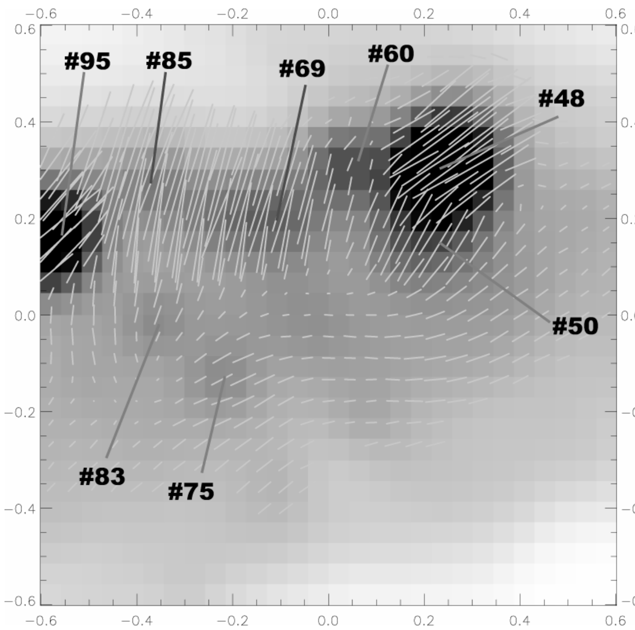

Fig. 3: The SIRPOL K-band image and polarization map around the group of stars associated with NGC 3576 IRS−1. The numbering of stars follows that of Figuerêdo et al. (2002). The coordinate unit is arc minute.

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, while there seems to be weak polarization in the NE-SW direction away from the central region — hence due to interstellar polarization — there is no systematic direction of polarization, particularly not in 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 structure (Loren 1989).

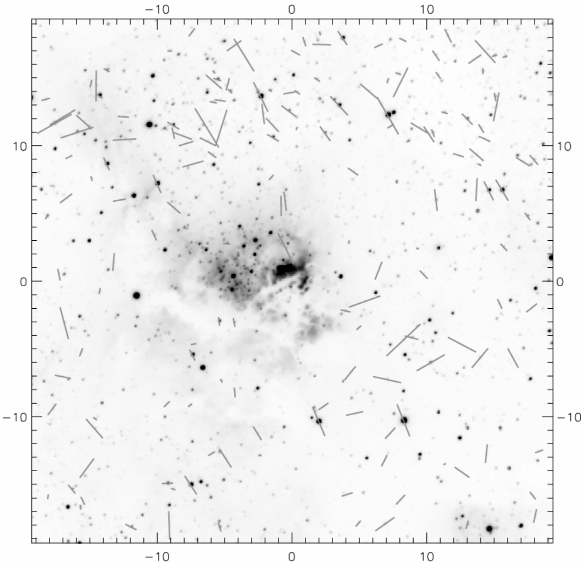

Fig. 4: Polarization in the H band of background stars in the NGC 3576 region. The degree polarization and position angle of the polarization of each background star is marked by a line. The H-band total intensity image is shown. The coordinate unit is arcmin.

3. Conclusions

Near-infrared polarimetric imaging of NGC 3567 shows an overall scattering pattern centrally symmetric around the luminous stellar group, indicating its dominant role in illuminating the nebulosity. Organized scattering patterns also reveal special dust distribution on small scales around embedded sources, e.g., a dust ridge associated with the nebulous IRS−1 #69. No systematic polarization of background stars is found, which may suggest an entangled magnetic field structure in a turbulent environment of massive star formation.

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