Introduction

CRL 2136 is a massive star-forming region consisting of the near-infrared (NIR) source IRS 1 and a bipolar reflection nebula located at a distance of 2 kpc (Kastner et al. 1992). IRS 1 poses a protostar with a luminosity of 10^5 L⊙, and its mass was estimated to be higher than 10 M⊙ (Kastner et al. 1992). Previous NIR imaging polarization (e.g., Minchin et al. 1991, Kastner et al. 1992) detected two bright lobes of near-infrared emission extended from IRS 1 and shock waves with respect to IRS 1. Their polarization data shows a centro-symmetrically aligned pattern in the nebulous surroundings IRS 1 and a linear alignment near IRS 1 with a position angle (PA) of ∼45°. Low resolution spectroscopy has detected deep absorption features of silicate at 9.7 µm (r = 5−7) and water ice at 3.07 µm (r = 2.7µ) (Willner et al. 1982). A CO emission line map shows blue- and red-shifted outflow components extending toward the southeast (−130°) and the northwest (−45°), respectively, approximately perpendicular to the direction of aligned polarization vectors near the central star (Kastner et al. 1994). The above-mentioned observational results are strong evidence for an optically thick torus, a possibly disk, and an envelope structure.

Near-infrared imaging polarimetry is a powerful technique to extract information of dust shell structures which is hard to detect from the total intensity images (e.g., Murakawa et al. 2008a). We obtained the H and K-band polarimetric images of CRL 2136 using the near-infrared camera EFOSC on the 8 m Subaru telescope on June 28, 2005. A turnable half-wave plate and a wire-grid polarizer allowed us to measure linear polarization. The Stokes IQUV parameter images, the degree of linear polarization, and the polarization orientation were derived from the observed data (Fig. 1 middle and bottom; see also the top-left sketch of CRL 2136). Our images show:

- The bright infrared source IRS 1 and fan-shaped nebulosities extending towards the south, east, west, and north.
- In the near-infrared images, the polarization vectors are centro-symmetrically aligned and the polarization reach PSI = 30 ° and PSI = 50 °.
- At IRS 1, the polarization vectors are systematically aligned along the polarization disk, which is spatially resolved in our data. In this region, the polarization is enhanced at a spot-like shape and as high as PSI = 32 ° and PSI = 21 °.
- A fan-shaped region with low polarizations between the southern and eastern lobes and IRS 1. This region is probably projected inner part of the envelope cavity.

Radiative transfer modeling

We have performed two-dimensional radiative transfer calculations to model the disk and in-falling envelope of CRL 2136. We constrain the model parameters by fitting the spectral energy distribution (SED), the total intensity images, and the polarization images. We used our own Monte Carlo radiative transfer code (STWH), which:

- Simulates scattering and thermal emission of radiation by spherical dust grains in a three-dimensional model geometry.
- Can treat multiple grain models.
- Allows a proper treatment of polarized light (Fischer et al. 1994)
- Uses techniques to improve the Monte Carlo noise in the resulting images (e.g., Witt 1977, Yusef-Zadeh et al. 1984)
- Converges the SEDs, the dust temperature, and the Stokes IQUV images.

We applied model geometries with a disk and in-falling envelope, given by the disk structure, a Keplerian orbit disk is often used. However, we find that Tomoe’s model (Tomoe 1982) fits better in the SED. For the envelope, we use the model of the slowly rotating, infalling envelopes (Ulich 1976, Cassen & Moumian 1981, Terhivuo 1984). These forms are given with the two-dimensional cylindrical coordinate \( r \) and \( \theta = \sqrt{r^2 + R^2} \).

Observations

HK band imaging polarimetry and radiative transfer modeling of CRL-2136

References