Observed HR diagrams and stellar evolution
ASP Conference Series, Vol. 274, 2002
Thibault Lejeune and João Fernandes, eds.

Near Infrared Imaging Polarimetry of Proto-Planetary Nebula - OH231.8+4.2

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Abstract. Proto-Planetary Nebulae (PPN) are a class of short-lived objects representing a period of around 10^3 years of stellar evolution between the Asymtotic Giant Branch and Planetary Nebula phases. This part of the Hertzsprung-Russell diagram is not very well understood from theory although it represents an important phase of low and intermediate mass ($0.8M_\odot \leq M \leq 8M_\odot$) stellar evolution. We present near infrared (NIR) linear and circular imaging polarimetry of the bipolar outflows of a well studied PPN - OH231.8+4.2 in the J-band (1.2μm). We detected high linear polarisation ($\sim$50%) in the lobes of the nebula. We detected a maximum circular polarisation of ($\sim$1.7%) in the J-band which is probably the first detection in a PPN at NIR wavelengths. We also present results from an optically thick computer model to generate the polarisation patterns from the PPN. From our observations and modelling we conclude that the high levels of NIR linear polarisation seen in the bipolar lobes arise from scattering off spherical, Rayleigh-like dust grains and the circular polarisation is generated by multiple scattering, off a small population of spherical, non-Rayleigh dust grains.

1. Introduction

OH231.8+4.2 (also known as the Rotten Egg Nebula) is a particularly well studied PPN located at a distance of $\sim$1300-1500 parsecs (Kastner et al. 1992; Alcolea et al. 1996). The central star of this bipolar nebula is thought to be a (M9III) Mira variable - QX pup (Cohen 1981; Kastner et al. 1998), having a period of $\sim$700 days (Kastner et al. 1992). The nebula is quite extended $\sim$10″x50″ (Bieging et al. 2000) and inclined at an angle of $\sim$36° (Shure et al. 1995) to the plane of the sky with the north lobe towards us.

The molecular envelope of the nebula is massive ($\sim 1M_\odot$) and elongated along the major axis of the nebula (Sanchez Contreras et al. 1997). The dust in the nebula ($\sim 0.01M_\odot$) is mainly confined to the walls of the bipolar lobes (Kastner et al. 1992). The nebula also shows Hα emission (Reipurth 1987) which is quite asymmetric, showing a much greater extent in the south than to the north. Many molecular species have been observed in OH231.8+4, like

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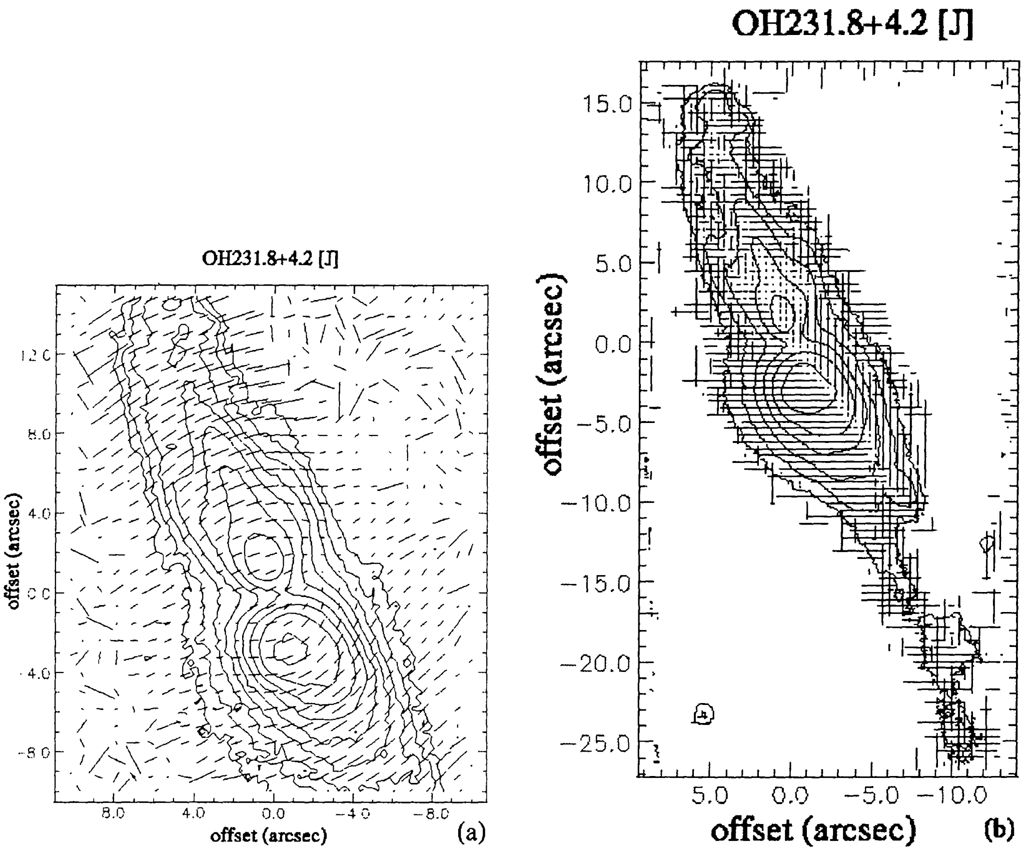

Figure 1. (a) J-band linear polarisation vector map superimposed on intensity contours of OH231.8+4.2. The pixel scale is 0.286″ and 1″ corresponds to 35% linear polarisation. (b) J-band circular polarisation vector map superimposed on intensity contours. The pixel scale is 0.143″ and 1″ corresponds to 0.3% circular polarisation.

NH_3, HCN, CO, H_2O, SiO, SO, SO_2, H_2S, CS and OCN (Morris et al. 1987 and references therein) suggesting an active chemistry induced by shocks (Sanchez Contreras et al. 1997).

2. Observations and results

The linear imaging polarimetry was obtained at the 3.8m United Kingdom Infrared Telescope on Mauna Kea in November, 1995. The pixel scale was 0.286″. The circular imaging polarimetry was obtained in January 1999 at the same telescope. The pixel scale was 0.143″.

2.1. Linear polarisation

We detect high levels of linear polarisation (~50%) in the lobes of the nebula (Ahmad 2001), at J, which is in agreement with previous observations. The polarisation vector map (Fig. 1a) shows a centro-symmetric pattern which is characteristic of illumination from a point source, suggesting that the reflection

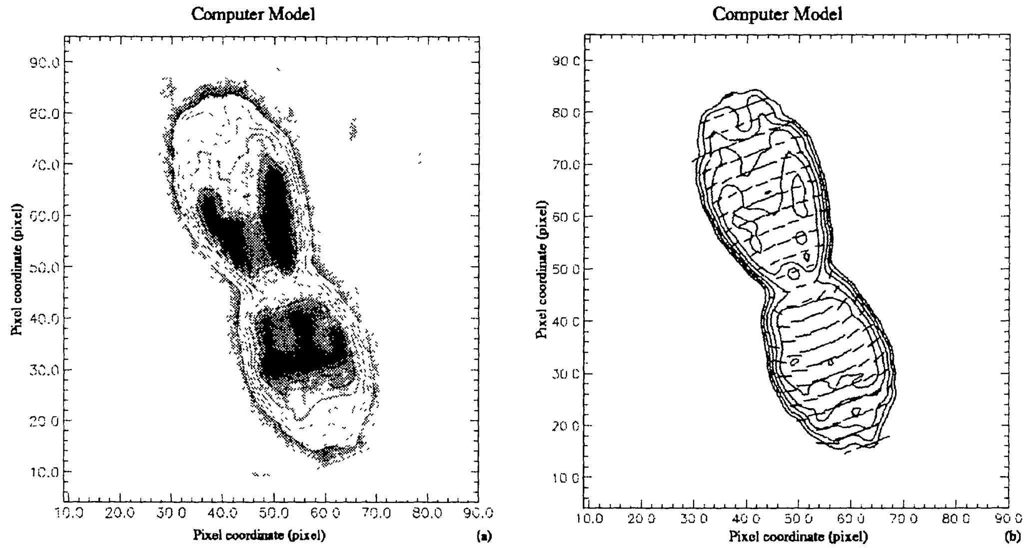

Figure 2. (a) 1.2μm intensity contours superimposed on a greyscale intensity image from the model. The star is at pixel (50,50). (b) 1.2μm linear polarisation map superimposed on intensity contour. 1$''$ corresponds to 25% linear polarisation.

nebula is seen by scattered light from the central star, which is obscured by a dense torus. The flattened polarisation vectors around the centre are generated by multiple scattering, indicating that it is optically thick at shorter wavelengths.

2.2. Circular polarisation

We report the first NIR, J-band circular polarisation detection in a PPN. The circular polarisation vector map is presented (Fig. 1b). The peak polarisation level detected in OH231.8+4.2, was ~1.7% in the south lobe (Ahmad 2001). There was not much circular polarisation detected in the north lobe. This might be due to the presence of more dust in the south lobe than the north lobe.

Circular polarisation can be generated by Mie scattering in an asymmetric dust envelope, although it can also be generated by aligned non-spherical dust particles. Since there is no observational evidence of aligned dust grains in OH231.8+4.2, we propose that the NIR circular polarisation observed in the nebula is due to multiple scattering from spherical, non-Rayleigh dust particles.

3. Computer Modelling

We present results from a modified version of the Monte Carlo scattering code (Menard 1989). The model nebula consists of an AGB circumstellar shell, bipolar elliptical lobes, an optically thick disk-like torus and a small scale torus oriented at an angle of 50° to the equatorial plane of the nebula. The small scale torus makes the source polarised (Gledhill 1991) and effectively focuses the light from the star towards the back wall of the north lobe and the front wall of the south lobe. The model nebula was tilted by ~40° with the north lobe towards us to match the tilt of OH231.8+4.2. By using a hollow north lobe and a dust filled south lobe, we were able to make the south lobe brighter than the north lobe and produce the structures seen in the NICMOS, HST observations (Bieging et al. 2000).

We used spherical, non-coated silicate dust particles and a power law size distribution of the form $n(a) \propto a^{-p}$, for the modelling. The correct levels of NIR linear polarisation were obtained using, a[0.01-1.0μm] and p=5.3. With our model, we are able to generate the NIR intensity structures (Fig. 2a) and linear polarisation levels of ~50% in the bipolar lobes (Fig. 2b) of the nebula at 1.2μm but a slightly higher degree of circular polarisation (~3%).

4. Conclusions

Based on our observations and Monte Carlo modelling of the nebula we suggest that most of the dust particles in OH231.8+4.2, are Rayleigh-sized and these are responsible for the high levels of NIR linear polarisation. There is also a small population of larger, non-Rayleigh dust particles, which generate NIR circular polarisation by multiple scattering.

We also suggest that there is more dust in the south lobe of the nebula. This asymmetry might be due to the presence of a binary system in OH231.8+4.2.

Acknowledgments. AA thanks the LOC for the various grants, which made it possible to attend the conference.

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