Magnetic fields in planetary nebulae and post-AGB nebulae

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Summary. The shaping of late-type stars is still an open question and several theories are suggested. Among them, is the action of magnetic fields. They have been detected in AGB stars via maser measurements and also measured in the central stars of some PNe. We present SCUBA sub-millimeter polarimetric observations (450 and 850 μm) of four bipolar planetary nebulae (PNe) and post-AGB stars (PAGBs), including two oxygen-rich and two carbon-rich nebulae, to determine the geometry of the magnetic field by dust alignment. The data obtained for NGC 6337, NGC 7027, NGC 6302 and CRL 2688, show a clear correlation between field orientation and nebular structure.

Key words: Magnetic Fields - Polarization - Planetary Nebulae - Post-AGB

1 Introduction

It is an observational fact that a large number of post-AGB nebulae (PNe and PAGBs) appear elliptical, bipolar or even multi-polar. To explain this deviation from the spherical geometry several hypotheses have been raised. The wind model relying on the interaction between a slow AGB wind with a faster post-AGB wind or the binary model where a close companion affects the mass-losing AGB star via common envelope evolution, mass transfer and/or tidal forces, are among the possible shaping agent. But the first phenomenon requires an initial asymmetry in the slow wind and there is still a lack of observational evidence for the occurrence of close binary systems during the AGB phase. A third process can be brought upon: the action of magnetic fields which may act as a “squeezer” around the central star of the PN and thereby give the dust its direction (in the sense of the outflow). Magnetic fields have been detected in AGB and post-AGB stars via maser measurements [6] and also measured in the central stars of some PNe [4]. Although their origin remains unknown so far – a dynamo effect resulting from an interaction between a slow rotating envelope and a fast rotating core has been proposed [1] – magnetic fields are now known to be present in the AGB and the post-AGB phase and we should not rule out this process as cause of the shaping.
2 The Polarimetric Observations

SCUBA polarimetric observations at 850\(\mu\)m realized by [3] suggest the presence of toroidal collimated magnetic fields in two carbon-rich objects, NGC 7027 and CRL 2688, as they show evidence for dust alignment. These toroidal fields would be required for the shaping. But the small number of polarization vectors made these results not conclusive enough to probe the presence of the fields and their action on the nebulae. We present here new 850\(\mu\)m and the first 450\(\mu\)m polarimetric observations of post-AGB stars also obtained with SCUBA. The linear polarization is measured as a percentage polarization, and a direction. The polarization is typically caused by the alignment of spinning dust grains, with their long axis perpendicular to the local magnetic field [2]. Thus, the measured angle of polarization is 90 degrees rotated with respect to the magnetic field. The degree of polarization does not give direct information on the strength of the magnetic field. We observed four targets: NGC 6537, CRL 2688, NGC 6302 and NGC 7027. Those observations were made in jiggle map observing mode at both wave-bands (450\(\mu\)m and 850\(\mu\)m). These data are unique as the instrument broke just after the observing run.

3 The Results

3.1 NGC 6537

NGC 6537 (Figure 1) is an oxygen-rich bipolar planetary nebula. The 850\(\mu\)m SCUBA map shows an elongation perpendicular to the outflow direction. The consistent orientation of the polarization vectors shows that the magnetic field (hereafter \(B\)) has a dominant direction along the equatorial plane (organized field), approximately perpendicular to the outflow direction. The dust alignment is therefore directed along the outflow. We can notice that the vectors do not cover all the nebula (they are located near the core) and also the absence of small polarization vectors toward the centre indicates that there is no change in geometry of \(B\) towards the core. This indicates a location some distance from the star (i.e. in a detached shell) [5]. Hence NGC 6537 presents a consistent toroidal magnetic field, located along its equatorial plane, in a circumstellar torus. We do not have strong evidence for the presence of magnetic fields in the lobes even if some vectors tend to curve in this direction.

3.2 NGC 7027

The young carbon-rich planetary nebula NGC 7027 (Figure 2) shows that at 450\(\mu\)m, polarization vectors cover all the nebula. The dominant direction of the magnetic field coincides with the equatorial plane. But the South-West part seems to be disturbed: the magnetic field may be “broken”. The degree of polarization is much reduced in the centre of the nebula and there is a lack of coherent direction there. This effect was also noted by [3] and may indicate that coherence is lost in the ionized region. Just like NGC 6537, NGC 7027 also present a toroidal magnetic field along the equatorial plane.
Fig. 1. 850\,\mu m SCUBA map of the Planetary Nebula NGC 6537. The polarization vector scale (showing the degree of polarization) is set at 40%.

3.3 CRL 2688

CRL 2688 (or Egg Nebula) (Figure 3) is a bright carbon-rich proto-planetary nebulae well known for its two pairs of searchlight beams. The 850-\mu m map shows an elongation of the PAGB in the direction of the polar outflows. The polarization vectors, which are in high number for this object, are localized all over the nebula. The field appears locally broken (North and South-West corners) and the degree of polarization strongly decreases near the centre. The lack of polarization in the centre suggests that the bright core is not polarised, or its polarization is averaged out over the JCMT resolution. But the most important aspect is the dual behavior of the magnetic field: on the eastern side of the NNE-SSW direction, the orientation of $B$ is mainly in the direction of the outflow, while on the western side, the magnetic field appears perpendicular to it. The 450-\mu m map (Fig. 3, bottom-right panel) shows the magnetic field at higher resolution, confirming the bimodal distribution. CRL 2688 presents a complex magnetic field structure with a poloidal and a toroidal field.
Fig. 2. 450µm SCUBA map of the Planetary Nebula NGC 7027. The polarization vector scale is set at 40%.

3.4 NGC 6302

NGC 6302 (Figure 4) is an oxygen-rich bipolar planetary nebula, whose polarimetric map obtained at 450µm shows only five polarization vectors. These vectors do not cover all the nebula but allow us to guess the presence of a consistent and organized magnetic field. The vectors do not line up with either the dark lane or the outflow. However, they are fairly well aligned with the ellipsoidal radio source in the centre of the nebula. The 450-µm polarization indicates that the magnetic field may be oriented in the direction of the inner outflow and then we cannot talk about toroidal magnetic field for this PN. We have no data for magnetic fields elsewhere in the outflows even at 850µm.

4 Discussion

The sub-millimeter data from SCUBA have shown the presence of magnetic fields via the presence of polarization in all our four targets. All but one (NGC 6302) present fields aligned with the polar directions and/or toroidal fields in the equatorial plane.
Fig. 3. 850µm (Top) and 450µm (Bottom) SCUBA maps of the PAGB CRL 2688. The polarization vector scale is set at 40%.
The alignment with the polar flow is interpreted as gas carrying the field with it. The polarization in all cases appears to be seen in the neutral molecular regions. A relation between $B$ and the physical properties of the PNe or PAGB can be possible. Looking at the chemistry of the nebulae we notice that the two oxygen-rich nebulae (NGC 6337 and NGC 6302) present collimated magnetic fields concentrated near the central star. We also have organized magnetic fields, resistant to distortion effects. The two carbon-rich nebulae (NGC 7027 and CRL 2688) show extended fields covering the entire nebula. Their magnetic fields are more disorganized than those of the two oxygen-rich nebulae. We can conclude regarding $B$ that there may be a dependence on the nature, geometry and size of the dust grains. The evolutionary stage of the nebulae could be taken into account. The nebulae of CRL 2688 (Post-AGB) and NGC 7027 (young PN) are younger than NGC 6337 (PN) and NGC 6302 (PN). It appears that older nebulae have better organized field than the younger ones. We believe first that magnetic fields are long lived and that toroidal magnetic fields are becoming dominant while the nebulae evolve. But this sample is too small to draw general conclusions and further studies are necessary.

5 Conclusion

We have presented the discovery of magnetic fields in four bipolar post-AGB stars namely NGC 6337, NGC 7027, NGC 6302 and CRL 2688. All objects show polarization indicative of grain alignment by magnetic fields which may suggest that
magnetic fields are not only common but also long lived in late type stars. Although the toroidal fields discovered can play an important role in the shaping of the nebulae, we suggest that, as the fields in AGB stars are dipole-like, the toroidal field structure appears later in the phase of evolution; in between, the equatorial field is wound up through the interaction with a companion. Hence the primary shaping agent would be a binary companion, the magnetic field action becoming more dynamically important later on.

References