Part III. Proto-planetary Nebulae

Detection of an inner torus in the protoplanetary nebulae OH231.8+4.2

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Abstract.
We performed the first VLBI observations of the SiO v=1 and v=2 J=1–0 masers in a Proto Planetary Nebula OH 231.8+4.2 (also known as the Rotten Egg nebula), at milliarcsecond resolution. Only the v=2 maser transition was detected. We detect several maser spots lying along a line which is almost perpendicular to the axis of symmetry of the Nebula. We find that all the emission is concentrated in an area of $\sim$ 10 mas, indicating that the SiO masers are originated very close to the surface of the star. One of the two emission areas presents an elongated structure with a clear velocity gradient. The detected emission is consistent with a torus, or disk, in rotation with a velocity of $\sim$6 km/s and with an infall velocity of $\sim$ 10 km/s.

1. Introduction

The evolution of the envelopes around AGB stars toward Planetary Nebulae (PNe), through the stage of Proto Planetary Nebulae (PPNe) is still yet poorly known. Contrarily to AGB envelopes that show a spherical symmetry, Planetary and Proto Planetary Nebulae present a conspicuous axial symmetry and very collimated jets. To explain their evolution several models (see Mellema 1995, Soker 1998a,b, and references therein) have postulated the presence of a dense ring or disk close to the central post-AGB object. Such a disk would have a double effect, on the one hand produces a mechanical collimation of the ejections, and on the other hand allows a mechanism for the accretion of material by the star.

The most popular of these models assume the presence of a dense disk or ring, very close to the star, that would collimate the stellar wind in the direction perpendicular to the disk plane. Other models also assume a central disk, but related to the accretion of circumstellar material by the star, either by providing an orbiting, long-lived reservoir of matter or/and acting as an accretion disk. In this case, the fast bipolar jets appear by interaction of the infalling material with the stellar magnetic field (a process similar to that explaining the outflows in forming stars). These theories both explain the very collimated post-AGB jets and the axial symmetry of PPNe. Moreover, accretion of circumstellar material explains the peculiar abundances found in the atmospheres of certain post-AGB stars, that would be affected by the composition of the reaccreted material (e.g.

Van Winckel et al. 1995), and the very high energy and momentum of the bipolar outflows in PPNe, that cannot be explained by radiation pressure and seem to require a release of gravitational energy (Bujarrabal et al. 1998).

Existing observations reveal the presence of central disks in several PPNe, but their spatial resolution only allows the study of extended regions, compared to the very inner regions of the disks that are relevant for the above processes. Fortunately, SiO masers are detected in one of the PPNe, OH231.8+4.2 (see Nyman et al. 1998), allowing VLBI observations of the close surroundings of the star.

OH 231.8+4.2 is a very well studied PPNe (see Sánchez Contreras et al. 1997, 2000), less than 1200 years old. It is situated at a distance of $\sim$ 1500 pc and its luminosity is $\sim 10^4 L_\odot$. It is composed, as far as we know, by at least one evolved star surrounded by a remarkable bipolar nebula. The symetry axis of the nebula, at P.A. = 21°, is inclined 36 ^{o} with respect to the plane of the sky (the North lobe is pointing toward us). The central core is a cold star (M9 III, $\sim 2000^o$ K) with a stellar radius of about 4.5 A.U deduced from its brightness temperature. Among the different PPNe known, it is one of the only one showing SiO maser emission allowing line VLBI observation at sub milliarcsecond resolution.

2. Observations and discussion

We performed observations of the v=1 and v=2 J=1–0 lines of SiO at 43.122080 and 42.820587 GHz with the NRAO Very Long Baseline Array in May 2000. The system was setup to record 4MHz of left and right circular polarizations in both lines. The correlation was produced at the VLBA correlator in Socorro (NM, USA) providing 128 spectral channels of the parallel and cross-hand polarization bands, achieving a spectral resolution of 0.22 km/s, and giving access to the four Stokes parameters and hence the linear polarization.

The data have been analyzed using the AIPS package in the standard way. Only maps of the v=2 line have been produced as the v=1 line was not detected (The v=2 line is known to be slightly stronger see Jewell et al. 1991, Nyman et al. 1998).

In Figure 1, Top part, we show the integrated flux map of the v=2 J=1–0 line of SiO. The resolution beam of our observation is 0.6 by 0.16 mas (PA –15°) and the noise level in the map is less than 50 mJy. The integrated peak flux is 35 Jy/beam. We map a square region of about 50 mas but we found that all the emission was concentrated in a small area of only few mas (up to 10 mas). The blue circle drawn on the map represent the diameter, at the map scale, of the central Mira variable star ($\sim$ 9 A.U.), and the red lines represent the symmetry axis of the bipolar Nebula in the plane of the sky.

All the detected emission arises from two regions. That in the western part of the map shows two strong components, while on the eastern side of the map a linear structure roughly orientate South-West to North-East. The whole emission is lying on a direction perpendicular to the symmetry axis of the Nebula. Another important geometrical remark is that the separation between the two emission structures is about 10 A.U. Considering the star's diameter,

this means that the detected emission is originated very close to the star, nearly at its surface.

The velocity analysis of our data shows the presence of a clear velocity gradient (Fig. 1, bottom): The projected velocity ranges from 43 km/s in the Southern spot down to 39 km/s in the extreme Eastern part. The other emission region in the West does not show any velocity structure. Both emission spots appear at a fixed position and present a broad line width of nearly 2 km/s.

The analysis and interpretation of the observed velocities are not trivial. In the case of a disk in a pure Keplerian rotation we would expect to observe the highest velocities on one edge of the detected torus/disk and to observe velocities close to systemic velocity on the line of sight of the center of the torus/disk. In our observations, we observed exactly the opposite behavior, with the redest velocities close to the line of sight of the center.

To explain this, we have postulated that the systemic velocity is combined with an infalling velocity. From our observations, we deduced that the needed infall velocity must be of the order of 10 km/s. The fact that the Western (eastern) side of the detected torus/disk is red (blue) shifted with respect to the systemic velocity of the source (~ 33 km/s)indicates that the disk is rotating clockwise. The rotation velocity can be extracted from the velocities observed on the edges of the structures. As the disk (or torus) might be bigger than the region emiting SiO masers this velocity can be only a lower limit. From the red shifted emission, we concluded that the rotation velocity is at least 6 km/s. The systemic velocity was deduced from single dish observations of the 12CO and 13CO transitions J=1-0 and J=2-1, and thermal SiO emission, and then confirmed by this observation.

Applying these previous observational values to a very simplistic model considering a disk in rotation and infall, and having an inclination of 36° with the plane of the sky, we have been able to fit quite well our observations and to reproduce well the velocity gradient of the elongated structure.

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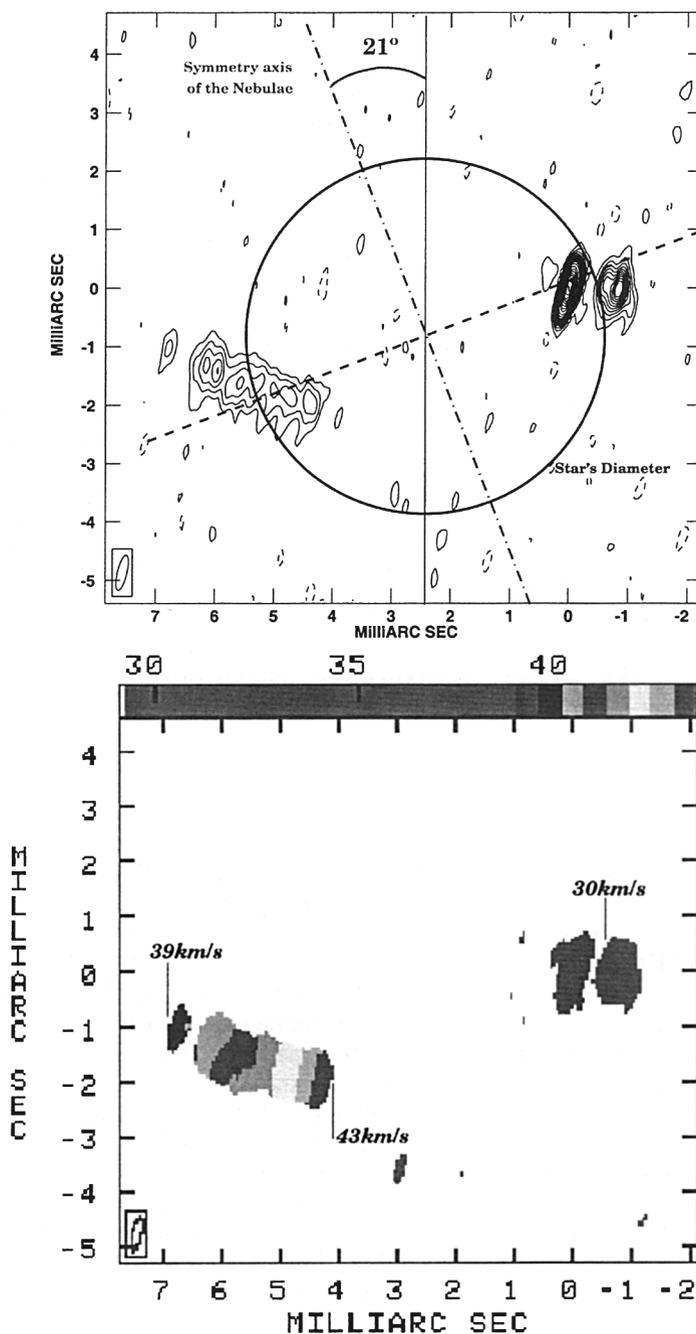Van Winckel H., Waelkens C.,& Waters L.B.F.M. 1995, A&A 193, L25

Figure 1.   Top, the integrated flux map of OH 231.8+4.2 for v=2 J=1–0 SiO maser transition. Bottom, the integrated velocity map showing the linear velocity gradient in the Eastern component. The systemic velocity of the source is 33km/s.