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OH maser emission toward the young planetary nebula K3-35

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Abstract. K 3-35 is one of the two planetary nebulae (PNe) where water maser emission has been detected, suggesting that these kind of objets departed from the AGB phase some decades ago. We present VLA (Very Large Array) observations of the 1720, 1667, 1665 and 1612 MHz OH maser emission from the central region of K 3-35. Circular polarization was found in the 1720, 1665, and 1612 MHz transitions. It is the only PN that we know exhibits OH 1720 MHz and the spots are located near the radio continuum peak position. The OH 1665 MHz spots are distributed in an elongated structure, along the minor axis of the radio continuum bipolar outflow, and they exhibit high circular polarization suggesting the presence of a toroidal magnetic field in K 3-35. An estimate of the magnitude of the magnetic field, derived from the 1665 lines, toward this young planetary nebula is ~ 0.14 mG at a radius of ~ 250 AU.

Key words. Stars: abundances – Stars: polarization – Stars: Planetary Nebulae – circumstellar matter – Stars: individual: K 3-35 – radio lines: stars

1. Introduction

K 3-35 (IRAS 19255+2123) is an extremely young planetary nebula in which we are observing the first stages of formation of collimated bipolar outflows. Its radio continuum emission at 3.6 cm exhibits an "S" shape with an extension of 2″ which is equivalent to 10,000 AU (assuming a distance of 5 kpc ; Zhang 1995). It is one of the two PNe known to have water maser emission (Miranda et al. 2001; De Gregorio-Monsalvo et al. 2004). The water maser spots, toward K 3-35, are at the center of the nebula, along the minor axis, at a radius of ~85 AU and also at the surprisingly large distance of 5000 AU from the star, at the tips of the jets (Miranda et al. 2001).

OH maser emission typical for oxygen-rich AGB envelopes, has been observed to trace bipolar outflow regions in several AGB stars (e.g. Gómez & Rodríguez, 1999; Imai et

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al. 2002). The OH maser lines can be polarized in presence of a magnetic field. The detection of magnetized disks toward PNe and proto-planetary nebula is crucial for understanding the generation of jets and bipolar structures. There are several models where the presence of toroidal magnetic fields have been invoked to explain bipolar planetary nebula (e.g. Rozyczka & Franco 1996; García-Segura 1997; Matt et al. 2000; Blackman et al. 2001).

Previous OH maser observations, made toward the young planetary nebula K 3-35 by Miranda et al. (2001), shown circularly polarized OH maser emission in the 1665 MHz line around the central region, with strong levels of circular polarization up to ≃50%, suggesting the presence of a magnetic field. The 1665 maser spots are distributed toward the central star in a band perpendicular to the outflow (Miranda et al. 2001). The OH 1667 MHz maser emission toward K 3-35 did not show circular polarization and the maser spots are distributed in two regions at the NE and at the SW along the major axis of the outflow (Figure 1).

The presence of magnetic fields have also been inferred in several proto-planetary nebulae (Zijlstra et al. 1989; Kemball & Diamond 1997; Vlemmings et al. 2002; Bains et al. 2003) but only toward a few PNe (Miranda et al. 2001, Greaves 2002; Jordan et al. 2005). The magnitude of the magnetic fields detected in envelopes of evolved objets goes from 1 G at a radius of r∼1 AU, to 10^{-4}G at r∼1000 AU and of the order of kG from the central stars of planetary nebula.

In this work we present new VLA data observations with higher spectral resolution from the OH maser emission in its four transitions (1720, 1667, 1665 and 1612 MHz) toward K 3-35 to be able to estimate the magnitude of the magnetic field with good accuracy.

2. VLA observations

We observed the OH maser emission toward K 3-35 at 1612, 1665, 1667 and 1720 MHz with the Very Large Array (VLA) of the NRAO in the A configuration on 2002 March 31. The calibration, imaging, and deconvolution of the data were carried out using the Astronomical Image Processing System (AIPS) of the NRAO. The spectral resolution after hanning-smoothing the data were ∼ 0.3 km s^{-1} for the 1667, 1665 MHz transitions and 1 km s^{-1} for the 1612, 1720 MHz observations. The detail description of the observations will appear in Gómez et al. (2005).

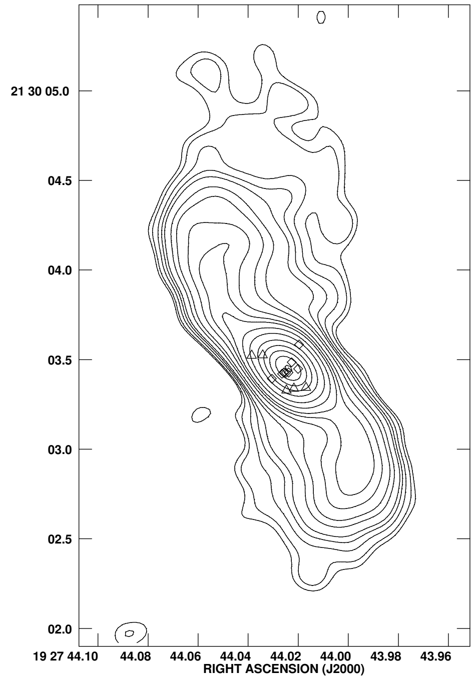

Fig. 1. OH 1665 (diamonds) and 1667 MHz (triangles) maser spots superposed on the 3.6 radio continuum image of K 3-35. The contours of the 3.6 continuum emission are −3, 3, 4, 6, 8, 10, 15, 20, 30, 40, 50, 70, 100, 150, 200, 250, 300 and 350 times 0.036 mJy beam^{-1}, the *rms* noise of the map and the sintesized beam is 0.″2 (Miranda et al. 2001; Gómez et al. 2003).

3. Results and Discussion

We detected the 1612, 1720, 1667 and 1665 MHz maser emission toward K3-35. Figures 2, 3, 4 and 5 show the 1720, 1667, 1665 and 1612 MHz velocity profiles of the integrated flux, or Stokes I (I=[I_{RCP} + I_{LCP}]/2), the left (I_{LCP}) and right (I_{RCP}) circular polarization emission and

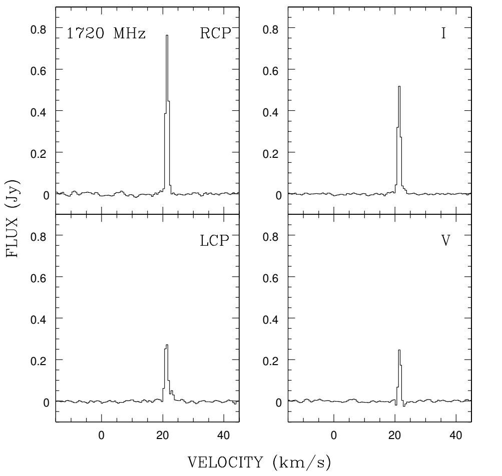

Fig. 2. The OH 1720 MHz spectra of the Stokes parameters I and V and the plots of the right (RCP) and left (LCP) circular polarizations.

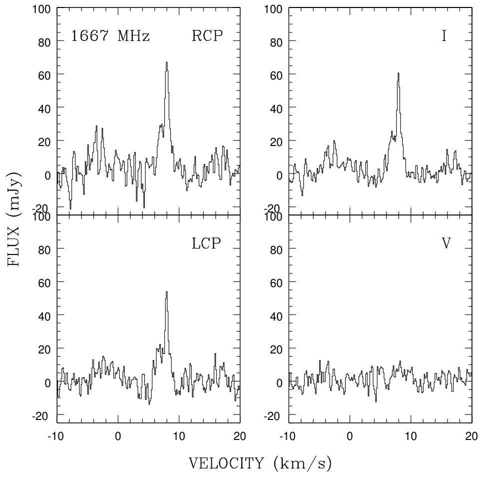

Fig. 3. The OH 1667 MHz spectra of the Stokes parameters I and V and the plots of the right (RCP) and left (LCP) circular polarizations.

the difference, or Stokes V spectrum, (V=[I_{RCP} - I_{LCP}]/2). The total intensity velocity profiles (Stokes I), for the four OH maser transitions, show emission in the velocity range from −5 to 23 km s^{-1}. After comparison with previous single dish observations (Engels et al. 1985; Te Lintel Hekkert 1991) we note that the total flux density for the 1612 MHz lines have decreased in ~35% in the last 20 years.

The 1720 MHz maser transition was first reported by Te Lintel Hekkert (1991), when K 3-35 was not considered as an evolved star, a single feature was found with a peak flux of ~4 Jy. In this work we observe that the peak flux decrease to 0.5 Jy and in both epochs the central velocity is around 21 km s^{-1}. Until now, K3-35 is the only one planetary nebula with detected OH 1720 MHz maser emission. The 1720 MHz masers are commonly observed in star forming regions and supernova remnants tracing shock molecular regions. It has been also observed toward a few proto planetary nebula (Deacon, Chapman & Green 2004).

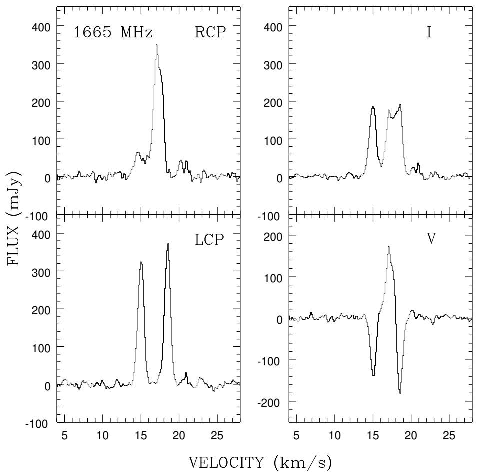

Fig. 4. The OH 1665 MHz spectra of the Stokes parameters I and V and the plots of the right (RCP) and left (LCP) circular polarizations.

3.1. Equatorial magnetic field in K 3-35?

The 1665 MHz maser spots seem to be distributed along the equator, tracing a band perpendicular to the outflow. Figure 6 show the OH 1665 LCP maser velocities plotted against the displacement from the center of the masers

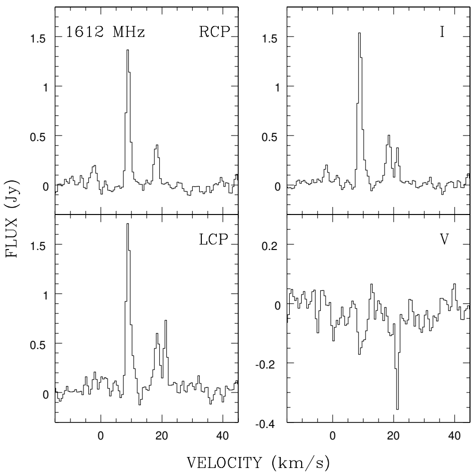

Fig. 5. The OH 1612 MHz spectra of the Stokes parameters I and V and the plots of the right (RCP) and left (LCP) circular polarizations.

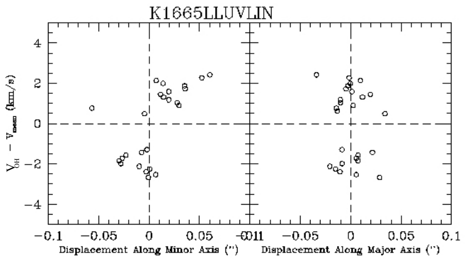

Fig. 6. OH 1665 MHz maser velocity plotted against the displacement along the minor axis of the outflow at a position angle of −45° (left) and along the major axis at a position angle of 45° (right).

along the minor axis, at a position angle of −45°. The distribution of the masers is in two groups which are blueshifted to the southeast and redshifted to the northwest, suggesting rotation. Assuming that we have a rotating torus-like structure with a radius of ~0.05 arcseconds, equivalent to ~4× 10^{15} cm, and with a rotation velocity of ~2 km s^{-1}, we obtain a virial mass for K 3-35 of ~ 1 $M_{\odot}$.

No complete Zeeman pattern was clearly detected, it could be due to velocity and magnetic field gradients effects. If at least one Zeeman pair is present in K 3-35, we can estimate the magnetic field for the 1665 MHz ob-

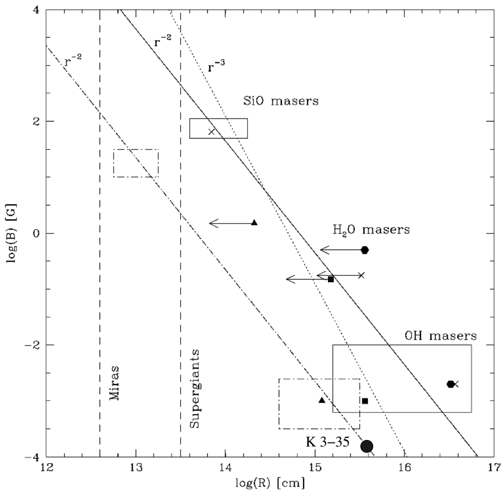

Fig. 7. Magnetic field strength, B, as a function of distance, R, from the center of the star taken from Vlemmings et al. (2002).

servations to be B_{LOS} ≃0.14 mG. This value is in agreement with the magnetic fields derived from OH polarization observations toward proto-planetary nebula. A comparison between the magnetic field estimates toward evolved stars as function of distance from the star has been made by Vlemmings et al. (2002), plotting a couple of models: solar-type (α=-2, $B \propto r^{\alpha}$) and for a dipole medium (α=-3). Figure 7 shows this plot taken from Vlemmings et al. (2002) where we superpose on the value for K 3-35. The strength of the magnetic field in K 3-35 is in agreement with a solar type but more observations are needed to confirm this result.

4. Conclusions

The study of circular polarization in OH maser lines is very useful to estimate the kinematics an magnetic fields in young planetary nebula. Using the VLA we imaged the 1720, 1667, 1665 and 1612 MHz masers toward K 3-35. This young planetary nebula is the only one that shows the 1720 MHz transition. The 1665 MHz line is probably in a rotating torus-like structure with a radius of ~4×10^{15} cm (~250 AU) that exhibits strong circular polarization, supporting the presence of an equatorial magnetic field of ~0.14 mG in K 3-35.

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