RevMexAA (Serie de Conferencias), **26**, 22–23 (2006)

OH MASER EMISSION TOWARD THE YOUNG PLANETARY NEBULA K3-35

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RESUMEN

K3-35 es una de las dos nebulosas planetarias (PNe) donde se ha reportado emisión máser de agua, sugiriendo que este tipo de objetos dejaron hace apenas unas décadas la fase AGB. Presentamos observaciones hechas con el VLA (Very Large Array) de la emisión máser de OH a 1720, 1667, 1665 y 1612 MHz hacia la región central de K 3-35. Los máseres de OH 1665 MHz están distribuidos en una estructura a lo largo del eje menor del flujo bipolar de radiocontinuo, y exhiben alta polarización circular, sugiriendo la presencia de un campo magnético toroidal. Una estimación de la magnitud del campo magnético hacia esta nebulosa planetaria joven, derivado de la línea 1665, es $\sim$ 0.14 mG a un radio de $\sim$ 250 AU.

ABSTRACT

K 3-35 is one of the two planetary nebulae (PNe) where water maser emission has been reported, suggesting that these kind of objets departed from the AGB phase only 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. The OH 1665 MHz maser 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 line, toward this young planetary nebula is $\sim$ 0.14 mG at a radius of $\sim$ 250 AU.

Key Words: **PLANETARY NEBULAE — PLANETARY NEBULAE: INDIVIDUAL: K 3-35 — POLARIZATION**

1. INTRODUCTION

OH maser emission typical for oxygen-rich AGB envelopes, has been observed to trace bipolar outflows in several AGB stars (e.g. Gómez & Rodríguez, 1999; Imai et 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), show circularly polarized OH maser emission in the 1665 MHz line around the central region, with strong levels of circular polarization up to $\simeq$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 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 objects goes from 1 G at a radius of r$\sim$1 AU, to 10^{-4}G at r$\sim$1000 AU and of the order of kG from the central stars of planetary nebula.

In this work we summarize the results of new VLA observations made with higher spectral resolution from the OH maser emission in its four ground state 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 (Gómez et al. 2006).

2. RESULTS AND DISCUSSION

Observations of the four OH maser transitions (1720, 1667, 1665 and 1612 MHz) where made with the Very Large Array (VLA) of the NRAO in the

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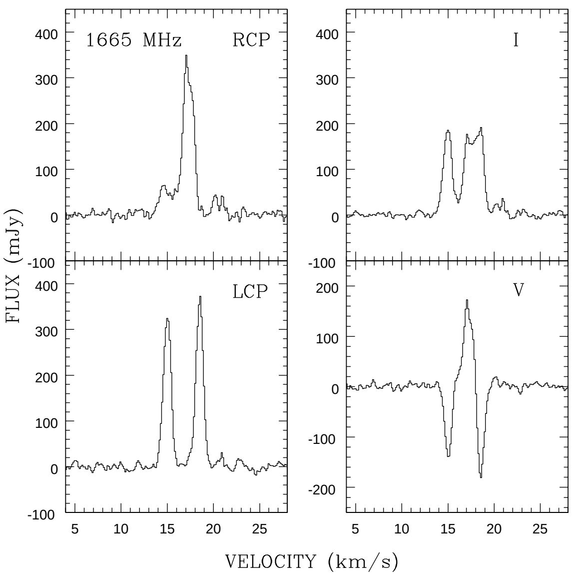

Fig. 1. The OH 1665 MHz spectra of the Stokes parameters I and V and the plots of the right (RCP) and left (LCP) circular polarizations.

A configuration on 2002 March 31. The calibration was made using the standard procedures. We detected the 1720, 1667, 1665 and 1612 MHz maser emission toward K3-35. Figure 1 shows the 1665 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 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 that extends from -5 to 23 km s^{-1}.

The 1665 MHz maser spots seem to be distributed along the equator, tracing a band perpendicular to the outflow. Figure 2 shows the OH 1665 LCP maser velocities plotted against the displacement from the center of the masers 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 $\sim$0.05 arcseconds, equivalent to $\sim 4\times 10^{15}$ cm, and with a rotation velocity of $\sim$2 km s^{-1}, we obtain a virial mass for K 3-35 of $\sim$ 1 $M_\odot$.

If at least one Zeeman pair is present in K 3-35 (see Figure 1), we can estimate the magnetic field for the 1665 MHz observations to be $B_{LOS} \simeq 0.14$ mG.

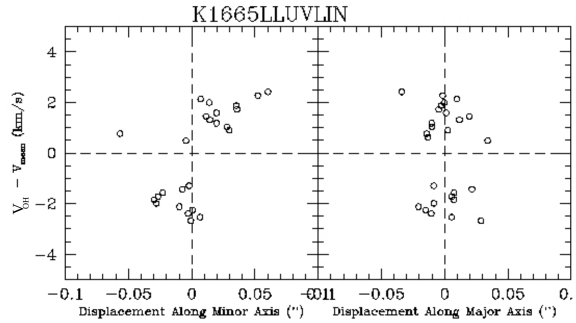

Fig. 2. OH 1665 MHz maser velocity plotted against the displacement along the minor axis of the outflow at a position angle of $-45°$ (left) and along the major axis at a position angle of 45° (right).

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). The strength of the magnetic field in K 3-35 is in agreement with a solar type star.

YG, DT and RF-H acknowledge financial support from DGAPA-UNAM and CONACyT, México.

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