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Water and OH Maser Emission from the Planetary Nebula K3-35

Yolanda Gómez

Instituto de Astronomía, UNAM-Morelia, Apdo. Postal 3-72 (Xangari), 58089 Morelia, Michoacán, México

Luis F. Miranda

Instituto de Astrofísica de Andalucía, CSIC, Apdo. Correos 3004, E-18080 Granada, Spain

Guillem Anglada

Instituto de Astrofísica de Andalucía, CSIC, Apdo. Correos 3004, E-18080 Granada, Spain, and Harvard-Smithsonian CfA, 60 Garden Street, Cambridge, MA 02138, USA

José M. Torrelles

Institut d'Estudis Espacials de Catalunya (IEEC/CSIC) and Instituto de Ciencias del Espacio (CSIC), Edifici Nexus, C/ Gran Capità 2-4, E-08034 Barcelona, Spain

Abstract. Water-vapour masers, typical of the envelopes in giant stars, are not expected to persist in planetary nebulae due to the ultraviolet radiation of the remnant star that progressively destroys the molecules. Recently, we have reported the first unambiguous detection of water maser emission in a planetary nebula, K 3-35 (Miranda et al. 2001). The water masers in K3-35 were detected 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 bipolar lobes. The existence of these water molecules is puzzling, and probably we are observing the very moment of transformation of a giant star into a planetary nebula. Miranda et al. (2001) also report the presence of polarization in the OH 1665 MHz masers, which are distributed towards the central star in a torus-like structure. Here we review the main results on this source.

1. Introduction

K 3-35 is an emission nebula that has been studied at optical, radio and infrared wavelengths. At radio and optical wavelengths it is characterized by an S-shaped emission morphology with a clear point-symmetric structure that attracted the attention of several authors (Aaquist & Kwok 1989; Aaquist 1993; Miranda et al. 2000; 2001). Point-symmetric morphologies have been observed in many planetary nebulae (Guerrero et al. 1999; López 2002). There was

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some controversy in the past about the nature of K3-35 (YSO vs. PN), since it appears projected towards the molecular cloud L 755. However, the currently available data (Miranda et al. 2000; 2001, and references therein) strongly support the classification of K3-35 as a PN. A summary of the observational data that strongly supports the PN classification are: the presence of strong He^+ emission at 4686Å, strong [NII] 6548 and 6583Å emission lines ([NII]/$H_\alpha \simeq 5$), the presence of [ArIV] and [OIII] emission lines ([OIII]/$H_\beta \simeq 30$), the location of K3-35 in the region occupied by OH/IR stars and PNe in the IRAS two-colour diagram, the OH maser emission from K3-35 is type II (typical in evolved stars). The sensitive observations of Dayal & Bieging (1996) reveal that the CO lines present two velocity components, a narrow component associated with the L755 cloud and a broader component apparently associated with K3-35.

Engels et al. (1985), through single-dish observations, detected water maser emission towards a position close to that of K3-35, but with their angular resolution ($\simeq$40″) it was not possible to establish whether this emission originates from K3-35 itself or from a YSO associated with the background molecular cloud L755. Also, the nature of K3-35 itself was unclear at that time, and an interpretation in terms of an HII region was favored. Water masers, typical of giant envelopes, were not expected in a PN because water molecules are rapidly destroyed when photoionization begins (Lewis 1989; Gómez, et al. 1990). In order to investigate the association of the water masers with K3-35, we carried out high angular resolution observations using the Very Large Array (VLA) of NRAO[8] in the A configuration. A detailed description of the observations and the main results obtained have been presented in Miranda et al. (2001).

2. Results and Discussion

We detect towards K 3-35 four active water maser regions located at very significant positions (see Figure 1; left, Table 1). A group of masers are located towards the core of the nebula, tracing the inner regions of a disk-like structure, while the rest are at the tips of the bipolar lobes, at a considerable distance of ~5000 UA from the central star (assuming a distance of 5 kpc to the nebula; Zhang 1995). This is the first object in the sky where water masers are detected at the tips of the precessing jets, which we believe are involved in the excitation mechanism. The water masers appear at an LSR velocity range from 20 to 40 km s^{-1}, and the strongest maser feature is located at the center of the nebula.

The OH 1665 and 1667 MHz masers were detected towards the bright core of K3-35 (see Figure 1; right, Table 2) confirming the association with the nebula. The 1665 MHz masers are distributed in a band perpendicular to the outflow with a radius $\simeq$630 AU, suggesting a torus-like structure. The 1667 MHz masers are located in two main groups, each displaced $\simeq$800 AU from the center, oriented along the outflow direction. Strong levels of circular polarization are present in the 1665 MHz line, suggesting the presence of a magnetic field of order of mG. It is the first time that a magnetic field is found in a torus-like structure, as required by some theoretical models (Rozyczka & Franco 1996; García-Segura 1997).

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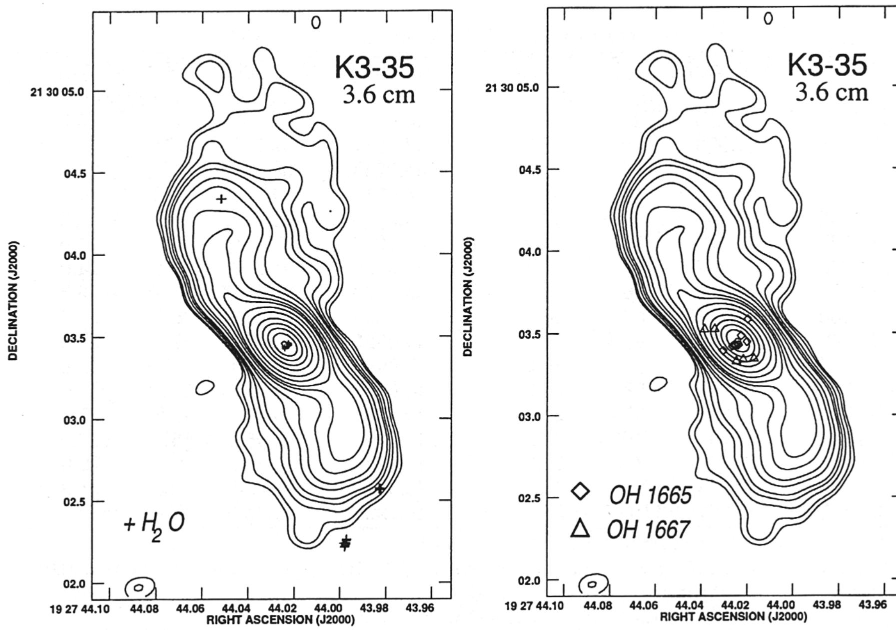

Figure 1. VLA 3.6-cm continuum contour map of K3-35 (beam size is 0.″2). Positions of the H_2O (left; crosses), OH 1665 (right; diamonds), and OH 1667 (right; triangles) maser spots are indicated. The LSR velocities and fluxes of the maser spots are given in Tables 1 and 2. The contours of the 3.6 continuum 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 (Miranda et al. 2001).

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Table 1. Parameters of the H_2O Masers in K 3-35[a]

α(J2000)[b] (s)	δ(J2000)[b] ($''$)	S_ν (mJy)	V^c_{LSR} (km s^{-1})	α(J2000)[b] (s)	δ(J2000)[b] ($''$)	S_ν (mJy)	V^c_{LSR} (km s^{-1})
43.9821	02.573	21	36.5	44.0517	04.339	64	25.3
43.9825	02.573	70	35.8	43.9971	02.266	121	24.6
43.9826	02.574	75	35.1	44.0243	03.439	23	24.6
43.9828	02.575	26	34.5	44.0519	04.338	298	24.6
43.9825	02.573	33	32.5	43.9970	02.264	96	24.0
43.9827	02.570	56	31.9	44.0242	03.428	61	24.0
43.9830	02.567	32	31.2	44.0520	04.337	795	24.0
43.9977	02.224	16	31.2	43.9970	02.260	57	23.3
43.9980	02.217	33	30.5	44.0225	03.446	218	23.3
43.9978	02.222	44	29.9	44.0521	04.337	1196	23.3
43.9975	02.233	55	29.2	43.9983	02.239	15	22.6
43.9975	02.234	59	28.6	44.0223	03.452	1010	22.6
43.9975	02.238	67	27.9	44.0521	04.337	822	22.6
43.9973	02.245	107	27.2	44.0224	03.453	1572	22.0
43.9973	02.255	163	26.6	44.0521	04.336	175	22.0
43.9972	02.264	221	25.9	44.0225	03.456	945	21.3
43.9971	02.267	193	25.3	44.0226	03.463	201	20.7

[a] As observed on September 6, 1999.
[b] Right ascension is 19^h 27^m and declination is +21° 30′. Relative positional errors are 0.″001. Uncertainty in the absolute coordinates is 0.″05.
[c] Velocity at the center of the channel (channel width is 0.6 km s^{-1}).

Table 2. Parameters of the OH masers in K 3-35[a]

OH 1665				OH 1667			
α(J2000)[b] (s)	δ(J2000)[b] ($''$)	S_ν (mJy)	V^c_{LSR} (km s^{-1})	α(J2000)[b] (s)	δ(J2000)[b] ($''$)	S_ν (mJy)	V^c_{LSR} (km s^{-1})
44.0226	03.485	14	22.2	44.0169	03.343	16	9.0
44.0197	03.584	13	21.1	44.0218	03.339	38	7.9
44.0201	03.449	40	20.0	44.0247	03.329	30	6.8
44.0239	03.428	121	18.9	44.0386	03.523	13	−1.9
44.0249	03.427	144	17.8	44.0342	03.524	17	−3.0
44.0257	03.429	98	16.7				
44.0256	03.427	107	15.6				
44.0265	03.421	106	14.1				
44.0306	03.393	39	13.4				

[a] As observed on September 6, 1999.
[b] Right ascension is 19^h 27^m and declination is +21° 30′. Relative positional errors are 0.″01 for the 1665 MHz data and 0.″05 for the 1667 data. Uncertainty in the absolute coordinates is 0.″05.
[c] Velocity at the center of the channel (channel width is 1.1 km s^{-1}).

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