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RADIO CONTINUUM AND H I OBSERVATIONS OF THE REMARKABLE PLANETARY NEBULA KJPN 8

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RESUMEN

Presentamos observaciones de radiocontinuo, con resolución angular del orden de un segundo de arco, hechas con el Very Large Array (VLA) hacia el centro de KjPn 8. Las observaciones se realizaron en tres épocas a lo largo de un período de 2.8 años. La apariencia de la nebulosa planetaria parece haber sufrido cambios, que tentativamente atribuímos a iluminación variable proveniente del núcleo. También presentamos observaciones de hidrógeno atómico hacia esta fuente hechas con el VLA con resolución angular del orden de 40″. Detectamos emisión asociada con esta nebulosa planetaria que sugiere la presencia de una masa del orden de 0.07 $M_\odot$ de hidrógeno atómico en la envolvente.

ABSTRACT

We present Very Large Array (VLA) continuum observations of the core of KjPn 8 made with arc second angular resolution and taken at three epochs over a period of 2.8 years. The radio appearance of the planetary nebula seems to have experienced changes, tentatively attributed to variable illumination coming from the nucleus. We also present VLA observations of atomic hydrogen toward this source, made with an angular resolution of about 40″. We detect associated emission that suggests the presence of a mass of atomic hydrogen of order 0.07 $M_\odot$ in the envelope.

Key words: **ISM: RADIO SOURCES — PLANETARY NEBULAE: INDIVIDUAL (KJPN 8) — RADIO CONTINUUM: ISM**

1. INTRODUCTION

The bipolar planetary nebula (PN) KjPn 8, with its 14′ × 4′ filamentary lobes, yet only ∼ 4″ diameter bright core, is possibly the most extraordinary one of this type yet discovered at optical wavelengths (López, Vázquez, & Rodríguez 1995). The simultaneous presence of an old, evolved structure traced by the bipolar lobes and of a compact bipolar jet system of very different orientation has made López et al. (2000) propose that we may be witnessing two distict planetary nebulae events, probably coming from a binary system. The large bipolar envelope is oriented at a PA ≈ 71° and the system of compact high-velocity bipolar jets at PA ≈ 126°. The giant bipolar envelope of KjPn 8 has been recently modeled by Steffen & López (1998) via analytic and hydrodynamic numerical simulations involving the action of a collimated, episodic jet driving into the ISM.

The physical conditions of the optical core have been derived from spectrophotometric observations by Vázquez, Kingsburgh, & López (1998), who find a low excitation core with ionic abundances corresponding to extreme type I PNe.

Huggins et al. (1997) and Forveille et al. (1998) have recently reported the detection of a massive, optically thick CO $J = 1 - 0$ disk around the core of KjPn 8. This CO molecular disk is 30″ in diameter and is expanding at $\sim$ 7 km s^{-1}. The axis of the disk is aligned with the compact high-velocity bipolar jets. The results of Huggins et al. (1997) and Forveille et al. (1998), suggest the presence of H_2 emission in the core of KjPn 8.

Indeed, a remarkable ring of excited H_2, 8″ in diameter, contained within the CO structure and sharing the same orientation has recently been detected by López et al. (1999). Furthermore, the NIR J, H, and K bands reveal a clumpy, extended core, in agreement with previous (López et al. 1997) VLA-B observations of the radio continuum, that traces the ionized gas.

In this paper we present new VLA observations made at 3.6 and 6-cm of the ionized core searching for possible variations in the appearance of this source. Since both ionized and molecular components have been found in KjPn 8, we also present sensitive observations of the H I line at 21-cm made with the goal of detecting a possible neutral component.

2. OBSERVATIONS

The 3.6 and 6-cm continuum as well as the H I line observations were made using the Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO).[1] The data were edited and calibrated using the software package Astronomical Image Processing System (AIPS) of NRAO. A distance of 1600 ± 230 pc (Meaburn 1997) to KjPn 8 will be adopted throughout this paper.

2.1. *Continuum Observations*

For all continuum observations an effective bandwidth of 100 MHz with two circular polarizations was employed. We obtained 3.6-cm observations in the B configuration during 1995 October 17 and 1998 July 17, and 6-cm observations in the A configuration during 1997 January 6. The on-source integration times of these observations were 3.2 (1995 October 17), 3.7 (1997 January 6), and 3.7 hours (1998 July 17). For maps made with natural weight and a Gaussian tapering of 220 kλ to the (u,v) data, we obtained maps for all three data sets with angular resolution of $\sim$ 0.″9. The flux densities observed for KjPn 8 are 1.3 ± 0.1, 1.0 ± 0.1, and 1.3 ± 0.1 mJy for the 1995, 1997, and 1998 data, respectively. To allow a more direct comparison between the maps at the three epochs, we restored them with a Gaussian beam having a full width at half-power of 0.″9. The three maps are shown in Figure 1.

Although all three maps show a source with an angular extent of about 4″, there appear to be significant differences between them, suggesting temporal variation of the structure. In particular, since the maps are separated in time by similar amounts (1.2 years between the 1995 and the 1997 maps and 1.5 years between the 1997 and 1998 maps), there is a vague impression of clockwise "rotation" of the major axis of the structure (see Fig. 1).

Can these variations result from the expansion of the planetary nebula? Since the ionized gas is believed to be expanding at a velocity of about 16 km s^{-1} (López et al. 2000), over the period of 2.8 years separating our observations we would expect motions of order $\sim 10^{14}$ cm. At a distance of 1.6 kpc (Meaburn 1997), these physical motions would correspond to only $\sim$ 0.″006, that would be undetectable for our angular resolution of 0.″9.

An alternative explanation could be provided if the ionization of the ring is changing with time, probably as the result of a time-variable radiation field.

For these proposed ionization changes to take place, it is needed that the recombination time of the gas does not exceed a few years. This requirement translates in electron densities above $\sim 4 \times 10^4$ cm^{-3}. If we assume that the observed flux densities are coming from a homogeneous source with an angular diameter at half maximum of $\sim$2″, an electron density of $\sim 2 \times 10^3$ cm^{-3} is derived. However, as it is obvious from Fig. 1 and in particular from the HST images of López et al. (2000), the emission is arising from much smaller solid angles, probably the inner ionized walls of the molecular ring mapped in CO by Huggins et al. (1997) and Forveille et al. (1998) and in H_2 by López et al. (1999). If we assume that all the radio continuum emission is coming from the two main emission regions (with dimensions of about 1.″0 × 0.″1) in the HST maps of López et al. (2000), we derive electron densities of $\sim 3 \times 10^4$ cm^{-3}, comparable with the required values. The rapid time variability of the ionized wind of the luminous blue variable star P Cygni has also been attributed to a very clumpy medium (Skinner et al. 1997).

What could be causing the time-variable ionizing field? The star at the core of KjPn 8 is most probably not a normal planetary nebula nucleus. López et al. (2000) have argued that, in addition to the star detected with the HST, a second object could be present at the center. The presence of a warped, compact disk in one of the stars could explain a variable illumination pattern ionizing the inner part of the large scale neutral disk. Other possible illumination effects have been discussed by Stapelfeldt et al. (1999) to explain a time-variable asymmetry observed in the accretion disk associated with the young object HH 30. Miranda & Torrelles (1998) have found morphological changes over a period of 1.3 years in the extremely young, double-shell planetary nebula IC 4997, attributing them to the presence of a time-variable, highly collimated flow impinging on the outer shell.

[1] NRAO is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

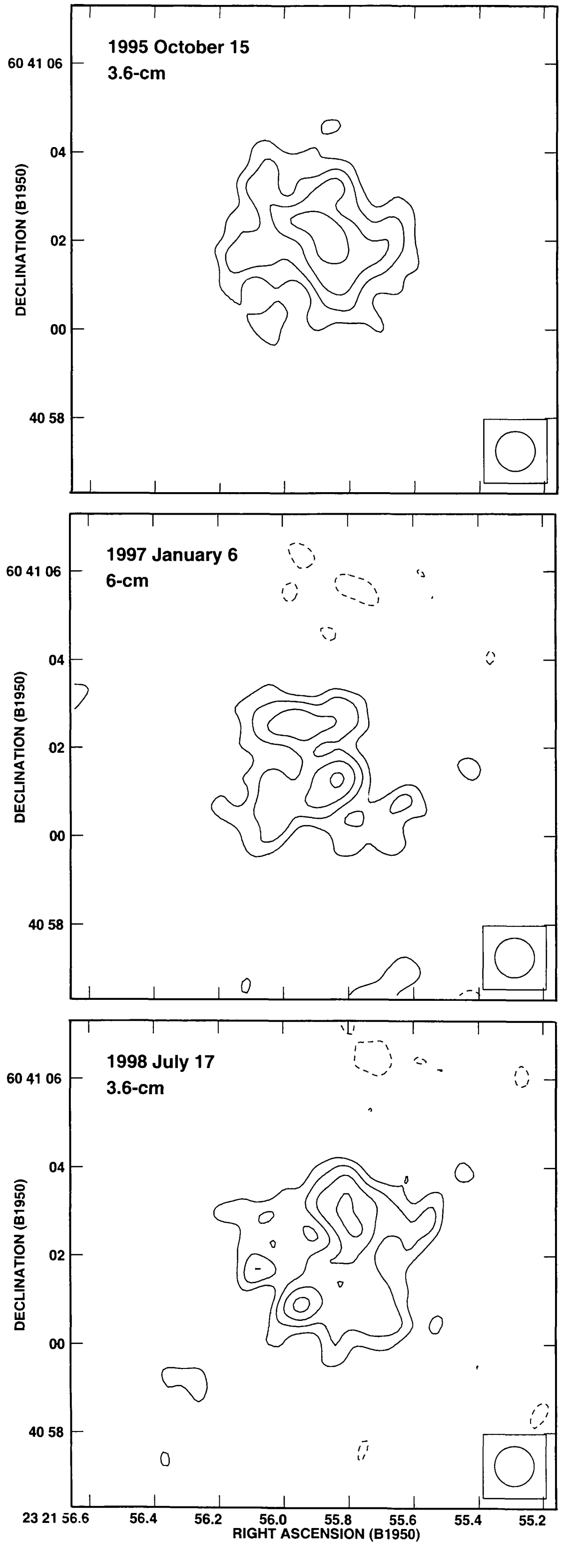

Fig. 1. Continuum contour maps of KjPn 8 for three different epochs. The contours are −3, 3, 4, 5, and 6 times 19 μJy beam^{-1}, the rms noise of the 1997 map. The half power contour of the restoring beam is shown in the bottom right corner of the panels.

In any case, given the modest signal-to-noise ratio of our results and the difficulties to account for the rapid recombination times required, confirmation with additional VLA and HST data is needed. It is very important to substantiate the reality of this unusual phenomenon, since it could provide unique information on the nature of the stellar nucleus.

There is an additional source in our field, located at $\alpha(1950) = 23^h\ 21^m\ 49\overset{s}{.}34 \pm 0\overset{s}{.}01$; $\delta(1950) = +60^\circ\ 40'\ 33\overset{''}{.}8 \pm 0\overset{''}{.}1$, about $1'$ to the SW of KjPn 8. This unresolved ($\leq 0\overset{''}{.}6$) source has flux densities of 0.20 ± 0.02 mJy and 0.23 ± 0.02 mJy at 3.6 and 6-cm, respectively, showing no evidence of variation at 3.6-cm between the 1995 and 1998 data. There is no known counterpart to this radio continuum source in the SIMBAD database or in the images of López et al. (1995). The *a priori* probability of finding a 3.6-cm source with the observed flux density inside a $2' \times 2'$ solid angle is about 8% (Windhorst et al. 1993), so an association with KjPn 8 cannot be argued on strong statistical grounds and it appears likely that this source is simply a background object.

2.2. *H I Observations*

The observations of atomic hydrogen at 21-cm were made on 1999 April 27 with the VLA in the D configuration. The on-source integration time was approximately 3.5 hours. We observed both circular polarizations with a velocity resolution of 10.3 km s^{-1} and a velocity coverage of $\sim$ 500 km s^{-1}. The source 2348+643 was used as phase and bandpass calibrator.

The search for neutral hydrogen in association with KjPn 8 was hampered by the strong line-of-sight H I emission coming from extended structures in the Galactic plane, where KjPn 8 with Galactic coordinates $l = 112\overset{\circ}{.}5; b = -0\overset{\circ}{.}1$, is located. The search for H I in planetary nebulae is known to be severely limited by this factor, and only about a dozen detections are known (Gussie & Taylor 1995). We also suffered from the presence of the supernova remnant Cas A, one of the brightest continuum sources in the sky, which is located at $\sim 2^\circ$ south of KjPn 8.

To search for line emission we subtracted the continuum in the (u,v) plane with the AIPS task UVLIN and produced maps of the individual channels. We detected extended line emission in the LSR velocity range of −117 to +17 km s^{-1}. We detect weak, compact H I emission in positional coincidence with KjPn 8 at the LSR velocity of −35 km s^{-1}, the systemic velocity of the associated molecular gas (Forveille et al. 1998). The positional coincidence and the agreement between the H I and CO LSR velocities suggest the existence of a real physical association. Only in this central channel was H I detected at the position of the planetary nebula. In Figure 2

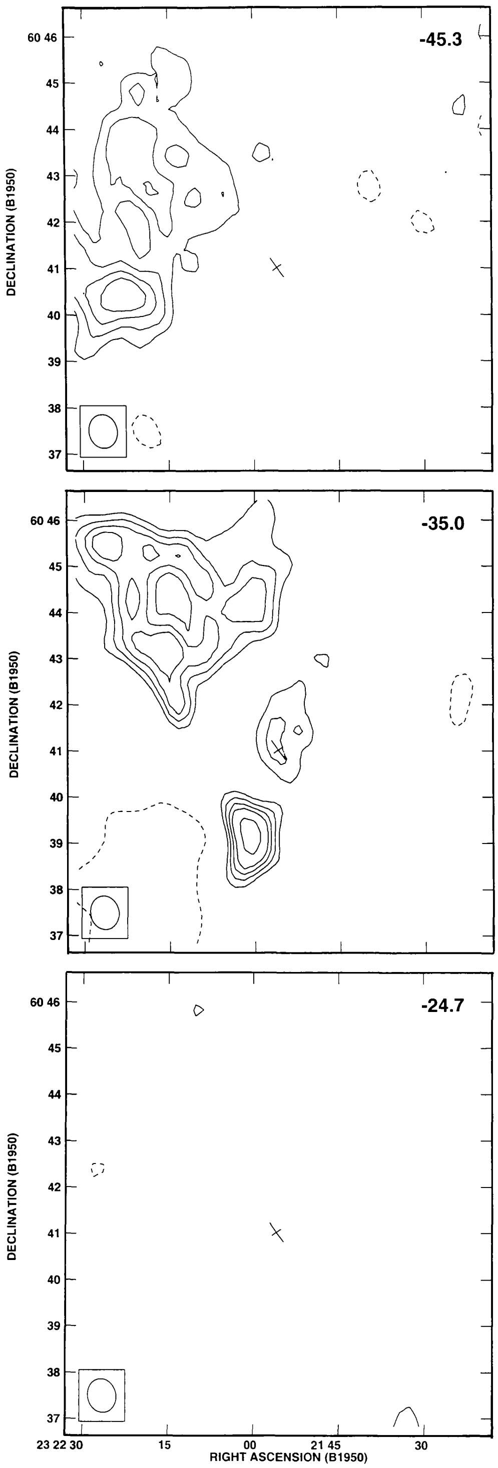

Fig. 2. H I line contour maps of KjPn 8 for three different LSR velocities, indicated in each panel. The contours are −3, 3, 4, 5, 6, and 8 times the rms noises of 1.8 (top map), 2.9 (center map), and 3.6 (bottom map) mJy beam^{-1}. The beam is shown in the bottom left corner. The cross marks the position and extent of the CO disk (Forveille et al. 1998).

we show line channel maps for the adjacent LSR velocities of −45.3, −35.0, and −24.7 km s^{-1}.

The flux density of this H I feature is 12 ± 3 mJy. Assuming a line width of ~ 10 km s^{-1}, an excitation temperature of 100 K for the H I, a distance of 1600 ± 230 pc, and that the emission is optically thin, we derive a mass of M(H I) = 0.07 ± 0.02 $M_\odot$. In comparison, the ionized mass has been estimated to be M(H II) ≃ 0.0005 $M_\odot$ (Huggins et al. 1997) and the molecular mass M(H_2) ≥ 0.03 $M_\odot$ (Forveille et al. 1998).

There are very few planetary nebulae with determinations of their ionized, atomic, and molecular components. NGC 6302 is one of these objects, with M(H II) ≃ 0.05 $M_\odot$, M(H I) ≃ 0.015 $M_\odot$, and M(H_2) ≃ 0.3 $M_\odot$ (Gómez, Rodríguez, & Moran 1993).

Given the limited angular resolution of the H I observations, it is not possible to ascertain where in the gaseous envelope is the atomic hydrogen located. There are two possible locations: first, it could be located at the interface between the ionized ring and the molecular disk. However, the overlays of ionized and molecular tracers shown by López et al. (2000) show that the ionized ring (traced by [S II]) fits tightly inside the molecular ring (traced by H_2), leaving very little space for an intermediate, atomic zone. The second possibility is that the H I comes from the outer layers of the envelope, photodissociated by interstellar UV radiation. The map shown in Fig. 2 suggests that the H I may be extended at the 1′ scale. Unfortunately, the signal-to-noise ratio is not large enough to provide a reliable size.

3. CONCLUSIONS

We have observed the remarkable planetary nebula KjPn 8 with the VLA in the centimeter continuum and in the 21-cm line of H I. Over a period of 2.8 years we undertook three observations over which the radio appearance of the planetary nebula seems to have experienced changes. We tentatively attribute these morphological changes to variable illumination coming from the nucleus. We also detect H I emission in association with KjPn 8, that implies a mass of order 0.07 $M_\odot$ in the envelope. The location of this atomic gas is not yet known because of the limited angular resolution, but we argue that it may be coming from the outer parts of the envelope, photodissociated by ambient interstellar UV radiation.

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REFERENCES

Forveille, T., Huggins, P. J., Bachiller, R., & Cox, R. 1998, ApJ, 495, L111
Gómez, Y., Rodríguez, L. F., & Moran, J. M. 1993, ApJ, 416, 620
Gussie, G. T., & Taylor, A. R. 1995, MNRAS, 273, 801
Huggins, P. J., Bachiller, R., Cox, R., & Forveille, T. 1997, ApJ, 483, L57
López, J. A., Meaburn, J., Bryce, M., & Rodríguez, L. F. 1997, ApJ, 475, 705
López, J. A., Meaburn, J., Kuhn, O., Rodríguez, L. F., Muxlow, T. W. B., Pedlar, A., & Thomasson, P. 1999, ApJ, 518, 778
López, J. A., Meaburn, J., Rodríguez, L. F., Vázquez, R., Steffen, W., & Bryce, M. 2000, ApJ, in press
López, J. A., Vázquez, R., & Rodríguez, L. F. 1995, ApJ, 455, L63
Meaburn, J. 1997, MNRAS, 292, L11
Miranda, L. F., & Torrelles, J. M. 1998, ApJ, 496, 274
Skinner, C. L., Exter, K. M., Barlow, M. J., Davis, R. J., & Bode, M. F. 1997, MNRAS, 288, L7
Stapelfeldt, K. R. et al. 1999, ApJ, 516, L95
Steffen, W., & López, J. A. 1998, ApJ, 508, 696
Vázquez, R., Kingsburgh, R., & López, J. A. 1998, MNRAS, 296, 564
Windhorst, R. A., Fomalont, E. B., Partridge, R. B., & Lowenthal, J. D. 1993, ApJ, 405, 498

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