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TIME VARIATION IN THE RADIO CONTINUUM EMISSION ASSOCIATED WITH THE SURROUNDINGS OF THE NUCLEUS OF THE PLANETARY NEBULA KjPn 8

L. F. Rodríguez and Y. Gómez

Instituto de Astronomía
Universidad Nacional Autónoma de México, Campus Morelia, México

and

J. A. López

Instituto de Astronomía
Universidad Nacional Autónoma de México, Ensenada, B. C., México

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RESUMEN

Presentamos nuevas observaciones de radiocontinuo de alta sensitividad y con resolución angular del orden de un segundo de arco, hechas con el Very Large Array (VLA) hacia la nebulosa planetaria KjPn 8. Estas observaciones se compararon con observaciones similares obtenidas 5.5 años atrás para buscar variaciones en el tiempo que se sugerían en anteriores observaciones. Nuestra comparación indica que la emisión asociada con el entorno del núcleo estelar decreció en un 40% en este período. Atribuimos tentativamente este decremento a variaciones en la eyección de gas por la estrella central.

ABSTRACT

We present new, high sensitivity, Very Large Array (VLA) continuum observations of the core of KjPn 8 made with arcsecond angular resolution. These observations were compared with similar observations taken 5.5 years earlier, in order to search for variations that seemed to be present in previous observations. Our comparison indicates that the emission associated with the surroundings of the stellar nucleus decreased by 40% over this period. We tentatively attribute this decrease to variations in the ejection of gas from the central star.

Key Words: **ISM: RADIO SOURCES — PLANETARY NEBULAE: INDIVIDUAL (KjPn 8) — RADIO CONTINUUM: ISM**

1. INTRODUCTION

The bipolar planetary nebula (PN) KjPn 8, with its $14' \times 4'$ filamentary lobes, yet only $\sim 4''$ 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 led López et al. (2000) to propose that we may be witnessing two distinct planetary nebulae events, probably coming from a binary system. The large bipolar envelope is oriented at a position angle PA $\approx 71°$ and the system of compact high-velocity bipolar jets is at PA $\approx 126°$. The giant bipolar envelope of KjPn 8 has been 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 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 ~ 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 & K bands reveal a clumpy, extended core, in agreement with previous (López et al. 1997) Very Large Array (VLA) observations made in the B configuration of the radio continuum, which traces the ionized gas.

From a comparison of VLA images made at three epochs, Rodríguez, Gómez, & López (2000) suggested that time variation could be present in the emission from the planetary nebula, but that given the modest signal-to-noise ratio of their results confirmation with additional very sensitive VLA data was required.

In this paper we present new VLA observations made at 3.6 cm of the ionized core that search more sensitively for possible variations in this source.

2. OBSERVATIONS

The 3.6 cm continuum observations were made on 2001 April 30 using the VLA of the National Radio Astronomy Observatory (NRAO).[1] The array was in the B configuration, providing an angular resolution of $\sim 1''$. An effective bandwidth of 100 MHz with two circular polarizations was employed. 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.

We compared the new data with the best available data set, that taken on 1995 October 17 also in the B configuration. The on-source integration times of the observations were 3.2 (1995 October 17), and 6.2 hours (2001 April 30). We refer to these epochs as 1995.8 and 2001.3. We made maps with natural weight and a Gaussian tapering of 150 kλ to the (u, v) data, obtaining images from both data sets with angular resolution of $\sim 1\farcs3$. The rms noises of the images were 12 and 8 μJy beam^{-1} for the epochs 1995.8 and 2001.3, respectively. The flux densities observed for KjPn 8 are 1.3 ± 0.1 and 1.2 ± 0.1 mJy for the 1995.8 and 2001.3 data, respectively. To allow a more direct comparison between the maps at the two epochs, we restored them with a Gaussian beam having a full width at half-power of $1\farcs3$. The maps for the two epochs, as well as a difference map ($2001.3 - 1995.8$), are shown in Figure 1.

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

3. DISCUSSION

Although both maps (see top and center panels of Fig. 1) show a source with an angular extent of about 4″, there appears to be a significant difference between them near the position of the stellar nucleus, indicated with a cross in Figure 1. The stellar nucleus of KjPn8 was recently detected in *HST* observations of López et al. (2000).

However, since the signal-to-noise ratio of these images is modest ($\sim$12 for the 1995 data and $\sim$18 for the 2001 data), these apparent variations could be due to noise fluctuations. A more objective test comes from searching for significant residuals in the difference map. We do detect these residuals, in the form of a negative region that has 5-σ significance (see bottom panel of Fig. 1), and coincides within $0\farcs2$ with the position of the nucleus. This residual feature has a flux density of -71 ± 14 μJy and indicates that emission present in 1995.8 had disappeared by 2001.3. Although with respect to the total flux density of the object this variation is only of order 5%, at the position of the residual the drop between the two epochs was of order 40%. These results are consistent with those presented by Rodríguez et al. (2000), that suggested that the emission from the central regions of the nebula had decreased in the 1997.0 and 1998.5 images with respect to the 1995.5 image.

The varying region is unresolved for our angular resolution of $1\farcs3$, about 0.01 pc at the distance of KjPn8. Assuming that the recombining region had an electron temperature of 10^4 K and that the free-free emission was optically-thin, we can estimate a lower limit for its electron density, $n_e \geq 1.1 \times 10^3$ cm^{-3}, and an upper limit for its total mass, $M \leq 4.7 \times 10^{-5}$ $M_\odot$.

As noted before, the region of variation, with position $\alpha(1950) = 23^h21^m55\fs81 \pm 0\fs03$; $\delta(1950) = +60°41'01\farcs9 \pm 0\farcs2$, coincides within $0\farcs2$ with the position of the stellar nucleus, $\alpha(1950) = 23^h21^m55\fs83 \pm 0\fs02$; $\delta(1950) = +60°41'01\farcs7 \pm 0\farcs1$, as determined by López et al. (2000) from *HST* observations.

A possible explanation for the observed variation is that the ionization of the gas is decreasing with

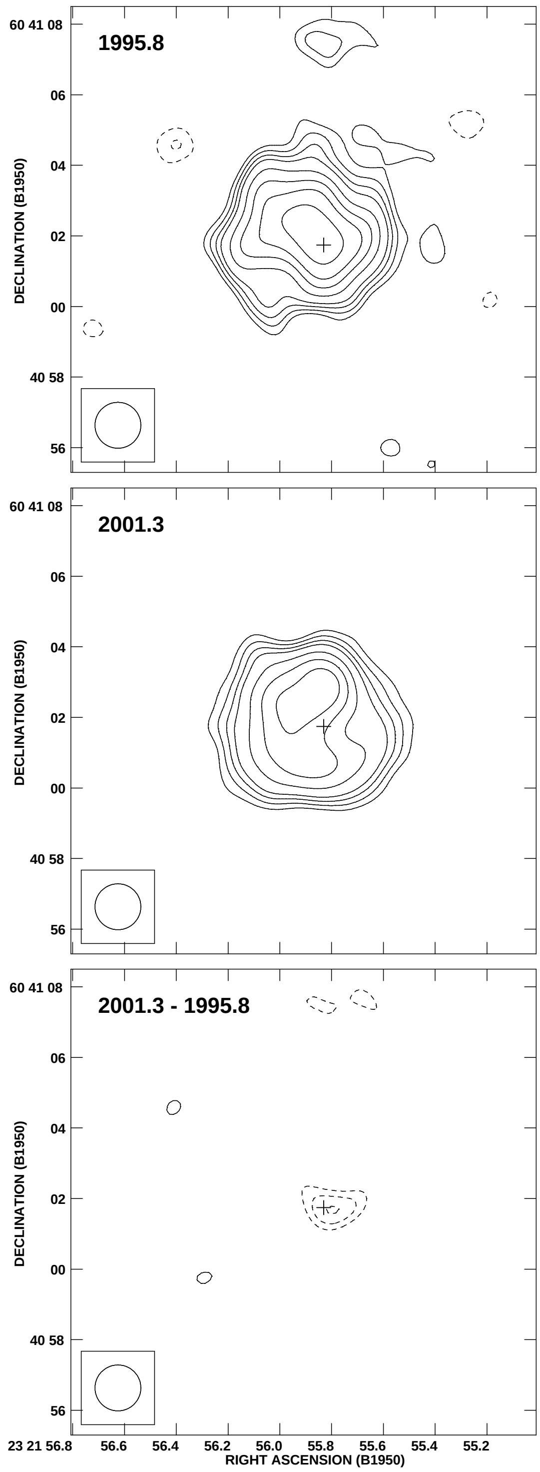

Fig. 1. Continuum images of KjPn 8 for 1995.8 (top) and 2001.3 (center), with contours of -4, -3, 3, 4, 5, 6, 8, 10, 12, and 15 times 10 μJy beam^{-1}, the average rms noise of the two maps. At the bottom we show the difference image ($2001.3 - 1995.8$), with contours of -5, -4, -3, 3, 4, and 5 times 14 μJy beam^{-1}, the rms noise of the map. The cross marks the position of the stellar nucleus.

time, probably as the result of a time-variable radiation field. For these proposed ionization changes to take place, the recombination time of the gas must not exceed several years. This requirement translates to electron densities above $\sim 2 \times 10^4$ 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. This value is comparable to the one derived from the Hα monochromatic *HST* images (López et al. 2000) for the $4''$ core of KjPn 8, which yield an electron density of $\sim 3 \times 10^3$, considering a filling factor of 0.5. We thus conclude that the typical electron density of the planetary nebula is too small to account for these fast variations. However, this possibility should be reconsidered if denser components are detected in the inner parts of the nebula.

Can these variations result from the expansion of a gas shell in the inner regions 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 5.5 years separating our observations we would expect motions of order $\sim 2 \times 10^{14}$ cm. At a distance of 1.6 kpc (Meaburn 1997), these physical motions would correspond to only $\sim 0\farcs01$, which would be undetectable for our angular resolution of $1\farcs3$. Much higher velocities, of order 10^3 km s^{-1}, would be needed to clear a region of about 0.01 pc in a few years.

Could the time-variable radio emission have been produced by a rapidly expanding shell or by variations in the mass loss rate of the fast wind itself? 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. The star at the core of KjPn 8 is most probably not a normal planetary nebula nucleus and could be ejecting gas in the form of shells or collimated jets. 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. A 6 cm MERLIN radio source reported by López et al. (1999) was estimated to be probably powered by a fast ($\sim 10^3$ km s^{-1}) stellar wind with a mass loss rate of $\sim 2 \times 10^{-6} M_\odot$ yr^{-1}. This MERLIN point source is found very close (within astrometric errors) to the location of the putative companion to the stellar core revealed by the *HST* observations. In this context, orbital interactions or wind accretion effects over one of the members of the pair could produce a variable wind outflow. However, the estimated separation of this pair is large, ~ 500 AU, which also poses some problems to this interpretation. A second *HST* imaging epoch should help to clarify the origin of the ongoing changes at the nebular core of KjPn 8.

4. CONCLUSIONS

We have reobserved the remarkable planetary nebula KjPn 8 with the VLA in the centimeter continuum. We compared the new observations with those taken 5.5 years earlier. We find that the radio emission from the immediate surroundings of the nucleus of the planetary nebula is variable. We tentatively attribute these morphological changes to variability in the mass-loss activity of the central star.

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Yolanda Gómez and Luis F. Rodríguez: Instituto de Astronomía, UNAM, Campus Morelia, Apdo. Postal 3–72, 58090 Morelia, Michoacán, México (l.rodriguez, y.gomez@astrosmo.unam.mx).
J. Alberto López: Instituto de Astronomía, UNAM, Apdo. Postal 877, 22860 Ensenada, B. C., México (jal@astrosen.unam.mx).