
Angular expansion in planetary nebulae from radio interferometric data

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Summary. The measurement of the angular expansion rate of a planetary nebula (PN), from radio interferometric data, provides a reliable method to establish the distance to PNe and in some cases the proper motion of ansae. We present a comparison of Very Large Array data sets toward the PN NGC 7009, the "Saturn Nebula", taken with a time separation of 8.09 years. This PN shows a pair of low-ionization knots along its major axis and in this work we confirm the proper motion of the knots previously measured at optical wavelengths. We find that the flux densities of the jets that connect the ansae with the main body of the nebula seem to have diminished in about 30% over the period between the two observations.

Key words: ISM–planetary nebulae:individual (M 2-43; NGC 7009)–stars: distances–techniques: interferometric

1 Introduction

Radio images of planetary nebulae (PNe) made with the Very Large Array (VLA) at high angular resolution $<0.1''$ ([15], [25], [7], [8], [10]) have revealed the presence of compact nebulae with non circular morphologies. It is believed that physically compact planetary nebulae are very young objects. Then, the origin and characteristic time for the appearance of non circular structures are a matter of great interest to understand the origin and formation of PNe. However, to confirm the young age proposed for these compact bipolar planetary nebulae, it is necessary to have accurate distances.

To date, the angular expansion technique, first applied in radio wavelengths by [18] to NGC 7027, seems to be very successful in estimating distances to planetary nebulae ([18], [19], [20], [7], [12], [13]; [14]; [11], [5]). This technique involves a measurement of the angular expansion rate of the nebula from radio interferometric data obtained at two epochs over a period of a few years. A distance estimate can be obtained based on a geometric and kinematic model for the nebula. Actually, it is the uncertainties of this model the limiting factor of the method to get the distance. For PNe with distances > 1 kpc the expected angular expansion rate is <2 mas yr⁻¹.

Recently, Guzmán et al. (2006) have been successful in estimating the angular expansion rate toward the compact planetary nebula M 2-43 (see Fig. 1), for which a distance of 6.9 ± 1.5 kpc, and a kinematic age of ~ 500 years were determined. The distance estimate was very important to confirm that M 2-43 is a young planetary nebula that is relatively remote from the Sun. This is the largest distance for a PN measured, up to now, with the angular expansion technique [10].

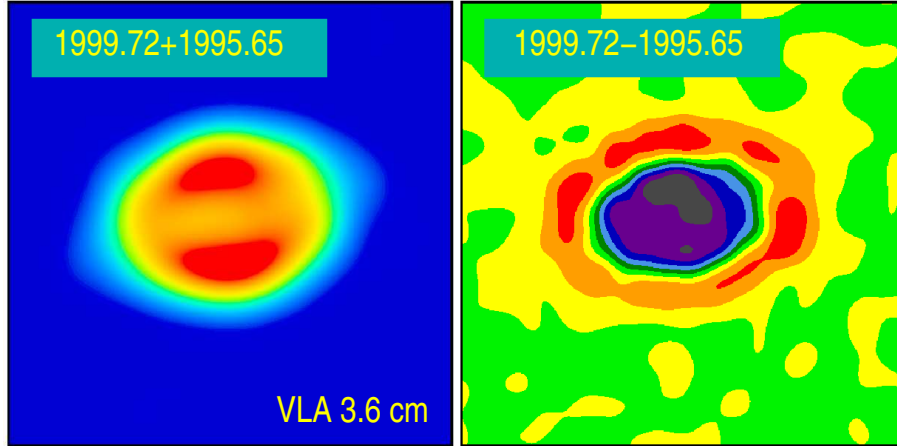


Fig. 1. Color images of the 3.6 cm continuum emission from M 2-43 for the average (left) of the two epochs (1995.65 and 1999.72) and the difference (right). For details of these results see [10].

Motivated with the result of M 2-43, we decided to attempt to measure the distance to NGC 7009 (PN G037.7-34.5), the "Saturn Nebula" (see Fig. 2), which is an elliptical PN that exhibits weak jets, along its major axis, that are connected to a pair of low-ionization knots, also called ansae. The ansae (handles) are present in PNe with bipolar, rotating, episodic jets (BRETS; e.g. [17]) and fast, low ionization emission regions (FLIERS; [3]).

In NGC 7009 the ansae are moving at radial velocities of 100 km s^{-1} , relative to the nucleus ([22], [2]). Looking in the literature measurements of proper motions toward other PNe, we found that only a handful of objects (KjPn 8; [21], Hen 2-90; [24], NGC 7009; [6]) have been measured. In particular, something that called our attention, was that at radio wavelengths there was no published measurement of proper motions of ansae. Previous measurements of proper motions of ansae in PNe have been done only in the optical regime. Then we decided to apply the cross-calibration technique not only to estimate the angular expansion rate of the main body of the nebula, in order to get its distance, but also to estimate the proper motions of the ansae. The details of this work can be found in [23].

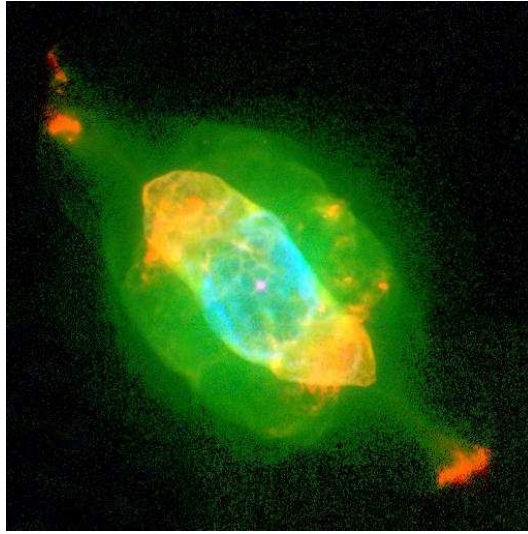


Fig. 2. HST Image of the "Saturn Nebula" PN NGC 7009 (Balick, et al.; <http://ad.usno.navy.mil/pne/images/ngc7009.jpg>).

2 Observations

The observations used for this work were taken from the archive of the VLA of the NRAO¹. The observations were made in 1989 March 28 (epoch 1989.24) and 1997 April 29 (epoch 1997.33), with a time separation of 8.09 years. Both sets of observations were made at 3.6 cm in the B configuration of the VLA. The data were reduced using the standard VLA procedures in the software package Astronomical Imaging Processing System (AIPS) of NRAO and then cross-calibrated using the procedure of [18].

3 Results

Fig. 3, shows a color image of the continuum 3.6 cm emission toward NGC 7009. It is possible to distinguish three main structures. The brightest (red color) correspond to the main body of the nebula with an elliptical shape and angular dimensions of $32'' \times 24''$. The second structure is constituted by the faint jets that emanate from the main body of the nebula and extend about $8''$ to the east and west, along the major axis of the nebula. Finally, the third structure are the ansae, with angular dimensions of a few arc sec. It is believed that the ansae are the termination points of the jets. Even when the ansae appear not as bright as the main body, it is possible to estimate with good accuracy the angular displacement of the peak position between the two epochs.

¹ The National Radio Astronomy Observatory is operated by Associated Universities Inc. under cooperative agreement with the National Science Foundation.

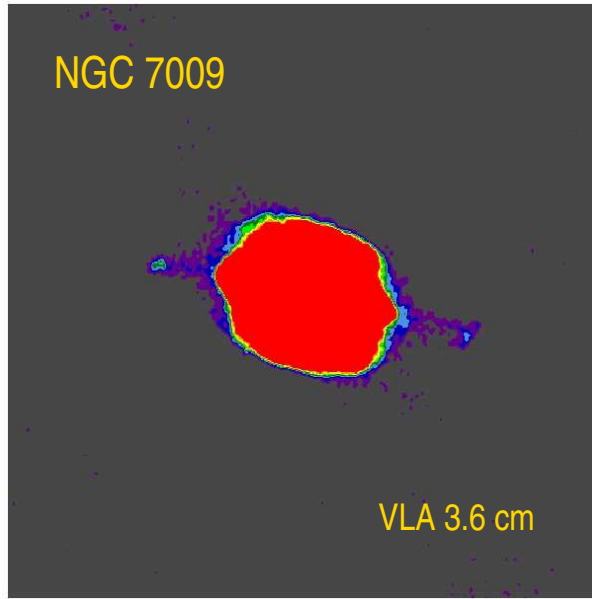


Fig. 3. Color image of the radio continuum at 3.6 cm of NGC 7009. This image correspond to the average of the two epochs (1989.24+1997.33). The ansae are clearly detected at both sides.

3.1 Proper motions of the ansae

Fig. 4 shows the displacement of the peak position of the eastern and western ansae in NGC 7009. The measurement of the proper motion for the eastern ansa is 23 ± 6 mas yr⁻¹ and for the western ansa is 34 ± 10 mas yr⁻¹. We found in the literature two previous measurements of these proper motions. From photographic plates [16] estimated a value of ~ 16 mas yr⁻¹ for the proper motion of the ansae in NGC 7009. A recent determination is that obtained by [6], who used HST images to obtain a value of 28 ± 8 mas yr⁻¹ for the eastern ansa (the western ansa was not included in the observations). These previous results are in good agreement with the derived by us using radio observations.

Assuming a distance of 0.86 ± 0.34 kpc, the average of 14 available values ([1], [6]), we obtain crude estimates for the velocities in the plane of the sky of 100 and 140 km s⁻¹, for the east and west ansae, respectively. Also assuming that the ansae move ballistically (i. e. with no acceleration or deceleration) we estimate an age of ~ 850 years if they originated from the central star and of ~ 300 years if they originated from the edge of the main body of the planetary nebula.

3.2 A lower limit to the distance of the nebula

After subtracting the older data (1989.24) of NGC 7009 from the more recent one (1997.33), we were expecting to see the characteristic expansion signature where an outer region of positive emission is surrounding an inner region of “negative”

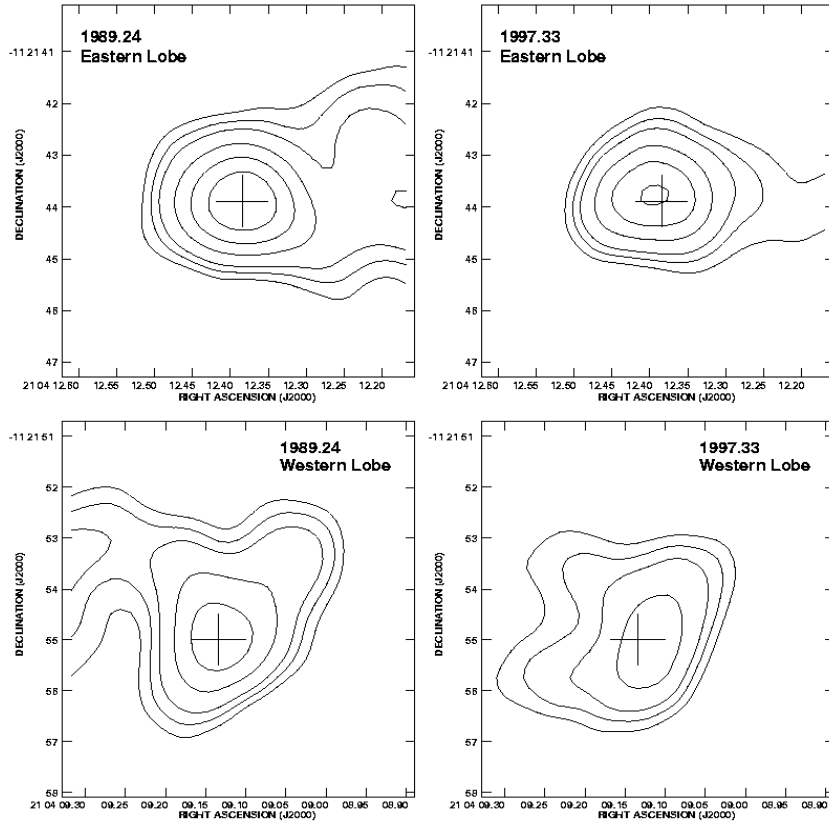


Fig. 4. Contour images of NGC 7009 at 3.6 cm for 1989.24 (left) and 1997.33 (right). The top and bottom parts of the panel show the eastern and western ansae, respectively. The crosses mark the peak position of the ansae for 1989.24. Note the small displacement of the peak position of the lobes for 1997.33. The contours are -4, 4, 5, 6, 8, 10, 12, 15, 20, 30, 40, 60, 80, 120, 200, 300, 400, and 500 times $19.5 \mu\text{Jy beam}^{-1}$, the average rms noise of the two images. The beam is $1''.74 \times 1''.50$.

emission, as was found for M 2-43 (see Fig. 1). However, we failed to detect a clear expansion signature (see Fig. 6), an only an upper limit to the expansion was obtained, resulting in a lower limit to the distance of ≥ 700 pc. This lower limit is consistent with the weighted average of 14 available values ([1], [6]), of 860 ± 340 pc.

3.3 A decreasing flux emission from the Jets

A comparison of the flux density of the main body in the two epochs shows that the flux remains constant (within $\leq 1\%$). However, there is a marginal evidence, for the east and west jets, that the flux density decreased from $\sim 0.9 \pm 0.1$ mJy in 1989.24 to $\sim 0.6 \pm 0.1$ mJy in 1997.33, a decrease of about 30%. Fig. 6 shows a close up of the western jet where this change in flux is more evident. Considering an electron

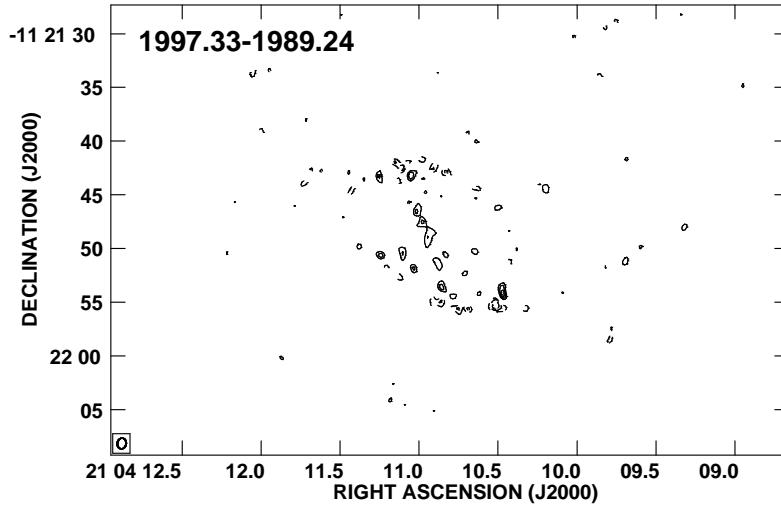


Fig. 5. 3.6 cm contour images of NGC 7009 for the difference 1997.33–1989.24 data. The contours are -5, -4, -3, 3, 4, and 5 times $20 \mu\text{Jy beam}^{-1}$. The synthesized beam ($1''.00 \times 0''.81$ with a position angle of -10°) is shown in the bottom left corner of the image [23].

density for the jets between $1000 - 4000 \text{ cm}^{-3}$ ([4], [9]) the recombination timescales are between 30 to 120 yrs, pointing out that this change over the 8-year period is consistent with recombination theory.

4 Conclusions

Interferometric data taken with a few years of separation can reveal the angular expansion of the nebula and it is possible to estimate its distance from this measurements (e.g. M 2-43; [10]).

In NGC 7009 we measured the proper motions of the ansae, obtaining values of 23 ± 6 and $34 \pm 10 \text{ mas yr}^{-1}$ for the eastern and western ansae, respectively. This is the first time that proper motions of ansae in planetary nebulae are determined with radio observations.

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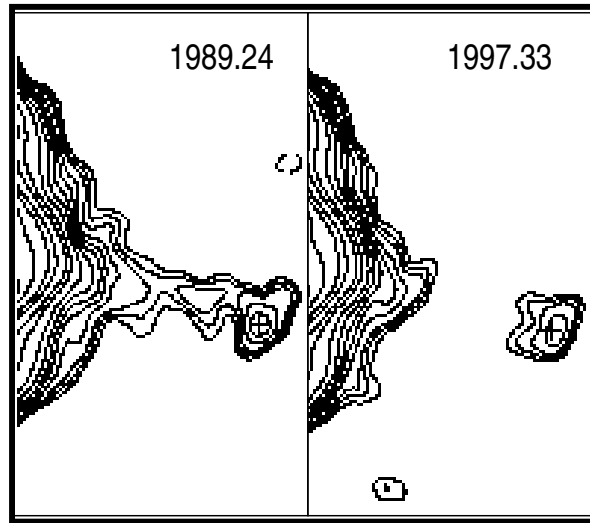


Fig. 6. 3.6 cm contour images for the western jet of NGC 7009 for the two epochs separated in time by 8.09 years. The contours are -4, -3, 3, 4, 5, 6, 8, 10, 12, 15, 20, 30, 40, 60, 80, 120, 200, and 300 times $12 \mu\text{Jy beam}^{-1}$. The crosses mark the peak position of the lobes for the 1989.24 epoch (see details in [23]).

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