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EXPANSION PARALLAX FOR THE COMPACT PLANETARY NEBULA M2-43

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RESUMEN

Presentamos observaciones de alta calidad en radiocontinuo hechas a 3.6 cm con el Very Large Array en dos épocas hacia la nebulosa planetaria M2-43. La comparación de las dos épocas, obtenidas con una separación de 4.07 años, muestra claramente la expansión de la nebulosa planetaria con una velocidad angular de 0.61±0.09 mas año^{-1}. Suponiendo que la velocidad de expansión en el plano del cielo (determinada de estas mediciones) y la velocidad de expansión en la línea de visión (determinada a partir de espectroscopía óptica disponible en la literatura) son iguales, encontramos una distancia de 6.9±1.5 kpc a la nebulosa planetaria. Esta es la mayor distancia a una nebulosa planetaria medida hasta ahora con esta técnica.

ABSTRACT

We present high quality radio continuum observations made with the Very Large Array at 3.6 cm at two epochs toward the planetary nebula M2-43. The comparison of the two epochs, obtained with a time separation of 4.07 years, clearly shows the expansion of the planetary nebula with an angular rate of 0.61±0.09 mas year^{-1}. Assuming that the expansion velocity in the plane of the sky (determined from these measurements) and the expansion velocity in the line of sight (determined from optical spectroscopy available in the literature) are equal, we find a distance to the planetary nebula of 6.9±1.5 kpc. This is the largest distance for a planetary nebula measured up to now with this technique.

Key Words: **PLANETARY NEBULAE: INDIVIDUAL (M2-43) — STARS: DISTANCES — TECHNIQUES: INTERFEROMETRIC**

1. INTRODUCTION

The distance to a planetary nebula (PN) is an essential parameter for studying the stellar and nebular parameters as well as the evolution of the central star. The measurement of the angular expansion parallax of a PN, from radio interferometric data obtained over a period of a few years, provides an accurate method to estimate the distance (Masson 1986).

This technique has been applied with success to several PNe (Masson 1986; 1989a; 1989b; Gómez, Rodríguez, & Moran 1993; Hajian, Terzian, & Bignell 1993; 1995; Kawamura & Masson 1996; Hajian & Terzian 1996; Christianto & Seaquist 1998). The angular expansion technique has also been used for *Hubble Space Telescope* WFPC2 data in several PNe (Reed et al. 1999; Palen et al. 2002).

In this paper we present an angular expansion study of the planetary nebula M2-43, made with Very Large Array (VLA) data taken at 3.6 cm with a time baseline of 4.07 years. Our main purpose was to detect for the first time this expansion and to use it to obtain an accurate distance estimate to this PN. The planetary nebula M2-43 (= PN G027.6+04.2) has been detected at radio wavelengths, showing a compact size with a diameter of 1$''$.5 for its major axis and ellipsoidal morphology (Aaquist & Kwok 1990). High-resolution radio free-free (2 cm) emission and hydrogen recombination line (Hα) images toward M2-43 show a similar structure with two bright peaks in the north-south direction (Lee & Kwok 2005). The extinction map structure derived by Lee & Kwok (2005) roughly follows that of the radio map. Expansion velocities for M2-43 measured with different ions are in the range from 26 to 30 km s^{-1} (Acker et al. 2002; Peña, Medina, & Stasińska 2003). Acker et al. (2002) found spectral evidence for turbulent velocities in [WC]-type PNe superimposed on a constant expansion velocity pattern. The modelling made by Acker et al. (2002) toward M2-43, taking into account the turbulence, gives an expansion velocity of 20 km s^{-1} with a turbulent component of 10 km s^{-1}. In addition, M2-43 has a high radial velocity value (with respect to the local standard of rest) of $+111.6 \pm 5$ km s^{-1} (Schneider et al. 1983). Previous estimates of the distance to M2-43 have been made using statistical methods and range from 1.4 kpc (Cahn et al. 1992) to 5 kpc (Acker et al. 2002). The central star of this PN has been classified as a Wolf-Rayet type [WC8], showing pure He and C in its atmosphere and its visual magnitude is $m_V = 15.7$ (Acker et al. 1992; Leuenhagen & Hamann 1998; Peña et al. 2003). An accurate distance value for M2-43 is needed to better know the physical parameters, evolutionary stage and to understand the difference between PNe with [WC] nuclei and normal PNe.

2. OBSERVATIONS

The observations were made in 1995 August 24 (epoch 1995.65) and 1999 September 19 (epoch 1999.72) with the VLA of the NRAO[1] at 3.6 cm in the A configuration. The time interval between observations was of 4.07 years. In both epochs the source 1328+307 was used as an absolute amplitude calibrator (with an adopted flux density of 5.21 Jy) and the source 1741–038 was used as the phase calibrator (with bootstrapped flux densities of 3.85±0.04 and 4.94±0.03 Jy for the first and second epochs, respectively). The data provided an angular resolution of $\sim 0\farcs3$ with natural weighting. The data were reduced using the standard VLA procedures and then cross-calibrated in phase and amplitude using the procedure of Masson (1986;1989). Since the (u,v) coverage and the integration time were very similar for both epochs, the synthesized beams differed by less than 5% and images for the two epochs were made with a restoring beam of $0\farcs32\times0\farcs31$ and a position angle of 0° for the major axis, the average of the individual beams for each epoch. In Figure 1 we show the individual images for each epoch as well as the difference image, made from the 1999.72 uv-data from which the clean components of the 1995.65 image were subtracted directly in the uv-plane. This difference image clearly shows the signature of expansion with the outer parts of the source appearing as positive and the inner parts of the source appearing as negative. A consistent result is obtain from subtracting the individual cross-calibrated images in the image-plane.

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3. INTERPRETATION AND RESULTS

We modeled the difference map (Fig. 1: bottom-left) following Gómez et al. (1993). A first image was made concatenating the two epoch data sets. A second image was made taking the first image and expanding it in a self-similar way by a factor of $(1 + \epsilon)$, where $\epsilon << 1$. The first image was then subtracted from the second one for different values of ϵ to produce a set of "model" images. From a χ^2-square fitting we find that the best agreement with the difference image is obtained for $\epsilon = 0.0075\pm0.0008$ (see Fig. 1: bottom-right). The good agreement between the difference image and the model suggests that the assumption of self-similar expansion in M2-43 is reasonable. The radius of maximum emission, θ, is estimated to be $0\farcs33 \pm 0\farcs03$ from the images of the full free-free emission (top part of Fig. 1). The angular expansion rate of this radius of maximum emission is

$$\dot{\theta} = \frac{\theta\ \epsilon}{\Delta t},$$

and from our measurements we find $\dot{\theta} = 0.61\pm0.09$ mas yr^{-1}. The distance to the planetary nebula will then be given by

$$\left[\frac{D}{pc}\right] = 211 \left[\frac{v_{exp}}{km\ s^{-1}}\right] \left[\frac{\dot{\theta}}{mas\ yr^{-1}}\right]^{-1},$$

where v_{exp} is the expansion velocity of the nebula at the point of maximum emission. In general the [O III] line widths are used to determine the expansion velocities in PNe. Peña et al. (2003) measured the line width of the [O III] line at 1/10 the maximum intensity. For M2-43 they obtain a value of 52 km s^{-1} where not only expansion but also turbulence and high velocity components are contributing. Acker et al. (2002) found spectral evidence for turbulent velocities in [WC]-type PN superimposed on a constant expansion velocity pattern. The modelling made by Acker et al. (2002), taking into account the turbulence, gives an expansion velocity for M2-43 of 20±3 km s^{-1}.

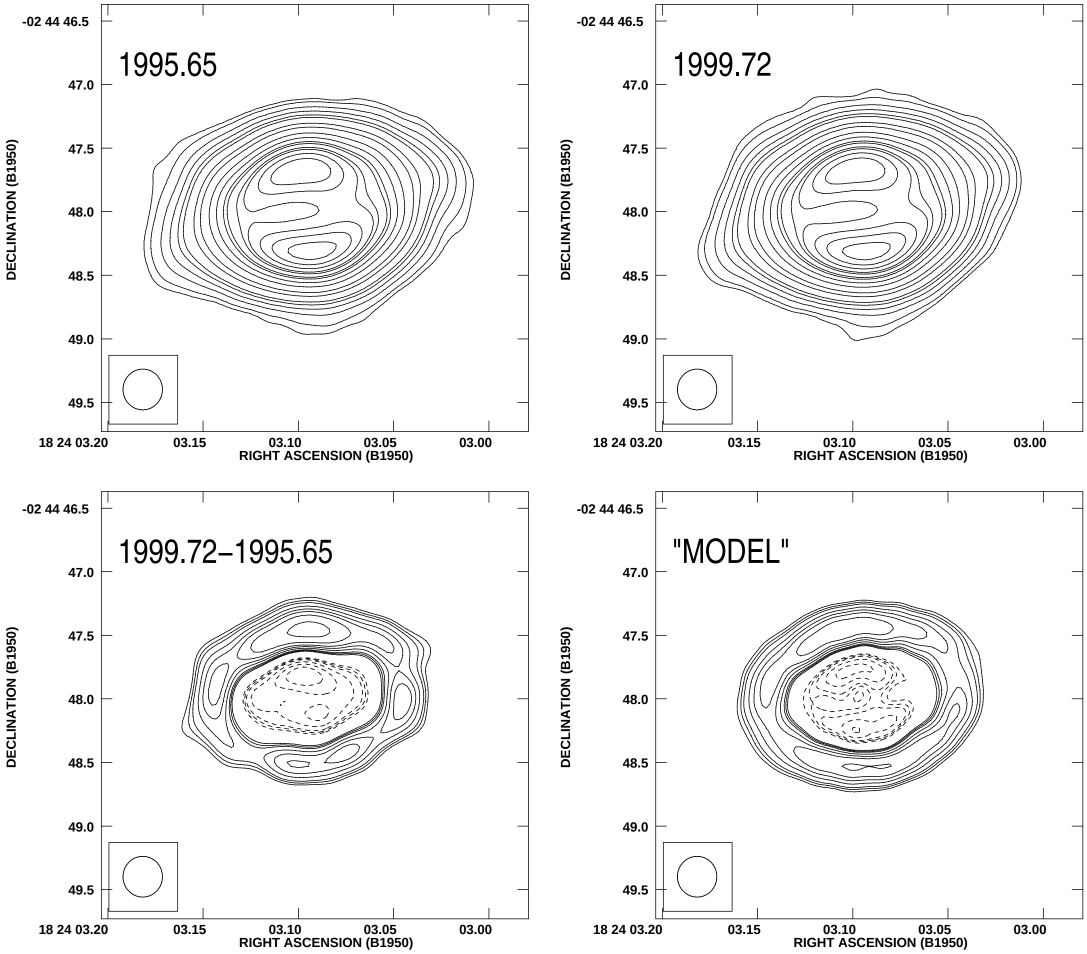

Fig. 1. Top: contour images of the 3.6 cm continuum emission from M2-43 for 1995.65 (left) and 1999.72 (right). The contours are −4, 4, 8, 20, 40, 70, 100, 200, 300, 500, 700, 900, 1000, 1100, 1200, 1300, 1500, 1700, and 1900 times 14 μJy beam^{-1}, the average rms noise of the images. Bottom: contours of the 3.6 cm difference image (left) and of the "model" (right) obtained as described in the text. The contours are −12, −10, −8, −6, −5, −4, 4, 5, 6, 8, 10, 12, 15, and 20 times 20 μJy beam^{-1}, the rms noise of the difference image. The restoring beam ($0\farcs32 \times 0\farcs31$ with a position angle of 0°) is shown in the bottom left corner of each image.

Adopting an expansion velocity of 20 km s^{-1} for M2-43 in combination with our angular expansion rate we estimate a distance of 6.9±1.5 kpc for M2-43. This value is roughly consistent with the distance value determined by Acker et al. (2002) of 5 kpc.

Expansion parallax distances using this radio technique have been determined now for nine planetary nebulae (Mellema 2004; Gómez et al. 1993). M2-43 is the most distant object in this list, followed by Vy 2-2 for which a distance of 3.6±0.4 kpc is estimated (Christianto & Seaquist 1998).

This value for the distance to M2-43 is consistent with the fact that it has a large radial LSR velocity of +111.6±5 km s^{-1} (Schneider et al. 1983). The deviation attributable to velocity dispersion with respect to their respective local standard of rest is around 40 km s^{-1} for PNe and 20 km s^{-1} for H II regions (Maciel & Dutra 1992). Then, assuming that the LSR radial velocity of the position where M2-43 is located is +111.6±40 km s^{-1}, we can plot this velocity and the distance estimated by us (see Figure 2) to show that both estimates are consistent with a relatively large distance for M2-43.

It is clear that the main limitation of this technique for the distance determination comes from the knowledge of the expansion velocity. Additional uncertainty in the distance determination is produced by the advance of the ionization front and the non-spherical geometry of the nebula. Recently, several authors have discussed the parallax method for distance determination by modelling the kinematics of the circumstellar envelopes, proposing correction

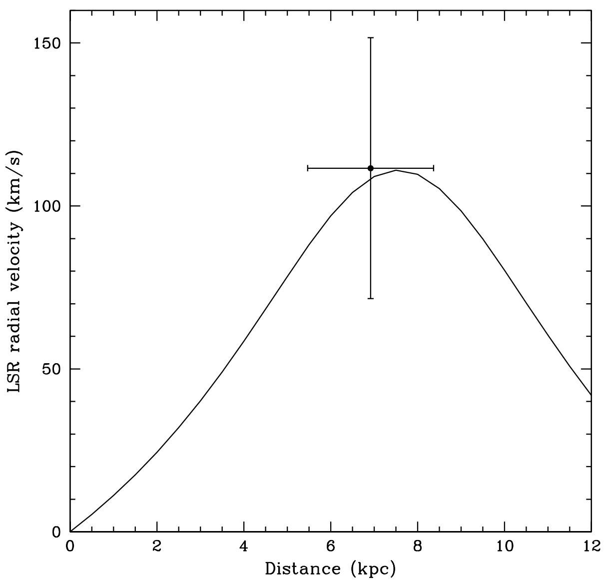

Fig. 2. In this figure we show (solid line) the expected LSR radial velocity as a function of distance to the Sun in the direction of M2-43 for the galactic rotation model of Brand & Blitz (1993). The point marks the estimated distance and the observed LSR radial velocity for M2-43.

factors between 1.3 and 3 for the distance estimates (Mellema 2005; Schönberner, Jacob, & Steffen 2005). However, the application of these correction factors requires of a very detailed knowledge of the structure of the PN that is not available at present for M2-43.

The total flux density derived from the 3.6 cm image (second epoch) is 248±1 mJy and the mean deconvolved angular diameter at FWHM is $0\farcs61$. Adopting a distance of 6.9 kpc for M2-43 and assuming that the source is a uniform sphere and that the radio continuum emission is optically thin at 3.6 cm, we derive an emission measure of 4.5×10^8 cm^{-6} pc, an ionized nebular mass of $\sim 0.035\ M_\odot$ and an electron density of $\sim 1.1 \times 10^5$ cm^{-3}. An estimate of the kinematic age for M2-43 ($\theta/\dot{\theta}$) is of $\sim$ 500 years indicating that this compact PN is very young.

4. CONCLUSIONS

We presented VLA observations made at 3.6 cm of the planetary nebula M2-43 during two epochs separated by 4.07 years. Assuming a self-similar expansion for the ionized gas we determine an expansion angular rate for M2-43 of 0.61±0.09 mas year^{-1} that in combination with an expansion velocity of 20 km s^{-1} imply a distance to the nebula of 6.9±1.5 kpc. This distance estimate is in agreement with the high radial LSR velocity reported for this nebula. Adopting a distance of 6.9 kpc we derive an ionized mass of 0.035 $M_\odot$ and a kinematic age of 500 years for M2-43, indicating that it is a very young and relatively remote planetary nebula.

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