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NEUTRAL HYDROGEN AND CONTINUUM *VLA* OBSERVATIONS OF THE PLANETARY NEBULAE NGC 6302 AND NGC 2440

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RESUMEN

Nuestro mapa de alta resolución angular de la componente de H I en absorción a -40 km s^{-1} en NGC 6302 confirma resultados previos en el sentido de que el gas está asociado con la nebulosa planetaria. El mapa de continuo de NGC 6302 muestra estructuras que podrían estar asociadas con los lóbulos ópticos extendidos ($\sim 1'$). En el caso de NGC 2440 ambas componentes de H I en absorción a 0 y 25 km s^{-1} producen atenuación uniforme sobre la nebulosa planetaria, sugiriendo que son causadas por nubes interestelares en la línea de visión que no están físicamente asociadas con NGC 2440. Nuestro mapa de continuo de esta nebulosa planetaria es similar al mapa de isofotas de Hα de Phillips, Reay, and Worswick (1980), apoyando la idea de que la extinción enfrente de NGC 2440 es uniforme.

ABSTRACT

Our high angular resolution map of the -40 km s^{-1} H I absorption feature in NGC 6302 confirms previous results in the sense that the absorbing gas is associated with the planetary nebula. The continuum map of NGC 6302 shows structures that may be associated with the extended ($\sim 1'$) optical lobes. In the case of NGC 2440 both H I absorption features at 0 and 25 km s^{-1} produce uniform attenuation across the face of the planetary nebula, suggesting that they are being caused by line-of-sight interstellar clouds unrelated to NGC 2440. Our continuum map of this nebula is similar to the Hα isophotal map of Phillips, Reay, and Worswick (1980), supporting the notion that the extinction is uniform over the extent of the nebula.

Key words: NEBULAE-PLANETARY — RADIO SOURCES-21-cm — STARS-LATE TYPE

I. INTRODUCTION

Young planetary nebulae are expected to have their outer parts neutral. Spergel, Giuliani, and Knapp (1983) have estimated that for a dusty planetary nebula formed by a large mass loss ($\dot{M} > 10^{-5}$ $M_\odot$ yr^{-1}), it will take more than 10^3 years for the central star to fully ionize the envelope. However, searches for this neutral gas (either in molecular or atomic form) have yielded very few detections. In the millimeter wavelength rotational transitions of CO, NGC 7027 (Mufson, Lyon, and Marionni 1975). IC 418 (Knapp *et al.* 1982), and NGC 2346 (Knapp 1985) have been detected. Neutral hydrogen (Rodríguez and Moran 1982) and hydroxil (Payne, Phillips, and Terzian 1985) have been detected in association with NGC 6302.

There is also evidence for neutral gas in the visible (forbidden lines of O I) and in the infrared (vibration-rotation emission lines of H_2) for several planetary nebulae. However, for these two last indicators the neutral mass cannot be derived adequately and it is unclear if they signal only traces of neutral gas or considerable amounts of it.

Pottasch and collaborators (Pottasch *et al.* 1982; Pottasch, Gathier, and Goss 1983; Pottasch 1983) and Rodríguez and García-Barreto (1984) have searched for H I toward several planetary nebulae. With the exception of NGC 6302 and possibly NGC 2440, all observed H I absorption lines can be attributed to interstellar clouds unrelated with the respective planetary nebulae. Rodríguez *et al.* (1985) have confirmed the association of H I with NGC 6302. The case of NGC 2440 is particularly interesting since one of the H I absorption components could be of interstellar or nebular origin (Pottasch *et al.* 1983; Rodríguez and García-Barreto 1984). The possibility of a nebular origin was supported also by the similarities between NGC 2440 and NGC 6302 (Calvet and Peimbert 1983). An observation with high angular resolution was required to determine whether the H I absorption was uniform across the nebula (favoring an interstellar origin) or localized as in the case of NGC 6302 (supporting a nebular origin).

In this paper we present high angular resolution *VLA* observations of the H I line and the continuum at 21-cm of NGC 6302 and NGC 2440. The observations are described and discussed in §II; our conclusions are given in §III.

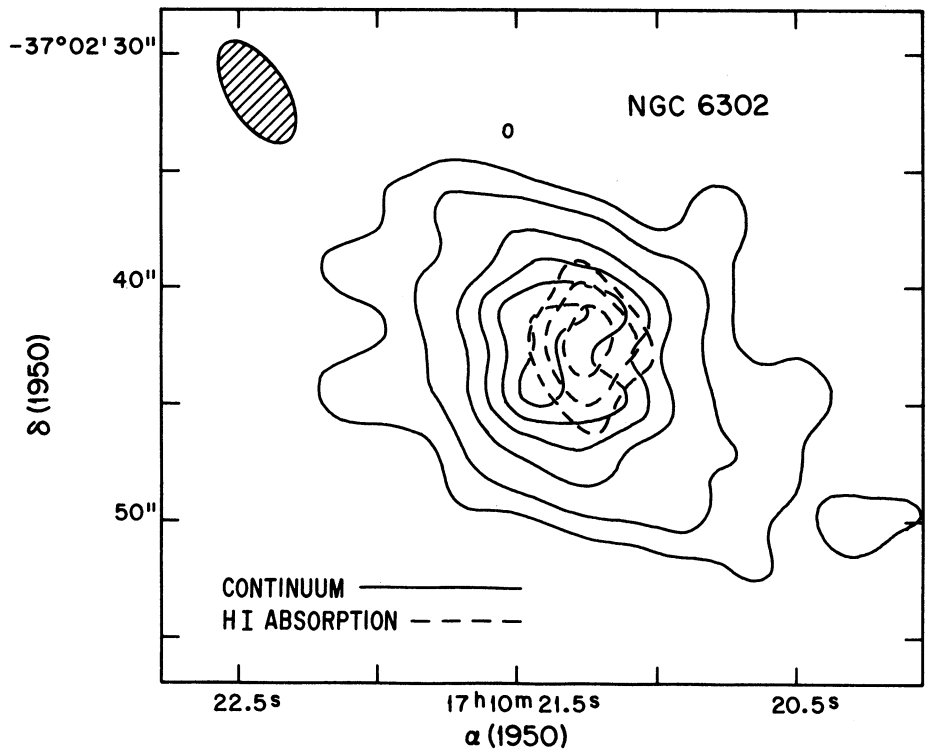

Fig. 1. Self-calibrated continuum map of NGC 6302 at 21-cm (solid lines). The contours are 0.03, 0.1, 0.3, 0.5, 0.7, and 0.9 of the peak flux density of 188 mJy/beam. A continuum-minus-H I absorption map (broken lines) is superposed on the figure. The H I absorption considered was for the range of −48.6 to −33.0 km s^{-1}. The contours for this map are 0.5, 0.7 and 0.9 of the peak flux of 53 mJy/beam.

II. OBSERVATIONS AND DISCUSSION

The observations were made in 1985 March 23-24 using the *Very Large Array*[1] in the A/B configuration. We observed in the spectral line mode using 31 channels of 24.414 kHz (5.2 km s^{-1}), after Hanning weighting. The channel 0 registered 75% of the full bandwidth of 3.125 MHz and was used to produce continuum maps of relatively high signal-to-noise ratio. The amplitude calibrator was 3C286 and the phase calibrators were 0733-174 (for NGC 2440) and 1748-253 (for NGC 6302). The data were edited and calibrated following the standard *VLA* procedures. The continuum maps were self-calibrated and are shown in Figures 1 and 2. The total 21-cm fluxes, obtained from the amplitude versus (u, v) distance plots, are 1.75 Jy for NGC 6302 and 0.38 Jy for NGC 2440. These fluxes are in good agreement with those determined by Rodríguez and García-Barreto (1984).

The continuum map of NGC 6302 shows in its central part two protuberances pointing to the west. Another protuberance to the NE is marginally present. These structures could mark the 'roots' of the large optical lobes evident in optical photographs that give this nebula its 'butterfly' appearance.

Maps were also made for each individual line channel. Both NGC 6302 and NGC 2440 have two absorption components. For NGC 6302 these components are centered at $V_{LSR} \simeq -40$ and +5 km s^{-1}, respectively. Maps were made for both features averaging three adjacent channels showing H I absorption. The +5 km s^{-1} absorption component appears to produce a uniform decrease in the brightness of the source. This is interpreted as indicative of absorption produced by a medium that has little variation over the angular extent of the planetary nebula, most probably a line-of-sight interstellar cloud. On the other hand, the −40 km s^{-1} H I component produces very localized absorption. We have superposed on Figure 1 the contours of a continuum-minus-absorption map that mark the position of the gas causing the −40 km s^{-1} absorption. These results are similar to those presented by Rodríguez *et al.* (1985), but have better angular resolution in declination (as a result of the mixed A/B *VLA* configuration).

In the case of NGC 2440 there are absorption features at $\sim$ 0 and $\sim$ 25 km s^{-1}, respectively. We made dirty maps in the −8.2 to 2.2 km s^{-1} range and in the 23.0 to 33.4 km s^{-1} range. These two ranges contain

1. The *VLA* forms part of the National Radio Astronomy Observatory, which is operated by Associated Universities, Inc., under contract with the National Science Foundation.

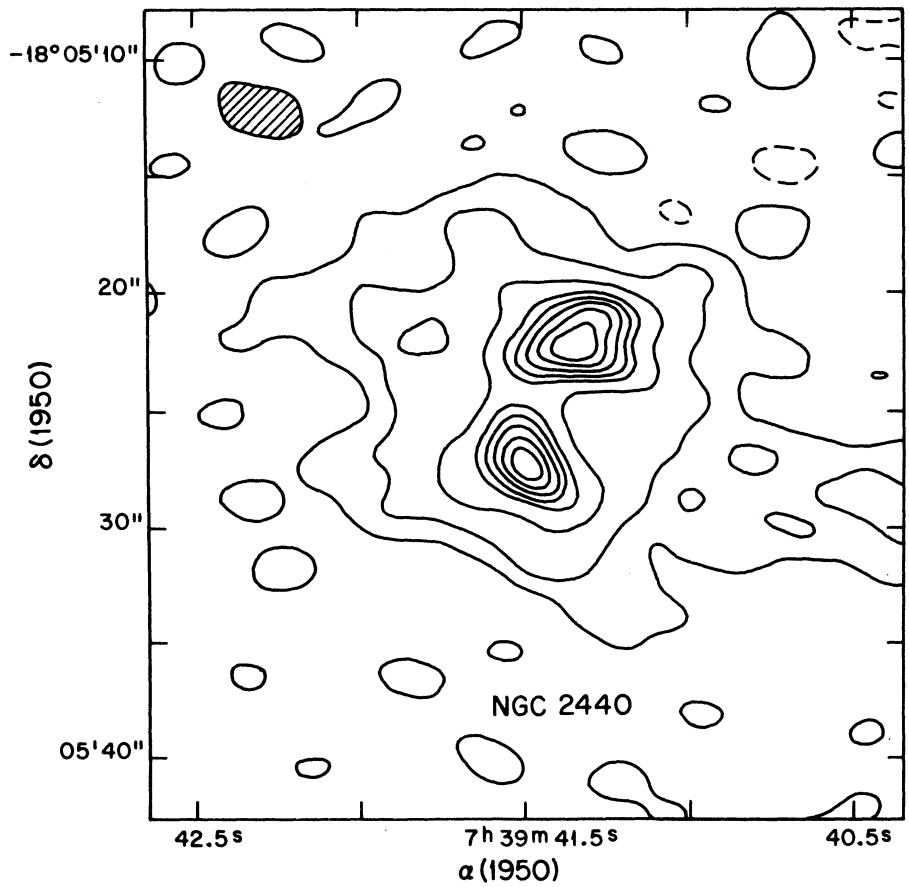

Fig. 2. Self-calibrated map of NGC 2440 in the continuum at 21-cm. The contours are −0.03, 0.03, 0.1, 0.3, 0.5, 0.6, 0.7, 0.8, and 0.9 of the peak flux density of 30.7 mJy/beam.

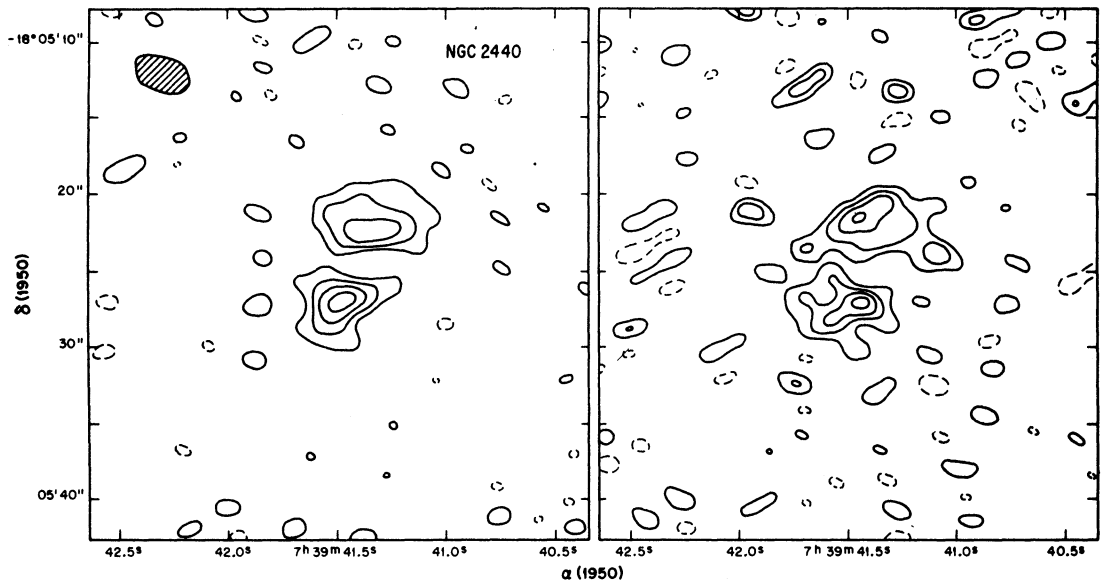

Fig. 3. Maps of NGC 2440 for the velocity ranges of −8.2 to 2.2 km s^{-1} (left) and 23.0 to 33.4 km s^{-1} (right). The contours are −0.3, 0.3, 0.5, 0.7 and 0.9 of the peak flux densities of 20.6 and 16.8 mJy/beam, respectively.

most of the absorption in the two features. The maps are shown in Figure 3. Although the signal-to-noise ratio is limited, the maps are similar to the continuum map shown in Figure 2. We interpret this result in the sense that the absorption is produced by line-of-sight interstellar clouds, as first proposed by Pottasch, Gathier, and Goss (1983). Furthermore, our continuum map (Figure 2) is similar to the short exposure Hα isophotal map of Phillips, Reay, and Worswick (1980, Figure 4). This similarity supports our suggestion that there is no localized absorption across the face of the nebula. We can also conclude that the decrease in optical emission at the center of NGC 2440 is not due to absorption but to lower emission measure. The optical and radio appearance of NGC 2440 can be accounted for qualitatively in terms of an ionized ring seen edgewise. This geometry produces the typical double maxima source surrounded by nebulosity.

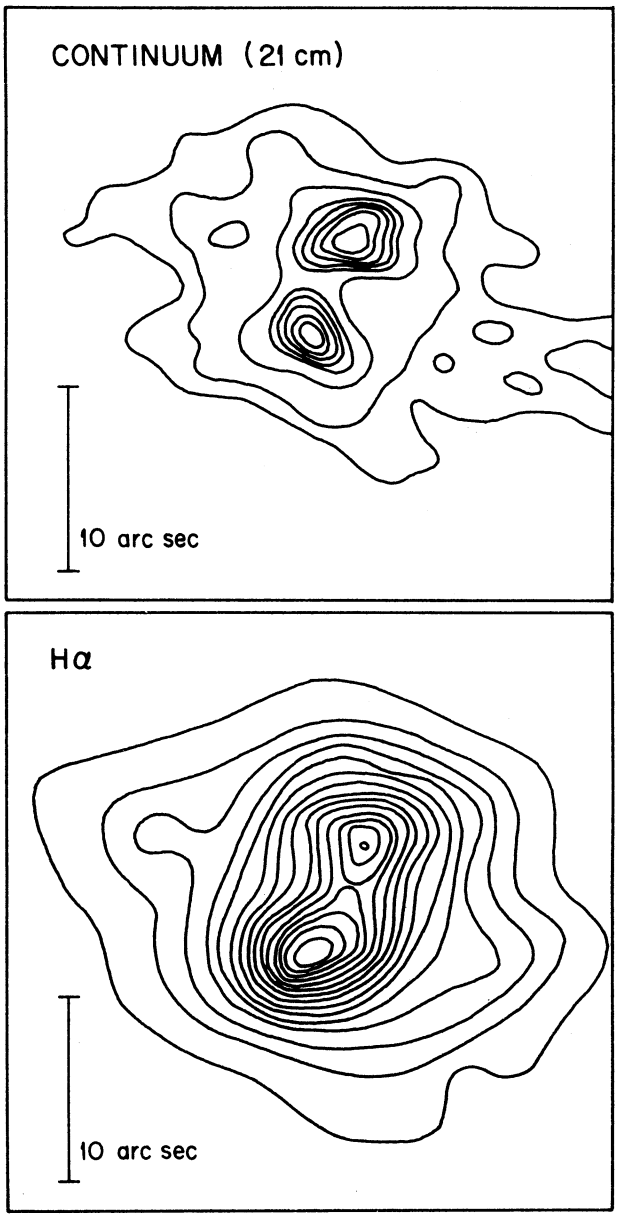

Fig. 4. Self-calibrated map of NGC 2440 in the continuum at 21-cm (top) and short exposure Hα isophotal map of Phillips *et al.* (bottom). The similarity between these maps suggest that the optical extinction toward NGC 2440 is uniform across the face of the nebula.

III. CONCLUSIONS

1. We confirmed the results of Rodríguez *et al.* (1985) that the -40 km s^{-1} H I absorption in NGC 6302 is produced by gas associated with the planetary nebulae. Our continuum map shows structures that may be related with the extended ($\sim 1'$) optical lobes.

2. The H I absorption features at 0 and 25 km s^{-1} observed toward NGC 2440 are most probably created by line-of-sight interstellar clouds unrelated to the planetary nebula. Our continuum map is similar to the Hα isophotal map of Phillips *et al.* (1980), supporting the conclusion that there is no localized absorption across the face of the nebula.

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