RevMexAA (Serie de Conferencias), **15**, 194–196 (2003)

RADIO DETECTION OF THE EXCITING SOURCES OF SHELL H II REGIONS IN NGC 6334

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RESUMEN

Presentamos los resultados de observaciones de alta sensitividad y resolución angular hechas con el VLA a varias frecuencias hacia el complejo de formación estelar NGC 6334. Encontramos que NGC 6334E, previamente descrita como esférica, tiene morfología de cáscara. Una región adicional con forma de cáscara, G351.02+0.65, fue cartografiada a 330 MHz. Cuatro de las fuentes en NGC 6334 presentan morfología de cáscara: sus diámetros van de 0.12 a 3.5 pc. Detectamos fuentes compactas de radio en el centro de las cáscaras NGC 6334E y NGC 6334A. Creemos que estas fuentes compactas están asociadas con las estrellas excitadoras de las regiones H II. Esta es la primera vez, para cualquier región H II, que la cáscara y el objeto central son detectados simultaneamente en el radio.

ABSTRACT

We present results of high-sensitivity, high-resolution, multi-frequency VLA observations toward the star-forming complex NGC 6334. We find that the H II region NGC 6334E, previously described as spherical, has a shell-like morphology. An additional shell-like radio source, G351.02+0.65, is mapped at 330 MHz. Four radio sources in the NGC 6334 complex present shell-like morphology; their diameters vary from 0.12 pc to 3.5 pc. Compact radio sources are detected at the center of the shells of NGC 6334E and NGC 6334A. These compact sources are believed to be associated with the exciting stars of the H II regions. This is the first time for any H II region that both the shell and the central object are detected simultaneously in the radio.

Key Words: **H II REGIONS — ISM: BUBBLES — STARS: MASS LOSS**

1. INTRODUCTION

The massive-star forming region NGC 6334 has been the subject of numerous studies at radio and infrared wavelengths. We have recently reported a detailed radio study of the whole region (Carral et al. 2002). In this paper we concentrate on four of the H II regions that exhibit a shell-like morphology: NGC 6334A, NGC 6334E, G351.20+0.70, and G351.02+0.65.

2. OBSERVATIONS

All observations reported here were made using the Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO).[6] The data were edited, calibrated, and imaged using the software package Astronomical Image Processing System (AIPS) of NRAO.

Various source parameters of the four shell-like H II regions are summarized in Table 1. Next, we briefly describe the results for the individual H II regions.

2.1. *NGC 6334A*

The 3.5 cm map of NGC 6334A in Figure 1 clearly shows its shell-like morphology. In addition to the shell-like structure, the 3.5 cm map shows an unresolved source located near the shell center. Its position is $\alpha(2000) = 17^{\rm h}20^{\rm m}19\overset{\rm s}{.}203$, $\delta(2000) = -35^\circ 54' 41\overset{''}{.}22$, with an error of $0\overset{''}{.}03$, and its flux density is 6.1 ± 0.9 mJy.

2.2. *NGC 6334E*

A natural-weighted 3.5 cm map of the NGC 6334E region is shown in Figure 2. This region was originally classified as spherical by Rodríguez, Cantó, & Moran (1982). Our map, however, shows that a shell-like classification is more appropriate. It also reveals a compact source at the center of the H II region. This source is unresolved ($\leq 0\overset{''}{.}3$; 510 AU) and has a flux density of 1.3 ± 0.1 mJy. The compact radio source

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[6]NRAO is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.

TABLE 1

PARAMETERS OF REGIONS WITH SHELL MORPHOLOGY IN NGC 6334

Region	Shell 6 cm Flux Density (Jy)	Diameter[a] (pc)	Thickness[a] (pc)	Central Source 3.5 cm Flux Density (mJy)
NGC 6334A	$\sim 10^{b}$	0.12	0.016	6.1 ± 0.9
NGC 6334E	$\sim 12^{b}$	0.25	0.03	1.3 ± 0.1
G351.20+0.70	4^{c}	1.1^{d}	0.2^{d}	...
G351.02+0.65	$\gtrsim 4.5$	3.5	0.4	...

[a]Rough estimates from the maps. [b]From Rodríguez, Cantó, & Moran (1982). [c]From Moran et al. (1990).
[d]From Figure 1 of Jackson & Kraemer (1999).

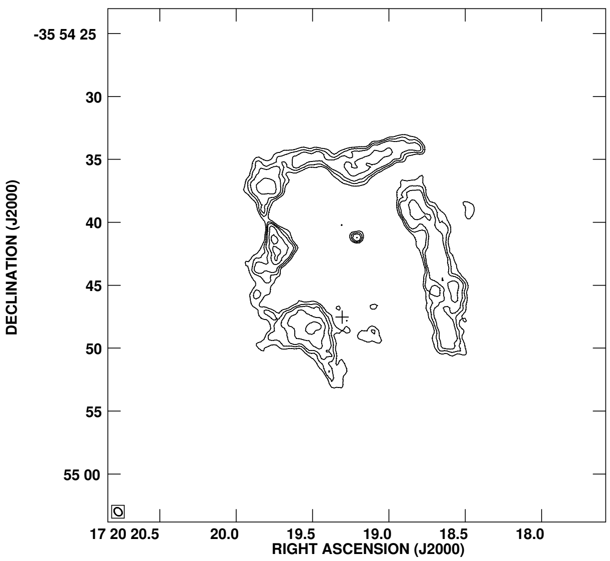

Fig. 1. The 3.5 cm image of the H II region NGC 6334A. Contours are −4, 4, 5, 6, 8, 10 and 12 times 1.3 mJy beam^{-1}, the rms noise of the image. The compact source near the center of the nebula is proposed to trace the exciting star. There are no known counterparts to this radio source. The small cross marks the position of IRS 19, taken from the Two Micron All-Sky Survey (2MASS). The half power contour of the beam ($0''.72 \times 0''.56$; PA = 41°) is shown in the bottom left corner of the image.

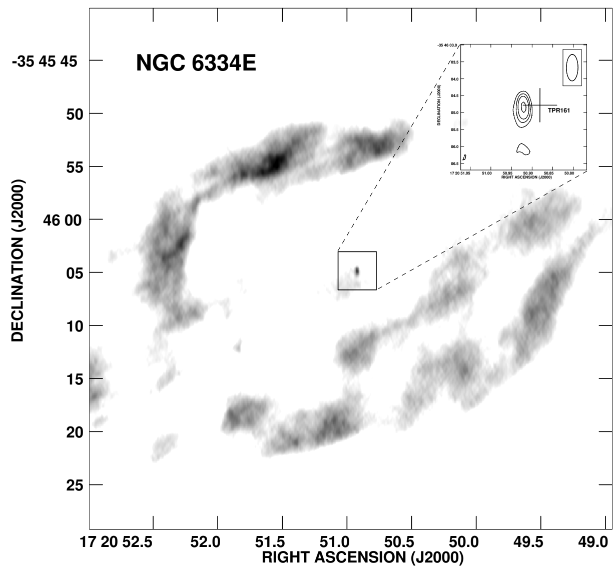

Fig. 2. Greyscale map at 3.5 cm of the shell-like H II region NGC 6334E, made with natural weighting. The emission shown is that above 0.6 mJy beam^{-1}, with a peak value of 2.1 mJy beam^{-1}. Contours (inset) are −4, 4, 5, 6, and 8 times 0.2 mJy beam^{-1}. The cross marks the position of the near infrared source, TPR161, taken from the Two Micron All Sky Survey (2MASS). The half power contour of the beam ($0''.78 \times 0''.34$; PA = −1°) is shown in the top right corner.

is located, with an estimated error of $0''.1$, at $\alpha(2000) = 17^{h}20^{m}50^{s}.9$, $\delta(2000) = -35°46'04''.8$, less than $0''.5$ from the red source TPR161 (Tapia, Persi, & Roth 1996) as measured by 2MASS.

2.3. *G351.20+0.70*

We refer the reader to the paper by Jackson & Kraemer (1999) for a detailed discussion of this source.

2.4. *G351.02+0.65*

This source is shown in Figure 3 where our 330 MHz contour plot has been superimposed on the red image of the Palomar Sky Survey. The radio morphology of G351.02+0.65 is shell-like with a large opening toward the south-west (SW). An asymmetry is also evident in the red image of the Palomar catalog where the source has a limb-brightened circular morphology but the circle is "truncated" towards the SW. The fact that the radio shell extends

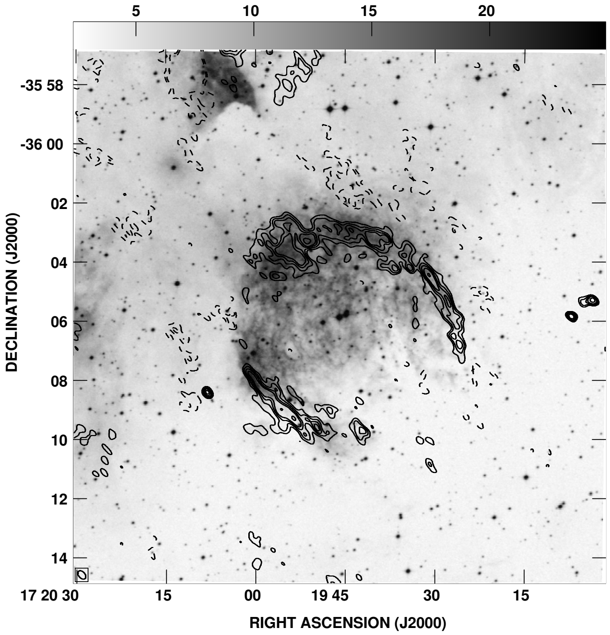

Fig. 3. Overlay of the VLA 330 MHz image (contours) of G351.02+0.65 on the Palomar red image. The radio continuum emission generally coincides well with the edge of the nebulosity seen in the Palomar plate. Several bright sources are seen in the radio contours; they are probably extra-galactic objects. The two bright stars at the center of the nebula are the binary system HD 319703. Contour levels for the 330 MHz continuum are −4, −3, 3, 4, 5, 6, 8, and 10 times 7 mJy beam^{-1}. The synthesized beam of the VLA image is shown in the bottom left corner.

further than the optical image suggests that the optical asymmetry arises from obscuration local to the NGC 6334 complex.

3. DISCUSSION AND CONCLUSIONS

Our detection of central sources associated with two young shells seems to suggest a wind-driven bubble scenario (e.g., Dyson & Williams 1997). Assuming that the central radio sources in NGC 6334E and NGC 6334A are associated with stellar winds, one can estimate the mass loss rate $\dot{M}$ following the calculations of Panagia & Felli (1975). If we assume a wind electron temperature of $T = 10^4$ K, a wind velocity of $v_{\rm exp} = 1000\,{\rm km\,s^{-1}}$, an average ionic charge of $\bar{Z} = 1$, and a mean atomic weight per electron, $\mu = 1.2$, we derive $\dot{M} = 8.5 \times 10^{-6}\,M_\odot\,{\rm yr}^{-1}$ for NGC 6334E, given the measured flux. The corresponding mechanical luminosity would be $L_{\rm w} = 2.7 \times 10^{36}\,{\rm erg\,s^{-1}}$. Similarly for NGC 6334A, the estimated mass-loss rate is $\dot{M} = 3.0 \times 10^{-5}\,M_\odot\,{\rm yr}^{-1}$ with a mechanical luminosity of $L_{\rm w} = 9.6 \times 10^{36}\,{\rm erg\,s^{-1}}$. Such high values of $\dot{M}$ have been measured in early-type stars with luminosities $L \sim 10^6\,L_\odot$ (e.g., Abbott, Bieging, & Churchwell 1981), but in NGC 6334E and NGC 6334A the ionization of each region implies an O7.5 ZAMS star with a corresponding luminosity of only $L \sim 8 \times 10^4\,L_\odot$. Furthermore, the large mechanical luminosities derived would imply large expansion velocities for these shell H II regions, velocities that are not observed. Our unpublished observations (Kurtz et al. 2003) of the central sources of NGC 6334A and NGC 6334E indicate that part of the radio emission is arising from non-thermal processes and that the derived mechanical luminosities could be overestimates.

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