Revista Mexicana de Astronomía y Astrofísica, **50**, 3–6 (2014)

NEW RADIO CONTINUUM OBSERVATIONS OF THE COMPACT SOURCE PROJECTED INSIDE NGC 6334A

Luis F. Rodríguez,[1,2] Josep M. Masqué,[1] Sergio A. Dzib,[1]
Laurent Loinard,[1] and Stanley E. Kurtz[1]

Received 2013 July 22; accepted 2013 September 9

RESUMEN

Se sabe que unas pocas regiones HII muestran una fuente compacta de radio cerca de su centro. La naturaleza de estas fuentes compactas no está bien establecida. Presentamos el análisis de datos tanto nuevos como de archivo del *Very Large Array* de la fuente compacta proyectada cerca del centro de la región HII NGC 6334A, parte del complejo de NGC 6334. Mostramos que la fuente es variable en el tiempo en escalas de años y para una época determinamos un espectro no-térmico, sugiriendo emisión sincrotrónica. Proponemos que esta fuente es la región de interacción de los vientos de un sistema binario masivo que podría ser la fuente ionizadora de NGC 6334A.

ABSTRACT

A handful of HII regions are known to exhibit a compact radio source near their centers. The nature of these compact radio sources is not well established. We present the analysis of new as well as archival Very Large Array observations of the compact source projected near the center of the NGC 6334A HII region, part of the NGC 6334 complex. We show that the compact source is time variable on a scale of years and determine for one epoch a non-thermal spectrum, suggestive of synchrotron emission. We propose that this source could be the wind interaction region of a massive binary system that could be the ionizing source of NGC 6334A.

Key Words: HII regions — ISM: individual objects (NGC 6334A) — radio continuum: stars

© Copyright 2014: Instituto de Astronomía, Universidad Nacional Autónoma de México

1. INTRODUCTION

It is well known that the centimeter continuum radiation from classic HII regions is dominated by strong free-free emission from the extended ionized gas present there. However, when observed with the high angular resolution provided by an interferometer, the extended emission is filtered out and one starts to detect compact sub-arcsecond sources of various natures. These sources include thermal (i.e. free-free) emitters such as hypercompact (HC) HII regions, externally ionized globules, proplyds, thermal jets, and ionized stellar winds. On the other hand, non thermal emitters include young low-mass stars that can have strong magnetospheric activity and emit detectable gyrosynchrotron radiation and massive binary stars that can produce synchrotron radiation in the region where their winds collide (see Rodríguez et al. 2012b for a more detailed discussion on these different types of radio sources).

Evidence for what could be a new type of compact radio source has recently become available. In the case of the well studied ultracompact HII region W3(OH), Dzib et al. (2013b) have reported that a compact radio source at its center is time variable and has a positive spectral index and a brightness temperature suggestive of partially optically-thick free-free radiation. This source is associated with the exciting source of the HII region and Dzib et al. (2013b) tentatively propose that the radio emission could arise in a static ionized atmosphere around a fossil photoevaporated disk. This radio source was originally detected by Kawamura & Masson (1998) but no further research has been published.

A similar compact radio source was reported by Carral et al. (2002), in this case at the center of the compact HII region NGC 6334A. This region,

[1]Centro de Radioastronomía y Astrofísica, Universidad Nacional Autónoma de México, Morelia, México.

[2]Astronomy Department, Faculty of Science, King Abdulaziz University, Saudi Arabia.

TABLE 1

VERY LARGE ARRAY OBSERVATIONS

Epoch	Frequency (GHz)	Phase Calibrator	Bootstrapped Flux (Jy)	Conf.	Synthesized Beam[b]	Flux Compact Source (mJy)	Project
1997 Feb 02	8.46	1733−130	9.18 ±0.01	A	$0''.67 \times 0''.53; +29^\circ$	7.0±0.8	AT202
2002 May 01	8.46	1744−312	0.615±0.001	A	$0''.53 \times 0''.20; -12^\circ$	3.3±0.5	AR474
2002 May 01	14.9	1744−312	0.860±0.009	A	$0''.30 \times 0''.12; +1^\circ$	1.7±0.4	AR474
2002 May 01	43.3	1744−312	1.00 ±0.01	A	$0''.15 \times 0''.05; -7^\circ$	≤1.0[a]	AR474
2006 Aug 18	8.46	1744−312	0.587±0.005	B	$1''.94 \times 0''.44; +3^\circ$	≤2.9[a]	S7810

[a]Three-sigma upper limit.

[b]Half power full width dimensions in arc seconds and position of major axis in degrees.

© Copyright 2014: Instituto de Astronomía, Universidad Nacional Autónoma de México

first reported by Rodríguez, Cantó & Moran (1982), is found in the massive star-forming complex NGC 6334, at a distance of 1.7 kpc. The location of the compact radio source, centered on the shell-like morphology displayed by NGC 6334A (see Figure 4 of Carral et al. 2002), suggests an association with the star exciting the HII region. To obtain additional information on the nature of these continuum radio sources at the center of compact and ultracompact HII regions, we have analyzed new as well as unpublished high angular resolution archive data from the Very Large Array (VLA) of the NRAO[3] taken toward NGC 6334A.

2. DATA REDUCTION

The search for these compact radio sources embedded in larger structures can only be performed using observations of the highest angular resolution possible. This seriously limits the observations that can be used. In Table 1 we list the data used in this study. The 1997 observations are those already reported by Carral et al. (2002). The 2002 observations were taken by us as a follow-up study to the Carral et al. (2002) results. Finally, the 2006 data are available in the VLA archives. The data were edited and calibrated using the software package Astronomical Image Processing System (AIPS) of NRAO. The 8.46 GHz observations were self-calibrated in phase and amplitude. The images were made using only visibilities with a baseline larger than 75 kλ, suppressing structures larger than $\sim 3''$. The flux densities determined for the compact source at the center of NGC 6334A are given in Table 1.

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

3. RESULTS

We found observations at 8.46 GHz for three epochs. Images from these observations are shown in Figure 1. The compact source is clearly detected in the first two epochs and an upper limit was set for the third epoch. Clearly, the source is time variable, with a flux density in 1997 about twice as large as in 2002. The upper limit for 2006 is not particularly stringent but it does indicate that the source has not gone back to flux densities comparable to those of 1997. For 1997 and 2006 the observations were centered on the nearby quasar J17204-3554 (Rodríguez, Gómez, & Tafoya 2012a) and the flux densities have been corrected for the response of the primary beam. The positions of the compact source determined for 1997 and 2002 differ by about $0''.4$ in the north-south direction (see Figure 1). We have checked the accuracy of the phase calibrators used and discarded the possibility of attributing this effect to a poorly determined position of these calibrators. There is a possibility that we are observing large proper motions but for the moment we will adopt the conservative hypothesis that this difference is simply due to the low declination of the source, which can introduce systematic shifts in position. We expect to test this discrepancy in the future with new observations.

There is no counterpart to the compact radio source at other wavelengths, despite sensitive searches in the optical (Russeil et al. 2012), infrared (Straw & Hyland 1989) and X-rays (Feigelson et al. 2009). Most probably, this is the result of the large extinction expected toward this embedded source.

For 2002 we also have observations at 14.9 and 43.3 GHz. The source is marginally detected at 14.9 GHz (see Table 1 and Figure 2) and an upper limit was set at 43.3 GHz. By fitting a power-law to the 8.46 and 14.9 GHz detections, we obtain the spec-

© Copyright 2014: Instituto de Astronomía, Universidad Nacional Autónoma de México

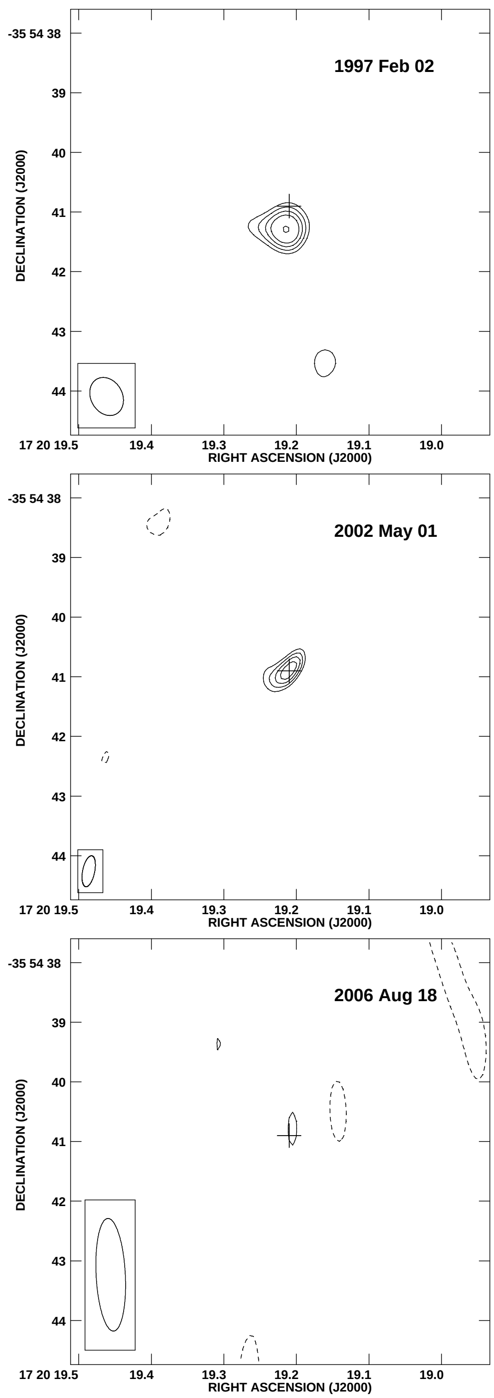

Fig. 1. VLA contour images of the 8.46 GHz continuum emission toward the compact source at the center of NGC 6334A for three different epochs. Contours are −4, −3, 3, 4, 5, 6, and 8 times the rms noise of each image (840, 450 and 960 μJy beam^{-1} for the 1997, 2002, and 2006 images, respectively). The cross marks the position of the compact source derived from the 8.46 GHz image of 2002, $\alpha(2000) = 17^h20^m19.''21$; $\delta(2000) = -35^\circ54'40.''9$.

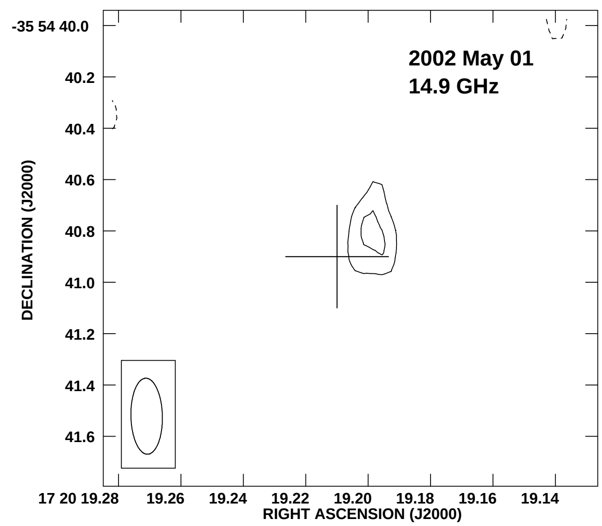

Fig. 2. VLA contour image of the 14.9 GHz continuum emission toward the compact source in NGC 6334A. Contours are −3, 3, and 4 times 400 μJy beam^{-1}, the rms noise of the image. The cross marks the position of the compact source derived from the 8.46 GHz image of the same epoch.

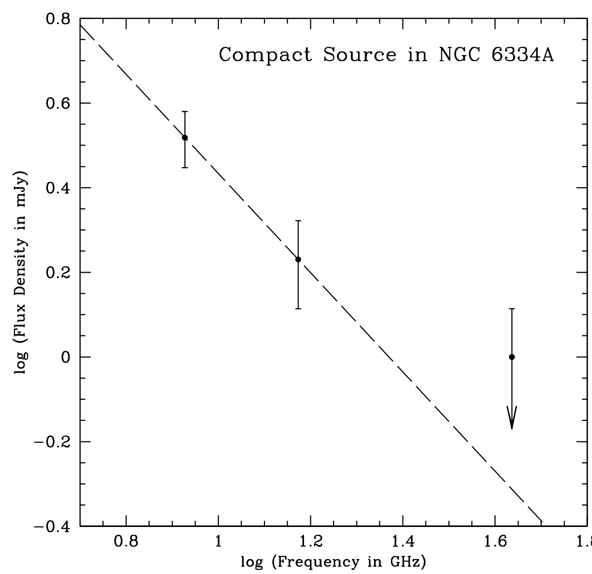

Fig. 3. Spectrum of the continuum emission of the compact source in NGC 6334A. The dashed line is the $S_\nu \propto \nu^{-1.2}$ fit.

tral index of the spectrum (see Figure 3), given by $S_\nu \propto \nu^{-1.2\pm0.5}$. This spectral index is consistent with the values expected from optically-thin synchrotron emission (i.e. Longair 2011). Our estimate of the spectral index was made assuming that the source is unresolved at all observed frequencies.

4. DISCUSSION AND CONCLUSIONS

Our results indicate that the compact radio continuum source at the center of NGC 6334A is time variable on a scale of years and has a spectral index suggestive of optically-thin synchrotron emission. The type of emission that best fits these characteristics corresponds to that coming from the wind interaction region of massive binary systems (see, for example, the case of Cyg OB2 #5 recently discussed by Ortiz-León et al. 2011 and Dzib et al. 2013a). In these sources the winds of the components of the binary produce a shocked region between the stars where electrons can reach relativistic speeds by Fermi acceleration, producing synchrotron emission. As the binary system rotates, the wind interaction region can move behind the optically thick free-free envelopes produced by the stellar winds and become undetectable. This interpretation can be tested with future observations, made over a long time span. In this type of sources the variability of the radio emission is clearly periodic (i.e. Dougherty & Williams 2000; Blomme et al. 2013). Furthermore, the synchrotron emitting region is very compact and can be detected and studied at the milli-arcsecond scale, with Very Long Baseline Interferometry observations (i.e. Ortiz-León et al. 2011; Dzib et al. 2013a).

We are also undertaking a reanalysis of good quality VLA observations of compact, ultracompact, and hypercompact HII regions to search for additional examples. With only two cases reported to date it is very difficult to reach general conclusions. For example, the compact source associated with W3(OH) appears to be thermal, while that associated with NGC 63334A and discussed here appears to be non-thermal, suggesting more than one origin for this type of source.

LFR, LL, and SEK are thankful for the support of DGAPA, Universidad Nacional Autónoma de México, and of Conacyt (Mexico). This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

REFERENCES

Blomme, R., et al. 2013, A&A, 550, A90
Carral, P., Kurtz, S. E., Rodríguez, L. F., Menten, K., Cantó, J., & Arceo, R. 2002, AJ, 123, 2574
Dougherty, S. M., & Williams, P. M. 2000, MNRAS, 319, 1005
Dzib, S. A., Rodríguez, L. F., Loinard, L., Mioduszewski, A., Ortiz-Len, G., & Araudo, A. 2013a, ApJ, 763, 139
Dzib, S. A., Rodríguez-Garza, C. B., Rodríguez, L. F., Kurtz, S., Loinard, L., Zapata, L., & Lizano, S. 2013b, ApJ, 772, 151
Feigelson, E. D., Martin, A. L., McNeill, C. J., Broos, P. S., & Garmire, G. P. 2009, AJ, 138, 227
Kawamura, J. H., & Masson, C. R. 1998, ApJ, 509, 270
Longair, M. S. 2011, High Energy Astrophysics (Cambridge: Cambridge Univ. Press)
Ortiz-León, G. N., Loinard, L., Rodríguez, L. F., Mioduszewski, A. J., & Dzib, S. A. 2011, ApJ, 737, 30
Rodríguez, L. F., Cantó, J., & Moran, J. M. 1982, ApJ, 255, 103
Rodríguez, L. F., Gómez, Y., & Tafoya, D. 2012a, MNRAS, 420, 279
Rodríguez, L. F., González, R. F., Montes, G., Asiri, H., Raga, A., & Cantó, J. 2012b, ApJ, 755, 152
Russeil, D., et al. 2012, A&A, 538, A142
Straw, S. M., & Hyland, A. R. 1989, ApJ, 342, 876

Sergio A. Dzib, Stanley E. Kurtz, Laurent Loinard, Josep M. Masqué, and Luis F. Rodríguez: Centro de Radioastronomía y Astrofísica, Universidad Nacional Autónoma de México, Apdo. Postal 3-72, (Xangari), 58089 Morelia, Michoacán, Mexico (s.dzib, s.kurtz, l.loinard, j.masque, l.rodriguez@crya.unam.mx).

© Copyright 2014: Instituto de Astronomía, Universidad Nacional Autónoma de México