# New Radio Supernova Remnants in the Core of M31

Lorant O. Sjouwerman[1] and John R. Dickel[2]

[1] *Joint Institute for VLBI in Europe (JIVE), Dwingeloo, The Netherlands, sjouwerman@jive.nl*
[2] *University of Illinois at Urbana-Champaign, Urbana IL, USA and ASTRON, Dwingeloo, The Netherlands, johnd@astro.uiuc.edu*

**Abstract.** Five 24-hour VLA observations at 8.4 GHz of the Andromeda galaxy have been combined into a very sensitive radio image of the central 500″ (1.7 kpc) of M31. The resulting image presented here has a resolution of 0.2″ and an rms noise level of about 4 $\mu$Jy. These observations have detected three new shell supernova remnants within 250 pc of the center of M31, with sizes and luminosities of typical older remnants. In addition, a somewhat extended 27 $\mu$Jy source with a full-width half maximum size of $0.73'' \times 0.33''$ ($2.5 \times 1.1$ pc) is detected at $00^{\rm h}42^{\rm m}43\overset{\rm s}{.}136$ and $41^\circ 16' 05\overset{''}{.}06$ (J2000) which is within the positional uncertainty of the Type Ia supernova S And of 1885.

## INTRODUCTION

The center of the Andromeda galaxy (M31) is an active area, containing an extended bright central radio core [1] with a central black hole candidate, M31* [2]. The central radio source M31* was found by Crane et al. [2], who were actually searching for the 100 year old radio remnant of the Type Ia supernova S Andromedae that appeared in 1885. Crane et al. did not detect any radio remnant of SN1885a, but instead found a 28 $\mu$Jy compact radio source which they suggested to be the central black hole. Subsequent monitoring of this source revealed it was variable, supporting their view [3]. In the total monitoring program of M31*, five 24-hour VLA observations were taken over a time-span of 5.5 years at a frequency of 8.4 GHz, where only the extended A or B arrays of the VLA were utilized so that smooth emission was filtered out and making it possible to find compact sources that otherwise would have been blended into the background.

The image presented here consist of the five 24-hour monitor observations of the central region of M31 from Crane et al., which have been combined and mosaiced into a very sensitive and large high-resolution 8.4 GHz radio image of the center of that galaxy. The resulting image shown in Fig. 1 has a resolution of 0.2″ and an rms noise level of about 4 $\mu$Jy. As well as a number of compact and faint $\mu$Jy sources for which the identification is currently under investigation, at least three

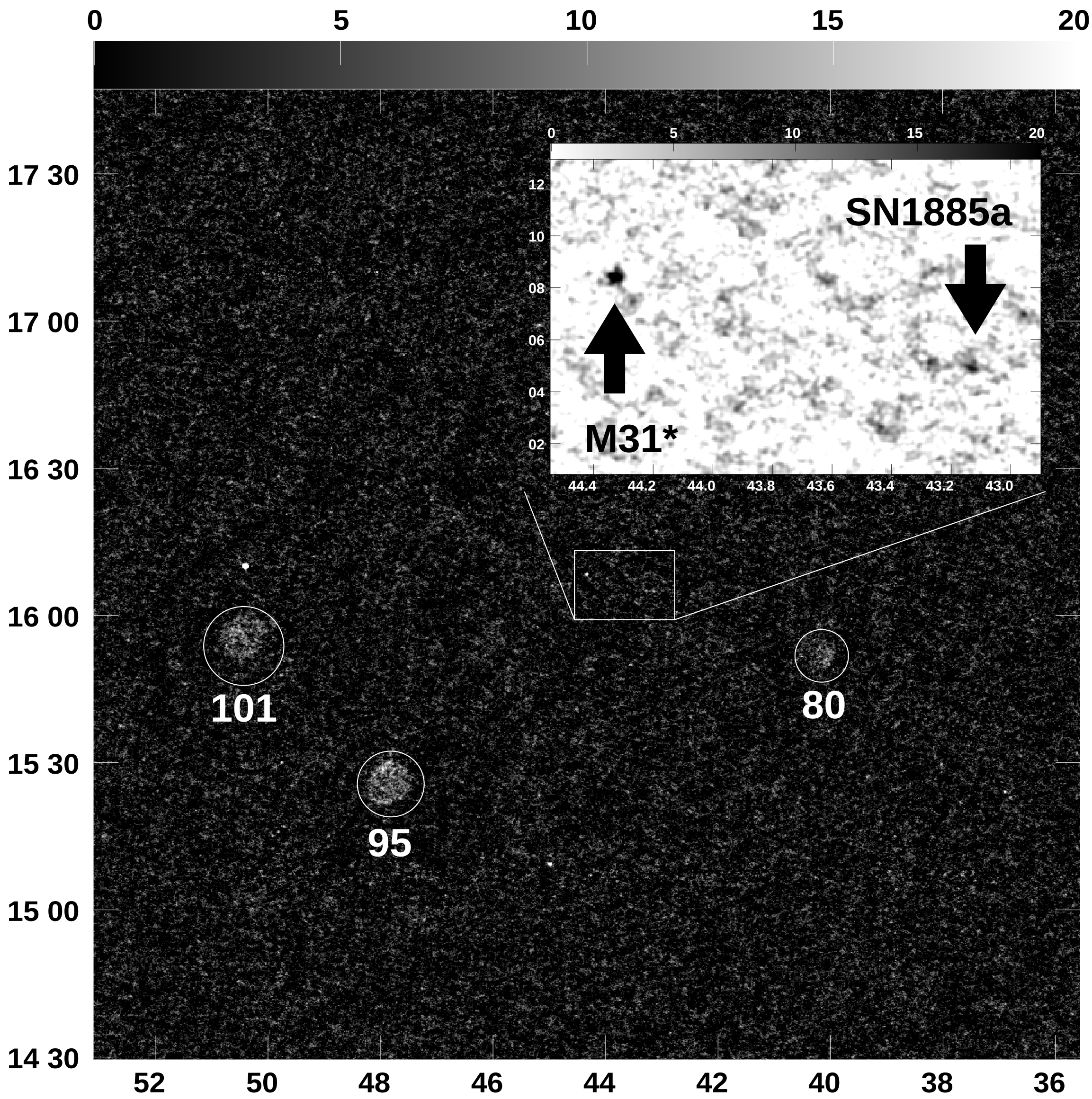


**FIGURE 1.** An 8.4 GHz VLA image of the central $200'' \times 200''$ of M31 (300 pc radius around M31* in the very center of the image) at $0.2''$ resolution. Right Ascension (J2000) is the horizontal coordinate, where the labels $00^h42^m$ are omitted for clarity; vertical is Declination (J2000) without the $41°$. The noise in this image is 3.9 $\mu$Jy, and the grey scale ranges from 0 to 20 $\mu$Jy. The newly discovered, older supernova remnants are labeled with the source numbers from a catalog by Braun [4]. The inset shows a blow-up of the very central region with the radio sources associated with M31* and the remnant SN1885a of S And. Again, the labels $00^h42^m$ and $41°16'$ are omitted for the RA and Dec, and the grey scale range is the same (but inverted).

new, older type and extended shell supernova remnants were detected within 250 pc of the center of M31. In addition, a somewhat extended 27 $\mu$Jy radio source is detected within the positional uncertainty of S And, which we propose here to be the radio remnant of SN1885a.

## THE NEW SUPERNOVA REMNANTS

Three newly detected supernova remnants lie within 250 pc of the center of M31, with sizes and luminosities of typical older remnants. They are summarized in Table 1, together with the proposed radio counterpart of SN1885a. $S_{\rm int}$ is the observed integrated flux density in mJy at 8.4 GHz, and $L_{\rm 1GHz}$ is the 1 GHz luminosity (in units of $10^{22}$ erg sec$^{-1}$ Hz$^{-1}$) scaled from the observed frequency of 8.4 GHz by the spectral index calculated by using our measurements and the 1.4 GHz measurements of Braun [4]. Because of low surface brightness and background confusion the flux densities of Braun's source "80" are uncertain and we adopt an approximate spectral index of $-0.5$ (average for supernova remnants [5]); the SN1885a remnant candidate was scaled by $-0.6$, more typical for young supernova remnants. The assumed distance to M31 is 700 kpc. $\Sigma_{\rm 1GHz}$ is the 1 GHz surface brightness (in units of $10^{-20}$ W m$^{-2}$ sr$^{-1}$). Three or four (or perhaps even more) supernova remnants within 1/8 kpc$^3$ indicates an active recent star formation. No estimate of the length of the star formation period has been attempted, because older, faint remnants remain undetected.

## A RADIO COUNTERPART OF SN1885A?

A somewhat extended 27 $\mu$Jy source with a full-width half maximum size of $0.73'' \times 0.33''$ ($2.5 \times 1.1$ pc) is detected at $00^{\rm h}42^{\rm m}43\overset{\rm s}{.}136$ and $41^\circ 16' 05\overset{''}{.}06$ (J2000), which is within the positional uncertainty of the supernova S And of the year 1885. An HST iron absorption feature reported by Fesen et al. [6], and also attributed to the remnant of SN1885a, appears to lie at $00^{\rm h}42^{\rm m}43\overset{\rm s}{.}005 \pm 0.002$ and $41^\circ 16' 04\overset{''}{.}44 \pm 0.02$ (J2000) in our radio image. This position was determined by rotating the HST image to the proper J2000 alignment and placing peak P2 of the double optical nucleus at the position of M31* on the radio image; our radio-optical position, at $14.90''$ West and $3.97''$ South of P2/M31*, differs from the Fesen et al's published J2000 position of the supernova remnant ($00^{\rm h}42^{\rm m}42\overset{\rm s}{.}89$ and $41^\circ 16' 05\overset{''}{.}0$ [6]) for unknown reasons. If the remnant is 3-4 pc across, which is not unreasonable for a 100 year old supernova remnant, we could be viewing different parts of the same object in the different wavelength bands as the expanding shell interacts with different parts of the surrounding medium.

**TABLE 1.** Supernova remnants detected within 250 pc of M31*

| R.A. and Dec. (J2000) | | Diameter (FWHM) ″ | pc | PA deg | $S_{int}$ mJy | Spectral Index | $L_{1GHz}$ | $\Sigma_{1GHz}$ | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| $00^h42^m40.^s26$ | $41°15'52.''1$ | 8.0×8.0 | 28×28 | - | 0.53 | [a] | 90. | 1.3 | 80 |
| $00^h42^m43.^s136$ | $41°16'05.''06$ | 0.73×0.33 | 2.5×1.1 | 64 | 0.027 | [b] | 6.1 | 16. | [c] |
| $00^h42^m47.^s82$ | $41°15'25.''7$ | 9.6×8.0 | 33×28 | 137 | 1.41 | −0.3 | 160. | 1.9 | 95 |
| $00^h42^m50.^s41$ | $41°15'56.''4$ | 11.6×8.4 | 40×30 | 143 | 1.29 | −0.5 | 220. | 2.1 | 101 |

$S_{int}$ is the observed integrated flux in density in mJy at 8.4 GHz.
$L_{1GHz}$ is the 1 GHz luminosity in units of $10^{22}$ erg sec$^{-1}$ Hz$^{-1}$
$\Sigma_{1GHz}$ is the 1 GHz surface brightness in units of $10^{-20}$ W m$^{-2}$ sr$^{-1}$
References correspond to source numbers in Braun 1990 [4]
[a]: Adopted spectral index of −0.5 because flux densities are confused
[b]: Adopted spectral index of −0.6 as typical of young SNRs
[c]: Radio remnant of SN1885a?

# SUMMARY

A high-sensitivity, high-resolution image of the central kpc of M31 has revealed at least three older type, previously unknown supernova remnants within 250 projected pc from the nucleus. Furthermore, a faint, extended radio source is located near the historical position of S Andromedae, the Type Ia supernova that appeared in 1885. These results indicate active recent star formation in the center of M31.

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