A possible radio supernova in NGC 3310

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Abstract. As part of an ongoing radio supernova monitoring program, a compact, variable, steep spectrum radio source has been discovered ~65 arcsec (~4 kpc) from the centre of the starburst galaxy NGC 3310. If the source is at the distance of NGC 3310, then its 5-GHz luminosity is $\sim 3 \times 10^{19}$ W Hz^{-1}. The source luminosity, together with its variability characteristics, compact structure (< 17 mas) and its association with a group of HII regions suggests that it is a previously uncatalogued Type II radio supernova. There is also evidence of an X-ray source coincident with the radio position.

THE MONITORING PROGRAM

The starformation rate (SFR) of a galaxy is an important parameter used over a wide range of astrophysics. Estimates of the SFR can be made via a number of methods, however the UV and optical methods are particularly difficult in starbursts because of the large extinction corrections required. In contrast, the radio and infra-red methods seem to give reasonably consistent results, resulting in the well known correlation between radio and FIR luminosities.

An independent estimate of the SFR can be derived from the supernova rate. If all stars with masses greater than 8 $M_\odot$ become supernovae via core collapse then, if a reasonable initial mass function is assumed, the SFR can be determined as a simple function of supernova rate. Since radio emission is not significantly affected by extinction, we have begun a search for new supernovae in nearby starburst galaxies by monitoring a sample every few months using a combination of MERLIN (Multi-Element Radio Linked Interferometer Network) and the VLA (Very Large Array). The ten galaxies in our sample, M82, NGC520, NGC891, NGC2146, UGC2866, NGC3310, NGC3628, NGC4038, NGC4631 and NGC6946, are selected to be within 15 Mpc.

The first monitoring session took place in November 2003 using the VLA in B configuration. Observations were made of all ten galaxies in the sample at 5, 8.4 and 15 GHz and mapped in AIPS using standard techniques. A second set of observations were conducted at 5 GHz with MERLIN in March 2004 which included all but NGC 4038 as this source is at too low a declination for observations at this latitude.

J103851+532927

In the analysis of the first epoch observations, a particularly strong radio source was found in the outer part of NGC 3310. This source was observed further with MERLIN in

January and March 2004 in order to provide further constraints on the size and spectral index. Figure 1 shows an optical image of NGC 3310 from the Digitised Sky Survey with the November VLA 5 GHz data as contours. The central region of the galaxy shows several compact components in good agreement with previous observations. The inset shows the March 2004 MERLIN 5 GHz map of the new source, known as J103851+532927.

In order to further investigate the nature of J103851+532927, archival data from both the VLA and MERLIN have also been imaged. Measurements, including both recent and archival observations, are given in Table 1 in [1]. Measurements of the flux density of J103851+532927 from all the observations that have been examined are plotted in Figure 2. Much of the early data give only upper limits, and any emission that is detected is much weaker than that measured post-1997.

The data shows a 5-fold increase in the flux density of J103851+532927 at 1.4 GHz sometime in the early 1990s, and a decrease of $\sim$10% per year between 1997 and 2004. This behaviour is consistent with that of a Type II supernova [2]. Using the November 2003 data, the spectral index, α (where $S \propto \nu^{+\alpha}$) of J103851+532927 is -1.67$\pm$0.49. There is no evidence of extended structure in the 2004 MERLIN observations and Gaussian fitting gives an upper limit of <17 mas. Assuming a distance to NGC 3310 of 13.3 Mpc ($H_0 = 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, [3]) this corresponds to a linear size of <1.1 pc. MERLIN observations, made at 4546, 4994 and 5186 MHz, also confirmed the steep spectral index (α -1.49$\pm$0.26) of the source.

A radio supernova?

The rise and subsequent decline of the radio light curve is strong evidence in favour of this hypothesis. The timescale of the decrease is consistent with that observed in known Type II radio rupernovae such as SN1979C [4], the radio luminosity of which decreased by less than a factor of two over two decades. If the source is at the distance of NGC 3310 then its radio luminosity is $\sim 3\times10^{19}$ W Hz^{-1}, also consistent with known Type II RSNs.

J103851+532927 lies within a cluster of HII regions [5], marked as crosses in Figure 1, hence star formation is ongoing and supernovae are likely. The weak pre-1997 emission could be due either to the existing HII regions or older SNRs. There is also a catalogued *ROSAT* X-ray source coincident (to within the large positional uncertainty) with the position of J103851+532927 ([6]) which has a luminosity of 1.78×10^{38} erg s^{-1} which is also consistent with known RSNs.

However, recent observations with *Chandra* show that there is another, much fainter, X-ray source that is coincident with the position of J103851+532927 to within $\pm 1''$(Jenkins & Ward, private communication).

A search for optical observations of NGC 3310, particularly during the early 1990s, reveals no obvious optical counterpart at the position of the radio supernova. It may be that the supernova was embedded in a dense molecular cloud and hence any optical emission may have been heavily reddened.

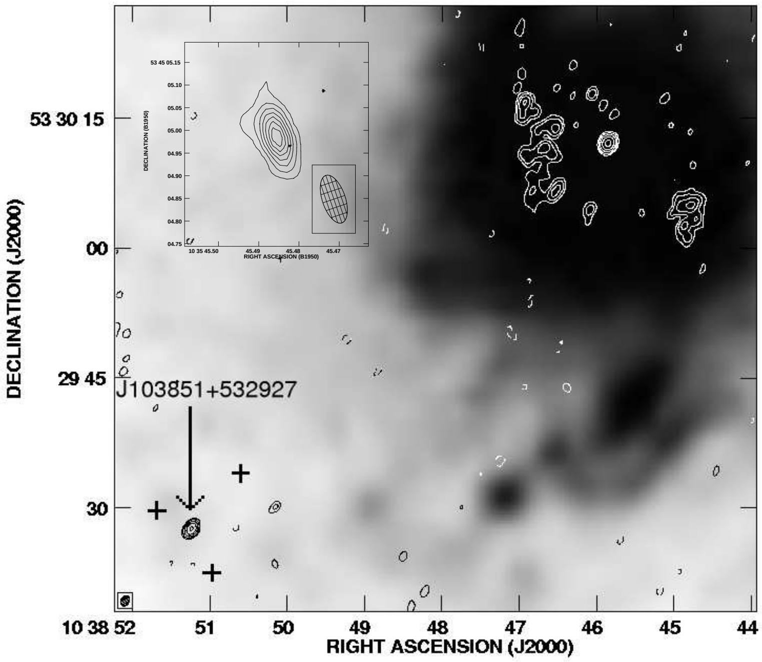

FIGURE 1. 2003 November 4.884 GHz image of NGC 3310 (contours) overlaid on a Digitised Sky Survey optical image (grey-scale). Contours are plotted at -1, 1, 2, 4, 8, 16 and 32 $\times$ 95 μJy. The crosses mark the positions of the three nearest HII regions reported by [5]. The inset shows the MERLIN 4994 MHz map of J103851+532927from 2004 March.

Other possibilities

There is a possibility that J103851+532927 could be either a background compact steep spectrum (CSS) or a GHz peaked spectrum (GPS) source. These sources tend to have double or triple component structures when observed with the $\sim$50 mas resolution of MERLIN, but our observations show the source to be unresolved to a limit of $\sim$17 mas. The variability of J103851+532927 would also seem to make this possibility less likely as CSS and GPS sources are not generally variable ([7], [8]).

A further possibility is that J103851+532927 could be a foreground Galactic pulsar, the variability being due to scintillation. The average pulsar spectral index is $\sim$1.6 (e.g. [9]), however J103851+532927 is not in existing pulsar catalogues (M. Kramer, private communication) despite its relatively high integrated flux density. The MERLIN observations would appear to rule out this possibility as, unlike most pulsars, the emission from J103851+532927 is unpolarised, and there is no sign of the scintillation which would be expected in a pulsar at such a high Galactic latitude ($b = 54°$).

CONCLUSIONS

The radio properties of the compact, steep spectrum source $\sim$4 kpc from the centre of NGC 3310 appear to be similar to those of known radio supernovae. Both the light curve

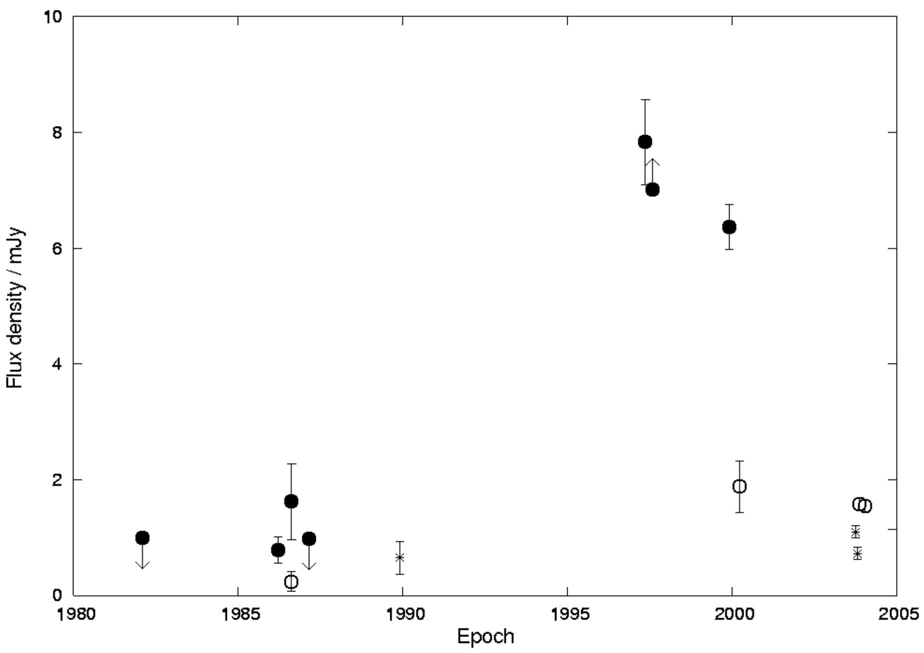

FIGURE 2. Light curve of J103851+532927 showing all measured flux densities from both recent and archival data. Filled circles, open circles and crosses indicate 1.4-, 5- and 8.4-GHz points respectively.

and the radio luminosity suggest that the source is a Type II radio supernova. The spectral index appears to be steeper than typical radio supernovae, although further observations are required to confirm this. At a typical expansion rate of $10^4\,\mathrm{km\,s^{-1}}$, at the distance of NGC 3310, a 15-yr-old SNR would have an angular size of $\sim$2 mas. Global VLBI observations have been applied for which should resolve the radio structure. The source will also continue to be included in our ongoing monitoring program.

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