# Flux Density Variations of Radio Sources in M82

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## ABSTRACT

M82 is one of the closest (D = 3.2 Mpc) starburst galaxies known, producing a large population of massive, rapidly evolving stars, and an equally large number of supernovae. We present here the results of the 2009-2010 monitoring sessions of the starburst galaxy M82, obtained with the Multi-Element Radio-Linked Interferometer Network (MERLIN) at 5-GHz and *e*-MERLIN at 6-GHz. Combining the 5-GHz MERLIN epochs to form a map with 11.8 μJy/beam noise level, 52 discrete sources, mostly supernova remnants and HII regions, are identified. These include three objects which were not detected in the 2002 5-GHz MERLIN monitoring session: supernova 2008iz, the transient source 43.78+59.3, and a new supernova remnant shell. Flux density variations, both in the long (1981 to 2010), medium (2002 to 2010) and short (2009 to 2010) term, are investigated. We find that flux densities of SNRs in M82 stay constant in most of the sample (~90-95%). In addition, aside from SN2008iz and the well-known variable source 41.95+57.5, four sources display long term variations over the period 1981-2010.

## OBSERVATIONS

The 2009 monitoring campaign of M82 consisted of seven wide-field MERLIN observations at a frequency of 4.994-GHz observed between May 2009 and April 2010. These were made using parallel hands of circular polarisation, and were correlated with a total bandwidth of 16 MHz divided into 32 channels. Across all epochs combined a total on-source integration time of 286.5hr was used. Each observing epoch was reduced and analysed individually and a deep exposure map was produced by combining all of these data. In addition to these, a single *e*-MERLIN observation was included in this study. This observation was made in December 2010 as part of the *e*-MERLIN commissioning programme and used a total bandwidth of 0.512GHz with a median frequency of 6.26GHz. These data were correlated into four individual sub-bands each divided into 512 frequency channels. These *e*-MERLIN observations were observed prior the installation of the new *e*-MERLIN wide-band IF system in spring 2011 and subsequently only one hand of polarisation was used and the data displayed reduced sensitivity in parts of the observing band.

## SOURCE VARIABILITY

To improve our analysis of variation, data taken over an 11-yrs period from 1981 (Kronberg et al. 2000) were added to the light curves when available. Changes in the flux density of the detected sources were studied in the short, medium and long term (over the 2009-2010, 2002-2010 and 1981-2010 periods respectively). A line S(t) (with t in month for short term and years for medium and long terms) was fitted through every light curve and the slope used to determine which sources displayed consistent flux density variations. The distribution of slopes was fitted with a Gaussian model (see Figure 1 below). Outliers (with rate of change outside of 4σ) indicate sources with noticeable variability (SN2008iz and the variable source 41.95+57.5, which show extreme variation, are not represented in these plots).

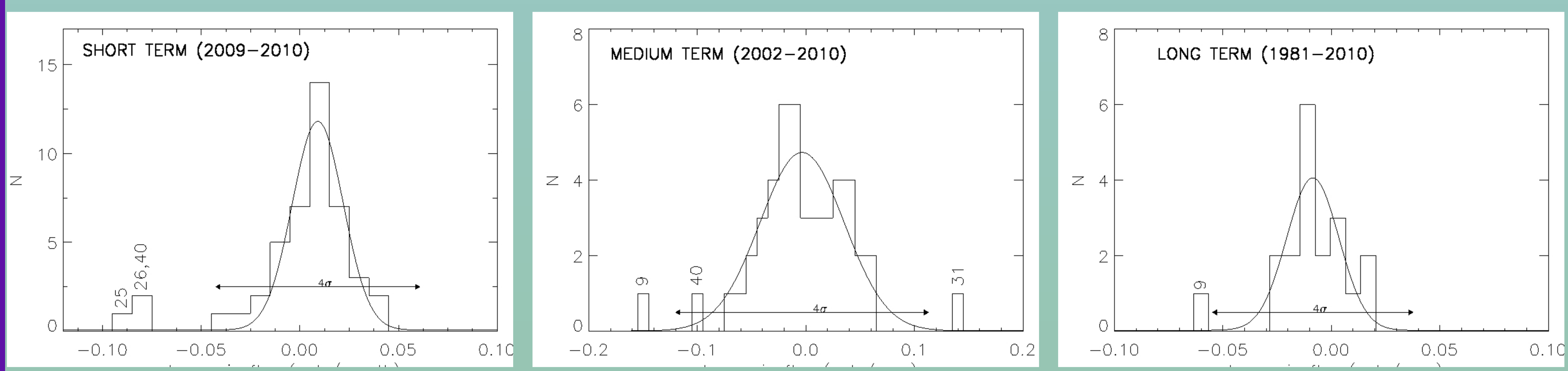
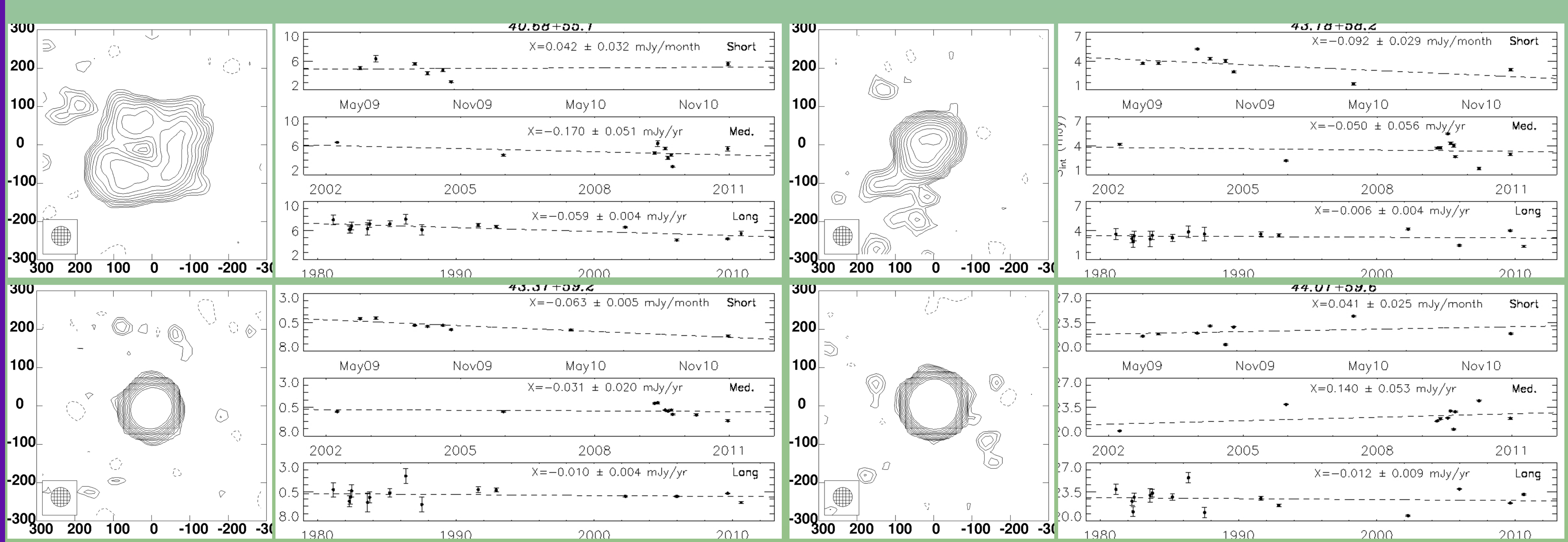



*Figure 1: Short (over the 2009-2010 period, left), medium (over the 2002-2010 period, centre) and long (over the 1981-2010 period, right) term variability. Numbers correspond to the ID of sources with rates of change outside a 4σ limit of the distribution: #9 - 40.68+55.1; #25 - 43.18+58.2; #26 - 43.31+59.2; #31 - 44.01+59.6; #40 - 45.17+61.2. Note that although source #40 lies within the 4σ limit, it still appears to be an outlier to the distribution, and will be considered as such. SN2008iz and the variable source 41.95+57.5 lie well outside the range of this plot and are not represented.*

A total of eight sources have shown flux density changes in the medium or short term, including 41.95+57.5, SN2008iz and the transient source 43.78+59.3. Four of the five other varying sources (43.18+58.2, 43.31+59.2, 44.01+59.6 and 45.17+61.2, see Figure 2) have small angular sizes, and are in fact the most compact SNR in M82 after 41.95+57.5 (Fenech et al. 2008). Based on expansion velocity measurements from VLBI and MERLIN data, Fenech et al. (2008) and Beswick et al. (2006) determined that these sources are amongst the youngest in M82, with ages ranging from 39 to 140 yrs (as of 2002). Consequently, their short and medium term brightness variations could be explained by changes in the circumstellar and interstellar mediums in which the shocks travel, with these sources being at a different temporal stage in their evolution, compared with the older more stable sources.



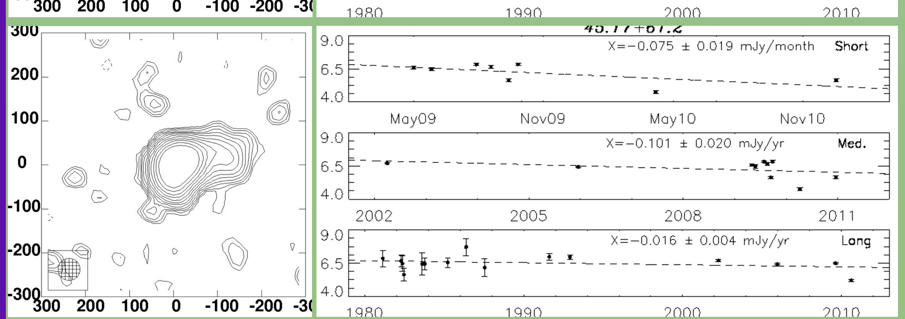


*Figure 2: Short, medium and long term light curves over the period 2009-2010 (top), 2002-2010 (centre) and 1981-2010 for sources showing noticeable decrease in flux density (aside from 41.95+57.5 and SN2008iz) in M82. A line was fitted to each curve (dashed line), with X characterising the variation in mJy/month and mJy/yr for short and medium/long terms respectively. Each panel is accompanied bya contour plot of the source from the combined 2009-2010 MERLIN data. The beam size is shown in the bottom left-hand panel.*

SNRs in M82 are expected to be the result of core-collapse supernova events with a massive, typically red supergiant (RSG), progenitor star (Fenech et al. 2010). At the time of the supernova explosion, there will be a complex circumstellar environment consisting of a slow-moving dense RSG wind followed by a wind-blown bubble of almost constant low density produced by the main-sequence low-density, high-velocity wind. It is generally accepted that following the evolution through the wind-blown bubble, it is likely that there will be a marked peak in flux density as the supernova ejecta travels from the low-density wind-blown bubble into the higher density ISM (particularly in the case of M82). This will primarily be caused by the production of a thin-dense shell at the edge of the wind-blown bubble. There will however, also be a subsequent decline in flux density as the ejecta traverses this shell and emerges into the ISM, traditionally considered the transitional phase from a supernova to a supernova remnant. It is possible that this could provide an explanation for the observed flux-density decay. Continued regular monitoring of these sources will give us more insights to their behaviour. It is now possible to carry this out with new sensitive instruments such as e-MERLIN and the EVLA, and we expect to get a more complete view of the evolution of SNRs in M82.

## 41.95+57.5 – KNOWN VARIABLE

This source has shown a continued decrease in flux density of ~8.8%/yr since its first observation in 1965 (Trotman 1996). This decay rate would imply that, at birth, the source would have had a flux density of ~30 Jy. These two facts (continuous decay and high flux density at birth) suggest that 41.95+57.5 is likely to be an exotic event and several suggestions have been made as to its nature, including the possibility that it may have been an off-axis gamma-ray burst.

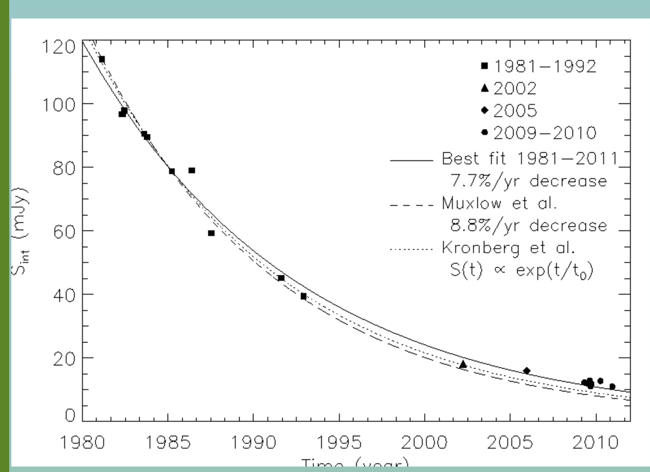


*Figure 3: Light curve for the source 41.95+57.5 over the period 1981-2010. Models for the flux density decrease are based on an exponential decay (Kronberg et al. 2000; dotted line), an 8.8%/yr decay (Muxlow et al. 2005; dashed line) and our best fit 7.7%/yr decay (solid line).*

As seen in Figure 3, 41.95+57.5 still shows a steady decrease in flux density. However, its rate of change seems to have decreased from 8.8%/yr to closer to 7.5%/yr (best fit decrease models give 7.7%/yr and 7.4%/yr over the periods 1981-2010 and 2002-2010 respectively). VLBI observations of 41.95+57.5 in November 1998 and February 2001 shows the source to be expanding at a rate of ~2000±500km/s. However, further VLBI data from 2005 shows that the apparent size of 41.95+57.5 may have decreased between 2001 and 2005 (30.4 mas in 2001 and 26.85 mas in 2005).

The unusually luminous radio supernova 1986J in NGC891 and 41.95+57.5 show some distinct similarities. Both sources display an asymmetric radio structure on milliarcsecond scales, modest expansion velocities, relatively high initial radio luminosities and a power-law flux density decay (Bietenholz et al. 2010). Both the possible decrease in apparent angular size and the small deviation from the historical flux density decline of 41.95+57.5 in these recent 5-GHz flux density measurements are consistent with the potential appearance of a new higher frequency central component within the shell. As such, this source may be undergoing an evolution analogous to that observed in SN1986J, albeit in a much older remnant. Unfortunately, the MERLIN and e-MERLIN observations presented here do not have adequate angular resolution to image in detail the structure of this source and, as yet, higher frequency (>1.6-GHz) VLBI observations have not confirmed this hypothesis. Further analysis of the variation in flux densities of 41.95+57.5 and SN1986J, both in time and frequency, would be needed to assess the similarity between the sources.

## 42.81+59.6 - SN2008iz

The light curve of SN2008iz from the presented MERLIN data and supplemented by data from Marchili et al. (2010) is shown in Figure 4. Following Marchili et al. (2010), the flux density decline after reaching peak brightness can be modelled using an exponential decay:

$S(t)=K_1(t-t_0)^{\beta}e^{-\tau}$ $\qquad \tau=K_2(t-t_0)^{\delta}$

where $t_0$ is the explosion date, which was fitted to be February 18, 2008. The 2009-2010 data display a flattening of the light-curve which does not seem to be properly fitted by an exponential model.

A power-law decay of the form

$S(t) \propto (t-t_0)^{\alpha}$

shows a better fit to the flux-density decrease.

Whilst further later time measurements are required to confirm these results, there is tentative evidence that the radio light curve of SN2008iz is showing a small reduction in the rate of its flux density decline.

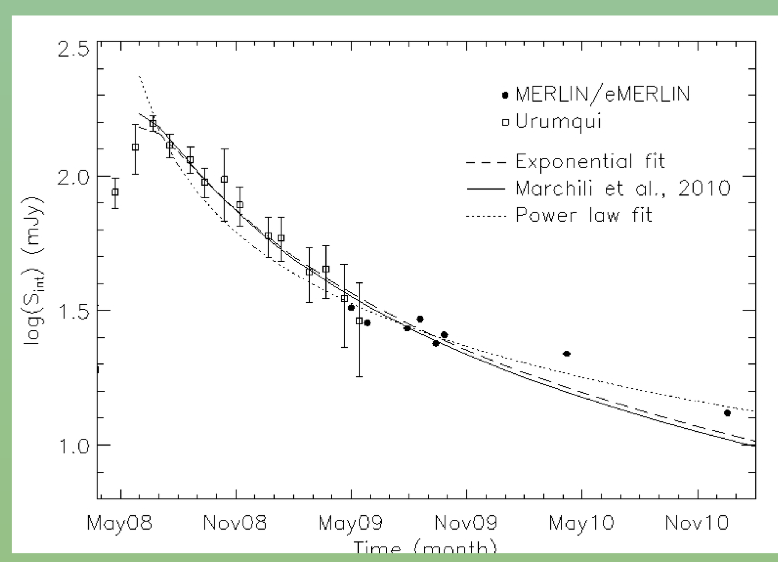



*Figure 4: Light curve for SN2008iz. 5-GHz data from single dish Urumqi observations (Marchili et al. 2010) and the MERLIN/e-MERLIN data are shown as open squares and filled circles respectively. An exponential decay model was fitted to the curve using both parameters from Marchili et al. 2010 - solid curve - and our best-fit parameters - dashed curve. A power-law decay model is also used - dotted curve - and displays the best fit to the decay part of the curve.*

## 44.28+61.1- A NEWLY DETECTED SNR SHELL

In order to search for possible new sources, each of the 51 known sources in M82 (Fenech et al. 2008) were imaged and subtracted from the uv-data. The resulting dataset was then re-imaged. Following inspection of this new image, one new source was identified. This source, located at position 09 55 53.00 +69 40 47.24 (J2000), has a peak flux density value of $S_{peak}$=99μJy/beam and an integrated flux density of 305 μJy. Being shell like in shape (Figure 5), it is most likely a supernova remnant.

By measuring the source extent, the age of the SNR can be inferred. The radius of the source was determined to be r=140±5 mas. At the distance of M82 (3.2 Mpc), this gives an estimated radius of 2.1 pc. Fenech et al. (2008) measured expansion velocities of SNRs in M82 to be between 2200 and 10500 km/s, with a mean velocity of $v_{exp}$= 5650 km/s. Using the latter value, we can estimate the age of 44.28+61.1 to be ~360 yrs.

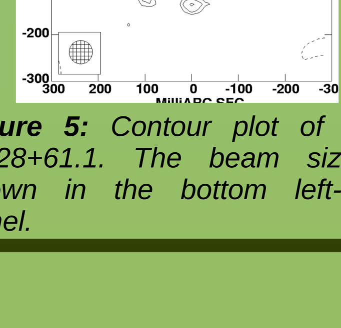


*Figure 5: Contour plot of SNR 44.28+61.1. The beam size is shown in the bottom left-hand panel.*

REFERENCES:
Beswick R. J. et al., 2006, MNRAS, 369, 1221
Bietenholz, M. F. et al., 2010, MNRAS, 409, 1594
Fenech, D. M. et al., 2008, MNRAS, 391, 1384
Fenech, D. M. et al., 2010, MNRAS, 408, 607
Kronberg, P.P. Et al., 2000, ApJ, 535, 706
Marchili N. et al., 2010,A&A, 509, 47
Muxlow, T. W. B. et al., 2005, Mm.S.A.I., 76, 586
Trotman W. M., 1996, M.Sc. Thesis, Univ. Manchester, UK