

Radio imaging of **Ultra Luminous Infrared galaxies (ULIRG)** is ideal to explore the connection between the starburst and the AGN phenomenon since it is unaffected by dust obscuration. We have made combined 18cm radio continuum, EVN and MERLIN observations of 13 ULIRGs that have the parsec and deci-parsec scale resolution necessary to distinguish between an AGN and radio supernovae or supernovae remnants at the centres of these galaxies, and assess the contribution of each to the total energy distribution.

## ULIRGs in the IRAS Bright Galaxy Sample

To date the best studied sample at high angular resolution of Luminous and Ultra Luminous Infrared galaxies is the IRAS Bright Galaxy sample (hereafter the BGS sample). Surveys with increasing angular resolution have been conducted with the VLA and VLBI:

- Condon et al (1990-1991) observed more than 40 compact sources (with  $z < 0.07$ ) using the VLA at 1.6, 5 and 8GHz.
- Lonsdale et al. (1993, L93) made snapshot VLBI observations of 31 compact sources from Condon et al. (1991). 21 of these were detected in VLBI baselines greater than 10 MA, prompting the authors to suggest that an AGN was responsible for the parsec scale structure.
- However, Smith et al. (1998a), in full track observations of Arp 220 showed that its parsec scale structure consists of radio supernovae or supernovae remnants.
- Following this, Smith et al. (1998b) modeled the L93 data fitting clustered luminous compact radio supernovae, showing that for most sources the parsec scale structure could be explained by starburst activity while for only a few sources the presence of an AGN was invoked to account for the parsec scale structure.

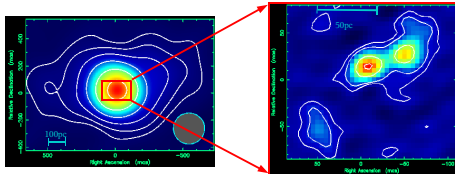
## The EVN-MERLIN survey of ULIRGs

We have made a systematic imaging survey of the complete sample of the 13 northern ( $\delta > 0$ ) compact ULIRGs in the BGS sample which showed evidence for detections  $> 1\text{mJy}$  on at least one baseline longer than 10 MA in Lonsdale et al's (1993) VLBI snapshots. Six further ULIRGs were already observed at the same resolution, hence the total sample consists of 19 objects.

The sources were observed with a combined MERLIN and EVN array at  $\lambda$  18cm in order to be able to separate the diffuse emission at MERLIN scales which can be due to thermal emission combined with synchrotron emission from electrons from supernovae diffused into the ISM, from the compact radio emission which can be due to an AGN or to synchrotron emission associated with single or clustered radio supernovae or supernovae remnants (SNRs).

The five brighter sources were observed in February 2002 with the combined MERLIN and EVN array with a sampling rate of 256 Mbits/s, and the remaining 8 sources were observed in May 2003, with a sampling rate of 512 Mbits/s. The EVN array consisted of six telescopes (Torun, Medicina, Onsala, Effelsberg, Westerbork, and the Jodrell Bank Lovell or the Mark 2 telescopes) yielding an average angular resolution of  $\sim 20\text{mas}$ . The MERLIN array consisted of six (February 2002) and seven telescopes (May 2003). Due to the relative weakness of the sources, the observations were made in phase-referencing mode with a cycle of 7 min on the source and 3 minutes on the nearby phase calibrator.

## UGC 05101



**MERLIN at 1.6 GHz**  
Uniformly weighted, Beam=230mas  
Peak=70.3mJy/bm, rms=0.5 mJy/bm  
 $S(\text{tot}) = 133.6\text{mJy}$

**EVN at 1.6 GHz**  
Uniformly weighted, Beam=22x17mas  
Peak=17.5mJy/bm, rms=0.3mJy/bm  
 $S(\text{tot}) = 71.38\text{mJy}$

	Flux Density	Size(mas)	$T_b$	$L$ (erg/s)
A	24.3 mJy	15.26 x 13.07	$1.7 \times 10^7\text{ K}$	$1.15 \times 10^{40}$
B	17.7 mJy	18.39 x 13.42	$3.2 \times 10^7\text{ K}$	$8.38 \times 10^{39}$
C	10.7 mJy	31.17 x 19.73	$7.0 \times 10^6\text{ K}$	$5.08 \times 10^{39}$

At the MERLIN resolution of 270 mas, UGC 05101 shows a 933 x 533 pc ( $1.3 \times 0.75$  arcsec at a distance  $d=158$  Mpc) disk-like emission elongated roughly east-west, dominated by a central bright component (similar to the Condon et al's (1991) 8.4 GHz VLA image measuring 1110 x 810 pc).

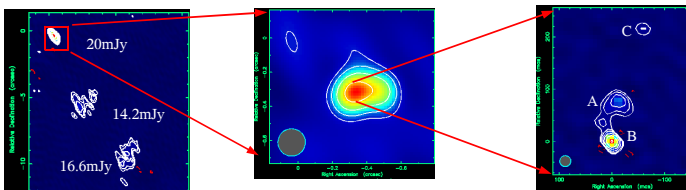
In the highest resolution (15 pc) EVN image  $\sim 53\%$  of the flux density is recovered in an apparently S-shaped source extending 128 x 140 pc. Three major components (A, B, C), relatively compact (5-13 pc) are embedded in weak extended radio emission, visible in the lower resolution images. Component A is closer to the peak brightness of the MERLIN image. The brightness temperatures  $T_b$  of components A and B are  $\sim 10^7\text{ K}$  while that of the more resolved component C is  $10^7\text{ K}$ , while their luminosities range from  $5 \times 10^{39} - 10^{40}$  erg/s.

These compact components are  $\sim 50$  times more luminous than the brightest radio supernovae (RSN) in Arp 220. They are also resolved and their sizes are too large for single RSN.

It appears that the nuclear structure of UGC 05101 can not be associated with RSN but is rather caused by an obscured AGN. This is consistent with Imanishi et al.'s (2003) detection of Fe K $\alpha$  line emission in X-rays, though the X-ray spectrum was measured with an aperture of 8 arcsec (5.6 kpc) which covers the whole radio source and hence it is not easy to correlate the position of the X-ray source and the radio emission.

Multi-frequency observations are needed to further explore this possibility.

## Mrk 266



**MERLIN 1.6 GHz tapered**  
Beam= 533 x 199 mas

**MERLIN Nominal Resolution**  
Spectral index  $\alpha(8.4-1.6) = 0.93$ .  
Beam= 160 mas

**EVN at 1.6 GHz**  
Naturally weighted  
Beam=27x18 mas  
Peak=4.2mJy/bm,rms=0.12mJy/bm  
 $S(\text{tot})=7.5\text{mJy}$

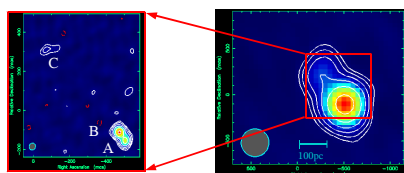
	Flux Density	Size (pc)	$T_b$	$L$ (erg/s)
A	1.67 mJy	18.74 x 13.74	$3.3 \times 10^5\text{ K}$	$4.00 \times 10^{38}$
B	3.40 mJy	2.73 x 2.02	$2.3 \times 10^7\text{ K}$	$8.19 \times 10^{38}$

Mrk 266 is a system of interacting galaxies (at a distance  $d=113$  Mpc) showing an interaction region in the middle (seen as a triple in our tapered MERLIN image) and tidal tails. The northern galaxy which is the target of our EVN observations is a LINER and the southern galaxy is a Seyfert 2. In our MERLIN image the northern component has a flux density of 21 mJy, and a spectral index  $\alpha_{1.6-8\text{GHz}} = 0.93$ .

High resolution EVN observations (21 mas = 107.1 pc) recover only 6 mJy ( $\sim 30\%$ ) of the MERLIN flux density and show a relatively compact ( $2 \times 2$  pc, 3.4 mJy) component (B) and arc-like emission which culminates in a more extended ( $18 \times 14$  pc) weaker (1.7 mJy) subcomponent (A)  $\sim 41$  pc away, while a third weak component is visible  $\sim 100$  pc further north. Their brightness temperature range from  $2.3 \times 10^7\text{ K}$  to  $3.3 \times 10^5\text{ K}$  and their luminosity from  $4 \times 10^{38}$  to  $8.2 \times 10^{38}$  erg/s.

Using an archival MERLIN image at 5 GHz we find that A has rising spectrum  $\alpha = -0.023$  and B a steep spectrum  $\alpha = 0.681$

## NGC 6286



**EVN at 1.6 GHz**  
Naturally weighted & Tapered  
Beam=36x34 mas  
Peak=10.5mJy/bm,rms=0.1mJy/bm  
 $S(\text{tot})=25.5\text{mJy}$

**MERLIN at 1.6 GHz**  
Naturally weighted, Beam=300 mas  
Peak=25.7 mJy/bm, rms=0.2 mJy/bm  
 $S(\text{tot}) = 32.2\text{mJy}$

	Size (pc)	$T_b$	$L$ (erg/s)
A	7.23 x 2.76	$2.6 \times 10^6\text{ K}$	$1.12 \times 10^{39}$
B	7.99 x 5.88	$8.9 \times 10^6\text{ K}$	$7.66 \times 10^{38}$
C	10.54 x 0.4	$1.2 \times 10^6\text{ K}$	$3.05 \times 10^{37}$

The MERLIN image recovers 32 mJy ( $\sim 25\%$  of the VLA flux density) and consists of two-components separated by 450 mas (150 pc at a distance  $d=73$  Mpc) at the same orientation as the 6.8 kpc radio source seen in the VLA image. At the 25 mas resolution of the EVN image, the brighter MERLIN component is resolved in two components (A, B) separated by 18.4 pc, with the brightest B located at the northeast. 200 parsec northeast of B, we detect the resolved out component C, which is the weaker component of the double in the MERLIN image.

All three components in NGC6286 are resolved with sizes between 4 and 10 parsecs, brightness temperatures ranging from  $1.02 \times 10^6\text{ K}$  (C) to  $8.9 \times 10^6\text{ K}$  (B) and luminosities from  $10^{37}$  to  $10^{39}$  erg/s, hence a few times higher than the RSN in Arp 220.

The fact that they are resolved argues against single RSN. It is plausible that one of the compact components may be due to a clump of supernovae. It is also possible that the brightest component are due to AGN activity.

## SUMMARY

In the three ULIRGs discussed in this poster, 50% to 70% of the total flux density is resolved out at parsec scale resolution. Their parsec scale structure consists of multiple components with sizes of a few to tens of parsecs, brightness temperatures ranging from  $10^5\text{ K}$  to  $10^7\text{ K}$  and luminosities from  $10^{37}$  erg/s to  $10^{40}$  erg/s (UGC05101). All components are too large to be single radio supernovae and their luminosities are a few thousand times brighter than Cas A but similar to the supernova 1989J. It is therefore possible that at least some of these components are clustered young radio supernovae (RSN) or supernovae remnants.

It appears that some of the high brightness temperature parsec scale emission is due to an AGN, in particular in UGC 05101 whose components are much more luminous than 1989J or the supernovae in Arp 220. This plausibility needs to be explored further with multi-frequency radio interferometric observations as well as X-ray observations.