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Giant Low Surface Brightness Galaxies

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Abstract: In this paper, we present radio observations of the giant low surface brightness (LSB) galaxies made using the Giant Metrewave Radio Telescope (GMRT). LSB galaxies are generally large, dark matter dominated spirals that have low star formation efficiencies and large HI gas disks. Their properties suggest that they are less evolved compared to high surface brightness galaxies. We present GMRT emission maps of LSB galaxies with an optically-identified active nucleus. Using our radio data and archival near-infrared (2MASS) and near-ultraviolet (GALEX) data, we studied morphology and star formation efficiencies in these galaxies. All the galaxies show radio continuum emission mostly associated with the centre of the galaxy.

1 Introduction

The study of low surface brightness galaxies (LSBGs) has been a subject of active interest over the last few decades. As recently as 30 years ago the existence of the low surface brightness galaxies was thought to be rare due to their intrinsic low surface brightness characteristics. Moreover, the whole population of the galaxies, currently designated as Low Surface Brightness Galaxies has gone almost disregarded in early extragalactic studies. The night sky is bright enough to mask very diffuse, faint galaxies and therefore detecting such objects is extremely difficult; sensitive telescopes are needed to detect them in the optical. However, once they were detected and their existence confirmed, their importance became apparent. LSBGs have many interesting physical properties, which can tell us about the formation and evolution of gas-rich, dark matter dominated galaxies.

Low surface brightness galaxies have a central disc surface brightness of $\mu_0 \geq 23$ mag arcsec^{-2} in B band (Impey & Bothun, 1997). They are rotationally dominated systems with usually diffuse stellar disks. The high gas fraction observed in these galaxies, combined with the overall low metallicity, suggests that they have had much less star formation compared to regular high surface brightness (HSB) galaxies, probably because their gas surface densities are well below the critical value required for star formation (van der Hulst et al. 1993). LSB galaxies usually have large HI discs that can extend over several optical disc scalelengths (de Blok, McGaugh & van der Hulst 1996; O'Neil et al. 2004; Das et al. 2007; Mishra et al. 2017). They can be divided into two groups, the giant low surface brightness (GLSB) galaxies, like Malin 1 which has a scalelength of 55 kpc (Bothun et al. 1987), and

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the more populous dwarf spirals (Schombert et. al. 2001). Previous studies suggest that LSB galaxies are relatively isolated compared to other types of galaxies, and the lack of galaxy interaction has left them less evolved compared to their HSB counterparts.

However, although we do not generally see AGN in LSB galaxies, a significant fraction of bulge-dominated GLSB galaxies do show AGN activity (Sprayberry et al. 1995; Galaz et al. 2011). Schombert (1998) studied a sample of GLSB galaxies and concluded that 30% of that sample showed AGN activity, especially those that have prominent bulges. Some of them are even radio bright and visible in X-rays (Das et al. 2009; Naik et al. 2010; Mishra et al. 2015).

In the present paper, we have carried out detailed multiwavelength (either 1280 or 1420 MHz (L band), 610 MHz, 325 and 240 MHz) radio study of a sample of seven (UGC 1378, UGC 1922, UGC 2936, UGC 4422, Malin 2, UGC 6614 and UM 163) GLSB galaxies with the Giant Metrewave Radio Telescope (GMRT).

2 Target Sources, Observations and Data Reduction

The sample consists of UGC 1378, UGC 1922, UGC 2936, UGC 4422, Malin 2, UGC 6614 and UM 163. The galaxy morphologies range from Sa to Sd types. Four galaxies in our sample are classified as members of groups. Supernova explosions have been recorded in three galaxies: UGC 1922, UGC 2936 and UGC 4422. Although LSB galaxies do not contain abundant quantities of molecular gas, CO observations have revealed the presence of molecular gas in UGC 1922 (O'Neil & Schinnerer 2003) and in UGC 6614, Malin 2 (Das et al. 2006; Das, Boone & Viallefond 2010). Four galaxies in our sample namely UGC 1378, UGC 1922, UGC 2936 and UGC 6614 have been observed in X-rays (Das et al. 2009). While a compact nuclear source has been detected in X- rays from UGC 2936 (Das et al. 2009) and UGC 6614 (Naik et al. 2010)

The observations were done using the GMRT (Swarup et al. 1991). The GMRT is the largest facility in the world for radio astronomical observation at a range of low frequencies from 150 MHz to 1.4 GHz. The GMRT operates as an earth rotation aperture synthesis array consisting of 30 Alt-Azimuth mounted parabolic dishes, each of 45m diameter of which 14 antennas are placed randomly in a compact central square array of 1 km $\times$ 1 km size, the rest of antennas being sparsely configured in Y shape having five antennas in the East and South arms, and six antennas in the West arm. The configuration of the central square gives a large number of baselines to maximize the UV-coverage near the origin of (u, v) plane; which is important in order to improve the sensitivity for a large scale emission from the extended source and the arm antennas form the baselines up to $\sim$ 25 km long to achieve the sensitivity at a high resolution. The central square provides the UV-coverage of 1 km with the shortest spacing of about $\sim$ 80 m by the antennas from the central square. Observations were carried out at 240 MHz, 325 MHz, 610 MHz and L band. The image processing of the GMRT visibility data was done using standard tasks in AIPS (Astronomical Image Processing System).

3 Results

We have mapped the radio continuum emission at the L band, 610, 325 and 240 MHz of a sample of seven GLSB galaxies using the GMRT. All the galaxies host an optically identified AGN. Below we give our results for each galaxy.

UGC 1378: This galaxy has a bright bulge with a LSB disk and faint spiral arms. No UV emission is detected from this galaxy. This galaxy is bright in the NIR band with emission arising from the entire disk. The galaxy shows compact radio emission with the single peak detected at 325 MHz, which is resolved into two peaks at 1420 and 610 MHz near the optical centre of the galaxy (see Fig. 1(a)) .

UGC 1922: This is a giant LSB galaxy with a prominent bulge but a faint disk that appears to have barely any spiral structure. Bright NUV emission is detected along the spiral arm of the galaxy in addition to other compact regions. The central parts of the galaxy are detected at 1420 MHz, 610 MHz and 325 MHz, as well as in the NIR (see Fig. 1(b)).

UGC 2936: UGC 2936 is almost an edge-on LSB galaxy and the AGN in this galaxy was identified by Sprayberry et al. (1995). No UV emission is detectable from this galaxy whereas extended radio emission is detected. The entire disk of the galaxy is detected in NIR and radio 610 and 1280 MHz bands in addition to the intense emission from the active nucleus (see Fig. 1(c)).

UGC 4422: UGC 4422 is a barred galaxy and the AGN in this barred galaxy was identified by Schombert (1998). Image shows bright NUV emission along the spiral arms in addition to the diffuse emission to the west of the centre. The NIR emission from this galaxy is extended and arises from the bar and spiral arms. The diffuse extended emission seen at 325 MHz along the spiral arms is not detected at 610 and 1420 MHz (see Fig. 1(d)). While at 1420 MHz and 610 MHz, the emission is concentrated in the central parts of the galaxy

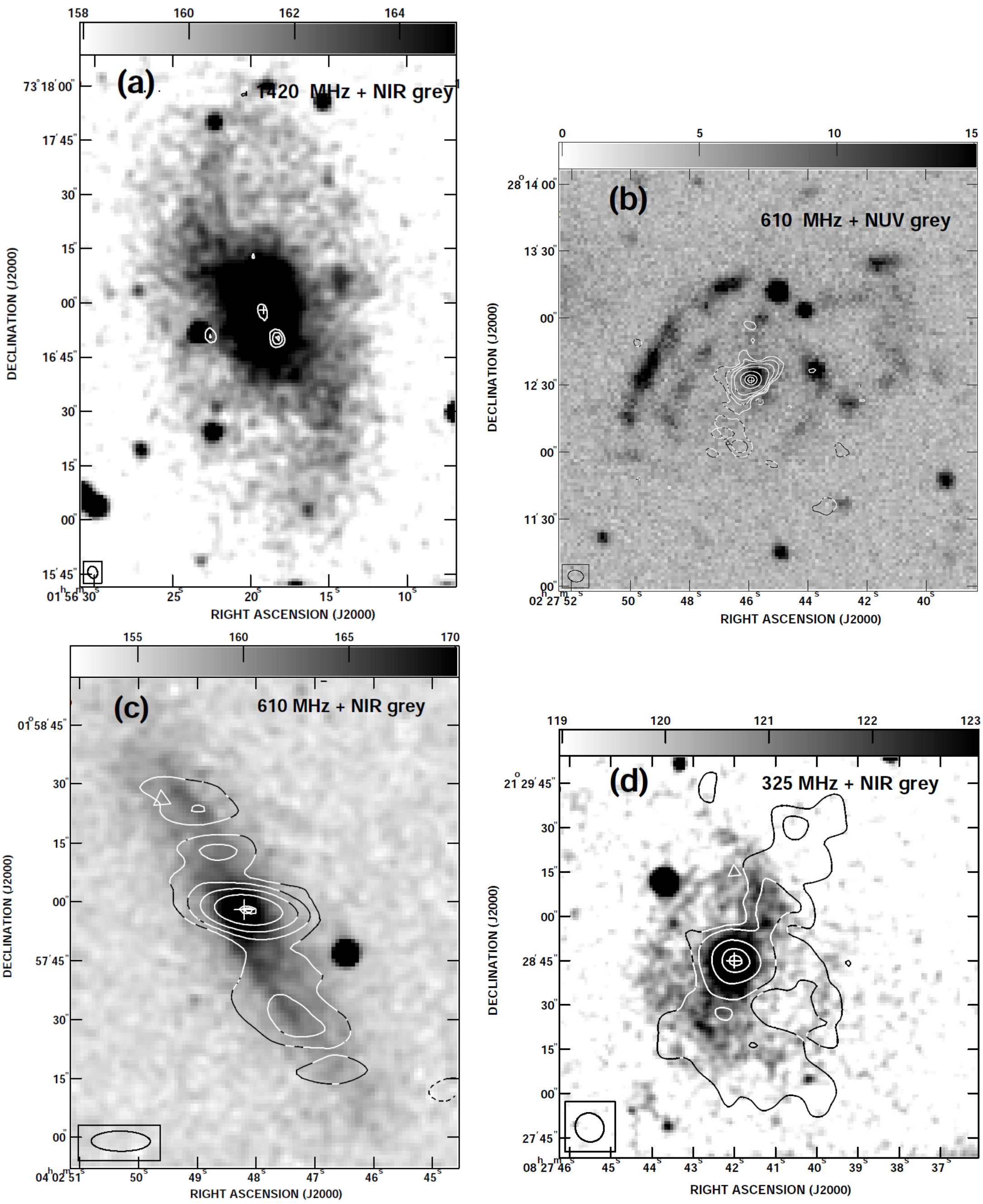
Malin 2: This is a well known giant LSB galaxy. It has a large bulge and its nucleus shows AGN activity at optical wavelengths (e.g. Ramya et al. 2011). No radio emission associated with the intense star forming disk detected in the NUV. Intense NUV emission indicates to a recent burst of star formation that has been triggered in this galaxy. NIR image shows featureless disk with bright core. Unresolved emission from the centre of the galaxy is detected at all the three observed frequencies i.e. 1280 MHz, 610 MHz and 240 MHz (see Fig. 1(e)).

UGC 6614: This is a relatively well studied giant LSB galaxy with the AGN detected in mm-wave continuum (Das et al., 2006), optical (Schombert 1998; Ramya et al. 2011), X-ray (Naik et al., 2010) and NIR (Rahman et al., 2007) wavelengths. Like in Malin 2, the NUV emission is detected over the entire disk with vigorous star formation seen in the ring and along the spiral arms of the galaxy. Radio emission at 610 MHz is detected from several compact regions near coincident with the NUV peaks near the central ring and along the spiral arms, indicating their origin in star-forming regions (see Fig. 1(f)).

UM 163: This galaxy was first studied by Sprayberry et al. (1995) were they identified the AGN in the optical bands. NUV emission is detected from the centre of the galaxy, from a ring close to the centre and along the spiral arms. NIR emission is detected from the bar of the galaxy, while 610 MHz radio emission is confined mainly to the core; extension of this emission is seen towards the south only in the images plotted up to 4 sigma level. At 1420 MHz, the emission is extended towards the north-west. Low resolution image at 325 MHz appears to show emission arising along the bar and also extended perpendicular to the bar (see Fig. 1(g)).

4 Summary

We detect radio emission from the nuclear region of all the seven galaxies at one or more radio bands. The spectra of five galaxies (UGC 1922, UGC 2936, UGC 4422, Malin 2 and UGC 6614) are flat and the galaxies appear to be core dominated. Two of the galaxies UGC 6614 and UM 163 show extended emission associated with their nuclei but show no correlation with star formation traced by other diagnostics. We interpret the extended emission as being due to the radio jets or lobes of the active nucleus. In UGC 6614, the radio jet extends out to a radius of 6.8 kpc and in UM 163, it extends out to 13 kpc. In both cases, the jet lies within the optical discs. Radio jets are relatively rare in spirals.


(a)
1420 MHz + NIR grey
(b)
610 MHz + NUV grey
(c)
610 MHz + NIR grey
(d)
325 MHz + NIR grey
DECLINATION (J2000)
RIGHT ASCENSION (J2000)

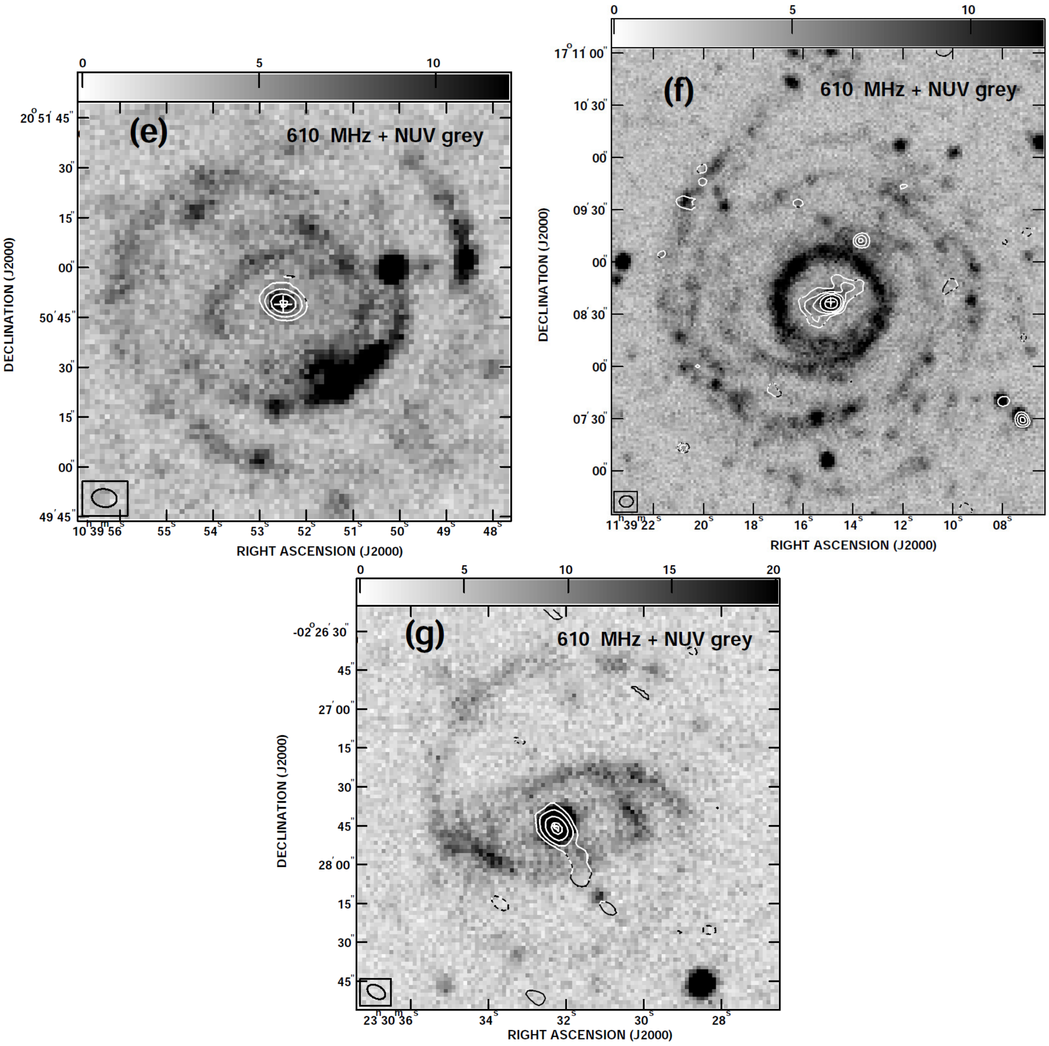


Figure 1: The cross marks the position of the optical centre. (a) UGC 1378: 1420 MHz contours are overlaid on NIR grey scale image. The contour levels of the 1420 MHz emission are 28$\times$ (-8,-4,4,8,13) μJy beam^{-1} for a beamsize of $3'' \times 2''$. (b) UGC 1922: The contours showing the 610 MHz emission are overlaid on NUV grey scale. The contour levels are plotted at 0.1 $\times$ (-8,-4,4,8,16,32,64,128,256,330) mJy beam^{-1}. The angular resolution is $7'' \times 5''$. (c) UGC 2936: The contours showing the 610 MHz emission are overlaid on NIR grey scale. The contour levels are plotted at 0.3 $\times$ (-8,-4,4,8,16,32,64,66) mJy beam^{-1}. The angular resolution is $15'' \times 5''$. (d) UGC 4422: The contours showing the 325 MHz emission are overlaid on NIR grey scale. The contour levels are plotted at 0.4 $\times$ (-4,-3,3,4,8,10,12,14) mJy beam^{-1}. The beamsize is $10'' \times 9''$. (e) Malin 2: The contours showing the 610 MHz emission are overlaid on NUV grey scale. The contour levels are plotted at 0.2 $\times$ (-8,-4,4,8,16,28) mJy beam^{-1}. The angular resolution is $7'' \times 5''$. (f) UGC 6614: The contours showing the 610 MHz emission are overlaid on NUV grey scale. The contour levels are plotted at 0.1 $\times$ (-6,-4,4,6,8,12,24,39) mJy beam^{-1}. The angular resolution is $8'' \times 6''$. (g) UM 163: The contours showing the 610 MHz emission are overlaid on NUV grey scale. The contour levels are plotted at 0.2 $\times$ (-8,-4,4,8,16,25,28) mJy beam^{-1}. The angular resolution is $7'' \times 5''$.

Diffuse radio continuum emission associated with star formation in the disc is detected from the galaxies UGC 2936 and UGC 4422 at one of our observed frequencies. We used our high-resolution maps at the L band and the NVSS maps at 45 arcsec resolution to separate the nuclear emission and disc emission. The radio emission outside the nucleus was presumed as being due to star formation and we found SFRs range from 0.15 to 3.6 $M_{\odot}$ yr^{-1}.

All the galaxies in our sample have been observed in the UV by GALEX and in the NIR by 2MASS thus allowing us to make a multiwavelength study of this sample. All our sample galaxies have bulges that are prominent in NIR. Extended UV discs are detected in five galaxies namely UGC 1922, UGC 4422, Malin 2, UGC 6614 and UM 163. NIR disc/bar emission is detected from UGC 2936, UGC 4422 and UGC 1378. UGC 4422 is the only sample galaxy which shows an extended UV disc and NIR disc/bar emission. We suggest that a recent burst of star formation has occurred in the five galaxies with extended UV discs out of which we find four reside in group environments. We find that most of the radio emission in UGC 1922 and UM 163 arises in the active nucleus. Since these two galaxies show bright NUV emission, this suggests a fresh star forming episode. The massive stars are yet to evolve into supernovae and give rise to non-thermal emission. On the other hand, hardly any NUV emission is detected from UGC 2936 but the galaxy shows that more than 80 per cent of its L-band radio emission arises from its star-forming disc. This argues for a star formation episode which is more than 10 - 100 Myr old and has since been quenched. It would be interesting to estimate stellar ages in these galaxies to confirm this scenario.

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