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Radio Observations of Bulgeless Spiral Galaxies

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Abstract. We present GMRT radio observations of a sample of bulgeless spiral galaxies. These galaxies appear to have no or minimal bulge in their centers and are hence disk dominated systems. They are are gas rich and nearly pure disk in morphology. Their nuclei host star clusters that appear as bright cores in the galaxy disks. Although bulgeless, they do show some star formation activity and in rare cases host AGN as well. Weak bars have been detected in some cases pointing to ongoing internal galaxy evolution. Our primary aim was to see if there was compact emission associated with AGN activity and extended emission from star formation. In this paper we present preliminary results for six galaxies. Three are detected at 1280 MHz in radio continuum; the emission is extended over the disk and associated with star formation. We do not see any radio emission associated with the nuclei in these galaxies.

1. Introduction

Bulgeless galaxies are late type spirals that have no bulge or a very small bulge in their center (Böker et al. 2002). Their centres often host compact stellar nuclei that appear as bright cores in the the optical images (Walcher et al. 2006). HST images indicate that these cores are compact nuclear star clusters that result in steeply rising central light profiles. The minimal bulge results in a nearly pure disk-like spiral galaxy (e.g. NGC 0300) which is gas rich but often fairly featureless. A few such galaxies have been found to host AGN activity (e.g. NGC 4395; Seyfert 1). This is surprising as galaxy bulges and AGN are thought to grow together in the nuclei of galaxies (e.g. Silk & Rees 1998) and most AGN in our nearby Universe are associated with bulges (e.g. Kauffmann & Haehnelt 2000). Such AGN are sometimes found to contain intermediate mass black holes (e.g. Peterson et al. 2005).

Table 1. Galaxy Sample

Galaxy Name (1)	Other Names (2)	Galaxy Type (3)	Distance Mpc (4)	Galaxy Position RA, δ (J2000) (5)
NGC 3445	UGC 06021	SAB(s)m	30.8	10h54m35.5s, +56d59m26s
NGC 3782	UGC 06618	SAB(s)cd	13.2	11h39m20.7s, +46d30m50s
NGC 3906	UGC 06797	SB(s)d	16.1	11h49m40.5s, +48d25m33s
NGC 4299	UGC 07414	SAB(s)dm	7.79	12h21m40.9s, +11d30m12s
NGC 4499	PGC 041537	SB(rs)b	55.7	12h32m04.9s, −39d58m57s
NGC 4540	UGC 07742	SAB(rs)cd	22.1	12h34m50.8s, +15d33m05s

Although disk dominated, most of these galaxies do not have strong spiral structure or disk star formation. Bars are found in a significant fraction but are usually weak and short compared to disk scale lengths. However the presence of bars does indicate that internal galaxy evolution is taking place; this can lead to the formation of bulges or pseudobulges in these galaxies (Kormendy & Kennicutt 2004). Understanding the star formation in these systems

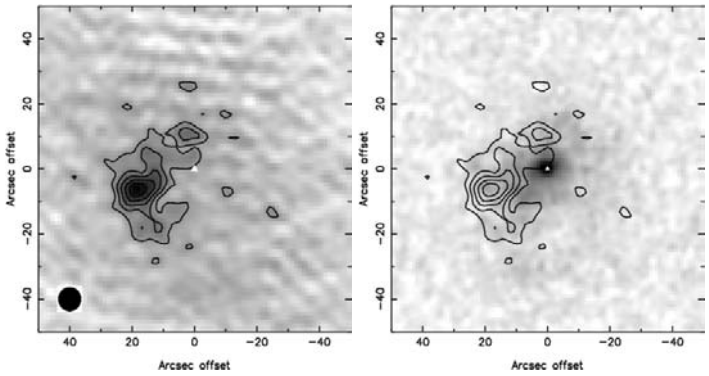

Figure 1. Left: The contours of the natural weighted GMRT 1280 MHz radio continuum map of NGC 3445 superimposed on the 2MASS near-IR image of the galaxy. The peak radio flux density is 2 mJy beam^{-1} and the beam$\sim$ 8″. The contours are 4, 6, 8, 10, 12 times the noise level which is 0.15 mJy beam^{-1}. The galaxy centre is marked with a filled triangle. Right: The contours of the above 1280 MHz radio map overlaid on the near-IR image. Note that the emission is offset from the center of the galaxy and lies mainly to the east of the nucleus.

will help us further understand this evolution. Another puzzle regarding these galaxies is that their halo angular momentum is higher than that expected for the ΛCDM universe (D'Onghia & Burkert 2004). Feedback processes can change this although it is not clear that it is enough. Comprehensive radio observations of these bulgeless late type systems is lacking. The radio continuum in the nucleus of NGC 4395 has been mapped at 1.4 GHz with the VLA and VLBI (e.g. Wrobel & Ho 2006). Elongated emission was found on subparsec scales suggesting outflows from the IMBH. However it is not clear that such emission is common in bulgeless late type galaxies. To improve our understanding of these systems we have observed a sample of 13 late type, bulgeless spirals in radio continuum at 1280 MHz using the GMRT. In the following sections we present preliminary findings for six galaxies from our sample.

2. Galaxy Sample and Observations

We present observations of a sample of six bulgeless spiral galaxies. All six galaxies in our present sample have been detected at some level in NVSS but the resolution of NVSS is poor ($\sim$ 45″). We need high resolution observations with greater sensitivity to understand the radio morphology. Our source sample is listed in Table 1 along with the galaxy types, coordinates and distances. Of these galaxies, two have weak bars (NGC 3782 and NGC 3906). NGC 3445 has patchy star formation over its disk but no clear spiral structure. The disks of the remaining galaxies appear to be fairly featureless.

Observations were done during 2008 May using the GMRT (Ananthakrishnan & Rao 2002) at 1280 MHz. Nearby radio source were used for phase calibration. The data was obtained in the native 'lta' format, converted to FITS format and then analysed using AIPS [1]. Bad data was iteratively edited and calibrated on a single channel until satisfactory gain solutions were obtained using standard tasks in AIPS. This was used to generate bandpass solutions. The central 110 channels were bandpass calibrated and averaged to obtain the continuum database. This was then imaged using IMAGR. Both natural and uniform weighted maps of the galaxies

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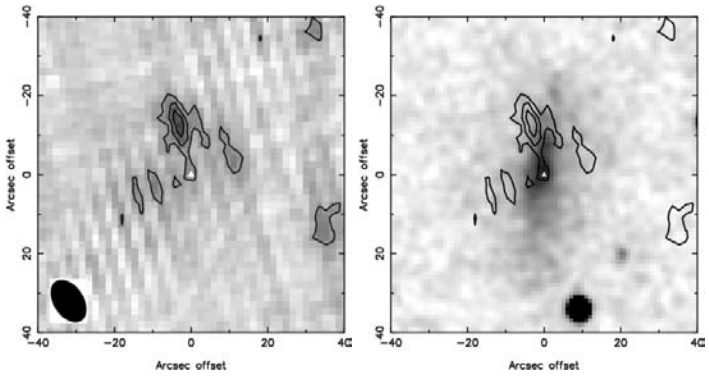

Figure 2. Left: Figure shows the contours of the natural weighted GMRT 1280 MHz radio continuum map of NGC 3782 superimposed on the 2MASS near-IR image of the galaxy. The peak radio flux is 2 mJy beam^{-1} and the beam$\sim$ 8″. The contours are 4, 6, 8, 10, 12 times the noise level which is 0.15 mJy beam^{-1}. The galaxy center is marked with a filled triangle. Right: Figure shows the contours of the above 1280 MHz radio map overlaid on the near-IR image. The radio emission is north of the galaxy center and mostly associated with the bar.

were made to obtain the extended structure and see if there is any compact emission associated with the nucleus.

3. Results

We have detected radio emission at 1280 MHz from three galaxies in our sample - NGC 3445, NGC 3782 and NGC 4299. For the other three galaxies no radio emission was detected. In all three detected galaxies the emission was located in the disk and is most likely associated with disk star formation. We did not observe any radio continuum from the nuclei of the galaxies; such emission could arise from the nuclear compact star cluster or perhaps from AGN activity. In the following paragraph we briefly summarise our results for the galaxies where we see emission.

(i) NGC 3445 : This galaxy appears to have a one armed spiral structure and patchy star formation associated with it. The radio emission (Figure 1) appears to be lying along this star forming region. It is also close to an irregular bar like feature in the disk which suggests that there may be ongoing internal evolution in the galaxy.

(ii) NGC 3782 : This galaxy has a more regular bar in the galaxy center but no apparent associated spiral structure in the disk. Our radio emission (Figure 2) lies close to the bar and is probably due to star formation triggered by the bar.

(iii) NGC 4299 : This galaxy has very faint spiral arms embedded in a fairly featureless disk. The radio continuum in our map (Figure 3) is probably associated with localized star formation in the galaxy disk. It is spread over the region south of the galaxy center.

4. Conclusions

We observed six late type, bulgeless spiral galaxies in radio continuum at 1280 MHz using the GMRT. Of these galaxies, three have been detected in radio emission. The emission is from the disks and associated with star formation. It suggests that though bulgeless, there is ongoing internal evolution in these galaxies.

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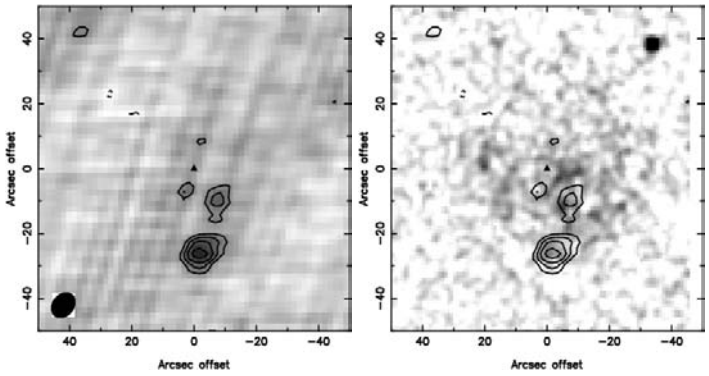

Figure 3. Left: Figure shows the contours of the GMRT 1280 MHz radio continuum map of NGC 4299 superimposed on the 2MASS near-IR image of the galaxy. The peak radio flux is 1.4 mJy beam^{-1} and the beam$\sim$ 7.3″. The contours are 2, 3, 4, 5, 6 times the noise level which is 0.25 mJy beam^{-1}. The galaxy center is marked with a filled triangle. Right: Figure shows the contours of the above 1280 MHz radio map overlaid on the near-IR image. Note that the emission is offset from the center of the galaxy and lies mainly south of the nucleus.

Research. We have used 2MASS images of NGC 3445, NGC 3782 and NGC 4299. This work has made use of the NASA/IPAC Science Archive.

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