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Discovery of a low-luminosity spiral DRAGN.*

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ABSTRACT

Standard galaxy formation models predict that large-scale double-lobed radio sources, known as DRAGNs, will always be hosted by elliptical galaxies. In spite of this, in recent years a small number of spiral galaxies have also been found to host such sources. These so-called spiral DRAGNs are still extremely rare, with only ~ 5 cases being widely accepted. Here we report on the serendipitous discovery of a new spiral DRAGN in data from the Giant Metrewave Radio Telescope (GMRT) at 322 MHz. The host galaxy, MCG+07-47-10, is a face-on late-type Sbc galaxy with distinctive spiral arms and prominent bulge suggesting a high black hole mass. Using WISE infra-red and GALEX UV data we show that this galaxy has a star formation rate of 0.16-0.75 M_☉ yr⁻¹, and that the radio luminosity is dominated by star-formation. We demonstrate that this spiral DRAGN has similar environmental properties to others of this class, but has a comparatively low radio luminosity of 1.12×10²² W Hz⁻¹, two orders of magnitude smaller than other known spiral DRAGNs. We suggest that this may indicate the existence of a previously unknown low-luminosity population of spiral DRAGNs.

Key words. Galaxies: spiral – Galaxies: jets – Radio continuum: galaxies

1. Introduction

Spiral DRAGNs (Double-lobed Radio sources Associated with Galactic Nuclei, Leahy 1993) are spiral galaxies that host large-scale double-lobed radio sources. The existence of such sources contradicts our existing models of galaxy formation (e.g. Hopkins et al. 2008), which predict that DRAGNs should be hosted exclusively by elliptical galaxies. Until recently, observations of DRAGNs in the local Universe confirmed this expectation (e.g. Matthews et al. 1964; Urry & Padovani 1995; Best et al. 2005).

Elliptical galaxies are formed as a result of mergers, the phenomenology of which also triggers the formation of DRAGNs (Chiaiberg & Marconi 2011; Chiaiberg et al. 2015). However, a spiral galaxy’s structure cannot withstand a major merger. Moreover, morphological transition from spiral to elliptical is thought to be a one-way process, at least in the local Universe. Consequently, the standard galaxy formation model does not predict the existence of spiral DRAGNs.

Nonetheless, a number of spiral DRAGNs have been discovered in recent years (e.g. Ledlow et al. 2001; Hota et al. 2011; Bagchi et al. 2014; Mao et al. 2015; Singh et al. 2015). While the first three spiral DRAGN discoveries were serendipitous, Mao et al. (2015) performed the first systematic search for these sources. Using the crowdsourced project Galaxy Zoo (Lintott et al. 2008), the authors cross-matched morphological classifications with the Faint Images of the Radio Sky at Twenty-Centimeters (FIRST, Becker et al. 1995) and the NRAO VLA Sky-Survey (NVSS, Condon et al. 1998). In this study, only one spiral DRAGN was found above L_{1.4 GHz} = 10²³ W Hz⁻¹. Singh et al. (2015) performed a similar analysis using the spiral galaxy catalogue of Meert et al. (2015) and reported the identification of four spiral DRAGNs in these data, including one that was previously known and three that were unknown. However, the precise identification of spiral DRAGN hosts remains contentious in the literature, and to date, only five spiral DRAGNs are widely accepted.

DRAGNs with spiral hosts may represent a rare phenomenon of elliptical galaxies transitioning back into spirals through accretion of gas and stars, perhaps from a companion. A key question is whether spiral DRAGNs are a result of non-standard physical properties, a result of their environment, or perhaps a combination of their nature and nurture. Studying spiral DRAGNs, as well as establishing their numbers more exactly, is vital to reconciling their role in standard galaxy formation theories.

In this Letter, we present the discovery of a new spiral DRAGN at 325 MHz with the Giant Metrewave Radio Telescope (GMRT; Swarup 1990). In Sect. 2 we outline the data processing and imaging steps. In Sect. 3 we present the discovery of this new spiral DRAGN with a description of its radio morphology and that of the host galaxy, as understood from available multi-wavelength data. In Sect. 4, using infra-red and UV data, we demonstrate that the host galaxy is star-forming and we compare its star formation rate to other spiral DRAGNs. Finally, in Sect. 5 we discuss the nature of this object and state our con-
clusions. In this work we assume a ΛCDM cosmology with $H_0 = 69.6 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.286$, and $\Omega_{\Lambda} = 0.714$ (Bennett et al. 2014), which we use to calculate distance, luminosity and star formation rate. At a redshift of $z = 0.017$, these values result in a conversion of $0.348 \text{kpc}''$. All uncertainties are quoted at 1σ.

2. Observations and data reduction

Observations of the galaxy groups NGC7618 and UGC 12491 were performed in full synthesis mode with the Giant Meterwave Radio Telescope (GMRT) at 325 MHz. The GMRT is a full aperture synthesis telescope located near Pune, India (Swarup 1990). It consists of 30 steerable dishes that are 45 m in diameter, with a longest interferometric baseline of 25.5 km, and 14 additional antennas located in a central 1 sq. km, to provide dense uv coverage at short spacings. The telescope operates at six frequencies: 150, 230, 325, 610, and 1420 MHz. In this work the 325 MHz receiver was used. The full width at half maximum (FWHM) of the GMRT primary beam at 325 MHz is approximately 81′ ± 4′.

The observation took place on 16 August 2014 under project code 25.059 (PI Mitsuishi). The observation was a single pointing with a phase centre of (J2000) $23^\text{h} 19^\text{m} 42^\text{s}$, and an elliptical Gaussian was fitted to each island, of which 69 were identified. This area is not covered by the Sloan Digital Sky Survey (SDSS). On inspection of the Digitized Sky Survey (DSS), the host galaxy (denoted C in Fig. 1), MCG+07-47-10, is a late-type galaxy with a classification of Sbc (Vorontsov-Vel’Yaminov & Arkhipova 1968), a galaxy with spiral arms and a bulge. The limited resolution of the DSS means that the presence of a bar cannot be ruled out. The optical DSS image of this galaxy is shown in Fig. 3 with the 5σ radio contour overlaid. The spiral arms of this face-on galaxy are clearly visible, and extended radio emission is seen coincident with the optical disk. If this emission were solely due to the core of the AGN, one would expect highly compact emission, unresolved by the GMRT in these data. Fig. 1 shows that the radio emission in this case is clearly resolved, with a diameter measured from the 3σ contour of approximately 45′, equivalent to five synthesized beam widths. Such extended radio emission indicates that active star formation is occurring throughout the disk and is due to the injection of cosmic ray electrons (CREs) into the interstellar medium (ISM) by the action of supernovae. These CREs produce non-thermal synchrotron emission, which is observable here.

This area is not covered by the Sloan Digital Sky Survey (SDSS); Alam et al. 2015), and no spectroscopic redshift information is currently available for this galaxy. However, MCG+07-47-10 is located close to the galaxy groups NGC 7618 ($z=0.0173$) and UGC 12491 ($z=0.0173$), the central galaxies of two nearby, galaxy groups of approximately equal mass. Kraft et al. (2006) found through X-ray observations that these galaxy groups are in the process of merging. Assuming that MCG+07-47-10 is associated with one of these galaxy groups, we adopt an 2 http://www.sdss.org/
L host galaxy) of approximately nosity at 322 MHz for this proposed spiral DRAGN (lobes and radio flux density values in Table. 1, we derive a radio lumin-
diameter of MCG\textsuperscript{+}\textsuperscript{+} size of 207 kpc at our assumed redshift. Additionally, the optical has an angular linear extent of
within the virial radius of both groups. (Kraft et al. 2006), MCG\textsuperscript{+}\textsuperscript{+} radius of these galaxy groups of approximately 600-800 kpc from NGC 7618 and 375 kpc (18\textdegreez\textapproximate redshift of
23.9
From the GMRT image, we find that this new spiral DRAGN
\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Src. & ID & Right Ascension & Declination & 1.4 GHz Flux & 322 MHz Flux & Spectral Index \\
& & (J2000) & (J2000) & (mJy) & (mJy) & \\
\hline
A & Northern Lobe & 23\textdegree 18\textquoteleft 06\arcsec & +43\textdegree 18\textquoteleft 18\arcsec & 7.8\pm 1.3 & 20.0\pm 2.0 & -0.6\pm 0.3 \\
B & Southern Lobe & 23\textdegree 18\textquoteleft 43\arcsec & +43\textdegree 12\textquoteleft 20\arcsec & 5.5\pm 0.5 & 16.1\pm 1.6 & -0.73\pm 0.21 \\
C & MCG\textsuperscript{+}07-47-10 & 23\textdegree 18\textquoteleft 33\arcsec & +43\textdegree 14\textquoteleft 49\arcsec & 3.9\pm 0.4 & 12.4\pm 1.5 & -0.79\pm 0.24 \\
\hline
\end{tabular}
\caption{Locations of the radio lobes and host galaxy of the spiral DRAGN with integrated fluxes and spectral indices.}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Left: Zoomed-in image of the northern lobe and host galaxy from Fig. 1. Right: Zoomed-in image of the southern lobe and host galaxy from Fig. 1. The measured rms noise (σ) around the source is approximately 68 \textmu Jy/beam. The contours for both images are at levels of 3, 5, 8, 10, 12, 24 and 48 \times σ. The resolution is 9.4\texttimes 8.3\arcsec and is shown in the bottom right and left corner as a filled-in ellipse.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Optical DSS image of the host galaxy (MCG\textsuperscript{+}07-47-10) for the spiral DRAGN. The contour shows the 5σ level of the 322 MHz radio data.}
\end{figure}


3.1. Additional radio data and integrated fluxes
MCG\textsuperscript{+}07-47-10 and the two lobes are detected by the NVSS (Condon et al. 1998), but not by the VLA Low-frequency Sky Survey redux (VLSSr, Lane et al. 2014; Cohen et al. 2007), TIFR GMRT Sky Survey (TGSS ADR, Intema et al. 2016), or the WEsterbork Northern Sky Survey (WENSS, Rengelink et al. 1997). In addition, the FIRST survey does not cover this area of the sky. In the NVSS, the three main components are detected, and the catalogue integrated fluxes for each component are shown in Table. 1.

From the combination of the NVSS data and the GMRT data presented in this work, the host galaxy is found to have a spectral index of α = −0.79 ± 0.24, which is a typical value for a star-forming spiral galaxies (α = −0.74 ± 0.03, Gioia et al. 1982).

4. Star formation rate
MCG\textsuperscript{+}07-47-10 is clearly detected in all four WISE bands (Wright et al. 2010). Based on colour-colour relationships (Lacy et al. 2004; Yan et al. 2013), the measured magnitude difference [W1]−[W2] = 0.184 indicates that MCG\textsuperscript{+}07-47-10 is classified as a star-forming galaxy, with values greater than 0.8 signifying an AGN. Normal spiral galaxies are seen to have a range of magnitude differences of ≈ 0.0-0.6 (Wright et al. 2010).

Using the derived relations between star formation rate (SFR) and observed luminosity in the WISE W3 and W4 bands (Jarrett et al. 2013), we find the SFR for MCG\textsuperscript{+}07-47-10 at 12\textmu m to be \textSigma 12\textapproximate 0.75 M\textsun yr\textsuperscript{−1} and at 22\textmu m to be \textSigma 22\textapproximate 0.51 M\textsun yr\textsuperscript{−1}. In addition, MCG\textsuperscript{+}07-47-10 is also detected in the near UV by GALEX (Martin et al. 2005). Following Kennicutt (1998), we find the UV SFR for MCG\textsuperscript{+}07-47-10 to be \textSigma UV\textapproximate 0.16 M\textsun yr\textsuperscript{−1}. Assuming no contribution from an AGN, the SFR for MCG\textsuperscript{+}07-47-10 derived from the radio data presented here is \textSigma 1.4 GHz\textapproximate 0.63 M\textsun yr\textsuperscript{−1} (Condon 1992, Eq.21), intermediate to the IR and UV derived SFRs. There are large un-
certainities associated with SFR indicators (Hopkins et al. 2003), therefore we estimate the SFR to be in the range of $0.16-0.75 M_\odot \text{yr}^{-1}$.

The SFR rate in galaxies can show an enormous range from virtually zero in gas-poor ellipticals and dwarf-galaxies to 0.63 $M_\odot \text{yr}^{-1}$ in gas-rich spirals (Kennicutt 1998). For comparison, MCG+07-47-10 has an SFR similar to the nearby Sb galaxy, NGC2683, which has an SFR $\approx 0.36 M_\odot \text{yr}^{-1}$ determined by Irwin et al. (2012). Compared to other spiral DRAGNS, Mao et al. (2015) found J1649+2635’s SFR to be $\approx 0.26-2.6 M_\odot \text{yr}^{-1}$. The two spiral DRAGNs found by Singh et al. (2015) (J0836+0532, J1159+5820) were found to have 9.99 and 2.89 $M_\odot \text{yr}^{-1}$, respectively. MCG+07-47-10 with an SFR range of $0.16-0.75 M_\odot \text{yr}^{-1}$ would be in the lower range of the SFR of J1649+2635 and other spiral DRAGNs.

5. Discussion and conclusions

We presented the discovery of the spiral DRAGN MCG+07-47-10. The host galaxy has clearly defined spiral arms, a prominent bulge, and hosts a 188 kpc DRAGN.

The radio source, first identified in NVSS, was not previously classified as a DRAGN, but rather as three separate radio sources. The deep GMRT observation detects the low surface brightness emission connecting the radio components, based on which we identify this radio source as a DRAGN for the first time.

The central component of the radio emission from the host galaxy appears extended in the NVSS and GMRT data. These new GMRT data show resolved radio emission emanating from the entirety of the host galaxy, as opposed to only the core. This suggests that the radio emission is not solely due to the presence of an AGN. Moreover, the total integrated radio flux density for the host galaxy gives an SFR that agrees well with SFRs calculated from the usage of the HyperLeda database (http://leda.univ-lyon1.fr) and NASA/IPAC Extragalactic Database. The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with the permission of these institutions.

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