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A radio continuum study of NGC 6209 and NGC 4603

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Abstract

We find three strong point-like radio-continuum sources in the direction of two nearby galaxies, NGC 6209 and NGC 4603. We present a multi-frequency analysis of both galaxies' radio-continuum components using radio-continuum data from the ASKAP, including EMU and POSSUM polarisation products, complemented by optical and infrared imaging from DSS2 and the WISE mission. We identify a radio point source (J165458.82–723442.63) located $\sim 32''$ from the centre of NGC 6209, with a steep spectral index, $\alpha = -1.17 \pm 0.18$; and two radio point sources: PS1 (J124054.94–405857.14) and PS2 (J124052.73–405854.09), offset from the centre of NGC 4603 by $40''$ and $22''$, and with spectral indices of $\alpha = -0.45 \pm 0.10$ and $\alpha = -1.43 \pm 0.10$, respectively. No linear polarisation was detected in POSSUM Stokes I , Q , and U data, and no infrared or optical counterparts were found at the same positions. Statistical source-count analysis gives probabilities of 1–7% for random alignment. The combination of published source counts, local source density estimates, weak polarisation and luminosities inconsistent with an intrinsic source (such as a SNR) indicates that the sources are most likely background quasars or radio galaxies. The negative spectral indices for all point sources indicate non-thermal synchrotron emission, consistent with the interpretation that these detections are unrelated to the two galaxies. These systems are similar to NGC 2082, where a comparable radio point source was also identified as a background object.

Keywords: Radio continuum: galaxies – Galaxies: spiral – Galaxies: ISM – Galaxies: NGC 6209 – Galaxies: NGC 4603

1 Introduction

Radio emission from galaxies mainly results from non-thermal synchrotron radiation, for example, from supernova remnants (SNRs), while thermal bremsstrahlung radiation comes from objects such as ionised HII regions or planetary nebulae (PNe) (Filipović and Tothill 2021b,a).

The ongoing Evolutionary Map of Universe (EMU) survey is a large-scale radio-continuum survey (Norris et al. 2021b; Hopkins et al. 2025) being conducted with the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope (Hotan et al. 2021). This telescope, along with the other Square Kilometre Array (SKA) precursors (MeerKAT, HERA, and MWA), has allowed many classes of

astrophysical objects to be discovered and studied in unprecedented detail, including SNRs (Filipović et al. 2022, 2023, 2025b; Mantovanini et al. 2025; Sasaki et al. 2025; Burger-Scheidlin et al. 2026; Lazarević et al. 2026) and SNR candidates (Smeaton et al. 2024b,a; Lazarević et al. 2024b); reflection nebulae (RNe) (Bradley et al. 2025b); pulsar wind nebulae (PWNe) (Lazarević et al. 2024a; Ahmad et al. 2025, 2026); Wolf-Rayet (WR) stars (Bradley et al. 2025a,c) and others (Velović et al. 2022, 2023; Bordiu et al. 2024, 2025; Smeaton et al. 2025b; Filipović et al. 2025a; Zakir et al. 2026); as well as the new class of objects known as Odd Radio Circles (ORCs) (Norris et al. 2021a, 2022; Koribalski et al. 2021; Gupta et al. 2025; Taziaux et al. 2025; Filipović et al. 2026) and improved radio catalogues (Pennock et al. 2021; Ball et al. 2023, 2025; Cotton et al. 2024; Norris et al. 2025; Cotton et al. 2026; Rajabpour et al. 2026). The improved sensitivity and resolution of new-generation radio telescopes have also enabled more detailed analyses of several known objects, better constraining their radio properties (Filipović et al. 2024; Asher et al. 2025; Smeaton et al. 2025a; Ghavam et al. 2025; Ingallinera et al. 2026; Castignani et al. 2026).

Radio-continuum observations of a nearby face-on spiral galaxy, NGC 2082, reveal a very strong point-like radio source within the galaxy’s structure and concluded that it is most likely of background origin (Balzan et al. 2022). Similarly, we examine two nearby galaxies, NGC 6209 and NGC 4603, with comparable structures to NGC 2082. These two galaxies provide suitable test cases for investigating compact radio sources in nearby face-on spiral systems, allowing us to distinguish between emission associated with star-formation processes and that arising from unrelated background radio galaxies.

NGC 6209 has visible magnitude $B = 13.16^1$, a physical diameter of 68 kpc, and is located 76 Mpc away ($z = 0.0196$)², corresponding to a scale of 0.4 kpc/". The other galaxy, NGC 4603, has $B = 12.42^1$, physical diameter 46 kpc, at a distance of 35 Mpc² ($z = 0.0086$), corresponding to 0.18 kpc/".

In this paper, we investigate the properties of NGC 6209 and NGC 4603, as observed with ASKAP surveys, complemented by Wide-Field Infrared Survey Explorer (WISE) and Second Digitised Sky Survey (DSS2) red photographic band imaging, with a particular focus on investigating the origin of the

radio-bright sources within the boundaries of each galaxy. In Section 2, we describe our observational data and the analysis method; in Section 3, we present the results; and in Section 4, we present the conclusions.

2 Observations and data

NGC 6209 and NGC 4603 were observed as part of the ASKAP EMU 944 MHz radio-continuum survey, as well as in the Rapid ASKAP Continuum Survey (RACS) (RACS-low 888 MHz, RACS-mid 1367 MHz, and RACS-high 1655 MHz; McConnell et al. 2020). We also use previous observations from the optical DSS2-Red survey and infrared observations from the WISE survey at wavelengths of 3.4 μm , 4.6 μm , and 12 μm .

2.1 ASKAP EMU

ASKAP observed NGC 6209 on 6th March 2025 as part of the EMU survey (tile EMU_1726–73, scheduling block SB71649), and NGC 4603 was observed on 25th April 2025 (tile EMU_1241–41, SB73186) at a central frequency of 944 MHz. The data were reduced using the standard ASKAPSoft data reduction pipeline (Guzman et al. 2019), which consists of multi-frequency synthesis imaging, multi-scale cleaning, and self-calibration, followed by convolution to a common beam size of $15'' \times 15''$ (Hopkins et al. 2025). We estimate a local Root Mean Squared (RMS) noise level of $\sim 25\text{--}30 \mu\text{Jy beam}^{-1}$ in both observations.

2.2 ASKAP RACS

ASKAP observed NGC 6209 and NGC 4603 as part of the RACS survey (McConnell et al. 2020) at three frequency bands: RACS-low (887 MHz; Duchesne et al. 2026), RACS-mid (1367 MHz; Duchesne et al. 2023), and RACS-high (1655 MHz; Duchesne et al. 2025). These observations were also processed using the standard ASKAPSoft data reduction pipeline.

The observing details, including observation dates, scheduling blocks, and beam sizes, are summarised in Table 1. The typical local RMS noise sensitivity is approximately $0.2\text{--}0.25 \text{ mJy beam}^{-1}$.

2.3 Wide-field Infrared Survey Explorer (WISE)

We also used archival WISE images at 3.4, 4.6, and 12 μm (bands W1, W2 and W3), retrieved from the

¹<https://simbad.cds.unistra.fr>

²<https://ned.ipac.caltech.edu>

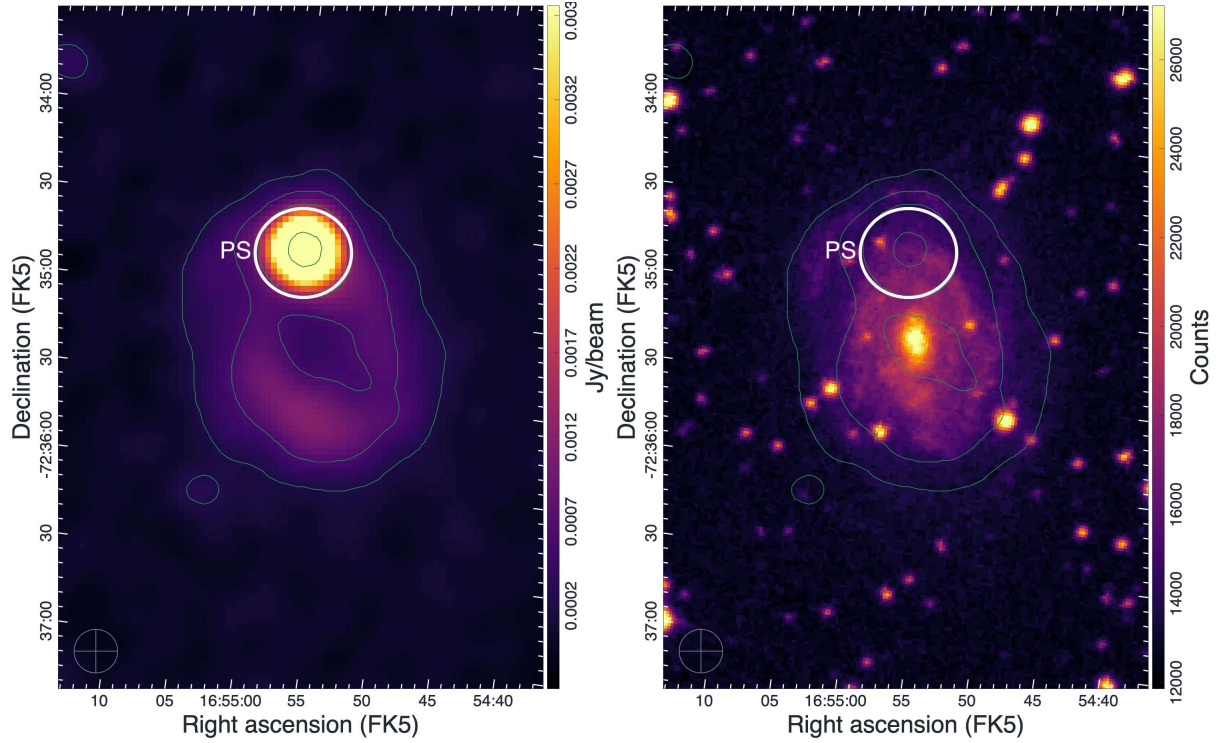


Fig. 1: Left: NGC 6209 – EMU radio-continuum image of NGC 6209. **Right:** NGC 6209 – DSS2 red optical image. Both images have contours from the EMU radio-continuum image at levels of 0.2, 0.6, 1.5, and 8 mJy beam⁻¹. All images are linearly scaled, and the EMU beam size (15''×15'') is shown in the bottom left corners. The white circle represent the study's point source PS.

Table 1: RACS observations of NGC 6209 and NGC 4603.

Galaxy	Survey	Frequency (MHz)	Observation Date	Tile (SB)	Beam Size ('' × '')
NGC 6209	RACS-low	887	12 Apr 2022	1714–73 (SB 39324)	10.4 × 6.6
NGC 6209	RACS-mid	1367	30 Dec 2020	1726–73 (SB 20509)	14.9 × 8.5
NGC 6209	RACS-high	1655	28 Jan 2022	1726–73 (SB 36610)	10.4 × 6.6
NGC 4603	RACS-low	887	18 Mar 2022	1250–43 (SB 38321)	12.6 × 11.7
NGC 4603	RACS-mid	1367	23 Jan 2021	1241–41 (SB 21855)	9.2 × 7.9
NGC 4603	RACS-high	1655	9 Jan 2022	1241–41 (SB 35629)	7.4 × 6.0

SkyView Virtual Observatory³. The angular resolutions are ~6.1'', 6.4'', and 6.5'' for 3.4, 4.6, and 12 μ m, respectively (Wright et al. 2010). Flux calibration and coaddition were performed using the standard WISE pipeline, with a typical 5σ point-source sensitivity of ~0.08, 0.11, and 1 mJy in W1, W2 and W3 in unconfused regions (Wright et al. 2010).

³<https://skyview.gsfc.nasa.gov>

2.4 Second Digitized Sky Survey, red photographic band

Archival images from the Second Digitised Sky Survey in the red photographic band (DSS2 red) were obtained from the SkyView Virtual Observatory³. The DSS2 red image has an angular resolution of 3'' and a pixel size of 1'', with an effective wavelength of approximately 650 nm (Lasker et al. 1996).

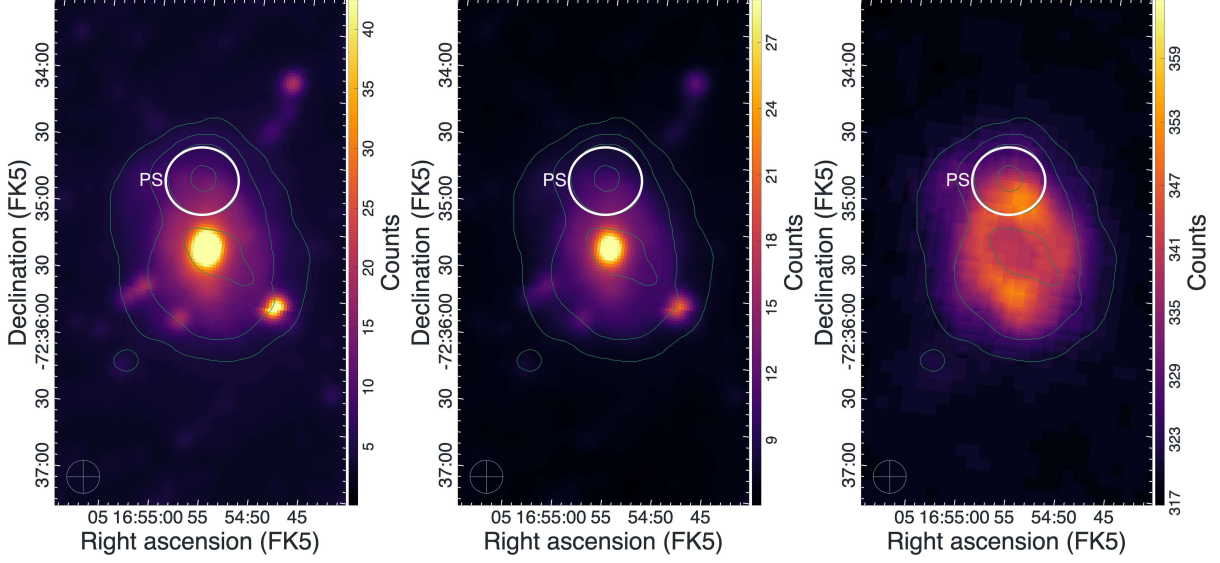


Fig. 2: NGC 6209 – IR WISE $3.4\mu\text{m}$ image (left), IR WISE $4.6\mu\text{m}$ image (middle), and IR WISE $12\mu\text{m}$ image (right). All images have contours from the EMU radio-continuum image at levels of 0.2, 0.6, 1.5, and 8 mJy beam^{-1} . All images are linearly scaled, and the EMU beam size ($15'' \times 15''$) is shown in the bottom left corners. The white circle represent the study’s point source PS.

2.5 Polarisation Sky Survey of the Universe’s Magnetism (POSSUM)

We also used polarisation data products from the ASKAP Polarisation Sky Survey of the Universe’s Magnetism (POSSUM) (Gaensler et al. 2025). POSSUM provides calibrated Stokes Q and U images across the ASKAP observing band, enabling studies of linearly polarised emission and magnetic field properties. The data are processed using the ASKAP-Soft pipeline, which includes calibration, imaging, and mosaicking procedures. The angular resolution and sensitivity are the same as the EMU observations, allowing direct comparison between total intensity and polarised emission.

3 Results and discussion

All radio images of NGC 6209 reveal a bright compact radio source (J165458.82–723442.63) situated approximately $32''$ from the galaxy’s centre (Figure 1, left).

Similarly, all radio observations of NGC 4603 reveal two distinct compact radio sources: Point Source 1 (PS1), J124052.73–405854.09, and Point Source 2 (PS2), J124054.94–405857.14, located $\sim 22''$ and $40''$, respectively, from the galaxy’s centre (Figure 3, left).

This is similar to what Balzan et al. (2022) found in NGC 2082. Possible interpretations for the nature of these point sources within the galaxy’s apparent boundaries include compact star-forming regions, luminous SNRs, radio supernovae, fast radio bursts (FRBs), compact HII regions, or unrelated background radio galaxies and active galactic nucleus (AGN). These possibilities can be assessed using various tests, including source morphology, multi-wavelength appearance, spectral indices, polarisation properties, luminosities, and statistical source-count analysis. In the following subsections, we investigate these characteristics to determine the most likely origin of the detected point radio sources.

3.1 Morphology

The compact radio sources were initially identified by their strong, compact morphology and relatively high surface brightness relative to the surrounding diffuse galactic emission. In the EMU images, the sources appear morphologically distinct from the extended radio structure of the host galaxies and remain unresolved at the ASKAP EMU resolution. Unlike typical star-forming regions, which generally follow galaxy spiral arms and exhibit associated optical or infrared emission, these compact source detections appear isolated from any obvious stellar or infrared counterparts.

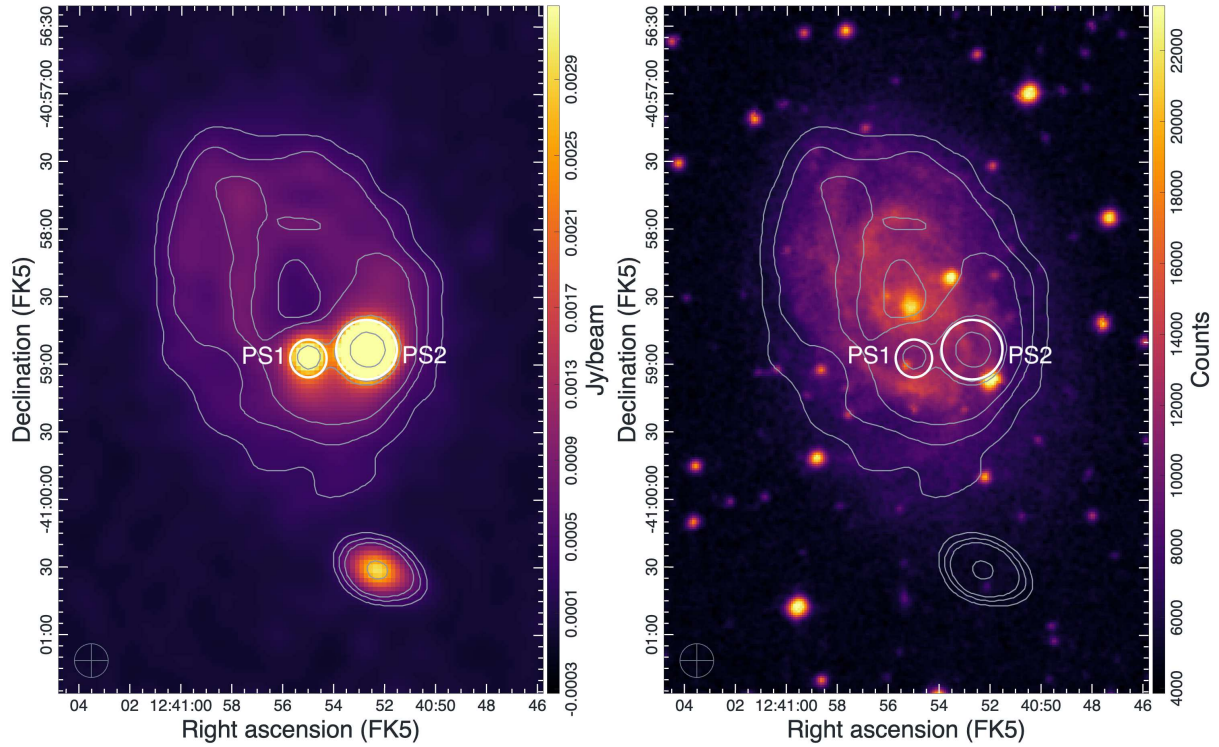


Fig. 3: Left: NGC 4603 – EMU radio-continuum image. **Right:** NGC 4603 DSS2 red optical image. Both images have contours from the EMU radio-continuum image at levels of 0.3, 0.5, 0.75, 2.3, 3, and 7.5 mJy beam⁻¹. All images are linearly scaled, and the EMU beam size (15''×15'') is shown in the bottom left corners. The white circles represent the study's point sources, PS1 and PS2.

The radio morphologies of NGC 6209 and NGC 4603 were overlaid on DSS2 red optical images (Fig. 1, left, and Fig. 3, left), using CARTA visualisation software (Rosolowsky et al. 2015). For both galaxies, the face-on galaxy appearance was clearly visible. However, no optical emission is coincident with the radio point sources detected in either NGC 6209 or NGC 4603. This suggests that they are unlikely to be associated with obvious stellar structures, regions of active star formation, or be associated with a radio supernova. The lowest contour is set to 0.2 mJy beam⁻¹, or about 6 σ , where the RMS is 25–30 μ Jy beam⁻¹.

A similar analysis was performed using WISE infrared images at 3.4, 4.6, and 12 μ m (Figs. 2 and 4). No infrared counterparts were found at the positions of the prominent point/compact radio sources. This further supports the conclusion that these objects are not associated with star-forming regions within the host galaxies.

The absence of any optical and infrared counterparts, combined with the compact, unresolved radio morphology, indicates that these sources are morphologically distinct from typical star-forming regions in their host galaxies.

3.2 Radio Flux Density Measurements

Radio flux densities for the point sources were estimated using EMU tiles at 944 MHz and across different RACS frequency bands (887.491 MHz, 1367.49 MHz, and 1655.49 MHz) via CARTA's integrated flux tool (Table 2). We assume flux density uncertainties of less than 10% (Filipović et al. 2022, 2026).

To measure the flux densities of NGC 6209 and NGC 4603's entire extended emission, we use the method described in Hurley-Walker et al. (2019a,b). We carefully selected a region that excludes any emission from both galaxies. We also measured the total integrated flux densities of NGC 6209 and NGC 4603 at the EMU frequency (Table 2).

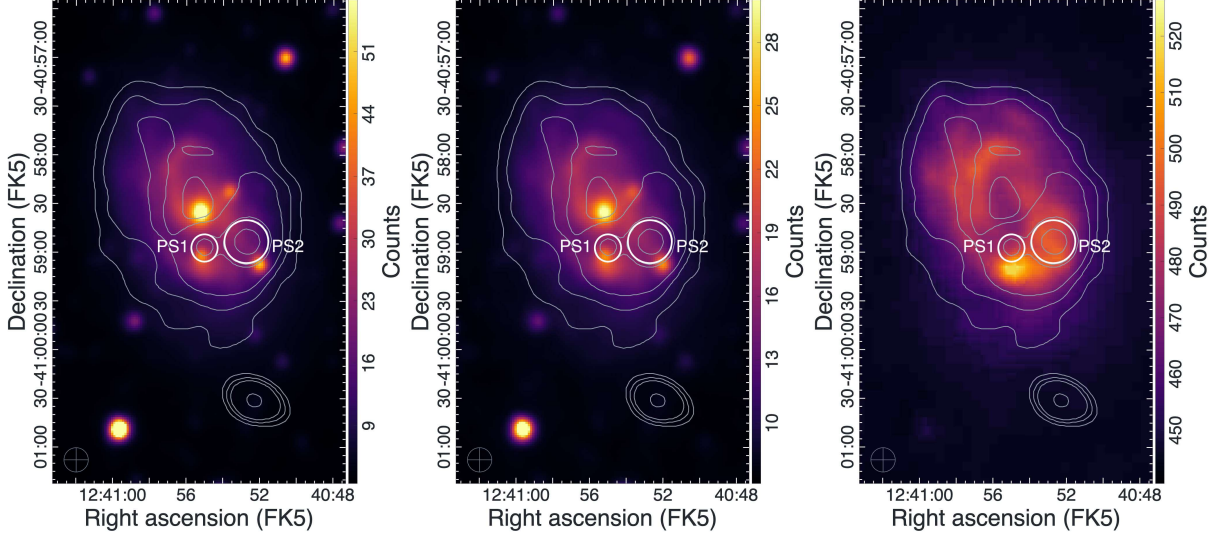


Fig. 4: NGC 4603 IR WISE $3.4\,\mu\text{m}$ image (left), IR WISE $4.6\,\mu\text{m}$ image (middle), and IR WISE $12\,\mu\text{m}$ image (right). All images have contours from the EMU radio-continuum image at levels of 0.3, 0.5, 0.75, 2.3, 3, and $7.5\,\text{mJy beam}^{-1}$. All images are linearly scaled, and the EMU beam size ($15''\times 15''$) is shown in the bottom left corners. The white circles represent the study’s point sources, PS1 and PS2.

Table 2: Radio-continuum flux density estimates (in Jy) for NGC 6209, NGC 4603 and the point radio sources as well as the spectral indices (α).

Frequency	Flux density (mJy)				
	NGC 6209		NGC 4603		
(MHz)	Galaxy	PS	Galaxy	PS1	PS2
944 (EMU)	29.5	18.4	70.8	3.43	17.7
887 (RACS-Low)	–	14.5	–	3.12	17.6
1367 (RACS-Mid)	–	10.8	–	2.89	9.55
1655 (RACS-High)	–	8.06	–	2.45	7.62
α (Spectral Index)	–	-1.17 ± 0.18	–	-0.45 ± 0.10	-1.43 ± 0.10

3.3 Spectral Index Determination

The spectral index, α , was calculated by fitting the measured flux densities (S_ν) at different frequencies (ν) using $S_\nu \propto \nu^\alpha$.

The spectral index results are shown in Table 2. A spectral index steeper (below) than approximately -0.3 indicates non-thermal emission, while a flat or positive value suggests a thermal origin (Filipović and Tothill 2021b).

For the point source in NGC 6209 (Fig. 5, left) and the two point sources in NGC 4603 (Fig. 5, centre and right), the estimated spectral indices are consistent with non-thermal synchrotron emission, which can

arise from either objects such as SNRs within galaxies or from background radio galaxies and AGN.

SNRs typically exhibit spectral indices of $\alpha \sim -0.5$ (Urošević 2014; Bozzetto et al. 2017, 2023), consistent with PS1 in NGC 4603, while background AGN generally show steeper spectra, with values ranging from ~ -0.7 to -1.5 (Cotton et al. 2024). The steep spectral indices observed for the source in NGC 6209 and PS2 in NGC 4603 are therefore more consistent with background radio galaxies or AGN. Radio supernovae at later stages can also exhibit such steep spectra (e.g. Yadav et al. 2014), but the lack of optical counterparts makes this interpretation unlikely.

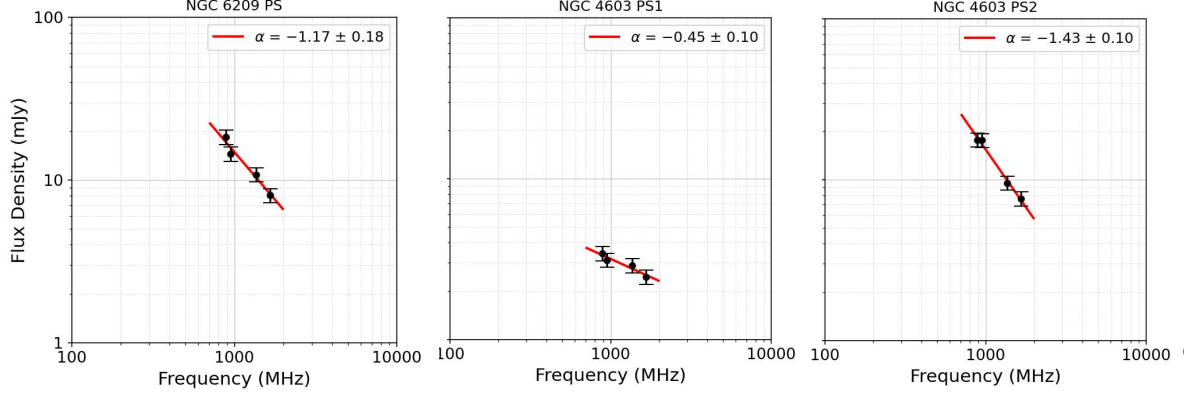


Fig. 5: Radio continuum spectra of the compact sources detected toward NGC 6209 and NGC 4603. The left panel shows the source projected toward NGC 6209, the centre panel shows PS1 in NGC 4603, and the right panel shows PS2 in NGC 4603. Solid lines represent power-law fits of the form $S_\nu \propto \nu^\alpha$.

3.4 Polarisation Analysis

Linear polarisation properties of the detected radio sources were investigated using Stokes I , Q , and U products from the POSSUM survey. The Stokes I image was inspected to verify its consistency with the total-intensity emission. As for Q and U , frequency-resolved image cubes were collapsed along the spectral axis using a mean estimator, producing frequency-averaged two-dimensional images for each Stokes parameter.

The linearly polarised intensity was calculated as:

$$P = \sqrt{Q^2 + U^2}, \quad (1)$$

The images were spatially matched to the contours, then carefully inspected for any degree of polarisation; the derived polarisations are low, of order 10^{-3} , with no evidence of extended or polarised structure.

The very low fractional polarisation (below 0.5%), together with the absence of extended or structured polarised emission, argues against the presence of strongly ordered magnetic fields associated with classical synchrotron-emitting SNRs. They usually exhibit polarisations of a few to a few tens of percent (Dickel and Milne 1976; Kothes et al. 2006). Although synchrotron emission is typically characterised by both non-thermal spectral indices and measurable linear polarisation, depolarisation effects can reduce the observed polarised fraction. Nevertheless, the low

observed polarisation is more consistent with unresolved background radio sources than with extended SNR-related emission within the host galaxies.

3.5 Radio Luminosity Estimates

To place the compact sources in a physical context, monochromatic radio luminosities were estimated at a reference frequency of 1 GHz. The flux density at 1 GHz was derived from the measured ASKAP flux densities, assuming a power-law spectrum of the form of $S_\nu \propto \nu^\alpha$, where α is the spectral index derived in Table 2.

The flux density at 1 GHz was therefore calculated as:

$$S_{1\text{ GHz}} = S_{\nu_0} \left(\frac{1\text{ GHz}}{\nu_0} \right)^\alpha, \quad (2)$$

where S_{ν_0} is the measured flux density at observing frequency ν_0 (Table 3).

The monochromatic luminosity was then computed assuming isotropic emission using:

$$L_{1\text{ GHz}} = 4\pi D^2 S_{1\text{ GHz}}, \quad (3)$$

where D is the luminosity distance in metres.

The derived luminosities in Table 3 (using the galaxy distances, and hence assuming that the sources are associated with the galaxies) are well below those typically associated with radio-loud AGN, which exhibit $L_{1\text{ GHz}} \sim 10^{23} - 10^{27} \text{ W Hz}^{-1}$ (Condon 1992; Mauch and Sadler 2007), and are also lower than those

Table 3: Flux densities scaled to 1 GHz using the measured spectral indices and point-source monochromatic radio luminosities at 1 GHz.

Source	ν_0 (MHz)	S_{ν_0} (mJy)	α	$S_{1\text{ GHz}}$ (mJy)	Distance (Mpc)	Distance (m) $\times 10^{24}$	$L_{1\text{ GHz}}$ (W Hz $^{-1}$)
NGC6209 PS	944	18.4	-1.17	17.2	76.008	2.345	1.19×10^{22}
NGC4603 PS1	944	3.43	-0.45	3.35	35.371	1.091	5.01×10^{20}
NGC4603 PS2	944	17.7	-1.43	16.3	35.371	1.091	2.44×10^{21}

of the most luminous radio transients such as supernovae, fast radio burst and gamma-ray burst afterglows ($L_{1\text{ GHz}} \sim 10^{22} - 10^{26} \text{ W Hz}^{-1}$; Bhandari et al. 2020; Chomiuk et al. 2021; Bietenholz et al. 2021). However, they are higher than the luminosities typically expected from individual SNRs, which generally lie in the range $L_{1\text{ GHz}} \sim 10^{18} - 10^{20} \text{ W Hz}^{-1}$ (Urošević 2014; Bozzetto et al. 2023).

Sources with radio luminosities in the range $10^{20} - 10^{22} \text{ W Hz}^{-1}$ may include luminous SNRs, superbubbles, compact HII regions, low-luminosity AGN (LLAGN), and background radio galaxies. Therefore, luminosity alone does not uniquely constrain the source class.

The luminosity of NGC 4603 PS1 ($5.01 \times 10^{20} \text{ W Hz}^{-1}$) lies near the upper end of the range expected for luminous SNRs and superbubbles. NGC 4603 PS2 ($2.44 \times 10^{21} \text{ W Hz}^{-1}$) lies within the intermediate luminosity regime, while the NGC 6209 source ($1.19 \times 10^{22} \text{ W Hz}^{-1}$) approaches the lower end of the luminosity range observed for some radio transients and compact extragalactic radio sources.

If the detected sources are unrelated background objects, the luminosities derived here represent lower limits, as they were calculated assuming the distances of NGC 6209 and NGC 4603. Their true luminosities would increase as the square of the distance and could therefore be consistent with the luminosities expected from AGN.

These results are similar to those of Balzan et al. (2022), who also found that the most likely explanation for a radio point source within the apparent extent of NGC 2082 is of background origin.

3.6 Probability of Chance Background Alignment

Finally, we estimate the likelihood that the compact radio detections observed toward NGC 6209 and NGC 4603 arise from chance alignment with unrelated background radio sources. The analysis is performed using two independent approaches. The first relies on

integral radio source counts from the literature (Wall 1994), while the second uses an empirical surface-density estimate derived directly from the surrounding EMU images.

These approaches allow an objective statistical assessment of how often radio sources with equal or greater flux density are expected to occur within the galaxies' projected areas purely by chance.

3.6.1 Probability from Integral Source Counts

While modern simulated radio skies (e.g., T-RECS, SKADS) provide updated counts that model angular clustering, we employ the Wall (1994) relation to establish a conservative, historical analytical baseline. The inherent limitations of this relation, such as cosmic variance and the assumption of a purely Poisson spatial distribution, are directly mitigated by our second, independent local empirical source density method.

They provide the cumulative number of radio sources brighter than a given flux density, $N(> S_\nu)$, per steradian at multiple observing frequencies. As no source-count curve is available at the EMU observing frequency (944 MHz), we adopt the nearest available frequency relation (1.41 GHz) from Wall (1994), assuming that the source counts do not vary significantly across this frequency range. The value of $N(> S_\nu)$ was read directly from the vertical axis using the measured flux density of each compact source.

The cumulative counts per steradian were converted to a surface density per square arcsecond using:

$$n(> S) = \frac{N(> S)}{4.25 \times 10^{10}}, \quad (4)$$

since $1 \text{ sr} = 4.25 \times 10^{10} \text{ arcsec}^2$. Assuming Poisson statistics, the probability of detecting at least one background source brighter than S within a projected area A is given by:

$$P(\geq 1) = 1 - e^{-nA} \quad (5)$$

As the two compact sources in NGC 4603 are spatially independent, the probability that both detections are unrelated background sources is given by the product of their individual probabilities.

This value represents the likelihood that two independent background radio sources of equal or greater flux density would be detected within the optical extent of the same galaxy purely by chance. The probabilities derived from the integral source–count approach are summarised in Table 4. The probabilities of chance alignment are 1.7% and 0.26% for both sources in NGC 4603 combined.

3.6.2 Local empirical source density

As an independent check on the integral source–count approach, we estimated the probability of chance alignment using a direct empirical measurement of the local source density in the vicinity of each galaxy.

Four square regions, each $30' \times 30'$, were defined in the cardinal directions (north, east, south, and west) around each galaxy, avoiding areas with obvious extended emission from the target systems. For NGC 4603, all four regions (N, E, S, W) were used. For NGC 6209, only three regions (N, S, W) were used, as the eastern region lies at the edge of the observed tile and was therefore excluded. Within each region, we counted the number of compact radio sources whose flux densities were equal to or greater than that of the point source under consideration.

The mean number of sources per box, $\langle N \rangle$, was converted into a surface density n_{local} :

$$n_{\text{local}} = \frac{\langle N \rangle}{A_{\text{box}}}, \quad (6)$$

where the area of each box is $A_{\text{box}} = (30')^2 = 3.24 \times 10^6 \text{ arcsec}^2$.

Assuming a random spatial distribution of background sources, the expected number of unrelated objects within the optical area of a galaxy ($\lambda = n_{\text{local}} A_{\text{gal}}$), and the probability of finding at least one such source follows Poisson statistics ($P(\geq 1) = 1 - e^{-\lambda}$ as per Equation 5).

For NGC 4603, which contains two compact detections, we additionally computed the probability that both sources are unrelated background objects, assuming statistical independence. This combined probability assumes a Poisson distribution in which background sources are completely independent. This

inherently does not account for the effects of angular clustering or spatial correlation among background radio galaxies.

Because this method relies directly on the observed source population in the EMU field, it naturally reflects the sensitivity and resolution of modern ASKAP data, as well as being at the exact same observing frequency. Consequently, the resulting probabilities are generally smaller than those inferred from historical integral source–count relations, i.e., 0.3–3% and 0.03% for both sources combined in NGC 4603.

These values (Table 5) indicate that the probability of a chance alignment between the detected compact sources and the host galaxies is low, particularly for the case of two sources within NGC 4603. While this statistically reduces the likelihood of a random projection, a low background probability alone does not definitively establish a physical association.

Statistical arguments alone cannot determine the nature of the sources. The probabilities must be considered together with the observed radio properties, including spectral index, polarisation, morphology, and the absence of optical and infrared counterparts.

4 Conclusions

We have investigated three compact radio sources projected toward NGC 6209 and NGC 4603 using ASKAP total–intensity data from EMU and RACS, together with polarisation information from POSSUM and multi–wavelength comparisons with DSS2 and WISE imaging.

The compact source projected toward NGC 6209 exhibits a steep spectral index, low fractional polarisation, no optical or infrared counterpart, and a luminosity of between 10^{20} and $10^{22} \text{ W Hz}^{-1}$. These properties are consistent with either a compact background radio source or a low-luminosity AGN, although the present data do not allow a unique classification.

NGC 4603 PS1 exhibits a somewhat flatter spectral index ($\alpha = -0.45 \pm 0.10$) and a luminosity near the upper end of the range expected for luminous SNRs and superbubbles. These properties are consistent with an origin inside NGC 4603. However, similar to the point source in NGC 6209, NGC 4603 PS2 exhibits a steep spectral index, intermediate luminosity, and no detected optical or infrared counterpart. These properties are more consistent with a background radio galaxy or low-luminosity AGN.

Table 4: Chance-alignment probabilities derived from integral source counts (Wall 1994). Values of $N(> S)$ were read from the source-count curve at the EMU frequency for each source flux density, converted to $n(> S)$, and used in the Poisson probability $P(\geq 1) = 1 - e^{-nA}$.

Source	S_{EMU} (mJy)	$N(> S)$ (sr $^{-1}$)	$n(> S)$ (arcsec $^{-2}$)	A_{gal} (arcsec ^{2})	$P(\geq 1)$
NGC 6209 PS	1.84	4.5×10^{10}	1.059×10^{-6}	9252.96	0.9%
NGC 4603 PS1	3.43	8×10^4	1.882×10^{-6}	20434.547	3.7%
NGC 4603 PS2	1.77	1.5×10^5	3.5294×10^{-6}	20434.547	6.9%
NGC 4603 (combined)	—	—	—	—	0.26%

Note: $n(> S) = N(> S)/(4.25 \times 10^{10})$ using $1 \text{ sr} = 4.25 \times 10^{10} \text{ arcsec}^2$. λ is the expected number of unrelated background sources within the galaxy’s optical area.

Table 5: Local (manual) chance-alignment probabilities using background counts measured in $30' \times 30'$ regions. For each source, $\langle N \rangle$ is the mean number of background sources with flux density $\geq S_{\text{thresh}}$ per box. The surface density is $n_{\text{local}} = \langle N \rangle / A_{\text{box}}$, and the Poisson probability within the galaxy optical area is $P(\geq 1) = 1 - \exp(-n_{\text{local}} A_{\text{gal}})$.

Field / source	S_{thresh} (mJy)	Box size	$\langle N \rangle$	n_{local} (arcsec $^{-2}$)	A_{gal} (arcsec ^{2})	$P(\geq 1)$
NGC 6209 (PS)	18.4	$30' \times 30'$	1.00	3.09×10^{-7}	9252.96	2.85×10^{-3} (0.285%)
NGC 4603 (PS1)	3.43	$30' \times 30'$	6.25	1.93×10^{-6}	20434.55	3.86×10^{-2} (3.86%)
NGC 4603 (PS2)	17.7	$30' \times 30'$	1.25	3.86×10^{-7}	20434.55	7.86×10^{-3} (0.786%)
NGC 4603 (two sources)	—	—	—	—	20434.55	2.73×10^{-4} (0.027%)

Note: $A_{\text{box}} = (30' \times 30') = 900 \text{ arcmin}^2 = 900 \times (60')^2 \text{ arcsec}^2 = 3.24 \times 10^6 \text{ arcsec}^2$.

To quantify the likelihood of chance alignment, we applied two independent approaches. First, probabilities were estimated from integral radio source counts (Wall 1994). Second, we obtained a local empirical estimate by measuring the surface density of field sources in large surrounding regions and scaling to the optical area of each galaxy. Both methods indicate that the probability of random alignment is low, which reduces the likelihood of a chance background projection — but this does not prove a physical association.

In general, our results for NGC 6209 and NGC 4603 are consistent with previous studies, particularly those for NGC 2082 (Balzan et al. 2022).

While the statistical analysis provides some support for physical association with the host galaxies, the observed radio properties favour a background interpretation for the steep-spectrum sources. Additional higher-angular-resolution observations, variability studies, and/or very long baseline interferometric observations will be required to unambiguously determine the nature of these sources.

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