

Caught in the act: Interaction-driven evolution in the nearby compact galaxy group Robert's Quartet (SCG0018-4854)

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ABSTRACT

We present a spatially resolved multiwavelength study of the compact galaxy group Robert's Quartet (RQ; SCG0018-4854), aimed at understanding interaction-driven galaxy evolution in dense environments. The system comprises four galaxies (NGC 87, NGC 88, NGC 89, and NGC 92) that span a range of masses and evolutionary states. Using UV-to-IR data from GALEX, DECaLS, MUSE/VLT (IFU), VISTA/VIRCAM, 2MASS, and WISE, we investigated the interplay between kinematics, star formation, and stellar populations across the group. The spatially resolved analysis reveals disturbed stellar and gas kinematics, enhanced turbulence, and asymmetric structures in all members, consistent with repeated gravitational interactions. The most massive galaxy, NGC 92, exhibits prominent tidal features, a bar, and ring-like star-forming structures, indicative of interaction-driven gas inflows. Another massive member, NGC 89, shows suppressed star formation and signatures of active galactic nucleus-driven feedback. Lower-mass galaxies NGC 88 and the dwarf galaxy NGC 87, by contrast, display enhanced star formation and, in one case, kinematic decoupling between stellar and gaseous components consistent with recent gas accretion. Combining UV-based age estimates with non-parametric star formation histories, we constrain the recent interaction timescale of the group to $\lesssim 500$ Myr, whereas the crossing timescale is 424 Myr. These results indicate that RQ is a dynamically young system undergoing ongoing assembly, where interactions, gas exchange, and feedback processes are actively shaping galaxy evolution. The dynamical complexity of the group further suggests that its present configuration may involve more than four progenitor components. In this context, RQ provides a valuable nearby analogue of compact, rapidly evolving groups observed at high redshift by recent JWST observations, offering a resolved view of the physical processes governing galaxy assembly in the early Universe.

Key words. galaxies: groups: general – galaxies: kinematics and dynamics – galaxies: spiral – galaxies: star formation – galaxies: structure

1. Introduction

Galaxy formation and transformation processes are fundamental to understanding their evolution. According to the hierarchical galaxy formation model, interactions between small galaxies at high redshift form the basis for the formation of present-day galaxies (Toomre & Toomre 1972). Thus, detailed studies of local interacting and merging systems offer valuable insights into phenomena prevalent in the distant universe. Multiple studies have compared properties (e.g. gas mass and star formation rate) of galaxies in the local and distant universe and found that they evolve with redshift (Mannucci et al. 2010; Behroozi et al. 2013; Madau & Dickinson 2014; Boyett et al. 2022). Thus, it is more relevant to compare physical processes and phenomena than absolute values. Interacting and merging systems are unique laboratories for understanding galaxy transformation; however, to have a complete picture, it is imperative to combine observational results with simulations. Barnes & Hernquist (1992) and subsequent numerical studies (e.g. Springel et al. 2005; Di Matteo et al. 2007, 2008; Bekki & Couch 2011) have shown that repeated interactions and mergers in dense environments can trigger a chain of evolutionary transformations. Tidal forces redistribute angular momentum, drive gas inflows towards galactic centres, and compress the interstellar medium, inducing

circumnuclear starbursts (Scott & Kaviraj 2014; Bitsakis et al. 2011; Yadav et al. 2023). These inflows can also feed central supermassive black holes, igniting active galactic nuclei (AGNs) and potentially initiating feedback that quenches further star formation (Weigel et al. 2018). Over time, the depletion of cold gas and tidal heating transform gas-rich, late-type galaxies into red, quiescent early-type systems (Verdes-Montenegro et al. 2001). Compact groups (CGs), therefore, serve as nearby analogues of the high-redshift universe, where interactions are more frequent (Rodríguez-Baras et al. 2014).

Compact groups of galaxies consist of a small number of galaxies, typically four to seven, separated by projected distances of only a few tens of kiloparsecs and have low velocity dispersions of ≈ 200 km/s (Hickson 1982; Hickson et al. 1992). Such proximity leads to strong gravitational interactions, frequent encounters, and a high probability of mergers occurring over relatively short timescales. As a result, they play an important role in the environment-driven evolution of galaxies (Mendes de Oliveira & Hickson 1994; Coziol & Plauchu-Frayn 2007). Observationally, CGs show remarkable diversity in morphology and activity, from irregular and spiral systems with intense star formation to lenticular and elliptical galaxies that are dynamically relaxed and quiescent (Hickson 1997, and references therein). Multiwavelength studies reveal that many CGs contain both gas-rich and gas-poor members within the same environment

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(Bitsakis et al. 2014; Walker et al. 2010). Star formation frequently occurs in tidal bridges, producing patchy UV and H α emission (de Mello et al. 2008; Tzanavaris et al. 2010). Some galaxies display rejuvenated star formation from fresh gas accretion or interaction-induced inflows (Gallagher et al. 2008; Torres-Flores et al. 2014), while others exhibit AGN-driven suppression or morphological quenching (Plana et al. 2020). A higher incidence of AGNs has been reported in CGs relative to field galaxies (Coziol et al. 1998; Martínez et al. 2010; Sohn et al. 2013), with the prevalence of nuclear activity often correlating with signs of tidal perturbation. This mixture of morphologies and activity levels reflects different evolutionary stages within a single gravitationally bound system, demonstrating how CGs evolve through cycles of star formation, merger-induced transformation, and feedback.

Dynamical models predict that galaxies in groups undergo strong interactions and merge on a dynamical timescale (Barnes 1985; Governato et al. 1996). However, major mergers are rare in CGs (Mendes de Oliveira & Hickson 1994). Compact group galaxies preferentially merge in a dry condition, after losing most of their gas through interactions (Coziol & Plauchu-Frayn 2007). This scenario is supported by HI observations showing disturbed distributions in CGs (Verdes-Montenegro et al. 2001), which suggest that their evolution is driven primarily by galaxy interactions and tidal stripping. Thus, it is important to reconstruct the evolutionary and interaction history of CGs by examining the properties of their member galaxies and relating them to the global properties of the group. Integral-field spectroscopy will help us reveal complex velocity fields and ionisation regions consistent with recent interactions. Such evidence supports the view that compact configurations accelerate both star formation and black-hole growth.

The paper is organised as follows. Section 2 describes the datasets. Section 3 explains the methods used for our analysis. Our results are presented in Sect. 4 followed by a discussion in Sect. 5. Our main conclusions are presented in Sect. 6. We adopted a flat Λ cold dark matter (Λ CDM) cosmology with $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ throughout our study.

2. Data

To investigate the stellar and ionised gas properties of the galaxies in RQ, we combined UV, optical, and IR data from multiple archives, each probing a complementary aspect of the system's evolution. The datasets are briefly described below.

Ultraviolet imaging. The far- and near-UV (FUV, NUV) images were obtained from the *Galaxy Evolution Explorer* (GALEX) archive, which is a NASA UV space telescope that works in imaging and spectroscopy modes. It has two imaging filters, FUV (1344–1786 Å) and NUV (1771–2831 Å) (Morrissey et al. 2007). GALEX observed RQ on 2005-09-09 and 2005-09-25 in NUV and FUV filters, with exposure times of 7419 and 4060 seconds, respectively. We accessed the science-ready data through the MAST portal¹. The UV emission traces recent star formation (up to 300 Myr), enabling us to identify young stellar complexes and tidal star-forming (SF) regions within the group.

Optical imaging. Deep g , r , i , and z -band optical images were taken from the Dark Energy Camera Legacy Survey (DECaLS;

Table 1. Details of the RQ galaxy groups.

Source	RA (hh mm ss)	Dec (dd mm ss)	Velocity (km/s)
NGC 87	00 21 14.21	−48 37 42.81	3426 ± 2.5
NGC 88	00 21 22.06	−48 38 25.21	3409 ± 3.9
NGC 89	00 21 24.36	−48 39 54.88	3295 ± 2.9
NGC 92	00 21 31.66	−48 37 28.82	3362 ± 14

Notes. Columns two and three list the coordinates of the galaxies in J2000. The radial velocity is tabulated in column four. The coordinates are listed from NED, and the velocity is estimated from MUSE data cubes.

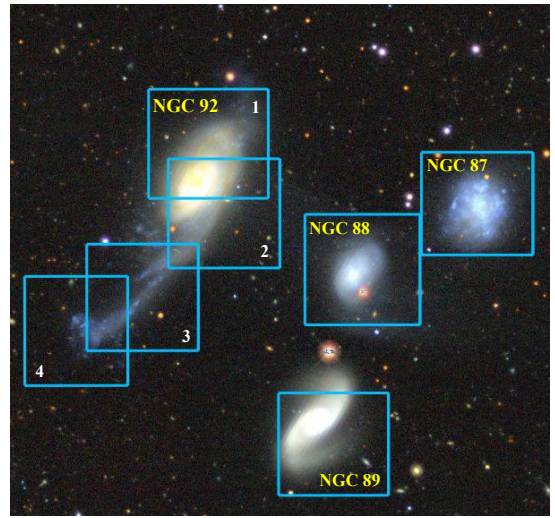


Fig. 1. Optical image of RQ. The blue squares show the locations of the MUSE-DEEP IFU data cube footprints. The optical image is derived from DECaLS (Dey et al. 2019). North is up, and east is left.

Dey et al. 2019) Data Release 10 (DR10). The data reach an approximate 5σ depth of $g = 23.72$, $r = 23.27$, $i = 23.50$ and $z = 22.22$ AB mag for a galaxy with an exponential disc profile and a half-light radius of 0.45 arcsec. The high surface-brightness ($\mu_r \approx 29 \text{ mag/arcsec}^2$) sensitivity of DECaLS enables the detection of faint tidal features and low surface-brightness structures, providing constraints on morphological disturbances and stellar mass distributions.

Optical integral-field spectroscopy. Optical integral-field spectroscopic data were obtained from the Multi Unit Spectroscopic Explorer (MUSE; Bacon et al. 2010) at the ESO Very Large Telescope (VLT). The MUSE data cube covers 4750–9350 Å range with a mean spectral resolution of $R \sim 3000$ and spatial sampling of $0.2''/\text{pixel}$ over a $1' \times 1'$ field of view. The science-ready MUSE-DEEP data cube of the galaxy group was retrieved from the ESO science archive portal². The galaxy group was observed from 2018-05-09 to 2018-07-20, and the programme ID is 0101.C-0329. The MUSE-DEEP data cube footprint of the galaxy group is shown in Fig. 1, where the optical image is derived from DECaLS (Dey et al. 2019). In this work, we utilised data cube 2 of the four available data cubes covering NGC 92 to investigate the stellar and gas kinematics along with stellar population properties of the central region of NGC 92. Additionally, we utilised data cube 3 to constrain the gas-phase metallicity of

¹ <https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html>

² <https://archive.eso.org/scienceportal/home>

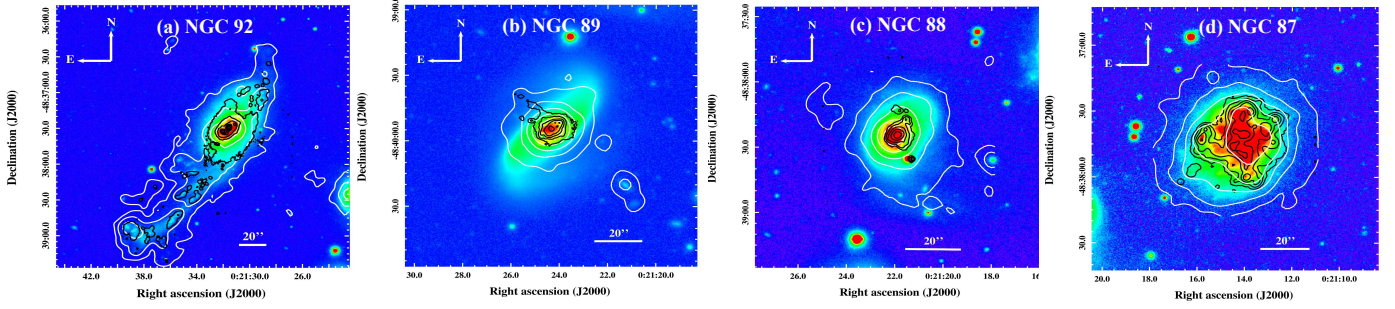


Fig. 2. Multiwavelength view of the RQ galaxies. DECaLS g-band images of (a) NGC 92, (b) NGC 89, (c) NGC 88, and (d) NGC 87 are shown with MUSE H α (black) and GALEX FUV (white) contours overlaid.

Table 2. Details of the archival imaging data used in this work.

Telescope/ Survey	Filter	Spatial sampling (arcsec/pixel)	FWHM (arcsec)	Point-source limit ($5\sigma^*/10\sigma^{**}$, AB mag)
GALEX	FUV	1.50	4.20	22.60*
GALEX	NUV	1.50	5.30	22.70*
DECaLS	g	0.26	0.97	23.95*
DECaLS	r	0.26	0.83	23.54*
DECaLS	i	0.26	0.77	23.80*
DECaLS	z	0.26	0.87	22.50*
2MASS	J	1.0	2.89	16.71**
2MASS	H	1.0	2.83	16.49**
2MASS	Ks	1.0	2.98	16.15**
VISTA	Ks	0.34	1.12	20.36*
WISE	W1	1.38	6.08	19.20*
WISE	W2	1.38	6.84	18.84*
WISE	W3	1.38	7.36	16.37*
WISE	W4	1.38	11.99	14.52*

Notes. GALEX: [Morrissey et al. \(2007\)](#); DECaLS: [Dey et al. \(2019\)](#); 2MASS: [Skrutskie et al. \(2006\)](#); VISTA: [Sutherland et al. \(2015\)](#); WISE: [Wright et al. \(2010\)](#).

the tail. We also used all four data cubes to produce an H α image of NGC 92.

Infrared imaging. Near-IR (J , H , K_s) images were retrieved from the Two Micron All Sky Survey (2MASS, [Skrutskie et al. \(2006\)](#)) Extended Source Catalogue, while mid-IR (W1 (3.4 μ m), W2 (4.6 μ m), W3 (12 μ m), and W4 (24 μ m)) data were taken from the Wide-field Infrared Survey Explorer (WISE, [Wright et al. 2010](#)). The measurements obtained from the 2MASS images were converted to flux units using scaling factors given in the respective image headers. For WISE, we used the scaling factors available in the documentation. We also utilised high-resolution K_s -band images from VISTA InfraRed CAMera (VIRCAM) with a 1.65° field of view at the Visible and Infrared Survey Telescope for Astronomy (VISTA) ([Sutherland et al. 2015](#)). Detailed information on the data used in this work is given in Table 2. In Fig 2. We present the DECaLS g-band images of all four member galaxies of RQ, overlaid with MUSE H α (black) and GALEX FUV (white) contours. NGC 92, NGC 88, and NGC 87 exhibit extended FUV emission beyond their optical extent.

3. Analysis

Our analysis combines morphological, photometric, and spectroscopic diagnostics to characterise the stellar and gas kinematics and stellar populations of the RQ member galaxies. It allows us to construct a coherent view of how tidal interactions, gas flows, and feedback shape their current evolutionary state.

3.1. Global properties using SED modelling

To characterise the global properties of NGC 87, NGC 88, NGC 89, and NGC 92, we performed broadband spectral energy distribution (SED) modelling. The analysis required multi-band photometry, which was obtained by convolving all images to match the *WISE* W4 point spread function (PSF). Source detection and segmentation maps were generated using the SExtractor software ([Bertin & Arnouts 1996](#)), adopting a detection threshold of 3σ on the DECaLS g -band image of each galaxy. The resulting segmentation maps were applied uniformly across all other bands to extract consistent flux measurements. Photometry was obtained in 13 bands spanning from the UV to the mid-IR: GALEX (FUV and NUV), DECaLS (g , r , i , and z), 2MASS (J , H , and K_s), and WISE (W1, W2, W3, and W4). In addition, VISTA K_s -band imaging was only used for the structural decomposition and GALFIT modelling owing to its higher spatial resolution.

The observed UV–optical–IR SEDs were modelled using the Code Investigating GALaxy Emission (CIGALE; [Boquien et al. 2019](#)), which implements the energy-balance principle for SED fitting to derive key physical properties such as the star formation rate (SFR), stellar mass (M_*), stellar population age, dust attenuation, and star formation history (SFH) parameters. CIGALE constructs model spectra through a Bayesian analysis framework by combining multiple physical modules. We adopted a delayed SFH with an optional burst/quench component (sfhdelayeddbq), coupled with [Bruzual & Charlot \(2003\)](#) single stellar population (SSP) models assuming a Salpeter initial mass function (IMF; [Salpeter 1955](#)) with mass limits of 0.1–100 $M_\odot$. The nebular emission from the interstellar medium was modelled using the nebular module, and dust attenuation was treated using the modified starburst law of [Calzetti et al. \(2000\)](#) with zero UV bump amplitude. Infrared emission from dust heated by stellar radiation was modelled using the dust emission models of [Draine et al. \(2007, 2014\)](#). To account for the contribution from an AGN, we included the SKIRTOR models of [Stalevski et al. \(2016\)](#). A summary of the CIGALE modules and their corresponding input parameters is presented in Table D.1. The derived stellar masses and global star formation rates for all four member galaxies are summarised in Table 3.

3.2. MUSE data cube analysis

We utilised the MUSE Wide Field Mode with no adaptive optics (WFM-NOAO) science-ready data cube of RQ for the spectroscopic analysis. The data were processed using version 3.1.0 of the Galaxy IFU Spectroscopy Tool (GIST; [Bittner et al. 2019](#)), a comprehensive framework designed for analysing fully reduced integral-field spectroscopic observations. The

Table 3. Stellar mass (M_*) and SFR derived from our broadband SED analysis.

Source	Stellar mass ($M_\odot$)	SFR ($M_\odot \text{yr}^{-1}$)
NGC 87	1.87×10^9	1.57 ± 0.19
NGC 88	6.26×10^9	0.39 ± 0.05
NGC 89	2.70×10^{10}	0.16 ± 0.03
NGC 92	5.61×10^{10}	1.08 ± 0.14

GIST pipeline employs the penalised pixel-fitting code (pPXF; Cappellari & Emsellem 2004; Cappellari 2017, 2022) to derive the stellar line-of-sight velocity distribution (LOSVD) and associated stellar kinematics, while the Gas and Absorption Line Fitting (GandALF) module (Sarzi et al. 2006; Falcón-Barroso et al. 2006) is used to fit emission lines and extract gaseous kinematics and line fluxes. Spatial binning was performed using the Voronoi tessellation method (Cappellari & Copin 2003) within the wavelength range 480–700 nm to achieve a target signal-to-noise ratio (S/N) of 40 per bin. The S/N was computed for each unbinned spaxel per spectral pixel ($\approx$ per Å) within the selected wavelength range. Spaxels with $S/N < 3$ were excluded from the binning process to minimise the contribution of noisy data before binning. The remaining spaxels were then adaptively combined until the target S/N of 40 per bin was reached, whereas individual spaxels with $S/N > 40$ were left unbinned. All spectra were subsequently corrected for galactic extinction in the direction of the target. A detailed discussion on MUSE analysis is presented in Keshri et al. (2025a,b).

3.2.1. Non-parametric star formation history

We derived global properties for each member of the group using SED modelling of multi-band images, which is discussed in detail in Sect. 3.1. Here, we utilised the MUSE data cube to derive spatially resolved mass-weighted stellar populations and SFHs of each galaxy in RQ using the SFH module of the GIST pipeline. This module employs the pPXF algorithm to perform a regularised full spectral fit, enabling the recovery of non-parametric SFHs and stellar population properties. The analysis was carried out on emission-line-subtracted spectra to ensure a robust continuum fit. Fitting was performed over the wavelength range 480–550 nm, incorporating an eighth-order multiplicative Legendre polynomial to correct for residual continuum mismatches between the observed and template spectra. The spectral modelling used a linear combination of templates from the MILES library (Vazdekis et al. 2010), which spans stellar ages from 0.03 to 14 Gyr and metallicities ($[M/H]$) in the range of -2.27 to $+0.40$. The models are based on the BaSTI isochrones (Pietrinferni et al. 2004, 2006, 2009, 2013) and assume a revised Kroupa IMF (Kroupa 2001).

3.2.2. Gas-Phase metallicity

To estimate the spatially resolved oxygen abundance across all galaxies, we derived the gas-phase metallicity (Z_{gas}) using the N2 diagnostic of Pettini & Pagel (2004), expressed as

$$12 + \log(\text{O}/\text{H}) = 8.9 + 0.57 \times \log(\text{N}2), \quad (1)$$

where N2 represents the flux ratio of the $[\text{NII}] \lambda 6583$ to $\text{H}\alpha$ emission lines. For reference, the solar metallicity corresponds to $12 + \log(\text{O}/\text{H}) = 8.66$ (Asplund et al. 2006).

The N2 index is highly sensitive to the gas-phase oxygen abundance, responding to both ionisation and chemical effects. When (O/H) falls below the solar value, the ionisation parameter and/or hardness of the ionising radiation typically increases, leading to a decrease in the $[\text{NII}]/[\text{NIII}]$ ratio. Conversely, at higher abundances, the secondary nature of nitrogen causes the (N/O) ratio to decline. These dependencies make N2 an efficient proxy for tracing metallicity variations. Using the resulting Z_{gas} maps, we investigated the radial and spatial metallicity gradients across each member of RQ, as discussed in the following sections.

3.2.3. BPT and WHAN classification

Understanding the relative contributions of star formation and AGN activity in interacting systems is essential for disentangling the physical processes governing galaxy evolution. Interactions can compress the interstellar medium, triggering enhanced star formation, while also driving gas inflows that feed central supermassive black holes. To examine the dominant ionisation mechanisms within the galaxies of RQ, we employed spatially resolved emission-line diagnostics derived from the MUSE IFU data. Emission-line fluxes extracted from the MUSE cube were used to construct Baldwin–Phillips–Terlevich (BPT; Baldwin et al. 1981) diagrams, which classify the ionisation sources based on characteristic nebular emission-line ratios. We used $[\text{OIII}]\lambda 5007/\text{H}\beta$ versus $[\text{NII}] \lambda 6583/\text{H}\alpha$ flux ratios, measured for each Voronoi bin across the MUSE field of view. These ratios separate regions ionised by hot, young stars in HII regions from those excited by harder radiation fields typically associated with AGNs. The theoretical upper limit for pure SF regions was defined by Kewley et al. (2001) using stellar population synthesis and photoionisation models. Galaxies located above this curve cannot be explained by star formation alone and are attributed to AGN-dominated ionisation. Large spectroscopic surveys, such as SDSS, have shown that galaxies populate the BPT plane in a characteristic ‘seagull-shaped’ distribution (Kauffmann et al. 2003). The left branch corresponds to ionisation due to star formation, the right to AGN-dominated systems, and the intermediate ‘composite’ region represents mixed ionisation from both mechanisms. The AGN branch itself bifurcates into a high-ionisation Seyfert sequence and a low-ionisation LINER sequence (Schawinski et al. 2007), reflecting different physical excitation processes such as low-luminosity AGNs, shock heating, or ionisation by evolved stars. We derived spatially resolved BPT classifications for the RQ galaxies. This approach enables us to map the spatial variation of ionisation mechanisms, identifying regions dominated by star formation, AGN activity, or a composite of both across the group members.

An important caveat in interpreting BPT diagnostics concerns the origin of emission-line ratios traditionally classified as LINER-like. Stasińska et al. (2008) demonstrated that ‘retired galaxies’ (RGs), which have ceased star formation, can occupy the same region of the BPT diagram as LINERs. In these systems, the ionising photons are not necessarily produced by accretion onto a supermassive black hole but may instead arise from hot, low-mass evolved stars, such as post-asymptotic giant branch (post-AGB) stars or white dwarfs that can ionise the surrounding interstellar medium and produce optical line ratios similar to those of LINERs. Consequently, a significant fraction of galaxies located along the LINER branch of the BPT

‘right wing’ may represent retired systems rather than genuine AGNs. To mitigate this ambiguity, [Cid Fernandes et al. \(2011\)](#) introduced the WHAN diagram, which combines the [NII]/H α flux ratio with the equivalent width (EW) of H α . This approach provides a more robust separation between true AGNs and ionisation from evolved stellar populations. The inclusion of H α EW effectively distinguishes weak AGNs (wAGNs) from RGs (galaxies that have stopped forming stars and whose residual gas is ionised by their low-mass hot evolved stars) and passive galaxies (galaxies with no emission lines), thereby refining the classification of low-ionisation spectra beyond the limits of the traditional BPT framework.

3.3. Dynamical state of RQ

The convenient way of estimating the dynamical state of a group is to measure the dimensionless crossing time, $H_0 t_c$, where H_0 is the Hubble-Lemaître constant. It measures the time taken by a galaxy to pass through the group and is estimated using the relation given by [Hickson et al. \(1992\)](#) as follows:

$$t_c = \frac{4R}{\pi\sigma_{3D}}, \quad (2)$$

where R represents the median of the 2D galaxy-galaxy separation vector in kiloparsec. We measured it by estimating the separation between each galaxy in arcseconds, then determined the median of these separations in arcseconds and converted it to the linear distance in kiloparsecs using the distance of RQ. The value σ_{3D} represents the 3D velocity dispersion and is defined as $\sigma_{3D} = \left[3(\langle v^2 \rangle - \langle v \rangle^2 - \langle \delta v^2 \rangle)\right]^{1/2}$, where $\langle v \rangle$ is the average of the radial velocities of each galaxy in the group and $\langle \delta v^2 \rangle$ is the average of velocity errors squared. We utilised velocity and error as given in Table 1.

We also estimated the line-of-sight (LOS) velocity dispersion (σ_G) of the group using a variant of the gapper estimator as described by [Beers et al. \(1990\)](#), since it is less biased for groups with a small number of members compared to the standard deviation. The method involves sorting the velocities (v_i) of each galaxy in ascending order and defining the gap as

$$g_i = v_{i+1} - v_i, \quad i = 1, 2, \dots, N-1. \quad (3)$$

Subsequently, the rest-frame LOS σ_G was estimated using the relation given by [Yang et al. \(2005\)](#); [Zheng & Shen \(2021\)](#)

$$\sigma_G = \frac{\sqrt{\pi}}{(1+z)N(N-1)} \sum_{i=1}^{N-1} w_i g_i. \quad (4)$$

Here, z is the CG redshift, and w_i is the weight defined as $w_i = i(N-i)$, where N represents the number of members in the CG.

Assuming that one of the galaxies moves at the centre-of-mass velocity of the group, σ_G should be corrected by a factor of $N(N-1)$ ([Eke et al. 2004](#)). Also, redshift measurement errors increase the σ_{LOS} estimate; thus, it should be removed in quadrature. The σ_{LOS} of each group is given by

$$\sigma_{LOS} = \sqrt{\max\left(0, \frac{N\sigma_G^2}{N-1} - \langle \delta v^2 \rangle\right)}. \quad (5)$$

Crossing time and velocity dispersion estimates suggest that RQ is a dynamically young CG with a crossing time (t_c) of ~ 424 Myr ($\log(H_0 t_c) \sim -1.52$) and a velocity dispersion of ~ 74 km/s.

4. Results

Robert’s Quartet provides an excellent nearby laboratory for investigating the impact of galaxy interactions on star formation, stellar populations, and gas dynamics in CG environments. Although the member galaxies reside within the same gravitational potential, they exhibit a wide diversity in morphology, stellar mass, star formation activity, and evolutionary state. This diversity highlights the complex and asynchronous nature of galaxy evolution in CGs. In the following sections, we analyse each galaxy individually, focusing on its structural properties, stellar populations, ionised-gas distribution, and kinematic signatures. Together, these properties trace different stages of interaction-driven evolution and transformation within the group environment.

4.1. NGC 92

NGC 92 is the most massive and actively SF member of RQ, with a stellar mass of $\sim 5.6 \times 10^{10} M_\odot$ and a total SFR of $\sim 1.1 M_\odot \text{ yr}^{-1}$, as derived from SED modelling. The *GALEX* FUV imaging reveals six prominent SF clumps in the galaxy, including the tidal tail, which extends up to ~ 30 kpc ([Temporin et al. 2005](#)). The derived ages of these clumps range from 27 to 204 Myr, with the central clump at an age of ~ 204 Myr (Fig. B.1). The tidal tail was also detected in X-ray observations of RQ ([Trinchieri et al. 2008](#)).

In optical images, NGC 92 exhibits a morphology reminiscent of a ring structure. Interactions are known to produce ring-like morphologies when an intruder passes close to a massive gas-rich disc galaxy ([Lynds & Toomre 1976](#); [Theys & Spiegel 1976](#)). Such encounters can additionally generate one-armed or asymmetric tidal structures, as demonstrated in the simulations of [Toomre \(1978\)](#), whose final configurations closely resemble the morphology of NGC 92. The galaxy also hosts a candidate tidal dwarf galaxy within the tidal tail ([Torres-Flores et al. 2009](#)), a double nucleus ([Danks & Alcaino 1981](#)), and a prominent dust lane. These features collectively indicate that NGC 92 undergoes strong interaction-driven evolution and likely plays a central role in shaping the dynamical state of the group.

To investigate the nature of the central structure in NGC 92, we examined the stellar and ionised-gas kinematics derived from the MUSE data. The stellar line-of-sight velocity field within the central $36'' \times 36''$ region (Fig. 3a) exhibits a well-ordered rotational pattern with amplitudes reaching ± 150 km/s. While the velocity field is broadly regular at intermediate radii, the innermost region shows subtle twists in the zero-velocity curve and isophotal asymmetries, suggesting the presence of non-axisymmetric structures such as a bar or perturbations induced by recent tidal interactions.

The H α velocity field (Fig. 3c) broadly follows the stellar rotation pattern, although stronger asymmetries are observed in the central region. Within this region, we identify two high surface-brightness components (hereafter nuclei 1 and nuclei 2), marked in the left panel of Fig. 4. The right panel of Fig. 4 shows the integrated spectra extracted from these nuclei, together with a zoomed-in view of the H α $\lambda 6563 \text{ \AA}$ and [NII] $\lambda \lambda 6548, 6583 \text{ \AA}$ emission lines used for the redshift measurements. Gaussian fitting yields systemic redshifts of $z_{\text{nuclei1}} = 0.011352 \pm 0.00006$ and $z_{\text{nuclei2}} = 0.010879 \pm 0.00004$, corresponding to a velocity offset of ~ 140 km/s. Although this offset could initially suggest dynamically distinct components, both nuclei lie along the same large-scale rotational gradient in the stellar and gas velocity

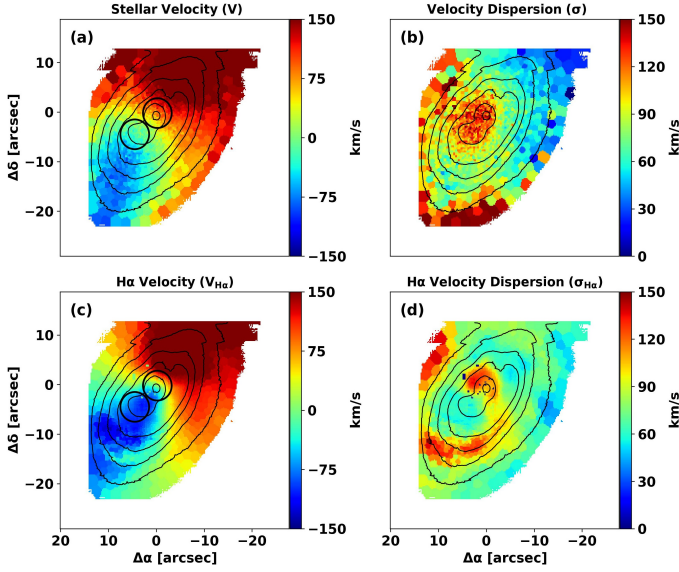


Fig. 3. Spatially resolved stellar and gas kinematic maps of NGC 92 derived from MUSE observations. Top row: (a) stellar velocity (V); (b) velocity dispersion (σ_*). Bottom row: (c) ionised gas ($H\alpha$) velocity ($V_{H\alpha}$); (d) gas velocity dispersion ($\sigma_{H\alpha}$). In each panel, north is up and east is left.

Table 4. Output of the three-component (bulge, bar, and disc) GALFIT model for NGC 92 in the VIRCAM/VISTA Ks -band image.

Bulge	R_e (kpc)	0.28
	n	0.65
Bar	R_e (kpc)	1.23
	n	0.62
Disc	R_s (kpc)	2.31

Notes. R_e is the effective radius in kiloparsec for the bulge and bar; R_s is the disc scale length in kiloparsec; and n is the Sersic index.

fields (Figs. 3a,c), with no clear evidence for kinematic decoupling. This indicates that the observed velocity difference is consistent with internal motions within the rotating disc rather than two separate galaxies.

To further investigate the central structure of NGC 92, we analysed the near-IR morphology using the VIRCAM/VISTA Ks -band image. We performed a 2D photometric decomposition with GALFIT (Peng et al. 2002). A detailed description of the decomposition methodology is provided in Keshri et al. (2025b), and the same procedure was adopted here to model the bulge, bar, and disc components. The bulge and bar were fitted with Sérsic profiles, while the disc was modelled with an exponential profile. The resulting structural parameters are listed in Table 4. The observed Ks -band image, best-fit model, residual map, and 1D surface-brightness profiles are presented in Fig. 5.

Previous work by Presotto et al. (2010) identified a bar in NGC 92 based on long-slit kinematic analysis and visual inspection of Ks -band NIR image, although no photometric decomposition was performed. Our 2D decomposition clearly reveals a prominent stellar bar with a length of 1.232 kpc. Combining the photometric and kinematic results, we find that the second ‘nucleus’ does not correspond to a dynamically distinct component. Instead, it is associated with the inner spiral-arm structure, where enhanced surface brightness and projection effects likely

mimic a secondary nucleus. This interpretation removes the need for a recent merger and suggests that the central morphology and kinematics of NGC 92 are primarily shaped by bar-driven dynamics and interaction-induced perturbations.

The stellar velocity dispersion map (σ_* ; Fig. 3b) further characterises the internal structure of NGC 92. Values exceeding ~ 120 km/s are confined to the central kiloparsec, indicating the presence of a dynamically hot central component or enhanced mass concentration. The pronounced central increase in σ_* , together with the twisting of the inner velocity field, is consistent with bar-driven secular evolution that has funnelled gas towards the centre and contributed to the growth of a disc-like pseudobulge. The $H\alpha$ velocity dispersion map ($\sigma_{H\alpha}$; Fig. 3d) reaches values above 120 km/s in the circumnuclear region, indicating strong gas turbulence. The enhanced $\sigma_{H\alpha}$ also traces the prominent dust lane visible in the optical image. Such dynamical disturbances are likely associated with ongoing star formation and gas inflow driven by interactions within the group.

Stellar population diagnostics provide further evidence for the complex evolutionary history of NGC 92. The mass-weighted age map (Fig. 6a) reveals an old stellar population (10–12 Gyr) concentrated in the central region, while significantly younger populations dominate the outer disc. These younger outer-disc populations are likely associated with tidally induced star formation, consistent with UV and optical imaging studies that show extended tidal features, disturbed spiral arms, and dust lanes (Torres-Flores et al. 2009, 2014).

The stellar metallicity map (Fig. 6b) exhibits a pronounced radial gradient, indicating more efficient chemical enrichment in the central regions and comparatively lower metallicities in the outer disc. The gas-phase metallicity map (Fig. 6c) shows oxygen abundances spanning ~ 8.5 – 8.9 , with localised enhancements across the disc. In contrast to the stellar component, the gas-phase metallicity distribution does not exhibit a radial gradient, suggesting efficient mixing of the ionised gas or recent inflows of lower-metallicity material that have flattened the abundance profile. The elevated gas-phase metallicities in the circumnuclear region (~ 8.8 – 8.9) coincide with regions of enhanced $\sigma_{H\alpha}$, supporting a scenario in which bar-driven inflows or interaction-induced shocks concentrate enriched gas near the centre, potentially sustaining recurrent circumnuclear star formation.

We further investigated the gas-phase metallicity along the tidal tail using a modified analysis of cube 3 of NGC 92, as indicated in Fig. 1. Voronoi binning was performed over the wavelength range 650–660 nm to achieve a target S/N of 20, while the remainder of the analysis followed the procedure described in Sect. 3.2. The resulting spatially resolved metallicity map is shown in Fig. 7. The derived oxygen abundances span ~ 8.5 – 9.1 dex, comparable to those measured in the galaxy’s central regions.

Previous slit-spectroscopy measurements of the SF regions along the tail by Torres-Flores et al. (2014) reported slightly lower metallicities (8.45–8.67 dex). Nevertheless, both studies indicate that the disc and tidal tail share similar metallicities, implying a relatively flat abundance profile with no strong radial gradient. This suggests that enriched gas has been redistributed from the inner regions towards the outskirts, likely through recent interactions. The presence of a common HI envelope (Pompei et al. 2007), together with the stellar mass ratios of NGC 88 to NGC 92 (1:8.8) and NGC 89 to NGC 92 (1:2.2), suggests that NGC 88 is the primary interacting companion, although the possibility of contribution from NGC 89 cannot be excluded.

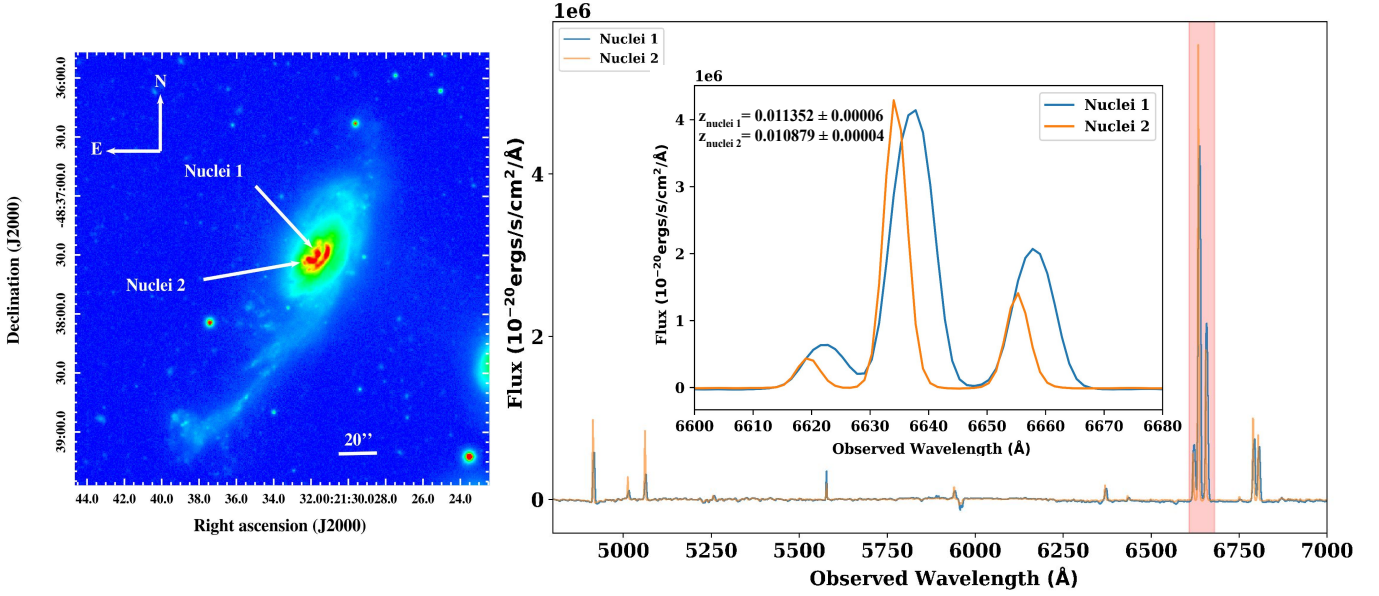


Fig. 4. Left: DECaLS g-band image of NGC 92. Right: MUSE spectra for nuclei 1 (blue) and nuclei 2 (orange) from the left panel, with zoomed-in views highlighting the H α and [NII] emission lines. Gaussian profiles are used to model these lines to calculate the redshifts for both nuclei.

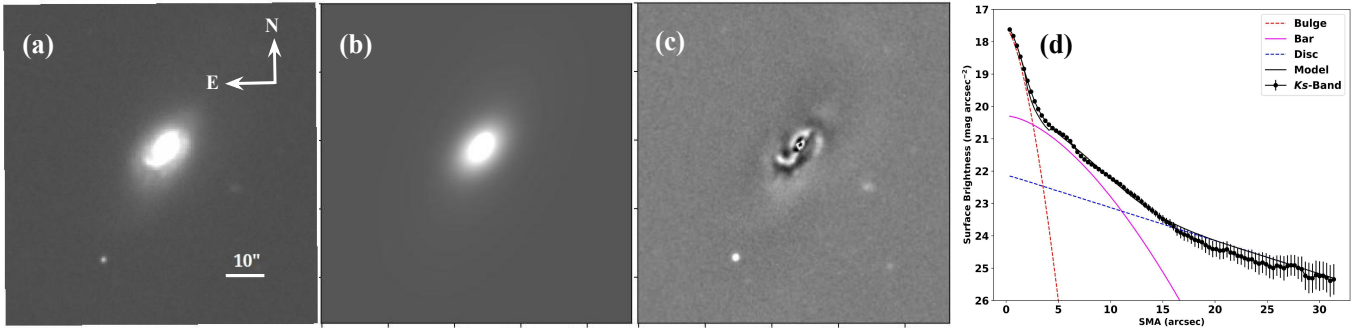


Fig. 5. Output of the GALFIT model along with the azimuthally averaged surface brightness profile of NGC 92. (a) K_s -band image of the galaxy. (b) Corresponding best-fit model. (c) Residual image. (d) Azimuthally averaged surface brightness of the best-fitting ellipses, plotted as a function of the semi-major axis (solid points) with the error bars representing the rms uncertainty of the intensity measured along each fitted isophote. The surface brightness profiles are decomposed into two Sérsic components and one exponential component, corresponding to a bulge (dashed red line), a bar (dashed magenta line), and a disc (dashed blue line). The solid black line shows the combined contribution of all three components.

These interactions appear to have strongly perturbed the outer disc while largely preserving the inner structure. The presence of a stellar bar in NGC 92 is consistent with this picture and resembles systems such as the Cartwheel galaxy, where head-on collisions disrupt the outer regions while leaving the inner structure comparatively intact (Mondal & Barway 2024). The combination of a stellar bar, enhanced central velocity dispersion, flattened gas-phase metallicity gradients, and young stellar populations indicates efficient gas mixing and interaction-driven gas redistribution sustaining recent star formation activity.

We also reconstructed the median SFH (Fig. 6d) from the full spectral fitting, providing an understanding of the mass assembly history of NGC 92. The SFH reveals two dominant phases. The first corresponds to a major early episode around ~ 10 Gyr ago, during which most of the stellar mass was assembled, consistent with the presence of an old population in the central region. The second component is significantly younger (~ 500 Myr) and is primarily associated with the disc and ring. This recent star formation episode is likely linked to tidally induced star formation triggered by the ongoing interaction with NGC 88.

4.2. NGC 89

NGC 89 is an SB0/a pec galaxy characterised by a relatively low SFR ($\sim 0.16 M_{\odot} \text{ yr}^{-1}$) and a high stellar mass ($M_{*} \sim 2.7 \times 10^{10} M_{\odot}$), as derived from the SED modelling. Its low SFR suggests that the galaxy undergoes – or has recently undergone – quenching, possibly driven by environmental processes such as gas stripping or internal feedback mechanisms. NGC 89 hosts a Seyfert 2 nucleus and H α emitting extraplanar filamentary structures on both sides of the disc, including a ~ 4 kpc jet-like filament extending towards the NE (Temporin et al. 2005). The SED fitting with CIGALE additionally requires an AGN component modelled using the SKIRTOR template, indicating a significant contribution of nuclear activity to the IR emission. These properties support a scenario in which AGN feedback suppresses star formation in the galaxy. Gas inflow triggered during a previous interaction with other group members may have fuelled the AGNs, while the resulting feedback contributed to the decline of star formation activity. Presotto et al. (2010) estimated an interaction timescale of ~ 200 – 700 Myr between NGC 89 and

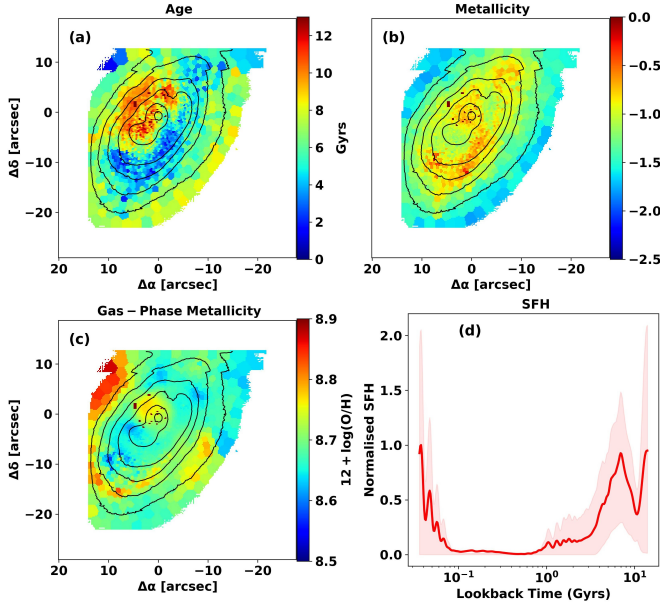


Fig. 6. Spatially resolved maps of the stellar population properties of NGC 92 derived from MUSE observations. (a) Mass-weighted stellar age. (b) Stellar metallicity ($[M/H]$). (c) Gas-phase metallicity ($12 + \log(O/H)$). (d) Average mass-weighted SFH of the galaxy as a function of look-back time. The red curve shows the mean SFH, while the shaded region represents the 16th–84th percentile range, indicating the spatial variation in SFH across the galaxy. The SFH is normalised to its peak value.

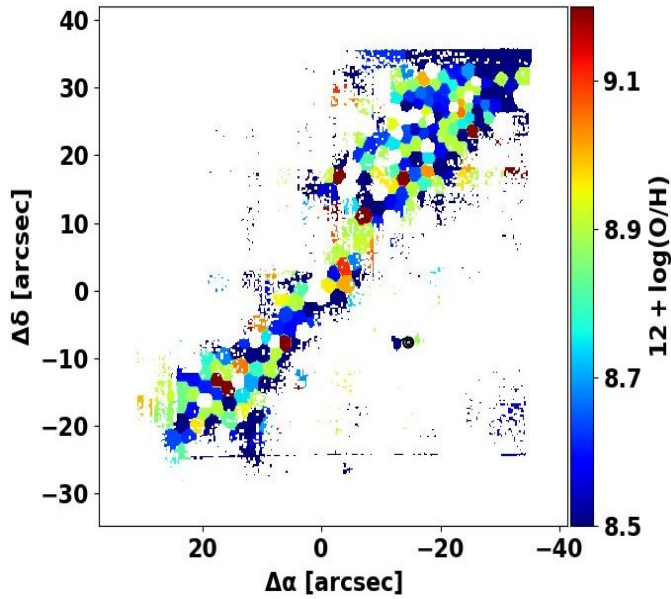


Fig. 7. Spatially resolved gas-phase metallicity ($12 + \log(O/H)$) of NGC 92's tail (cube 3 in Fig. 1).

NGC 92, suggesting that gas exchange between the two galaxies may be linked to both the AGN activity and the extraplanar emission. In the specific SFR (sSFR)- M_* (Fig. D.2), NGC 89 lies in the green-valley region, consistent with a transition or post-starburst evolutionary phase. It is also the only galaxy in the group with no HI detection (Pompei et al. 2007).

The stellar velocity field (Fig. 8a) exhibits a regular and symmetric rotation pattern with amplitudes reaching ± 150 km/s. The stellar velocity dispersion (σ_* , Fig. 8b) shows a pronounced

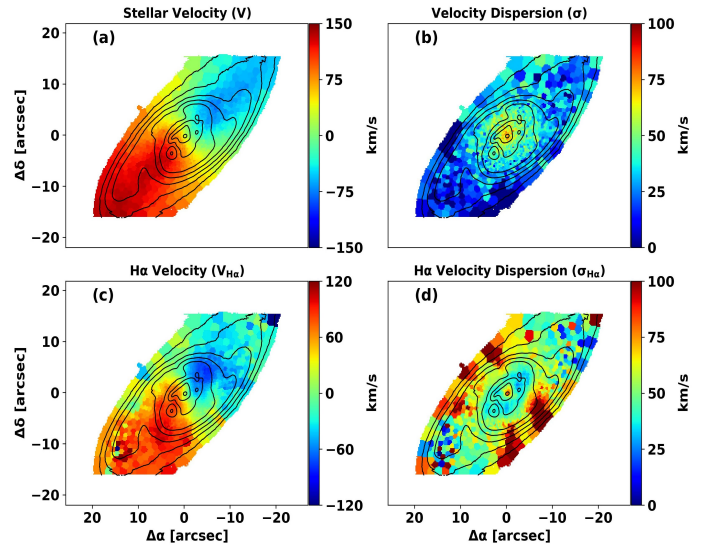


Fig. 8. Spatially resolved stellar and gas kinematic maps of NGC 89 derived from MUSE observations. All the panels are the same as in Fig. 3.

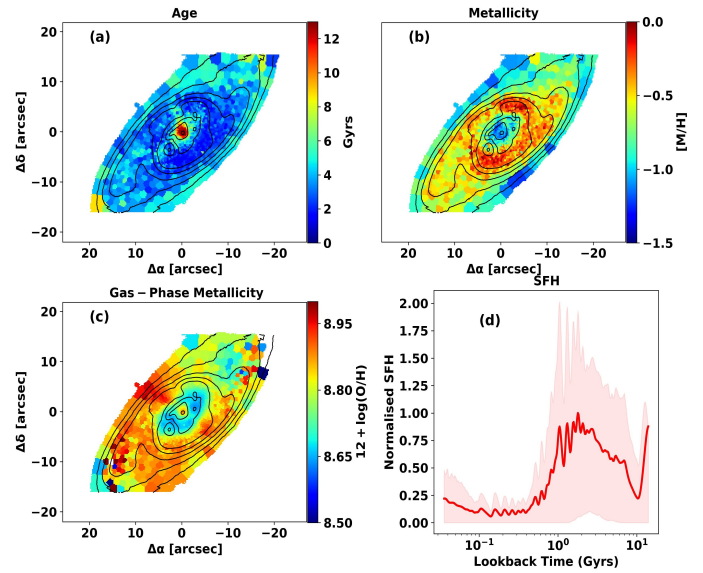


Fig. 9. Spatially resolved maps of the stellar population properties of NGC 89 derived from MUSE observations. All the panels are the same as in Fig. 6.

central peak, with values of ~ 80 – 100 km/s in the inner few arcseconds, declining to ~ 20 – 30 km/s towards the outskirts. Such elevated central σ_* values are characteristic of a dynamically hot bulge or inner spheroidal component commonly associated with AGN-host galaxies. The $H\alpha$ velocity field (Fig. 8c) broadly follows the stellar rotation pattern. In contrast, the gas velocity dispersion ($\sigma_{H\alpha}$; Fig. 8d), exhibits widespread enhancements, particularly in the NE and SW regions, where values rise to ~ 80 – 100 km/s. These elevated dispersions are indicative of turbulent gas motions, possibly associated with shocks or AGN-driven outflows.

The mass-weighted stellar age distribution (Fig. 9a) reveals an old stellar population (10 – 12 Gyr) concentrated in the central region, while the disc is dominated by intermediate-age stellar populations (≤ 4 Gyr). This suggests that the central mass concentration was assembled at early epochs, while the disc experienced

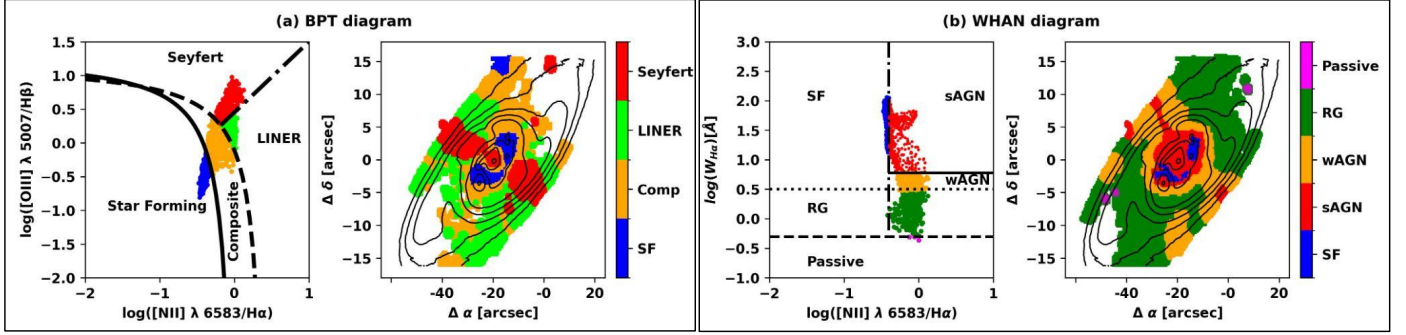


Fig. 10. Ionisation diagnostic diagram of NGC 89. Panel a: (left) BPT diagnostic diagram, classifying emission-line spaxels into star-forming (blue), composite (orange), LINER (green), and Seyfert (red) regions. (right) Spatial BPT map of the galaxy, showing a Seyfert-like nucleus surrounded by composite and LINER regions. Panel b: (left) WHAN diagram plotting $\log([\text{NII}]/\text{H}\alpha)$ versus $\text{H}\alpha$ equivalent width, separating AGN, retired galaxies (RG), and star-forming regions. (right) Spatial WHAN map confirming a central strong AGN (sAGN) region surrounded by weak AGN (wAGN), RG, and SF ring-like ionisation in the disc. Contours in all spatial panels trace the white light continuum isophotes.

more extended or episodic star formation. The stellar metallicity distribution ($[\text{M}/\text{H}]$; Fig. 9b) exhibits a pronounced radial gradient. The central few arcseconds are comparatively metal-poor, while metallicity reaches nearly solar values in a ring-like structure located at $\sim 8\text{--}10$ arcsec from the centre, followed by a negative gradient at larger radii.

The gas-phase metallicity map (Fig. 9c) spans $\sim 8.5\text{--}8.95$ dex, with the highest values observed in the NE, S, and SW regions of the disc, possibly tracing localised enrichment or outflows of metal-rich gas. The SFH (Fig. 9d) indicates an extended period of star formation over several gigayears, with comparatively little evidence for very recent star formation (within the last 1 Gyr) relative to the other galaxies in our sample. The lack of significant contributions from young stellar populations (<100 Myr) further supports the interpretation of NGC 89 as a quenched or post-starburst galaxy.

The ionisation diagnostics provide the clearest evidence for nuclear activity in NGC 89. The BPT diagram (Fig. 10, top left) classifies the emission-line spaxels using the $[\text{OIII}]/\text{H}\beta$ and $[\text{NII}]/\text{H}\alpha$ line ratios. The spaxels populate all four classical regimes: SF (blue), composite (yellow), LINER (lime), and Seyfert (red). The spatially resolved BPT map (Fig. 10, top right) confirms the presence of a Seyfert 2 nucleus surrounded by a SF ring, together with extended Seyfert-like emission.

The WHAN diagram (Fig. 10, bottom left) provides complementary constraints on the dominant ionisation sources by separating strong AGNs (sAGNs) and wAGNs from RGs and passive regions using both emission-line ratios and $\text{H}\alpha$ EW. NGC 89 spans a broad range in the WHAN plane, with a substantial fraction of spaxels occupying the sAGN and wAGN regions, while others lie in the RG regime. The spatially resolved WHAN map (Fig. 10, bottom right) broadly mirrors the BPT classification, revealing a prominent sAGN nucleus surrounded by wAGN- and RG-like regions, along with a central SF ring. Extended sAGN emission towards the NE direction suggests the presence of a galaxy-scale outflow, consistent with the extraplanar emission reported by Presotto et al. (2010). However, no associated X-ray emission from the extended narrow-line region has been detected (Trinchieri et al. 2008), despite the commonly observed correlation between $\text{H}\alpha$ outflows and X-ray features (Bomans et al. 1997; Strickland et al. 2004; Zhang et al. 2024).

In addition to the Seyfert nucleus, NGC 89 hosts a young and metal-rich circumnuclear SF ring. The origin of both the nuclear ring and the outflow may be linked either to bar-driven gas inflow or to interaction-driven fuelling of the central black

hole. Nuclear rings and discs are commonly observed in barred galaxies (Gadotti et al. 2019, 2020; Keshri et al. 2025b), although merger-driven origins have also been proposed for unbarred systems (Mayer et al. 2008; Corsini et al. 2012). In merger-driven scenarios, nuclear discs are generally not expected to show strong radial gradients in stellar age and metallicity, unlike the well-defined gradients observed in barred galaxies (Bittner et al. 2020). Although the disturbed morphology of NGC 89 makes it difficult to constrain the presence of a bar photometrically, the clear stellar population gradients across the nuclear disc favour a bar-driven origin. These results suggest that bar-driven gas inflow is the most likely mechanism responsible for fuelling the AGNs, driving the galactic-scale outflow, and sustaining the circumnuclear SF ring.

4.3. NGC 88

NGC 88 is a peculiar S0 galaxy within RQ, exhibiting ongoing star formation, tidal features, and kinematically disturbed structures. SED modelling with CIGALE yields a stellar mass of $\sim 6.26 \times 10^9 M_{\odot}$, placing it among the low- to intermediate-mass systems in the group. The total SFR derived from the SED fit is $(\sim 0.4 M_{\odot} \text{ yr}^{-1})$, and in the $\text{sSFR}-M_{\ast}$ plane (Fig. D.2), NGC 88 lies within the SF sequence. The FUV-based SFR is $\sim 0.44 M_{\odot} \text{ yr}^{-1}$, and the UV-derived age is ~ 128 Myr. Pompei et al. (2007) reported a common HI envelope between NGC 88 and NGC 92, suggesting that recent star formation may be triggered or sustained by ongoing gravitational interactions within the group.

The stellar velocity map (Fig. 11a) reveals a rotating disc with velocities reaching ± 50 km/s. The stellar velocity dispersion ($\sigma_{\ast}$, Fig. 11b) is generally low ($\sigma_{\ast} < 30$ km/s), with localised enhancements up to ~ 50 km/s in the outer regions. In contrast, the $\text{H}\alpha$ velocity field (Fig. 11c) is more irregular, with the core and outer disc exhibiting distinct rotation patterns. The outer gas disc is misaligned with respect to the stellar rotation axis, indicating kinematic decoupling and supporting a recent gas accretion scenario, while the central gas kinematics are broadly consistent with the stellar component. Such kinematic misalignments are commonly observed in S0 galaxies undergoing morphological transformation and are often attributed to minor mergers or external gas accretion (McDermid et al. 2007; Jin et al. 2016; Bryant et al. 2019; Zhou et al. 2022; Ristea et al. 2022; Zinchenko 2023). Simulations show that misalignments between stellar and gas discs can persist for ~ 2 Gyr, with the

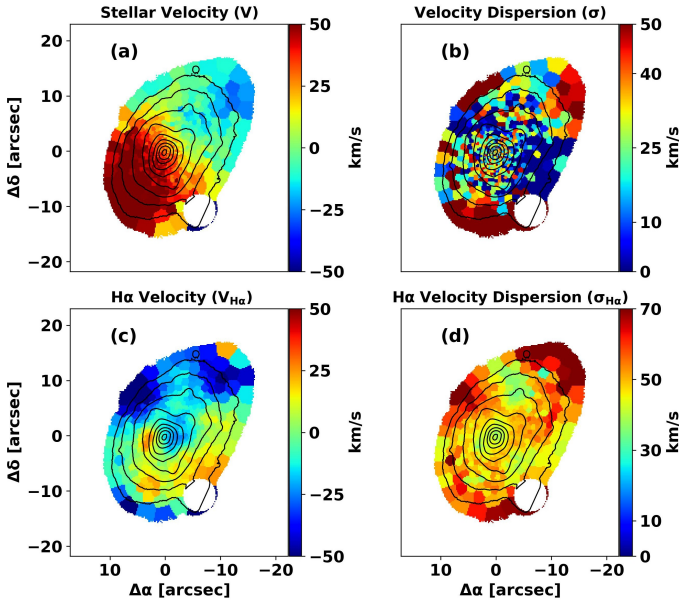


Fig. 11. Spatially resolved stellar and gas kinematics maps of NGC 88 derived from MUSE observations. All the panels are the same as in Fig. 3.

central regions realigning more rapidly than the outskirts (van de Voort et al. 2015). The gas velocity dispersion ($\sigma_{H\alpha}$, Fig. 11d) is elevated in the outer regions and exhibits significant spatial variation, indicating turbulent gas dynamics, possibly driven by tidal heating.

The mass-weighted stellar age (Fig. 12a) is dominated by an intermediate-age population ($\sim 1\text{--}3$ Gyr). The stellar metallicity distribution ($[M/H]$; Fig. 12b) spans ~ -1.5 to -0.3 dex across the disc, with the highest values in the NW region. In contrast, the SE disc is comparatively metal-poor, indicating younger, less-evolved stellar populations, possibly associated with the inflow of metal-poor gas from NGC 92. The gas-phase metallicity (Fig. 12c) ranges from ~ 8.4 to 8.8 dex with slightly lower values in the central regions than in the outskirts and is broadly consistent with that of NGC 92. The average SFH distribution (Fig. 12d) shows a prominent peak at ~ 1 Gyr, indicating that a significant fraction of the stellar mass was assembled during this epoch.

The combined kinematic and stellar population properties of NGC 88 indicate ongoing gas transfer between NGC 88 and NGC 92, as evidenced by the observed kinematic misalignment between the stellar and gaseous discs. The stellar and gas-phase metallicity distributions further support this scenario.

4.4. NGC 87

NGC 87 is morphologically classified as an irregular and peculiar system. SED modelling with CIGALE yields a stellar mass of $M_* \sim 1.87 \times 10^9 M_\odot$ (Table 3), placing it in the dwarf-galaxy regime. Dwarf galaxies typically have lower stellar masses ($M_* \leq 10^{10} M_\odot$) and smaller physical sizes than galaxies along the Hubble sequence (Lelli 2022). *GALEX* UV imaging reveals an extended UV disc, with an FUV-derived SFR of $1.14 M_\odot \text{yr}^{-1}$ and a corresponding UV age of ~ 32 Myr (Table B.2). The combination of low stellar mass and elevated SFR classifies NGC 87 as a star-forming dwarf galaxy (SFDG). Approximately 70% of dwarf galaxies are actively forming stars and are classified as SFDGs (Karachentsev et al. 2004). Their compact sizes, low

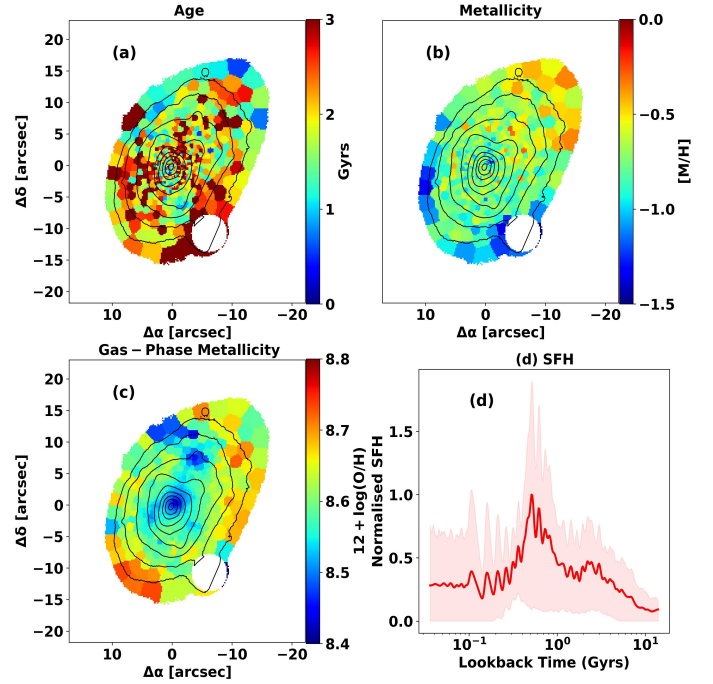


Fig. 12. Spatially resolved maps of stellar population properties of NGC 88 derived from MUSE observations. All the panels are the same as in Fig. 6.

rotational velocities ($V_{\text{rot}} \leq 100$ km/s), high gas fractions, and subsolar metallicities lead to star formation processes that differ from those in massive disc galaxies (Bergvall 2012). Stellar feedback and environmental effects further regulate their star formation activity (Meurer et al. 1995). Although SFDGs are most commonly found in low-density environments with few massive neighbours (Weisz et al. 2014a,b), the presence of NGC 87 within RQ shows that such systems can also sustain active star formation in dense environments.

MUSE kinematic and stellar population maps of NGC 87 are shown in Figs. 13 and 14, respectively. Its stellar velocity field (Fig. 13a) exhibits a well-ordered rotation spanning -50 to $+50$ km/s, indicating a rotating disc despite the galaxy's irregular morphology. The $H\alpha$ velocity field (Fig. 13c) closely follows the stellar kinematics, suggesting co-rotation of stars and gas. The velocity dispersion provides further insight into the dynamical state of the group. The stellar velocity dispersion (σ_* ; Fig. 13b) remains low ($\sim 10\text{--}20$ km/s) across most of the disc, consistent with a dynamically cold stellar component typical of dwarf galaxies (Walker et al. 2007). In contrast, the gas velocity dispersion ($\sigma_{H\alpha}$; Fig. 13d) reaches values up to ~ 70 km/s in the outer regions, indicating enhanced turbulence in the ionised gas component.

The mass-weighted stellar age map (Fig. 14a) shows younger stellar populations (~ 0.5 Gyr) dominating the outer disc, while relatively older populations ($\sim 2\text{--}3$ Gyr) are concentrated towards the centre. The stellar metallicity, $[M/H]$ (Fig. 14b), is subsolar across the galaxy, ranging from -0.5 to -1.0 dex, consistent with the low chemical enrichment expected in low-mass systems. The gas-phase metallicity (Fig. 14c) is relatively uniform across the disc, with $12 + \log(O/H) \sim 8.3\text{--}8.5$. Low-mass galaxies with elevated star formation rates are known to exhibit lower metallicities (Ellison et al. 2008; Mannucci et al. 2010; Yates et al. 2012), likely due to the removal of enriched material through stellar winds and supernova-driven outflows

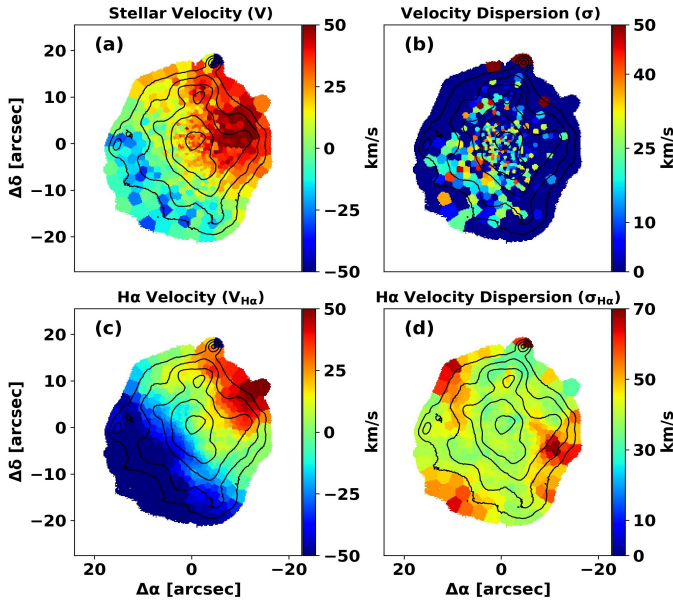


Fig. 13. Spatially resolved stellar and gas kinematic maps of NGC 87 derived from MUSE observations. All the panels are the same as in Fig. 3.

(Mac Low & Ferrara 1999). The reconstructed average SFH (Fig. 14d) shows enhanced activity in recent epochs (100 Myr–1 Gyr), indicative of a bursty SFH.

Despite its irregular morphology, NGC 87 exhibits ordered rotation. The low stellar and gas velocity dispersions (σ_* and $\sigma_{H\alpha}$), together with a recent SFH and extended UV emission relative to the optical light, indicate the presence of young, massive stellar populations distributed across the galaxy. The subsolar stellar metallicity and relatively flat gas-phase metallicity gradient further suggest efficient mixing of metals throughout the disc. These results show that low-mass galaxies can sustain significant star formation even within a compact, interaction-dominated environment.

5. Discussions

The CG RQ consists of four morphologically distinct galaxies in close proximity, spanning a stellar mass range of $9.2 < \log_{10}(M_*/M_\odot) < 10.8$. Despite sharing a common environment, the group exhibits a striking diversity in evolutionary states: three members are actively forming stars, while one galaxy is relatively quenched and appears to transition towards a passive phase, likely driven by AGN activity and gas depletion within the group environment. Such coexistence between SF and quenched systems is a characteristic feature of CGs, reflecting asynchronous galaxy evolution driven by repeated gravitational interactions. Thus, RQ serves as a laboratory for studying CG evolution.

The interaction history of the RQ further supports this picture. Previous estimates suggest a recent encounter between NGC 92 and NGC 89 on timescales of ~ 200 – 700 Myr (Presotto et al. 2010), while our UV-based age estimates and non-parametric SFHs indicate a similarly recent interaction epoch ($\lesssim 500$ Myr) across all group members. This implies that the system is currently in an active phase of dynamical evolution, in which tidal interactions and gas exchange simultaneously trigger star formation and fuel nuclear activity. In this context, RQ can

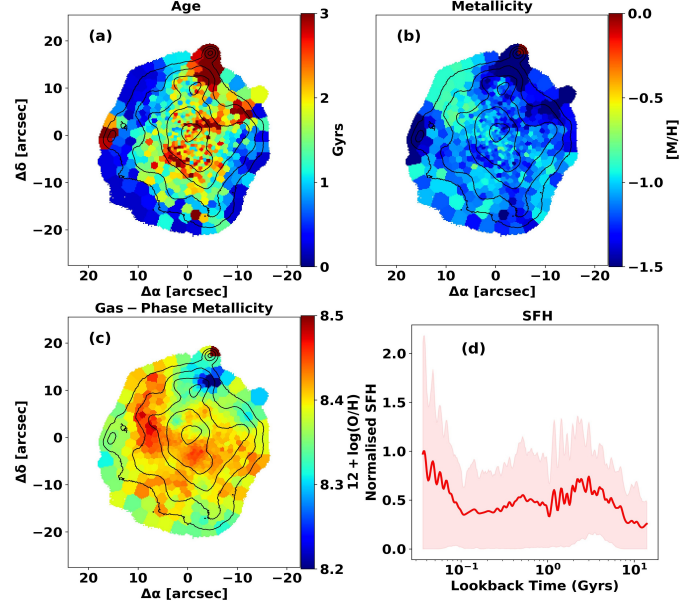


Fig. 14. Spatially resolved maps of the stellar population properties of NGC 87 derived from MUSE observations. All the panels are the same as in Fig. 6.

be regarded as a southern analogue of HCG 16, a well-studied CG exhibiting strong kinematic disturbances and enhanced star formation. The presence of disturbed morphologies, asymmetric velocity fields, and widespread star formation in RQ reinforces the interpretation that tidal forces and repeated close encounters are efficiently redistributing angular momentum and funnelling gas towards galaxy centres, thereby sustaining both starburst and AGN phases. More broadly, this suggests that RQ represents a dynamically young CG in which interaction-driven transformation is currently ongoing.

To further assess the dynamical state of RQ, we estimated the group crossing time and velocity dispersion (Sect. 3.3). We derive a crossing time of ~ 424 Myr ($\log(H_0 t_c) \sim -1.52$) and velocity dispersion of ~ 74 km/s, placing the system in the early (stage 1) phase of CG evolution as defined by Montaguth et al. (2025). Our estimate of crossing time differs from previous estimates (e.g. Pompei et al. 2007), who treated RQ as a quintet by including an additional member. Their larger group membership led to a higher estimate of velocity dispersion. Our analysis considers only the four spectroscopically confirmed members of RQ, consistent with the current group definition. The presence of only one passive galaxy in the group further supports this early-stage classification, where most members are still actively forming stars.

The combination of short crossing time and low velocity dispersion indicates that RQ is a dynamically young system that has not yet reached virial equilibrium. Such conditions imply that the member galaxies undergo repeated close encounters on relatively short timescales, consistent with the interaction epoch inferred from UV ages and SFHs ($\lesssim 500$ Myr). The close agreement between the crossing time and the recent interaction timescale suggests that the current phase of enhanced star formation and AGN activity is directly linked to ongoing group assembly. Moreover, the observed kinematic disturbances and localised SF regions are characteristic of systems in which gravitational interactions are still actively redistributing mass and angular momentum. Taken together, these results support a scenario in which RQ is in the early stages of hierarchical assembly,

where dynamical evolution, gas inflow, and star formation are tightly coupled.

The metallicity distribution of the group members provides additional insight into the assembly history of RQ. The predominantly sub-solar metallicities and relatively weak radial gradients are consistent with a scenario in which the system has been assembled through successive interactions and mergers involving low-mass, metal-poor progenitors. Such properties are commonly observed in dynamically young CGs, where repeated encounters and gas mixing act to homogenise the chemical composition. In this context, RQ can be regarded as a nearby example of CG formation driven by hierarchical assembly.

An important implication of our analysis emerges from the dynamical and structural complexity of NGC 92. The presence of kinematically distinct components, together with prominent tidal features and enhanced star formation, suggests that this system may be the remnant of a recent merger event rather than a single undisturbed spiral galaxy. If confirmed, this interpretation implies that the RQ may not represent a strictly four-member system but rather the outcome of interactions involving additional progenitor galaxies, effectively making it a dynamically evolving group. This highlights the transient nature of CGs, where ongoing mergers and accretion can modify both the internal structure of galaxies and the apparent group membership.

A similar picture is emerging from recent high-redshift observations with the *James Webb Space Telescope* (JWST). Compact group-like systems identified at $z \sim 5$ (Jin et al. 2023) and $z \sim 7$ (Wei et al. 2026) exhibit dynamically young, non-virialised structures characterised by strong interactions, elevated star formation rates, and extreme ionisation conditions. These systems show clear signatures of rapid gas accretion, mergers, and efficient feedback operating on short dynamical timescales. The close resemblance between these properties and those observed in RQ suggests that the latter may represent a low-redshift analogue of such pre-virialised systems. In addition, recent JWST observations of Stephan's Quintet have revealed the complex interplay between galaxy interactions, shocks, and the multiphase interstellar medium in compact environments, further reinforcing the connection between local and distant systems. As such, RQ provides a valuable nearby laboratory in which the physical processes governing galaxy assembly, gas accretion, and feedback have been studied in spatial detail, thereby offering a practical framework for interpreting JWST observations of galaxy evolution in the early Universe.

6. Conclusions

We presented a multiwavelength analysis of the compact galaxy group RQ (SCG0018-4854) using UV, optical, near-IR imaging, and spatially resolved MUSE IFU data. Our results indicate that the system is dynamically young and currently undergoes active interaction-driven evolution. The relatively low crossing time (~ 424 Myr), low velocity dispersion, and consistent interaction timescales (≤ 500 Myr) derived from UV ages and SFHs suggest that the group is in an early stage of assembly.

The member galaxies exhibit a diverse range of evolutionary states, including ongoing star formation, recent gas accretion, and AGN-driven quenching, highlighting the coexistence of multiple transformation pathways within a single galaxy group. The disturbed kinematics, enhanced star formation, and relatively uniform metallicity distributions further support a scenario in which repeated interactions and gas exchange are actively redistributing mass and angular momentum across the system.

A key result of this study is the dynamical and structural complexity of NGC 92, which shows evidence for a recent merger event. This suggests that RQ may not represent a strictly four-member system but rather a dynamically evolving configuration involving additional progenitor galaxies. This highlights the transient nature of CGs and the importance of hierarchical assembly in shaping their observed properties.

Finally, the physical conditions observed in RQ, characterised by strong interactions, enhanced star formation, and short dynamical timescales, closely resemble those seen in high-redshift galaxies. In this context, the system provides a valuable nearby analogue for compact, rapidly assembling structures now being probed with the *JWST*. Our results demonstrate that detailed studies of local CGs can offer important insights into the processes governing galaxy assembly, gas accretion, and feedback in the early Universe. Also, observations with ALMA could trace the molecular gas reservoirs and resolve the interplay between dense gas, star formation, and feedback processes, particularly in the ring-like structure of NGC 92. Complementary hydrodynamical simulations constrained by the specific mass distribution, orbital configuration, and gas content of RQ would allow a quantitative reconstruction of its interaction history and future evolution. Such models would be essential for testing the proposed origins of the ring structure, AGN fuelling, and gas mixing and for predicting the eventual fate of the group.

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Appendix A: Detection of SFCs and SFR estimation

Star-forming regions appear as bright clumps in the background-subtracted *GALEX* FUV and NUV images. To systematically detect these regions across all galaxies of RQ, we used the SExtractor software (Bertin & Arnouts 1996). Source detection was performed on the *GALEX* NUV images with the following configuration: DETECT_THRESH=5 σ (where σ is the global background noise), DETECT_MINAREA=10 pixels, DEBLEND_NTHRESH=16, and DEBLEND_MINCONT=0.0005. For NGC 87, NGC 88, and NGC 89, one prominent SF region was detected in each galaxy, which covers the light from the entire galaxy, whereas we were able to detect six regions in NGC 92, consistent with the spatial resolution of the *GALEX* data. Aperture photometry of the detected regions was performed using the Photutils package³, yielding FUV and NUV fluxes for each source.

These UV-bright regions trace populations of young, massive stars, whose observed magnitudes are affected by both Galactic and internal extinction. Galactic extinction in the FUV and NUV bands was corrected using the extinction law of Cardelli et al. (1989), expressed as

$$< \frac{A(\lambda)}{A(V)} > = a(x) + \frac{b(x)}{R_v}, \quad (\text{A.1})$$

where x is the wave number and the functions $a(x)$ and $b(x)$ are defined in Cardelli et al. (1989). We adopted $R_v = 3.1$ for the Milky Way and used $A(V) = 0.054$ for NGC 87 and $A(V) = 0.053$ for NGC 88, NGC 89, and NGC 92.

In addition to Galactic extinction, it is crucial to correct for internal extinction, which arises from dust within the SF regions themselves. It was corrected using the UV spectral slope (β), defined by $f_\lambda \propto \lambda^\beta$, which quantifies dust attenuation in the UV continuum after Galactic correction and is applicable over the wavelength range 1250–2600 Å (Calzetti et al. 1994). For the *GALEX* filters, β was computed as

$$\beta = -0.4 \frac{m_{FUV} - m_{NUV}}{\log(\lambda_{FUV}/\lambda_{NUV})} - 2.0, \quad (\text{A.2})$$

where m_{FUV} and m_{NUV} are the Milky Way extinction-corrected magnitudes, and λ_{FUV} and λ_{NUV} are the central wavelengths of the respective filters. The colour excess was then derived following Calzetti et al. (2000):

$$\beta = -2.616 + 4.684E(B - V). \quad (\text{A.3})$$

From $E(B - V)$, the internal extinction at a given wavelength was calculated using the (Calzetti et al. 2000) relation:

$$A_\lambda = k'(\lambda)E_s(B - V), \quad (\text{A.4})$$

where $E_s(B - V)$ is the colour excess applicable to the stellar continuum, and $k'(\lambda)$ is the attenuation curve defined as

$$k'(\lambda) = -2.659(-2.15 + \frac{1.509}{\lambda} - \frac{0.198}{\lambda^2} + \frac{0.011}{\lambda^3}) + R'_v. \quad (\text{A.5})$$

Here, $R'_v = 4.05 \pm 0.80$ and $\lambda \in [1200\text{Å}, 6300\text{Å}]$ (Calzetti et al. 2000).

The stellar colour excess is related to the total colour excess by

$$E_s(B - V) = (0.44 \pm 0.03)E(B - V). \quad (\text{A.6})$$

³ <https://photutils.readthedocs.io/en/stable/aperture.html>

Table B.1. Starburst99 model parameters used in this work.

Parameter	Value
Star Formation	Instantaneous
Cluster mass range	$10^7 M_\odot - 10^9 M_\odot$
Stellar IMF	Kroupa (1.3,2.3)
Mass Boundaries for IMF	$0.1 M_\odot, 0.5 M_\odot, 100 M_\odot$
Stellar evolution track	Geneva (high mass loss)
Metallicity	Solar ($Z=0.02$)
Age range	1-900 Myr
Supernova cut-off mass	$8 M_\odot$
Black hole cut-off mass	$120 M_\odot$

using the estimated extinction, we calculate the extinction-corrected luminosity as

$$L_{corr} = L_{obs} \times 10^{0.4E_\lambda(B-V)K'(\lambda)}. \quad (\text{A.7})$$

here, L_{obs} denotes the luminosity measured before correcting for dust extinction.

To investigate star formation activity in galaxies, it is essential to examine SF regions across multiple wavelengths, as different populations of stars emit at different wavelengths. Ultraviolet emission serves as an effective tracer of recent star formation (up to ~ 300 Myr), as it predominantly originates from young high-mass O, B-type stars (Davies et al. 2016).

We estimated the SFRs using the *GALEX* FUV band, following the calibrations provided by Kennicutt et al. (2009). The extinction-corrected luminosities were used to derive the SFRs according to the following relation:

$$SFR_{FUV}(M_\odot \text{ yr}^{-1}) = 4.6 \times 10^{-44} L_{corr}(FUV). \quad (\text{A.8})$$

Here, L_{corr} denotes the extinction-corrected luminosity in units of erg s^{-1} . The derived SFRs for each galaxy are presented in Table B.2.

Appendix B: Age of the SF regions

To estimate the ages of the SF regions, we employed the Starburst99 stellar population synthesis code (Leitherer et al. 1999), widely used for modelling actively SF galaxies. Starburst99 provides spectrophotometric predictions for simple stellar populations (SSPs) based on evolutionary tracks and various stellar atmosphere models. Synthetic stellar spectra were generated using the input parameters listed in Table B.1. The model spectra were convolved with the effective area curves of the *GALEX* FUV and NUV filters to compute the model-predicted fluxes in each band, using

$$F_{cal}(\lambda) = \frac{\int F(\lambda), EA(\lambda), d\lambda}{\int EA(\lambda), d\lambda}, \quad (\text{B.1})$$

where $F_{cal}(\lambda)$ is the calibrated flux, $F(\lambda)$ is the model flux and $EA(\lambda)$ denotes the effective area of the corresponding *GALEX* filter. All fluxes are expressed in units of $\text{erg s}^{-1} \text{ cm}^{-2} \text{ Å}^{-1}$. The resulting fluxes were converted to AB magnitudes to compute theoretical FUV–NUV colours. By comparing these with the extinction-corrected observed FUV–NUV colours, we estimated the ages of the SF clumps in each galaxy. The derived ages are summarised in Table B.2. Fig. B.1 presents the age distribution of SF regions in NGC 92, based on their UV colours (left panel) and their corresponding spatial distribution within the galaxy (right panel).

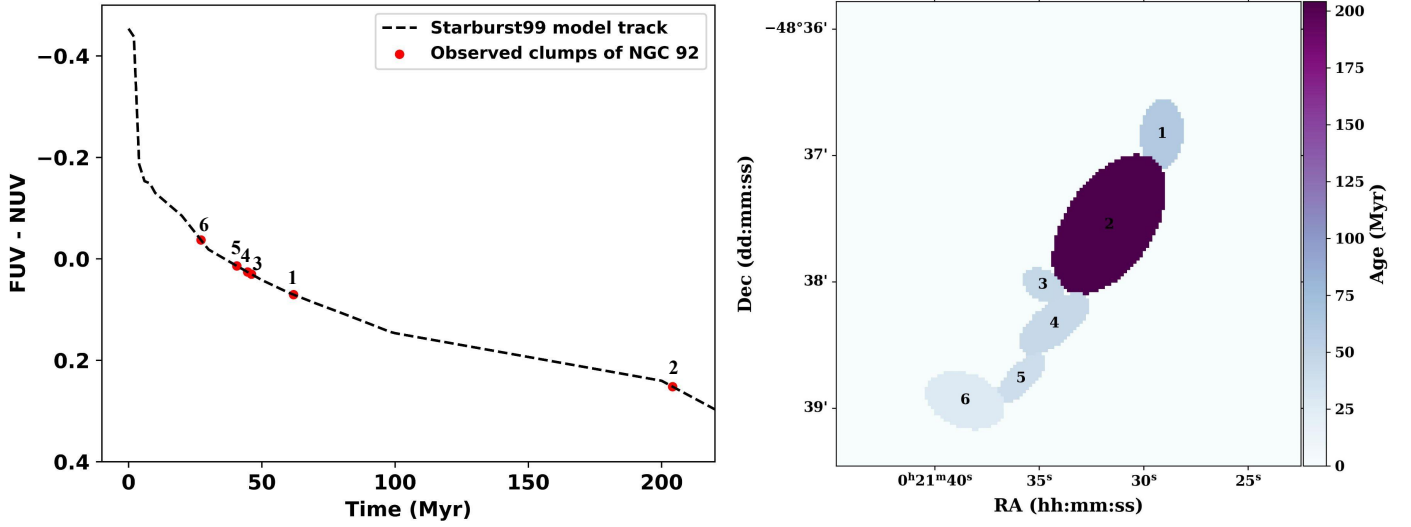


Fig. B.1. **Left:** Extinction-corrected observed (FUV-NUV) colours of SF regions in NGC 92 (red circles) plotted as a function of age. The dashed black line represents the theoretical colour-age relation obtained from a Starburst99 model. **Right:** Spatial distribution of SF regions in NGC 92, colour-coded by their derived ages.

Table B.2. SFR and age of the regions identified in each galaxy.

Name	SFR_{FUV} ($M_{\odot} \text{ yr}^{-1}$)	Age (Myr)
NGC 87	1.142 ± 0.037	31.97
NGC 88	0.444 ± 0.007	127.57
NGC 89	0.586 ± 0.017	275.54
NGC 92	0.018 ± 0.002	61.90 (1)
	0.942 ± 0.029	204.13 (2)
	0.015 ± 0.002	46.10 (3)
	0.044 ± 0.006	44.70 (4)
	0.022 ± 0.003	40.63 (5)
	0.072 ± 0.008	27.18 (6)

Description: For NGC 87, NGC 88, and NGC 89, one prominent SF region was detected, which covers the light from the entire galaxy, whereas we were able to detect six regions in NGC 92.

Appendix C: BPT classification of galaxies

Appendix D: Input and output parameters of CIGALE modelling

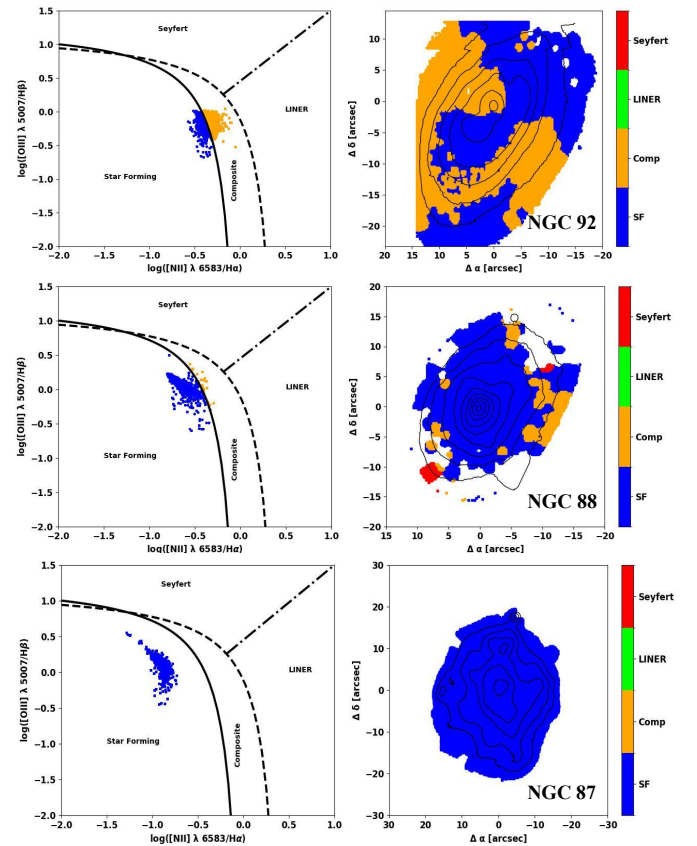


Fig. C.1. BPT classification of NGC 92 (top), NGC 88 (middle), and NGC 87 (bottom).

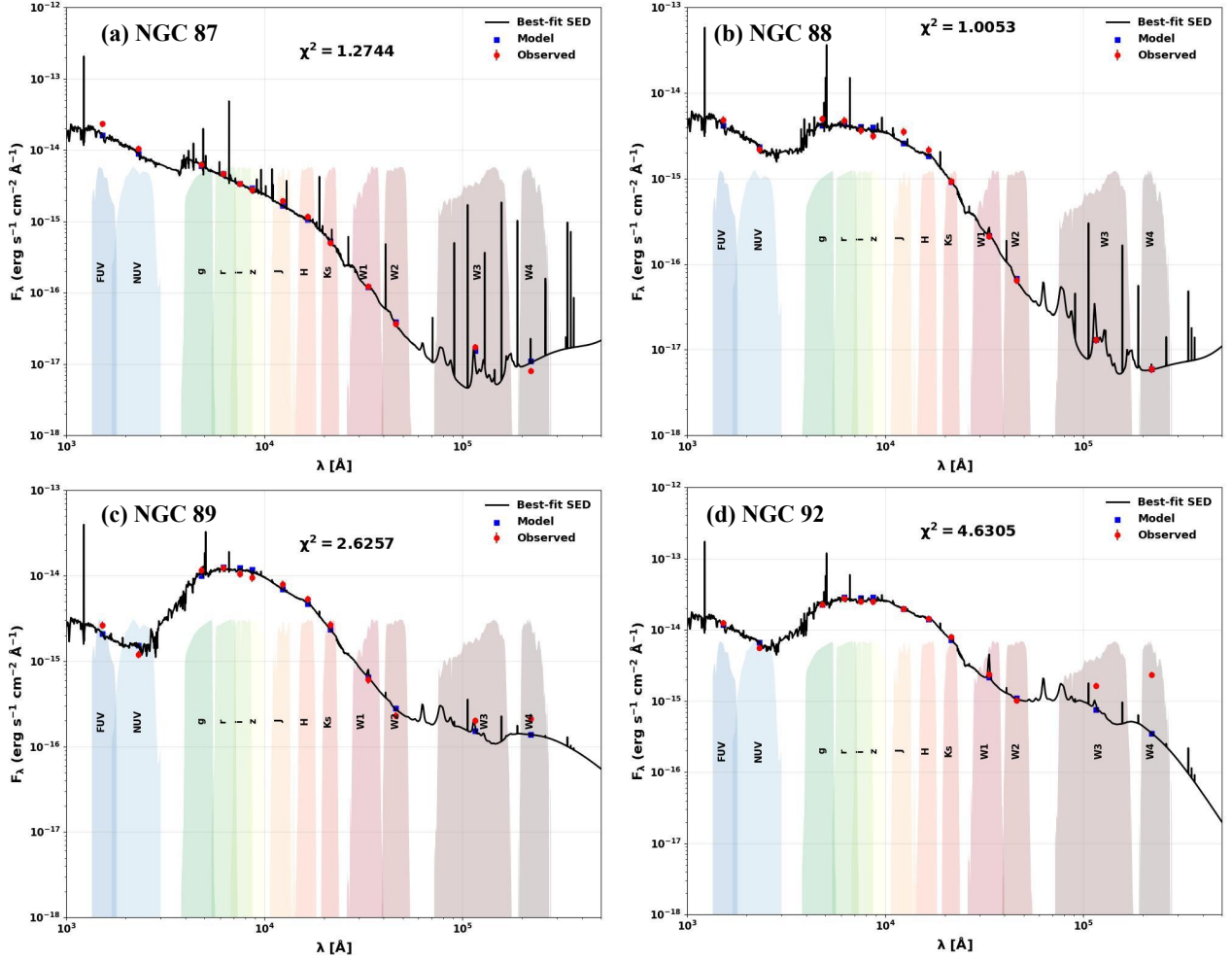


Fig. D.1. CIGALE SED fits for the RQ quartet: NGC 87 (top-left), NGC 88 (top-right), NGC 89 (bottom-left), and NGC 92 (bottom-right). The best-fitting models are overlaid on observed photometric data in each panel.

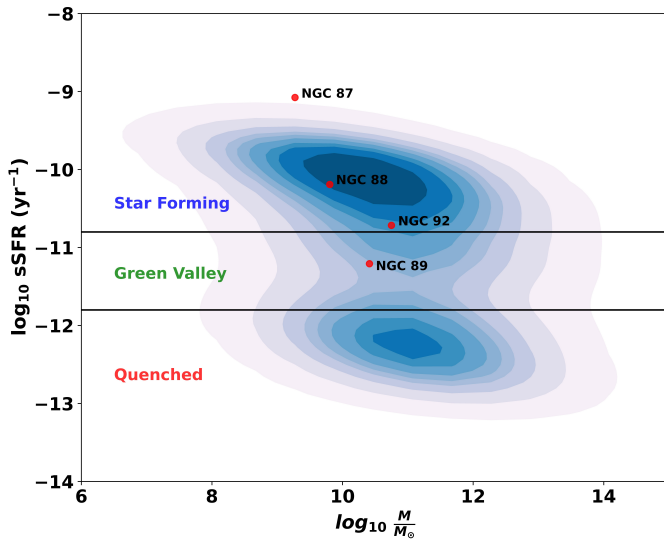


Fig. D.2. SF main sequence of galaxies. Here, the red symbols represent the galaxies of RQ. The contour shows the density map of the data points from the GSLWC-X2 catalogue (Salim et al. 2016, 2018).

Table D.1. Input parameters for SED fitting with CIGALE.

Parameter	Value
Star formation history (sfhdelaydbq)	
e-folding time of the main stellar population	200.0, 500.0, 700.0, 1000.0, 2000.0, 3000.0, 4000.0, 5000.0
Age of the main stellar population	1000, 2000, 3500, 5000, 6500, 8000, 10500
Age of the late burst/quench episode	100.0, 200.0, 300.0, 400.0, 500.0
Ratio of the SFR after/before burst/quench	0.0, 0.1, 0.2, 0.4, 0.7, 1.0, 5.0, 10.0, 100.0
Instance without any burst	1.0
Stellar population synthesis (bc03)	
IMF	Salpeter
Metallicity	0.004, 0.008, 0.02, 0.05
Separation between the young and the old stellar populations	10 Myr
Nebular emission (nebular)	
Ionisation parameter	-2.0
Gas metallicity	0.004, 0.008, 0.012, 0.02, 0.033
Electron density	100 cm^{-3}
Dust attenuation (dustatt _ modified _ starburst)	
Colour excess of the nebular lines light for both the young and old population	0.3
Reduction factor to apply on E_BV_lines to compute E(B-V)s	0.44
Central wavelength of the UV bump in nm	217.5
Width (FWHM) of the UV bump in nm	35.0
UV bump amplitude	0.0
Slope delta of the power law	0.0
Filters for which the attenuation will be computed and added	FUV and NUV
Dust emission (dl2014)	
Mass fraction of polycyclic aromatic hydrocarbon (PAH)	0.5, 1.12, 2.5, 3.19, 5.26
Minimum radiation field	0.5, 1.0, 5, 10, 15, 25
Power-law slope	1.5, 2.0
Fraction illuminated from Umin to Umax	0.001, 0.01, 0.1, 0.5
AGN module (skirtor2016) (NGC 89)	
Average edge-on optical depth at 9.7 μm	3, 7
Power-law exponent that sets the radial gradient with the polar angle	1.0
Index that sets the dust density gradient with the polar angle	1.0
Inclination, i.e. viewing angle, position of the instrument w.r.t. the AGN axis	30, 70
Disc spectrum	Schartmann spectrum
AGN fraction	0.0, 0.05, 0.1, 0.2, 0.3, 0.4, 0.8
Wavelength range in microns used to compute the AGN fraction	0/0
Extinction law of the polar dust	SMC
E(B-V) for the extinction in the polar direction in magnitudes	0.0, 0.03, 0.2, 0.4
Temperature of the polar dust	100.0 K
Emissivity index of the polar dust	1.6