A meeting at $z \sim 3$: Young massive galaxies and an AGN within 30 kpc of the luminous QSO LBQS 0302−0019

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ABSTRACT

Context. Contrary to expectations from scenarios of black hole growth driven by galaxy interactions and mergers, dual active galactic nuclei (AGN) with kiloparsec separations are rarely observed and are very difficult to identify, in particular at high redshifts (i.e. $z > 2$).

Aims. Focussing on the recently discovered dual AGN system LBQS 0302−0019 at $z = 3.29$, we seek to identify further group members in its environment and to understand their formation history through deep high-angular-resolution imaging.

Methods. We present deep Hubble Space Telescope (HST) Wide-field Camera 3 near-infrared imaging of LBQS 0302−0019. In combination with ground-based VLT/HAWK-I imaging, we infer accurate sizes, colours, ages, and stellar masses of companion galaxies.

Results. We clearly detect four companion objects close to LBQS 0302−0019 that also have faint signatures in the ground-based images. We constrain light-weighted ages and masses for the two most prominent companions, Jil1 and Jil2, to $t_\text{age} = 13.2^{+0.9}_{-0.8}$ Myr and $t_\text{age} = 13^{+0.9}_{-0.8}$ Myr, respectively.

Conclusions. If the young starburst of Jil2 had been accompanied by sustained black hole growth, Jil2 may have contributed He ionising flux to create the large He$\alpha$ Lya proximity zone around LBQS 0302−0019. Hence, the duration of the current luminous AGN episode of LBQS 0302−0019 may have been overestimated.

Key words. Galaxies: interactions - Galaxies: high-redshift - Galaxies: active - Galaxies: starburst - quasars: individual: LBQS0302−0019

1. Introduction

During the evolution of massive galaxies, their nuclei are expected to show recurrent phases of activity in order to grow their super-massive black holes (SMBHs) as observed from the cosmic accretion rate distribution (e.g. Soltan 1982; Marconi et al. 2004; Schulze et al. 2015; Georgakakis et al. 2017). While mergers of galaxies were initially thought to be the dominating mechanism triggering such activity (e.g. Sanders et al. 1988; Hopkins et al. 2008), this has been strongly debated in recent years (e.g. Mechtley et al. 2016; Villforth et al. 2017; Weigel et al. 2018; Marian et al. 2019). Nevertheless, to confirm the former scenario, a strong interest has been growing to identify so-called dual and binary active galactic nuclei (AGN), where two SMBHs with separations of 100 kpc down to a few parsecs are active simultaneously (see De Rosa et al. 2019 for a recent review).

2. Overview

The luminous QSO LBQS 0302−0019 at $z = 3.29$ has been extensively studied to infer the properties of the intergalactic medium (IGM) along our line of sight (e.g. Hu et al. 1995; Steidel et al. 2003; Jakobsen et al. 2003; Tummuangpak et al. 2014; Schmidt et al. 2017). It is one of the rare UV-transparent luminous QSOs that allow the He I Ly$\alpha$ absorption of the IGM to be investigated in detail together with the proximity zone caused by the enhanced ionising photon flux around the QSO (e.g. Jakobsen et al. 1994; Syphers & Shull 2014). A large proximity zone of 13.2 Mpc is determined for LBQS 0302−0019 (Worseck et al. 2021), which implies a long AGN phase of $> 11$ Myr so far.
Analyzing archival Multi-Unit Spectroscopic Explorer (MUSE) observations of LBQS 0302−0019, Husemann et al. (2018a, hereafter Paper I) reported the serendipitous discovery of an obscured AGN about 20 kpc away from the QSO based on Lyα, C iv λ1548, 1550, He ii λ1630, and [C ii] λ1907, 1909 UV emission-line diagnostics. In particular, the He ii line luminosity log(L_{He/ii}) = 42.24 ± 0.05 was inconsistent with being induced by LBQS 0302−0019 given the compact, point-like spatial distribution of the emission and its corresponding low cross-section. The He ii luminosity can be more easily explained by an AGN of around 1/500–1/1000 the luminosity of LBQS 0302−0019 (corresponding to L_{AGN} ~ 10^{45} erg s^{-1}) if located within the compact He ii region, where the major uncertainty is the distance of the recombining clouds to the embedded AGN. Radio observations could not identify radio emission associated with the obscured AGN, Frey & Gabányi (2018), dubbed Ji, but those observations were too shallow to detect an AGN at the estimated luminosity. Follow-up ground-based K-band imaging and NIR spectroscopy have been presented in Husemann et al. (2018a, hereafter Paper II), which successfully detected Ji’s host galaxy with rest-frame optical line ratios consistent with an obscured AGN interpretation. While the NIR image obtained with the High Acuity Wide field K-band Imager (HAWK-I) at the Very Large Telescope (VLT) reveals signatures of distortion in the morphology, a clear interpretation is limited by the depth and resolution of the ground-based observations. Nevertheless, these observations implied massive host galaxies for both AGN of about 10^{11} M_☉, corresponding to a large overdensity at redshift z = 3.29.

In this paper we combine our previous observations from MUSE and HAWK-I with a deep Hubble Space Telescope (HST) Wide-field Camera 3 (WFC3) NIR image of this system. Combining all the information allows us to provide new details on the morphology and the stellar populations of the galaxies as well as a more refined association of the rest-frame UV emission lines with the host galaxies. Throughout the paper we assume a concordance cosmology with H_0 = 70 km s^{-1}Mpc^{-1}, Ω_m = 0.3, and Ω_Λ = 0.7.

2. Deep HST WFC3/IR imaging of LBQS 0302−0019

2.1. Observations and data reduction

LBQS 0302−0019 was observed on 2018 August 30 with the infrared channel of WFC3 aboard HST under programme GO15480 (PI: Bernd Husemann). We used the F125W filter corresponding to the J band for which HST provides an angular resolution of ~0.136, which is significantly under-sampled at the native WFC3/IR detector plate scale of ~0.213 pixel^{-1}. Additionally, the QSO is bright, with a magnitude of m_K = 15.4 mag (Vega), which demands a dedicated observing strategy to achieve a high contrast and increased spatial sampling. Hence, we divided the four-orbit observations into a series of 40 short (44 s) and 32 long (223 s) dithered exposures as follows.

Given the small angular size of the overall system of a few arcseconds, we used the IRSUB256 sub-aperture of the detector to significantly reduce the data rate and buffer space needed for the many exposures. A two-point dither pattern with an offset of 5''/2 was combined with a rectangular four-point dither pattern to optimally oversample the point-spread function (PSF). The SPARS10 readout sequence with seven sampling points (i.e. 44 s exposure time) and the SPARS25 readout sequence with eleven sampling points (i.e. 223 s exposure time) was used for the short and long exposures, respectively. At each dither position we obtained five and four individual exposures for the short and long exposure sequences, respectively. This observing sequence accumulated 1760 s of short exposures and 7136 s of long exposures; the short exposure sequence was taken first to minimise detector persistence effects.

The automatic HST archive pipeline processing only combines the frames of an individual dither position and does not combine all long and short observations into one optimally combined frame with increased sampling. We therefore made use of the individually calibrated frames provided by the automatic processing and drizzled all the long observations and all the short observations into two combined frames with the DrizzlePak package (Avila et al. 2015), adopting an output sampling of 0.06 pixel^{-1} with a drop size of 0.8. To correct the bright QSO core observation of LBQS 0302−0019 from persistence effects, we replaced the count rates of the central 8 × 8 pixels (0.548 × 0.548) in the combined long exposure with those of the combined short exposure. The fully combined HST image is shown in Fig. I.

2.2. Estimation of the point-spread function

One critical aspect for the HST image analysis is an accurate estimation of the PSF during the HST observations. Because re-constructed PSFs from the WFC3/IR PSF library produced unacceptable residuals, we searched for archival WFC3/IR exposures in the F125W filter, which were taken close to our observations, to derive a fully empirical PSF. A stellar field centred on WISE 0830−6323 was observed a couple of orbits before our observations (GO15468, PI: Jacqueline Faherty). The observations consist of four dithered exposures obtained with the SPARS25 read-out sequence and 16 sampling points. We combined the fully calibrated individual frames using DrizzlePak, employing the same settings as for our LBQS 0302−0019 observations. We extracted the images of four isolated bright stars and six fainter stars close to the centre of the field of view with offsets ranging from 10'' to 50'' with respect to the QSO camera position. We averaged the images of the bright and faint stars and replaced count rates of the central 8×8 pixels at the core of the averaged bright star image with that of the averaged faint star image to avoid the impact of persistence on the PSF shape. In order to account for potential systematic uncertainties in the empirical PSF, we also averaged only three of the four bright stars and five of the six faint stars; this led to 24 different PSF combinations, which we later used to determine the uncertainties of the derived parameters.

2.3. PSF subtraction and identification of companions

Based on the empirically constructed PSF for our HST/WFC3 observations, we subtracted the QSO contribution from the image by scaling the entire PSF using galfit (Peng et al. 2002, 2010). Unlike the processing of our deep VLT/HAWK-I image, we were unable to properly model the 2D surface brightness distribution of the QSO host galaxy. This was likely caused by the combination of several effects: 1) the F125W filter probes bluer wavelengths, where the contrast between QSO and host emission is much higher, 2) the PSF of HST has a lot more substructure exactly on the expected host galaxy scales, and 3) the time difference and positional differences between the empirical PSF observations and our observations can cause subtle differences in the exact PSF shape. In any case, a simple PSF subtraction of the QSO is sufficient to uncover the position and brightness of several companion galaxies around LBQS 0302−0019, which is the primary aim of the observations.
With the improved angular resolution and sensitivity of our HST imaging, we find that the source initially termed ‘Jil’ is resolved into three distinct galaxies with different sizes and brightnesses, as highlighted in Fig. 1. Those components are consistent with the additional diffuse extended emission in the VLT/HAWK-I Ks-band image around the location of Jil, presented in Paper II, which is now designated as Jil1. The components are separated by about 1′, corresponding to roughly 8 kpc at the redshift of the QSO. Given the separation of the components, it is much more likely that we see three individual galaxies than one galaxy with bright knots. In addition to the close complex of three galaxies to the east of LBQS 0302−0019, we already found tentative evidence in the VLT/HAWK-I image for another galaxy companion to the south. The HST image confirms a distinct source at the expected location, which we designate as Jil4. Hence, we can report the clear detection of four companion galaxies within a radius of 30 kpc around the luminous QSO, and we explore their physical parameters below.

### 2.4. Morphological parameters and brightness

We inferred the magnitude and morphological parameters for each component by adding single Sersic components to the galfit model at the respective locations. Thereby, we inferred the brightness, effective radius, Sersic index, axis ratio, and position angle for each component. The measured parameters and their estimated uncertainties are listed in Table 1. In order to determine the uncertainties, we performed Monte Carlo simulations and re-fitted the image 250 times with randomly drawing values from a Gaussian distribution centred on the initial value with the noise as standard deviation. One of the 24 empirical PSFs was used for each iteration to incorporate the systematic uncertainty of the PSF into the Monte Carlo simulations.

Afterwards, we also modelled the VLT/HAWK-I Ks-band image with galfit, but keeping the relative positions, sizes, Sersic indices, elongations, and position angles fixed to the best-fit values obtained from the HST image. The only free parameters were the Ks-band magnitudes of the components. We per-

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**Table 1.** Physical parameters of identified companion galaxies.

| $r_e$ | $b/a$ | $m_{F125W}$ (AB)$^a$ | $m_{Ks}$ (AB)$^a$ | $m_{F125W} - m_{Ks}$ | $t_s^b$ | $\log(M_*/L_\odot)^c$ | $\log(M_*/M_\odot)^d$ |
|------|------|-----------------|----------------|-----------------|--------|----------------|----------------|
| Jil1 3.8 ± 0.5 0″75 ± 0″12 | 0.60 ± 0.05 | 23.70 ± 0.27 | 22.22 ± 0.03 | 1.48 ± 0.30 | 252.90±0.12 | −0.89±0.05 | 11.78±0.12 |
| Jil2 1.3 ± 0.5 0″76 ± 0″65 | 0.26 ± 0.07 | 24.74 ± 0.53 | 24.75 ± 0.23 | −0.01 ± 0.75 | 19.50±0.14 | −1.50±0.05 | 9.40±0.14 |
| Jil3 1.6 ± 0.9 0″13 ± 0″11 | 0.54 ± 0.08 | 25.69 ± 0.25 | > 25.78 | < 0.40 | < 25.78 | < 0.40 | < 25.78 |
| Jil4 0.7 ± 0.1 0″26 ± 0″01 | 0.60 ± 0.04 | 24.81 ± 0.11 | 24.02 ± 0.09 | 0.80 ± 0.19 | 98.4±0.1 | −1.0±0.04 | 10.2±0.04 |

**Notes.**

- $^a$ Best-fit Sersic index estimated from the HST image.
- $^b$ Best-fit effective radius estimated from the HST image.
- $^c$ Best-fit integrated brightness in the HST image.
- $^d$ Best-fit integrated brightness in the HAWKI-I image assuming morphological parameters inferred from the HST image.
- $^e$ Best-fit luminosity-weighted age of single-stellar population model from the observed colors without dust attenuation.
- $^f$ Best-fit mass-to-light ratio of the best-fit single-stellar population model.
- $^g$ Best-fit integrated stellar mass given the luminosity and age of the single-stellar population.
Fig. 2. Estimation of stellar population age and stellar mass based on the observed F125W–Ks colour. Top panel: Stellar population synthesis spectra from Bruzual & Charlot (2003) redshifted to $z = 3.29$ for various stellar ages in the wavelength range of interest. The spectra are normalised to a $K_s$-band flux of unity. The VLT/HAWK-I $K_s$ and WFC3/IR F125W filter curves are shown for comparison. Lower left panel: Evolution of the observed F125W–$K_s$ (roughly rest-frame $U$–$V$) colour with stellar ages up to 1 Gyr and three metallicities. The measured colours and their uncertainty bands for Jil1, Jil2, and Jil4 are overplotted as horizontal stripes, while the upper limit for Jil3 is highlighted by arrows. Lower right panel: Logarithmic mass-to-light ratio ($\log(M_*/L_V)$) as a function of stellar age. The confidence intervals in age for the galaxies are shown as vertical stripes, as determined from the stellar population synthesis spectra. The upper limit on the age for Jil3 is again highlighted by arrows.

formed Monte Carlo simulations with \texttt{galfit} in the same manner as for the \textit{HST} image. Jil3 was not always clearly detected, so we determine a 99% confidence lower limit. The $K_s$ magnitudes and F125W–$K_s$ colour terms are listed in Table 1.

3. Physical properties of the companion galaxies

3.1. Galaxy ages and stellar masses

In order to determine more precise stellar masses than those predicted based on the single $K_s$ band in Paper II, we compared the measured F125W–$K_s$ colours with single stellar population (SSP) models from Bruzual & Charlot (2003). We show redshifted SSP spectra for different stellar population ages in the upper panel of Fig. 2 and highlight the respective transmission curve of the WFC3/IR F125W and HAWK-I $K_s$ filters for comparison. The observed F125W–$K_s$ colour is very sensitive to the age of the SSP, as shown in the lower left panel of Fig. 2 for three different metallicities (half-solar, solar, and twice solar). From the observed colours, we inferred the age by linearly interpolating the age grid for solar metallicity and used the colour uncertainty and difference in metallicities to determine a 1σ confidence interval. The SSP ages correspond to a certain mass-to-light ($M_*/L_V$) ratio for the rest-frame $V$ band, as shown in the lower left panel of Fig. 2. For Jil3, we estimated corresponding upper limits for the age and $M_*/L_V$ from the upper limit in colour and list all inferred parameters in Table 1.

All galaxies appear young, with ages less than 300 Myr, for the dominant light-weighted SSP. This is less than 20% of the age of the Universe at $z = 3.29$. Hence, the group of galaxies around LBQS 0302–0019 must have established recently and must have been undergoing intense star formation activity. The oldest galaxy with the reddest colours is the brightest component, Jil1. The high Sersic index implies that this galaxy is compact and has likely already experienced a series of mergers, growing in mass, in addition to continuous star formation. We used the mass-to-light ratios directly inferred from the colours to estimate a stellar mass for each component, which are listed in Table 1. The stellar mass for Jil1 of $\log(M_*/M_\odot) = 11.2^{+0.3}_{-0.1}$ is fully consistent with our previous, less accurate estimate of $\log(M_*/M_\odot) = 10.9 \pm 0.5$ from VLT/HAWK-I (Paper II). Notably, we discovered more than one companion with masses close to or greater than that of the Milky Way. This is consistent with our previous interpretation that LBQS 0302–0019 is associated with a group of galaxies within an exceptionally massive dark matter halo.

3.2. Association with the Ly$\alpha$ and He$\text{ii}$ emission

The MUSE observations presented in Paper I were obtained as part of programme 094.A-0767(A) (PI: T. Shanks) and cover the wavelength range 4750 Å to 9300 Å over a $1' \times 1'$ field of view at 0''2 sampling. From the bright QSO continuum, a wavelength-dependent PSF was reconstructed using a median filter that ef-
fectively clipped narrow-line emission. This PSF was scaled in flux to match the brightest spaxel at the QSO position and subtracted from the data, which is a similar approach to what has been used in other works (e.g. Borissova et al. 2016, Drake et al. 2019). More details of the MUSE data processing can be found in Paper I. Narrow-band images were extracted from the QSO-subtracted data in Paper I, which revealed an extended Lyα nebula around LBQS 0302–0019, as commonly observed around high-redshift QSOs (e.g. Heckman et al. 1991, Borissova et al. 2016, Arrigoni Battaia et al. 2019, Drake et al. 2019, Farina et al. 2019, O’Sullivan et al. 2020). In order to characterise the asymmetry of the nebula, we measured the asymmetry parameter, α = 0.55, as defined by Arrigoni Battaia et al. (2019) and a displacement of the flux-weighted centroid of the Lyα nebula with respect to the QSO position of d_{QSO−Neb} = 0″.76 (5.7 kpc) within the 2σ isophotal limiting area of 105.3 arcsec². These values are fully consistent with the mean asymmetries and characteristics of Lyα nebulae studied by Arrigoni Battaia et al. (2019). Nevertheless, we had already concluded from the comparison of the HAWK-I and MUSE data in Paper II that the high surface brightness Lyα emission of the Lyα nebula is clearly associated with the neighbouring galaxy that is driving the asymmetry. The nearly point-like He ii emission appeared slightly offset from the bright companion galaxy when comparing the HAWK-I and MUSE data. As highlighted in Fig. 3 the high-resolution and higher-quality WFC3 image allows for a much more secure association of nebular line emission with the distinct companion galaxies.

The Lyα emission surface brightness peaks in between Jil1 and Jil2, which is likely caused by a superposition of individual Lyα nebulae, possibly together with emission from stripped material of the interacting galaxies. As noted by Wisotzki et al. (2016), all isolated star-forming galaxies at z > 3 are surrounded by a Lyα halo with an effective radius about ten times larger than the one estimated from starlight. However, we noticed that no excess in Lyα emission is associated with Jil4 beyond the surface brightness of the diffuse Lyα symmetrically surrounding the QSO, as shown in Paper I. Hence, we cannot verify its physical association with the system despite the fact that the obtained colours imply sensible galaxy properties at the QSO redshift. Similarly, Jil3 is too close to Jil1 to separate the emission of both components, so Jil3 may simply be embedded within Jil1’s extended Lyα nebula or might actually be at a different redshift. A chance projection could be an alternative explanation for the extreme colours of Jil3, but a physical association cannot be ruled out with the current data.

With the HST imaging we can conclusively associate all the narrow He ii emission detected by MUSE with the companion Jil2 (Fig. 1) instead of the more massive galaxy Jil1. This is what we initially assumed from the HAWK-I image presented in Paper II despite the small but noticeable spatial offset. Given the high mass and very young age of Jil2, it is worth discussing whether stellar evolution alone might explain the associated nebular He ii emission or if additional ionisation by an AGN is a necessity.

3.3. The origin of He ii λ1640 emission in Jil2

Given the energy of 54 eV required to fully ionise helium, the necessary hard radiation field is usually not produced by an evolved stellar population. In addition to AGN, the radiation field of some types of hot, massive stars is sufficient to fully ionise helium. While this seems to naturally point towards classical Wolf-Rayet stars (e.g. Schaerer & Vacca 1998), their budget of He ii-ionising flux can be effectively zero at high metallicity (Sander & Vink 2020). Instead, only Wolf-Rayet stars with weaker winds and stripped-envelope stars without strong winds manage to produce considerable amounts of He ii-ionising flux. Consequently, the production of He ii-ionising flux is fostered by lower metallicities as the lower available opacity shifts the onset.
of Wolf-Rayet-type winds to higher and higher masses (Sander & Vink 2020). As all these stars are very short lived; only galaxies undergoing a rare phase of intense star formation are capable of ionising significant amounts of helium. Examples are local low-metallicity dwarf galaxies (e.g. Kehrig et al. 2015, 2018; Sencyna et al. 2020) or rare galaxies detected in deep spectroscopic galaxy surveys at intermediate redshift (e.g. Cassata et al. 2013) Nanayakkara et al. 2019] Saxena et al. 2020).

Wolf-Rayet stars typically show broad He ii emission lines of \( \sim 1000 \text{ km s}^{-1} \) full width at half maximum (FWHM) as part of their powerful stellar winds (e.g. Crowther 2007; Wolford et al. 2014). Hence, a prominent broad He ii component is expected for a Wolf-Rayet galaxy in which such stars are a significant population (e.g. Brinchmann et al. 2008; Miralles-Caballero et al. 2016; Liang et al. 2020). The He ii line detected with MUSE for Jil2 is narrow instead, with a FWHM of only \( \sim 300 \text{ km s}^{-1} \), as characterised in Paper I, and therefore is incompatible with a traditional Wolf-Rayet galaxy interpretation. At low metallicity (\( Z \ll 0.1Z_{\odot} \)), very massive stars with a WNH-type spectrum can efficiently produce narrow He ii emission (Grafener & Vink 2015), but the reported line ratio of He ii / [O III] is narrow instead, with a FWHM of \( \sim 400 \text{ to } 2200 \text{ km s}^{-1} \), as characterised in Paper I, with the companion Jil2 rather than the more massive galaxy Jil1. The stellar mass of Jil2 = \( 11 \text{ M}_{\odot} \) as inferred from Paper I, Jil1 is the oldest and slowly evolving in a group environment. Jil1 is the oldest and massive galaxy of the companions, \( t_{\text{age}} = 252 \pm 222 \text{ Myr} \) and \( \log(M_{\text{He}}/[M_{\odot}]) = 11.2 \pm 0.7 \). This galaxy corresponds to the previously identified companion in ground-based VLT/HAWK-I changedeservation, as initially identified in Paper II.

More importantly, we were able to robustly associate the strongly nebular He ii emission, initially discovered with MUSE in Paper I, with the companion Jil2 rather than the more massive companion Jil1. Although we inferred a young age of only \( \sim 40 \text{ Myr} \) for Jil2 based on the \( U - V \) colour, a stellar origin for the He ii emission could be ruled out given that the He ii line luminosity, width, and UV line ratios reported in Paper I cannot be reproduced with current stellar evolution models. As already suggested in Papers I and II, an AGN in Jil2 remains the only viable explanation for the He ii emission, but a minor stellar contribution is possible.

The inferred age of Jil2 tightly constrains the timing of the intense starburst with a maximum delay of the AGN phase to \( t_{\text{age}} = 19^{+14}_{-7} \text{ Myr} \). This allows us to speculate about the origin of the exceptionally large (13.2 Mpc) He ii proximity zone around LBQS 0302−0019 that has been used to infer a lower limit to the duration of its current radiatively efficient accretion episode of \( > 11 \text{ Myr} \) (Worseck et al. 2021). However, such modelling depends on the UV background radiation field and assumes that only the luminous QSO creates the likely irregular bubble of fully ionised helium, of which we observe a single line of sight to the QSO. The obscured AGN in Jil2 may be acting as an additional source of He ii-ionising photons, potentially in various directions due to the galaxy motion in the last few megayears, creating the exceptionally large He ii proximity zone around LBQS 0302−0019. Consequently, the duration of the QSO episode of LBQS 0302−0019 may have been overestimated. A test of this hypothesis demands VLT/MUSE and deep imaging observations for a statistical sample of QSOs with observable He ii proximity zones to uncover a potential link between the specific environment properties and the QSO proximity zone sizes.

Despite the proximity of Jil2 to the luminous QSO LBQS 0302−0019, we have already argued against a simple QSO fluorescence scenario for the production of He ii 11640 Å in Paper I. The incident ionising flux of the QSO is only sufficient with the observed He ii line luminosity for extreme assumptions (e.g. all photons ionising only helium and not hydrogen), which should not be valid. Our conclusion was that there must be an intrinsic source in Jil2 that provides the necessary photons requiring an AGN bolometric luminosity as low as \( L_{\text{AGN}} \simeq 10^{46} \text{ erg s}^{-1} \). The young age of Jil2, a few tens of megayears, requires a rapid evolution of the host galaxies, which also implicitly demands significant black hole growth during this period in the co-evolution picture (e.g. Kormendy & Ho 2013).

4. Summary and conclusion

In this paper we have presented new NIR HST images of the dual AGN system Jil1+LBQS 0302−0019 taken with WFC3/IR in the F125W filter (J band). We identified four distinct galaxies close to LBQS 0302−0019, at least two of which are physically associated with the QSO. Combining the previous VLT/HAWK-I Ks photometry in Paper II with the HST J band allowed us to construct the corresponding integrated rest-frame U − V colours for each component. When we compared these to stellar population models, we inferred light-weighted stellar population ages of \( < 300 \text{ Myr} \), suggesting that the companions are rapidly evolving in a group environment. Jil1 is the oldest and most massive galaxy of the companions, with \( t_{\text{age}} = 252^{+222}_{-109} \text{ Myr} \) and \( \log(M_{\text{He}}/[M_{\odot}]) = 11.2 \pm 0.7 \). This galaxy corresponds to the previously identified companion in ground-based VLT/HAWK-I changedeservation, as initially identified in Paper II.

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