RUBIES Reveals a Massive Quiescent Galaxy at z=7.3

ANDREA WEIBEL,¹ ANNA DE GRAAFF,² DAVID J. SETTON,^{3,*} TIM B. MILLER,⁴ PASCAL A. OESCH,^{1,5,6} GABRIEL BRAMMER,^{5,6} CLAUDIA D.P. LAGOS,^{7,8,5} KATHERINE E. WHITAKER,^{9,5} CHRISTINA C. WILLIAMS,^{10,11} JOSEPHINE F.W. BAGGEN,¹² RACHEL BEZANSON,¹³ LEINDERT A. BOGGAARD,^{2,14} NIKKO J. CLERI,^{15,16,17} JENNY E. GREENE,³ MICHAELA HIRSCHMANN,¹⁸ RAPHAEL E. HVIDING,² ADARSH KURUVANTHODI,¹ IVO LABBÉ,¹⁹ JOEL LEJA,^{15,16,17} MICHAEL V. MASEDA,²⁰ JORRYT MATTHEE,²¹ IAN MCCONACHIE,²⁰ ROHAN P. NAIDU,^{22,†} GUIDO ROBERTS-BORSANI,¹ DANIEL SCHAERER,^{1,23} KATHERINE A. SUESS,²⁴ FRANCESCO VALENTINO,^{25,5} PIETER VAN DOKKUM,¹² AND BINGJIE WANG (王冰洁)^{15,16,17}

¹Department of Astronomy, University of Geneva, Chemin Peqasi 51, 1290 Versoix, Switzerland

²Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117, Heidelberg, Germany

³Department of Astrophysical Sciences, Princeton University, 4 Ivy Lane, Princeton, NJ 08544, USA

⁴Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA), Northwestern University, 1800 Sherman Ave, Evanston,

IL 60201, USA

⁵Cosmic Dawn Center (DAWN), Denmark

⁶Niels Bohr Institute, University of Copenhagen, Jagtvej 128, København N, DK-2200, Denmark

⁷ International Centre for Radio Astronomy Research (ICRAR), M468, University of Western Australia, 35 Stirling Hwy, Crawley, WA

6009, Australia

⁸ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D)

⁹Department of Astronomy, University of Massachusetts, Amherst, MA 01003, USA

¹⁰NSF's National Optical-Infrared Astronomy Research Laboratory, 950 North Cherry Avenue, Tucson, AZ 85719, USA

¹¹Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721, USA

¹²Department of Astronomy, Yale University, New Haven, CT 06511, USA

¹³Department of Physics and Astronomy and PITT PACC, University of Pittsburgh, Pittsburgh, PA 15260, USA

¹⁴Leiden Observatory, Leiden University, PO Box 9513, NL-2300 RA Leiden, The Netherlands

¹⁵Department of Astronomy & Astrophysics, The Pennsylvania State University, University Park, PA 16802, USA

¹⁶Institute for Computational & Data Sciences, The Pennsylvania State University, University Park, PA 16802, USA

¹⁷Institute for Gravitation and the Cosmos, The Pennsylvania State University, University Park, PA 16802, USA

¹⁸Institute of Physics, Laboratory for galaxy evolution, EPFL, Observatory of Sauverny, Chemin Pegasi 51, 1290 Versoix, Switzerland

¹⁹Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Melbourne, VIC 3122, Australia

²⁰Department of Astronomy, University of Wisconsin-Madison, 475 N. Charter St., Madison, WI 53706, USA

²¹Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria

²²MIT Kavli Institute for Astrophysics and Space Research, 77 Massachusetts Ave., Cambridge, MA 02139, USA

²³CNRS, IRAP, 14 Avenue E. Belin, 31400 Toulouse, France

²⁴Department for Astrophysical & Planetary Science, University of Colorado, Boulder, CO 80309, USA

²⁵ European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany

ABSTRACT

We report the spectroscopic discovery of a massive quiescent galaxy at $z_{\rm spec} = 7.29 \pm 0.01$, just ~ 700 Myr after the Big Bang. RUBIES-UDS-QG-z7 was selected from public JWST/NIRCam and MIRI imaging from the PRIMER survey and observed with JWST/NIRSpec as part of RUBIES. The NIRSpec/PRISM spectrum reveals one of the strongest Balmer breaks observed thus far at z > 6, no emission lines, but tentative Balmer and Ca absorption features, as well as a Lyman break. Simultaneous modeling of the NIRSpec/PRISM spectrum and NIRCam and MIRI photometry (spanning $0.9-18 \,\mu$ m) shows that the galaxy formed a stellar mass of $\log(M_*/M_{\odot}) = 10.23^{+0.04}_{-0.04}$ before $z \sim 8$, and ceased forming stars $50-100 \,\text{Myr}$ prior to the time of observation, resulting in $\log(\text{sSFR/Gyr}^{-1}) < -1$. We measure a small physical size of $209^{+23}_{-24} \,\text{pc}$, which implies a high stellar mass surface density within the effective radius of $\log(\Sigma_{*,e}/M_{\odot}\,\text{kpc}^{-2}) = 10.85^{+0.11}_{-0.12}$ comparable to the highest densities measured in quiescent galaxies at $z \sim 2 - 5$. The 3D stellar mass density profile of RUBIES-UDS-QG-z7 is remarkably similar to the central densities of local massive ellipticals, suggesting that at least some of their cores may have already been in place at z > 7. The discovery of RUBIES-UDS-QG-z7 has strong implications for galaxy formation models: the estimated number density of quiescent galaxies

at $z \sim 7$ is $> 100 \times$ larger than predicted from any model to date, indicating that quiescent galaxies have formed earlier than previously expected.

Keywords: cosmology: observations — galaxies: evolution — galaxies: formation

1. INTRODUCTION

The existence of massive quiescent galaxies in the early Universe has posed a longstanding challenge for galaxy formation models, sparking an extensive search for the highest redshift quiescent galaxies (e.g. Marchesini et al. 2010; Gobat et al. 2012; Glazebrook et al. 2017; Schreiber et al. 2018a; Santini et al. 2019; Carnall et al. 2020; Forrest et al. 2020a,b; Valentino et al. 2020; Gould et al. 2023; Antwi-Danso et al. 2023; Urbano Stawinski et al. 2024). Although the latest generation of cosmological simulations are able to form massive quiescent galaxies at a rate that matches observations for galaxies with stellar masses $M_* > 10^{10} \,\mathrm{M}_{\odot}$ out to $z \sim 3$, the predicted number density of such systems drops dramatically toward higher stellar masses and redshifts (e.g. Lovell et al. 2023; Lagos et al. 2024; Kimmig et al. 2023; Hartley et al. 2023). However, it is likely that there are quiescent galaxies at even earlier times: approximately half of the compact massive galaxies found at $z \sim 2-3$ are already quiescent (Brammer et al. 2011; Whitaker et al. 2012; van Dokkum et al. 2015), which implies that these systems must have formed a stellar mass > $10^{10} \,\mathrm{M_{\odot}}$ and ceased forming stars within just \sim 2-3 Gyr after the Big Bang. The stellar mass densities in the compact quiescent galaxies are also remarkably high, and these systems are therefore thought to evolve into the centers of massive early-type galaxies at the present day (Bezanson et al. 2009; van Dokkum et al. 2014; Belli et al. 2014).

The cores of massive early-type galaxies in the local Universe thus may have already been in place at z > 3. Indeed, deep spectroscopic studies of massive quiescent galaxies at $z \sim 2$ have shown that the stellar populations are very old and strongly α -enhanced (Kriek et al. 2016; Jafariyazani et al. 2020; Beverage et al. 2024a,b), indicating that these galaxies formed in a rapid burst of star formation at z > 3 and possibly as early as $z \sim 8$. This is further corroborated by the finding of massive quiescent galaxies at $z \sim 3-4$ for which the formation timescales inferred from photometry and/or ground-based spectroscopy imply that some systems formed and quenched already at z > 6 (e.g. Schreiber et al. 2018a; Carnall et al. 2020; Antwi-Danso et al. 2023). However, prior to quenching, the star-formation histories (SFHs) of these galaxies are notoriously uncertain and sensitive to systematic modeling assumptions. Pinning down their formation histories requires directly observing progenitors at higher redshifts.

Although compact star-forming galaxies have been found at $z \gtrsim 3$ (e.g. Shibuya et al. 2015; Bouwens et al. 2022a), the search for massive quiescent galaxies at these high redshifts has been limited by the wavelength coverage of the Hubble Space Telescope (HST) and groundbased near-infrared (IR) facilities, which do not extend beyond the Balmer break (rest-frame $\sim 4000 \text{ Å}$) for $z \gtrsim 3-4$ (e.g. Glazebrook et al. 2017; Schreiber et al. 2018b; Forrest et al. 2020b; Antwi-Danso et al. 2023; Tanaka et al. 2024). Space-based observations with Spitzer extended the wavelength coverage in the near-IR, aiding the identification of robust quiescent galaxy candidates at $z \sim 3-5$ (e.g. Schreiber et al. 2018b; Merlin et al. 2018, 2019; Carnall et al. 2020; Gould et al. 2023). However, source confusion due to poor spatial resolution and comparatively shallow photometric constraints left the nature of many other candidates ambiguous.

With its high sensitivity, resolution and broad wavelength coverage in the near- and mid-IR, the James Webb Space Telescope (JWST) provides a major leap forward in the search for high-redshift quiescent galaxies. Deep near-IR imaging of extragalactic legacy fields with JWST/NIRCam (Rieke et al. 2023) has yielded a large number of robust photometric candidates at $z \sim 3-5$ (e.g. Carnall et al. 2023a; Valentino et al. 2023; Long et al. 2024; Alberts et al. 2023). Followup spectroscopy with JWST/NIRSpec (Jakobsen et al. 2022) has confirmed the quiescent nature and high stellar masses for several candidates, with redshifts as high as $z \sim 4.5 - 5.0$ (Carnall et al. 2023b, 2024; Nanayakkara et al. 2024: Glazebrook et al. 2024: Setton et al. 2024: de Graaff et al. 2024a; Barrufet et al. 2024; Wu 2024). The discovery of these galaxies continues to challenge galaxy formation models, as the number densities of massive quiescent galaxies in cosmological simulations are up to 2 orders of magnitude below the observational estimates at $z \gtrsim 4$ (Valentino et al. 2023; de Graaff et al. 2024a; Weller et al. 2024; Lagos et al. 2025). Surprisingly, the SFHs inferred from the NIRSpec spectra of some of these

^{*} Brinson Prize Fellow

[†] NHFP Hubble Fellow

early massive quiescent galaxies point to an extremely early burst of star formation (z > 8) as well as very early quenching (z > 7).

It remains unclear whether the corresponding progenitors have already been identified. Looser et al. (2024) and Strait et al. (2023) have reported the discovery of two galaxies at $z \sim 5-7$ that show no signs of star formation in the most recent $\sim 5 - 10$ Myr. Yet, these systems have stellar masses that are over 100 times lower than the massive quiescent galaxies found at $z \sim 2-5$, and are likely only temporarily quiescent (e.g., Dome et al. 2024). Other sources at $z \sim 7-8$ have been found to have Balmer breaks from both photometry and spectroscopy (Laporte et al. 2023; Vikaeus et al. 2024; Trussler et al. 2024; Witten et al. 2024; Kuruvanthodi et al. 2024). However, the measured break strengths are typically small, stellar masses are often low, spectroscopic confirmations remain rare, and the presence of emission lines points to ongoing star formation activity in many of these systems. Labbé et al. (2023), Wang et al. (2024) and Williams et al. (2024) demonstrated that there may be very massive galaxies with significant Balmer breaks among the mysterious population of compact red sources dubbed Little Red Dots (LRDs; Matthee et al. 2024) at $z \sim 7-8$, and full spectral modeling by Wang et al. (2024) revealed that their SFHs appear similar to those of the massive quiescent galaxies found at $z \sim 4-5$. If these sources are indeed confirmed to be massive galaxies, their central stellar densities match those of the compact quiescent systems found at $z \sim 2$ (Baggen et al. 2023, 2024). However, the stellar masses of LRDs are still highly uncertain – at the ~ 1 dex level – due to the likely presence of luminous active galactic nuclei (AGN) that may dominate the spectral energy distribution (SED) at rest-frame optical wavelengths (e.g., Williams et al. 2024; Wang et al. 2024).

In this paper, we report the discovery of a massive quiescent galaxy at z = 7.3, RUBIES-UDS-QG-z7, confirmed spectroscopically with JWST/NIRSpec as part of the Cycle 2 program RUBIES. We describe our photometric selection and spectroscopic observations in Section 2 and perform stellar population modeling in Section 3 to infer the SFH and stellar population properties. The morphology and estimated stellar mass density profile are presented in Section 4. We place RUBIES-UDS-QG-z7 in the context of the $z \sim 7$ galaxy population in Section 5 and discuss its connection to quiescent galaxies at lower redshifts, star-forming progenitors at z > 8as well as the lack of massive quiescent galaxies at $z \sim 7$ in simulations. A summary and our main conclusions can be found in Section 6. Throughout this work we use a flat Λ CDM cosmology with cosmological parameters from the nine-year Wilkinson Microwave Anisotropy Probe Observations (Hinshaw et al. 2013), h = 0.6932 and $\Omega_{m,0}=0.2865$. Magnitudes are reported in the AB system.

2. DATA

2.1. Imaging data

The main target of this paper, RUBIES-UDS-QG-z7 lies in the UDS field at (R.A., Dec.) = (2:17:43.11,-05:06:44.27) and was originally detected in the publicly available JWST/NIRCam data from the Public Release IMaging for Extragalactic Research program (PRIMER; GO-1837; PI J. Dunlop; see, e.g., Donnan et al. 2024). PRIMER obtained 8 bands of JWST/NIRCam photometry (F090W, F115W, F150W, F200W, F277W, F356W, F410M, and F444W) as well as two MIRI filters (F770W, F1800W). RUBIES-UDS-QG-z7 was identified as a high-priority ('Priority 0') target for spectroscopic follow-up based on its high photometric redshift, bright apparent magnitude (F444W ≈ 24.6) and the red shape of its spectral energy distribution (SED), which suggested that it was a massive, evolved galaxy at high redshift.

We use the reduced image mosaics of the UDS field from the DAWN JWST Archive (DJA; version 7.2). These data are reduced using the grizli pipeline (Brammer 2023a) and are drizzled to a pixel scale of $0.0^{\prime\prime}$ 04 pix⁻¹. For more details on the initial data reduction see Valentino et al. (2023). For the purpose of analyzing the surface brightness profile, we also produce a custom reduction of the F200W filter in the northern half of the UDS-mosaic on a $0.0^{\prime\prime}$ 02 pix⁻¹ pixel scale (see Section 4.1).

2.2. Photometry

Following Weibel et al. (2024), the NIRCam images are matched to the F444W resolution using empirical point spread function (PSF) models before performing 0."32 diameter aperture photometry using **SourceExtractor** (Bertin & Arnouts 1996). Source detection is based on an inverse-variance weighted stack of all the broad-band long-wavelength images (F277W, F356W and F444W) and fluxes are scaled to total based on Kron apertures and an encircled energy correction to account for the flux in the wings of the PSFs.

To obtain MIRI fluxes we measure the flux enclosed in 0.0000 diameter apertures, after subtracting the local background as a sigma-clipped median flux in a 101×101 pixels cutout centered on the source. To match to F444W resolution, we multiply the measured flux by the ratio of the encircled energies at 0.00000 diameter of the

RA	34.4296173		
DEC	-5.1122962		
NIRCam			
F090W	-3.7±7.7		
F115W	45.2 ± 7.9		
F150W	$75.7 {\pm} 6.7$		
F200W	$108.3 {\pm} 5.6$		
F277W	$186.0{\pm}9.3$		
F356W	$469.6 {\pm} 23.5$		
F410M	522.5 ± 26.1		
F444W	$527.6 {\pm} 26.4$		
MIRI			
F770W	673.7 ± 94.8		
F1800W	377 ± 1043		

 Table 1. Positions in degrees and NIRCam and MIRI photometric fluxes measured for RUBIES-UDS-QG-z7 in nJy.

F444W and the MIRI PSF respectively. This allows us to then scale the fluxes to total in the same way as the NIRCam fluxes.

We note that the MIRI image reduction on the DJA used an older version of the calibration reference files. We therefore finally correct the measured fluxes using the absolute photometric calibration of the latest reference file (version 203; a correction factor of 0.85 and 1.03 for the F770W and F1800W imaging, respectively).

Our photometric measurements in all filters are listed in Table 1.

2.3. Spectroscopic data

NIRSpec spectra for RUBIES-UDS-QG-z7 were obtained on July 25, 2024 as part of the Red Unknowns: Bright Infrared Extragalactic Survey (RUBIES) (GO-4233; PIs A. de Graaff and G. Brammer, de Graaff et al. 2024b). RUBIES is a JWST Cycle 2 program of NIRSpec multi-shutter array (MSA) observations (Ferruit et al. 2022) targeting galaxies in the two extragalactic legacy fields CANDELS EGS and UDS (Koekemoer et al. 2011; Grogin et al. 2011). In the UDS field, the RUBIES sources were selected from public JWST/NIRCam imaging obtained by the PRIMER The MSA exposures consisted of 48 minsurvey. utes each with the low-resolution PRISM/CLEAR and the medium-resolution G395M/F290LP disperser/filter combinations. A 3-point nodding pattern was used to observe each target in a 1×3 configuration of open microshutters.

Full details of the NIRSpec data reduction are provided in Heintz et al. (2024) and de Graaff et al. (2024b). Briefly, we use version 3 of the msaexp (Brammer 2023b) pipeline. Compared to version 2 of msaexp described in Heintz et al. (2024), this uses updated reference files for improved flux calibration and custom calibration files for the bar shadow correction, which were constructed from observations of blank sky shutters.

We present the PRISM spectrum, both in 2D and in 1D, along with the best-fitting SED (see Section 3) and the NIRCam photometry in Figure 1. Remarkably, the source shows a clear Balmer break and a Lyman break, unambiguously putting it at a redshift of $z_{\rm spec} = 7.29 \pm$ 0.01. There are no emission lines detected at the > 1 σ level. The inset in the bottom panel shows a zoom-in to the region around the Balmer break and highlights the position of various absorption features: The Balmer lines H γ , H δ , H ϵ , H ζ and H η as well as the Ca H and K lines. While the individual absorption features are observed at a relatively low signal-to-noise ratio (SNR), their combined occurrence makes it unlikely that they are a result of noise.

For completeness, we also show the G395M data in Appendix A, although the SNR of this spectrum is too low to distinguish any features.

3. SED MODELING

To infer the physical properties of RUBIES-UDS-QGz7, we use the Bayesian SED fitting tool Prospector (Johnson & Leja 2017; Leja et al. 2017; Johnson et al. 2021) with the nested sampling code dynesty (Speagle 2020) to simultaneously fit the PRISM spectrum as well as the NIRCam and MIRI photometry.

3.1. Prospector Setup

We largely follow the same methodology described in detail in de Graaff et al. (2024a). Briefly, we use the stellar population synthesis models from the Flexible Stellar Population Synthesis (FSPS) package (Conroy et al. 2009; Conroy & Gunn 2010), with the MILES spectral library (Sánchez-Blázquez et al. 2006), MIST isochrones (Choi et al. 2016; Dotter 2016), and assuming the initial mass function of Chabrier (2003). We allow the redshift to vary within ± 0.1 around the best-fit redshift of z = 7.288 measured with msaexp. Due to the comparatively lower signal-to-noise of the spectrum (relative to the massive quiescent galaxy in de Graaff et al. (2024a)), we also opt to use a lower order (n=2) polynomial in order to flux calibrate the spectrum to the photometry using the Prospector PolySpecFit procedure. However, our inferred SFHs are insensitive to the particular choice of calibration order.

We fit a non-parametric SFH that utilizes the continuity prior of Prospector described in Leja et al. (2019).



Figure 1. NIRSpec/PRISM Spectrum of RUBIES-UDS-QG-z7. Top: 2D SNR spectrum. Bottom: 1D spectrum of RUBIES-UDS-QG-z7 in red, with 1 σ uncertainties in gray. The NIRCam photometry is shown as orange dots and the best-fitting SED from Prospector in blue (see Section 3). The 1D PRISM spectrum has been scaled by the calibration vector inferred by Prospector to account for slit-loss. A zoom-in to the region around $\lambda_{rest} \sim 0.4 \,\mu$ m is shown in the inset panel, where we highlight the position of various absorption features. Note also that the best-fitting SED latches on the Balmer absorption lines.

Due to the higher redshift (and younger age of the Universe at the time of observation) for our source, we adopt a different binning scheme than the one described in de Graaff et al. (2024a). We divide the most recent 100 Myr of cosmic time into 3 bins of 10, 40, and 50 Myr respectively, and fill the remaining earlier cosmic time with 5 linearly spaced bins with widths of ~ 125 Myr, for a total of 8 bins of star formation. We assume a two-parameter Kriek & Conroy (2013) dust law with attenuation around old (t > 10 Myr) stars fit in the range $\tau \in [0, 2.5]$ and a free dust index $\delta \in [-1, 0.4]$ that allows for deviations from the Calzetti et al. (2000) dust law and includes a UV bump that depends on the slope parameterized as in Noll et al. (2009). We fix the attenuation around young (t < 10 Myr) stars to be twice that of the older populations. We fit the stellar metallicity as a free parameter with a logarithmically sampled uniform prior in the range $\log(Z/Z_{\odot}) \in [-1, 0.19]$. We mask all wavelengths shorter than rest-frame 1200Å to avoid contributions from intergalactic medium absorption. For better visual comparison to the observational data in Figures 1 and 2, we apply IGM attenuation to the best-fitting SED using the model from Inoue et al. (2014). Before fitting, all models are convolved with a line spread function that is a factor 1.3 narrower than the resolution curves available on the JWST User Documentation following e.g., Curtis-Lake et al. (2023); de Graaff et al. (2024a) to account for the better resolution of compact sources. We additionally allow for free velocity dispersion parameters that smooth both the stellar continuum and ionized gas emission, that we allow to vary in the range [0,500] km/s to marginalize over the uncertainty in the line spread function in addition to the intrinsic dispersion of the galaxy.

Our initial best-fitting model favors a low metallicity of $Z_{\rm low} = 0.11^{+0.02}_{-0.01} Z_{\odot}$ which is close to the edge of the prior at $0.1 Z_{\odot}$. However, we argue that even lower metallicities are not plausible given the high stellar mass of RUBIES-UDS-QG-z7 and considering the observed stellar mass-metallicity relation at these redshifts (e.g.,





F150W F200W F277W F356W F410M

F770W F1800W

F444W

Figure 2. Top: NIRCam and MIRI imaging cutouts of RUBIES-UDS-QG-z7. Middle: The posterior median SED from Prospector along with the NIRCam + MIRI photometry, which constrains the fit over the rest-frame optical to near-IR. We further plot the MSA slit position on an inset showing a 2''.04 × 2''.04 RGB-cutout around the source. Bottom: Fitted nonparametric SFHs for the low-metallicity fit ($Z = 0.11 Z_{\odot}$) in red and the high-metallicity ($Z = 1.19 Z_{\odot}$) fit in khaki. This shows a rising SFH for RUBIES-UDS-QG-z7 which peaks at $z \sim 8 - 9$, followed by a rapid decline in the SFR at $z \sim 8$ and little to no star formation in the past ≥ 50 Myr. For comparison, we overplot bright sources at $z \geq 8$ with their SFR-values as published in Akins et al. (2023) (COS-z8M1), Bunker et al. (2023) (GN-z11), Castellano et al. (2024) (GHZ2/GLASS-z12), and Carniani et al. (2024) (JADES-GS-z14-0), as well as three samples of UV-bright objects at z > 7.7 plotted with their published values of $M_{\rm UV}$, converted to SFR with the relation from Kennicutt (1998), assuming no dust. Grey: photometrically selected targets for follow-up with ALMA through REBELS from Bouwens et al. (2022b), light blue: a compilation of NIRSpec observations by Roberts-Borsani et al. (2024a), and light green: objects from the JWST BoRG-survey (Roberts-Borsani et al. 2024b). This illustrates that plausible progenitors of RUBIES-UDS-QG-z7 at $z \sim 8 - 9$, and perhaps at even higher redshifts are either dust-obscured or have yet to be discovered or at least spectroscopically confirmed.

Nakajima et al. 2023; Curti et al. 2024) or the metallicities of similar-mass and more-massive quiescent galaxies at lower redshift (e.g., Choi et al. 2014; Beverage et al. 2024a). Since we cannot entirely rule out an even lower metallicity, we discuss this possibility in Section 5.3. Further, due to the low resolution and SNR of the PRISM spectrum, the metallicity is only measured indirectly and is sensitive to the detailed shape of the continuum. Instead, the low metallicity may indicate a systematic mismatch between the SPS libraries and the observed SED due to the abundance patterns of stars formed in a rapid burst being α -enhanced, as observed in z = 1 - 3 quiescent systems (Beverage et al. 2024b). α -enhancement can affect the UV continuum shape at the 20-40% level (e.g., Vazdekis et al. 2015; Choi et al. 2019). Recently, Park et al. (2024) have published novel α -enhanced isochrone and spectral libraries, and found similar effects of α -enhancement on the continuum. Implementing these new models in SED-fitting codes and exploring their effect on the inferred metallicity and other physical properties will be the subject of future work. Here, we follow an approach similar to the one in de Graaff et al. (2024a) (see their Section 4), and attempt to account for this systematic uncertainty due to our inability to marginalize over the effect of varying abundance patterns by running a second fit with a prior on the metallicity of $Z \gtrsim 0.3 \, \mathrm{Z}_{\odot}$, which returns a fit that converges to $Z_{\mathrm{high}} = 1.19^{+0.24}_{-0.27} \, \mathrm{Z}_{\odot}$. Comparing the reduced χ^2 of the two fits, we find $\chi^2_{low-Z} = 535.05$ and $\chi^2_{\rm high-Z} = 538.78$, meaning that we cannot confidently distinguish between the two based on the quality of the fit. The higher metallicity is compensated in the fit by a slightly lower A_V, marginally lower mass, and a younger age with slightly more star formation in the past $\sim 100 \,\mathrm{Myr}$. The resulting physical parameters for both fits are listed in Table 2, and the posterior distributions of the most important fitting parameters are shown in Figure 8 in Appendix B. We emphasize that the low and high metallicity fits are meant to represent the range of plausible metallicities, and likely do not provide meaningful constraints on Z_* individually. However, as can be seen in Figure 8, all the key physical parameters are well constrained independent of Z_* .

3.2. Star Formation History

In Figure 2 we show the best-fitting SED from **Prospector** out to rest-frame near-IR wavelengths, along with the NIRCam+MIRI photometry in the middle panel. The bottom panel shows the inferred non-parametric SFH for the low metallicity and the high metallicity fit.

Both SFHs indicate that RUBIES-UDS-QG-z7 forms more than half of its mass in a burst lasting $\sim 100 -$ 200 Myr at around $z \sim 8 - 9$, and with a SFR of $\sim 100 \,\mathrm{M}_{\odot} \,\mathrm{yr}^{-1}$. Then, the SFR drops to $< 3 \,\mathrm{M}_{\odot} \,\mathrm{yr}^{-1}$ within a few 10s of Myr around $z \sim 8$. The high metallicity fit allows for some more star formation below $z \sim 8$, while the low metallicity fit favours slightly earlier quenching and a more extended SFH at $z \gtrsim 11$. Importantly, both SFHs indicate that the galaxy has a stellar mass of $\log(M_*/M_{\odot}) \sim 10.2$ and a specific SFR of $\log(\text{sSFR/Gyr}^{-1}) \lesssim -1$ when averaged over the past 50 Myr. As a test on the robustness of these properties with regard to changing the SFH-prior, we perform another Prospector run assuming the bursty continuity prior as described in Tacchella et al. (2022), which allows for more drastic changes in the SFR from one time-bin to the next. This increased flexibility is reflected in larger uncertainties on the SFR in time-bins prior to 50 Myr before the time of observation. Crucially, the inferred stellar mass, dust attenuation and SFR_{50} are consistent within errors with those inferred with the continuity prior. In fact, the bursty continuity prior favors an even lower SFR_{50} . We further refer the reader to de Graaff et al. (2024a) who explored the effect of using parametric forms of the SFH such as a delayed- τ , and a rising SFH model to fit a massive quiescent galaxy at $z \sim 4.9$ whose SED resembles that of RUBIES-UDS-QG-z7 (see Figure 4), and found no significant changes in the inferred physical parameters.

To get an alternative direct measurement of the upper limit on the recent star formation, we use the python tool lmfit to fit a single Gaussian to the PRISM and G395M spectrum respectively within ± 30 Å rest-frame of the H β line center at $\lambda_{H\beta} = 4861$ Å after subtracting the continuum as the median in that wavelength window. Since the continuum-subtracted spectra are dominated by noise, we enforce a positive amplitude for the fit and constrain the line center to be within ± 5 Å of $\lambda_{H\beta}$, as well as the dispersion to be within 200 and 400 km/s to avoid unreasonably wide and/or offcentered fits. The values for the dispersion are based on the relation from Forrest et al. (2022) for the dynamical mass M_{dyn} . Assuming $M_{dyn} = M_*$, which can be interpreted as a lower limit on M_{dyn} , this yields $\sigma \approx 225 \,\mathrm{km/s}$. From the inferred uncertainty in the fit we get a 2σ upper limit on the line flux that is allowed by the data. We then convert the approximate best-fitting dust extinction parameter $A_V = 0.3$ to a Balmer decrement to obtain an upper limit on the H α flux which we can finally translate into an upper limit on the recent SFR using the relation from Kennicutt (1998), obtaining ${\rm SFR}_{\rm lines} < 6.6\,{\rm M}_{\odot}\,{\rm yr}^{-1}$ and ${\rm SFR}_{\rm lines} < 5.8\,{\rm M}_{\odot}\,{\rm yr}^{-1}$

from the PRISM and G395M spectrum respectively. This is significantly less constraining than the measurement from Prospector of $SFR_{10} = 0.64^{+0.83}_{-0.60} M_{\odot} \text{ yr}^{-1}$ for the low metallicity model (see Table 2), due to the fact that the Prospector fit is informed by the absence of multiple lines and the continuum shape of the spectrum. It nevertheless provides another confirmation that the recent star formation rate of RUBIES-UDS-QG-z7 must be low.

The secondary y-axis on the right of the bottom panel of Figure 2 shows $M_{\rm UV}$ values that are directly inferred from the SFR, assuming the relation from Kennicutt (1998) and no dust extinction. For comparison with the SFH of RUBIES-UDS-QG-z7, we collect literature sources with the brightest $M_{\rm UV}$ known at z > 7.7 (i.e., at epochs before RUBIES-UDS-QG-z7 stopped forming stars): a sample of objects selected for follow-up with ALMA through REBELS from Bouwens et al. (2022b), a compilation of galaxies observed with NIRSpec from Roberts-Borsani et al. (2024a) and a sample of sources identified in pure-parallel HST-imaging and spectroscopically confirmed through the BoRG-JWST survey (Roberts-Borsani et al. 2024b). All of these sources remain below the unobscured $M_{\rm UV} \lesssim -23$ suggested by the $\sim 50 - 150 \,\mathrm{M_{\odot} \, yr^{-1}}$ SFR in the SFH of RUBIES-UDS-QG-z7. We also show a dust-obscured ($A_V \sim 1.6$) galaxy at $z \sim 8.4$ from Akins et al. (2023) named COSz8M1 with an inferred SFR₁₀₀ ~ $59 \,\mathrm{M_{\odot}yr^{-1}}$. Only this object and three sources from Bouwens et al. (2022b) are consistent with the SFH of RUBIES-UDS-QG-z7 within the 1σ uncertainties. All of them rely on photometric data only, and the sources from Bouwens et al. (2022b) were selected over an area of as much as $\sim 7 \, \text{deg}^2$, whereas the total area covered by RUBIES is only ~ 150 arcmin². Finally, we show three remarkably luminous galaxies at z > 10, GN-z11, GHZ2/GLASS-z12 and JADES-GS-z14-0 with values of SFR_{10} as published in Bunker et al. (2023), Castellano et al. (2024), and Carniani et al. (2024). While these sources are consistent with potentially being progenitors of RUBIES-UDS-QGz7, its SFH is too poorly constrained at $z \gtrsim 10$ to draw further conclusions. However, no sources with SFRs as high as the ones predicted during the burst at $z \sim 8-9$ have been spectroscopically confirmed to date, with photometric candidates being either dust-obscured and/or discovered in wider area imaging. For a more extended discussion on the possible progenitors of RUBIES-UDS-QG-z7, see Section 5.3.

4. STRUCTURAL PROPERTIES

To characterize the morphology of RUBIES-UDS-QGz7, we first fit a Sérsic profile to the imaging, and then

Table 2. Physical properties of RUBIES-UDS-QG-z7, as measured with **Prospector** for the low metallicity (low-Z) and the high metallicity (high-Z) fit.

quantity	low-Z	high-Z
$z_{ m spec}$	$7.287^{+0.007}_{-0.006}$	$7.290\substack{+0.005\\-0.006}$
$\log(M_*/{ m M}_{\odot})$	$10.23_{-0.04}^{+0.04}$	$10.19\substack{+0.04 \\ -0.04}$
$\log(\Sigma_*/M_\odot{\rm kpc}^{-2})$	$10.85\substack{+0.11 \\ -0.12}$	$10.80\substack{+0.11 \\ -0.12}$
$\rm SFR_{10}~[M_{\odot}yr^{-1}]$	$0.64^{+0.83}_{-0.60}$	$1.08\substack{+1.55 \\ -0.98}$
$\rm SFR_{50}~[M_{\odot}yr^{-1}]$	$0.83^{+11.11}_{-0.76}$	$2.13^{+5.54}_{-1.92}$
$\rm SFR_{100}~[M_{\odot}~yr^{-1}]$	$0.84^{+20.16}_{-0.78}$	$48.89^{+21.12}_{-13.04}$
$A_V [mag]$	$0.31\substack{+0.08 \\ -0.08}$	$0.25\substack{+0.09 \\ -0.07}$
t_{50} [Gyr]	$0.20^{+0.07}_{-0.02}$	$0.16\substack{+0.03 \\ -0.02}$
$t_{90} \mathrm{[Gyr]}$	$0.12\substack{+0.01 \\ -0.01}$	$0.07\substack{+0.01 \\ -0.01}$
$\log(Z/{ m Z}_{\odot})$	$-0.94^{+0.05}_{-0.04}$	$0.07\substack{+0.08 \\ -0.11}$

use this measurement to estimate the stellar mass surface density as well as a 3D density profile.

4.1. Sérsic Profile Fitting

We first use the F200W filter to measure the morphology of RUBIES-UDS-QG-z7, as this is the NIRCam filter with the highest SNR for which imaging at a pixel scale of 0.02 is available. Size measurements in longer wavelength filters are discussed further below. We select bright, but not saturated, and isolated stars and use the python tool psf.EPSFBuilder ¹ (Anderson & King 2000; Anderson 2016) from the photutils package (Bradley et al. 2022) to derive an effective PSF.

Next, we use the empirical PSF to perform single Sérsic profile fitting with the **pysersic** package (Pasha & Miller 2023)². To sample the posterior we use the No U-turn sampler implemented in **numpyro** (Hoffman et al. 2014; Phan et al. 2019). We use two chains with 1000 warm-up and 2000 sampling steps each. This results in effective sample sizes > 1200 for all parameters and $\hat{r} < 1.01$ indicating robust sampling (Vehtari et al. 2021).

We find that the source is marginally resolved, with a major axis size of approximately 2 pixels, corresponding to a physical size of $R_{\rm e} = 209^{+33}_{-24}$ pc. The source is round $(b/a = 0.89^{+0.08}_{-0.14})$ and has a poorly constrained Sérsic index, $n = 2.4^{+1.5}_{-0.9}$. Regardless of the uncertain Sérsic index, the small size implies a high stellar mass surface density within the effective radius of $\log(\Sigma_{*,e}/M_{\odot} \text{ kpc}^{-2}) = 10.85^{+0.11}_{-0.12}$.

- ¹ https://photutils.readthedocs.io/en/stable/api/photutils.psf. EPSFBuilder.html
- ² https://github.com/pysersic/pysersic

In Figure 3 (left panel), we compare this density to quiescent galaxies from the literature. First, we compile a sample of 225 quiescent galaxies at $z \sim 2-3$ with $\log(M_*/M_{\odot}) > 10.5$ from the 3DHST catalog (Skelton et al. 2014), using the UVJ-color cuts from Muzzin et al. (2013) and matching with the size fits from van der Wel et al. (2012, selecting only good fits with flag=0) to compute the surface density within the effective radius for each object, similar to the sample in Whitaker et al. (2017). In addition, we show the surface densities of the massive quiescent galaxy at z = 4.66 in Carnall et al. (2023b), of the extremely massive $(M_* = 10^{11} \,\mathrm{M_{\odot}})$ quiescent galaxy RUBIES-EGS-QG-1 at z = 4.9 from de Graaff et al. (2024a), of the compact core component of a z = 3.97 quiescent galaxy from Setton et al. (2024), and the highest density measured in lensed star clusters at $z \sim 6$ by Vanzella et al. (2023). The surface mass density of RUBIES-UDS-QG-z7 is comparable to those of the densest quiescent galaxies at $z \sim 2-3$ as well as the most massive quiescent systems at $z \sim 4-5$, and only a factor ~ 4 less dense than the highest densities measured in star clusters at $z \sim 6$.

Following the same methodology, we also fit single Sérsic profiles to the NIRCam filters in the long wavelength channel, where F356W and F444W probe the rest-frame optical continuum, but both the pixel scale and PSF FWHM are a factor ~ 2 larger (for reference, we show the PSF half width at half maximum of F200W and F444W in Figure 3). On the pixel scale of $0^{\prime\prime}_{..}04$, we measure sizes of $\lesssim 0.5$ pixels, close to the edge of the prior at 0.25 pixels, indicating that RUBIES-UDS-QG-z7 is not resolved in the rest-optical. Taking the 95th percentiles of the posterior distributions as upper limits on the physical size, we find $R_{\rm e} < 103 \, {\rm pc}$ and $R_{\rm e} < 88 \, {\rm pc}$ in F356W and F444W respectively. Under the assumption that our PSF-models are accurate and noise-free, this indicates that RUBIES-UDS-QG-z7 is at least a factor $\times 2$ smaller in the rest-optical than in the rest-UV, which is stronger than (but qualitatively consistent with) the color gradients found in massive quiescent galaxies at $z \sim 1-4$ (e.g. Suess et al. 2019, 2022; Cutler et al. 2024; Ji et al. 2024; Wright et al. 2024). Crucially, this would further imply that the stellar mass density is at least a factor $\times 4$ higher than inferred above.

4.2. Stellar Mass Density Profiles

To estimate the 3D mass profile, we follow the methodology described in Bezanson et al. (2009). We perform an Abel transform to deproject the 2D Sérsic profile measured from the F200W imaging, assuming that the mass density profile is spherically symmetric and that the mass-to-light ratio is constant with radius.

As noted above, the assumption of a constant M/L ratio is conservative given the observed F200W and F444W sizes, and may underestimate the true stellar mass density of this object.

The resulting mass density profile of RUBIES-UDS-QG-z7 is shown in Figure 3, and reveals a very high stellar mass density of $\sim 10^{11} \,\mathrm{M_{\odot} \, kpc^{-3}}$ at the effective radius. For comparison, we also compute the mass density profile of RUBIES-EGS-QG-1 (de Graaff et al. 2024a), and of the triply imaged LRD from Furtak et al. (2024), assuming $R_{\rm e} = 30 \,{\rm pc}, \ M_* = 10^{9.15} \,{\rm M}_{\odot}$ (corresponding to the upper limit on the stellar mass specified in their paper), and n = 1.5. Further, we show the median as well as the 16th and 84th percentile mass density profile of the sample of massive $(\log(M_*/M_{\odot}) > 10.5)$ quiescent galaxies at $z \sim 2-3$ described above. In a similar manner, we compile a sample of 514 $z \sim 0$ quiescent galaxies from the Galaxy And Mass Assembly survey (GAMA; Driver et al. 2011; Liske et al. 2015; Baldry et al. 2018), with masses $\log(M_*/M_{\odot}) > 11$ from Driver et al. (2016), adopting the selection of quiescent galaxies from de Graaff et al. (2022) and the size fits in the r-band from Kelvin et al. (2012) to compute a median as well as 16th and 84th percentile mass profiles of massive quiescent galaxies in the local Universe.

In comparison to the sources at $z \gtrsim 4.5$, we find that the mass density profile of RUBIES-UDS-QGz7 lies $\sim 0.5 \,\mathrm{dex}$ below that of RUBIES-EGS-QG-1, and 0.1 - 0.2 dex below that of the massive quiescent galaxy from Carnall et al. (2023b) at all displayed radii. The triply imaged LRD shows a much more centrally peaked profile, reaching densities comparable to that of RUBIES-UDS-QG-z7 at radii of ~ 10 pc, where the mass density profiles are poorly constrained based on the available imaging data. On the other hand, the mass density profile of RUBIES-UDS-QG-z7 is remarkably consistent with the densest compact quiescent galaxies at $z \sim 2-3$, and it lies $\sim 0.2 \,\mathrm{dex}$ above the 84th percentile of the local early-type galaxy profiles at radii $\lesssim 300 \,\mathrm{pc}$ with some individual $z \sim 0$ profiles sill being consistent with the profile of RUBIES-UDS-QG-z7. Both $z \sim 2-3$ and local ellipticals show higher densities at larger radii due to their more extended morphologies which can be explained by the accretion of smaller satellite systems between 0 < z < 2 (e.g. Bezanson et al. 2009; Naab et al. 2009). As also discussed there, the difference in central densities between massive quiescent galaxies at cosmic noon and local ellipticals is consistent with inside-out growth scenarios, where the $z \sim 2-3$ galaxies evolve into the cores of local ellipticals. Critically, this suggests that it is possible for the cores of





Figure 3. Left: Projected stellar mass surface density within R_e versus redshift for RUBIES-UDS-QG-z7 compared to the massive quiescent galaxy at z = 4.9 from de Graaff et al. (2024a), a massive quiescent galaxy at z = 4.66 from Carnall et al. (2023b), the core component of a massive quiescent galaxy at z = 3.97 from Setton et al. (2024), the densest star cluster found in the Sunrise arc by Vanzella et al. (2023), and a sample of 225 massive quiescent galaxies at $z \sim 2-3$ selected from the 3DHST survey. The surface density of RUBIES-UDS-QG-z7 is consistent with the densities of massive quiescent galaxies at $z \sim 2-3$, and only a factor ~ 4 below that of the densest known star clusters at $z \sim 6$. Right: Mass density profiles of some of the objects shown on the left, as well as of the triply imaged LRD from Furtak et al. (2024). For the quiescent galaxies at $z \sim 2-3$, we show the median stellar mass profile and shade the region between the 16th and 84th percentiles. Similarly, we compile a sample of 514 massive quiescent galaxies at $z \sim 0$ from the GAMA survey, and show the respective median and percentile profiles. The stellar mass density of RUBIES-UDS-QG-z7 at $R \sim 300$ pc is consistent with the latter, indicating that the cores of some local ellipticals may be in place at $z \sim 7$.

present-day massive galaxies to already form within the first 700 Myr.

5. DISCUSSION

Through detailed analysis of the JWST photometric and spectroscopic data, we have established that RUBIES-UDS-QG-z7 has formed a stellar mass > $10^{10} \,\mathrm{M_{\odot}}$ by $z \sim 8$, retaining a compact morphology with $R_{\rm e} \sim 200 \,{\rm pc}$, and then stopped forming stars rapidly within a few 10s of Myr and remained quiescent with $\log(\text{sSFR/Gyr}^{-1}) \lesssim -1$ for the past ~ 50 - 100 Myr. This makes RUBIES-UDS-QG-z7 the highest redshift bonafide massive quiescent galaxy confirmed to date, and raises major questions: How was this galaxy able to form and quench in just 700 Myr? What would its likely progenitors and descendants look like? Below, we compare the spectral shape of RUBIES-UDS-QG-z7 to other red objects at similar redshift, place RUBIES-UDS-QGz7 in the context of galaxy formation models as well as the general galaxy population at $z \sim 7$, and discuss its possible past and future.

5.1. A Unique, Quiescent Galaxy at $z \sim 7$

To put RUBIES-UDS-QG-z7 in context, we compare it against new classes of red and/or (mini-)quenched objects discovered recently with JWST in Figure 4. For illustrative purposes, we have normalized the spectra to the median flux at $\lambda_{\text{rest}} \in (0.39, 0.41) \mu m$. First, we show the "(mini-)quenched" object from Looser et al. (2024) (which coincidentally lies at the exact same redshift as RUBIES-UDS-QG-z7, z = 7.29, but in the GOODS-S field), as well as a similar object presented in Strait et al. (2023) at z = 5.2. Both sources show a significantly weaker Balmer Break and, crucially, a very steep (blue) rest-UV slope, indicative of more recent starformation than in RUBIES-UDS-QG-z7, which shows $\beta = -0.84 \pm 0.15$. Moreover, we find that the flux density at $\sim 0.4 \,\mu m$ rest-frame of the Looser et al. (2023) source is lower by a factor ~ 12 . Combined, this clearly distinguishes RUBIES-UDS-QG-z7 from these objects that have lower stellar masses (~ $10^{7.6-8.7} M_{\odot}$), and stopped forming stars more recently ($\leq 10 - 30 \,\mathrm{Myr}$).

Next, we compare with the triply imaged LRD from Furtak et al. (2024) at z = 7.05. With a F115W –



Figure 4. Comparison of RUBIES-UDS-QG-z7 to various spectra from the literature: the low-mass, recently quenched galaxies (also referred to as (mini-)quenched) at $z \sim 7.3$ from Looser et al. (2024) and at $z \sim 5.2$ from Strait et al. (2023), the triply imaged LRD from Furtak et al. (2024), and the massive quiescent galaxy at z = 4.9 from de Graaff et al. (2024a). While the former two show much stronger UV-emission than RUBIES-UDS-QG-z7, the LRD shows a much redder rest-optical continuum and a broad H β emission line. For its redshift, the spectrum of RUBIES-UDS-QG-z7 is unique. However, it shows remarkable agreement with the spectral shape of the z = 4.9 massive quiescent galaxy.

F200W color of 0.95 mag, reflecting a relatively red rest-UV spectrum, and F277W - F444W = 1.13, RUBIES-UDS-QG-z7 lies just inside the color selection boxes proposed for LRDs by Labbe et al. (2023) and Greene et al. (2024). We specifically choose the LRD of Furtak et al. (2024) for comparison, because it lies at a similar redshift, has a very high quality spectrum thanks to its lensing magnification, and it does not have strong [O III] emission (which many other LRDs do; see, e.g., Greene et al. 2024). While its spectrum matches that of RUBIES-UDS-QG-z7 well up to $\lambda_{rest} = 0.4 \mu m$, including a strong Balmer break, the spectrum of the LRD continues to rise towards longer wavelengths and shows a broad $H\beta$ emission line. Both of these features may be attributed to a dust-obscured AGN that dominates the SED at rest-frame optical wavelengths. However, as can be clearly seen in Figure 4, RUBIES-UDS-QG-z7 lacks the characteristic rising red continuum of LRDs and its red color between F277W and F356W is solely due to the Balmer Break, while F356W - F444W = 0.13indicates a relatively flat optical continuum in f_{ν} .

Finally, the spectrum of the massive quiescent galaxy RUBIES-EGS-QG-1 at z = 4.9 (de Graaff et al. 2024a) matches that of RUBIES-UDS-QG-z7 remarkably well, corroborating the interpretation that RUBIES-UDS-QG-z7 is truly a massive quiescent galaxy at z = 7.3.

To further highlight the uniqueness of RUBIES-UDS-QG-z7, we quantify the strength of its Balmer break, which roughly traces the age of the underlying stellar populations or the time since quenching (e.g., Hamilton 1985; Kauffmann et al. 2003; Kriek et al. 2006). Using the wavelength windows defined in Wang et al. (2024)that avoid prominent nebular emission lines around restframe 4000 Å we measure the break strengths of all five objects shown in Figure 4, as well as the three objects presented in Wang et al. (2024). These measurements are performed consistently on v3 spectra from the DJA, and in f_{ν} , to be consistent with historical definitions of the break strength (e.g. Bruzual A. 1983; Balogh et al. 1999). A compilation of break strengths is shown in Figure 5, including the object YD4 in the A2744 cluster whose break strength has recently been published by Witten et al. (2024). For reference, we further plot the median relation from stacked NIRSpec spectra from Roberts-Borsani et al. (2024a) and a sample of sources with NIRSpec spectroscopic redshifts compiled by Kuruvanthodi et al. (2024) who measured the Balmer breaks from photometry. While their choice of photometric filters to measure the break avoids the [OIII] and $H\beta$ lines, weaker emission lines contribute to the breaks of approximately half of their objects.

With a break strength of 2.53 ± 0.21 , RUBIES-UDS-QG-z7 has one of the strongest Balmer breaks mea-



Figure 5. Balmer Break strength vs. redshift for the 5 sources shown in Figure 4, three objects with strong breaks from Wang et al. (2024), YD4 as published in Witten et al. (2024), the median relation from stacked NIRSpec spectra from Roberts-Borsani et al. (2024a), and a sample of objects with NIRSpec spectroscopic redshifts and breaks measured from photometry (Kuruvanthodi et al. 2024). RUBIES-UDS-QG-z7 shows one of the strongest Balmer breaks measured at $z \gtrsim 7$ to date, comparable to the break strength measured in the massive quiescent galaxy at z = 4.9 (de Graaff et al. 2024a).

sured at $z \gtrsim 6$ in any galaxy so far, close to the one of RUBIES-EGS-QG-1 at z = 4.9 (2.65 ± 0.07). In our compilation, only two sources show even stronger breaks: One object from Wang et al. (2024) which reaches 2.92±0.18 at a slightly lower redshift of z = 6.68, and the triply imaged LRD from Furtak et al. (2024) with 3.33 ± 0.15 at z = 7.05. Due to the possible AGN contribution to the spectrum around 4000 Å in both of these sources and their likely high dust content, those breaks are however more difficult to interpret (for the latter source, see also Ma et al. 2024).

5.2. Descendants of RUBIES-UDS-QG-z7

The early quiescence and high stellar mass of RUBIES-UDS-QG-z7 raises the question of what its descendants may look like. As discussed in Section 4, the high stellar mass surface density is consistent with the range in densities found in compact massive quiescent galaxies at $z \sim 2$ (e.g. Whitaker et al. 2017), and also the sources observed with JWST at $z \sim 3 - 5$ (Setton et al. 2024; Carnall et al. 2023b; de Graaff et al. 2024a). Moreover, the 3D stellar mass density profile falls within

the 1σ scatter of the mass profiles of massive quiescent galaxies at $z \sim 2-3$ from 3DHST and lies only a factor $\sim 2-3$ above the typical profiles of local quiescent galaxies from the GAMA survey, consistent with findings in Bezanson et al. 2009 where massive quiescent galaxies at $z \sim 2-3$ are identified as plausible progenitors of the cores of local ellipticals. This suggests that RUBIES-UDS-QG-z7 is a likely progenitor of the compact massive galaxies seen at $z \sim 2-3$, and that the cores of some elliptical galaxies in the local Universe were already in place by $z \sim 7$. We note that the inferred metallicity in our low metallicity fit is probably inconsistent with such a scenario which may in turn point towards a higher metallicity for RUBIES-UDS-QG-z7. As discussed above, accurately constraining Z_* is not possible given the available data and models.

Turning to the SFH, it is tempting to also consider RUBIES-UDS-QG-z7 as a direct progenitor of the extremely old massive quiescent galaxies that have been recently discovered and characterized with JWST at $z \sim 2-5$ (e.g. Carnall et al. 2024; de Graaff et al. 2024a; Glazebrook et al. 2024; Park et al. 2024): the SFHs of these systems are consistent with having formed their stellar mass at $z \gtrsim 8$ and quenched at a similar redshift as RUBIES-UDS-QG-z7. However, the stellar masses of these galaxies in the literature are up to an order of magnitude higher. If RUBIES-UDS-QG-z7 were to evolve into such a galaxy, it would either have to rejuvenate quickly and go through a second burst of star formation, to then quench rapidly again. Or alternatively, one or even a few major mergers with similarly massive quiescent systems would be required to reach $\sim 10^{11} \mathrm{M}_{\odot}$ by $z \sim 4-5$. Given the estimated low number density of such objects (see Section 5.4), this seems unlikely. A more in-depth analysis of a possible overdensity around RUBIES-UDS-QG-z7 remains to be done in future work. Perhaps most likely, RUBIES-UDS-QG-z7 is not a direct progenitor of the very massive systems at $z \sim 4-5$, and may instead maintain its current mass or experience more gradual mass growth to become a massive compact quiescent galaxy as observed at $z \sim 2-3$. Interestingly, quiescent galaxies with masses comparable to that of RUBIES-UDS-QG-z7 appear to be the most compact of all quiescent galaxies at 1 < z < 3 in Cutler et al. (2024).

5.3. Progenitors of RUBIES-UDS-QG-z7

Independent of our priors on the SFH and the metallicity in the SED fitting, we know with confidence that RUBIES-UDS-QG-z7 must have formed a substantial fraction of its stars in a burst between $z \sim 8 - 9$ at a star formation rate of $\sim 100 \,\mathrm{M_{\odot} yr^{-1}}$. Assuming no

dust and the conversion from Kennicutt (1998), this corresponds to a very bright absolute UV-magnitude of $M_{\rm UV} \sim -23.7$. Although a few photometrically-selected candidates exist at $z \sim 8$ with $M_{\rm UV} \sim -23$ (Bouwens et al. 2022b), no such object has been spectroscopically confirmed to date, with the brightest spectroscopicallyconfirmed objects lying around $M_{\rm UV} \sim -22$ at $z \sim 8$ (as shown in Figure 2; e.g. Roberts-Borsani et al. 2024b). Moreover, these photometric candidates were selected over a very large area of $\sim 7 \, \text{deg}^2$ (compared to the $\sim 300 \,\mathrm{arcmin}^2$ survey area of CEERS and PRIMER), and thus have a number density that is nearly two dex lower than our estimate of the number density of RUBIES-UDS-QG-z7 (see Section 5.4). Purely starforming galaxies reaching very bright UV magnitudes $(M_{\rm UV} \sim -23$ to -24.7) have recently been found at $z \sim 2.4 - 3.6$ (Margues-Chaves et al. 2020, 2022), showing that such objects exist at later times. If and how they are related to RUBIES-UDS-QG-z7 and other highredshift populations, remains to be established.

There are a few possible explanations for the missing UV-bright progenitors. First, they may be dustobscured and thus have so far eluded spectroscopic confirmation by JWST. If they are sufficiently dusty, they may have been challenging to detect prior to JWST and are only recently being followed-up spectroscopically through surveys like RUBIES. One photometric candidate for a dust-obscured progenitor, COS-z8M1 (Akins et al. 2023), is shown in Figure 2. An even more extreme candidate at a slightly lower redshift of $z \sim 7.6$ is presented in the same paper. Other possible progenitors may be found among the population of LRD-like sources at $z \gtrsim 8$, the stellar masses and SFHs of which appear to match well with that of massive quiescent galaxies at $z \sim 4-5$ and RUBIES-UDS-QG-z7 (Williams et al. 2024; Wang et al. 2024), although the inferred stellar population properties of these sources are still very uncertain. However, if these sources do host a significant stellar component, they may evolve into an object like RUBIES-UDS-QG-z7 by $z \sim 7$ once the AGN component has shut down and possibly also quenched star formation. It is important to note that the low dust attenuation inferred from the spectrum of RUBIES-UDS-QG-z7 requires that in such a scenario, most of the dust must be destroyed or removed from the galaxy, at least along the line of sight, in a relatively short timescale ($\leq 100 \,\mathrm{Myr}$).

Second, the SFH of objects like RUBIES-UDS-QGz7 could be more extended than the **Prospector** fits suggest, lowering the required SFR in the most recent burst. The continuity prior applied in our SED-fitting (Leja et al. 2019) is however already conservative in

this regard. Nevertheless, we find that, if we extend the lower boundary of the metallicity prior in our SEDfitting to $Z = 0.01 \,\mathrm{Z}_{\odot}$, the fit converges to a metallicity of $Z = 0.04^{+0.03}_{-0.02} \mathrm{Z}_{\odot}$ and a more extended SFH that requires substantial star formation $(SFR \sim 50 \,\mathrm{M_{\odot} yr^{-1}})$ at $z \gtrsim 15$. However, these results seem implausible: the very low metallicity lies nearly two dex below the stellar mass-metallicity relation of massive quiescent galaxies at $z \sim 1-3$ (e.g., Choi et al. 2014; Beverage et al. 2024b), and such an early stellar mass assembly history would likely be in tension with the standard cosmological model (Boylan-Kolchin 2023). A significantly more extended SFH would also raise the major problem that thus far no sources have been found with such high star formation rates at z > 10. As can be seen in Figure 2, objects as bright as JADES-GS-z14-0, GHZ2 or GNz11 on the other hand do form plausible progenitors of RUBIES-UDS-QG-z7 for the metallicities explored throughout this paper.

Third, as discussed in de Graaff et al. (2024a) in the context of RUBIES-EGS-QG-1, the number density of sources like RUBIES-UDS-QG-z7 is expected to be low $(\log(n/\mathrm{Mpc}^{-3}) = -5.8^{+0.5}_{-0.8}$, see Section 5.4), and uncertain, given that we have only discovered one such source in the available JWST imaging and spectroscopic data. Cosmic variance and the fact that the probed cosmic volume decreases towards higher redshifts may therefore help explaining why we have not yet seen the progenitors of RUBIES-UDS-QG-z7. Moreover, star formation may happen in short and intense bursts at $z \gtrsim 8$ (as suggested by, e.g., Dekel et al. 2023). Since the observed number density depends not only on the number density of massive galaxies, but also on the duty cycle of star formation, this may explain the lack of observed UV-luminous progenitors at z > 8. We note that the time of $\sim 125 \,\mathrm{Myr}$ that RUBIES-UDS-QG-z7 spends in a bursting phase according to our modeled SFH in e.g., the low metallicity fit (Figure 2) is to some extent a result of our choice of SFH time bins. In reality, it may form in one or multiple shorter bursts. Finally, we note that variations in the initial mass function (IMF) may reduce the inferred stellar mass and thereby the maximum SFR in the SFH (see e.g., van Dokkum & Conroy 2024).

5.4. The absence of z > 7 quiescent galaxies in simulations

Early quiescent galaxies have long represented a key challenge for galaxy formation models and simulations. The challenge is to form a massive galaxy that not only ceases forming stars, but also remains quiescent for a prolonged period of time within the first Gyr of cosmic



Figure 6. Number density of quiescent galaxies as a function of redshift compared to the inferred number density of objects like RUBIES-UDS-QG-z7 (red star), with $\log(M/M_{\odot}) > 10$ and a specific SFR of $\log(sSFR/Gyr^{-1}) <$ -1. Lines are based on various simulations (EAGLE, GAL-FORM, SHARK, Simba, Illustris TNG100). The dashed lines represent extrapolated upper limits based on the simulation box sizes. Open symbols show lower redshift observational constraints from JWST, where the stellar mass cuts and definitions of quiescence vary between different paper. The highest redshift point from Valentino et al. (2023) is an upper limit, meaning that no quiescent galaxies have been found in the probed volume. The inferred number density of quiescent galaxies at $z \sim 7$ based on RUBIES-UDS-QG-z7 in the current survey volume is surprisingly high, and lies $\gtrsim 100 \times$ above the extrapolation of lower redshift trends.

history. With an inferred stellar mass of $\log(M_*/M_{\odot}) = 10.23 \pm 0.04$ and a specific SFR of $\log(\text{sSFR/Gyr}^{-1}) < -1$ at $z = 7.29 \pm 0.01$, RUBIES-UDS-QG-z7 is by far the most distant galaxy confirmed so far that unambiguously qualifies as a massive quiescent galaxy (see Figure 4), pushing the previous record at $z \sim 5$ closer to the Big Bang by 500 Myr. The predicted number density of massive sources $(M_* > 10^{10} M_{\odot})$ with $\log(\text{sSFR/Gyr}^{-1}) < -1$ drops extremely rapidly with redshift in current galaxy evolution models. For example, the FLARES simulation predicts a number density of $\log(n/\text{Mpc}^{-3}) < -8$ for such galaxies at z > 7 (Lovell et al. 2023).

Assuming that RUBIES-UDS-QG-z7 is unique in the total survey volume of ~ 300 arcmin² of PRIMER-UDS and CEERS, a conservative estimate of the number density of quiescent galaxies in the redshift bin z = 7 - 8 is $\log(n/\text{Mpc}^{-3}) = -5.8^{+0.5}_{-0.8}$, where uncertainties are

computed based on Poisson statistics using the frequentist confidence interval (see Maxwell 2011). This is a factor > $150 \times$ higher than expected from the FLARES simulation. If we only considered the survey volume of RUBIES alone, i.e., only the area covered by NIRSpec observations (~ 150 arcmin^2 ; de Graaff et al. 2024b), the inferred number density and the discrepancy with FLARES would be another factor ~ $2 \times$ higher.

In Figure 6, we compare the number density of $z \sim$ 7 massive quiescent galaxies (defined here as sources with $M_* > 10^{10} \,\mathrm{M_{\odot}}$ and $\log(\mathrm{sSFR/Gyr^{-1}}) < -1)$ inferred from RUBIES-UDS-QG-z7 to the number densities of such systems measured from various simulations (FLARES, Lovell et al. 2023; EAGLE, Schaye et al. 2015; Crain et al. 2015; GALFORM, Lacey et al. 2016; SHARK, Lagos et al. 2018, 2024, Simba, Davé et al. 2019; Illustris-TNG100 Pillepich et al. 2018), as well as recent observational constraints based on JWST data (Nanavakkara et al. 2024; Carnall et al. 2023a; Valentino et al. 2023; Alberts et al. 2023), although we note that these observational studies use different selection criteria for the stellar mass and different definitions of quiescence. Apart from FLARES and SHARK, simulations largely only provide upper limits on the number density of massive quiescent galaxies at $z \gtrsim 6$, because there are no such sources within the respective simulated volumes. The steeply declining number densities at $z \sim 2-6$ seen in all the simulations shown in Figure 6 however suggest number densities at $z \sim 7$ comparable to or even lower than those in FLARES.

This indicates that star formation efficiencies, cold gas in- and outflows as well as feedback mechanisms may have to be revisited in simulations at high redshifts, in order to grow and subsequently quench more massive galaxies early on. From the observational side, it will be important to improve the number density estimates of sources like RUBIES-UDS-QG-z7 in wider area data covering larger volumes to provide more stringent constraints. Lagos et al. (2025) also show that even at lower redshifts, $z \approx 3-4$, where some of the simulations do predict enough massive quiescent galaxies, their predicted SFHs may not be bursty enough compared with observations. This shows that measuring number densities, together with inferring SFHs and other intrinsic galaxies properties, provides stringent constraints on cosmological galaxy formation simulations.

6. SUMMARY AND CONCLUSIONS

We have presented the NIRSpec/PRISM spectrum of a massive quiescent galaxy, RUBIES-UDS-QG-z7, at $z = 7.29 \pm 0.01$ which was observed as part of the JWST Cycle 2 program RUBIES. RUBIES-UDS-QG-z7 represents the highest redshift massive quiescent galaxy known to date by $\Delta z > 2$. Through simultaneous modeling of the spectrum and the NIRCam and MIRI photometry, we find that RUBIES-UDS-QG-z7 formed most of its mass of $\log(M_*/M_{\odot}) = 10.23^{+0.04}_{-0.04}$ in a burst of star formation (SFR_{peak} ~ $100 \,\mathrm{M_{\odot}yr^{-1}}$) at $z \sim 8 - 9$ and then stopped forming stars quickly, resulting in a low log(sSFR/Gyr⁻¹) < -1 in the last 50 Myr. While the stellar mass and the rough shape of the SFH are well constrained, we find similarly good fits for metallicities < $0.1 Z_{\odot}$ as well as > $1 Z_{\odot}$, likely due to non-solar abundance patterns in early and rapidly forming galaxies like RUBIES-UDS-QG-z7 which are not yet accounted for in available stellar population models.

The compact morphology of RUBIES-UDS-QG-z7 $(R_{\rm e} = 209^{+33}_{-24} \,{\rm pc})$ implies high stellar mass densities comparable to those measured in massive quiescent galaxies at $z \sim 4-5$, the densest quiescent systems at $z \sim 2-3$, as well as the inner $\sim 300 \,{\rm pc}$ of local ellipticals, indicating that the cores of some of them may be in place already at $z \sim 7$.

Progenitors of RUBIES-UDS-QG-z7 are expected to be highly star-forming systems at $z \sim 8 - 9$. Only few photometric candidates with UV-magnitudes directly implying sufficiently high SFRs have been found at those redshifts, and only over much larger areas. However, the progenitors of RUBIES-UDS-QG-z7 may be dust-obscured making their detection and characterization more challenging. Photometric candidates for such dust-obscured, highly star-forming systems at $z \sim 8$ are slowly being found thanks to deep NIRCam+MIRI imaging (e.g., Akins et al. 2023). Spectroscopic confirmation of such candidates will be critical to shed more light on the possible formation pathway of RUBIES-UDS-QG-z7.

The detection of RUBIES-UDS-QG-z7 in a survey area of just ~ 300 arcmin² implies a number density of $\log(n/\mathrm{Mpc}^{-3}) = -5.8^{+0.5}_{-0.8}$, which is comparable to observations of quiescent galaxies at $z \sim 4-5$, but > 100× higher than predictions by simulations at $z \sim 7$. Creating such a distant quiescent galaxy therefore represents a challenge for our current galaxy formation theories and may require a revision of our modeling assumptions.

In the future, it will be critical to search for sources similar to RUBIES-UDS-QG-z7 at these redshifts, but over wider area JWST fields in order to refine the number density estimate of quiescent galaxies at z > 6. Additionally, deep medium/high resolution NIRSpec spectroscopy has the potential to reveal various absorption features for RUBIES-UDS-QG-z7 itself, which are only tentatively or not at all detected in the current PRISM spectrum. These would provide better constraints on the SFH and a more direct measurement of elemental abundances. Finally, sub-mm observations from, e.g., ALMA could constrain the gas and dust properties to gain further insight into the possible quenching mechanisms. RUBIES-UDS-QG-z7 thus represents a unique opportunity to study and understand the emergence of the first quiescent galaxies in the early Universe.

ACKNOWLEDGEMENTS

We thank the PRIMER team for making their imaging data publicly available immediately. This work is based on observations made with the NASA/ESA/CSA James Webb Space Telescope. The data were obtained from the Mikulski Archive for Space Telescopes at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-03127 for JWST. These observations are associated with program #4233. Support for program #4233 was provided by NASA through a grant from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-03127. This research was supported by the International Space Science Institute (ISSI) in Bern, through ISSI International Team project #562. The Cosmic Dawn Center is funded by the Danish National Research Foundation (DNRF140). This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number MB22.00072, as well as from the Swiss National Science Foundation (SNSF) through project grant 200020_207349. Support for this work was provided by The Brinson Foundation through a Brinson Prize Fellowship grant. Support for this work for RPN was provided by NASA through the NASA Hubble Fellowship grant HST-HF2-51515.001-A awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Incorporated, under NASA contract NAS5-26555. TBM was supported by a CIERA fellowship.

Facilities: JWST(NIRSpec, NIRCam)

Software: All software packages used in this work are publicly available on Github: grizli, msafit, msaexp, Prospector, sedpy. We acknowledge: astropy (Astropy Collaboration et al. 2013, 2018, 2022), matplotlib (Hunter 2007), numpy (Harris et al. 2020), scipy (Virtanen et al. 2020), lmfit (Newville et al. 2024), eMPT (Bonaventura et al. 2023), the jwst pipeline (Bushouse et al. 2024), msaexp (Brammer 2024a), grizli (Brammer 2024b),

- Akins, H. B., Casey, C. M., Allen, N., et al. 2023, ApJ, 956, 61, doi: 10.3847/1538-4357/acef21
- Alberts, S., Williams, C. C., Helton, J. M., et al. 2023, arXiv:2312.12207, arXiv:2312.12207, doi: 10.48550/arXiv.2312.12207
- Anderson, J. 2016, Empirical Models for the WFC3/IR PSF, Instrument Science Report WFC3 2016-12, 42 pages
- Anderson, J., & King, I. R. 2000, PASP, 112, 1360, doi: 10.1086/316632
- Antwi-Danso, J., Papovich, C., Esdaile, J., et al. 2023, arXiv e-prints, arXiv:2307.09590, doi: 10.48550/arXiv.2307.09590
- Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, A&A, 558, A33, doi: 10.1051/0004-6361/201322068
- Astropy Collaboration, Price-Whelan, A. M., Sipőcz, B. M., et al. 2018, AJ, 156, 123, doi: 10.3847/1538-3881/aabc4f
- Astropy Collaboration, Price-Whelan, A. M., Lim, P. L., et al. 2022, ApJ, 935, 167, doi: 10.3847/1538-4357/ac7c74
- Baggen, J. F. W., van Dokkum, P., Labbé, I., et al. 2023, ApJL, 955, L12, doi: 10.3847/2041-8213/acf5ef
- Baggen, J. F. W., van Dokkum, P., Brammer, G., et al. 2024, ApJL, 977, L13, doi: 10.3847/2041-8213/ad90b8
- Baldry, I. K., Liske, J., Brown, M. J. I., et al. 2018, MNRAS, 474, 3875, doi: 10.1093/mnras/stx3042
- Balogh, M. L., Morris, S. L., Yee, H. K. C., Carlberg, R. G., & Ellingson, E. 1999, ApJ, 527, 54, doi: 10.1086/308056
- Barrufet, L., Oesch, P., Marques-Chaves, R., et al. 2024, arXiv e-prints, arXiv:2404.08052, doi: 10.48550/arXiv.2404.08052
- Belli, S., Newman, A. B., & Ellis, R. S. 2014, ApJ, 783, 117, doi: 10.1088/0004-637X/783/2/117
- Bertin, E., & Arnouts, S. 1996, A&AS, 117, 393, doi: 10.1051/aas:1996164
- Beverage, A. G., Kriek, M., Suess, K. A., et al. 2024a, ApJ, 966, 234, doi: 10.3847/1538-4357/ad372d
- Beverage, A. G., Slob, M., Kriek, M., et al. 2024b, arXiv e-prints, arXiv:2407.02556, doi: 10.48550/arXiv.2407.02556
- Bezanson, R., van Dokkum, P. G., Tal, T., et al. 2009, ApJ, 697, 1290, doi: 10.1088/0004-637X/697/2/1290
- Bonaventura, N., Jakobsen, P., Ferruit, P., Arribas, S., & Giardino, G. 2023, A&A, 672, A40, doi: 10.1051/0004-6361/202245403
- Bouwens, R. J., Illingworth, G. D., van Dokkum, P. G., et al. 2022a, ApJ, 927, 81, doi: 10.3847/1538-4357/ac4791
- Bouwens, R. J., Smit, R., Schouws, S., et al. 2022b, ApJ, 931, 160, doi: 10.3847/1538-4357/ac5a4a

- Boylan-Kolchin, M. 2023, Nature Astronomy, 7, 731, doi: 10.1038/s41550-023-01937-7
- Bradley, L., Sipőcz, B., Robitaille, T., et al. 2022, astropy/photutils: 1.5.0, 1.5.0, Zenodo, doi: 10.5281/zenodo.6825092
- Brammer, G. 2023a, grizli, 1.9.11, Zenodo, doi: 10.5281/zenodo.1146904
- —. 2023b, msaexp: NIRSpec analyis tools, 0.6.17, Zenodo, doi: 10.5281/zenodo.7299500
- Brammer, G. 2024a, msaexp: NIRSpec analyis tools, 0.8.5, Zenodo, doi: 10.5281/zenodo.7299500
- 2024b, grizli, 1.11.9, Zenodo, doi: 10.5281/zenodo.1146904
- Brammer, G. B., Whitaker, K. E., van Dokkum, P. G., et al. 2011, ApJ, 739, 24, doi: 10.1088/0004-637X/739/1/24
- Bruzual A., G. 1983, ApJ, 273, 105, doi: 10.1086/161352
- Bunker, A. J., Saxena, A., Cameron, A. J., et al. 2023, A&A, 677, A88, doi: 10.1051/0004-6361/202346159
- Bushouse, H., Eisenhamer, J., Dencheva, N., et al. 2024, JWST Calibration Pipeline, 1.14.0, Zenodo, doi: 10.5281/zenodo.10870758
- Calzetti, D., Armus, L., Bohlin, R. C., et al. 2000, ApJ, 533, 682, doi: 10.1086/308692
- Carnall, A. C., Walker, S., McLure, R. J., et al. 2020, MNRAS, 496, 695, doi: 10.1093/mnras/staa1535
- Carnall, A. C., McLeod, D. J., McLure, R. J., et al. 2023a, MNRAS, 520, 3974, doi: 10.1093/mnras/stad369
- Carnall, A. C., McLure, R. J., Dunlop, J. S., et al. 2023b, Nature, 619, 716, doi: 10.1038/s41586-023-06158-6
- Carnall, A. C., Cullen, F., McLure, R. J., et al. 2024, MNRAS, 534, 325, doi: 10.1093/mnras/stae2092
- Carniani, S., Hainline, K., D'Eugenio, F., et al. 2024, Nature, 633, 318, doi: 10.1038/s41586-024-07860-9
- Castellano, M., Napolitano, L., Fontana, A., et al. 2024, ApJ, 972, 143, doi: 10.3847/1538-4357/ad5f88
- Chabrier, G. 2003, PASP, 115, 763, doi: 10.1086/376392
- Choi, J., Conroy, C., & Johnson, B. D. 2019, ApJ, 872, 136, doi: 10.3847/1538-4357/aaff67
- Choi, J., Conroy, C., Moustakas, J., et al. 2014, ApJ, 792, 95, doi: 10.1088/0004-637X/792/2/95
- Choi, J., Dotter, A., Conroy, C., et al. 2016, ApJ, 823, 102, doi: 10.3847/0004-637X/823/2/102
- Conroy, C., & Gunn, J. E. 2010, ApJ, 712, 833, doi: 10.1088/0004-637X/712/2/833
- Conroy, C., Gunn, J. E., & White, M. 2009, ApJ, 699, 486, doi: 10.1088/0004-637X/699/1/486
- Crain, R. A., Schaye, J., Bower, R. G., et al. 2015, MNRAS, 450, 1937, doi: 10.1093/mnras/stv725

Curtis-Lake, E., Carniani, S., Cameron, A., et al. 2023, Nature Astronomy, 7, 622, doi: 10.1038/s41550-023-01918-w

- Cutler, S. E., Whitaker, K. E., Weaver, J. R., et al. 2024, ApJL, 967, L23, doi: 10.3847/2041-8213/ad464c
- Davé, R., Anglés-Alcázar, D., Narayanan, D., et al. 2019, MNRAS, 486, 2827, doi: 10.1093/mnras/stz937
- de Graaff, A., Trayford, J., Franx, M., et al. 2022, MNRAS, 511, 2544, doi: 10.1093/mnras/stab3510
- de Graaff, A., Setton, D. J., Brammer, G., et al. 2024a, Nature Astronomy, doi: 10.1038/s41550-024-02424-3
- de Graaff, A., Brammer, G., Weibel, A., et al. 2024b, arXiv e-prints, arXiv:2409.05948,
 - doi: 10.48550/arXiv.2409.05948
- Dekel, A., Sarkar, K. C., Birnboim, Y., Mandelker, N., & Li, Z. 2023, MNRAS, 523, 3201, doi: 10.1093/mnras/stad1557
- Dome, T., Tacchella, S., Fialkov, A., et al. 2024, MNRAS, 527, 2139, doi: 10.1093/mnras/stad3239
- Donnan, C. T., McLure, R. J., Dunlop, J. S., et al. 2024, MNRAS, 533, 3222, doi: 10.1093/mnras/stae2037
- Dotter, A. 2016, ApJS, 222, 8, doi: 10.3847/0067-0049/222/1/8
- Driver, S. P., Hill, D. T., Kelvin, L. S., et al. 2011, MNRAS, 413, 971, doi: 10.1111/j.1365-2966.2010.18188.x
- Driver, S. P., Wright, A. H., Andrews, S. K., et al. 2016, MNRAS, 455, 3911, doi: 10.1093/mnras/stv2505
- Ferruit, P., Jakobsen, P., Giardino, G., et al. 2022, A&A, 661, A81, doi: 10.1051/0004-6361/202142673
- Forrest, B., Annunziatella, M., Wilson, G., et al. 2020a, ApJL, 890, L1, doi: 10.3847/2041-8213/ab5b9f
- Forrest, B., Marsan, Z. C., Annunziatella, M., et al. 2020b, ApJ, 903, 47, doi: 10.3847/1538-4357/abb819
- Forrest, B., Wilson, G., Muzzin, A., et al. 2022, ApJ, 938, 109, doi: 10.3847/1538-4357/ac8747
- Furtak, L. J., Labbé, I., Zitrin, A., et al. 2024, Nature, 628, 57, doi: 10.1038/s41586-024-07184-8
- Glazebrook, K., Schreiber, C., Labbé, I., et al. 2017, Nature, 544, 71, doi: 10.1038/nature21680
- Glazebrook, K., Nanayakkara, T., Schreiber, C., et al. 2024, Nature, 628, 277, doi: 10.1038/s41586-024-07191-9
- Gobat, R., Strazzullo, V., Daddi, E., et al. 2012, ApJL, 759, L44, doi: 10.1088/2041-8205/759/2/L44
- Gould, K. M. L., Brammer, G., Valentino, F., et al. 2023, AJ, 165, 248, doi: 10.3847/1538-3881/accadc
- Greene, J. E., Labbe, I., Goulding, A. D., et al. 2024, ApJ, 964, 39, doi: 10.3847/1538-4357/ad1e5f

- Grogin, N. A., Kocevski, D. D., Faber, S. M., et al. 2011, ApJS, 197, 35, doi: 10.1088/0067-0049/197/2/35
- Hamilton, D. 1985, ApJ, 297, 371, doi: 10.1086/163537
- Harris, C. R., Millman, K. J., van der Walt, S. J., et al. 2020, Nature, 585, 357, doi: 10.1038/s41586-020-2649-2
- Hartley, A. I., Nelson, E. J., Suess, K. A., et al. 2023, MNRAS, 522, 3138, doi: 10.1093/mnras/stad1162
- Heintz, K. E., Brammer, G. B., Watson, D., et al. 2024, arXiv e-prints, arXiv:2404.02211, doi: 10.48550/arXiv.2404.02211
- Hinshaw, G., Larson, D., Komatsu, E., et al. 2013, ApJS, 208, 19, doi: 10.1088/0067-0049/208/2/19
- Hoffman, M. D., Gelman, A., et al. 2014, J. Mach. Learn. Res., 15, 1593
- Hunter, J. D. 2007, Computing in Science and Engineering, 9, 90, doi: 10.1109/MCSE.2007.55
- Inoue, A. K., Shimizu, I., Iwata, I., & Tanaka, M. 2014, MNRAS, 442, 1805, doi: 10.1093/mnras/stu936
- Jafariyazani, M., Newman, A. B., Mobasher, B., et al. 2020, ApJL, 897, L42, doi: 10.3847/2041-8213/aba11c
- Jakobsen, P., Ferruit, P., Alves de Oliveira, C., et al. 2022, A&A, 661, A80, doi: 10.1051/0004-6361/202142663
- Ji, Z., Williams, C. C., Suess, K. A., et al. 2024, arXiv e-prints, arXiv:2401.00934, doi: 10.48550/arXiv.2401.00934
- Johnson, B., & Leja, J. 2017, Bd-J/Prospector: Initial Release, v0.1, Zenodo, doi: 10.5281/zenodo.1116491
- Johnson, B., Foreman-Mackey, D., Sick, J., et al. 2021, dfm/python-fsps: python-fsps v0.4.0, v0.4.0, Zenodo, doi: 10.5281/zenodo.4577191
- Kauffmann, G., Heckman, T. M., White, S. D. M., et al. 2003, MNRAS, 341, 33, doi: 10.1046/j.1365-8711.2003.06291.x
- Kelvin, L. S., Driver, S. P., Robotham, A. S. G., et al. 2012, MNRAS, 421, 1007, doi: 10.1111/j.1365-2966.2012.20355.x
- Kennicutt, Robert C., J. 1998, ARA&A, 36, 189, doi: 10.1146/annurev.astro.36.1.189
- Kimmig, L. C., Remus, R.-S., Seidel, B., et al. 2023, arXiv e-prints, arXiv:2310.16085,
 - doi: 10.48550/arXiv.2310.16085
- Koekemoer, A. M., Faber, S. M., Ferguson, H. C., et al. 2011, ApJS, 197, 36, doi: 10.1088/0067-0049/197/2/36
- Kriek, M., & Conroy, C. 2013, ApJL, 775, L16, doi: 10.1088/2041-8205/775/1/L16
- Kriek, M., van Dokkum, P. G., Franx, M., et al. 2006, ApJ, 645, 44, doi: 10.1086/504103
- Kriek, M., Conroy, C., van Dokkum, P. G., et al. 2016, Nature, 540, 248, doi: 10.1038/nature20570

- Kuruvanthodi, A., Schaerer, D., Marques-Chaves, R., et al. 2024, A&A, 691, A310, doi: 10.1051/0004-6361/202451622
- Labbé, I., van Dokkum, P., Nelson, E., et al. 2023, Nature, 616, 266, doi: 10.1038/s41586-023-05786-2
- Labbe, I., Greene, J. E., Bezanson, R., et al. 2023, arXiv e-prints, arXiv:2306.07320, doi: 10.48550/arXiv.2306.07320
- Lacey, C. G., Baugh, C. M., Frenk, C. S., et al. 2016, MNRAS, 462, 3854, doi: 10.1093/mnras/stw1888
- Lagos, C. d. P., Tobar, R. J., Robotham, A. S. G., et al. 2018, MNRAS, 481, 3573, doi: 10.1093/mnras/sty2440
- Lagos, C. d. P., Bravo, M., Tobar, R., et al. 2024, MNRAS, 531, 3551, doi: 10.1093/mnras/stae1024
- Lagos, C. d. P., Valentino, F., Wright, R. J., et al. 2025, MNRAS, 536, 2324, doi: 10.1093/mnras/stae2626
- Laporte, N., Ellis, R. S., Witten, C. E. C., & Roberts-Borsani, G. 2023, MNRAS, 523, 3018, doi: 10.1093/mnras/stad1597
- Leja, J., Carnall, A. C., Johnson, B. D., Conroy, C., & Speagle, J. S. 2019, ApJ, 876, 3, doi: 10.3847/1538-4357/ab133c
- Leja, J., Johnson, B. D., Conroy, C., van Dokkum, P. G., & Byler, N. 2017, ApJ, 837, 170, doi: 10.3847/1538-4357/aa5ffe
- Liske, J., Baldry, I. K., Driver, S. P., et al. 2015, MNRAS, 452, 2087, doi: 10.1093/mnras/stv1436
- Long, A. S., Antwi-Danso, J., Lambrides, E. L., et al. 2024, ApJ, 970, 68, doi: 10.3847/1538-4357/ad4cea
- Looser, T. J., D'Eugenio, F., Maiolino, R., et al. 2023, arXiv e-prints, arXiv:2306.02470, doi: 10.48550/arXiv.2306.02470
- -. 2024, Nature, 629, 53, doi: 10.1038/s41586-024-07227-0
- Lovell, C. C., Roper, W., Vijayan, A. P., et al. 2023, MNRAS, 525, 5520, doi: 10.1093/mnras/stad2550
- Ma, Y., Greene, J. E., Setton, D. J., et al. 2024, arXiv e-prints, arXiv:2410.06257, doi: 10.48550/arXiv.2410.06257
- Marchesini, D., Whitaker, K. E., Brammer, G., et al. 2010, ApJ, 725, 1277, doi: 10.1088/0004-637X/725/1/1277
- Marques-Chaves, R., Pérez-Fournon, I., Shu, Y., et al. 2020, MNRAS, 492, 1257, doi: 10.1093/mnras/stz3500
- Marques-Chaves, R., Schaerer, D., Álvarez-Márquez, J., et al. 2022, MNRAS, 517, 2972, doi: 10.1093/mnras/stac2893
- Matthee, J., Naidu, R. P., Brammer, G., et al. 2024, ApJ, 963, 129, doi: 10.3847/1538-4357/ad2345
- Maxwell, E. A. 2011, arXiv e-prints, arXiv:1102.0822, doi: 10.48550/arXiv.1102.0822

- Merlin, E., Fontana, A., Castellano, M., et al. 2018, MNRAS, 473, 2098, doi: 10.1093/mnras/stx2385
- Merlin, E., Fortuni, F., Torelli, M., et al. 2019, MNRAS, 490, 3309, doi: 10.1093/mnras/stz2615
- Muzzin, A., Marchesini, D., Stefanon, M., et al. 2013, ApJ, 777, 18, doi: 10.1088/0004-637X/777/1/18
- Naab, T., Johansson, P. H., & Ostriker, J. P. 2009, ApJL, 699, L178, doi: 10.1088/0004-637X/699/2/L178
- Nakajima, K., Ouchi, M., Isobe, Y., et al. 2023, ApJS, 269, 33, doi: 10.3847/1538-4365/acd556
- Nanayakkara, T., Glazebrook, K., Jacobs, C., et al. 2024, Scientific Reports, 14, 3724, doi: 10.1038/s41598-024-52585-4
- Newville, M., Otten, R., Nelson, A., et al. 2024, lmfit/lmfit-py: 1.3.2, 1.3.2, Zenodo, doi: 10.5281/zenodo.12785036
- Noll, S., Burgarella, D., Giovannoli, E., et al. 2009, A&A, 507, 1793, doi: 10.1051/0004-6361/200912497
- Park, M., Conroy, C., Johnson, B. D., et al. 2024, arXiv e-prints, arXiv:2410.21375,
 - doi: 10.48550/arXiv.2410.21375
- Pasha, I., & Miller, T. B. 2023, The Journal of Open Source Software, 8, 5703, doi: 10.21105/joss.05703
- Phan, D., Pradhan, N., & Jankowiak, M. 2019, arXiv preprint arXiv:1912.11554
- Pillepich, A., Nelson, D., Hernquist, L., et al. 2018, MNRAS, 475, 648, doi: 10.1093/mnras/stx3112
- Rieke, M. J., Kelly, D. M., Misselt, K., et al. 2023, PASP, 135, 028001, doi: 10.1088/1538-3873/acac53
- Roberts-Borsani, G., Treu, T., Shapley, A., et al. 2024a, arXiv e-prints, arXiv:2403.07103, doi: 10.48550/arXiv.2403.07103
- Roberts-Borsani, G., Bagley, M., Rojas-Ruiz, S., et al. 2024b, arXiv e-prints, arXiv:2407.17551, doi: 10.48550/arXiv.2407.17551
- Sánchez-Blázquez, P., Peletier, R. F., Jiménez-Vicente, J., et al. 2006, MNRAS, 371, 703, doi: 10.1111/j.1365-2966.2006.10699.x
- Santini, P., Merlin, E., Fontana, A., et al. 2019, MNRAS, 486, 560, doi: 10.1093/mnras/stz801
- Schaye, J., Crain, R. A., Bower, R. G., et al. 2015, MNRAS, 446, 521, doi: 10.1093/mnras/stu2058
- Schreiber, C., Glazebrook, K., Nanayakkara, T., et al. 2018a, A&A, 618, A85, doi: 10.1051/0004-6361/201833070
- —. 2018b, A&A, 618, A85,
 doi: 10.1051/0004-6361/201833070
- Setton, D. J., Khullar, G., Miller, T. B., et al. 2024, ApJ, 974, 145, doi: 10.3847/1538-4357/ad6a18

- Shibuya, T., Ouchi, M., & Harikane, Y. 2015, ApJS, 219, 15, doi: 10.1088/0067-0049/219/2/15
- Skelton, R. E., Whitaker, K. E., Momcheva, I. G., et al. 2014, ApJS, 214, 24, doi: 10.1088/0067-0049/214/2/24
- Speagle, J. S. 2020, MNRAS, 493, 3132, doi: 10.1093/mnras/staa278
- Strait, V., Brammer, G., Muzzin, A., et al. 2023, ApJL, 949, L23, doi: 10.3847/2041-8213/acd457
- Suess, K. A., Kriek, M., Price, S. H., & Barro, G. 2019, ApJ, 877, 103, doi: 10.3847/1538-4357/ab1bda
- Suess, K. A., Bezanson, R., Nelson, E. J., et al. 2022, ApJL, 937, L33, doi: 10.3847/2041-8213/ac8e06
- Tacchella, S., Conroy, C., Faber, S. M., et al. 2022, ApJ, 926, 134, doi: 10.3847/1538-4357/ac449b
- Tanaka, M., Onodera, M., Shimakawa, R., et al. 2024, ApJ, 970, 59, doi: 10.3847/1538-4357/ad5316
- Trussler, J. A. A., Conselice, C. J., Adams, N., et al. 2024, MNRAS, 527, 11627, doi: 10.1093/mnras/stad3877
- Urbano Stawinski, S. M., Cooper, M. C., Forrest, B., et al. 2024, The Open Journal of Astrophysics, 7, 46, doi: 10.33232/001c.120087
- Valentino, F., Tanaka, M., Davidzon, I., et al. 2020, ApJ, 889, 93, doi: 10.3847/1538-4357/ab64dc
- Valentino, F., Brammer, G., Gould, K. M. L., et al. 2023, ApJ, 947, 20, doi: 10.3847/1538-4357/acbefa
- van der Wel, A., Bell, E. F., Häussler, B., et al. 2012, ApJS, 203, 24, doi: 10.1088/0067-0049/203/2/24
- van Dokkum, P., & Conroy, C. 2024, ApJL, 973, L32, doi: 10.3847/2041-8213/ad77b8
- van Dokkum, P. G., Bezanson, R., van der Wel, A., et al. 2014, ApJ, 791, 45, doi: 10.1088/0004-637X/791/1/45
- van Dokkum, P. G., Nelson, E. J., Franx, M., et al. 2015, ApJ, 813, 23, doi: 10.1088/0004-637X/813/1/23

- Vanzella, E., Claeyssens, A., Welch, B., et al. 2023, ApJ, 945, 53, doi: 10.3847/1538-4357/acb59a
- Vazdekis, A., Coelho, P., Cassisi, S., et al. 2015, MNRAS, 449, 1177, doi: 10.1093/mnras/stv151
- Vehtari, A., Gelman, A., Simpson, D., Carpenter, B., & Bürkner, P.-C. 2021, Bayesian analysis, 16, 667
- Vikaeus, A., Zackrisson, E., Wilkins, S., et al. 2024, MNRAS, 529, 1299, doi: 10.1093/mnras/stae323
- Virtanen, P., Gommers, R., Oliphant, T. E., et al. 2020, Nature Methods, 17, 261, doi: 10.1038/s41592-019-0686-2
- Wang, B., Leja, J., de Graaff, A., et al. 2024, ApJL, 969, L13, doi: 10.3847/2041-8213/ad55f7
- Weibel, A., Oesch, P. A., Barrufet, L., et al. 2024, MNRAS, 533, 1808, doi: 10.1093/mnras/stae1891
- Weller, E. J., Pacucci, F., Ni, Y., Hernquist, L., & Park, M. 2024, arXiv e-prints, arXiv:2406.02664, doi: 10.48550/arXiv.2406.02664
- Whitaker, K. E., Kriek, M., van Dokkum, P. G., et al. 2012, ApJ, 745, 179, doi: 10.1088/0004-637X/745/2/179
- Whitaker, K. E., Bezanson, R., van Dokkum, P. G., et al. 2017, ApJ, 838, 19, doi: 10.3847/1538-4357/aa6258
- Williams, C. C., Alberts, S., Ji, Z., et al. 2024, ApJ, 968, 34, doi: 10.3847/1538-4357/ad3f17
- Witten, C., McClymont, W., Laporte, N., et al. 2024, arXiv e-prints, arXiv:2407.07937, doi: 10.48550/arXiv.2407.07937
- Wright, L., Whitaker, K. E., Weaver, J. R., et al. 2024, ApJL, 964, L10, doi: 10.3847/2041-8213/ad2b6d
- Wu, P.-F. 2024, arXiv e-prints, arXiv:2409.00471, doi: 10.48550/arXiv.2409.00471

A. G395M SPECTRUM

In addition to the PRISM spectrum shown above, RU-BIES also obtained a higher resolution G395M grating spectrum. This is shown in Figure 7, zoomed-in on the $\lambda_{\text{rest}} \in (0.35, 0.45) \, \mu m$ range. The SNR is not sufficient to reveal any absorption features or provide any other further insights, which is why we do not use the grating spectrum in the analysis outlined in this work.

B. Prospector POSTERIOR DISTRIBUTIONS

As an overview of the SED-fitting results from our **Prospector** runs, we present the posterior distributions of the key parameters in a corner plot in Figure 8.



Figure 7. NIRSpec/G395M spectrum of RUBIES-UDS-QG-z7, zoomed in on the region around $0.4 \mu m$. The position of possible absorption features are highlighted, but the SNR of the spectrum is not sufficient to unambiguously reveal any significant features.



Figure 8. Posterior distributions of the key parameters from the Prospector runs. Results from the low metallicity fit are shown in red, and those from the high metallicity run in khaki. The displayed contours correspond to 0.5, 1, 1.5, 2, and 3σ confidence regions.