

Aether-SHELLQs: JWST integral-field spectroscopy of candidate obscured quasars at $z \sim 6$

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ABSTRACT

We present James Webb Space Telescope (JWST) NIRSpec integral field unit (IFU) observations of six galaxies at $z \sim 6$, obtained as part of the *Aether* project (General Observers program 5645). The targets were originally identified by the Subaru High- z Exploration of Low-Luminosity Quasars (SHELLQs) survey, as candidate obscured quasars with luminous ($\gtrsim 10^{43}$ erg s^{−1}) but narrow ($\lesssim 500$ km s^{−1}) Ly α emission. Two objects exhibit a broad component in their Balmer lines (FWHM > 3000 km s^{−1}), indicating the presence of active galactic nuclei (AGNs), while the remaining four show similar profiles in permitted and forbidden lines. Combining these data with similar SHELLQs objects reported previously, we find that the presence of broad lines is strongly correlated with Ly α luminosity ($L_{\text{Ly}\alpha}$); the inferred AGN fraction is $>77\%$ and $<15\%$ above and below $L_{\text{Ly}\alpha} = 10^{44}$ erg s^{−1}, respectively. Dust-extinction corrections inferred from the Balmer decrement would imply unrealistically high Ly α luminosities, **suggesting that the line-emitting gas consists of multiple zones.** The IFU data reveal diverse spatial structures. The AGN hosts are compact, whereas the other galaxies show extended ionized gas on scales up to 10 kpc and star formation rates of $60 - 600 M_{\odot}$ yr^{−1}. One of the extended objects exhibits a signature of rotation, while most of the others show little ordered kinematics, with velocity widths (FWHM) up to $200 - 300$ km s^{−1}. These objects populate the intermediate luminosity regime between classical luminous quasars and the low-luminosity AGNs discovered by JWST, including Little Red Dots, potentially linking the two populations.

1. INTRODUCTION

Observations over the past few decades have revealed an unexpectedly complex population of active galactic nuclei (AGNs) in the epoch of reionization (EoR, referring to $z \geq 6$ in this paper). On one hand, wide-field ($>100 \text{ deg}^2$) surveys with ground-based facilities discovered classical luminous quasars, which have typical absolute magnitudes of $M_{\text{UV}} < -24$ at the rest-frame ultraviolet (UV) wavelengths (e.g., Fan et al. 2023). These quasars exhibit the familiar signatures of AGN activity, including strong X-ray and mid-infrared emission, radio emission in roughly 10% of sources (e.g., Bañados et al. 2015), together with flux variability.

On the other hand, the James Webb Space Telescope (JWST; Rigby et al. 2023) has uncovered a numerous population of galaxies showing broad components in H I Balmer lines, with the full-widths at half maximum (FWHM) exceeding 1000 km s^{-1} (e.g., Carnall et al. 2023; Harikane et al. 2023; Larson et al. 2023; Onoue et al. 2023; Kokorev et al. 2023; Übler et al. 2023; Fujimoto et al. 2024; Furtak et al. 2024; Juodžbalis et al. 2024, 2026; Killi et al. 2024; Labbé et al. 2024; Lin et al. 2024, 2026; Kocevski et al. 2023, 2025; Maiolino et al. 2024; Schindler et al. 2025; Taylor et al. 2025a,b; Tripodi et al. 2025; Wang et al. 2024; Akins et al. 2025a; Naidu et al. 2025). These objects have been found from observations covering a few 100 arcmin^2 at most, and are characterized by much lower luminosities with $M_{\text{UV}} > -21$. Many of them are associated with the population called “Little Red Dots” (LRDs; Matthee et al. 2024), defined by compact morphology and V-shaped spectral energy distributions (SEDs) with blue rest-UV and red rest-optical colors (e.g., Labbé et al. 2023, 2025; Setton et al. 2025). A number of theoretical studies suggest that LRDs are mass-accreting supermassive black holes (SMBHs) surrounded by optically-thick gas envelop (e.g., Inayoshi & Maiolino 2025; Liu et al. 2025; Lin et al. 2026; Rusakov et al. 2026), but this scenario has yet to be firmly established.

If these galaxies are interpreted as low-luminosity AGNs, their number density is surprisingly high. It exceeds expectations from extrapolations of the classical quasar luminosity function (LF; e.g., Matsuoka et al. 2018c, 2023; Niida et al. 2020; Schindler et al. 2023) by one to two orders of magnitude (e.g., Harikane et al. 2023; Greene et al. 2024; Kocevski et al. 2025; Maiolino et al. 2024). However, unlike classical quasars, these objects lack X-ray (Ananna et al. 2024; Maiolino et al. 2025; Yue et al. 2024), mid-infrared (e.g., Wang et al. 2025; Williams et al. 2024; Setton et al. 2025), and radio

detections (e.g., Akins et al. 2025b; Mazzolari et al. 2026; Gloudemans et al. 2025; Perger et al. 2025), show little variability (Kokubo & Harikane 2025; Tee et al. 2025), and exhibit SEDs that are difficult to reproduce with standard AGN-galaxy composite models (Ma et al. 2025, but see, e.g., Labbé et al. 2024). Thus, two apparently distinct AGN populations now coexist in the EoR, separated not only by luminosity but also by their multi-wavelength properties. The number density of LRDs has been reported to peak around the EoR (e.g., Ma et al. 2026), but more recent studies suggest that the redshift distribution may be more extended, reaching a maximum around $z \sim 5 - 6$, once selection biases are taken into account (e.g., Rinaldi et al. 2026). On the other hand, quasars become much more abundant at lower redshifts.

A crucial question is whether, and how, these populations are physically connected. The answer may lie in the intermediate luminosity regime ($-24 < M_{\text{UV}} < -21$), which remains poorly explored. Objects in this range are too rare for deep JWST pencil-beam surveys, yet too faint to be efficiently identified in most past wide-field surveys. Without a systematic study of this regime, it remains unclear whether the apparent dichotomy reflects a fundamentally different nature, such as accretion modes of SMBHs or surrounding gas environments (e.g., Inayoshi et al. 2025; Pacucci & Narayan 2024; Inayoshi & Maiolino 2025).

The Subaru High- z Exploration of Low-Luminosity Quasars (SHELLQs; Matsuoka et al. 2016) survey is uniquely suited to address this gap. It is a project to search for EoR quasars based on the Hyper Suprime Cam (HSC; Miyazaki et al. 2018) Subaru Strategic Program (Aihara et al. 2018) survey, whose widest component has imaged an area of 1100 deg^2 down to the 5σ limiting magnitudes of $(g, r, i, z, y) = (26.5, 26.5, 26.2, 25.2, 24.4)$ for point sources (Aihara et al. 2022). SHELLQs has so far reported spectroscopic identification of 182 unobscured quasars at $5.6 < z < 7.1$ (Matsuoka et al. 2018b,a, 2019b,a, 2022, 2024, 2025a). This sample extends well into the intermediate luminosity range. Extensive follow-up observations are being carried out with JWST, Atacama Large Millimeter/submillimeter Array (ALMA), and other facilities, tracing the stellar (Ding et al. 2023, 2025; Onoue et al. 2025, M. Onoue et al. 2026, in preparation) and gaseous (Izumi et al. 2018, 2019, 2021a,b; Phillips et al. 2025; Sawamura et al. 2025) components of the host galaxies as well as the surrounding environments (Arita et al. 2026).

The SHELLQs survey has also identified 35 galaxies with extremely strong Ly α emission at $5.8 < z < 6.9$.

Based on the high luminosities ($L_{\text{Ly}\alpha} > 10^{43} \text{ erg s}^{-1}$) and small widths ($\text{FWHM} < 500 \text{ km s}^{-1}$), these objects have been reported as candidate obscured (narrow-line) quasars. Matsuoka et al. (2025b) observed 11 of them (and two quasars with similar $\text{Ly}\alpha$ profiles) with JWST/NIRSpec, and found a surprisingly high detection rate ($>60\%$) of broad Balmer lines, confirming the presence of AGNs. The Balmer decrements indicate dust obscuration of up to $A_V \sim 3$, which is likely responsible for the absence of broad $\text{Ly}\alpha$ in the rest-UV spectra. Some of these objects show continuum slopes that are consistent with the V-shape spectra of LRDs. Furthermore, the non-detection in Chandra observations (Iwasawa et al. 2026) indicates X-ray luminosities much lower than expected from the rest-optical emission assuming a typical AGN SED, similar to what is seen in LRDs. These partially-obscured AGNs with intermediate luminosities may thus represent a key population, bridging classical UV-luminous quasars and the low-luminosity AGNs identified by JWST.

This paper presents JWST/NIRSpec integral field unit (IFU) observations of six SHELLQs objects, drawn from the above class of candidate obscured quasars. By examining both nuclear and extended emission properties, we aim to investigate the nature of these intriguing objects, including the presence of AGN signatures and the global gas kinematics. We describe the observations and data reduction in §2, and then present results and discussion in §3. A summary and conclusions follow in §4. We adopt the cosmological parameters $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$. All magnitudes are presented in the AB system (Oke & Gunn 1983). The rest-UV absolute magnitudes (M_{UV}) and $\text{Ly}\alpha$ line luminosities ($L_{\text{Ly}\alpha}$) and widths are reported as measured, i.e., without correction for dust extinction or intergalactic medium (IGM) absorption, unless otherwise noted. We report wavelengths in both the rest frame (λ_{rest}) and the observed frame (λ_{obs}), depending on the context.

2. OBSERVATIONS

Table 1 lists the six objects analyzed in this work. They were originally identified in the SHELLQs survey through rest-UV spectroscopy, using the Subaru Telescope and the Gran Telescopio Canarias (Matsuoka et al. 2016, 2018b,a, 2019a, 2024). G12 and G13 were discovered and reported in the early phase of the project, and do not quite meet our latest criteria of candidate obscured quasars ($L_{\text{Ly}\alpha} > 10^{43} \text{ erg s}^{-1}$ and $\text{FWHM} < 500 \text{ km s}^{-1}$; e.g., Matsuoka et al. 2025a). We include these two objects in the present analysis as borderline candidates.

The JWST observations were carried out in Cycle 3 as part of the General Observers (GO) program 5645 (the *Aether* project; E. Farina et al., 2026, in preparation). It is a Survey-category program targeting all the 343 quasars at $5.7 < z < 7.0$ that were known at the time of proposal preparation, without any additional selection.¹ The program used NIRSpec with the high-resolution grating G395H and transmission filter F290LP. This configuration provides wavelength coverage from 2.87 to 5.14 μm , with the spectral resolution $R \sim 2700$. The observations were carried out in the IFU mode, which provides a $3'' \times 3''$ square field of view with a spaxel scale of $0''.1$. A physical gap between the NIRSpec detectors results in a $\sim 0.1\text{-}\mu\text{m}$ wavelength gap around 3.98 – 4.20 μm , whose exact cutoffs depend on the IFU slice. The total exposure time on source was 2600 sec per target, divided into 4-point dithers $\times$ 1 integration $\times$ 9 groups. The CYCLING dither pattern was used with the SMALL spatial scale. The readout mode was NRSIRS2.

Following Loiacono et al. (2024), we reduced the data using the JWST NIRSpec official pipeline (CRDS version: 12.1.11, context: jwst_1322.pmap). Between Stage 1 (mostly dealing with the ramp reconstruction) and Stage 2 (dealing with flat fielding and other instrument-dependent calibrations), we apply an aggressive flagging of poorly sampled ramps, similar to the TEMPLATES approach (Hutchison et al. 2024). Contrary to E. Farina et al. (2026, in preparation) and R. Decarli et al. (2026, in preparation), after Stage 3 (dealing with the outlier rejection and the cube reconstruction) we do not remove spectral spikes in an ad hoc manner, as the narrow lines of the present targets may be erroneously identified as cosmic rays. The final cubes have a spatial sampling of $0''.1$ per pixel and a spectral sampling of 6.65 $\text{\AA}$ per channel. The astrometry of the cubes is corrected so that the quasars lie at their nominal position from the respective discovery papers.

3. RESULTS AND DISCUSSION

3.1. Nuclear Emission

We extracted the nuclear spectra by integrating the flux over a 7×7 spaxel ($0''.7 \times 0''.7$) aperture, centered on the flux-weighted centroid. We generated Point Spread Function (PSF) models with the JWST Expo-

¹ A few targets were excluded from the sample due to the lack of suitable guide stars.

Table 1. Targets of this work

Name (Formal HSC name)	$z_{\text{Ly}\alpha}$	$\log (L_{\text{Ly}\alpha}/[\text{erg s}^{-1}])$	FWHM (km s^{-1})	M_{UV}	Ref
G03 (<i>J093543.32</i> – <i>011033.3</i>)	6.08	44.12 ± 0.01	<230	-21.97 ± 0.18	4
G04 (<i>J125437.08</i> – <i>001410.7</i>)	6.13	44.03 ± 0.01	310 ± 20	-20.91 ± 0.32	4
G08 (<i>J090544.65</i> + <i>030058.9</i>)	6.27	43.89 ± 0.02	250 ± 40	-22.55 ± 0.11	2
G12 (<i>J120924.01</i> – <i>000646.5</i>)	5.86	43.01 ± 0.04	580 ± 50	-22.51 ± 0.05	3
G13 (<i>J120754.14</i> – <i>000553.3</i>)	6.01	42.92 ± 0.05	420 ± 160	-22.77 ± 0.06	1
G14 (<i>J121503.42</i> – <i>014858.7</i>)	6.05	43.37 ± 0.03	320 ± 20	-23.11 ± 0.02	5

NOTE— The $\text{Ly}\alpha$ redshifts ($z_{\text{Ly}\alpha}$) were determined from the observed wavelengths of the line peak. The $\text{Ly}\alpha$ luminosities and FWHMs (corrected for instrumental resolution) and the rest-UV continuum magnitudes at $1450 \text{ \AA}$ (M_{UV}) are reported as measured, without correction for dust extinction or IGM absorption. The last column lists the reference papers; (1) Matsuoka et al. (2016), (2) Matsuoka et al. (2018b), (3) Matsuoka et al. (2018a), (4) Matsuoka et al. (2019a), (5) Matsuoka et al. (2024).

sure Time Calculator (ETC; Pontoppidan et al. 2016),² and used them to correct for chromatic aperture loss (Horne 1986). The flux-weighted centroid of each PSF model was matched to that of the observed IFU data cube to sub-pixel accuracy. The obtained spectra are presented in Figure 1. The formal flux errors provided by the JWST pipeline tend to underestimate the effective noise due to correlated background residuals and other factors. We therefore estimated the noise empirically from source-free regions in each wavelength channel, and added it to the formal errors in quadrature.³

We modeled and fitted the observed spectra in exactly the same way as in Matsuoka et al. (2025b). For details, we refer the reader to that paper; here we briefly summarize the key points. The continuum emission was assumed to follow a power-law function. The Fe II pseudo-continuum was included in the model, using the Boroson & Green (1992) template with the velocity broadening tied to emission lines. This component, however, is very weak in our objects and has little impact on the model fitting. The forbidden and permitted line profiles were modeled with two and three Gaussian components, respectively. A third Gaussian component was included only when it has more than 5σ significance and the Bayesian information criterion (BIC; e.g., Liddle

2007) is reduced by more than 10. The instrumental line broadening was taken into account, using the disperser resolution as a function of wavelength taken from the JWST User Documentation.⁴

The model fitting was performed with the least- χ^2 method. The best-fit models around $\text{H}\beta + [\text{O III}] \lambda 4959$, 5007 and around $\text{H}\alpha$ are presented in Figure 2. We found that G08, G12, G13, and G14 have consistent profiles in the forbidden and permitted lines. On the other hand, the presence of a third Gaussian component is strongly favored in the permitted lines of G03 and G04, with a reduction in $\text{BIC} \gg 10$. Following Matsuoka et al. (2025b), we decomposed the permitted line fluxes of these two objects into narrow-line (NL) and broad-line (BL) components. The NL component is assumed to share the same profile as the forbidden lines, and the remaining emission is attributed to the BL component. Table 4 in the Appendix A lists the measured emission line fluxes as well as the properties of other emission components.

We derived the systemic redshift (z_{sys}) of each object from the narrowest Gaussian component of emission lines in the best-fit model. Table 2 reports these values, as well as the FWHMs of the three Gaussian components (w_1 , w_2 , and w_3) and the rest-frame equivalent widths (EWs) of $[\text{O III}] \lambda 5007$, $\text{H}\beta$, and $\text{H}\alpha$. The Balmer decrements indicate the dust extinction of $A_V \sim 0 - 2$, assuming the intrinsic flux ratio of $\text{H}\alpha/\text{H}\beta = 2.86$ and the Small Magellanic Cloud extinction law (Pei 1992). The table also reports continuum and line luminosities corrected for dust extinction. We denote the $\text{H}\alpha$ lumi-

² Other *Aether* studies typically use the PSF models constructed from the wings of broad emission lines originating from unresolved quasar nuclei (e.g., R. Decarli et al. 2026, in preparation). We adopt a different approach here, as our objects do not always exhibit broad emission lines.

³ The empirical scatter alone does not fully capture the statistical uncertainty structure propagated through the pipeline processing, particularly in regions where the detector response and source Poisson contribution vary significantly. We therefore conservatively combined the two noise estimates in quadrature, which may overestimate the true noise.

⁴ <https://jwst-docs.stsci.edu>

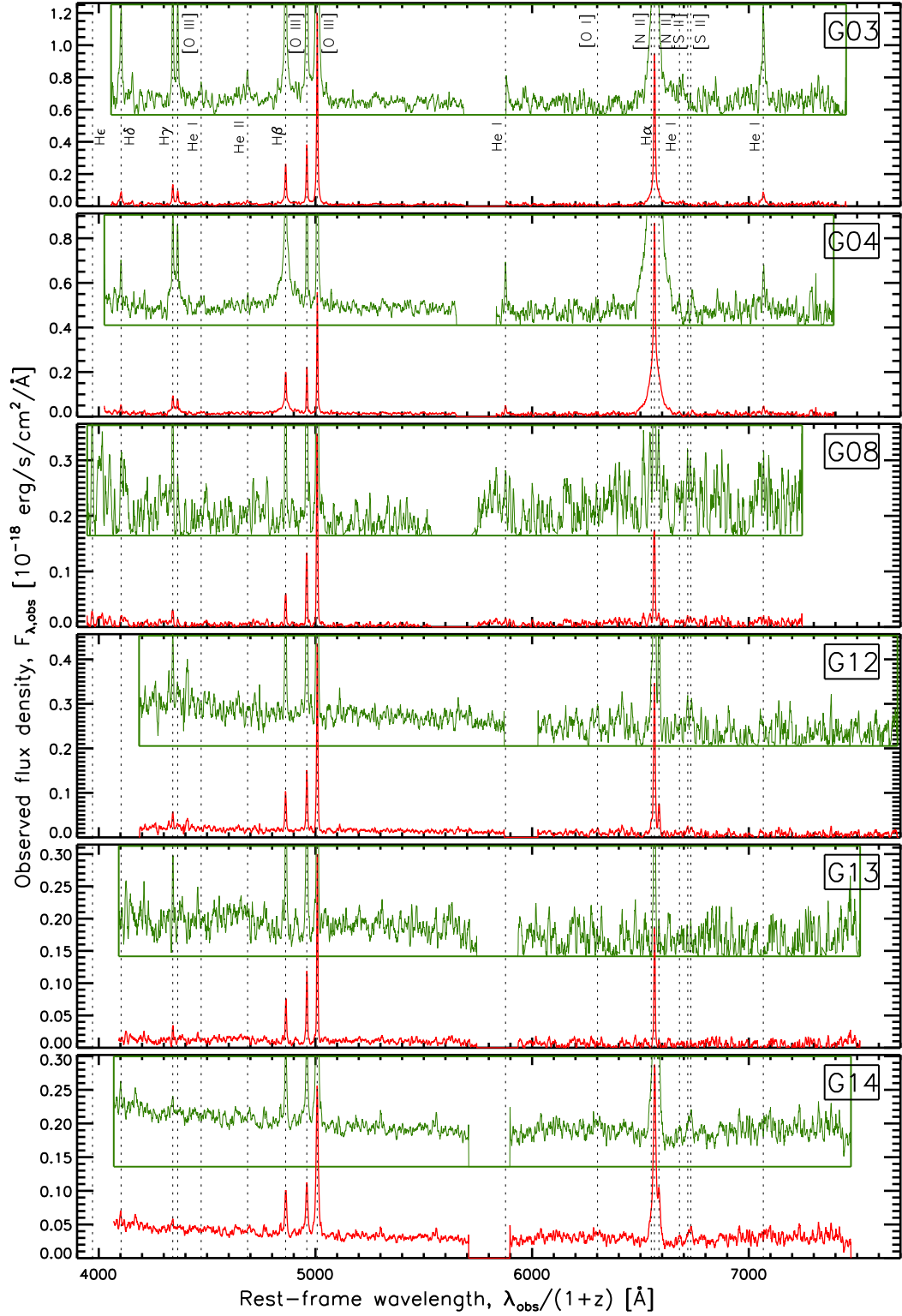


Figure 1. Nuclear spectra extracted from the IFU data cubes for each object (red lines). The flux density is given in the observer's frame, while the wavelength is given in the rest frame for the purpose of presentation, using the systemic redshifts determined from the spectral models. The insets with the green lines show the same spectra plotted on an expanded scale, to make fainter emission features apparent. The dotted lines indicate the expected central wavelengths of common emission lines, as labeled in the top panel.

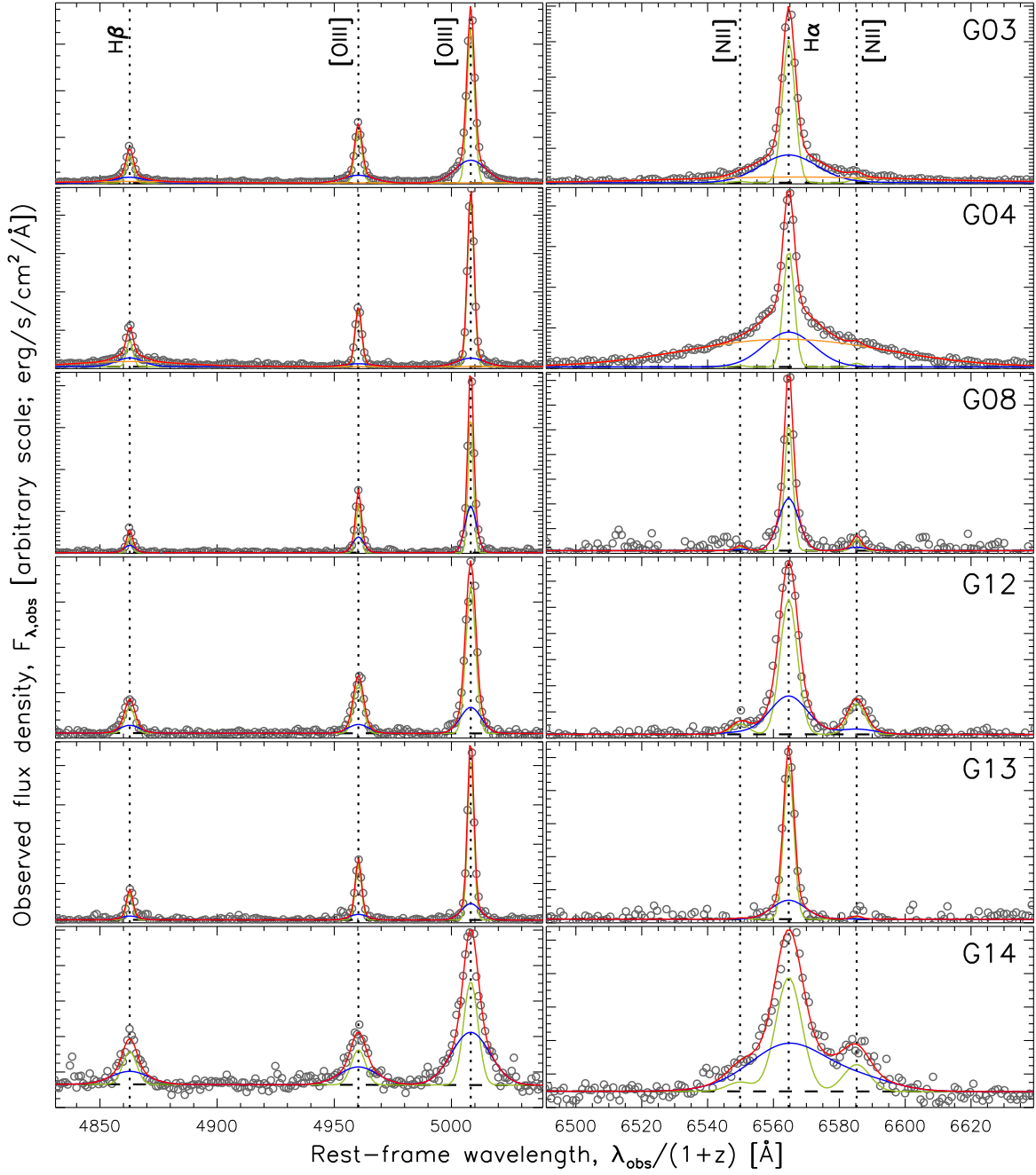


Figure 2. The best-fit spectral models (red lines) compared with the observed spectra (open circles) around H β + [O III] λ 4959, 5007 (left panels) and around H α + [N II] λ 6585, 6550 (right panels). The models include a power-law and Fe II continuum (black dashed lines) and emission lines, each modeled as the sum of two or three Gaussian components (green, blue, and orange lines). The dotted lines indicate the expected wavelengths of the emission lines, as labeled in the top panels.

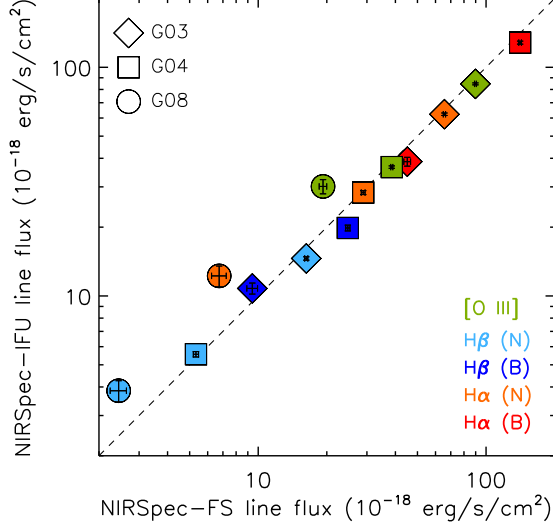


Figure 3. Comparison of the emission line fluxes in the nuclear spectra between the FS and IFU measurements. The diamonds, squares, and circles represent G03, G04, and G08, respectively, which were observed in the both modes. Colors indicate [O III] $\lambda 5007$ (green), the NL/BL components of H β (light blue/blue), and the NL/BL components of H α (orange/red). The dashed line indicates the one-to-one relation.

nosities of the NL and BL components as $L_{\text{H}\alpha, \text{N}}$ and $L_{\text{H}\alpha, \text{B}}$, respectively.

G03, G04, and G08 were also observed with the NIRSpec Fixed-Slit (FS) mode as part of an independent program GO 3417. The same grating and transmission filter were used, while the total exposure time on source (3700 sec) was moderately longer than the present IFU observations. Figure 3 compares the [O III] $\lambda 5007$, H β , and H α line fluxes of the three objects between the FS (Matsuoka et al. 2025b) and the present IFU measurements. We observe excellent agreement between the two measurements for G03 and G04, which supports the robustness of the observations, data reduction, and spectral modeling across different instrumental modes. On the other hand, the IFU spectrum of G08 yields higher line fluxes than the FS spectrum. This is likely because the aperture-loss correction was based on a PSF model, whereas G08 is more spatially extended than G03 and G04 (see §3.2). In what follows, we will adopt the FS measurements for the nuclear spectra of these three objects to take advantage of their higher S/N.

Figure 4a compares $L_{\text{H}\alpha, \text{N}}$ with the Ly α luminosity $L_{\text{Ly}\alpha}$.⁵ Note that $L_{\text{H}\alpha, \text{N}}$ has been corrected for

dust extinction, while $L_{\text{Ly}\alpha}$ is as observed, without any correction for dust or IGM absorption. The figure demonstrates that the observed $L_{\text{Ly}\alpha}/L_{\text{H}\alpha, \text{N}}$ ratios are lower than expected in Case B recombination conditions (e.g., Brocklehurst 1971; Hayes 2015). On the other hand, using a dust-extinction correction inferred from the Balmer decrement would result in unreasonably high Ly α luminosity in many objects ($L_{\text{Ly}\alpha} = 10^{45-50}$ erg s $^{-1}$; e.g., Umeda et al. 2025). Correcting $L_{\text{Ly}\alpha}$ for IGM absorption would make the situation even worse. This indicates that the observed Ly α did not suffer the same extinction as H α . In other words, the gas region emitting the hydrogen lines is likely composed of at least two zones. We speculate that dense gas clouds with moderate dust extinction (nearly opaque to Ly α , but allowing partial transmission of H α) are embedded within the ambient dust-free/poor gas; the observed Ly α originates mostly from the ambient gas, while H α comes from the entire region. It is worth noting that Ly α is also subject to resonant scattering, which, together with dust extinction, can significantly modify its spatial distribution. This is illustrated by the extended Ly α halos around lower-redshift quasars observed with the Multi Unit Spectroscopic Explorer (MUSE) on the Very Large Telescope (VLT), where emission is found on circumgalactic scales (e.g., Borisova et al. 2016; Arrigoni Battaia et al. 2019).

Matsuoka et al. (2025b) analyzed the NIRSpec FS spectra of 11 similar galaxies (along with two quasars showing similar Ly α profiles) drawn from the SHELLQs sample, and reported that seven of them exhibit broad rest-optical lines. We found consistent fitting results for the three common objects with the present work; G03 and G04 have broad lines, while G08 does not. The additional three objects presented here have somewhat lower $L_{\text{Ly}\alpha}$ than these objects, and two of them (G12 and G13) do not show detectable broad Balmer lines. G14 exhibits broad Balmer lines, but their widths are comparable to those of the forbidden [O III] lines, suggesting that they trace galaxy-scale gas dynamics (see Sec 3.3 for further discussion). Figure 4b summarizes these results; the $L_{\text{H}\alpha, \text{B}}$ upper limits of the NL objects were estimated by artificially adding a mean BL profile of the BL objects with varying amplitudes and correcting for dust extinction with $A_V(\text{N})$. Even if the NL objects had an undetectable BL component in H α , their luminosities would still be significantly lower than those of the BL objects. For reference, LRDs and other low-luminosity AGNs discovered by JWST span a broad range of H α luminosities, from $L_{\text{H}\alpha, \text{B}} \sim 10^{41}$ to 10^{44} erg s $^{-1}$ (e.g., Kocevski et al. 2023; Greene et al. 2024;

⁵ Ly α has a narrow profile overall (FWHM < 500 km s $^{-1}$, as defined by the SHELLQs criteria for candidate obscured quasars), while there is a hint of a weak broad component in some objects (Matsuoka et al. 2025b).

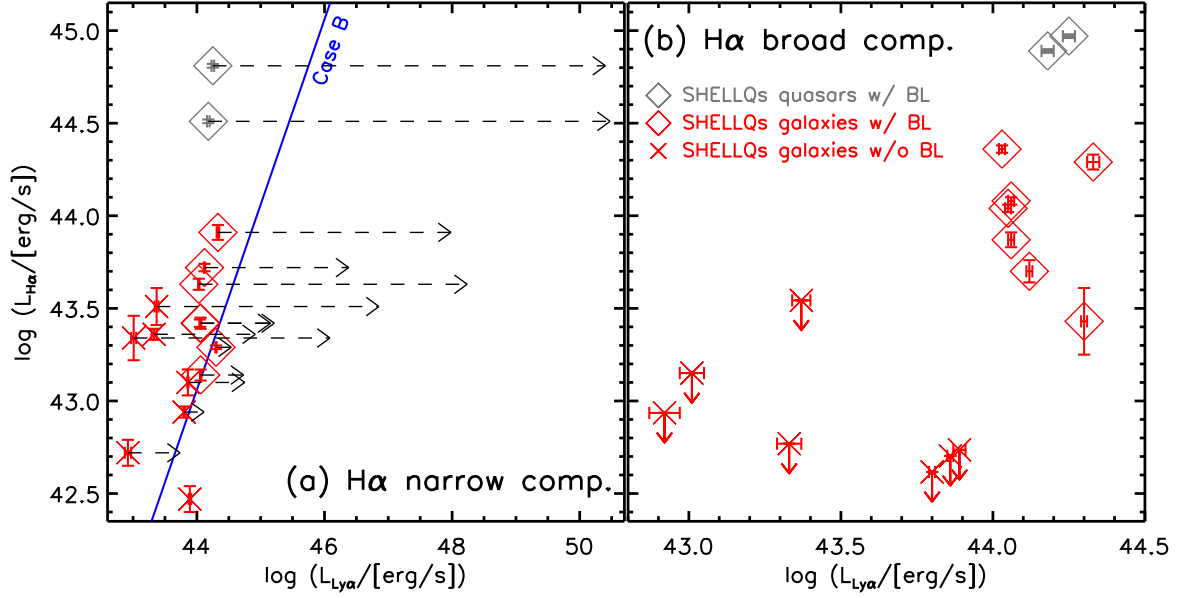


Figure 4. Comparison of $H\alpha$ luminosities in the NL (panel a) and BL (panel b) components with $Ly\alpha$ luminosities measured for the SHELLQs objects. Thirteen objects from Matsuoka et al. (2025b) and three additional objects from the present analysis are shown. Galaxies with broad Balmer lines are indicated by red diamonds, those without by red crosses, and two quasars with similar $Ly\alpha$ profiles by gray diamonds. The downward arrows represent 3σ upper limits. The solid line represents the ratio expected in Case B recombination conditions (e.g., Brocklehurst 1971; Hayes 2015). Note that $L_{H\alpha,N}$ and $L_{H\alpha,B}$ have been corrected for dust extinction, while $L_{Ly\alpha}$ has not. The dashed arrows in panel a represent the dust-extinction correction for $L_{Ly\alpha}$ inferred from the Balmer decrement.

Table 2. Spectral properties from the best-fit models

	G03	G04	G08	G12	G13	G14
z_{sys}	6.075	6.130	6.272	5.857	6.014	6.054
w_1 (km s $^{-1}$)	185 ± 1	152 ± 2	94 ± 6	265 ± 9	136 ± 5	410 ± 20
w_2 (km s $^{-1}$)	920 ± 10	810 ± 20	320 ± 10	610 ± 50	530 ± 50	1150 ± 50
w_3 (km s $^{-1}$)	3850 ± 170	3240 ± 50	...	...	...	...
EW ([O III])	1090 ± 100	360 ± 30	920 ± 160	230 ± 40	250 ± 50	83 ± 9
EW ($H\alpha$, N)	970 ± 70	350 ± 20	300 ± 50	390 ± 70	230 ± 40	140 ± 20
EW ($H\alpha$, B)	600 ± 50	1570 ± 100	...	...	...	...
$A_V(N)$	1.09 ± 0.05	1.57 ± 0.08	0.29 ± 0.29	1.28 ± 0.34	0.34 ± 0.21	1.45 ± 0.29
$A_V(B)$	0.62 ± 0.19	2.22 ± 0.09	...	...	...	...
$\log L_{5100}$	40.77 ± 0.09	41.61 ± 0.04	40.29 ± 0.13	41.17 ± 0.15	40.60 ± 0.09	41.65 ± 0.13
$\log L_{[\text{O III}]}$	44.04 ± 0.02	43.90 ± 0.04	43.25 ± 0.13	43.55 ± 0.16	43.02 ± 0.09	43.60 ± 0.14
$\log L_{H\alpha,N}$	43.75 ± 0.02	43.56 ± 0.03	42.82 ± 0.10	43.34 ± 0.12	42.72 ± 0.07	43.51 ± 0.10
$\log L_{H\alpha,B}$	43.39 ± 0.06	44.42 ± 0.03	...	...	...	...

NOTE— The rest-frame EWs of [O III] $\lambda 5007$ and $H\alpha$ (NL and BL components) are reported in units of $\text{\AA}$. The luminosities have been corrected for dust extinction and are presented in units of erg s^{-1} .

Matthee et al. 2024). Our BL objects occupy the upper end of and partially extend beyond this distribution.

We interpret our BL objects as hosting AGN, whose signature is obscured by dust in the rest-UV spectra. The FS measurements of the $H\alpha$ BL width and luminosity provide the black hole mass (M_{BH}) estimates of $\log(M_{\text{BH}}/M_{\odot}) = 8.21 \pm 0.03$ and 8.46 ± 0.01 for G03 and G04, respectively (Matsuoka et al. 2025b).⁶ On the other hand, Iwasawa et al. (2026) reported that G03 and G04, along with two similar objects (G01 and G02), were not detected in their Chandra observations, which indicate significantly lower X-ray to rest-optical luminosity ratios than those of normal AGNs. This is similar to the situation observed in LRDs, as described in §1.

We have further examined radio images from the LOFAR Two-metre Sky Survey (LoTSS; Shimwell et al. 2017) at 144 MHz and the Very Large Array Sky Survey (VLASS; Lacy et al. 2020) at 3 GHz, but none of the present six objects (only four of them are found in the VLASS footprint) is individually detected. They also remain undetected in the stacked data, which reach the 3σ luminosity limits of $7.3 \times 10^{25} \text{ W Hz}^{-1}$ (LoTSS) and $5.0 \times 10^{25} \text{ W Hz}^{-1}$ (VLASS). The LoTSS stack provides a 3σ upper limit on the radio loudness, $L_{\nu}(1.4\text{GHz})/L_{\nu}(2500\text{\AA}) < 1300$, assuming a radio spectral index of $\alpha = 0.7$. This limit is significantly higher than the conventional threshold between radio-loud and radio-quiet AGNs. Much deeper observations are required to constrain their nature based on the radio emission.

As the NIRSpec-observed sample grows, it is becoming clear that the presence of an AGN is closely linked to $\text{Ly}\alpha$ luminosity; broad rest-optical lines appear ubiquitous at $L_{\text{Ly}\alpha} > 10^{44} \text{ erg s}^{-1}$ and rapidly disappear toward lower luminosities. At face value, this indicates AGN fractions of $>77\%$ (7 out of 7 objects; 1σ confidence level under binomial statistics) and $<15\%$ (0 out of 7 objects) above and below $L_{\text{Ly}\alpha} = 10^{44} \text{ erg s}^{-1}$, respectively. The fairly sharp transition in the AGN fraction is intriguing. It indicates that the LF of non-AGN $\text{Ly}\alpha$ emitters (LAEs) intersects the AGN LF at $L_{\text{Ly}\alpha} \sim 10^{44} \text{ erg s}^{-1}$, above which AGNs become the dominant population. This transition luminosity corresponds to a star formation rate (SFR) of $\sim 100 f_{\text{esc}}^{-1} M_{\odot} \text{ yr}^{-1}$, assuming Case B recombination conditions and the $H\alpha$ -SFR relation of Kennicutt (1998). Here f_{esc} represents the $\text{Ly}\alpha$ photon escape fraction, whose typi-

cal value is $0.05 - 0.2$ at $z \sim 6$ (e.g., Tang et al. 2023; Chen et al. 2024; Saxena et al. 2024).

At lower redshifts ($z \sim 2$), it has been reported that the AGN fraction among LAEs increases more gradually, from nearly 0% at $L_{\text{Ly}\alpha} = 10^{42.5} \text{ erg s}^{-1}$ to 100% at $10^{43.5} \text{ erg s}^{-1}$ (Sobral et al. 2018; Spinoso et al. 2020). The higher LAE number density at $z \sim 6$ (e.g., Konno et al. 2016) may be responsible for the higher transition luminosity, where the steep fall-off of the (non-AGN) LAE LF may cause the sharp transition. In addition, the IGM H I opacity is much higher at $z \sim 6$ than at $z \sim 2$. Hard radiation fields can create large ionized bubbles preferentially around AGNs, which may help $\text{Ly}\alpha$ photons escape IGM absorption. Alternatively, dust extinction may be more significant at the lower (observed) $\text{Ly}\alpha$ luminosities, obscuring AGN signatures at both rest-UV and rest-optical wavelengths. Indeed, Figure 4a shows that the $L_{\text{Ly}\alpha}/L_{H\alpha}$ ratios of the objects without broad Balmer lines are further offset from the Case B value than those with broad Balmer lines.

Nevertheless, we note that the above arguments are subject to several selection biases. Since the primary goal of SHELLQs was to discover unobscured quasars with strong, unresolved continuum emission, its photometric selection was not optimized for obscured quasars, either in terms of color or spatial extent. Figure 5 demonstrates that the selection becomes incomplete particularly at $L_{\text{Ly}\alpha} < 10^{44} \text{ erg s}^{-1}$, due to the adopted magnitude cut of $z_{\text{AB}} < 24$. At a given $L_{\text{Ly}\alpha}$, objects with higher $\text{Ly}\alpha$ EWs tend to be excluded from the selection, because of their fainter continuum (and thus total) emission. We also note that the $\text{Ly}\alpha$ luminosities have not been corrected for unknown dust extinction and/or IGM absorption; such a correction could yield significantly higher $L_{\text{Ly}\alpha}$ than presented here. Finally, the AGN fraction considered here includes only objects with detectable broad Balmer lines. AGNs with heavier dust obscuration are not included and may therefore be missed. Such a population could be identified using other AGN tracers, such as high-ionization lines or multi-wavelength properties; this remains for future studies (e.g., K. Aoki et al. 2026, in preparation).

3.2. Extended Emission

We now turn our attention to spatially extended emission in the IFU data cube. Figure 6 presents the continuum, $[\text{O III}] \lambda 5007$, and $H\alpha$ emission maps centered on each of the six objects. The continuum emission was integrated over $\lambda_{\text{rest}} = 4200 - 5500 \text{ \AA}$, after masking emission lines. We performed 5σ clipping at each wavelength channel, and then used the inverse-variance-

⁶ E. Farina et al. (2026, in preparation) will provide consistent M_{BH} measurements across the whole *Aether* sample, including these two objects.

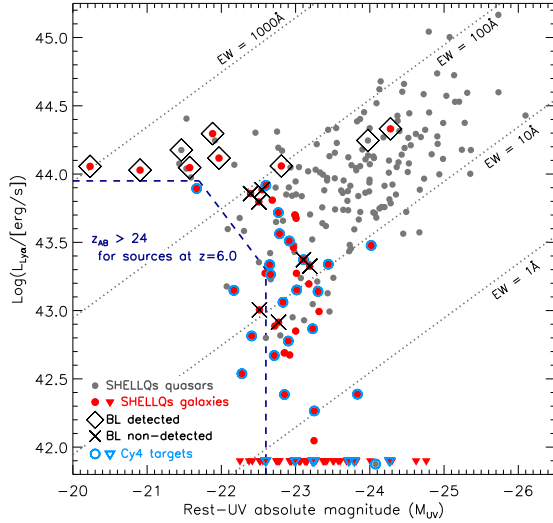


Figure 5. Rest-UV continuum magnitudes and Ly α luminosities of all SHELLQs quasars (gray dots) and galaxies (red dots; those without Ly α detection are represented by red triangles, plotted at an arbitrary vertical position). The dotted lines represent constant rest-frame EWs of 1, 10, 100, and 1000 Å. Sources to the left and bottom of the dashed lines are fainter than the SHELLQs limiting magnitude ($z_{AB} = 24.0$) at $z = 6.0$. The objects with existing JWST/NIRSpec measurements are marked by diamonds (those with broad lines) and crosses (those without detectable broad lines). The G0 7491 targets currently being observed in Cycle 4 are outlined in blue; see §4 in the text.

weighted mean for flux integration at each spaxel. Apparent snowball features were identified and removed by visual inspection. Finally, detector-based stripe patterns were removed following the recipe in Decarli et al. (2024). The line emission maps were created in a similar manner, but without 5σ clipping. This is because the [O III] and H α lines are sufficiently strong to be detected in some individual wavelength channels. While some cosmic ray impacts may leak through this process, their effect is expected to be minimal, as the emission lines span a much narrower velocity range than the continuum, and obvious snowball features were removed manually. The line fluxes were simply summed over the velocity range corresponding to the FWHM of the second Gaussian component in the best-fit model (i.e., w_2 in Table 2).

Figure 6 demonstrates a wide range of apparent morphologies, from unresolved to significantly extended. This is remarkable, given that all the objects were identified as point sources at the resolution of Subaru/HSC ($\sim 0''.7$ at rest-UV wavelengths). We measured the flux ratios between 3×3 and 5×5 spaxel apertures (R_{35}) as a rough indicator of source concentration, and compared them with those of the PSF model generated with the

Table 3. Source concentration relative to PSF

Object	Continuum	[O III]	H α
G03	1.04 ± 0.04	0.94 ± 0.01	0.96 ± 0.01
G04	0.88 ± 0.02	0.92 ± 0.01	0.97 ± 0.01
G08	0.97 ± 0.04	0.83 ± 0.01	0.84 ± 0.02
G12	0.69 ± 0.01	0.59 ± 0.01	0.58 ± 0.01
G13	0.78 ± 0.01	0.70 ± 0.01	0.68 ± 0.01
G14	0.86 ± 0.01	0.88 ± 0.01	0.81 ± 0.01

NOTE— This table lists the source concentration quantified by $R_{35}/R_{35}^{\text{PSF}}$ (see text) for continuum at $\lambda_{\text{rest}} = 4400 - 5200$ Å, [O III] $\lambda 5007$, and H α .

JWST ETC (R_{35}^{PSF}). Table 3 lists the ratios $R_{35}/R_{35}^{\text{PSF}}$. The uncertainties were estimated by repeating the measurements after adding random flux fluctuations to the images based on the associated error maps. The table shows that G03 and G04 exhibit compact morphology overall, which are consistent with the PSF. Together with the presence of broad emission lines, these measurements indicate that both the continuum and line emission are dominated by unresolved AGN. In contrast, the remaining four objects without broad lines tend to be more extended. In particular, the significant extents of the line emission indicate both a substantial reservoir of interstellar gas and an extended ionizing radiation field. This is most significant in G12 and G13, in which the line emission reaches projected extents of up to 10 kpc and 5 kpc (in proper distance), respectively. Assuming that the H α photons are produced in H II regions around massive stars, the inferred SFRs are 60 ± 10 , 570 ± 140 , 70 ± 10 , and $280 \pm 60 M_{\odot} \text{ yr}^{-1}$ in G08, G12, G13, and G14, respectively, using the Kennicutt (1998) relation. The SFRs have been corrected for dust extinction, assuming the $A_V(N)$ values reported in Table 2. The continuum emission tends to be less extended, which may indicate the concentration of stellar populations within the central few pixels (~ 1 kpc across) and/or the presence of some AGN radiation from the unresolved nuclei.

We measured the kinematics of the ionized gas using [O III] $\lambda 5007$ emission, and present the maps of mean velocity and velocity width (FWHM, corrected for instrumental broadening) in Figure 7. The [O III] line was chosen because it is brighter than H α (the NL component for G03 and G04) and the background continuum emission is more spatially uniform at shorter wavelengths. G04, G08, and G13 exhibit similar gas kinematics, with little spatial structure of the mean velocity and moderate velocity width up to $\sim 200 \text{ km s}^{-1}$. G03 has

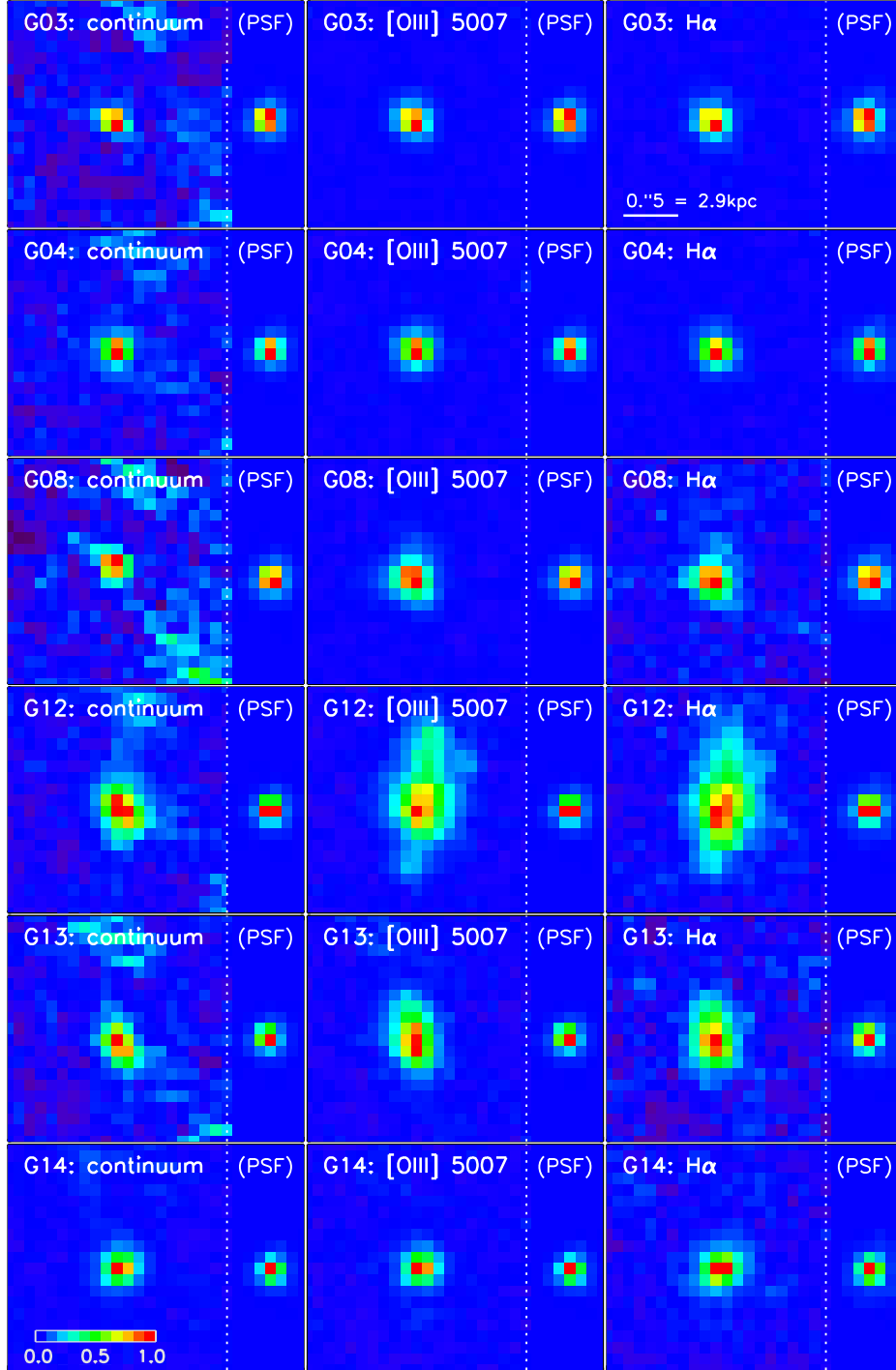


Figure 6. NIRSpec IFU maps for the six galaxies. Colors represent peak-normalized flux on a linear scale, increasing from blue to red (color bar is shown in the bottom left panel). Each row corresponds to one galaxy (G03, G04, G08, G12, G13, and G14 from top to bottom), and the panels from left to right show the continuum emission integrated over $\lambda_{\text{rest}} = 4200 - 5500 \text{ \AA}$, the [O III] $\lambda 5007$ line, and the H α line, respectively. In each panel, the corresponding PSF model is shown to the right of the object image. Each panel covers $2'' \times 2''$, compared to the full IFU field of view of $3'' \times 3''$. The scale bar in the top right panel represents $0.5''$ (2.9 kpc in proper distance at $z = 6$). North is up and East is to the left.

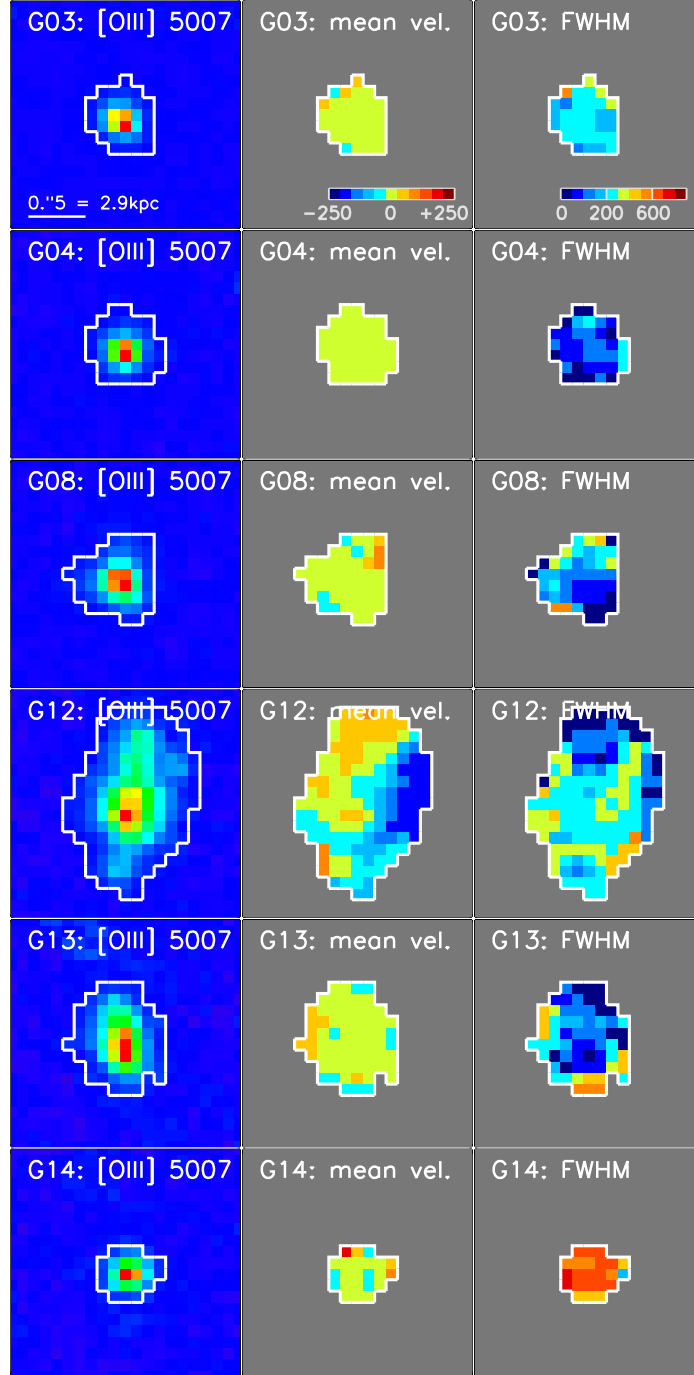


Figure 7. NIRSpect IFU maps for the six galaxies. Each row corresponds to one galaxy (G03, G04, G08, G12, G13, and G14 from top to bottom), and the panels from left to right show the maps of integrated flux (equivalent to the middle-column panels of Figure 6, including some continuum contribution), mean velocity, and velocity width (FWHM) of the [O III] $\lambda 5007$ emission. Spaxels used for the velocity measurements are outlined by the thick white lines. In the outer regions of the galaxies, we binned several (up to five) spaxels to increase S/N for the velocity measurements. The scale bar in the top left panel corresponds to $0.5''$ (2.9 kpc in proper distance at $z = 6$). In the middle-column panels, the color scale represents 11 velocity bins ranging from -250 to $+250 \text{ km s}^{-1}$, with a spacing of 50 km s^{-1} . In the right panels, the bluest four colors correspond to 50 km s^{-1} velocity bins spanning $0 - 200 \text{ km s}^{-1}$, the middle four to 100 km s^{-1} bins spanning $200 - 600 \text{ km s}^{-1}$, and the reddest three to 200 km s^{-1} bins spanning $600 - 1200 \text{ km s}^{-1}$. The corresponding color bars are shown in the top middle and top right panels.

a similar structure, but with slightly elevated velocity width of $200 - 300 \text{ km s}^{-1}$. A signature of galaxy rotation may be visible only in G12, where the northern and western regions exhibit significant redshift (up to 100 km s^{-1}) and blueshift (up to 200 km s^{-1}), respectively, relative to the systemic velocity. This pattern is somewhat inconsistent with the naive expectation that, if the apparent elongation of the galaxy is due to inclination, the velocity gradient would align with the major axis oriented north-south. This discrepancy may be partly due to star formation driven outflows, which could perturb the global velocity field from simple rotational motion. Finally, G14 exhibits peculiar kinematics, characterized by extremely high velocity width reaching almost 1000 km s^{-1} . We discuss this object further in the next section.

3.3. *J121503.42–014858.7 (G14)*

G14 was previously reported by Matsuoka et al. (2024) to be part of a physical quasar pair. The pair was identified as consisting of a brighter, more compact object (“C1” with $M_{1450} = -23.11$, corresponding to G14 in this paper) and a fainter, more extended companion (“C2” with $M_{1450} = -22.66$). The two objects exhibit strong Ly α lines at almost identical wavelengths, which provide a common redshift of $z = 6.05$. Their angular separation ($2''.0$) corresponds to a projected proper distance of 12 kpc , suggesting that they are physically associated. Indeed, a bridging gas structure was detected in Ly α emission. Follow-up ALMA observations (Izumi et al. 2024) further revealed spectacular [C II] $158\text{-}\mu\text{m}$ emission bridging and surrounding the two objects, providing clear evidence for their dynamical interaction.

The two objects each show a relatively broad Ly α component with FWHM of 1500 km s^{-1} (G14) and 1300 km s^{-1} (C2). Their continuum and Ly α luminosities are much higher than those of typical galaxies, making it unlikely that such luminous objects would form a close pair by chance. Based on these properties, Matsuoka et al. (2024) proposed that both objects are likely quasars. However, the rest-optical spectrum of G14 (see Figures 1 and 2) reveals that its [O III] lines are similarly broad. Both permitted and forbidden lines are well fitted with a combination of two Gaussians, and the FWHM of the broader component ($w_2 = 1200 \text{ km s}^{-1}$; see Table 2) is consistent with that of the broad Ly α component. The [C II] line from the ALMA observations also exhibits a broad component with a similar width, FWHM = 1200 km s^{-1} . Therefore, we conclude that the broad line profile of G14 is not produced by gas motion due to the gravity of an SMBH, and thus it is unclear whether this

object hosts a quasar. Its [O III] $\lambda 5007/\text{H}\beta$ ratio (~ 3.7) is moderately high, but this alone cannot securely classify the object as a quasar, as JWST has revealed high- z star-forming galaxies with similarly strong high ionization lines (e.g., Scholtz et al. 2025).

Figure 7 shows that G14 has extremely high velocity width compared to the other galaxies. Normal star-forming galaxies are not expected to produce line profiles significantly broader than 500 km s^{-1} , even in the presence of galactic outflows (e.g., Newman et al. 2012; Swinbank et al. 2019). The turbulent gas kinematics of G14 may be attributed to dynamical interaction with the companion galaxy C2, located to the east-southeast. The present NIRSpec data cube covers C2 at the edge of the IFU field of view. A detailed analysis of the extended emission in the G14-C2 system will be presented in S. Onorato et al. (2026, in preparation).

4. SUMMARY AND CONCLUSIONS

This paper presents the NIRSpec IFU observations of six galaxies at $z \sim 6$, obtained as part of the JWST GO 5645 program (the *Aether* project). The targets were originally identified by the SHELLQs project, as candidate obscured quasars with luminous ($\gtrsim 10^{43} \text{ erg s}^{-1}$) but narrow ($\lesssim 500 \text{ km s}^{-1}$) Ly α emission. The NIRSpec spectra revealed that two objects (G03 and G04) have broad line components (FWHM $> 3000 \text{ km s}^{-1}$) only in permitted Balmer lines, indicating the presence of AGN. The remaining four objects (G08, G12, G13, and G14) show similar profiles in the permitted and forbidden lines.

We combined the above sample with similar SHELLQs objects presented in Matsuoka et al. (2025b), and analyzed their Ly α and H α luminosities. Overall, we found that the dust-extinction correction inferred from the Balmer decrement would result in unreasonably high values of $L_{\text{Ly}\alpha}$. This may indicate that the line-emitting gas consists of multiple zones. We also found that the presence of broad permitted lines is strongly coupled with Ly α luminosity. The inferred AGN fraction is $>77\%$ and $<15\%$ (1σ confidence level) above and below $L_{\text{Ly}\alpha} = 10^{44} \text{ erg s}^{-1}$, respectively. The fairly sharp transition in AGN fraction may be explained by the relatively high LAE number density at $z \sim 6$ and a sharp fall-off of the (non-AGN) LAE LF at the luminous end. The IGM and/or dust absorption of Ly α photons may also be at work.

The extended emission of the six objects exhibits a wide range of apparent morphologies. The two AGN hosts (G03 and G04) have compact morphology, while the other four objects exhibit more extended emission. In particular, the ionized gas of G12 and G13 extends

to 10 kpc and 5 kpc in diameter, respectively. The total SFRs estimated from the $H\alpha$ luminosities of the four objects range from 60 to $600 M_{\odot} \text{ yr}^{-1}$. G03, G04, G08, and G13 show little ordered kinematics, with moderate velocity widths (FWHM) up to $200 - 300 \text{ km s}^{-1}$. A signature of rotation may be visible only in G12. Finally, G14 exhibits an extremely high velocity width, reaching 1000 km s^{-1} . While this object was thought to be a quasar, such a large width of the forbidden [O III] line calls into question whether there is a broad line region in this object.

Combined with the previous work by Matsuoka et al. (2025b), the present analysis reveals the diverse nature of candidate obscured quasars discovered by SHELLQs. Broad permitted lines, indicative of AGN activity, appear almost ubiquitously at the highest $\text{Ly}\alpha$ luminosities. Objects with weaker $\text{Ly}\alpha$ are more likely dominated by star-forming galaxies, some of which exhibit considerably extended regions of ionized gas and total SFR well above $100 M_{\odot} \text{ yr}^{-1}$. The possible presence of obscured AGNs in these objects, which may be traced by high ionization lines or multi-wavelength properties, is left for future studies (e.g., K. Aoki et al. 2026, in preparation). Those candidate obscured quasars occupy the intermediate luminosity regime between classical quasars and the low-luminosity AGNs discovered by JWST, including LRDs, potentially bridging the two populations. JWST/NIRSpec observations of 30 additional SHELLQs objects (see Figure 5) are planned in the Cycle 4 GO 7491 program, promising a more complete exploration of the diversity within this population.

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The GO 5645 data of the six objects described here may be obtained from the MAST archive at [doi:10.17909/yvyw-8667](https://doi.org/10.17909/yvyw-8667). The data available there, however, were pipeline-processed at the STScI, and are therefore not identical to those presented in this paper.

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Table 4. Emission line fluxes and continuum properties

	G03	G04	G08	G12	G13	G14
Emission lines, NL component						
H6	3.47 ± 0.25	1.10 ± 0.14	0.78 ± 0.16	...	...	1.72 ± 0.35
H5	6.57 ± 0.21	2.24 ± 0.12	1.69 ± 0.22	2.00 ± 0.30	1.11 ± 0.15	1.32 ± 0.27
H β	14.59 ± 0.25	5.56 ± 0.15	3.85 ± 0.41	5.10 ± 0.62	3.19 ± 0.25	5.71 ± 0.62
H α	62.34 ± 0.78	28.33 ± 0.56	12.24 ± 1.28	23.35 ± 2.76	10.32 ± 0.72	27.83 ± 2.87
He I $\lambda 4473$	0.69 ± 0.14	<0.43	<0.24	<0.49	<0.22	<0.61
He II $\lambda 4687$	1.04 ± 0.16	0.28 ± 0.08	<0.38	<0.50	<0.50	<1.12
He I $\lambda 5877$	7.12 ± 1.52	1.31 ± 0.11	0.63 ± 0.17	...	...	...
He I $\lambda 6679$	<1.40	<0.82	<0.76	<0.74	<0.47	<1.45
He I $\lambda 7067$	4.35 ± 0.33	1.00 ± 0.19	1.02 ± 0.27	<0.93	<0.24	2.05 ± 0.54
[O III] $\lambda 4363$	4.93 ± 0.20	2.81 ± 0.15	0.51 ± 0.12	<1.06	<0.28	<1.14
[O III] $\lambda 5007$	84.62 ± 0.83	36.61 ± 0.45	30.13 ± 2.15	24.72 ± 2.26	18.35 ± 0.78	21.28 ± 2.27
[O I] $\lambda 6300$	<0.16	<0.75	<0.57	0.72 ± 0.19	<0.46	1.26 ± 0.35
[N II] $\lambda 6585$	1.67 ± 0.30	0.91 ± 0.23	0.95 ± 0.19	4.50 ± 0.44	<0.69	7.56 ± 0.87
[S II] $\lambda 6716$	<0.27	<0.92	0.67 ± 0.21	0.95 ± 0.24	<0.24	<1.93
[S II] $\lambda 6731$	<0.37	<0.48	0.61 ± 0.20	0.85 ± 0.24	<0.74	2.12 ± 0.46
Emission lines, BL component						
H6	4.33 ± 0.85	<3.25	...	...	...	...
H5	2.47 ± 0.65	6.63 ± 0.60	...	...	...	...
H β	10.79 ± 0.60	19.83 ± 0.58	...	...	...	...
H α	38.67 ± 1.71	128.22 ± 1.94	...	...	...	...
He I $\lambda 4473$	<0.99	<0.55	...	...	...	...
He II $\lambda 4687$	2.91 ± 0.55	<0.99	...	...	...	...
He I $\lambda 5877$	1.13 ± 0.27	1.26 ± 0.16	...	...	...	...
He I $\lambda 6679$	5.60 ± 0.92	<1.31	...	...	...	...
He I $\lambda 7067$	8.69 ± 1.14	5.20 ± 1.02	...	...	...	...
Fe II $\lambda 4434\text{-}4684$	<3.21	<2.58	...	...	...	...
Power-law continuum						
F_{5100}	10.86 ± 0.29	14.05 ± 0.26	4.57 ± 0.14	15.33 ± 0.15	10.09 ± 0.14	35.50 ± 0.15
Slope	-0.70 ± 0.13	-0.80 ± 0.09	0.85 ± 0.19	-2.19 ± 0.08	-1.86 ± 0.10	-1.02 ± 0.03

NOTE— Line fluxes and continuum flux densities at 5100 Å (F_{5100}) are given in units of 10^{-18} erg s $^{-1}$ cm $^{-2}$ and 10^{-21} erg s $^{-1}$ cm $^{-2}$ Å $^{-1}$, respectively. The flux upper bounds are defined as the 3σ upper limits.

APPENDIX

A. SPECTRAL MEASUREMENTS

The emission line fluxes and continuum properties of the six objects were measured from the best-fit spectral models, and are reported in the observer’s frame in Table 4.

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