

GA-NIFS: interstellar medium properties and tidal interactions in the evolved massive merging system B14-65666 at $z = 7.152$

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ABSTRACT

We present *JWST*/NIRSpec IFU observations of the $z = 7.152$ galaxy system B14-65666, as part of the GA-NIFS survey. Line and continuum emission in this massive system ($\log_{10}(M_*/M_\odot) = 9.8 \pm 0.2$) is resolved into two strong cores surrounded by diffuse emission, as seen in recent *JWST*/NIRCam imaging. Our data set contains detections of [O II] $\lambda\lambda$ 3726,3729, [Ne III] $\lambda\lambda$ 3869,3968, Balmer lines, [O III] $\lambda\lambda$ 4959,5007, He I λ 5875, and weak [O III] λ 4363. Each spectrum is fit with a model that consistently incorporates interstellar medium conditions (i.e. electron temperature, T_e , electron density, n_e , and colour excess, $E(B - V)$). The resulting line fluxes are used to constrain the gas-phase metallicity ($Z_g \sim 0.2 - 0.3$ solar) and $H\beta$ -based star formation rate for each region. Common line ratio diagrams (O32–R23, R3–R2, Ne3O2–R23) reveal that each line-emitting region lies at the intersection of low- and high-redshift galaxies, suggesting low ionization and higher metallicity compared to the predominantly lower-mass galaxies studied with the *JWST*/NIRSpec IFU so far at $z > 5.5$. Spaxel-by-spaxel fits reveal evidence for both narrow (FWHM < 400 km s $^{-1}$) and broad (FWHM > 500 km s $^{-1}$) line emission, the latter of which likely represents tidal interaction or outflows. Comparison to ALMA [C II]158 μ m and [O III]88 μ m data shows a similar velocity structure, and we explore optical-far infrared diagnostics. The two core galaxies both lie on the mass-metallicity relation at $z > 4$, but show contrasting properties (e.g. M_* , Z_g), suggesting distinct evolutionary pathways. Combining the NIRSpec IFU and ALMA data sets, our analysis opens new windows into the merging system B14-65666.

Key words: galaxies: high-redshift – galaxies: interactions – galaxies: ISM – galaxies: kinematics and dynamics.

1 INTRODUCTION

The first 1 Gyr of the Universe ($z > 6$) was a unique era of cosmic time. The first galaxies emerged (e.g. N. Laporte et al. 2021; E. Curtis-Lake et al. 2023; S. Carniani et al. 2025) and started the process of ionizing their surroundings (e.g. E. Bañados et al. 2018; K. Nakajima et al. 2023). Galaxy formation was rapid

and fruitful, with high galaxy merger rates (e.g. Q. Duan et al. 2025), and evidence for increasing volume density of molecular gas (e.g. D. A. Riechers et al. 2019; M. Aravena et al. 2024; C. Ragone-Figueroa et al. 2024) and star formation rate (SFR; e.g. C. Gruppioni et al. 2020; Y. Khusanova et al. 2021; A. Traina et al. 2024) with increasing cosmic time, based on extrapolation from $3 < z < 6$.

The first $z > 6$ galaxies were detected less than three decades ago (e.g. X. Fan et al. 2001; E. M. Hu et al. 2002; E. R. Stanway, A. J. Bunker & R. G. McMahon 2003; Y. Taniguchi et al. 2005), but

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through the advent of cutting edge telescopes, the redshift frontier has already been extended to within the first ~ 300 Myr of the Universe ($z > 13$; e.g. S. Carniani et al. 2024; V. Kokorev et al. 2025; J. Witstok et al. 2025). Morpho-kinematic studies of high-redshift galaxies with ALMA revealed a population of relaxed rotating disc galaxies (e.g. M. Neeleman et al. 2020; F. Lelli et al. 2021; R. Herrera-Camus et al. 2022; L. E. Rowland et al. 2024), but many observations revealed clumpy or merging systems (e.g. S. Carniani et al. 2018; G. C. Jones et al. 2021; L. L. Lee et al. 2025). This was supported by the results of zoom-in cosmological simulations, which showed that bright $z > 6$ galaxies accreted mass through frequent interactions with lower-mass satellites and/or collisions (e.g. M. Kohandel et al. 2019; A. Pallottini et al. 2022). However, most spectroscopic ALMA observations featured low spatial resolution (~ 1 arcsec, corresponding to ~ 6 kpc at $z = 6$).

This picture was made even clearer with the advent of *James Webb Space Telescope* (*JWST*; J. P. Gardner et al. 2023) and the integral field unit (IFU) on the NIRSpec instrument (T. Böker et al. 2022; P. Jakobsen et al. 2022). With a narrow point spread function (~ 0.1 – 0.2 arcsec or 0.6 – 1.2 kpc at $z = 6$; F. D’Eugenio et al. 2024), the NIRSpec IFU is able to map multiple bright rest-UV and rest-optical lines at $z > 4$ (e.g. $H\alpha$, $[\text{O III}]\lambda\lambda 4959, 5007$). While *JWST* follow-up observations of some galaxies classified as rotators based on previous rest-frame far-infrared (FIR) observations confirmed their nature (e.g.; ALESS73.1, F. Lelli et al. 2021; E. Parlanti et al. 2024; GN20, J. A. Hodge et al. 2012; H. Übler et al. 2024b), other galaxies were found to feature clumpy morphologies, close companions, and sometimes outflows (e.g.; HZ10, G. C. Jones et al. 2017, 2025c; HZ4, R. Herrera-Camus et al. 2022; E. Parlanti et al. 2025; COS3018, R. Smit et al. 2018; J. Scholtz et al. 2025). Due to the detection of multiple emission lines, these data were used to map morphology, kinematics, and the interstellar medium (ISM) conditions (e.g. electron density n_e and temperature T_e , and gas-phase metallicity Z_g) of each target.

A number of *JWST*/NIRSpec IFU observations have already detailed the properties of $z > 6$ galaxies (e.g. T. Hashimoto et al. 2023a; R. Decarli et al. 2024; W. Liu et al. 2024; G. Venturi et al. 2024; S. Fujimoto et al. 2025; J. Lyu et al. 2025; M. Messa et al. 2025; J. Scholtz et al. 2025). Many of these have been acquired as part of the Galaxy Assembly with NIRSpec Integral Field Spectroscopy (GA-NIFS).¹ Guaranteed Time Observation (GTO) survey (Cycles 1 and 3; PIs R. Maiolino & S. Arribas; e.g. M. A. Marshall et al. 2023; S. Arribas et al. 2024; G. C. Jones et al. 2024; C. Marconcini et al. 2024; H. Übler et al. 2024a; C. Marconcini et al. 2025; M. A. Marshall et al. 2025; J. Scholtz et al. 2025). This survey, which includes 55 targets between $2 < z < 11$, was designed to exercise the power of the NIRSpec IFU through observations of a variety of well-studied galaxies (e.g. star-forming galaxies, active galactic nucleus [AGN] host galaxies, quasars). In this work, we present the GA-NIFS observations of the $z \sim 7.152$ Lyman break galaxy (LBG) B14-65666.

A key factor in the discovery of B14-65666 was the Ultra Deep Survey with the VISTA (Visible and Infrared Survey Telescope for Astronomy; J. P. Emerson & W. J. Sutherland 2010) telescope (UltraVISTA; H. J. McCracken et al. 2012), which targeted the COSMOS field (N. Scoville et al. 2007) in Y , J , H , and K_s near-infrared bands. Combining UltraVISTA DR1 with other optical and infrared data, R. A. A. Bowler et al. (2012) first reported B14-65666 as one of only four robust $z > 6.5$ galaxies from a sample

of $> 2 \times 10^5$ detected sources. R. A. A. Bowler et al. (2014) performed a follow-up photometric SED modelling analysis combining UltraVISTA DR2 and additional data, improving the accuracy of the photometric redshift of this source.

The first resolved image of this source was taken with *HST*/WFC3 F140W (R. A. A. Bowler et al. 2017), where two closely separated clumps (aligned nearly east–west) are visible. ALMA follow-up observations of the source were first performed in R. A. A. Bowler et al. (2018), where B14-65666 was the only dust continuum detected source in Band 6 in a sample of six luminous LBGs. T. Hashimoto et al. (2019) confirmed the dust continuum detection and morphology of this source. In addition, they detected the spatially resolved $[\text{C II}]\lambda 158\mu\text{m}$ ($L_{[\text{C II}]\lambda 158\mu\text{m}} = (11.0 \pm 1.4) \times 10^8 L_\odot$) and $[\text{O III}]\lambda 88\mu\text{m}$ ($L_{[\text{O III}]\lambda 88\mu\text{m}} = (34.4 \pm 4.1) \times 10^8 L_\odot$) FIR lines, which provided spectroscopic redshift confirmation ($z_{\text{sys}} = 7.1520 \pm 0.0003$)² Modelling of the two-point dust SED yielded $T_{\text{dust}} \sim 50$ – 60 K and $L_{\text{FIR}} \sim 10^{12} L_\odot$. The dust continuum emission appears to be elongated, potentially aligned with the two components (see also R. A. A. Bowler et al. 2022 who find the dust to be between the two UV clumps). Based on these properties, Hashimoto et al. suggest that B14-65666 is a merger-driven starburst.

Follow-up ALMA observations did not return a significant $[\text{N II}]\lambda 122\mu\text{m}$ emission ($< 8.1 \times 10^7 L_\odot$), but strong underlying FIR continuum emission (Y. Sugahara et al. 2021). Detailed dust SED modelling returned similar T_{dust} and L_{FIR} constraints as T. Hashimoto et al. (2019), with an additional estimate on the dust mass of $M_{\text{dust}} \sim 10^7 M_\odot$. Similarly, ALMA observations of reliable molecular gas tracers ($\text{CO}(7-6)$, $\text{CO}(6-5)$, $[\text{C I}](2-1)$) and their underlying dust continuum emission resulted in non-detections (T. Hashimoto et al. 2023a). The molecular gas mass estimates implied by these non-detections are in agreement with the mass found through scaling relations based on the detection of $[\text{C II}]\lambda 158\mu\text{m}$ (S. C. Madden et al. 2020), FIR continuum emission (Q. Li, D. Narayanan & R. Davé 2019), and the kinematics of the $[\text{C II}]\lambda 158\mu\text{m}$ emission (T. Hashimoto et al. 2019): $M_{\text{mol}} = 10^{8.7-11.0} M_\odot$.

JWST/NIRCam imaging of B14-65666 was presented by Y. Sugahara et al. (2025) as part of the ‘Reionization and the ISM/Stellar Origins with *JWST* and ALMA’ (RIOJA) project (*JWST* GO1 PID1840; PIs: J. Álvarez-Márquez and T. Hashimoto; T. Hashimoto et al. 2023b). From the flux excess between the F356W and F444W bands they infer the presence of strong $[\text{O III}]\lambda 5007$ emission (rest-frame equivalent widths of 1000–2000 Å; as expected from the observed Spitzer colours; R. A. A. Bowler et al. 2014). Interestingly, the inferred $[\text{O III}]\lambda 5007$ emission peaks in the Eastern component of the source, where the rest-frame UV emission is weaker. Through SED fitting of the resolved NIRCam and ALMA multi-band fluxes, Y. Sugahara et al. (2025) derive a stellar mass of $\log_{10}(M_*/M_\odot) = 9.78^{+0.16}_{-0.18}$ and a relatively low metallicity of $(Z_*/Z_\odot) = 0.21^{+0.05}_{-0.04}$. The extremely high spatial resolution of the NIRCam data reveals that the Eastern component is compact, while the Western component is spatially extended. Additional low surface brightness features are

²Because it was the first galaxy in the Epoch of Reionization (EoR) with spatially resolved emission in three powerful tracers ($[\text{C II}]\lambda 158\mu\text{m}$, $[\text{O III}]\lambda 88\mu\text{m}$, and dust continuum emission), it was given the alternative alias of ‘Big Three Dragons’ after a combination of tiles in the game *Mahjong*.

¹<https://ga-nifs.github.io/>

Table 1. *JWST* NIRSpec/IFU observation properties.

Grating/filter	G395M/290LP
Readout pattern	NRSIRS2
Groups/int	25
Ints/exp	1
Exposures/dithers	8
Total time (ks)	14.7

identified as tidal tails. Recent *JWST*/MIRI MRS observations (C. Prieto-Jiménez et al. 2025) revealed strong $H\alpha$ emission from the two core components, with component E exhibiting a higher dust attenuation.

In this work, we exploit NIRSpec IFU observations from $\lambda_{\text{obs}} = 2.9\text{--}5.3\ \mu\text{m}$ to directly map the strength of the rest-frame optical emission lines across the source. In Section 2, we describe both our new *JWST*/NIRSpec IFU data for B14-65666 as well as archival data explored in this work. The NIRSpec data are then analysed in Section 3. We interpret and discuss these results in Section 4 and conclude in Section 5. We use a standard concordance cosmology (i.e. $H_0 = 70\ \text{km s}^{-1}\ \text{Mpc}^{-1}$, $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$) throughout, where 0.1 arcsec corresponds to $\sim 0.52\ \text{kpc}$ at $z = 7.152$. A G. Chabrier (2003) initial mass function (IMF) with an upper mass limit of $100\ M_\odot$ is assumed.

2 DATA DESCRIPTION

2.1 *JWST*/NIRSpec IFU

The data analysed here originated from GA-NIFS observations as part of project 1217 (PI: N. Luetzgendorf; details in Table 1). An eight-point ‘MEDIUM’ dither pattern was used, with a starting point of ‘1’. Data were taken at medium spectral resolution (G395M/F290LP; $R \sim 1000$), covering $\lambda_{\text{obs}} = 2.871\text{--}5.270\ \mu\text{m}$ ($\lambda_{\text{rest}} \sim 3522\text{--}6465\ \text{\AA}$ at $z = 7.1520$). No *leakcal* or background exposures were taken. The data were calibrated with the STScI pipeline (v1.15.0, CRDS 1241), with custom outlier rejection (F. D’Eugenio et al. 2024), custom masks for contamination by cosmic ray strikes (‘snowballs’) and open MSA shutters leakage, 1/f noise corrections for count-rate maps, and drizzle weighting to create a data cube with spatial pixels (spaxels) of width 0.05 arcsec (see M. Perna et al. 2023 for full details of reduction). To ease spatial comparison of emission at different wavelengths, we homogenize the PSF of the cube (see Appendix A).

Previous analyses of *JWST*/NIRSpec IFU data (e.g. G. C. Jones et al. 2024; H. Übler et al. 2024b; E. Parlanti et al. 2025) found astrometric errors due to the pointing accuracy of *JWST* (~ 0.1 arcsec; J. Rigby et al. 2023). To correct this, we align our data to the *Gaia* DR3 reference frame (Gaia Collaboration et al. 2016, 2021) through a comparison to *JWST*/NIRCam data (see Appendix B).

No background exposures were included in these observations, so we manually performed a background subtraction. For each wavelength of our data cube, we first temporarily mask the containing significant emission, and then use the PHOTUTILS task *Background2D* with a box size of 10 px and filter size of 5 px to create a spatially smoothed background map. These background maps are merged into a background cube, which is spectrally smoothed using a median filter of width 25 channels. We verify that this background cube does not contain any spectral features, and subtract it from the observed data cube.

JWST/NIRSpec IFU observations of high-redshift galaxies revealed the presence of sinusoidal artefacts (‘wiggles’) in single-spaxel spectra (e.g. M. Perna et al. 2023; R. Decarli et al. 2024; L. Ulivi et al. 2025). These wiggles, which were caused by undersampling of the PSF, were more noticeable for drizzled maps featuring bright point sources coincident with extended emission (i.e. AGN and QSOs). We have followed the procedure of M. Perna et al. (2023) to inspect our data for these wiggles, finding little evidence of strong wiggles in our data. While their presence may be detected as high-frequency residuals in spectral fits (see analysis in Section 3.1), they are very low-level ($\lesssim 2$ per cent, or $< 2\sigma$), so a correction is not applied.

2.2 ALMA

Due to the bright nature of this high-redshift source, ALMA has been used to target its emission in CO(6–5), CO(7–6), and [C I](2–1) (2018.1.01673.S, PI Hashimoto), [C II]158 μm (2016.1.00954.S, PI Inoue), [O III]88 μm (2016.1.00954.S and 2017.1.00190.S, PI Inoue), and [N II]122 μm (2019.1.01491.S, PI Inoue). In order to compare the distribution of these lines (with their underlying continuum emission) and our data, we re-image each data set.

To begin, we download all data from the ALMA data archive and run the calibration pipeline provided by NRAO staff.³ The calibrated data for B14-65666 was split out, and a 30 s time average was performed to ease data usage. Data were combined for each band (3, S. Claude et al. 2008; A. R. Kerr et al. 2014; 6, G. A. Ediss et al. 2004; A. R. Kerr et al. 2004; 7, S. Mahieu et al. 2012; 8, Y. Sekimoto et al. 2008).

Continuum images were created with the CASA task *tclean* in multi-frequency synthesis (MFS) mode, natural weighting, cell sizes of 1/5th the full width at half-maximum (FWHM) of the minor axis of the synthesized beam, and excluding all data within $\pm 1000\ \text{km s}^{-1}$ of expected line emission. ‘Clean’ continuum maps were created by cleaning down to $3\times$ the RMS noise level of initial ‘dirty’ images.

No significant line emission is detected for CO(6–5), CO(7–6), [C I](2–1), or [N II]122 μm (as originally found by T. Hashimoto et al. 2023a and Y. Sugahara et al. 2021), while [C II]158 μm and [O III]88 μm are strongly detected. For the latter two lines, we create clean line + continuum cubes using CASA *tclean* in ‘cube’ mode with natural weighting and cell sizes of 1/5th the FWHM of the minor axis of the synthesized beam. Each cube is continuum subtracted in the image plane.⁴ using the CASA task *imcontsub*. The continuum level in each spaxel is found by fitting the line-free channels in the spectrum with a first-order polynomial (using the same $\pm 1000\ \text{km s}^{-1}$ range as above), and the resulting continuum emission is removed. This results in a continuum-free data cube.

2.3 *JWST*/NIRCam

B14-65666 was observed with *JWST*/NIRCam in multiple filters as part of Project 1840 (PI J. Alvarez-Marquez; see detailed analysis of Y. Sugahara et al. 2025). Of these, we use only the F356W filter for astrometric correction (see Appendix B). This NIRCam image was downloaded from the Mikulski Archive for Space

³2019.1.01491.S was calibrated directly by the ALMA helpdesk.

⁴Due to the resolved, relatively weak nature of the line emission, this is preferable to visibility-space continuum subtraction.

Table 2. Details of elliptical apertures used in this work, as adopted from *JWST*/MIRI analysis of C. Prieto-Jiménez et al. (2025). We include the central position (RA and Dec.), half-width at half-maximum (HWHM) along the major and minor axes, and position angle (PA). We primarily utilize the first two apertures, which are designed to capture emission from the two core galaxies.

Aperture Name	RA [°]	Dec. [°]	HWHM [″×″]	PA [°]
E	150.4195767	1.9146156	0.211 × 0.201	112.83
W	150.4194613	1.9145781	0.228 × 0.177	112.83
E + W	150.4195242	1.9145981	0.456 × 0.343	85.83
Total	150.4195242	1.9145981	0.9 × 0.9	-

Telescopes (MAST⁵). By inspecting the position of a *Gaia* DR3 reference star in the F356W image, we determine a spatial offset and align it to *Gaia* frame.

3 NIRSPEC ANALYSIS

Our *JWST*/NIRSpec IFU data cube allows us to explore line and continuum emission from B14-65666 on a spatially and spectrally resolved basis. In this section, we first characterize the field by fitting integrated spectra using emission-based apertures (Section 3.1). We then exercise the power of the NIRSpec IFU by extracting and fitting spectra from each individual spaxel (Section 3.2), opening a more detailed view into the ISM conditions and morpho-kinematics of B14-65666.

3.1 Spatially integrated spectral analysis

First, we characterize the emission in the field by extracting integrated spectra from our NIRSpec data cube using the apertures created by the recent *JWST*/MIRI analysis of B14-65666 by C. Prieto-Jiménez et al. (2025), which are listed in Table 2. These apertures were created to characterize the two bright cores of emission (named ‘E’ and ‘W’), as well as their sum (‘E + W’) and a larger aperture that is designed to capture all significant line emission (‘Total’). We proceed with apertures ‘E’ and ‘W’ in this subsection. Throughout this work, we will refer to these apertures as ‘cores’. After extracting each spectrum, we perform an aperture loss correction (see Appendix A for details).

3.1.1 Model description

For the spectrum from each aperture, we assume that the continuum is described by a single power law model. Since the bluest edge of our data ($\lambda_{\text{rest}} \sim 3620\text{\AA}$) extends slightly bluewards of the Balmer break ($\lambda_{\text{rest}} \sim 3646\text{\AA}$), it is possible that the continuum is affected by Balmer absorption features and/or in a change in slope bluewards of [Ne III] $\lambda 3869$, as seen in quenched galaxies (e.g. T. J. Looser et al. 2024; F. D’Eugenio et al. 2025). However, we do not detect such features in our data, and the simple model returns low residuals (see Fig. 1).

To account for line emission, we include contributions from [O II] $\lambda\lambda 3726, 3729$, [Ne III] $\lambda\lambda 3869, 3968$, Balmer lines (H η , H ζ , H δ , H ϵ , H β), He I $\lambda 3889$, [O III] $\lambda 4363$, [O III] $\lambda\lambda 4959, 5007$, and He I $\lambda 5875$ in our model. Because some lines exhibit asymmetric wings, we follow other investigations of high- z galaxies with

NIRSpec and fit each emission line with two components: one narrow (FWHM $\leq 350 \text{ km s}^{-1}$) and one broad, representing tidal features or an outflow ($350 \leq \text{FWHM} \leq 1000 \text{ km s}^{-1}$; e.g. I. Lamperti et al. 2024; B. Rodríguez Del Pino et al. 2024). A one-Gaussian fit returns large residuals for each of the strong lines ([O III] $\lambda 5007$, [O III] $\lambda 4959$, [O II] $\lambda\lambda 3726, 3729$), suggesting that a two-Gaussian fit is needed. This approach is preferred to Voigt profiles (e.g. G. C. Jones et al. 2024), as it allows for the fitting of asymmetric lines.

Due to the spectral blending of multiple lines (e.g. He I $\lambda 3889$ and H ζ , [Ne III] $\lambda 3968$ and H η), a global fit of each extracted spectrum results in poor constraints on line fluxes. To lower the degrees of freedom in our model, we make the standard assumption of case B recombination (J. G. Baker & D. H. Menzel 1938; e.g. W. Hu et al. 2024; G. Venturi et al. 2024; M. Solimano et al. 2025)⁶ and use the python package PYNEB (V. Luridiana, C. Morisset & R. A. Shaw 2015) to calculate line ratios based on ISM conditions (i.e. electron temperature T_e , electron density n_e , and $B - V$ colour excess $E(B - V)$; see further discussion in Appendix C).

We fit each extracted spectrum in stages. First, we examine a broad wavelength range that includes only the strongest line ([O III] $\lambda 5007$) and the underlying continuum. Using LMFIT, we fit for the continuum properties (i.e. power law slope and normalization) and the fluxes ($F_{[\text{O III}]\lambda 5007, \text{N}}$, $F_{[\text{O III}]\lambda 5007, \text{B}}$), widths (FWHM_N, FWHM_B), and redshifts (z_{N} , z_{B}) of the narrow and broad components of [O III] $\lambda 5007$. An initial fit is performed where all variables are allowed to vary. The results of this fit are inspected, and components with poorly determined (i.e. $< 3\sigma$) or negligible fluxes (i.e. $< 10^{-21} \text{ erg s}^{-1} \text{ cm}^{-2}$) are removed from the model before the fit is repeated. This process repeats until LMFIT reports convergence. In the following steps, we assume that these linewidths and redshifts are applicable to each line, and apply the component rejection criteria at each step.

Next, we isolate the wavelength ranges around the strongest observed Balmer line (H β) and helium line (He I $\lambda 5875$), and find the fluxes of the narrow and broad components of each. While the ratio of the two lines in the [O II] $\lambda\lambda 3726, 3729$ doublet is a useful tracer of electron density (e.g. L. J. Kewley et al. 2019), their close separation requires high spectral resolution for detailed fitting ($R \gtrsim 2700$; J. Comparat et al. 2013). This is achievable with high-resolution *JWST*/NIRSpec gratings (e.g. J. Chisholm et al. 2024; B. Rodríguez Del Pino et al. 2024), but our resolution is a factor of ~ 3 more coarse. Therefore, we fix n_e to the fiducial value of $n_e = 200 \text{ cm}^{-3}$ (Y. Sugahara et al. 2025), calculate the ratio of [O II] $\lambda 3726$ /[O II] $\lambda 3729$ using PYNEB, and fit for the fluxes of each line with LMFIT.

For the next step, we consider a range that contains the next two strongest observed Balmer lines (H γ and H δ), as well as two oxygen lines ([O III] $\lambda 4959$, [O III] $\lambda 4363$). The flux ratios of each Balmer line pair are related through ISM conditions and dust extinction (here parametrized as $E(B - V)$, where we assume a D. Calzetti et al. 2000 dust attenuation curve), while [O III] $\lambda 4363$ /[O III] $\lambda 5007$ is a strong function of T_e , and [O III] $\lambda 4959$ /[O III] $\lambda 5007$ (which is fixed by atomic physics to be 2.984) is only a function of $E(B - V)$. Thus, by taking our previously measured H β flux and assuming a fiducial density, we are able to fit for the fluxes of the narrow and broad components of these four lines self-consistently with few parameters ($T_{e, \text{N}}$, $T_{e, \text{B}}$,

⁵<https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html>

⁶Although we note that the applicability of this assumption for high-redshift galaxies has been called into question (e.g. C. Scarlata et al. 2024).

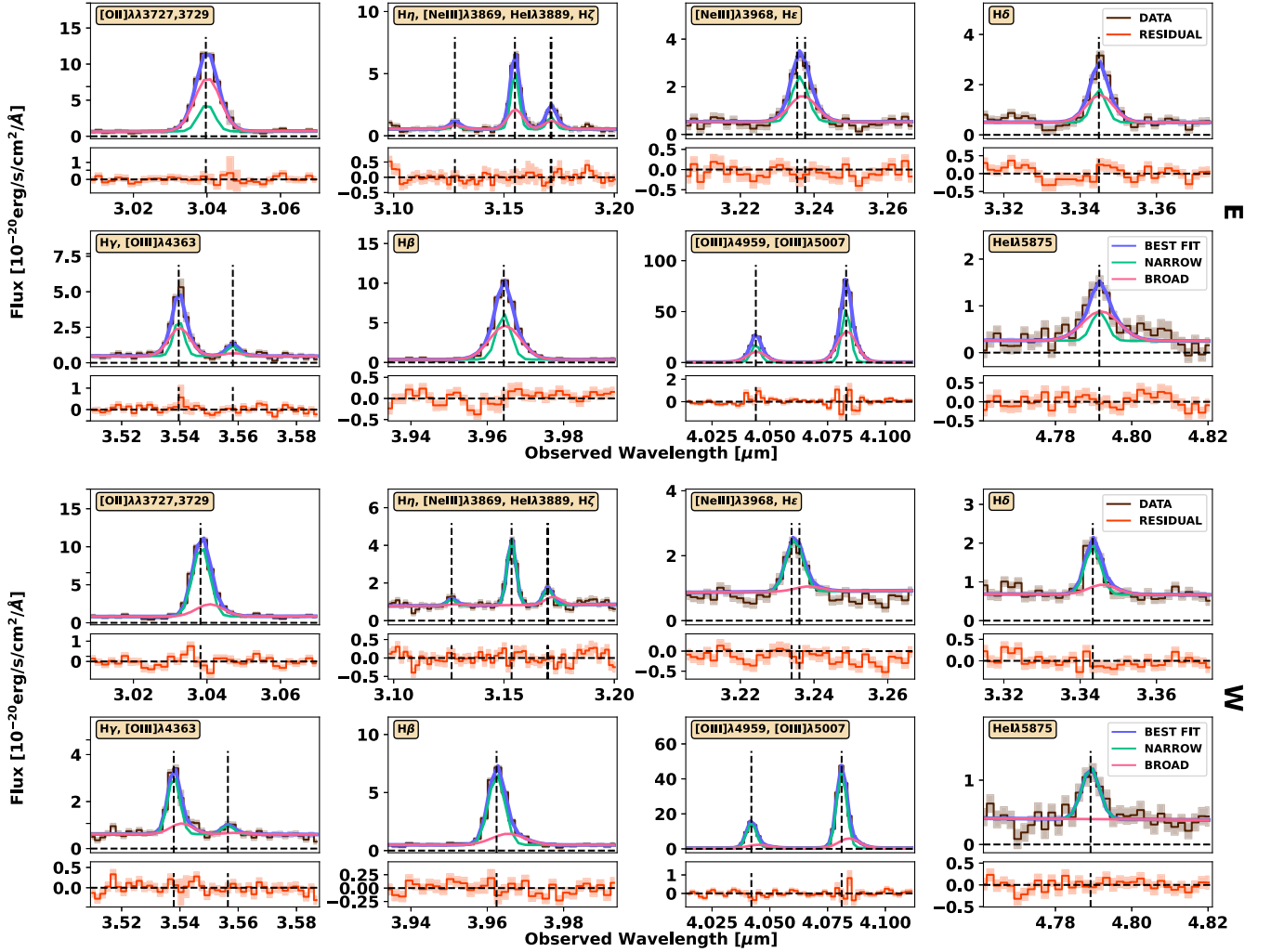


Figure 1. Spectra extracted from our *JWST*/NIRSpec IFU data cube using the two primary apertures (E and W, see Table 2). Aperture loss corrections (see Appendix A) have been applied to each spectrum. We zoom in around each emission line and present the observed spectrum, the best-fitting model, and its narrow and broad components. The residual is included in the lower panel. The redshifted wavelengths of each fit line (using the best-fitting redshift of the narrow component) are marked with vertical dashed lines.

$E(B - V)_N$, $E(B - V)_B$). The work of Y. Sugahara et al. (2025) estimated the dust reddening of the stellar continuum in this system to be $A_V^* \sim 0.3 - 1.2$, which corresponds to ionized gas colour excess of $E(B - V) \sim 0.2 - 0.7$. Thus, if our fits return large uncertainties on $E(B - V)$ or T_e (i.e. best-fitting values that are $< 3 \times$ the reported uncertainty), then we assume a value of $E(B - V) = 0.2$ (i.e. the smallest value found by Y. Sugahara et al. 2025) or $T_e = 1.2 \times 10^4$ K (Y. Sugahara et al. 2025), respectively.

As a final step, we fit for the flux of $[\text{Ne III}]\lambda 3869$. The flux of $[\text{Ne III}]\lambda 3968$ is calculated using the ratio of $[\text{Ne III}]\lambda 3968/[\text{Ne III}]\lambda 3869$ (as fixed by atomic physics; 0.301), and we use the previously determined ISM properties and line fluxes to calculate the fluxes of each remaining Balmer line ($\text{H}\eta$, $\text{H}\epsilon$) and helium line ($\text{He I } \lambda 3889$).

Our fits take the fiducial line spread function (LSF) of NIRSpec⁷ into account. This varies from ~ 400 km s⁻¹ (FWHM) at

the wavelength of $[\text{O II}]\lambda\lambda 3726, 3729$ to ~ 300 km s⁻¹ at the wavelength of $\text{He I } \lambda 5875$. We experimented with allowing the LSF to vary from the fiducial value by 50 per cent (e.g. A. Graaff et al. 2024), but the resulting fits were not well-constrained. The LSF-corrected FWHM and redshift of all lines are fixed for each narrow and broad component.

For each spectrum, our model therefore has two contributions: the power-law continuum (with a variable slope and normalization) and the broad and narrow line-emitting components (each with its variable T_e , z , FWHM, $E(B - V)$, and dust-corrected fluxes of all independent lines: $[\text{O II}]\lambda 3726$, $[\text{Ne III}]\lambda 3869$, $\text{H}\beta$, $[\text{O III}]\lambda 5007$, $\text{He I } \lambda 5875$). The best-fitting continuum and line properties are presented in Table 3 while the resulting spectra are shown in Fig. 1.

3.1.2 Results and further measurables

Each spectrum features strong line emission (Fig. 1), with best-fitting T_e values within 1σ of the fiducial value of 1.2×10^4 K (Table 3), comparable to conditions in other high-redshift galaxies

⁷As recorded in the *JWST* documentation: <https://jwst-docs.stsci.edu/jwst-near-infrared-spectrograph/nirspec-instrumentation/nirspec-dispersers-and-filters>

Table 3. Best-fitting continuum and observed (i.e. not dust corrected) line properties of each component, as derived through spectral fits. The best-fitting continuum slope is defined as the power law slope of F_λ , and the flux density at $\lambda_{\text{obs}} = 4\mu\text{m}$ is given in units of $[10^{-20}\text{erg s}^{-1}\text{cm}^{-2}\text{\AA}^{-1}]$. For the narrow and broad component, we list the intrinsic (LSF-corrected) FWHM (in units of $[\text{km s}^{-1}]$) and redshift. The best-fitting fluxes of each line are given in units of $[10^{-20}\text{erg s}^{-1}\text{cm}^{-2}]$. We only list the fluxes of the independent lines, and note that the dependent line fluxes ($[\text{O II}]\lambda 3726$, $[\text{Ne III}]\lambda 3869$, $[\text{O III}]\lambda 4959$, $[\text{O III}]\lambda 4363$, and multiple Balmer lines) are determined using the listed T_e , $E(B - V)$, and the assumed $n_e = 200\text{cm}^{-3}$ (see Section 3.1.1).

		E	W
Continuum slope		-1.01 ± 0.24	-1.45 ± 0.17
$F(\lambda_{\text{obs}} = 4\mu\text{m})$		0.357 ± 0.007	0.480 ± 0.007
$T_e [10^4\text{K}]$	N	1.34 ± 0.22	1.16 ± 0.10
	B	1.00 ± 0.32	(1.2)
$E(B - V)$	N	(0.2)	0.38 ± 0.07
	B	(0.2)	(0.2)
FWHM	N	156 ± 13	231 ± 8
	B	653 ± 11	698 ± 26
z	N	7.1526 ± 0.0001	7.1487 ± 0.0001
	B	7.1533 ± 0.0001	7.1551 ± 0.0007
$F_{[\text{O II}]\lambda 3727}$	N	86 ± 10	224 ± 8
	B	273 ± 13	62 ± 9
	Total	359 ± 17	286 ± 12
$F_{\text{Ne III}\lambda 3968}$	N	210 ± 18	174 ± 7
	B	135 ± 24	(0)
	Total	344 ± 30	174 ± 7
$F_{\text{H}\beta}$	N	273 ± 13	324 ± 8
	B	432 ± 17	104 ± 9
	Total	705 ± 22	428 ± 12
$F_{[\text{O III}]\lambda 5007}$	N	2472 ± 98	2318 ± 57
	B	3133 ± 97	599 ± 59
	Total	5605 ± 138	2917 ± 82
$F_{\text{He I}\lambda 5875}$	N	32 ± 12	46 ± 5
	B	75 ± 20	(0)
	Total	107 ± 23	46 ± 5

(e.g. W. Hu et al. 2024; A. Torralba-Torregrosa et al. 2024; T. Y.-Y. Hsiao et al. 2024a). From all of the regions and components, only the narrow component of component ‘W’ features dust attenuation higher than the fiducial value.

The residuals around $[\text{O III}]\lambda 5007$ (lower panels of Fig. 1) show sawtooth-like patterns. These residuals are only a few per cent of the peak flux of $[\text{O III}]\lambda 5007$, and may imply a non-Gaussian LSF or emission profile. While these patterns are similar to those obtained when fitting a spectrum with a model that is lacking complexity (e.g. M. Ginolfi et al. 2020), the addition of another free Gaussian component (representing either an outflow or an additional emitter) does not improve the fit. At first glance, they appear to be similar to the ‘wiggles’ seen in other IFU studies (e.g. M. Perna et al. 2023). However, these features are mostly seen from single-spaxel extractions that undersample the PSF, resulting in large-amplitude oscillations over a wide wavelength range. Since we extract spectra using larger apertures and observe artefacts that only appear within the FWHM of each line, they are likely not wiggles.

The use of a single continuum model (measured around $[\text{O III}]\lambda 5007$) for the full wavelength range results in low residuals for most of the lines explored here. One minor exception is that of $[\text{Ne III}]\lambda 3968 + \text{H}\eta$ in component ‘W’, where the continuum

Table 4. Best-fitting line ratios, gas-phase metallicities (M. Curti et al. 2020), $\text{H}\beta$ -based SFRs, and ionization parameter U (see Section 3.1.2) of each region. All values are dust corrected using the best-fitting $E(B - V)$ values listed in Table 3.

		E	W
O32	N	9.41 ± 1.29	2.68 ± 0.13
	B	3.77 ± 0.23	3.18 ± 0.61
	Total	5.12 ± 0.29	2.73 ± 0.13
R3	N	8.84 ± 0.56	6.82 ± 0.23
	B	7.08 ± 0.36	5.64 ± 0.73
	Total	7.76 ± 0.31	6.67 ± 0.22
R2	N	0.94 ± 0.13	2.54 ± 0.12
	B	1.88 ± 0.12	1.78 ± 0.33
	Total	1.52 ± 0.09	2.44 ± 0.11
R23	N	12.74 ± 0.74	11.65 ± 0.34
	B	11.33 ± 0.52	9.31 ± 1.02
	Total	11.88 ± 0.43	11.35 ± 0.33
Ne3O2	N	1.00 ± 0.16	0.31 ± 0.02
	B	0.20 ± 0.04	–
	Total	0.39 ± 0.04	0.28 ± 0.02
$Z_g [Z_\odot]$	N	0.18 ± 0.03	0.32 ± 0.04
	B	0.27 ± 0.04	0.30 ± 0.05
	Total	0.23 ± 0.03	0.32 ± 0.04
$\text{SFR}_{\text{H}\beta}$	N	39 ± 19	99 ± 38
	B	61 ± 27	13 ± 6
	Total	100 ± 33	113 ± 38
$\log_{10}(U)$	N	-2.24 ± 0.05	-2.68 ± 0.02
	B	-2.56 ± 0.02	-2.62 ± 0.07
	Total	-2.45 ± 0.02	-2.67 ± 0.02

appears to be overestimated. Because the continuum of neighbouring lines ($\text{H}\zeta$ and $\text{H}\delta$) are well-estimated, this may reflect a calibration issue in this wavelength range (e.g. unflagged cosmic ray hits or improper background subtraction). But because the line fluxes of $[\text{Ne III}]\lambda 3968$ and $\text{H}\eta$ are estimated using other line fluxes and ISM conditions, this does not affect any of our findings.

We use the best-fitting line fluxes to calculate standard line ratios:

- (i) $\text{O}32 \equiv [\text{O III}]\lambda 5007 / ([\text{O II}]\lambda\lambda 3726, 3729)$
- (ii) $\text{R}3 \equiv [\text{O III}]\lambda 5007 / \text{H}\beta$
- (iii) $\text{R}2 \equiv [\text{O II}]\lambda\lambda 3726, 3729 / \text{H}\beta$
- (iv) $\text{R}23 \equiv ([\text{O III}]\lambda\lambda 4959, 5007 + [\text{O II}]\lambda\lambda 3726, 3729) / \text{H}\beta$
- (v) $\text{Ne}3\text{O}2 \equiv [\text{Ne III}]\lambda 3869 / ([\text{O II}]\lambda\lambda 3726, 3729)$

All of these (with the exception of Ne3O2) are then used to calculate the gas-phase metallicity using the strong-line diagnostics calibrated by M. Curti et al. (2020, see their table 2 and equation 1). The resulting values are listed in Table 4. We find total gas-phase metallicities of $(Z_g/Z_\odot) \sim 0.2 - 0.3$ for each region, in general agreement with the values derived by Y. Sugahara et al. (2025) using optical-FIR diagnostics (i.e. $Z_g/Z_\odot \simeq 0.2$).

Next, we infer the SFR using the best-fitting dust-corrected $\text{H}\beta$ flux. This is converted to an $\text{H}\alpha$ flux using the extinction-free ratio of $\text{H}\alpha/\text{H}\beta$ (as derived with PyNEB assuming case B recombination). The conversion of N. A. Reddy et al. (2018), which is appropriate for the metallicity of this system ($Z_g/Z_\odot \sim 0.28$), is then used to convert the estimated $\text{H}\alpha$ flux to SFR. When calculating the uncertainty of this value, we include the errors on T_e , $\text{H}\beta$ flux, and $E(B - V)$ (where a minimum uncertainty of 0.1 is assumed).

The combination of apertures E and W yield a total SFR = $213 \pm 50 M_\odot \text{yr}^{-1}$, which is in agreement with the SED-based estimate of T. Hashimoto et al. (2019, SFR = $200^{+82}_{-38} M_\odot \text{yr}^{-1}$) as

well as the instantaneous ($\text{SFR}_0 = 225^{+71}_{-56} M_\odot \text{yr}^{-1}$) and 10 Myr-averaged ($\text{SFR}_{10\text{Myr}} = 207^{+65}_{-51} M_\odot \text{yr}^{-1}$) values from Y. Sugahara et al. (2025). Since $\text{SFR}_{\text{H}\alpha}$ traces star formation over the past 5 Myr (e.g. J. A. Flores Velázquez et al. 2021; S. Tacchella et al. 2022), this agreement is expected. The fact that our SFR (from only the two core galaxies) is comparable to the other values (which were derived from the entire field) suggests that the majority of the star formation activity originates from the core galaxies rather than the diffuse emission.

We are also able to determine if this source lies on the star-forming main sequence (SFMS). By combining the best-fitting stellar mass of the system ($\log_{10}(M_*/M_\odot) = 9.78^{+0.16}_{-0.18}$; Y. Sugahara et al. 2025) with the framework of J. S. Speagle et al. (2014), the expected SFMS-based SFR of this source is $40^{+50}_{-22} M_\odot \text{yr}^{-1}$. The framework of R. M. Mérida et al. (2025) yields a similar expected value of $\text{SFR} = 47^{+42}_{-22} M_\odot \text{yr}^{-1}$. The fact that we find a much higher SFR implies that B14-65666 is undergoing a starburst episode, in agreement with T. Hashimoto et al. (2019). This is also true for each core independently.

The O32 ratio has been shown to be an excellent tracer of the ionization parameter U (e.g. T. Nagao, R. Maiolino & A. Marconi 2006; C. Papovich et al. 2022). Following other recent works (e.g. J. Witstok et al. 2021; K. Boyett et al. 2024; S. Zamora et al. 2025), we convert the derived O32 values to U using the relation of A. I. Díaz et al. (2000):

$$\log_{10}(U) = 0.80 \log_{10}(\text{O32}) - 3.02 \quad (1)$$

which was derived using single-star ionization models. This yields values of $-2.7 \lesssim \log_{10}(U) \lesssim -2.2$ for the two core galaxies. Thus, the regions of B14-65666 show similar ionization parameters as galaxies in the $2.7 < z < 6.3$ sample of N. A. Reddy et al. (2023) and the lower redshift ($1.1 < z < 2.3$) sample of C. Papovich et al. (2022).

3.2 Spaxel-by-spaxel fits

We can exploit the power of the NIRSpect IFU to extract physical properties on a spatially resolved basis by fitting combined line and continuum models to the spectra of each spaxel. This is enhanced through direct comparison to morpho-kinematic maps of ALMA data, which we create in an identical fashion.

3.2.1 NIRSpect IFU map creation

Due to the lower S/N of the spaxel-based spectra, we adopt a streamlined version of the model and fitting procedure of Section 3.1 to investigate the spatial distribution of emission and ISM properties. First, we extract the spectrum from each spaxel and isolate the wavelength range spanning $[\text{O II}]\lambda\lambda 3726, 3729$ to $[\text{O III}]\lambda 5007$ ⁸. Instead of the multi-stage approach of Section 3.1, we fit the spectrum of each spaxel using a single model consisting of a power-law continuum and narrow and broad line contributions from $[\text{O II}]\lambda\lambda 3726, 3729$, $[\text{Ne III}]\lambda\lambda 3869, 3968$, Balmer lines ($\text{H}\zeta$, $\text{H}\epsilon$, $\text{H}\delta$, $\text{H}\gamma$, $\text{H}\beta$), $[\text{O III}]\lambda 4363$, and $[\text{O III}]\lambda\lambda 4959, 5007$. The redshifts and intrinsic linewidths of the narrow and broad component of each line are set to be equal.

While we explore a fit with a fiducial n_e and free $E(B - V)$ and T_e (as in the multi-stage model), we find that the S/N is too low to

⁸This wavelength range excludes $\text{He I}\lambda 5875$, which is too faint to spatially map.

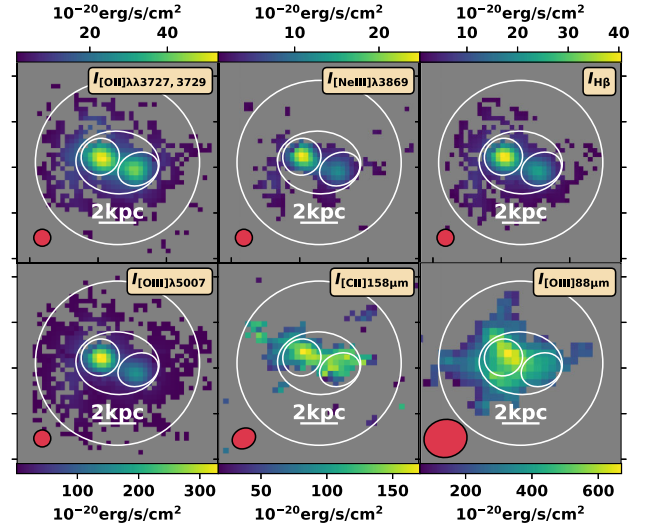


Figure 2. Integrated total fluxes of emission lines, as derived through spaxel-by-spaxel fit. Only $> 3\sigma$ fluxes are shown. Each panel displays a field of view of 2.2×2.2 arcsec centred on $10^{\text{h}}01^{\text{m}}40^{\text{s}}69 + 1^{\circ}54'52''.55$. A physical scale bar of 2 kpc is included in each panel.

constrain these conditions. Instead, we fix $E(B - V) = 0.2$ and $T_e = 1.2 \times 10^4$ K throughout. By using the ISM conditions and PYNEB, we lower the degrees of freedom in the model by predicting line ratios. Thus, the free variables for each spectrum are the continuum properties (slope and normalization) and independent fluxes ($F_{[\text{O II}]\lambda 3726}$, $F_{[\text{Ne III}]\lambda 3869}$, $F_{\text{H}\beta}$, and $F_{[\text{O III}]\lambda 5007}$) of the narrow and broad components of each line. As in Section 3.1.1, we reject components of lines with signal-to-noise levels of $< 3\sigma$.

The resulting total intensity maps are included in Fig. 2. Note that because of our model assumptions, the corresponding map of $[\text{Ne III}]\lambda 3968$ is identical to that of $[\text{Ne III}]\lambda 3869$, but with a constant scaling factor (see Appendix C). Similarly, each of the other Balmer lines can be found from the $\text{H}\beta$ distribution, and $[\text{O III}]\lambda 4959$ and $[\text{O III}]\lambda 4363$ can be found from the $[\text{O III}]\lambda 5007$ distribution.

Our fits also allow us to explore the kinematics of the field by extracting parameters from each spaxel. This is done by considering the best-fitting $[\text{O III}]\lambda 5007$ model, converting it to a cumulative distribution function (CDF), and calculating multiple non-parametric v_N values (i.e. velocities at which the CDF reaches $N\%$). In each case we assume a fiducial zero-velocity redshift of $z = 7.1520$. Fig. 3 shows v_{50} (the mean velocity) and the asymmetry ($|v_{50} - v_{10}| - |v_{50} - v_{90}|$), while Fig. 4 shows $w_{80} \equiv v_{90} - v_{10}$ (a measure of linewidth). We note that in the case that the spectrum of a spaxel is best fit by a single component (either narrow or broad), the resulting asymmetry is zero.

3.2.2 ALMA map creation

Previous analyses of the ALMA data for this source created moment maps (T. Hashimoto et al. 2019; Y. Sugahara et al. 2021; T. Hashimoto et al. 2023a; Y. Sugahara et al. 2025), which are non-parametric measures of the total intensity (moment 0), intensity-weighted mean velocity (moment 1), and velocity dispersion (mo-

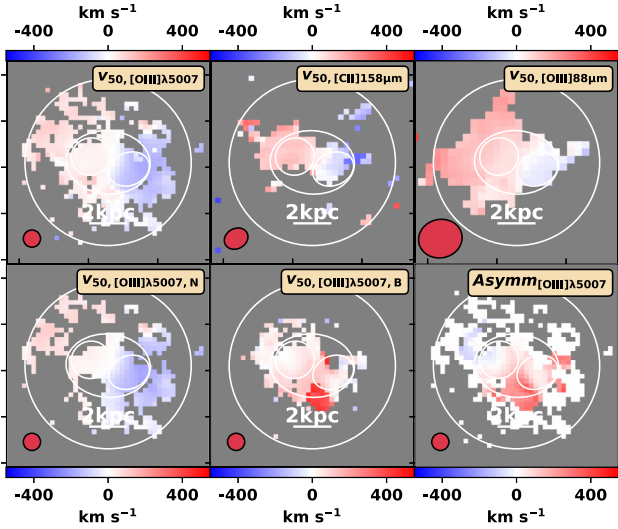


Figure 3. Line of sight velocity maps, as derived through spaxel-by-spaxel fits. The top row includes maps of v_{50} (i.e. the velocity at which each line reaches 50 per cent of its total flux) for [O III] λ 5007, [C II]158 μ m, and [O III]88 μ m. Maps of v_{50} for the narrow and broad component of [O III] λ 5007 are shown in the first two panels of the lower row. The bottom right panel presents the best-fitting asymmetry of [O III] λ 5007 (see Section 3.2.1 for definition). Each panel displays a field of view of 2.2×2.2 arcsec centred on $10^{\text{h}}01^{\text{m}}40^{\text{s}}.69 + 1^{\circ}54'52''.55$. A physical scale bar of 2 kpc is included in each panel. For each, we show the PSF as a red ellipse to the lower left. North is up and east is to the left.

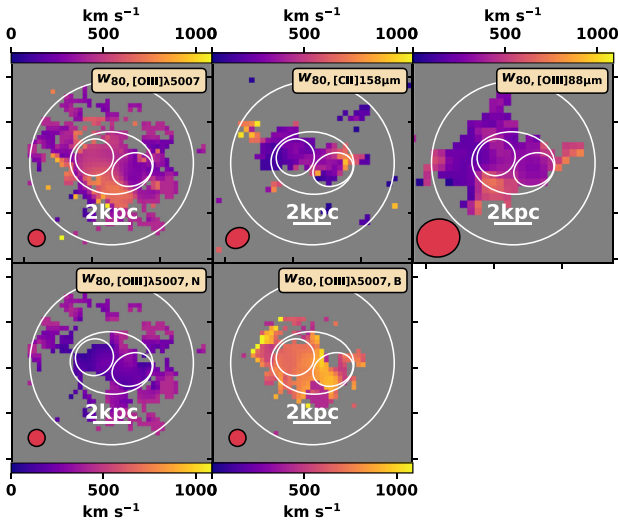


Figure 4. Maps of w_{80} (i.e. the difference in velocity between the points at which each line reaches 10 per cent and 90 per cent of its total flux), as derived through spaxel-by-spaxel fits for [O III] λ 5007, [C II]158 μ m, and [O III]88 μ m. Maps of w_{80} for the narrow and broad component of [O III] λ 5007 are shown in the lower row. Each panel displays a field of view of 2.2×2.2 arcsec centred on $10^{\text{h}}01^{\text{m}}40^{\text{s}}.69 + 1^{\circ}54'52''.55$. A physical scale bar of 2 kpc is included in each panel. For each, we show the PSF as a red ellipse to the lower left. North is up and east is to the left.

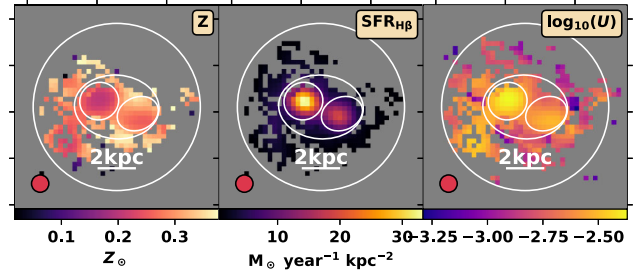


Figure 5. Line ratio diagnostics, as derived through spaxel-by-spaxel fit. Each panel displays a field of view of 2.2×2.2 arcsec centred on $10^{\text{h}}01^{\text{m}}40^{\text{s}}.69 + 1^{\circ}54'52''.55$. A physical scale bar of 2 kpc is included in each panel. For each, we show the PSF as a red ellipse to the lower left. North is up and east is to the left.

ment 2),⁹ Here, we instead use Gaussian models to fit the ALMA data on a spaxel-by-spaxel basis, resulting in morpho-kinematic maps that may be directly compared to our NIRSpc maps.

Because each ALMA data cube only contains a single line ([C II]158 μ m or [O III]88 μ m), the fitting process is much simpler than that of Section 3.1 or 3.2. First, we construct an error spectrum for each continuum-subtracted data cube by taking the RMS noise level of each spectral channel. Considering the possibility that each line may be fit by two Gaussian components (i.e. narrow and broad), the spectrum extracted from each spaxel is fit with these two Gaussians and an underlying first-order polynomial continuum using LMFIT. However, this approach only reveals a few spaxels where a two-Gaussian model returns a better fit (i.e. a lower reduced χ^2) in either cube. Because these potential areas are smaller than a synthesized beam and are not aligned with the broad emission found in [O III] λ 5007 emission, they are likely artefacts (e.g. incomplete continuum subtraction, data combination, imaging). Thus, we adopt a single-Gaussian model. The resulting total intensity, v_{50} , and w_{80} maps are included in Figs 2, 3, and 4, respectively.

3.2.3 Distribution of emission

All of the rest-optical lines feature similar morphologies, with emission focused in the cores (with the E nucleus being brighter), and weaker diffuse emission. The rest-FIR lines are qualitatively similar. The ALMA and *JWST* lines are further compared in Section 4.2.

We find that [O III] λ 5007, [C II]158 μ m, and [O III]88 μ m feature similar distributions of v_{50} (Fig. 3), with a strong east-west velocity gradient. There are slight differences between the maps, which may be ascribed to differences in sensitivity and resolution (e.g. beam smearing, spatial binning). As seen in other works (e.g. K. Telikova et al. 2025), [C II]158 μ m and [O III]88 μ m show similar line-of-sight velocity maps. Our v_{50} maps of the ALMA-detected lines are similar to the moment 1 maps created by T. Hashimoto et al. (2019), but differ slightly due to differences in imaging (e.g. spaxel size) and velocity measurement method (i.e. Gaussian fit versus moment 1). While such a symmetric velocity field could be interpreted as a signature of rotation, the disparate properties of each core (see Table 4, Fig. 5) suggest a major merger

⁹See CASA toolkit manual for more details: https://www.aoc.nrao.edu/~kgolap/casa_trunk_docs/CasaRef/image.moments.html

instead (see Section 4.5 for further discussion).

The narrow and broad components of [O III] λ 5007 show different spatial distributions (see Appendix D for more details) and velocity offsets (Fig. 3). Due to this, there is a region of positive asymmetry to the southeast of core W that indicates a more powerful red broad component. Indeed, the channel maps of both [O III] λ 4959 and [O III] λ 5007 contain low-level redshifted emission in this area, which may indicate a tidal feature or outflow.

We are also able to calculate w_{80} for each line (Fig. 4). Core E has a higher mean w_{80} ($\sim 470 \text{ km s}^{-1}$) than core W ($\sim 370 \text{ km s}^{-1}$), which is primarily caused by the stronger broad component in core E. The w_{80} map of [O III] λ 88 μm shows a region with elevated velocity dispersion south of core E which slightly overlaps with the broad [O III] λ 5007 emission, but the two cores show similar $w_{80, [\text{O III}]\lambda 88 \mu\text{m}}$.

The two ALMA ν_{50} maps are more similar to that of the narrow component of [O III] λ 5007, suggesting that the gas emitting broad [O III] λ 5007 is not detected in [C II] λ 158 μm or [O III] λ 88 μm . We note that the *JWST*/MIRI observations did not detect broad H α emission, which appears to be at odds with our detection of narrow and broad Balmer emission. However, this is likely simply due to lower sensitivity (see discussion in C. Prieto-Jiménez et al. 2025).

3.2.4 Further measurables

The best-fitting total line maps (i.e. narrow + broad flux; Fig. 5) are used to create maps of gas-phase metallicity, SFR, and U (see Section 3.1 for ratio definitions and diagnostic information). The resulting maps for the combined best-fitting models are shown in Fig. 5.

Each map yields results that broadly agree with the integrated spectral analysis of Section 3.1.2. That is, the W core features higher metallicity and lower $\log_{10}(U)$. In addition, a high-ionization and low- Z arc (which is detected in [O II] $\lambda\lambda$ 3726, 3729, H β , and [O III] λ 5007; Fig. 2) is visible to the southeast. The SFR $_{\text{H}\beta}$ map (which is a scaled version of the H β map of Fig. 2) is less illustrative, as a uniform dust correction has been applied. Because of this, the SFR density in this map may be treated as a minimum value.

4 DISCUSSION

4.1 Line ratio diagrams

Due to the wavelength coverage of our data, we do not have access to [N II] $\lambda\lambda$ 6548, 6584 or [S II] $\lambda\lambda$ 6716, 6731, and cannot utilize the standard [N II]-BPT or [S II]-VO87 diagrams (J. A. Baldwin, M. M. Phillips & R. Terlevich 1981; S. Veilleux & D. E. Osterbrock 1987) to search for evidence of AGN excitation. But the wealth of detected emission lines (see Table 3) allows us to explore the nature of this field using other diagnostics: O32–R23, R3–R2, and Ne3O2 (see definitions in Section 3.1).

The ratios of the E and W cores of B14-65666 are shown in Fig. 6. For comparison we also show the dust-corrected line ratios of low-redshift galaxies from Sloan Digital Sky Survey-III/Baryonic Oscillation Spectroscopic Survey (BOSS; K. S. Dawson et al. 2013; D. Thomas et al. 2013), $5.5 \lesssim z \lesssim 9.5$ galaxies from the JADES survey (A. J. Cameron et al. 2023), $4.6 \lesssim z \lesssim 7.9$ galaxies from S. Mascia et al. (2023), $6.9 \lesssim z \lesssim 9.0$ galaxies from the CEERS survey (M. Tang et al. 2023), A2744-YD4 ($z = 7.88$;

C. Witten et al. 2025), and the $5 \lesssim z \lesssim 9$ stacks created by G. Roberts-Borsani et al. (2024). Each of the line ratios from high-redshift galaxies has either been corrected for dust attenuation or has been measured for galaxies with no significant attenuation. Generally, we find that the different components of B14-65666 lie within the scatter of the *JWST*-observed galaxies, at the upper edge of the scatter of the low-redshift galaxies. Below we discuss the physical interpretation of this line ratio distribution.

All of these ratios are dependent on the ionization parameter U and metallicity Z_g (e.g. L. J. Kewley & M. A. Dopita 2002; M. Shirazi, J. Brinchmann & A. Rahmati 2014; A. J. Cameron et al. 2023). In general, R23, R2, and R3 are stronger tracers of Z_g (e.g. C. C. Steidel et al. 2016; M. Curti et al. 2020), while Ne3O2 and O32 are more dependent on U (e.g. M. V. Penston et al. 1990; E. M. Levesque & M. L. A. Richardson 2014). The low-redshift galaxies show a positive correlation in each diagnostic plot, while the high-redshift galaxies lie at higher O32 and Ne3O2 (suggesting higher U , A. J. Cameron et al. 2023). Both regions of B14-65666 lie near the intersection of low-redshift and previously *JWST*-observed galaxies.

The metallicity of each region of B14-65666 was found to be $\sim 0.2 - 0.3 Z_{\odot}$ (Section 3.1), allowing us to use these diagrams to compare ionization states. Since the B14-65666 regions have low O32 and Ne3O2 compared to the other high-redshift sources, this suggests that our sources have relatively low ionization parameters. The high Z_g and low U (compared to other high-redshift galaxies) suggests that B14-65666 could represent a system of evolved galaxies in the early Universe where significant star formation has occurred (resulting in a higher M_* and Z_g). Indeed, they lie at the high- Z_g and high- U edge of low-redshift galaxies, despite having much less time to form stars and enrich their environments.

4.2 ALMA–*JWST* comparison

While *JWST* is a powerful tool to explore the characteristics of high-redshift galaxies, it also features a strong synergy with ALMA that has only recently begun to be explored. This includes the possibility of detecting Lyman continuum leaking galaxies by comparing [C II] λ 158 μm and [O III] λ 5007 (e.g. H. Katz et al. 2020; R. Ura et al. 2023), using *JWST*-based gas-phase metallicities and ALMA-based CO observations to derive molecular gas masses (e.g. D. Narayanan et al. 2012), and comparing [O III] λ 5007/[O III] λ 88 μm to place tight constraints on electron temperature (e.g. M. Stiavelli et al. 2023).

4.2.1 Lyman continuum leakage

The escape of Lyman continuum photons is a key process in the study of how the Universe was reionized, but due to the opacity of the IGM, this quantity is usually explored using indirect tracers (e.g. Y. I. Izotov et al. 2018; J. Chisholm et al. 2022; S. Mascia et al. 2023). A novel approach was proposed by H. Katz et al. (2020), who used high-resolution cosmological simulations to train a logistic regression model to predict whether a galaxy has a high Lyman continuum escape fraction ($f_{\text{esc}}^{\text{LyC}} > 10$ per cent; ‘Lyman leakers’) using multiple strong rest-UV and FIR lines.

Before the advent of *JWST*, the most easily applied diagnostic was between two FIR lines that were observable with ALMA ([C II] λ 158 μm and [O III] λ 88 μm). From this diagnostic, H. Katz et al. (2020) predict that B14-65666 is likely a non-leaker. How-

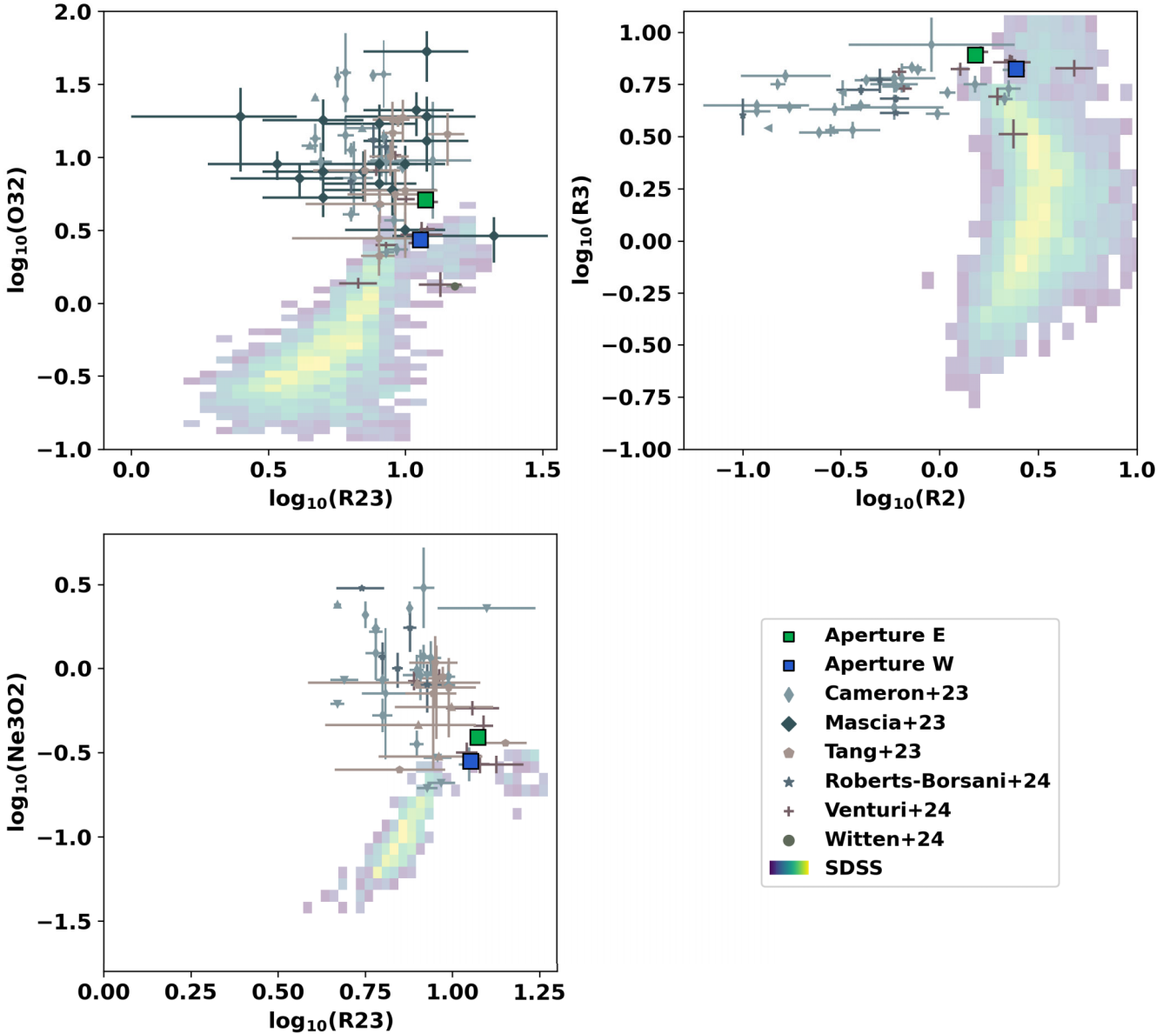


Figure 6. Distribution of line ratios for the apertures E and W: O32–R23 (top left), R3–R2 (top right), and Ne3O2–R23 (bottom left). For comparison we also show the dust-corrected line ratios of low-redshift galaxies from BOSS (D. Thomas et al. 2013) and higher redshift galaxies previously observed with *JWST*/NIRSpec ($5.5 \lesssim z \lesssim 9.5$, A. J. Cameron et al. 2023; $4.6 \lesssim z \lesssim 7.9$, S. Mascia et al. 2023; $6.9 \lesssim z \lesssim 9.0$, M. Tang et al. 2023; $5 \lesssim z \lesssim 9$, G. Roberts-Borsani et al. 2024; $6.4 \lesssim z \lesssim 7.9$, G. Venturi et al. 2024; and $z = 7.88$, C. Witten et al. 2025).

ever, the strongest predictor of high $f_{\text{esc}}^{\text{LyC}}$ was found to be between [O III] $\lambda 5007$ and [C II] $158\mu\text{m}$. Since [C II] $158\mu\text{m}$ can trace neutral gas (e.g. D. Vizgan et al. 2022, but see also e.g. A. Zanella et al. 2018; S. C. Madden et al. 2020) and [O III] $\lambda 5007$ traces ionized gas, a high value of this ratio could indicate a higher level of ionized gas and thus more avenues of escape for Lyman continuum photons. Here, we examine this ratio in B14-65666.

Because the astrometric uncertainty of the ALMA images is comparable to the spaxel size of our *JWST*/NIRSpec data (see Appendix B3), we do not consider the spatial distribution of line ratios from ALMA and *JWST*. Instead, we consider the total line flux ratios of each using the ‘Total’ aperture (Table 2).

We find $\log_{10}(L_{[\text{C II}]158\mu\text{m}} [\text{erg s}^{-1}]) = 42.64 \pm 0.06$, and $\log_{10}(L_{[\text{O III}]\lambda 5007} [\text{erg s}^{-1}]) = 43.65 \pm 0.02$ (with no dust

extinction correction). Despite this relatively high value of $\log_{10}(L_{[\text{O III}]\lambda 5007})$, these integrated values place B14-65666 in the ‘non-leakers’ region of the H. Katz et al. (2020) diagram, in agreement with the classification based on the [C II] $158\mu\text{m}$ –[O III] $88\mu\text{m}$ diagnostic. While the application of a dust correction ($E(B - V) > 0$) will result in a higher [O III] $\lambda 5007$ luminosity and push B14-65666 towards the leaker regime, a large correction ($E(B - V) > 0.68$) is required for a leaker probability of > 50 per cent.

4.2.2 Electron density

A previous exploration of $[\text{O III}]\lambda\lambda 4959, 5007/[\text{O III}]88\mu\text{m}$ was performed by Y. Sugahara et al. (2025), who combined ALMA and *JWST*/NIRCam observations of B14-65666 to explore how the electron density varies across this source. While these previous observations featured higher spatial resolution, our *JWST*/NIRSpec data allow us to directly characterize the rest-optical line and continuum emission. We repeat this analysis here using our NIRSpec IFU data. Similarly to above, we do not investigate the spatial distribution of this ratio due to astrometric alignment issues, but use the fluxes found using the ‘Total’ aperture and PyNEB to constrain the density.

The ratio of the best-fitting $[\text{O III}]\lambda 5007$ and $[\text{O III}]88\mu\text{m}$ fluxes (2.6 ± 0.3) falls outside the ratios explored by PyNEB ($\gtrsim 3.8$). While this could be interpreted as very low density ($\log_{10}(n_e) < 10^1 \text{ cm}^{-3}$), we note that we may recover our fiducial density ($\log_{10}(n_e) = 10^2 \text{ cm}^{-3}$) by adopting a reasonable $E(B - V) \gtrsim 0.09$. Since the field contains regions of both high (e.g. ‘W’) and low dust extinction (‘E’), this extinction is reasonable. While it is not straightforward to derive a global dust correction, this $[\text{O III}]\lambda 5007/[\text{O III}]88\mu\text{m}$ ratio suggests that B14-65666 does not feature areas of extremely high density (which would require a very high ratio).

To investigate this further, we require higher spectral resolution observations of $[\text{O II}]\lambda\lambda 3726, 3729$ (i.e. *JWST*/NIRSpec G395H/F290LP) and/or higher spatial resolution and sensitivity observations of $[\text{O III}]88\mu\text{m}$ (i.e. ALMA).

4.3 Presence of dust

The fact that this source is detected in FIR continuum emission with ALMA (e.g. T. Hashimoto et al. 2019) implies that there is a significant dust reservoir in the field. Through a detailed analysis of the dust SED (which has three detections and one non-detection), Y. Sugahara et al. (2021) find a total dust mass of $\sim 10^{6-8} M_\odot$ (in agreement with previous results; T. Hashimoto et al. 2019). The recent SED modelling of Y. Sugahara et al. (2025) found a stellar continuum dust attenuation of $A_V^* = 0.78^{+0.07}_{-0.06}$ (corresponding to ionized gas $E(B - V) \sim 0.4$; D. Calzetti et al. 2000) for the full source. Our *JWST*/NIRSpec spectra are well fit by models with low $E(B - V) = 0.2 - 0.4$, but we lack the sensitivity and wavelength coverage necessary to estimate dust attenuation further (see Appendix C3 for further discussion of this).

Most of the previous studies of the FIR emission used the spatially resolved Band 6 and 8 data to construct SEDs for the E and W cores, which were then analysed with different models (i.e. a blackbody model, T. Hashimoto et al. 2019; Bagpipes, A. C. Carnall et al. 2018; Y. Sugahara et al. 2025; or CIGALE, S. Noll et al. 2009; M. Boquien et al. 2019; C. Prieto-Jiménez et al. 2025). But since each used slightly different spatial apertures (which were centred on line emission rather than continuum emission), we consider the dust morphology of this field (see Fig. 7).

Our analysis of the rest-UV and rest-optical line emission shows that these originate primarily from two bright cores, with weaker diffuse emission. Emission from the rest-FIR lines $[\text{C II}]158\mu\text{m}$ and $[\text{O III}]88\mu\text{m}$ also is also focused in the two core regions. Similarly, Band 8 continuum emission (underlying $[\text{O III}]88\mu\text{m}$ and tracing the peak of the dust SED) originates from core W and features a significant diffuse component. But Band 6 emission (underlying $[\text{C II}]158\mu\text{m}$) is focused in an arc-like fea-

ture between the two core regions (~ 0.2 arcsec from the centre of either core). This morphology was also reported by previous works (T. Hashimoto et al. 2019; Y. Sugahara et al. 2025), and thus is likely not an artefact introduced by our calibration or imaging processes. This offset is also larger than the positional uncertainty of the related $[\text{C II}]158\mu\text{m}$ map (~ 0.03 arcsec; Appendix B3). Neither Band 7 nor Band 3 maps contain morphological information due to lack of spatial resolution and lack of detection, respectively. Because the emission in each ALMA band is not coincident, it possibly originates from different dust reservoirs: one dust reservoir located in core W (see Band 8 image in panel d of Fig. 7), as well as a separate dust reservoir between the cores (Band 6). Alternatively, dust temperature gradients have been observed at high redshift (e.g. G. Calistro Rivera et al. 2018; C. Dong et al. 2019; T. Tsukui et al. 2023), which would allow for this change in morphology. Indeed, the previous SED fits found different dust temperatures in each core (e.g. T. Hashimoto et al. 2019; Y. Sugahara et al. 2025).

While a spatially resolved FIR SED analysis would unlock a deeper understanding of the dust properties and distribution (e.g. T. Tsukui et al. 2023), it requires time-intensive observations and is currently only feasible for bright sources (e.g. starburst galaxies, QSO host galaxies). The lack of detection in Band 3 and the low spatial resolution of Band 7 means that such a spatially resolved analysis of the FIR emission would only feature two SED points, and would thus be biased by assumptions of flux distribution, dust properties, and/or the use of a FIR template. With the data available, we may only state that the B14-65666 field contains dust that is spatially offset from the bright core regions. This dust may have been expelled by stellar winds (e.g. S. Veilleux, G. Cecil & J. Bland-Hawthorn 2005), or may be affected by the ongoing galaxy merger (e.g. Y. Tamura et al. 2023).

4.4 Mass-metallicity relation

It has been well established that the properties of most galaxies at a set redshift tend to scale with each other. Examples of this are seen in the observed relations between stellar mass and rotational velocity (i.e. the Tully–Fisher relation; R. B. Tully & J. R. Fisher 1977), SFR and M_* (star-forming main sequence; K. G. Noeske et al. 2007), and the surface densities of molecular and stellar mass (molecular gas main sequence; L. Lin et al. 2019). Here, we investigate the placement of B14-65666 on the relation between stellar mass and gas-phase metallicity, or the mass-metallicity relation (MZR; J. Lequeux et al. 1979).

To examine the location of B14-65666 with respect to the high-redshift MZR, we display Z_g (derived using the line diagnostics of M. Curti et al. 2020; Section 3.1.2) and M_* (derived by a BAGPIPES fit to the observed SED; Y. Sugahara et al. 2025) for core E and core W in Fig. 8. These values are compared to existing best-fitting MZR relations (K. E. Heintz et al. 2023; K. Nakajima et al. 2023; M. Curti et al. 2024) as well as $z > 5$ galaxies with Z_g and M_* from *JWST*/NIRSpec IFU observations (S. Arribas et al. 2024; C. Marconcini et al. 2024; G. Venturi et al. 2024; C. Marconcini et al. 2025; M. Messa et al. 2025; J. Scholtz et al. 2025). We find that the observed galaxies lie above the MZR as derived by K. E. Heintz et al. (2023) and M. Curti et al. (2024), and are closer to the relation of K. Nakajima et al. (2023).

However, there are important caveats to this interpretation that must be discussed. Primarily, the IFU targets (which mainly originate from the GA-NIFS survey) are not a representative sample

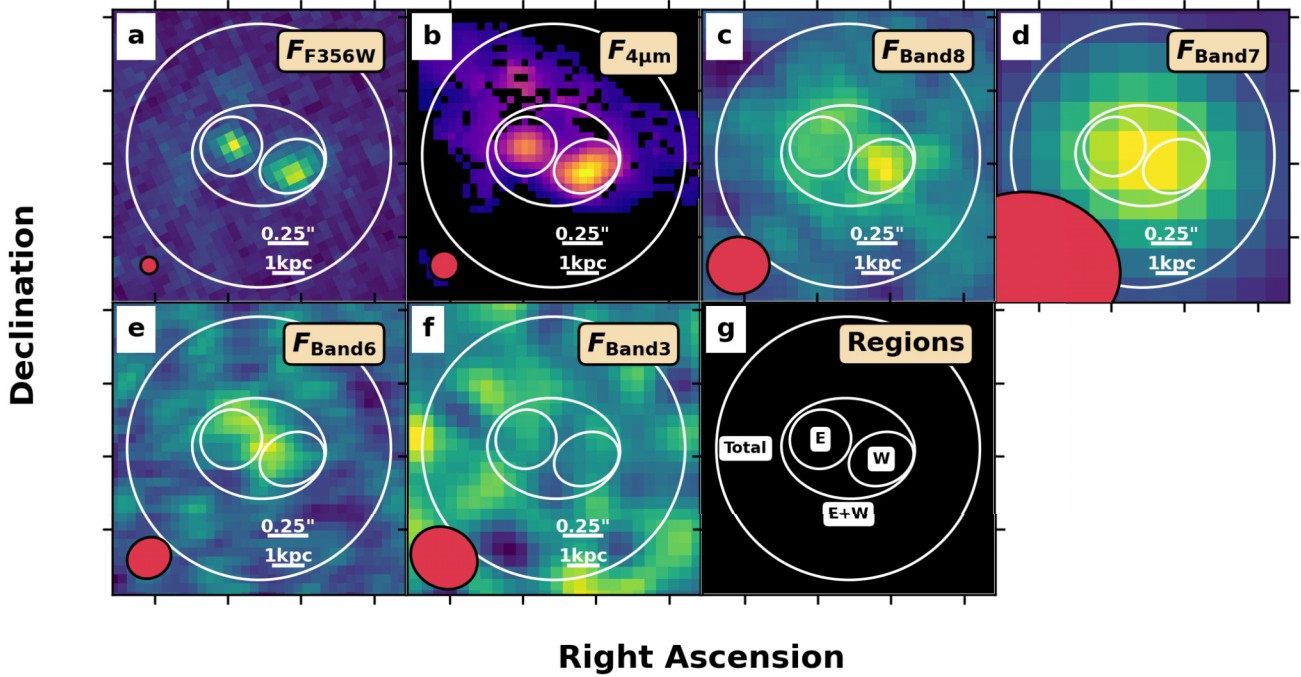


Figure 7. Gallery of multi-wavelength continuum data (see Table 5 for details) in order of increasing λ_{obs} . Each panel displays a field of view of 1.8×1.8 arcsec ($\sim 9.3 \times 9.3$ kpc²), centred on $10^{\text{h}}01^{\text{m}}40^{\text{s}}.6858 + 1^{\circ}54'52''.553$. An angular and physical scale is shown in each panel. The regions of study (which are adopted from C. Prieto-Jiménez et al. 2025) are shown in panel h. For each, we show the PSF as a red ellipse to the lower left. North is up and east is to the left. The *JWST*/NIRSpec continuum map (panel b; $\lambda_{\text{obs}} = 4 \mu\text{m}$), which was derived through spaxel-by-spaxel fit (see Section 3.2 for details), is displayed in a different colour map for emphasis.

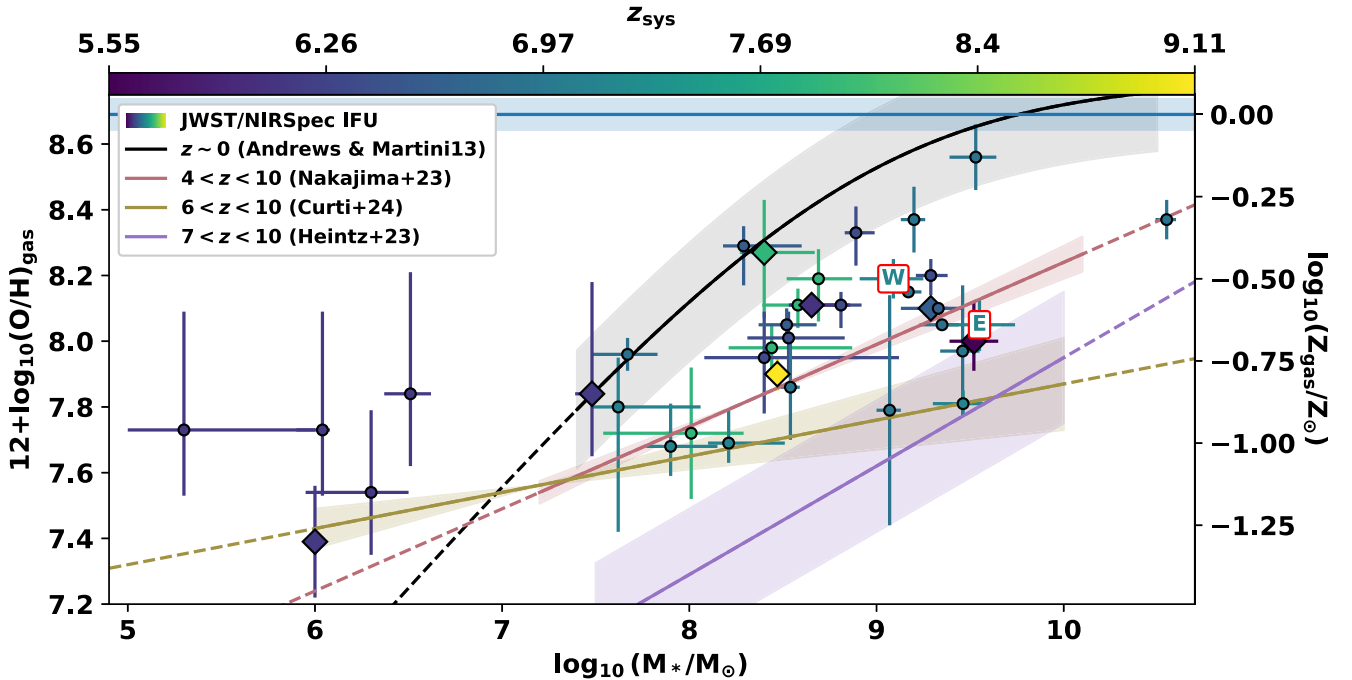


Figure 8. Gas-phase metallicities of $z > 5$ galaxies observed with the *JWST*/NIRSpec IFU as a function of stellar mass (H. Übler et al. 2023; S. Arribas et al. 2024; X. Ji et al. 2024; C. Marconcini et al. 2024; G. Venturi et al. 2024; H. Übler et al. 2024a; S. Fujimoto et al. 2025; C. Marconcini et al. 2025; M. Messa et al. 2025; J. Scholtz et al. 2025). Each point is coloured by redshift. Values that represent entire fields rather than regions are shown as diamonds. We also show previously determined MZR fits from local studies (B. H. Andrews & P. Martini 2013) and high-redshift studies (K. E. Heintz et al. 2023; K. Nakajima et al. 2023; M. Curti et al. 2024). Our values of core E and core W are shown by ‘E’ and ‘W’, respectively.

Table 5. List of continuum data. For each data set, we list a representative wavelength in the observed and rest frame (assuming $z = 7.1520$): pivot wavelengths for each *JWST* imaging filter and average wavelengths for each ALMA band.

Instrument	Name	λ_{obs} [μm]	λ_{rest} [μm]
<i>JWST</i> /NIRCam imaging	F356W	3.563	0.437
<i>JWST</i> /NIRSpec IFU	4 μm	4.000	0.491
ALMA	Band 8	740.228	90.803
ALMA	Band 7	999.308	122.584
ALMA	Band 6	1332.411	163.446
ALMA	Band 3	3331.027	408.615

of galaxies, but are instead biased towards bright, well-studied objects (e.g. SPT0311-58-E with $\log_{10}(M_*/M_{\odot}) = 10.55^{+0.05}_{-0.06}$, S. Arribas et al. 2024). While these observations result in the detection of smaller satellite galaxies (e.g. SPT0311-58-L1 with $\log_{10}(M_*/M_{\odot}) = 8.54 \pm 0.05$, S. Arribas et al. 2024), we lack a more complete, unbiased data set of IFU-detected galaxies in this redshift range ($6 \lesssim z \lesssim 9$). The galaxies at $\log_{10}(M_*/M_{\odot}) < 7$ originate from the work of M. Messa et al. (2025), where gravitational magnification ($\mu \sim 20$) allows for the characterization of dwarf galaxies. The high-metallicity source is SPT0311-58-C3, which lies near the edge of the IFU field of view and thus may suffer from low sensitivity. As noted above, these works also use different methods to derive Z_g and M_* . A uniform analysis of NIRSpec IFU data will be performed in a future work.

We find that the cores of B14-65666 are among the most massive galaxies in our collected sample, but they still lie on an extrapolation of the K. Nakajima et al. (2023) MZR trend. This suggests that the masses of each core are not dominated by a large reservoir of pristine gas (which would result in a lower metallicity), but they are also unlikely to have lost large amounts of gas via outflows or tidal interactions (which would result in a higher metallicity). Instead, it appears that the cores of B14-65666 have formed stars and enriched their gas in a similar fashion to other high-redshift galaxies.

4.5 Nature of core components

The two core galaxies of B14-65666 are closely associated, with a projected distance of ~ 0.43 arcsec (corresponding to ~ 2.2 kpc) and a velocity offset of ~ 175 km s $^{-1}$. Both cores appear to be undergoing a starburst episode (Section 3.1.2). Despite this, some of their properties reveal distinct natures. On one hand, core E appears to have a significant molecular reservoir (as suggested by its strong [C II]158 μm emission; e.g. A. Zanella et al. 2018; S. C. Madden et al. 2020), lower Z_g , and higher ionization parameter U . With a compact *JWST*/NIRCam morphology and high M_* , this core likely represents a galaxy undergoing a burst of star formation activity.

Core W is the opposite in multiple aspects: it has a lower M_* and amount of molecular gas (i.e. weaker [C II]158 μm), higher Z_g , and lower U . As seen in Fig. 8, this core lies above the high- z MZR, putting it closer to more evolved, lower- z populations. Thus, this core appears to be a galaxy that has used much of its molecular gas in star formation.

Fig. 3 shows that there is a clear velocity gradient between these two galaxies, with a broad, redshifted component between them. Such a velocity gradient could be interpreted as a sign of rotation, but this is unlikely here due to the presence of two

clearly separated galaxies (i.e. core E and core W) with different properties. Since the line and continuum emission peak in one (or both) of the cores rather than between them (except for the ALMA Band 6 continuum, see Section 4.3), it is unlikely that this represents a single rotating galaxy, even accounting for the effects of dust obscuration.

Instead, it is likely that these cores represent merging galaxies that have undergone multiple close interactions in the past, as suggested by previous works (T. Hashimoto et al. 2019; C. Prieto-Jiménez et al. 2025; Y. Sugahara et al. 2025). Such interactions would strip gas off of each galaxy (explaining the presence of the surrounding diffuse emission), and could boost or lower star formation in each source (e.g. P. Di Matteo et al. 2008; K. Horstman et al. 2021; S. L. Ellison et al. 2022). The redshifted, broad line emission between the clumps (which is found here for the first time) could then represent stripped gas from a previous interaction.

This behaviour has been observed in other systems, such as CR7 (C. Marconcini et al. 2025): a $z = 6.6$ field composed of three primary components, an extended Ly α halo, and multiple minor components. An SED fit yielded SF histories (SFHs) for each component, revealing evidence for a past merger-induced starburst. SED fitting of B14-65666 by Y. Sugahara et al. (2025) suggest that the SFH of this field is dominated by a starburst ~ 10 Myr prior to $z = 7.1520$. Additional observations with *JWST*/NIRSpec (e.g. to observe Ly α and enable further SED modelling) could be useful for characterizing this field.

5 CONCLUSIONS

In this work, we have presented new *JWST*/NIRSpec IFU observations of the $z = 7.1520$ galaxy B14-65666 as part of the GA-NIFS survey. Through combination with archival data from *JWST*/NIRCam and ALMA, we are able to explore the morphokinematics and ISM conditions on a spectral and spatial basis.

We confirm that the emission from this object primarily originates from two bright cores (‘core E’ and ‘core W’), surrounded by low-level diffuse emission. Spectra extracted from each core reveal significant emission of [O II] $\lambda\lambda 3726, 3729$, [Ne III] $\lambda\lambda 3869, 3968$, [O III] $\lambda\lambda 4959, 5007$, several Balmer lines (H β , H γ , H δ , H ϵ , H ζ , H η), He I $\lambda 5875$, He I $\lambda 3889$, and weak [O III] $\lambda 4363$. By using PYNEB to calculate line ratios for given electron conditions (T_e and n_e), we are able to account for blended lines and the relatively low spectral resolution of the data ($R \sim 1000$). By combining these data with previous ALMA [C II]158 μm and [O III]88 μm data, we are able to characterize the field with unprecedented detail.

Using strong line diagnostics (M. Curti et al. 2020), we constrain the gas-phase metallicity of each core to be $\sim 0.2\text{--}0.3 Z_{\odot}$. The line ratios of each core lie within the scatter of other $z \sim 5.5\text{--}9.5$ galaxies observed with *JWST*/NIRSpec (A. J. Cameron et al. 2023; M. Tang et al. 2023), but with low O32 and Ne3O2 (i.e. low U) and high R23 and R2 (i.e. higher Z_g). Since these properties are more similar to the high-ionization tail of the distribution of low-redshift galaxies observed in BOSS (D. Thomas et al. 2013), we propose that B14-65666 represents a system of currently starbursting galaxies in the early Universe, where significant star formation has already occurred.

Next, we maximize the potential of our three-dimensional data set by performing spaxel-by-spaxel fits. This reveals that the emission of each *JWST*/NIRSpec- and ALMA-detected lines are concentrated in the two cores. By fitting the rest-UV and rest-optical

lines with a broad and narrow component, we find a region of redshifted, broad emission between the two cores. This likely represents a tidal interaction between the two cores (or possibly an outflow). On the other hand, the narrow emission shows a clear east–west red–blue velocity gradient, which is also seen in [C II]158 μ m and [O III]88 μ m.

The ALMA and *JWST* data are combined to test optical-FIR line diagnostics of the full field. These suggest that B14-65666 may not be a significant Lyman continuum leaker and is unlikely to feature a high n_e (but this depends on the adopted dust extinction). A comparison of the continuum and line maps suggests that B14-65666 may have a complex dust distribution.

The M_* of B14-65666 (as derived by Y. Sugahara et al. 2025) is combined with our precise estimate of Z_g to examine if this source lies on the high-redshift MZR. By comparing these values with other *JWST*/NIRSpec IFU-derived values and best-fitting trends of representative galaxies, we find that cores of B14-65666 lie on the high-redshift MZR. This suggests the lack of a large molecular reservoir or gas expulsion via feedback, which would result in significant offset from the relation.

By combining multiple tracers (e.g. Z_g , line morphokinematics), we determine that the two cores feature drastically different properties. Core W is a less massive, lower-metallicity galaxy that appears to have already used up much of its molecular gas reservoir in star formation (based on the less significant [C II]158 μ m peak). Core E features a higher M_* and a higher [C II]158 μ m luminosity, suggesting higher potential for future star formation. When combined with the kinematics we have observed, the two cores of B14-65666 likely represent a massive merger of two disparate galaxies in the early Universe, which have created tidal features through their past interactions.

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DATA AVAILABILITY

The *JWST*/NIRSpec data used in this research were obtained within the NIRSpec-IFU GTO programme GA-NIFS (PID 1217) and are publicly available on the MAST archive, along with all analysed *JWST*/NIRCam data. Data presented in this work will be shared upon reasonable request to the corresponding author.

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APPENDIX A: PSF TREATMENT

The *JWST*/NIRSpec IFU PSF is known to vary strongly with wavelength (e.g. F. D’Eugenio et al. 2024). Recent works (e.g. G. C. Jones et al. 2025a) have used NIRSpec IFU observations of standard stars to demonstrate that the python package STPSF¹⁰ is able to accurately characterize the PSF. Following the approach of other works (e.g. C. Prieto-Jiménez et al. 2025; G. C. Jones et al. 2025b), we first use STPSF to find the PSF of each spectral channel in our data cube. We then homogenize the PSF of our data cube to the coarsest PSF by convolving each spectral channel with a kernel determined using the PHOUTILS (L. Bradley et al. 2023) task *create_matching_kernel*.

Next, we determine the aperture loss correction for each aperture of Table 2 using the common PSF. Assuming an unresolved point source (e.g. C. Prieto-Jiménez et al. 2025), we take the ratio of the total flux and the flux inside each aperture. While the higher spatial resolution *JWST*/NIRCam observations of Y. Sugahara et al. (2025) found that the eastern core is indeed compact ($r_e < 0.016$ arcsec), the western core is instead elongated with a length of ~ 0.3 arcsec and may feature small-separation clumps. Our data feature a PSF with FWHM ~ 0.19 arcsec, so our assumption of a point source is appropriate for the eastern core but may result in a slight underestimation of the western flux.

APPENDIX B: ASTROMETRIC CORRECTION

In this work, we compare *JWST*/NIRSpec IFU data with ALMA observations. This comparison requires a trustworthy astrometric correction, as even small offsets can introduce artificial features (e.g. spatial gradients in line ratio maps). Here, we align an archival NIRCam image to the *Gaia* DR3 frame (*Gaia* Collaboration et al. 2016, 2021) using a comparison to NIRCam data

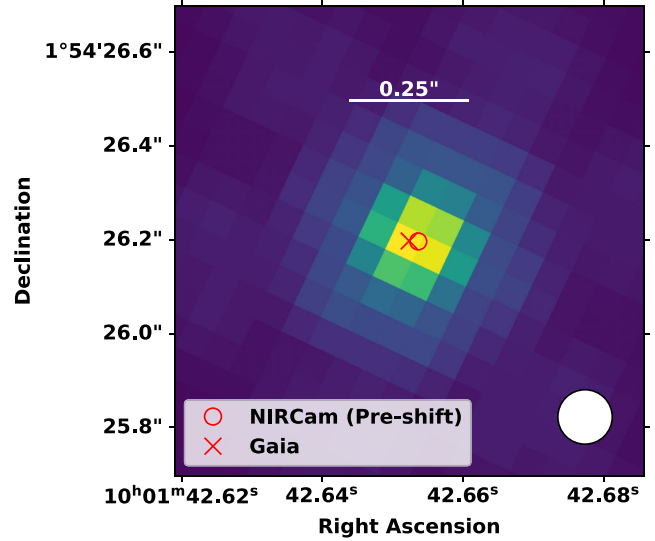


Figure B1. Comparison of *JWST*/NIRCam F356W data with position of star from the *Gaia* DR3 catalogue. The *Gaia* position is shown as a red X, while the best-fitting centroid of the NIRCam image is shown by a red circle. The PSF is shown as a circle to the lower right.

(Appendix B1), use this aligned NIRCam image to correct the astrometry of our NIRSpec data (Appendix B2), and discuss the astrometric uncertainty of the ALMA data (Appendix B3).

B1 NIRCam alignment

To begin, we search the *Gaia* archive¹¹ for reference stars near B14-65666, and select the closest *Gaia* star with proper motion information (*Gaia* DR3 3836051483531923200). Although B14-65666 benefits from multiple archival NIRCam data sets (see Section 2.3), our chosen *Gaia* star is masked in all but one filter (F356W). After correcting the position of this star for proper motion (an offset of 31.6 ± 0.4 mas, where the uncertainty takes the positional uncertainty and error on proper motion into account) and fitting a 2D Gaussian to the NIRCam image using LMFIT, we find that the centroid is offset by 20.5 ± 0.7 mas (where the error is taken from the LMFIT output). This offset is small (Fig. B1) but significant, so we align the NIRCam data by adjusting the image header.

B2 NIRSpec alignment

To determine if our data are affected by a pointing error, we use the *Gaia*-aligned *JWST*/NIRCam F356W image. By convolving our IFU data cubes with the corresponding NIRCam filter transmission curve, we compare the spatial distribution of emission. The resulting comparison is shown in the top panel of Fig. B2. The NIRSpec IFU and NIRCam data are misaligned, with an offset of 92 ± 8 mas (where the uncertainty is taken from a 2D Gaussian fit to the western emission with LMFIT). This is fully consistent with the pointing uncertainty of *JWST* (e.g. J. Rigby et al. 2023), but to enable comparison with other data sets, we correct our NIRSpec IFU cube for this offset. By combining all relevant uncertainties (i.e. on *Gaia* position and proper motion, NIRCam centroid, and NIRSpec

¹⁰<https://stpsf.readthedocs.io/en/latest/>

¹¹<https://gea.esac.esa.int/archive/>

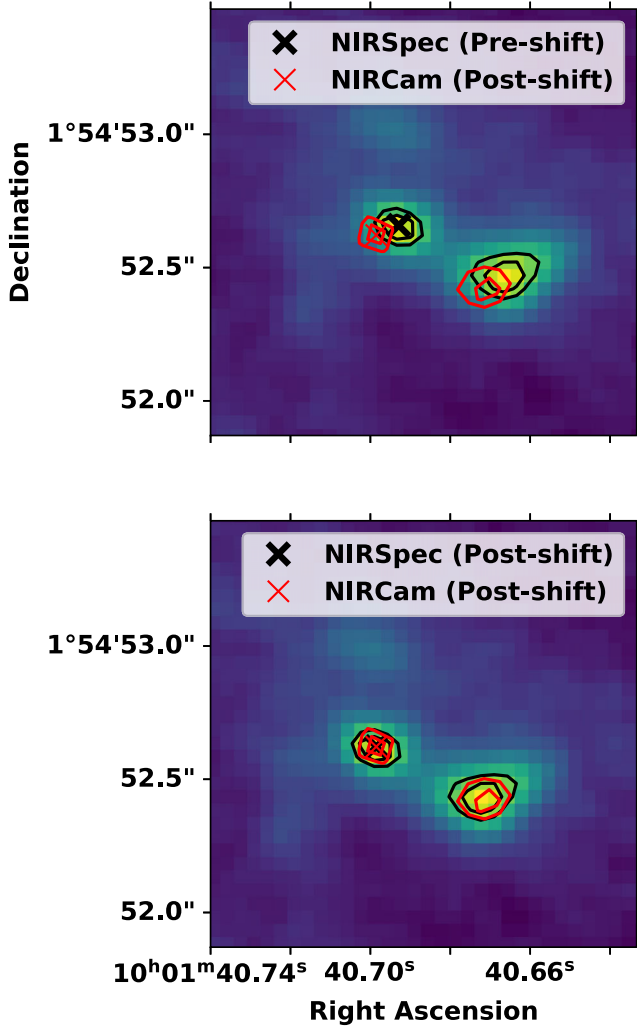


Figure B2. Comparison of *JWST*/NIRCam images and *JWST*/NIRSpec IFU data cube integrated over F356W NIRCam filter bandpass. In each panel, the collapsed NIRSpec emission is depicted as the background colour and illustrative black contours, while the NIRCam data are shown as red contours. The *JWST* emission in the top panel is shown without the astrometric correction, while the lower panel includes the alignment to the NIRCam data.

centroid), we determine an absolute astrometric uncertainty of 5 mas.

B3 ALMA astrometry

According to the ALMA technical handbook¹², the positional uncertainty of ALMA is a function of the resolution and peak S/N:

$$\Delta_{\text{acc}} = \frac{\text{FWHM}_{\text{beam}}}{0.9 \times \text{S/N}_{\text{pk}}} \quad (\text{B1})$$

Using this, we first consider the moment 0 map of [C II]158 μm studied here, which features a beam of FWHM 0.268 \times 0.218 arcsec (i.e. geometric mean of 0.242 arcsec) and an $\text{S/N}_{\text{pk}} \sim 8$. This results in $\Delta_{\text{acc}} = 34$ mas. Applying the same process to

the moment 0 map of [O III]88 μm implies $\Delta_{\text{acc}} = 52$ mas. However, the ALMA technical handbook notes that the true positional uncertainties are likely higher due to extended structure and high frequencies. Because the ALMA positional uncertainty may be improved through better sensitivity or resolution, future additional [C II]158 μm or [O III]88 μm observations will result in tighter constraints.

Because these uncertainties are comparable to the spaxel size of our NIRSpec data (50 mas), any detailed spatial comparison of NIRSpec and ALMA data is not advisable. However, integrated flux comparisons using large apertures are still possible.

APPENDIX C: LINE RATIO DETERMINATION

Throughout this work, we use line ratios derived using PYNEB. This allows us to self-consistently fit and analyse line emission using a single framework. The details of these assumptions are given here.

C1 Dust-free line ratios

One vital pair of ISM properties are the electron density and temperature. The electron density in galaxies has been derived for $z \sim 2.3$ galaxies ($n_e = 250 \text{ cm}^{-3}$; e.g. R. L. Sanders et al. 2016), as well as for $z > 6$ galaxies using *JWST* data ($n_e = 100\text{--}500 \text{ cm}^{-3}$; e.g. M. Curti et al. 2023; K. Nakajima et al. 2023; Z. Chen et al. 2024; W. Hu et al. 2024; A. Torralba-Torregrosa et al. 2024). More generally, Y. Isobe et al. (2023) characterize the redshift evolution of n_e , yielding a range of $n_e \sim 200\text{--}1000 \text{ cm}^{-3}$ for a source at $z \sim 7$. Below we will explore a range of $n_e = 100\text{--}1000 \text{ cm}^{-3}$ (as suggested by M. Tang et al. 2023).

Similarly, the electron temperature is found to be $\sim 1.5 \times 10^4 \text{ K}$ for high-redshift sources (e.g. W. Hu et al. 2024; A. Torralba-Torregrosa et al. 2024; T. Y.-Y. Hsiao et al. 2024b). While a broad range of $T_e = [0.5\text{--}20] \times 10^4 \text{ K}$ is explored by Z. Chen et al. (2024), we restrict our exploration to temperatures where PYNEB is able to calculate each dust-corrected Balmer ratio ($T_e = [0.5\text{--}3.0] \times 10^4 \text{ K}$).

Previously, Y. Sugahara et al. (2025) assumed $T_e = 1.2 \times 10^4 \text{ K}$ and $n_e = 200 \text{ cm}^{-3}$ when interpreting *JWST*/NIRCam observations of B14-65666. Through a comparison of the observed [O III] $\lambda\lambda 4959, 5007$ /[O III]88 μm ratio to results from CLOUDY (G. J. Ferland et al. 1998, 2017), they were able to rule out low ($< 10^2 \text{ cm}^{-3}$) and high electron densities ($> 10^3 \text{ cm}^{-3}$). For our exploration, we mark the locations of these fiducial values of $n_e = 200 \text{ cm}^{-3}$ and $T_e = 1.2 \times 10^4 \text{ K}$ in each plot, and the resulting ratio values are listed in Table C1.

First, we explore Balmer line ratios using the PYNEB task *getEmissivity*. The resulting distribution of $\text{H}\gamma/\text{H}\beta$ values (first panel of Fig. C1) shows that this ratio features a much stronger dependence on T_e than n_e . The other Balmer ratios show a similar dependence on T_e , with a < 6 per cent deviations from their fiducial value over our explored parameter space.

Next, we explore the range of multiple oxygen line ratios. The first ratio ([O III] $\lambda 5007$ /[O III] $\lambda 4959$) is fixed by atomic physics and therefore does not vary with n_e or T_e . On the other hand, [O II] $\lambda 3729$ /[O II] $\lambda 3726$ is strongly dependent on n_e , ([O III] $\lambda 5007$ /[O III] $\lambda 4363$) is dependent on T_e , and ([O III] $\lambda 5007$ /[O III]88 μm) is dependent on both parameters. Due to the large variation in the latter two ratios (i.e. more than 1 dex), we present the logarithm of each in Fig. C1.

¹²<https://almascience.eso.org/documents-and-tools/cycle12/alma-technical-handbook>

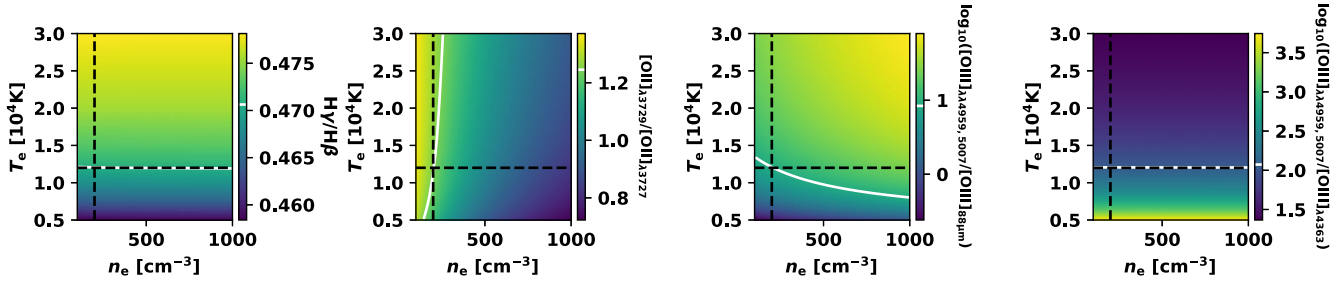


Figure C1. Demonstration of how line ratios vary with respect to T_e and n_e , with $E(B - V) = 0.0$. The fiducial values ($n_e = 200 \text{ cm}^{-3}$ and $T_e = 1.2 \times 10^4 \text{ K}$) are marked with dashed black lines, while the resulting ratio is marked in the colour bar with a white line. White lines in each panel show ISM conditions that produce the same ratio as the fiducial values.

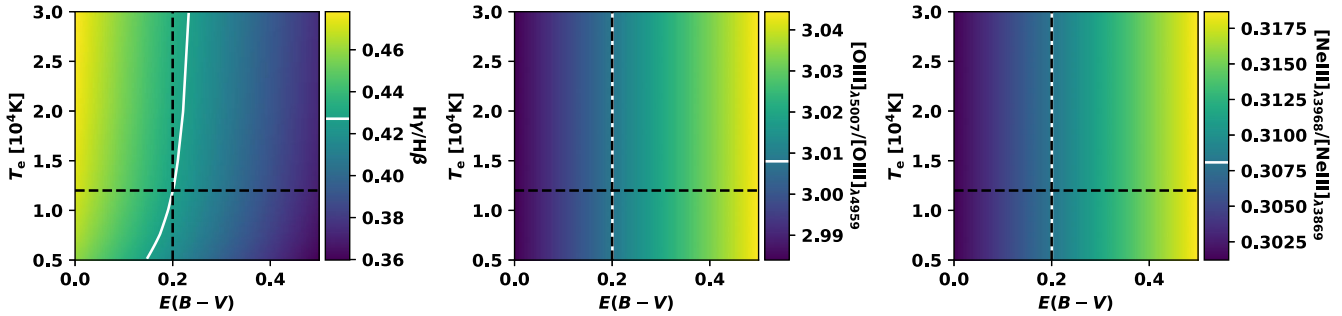


Figure C2. Demonstration of how line ratios vary with respect to T_e and $E(B - V)$, with a constant $n_e = 200 \text{ cm}^{-3}$. The fiducial temperature ($T_e = 1.2 \times 10^4 \text{ K}$) and $B - V$ colour excess ($E(B - V) = 0.2$) are marked with dashed black lines, while the resulting ratio is marked in the colour bar with a white line. White lines in each panel show ISM conditions that produce the same ratio as the fiducial values.

Table C1. Dust-corrected line ratios found using PYNEB using fiducial electron properties ($n_e = 200 \text{ cm}^{-3}$ and $T_e = 1.2 \times 10^4 \text{ K}$) and either $E(B - V) = 0, 0.1, \text{ or } 0.4$. Italicized entries are independent of density and temperature.

$E(B - V)$	0.0	0.1	0.4
$H\alpha/H\beta$	2.828	3.179	4.517
$H\gamma/H\beta$	0.471	0.448	0.388
$H\delta/H\beta$	0.261	0.252	0.194
$H\epsilon/H\beta$	0.160	0.147	0.113
$H\zeta/H\beta$	0.106	0.096	0.072
$H\eta/H\beta$	0.074	0.066	0.049
$[\text{O III}]\lambda 5007/[\text{O III}]\lambda 4959$	2.984	2.996	3.032
$[\text{O II}]\lambda 3729/[\text{O II}]\lambda 3726$	1.246	1.246	1.247
$[\text{O III}]\lambda 5007/[\text{O III}]\lambda 88 \mu\text{m}$	6.282	4.165	1.213
$[\text{O III}]\lambda 5007/[\text{O III}]\lambda 4363$	88.623	93.972	112.035
$[\text{Ne III}]\lambda 3968/[\text{Ne III}]\lambda 3869$	0.301	0.305	0.315

Like $[\text{O III}]\lambda 5007/[\text{O III}]\lambda 4959$, the ratio $[\text{Ne III}]\lambda 3869/[\text{Ne III}]\lambda 3968$ is fixed by atomic physics, and thus is not dependent on n_e or T_e . Because of this, we present the fiducial value in Table C1 but do not show a distribution.

C2 Dust reddening

In addition, line ratios may be affected by dust extinction. In the case of a dust-free environment, $E(B - V) = 0$, and the line ratios discussed in the previous subsection would be appro-

priate. However, even for $E(B - V) \lesssim 0.5$, line ratios will differ significantly from their extinction-free values. To demonstrate this, Fig. C2 shows the $T_e - E(B - V)$ grid for $H\gamma/H\beta$, $[\text{O III}]\lambda 5007/[\text{O III}]\lambda 4959$, and $[\text{Ne III}]\lambda 3968/[\text{Ne III}]\lambda 3869$.

For each of the Balmer ratios, over the range of parameters considered, $E(B - V)$ has more of an effect on the observed ratio than T_e . This is also true for the oxygen and neon ratios, which are temperature-independent. While the oxygen and neon ratios only vary a few per cent from the fiducial values ($\lesssim 3$ per cent), the Balmer ratios have larger variations that increase with transition number (e.g. ~ 15 per cent for $H\gamma/H\beta$ and ~ 30 per cent for $H\zeta/H\beta$).

C3 Line ratio interpretation

It is clear that some line ratios are strong tracers of ISM conditions. A high $[\text{O III}]\lambda 5007/[\text{O III}]\lambda 4959$ or $[\text{Ne III}]\lambda 3968/[\text{Ne III}]\lambda 3869$ ratio implies strong dust reddening, while in the absence of reddening a low $[\text{O II}]\lambda 3729/[\text{O II}]\lambda 3726$ ratio will suggest a high electron density, and a high Balmer ratio (e.g. $H\gamma/H\beta$) traces a high electron temperature. But there is some ambiguity between n_e , T_e , and $E(B - V)$, as shown by the curved lines of constant ratio in Figs C1 and C2.

While $[\text{O III}]\lambda 5007/[\text{O III}]\lambda 4959$ and $[\text{Ne III}]\lambda 3968/[\text{Ne III}]\lambda 3869$ appear to be good tracers of $E(B - V)$, their small wavelength separations result in small changes in the observed ratio (e.g. $\lesssim 1$ per cent for $E(B - V) \lesssim 0.5$) which would require high-S/N observations to

constrain. In addition, we have assumed case B recombination here, while case A recombination would result in altered Balmer ratios (e.g. C. Scarlata et al. 2024). We fit each observed profile in this work with two components (i.e. narrow and broad), adding an additional complication to ratio interpretation.

With these notes in mind, we make several assumptions for our fitting procedure. First, since we lack any strong tracers of n_e (i.e. the spectral resolution to resolve the $[\text{O II}]\lambda\lambda 3726, 3729$ doublet), we fix n_e to the fiducial value of 200 cm^{-3} used by Y. Sugahara et al. (2025). Next, we conservatively fix $E(B - V)$ to the value found by Y. Sugahara et al. (2025) for the full B14-65666 system (0.2). Finally, we assume that all lines originate from the same medium, such that each line may be characterized by the same ISM conditions (n_e , T_e , and $E(B - V)$).

APPENDIX D: COMPARISON OF NARROW AND BROAD EMISSION

In Section 3.2, we extract the spectra from each spaxel of our data and fit them to determine the spatial distribution of line and continuum emission, as well as ISM properties. While most of our discussion focuses on the total emission, our model includes both narrow and broad components. To demonstrate the significance of these detected components, we show the best-fitting narrow and broad emission maps of the two brightest lines ($\text{H}\beta$ and $[\text{O III}]\lambda 5007$) in Fig. D1.

Emission from the narrow components of both lines is focused in the two cores, while the broad emission primarily emanates from the E core. We emphasize that the fitting of each spaxel-based spectrum was performed independently, and a signal-to-noise limit of $> 3\sigma$ was enforced for each fit to be accepted.

This is further demonstrated in Fig. D2, where we show extracted spectra from four spaxels between the cores (see positions A–D in Fig. D1), their best-fitting models, and the residuals. Each $\text{H}\alpha$ and $[\text{O III}]\lambda\lambda 4959, 5007$ line shows significant broad emission, with different strengths and velocity offsets from the narrow emission.

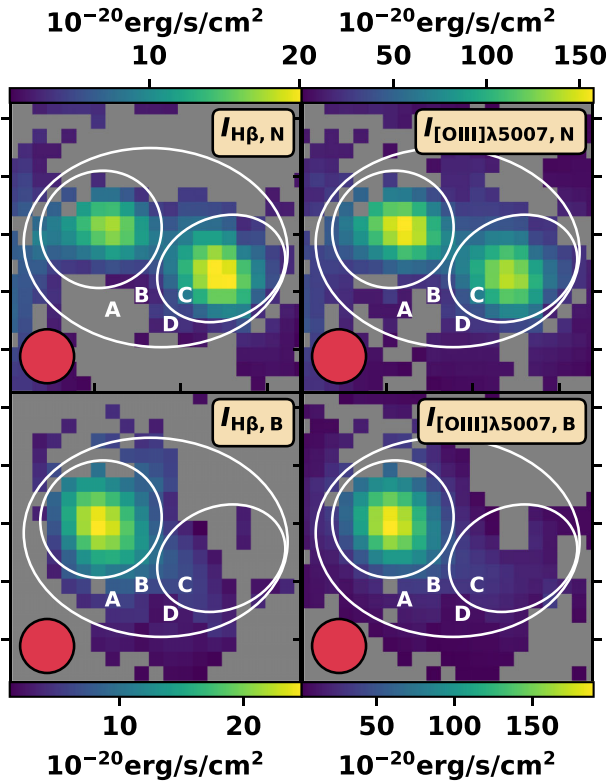


Figure D1. Integrated fluxes of narrow (top row) and broad (bottom row) components of $\text{H}\beta$ (left column) and $[\text{O III}]\lambda 5007$ (right column), as derived through spaxel-by-spaxel fit. Each panel displays a field of view of 1.0×1.0 arcsec centred on $10^{\text{h}}01^{\text{m}}40^{\text{s}}.69 + 1^{\circ}54'52''.55$. For each, we show the PSF as a red ellipse to the lower left. North is up and east is to the left. We mark the locations of four spaxels (A through D), from which we extract spectra (Fig. D2).

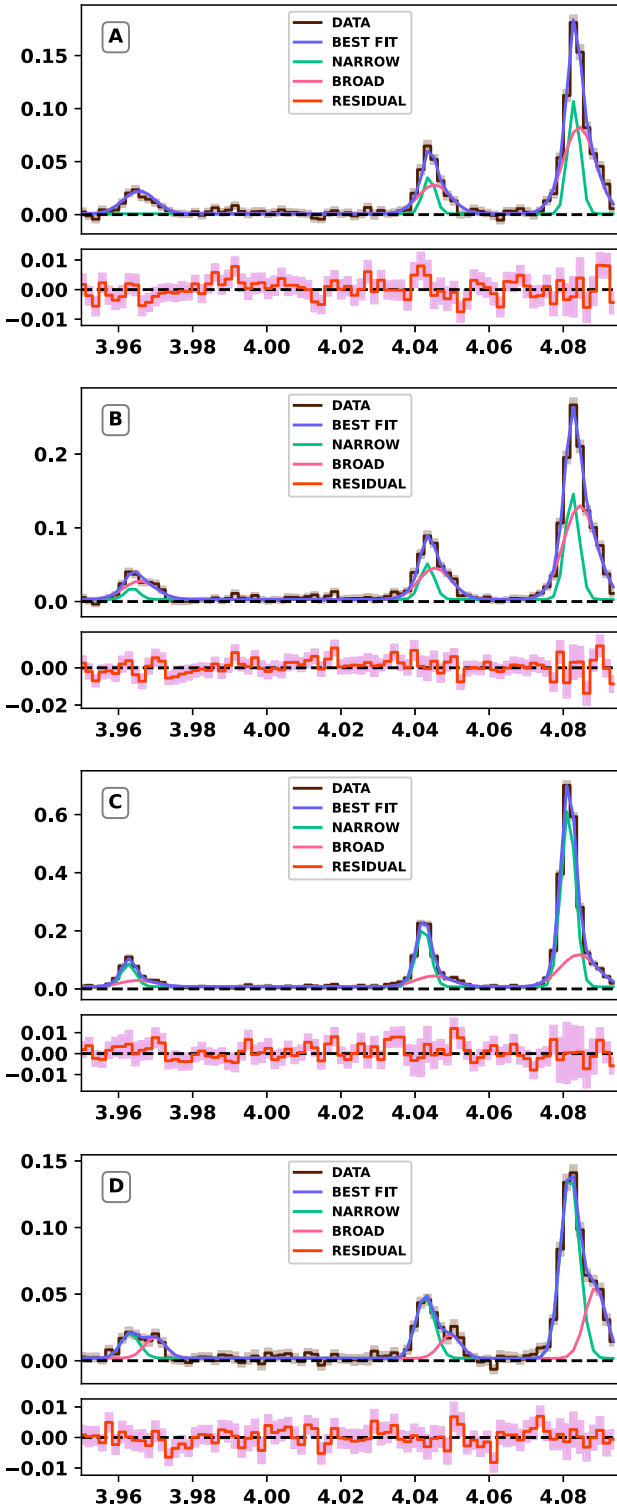


Figure D2. Spectra extracted from four spaxels of our *JWST*/NIRSpec IFU data cube (see Fig. D1). We isolate the wavelength range containing $H\beta$ and $[O\ III]\lambda\lambda 4959, 5007$, and present the observed spectrum, the best-fitting model, and its narrow and broad components. The residual is included in the lower panel.

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