

A deep dive down the broad-line region: permitted O I, Ca II and Fe II emission in an AGN Little Red Dot at $z = 5.3$

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ABSTRACT

We present a spectroscopic analysis of a broad-line active galactic nucleus (AGN) selected as little red dot at $z = 5.3$ behind the Bullet cluster (Bz5.3), based on *JWST*/NIRCam and NIRSpect data. The detection of strong Fe II, O I, and Ca II triplet emission lines, along with the evidence of **broad Balmer lines**, provides unambiguous evidence of a broad-line region (BLR) and an accreting supermassive black hole. Notably, we report the **first detection of the $\lambda 1304$ bump** (i.e., blend of O I $\lambda 1304$ and Si II) at high redshift, a feature commonly seen in local AGNs but not yet reported in the early Universe. The O I $\lambda 1304/\lambda 8446$ photon ratio is highly suppressed (0.1–0.3), implying significant internal dust extinction, with estimated dust attenuation $A_V \sim 0.4$ –1.0. We identify Ly β fluorescence as the dominant excitation mechanism of the low-ionization lines, with additional contributions from collisional excitation. High O I $\lambda 8446$ equivalent width and weak O I $\lambda 7774$ support this interpretation. The detection of iron emission, whether from broad permitted or narrow forbidden lines, supports the presence of a **stratified BLR**, as also recently proposed in local LRDs. Photoionization modeling of O I $\lambda 8446$ and Ca II further suggests the coexistence of multiple gas phases with distinct densities and ionization states, highlighting the complexity of the BLR. Bz5.3 thus offers a rare window into early AGN activity and BLR physics at early times.

Keywords: Astrophysical black holes (98), AGN host galaxies (2017), Galaxy spectroscopy (2171)

1. INTRODUCTION

The Broad Line Region (BLR) — a compact, high-density ($n_h \sim 10^9$ – 10^{10} cm⁻³) and high-velocity (FWHM ~ 1000 – 10000 km s⁻¹) region within $\lesssim 1$ pc of a supermassive black hole (SMBH) — produces the broad emission lines observed

in active galactic nuclei (AGNs). These lines, including Balmer lines, Mg II, C IV, Fe II, O I, and the Ca II triplet, provide key insights into the structure, kinematics, and chemical composition of the gas surrounding SMBHs (see H. Netzer 2013). Among them, low-ionization lines (LILs) like Fe II, O I, and Ca II $\lambda 8498, 8542, 8662$ are especially valuable for probing the outer BLR.

Understanding the excitation and distribution of UV–optical iron emission is crucial, as Fe II is a major coolant of the BLR and reflects the gas energy budget (B. J. Wills et al. 1985; Y. Matsuoka et al. 2007). Its emission also traces chemical enrichment across cosmic time (F. Hamann & G. Ferland 1999, 1993; Y. Yoshii et al. 1998). The main excitation mechanisms are Ly α fluorescence and collisional excitation (S. A. Grandi 1980; A. Rodríguez-Ardila et al. 2002), with near-IR Fe II lines especially linked to the former. Thanks to studies using reverberation mapping, Fe II is found to arise in the outer BLR, where its spectral profile and equivalent width encode the physical conditions (J. Kovačević et al. 2010; J. A. Baldwin et al. 2004). Interestingly, UV Fe II features have recently been reported in two AGN “Little Red Dots” (LRDs), A2744-45924 at $z = 4.47$ (I. Labbe et al. 2024) and CAPERS-LRD-z9 at $z = 9.288$ (A. J. Taylor et al. 2025), directly linking them to BLR origin. Optical Fe II lines are instead typically weak in JWST-selected broad-line AGN, possibly due to the reduced metallicity of their broad line region (B. Trefoloni et al. 2024). Despite the large number of studies of Fe II in AGNs (e.g., P. Marziani et al. 2013; H. Netzer & B. J. Wills 1983; B. J. Wills et al. 1985; T. A. A. Sigut & A. K. Pradhan 1998, 2003; E. M. Verner et al. 1999; E. Verner et al. 2003, 2004; J. A. Baldwin et al. 2004; Y. Tsuzuki et al. 2006; R. J. Rudy et al. 2000; X.-B. Dong et al. 2009; J. Kovačević-Dojčinović et al. 2025; I. Labbe et al. 2024; B. Trefoloni et al. 2024; G. J. Ferland et al. 2020), interpreting the blended Fe II pseudo-continuum remains challenging given the complex energy levels of Fe II and the mixed excitation mechanisms.

Complementary diagnostics come from simpler atoms thought to trace similar BLR regions and excitation conditions. Neutral oxygen (O I) and singly-ionized calcium (Ca II) often correlate with Fe II in strength and width (A. Rodríguez-Ardila et al. 2002; M. Joly 1987; Y. Matsuoka et al. 2007, 2008; P. Marziani et al. 2013; G. J. Ferland & S. E. Persson 1989; S. E. Persson 1988), reflecting their comparable ionization potentials (16.2, 13.6, and 11.9 eV for Fe II, O I, and Ca II, respectively). The O I λ 8446 line lacks a narrow component and is associated with Ly β fluorescence (S. A. Grandi 1980; R. J. Rudy et al. 1989). Emission at O I λ 1304, O I λ 8446, and O I λ 11287 is expected in a 1:1:1 photon ratio, with deviations indicating alternative mechanisms like recombination or collisional excitation (A. Laor et al. 1997; A. Rodríguez-Ardila et al. 2002; Y. Matsuoka et al. 2005, 2007, 2008). Additional O I lines such as O I λ 7774 and O I λ 7990 help refine the dominant processes.

Ca II emission arises primarily from the near-IR triplet (Ca II λ 8498,8542,8662: λ 8498, λ 8542, λ 8662), emitted from neutral, optically thick gas shielded from hard radiation (G. J. Ferland & S. E. Persson 1989; M. Joly 1989). Comparisons between Ca II λ 8498,8542,8662, O I, and Fe II emission, both

in flux and kinematics, constrain the gas density, ionization, and geometry of the BLR (Y. Matsuoka et al. 2007, 2008).

Y. Matsuoka et al. (2008) found that these diagnostics in low-redshift quasars ($z < 1$) show little redshift or luminosity dependence, suggesting similar gas densities and ionizing fields, possibly mixed with dust.

Until now, such studies have been largely limited to $z < 1$ due to sensitivity and resolution limits. Only two exceptions exist at higher redshifts: a $z \sim 2.26$ “Rosetta Stone” quasar with Ca II emission (I. Juodžbalis et al. 2024), and the $z \sim 4.5$ LRD A2744-45924 with O I, Ca II λ 8498,8542,8662.

In this Letter, we present the discovery of Bullet-LRD-z5.3 (hereafter Bz5.3), an AGN host at $z_{\text{spec}} = 5.2907 \pm 0.0002$, magnified by a factor $\mu = 2.2^{+0.9}_{-0.8}$. Using JWST/NIRSpec prism spectroscopy, we report the first detection of the O I λ 1304 bump (blend of O I λ 1304 and Si II) at $z > 1$, along with strong O I λ 8446, Ca II λ 8498,8542,8662, and rest-UV/optical Fe II emission. These observations offer a rare opportunity to probe BLR structure and excitation at early cosmic times. Data are presented in Sect. 2, results in Sect. 3, discussion in Sect. 4, and conclusions in Sect. 5.

Throughout the paper we adopt the Λ CDM cosmology from Planck Collaboration et al. (2020): $H_0 = 67.4 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.315$, and $\Omega_\Lambda = 0.685$. Thus, the angular scale is 6.238 kpc/arcsec at $z = 5.2907$.

2. DATA

The Bullet cluster was observed with NIRCcam (M. J. Rieke et al. 2023) in JWST Cycle 3 in January 2025 (GO program 4598, PI Bradač). We obtained imaging in eight filters, F090W, F115W, F150W, F200W, F277W, F356W, F410M and F444W with exposure times of ~ 6.4 ks each. In addition we use the archival HST/ACS observations in F606W, F775W and F850LP filters (programs 10200 and 10863, PI Jones & Gonzalez) and F814W filter (program 11099, PI Bradač). The images were processed with a modified version of the stage 1 and stage 2 JWST pipeline, the Canadian NIRISS Unbiased Cluster Survey (CANUCS) data reduction pipeline (full details in G. T. E. Sarrouh et al. 2025), before being drizzled onto a 40 milliarcsec pixel grid using the *grizli* code (G. Brammer 2019). Bright cluster and foreground galaxies as well as intracluster light are removed from the images following the procedure outlined in N. S. Martis et al. (2024). Photometry is performed on the subtracted, psf-matched images convolved to the F444W filter resolution.

Bz5.3 was photometrically selected as an LRD using the NIRCcam data, following standard color and compactness criteria (V. Kokorev et al. 2024). It was followed up with NIRSpec/prism ($R \sim 30 - 400$) with the Micro-Shutter Assembly (MSA) as part of the same GO program 4598. NIRSpec/prism data have also been reduced and the redshift of the source has been estimated following the procedure de-

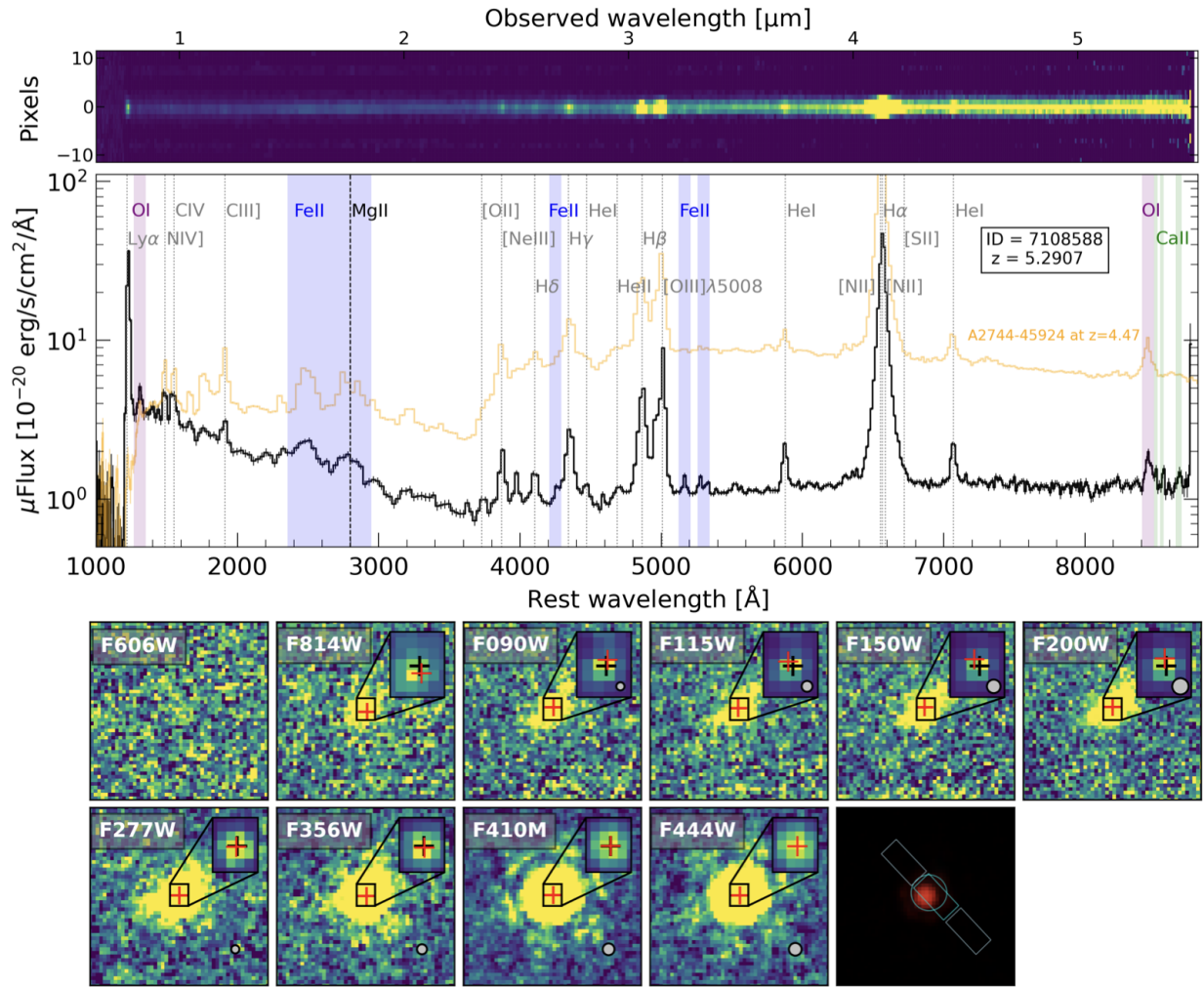


Figure 1. HST/ACS and NIRCcam photometry, and NIRSpect spectra of Bz5.3. Top panels: 2D and 1D NIRSpect spectra. Fluxes are not corrected for magnification. Lines of interest for this work are highlighted by colored vertical bars. Other detected emission lines are marked with dashed gray vertical lines. The y-axis scale of the 1D spectrum is logarithmic. For comparison the spectrum of A2744-45924 at $z = 4.47$ is shown in light orange. Bottom panels: NIRCcam cut-out photometry in different filters, specified at the top left corner of each panel, and RGB image made combining the F444W, F356W, and F277W for red, F150W and F200W for green, and F090W and F115W filters for blue. Cutouts images are $2'' \times 2''$ in size. In each panel, there is an inset zooming-in on the center region to show the flux centroid of the filter (red cross), compared to the flux centroid in F444W (black cross). The PSF size of each NIRCcam filter is shown as a gray circle in the bottom right corner of each panel (or zoom-in inset).

scribed in [G. T. E. Sarrouh et al. \(2025\)](#). From the 2D spectral reduction, a 1D spectrum is extracted using an optimal extraction based on the source spatial profile. We correct for slit losses by scaling the 1D spectrum to the observed photometry. Specifically, we perform photometry in the region covered by the MSA slit, then fit a Chebyshev polynomial to the ratio of the observed photometry and synthetic photometry obtained from convolving the spectrum within each filter. The 1D spectrum is then multiplied by the derived polynomial.

To estimated magnification due to lensing, a strong lensing model was derived using the parametric lens modeling tool *Lenstool* ([J. P. Kneib et al. 1996](#); [E. Jullo et al. 2007](#); [E. Jullo & J. P. Kneib 2009](#)) and is constrained with a cata-

logue of 113 multiple images from 28 background galaxies with spectroscopic redshifts. The catalogue of multiple images was derived using JWST data. It includes multiple image candidates included in [S. Cha et al. \(2025\)](#) lens model, harnessing NIRCcam imaging, and adds additional NIRSpect spectroscopic redshifts for 22 galaxies. The derived magnification of Bz5.3 is $\mu = 2.2^{+0.9}_{-0.8}$. This estimate and uncertainty are derived from several lens model parameterizations to take into account the mass model uncertainty in the southern part of the main cluster, where Cz5.5 is situated. For the discussion of the lens model and the catalogues of strong lensing constraints see [Rihtaršič et al, in prep.](#) Unless otherwise specified, quantities are corrected for magnification, and errors take into account magnification uncertainties.

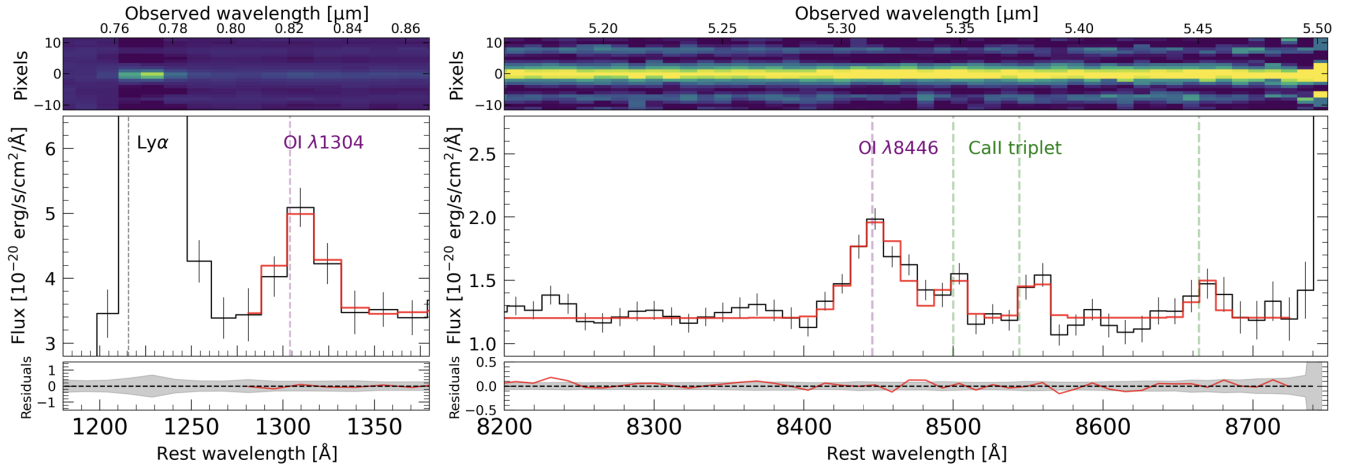


Figure 2. Zoom-in of the 2D and 1D spectra of Bz5.3. The observed spectrum is shown in black, and the best-fitting model is shown in red. Residuals are shown at the bottom of each panel, where the shaded gray area represents the 1σ noise level. Left panel: zoom on the $\lambda 1304$ bump. The vertical pink line is at the laboratory rest wavelength of the O I $\lambda 1304$ emission line. The vertical dashed black line marks the Ly α line. Right panel: zoom-in on the O I $\lambda 8446$ emission line and on the Ca II $\lambda 8498, 8542, 8662$ triplet. Vertical lines are set at laboratory rest wavelength for these emission lines. The scale of the y-axis is linear.

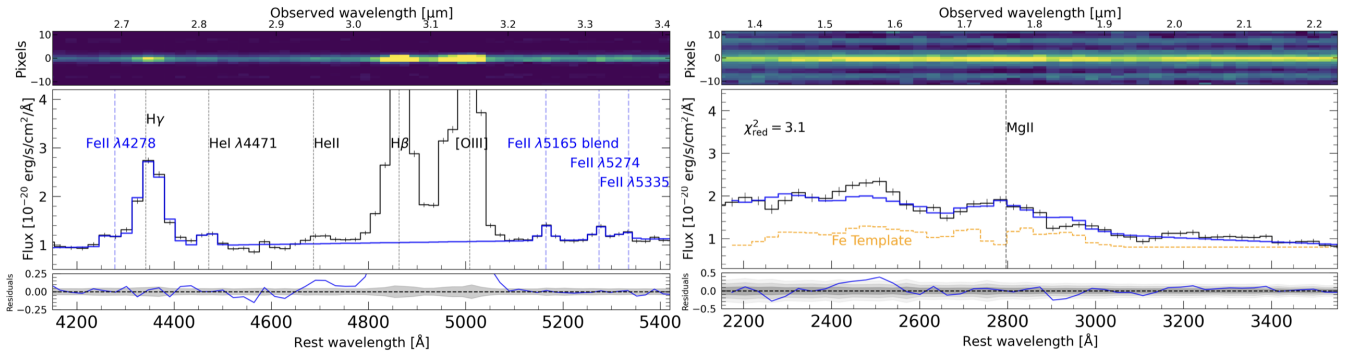


Figure 3. Zoom-in of the 2D and 1D spectra of Bz5.3. The observed spectrum is shown in black, while the best-fitting model is shown in blue. Residuals are shown at the bottom of each panel, where the shaded dark gray area represents the 1σ noise level. Top panel: zoom on the Fe II emission in the optical. The vertical lines are at the laboratory rest wavelength of the reported emission line. Bottom panel: zoom on the Fe II complex in the UV and Mg II emission line. 2 and 3σ noise levels are reported in the residual as shaded lighter gray area.

An inspection of the available Chandra 500 ks data targeting the Bullet Cluster (D. Clowe et al. 2006) reveals no significant X-ray emission at the position of Bz5.3, consistent with the lack of X-ray detections reported for other LRD samples (T. T. Ananna et al. 2024; M. Yue et al. 2024; A. Sacchi & A. Bogdan 2025).

3. ANALYSIS AND RESULTS

Figure 1 show the 2D and 1D spectra of Bz5.3, along with all the available NIRCcam photometry of the source. Bz5.3 is a point source in F444W and F410M, while shows extended emission in all the other filters (see App. A for more details). Based on the flux centroids, we find no significant spatial variation ($\leq 0.04''$) between the emitting region in the bluest UV (F814w) and in near UV (F150W).

The blue UV slope ($\beta_{UV,spec} = -1.6 \pm 0.1$), red optical slope ($\beta_{opt,spec} = 0.66 \pm 0.09$), and compactness in F444W together

classify Bz5.3 as an LRD, in compliance with the standard criteria reported in V. Kokorev et al. (2024) and D. D. Kocovski et al. (2025).

Several clear AGN signatures and a prominent Balmer break are evident upon visual inspection of the spectra. Notably, we detect Ly α , O I $\lambda 1304$, N IV], C IV, C III], Mg II and Fe II, [O II], [Ne III] $\lambda\lambda 3869, 3967$, H δ , Fe II $\lambda 4278$, H γ , narrow H β , He I $\lambda 4471$, [O III] $\lambda 5007$, Fe II $\lambda 5165 \lambda 5274 \lambda 5335$, He I $\lambda 5877$, [N II] $\lambda 6584$, narrow H α , [S II], He I $\lambda 7067$, O I $\lambda 8446$, Ca II $\lambda 8498, 8542, 8662$, emission lines, as well as broad H α emission with a full width at half maximum (FWHM) of $4600 \pm 50 \text{ km s}^{-1}$, and broad H β emission with FWHM = $5100 \pm 500 \text{ km s}^{-1}$. Using the virial relation from A. E. Reines & M. Volonteri (2015), this broad H α line implies a black hole (BH) mass of $\log(M_{BH}/M_{\odot}) = 8.5 \pm 0.3$. Analogously, using the virial relations from J. E. Greene & L. C. Ho (2005) and M. Vestergaard & P. S. Osmer (2009),

we derive a BH mass of $\log(M_{\text{BH}}/M_{\odot}) = 8.0 \pm 0.3$, which is fully consistent with the one from $\text{H}\alpha$.

In this work, however, we focus on the discussion of the BLR properties as derived from the O I, Ca II, and Fe II emission lines. Therefore, in this section, we describe the fitting methodology and present the results for these lines only. A complete analysis and discussion of the other source's properties is deferred to a following and more extensive work (Tripodi et al., in prep.).

3.1. Continuum and line fitting

The underlying continuum of the $\lambda 1304$ bump and of O I $\lambda 8446$ + Ca II $\lambda 8498, 8542, 8662$ is modeled separately using a linear relation² and power-law, respectively, both with free slope and normalization. Each emission line is modeled as a single Gaussian.

The FWHM is fixed to be the same for each line in the Ca II $\lambda 8498, 8542, 8662$ triplet. The relative intrinsic ratio of the triplet is found to be 1:9:5 in an optically thin regime, and flattens to 1:1:1 for optically thick media, as derived from analysis of stars (M. G. Guarcello et al. 2014). R. J. Rudy et al. (2000) found that, in the AGN I Zw 1, this ratio is 1:1.15:0.83 probably due to different gas conditions w.r.t a simple optically thick homogeneous medium, and this assumption has been adopted also in the analysis of quasars by Y. Matsuoka et al. (2008). Given the lack of precise prescriptions in this regard, we choose to leave the flux relative intensities free and see whether our results align, or not, with the above mentioned values.

As mentioned in Sect. 1, modeling the Fe II pseudo-continuum is particularly challenging, and empirical templates from low-redshift well-studied sources are often used to fit the observed data (e.g. I. Labbe et al. 2024). In particular, we adopted the template from M. Vestergaard & B. J. Wilkes (2001) to model the Fe II signatures in the UV, which are also blended with the Mg II emission. The Mg II line is fitted with a single Gaussian, and the underlying continuum with a power-law relation as described above. The template has been convolved with the resolution of the instrument.

The Fe II emission lines detected in the optical, Fe II $\lambda 4278$, Fe II $\lambda 5165$, Fe II $\lambda 5274$ and Fe II $\lambda 5335$, are modeled as a single Gaussian each, and the underlying continuum as a power law. We do not adopt empirical templates since some of the observed intensities of optical Fe II lines are not as theoretically expected (see Sect. 4 and J. Kovačević-Dojčinović et al. 2025). The FWHM of all these transitions is fixed to be the same, since they are thought to arise from the same

region. Fe II $\lambda 4278$ is blended with $\text{H}\gamma$ + [O III] $\lambda 4364$ and He I $\lambda 4471$, therefore we also model $\text{H}\gamma$ + [O III] $\lambda 4364$ and He I $\lambda 4471$ as two independent Gaussians. Other emission lines at $4200\text{\AA} < \lambda_{\text{rest}} < 5400\text{\AA}$ have been masked. The results of the fit are shown in Figure 2 for the O I and Ca II complexes, and in Figure 3 for Fe II and Mg II.

Details on the specific fitting procedure used and the derivation of the measured quantities can be found in Appendix B. Flux, FWHM and EW of all the fitted lines are reported in Table 1. FWHMs are corrected for instrumental broadening (see Appendix B for details).

3.2. Constitution of the $\lambda 1304$ Bump

The $\lambda 1304$ bump typically seen in AGN spectra is the result from a blending of an O I triplet at $\lambda 1302.17$, $\lambda 1304.86$, and $\lambda 1306.03$ (named so far as O I $\lambda 1304$), and a Si II doublet at $\lambda 1304.37$ and $\lambda 1309.27$ (hereafter just Si II). The blending is usually very strong in most quasars, preventing a reliable estimate of the relative contributions of O I and Si II to the blend. However, A. Laor et al. (1997) were able to estimate the O I and Si II fractions in the blend for I Zw 1, given that the Si II was clearly detected. They found that 50% (56%) of the bump flux is due to O I in the optically thin (thick) Si II doublet case. Moreover, A. Rodríguez-Ardila et al. (2002) estimated that in three narrow-line Seyfert 1 galaxies the average proportion of the O I flux is 75%, while Y. Matsuoka et al. (2007) reported a larger range of O I fractions in 5 quasars at $0.15 < z < 1.1$, ranging from 20% to 98%. Y. Matsuoka et al. (2007) also presented some theoretical considerations regarding the possible strengthening of the Si II line: in particular, Si II flux can be enhanced in the large optically emitting cloud (LOC) scenario or in a gas with unusually large micro-turbulent velocities (as also suggested by M. Bottorff et al. 2000). The latter scenario, however, implies a significant suppression in the Ly β fluorescence rate, which is not our case as discussed in Sect. 4.4.

The spectral resolution of our data prevents us from resolving the bump; therefore, we fit the bump with a single Gaussian. For the following calculations, we assume a O I $\lambda 1304$ fraction of 50% to correct for the Si II contamination, which corresponds -on average- to the results found in literature.

3.3. Emission line measurements

Here we present the results obtained by performing the fit of the lines of interest in Bz5.3 using the method described in Sect. 3.1. These are also summarized in Table 1.

O I $\lambda 1304, 7774, 7790, 8446$. We clearly detect both the $\lambda 1304$ bump at $S/N = 5$, and $\lambda 8446$ at $S/N = 9.6$, while $\lambda 7774$ and $\lambda 7790$ remain undetected. Given that the prism spectral resolution (R) increases by a factor of 10 between $\lambda_{\text{rest}} = 1304 \text{\AA}$ and $\lambda_{\text{rest}} = 8446 \text{\AA}$, the $\lambda 1304$ bump remains unresolved, while for $\lambda 8446$ we measure a broadening of $\text{FWHM} =$

² The linear relation provided a better model for the underlying continuum of the $\lambda 1304$ bump than a power-law given that the available wavelength range of continuum emission is small, since the bump lies close to the Ly α and N V emission.

Table 1. Results from the emission line fitting procedure

Line	μFlux [10^{-18} erg s $^{-1}$ cm $^{-2}$]	FWHM [km s $^{-1}$]	EW [\AA]
O \AA 1304 †	$3.2^{+1.4}_{-1.0}$	–	15^{+8}_{-6}
O \AA 7774	< 0.4	–	–
O \AA 7790	< 0.5	–	–
O \AA 8446	1.86 ± 0.15	940^{+50}_{-100}	25 ± 2
Ca \AA 8498	$0.39^{+0.13}_{-0.11}$	–	5.7 ± 1.5
Ca \AA 8542	0.40 ± 0.11	–	5.4 ± 1.5
Ca \AA 8662	$0.34^{+0.16}_{-0.14}$	–	4.6 ± 2
Fe \AA 4278	0.609 ± 0.108	–	9 ± 2
Fe \AA 5165	$0.588^{+0.094}_{-0.091}$	–	9 ± 1
Fe \AA 5274	$0.528^{+0.083}_{-0.079}$	–	7 ± 1
Fe \AA 5335	0.313 ± 0.077	–	4 ± 1
Mg \AA II	2.11 ± 0.34	–	25^{+5}_{-4}

Notes. Fluxes reported here are not corrected for magnification. † Results reported here do not consider the possible contamination from Si II.

940^{+50}_{-100} km s $^{-1}$. The measured observed fluxes are reported in Table 1. Given these estimates, we derive the following flux ratios for $\lambda 7774$, $\lambda 7790$ over $\lambda 8446$: $r_{7774/8446} < 0.23$, $r_{7790/8446} < 0.28$. To estimate the upper limit on flux ratio between $\lambda 1304$ and $\lambda 8446$ we assuming a fraction of O \AA 1304 of 100%, implying $r_{1304/8446} \leq 1.7^{+0.8}_{-0.6}$. If assuming the contamination of Si II $\lambda 1309$ on the O \AA 1304 to be of order 50% (see Sect. 3.2 for discussion), the flux ratio becomes $r_{1304/8446, \text{corr}} = 0.9 \pm 0.3$. These correspond to photon flux ratios of $\text{ROI}_{\text{UV}} < 0.27^{+0.12}_{-0.09}$, and $\text{ROI}_{\text{UV, corr}} \leq 0.13^{+0.06}_{-0.04}$, respectively³.

Ca \AA 8498,8542,8662 triplet. Each line in the calcium triplet is detected with S/N = 5, 5, 4, respectively. The measured observed fluxes are reported in Table 1. At face value, these correspond to relative ratios of 1:1.01:0.87 for $\lambda 8498:\lambda 8542:\lambda 8662$. This is close to the ratios derived for I Zw 1 by R. J. Rudy et al. (2000). The photon flux ratio for the Ca II multiplet and the O \AA 8446 ($\text{ROI}_{\text{Ca II}}$), assuming a representative wavelength of 8579 \AA , is $\text{ROI}_{\text{Ca II}} = 0.62^{+0.16}_{-0.12}$.

Fe II emission lines. In the UV, the template seems to properly model the blend of Mg II and Fe II at $\lambda_{\text{rest}} = 2800\text{\AA}$, and it reproduces the spectral shape at $2200\text{\AA} \lesssim \lambda_{\text{rest}} \lesssim 2600\text{\AA}$. However, the observed flux intensity of the Fe II lines in the $2200\text{\AA} \lesssim \lambda_{\text{rest}} \lesssim 2600\text{\AA}$ regime is not well described by the template. This discrepancy is partially solved when varying

³ The photon flux ratio (region of interest or ROI) between two emission lines, at λ_i and λ_j , is defined as $\text{ROI}_{ij} = n(\lambda_i)/n(\lambda_j)$, where $n(\lambda_i) = F_\lambda^i/E_i$ [photons s $^{-1}$ cm $^{-2}$] is the photon flux of the line i with flux F_λ^i [erg s $^{-1}$ cm $^{-2}$] and with energy of the emitting photons $E_i = hc/\lambda_i$ [erg].

the flux ratios of the Fe II emission in $2200\text{\AA} \lesssim \lambda_{\text{rest}} \lesssim 2600\text{\AA}$ compared to the Fe II emission around Mg II (see Appendix C and I. Labbe et al. 2024). The variation of the intrinsic flux ratios implies that the observed gas conditions differ from those assumed in the template model (M. Vestergaard & B. J. Wilkes 2001), but it is difficult to draw strong conclusions based on the poor resolution of the data available.

In the optical, the Fe II lines are well modeled by a single Gaussian, but are all unresolved at the spectral resolution of the prism.

4. DISCUSSION

4.1. Evidence for the broad-line region stratification

The detection of iron emission in the UV and in the optical gives us unambiguous evidence of an AGN (see Sect. 1). This is further corroborated by the detection of the O I and Ca II lines and the broad H α emission. Although we are unable to spectrally resolve—and thus model in detail—the iron multiplets in the UV, the detection of the iron signatures across the spectrum supports a scenario in which emission lines throughout the spectrum arise from the BLR, photoionized by the central BH (see also discussion in I. Labbe et al. 2024).

In cases like Bz5.3 with poor spectral resolution, there is a current debate whether these features arises from the broad emitting region or the narrower one, i.e. if these are broad permitted emission lines (I. Labbe et al. 2024; J. Kovačević-Dojčinović et al. 2025), or narrow forbidden ones (X. Lin et al. 2025).

Following the first interpretation, in the optical we detect two categories of Fe II emission lines. Fe \AA 4278 is classified as an ‘inconsistent’ Fe II line, while Fe \AA 5165, Fe \AA 5274 and Fe \AA 5335 as ‘consistent’ ones. The appearance of lines that should be negligible based on their transition probabilities, namely ‘inconsistent’ lines, has been recently studied and classified by J. Kovačević-Dojčinović et al. (2025). Based on the reported classification, Fe \AA 4278 belongs to the P+ group of ‘inconsistent’ lines. These are thought to arise either from lines from higher energy levels at similar wavelengths overlapping with these weak lines or from the same levels as consistent lines but amplified by unknown atomic processes. The presence and strength of ‘inconsistent’ emission lines is known to increase for $\text{FWHM}_{\text{Fe II, opt}} < 5000$ km s $^{-1}$. In the case of Bz5.3, the prism resolution limits the measured FWHM to be $\lesssim 1800$ km s $^{-1}$ in the optical and $\lesssim 3000$ km s $^{-1}$ in the UV, consistent with this trend. The diversity in both intensity, and possibly widths, among the consistent and inconsistent lines suggests that they originate from regions with varying physical conditions and distances from the BH, indicating a stratification of the Fe II emitting regions, and thus of the BLR (J. Kovačević-Dojčinović et al. 2025).

The more stringent constraint on their line widths ($\text{FWHM}_{\text{Fe II, opt}} \lesssim 1800 \text{ km s}^{-1}$) favours the second interpretation for the nature of the optical iron features. Indeed, [Fe II] have been recently detected and modeled in two local LRDs by X. Lin et al. (2025). Based on the comparison with photoionization models and the FWHM of [Fe II] ($\sim 200 - 300 \text{ km s}^{-1}$), they propose the [Fe II]-emitting region to lie right at the edge of the BLR, supporting the view of a stratified inner region, and just outside the cool gas envelope. For Bz5.3 the presence of the cool-gas envelope can be supported by the evidence of the Balmer break, given that Balmer absorption features, if present, are not detectable at the current resolution.

4.2. Dust attenuation and origin of UV continuum

According to the Grotrian diagram⁴ for O I (see e.g. Figure 3 in S. A. Grandi 1980), the ROI of $\lambda 1304/\lambda 8446$ (ROI_{UV}) must be equal to unity, in principle only decreasing when reddening is present. This is why the photon flux ratio between $\lambda 1304$ and $\lambda 8446$ has been used as reddening indicator (e.g., R. J. Rudy et al. 1989; A. Laor et al. 1997; A. Rodríguez-Ardila et al. 2002; Y. Matsuoka et al. 2005). These works also suggest that the ROI_{UV} can deviate from unity⁵, down to 0.63 even in the absence of reddening. This could be due to (i) Balmer continuum absorption of $\lambda 1304$ photons, or (ii) the production of $\lambda 8446$ by collisional excitation, or (iii) by collisional de-excitation destroying $\lambda 1304$ photons (J. Kwan & J. H. Krolik 1981; S. A. Grandi 1980). For Bz5.3, we estimated an ROI_{UV} between 0.1 and 0.3 (see Sect. 3.3) therefore, even if the $\lambda 1304$ is severely affected by destruction mechanisms or the $\lambda 8446$ is pumped by collisional excitation, these mechanisms are not sufficient to explain such a break of the one-to-one photon relation between $\lambda 8446$ and $\lambda 1304$ (as also discussed in A. Rodríguez-Ardila et al. 2002). Since we do observe a Balmer break in Bz5.3, and since these features have been associated with dense gas near AGN (K. Inayoshi & R. Maiolino 2025; X. Ji et al. 2025; R. P. Naidu et al. 2025; A. de Graaff et al. 2025), a discussion of Balmer-continuum absorption is warranted. Comparing Bz5.3 to A2744-45924 (see Figure 1) reveals that our AGN has a weaker break and steeper UV slope. This implies that Balmer absorption near $\lambda 1304$ may not be dominant, since the weak break compounds the decreasing bound-free cross section blueward of the Balmer limit. Independent evidence for weak neutral-gas absorption comes from the sharpness of the Ly α break in Bz5.3, suggesting that the UV photons prop-

agate through a path largely free of neutral hydrogen, which would otherwise leave a spectral-absorption imprint, as seen in the smooth Ly α break of A2744-45924. Thus, we favour dust playing a major role in altering the observed O I ratio.

We derive $E(B - V)$ and the dust attenuation (A_V) considering the observed ROI_{UV} derived in Sect. 3.3, both the intrinsic ROI_{UV} presented above, and assuming the Calzetti law for the dust attenuation curve (D. Calzetti et al. 1996). Results are reported in Table 2. Our findings points toward relatively high values of dust attenuation in the BLR, ranging from 0.4 to 1.0.

To assess the origin of the continuum under the O I $\lambda 1304$ line, we use the range of derived dust attenuation to correct the observed UV β slope, $\beta_{\text{UV}} = -1.6 \pm 0.1$. Assuming $A_V \in [0.4, 1.0]$, we obtain intrinsic UV beta slopes of $\beta_{\text{UV, int}} = [-2.8, -2.0]$. This is broadly consistent with a standard accretion disk (i.e. $\beta = -2.3$, see N. I. Shakura & R. A. Sunyaev 1976), and towards the steepest end with extreme star formation. Similar steep intrinsic UV slopes have been recently found both in the local LRDs at $z \sim 0.1 - 0.2$ (X. Lin et al. 2025), and in LRDs at $z > 4$ (see e.g. I. Labbe et al. 2024; R. Tripodi et al. 2024). These works favor the interpretation of the UV being dominated by AGN light, also motivated by the high EW of the UV emission lines.

4.3. Insights from the Ca II transitions

Comparisons of the Ca II triplet with H β and Fe II feature strengths could better constrain BLR properties and geometry. However, such analysis is hindered by: (1) the limited resolution of the prism, which prevents detailed modeling of UV Fe II emission; and (2) large uncertainties in de-reddened line fluxes due to the variable dust attenuation inferred from the O I $\lambda 1304/\lambda 8446$ ratio. Estimating attenuation from the broad Balmer lines is even more uncertain due to blending with nearby features (e.g., [O III] $\lambda 5007$, [O III] $\lambda 4364$, Fe II) at the current resolution.

The near-unity relative strengths of the Ca II $\lambda 8498, 8542, 8662$ lines suggest they are optically thick (G. J. Ferland & S. E. Persson 1989), consistent with the redshift in their centroids (Figure 2), as expected from resonant scattering. Other Ca II lines—such as H, K, and the forbidden $\lambda 7291$ and $\lambda 7324 \text{ \AA}$ —are typically absent in AGNs (G. J. Ferland & S. E. Persson 1989) and are also undetected in Bz5.3. The Ca II $\lambda 8498, 8542, 8662/\text{O I } \lambda 8446$ flux ratio varies across AGNs but is generally near unity (minimum 0.35 ± 0.19 ; G. J. Ferland & S. E. Persson 1989); for Bz5.3, we find $0.61_{-0.12}^{+0.15}$, consistent with this range.

4.4. Excitation mechanisms in the BLR

If Ly β fluorescence is the dominant excitation mechanism, the O I transitions at $\lambda 1304$, $\lambda 8446$, and $\lambda 11287$ should appear in a 1:1:1 photon flux ratio. However, this ratio can be

⁴ A Grotrian diagram, or term diagram, shows the allowed electronic transitions between the energy levels of atoms. They can be used for one-electron and multi-electron atoms.

⁵ Values of $\text{ROI}_{\text{UV}} = 1$ and $= 0.63$ corresponds to intrinsic flux ratios of 6.5 and 4, respectively.

Table 2. $E(B - V)$ and dust attenuation from the O I lines

	ROI _{UV,int} = 1.0		ROI _{UV,int} = 0.63	
	no Si II	Si II	no Si II	Si II
$E(B - V)$	0.16 ± 0.04	0.24 ± 0.04	0.10 ± 0.04	0.19 ± 0.04
A_V	0.65 ± 0.20	1.0 ± 0.20	0.42 ± 0.20	0.80 ± 0.20

Notes. The columns specify the assumptions made to compute the values of dust attenuation.

altered by three competing processes: recombination, collisional excitation, and continuum fluorescence. The presence or absence of auxiliary O I lines such as $\lambda 7774$ and $\lambda 7990$ provides diagnostic power to identify the dominant mechanisms (see Sect. 1; S. A. Grandi 1980; H. Landt et al. 2008; Y. Matsuoka et al. 2005, 2007, 2008).

Ly β fluorescence and collisional excitation are the main sources of O I λ 8446 emission in the BLR. S. A. Grandi (1980) first identified the absence of a narrow O I λ 8446 component — supporting a BLR origin — and proposed Ly β fluorescence as the dominant mechanism, later confirmed by the 1:1:1 line ratio in I Zw 1 (R. J. Rudy et al. 1989). Subsequent studies showed collisional excitation is also significant (A. Rodríguez-Ardila et al. 2002; H. Landt et al. 2008), while continuum fluorescence plays a minor role. Photoionization models by Y. Matsuoka et al. (2007) showed both mechanisms operate efficiently in gas with $n_H \sim 10^{11.5} \text{ cm}^{-3}$ and $\log(U) \sim -2.5$.

In Bz5.3, we clearly detect O I λ 8446, Ca II λ 8498,8542,8662 triplet and we have upper limits on O I λ 7774 and O I λ 7990. Consistent with a BLR origin, O I λ 8446 exhibits broad emission (see Table 1), though it is several thousand km s^{-1} narrower than the broad Balmer lines—supporting the notion of a stratified BLR. In agreement with the aforementioned studies in local AGNs, for Bz5.3, Ly β fluorescence is the main production mechanism of LILs based on the following evidence. (1) The high equivalent width of O I λ 8446 can be explained only in the presence of Ly β pumping the production of O I λ 8446 photons. Indeed, it has been shown that in the presence of mechanisms hampering the Ly β fluorescence efficiency, e.g. turbulent gas, the EW of O I λ 8446 decreases to $< 10 \text{ \AA}$ (Y. Matsuoka et al. 2007; M. Bottorff et al. 2000). (2) The weakness of the O I λ 7774, λ 7990 emission lines compared to O I λ 8446. Indeed their flux ratios are expected to be > 1 for pure recombination, while O I λ 7774, λ 7990 are just a few percents of O I λ 8446 ($< 10 - 20\%$) in case of a combination of Ly β fluorescence and collisional excitation (Y. Matsuoka et al. 2007).

Indeed, we also observe the presence of other competing mechanisms given that the O I λ 1304/ λ 8446 photon flux ratio is much lower than unity. We can rule out recombination as a player in fostering the production of LILs, since O I λ 7774/ λ 8446 < 0.23 (O I λ 7774/ λ 8446 ~ 1.1 for recombination). Instead, this flux ratio is close to the expected one

for collisional excitation (0.3, see Y. Matsuoka et al. 2007). In contrast, the O I λ 7990/ λ 8446 ratio of < 0.28 is rather uninformative, since it is expected to be ~ 0.05 for continuum fluorescence (S. A. Grandi 1980).

We can rule out continuum fluorescence given that $\text{EW}(\text{O I}\lambda 8446) = 24 \pm 2 \text{ \AA}$, while $\text{EW}(\text{O I}\lambda 8446) \leq 1 \text{ \AA}$ is expected (Y. Matsuoka et al. 2007). This high equivalent width also supports the role of collisional excitation, which is more effective for higher EW(O I λ 8446) that implies higher densities (Y. Matsuoka et al. 2007).

The contribution from scattered light is also ruled out, since we would expect much higher O I λ 1304/ λ 8446 ratio than observed, roughly proportional to the scattered fraction.

The complexity of the BLR in LRD is highlighted by comparing the results for the EW(O I λ 8446) and ROI_{Ca II} with simple photo-ionization models. In particular, we use the models provided in Y. Matsuoka et al. (2007), who performed a similar analysis for QSOs at $z < 1$. The BLR gas in their work was modeled to have a constant hydrogen density and exposed to the ionizing continuum radiation with varying photon flux, Φ , connected to the ionization parameter as $U \equiv \Phi/(n_H c)$ where c is the speed of light. They performed calculations with (n_H, U) sets in a range of $10^7 \leq n_H \leq 10^{14} \text{ cm}^{-3}$, and $10^{-5} \leq U \leq 10^0$, stepped by 0.5 dex. They have a BLR gas with $N_H = 10^{23} \text{ cm}^{-2}$ and $v_{\text{turb}} = 0 \text{ km s}^{-1}$, where N_H is the column density and v_{turb} is the microturbulent velocity. We do not consider other models presented in their work with higher v_{turb} values, since they imply $\text{EW}(\text{O I}\lambda 8446) \leq 10 \text{ \AA}$, in contrast with our observations. Therefore, based on their ‘standard’ model and the observed EW(O I λ 8446) and ROI_{Ca II} for Bz5.3, we find that $-4 < \log(U) < -3.5$, and $n_H \sim 10^{9.5} \text{ cm}^{-3}$ (see Figure 7 in Y. Matsuoka et al. 2007). However, other models favour higher densities and ionization to reproduce Fe II emission in local AGNs ($\log(n_H/\text{cm}^{-3}) \sim 10 - 11$, $\log(U) \sim -2.5$, e.g. X. Lin et al. 2025). A step forward would be to generate tailored models to reproduce the observed complex stratification observed in the BLR taking into account constraints from Fe II emission, which is however beyond the scope of this Letter (see e.g., X. Lin et al. 2025; S. Panda et al. 2020; D. Dias dos Santos et al. 2024).

5. SUMMARY AND CONCLUSIONS

In this work, we present a spectroscopic study of BLR LIL diagnostics in Bz5.3, a $z = 5.3$ AGN host galaxy, based

on *JWST*/NIRCam and NIRSpect observations covering rest-frame UV to optical wavelengths. Our main conclusions are as follows:

- The detection of Fe II, $\lambda 1304$ bump, broad O I, and Ca II triplet emission lines supports the presence of a BLR and thus an AGN in Bz5.3, already suggested by evidence of broad Balmer emission.
- We report the first detection of the $\lambda 1304$ bump at high redshift, a key spectral signature of the BLR previously seen only in local AGN. This detection extends the study of local diagnostics of the BLR physical conditions to $z > 5$.
- While the iron features in Bz5.3 may arise from either broad permitted or narrow forbidden transitions, the diversity in line strengths and widths—along with their consistency with recent models—supports the presence of physically distinct emitting regions. Regardless of the interpretation, the observed iron emission points to a stratified BLR.
- Excitation diagnostics suggest that Ly β fluorescence is the primary mechanism powering the O I lines, particularly O I $\lambda 8446$, with collisional excitation also contributing. Recombination and continuum fluorescence are disfavored based on upper limits on O I $\lambda 7774$ and O I $\lambda 7990$, and the large equivalent width of O I $\lambda 8446$ ($24 \pm 2 \text{ \AA}$).
- The photon flux ratio O I $\lambda 1304/\lambda 8446$ is significantly below unity (0.1–0.3), pointing to substantial dust attenuation within the BLR. We derive $A_V \sim 0.4\text{--}1.0$ based on these ratios. We disfavor bound-free absorption since the weak break compounds the decreasing bound-free cross section blue-ward of the Balmer limit.
- The Ca II triplet shows nearly equal line ratios, indicating optically thick conditions. This observation is consistent with an observed redshift of the line centroid, as expected from resonant scattering. The measured Ca II/O I $\lambda 8446$ flux ratio (~ 0.6) is consistent with low-redshift AGNs, further supporting a BLR origin for these lines.
- Comparison with photoionization models suggests that the observed O I $\lambda 8446$ and ROI_{CaII} features in Bz5.3 are best reproduced by a low-ionization, high-density BLR component, distinct from the conditions typically required for iron emission. This apparent tension further supports a stratified BLR structure, with multiple gas phases coexisting under different physical conditions—underscoring the need for tailored models to capture this complexity.

A detailed study of the BLR through LIL diagnostics such as Fe II, O I and Ca II, have usually been limited to the low- z Universe ($z < 1$), mainly due to a combination of poor resolution and sensitivity. This is especially true for O I $\lambda 1304$, which is usually faint and often blended with Ly α emission or hidden by Ly α damping wings (see e.g., I. Labbe et al. 2024). Taken together, our findings provide a rare and detailed glimpse into BLR conditions at early times in LRDs, demonstrating the power of *JWST* spectroscopy in probing AGN physics in the early Universe.

While extending this analysis to a large population of high-redshift galaxies remains challenging — particularly for the faint and blended O I $\lambda 1304$ bump — targeted, deep observation of carefully selected sources offers a promising path forward for probing the structure and physics of the BLR in the early Universe. In parallel, the recent discovery of local LRD analogs provides a valuable laboratory for investigating BLR properties in greater detail. Tailored UV spectroscopic follow-up with instruments like HST/COS for local LRDs and *JWST*/NIRSpect gratings for high- z ones will be essential for bridging the gap between low- and high-redshift LRDs, enabling a more complete picture of BLR excitation mechanisms and evolution over cosmic time.

Data Availability: all the *JWST* data used in this paper can be found in MAST: [10.17909/2hvk-5h89](https://mast.stsci.org/missionMain.do).

ACKNOWLEDGEMENTS

RT, MB, NM, VM, AH, GR, JJ, and GF acknowledge support from the ERC Grant FIRSTLIGHT and from the Slovenian national research agency ARIS through grants N1-0238 and P1-0188. GR and MB acknowledge support from the European Space Agency through Prodex Experiment Arrangement No. 4000146646. This research was enabled by grant 18JWST-GTO1 from the Canadian Space Agency, and Discovery Grants from the Natural Sciences and Engineering Research Council of Canada to MS, RA, and AM. This research used the Canadian Advanced Network For Astronomy Research (CANFAR) operated in partnership by the Canadian Astronomy Data Centre and The Digital Research Alliance of Canada with support from the National Research Council of Canada, the Canadian Space Agency, CANARIE and the Canadian Foundation for Innovation. This work is based on observations made with the NASA/ESA/CSA James Webb Space Telescope. The data were obtained from the Mikulski Archive for Space Telescopes at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-03127 for *JWST*. These observations are associated with program #4598. Support for program #4598 was provided by NASA through a grant from the Space Telescope Science Institute, which is operated by the Association

of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-03127. BL is supported by the international Gemini Observatory, a program of NSF NOIRLab, which is managed by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the

U.S. National Science Foundation, on behalf of the Gemini partnership of Argentina, Brazil, Canada, Chile, the Republic of Korea, and the United States of America.

APPENDIX

A. GALFIT FIT

In the left panel of Figure 4, we show the results of the `GalFit` modeling of Bz5.3 with a point source. We find strong residuals in all filters except F410M and F444W, where the source is unresolved and fully consistent with a point source. Therefore, we add an additional component for all the filters at $\lambda < 4 \mu\text{m}$ in the form of a Sérsic profile with varying index n and half-light radius R_e . As shown in the right panel of Figure 4, this setup produces good results with few residuals.

B. DETAILS ON THE SPECTRAL FITTING PROCEDURE

Regarding the fit of the spectral features reported in Sect. 3.1, we explore the parameter space with a Markov chain Monte Carlo (MCMC) algorithm implemented in the EMCEE package, assuming uniform priors for slopes, normalizations, and FWHM of the Gaussian. Priors on the FWHM of narrow lines are tight, taking into account the known varying resolution with wavelength of the prism. We consider $\text{FWHM}_{\text{prior}} \in [0.8, 1.2]$ spectral resolution element, whose size varies with wavelength. The prior on the peak wavelength is Gaussian, centered on $z_{\text{source}} = 5.2907$, and with $\sigma = 10 \text{Å}$, corresponding to the best spectral resolution achieved in the spectrum at the source's redshift. We consider 10 walkers per parameter and 2500 trials, with a typical burn-in phase of ~ 300 trials.

We compute the integrated line fluxes by integrating the best-fitting functions for each emission line, which are quoted as the 50th percentile, and we derive the error from the 16th and 84th percentiles. Upper or lower limits are given at 3σ . When measuring line widths, an additional complication is given by the instrumental broadening effect by the detector line spread function (LSF), which can be approximated as a Gaussian profile of a certain FWHM (P. Jakobsen et al. 2022). Therefore, we report de-convolved FWHM computed via $\text{FWHM}_{\text{dec}} = \sqrt{\text{FWHM}_{\text{obs}}^2 - \text{FWHM}_{\text{LSF}}^2}$ relation, where FWHM_{obs} and FWHM_{LSF} are the observed and instrumental FWHM (publicly available in the JWST website), respectively. We mention that LSF correction are usually negligible for broad lines in the rest-frame optical regime, e.g. > 10 times wider than the FWHM_{LSF} . FWHM below the spectral resolution of the instrument are not reported. We measure the EW of emission lines for each trial in the chain. Then, we derive the best-fitting value from the 50th percentile of the EW's chain, and the error on EW from the 16th and 84th percentiles.

C. ALTERNATIVE Fe II AND Mg II FIT

As shown in the bottom panel of Figure 3 and in Sect. 3.3, the template from M. Vestergaard & B. J. Wilkes (2001) are able to reproduce the overall shape of the Fe II emission in $2200 \text{Å} \lesssim \lambda_{\text{rest}} \lesssim 2600 \text{Å}$, however the flux ratios of the Fe II transitions assumed in the template differ from the observed ones in Bz5.3. Therefore, to allow more flexibility in the model, we splitted the template into two sections separated at $\lambda_{\text{rest}} = 2700 \text{Å}$, isolating the Mg II emission region from the rest of the Fe II pseudo-continuum. We show the results in Figure 5. The fit is now much closer to the observed data at $\lambda_{\text{rest}} < 2700 \text{Å}$, as shown by the lower reduced χ^2 value compared to the previous fit. This implies that a proper modeling of the Fe II emission would require higher resolution data to better resolve the pseudo-continuum followed by templates with different assumptions for the gas conditions.

REFERENCES

- Ananna, T. T., Bogdán, Á., Kovács, O. E., Natarajan, P., & Hickox, R. C. 2024, *ApJL*, 969, L18, doi: [10.3847/2041-8213/ad5669](https://doi.org/10.3847/2041-8213/ad5669)
- Baldwin, J. A., Ferland, G. J., Korista, K. T., Hamann, F., & LaCluzé, A. 2004, *ApJ*, 615, 610, doi: [10.1086/424683](https://doi.org/10.1086/424683)
- Bottorff, M., Ferland, G., Baldwin, J., & Korista, K. 2000, *ApJ*, 542, 644, doi: [10.1086/317051](https://doi.org/10.1086/317051)
- Brammer, G. 2019, Grizli: Grism redshift and line analysis software., Astrophysics Source Code Library, record ascl:1905.001
- Calzetti, D., Kinney, A. L., & Storchi-Bergmann, T. 1996, *ApJ*, 458, 132, doi: [10.1086/176797](https://doi.org/10.1086/176797)
- Cha, S., Cho, B. Y., Joo, H., et al. 2025, *ApJL*, 987, L15, doi: [10.3847/2041-8213/add2f0](https://doi.org/10.3847/2041-8213/add2f0)

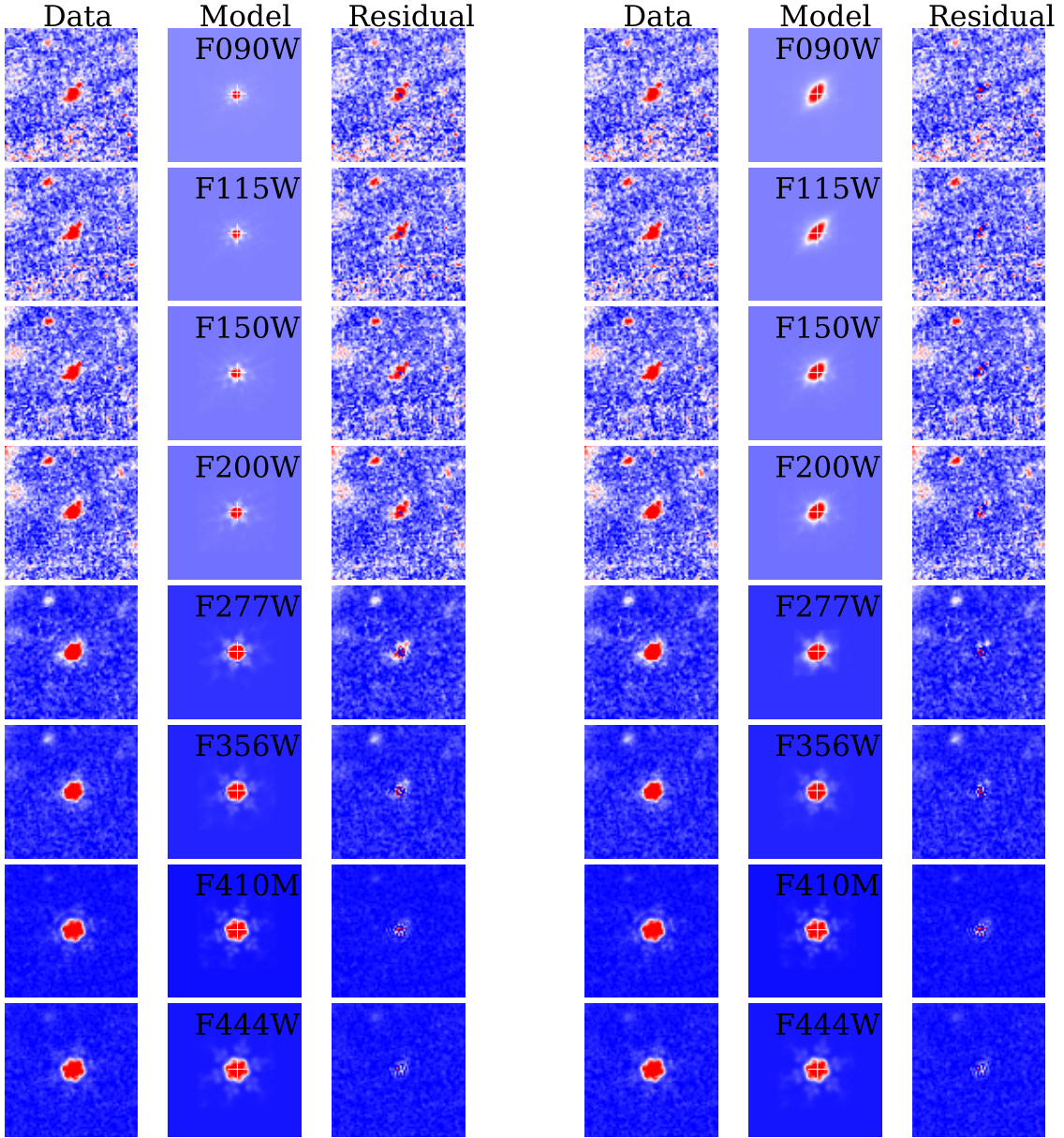


Figure 4. Results of modeling Bz5.3 with Galfit. Left panels: data and results assuming a single point source as model for each filter. The white cross indicates the centroid of the model. Right panels: data and results assuming as model a combination of a point source and a Sérsic profile for each filter with $\lambda < 4 \mu\text{m}$, a single point source otherwise.

Clowe, D., Bradač, M., Gonzalez, A. H., et al. 2006, ApJL, 648, L109, doi: [10.1086/508162](https://doi.org/10.1086/508162)

de Graaff, A., Rix, H.-W., Naidu, R. P., et al. 2025, arXiv e-prints, arXiv:2503.16600, doi: [10.48550/arXiv.2503.16600](https://doi.org/10.48550/arXiv.2503.16600)

Dias dos Santos, D., Panda, S., Rodríguez-Ardila, A., & Marinello, M. 2024, Physics, 6, 177, doi: [10.3390/physics6010013](https://doi.org/10.3390/physics6010013)

Dong, X.-B., Wang, T.-G., Wang, J.-G., et al. 2009, ApJL, 703, L1, doi: [10.1088/0004-637X/703/1/L1](https://doi.org/10.1088/0004-637X/703/1/L1)

Ferland, G. J., Done, C., Jin, C., Landt, H., & Ward, M. J. 2020, MNRAS, 494, 5917, doi: [10.1093/mnras/staa1207](https://doi.org/10.1093/mnras/staa1207)

Ferland, G. J., & Persson, S. E. 1989, ApJ, 347, 656, doi: [10.1086/168156](https://doi.org/10.1086/168156)

Grandi, S. A. 1980, ApJ, 238, 10, doi: [10.1086/157952](https://doi.org/10.1086/157952)

Greene, J. E., & Ho, L. C. 2005, ApJ, 630, 122, doi: [10.1086/431897](https://doi.org/10.1086/431897)

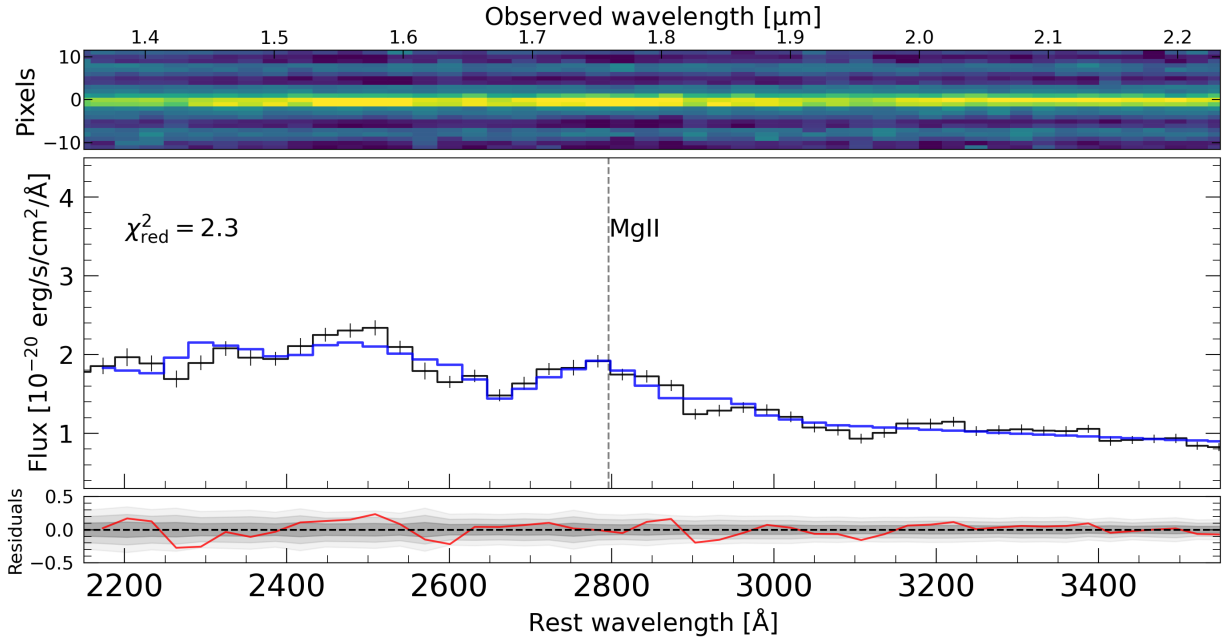


Figure 5. Zoom-in of the 2D and 1D spectra of Bz5.3 on the Fe II complex in the UV and Mg II emission line. The observed spectrum is shown in black, while the best-fitting model is shown in blue. Residuals are shown at the bottom of each panel, where the shaded dark gray area represents the 1σ noise level. 2 and 3σ noise levels are reported in the residual as shaded lighter gray area.

- Guarcello, M. G., Drake, J. J., Wright, N. J., García-Alvarez, D., & Kraemer, K. E. 2014, *ApJ*, 793, 56, doi: [10.1088/0004-637X/793/1/56](https://doi.org/10.1088/0004-637X/793/1/56)
- Hamann, F., & Ferland, G. 1993, *ApJ*, 418, 11, doi: [10.1086/173366](https://doi.org/10.1086/173366)
- Hamann, F., & Ferland, G. 1999, *ARA&A*, 37, 487, doi: [10.1146/annurev.astro.37.1.487](https://doi.org/10.1146/annurev.astro.37.1.487)
- Inayoshi, K., & Maiolino, R. 2025, *ApJL*, 980, L27, doi: [10.3847/2041-8213/adaebd](https://doi.org/10.3847/2041-8213/adaebd)
- Jakobsen, P., Ferruit, P., Alves de Oliveira, C., et al. 2022, *A&A*, 661, A80, doi: [10.1051/0004-6361/202142663](https://doi.org/10.1051/0004-6361/202142663)
- Ji, X., Maiolino, R., Übler, H., et al. 2025, arXiv e-prints, arXiv:2501.13082, doi: [10.48550/arXiv.2501.13082](https://doi.org/10.48550/arXiv.2501.13082)
- Joly, M. 1987, *A&A*, 184, 33
- Joly, M. 1989, *A&A*, 208, 47
- Jullo, E., & Kneib, J. P. 2009, *MNRAS*, 395, 1319, doi: [10.1111/j.1365-2966.2009.14654.x](https://doi.org/10.1111/j.1365-2966.2009.14654.x)
- Jullo, E., Kneib, J. P., Limousin, M., et al. 2007, *New Journal of Physics*, 9, 447, doi: [10.1088/1367-2630/9/12/447](https://doi.org/10.1088/1367-2630/9/12/447)
- Juodžbalis, I., Ji, X., Maiolino, R., et al. 2024, *MNRAS*, 535, 853, doi: [10.1093/mnras/stae2367](https://doi.org/10.1093/mnras/stae2367)
- Kneib, J. P., Ellis, R. S., Smail, I., Couch, W. J., & Sharples, R. M. 1996, *ApJ*, 471, 643, doi: [10.1086/177995](https://doi.org/10.1086/177995)
- Kocevski, D. D., Finkelstein, S. L., Barro, G., et al. 2025, *ApJ*, 986, 126, doi: [10.3847/1538-4357/adbc7d](https://doi.org/10.3847/1538-4357/adbc7d)
- Kokorev, V., Caputi, K. I., Greene, J. E., et al. 2024, *ApJ*, 968, 38, doi: [10.3847/1538-4357/ad4265](https://doi.org/10.3847/1538-4357/ad4265)
- Kovačević, J., Popović, L. Č., & Dimitrijević, M. S. 2010, *ApJS*, 189, 15, doi: [10.1088/0067-0049/189/1/15](https://doi.org/10.1088/0067-0049/189/1/15)
- Kovačević-Dojčinović, J., Dojčinović, I., Lakićević, M., & Popović, L. Č. 2025, *A&A*, 694, A289, doi: [10.1051/0004-6361/202450516](https://doi.org/10.1051/0004-6361/202450516)
- Kwan, J., & Krolik, J. H. 1981, *ApJ*, 250, 478, doi: [10.1086/159395](https://doi.org/10.1086/159395)
- Labbe, I., Greene, J. E., Matthee, J., et al. 2024, arXiv e-prints, arXiv:2412.04557, doi: [10.48550/arXiv.2412.04557](https://doi.org/10.48550/arXiv.2412.04557)
- Landt, H., Bentz, M. C., Ward, M. J., et al. 2008, *ApJS*, 174, 282, doi: [10.1086/522373](https://doi.org/10.1086/522373)
- Laor, A., Jannuzi, B. T., Green, R. F., & Boroson, T. A. 1997, *ApJ*, 489, 656, doi: [10.1086/304816](https://doi.org/10.1086/304816)
- Lin, X., Fan, X., Cai, Z., et al. 2025, arXiv e-prints, arXiv:2507.10659, <https://arxiv.org/abs/2507.10659>
- Martis, N. S., Sarrouh, G. T. E., Willott, C. J., et al. 2024, <https://arxiv.org/abs/2401.01945>
- Marziani, P., Sulentic, J. W., Plauchu-Frayn, I., & del Olmo, A. 2013, *ApJ*, 764, 150, doi: [10.1088/0004-637X/764/2/150](https://doi.org/10.1088/0004-637X/764/2/150)
- Matsuoka, Y., Kawara, K., & Oyabu, S. 2008, *ApJ*, 673, 62, doi: [10.1086/524193](https://doi.org/10.1086/524193)
- Matsuoka, Y., Oyabu, S., Tsuzuki, Y., & Kawara, K. 2007, *ApJ*, 663, 781, doi: [10.1086/518399](https://doi.org/10.1086/518399)
- Matsuoka, Y., Oyabu, S., Tsuzuki, Y., Kawara, K., & Yoshii, Y. 2005, *PASJ*, 57, 563, doi: [10.1093/pasj/57.4.563](https://doi.org/10.1093/pasj/57.4.563)
- Naidu, R. P., Oesch, P. A., Brammer, G., et al. 2025, arXiv e-prints, arXiv:2505.11263, doi: [10.48550/arXiv.2505.11263](https://doi.org/10.48550/arXiv.2505.11263)

- Netzer, H. 2013, *The Physics and Evolution of Active Galactic Nuclei*
- Netzer, H., & Wills, B. J. 1983, *ApJ*, 275, 445, doi: [10.1086/161545](https://doi.org/10.1086/161545)
- Panda, S., Martínez-Aldama, M. L., Marinello, M., et al. 2020, *ApJ*, 902, 76, doi: [10.3847/1538-4357/abb5b8](https://doi.org/10.3847/1538-4357/abb5b8)
- Persson, S. E. 1988, *ApJ*, 330, 751, doi: [10.1086/166509](https://doi.org/10.1086/166509)
- Planck Collaboration, Aghanim, N., Akrami, Y., et al. 2020, *A&A*, 641, A6, doi: [10.1051/0004-6361/201833910](https://doi.org/10.1051/0004-6361/201833910)
- Reines, A. E., & Volonteri, M. 2015, *ApJ*, 813, 82, doi: [10.1088/0004-637X/813/2/82](https://doi.org/10.1088/0004-637X/813/2/82)
- Rieke, M. J., Robertson, B., Tacchella, S., et al. 2023, 16, doi: [10.3847/1538-4365/acf44d](https://doi.org/10.3847/1538-4365/acf44d)
- Rodríguez-Ardila, A., Viegas, S. M., Pastoriza, M. G., Prato, L., & Donzelli, C. J. 2002, *ApJ*, 572, 94, doi: [10.1086/340192](https://doi.org/10.1086/340192)
- Rudy, R. J., Mazuk, S., Puetter, R. C., & Hamann, F. 2000, *ApJ*, 539, 166, doi: [10.1086/309222](https://doi.org/10.1086/309222)
- Rudy, R. J., Rossano, G. S., & Puetter, R. C. 1989, *ApJ*, 342, 235, doi: [10.1086/167587](https://doi.org/10.1086/167587)
- Sacchi, A., & Bogdan, A. 2025, arXiv e-prints, arXiv:2505.09669, doi: [10.48550/arXiv.2505.09669](https://doi.org/10.48550/arXiv.2505.09669)
- Sarrouh, G. T. E., Asada, Y., Martis, N. S., et al. 2025, arXiv e-prints, arXiv:2506.21685, doi: [10.48550/arXiv.2506.21685](https://doi.org/10.48550/arXiv.2506.21685)
- Shakura, N. I., & Sunyaev, R. A. 1976, *MNRAS*, 175, 613, doi: [10.1093/mnras/175.3.613](https://doi.org/10.1093/mnras/175.3.613)
- Sigut, T. A. A., & Pradhan, A. K. 1998, *ApJL*, 499, L139, doi: [10.1086/311369](https://doi.org/10.1086/311369)
- Sigut, T. A. A., & Pradhan, A. K. 2003, *ApJS*, 145, 15, doi: [10.1086/345498](https://doi.org/10.1086/345498)
- Taylor, A. J., Kokorev, V., Kocevski, D. D., et al. 2025, arXiv e-prints, arXiv:2505.04609, doi: [10.48550/arXiv.2505.04609](https://doi.org/10.48550/arXiv.2505.04609)
- Trefoloni, B., Ji, X., Maiolino, R., et al. 2024, arXiv e-prints, arXiv:2410.21867, doi: [10.48550/arXiv.2410.21867](https://doi.org/10.48550/arXiv.2410.21867)
- Tripodi, R., Martis, N., Markov, V., et al. 2024, arXiv e-prints, arXiv:2412.04983, doi: [10.48550/arXiv.2412.04983](https://doi.org/10.48550/arXiv.2412.04983)
- Tsuzuki, Y., Kawara, K., Yoshii, Y., et al. 2006, *ApJ*, 650, 57, doi: [10.1086/506376](https://doi.org/10.1086/506376)
- Verner, E., Bruhweiler, F., Verner, D., Johansson, S., & Gull, T. 2003, *ApJL*, 592, L59, doi: [10.1086/377571](https://doi.org/10.1086/377571)
- Verner, E., Bruhweiler, F., Verner, D., et al. 2004, *ApJ*, 611, 780, doi: [10.1086/422303](https://doi.org/10.1086/422303)
- Verner, E. M., Verner, D. A., Korista, K. T., et al. 1999, *ApJS*, 120, 101, doi: [10.1086/313171](https://doi.org/10.1086/313171)
- Vestergaard, M., & Osmer, P. S. 2009, *ApJ*, 699, 800, doi: [10.1088/0004-637X/699/1/800](https://doi.org/10.1088/0004-637X/699/1/800)
- Vestergaard, M., & Wilkes, B. J. 2001, *ApJS*, 134, 1, doi: [10.1086/320357](https://doi.org/10.1086/320357)
- Wills, B. J., Netzer, H., & Wills, D. 1985, *ApJ*, 288, 94, doi: [10.1086/162767](https://doi.org/10.1086/162767)
- Yoshii, Y., Tsujimoto, T., & Kawara, K. 1998, *ApJL*, 507, L113, doi: [10.1086/311690](https://doi.org/10.1086/311690)
- Yue, M., Eilers, A.-C., Ananna, T. T., et al. 2024, *ApJL*, 974, L26, doi: [10.3847/2041-8213/ad7eba](https://doi.org/10.3847/2041-8213/ad7eba)