



Pseudo Little Red Dot: An Active Black Hole Embedded in a Dense and Dusty, Metal-poor Starburst Galaxy at $z = 5.96$

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Abstract

We present a study of a pseudo little red dot with no metal lines (Pseudo-LRD-NOM), a highly magnified low-mass galaxy behind the lensing cluster A370 at $z = 5.96$. We classify this object as a pseudo-LRD because its red rest-frame optical color is contaminated by a prominent $H\alpha$ line (with $EW_0 \gtrsim 800 \text{ \AA}$) present in its JWST NIRSpec spectrum. $H\alpha$ is dominated by a narrow component and also has a minor broad component indicative of an active black hole with $M_{\text{BH}} \approx 5.6 \times 10^6 M_\odot$. A narrow $H\beta$ emission line is also detected (where the signal-to-noise ratio, S/N, is 8), producing a Balmer decrement (narrow) $H\alpha/H\beta = 11$. The rest-frame UV spectral slope is $\beta_{\text{UV}}^{\text{spec}} = -1.20 \pm 0.28$. All these features can be ascribed to high dust attenuation. However, no $[\text{O III}]\lambda 5007$ or any other metal lines are detected in the spectrum, so $[\text{O III}]\lambda 5007/H\beta < 0.25$, at odds with a simple dust-attenuation explanation. Accounting for all the spectral properties requires the model of a starburst with moderate color excess $E(B - V) \approx 0.2\text{--}0.5$, high gas density ($n_{\text{H}} \gtrsim 10^6 \text{ cm}^{-3}$), and low- to extremely-low gas/stellar metallicities ($Z = 0.01\text{--}0.1 Z_\odot$). The demagnified stellar mass is $2.25^{+1.30}_{-0.83} \times 10^7 M_\odot$, and the stellar-mass surface density is $\Sigma_* = 418^{+725}_{-310} M_\odot \text{ pc}^{-2}$, similar to that of massive/nuclear star clusters. Pseudo-LRD-NOM provides evidence of massive black-hole growth occurring in a high-density, dusty starburst that is at the early stages of its chemical enrichment, and is likely a precursor to a real LRD.

Unified Astronomy Thesaurus concepts: Emission line galaxies (459); Active galaxies (17); Galaxy abundances (574); Galaxy spectroscopy (2171); High-redshift galaxies (734)

1. Introduction

Understanding the formation of the galaxies that we see in the Universe today requires tracing their building blocks in cosmic time. These smaller units carried the imprint of the first stellar populations formed in those galaxies, as well as of the initial steps of chemical enrichment (e.g., V. Lebouteiller et al. 2013). At the same time, they are supposed to be the sites where black holes formed and efficiently started to grow (J. E. Greene et al. 2020). Therefore, spectroscopic studies of low-stellar-mass galaxies (with $M_* < 10^9 M_\odot$) at high redshifts can provide the key to unveiling the very basis of galaxy evolution.

The spectral properties of low-stellar-mass galaxies, commonly called *dwarf galaxies* due to their relatively small sizes, have been extensively studied at low redshifts (e.g., G. Östlin et al. 2001; N. G. Guseva et al. 2009; E. Pérez-Montero et al. 2013; R. Amorín et al. 2014; H. Yang et al. 2017). They are typically characterized by prominent emission lines, indicative of high ionization states at subsolar metallicities. In the rare cases that the metallicity is very low (e.g., Y. I. Izotov et al. 2024), the metal lines are weak or absent, resembling the conditions that are expected to have been more common at early cosmic times.

However, until recently, spectroscopic observations of low-mass galaxies at high z were very challenging for existing telescopes, and thus only a handful of cases behind lensing fields could be studied (e.g., E. Vanzella et al. 2016, 2021;

W. Karman et al. 2017). Thanks to the advent of JWST (J. P. Gardner et al. 2023), the study of low-mass galaxies up to the Epoch of Reionization has now become routinely possible even in nonlensed fields (e.g., D. Schaerer et al. 2022; M. Castellano et al. 2024; R. Endsley et al. 2024; A. Harshan et al. 2024; E. Iani et al. 2024; P. Rinaldi et al. 2025b; J. A. A. Trussler et al. 2025).

In parallel, another high- z galaxy population whose study has boomed in the JWST era is that of the so-called little red dots (LRDs; e.g., V. Kokorev et al. 2024; J. Matthee et al. 2024). These sources are characterized by being very compact (e.g., J. F. W. Baggen et al. 2024) and having a V-shaped $f_\lambda(\lambda)$ spectral energy distribution (SED; e.g., D. D. Kocevski et al. 2025). Virtually all of them harbor broad-line active galactic nuclei (BLAGN; e.g., J. E. Greene et al. 2024; R. E. Hviding et al. 2025). Based on the Balmer-line broadening, the central black holes appear to be overmassive with respect to their host galaxies (e.g., Y. Harikane et al. 2023; R. Maiolino et al. 2024), in relation to what is expected from the local $M_{\text{BH}}\text{--}M_*$ relation (J. Magorrian et al. 1998; A. E. Reines & M. Volonteri 2015), although the extent of this effect is unclear, as other physical mechanisms could contribute to the Balmer-line broadening (e.g., V. Rusakov et al. 2026). In addition, LRDs can show complex morphologies in the rest-frame UV, in spite of their compactness (e.g., P. Rinaldi et al. 2025a).

By selection most LRDs lie at $z > 4$ and are typically hosted by low-mass galaxies, which sometimes are not even detected (e.g., C.-H. Chen et al. 2025). Nonetheless, their metallicities do not stand out for being lower than average at high z , with the exception of a few known cases with



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$Z \sim 0.1 Z_{\odot}$ (A. J. Taylor et al. 2025; R. Tripodi et al. 2025), including QSO 1 behind the lensing cluster A2744 (L. J. Furtak et al. 2023; F. D’Eugenio et al. 2026; R. Maiolino et al. 2026b). This is also the case for other kinds of active galactic nuclei (AGNs) at high redshifts, whose hosts are rarely metal-poor (e.g., K. Matsuoka et al. 2018; M. Mignoli et al. 2019; H. Uebler et al. 2023).

In LRD studies, galaxies with prominent emission lines driving the V-shaped SED colors are typically excluded (e.g., D. D. Kocevski et al. 2025). This is because the main goal is to select sources with a steeply rising rest-frame optical continuum, which, in combination with the compactness criterion, allows for the identification of AGN candidates. We will argue that those discarded objects, which hereafter we call *pseudo-LRDs*, may merit attention on their own, as some of them could also contain AGNs that are normally not accounted for in AGN demographic studies.

In this paper we present the analysis of a highly magnified low-mass galaxy, found behind the lensing cluster A370 at $z = 5.96$, which we name Pseudo-LRD-NOM (for “pseudo-LRD with no metal lines”) hereafter. This source stands out for having a rather unusual spectrum: It is characterized by the presence of a very prominent $H\alpha$ emission line, a much fainter but still significantly detected $H\beta$ line, but no $[O\text{ III}]\lambda 5007$ or any other metal lines. In addition, the rest-frame UV spectral slope $\beta_{\text{UV}}^{\text{spec}}$ is quite high (low in modulus), which is indicative of significant dust attenuation.

The paper is organized as follows: In Section 2 we describe the utilized datasets, while in Section 3 we justify the motivation for the pseudo-LRD classification of our object. In Section 4 we present the spectroscopic and photometric properties of Pseudo-LRD-NOM, and investigate under which physical conditions all those properties can simultaneously be explained. In Section 5 we discuss our findings and compare some main properties of Pseudo-LRD-NOM and real LRDs. Finally, in Section 6 we present some concluding remarks. Throughout this paper, we consider a cosmology with $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Omega_{\Lambda} = 0.7$, and a G. Chabrier (2003) initial mass function (IMF).

2. Datasets

2.1. The Lensing Cluster A370

The source analyzed here is gravitationally lensed by the massive galaxy cluster A370 (A370) at $z = 0.375$. This cluster is one out of the six targets included in the Hubble Space Telescope (HST) Frontier Fields program (J. M. Lotz et al. 2017; M. Bradač et al. 2019). Its background sources have been spectroscopically followed up from the ground in the pre-JWST era (e.g., J. Richard et al. 2021). With JWST, A370 and its background have been observed in a number of programs, including the Cycle 1 GTO CANUCS (PI: C. Willott, PID #1208); Cycle 2 GO program MAGNIF (PI: F. Sun; PID #2883); and program PID #3538 (PI: E. Iani).

The increasing data availability has allowed for a continuous improvement of the A370 lensing model. The latest versions, which incorporate JWST data, are those by R. Gledhill et al. (2024) and J. M. Diego et al. (2025). Here we adopt the magnification factor derived in the latter (i.e., $\mu = 15.7 \pm 0.4$).

2.2. JWST Spectroscopy

We analyzed the source JWST spectrum taken with the Near Infrared Spectrograph’s Micro-shutter Array (NIRSpec/MSA;

P. Ferruit et al. 2022) as part of the JWST Cycle 1 GTO program CANUCS (PI: C. Willott, PID #1208). This spectrum covers the wavelength range $0.6\text{--}5.3 \mu\text{m}$ and has been obtained with the NIRSpec low-dispersion PRISM ($R = 30\text{--}300$). The spectrum was retrieved from the DAWN JWST Archive (DJA), and detailed data-reduction steps can be found in G. T. E. Sarrouh et al. (2026).

2.3. Photometric Data

We retrieved and reprocessed all the NIRCcam imaging available for A370. This includes imaging from the JWST programs CANUCS (PI: C. Willott, PID #1208), MAGNIF (PI: F. Sun; PID #2883), JUMPS (PI: C. Withers; PID #5890), VENUS (PI: S. Fujimoto; PID #6882), and programs PID #3538 (PI: E. Iani) and PID #5324 (PI: J. Pierel). For the data reduction, we employed our own custom NIRCcam pipeline, which has already been tested and successfully applied in other JWST studies, including P. Rinaldi et al. (2023), R. Navarro-Carrera et al. (2024), E. Iani et al. (2024), and K. I. Caputi et al. (2024). Our software is based on the JWST pipeline version 1.20.2 (H. Bushouse et al. 2023), with the Calibration Reference Data System (CRDS) pipeline mapping (pmap) version 1471. It also includes extra steps similar to those described by M. B. Bagley et al. (2023), including corrections for $1/f$ noise, stray-light effects (wisps), and residual cosmic rays (snowballs).

As our source is compact, we measured $0''.3$ -diameter aperture photometry and applied aperture corrections. We validated our photometry for Pseudo-LRD-NOM against the photometry provided in the publicly available CANUCS photometric catalog (Data Release 1; see G. T. E. Sarrouh et al. 2026), for the common passbands. We also considered the available HST photometry in this catalog, corresponding to images that have been obtained from the HST CLASH and Frontier Fields programs (M. Postman et al. 2012; J. M. Lotz et al. 2017). We note that the choice of aperture, between $0''.3$ and $0''.7$ diameter (corrected to total), and Kron apertures, does not affect the outcome of our SED fitting analysis (Section 4.3).

3. The Source Pseudo-LRD-NOM

Our target source appears red and compact in the JWST NIRCcam images (Figure 1). Its red color is boosted by the presence of a prominent $H\alpha$ line, which we analyze in Section 4. If we subtract from the F444W photometry the flux-density excess produced by $H\alpha$ over the continuum, we see that the source has a more moderate red color, as we show in Figure 2. We computed the corrected F444W photometry by adding 0.46 mag to the originally measured magnitude. This minimum correction corresponds to the lower limit of the total $H\alpha$ rest-frame $\text{EW}_0 \gtrsim 800 \text{ \AA}$ derived from the NIRSpec PRISM spectrum (see Section 4 and Figure 3), as obtained using the formula provided by E. Mármol-Queraltó et al. (2016).

The measured colors are $F150W\text{--}F200W = -0.27 \pm 0.09$ and $F277W\text{--}F444W = 1.31 \pm 0.07$ (before correction for $H\alpha$), changing to $F277W\text{--}F444W \lesssim 0.85$ (after correction for $H\alpha$). So, formally, the source would be classified as an LRD if no $H\alpha$ flux-density excess correction were applied, as it has SED slopes $\beta_{\text{UV}}^{150-200} = -2.74 \pm 0.09$ and $\beta_{\text{opt}}^{277-444} = 0.62 \pm 0.07$. Once the minimum correction for $H\alpha$ is introduced, we get $\beta_{\text{opt}}^{277-444} < -0.30$. This means that the source does not satisfy

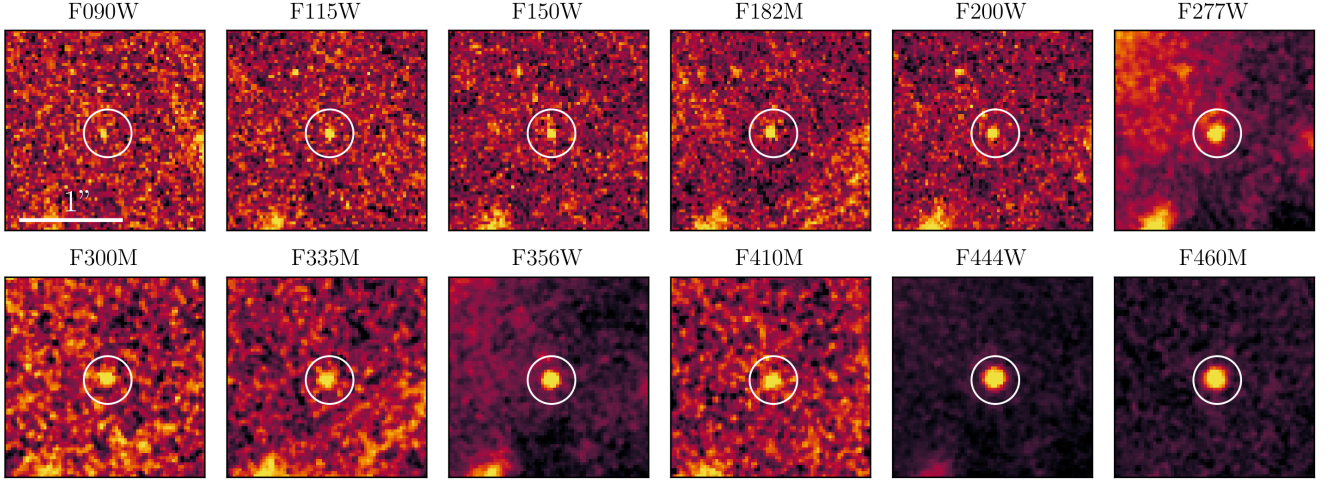


Figure 1. Postage stamps of Pseudo-LRD-NOM in different JWST/NIRCam bands. The two reddest filters shown, i.e., F444W and F460M, encompass the bright $H\alpha$ line.

the LRD-selection criterion proposed by D. D. Kocevski et al. (2025), while it would still satisfy the less-strict criteria adopted by other authors (V. Kokorev et al. 2024; P. Rinaldi et al. 2026). Our source would rather be classified as a little blue dot (LBD), following the criteria proposed by M. Brazzini et al. (2026).

Given the fact that the prominent $H\alpha$ emission line is the main driver of the red (F277W – F444W) color of our source, we adopt the term “pseudo-LRD” for it. Nonetheless, we highlight that, independently of the formal definition, the important point is that our source is very compact and harbors a BLAGN, as LRDs and (at least some) LBDs do (P. Madau & R. Maiolino 2026).

In addition, the large photometric differences observed between the F410M and F460M filters, and then F460M and F480M, suggest that $EW_0(H\alpha)$ is significantly larger than what is inferred from the spectral lower limit previously discussed. Applying the same formula quoted previously from E. Mármol-Querales et al. (2016), we derive that the total $H\alpha$ line has $EW_0(H\alpha) \approx (1200 \pm 300) \text{ \AA}$. This would imply that Pseudo-LRD-NOM is dominated by very young stellar populations (C. Prieto-Jiménez et al. 2025).

We present a complete SED analysis of Pseudo-LRD-NOM in Section 4.3 and provide its coordinates in Table 1.

4. Spectral and Photometric Analysis of Pseudo-LRD-NOM

4.1. Balmer-line Profiles

Figure 3 shows the NIRSpec PRISM spectrum of our target. The Balmer $H\alpha$ and $H\beta$ emission lines are clearly visible, while no other lines are detected. The integrated $H\alpha$ line has a signal-to-noise ratio (S/N) > 25 , while $S/N(H\beta) \approx 8$. Given this, the lack of $[O III]\lambda 5007$ emission is immediately striking.

We fitted the profiles of the $H\alpha$ and $H\beta$ lines using the Python package UNITE v3.0.0 (R. E. Hviding et al. 2025). To correct for the line spread function (LSF), we used the NIRSpec built-in LSF data (A. de Graaff et al. 2024), which takes into account the position of the object in the NIRSpec slitlet, as well as the source morphology. Our results indicate that the $H\alpha$ line has two components, a main narrow one and another that is fainter and broader (Figure 4). The line profile

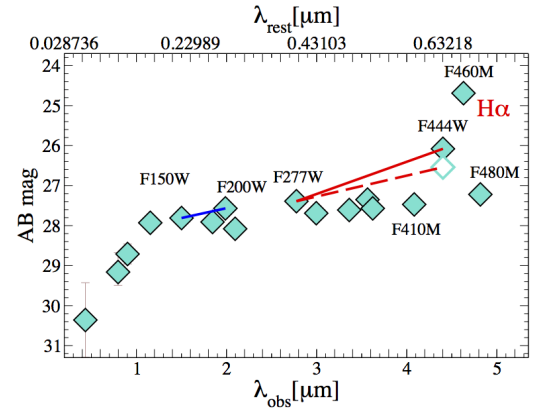


Figure 2. Observed photometry of Pseudo-LRD-NOM, uncorrected for magnification. For the F444W passband we show two data points, one corresponding to the original photometry (filled diamond) and another one obtained after correcting for the (minimum) flux-density excess produced by the prominent $H\alpha$ emission line over the continuum (empty diamond). The lines join the data points at the passbands that are typically used to define the LRD color selection at $z \sim 6$: F115W–F200W (blue) and F277W–F444W (red solid and dashed for the original and $H\alpha$ -corrected F444W photometry, respectively). Even applying the minimum photometric correction for the $H\alpha$ line, the source moves out of the LRD-selection criterion defined in D. D. Kocevski et al. (2025).

fitting with a Gaussian broad component is preferred, but considering either a Lorentzian or exponential profile for the broad component yields very similar results. This is based on the Watanabe–Akaike information criterion (WAIC; S. Watanabe 2015), for which we get $\Delta(WAIC) < 1$ between the different two-component models. Instead, based on the same criterion, the single component models can be discarded, as they yield $\Delta(WAIC) \gtrsim 16$ with respect to the two-component ones.

The $H\beta$ line is best fitted solely with a narrow component, as the expected broad component lies below the noise level. All our measured line fluxes are given in Table 1.

For the broad component of the $H\alpha$ line, we measured a full width at half maximum (FWHM) of $3214^{+841}_{-1005} \text{ km s}^{-1}$. This large broadening indicates the presence of an active black hole at the center of our source, as is the case for basically all LRDs

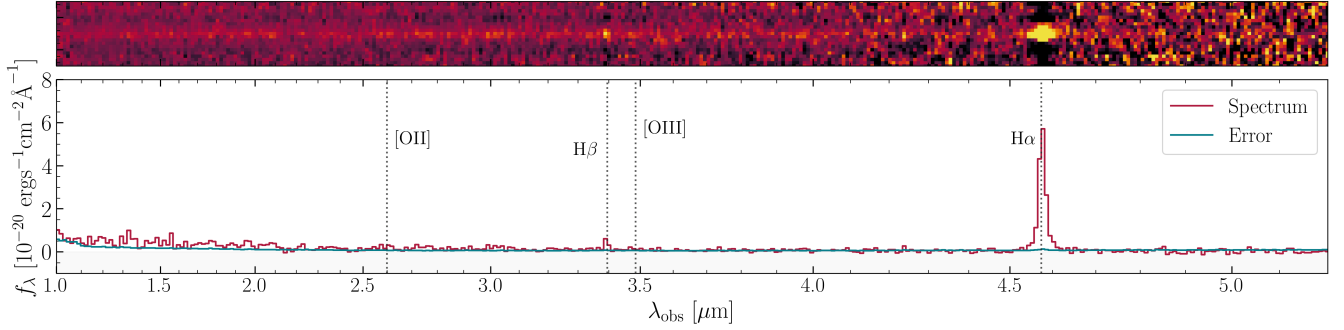


Figure 3. NIRSpect PRISM spectrum of Pseudo-LRD-NOM. While $H\alpha$ and $H\beta$ are clearly visible, no other emission lines are detected.

(e.g., R. E. Hving et al. 2025). Note that a symmetric broadening of an emission line can be due to other factors, particularly clump rotation (e.g., R. A. Cooper et al. 2025). However, the large value of the $H\alpha$ broad-component FWHM makes the clump-rotation hypothesis unlikely, and crucially, no clumps are visible in the high-spatial-resolution NIRCcam images of Pseudo-LRD-NOM. We can also discard that the line broadening is produced by other effects related to stellar kinematics, because such broadenings are typically much smaller than the value measured here for Pseudo-LRD-NOM’s $H\alpha$ emission line (e.g., G. Tenorio-Tagle et al. 2010; R. O. Amorín et al. 2024).

Based on the $H\alpha$ -line broad component, we can obtain an estimate of the central black hole mass, following the prescription by J. E. Greene & L. C. Ho (2005). Considering the line FWHM and magnification-corrected flux, we get $M_{\text{BH}} = 5.6^{+2.9}_{-3.4} \times 10^6 M_{\odot}$. The error budget in this mass estimate is dominated by the error in the $H\alpha$ broad-component FWHM, given the functional dependence on it in the J. E. Greene & L. C. Ho (2005) formula. This means that Pseudo-LRD-NOM hosts a massive black hole, but among the smallest typically found in LRDs at these redshifts, which can reach up to $\sim 10^9 M_{\odot}$ (e.g., R. Maiolino et al. 2025; A. J. Taylor et al. 2025).

In turn, the flux measured on the narrow component of $H\alpha$ can be used to obtain an estimate of the ongoing star formation rate (SFR) in the galaxy, under the assumption that existing calibrations to obtain SFRs from $L(H\alpha)$ for high- z galaxies are applicable to Pseudo-LRD-NOM. As we will show in Section 4.3, the minimum color excess on the stellar models that can satisfactorily explain the spectral continuum of this source is $E(B - V) \approx 0.18$. Assuming the dust-attenuation law by D. Calzetti et al. (2000), which is adequate for high- z star-forming galaxies (R. J. McLure et al. 2018), we find that the magnification- and dust-corrected $L(\text{narrow } H\alpha) \gtrsim (4.2^{+0.46}_{-0.36}) \times 10^{41} \text{ erg s}^{-1}$. To convert this minimum $H\alpha$ luminosity into an SFR, we considered the formula provided by A. E. Shapley et al. (2023), which is valid for low metallicities. We obtain $\text{SFR}(H\alpha) \gtrsim (0.90^{+0.10}_{-0.08}) M_{\odot} \text{ yr}^{-1}$, which is very similar to the value obtained if we consider the conversion formula provided by R. L. Theios et al. (2019) instead: $\text{SFR}(H\alpha) \gtrsim (0.96^{+0.11}_{-0.09}) M_{\odot} \text{ yr}^{-1}$.

4.2. Line Ratios and Their Implications

4.2.1. Interpretation of the Line Ratios

The measured fluxes for the narrow component of $H\alpha$ and the total $H\beta$ imply a Balmer decrement $H\alpha/H\beta = 11.0^{+2.0}_{-1.7}$, which is substantially higher than the value expected for a

typical warm gas cloud with no dust, following case B recombination (D. E. Osterbrock & G. J. Ferland 2006). High values of the $H\alpha/H\beta$ ratio are commonly found among LRDs (e.g., F. D’Eugenio et al. 2025; A. de Graaff et al. 2025; L. J. Furtak et al. 2025; G. P. Nikopoulos et al. 2026). A priori, such a high Balmer decrement is expected to be associated with a high dust attenuation of the warm gas. If we assume, for example, the dust reddening law by D. Calzetti et al. (2000), we obtain that a color excess $E(B - V) \approx 0.88$ would be necessary to explain the observed $H\alpha/H\beta$ ratio solely via dust attenuation. A very similar value would be obtained if we considered instead a “gray” attenuation curve, as that proposed in, e.g., V. Markov et al. (2025), as the differences with the D. Calzetti et al. (2000) reddening law are only significant in the UV. In any case, the choice of reddening law is incidental: None of our main results or conclusions significantly depend on the considered prescription.

However, simply invoking dust attenuation is not sufficient to explain why no metal lines are detected in the spectrum of Pseudo-LRD-NOM. While dust attenuation could explain most of these nondetections, the lack of $[O\text{ III}]\lambda 5007$ in particular is the key to infer that the situation is more complex. If the presence of dust attenuation were the only cause of $[O\text{ III}]\lambda 5007$ being undetected in the spectrum, then under standard conditions $H\beta$ should be undetected as well. In the following discussion, we analyze plausible solutions to this problem.

Before any further analysis, though, there is a possible caveat to be considered. It could be that the flux of the $H\beta$ line as it is observed comes partly or totally from the broad-line region, but appears as having only a narrow component because all flux beyond a central narrow window around the line center lies below the noise level. These considerations could change the narrow $H\alpha/H\beta$ value quoted previously. However, while at least a part of the $H\beta$ flux comes from the host galaxy (or a narrow-line region), the problem remains the same: The lack of $[O\text{ III}]\lambda 5007$ emission in the galaxy spectrum is a priori difficult to be reconciled with a simple dust-attenuation explanation.

Instead, if all the observed $H\beta$ flux were part of the broad-line component and there is no flux associated with the narrow component of $H\beta$, then the lack of $[O\text{ III}]\lambda 5007$ detection would not be puzzling, but rather a simple consequence of dust attenuation. To investigate if this could be the case, we performed a set of Monte Carlo simulations, as follows: We considered the broad component of $H\alpha$ and renormalized it such that its peak flux-density value coincided with the $H\beta$ flux-density peak. We also rebinned the profile to account for the different spectral resolutions of the NIRSpect PRISM at the $H\alpha$ and $H\beta$ observed

Table 1
Coordinates and Main Spectral Line Measurements for Pseudo-LRD-NOM

Name	R.A. (J2000)	Decl. (J2000)	$z_{\text{spec.}}$	$f(\text{narrow H}\alpha)^a$ FWHM (narrow H α) ^c	$f(\text{broad H}\alpha)^a$ FWHM (broad H α) ^c	$f(\text{H}\beta)^{a, b}$ FWHM (H β) ^{c, d}	$f([\text{O III}]\lambda 5007)^a$
Pseudo-LRD-NOM	02:39:56.12	-01:34:25.19	5.96	$969.6^{+105.9}_{-82.3}$ 741^{+143}_{-126}	$332.4^{+124.0}_{-145.4}$ 3214^{+841}_{-1005}	$88.3^{+13.2}_{-11.6}$ 741^{+143}_{-126}	<23.2

Notes.

^a Line fluxes are given in units of $10^{-20} \text{ erg cm}^{-2} \text{ s}^{-1}$ and are not corrected for magnification.

^b A single narrow component is fitted to the H β line profile. The expected broad component is below the noise level (Figure 4).

^c The values of the FWHM are given in units of km s^{-1} .

^d By default the UNITE routine adjusts the same FWHM for the narrow components of H α and H β .

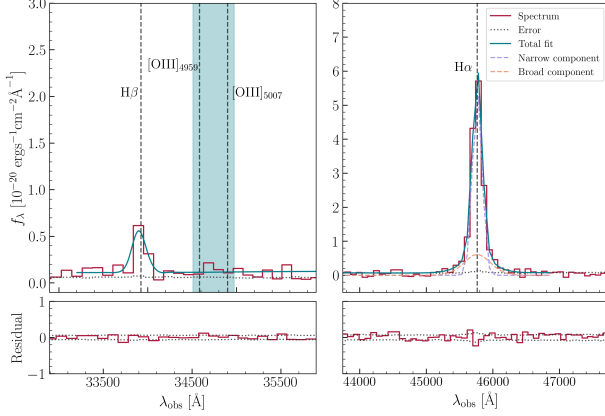


Figure 4. Zoomed-in views of the H β and H α spectral lines (left and right panels, respectively). While a narrow and a broad component are clearly detected for H α , only a narrow component is fitted for H β , with the expected broad component lying below the noise level.

wavelengths. Then we made 1000 mock realizations of the H α broad-line component by assigning to each spectral element a random flux-density value obtained from a Gaussian distribution centered at the real (renormalized) flux density, with an rms given by the noise level in the H β spectral window. For each resulting mock broad line we measured the FWHM. Our results are presented in Figure 5. The obtained distribution of FWHM for the simulated broad-line components has a median/rms $\text{FWHM}(\text{H}\alpha) = (3108 \pm 156) \text{ km s}^{-1}$, which is consistent within the errors with the FWHM of the real H α broad component ($3214^{+841}_{-1005} \text{ km s}^{-1}$). The measured $\text{FWHM}(\text{H}\beta)$ is $>10\sigma$ away. Therefore, we conclude that the observed H β line is genuinely dominated by the narrow component. In the following discussion, we will then consider that $f(\text{H}\beta) = f(\text{narrow H}\beta)$.

4.2.2. The $\text{H}\alpha/\text{H}\beta$ versus $[\text{O III}]\lambda 5007/\text{H}\beta$ Diagram

In Figure 6 we show the (narrow) $\text{H}\alpha/\text{H}\beta$ versus $[\text{O III}]\lambda 5007/\text{H}\beta$ ratios for our source. For context we also plot the ratios corresponding to a general sample of low-mass galaxies at $z > 4$ (R. A. Cooper et al. 2026, in preparation) and a few LRDs from the literature (L. J. Furtak et al. 2023; J. E. Greene et al. 2024; F. D'Eugenio et al. 2026; R. Maiolino et al. 2026b). From this figure we can see that the vast majority of low-mass galaxies follow a broad correlation in this diagram, as it is expected from the canonical situation in which the oxygen abundance (which is one of the main parameters governing the $[\text{O III}]\lambda 5007/\text{H}\beta$ ratio) increases with dust attenuation, as given by the $\text{H}\alpha/\text{H}\beta$ ratio. Instead, some LRDs appear to be off this relation. This is particularly evident for our source

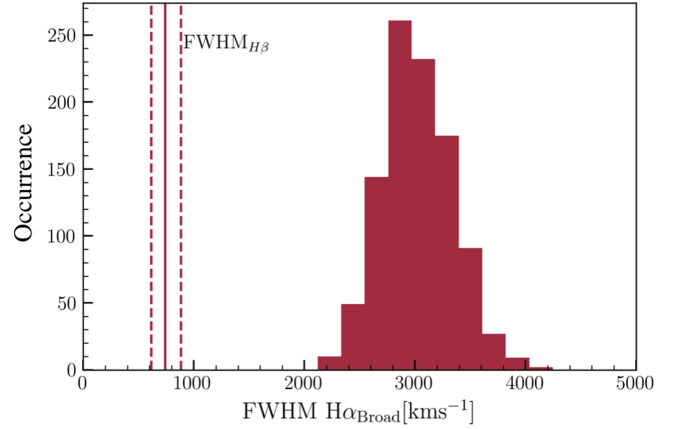


Figure 5. FWHM distribution for 1000 mock realizations of the broad H α line obtained after renormalizing its peak to the peak flux of H β and degrading its S/N ratio to that observed in the H β spectral window. In all cases, these FWHM are much larger than that observed for H β . This means that H β is genuinely dominated by a narrow component.

Pseudo-LRD-NOM, which strongly suggests that the physical conditions are different in these objects.

The upper limit on the $[\text{O III}]/\text{H}\beta$ ratio (<0.25) can be used to obtain an estimate of the upper limit of the gas metallicity $12 + \log_{10}(\text{O}/\text{H})$. Although in principle the relation between these two quantities is bivariate, the upper metallicity branch can safely be discarded by the lack of metal lines in the spectrum. Considering the recent calibration obtained by E. Cataldi et al. (2025), for Pseudo-LRD-NOM we obtain $12 + \log_{10}(\text{O}/\text{H}) < 7.0$, i.e., $<0.02 Z_{\odot}$. (This value would be even lower considering other calibrations from the literature.) So this would suggest that the interstellar medium (ISM) warm gas in Pseudo-LRD-NOM's host is close to pristine condition. However, these calibrations are based on galaxies whose ISM's densities are less extreme than for Pseudo-LRD-NOM, so their application to LRDs may not be straightforward, as we discuss later.

We produced a range of line emission models using the software CLOUDY (G. J. Ferland et al. 2013, 2017) to investigate under which conditions the observed line ratios of Pseudo-LRD-NOM can be reproduced. For our ionizing source, we consider stellar population models from BPASS (J. J. Eldridge et al. 2017) that include a burst in star formation and binary systems. We consider both solar and subsolar metallicities for the stellar and gas-phase metallicities and employ stellar populations with ages in the range 10^6 – 10^8 yr. These stars are the only source of ionizing photons, and no dust is present in any of our models.

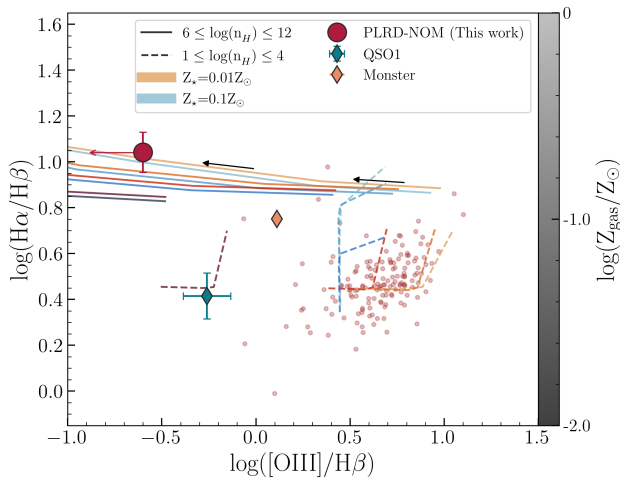


Figure 6. Balmer decrement $H\alpha/H\beta$ versus $[O\ III]\lambda 5007/H\beta$ for our source Pseudo-LRD-NOM (red filled circle) and LRDs from the literature: the Monster (orange diamond; J. E. Greene et al. 2024; I. Labbé et al. 2025) and QSO 1 (teal diamond; F. D’Eugenio et al. 2026; L. J. Furtak et al. 2025; R. Maiolino et al. 2026b), both behind A2744. The small orange circles represent a general sample of low-stellar-mass ($M_* < 10^9 M_\odot$) galaxies at $z > 4$ (Cooper et al. 2026, in preparation). The solid lines show the line ratios predicted by CLOUDY models for a starburst with age 1 Myr, and a range of gas and stellar metallicities, as indicated in the intensity bar and inset label. The tracks move along the gas volume density values n_H , in the range specified in the inset label.

Although we will argue in Section 4.3 that Pseudo-LRD-NOM has actually nonnegligible dust attenuation of its spectral continuum, the main objective here is to show that the spectral line ratios can be explained even without invoking the presence of dust. We will discuss later the implications of the high Balmer decrements being partly produced by dust attenuation (see Section 4.3).

In Figure 6 we show the CLOUDY model tracks corresponding to a very young starburst with age 1 Myr. We see that only models with high gas density ($n_H > 10^6 \text{ cm}^{-3}$) can reproduce Pseudo-LRD-NOM’s line ratios. Different combinations of stellar and gas metallicities between $0.01 Z_\odot$ and $0.1 Z_\odot$ are similarly suitable. Note that the high gas densities needed for our source are above the $[O\ III]\lambda 5007$ critical density, which is $7 \times 10^5 \text{ cm}^{-3}$ (A. Baskin & A. Laor 2005; D. E. Osterbrock & G. J. Ferland 2006). This means that, in Pseudo-LRD-NOM, the $[O\ III]\lambda 5007$ line emission would mainly be governed by collisional excitation rather than photoionization.

Therefore, the extremely low metallicities inferred from calibrations based on more normal galaxies should be taken with caution in this case, as very high gas densities can also be a driver of low $[O\ III]/H\beta$ ratios. Deeper spectroscopic data allowing for a more stringent constraint on the $[O\ III]\lambda 5007$ emission is necessary to conclude on extremely low metallicities for Pseudo-LRD-NOM. In any case, we note that the CLOUDY model predictions do take into account the degeneracies between gas density and stellar/gas metallicities, and still low-metallicity values $\lesssim 0.1 Z_\odot$ are derived from them.

The physical conditions derived for Pseudo-LRD-NOM are in contrast to those for the vast majority of low-mass galaxies, whose line ratios can be reproduced by models of starbursts with much lower gas densities (Figure 6). At the same time, the line ratios of QSO 1 can also be reproduced with models of

Table 2
Best-fit SED Parameters for Pseudo-LRD-NOM

Parameter	Stellar + Nebular	Stellar + AGN
Reduced χ^2	2.05	1.12
$\log_{10}(M/M_\odot)^a$	8.68 ± 0.72	8.55 ± 0.20
$E(B - V)^b$	0.33 ± 0.20	0.45 ± 0.17
Age (Myr)	124.2 ± 95.3	$44.5^{+44.5}_{-40.2}$
Stellar metallicity	$0.0001 \approx 0.7\% Z_\odot^c$	$0.0001 \approx 0.7\% Z_\odot^c$

Notes. Results at fixed $z_{\text{spec}} = 5.96$.

^a The quoted stellar masses do not carry any magnification correction.

^b The color excess applies only to the stellar component.

^c This considers that the solar metal fraction is $Z_\odot = 0.014$ (M. Asplund et al. 2009).

starbursts with moderate densities, but only in combination with very low gas/stellar metallicities.

Crucially, the CLOUDY models considered here do not incorporate any dust attenuation, which indicates that the physical conditions of the host in which Pseudo-LRD-NOM is embedded can be explained without invoking any dust. The very high densities and low metallicities that are necessary to reproduce the spectral lines of Pseudo-LRD-NOM are similar to those of nuclear star clusters or protoglobular clusters (e.g., E. Vanzella et al. 2023; A. Adamo et al. 2024). We note that recently Z. Yan et al. (2026) also analyzed the physical conditions to explain the high Balmer decrements observed in some LRDs without the need of dust. However, these models were based on the assumption that the main radiation source is the central AGN, while here we only consider stellar emission to model Pseudo-LRD-NOM.

Figure 7 is equivalent to Figure 6, but shows CLOUDY model tracks corresponding to older starbursts with ages 10 and 100 Myr. We see that in these two cases we can also reproduce the spectral line ratios of Pseudo-LRD-NOM with the models of dust-free, very dense starbursts. However, interestingly, as the age increases, only very-low-gas-metallicity models are suitable.

4.3. Further Clues from the Spectral Slope $\beta_{\text{UV}}^{\text{spec}}$ and SED Fitting on the Photometry

To further understand Pseudo-LRD-NOM’s nature, we study its SED as traced by the HST and NIRCам broadband photometry. We considered total photometry in all passbands, but we explicitly excluded both the F444W and F460M filter flux densities, as they are significantly affected by the $H\alpha$ emission.

To perform the SED fitting, we made use of the code CIGALE (M. Boquien et al. 2019), considering different combinations of stellar+nebular and stellar+AGN models. For the stellar templates we employed a delayed star formation history with a secondary burst, allowing the age of the stellar population to select from 1 Myr to 1000 Myr. Stellar populations are produced from BC03 models (G. Bruzual & S. Charlot 2003), with stellar metallicities varying between $Z_\odot$ and $\sim 1/1000 Z_\odot$. We included the effect of dust attenuation following a modified D. Calzetti et al. (2000) attenuation law with $E(B - V)$ values ranging from 0 to 1. For the stellar+nebular model, nebular emission is included with a fixed ionization parameter $\log_{10}(U) = -2$ and gas-phase metallicities varying across the same range as the stellar metallicity.

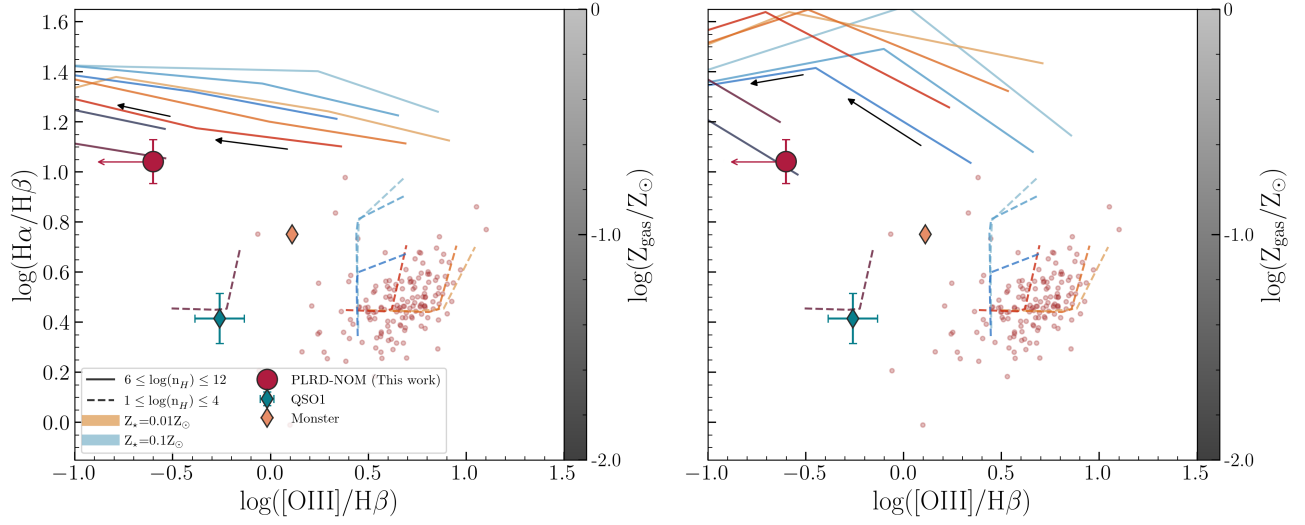


Figure 7. The same as Figure 6, but showing CLOUDY model tracks for older starbursts with ages 10 Myr (left) and 100 Myr (right). These plots indicate that any stellar age ≥ 10 Myr simultaneously requires very low stellar and gas metallicities to reproduce the line ratios of Pseudo-LRD-NOM.

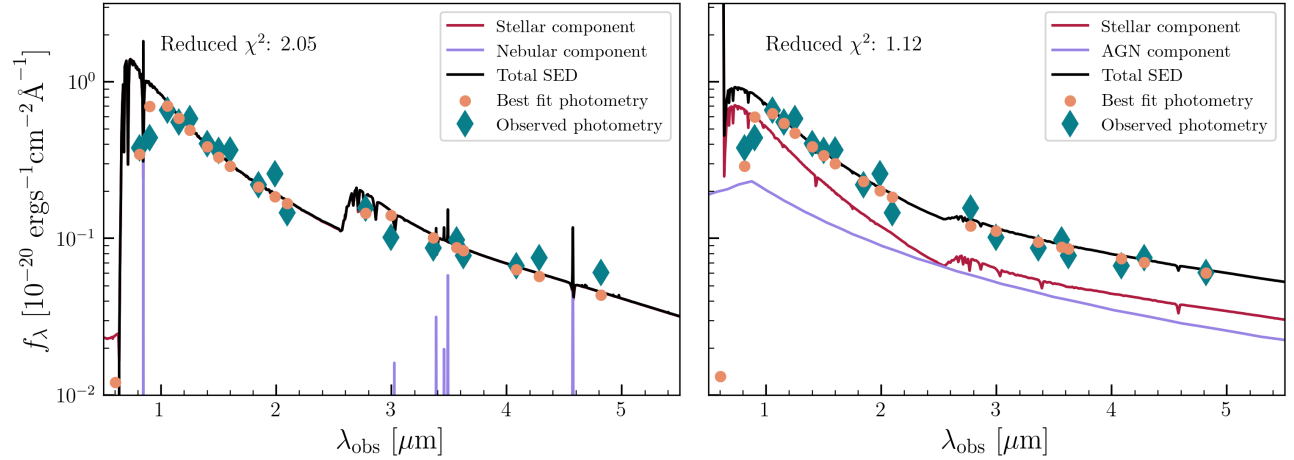


Figure 8. The best-fit SEDs obtained with CIGALE on the source NIRCcam photometry, with different model combinations. Left: stellar template + nebular emission. The nebular emission contribution is virtually insignificant. Right: stellar template + AGN. Although the AGN is subdominant at rest-frame UV wavelengths, it makes for about 40% of the total light in the rest-frame optical. The best-fit parameters are given in Table 2.

In the stellar+AGN model, we utilize the SKIRTOR 2016 AGN model (M. Stalevski et al. 2016) with an opening angle of 70° and AGN fractions of 0, 0.01, and 0.1–0.9 with steps of 0.1.

Figure 8 shows the best-fit SEDs obtained using a combination of stellar and nebular templates, and a combination of stellar and AGN templates. We see that both combinations produce a good fit to the total SED, with the combination of stellar and AGN templates slightly preferred. The derived AGN contribution to the SED is about $\sim 10\%$ – 40% , depending on the wavelength range. In any case, both template combinations yield very similar stellar masses, indicating that the obtained stellar mass can be considered robust. Reassuringly, for any of the template combinations, the properties of the stellar component are quite similar: In both cases, the stellar metallicity is the lowest possible, the age is quite young (≈ 44 – 124 Myr), and the color excess is significant. Forcing CIGALE to consider only higher metallicity models and/or higher ages reduces the output $E(B - V)$ value,

but the resulting reduced χ^2 is significantly higher, indicating that these alternative solutions are not preferred.

We investigated whether this need for dust attenuation for the stellar continuum could be related to the special conditions revealed by the spectral properties of Pseudo-LRD-NOM. To do this we compared the rest-frame UV continuum slope directly derived from the spectrum (as the continuum is detected at those rest-frame wavelengths) with those produced by CLOUDY for the models that best reproduce the spectral line ratios (Figures 6 and 7). From the observed spectrum we get $\beta_{\text{UV}}^{\text{spec}} = -1.20 \pm 0.28$, where the error corresponds to the standard deviation obtained from bootstrapping over 500 iterations, with the spectrum being perturbed according to the error spectrum. Instead, from the CLOUDY models that fit the line ratios we get that the intrinsic β_{UV} values are very small ($\beta_{\text{UV}} < -2$). Therefore, we conclude that a nonnegligible amount of dust attenuation is also necessary to reproduce the relatively red rest-frame UV slope measured on Pseudo-LRD-NOM’s spectrum.

For the case of a 1 Myr old starburst, there are multiple CLOUDY tracks that reproduce our Pseudo-LRD-NOM's spectral line ratios. They all have β_{UV} values between -2.8 and -2.9 , which implies that a color excess $E(B - V) \approx 0.4$ would be necessary to reproduce $\beta_{UV}^{\text{spec}} = -1.20$ measured on Pseudo-LRD-NOM's spectrum (assuming the D. Calzetti et al. 2000 dust-attenuation law; see, e.g., N. A. Reddy et al. 2018). For a 10 Myr old starburst, only models with very high gas density ($n_H > 10^{10} \text{ cm}^{-3}$) and very low metallicities ($Z \approx 0.01 Z_\odot$) can reproduce the observed line ratios. Such models have $\beta_{UV} = -3.2$, so a value $E(B - V) \approx 0.5$ is required to flatten the rest-frame UV slope to the observed value. Finally, for the 100 Myr old starburst, the track that reproduces the line ratios has $\beta_{UV} = -2.05$, which implies the need of $E(B - V) \approx 0.2$ to account for the observed $\beta_{UV}^{\text{spec}} = -1.20$.

In the light of these findings, it is likely that the $H\alpha/H\beta$ line ratio is at least partly affected by dust attenuation. The color excess values derived previously imply that the effect of dust attenuation could by itself produce an $H\alpha/H\beta$ ratio between ≈ 3.9 and 6.2 , but not as high as the measured $H\alpha/H\beta = 11.0$. Some previous works have found that in some galaxies, the gas could have up to $\times 2$ higher attenuation in the UV than in the stars (e.g., N. A. Reddy et al. 2020; I. Shivaeei et al. 2020). If this were the case, the resulting $H\beta$ line could be up to $\approx 15\%$ more attenuated than inferred from the continuum color excess (also assuming the D. Calzetti et al. [2000] dust-attenuation law). Considering this, the $H\alpha/H\beta$ ratio could be as high as ≈ 7 . In no case, however, we can explain the observed $H\alpha/H\beta = 11.0$ ratio directly measured from the spectrum solely based on the effect of dust attenuation.

At the same time, one has to consider that the $[O III]/H\beta$ is virtually independent of dust attenuation. If the intrinsic (unattenuated) $H\alpha/H\beta$ value were very low, then Pseudo-LRD-NOM would be located close to QSO 1 in Figure 6. The inferred gas densities would be lower, but also so would the necessary gas/stellar metallicities. And this would have to be coupled with high dust extinction to reproduce the observed line ratios for Pseudo-LRD-NOM, resulting in a more intriguing scenario, which we discuss in Section 5.

The stellar mass derived from the SED fitting is $\log_{10}(M_*/M_\odot) = 8.55 \pm 0.20$, which after correction for magnification becomes $\log_{10}(M_*/M_\odot) = 7.35 \pm 0.21$ (adopting $\mu = 15.7 \pm 0.4$). Considering the dust- and magnification-corrected SFR lower limit that we derived in Section 4.1, i.e., $\text{SFR}(H\alpha) \gtrsim 0.90_{-0.08}^{+0.10} M_\odot \text{ yr}^{-1}$, we get a specific SFR value $\log_{10}(\text{sSFR}/\text{yr}^{-1}) \gtrsim -7.40 \pm 0.44$ (which is independent of magnification). This high minimum sSFR implies that Pseudo-LRD-NOM is a starburst galaxy, following the empirical starburst definition of K. I. Caputi et al. (2017, 2021).

Finally, the estimated half-light radius of the source, as obtained from the F150W-band image, is $(520 \pm 270) \text{ pc}$. After correcting it for magnification (by dividing it by $\sqrt{\mu}$), it becomes $R_{1/2} = (131 \pm 68) \text{ pc}$. This gives a stellar-mass surface density $\Sigma_* = 418_{-310}^{+725} M_\odot \text{ pc}^{-2}$ (independent of magnification). This is similar to the stellar surface density found in massive star clusters (E. Vanzella et al. 2023; L. Mowla et al. 2024) and even compatible within the error bars with the stellar surface density of nuclear star clusters (e.g., N. Neumayer et al. 2020; K. Fahrion et al. 2021).

5. Discussion

5.1. The Complex Scenario Revealed by the Simple Spectrum of Pseudo-LRD-NOM

The spectral properties of Pseudo-LRD-NOM are quite unusual, as they include a high Balmer decrement (narrow) $H\alpha/H\beta = 11.0$ simultaneously with a low ratio $[O III]\lambda 5007/H\beta < 0.25$. High Balmer decrements are relatively common among LRDs (e.g., G. P. Nikopoulos et al. 2026; V. Rusakov et al. 2026). Although some first studies have explained them simply by the presence of dust attenuation, subsequent analyses suggested a more complicated picture (e.g., P. G. Perez-Gonzalez et al. 2024; D. J. Setton et al. 2025). Very recently, Z. Yan et al. (2026) showed that high Balmer decrements can be explained via high-density gas emission from the AGN broad-line region within the LRDs, without the need for invoking dust.

The situation for Pseudo-LRD-NOM is somewhat different, as the high $H\alpha/H\beta$ is dominated by the narrow-line components, which originate in the narrow-line region or the galaxy host. We have not made the difference between the two in this paper, as the available spectrum does not have the necessary spatial information for this purpose. However, we note that it is unlikely that the Pseudo-LRD-NOM's spectrum originates in a narrow-line region, even if the narrow components of the Balmer ($H\alpha$, $H\beta$) lines have a FWHM compatible with them. This is because typically the gas in narrow-line regions is significantly less dense than in H II regions (D. Kakkad et al. 2018), and here we showed that the observed line ratios require the presence of very dense gas. Moreover, the ratio between the $H\alpha$ narrow and broad-component luminosities in our source is $\approx 2.9 \pm 0.4$, which is significantly higher than the value that would be expected if the narrow component were originated in a narrow-line region (e.g., J. Stern & A. Laor 2012).

In any case, the conclusion of the gas being metal-poor would not be affected, as the relations between the main line ratios and oxygen abundances for narrow-line regions and H II regions mainly differ around and above the solar value (P. Zhu et al. 2024). In addition, although invoking dust attenuation is in principle not necessary to explain the high $H\alpha/H\beta$, we do infer the presence of dust from the relatively flat rest-frame UV continuum slope $\beta_{UV}^{\text{spec}} = -1.20$ in Pseudo-LRD-NOM's spectrum.

Figure 9 shows a comparison of the Pseudo-LRD-NOM and QSO 1 spectra. A main difference between the two is the strength of the Balmer break, which is very evident for QSO 1 (X. Ji et al. 2025), and absent for Pseudo-LRD-NOM. The prominent Balmer breaks observed in some LRDs do not have a stellar origin, but are rather produced by ultra-dense ($n_H \gtrsim 10^{10} \text{ cm}^{-3}$) and turbulent gas, most likely present in the AGN broad-line region (e.g., K. Inayoshi & R. Maiolino 2025). This ultra-dense gas can trap the UV photons produced by the black hole accretion, resulting in the sharp spectral drop observed at short wavelengths (e.g., H. Liu et al. 2025). The lack of such a sharp feature for Pseudo-LRD-NOM may be indicating that its central black hole is not surrounded by such ultra-dense gas structure. And the gas in its host galaxy, even if dense, does not reach the ultra-high densities of the gas in LRD's broad-line regions.

The lack of a significant Balmer break makes Pseudo-LRD-NOM resemble other kinds of AGNs found to be hosted by

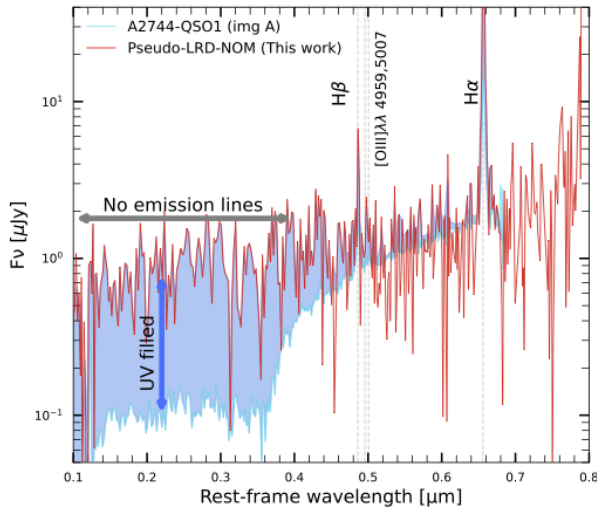


Figure 9. Comparison of the Pseudo-LRD-NOM and QSO 1 spectra, renormalized at rest-frame wavelength $\approx 0.53 \mu\text{m}$.

low-metallicity galaxies at high z (e.g., H. Uebler et al. 2023). In all these sources, the flux of UV photons is high enough to make the Balmer break disappear.

5.2. An Active Black Hole in a Dense Star Cluster

Interestingly, most of the light of Pseudo-LRD-NOM can be explained by having a stellar origin, with the need of only a relatively minor AGN component for the SED. The presence of an AGN becomes most evident by the identification of a broad component in the $H\alpha$ line. Although a broad-line component could in principle have a different origin, its FWHM is so large that the association with an active black hole is the most likely explanation. The presence of a BLAGN is now recognized as quintessential to the LRD nature. However, the black hole masses derived from the line broadening are systematically higher than what is expected from the local (and even high- z) M_{BH} versus M_* relation (e.g., Y. Harikane et al. 2023; F. Pacucci et al. 2023). The situation for Pseudo-LRD-NOM is similar: We find $M_{\text{BH}}/M_* \approx 0.18$, which means that the central black hole is overmassive by 1–2 orders of magnitude. So the presence of overmassive black holes is not exclusive to LRDs, but rather also applies to other types of AGNs at high z (e.g., M. Onoue et al. 2019; Y. Harikane et al. 2023; J. Wolf et al. 2026). Alternatively, it could be that the line broadening is enhanced by physical processes other than kinematics of the broad-line region, in which case the black hole masses could be overestimated. For example, electron scattering in dense ionized gas clouds could be partly responsible for the line broadening (e.g., A. Laor 2006; K. Inayoshi & L. C. Ho 2026a).

Pseudo-LRD-NOM’s host appears to be a dense and dusty starburst, with a stellar density typical of massive star clusters and even nuclear star clusters. The simultaneous presence of an AGN and a nuclear star cluster in LRDs has been recently proposed via theoretical considerations (e.g., K. Inayoshi et al. 2026b). The spectral properties of Pseudo-LRD-NOM reveal that this combination is present in this source. As a matter of fact, the connection between nuclear star clusters and black hole growth has been investigated since at least a few decades ago (e.g., S. F. Portegies Zwart et al. 2004, 2006).

In general, it is believed that the presence of nuclear star clusters could facilitate the efficient growth of massive black holes by funneling gas to the galaxy center (e.g., J. P. Naiman et al. 2015; C. Partmann et al. 2025; Z. Su et al. 2025). They could potentially explain the early growth of massive black holes via synchronized episodes of black hole accretion and nuclear star formation. The identification and further study of other low-mass galaxies with nuclear activity and high stellar/gas densities are necessary to understand the details of this phenomenon.

Recently A. Dekel et al. (2025) proposed a mechanism for LRD formation: Star clusters merging to form compact central star clusters. Each star cluster carries a core-collapse black hole, which contributes to the formation of a central, massive black hole in the merging process. A series of gas-rich compaction events deepen the galaxy central potential well, allowing for the retention of the central black hole. In this scenario, which is similar to that considered by K. Inayoshi et al. (2026b), Pseudo-LRD-NOM could represent a system that is in between compaction events. The inflow of pristine gas from the dark matter halo could keep the metallicity low until the compaction triggers new star formation activity and subsequent chemical enrichment. So, in summary, Pseudo-LRD-NOM could constitute an LRD in the making.

We note that Pseudo-LRD-NOM’s nature is in principle different from that of the local *blueberry galaxies* studied by H. Yang et al. (2017) and the sources studied by D. M. Elmegreen & B. G. Elmegreen (2017). These galaxy populations have low masses and are metal-poor, but are also significantly less compact than Pseudo-LRD-NOM. Therefore, their resulting stellar-mass surface densities are also lower. In addition, by selection these galaxies are dust-free and have no reported evidence of the presence of black hole activity.

5.3. The Simultaneous Presence of Extremely Low Metallicities and Dust Attenuation

Another property inferred for Pseudo-LRD-NOM’s host is its very low metallicity: $Z = 0.01\text{--}0.1 Z_\odot$ for the gas and stars from the spectral modeling, and even lower stellar metallicities from the SED fitting. Substellar metallicities are the rule among low-mass galaxies at high z , and some LRD hosts have been found to have gas metallicities of $\sim 0.1 Z_\odot$ (e.g., R. Maiolino et al. 2026b; A. J. Taylor et al. 2025; R. Tripodi et al. 2025). Pseudo-LRD-NOM appears to be at an earlier stage of chemical enrichment.

It is particularly noteworthy that this source appears to exhibit simultaneously very low metallicities and significant dust attenuation. The presence of dust in metal-poor galaxies is known at low z (e.g., F. Galliano et al. 2005; A. Rémy-Ruyer et al. 2013; Y. I. Izotov et al. 2014). It has also been reported in metal-poor, star-forming galaxies at high z , particularly gamma-ray burst hosts (K. E. Heintz et al. 2023b). It can be explained via a quick dust injection produced by supernovae (e.g., H. Hirashita et al. 2002; S. Martínez-González et al. 2022) or carbon-enriched Wolf Rayet stars (R. M. Lau et al. 2021), before the galaxy becomes significantly metal-enriched. Early metal pollution from massive stars has recently been invoked to explain the metal abundances of higher- z galaxies, such as GNz11 (S. Ebihara et al. 2026).

Thus Pseudo-LRD-NOM could be at a more advanced chemical enrichment stage than sources dominated by pristine gas, but still be at the initial stages of chemical enrichment.

Alternatively, the low metallicity could be maintained by a continuous accretion of pristine gas from the dark matter halo in which Pseudo-LRD-NOM resides, producing metal dilution (e.g., G. Cresci et al. 2010; P. Troncoso et al. 2014; K. E. Heintz et al. 2023a). The search for signatures of inflowing gas in other sources that do show metal lines in their spectra would help to test this scenario.

The results of the SED fitting suggest that Pseudo-LRD-NOM's host is a young starburst with age 44–124 Myr. In turn, the flux-density excess (with respect to the continuum) observed in the F460M filter due to the presence of $H\alpha$ indicates that $EW_0(H\alpha) \approx 1200 \text{ \AA}$. This high value also indicates that Pseudo-LRD-NOM must be dominated by young stellar populations, in agreement with the results of the SED fitting.

The presence of an early dusty phase before starbursts shine dust-free has been predicted for the formation of luminous UV galaxies at early cosmic times (A. Ferrara et al. 2025). In this scenario, the produced dust would be pushed to the galaxy outskirts once supernova-driven gas outflows become important. These gas outflows are also a natural consequence of stellar evolution. Pseudo-LRD-NOM could be to our knowledge the first reported example of such an early phase of star formation activity.

The suppression of metal lines in Pseudo-LRD-NOM's spectrum is to some extent the consequence of the high gas density, and this parameter is degenerate with metallicity. This is why typical calibrations of $[O III]/H\beta$ versus oxygen abundance do not apply to Pseudo-LRD-NOM. In any case, we note that the CLOUDY model predictions shown in Figures 6 and 7 take into account those degeneracies, and from them we derive that even at high gas densities, low-stellar/gas-metallicity values $\lesssim 0.1 Z_\odot$ are necessary to reproduce the spectral properties of Pseudo-LRD-NOM.

A further intriguing possibility is that Pseudo-LRD-NOM could be hosting Population III (Pop III) stars. These stellar populations are in principle expected to have spectra with only emission lines produced by H and He atomic transitions (e.g., K. Nakajima & R. Maiolino 2022), but some minor metal self-pollution may be possible, even while Pop III stars still dominate the new star-forming regions (e.g., R. Sarmento et al. 2017; E. Rusta et al. 2025). To date, only a small amount of high- z candidates have been found to likely host significant Pop III star formation activity (e.g., E. Vanzella et al. 2023; T. Morishita et al. 2025; R. Maiolino et al. 2026a).

The lack of detectable He II $\lambda 4686$ emission in Pseudo-LRD-NOM's spectrum prevents us to extract such a conclusion. We note that the spectral continuum is marginally detected at the position of the He II $\lambda 4686$ emission line, and thus the line should also be detected if such emission were present, unless the dust attenuation on the gas is larger than in the stellar component.

We tested the hybrid Pop III stellar templates from E. Rusta et al. (2025) for the fitting of Pseudo-LRD-NOM's SED. We found that the resulting best-fit model yielded a reduced χ^2 that is $>2\sigma$ higher than the value obtained for the SED fitting with the stellar models considered in Section 4.3. Thus the presence of Pop III stars does not appear to be significant in our source. A wider investigation of sources like Pseudo-LRD-NOM, and dwarf galaxies in general at high z , is necessary to find sources with a significant presence of first stellar generations.

6. Conclusions

We presented a detailed study of Pseudo-LRD-NOM, a compact, low-mass galaxy at $z = 5.96$ that appears to be at the early stages of star formation activity. This source would fail the LRD classification because of its red rest-frame optical color being contaminated by the presence of a prominent $H\alpha$ line. It would comply instead with the LBD selection criteria recently proposed by M. Brazzini et al. (2026).

We inferred the presence of an active, massive black hole in Pseudo-LRD-NOM from $H\alpha$ having a very broad component, whose large FWHM cannot be explained by stellar kinematics. We argued that the study of pseudo-LRDs has so far been largely neglected in the literature, still it could be important to obtain a complete AGN census at high redshifts.

Moreover, Pseudo-LRD-NOM provides evidence for an active black hole being embedded in a high-density, dusty starburst that is still at the early stages of its chemical enrichment. Pseudo-LRD-NOM is likely the precursor to a real LRD, with the massive central black hole already in place, but without yet having the ultradense cocoon that would produce a prominent Balmer break in its spectrum. The study of more pseudo-LRDs residing in low-mass galaxies could be a key route to investigating the connection between massive black hole growth and nuclear star clusters, as well as the LRD formation mechanisms. In addition, integral field spectroscopic studies with medium/high spectral resolution, with JWST and future 30–40 m-class ground-based telescopes, will be necessary to reveal in detail the dynamics and other physical processes at play in these sources.

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