

Wings of little dots: Exponential broad lines from a stratified BLR

Piero Madau^{1,2}, Roberto Maiolino^{3,4,5}, Jan Scholtz^{3,4}, and Francesco D'Eugenio^{3,4}

¹ Dipartimento di Fisica “G. Occhialini,” Università degli Studi di Milano-Bicocca, Piazza della Scienza 3, I-20126 Milano, Italy

² Department of Astronomy & Astrophysics, University of California, 1156 High Street, Santa Cruz, CA 95064, USA

³ Kavli Institute for Cosmology, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK

⁴ Cavendish Laboratory, University of Cambridge, 19 JJ Thomson Avenue, Cambridge CB3 0HE, UK

⁵ Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK

April 7, 2026

ABSTRACT

We investigate the origin of the broad exponential wings observed in a significant fraction of the H α profiles of JWST-discovered little red dots (LRDs) and **little blue dots (LBDs)**. Recent studies have shown that exponential broad-line profiles are not a prerogative of LRDs, **are often also present in LBDs**, and need not imply that electron scattering is the dominant broadening mechanism in every source. Motivated by our unification picture in which LRDs are the dust-reddened, **high-inclination counterparts of compact blue broad-line AGNs**, we model the broad Balmer emission with a virialized, **radially stratified broad-line region (BLR)**. In this framework, the observed profile is the luminosity-weighted superposition of clouds spanning a range of radii and therefore a range of characteristic virial velocities. We show that such a stratified BLR can reproduce the extended exponential-like wings observed in three representative LRDs, without requiring electron scattering to be the primary origin of the broad wings. Our results support a picture in which the broad wings and the line cores encode different physics: the wings arise primarily from virial BLR stratification, whereas the cores retain additional imprints of absorption and radiative transfer in dense gas. The successful fits further suggest that the cloud radial distribution peaks near the dust sublimation radius, while the exponential wings are shaped by the line-emitting inner BLR shells where the higher virial velocities produce the high-velocity tails. This offers a simple physical explanation for the exponential wings of little dots, without invoking exotic new components or scenarios.

Key words. Accretion (14); Active galactic nuclei (16); James Webb Space Telescope (2291); Supermassive black holes (1663)

1. Introduction

The James Webb Space Telescope (JWST) has uncovered a large population of moderate-luminosity broad-line active galactic nuclei (BLAGNs) at $z \gtrsim 4$, powered by accretion onto early massive black holes with inferred masses of order 10^6 – $10^8 M_\odot$ (e.g., Harikane et al. 2023; Maiolino et al. 2024; Taylor et al. 2025; Juodžbalis et al. 2026), and partitioned by their UV-optical continuum slopes into “little red dots” (LRDs) and “little blue dots” (LBDs) (Brazzini et al. 2026). These sources are distinguished by broad Balmer emission, compact morphologies, weak X-ray emission, and, in the case of LRDs, red or V-shaped UV-optical continua with strong Balmer breaks. Their spectra often lack the prominent high-ionization features typical of classical unobscured AGNs, indicating that the physical conditions of the line-emitting and circumnuclear gas differ substantially from those in standard quasar populations (e.g., Matthee et al. 2024; Greene et al. 2024; Lambrides et al. 2024; Kocevski et al. 2025; Wang et al. 2025; Hainline et al. 2025; Akins et al. 2025; Delvecchio et al. 2025; Barro et al. 2026; Hviding et al. 2025; Maiolino et al. 2025; Tang et al. 2025; Zucchi et al. 2026).

A major focus of recent work has been the origin of the broad H α line profiles in these systems, and more generally

of the broad hydrogen and helium emission lines. Rusakov et al. (2026) argued that, in high-quality LRD spectra, the broad exponential wings are produced primarily by Thomson scattering in compact, Compton-thick ionized cocoons. In this interpretation, the intrinsic line cores are much narrower, implying substantially lower black-hole masses than standard virial estimates. By contrast, Scholtz et al. (2026) showed from a larger sample of 32 JWST AGNs that exponential profiles are not unique to LRDs, **are often also present in LBDs**, and are not universally preferred over Lorentzian or multicomponent Gaussian descriptions. They further demonstrated that exponential wings can arise naturally from the superposition of virialized BLR clouds spanning a range of radii, without requiring scattering to dominate the line broadening.

At the same time, Matthee et al. (2026) have emphasized that the line cores vary systematically with continuum color and Balmer-break strength: blue sources show relatively narrow central cores, redder systems exhibit P-Cygni-like absorption, and the reddest sources display absorption-dominated cores, while broad exponential wings remain present throughout the sequence. This suggests that the wings and cores may encode different physics, with the former tracing the intrinsic BLR velocity field and the latter

the radiative-transfer and absorption effects of dense circumnuclear gas.

In a recent paper, [Madau & Maiolino \(2026\)](#) proposed that LRDs are the dust-reddened, high-inclination counterparts of compact blue broad-line AGNs powered by super-Eddington accretion. In that picture, a geometrically thick funnel produces a strongly anisotropic ionizing continuum, while an equatorially concentrated BLR and a modest dusty screen explain the large Balmer equivalent widths, weak high-ionization lines, and red continua of LRDs without invoking a fully enclosing cocoon. Motivated by this framework, here we investigate whether the observed exponential H α wings in representative LRD spectra can be reproduced by a virial radially stratified BLR and whether the detailed line cores require additional absorption. Our goal is to assess whether BLR stratification provides a simple common origin for the broad wings of both populations, while allowing the core morphology to retain the imprint of dense circumnuclear gas.

2. The stratified BLR of little dots

A natural alternative to dominant electron scattering is that broad Balmer profiles are produced by a radially stratified BLR, in which clouds at different radii contribute different characteristic velocities. This interpretation is motivated by the fact that exponential wings are not unique to LRDs, are also found in LBDs, and can arise naturally from the stratification of virialized BLR clouds rather than from a separate scattering cocoon. [Scholtz et al. \(2026\)](#) explicitly argue that exponential wings can emerge from BLR stratification in virial motion, and that stacking or superposing multiple kinematic BLR components tends to produce profiles that are indistinguishable from exponential, even when the individual components are not themselves exponential. Exponential or exponential-like broad-line wings are also not unique to JWST-discovered sources. A classic case is the H α profile of the low-luminosity Seyfert NGC 4395, where symmetric exponential wings were identified by [Laor \(2006\)](#); more generally, [Kollatschny & Zetzl \(2013\)](#) discussed exponential profiles as one of the standard phenomenological broad-line shapes in classical AGNs.

The logic of our model is simple. In a super-Eddington funnel geometry, the escaping continuum is highly anisotropic: near-polar observers see a brighter, harder ionizing spectral energy distribution (SED), whereas along equatorial directions self-shadowing suppresses the hardest XUV/soft-X-ray photons and reshapes the continuum ([Wang et al. 2014](#); [Lupi et al. 2024](#); [Madau 2026](#)). If the BLR is concentrated toward the equatorial plane, it is illuminated by a softer, more self-shielded continuum than that seen by low-inclination observers, naturally weakening high-ionization lines while preserving strong Balmer emission. A modest-covering dusty component associated with the outer BLR or a compact circumnuclear obscurer then reddens high-inclination sightlines into the V-shaped continua of LRDs, while lower-inclination views appear as LBDs ([Madau & Maiolino 2026](#)). In this picture, the observed differences between LRDs and LBDs arise primarily from orientation and line-of-sight processing rather than from intrinsically different engines or evolutionary stages (e.g., [Kido et al. 2025](#); [Naidu et al. 2025](#); [Pacucci et al. 2026](#)). The model predicts broader and more extended high-EW tails for the Balmer lines in LRDs than in LBDs, owing

to the suppression of the observed continuum along dust-intercepted, high-inclination sightlines.

Following [Madau & Maiolino \(2026\)](#), we model the BLR as an equatorially concentrated cloud distribution by specifying the mean number of clouds along a direction of polar angle i as

$$N(i) = N_0 \exp\left[-\frac{\cos^2 i}{2\sigma_c^2}\right], \quad (1)$$

where σ_c sets the angular thickness of the cloud distribution about the equatorial plane. The corresponding escape probability for direct disk photons is

$$P_{\text{esc}}(i) = \exp[-N(i)]. \quad (2)$$

We fix the normalization N_0 by requiring that the angle-averaged probability of intercepting at least one cloud equals the global BLR covering factor,

$$C_{\text{BLR}} = \int_0^{\pi/2} [1 - P_{\text{esc}}(i)] \sin i \, di, \quad (3)$$

where symmetry about the mid-plane has been assumed. For any chosen pair of values $(\sigma_c, C_{\text{BLR}})$, equation (3) is solved for N_0 . The corresponding normalized angular weighting of BLR clouds is then

$$p(i) = \frac{[1 - P_{\text{esc}}(i)] \sin i}{\int_0^{\pi/2} [1 - P_{\text{esc}}(i')] \sin i' \, di'}. \quad (4)$$

In our picture, the BLR extends over a range of radii interior to the dust sublimation boundary. This is physically motivated by the fact that, beyond the sublimation radius, surviving dust dominates over gas absorption of ionizing photons, so that only a small fraction of the ionizing continuum is available for gas ionization and line emission. Nebular emission is therefore strongly suppressed there, in addition to being affected by dust extinction ([Netzer & Laor 1993](#)). We write the radial cloud distribution as

$$\frac{dN}{dr} \propto r^{\alpha-1} \exp\left(-\frac{r}{r_{\text{sub}}}\right), \quad (5)$$

where r_{sub} is the dust sublimation radius ([Barvainis 1987](#)),

$$r_{\text{sub}} = 2.3 \left(\frac{L_{\text{UV}}}{10^{45.5} \text{ erg s}^{-1}} \right)^{1/2} \left(\frac{T_{\text{sub}}}{1000 \text{ K}} \right)^{-2.8} \text{ pc}, \quad (6)$$

which we take to define the characteristic outer scale of the BLR, and the slope α controls the relative weighting of inner and outer BLR clouds. Since the emergent H α line power of a cloud, $P_{\text{H}\alpha}^c(r, i)$, depends on both radius and BLR angle, the line profile is written as

$$\frac{dL}{dv}(v) = \int dr \frac{dN}{dr} \int di p(i) P_{\text{H}\alpha}^c(r, i) G[v; \sigma(r)], \quad (7)$$

where $G(v; \sigma)$ is the Gaussian kernel describing the effective one-dimensional distribution of cloud bulk velocities at fixed radius r . Assuming virial motion, the characteristic velocity scales as

$$v_{\text{vir}}(r) = \left(\frac{GM_{\text{BH}}}{r} \right)^{1/2}. \quad (8)$$

In the phenomenological fits considered here, we parameterize the local one-dimensional width as

$$\sigma(r) = f_{\text{vir}} v_{\text{vir}}(r), \quad (9)$$

where f_{vir} absorbs geometric and kinematic factors, as well as source-to-source variations in M_{BH} relative to the fiducial value adopted in the model. In the purely virial limit, f_{vir} is equivalent to a rescaling of the adopted fiducial black-hole mass, since the profile width depends on the combination $f_{\text{vir}} M_{\text{BH}}^{1/2}$. If the BLR kinematics had an ordered in-plane component, an explicit dependence on the observer inclination i_{obs} would enter through an additional factor of $\sin i_{\text{obs}}$.

The inner BLR therefore contributes the high-velocity tails, while larger radii supply the low-velocity core. In this way, a continuous radial distribution of virialized clouds can generate broad exponential-like wings without requiring scattering to dominate the profile, as detailed in the next section. This interpretation also naturally accommodates the fact that different lines need not have identical profiles: higher-ionization lines arise at smaller radii and should therefore be broader than Balmer lines, a behavior that is difficult to reconcile with a single dominant scattering medium but follows straightforwardly in a stratified BLR. This is consistent with the recent analysis of GS-3073 by [Brazzini et al. \(2026\)](#), who found that HeII $\lambda 4686$ is substantially broader than H α , despite the latter being well described by an exponential profile. More generally, BLR stratification is already a standard ingredient of AGN physics, supported by reverberation-mapping studies showing that higher-ionization lines are emitted closer to the black hole than the Balmer lines (e.g., [Peterson 1993](#); [Pancoast et al. 2014](#); [Grier et al. 2017](#); [Netzer 2020](#)), so our model does not invoke a new or exotic component but rather a structure that is already known to be present.

3. Line profiles

To illustrate the implications of our stratified BLR framework, we construct detailed line-profile models for three representative JWST broad-line AGNs: GN-68797, GN-9771, and GS-13971. All three are LRDs with deep NIRSpec grating spectroscopy and are included in the recent line-profile analysis of [Scholtz et al. \(2026\)](#), where they are classified as absorbed LRDs. Their spectroscopic redshifts are $z = 5.04$, 5.53 , and 5.48 , respectively. In the [Matthee et al. \(2026\)](#) sample, the total H α rest-frame equivalent widths inferred from the PRISM spectra are $1306 \text{ \AA}$ for GN-68797, $1713 \text{ \AA}$ for GN-9771, and $894 \text{ \AA}$ for GS-13971, confirming that all three are strong Balmer emitters within the broader JWST broad-line population.

We generated grids of photoionization models with the C23 release of CLOUDY ([Chatzikos et al. 2023](#)), tailored to typical BLR conditions with hydrogen density $n_{\text{H}} = 10^{10} \text{ cm}^{-3}$ and column density $N_{\text{H}} = 10^{23} \text{ cm}^{-2}$. We adopted a metallicity $Z = 0.1 Z_{\odot}$, representative of galaxies at the redshifts where LRDs (and LBDs) are most commonly found,¹ and explored a grid of ionization pa-

rameters $-4 \leq \log U \leq 0$ in steps of 0.5 dex. For the line-profile calculations we adopt a fiducial central engine with $M_{\text{BH}} = 10^{7.5} M_{\odot}$ and $\dot{m} = 32$, thereby fixing the angle-dependent ionizing photon rate $Q_{\text{HI}}(i)$ incident on BLR clouds at polar angle i . Each value of U then maps to a characteristic BLR radius through

$$r(U, i) = \left[\frac{Q_{\text{HI}}(i)}{4\pi c n_{\text{H}} U} \right]^{1/2}. \quad (10)$$

In this sense, the cloud distribution entering the profile integral in Equation (7) is implemented most directly as a distribution in ionization parameter, dN/dU , with the corresponding radial weighting obtained through the mapping between U and r .

For the profile fits, we normalize both the observed spectrum and the model to the peak flux density of the observed total H α profile. The BLR covering factor C_{BLR} and angular thickness σ_c are fixed to representative values, guided by the equivalent width (EW) analysis discussed below but not uniquely determined by it, since the predicted EWs depend in part on the trade-off between covering factor and observer inclination. The radial stratification parameter α and the effective virial factor f_{vir} are instead treated as free parameters. For smooth profile construction, the CLOUDY H α line powers are log-linearly interpolated across the sampled $\log U$ grid. In GN-68797 and GS-13971, the absorption profile, narrow H α component, and continuum are fixed to the published line-profile decomposition of [Scholtz et al. \(2026\)](#). For GN-9771, we adopt a two-step procedure: we first fit the full profile with the stratified BLR multiplied by a free absorption component and a free narrow Gaussian, then fix the resulting narrow and absorption profiles and refit only the red wing to determine the final BLR parameters. Because in all three objects the blue side of the line is affected by absorption, we fit only the red wing over the velocity interval $200 < v < 5000 \text{ km s}^{-1}$. We exclude the innermost $|v| < 200 \text{ km s}^{-1}$ around line center because that part of the profile is most sensitive to uncertainties in the systemic velocity, the fixed narrow-line decomposition, and absorption-related core structure. This allows the fit to focus on the velocity range most directly tracing the stratified BLR responsible for the extended wings. We then add the stratified broad-line component and compare the resulting normalized model profiles directly to the data.

Figure 1 shows the best-fit stratified-BLR model for the LRD GN-68797. Despite the simplicity of the model, the agreement with the data is excellent: the broad exponential-like wings, the suppressed core, and the overall shape of the observed profile are all reproduced well. Fitting the red wing only, we obtain a best-fit for a reduced chi-square of $\chi^2/\text{dof} = 1.70$, with radial-slope parameter of $\alpha = 2.75$ and an effective virial factor $f_{\text{vir}} = 1.35$, adopting a sublimation radius of $r_{\text{sub}} = 7.2 \times 10^{18} \text{ cm}$. In our parameterization, $\alpha = 2.75$ implies a cloud distribution weighted toward large radii, near the dust sublimation scale, rather than being dominated by the innermost BLR. At the same time, inner clouds still make a disproportionate contribution to the highest-velocity tails, since the local velocity width scales as $v_{\text{vir}} \propto r^{-1/2}$. The broad, nearly exponential wings therefore arise naturally from the superposition of virialized clouds spanning a range of radii, rather than from a single characteristic emitting radius.

This interpretation is qualitatively consistent with the stratified BLR picture inferred in low-redshift AGNs from

¹ While the H α emissivity is less sensitive to metallicity than metal-line diagnostics, changing Z modifies the thermal balance, ionization structure, and diffuse continuum of the BLR gas, and therefore can affect both the H α line power and its EW at a moderate level.

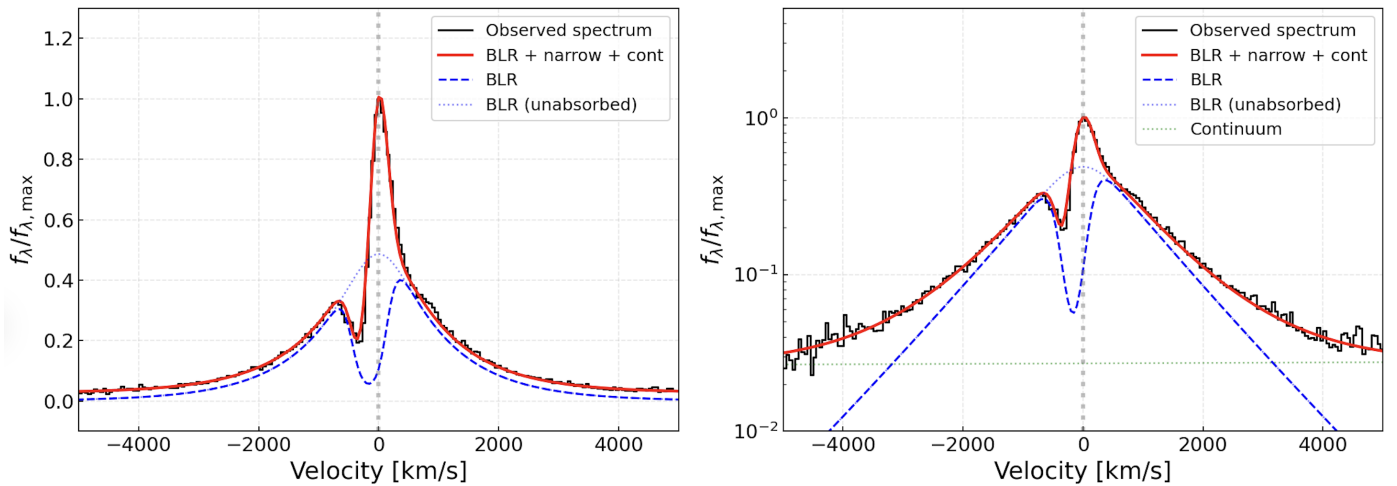


Fig. 1. Best-fit stratified-BLR model for the LRD GN-68797. Left: linear-scale view of the observed H α profile (black) and best-fit model (red), obtained by fitting only the red wing of the line. The blue dashed curve shows the absorbed broad stratified BLR component, while the blue dotted curve shows the corresponding unabsorbed BLR profile; the difference between the two illustrates the effect of the fixed absorption profile adopted from the published line-profile decomposition (Scholtz et al. 2026). Right: the same comparison on a logarithmic scale, highlighting the extended, nearly exponential wings. The fit is obtained for a reduced chi-square of $\chi^2/\text{dof} = 1.70$, with $\alpha = 2.75$ and $f_{\text{vir}} = 1.35$, assuming $r_{\text{sub}} = 7.2 \times 10^{18}$ cm. The model reproduces the broad wings and the overall profile shape, supporting an interpretation in which the extended wings arise from the superposition of virialized clouds spanning a range of radii, while the suppressed core is shaped by line-of-sight absorption and the fixed narrow H α component.

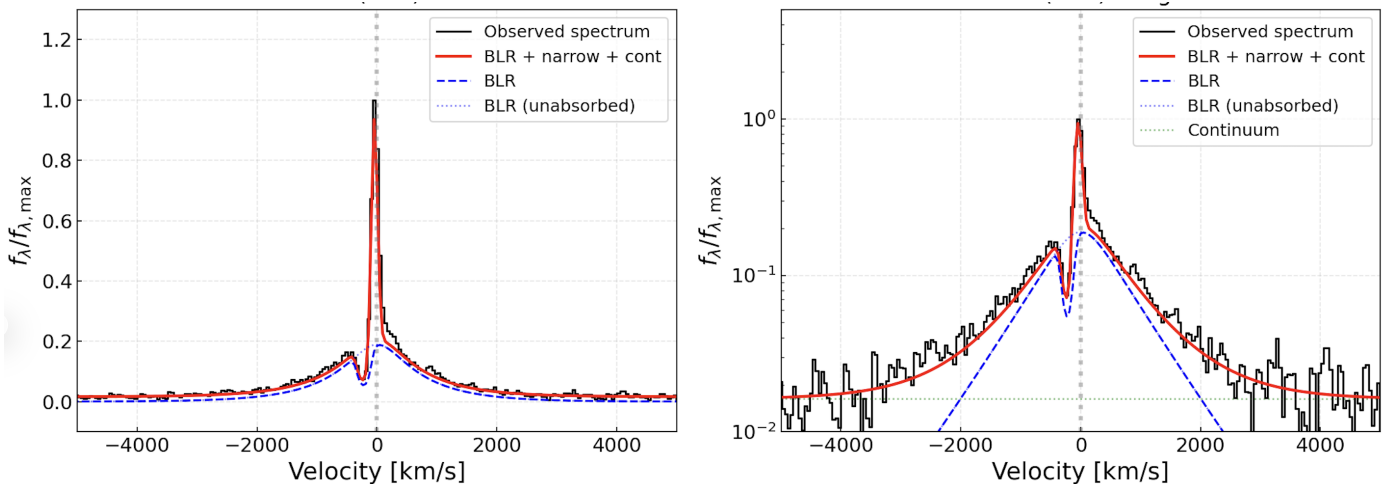


Fig. 2. Best-fit stratified-BLR model for the LRD GS-13971. Left: linear-scale view of the observed H α profile (black) and best-fit model (red), again fitting only the red wing of the line. The blue dashed curve shows the absorbed broad stratified BLR component and the blue dotted curve the corresponding unabsorbed BLR profile, illustrating the effect of the fixed absorption component adopted from the published decomposition. Right: the same comparison on a logarithmic scale, emphasizing the extended wings. The best fit is obtained for a reduced chi-square of $\chi^2/\text{dof} = 1.07$, with $\alpha = 2.75$ and $f_{\text{vir}} = 0.99$, adopting the same fiducial sublimation radius.

reverberation mapping and velocity-resolved broad-line studies, which indicate that different parts of the line profile probe gas spanning a range of radii and exhibiting distinct kinematic signatures, including virialized motion, inflow, and outflow (e.g., Peterson 1993; Pancoast et al. 2014; Grier et al. 2017; Netzer 2020), and with the idea that the low-ionization BLR is associated with the region where the outer accretion disk merges into the inner edge of the dusty torus (Goad et al. 2012).

The parameter $f_{\text{vir}} = 1.35$ indicates that the effective one-dimensional velocity width required by the fit is somewhat larger than the fiducial virial scaling, absorb-

ing both geometric and kinematic effects as well as any mismatch between the adopted fiducial black-hole mass, $M_{\text{BH}} = 10^{7.5} M_{\odot}$, and the true mass of the source. This is qualitatively consistent with the literature estimates for GN-68797, for which published non-scattering profile fits imply $\log(M_{\text{BH}}/M_{\odot}) \simeq 8.0\text{--}8.1$, about 0.5 dex above our baseline value.

Similar results are obtained for the LRDs GS-13971 and GN-9771, whose line-profile decompositions are shown in Figures 2 and 3. In both cases the agreement between the data and the stratified BLR model is excellent. For GS-13971 we obtain a best fit with reduced chi-square

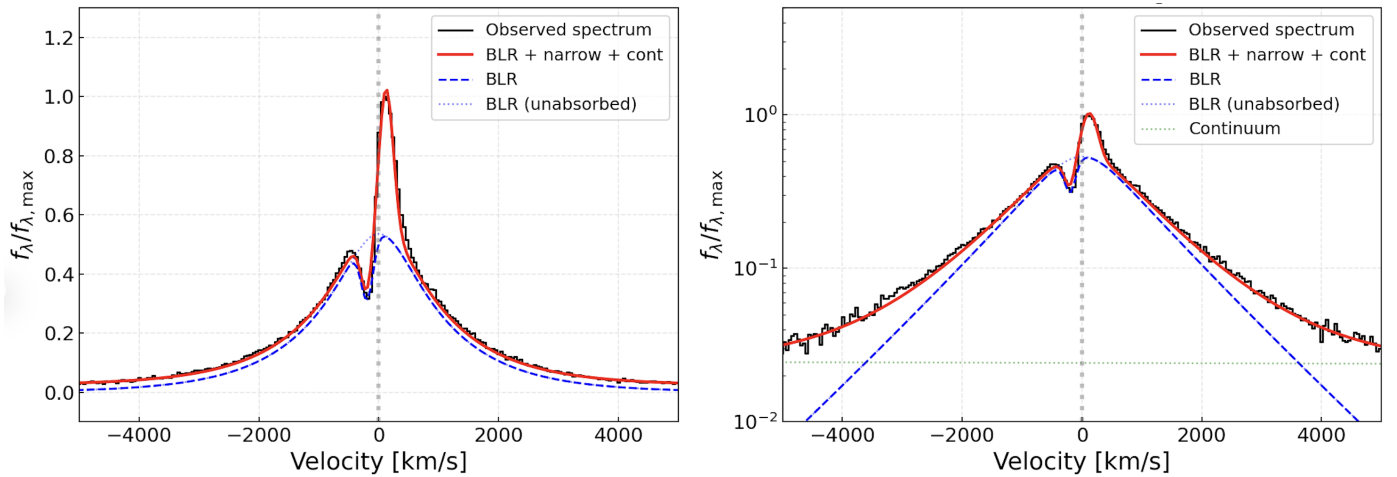


Fig. 3. Best-fit stratified-BLR model for the LRD GN-9771. Left: linear-scale view of the observed H α profile (black) and best-fit model (red), again fitting only the red wing of the line. The blue dashed curve shows the absorbed broad stratified BLR component and the blue dotted curve the corresponding unabsorbed BLR profile, illustrating the effect of the fixed absorption component adopted from the published decomposition. Right: the same comparison on a logarithmic scale, emphasizing the extended wings. The best fit is obtained for a reduced chi-square of $\chi^2/\text{dof} = 1.22$, with $\alpha = 2.75$ and $f_{\text{vir}} = 1.44$, adopting the same fiducial sublimation radius. As for GN-68797 and GS-13971, the model provides an excellent description of the broad, nearly exponential wings, indicating that a radially stratified BLR weighted toward large radii can account naturally for the observed line profile.

$\chi^2/\text{dof} = 1.07$, $\alpha = 2.75$, and $f_{\text{vir}} = 1.0$, while for GN-9771 we find $\chi^2/\text{dof} = 1.22$, $\alpha = 2.75$, and $f_{\text{vir}} = 1.44$. As in GN-68797, the model reproduces the extended, nearly exponential wings, and in both sources the preferred value of α is essentially the same as in the first LRD. This indicates that all three absorbed LRDs favor a BLR cloud distribution weighted toward large radii, near the dust sublimation scale, while the inner BLR still provides the highest-velocity tails through the virial scaling. In this sense, it is not surprising that the three AGNs converge to very similar radial slopes: despite differences in core structure and absorption, they show comparable broad H α morphologies and similarly extended wings, so the fits naturally select a similar balance between outer-BLR weighting and inner-BLR kinematic broadening.

4. Discussion and summary

So far we have focused on fitting the shape of the broad H α profile. If the BLR is flattened and its kinematics are dominated by ordered in-plane motion, then the large line widths inferred here are naturally suggestive of high observer inclinations, since the projected velocity field increases approximately as $\sin i_{\text{obs}}$ (e.g., Peterson et al. 2004; Pancoast et al. 2014; Netzer 2020). It is then natural to ask whether the same stratified-BLR framework, supplemented by representative choices for the BLR covering factor and angular thickness, can also account for the large observed H α EWs of the three LRDs. To this end, we evaluate the inclination dependence of the broad-line EW within the same model adopted for the profile fitting.

In our model, the BLR is described by an equatorially concentrated cloud distribution with covering factor $C_{\text{BLR}} = 0.1$ and angular thickness $\sigma_c = 0.17$. A global covering factor of $\simeq 0.1$ is consistent with standard estimates for low- z Type 1 AGNs (e.g., Peterson 2006; Pandey et al. 2023, see also Madau & Maiolino 2026). This angular thickness implies a geometrically flattened BLR, in which the

probability of intercepting clouds increases strongly toward the equatorial plane. The broad-line profile is produced by a radially stratified distribution of virialized clouds, while the observed EW depends on the inclination-dependent continuum against which the line is seen. We compute $\text{EW}(i_{\text{obs}})$ using the formalism of Madau & Maiolino (2026), in which the broad-line and nebular continuum emission are treated as isotropic, while the direct and transmitted optical continuum increases toward lower observer inclinations. Because the direct continuum is progressively suppressed toward high inclinations, the model naturally predicts larger H α EWs for more edge-on sightlines (Madau 2026; Madau & Maiolino 2026).

This trend is borne out by the calculations. Table 1 shows the predicted broad, narrow, and total H α equivalent widths for a representative set of observer inclinations. For all three LRDs, the total EW increases steeply toward equatorial sightlines, reaching values comparable to those observed only for $i_{\text{obs}} \gtrsim 75^\circ$. This provides an independent consistency check on the high-inclination interpretation suggested by the profile fitting and by the red continua of these sources. For the best-fit value $\alpha = 2.75$, the broad H α EW rises from only $\sim 190 \text{ \AA}$ for nearly polar sightlines to $\sim 700 \text{ \AA}$ at 75° and $\sim 1700 \text{ \AA}$ at 85° . The observed total EWs of the three LRDs therefore fall naturally within the range expected for highly inclined observers. At fixed angular thickness, the predicted EW increases with BLR covering factor, so somewhat lower inclinations could in principle reproduce the observed values if C_{BLR} were larger than the representative value adopted here. Nevertheless, for a modest covering factor and a strongly equatorial angular distribution, the observed H α EWs are naturally matched only at high inclinations, consistent with the interpretation suggested independently by the red continua and absorption features.

The profile fitting leads to a similarly coherent picture. All three LRDs are well reproduced with the same radial slope, $\alpha = 2.75$, indicating that the cloud distribution

Table 1. Predicted broad, narrow, and total H α equivalent widths as a function of observer inclination for the three LRDs, adopting the best-fit radial slope $\alpha = 2.75$, a BLR covering factor $C_{\text{BLR}} = 0.1$, and an angular thickness $\sigma_c = 0.17$. The narrow-to-broad H α flux ratios are fixed to the values inferred from the line-profile decompositions. Boldface highlights representative high-inclination solutions whose total EWs are closest to the observed values. Because the same C_{BLR} , σ_c , α , and fiducial central engine are adopted for all three sources, the predicted broad H α EW depends only on observer inclination and is therefore identical across the three columns; the source-to-source differences in total EW arise solely from the different adopted narrow-to-broad flux ratios.

i_{obs}	GN-68797			GS-13971			GN-9771		
	EW _{BLR} (Å)	EW _{NLR} (Å)	EW _{tot} (Å)	EW _{BLR} (Å)	EW _{NLR} (Å)	EW _{tot} (Å)	EW _{BLR} (Å)	EW _{NLR} (Å)	EW _{tot} (Å)
30°	186	50	236	186	43	229	186	6	193
50°	268	72	340	268	62	330	268	9	277
70°	534	143	676	534	123	656	534	18	551
75°	708	189	897	708	163	871	708	24	732
80°	1022	273	1295	1022	235	1257	1022	34	1056
85°	1718	459	2176	1718	394	2112	1718	57	1775
Observed		1306			894			1713	

is weighted toward the outer BLR, near the sublimation scale, while the inner BLR still supplies the highest-velocity tails through the virial scaling $v_{\text{vir}} \propto r^{-1/2}$. Although α is in principle partially degenerate with the adopted fiducial black-hole mass,² in practice the three LRDs all converge to the same best-fit value, $\alpha \simeq 2.75$, whereas the source-to-source differences are captured mainly by f_{vir} . This suggests that the preferred radial stratification is a stable feature of the fits. The fitted values of the effective virial parameter provide an additional consistency check. For GN-68797 and GN-9771 we obtain $f_{\text{vir}} = 1.35$ and $f_{\text{vir}} = 1.44$, respectively, while for GS-13971 we find $f_{\text{vir}} \simeq 1$. Thus, in one source the fiducial virial scaling is already sufficient, whereas in the other two a modest upward correction is required, plausibly reflecting a combination of geometry, kinematics, and the fact that the true black-hole mass may exceed the reference value adopted in the model.

Our results therefore support the following picture. A BLR with moderate covering factor, strong equatorial concentration, and radial stratification can simultaneously account for three otherwise puzzling features of LRDs: very large Balmer equivalent widths, broad exponential wings, and absorption-distorted cores. Within this framework, the large H α EWs do not require unusually large covering factors, but follow naturally from super-Eddington SEDs that provide a higher ionizing-to-optical photon budget than standard quasar composites, thereby boosting the intrinsic line-to-continuum ratio. Likewise, the broad wings need not be attributed primarily to Thomson scattering, but emerge from the radial superposition of virialized clouds. This does not exclude a minor contribution from electron scattering – which may well operate in the dense inner regions of these systems – but rather shows that it is not required as the dominant mechanism shaping the wings.

The blueshifted absorption troughs detected in all three LRDs are consistent with a P-Cygni interpretation, in which the absorbing gas has a net outflow component along the observer’s line of sight. In super-Eddington accretion flows, radiatively driven material launched from the disc surface (e.g., Murray et al. 1995; Proga & Kallman 2004)

could naturally produce such blueshifted absorption. The absorber must lie at radii comparable to or larger than the BLR, since it imprints on the broad H α profile rather than on the continuum alone. Because the densest wind streamlines are concentrated near the equatorial plane, they are preferentially intercepted by high-inclination LRD sightlines, whereas lower-inclination LBD sightlines cross a much smaller absorbing column, naturally accounting for the much weaker incidence of Balmer absorption in LBDs.

Although our stratified-BLR model does not by itself predict a one-to-one relation between Balmer-break strength and exponential-wing prominence (Matthee et al. 2026), a qualitative connection is natural: if stronger Balmer breaks trace a larger column of dense circumnuclear gas, they may also correspond to a larger effective BLR covering factor and/or a larger mass of BLR clouds along equatorial sightlines. The resulting increase in the number of virialized kinematic components contributing to the integrated profile would enhance the prominence of the nearly exponential wings. This qualitative connection should, however, be viewed in the context of the current observational uncertainty, since the relation between stronger Balmer breaks and more prominent exponential wings reported by Matthee et al. (2026) was not confirmed by Scholtz et al. (2026). The three LRDs studied here are consistent with a picture in which stratified BLRs viewed at high inclination can account for both the broad exponential wings and the large Balmer equivalent widths, providing a simple and physically plausible explanation for at least part of the LRD phenomenon.

References

- Akins, H. B., Casey, C. M., Lambrides, E., et al. 2025, ApJ, 991, 37
- Barro, G., Pérez-González, P. G., Kocevski, D. D., et al. 2026, ApJ, 997, 48
- Barvainis, R. 1987, Astrophysical Journal, 320, 537
- Brazzini, M., D’Eugenio, F., Maiolino, R., et al. 2026, arXiv e-prints, arXiv:2601.22214
- Chatzikos, M., Bianchi, S., Camilloni, F., et al. 2023, Rev. Mexicana Astron. Astrofis., 59, 327
- Delvecchio, I., Daddi, E., Magnelli, B., et al. 2025, A&A, 704, A313

² For a larger adopted M_{BH} , the virial velocities increase at all radii, which could be partially compensated by a larger α that shifts more weight toward the lower-velocity outer BLR; conversely, a smaller M_{BH} would favor a flatter radial distribution.

- Goad, M. R., Korista, K. T., & Ruff, A. J. 2012, *MNRAS*, 426, 3086
- Greene, J. E., Labbe, I., Goulding, A. D., et al. 2024, *ApJ*, 964, 39
- Grier, C. J., Trump, J. R., Shen, Y., et al. 2017, *ApJ*, 851, 21
- Hainline, K. N., Maiolino, R., Juodžbalis, I., et al. 2025, *ApJ*, 979, 138
- Harikane, Y., Zhang, Y., Nakajima, K., et al. 2023, *ApJ*, 959, 39
- Hviding, R. E., de Graaff, A., Miller, T. B., et al. 2025, *A&A*, 702, A57
- Juodžbalis, I., Maiolino, R., Baker, W. M., et al. 2026, *MNRAS*, 546, stag086
- Kido, D., Ioka, K., Hotokezaka, K., Inayoshi, K., & Irwin, C. M. 2025, *MNRAS*, 544, 3407
- Kocevski, D. D., Finkelstein, S. L., Barro, G., et al. 2025, *ApJ*, 986, 126
- Kollatschny, W. & Zetzl, M. 2013, *A&A*, 549, A100
- Lambrides, E., Garofali, K., Larson, R., et al. 2024, *arXiv e-prints*, arXiv:2409.13047
- Laor, A. 2006, *ApJ*, 643, 112
- Lupi, A., Trinca, A., Volonteri, M., Dotti, M., & Mazzucchelli, C. 2024, *A&A*, 689, A128
- Madau, P. 2026, *A&A*, 708, A116
- Madau, P. & Maiolino, R. 2026, *arXiv e-prints*, arXiv:2602.22386
- Maiolino, R., Risaliti, G., Signorini, M., et al. 2025, *MNRAS*, 538, 1921
- Maiolino, R., Scholtz, J., Curtis-Lake, E., et al. 2024, *A&A*, 691, A145
- Matthee, J., Naidu, R. P., Brammer, G., et al. 2024, *ApJ*, 963, 129
- Matthee, J., Torralba, A., Pezzulli, G., et al. 2026, *arXiv e-prints*, arXiv:2603.17667
- Murray, N., Chiang, J., Grossman, S. A., & Voit, G. M. 1995, *ApJ*, 451, 498
- Naidu, R. P., Matthee, J., Katz, H., et al. 2025, *arXiv e-prints*, arXiv:2503.16596
- Netzer, H. 2020, *MNRAS*, 494, 1611
- Netzer, H. & Laor, A. 1993, *ApJ*, 404, L51
- Pacucci, F., Ferrara, A., & Kocevski, D. D. 2026, *arXiv e-prints*, arXiv:2601.14368
- Pancoast, A., Brewer, B. J., & Treu, T. 2014, *MNRAS*, 445, 3055
- Pandey, A., Czerny, B., Panda, S., et al. 2023, *A&A*, 680, A102
- Peterson, B. M. 1993, *PASP*, 105, 247
- Peterson, B. M. 2006, in *Physics of Active Galactic Nuclei at all Scales*, ed. D. Alloin, Vol. 693, 77
- Peterson, B. M., Ferrarese, L., Gilbert, K. M., et al. 2004, *ApJ*, 613, 682
- Proga, D. & Kallman, T. R. 2004, *ApJ*, 616, 688
- Rusakov, V., Watson, D., Nikopoulos, G. P., et al. 2026, *Nature*, 649, 574
- Scholtz, J., D'Eugenio, F., Maiolino, R., et al. 2026, *arXiv e-prints*, arXiv:2603.22277
- Tang, M., Stark, D. P., Plat, A., et al. 2025, *ApJ*, 991, 217
- Taylor, A. J., Finkelstein, S. L., Kocevski, D. D., et al. 2025, *ApJ*, 986, 165
- Wang, B., de Graaff, A., Davies, R. L., et al. 2025, *ApJ*, 984, 121
- Wang, J.-M., Qiu, J., Du, P., & Ho, L. C. 2014, *ApJ*, 797, 65
- Zucchi, G., Ji, X., Madau, P., et al. 2026, *A&A*, 707, A52