Radiative filtering unifies broad-line phenomenology in active galactic nuclei

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Broad lines appear only when enough ionizing radiation survives the path from the central engine to the BLR. A rising intrinsic photon supply and a declining transmission naturally create a finite line-production window.

The physical idea

Broad emission lines (BELs) weaken or disappear at both ends of the accretion sequence: in low-luminosity AGNs/LINERs and in high-accretion weak-line quasars. These regimes are usually explained separately.

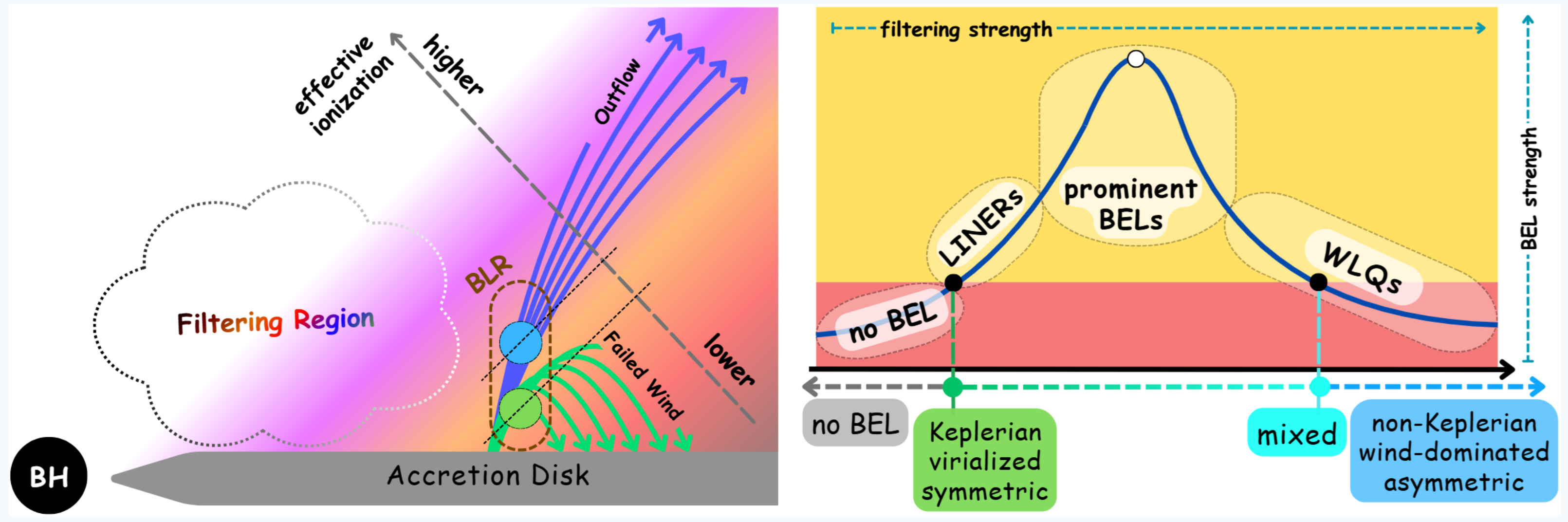
The relevant control variable is not the luminosity emitted by the central engine, but the ionizing field that reaches the broad-line region (BLR):

$$\Phi_{\rm eff} = \Phi_{\rm int}\,T_{\rm net}$$

$$\phi_{\rm BEL}\,T_{\rm net} \geq 1$$

At low accretion rate, intrinsic ionizing-photon production is insufficient. At high accretion rate, inner-disk structure and/or winds increasingly filter, redirect, or reprocess the ionizing continuum. The product therefore peaks at an intermediate state.

Unified phenomenology



The same transmission-regulated condition links no-BEL systems, LINERs, ordinary broad-line AGNs, and weak-line quasars. Filtering may also shift the dominant emitting region from virialized gas toward outflowing gas, changing line profiles and reverberation signatures.

Minimal quantitative realization

For Hβ, define the intrinsic photon-flux ratio

$$\phi_{\rm H\beta} = \frac{\Phi_{\rm H}}{\Phi_{\rm H\beta,min}}, \qquad \Phi_{\rm H\beta,min} \simeq 3\times10^{17}\,{\rm s^{-1}\,cm^{-2}}.$$

The thin-disk calculation is represented by

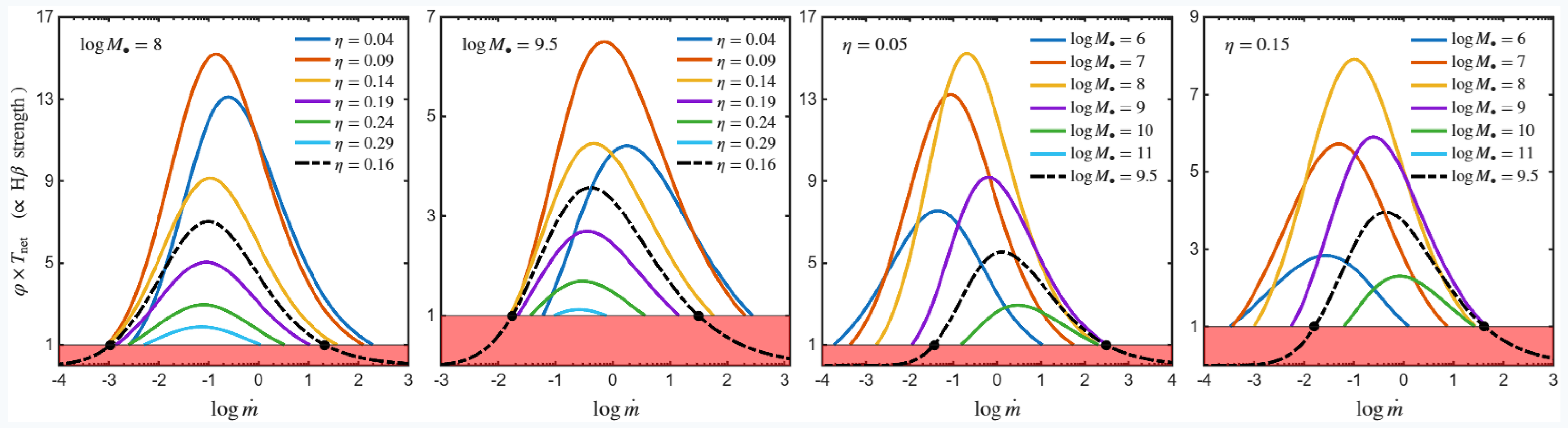
$$\phi_{\rm H\beta} \simeq 3.4\times10^{3}\,X^{1/5}\exp\!\left[-\frac{1}{160X^{3/4}}\right], \quad X = \eta^{1/2}\dot{m}^{0.3}M_\bullet^{-0.3}.$$

Filtering is described phenomenologically by bounded sigmoid transmission factors in $\dot{m}$, $M_\bullet$, and η:

$$T_{\rm net} = T(\dot{m})\,T(M_\bullet)\,T(\eta).$$

The specific sigmoid form is illustrative; the finite window requires only sufficiently strong high-accretion suppression.

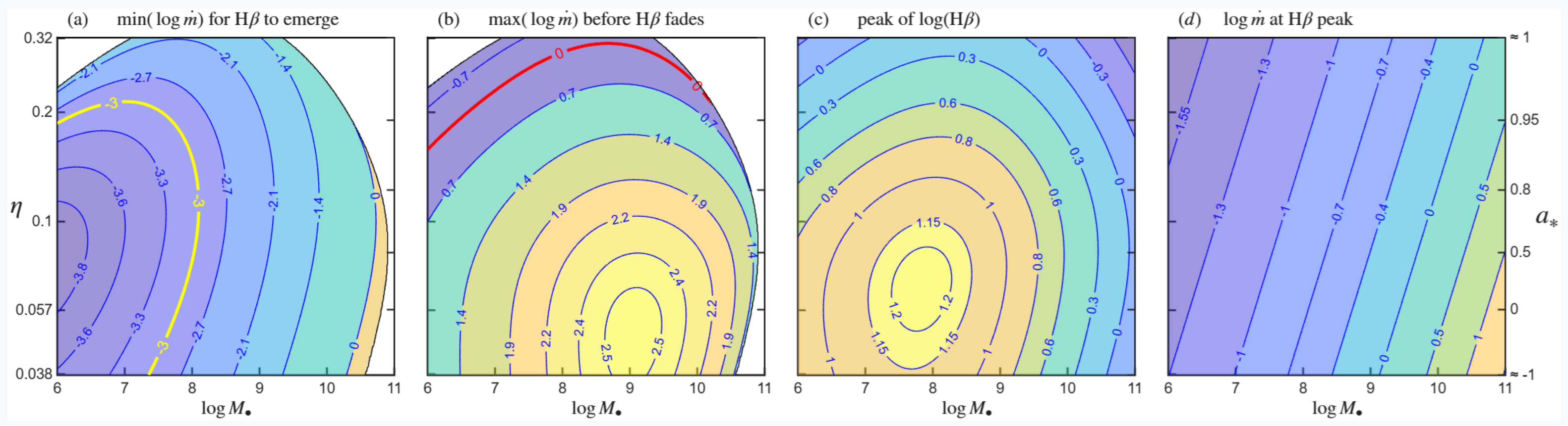
A finite Hβ production window



For fixed black-hole mass and radiative efficiency, the effective line-forming quantity $\phi_{\rm H\beta}T_{\rm net}$ rises, reaches a bounded maximum, and falls. The two threshold crossings define the lower and upper accretion-rate limits for observable broad Hβ.

Low $\dot{m}$: too few ionizing photons $\longleftrightarrow$ High $\dot{m}$: too little transmission

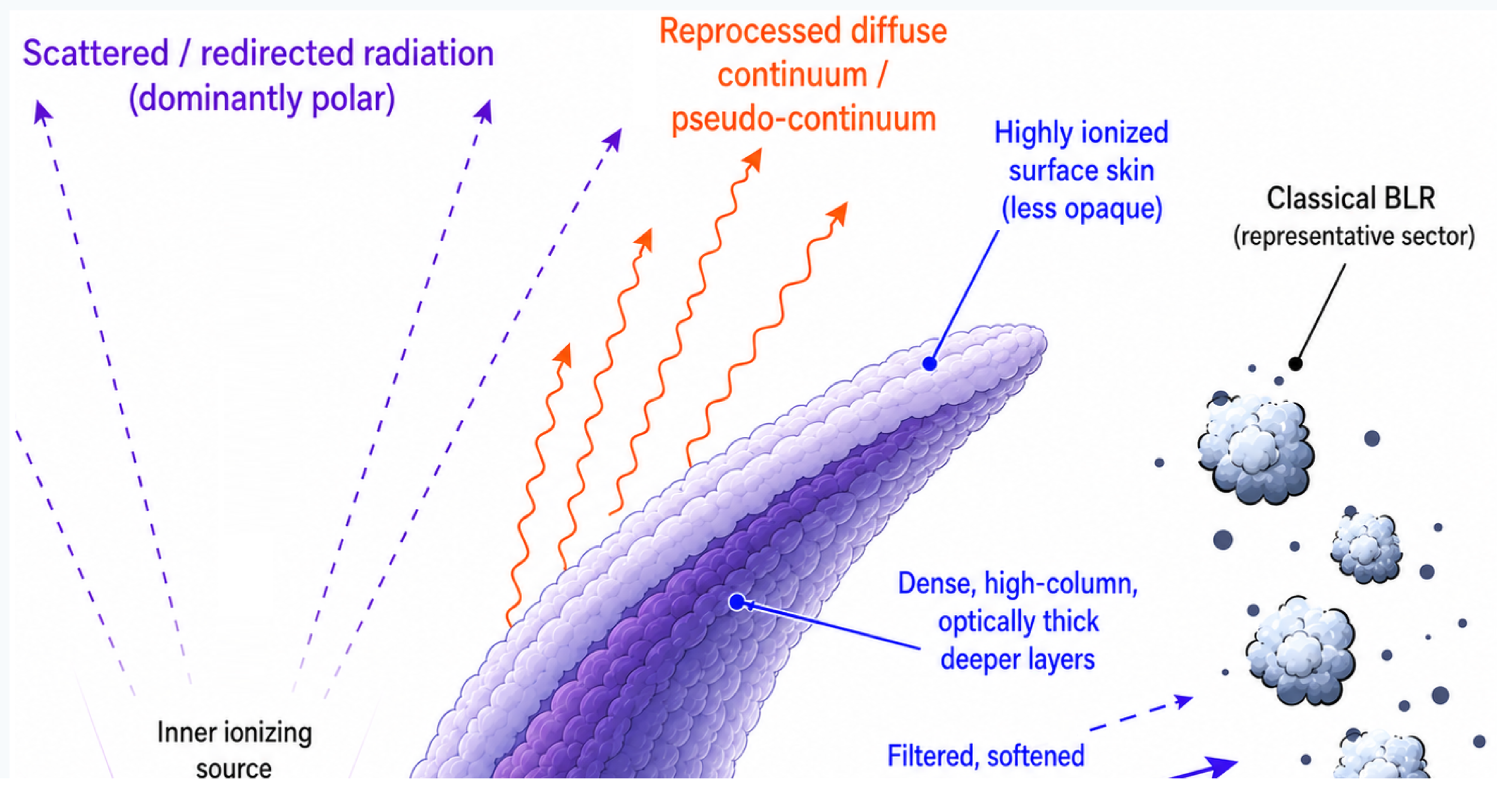
The boundary is not universal



Both the onset and disappearance of broad Hβ depend jointly on black-hole mass, accretion rate, and radiative efficiency. There is no single universal Eddington-ratio boundary separating BEL and non-BEL sources.

The maps show: (a) minimum $\log\dot{m}$ for Hβ emergence; (b) maximum $\log\dot{m}$ before fading; (c) peak line-forming strength; and (d) the accretion rate at that peak.

Possible filtering layer



What the framework explains

- **Weak-line populations:** LINERs and low-luminosity AGNs fail at the low-photon boundary; WLQs fail at the high-filtering boundary.
- **Ionization-dependent suppression:** high-ionization lines weaken before low-ionization lines as the transmitted SED softens.
- **Baldwin effect:** line flux grows more slowly than the observed continuum when transmission and ionizing-photon conversion decline.
- **$R_{\rm Fe}$ sequence:** progressive Hβ suppression can amplify the rise of optical Fe II/Hβ at high accretion rate.
- **BLR holidays and changing states:** time-variable filtering decouples the observed UV continuum from the continuum driving the BLR.
- **Scaling-relation breakdown:** observed luminosity ceases to trace the incident ionizing field, biasing radius-luminosity and virial relations.

Five falsifiable predictions

1. At fixed high $\lambda_{\rm Edd}$, BEL equivalent widths correlate more tightly with filtering diagnostics ($\Delta\alpha_{\rm ox}$, X-ray absorption, $N_{\rm H}$) than with optical/UV luminosity.
2. Highly accreting X-ray-weak sources lie below the canonical Hβ radius-luminosity relation.
3. High-ionization/low-ionization line ratios decline systematically with increasing filtering strength.
4. Stronger filtering accompanies enhanced high-ionization-line blueshift, asymmetry, and non-virial velocity-resolved response.
5. BEL detection fractions vary across the multidimensional $(\lambda_{\rm Edd}, M_\bullet, \eta)$ space rather than across a single critical $\lambda_{\rm Edd}$.

Take-home message

AGN broad-line phenomenology is globally regulated by the transmitted ionizing radiation field, not by intrinsic luminosity or the mere presence of BLR gas.

Main consequence: standard BLR observables and scaling relations should become unreliable whenever radiative filtering decouples the continuum seen by the observer from the continuum seen by the line-emitting gas.

Scan to contact

Acknowledgments and selected references

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