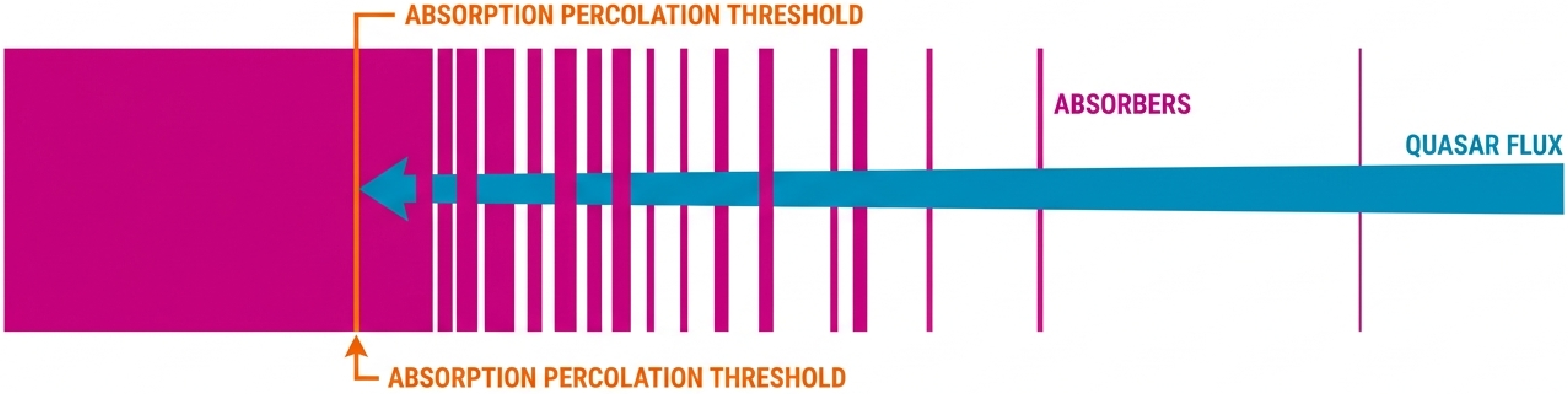
The Lyman-Alpha Forest and the Absorption Percolation Threshold



ABSTRACT

The abrupt rise in high-redshift Lyman-Alpha opacity—the Gunn-Peterson trough—is traditionally interpreted as a unique global reionization boundary marking the epoch when the intergalactic medium transitioned from neutral to ionized. This presentation introduces a robust physical alternative grounded in present-epoch physics: a smooth increase in line-of-sight absorber overlap naturally generates a sharply nonlinear collapse in transmitted flux.

We redefine the high-redshift opacity rise not as a uniquely identified global boundary in cosmic time, but as an **Absorption Percolation Threshold** in a dynamically active, structured absorber field.

NotebookLM

The Optical Threshold

Disentangling Observation from Historical Inference

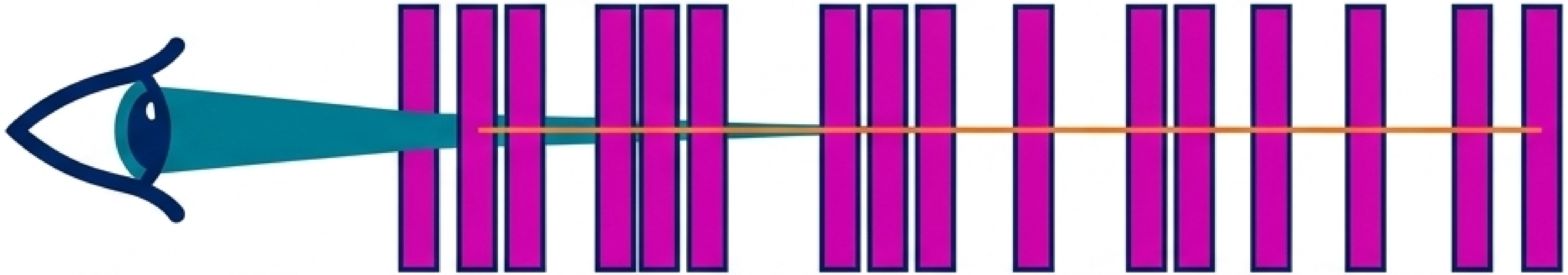
What is Directly Measured	What is Not Directly Measured
Absorption lines	Global neutral fraction of the diffuse intergalactic medium
Flux suppression	Reionization completion redshift
Damping-wing-like red-side attenuation along specific sightlines	Unique universal historical boundaries

A spectrum ordered in nominal redsift is not, by itself, an irrefutable timeline of cosmic age. The high-redshift Lyman-Alpha data directly establish is a sharp increase in line-of-sight opacity and extended near-zero transmission segments. However, the conversion of an opacity rise into a universal historical sequence is contingent upon prior cosmological framing, radiative-transfer assumptions, and continuum reconstruction. The absorption is a physical reality; the global cosmic-time boundary is a secondary interpretation imposed upon the data.

NotebookLM

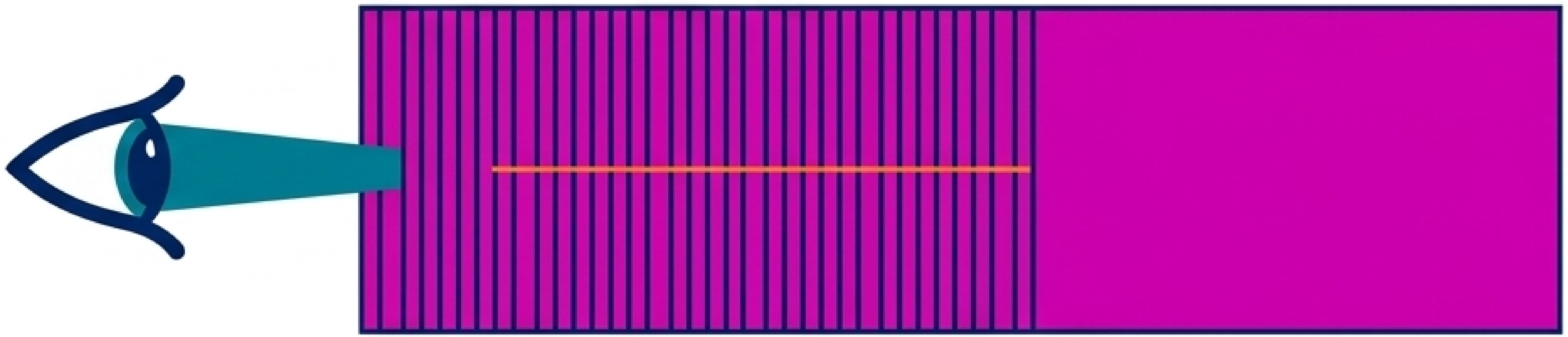
The Optical Threshold
The Gunn-Peterson Trough as an Optical Limit

Short Line of Sight (Sparse Absorbers)



In a vast, sparsely wooded jungle, an observer initially sees through the gaps and knows the forest continues.

Long Line of Sight (Dense Absorbers)



Beyond a critical distance, the accumulated trunks and foliage overlap, closing the visual gaps and creating a solid wall. The observer can no longer see farther, even though the forest has not ended.

In a structured cosmic absorber field, line-of-sight visibility collapses sharply once enough absorbers accumulate. An abrupt loss of visibility beyond a threshold distance does not prove that the universe itself changes ontological state at that exact location.

NotebookLM

The Optical Threshold

Mechanics of the Absorption Percolation Threshold

$$C = \underbrace{\lambda}_{\text{Absorber encounter rate per unit velocity}} \times \overbrace{\underbrace{w_{eff}}_{\text{Characteristic width of a typical system}}}^{\text{Effective covering factor in velocity space}}$$

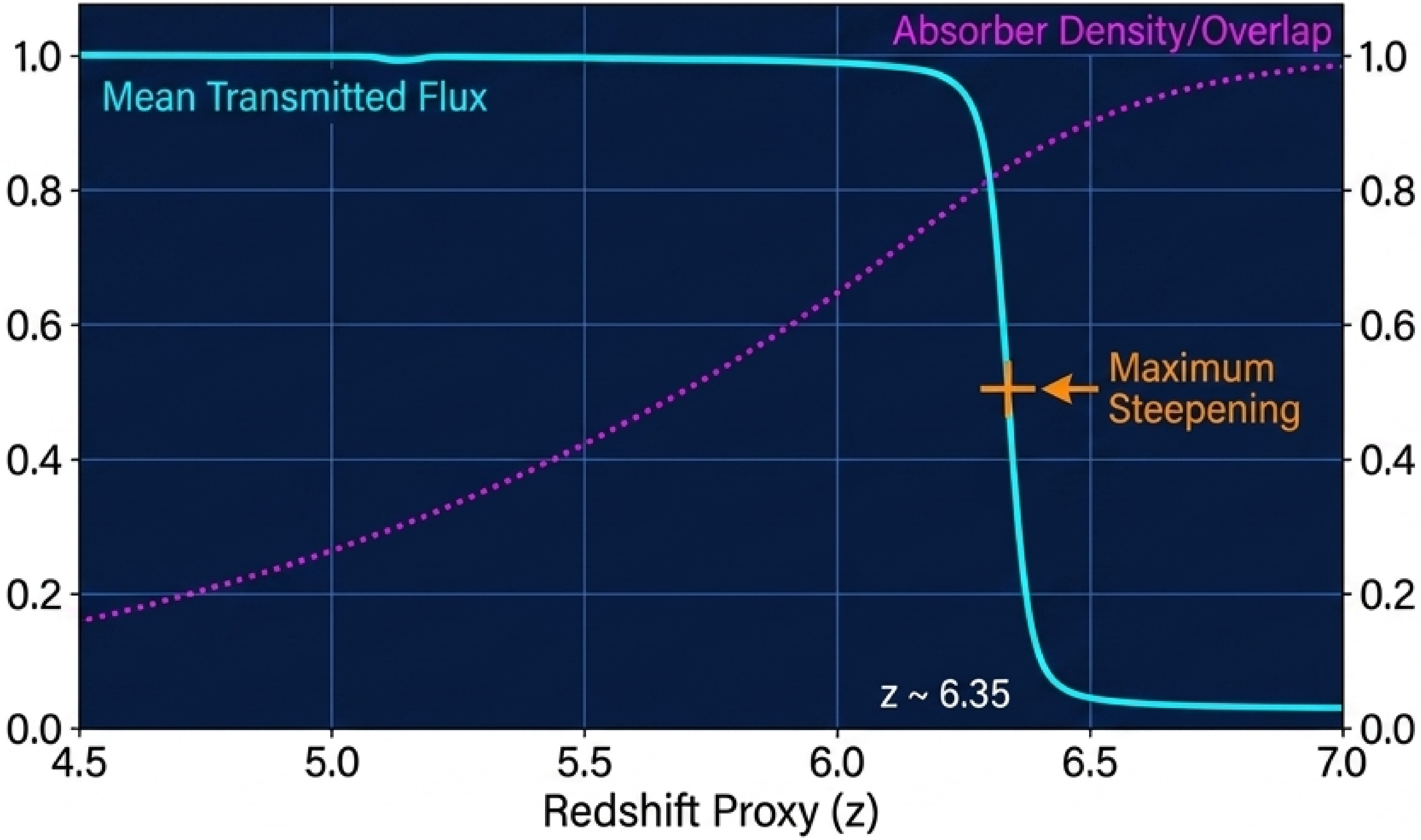
The Absorption Percolation Threshold (APT) mechanism is conceptually distinct from a cosmic reionization boundary. It evaluates line-of-sight coverage in velocity space. As a sightline probes deeper into the structured cosmic web, the absorber encounter rate and characteristic absorption width gradually increase.

When the product of these factors—the effective covering factor in velocity space—crosses order unity, the overlap of partially saturated absorbers causes persistent transmission gaps to vanish. The resulting nonlinear collapse in transmitted flux produces an extended near-trough regime, independent of any global epochal phase change.

NotebookLM

The Optical Threshold

Smooth Absorber Gradients Produce Sharply Nonlinear Flux Collapse



A direct numerical simulation placed 200 absorber components along a sightline with smoothly scaling depth and width. No discontinuities or epoch boundaries were inserted.

Despite the smooth underlying gradient, the transmitted flux collapsed nonlinearly from 1.000 at low-z to 0.042 at high-z. Both the $F < 0.20$ and $F < 0.10$ thresholds were crossed within the same transition bin centered near $z \sim 6.35$.

The maximum steepening in effective optical depth reached 15.3 per unit redshift, with the analytic covering-factor proxy rising to $C \sim 11.8$.

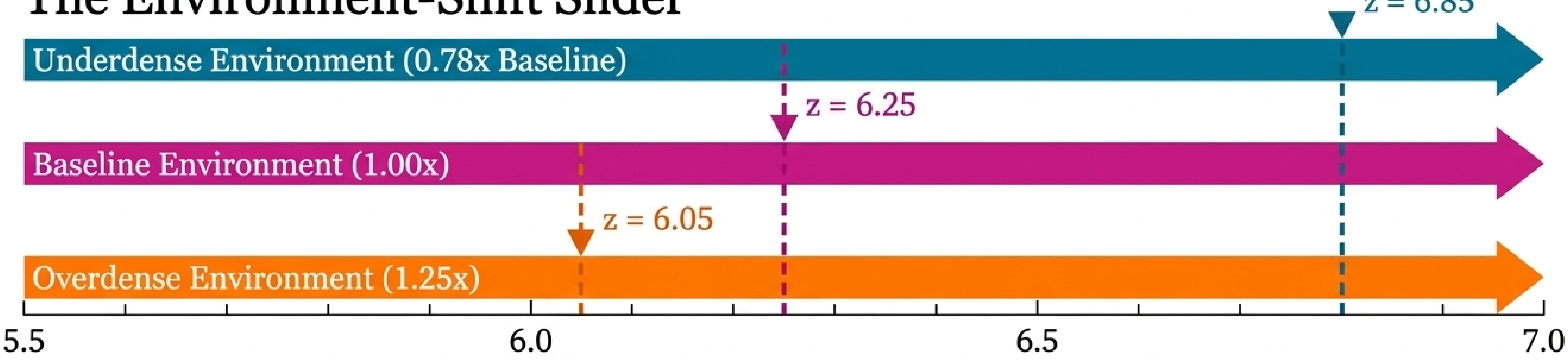
A continuous gradient perfectly mirrors the canonical Gunn-Peterson onset.

NotebookLM

The Optical Threshold

Environment Dependence of the Apparent Onset Redshift

The Environment-Shift Slider



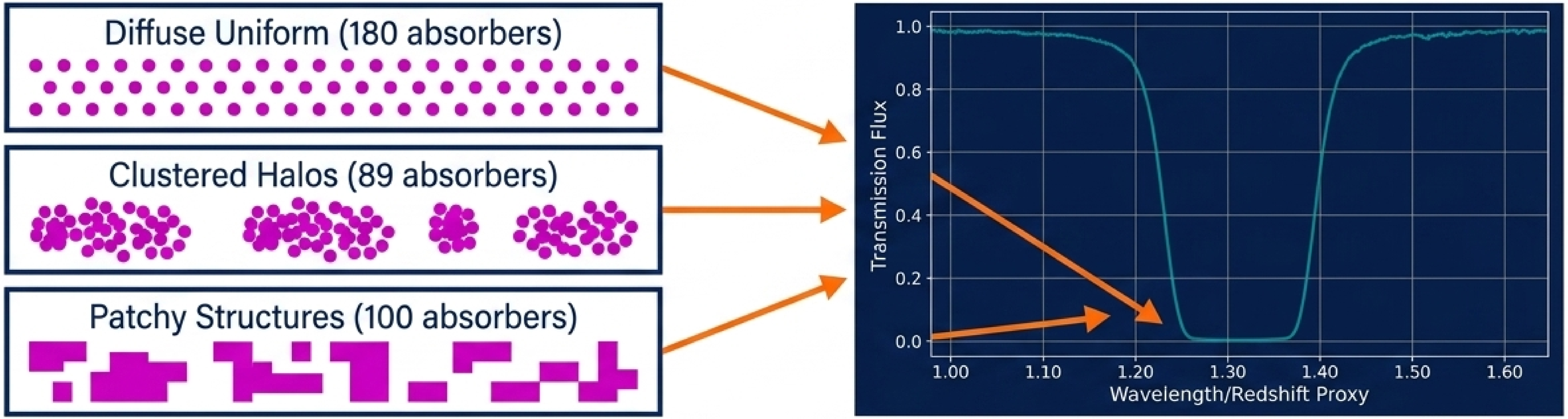
If the high-redshift opacity rise marks a global time epoch, the onset should be universally fixed. The APT mechanism, however, dictates that the threshold is environment-sensitive. Simulations demonstrate that modest line-of-sight absorber density changes (0.78x, 1.00x, and 1.25x the baseline) shift the apparent onset redshift across a span of ~ 0.9 in z. Dense regions reach the threshold earlier at lower redshift, while voids reach it later at higher redshift. The sightline-to-sightline variance observed in quasar data is not patchy reionization, but the exact mathematical signature of a percolation threshold operating in a heterogeneous heterogeneous cosmic web.

NotebookLM

The Optical Threshold

Interpretive Non-Uniqueness of the Strong-Suppresiion Spectral Class

The Trough Non-Uniqueness Matrix

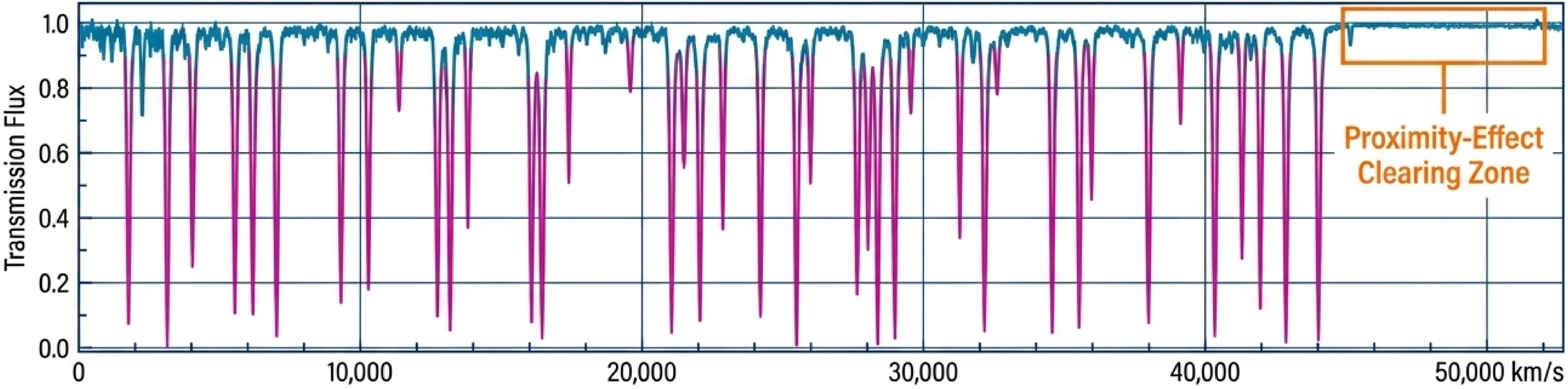


A strongly dark Lyman-Alpha transmission regime is a robust observational reality, but it is fundamentally non-unique. It cannot definitively diagnose a single physical absorber ontology. Simulations confirm that diffuse uniform environments, clustered discrete systems, and patchy architectural coverage all generate nearly identical strong-suppression classes—each yielding a mean transmitted flux of ~ 0.100 and an effective optical depth of ~ 2.305 (within 0.3% of one another). The existence of a dark trough does not mathematically or physically compel the standard historical ontology.

NotebookLM

The Optical Threshold

Generating the Forest Without Metric Expansion



The redshift ordering of the Lyman-Alpha forest does not necessitate an expanding metric coordinate system. A sightline simply passes through the **kinematically organized domains of a living cosmic web**—filaments, nodes, and voids.

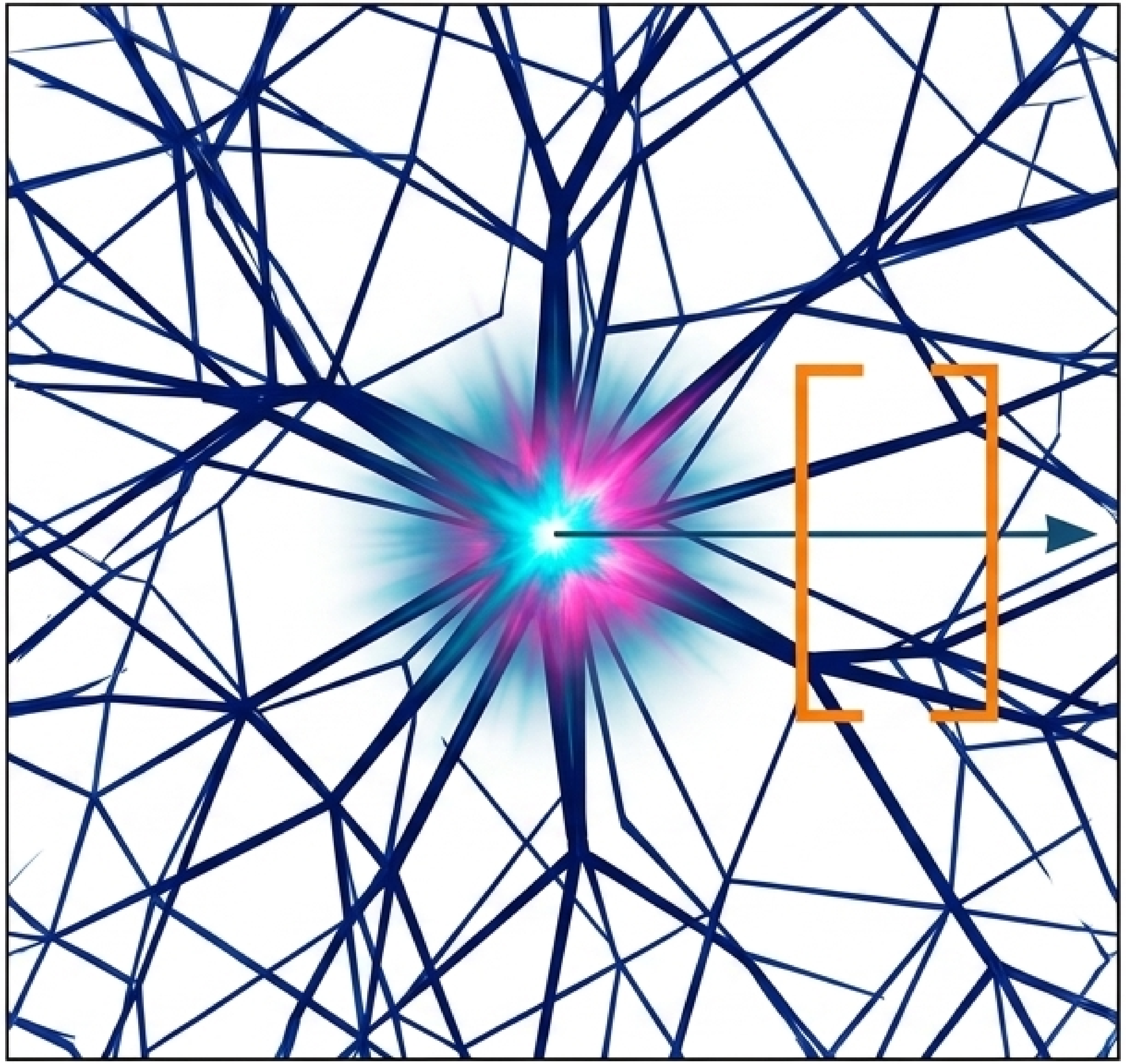
By populating a non-expanding velocity-structured sightline with varied weak and strong absorbers, a multi-line absorption hierarchy naturally emerges. This purely kinematic model accurately reproduces feature depths, inter-line spacings, and source-proximity clearings, yielding a mean transmitted flux of 0.965 and an effective optical depth of 0.036 in the forest regime.

NotebookLM

Reinterpreting the High-Redshift Opacity Rise

The observational data is uncontested: the hydrogen is real, the absorption lines are real, and the high-z opacity rise is real. However, a sudden observational boundary is an optical illusion of physical overlap, not a temporal phase change of reality.

By treating the Gunn-Peterson trough as an Absorption Percolation Threshold, the high-redshift opacity rise is most naturally read as a visibility limit in a dynamically active absorber This framework renders the highest-redshift quasar observations fully compatible with a non-expanding, infinite-age universe governed entirely by present-epoch physics.



NotebookLM