Observer-Centred Effective-Index Propagation for Recursive Survival Geometry

The optically inverted vacuum layer as a conditional bridge model

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Observer-centred effective-index revision

Abstract

This note formulates a conditional optical layer that can be read alongside Recursive Survival Geometry (RSG), Surtea-Austin recursive topology, and related layered informational models. The observer's past light cone is represented by one or more effective radial indices that increase with lookback radius. This is not a literal claim that the universe contains a privileged low-density central cavity surrounded by a high-density outer shell. Instead, the centre is the observer's reception event, and the outward increase in effective optical density is a readout of earlier, denser, more highly redshifted epochs. The redshift index $n_z(r) = 1 + z(r)$ is treated as a calibrated phase-period and energy-transformation readout, while any ray index $n_{\rm ray}(r)$ used for angular redistribution must be separately checked against metric observables. In the lossless limit this energy transformation is coupled to unitary periodicity: photon energy changes as the received frequency and period change, while the local measured speed of light remains c for every freely falling local observer.

Notation

Symbol	Meaning
O	Observer reception event; the operational centre of the observer's past light cone.
r	Observer-centred radial coordinate along the past light cone. Larger r means larger lookback distance, not a literal present-day radial shell.
R_u	Observable radius or horizon scale used in the original normalized plots.
$R_{\rm obs}$	Effective observational horizon or outer radius used to normalize toy optical profiles.
$n(r)$	Effective refractive index in the original optical-layer notation. In the revised reading this is identified with, or replaced by, $n_{\rm eff}(r)$.
$v(r)$	Coordinate light speed in the original notation, $v(r) = c/n(r)$.
t_0	Cosmic time at observation.
$t_{\rm em}$	Cosmic time at emission.
z	Cosmological redshift.
$a(t)$	FLRW scale factor.
χ	Comoving radial coordinate in the FLRW metric.
$S_k(\chi)$	Curvature-dependent FLRW angular-distance function.
$H(z)$	Hubble expansion rate as a function of redshift.
H_0	Present-day Hubble constant.
q_0	Present-day deceleration parameter.
$\Omega_m, \Omega_r, \Omega_\Lambda, \Omega_k$	Matter, radiation, dark-energy, and curvature density parameters.
$n_{\rm eff}(r)$	Generic observer-centred effective refractive index; an optical readout of curved-space propagation, not a material index of an ether.
$n_z(r)$	Redshift or phase-period index, calibrated in the baseline model by $n_z(r) = 1 + z(r)$.
$n_{\rm ray}(r)$	Ray or angular-redistribution index used in the gradient-index ray equation; it need not equal $n_z(r)$ unless a metric calibration justifies that identification.
$n_{\rm GR}$	Weak-field gravitational optical index used for comparison with standard lensing by an isolated mass.
$v_{\rm coord}(r)$	Coordinate/effective light speed in the optical readout, $v_{\rm coord} = c/n_{\rm eff}(r)$. Local observers still measure c.
c	Locally measured speed of light in vacuum.
Φ	Weak-field gravitational potential.
k^μ	Photon wavevector.
u^μ	Four-velocity of an emitter or observer.
ω	Photon frequency measured by an observer, $\omega = -k_\mu u^\mu$.
$\mathcal{E}_\gamma$	Photon energy, related to frequency by $\mathcal{E}_\gamma = \hbar\omega$.
$\mathcal{T}$	Wave period or recurrence interval, $\mathcal{T} = 2\pi/\omega$ in angular-frequency convention.

Symbol	Meaning
$\mathcal{U}$	Unitary phase-transport operator in the lossless periodic limit.
ϵ_0, μ_0	Vacuum permittivity and permeability.
$\epsilon(r), \mu(r)$	Effective optical bookkeeping parameters, often written $\epsilon_0 n_{\text{eff}}(r)$ and $\mu_0 n_{\text{eff}}(r)$.
$\epsilon_{\text{eff}}, \mu_{\text{eff}}$	Effective permittivity and permeability in the optical-medium notation.
Z, Z_0, Z_{eff}	Impedance, vacuum impedance, and effective impedance. With $\epsilon = \epsilon_0 n_{\text{eff}}$ and $\mu = \mu_0 n_{\text{eff}}$, $Z = Z_0$.
Y, Y_{eff}	Admittance and effective admittance. Since Z remains constant, Y remains constant.
E, B, H	Electric field, magnetic flux density, and magnetic field intensity.
$u = T^{00}$	Electromagnetic energy density in the effective bookkeeping model.
$T^{\mu\nu}$	Stress-energy tensor.
$\mathbf{S}$	Poynting vector, $\mathbf{S} = \mathbf{E} \times \mathbf{H}$.
s	Ray arclength parameter in the gradient-index optical equation.
ψ	Angle between a ray direction and the radial direction.
b	Optical impact parameter, $b = n_{\text{eff}}(r) r \sin\psi$.
$\sigma_n = (X_n, \varphi_n, \mu_n, S_n)$	Structured recursive state in the RSG bridge notation: support, phase projection, measure data, and survival weight.
X_n	Topological support carried by a recursive state.
φ_n	Smooth transport or phase projection in which the radial optical profile is placed.
S_n, p_i	Survival weight and normalized observational representation weights for histories.
Ω^2	Admissible trajectory-shaping term in the broader framework.
ΓW	Survival and resolution filtering factor for the arriving light bundle.

Positioning Note

This draft should be read as a bridge model, not as a claim that RSG or Surtea-Austin topology proves the optical profile. The intended layering is editorial and comparative: Surtea topology supplies a language of support, closure, boundary, class, and interaction; RSG supplies recursive histories, survival weighting, and observational dominance; the present note supplies a smooth optical-medium interpretation for one possible continuum phase layer.

In the terminology of the companion RSG notes, the radial variable r is not placed directly on a bare topological support. It enters only after a smooth phase or transport fibre has been selected and the projected recursive sequence is approximated by a continuum profile.

Claim Status and Scope

The model is easiest to defend if its claims are kept in separate layers:

Layer	Status	Role in this note
FLRW redshift and null propagation	Standard metric physics	Provides the calibration target: $1 + z = a(t_0)/a(t_{\mathrm{em}})$ and $r(z) = c\int_0^z H^{-1}(z')\,\mathrm{d}z'$ in a flat reference model.
Redshift index $n_z(r)$	Optical gauge choice	Encodes phase-period dilation and photon energy transformation by the baseline choice $n_z(r) = 1 + z(r)$.
Ray index $n_{\mathrm{ray}}(r)$	Conditional angular model	May be used in a gradient-index ray equation only after checking that it reproduces, approximates, or usefully re-expresses the corresponding metric distance and lensing observables.
RSG/Surtea bridge	Conditional correspondence	Places n_z and n_{ray} on a smooth projected phase fibre over recursive histories; it does not put differential equations directly on bare topological supports.
Effective electromagnetic parameters	Bookkeeping layer	Uses ϵ_{eff} and μ_{eff} as impedance-matched optical parameters, not as evidence that local vacuum constants vary.
Empirical status	Open test programme	Requires constrained profiles, numerical ray integration, distance-duality checks, and high-redshift maturation diagnostics before the optical layer can be treated as more than a bridge model.

Discrete and Continuous Time

We do not choose between recursive/discrete time and differential/continuous time as competing foundations. The primitive object is a discrete recursive history of structured states. Continuous time appears only after selecting a smooth transport or phase fibre and taking a continuum approximation of the projected sequence. Thus equations such as

$$\frac{\mathrm{d}\Theta}{\mathrm{d}t} = \Pi, \tag{0.1}$$

$$\frac{\mathrm{d}\Pi}{\mathrm{d}t} = -\Omega^2\Theta, \tag{0.2}$$

or the optical ray equations used below are effective continuum descriptions of a projected recursive layer, not primitive laws on the bare Surtea-topological support.

Editorial Position of the Model

The strong central idea is to treat gravitational and cosmological light propagation as an effective gradient-index optical problem. The safe interpretation is observer-centred: every observer sits at the centre of that observer's own observable horizon, and every observer may construct a radial optical description of the light arriving on that observer's past light cone.

The model therefore uses the word "centre" operationally, not cosmologically. The centre is the receiving observer. It is not an absolute centre of the universe. Likewise, the outward increase in effective optical density is not a claim that the present universe literally has a radial matter density gradient. It is a past-light-cone projection: distant light comes from earlier cosmic times, and earlier cosmic times were denser.

The phrase "optically inverted" is kept because it captures the core visual analogy. A standard isolated mass often behaves like a converging optical index profile, with the largest effective index near the mass. The observer-centred cosmological readout considered here can be represented with an effective index that rises with lookback radius. In that representation, non-radial incoming rays can show outward effective curvature, like a diverging gradient-index lens.

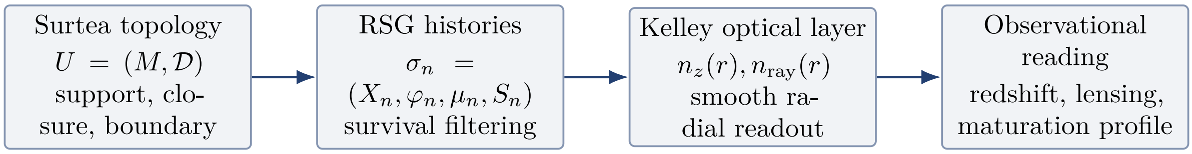
Interpretive Guardrails

Several distinctions are essential:

- The model is an effective optical representation, not a material ether theory.
- The radial coordinate labels the observer's past light cone, not a literal present-day shell structure.
- $n_{\text{eff}}(r)$ describes coordinate propagation, delay, angular redistribution, and redshift bookkeeping.
- In calibrated work, the redshift/period index $n_z(r)$ should be distinguished from any ray-bending index $n_{\text{ray}}(r)$.
- The local speed of light remains invariant and equal to c.
- The expression $v_{\text{coord}} = c/n_{\text{eff}}(r)$ is only a coordinate or effective speed in the chosen optical representation.
- Redshift must be derived from the metric, time component, or propagation relation, not asserted solely from the sign of a gradient in n.
- Photon energy transformation should be read through frequency and period transformation, $\mathcal{E}_\gamma = \hbar\omega$, not through a change in local light speed.
- Lossless phase-period transport is unitary. Survival filtering and attenuation belong to the separate non-unitary ΓW layer.
- If $\epsilon(r) = \epsilon_0 n(r)$ and $\mu(r) = \mu_0 n(r)$, then both impedance and admittance remain constant.

1 Layered Interpretation

The role of the inverted-vacuum profile is to give a possible optical reading of the smooth transport layer used by the broader RSG program. The underlying Surtea layer remains topological and discrete. The RSG layer generates histories and assigns persistence weights. Kelley's optical layer then asks what the light-like limit looks like if the continuum phase projection carries an observer-centred redshift index $n_z(r)$ and, where separately calibrated, a ray index $n_{\rm ray}(r)$ that increases toward the observer's horizon.



Continuum equations enter after selecting a smooth phase fibre; the optical profile is a conditional model of that projected transport layer.

Figure 1: Layered placement of the inverted-vacuum note within the surrounding work. The optical model is a conditional continuum layer placed over recursive histories, not a replacement for the underlying topological or survival-filtering framework.

2 Conceptual Picture

The universe is homogeneous and isotropic on very large scales, but the light received from greater distance was emitted at earlier cosmic times. Those earlier epochs were denser, hotter, and more strongly coupled to the expansion history of the universe. In an observer-centred optical description, this historical fact can be represented as an effective radial index:

$$n_{\rm eff} = n_{\rm eff}(r), \tag{2.1}$$

where r measures distance along the observer's past light cone.

The original intuitive picture may be stated as follows. The observed light field is optically inverted compared with the familiar picture of a star or planet. Around an isolated central mass, the optical analogy normally places the largest effective index near the centre, producing a converging lens. In the cosmological past-light-cone readout, the observer sits at the low-index receiving end of the light cone, while earlier and more distant emission surfaces may be assigned a larger effective optical index.

This creates a useful image:

$$\text{near observer} \quad \longrightarrow \quad \text{low effective optical density}, \tag{2.2}$$

$$\text{large lookback radius} \quad \longrightarrow \quad \text{high effective optical density}. \tag{2.3}$$

The important correction is that this is not a literal cavity-and-shell cosmology. It is an optical projection of the observer's received light history.

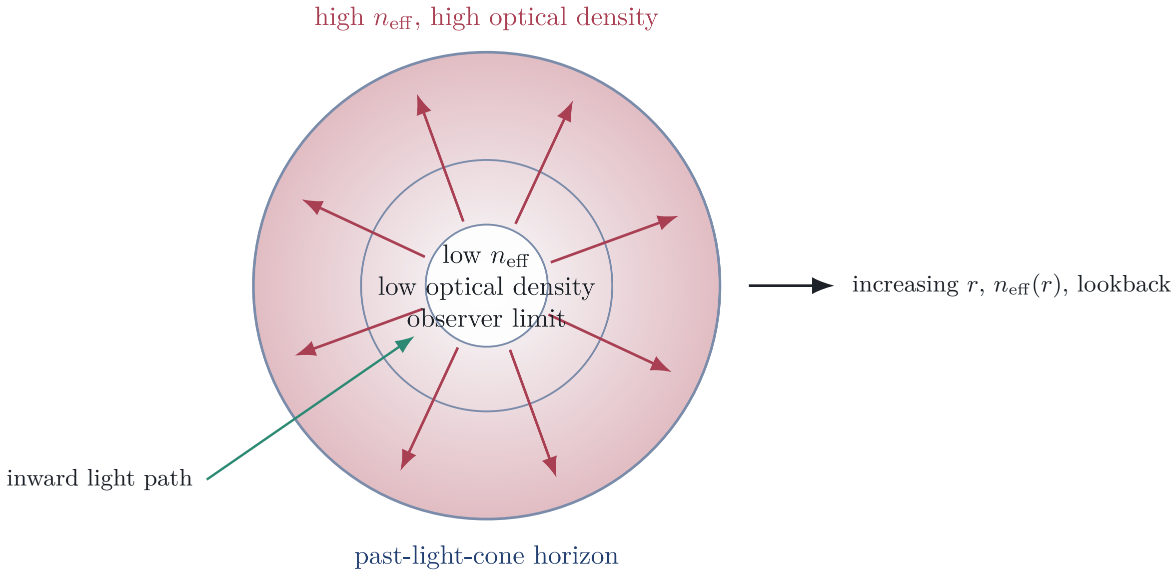


Figure 2: Conceptual cross-section of the optically inverted effective layer. The original cavity-and-shell image is retained as an optical diagram, but the centre is the observer's reception event and the outer shell represents large lookback radius rather than a privileged present-day cosmic wall.

3 Observer-Centred Past-Light-Cone Geometry

Every observer has an observable universe centred on that observer. The observable horizon is therefore observer-dependent. If an observer at event O receives light from a galaxy at redshift z, the relevant radial structure is not a present-time Euclidean sphere with the observer at a special cosmological centre. It is the past light cone of O.

On that past light cone, larger radial distance corresponds to earlier emission time:

$$r \uparrow \quad \Longleftrightarrow \quad t_{\text{em}} \downarrow, \tag{3.1}$$

and earlier emission time corresponds, in standard cosmology, to larger redshift:

$$t_{\text{em}} \downarrow \quad \Longleftrightarrow \quad z \uparrow . \tag{3.2}$$

Thus an outward-rising effective index can be interpreted as

$$r \uparrow \quad \Longleftrightarrow \quad z(r) \uparrow \quad \Longleftrightarrow \quad n_z(r) \uparrow . \tag{3.3}$$

4 Effective Indices and Coordinate Speed

The generic symbol n_{eff} is useful in conceptual diagrams, but calibrated work should distinguish two roles. The first is the redshift or phase-period index

$$n_z = n_z(r), \tag{4.1}$$

with $n_z(0) = 1$ at the observer by normalization. The second is a possible ray or angular-redistribution index

$$n_{\text{ray}} = n_{\text{ray}}(r), \tag{4.2}$$

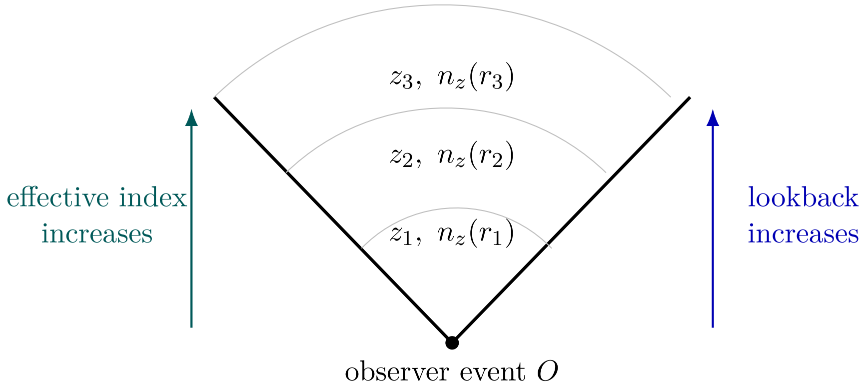


Figure 3: Observer-centred interpretation. The centre is the reception event, not a privileged cosmological cavity. Larger radius labels earlier emission events on the past light cone.

which may be inserted into a gradient-index ray equation only after it has been checked against metric lensing and distance observables.

If an index $n_{\rm eff}$ increases with lookback radius, then the corresponding effective coordinate speed is

$$v_{\rm coord}(r) = \frac{c}{n_{\rm eff}(r)}. \tag{4.3}$$

This equation should be read carefully. It is not a claim that a local laboratory at large redshift measures light to move slower than c. It is a coordinate statement about a chosen optical readout constructed by the receiving observer. In the baseline redshift calibration this readout is $n_{\rm eff} = n_z = 1 + z$; in ray diagrams it is safer to write $n_{\rm eff} = n_{\rm ray}$ until the angular optics have been calibrated.

As light is represented as moving inward from large lookback radius toward the observer, it moves from larger $n_{\rm eff}$ toward smaller $n_{\rm eff}$. In the optical coordinate description, the effective coordinate speed increases toward

$$v_{\rm coord}(0) = c. \tag{4.4}$$

This gives the intuitive statement that the light moves from an optically thicker region of the past-light-cone readout into an optically thinner region near the observer.

The original phrase "thin vacuum" may be retained as an analogy only if it is explicitly understood as optical density, not a literal mechanical substance. A safer wording is:

$$\text{the effective optical density decreases toward the observer.} \tag{4.5}$$

5 Retired Heuristic Optical Ansatz

The original draft used a Schwarzschild-inspired heuristic to motivate a radial optical profile,

$$n(r) = \frac{R}{r}\sqrt{B(R)}, \tag{5.1}$$

where $B(R)$ is the metric component related to time dilation. In the present bridge reading, this expression is retained only as historical motivation for the optical analogy. It is not the calibrated cosmological profile used below, not a final cosmological metric, and not evidence for a literal central cavity.

For the observable universe, with a notional radius R_u and mass M_u, the heuristic picture says that the effective index near the horizon reaches a maximum, similar to an optical lens with a graded thickness or density profile. A corresponding potential-like diagnostic may be written

$$\Phi(r) \propto r^2. \tag{5.2}$$

This is best treated as a toy continuum optical profile, not as a present-day radial mass distribution. Any physical use of the profile must be replaced by or calibrated against the metric observables in the next section.

The weak-field optical relation used for comparison is

$$n \approx 1 - \frac{2\Phi}{c^2}. \tag{5.3}$$

For an ordinary central mass, $\Phi < 0$ near the centre and n is largest near the centre. The inverted layer reverses the optical readout: n_{eff} is smallest at the observing event and rises with lookback radius.

6 Metric Calibration of the Redshift Index

The redshift index should be calibrated against the spacetime metric. In a homogeneous and isotropic cosmology, the FLRW line element is

$$\mathrm{d}s^2 = -c^2\,\mathrm{d}t^2 + a^2(t)\left[\mathrm{d}\chi^2 + S_k^2(\chi)\,\mathrm{d}\Omega^2\right]. \tag{6.1}$$

For radial null propagation,

$$\mathrm{d}s^2 = 0, \tag{6.2}$$

so

$$c\,\mathrm{d}t = a(t)\,\mathrm{d}\chi. \tag{6.3}$$

The cosmological redshift is

$$1 + z = \frac{a(t_0)}{a(t_{\text{em}})}. \tag{6.4}$$

Equivalently, in covariant form,

$$1 + z = \frac{(k_\mu u^\mu)_{\text{em}}}{(k_\mu u^\mu)_{\text{obs}}}, \tag{6.5}$$

where k^μ is the photon wavevector and u^μ is the four-velocity of the emitter or observer.

A simple optical readout is then

$$n_z(r) = 1 + z(r). \tag{6.6}$$

This identifies the redshift index with the accumulated cosmological time-dilation factor. It is not the only possible gauge choice, but it is a natural first worked profile because it ties the optical analogy directly to a standard observable.

This calibration does not by itself prove that the same scalar should be used as the ray index in every angular calculation. In a homogeneous FLRW geometry, redshift, distance, and angular-diameter behaviour are linked by the metric and by the optical Jacobi map. A gradient-index ray calculation should therefore be treated as a candidate representation of angular redistribution, not as an automatic consequence of $n_z(r) = 1 + z(r)$.

7 Energy Transformation and Unitary Periodicity

The energy transformation associated with redshift is most cleanly expressed through frequency and period. For a photon measured by an observer with four-velocity u^μ,

$$\omega = -k_\mu u^\mu, \qquad \mathcal{E}_\gamma = \hbar\omega. \tag{7.1}$$

The redshift relation gives

$$\frac{\omega_{\rm obs}}{\omega_{\rm em}} = \frac{\mathcal{E}_{\gamma,\rm obs}}{\mathcal{E}_{\gamma,\rm em}} = \frac{1}{1+z} = \frac{1}{n_z(r)}. \tag{7.2}$$

Equivalently, using the angular-frequency period

$$\mathcal{T} = \frac{2\pi}{\omega}, \tag{7.3}$$

one has

$$\frac{\mathcal{T}_{\rm obs}}{\mathcal{T}_{\rm em}} = 1+z = n_z(r). \tag{7.4}$$

Thus the optical index can be read as a period-dilation factor: photon energy decreases between emission and observation because the received phase cadence is slower, not because local light speed has changed.

In the lossless light-like limit, this transformation should be coupled to unitary periodicity. Let $\mathcal{H}(\tau)$ denote the local phase generator on the selected smooth phase fibre. The general lossless transport is the path-ordered unitary

$$\mathcal{U}(\tau_2,\tau_1) = \mathcal{P}\exp\left[-\frac{i}{\hbar}\int_{\tau_1}^{\tau_2}\mathcal{H}(\lambda)\,\mathrm{d}\lambda\right], \qquad \mathcal{U}^\dagger\mathcal{U} = I. \tag{7.5}$$

In a locally constant or adiabatic patch this reduces to the simpler exponential form $\exp(-i\mathcal{H}\tau/\hbar)$. If a component has period $\mathcal{T}$, its recurrence condition is

$$\mathcal{U}(\tau+\mathcal{T},\tau)\psi = \exp(i\alpha)\psi, \tag{7.6}$$

or, for a local energy eigencomponent in the adiabatic approximation,

$$\frac{\mathcal{E}_\gamma\mathcal{T}}{\hbar} = 2\pi m + \alpha, \qquad m\in\mathbb{Z}. \tag{7.7}$$

The product $\mathcal{E}_\gamma\mathcal{T}$ therefore expresses the same phase periodicity before and after redshift when the transport is lossless. In RSG language, this is the $\Gamma\to 0$ light-like limit: energy and period are re-expressed by the observer's phase readout, while survival weight is not attenuated by this unitary transformation.

8 One Worked Profile

For a spatially flat reference cosmology, the comoving distance to redshift z is

$$r(z) = c\int_0^z \frac{\mathrm{d}z'}{H(z')}, \tag{8.1}$$

where

$$H(z) = H_0\sqrt{\Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_\Lambda}. \tag{8.2}$$

If curvature is included, the additional term is

$$\Omega_k(1+z)^2. \tag{8.3}$$

The redshift-index profile is obtained by inverting $r(z)$ to find $z(r)$:

$$n_z(r) = 1 + z(r). \tag{8.4}$$

At low redshift, define

$$x = \frac{H_0 r}{c}. \tag{8.5}$$

The inverse distance-redshift expansion gives

$$z(r) = x + \frac{1+q_0}{2}x^2 + O(x^3), \tag{8.6}$$

where the present deceleration parameter is

$$q_0 = \frac{\Omega_m}{2} + \Omega_r - \Omega_\Lambda. \tag{8.7}$$

Thus

$$n_z(r) = 1 + \frac{H_0 r}{c} + \frac{1+q_0}{2}\left(\frac{H_0 r}{c}\right)^2 + O(r^3). \tag{8.8}$$

This is a defensible first profile because it follows from a standard cosmological distance-redshift relation.

For diagrammatic work, a toy profile is also useful:

$$n_{\text{ray}}^{\text{toy}}(r) = 1 + \eta\left(\frac{r}{R_{\text{obs}}}\right)^2, \qquad \eta > 0. \tag{8.9}$$

This toy profile is not proposed as a measured law. It is a simple analytic case that exposes the ray-bending consequence of an outward-rising ray index.

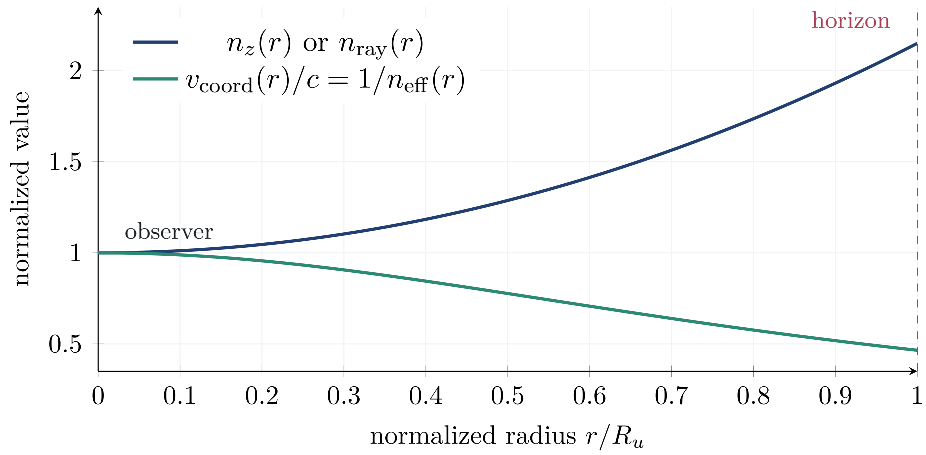


Figure 4: Normalized conceptual profile for the smooth phase layer. A redshift or ray index increases outward with lookback radius, while the coordinate speed $v_{\text{coord}} = c/n_{\text{eff}}$ decreases outward and increases inward in the chosen optical readout. Local measurements of light speed remain invariant.

9 Original Objective Light Path, Revised

The original objective light path can be preserved with corrected wording:

1. Because the effective refractive index $n_{\text{eff}}(r)$ is normalized to its minimum near the observer,

$$n_{\text{eff}}(0) = 1, \tag{9.1}$$

and increases with lookback radius, the coordinate speed

$$v_{\text{coord}}(r) = \frac{c}{n_{\text{eff}}(r)} \tag{9.2}$$

is highest at the observer. As light is represented as propagating inward from the past-light-cone periphery toward the observer, it moves from a higher-index optical region to a lower-index optical region.

This produces coordinate acceleration in the optical description, approaching

$$v_{\text{coord}}(0) = c. \tag{9.3}$$

The physical correction is that this is not a locally measured change in the speed of light. Any local inertial observer on the path measures c.

2. Standard weak-field gravitational lensing by a central mass is commonly represented as a converging lens. In the weak-field optical analogy,

$$n_{\text{GR}} \approx 1 - \frac{2\Phi}{c^2}, \tag{9.4}$$

and near an attractive mass $\Phi < 0$, so n_{GR} is larger near the mass. Rays bend toward larger n, producing convergence.

The observer-centred ray readout is inverted in the following narrower sense: if a calibrated ray index $n_{\text{ray}}(r)$ increases outward along the observer's past light cone, then

$$\nabla n_{\text{ray}} = \frac{\mathrm{d}n_{\text{ray}}}{\mathrm{d}r}\hat{\mathbf{r}}, \qquad \frac{\mathrm{d}n_{\text{ray}}}{\mathrm{d}r} > 0, \tag{9.5}$$

points outward. Non-radial rays are then curved outward in that effective gradient-index representation. This statement concerns n_{ray}, not the redshift index n_z by itself.

This should be described as outward effective ray curvature or diverging gradient-index behaviour, not immediately as a literal repulsive force.

3. The redshift statement must be metric-based. In general relativity, photon frequency is measured by

$$\omega = -k_\mu u^\mu. \tag{9.6}$$

The redshift between emission and observation is therefore

$$1 + z = \frac{\omega_{\text{em}}}{\omega_{\text{obs}}} = \frac{(k_\mu u^\mu)_{\text{em}}}{(k_\mu u^\mu)_{\text{obs}}}. \tag{9.7}$$

In FLRW cosmology this becomes

$$1 + z = \frac{a(t_0)}{a(t_{\text{em}})}. \tag{9.8}$$

Once this has been established, the optical model may encode it with

$$n_z(r) = 1 + z(r). \tag{9.9}$$

This is safer than saying that redshift follows only because light moves from higher n to lower n.

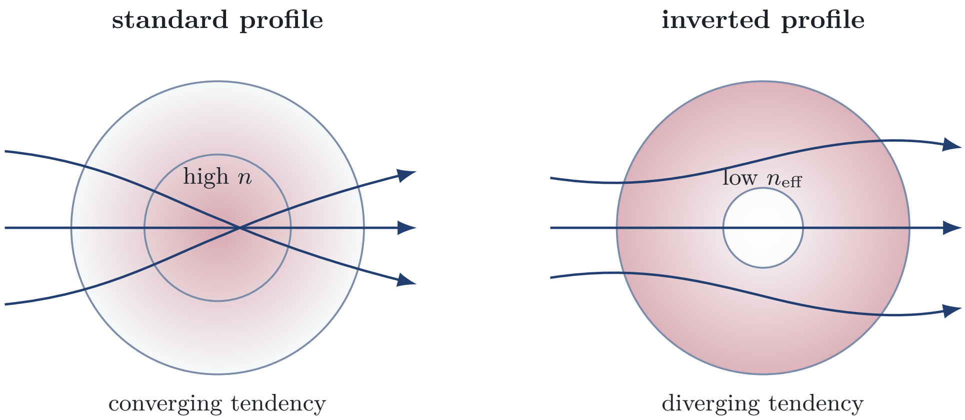


Figure 5: Comparison between a conventional centrally dense gravitational index profile and the proposed optically inverted profile. In the inverted case, off-axis rays tend to bend away from the low-index observer-centred region, giving a conditional optical mechanism for differential representation of light-like histories.

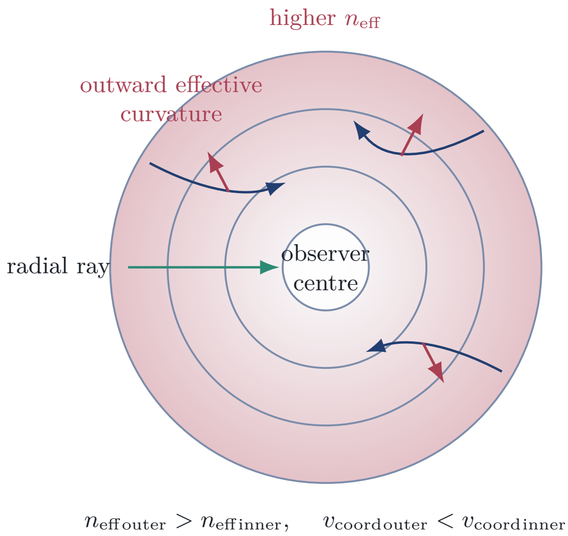


Figure 6: Objective light paths in the inverted index field. A radial ray can reach the observer, while off-axis rays experience a bending tendency toward the higher-index outer region in the effective optical readout.

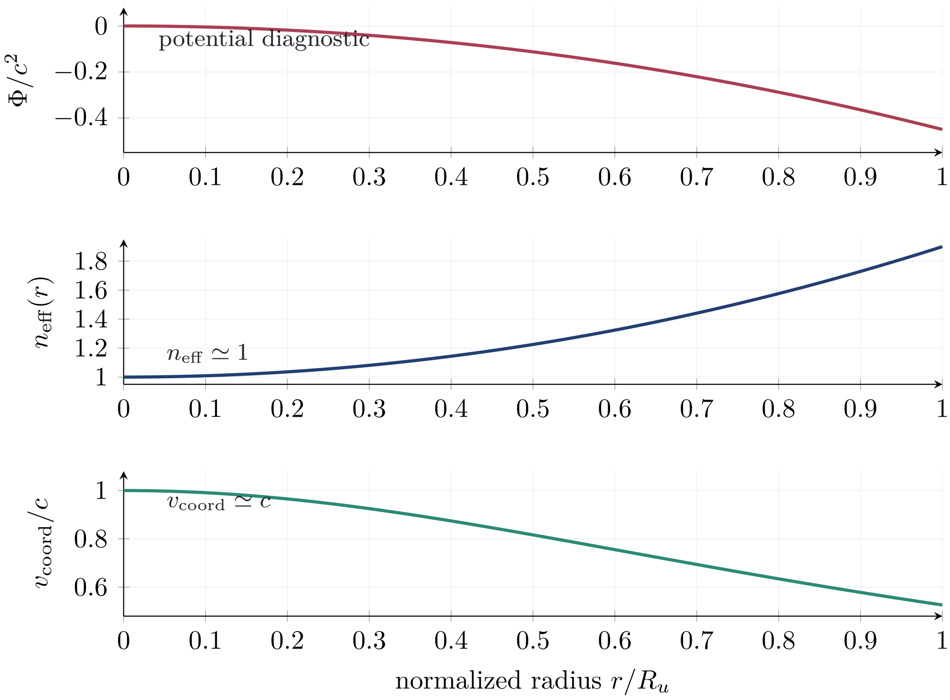


Figure 7: Aligned conceptual profiles for potential-like diagnostic, refractive index, and coordinate light speed. The plotted forms are normalized illustrations of the relations used in the text, not a final cosmological fit.

4. In the effective electromagnetic bookkeeping version of the model, the vacuum parameters may be written as

$$\epsilon(r) = \epsilon_0 n_{\mathrm{eff}}(r), \tag{9.10}$$

$$\mu(r) = \mu_0 n_{\mathrm{eff}}(r). \tag{9.11}$$

Moving inward toward the observer, both effective parameters decrease toward

$$\epsilon(0) = \epsilon_0, \qquad \mu(0) = \mu_0. \tag{9.12}$$

This can be described as a decrease in an effective optical storage parameter or effective polarisation bookkeeping parameter.

The impedance is

$$Z = \sqrt{\frac{\mu}{\epsilon}} = \sqrt{\frac{\mu_0 n_{\mathrm{eff}}}{\epsilon_0 n_{\mathrm{eff}}}} = \sqrt{\frac{\mu_0}{\epsilon_0}} = Z_0 \approx 377\,\Omega. \tag{9.13}$$

Since Z remains constant, the admittance

$$Y = \frac{1}{Z} \tag{9.14}$$

also remains constant. Therefore the draft should not say that admittance increases. The better replacement is that optical density or the effective optical storage parameter increases.

Any claim about changes in the fine-structure constant must be stated as speculative unless a full physical mechanism is supplied. In this paper, $\epsilon(r)$ and $\mu(r)$ are best treated as effective optical parameters, not as direct evidence that local electromagnetic constants vary.

5. The Maxwell stress-energy tensor $T^{\mu\nu}$ describes electromagnetic energy density, momentum density, and stress. In a medium-like optical bookkeeping model, the field energy density is

$$u = T^{00} = \frac{1}{2}\left(\epsilon E^2 + \frac{1}{\mu} B^2\right). \tag{9.15}$$

With

$$\epsilon = \epsilon_0 n_{\text{eff}}, \qquad \mu = \mu_0 n_{\text{eff}}, \tag{9.16}$$

this becomes

$$u = \frac{1}{2}\left(\epsilon_0 n_{\text{eff}} E^2 + \frac{B^2}{\mu_0 n_{\text{eff}}}\right). \tag{9.17}$$

The magnetic term scales as $1/n_{\text{eff}}$ if B is held fixed. The earlier factorization

$$u \neq \frac{1}{2} n_{\text{eff}} \left(\epsilon_0 E^2 + \frac{B^2}{\mu_0}\right) \tag{9.18}$$

is not generally valid.

If both electromagnetic contributions are intended to scale together, the paper must either use E and H consistently or state the plane-wave relations being assumed. For example, in a locally homogeneous effective medium,

$$\mathbf{S} = \mathbf{E} \times \mathbf{H}, \tag{9.19}$$

and the relationship between E, B, H, phase velocity, and impedance must be fixed before assigning a single scaling law to u.

6. Because we view the universe through its light history, the observed optical field can be represented as increasing in effective density with lookback radius. In the gradient-index description, this produces an outward optical gradient:

$$\partial_r n_{\text{eff}} > 0. \tag{9.20}$$

The ray equation in gradient-index optics is

$$\frac{\mathrm{d}}{\mathrm{d}s}\left(n_{\text{ray}} \frac{\mathrm{d}\mathbf{x}}{\mathrm{d}s}\right) = \nabla n_{\text{ray}}. \tag{9.21}$$

Thus rays curve toward larger n_{ray}. Since larger n_{ray} lies outward in the observer-centred ray readout, the result is a diverging optical behaviour.

This is the strongest version of the original "repulsive" idea. The paper should first describe it as a gradient-index ray effect. A physical repulsive force would require a separate dynamical medium model.

10 Ray-Bending Diagram

For a spherically symmetric index, ray paths extremize the optical path length

$$\mathcal{L} = \int n_{\text{ray}}(\mathbf{x})\,\mathrm{d}s. \tag{10.1}$$

The conserved impact parameter is

$$b = n_{\text{ray}}(r) r \sin\psi, \tag{10.2}$$

where ψ is the angle between the ray direction and the radial direction. Only rays with suitable impact parameter reach the observer. Others are redistributed by the outward-rising optical index.

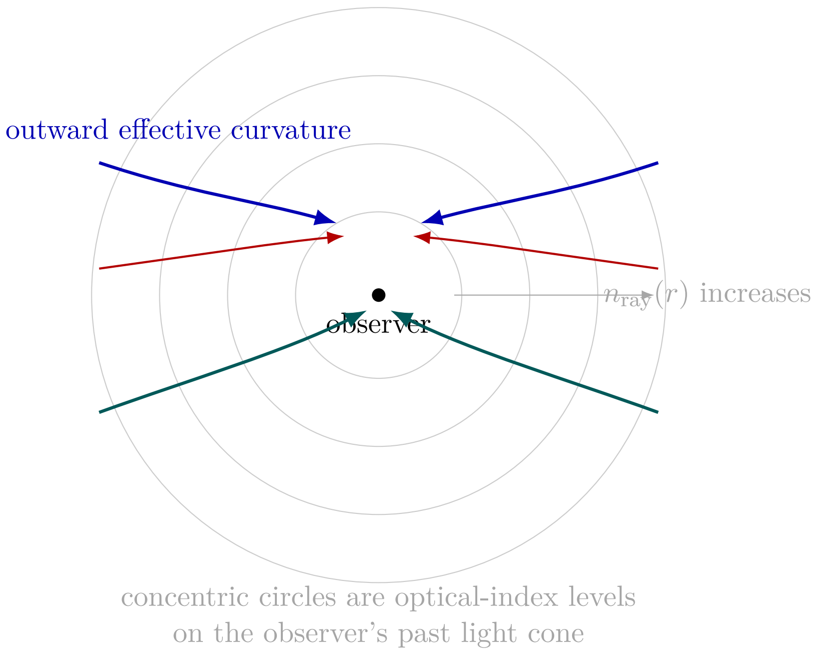


Figure 8: Diverging gradient-index behaviour. Since $n_{\rm ray}(r)$ rises outward, the optical gradient points away from the observer in this coordinate readout.

11 Optical Inversion and Standard Lensing

The standard weak-field optical analogy around an isolated mass is converging. The effective index is largest near the mass, and rays bend inward toward the higher-index region. This corresponds to the familiar focusing of light by stars, galaxies, and clusters.

The present model is optically inverted only in the observer-centred past-light-cone sense. The lowest redshift index is assigned to the observer, while higher redshift index is assigned to larger lookback radius. A diverging ray pattern follows only when the calibrated ray index $n_{\rm ray}(r)$ also rises outward in the chosen coordinate readout.

This comparison should be made carefully:

$$\text{isolated mass lens} \quad \Rightarrow \quad n \text{ highest near mass} \quad \Rightarrow \quad \text{converging behaviour,} \tag{11.1}$$

$$\begin{aligned} \text{observer-centred cosmological readout} \quad &\Rightarrow \quad n_{\rm eff} \text{ highest at large lookback radius} \\ &\Rightarrow \quad \text{diverging behaviour.} \end{aligned}$$

The second statement is not a claim that the observer is physically surrounded by a real high-density shell. It is a statement about how received light can be mapped into a radial optical index.

12 Effective Electromagnetic Bookkeeping

The vacuum should not be described as a material substance unless the paper supplies a complete medium model. The optical analogy does not require an ether. Nevertheless, effective medium parameters can be useful as a bookkeeping device. They should be read as impedance-matched optical parameters, not as direct claims that local vacuum constants vary.

The effective permittivity and permeability are

$$\epsilon_{\text{eff}}(r) = \epsilon_0 n_{\text{eff}}(r), \qquad \mu_{\text{eff}}(r) = \mu_0 n_{\text{eff}}(r). \tag{12.1}$$

Then

$$\frac{1}{\sqrt{\epsilon_{\text{eff}}\mu_{\text{eff}}}} = \frac{c}{n_{\text{eff}}(r)}. \tag{12.2}$$

This reproduces the coordinate/effective propagation speed.

The impedance is unchanged:

$$Z_{\text{eff}} = \sqrt{\frac{\mu_{\text{eff}}}{\epsilon_{\text{eff}}}} = Z_0. \tag{12.3}$$

The admittance is also unchanged:

$$Y_{\text{eff}} = \frac{1}{Z_{\text{eff}}} = \frac{1}{Z_0}. \tag{12.4}$$

Thus the increase in n_{eff} should be called an increase in effective optical density or optical storage parameter, rather than an increase in admittance.

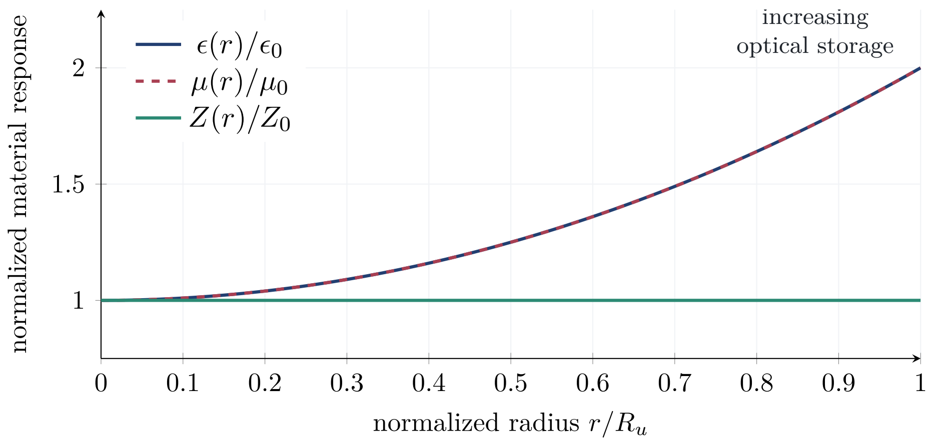


Figure 9: Vacuum permittivity and permeability rise with the effective refractive index, while the impedance $Z = \sqrt{\mu/\epsilon}$ remains constant in this simplified optical bookkeeping layer. The admittance remains constant as well.

13 Stress-Energy Interpretation

The corrected energy-density expression is

$$u = \frac{1}{2}\left(\epsilon_0 n_{\text{eff}} E^2 + \frac{B^2}{\mu_0 n_{\text{eff}}}\right). \tag{13.1}$$

This expression contains two distinct scalings if E and B are treated as independent coordinate field amplitudes.

For a plane wave in a locally homogeneous effective medium, one may instead use the E and H fields and the impedance relation. Since Z is constant, the ratio between E and H remains fixed:

$$E = ZH. \tag{13.2}$$

In that case, one can describe the wave energy with assumptions matched to the local plane-wave relation. The paper should state these assumptions before claiming that the whole stress-energy tensor scales by a single factor of n.

The stress tensor itself can still be used conceptually:

$$\nabla_\mu T^{\mu\nu} = 0, \tag{13.3}$$

but in curved spacetime this conservation law is geometric and covariant. A coordinate gradient in an optical readout should not automatically be reinterpreted as a literal force unless a dynamical medium has been defined.

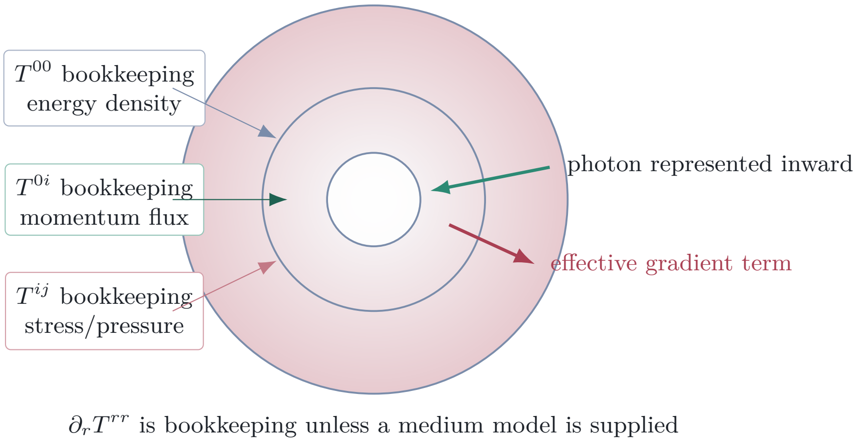


Figure 10: Schematic stress-energy bookkeeping for inward-represented light. Energy density, momentum flux, and stress should be treated as effective optical quantities unless a physical medium model is supplied. In the surrounding RSG language, this is a continuum bookkeeping device for the representation of light-like histories.

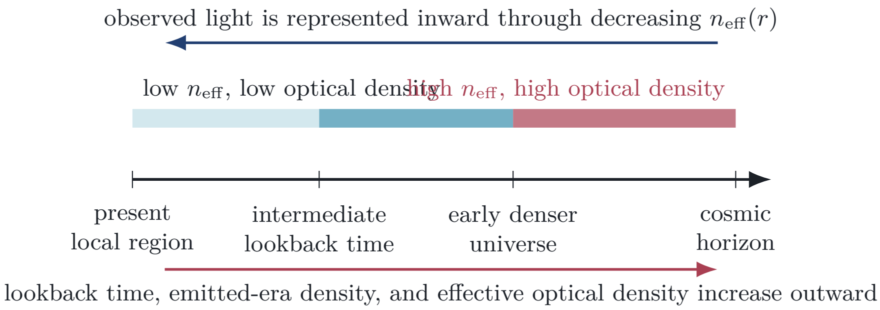


Figure 11: The radial coordinate also represents observational lookback time in this interpretation. More distant shells correspond to earlier, denser, higher-redshift regions of the observable universe, making the profile relevant to high-redshift maturation tests.

14 Summary of the Objective Light Path

The original summary can be retained with corrected terminology:

- Effective coordinate velocity increases inward, approaching c at the observer.
- Local light speed remains invariant and equal to c.

- Frequency shift is derived from the metric or propagation relation, then encoded in $n_z(r)$.
- Photon energy transformation follows $\mathcal{E}_{\gamma,\mathrm{obs}}/\mathcal{E}_{\gamma,\mathrm{em}} = 1/n_z(r)$, while the corresponding period stretches by $n_z(r)$.
- In the lossless light-like limit, phase transport is unitary and periodic; survival attenuation belongs to the separate ΓW layer.
- Effective optical density decreases inward as $n_{\mathrm{eff}}(r)$ decreases.
- Effective permittivity and permeability decrease inward if the bookkeeping choice $\epsilon = \epsilon_0 n_{\mathrm{eff}}$ and $\mu = \mu_0 n_{\mathrm{eff}}$ is used.
- Impedance and admittance remain constant under that choice.
- Divergence increases for non-radial rays only in an outward-rising calibrated ray-index readout $n_{\mathrm{ray}}(r)$.
- Energy-density scaling must use

  $$u = \frac{1}{2}\left(\epsilon_0 n_{\mathrm{eff}} E^2 + \frac{B^2}{\mu_0 n_{\mathrm{eff}}}\right), \tag{14.1}$$

  unless a plane-wave field relation is explicitly imposed.
- Momentum flux and stress should be discussed as effective optical quantities unless a material vacuum model is supplied.

15 Compatibility with the Companion Framework

In the broader trajectory-selection language, the three pieces can be separated cleanly:

$$\Omega^2 \quad \text{gives admissible trajectory shaping,} \tag{15.1}$$

$$n_z(r),\ n_{\mathrm{ray}}(r) \quad \text{give the redshift and ray readouts of that shaping,} \tag{15.2}$$

$$\Gamma W \quad \text{gives survival and resolution filtering of the arriving bundle.} \tag{15.3}$$

This lets the optical-index model remain compatible with the larger framework without forcing it to carry the full ontological weight of the theory.

This placement also preserves the modest form used in the high-redshift maturation brief. If the inverted-vacuum layer is supported, then it gives a natural way to encode horizon-directed maturation, redshift, and lensing divergence inside the same survival-filtering vocabulary. If it is not supported, the underlying topological and recursive-survival framework remains intact.

More explicitly, the optical layer should feed the high-redshift maturation model through observables rather than through rhetoric. The redshift index $n_z(r)$ supplies the phase-period and photon-energy transformation along the past light cone. A separately calibrated $n_{\mathrm{ray}}(r)$ may supply angular redistribution or resolution weighting for the arriving bundle. These can then enter the existing RSG maturation diagnostics without changing the survival law itself:

$$p_i(z) = \frac{S_i(z)}{\sum_j S_j(z)}, \qquad S_i(z) = S_i(z_{\mathrm{init}}) \exp\left[-\int_z^{z_{\mathrm{init}}} \Gamma_i(\sigma_i(z'))W_i(\varphi_i(z')) \left|\frac{\mathrm{d}t}{\mathrm{d}z'}\right| \mathrm{d}z'\right]. \tag{15.4}$$

If a candidate substrate or resolution channel is added, it should appear as an explicitly named additional loss or weighting term, as in the companion high-redshift brief, rather than being hidden inside the optical index. This keeps three roles separate:

$$n_z(r) \quad \text{tracks phase-period and energy transformation,} \tag{15.5}$$

$$n_{\text{ray}}(r) \quad \text{tracks candidate angular redistribution,} \tag{15.6}$$

$$\Gamma W \quad \text{tracks non-unitary survival filtering.} \tag{15.7}$$

16 Best Next Technical Step

The next paper-strengthening step is to produce:

1. one calibrated redshift profile $n_z(r)$, preferably starting with $n_z(r) = 1 + z(r)$ from a standard FLRW distance-redshift relation;
2. one explicit choice for whether the ray index is identified with $n_z(r)$, derived from an optical metric, or left as a separate calibrated function $n_{\text{ray}}(r)$;
3. one numerical ray-bending diagram obtained from

$$\frac{\mathrm{d}}{\mathrm{d}s}\left(n_{\text{ray}}\frac{\mathrm{d}\mathbf{x}}{\mathrm{d}s}\right) = \nabla n_{\text{ray}}; \tag{16.1}$$

4. one comparison with standard lensing, luminosity distance, angular-diameter distance, or redshift observables.

This keeps the paper's original intuition while making the central claim much more defensible: cosmological light propagation can be represented as an observer-centred effective gradient-index optical problem.

Concluding Statement

There is a strong paper here if the model is presented as effective optical propagation rather than literal cosmological shell physics. The universe does not need a privileged centre, a material ether, or a literal outer wall for the analogy to work. What is needed is a carefully defined redshift index $n_z(r)$ on the observer's past light cone, a separately justified ray index $n_{\text{ray}}(r)$ if angular redistribution is claimed, and a demonstration that the resulting equations reproduce, approximate, or usefully reframe known cosmological observables.

The proposal should also be allowed to fail. It would be weakened if the same free index had to be redefined separately for every observable, if an observer-centred ray model predicted a real anisotropy around the observer, if distance duality failed without an explicit physical mechanism, or if the RSG survival layer added no constrained prediction beyond the FLRW calibration.

A Observer-Centred Redshift Index

In the main text, $n_{\text{eff}}(r)$ denotes the general observer-centred effective index. In this appendix we define the first specialized use of that index: the redshift index

$$n_z(r). \tag{A.1}$$

This index records cosmological redshift, phase-period stretching, and photon energy transformation on the observer's past light cone.

Let r denote a radial coordinate on the observer's past light cone. In a spatially flat reference cosmology, the comoving distance to redshift z is

$$r(z) = c \int_0^z \frac{\mathrm{d}z'}{H(z')}. \tag{A.2}$$

The inverse relation gives

$$z = z(r). \tag{A.3}$$

The observer-centred redshift index is then defined by

$$n_z(r) = 1 + z(r). \tag{A.4}$$

In FLRW cosmology, the same quantity is determined by the scale factor:

$$1 + z = \frac{a(t_0)}{a(t_{\text{em}})}. \tag{A.5}$$

Therefore

$$n_z(r) = \frac{a(t_0)}{a(t_{\text{em}}(r))}. \tag{A.6}$$

Equivalently, using the photon wavevector k^μ and the four-velocity u^μ of the emitter or observer,

$$n_z(r) = 1 + z(r) = \frac{(k_\mu u^\mu)_{\text{em}}}{(k_\mu u^\mu)_{\text{obs}}}. \tag{A.7}$$

Thus $n_z(r)$ is not introduced as a material refractive index of the vacuum. It is an effective optical readout of propagation on the observer's past light cone. It records how far back along the light cone the received radiation was emitted.

When the effective-index model is being used only to describe redshift or cosmological time dilation, one may write

$$n_{\text{eff}}(r) = n_z(r) = 1 + z(r). \tag{A.8}$$

The corresponding coordinate or effective speed is

$$v_z(r) = \frac{c}{n_z(r)}. \tag{A.9}$$

This is a coordinate speed in the observer's optical representation. It is not a locally measured speed of light. Every local freely falling observer still measures light to propagate at

$$c. \tag{A.10}$$

The same index describes the stretching of wave period. If T_{em} is the emitted period and T_{obs} is the observed period, then

$$T_{\text{obs}} = n_z(r) T_{\text{em}}. \tag{A.11}$$

The observed frequency therefore satisfies

$$\nu_{\rm obs} = \frac{\nu_{\rm em}}{n_z(r)}. \tag{A.12}$$

For photon energy,

$$E_{\rm obs} = h\nu_{\rm obs} = \frac{h\nu_{\rm em}}{n_z(r)} = \frac{E_{\rm em}}{n_z(r)}. \tag{A.13}$$

Thus $n_z(r)$ may also be read as an energy-transformation index:

$$\mathcal{E}_{\gamma,\rm obs} = \frac{\mathcal{E}_{\gamma,\rm em}}{n_z(r)}. \tag{A.14}$$

This appendix does not define the ray-bending index. Angular redistribution, lensing, or diverging gradient-index behaviour require a separately specified ray index,

$$n_{\rm ray}(r). \tag{A.15}$$

This distinction prevents the reader from assuming that the redshift calibration

$$n_z(r) = 1 + z(r) \tag{A.16}$$

automatically determines ray bending.

In the simplest scalar optical model, one may impose

$$n_{\rm ray}(r) = n_z(r) = n_{\rm eff}(r). \tag{A.17}$$

However, this identification is an additional modelling assumption rather than a definition. Appendix A defines only the observer-centred redshift index $n_z(r)$.

B Defining and Testing the Effective Indices

The minimum technical requirement for the optical layer is a carefully defined redshift index on the observer's past light cone. The radial coordinate must first be tied to an observable distance-redshift relation, for example

$$r(z) = c\int_0^z \frac{{\rm d}z'}{H(z')}. \tag{B.1}$$

A baseline calibration is then

$$n_z(r(z)) = 1 + z. \tag{B.2}$$

This choice identifies the redshift index with the accumulated cosmological time-dilation factor. It is a coordinate readout of propagation on the past light cone, not a claim that the vacuum is a material substance.

If angular redistribution is claimed, the corresponding rays require a ray index $n_{\rm ray}$ and are defined by the optical path functional

$$\mathcal{L} = \int n_{\rm ray}(\mathbf{x})\,{\rm d}s, \tag{B.3}$$

with ray equation

$$\frac{\rm d}{{\rm d}s}\left(n_{\rm ray}\frac{{\rm d}\mathbf{x}}{{\rm d}s}\right) = \nabla n_{\rm ray}. \tag{B.4}$$

For a spherically symmetric profile, the conserved optical impact parameter is

$$b = n_{\mathrm{ray}}(r) r \sin\psi. \tag{B.5}$$

The model becomes testable by comparing the optical readout against standard cosmological observables:

$$\mathcal{O}_{\mathrm{eff}} = \{n_z(r), n_{\mathrm{ray}}(r), z(r), D_A(z), D_L(z), \Delta\theta(b, z)\}\,. \tag{B.6}$$

Here D_A is angular-diameter distance, D_L is luminosity distance, and $\Delta\theta$ denotes the angular redistribution or bending predicted by the gradient-index ray equation. The standard distance-duality relation provides one immediate consistency check:

$$D_L(z) = (1+z)^2 D_A(z). \tag{B.7}$$

Thus the appendix-level validation problem is simple to state: choose $n_z(r)$, decide whether and how $n_{\mathrm{ray}}(r)$ is related to it, integrate the ray equation only for the calibrated n_{ray}, and determine whether the resulting redshift, distance, and angular-redistribution functions reproduce, approximate, or usefully re-express the corresponding FLRW and lensing observables.

A constrained version of the model should publish its failure conditions alongside its fits. The optical layer is not strengthened by allowing n_z, n_{ray}, Γ, and W to vary freely until the desired observation is reproduced. It is strengthened only if these functions are fixed by independent rules and then survive comparison with redshift, distance, lensing, and maturation data.