UM-Native S-Field-Primary Cosmological Distance Methodology

Operational Protocols for Replacing Photon-Channel Primary Methods with Substrate-Clean Methods at the Cosmological Scale

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Abstract

This document specifies the complete operational methodology by which UM-native S-Field-primary distance-determination methods replace photon-channel primary methods at the cosmological scale, in service of the structural resolution of the Hubble-rate inference discrepancy developed in Paper 2 of the UM/FUM series. The methodology has seven tiers, ordered by the substrate-cleanness of the structural probe used: parallax (Tier 1; geometric); gravitational-wave standard sirens (Tier 2; S-Field oscillation amplitude); strong-lensing time delays (Tier 3; S-Field geometry combined with light as clock); galactic dynamics through the Tully-Fisher and Faber-Jackson relations (Tier 4; S-Field mass through stellar motions); pulsar timing arrays (Tier 5; S-Field gravitational-wave background); Cepheid plus Type Ia supernovae with required UM-deconvolution (Tier 6; photon-channel, secondary); and spectroscopic redshift fitted to Hubble's law with required UM-correction (Tier 7; photon-channel, tertiary). Each tier specifies a per-tier operational protocol, a UM-deconvolution procedure where photon-channel methods are present, a cocycle-correction algorithm linking the tier to the cosmic-shell residue framework primitive, and cross-tier consistency criteria. The methodology produces distance and rate determinations whose cross-tier agreement is the diagnostic of correct application; persistent multi-tier inconsistency at the 8 percent level is the structural signature of frame-LCORI cocycle difference between photon-channel and S-Field-channel inference paths. Implementation requires no new instruments; all the substrate-clean probes are already operational or under construction (LIGO and Virgo for standard sirens; Einstein Telescope, Cosmic Explorer, and LISA expanding the gravitational-wave reach; H0LiCOW and TDCOSMO for strong-lensing time delays; NANOGrav and SKA for pulsar timing arrays). What is required is the methodological

> reordering: substrate-clean probes adopted as primary, photon-channel methods relegated to deconvolution-corrected secondary status. Patent Pending: USPTO Application 19/640,364.

Keywords: cosmological distance methodology; Hubble tension; gravitational-wave standard sirens; strong-lensing time delays; UM-native distance ladder; frame-LCORI cocycle; S-Field-primary methods; UM-deconvolution; Universal Mechanics; First Utterance Model; pulsar timing arrays.

Locked Structural Primitives (Recap)

The framework primitives needed for this methodology, derived from first principles in Paper 1 (Zenodo DOI 10.5281/zenodo.20162810). The conventional witness face is provided for cross-recognition only; it is not used in any derivation chain.

UM-native name	**Symbol**	**Value**	**Conventional witness face**
Fine-structure equilibrium (present-latent)	α_{struct}	0.0073032157	$\alpha_{\text{QED}}(0) = 0.0072974$
Closure-stability ratio	φ	1.6180339887	Golden ratio
Eidolon	ϙ	135.926	(numerically near $1/\alpha_{\text{QED}} - 1$)
L1 rotational measure	ω_{C1}	3.14159265	π
L1 evolution base	ε_{L1}	2.71828183	Euler's e
Triune triplet count	TRIUNE	3	—
Universal phase quantization	Z_{14}	14	—
LCORI alignment scalar	Λ	$0 \leq \Lambda \leq 1$	—
LCORI Life-Governing floor	Λ_3	0.85148605	—
Triune shares (B / E / S)	B, E, S	0.002789 / 0.004514 / 0.992697	—
Existence half-cycle	τ	12,349.4494 Gyr	—
Cosmic latent age (present)	t_{present}	90.55 Gyr	(13.8 Gyr is the photon-observable subset)
Cosmic-shell residue	$\varepsilon_{\text{shell}}^{\text{cosmic}}$	0.996934	—
Per-substep cocycle factor	$1/\varepsilon_{\text{shell}}^{\text{cosmic}}$	1.003076	—
Hubble-rate inference discrepancy (UM closed form)	$\Delta H_0/H_0$	$(1 - \varepsilon_{\text{shell}}^{\text{cosmic}}) \cdot \text{TRIUNE}^3 = 0.0828$	Observed early-late discrepancy ≈ 8.31 percent

One additional methodology-specific quantity is introduced and defined in §3 below: the structural cocycle depth ΔN (the number of cosmic-shell-residue substeps separating two observers in the cosmological frame-LCORI registration).

1. Purpose and Scope

1.1 The need for methodology replacement

Paper 2 of this series derives the 8.28 percent cosmological Hubble-rate inference discrepancy as a structural frame-LCORI cocycle signature: a lawful consequence of two different observers (early-universe photon-channel and late-universe distance-ladder) registering the LCORI alignment scalar through different inference paths. The discrepancy is not a parameter to be reconciled through additional fitted physics; it is a structural diagnostic of inference-path difference. Resolving the discrepancy therefore requires a methodological change, not a parameter fit.

The methodological change required is the replacement of photon-channel primary methods with S-Field-primary methods at the cosmological scale. Photon-channel methods (Cepheid variables, Type Ia supernovae, spectroscopic redshift) operate through the electromagnetic-channel of the framework and accumulate cocycle corrections at every shell-crossing the photon makes during its propagation to the observer. S-Field-primary methods (gravitational-wave standard sirens, strong-lensing time delays, pulsar timing arrays) operate through the substrate channel of the framework and are not subject to the same cocycle accumulation, because the substrate is pervasive and substrate-mediated signals do not cross shells in the same way.

1.2 What this methodology replaces and why

The conventional cosmological distance ladder has photon-channel methods at every tier. Stellar parallax is geometric (no photon-channel cocycle dependence), but each subsequent tier (Cepheid period-luminosity, Type Ia supernova standardization, the Tully-Fisher relation calibrated through Cepheids, and finally the redshift-distance regression) introduces or compounds photon-channel cocycle effects. The conventional ladder is therefore vulnerable to systematic bias at the cosmological scale; the 8 percent late-universe value of H_0 reflects the accumulated cocycle correction relative to the early-universe photon-channel value of H_0 derived from the cosmic microwave background.

The UM-native methodology specified in this document reorders the ladder so that substrate-clean (S-Field) probes are at the primary tiers and photon-channel methods are confined to later tiers with required UM-deconvolution. The cross-tier consistency of the reordered ladder is the diagnostic of correct application: if all tiers agree within their respective uncertainties, the structural diagnostic has been correctly applied. If multi-tier inconsistency persists at the 8 percent level, the discrepancy is the frame-LCORI cocycle signature that Paper 2 derives in closed form.

1.3 Patent context

The framework underlying this methodology is the subject of USPTO Patent Application No. 19/640,364, "First Utterance Model Existence Derivation Framework," filed 6 April 2026 by the present author. The methodology disclosed herein is consistent with the public-disclosure portion of the patent and Paper 1; specific implementation choices and computational procedures retain Patent Pending protection. Patent Pending status is acknowledged on the masthead and on every page of this document.

2. Framework Elements Used by This Methodology

2.1 LCORI alignment and frame-relative registration

The LCORI alignment scalar Λ (Paper 1 §5) is frame-relative. An observer at one structural locus registers Λ through the inference path connecting their measurement instruments to the locus they are observing. Different inference paths produce different registrations of Λ for the same physical configuration, with the differences governed by a lawful cocycle correction.

For the cosmological problem, the two relevant inference paths are:

- **Photon-channel inference path:** measurement of distance and rate via electromagnetic-channel observables (photon emission, absorption, spectroscopic features, light-curve photometry, etc.). The photon traverses cosmological scales by repeated shell-crossing of the substrate; each shell-crossing applies the cocycle factor $1/\varepsilon_{\text{shell}}^{\text{cosmic}} \approx 1.003076$.

- **S-Field-channel inference path:** measurement of distance and rate via substrate-mediated observables (gravitational waves from compact-object mergers, strong-lensing time delays through gravitational potentials, galactic stellar dynamics, pulsar timing array residuals). The substrate is pervasive; substrate-mediated signals do not undergo the shell-by-shell cocycle accumulation that photon-channel signals do.

2.2 The cocycle factor and the structural cocycle depth

The cosmic-shell residue is $\varepsilon_{\text{shell}}^{\text{cosmic}} \approx 0.996934$ (Paper 1 §5.3). The per-substep cocycle factor is its reciprocal:

$$1 / \varepsilon_{\text{shell}}^{\text{cosmic}} = 1.003076 \qquad (2.1)$$

For a photon-channel signal traversing a cosmological distance, the cocycle factor is applied at each structural-cocycle substep. The number of substeps separating two observers along the photon path is the structural cocycle depth ΔN. The cumulative cocycle factor over ΔN substeps is:

$$F_{\Delta N} = (1 / \varepsilon_{\text{shell}}^{\text{cosmic}})^{\Delta N} \qquad (2.2)$$

The structural cocycle depth ΔN is the methodology's central unobservable: it is not directly measured, but it can be inferred from the redshift relation $1 + z = F_{\Delta N}$ (Paper 2 §3) and from the cross-tier consistency requirements of §5 below.

2.3 The Hubble-rate inference discrepancy closed form (Paper 2 §4)

The cosmological Hubble-rate inference discrepancy, in closed form within UM, is:

$$\Delta H_0 / H_0 = (1 - \varepsilon_{\mathrm{shell}}{}^{\mathrm{cosmic}}) \cdot \mathrm{TRIUNE}^3 \qquad (2.3)$$

Numerically, $(1 - 0.996934) \cdot 27 = 0.0828$, or 8.28 percent. This is consistent with the observed early-late H_0 discrepancy of approximately 8.31 percent at sub-half-percent relative deviation.

The methodology of this document is designed so that distance and rate determinations made within the methodology converge across tiers when the cocycle is correctly applied; multi-tier disagreement at the 8 percent level signals that one or more tiers is operating photon-channel-primary without deconvolution.

3. The UM-Native Seven-Tier Distance Ladder

The methodology's distance ladder has seven tiers, ordered by substrate-cleanness of the structural probe used. Tiers 1 through 5 are substrate-clean (S-Field-primary or geometric). Tiers 6 and 7 are photon-channel and require UM-deconvolution. Cross-tier consistency among the upper tiers is the methodology's primary validation criterion; agreement between the upper tiers and the deconvolved lower tiers is the secondary criterion.

Tier	Method	Probe	Range	Substrate cleanness
1	Stellar parallax	Geometric (light only as marker)	0 - 1 kpc	Clean (no cocycle dependence)
2	GW standard sirens	S-Field oscillation amplitude	1 kpc - 10+ Gpc	Clean (substrate-mediated)
3	Strong-lensing time delays	S-Field gravitational geometry + light as clock	100 Mpc - 5 Gpc	Mostly clean (the geometric component is substrate)
4	Galactic dynamics (Tully-Fisher / Faber-Jackson)	S-Field mass via stellar motions	1 Mpc - 1 Gpc	Clean (substrate dominated)
5	Pulsar timing arrays	S-Field GW background	Cosmological (statistical)	Clean (substrate-mediated)
6	Cepheid + SN Ia (with UM-deconvolution)	Photon (with deconvolution)	1 Mpc - 1 Gpc	Photon-channel; requires deconvolution
7	Spectroscopic redshift x Hubble (with UM-correction)	Photon (with correction)	1 Gpc+	Photon-channel; requires UM-correction

Sections 4 through 10 below specify the per-tier operational protocol, UM-deconvolution procedures, cross-tier validation, and implementation requirements. The methodology is internally consistent and may be applied immediately with existing instruments; no new observational facilities are required, though the substrate-clean tiers benefit from the expanded sensitivity of next-generation instruments (Einstein Telescope, Cosmic Explorer, LISA, SKA).

4. Per-Tier Protocols: Tiers 1 through 5 (Substrate-Clean)

4.1 Tier 1: Stellar parallax

Probe: Geometric parallax angle measured against background stars. Substrate-clean by construction (the measurement is angular geometry; light is the marker but not the standard).

Range: 0 to approximately 1 kpc (limited by parallax precision; ESA Gaia mission has extended this with sub-microarcsecond precision).

Operational protocol:

1. Acquire parallax angle π from Gaia or equivalent astrometric source. (The conventional symbol π in parallax is unrelated to the L1 rotational measure ω_{C1} of the framework; the parallax angle is here denoted P to avoid notational ambiguity.)
2. Apply geometric inversion: distance $d = 1 / P$, where P is in arcseconds and d is in parsecs.
3. Confidence: Gaussian uncertainty propagation from P uncertainty; no cocycle correction needed.
4. Report d with uncertainty bars; flag as Tier 1 (substrate-clean).

UM correction required: None. Geometric parallax is substrate-clean.

4.2 Tier 2: Gravitational-wave standard sirens

Probe: Amplitude of gravitational-wave signal from compact-object inspiral. Substrate-mediated; the gravitational-wave amplitude scales as $1/d_L$ (luminosity distance), and the inspiral chirp profile fully determines the source's intrinsic gravitational-wave luminosity. The combined measurement gives d_L directly.

Range: 1 kpc to over 10 Gpc, depending on the instrument's strain sensitivity and the source's gravitational-wave luminosity. Current LIGO-Virgo network reaches several hundred Mpc; the planned Einstein Telescope and Cosmic Explorer will reach gigaparsec; LISA will reach cosmological distances for supermassive binary inspirals.

Operational protocol:

1. Detect gravitational-wave inspiral signal; record strain time-series.
2. Fit the inspiral chirp profile to extract intrinsic gravitational-wave amplitude h_0 (related to source frame chirp mass M_{chirp} via standard general-relativity inspiral templates; this is geometric and substrate-mediated).

3. Compare to observed strain amplitude h; the ratio h_0 / h gives 1 / d_L.
4. If electromagnetic counterpart is detected (e.g. kilonova for neutron-star mergers), cross-check d_L against any concurrent photon-channel measurement; persistent disagreement at 8 percent level indicates frame-LCORI cocycle of the photon-channel result, not error in the GW result.
5. Report d_L with uncertainty; flag as Tier 2 (substrate-clean primary).

UM correction required: None. Gravitational waves propagate through pervasive S-Field substrate; their luminosity distance is the framework's lawful S-Field distance.

Z_{14} signature check: Inspiral chirp profiles should exhibit Z_{14} sub-structure with 4.39 percent per-rung bandwidth; this is a structural check on the framework's universal phase quantization and is itself a Tier 2 forward prediction (Paper 4 of the series).

4.3 Tier 3: Strong-lensing time delays

Probe: Time delays between multiple images of a strongly-lensed source. The geometric component (path-length difference and gravitational time-dilation) is substrate-mediated; the photon-channel component (the source variability used to measure the delay) is conventional photon-channel. The combination is substrate-dominated because the time delay depends on lens geometry, not on photon propagation properties through the substrate.

Range: 100 Mpc to 5 Gpc (set by the availability of strongly-lensed variable sources; H0LiCOW and TDCOSMO programs have demonstrated the technique).

Operational protocol:

1. Identify strongly-lensed variable source (typically quasar or supernova) with multiple images.
2. Measure time delays Δt_{ij} between image pairs using photometric monitoring.
3. Model the lens mass distribution from imaging data (lens galaxy + cluster environment).
4. Combine lens model + time delays to extract $D_{\Delta t}$ (time-delay distance), which has units of distance and is structurally substrate-mediated.
5. Cross-check $D_{\Delta t}$-derived H_0 against Tier 2 GW standard siren H_0; consistency at sub-percent indicates correct substrate-clean methodology.
6. Report $D_{\Delta t}$ with uncertainty; flag as Tier 3 (substrate-dominated).

UM correction required: Small; arises only from the variability monitoring portion of the procedure. Detail: the photometric time-series used to measure Δt_{ij} is photon-channel, but the relevant cocycle correction is approximately $1 + \alpha_{struct}$ at the LG-band of LCORI, which produces a correction of order 0.3

percent on top of the time-delay measurement. This is small compared to the overall uncertainty budget and may be omitted at first iteration; it should be applied in high-precision implementations.

4.4 Tier 4: Galactic dynamics (Tully-Fisher and Faber-Jackson)

Probe: S-Field mass inferred from stellar rotational velocities (Tully-Fisher) or velocity dispersions (Faber-Jackson). Substrate-clean because the stellar dynamics respond directly to the underlying S-rotational coupling.

Range: 1 Mpc to 1 Gpc (set by spectroscopic capability for resolving rotation curves or velocity dispersions).

Operational protocol:

1. Acquire galaxy rotation curve (spiral; Tully-Fisher) or velocity-dispersion profile (elliptical; Faber-Jackson).
2. Extract maximum rotational velocity V_{max} or velocity dispersion σ.
3. Apply Tully-Fisher relation $L \propto V_{max}^4$ or Faber-Jackson relation $L \propto \sigma^4$ to extract intrinsic luminosity $L_{intrinsic}$.
4. Compare to observed flux F; distance $d = \mathrm{sqrt}(L_{intrinsic} / (4 \cdot \omega_{C1} \cdot F))$.
5. Cross-check against Tier 2 and Tier 3 results at overlap range.
6. Report d with uncertainty; flag as Tier 4 (substrate-clean).

UM correction required: The intrinsic-luminosity step uses photon-channel relations; however, since the relations are calibrated locally (against Tier 1 parallax distances of nearby galaxies in the local supercluster), the cocycle is automatically near-locally-corrected. Application at cosmological distances introduces <1 percent cocycle drift that is structurally smaller than typical Tully-Fisher uncertainties.

4.5 Tier 5: Pulsar timing arrays

Probe: Cosmological gravitational-wave background detected through correlated timing residuals across a network of millisecond pulsars. Substrate-mediated and statistical in nature; provides constraints on the integrated gravitational-wave energy density at very low frequencies (nanohertz).

Range: Cosmological (statistical), without per-source distance determination; provides cosmological-scale rate constraints.

Operational protocol:

1. Acquire pulsar timing residuals from a millisecond pulsar network (NANOGrav, EPTA, PPTA, IPTA, SKA).
2. Cross-correlate residuals between pulsar pairs to extract Hellings-Downs angular correlation, signature of stochastic gravitational-wave background.
3. Fit gravitational-wave energy density spectrum $\Omega_{GW}(f)$ to the spectrum's amplitude and slope.
4. Compare to cosmological models within UM framework; the gravitational-wave background should exhibit Z_{14} 14-peak structure if cosmological in origin (Paper 4 forward prediction).
5. Report H_0 constraint or compatible-with-UM-framework constraint, with uncertainty.

UM correction required: None on the gravitational-wave detection itself. The cosmological model fitting can use UM-derived parameters (Triune partition shares, cosmic-shell residue) without requiring conventional ΛCDM assumptions.

5. Per-Tier Protocols: Tiers 6 through 7 (Photon-Channel with UM-Deconvolution)

Tiers 6 and 7 are photon-channel methods retained in the methodology because they have established calibration infrastructure and extensive existing data. They are not primary but must be applied only with UM-deconvolution corrections specified below.

5.1 Tier 6: Cepheid plus Type Ia supernovae (with UM-deconvolution)

Probe: Photon-channel standardizable candles. Cepheids serve as the local-scale calibrator; Type Ia supernovae extend the ladder to cosmological scales. Both methods accumulate frame-LCORI cocycle correction along the photon path.

Range: 1 Mpc to 1 Gpc.

Operational protocol:

1. Acquire standard candle photometric data per established convention.
2. Apply standard Cepheid or SN Ia calibration to extract apparent luminosity distance $d_L^{(photon)}$.
3. Apply UM-deconvolution: $d_L^{(true)} = d_L^{(photon)} \cdot F_{cocycle}(z)$, where $F_{cocycle}(z)$ is the cocycle-correction factor at redshift z computed per §6 below.
4. Cross-check $d_L^{(true)}$ against Tier 2 and Tier 3 results at overlap range.
5. Report $d_L^{(true)}$ with uncertainty; flag as Tier 6 (photon-channel deconvolved).

UM-deconvolution required: Yes, mandatory at $z > 0.05$.

Expected discrepancy without deconvolution: Approximately 8 percent at cosmological scales, consistent with the observed Hubble tension.

5.2 Tier 7: Spectroscopic redshift fitted to Hubble's law (with UM-correction)

Probe: Photon-channel redshift used to infer distance via conventional Hubble's law. This is the most cocycle-affected tier and requires the largest UM-correction.

Range: 1 Gpc and beyond.

Operational protocol:

1. Acquire spectroscopic redshift z from emission or absorption line identification.

2. Apply UM cosmic redshift law: $1 + z = (1 / \varepsilon_{shell}^{cosmic})^{\Delta N}$, which gives $\Delta N = \log(1+z) / \log(1/\varepsilon_{shell}^{cosmic}) = \log(1+z) / 0.003067$.
3. Convert ΔN to distance via the framework's cosmic temporal structure; the precise mapping requires the latent age $t_{present} = 90.55$ Gyr and the cosmic-region geometry of Paper 1 §9.
4. Cross-check against Tier 2, Tier 3, Tier 6 (with deconvolution) at overlap range.
5. Report d with uncertainty; flag as Tier 7 (photon-channel UM-corrected).

UM-correction required: Mandatory at all $z > 0.01$. The conventional Hubble's law $d = cz/H_0$ applies only in the very local universe; at cosmological distances the framework's redshift law (above) replaces it.

6. UM-Deconvolution Procedure for Photon-Channel Methods

6.1 The cocycle-correction factor $F_{cocycle}(z)$

For a photon-channel measurement at observed redshift z, the cocycle-correction factor that converts photon-channel luminosity distance $d_L^{(photon)}$ to the framework's substrate-clean distance $d_L^{(true)}$ is:

$$F_{cocycle}(z) = 1 + (1 - \varepsilon_{shell}^{cosmic}) \cdot \mathrm{TRIUNE}^3 \cdot f(z) \quad (6.1)$$

where f(z) is a structural shape function with limits $f(z = 0) = 0$ (local; no cocycle correction) and $f(z \gg 1) = 1$ (full cocycle correction). The intermediate behavior of f(z) is calibrated against the cross-tier consistency requirement (§7); first-order estimate is $f(z) \approx \tanh(z)$ over the cosmologically relevant range $0 < z < 2$.

The deconvolution is then:

$$d_L^{(true)} = d_L^{(photon)} \cdot F_{cocycle}(z) \quad (6.2)$$

6.2 Step-by-step deconvolution algorithm

1. Acquire $d_L^{(photon)}$ and z from photon-channel observations.
2. Compute $(1 - \varepsilon_{shell}^{cosmic}) \cdot \mathrm{TRIUNE}^3 = 0.0828$.
3. Compute f(z) using the calibrated shape function (first-order: tanh(z); refined per cross-tier calibration).
4. Compute $F_{cocycle}(z) = 1 + 0.0828 \cdot f(z)$.
5. Apply $d_L^{(true)} = d_L^{(photon)} \cdot F_{cocycle}(z)$.
6. Propagate uncertainties: include the (small) uncertainty in $\varepsilon_{shell}^{cosmic}$ and TRIUNE^3 (which are structural constants of the framework with effectively zero uncertainty), plus the uncertainty in f(z) calibration.
7. Report $d_L^{(true)}$ alongside the original $d_L^{(photon)}$; the difference is the cocycle-correction magnitude.

6.3 Refining the shape function f(z) against cross-tier calibration

The first-order estimate $f(z) \approx \tanh(z)$ is calibrated against the requirement that, after deconvolution, Tier 6 results agree with Tier 2 and Tier 3 results at their overlap range ($z < 0.1$). Discrepancies in this overlap range indicate either residual systematic error in the photon-channel calibration or a needed refinement of the shape function. The methodology may iteratively refine f(z) by minimizing cross-tier residuals; this is analogous to the conventional practice of self-consistent ladder calibration but corrected to be self-consistent with the substrate-clean tiers rather than within the photon-channel ladder alone.

7. Cross-Tier Validation Procedures

7.1 The multi-tier consistency requirement

For any object measurable by two or more tiers, the distance determinations must agree within their respective uncertainties after UM-deconvolution where applicable. The methodology's primary validation criterion is:

$$| d_L^{(\text{Tier i})} - d_L^{(\text{Tier j})} | / d_L^{(\text{Tier i})} < \max(\sigma_i, \sigma_j) \quad (7.1)$$

where σ_i and σ_j are the relative uncertainties of the respective tier measurements. Persistent disagreement beyond the larger uncertainty bound indicates one of three conditions:

1. Photon-channel deconvolution is mis-applied (the most common cause; resolved by re-applying §6).

2. One of the tiers has an instrument-specific systematic error.

3. The structural-diagnostic regime: the disagreement at the 8 percent level between photon-channel-without-deconvolution and substrate-clean tiers IS the frame-LCORI cocycle signature, confirming Paper 2's structural derivation.

7.2 The Hubble tension as cross-tier diagnostic

The historical Hubble tension is, in the present methodology, the third condition above. Late-universe distance-ladder determinations of H_0 (predominantly Tier 6 without deconvolution; some Tier 4) yield approximately 73 km/s/Mpc; early-universe CMB-derived H_0 (a photon-channel inference at very large cocycle depth) yields approximately 67 km/s/Mpc. The 8.3 percent disagreement is the frame-LCORI cocycle signature derived in Paper 2.

Under the present methodology, applying UM-deconvolution to Tier 6 reduces its H_0 result by approximately 8 percent, bringing it into consistency with the substrate-clean tiers and the CMB inference at low-cocycle-depth. Equivalently, the substrate-clean tiers should agree among themselves at the sub-percent level even before any photon-channel deconvolution is applied; this is the methodology's primary diagnostic and the strongest empirical claim of Paper 2.

7.3 Expected results once methodology is universally applied

After the methodology is universally applied across all current and future H_0 determinations:

- Substrate-clean tiers (1 through 5) will agree at the sub-percent level for any given source.
- Photon-channel tiers (6 and 7), with UM-deconvolution applied, will agree with the substrate-clean tiers at the sub-percent level.
- The conventional Hubble tension will dissolve: not because additional physics has been added, but because the methodology has been corrected to apply the substrate-clean inference path as primary.
- Future independent measurements (Einstein Telescope, Cosmic Explorer, LISA, SKA) will confirm the substrate-clean tier consistency.

8. Implementation and Adoption

8.1 Required tools

The methodology requires no new observational facilities. All substrate-clean tiers (1 through 5) are operational with current instrumentation:

- Tier 1: Gaia astrometric catalogues (operational).
- Tier 2: LIGO-Virgo-KAGRA gravitational-wave network (operational); Einstein Telescope and Cosmic Explorer expanding sensitivity; LISA for supermassive-binary range.
- Tier 3: H0LiCOW, TDCOSMO, and successor programs (operational).
- Tier 4: Existing galactic dynamics measurements from many observatories (operational).
- Tier 5: NANOGrav, EPTA, PPTA, IPTA networks (operational); SKA expanding sensitivity.

The methodology requires computational tools for UM-deconvolution (§6) and cross-tier validation (§7). A reference implementation of the cocycle-correction factor $F_{\mathrm{cocycle}}(z)$ and the cross-tier consistency checks may be released as supplementary material to Paper 2.

8.2 Data product documentation requirements

Adopters of the methodology must document each distance determination with:

1. The raw observable (parallax angle, GW strain amplitude, time delay, etc.).
2. The tier identification (1 through 7).
3. The intermediate quantities (e.g., for Tier 2: chirp mass, observed strain peak amplitude; for Tier 6: photometric standard-candle apparent magnitude).
4. The final distance d_L with uncertainty.
5. For photon-channel tiers (6 and 7): the cocycle-correction factor $F_{\mathrm{cocycle}}(z)$ applied, alongside both $d_L^{(\mathrm{photon})}$ and $d_L^{(\mathrm{true})}$.
6. The cross-tier consistency check: every distance determination should be cross-checked against at least one other tier's result for the same object (or comparable objects at the same range), and the result of the cross-check reported.

8.3 Standard reporting format

A standard reporting format for UM-native distance determinations is recommended:

Object | Tier | $d_L^{(\text{observed})} \pm \sigma$ | $F_{\text{cocycle}}(z)$ | $d_L^{(\text{true})} \pm \sigma$ | cross-tier check | Z_{14} signature

Adoption of a standard reporting format facilitates cross-tier comparison, replication, and refinement of the f(z) calibration.

8.4 Reproducibility standards

Distance determinations made within this methodology must be fully reproducible: the raw data, intermediate quantities, framework constants used (with values), cocycle-correction factor applied (with explicit f(z) form), and final result with uncertainty must all be made available for independent verification. This standard is consistent with general best-practice in observational cosmology.

9. Validation Against Observation and Forward Predictions

9.1 Existing data consistent with the methodology

Several existing observational results are already consistent with the methodology's substrate-clean primary structure:

- The GW170817 standard-siren measurement of $H_0 = 70^{+12}_{-8}$ km/s/Mpc is consistent (within its substantial uncertainty) with both the CMB-derived value (67.4) and the conventional ladder value (73.0). This is the first substrate-clean cosmological-scale H_0 determination, and as more standard-siren events accumulate, the methodology predicts that the substrate-clean result will converge to the CMB-derived value rather than the conventional-ladder value.

- Strong-lensing time-delay measurements (H0LiCOW, TDCOSMO) have produced results clustering around 73 km/s/Mpc, but with significant variation across lens systems. The methodology predicts that the variation is attributable to differing levels of photon-channel contamination across lens systems, and that the substrate-mediated geometric component of strong lensing should converge to the CMB-derived value once the photon-channel monitoring contribution is appropriately accounted for.

- Pulsar-timing-array measurements of the gravitational-wave background (NANOGrav 15-year data set) are emerging and provide independent constraints on cosmological dynamics; the methodology predicts Z_{14} 14-peak structure in the GW background spectrum if cosmological in origin.

9.2 Forward predictions specific to the methodology

The methodology generates several specific forward predictions whose verification or falsification will validate or constrain the framework:

(1) Substrate-clean tier consistency. As more GW standard sirens accumulate (Einstein Telescope era), the population-averaged H_0 from Tier 2 should converge to a value statistically distinguishable from the conventional-ladder value of 73 km/s/Mpc, falling closer to the CMB-derived value of 67-68 km/s/Mpc, within the methodology's predicted 8.28 percent structural offset.

(2) Cross-tier diagnostic of photon-channel cocycle. Photon-channel measurements at high z (Tier 7) that are corrected via UM-deconvolution (§6) should produce H_0 values consistent with substrate-clean tiers; uncorrected, they should diverge from substrate-clean tiers by 8 percent.

(3) JWST early-universe anomalies. Reported anomalies in early-universe observations from the James Webb Space Telescope (apparent over-density of massive galaxies at high z; apparent age tensions) are predicted to dissolve when the photon-channel cocycle correction is applied to the JWST-derived distances and ages.

(4) GW chirp Z_{14} sub-structure. Compact-binary inspirals should exhibit Z_{14} 14-peak structure in chirp-frequency evolution at sufficient sensitivity. This is detectable with Einstein Telescope and Cosmic Explorer.

(5) Strong-lensing time-delay convergence. Sufficient strong-lensing systems analyzed within the methodology will converge to a sub-percent H_0 determination consistent with substrate-clean tiers; persistent variability is attributed to differing levels of photon-channel contamination across lens-system monitoring quality.

9.3 Falsification surface

The methodology is falsifiable. Specific failure modes that would constrain or falsify it:

- If substrate-clean tiers (1 through 5) persistently disagree with each other beyond their uncertainties when measuring the same source or comparable sources, the methodology's substrate-clean-equivalence claim is falsified.

- If UM-deconvolution of photon-channel measurements (Tier 6 and 7) does not bring them into consistency with substrate-clean tiers, the deconvolution procedure is incorrect or the cocycle structure is mis-derived.

- If the predicted Z_{14} sub-structure in GW chirps or PTA backgrounds is not observed at sufficient sensitivity, the framework's Z_{14} universal phase quantization is constrained or falsified, with downstream implications for the methodology.

- If the JWST early-universe anomalies persist after UM-deconvolution is applied, the methodology has not correctly accounted for the high-z cocycle behavior, and the f(z) shape function or the upstream framework requires revision.

10. Discussion

10.1 Comparison to conventional methodology

Conventional cosmological distance methodology places photon-channel methods at every tier and treats the Hubble tension as a parameter discrepancy. The methodology specified in this document treats the same observations differently:

- **Tier ordering:** conventional places photon-channel Cepheid + SN Ia as the primary cosmological-scale ladder; the present methodology demotes them to Tier 6 and requires UM-deconvolution.
- **Primary probe:** conventional has no substrate-clean primary; the present methodology places GW standard sirens (Tier 2) as the primary cosmological-scale probe.
- **Interpretation of multi-tier disagreement:** conventional reads disagreement as a problem to fix through parameter tuning; the present methodology reads disagreement as a structural diagnostic of cocycle inference-path difference.
- **Resolution of the Hubble tension:** conventional approaches add new physics (early dark energy, modified gravity, etc.) to the cosmological model; the present methodology resolves the tension through methodological reordering without requiring new physics beyond the UM framework.

10.2 Limitations

The methodology has several explicit limitations:

1. The shape function f(z) for the UM-deconvolution is first-order specified as tanh(z); refinement to higher-order forms requires cross-tier calibration as more substrate-clean measurements accumulate.
2. Substrate-clean tiers currently have larger per-measurement uncertainties than the well-calibrated photon-channel ladder. Methodology adoption requires statistical accumulation of substrate-clean measurements to drive uncertainties below the photon-channel level.
3. The Tier 5 (PTA) constraints are statistical and integrated rather than per-source; they validate the substrate-clean framework but do not provide per-source distance determinations.
4. The methodology assumes the framework's cosmic-shell residue and Triune partition are correct; if those are revised in the locked corpus, the cocycle-correction factor $F_{\text{cocycle}}(z)$ must be re-computed.

10.3 Open questions for further methodology development

Several open questions remain for future development:

1. The detailed form of f(z) beyond tanh(z) first-order approximation; this should be calibrated against accumulating substrate-clean measurements.

2. The shell-depth cocycle corrections at non-cosmic shells (e.g., galactic-cluster shell, $\mu_D = 5 + 3 = 8$); these are needed for proper handling of intermediate-scale distance measurements.

3. The Z_{14} structural signatures in GW chirps and PTA backgrounds; detection of these signatures is a Tier 2 forward prediction (Paper 4 of the series) and would simultaneously validate the framework's structural quantization.

4. Integration with conventional ΛCDM phenomenology where existing fit parameters can be reinterpreted within UM rather than discarded; this is a presentation question affecting community adoption.

Closing

This methodology specifies the operational procedures by which UM-native S-Field-primary methods replace photon-channel primary methods at the cosmological scale. The methodology is internally consistent, immediately applicable with existing instruments, and produces specific testable predictions. It rests on the foundational framework of Paper 1 (Zenodo DOI 10.5281/zenodo.20162810) and the closed-form derivation of the Hubble-rate inference discrepancy in Paper 2 of the UM/FUM series.

The methodology's central claim is that the Hubble tension is not a parameter discrepancy requiring new fitted physics; it is a structural diagnostic of inference-path difference between photon-channel and substrate-clean measurement protocols, fully derived in closed form within Universal Mechanics. Resolution comes through methodological reordering rather than parameter tuning.

Adoption requires no new instruments. The substrate-clean tiers are operational or under construction. What is required is the methodological commitment to substrate-clean primary methods and the application of UM-deconvolution to retained photon-channel tiers.

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Universal Mechanics · First Utterance Model
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