Supplementary Material: The Unified Applicable Timeframe (UAT) and the Resolution of the Hubble Tension

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1 Sensitivity to Large Scale Structure (LSS)

A common critique of early-universe modifications is the potential introduction of an S_8 tension (clustering of matter). In the UAT framework, the modification k_{early} is compensated by the shift in ω_{cdm}[cite: 14, 76].

1.1 The S_8 Parameter

The UAT model predicts a value of $S_8 = \sigma_8\sqrt{\Omega_m/0.3}$ consistent with KiDS-1000 and DES Y3 observations[cite: 141]:

$$S_8^{\text{UAT}} = 0.812 \pm 0.015 \tag{1}$$

This demonstrates that UAT does not resolve the H_0 tension at the cost of exacerbating the LSS tension, maintaining a global fit better than ΛCDM[cite: 6, 86].

2 Detailed Predictions for Future Observatories

The UAT framework is uniquely falsifiable due to its specific predictions for the effective number of relativistic species and the sound horizon[cite: 106, 107].

2.1 CMB-S4 and Simons Observatory

The UAT model predicts a clear signature in the high-ell damping tail of the CMB power spectrum[cite: 109].

- **Prediction**: $N_{\text{eff}} = 4.78 \pm 0.14$[cite: 76].
- **Observational Test**: CMB-S4 is expected to reach a precision of $\sigma(N_{\text{eff}}) \approx 0.03$[cite: 109]. A detection of $N_{\text{eff}} > 3.046$ at more than 5σ would constitute a definitive validation of the UAT mechanism[cite: 109].

2.2 BAO at High Redshift (DESI)

UAT predicts a shift in the BAO scale due to the 5.16% reduction in r_d[cite: 81, 82].

- **Prediction**: The Hubble flow at $z > 2$ (Lyman-alpha forest) should follow the UAT expansion rate $E_{\text{UAT}}(z)$[cite: 30, 110].
- **Observational Test**: DESI measurements of $d_H(z)/r_d$ will distinguish UAT from late-time dark energy solutions[cite: 110].

3 Response to Potential Reviewer Queries

Query 1: Origin of ΔN_{eff} *Response:* Unlike "Dark Radiation" models, ΔN_{eff} in UAT is not a free particle species but an effective contribution to the energy-momentum tensor arising from the discretization of the gravitational field in Loop Quantum Gravity (LQG)[cite: 13, 166].

Query 2: Coincidence Problem *Response:* The UAT framework naturally explains why the modification occurs in the early universe, as the quantum-to-classical transition in the applicable timeframe is triggered by the density reaching the Barbero-Immirzi threshold[cite: 18, 22].

References