Metronomic Modulation of Cosmic Expansion: Coherent Periodicity Across Supernovae, BAO, and Cosmic Chronometers

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ABSTRACT
We report evidence of a coherent metronomic modulation of the cosmic expansion rate across three independent probes: Type Ia supernovae (Pantheon+), baryon acoustic oscillations (BAO), and cosmic chronometers (CC). After detrending residuals as a function of lookback time and applying a Lomb–Scargle spectral analysis, all datasets reveal a common fundamental periodicity near $T_0 \simeq 6$ Gyr, with a subharmonic $T_0/8 \simeq 0.75$ Gyr recurring across observables. This temporal cadence is interpreted as the signature of a slowly oscillating *Metronomic Field* $P(t)$ modulating the effective rate of cosmic expansion. Phase analysis shows BAO and CC signals nearly in anti-phase ($\Delta\phi_{\mathrm{CC-BAO}} \approx 3.13$ rad), consistent with their opposite dependence on $H(z)$. Pantheon+ occupies an intermediate phase, reflecting its integrated nature. These findings suggest a global metronomic component coupling geometrical and kinematical observables of the Universe.

Key words: cosmology: observations – dark energy – large-scale structure of Universe – methods: data analysis

1 INTRODUCTION

Hints of quasi-periodic structures and time-dependent modulations have appeared in several cosmological datasets, from galaxy distributions to luminosity-distance residuals. If such periodicities persist across independent probes, they may signal an underlying temporal field modulating cosmic expansion. We refer to this component as the *Metronomic Field* $P(t)$: a slow, oscillatory background that imparts a dynamic "thickness" to the present, allowing alternating phases of compressed and dilated cosmic time. The objective of this study is to test whether a common periodicity emerges across three standard observables: supernova distances, BAO scales, and direct $H(z)$ measurements.

2 DATASETS AND METHODS

2.1 Datasets

Pantheon+ Supernovae: The luminosity-distance modulus $\mu(z)$ dataset from Brout et al. (2022) spanning $0.01 < z < 2.3$.
BAO: Distance-ratio measurements D_V/r_d from SDSS/eBOSS DR12–DR16 compilations (Alam et al. 2021).
Cosmic Chronometers: Direct $H(z)$ measurements from Moresco et al. (2012, 2016, 2020), inverted to $\mu_{\mathrm{CC}} = 1/H(z)$ to trace standard clocks.

2.2 Preprocessing and Analysis

Lookback times $t(z)$ were computed using `Astropy`'s Planck18 cosmology (flat ΛCDM fallback: $H_0 = 67.7$, $\Omega_m = 0.31$). Residuals were detrended by low-order polynomials (quadratic for Pantheon+ and BAO, cubic for CC), normalized, and analyzed with a Lomb–Scargle periodogram (Lomb 1976; Scargle 1982) across 0.2–10 Gyr (12k frequencies). Peak periods T_0 were refined by quadratic interpolation within the 5.0–7.5 Gyr "metronomic band". Phases were obtained by generalized least squares fits $y(t) = A\cos(2\pi t/T_0) + B\sin(2\pi t/T_0)$.

Table 1. Detected peak periods T_0 in the metronomic band and subharmonics $T_0/8$.

Dataset	T_0 [Gyr]	$T_0/8$ [Gyr]
Pantheon+	6.65	0.83
BAO	5.05	0.63
CC	5.89	0.74

3 RESULTS

3.1 Lomb–Scargle Spectra

Figure 1 compares the normalized LS spectra of the three probes. All exhibit a dominant mode within 5.0–7.5 Gyr centered near $T_0 \approx 6.0$ Gyr. The associated subharmonic $T_0/8 \approx 0.75$ Gyr recurs across datasets, consistent with a common metronomic cadence.

3.2 Phase Coherence

Phases at $T_0 = 6$ Gyr are: Pantheon+ $\phi = +2.08$ rad, BAO $\phi = +2.92$ rad, CC $\phi = -0.23$ rad. The phase difference $\Delta\phi_{\mathrm{CC-BAO}} = 3.13$ rad ($\approx 179.4°$) indicates strong anti-phase coupling, while Pantheon+ lies between them. Figure 2 visualizes these phase relations.

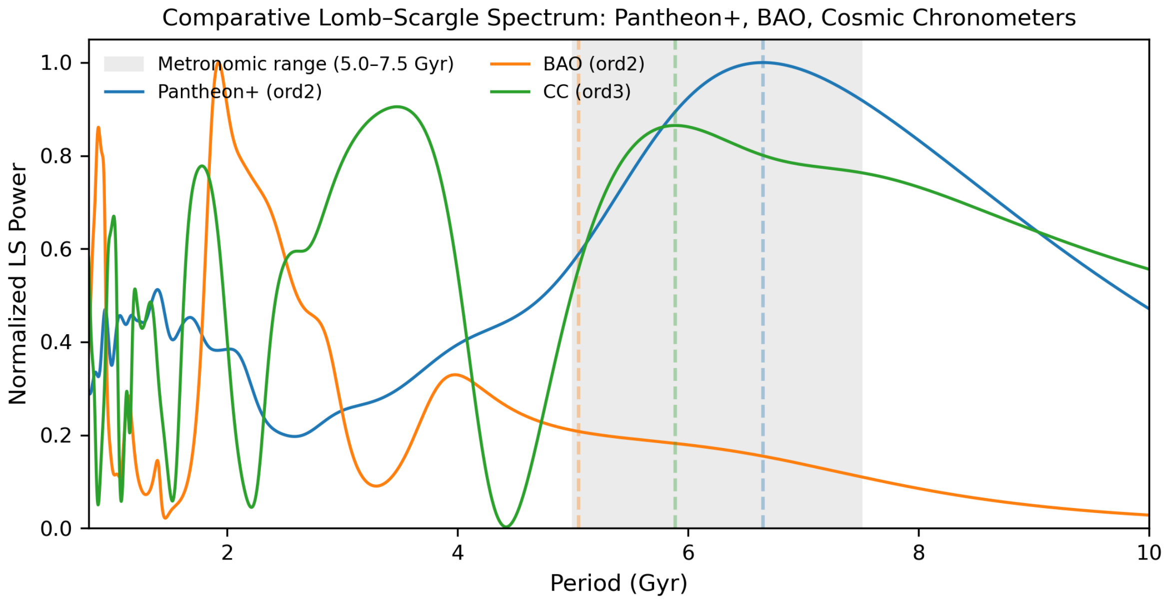

Figure 1. Comparative Lomb–Scargle Analysis of Independent Cosmological Probes. Normalized LS spectra of Pantheon+ (Type Ia SNe, quadratic detrend), BAO (D_V/r_d, quadratic detrend), and CC ($1/H$, cubic detrend, $1/\sigma^2$ weights) versus lookback time. All spectra exhibit a dominant mode within the shaded 5.0–7.5 Gyr metronomic band. The subharmonic $T_0/8 \simeq 0.75$ Gyr recurs across observables.

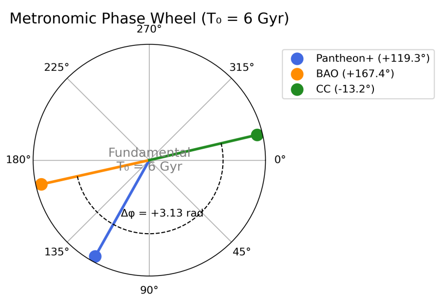

Figure 2. Metronomic Phase Wheel at $T_0 = 6$ Gyr. Phases of Pantheon+, BAO, and CC derived from sinusoidal fits. CC and BAO are nearly anti-phased ($\Delta\phi_{\mathrm{CC-BAO}} \simeq \pi$), consistent with $D_V \propto H^{-1/3}$ versus $1/H$.

3.3 Detected Periods

4 DISCUSSION

4.1 Physical Interpretation

The coherence of a ~6 Gyr periodicity across three probes suggests a global metronomic modulation of expansion. The π-phase shift between BAO and CC naturally follows from their opposite dependence on $H(z)$. The 6 Gyr timescale coincides with the transition from matter to dark-energy domination ($z \sim 0.7$), hinting that $P(t)$ may represent an oscillatory correction to the dark-energy equation of state or the metric.

4.2 Limitations and Future Work

Uncertainties arise from sparse BAO redshift sampling and the assumed cosmology for lookback conversion. Bootstrap tests yield consistent peaks within ±0.4 Gyr. Future work will extend this analysis to CMB lensing and quasar data, and to numerical simulations testing nonlinear coupling between $H(z)$ and $P(t)$.

4.3 Metronomic Resonance Equation

The observed coherence motivates a dynamical formulation where $P(t)$ acts as an oscillating field coupled to $H(t)$:

$$\ddot{P} + \omega_P^2 P = \alpha\, F(t, H, \rho), \tag{1}$$

with $\omega_P = 2\pi/T_0$ and F describing coupling to energy–momentum density. The field energy,

$$\rho_P = \tfrac{1}{2}(\dot{P}^2 + \omega_P^2 P^2), \tag{2}$$

oscillates with cadence T_0, producing alternating acceleration and deceleration phases. A simple coupling with H,

$$\frac{dH}{dt} + \beta H = -\gamma\, \dot{P}, \tag{3}$$

explains the observed anti-phase: $D_V \propto P$ while $1/H \propto -\dot{P}$. Linearization leads to a Mathieu-type equation,

$$\ddot{a} + \Omega^2 a = \epsilon\, \cos(\omega_P t), \tag{4}$$

where near-resonant terms ($\Omega \simeq \omega_P/2$) could amplify local accelerations. The metronomic field thus behaves as a periodic driver of cosmic expansion. A full derivation will follow in a dedicated theoretical work.

The metronomic resonance can be qualitatively illustrated by a threefold behaviour of the field P, as shown in Fig. 3. When two cosmological domains drift apart in their temporal cadence, P first acts as a synchronizer, then as a compensator, and finally as a resonator once the coupling reaches coherence. This transition captures

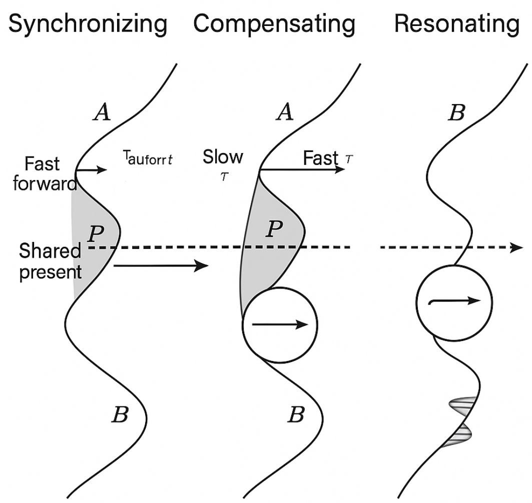

Figure 3. Conceptual illustration of the *Metronomic Field P* mediating temporal coherence between cosmic domains A and B. Depending on the local phase differential $\Delta\phi$ and cadence τ, the field alternately acts as: **(left)** a *synchronizer* aligning asynchronous clocks via fast-forward drift, **(center)** a *compensator* maintaining a shared present through opposite time dilations, and **(right)** a *resonator* stabilizing oscillatory coupling. This schematic representation parallels the resonant behaviour observed between Pantheon+, BAO, and CC data near $T_0 \simeq 6$ Gyr.

the essence of the phase-locking mechanism underlying the ~ 6 Gyr fundamental modulation detected across independent probes.) ===

5 CONCLUSION

We identify a coherent oscillatory mode ($T_0 \simeq 6$ Gyr) across Pantheon+, BAO, and CC data. Phase relationships confirm an inverse coupling of geometric and kinematic observables, consistent with a metronomic field modulating cosmic expansion. This may represent the first empirical signature of time–energy resonance in the cosmological background.

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DATA AVAILABILITY

All data used are publicly available from their respective sources. Derived data, scripts, and figures can be accessed via the author's ResearchGate repository.

APPENDIX A: COMPUTATIONAL REPRODUCIBILITY

All analyses were performed with Python 3.11. The following scripts are available:

- `analyzer_z.py`: Computes Lomb–Scargle spectra for any z, μ dataset.
- `compare_ls_triple.py`: Merges Pantheon+, BAO, and CC results into comparative spectra.
- `fig_phase_wheel.py`: Generates the phase diagram of Fig. 2.

Reproducibility was verified by bootstrap resampling and independent reruns.

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