

16 – Cosmic Chronometers and Differential Ageing

Empirical tests of constrained temporal structure

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Abstract

This paper examines cosmic chronometers as probes of global temporal structure under the Time-Symmetric Parity Constraint (TSPC). Differential age measurements of passively evolving stellar populations are treated not as reconstructions of an expansion history, but as relative clocks sampling the mapping between redshift and elapsed proper time. Under TSPC, this mapping is not freely adjustable, but constrained by global temporal symmetry. Chronometer data therefore function as an admissibility test rather than a parameter-

estimation tool. Persistent, redshift-dependent departures from the constrained time-redshift relation are interpreted as resistance to the imposed geometry rather than as motivation for parametric extension. The analysis deliberately excludes absolute age calibration, stellar population modelling, and forecast-driven optimisation, focusing instead on whether differential ageing provides a genuine empirical pressure point for a geometry-first cosmological framework.

1. Introduction

TSPC imposes a restriction not only on spatial geometry but on temporal structure. If the universe is constrained to evolve symmetrically away from a shared low-entropy origin at $T = 0$, reaching a maximal-entropy tipping epoch before contracting symmetrically toward a terminal state, then the mapping between redshift and elapsed proper time cannot be treated as an arbitrary function to be inferred retrospectively from data. It must instead be consistent with the imposed temporal symmetry. Cosmic chronometers offer a distinctive means of probing this mapping.¹ By comparing the differential ages of passively evolving stellar populations at neighbouring redshifts, chronometer measurements access relative time intervals directly, without reliance on standard candles or rulers. Their empirical content lies not in absolute age determination, but in the rate at which proper time accumulates with redshift.

In conventional cosmological analyses, chronometer data are typically used to reconstruct the expansion history through flexible parameterisations of $H(z)$.²

¹ Jimenez, R. and Loeb, A., *Constraining cosmological parameters based on relative galaxy ages*, Astrophysical Journal, 573, 37–42 (2002). Introduced the cosmic-chronometer method, showing that differential ageing of passively evolving galaxies provides direct access to dz/dt without reliance on standard candles or rulers. The method probes the redshift–time relation itself rather than distance geometry, making it sensitive to temporal structure independently of spatial assumptions.

² Stern, D., Jimenez, R., Verde, L., Kamionkowski, M. and Stanford, S. A., *Constraining the equation of state of dark energy. I: $H(z)$ measurements*, Journal of Cosmology and Astroparticle Physics, 02, 008 (2010), doi: 10.1088/1475-7516/2010/02/008. Representative chronometer compilation used to constrain expansion history via direct $H(z)$ measurements inferred from differential galaxy ageing.

Deviations are absorbed through adjustments to background functions or through modelling uncertainties associated with stellar evolution. In this context, chronometers contribute to constraint tightening, but they are not permitted to challenge the admissibility of the assumed temporal structure itself.

The present paper adopts a different stance. Under TSPC, the redshift–time relation is restricted by global symmetry and cannot be freely deformed. Chronometer measurements therefore test not whether a smooth $H(z)$ curve can be fitted, but whether the implied accumulation of proper time remains consistent with the constrained geometry. Persistent, structured departures from the expected differential ageing profile cannot be neutralised without undermining the constraint itself.

The scope of this paper is deliberately limited. It does not attempt to refine stellar population models, to adjudicate absolute galaxy ages, or to forecast the performance of future surveys. Its sole purpose is to establish whether cosmic chronometers, treated strictly as differential clocks, provide a clean empirical test of global temporal admissibility within a geometry-first cosmological framework.

Subsequent sections introduce the minimal formal relations required to express differential ageing, interpret chronometer measurements under constraint, and examine their role as temporal discriminators complementary to spatial tests such as void geometry.

2. Geometric framework for chronometer-based tests

2.1 Why chronometers may be treated as differential clocks

Cosmic chronometers are intended to probe temporal structure through differential ageing rather than absolute dating. The method is based on passively evolving stellar populations whose spectra allow relative age differences to be estimated across neighbouring redshifts. The observational content is therefore carried primarily by age gradients, not by absolute ages.

This distinction matters. Absolute age estimation is unavoidably entangled with stellar population modelling, metallicity evolution, and assumptions about star-formation history.³ By contrast, differential ageing is designed to suppress sensitivity to unknown formation time. A constant offset in formation epoch cancels to leading order when neighbouring redshift bins are compared, leaving an estimate of the rate at which elapsed proper time accumulates with redshift.

³ Moresco, M. et al., *Improved constraints on the expansion rate of the Universe up to $z \sim 1.1$ from the spectroscopic evolution of cosmic chronometers*, Journal of Cosmology and Astroparticle Physics, 08, 006 (2012), doi: 10.1088/1475-7516/2012/08/006. Sets out chronometer sample selection and quantifies dominant systematics (stellar population synthesis, metallicity, star formation history) and how the differential method mitigates them.

Within the present framework, chronometers are therefore treated as probes of the mapping between redshift and elapsed proper time along the cosmological flow. The method is not taken to reconstruct an arbitrary expansion history. It is taken to test whether the redshift–time mapping implied by a globally constrained geometry remains admissible when confronted with differential clock data.

The role of chronometers in the empirical programme is thus the temporal analogue of the void-based Alcock–Paczynski test. Spatial admissibility is interrogated by a ratio of radial and transverse scales. Temporal admissibility is interrogated by the rate at which proper time accumulates with redshift. In both cases, discriminatory power arises only when background freedom is restricted rather than negotiated.

2.2 Differential ageing and the redshift–time mapping

The formal content required for the chronometer test is closed and minimal. All subsequent interpretation refers back to the relations below.

(1) Differential relation between elapsed proper time and redshift

$$\frac{d\tau}{dz} = - \frac{1}{(1+z)H(z)}$$

This relation expresses the rate at which elapsed proper time accumulates with redshift under a given background mapping.⁴ For sufficiently small redshift intervals, the corresponding finite-difference form is:

$$\Delta\tau \approx - \frac{\Delta z}{(1+z)H(z)}$$

(2) Chronometer content expressed as a time–redshift gradient

Chronometer measurements are treated as estimates of a differential ageing gradient inferred from passively evolving stellar populations:

$$\left(\frac{d\tau}{dz}\right)_{\text{obs}}$$

This observed gradient is compared directly with the gradient implied by the background mapping defined in (1).

(3) Distortion under an assumed temporal mapping

Let quantities labelled “ass” denote the assumed mapping used to interpret redshift as elapsed proper time, and quantities labelled “true” denote the correct mapping.

$$\alpha_\tau(z) = \frac{\left(\frac{d\tau}{dz}\right)^{\text{ass}}}{\left(\frac{d\tau}{dz}\right)^{\text{true}}}$$

⁴ Simon, J., Verde, L. and Jimenez, R., *Constraints on the redshift dependence of the dark energy potential*, Physical Review D, 71, 123001 (2005), doi: 10.1103/PhysRevD.71.123001. Uses the chronometer differential-age formalism and the relation between dz and dt to obtain direct H(z) constraints.

Using the differential relation in (1), the same temporal scaling may be expressed equivalently in terms of the implied expansion mappings:

$$\alpha_\tau(z) = \frac{H^{\text{true}}(z)}{H^{\text{ass}}(z)}$$

(4) *TSPC closure statement*

Within TSPC, the mapping between redshift and elapsed proper time is not treated as a freely deformable fit function. It is determined, up to the limited degrees of freedom admitted by the global parity constraint imposed on the geometry, with symmetry anchored at $T = 0$ and with the tipping epoch treated as a derived extremum rather than a symmetry point. Chronometer gradients are therefore employed as a temporal admissibility test: persistent, redshift-dependent disagreement between

$$\left(\frac{d\tau}{dz}\right)_{\text{obs}}$$

and the constrained mapping is interpreted as resistance to the constraint itself, rather than as motivation for parametric extension.

2.3 Interpretation under temporal constraint

The relations set out in Section 2.2 establish a closed mapping between redshift and elapsed proper time along the cosmological flow. Once this mapping is fixed, the interpretation of chronometer measurements becomes conceptually straightforward. Chronometer data probe not absolute ages, but the rate at which proper time accumulates with redshift, and therefore interrogate the temporal component of the background geometry directly.

The crucial point is that differential ageing does not diagnose dynamics. It does not depend on assumptions about the initial formation time of galaxies, nor does it require reconstruction of a global expansion history. When treated strictly as differential clocks, chronometers measure relative time intervals that are insensitive, to leading order, to unknown offsets in stellar age calibration. In this respect they parallel the role played by voids in spatial tests of geometry.

In conventional analyses, chronometer measurements are embedded within flexible reconstructions of $H(z)$. Deviations are absorbed through smoothing procedures, nuisance parameters, or modelling freedom associated with stellar populations. Under such treatments, chronometers contribute to constraint tightening but are not permitted to challenge the admissibility of the assumed temporal structure. The possibility that the time–redshift mapping itself might fail is effectively precluded.

Under TSPC, this interpretive option is not available. The accumulation of proper time with redshift is restricted by global temporal symmetry anchored at $T = 0$. As a result, persistent, redshift-dependent departures of the observed differential ageing gradient

from the constrained mapping cannot be dismissed as artefacts of fitting strategy or modelling uncertainty without undermining the constraint itself.

This shift in interpretation alters the empirical role of chronometers. Rather than serving as inputs to a best-fitting expansion history, they function as temporal admissibility tests. Agreement across redshift supports the internal coherence of the constrained temporal geometry; systematic deviation constitutes resistance to it. As with the spatial Alcock–Paczyński test, the emphasis is not on precision, but on coherence and persistence.

Chronometers therefore occupy a logically distinct position among empirical probes. They test the temporal aspect of the same geometric structure interrogated spatially by voids. In doing so, they provide a complementary pressure point for a framework in which geometry is imposed and then tested, rather than inferred retrospectively from data.

3. Chronometers as temporal discriminators

Cosmic chronometers acquire discriminatory power only when the mapping between redshift and elapsed proper time is treated as something that may fail, rather than as something that must be reshaped until agreement is achieved. Their empirical significance therefore depends not primarily on precision, but on the interpretive stance adopted toward temporal structure.

In mainstream cosmological analyses, chronometer measurements are typically embedded within flexible reconstructions of the expansion history. Deviations are absorbed through smoothing procedures, through redshift-dependent nuisance parameters, or through allowances for stellar population modelling uncertainties. Within this framework, chronometers contribute to tightening bounds on parameterised forms of $H(z)$, but they are not permitted to challenge the admissibility of the underlying time–redshift relation itself.

Under TSPC, this interpretive flexibility is deliberately curtailed. The accumulation of proper time with redshift is restricted by a global temporal symmetry anchored at $T = 0$. As a result, chronometer measurements test not whether a smooth expansion history can be reconstructed, but whether the implied differential ageing remains compatible with the constrained temporal geometry. The discriminatory character of the test becomes apparent when redshift dependence is considered. A constant offset in differential ageing could plausibly be attributed to calibration error or to residual modelling uncertainty. A structured, redshift-dependent deviation, persisting across independent chronometer samples, cannot be dismissed in this way without undermining the constraint itself. Under a geometry-first framework, such behaviour constitutes resistance rather than noise.

This use of chronometer data contrasts sharply with forecast-driven analyses, where their primary role is to improve sensitivity to extended parameterisations of dark

energy or modified gravity. In the present framework, no such parameter space is being explored. Chronometers are employed instead to test whether a globally constrained temporal structure can be sustained when confronted with observations that directly sample elapsed proper time.

In this sense, cosmic chronometers function as the temporal analogue of the Alcock–Paczyński test applied to void geometry. Both probe relative mappings rather than absolute calibration, and both become decisive only when background freedom is restricted. Where flexibility treats deviation as something to be negotiated, constraint treats it as something to be confronted.

Chronometers therefore occupy a distinctive place among empirical probes. They do not refine the framework incrementally, nor do they offer a route to improved parameter estimation. They test coherence. Agreement across redshift supports the internal consistency of the constrained temporal geometry. Persistent deviation exposes structural weakness if it exists.

4. Consequences under the Time-Symmetric Parity Constraint

Under TSPC, temporal structure is not inferred piecemeal from observations, but imposed globally as an algebraic restriction on the spacetime geometry. The mapping between redshift and elapsed proper time is therefore not an object of continuous adjustment. It is fixed, up to tightly bounded freedom, by the requirement of symmetry about the low-entropy origin at $T = 0$, with the tipping epoch emerging as a derived extremum rather than as a symmetry point.

This has immediate consequences for the interpretation of chronometer data. In frameworks that permit temporal flexibility, discrepancies between observed differential ageing and a reconstructed expansion history can always be neutralised by reshaping the background mapping. Under the parity constraint, this manoeuvre is curtailed. Only mappings compatible with the imposed symmetry are admissible, and persistent disagreement cannot be eliminated without abandoning the constraint itself.

As a result, chronometer measurements acquire a different empirical status. They are no longer treated as inputs to a smoothing or fitting exercise, but as checks on the internal coherence of the constrained temporal geometry.⁵ Apparent deviations are not automatically interpreted as evidence for additional freedom in the expansion history.

⁵ Moresco, M. et al., *A 6% measurement of the Hubble parameter at $z \sim 0.45$: direct evidence of the epoch of cosmic re-acceleration*, Journal of Cosmology and Astroparticle Physics, 05, 014 (2016), doi: 10.1088/1475-7516/2016/05/014. Illustrates the level of achievable $H(z)$ precision with carefully controlled chronometer systematics, and the way results are used in mainstream acceleration reconstructions. (Cosmic chronometers refer to passively evolving stellar populations whose differential ages at neighbouring redshifts provide direct estimates of relative elapsed proper time, independent of standard candles or standard rulers.)

Instead, they are examined for structure, persistence, and redshift dependence, precisely because those features cannot be absorbed without structural cost.

The implications are clearest when chronometer behaviour is considered across extended redshift ranges. A framework constrained by global symmetry is expected to impose coherence across epochs. If the geometry is admissible, the accumulation of proper time inferred from chronometers should track the constrained mapping consistently. Conversely, systematic redshift-dependent departures signal resistance to the imposed structure rather than local modelling error.

This consequence does not depend on the absolute precision of chronometer measurements, nor on the details of stellar population synthesis. The effect in question is qualitative rather than incremental. The issue is not whether deviations are small, but whether they are structured and persistent. Under constraint, even modest but coherent departures carry interpretive weight, because the usual avenues for accommodation are deliberately closed.

Chronometers therefore function in a manner analogous to consistency conditions in algebraic systems. They do not refine the framework; they test whether it can be maintained at all. Agreement supports the internal coherence of TSPC. Failure to do so exposes structural incompatibility.

In this way, temporal measurements join spatial and propagational probes in a unified empirical strategy. Each interrogates a different aspect of the same imposed geometry, and each is selected not for its statistical leverage, but for its capacity to resist interpretive flexibility. The role of chronometers within this programme is to test whether the constrained temporal structure implied by TSPC can be sustained when confronted with direct measures of differential ageing.

5. Relation to other empirical probes

The role assigned to cosmic chronometers in the present analysis is not isolated. It forms part of a deliberately selective empirical strategy in which different classes of observation interrogate different aspects of the same global geometric constraint. What distinguishes chronometers is that they probe the temporal component of the background geometry directly, with minimal dependence on spatial modelling or dynamical evolution.

Other empirical probes considered elsewhere in the compendium occupy complementary positions. Void-based Alcock–Paczyński measurements test spatial admissibility, examining whether the mapping between angular and radial distances preserves isotropy when background freedom is restricted. Gravitational lensing probes geometry along dense lines of sight, where matter is present but the angular-diameter mapping remains central. Gravitational-wave observations interrogate spacetime propagation, testing whether signal travel is consistent with a constrained metric rather than with freely adjusted distance measures.

Chronometers differ from these probes in that they address neither spatial geometry nor propagation, but the accumulation of proper time itself. In this sense, they provide the temporal analogue to spatial admissibility tests. Both depend on relative measures rather than absolute calibration, and both acquire discriminatory power only when the background mapping is not treated as freely deformable.

The ordering of empirical probes within the compendium is therefore logical rather than historical. Spatial geometry is addressed first, because it underlies all distance inference. Temporal structure follows, because the mapping between redshift and elapsed time conditions the interpretation of expansion, growth, and ageing. Propagational tests are treated separately, as they probe the consistency of signal transmission within the same constrained geometry. Each probe is chosen not for its novelty or statistical reach, but for its capacity to resist accommodation.

This selectivity is intentional. Many commonly cited cosmological observables are excluded from the present programme because they reward parameter freedom rather than enforce structural discipline. Chronometers are retained precisely because they cannot be neutralised by local adjustments without global cost. When background freedom is curtailed, their agreement or disagreement carries interpretive weight.

In this context, chronometer measurements should not be read as alternative routes to precision cosmology, nor as supplements to parameter estimation exercises. Their role is foundational. They test whether the temporal structure implied by TSPC can be sustained when confronted with direct measures of differential ageing. Together with spatial and propagational probes, they form a coherent empirical programme in which geometry is imposed and then tested, rather than inferred retrospectively from data.

6. Summary and limits

This paper has examined cosmic chronometers as probes of global temporal structure under TSPC. By treating chronometer measurements as differential clocks and by restricting the interpretive freedom usually granted to the redshift–time mapping, the analysis has focused on whether a constrained temporal geometry can be sustained when confronted with observations that directly sample elapsed proper time.

The central claim has been deliberately modest. Cosmic chronometers are not presented as precision tools for reconstructing an expansion history, nor as independent arbiters between competing cosmological models. Their value lies instead in their capacity to function as temporal admissibility tests when background freedom is curtailed. Under TSPC, the accumulation of proper time with redshift is not freely deformable. As a result, persistent, redshift-dependent disagreement between observed differential ageing and the constrained mapping cannot be neutralised through parametric adjustment without undermining the constraint itself.

This makes chronometer measurements a genuine empirical pressure point. Agreement across redshift supports the internal coherence of the constrained temporal structure;

systematic deviation constitutes resistance to it. The test is therefore binary in character. It does not refine the framework incrementally, but confronts it with the possibility of failure. In this respect, chronometers differ sharply from many commonly used cosmological observables, which reward flexibility and thereby blur the distinction between explanation and accommodation. The limits of the present analysis should also be clear. No claim is made that existing chronometer datasets already deliver a decisive verdict. Nor is it asserted that differential ageing alone can adjudicate between all cosmological frameworks. The purpose of the paper has been narrower: to establish that, within a geometry-first approach, chronometers occupy a logically prior position among temporal probes, and that their force cannot be reduced once interpretive freedom is deliberately constrained.

Finally, it should be emphasised that this paper addresses temporal structure only. Other aspects of TSPC are tested by complementary probes treated elsewhere in this compendium of papers, including spatial admissibility tests based on void geometry and propagational tests based on gravitational-wave observations. Taken together, these probes form a selective empirical programme in which each test is chosen for its capacity to resist interpretive flexibility and to expose structural weakness if it exists. In this sense, cosmic chronometers are not presented as data to be accommodated, but as tests to be endured. Whether the constrained temporal geometry implied by TSPC passes that test is a matter for observation. The role of the framework is not to guarantee success, but to make failure unambiguous.

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