

CHANGISM · VOLUME II

Relational Tempo Cosmology

*A Change-First Framework for Cosmic Time, Averaging, and
Cosmological Inference*

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Preface

I wrote this book because a familiar achievement of modern physics seemed to leave behind an unfinished question. Relativity abolished the need for Newton's universal temporal flow. It replaced a single master clock with proper times along particular physical histories, coordinate systems constructed for particular purposes, and lawful relations among clocks, signals and events. Yet cosmology routinely describes the history of the entire Universe through one scale factor evolving with respect to one cosmic-time parameter. What, exactly, is that parameter, and how far does its physical authority extend?

There is no contradiction in the standard answer. In a perfectly homogeneous and isotropic FLRW spacetime, cosmic time is a legitimate and exceptionally useful construction. The symmetry of the model selects a natural family of ideal comoving observers whose proper times can be coordinated into a common cosmological ledger. This book does not argue that FLRW cosmic time is a conceptual mistake, still less that modern cosmology has simply smuggled Newtonian absolute time back into physics.

The question begins when that symmetry-supported construction is extended to the actual late Universe. Matter has differentiated into voids, walls, filaments, clusters, galaxies and gravitationally bound systems with distinct regional histories. Observations reach us along the past light cone through a succession of emission, propagation, interaction, calibration and registration processes. Spatial averaging, dynamical evolution, observational fitting and light-cone reconstruction are not automatically the same operation. The central concern of this book is whether compressing those differentiated relations into one homogeneous cosmic history may conceal information significant enough to affect cosmological inference.

I came to this problem through Changism, the philosophical framework from which Relational Tempo Cosmology draws its ontological motivation. Changism begins from the primacy of productive, relational change. Physical processes do not first occupy a pre-existing temporal container and then begin to act. Their interactions, recurrences, differences and records supply the material from which temporal order is constructed. Clocks count organized physical activity; signals connect events; records preserve outcomes; and wider temporal ledgers coordinate these local achievements. Time, on this account, is derivative without being arbitrary, and relational without being merely subjective.

Relational Tempo Cosmology asks whether this change-first discipline can clarify the relationship among regional physical histories, clock comparisons, cosmological averaging and the global histories inferred from observations. But the relationship between Changism and RTC must be stated carefully:

Changism motivates RTC; it does not entail its physical models or guarantee its empirical hypotheses.

RTC is therefore not Changism translated directly into equations. No ontology, however coherent, can determine the magnitude of cosmological backreaction, supply a missing closure relation, establish an environmental dependence in the data or show that dark energy is unnecessary. Those conclusions would require determinate models and successful observational tests. A reader may reject Changism while finding elements of RTC's formal framework, methodological discipline or empirical programme worth pursuing. Conversely, accepting Changism would not establish that regional tempo differentiation has any cosmologically significant effect.

The book is written for several overlapping audiences. Philosophers of time, process and science may be principally interested in the distinction between fundamental change, objective metric order and derivative temporal ledgers. Cosmologists and relativists may approach it through the fitting problem, relativistic averaging, timescape cosmology and the relation between regional histories and fitted observables. Researchers concerned with the Hubble-parameter tension, apparent acceleration or environmental effects may focus upon the proposed tests and their rival explanations. More broadly, the book is intended for readers interested in what must happen before an ontological proposal can become a scientifically vulnerable research programme.

The technical demands consequently vary across the book. Some sections are principally philosophical; others assume familiarity with relativity, cosmology or statistical inference; the appendices are designed for readers who wish to inspect the mathematical and observational machinery closely. No reader is expected to approach every part with the same purpose. Nor is acceptance of the Changist ontology a condition of entry. The empirical proposals should be judged by the same standards whether the reader is sympathetic, indifferent or hostile to their philosophical origin.

This is an ambitious book, but it is not a declaration of a completed alternative cosmology. It offers an ontological interpretation, a relational framework, a formal core, candidate model structures and a programme of observational discrimination. It does not provide a unique closed dynamics for an inhomogeneous Universe. It does not demonstrate that the cosmological constant is an artefact, establish that apparent acceleration results from clock calibration, or claim completed observational confirmation. It does not deny relativity, the objectivity of proper-time differences or the empirical achievements of Λ CDM. Nor does it suggest that a change of coordinates or time parameter can make luminosity distances, redshifts, angular scales or structure-growth observations disappear.

The book's stronger physical proposals must therefore be allowed to fail. If the predicted regional or environmental signatures are absent, sufficiently restrictive null results must narrow or reject the models that predicted them. Their failure cannot be redescribed as a deeper confirmation of Changism. Equally, if an RTC model were to succeed across independent observational channels, that success would support the tested physical model without proving that Changism is the uniquely correct ontology. Philosophical motivation, mathematical construction and empirical confirmation remain connected but distinct.

This separation is the reason for the brief guide to the six evidential levels that follows this preface. The guide identifies the different kinds of work undertaken in the book and the evidential burden appropriate to each. The subsequent list of principal notation and abbreviations provides a compact reference for the symbols that recur across the philosophical, geometrical, cosmological and statistical discussions. Readers are invited throughout to ask what kind of claim is being made, what would count as evidence for it, and what exactly would have to be surrendered if it failed.

Those reading primarily for the physics may proceed through Sections 1–3 and then move directly to Section 6. Sections 4 and 5 develop the conceptual lineage of the relational stance through dependent tempo and relational facts, but the formal and empirical programme does not require agreement with those comparisons. Sections 6–12 construct the physical and mathematical route from proper clock counts to cosmological comparison networks, averaging structures and light-cone observables. Sections 13–16 form the empirical spine of the book: they state the central hypothesis, give it quantitative form, compare it with rival explanations and specify the observational programme and its falsifiers. Section 17 confronts the principal objections, Section 18 considers the conditional implications for cosmic fate, and Section 19 gathers the argument without converting its open questions into conclusions. Appendices A–E provide the derivations, parameterizations, mock designs, campaign structures and reproducibility requirements through which particular implementations may be audited.

The deepest commitment of this book is therefore methodological as much as ontological. Philosophy can reveal an assumption that has become invisible through familiarity. It can distinguish a useful representation from the reality represented and ask whether a successful construction has been granted more authority than its conditions warrant. But philosophy cannot decide in advance whether correcting that assumption changes any observation. To cross that boundary, the proposal must become mathematically determinate, confront its strongest rivals and accept the possibility of an unfavourable answer.

My purpose is not to replace the old master clock with a new substance called Change, or to turn a philosophical metaphor into a cosmological mechanism. It is to ask whether the Universe can be described more faithfully by beginning with

physical processes, signals and records, and treating the global cosmic history as a disciplined construction from their relations. The answer may be that the homogeneous ledger remains an extraordinarily accurate effective description. It may require a modest correction, a more substantial reconstruction, or no departure from standard cosmology at all.

The book is written so that each of those outcomes can be recognized for what it is. That is the intellectual contract under which the arguments that follow should be read.

A Brief Guide to the Six Evidential Levels

Relational Tempo Cosmology moves between ontology, interpretation, mathematical construction and observational science. To keep these tasks distinct, the book classifies its substantive claims into six levels.

These are not six degrees of certainty, nor stages through which a philosophical idea automatically becomes established physics. They identify what kind of claim is being made, what evidence is appropriate to it, and what its success or failure would—and would not—establish. A single chapter may operate at several levels, but no argument may slide between them without justification.

The governing rule is:

No claim may borrow more evidential force than belongs to its own level.

1. Ontology

The ontological level asks what is fundamental. Changism proposes that concrete actuality is productive, relational change and that temporal ledgers arise within organized change. Time is therefore derivative, although temporal relations, metric order and clock differences remain objectively real.

This thesis can guide physical interpretation, but it does not by itself calculate the Hubble parameter, determine the magnitude of cosmological backreaction or establish that dark energy is unnecessary.

2. Interpretation

The interpretive level asks what established physics means without changing its equations or predictions. At this level, proper time may be understood as invariant metric order physically realized through proper count, while FLRW cosmic time may be understood as a symmetry-selected cosmological ledger rather than an independently flowing substance.

When no observable prediction changes, the result is an interpretation of existing physics, not a new physical theory.

3. Framework

The framework level specifies how a relational cosmology should be constructed. Tempo assignments must be explicitly reference-indexed; distant comparisons must include a physical protocol; coordinate quantities must be distinguished from

observables; and global ledgers must be constructed from relations among processes, signals and records.

A framework organizes and constrains possible models. It does not yet provide a unique dynamics or determine numerical predictions.

4. Model

The model level introduces a specific mathematical implementation. A model must identify its geometry, matter content, observer congruences, reference clocks, averaging domains, propagation rules, closure relations, parameters and observable quantities.

To become physically competitive, it must be determinate, covariant, parsimonious and capable of recovering established FLRW results in the appropriate limit. The failure of one model does not automatically refute every model compatible with the broader framework.

5. Empirical hypothesis

The empirical-hypothesis level states what is expected to differ physically. The central example is the Homogeneous Ledger Misidentification Hypothesis: regional differentiation may materially affect what is inferred when observations are compressed into a single homogeneous cosmological history.

The strength of the claim must always be specified. Evidence for a small correction would not show that the cosmological constant can be eliminated. Failure of the strongest version could still leave weaker versions open, while sufficiently restrictive null results could reduce the effect to observational insignificance.

6. Test

The test level specifies how an empirical hypothesis will be exposed to possible failure. A valid test identifies the model and its rivals, the observable contrast, the datasets, the relevant systematics, the predicted sign and magnitude, the materiality threshold and the outcome that would count against the proposal.

The strongest evidence is cross-predictive: parameters fitted in one observational channel successfully predict effects in others. A favourable fit obtained by assigning a separate adjustable function to every dataset does not constitute a unified explanation.

The six levels classify the work being undertaken; they do not certify that every task has already been completed. This book develops a Changist ontology, an interpretation of relativistic and cosmological time, a relational framework, a

formal core and a falsifiable empirical programme. It does not claim to have derived a unique dynamical closure or completed a replacement for Λ CDM.

The relations among the levels are therefore deliberately asymmetric. Ontology may motivate an interpretation, and interpretation may guide a framework, but motivation is not derivation and compatibility is not confirmation. Empirical success would support the model tested without uniquely proving Changism. Empirical failure must narrow or eliminate the affected physical proposal, but it need not erase every ontological or interpretive insight from which that proposal arose.

Section 2 develops these distinctions fully. Sections 13–16 form the empirical spine of the book, while Appendices A–E supply the derivations, parameterizations, mock designs and reproducibility machinery through which particular implementations can be assessed.

Throughout the book, the reader may therefore ask three questions:

What level does this claim occupy? What evidence is appropriate to that level? What exactly would change if the claim failed?

Principal Notation and Abbreviations

The notation in *Relational Tempo Cosmology* serves several different levels of analysis: relativistic geometry, process comparison, spatial averaging, observational reconstruction and statistical testing. This guide collects the principal symbols and abbreviations that recur across those levels.

It is a navigational reference, not a replacement for the full definitions and qualifications supplied where each quantity is introduced. Symbols used only within a single derivation are normally defined locally and omitted here.

General conventions

- The metric signature is $(-+++)$.
- The speed of light is denoted by c . Sections 9–10 and Appendix A use geometric units $c = 1$ unless c is restored explicitly.
- An overdot denotes differentiation with respect to the time parameter declared in the relevant section. It must not be interpreted as differentiation with respect to an unqualified universal time.
- A subscript 0 denotes the present epoch or present fitted value where this is explicitly stated.
- A subscript *cal* denotes the calibration epoch of Appendix B. That epoch is not identified with the present.
- A subscript *ref* denotes a fixed reference value or reference distribution.
- An asterisk normally marks a registered pivot or reference value. It does not mean “present epoch” unless expressly defined that way.
- The labels v , f and w denote void-like, filament-like and wall-like regions or populations.
- The labels R , S and L denote reference processes, reference networks or constructed ledgers.
- D denotes a specified averaging domain. In some appendix expressions the same domain label appears as D , as in τ_D or a_D .

- Bare r is reserved for the relative drift of the wall–domain tempo ratio. Comoving distance is denoted by χ . The subscripted quantity r_d denotes the sound horizon at the baryon drag epoch.

Geometry, clocks and relational tempo

Symbol	Meaning
$g_{ab}, g_{\mu\nu}$	Spacetime metric. Latin or Greek indices are used according to the local geometrical context.
χ^μ	Spacetime coordinates.
c	Invariant local causal-propagation speed in vacuum. It is not an absolute speed of change.
γ_A	Worldline or physical history of system A . This use of γ must be distinguished from the ledger-conversion factors below.
τ	Proper time along a specified timelike worldline.
t	Coordinate-time or model-time parameter specified by the local construction.
t_L	Time parameter of reference ledger L .
τ_r	Proper time of the observer class associated with region r .
$N_A[\gamma_A]$	Accumulated count, phase or succession of an admissible physical process A along its history.
ν_C	Calibrated proper frequency of clock process C , as in $d N_C = \nu_C d\tau$.
P_{AB}	Physical protocol pairing events or records associated with processes A and B .
$\Gamma_{A B,P}$	Pairwise tempo ratio $d N_A / d N_B$ under protocol P : first process per second process.
$\bar{\Gamma}_{A B,P}$	Accumulated count ratio over a specified finite interval.
$\Gamma_R(\chi)$	Derived continuous tempo representation at χ , relative to reference network R . It is not an intrinsic speed of change at χ .
$\eta_{AB,P}$	Logarithmic tempo ratio, $\eta_{AB,P} = \ln \Gamma_{A B,P}$.
Ω_C	Multiplicative tempo holonomy around closed comparison loop C . An integrable scalar representation requires $\Omega_C = 1$ after known effects have been included.

Symbol	Meaning
$\gamma_{r L}$	Regional ledger-conversion factor $d t_L / d \tau_r$: ledger time per regional proper time.
$\dot{\gamma}_w, \dot{\gamma}_v$	Timescape phenomenological lapses for wall and void observers relative to the volume-average parameter.
α_{RS}	Conversion ratio $d N_R / d N_S$ between reference ledgers R and S .
α	Reserved coarse-grained wall-domain tempo ratio, $\alpha = d \tau_w / d \tau_D$. Under the specified timescape identification, $\alpha = 1 / \dot{\gamma}_w$.
$\delta\alpha(x, \tau_D)$	Local modulation of the domain-level ratio, defined so that $\langle \delta\alpha \rangle_D = 0$.
$r(\tau_D)$	Relative drift $d \ln \alpha / d \ln a_D = H_D^{-1} d \ln \alpha / d \tau_D$.
η_α	Constant relative-drift parameter of the linear-drift model. It exists as a fitted component only for that model form.

The four uses of gamma-like notation are therefore distinct:

- γ_A : a worldline;
- $\Gamma_{A|B,P}$: a process-count ratio;
- $\gamma_{r|L}$: a regional ledger-conversion factor;
- $\dot{\gamma}_w$: the timescape wall lapse.

Cosmology and spatial averaging

Symbol	Meaning
$a(t)$	FLRW scale factor.
$H = \dot{a} / a$	Hubble expansion rate relative to the time parameter used in the stated model.
H_0	Expansion rate evaluated at the present epoch within a declared model or inference pipeline. Superscripts identify distinct operational routes where necessary.
$q = -\ddot{a} a / \dot{a}^2$	Deceleration descriptor relative to the specified ledger.
q_R	Deceleration descriptor relative to reference ledger R .
z	Observed redshift.

Symbol	Meaning
Λ	Cosmological constant.
Ω_m, Ω_Λ	Matter and cosmological-constant density parameters.
u^a	Four-velocity field of a specified observer or matter congruence.
$\theta = \nabla_a u^a$	Local expansion scalar of that congruence.
σ^2	Shear magnitude or shear scalar, as defined locally.
V_D	Proper volume of averaging domain D .
$\langle X \rangle_D$	Riemannian volume average of X over D .
a_D	Volume scale factor of domain D .
H_D	Expansion rate of the domain scale factor relative to the domain parameter.
$H_{D \mid R, P}$	Expansion of domain D relative to reference ledger R under protocol P .
Q_D	Buchert kinematical-backreaction term, constructed from expansion variance and shear.
$\langle R \rangle_D$	Averaged scalar curvature of the spatial hypersurface over D .
f_v, f_f, f_w	Evolving volume fractions of void-like, filament-like and wall-like regions.
$\dot{a}, \dot{H}$	Timescape volume-average or “bare” scale factor and Hubble parameter.
a_d, H_d	Timescape “dressed” scale factor and Hubble parameter inferred by wall observers.

Light-cone and observational quantities

Symbol	Meaning
χ	Comoving radial distance.
n	Observed sky direction or line-of-sight unit vector.
D_L	Luminosity distance.
D_A	Angular-diameter distance.
D_M	Transverse comoving distance used in BAO analyses.

Symbol	Meaning
$D_H = c / H(z)$	Hubble distance.
D_V	Isotropic volume-averaged BAO distance.
r_d	Comoving sound horizon at the baryon drag epoch.
μ	Distance modulus.
$\Delta\mu_i$	Distance-modulus or Hubble residual for object i .
$\dot{z}$	Redshift drift with respect to the stated observer time.
$Z_{R,p}$	Reference-indexed redshift drift dz / dN_R .
κ	Weak-lensing convergence.
$P_X(k, z)$	Power spectrum of field X , as a function of wavenumber k and redshift z .
C_l^{XY}	Angular cross-spectrum or auto-spectrum of fields X and Y at multipole l .
Φ	Newtonian gravitational potential in the weak-field discussion; in the timing discussion, the same letter denotes the phase of a periodic process. The context fixes the meaning.

Empirical and statistical notation

Symbol	Meaning
$E_{i,p}^{raw}$	Raw environment proxy of registered proxy family p for object i .
$\tilde{E}_{i,p}$	Environment proxy standardized using frozen reference moments, not moments recomputed within the analysed sample.
A_i	Channel amplitude predicted by a specified RTC implementation after the registered projection.
$\hat{\beta}_i$	Coupling estimated from the observational data in channel i . Conditional on the model and stated assumptions, its expectation may equal A_i ; the two are not identical quantities.
$\Delta_{obs,i}$	Channel-level observational residual.
X_i	Vector of registered control covariates for object i .
ϵ_i	Object-level regression error or residual scatter. It is distinct from the residual fields ϵ_α and ϵ_κ .

Symbol	Meaning
$\psi = \ln \alpha$	Unconstrained logarithmic parameterisation used to guarantee $\alpha > 0$.
ζ_α	Centred latent transform used to impose positivity and zero domain mean on $1 + \delta\alpha$.
b_α	Coupling between the tempo-modulation field and the matter-density contrast in the density-biased model.
ϵ_α	Registered residual field not represented by the density-correlated component.
$\sigma_\alpha(R, z)$	Root-mean-square modulation amplitude on smoothing scale R at redshift z ; a derived reporting quantity, not an independent fitted freedom.
b_κ	Latent coupling of the projected modulation to weak-lensing convergence.
ϵ_κ	Residual field in the projected-modulation model.
$\lambda_{RTC}^{(d,m)}$	Independent parameter vector for an admitted pairing of domain-ratio form d and modulation form m .
$p = p_d + p_m$	Dimension of the independent fitted parameter vector.
F_i	Full forward operator mapping physical parameters to the predicted records of channel i .
J_{ia}	Registered linear response of channel i to parameter component a .

A **rung** is one complete, pre-registered pairing of a domain-ratio form d with a modulation form m . It is not an individual constant, linear, binned or projected component, and the term does not imply that all rungs form a universally nested sequence. Models are indexed directly by (d, m) .

Principal abbreviations

Abbreviation	Meaning
BAO	Baryon acoustic oscillation or oscillations
CMB	Cosmic microwave background
DESI	Dark Energy Spectroscopic Instrument
FLRW	Friedmann–Lemaître–Robertson–Walker
GW	Gravitational wave
HLMH	Homogeneous Ledger Misidentification Hypothesis

Abbreviation	Meaning
ISW	Integrated Sachs–Wolfe effect
kSZ	Kinetic Sunyaev–Zel’dovich effect
Λ CDM	Lambda cold-dark-matter cosmology
NC	Null commitment, numbered NC-1 to NC-9 in Section 16
PTA	Pulsar timing array
RQM	Relational Quantum Mechanics
RTC	Relational Tempo Cosmology
SH0ES	Supernova H_0 for the Equation of State
SN Ia	Type Ia supernova
TRGB	Tip of the red-giant branch

No symbol in this guide should be read as introducing an absolute temporal background. In particular, $\Gamma_R(x)$, α and $\delta\alpha$ are constructed, reference-indexed comparison quantities. Their physical content depends upon the processes, observer families, domains, signal paths and comparison protocols specified by the relevant model.

1. Introduction: The Return of the Cosmic Master Clock

Modern physics is often said to have abolished the universal clock. Newton had conceived absolute time as flowing uniformly and independently of everything that happened within it. Events could be assigned positions in this temporal medium, while the medium itself remained unaffected by matter, motion, observation or physical change. Every clock was, in principle, an imperfect instrument attempting to track the same invisible, universal passage ([Newton 1999, pp. 408–409](#)).

Relativity dismantled that picture. There is no operationally privileged clock whose readings define the tempo of the entire universe. Clocks following different worldlines can accumulate different totals between relevant events. Their readings depend upon their motion, their gravitational conditions and their paths through spacetime. Simultaneity at a distance requires a specified procedure and is not shared universally by all observers. What remains objective is not one master temporal flow, but a structure of invariant intervals, causal relations, signal connections and lawful translations among local records ([Einstein 1905](#); [Misner, Thorne and Wheeler 1973](#)).

This transformation is sometimes summarized by saying that relativity replaced absolute time with proper times. The plural matters. Proper time is associated with a particular timelike worldline, not distributed universally throughout the cosmos ([Misner, Thorne and Wheeler 1973](#)). Operationally, it is accessed through the accumulated activity of an admissible clock: oscillations occur, phases develop, atomic transitions are counted, circuits update, and records are progressively formed. Two clocks that separate and reunite may display different totals, not because one received less of a substance called Time, but because the physical processes travelling along the two histories accumulated differently.

Yet cosmology appears to complicate this relativistic victory. The standard description of the universe restores something that looks remarkably like a universal clock. In the Friedmann–Lemaître–Robertson–Walker model, the whole cosmos is represented through a single scale factor $a(t)$ evolving with respect to one cosmic-time parameter t :

$$ds^2 = -c^2 dt^2 + a^2(t) d\Sigma_k^2.$$

The parameter t labels a succession of homogeneous spatial hypersurfaces. Ideal observers comoving with the cosmological matter distribution share this cosmic time, and the expansion of the universe is expressed through the Hubble parameter

$$H(t) = \frac{1}{a} \frac{da}{dt}.$$

At first glance, this can look like the return of Newton's master clock: one cosmic beat against which the evolution of everything is measured.

That conclusion would be too quick. FLRW cosmic time is not Newtonian absolute time restored under a relativistic name. It does not exist independently of geometry, nor does relativity require every possible spacetime to possess it. It arises because an exactly homogeneous and isotropic geometry selects a natural congruence of ideal comoving observers and a corresponding foliation orthogonal to their worldlines. Their proper times can be coordinated into one global parameter because the model assumes away the

regional differences that would otherwise obstruct such a construction. Cosmic time is therefore a legitimate consequence of FLRW symmetry ([Ellis and van Elst 1999](#)).

It is best understood as a **symmetry dividend**, not a universal birthright.

The foundational question begins when the idealized construction is extended from an exactly homogeneous model to the actual late universe. Matter is not smoothly distributed. It has organized into stars, galaxies, groups, clusters, filaments, sheets and enormous underdense voids. Most of the cosmic volume appears to reside in voids, while astronomers and their instruments necessarily inhabit gravitationally bound structures. Regional densities, curvatures, shear and expansion histories differ. Photons reaching us do not arrive from a homogeneous spatial slice but travel along null paths through this evolving cosmic web. Our cosmological knowledge is assembled from emissions, propagations, receptions, calibrations and records distributed across different physical environments ([Cautun et al. 2014](#)).

The standard approach does not ignore these facts. Perturbation theory, structure-formation simulations, peculiar-velocity corrections, lensing calculations and survey-selection models incorporate inhomogeneity with extraordinary sophistication. The empirical success of the standard Λ CDM framework across the cosmic microwave background, primordial light-element abundances, large-scale structure, baryon acoustic oscillations and supernova observations must not be understated ([Planck Collaboration 2020](#); [Alam et al. 2021](#); [Brout et al. 2022](#)). The question is not whether standard cosmology knows that the universe is lumpy. It plainly does.

The more specific question is whether the relationship between the lumpy universe and its smooth cosmological representation has been completely understood.

A spatial average of an inhomogeneous geometry need not evolve like an exactly homogeneous solution of Einstein's equations. Averaging density, averaging curvature, averaging expansion, fitting a smooth metric and calculating observations on the past light cone are distinct operations. They cannot be assumed to yield the same result merely because the universe becomes statistically homogeneous on sufficiently large scales. This is the cosmological fitting problem: what smooth model should be fitted to a structured universe, which quantities should be averaged, and how do the parameters of the fitted model relate to the physical conditions that generated the observations? The problem was articulated explicitly by Ellis and Stoeger and subsequently developed through several approaches to relativistic averaging and inhomogeneous cosmology ([Ellis and Stoeger 1987](#)).

Buchert's scalar-averaging formalism demonstrates one part of the difficulty ([Buchert 2000](#)). For a spatial domain D , a regional volume scale factor can be defined by

$$a_D = \left(\frac{V_D}{V_{D0}} \right)^{1/3}.$$

The averaged equations contain a kinematical backreaction term,

$$Q_D = \frac{2}{3} \left(\langle \theta^2 \rangle_D - \langle \theta \rangle_D^2 \right) - 2 \langle \sigma^2 \rangle_D,$$

which records the variance of regional expansion and the contribution of shear. Even when the local geometry everywhere obeys Einstein's equations, the evolution of the average need not coincide with the evolution obtained by first homogenizing the matter

distribution and then solving those equations. Averaging and dynamical evolution do not generally commute ([Buchert 2000](#)).

Timescape cosmology gives this problem a specifically chronometric interpretation. It models the late universe through expanding voids and denser wall regions, distinguishes their regional histories, and introduces a lapse relation between a volume-average parameter and the proper time of observers in gravitationally bound systems. In this model, apparent acceleration can arise partly from the way wall observers calibrate the volume-average evolution, without requiring a conventional dark-energy component. Timescape therefore offers an important precedent for treating cosmic clock calibration as part of the cosmological fitting problem rather than as an incidental correction ([Wiltshire 2007a](#); [Wiltshire 2007b](#); [Wiltshire 2009](#)).

The present book develops this possibility from a different ontological starting point. It introduces **Relational Tempo Cosmology**, a Changist framework for reconstructing cosmic averaging without treating either global or regional times as independently flowing quantities.

Changism begins from the primacy of change. Physical processes do not first exist as static entities and then enter a pre-existing temporal container. Their activity, interaction, recurrence, differentiation and record-production are ontologically prior to the ledgers constructed to compare them. Time, in this framework, is not a substance, force, dimension of passage or invisible background. It is the organized comparative structure through which changes are counted, standardized, coordinated and represented: clock readings, recurrence counts, synchronization rules, signal exchanges, coordinate assignments, retained records and ratios among processes.

This does not make temporal quantities arbitrary. Changism rejects reified Time, not objective metric structure. Proper-time differences are physically real. Differential ageing is real. Gravitational and kinematic clock comparisons are measurable and technologically indispensable. A coordinate change cannot erase the different readings of reunited clocks. But none of these facts requires the additional claim that clocks detect different amounts or rates of a temporal substance. Relativistic geometry represents invariant organization among physical histories; proper counts physically realize that organization through accumulated process activity.

The same discipline must be brought into cosmology. A cosmological expansion rate is not an absolute rate at which the universe changes relative to Time. It is a relation between a chosen measure of spatial or volumetric change and a specified physical or representational clock ledger. The expression

$$H = \frac{1}{a} \frac{da}{dt}$$

does not become meaningless once t is recognized as derivative. It becomes more explicit about its conditions of application. The parameter t identifies the ledger relative to which the scale-factor change is expressed. In an exact FLRW model, that ledger is supplied naturally by the comoving congruence. In an inhomogeneous cosmos, its relationship to regional observers, clock processes and light-cone observations becomes a physical question rather than something guaranteed by symmetry.

Relational Tempo Cosmology therefore begins from three principles:

No tempo without a reference.

No reference without a physical process.

No distant comparison without a protocol.

A process is not intrinsically fast or slow. Tempo is always comparative:

$$\Gamma_{A|B,P} = \frac{dN_A}{dN_B},$$

where N_A and N_B denote the accumulated counts of specified physical processes and P denotes the procedure by which their stages or records are compared. The relation may involve reunion, exchanged signals, an observer congruence, a synchronization convention or a defined cosmological fitting procedure. Without these specifications, the notion of an absolute rate of change has no operational meaning.

A continuous cosmological tempo structure must therefore not be imagined as a field assigning an independent “speed of Time” to every point. Its more fundamental form is a network of relations among physical processes, worldlines, signals and records. Once a reference family R is selected, a reference-indexed field may be constructed:

$$\Gamma_R(x) = \frac{dN_x}{dN_R}.$$

The subscript is indispensable. It records the dependence of the assignment upon a chosen comparison standard. Another reference family will produce a different description, connected to the first through lawful translation. No particular ledger becomes the true clock of the universe merely because it is convenient, stable or mathematically simple.

The project may consequently be described as a **Changescape** approach. The word does not name a new substance distributed across the cosmos. It names a differentiated landscape of physical process relations: regional expansion, clock accumulation, matter development, photon propagation and record formation. Global cosmological time emerges only when selected relations within this landscape are compressed into a common ledger.

This approach extends timescape’s central insight while revising its conceptual grammar. Rather than beginning with two temporal rates—wall time and volume-average time—Relational Tempo Cosmology begins with actual processes and the protocols relating their counts. A volume-average parameter is treated openly as an averaging ledger, not as a clock carried by a notional observer outside all regions. The wall-void lapse becomes one special relation within a more general continuous comparison structure. Chronometric tempo, regional expansion and material development are kept distinct rather than collapsed into one vague pace of the universe ([Wiltshire 2007a](#); [Wiltshire 2007b](#); [Wiltshire 2009](#)).

This distinction matters because not every process difference is a clock-rate difference. A reaction may proceed slowly because of temperature; star formation may decline because gas has been exhausted; a region may expand rapidly while its local atomic standards retain their usual mutual ratios. For a physical variable X , its rate relative to a reference ledger can be factorized schematically as

$$\frac{dX}{dN_R} = \frac{dX}{dN_C} \frac{dN_C}{dN_R},$$

where N_C is a local clock count. The first factor concerns the local dynamics of X ; the second concerns the chronometric relation between the local clock and the selected reference. Relational Tempo Cosmology must calculate both without mistaking either for an absolute temporal rate.

The observational priority of the framework is therefore the past light cone, not an imagined view of the universe from outside. Cosmology observes photons emitted by distant systems and received by local instruments. Redshift already possesses an explicitly relational form:

$$1 + z = \frac{(k_a u^a)_e}{(k_a u^a)_o},$$

relating the photon wave vector k^a to the four-velocities of emitter and observer. Luminosity distance, angular-diameter distance, lensing, redshift drift and baryon acoustic measurements are all constructed from networks of emission, propagation, reception and calibration. A global expansion history should be answerable to those records; it should not acquire ontological priority merely because it provides an elegant way of organizing them ([Ellis, Maartens and MacCallum 2012](#)).

This reversal of explanatory order can be stated simply:

local processes and records → signal-mediated comparisons
→ regional relations → averaged cosmic ledger .

The standard FLRW procedure often begins in the opposite direction:

global cosmic parameter $t \rightarrow a(t) \rightarrow$ regional observations as perturbations .

These directions need not be incompatible. A successful cosmology must move between model and observation in both directions. The question is which structure is treated as physically primary and whether the compression from the first sequence into the second discards information significant enough to alter cosmological inference.

That question has acquired particular urgency from several observational tensions. The value conventionally denoted H_0 is inferred differently from early-universe observations interpreted through Λ CDM and from local distance-ladder calibrations. These are not literally two clocks directly reading one cosmic quantity. They are two families of procedures combining different records, calibrators and modelling assumptions. Likewise, recent DESI DR2 indications that a cosmological constant may not provide the best fit when baryon acoustic oscillation and CMB data are combined with several alternative supernova compilations have reopened questions about the adequacy of the standard late-universe template. None of these discrepancies establishes that cosmic averaging or regional tempo is responsible. They identify places where the identification of several procedures with one homogeneous cosmic history can be tested ([Planck Collaboration 2020](#); [Riess et al. 2022](#); [Lodha et al. 2025](#)).

A closely related recent proposal by Clifton and Hyatt treats the Hubble tension as a manifestation of the cosmological fitting problem. It distinguishes statistical homogeneity of spatial averages from the stronger requirement that the universe be represented by a spacetime possessing explicit FLRW symmetry, showing how different observables may yield different fitted expansion rates. Its connection between the fitting problem and

radial BAO measurements makes it an especially important physical interlocutor for the present framework ([Clifton and Hyatt 2024](#)).

Relational Tempo Cosmology does not assume that such approaches will eliminate dark energy. Nor does it infer from the reference-dependence of acceleration that observed acceleration is unreal. The sign of a second derivative can change under reparameterization, but luminosity distances, redshifts, angular scales and clustering observations cannot be transformed away. A viable theory must reproduce them. Replacing t with another ledger without altering any observable relation would constitute reinterpretation, not new cosmology.

The more demanding empirical proposal explored here is the Homogeneous Ledger Misidentification Hypothesis, stated canonically in Section 2.5:

Homogeneous Ledger Misidentification Hypothesis (HLMH). *When records generated, propagated and registered across regionally differentiated gravitational and expansion environments are interpreted through a single homogeneous FLRW clock and scale-factor history, some part of the mismatch among regional expansion, averaged expansion and fitted expansion is absorbed into the homogeneous fit and represented as apparent late cosmic acceleration, disagreement among inferred cosmological parameters, or both.*

Whether this effect is negligible, corrective or cosmologically decisive is not settled by Changist ontology. It must be determined mathematically and observationally.

The book accordingly operates at several levels. First, it presents the Changist distinction between fundamental change, objective metric order and derivative temporal ledgers. Second, it relates this distinction to dependent origination and to the relational structure of Rovelli's interpretation of quantum mechanics, while resisting the claim that either supplies cosmological field equations. Third, it reconstructs proper time, proper count and comparative process rate as the foundation of a cosmological comparison network. Fourth, it examines FLRW cosmic time, the fitting problem, Buchert averaging and timescape cosmology. Fifth, it formulates a reference-indexed continuous tempo structure and identifies the conditions under which it could become a genuine physical model. Finally, it specifies observational discriminators involving the Hubble-parameter split, environmental dependence, redshift drift, supernovae, BAO, lensing, structure growth and the CMB ([Rovelli 1996](#)).

The ambition is substantial, but the initial claim is limited. This book does not provide a completed replacement for Λ CDM, derive a unique closure relation for cosmological backreaction, or demonstrate that dark energy is an artefact. It develops a framework in which those possibilities can be stated without reintroducing absolute time, formulated mathematically without ontological confusion, and exposed to empirical failure.

Relativity taught physics how to live without one universal clock. Cosmology showed why, under extraordinary symmetry, one cosmic clock could nevertheless be constructed. The task now is to determine whether that construction remains adequate once the universe differentiates into regions with distinct physical histories.

The cosmic master clock may never have returned as a substance. But it may have returned as a habit of representation. The purpose of Relational Tempo Cosmology is to ask what becomes visible when that habit is finally made explicit.