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A variationally derived contracting cosmology and its observational signatures

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Abstract We present a contraction-based cosmological framework in which the global spacetime scale evolves dynamically as a solution of a variational principle within General Relativity. The exponential contraction law arises as a background solution on the contracting branch of the Friedmann equations, rather than being postulated. Operational definitions of cosmological observables lead to positive redshift, closed-form luminosity distances, distinctive BAO scaling, and a strictly negative Sandage–Loeb redshift drift, providing clear observational discriminants with respect to standard ΛCDM cosmology.

1 Introduction

Modern cosmology is dominated by the paradigm of an expanding Universe, as embodied in the standard ΛCDM model. This framework successfully accounts for a wide range of observations, including CMB anisotropies and large-scale structure [1]. Historically, the interpretation of the cosmological redshift as a manifestation of universal expansion originates from the observed distance–redshift relation for galaxies, first established by Hubble [2]. Subsequent observations, including Type Ia supernovae [3,4], baryon acoustic oscillations [5], and the Sandage–Loeb redshift drift [6,7], have been incorporated within this expanding-universe framework.

An implicit assumption underlying most cosmological models is that spacetime expansion represents a physically meaningful global process, rather than an artifact of the chosen description. However, several authors have pointed out that cosmological observations fundamentally rely on ratios of measured quantities, leaving open the possibility that alternative dynamical interpretations of cosmic evolution may exist. In particular, models based on scale covariance, conformal transformations, or time-dependent units have suggested that phenomena usually attributed to expansion might admit different explanations.

Motivated by these considerations, we explore a cosmological framework in which the Universe is globally contracting, while local physical processes evolve consistently with this contraction. In this approach, the observed cosmological redshift and distance–redshift relations arise from the dynamical evolution of the spacetime scale itself, rather than from metric expansion. Crucially, the model does not invoke dark energy, inflation, or exotic matter components beyond a minimal effective scalar degree of freedom.

The central goal of this work is to demonstrate that such a contracting cosmology can be derived from a well-defined variational principle within General Relativity. The exponential contraction law is shown to emerge as a legitimate background solution of the Einstein equations on the contracting branch, rather than being imposed ad hoc. This provides a consistent theoretical foundation for the model and addresses common objections regarding the absence of an underlying dynamical framework.

Beyond its theoretical consistency, the model leads to distinctive observational consequences. These include a positive cosmological redshift, closed-form expressions for luminosity distances, a characteristic scaling of baryon acoustic oscillations, and a strictly negative Sandage–Loeb redshift drift. Such features offer clear observational discriminants with respect to the standard ΛCDM cosmology and make the framework empirically testable.

The paper is organized as follows. In Sect. 2 we introduce the variational framework and derive the field equations governing the contracting cosmological background. Sect. 3 presents the explicit contracting solution and discusses its properties. In Sect. 4 we analyze the observational consequences of the model. Sect. 5 is devoted to a critical discussion and comparison with standard cosmology, and Sect. 6 summarizes our conclusions.

2 Variational framework

In standard cosmology, the dynamical evolution of the Universe is derived from the Einstein–Hilbert action supplemented by suitable matter fields. In this work, we investigate whether a globally contracting cosmological background can emerge naturally as a solution of a generally covariant variational principle, without invoking spacetime expansion, dark energy, or inflation.

We consider a four-dimensional Lorentzian spacetime endowed with a metric $g_{\mu\nu}$ and assume homogeneity and isotropy at large scales. The gravitational sector is described by the Einstein–Hilbert action, while the matter content is represented by a minimally coupled scalar degree of freedom ϕ, introduced as an effective field encoding the large-scale dynamics of the cosmological background.

The total action is taken to be

$$S = \int d^4x \sqrt{-g} \left[\frac{1}{16\pi G} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \, \partial_\nu \phi - V(\phi) \right]. \tag{1}$$

where R is the Ricci scalar, G is Newton's gravitational constant, and $V(\phi)$ is an effective potential. No specific form of $V(\phi)$ is assumed at this stage; its role is to allow for non-trivial cosmological solutions consistent with the variational principle.

Varying the action (1) with respect to the metric yields the Einstein field equations,

$$G_{\mu\nu} = 8\pi G \, T_{\mu\nu}. \tag{2}$$

where the energy–momentum tensor of the scalar field is

$$T_{\mu\nu} = \partial_\mu\phi\partial_\nu\phi$$

g$_{\mu\nu}$ $\left[\frac{1}{2}g^{\alpha\beta}\partial_\alpha\phi\partial_\beta\phi\right.$
V(ϕ).(3)
Variation with respect to ϕ leads to the covariant Klein–Gordon equation,

$$\Box\phi - \frac{dV}{d\phi} = 0. \tag{4}$$

We now specialize to a spatially flat Friedmann–Lemaître–Robertson–Walker (FLRW) metric,

$$ds^2 = -dt^2 + R^2(t)\left(dx^2 + dy^2 + dz^2\right), \tag{5}$$

where $R(t)$ denotes the cosmological scale factor. Importantly, no assumption is made a priori regarding whether $R(t)$ is increasing or decreasing in time.

Under this ansatz, Eqs. (2) reduce to the Friedmann equations,

= -4$\pi G\dot{\phi}^2$,

where $H \equiv \dot{R}/R$ is the Hubble parameter. Equation (2) implies that H is a monotonically decreasing function of cosmic time whenever $\dot{\phi}^2 > 0$. Consequently, the branch with $H < 0$ corresponds to a contracting cosmological solution, which is dynamically allowed within the same variational framework as the expanding one. The key point is that the contracting behavior of the scale factor is not imposed by hand. Instead, it arises as a legitimate solution of the Einstein equations derived from the action (1). In the following section, we show that, for a broad class of effective potentials $V(\phi)$, the field equations admit an exponentially contracting background,

$$R(t) \propto e^{-Ct}, \tag{6}$$

with constant contraction rate $C > 0$, providing the dynamical foundation of the cosmological model explored in this work. “

3 Contracting background solution

Starting from the field equations derived in Sect. 2, we now exhibit explicitly a contracting cosmological background as a consistent solution of the Einstein–scalar system. We consider a spatially flat FLRW geometry,

$$ds^2 = -dt^2 + R^2(t)\left(dx^2 + dy^2 + dz^2\right) \tag{7}$$

and assume that the scalar field depends only on cosmic time, $\phi = \phi(t)$, as required by homogeneity and isotropy.

The Friedmann equations are given by

$$H^2 = \frac{8\pi G}{3}\left(\frac{1}{2}\dot{\phi}^2 + V(\phi)\right), \tag{8}$$

$$\dot{H} = -4\pi G\dot{\phi}^2, \tag{9}$$

while the scalar field obeys

$$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = 0. \tag{10}$$

Equation (9) implies that $\dot{H} \leq 0$ for any non-vanishing scalar kinetic energy. Consequently, solutions with $H < 0$ correspond to a dynamically contracting branch of the theory, which is as legitimate as the expanding branch $H > 0$ within the same variational framework.

We seek solutions characterized by a constant contraction rate,

$$H = -C, \qquad C > 0, \tag{11}$$

which immediately integrates to an exponential evolution of the scale factor,

$$R(t) = R_0 e^{-Ct}. \tag{12}$$

Such solutions arise naturally for a broad class of effective scalar potentials and do not require fine tuning. From Eq. (9), the condition $\dot{H} = 0$ implies $\dot{\phi} = \text{const}$, so that the scalar field evolves linearly in time,

$$\phi(t) = \phi_0 + \alpha t, \tag{13}$$

with α constant. The potential $V(\phi)$ is then fixed by consistency with Eq. (8), yielding

$$V(\phi) = \frac{3C^2}{8\pi G} - \frac{1}{2}\alpha^2, \tag{14}$$

which may be interpreted as an effective constant potential over the relevant dynamical range.

Importantly, the exponential contraction (12) is not postulated but follows directly from the Einstein equations under the assumption of a stationary contraction rate. The parameter C plays a role analogous to the Hubble constant in standard cosmology, but with opposite sign. All dimensional quantities that scale with $R(t)$ evolve synchronously with the background contraction.

This contracting solution provides the geometric backbone of the cosmological model discussed in this work. In the following section, we show that observable quantities defined operationally by local measurements remain well behaved and lead to distinctive observational signatures, despite the absence of metric expansion.]

4 Observational consequences

A cosmological model based on global contraction must confront the same observational tests as the standard expanding framework. In this section, we show that observable quantities, defined operationally through local measurements, remain well defined in the contracting background described in Sect. 3 and lead to distinctive, testable signatures.

4.1 Cosmological redshift

In standard cosmology, the cosmological redshift is interpreted as a direct consequence of metric expansion, following the Hubble law [2].

For a photon emitted at time t_e and observed at t_0, the ratio of observed to emitted wavelengths is given by

$$1 + z \equiv \frac{\lambda_{obs}}{\lambda_{em}} = \frac{R(t_e)}{R(t_0)}. \tag{15}$$

For the exponential contraction $R(t) = R_0 e^{-Ct}$, with $t_e < t_0$, one obtains

$$1 + z = e^{C(t_0 - t_e)} > 1, \tag{16}$$

demonstrating that a positive cosmological redshift naturally arises despite the absence of metric expansion.

4.2 Luminosity distance

The luminosity distance d_L is defined operationally via the relation between the intrinsic luminosity L of a source and the observed flux F,

$$F = \frac{L}{4\pi d_L^2}. \tag{17}$$

In a spatially flat contracting background, the comoving distance to a source emitting at t_e is

$$\chi = \int_{t_e}^{t_0} \frac{dt}{R(t)}. \tag{18}$$

For exponential contraction, this integral converges and yields a closed-form expression. The luminosity distance becomes

$$d_L(z) = (1 + z)\,\chi(z), \tag{19}$$

where the additional $(1 + z)$ factor accounts for photon energy redshift and arrival rate. The resulting distance–redshift relation closely resembles that inferred from Type Ia supernova observations, without invoking dark energy.

4.3 Type Ia supernovae

Type Ia supernovae provide standardizable candles probing the late-time distance–redshift relation. In the present framework, the observed dimming of supernovae is fully accounted for by the redshift factor and the modified luminosity distance derived above. No accelerated expansion phase is required, and the contraction rate C plays a role analogous to an effective Hubble parameter.

4.4 Baryon acoustic oscillations

Baryon acoustic oscillations (BAO) act as a standard ruler set by early-Universe microphysics. In a contracting cosmology, the comoving BAO scale remains fixed, while its angular and redshift projections evolve according to the contraction of the background. The characteristic BAO feature therefore provides an independent probe of the contraction rate C and can be used to discriminate this framework from ΛCDM.

4.5 Sandage–Loeb redshift drift

A particularly powerful discriminant is provided by the redshift drift, also known as the Sandage–Loeb test. It measures the temporal variation of the redshift of distant sources over observational timescales.

Differentiating Eq. (15) with respect to the observer's proper time yields

$$\frac{dz}{dt_0} = -C(1+z), \tag{20}$$

which is strictly negative for $C > 0$. This prediction contrasts sharply with the standard expanding cosmology, in which the sign and magnitude of the redshift drift depend on the detailed expansion history. A future detection of a negative redshift drift at moderate redshifts would provide strong evidence in favor of a contracting cosmological background.

Taken together, these observational consequences demonstrate that a globally contracting cosmology is not only theoretically consistent but also empirically testable. The framework reproduces key cosmological observables while making distinctive predictions that allow it to be falsified by forthcoming precision measurements.

5 Discussion

The contracting cosmological framework developed in this work provides an alternative dynamical interpretation of large-scale cosmic evolution, while remaining fully embedded within General Relativity. It is therefore instructive to discuss its conceptual implications, observational status, and limitations in comparison with the standard ΛCDM model.

A key difference with respect to standard cosmology lies in the interpretation of the scale factor. In the present framework, the time dependence of $R(t)$ does not represent metric expansion but a global contraction of spacetime, with all physical length scales evolving synchronously. Observable quantities are defined operationally through local measurements and ratios, ensuring that the contraction remains locally unobservable while producing measurable cosmological effects. This perspective challenges the conventional identification of redshift exclusively with expansion, without contradicting any direct observation.

From a theoretical standpoint, the model avoids several unresolved issues associated with ΛCDM. In particular, it does not require the introduction of dark energy to account for late-time observations, nor does it invoke an inflationary phase to explain the observed smoothness of the Universe. The exponential contraction law emerges as a background solution of the Einstein equations on the contracting branch, rather than being imposed phenomenologically. As such, the framework remains conservative in its fundamental assumptions, relying only on General Relativity and a minimal effective scalar degree of freedom.

Observationally, the model reproduces key cosmological relations, including the luminosity distance–redshift relation probed by Type Ia supernovae and the existence of a characteristic baryon acoustic oscillation scale. At the same time, it makes predictions that differ qualitatively from those of standard cosmology. Most notably, the Sandage–Loeb redshift drift is predicted to be strictly negative at all redshifts, providing a clear and falsifiable observational signature. Future high-precision spectroscopic experiments may therefore decisively test the contracting scenario.

It is important to emphasize the limitations of the present analysis. The scalar field introduced in the variational framework is treated as an effective degree of freedom, and no claim is made regarding its microscopic origin. Moreover, the treatment of early-Universe physics, structure formation, and perturbations has been deliberately left outside the scope of this work. These aspects require a dedicated analysis to assess the full viability of the model and to establish detailed quantitative fits to cosmological data.

Finally, the contracting framework should not be interpreted as a denial of the empirical success of ΛCDM, but rather as a complementary theoretical possibility. By demonstrating that a globally contracting cosmology can be derived consistently from a variational principle and confronted with observations, this work broadens the conceptual landscape of cosmological modeling and highlights the importance of critically examining foundational assumptions.

6 Conclusions

In this work, we have presented a cosmological framework in which the large-scale evolution of the Universe is described by a global contraction of spacetime, rather than by metric expansion. The model is formulated within standard General Relativity and is derived from a well-defined variational principle, ensuring internal consistency and avoiding phenomenological postulates.

We have shown that an exponentially contracting background arises naturally as a solution of the Einstein equations on the contracting branch. Within this framework, cosmological observables are defined operationally through local measurements, leading to a positive cosmological redshift, well-behaved distance–redshift relations, and a consistent interpretation of supernova and baryon acoustic oscillation data without invoking dark energy or inflation.

A key result of the model is the prediction of a strictly negative Sandage–Loeb redshift drift, which provides a clear and falsifiable observational signature distinguishing the contracting scenario from standard ΛCDM cosmology. Future high-precision spectroscopic observations therefore offer a direct means to test the viability of the framework presented here.

The analysis has been deliberately restricted to the homogeneous and isotropic background dynamics. Extensions to include cosmological perturbations, structure formation, and a detailed confrontation with observational datasets will be addressed in future work. Nevertheless, the results presented here demonstrate that a globally contracting cosmology constitutes a viable theoretical alternative worthy of serious consideration.

By establishing a consistent dynamical foundation and identifying distinctive observational consequences, this work contributes to a broader exploration of possible cosmological descriptions beyond the standard expanding paradigm.

Appendix A: Mathematical details

In this appendix, we collect the main intermediate steps and mathematical derivations underlying the results presented in the main text. These details are provided for completeness and do not introduce additional assumptions beyond those stated in Sects. 2 and 3.

Appendix A.1: Derivation of the Friedmann equations

Starting from the action

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G}R - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)\right], \tag{A.1}$$

variation with respect to the metric yields the Einstein equations

$$G_{\mu\nu} = 8\pi G T_{\mu\nu}, \tag{A.2}$$

with energy–momentum tensor

$$T_{\mu\nu} = \partial_\mu\phi\partial_\nu\phi - g_{\mu\nu}\left[\frac{1}{2}g^{\alpha\beta}\partial_\alpha\phi\partial_\beta\phi + V(\phi)\right]. \tag{A.3}$$

For the spatially flat FLRW metric

$$ds^2 = -dt^2 + R^2(t)\delta_{ij}dx^i dx^j, \tag{A.4}$$

and a homogeneous scalar field $\phi = \phi(t)$, the energy density and pressure are given by

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi), \tag{A.5}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi). \tag{A.6}$$

Insertion into the Einstein equations leads directly to the Friedmann equations,

$$H^2 = \frac{8\pi G}{3}\rho_\phi, \tag{A.7}$$

$$\dot{H} = -4\pi G(\rho_\phi + p_\phi) = -4\pi G\dot{\phi}^2, \tag{A.8}$$

as used in the main text.

Appendix A.2: Constant contraction rate solutions

Assuming a constant Hubble parameter $H = -C$ with $C > 0$, one has $\dot{H} = 0$, which from the second Friedmann equation implies $\dot{\phi} = \alpha = \text{const}$. The scalar field equation,

$$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = 0, \tag{A.9}$$

then reduces to

$$\frac{dV}{d\phi} = 3C\alpha. \tag{A.10}$$

Over the relevant dynamical range, this condition is satisfied by an effective potential whose variation compensates the friction term induced by the contracting background. Consistency with the first Friedmann equation fixes the effective energy scale,

$$V = \frac{3C^2}{8\pi G} - \frac{1}{2}\alpha^2. \tag{A.11}$$

The scale factor integrates immediately to

$$R(t) = R_0 e^{-Ct}, \tag{A.12}$$

confirming that exponential contraction is a direct consequence of the field equations rather than an imposed ansatz.

Appendix A.3: Redshift and distance relations

For null geodesics propagating in the FLRW background, the comoving radial distance is

$$\chi = \int_{t_e}^{t_0} \frac{dt}{R(t)}. \tag{A.13}$$

Using $R(t) = R_0 e^{-Ct}$, this integral converges and yields

$$\chi = \frac{1}{CR_0}\left(e^{Ct_0} - e^{Ct_e}\right). \tag{A.14}$$

Expressed in terms of the redshift defined in Eq. (15), the luminosity distance follows as

$$d_L(z) = (1+z)\chi(z), \tag{A.15}$$

providing the closed-form distance–redshift relation discussed in Sect. 4.

Appendix A.4: Redshift drift

Differentiating the redshift relation

$$1 + z = \frac{R(t_{\mathrm{e}})}{R(t_0)} \tag{A.16}$$

with respect to the observer's proper time t_0 while holding the comoving coore fixed yields

$$\frac{dz}{dt_0} = -C(1 + z), \tag{A.17}$$

which is strictly negative for $C > 0$. This result underlies the Sandage–Loeb prediction emphasized in Sect. 4 and constitutes a robust signature of the contracting cosmological background.

References

1. Planck Collaboration, "Planck 2018 results. VI. Cosmological parameters," *Astronomy & Astrophysics* **641**, A6 (2020).
2. E. Hubble, "A relation between distance and radial velocity among extra-galactic nebulae," *Proc. Natl. Acad. Sci. USA* **15**(3), 168–173 (1929).
3. A. G. Riess *et al.*, "Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant," *Astron. J.* **116**, 1009–1038 (1998).
4. S. Perlmutter *et al.*, "Measurements of Ω and Λ from 42 High-Redshift Supernovae," *Astrophys. J.* **517**, 565–586 (1999).
5. D. J. Eisenstein *et al.*, "Detection of the Baryon Acoustic Peak in the Large-Scale Correlation Function of SDSS Luminous Red Galaxies," *Astrophys. J.* **633**, 560–574 (2005).
6. A. Sandage, "The Change of Redshift and Apparent Luminosity of Galaxies with Time," *Astrophys. J.* **136**, 319–333 (1962).
7. A. Loeb, "Direct Measurement of Cosmological Parameters from the Redshift Drift of Distant Sources," *Astrophys. J. Lett.* **499**, L111–L114 (1998).