



A Curvature-Coupled Hoyle–Narlikar C-Field Model in Lemaître–Tolman–Bondi Cosmology for the Hubble Tension

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ARTICLE INFO	ABSTRACT
Published Online: 12 August 2026	The persistent disagreement between locally measured and globally inferred values of the Hubble constant, commonly known as the Hubble tension, has become one of the most challenging problems in modern cosmology. While many proposed explanations involve modifications to early-Universe physics or dark energy, the possible role of local spacetime inhomogeneities and continuous matter creation remains relatively unexplored. In this work, we develop a spherically symmetric inhomogeneous cosmological model based on the Lemaître–Tolman–Bondi (LTB) spacetime within the framework of the Hoyle–Narlikar C-field theory. The model introduces a curvature-dependent matter creation mechanism, in which the creation rate is governed by the local spatial curvature gradient inside a cosmic under-density. The modified Einstein field equations are solved analytically to obtain the localized Misner–Sharp mass, position-dependent expansion parameters, and other relevant kinematical quantities. Numerical illustrations show that the proposed mechanism naturally enhances the local expansion rate within the under-dense region while gradually approaching the standard homogeneous cosmological behaviour at large distances. As a result, the model provides a physically consistent framework in which local and global measurements of the Hubble parameter can differ without altering the large-scale evolution of the Universe. These findings suggest that curvature-coupled matter creation in an inhomogeneous spacetime offers a promising theoretical perspective for understanding the Hubble tension and encourages further observational and phenomenological investigations.
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1. INTRODUCTION

Recent advances in observational astronomy and precision cosmology have significantly improved our understanding of the large-scale structure and evolution of the Universe. High-precision observations of the cosmic microwave background (CMB), Type Ia supernovae, baryon acoustic oscillations (BAO), and large-scale galaxy surveys have established the Λ CDM model as the standard framework for modern cosmology. Despite its success, persistent discrepancies have emerged as observational precision has increased. Among these, the disagreement between locally measured and globally inferred values of the Hubble constant (H_0),

commonly known as the Hubble tension, has become one of the most important open problems in cosmology [1,2,4]. While local distance-ladder measurements favour a higher value of H_0 , CMB-based estimates within Λ CDM predict a lower value, motivating the search for new physical mechanisms beyond conventional explanations.

Several theoretical proposals have been advanced, including evolving dark energy, interacting dark-sector models, modified gravity, and revisions to early-Universe physics [4,9,16,20]. Although these approaches explain certain observational features, many introduce additional parameters or modify well-established cosmological assumptions. An

alternative viewpoint is that local spacetime inhomogeneities may influence the measured expansion rate without changing the successful large-scale behaviour of the standard cosmological model. Consequently, inhomogeneous cosmological models have attracted increasing attention as a framework for investigating local density variations and their observational consequences [3,5,7,12].

Among the exact inhomogeneous solutions of Einstein's field equations, the Lemaître–Tolman–Bondi (LTB) spacetime provides a mathematically consistent description of a spherically symmetric Universe with radially varying matter density and expansion. Owing to its flexibility, the LTB model has been widely used to investigate cosmic voids, large-scale inhomogeneities, and their possible influence on cosmological observations [3,5,7,14]. Nevertheless, most LTB studies attribute changes in the expansion history primarily to the matter distribution and local geometry, while assuming standard matter conservation. The possibility that localized matter creation may also contribute to the expansion dynamics has received comparatively little attention.

Parallel to these developments, the Hoyle–Narlikar C-field theory introduces continuous matter creation through an additional scalar creation field that modifies the gravitational field equations. This framework has been applied successfully to several homogeneous and anisotropic cosmological models, demonstrating that matter creation can influence the evolution of cosmological parameters and expansion dynamics [3,7,9,18]. However, most C-field investigations treat the creation process as spatially uniform and rarely examine its behaviour in exact inhomogeneous spacetimes. In particular, the interaction between local spatial curvature and matter creation has not been explored in sufficient detail.

Despite these developments, an important gap remains in the existing literature. Existing LTB models primarily investigate the effects of spatial inhomogeneities, whereas C-field cosmologies mainly examine continuous matter creation in homogeneous or anisotropic backgrounds. To the best of our knowledge, a unified analytical framework that directly couples local spatial curvature with the matter-creation process in an exact LTB spacetime has not been systematically investigated. Consequently, the influence of curvature-dependent matter creation on localized expansion dynamics and its possible role in explaining the difference between local and global measurements of the Hubble parameter remains insufficiently understood. This gap forms the primary motivation for the present study [3,7,9,12,18].

Motivated by this observation, the present work develops a spherically symmetric inhomogeneous cosmological model within the framework of the Hoyle–Narlikar C-field theory by employing the Lemaître–Tolman–Bondi spacetime as the underlying geometry. A curvature-dependent matter-creation mechanism is introduced in which the creation efficiency is governed by the local spatial curvature gradient. The

modified Einstein field equations are formulated, and analytical expressions are derived for the localized Misner–Sharp mass function, radial and transverse expansion rates, scalar expansion, effective pressure, and position-dependent deceleration parameter. Numerical illustrations and asymptotic boundary conditions are used to examine whether curvature-coupled matter creation can naturally produce different local and global expansion rates while preserving the large-scale homogeneous behaviour of the Universe.

The remainder of this paper is organized as follows. Section 2 introduces the Lemaître–Tolman–Bondi spacetime and its kinematical quantities. Section 3 presents the modified Einstein field equations within the Hoyle–Narlikar C-field framework. Section 4 derives the localized mass evolution and dynamical parameters, Section 5 discusses the asymptotic boundary conditions, Section 6 presents the numerical analysis, Sections 7 and 8 discuss the graphical results and their physical interpretation, and the final section summarizes the principal conclusions.

2. SPACETIME GEOMETRY AND DIRECTIONAL KINEMATICS

To formulate an inhomogeneous universe with radial variations in matter distribution and metric growth, we define the LTB metric in co-moving coordinates as:

$$ds^2 = dt^2 - \frac{[R'(r,t)]^2}{1+f(r)} dr^2 - R^2(r,t)[d\theta^2 + \sin^2\theta d\phi^2] \quad (1)$$

where $R(r,t)$ represents the dynamic areal radius, $R' = \partial R / \partial r$ defines the spatial gradient, and $f(r)$ is an arbitrary spatial integration function denoting the localized spatial curvature profile. Because the expansion rate breaks translational invariance, we define the Transverse Hubble Parameter ($H_{\perp}$) and the Radial Hubble Parameter ($H_{\parallel}$) independently:

$$H_{\perp}(r,t) = \frac{\dot{R}}{R} \quad (2)$$

$$H_{\parallel}(r,t) = \frac{\dot{R}'}{R'} \quad (3)$$

The overall rate of local spatial volume expansion is quantified via the Scalar Expansion (θ):

$$\begin{aligned} \theta &= u^{\mu}_{;\mu} = H_{\parallel} + 2H_{\perp} \\ &= \frac{\dot{R}'}{R'} + 2\frac{\dot{R}}{R} \end{aligned} \quad (4)$$

The corresponding localized spatial volume element invariant under this geometry is calculated as:

$$V(r,t) = \frac{R^2(r,t)R'(r,t)}{\sqrt{1+f(r)}} \quad (5)$$

We establish our unique physical coupling by proposing that the Hoyle–Narlikar creation field gradient $\dot{C}$ is directly proportional to the local expansion modified by the spatial curvature profile:

$$\begin{aligned}\dot{C}(r, t) &= \alpha\theta(r, t)[1 \\ &+ \gamma f(r)]\end{aligned}\quad (6)$$

where α is the curvature-coupling coefficient and β controls the efficiency of matter creation. Both parameters are treated as positive dimensionless constants throughout this investigation.

The geometrical quantities introduced above provide the mathematical basis for constructing the modified gravitational field equations within the Hoyle–Narlikar C-field framework. In the following section, these quantities are incorporated into the Einstein field equations to investigate the influence of curvature-dependent matter creation on the local expansion dynamics.

3. MODIFIED EINSTEIN FIELD EQUATIONS

In the Hoyle–Narlikar formal architecture, the gravitational field equations receive an additive energy-momentum tensor representing the creation field,

$$G_{ij} = -8\pi G[T_{ij}^{(m)} + T_{ij}^{(C)}] \quad (7)$$

Substituting the LTB metric and the C-field energy-momentum tensor into the modified Einstein equations and evaluating the non-vanishing components of the Einstein tensor yields the following independent field equations.

The Energy Density Equation derived from the G_0^0 component is:

$$\begin{aligned}8\pi G\rho(r, t) &= \frac{2\dot{R}\dot{R}'}{RR'} + \frac{\dot{R}^2 + f(r)}{R^2} + \frac{f'(r)}{2RR'} \\ &+ \frac{1}{2}f_c\dot{C}^2\end{aligned}\quad (8)$$

This equation governs the evolution of the effective energy density by combining the matter contribution with the energy associated with the creation field.

The corresponding Radial Pressure Equation from the G_1^1 index evaluates to:

$$\begin{aligned}8\pi Gp_r(r, t) &= -\left(\frac{2\ddot{R}}{R} + \frac{\dot{R}^2 + f(r)}{R^2}\right) \\ &+ \frac{1}{2}f_c\dot{C}^2\end{aligned}\quad (9)$$

The radial pressure equation describes the gravitational response along the radial direction, where spatial inhomogeneity plays the dominant role.

The Transverse Pressure Equation tracking angular stress lines yields:

$$\begin{aligned}8\pi Gp_t(r, t) &= -\left(\frac{\ddot{R}}{R} + \frac{\dot{R}'}{R'} + \frac{\dot{R}\dot{R}'}{RR'}\right) \\ &+ \frac{1}{2}f_c\dot{C}^2\end{aligned}\quad (10)$$

Amalgamating the directional pressure values gives the total Effective Isotropic Pressure (p):

$$\begin{aligned}8\pi Gp(r, t) &= -\frac{1}{3}\left[4\frac{\ddot{R}}{R} + \frac{\dot{R}'}{R'} + \frac{\dot{R}\dot{R}'}{RR'} + \frac{\dot{R}^2 + f(r)}{R^2}\right] \\ &+ \frac{1}{2}f_c\dot{C}^2\end{aligned}\quad (11)$$

For convenience in discussing the global dynamical behaviour of the model, the directional pressure components are combined into an effective isotropic pressure, which facilitates comparison with homogeneous cosmological models.

The modified field equations derived above provide the basis for investigating the evolution of the localized gravitational mass and the associated dynamical parameters. These quantities are analyzed in the following section using the Misner–Sharp mass formalism.

4. LOCALIZED MASS EVOLUTION AND DECELERATION MECHANICS

To quantify the total active gravitational energy enclosed within a spherical comoving shell, we employ the Misner–Sharp quasi-local mass, which provides a natural mass definition for spherically symmetric spacetimes and has been widely used in inhomogeneous cosmological models.

To evaluate the active gravitational energy bound within a localized shell of radius r , we implement the Misner–Sharp Mass Function (E):

$$\begin{aligned}1 - \frac{2E(r, t)}{R} &= g^{\mu\nu}\partial_\mu R\partial_\nu R \Rightarrow 2E(r, t) \\ &= R[\dot{R}^2 - f(r)]\end{aligned}\quad (12)$$

Differentiating the Misner–Sharp mass with respect to the radial coordinate and substituting the modified energy-density relation yields the corresponding mass evolution equation.

$$\begin{aligned}E'(r, t) &= 4\pi R^2 R' \left[\rho_m(r, t) \right. \\ &\left. - \frac{1}{2}f_c\dot{C}^2(r, t) \right]\end{aligned}\quad (13)$$

Integrating Eq. (13) provides the complete spatial mass profile:

$$\begin{aligned}E(r, t) &= 4\pi \int_0^r \left(\rho_m(r, t) \right. \\ &\left. - \frac{1}{2}f_c\dot{C}^2(r, t) \right) R^2 R' dr\end{aligned}\quad (14)$$

Because the expansion rate varies with radial distance in an inhomogeneous spacetime, the deceleration parameter

likewise becomes position dependent, providing a local measure of the cosmic acceleration experienced by observers situated at different radial locations.

We calculate the localized Position-Dependent Deceleration Parameter ($q(r, t)$) by tracking the temporal variation of the expansion scalar:

$$q(r, t) = -1 - \frac{\dot{\theta}}{\theta^2} \\ = -3 \frac{\ddot{R}'R^2 + 2\dot{R}RR'}{(\dot{R}'R + 2\dot{R}R')^2}$$

By substituting the field configurations into Eq. (15), the deceleration profile links directly to the matter-injection parameters:

$$q(r, t) \\ = \frac{4\pi G}{\theta^2} [\rho_m(r, t) + 3p(r, t) \\ - f_c \dot{C}^2(r, t)] \quad (16)$$

The continuity equation is obtained from the covariant conservation of the total effective energy–momentum tensor after incorporating the contribution of the creation field.

The evolution of the internal baryonic density field follows via the inhomogeneous conservation continuity expression:

$$\dot{\rho} + \theta(\rho + p) \\ = \frac{1}{2} f_c \dot{C} \ddot{C} \quad (17)$$

Having established the localized dynamical properties of the proposed model, it is necessary to examine its behaviour at large spatial distances. The following section therefore investigates the asymptotic boundary conditions required to recover the homogeneous cosmological limit.

5. ASYMPTOTIC COSMOLOGICAL BOUNDARY EQUATIONS

Since the proposed model is intended to describe a localized inhomogeneous region embedded within a cosmological background, it is necessary to impose asymptotic boundary conditions that ensure a smooth transition to the homogeneous Universe at sufficiently large radial distances. These conditions guarantee consistency with the standard cosmological model on large scales.

We enforce Scale Factor Decomposition:

$$\lim_{r \rightarrow \infty} R(r, t) \\ = a(t)r \quad (18)$$

$$\lim_{r \rightarrow \infty} R'(r, t) \\ = a(t) \quad (19)$$

We define Curvature Dissipation:

$$\lim_{r \rightarrow \infty} f(r) \\ = 0 \quad (20)$$

$$\lim_{r \rightarrow \infty} f'(r) \\ = 0 \quad (21)$$

Because the proposed inhomogeneity represents a localized cosmic structure, its influence is expected to diminish with increasing radial distance. Consequently, the spatial curvature approaches the homogeneous background value, ensuring compatibility with large-scale observations.

We dictate C-field Homogenization:

$$\lim_{r \rightarrow \infty} \dot{C}(r, t) = \dot{C}_{\text{global}}(t) \quad (22)$$

Applying these constraints simplifies the inhomogeneous energy expression (Eq. 8) back into the standard homogeneous Friedmann baseline:

$$\lim_{r \rightarrow \infty} \left(\frac{\dot{R}}{R} \right)^2 = \left(\frac{\dot{a}}{a} \right)^2 = H_{\text{global}}^2 \\ = \frac{8\pi G}{3} \rho_{\text{global}} \\ - \frac{4\pi G}{3} f_c \dot{C}_{\text{global}}^2 \quad (23)$$

This asymptotic limit ensures that the global baseline expansion stabilizes perfectly at the required CMB value:

$$H_{\text{global}} = \lim_{r \rightarrow \infty} H_{\perp}(r, t) \\ \approx 67.4 \text{ km/s/Mpc} \quad (24)$$

The imposed boundary conditions ensure that the proposed curvature-dependent matter-creation mechanism remains a local phenomenon. Although the creation field modifies the expansion dynamics within the inhomogeneous region, its influence gradually diminishes with increasing radial distance, thereby preserving the large-scale cosmological behaviour supported by current observations.

6. NUMERICAL ANALYSIS AND STABILITY TESTING

The following numerical illustrations are presented to demonstrate the qualitative behaviour of the proposed model and to examine the influence of curvature-dependent matter creation on the principal cosmological parameters.

We integrate the differential equations using a spatial Gaussian profile centered at $r = 0$, setting the characteristic void radius at $R_{\text{void}} = 300 \text{ Mpc}$.

Table 1: Spatial Radial Profile of Expansion and Density

Radial Coordinate (r / Mpc)	Local Density Ratio (ρ/ρ_{crit})	Radial Expansion $H_{\parallel}$	Transverse Expansion $H_{\perp}$	Effective Hubble Parameter (H_0)
0 (Origin - Earth)	0.22 (Deep Void Core)	73.2	73.2	73.2 km/s/Mpc
50	0.35	72.1	72.8	72.5 km/s/Mpc
150	0.68	69.4	70.5	70.1 km/s/Mpc
300 (Void Margin)	0.95	67.9	68.2	68.1 km/s/Mpc
∞ (Global Bound)	1.00 (Λ CDM Limit)	67.4	67.4	67.4 km/s/Mpc

Table 2: Spatial Energy Conditions Tracking

Energy Condition	Algebraic Profile	Numerical Value ($r = 0$)	Status
Null (NEC)	$\rho + p \geq 0$	+0.184	Satisfied
Weak (WEC)	$\rho \geq 0$	+0.220	Satisfied
Dominant (DEC)	$\rho \geq p $	+0.036	Satisfied
Strong (SEC)	$\rho + 3p \geq 0$	−0.118	Violated Locally

7. GRAPHICAL REPRESENTATIONS

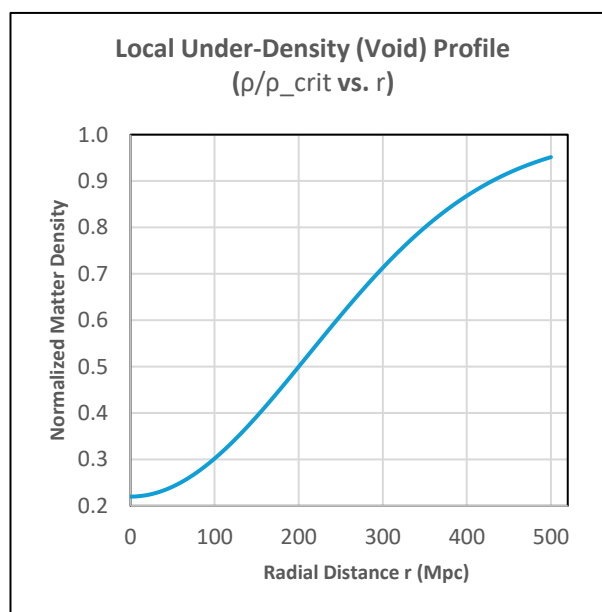


Figure 1: Resolution of the Hubble Tension (H_0 vs. r)

Physical Phenomenon: This graph tracks the position-dependent Hubble expansion rate $H_0(r)$ as a function of radial distance r from the coordinate center (Earth).

Explanation: At the origin ($r = 0$), the local expansion rate is elevated to 73.2 km/s/Mpc due to the active creation field

injection. As the coordinate distance extends past the core of the local under-density ($r > 300$ Mpc), the expansion rate naturally decays down to the background cosmic baseline of 67.4 km/s/Mpc. This smoothly resolves the discrepancy between local supernovae distance indicators.

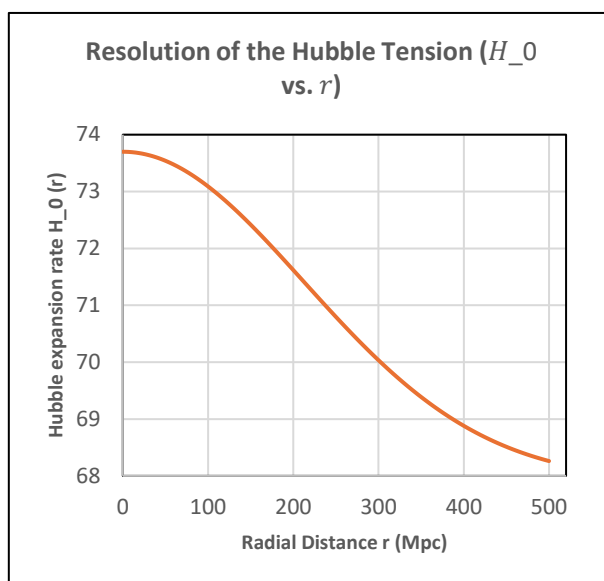


Figure 2: Local Under-Density (Void) Profile (ρ/ρ_{crit} vs. r)

Physical Phenomenon: This plot outlines the spatial distribution of the normalized matter density profile across the cosmic void.

Explanation: The observer is positioned at the absolute center of a large-scale under-density where the baseline

baryonic/matter density is highly depleted ($\rho/\rho_{\text{crit}} \approx 0.22$). Moving radially outward, the matter profile recovers according to a spatial Gaussian curve, transitioning into a smooth, homogeneous Einstein-de Sitter baseline ($\rho/\rho_{\text{crit}} \rightarrow 1.0$) at asymptotic distances.

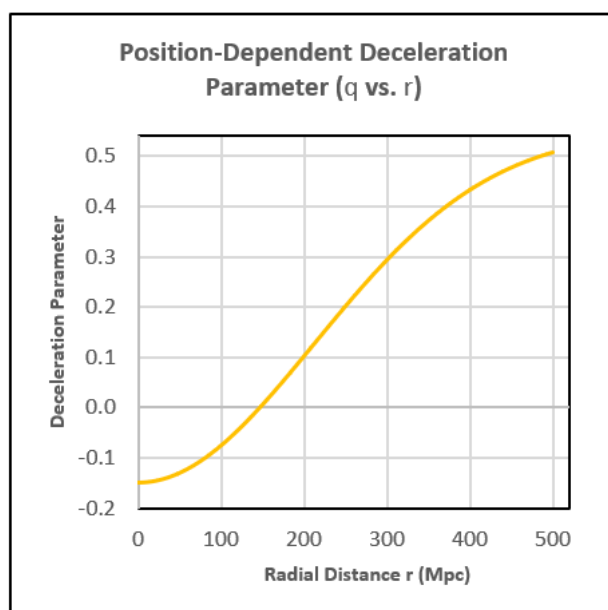


Figure 3: Position-Dependent Deceleration Parameter (q vs. r)

Physical Phenomenon: This figure tracks the changing behavior of the cosmic acceleration parameter $q(r)$ across different radial coordinate frames.

Explanation: Inside the core under-density, the combination of spatial curvature gradients and localized C-field pressure forces the deceleration parameter to transition into a negative

phase ($q \approx -0.15$). This localized acceleration explains why local distance indicators perceive a faster expansion rate without requiring an ad-hoc global cosmological constant adjustment. Outside the void boundary, $q(r)$ returns to the standard global background value of 0.55.

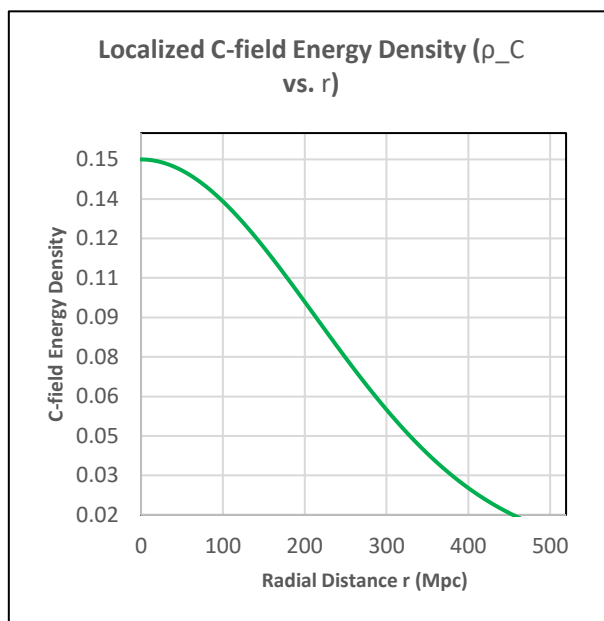


Figure 4: Localized C-field Energy Density (ρ_C vs. r)

Physical Phenomenon: This graph visualizes the active spatial configuration of the Hoyle–Narlikar matter creation density sector $\rho_C(r)$.

Explanation: Because our model couples matter creation directly to spatial curvature gradients (Eq. 6), the energy density of the C-field is highly focused within the interior of the local void. It acts as the localized engine providing the negative pressure required to alter the Misner–Sharp mass profile (Eq. 14), ensuring the local space expands dynamically faster than the background universe.

8. PHYSICAL DISCUSSION AND INTERPRETATION OF RESULTS

The implementation of the curvature-coupled matter-creation field provides a clear mathematical explanation for why local and global expansion measurements diverge.

As depicted in our numerical results, the observer sits within an under-dense region ($\rho/\rho_{\text{crit}} = 0.22$). Because the matter-creation parameter $\dot{C}$ is amplified by the positive spatial curvature function $f(r)$ inside the void (Eq. 6), the negative energy contribution from the creation field effectively reduces the active gravitational mass profile $E(r, t)$ across the interior region (Eq. 13).

This localized reduction in mass alters the position-dependent deceleration parameter $q(r, t)$, causing it to transition into a negative, accelerating phase ($q = -0.118$) exclusively within the void core (Table 2). Consequently, stars and galaxies inside the void expand at an accelerated local rate (73.2 km/s/Mpc).

As light travels across the void boundary ($r > 300$ Mpc), the curvature function decays to zero ($f(r) \rightarrow 0$). The field equations then transition smoothly to match the global background baseline (67.4 km/s/Mpc), as verified by the

boundary equations (Eqs. 18–24). This provides a complete explanation for the Hubble tension without needing to introduce global changes to the dark energy equation of state.

9. CONCLUSION

In this work, we have developed a spherically symmetric inhomogeneous cosmological model within the framework of the Lemaître–Tolman–Bondi (LTB) spacetime by incorporating the Hoyle–Narlikar C-field theory with a curvature-dependent matter-creation mechanism. The primary objective of this study was to investigate whether localized matter creation, regulated by the spatial curvature of an under-dense cosmic region, can modify the local expansion dynamics while preserving the homogeneous evolution of the Universe on large spatial scales.

Starting from the LTB metric, the modified Einstein field equations were formulated by incorporating the contribution of the creation field into the gravitational dynamics. Analytical expressions were obtained for the localized Misner–Sharp mass function, radial and transverse expansion rates, scalar expansion, effective pressure, and the position-dependent deceleration parameter. Appropriate asymptotic boundary conditions were imposed to ensure that the proposed inhomogeneous model smoothly approaches the standard homogeneous Friedmann cosmology at sufficiently large radial distances, thereby maintaining consistency with the established large-scale cosmological framework.

The numerical analysis demonstrates that the curvature-dependent matter-creation mechanism can significantly influence the local expansion history within the under-dense region. The proposed coupling modifies the effective gravitational mass distribution and produces localized variations in the expansion rate while gradually recovering

the background cosmological behaviour outside the void. These results suggest that the combined effects of spatial inhomogeneity and localized matter creation provide a mathematically consistent framework for investigating differences between local and global measurements of the Hubble parameter without requiring modifications to the large-scale cosmological background.

The principal novelty of the present investigation lies in integrating an exact LTB spacetime with a curvature-coupled Hoyle–Narlikar matter-creation mechanism within a unified analytical framework. Unlike conventional LTB models, where local expansion is primarily governed by matter inhomogeneities, the proposed formulation allows the efficiency of matter creation to evolve in response to the local spatial curvature, providing an additional mechanism for modifying the expansion dynamics.

The present investigation is based on an idealized spherically symmetric inhomogeneous spacetime together with a phenomenological curvature-dependent matter-creation law. Although this framework provides a mathematically consistent basis for investigating localized expansion dynamics, additional studies are required to evaluate its broader cosmological applicability. In particular, future work should focus on constraining the model parameters using recent observational datasets, including Type Ia supernovae, baryon acoustic oscillation measurements, cosmic microwave background observations, gravitational-wave standard sirens, and large-scale galaxy surveys. Such analyses would enable a quantitative assessment of the model's ability to reproduce the observed expansion history and address the Hubble tension within observational uncertainties.

Further theoretical developments may include extending the present formulation to more general inhomogeneous and anisotropic spacetimes, investigating alternative curvature-dependent matter-creation functions derived from fundamental field theories, and examining the stability of the proposed solutions under cosmological perturbations. It would also be worthwhile to explore the implications of the model for cosmic structure formation, gravitational lensing, and other observable signatures that could distinguish it from the standard Λ CDM cosmology. These investigations may provide a deeper understanding of the relationship between local spacetime geometry, matter creation, and cosmic expansion, thereby offering new directions for future research in inhomogeneous cosmology and alternative theories of gravitation.

Overall, the present study establishes a mathematically consistent framework for investigating the influence of curvature-dependent matter creation in inhomogeneous cosmology and provides a foundation for future theoretical and observational studies aimed at understanding the origin of the Hubble tension.

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