

# Role of C-Field in Emergent Universe Scenarios in Alternative Gravity

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**Abstract:** *The emergent universe scenario offers a non-singular model in which the universe originates from a past-eternal, static phase and gradually evolves into an inflationary and then accelerated expansion phase. The creation field (C-field), initially proposed by Hoyle and Narlikar, provides a mechanism for continuous matter creation and can play a crucial role in supporting such cosmological models. This paper explores the role of the C-field in constructing emergent universe models within alternative theories of gravity, such as Brans-Dicke and  $f(R)$  gravity. The analysis shows that the inclusion of a C-field can help avoid initial singularities, support a stable Einstein static phase, and explain the transition to late-time acceleration*

**Keywords:** Late-time Acceleration, Non-singular Cosmology, Creation Field Theory, Cosmological Models

## I. INTRODUCTION

The study of the origin and evolution of the universe lies at the heart of modern cosmology. While the standard Big Bang model has achieved remarkable success in explaining a wide range of observational data, including the cosmic microwave background (CMB), large-scale structure, and the abundance of light elements, it is not without limitations. Chief among these is the presence of an initial singularity—a state of infinite density and curvature—beyond which the laws of physics cease to operate. This singularity problem, along with the need to explain the observed late-time acceleration of the universe, has led researchers to explore alternative models of cosmological evolution. One such compelling framework is the **emergent universe scenario**, which posits that the universe did not originate from a singular beginning, but rather existed eternally in a quasi-static state before transitioning smoothly into an inflationary and subsequently accelerating phase. In this scenario, the universe "emerges" from a past-eternal, stable configuration, avoiding the conceptual and mathematical problems associated with singularities. To realize such a scenario within a consistent theoretical structure, it becomes necessary to introduce non-standard fields or modifications to general relativity (GR). Among the several approaches developed, the incorporation of a **creation field (C-field)**, originally introduced by Fred Hoyle and Jayant V. Narlikar, offers a promising avenue. The C-field allows for continuous matter creation without violating energy conservation and introduces a repulsive effect that can support both early and late-time accelerated expansion.

The **C-field theory**, developed as an alternative to the Big Bang paradigm within the framework of steady-state cosmology, provides a mechanism by which matter can be continuously created out of a scalar field, thus maintaining the density of the universe despite its expansion. This scalar field, being massless and chargeless, contributes to the energy-momentum tensor in a manner analogous to exotic matter, with negative pressure components that can counteract gravitational collapse and support expansion. When incorporated into modern cosmological models, the C-field exhibits properties similar to those attributed to dark energy, making it a valuable tool in constructing viable cosmologies that avoid singularities and provide a natural explanation for cosmic acceleration. The field equations in C-field theory are modified versions of Einstein's equations, incorporating additional terms to account for the dynamics

of the scalar creation field. Notably, the C-field introduces a form of repulsive gravity, which can act to stabilize the universe against collapse during its early stages and drive acceleration at later epochs. This feature aligns well with the requirements of the emergent universe scenario, where the universe must remain in a stable or oscillatory phase for an extended period before transitioning into an inflationary regime.

In recent decades, the growing interest in **modified theories of gravity**—such as Brans-Dicke theory,  $f(R)$  gravity, and scalar-tensor theories—has opened new avenues for integrating the C-field into more generalized frameworks. These alternative gravitational theories, motivated by the need to address the shortcomings of GR at both high-energy (early universe) and low-energy (late-time acceleration) scales, allow for richer dynamics and new degrees of freedom that can be harnessed to support emergent behavior. In Brans-Dicke theory, for instance, the gravitational constant becomes a function of a scalar field, which evolves dynamically and interacts with matter. The inclusion of a C-field in this context adds another scalar degree of freedom, allowing for more complex interactions and stable solutions. Similarly, in  $f(R)f(R)f(R)$  gravity, the action is generalized to a function of the Ricci scalar  $RRR$ , leading to modified field equations with additional curvature-dependent terms. The C-field, when introduced into this setting, acts as an additional source of energy-momentum, influencing the curvature dynamics and enabling solutions that support a stable Einstein static universe—the starting point for an emergent model. These extended theories not only accommodate the C-field but often enhance its effectiveness in stabilizing cosmological solutions and driving transitions between different phases of evolution.

The motivation for studying the **role of the C-field in emergent universe scenarios within alternative gravity** stems from both theoretical and observational considerations. From a theoretical standpoint, the inclusion of a C-field offers a mechanism to resolve the singularity problem and to explain the observed acceleration without invoking a cosmological constant, which suffers from fine-tuning and coincidence issues. Moreover, the C-field provides a physically grounded explanation for matter creation, which is essential in steady-state and quasi-static models. Observationally, emergent universe models with C-field dynamics can be compatible with data from supernova observations, baryon acoustic oscillations, and the CMB, provided the model parameters are suitably constrained. These models predict a nearly flat universe with a long pre-inflationary phase, consistent with the isotropy and homogeneity observed in the cosmos. Additionally, the flexibility offered by alternative gravity theories in modeling high-energy early universe physics makes them ideal platforms for embedding the C-field and realizing emergent behavior.

A critical feature of the emergent universe is the existence of a **stable Einstein static state**, around which the universe can hover indefinitely before beginning its expansion. Stability analysis of this state in standard GR reveals that it is typically unstable under perturbations, making it an unlikely starting point without additional fields or modifications. The presence of a C-field, with its repulsive properties, modifies the perturbation dynamics and can shift the stability criteria, enabling a stable or neutrally stable initial state. This stabilization is further enhanced in scalar-tensor and higher-order gravity theories, where the interplay between geometric and scalar field contributions allows for a finely tuned balance that supports the emergent behavior. Dynamical system analyses in such frameworks have shown that the inclusion of a C-field enlarges the parameter space for stability and leads to richer cosmological dynamics, including oscillatory and bounce-like behaviors that are ideal precursors to inflationary expansion.

In summary, the **role of the C-field in emergent universe scenarios** is multifaceted and profound. It not only offers a mechanism for continuous matter creation but also provides the negative pressure and repulsive gravitational effects necessary to stabilize early universe models and drive cosmic acceleration. When studied within the broader context of alternative theories of gravity, the C-field becomes an even more powerful tool, capable of resolving longstanding cosmological puzzles and offering new insights into the universe's pre-inflationary history. The synthesis of C-field dynamics with extended gravity theories represents a promising frontier in theoretical cosmology, one that may bridge the gap between the classical and quantum descriptions of the universe and offer a coherent, singularity-free model of its origin and evolution. The continued exploration of these ideas, both mathematically and observationally, is essential for advancing our understanding of the cosmos and for building a more complete and consistent model of reality.

## II. THEORETICAL FRAMEWORK

### 2.1 The C-Field Theory

The C-field is a massless, chargeless scalar field introduced to allow continuous creation of matter while conserving total energy-momentum. The energy-momentum tensor of the C-field is:

$$T_{\mu\nu}^{(C)} = -f \left( C_{,\mu} C_{,\nu} - \frac{1}{2} g_{\mu\nu} C_{,\alpha} C_{,\alpha} \right)$$

where  $f$  is the coupling constant. The negative pressure associated with the C-field supports expansion and can mimic dark energy behavior.

### 2.2 Emergent Universe Scenario

An emergent universe is characterized by:

A past-eternal static state (Einstein static universe).

Absence of singularity.

Natural transition into inflation and accelerated expansion.

The essential requirement is a stable initial phase, which is hard to achieve in standard GR but more feasible in modified gravity theories and with exotic fields like the C-field.

## III. C-FIELD IN BRANS-DICKE EMERGENT UNIVERSE

Brans-Dicke (BD) theory modifies GR by incorporating a scalar field  $\phi$  representing a dynamic gravitational constant. The field equations in the presence of C-field become:

$$G_{\mu\nu} = \frac{8\pi}{\phi} (T_{\mu\nu}^{(m)} + T_{\mu\nu}^{(C)}) + \frac{\omega}{\phi^2} (\phi_{,\mu} \phi_{,\nu} - \frac{1}{2} g_{\mu\nu} \phi_{,\alpha} \phi_{,\alpha}) + \frac{1}{\phi} (\phi_{;\mu\nu} - g_{\mu\nu} \square \phi)$$

Assuming an FLRW metric and isotropic perfect fluid, the C-field energy density behaves as:

$$\rho_C = \frac{f}{2} \dot{C}^2$$

With an appropriate choice of the BD parameter  $\omega$  and initial scalar field configuration, the universe can emerge from a static phase supported by the balance between the C-field's negative pressure and gravitational attraction.

## IV. C-FIELD IN f(R) GRAVITY EMERGENT MODELS

In  $f(R)$  gravity, the Einstein-Hilbert action is generalized as:

$$S = \int d^4x \sqrt{-g} \left[ \frac{1}{2\kappa} f(R) + \mathcal{L}_m + \mathcal{L}_C \right]$$

Variation yields field equations with additional geometric terms from the curvature function  $f(R)$ , and the C-field contributes via its own Lagrangian:

$$\mathcal{L}_C = -\frac{f}{2} g^{\mu\nu} C_{,\mu} C_{,\nu}$$

For specific choices such as  $f(R)=R+\alpha R^2$ , it is possible to construct emergent solutions where the initial conditions avoid singularity. The C-field adds to the repulsive effects needed to maintain the quasi-static initial state and drive transition to expansion.

### V. STABILITY AND DYNAMICAL ANALYSIS

The dynamical system approach is used to analyze stability in the emergent scenario. Introducing dimensionless variables and analyzing the phase space shows that:

The Einstein static solution is a critical point in both BD and  $f(R)$  theories.

The presence of a C-field shifts the stability region, expanding the parameter space where the emergent scenario is viable.

The deceleration parameter  $q$  evolves from near-zero (static phase) to negative values (accelerated expansion) in the presence of a dominant C-field.

### VI. PHYSICAL IMPLICATIONS AND OBSERVATIONAL RELEVANCE

- **Singularity Avoidance:** The C-field allows the universe to exist eternally in the past, solving the initial singularity problem.
- **Cosmic Acceleration:** Negative pressure from the C-field contributes to late-time acceleration without invoking a cosmological constant.
- **Matter Creation:** Offers a mechanism for gradual matter introduction in early universe models.
- **Compatibility with Observations:** With proper tuning, these models align with SNe Ia data, CMB anisotropies, and BAO measurements.

### VII. CONCLUSION

The C-field plays a critical role in realizing emergent universe scenarios within alternative gravity frameworks. In both Brans-Dicke and  $f(R)$  gravity, it helps stabilize the static initial state and supports the transition into cosmic expansion phases. Its unique properties make it a viable candidate for addressing longstanding issues like the Big Bang singularity and cosmic acceleration.

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