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A Novel Cosmological Model: Radiation-Driven Inflation with Local Causal Horizons and Redshift Energy Redistribution

I propose a cosmological model in which the inflationary epoch is driven by radiation pressure rather than a scalar inflaton field. Beginning with linear expansion at the Planck epoch, the universe transitions to exponential inflation at $t \approx 10^{22}\, t_P$ as spacetime stretches beyond causal horizons, redefining the speed of light (c) as a locally invariant parameter. Energy lost to photon redshift is hypothesized to be redistributed into radiation pressure, thereby fueling inflation and ensuring energy conservation in an expanding universe. Local Minkowski patches preserve the invariance of c, addressing the horizon and flatness problems while reconciling special relativity with cosmological superluminal recession. Eight observational tests are outlined, with expected signatures in the CMB, gravitational waves, and large-scale structure. Current data align with ΛCDM but do not exclude this model, leaving a path open for validation with future high-precision experiments.

1. Introduction

The standard ΛCDM cosmology describes a hot Big Bang at $t = 0$, followed by a brief inflationary period from $t \approx 10^{-36}\,\mathrm{s}$ to $10^{-34}\,\mathrm{s}$. This epoch is driven by a scalar "inflaton" field, whose potential produces exponential expansion ($a(t) \propto e^{Ht}$) [1, 2]. This resolves the horizon and flatness problems and leaves imprints in the cosmic microwave background (CMB). Yet, despite its success, ΛCDM depends on speculative ingredients: an undetected inflaton particle, fine-tuned potential landscapes, and a tolerance for the apparent non-conservation of energy due to photon redshift.

I introduce a radiation-driven alternative. My model begins with linear expansion, transitions naturally into exponential inflation once photons dominate and horizons disconnect, and continues into the modern accelerating era. Three central principles distinguish this framework:

1. **No inflaton required.** Radiation pressure itself, boosted by redshift energy, drives inflation.
2. **Energy conservation restored.** Energy lost to redshift is thermodynamically recycled into radiation pressure, doing work on the expanding universe.
3. **Local invariance of c.** Within each causal patch, observers measure the same speed of light, consistent with Einstein's postulates. Globally, superluminal recession arises naturally from causal disconnection.

2. Theoretical Framework

2.1 Early Linear Expansion ($t = 0$ to $t = 10^{20}\, t_P$)

At the Planck epoch ($t = 1\, t_P = 5.39 \times 10^{-44}\,\mathrm{s}$), the universe expands linearly with scale factor $a(t) \propto t$. Its proper size is $R(t) = ct$, and the energy density is Planck-scale:

$$\rho \approx 5 \times 10^{96}\,\mathrm{kg\,m^{-3}}.$$

The Friedmann equation governs expansion:

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} - \frac{kc^2}{a^2},$$

with $H = 1/t$ and negligible curvature. At this stage, photons are absent, so radiation pressure does not yet contribute.

2.2 Onset of Radiation Pressure ($t = 10^{20}\, t_P$)

By $t \sim 10^{20}\, t_P$ ($\sim 10^{-36}\,\mathrm{s}$), particle formation produces photons in a quark-gluon plasma at $T \approx 10^{28}\,\mathrm{K}$. Radiation pressure emerges:

$$P = \frac{1}{3}\rho c^2, \qquad \rho = \frac{aT^4}{c^2},$$

with $a = 7.566 \times 10^{-16}\,\mathrm{J\,m^{-3}\,K^{-4}}$. This yields $P \sim 10^{92}\,\mathrm{Pa}$. While enormous, gravity still dominates, and expansion remains decelerating.

2.3 Causal Disconnection and Local Invariant c ($t = 10^{22}\, t_P$)

At $t \approx 10^{22}\, t_P$ ($\sim 10^{-34}\,\mathrm{s}$), the universe's radius exceeds its Schwarzschild-like horizon:

$$r_s = \frac{2GM}{c^2}, \quad M = \rho \cdot \frac{4}{3}\pi R^3, \quad R = ct.$$

When the particle horizon $d_p \approx ct$ surpasses r_s, regions decouple causally.

Inside each horizon patch, observers measure $c = 3 \times 10^8\,\mathrm{m/s}$, consistent with Einstein's train and rocket thought experiments. Globally, however, recession velocities exceed c, as in standard cosmology. I parameterize this as:

$$c_{\text{eff}} = c_0\left(\frac{a_0}{a}\right)^{\beta}, \qquad \beta > 0,$$

not implying a literal variation of c, but rather encoding its locality. Thus, c remains invariant for any observer within their causal horizon, while globally superluminal expansion reflects disconnection, not a violation of relativity.

2.4 Redshift Energy Redistribution

In ΛCDM, photon energy diminishes as wavelengths stretch:

$$E = \frac{hc}{\lambda}, \quad \lambda \propto a, \quad E \propto a^{-1}.$$

The apparent loss of energy is attributed to expansion, with no global conservation law.

My model resolves this paradox: energy lost to redshift is absorbed at causal horizons and redistributed into radiation pressure, effectively doing work on the metric:

$$\Delta E_{\text{redshift}} \;\rightarrow\; \Delta P_{\text{radiation}} \cdot V.$$

2.4.1 Redshift as Work on the Metric

Einstein's equivalence principle identifies gravity with acceleration. This provides a concrete way to see redshift not as destruction of energy, but as its conversion into kinetic work.

Thought experiment: Consider a blue laser fired upward from the surface of a planet. The photons climb out of the gravitational potential and arrive at a distant observer redshifted. To the observer, each photon appears to carry less energy. Yet the laser at the source experienced the full mass–energy of the emitted photons: it transferred momentum consistent with their unredshifted energy and radiation pressure.

Where has the "missing" energy gone? It has been invested into the gravitational field, performing the work necessary to lift the photons out of the potential well.

By analogy, in cosmology, photons emitted at early times lose energy through cosmological redshift. Locally, the emitting region experiences their full radiation pressure. But globally, the apparent deficit is not lost; it has been converted into **work on the metric** - specifically, into accelerated expansion.

$$\Delta E_{\text{photon}} \;=\; W_{\text{expansion}}.$$

2.4.2 Horizon Thermodynamics and Redistribution Mechanism

Building on this analogy, I propose that causal horizons act as mediators of redshift energy:

1. **Energy Transfer.** Photon energy decreases as $E \propto a^{-1}$. Instead of vanishing, this energy is absorbed at particle horizons or Schwarzschild-like causal boundaries.
2. **Gravitational Redshift Mapping.** Just as gravitational redshift transfers energy into the field, cosmological redshift transfers energy into the expansion of the metric.
3. **Horizon Thermodynamics.** Horizons possess entropy ($S \propto A/4$) and temperature (Gibbons–Hawking). Redshifted energy contributes to horizon entropy, and via Padmanabhan's thermodynamic gravity framework [3], re-emerges as pressure doing work on expansion.
4. **Pressure Enhancement.**

$$P = \frac{1}{3}\rho c_{\text{eff}}^2 + \Delta P_{\text{redshift}},$$

modifying the acceleration equation:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3P}{c^2}\right).$$

With $\Delta P_{\text{redshift}} > 0$, the expansion accelerates without invoking an inflaton.

2.4.3 Formal Considerations

To formalize this mechanism requires:

- Quantum field theory in curved spacetime to describe photon–horizon interactions.
- Horizon thermodynamics (Padmanabhan’s emergent gravity, Bekenstein–Hawking entropy) to model energy absorption and re-emission.
- Numerical simulations of modified Friedmann dynamics with $\Delta P_{\text{redshift}}$.

2.5 Modern Era

At $t \approx 2.6 \times 10^{71}\, t_P$ (13.8 Gyr), the CMB temperature is $T = 2.7\,\mathrm{K}$, and radiation pressure has diminished to $P \sim 10^{-31}\,\mathrm{Pa}$. Yet the same horizon-mediated mechanism persists: redshift energy continues to fuel cosmic acceleration, contributing to the late-time dynamics typically attributed to dark energy ($\Omega_\Lambda \approx 0.7$).

3. Conceptual Advances

1. **No inflaton required.** Inflation arises naturally from radiation pressure enhanced by redshift energy, removing the need for an undetected scalar field.
2. **Energy conservation restored.** Redshift energy is recycled into radiation pressure, aligning expansion with thermodynamic principles.
3. **Local invariance of c.** Einstein’s postulate holds within causal patches, while superluminal recession is explained by horizon separation.

4. Observational Tests and Expected Signatures

I propose eight observational tests, each with distinct signatures that could differentiate this model from ΛCDM.

4.1 CMB Anisotropies

- **Test:** Measure the CMB power spectrum and B-mode polarization with high precision.
- **Expected Signature:** Enhanced small-scale fluctuations at multipoles $l > 1000$, along with detectable B-mode polarization at $l < 100$ ($r \approx 0.05$–0.1).

4.2 Redshift-Dependent Radiation Energy Density

- **Test:** Observe the scaling of radiation energy density $\rho_{\text{radiation}}$ with redshift.
- **Expected Signature:** At $z > 1100$, $\rho_{\text{radiation}}$ should deviate from the standard $\propto a^{-4}$ scaling.

4.3 Gravitational Wave Background (GWB)

- **Test:** Search for a stochastic GWB from the inflationary epoch.
- **Expected Signature:** A peak at $\sim 10^{-9}\,\text{Hz}$, with characteristic strain $h_c \approx 10^{-15}$.

4.4 Hubble Tension and Late-Time Acceleration

- **Test:** Measure the Hubble constant H_0 and dark energy equation of state w.
- **Expected Signature:** $H_0 \approx 70\,\text{km/s/Mpc}$, with w between -0.8 and 0 at $z < 1$.

4.5 Horizon-Scale Structure

- **Test:** Map large-scale structure at 10–100 Mpc.
- **Expected Signature:** Enhanced clustering and anomalously large voids.

4.6 Spectral Line Shifts

- **Test:** Analyze high-redshift spectra.
- **Expected Signature:** Broadening or energy shifts of 0.1–1% at $z > 5$.

4.7 Thermodynamic Horizon Signatures

- **Test:** Probe entropy and flux at cosmic horizons.
- **Expected Signature:** Horizon entropy growth $\Delta S \sim 10^{120} k_B$.

4.8 Primordial Nucleosynthesis

- **Test:** Measure abundances of light elements.
- **Expected Signature:** 1–5% increase in ^{4}He and decrease in deuterium.

5. Comparison with ΛCDM

Feature	CDM	Radiation-Driven Model
Inflation driver	Scalar inflaton field	Radiation pressure + redshift energy
Energy conservation	Not globally defined	Thermodynamically enforced via horizons
Speed of light	Globally invariant	Locally invariant within horizons
Horizon/flatness problems	Solved by inflaton	Solved by radiation + horizons
Dark energy	Cosmological constant (Λ)	Continuation of redshift-radiation mechanism
CMB predictions	Standard spectrum	Small-scale enhancements, possible B-mode differences

Feature	ΛCDM	Radiation-Driven Model
Hubble tension	Unresolved	Natural intermediate H_0
Observational status	Supported but incomplete	Consistent with data, not yet falsified

6. Discussion

This framework reframes inflation as a thermodynamic process intrinsic to radiation, requiring no speculative inflaton. It provides a mechanism for energy conservation in expanding spacetime and reconciles relativity's local postulates with cosmological horizons.

Challenges remain. The exact dynamics of redshift energy redistribution require further mathematical development, and numerical simulations of the modified Friedmann equations are essential. Observational discrimination will rely on future missions (CMB-S4, Euclid, LISA, SKA).

7. Conclusion

I present a cosmology in which radiation pressure, modulated by causal horizons and redshift energy, drives both inflation and present-day expansion. This model eliminates the need for a hypothetical inflaton, restores thermodynamic consistency, and reconciles Einstein's local invariance of c with cosmological superluminality. Current data are compatible with ΛCDM, but the proposed observational tests provide a path to validation or falsification.

References

[1] Planck Collaboration, *Planck 2018 Results. VI. Cosmological Parameters,* Astron. Astrophys. 641, A6 (2020). [2] Guth, A. H., *Inflationary Universe,* Phys. Rev. D 23, 347 (1981). [3] Padmanabhan, T., *Thermodynamical Aspects of Gravity: New Insights,* Rep. Prog. Phys. 73, 046901 (2010). [4] BICEP2/Keck Collaboration, *Improved Constraints on Primordial Gravitational Waves,* Phys. Rev. Lett. 121, 221301 (2018).