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Sergiu Vasili Lazarev *

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The Neutrino Energy Density Paradox: Testing Internal Consistency of Hot Big Bang Thermodynamics

A Proposed Observational Framework for Redshift Universality

Sergiu Vasili Lazarev

NMSI Research Institute, Arad, Romania; cycletermo@gmail.com

Abstract

The standard Hot Big Bang (HBB) model predicts thermal production of relic neutrinos with number density $n_\nu \approx 336$ cm^{-3} at decoupling temperature $T_{dec} \approx 1$ MeV. We present a mathematical analysis examining the internal consistency of the axiom system {number density, mean energy, critical density} under the hypothesis that neutrino energy remains unchanged after decoupling. Using elementary arithmetic and De Morgan's logic, we show that this axiom system leads to an energy density exceeding the observed critical density by a factor of approximately 2.5×10^5, demonstrating internal inconsistency. The standard cosmological model resolves this through metric redshift $E \propto 1/a$, which reduces neutrino energy by the required factor. However, this mechanism has not been directly verified for neutrinos. We propose a multi-method observational program to test redshift universality: (1) re-analysis of SN1987A neutrino data, (2) future core-collapse supernovae at $z > 0.01$, (3) Diffuse Supernova Neutrino Background spectral analysis, and (4) direct Cosmic Neutrino Background detection. We estimate that a "golden event" (supernova at $z > 0.01$ with >500 detected neutrinos) has approximately 30% probability of occurrence during 2027-2035, potentially enabling direct comparison of z_ν versus z_γ with significance exceeding 5σ.

Keywords: relic neutrinos; cosmic neutrino background; Big Bang nucleosynthesis; cosmological parameters; ΛCDM model; supernova neutrinos; redshift

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1. Introduction

1.1. Background

The Lambda Cold Dark Matter (ΛCDM) cosmological model, based on the Hot Big Bang (HBB) framework, has achieved remarkable success in explaining diverse cosmological observations including the cosmic microwave background (CMB) anisotropies [1], baryon acoustic oscillations (BAO) [2], and Type Ia supernova distances [3]. A fundamental prediction of this model is the existence of a Cosmic Neutrino Background (CνB) produced during the first seconds after the Big Bang [4,5].

According to standard cosmology, neutrinos decoupled from the primordial plasma at temperature $T_{dec} \approx 1$ MeV ($t \approx 1$ s), leaving a relic population with present-day number density $n_\nu \approx 336$ cm^{-3} (summing over all flavors and antineutrinos) and temperature $T_{\nu,0} \approx 1.95$ K [4]. The cooling from MeV to sub-meV energies is attributed to cosmological redshift, whereby the energy of free-streaming relativistic particles decreases proportionally to the inverse of the cosmic scale factor: $E \propto 1/a$.

1.2. Current Observational Status

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Despite decades of experimental effort, direct detection of the CνB remains elusive due to the extremely low interaction cross-sections at sub-meV energies [6]. Current constraints on relic neutrinos come primarily from indirect cosmological probes:

- CMB observations constrain the effective number of relativistic species: $N_{eff} = 2.99 \pm 0.17$ [1]
- Large-scale structure observations limit the sum of neutrino masses: $\Sigma m_\nu < 0.12$ eV (95% CL) [1]
- Big Bang nucleosynthesis abundance ratios are consistent with three light neutrino species [7]

Recent years have seen growing interest in cosmological tensions, including the Hubble tension ($H_0 = 73.04 \pm 1.04$ km/s/Mpc locally [3] versus 67.4 ± 0.5 km/s/Mpc from CMB [1]), early massive galaxies observed by JWST [8], and BAO anomalies reported by DESI [2]. These motivate careful examination of model assumptions.

1.3. Objectives

This work pursues two objectives:

1. To present a pedagogical analysis of the internal consistency requirements for HBB neutrino thermodynamics, explicitly identifying the role of metric redshift in resolving what would otherwise be a severe energy density paradox.
2. To propose a concrete observational program for testing the universality of cosmological redshift by comparing neutrino and photon redshifts from the same astrophysical sources.

2. Methods

2.1. Axiomatic Framework

We examine the logical consistency of three propositions derived from standard cosmology:

Proposition A1 (Number Density): The relic neutrino number density is $n_\nu = 336$ cm^{-3}.

This follows from entropy conservation and the Fermi-Dirac distribution at decoupling [4]:

$$n_\nu = (3/11) \times (2\zeta(3)/\pi^2) \times T_{\gamma,0}^3 \times 6 \approx 336 \text{ cm}^{-3}$$

where $T_{\gamma,0} = 2.725$ K is the present CMB temperature, and the factor 6 accounts for three flavors plus antineutrinos.

Proposition A2 (Energy Without Redshift): If neutrino energy is not reduced after decoupling, the mean energy remains $\langle E_\nu \rangle \approx 3.15 \times T_{dec} \approx 3.8$ MeV.

This represents a counterfactual hypothesis—what would occur in the absence of any cooling mechanism.

Proposition A3 (Critical Density): The observed critical density is $\rho_{crit} \approx 5 \times 10^3$ eV cm^{-3}.

This is derived from measurements of H_0 via the relation $\rho_{crit} = 3H_0^2/(8\pi G)$ [1].

2.2. Consistency Analysis

We calculate the neutrino energy density under the counterfactual hypothesis A2:

$$\rho_\nu = n_\nu \times \langle E_\nu \rangle = 336 \text{ cm}^{-3} \times 3.8 \times 10^6 \text{ eV} = 1.28 \times 10^9 \text{ eV cm}^{-3}$$

The ratio to critical density:

$$\Omega_\nu = \rho_\nu / \rho_{crit} = 1.28 \times 10^9 / 5 \times 10^3 \approx 2.5 \times 10^5$$

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This exceeds unity by over five orders of magnitude, whereas cosmological observations constrain $\Omega_\nu < 0.006$ [1].

2.3. Logical Structure

The inconsistency of {A1, A2, A3} can be expressed formally:

$\neg(A1 \wedge A2 \wedge A3)$

By De Morgan's law:

$\neg A1 \vee \neg A2 \vee \neg A3$

At least one proposition must be false. Since A1 and A3 derive from well-established physics and observations, standard cosmology resolves this by rejecting A2—i.e., by invoking metric redshift to reduce neutrino energies.

2.4. Proposed Observational Tests

We propose testing the universality of metric redshift through four complementary methods:

Method 1: SN1987A Re-analysis

Using archival data from Kamiokande-II (11 events), IMB (8 events), and Baksan (5 events) [9–11], we can constrain the neutrino redshift. At distance $D \approx 50$ kpc, the expected cosmological redshift $z \approx 5\times10^{-6}$ produces energy shifts of ~50 eV, below detector resolution. However, temporal evolution analysis of the neutrino spectrum may provide constraints.

Method 2: Future Supernovae at $z > 0.01$

Next-generation detectors including Hyper-Kamiokande [12], JUNO [13], and DUNE [14], coordinated through SNEWS 2.0 [15], will detect thousands of neutrinos from Galactic supernovae and potentially hundreds from supernovae at $z \sim 0.01$. At this distance, a 1% energy shift becomes measurable with sufficient statistics.

Method 3: Diffuse Supernova Neutrino Background

The DSNB spectrum depends on the cosmological integration kernel [16]. Different redshift models predict different spectral shapes, potentially distinguishable with Hyper-Kamiokande and JUNO sensitivities expected by 2030.

Method 4: Direct CνB Detection

The PTOLEMY experiment proposes detecting relic neutrinos via capture on tritium [6]. While extremely challenging, this would directly probe the present-day neutrino energy distribution.

3. Results

3.1. Energy Density Calculation

Under the counterfactual hypothesis of no energy cooling:

Parameter	Value	Source
n_ν	336 cm^{-3}	Entropy conservation [4]
$\langle E_\nu \rangle$ (no cooling)	3.8 MeV	Fermi-Dirac at T_{dec}
ρ_ν (calculated)	1.28×10^9 eV cm^{-3}	$n_\nu \times \langle E_\nu \rangle$
ρ_{crit} (observed)	5×10^3 eV cm^{-3}	From H_0 [1]
Ω_ν (calculated)	2.5×10^5	Ratio
Ω_ν (observed limit)	< 0.006	Planck 2018 [1]

The discrepancy factor is approximately 4×10^7.

3.2. Resolution Options

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Three logical possibilities exist:

Option 1 (¬A1): The neutrino number density differs substantially from 336 cm^{-3}.

Required: $n_{\nu,consistent} \approx 1.3 \times 10^{-3}$ cm^{-3} (reduction factor ~2.6×10^5)

Assessment: Would require abandonment of standard thermal history or unknown neutrino disappearance mechanism. No independent evidence supports this.

Option 2 (¬A2): Neutrino energy has been reduced by a cooling mechanism.

Required: $\langle E_\nu \rangle_{consistent} \approx 15$ eV (reduction factor ~2.5×10^5)

Assessment: This is the standard cosmological solution via metric redshift. ΛCDM actually predicts even greater cooling (to ~0.5 meV), a factor of ~10^4 beyond the minimum required for consistency.

Option 3 (¬A3): The critical density differs substantially from measured values.

Required: $\rho_{crit,consistent} \approx 2 \times 10^{11}$ eV cm^{-3} (factor ~4×10^7 larger)

Assessment: Would require $H_0 \approx 7000$ km/s/Mpc, incompatible with all local measurements.

3.3. Testability Assessment

Observable	ΛCDM Prediction	Alternative	Current Status
MeV neutrino background	Absent (cooled)	Present if no cooling	Not detected
z_ν from SN1987A	~5×10^{-6}	Could differ	Inconclusive (below resolution)
z_ν from SN at $z=0.01$	$= z_\gamma$	Could differ	Awaiting observation
DSNB spectrum shape	With $(1+z)^{-1}$ kernel	Without kernel	Upper limits only
Direct CνB	~0.5 meV	~MeV if no cooling	Not yet attempted

3.4. Golden Event Probability

For a core-collapse supernova at $z > 0.01$ detectable by next-generation neutrino observatories:

- Galactic SN rate: ~2-3 per century
- Rate within $z < 0.05$: ~0.5 per year (all types); ~0.2 per year (core-collapse detectable)
- Cumulative probability 2027-2035: ~30%

Expected significance for $z = 0.01$, $N = 500$ events: - Energy shift: $\Delta(kT) \approx 30$ keV at $T \sim 3$ MeV - Statistical uncertainty: $\sigma_T \approx 4$ keV - Significance: ~7.5σ for complete absence versus full redshift

4. Discussion

4.1. Interpretation

The analysis presented here is pedagogical rather than novel—the resolution of the neutrino energy density problem through cosmological redshift is well-established in standard cosmology [4,5]. However, we emphasize that this resolution has not been directly verified for neutrinos. All current evidence for cosmological redshift comes from electromagnetic observations (CMB, galaxy spectra, SNIa).

The proposed observational program would provide the first direct test of redshift universality for weakly-interacting particles. A positive result ($z_\nu = z_\gamma$) would strengthen confidence in the

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ΛCDM framework. A discrepant result would have profound implications requiring careful scrutiny before drawing conclusions.

4.2. Relation to Current Tensions

The Hubble tension and other cosmological discrepancies [17] have motivated exploration of extensions to ΛCDM. While the neutrino consistency test proposed here is independent of these tensions, it addresses a foundational assumption—metric redshift universality—that underlies all distance-redshift relations in cosmology.

4.3. Alternative Theoretical Frameworks

Several theoretical frameworks predict or allow deviations from universal redshift, including:

- Tired light models (historically disfavored by surface brightness tests)
- Variable constants cosmologies
- Modified dispersion relations from quantum gravity
- Interaction-dependent propagation effects

The New Subquantum Informational Mechanics (NMSI) framework [18–20] represents one such alternative, proposing that redshift may have interactional rather than purely metric origin. The observational tests proposed here could discriminate between such alternatives and standard cosmology.

4.4. Limitations

This analysis has several limitations:

1. The counterfactual hypothesis (A2) is constructed specifically to demonstrate the necessity of cooling—it is not a competing physical model.
2. Neutrino spectroscopy from distant supernovae depends on uncertain emission models for proto-neutron star cooling.
3. The DSNB spectral shape test depends on the star formation history, introducing model dependence.
4. Direct CνB detection faces formidable technical challenges that may not be overcome within the proposed timeframe.

5. Conclusions

We have presented a systematic analysis of the internal consistency requirements for Hot Big Bang neutrino thermodynamics. The key findings are:

1. **Mathematical necessity of cooling:** Without an energy reduction mechanism, the predicted neutrino energy density would exceed critical density by factor ~10^5, creating severe inconsistency with observed cosmology.
2. **Standard resolution:** ΛCDM resolves this through metric redshift $E \propto 1/a$, reducing neutrino energies by the required factor (and more).
3. **Untested assumption:** The universality of metric redshift for neutrinos has not been directly verified observationally.
4. **Proposed tests:** A multi-method observational program using SN1987A re-analysis, future supernovae at $z > 0.01$, DSNB spectroscopy, and direct CνB detection could test redshift universality within the next decade.
5. **Discrimination capability:** A golden event (supernova at $z > 0.01$, probability ~30% by 2035) could distinguish $z_\nu = z_\gamma$ from $z_\nu \neq z_\gamma$ at >5σ significance.

We encourage the neutrino astronomy community to include redshift universality tests in the science programs of next-generation detectors.

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References

1. Planck Collaboration. Planck 2018 results. VI. Cosmological parameters. *Astron. Astrophys.* **2020**, *641*, A6. https://doi.org/10.1051/0004-6361/201833910
2. DESI Collaboration. DESI 2024 VI: Cosmological Constraints from the Baryon Acoustic Oscillations. *arXiv* **2024**, 2404.03002.
3. Riess, A.G.; Yuan, W.; Macri, L.M.; et al. A Comprehensive Measurement of the Local Value of the Hubble Constant. *Astrophys. J. Lett.* **2022**, *934*, L7. https://doi.org/10.3847/2041-8213/ac5c5b
4. Lesgourgues, J.; Pastor, S. Massive neutrinos and cosmology. *Phys. Rep.* **2006**, *429*, 307–379. https://doi.org/10.1016/j.physrep.2006.04.001
5. Kolb, E.W.; Turner, M.S. *The Early Universe*; Addison-Wesley: Redwood City, CA, USA, 1990.
6. Betti, M.G.; Biasotti, M.; Boscá, A.; et al. Neutrino physics with the PTOLEMY project. *J. Cosmol. Astropart. Phys.* **2019**, *2019*, 047. https://doi.org/10.1088/1475-7516/2019/07/047
7. Particle Data Group. Review of Particle Physics. *Prog. Theor. Exp. Phys.* **2024**, 2024, 083C01. https://pdg.lbl.gov
8. Labbé, I.; van Dokkum, P.; Nelson, E.; et al. A population of red candidate massive galaxies ~600 Myr after the Big Bang. *Nature* **2023**, *616*, 266–269. https://doi.org/10.1038/s41586-023-05786-2
9. Hirata, K.; Kajita, T.; Koshiba, M.; et al. Observation of a neutrino burst from the supernova SN1987A. *Phys. Rev. Lett.* **1987**, *58*, 1490–1493. https://doi.org/10.1103/PhysRevLett.58.1490
10. Bionta, R.M.; Blewitt, G.; Bratton, C.B.; et al. Observation of a neutrino burst in coincidence with supernova 1987A. *Phys. Rev. Lett.* **1987**, *58*, 1494–1496. https://doi.org/10.1103/PhysRevLett.58.1494
11. Alekseev, E.N.; Alekseeva, L.N.; Volchenko, V.I.; Krivosheina, I.V. Possible detection of a neutrino signal on 23 February 1987 at the Baksan underground scintillation telescope. *JETP Lett.* **1987**, *45*, 589–592.
12. Abe, K.; Abe, K.; Aihara, H.; et al. Hyper-Kamiokande Design Report. *arXiv* **2018**, 1805.04163.
13. An, F.; An, G.; An, Q.; et al. Neutrino Physics with JUNO. *J. Phys. G* **2016**, *43*, 030401. https://doi.org/10.1088/0954-3899/43/3/030401
14. Abi, B.; Acciarri, R.; Acero, M.A.; et al. Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report. *J. Instrum.* **2020**, *15*, T08008. https://doi.org/10.1088/1748-0221/15/08/T08008
15. Al Kharusi, S.; Backes, K.M.; Baldini, A.; et al. SNEWS 2.0: A next-generation supernova early warning system. *New J. Phys.* **2021**, *23*, 031201. https://doi.org/10.1088/1367-2630/abde33
16. Beacom, J.F. The Diffuse Supernova Neutrino Background. *Annu. Rev. Nucl. Part. Sci.* **2010**, *60*, 439–462. https://doi.org/10.1146/annurev.nucl.010909.083331
17. Di Valentino, E.; Mena, O.; Pan, S.; et al. In the realm of the Hubble tension—a review of solutions. *Class. Quantum Grav.* **2021**, *38*, 153001. https://doi.org/10.1088/1361-6382/ac086d
18. Lazarev, S.V. New Subquantum Informational Mechanics (NMSI): A Complete Axiomatic Framework. *Preprints* **2025**, 2025120209. https://doi.org/10.20944/preprints202512.2009.v1
19. Lazarev, S.V. The π-Indexed Riemann Oscillatory Network. *Preprints* **2025**, 2025122536. https://doi.org/10.20944/preprints202512.2536.v1
20. Lazarev, S.V. The Subquantum Void as RON_NMSI Memory Network. *Preprints* **2026**, 2026010354. https://doi.org/10.20944/preprints202601.0354.v1
21. Mirizzi, A.; Tamborra, I.; Janka, H.-T.; et al. Supernova neutrinos: production, oscillations and detection. *Riv. Nuovo Cim.* **2016**, *39*, 1–112. https://doi.org/10.1393/ncr/i2016-10120-8
22. Scholberg, K. Supernova Neutrino Detection. *Annu. Rev. Nucl. Part. Sci.* **2012**, *62*, 81–103. https://doi.org/10.1146/annurev-nucl-102711-095006

 doi:10.20944/preprints202601.1837.v1

23. Super-Kamiokande Collaboration. Diffuse supernova neutrino background search at Super-Kamiokande. *Phys. Rev. D* **2021**, *104*, 122002. https://doi.org/10.1103/PhysRevD.104.122002
24. Super-Kamiokande Collaboration. Solar Neutrino Measurements in Super-Kamiokande-IV. *Phys. Rev. D* **2016**, *94*, 052010. https://doi.org/10.1103/PhysRevD.94.052010