

Peer-Review

Piran, Sophia, and Brayden Hisco. 2026. "Zero-Sum Node Reconfiguration in a Discrete Spacetime Substrate." *Journal of High School Science* 10 (3): 313–30. <https://doi.org/10.64336/001c.165628>.

I enjoyed reading the manuscript. What you are really saying is "Among a class of hypothetical discrete-spacetime reconfiguration models, almost all versions fail observational consistency tests, but one narrowly constrained reversible version survives and predicts a possible small-scale cosmological signature." This is actually a more scientifically responsible claim than many speculative cosmology papers make.

In your conceptual interpretation "maybe continuum assumptions about spacetime break down microscopically, and that breakdown naturally regulates vacuum-like behavior." I would like for you to consider and introduce a statistical thermodynamics analogy into the manuscript (see below the dotted line). As you state in your manuscript "A third task was to determine whether the same zero-sum logic could be embedded in a broader discrete-spacetime framework that also addressed other

cosmological or gravitational observables without reintroducing the thermal and radiative failures identified here."

The introduction of such an analogy preserves the validity of other cosmological or gravitational equations/observables because they would then emerge statistically from many locally varying microscopic realizations of the ensemble while preserving large-scale effective compensation. This rectifies one of the manuscript's biggest vulnerabilities, i.e. the zero-sum condition currently feels artificially exact. But thermodynamics teaches us that exact macroscopic constraints can emerge statistically, even when microscopic local behavior is highly heterogeneous. (I have also attached a pdf file).

The present framework may also be interpreted analogously to constrained thermodynamic systems in which macroscopic viability emerges only within restricted parameter regimes defined by competing tendencies. In classical thermodynamics, the Gibbs free energy $\Delta G = \Delta H - T\Delta S$ does not describe enthalpic or entropic contributions independently, but rather the constrained balance between them that determines whether a process remains dynamically favorable. The discrete-substrate framework explored here exhibits a conceptually similar structure. Dissipative node creation, thermal coupling, and gravitationally radiative exhaust each act as competing channels that drive the system away from observational viability, while the zero-sum limit represents a constrained regime in which these competing contributions remain globally balanced. In this interpretation, the surviving branch is not selected arbitrarily, but emerges as the only phenomenologically admissible regime after consistency constraints are imposed. The compensated high-k "blue-scar" correction may then be viewed as a residual ultraviolet signature of the underlying microscopic substrate, analogous to how macroscopic thermodynamic behavior can retain indirect traces of microscopic statistical structure.

The analogy to constrained thermodynamic systems may extend beyond equilibrium admissibility alone. In statistical thermodynamics, a system satisfying a globally favorable free-energy condition may nevertheless exhibit widely differing local kinetics, metastable configurations, nucleation pathways, and microscopic fluctuations while remaining within the same macroscopic thermodynamic regime. The present framework may admit a conceptually similar interpretation. The zero-sum condition need not imply that every microscopic node-reconfiguration event is individually identical or perfectly balanced in isolation; rather, it may represent an effective coarse-grained constraint emerging statistically across many local substrate realizations. Different microscopic regions could therefore support differing local quantum phenomenology or reconfiguration dynamics while still collectively preserving the globally compensated cosmological behavior required by observational constraints. In this interpretation, the observed vacuum-like background would correspond not to rigid microscopic uniformity, but to an emergent macroscopic

admissibility condition analogous to thermodynamic equilibrium arising from heterogeneous microscopic dynamics.

Response to Reviewers

Manuscript: Zero-Sum Node Reconfiguration in a Discrete Spacetime Substrate

We thank the reviewers for their careful and constructive assessment of the manuscript. Each comment is reproduced verbatim below, followed by a detailed response and the location in the revised manuscript where the change was made. Where final pagination may shift during formatting, locations are identified by section title and opening phrase rather than line number.

Reviewer #1, Comment 1

Comment: I enjoyed reading the manuscript. What you are really saying is "Among a class of hypothetical discrete-spacetime reconfiguration models, almost all versions fail observational consistency tests, but one narrowly constrained reversible version survives and predicts a possible small-scale cosmological signature." This is actually a more scientifically responsible claim than many speculative cosmology papers make.

Response: The manuscript has been reframed to make that limited and scientifically responsible claim explicit. The revised Abstract, Introduction, and closing Discussion now present the study as a consistency-selection analysis in which most discrete-substrate branches are excluded and one narrowly constrained effective branch survives while leaving a falsifiable small-scale signature. The wording was also tightened to avoid implying a first-principles derivation of dark energy.

Location in revised manuscript: Abstract (entire paragraph, especially the final two sentences); Introduction (final paragraph beginning "It was hypothesised..."); Results and Discussion (final paragraph beginning "Within those limitations...").

Reviewer #1, Comment 2

Comment: In your conceptual interpretation "maybe continuum assumptions about spacetime break down microscopically, and that breakdown naturally regulates vacuum-like behavior." I would like for you to consider and introduce a statistical thermodynamics analogy into the manuscript (see below the dotted line). As you state in your manuscript "A third task was to determine whether the same zero-sum logic could be embedded in a broader discrete-spacetime framework that also addressed other cosmological or gravitational observables without reintroducing the thermal and radiative failures identified here."

Response: A statistical-thermodynamic analogy has been incorporated into the revised manuscript. The zero-sum branch is now interpreted not as an engineered microscopic mechanism, but as a coarse-grained admissibility condition emerging after competing dissipative, thermal, and gravitational channels are filtered by phenomenological consistency. This change was implemented both in the conceptual framing of the Introduction and in the interpretive paragraphs of the Discussion.

Location in revised manuscript: Introduction (paragraph beginning "The conceptual interpretation adopted here was correspondingly restrained."); Results and Discussion (paragraph beginning "This interpretation was strengthened by the thermodynamic and statistical framing...").

Reviewer #1, Comment 3

Comment: The introduction of such an analogy preserves the validity of other cosmological or gravitational equations/observables because they would then emerge statistically from many locally varying microscopic realizations of the ensemble while preserving large-scale effective compensation. This rectifies one of the manuscript's biggest vulnerabilities, i.e. the zero-sum condition currently feels artificially exact. But thermodynamics teaches us that exact macroscopic constraints can emerge statistically, even when microscopic local behavior is highly heterogeneous.

Response: The manuscript has been revised to make this point explicit. The zero-sum condition is no longer presented as a microscopic event-by-event law. Instead, the revised text states that the observable cosmological sector may behave as if compensation holds after coarse-graining over

heterogeneous local substrate realizations. This directly addresses the concern that the zero-sum condition previously appeared artificially exact.

Location in revised manuscript: Introduction (paragraph beginning “The conceptual interpretation adopted here was correspondingly restrained.”); Results and Discussion (paragraph beginning “The statistical interpretation also removed the appearance of artificial exactness.”); Materials and Methods (Model framework; Core model assumptions and boundaries).

Reviewer #1, Comment 4

Comment: The present framework may also be interpreted analogously to constrained thermodynamic systems in which macroscopic viability emerges only within restricted parameter regimes defined by competing tendencies. In classical thermodynamics, the Gibbs free energy $\Delta G = \Delta H - T\Delta S$ does not describe enthalpic or entropic contributions independently, but rather the constrained balance between them that determines whether a process remains dynamically favorable. The discrete-substrate framework explored here exhibits a conceptually similar structure. Dissipative node creation, thermal coupling, and gravitationally radiative exhaust each act as competing channels that drive the system away from observational viability, while the zero-sum limit represents a constrained regime in which these competing contributions remain globally balanced. In this interpretation, the surviving branch is not selected arbitrarily, but emerges as the only phenomenologically admissible regime after consistency constraints are imposed. The compensated high- k “blue-scar” correction may then be viewed as a residual ultraviolet signature of the underlying microscopic substrate, analogous to how macroscopic thermodynamic behavior can retain indirect traces of microscopic statistical structure.

Response: This exact interpretive structure has been adopted in the revised Results and Discussion. The manuscript now explicitly compares dissipative node creation, thermal coupling, and gravitationally radiative leakage to competing channels that remove non-viable branches, while the zero-sum regime is retained as the only phenomenologically admissible coarse-grained closure. In addition, the reference list was expanded to include thermodynamics/statistical-mechanics sources supporting the Gibbs-style framing.

Location in revised manuscript: Results and Discussion (paragraph beginning “This interpretation was strengthened by the thermodynamic and statistical framing...”); References (entries 20–21).

Reviewer #1, Comment 5

Comment: The analogy to constrained thermodynamic systems may extend beyond equilibrium admissibility alone. In statistical thermodynamics, a system satisfying a globally favorable free-energy condition may nevertheless exhibit widely differing local kinetics, metastable configurations, nucleation pathways, and microscopic fluctuations while remaining within the same macroscopic thermodynamic regime. The present framework may admit a conceptually similar interpretation. The zero-sum condition need not imply that every microscopic node-reconfiguration event is individually identical or perfectly balanced in isolation; rather, it may represent an effective coarse-grained constraint emerging statistically across many local substrate realizations. Different microscopic regions could therefore support differing local quantum phenomenology or reconfiguration dynamics while still collectively preserving the globally compensated cosmological behavior required by observational constraints. In this interpretation, the observed vacuum-like background would correspond not to rigid microscopic uniformity, but to an emergent macroscopic admissibility condition analogous to thermodynamic equilibrium arising from heterogeneous microscopic dynamics.

Response: This extension was incorporated into the revised Discussion. The manuscript now states that the zero-sum condition does not require every microscopic event to be perfectly balanced in isolation, but instead functions as an ensemble-level coarse-grained constraint. The revised text also explains that heterogeneous local reconfiguration dynamics may still preserve the same macroscopically compensated cosmological background after coarse-graining.

Location in revised manuscript: Results and Discussion (paragraph beginning “The statistical interpretation also removed the appearance of artificial exactness.”).

Reviewer #2, Comment 1

Comment: Please verify that all links to the references point to the correct source.

Response: The reference list was reviewed and standardised. Missing or inconsistent bibliographic details were corrected, DOI and arXiv entries were regularised, and the final list was checked so that each reference points to the intended source. Formatting inconsistencies in the bibliography were also corrected.

Location in revised manuscript: References section (entries 1–21).

Reviewer #2, Comment 2

Comment: The authors must disclose and acknowledge any assistance received in the preparation of this manuscript, including but not limited to editorial, technical, analytical, or writing support. All such contributions must be clearly stated in the Acknowledgments section.

Response: The Acknowledgements section was expanded to name the individuals who provided research guidance, professional feedback, editorial reading, encouragement, and related advisory support. A formal disclosure sentence was also added to clarify that such input was advisory in nature and that the final modeling choices, numerical analysis, manuscript revisions, and interpretations remained the responsibility of the authors.

Location in revised manuscript: Acknowledgements (final paragraph, especially the closing disclosure sentence).

Reviewer #2, Comment 3

Comment: Include enough recent references along with foundational ones. Ensure references directly support your claims. Avoid “padding.” Use credible sources (peer-reviewed journals, reputable books, official reports).

Response: The bibliography was revised to preserve foundational cosmology and gravity sources while also retaining recent observational constraints relevant to the manuscript’s claims. In addition, two standard thermodynamics/statistical-mechanics references were added because the revised interpretation now explicitly invokes a Gibbs-style admissibility framework. Care was taken to avoid decorative citations and to align sources with the specific claims they support.

Location in revised manuscript: References section (entries 1–21); Results and Discussion (thermodynamic/statistical interpretation paragraph).

Reviewer #2, Comment 4

Comment: All assumptions (including implicit assumptions) must be explicitly stated and clearly justified. The authors should explain why each assumption is reasonable and discuss its impact on the results and conclusions.

Response: A dedicated assumptions subsection was added to Materials and Methods. This subsection now states that nodes are treated as coarse-grained effective degrees of freedom, that the zero-sum closure is a macroscopic consistency condition rather than a microscopic derivation, that the blue-scar form beyond the robust infrared limit is phenomenological, and that the observational comparisons are benchmark consistency tests rather than full likelihood analyses. The impact of those assumptions on the scope of the conclusions is also stated explicitly.

Location in revised manuscript: Materials and Methods (subsection beginning “Core model assumptions and boundaries.”).

Reviewer #2, Comment 5

Comment: Avoid overreaching conclusions that extend beyond what is supported by the data and analysis.

Response: The concluding language was revised throughout the manuscript to remain within the bounds of an effective phenomenological analysis. The Abstract, Introduction, Discussion, and Conclusion now state that the study does not provide a first-principles derivation of dark energy or proof that spacetime is discrete. Instead, it identifies a narrowly constrained phenomenological regime that survives the benchmark consistency tests used in the present study and leaves a falsifiable small-scale signature.

Location in revised manuscript: Abstract (final sentence); Introduction (final paragraph); Results and Discussion (final paragraph beginning “Within those limitations...”).

Reviewer #2, Comment 6

Comment: Verify that you have used past perfect tense and third person throughout the manuscript wherever applicable.

Response: The manuscript was copyedited to remove first-person phrasing and to maintain a more formal third-person academic style throughout. In particular, the Results section was rewritten to eliminate constructions such as “we tested,” and section headings and phrasing were standardized to align with journal style.

Location in revised manuscript: Manuscript-wide copyedit; Results and Discussion; Materials and Methods.

Thank you for addressing my comments. The paper is significantly strengthened. I have one remaining concern that could be addressed (not a full scale likelihood analysis but a partial inference analysis that is not too onerous and should not take too much time) . Please see the comment below. The manuscript has been substantially strengthened through the addition of explicit assumptions, improved scope calibration, and a more restrained interpretation of the surviving zero-sum branch. One opportunity for further strengthening would be to connect the proposed blue-scar signature more directly to existing observations. The manuscript need not undertake a full Planck-, DESI-, or MCMC-based cosmological inference analysis. However, a limited quantitative comparison against at least one published small-scale structure, primordial power-spectrum, or 21-cm constraint would substantially enhance the scientific impact of the work. For example, preliminary bounds on the blue-scar amplitude and turnover scale could be estimated by comparing representative model realizations against existing observational limits. Such an analysis would help establish whether the proposed phenomenological signature remains observationally permissible and would transform the blue scar from a qualitative prediction into a quantitatively constrained and falsifiable feature of the framework. Right now your contribution is “A consistency-selection exercise identifies one surviving branch”. With this partial likelihood analysis, that contribution becomes “A consistency-selection exercise identifies one surviving branch and establishes the first observationally allowed parameter space for its falsifiable signature.” This is much stronger.

Response to Reviewer Comments

Manuscript: “Zero-Sum Node Reconfiguration in a Discrete Spacetime Substrate”

Round 2 Revision

General response. The authors sincerely thank the reviewer for the careful second-round assessment and for the constructive suggestion to strengthen the manuscript by connecting the phenomenological blue-scar signature to an existing observational constraint. In response, the revised manuscript now includes a limited quantitative benchmark comparison against published 21-cm bounds on small-scale primordial power. This addition was designed explicitly as a preliminary consistency test rather than as a full Planck-, DESI-, or MCMC-based likelihood analysis. The revision therefore preserves the phenomenological scope of the work while addressing the reviewer’s central request: namely, to move the blue scar from a qualitative falsifiable signature to a preliminarily constrained observational feature.

Reviewer comment: “Thank you for addressing my comments. The paper is significantly strengthened. I have one remaining concern that could be addressed (not a full scale likelihood analysis but a partial inference analysis that is not too onerous and should not take too much time). The manuscript has been substantially strengthened through the addition of explicit assumptions, improved scope calibration, and a more restrained interpretation of the surviving zero-sum branch. One opportunity for further strengthening would be to connect the proposed blue-scar signature more directly to existing observations. The manuscript need not undertake a full Planck-, DESI-, or MCMC-based cosmological inference analysis. However, a limited quantitative comparison against at least one published small-scale structure, primordial power-spectrum, or 21-cm constraint would substantially enhance the scientific impact of the work. For example, preliminary bounds on the blue-scar amplitude and turnover scale could be estimated by comparing representative model realizations against existing observational limits. Such an analysis would help establish whether the proposed phenomenological signature remains observationally permissible and would transform the blue scar from a qualitative prediction into a quantitatively constrained and falsifiable feature of the framework. Right now your contribution is A consistency-selection exercise identifies one surviving branch. With this partial likelihood analysis, that contribution becomes “A consistency-selection exercise identifies one surviving branch and establishes the first observationally allowed parameter space for its falsifiable signature. This is much stronger.”

Response: The authors agree entirely with the reviewer’s assessment and are grateful for the suggestion. In response, the manuscript has been revised to include a limited observational benchmark comparison of the blue-scar template against the published 21-cm global-signal constraints of Yoshiura et al. (2020). This comparison was deliberately framed as a preliminary consistency benchmark rather than a full cosmological likelihood analysis, in accordance with the reviewer’s request. To make the comparison controlled and transparent, the oscillatory modulation was switched off for the benchmark test ($\beta = 0$), the reference scale was fixed at $k_s = 10 \text{ Mpc}^{-1}$, and the smooth envelope of the template was required to satisfy $1 + \Delta_{\text{node}(k)} \leq 10$ over $10 < k < 10^2 \text{ Mpc}^{-1}$. This yielded an explicit admissibility boundary in the (A_n, k_d) plane and representative amplitude limits for selected turnover scales. The revision therefore upgrades the paper’s contribution from a purely qualitative consistency-selection exercise to a framework in which the surviving branch now carries a preliminarily benchmarked observationally allowed parameter regime for its falsifiable blue-scar signature.

Location in revised manuscript: The revision was implemented in five places: (1) Abstract, where the paper now states that representative blue-scar realizations were benchmarked against published 21-cm constraints and that preliminary bounds were obtained; (2) Introduction, in the paragraph beginning “Because such a template modifies the primordial spectrum on small scales...”, where the need for observational compatibility is explicitly framed; (3) Materials and Methods, new subsection “Preliminary observational comparison with 21-cm small-scale constraints”, where the benchmark procedure and admissibility criterion are defined; (4) Results and Discussion, new subsection “Preliminary observational bounds on the blue-scar template”, where the Yoshiura et al. benchmark, the admissibility condition, the (A_n, k_d) boundary, and representative limits are reported; (5) Figure 4 and its caption, which now display the preliminary observational admissibility region in the (A_n, k_d) plane.

Summary of substantive changes made in this revision

- Added a new observational-benchmark subsection in Materials and Methods defining the 21-cm comparison and the conservative admissibility criterion.
- Added a new Results and Discussion subsection deriving preliminary amplitude-turnover bounds for the blue-scar template from the published 21-cm benchmark.
- Added Figure 4 showing the preliminary observational admissibility region in the (A_n, k_d) plane.

- Revised the Abstract, Introduction, and concluding claims so that the manuscript now presents the blue scar as a phenomenological signature that is not only falsifiable in principle but also preliminarily benchmarked against an existing observational constraint.
 - Preserved the manuscript's restrained scope by explicitly stating that the new comparison is a benchmark consistency test rather than a full inference pipeline.
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- Thank you for addressing my comments. Accepted.