


THE EPISTEMOLOGICAL STATUS OF MULTIVERSE HYPOTHESES: THE LIMITS OF SCIENTIFIC FALSIFIABILITY AND THE MHESI MULTI-AXIS EVALUATIVE FRAMEWORK

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Abstract: Multiverse hypotheses — a family of cosmological and physical proposals according to which the universe we observe is one of many physically realised universes, the others being either causally disconnected from ours, or distinguished by different fundamental constants, or distinguished by different fundamental laws — have moved since the 1990s from speculative ideas at the margins of theoretical physics into widely discussed components of mainstream cosmological discourse. Four principal variants crystallised in the 2016–2022 literature: eternal inflation plus the string landscape, Tegmark's Level IV mathematical universe, the Everettian multiplicity of quantum-mechanical branches extended by parameter variation, and bubble-nucleation cosmology. The empirical status of these hypotheses is in every case the same: no direct observation of another universe is possible in principle, because the defining property of another universe is precisely that it is not causally accessible from ours. In this article I propose, as the original contribution, the Multiverse Hypothesis Epistemic Status Index (MHESI), a normalised composite metric — bounded on $[0,1]$ — that integrates five epistemological dimensions (the strict Popperian falsifiability principle, Lakatosian research-programme progressivity, Dawid's non-empirical confirmation, internal mathematical-physical coherence, and predictive distinctiveness from non-multiverse alternatives) and returns a quantitative ranking of competing multiverse proposals along the axis of epistemic-scientific status. Applied to the four canonical multiverse variants, MHESI returns values in the range 0.20–0.50, indicating that no current multiverse hypothesis fully satisfies any operational demarcation criterion, but that the variants differ considerably in which criterion they best satisfy.

Keywords: *multiverse, falsifiability, demarcation problem, non-empirical confirmation, eternal inflation, string landscape, Tegmark Level IV, Everettian quantum mechanics, philosophy of cosmology, Bayesian methodology.*

INTRODUCTION

The demarcation problem — the question of how scientific theories should be distinguished from non-scientific or pseudo-scientific ones — is one of the oldest and most contested problems in twentieth-century philosophy of science. The Popperian criterion of falsifiability, articulated in the 1934 *Logik der Forschung* and refined through six decades of subsequent work, held that a theory counts as scientific if and only if it makes predictions that could in principle be empirically refuted. The Lakatosian refinement (1970) supplemented this with the requirement that scientific research programmes should be progressive — that successive theoretical refinements should

generate novel empirical predictions, rather than merely accommodating existing observations. The Kuhnian paradigm-comparison framework (1962/1970) treated theory-acceptance as a more historically-situated process governed by paradigm-specific puzzle-solving rather than by single decisive empirical tests. None of these classical demarcation frameworks was designed with the multiverse case in mind, and each faces specific difficulties when applied to it (Smeenk & Ellis, 2017; Carroll, 2019; Dardashti et al., 2019).

The multiverse case differs from the canonical demarcation cases in a structurally significant respect: the defining property of an other-universe is that it is, in principle, causally inaccessible from our own. This is not an incidental empirical limitation that future observational improvements could overcome; it is a constitutive feature of the multiverse concept. The implication is that no direct observation of another universe is possible, and the empirical-falsifiability question therefore reduces to whether the multiverse hypothesis generates indirect predictions — about the statistical distribution of observed properties of our universe, about the structure of cosmic perturbation patterns, about the small-scale features of the matter power spectrum, about the typicality of observed Standard-Model parameter values — that distinguish it from non-multiverse alternatives (Ellis, 2017; Smeenk & Ellis, 2017; Azhar & Butterfield, 2017).

The 2016-2022 philosophical literature on multiverse epistemology divides into four broad camps. The first camp — represented prominently by Ellis and Silk in their 2014 *Nature* critique “Defend the integrity of physics,” and developed within the 2016-2022 window by Rovelli (2016, 2019), Hossenfelder (2018, 2021), and aligned voices — defends a strict Popperian-falsifiability standard and argues that multiverse hypotheses fail this standard and should therefore not be regarded as scientific in the same sense as, e.g., the Standard Model of particle physics. The second camp — represented prominently by Carroll's (2018, 2019) “Beyond Falsifiability,” Dawid's (2013, 2019) non-empirical theory confirmation programme, and Tegmark's (2014) book-length defence of the mathematical-universe hypothesis — argues that falsifiability is an inadequate criterion for evaluating modern fundamental-physics theories and that alternative epistemic criteria (no-alternatives arguments, unexpected explanatory connections, meta-inductive arguments) should be admitted as legitimate sources of theoretical confidence. The third camp — represented by Friederich (2018, 2019, 2021), Manson (2020, 2022), Landsman (2019), and Barnes (2018, 2020) — analyses the structure of the underlying Bayesian inference and selection-effect arguments without taking a strong position on the broader demarcation question. The fourth camp — represented by Azhar and Butterfield (2017), Azhar's (2015, accessed via in-window work) analyses of typicality, and Smeenk's (2017, 2019) historical-philosophical contextualisation — focuses on the methodological prerequisites that any successful multiverse-scientific-status argument would need to satisfy, particularly regarding the specification of probability measures over the multiverse and the formal treatment of typicality (Azhar & Butterfield, 2017; Smeenk, 2019; Smeenk & Ellis, 2017).

The dialectical situation in mid-2022 was that the demarcation question for multiverse hypotheses remained unresolved, that the four camps articulated genuinely different positions whose adequate adjudication required engagement with substantive issues in the foundations of philosophy of science, and that no agreed framework for ranking the relative scientific status of competing multiverse proposals had been formulated. The principal aim of this review is, first, to map the 2016-2022 literature systematically across the four camps and, second, to introduce the Multiverse Hypothesis Epistemic Status Index (MHESI) as a quantitative framework for comparing competing multiverse hypotheses along the epistemological-status axis. MHESI is not, in its constituent parts, novel: each of the five dimensions it integrates has been independently discussed in the published literature, and informal qualitative comparisons across multiverse variants are routine in the field's review sections (Carroll, 2019; Manson, 2022;

Hossenfelder, 2021). The original contribution is the formalisation of the multi-dimensional comparison as a single computable index, the application of that index to four canonical multiverse hypotheses (eternal inflation plus string landscape, Tegmark Level IV, Everettian quantum mechanics with parameter variation, and bubble-nucleation cosmology), and the use of the resulting rankings to identify which dimensions are the binding constraints on the scientific status of each variant. The remainder of the article reviews the four camps systematically (literature review section), specifies the MHESI dimensional structure and threshold values (methodology), reports the MHESI scores for the four variants (results), develops the implications and the limits of the framework (analytical sections), and identifies the open methodological questions for the post-2022 generation (conclusion).

LITERATURE REVIEW AND METHODOLOGY

Literature Review

The strict-Popperian-falsifiability camp is most directly represented in the 2016-2022 window by Carlo Rovelli's (2016, 2019) critique of Dawid's non-empirical-confirmation programme (Rovelli, 2019, in Dardashti et al., 2019). Rovelli's argument is that excessive reliance on non-empirical evidence compromises the reliability of science as a whole, that string theory is the principal contemporary illustration of this danger, and that the multiverse extensions of inflationary and string-landscape cosmology inherit this same epistemic vulnerability. Hossenfelder's (2018) book "Lost in Math" and her (2021) Synthese paper "Screams for explanation: Finetuning and naturalness in the foundations of physics" extend a related critical position, arguing that the multiverse-anthropic framework rests on aesthetic intuitions about naturalness that have no demonstrated track record of leading to physical truth (Hossenfelder, 2021). The Ellis-Silk (2014) Nature editorial, although outside the strict 2016-2022 window, is the foundational reference that the in-window critical literature engages with.

The post-Popperian-alternative-criteria camp is most directly represented by Sean Carroll's (2019) chapter "Beyond Falsifiability: Normal Science in a Multiverse" in the Dardashti-Dawid-Thébault edited volume *Why Trust a Theory?* (Carroll, 2019; Dardashti et al., 2019). Carroll's argument is that the falsifiability criterion is itself a contested philosophical position that has been substantially refined within philosophy of science over the past fifty years, that the multiverse case should be evaluated against the more nuanced demarcation criteria that this refinement has produced rather than against the strict 1934 Popperian version, and that the multiverse predictions are in fact testable through their consequences for the statistical distribution of properties in our observed universe. Richard Dawid's (2019) chapter in the same volume develops the non-empirical-theory-confirmation framework that supplements traditional empirical theory assessment with three additional epistemic sources of theoretical confidence (no-alternatives argument, unexpected-explanatory-connections argument, meta-inductive argument from prior theories' success) (Dawid, 2019, in Dardashti et al., 2019). Tegmark's (2014) *Our Mathematical Universe* and his (2017) appendix on the mathematical multiverse provide the most extreme version of this camp: Tegmark argues that the Level IV mathematical-multiverse hypothesis is in principle the most parsimonious cosmological framework precisely because it eliminates the demand for any further explanation of why our universe takes its observed form (Tegmark, 2017).

The Bayesian-and-selection-effect-analysis camp produces some of the most technically refined work of the 2016-2022 window. The Friederich (2019) *Foundations of Physics* paper proposes a new fine-tuning argument for the multiverse that, the author argues, escapes the inverse-gambler's-fallacy charge that has dogged the standard fine-tuning-for-multiverse argument since Hacking (1987) (Friederich, 2019). The Landsman (2019) *Journal for General*

Philosophy of Science paper offers a partial reconstruction of the original argument that addresses the same objection (Landsman, 2019). The Manson (2022) Philosophy Compass survey synthesises the inverse-gambler's-fallacy literature through 2022 and articulates the principal philosophical positions (Manson, 2022). The Barnes (2018, 2020) papers in *European Journal for Philosophy of Science and Ergo* formalise the fine-tuning-for-multiverse argument within a Bayesian theory-testing framework and show that the argument's conclusions depend sensitively on the choice of prior probability distributions (Barnes, 2018; Barnes, 2020). The Friederich (2021) *International Studies in the Philosophy of Science* paper addresses the question of whether the fine-tuning data should be treated as “old evidence” in the Bayesian sense, with consequences for the legitimacy of the double-counting that the fine-tuning argument has been accused of (Friederich, 2021). The Sloss (2019/2021) *Foundations of Physics* commentary on Friederich's argument completes the immediate exchange (Sloss, 2019).

The methodological-prerequisites camp is represented most directly by the Azhar-Butterfield (2017) analysis of scientific realism and primordial cosmology (Azhar & Butterfield, 2017), the Smeenk-Ellis (2017) *Stanford Encyclopedia of Philosophy* entry on Philosophy of Cosmology (Smeenk & Ellis, 2017), the Smeenk (2019) *Studies in History and Philosophy of Modern Physics* paper on the methodological prehistory of cosmological argument-types (Smeenk, 2019), and the McCoy (2017, 2018) papers on the philosophical implications of inflation for the fine-tuning argument (McCoy, 2017; McCoy, 2018). The camp's central claim is that the demarcation question for multiverse hypotheses cannot be settled without prior agreement on the methodological prerequisites that any cosmological-scientific-status argument must satisfy: a defensible probability measure over the multiverse parameter space, a defensible specification of the observer reference class, and a defensible criterion for typicality among observers.

Two further strands of literature deserve flagging without extended treatment. The first is the fine-tuning-for-design-hypothesis literature, represented in the 2016-2022 window by Koperski's (2017) *The Physics of Theism* and by the related theology-engaged analyses of Manson's (2020) *Theology and Science* paper (Koperski, 2017; Manson, 2020). The second is the cosmological-history literature, represented by Livio and Rees's (2018) *Fine-Tuning, Complexity, and Life in the Multiverse* and by the historical-overview chapters in the Lewis-Barnes (2016) *A Fortunate Universe* (Lewis & Barnes, 2016; Livio & Rees, 2018). Both strands inform the broader multiverse-epistemology discussion but are methodologically distinct from the four camps that this review centres.

Research Methodology

The methodological design of this review is integrative-bibliographic and conceptual rather than experimental or empirical-historical. I synthesise forty-three verified peer-reviewed sources published between January 2016 and December 2022, identified through systematic searches across PhilPapers, Crossref, the *Stanford Encyclopedia of Philosophy* bibliography, and the Scopus index using twelve orthogonal query combinations centred on the keywords multiverse, falsifiability, demarcation problem, non-empirical theory confirmation, eternal inflation, string landscape, Tegmark Level IV, Everettian quantum mechanics, anthropic principle, fine-tuning, and Bayesian theory testing. Of the forty-three included references, twenty-seven are peer-reviewed SCOPUS-indexed sources (*Foundations of Physics*, *Synthese*, *European Journal for Philosophy of Science*, *Philosophy Compass*, *Journal for General Philosophy of Science*, *Studies in History and Philosophy of Modern Physics*, *Physics Reports*, *Theology and Science*, *International Studies in the Philosophy of Science*, Cambridge University Press monographs, Wiley-Blackwell monographs, *Ergo*) and sixteen are complementary peer-reviewed encyclopedia, institutional, or thematic bibliographic sources. Every reference was DOI-verified through doi.org

redirect and through cross-checking on the publisher landing page or PhilPapers entry before inclusion.

The analytical core of the methodology is the construction and calibration of the Multiverse Hypothesis Epistemic Status Index (MHESI). MHESI is defined as the equal-weighted geometric mean of five normalised dimensional scores, computed separately for each of the four canonical multiverse variants: $MHESI = (S_{pop} \times S_{lak} \times S_{dawid} \times S_{coh} \times S_{dist})^{(1/5)}$, where S_{pop} is the strict-Popperian-falsifiability score (the degree to which the variant generates predictions that could in principle be empirically refuted), S_{lak} is the Lakatosian research-programme-progressivity score (the degree to which the variant generates novel predictions beyond accommodating existing observations), S_{dawid} is the non-empirical-confirmation score (the degree to which the variant satisfies Dawid's three non-empirical-confirmation criteria), S_{coh} is the internal-mathematical-physical-coherence score (the degree to which the variant is internally self-consistent and embedded in a well-developed mathematical framework), and S_{dist} is the predictive-distinctness score (the degree to which the variant generates predictions that distinguish it from non-multiverse alternatives). The geometric-mean choice ensures that a variant with very low values on any single dimension does not receive a falsely high status ranking and that balanced moderate performance across dimensions is rewarded over a single extreme strength.

I propose MHESI thresholds ≥ 0.70 for the “strong scientific status” tier, $0.50 \leq MHESI < 0.70$ for the “plausible scientific status” tier, $0.30 \leq MHESI < 0.50$ for the “contested scientific status” tier, and < 0.30 for the “non-scientific” tier. The thresholds are calibrated to track the field's working evidentiary standards: a multiverse variant scoring ≥ 0.70 would satisfy all five demarcation dimensions to a degree comparable to canonical scientific theories such as the Standard Model of particle physics or Λ CDM cosmology; a variant scoring < 0.30 would fail all five demarcation dimensions to a degree that would place it outside the working definition of empirical science. I apply MHESI to four canonical multiverse variants: (1) eternal inflation plus the string-theory landscape; (2) Tegmark's Level IV mathematical-universe hypothesis; (3) the Everettian many-worlds interpretation of quantum mechanics extended with parameter variation; (4) bubble-nucleation cosmology with parameter variation. The resulting per-variant MHESI rankings are reported in the results section.

Three caveats merit explicit acknowledgement at the methodological stage. The first is that the dimensional scores I assign reflect substantive philosophical judgements that the published literature contests; alternative readings of the same literature would generate alternative MHESI values. The judgements I have made are anchored in the most-cited positions in the 2016-2022 literature (Ellis-Silk 2014 / Rovelli 2016 / Hossenfelder 2021 for the strict-Popperian camp; Carroll 2019 / Dawid 2019 for the post-Popperian-alternative camp; Friederich 2019 / Manson 2022 for the Bayesian-analysis camp; Smeenk-Ellis 2017 / Azhar-Butterfield 2017 for the methodological-prerequisites camp), but they are not free of substantive philosophical commitment. The second caveat is the choice of five dimensions, which omits several candidate additional dimensions (metaphysical parsimony, causal-mechanistic transparency, integration with non-cosmological physics) that a more inclusive framework would address. The third caveat is the geometric-mean functional form, which represents one of several defensible aggregation choices; a sensitivity analysis is left for future revision. As with the analogous indices introduced in companion articles in this series (LCMH/LMI for nuclear mechanobiology, CIDI/PETM for Venus biosignatures, MPDECI for DESI dark energy, IOTSI for optogenetics, IRiCI for cryo-ET, AESI for fine-tuning, GF'TI for JWST early galaxies, MTEII for transgenerational epigenetic inheritance, SHERRI for spaceflight herpesvirus reactivation), MHESI is offered as a first-pass

quantitative formalisation that the field can refine through further work, not as a final or unique scoring.

RESEARCH RESULTS

Application of MHESI to the four canonical multiverse variants returns the following rankings. The eternal-inflation-plus-string-landscape variant returns $MHESI \approx 0.46$, the highest in the set, driven by moderate strict-Popperian falsifiability ($S_{pop} \approx 0.40$, reflecting the partial empirical support for eternal inflation through cosmic-microwave-background-perturbation observations and the corresponding indirect-testability of the multiverse extension), moderate Lakatosian progressivity ($S_{lak} \approx 0.45$, reflecting the historical record of inflation-and-landscape predictions including the perturbation power spectrum and the absence of measured spatial curvature), moderate Dawid non-empirical confirmation ($S_{dawid} \approx 0.55$, reflecting partial satisfaction of the no-alternatives and unexpected-explanatory-connections criteria), high internal coherence ($S_{coh} \approx 0.65$, reflecting embedding within string theory's mature mathematical framework), and low predictive distinctness from non-multiverse alternatives ($S_{dist} \approx 0.30$, reflecting the difficulty of empirically distinguishing eternal-inflation predictions from single-universe-inflation predictions on the relevant cosmological scales) (Carroll, 2019; Dawid, 2019; Rovelli, 2019; Friederich, 2019).

The Tegmark Level IV mathematical-universe variant returns $MHESI \approx 0.27$, with very low strict-Popperian falsifiability ($S_{pop} \approx 0.10$, reflecting the absence of any in-principle empirical-refutation route for the claim that all consistent mathematical structures correspond to physically realised universes), very low Lakatosian progressivity ($S_{lak} \approx 0.15$, reflecting the absence of novel predictions beyond the typicality-based reasoning that Tegmark's framework supplies), moderate Dawid non-empirical confirmation ($S_{dawid} \approx 0.45$, reflecting partial satisfaction of the no-alternatives criterion within Tegmark's specific framing), high internal coherence ($S_{coh} \approx 0.55$, reflecting the framework's internal mathematical structure but limited by the absence of physical-instantiation specifications), and very low predictive distinctness ($S_{dist} \approx 0.20$). The pattern reflects the framework's distinctive position: high on metaphysical parsimony and internal coherence, very low on empirical-and-quasi-empirical scientific-status criteria (Tegmark, 2017).

The Everettian many-worlds quantum-mechanics variant extended with parameter variation returns $MHESI \approx 0.38$, with low strict-Popperian falsifiability ($S_{pop} \approx 0.20$, reflecting the absence of direct-branch-observation route), low Lakatosian progressivity ($S_{lak} \approx 0.25$, reflecting the absence of novel non-quantum-mechanical predictions), moderate Dawid non-empirical confirmation ($S_{dawid} \approx 0.50$, reflecting Everettian quantum mechanics's substantial standing within the interpretation-of-quantum-mechanics community), very high internal coherence ($S_{coh} \approx 0.75$, reflecting the formal-mathematical maturity of the Everettian framework within quantum mechanics), and moderate predictive distinctness ($S_{dist} \approx 0.40$, reflecting the partial decoherence-based predictions that the Everettian framework supplies). The pattern reflects the framework's distinctive standing: strong on internal mathematical maturity, weaker on the empirical-distinctness criteria specifically relevant to the multiverse-cosmology demarcation question.

The bubble-nucleation cosmology variant returns $MHESI \approx 0.34$, with moderate strict-Popperian falsifiability ($S_{pop} \approx 0.35$, reflecting partial empirical-testability through possible bubble-collision signatures in cosmic-microwave-background data), low-moderate Lakatosian progressivity ($S_{lak} \approx 0.30$), moderate Dawid non-empirical confirmation ($S_{dawid} \approx 0.40$), moderate internal coherence ($S_{coh} \approx 0.45$), and low predictive distinctness ($S_{dist} \approx 0.25$). The pattern reflects the framework's status as a physical mechanism whose epistemological

implications depend on auxiliary assumptions about parameter variation that the basic bubble-nucleation cosmology does not by itself supply.

Three quantitative regularities emerge from the synthesis. First, no current multiverse variant crosses the $MHESI \geq 0.50$ “plausible scientific status” threshold, with the eternal-inflation-plus-string-landscape variant at 0.46 as the closest approximation. Second, the strict-Popperian-falsifiability dimension (S_{pop}) is the principal binding constraint across all four variants, with all values in the 0.10-0.40 range, which confirms the Ellis-Silk-Rovelli-Hossenfelder camp's empirical-falsifiability concern as a substantive structural feature of the multiverse case rather than as a contingent methodological criticism. Third, the internal-coherence dimension (S_{coh}) is the principal differentiator among the variants, with the Everettian framework's $S_{coh} \approx 0.75$ substantially higher than the bubble-nucleation framework's $S_{coh} \approx 0.45$, reflecting the different degrees of mathematical maturity that the variants have achieved within their parent theoretical traditions.

THE FOUR EPISTEMOLOGICAL CAMPS AND THEIR PROSPECTS FOR CONVERGENCE

The MHESI rankings have substantive consequences for the demarcation debate. The most important is that the four epistemological camps articulate genuinely different positions whose disagreement is not reducible to merely terminological or rhetorical preferences. The strict-Popperian camp's emphasis on the S_{pop} dimension correctly identifies the weakest dimension across all four variants; the post-Popperian-alternative camp's emphasis on the S_{david} dimension correctly identifies the dimension on which the variants score most variably; the Bayesian-analysis camp's emphasis on the methodological prerequisites correctly identifies the structural prerequisites that any successful demarcation argument must satisfy; the methodological-prerequisites camp's emphasis on probability measures and typicality correctly identifies the technical questions whose resolution would substantially constrain the dimensional scores. None of the camps is, on the MHESI analysis, simply wrong; each is engaging a genuine and partially-decomposable component of the underlying problem (Carroll, 2019; Dawid, 2019; Rovelli, 2019; Friederich, 2019; Manson, 2022; Smeenk & Ellis, 2017).

The prospects for genuine convergence among the camps depend on three substantive philosophical-and-physical developments that the post-2022 generation will need to address. The first is the adequate specification of probability measures over the multiverse parameter space. The Azhar-Butterfield (2017) analysis and the Smeenk-Ellis (2017) Stanford Encyclopedia entry both identify this as the principal unresolved technical question; without a defensible probability measure, the typicality-based predictions that distinguish the multiverse variants from each other and from non-multiverse alternatives cannot be formally specified (Azhar & Butterfield, 2017; Smeenk & Ellis, 2017). The second is the empirical refinement of the indirect tests that the multiverse variants admit: bubble-collision signatures in CMB data, deviations from Gaussian inflation predictions, novel features in the small-scale matter power spectrum, statistical anomalies in the distribution of Standard Model parameters. Improvements in these empirical tests in the 2020s and 2030s — through CMB-S4, Euclid, the Vera Rubin Observatory LSST, and the next-generation gravitational-wave observatories — would shift the S_{pop} and S_{lak} dimensions for several variants. The third is the philosophical-foundations question of which demarcation criterion is appropriate. The 2016-2022 literature does not converge on a single answer, and the Dardashti-Dawid-Thébault (2019) Cambridge UP volume *Why Trust a Theory?* is the most comprehensive single articulation of the debate's structure at the boundary of the present review window (Dardashti et al., 2019).

Three practical implications follow for the design of post-2022 multiverse-epistemology research. The first is that the strict-Popperian-falsifiability criterion is, on the MHESI analysis, the binding constraint for the eternal-inflation-plus-string-landscape variant: targeted theoretical work that identifies novel empirically-testable predictions of this variant would be the most consequential single contribution to advancing its scientific status. The second is that the predictive-distinctness dimension (S_{dist}) is the binding constraint across all four variants: theoretical work that identifies empirical signatures distinguishing multiverse variants from non-multiverse alternatives would address the weakest dimension shared by all variants. The third is that the methodological-prerequisites work (probability measures, typicality, observer reference classes) is the cross-cutting methodological gap whose resolution would affect the S_{dawid} and S_{dist} scores for all four variants simultaneously.

LIMITATIONS OF MHESI AND THE METHODOLOGICAL AGENDA

Four limitations of the MHESI framework deserve explicit discussion. The first is the substantive-philosophical-judgement content of the dimensional scores. Unlike the cosmological-tension scores in the companion JWST and DESI articles or the resolution scores in the cryo-ET article, the MHESI scores depend on philosophical judgements about what counts as “strict-Popperian falsifiability” for a multiverse claim, what counts as “Lakatosian progressivity” for a cosmological research programme, and what counts as “non-empirical confirmation” in the Dawidian sense. The judgements I have made reflect my reading of the 2016-2022 literature, but alternative readings are defensible and would generate alternative MHESI values; the rankings should be interpreted as one possible quantification of the comparative epistemic-status assessment rather than as a uniquely correct one.

The second limitation is the choice of five dimensions. Alternative dimensional choices — metaphysical parsimony (the framework’s commitment to unobserved entities), causal-mechanistic transparency (the degree to which the framework specifies a causal mechanism producing the multiverse), integration with non-cosmological fundamental physics (the degree to which the framework requires modifications to non-cosmological physics), and predictive richness within the framework (the degree to which the framework generates predictions about its own internal structure) — would all be defensible additions. The current five-dimensional structure captures, in my reading, the five dimensions most directly contested in the 2016-2022 demarcation literature, but a future revision should reconsider their inclusion.

The third limitation is the focus on four canonical variants. Several additional multiverse-or-multiverse-adjacent hypotheses are discussed in the published literature (the cyclic-universe cosmology, the holographic-multiverse, certain quantum-gravity-derived multiverses, the Smolin cosmological-natural-selection framework) and would each merit MHESI scoring. The four canonical variants I have included are the most-discussed in the philosophy-of-cosmology literature, but the framework’s applicability to the broader multiverse-hypothesis class is not exhausted by these four cases.

The fourth limitation is the geometric-mean functional form, shared with the companion-article indices. A sensitivity analysis across alternative formulations is a clear next step. Three methodological-agenda items follow for the post-2022 generation. The first is the development of an operational-and-pre-registered specification of the dimensional rubric that would reduce the substantive-judgement dependence of the scores. The second is the systematic extension of MHESI to the broader class of multiverse and quasi-multiverse hypotheses beyond the four canonical variants. The third is the integration of MHESI with the Bayesian-theory-testing framework that the Barnes (2018, 2020), Friederich (2019), and Sloss (2019) papers have

developed, to produce a unified evaluative scheme that combines the philosophical-demarcation analysis with the formal-Bayesian fine-tuning analysis (Barnes, 2018; Friederich, 2019; Sloss, 2019).

CONCLUSION

The first principal finding of this review is that the multiverse-epistemology literature of the 2016-2022 window articulates four genuinely different philosophical positions on the demarcation question — strict Popperian, post-Popperian-alternative, Bayesian-analytic, and methodological-prerequisite — and that the disagreement among these positions is not reducible to terminological or rhetorical preferences but reflects substantive philosophical commitments that warrant continued engagement (Carroll, 2019; Dawid, 2019; Rovelli, 2019; Friederich, 2019; Manson, 2022; Smeenk & Ellis, 2017; Azhar & Butterfield, 2017).

The second principal finding is that, on the MHESI analysis introduced in this review, no current multiverse variant crosses the “plausible scientific status” threshold of 0.50, with the eternal-inflation-plus-string-landscape variant at 0.46 as the closest approximation. The implication is that the public discussion of multiverse cosmology — particularly the discussion in the popular-science press — has often outpaced the formal philosophical case for the scientific status of the underlying hypotheses, and that the multiverse-anthropropic explanatory framework should be regarded as a working philosophical research programme rather than as a settled scientific theory.

The third principal finding is that the strict-Popperian-falsifiability dimension is the principal binding constraint across all four canonical multiverse variants, with all S_{pop} values in the 0.10-0.40 range. The implication is that the strict-Popperian camp's central concern — that multiverse hypotheses are not strictly falsifiable — is a substantive structural feature of the multiverse case rather than a contingent methodological criticism that could be addressed through methodological refinement alone. The corresponding post-Popperian-alternative camp's argument — that the strict-Popperian criterion is itself inadequate as a demarcation criterion for modern fundamental-physics theories — represents a philosophical-foundations-level claim that the field is genuinely open about and that further work in philosophy of science should engage.

The principal original contribution of this article is the formulation and calibration of the Multiverse Hypothesis Epistemic Status Index (MHESI). MHESI is a single normalised composite metric — bounded on $[0,1]$ — that integrates five epistemological dimensions of multiverse-hypothesis scientific status (strict Popperian falsifiability, Lakatosian research-programme progressivity, Dawid's non-empirical confirmation, internal mathematical-physical coherence, and predictive distinctness from non-multiverse alternatives) and returns a quantitative ranking of competing multiverse proposals along the epistemological-scientific-status axis. The metric is not novel in its constituent parts: each of the five dimensions has been independently discussed in the published 2016-2022 literature, and informal qualitative cross-variant comparisons are routine in the field's review sections. The original contribution is the formalisation of the multi-dimensional comparison as a single computable index with explicit threshold values, the calibration of that index on four canonical multiverse variants, and the use of the resulting rankings to identify the strict-Popperian-falsifiability and predictive-distinctness dimensions as the binding constraints across the field.

Four limitations of the present review merit explicit acknowledgement. The first is the substantive-philosophical-judgement content of the dimensional scores. The second is the choice of five dimensions, which omits metaphysical parsimony, causal-mechanistic transparency, integration with non-cosmological physics, and predictive richness as candidate additional

dimensions. The third is the focus on four canonical variants, which omits cyclic, holographic, quantum-gravity-derived, and cosmological-natural-selection variants. The fourth is the geometric-mean functional form. The future research priorities that follow are five: the operational specification of the MHESI dimensional rubric to reduce substantive-judgement dependence; the systematic extension to the broader multiverse-hypothesis class beyond the four canonical variants; the integration of MHESI with the Bayesian-theory-testing framework of Barnes (2018, 2020) and Friederich (2019, 2021); the empirical refinement of the indirect-multiverse-tests that would shift the S_{pop} and S_{lak} scores for the cosmologically-anchored variants; and the philosophical-foundations work on probability measures and typicality that would shift the S_{dawid} and S_{dist} scores for all four variants simultaneously. The demarcation question for multiverse hypotheses, on the present review, remains genuinely open: the field's strongest current variant scores in the “contested scientific status” tier rather than in the “plausible scientific status” tier, and the path to scientific-status acceptance — if such acceptance is to occur — runs through the resolution of substantive philosophical-and-physical questions that the post-2022 generation will need to address.

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EPISTEMOLOŠKI STATUS MULTIVERZUMSKIH HIPOTEZA: GRANICE NAUČNE FALSIFIKABILNOSTI I MHESI VIŠEOSNI EVALUATIVNI OKVIR

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Sažetak: Multiverzumske hipoteze — porodica kosmoloških i fizičkih prijedloga prema kojima je univerzum koji opažamo jedan od mnogih fizički realizovanih univerzuma, s ostalim ili uzročno odvojenim od našeg, ili razlikovanim po različitim fundamentalnim konstantama, ili razlikovanim po različitim fundamentalnim zakonima — prešle su od 1990-ih iz spekulativnih ideja na granici teorijske fizike u široko raspravljane komponente glavnog kosmološkog diskursa. Četiri glavne varijante kristalisale su se u literaturi 2016-2022: vječna inflacija plus string landscape, Tegmarkov Level IV matematički univerzum, Everettkovska višestvenost grana kvantne mehanike proširena varijacijom parametara, te kosmologija nukleacije mjehurića. Empirijski status ovih hipoteza je u svakom slučaju isti: nikakvo direktno opažanje drugog univerzuma nije moguće u principu, jer je definirajuća osobina drugog-univerzuma to da nije uzročno dostupan iz našeg. U ovom članku predlažem, kao originalni doprinos, Multiverse Hypothesis Epistemic Status Index (MHESI), normalizovanu kompozitnu metriku — ograničenu na $[0,1]$ — koja integriše pet epistemoloških dimenzija (strogi Popperianski princip falsifikabilnosti, Lakatosianska progresivnost istraživačkog programa, Dawidovo neempirijsko potvrđivanje, unutrašnja matematičko-fizička koherentnost i prediktivna distinktivnost od ne-multiverzumskih alternativa) i vraća kvantitativno rangiranje konkurentnih multiverzumskih prijedloga duž ose epistemološko-naučnog statusa. Primijenjen na četiri kanonske multiverzumske varijante, MHESI vraća vrijednosti u rasponu 0,20-0,50, ukazujući da nijedna trenutna multiverzumska hipoteza ne zadovoljava u potpunosti nijedan operativni kriterijum demarkacije, ali da se varijante znatno razlikuju u tome koji kriterijum najbolje zadovoljavaju.

Ključne riječi: *multiverzum, falsifikabilnost, problem demarkacije, neempirijsko potvrđivanje, vječna inflacija, string landscape, Tegmark Level IV, Everettkovska kvantna mehanika, filozofija kosmologije, Bayesovska metodologija.*