New Physics Scales from the Causal Mass Gap Equation:

Predictions at 3.07 TeV and 1.22 PeV
from the UAT/UCP Causal Coherence Constant $\kappa_{\text{crit}} = 10^{-78}$

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Abstract

The Causal Mass Gap equation $E(n) = E_{\text{Planck}} \times \kappa_{\text{crit}}^{1/n}$, derived from the Unified Applicable Time (UAT) and Unified Causal Principle (UCP) framework, connects the Planck scale to lower energy scales through the causal coherence constant $\kappa_{\text{crit}} = 10^{-78}$. The exponent $1/n$ determines which physical scale emerges. Previously documented values include $n = 1/\alpha \approx 0.64$ (dark energy, $\sim 10^{-94}$ eV) and $n = 4$ (QCD confinement, ~ 386 MeV). This work presents two new predictions from the same equation with zero additional free parameters: $n = 5$ yields $E(5) \approx 3.07$ TeV, a scale accessible at the Large Hadron Collider and future colliders; $n = 6$ yields $E(6) \approx 1.22$ PeV, a scale relevant to neutrino physics and ultra-high-energy cosmic rays. We provide detailed derivations, comparisons with known physics scales, analysis of experimental signatures, and explicit falsification conditions. If these scales correspond to physical thresholds —new gauge bosons, supersymmetric particles, or neutrino mass generation mechanisms— they should manifest as resonances or anomalies in collider, neutrino, and cosmic ray data within the next two decades. If no signal is detected, the predictions are falsified. The predictions require no parameter adjustment beyond the independently calibrated κ_{crit}.

1 Introduction

The Unified Applicable Time (UAT) and Unified Causal Principle (UCP) framework [1, 2] establishes a fundamental connection between the Planck scale and observable physics through the causal coherence constant $\kappa_{\text{crit}} = 10^{-78}$. This dimensionless constant defines the maximum tolerance of the universe to retrocausal influence: while the future can exert a tiny regulatory pressure on the present, this influence is suppressed by 78 orders of magnitude to prevent causal paradoxes [2].

The Causal Mass Gap equation [3] expresses this connection quantitatively:

$$\boxed{E(n) = E_{\text{Planck}} \times (\kappa_{\text{crit}})^{1/n}} \tag{1}$$

where $E_{\text{Planck}} = \sqrt{\hbar c^5/G} \approx 1.22 \times 10^{28}$ eV is the Planck energy, and n is an integer (or rational number) that determines which physical scale emerges. Different values of n correspond to different physical regimes, from cosmology to particle physics.

Previously documented scales from Eq. (1) include:

- $n = 1/\alpha \approx 0.64$ (where $\alpha = \varphi/2 + 3/4 \approx 1.559$): $E \approx 3.04 \times 10^{-94}$ eV — the dark energy density, matching the observed cosmological constant to $\sim 1\%$ [4].
- $n = 4$: $E \approx 3.86 \times 10^{8}$ eV (386 MeV) — the QCD confinement scale, coinciding with $\Lambda_{\text{QCD}} \sim 217$ MeV and the hadron mass spectrum [5].

This work presents two new scales from the same equation, corresponding to $n = 5$ and $n = 6$, that have not been previously documented. These scales fall in the TeV and PeV ranges, where current and future experiments are actively searching for new physics.

2 The Causal Mass Gap Equation

2.1 Origin of the Equation

The Causal Mass Gap equation emerges from the requirement that the causal membrane —the boundary between the observable universe and the trans-Planckian regime— enforce coherence across all energy scales. The constant $\kappa_{\text{crit}} = 10^{-78}$ is the fundamental limit on retrocausal flux: only one part in 10^{78} of the information at the Planck scale can influence the present without generating paradoxes.

For a physical scale characterized by an integer (or rational) number n of interacting degrees of freedom, the energy at which causal coherence becomes dominant is given by Eq. (1). The exponent $1/n$ reflects the fact that causal coherence is distributed across n independent channels or dimensions. The larger n, the more the Planck-scale suppression is "diluted," and the higher the resulting energy scale.

2.2 Physical Interpretation of n

The integer n can be interpreted as:

1. **Number of causal channels:** The causal membrane has n independent channels through which retrocausal information can flow. The suppression κ_{crit} is distributed equally among these channels, so each channel experiences a suppression of $(\kappa_{\text{crit}})^{1/n}$.

2. **Dimensionality of the coherence subspace:** The 8-phase coherence matrix that determines the vacuum structure [4] has rank 4 (the even-parity subsystem is a 4×4 complex matrix). The values $n = 4, 5, 6$ correspond to different embeddings of this matrix in higher-dimensional coherence spaces.

3. **Hierarchy of scales:** Each integer n generates a distinct energy scale. The sequence $n = 4, 5, 6, \ldots$ produces a hierarchy of scales: QCD $\to$ TeV $\to$ PeV $\to$ GUT $\to$ Planck, naturally explaining why physics organizes itself into distinct energy regimes.

3 All Causal Scales from $n = 1$ to $n = 10$

Table 1 shows the complete sequence of causal scales for integer n from 1 to 10.

Table 1: All causal scales from the Causal Mass Gap equation.

n	**Exponent** $1/n$	E [**eV**]	E [**GeV**]	**Physical Regime**
1	1.000000	1.22×10^{-50}	—	Membrane vacuum
2	0.500000	1.10×10^{-11}	—	Ultra-low energy
3	0.333333	1.55×10^{2}	—	Atomic scale
4	**0.250000**	3.86×10^{8}	**0.386**	**QCD confinement**
5	**0.200000**	3.07×10^{12}	**3070**	**TeV — NEW PHYSICS**
6	**0.166667**	1.22×10^{15}	1.22×10^{6}	**PeV — NEW PHYSICS**
7	0.142857	1.24×10^{17}	—	GUT intermediate
8	0.125000	3.28×10^{18}	—	GUT scale
9	0.111111	3.05×10^{19}	—	GUT/Planck
10	0.100000	1.53×10^{20}	—	Planck vicinity

The scales for $n = 5$ and $n = 6$ (highlighted in bold) are the new predictions of this work. They fall in energy ranges that are experimentally accessible: the TeV scale is within reach of the LHC and future colliders, and the PeV scale is probed by neutrino telescopes and ultra-high-energy cosmic ray observatories.

4 Prediction 1: The TeV Scale ($n = 5$)

4.1 Derivation

$$E(5) = E_{\text{Planck}} \times (10^{-78})^{1/5} = 1.22 \times 10^{28} \times 10^{-78/5} = 1.22 \times 10^{28} \times 10^{-15.6} \approx 3.07 \times 10^{12} \text{ eV} \tag{2}$$

In more familiar units:

$$E(5) = 3.07 \text{ TeV} \tag{3}$$

4.2 Physical Interpretation

A new physics scale at approximately 3 TeV has been anticipated by multiple theoretical frameworks:

1. **New gauge bosons (Z', W'):** Many extensions of the Standard Model predict additional heavy gauge bosons with masses in the TeV range. A Z' boson at ~ 3 TeV would appear as a resonance in dilepton (e^+e^-, $\mu^+\mu^-$) invariant mass distributions.

2. **Supersymmetry (SUSY):** In supersymmetric extensions of the Standard Model, the superpartners of quarks and gluons (squarks, gluinos) are expected to have masses in the TeV range. A gluino at ~ 3 TeV would decay into jets plus missing transverse energy.

3. **Extra dimensions:** Kaluza-Klein excitations of gravitons in models with large extra dimensions could appear as resonances at TeV-scale masses.

4. **Composite Higgs:** If the Higgs boson is a composite particle, the scale of compositeness could be ~ 3 TeV, with observable effects in Higgs coupling deviations and vector boson scattering.

5. **Dark matter mediators:** A new particle mediating interactions between dark matter and Standard Model particles could have a mass of ~ 3 TeV, accessible through missing energy signatures at colliders.

In the UAT/UCP framework, the $n = 5$ scale represents the energy at which the causal membrane begins to affect particle interactions through a fifth causal channel. This could manifest as a new interaction mediated by the membrane itself, or as a threshold above which the Standard Model effective field theory breaks down.

4.3 Observable Consequences

Table 2: Observable quantities derived from $E(5) \approx 3.07$ TeV.

Quantity	**Value**	**Units**
Energy	3.07×10^{12}	eV
Energy	3.07	TeV
Frequency (E/h)	7.42×10^{26}	Hz
Compton wavelength (hc/E)	4.04×10^{-19}	m
Compton wavelength	0.000404	fm
Temperature (E/k_B)	3.56×10^{16}	K
Geometric cross section (λ^2)	1.63×10^{-37}	m^2

4.4 Experimental Signatures

LHC searches (ATLAS, CMS):

1. **Dijet resonance:** A peak in the dijet invariant mass distribution at $m_{jj} \approx 3.1$ TeV. Current LHC limits on dijet resonances extend to several TeV; a dedicated search at this specific mass would test the prediction.

2. **Dilepton resonance:** A peak in e^+e^- or $\mu^+\mu^-$ invariant mass at $m_{\ell\ell} \approx 3.1$ TeV. The clean experimental signature makes this one of the most sensitive channels.

3. **Missing transverse energy:** If the $n = 5$ scale is associated with a dark sector, events with large missing E_T and accompanying jets or leptons would be the signature.

4. **Vector boson scattering:** Anomalous growth of $W^\pm W^\pm$ or W^+W^- scattering cross sections at $\sqrt{s} \sim 3$ TeV, indicating new physics unitarizing the longitudinal gauge boson scattering.

Future colliders:

1. **HL-LHC (2030s):** The high-luminosity upgrade will extend the reach for dijet and dilepton resonances to ~ 8 TeV, thoroughly covering the 3 TeV prediction.

2. **FCC-hh ($\sqrt{s} = 100$ TeV):** The proposed Future Circular Collider would produce particles at the 3 TeV scale with enormous cross sections, allowing detailed study of their properties.

4.5 Falsification Condition

If no resonance or anomaly is detected at 3.07 ± 0.6 TeV (20% tolerance) in dijet, dilepton, or missing energy channels with the full HL-LHC dataset or with FCC-hh, the $n = 5$ prediction is falsified.

5 Prediction 2: The PeV Scale ($n = 6$)

5.1 Derivation

$$E(6) = E_{\text{Planck}} \times (10^{-78})^{1/6} = 1.22 \times 10^{28} \times 10^{-78/6} = 1.22 \times 10^{28} \times 10^{-13.0} \approx 1.22 \times 10^{15} \text{ eV} \tag{4}$$

In more familiar units:

$$E(6) = 1.22 \text{ PeV} = 1.22 \times 10^{6} \text{ GeV} \tag{5}$$

5.2 Physical Interpretation

The PeV scale is of fundamental importance in particle physics and astrophysics:

1. **Neutrino mass generation (seesaw mechanism):** The smallness of neutrino masses ($m_\nu \lesssim 0.1$ eV) is naturally explained if they are generated by physics at a high scale M_R via the seesaw relation $m_\nu \sim v^2/M_R$, where $v \approx 246$ GeV is the electroweak VEV. For $m_\nu \sim 0.1$ eV, $M_R \sim 6 \times 10^{14}$ eV ≈ 0.6 PeV, remarkably close to the $E(6) \approx 1.22$ PeV prediction.

2. **Peccei-Quinn scale (axion physics):** The axion, a hypothetical particle proposed to solve the strong CP problem, has a mass and coupling determined by the Peccei-Quinn symmetry breaking scale f_a. Astrophysical and cosmological constraints place f_a in the range 10^9-10^{17} eV. The value $E(6) \approx 1.22 \times 10^{15}$ eV falls within this range.

3. **Leptoquarks and leptogluons:** Hypothetical particles coupling quarks to leptons could have masses in the PeV range, with observable effects in flavor physics and rare decays.

4. **Flavor symmetry breaking:** The scale at which the flavor symmetries of the Standard Model are broken could be in the PeV range, explaining the observed pattern of quark and lepton masses and mixing angles.

In the UAT/UCP framework, the $n = 6$ scale represents the energy at which six causal channels become active. At this scale, the causal membrane may generate the heavy right-handed neutrinos required for the seesaw mechanism, or may trigger the breaking of flavor symmetries.

5.3 Observable Consequences

Table 3: Observable quantities derived from $E(6) \approx 1.22$ PeV.

Quantity	**Value**	**Units**
Energy	1.22×10^{15}	eV
Energy	1.22	PeV
Frequency (E/h)	2.95×10^{29}	Hz
Compton wavelength (hc/E)	1.02×10^{-21}	m
Compton wavelength	1.02×10^{-6}	fm
Temperature (E/k_B)	1.42×10^{19}	K

5.4 Experimental Signatures

Neutrino telescopes (IceCube, KM3NeT, GRAND):

1. **Glashow resonance:** The resonant production of W^- bosons by $\bar{\nu}_e$ at $E_\nu \approx 6.3$ PeV (the Glashow resonance) is a standard candle for neutrino astronomy. An anomaly in the event rate or spectrum near this energy could indicate new physics at the $E(6) \approx 1.22$ PeV scale.

2. **Anisotropy in UHE neutrino sky:** If the PeV scale is associated with a specific astrophysical source class, the arrival directions of neutrinos in this energy range should show clustering or correlation with known sources.

3. **Spectral features:** A break, bump, or cutoff in the diffuse neutrino spectrum at $E_\nu \sim 1.2$ PeV would be a smoking-gun signature of new physics at the causal scale.

Ultra-high-energy cosmic rays (Pierre Auger, Telescope Array):

1. **Composition changes:** If the $n = 6$ scale affects hadronic interactions, the chemical composition of cosmic rays in the PeV range may deviate from extrapolations of lower-energy measurements.

2. **Ankle and GZK features:** The cosmic ray spectrum exhibits characteristic features at $\sim 5 \times 10^{18}$ eV (the ankle) and $\sim 5 \times 10^{19}$ eV (the GZK cutoff). While these are understood within Standard Model astrophysics, a feature near 1.2×10^{15} eV would be anomalous.

Cosmology:

1. **Neutrino mass sum:** Current cosmological constraints give $\sum m_\nu < 0.12$ eV (Planck 2018). If the seesaw scale is $M_R \approx 1.22$ PeV, the predicted neutrino mass sum is in the range 0.01-0.1 eV, testable with future CMB and large-scale structure surveys (CMB-S4, Euclid).

2. **B-mode polarization:** If the $n = 6$ scale is associated with inflation or cosmic strings, primordial gravitational waves could leave an imprint on CMB B-mode polarization.

5.5 Falsification Condition

If no anomaly is detected at 1.22 ± 0.24 PeV (20% tolerance) in neutrino, cosmic ray, or cosmological data by 2040, the $n = 6$ prediction is constrained. Given the difficulty of PeV-scale experiments, a null result may not definitively falsify the prediction but would place strong upper limits on the coupling strength of the causal membrane at this scale.

6 The Hierarchy of Causal Scales

The sequence $n = 4, 5, 6, \ldots$ generates a natural hierarchy of energy scales, spanning from the QCD scale to the Planck scale:

$$E(4) \approx 3.86{\times}10^{8}\ \text{eV} \longrightarrow E(5) \approx 3.07{\times}10^{12}\ \text{eV} \longrightarrow E(6) \approx 1.22{\times}10^{15}\ \text{eV} \longrightarrow \cdots \longrightarrow E(\infty) = E_{\text{P}} \tag{6}$$

Each increment of n increases the energy scale by a factor of approximately $10^{3.6}$ to $10^{3.0}$. This is not an arbitrary spacing — it reflects the fact that each additional causal channel "dilutes" the Planck-scale suppression by one additional factor of $\kappa_{\text{crit}}^{1/n(n+1)} \approx 10^{78/n(n+1)}$.

The full hierarchy is illustrated in Table 4.

Table 4: The causal scale hierarchy from $n = 4$ to the Planck scale.

n	E [eV]	Scale	Step Factor	Physical Domain
4	3.86×10^{8}	386 MeV	—	Strong interaction (QCD)
5	3.07×10^{12}	3.07 TeV	$\times 7.95 \times 10^{3}$	New physics (colliders)
6	1.22×10^{15}	1.22 PeV	$\times 3.97 \times 10^{2}$	New physics (neutrinos)
7	1.24×10^{17}	124 PeV	$\times 1.02 \times 10^{2}$	GUT intermediate
8	3.28×10^{18}	3.28 EeV	$\times 2.65 \times 10^{1}$	GUT scale
9	3.05×10^{19}	30.5 EeV	$\times 9.30 \times 10^{0}$	GUT/Planck
10	1.53×10^{20}	153 EeV	$\times 5.02 \times 10^{0}$	Planck vicinity
∞	1.22×10^{28}	1.22×10^{19} GeV	—	Planck scale

The step factor decreases as n increases, reflecting the convergence toward the Planck scale. The largest jumps occur at low n: from QCD ($n = 4$) to TeV ($n = 5$) is a factor of ~ 8000, while from $n = 9$ to $n = 10$ is only a factor of ~ 5. This means the causal hierarchy naturally produces widely separated scales at low energies (where we have QCD, electroweak, and possibly TeV physics) and more closely spaced scales near the Planck regime.

7 Comparison with Other Approaches

Table 5 compares the UAT/UCP causal hierarchy with other theoretical frameworks that predict new physics scales.

Table 5: Comparison of new physics scale predictions.

Framework	**Predicted Scale**	**Energy**	**Free Parameters**
Minimal SUSY (MSSM)	Superpartner masses	$\sim$ 1-10 TeV	$\sim$ 100+
Large extra dimensions	KK graviton mass	$\sim$ 1-10 TeV	$\sim$ 2-3
Seesaw (Type I)	Right-handed neutrino mass	10^{14}-10^{16} eV	$\sim$ 2-3
Axion (KSVZ/DFSZ)	Peccei-Quinn scale f_a	10^{9}-10^{17} eV	$\sim$ 1-2
UAT/UCP ($n = 5$)	**Causal scale 5**	**3.07 TeV**	**0**
UAT/UCP ($n = 6$)	**Causal scale 6**	**1.22 PeV**	**0**

The UAT/UCP predictions are unique in that they require **zero free parameters** beyond the independently calibrated κ_{crit}. The values 3.07 TeV and 1.22 PeV are not fitted to any experimental data — they follow directly from Eq. (1) with $n = 5, 6$ and $\kappa_{\text{crit}} = 10^{-78}$.

8 Limitations

We explicitly acknowledge the following limitations:

1. **The integer n is not derived from first principles.** The values $n = 5, 6$ are postulated as the next integers in the sequence $n = 4$ (QCD). A rigorous derivation of why specific integers correspond to specific physical phenomena requires a formal mapping between the causal membrane and the Standard Model gauge group.

2. **$\kappa_{\text{crit}} = 10^{-78}$ has an uncertainty of ± 0.5 dex.** This propagates to an uncertainty of approximately a factor of ~ 1.4 in $E(5)$ and ~ 1.35 in $E(6)$. The precise values 3.07 TeV and 1.22 PeV should be understood as central estimates with these uncertainties.

3. **The causal membrane is not part of mainstream physics.** Its constants have not been independently validated by third-party experiments. The predictions in this work are tests of the framework, not consequences of established theory.

4. **Experimental accessibility:** The PeV scale ($n = 6$) is at the limit of current experimental capabilities. Definitive tests may require next-generation facilities (IceCube-Gen2, GRAND) that will not be operational until the 2030s.

5. **Alternative explanations:** Even if a signal is detected at 3.07 TeV or 1.22 PeV, it could be explained by physics beyond the Standard Model that is unrelated to the causal membrane. A positive detection would motivate further investigation but would not uniquely confirm the UAT/UCP framework.

9 Conclusion

The Causal Mass Gap equation $E(n) = E_{\text{Planck}} \times \kappa_{\text{crit}}^{1/n}$ generates a hierarchy of energy scales from the Planck scale down to the dark energy scale. The previously documented values $n = 1/\alpha$ (dark energy) and $n = 4$ (QCD confinement) are now extended to $n = 5$ and $n = 6$, yielding two new predictions:

$$\boxed{E(5) \approx 3.07 \text{ TeV}} \qquad \boxed{E(6) \approx 1.22 \text{ PeV}}$$

Key findings:

1. The $n = 5$ scale (3.07 TeV) falls within the reach of the LHC and future colliders. A resonance or anomaly at this energy would be a signature of causal membrane physics.

2. The $n = 6$ scale (1.22 PeV) coincides with the typical seesaw scale for neutrino mass generation and the Peccei-Quinn scale for axion physics. Anomalies in neutrino or cosmic ray data at this energy could indicate the presence of the causal membrane.

3. The causal hierarchy $n = 4, 5, 6, \ldots$ naturally generates the separation between the QCD, TeV, PeV, GUT, and Planck scales, offering a possible resolution to the hierarchy problem of particle physics.

4. Both predictions require zero free parameters beyond $\kappa_{\text{crit}} = 10^{-78}$, which is independently calibrated from cosmology and information theory.

5. Both predictions are falsifiable with current or near-future experimental data.

The same constant that determines the dark energy density and the QCD confinement scale may also determine the energy scale of the next discoveries in particle physics. Whether nature has chosen $n = 5$ and $n = 6$ as the next rungs of the causal hierarchy is for experiment to decide.

One constant. $\kappa_{crit} = 10^{-78}$.
One equation. $E(n) = E_{Planck} \times \kappa_{crit}^{1/n}$.
Two new predictions. 3.07 TeV and 1.22 PeV.
Zero free parameters.
Experiment will judge.

Data and Code Availability

The Python script computing all causal scales and their observable consequences is available as supplementary material. It uses only standard scientific libraries (NumPy, SciPy) and CODATA 2018 fundamental constants.

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References

[1] M. A. Percudani, *Universal Applied Time (UAT/UCP): A Fundamental Theory of Cosmology from First Principles*, Zenodo, 2024. DOI: `10.5281/zenodo.17729221`.

[2] M. A. Percudani, *The Causal Coherence Constant κ_{crit}: A Fundamental Limit on Retrocausal Influence*, Zenodo, 2024. DOI: `10.5281/zenodo.18210808`.

[3] M. A. Percudani, *The Causal Pillars of the UAT Framework: Core and Derived Equations*, Zenodo, 2025.

[4] M. A. Percudani, *First-Principles Resolution of the Cosmological Constant Problem*, Zenodo, 2025. DOI: 10.5281/zenodo.21109424.

[5] M. A. Percudani, *The Causal Membrane and the QCD Scale*, Zenodo, 2026.

[6] Planck Collaboration, *Planck 2018 results. VI. Cosmological parameters*, A&A, 641, A6 (2020).

[7] Particle Data Group, *Review of Particle Physics*, Phys. Rev. D, 110, 030001 (2024).

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Causal Mass Gap: $E(n) = E_{Planck} \times \kappa_{crit}^{1/n}$

$n = 5$*: 3.07 TeV (LHC)* $\quad n = 6$*: 1.22 PeV (IceCube)*

Zero free parameters. Falsifiable.