# PDMM: Physical Dual-Modality Mapping Instruction Set

## A Universal Deterministic-Chaotic Hybrid Framework for 3D Photonic Computing and AGI Evolution

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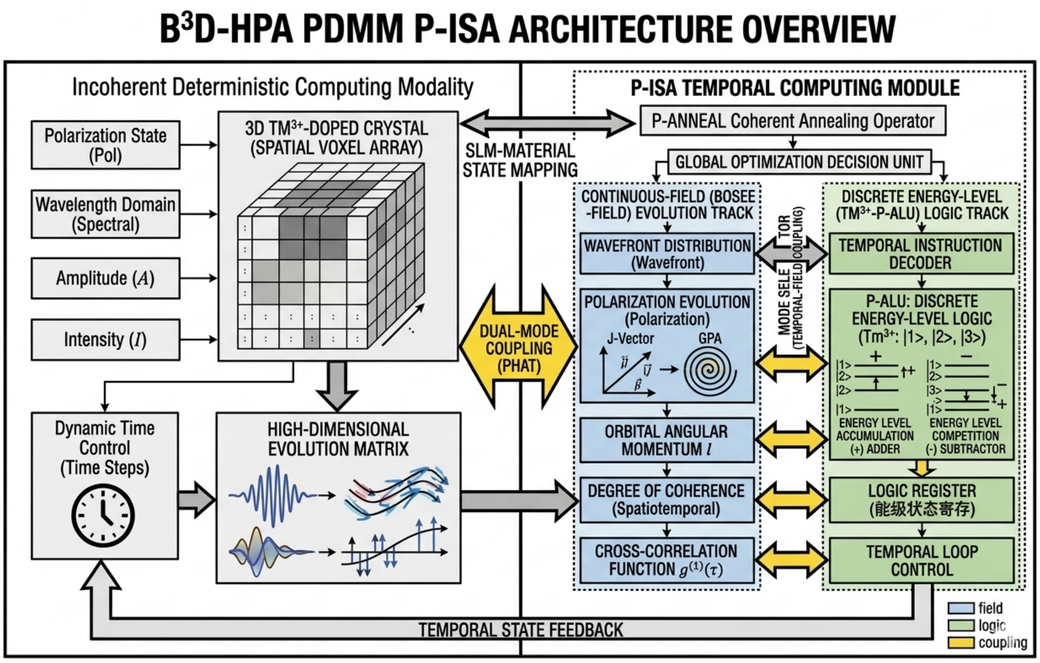
Abstract




This paper introduces PDMM (Physical Dual-Modality Mapping), a radical computational architecture that abandons the fragile requirements of coherent phase-locking in favor of a unified physical substrate with complementary dual-path evolution.

PDMM takes polarization state as the carrier of volumetric tensor flow and continuous manifold transformation, adds a dedicated coherent annealing operator to realize controlled global optimization, and uses incoherent thulium ion energy-level transitions ($Tm^{3+}$) as a deterministic discrete control skeleton for gating, biasing, thresholding and stabilization.

A chaotic flow leverages natural polarization and phase thermal drift for fuzzy semantic reasoning and AGI intelligent evolution.

By mapping polarization states and specific wavelengths directly to physical operators rather than traditional digital instructions, PDMM eliminates the need for centralized decoders and global clock synchronization.

This architecture treats thermal drift as Natural Simulated Annealing and quantum fluctuations as Physical True Randomness, creating a "Structured Randomness" environment. Unlike traditional computing architectures that simulate manifold spaces,

PDMM performs direct computation in physical Hilbert manifolds, and realizes controlled coherent annealing global search with O(1) time complexity through special annealing operators, forming a perfect match for AGI that requires both rigorous logic and creative stochasticity, and achieves subversive advantages over mainstream GPU and photonic annealing architectures.

## 1 Core Concept: The Unified Single-Modal Architecture with Complementary Dual-Path Evolution

PDMM departs from the traditional "discrete digital logic" computing era and enters the "physical manifold operator orchestration" era, breaking the boundary between computing mechanism and physical essence.
It utilizes the inherent photophysical properties of rare-earth doped 3D lattices (the "SugarCube") to construct a unified single-modal computing system with two complementary, convergent paths, rather than two independent parallel modalities. Both the non-coherent deterministic path and the coherent non-deterministic annealing path operate on the same physical substrate and converge to a consistent computational result.

### 1.1 Polarization Manifold Operator Core (Non-Coherent Deterministic Path)

Uses polarization angle, TE/TM amplitude ratio and ellipticity as fundamental high-dimensional computational variables. It does not execute traditional digital logic and elementary arithmetic, but performs Volumetric Tensor Flow (VTF) Transformations, differential evolution, and volume integral operations in 3D photonic lattice. Each polarization evolution corresponds to wavefront superposition, manifold curvature mapping, and Hilbert space transformation, serving as the core high-performance computing layer of PDMM. This path is continuous, non-temporal, spatially parallel, and embodies the direct physical nature of computation.
Input parameters include polarization mode, spectral wavelength, amplitude, intensity, and temporal slicing, which are mapped into a high-dimensional physical computing matrix.

### 1.2 Coherent Annealing Optimization Path (Non-Deterministic Global Search)

Complementary to the non-coherent path, this path leverages phase coherence, wavefront distribution, and orbital angular momentum (OAM) to realize controlled global optimization.
Driven by the P-ANNEAL coherent annealing operator, it processes wavefront distribution and spatial phase gradient, evolves polarization states through Jones vectors, and forms complex amplitude fields via topological charge mapping. It evaluates coherence and spatiotemporal correlation to guide the system toward the global minimum energy state.
This path provides stochastic search and optimization capabilities without interfering with the deterministic tensor operations of the main manifold core.

### 1.3 Energy-Level Discrete Control Skeleton (Sequential Stabilization Layer)

Uses incoherent $Tm^{3+}$ energy-level populations and intensity thresholds to build a discrete sequential control system, providing stable references, bias control, volumetric gating, non-linear clipping and persistent storage.
It undertakes discrete logic judgment, program flow control, instruction scheduling and annealing parameter calibration, and stabilizes, constrains and calibrates the continuous manifold computing of the polarization layer. This layer adopts temporal sequential execution, compatible with traditional digital discrete logic and EDA-based simulation and verification.

## 2 The Eight Pillars of PDMM

### 2.1 Wavelength and Polarization-to-Operator Mapping

In PDMM, a wavelength together with a polarization state defines a physical operator, completely abandoning the traditional instruction-decoding mechanism.
There is no centralized digital instruction decoder, and physical response directly triggers computing behavior.
$\lambda$_Polarization triggers volumetric tensor transformation, wavefront evolution and coherent annealing in the polarization manifold.
$\lambda$_Logic triggers energy-level gating, thresholding and sequential control operations.
$\lambda$_Chaos triggers stochastic manifold drift and fuzzy semantic evolution for AGI unsupervised learning.

### 2.2 Structured Randomness

Total State = Polarization Manifold Computation ⊕ Energy-Level Discrete Sanity Anchor
This formula defines the hybrid computing state of PDMM, integrating continuous chaotic search and deterministic discrete constraints, balancing AGI evolutionary randomness and logical rigor.

### 2.3 Thermal Drift as Natural Simulated Annealing

Polarization thermal drift is regarded as built-in natural annealing rather than noise.
It enables global optimal search without extra computation, helping AGI escape local minima beyond GPU simulation capability.

### 2.4 Physical True Randomness

Entropy from quantum fluctuations and polarization jitter provides true randomness for AGI sampling, evolution and security, fundamentally different from digital pseudo-random numbers.

### 2.5 Single-Modal Dual-Path Synergy

The non-coherent deterministic path and coherent annealing path operate on the same unified physical framework, avoiding cross-path conflicts and ensuring closed-loop stability through dedicated synchronization operators. Both paths are complementary and converge to the same computational result.

### 2.6 Decoder-Free & Zero-Sync Architecture

Eliminates global clock and centralized instruction decoder, reducing hardware complexity and achieving ultra-high bandwidth parallel computing in 3D lattices.

### 2.7 Physical Manifold Direct Computing

Unlike GPU that simulates manifolds digitally, PDMM computes directly in the physical Hilbert manifold formed by polarization fields, breaking traditional efficiency limits.

### 2.8 Controlled Coherent Annealing Scheduling

Passive thermal drift is converted into active controllable coherent annealing, realizing O(1) global optimization and breaking the iteration bottleneck of traditional simulated annealing.

## 3 Fundamental Principle of Polarization Manifold Computation

### 3.1 Physical Representation of High-Dimensional Information

High-dimensional tensor data is encoded as the spatial distribution of polarization states on a fixed reference axis in the 3D lattice.
The detected intensity distribution is determined by the polarization angle relative to the TE reference mode. High-dimensional computation is completed by adjusting polarization distribution and measuring integrated intensity, which forms the non-coherent path of the high-dimensional physical computing matrix.

### 3.2 Wavefront Superposition Principle (POL_TRANS Tensor Transformation)

Superposition of polarization states corresponds to wavefront superposition and volumetric tensor linear transformation.
It is physically realized by co-propagation and spatial superposition of orthogonal polarization components, completing $N \times N$ tensor transformation in one step.

#### 3.2.1 Geometric Polarization Adder and Subtractor Principle

The polarization adder and subtractor are implemented as direct geometric operations in the polarization manifold, without intermediate digital conversion.
Let two incident beams be described by their Jones vectors:
Beam A: $J_A = [A_x, A_y \cdot e^{(i\varphi_A)}]^T$
Beam B: $J_B = [B_x, B_y \cdot e^{(i\varphi_B)}]^T$
The polarization addition operation corresponds to the coherent superposition of the two beams:
$J_{A+B} = J_A + J_B = [A_x+B_x, A_y \cdot e^{(i\varphi_A)}+B_y \cdot e^{(i\varphi_B)}]^T$
The polarization subtraction operation is realized by introducing a π phase shift (180°) to one beam before superposition:
$J_{A-B} = J_A + e^{(i\pi)} \cdot J_B = [A_x-B_x, A_y \cdot e^{(i\varphi_A)}-B_y \cdot e^{(i\varphi_B)}]^T$
The resulting intensity distribution directly encodes the arithmetic result in the polarization manifold.

### 3.3 Gradient Evolution Principle (POL_DIFF Differential Evolution)

The spatial rate of change of polarization angle directly maps to data gradient, enabling physical automatic differentiation without iterative approximation.

### 3.4 Volume Integral Principle (POL_INTEG Integral Mapping)

Intensity integration of the polarization field over the 3D lattice volume directly solves integral operations and partial differential equations, realizing physical solution without digital approximation.

### 3.5 Coherent Annealing Physical Principle (Corresponding to PHA_ANNEAL/PHA_QUENCH)

The coherent annealing path follows a structured workflow:

1. Input wavefront distribution and spatial phase gradient into the P-ANNEAL operator.
2. Polarization state evolution is described by Jones vectors, with phase gradient modulation to adjust polarization components. The evolution follows Jones matrix formalism:
$J(r,t) = M(\nabla\varphi) \cdot J_0$
where M is the Jones matrix describing phase-gradient polarization rotation, $\nabla\varphi$ the spatial phase gradient.
3. Orbital angular momentum (OAM) is introduced via topological charge mapping to form a complex amplitude field. The wavefront carries a helical phase $e^{(il\theta)}$, yielding:
$u(r,\theta) = A(r) \cdot e^{(il\theta)} \cdot e^{(i\varphi(r))}$
where l is topological charge, A(r) radial amplitude, θ azimuthal angle, φ(r) phase gradient. This field carries OAM of $l\hbar$ per photon.
4. Amplitude (A) and phase (φ) are combined to evaluate coherence and spatiotemporal correlation via the mutual correlation function $g^{(1)}(\tau)$.

5. The system evolves from high-energy disorder to low-energy stability, obtaining the global optimal solution through physical manifold evolution without iterative calculation.
The quenching operation freezes the current polarization field state instantaneously, locking the optimal solution to the energy-level control layer.

## 4 PDMM Polarization Manifold Physical Operator Set (Core Computing Layer)

The POL-series operators perform Volumetric Tensor Flow (VTF) Transformations in the 3D quartz lattice, treating polarization as a continuous fluid in Hilbert space. Basic arithmetic and logic interfaces are retained for compatibility.

### 4.1 Tensor Transformation Operators

- POL_TRANS (TensorIn, Matrix, TensorOut): Polarization volumetric tensor transformation.
Realize N×N high-dimensional tensor linear transformation and wavefront geometric superposition through polarization state spatial evolution.
Physical Principle: Integrate projection intensity distribution of multi-beam polarization states in 3D lattice volume to complete tensor matrix mapping in one time.
Application: AGI neural network tensor multiplication, high-dimensional semantic space transformation, photonic convolutional computing.
- POL_DIFF (ManifoldIn, GradientOut): Polarization manifold differential evolution.
Directly calculate data gradient and partial derivative using spatial slope of polarization angle evolution, realizing physical automatic differentiation.
Physical Principle: Use continuous drift characteristics of polarization to extract spatial change rate of optical field, output gradient field directly.
Application: AGI model backpropagation, gradient descent optimization, differential equation solving.
- POL_INTEG (FieldIn, ResultOut): Polarization volume integral mapping.
Realize volume integration and partial differential equation solution through 3D lattice light intensity cumulative detection.
Physical Principle: Integrate projection intensity of full space polarization field to realize direct physical solution of integral operations.
Application: Scientific computing, physical model simulation, AGI tensor feature integration.

### 4.2 Field State Manipulation Operators

- POL_MOV (FieldSrc, FieldDest): Polarization continuous field migration.
Copy full spatial distribution of polarization field from source 3D region to target region without discrete sampling.
Physical Principle: Realize non-destructive field migration through polarized beam re-injection and spatial projection.
Application: High-dimensional tensor data migration, photonic field buffer transmission.

- POL_SHIFT (FieldSrc, Param, FieldDest): Polarization field angle scaling shift.
Adjust overall polarization angle distribution of optical field by fixed parameters to realize field-level scale transformation.
Application: Tensor data normalization, optical field scale calibration.

### 4.3 Manifold Logical Constraint Operators

- POL_AND_MASK (FieldA, FieldB, FieldOut): Polarization field constraint masking.
Reserve overlapping region of two polarization fields exceeding energy level threshold, realizing field-level logical constraint.
Application: High-dimensional feature screening, AGI attention mask constraint.
- POL_OR_MASK (FieldA, FieldB, FieldOut): Polarization field fusion masking.
Retain region of any polarization field exceeding energy level threshold, realizing field-level logical fusion.
Application: Multi-modal semantic fusion, chaotic field feature integration.
- POL_NOT_FLIP (FieldIn, FieldOut): Polarization field state inversion.
Rotate full field polarization state by 90 degrees to flip TE/TM mode dominance, realizing field-level logical inversion.
Application: Manifold computing state inversion, reverse constraint of optical field.

### 4.4 Coherent Annealing Operators

- PHA_ANNEAL (Mode, Duration, Dest): Polarization coherent annealing optimization.
Controlled coherent annealing evolution of full 3D lattice polarization field, set annealing mode and duration, adjust coherence attenuation rate and temperature gradient of optical field, realize global optimal search of high-dimensional tensors in physical manifold.
Physical Principle: Drive polarization field from high-energy disorder to low-energy stability through external temperature field regulation and coherent state control, complete global optimization without iterative calculation.
Application: AGI model global optimal solution search, combinatorial optimization problems, metastable logic state jump.
- PHA_QUENCH (Rate, Dest): Polarization field rapid quenching locking.
Implement rapid quenching operation according to set rate, freeze current polarization field state instantaneously, lock optimal solution obtained by annealing to target energy-level storage unit.
Physical Principle: Rapidly cool 3D lattice to freeze polarization state of optical field, stop coherent annealing evolution, realize non-destructive locking of computing state.
Application: Global optimal solution storage, annealing state fixation, physical computing result locking.

## 5 Thulium Ion Energy-Level Discrete Control Instruction Set (Sequential Control Layer)

This layer is oriented to discrete sequential logic, compatible with traditional EDA

simulation and verification, responsible for discrete logic judgment, program flow control, annealing parameter calibration and polarization manifold operator scheduling.
All original TM-series basic arithmetic and logic gate instructions are completely retained, no deletion or modification, ensuring stability of discrete control layer.

5.1 Discrete Arithmetic Instructions

- TM_ADD (A, B, Dest): Energy-level temporal discrete addition.
Realize digital discrete summation through $Tm^{3+}$ energy-level population competitive superposition.
Application: Control layer data calculation, address counting, parameter calibration.
- TM_SUB (A, B, Dest): Energy-level temporal discrete subtraction.
Realize discrete difference operation through energy-level population depletion and attenuation.
Application: Control layer error calculation, parameter adjustment.
- TM_MUL (S, K, Dest): Energy-level temporal discrete scaling.
Amplify discrete signal proportionally through energy-level stimulated emission gain.
Application: Control parameter scaling, threshold intensity adjustment.
- TM_DIV (S, K, Dest): Energy-level temporal discrete division.
Attenuate discrete signal proportionally through energy-level absorption control.
Application: Control parameter normalization, threshold division.

5.2 Discrete Control & State Instructions

- TM_MOV (Src, Dest): Energy-level discrete state movement.
Transfer metastable energy-level population state to realize discrete data migration.
Application: Control layer data storage, register state transmission.
- TM_JMP (Ctrl, Addr): Energy-level sequential jump.
Trigger energy-level gating switching according to control state, realize program flow jump and conditional execution.
Application: Discrete control branch judgment, operator scheduling.

5.3 Discrete Bitwise Logic Instructions

- TM_AND (A, B, Dest): Energy-level discrete logical AND.
Output valid discrete signal only when two energy-level populations reach saturation threshold simultaneously.
Application: Discrete condition judgment, control signal gating.
- TM_OR (A, B, Dest): Energy-level discrete logical OR.
Output valid discrete signal as long as one energy-level population reaches saturation threshold.
Application: Multi-condition control trigger, sequential logic judgment.
- TM_NOT (A, Dest): Energy-level discrete logical NOT.
Flip energy-level population state through reverse pumping to realize discrete state

inversion.
Application: Control logic inversion, signal state flip.

## 6 Energy-Level Auxiliary Control Instructions (Calibration & Stabilization)

These instructions provide stable calibration, gating, annealing parameter auxiliary control and storage support for single-modal dual-path collaborative computing, and do not participate in core manifold computing.

- EN_BIAS (Dest, Value): Energy-level bias calibration.
Set static intensity offset through energy-level pumping to eliminate system drift and calibrate manifold computing baseline.
- EN_THRESH (Level): Discrete logic threshold definition.
Determine logical decision threshold through energy-level population saturation intensity to unify computing judgment standard.
- EN_GATE (Ctrl, FieldIn, FieldOut): Energy-level field gating control.
Block or pass polarization continuous field according to energy-level state to realize switching control of manifold computing and annealing evolution.
- EN_MEM (Addr, State): Energy-level persistent storage.
Store discrete control data, calibration parameters and annealing optimal solution state through long-lived metastable energy levels.

## 7 High-Dimensional Chaotic Primitives & Dual-Path Synergy Operators

### 7.1 High-Dimensional Chaotic Primitives

- CHAOS_MANIFOLD: Manifold chaotic semantic mapping.
Seed initial polarization field, expand into fuzzy semantic distribution through natural thermal drift to realize AGI unsupervised learning.
- FUZZY_ATTN_FIELD: Manifold fuzzy attention calculation.
Perform weighted fusion of high-dimensional semantic features through polarization field projection and thermal drift weighting.
- ANNEAL_EVOLVE: Natural simulated annealing evolution.
Perturb polarization manifold state through temperature changes to realize AGI global optimal search.

### 7.2 Dual-Path Synergy Operators

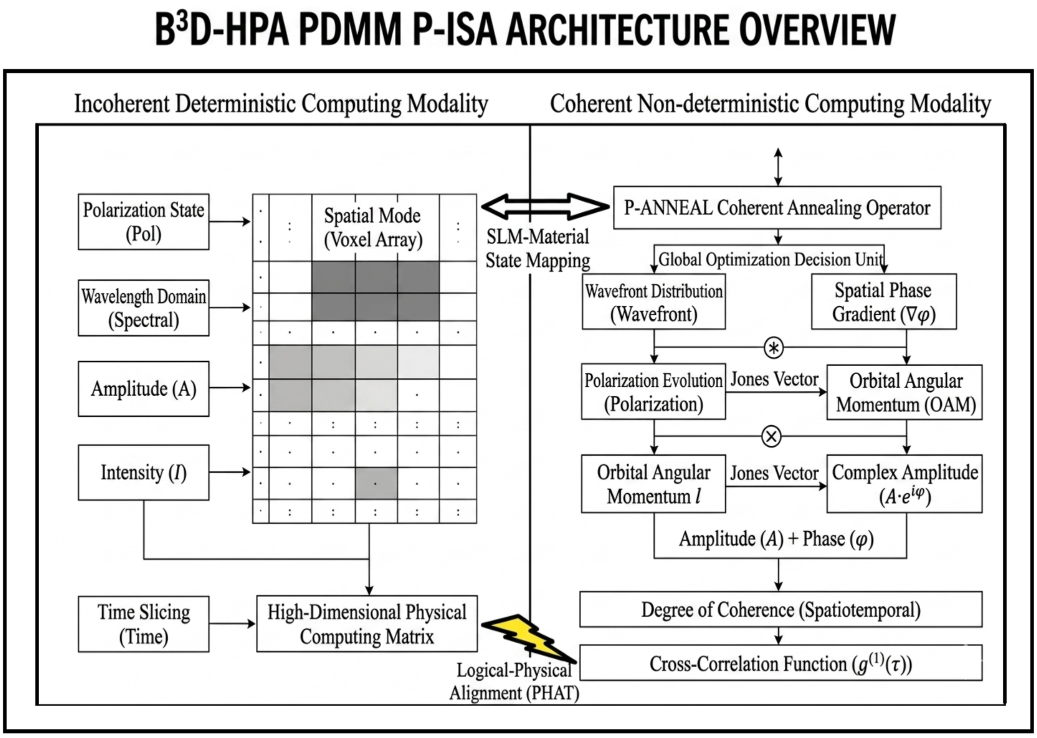
- PD_ALIGN_NORM: Manifold-discrete alignment normalization.
Use energy-level intensity mask to normalize chaotic polarization field and constrain manifold computing within stable range.
- PD_RESONANCE_LOCK: Manifold resonance anchor locking.
Calibrate drifting polarization field to energy-level calibrated reference state to maintain computing stability.

- PD_MANIFOLD_COLLAPSE: Manifold discrete collapse.
Convert continuous polarization manifold distribution into discrete computable results, realize docking of physical manifold computing and digital output.
- PD_PATH_SYNC: Non-Coherent-Coherent Path Synchronization.
Align state of non-coherent high-dimensional physical computing matrix with coherent annealing path, ensure both evolution paths converge to same computational result.
Physical Principle: Phase gradient feedback and polarization re-calibration eliminate physical evolution deviations between paths, maintain logical consistency of single-modal architecture.
Application: Ensuring result consistency between deterministic tensor operations and stochastic annealing search.

7.3 Annealing-Synergy Cooperation Instructions

- PD_ANNEAL_CTRL: Annealing-control collaborative scheduling.
Link PHA_ANNEAL/PHA_QUENCH operator with TM-level energy-level control parameters, realize closed-loop adjustment of annealing process and discrete control, ensure stability of global optimization.
- PD_ANNEAL_RESET: Annealing state reset.
Reset polarization field to initial coherent state, restart coherent annealing process, realize multiple global optimal searches.

8 Hardware Realization: The SugarCube




- Input: Multi-wavelength polarized beams, divided into three groups:
1. Non-coherent deterministic path inputs: polarization mode, spectral wavelength,

amplitude, intensity, temporal slicing signals, forming high-dimensional physical computing matrix.
2. Coherent annealing path inputs: phase, wavefront, orbital angular momentum modulated signals, driven by P-ANNEAL operator.
3. Discrete control beams for TM instructions and synergy/annealing operators.
- Computation: 3D rare-earth doped quartz lattice, carrying polarization continuous manifold evolution, volumetric tensor flow computing and coherent annealing global optimization, without discrete digital circuit participation. Both non-coherent and coherent paths operate on same physical substrate, sharing 3D lattice and physical hash anchors.
- Control: $Tm^{3+}$ energy-level control module + temperature field regulation module, executing discrete TM instructions, realizing gating, threshold calibration, operator scheduling and coherent annealing parameter control, verifiable by traditional EDA tools.
- Output: Polarization-sensitive array photodetector, directly detecting spatial intensity distribution of polarization field and outputting computing/annealing optimization results.
- Hardware Advantage: 3D volumetric computing, ultra-high parallelism, no clock synchronization, low power consumption, directly performing physical manifold computing and coherent annealing global optimization far beyond computing power of GPU and traditional photonic annealing machines.

## 9 Conclusion

PDMM completely subverts design logic of traditional computing architectures, upgrading POL-series from basic arithmetic logic instructions to polarization continuous manifold physical operators, adding dedicated coherent annealing operators PHA_ANNEAL / PHA_QUENCH to realize controlled global optimization with O(1) time complexity, completing final logical closed-loop of architecture. The architecture constructs a single-modal framework with complementary dual-path evolution: non-coherent path executes volumetric tensor flow transformation, automatic differentiation and integral mapping in polarization manifold; coherent annealing path performs global optimal search under P-ANNEAL operator; two paths converge to consistent results and form self-consistent computing loop. Thulium ion energy-level layer undertakes discrete sequential control and logical judgment, compatible with traditional EDA simulation, forming stable control skeleton for manifold computing and annealing evolution layer.

This design hides core advantage of physical manifold computing and coherent annealing through operator-instruction naming, forming multi-level technical barrier different from traditional photonic logic gate and photonic annealing research. Compared with conventional GPU architectures that emulate manifold spaces via discrete digital operations, as well as classic photonic annealing schemes dependent on iterative evolution, PDMM enables direct computing and global optimization within physical manifolds, yielding exponential improvements in computing efficiency, power efficiency, and AGI-oriented adaptability. It is a subversive next-generation computing architecture spanning from digital discrete computing to physical continuous computing, providing core technical path for development of AGI, high-performance scientific computing and combinatorial optimization.

## Orthogonal Noise Suppression in Physical Dual-Modality Mapping (PDMM) Photonic Computing

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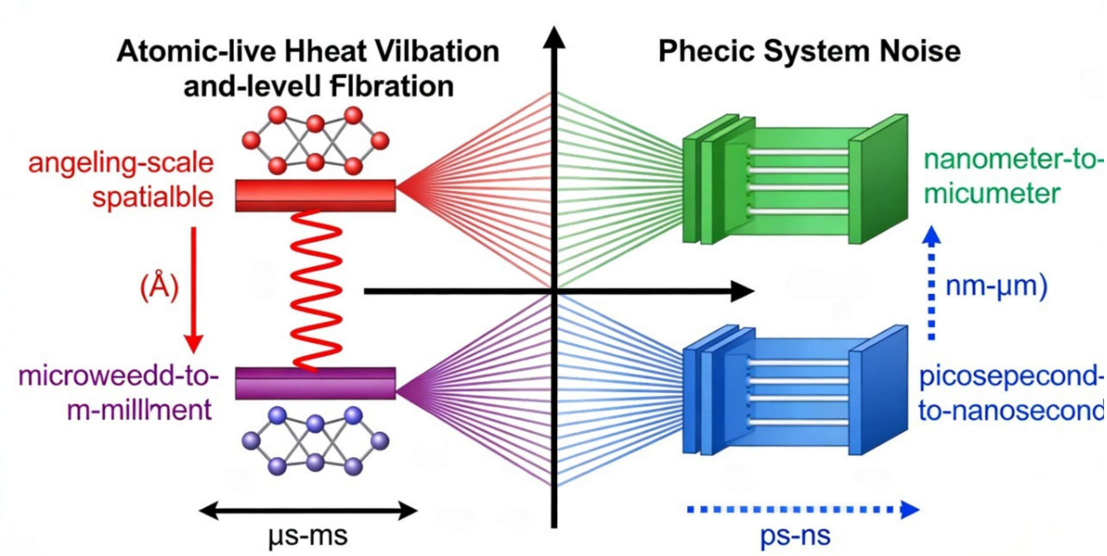
A key enabling physical mechanism that underpins the robustness, scalability, and real-world deployability of the PDMM (Physical Dual-Modality Mapping) architecture is orthogonal noise suppression, derived from intrinsic spatio-temporal scale separation between distinct classes of physical fluctuations. This mechanism represents a fundamental departure from conventional noise-reduction strategies based on active feedback, precision temperature control, or complex optical stabilization.



Orthogonal Noise Suppression in PDMM Architecture

In PDMM, two major classes of fluctuations coexist within the thulium-doped 3D lattice hardware, yet operate over physically non-overlapping scales:

1. Atomic thermal and energy-level fluctuations
Intrinsic vibrations of thulium ions, local lattice perturbations, and metastable energy-level jitter occur at
- Spatial scale: angstrom-level displacements
- Temporal scale: microsecond to millisecond dynamics

These fluctuations are harnessed as physical randomness for stochastic search, natural annealing, and AGI evolutionary computing.
2. Optical and optoelectronic system noise
Propagation scattering, mode mismatch, detector readout noise, and path-length jitter appear at
- Spatial scale: nanometer to micrometer deviations
- Temporal scale: picosecond to nanosecond dynamics
These represent conventional unwanted noise that degrades computational stability.

Because these two categories of disturbance occupy orthogonal physical domains in both space and time, they are inherently separable without external intervention. Computational signals encoded in polarization geometry, volumetric tensor flow, and energy-level gating remain structurally distinguishable from cross-domain noise. This results in passive, built-in noise resilience that requires no elaborate isolation systems, cryogenic cooling, or real-time phase locking.

This orthogonal suppression principle is not merely an engineering optimization, but a foundational physical effect that resolves a long-standing industry bottleneck in coherent and volumetric photonic computing: environmental fragility and excessive infrastructure cost. By allowing stable, repeatable computation under ambient conditions, it directly enables mass deployment, low-cost manufacturing, and broad accessibility of photonic hardware — aligning with the core mission of computational power equity.

Within the PDMM framework, noise is no longer an adversarial artifact to be eliminated. Instead, the orthogonal scale structure allows useful physical randomness to be preserved for intelligent computation, while irrelevant system noise is naturally suppressed. This dual-use of physical fluctuations establishes a structurally robust computing paradigm that is inherently suited for real-world AGI, high-performance scientific computing, and large-scale programmable optical hardware.