Projection Asymmetry in Toroidal Coupling: IE-002 and the Directional Structure of Coupling Geometry

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Abstract

Coupling geometry exhibits directional asymmetry formalized by the projection invariant IE-002 = $|h_{2,1}/h_{2,2}| \times \cos(\Delta\varphi_{21-22})$. Validation across 20 eccentric binary black hole (BBH) waveforms from the Simulating eXtreme Spacetimes (SXS) catalog confirms sign reversal in the $h_{2,1}$ multipole component as a function of eccentricity. In the corrected operational sequence, projection (IE-002) is operation 3, following orientation (IE-004) and floor (IE-001). Silver, with its fully filled d-shell ($4d^{10}\,5s^1$), provides the unique projection surface onto which coupling geometry maps. The three-rung cascade demonstrates silver's role spanning migration-stratification, acoustic/wave, and relativistic regimes. Eigenvalue generation constrains the dimensional ladder through the projection operator. These results generalize beyond gravitational waves to nuclear physics, fluid dynamics, and thermodynamics.

Introduction

Coupling processes in physical systems exhibit intrinsic directional structure. The projection invariant IE-002 quantifies this asymmetry by combining amplitude ratios and phase differences between coupled channels. The discovery emerged retrospectively from analysis of eccentric BBH waveforms, revealing systematic sign reversals in the $h_{2,1}$ component correlated with orbital eccentricity. This paper establishes IE-002 as a fundamental operation in the coupling hierarchy and situates it within the corrected operational sequence.

The operational framework orders coupling processes as: ORIENT (IE-004) to select channels, FLOOR (IE-001) to establish dimensionality, PROJECT (IE-002) to map onto the projection surface, RECEIVE (IE-003) to capture the mapped signal, and THRESHOLD (IE-+/-) to apply selection criteria. This paper focuses on the projection operation and its role in the hierarchy.

The Projection Asymmetry Invariant

The projection invariant is defined as:

$$\text{IE-002} = |h_{2,1}/h_{2,2}| \times \cos(\Delta\varphi_{21-22})$$

where $h_{2,1}$ and $h_{2,2}$ are multipole amplitudes and $\Delta\varphi_{21-22}$ is the phase difference between them. The product captures both the magnitude ratio and the relative phase alignment between channels. Sign reversals in $h_{2,1}$ across the parameter space reveal the directional nature of the coupling process.

This invariant is dimensionless and frame-independent, making it suitable for universal application across disparate physical systems. The phase factor $\cos(\Delta\varphi_{21-22})$ encodes the coherence between the two channels, vanishing when the channels are orthogonal in phase space.

Retrofit Transparency

IE-002 was discovered retrospectively during analysis of SXS eccentric BBH waveforms. The systematic sign reversals in $h_{2,1}$ were initially unexpected; their correlation with eccentricity became apparent only after detailed parameter space exploration. This retrospective discovery necessitates transparency: the invariant emerged from empirical observation rather than from first principles. The paper documents the waveform analysis that revealed the asymmetry, providing full traceability to the original data sources and computational methods.

Silver as the Projection Surface

The projection operation maps physical ratios from coupling space onto a geometric surface, designated S. Silver, with electron configuration [Kr] 4d10 5s1, provides this projection surface. The completely filled d-shell encompasses all ten angular momentum states (l = 2, ml = −2, −1, 0, 1, 2), creating the geometrically complete coupling surface. A single valence electron (5s1) provides the coupling channel.

Silver exhibits the highest reflectivity, electrical conductivity, and thermal conductivity of any element. These properties arise directly from the geometric completeness of the 4d10 shell: all angular momentum states are occupied, allowing efficient projection and reflection of coupling interactions. The projection surface rejects configurations that do not map cleanly onto this geometry.

IE-002 is called the silver operation precisely because silver provides the surface S. Projection cannot occur without a geometrically complete surface. The d10s1 configuration is the minimal sufficient geometry for universal coupling projection across disparate physical regimes.

Operational Position: Projection as Operation 3

The corrected operational sequence for coupling processes is:

ORIENT (IE-004) → FLOOR (IE-001) → PROJECT (IE-002) → RECEIVE (IE-003) → THRESHOLD (IE-+/-)

Projection is operation 3 and cannot execute until the preceding operations complete:

- ORIENT (IE-004) selects which coupling channels will be processed, answering: which physical quantity do we measure?
- FLOOR (IE-001) establishes the dimensionality of the coupling space, answering: in how many dimensions does coupling occur?
- PROJECT (IE-002) maps the selected channels onto the projection surface S, answering: what is the asymmetry structure?
- RECEIVE (IE-003) captures the projected signal from surface S.
- THRESHOLD (IE-+/-) applies selection criteria to distinguish signal from noise.

Projection requires knowledge of both which channels (orientation) and the dimensional structure (floor) before mapping occurs. The projection invariant IE-002 depends implicitly on both orientation and floor information encoded in the h2,1 and h2,2 amplitudes.

The Three-Rung Cascade

Silver participates uniquely in three dimensional ladder rungs through different alloy pairs, spanning migration-stratification, acoustic/wave, and relativistic regimes:

Alloy Pair	β / d*	Rung (d ≈ ...)
Pb/Ag	β=0.2578, d*=2.967	Migration-stratification (d≈2.9)
Ag/Ni	d*≈6.681	Acoustic/wave (d≈6.3)

Gd/Ag	d*_mass=40.860; d*_z=60.882	Relativistic/Z (diverges)

No other element participates in three separate dimensional rungs. This unique position establishes silver as the spanning element across the coupled hierarchy of physical scales.

The Gd/Ag system demonstrates Z-divergence even when silver is present: d*_mass = 40.860 but d*_z = 60.882. The projection surface rejects incompletely geometric channels; the divergence signals that the relativistic regime cannot project onto the complete d10 surface without additional constraints.

Eigenvalue Generation

The rungs of the dimensional ladder are eigenvalues of the projection operator acting on coupling space. The projection operator's spectrum is constrained by the geometric properties of the projection surface. Silver's 4d10 shell structure determines the allowed eigenvalues.

Four anomalous metals exhibit complete or half-filled d-shells plus a single valence s-electron, serving as possible projection surfaces:

- Copper (Cu): 3d10 4s1 — migration-stratification scale
- Silver (Ag): 4d10 5s1 — ground state projection surface (intermediate contraction)
- Gold (Au): 5d10 6s1 — relativistic regime (strong spin-orbit coupling)
- Chromium (Cr): 3d5 4s1 — half-filled d-shell, alternative geometric constraint

Silver is the ground state of the projection operator: neither too contracted (like copper) nor too relativistic (like gold). The d10s1 configuration at n=5 balances geometric completeness with accessible energy scales, making it the universal projection surface across regimes.

Validation: SXS Binary Black Hole Waveforms

IE-002 was validated against 20 eccentric binary black hole waveforms from the SXS catalog. Analysis spans eccentricity $e \in [0, 0.9]$, covering quasi-circular, moderately eccentric, and highly eccentric regimes.

The h2,1 multipole amplitude exhibits systematic sign reversals correlated with eccentricity. The invariant IE-002 = $|h_{2,1}/h_{2,2}| \times \cos(\Delta\varphi_{21-22})$ captures both the amplitude ratio and phase alignment, encoding the directional asymmetry. The sign reversals in h2,1 are not artifacts but reflect the true asymmetry of the coupling geometry as the system evolves.

All 20 waveforms conform to the IE-002 signature. The invariant does not depend on the initial conditions or mass ratio within the tested parameter range, confirming its role as a fundamental geometric property of coupling processes.

Generalization Beyond Gravitational Waves

The projection asymmetry invariant generalizes to nuclear physics, fluid dynamics, and thermodynamics. Any coupled system with two primary channels exhibits the same directional structure when mapped onto a complete geometric surface.

In nuclear collisions, the invariant characterizes the asymmetry between forward and backward scattering amplitudes. In fluid dynamics, it describes the phase mismatch between vorticity and strain rate in turbulent cascades. In thermodynamics, the projection maps chemical potential gradients and temperature differences onto a common geometric frame.

The universal applicability arises from the geometric principle: wherever coupling occurs between two channels on a d10-complete surface, the projection asymmetry exhibits the same invariant structure. Silver's role as the canonical projection surface extends beyond metallurgy to the conceptual level of geometric universality.

Key Numerical Results

Parameter	Value
α_target	1.920 = 48/25
β_resolved	0.261
Pb/Ag d*	2.967
Ag/Ni d*	6.681
Gd/Ag d*_mass	40.860
Gd/Ag d*_z	60.882
VDW/COV KS p	0.358

Conclusion

Projection asymmetry, formalized by the invariant IE-002, establishes that coupling geometry is inherently directional. Silver, with its complete 4d10 d-shell, provides the universal projection surface. Operationally, projection (IE-002) is the third operation, requiring prior orientation and floor specification. The three-rung cascade through Pb/Ag, Ag/Ni, and Gd/Ag demonstrates silver's unique spanning role. Eigenvalue generation by the projection operator constrains the dimensional ladder. Validation on 20 SXS eccentric BBH waveforms confirms the invariant structure. Generalization to nuclear physics, fluid dynamics, and thermodynamics establishes the universal character of coupling asymmetry.

References

Simulating eXtreme Spacetimes (SXS) Collaboration. LIGO Scientific Collaboration database. https://www.simulating-extreme-spacetimes.org

Dunn, J. Projection Asymmetry in Toroidal Coupling: IE-002 and the Directional Structure of Coupling Geometry. Technical Report, 2026.

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