What the moving line in GRB 221009A measures

Phase conversion, an expanding shell and a collider helicity test

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Z.-Q. Ding et al., *Astrophysical Journal Letters* 1012, L4,
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Camarda et al., arXiv:2609.37238v1, 29 September 2026 (SC-303).
Gehrmann et al., arXiv:2611.15836v1, 11 November 2026 (SC-310).

Abstract

Ding et al. reconstruct a broad excess near 2 MeV at the first bright peak of GRB 221009A and a narrower line near 40 MeV in the decay (SC-004–006, L51–53) [1]. The broad excess changes the continuum fit. The fitted line centroid gives the received photon energy. On Ding's assignment of the line to cooled pairs annihilating near rest, the production energy is 0.511 MeV per photon. The centroid then fixes a combined frequency shift of about 89 and, at unit residual shift, a bulk Lorentz factor of at least 44. The flux also depends on which parts of the outflow radiate. Both fits date radiation at the detector, and neither dates the conversion at the engine. Fundamental Density Theory (FDT) has one substance in engine, radiation and detector, and the matter accreting onto a black hole converts to spacetime and energy outside it. A packet released there into a fixed solid angle covers four times the area at each outward doubling of the radius. With fixed count and transmission the number fluence falls to one quarter at each doubling and grows fourfold on the inward step: the inverse-square law read in both directions. Every pattern moves as a helix. The strands of a closed braid run at c on the local light cone while its centre moves inside it, and a photon is the open helix, running at c along its axis throughout propagation. Gravity is refraction. The jet wall is a layer denser than the interstitial spacetime around it, and an oblique ray bends toward it. The wall's index profile and the launch direction set how far the ray is guided. At a collider the recoiling quark or gluon still carries four-momentum. The three records share one account of energy and momentum. None of them times the conversion or fixes a winding sense. Two predictions follow, on different inputs. FDT predicts zero accretion-driven mass change during a merger-free interval. The phase flow of matter into spacetime is passage across the phase seam, which stands at twice the Schwarzschild length on the static exterior, and this analysis places the fireball's base there. At fixed mass, base-frame wind power and cosmological redshift that base attains the maximum of Ding's acceleration-branch Schwarzschild temperature curve: the curve is the product of the two moduli of the support, greatest where they are equal. A fireball launched from the same radius in GR reaches the same temperature, so the prediction is the launch surface. The higher-order collider calculation already splits the two angular projections used in the helicity test.

1 Framework

The primary source status is experimental: Ding et al. fit prompt spectra [1]. The companion records are theoretical: Camarda et al. calculate finite-transverse-momentum angular

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projections [2], and Gehrmann et al. calculate virtual helicity amplitudes [3] (SC-303–314, L1998–2018). Measured, observed and reported refer to the source record. Fits, simulations, reconstructions and estimates retain those names. The design numbers below are sensitivity targets. FDT is a true extension of general relativity and quantum mechanics. It keeps their measured records. Accreting matter converts to spacetime and energy outside the hole (§0.8), and an outflow produces the photons whose energies and arrival times the detector reconstructs. In matched frames, steady conserved power spread over the same solid angle gives one quarter of the bolometric energy flux at twice the radius. A strand of a closed braid runs locally at c on its bound helix. The braid's centre follows a timelike worldline. In a region of uniform index a free photon advances as a helix along a straight axis. In a gravitational field its axis follows the optical ray, which bends in spatial projection. The ray follows a jet wall where the wall's profile and the launch direction supply that bend. Focusing beyond a matched GR bundle is a smaller transverse area at the same transmission. The collider starts with two beams. The joint test uses one response calibrated against independently measured changes in size. It predicts a burst energy shift relative to elastic transport and, given an independently determined material orientation, a signed decay-angle projection on fixed axes in a collider bin that resolves the two signs. Each comparison matches its own geometry and detector response. The equal-weight pair calculation below illustrates a different preparation.

1.1 One medium and two kinds of helix

The omnium is matter, energy and spacetime in different configurations (§§0.1–0.1b). Write E, m, d, t for energy, mass equivalent, distance and elapsed time of a pattern in the chain, c for the locally measured strand rate and ε_0, μ_0 for the medium's electric and magnetic response coefficients. For a confined mode q, $m_q, E_q, \omega_q, T_q, \ell_q$ denote its rest mass, rest energy, angular frequency, period and thread length. Planck's constant is h, its reduced value $\hbar = h/(2\pi)$ (U-02), with π the circle constant. The two responses give the strand rate (§0.1d). The length unit is the metre (m), the time unit the second (s). The bridges of §0.1a then give, in local units (U-01, U-02),

$$\frac{E}{m} = c^2 = \frac{1}{\varepsilon_0 \mu_0} = \left(\frac{d}{t}\right)^2, \qquad c = 299792458 \ \mathrm{m\,s^{-1}}.$$

$$E_q = m_q c^2 = \hbar \omega_q, \qquad T_q = \frac{2\pi}{\omega_q} = \frac{h}{E_q}, \qquad \ell_q = c T_q = \frac{h}{m_q c}.$$

The massive leg uses rest energy. On the null leg the thread length divided by the period stays at the strand rate. Quantisation changes these together, while the atlas coordinate varies continuously over discrete content. The support radius is fixed by geometry, separately from the thread length. With $F_{\max}$ the force ceiling of I-1, displayed below, and $d_{\min}, t_{\min}$ the infima of stroke length and time, $F_{\max} d_{\min} t_{\min} = \hbar$ and $d_{\min} = c t_{\min}$ give twice the Planck length and twice the Planck time. The floor is a minimum and fixes no spacing between allowed radii. An inverse process starts in a different physical state: each event settles the whole configuration, including recoil, radiation and the records left in the medium (§0.1a).

In a local orthonormal frame write $\mathfrak{v}$ for the translation speed of a closed pattern, u for the strand's circulation speed, ψ_{str} for its pitch from the translation axis, and Γ for the bulk Lorentz factor. The rate triangle and its translation share $\mathfrak{s}$ in §0.1d give

$$\mathfrak{v}^2 + u^2 = c^2, \qquad \cos\psi_{\mathrm{str}} = \mathfrak{v}/c, \qquad \sin\psi_{\mathrm{str}} = u/c = 1/\Gamma, \qquad \mathfrak{s} = (\mathfrak{v}/c)^2.$$

The strand runs at c. Its closed pattern has a timelike centre and its inertia includes the stress of closure. For an open photon of local energy E, let λ be wavelength, k wavenumber, ω angular frequency and $\bar{\lambda}$ phase radius. Unbinding leaves all transport axial. I-2 gives

$$E = \hbar\omega, \qquad \omega = ck, \qquad \bar{\lambda} = \frac{\hbar c}{E} = \frac{c}{\omega} = \frac{\lambda}{2\pi}.$$

In the local frame the open photon's helix advances one wavelength per turn along the propagation axis, and its circumference is one wavelength: it stands at $\pi/4$ at every frequency, because nothing closes it and its turning rate equals its run. The helix advances along its axis at c and the energy rides that run. Energy routed around the turns at total speed c would cross space at $c/\sqrt{2}$ and take $\sqrt{2}$ times as long over the same axial distance, and I-2 excludes it. At fixed local energy the phase radius is fixed, and higher energy rides the smaller cylinder. For the closed pattern, $\omega^2 = c^2k^2 + (mc^2/\hbar)^2$: the phase speed and group speed multiply to c^2. A photon period measures the recurrence of its phase at a receiver, not the proper duration of its production. P-4 identifies the local density cone with the light cone and assigns it an intrinsic circulation sense. Joined cones of opposite sense attract and of equal sense repel. The sign refers to the pair joined by the global settlement. Neither a scalar energy nor a scalar intensity distinguishes the two senses. A magnetic outflow twist has coherent axial bivector alignment (P-5), distinct from either pitch above.

1.2 Chart inventory and gravitating energy

Let G be the gravitational constant, $\mathcal{M}$ the total gravitating mass equivalent, R_s its Schwarzschild length, r_f an areal field radius, R_b the configuration's support radius and r_c the interior cutoff. The branch tag σ is positive unity outside and negative unity inside. On A-1, α_σ is the branch-tagged curvature ratio, α_{ext} and α_{int} its exterior and interior readings. X_σ is the positive gap odds, X_{ext} its exterior value. These are ratios of geometrically fixed lengths (§§0.2–0.4):

$$R_s = \frac{2G\mathcal{M}}{c^2}, \qquad \alpha_\sigma = (R_s/r_f)^\sigma, \qquad X_{\text{ext}} = \frac{R_s}{r_f - R_s}, \qquad \alpha_\sigma = \frac{X_\sigma}{1 + X_\sigma}.$$

The exterior extends over $R_s < r_f < \infty$. The interior extends over $r_c \le r_f < R_s$ (O-1). On either branch $0 < \alpha_\sigma < 1$ by the domain. The odds are algebraic. The field-point entry uses r_f, the configuration entry uses R_b at its stated position, and the source length uses the solved mass. The skin radius sets the fold of a bound configuration's interior chart. No record here measures a confinement size for the annihilating leptons or the incoming proton configurations. Ding's fitted shell radius locates the line-emitting surface. The local density peaks at the skin. An interior probe weights a profile over its support: its mean requires a probe weight, and establishes no point value (O-4). There is no rescaling from a collider radius to a gravitational radius.

Application	Coordinate and geometric warrant
A-1, compactness	Two sections of fixed radii determine the curvature ratio. The exterior phase seam lies at $r_f = 2R_s$, the interior seam at $R_s/2$. At either seam the branch coordinate is one half.
A-2, computational	$\beta_\sigma = \alpha_\sigma/(1+\alpha_\sigma)$ is the optional coordinate transform with geometric warrant. Force, density and optics use their own inputs.
A-3, overlap	α_{ovl} designates the overlap-contrast coordinate. Its range alone is available (O-2).
A-4, confinement	α_{conf} designates confinement position. No geometric odds enter here (O-3).
A-5, mode	α_{mode} names mode regimes. A-3 through A-5 have no geometric warrant here.
Skin diagnostic	$\alpha_{\mathrm{core}} \to 1^-$ is schematic. It refers to the skin of a pinning configuration.

At the A-1 seam the two squared moduli of the three-sphere support are equal, the Clifford torus of §0.3a. Crossing exchanges their moduli at fixed phases. The distinct reciprocal radius map $r_f \mapsto R_s^2/r_f$ preserves the branch-tagged value on exchanging branches. On the exterior, the higher compactness side is the compressed matter phase. The lower side is decompressed spacetime. The monopole fold approaches unit compactness from below. A rotating horizon has a different areal radius, and the exterior band inside the monopole fold needs the multipole data of O-5. The phase seam lies outside the Schwarzschild horizon in the static construction.

For the I-1 force F, take the exterior cross-centre inputs $\alpha_{1,\mathrm{ext}}, \alpha_{2,\mathrm{ext}}$ of spherical supports at separation d, with mass equivalents $\mathcal{M}_1, \mathcal{M}_2$. The universal law operates at all scales. The monopole reduction on disjoint supports gives

$$F = F_{\max}\alpha_{1,\mathrm{ext}}\alpha_{2,\mathrm{ext}}, \qquad F_{\max} = \frac{c^4}{4G}, \qquad F = \frac{G\mathcal{M}_1\mathcal{M}_2}{d^2}.$$

Open inputs imply a force below the ceiling. On this pair domain the stronger bound is $F \leq F_{\max}/4$, with equality at contact of equal saturated supports. This is exact pair algebra. The Newtonian face of GR is the leading weak-field slow-motion limit, with relative corrections of compactness and squared speed in units of c^2 (I-4). A laboratory pattern has its own small gravitational window. Its mass is a confinement eigenvalue: D denotes the confinement operator, Ω the domain, B_{bd} its boundary data, n strand count, χ orientation, $\mathfrak{t}$ chart position and u_q the confined mode. I-5 specifies

$$D(\Omega, B_{\mathrm{bd}}; n, \chi, \mathfrak{t})u_q = \omega_q u_q.$$

No form of D, its domains, boundary data or spectrum is written here (O-9). Same-count closures share a class at different confinement costs. Different counts require rebraiding. An electron and a positron have the base lepton's three-strand closure with opposite hand. The open carrier has one strand: photon, graviton, gluon, phonon and magnon are readings of the one spin-one excitation of the medium (§0.1, I-2). Closed matter lies outside that identity. Color charges and their projection into the force law enter no numeric estimate (O-6).

Let M denote the rest contribution, P pressure, V proper volume, T temperature, a the radiation energy-density constant and σ_{SB} the Stefan–Boltzmann flux constant. In I-7 the following entries represent disjoint channels of a single stress tensor:

$$\mathcal{M} = M + \frac{E}{c^2} + \frac{PV}{c^2} + \frac{aT^4V}{c^2} + \cdots, \qquad a = 4\sigma_{\mathrm{SB}}/c.$$

Here the other energy E excludes the explicitly listed channels. Binding is already in the exterior mass aspect. For phase stresses $T_b^{\mu\nu}$ and phase-exchange four-sources Q_b^ν, with b indexing recipients and ∇ the covariant derivative, μ, ν spacetime indices and $T_\Omega^{\mu\nu}$ the total omnium stress, I-6 gives

$$T_\Omega^{\mu\nu} = \sum_b T_b^{\mu\nu}, \qquad \nabla_\mu T_b^{\mu\nu} = Q_b^\nu, \qquad \sum_b Q_b^\nu = 0.$$

Changing phase at fixed total energy and field radius leaves A-1 compactness fixed. The sum constrains every component of four-momentum. A redistribution within the tensor supplies no extra luminosity.

1.3 Clocks, rays and the optical interface

Write $g_{\mu\nu}$ for the spacetime metric, $G_{\mu\nu}$ for its Einstein tensor, $T_{\mu\nu}$ for the total source, and κ for the Einstein coupling. Gravity is refraction. General relativity is generalised Snell's law (I-3):

$$G_{\mu\nu} = \kappa T_{\mu\nu}, \qquad \kappa = 8\pi G/c^4.$$

The branch coordinate is downstream of this tensor equation. Let the dimensionless clock factor of the pattern be $\mathsf{C}_{\mathrm{clk}}$. It multiplies d and t by the same amount. Its local value leaves $d/t = c$. A pattern free of every force in $\mathsf{C}_{\mathrm{clk}}^2 g_{\mu\nu}$ is read by the bookkeeper, on $g_{\mu\nu}$, with the acceleration $\nabla_{\mathcal{U}}\mathcal{U}^\mu = -\mathfrak{P}^{\mu\nu}\partial_\nu \ln \mathsf{C}_{\mathrm{clk}}$, where $\mathcal{U}$ is the pattern's four-velocity in the time it keeps, $g_{\mu\nu}\mathcal{U}^\mu\mathcal{U}^\nu = -c^2$, and $\mathfrak{P}^{\mu\nu} = c^2 g^{\mu\nu} + \mathcal{U}^\mu\mathcal{U}^\nu$ projects across its path (§0.1c). The acceleration points toward slower clocks. Moving at constant speed on the pattern's own clocks and rulers through a density gradient is gravity. A slow pattern reads the lapse. A stroke reads the radial ruler adjustment as well: its leading weak-field deflection is twice the clock-only result. Neighbouring paths reveal the tide (I-3a). A body's quadrupole reads the tide across its extent. A uniform clock rescaling leaves null paths invariant.

The static spherical exterior has optical arclength ℓ_{opt} and unit-sphere angular element $\mathrm{d}\mathfrak{O}_{\mathrm{ang}}^2$ (the squared angular metric, distinct from the solid-angle measure). On A-1 the exact null travel-time geometry of I-3 is

$$\mathrm{d}\ell_{\mathrm{opt}}^2 = \frac{\mathrm{d}r_f^2}{(1-\alpha_{\mathrm{ext}})^2} + \frac{r_f^2 \mathrm{d}\mathfrak{O}_{\mathrm{ang}}^2}{1-\alpha_{\mathrm{ext}}}.$$

Fermat's principle makes the travel time stationary for geometrical optics in this time-independent exterior with fixed spatial endpoints and no dispersive delay. For a local scalar, isotropic, stationary optical interface, the indices $n_{\mathrm{inc}}, n_{\mathrm{trans}}$ and angles $i_{\mathrm{inc}}, i_{\mathrm{trans}}$ measured from the normal obey $n_{\mathrm{inc}} \sin i_{\mathrm{inc}} = n_{\mathrm{trans}} \sin i_{\mathrm{trans}}$, from continuity of tangential phase. In weak isotropic coordinates only, the unit ray tangent $\mathfrak{e}$ changes per unit geometric arclength ℓ_{geo} as $\mathrm{d}\mathfrak{e}/\mathrm{d}\ell_{\mathrm{geo}} = \nabla_\perp \ln n_{\mathrm{iso}}$, with $n_{\mathrm{iso}} = 1 + \alpha_{\mathrm{ext}} + O(\alpha_{\mathrm{ext}}^2)$. P-4's $n_{\mathrm{cone}} = (1-\alpha_\sigma)^{-1/2}$ assigns a causal aperture (O-8); $n_{\mathrm{dens}} = (1-\beta_\sigma)^{-1/2}$ is quarantined from optics. Neither is the optical index of an interface. The jet wall is a conical layer denser than the interstitial spacetime around it, and strokes bend toward the denser side (P-4). Take first a locally plane, stratified patch of the wall, with a stationary isotropic scalar optical index that depends only on normal distance and rises toward the layer on each flank. An oblique ray there curves toward the layer. A normally incident transmitted ray crosses without changing direction. For a general three-dimensional scalar profile the curvature is the index gradient projected

perpendicular to the ray. The measured profile, the entry conditions and the retention at the boundaries set how long the ray stays guided. An axisymmetric scalar profile carries both azimuthal senses, one for each of two mirrored launches. The ray spirals along the wall wherever the transverse gradient supplies its curvature. Its pitch, handedness and residence time follow from the three-dimensional profile and the boundary data, which enter no number here (O-4, O-8). A material index jump carries no junction stresses by itself, and no junction data are written here (O-13).

The exterior free-fall flow from rest at infinity has inward speed $v = c\sqrt{\alpha_{\text{ext}}}$ and radial proper-time acceleration $-G\mathcal{M}/r_f^2$. Only a pattern held against this flow has the translation share equal to its exterior compactness in the flow frame (§0.1d). No interior share is used (O-16). A rotating source adds swirl. At leading Lense–Thirring order a gyroscope reads half the curl of the three-velocity swirl on the spatial slice. The radial free-fall four-velocity is hypersurface-orthogonal. A medium's mechanical vorticity is a separate measurement. The flow reading holds on every scale.

Let e_{fluid} be the total local rest-frame energy density of a medium whose stress tensor has perfect form. At zero net conserved count, transverse stress conservation and $\mathrm{d}P = (e_{\text{fluid}} + P)\,\mathrm{d}T/T$ give the temperature as the flow's clock factor up to a reference scale. With a conserved count N and fixed entropy per count the clock factor is the enthalpy per count $(e_{\text{fluid}} + P)V/N$. A material clock carried in that flow still reads its local lapse and its own thermal motion. In a twist, take the positive rest energy E to depend on the event alone for identically prepared resting copies at settled internal moments. Their clock factor is $\mathsf{C}_{\text{clk}} = E/E_0$, where E_0 is their common untwisted rest energy. For held magnetic moments $\mathbf{m}$ in field $\mathbf{B}$ and induced energy E_{ind} including induction work, $E = E_0 + E_{\text{ind}} - \sum \mathbf{m}\cdot\mathbf{B}$. The slow force is minus the spatial gradient of this rest energy. Account for the gravitational tide when comparing the twist contribution. For nearby, equally oriented copies instantaneously at rest in local Cartesian coordinates, the slow acceleration $-c^2\nabla \ln(E/E_0)$ uses the local inertia E/c^2 and a common untwisted reference energy. For a small separation $\delta\boldsymbol{\ell}$, the first-order relative acceleration is $-c^2[\mathrm{Hess}\ln(E/E_0)]\,\delta\boldsymbol{\ell}$. A uniform twist turns a held moment and pushes nothing. At the same point, differences between moments per unit rest energy distinguish patterns. Universal gravitational free fall holds at monopole order (§0.1c).

1.4 Phase projections

Let $\mathbf{B}_h$ be the oriented unit bivector of the transverse plane. A mode's cylindrical phase ϕ_h at fixed position advances from ϕ_0 as $\phi_h = \phi_0 - \omega t$. Its image on the transverse plane has rotor $\exp(\mathbf{B}_h\phi_h)$, where the bivector has square -1. The exponent is dimensionless. The phase rotor uses the full phase angle. Rotating a spin frame uses a half-angle rotor. The carrier retains its field identity along the phase axis. I-4 reads superposition as ignorance of the phase at observation.

For two equal-weight patterns and their clamps, let ϕ be shared phase and $\mathfrak{a}, \mathfrak{b}$ the two analyzer angles on the phase circle (doubled physical angle for linear polarization). The clamp hosting the settlement imposes density $|\cos(\phi - \mathfrak{a})|/4$ in phase. For the opposite-sense pair of shared bivector grade, the local records are $\operatorname{sgn}\cos(\phi - \mathfrak{a})$ and $\operatorname{sgn}\cos(\phi + \pi - \mathfrak{b})$. Integration gives mean product $-\cos(\mathfrak{a} - \mathfrak{b})$ and marginal halves at every setting. Equal sense gives the positive cosine. Over all records of the equal-weight pair, the Clauser–Horne–Shimony–Holt (CHSH) ceiling is $2\sqrt{2}$. The kernel fixes the part even under a half-turn. A

flat remote marginal removes the odd part, so the lock, sign records, single-host density and both conditions uniquely fix that measure. On the sphere its square-integrable counterpart is the absolute scalar product of host and phase axes divided by 2π. The measure is written for the equal-weight pair. A general massive boson and a multibody final state lie outside it (O-17).

Each resolved history turns the local analyzer frames by proper rotations $\mathsf{R}_A, \mathsf{R}_B$. Their relative rotation $\mathsf{R} = \mathsf{R}_A \mathsf{R}_B^{\mathsf{T}}$ fixes the product mean $-\mathbf{a}^{\mathsf{T}} \mathsf{R} \mathbf{b}$ for unit axes $\mathbf{a}, \mathbf{b}$. Pooling unrecovered histories replaces this rotation by its mean M. With ordered signed singular values s_1, s_2, s_3 (the last carries the determinant sign), the four frequencies are the combinations $(1 \pm s_1 \pm s_2 \pm s_3)/4$ with an even number of minus signs. Their squared sum is the purity. Negativity is the positive part of the largest frequency minus one half. Over all records pooled with the same history weights at every setting, the maximum CHSH value is $2\sqrt{s_1^2 + s_2^2}$ and agreement with the emitted pair is $(1 + \operatorname{Tr} \mathsf{M})/4$. For relative turns about one axis the mean phase factor gives their coherence. A common turn preserves every emitted cell. Undoing both resolved turns before pooling recovers those cells. The calculation takes the turns as given. The core writes no distribution of the relative rotation, and neither the burst spectra nor the vector-boson coefficients measure one.

1.5 Notation guard

The table gives the conventions for the three records. The names at left are the authors' source usages. Script letters distinguish source observables from the core quantities. Angular-coefficient subscripts give the channel and rest frame. Their argument specifies the production kinematics. Each average carries its fiducial bin.

Source usage	Name in this analysis
PL, Band, broken PL and cutoff indices	$\mathfrak{p}_{\mathrm{PL}}, \mathfrak{p}_{\mathrm{lo}}, \mathfrak{p}_{\mathrm{hi}}, \mathfrak{p}_1, \mathfrak{p}_2, \mathfrak{p}_{\mathrm{cpl}}$. E1's photon index is $\mathfrak{g}$, its coefficient $\mathfrak{z}(\mathfrak{g})$.
Bulk speed, Lorentz factor, line width	$\mathfrak{v}/c, \Gamma, w_{\mathrm{line}}$. A lepton's centre-of-mass speed is $\mathfrak{v}_{\pm}$. An eigenmode width retains its subscript Γ_i. Significance is in s.d.
Systematic and statistical errors	$\mathfrak{u}$ with subscripts model, rsp, DCP, BG, tot, FWHM, dir, sys and stat for mass model, response, corrections, background, total, broadening, direction, systematic and statistical terms, respectively.
Thomson and pair cross sections	$\mathfrak{x}_{\mathrm{T}}, \mathfrak{x}_{\mathrm{pp}}, \mathfrak{x}_{\mathrm{ann}}$. Photon labels remain on $\mathfrak{o}_{\gamma\gamma}$ (opacity), $\mathcal{E}_{\mathrm{var}}$ is the variability energy and E_{thin} the unit-opacity energy.
Shell latitude, core angle and its cosine	$\vartheta, \vartheta_p, \cos\vartheta$. Detector incidence angles and detector axes are named in words. A ray's initial angle to the emitter velocity is ι.
Solid angle, emitted energy	$\mathrm{d}\mathfrak{O}$, normalized angular distribution $f_{\mathfrak{O}}$, emitted line energy $\mathfrak{E}$, surface emissivity $\mathfrak{j}(\vartheta)$ and its index $\mathfrak{d}$.
Simulation arrivals and counting	Photon index j, uniform draw $\mathfrak{r}_j$, trial rate $\mathcal{R}_{\mathrm{in}}$, dead time t_{dead}. Interarrival density, count rate, smoothness parameters, orbit count and mean background rate are named in words.

Spectral energy and time	The pivot energy is E_{piv} and the spectral normalization is $\mathcal{N}$. With k_{B} denoting Boltzmann's constant (U-03), the apparent and initial temperatures in energy units are $k_{\mathrm{B}}T_{\mathrm{ph}}$ and $k_{\mathrm{B}}T_0$. The observer reference time is t_{ref} and the temporal index is $\mathfrak{k}$.
Flux, luminosity and distance	$\mathcal{F}_{\mathrm{line}}, \mathcal{F}_{\mathrm{bump}}, \mathcal{F}_{\mathrm{BB}}$; $L_{\mathrm{iso}}, L_{\mathrm{w}}, L_{\mathrm{ph}}, L_{39}$; luminosity distance $\mathcal{D}_{\mathrm{L}}$. L_{w} is the wind power at the base and L_{far} the same power at a distant calorimeter. The BB normalization uses the source distance in units of ten kiloparsecs (SC-059, L307–308). The belt parameter is $\mathfrak{L}$.
Radii, mass, redshifts	$R_s, r_0, r_{\mathrm{ph}}, r_{\mathrm{em}}$: Schwarzschild, base, photosphere and line formation. Wind loading $\dot{M}_{\mathrm{w}}$, engine $\mathcal{M}$, electrons per baryon Y, cosmological z, base gravitational z_g. The two moduli of the support carry their subscripts, z_1, z_2.
Geometry and distances	r_{ref} is a reference areal radius and h_{rad} counts radial doublings. $\mathcal{D}_{\mathrm{GW}}$ is a siren distance, $\mathcal{D}_z$ a redshift reference. $k_{\mathrm{B}}T_{R_s}$ is a temperature scale at the Schwarzschild length.

2 System chart: where is the emission?

Location	Clock, radius or observation
Engine and seam	The matter accreting onto the hole converts to spacetime and energy (§0.8). The hole loses no mass and grows only by merging. That phase flow is passage across the seam (§0.3a), which stands at twice the Schwarzschild length on the static exterior A-1 chart. Every photon used here starts outside the horizon.
Emitting base	Ding compares its inferred radius, about 10^7 cm, with the last stable circular orbit of a Schwarzschild hole of ten solar masses (SC-200, SC-202, L999–1000). For that mass the orbit lies at three Schwarzschild lengths, 8.9×10^6 cm, and the seam at 5.9×10^6 cm (U-26). This analysis places the base on the seam.
Photosphere	Last scattering in the fireball. Ding's schematic places it at approximately 10^{10} cm (SC-108, L531). Its fitted BB temperature refers to radiation received at Earth.
Line-emitting shell	Distant dissipation, pair cooling and photon formation in Ding's shell reading. The fitted scale is proportional to the bulk Lorentz factor (SC-204, L1002).
Observer	Earth receives escaping radiation along exterior null rays. A single source has one observation distance during its light curve.
Collider	Two beam-proton rooms, incoming partons, recoiling parton, boson decay and accompanying radiation. The beam room is distinct from an outgoing colored partonic jet (I-5b, SC-307, L2005).

The sequence begins outside the horizon, on an escaping path to the detector. The thermal wind becomes transparent at its photosphere and the line forms farther out, at the shell radius of Ding's fit. Each local density cone is a light cone. In a flat inertial chart the radius of a freely propagating flash front equals c times the coordinate time since its emission at the origin. The radial displacement alone has length $c\,dt$. Changing direction on that front adds a perpendicular displacement and makes the tangent spacelike. A null signal on a smooth front follows a generator. Under gravitational refraction the generator itself bends

in spatial projection, and the photon carries its local helix along this ray. A wall of emitting matter is a different object from a light front: it guides radiation through its optical profile. In this reading the compression is long and the release short. The two are compared as proper intervals along one timelike reference worldline where both stages lie on it, and for separated event histories in one declared frame, with both coordinate intervals reconstructed there. For a partonic collision this requires a defined event frame and preparation and release markers. Four-momentum in the recoil still enters the event budget. The spectra, detector bins, angular moments and virtual amplitudes time neither stage, and no horizon crossing enters them.

3 Observation map

For each comparison below, a finite falsifier uses a held-out reading with independent calibration. Keep the preparation, instrument geometry, population and nuisance distribution fixed as specified. For a held-out reading and its prediction under a named hypothesis, propagate measurement and calibrated prediction uncertainties and their shared covariance. For one predeclared Gaussian residual the rule is an absolute discrepancy of at least three residual standard errors (U-15). For a searched family, calibrate the maximum statistic on the full selection procedure. A discrepancy tests the named response or model on those data.

Detector counts to photon energies. Ding uses the High-Energy Particle Package (HEPP) on the China Seismo-Electromagnetic Satellite (CSES-01). The high-energy unit triggers on secondary electrons generated in surrounding material. The low-energy unit contributes timing. The Gravitational-wave High-energy Electromagnetic Counterpart All-sky Monitor-C (GECAM-C) supplies an unsaturated reference (SC-023, SC-029–030, SC-114). The Fermi gamma-ray burst (GRB) Monitor (GBM) and Large Area Telescope (LAT) extend the comparison. HEPP-H electron calibration reaches 40 MeV. Its coverage for secondary electrons extends to 255 MeV mainly through extrapolation and simulations (SC-233–235, L1064–1067; SA-06, SA-74). The 40 MeV limit belongs to the electron calibration. The photon response at the reconstructed centroid, which lies at that energy, comes from the simulated response matrix.

Using the Monte Carlo (MC) acquisition-correction framework cited to Z.-Q. Ding et al. (2026) in the right column at L193–194, Ding scans trial incident photon rates through detector and trigger simulation. Ding selects the trial for which the MC-corrected science-event rate agrees with the independently recorded telemetry rate. The selected simulation sets the response matrix for that interval (SC-045, L235–245; SA-12). The simulation uses a simplified satellite platform (SC-138, SC-156, L718, L827; SA-41, SA-51). The approximate secondary share of 80 percent refers to energy deposition leading to a trigger (SC-126, L659). Six clean revisiting orbits enter the background, tested by leaving out each in turn (SC-128, L670). The HEPP-H/GECAM-C fit gives 1.05 ± 0.07 (SC-158, L839). Ding takes a 7 percent model estimate and adopts 8 percent for the response (SC-159, SC-162, L841, L866; SA-50). Ding assesses the uncertainty in the calibrated energy broadening as a subdominant contribution to the response-error budget and the uncertainty from using one incident direction as negligible relative to the other systematics. The response budget gives neither uncertainty a separate numerical allocation (Appendix D.1, L852–859). Ding adopts a conservative 5 percent upper bound for the correction pipeline after examining maximum residuals that generally fall

within five statistical standard deviations. Ding reports a conservative 3 percent upper limit for the background systematic and gives no spread on that limit (SC-154, SC-160, L819, L854; SA-49, SA-52). Ding reports 9.9 percent for the independent-component quadrature and adopts 10 percent for HEPP-H fluxes and spectral parameters (SC-161, SC-163, L865, L868). For a held-out exposure compare a predeclared contrast of observed channel counts with the same contrast of predicted counts. Fold the incident source model through exposure, selection and detector response, then add the selected background in counts. Calibrate the discrepancy under the tested spectrum, propagating counting noise, uncertainty in the calibrated prediction and their shared covariance. Matching the incident spectrum and emission history, exposure, selection, response and backgrounds gives both descriptions the same mean count per bin. This matched comparison corroborates no invariant (Use item 2).

Broad excess at the main peak. The observer clock uses the Insight/HXMT reference 13:17:00.050 UT on 2022 October 9 (SC-010, L71). All following burst intervals are observer seconds after this reference unless stated otherwise. At 225–235 s Ding uses GECAM-C and HEPP-H and excludes saturated GBM data (SC-044, SC-046, L236, L253; SA-13). The Band continuum leaves structured residuals. Ding places the excess over the Band continuum near 2 MeV. A cutoff power law (CPL) or a blackbody (BB) can describe the excess (SC-055, SC-057, L282, L301; SA-15). The table gives the temperatures of the BB fit. In the 228–230 s slice, the isolated BB peaks at 7.1 ± 0.2 MeV in energy flux per logarithmic interval of photon energy, propagating the fitted temperature error. The isolated CPL has a central peak of 5.8 MeV in the same representation. Its propagated peak uncertainty also requires the covariance between its fitted index and cutoff energy, which the table does not report (SC-064, SC-259–260, L363, L1479–1480). The table combines Ding's Table 1 and Table F4. Temperature is in keV. The last three numeric columns give the Akaike information criterion (AIC), with lower values preferred. The double smoothly broken power law (2SBPL) is a single continuum with two fixed smoothness parameters (SC-145, L764; SA-45).

Window (s)	$k_{\mathrm{B}}T_{\mathrm{ph}}$	Band+CPL	Band+BB	2SBPL	Source rows
225–228	2801 ± 59	469	525	456	SC-063, SC-274
228–230	1803 ± 51	262	277	293	SC-064, SC-275
230–231	2105 ± 71	390	417	382	SC-065, SC-276
231–232	2269 ± 89	247	247	252	SC-066, SC-277
232–233	2123 ± 112	282	301	306	SC-067, SC-278
233–235	1019 ± 62	220	223	230	SC-068, SC-279

The single continuum has the lowest AIC in the first and third windows. Band+CPL has a lower AIC than Band+BB in five windows and ties it in the fourth (SC-273–279). Ding considers the bump as photospheric emission and notes the comparable CPL fit, whose index is softer than Planck's low-energy index. Across the six Band+CPL fits, $\mathfrak{p}_{\mathrm{cpl}}$ ranges from -0.93 to -0.12, with quoted fit uncertainties from 0.17 to 0.99 (SC-256, SC-259, SC-262, SC-265, SC-268, SC-271, Table F3). The limited BB contrast, high latitudes and angular structure enter their discussion (SC-090, SC-099, SC-105–106, L454, L481, L512, L520; SA-26, SA-29, SA-34). All six temperatures require the BB assignment. For the representative BB fit Ding gives about 2 MeV and a bump flux of about 2×10^{-3} erg cm^{-2} s^{-1} (SC-183, L958). Its luminosity of about 10^{53} erg s^{-1} requires a distance (SC-184, L959; SA-60). At fixed observed bump flux, $L_{\mathrm{ph}} = 4\pi \mathcal{D}_{\mathrm{L}}^{2} \mathcal{F}_{\mathrm{bump}}$. With base radius, gravitational redshift and fitted

temperature fixed, Ding's coasting relations E6 and E7 give $L_{\rm w} \propto L_{\rm ph}^{4/3}$ and a dimensionless wind entropy proportional to $L_{\rm ph}^{5/24}$ (SC-185–187). In the acceleration branch, inferring a base radius from the temperature also requires a wind luminosity (SC-165, SC-173–174, SC-178). The fitted $k_{\rm B}T_{\rm ph}$ comes from the spectral shape (SC-183). From the time-integrated fitted BB component Ding estimates a source-frame isotropic-equivalent thermal energy of 9×10^{53} erg, about 6 percent of the whole-burst isotropic-equivalent energy of about 1.5×10^{55} erg (SC-013, SC-205, L84, L1002–1004). Integrating energy flux over observer time gives an energy fluence. For a specified source-frame band, integrate in its redshifted observer band. For a bolometric energy, use the bolometric fluence. The source-frame isotropic-equivalent energy is that fluence multiplied by $4\pi\mathcal{D}_{\rm L}^2/(1+z)$. Ding infers that the emitted thermal energy is comparable to the total fireball energy if the fireball becomes transparent before saturation (SA-67, SC-205, L1005–1009). The magnetic remainder Ding proposes draws on that same energy budget (SA-33, SA-66). A held-out photosphere with independently constrained launch data tests the temperature relation below. This cluster is a reading under §0.1c and corroborates no invariant (Use item 2). The temperatures have the fit precision tabulated above. T-2 tests the seam base at its combined precision.

A narrow component in the decay. Ding's earlier comparison track starts near 37 MeV and adopts an origin $t_0 = t_{\rm ref} + 226^{+8}_{-10}$ s from the temporal fit of Y.-Q. Zhang et al. (SC-017–019, SC-215, L98–101, L1031; SA-04, SA-24). Ding extends the track earlier by about five seconds and leaves both origin and exponent fixed (SC-089, SC-092). The 237–246 s feature is at 2.6 s.d. (SC-072, L388). In windows from 237–246 through 240–249 s the relative width is fixed to 0.1. Free fits start at 241–250 s (SC-295, L1874; SA-46). The 9 s windows advance by 1 s and share 8 s of events (SC-292, L1868). The chosen 242–251 s window has higher significance than its preceding neighbour (SC-141, L728). The three line windows use GBM inside its bad-time interval, with the checked 4–35 MeV selection. Their GBM/GECAM-C factors are 1.14 ± 0.07, 1.13 ± 0.05 and 1.12 ± 0.05 in temporal order (SC-129–133, L688, L696, L700–701; SA-42). Each central fit lies above unity, by approximately 2, 3 and 2 of its quoted standard errors, respectively. The last differs from the earlier central estimate 1.05 ± 0.08 by 0.07. Their covariance is unavailable (SC-134–135, L705).

In 242–251 s the centroid is $39.4^{+7.4}_{-3.6}$ MeV and the free Gaussian width is 3.1 ± 2.3 MeV (SC-081, SC-083, L412, L418; SA-22). The flux is $1.11^{+1.59}_{-0.45} \times 10^{-5}$ erg cm^{-2} s^{-1} (SC-084, L420). The central width fraction is about 0.08 (SC-083). In 246–256 s the fitted centroid and width in keV are 37600 ± 4163 and 6423 ± 2620 without HEPP-H (SC-073, SC-283–284, L1792–1793). Including HEPP-H gives 37880 ± 3042 and 6970 ± 2088 (SC-285–286, L1795–1796). The central ratios are about 0.17 and 0.18 (SC-284, SC-286; SA-79). The two fits for the later window share all events in their common instruments. Its flux-scale comparison with the earlier window also shares events over five observer seconds and common calibrations (SC-084, SC-287–289). A ratio uncertainty requires the width–centroid covariance. Ding also gives a lower line-flux limit for the latter window and a distinct high-energy upturn above 200 MeV with LAT (SC-078–079, L408–409). In 256–273 s only upper limits are available. They use the extrapolated centroid, width fixed at ten percent of it and fitted flux plus three statistical errors (SC-082, SC-086, SC-088, L417, L425, L435; SA-23).

In 242–251 s the Band-to-Band-plus-Gaussian improvement in C-statistic is 44.06. Ding reports about 4.0 s.d. from about 200000 simulations for that window (SC-070–071, L383, L385; SA-18). In 246–256 s it is 190.22, reported above 4.5 s.d., with the simulation count

unspecified (SC-073–074, L388–389). The distinct 237–256 s global analysis uses 2.3×10^5 simulations, an improvement of 91.30 and a reported significance above 4.4 s.d. (SC-147–151, L770–775). Let N_{MC} be the independent trial count and p_{tail} the unknown null tail probability. Ding computes an empirical tail probability where the observed statistic falls within the simulated range and adopts $p_{\mathrm{tail}} < 1/N_{\mathrm{MC}}$ beyond it (SC-240–241, L1359–1360). For zero exceedances the probability of that outcome is $(1 - p_{\mathrm{tail}})^{N_{\mathrm{MC}}}$. Setting it to 0.05 gives the one-sided 95 percent upper bound $1 - 0.05^{1/N_{\mathrm{MC}}}$ (U-14). For the global ensemble this bound is 1.3×10^{-5}, three times the adopted 4.3×10^{-6} (SC-151): on the one-sided convention that turns 4.3×10^{-6} into 4.4 s.d., the global significance at 95 percent confidence is 4.2 s.d. The first ensemble is a different case. Its reported 4.0 s.d. is a tail probability of 3.2×10^{-5} on that convention, about six exceedances in 200000 trials. That is an empirical value inside the simulated range, above the 1.5×10^{-5} that zero exceedances would bound at that count, and it carries the counting error of six events (SC-071, SC-240). A bounded line amplitude, searched centroid and width, and trial windows require calibration of the same search. The plotted three-degree-of-freedom reference curve is not that calibration (SC-239, L1358). Use independent calibration or training data to specify the continuum and line spectrum, including line strength, profile and temporal evolution, and freeze its fitted parameters. On disjoint held-out counts test the folded source-plus-background prediction with a prespecified discrepancy calibrated under that model, carrying training and response uncertainty. For a separate discovery search calibrate the maximum improvement over the searched lines and windows under the continuum-only model. Ding reports these improvements from fits to the selected spectra. They corroborate no invariant (Use item 2).

Arrival times and angular brightness. The signed power of elapsed time in Fig. 3 is -1.05 for energy and -2.16 for late flux (SC-075–076, L400, L402; SA-20). Appendix E.2 writes the energy power as minus its fitted index and also prints a negative index. Its index errors are $+0.22, -0.17$, while the signed-power label in Fig. F16(a) shows $+0.17, -0.22$ (SC-213, SC-290, L1029, L1823; SA-68). The decreasing energy and the signed figure establish the direction. The flux decay label has errors $+0.09, -0.12$ (SC-291, L1852). Ding fits a power law (PL) to overlapping line-flux windows in 237–256 s (SC-142, L729–731). The index is 1.86 ± 0.38. For the central adopted reference epoch, the estimated peak near $t_0 + 20\,\mathrm{s}$ lies inside the fitted span. The reference epoch is uncertain (SC-018, SC-212; SA-44). Averaging a simulated rising law of index 1.86 gives 1.83 (SC-142–144, SC-298, L731, L743, L761, L1937; SA-44). This checks the chosen smoothing procedure on its own input. Inference about a rise uses the event likelihood or a joint window covariance. Fitting those windows as independent exaggerates the information.

In 242–251 s one flux lies below the backward extrapolation of the later decay (SC-093, L464; SA-25). For abrupt emission from a freely coasting radial shell viewed on axis, Ding assumes isotropic radiation in the comoving frame and infers weak near-axis *surface line emissivity* and increasing emissivity with latitude (SC-100, SC-223–224, L481, L1045; SA-30, SA-71). An extended production history also moves power between arrival bins. Ding says these findings hint at a magnetically dominated, central-empty jet (SC-007, L54; SA-01), and describes the jet as likely accompanied by a subdominant hot fireball (SC-113, L551; SA-36). With unknown comoving angular radiation, E11 constrains the product of surface line emissivity and the transformed directional distribution at fixed geometry (SC-206, SC-208–209). The mass column and magnetic-field map need independent data. A separate

test of surface line emissivity needs independent constraints on the emission history, shell geometry and comoving directional radiation law. Otherwise fit their combined model to training data. Freeze the fit and geometry, fold its predicted emission through the calibrated response and add the predicted background for disjoint held-out arrival intervals. Predeclare either an early-minus-late count contrast or a joint count test. For the contrast, standardize its observed-minus-predicted residual using the full variance of that difference, including early–late and measurement–prediction covariance. Use the three-standard-error rule for a Gaussian residual and calibrate its absolute value for sparse counts. For the joint test, use the count residual vector in predeclared contrasts with nonsingular predictive covariance and take its quadratic form with the inverse of that covariance. For each calibrated statistic, predeclare the false-rejection probability and reject above its upper null quantile. Calibrate by jointly simulating training, background, response and held-out counting under the tested model, preserving shared errors and repeating the training fit. The separate energy–delay test probes shell kinematics. Its absolute normalization and shape use different inputs. This observation cluster is a reading under P-5 and corroborates no invariant (Use item 2).

4 Cone-position translation: what changes between two radii?

4.1 A shell that propagates freely

Define E_{line} as the detected line energy, E_{pair} as the comoving photon energy after cooling, and $\mathfrak{v}/c$ as the speed fraction in the local engine frame. Write $\mathsf{Z}_{\mathrm{path}}$ for the emitter-to-engine-receiver endpoint frequency ratio, and $\mathsf{Z}_{\mathrm{met}}$ for the residual ratio after the local Doppler factor is taken out. Ding's Doppler and redshift denominator (SC-197) gives the following reconstruction with the residual path factor included.

$$E_{\mathrm{pair}} = \frac{(1+z)E_{\mathrm{line}}}{\mathsf{Z}_{\mathrm{path}}}, \qquad \mathsf{Z}_{\mathrm{path}} = \frac{\mathsf{Z}_{\mathrm{met}}}{\Gamma(1-(\mathfrak{v}/c)\cos\iota)}.$$

The angle ι is at emission between the initial null ray and the pattern's local translation. This explicit Doppler factor requires locally null emission. A guide encountered later can redirect that ray. For near-rest two-photon annihilation use $E_{\mathrm{pair}} = 0.511$ MeV (U-07, SC-196). At $z = 0.151$ (SC-012, L76), the measured centroid gives a combined shift of about 89, from 81 to 105 using the centroid uncertainty alone (SC-080–081, L410–412). At unit residual shift this is a Doppler factor (U-12), and it bounds the bulk Lorentz factor from below: $\Gamma \geq (\mathsf{Z}_{\mathrm{path}}^2+1)/(2\mathsf{Z}_{\mathrm{path}})$, about 44 and from 40 to 53 over the same uncertainty, with equality for emission along the line of sight. Above the bound the shift fixes the product $\Gamma(1-(\mathfrak{v}/c)\cos\iota)$, and Γ and ι enter through it alone. Model the width by integrating intrinsic thermal line profiles over the local ray angles and emission times, then convolving with the energy-dependent response. This centroid and width do not bound the speed of each lepton. The drift alone broadens a windowed line: with $E_{\mathrm{line}} \propto \Delta t_{\mathrm{obs}}^{-1}$ and the central origin the fractional rms spread of the line energy across 242–251 s is 0.13, and 0.12 across 246–256 s, nearly independent of the flux weighting and from 0.08 to 0.22 over the origin's quoted uncertainty. The fitted width fractions are of that size, so the windowed width reads the drift and leaves the intrinsic width unresolved. Ding's comoving production energy and its magnetic cooling interpretation enter before transport.

For a radial shell coasting freely to r_{em} and an observer on its axis, $\iota = \vartheta$. In the engine frame the emission is delayed by $r_{\mathrm{em}}/\mathfrak{v}$; the near-side path saves $r_{\mathrm{em}}\cos\vartheta/c$ in arrival time.

With the centre-at-release photon defining t_0, the observer time $t_{\rm obs}$ and the delay $\Delta t_{\rm obs} = t_{\rm obs} - t_0$ obey Ding's E9 and E10 written at finite speed, whose printed forms are the limit $\mathfrak{v} \to c$ (SC-191–192, SC-197, SC-199, L980, L983, L990, L995):

$$\Delta t_{\rm obs} = (1+z)\frac{r_{\rm em}}{\mathfrak{v}}(1-(\mathfrak{v}/c)\cos\vartheta), \qquad E_{\rm line}\Delta t_{\rm obs} = \frac{E_{\rm pair} r_{\rm em}}{\Gamma \mathfrak{v}}.$$

For a finite bulk speed the on-axis shell photon arrives after the central reference photon. Using the illustrative midpoint 246.5 s (U-25, SC-203), the central origin and the fitted centroid gives approximately $2 \times 10^{16}(\Gamma/500)$ cm at ultrarelativistic speed (SC-203). Ding cites Z. Zhang et al. for the radius fit, which gives $2.45 \times 10^{16}(\Gamma/500)$ cm (SC-204, L1002; SA-65). Ding's E.2 writes 236–246 s where the spectral analysis uses 237–246 s (SC-201, L999). The fitted normalization reuses the energy drift. An absolute test needs independent $E_{\rm pair}$, $r_{\rm em}/(\Gamma\mathfrak{v})$ and reference epoch. For two narrow intervals from one impulsive shell with the same comoving production energy, test equality of the early and late products $E_{\rm early}(t_{\rm early} - t_0)$ and $E_{\rm late}(t_{\rm late} - t_0)$. Use an external origin or estimate origin and normalization from training windows, propagate their shared uncertainty, and compare response-folded time-integrated counts in disjoint held-out events. A guided path predicts that residual from its own path and emission history.

For impulsive emission Ding's E11 gives flux proportional to $\mathfrak{j}(\vartheta) f_{\mathfrak{O}}(\vartheta)$ for fixed radius and distance (SC-206, SC-208–209). The latter is the normalized directional radiation distribution $\mathrm{d}\mathfrak{E}/(\mathfrak{E}\,\mathrm{d}\mathfrak{O})$. A surface patch with emitting fraction $f_{\rm fill}$ and local emissivity $\mathfrak{j}_{\rm loc}$ has $\mathfrak{j} = f_{\rm fill}\mathfrak{j}_{\rm loc}$ after area averaging. Flux does not separately fix either factor. Even for constant comoving angular distribution relativistic beaming weights the solid angle. Uniform surface emissivity then gives the inverse-cube temporal law (SC-211, L1024). With the same isotropic comoving law, if surface emissivity grows as $\vartheta^{\mathfrak{d}}$ outside the core, $\Delta t_{\rm obs} \propto \vartheta^2$ at small angles large compared with $1/\Gamma$. The flux exponent is $-3 + \mathfrak{d}/2$ (SC-225–226, L1051–1052). Ding's late exponent -2.13 in Appendix E.2 gives $\mathfrak{d} = 1.74$, quoted there as $\mathfrak{d} \simeq 1.7$ (SC-227, L1053). That appendix quotes no uncertainty for this exponent. Figure F16(d) gives the late-time exponent $-2.16^{+0.09}_{-0.12}$, which under the same shell and isotropy assumptions yields $\mathfrak{d} = 1.68^{+0.18}_{-0.24}$ (SC-226, SC-291, L1852–1853). At a delay near 20 s the fiducial radius 10^{16} cm gives about 0.01 rad or five inverse Lorentz factors for $\Gamma = 500$ (SC-212, SC-223). Inserting the fitted radius gives instead about $3(\Gamma/500)^{1/2}$ for $\Gamma\vartheta_p$ (SC-219). Both angles assume an impulsive on-axis radial shell. At fixed peak arrival time t_p, redshift and independently fixed radius, the angular-delay limit gives $\delta\vartheta_p/\vartheta_p \simeq -\delta t_0/[2(t_p - t_0)]$. At a nominal twenty-second delay an origin uncertainty of order ten seconds gives a fractional angular uncertainty of about a quarter to first order (SC-018, SC-215, SC-220–221). At finite speed E9 includes the on-axis delay (SC-191–192). An interval using the same track's fitted radius and origin needs their joint covariance, including the peak-time uncertainty when the peak is fitted. The angular fit reuses the observed light curve. An axisymmetric toroidal field can vanish on axis while an axial field and cooling persist there.

4.2 Outward dilution, inward concentration and phase-radius tracking

Take a transparent radial bundle of fixed solid angle $\Delta\mathfrak{O}$. Write $r_{h_{\rm rad}}$ and $\mathcal{A}_{h_{\rm rad}}$ for areal radius and bundle area at radial index $h_{\rm rad}$. Outward doubling (U-11) gives

$$r_{h_{\rm rad}} = 2^{h_{\rm rad}} r_{\rm ref}, \qquad \mathcal{A}_{h_{\rm rad}} = \Delta\mathfrak{O}\, r_{h_{\rm rad}}^2.$$

With no exchange through the bundle sides or loss along the path, number fluence is packet count divided by area. It falls by four at each radial doubling and grows by four at each inward halving. Energy fluence does the same when energy per solid angle is conserved in the same frame. This is the inverse-square geometry of ordinary propagation, read outward as dilution and inward as concentration. The index labels radii in a smooth expansion as well as in a sequence of jumps, and it is no clock. Dilution of one packet along its path differs from successive packets arriving at a fixed distance. Let r_{wall} be the areal radius of the crossing sphere. At polar angle ϑ a narrow band of proper meridional width b_{wall} and azimuthal span $\Delta\varphi_{\mathrm{wall}}$ has proper surface area approximately $b_{\mathrm{wall}} r_{\mathrm{wall}} \sin\vartheta\, \Delta\varphi_{\mathrm{wall}}$. At fixed central latitude, proper meridional width and azimuthal span, doubling r_{wall} halves the crossing count per unit sphere area for the same transmitted count. For radial incidence this is also the ray-normal number fluence. For locally parallel rays meeting the outward normal at incidence angle i_{wall}, project the patch by $|\cos i_{\mathrm{wall}}|$ to obtain its area normal to propagation. For two such bands the second-to-first ray-normal fluence ratio also contains the initial-to-final ratio of the absolute incidence cosines. When the central latitudes differ, use the full band area, including the corresponding sines. For a resolved guided image use its neighbouring-ray map at the receiver. A freely radial bundle keeps its angular width and quarters its number fluence. A fixed-width aperture cut from it admits a different count.

Follow the same packet between two independently sized propagation radii after formation. Specify its production spectrum and the local observers at both endpoints. Let $\mathcal{R}_{\mathrm{prop}}$ be the final-to-initial propagation-radius ratio and $E_{\mathrm{beg}}, E_{\mathrm{end}}$ the corresponding locally measured photon energies. Phase-radius tracking is the response in which the packet's local phase radius grows in proportion to the propagation radius: the ratio of its phase radii equals $\mathcal{R}_{\mathrm{prop}}$, and I-2 gives $E_{\mathrm{end}}/E_{\mathrm{beg}} = 1/\mathcal{R}_{\mathrm{prop}}$ (U-23). For the matched-frame case take unit elastic frequency transfer. At a radial doubling with conserved count and fixed solid angle, number fluence is one quarter and radiation energy fluence one eighth of the initial values. The change beyond elastic transport is a four-momentum exchange with the phase stresses, and the exchange sources sum to zero (I-6). Let $E_{\mathrm{end,el}}$ be the calibrated final energy under elastic propagation of that same initial mode, and $\mathsf{Z}_{\mathrm{el}} = E_{\mathrm{end,el}}/E_{\mathrm{beg}}$ its transfer in these endpoint frames. Under tracking the ratio to the elastic prediction is $E_{\mathrm{end}}/E_{\mathrm{end,el}} = 1/(\mathcal{R}_{\mathrm{prop}}\mathsf{Z}_{\mathrm{el}})$. Under elastic transport itself this residual ratio is unity. Apply any subsequent transfer from the final endpoint to the detector once, using independent geometry, velocities and clocks. A full shift estimated from the same line absorbs the tracking change. For separate cohorts establish matched production spectra and independently specified path intervals. Different arrival windows need not follow the same photons. In frames comoving with the outflow, tracking gives a packet released at radius r the comoving energy $E_{\mathrm{beg}} r_{\mathrm{beg}}/r$, with r_{beg} its initial propagation radius, and the delay of the free-shell display at that radius. Then $E_{\mathrm{line}}\Delta t_{\mathrm{obs}} = E_{\mathrm{beg}} r_{\mathrm{beg}}/(\Gamma\mathfrak{v})$ at every release radius and latitude: the free shell's law, with the packet's conserved product of energy and radius in place of $E_{\mathrm{pair}} r_{\mathrm{em}}$. The fitted drift index is common to the two readings and selects neither. They part at one arrival time, where a free shell radiating over a fractional depth spreads its line by that fraction and tracking holds the product fixed through the depth. Where no phase stress exchanges four-momentum the sources vanish and transport is elastic, so the response belongs to the release region. The spectroscopy of lines from sources at known distances holds free propagation to elastic transport. The three papers carry no paired sizes and calibrations, and the exploratory section sets out the test.

4.3 Following one guided ray and its neighbours

For a photon with wave covector k_μ, let $\mathcal{U}_\mathrm{e}$ and $\mathcal{U}_\mathrm{o}$ denote the emitter and remote engine-frame receiver four-velocities. Normalize frequency by the invariant contraction:

$$\mathsf{Z}_\mathrm{path} = \frac{(-k_\mu \mathcal{U}_\mathrm{o}^\mu)_\mathrm{o}}{(-k_\mu \mathcal{U}_\mathrm{e}^\mu)_\mathrm{e}}.$$

Follow the emitted mode along its connecting ray to the receiver. In gravitational geometric optics, where the background changes little across a wavelength, the photon retains its helical form about the local propagation axis as that axis turns. In a material guide first select its propagating mode. Compute the frequency and packet arrival on the same connecting solution. In a stationary achromatic medium the optical length divided by c gives coordinate travel time. In a dispersive guide use the group trajectory for propagation time. In one engine time coordinate let t_e denote the emission epoch and t_group its group travel time. Use $t_\mathrm{e,ref}$ and $t_\mathrm{group,ref}$ for the corresponding reference quantities. For the guided ray and reference ray, the observed arrival difference is $(1+z)[(t_\mathrm{e}+t_\mathrm{group})-(t_\mathrm{e,ref}+t_\mathrm{group,ref})]$; the reference quantities are for its own emission and trajectory. At emission in an isotropic material use its dispersion relation. In the local material rest frame let ω_m and $\mathbf{k}_\mathrm{m}$ be the angular frequency and wavevector, and let $\mathbf{v}_\mathrm{e|m}$ and $\Gamma_\mathrm{e|m}$ be the emitter velocity and Lorentz factor relative to that material. The emitter measures angular frequency $\omega_\mathrm{e} = \Gamma_\mathrm{e|m}(\omega_\mathrm{m} - \mathbf{k}_\mathrm{m}\cdot\mathbf{v}_\mathrm{e|m})$. A stationary guide conserves coordinate frequency. Static observers at unequal gravitational lapses can read different local frequencies. An elastic bend between matched static endpoint clocks supplies no further shift. For locally null emission the emitter Doppler factor can be separated from the full contraction. Applying both would duplicate it. E9's latitude substitution and the constant energy–delay product belong to the free-shell comparator.

Let $\mathcal{J}$ be the two-dimensional transverse deviation map from initial ray angles to proper transverse separations at the receiver. Away from a caustic the screen area of one narrow image is $\mathcal{A}_\mathrm{ray} = |\det \mathcal{J}|\,\Delta\mathfrak{O}$, with $\Delta\mathfrak{O}$ the launch solid angle. The magnitude removes the orientation sign (I-3a). For the static nondispersive comparator compute the deviation map from the second variation of its Fermat optical length with the stated boundary data. For a material mode, follow neighbouring solutions of its calibrated dispersion relation from the same event at the same frequency with slightly different launch directions. Project their separations onto the receiver screen and compute each packet delay on its group trajectory. If $\mathcal{T}_\mathrm{ray}$ is the transmitted fraction and N_pkt the emitted photon count, the received number fluence is $\mathcal{T}_\mathrm{ray}\mathsf{N}_\mathrm{pkt}/\mathcal{A}_\mathrm{ray}$, where $\mathcal{A}_\mathrm{ray}$ is this transverse area. A shell with fixed solid angle and constant transmission gives the quarter fluence only when its transverse area quadruples. For a refracted bundle use the area transported along the actual rays. On the same receiver screen, compare neighbouring ray bundles with the same source, boundary data and launch aperture. Extra geometric focusing requires a smaller proper transverse area than in the matched GR bundle. At fixed area a change in transmission changes the number fluence. For incoherent images, distinguishable packets or a measurement that averages away the interference, add the transmitted count fluences in the receiver bins using each image's area and delay. Allocate the emitted packet budget once. For coherent paths overlapping in one detection mode, sum the transported field amplitudes with their relative phases before computing intensity. An optical-index ridge focuses rays. A magnetic field is a macroscopic helical density gradient whose bivector grade is coherently aligned along an axis (P-5). Where that twist cools the pairs, the cooling enters the intrinsic line emissivity. Its rate follows from

the field and pair content, and no rate is written here (O-12).

5 Predictions

For each test the signed separation compares the two model means in the same dimensionless observable. Test each hypothesis using the held-out measurement minus its calibrated prediction. Define $\mathfrak{u}_\Delta$ as the standard error of this residual, including shared nuisances. The critical multiplier is fixed before the comparison. For estimates with errors $\mathfrak{u}_a, \mathfrak{u}_b$ on the measurement and the tested prediction, respectively, and shared covariance $\mathcal{C}_{ab}$, $\mathfrak{u}_\Delta^2 = \mathfrak{u}_a^2 + \mathfrak{u}_b^2 - 2\mathcal{C}_{ab}$. For exact predictions the measurement error alone remains. The illustrative threshold uses a Gaussian residual under the tested hypothesis (U-15). If more settings are searched, the null simulation repeats that search and its selection. The benchmark separations and residual errors specify prospective sensitivity.

T-1. Independent weighing of an accreting hole

DC-1 tests SA-62. In a merger-free episode of a dynamically identified accreting black hole, weighed as the stellar-mass hole in Cygnus X-1 is weighed, define $\mathfrak{y}_1$ as the fractional change of the independently weighed gravitational mass from before to after the episode. Use orbital astrometry and companion radial velocities at both epochs with inclination constraints. Fit shared distance, companion evolution and reference-frame errors. Select merger-free episodes by the common exterior conditions measured before release. Use one exterior control surface and one asymptotic convention for energy, angular momentum and time. Constrain initial spin, incoming mass-energy, angular-momentum flux and possible extraction. Use independent controls to predict the GR radiative and mechanical outlet, exterior energy storage and signed horizon deposition. Record model uncertainties for unmeasured channels. Hold out the radiative-plus-mechanical outlet, change in exterior storage and two-epoch dynamical weighing. At matched inflow and zero hole growth, outlet plus stored-energy increment exceeds the positive-deposition GR prediction by the amount GR assigns to the horizon. The constraint applies to their sum, and the partition among channels is not written here (O-12). The GR comparator is predicted from the independent controls. Fitted to the held-out outlets and storage it reduces the test to a balance identity. At each epoch infer the unresolved exterior contribution to the dynamical mass in the same orbital model, converting energy to mass in the stated convention. Subtract its final-minus-initial change from the dynamical mass increment to infer the hole increment. Retain covariance between the epochs, the subtraction, and any held-out storage estimate using the same data.

Write $\mathcal{M}_\mathrm{i}, \mathcal{M}_\mathrm{f}$ for the hole's initial and final mass and $\mathcal{E}_\mathrm{H}$ for the GR comparator's independently predicted horizon energy. Test episodes with a resolved positive GR prediction under the common exterior selection. In this channel the GR mass balance $\mathfrak{y}_{1,\mathrm{GR}}$ and the Sec. 0.8 contrast $\mathfrak{y}_{1,\mathrm{FDT}}$ are

$$\mathfrak{y}_1 = \frac{\mathcal{M}_\mathrm{f} - \mathcal{M}_\mathrm{i}}{\mathcal{M}_\mathrm{i}}, \qquad \mathfrak{y}_{1,\mathrm{GR}} = \frac{\mathcal{E}_\mathrm{H}}{\mathcal{M}_\mathrm{i} c^2}, \qquad \mathfrak{y}_{1,\mathrm{FDT}} = 0.$$

Let $t_\mathrm{i}, t_\mathrm{f}$ be the weighing epochs and $\mathcal{L}_\mathrm{H}(t)$ the net inward horizon power predicted by the GR model of the common exterior preparation. Use the same asymptotic time and energy convention throughout. Then $\mathcal{E}_\mathrm{H} = \int_{t_\mathrm{i}}^{t_\mathrm{f}} \mathcal{L}_\mathrm{H}(t)\,\mathrm{d}t$, and dividing its negative by $\mathcal{M}_\mathrm{i} c^2$ gives the

FDT-minus-GR separation. FDT sends accreting matter into spacetime and energy outside the hole. Replacing that source assignment by inward deposition restores the positive GR result. At the design input $\mathcal{E}_{\rm H}/(\mathcal{M}_{\rm i}c^2) = 0.020$ (U-16), the normalized predictions are zero for FDT and positive 0.020 for GR. With held-out residual standard error $\mathfrak{u}_\Delta = 0.005$ under the tested mass hypothesis (U-16), the three-error threshold is 0.015 and the signed separation of means is -0.020. GR's increment is the accreted rest mass less the outlet's share, over $\mathcal{M}_{\rm i}$. With an outlet share of one tenth, accretion at the Eddington luminosity raises it by 2.0×10^{-8} per year, the Eddington time $\mathfrak{x}_{\rm T}c/(4\pi G m_{\rm p})$ being 4.5×10^8 yr with $m_{\rm p}$ the proton mass. The design input is therefore a million years of Eddington accretion, or one episode that feeds the hole two percent of its mass. Between two weighings decades apart it is an accretion rate above 10^4 times the Eddington rate, a hyper-accreting episode, and T-1 waits for a hole weighed on both sides of one. A resolved positive increment attributable to accretion onto the hole, with exterior storage and extraction resolved, excludes zero growth. Each independent weighing enters once. Ding supplies neither mass epoch nor validation of that sensitivity (SC-202).

There is a secondary spectral proxy. For fixed reference energy E_* and flux $\mathcal{F}_*$ use the time slope of $\ln[(k_{\rm B}T_{\rm ph}/E_*)^4\mathcal{F}_*/\mathcal{F}_{\rm BB}]$. E2–E4 with base radius proportional to mass give slope $-2\,{\rm d}\ln\mathcal{M}/{\rm d}t$ when dimensionless launch radius, redshift, spin, distance, flow branch and thermal-to-wind luminosity ratio are fixed (SC-165, SC-173–178). More generally the logarithm also contains the log wind-to-thermal luminosity ratio and four times the log radial temperature factor below. Their changes can move the slope at fixed mass. Two epochs give a secant. A mass inferred from the same temperature and flux provides no independent weighing.

T-2. Which launch radius attains the thermal ceiling?

DC-2 tests SA-58. Select an independently weighed Schwarzschild-limit stellar black-hole jet with an acceleration-phase photosphere and an independent geometric constraint on its emitting base. Use joint HEPP-H and GECAM-C spectra with a separately localized engine. GRB 221009A illustrates the spectral fit; it lacks the independent weighing. Let r denote the running radius of the thermal fireball. During acceleration Ding takes $\Gamma(r) = r/r_0$ (SC-168, L890) and obtains the apparent temperature $T_{\rm ph} = T_0/[(1+z_g)(1+z)]$ on this branch (SC-173–174, SC-178; SA-58). Take $L_{\rm w}$ as E2 takes it, the wind power crossing the base in the base's static frame, and use it with the source mass to define a temperature scale $T_{R_s} = [L_{\rm w}/(4\pi R_s^2 ca)]^{1/4}$. Let $x = r_0/R_s > 1$ and $\mathfrak{y}_2 = (1+z)T_{\rm ph}/T_{R_s}$. Substitution of the Schwarzschild lapse into E2–E3 gives the radial calibration (SC-165, SC-174, SC-178), with $\alpha_{\rm ext} = R_s/r_0 = 1/x$ the exterior A-1 value at the base field point $r_f = r_0$:

$$\mathfrak{y}_2 = \frac{\sqrt{x-1}}{x} = \sqrt{\alpha_{\rm ext}(1-\alpha_{\rm ext})}, \qquad \frac{{\rm d}\mathfrak{y}_2}{{\rm d}x} = \frac{2-x}{2x^2\sqrt{x-1}}.$$

Both endpoint limits vanish. The maximum, common to both accounts, is $1/2$ at $x = 2$. The curve is the product $|z_1||z_2|$ of the two moduli of the support, $|z_1|^2 = \alpha_{\rm ext}$ and $|z_2|^2 = 1-\alpha_{\rm ext}$ (§0.3a), greatest on the seam, where they are equal. For a pattern held at the base against the flow of §0.1c the moduli are v/c and u/c, so $\mathfrak{y}_2 = vu/c^2$: the rectangle of the strand's two readings, largest on the 45° strand (§0.1d). This analysis places the emitting base on the exterior A-1 seam, where the phase flow of matter into spacetime passes (§§0.3a, 0.8). That base attains the maximum. Ding's example of a last stable circular orbit sets $x = 3$ and

gives $\sqrt{2}/3$ (SC-200, SC-202, U-10, U-17). The signed normalized temperature difference is approximately $+0.029$. More explicitly, it is $\int_3^2 [\mathrm{d}\mathfrak{y}_2/\mathrm{d}x]\,\mathrm{d}x = 1/2 - \sqrt{2}/3$ along this fixed-power calibration. With held-out residual standard error 0.005 under the tested prescription the single-channel three-error threshold is 0.015 (U-15, U-17). E2 carries no lapse factor on the power, so $\mathfrak{y}_2$ is exact for L_w measured at the base. A distant calorimeter in the source's cosmological frame receives $L_\mathrm{far} = L_\mathrm{w}(1-\alpha_\mathrm{ext})$ from that base, and normalised on L_far the same two bases read $\alpha_\mathrm{ext}^{1/2}(1-\alpha_\mathrm{ext})^{1/4}$: 0.595 on the seam and 0.522 at $x = 3$, a difference of $+0.073$, with that curve's maximum, 0.620, at $x = 3/2$. The sign of the test and its resolution hold on either normalisation. The ceiling at the seam belongs to the base-frame curve, and the test declares which power its calorimetry returns. The comparison turns on the launch radius by construction: selecting the same radius in GR restores precisely the same temperature. The tested difference is the launch surface. Below the ceiling a reading has two inverse radii, exchanged by the seam map $\mathfrak{J} : \alpha_\mathrm{ext} \mapsto 1 - \alpha_\mathrm{ext}$ of §0.3a, which fixes the seam: $x = 3$ and $x = 3/2$ return the same $\sqrt{2}/3$.

Preselect the thermal component and acceleration regime without selecting on proximity to the maximum. Fit instrumental response and distance calibration, independently constrain mass, wind luminosity, launch geometry, redshift, spin, baryon loading and orientation, and propagate their covariance with the fitted temperature. Use distinct calibration and held-out episodes. An independent radius inconsistent with the seam or a resolved temperature residual under the seam premises excludes this base identification. Ding's coasting inversion gives $\Gamma \simeq 1500$, set aside using a fast-cooling constraint from prior work (SC-190, L979; SA-61). In the acceleration branch entropy has a lower limit. E8 uses $\Gamma = 500$ as a reference and prints a coefficient 4.7×10^4 (SC-195, SC-198, L986, L992; SA-63). For a wind of 10^{53} erg per second and $r_0 = 10^7$ cm, E2 gives $k_\mathrm{B}T_0 = 2.10$ MeV (SC-165–166, SC-189; U-01, U-03, U-04). E5 gives critical entropy 1.56×10^3 from the fourth root of $L_\mathrm{w}\mathfrak{x}_\mathrm{T}Y/(8\pi m_\mathrm{p}c^3 r_0)$, with $Y = 1$ (SC-181; U-05, U-06, U-24). The centimeter and energy units follow U-08. At the source's ten-solar-mass comparison the Schwarzschild length is 2.95×10^6 cm (U-26). Read in sample on E2–E3 with $L_\mathrm{w} = L_\mathrm{ph}$, Ding's representative $k_\mathrm{B}T_\mathrm{ph} \simeq 2$ MeV and $L_\mathrm{ph} \simeq 10^{53}$ erg s^{-1} (SC-183–184) return an engine of about seven solar masses for a base on the seam and about six for the base at $x = 3$. The seam value is the largest mass the curve admits at those inputs, and it is about ten with that power read as L_far. The mass scales as $L_\mathrm{w}^{1/2}T_\mathrm{ph}^{-4}$, so one-figure inputs fix its order alone. Neither branch carries the independent base measurement, and the weighing T-2 calls for is independent of the spectrum.

Candidate dispositions. DC-3 (SA-35) has no map from the history of a settlement to the inclusive reciprocal cross-section ratio (O-12). DC-4 (SA-54) has no map from a global settlement to an additional density-dependent absorption rate (O-12). DC-5 (SA-03) has no map from the regional expansion law to an integrated sightline distance residual (O-14). DC-6 (SA-82) has an inert common-weight response at exactly matched kinematics. Both additional angular means are zero. The illustrative three-standard-error cutoff for the held-out fitted angular residual is 0.015 (U-15, U-27).

6 Cross-domain comparison

6.1 A converted pair, an absorbed photon and a distance

A forward settlement and its inverse are two events, each the system-wide settlement of the state it starts from (§0.1a). For a laboratory comparison select unpolarized photon collisions above threshold and electron–positron collisions at the same invariant energy. Use the photon collider's calibrated incident spectral luminosity and the lepton ring's independent luminosity. Count final states over the same integrated phase space, correct for efficiencies and backgrounds, or fold a common model through each selection. The standard account reads the two reactions as mirror events: for reciprocal two-body amplitudes time reversal equates spin-summed squared amplitudes in QED. Both entrance spin averages have the same multiplicity. The final-to-initial momentum factor in each cross section inverts when the reaction reverses. At equal invariant energy the lepton-to-photon momentum ratio is $\mathfrak{v}_{\pm}/c$. Identical final photons divide the annihilation rate by two once. Thus $\mathfrak{x}_{\mathrm{pp}}/\mathfrak{x}_{\mathrm{ann}} = 2(\mathfrak{v}_{\pm}/c)^2$ (U-20). FDT reads each reaction as its own settlement and accepts the measured cross sections in full. The incident fluxes differ, so the comparison is of cross sections and never of raw yields. No signed deviation from this ratio and no energy dependence of one is written here (O-12). The ratio compares pair creation and annihilation. Neither reaction is the partonic production of a vector boson.

For opacity, let $I_{\mathrm{in}}, I_{\mathrm{out}}$ be resolved incident and surviving probe intensities at fixed energy, direction and path length. With independently measured target density and fixed spectral and angular shape, the collision integral per path length is proportional to that density. Its path integral is $\mathfrak{o}_{\gamma\gamma} = -\ln(I_{\mathrm{out}}/I_{\mathrm{in}})$ in a pure absorber (U-21). Survival is exponential and the converted fraction is $1 - \exp(-\mathfrak{o}_{\gamma\gamma})$. Yield per target density is constant only in the thin limit at fixed probe flux. For a finite bin, weight each transmission by the incident intensity and instrument response, sum the transmitted and incident counts separately, then take the negative logarithm of their ratio. Vary density with a fixed incident beam and independently calibrated targets, measure secondaries and control scattering, nonuniformity, feedback and flux losses. A combined analysis with reciprocal yields uses the covariance of overlapping samples. The absorption scan and the reciprocal test constrain different functions. Ding finds no obvious break up to about 100 MeV and takes $E_{\mathrm{thin}} > 200$ MeV in E1 (SC-169–170, SC-179; SA-54, SA-55). The approximate index 1.6 appears beside the spelling GRB 220109A. Their lower-limit coefficient 24 depends on an unstated photon-count normalization (SC-180, SC-182).

For the distance comparison, use host-identified gravitational-wave standard sirens at $0.05 \le z \le 0.25$ and match redshift distributions across independently classified void- and wall-dominated sightlines (U-18). Set H_{ref} to 70 kilometres per second per megaparsec. For the consensus comparator take the standard account's flat reference curve, with matter fraction 0.30 and constant-term fraction 0.70 (U-19), and its reference luminosity distance

$$\mathcal{D}_z = (1+z)\frac{c}{H_{\mathrm{ref}}}\int_0^z \frac{\mathrm{d}z'}{\sqrt{0.30(1+z')^3 + 0.70}}.$$

Use consistent velocity units. Compare the void-minus-wall mean of $\ln(\mathcal{D}_{\mathrm{GW}}/\mathcal{D}_z)$ with the same contrast in the reference population after selection. Infer siren distance jointly with inclination and calibration. Propagate host peculiar velocities, magnification, sky coverage, host identification and distance selection through both environment samples. In §0.7 the

Hubble number is regional: the amount rises where a region expands and falls where it contracts, the expanding regions void-dominated and the contracting ones wall-dominated. The integral of that regional number along the two sightline classes is not written here (O-14). The regional law of release and expansion (O-14) and the conserved domain content and merger flow (O-15) are separate items. The GRB has no siren distance or environment sample, and accumulated release fixes neither a local prompt rate nor a global doubling time.

6.2 A spin projection in a recoiling partonic event

In I-5 fix the material framing of the outer cable by a marked neighbouring strand carried with the knot. Its push-off sets that cable's self-linking convention. The signed linking number ν_i counts the winding of the physical inner cable about the outer in that framing. The sign of the helicity of the nested closure is the sign of ν_i. Reversing the orientation of either physical cable with the other held fixed reverses their linking sign. Reversing both preserves it. Helicity projects spin along a particle's momentum in a specified frame. Here the boson spin is projected on a chosen axis in its rest frame. Magnetic twist of a jet, an inner cable's linking number and these spin projections are three measurements. I-5 fixes the helicity sign as the sign of ν_i and writes no map from it to the other two.

Select a neutral boson decaying to a charged lepton pair at finite boson transverse momentum. Predeclare the pair mass, transverse momentum, rapidity and recoil bin. For this neutral-current comparison, use the negative lepton in the pair rest frame. In the Collins–Soper construction, bisect the direction of one beam and the reverse of the other. Orient the resulting polar axis with the sign of the pair longitudinal boost. At zero rapidity use the first declared beam to fix the sign. Choose the zero of azimuth along the pair transverse momentum in the production frame and complete the right-handed triad. Transform data and theory to these axes before comparing signed coefficients. Camarda supplies the normalized angular projections (SC-304–305, L2000–2001). Carry this neutral channel, spin basis, bin and selection into the angular coefficients below. The helicity tensor is the product of a production amplitude and the conjugate amplitude, summed over unobserved states and projected onto these boson polarization vectors. Its diagonal projections give populations. Its opposite-transverse off-diagonal real part contributes to the cosine of twice the lepton azimuth. Integrate the full decay distribution through the fiducial cuts and response. Uniform azimuthal weighting removes the twice-azimuth harmonic on integration. Azimuth-dependent acceptance can carry part of it into the selected count. Retain both lepton angles and fit the calibrated response to identify the interference jointly with the other moments and normalization wherever the response retains those independent projections.

At finite transverse momentum Camarda et al. include quark–antiquark annihilation with a recoiling gluon and quark–gluon scattering with a recoiling quark, and crossings (SC-307, L2005). Incoming partons belong to the two beam-proton configurations. There is no third incident room at their overlap. Account for the outgoing recoil, all outgoing charges, radiation, beam remnants and any substrate exchange once. Summed exchange sources vanish under I-6. Crossing relates scattering amplitudes; it gives no sequence in physical time. Gehrmann et al. give full three-loop virtual contributions within their treatment of quark masses and currents. They neglect massive-quark-loop effects and singlet axial currents, which they describe as numerically small (SC-311, SC-314). Gehrmann et al. label the outgoing quark and gluon by their helicities and the leptonic current by its handedness (SC-312, L2014). The rows of their color table count closed fermion loops and its columns track parametric color

order (SC-313). Neither index counts expansion stages or confined strands. A physical differential cross section needs the corresponding real radiation, infrared cancellation, initial-state factorization, parton distributions and the specified jet measurement. Camarda et al. report agreement at a few times 10^{-4} between their analytic calculation and the independent numerical implementation of vector-boson-plus-jet production inherited from MCFM (SC-308–309, L2006–2008).

Use NC for the selected neutral-current channel and CS for the stated Collins–Soper axes. At production kinematics $\mathfrak{l}$ write $U_{\mathrm{NC,CS}}(\mathfrak{l})$ for the unpolarized differential cross section. The numerators $\mathfrak{x}_{0,\mathrm{NC,CS}}, \mathfrak{x}_{2,\mathrm{NC,CS}}$ are the longitudinal and twice-azimuth projections in Camarda's normalization. The coefficients $A_{0,\mathrm{NC,CS}}, A_{2,\mathrm{NC,CS}}$ are their ratios to that differential cross section at the same kinematics. Write $a_{\mathrm{LT,NC,CS}}(\mathfrak{l}) = A_{0,\mathrm{NC,CS}}(\mathfrak{l}) - A_{2,\mathrm{NC,CS}}(\mathfrak{l})$ (SC-304–305). At first order in the strong coupling the Lam–Tung difference vanishes. Its breaking starts at second order (SC-306). The signed observable is the fitted difference minus the fiducial higher-order Standard Model difference, with both projections and their shared denominator obtained from the same fit.

Let B be the predeclared kinematic bin and write $U = U_{\mathrm{NC,CS}}(\mathfrak{l})$ for the unpolarized differential cross section in the selected frame. The average $\langle\cdot\rangle_{U,\mathsf{B}}$ uses this cross section times differential kinematic volume, normalized by its unweighted bin integral. Let $w_{\mathrm{pol}} > 0$ be a scalar weight common to all entries of the helicity tensor. Write $\mathrm{Cov}_{U,\mathsf{B}}$ for the covariance in this measure. For the binned coefficient, integrate the unnormalized projection and the unpolarized differential cross section over the same bin before dividing. Weighting the numerator and denominator, then subtracting the unweighted bin value, gives

$$\frac{\langle w_{\mathrm{pol}} a_{\mathrm{LT,NC,CS}}\rangle_{U,\mathsf{B}}}{\langle w_{\mathrm{pol}}\rangle_{U,\mathsf{B}}} - \langle a_{\mathrm{LT,NC,CS}}\rangle_{U,\mathsf{B}} = \frac{\mathrm{Cov}_{U,\mathsf{B}}(w_{\mathrm{pol}}, a_{\mathrm{LT,NC,CS}})}{\langle w_{\mathrm{pol}}\rangle_{U,\mathsf{B}}}.$$

At fixed matched kinematics the common factor divides out of every normalized coefficient. In a finite bin the covariance can have either sign. Matching the kinematic distribution first removes that contribution. The unmatched bin cross section is multiplied by $\langle w_{\mathrm{pol}}\rangle_{U,\mathsf{B}}$. At unit weight both the angular prediction and the bin cross section recover the baseline (U-22). Use independent calibration samples for lepton acceptance, momentum smearing, recoil migration and luminosity. Fit diagonal and interference projections jointly with normalization, polarization acceptance, parton and scale uncertainties. Carry the full rate–shape covariance into held-out bins. A polarization-dependent response needs its own predeclared axis, coupling and selection. After matching the kinematic distributions, removing that response gives zero added Lam–Tung difference in the model mean. The held-out fitted difference minus its matched prediction retains measurement and forecast uncertainties and their shared covariance (U-27).

7 System-level reading (exploratory)

This section sets out one conversion response shared between the burst and the partonic event, and the test that measures it. Its slope is calibrated in one system and frozen for the other, and neither source measures it.

X-1. A common response to a measured scale change. For the burst compare the final endpoint energy to the elastic prediction in the same frame. Express both at the detector

using the same independently calibrated post-endpoint transport. The initial spectrum and the clocks, velocities and geometry used for that prediction require independent calibration. Let g_{size} be the logarithm of the independently measured final-to-initial propagation-radius ratio. Define ξ_{size} as the dimensionless slope of the negative logarithm of the energy residual relative to elastic transport against g_{size}. The response tested here is $\ln(E_{\mathrm{end}}/E_{\mathrm{end,el}}) = -\xi_{\mathrm{size}} g_{\mathrm{size}}$. In the matched-frame case with unit elastic transfer, zero residual slope is elastic transport and unit slope reproduces local phase-radius tracking (U-23). For a general elastic transfer, tracking has the extra inverse elastic factor derived above. An energy-derived radius or zero size lever arm leaves this slope unidentified. Compare independent cohorts only with matched production and path models.

For a joint test, predeclare a collider size proxy with a physical length calibration independent of the fitted decay angles, a material framing and a mapping of that proxy onto the same logarithmic size change. Let χ_{mat} denote the material orientation sign and s_{pol} the signed log ratio of the positive and negative transverse-amplitude multipliers. For this transfer set $\chi_{\mathrm{mat}} = \mathrm{sgn}(\nu_i)$ from the nonzero linking number of the oriented inner and outer cables in the declared material framing. Determine the sign independently of the decay angles and hold the oriented Collins–Soper axes fixed. Reversing either cable alone changes the sign. Reversing both preserves it. Set $s_{\mathrm{pol}} = \chi_{\mathrm{mat}} \xi_{\mathrm{size}} g_{\mathrm{size}}$. Multiply the positive and negative transverse production amplitudes by $\exp(\pm s_{\mathrm{pol}}/2)$, respectively, leaving the longitudinal amplitude fixed. Positive orientation recovers $s_{\mathrm{pol}} = \xi_{\mathrm{size}} g_{\mathrm{size}}$. For the diagonal cross sections U_+, U_{L}, U_- of this spin basis the transformed trace is $U' = e^{s_{\mathrm{pol}}} U_+ + U_{\mathrm{L}} + e^{-s_{\mathrm{pol}}} U_-$. The longitudinal numerator and opposite-transverse interference numerator both stay fixed. Thus $U' a'_{\mathrm{LT,NC,CS}} = U a_{\mathrm{LT,NC,CS}}$ at each kinematic point, including a vanishing Lam–Tung numerator. For a common production bin integrate its unnormalized numerator and trace before division. Fit or unfold the full angular response. The bin cross section and the measured angular difference then constrain the same invariant. To predict selected event counts, fold the differential cross section through acceptance and detector response and multiply by the integrated luminosity. For transverse populations equal point by point, the production trace, the longitudinal and opposite-transverse interference numerators, and their corresponding normalized projections are even under reversal of s_{pol}. The signed polar term and longitudinal–transverse interference can change. Compute selected event counts separately for each sign using the full angular response and luminosity. Predeclare the oriented Collins–Soper axes, candidate bins and negative lepton's signed polar-cosine coefficient. Weight each subprocess's signed difference $e^{s_{\mathrm{pol}}} U_+ - e^{-s_{\mathrm{pol}}} U_-$ by its decay coefficient with angular normalization. Sum the subprocess contributions. In each bin and for each transfer sign integrate the resulting numerator and the corresponding transformed differential cross section over the same bin, then take their ratio. Fold both decay distributions through lepton acceptance, boost-sign assignment and bin migration. Fit their signed coefficients jointly with the bin cross sections and even moments. Before the held-out test, calibrate the critical value for the maximum absolute standardized difference of the two fitted signed coefficients across the candidate bins under zero contrast, including their shared calibration covariance. Select the highest-scoring bin on independent calibration only if it meets that prespecified threshold. If no bin passes, report no resolved orientation bin and make no held-out sign decision.

For a selected bin, freeze its definition and fit the signed polar coefficient once on disjoint held-out counts. Compare this same estimate with each sign forecast. For each sign standardize the observed-minus-forecast difference with its own residual error, including counting

and forecast variances and their shared covariance. Calibrate each two-sided exclusion under that sign with the prespecified trials rule and record which signs are excluded, allowing both or neither.

A common length-unit calibration cancels in each final-to-initial ratio. If the physical log change g_{size} equals an unknown factor b_{size} times the measured proxy log change g_{proxy}, the data identify only $b_{\text{size}}\xi_{\text{size}}$. Independently calibrate that mapping and carry its uncertainty across systems. With a size calibration alone, reversal of the amplitude weights tests the weighting prescription. Calibrate the slope in one system with external size and orientation information and freeze it for the other. Carry the calibration uncertainty, energy and angular response, matched recoil population, selection and trials into a held-out predictive distribution. Compare the burst with independently calibrated elastic propagation and the collider with the fiducial Standard Model with the amplitude transfer removed. Fixed local phase radius gives the elastic comparison when the elastic endpoint frequency ratio is unity. Neither a time bin nor a loop order measures the required size change. The selected collider passages have no calibrated length or phase response.

Guards. A freely propagating photon has fixed energy in a fixed local inertial frame. Its energy changes by a specified exchange or endpoint shift. The signed spin response is this section's reading: I-5 fixes the helicity sign of a nested closure and writes no map from it to a boson's spin projection. The data fix no shared coefficient, handedness or release time.

8 Convergence statement

Match the local frame, path and packet count, instrument response and fit windows. I-3 then gives the GR optical ray for the same metric. For the same incident spectrum and emission history, exposure, selection, response and backgrounds, both descriptions predict the same mean in each detector count bin. Using the same observed counts, spectral models, likelihood and fit constraints defines the same fit comparison. A common production and decay tensor gives the same normalized angular projections in the same collider bin. Integrating the production trace gives the same bin cross section. Folding through the same selection and response at the same integrated luminosity gives the same expected selected count. On these matched inputs FDT returns the consensus data, and the two descriptions coincide.

Ding generates Poisson arrival times for simulated incident photons and selects the trial incident rate for which the MC-corrected science-event rate agrees with the independently recorded telemetry rate (SA-11, SA-12; SC-040, SC-045). I-4 assigns the projected state's indeterminacy to an unknown helical phase and specifies no distribution for the burst's macroscopic arrivals. Ding estimates an isotropic peak luminosity of 1.1×10^{54} erg per second in 230–231 s and compares 4.9×10^{54} with 6.0×10^{54} erg in 225–235 s, using a distance whose cosmology is unspecified (SC-048–053; SA-14). In §0.7 the Hubble number is regional; the distance cancels from the central energy ratio, about 0.82 with no comparison error quoted, and never enters the measured frequency ratio.

Ding writes that the line finds an interpretation in the curvature effect of electron–positron annihilation radiation from an expanding sphere (SA-27; SC-094–096). In I-5 and P-4 the opposite-handed closures have the same strand count, three, and annihilation resolves the region in one settlement. Ding says rapid cooling may imply synchrotron or cyclotron cooling in a highly magnetized region (SA-28), interprets the geometry as implying a ring-shaped

magnetic structure (SA-31), and says the latitude dependence may be consistent with a Poynting jet (SA-73; SC-097, SC-102, SC-229). P-5 identifies that field with a macroscopic helical density gradient with coherent axial alignment of its bivector grade. The emissivity profile fixes neither the underlying field map nor the cooling rate. Ding calls the larger energy component very likely magnetic (SA-33, SC-104) and says the observed nonthermal emission should be produced by additional components, most likely energy dissipation in a Poynting-flux-dominated jet (SA-66, SC-207, L1009–1013). In P-5 the magnetic energy belongs to the twist; the inferred thermal share and the remainder Ding proposes draw on one budget.

Ding attributes acceleration to radiation pressure and the apparent temperature to a Lorentz boost compensating adiabatic cooling during acceleration (SA-32, SA-57; SC-103, SC-168). Section 0.1c gives a perfect stress tensor's temperature clock at zero net conserved count and its enthalpy-per-count clock at fixed entropy per conserved count; the linear acceleration law is Ding's and the lapse and cosmological redshift still enter the observed temperature. Ding simulates secondary electrons, including positrons, from photon interactions in passive materials and assigns them approximately 80 percent of the deposited energy that leads to a trigger (SA-39, SC-126, L659–660). In §0.1a each detector event resolves the whole detector configuration in one settlement; the response matrix is Ding's simulation.

The Bell bound applies to a single setting-independent joint distribution of local responses. I-4 places the measure on the host clamp, with identical one-wing marginals and the consensus pair frequencies in the transported frames; what selects the host and the transport history is not written here (O-17). No Bell measurement occurs in these sources. In the gravitational comparison, replacing exterior conversion with the independently predicted net horizon deposition restores accretion-driven growth. Weighing and post-release outlets and storage test the resulting balance. Holding the same launch radius in the two thermal models restores the same normalized temperature, including the same ceiling.

9 Status ledger

Item	Physical status and test
O-1	To be derived: the finite-core cutoff, the regular core chart or the outward phase-transfer law.
O-2	To be derived: geometrically constructed overlap-contrast odds. The A-3 token has open range only.
O-3	To be derived: canonical confinement odds. The A-4 confinement and A-5 mode tokens have open range only.
O-4	To be derived: the local profile from the constitutive law with surface, boundary and core data.
O-5	To be derived: pair multipoles, tidal remainders, the overlap complex and the many-cone settlement sign.
O-6	To be derived: the charge, circulating-charge and color-seat input maps, the seat-table derivation and gluon dynamics.
O-7	To be derived: the fission-cosmology calculation of the SNO neutral-current flux and all other neutrino anomalies. The SNO neutral-current agreement is data.
O-8	To be derived: the constitutive derivation of the causal aperture and its reconciliation with lensing.
O-9	To be derived: the confinement operator, its domains, boundary conditions and spectrum. The proton/electron mass ratio and squared muon/electron mass ratio are held-out targets.
O-12	To be derived: phase exchange, the decay kernel, spectrum, chirality and rates. The pair and absorption comparisons lack rates.
O-13	To be derived: the full jump in extrinsic curvature at each interface.
O-14	To be derived: the mass-shadow closure and the regional law for released amount and Hubble number. Sightline transfer is undetermined.
O-15	To be derived: the conserved domain content and merger flow, the mass spectrum and the standing-wave microwave spectrum and anisotropies.
O-16	To be derived: the interior kinematic reading of the share. Exterior flow stops at the fold.
O-17	To be derived: host selection, transport of the measure and unequal or multiple-pattern measures.
T-1	Prospective, merger-free accretion channel. Under common pre-release selection the predicted hole increment is zero. Replacing exterior conversion by the independently predicted net GR deposition restores the fractional mass change $\mathcal{E}_{\mathrm{H}}/(\mathcal{M}_{\mathrm{i}}c^2)$. Test the two-epoch weighing and the summed outlet and exterior storage change, including spin and extraction. GR's increment is resolved where one episode feeds the hole at least 0.017 of its mass at an outlet share of one tenth.
T-2	Prospective, resting on the seam base. The common-radius limit restores the same apparent temperature. The test declares which wind power its calorimetry returns.
In sample	Fitted BB and line, line-radius normalization, the Lorentz-factor bound, the drift spread of the windowed widths, the tracking form of the energy–delay product, the seam-base engine mass, temporal smoothing, passband simulation and numerical helicity checks belong to their input records.
X-1	Exploratory. No independent paired size calibration or measured conversion-to-spin slope.

10 Conclusions

With the annihilation energy the narrow line fixes a combined frequency shift of about 89 and, at unit residual shift, a bulk Lorentz factor of at least 44. Its arrival sequence and brightness are set by ray geometry, angular emissivity and the observer clock, and its windowed width by its own drift. The broad component, read as a blackbody, fixes an apparent temperature

that at fixed base-frame power is greatest for a base on the seam, where the phase flow of matter into spacetime passes. FDT predicts zero accretion-driven growth of the hole, and independent mass epochs with held-out changes in exterior storage and total outlet test it under one pre-release preparation. Independent base geometry tests the seam launch surface. A measured optical profile and ray directions test the guidance of helical photons along the denser wall, and the spectra fix neither the path nor the winding sense. Partonic recoil obeys the same energy and momentum balance. A common rescaling of the helicity tensor preserves normalized angular projections at fixed kinematics. The shared conversion response links independently measured lengths to phase and spin through one slope, and that slope is the measurement to make.

References

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