Why ACT Predicts No Spontaneous X-Ray Emission: Detailed Balance and the Donadi Bound

A Working Note

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Abstract

The strongest experimental constraint on gravity-related collapse is the underground X-ray search of Donadi et al. (*Nature Physics* **17**, 74 (2021)), which excluded the parameter-free Diósi–Penrose (DP) model by the absence of the spontaneous radiation it predicts. This note shows that the Anchored Causality Theory (ACT) mass-coupled channel—in either its gravitational realization (Variant G) or its postulated universal realization (Variant U)—predicts *no* signal in that experiment, not by tuning, but as a structural consequence of the fluctuation-dissipation theorem. The argument is elementary and general: any environmental channel in thermal equilibrium satisfies the Kubo–Martin–Schwinger (KMS) detailed-balance condition, under which the rate of energy transfer *from* the bath *to* the system at energy E carries the Boltzmann factor e^{-E/k_BT}. At the X-ray energies probed by Donadi et al. ($E \sim 10$ keV) and ambient temperature, this factor is $\sim 10^{-168{,}000}$. DP and CSL are constrained precisely because their noise is white—an effectively infinite-temperature bath that pumps energy at all frequencies. The same KMS factor that forbids X-ray emission *enhances* low-frequency anchoring through the thermal occupation $\coth(\hbar\omega/2k_BT) \approx 2k_BT/\hbar\omega$, so ACT simultaneously predicts strong decoherence and zero anomalous radiation from a single structure. The note states the theorem, gives the numbers, locates the honest constraint frontier for α_{eff} (low-frequency force-noise experiments, not X-ray searches), and situates the result against dissipative and colored-noise CSL precedents.

1 The Constraint to Be Evaded

1.1 What Donadi et al. measured

The DP model attributes wavefunction collapse to gravity, with collapse rate $\Gamma_{\text{DP}} = E_G/\hbar$, where E_G is the gravitational self-energy of the difference between superposed mass distributions, regularized at a length scale R_0. Collapse noise drives momentum diffusion; diffusing charged particles radiate. For nuclei and electrons in bulk matter, DP therefore predicts a steady flux of spontaneous X-ray photons with a calculable spectrum $\propto 1/E$ and a rate fixed (for given R_0) with *no free amplitude.* Donadi et al. operated a high-purity germanium detector at the Gran Sasso underground laboratory, observed no excess over background in the tens-of-keV band, and thereby excluded $R_0 \lesssim 0.5$ Å. Since the parameter-free version of DP requires R_0 at the nuclear scale ($\sim 10^{-15}$ m), and even the most charitable choice (the nuclear wavepacket size, $\sim 10^{-12}$ m) falls inside the excluded region, the natural DP model is ruled out.

1.2 Why DP radiates

The structural cause, identified already in the CSL energy-conservation problem, is that collapse noise in DP and CSL is *white*: the stochastic field has a flat spectral density at all frequencies and no accompanying dissipation. A noise field with spectral weight at frequency ω can transfer energy $\hbar\omega$ to a particle at a rate proportional to that weight; a white spectrum therefore pumps energy into matter at every frequency, including the X-ray band. Formally, white noise is the $T \to \infty$ limit of a thermal bath. The Donadi experiment is best understood not as a test of "gravity-related collapse" in general but as a thermometer: it measures the effective temperature of the collapse noise at X-ray frequencies and finds it must be far below the white-noise (infinite-T) value.

2 The No-Radiation Theorem for Thermal Channels

2.1 Setup

ACT's mass-coupled channel is a system–environment interaction $H_{\text{int}} = \hat{\mathcal{O}} \otimes \hat{X}$ with $\hat{\mathcal{O}}$ the system operator carrying the M-proportional coupling (gradient expansion of $\int T^{00}\Phi_{\text{env}}$) and $\hat{X}$ an operator of an environmental bath in thermal equilibrium at temperature T. The unsymmetrized noise spectrum is

$$S_X(\omega) = \int_{-\infty}^{\infty} dt\, e^{i\omega t}\, \langle \hat{X}(t)\hat{X}(0)\rangle_T. \tag{1}$$

By convention, $S_X(\omega)$ at $\omega > 0$ governs processes in which the *system emits* energy $\hbar\omega$ into the bath, and $S_X(-\omega)$ governs processes in which the *system absorbs* energy $\hbar\omega$ from the bath.

Lemma 1 (Decoherence–diffusion link)**.** *Any channel producing position decoherence at rate* Γ_x *via the Lindblad double-commutator* $-\Gamma_x[\hat{x}, [\hat{x}, \rho]]$ *necessarily produces momentum diffusion* $D_p = 2\hbar^2\Gamma_x$*.*

This is the standard result, and it is why the Donadi strategy is powerful: *any* position-localization mechanism—DP, CSL, or ACT—feeds momentum diffusion and is therefore a candidate radiation source. ACT cannot and does not evade the lemma. It evades the next step.

Theorem 1 (Thermal channels radiate thermally)**.** *Let the environmental bath be in thermal equilibrium at temperature* T*, so that its correlation functions satisfy the KMS condition. Then*

$$S_X(-\omega) = e^{-\hbar\omega/k_B T}\, S_X(\omega), \tag{2}$$

and the rate at which the channel induces photon emission at energy $E = \hbar\omega$ *from matter in (or near) its ground state is suppressed, relative to a white-noise channel of equal low-frequency strength, by the factor*

$$\frac{R_{thermal}(E)}{R_{white}(E)} \;\sim\; n_T(E) \;\approx\; e^{-E/k_B T}, \qquad n_T(E) = \frac{1}{e^{E/k_B T} - 1}. \tag{3}$$

Proof sketch. For a charged particle to emit a photon of energy E, the energy must be supplied by the noise field: the emission process at lowest order is absorption of energy E from the bath channel accompanied by photon emission (noise-induced bremsstrahlung). The absorption rate is proportional to the bath spectral weight at $-\omega$, i.e., to $S_X(-\omega)$. The KMS condition (2), which holds for any bath in thermal equilibrium (it is equivalent to detailed balance), gives $S_X(-\omega) = e^{-\hbar\omega/k_B T} S_X(\omega)$. A white-noise (classical, infinite-T) channel instead has $S_X(-\omega) = S_X(\omega) = S_0$ at all frequencies. Taking the ratio at fixed low-frequency normalization yields Eq. (3). ☐

The fluctuation-dissipation theorem is the integrated statement of the same physics: the noise kernel N and dissipation kernel γ of the ACT influence functional satisfy $\tilde{N}(\omega) = \hbar\tilde{\gamma}(\omega)\coth(\hbar\omega/2k_BT)$, so the channel's noise is paired with dissipation and the system *thermalizes to the ambient temperature* instead of heating without bound. A particle in thermal equilibrium with its environment exchanges energy in detailed balance and produces no net anomalous radiation: whatever it absorbs at thermally occupied frequencies it re-emits as ordinary thermal physics, and at frequencies far above $k_BT/\hbar$ there is nothing to absorb.

2.2 The numbers

The Donadi et al. analysis band is at $E \sim$ 10–100 keV. At ambient underground temperature $T \approx 300$ K, $k_BT \approx 0.026$ eV, so at the soft end of the band:

$$\frac{E}{k_BT} \approx \frac{10^4 \text{ eV}}{0.026 \text{ eV}} \approx 3.9 \times 10^5, \qquad e^{-E/k_BT} \approx 10^{-168{,}000}. \tag{4}$$

The predicted ACT signal in the germanium detector is zero to a precision beyond any conceivable experiment—not because α_{eff} is small, but because the suppression factor (3) is independent of the coupling strength. The conclusion is therefore strong:

Corollary 1 (Coupling-independence of the evasion)**.** *The Donadi bound constrains the* spectrum *(effective temperature) of the localization noise, not its coupling. An FDT-consistent channel of arbitrary strength α_{eff} predicts no observable signal in any X-ray emission search. Variant G and Variant U evade the bound identically, for the same structural reason.*

2.3 The same factor that forbids X-rays drives anchoring

The KMS/FDT factor cuts both ways, and in ACT's favor. At the low frequencies relevant to anchoring—the quasi-static monitoring of a slowly evolving superposition, $\hbar\omega \ll k_BT$—the thermal occupation is large:

$$\coth\left(\frac{\hbar\omega}{2k_BT}\right) \approx \frac{2k_BT}{\hbar\omega} \gg 1. \tag{5}$$

The anchoring functional $\Phi_{\mathcal{O}}$, which integrates the noise kernel over the superposition's lifetime, is dominated by exactly this thermally enhanced low-frequency weight. A single thermal spectrum therefore yields *simultaneously*: strong, temperature-dependent decoherence at low frequency (the anchoring transition) and Boltzmann-vanishing emission at high frequency (the Donadi evasion). No parameter is tuned to achieve this; it is the shape of every thermal bath in nature. By contrast, DP and CSL bought their localization with a flat spectrum and paid for it in X-rays.

3 Honest Accounting: Where the Real Constraints Live

Evading the X-ray bound does not leave α_{eff} unconstrained; it relocates the constraint frontier to low frequencies, where the thermal channel is *active.* The relevant existing experiments are:

1. **Low-frequency force-noise bounds.** A universal mass-coupled channel exerts fluctuating forces on test masses. LISA Pathfinder's differential acceleration noise ($\sim$ femto-$g/\sqrt{\text{Hz}}$ at mHz frequencies), torsion-balance experiments, and atom interferometry all bound anomalous force noise on mass-coupled channels in precisely the band where ACT's channel has thermal weight. Translating these into a quantitative exclusion region for $\alpha_{\text{eff}}(T, \tilde{\gamma})$ is the necessary next calculation; until it is done, ACT cannot claim its viable parameter space is nonempty for signal levels reachable by the Stage-2 isotope experiment.

2. **Cryogenic cantilever and levitated-oscillator heating.** Vinante-type millikelvin cantilever experiments bound anomalous heating. For an FDT-consistent channel the prediction is thermalization toward the *ambient* bath temperature, so these become consistency checks on the channel's assumed temperature rather than kill-shots; but if the ACT channel couples to a bath warmer than the cryostat (e.g., room-temperature surroundings penetrating the shielding), residual heating bounds do apply and must be computed.

3. **Equilibrium physics.** A channel in detailed balance contributes to ordinary thermalization rates. Any α_{eff} large enough to dominate molecular decoherence must not visibly accelerate thermal relaxation in precision calorimetry. An order-of-magnitude consistency estimate belongs in the full paper.

Relation to prior art. The move from white to structured noise is not unprecedented, and the manuscripts should cite the lineage. Dissipative CSL (Smirne and Bassi, 2015) adds a dissipation partner to CSL with a new free "noise temperature" parameter; colored-noise CSL (Adler and Bassi) imposes a high-frequency cutoff; and Donadi et al. themselves note that their bound weakens for non-white spectra. ACT's position is distinct in one respect that should be stated plainly: in dissipative/colored CSL the spectrum's shape and temperature are *additional postulates* adjusted to evade constraints, whereas in ACT the spectrum is thermal *because the channel is an environmental bath*—the KMS condition is not a model choice but a property of thermal equilibrium. ACT gets the evasion for free; collapse models must buy it parameter by parameter. This is the FDT-consistency advantage made quantitative, and it is the central claim of this note.

What Variant G still owes. The corollary shows Variant G evades Donadi. It does not show Variant G is *testable*: with the coupling fixed at Newton's constant, thermal gravitational potential fluctuations from laboratory environments yield decoherence rates many orders of magnitude below the Stage-2 sensitivity of the isotope experiment. Variant G is safe but, on current estimates, experimentally inert. The testable version of ACT is Variant U, whose α_{eff} is now bounded below by Stage-1 interferometry sensitivity (for detectability) and above by the low-frequency force-noise bounds of item 1. Whether that window is open is a calculable question and the single most important open problem in ACT's experimental program.

4 Summary

1. Donadi et al. excluded parameter-free DP via the absence of spontaneous X-rays. The radiation prediction follows from white (infinite-temperature) collapse noise, not from mass-coupled localization as such.

2. Any thermal-equilibrium channel obeys KMS detailed balance: energy transfer from bath to system at energy E is suppressed by $e^{-E/k_BT} \sim 10^{-168{,}000}$ at 10 keV and 300 K. ACT's channel is thermal by construction; its predicted Donadi-band signal is zero, independently of α_{eff}.

3. The same thermal spectrum enhances low-frequency anchoring by $2k_BT/\hbar\omega$. Strong decoherence and zero X-rays are one structure, not a tuning.

4. The real constraint frontier for α_{eff} is low-frequency force noise (LISA Pathfinder, torsion balances, atom interferometry). Computing the allowed window between those bounds and Stage-1/2 detectability is the next calculation, and the full paper should not claim viability until it is done.