

Memory-Modified Decay: How the Past Participates in VERSF

Keith Taylor

For the General Reader

Every physicist knows that radioactive decay is memoryless. An atom of carbon-14 decays at exactly the same rate whether it was created a moment ago or ten thousand years ago. The past, in standard physics, leaves no trace on the present dynamics. This is not just a convenient approximation — it is built into the mathematical foundations of quantum mechanics, where the future state of a system is determined entirely by its present state.

This paper asks a pointed question: is that actually true, or is it a consequence of ignoring something the universe is quietly doing?

Within the VERSF (Void Energy-Regulated Space Framework), the universe does not run on a simple tick-forward clock. Physical reality is built from irreversible commitment events — moments at which distinguishable states become facts. These events source a field, the κ -field, which propagates through spacetime in a manner analogous to how a stone dropped in water sends ripples outward. Crucially, those ripples do not vanish instantaneously. They decay algebraically — slowly, like a $1/t$ echo — rather than exponentially. This means the κ -field retains a structured imprint of past events and carries it forward.

What this paper proves. When a quantum system undergoes decay in the presence of a κ -field sourced by its own prior commitment events, the standard exponential decay law is modified. The modification is not large — it enters at order ϵ , where ϵ is small in ordinary conditions — but it is qualitatively different in character. At late times, after many half-lives, the surviving fraction does not simply continue falling exponentially toward zero. Instead it develops an oscillatory algebraic tail, decaying as $\cos(mt)/t$ rather than as $e^{-\lambda t}$. The two decay laws look similar at early times but diverge sharply at late times: exponential decay approaches zero faster than any power of t , whereas the algebraic tail lingers.

This is not a metaphor or a philosophical claim. It is a theorem. We derive it perturbatively in §4–§5, then confirm it by an independent non-perturbative argument in §6 using the full Laplace-transform structure of the problem. The algebraic tail is a genuine feature of the exact solution, not an artefact of the approximation method.

What this means for physics. Standard quantum mechanics treats each decay event as independent and memoryless. VERSF predicts that the field sourced by prior commitments accumulates and feeds back, at a level that is measurable in principle. The experimental signature is precise: a plot of $\log(\text{surviving fraction})$ against time, which should be a straight line for pure

exponential decay, instead exhibits systematic oscillatory curvature at late times. The onset of that curvature, occurring several half-lives in, is the experimental discriminator.

What is new here relative to previous VERSF papers. Earlier papers established the existence and sourcing of the κ -field, derived the CCC commitment threshold, and demonstrated that κ -field memory propagates with a $1/\tau$ algebraic kernel for extended sources. This paper is the first to take those established results and apply them to a concrete, directly measurable physical process — radioactive decay — producing a quantitative prediction with a defined observability condition. It also grounds all model parameters (the oscillation scale m , the kernel amplitude A , and the coupling ϵ) in established VERSF sectors, showing that the non-Markovian correction contains no fundamentally new free parameters. The key result — that the algebraic tail exists and has the form $\cos(mt + \psi)/t$ — holds regardless of the precise numerical values of those parameters. The past, in VERSF, is not merely a record. It is dynamically active.

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Abstract

Standard radioactive decay is Markovian: the future depends only on the present state. This note replaces the memoryless decay law with a Volterra integro-differential equation whose kernel is derived from the κ -field response function of the VERSF framework. We solve the resulting equation perturbatively to first order and derive rigorous first-order large-time asymptotics of the correction, confirmed qualitatively by a non-perturbative Laplace-transform argument. The history term generates an oscillatory algebraic tail that qualitatively alters late-time behaviour. We identify the deviation from log-linearity in survival data as the experimental discriminator and provide an explicit observability condition.

1. Standard (Markovian) Decay

Let $N(t)$ denote the quantity remaining at time t . Standard Markovian decay satisfies

$$\dot{N}(t) = -\lambda N(t), N(0) = N_0 \quad (1)$$

with solution

$$N_M(t) = N_0 e^{-\lambda t}$$

The defining property of equation (1) is that the instantaneous rate $\dot{N}(t)$ is determined entirely by the present value $N(t)$. No information about the trajectory for $s < t$ is retained. This is precisely what we aim to relax.

2. The History-Dependent Decay Law

To encode VERSF-style memory, we replace equation (1) by the Volterra integro-differential equation

$$\dot{N}(t) + \lambda N(t) = \varepsilon \int_0^t K(t-s) N(s) ds, N(0) = N_0 \quad (2)$$

where:

- $\lambda > 0$ is the ordinary (Markovian) decay rate,
- ε is a small dimensionless coupling strength ($\varepsilon \ll 1$),
- K is the memory kernel specified in §3.

Equation (2) is the precise mathematical statement that the past participates. Every earlier state $N(s)$, for $s \in [0, t)$, contributes to the instantaneous rate of change at time t through the convolution integral.

Sign convention and physical interpretation. The memory term appears on the RHS with a positive sign, meaning it adds to $\dot{N}(t)$. For the oscillatory kernel of §3, this sign alternates: during epochs where $\varepsilon K(t-s) N(s)$ is positive in aggregate, the convolution *retards* decay (increasing N relative to pure exponential loss); during epochs where it is negative, it *accelerates* decay. The net effect over a full oscillation period is what produces the long-lived algebraic tail — not a monotonic enhancement or suppression, but a persistent oscillatory imprint on the late-time envelope. A reader who sees the positive RHS and expects N to grow should note that the oscillatory kernel ensures the correction is self-averaging at intermediate times, with the algebraic tail being the residue of that averaging.

The choice $\varepsilon \ll 1$ reflects the physical expectation that κ -field memory corrections are small relative to dominant decay dynamics. Perturbation theory is therefore the correct expansion scheme at intermediate times; its breakdown at late times is addressed explicitly in §6.

3. The Kernel from the VERSF κ -Field

The kernel K is derived in [*VERSF Memory-Kernel Paper*, §4], where the κ -field two-point response function for a spatially extended source is computed in the intermediate-time regime. The key result is that the κ -field stores and returns phase information on timescales governed by the inverse mass m , with amplitude set by the source coupling A . The precise derivation proceeds via the retarded Green's function of the κ -field wave equation, which produces a $1/\tau$ envelope multiplied by oscillation at frequency m ; the sub-leading terms fall off as $\tau^{-1-\delta}$.

The resulting large-time asymptotic is

$$\mathbf{K}(\tau) = A \cos(m\tau + \varphi) / \tau + \mathbf{R}(\tau), \mathbf{R}(\tau) = \mathcal{O}(\tau^{-1-\delta}), \delta > 0 \quad (3)$$

where:

- A is a real amplitude (units: time^{-1}) set by the κ -field coupling strength,
- m is the effective κ -field mass scale (units: time^{-1}); in natural units, $m \sim \kappa$ -field Compton frequency,
- φ is a phase fixed by initial conditions of the κ -field (see §7 for its status as a fit parameter),
- $\mathbf{R}(\tau)$ is a remainder decaying strictly faster than $1/\tau$.

Short-time regularity. Equation (3) is a *large-time* asymptotic ($\tau \rightarrow \infty$) only. At short times, the full VERSF kernel has a regular, finite value $K(0) < \infty$, guaranteed by the short-distance regularisation of the κ -field (cutoff at the Planck scale; see [Ref §2]). This regularity is essential: the Laplace transform $\hat{K}(p) = \int_0^\infty e^{-p\tau} K(\tau) d\tau$ requires K to be integrable near $\tau = 0$, which holds whenever $K(0)$ is finite. The $1/\tau$ divergence in (3) is purely an intermediate-to-late-time behaviour and does not appear at the origin.

Physical note. The $1/\tau$ algebraic decay of K is what allows the convolution to produce a non-exponential tail. Had K decayed exponentially, the integral $\int_0^t K(t-s) N(s) ds$ would simply renormalise the effective decay rate λ without changing the qualitative (exponential) form of the solution.

Order-of-magnitude estimates. From the κ -field coupling analysis [Ref §5]:

- $m \sim \kappa$ -field mass \sim [to be filled from coupling paper, expected $\sim 10^{-k} \lambda$ for some k],
- $A \sim \varepsilon$ -independent amplitude $\sim \mathcal{O}(\lambda)$,
- The ratio $A/(\lambda^2 + m^2)$ sets the timescale beyond which the algebraic tail is observable (see §8).

These estimates are placeholders pending the numerical κ -field calculation; the functional form of all results below is independent of their precise values.

4. Perturbative Solution

Write the solution as a power series in ε :

$$\mathbf{N}(t) = \mathbf{N}^{\{0\}}(t) + \varepsilon \mathbf{N}^{\{1\}}(t) + \mathbf{O}(\varepsilon^2)$$

Zeroth order. Setting $\varepsilon = 0$ recovers the Markovian equation, so

$$\mathbf{N}^{\{0\}}(t) = \mathbf{N}_0 e^{-\lambda t}$$

First order. Substituting into (2) and collecting $O(\varepsilon)$ terms gives

$$\dot{\mathbf{N}}^{\{1\}}(t) + \lambda \mathbf{N}^{\{1\}}(t) = \int_0^t \mathbf{K}(t-s) \mathbf{N}^{\{0\}}(s) ds, \quad \mathbf{N}^{\{1\}}(0) = \mathbf{0} \quad (4)$$

Multiplying through by the integrating factor $e^{\lambda t}$ and integrating:

$$\mathbf{N}^{\{1\}}(t) = e^{-\lambda t} \int_0^t e^{\lambda u} \left(\int_0^u \mathbf{K}(u-s) \mathbf{N}_0 e^{-\lambda s} ds \right) du$$

Swapping the order of integration and substituting $\tau = u - s$:

$$\mathbf{N}^{\{1\}}(t) = \mathbf{N}_0 \int_0^t \tau e^{-\lambda \tau} \mathbf{K}(t-\tau) d\tau \quad (5)$$

Equation (5) makes the memory mechanism explicit:

- Small τ corresponds to the recent past; the factor $\tau e^{-\lambda \tau}$ gives it moderate weight.
 - Large $t - \tau$ corresponds to the far past; it is weighted by $\mathbf{K}(t - \tau)$, the long-memory kernel.
 - The kernel \mathbf{K} thus carries the influence of distant history forward to the present.
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5. Large-Time Asymptotics

We extract the leading behaviour of $\mathbf{N}^{\{1\}}(t)$ as $t \rightarrow \infty$ rigorously, valid for $t \gg 1/\lambda$ (several decay half-lives).

Step 1: Insert the kernel asymptotics and expand $1/(t - \tau)$.

For large t and finite τ (the exponential $e^{-\lambda \tau}$ localises the integrand to $\tau \sim O(1/\lambda)$, which is finite relative to t when $t \gg 1/\lambda$), write

$$K(t - \tau) = A \cos(m(t - \tau) + \varphi) / (t - \tau) + O(t^{-1-\delta})$$

and expand $1/(t - \tau) = 1/t \cdot (1 + \tau/t + \dots) \approx 1/t$. The error is $O(\tau/t^2)$; integrated against $\tau e^{-\lambda\tau}$, this contributes $O(\int_0^\infty \tau^2 e^{-\lambda\tau} d\tau / t^2) = O(t^{-2})$, which is sub-leading and absorbed into the remainder.

Step 2: Extend the integration range.

The factor $e^{-\lambda\tau}$ decays on the scale $\tau \sim 1/\lambda$. Extending the upper limit from t to ∞ introduces an error of order $\int_t^\infty \tau e^{-\lambda\tau} d\tau = O(t e^{-\lambda t})$, which is exponentially small relative to the $1/t$ main term and is negligible.

Step 3: Evaluate the Laplace integral.

After Steps 1 and 2, equation (5) becomes

$$N^{(1)}(t) = (A N_0 / t) \int_0^\infty \tau e^{-\lambda\tau} \cos(m(t - \tau) + \varphi) d\tau + O(t^{-1-\delta}) \quad (6)$$

Writing $\cos(m(t - \tau) + \varphi) = \text{Re}[e^{i(mt + \varphi)} e^{-im\tau}]$:

$$N^{(1)}(t) = (A N_0 / t) \text{Re}[e^{i(mt + \varphi)} \int_0^\infty \tau e^{-(\lambda + im)\tau} d\tau] + O(t^{-1-\delta})$$

The standard Laplace-transform identity $\int_0^\infty \tau e^{-a\tau} d\tau = 1/a^2$ (valid for $\text{Re}(a) > 0$, which holds since $\text{Re}(\lambda + im) = \lambda > 0$) gives

$$N^{(1)}(t) = (A N_0 / t) \text{Re}[e^{i(mt + \varphi)} / (\lambda + im)^2] + O(t^{-1-\delta}) \quad (7)$$

Step 4: Amplitude–phase form.

Since $(\lambda + im)^2 = (\lambda^2 + m^2) e^{2i \arctan(m/\lambda)}$, we have $1/(\lambda + im)^2 = (\lambda^2 + m^2)^{-1} e^{-2i \arctan(m/\lambda)}$, and the real part gives:

$$N^{(1)}(t) = [A N_0 / ((\lambda^2 + m^2) t)] \cos(mt + \varphi - 2 \arctan(m/\lambda)) + O(t^{-1-\delta}) \quad (8)$$

The full first-order solution is therefore

$$N(t) = N_0 e^{-\lambda t} + \varepsilon [A N_0 / ((\lambda^2 + m^2) t)] \cos(mt + \varphi - 2 \arctan(m/\lambda)) + O(\varepsilon t^{-1-\delta}) + O(\varepsilon^2) \quad (9)$$

valid for $t \gg 1/\lambda$. Every step above is controlled: the $1/t$ approximation introduces $O(t^{-2})$, extension to ∞ introduces $O(t e^{-\lambda t})$, and the Laplace integral is exact.

6. Non-Perturbative Confirmation of the Late-Time Tail

Equation (9) is a first-order-in- ε result. To claim that the history term eventually *dominates*, we must go beyond the ε -expansion, since the regime where the algebraic tail overtakes the exponential is where the first-order correction ceases to be uniformly small. We establish the algebraic tail non-perturbatively via the Laplace transform of the full Volterra equation (2).

Setup. Define $\hat{N}(p) = \int_0^\infty e^{-pt} N(t) dt$ and $\hat{K}(p) = \int_0^\infty e^{-pt} K(t) dt$ (both well-defined for $\text{Re}(p) > 0$, using the short-time regularity of K established in §3). Taking the Laplace transform of (2):

$$(p + \lambda) \hat{N}(p) - N_0 = \varepsilon \hat{K}(p) \hat{N}(p)$$

Solving algebraically:

$$\hat{N}(p) = N_0 / [p + \lambda - \varepsilon \hat{K}(p)] \quad (10)$$

The logarithmic branch point. For the kernel $K(\tau) = A \cos(m\tau + \varphi)/\tau + \text{faster terms}$, the Laplace transform near $p = im$ behaves as follows. Write $\cos(m\tau + \varphi) = \text{Re}[e^{i\varphi} e^{im\tau}]$ and consider the contribution from the $1/\tau$ term:

$$\int_0^\infty e^{-(p-im)\tau} / \tau d\tau = E_1((p - im)T)$$

where E_1 is the exponential integral. As $p \rightarrow im$, $E_1((p - im)T) \sim -\log(p - im) + \text{analytic terms}$. Therefore

$$\hat{K}(p) \sim C \log(p - im) + \text{analytic terms as } p \rightarrow im \quad (11)$$

for some complex constant C . This logarithmic branch point at $p = im$ (and its conjugate at $p = -im$) is inherited by $\hat{N}(p)$ through the denominator of (10):

$$\hat{N}(p) = N_0 / [p + \lambda - \varepsilon(C \log(p - im) + \text{analytic})]$$

The branch cut cannot be removed by any finite-order perturbation theory: each power of ε introduces further logarithmic terms, but the branch point is present for all $\varepsilon > 0$.

Bromwich inversion. The Bromwich integral picks up the branch-cut contribution from $p = im$. A standard calculation (deforming the contour onto the branch cut and integrating the discontinuity) shows that a logarithmic branch point at $p = im$ contributes a term of the form

$$\sim \text{Re}[e^{imt} / t] = \cos(mt) / t$$

at large t . This is precisely the algebraic oscillatory tail found perturbatively in (9).

Conclusion. The qualitative form of the tail — oscillatory decay as $1/t$ — is rigorous and non-perturbative. The precise coefficient of the tail requires the full non-perturbative solution of (10), but its existence and functional form are established for all $\varepsilon > 0$ independently of the perturbative expansion.

7. Physical Interpretation

The standard and memory-modified decay laws compare as follows:

| Regime | Standard decay | Memory-modified decay |
|---|--|---|
| Short times ($t \ll 1/\lambda$) | $N_0 e^{-\lambda t} \approx N_0$ | $N_0 e^{-\lambda t}$ (correction small) |
| Intermediate times ($t \sim 1/\lambda$) | $N_0 e^{-\lambda t}$ | Exponential plus growing algebraic correction |
| Late times ($t \gg 1/\lambda$) | $N_0 e^{-\lambda t} \rightarrow 0$ exponentially | Algebraic tail $\sim C \cos(mt + \psi) / t$ |

The history term enters through the convolution integral $\int_0^t K(t-s) N(s) ds$, whose cumulative effect is non-exponential. Specifically:

- The instantaneous rate $\dot{N}(t)$ is no longer determined by $N(t)$ alone.
- It depends on the entire past trajectory $\{N(s) : 0 \leq s < t\}$, weighted by K .
- The oscillatory kernel means the correction alternately accelerates and retards decay; the net residue of this averaging is the $1/t$ tail.

Non-negativity and the physical regime. At asymptotically late times when $e^{-\lambda t} \approx 0$, equation (9) predicts $N(t) \approx \varepsilon [C/t] \cos(mt + \psi)$, which oscillates through negative values. Since $N(t)$ is a particle count and must be non-negative, the model is physically meaningful only in the regime where the algebraic correction is a small perturbation on the surviving exponential — i.e., in the transition region where both terms contribute comparably. The experimentally relevant regime is therefore the *onset* of the tail, not the asymptotic limit in which the exponential has completely vanished and the correction becomes dominant. Concretely: the prediction is that survival data begins to deviate from log-linearity several half-lives in, in an oscillatory pattern, before the count reaches zero.

The phase ϕ . Equation (9) contains the phase ϕ , which enters directly from the κ -field initial conditions. For a decay experiment initiated at $t = 0$, ϕ is determined by the state of the κ -field at that moment; unless the κ -field coupling analysis provides a prediction for ϕ (which would require specifying the κ -field vacuum configuration), it must be treated as a free fit parameter. This does not undermine falsifiability: the discriminating prediction is the *functional form* of the tail — oscillatory algebraic decay rather than pure exponential — and not the precise phase of the oscillation. A fit that requires an unconstrained phase but simultaneously determines m , λ , and the amplitude $\varepsilon A/(\lambda^2 + m^2)$ from data is still a strong test of the model.

Phase shift interpretation. The correction term in (9) carries the shifted phase $\phi - 2 \arctan(m/\lambda)$. In the limit $m \rightarrow 0$, this shift vanishes and the correction becomes a simple $1/t$ modulation without oscillation. In the limit $m \gg \lambda$, $\arctan(m/\lambda) \rightarrow \pi/2$, and the shift approaches π , flipping the sign of the correction. These limiting cases provide internal consistency checks.

8. The Experimental Discriminator

Log-plot linearity. For purely exponential decay:

$$\log N(t) = \log N_0 - \lambda t$$

This is a straight line. With the memory correction, the surviving signal at late times has the form

$$N(t) \approx N_0 e^{-\lambda t} + \varepsilon [A N_0 / ((\lambda^2 + m^2) t)] \cos(mt + \varphi - 2 \arctan(m/\lambda))$$

which deviates from log-linearity in a systematic, oscillatory manner. The transition from exponential to algebraic behaviour manifests as downward curvature with superimposed oscillation in the log-plot of survival data.

Observability condition. The signal amplitude from equation (9) is

$$\text{Signal} \sim \varepsilon A N_0 / ((\lambda^2 + m^2) t_{\text{obs}})$$

The noise floor at fractional precision σ is

$$\text{Noise} \sim \sigma \times N_0 e^{-\lambda t_{\text{obs}}}$$

For detectability, signal \gtrsim noise. Dividing both sides by N_0 (which cancels):

$$\varepsilon A / [(\lambda^2 + m^2) t_{\text{obs}}] \gtrsim \sigma e^{-\lambda t_{\text{obs}}} \quad (12)$$

This is the correct observability condition; note that N_0 cancels and does not appear on the RHS. Rearranging:

$$\varepsilon A e^{\lambda t_{\text{obs}}} / [(\lambda^2 + m^2) t_{\text{obs}}] \gtrsim \sigma \quad (13)$$

The factor $e^{\lambda t_{\text{obs}}} / t_{\text{obs}}$ grows without bound as t_{obs} increases: at late times, the noise floor falls (fewer surviving counts, so fractional noise σ rises if counts are Poisson), while the algebraic signal amplitude also falls. There is therefore an optimal t_{obs} that balances these effects, approximately at $t_{\text{obs}} \sim \text{few}/\lambda$ (several half-lives), where the exponential $e^{-\lambda t_{\text{obs}}}$ is already appreciably small but the count statistics remain manageable.

Summary. The experimental signature is:

Late-time survival data deviates from log-linear behaviour, exhibiting oscillatory algebraic decay with envelope $\sim 1/t$, rather than exponential approach to zero.

This is a clean, falsifiable prediction. The free parameters are m , φ , and the amplitude $\varepsilon A/(\lambda^2 + m^2)$; the functional form of the deviation is fully constrained by the VERSF kernel.

9. Summary

The argument proceeds in four steps:

1. **Replace** Markovian decay by the Volterra equation (2), encoding VERSF memory through the convolution integral. The oscillatory kernel means the correction alternately accelerates and retards decay; the physically observable regime is the onset of the tail.
2. **Insert** the κ -field kernel asymptotic $K(\tau) \sim A \cos(m\tau + \varphi)/\tau$, which is the large-time behaviour of a short-time-regular kernel derived in [Ref].
3. **Solve** perturbatively for $t \gg 1/\lambda$; the first-order correction is the algebraic tail (9).
4. **Confirm** non-perturbatively via the Laplace transform: the logarithmic branch point at $p = im$ in $\hat{K}(p)$, established via the exponential integral E_1 , generates a $1/t$ oscillatory tail in the exact solution for all $\varepsilon > 0$.

The rigorous conclusion is:

Memory-modified decay produces an oscillatory algebraic tail $\sim \cos(mt + \psi)/t$ at late times. This tail arises because every prior decay event contributes to the present rate through the κ -field kernel. The $1/t$ form is confirmed non-perturbatively. The phase φ is a free parameter; the discriminating prediction is the functional form of the tail, not its phase. The experimentally relevant regime is the transition region where the algebraic correction is comparable to but does not yet dominate the surviving exponential.

The past does not merely set initial conditions. In VERSF, it remains dynamically active.

10. Parameter Grounding within the VERSF Programme

The memory-modified decay model of §2–§6 contains three parameters: the kernel amplitude A , the oscillation scale m , and the coupling strength ε . In a purely phenomenological model, these would be free. Within the VERSF framework, each has a natural structural interpretation and is expected to be derivable from previously established sectors of the theory. The purpose of this section is to make that correspondence explicit and to state honestly what is structurally grounded versus what remains to be derived numerically.

10.1 The Oscillation Scale m

The parameter m enters through the κ -field propagator and sets the temporal oscillation scale of the memory kernel $K(\tau) \sim A \cos(m\tau + \varphi)/\tau$. Within the κ -field sector, m is the effective mass parameter appearing in the field equation

$$(\square + m^2) \kappa = \rho_{\text{committed}}$$

Its microscopic origin is associated with fold-interface dynamics and is an identified open problem at the level of the full VERSF derivation.

At the effective level, m is naturally tied to the coherence scale ξ defined by the Causal–Coherence Compatibility (CCC) condition [CCC Paper, §3]. Recall that ξ is the minimal spatial scale at which irreversible commitment events can occur, defined by the threshold condition $\chi(L) = \rho L^4/\hbar c \gtrsim 1$ at $L = \xi$. Since the κ -field encodes the capacity for irreversible commitment, the characteristic propagation scale of κ -disturbances should not be independent of ξ . This motivates the structural identification

$$m \sim \xi^{-1} \text{ (up to dimensionless } O(1) \text{ factors)}$$

This identification is not imposed by hand but reflects the expectation that the same physical scale governing fact formation also governs the persistence of fact-induced field perturbations. The precise dimensionless coefficient awaits derivation from fold-interface dynamics.

10.2 The Kernel Amplitude A

The amplitude A controls the strength of the memory contribution. Within VERSF, κ -field source terms are not arbitrary: they are uniquely constrained to be functions of committed distinguishability, with source strength

$$S(\mathbf{x}, t) = \rho_{\text{committed}}(\mathbf{x}, t)$$

The amplitude A is therefore not an independent parameter but an effective quantity arising from the spatially extended source distribution. For an extended system, the effective kernel is obtained by integrating the point-source κ -field propagator over the source volume:

$$A = \alpha_{\kappa} \int_{\text{source}} \rho_{\text{committed}}(\mathbf{x}) W(\mathbf{x}) d^3x$$

where:

- α_{κ} is a dimensionless normalisation factor determined by the κ -field coupling (derivation in [Ref §5]),
- $W(\mathbf{x})$ is a geometric weighting function arising from the extended-source reduction of the retarded propagator. It is not an arbitrary function introduced to absorb unknowns: its functional form is uniquely fixed by the propagator geometry and is derived explicitly in [Ref §4].

This identification explains why the algebraic $1/\tau$ kernel arises in extended systems: it is the cumulative effect of spatially distributed commitment events, not a property of isolated point sources. The numerical value of α_{κ} is not yet computed; it is an identified open item in the κ -field coupling programme.

10.3 The Coupling Strength ε

The parameter ε governs the overall magnitude of the memory correction. Rather than treating it as an arbitrary small constant, ε is more naturally identified with the sensitivity of the local decay dynamics to κ -field perturbations. In the decay context this specialises to

$$\varepsilon \equiv d\lambda_{\text{eff}} / d\kappa |_{\{\kappa_0\}}$$

i.e. the derivative of the effective decay rate with respect to the local κ -field value, evaluated at the background κ_0 . This is the concrete realisation in the decay setting of the more general functional derivative

$$\varepsilon \sim (\delta F / \delta \kappa) |_{\{\kappa_0\}}$$

where F is the evolution functional whose κ -field variation generates the memory term; the two expressions are equivalent in the decay context.

χ -dependence. The response coefficient is expected to depend on the local commitment density relative to the CCC threshold $\chi(L) = \rho L^4/\hbar c$:

$$\varepsilon = \varepsilon(\chi)$$

In high-density regimes ($\chi \gg 1$), the system is far above the commitment threshold; small perturbations in κ have negligible effect on an already robustly committed system, so $\varepsilon \ll 1$. Near the threshold ($\chi \sim 1$), even small perturbations in κ can significantly affect whether commitment occurs, and ε is expected to increase markedly. The smallness of ε in ordinary macroscopic conditions is therefore not an arbitrary assumption but a structural consequence of operating far above the CCC commitment threshold. This provides an independent physical justification for the perturbative expansion of §4.

10.4 Summary and Epistemic Status

The three parameters of the memory-modified decay model admit the following structural identifications:

| Parameter | Structural identification | Status |
|---------------|--|--|
| m | $m \sim \xi^{-1}$, tied to CCC coherence scale | Structurally grounded; dimensionless coefficient open |
| A | $A \sim \alpha_{\kappa} \int \rho_{\text{committed}} W d^3x$ | Structurally grounded; α_{κ} not yet numerically derived |
| ε | $\varepsilon \sim d\lambda_{\text{eff}}/d\kappa _{\{\kappa_0\}}$, χ -dependent response | Structurally grounded; functional form of $\varepsilon(\chi)$ open |

Epistemic precision. The claim of this section is not that the parameters are numerically determined — they are not, and it would be incorrect to say so. The claim is that each parameter is *structurally grounded*: its physical meaning is fixed by established VERSF sectors (the CCC

analysis, the κ -field source coupling, and the threshold response framework), and its derivation is an identified open problem rather than a conceptual gap.

The key point for experimental purposes. The late-time algebraic tail is independent of the precise numerical values of m , A , and ε . It follows solely from the structural form of the kernel — specifically, the $1/\tau$ asymptotic decay established in §3. The existence and functional form of the $1/t$ oscillatory correction in equation (9) hold for any nonzero values of these parameters; what the parameters control is the amplitude and frequency of the tail, not whether it is present. This insulates the main prediction from the objection that the constants have not yet been computed.

Closing the loop. Substituting the structural identifications $m \sim \xi^{-1}$, $A \sim \alpha_{\kappa} q_{\text{eff}}$, and $\varepsilon \sim d\lambda_{\text{eff}}/d\kappa_{\{\kappa_0\}}$ into equation (9) shows that the observable tail amplitude is determined entirely by three physical quantities: committed distinguishability (through A), coherence scale (through m), and κ -field response sensitivity (through ε). No additional free parameters enter.

The non-Markovian decay correction is therefore not an ad hoc modification of quantum decay theory, but a direct consequence of the same structural principles that govern fact formation, field sourcing, and emergent spacetime dynamics within VERSF.