Individual Completion of Metastable Decay: A Constructive Program after Einstein's *Reply to Criticisms*

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Draft for circulation. The numerical analog is supplied as a companion program; it is a schema, not a nuclear model.

Abstract

Einstein's 1949 *Reply to Criticisms* does not propose a hidden-variable dressing of the existing quantum formalism. It states a successor-theory demand: a complete description of the individual situation whose laws, per se, have nothing to do with statistics; statistical quantum theory would then stand to that description as statistical mechanics stands to classical mechanics. This paper converts that demand into a predictive primitive for the case Einstein used as his example—the decay of a metastable individual and the mark it writes. The primitive is a first-event time T*(S) fixed by a complete individual state S. Laboratory preparations specify only a coarse cell S_coarse; the unread remainder S_perp decides the instant. A deterministic analog (metastable well plus a finite Fourier background with definite phases) is integrated: specified phases yield a unique T*; unstructured phases yield a waiting-time histogram; partial readout of phases narrows Var(T*). The program is thereby empirically constrained without being forced to sit Bell's examination for local completions of the quantum correlators. Nuclei are not the first test. Characterized analog systems are.

Keywords: Einstein 1949 Reply; incompleteness; individual description; metastable decay; arrival time; field ontology; analog tests

1. The problem as Einstein stated it

In the *Reply to Criticisms* Einstein grants the empirical success of statistical quantum theory and refuses the claim that the ψ-function is a complete description of an individual system. His working example is the radioactive atom, later coupled to a registration strip. The wavefunction assigns probabilities for when the particle is found outside the barrier, or where the mark appears. Treating those probabilities as the last word about *this* atom, or *this* mark, forces an implausible story once the situation is macroscopic: either the individual has a definite decay time that the theory does not contain, or the mark on the strip does not exist until it is looked at. Einstein takes the first horn. The ψ-function describes an ensemble. A complete theory of the individual would have to introduce conceptual elements that lie outside the present scheme.

He then states the successor relation that organizes this paper. If a complete description of individuals is achieved, statistical quantum theory would take, within future physics, an approximately analogous position to that of statistical mechanics within classical mechanics. The laws of the complete description would represent relations among all the conceptual elements of that description which, per se, have nothing to do with statistics. He is rather firmly convinced that the development will be of this type, and that the path will be lengthy and difficult.

Two remarks of method follow immediately. First, the demand is not that one recover the Born-rule correlators of the present theory by adjoining a parameter λ to ψ. Einstein rejected that project as too cheap when Bohm published it. Second, the demand is not a proof that nature is deterministic. It is a consistency requirement across scales, and a research program: do not declare an incomplete description final while treating the laboratory record as definite.

2. Two texts, two examinations

The 1935 Einstein–Podolsky–Rosen argument works inside the existing theory with a criterion of reality and a definition of completeness: if a value can be predicted with certainty without disturbing a distant system, that value is an element of reality; quantum mechanics does not contain it; therefore the description is incomplete. The 1949 *Reply* runs a different brief. The ψ-function as complete-for-the-individual makes the macroscopic record ontologically unstable. The honest reading of the present theory is ensemble-only. The future theory should describe the individual without statistics as primitive. The continuum field program is Einstein's candidate direction, not a λ-supplement.

Much of the later foundations literature tries the 1949 text under 1935 rules, then grades the result with Bell's 1964 constraint on local completions of the quantum predictive structure. That composite is teachable. It is not forced by the *Reply*. Bell constrains local hidden-variable models of the existing correlators. A program that refuses those correlators as the final list of what an individual system *is* is not thereby refuted. It is simply unwritten. The purpose of this paper is to write the unwritten part far enough that it predicts a number.

3. Axioms of individual completion

The following are constraints on a successor, not slogans about the present algorithm.

A1. Individual completeness. The state of this metastable system on a time-slice is a definite configuration of the fundamental field (and of the geometry on which the field is defined). There is a fact about when the mark is written. Statistical quantum theory does not contain that fact.

A2. Laws without primitive chance. The dynamical law relates elements of the complete description. Probability is not a term in the law. It appears when the complete description is replaced by a cell in a coarse partition—the laboratory preparation.

A3. Events are field facts. Decay is the first crossing of a local functional of the field. The counter pulse and the ink mark are concentrated regions of the same field. Measuring instruments are not a second ontology.

A4. Time belongs to the description. The decay instant T* is an event time on the worldtube of the system. Orthodox quantum mechanics has no unique, generally accepted arrival-time observable. That absence is a symptom of incompleteness, not a prohibition on T*.

A5. Statistics survive as coarse-graining. When many systems share a coarse cell and differ in unread structure, first-exit times may look exponential at that grain. This is the kinetic-theory relation Einstein asked for. It is not the demand that one run with one setting produce a CHSH combination.

A6. Predictive content is conditional on S. A theory that only outputs a rate Γ is still the incomplete theory. Completion means: narrow S, narrow T*. If better individual data never shrink the uncertainty in T*, the program has failed.

4. The prediction primitive

Write the complete individual state at a reference slice as a decomposition

$$S = S_{coarse} \oplus S_{perp} .$$

S_coarse is what a preparation fixes: an energy window, a lump roughly in a well, a barrier of roughly given height. S_perp is the remainder: the fine profile of the lump and a definite realization of whatever background field the theory posits (mode phases, residual radiation, geometric micro-structure). The laboratory does not presently list S_perp. That is not an argument that S_perp is unreal.

Let ϕ_S be the solution of a deterministic field equation with Cauchy data S. Define an event functional $E[\phi]$ on an exit surface, for example the flux through that surface, and a threshold E_c set by the same ontology (the writing of a mark). The prediction primitive is

$$T^*(S) = \inf \{ t > t_0 : E[\phi_S](t) \geq E_c \} .$$

There is no probability in that sentence. If S is given, T* is given. If only S_coarse is given, T* is distributed over the fiber of S_perp compatible with the preparation. The statistical theory is the theory of that fiber.

Three candidate remainders, ranked by fidelity to Einstein's field program rather than by present popularity:

Rank	Remainder S_perp	How T* is fixed	Cost
1	Fine lump profile plus a definite background-field realization (mode phases)	Classical threshold crossing in a driven nonlinear field	Must identify the background (geometry, residual radiation, vacuum as a real field)
2	Crest location inside a guiding field	First crossing of a surface is unique	Guiding structure is extra furniture; Einstein judged Bohm too cheap
3	Planck-scale ontological microstate	Ontological states permute; an undecayed class maps to a decayed class at a definite step	T* exists in principle; no access path yet

Table 1. Candidate ontic remainders. The near-term constructive work of this paper occupies Rank 1.

5. A constructive analog

A nucleus is the last test, not the first. What is required immediately is a schema in which T*(S) can be computed, in which unread S_perp reproduces a waiting-time law, and in which partial readout of S_perp narrows Var(T*). The following one-dimensional analog supplies that schema. It is not a model of α-decay. It is a model of the logical relation Einstein named.

5.1 Dynamics

Let q(t) stand for the crest coordinate of a concentrated lump. The conservative force derives from a biased well with a finite barrier. Superposed on it is a background drive with a finite number of definite Fourier phases—the analog of S_perp:

$$m\, d^2q / dt^2 = F(q) + \kappa \Sigma_k A_k \sin(\omega_k t + \theta_k) .$$

The event is the first passage of q through an exit coordinate q_exit. Given (q(0), p(0), $\{\theta_k\}$), the ordinary differential equation returns exactly one first-exit time, or none within a cutoff. A laboratory preparation that fixes only a coarse window around (q(0), p(0)) and leaves the phases unspecified is an incomplete description of this individual.

5.2 Two individuals, one coarse well

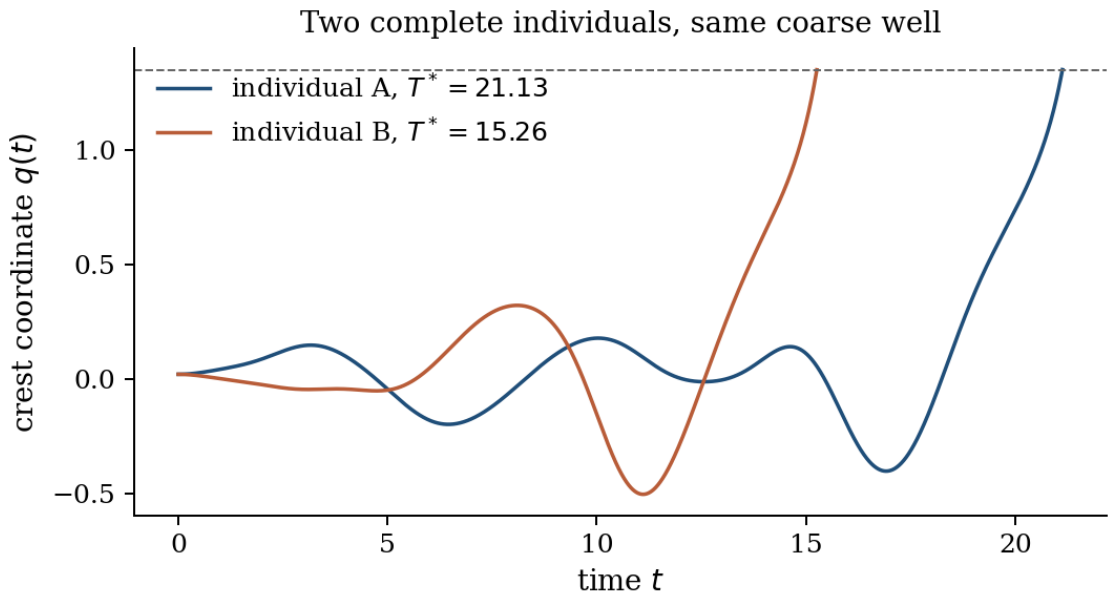


Figure 1. Two complete individuals. The static well and the amplitude spectrum of the drive are the same; only the background phases differ. Each run has a definite crest trajectory and a definite first-exit time T.*

This is the Brownian-motion relation made visible. The molecules of 1905 have become the unread phases. The diffusion equation of 1905 has become the waiting-time law of the unread ensemble. The individual path was always there.

5.3 Unread remainder and the statistical shadow

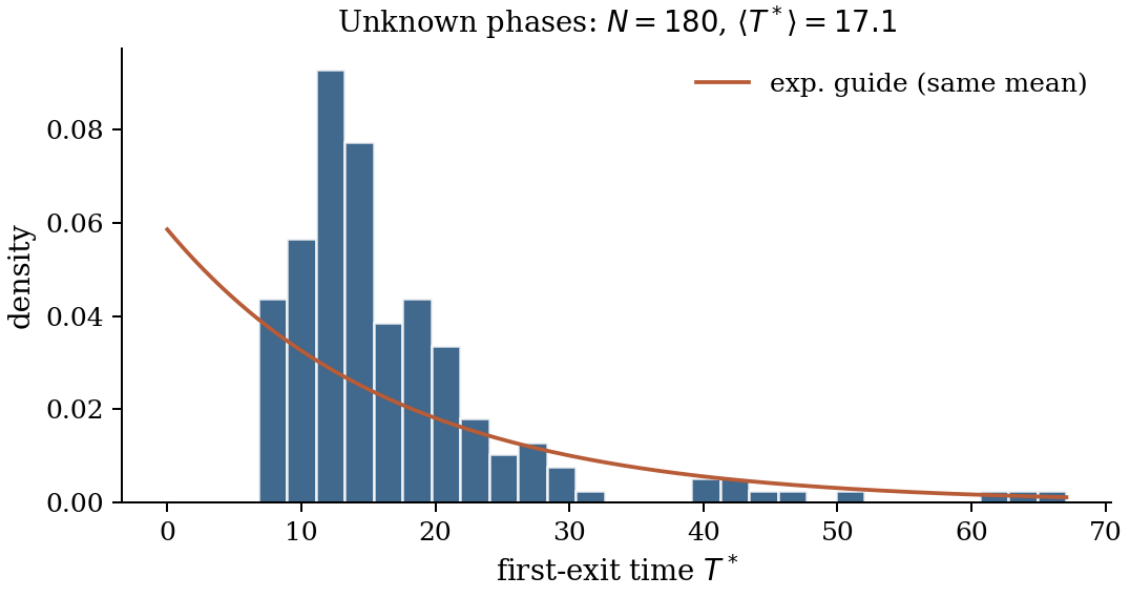


Figure 2. Histogram of first-exit times when phases are drawn from an unstructured prior on the torus, the analog of a laboratory preparation that does not control S_perp. An exponential with the same mean is drawn as a guide, not as a fitted law. The point is architectural: statistics appear when the complete description is withheld.

5.4 Conditional narrowing

Axiom A6 requires more than an ensemble plot. If the remainder is physical, reading more of it must shrink the uncertainty in T*. Figure 3 reports that test inside the analog. A reference phase vector is held fixed. The first m phases are treated as known; the remaining N−m phases are resampled. The variance of T* over the unread block falls as m increases, and collapses when the description is complete.

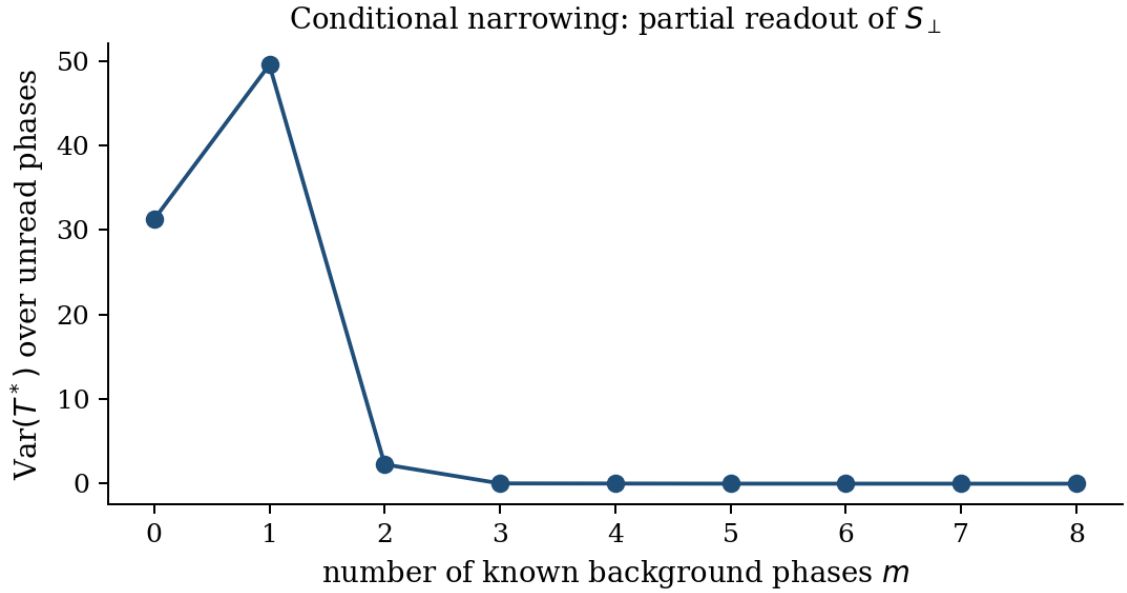


Figure 3. Partial readout of S_perp. The vertical axis is the variance of T induced by the still-unread phases. This plot is the falsifiable heart of the program. A proposed completion that cannot produce a downward curve of this kind in some analog has no predictive content.*

6. From analog to field

Einstein's own positive program in the later pages of the *Reply* is not an oscillator. It is a continuous field on a four-dimensional continuum, generally covariant, without singularities, with particles not inserted as extra objects beside the field. Measuring rods and clocks are not to stand outside the field. The analog of Section 5 is a scaffold. The intended lift is:

$$\partial_t^{\,2}\,\phi = \Delta\phi - V'(\phi) + \varepsilon\, N(\phi, \partial\phi)\ ,$$

where a metastable lump is a regular concentrated solution, the barrier is a feature of V, the remainder N is a local coupling to a definite background (or to finer ripples of ϕ itself), and the mark is a second lump written when a flux functional on an exit surface crosses threshold. No collapse. No external apparatus. The same ontology on both sides of the 'measurement.'

Several costs of the analog must be paid on the way up. The present drive is put in by hand; in a finished theory it must be the same field. The analog is 1+1 and not generally covariant. Locality of the PDE is cheap here because Einstein's distant-correlation problem has not yet been posed inside the complete description. That problem is real. It is a problem for a successor that already assigns T* to each lump, not a reason to withhold T*.

7. An empirical sequence

A completion that cannot be squeezed is commentary. The test is conditional narrowing in systems whose remainder is partly readable.

Step 1. Freeze the event definition: first crossing of a specified surface or functional. Do not shop among POVMs until the ontology is fixed.

Step 2. Write T*[S_coarse, S_perp] for one analog whose background can be diagnosed: an optical trap with a controlled noise floor, a Josephson washboard with a characterized drive, a false-vacuum analog in a condensate, an attosecond barrier in a measured field.

Step 3. Prove the coarse-grain limit: an unstructured average over the remainder yields a waiting-time law whose rate is set by barrier data. This is the statistical-mechanics analogy made calculable.

Step 4. Partial readout. Measure a slice of S_perp. Predict an interval I for T*. Increase the measured slice. I must shrink. If it does not, Rank 1 is wrong for that analog.

Step 5. Promote the analog to a field lump so that the mark is written in the same field.

Step 6. Only then ask whether two distant lumps can inherit correlated remainders from a common preparation without a nonlocal term in the field equation. That is Einstein's hard problem. It is not the entrance examination.

To claim an exact decay instant for a prepared uranium nucleus tomorrow would be fraud: S_perp is not readable there. To claim an exact instant for a characterized analog, given measured phases, is a physics paper. The program is ordered so that the fraud is not required.

8. What the program refuses

It refuses to start from ψ and add λ so that the Born correlators are recovered by construction. That is a different project, with a different literature and a different theorem. It refuses to treat the decay rate Γ as fundamental and T* as meaningless. It refuses to place the counter outside the field. It refuses the homework assignment 'give one setting A and exhibit the CHSH combination.' One run produces one mark at one time. It refuses the inference from 'we cannot read S_perp today' to 'S_perp does not exist.'

If a later, generally covariant, singularity-free field theory makes distant marks correlate as quantum mechanics reports, that will be a discovery inside the complete description. It is not a precondition for writing T*(S). Asking the missing individual theory to perform a correlator audit is of a kind with asking kinetic theory, before molecules were tracked, to reproduce every coefficient in a particular Fourier series for a gas before one is allowed to believe that molecules have positions.

9. Relation to neighboring programs

Bohmian mechanics already assigns definite crossing times. That is a virtue relative to textbook quantum theory, which does not. It is not Einstein's program. The guiding wave is extra furniture; the construction is built to reproduce the present statistical scheme; Einstein's recorded judgment was that the way seemed too cheap. The present paper borrows the *event* (first crossing) and declines the *architecture* (pilot wave as fundamental).

Stochastic electrodynamics treats the vacuum as a real classical field with a Lorentz-invariant spectrum. That is closer in spirit: the unread structure is a field. In typical presentations the field is itself an ensemble. The completion envisaged here requires, for each run, one realization.

Ontological models of the 't Hooft type make the stronger claim that quantum amplitudes are bookkeeping for a deterministic permutation of micro-states. They satisfy A1–A2 in principle. They do not yet offer a readable S_perp at laboratory scales. They belong to Rank 3.

Unified field theory as Einstein pursued it remains the intended ceiling: regular, particle-like solutions of a single field; instruments inside the field; statistics only as ignorance. The analog is a ladder, not a substitute ceiling.

10. Conclusion

The *Reply* is a program, not a model. The program has a success criterion that the later literature mostly declined to use: a complete individual description whose laws do not contain chance, from which the statistical theory reappears as the theory of unread structure. For metastable decay that criterion is an exact first-event time T*(S).

This paper supplied the missing primitive, a set of axioms that keep the primitive faithful to 1949 rather than to 1935-plus-1964, a computable analog in which specified remainders yield specified instants, and an empirical sequence whose first honest tests are characterized analogs rather than nuclei. The companion integration shows the three required behaviors on one page: individual trajectories with definite T*, a statistical shadow when the remainder is unread, and variance collapse under partial readout.

Whether nature's unread structure is a background field, a finer ripple of the same field, or something that will force the continuum itself to be retired is not settled here. Einstein left that open; he kept the continuum because he had no organic replacement. What is settled is the shape of the question. The question is not 'how

does this analog reproduce the Bell correlators.' The question is whether a complete individual state, once even partly read, tells you when the mark is written.

Acknowledgments

The reading of Einstein used here is the 1949 *Reply* as a whole, including the later pages on the field program, measuring instruments, and the continuum, not the quantum section isolated and re-graded as an EPR appendix.

References

Einstein, A. (1949). Remarks concerning the essays brought together in this co-operative volume. In P. A. Schilpp (Ed.), *Albert Einstein: Philosopher-Scientist* (pp. 665–688). Open Court.

Einstein, A., Podolsky, B., & Rosen, N. (1935). Can quantum-mechanical description of physical reality be considered complete? *Physical Review, 47*, 777–780.

Einstein, A. (1905). Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen. *Annalen der Physik, 17*, 549–560.

Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics Physique Fizika, 1*, 195–200.

Bell, J. S. (1987/2004). *Speakable and Unspeakable in Quantum Mechanics* (2nd ed.). Cambridge University Press. See especially the appendix addressing Jammer.

Jammer, M. (1974). *The Philosophy of Quantum Mechanics*. Wiley.

Born, M. (Ed.). (1971). *The Born–Einstein Letters*. Macmillan. (Einstein on Bohm: 'that way seems too cheap to me.')

Bohm, D. (1952). A suggested interpretation of the quantum theory in terms of 'hidden' variables. *Physical Review, 85*, 166–193.

Leavens, C. R. (1990). Arrival-time distributions. *Physical Review A*; and subsequent Bohmian tunneling-time papers.

Coleman, S. (1977). Fate of the false vacuum. *Physical Review D, 15*, 2929–2936.

de la Peña, L., & Cetto, A. M. Work on stochastic electrodynamics and the zero-point field as ontic structure.

't Hooft, G. (2016). *The Cellular Automaton Interpretation of Quantum Mechanics*. Springer.

van Dongen, J. (2010). *Einstein's Unification*. Cambridge University Press.

Maudlin, T. (1995). Three measurement problems. *Topoi, 14*, 7–15. (On additional-variables theories versus hidden-variables terminology.)

Companion code: ontic_decay_toy.py (prediction primitive and ensemble); make_figures.py (Figures 1–3).