What the entropic clock counts

Settlements, kept time and the arrow in an isolated condensate

Manuel Alfaro

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Target: Giovanni Barontini, *Testing the problem of time with cold atoms*, Physical Review Research **8**, L022047 (2026), published 11 June 2026; DOI 10.1103/1h9j-df4k (L1–L10, L21).

Abstract

Barontini [1] realizes a well-isolated Bose–Einstein condensate of about 2.4×10^4 ^{87}Rb atoms in a conservative trap divided by a thin optical barrier into an observed and an unobserved region, with no measurable dissipation or loss over the roughly 100 ms of the experiment (L11–L13, L132–L142). From the observed region's coarse-grained entropy he builds an entropic time that orders its events across repeated cycles of filling and emptying, and he derives a Schrödinger equation in that time which reproduces the measured width (L15–L18). Fundamental Density Theory (FDT) is a true extension of general relativity and quantum mechanics. With the entropy per atom of order unity, the entropic time counts, weighted by that entropy, the atoms that enter and leave the observed region: the record of the condensate's successive system-wide settlements. Each atom keeps its own time by circulating; the condensate's clock factor, at conserved count and fixed entropy per count, is its enthalpy per count, the reading of its flow. The arrow is the settlement's: events do not commute, and a process run backward is never the mirror of the forward event. For the same data FDT returns the ordering, the stopping of entropic time when no atoms cross, the constant total entropy and the measured width. One prospective prediction concerns the Loschmidt echo the source proposes: the residual of the observed region's count after a reversed evolution.

1 Framework

The target is experimental. Measured quantities are measurements; the reduced model, the analogy with minisuperspace cosmology and the numerical solution are the source's constructions and are read as such. Physical loci L refer to the line-numbered text record of the published Letter (591 lines, extracted from the publisher's PDF, SHA-256 prefix `7c2dd0eacfd9e8a7`). Equation numbers refer to the same Letter unless another source is named. Core clause numbers refer to the locked definitions and invariants [2]. FDT is a true extension of general relativity and quantum mechanics.

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A clock, a length, a source

In 0.1 the omnium has energy E, mass m, electric and magnetic response coefficients ε_0, μ_0, and strand rate c. A thread covers length d in duration t, and one state sets all four readings:

$$E/m = c^2 = 1/(\varepsilon_0\mu_0) = (d/t)^2.$$

For a closed pattern of rest energy $E_0 = mc^2$ the period is $T_0 = h/E_0$; Planck's constants are h and $\hbar = h/(2\pi)$. A closed pattern's strand runs at c on a helix: the translation square and the circulation square sum to the strand square, and the pattern keeps time by circulating, $c\,\mathrm{d}\tau = u\,\mathrm{d}t$ for circulation rate u (0.1d). An open stroke runs at c and keeps no time (I-2). Clocks and rulers are closed patterns of the omnium; their kept time and thread length move together so that d/t measured on the spot stays c, and there is no background metric that clocks and rulers merely read: their adjustment is the geometry (0.1a). Every physical time belongs to a pattern: the time it keeps, a pattern-to-probe measurement, or the floor (0.1b).

Newton's constant is G. The force ceiling, the Einstein coupling and the floor obey 0.1a and 0.2:

$$F_{\max} = \frac{c^4}{4G}, \qquad \kappa = \frac{8\pi G}{c^4}, \qquad d_{\min}^2 = \frac{\hbar c}{F_{\max}} = 4\ell_P^2, \qquad t_{\min} = d_{\min}/c.$$

These are one-sided infima; the floor imposes no lattice of intervals.

Every step is a system-wide settlement: the global optimisation is solved at every step from the state the system is in, events do not commute, and a process run backward is never the mirror of the forward event (0.1a). A settlement is m-to-n and global; m and n count the components that enter and leave it, and a response is never computed particle by particle or pair by pair. The core names no objective for the optimisation; the reading of the entropic time given below is this analysis' reading.

Chart inventory and the force law

Write $\mathcal{M}$ for total gravitating energy in mass units, r_f for a field-point radius and $R_s = 2G\mathcal{M}/c^2$ for the source radius (0.3, 0.5). On A-1 the exterior coordinate is $\alpha_{\mathrm{ext}}(r_f) = R_s/r_f = \mathcal{M}c^2/(2F_{\max}r_f)$ on $R_s < r_f$, strictly inside the open unit interval (I-6). The interior chart, its cutoff r_c and the applications A-2 to A-5 enter no number here; no odds assignment is used (O-1, O-2, O-3). A laboratory pattern's window is small, and the small number is a correct reading (0.1c). For two nonoverlapping spherical supports of masses $\mathcal{M}_1, \mathcal{M}_2$ at centre separation d_{sep}, I-1 gives the exact monopole reduction

$$F = F_{\max}\,\alpha_1(d_{\mathrm{sep}})\,\alpha_2(d_{\mathrm{sep}}) = \frac{G\mathcal{M}_1\mathcal{M}_2}{d_{\mathrm{sep}}^2},$$

with no multipole or overlap remainder used here (O-5).

Density equivalence and the medium's clock factor

Mass, energy, pressure and temperature enter one total, each channel once (I-7):

$$\mathcal{M} = M + E/c^2 + PV/c^2 + aT^4V/c^2 + \ldots,$$

with P the pressure, V the volume, T the temperature and a the radiation constant. For a medium whose stress tensor has perfect form, with a conserved count N and fixed entropy per count, the clock factor $\mathfrak{m}$ of 0.1c is the enthalpy per count, $(E+PV)/N$. It is the reading of the medium's flow: it rescales the metric in which the flow is free, never the time kept by a clock the medium carries; that clock runs on the lapse where it sits, and its thermal shift is the time dilation of its own thermal motion (0.1c). A clock factor never stands in an α, force, optical or density slot.

Notation guard

The source writes α for the slope of the observed region's mass with its clock field, $M(\phi) = \alpha\phi$ (L348), Λ for the entropy-dependent pump of its Eq. (6) (L367–L370), Φ for a global phase and V for the barrier height as a fraction of its maximum (L268–L270). Here they are $\mathfrak{a}$, Π_{p}, Φ_{g} and $\mathcal{V}$; α is reserved for the FDT coordinate, V for volume. The source's σ is written σ_τ, its entropic-time unit (L246). Its ϕ (the observed region's centre of mass along x), a (the width coordinate), Σ (the condensate's root-mean-square width), Γ (the gain–loss rate), S and s (the observed region's entropy and the entropy per atom) and N (the number of atoms in the observed region) keep their meanings; the total count is N_{tot}.

2 System chart

The record: a condensate of $N_{\mathrm{tot}} \simeq 2.4 \times 10^4$ ^{87}Rb atoms oscillates along x in a crossed optical dipole trap at 1070 nm and 1550 nm with trapping frequencies $\simeq 2\pi \times (25, 70, 70)$ Hz; a barrier about 8 μm wide, made with 675 nm light from a digital micromirror device, sits in the plane $x = 0$ (L132–L139). Over the roughly 100 ms of interest the system shows no measurable dissipation or particle loss and evolves with a time-independent Hamiltonian, $\hat{H} = \hat{H}_{\mathrm{bright}} + \hat{H}_{\mathrm{dark}} + \hat{H}_{\mathrm{coupling}}$ (L139–L146). The maximum coupling is $H^{\max}_{\mathrm{coupling}}/k_B \simeq 255$ nK (L271–L272).

FDT reads the components as follows. Each ^{87}Rb atom is a closed braid configuration of the omnium (I-5): it keeps its class when it crosses the barrier, and its rest energy is read, never derived; no form of the confinement operator is written here (O-9). With the atomic mass $m = 1.44316 \times 10^{-25}$ kg [3], the rest energy is $E_0 = 1.29705 \times 10^{-8}$ J and the period it keeps is $T_0 = h/E_0 = 5.1086 \times 10^{-26}$ s. The condensate is one pattern of closed patterns, a medium; the barrier divides its support into two regions, never two containers (0.1b). The trap, the barrier and the imaging light are strokes of the one carrier (I-2); they keep no time and they carry the potentials the atoms move in.

The gravitational windows are small and correct (0.1c, I-6). On A-1 an atom read at a length of 5.3×10^{-9} m has $\alpha_{\mathrm{ext}} = 4.04 \times 10^{-44}$; read at 10^{-6} m it has 2.14×10^{-46}; the whole condensate read at 10^{-5} m has 5.14×10^{-43}. Two halves of the condensate, 1.732×10^{-21} kg each at a centre separation of 10^{-5} m, attract with $F = 2.0 \times 10^{-42}$ N (I-1); their mutual potential energy, 2.0×10^{-47} J, is 5.7×10^{-18} of the maximum coupling energy 3.52×10^{-30} J. The barrier, never the two regions' gravity, sets the exchange. The laboratory lapse, the metric's response to the stress tensor (I-3), is common to both regions: across the barrier's width along the local gravitational acceleration the fractional difference is $g\,w/c^2 = 8.73 \times 10^{-22}$ for $w = 8\,\mu$m. Curvature is read between neighbours (I-3a); at

this precision the two regions share one clock factor of the gravitational window, and the comparison of the regions carries none of it.

3 Observation map

Isolation and the timeless Hamiltonian. The source realizes an isolated system with a time-independent Hamiltonian as an experimental analog of the Wheeler–DeWitt problem, in which the constraint $\hat{H}\Psi = 0$ admits no external parameter for ordering change (L23–L26, L80–L84, L139–L142). In FDT there is no background time that clocks merely read: the condensate's own patterns keep time, and every step is the condensate's system-wide settlement (0.1a, 0.1b).

Two regions and the gain–loss term. The source describes the observed region by $\hat{H}^{\mathrm{eff}}_{\mathrm{bright}} = \hat{H}_{\mathrm{bright}} - i\hbar\Gamma/2$, the last term accounting for atoms gained and lost across the barrier, and writes the mean-field Hamiltonian of its Eq. (2) with the normalization set to the observed count N (L156–L203). FDT reads each change of N as a component entering or leaving the observed region in the condensate's settlements; the count is a record of those settlements, solved for the whole condensate at every step (0.1a).

The analog of minisuperspace. In Eq. (2) the source takes the centre of mass ϕ as a massive scalar clock field, the radial coordinate as a scale factor and the Σ^{-3} term as a dust potential, and notes that ϕ is not monotonic in a recollapsing region, so that no single arrow spans one cycle when ϕ is the clock (L204–L231). FDT accepts the reduced model as the source's model. A coordinate that turns back at each recollapse orders nothing by itself; the order of events is the order of settlements (0.1a).

The entropic time. The source defines

$$\tau(\lambda) = \frac{\sigma_\tau}{k_B}\int_\lambda \left|\frac{\mathrm{d}S}{\mathrm{d}\phi}\right| |\mathrm{d}\phi| \qquad \text{(Eq. (3), L237–L244)},$$

which keeps its direction as long as $\mathrm{d}S$ and $\mathrm{d}\phi$ share a sign (L248–L249). He measures N, ϕ, the entropy per atom s and the width Σ from every image, takes $S = Ns$, and reports that s stays of order unity, so that entropy flow follows atom-number dynamics (L256–L264, L566–L569). On that record, with s fixed,

$$\tau = \frac{\sigma_\tau}{k_B}\int |\mathrm{d}S| = \frac{\sigma_\tau s}{k_B}\int |\mathrm{d}N|.$$

The entropic time counts, weighted by s, the atoms that enter and leave the observed region. FDT reads that count as the observed region's record of the condensate's settlements (0.1a); this is the analysis' reading of the count, and it needs no density coordinate.

Three readings of time in one condensate. Kept time belongs to each atom: its strand circulates and its period is $T_0 = 5.1086 \times 10^{-26}$ s, whether or not any atom crosses the barrier (0.1d, I-5). The condensate's clock factor is its enthalpy per count, at conserved total count and fixed entropy per count (0.1c, I-7): the reading of its flow, never the rate of a clock it

carries. The entropic time is the settlement record of the observed region. The three are kept apart: the entropic time stops when no atoms cross (L284–L286, L301–L303), while every atom keeps time through that interval.

The measured ordering. Over 120 ms with an image every 2 ms and several barrier heights, τ grows monotonically almost everywhere; its slope with laboratory time follows the entropy flow; the relative 1σ statistical uncertainty of each point is about 5%; and the entropy of the whole system is constant within the error bars (L256–L288). Ordered by τ, the measured ϕ and Σ follow the laboratory order except for a few wiggles where $\mathrm{d}S$ and $\mathrm{d}\phi$ change sign under coarse sampling (L289–L295). At low barrier the observed region fills and empties cyclically, no entropic time elapses between one emptying and the next filling, the clock field is bounded by the barrier's thickness, and at $\mathcal{V} \simeq 1$ the evolution stops cycling and the entropic time stops (L296–L312). FDT accepts every measured value. A constant total entropy with a growing coarse entropy of one region is one settlement record read from inside: the observed region's count changes while the condensate's state is solved as a whole at every step (0.1a).

The Schrödinger equation in entropic time. From the stationary equation of the observed region, a Feshbach–Villars decomposition keeping the onward solutions and the definition of τ, the source obtains

$$i\hbar\,\partial_\tau \psi(\tau, a) = \Phi_{\mathrm{g}}(\tau)\,\psi(\tau, a) + \Pi_{\mathrm{p}}(\tau)\,H_{\mathrm{geom}}\,\psi(\tau, a) \qquad \text{(Eq. (6), L336–L365)},$$

with $\Phi_{\mathrm{g}} = \mathfrak{a}\omega\phi^2\,\mathrm{d}_\tau\phi$ a global phase and $\Pi_{\mathrm{p}} = (\partial_\phi S)^{-1} k_B/(\sigma_\tau \omega\phi)$ an entropy-dependent energy pump; strictly unitary evolution returns only at zero entropy flow, and the equation is undefined where no entropy flows (L367–L390). Solved by split-step Fourier on 8192 sites over 200 μm with $\mathrm{d}\tau = 25\,\sigma_\tau$ for $250 \times 10^3\,\sigma_\tau$, it reproduces the measured width at $\mathcal{V} \simeq 0$ (L391–L403). In FDT Newton, general relativity and quantum mechanics are one state read through one chain (I-4): the observed region's evolution, read against its own settlement record, returns the same equation and the same width. The pump's derivative hands energy between the width coordinate and the exchange; each channel enters $\mathcal{M}$ once (I-7). The source reads the wavefunction's spread as a superposition; FDT reads superposition as ignorance of helical phase at observation, and it returns the same Born frequencies (I-4).

Thermal time and the proposed tests. The source relates its construction to the thermal time hypothesis and lists further tests: comparisons of different internal clocks, a controlled bounce, accurate tests of reversibility through a Loschmidt echo, analog black holes and tunneling between the regions (L421–L447). In FDT the temperature and pressure of a medium at zero net count are its clock factor (0.1c, I-7); that factor is the reading of the medium's flow, and the entropic time is a record of settlements; the two coincide in no limit used here. The Loschmidt echo tests the settlement's direction directly; it is the prediction below.

4 Cone-position translation

Source term	FDT reading
Wheeler–DeWitt constraint, no external time	no background metric that clocks merely read; the system's own patterns keep time (0.1a)
observed and unobserved sectors	two regions of one support (0.1b)
gain–loss term $-i\hbar\Gamma/2$	components entering and leaving the observed region in each settlement (0.1a)
entropic time τ	the observed region's settlement record, weighted by s
clock field ϕ	a coordinate of the observed region, which turns back at each recollapse
scale factor, width Σ	the observed region's extent
"big bang", "big crunch"	the observed region's filling and emptying; FDT has no singularity anywhere (0.8)
"heat death" at $\mathcal{V} \simeq 1$	a stationary record: no atoms cross, and no entropic time elapses
arrow of time	settlements do not commute; a process run backward is never the mirror (0.1a)
entropy pump Π_{p}	energy handed between the width and the exchange, each channel once (I-7)
thermal time	the medium's clock factor, the reading of its flow (0.1c)

The atoms keep their class across the barrier; nothing is re-braided, created or ejected (I-5). The standard account explains the arrow by a past hypothesis, an exceptionally low-entropy initial macrostate (L31–L33). FDT reads the arrow from the settlement itself: going forward needs only the state, and a process run backward is never the mirror of the forward event (0.1a). The source names the filling and emptying of the observed region a big bang and a big crunch, in analogy with minisuperspace cosmology (L116–L118). FDT reads them as loading and draining of one region of a laboratory condensate; it has no singularity anywhere (0.8), and the source reports that the observed region never reaches its analog singularity (L303–L306). The source reads the low-barrier exchange as almost entirely reversible (L299–L300). FDT reads each cycle as new settlements from the state the condensate is in; the near-return of the count is accepted as measured, and the echo below asks whether a reversed process returns it.

5 Prediction

P-1. The residual of a Loschmidt echo on the condensate

The source proposes accurate tests of reversibility through a Loschmidt echo (L443). Run the low-barrier cycle at $\mathcal{V} \simeq 0$ forward through the filling of the observed region for a fixed laboratory interval, apply the reversal, evolve for the same interval, and read the observed count. The statistic is the residual fraction $\delta = (N_{\mathrm{end}} - N_{\mathrm{start}})/N_{\mathrm{peak}}$, compared with δ_{model}, the echo of the source's Eq. (6) and its mean-field model for the same Hamiltonian with the measured imperfections of the reversal included. In the standard account a reversed process mirrors the forward one, so $\delta - \delta_{\mathrm{model}} = 0$. FDT predicts $\delta - \delta_{\mathrm{model}} \neq 0$: the reversed run is a new settlement from the state the condensate is in, never the mirror of the forward one (0.1a). This predicts existence; the sign and the size of the residual are to be derived (D-1).

Design: take the source's relative 1σ uncertainty of about 5% per point (L281–L282) as the per-run standard error of δ, and $n = 100$ independent runs. The standard error of the mean residual is $0.05/\sqrt{100} = 0.005$, and the decision boundary at three standard errors is 0.015. A mean residual farther than 0.015 from δ_{model} supports FDT; the two-sided false rejection is 0.0027 (0.00135 on each side). A mean residual within ± 0.015 of δ_{model} rules out a residual of 0.03 or more, the investigator's point, with power 0.99865. Reaching a boundary of 0.01 at the same per-run error takes 225 runs.

6 Cross-domain

The null cone. Chandrasekaran's quantization of vacuum general relativity defines a clock along an incoming null generator, set at the past cap [4]. An open stroke keeps no time (I-2); the clock and ruler that mark a cap are closed patterns of the medium (0.1a,b). The vacuum construction supplies the geometry of the spacetime phase; this condensate supplies time kept and recorded by closed patterns of the matter phase, with no external clock. The two are one substance in two phases (0.1, 0.8), and the problem of time they share is answered from inside in both.

Kept time in free fall. The same species keeps time in the quantum phase of free fall, where an interferometer counts the excess kept by the falling arm in the atom's own period [5]. That record reads kept time directly; this one reads the settlement record of a region; the period T_0 is common to both.

The arrow. Time's arrow points downhill: going forward needs only the state, and going back needs a new settlement that is never the mirror of the forward one [6]. The echo of P-1 puts that statement on a condensate whose entropy is constant as a whole.

7 Convergence statement

With the same trap, barrier settings, atom numbers, entropy method and imaging, FDT returns the measured record: the entropic time grows monotonically almost everywhere, flows faster with exchange and stops without it; the total entropy is constant within the error bars; the ordering of ϕ and Σ follows the laboratory order up to the reported wiggles; the low-barrier cycles, the bound on the clock field and the stationary end at $\mathcal{V} \simeq 1$ appear as measured; and the Schrödinger equation in entropic time reproduces the width at $\mathcal{V} \simeq 0$ (L256–L312, L391–L403). The map is the identity on the data: the entropic time is computed from the same $S = Ns$, and the reduced model and its solution are the source's. No FDT channel changes these numbers: the regions share the laboratory lapse to 8.73×10^{-22}, their mutual gravity is 5.7×10^{-18} of the barrier's energy scale, and the windows of the atoms and the condensate lie between 2×10^{-46} and 5×10^{-43}. Declining the past hypothesis, the cosmological names and the reading of the exchange as reversible changes no measured value. The one divergence is P-1, where 0.1a supplies the input the standard account does not contain: a reversed process is never the mirror of the forward one.

8 Status ledger

Row	Status
Record	Measured values accepted as reported (L132–L312).
Model	The reduced model of Eq. (2), its minisuperspace analogy and the solution of Eq. (6) are the source's (L156–L403).
Reading	The entropic time as the observed region's settlement record is this analysis' reading; the core names no objective for the settlement (0.1a).
Window	The clock factor as enthalpy per count rests on a stress tensor of perfect form at conserved count and fixed entropy per count (0.1c); the source reports s of order unity (L566–L569).
P-1	Designed at the investigator's point, a residual of 0.03 with $n = 100$ runs; predicts existence only.
D-1	To be derived: the sign and size of the echo residual, from the settlement's dynamics.
O-9	No form of the confinement operator is written; the rest energy of ^{87}Rb is read.
O-1, O-2, O-3, O-5	Enter no number here.

9 Conclusions

An isolated condensate orders its own events: the entropic time counts the atoms that cross between two regions of one support, and it stops when none cross. In FDT that count is the record of the condensate's settlements, the atoms keep time throughout by circulating, and the condensate's clock factor is its enthalpy per count. The arrow is the settlement's, not a boundary condition's. FDT returns every measured value, and the Loschmidt echo the source proposes decides whether a reversed run mirrors the forward one.

References

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