Dark points that outrun light, read on the orbit lattice

An FDT analysis of Bucher *et al.*, "Superluminal correlations in ensembles of optical phase singularities", Nature **651**, 920–926 (2026)

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Fundamental Density Theory

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Core v6.8 (author lock 2026-11-20) · companion to *The orbit lattice: turning without travelling*

Abstract

Bucher and colleagues image the dark points of a phonon-polariton field in hexagonal boron nitride twenty nanometres and three femtoseconds at a time, and find that these points run at a mean of $(1.04 \pm 0.04)c$, with 29% of them faster than light and formally divergent rates at the moment two of them meet. The data stand as measured. Read on the orbit lattice of the locked core [1, 2], every site of the membrane turns on its own circle and none travels; a dark point is a place where the written turning cancels, and at each instant it is made by different sites. Its rate is a fifth rate of the phase law, beside the turning rate, the phase rate, the run and the drift, and it alone has no bound, because nothing moves with it. The rate is the ratio of how fast the turning changes at a place to the winding density there, the bivector grade of the map between neighbours, and it is unbounded where that grade vanishes: the tangency of two nodal lines, which the record sees as a pair of opposite charges meeting on a parabola. From that tangency alone the share of dark points faster than v falls as v^{-2}, and for a Gaussian field it is $v_0^2/(v_0^2+v^2)$, which returns the record's 29% and its 0.4% for free space from its two mean rates. The camera gets the rate of the minimum exactly right. A signal is a different measurement: a bit chosen at one place after the pattern is under way, and the time at which it is first read at another. FDT returns the record in full and no divergence follows. What it declines is the reading of a dark point as a thing that travels, accelerates and is attracted.

1 The record

The source [3] excites hyperbolic phonon-polariton wavepackets in a flake of isotopically pure $h^{11}BN$ with mid-infrared pulses and images the near field in an ultrafast transmission electron microscope. A reference interaction before the sample lets the microscope recover, at each place, the amplitude and the phase of the near-field component along the electron's path. Places where the amplitude is zero and the phase winds by $\pm 2\pi$ are the phase singularities; this manuscript calls them dark points. Table 1 lists what the source measures and prints.

The source states its own reading of the rates. Phase singularities "do not carry energy or information" and their apparent superluminal motion is "a pure kinematic property of the evolving phase landscape" [3]; the unbounded rates are a consequence of the continuity of the phase. It also carries the particle analogy of singular optics: a singularity is likened to a

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quantity	the source's value	locator
sample	$h^{11}BN$ flake, 40–50 nm thick, on a 20 nm SiN membrane; field of view 21×21 μm^2	Methods
excitation	mid-infrared pulses, $\lambda_0 = 7$ μm, field cycle $T = 23.3$ fs	p. 921
polariton wavelength	$\lambda_{PhP} \approx \lambda_0/11 \approx 630$ nm	p. 921
phase rate over group rate	$v_{ph}/v_g \approx 12 \pm 1$; group rate more than 100 times slower than c	pp. 921, 924
resolution	20 nm $\approx \lambda_{PhP}/30$ and 3 fs $\approx T/8$	p. 921
frames	285 raw frames over about 855 fs; each amplitude and phase reconstruction uses 15 sequential raw frames; a linear interpolation gives a 0.2 fs movie for tracking	Methods
ensemble	about 50 singularities tracked in each frame, charges ± 1	p. 923
mean rate	$\langle v \rangle \approx (1.04 \pm 0.04)c = 3.12 \times 10^8$ m s^{-1}; the Gaussian random wave model gives $(1 \pm 0.1)c$	p. 924, Fig. 3
share faster than c	29%; for free space at the same laser parameters $\langle v \rangle \approx 0.1c$ and 0.4%	p. 924
near a meeting	opposite charges approach on a curve that is a parabola in space and time, with formally divergent rates	Fig. 2
distance correlations	$g_{+\|+}(R)$, $g_{+\|-}(R)$ as for the particles of a liquid; joint distributions $P(v, R)$ match the model	Figs. 3, 4

Table 1: The record of [3]. The first six rows describe the platform and the measurement; the last five are its results. The largest average power on the sample is 12 mW at 1 MHz (Methods).[A01–A09]

particle, a meeting of opposite charges to the annihilation of a particle with its antiparticle, and the approach to an acceleration; the heavy tail of the rates is reported as the place where that analogy breaks. Sections 2 to 5 read the same record on the orbit lattice, where the analogy is never entered.

2 The membrane as an orbit lattice

What turns. The membrane is a lattice of two kinds of site, boron and nitrogen, closures whose saturated cores are the pinning sites of the material's Chladni volume (P-3), with the interstitial omnium between them. In the band the source drives, the two sublattices turn against each other, each holding the other in place: the turning held by inertia, with the holding term of the compound lattice [2]. The open stroke that drives it is the orbit wave of the omnium itself, and the phonon polariton is the two turning together: one carrier, in the lattice's geometry (I-2). No carrier crosses from site to site. The omnium between the sites settles each neighbour with the next (0.1a, 0.1b).

The phase law. In one orbit wave the site at $\mathbf{y}$ is displaced by $u_1 + iu_2 = \mathfrak{r}\, e^{i(\mathbf{k}\cdot\mathbf{y} - \omega t + \varphi_0)}$: a circle of radius $\mathfrak{r}$, a fixed fraction of a turn behind its neighbour. The edges of the flake launch many such waves at once, of one band of rates about $\omega_0 = 2\pi/T$ and of every direction in the plane. Their sum at a site is again a circle,

$$u_1 + iu_2 = \psi(\mathbf{y}, t)\, e^{-i\omega_0 t}, \qquad \psi(\mathbf{y}, t) = \sum_m \mathfrak{r}_m\, e^{i(\mathbf{k}_m\cdot\mathbf{y} - (\omega_m - \omega_0)t + \varphi_m)}, \tag{1}$$

whose radius $|\psi|$ and start azimuth $\arg\psi$ change slowly against the turning. Each site is $\psi = A\, e^{i\varphi}$, the projection of a helix on the plane normal to its axis: the quantum face, site by site (I-4). The microscope reads ψ through one component of the near field, and the amplitude and phase maps of the source are maps of these circles: how large each one is, and where on it the dot stands.

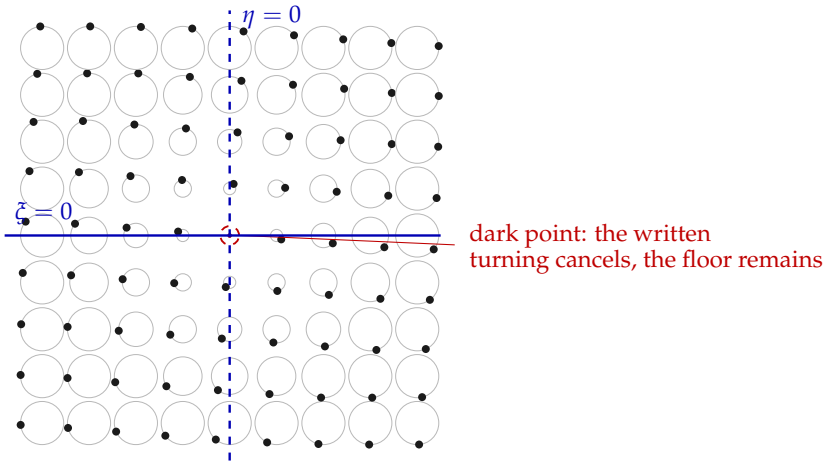

Figure 1: A dark point on the orbit lattice. Every site turns on its own circle; the circles shrink toward the place where the two nodal lines of the written turning cross, and the dots' azimuths wind once round it. No site is at the dark point for longer than the lines take to pass over it, and no site travels.

The unit. Each quantum of the field is one unit $\hbar$ of circulation of the whole pattern, the cost of circulation being $\omega = dE/dL$ [2]. Spread over the flake in view, of mass 4.2×10^{-14} kg for the density 2.1 g cm^{-3} of hBN and the mid thickness, one unit turns each of its 10^{12} cells on a circle of radius 3.1×10^{-18} m.[C02] The quantum has no place narrower than the lattice (0.1b). Were the whole of the largest pulse the source uses, 12 nJ, written into the flake in view, the circles would have the radius 2.0 pm and each dot the speed 0.54 km s^{-1}, $1.8 \times 10^{-6}\,c$.[C05]

Five rates. A phase law has a turning rate, a phase rate, a run and a drift [2]. A field of many orbit waves has a fifth: the rate at which a place of cancelled turning is re-chosen among the sites. Table 2 gives the five for this membrane.

rate	in the membrane	what has it
turning rate $\lvert\psi\rvert\,\omega_0$	below 0.54 km s^{-1}, $1.8 \times 10^{-6}\,c$	each site, on its own circle
phase rate ω/k	$\lambda_{\mathrm{PhP}}/T = 0.090\,c$	the fronts of one orbit wave
run $d\omega/dk$	$c/133$, from $v_{\mathrm{ph}}/v_g \approx 12$	a modulation of the turning; a written change
drift	0	no site leaves its circle
dark-point rate $\lvert\mathbf{v}_{\mathrm{d}}\rvert$	mean $1.04\,c$; no bound	a place, re-chosen at every instant

Table 2: The five rates of the membrane's turning. The first four are bounded; the strand rate c bounds every one that a strand has (0.1d). The fifth belongs to no strand.[A04–A06]

Over one micrometre light takes 3.34 fs, a written change running at $c/133$ takes 0.44 ps, and a dark point at the mean rate is re-chosen across it in 3.2 fs.[A07] The three numbers belong to three different things. The slowest of them is the only one that carries what a driver writes.

3 What a dark point is

Write $\psi = \xi + i\eta$. Each quadrature has its nodal lines, the lines of a driven plate where that quadrature writes no turning (P-2). A dark point is a crossing of a nodal line of ξ with a nodal line of η: the one place in its neighbourhood where the written turning cancels altogether (Fig. 1). Three statements follow from the lattice.

- *It is made of different sites at every instant.* A trough of one orbit wave is made of different dots in each frame: follow any dot and it goes nowhere [2]. A dark point is the same in two dimensions. The sites under it now were turning on full circles a moment ago and will be again; the sites under it next are other sites. Nothing passes from the first place to the second.
- *It is dark and never empty.* At the crossing the turning that was written cancels. The turning nobody wrote does not: no term of the chain $E/m = c^2 = 1/(\varepsilon_0\mu_0) = (d/t)^2$ vanishes (0.1), so every wave of the lattice keeps a floor, the record's half unit, with the heat's share above it, $\bar{n} = 1.06 \times 10^{-3}$ of a unit in a wave of this rate at 300 K.[C01] The microscope's zero is a zero of the written amplitude.
- *Its charge is a bivector's sign.* The map between neighbours has the winding density

$$W \equiv \partial_1\xi\,\partial_2\eta - \partial_2\xi\,\partial_1\eta = \mathrm{Im}\left(\partial_1\psi^*\,\partial_2\psi\right), \tag{2}$$

  the bivector grade of $\nabla\xi \wedge \nabla\eta$ in the plane of the membrane. Round a dark point the azimuths wind once, by $+2\pi$ where $W > 0$ and by -2π where $W < 0$.[B02] The charge ± 1 is the hand of that winding, read between neighbours (I-3a), and it is carried by no site.

4 The rate of a dark point

Proposition 1 (the fifth rate)**.** *A dark point of the field* (1) *is re-chosen at the rate*

$$\mathbf{v}_\mathrm{d} = \frac{1}{W}\left(\partial_t\eta\,\partial_2\xi - \partial_t\xi\,\partial_2\eta,\;\; \partial_t\xi\,\partial_1\eta - \partial_t\eta\,\partial_1\xi\right), \tag{3}$$

every derivative taken at the dark point. Its numerator is bounded by the rates and wave numbers of the field. Its denominator is the winding density, and $|\mathbf{v}_\mathrm{d}|$ *has no bound where* $W \to 0$*.*

Proof. The dark point is the place where $\xi = 0 = \eta$ at each instant, so along it $\partial_t\xi + \mathbf{v}_\mathrm{d}\cdot\nabla\xi = 0$ and $\partial_t\eta + \mathbf{v}_\mathrm{d}\cdot\nabla\eta = 0$. These are two linear equations for the two components of $\mathbf{v}_\mathrm{d}$, with the determinant W; Cramer's rule gives (3). □

Tracked zeros of a field of forty orbit waves follow (3) to two parts in a million.[B01] The proposition says where the rate comes from. Nothing in it is a speed of a site or of a strand: $\partial_t\psi$ is how fast the circle at a place changes, $\nabla\psi$ is how the circles differ between neighbours, and their ratio is a length over a time that no pattern covers.

Two lines crossing. Where a nodal line advances at the rate u normal to itself across another that it meets at the angle θ, their crossing runs along the second at $u/\sin\theta$. With u at the membrane's phase rate, $0.090\,c$, the crossing passes c when the lines stand within 5.2° of each other, and it has no bound as they close.[B06] This is the closing of a pair of scissors, and the rate of the point where the blades meet is no blade's.

The meeting of two charges. The two crossings of one pair of nodal lines have opposite signs of W. When the lines draw apart, the two crossings run together and are gone at the instant the lines are tangent, where $W = 0$. In the normal form of a tangency, $\xi = y$ and $\eta = x^2 - \beta\,(t_a - t)$, the crossings stand at $x = \pm\sqrt{\beta\tau}$ with $\tau = t_a - t$:

$$R = 2\sqrt{\beta\tau}, \qquad |\mathbf{v}_\mathrm{d}| = \frac{\beta}{R}, \qquad |\mathbf{v}_\mathrm{d}|\,R = \beta. \tag{4}$$

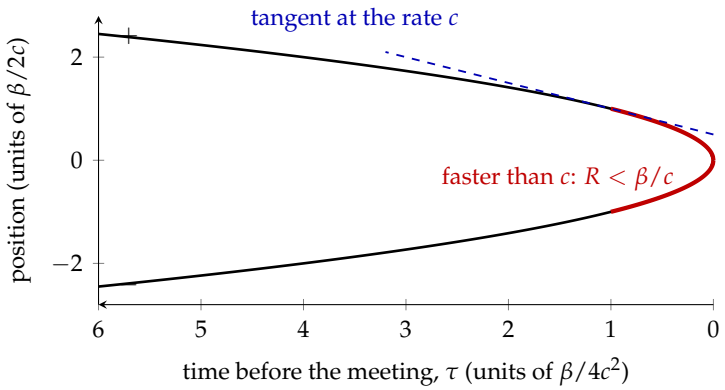

Figure 2: The meeting of two charges, eq. (4). The two crossings of one pair of nodal lines run together on a parabola. Inside the separation $R = \beta/c$ each is re-chosen faster than light (red), for the time $\tau = \beta/4c^2$; at the tangency the rate has no bound.

The two points trace a parabola in space and time, $\tau = x^2/\beta$, and their rate has no bound as $\tau \to 0^+$ (Fig. 2).[B03, B04] This is the curve of the source's Fig. 2 and its formally divergent rate. It is one event of two lines. No force acts between the two points, and neither has inertia to accelerate: a dark point is no source, it has no $\mathscr{M}$, and the pair expression of I-1 has no pair here. The same event read backward in time is the appearance of a pair, with unbounded rates of the other sign, as the source reports for its relative-rate distribution.

Proposition 2 (the tail)**.** *Near a meeting a dark point is faster than v for the time $\beta/(4v^2)$, so the share of dark points faster than v falls as v^{-2} for every field. For a Gaussian field that is isotropic in the plane the share is exactly*

$$P\big(|\mathbf{v}_\mathrm{d}| > v\big) = \frac{v_0^2}{v_0^2 + v^2}, \qquad v_0 = \frac{\sigma_t}{\sigma_k}, \qquad \langle|\mathbf{v}_\mathrm{d}|\rangle = \frac{\pi}{2}\, v_0, \tag{5}$$

with σ_t and σ_k the root-mean-square values of one quadrature's time derivative, taken about the band's mean rate, and of one component of its gradient. The mean square rate has no finite value.

Proof. The first statement is (4) with $R = \beta/v$. For the second, write the two conditions of Proposition 1 as $\mathsf{M}\,\mathbf{v}_\mathrm{d} = -(\partial_t\xi, \partial_t\eta)$ with M the matrix of the two gradients, $\det\mathsf{M} = W$. At a zero of an isotropic Gaussian field the time derivatives and the gradients are independent, so for a given M the rate is Gaussian with the density $(|W|/2\pi\sigma_t^2)\exp(-|\mathsf{M}\mathbf{v}_\mathrm{d}|^2/2\sigma_t^2)$. Zeros are counted with the weight $|W|$. Taking $\mathbf{v}_\mathrm{d}$ along the first axis and averaging W^2 over the second column of M leaves $\sigma_k^2\rho^2\exp(-v^2\rho^2/2\sigma_t^2)$ with $\rho^2 = (\partial_1\xi)^2 + (\partial_1\eta)^2$, whose average over ρ^2 is proportional to $(1 + v^2/v_0^2)^{-2}$. This is the density of $\mathbf{v}_\mathrm{d}$ in the plane; integrating it outside the circle of radius v gives (5), and its first moment is $\pi v_0/2$. □

A sample of two million zeros returns (5) to four parts in a thousand at every rate tried.[B05, B07, B08] Three numbers of the record follow from its two mean rates and nothing else. At the mean $\langle v\rangle = c$ of the source's model the share faster than light is $1/(1 + (\pi/2)^2) = 28.8\%$, and at the measured $1.04\,c$ it is 30.5%, against the 29% the source reports for data and model. At the free-space mean $0.1\,c$ it is 0.40%, the source's 0.4%.[A08] The heavy tail that the source reports as the breakdown of the particle analogy is the tangency of nodal lines, counted. With $v_0 = 2\langle v\rangle/\pi$ the density of (5) is $8\pi^2\langle v\rangle^2|v|/(4\langle v\rangle^2 + \pi^2|v|^2)^2$, the source's eq. (2), after [4].

Why this membrane. The scale $v_0 = \sigma_t/\sigma_k$ is how fast the circles change at a place over how steeply they differ between neighbours. The source reports that the slow run of the membrane's turning widens its band of wave vectors and raises the mean to $1.04\,c$ from the $0.1\,c$ of free space at the same laser parameters, and the measurement and its model are accepted in full. The value of v_0 from the membrane's kernel is not derived here (D-S1).

5 A rate and a signal

The microscope gets the rate of the minimum exactly right. One patch of the membrane goes dark as the turnings arriving there cancel; a moment later they cancel farther along; the sequence crosses the frame faster than light, and the camera records it faithfully. What the sequence establishes is how fast the minimum is re-chosen. It does not establish that the first darkening brought about the second. Both are written by the same field of orbit waves, launched earlier from the same edges, and each place settles with its own neighbours (0.1a). The omnium is one plate, and the sand at two of its nodes moves alike because the driver is one (P-2).

To ask whether anything passes from the first place to the second is to make a different measurement, and the orbit lattice says what it is. A driver's push at a place enters the turning elsewhere through the lattice's response, a causal convolution of the driver with that response [2]: I-1's rule for a driven observable. A written change runs at the run, here $c/133$, and nothing a strand carries runs faster than the strand rate (0.1d).

The protocol. After the pattern is under way, choose a bit at the place A: a second pulse on the membrane there, or none. Record the turning at the place B, a distance R away, for both values of the bit, and take the difference of the two records as a function of time.

- *Zero.* The difference at B for every time earlier than R/c after the choice. For $R = 1\ \mu$m that is the first 3.34 fs.
- *What the lattice returns.* Zero in that window. The difference appears at B when the written change arrives, at the run: 0.44 ps for the same micrometre.[A07]
- *What would end it.* A difference at B inside the window, at any size above the record's noise, is a bit read before light has crossed the gap. That would establish signalling faster than light, and it would end 0.1d.
- *What the dark points do meanwhile.* They are re-chosen across the same micrometre in 3.2 fs at the mean rate, and 29% of them faster than light, with either value of the bit.

Tracking a dark point measures the first of these things and is silent on the second. The source claims no signal, and its statement that the singularities carry no energy or information is the same statement. The title's "superluminal correlations" are the joint statistics of rates and distances of the zeros of one field: correlations of places on one phase law.

6 Where the core enters

Chart inventory. No chart of the Alpha Lock is entered and no application of 0.4 is used. The turn ratio $\mathfrak{h}$ of an orbit wave, the winding density W and the scale v_0 are kinematic and stand

in no force, optical or density slot. The packing set by an orbit wave is the packing density of the dots, named as such [2] (0.6). Table 3 declares the symbols this manuscript adds.

The invariants.

I-1. Used as the rule for a driven observable in Section 5. The pair expression is not applied to dark points, which are no sources.

I-2. One carrier: the phonon polariton is the stroke and the lattice's held turning together, and no second carrier joins two dark points.

I-3, I-3a. A dark point, its charge and its rate are read between neighbours: W is the bivector grade of the neighbour map, and a single site shows a circle and no singularity.

I-4. Each site is $\psi = A\, e^{i\varphi}$; the microscope's phase map is the map of helical phases, and its reconstruction is the reading of φ that Section 9 of [2] asks of a probe.

I-5. A carrier changes no helix count; the appearance and meeting of dark points change no closure of the lattice.

I-6. The bounded rates of Table 2 are bounded by their domains. The dark-point rate is a ratio whose denominator passes through zero, and it is typed as unbounded.

I-7. The field's energy enters $\mathscr{M}$ once, as E/c^2. An isotope substitution moves the rates of the turning through the inertial sensitivity $-\frac{1}{2}$ at a fixed kernel [2]: $h^{10}BN$ turns 2.75% faster than $h^{11}BN$ on the reduced mass of the pair, against the recorded shift of 35 cm^{-1} between the two monoisotopic crystals, 2.6% [6].[C03, C04] The dark-point statistics move with the band through v_0; the density-channel sensitivity is to be derived (D-L3 of [2]).

ψ, ξ, η	written turning at a site, $\xi + i\eta$; its quadratures	$\mathbf{v}_\mathrm{d}$	rate at which a dark point is re-chosen
$\mathfrak{r}_m$, $\mathbf{k}_m$, ω_m	radius, wave vector and rate of one orbit wave	W	winding density, eq. (2)
ω_0, T	the band's central rate; its cycle	β, τ	constant of a tangency; time before it
R	separation of two dark points	v_0, σ_t, σ_k	scale of the rates; r.m.s. time derivative and gradient of a quadrature

Table 3: Symbols this manuscript adds. Core symbols keep their core meanings: c the strand rate, $\mathscr{M}$ the total gravitating energy.

7 Readings declined

- The standard account treats a phase singularity as a particle-like object that keeps its identity along a trajectory, with a velocity of its own. FDT reads a place where the written turning of the lattice cancels, made by different sites at every instant, none of which travels (0.1a, 0.1b, I-2); the measured positions, charges and rates are accepted in full.
- The standard account describes two opposite charges as accelerating toward each other and annihilating as a particle does with its antiparticle. FDT reads one tangency of two nodal lines, with no force between the points and no inertia in either (P-2, I-1); the measured parabola and the measured rates near it are accepted in full.

- The standard account reads the zero of the field as a place where nothing is. FDT reads a place where the written turning cancels and the floor's turning remains, since no term of the chain vanishes (0.1); the measured zero of the written amplitude is accepted in full.
- Reports of the measurement describe darkness that travels faster than light. FDT reads c as the strand rate, which every strand has and no strand exceeds (0.1d), and the dark-point rate as the rate of no strand; the measured $(1.04 \pm 0.04)c$ is accepted in full.

8 Convergence statement

Every identity of Sections 3 and 4 is kinematic and holds for the zeros of any smooth field of circles. For the same source and data FDT returns the record by the following maps.

- *The rates.* Equation (3) is the rate the source measures by finite differences along its tracks; (4) is the parabola of its Fig. 2; (5) is the source's eq. (2), and it returns the 29% and the 0.4% from the two means.
- *The correlations.* The distance correlations and the joint distributions $P(v, R)$ are statistics of the zeros of the Gaussian field (1); the source's agreement with the Gaussian random wave model is accepted as it stands.
- *Causality.* The source states that the singularities carry no energy or information. FDT states the same of a place that no site occupies for longer than a nodal line takes to pass, and returns zero for the protocol of Section 5.
- *The membrane.* The polariton's wavelength, its phase rate and its run are taken from the source; the inertial isotope shift is the recorded one to within the change of the kernel.

No divergence follows from any identity of this manuscript: it supplies no additional source, no constitutive input and no changed observable dictionary. FDT and the source agree on every number and on the absence of a signal. They part on what a dark point is, and the orbit lattice settles that without a new measurement: a thing that travelled would be made of the same sites from frame to frame, and it is not.

9 Status ledger

result	rests on	status
The record's arithmetic and the five rates (Tables 1, 2)	the source	recomputed from the source's values
A site's circle ψ as the sum of orbit waves (1)	I-2, I-4, [2]	derived (kinematics)
Dark point as a crossing of nodal lines; charge as the sign of W	P-2, I-3a	derived, exact
The fifth rate (Proposition 1)	kinematics	derived, exact
The meeting of two charges (4)	kinematics	derived, exact in the normal form
The tail and the share (5) (Proposition 2)	kinematics; Gaussian, isotropic field	derived; the v^{-2} tail for every field
The floor at a dark point	0.1	derived; the half unit is the record's (D-L5 of [2])
The protocol of Section 5 and its zero	I-1 (driven observable), 0.1d	derived
D-S1. The scale v_0, and with it the mean rate $1.04\,c$, from the membrane's kernel	P-3, I-2	to be derived
D-S2. The hyperbolic law of the membrane's turning from the stroke between clamps	I-2, P-3	to be derived (D-05 of [5])
Maps from a charge to an I-1 input; the kernel of the compound lattice	I-1	to be derived (O-6)

A Receipt

The script `receipt_superluminal_dark_points.py` recomputes every printed number and every identity of this manuscript: the record's arithmetic and the shares (A01–A09), the rate of a dark point against tracked zeros of a field of forty orbit waves, the charge, the normal form of a meeting, the crossing of two lines and the statistics of two million zeros (B01–B08), and the floor, the unit, the isotope shift and the sites' speed (C01–C05). Its output is `receipt_superluminal_dark_points.out.txt`. Result: **22/22 PASS**. The grey tags in the text name the checks.

References

[1] *Core FDT invariants*, v6.8, locked 20 November 2026. Clauses are cited by section: 0.1–0.8, I-1 to I-7, P-1 to P-5, O-1 to O-17.

[2] M. Alfaro, *The orbit lattice: turning without travelling, and how a driver writes it*, foundation paper, densitytheory.com, 25 November 2026 (core v6.8): the four rates, the cost of circulation, the control law, and rows D-L3 and D-L5 of its status ledger.

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