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Research Article

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Dark energy at the Compton threshold: a self-gravitating frozen vacuum confronted with DESI DR2

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Abstract

Baryon acoustic oscillations from DESI DR2, combined with the cosmic microwave background and type Ia supernovae, prefer dark energy that is evolving away from $w = -1$. The simplest physical candidate is a thawing scalar field. We organise its physics around one dimensionless number, the expansion per tick of the field's Compton clock, $\varepsilon = \hbar H/mc^2 = m_P^2/2M_H m$, where M_H is the energy inside the Hubble sphere. Three results follow. (i) Exact solutions show that a coherent field turns from vacuum ($w = -1$) into matter ($\langle w\rangle = 0$) across the band $0.3 \lesssim \varepsilon \lesssim 2.2$. (ii) We propose that the frozen vacuum sets its own clock, $(mc^2/\hbar)^2 = \lambda\,(8\pi G/3)\,\rho_{\rm frozen}$, equivalently $\varepsilon^2\Omega_{\rm frozen} = 1/\lambda$: the field thaws when it dominates, so the questions "why does dark energy dominate now?" and "why does it evolve now?" become one. For a quadratic potential the principle fixes the initial displacement, $\phi_i = \sqrt{6/\lambda}\,M_{\rm red}$, and the model has the same number of free parameters as ΛCDM. (iii) We fit DESI DR2 BAO, Planck 2018 distance priors and, in turn, Pantheon+, Union3, DES-Y5 and DES-Dovekie. The threshold-centre value $\lambda = 1$ ($m = 0.90\,H_0 \simeq 1.3\times10^{-33}$ eV, $w_0 \simeq -0.89$, $w_a \simeq -0.18$) gives $\Delta\chi^2 = -0.4$, -3.8, -9.0 and -2.2 relative to ΛCDM, with the same number of free parameters. The free-fall value $\lambda = 3/2$, which we had singled out before fitting, is preferred by DES-Y5 (-5.0) but disfavoured by Pantheon+ ($+8.0$) and by the recalibrated DES-Dovekie ($+6.4$). Thawing fields with $m \gtrsim 1.3\,H_0$ are disfavoured by every sample, and the CPL "phantom crossing" is an artefact of the parametrization. Combined with the stochastic equilibrium of a light field during inflation, the principle fixes the inflationary Hubble rate at $H_{\rm inf} \simeq 6$ meV (an energy scale of about 5 TeV), recovering the known numerical relation $\rho_{\rm DE}^{1/4} \sim M_{\rm EW}^2/M_P$ as a consequence. The model predicts that w never crosses -1 and that cosmic acceleration ends in about 30 Gyr.

Keywords: dark energy; thawing quintessence; DESI; coincidence problem; ultralight scalar fields; stochastic inflation.

1 Introduction

DESI DR2 baryon acoustic oscillations (BAO), combined with the cosmic microwave background (CMB) and type Ia supernovae (SNe), prefer a time-dependent dark-energy equation of state over a cosmological constant at 2.8–4.2σ, depending on the supernova sample [1]. In the CPL parametrization $w = w_0 + w_a(1-a)$ the preferred region has $w_0 > -1$, $w_a < 0$ and $w_0 + w_a < -1$, so that w appears to cross -1 in the past. A crossing is hard to realise with a single canonical field, and several analyses have shown that thawing quintessence [2, 3] reproduces the data without one [4, 5].

A thawing field raises two questions. Why is its mass of order the present Hubble rate, $m \sim \hbar H_0/c^2 \sim 10^{-33}$ eV? And why does it start to roll just when dark energy comes to dominate? The first is the usual fine-tuning problem; the second is a sharpened form of the coincidence problem.

This paper addresses the second question with a concrete principle and confronts it with data. We use the dimensionless quantity

$$\varepsilon \equiv \frac{\hbar H}{mc^2} = \frac{\lambda_C}{R_H} = \frac{m_P^2}{2M_H m}, \tag{1}$$

the fractional expansion of the universe per radian of the field's Compton clock. Here $\lambda_C = \hbar/mc$, $R_H = c/H$, $m_P^2 = \hbar c/G$, and the last equality uses $2GM_H/R_H = c^2$, which follows from $H^2 = (8\pi G/3)\rho$ for the Misner–Sharp energy $M_H = \frac{4\pi}{3}R_H^3\rho$ inside the Hubble sphere of a flat universe [6]. In this language:

- a coherent field is vacuum while $\varepsilon \gtrsim 2$ and matter once $\varepsilon \lesssim 0.3$ (Section 2);
- a thawing field today has $\varepsilon_0 = H_0/m \simeq 1$: we live inside its threshold band (Section 3);
- the principle $\varepsilon^2\Omega_{\rm frozen} = 1/\lambda$ ties the threshold crossing to the epoch of domination and removes one free parameter (Section 4);
- the principle is tested against DESI DR2 with four supernova samples (Section 5);
- the field amplitude it requires follows from the stochastic dynamics of light fields during a low-scale inflation (Section 6).

Section 7 collects predictions and falsifiers. Numbers use units $c = \hbar = 1$ where convenient, and $M_{\rm red} = (8\pi G)^{-1/2}$.

2 The Compton threshold: a band, not a point

A free homogeneous scalar field obeys $\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$. The solutions regular at $t = 0$ are

$$\phi \propto (mt)^{-1/4}J_{1/4}(mt) \quad (H = 1/2t), \qquad \phi \propto \frac{\sin mt}{mt} \quad (H = 2/3t), \tag{2}$$

in the radiation and matter eras. Both are frozen (vacuum-like, $w = -1$) at early times and oscillate at the Compton frequency (matter-like, $\langle w\rangle \to 0$, $\rho \propto a^{-3}$) at late times. Evaluating the closed forms (Fig. 1):

- the field thaws ($1 + w > 0.02$) at $\varepsilon = 2.00$ (radiation) and 2.22 (matter);
- $\langle w\rangle$ exceeds $-1/2$ at $\varepsilon = 0.40$ and 0.45;
- the density has halved at $\varepsilon = 0.30$ and 0.38.

The transition therefore occupies the band

$$0.3 \lesssim \varepsilon \lesssim 2.2 \quad \Longleftrightarrow \quad 0.23\, m_P^2 \lesssim mM_H \lesssim 1.7\, m_P^2. \tag{3}$$

The second form, through Eq. (1), states the textbook condition $m \sim H$ [7] as a relation between the mass of the field, the mass of the universe inside the Hubble sphere and the Planck mass.

Scope. The band describes coherent fields (condensates) and gravitational particle production [8]. It does not describe thermal particles, which become non-relativistic when the temperature drops below their mass: the electron does so at $1 + z \simeq 2 \times 10^9$, while $\varepsilon = 1$ for the electron at $1 + z \simeq 2 \times 10^{20}$.

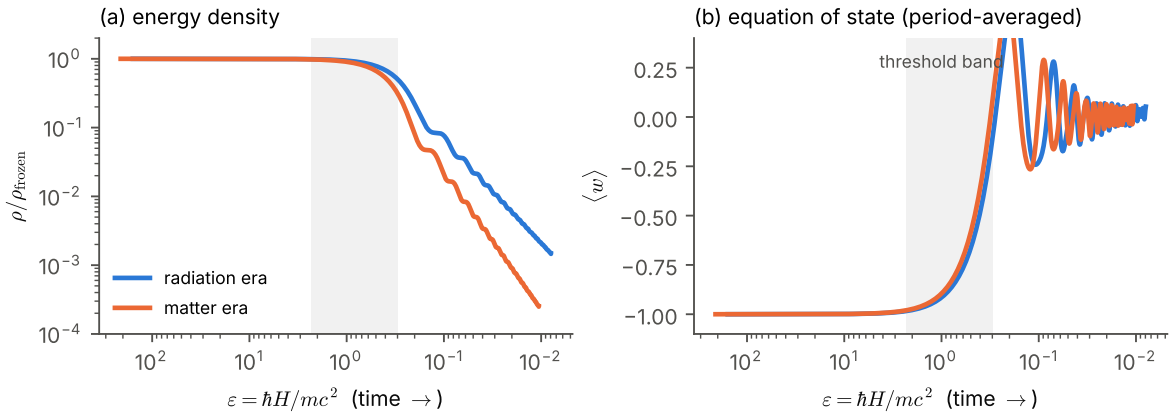


Figure 1: Exact solutions of a free scalar field in the radiation and matter eras, plotted against $\varepsilon = \hbar H/mc^2$ (time runs to the right). The shaded band $0.3 < \varepsilon < 2.2$ is where the field turns from vacuum (constant density, $w = -1$) into matter ($\rho \propto a^{-3}$, $\langle w \rangle \to 0$). Panel (b) averages kinetic and potential energy over a sliding window before forming w.

m/H_0	w_0	w_a	$w_0 + w_a$	$\phi_i/M_{\rm red}$	q_0	first end of acceleration
0.5	−0.964	−0.054	−1.02	4.18	−0.50	beyond $a = 30$
0.7	−0.931	−0.106	−1.04	3.06	−0.46	$a = 9.6$, in 53 Gyr
1.0	−0.860	−0.214	−1.07	2.25	−0.39	$a = 2.9$, in 22 Gyr
1.25	−0.784	−0.331	−1.11	1.90	−0.30	$a = 1.8$, in 11 Gyr
1.5	−0.693	−0.470	−1.16	1.69	−0.21	$a = 1.4$, in 5 Gyr
2.0	−0.478	−0.806	−1.28	1.48	+0.04	already decelerating

Table 1: Canonical quadratic field with $\Omega_m = 0.31$, $\Omega_\phi = 0.69$ today. ϕ_i is the frozen initial value; q_0 is the deceleration parameter today; the last column gives the first epoch at which q turns positive.

3 Thawing at the threshold

We take a flat universe with matter, radiation and a canonical field with $V = \frac{1}{2}m^2\phi^2$, frozen at ϕ_i deep in the radiation era. For each m the value ϕ_i is fixed by $\Omega_\phi = 0.69$ today. The single ODE is integrated in $\ln a$, and $w(a)$ is projected on CPL by a least-squares fit over $0.4 < a < 1$ (Table 1, Fig. 2).

The thawing line. The CPL projections lie on $w_a = -1.558(1 + w_0)$ with residual 5×10^{-3}. A nearly straight track was found for calibrated thawing models in Ref. [9]; the slope quoted here is our fit for the quadratic potential.

The phantom crossing is an artefact. Every projection has $w_0 + w_a < -1$, so the CPL form crosses $w = -1$ in the past, while the exact $w(z)$ never does (Fig. 2b). A CPL fit with $w_0 + w_a < -1$ is therefore not evidence for phantom physics [4, 5].

A Planckian displacement. At threshold $m \sim H$, so a field of energy $\frac{1}{2}m^2\phi^2$ carries a density of order the critical density, $\sim 3H^2M_{\rm red}^2$, only if $\phi \sim M_{\rm red}$. Table 1 gives $\phi_i = 2$–$4\,M_{\rm red}$ in the range the data allow (Section 5). This is mildly in tension with the swampland distance conjecture [10], although the field rolls only a fraction of $M_{\rm red}$ by today.

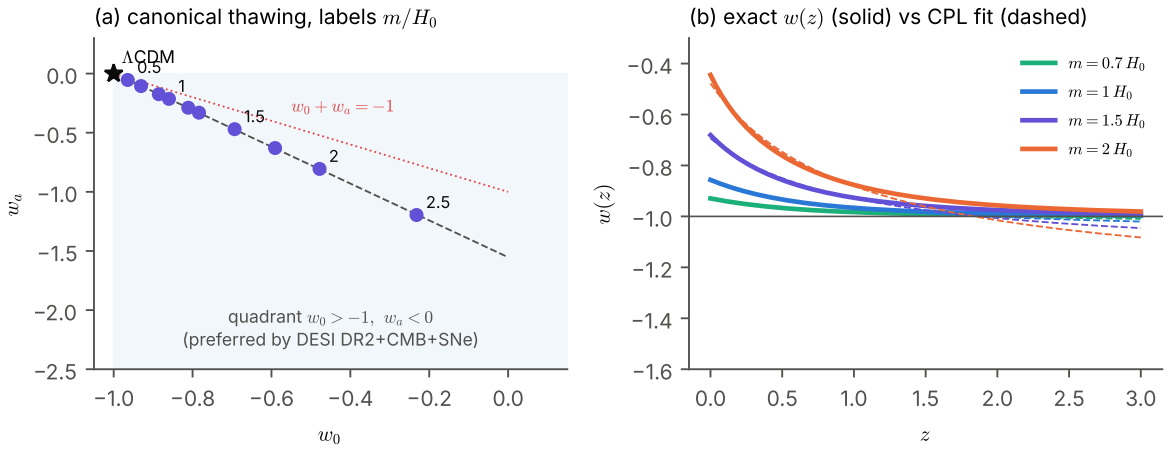


Figure 2: (a) CPL projections of canonical thawing for several m/H_0, on the thawing line $w_a \simeq -1.56(1 + w_0)$ (dashed). The shaded quadrant is the one preferred by DESI DR2 with CMB and supernovae; the dotted line marks $w_0 + w_a = -1$. (b) The exact $w(z)$ (solid) never crosses -1, while its CPL projection (dashed) does.

We live in the band. The data of Section 5 prefer $m \simeq (0.6\text{–}1.0)H_0$, i.e. $\varepsilon_0 \simeq 1\text{–}1.6$: today's universe sits inside the threshold band (3) of its lightest coherent field, near the edge where thawing begins.

4 A self-gravitating frozen vacuum

The band (3) is kinematic: it says when a field of given mass thaws, not why the mass of the dark-energy field puts its thaw at the epoch of domination. A dynamical principle must supply a relation between m, the frozen energy $\rho_{\rm frozen}$ and H that does not follow from the Friedmann equation.

The principle. *The Compton frequency of the frozen vacuum field is set by the gravity of its own energy:*

$$\left(\frac{mc^2}{\hbar}\right)^2 = \lambda\,\frac{8\pi G}{3}\,\rho_{\rm frozen}, \qquad \lambda = \mathcal{O}(1). \tag{4}$$

Dividing by $H^2 = (8\pi G/3)\rho_{\rm tot}$ gives the exact consequence

$$\varepsilon^2\,\Omega_{\rm frozen} = \frac{1}{\lambda}. \tag{5}$$

While the field is a minor component, $\Omega_{\rm frozen} \ll 1$ and $\varepsilon \gg 1$: it is frozen. It enters the threshold band ($\varepsilon \sim 1$) precisely when its share of the density becomes of order unity. *The vacuum turns into matter when it dominates.* The two coincidences, why dark energy dominates now and why it evolves now, become one.

Realizations. For $V = \frac{1}{2}m^2\phi^2$, $\rho_{\rm frozen} = \frac{1}{2}m^2\phi_i^2$ and Eq. (4) reads

$$\phi_i = \sqrt{6/\lambda}\,M_{\rm red}. \tag{6}$$

For a pseudo-Nambu–Goldstone field, $V = L^4[1 + \cos(\phi/f)]$ [11], it reads $\lambda = 3(M_{\rm red}/f)^2$. In both cases $\lambda = \mathcal{O}(1)$ is the statement that the field range is Planckian, so the principle explains why the displacement of Section 3 has the size it has. Given λ and Ω_m, the mass m is no longer free: the model has the same parameters as ΛCDM.

Natural values of λ.

- $\lambda = 1$: the frozen energy, taken alone, would drive a de Sitter expansion with $H_\Lambda^2 = (8\pi G/3)\rho_{\rm frozen}$; $\lambda = 1$ says $\varepsilon(H_\Lambda) = 1$, i.e. *the frozen vacuum sits at the centre of the threshold band of its own expansion*: its Compton wavelength equals the radius c/H_Λ of the horizon its energy generates, and that energy contains exactly $S_\Lambda/2\pi$ quanta, with S_Λ the horizon entropy. Prediction: $m = 0.902\,H_0$, $\phi_i = 2.45\,M_{\rm red}$, $(w_0, w_a) = (-0.886, -0.175)$.
- $\lambda = 3/2$: the Compton frequency equals the free-fall frequency of the field's own energy, $\omega^2 = 4\pi G\rho$. Prediction: $m = 1.166\,H_0$, $\phi_i = 2.00\,M_{\rm red}$, $(w_0, w_a) = (-0.811, -0.289)$.
- $\lambda = 6$: Jeans length equal to Compton length. No acceleration today: excluded.

An analytic bound explains the last case. For $\chi = a^{3/2}\phi$ the field equation becomes $\ddot\chi + \omega^2\chi = 0$ with $\omega^2 = m^2 - \frac{9}{4}H^2 - \frac{3}{2}\dot H = m^2 + 6\pi G p$, where p is the total pressure. A frozen field that dominates has $p \simeq -\rho_{\rm frozen}$, so it is overdamped by its own pressure only if $m^2 < 6\pi G\rho_{\rm frozen}$, i.e. $\lambda < 9/4$. Matter delays the onset of oscillation, and numerically the field accelerates the universe today for $\lambda \le 2.5$ but not for $\lambda \ge 3$. A transparency note: before the fits of Section 5 we had singled out $\lambda = 3/2$; the threshold-centre reading of $\lambda = 1$ was recognised afterwards. We therefore report both and the full profile in λ.

The alternative: always at threshold. A principle that keeps the field permanently inside the band, $V'' \simeq H^2$, is realised by tracker potentials $V \propto \phi^{-\alpha}$ [12]. Tuned to $\Omega_\phi = 0.69$, they give $w_a = +0.08$ to $+0.14$ for $\alpha = 1/2$–4 (with $w_0 = -0.86$ to -0.49): freezing dark energy, opposite to the DESI preference. Exponential potentials give scaling solutions without acceleration. Tracking is therefore disfavoured, and the self-gravitating principle is the one we test.

5 Confrontation with DESI DR2

5.1 Data and method

We use:

- *BAO*: the 13 DESI DR2 measurements of D_M/r_d, D_H/r_d and D_V/r_d for $0.295 \le z_{\rm eff} \le 2.33$ with their full covariance [1]; r_d from the fitting formula of Ref. [13] including $\sum m_\nu = 0.06\,$eV;
- *CMB*: the Planck 2018 distance priors (R, ℓ_A, ω_b) and their correlations [14], which compress the CMB information on the background expansion and are appropriate here because the field is frozen and negligible before recombination;
- *SNe*, one sample at a time, with the absolute magnitude marginalised analytically: Pantheon+ ($z > 0.01$, statistical plus systematic covariance) [15]; Union3 (22 compressed nodes) [16]; DES-Y5 as originally released [18]; and its recalibration DES-Dovekie [17], which lowers the DES preference for evolving dark energy.

Free parameters are h, ω_m and ω_b for every model, plus (w_0, w_a) for CPL. For the field, the background is obtained by integrating the scalar equation from $a = 10^{-5}$; in the self-gravitating model ϕ_i is fixed by Eq. (6) and m is solved for so that the universe is flat. We minimise χ^2 with Nelder–Mead and restarts.

As a calibration of this compressed likelihood, our CPL best fits are $(w_0, w_a) = (-0.856, -0.517)$, $(-0.688, -0.991)$, $(-0.768, -0.776)$ and $(-0.823, -0.639)$ for Pantheon+, Union3, DES-Y5 and DES-Dovekie, within about half a standard deviation of the published values [1, 17]. Our $\Delta\chi^2_{\rm CPL}$ are smaller in magnitude than the published ones by 3–4 units, as expected from replacing the full CMB likelihood by distance priors, so our significances are conservative.

model	extra params	m/H_0	$\Delta\chi^2$ vs ΛCDM			
			Pantheon+	Union3	DES-Y5	DES-Dovekie
ΛCDM ($\chi^2_{\rm min}$)	0	—	1420.2	42.9	1663.8	1649.5
CPL w_0w_a	2	—	−7.2	−13.4	−17.5	−10.4
self-gravitating, $\lambda = 0.75$	0	0.76	−2.1	−3.6	−8.5	−3.7
self-gravitating, $\lambda = 1$	0	0.90	**−0.4**	**−3.8**	**−9.0**	**−2.2**
self-gravitating, $\lambda = 1.25$	0	1.02	+2.8	−3.1	−7.9	+1.0
self-gravitating, $\lambda = 3/2$	0	1.15	+8.0	−1.7	−5.0	+6.4
self-gravitating, $\lambda = 2$	0	1.38	+25.5	+4.7	+8.1	+25.6

Table 2: Fits to DESI DR2 BAO + Planck 2018 distance priors + one supernova sample. The first row gives $\chi^2_{\rm min}$ of ΛCDM; the others give $\Delta\chi^2 = \chi^2_{\rm min} - \chi^2_{\Lambda\rm CDM}$. The self-gravitating models have the same number of free parameters as ΛCDM, so $\Delta\chi^2$ equals the difference in AIC and BIC. m/H_0 is the value at the best fit; it varies by less than 0.002 between samples.

5.2 Results

Table 2 and Fig. 3 give four results.

1. *The threshold-centre vacuum fits at least as well as ΛCDM with every sample, with no extra parameter.* For $\lambda = 1$, $\Delta\chi^2 = -0.4$ (Pantheon+), −3.8 (Union3), −9.0 (DES-Y5) and −2.2 (DES-Dovekie). Since the parameter count is the same, these are also the differences in AIC and BIC. With Union3 and DES-Y5, $\lambda = 1$ lies within $\Delta\chi^2 \simeq 0.5$ of the best λ in our scan; Pantheon+ and DES-Dovekie prefer $\lambda \simeq 0.5$–0.75 ($m \simeq 0.6$–$0.75\,H_0$), closer to ΛCDM, by $\Delta\chi^2 \simeq 1.5$–2.

2. *The free-fall value is sample-dependent.* For $\lambda = 3/2$, $\Delta\chi^2 = +8.0$, −1.7, −5.0 and +6.4. It is preferred over ΛCDM by DES-Y5 and disfavoured by Pantheon+ (a likelihood ratio of $e^4 \approx 55$) and by DES-Dovekie. The recalibration of the DES sample alone moves $\Delta\chi^2$ from −5.0 to +6.4, a shift comparable to the spread between samples: $\lambda = 3/2$ cannot be decided until the supernova calibration settles.

3. *Heavy thawing fields are excluded.* For $m \gtrsim 1.3\,H_0$ ($\lambda \gtrsim 1.8$) the fit is worse than ΛCDM for every sample; at $m = 1.38\,H_0$ ($\lambda = 2$) Pantheon+ gives $\Delta\chi^2 = +25.5$, and for a free thawing field at $m = 1.5\,H_0$ it gives +38. Matching the central CPL values (Table 1) suggested $m \simeq 1$–$1.5\,H_0$; the exact fit shows that this is misleading, because the CPL best fits lie off the thawing line (Fig. 3b) and the data constrain $w(z)$ at $z \sim 0.3$–1, not (w_0, w_a).

4. *CPL fits better, at the cost of two parameters and a phantom phase.* The further improvement of CPL over the self-gravitating vacuum with $\lambda = 1$, −6.8, −9.6, −8.5 and −8.2 for two more parameters, comes from the region $w_0 + w_a < -1$ that no canonical field reaches. Whether that improvement survives a full Bayesian comparison is disputed [5].

6 Where the amplitude comes from

The principle relates m to $\rho_{\rm frozen}$ but does not fix either. We now ask what fixes the frozen amplitude.

Stochastic equilibrium. During inflation a field lighter than $H_{\rm inf}$ receives a quantum kick of size $H_{\rm inf}/2\pi$ per e-fold, so its displacement grows as a random walk. At equilibrium [19]

$$\langle\phi^2\rangle = \frac{3H_{\rm inf}^4}{8\pi^2 m^2}, \qquad \rho_{\rm frozen} = \tfrac{1}{2}m^2\langle\phi^2\rangle = \frac{3H_{\rm inf}^4}{16\pi^2}, \tag{7}$$

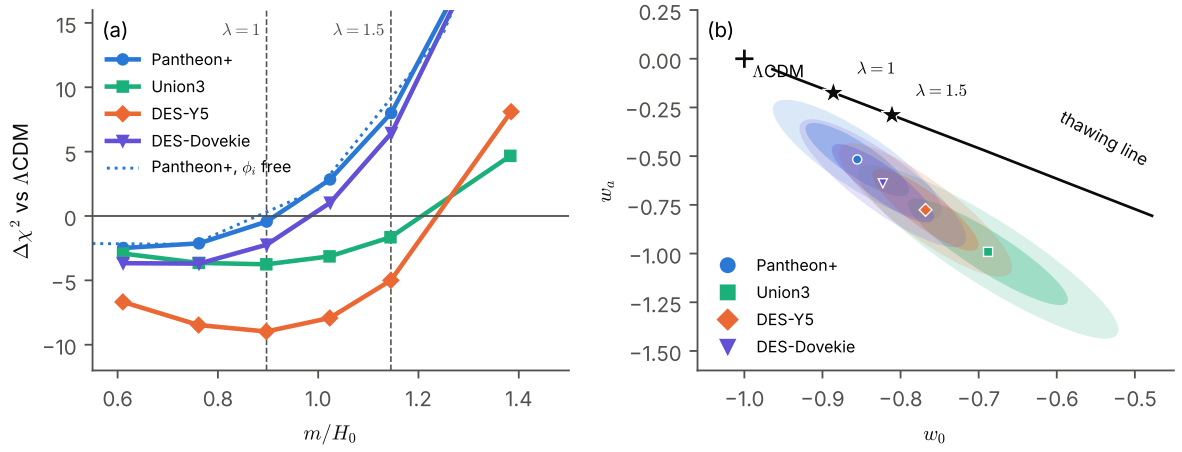


Figure 3: (a) $\Delta\chi^2$ relative to ΛCDM of the self-gravitating frozen vacuum, as a function of the mass it implies ($\lambda = 0.5$–2 from left to right), for DESI DR2 + Planck distance priors + each supernova sample (lines connect the six fitted values of λ). The dotted line is the profile of the free thawing field (initial value free) with Pantheon+. Dashed verticals mark $\lambda = 1$ and $3/2$. (b) CPL best fits for the four supernova samples with Fisher 1σ and 2σ regions, the thawing line of the quadratic field, and the CPL projections of the two self-gravitating predictions (stars). The data do not lie on the thawing line; the exact fits in panel (a), not the projections, decide.

independently of m. Ringeval et al. showed that this reproduces the observed dark-energy density for $H_{\rm inf} \approx 6 \times 10^{-3}\,\mathrm{eV}$ after $N \gtrsim 10^{60}$ e-folds [20]; see also Ref. [21].

Stochastic equilibrium plus self-gravity. Inserting Eq. (7) into Eq. (4):

$$m = \sqrt{\lambda}\,\frac{H_{\rm inf}^2}{4\pi M_{\rm red}}. \tag{8}$$

With the fitted mass this gives $H_{\rm inf} = 6.3 \times 10^{-3}\,\mathrm{eV}$ for $\lambda = 1$ ($6.5 \times 10^{-3}\,\mathrm{eV}$ for $\lambda = 3/2$; the dependence on λ nearly cancels), an inflationary energy scale of 5.2 TeV, and about 10^{61} e-folds to reach equilibrium. The dark-energy scale is then $\rho_{\rm DE}^{1/4} \sim H_{\rm inf} \sim E_{\rm inf}^2/M_P$. This recovers, as a consequence of two dynamical statements, the numerical relation $\rho_{\rm DE}^{1/4} \sim M_{\rm EW}^2/M_P$ noted by Arkani-Hamed et al. [22]. One coincidence remains: why the last inflationary phase took place near the electroweak scale. The price is an extremely long, low-scale inflation.

Relation to the everpresent-Λ count. In causal-set cosmology the vacuum energy is a Poisson fluctuation of the number N of spacetime elements, $\Lambda\ell_P^2 \sim N^{-1/2}$, which gives the observed order of magnitude [23]. Its current realizations fit the CMB poorly unless the fluctuating term is suppressed at early times [24]. The random walk of Eq. (7) realises a $\sqrt{N}$ law dynamically, but stores it in a field with $V \geq 0$, which keeps only the positive branch and is frozen, hence harmless, at early times.

Earlier crossings and dark matter. Fields with $m \gg H_0$ crossed the band earlier and now behave as matter. A field that crosses at a_c in the radiation era with vacuum share f would by itself bring matter–radiation equality to $a_{\rm eq} = a_c/f$. For it to be all of the dark matter ($a_{\rm eq} \simeq 1/3400$),

$$f \simeq 1.3 \times 10^{-4}\left(\frac{m}{10^{-20}\,\mathrm{eV}}\right)^{-1/2}. \tag{9}$$

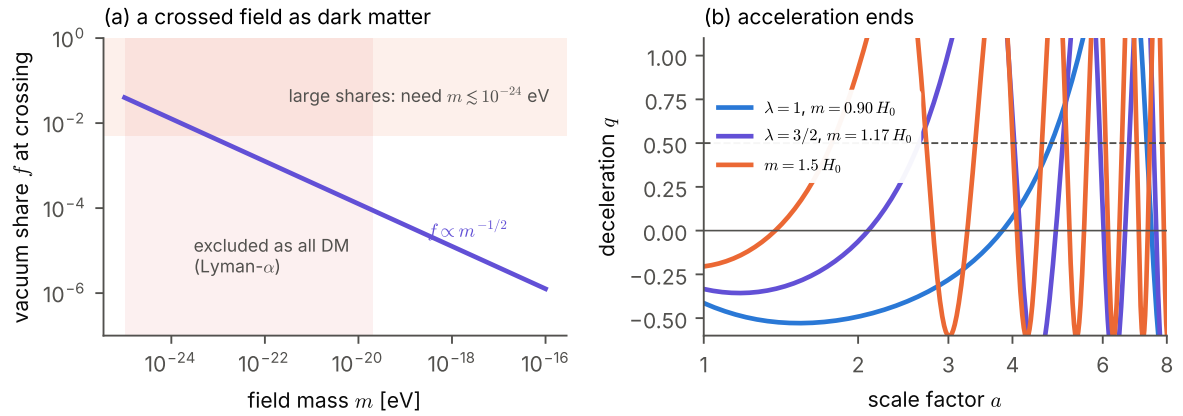


Figure 4: (a) Vacuum share a field must carry at its crossing to become all of the dark matter, Eq. (9); masses below $2 \times 10^{-20}\,\mathrm{eV}$ are excluded as all of the dark matter by Lyman-α data. (b) Instantaneous deceleration parameter for canonical thawing. Acceleration ends at the first crossing of $q = 0$; afterwards q oscillates around the matter-like average $+1/2$ (dashed).

With $m \gtrsim 2 \times 10^{-20}\,\mathrm{eV}$ from the Lyman-α forest [25], $f \lesssim 10^{-4}$ (Fig. 4a). In the stochastic picture this holds automatically: Eq. (7) gives every light field the same $\rho_{\mathrm{frozen}} = 3H_{\mathrm{inf}}^4/16\pi^2$, which at a crossing with $H_c \simeq m$ is a share $f = H_{\mathrm{inf}}^4/(16\pi^2 m^2 M_{\mathrm{red}}^2) \approx 10^{-26}(10^{-20}\,\mathrm{eV}/m)^2$. Only the field crossing today carries an order-one share; the same mechanism cannot also produce ultralight dark matter.

7 Predictions and falsifiers

After its first crossing the field oscillates and dark energy turns into dark matter. The deceleration parameter turns positive, then oscillates around $+1/2$ with short recurrent episodes of acceleration (Fig. 4b). For $\lambda = 1$ the first end of acceleration comes at $a = 3.8$, in about 28 Gyr; there is no eternal de Sitter phase.

Table 3 lists the claims. The sharpest tests are two. A genuine phantom equation of state rules out the canonical threshold field. A dark-energy equation of state equal to -1 to high precision rules out any field inside the band today, and with it the principle. Between these, the self-gravitating vacuum with $\lambda = 1$ predicts a specific curve $w(z)$ with no free parameter, which DESI DR3, Euclid and the Rubin Observatory supernova sample can test.

8 Conclusion

The physics of a thawing dark-energy field can be stated with one number, the expansion per Compton tick $\varepsilon = \hbar H/mc^2 = m_P^2/2M_H m$. A coherent field turns from vacuum into matter across $0.3 \lesssim \varepsilon \lesssim 2.2$, and the present universe sits inside that band.

The self-gravitating frozen vacuum, $\varepsilon^2\Omega_{\mathrm{frozen}} = 1/\lambda$, makes the thaw coincide with domination, reduces the two coincidences of dark energy to one, and removes the field's mass as a free parameter. With $\lambda = 1$, the value for which the frozen vacuum sits at the centre of the threshold of its own expansion, it fits DESI DR2, Planck and each of four supernova samples at least as well as ΛCDM with the same number of parameters. With the stochastic dynamics of a light field during inflation, the remaining coincidence becomes the electroweak scale of the last inflationary phase.

The model is sharply falsifiable: it allows no phantom phase, predicts $w(z)$ with no free parameter, and predicts that the acceleration of the universe will end.

claim	status	falsified by
threshold band $0.3 < \varepsilon < 2.2$ for coherent fields	exact	—
CPL phantom crossing of thawing fields is an artefact	exact (numerical)	—
thawing field with $m \simeq (0.6\text{–}1)H_0$	fits all four SN samples	a genuine $w < -1$ at any redshift
self-gravitating vacuum, $\lambda = 1$: $w_0 = -0.886$, $w_a = -0.175$, $m = 0.90\,H_0$	$\Delta\chi^2 \leq 0$ for all samples	$w(z)$ data off the predicted curve; $w = -1$ to high precision
self-gravitating vacuum, $\lambda = 3/2$	disfavoured by 2 of 4 SN samples	the recalibrated supernova samples
tracking (always at threshold)	disfavoured	—
end of acceleration in $\sim 30\,\mathrm{Gyr}$ ($\lambda = 1$)	prediction	$w = -1$ to high precision at low z
inflation at $H_{\rm inf} \simeq 6\,\mathrm{meV}$, $N \gtrsim 10^{61}$	consequence	primordial tensor modes from high-scale inflation with no later TeV phase

Table 3: Claims, their status and what would falsify them.

Data and code availability

The DESI DR2 BAO, Pantheon+, Union3 and DES-Y5 data are public; we used the versions distributed with the Cobaya sampler. The scripts that produce every number, table and figure are provided as supplementary material: `figs.py` (exact solutions and thawing runs), `principles.py`, `lam_values.py` and `selffreeze.py` (dynamical principles), `like.py`, `job.py` and `profile.py` (likelihood and fits), `fig_data.py` (Fig. 3).

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