Fermionic Universe Hypothesis: Emergent Gravity and Dark Components from a Single Fermion Field

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Abstract

This work formulates the Fermionic Universe Hypothesis (FUH), in which a fundamental multicomponent fermion field ψ is regarded as the source of at least a part of the observed particles and interactions. Gauge fields and gravity are treated not as independent fundamental entities but as collective excitations and emergent effects of a fermionic condensate of ψ. The model is defined by a fundamental Lagrangian with four-fermion interactions and the corresponding low-energy effective Lagrangian, and it leads to a set of falsifiable cosmological and astrophysical predictions.

Introduction

Modern physics seeks to unify the electroweak and strong interactions with a consistent quantum theory of gravity. The Standard Model successfully describes gauge interactions based on the SU(3)×SU(2)×U(1) group, while General Relativity describes classical gravity, but their full unification remains an open problem. In the Fermionic Universe Hypothesis a single fundamental field ψ is postulated, for which a microscopic Lagrangian is specified; due to internal symmetries, their spontaneous breaking, and four-fermion interactions, effective gauge fields and an emergent metric arise from ψ, so that dark matter, dark energy, and gravity are described as different regimes of the fermionic condensate.

Main ideas

- In the FUH model the only fundamental degree of freedom is a single fermion field ψ with internal components, for which a microscopic Lagrangian with a kinetic term and four-fermion interactions is specified; via a Hubbard–Stratonovich transformation these interactions can be rewritten in terms of effective gauge fields A_μ, interpreted as composite excitations of ψ.

- Spontaneous condensation of ψ (⟨ψ̄ψ⟩ ≠ 0) generates a fermionic condensate and induces effective masses for fermions and composite bosonic modes without introducing a separate fundamental Higgs field, while macroscopic gravity is described as induced spacetime curvature emerging from the energy–momentum tensor T_μν[ψ].

Observational implications

• On cosmological scales the ψ condensate behaves as cold dark matter at early times ($w_\psi \approx 0$) and as dynamical dark energy at late times ($w_\psi < -1$), thereby determining $\rho_\psi(a)$ and the expansion history $H(z)$; this allows the model to be tested using CMB, BAO, Type Ia supernovae and lensing data, including in the context of the Hubble tension.

• In the strong-field regime fermionic condensates of ψ can describe compact objects, including black holes without a central singularity; comparing the masses, shadows and spectra of such configurations with EHT observations and gravitational-wave events (LIGO/Virgo) provides an additional class of tests of FUH.

Full Lagrangian and equations of motion

In FUH the fundamental degree of freedom is a single fermion field ψ. At the microscopic level the dynamics is specified by the Lagrangian

$$L_{fund} = \bar\psi (i \gamma^\mu \partial_\mu - m) \psi - \lambda (\bar\psi \psi)^2 - \kappa (\bar\psi \gamma^\mu \psi)(\bar\psi \gamma_\mu \psi) + \eta (\bar\psi \psi - v)^2.$$

The first term describes a free fermion of mass m. The second and third terms provide short-range four-fermion interactions through which the field ψ condenses and gives rise to collective (emergent) modes that play the role of gauge and gravitational degrees of freedom, in the spirit of induced-gravity and emergent-gauge-field scenarios. The term $\eta (\bar\psi \psi - v)^2$ fixes a non-zero vacuum expectation value v and describes a phase transition into a fermionic condensate, analogous in spirit to the Higgs mechanism.

In the low-energy limit one introduces composite, i.e. ψ-defined, effective fields

$A_\mu(x) = \beta \langle \bar\psi \gamma_\mu \psi \rangle$ — an emergent gauge potential,

$g_{\mu\nu}(x) = \eta_{\mu\nu} + \alpha \langle \bar\psi \gamma_{(\mu} i \partial_{\nu)} \psi \rangle$ — an emergent metric.

After integrating out high-frequency modes of ψ the effective action acquires terms of the form $R / (16 \pi G_{ind})$ and $-(1/4) F_{\mu\nu} F^{\mu\nu}$ with induced constants G_{ind}, g_{ind} and an effective cosmological constant Λ_{eff}. Thus gravity and the gauge field are described by the standard Einstein–Hilbert and Maxwell terms but are interpreted as collective excitations of the fermionic condensate rather than independent fundamental fields.

The low-energy effective Lagrangian has the form

$L_{eff} = \bar{\psi}(i \gamma^\mu \nabla_\mu - m_{eff}) \psi - \Lambda_{eff} - (1/4) F_{\mu\nu} F^{\mu\nu} + R / (16 \pi G_{ind}) + a_1 R^2 + a_2 R_{\mu\nu} R^{\mu\nu} + b_1 (\bar{\psi} \psi)^3 + b_2 (\bar{\psi} \gamma^\mu \psi)(\bar{\psi} \gamma_\mu \psi)(\bar{\psi} \psi) + c_1 R \bar{\psi} \psi + c_2 R_{\mu\nu} \bar{\psi} \gamma^\mu \nabla^\nu \psi + d_1 (\nabla_\alpha F_{\mu\nu})(\nabla^\alpha F^{\mu\nu})$.

Within a truncated effective description (including operators up to fourth order in the fields and second order in derivatives) the coefficients a_i, b_i, c_i and d_1 are treated as dimensionless parameters depending on the fundamental fermionic sector and the ultraviolet cutoff; the corresponding terms are interpreted as higher-dimension operators, relevant only for discussing the limits of validity of the model, whereas in the phenomenological analysis of cosmology and compact objects the leading role is played by the first four terms. Here $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$, and the induced constants m_{eff}, G_{ind}, Λ_{eff} and the effective charge g_{ind} are also expressed through the parameters of the fermionic sector.

Variation with respect to $\bar{\psi}$ gives a generalized Dirac equation in the background of the emergent fields

$$i \gamma^\mu \nabla_\mu \psi - m_{eff} \psi = [2 \lambda (\bar{\psi} \psi) + 2 \eta (\bar{\psi} \psi - v)] \psi + g_{ind} \gamma^\mu A_\mu \psi.$$

The left-hand side describes the propagation of a spin-1/2 fermion in the metric $g_{\mu\nu}[\psi]$, while the right-hand side encodes the effective mass generated by the condensate and the induced gauge interaction with charge g_{ind}. Variation with respect to the composite field A_μ leads to a Maxwell-type equation

$$\partial_\mu F^{\mu\nu} = g_{ind} \bar{\psi} \gamma^\nu \psi,$$

which is interpreted as the dynamics of an emergent gauge field entirely generated by ψ-currents. The gravitational sector is described by the Einstein equations with an induced gravitational constant

$$R_{\mu\nu} - (1/2) g_{\mu\nu} R = 8 \pi G_{ind} T_{\mu\nu}[\psi],$$

where the energy–momentum tensor $T_{\mu\nu}$ is built solely from the fermion field and its condensate; the energy density ρ_ψ and pressure p_ψ follow from the fundamental Lagrangian L_{fund} in the standard way.

All subsequent cosmology (homogeneous condensate $\psi(a)$, density $\rho_\psi(a)$, equation-of-state parameter $w_\psi(a)$, Friedmann equation with $\rho_{total} = \rho_m a^{-3} + \rho_\psi(a)$) and the astrophysics of compact objects (fermionic "black holes" with profile $\psi(r)$ and a shadow consistent with EHT data) are treated as macroscopic solutions of these equations. In this sense both geometry and effective fields appear as different phases and regimes of one and the same fundamental fermion field ψ.

Basic symmetries of L_eff

- Lorentz invariance in vacuum and invariance under general coordinate transformations on large scales, so that at low energies the theory reproduces an effective metric and GR-like dynamics.

- Gauge symmetries of the visible sector (at minimum $U(1)_{em}$, optionally extended to $SU(3)\times SU(2)\times U(1)$) together with global/gauge symmetries of the ψ-sector: ψ may either be a singlet of the SM group or carry its own dark charge.

- Global ψ-number symmetry (analogous to $U(1)_\psi$) or a ψ-parity $\psi \to -\psi$, which constrains the allowed four-fermion and mixed operators, plus possible discrete symmetries that protect the stability of the dark component.

Structure of the effective Lagrangian

Given these symmetries, it is natural to decompose L_eff into several blocks:

- Gravitational sector: scalar curvature R, a cosmological term, possible corrections of the form R^2, $R_{\mu\nu} R^{\mu\nu}$, and other higher-curvature operators suppressed by the scale Λ.

- Fermionic ψ-sector: kinetic term $\bar\psi\, i \gamma^\mu \nabla_\mu \psi - m_\psi \bar\psi \psi$ and four-fermion interactions $(\bar\psi \Gamma \psi)^2$, including scalar, pseudoscalar, vector and tensor structures in the spirit of Nambu–Jona-Lasinio-type models and gravity-induced contact terms.

- Gauge fields: the standard $-(1/4) F_{\mu\nu} F^{\mu\nu}$ for the visible sector and, if desired, a dark gauge term $-(1/4) F'_{\mu\nu} F'^{\mu\nu}$, plus possible kinetic mixings.

- Operators coupling ψ to the visible sector: symmetry-allowed dimension-5/6 portals such as $(\bar\psi \psi)(H^\dagger H)$, $(\bar\psi \gamma^\mu \psi) J^{vis}_\mu$ and analogous constructions, if one wishes to anchor ψ at least schematically in particle physics.

Effective Lagrangian for $d \leq 4$

Let $g_{\mu\nu}$ be the metric, ψ the fundamental fermion and A_μ the visible U(1) (or more general) gauge potential. Then:

- Gravity ($d = 2,4$):
- Einstein–Hilbert term and cosmological constant:
- $(M_{pl}^2 / 2)\, R$
- $-\Lambda_0$

These pieces are crucial both for cosmology (FRW background, effective dark energy) and for black holes (Schwarzschild/Kerr-type solutions).

- Fermionic ψ-sector ($d = 4$):
- $\bar{\psi}\, i\, \gamma^\mu\, \nabla_\mu\, \psi - m_\psi\, \bar{\psi}\psi$
- a possible self-interaction potential $V_4(\bar{\psi}\psi)$ consistent with the symmetries.

This controls the basic condensate dynamics and is important both for the cosmological background (ρ_ψ, p_ψ) and for the structure of compact objects.

- Gauge sector ($d = 4$):
- $-(1/4)\, F_{\mu\nu} F^{\mu\nu}$ (and, if desired, a dark $-(1/4)\, F'_{\mu\nu} F'^{\mu\nu}$).

This sector is essential for electromagnetic observables of black holes (shadow, accretion disk), while in cosmology it plays a secondary role.

Dimension-5 operators (if needed)

If no Higgs scalar or additional fields are introduced, one can minimally include

- ψ–portals to curvature and gauge fields:
- $(c_5^R / \Lambda)\, R\, \bar{\psi}\psi$
- $(c_5^F / \Lambda)\, \bar{\psi}\sigma^{\mu\nu}\, \psi\, F_{\mu\nu}$

These operators are mainly relevant for strong-gravity regimes and possible spin-dependent effects near black holes; for the homogeneous cosmological background, dimension-5 terms can usually be treated as suppressed.

Dimension-6 operators

This is where the main "meat" of the condensate and cosmology appears.

1. Four-fermion interactions of ψ

- Scalar channel:
- $(G_S / \Lambda^2) (\bar{\psi} \psi)^2$
- Pseudoscalar channel:
- $(G_P / \Lambda^2) (\bar{\psi} i \gamma_5 \psi)^2$
- Vector/axial channel:
- $(G_V / \Lambda^2) (\bar{\psi} \gamma^\mu \psi)(\bar{\psi} \gamma_\mu \psi)$
- $(G_A / \Lambda^2) (\bar{\psi} \gamma^\mu \gamma_5 \psi)(\bar{\psi} \gamma_\mu \gamma_5 \psi)$

These coefficients are critical:

- in cosmology they determine the equation of state of the condensate $w_\psi(a)$, the sound speed and the possibility of a transition from "dark matter–like" to "dark energy–like" behaviour;
- in black holes they control the stability of the ψ-condensate, the presence or absence of a finite-density core, and the pressure profile inside the object.

2. High-curvature gravitational terms

- $\alpha_1 R^2$
- $\alpha_2 R_{\mu\nu} R^{\mu\nu}$
- (optionally) $\alpha_3 C_{\mu\nu\rho\sigma} C^{\mu\nu\rho\sigma}$ (the square of the Weyl tensor),

with coefficients α_i / Λ^2.

- For cosmology:
- such terms affect the early Universe (R^2-inflation à la Starobinsky, modifications of the growth of perturbations).
- For black holes:

• they modify the horizon structure, the spectrum of quasinormal modes, and possible deviations in the shape of the shadow and the ringdown.

3. ψ–curvature coupling operators

• $(\beta_1 / \Lambda^2) R (\bar{\psi}\psi)$

• $(\beta_2 / \Lambda^2) R_{\mu\nu} (\bar{\psi}\gamma^\mu \nabla^\nu \psi)$ (or symmetrized variants allowed by the symmetries)

Role:

• in cosmology, these operators allow the effective $w_\psi(a)$ to depend on curvature (a unified dark component, non-trivial H(z) dynamics);

• in black holes, they control how strongly the condensate "feels" the curvature, influencing the ψ profile near the horizon.

4. ψ–F_μν operators

If ψ carries charge or there is kinetic mixing, one can include

• $(\kappa_1 / \Lambda^2) (\bar{\psi}\gamma^\mu \psi) \nabla^\nu F_{\mu\nu}$

• $(\kappa_2 / \Lambda^2) (\bar{\psi}\sigma^{\mu\nu} \psi) F_{\mu\nu}$ (ψ-magnetic moments, etc.)

For cosmology these terms are usually not essential; for black holes and astrophysics they can produce non-trivial spin- and charge-dependent effects in the vicinity of the horizon and in accretion flows.

Field content and symmetries

We take the metric $g_{\mu\nu}$ and a homogeneous fermionic condensate ψ (in practice treated as an effective fluid described by the scalars ρ_ψ and p_ψ). We assume general covariance, local Lorentz invariance and a global $U(1)_\psi$ symmetry (or $\psi \to -\psi$) in order to control the allowed four-fermion terms.

Background operators ($d \le 4$)

The minimal background Lagrangian is

- gravity and cosmological term:
- $(M_{pl}^2 / 2)\, R - \Lambda_0$
- kinetic term and mass of ψ:
- $\bar\psi\, i\, \gamma^\mu \nabla_\mu \psi - m_\psi \bar\psi \psi$
- leading scalar four-fermion channel:
- $(G_S / \Lambda^2)\, (\bar\psi \psi)^2$

The combination of m_ψ and G_S controls the formation of a BCS/NJL-like condensate with effective pressure and energy density, allowing one to realize dark matter, dark energy or a unified dark fluid.

Operators affecting the equation of state

To obtain a flexible $w_\psi(a)$, it is sufficient to add two further types of terms with $d \le 6$:

- Vector four-fermion interaction:
- $(G_V / \Lambda^2)\, (\bar\psi \gamma^\mu \psi)(\bar\psi \gamma_\mu \psi)$

This term affects the stiffness of the fluid and the sound speed, which is important for stability and for the growth of perturbations.

- First-level coupling to curvature:
- $(\beta_1 / \Lambda^2)\, R\, (\bar\psi \psi)$

This operator makes the effective pressure of the condensate sensitive to $H(t)$ and R, enabling a dynamical transition from a “pseudo-CDM” to a “pseudo-DE” regime at late times, in analogy with scalar EFTs of dark energy.

All other operators (R^2, $R_{\mu\nu} R^{\mu\nu}$, ψ–$F_{\mu\nu}$ and more exotic terms) can, to first approximation, be neglected for pure cosmology and reserved for a dedicated “high-curvature/BH physics” analysis.

What is critical specifically for cosmology

- Λ_0, m_ψ and G_S determine whether the condensate exists and what its baseline energy density and pressure are (i.e. the baseline w_ψ).

- G_V and β_1 control the dynamics of perturbations and the late-time evolution of $w_\psi(a)$, and therefore the CMB, BAO and SNe Ia observables, in the spirit of the EFT of cosmic acceleration.

In the analysis of the FRW background and linear cosmological perturbations we effectively use only the minimal subset of parameters Λ_0, m_ψ, G_S, G_V and β_1; all other operators remain in the full L_{eff} and become important only for describing strong-gravity regimes and the ultraviolet structure of the theory.

General principles of portals

In this work the field ψ is treated as a singlet under the Standard Model gauge group, and its coupling to the visible sector is described by effective portal operators that are invariant under $SU(3)\times SU(2)\times U(1)$ and, where possible, preserve ψ-number or a Z_2 symmetry $\psi \to -\psi$.

Scalar (Higgs) portal

- d = 5: $(c_{H1} / \Lambda)\, (\bar{\psi} \psi)(H^\dagger H)$

- d = 5: $(c_{H5} / \Lambda)\, (\bar{\psi}\, i \gamma 5\, \psi)(H^\dagger H)$

These terms contribute to the effective mass of ψ and modify the Higgs potential, thereby linking the ψ-condensate to the electroweak scale and allowing collider and astrophysical data to constrain the model.

Fermion portal through Standard Model fermions

- d = 6: $(c_S^{(f)} / \Lambda^2)\, (\bar{\psi} \psi)(\bar{f} f)$

- d = 6: $(c_V^{(f)} / \Lambda^2)\, (\bar{\psi} \gamma^\mu \psi)(\bar{f} \gamma_\mu f)$

Here f denotes quarks or leptons of the Standard Model. Such operators mediate momentum and energy exchange between the ψ-fluid and visible matter in the early Universe and provide channels for production and annihilation of ψ.

Portal via a heavy vector-like mediator

One can also consider a scenario with an additional heavy fermion χ that couples both to ψ and to Standard Model fermions. After integrating out χ, one obtains effective four-fermion operators of the same type as above, realizing the fermion portal at a more fundamental level.

In the present version of FUH these portals are introduced only as a schematic mechanism linking ψ to the Standard Model and do not enter the cosmological analysis: the parameters of the minimal cosmological subset do not depend on c_H1, c_H5, c_S^(f), or c_V^(f). A detailed phenomenological study of these operators (collider tests, direct dark-matter searches, BBN and CMB bounds) is left for future work. Portal operators in FUH thus fulfil two key roles: they connect the fermionic condensate ψ to the observable world via gauge-invariant interactions and open channels for experimental tests of the model at colliders, in direct-detection experiments, and in cosmology. At the same time, in this paper they do not affect cosmological dynamics: their parameters are absent from the basic set Λ_0, m_ψ, G_S, G_V, β_1 and do not influence the analysis of FRW backgrounds or linear perturbations. Their phenomenology — collider signatures, BBN and CMB constraints, and possible astrophysical manifestations — is deferred to future studies. In this sense the portals act as a bridge between the internal dynamics of FUH and the observable Universe, a bridge that still needs to be quantified in detail.

Observables and Bayesian model comparison

The planned strategy for testing FUH is based on a staged analysis of cosmological data. In the first step, the basic parameter set (Λ_0, m_ψ, G_S, G_V, β_1) is fitted to a combination of observations of the cosmic microwave background (Planck, ACT, SPT), baryon acoustic oscillations and type-Ia supernova samples using a standard MCMC pipeline built on CAMB/CLASS and existing Bayesian-inference packages. This combined approach has already proven effective for testing extensions of ΛCDM and models with dynamical dark energy.

In the second step, one checks whether the dynamics of the ψ condensate can alleviate or remove the H_0 tension via a time-dependent equation of state and/or an effective dark-energy density at low redshifts. For this purpose late-time measurements of H_0 are combined with early-time CMB constraints within a single model, in analogy with studies of dark energy that crosses the phantom divide and scenarios with an evolving $H_0(z)$.

The comparison of FUH with ΛCDM and related extensions will be carried out in a Bayesian framework by computing the full Bayesian evidence for each model and the corresponding Bayes factors. To estimate the evidence, adaptive importance-sampling algorithms (Population Monte Carlo, MultiNest and their implementations in CosmoPMC and similar codes) are planned, as they have already been used to compare dark-energy and modified-gravity cosmologies with joint CMB+BAO+SNe data sets. The key criterion will be not only the quality of the fit but also the predictive power: the extra FUH parameters must yield a statistically significant improvement in the data description in order to compensate for the Bayesian penalty associated with increased model complexity.

FUH within ΛCDM

ΛCDM remains for me the working standard cosmological model, and my Fermionic Universe Hypothesis does not try to overturn it but instead provides a microscopic explanation of the dark components within the same Friedmann background dynamics. I adopt the basic ΛCDM assumptions of a homogeneous and isotropic universe described by general relativity and the Friedmann equations, with a composition of roughly 5% ordinary (baryonic) matter, 25% cold dark matter, and 70% dark energy in the form of a cosmological constant Λ. This model is well supported by observations of the cosmic microwave background, baryon acoustic oscillations, type Ia supernovae, and weak gravitational lensing, and is therefore commonly referred to as the concordance cosmology.

In my hypothesis, the roles of cold dark matter and dark energy are both taken over by a single fermionic field with four-fermion interactions: in low-density regions its condensate behaves effectively as cold dark matter, while on cosmological scales the same condensate generates an effective negative pressure equivalent to dark energy. On the level of background evolution I do not modify the Friedmann equations or spoil the ΛCDM fit to the data; instead, I reinterpret the usual parameters Ωm and ΩΛ as effective contributions of the fermionic condensate.

I therefore emphasize that FUH is constructed within the standard FRW geometry and uses the same cosmological data sets (CMB, BAO, SN Ia) as constraints on the condensate parameters, not as arguments against ΛCDM. My goal is to propose a microscopic mechanism for cold dark matter and effective dark energy that is fully compatible with current ΛCDM estimates of their densities and an equation of state parameter close to minus one.

Comparison with alternative approaches

- String theory: considers one-dimensional fundamental objects (strings) living in a space with extra dimensions; gauge fields and gravity are embedded in a single string dynamics, but a fermion field does not play a singled-out role as a universal building block, in contrast to FUH.

- Loop quantum gravity: quantizes the geometry of spacetime itself and yields a discrete spectrum of geometric quantities without introducing a new fundamental matter field; in FUH, by contrast, geometry is treated as emergent, generated by the condensate of ψ.

- Extra-dimension models: explain hierarchies and the structure of interactions through the geometry of extra dimensions and typically predict new bosons and Kaluza–Klein excitations; FUH instead relies on a single fermion field and its condensation, without introducing additional dimensions or elementary bosonic degrees of freedom.

Limitations and scope of the present version of FUH

In this work a minimal version of the Fermionic Universe Hypothesis is considered, based on the fundamental Lagrangian L_{fund} for a single fermion field ψ and its emergent gravitational and gauge degrees of freedom described by the effective Lagrangian L_{eff}. Additional speculative ingredients, such as specific TeV-scale resonances, detailed predictions for the m_p/m_e ratio, modifications of an effective G_{eff} depending on local density, and dedicated scenarios for dark matter and dark energy built on FCP-like states, are not used in the present version of the model and are left outside the scope of the analysis. The focus is on formulating a fermionic effective field theory with higher-dimension operators, discussing its consistency as an effective theory (with a finite ultraviolet cutoff), and outlining a programme of observational tests in cosmology and the astrophysics of compact objects.

Black holes in the Fermionic Universe Hypothesis

In FUH, black holes are treated as highly concentrated condensates of the fermion field ψ, where the local energy density ρ_ψ becomes very large and produces strong spacetime curvature; the dense state is generated by four-fermion interactions, while the macroscopic properties are described by an emergent metric $g_{\mu\nu}[\psi]$. In this picture the ψ condensate enhances the effective attraction and forms a region with radius of order $r_s \approx 2GM/c^2$, whose interior structure is a stable “fermion lump” of finite density, and the entropy is naturally expressed as $S \approx A/4$ due to the quantum degrees of freedom of ψ on the horizon.

This approach aims to relate singularity avoidance and the information paradox to the quantum state of the condensate instead of a classical point, and to obtain testable effects: small deviations in the structure of accretion disks, emission spectra, and ring images/shadows of black holes (EHT, LIGO/Virgo) compared to standard Kerr solutions in GR.

Connection to the Hubble tension and ACT DR6

In the Fermionic Universe Hypothesis the large-scale dynamics is governed by a single fermion field ψ: dark matter and dark energy are interpreted as different phases of its condensate with equation of state $w_\psi(a) = p_\psi / \rho_\psi$. At early times the condensate behaves like cold dark matter ($w_\psi \approx 0$), while at late times it acquires negative pressure ($w_\psi < -1$) and drives accelerated expansion.

This framework is proposed as an alternative to extended ΛCDM models that add separate components or modify gravity in a purely phenomenological way. Recent analyses of the final ACT DR6 data set show that many such extensions fit the high-precision CMB temperature and polarization spectra poorly, while simultaneously reinforcing the Hubble tension: H_0 inferred from early-Universe data and from local measurements remains inconsistent, and simple tweaks of ΛCDM do not resolve this discrepancy.

In FUH there is no separate early-dark-energy episode and no new fields beyond the standard content: the same ψ condensate that sources structure formation also provides the late-time vacuum-like component. The pressure p_ψ and density ρ_ψ are determined by microscopic self-interaction, so the expansion history H(z) becomes an emergent property of the fermionic fluid. By construction the model can mimic ΛCDM at high redshift (remaining compatible with ACT, Planck, and SPT CMB data) while allowing controlled deviations at low z, precisely where the Hubble tension appears.

This sets up a concrete testing programme. Once an explicit form of $w_\psi(a)$ is derived from the microphysics, the model can be implemented in standard Boltzmann codes such as CAMB or CLASS to compute CMB spectra, baryon acoustic oscillations, supernova distance–redshift relations, and the growth of structure. The key criteria are: preserving agreement with ACT DR6 constraints on CMB spectra and lensing, and at the same time yielding a somewhat higher late-time value of H_0 than the ΛCDM estimate from the CMB, without conflicting with BAO and SNe Ia data. In this sense, the new ACT results do not rule out FUH but rather narrow the space of viable extensions and point towards models in which cosmic acceleration and dark matter emerge from a single microscopic fermion field ψ.

Observational tests of the Fermionic Universe Hypothesis

In FUH a single fermion field ψ plays the role of both dark matter and dark energy: in the early Universe it behaves like almost cold matter ($w_\psi \approx 0$), while at late times it behaves like dark energy with $w_\psi < -1$, determining $\rho_\psi(a)$ and $H(z)$.

Test plan:

- Introduce a parametrization of $w_\psi(a)$ and a small set of field parameters (mass, self-interaction).

- Replace "CDM + Λ" by ψ in CAMB or CLASS and compute the CMB spectrum, $H(z)$, and the growth of structure.

- Compare with Planck, ACT DR6, BAO, SNe Ia, and lensing data and check whether ψ-cosmology can preserve the precise CMB fit and at the same time naturally raise the local H_0, alleviating the Hubble tension.

Additionally, one can model accretion flows and shadows of ψ-cores and compare them with EHT observations and LIGO/Virgo signals; successfully reproducing masses, shadows, and spectra at the level of classical black holes would be a strong argument in favour of the fermionic picture.

Conclusion

The Fermionic Universe Hypothesis treats dark matter, dark energy, and gravity as emergent phenomena of a single fermion field ψ whose condensate generates gauge fields and the spacetime metric as collective low-energy excitations. On cosmological scales this condensate behaves as cold dark matter at early times and as dynamical dark energy at late times, so that one and the same component can be constrained by CMB, BAO, type-Ia supernovae, and lensing data, including the region relevant for the Hubble tension. In this sense FUH functions as a minimal microscopic completion of the ΛCDM background rather than a competing large-scale cosmology. It also ties the properties of the condensate directly to observable effective quantities such as the expansion history $H(z)$ and the equation of state $w(a)$. In the strong-field regime the theory predicts nonsingular black-hole–like objects whose masses, shadows, and gravitational-wave signals can be tested with Event Horizon Telescope and LIGO/Virgo observations, making FUH a quantitatively falsifiable single-field alternative to the ΛCDM + GR description of the dark sector and gravity.

Sources

1. Four-fermion interactions and condensation

• Y. Nambu, G. Jona-Lasinio, “Dynamical Model of Elementary Particles Based on an Analogy with Superconductivity. I”, Phys. Rev. 122, 345 (1961).

• M. E. Peskin, D. V. Schroeder, An Introduction to Quantum Field Theory, Addison-Wesley (1995).

2. Auxiliary fields and effective bosons

• J. Zinn-Justin, Quantum Field Theory and Critical Phenomena, Oxford Univ. Press (4th ed., 2002).

• S. Coleman, Aspects of Symmetry, Cambridge Univ. Press (1985).

3. Effective theories and composite gauge fields

• S. Weinberg, The Quantum Theory of Fields, Vol. 2: Modern Applications, Cambridge Univ. Press (1996).

• H. Georgi, “Effective Field Theory”, Ann. Rev. Nucl. Part. Sci. 43, 209 (1993).

4. Induced and emergent gravity

• A. D. Sakharov, “Vacuum Quantum Fluctuations in Curved Space and the Theory of Gravitation”, Dokl. Akad. Nauk SSSR 177, 70 (1967); reprinted in Gen. Rel. Grav. 32, 365 (2000).

• T. Jacobson, “Thermodynamics of Spacetime: The Einstein Equation of State”, Phys. Rev. Lett. 75, 1260 (1995).