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DESI Observations and the Earlier Predictions of Norma G. Sánchez : Evolving Dark Energy = $\Lambda(t)$ solves the cosmological constant problem

Summary: Recent results from the Dark Energy Spectroscopic Instrument (DESI) (2024, 2025) suggest an evolving dark energy over cosmic time, weakening as the universe ages. This observational hint strongly agree with the earlier theoretical predictions by Norma G. Sánchez (2019, 2021), who found that dark energy arises from the evolving cosmological vacuum, the vacuum of the universe: a cosmological constant rate $\Lambda(t)$, as there exists a Hubble rate $H(t)$ from which H_0 is the value today, ***solving at the same time the so called cosmological "constant" problem".*** The two very different values: the observed value today $\Lambda_0 = 100^{-122}$ (in Planck units) and the theoretically computed particle physics value $\Lambda_Q = 100^{+122}$ correspond to *the same observable* but in very *different gravity states*: they are *classical-quantum duals of each other*: the Λ_0 value today is the classical/semiclassical gravity vacuum today (low energy, dilute, large size, high entropy 100^{+122} , void dominated universe), *dual* (*in the precise sense of the classical-quantum duality of Nature*) of the quantum gravity vacuum (high-energy, trans-Planckian, small size, lower entropy 100^{-122}, very early universe). DESI's observational evidence is compared with Sánchez's theoretical results, and with de Vega & Sánchez 2023, and their implications are discussed. The observed dark energy today originates from the cosmological quantum vacuum of light particles, providing a continuous energy distribution *which reproduce the data.* ***There is no fine tuning of any kind neither exotic physics needed here.*** The *theoretically derived* equation of state is: $P = w(z)\,\mathcal{H}$ with the result being $w(z)$ slightly < -1 , asymptotically reaching -1 from below. $w(z=0)$ today is found slightly below -1 by an amount ranging from (-1.5×10^{-3}) to (-8×10^{-3}), $(-0.00794 < w(0) + 1 < -0.00156)$. In the far

future ($H_0 \ t \gtrsim 1$): $a(t) \simeq a\,(\text{today}) \exp\left[\, c_1 \, H_0 \, t + c_2 \, (H_0 \, t)^2 \,\right]$, with $c_1 \equiv \sqrt{\Omega_\Lambda} = 0.87$, $0.00452 < c_2 < 0.00872$, and the Hubble radius $1/H$ will start decreasing as $1 / [\, H_0 \sqrt{\log a(t)}\,]$.

DESI Results on Dark Energy

Survey and Methods

DESI has measured over 13 million galaxy and quasar spectra, producing the most precise 3D map of the universe to date, spanning up to 11 billion years of cosmic history. By combining baryon acoustic oscillations (BAO) with complementary data (CMB, supernovae Ia, weak lensing), DESI provides stringent constraints on the cosmic expansion history.

Key Findings

1. Consistency : DESI data alone remains consistent with the standard cosmological model with a constant Λ, both ΛCDM and ΛWDM. We do not discuss here the DM problem but recall that at the large scales both CDM and WDM are consistent with observations. At the small galactic scales and smaller, only WDM is consistent , CDM + baryonic recipes do not fit all known observations, which is known as the CDM + baryon crisis).

2. Hints of evolution: When combined with external datasets, DESI reveals signals at the 2.8σ – 4.2σ level suggesting that dark energy is not constant, but has weakened over time.

3. Temporal behavior: Some reconstructions indicate that dark energy was stronger when the universe was about 70% of its current age and is now about 10% weaker.

4. Future implications: Such behavior not lead to radically different cosmic scenarios — but is rather natural because as the universe expands, its vacuum energy disminishes, which slower its acceleration and this variation leads to a potential reversal of expansion in the very far future.

Significance

These findings provide support to the theoretical result and physical understanding that the cosmological constant is a rate $\Lambda(t)$ (as the Hubble constant is a rate too : the Hubble rate H(t) which value today at t_0 is $H(t_0) = H_0$, and open the possibility that dark energy is evolving with cosmic time. See here below, and the References in this paper.

Sánchez's results on a Varying Vacuum Energy imply at the same time among other results, a solution to the so-called cosmological constant problem: As is known, Quantum field theory predicts a huge vacuum energy density in the early universe — typically 120 orders of magnitude larger than the observed value today. Yet cosmological measurements point to a tiny effective cosmological constant driving the present accelerated expansion

- *Int. J. Mod. Phys. A (2019):* Sánchez addressed the problem of quantum physics at the Planck scale and beyond, and among the results of such approach, it is the understanding that dark energy is nothing but the cosmological quantum vacuum, which is not static but evolves with cosmic time. In her approach, the vacuum energy is supplied by quantum fluctuations of light particles (such as axions and light neutrinos), and its value naturally decreases as the universe expands. The mechanism implies that the early universe indeed had an extremely high vacuum energy, consistent with pre-inflationary scales, but that this energy decays dynamically to yield the much smaller value we observe today. There is no fine-tuning of any kind, no any exotic physics.

Phys. Rev. D (2021): Sánchez extended this framework by showing that the universe can be described in terms of quantum discrete levels, bridging the Planck-scale vacuum state of the primordial universe with the present-day dark energy. In this picture, the vacuum energy density is not an arbitrary constant, but a quantized, evolving quantity.

The high primordial value is thus a natural consequence of quantum vacuum physics in the trans-Planckian regime, while the current low value arises from the cosmological evolution of the vacuum itself.

Solution framework: *Sánchez's approach provides a self-consistent explanation of the cosmological constant problem:*

- The very high primordial value corresponds to the quantum vacuum at the earliest, near-Planckian and higher epoch.

- The very low present value emerges from the dynamical relaxation of this vacuum energy as the universe expands, diluted and regulated by the contributions of light particles. This is the classical/ semiclassical dual state value of the quantum/ super-planckian state value of the very early epoch.

- *Dark energy is not an unexplained small constant, but the residual quantum vacuum energy that continues to evolve, matching the observations of cosmic acceleration.*

The cosmological "constant" is a vacuum energy density rate Λ (t) which evolves in the universe , which value today Λ_0 is the observed one, related to the Hubble rate H(t) which value today is the Hubble constant H_0.

- The observed dark energy in the universe today is a quantum vacuum effect due to the classical cosmic space-time expansion. That is to say, dark energy in the present universe is a semiclassical gravity effect. Dark energy today arises from the quantum vacuum of light particles in FRW cosmological space-time in an analogous way to the Casimir vacuum effect of quantum fields in Minkowski space-time with non-trivial boundary conditions.

- Dark energy today is *the classical gravity dual state* (100^{-122} in units of Planck energy) of the quantum gravity (trans-Planckian 100^{+122}) very early universe state. The observed value $\Lambda_0 = \Lambda_{today} = 100^{-122}$, and the huge computed value $\Lambda = 100^{+122}$ (in Planck units) are *both* correct and correspond to the *same physical observable* (vacuum energy density) but *in different gravity states*: classical/semiclassical gravity today universe, and quantum gravity /trans-Planckian very early universe, respectively. *Duality here is the classical-quantum duality of Nature*, which is general and not restricted to the type of space-times or number of dimensions, which can be extended to include gravity : *classical-quantum gravity duality* across the Planck scale (Sanchez *"trilogy 2019" IJMPD 2019, IJMPA 2019 , PRD 2021).*

-de Vega and Sanchez, Universe 2023 **:** The explicit late dark energy equation of state today as a function of the redshit is theoretically derived to be: $P = w(z)\, \mathcal{H}$

with the result for $w(z)$ to be slightly

$$w(z) < -1 \,,$$

$w(z)$ asymptotically reaching the value −1 from below. We find that $w(z{=}0)$ today is slightly below −1 by an amount ranging from:

$$(-1.5 \times 10^{-3}) \qquad \text{to} \qquad (-\,8 \times 10^{-3})$$

$$-0.00794 < w(0) + 1 < -0.00156.$$

We predict the lightest neutrino contribution as a Dirac fermion with mass m=3.2 meV, (meV= 0.001 eV) and we predict the axion mass to be in the range between 4 and 5 meV, which is within the range of axion masses allowed by the astrophysical and cosmological constraints,

de Vega & Sánchez found that the universe will expand in the future faster than the de Sitter universe as an exponential in the square of the cosmic time. More precisely: that the Universe will reach in the far future ($H_0\, t \gtrsim 1$) an asymptotic phase where it expands exponentially as:

$$a(t) \simeq a\,(\text{today}) \, \exp\,[\, c_1 H_0 t + c_2 (H_0\, t)^2 \,]$$

where

$$c_1 \equiv \sqrt{\Omega_\Lambda} = 0.87, \qquad 0.00452 < c_2 < 0.00872,$$

H_0 stands for the Hubble parameter today. The time scale of the accelerated expansion is huge: $\sim (1/H_0)$ =13.4 Gyr. In the exponent of Equation the quadratic term dominates over the linear term by a time $t \sim (100/H_0)$ to $(200/H0)$. The Hubble radius $1/H$ decreases with time as $1 /[\, H_0 \sqrt{\log a(t)}\,]$.

Comparative Analysis

	DESI (2025)	Sánchez (2019–2021)
Nature of dark energy	Observed:as weakening over time (2.8–4.2σ)	Quantum vacuum, intrinsically variable
Origin of change	Empirical:galaxy surveys+ cosmological probes	Theoretical: contributions from light quantum particle fields
Time evolution	Density decreasing as the universe ages	Built-in dynamical behavior of vacuum energy
Theoretical framework	Observational cosmology(ΛCDM extensions)	Quantum cosmology of the vacuum
Implications	ChallengesΛCDM; suggests new physics	Provides quantum foundation for evolving Λ

The huge difference between the observed value of the cosmological classical vacuum energy Λ_0 today and the theoretically evaluated quantum particle physics vacuum Λ_Q, must correctly and physically be like that, because the two values naturally correspond to two huge different physical vacua and eras:

The observed Λ value today is in the classical, large and dilute (mostly empty) universe today, (termed voids and supervoids in cosmological observations, termed vacuum space-time in classical gravitation), which is consistent with the very low observed Λ vacuum value, (10^{-122} in Planck units), while the computed quantum value Λ_Q corresponds to the quantum, small and highly dense energetic universe in its far (trans-Planckian) past, and this is consistent with its extremely high, trans-Planckian, value (10^{+122} in Planck units).

As is well known, the theoretical value $\Lambda_Q \simeq 10^{+122}$ is clearly trans-Planckian, this value corresponds and fits correctly the value of Λ_Q in the far past trans-Planckian era and its physical properties: quantum size and time 10^{-61}, quantum (Gibbons-Hawking) temperature 10^{61} and entropy 10^{-122}.

Consistently too, the trans-Planckian era provides *the quantum precursor of inflation* from which the known classical/semiclassical inflation era (which is at the GUT scale) , its CMB observables and quantum corrections *are recovered* in agreement with the set of well established cosmological observations.

The quantum dual value Λ_Q is precisely the quantum vacuum value energy density $\rho_Q = 10^{122}\,\rho_P$ obtained from particle physics:

$$\rho_Q = (\Lambda_Q / \lambda_P)\, \rho_P \quad = \; (\rho_P / \rho_\Lambda)\, \rho_P = 10^{122}\, \rho_P$$

$$\Lambda = 3H^2 = \lambda_P \left(\frac{H}{h_P}\right)^2 = \lambda_P \left(\frac{l_P}{L_H}\right)^2 = (2.846 \pm 0.076)\ 10^{-122}\ m_P^2$$

$$\Lambda_Q = 3H_Q^2 = \lambda_P \left(\frac{h_P}{H}\right)^2 = \lambda_P \left(\frac{L_H}{l_P}\right)^2 = (0.3516 \pm 0.094)\ 10^{122}\ h_P^2$$

$$\Lambda_Q = \frac{\lambda_P^2}{\Lambda}, \qquad \lambda_P = 3h_P^2$$

(The subscript P stand for the corresponding Planck constant scale values only depending of the fundamental constants (G, c, h/2π) : Planck mass m_P, Planck length l_P, Planck Hubble constant $h_P = c/l_P$, Planck cosmological constant $\lambda_P = 3h_P{}^2$).

The trans-Planckian value is consistently in such way because is a extreme quantum gravity (trans-Planckian) vacuum in the extreme quantum past 10^{-61} t_P with minimal entropy $S_Q = 10^{-122} = \Lambda = \rho_\Lambda$. This explain why the classical gravitational vacuum Λ or ρ_Λ coincides with such observed low value 10^{-122} in Planck units, and why their corresponding quantum gravity precursor vacuum has such extremely high trans-Planckian value 10^{+122}. The classical gravitational entropy S_Λ today has precisely such high value:

$$S_\Lambda = s_P\ \left(\frac{\rho_Q}{\rho_P}\right) = s_P\ \left(\frac{\lambda_P}{\Lambda}\right) = s_P\ 10^{+122}$$

$$S_Q = s_P\ \left(\frac{\rho_\Lambda}{\rho_P}\right) = s_P\ \left(\frac{\Lambda}{\lambda_P}\right) = s_P\ 10^{-122}$$

s_P and λ_P stand for the corresponding Planck constant scale values only depending on the fundamental constants (G, c, h/2π).

Conclusion

DESI's unprecedented mapping of cosmic expansion offers the first statistically significant observational hints that dark energy may evolve over time. These results echo the earlier theoretical results of Norma G. Sánchez, who proposed that dark energy is not a fixed cosmological constant but a dynamical expression of the quantum vacuum.

Beyond this, Sánchez's framework provides a concrete resolution to the long-standing cosmological constant problem: the apparent discrepancy between the enormous vacuum energy predicted by quantum field theory in the early universe and the tiny value observed today.

In her work, the primordial vacuum energy was naturally very high, consistent with pre-inflationary physics, and has dynamically decreased through cosmic evolution to reach its present low level. This process avoids fine-tuning and transforms the cosmological constant into an evolving quantity grounded in quantum cosmology.

Together, the synergy between DESI's data and our previous theory results strengthens the case for a paradigm shift: dark energy is best understood as an evolving vacuum energy. This convergence of observation and theory could open the way to a unified framework bridging quantum physics, cosmic acceleration, and the ultimate fate of the universe.

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