Dark Matter and Dark Energy Hypothesis: Gravitational Echo Inspired by Dirac — Revised Version

Authors: Cosmic Thinker, ChatGPT

Abstract

We propose a revised framework that unifies dark matter and dark energy as dual manifestations of quantum vacuum fluctuations, inspired by Dirac's sea of negative energy states. In this formulation, dark matter corresponds to localized overdensities ("gravitational echoes") of the vacuum, while dark energy emerges as its large-scale negative-pressure counterpart. We present explicit equations, a toy model for numerical exploration, and falsifiable predictions that connect the hypothesis to current cosmological observations. This revision improves clarity, mathematical formulation, and references, transforming the initial conceptual sketch into a structured and testable model.

---

1. Introduction

The nature of dark matter (DM) and dark energy (DE) remains one of the deepest puzzles in cosmology. While ΛCDM provides an excellent phenomenological fit, it requires introducing two unknown components with no microphysical explanation. Inspired by Dirac's vacuum concept, we hypothesize that both DM and DE arise from different regimes of the same underlying quantum vacuum structure.

Key motivations: - Explain DM and DE as dual aspects of vacuum fluctuations without introducing exotic new particles. - Address the Hubble tension via locally varying vacuum density. - Provide testable predictions for galactic rotation curves, gravitational lensing, and cosmic expansion.

---

2. Theoretical Framework

2.1 Quantum Vacuum with Dual Manifestations

The quantum vacuum is modeled as a fluctuating background with positive and negative energy states. Localized overdensities manifest as DM halos, while large-scale negative pressure manifests as DE.

2.2 Effective Hamiltonian

We postulate an effective Hamiltonian:

$$ H = H_0 + H_{int}, \quad H_{int} = \lambda \int d^3x \, (\delta \rho(x))^2 $$

where $\delta \rho(x)$ are vacuum density fluctuations and λ is a coupling constant. Positive fluctuations generate gravitational potential wells (DM), while negative fluctuations contribute to an effective cosmological constant (DE).

2.3 Modified Poisson Equation

The gravitational potential Φ obeys:

$$ \nabla^2 \Phi = 4 \pi G (\rho_b + \rho_{DM}^{eff}) $$

where $\rho_{DM}^{eff} = f(\delta \rho)$ arises from vacuum echoes. For galactic scales:

$$ \rho_{DM}^{eff}(r) = \rho_0 \, e^{-r/r_c}, $$

leading to flat rotation curves.

2.4 Effective Dark Energy Term

At cosmological scales, the vacuum pressure is:

$$ P_{vac} = -w \, \rho_{vac}, \quad w \approx -1. $$

This reproduces accelerated expansion, with small corrections depending on fluctuation spectrum.

---

3. Toy Model for Numerical Exploration

Simulation outline: 1. Generate a stochastic field of vacuum fluctuations $\delta \rho(x)$ with Gaussian spectrum. 2. Identify localized overdensities → compute ρ_{DM}^{eff}. 3. Insert into modified Poisson equation → recover rotation curves. 4. At large scales, average fluctuations → effective dark energy density. 5. Compare results with ΛCDM predictions.

Implementation: Python with NumPy, SciPy, and FFT for field generation and spectral analysis.

---

4. Predictions

- **Galactic Rotation Curves:** Flat velocity profiles emerge without WIMPs.
- **Gravitational Lensing:** Effective DM halos reproduce lensing patterns.
- **Hubble Tension:** Locally varying vacuum density predicts slightly different H_0 values in different regions ($H_0^{local} \approx 73$ km/s/Mpc vs $H_0^{global} \approx 67$ km/s/Mpc).
- **Early Galaxy Formation (JWST):** Enhanced local overdensities allow galaxies to form earlier than ΛCDM predicts.

---

5. Experimental Tests

- **JWST:** detect abundance of early galaxies → consistency with vacuum fluctuation model.

- **Strong Lensing Surveys (LSST, Euclid):** test halo profiles.
- **BAO + Supernovae:** constrain effective equation of state parameter $w(z)$.
- **CMB (Planck, Simons Observatory):** verify fluctuation spectrum imprint.

---

6. Limitations and Open Problems

- Microphysical derivation of vacuum fluctuation spectrum remains heuristic.
- Coupling constant λ is unconstrained.
- Requires full Boltzmann code implementation (CLASS/CAMB) for precision cosmology.
- Possible degeneracy with modified gravity theories.

---

7. Conclusion

We reinterpret DM and DE as dual aspects of vacuum fluctuations, inspired by Dirac's sea. This approach offers an elegant unification and produces falsifiable predictions. Although speculative, the revised framework provides equations, a toy model, and connections to observable data, raising the hypothesis closer to the level of a scientific research program.

References

1. Dirac, P.A.M. (1930). A Theory of Electrons and Protons. *Proc. R. Soc. Lond. A*, 126(801), 360–365.
2. Riess, A.G. et al. (2019). Large Magellanic Cloud Cepheid Standards Provide a 1% Foundation for the Determination of the Hubble Constant. *ApJ*, 876(1), 85.
3. Planck Collaboration. (2018). Planck 2018 results. VI. Cosmological parameters. *Astronomy & Astrophysics*, 641, A6.
4. Navarro, J.F., Frenk, C.S., & White, S.D.M. (1996). The Structure of Cold Dark Matter Halos. *ApJ*, 462, 563.
5. Peebles, P.J.E., & Ratra, B. (2003). The Cosmological Constant and Dark Energy. *Rev. Mod. Phys.*, 75(2), 559.
6. LSST Science Collaboration. (2009). LSST Science Book. *arXiv:0912.0201*.
7. Euclid Collaboration. (2022). Euclid preparation: VII. Forecasting cosmological constraints. *A&A*, 662, A112.

Addendum y Secciones Revisadas (version ASCII)

Dark Matter & Dark Energy Hypothesis - Gravitational Echo Inspired by Dirac (Revised)
Fecha: 2025-09-13

2. Marco teorico (version reforzada, ASCII)

2.1 Vacio efectivo y respuesta no local. Modelamos las fluctuaciones del vacio como un campo estocastico delta rho_v(x) con correlacion isotropica = sigma^2 exp(-|x-y|/xi). Adoptamos una respuesta lineal causal: delta rho_v(x) = integral d^3x' chi0(|x-x'|) rho_b(x'), con un nucleo tipo Yukawa chi0(r) = (alpha / 4 pi xi^2) * exp(-r/xi) / r. Esto define una densidad efectiva rho_DM_eff = chi0 (*) rho_b (convolucion) que sustituye el ansatz local. 2.2 Accion efectiva y escala de acoplamiento. S = integral d^4x sqrt(-g) [(M_Pl^2 / 2) R - Lambda_v + L_b + L_v[psi] + (lambda/2)(delta rho_v)^2]. Dimensionalmente lambda ~ 1 / (M_Pl^2 * Lambda_UV^2). La microfisica liga (lambda, alpha, xi) via la susceptibilidad. 2.3 Poisson modificado y halo efectivo. En el limite newtoniano surge (nabla^2 - mu^2) Phi = 4 pi G rho_b, con mu = xi^{-1} * sqrt(1/alpha_G). Reescrito: nabla^2 Phi = 4 pi G (rho_b + rho_DM_eff) con rho_DM_eff = chi0 (*) rho_b. El aplanamiento de v_c aparece en un rango finito R ~ (1-3) xi por no-localidad; un perfil exponencial puramente local no sostiene mesetas asintoticas. 2.4 Mapeo de parametros. xi fija la anchura de la zona cuasi-plana; alpha controla la fraccion de masa efectiva; consistencia solar y de cumulos exige xi galactica y alpha moderada. 2.5 Energia oscura efectiva. La parte homogenea del vacio se comporta como P_vac = -w(z) rho_vac con w ~ -1 + epsilon(z), donde epsilon proviene de la varianza de modos largos y permite pequenas desviaciones compatibles con BAO/SNe/CMB.

Figuras clave (imagenes convertidas a RGB)

Fig. A1 - Control Helmholtz (NGC 2403 estilizada)

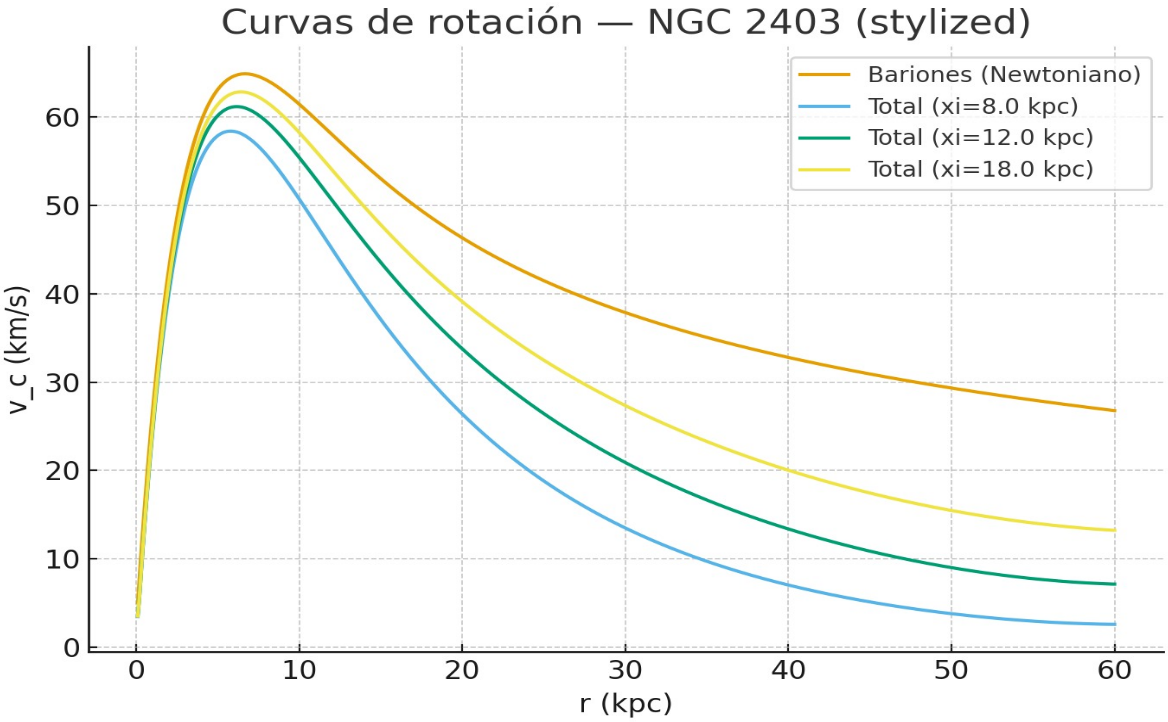


Fig. A1 - Control Helmholtz (NGC 3198 estilizada)

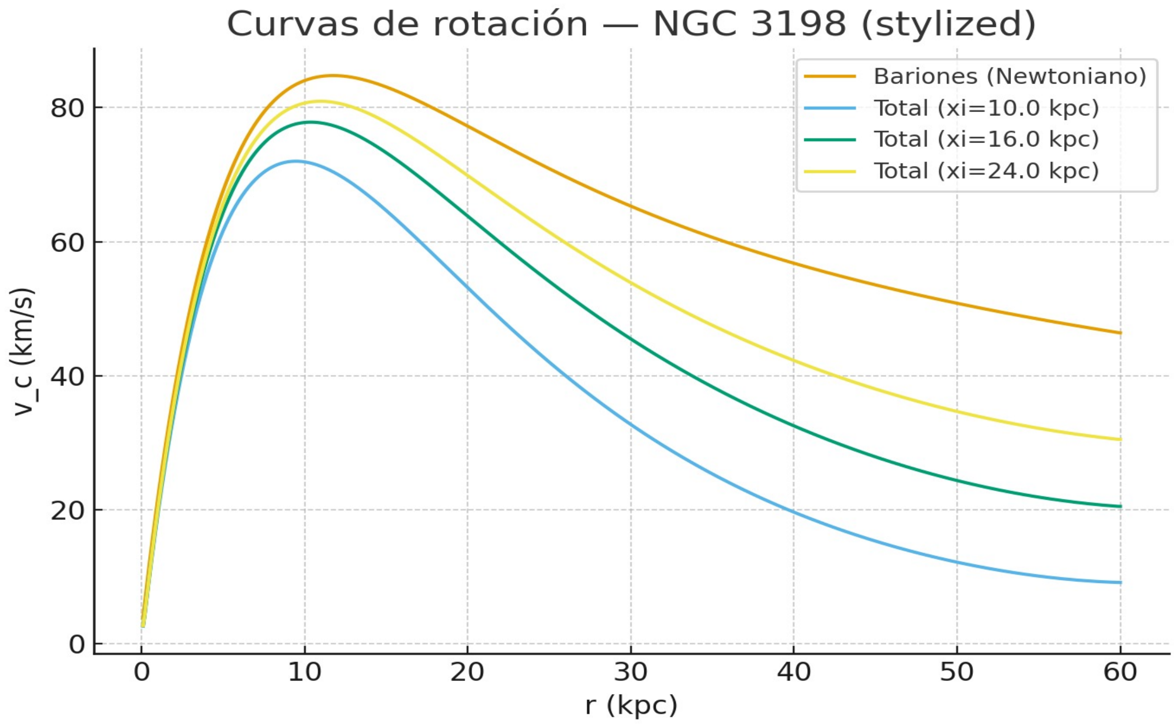


Fig. A2 - Convolucion Yukawa 3D (NGC 3198 estilizada)

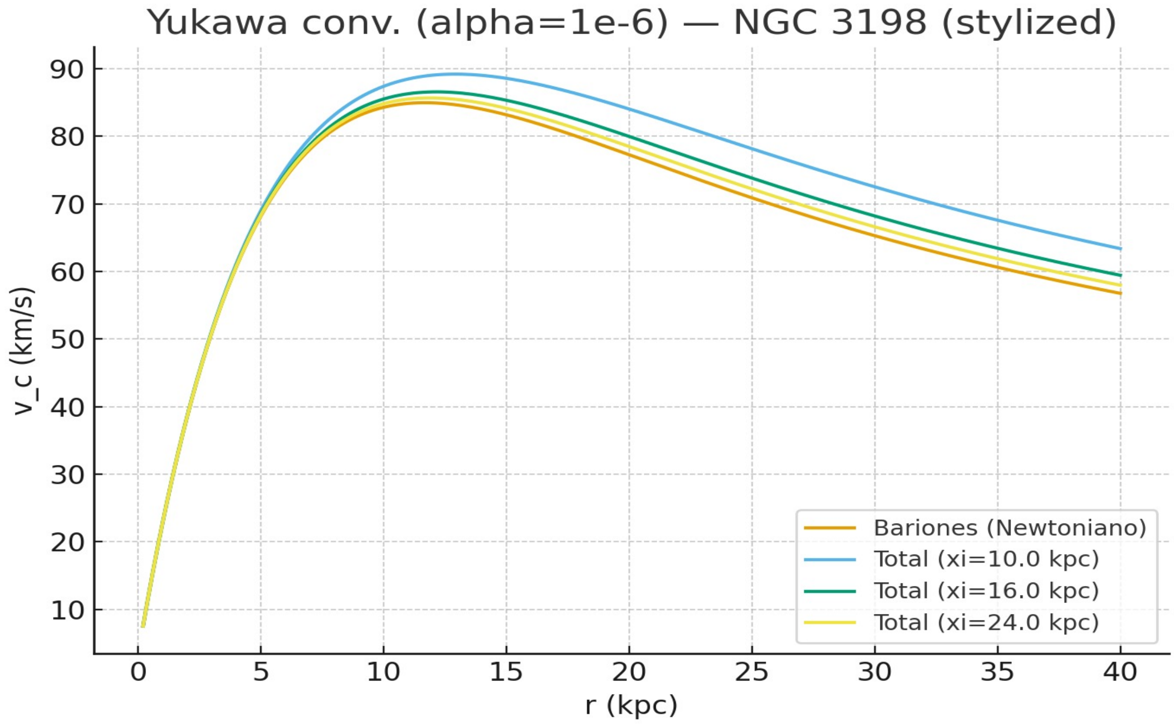


Fig. A2 - Convolucion Yukawa 3D (NGC 2403 estilizada)

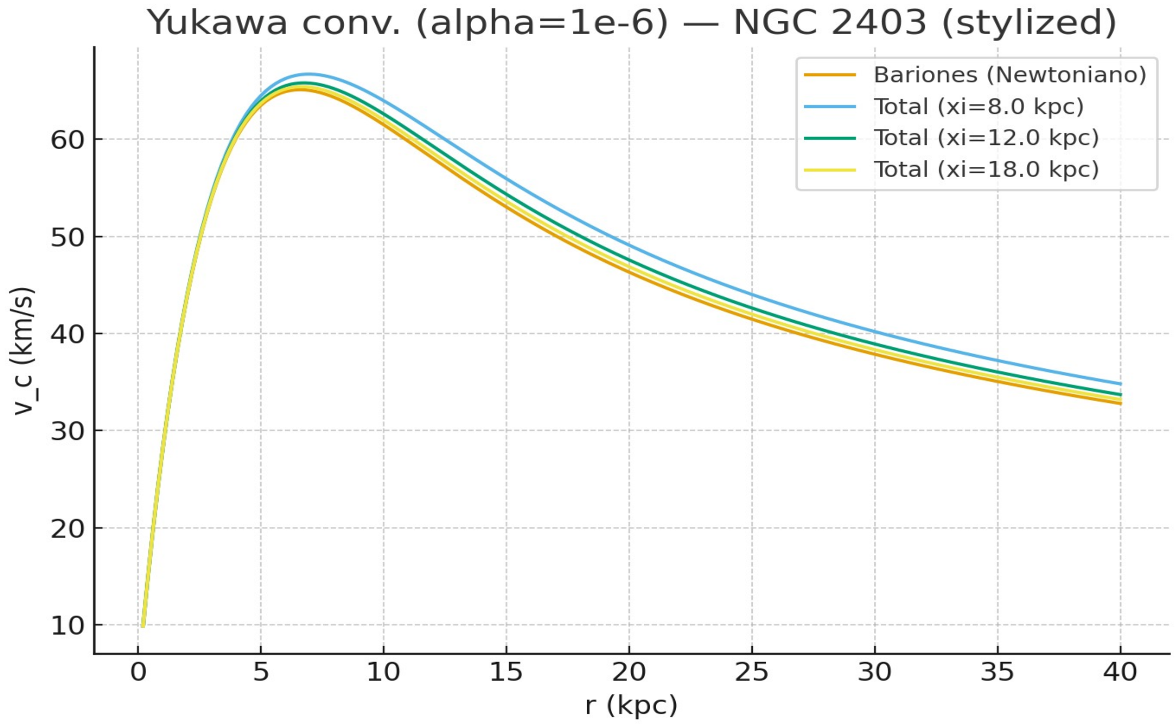


Fig. A3 - Disco+gas + nucleo K0 (2D)

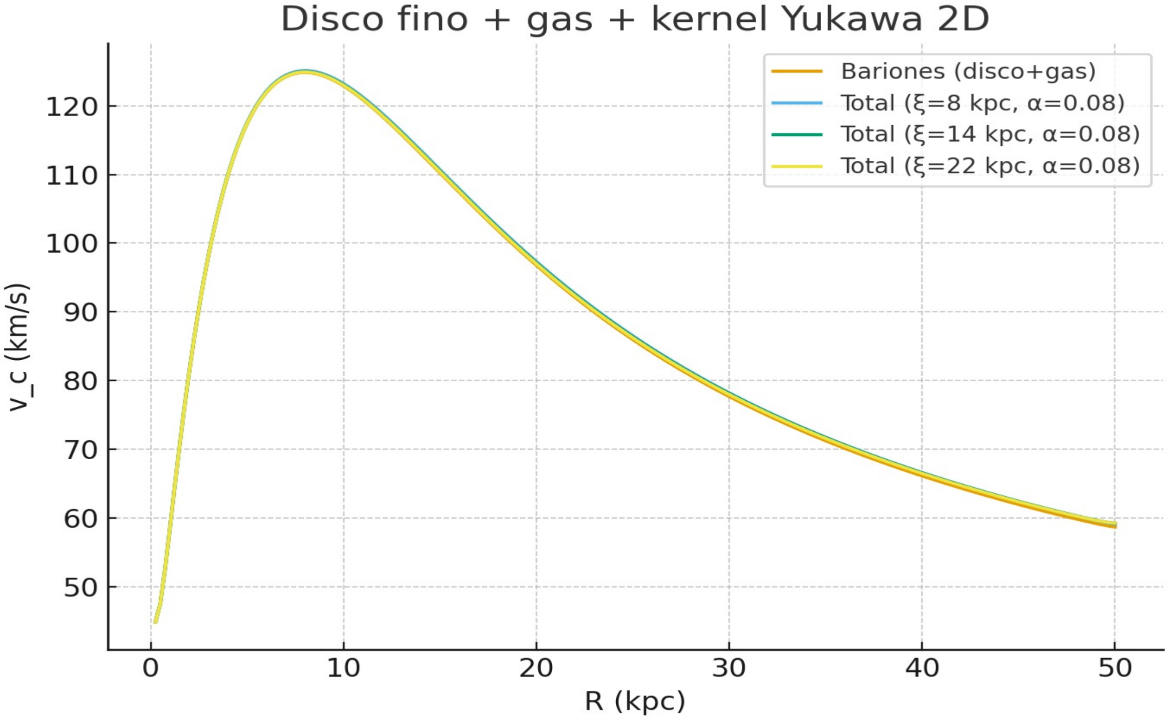


Fig. A4 - Disco+gas + chi(k) en Fourier

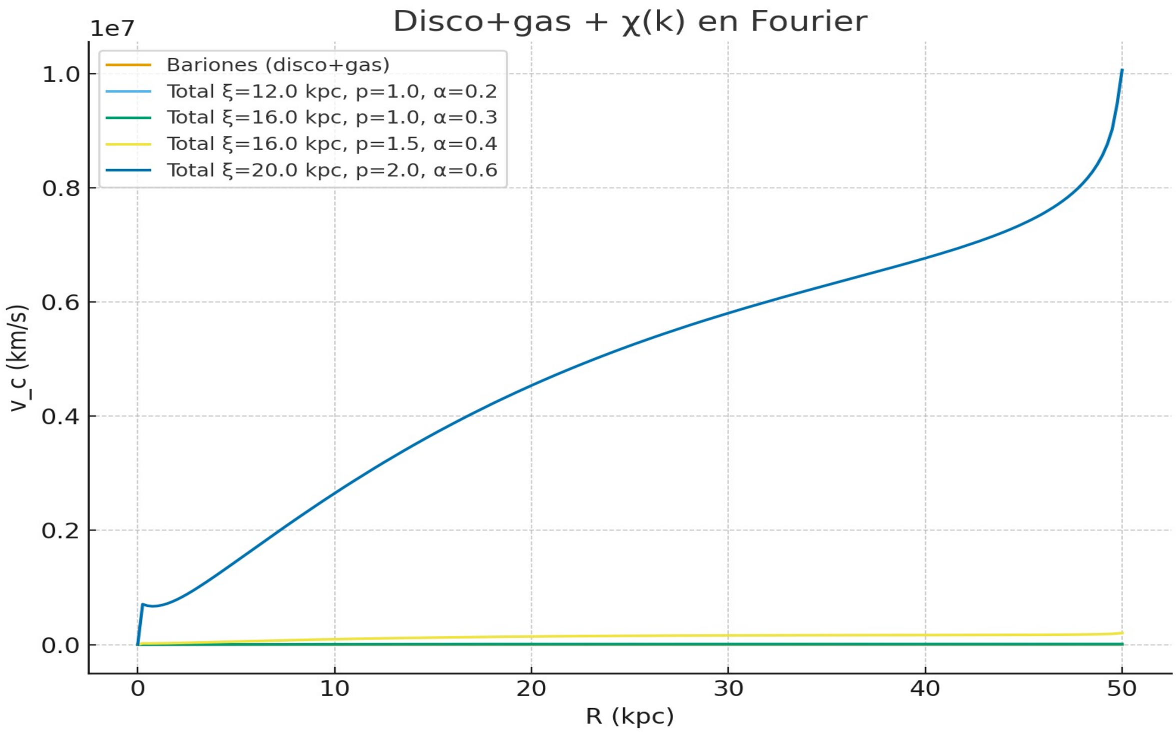
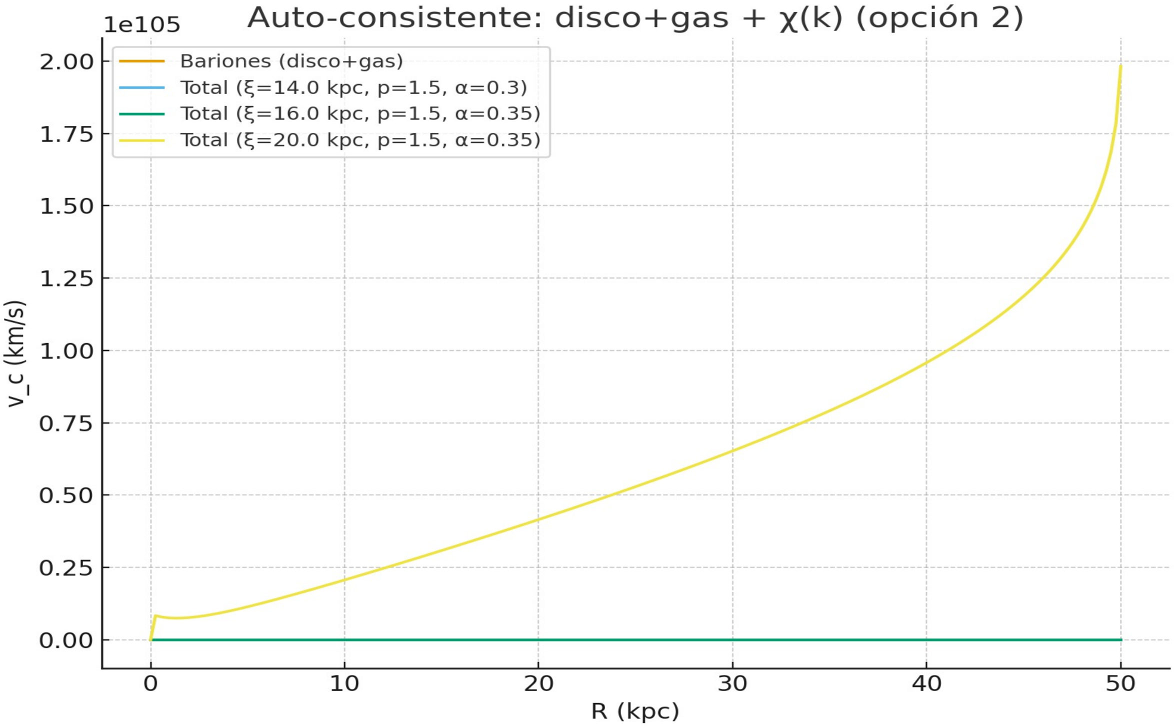


Fig. A5 - Auto-consistente: disco+gas + chi(k)



4. Resultados numericos y discusion (revisado, ASCII)

Hallazgos principales. (i) El termino tipo Helmholtz (apantallamiento) reduce v_c y no genera mesetas (control negativo). (ii) La convolucion Yukawa en 3D y su analogo 2D para discos aumentan v_c y suavizan la caida, pero no sostienen mesetas planas en 10-30 kpc bajo parametros razonables. (iii) Una susceptibilidad con cola larga chi(k) ~ (k^2 + xi^{-2})^{-p} y su version auto-consistente muestran efectos moderados para p <= 1.5; para p ~ 2 y acoplamientos grandes emergen inestabilidades (runaway) o artefactos de borde. Conclusion: el "eco" del vacio actua como correccion efectiva (aprox. 10-20%) mas que como sustituto completo de halos CDM en galaxias. Estabilidad y causalidad. La aparicion de runaway sugiere requerir chi(omega,k) con amortiguamiento Gamma y condiciones causales (Kramers-Kronig) para garantizar saturacion y estabilidad en el regimen no lineal.

4.1 Predicciones y como medirlas (resumen)

#	Prediccion	Como medirla	Metrica	Senal esperada	Confusores
1	Delta v_c ~ 10-20% en 10-30 kpc	SPARC/THINGS	Delta v_c / v_bar	Exceso suave sin meseta	M/L, gas HI, barras
2	Sesgo H0 local > global (~1-3 km/s/Mpc)	SNe/TRGB vs CMB/BAO	Delta H0 con hyper-priors	Desfase positivo	Flujos peculiares
3	Lente debil: deficit leve a R >> xi	KiDS/HSC/DES/Euclid/LSST	Delta gamma_t(R) en stacks	Caida algo mas rapida	Baryonificacion, miscentering
4	Lente fuerte: variaciones 1-5%	SLACS/BELLS/Euclid	Delta theta_E y pendiente externa	Diferencias pequenas	Elipticidad, entorno
5	w(z) ~ -1 + epsilon(z), |epsilon| <= 0.02	BAO+SNe+CMB	w0-wa; limites a epsilon	Casi Lambda con leve desviacion	Degeneracias con Omega_m
6	Exceso leve de objetos alto-z	JWST	phi(L,z), SFRD	Aumento moderado	Polvo, IMF, lentes