Anisotropic Universes in Light of Background Observations

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November 4, 2026

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Anisotropic Universes in Light of Background Cosmological Observations

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Is our universe totally isotropic?

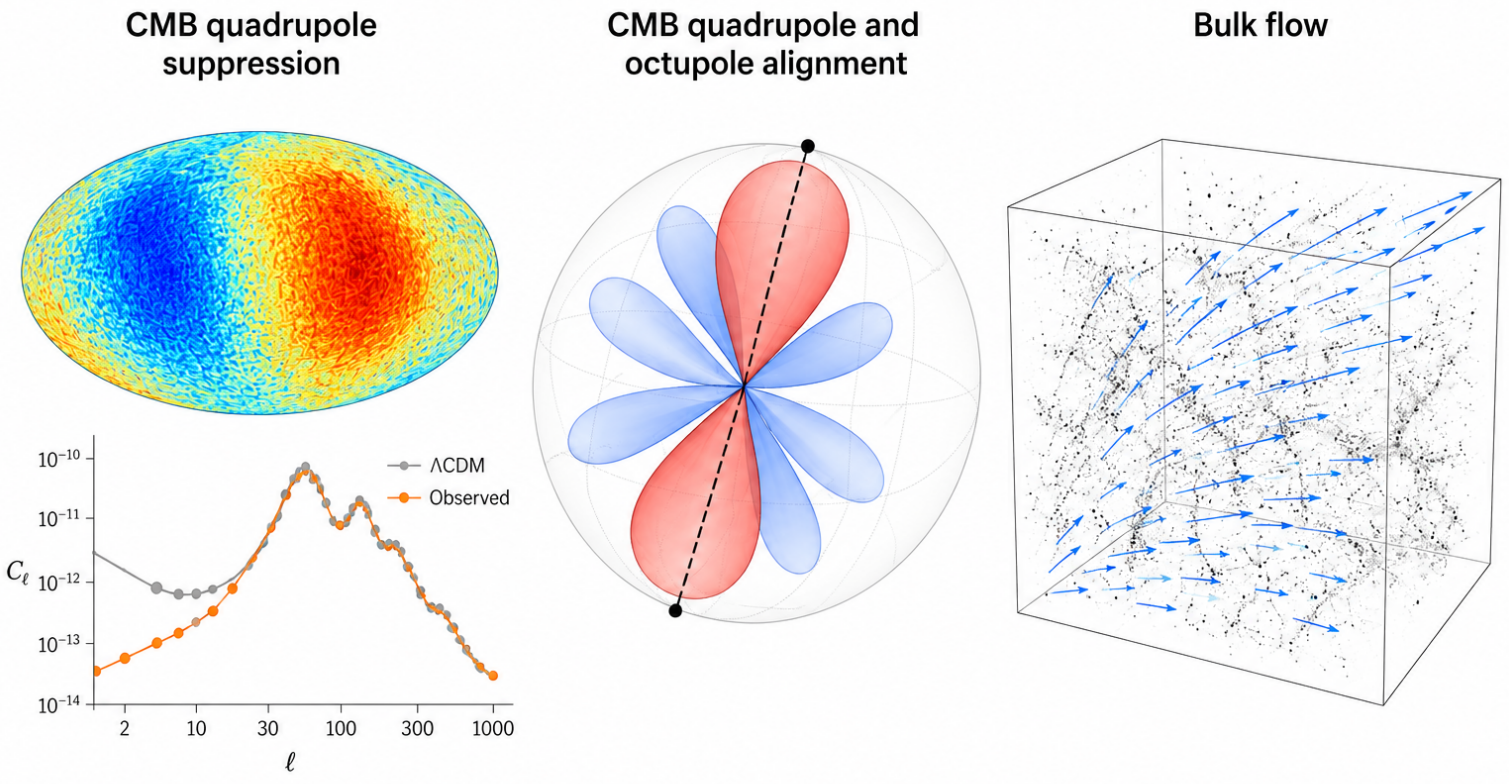


Figure: Some problems related to ΛCDM that motive an anisotropic background.

CMB Quadrupole Suppression

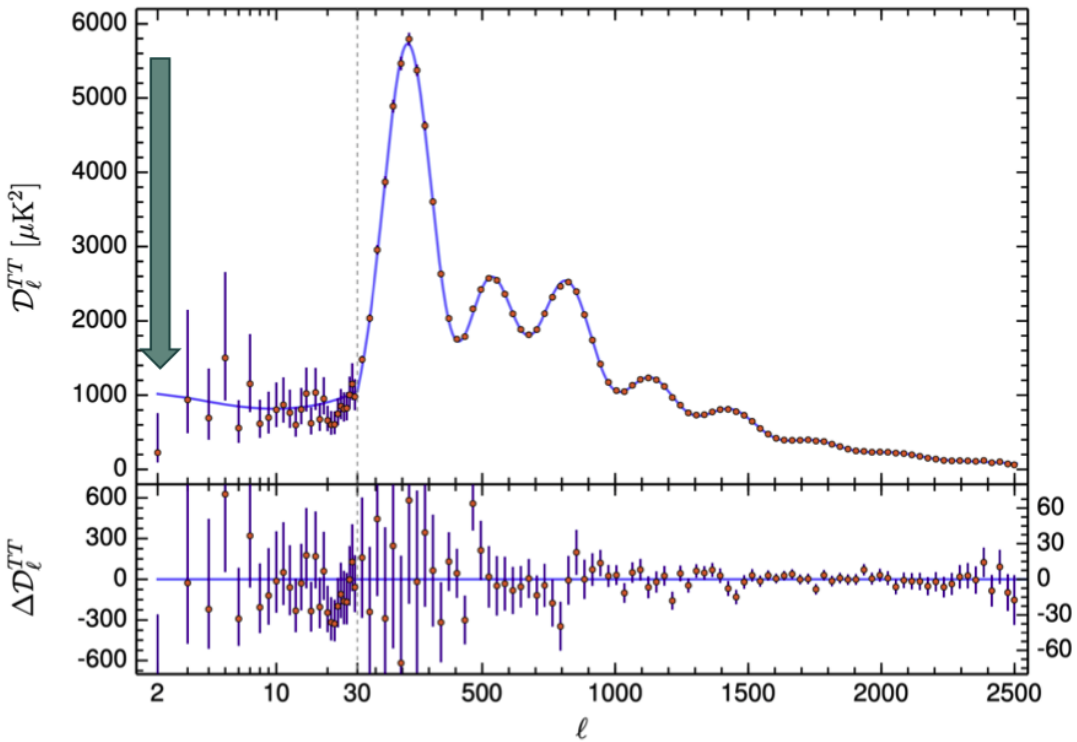


Figure: The first data point is lower than the expect value for ΛCDM. [1]

$$\left|\frac{\delta T}{T}\right| \lesssim \left|\int_{t_{\rm de}}^{t_0} \dot{\sigma} dt\right| = \left|\sigma_{t_0} - \sigma_{t_{\rm de}}\right|. \tag{1}$$

[1] Jahmour Givans/ Berkeley Cosmology Semina / January 28, 2025

Bianchi-I universes

$$\mathcal{S} = \int \mathrm{d}x^4 \sqrt{-g} \left\{ \frac{m_{\rm pl}^2}{2} R + \mathcal{L}_{\rm r} + \mathcal{L}_{\rm b} + \mathcal{L}_{\rm cdm} + \mathcal{L}_{\rm DE} \right\}. \qquad (2)$$

- Bianchi-I metric.

$$\mathrm{d}s^2 = -\mathrm{d}t^2 + a^2(t)\gamma_{ij}(t)\mathrm{d}x^i\mathrm{d}x^j, \quad \gamma_{ij}(t) = \left[e^{2\beta_i(t)}\right]\delta_{ij}, \quad \sum_i \beta_i = 0.$$

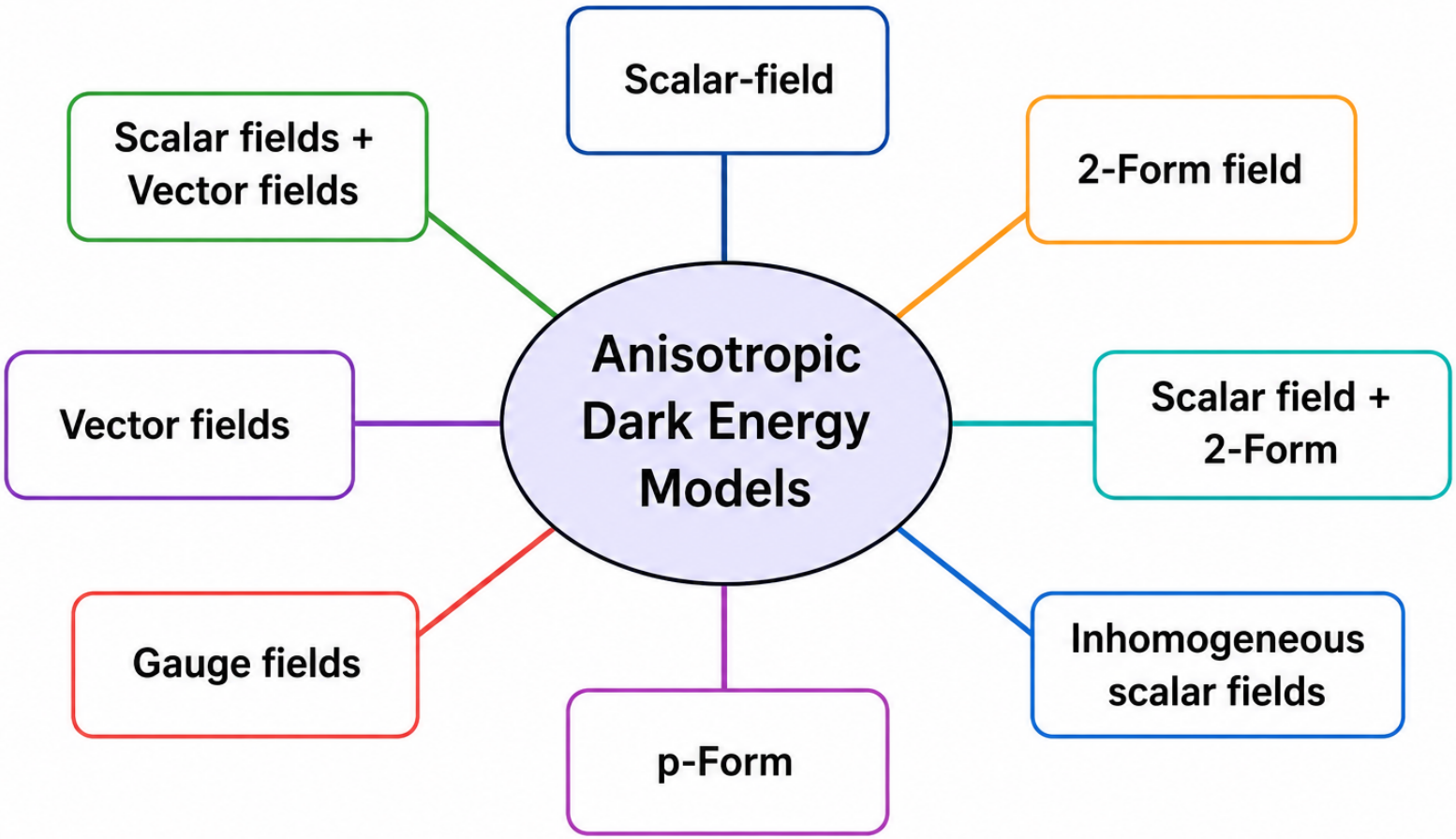
- For simplicity, we consider the following metric

$$\mathrm{d}s^2 = -\mathrm{d}t^2 + a^2(t)\left\{e^{-2\sigma}\mathrm{d}x + e^{\sigma}\left(\mathrm{d}y + \mathrm{d}z\right)\right\}. \qquad (3)$$

$$3m_{\rm pl}^2 H^2 = \rho_{\rm r,m} + \rho_{\rm DE}. \qquad (4)$$

- Nevertheless, what is $\rho_{\rm DE}$?

Anisotropic DE models



Scalar field coupled to a vector field

- Anisotropic Quintessence (AQ) [2].

Anisotropic k-essence

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$$\mathcal{L}_{\rm DE} = -\frac{1}{2}\nabla_\mu\phi\nabla^\mu\phi - \frac{1}{4}f^2_{\rm AQ}(\phi)F_{\mu\nu}F^{\mu\nu} - V_{\rm AQ}(\phi), \qquad (5)$$

[2] Orjuela-Quintana, J. Bayron, et al. "Anisotropic k-essence." Physics of the Dark Universe 33 (2021): 100857.

Scalar field coupled to a 2-form field

- 2-Form field (FQ) [3].

Anisotropic 2-form dark energy

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$$\mathcal{L}_{\rm DE} = -\frac{1}{2}\nabla_\mu\phi\nabla^\mu\phi - \frac{1}{12}f_{\rm FQ}(\phi)H_{\mu\nu\alpha}H^{\mu\nu\alpha} - V_{\rm FQ}(\phi) \qquad (6)$$

[3] Almeida, Juan P. Beltrán, et al. "Anisotropic 2-form dark energy." Physics Letters B 793 (2019): 396-404.

Inhomogeneous scalar field

- Solid dark energy (SDE) [4].

Anisotropic solid dark energy

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$$\mathcal{L}_{\rm DE} = -\sum_I F^I\left(X^I\right), \quad X^I \equiv g^{\mu\nu}\nabla_\mu\phi^I\nabla_\nu\phi^I. \tag{7}$$

[4] Motoa-Manzano, Josué, et al. "Anisotropic solid dark energy." Physics of the Dark Universe 32 (2021): 100806.

Gauge field with internal symmetry

- Einstein Yang Mills Higgs (EYMH) [5].

Anisotropic Einstein Yang-Mills Higgs Dark Energy

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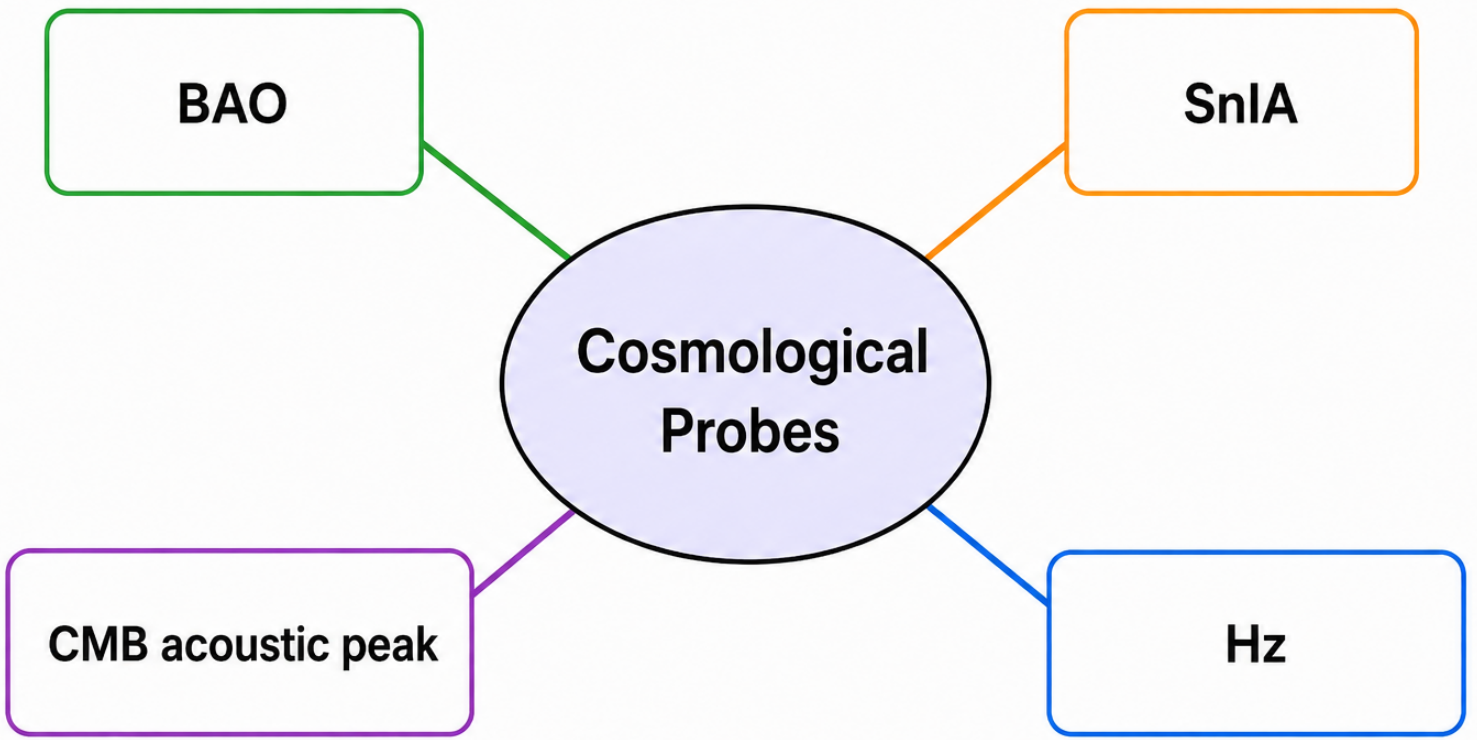
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$$\mathcal{L}_{\rm DE} = -\frac{1}{4}F^{a}{}_{\mu\nu}F_{a}^{\mu\nu} - \frac{1}{2}D_{\mu}\mathcal{H}^{a}D^{\mu}\mathcal{H}_{a} - V(\mathcal{H}^{2}) \tag{8}$$

[5] Orjuela-Quintana, J. Bayron, et al. "Anisotropic Einstein Yang-Mills Higgs Dark Energy." Journal of Cosmology and Astroparticle Physics 2020.10 (2020): 019.

Observational Data-Set



Results

Parameter	ΛCDM	AQ	SDE	2-Form	EYMH
$\Omega_{\rm cdm}$	$0.2436^{+0.0068}_{-0.007}$	$0.2432^{+0.0069}_{-0.0070}$	$0.2437^{+0.0067}_{-0.0071}$	$0.2444^{+0.0068}_{-0.0071}$	$0.2436^{+0.0068}_{-0.0071}$
$100\omega_{\rm b}$	$2.276^{+0.015}_{-0.015}$	$2.279^{+0.016}_{-0.016}$	$2.28^{+0.015}_{-0.015}$	$2.281^{+0.016}_{-0.016}$	$2.277^{+0.015}_{-0.015}$
h	$0.7049^{+0.0074}_{-0.0075}$	$0.7041^{+0.0074}_{-0.0073}$	$0.7037^{+0.0074}_{-0.0075}$	$0.7034^{+0.0075}_{-0.0075}$	$0.7047^{+0.0074}_{-0.0075}$
$\Omega_{\rm DE}$	$0.7105^{+0.0076}_{-0.0074}$	$0.7107^{+0.0074}_{-0.0075}$	$0.7102^{+0.0077}_{-0.0073}$	$0.7094^{+0.0077}_{-0.0074}$	$0.7104^{+0.0077}_{-0.0074}$
$10^4\Sigma_0$	-	$9.67^{+1.09}_{-4.19} \times 10^{-23}$	$-6.269^{+49.1}_{-23.9}$	$53.0^{+237}_{-28.5}$	8.744×10^{-4}
Param_1	-	$0.0026^{+0.44}_{-0.44}$	$0.039^{+0.014}_{-0.039}$	$1.072^{+0.14}_{-1.1}$	1
Param_2	-	50.37	$0.0386^{+0.0139}_{-0.0386}$	$32.44^{+18.0}_{-6.0}$	-35

Table: Mean values and 68% confidence limits on cosmological parameters for the considered DE models.

Anisotropic 2-Form

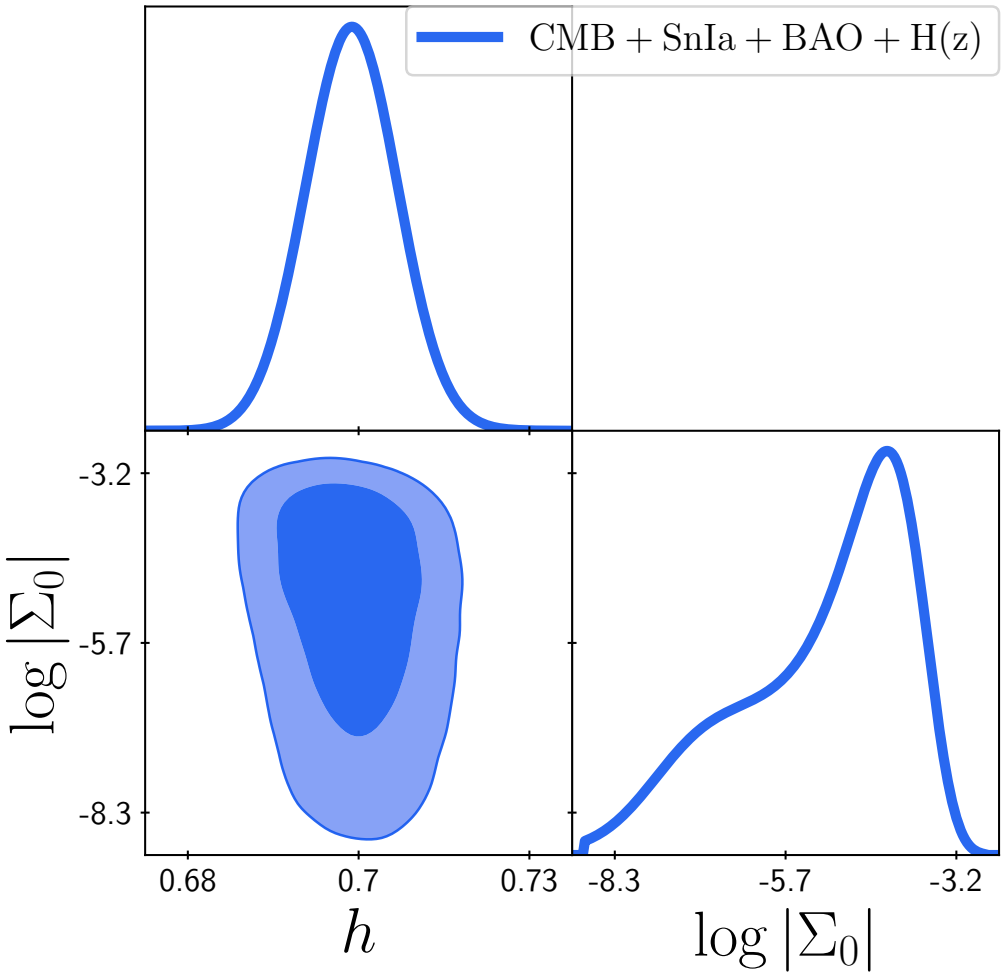


Figure: 68% and 95% confidence contours for the parameters $\{h,\ \Sigma_0\}$ of the 2-Form model.

Angular distance in Bianchi-I

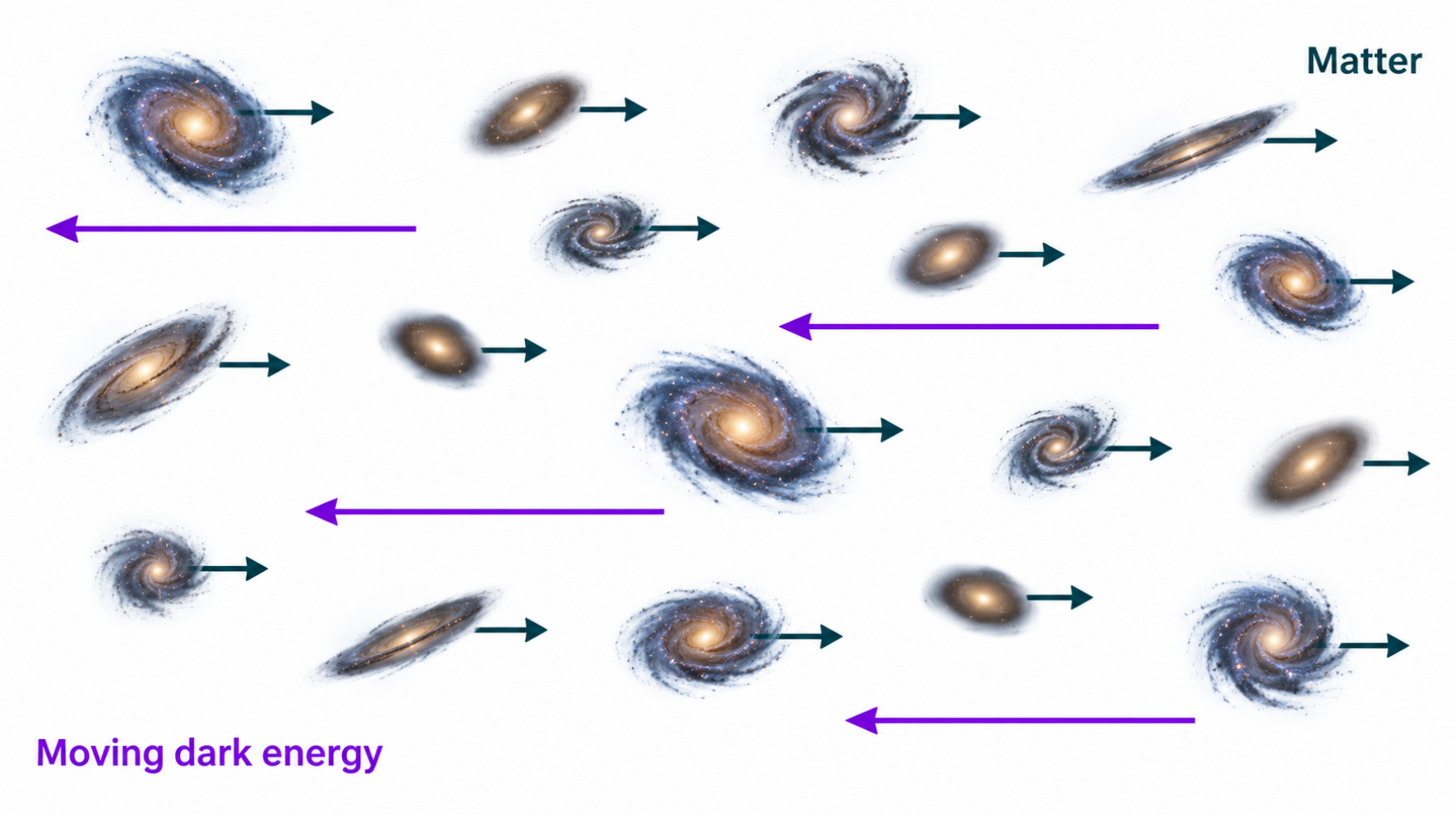
- Anisotropic redshift

$$1 + z(\hat{\mathbf{p}}) = \frac{1}{a} \frac{\left(1 - e^2 \sin^2 \theta\right)^{1/2}}{\left(1 - e^2\right)^{1/3}}, \tag{9}$$

$$d_L\left(z, \hat{\mathbf{p}}\right) = (1 + z) \int_{a(z)}^{1} \frac{da}{a^2 H} \frac{\left(1 - e^2\right)^{1/6}}{\left(1 - e^2 \cos^2 \theta\right)^{1/2}}. \tag{10}$$

- To do:
  1. Gravitation waves.
  2. Bao radial.
  3. Structure formation.
  4. CMB, etc.

Moving KGB



Moving KGB

Horndeski in motion

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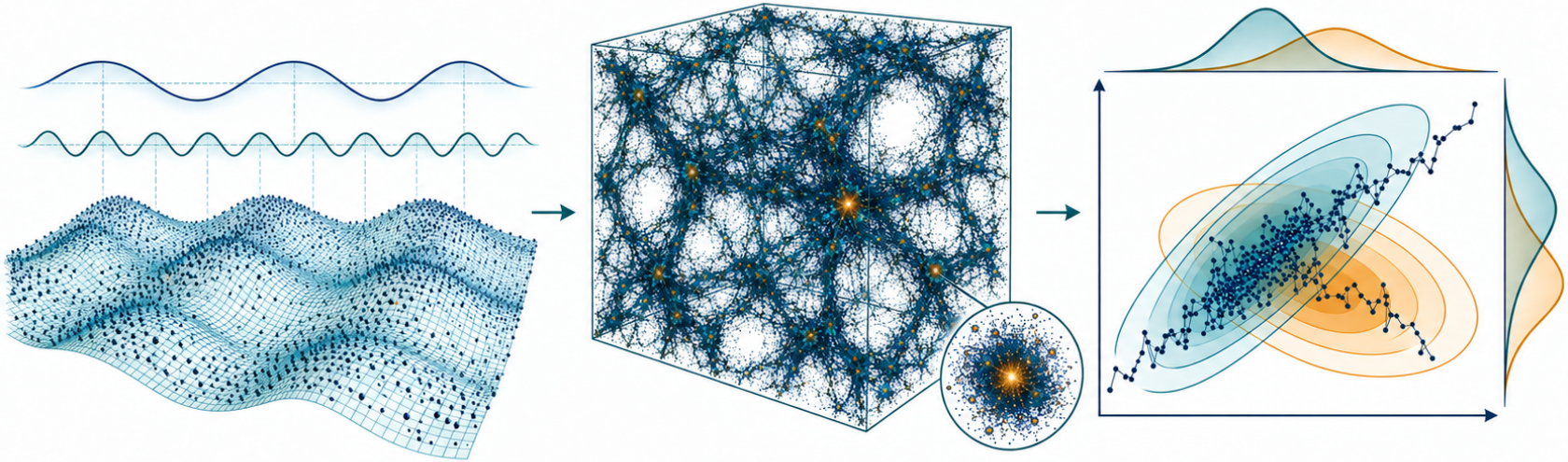
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$$\mathcal{L}_{\rm DE} = G_2(X) - G_3(X)\Box\phi, \qquad \phi = \varphi(t) + \lambda_i\, x^i. \qquad (11)$$

From Background Evolution to Nonlinear Structure Formation and Observables

- Elena Giusarma (MTU), Luz Angela Garces (ECCI), Bayron Orjuela (UV), Jose Palacios (UV).



Cosmology with an Expanding Solid

Multifield curved solid: Early dark energy and perturbation instabilities

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(Dated: September 4, 2024)

$$\mathcal{L}_{\rm DE} = -\frac{1}{2}\nabla_\mu \phi^A \nabla^\mu \phi^B G_{AB} - V(\phi^A). \tag{13}$$

$$d\ell^2 = d\varphi^2 + f(\varphi)^2 \delta_{IJ}\phi^I \phi^J \tag{14}$$

VCDM

Dynamical dark energy parameterizations in VCDM

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The matter-density PDF in phantom-crossing VCDM

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- Lina Castiblanco and Cora Uhlemann (*Universität Bielefeld*),
- Alexander Gallego, Pedro Ibarbo, Bayron Orjuela, and Jose Palacios (*Universidad del Valle*).

Conclusions

- For a scalar field coupled to a vector field and a scalar field with internal symmetry, the anisotropy remains close to zero.
- For an inhomogeneous scalar field, the anisotropy is of the order of 10^{-4}
- For an scalar field the anisotropy is on the order of 10^{-2}, in fact, the isotropic case is excluded by the observations considered.
- In contrast to usual quintessence models, the observations favor values of λ_{FQ} that are not close to zero.

Thanks