Testing the EP with the QE

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Can QE test universal free fall?

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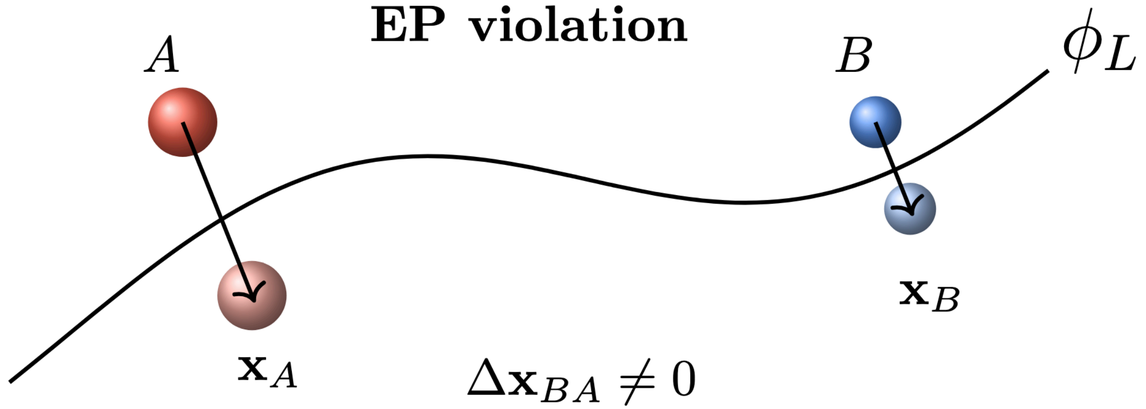


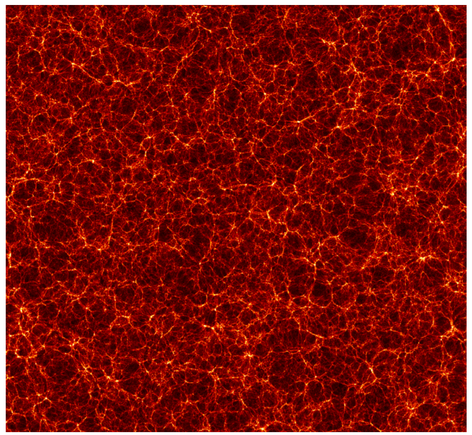
$$\Delta\mathbf{x}_{BA} \propto \epsilon$$

$$\langle \delta_A \delta_B \rangle_L \supset \epsilon \delta_L$$

Falling Dark Matter

Dark-matter non-linear due to gravity

$$\delta \sim \delta_1 + \delta_2 + \ldots$$



Credit: AbacusSummit

$$\delta_1^2$$

Non-linear growth (G)

l=0

$$\vec{\Psi} \cdot \vec{\nabla} \delta_1$$

Shift (S)

l=1

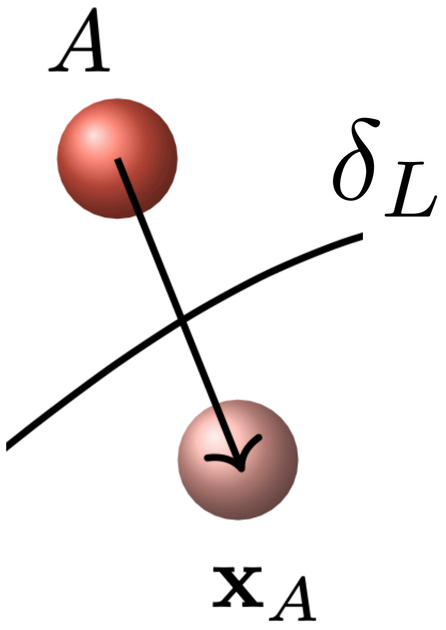
$$\left(\left[\frac{\partial_i \partial_j}{\partial^2} - \frac{1}{3} \right] \delta_1 \right)^2$$

Tidal (T)

l=2

e.g. Sherwin+,2012,Schmitfull+,2015Desjacques+,2018

Falling Dark Matter

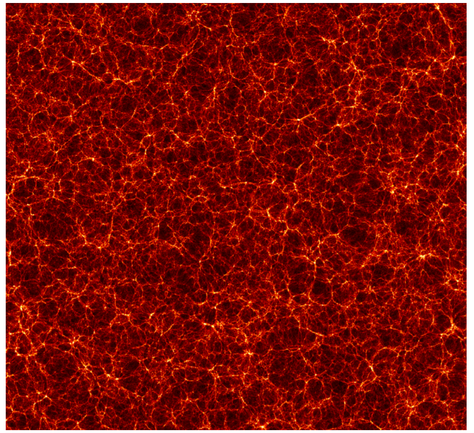


$$\delta \sim \delta_1 + \delta_2 + \ldots$$

$$\vec{\Psi} \cdot \vec{\nabla} \delta_1$$

$$\delta_1(\vec{x} + \vec{\Psi}_L)$$

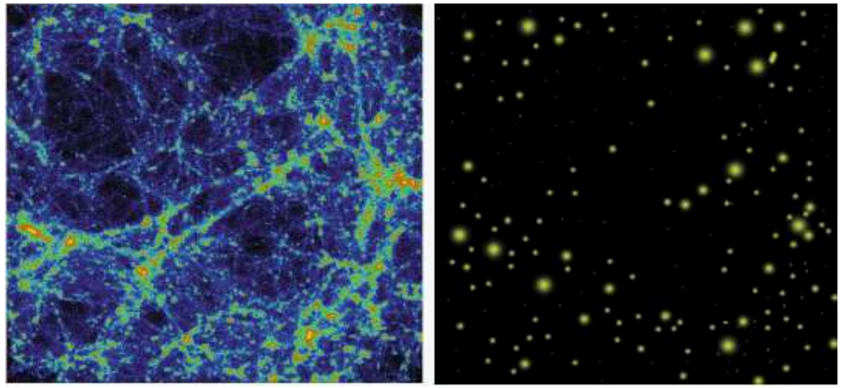
$$T_{\rm cmb}(\hat{n} + \vec{d}_L)$$



Credit: AbacusSummit

Falling Galaxies

Galaxies are biased tracers of non-linear dark matter



Credit: Cooray & Sheth

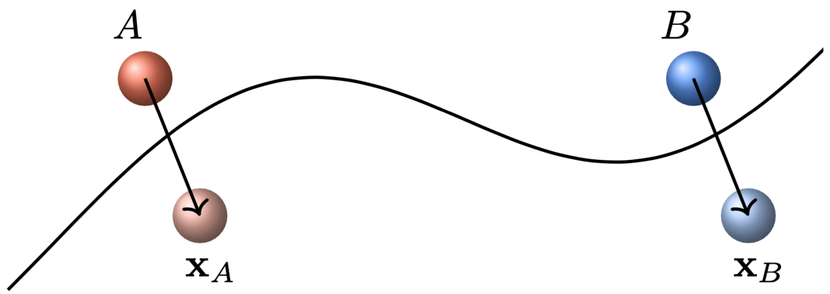
$$\delta_g \sim b_1\delta_1 + (b_1 + 21/17b_2)\delta_G + b_1\delta_S + (b_1 + 7/2b_{s^2})\delta_T$$

↓

No new additional bias!

$$b_1\delta_1(\vec{x} + \vec{\Psi}_L)$$

Shifting under a long-mode



$$B_{ABL} \sim \langle \delta_L(\vec{K}) \delta_A(\vec{k}_A) \delta_B(\vec{k}_B) \rangle$$

$$f_{AB}\delta_L = \langle \delta_A(\vec{k}_1) \delta_B(\vec{k}_2) \rangle_{\mathrm{L}} \qquad f = \frac{B(\vec{K}, \vec{k})}{P_L}$$

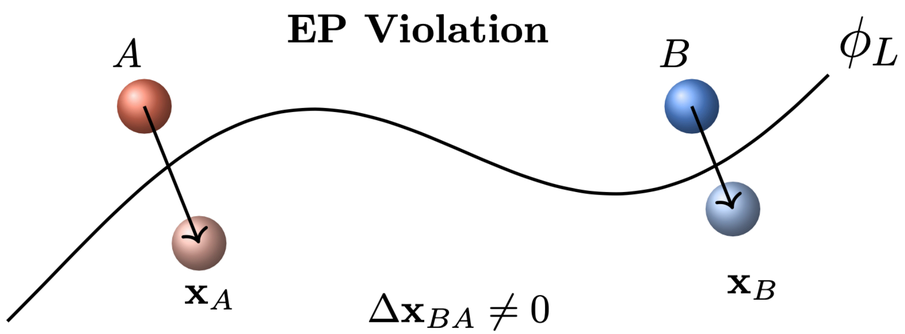
e.g. Lewis+2011, Lewis 2011, Barreira & Schmidt 2017, Carron&Lewis 2024

Symmetric Anti-symmetric

$$f_{AB}(\mathbf{k}_1, \mathbf{k}_2) = C^{\mathrm{G}}_{(AB)} f^{(+)}_{\mathrm{G}}(\mathbf{k}_1, \mathbf{k}_2) + C^{\mathrm{G}}_{[AB]} f^{(-)}_{\mathrm{G}}(\mathbf{k}_1, \mathbf{k}_2)$$
$$+ C^{\mathrm{S}}_{(AB)} f^{(+)}_{\mathrm{S}}(\mathbf{k}_1, \mathbf{k}_2) + \boxed{0}$$
$$+ C^{\mathrm{T}}_{(AB)} f^{(+)}_{\mathrm{T}}(\mathbf{k}_1, \mathbf{k}_2) + C^{\mathrm{T}}_{[AB]} f^{(-)}_{\mathrm{T}}(\mathbf{k}_1, \mathbf{k}_2),$$

Preliminary

Now break the EP



$$\epsilon \frac{b_{1B} b_{\epsilon,SA} - b_{1A} b_{\epsilon,SB}}{2} + \frac{b_{1B} b_{1A} - b_{1A} b_{1B}}{2}$$

$$f_{AB}(\vec{K}, \vec{k}) \supset C^{S}_{[AB]} f^{(-)}_{S}(\vec{K}, \vec{k}) \underset{K \to 0}{\sim} \epsilon \frac{\vec{k} \cdot \vec{K}}{|\vec{K}|^2}$$

Kehagias, Riotto, Petroni, Peloso,Creminelli, Simonović, Valageas, Lewandowski, Vernizzi, ...

Motivation to study (mixed) bispectrum to detect violations of EP

- **But covariance is hard**
- **Combination with trispectrum? Shot noise? Window functions? Systematics?**

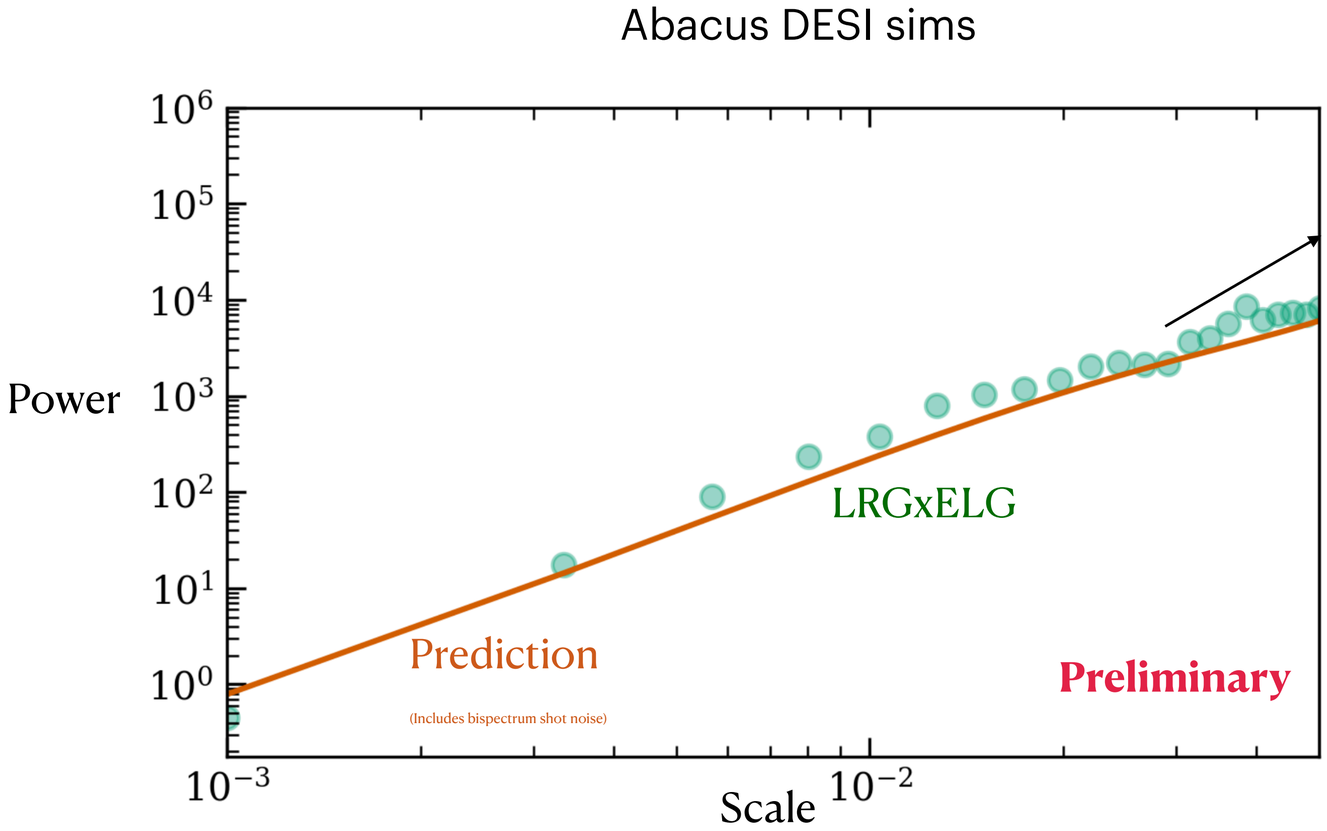
e.g. Chan&Bolt 2017, Sugiyama+2023

LSS QE

$$\langle \delta_A(\vec{k}_1)\delta_B(\vec{k}_2)\rangle_{\text{fixed } \delta_L} \sim f(\vec{k}_1, \vec{k}_2 = \vec{K} - \vec{k}_1)\delta_L$$

$$\widehat{\delta_L} \sim \frac{\delta_A \delta_B}{f}$$

e.g. Lewis 2011, Schimitfull+ 2015, de Putter 2018, Dai+ 2020, Li+2020, Darwish+ 2020, Carron&Lewis 2024



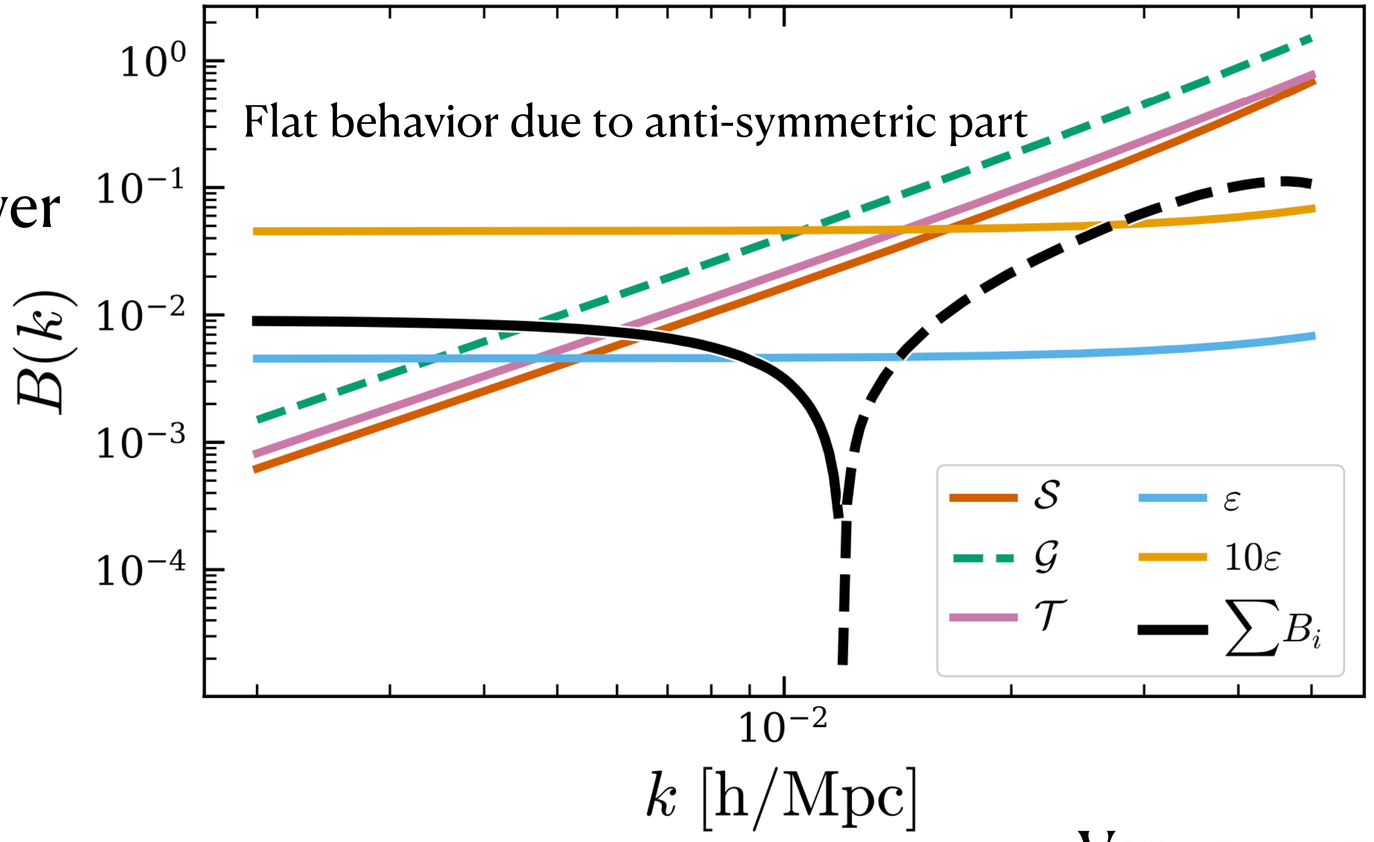
$$\langle \widehat{\delta_L}^{AB} \delta_{\text{matter}} \rangle \sim B^{ABm}(\vec{K}, \vec{k}_1, \vec{k}_2)$$

Main cost a bunch of FFTs. Widely applied for CMB secondaries.

GPU code with applications on EP, non-linearity and PNG

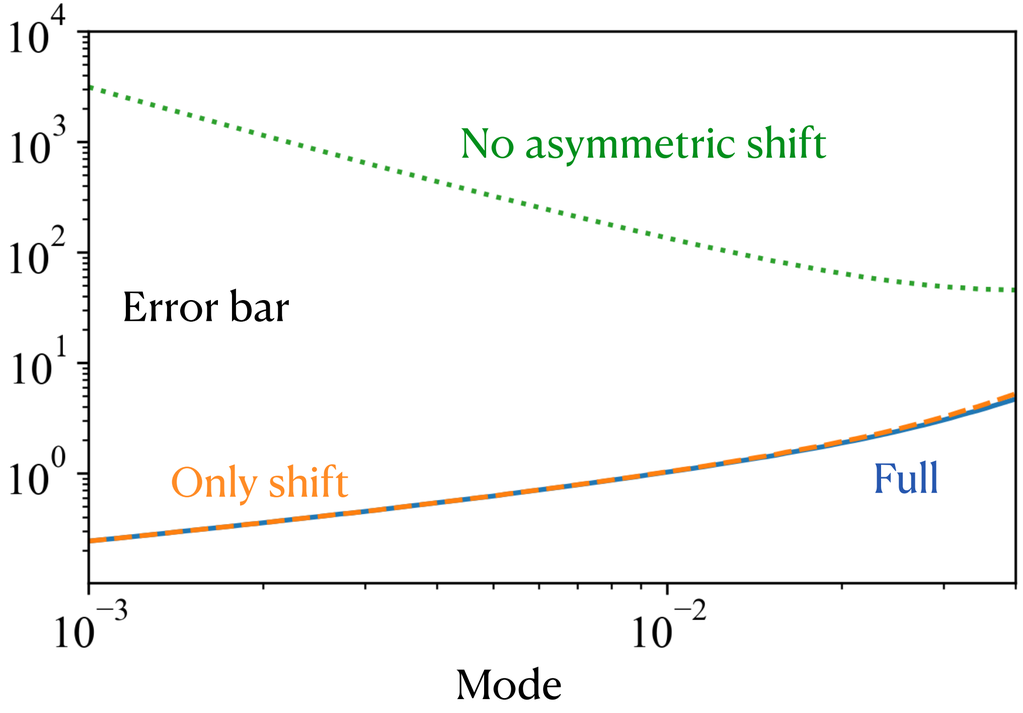
Effective reconstruction bias

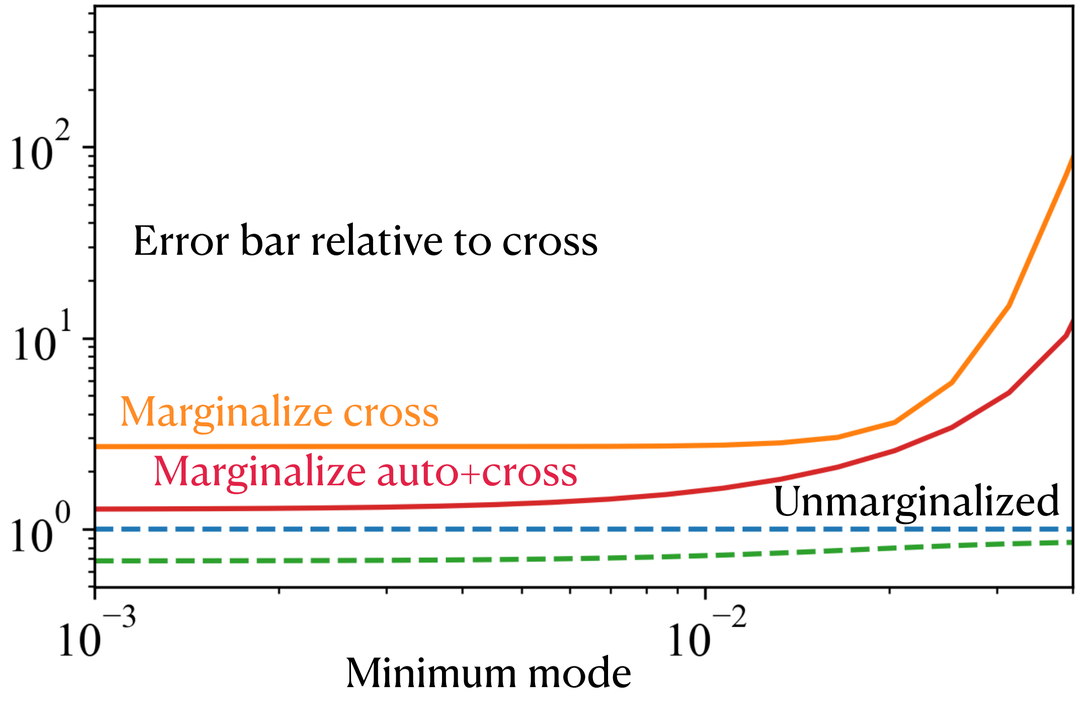
Cross-Power/Linear Power



Very exaggerated example

Preliminary forecasts





Preliminary

Imagine a Stage V survey

Ideally.... $\lim_{x\to 0} \sigma^2(K)_{\rm joint} \sim \sigma^2_{\rm single} k^{-3}_{\rm max} \sim \sigma^2_{\rm single}/N_{\rm modes}$

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