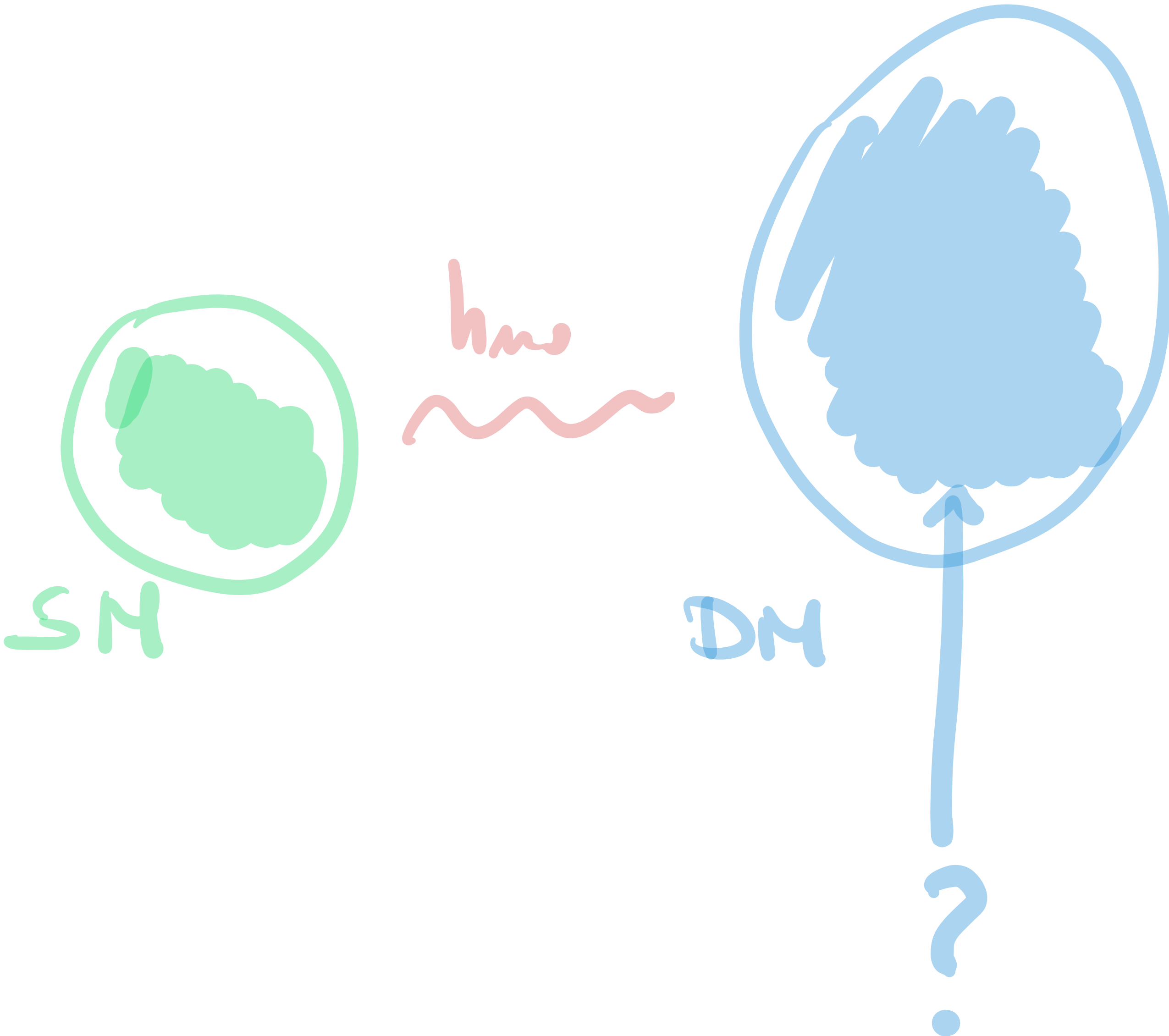
New Forces in the Dark

* 2204.08484 with Archidiacono, Castorina, Salvioni
* To appear with Bottaro, Costa, Castorina, Salvioni

Dark Sector interacts with the SM only through gravity

(non-thermally produced)

see for example A. Tesi's talk



COSMOLOGY ALLOWS US TO PROBE STRUCTURE IN THE DARK SECTOR INDEPENDENTLY ON ITS COUPLING TO SM.

Precision tests in the Dark Sector

* DM is COLD

  - 2107.09664 Durrain et al.
  - 0501562 Viel et al.

  No DROP in P(k)

  $f_{wo} < 10\%$

* Λ is just a constant

  - 2012.07554, 2003.07956 D'Amico et al.

  $1 \leq w \leq -0.48$

  Comparing angular distances @ different redshift.

* DM is COLLISIONLESS

  ↕

  @ LARGE SCALES ITS DYNAMICS IS DOMINATED BY A SINGLE GRAVITATIONAL POTENTIAL

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CDM in Cosmology

BKD

$$\begin{cases} \dot{\bar\rho}_x + 3H\bar\rho_x = 0 \quad \text{(zero pressure)} \\ H^2 = 8\pi G_N \sum_I \bar\rho_I \end{cases}$$

Linear Fluctuations

Let us focus on modes with $H/k \ll 1$

$$\begin{cases} \dot\delta_x \simeq -\bar\nabla\cdot\bar v_x \\ \dot{\bar v}_x + H\bar v_x = -\bar\nabla\psi \end{cases}$$

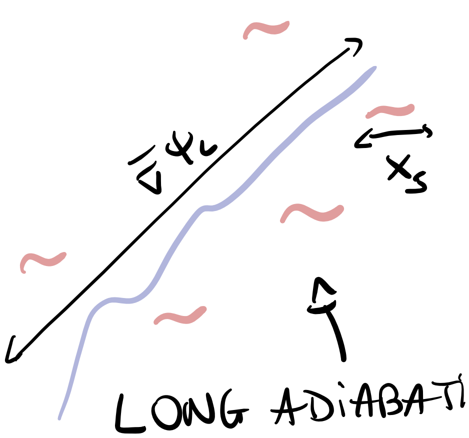
VELOCITY FLUCTUATIONS FOLLOW THE SAME GRAVITATIONAL FORCE

$$\nabla^2\psi \sim G_N\bar\rho\,\delta_x$$

Non-linear Fluctuations

$$\dot{\bar v}_x + H\bar v_x + (\bar v_x\cdot\bar\nabla)\bar v_x = -\bar\nabla\psi$$

Creminelli et al
1304.3557



LONG ADIABATIC MODE

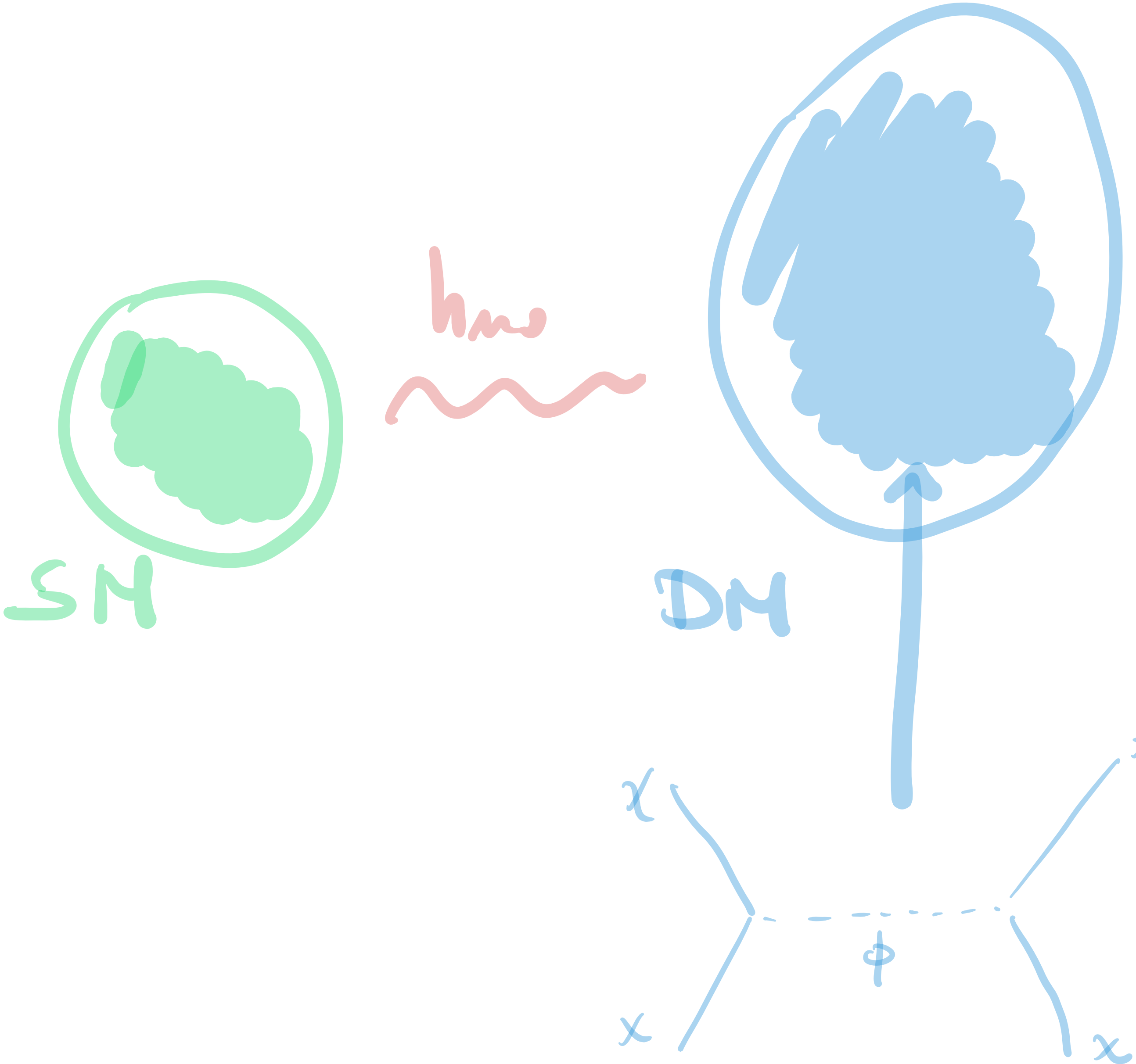
Equivalent

$$\equiv \quad \bar x_s + \delta\bar x_L$$

BOOST ON SHORT SCALES

⇓

RECURSION RELATIONS



How cosmology is affected by long-range DM self-interactions?

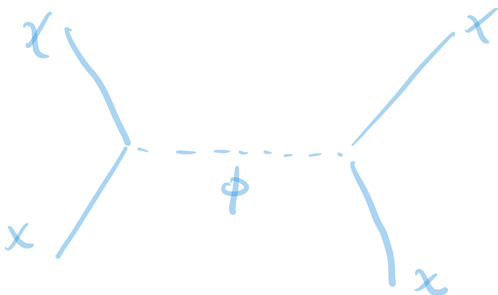
- BKD
- LINEARITY

} ← Archidiacono, Castorina, Salvioni 2204.08484

- NON-LINEARITY ← Bottaro, Costa, Castorina, Salvioni TO APPEAR

Setup

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 + \frac{m_\chi^2}{2}\chi^2 + \frac{\kappa\phi}{2}\chi^2$$



$\equiv$ New Force @ large scales

$$\phi \to \frac{1}{G_S^{1/2}} s \, , \quad \kappa / G_S^{1/2} \equiv m_\chi^2$$

DM mass field-dependent

$$\mathcal{L} = \frac{m_\chi^2 (1+s)}{2}\chi^2 + \frac{1}{2 G_S}(\partial\phi)^2 \qquad \beta \equiv \frac{G_S}{4\pi G_N}$$

Here we assume $m_\phi < H_0 \sim 10^{-33}$ eV

Naturalness: $\frac{\kappa^2}{16\pi^2} < m_\phi < H_0$

↓ upper bound on the DM mass: $m_\chi \lesssim \left(\frac{H_0 M_{Pl}}{\beta}\right)^{1/2} \sim 10^{-2}$ eV

IMPRINTS IN COSMOLOGY

* modification of distances

$$D(z) \sim \left(H + \Delta H\right)^{-1}$$

$$\dot{n}_x = 0 = \frac{d}{dt}\left(\bar{\rho}_x / m_x\right) = \dot{\bar{\rho}}_x + 3H\bar{\rho}_x - \frac{\dot{m}_x}{m_x}\bar{\rho}_x$$

$$\frac{\dot{m}_x}{m_x} = \tilde{m}_s \dot{s} \sim \beta \tilde{m}_s^2 H$$

$$\tilde{m}_s = \frac{\partial \log m_x}{\partial s}$$

EVOLUTION of DM mass

EVOLUTION of BKD 5th force

SOURCED BY DM ITSELF

* matter fluctuations

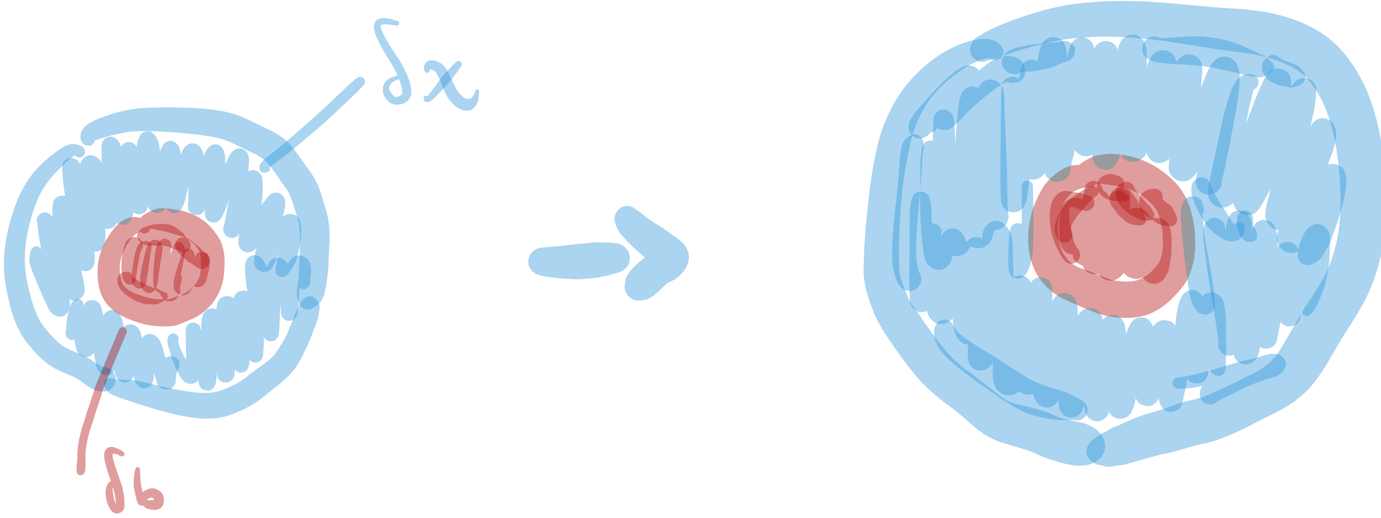
$$\theta_x' + (H + \Delta H)\,\theta_x - k^2(\psi + \Delta\psi) = 0$$

$$k^2\psi \sim (H + \Delta H)^2\,\delta_m$$

$$\delta_m \equiv f_x\,\delta_x + (1-f_x)\,\delta_b$$

BKD modification lead to seculae effects on TOTAL MATTER FLUCTUATIONS

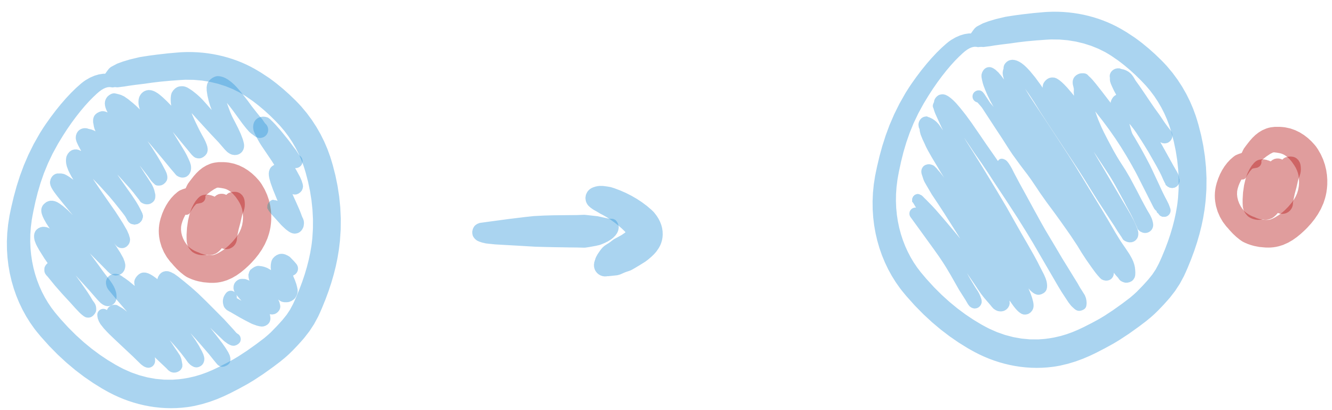
$$\delta_m \sim \delta_m\big|_{\Lambda CDM}\left(1 + \beta\,\tilde{m}_s^2\,f_x^2 \log\frac{a}{a_{eq}}\right)$$



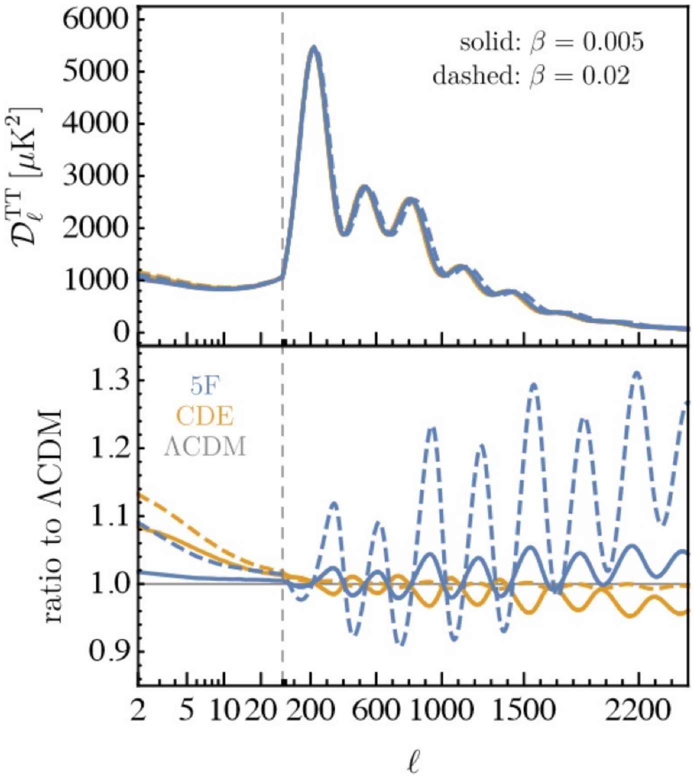
$$\delta_r \equiv \delta_x - \delta_b$$

$$\delta_r \sim \beta m_s^2 \, \delta_r \big|_{\Lambda CDM}$$

the new force sources growing relative density + relative velocity fluctuations



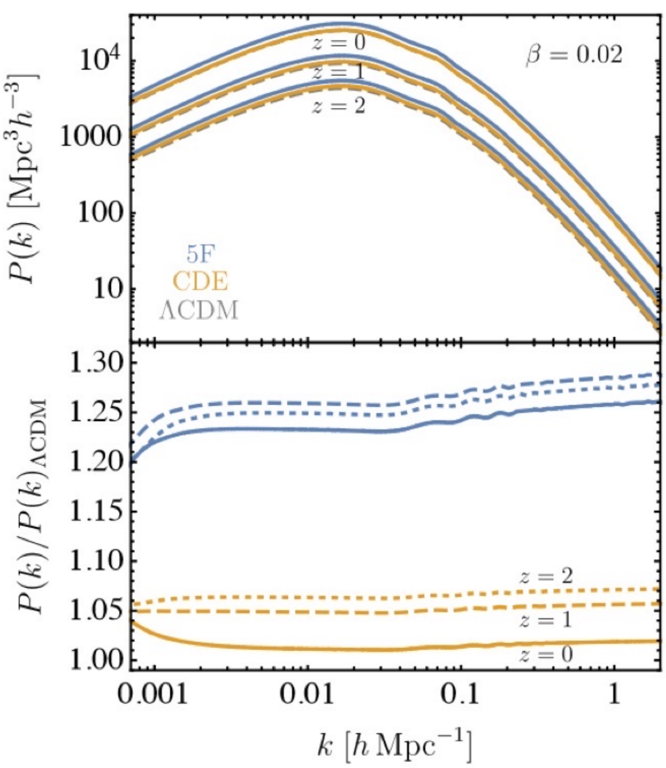
CMB mostly affected by bkd modification through projection effects



$$\ell_n \simeq \frac{n\pi}{c_s \tau_{rec}} D_A(\tau_{rec})$$

$$D_A \sim \int_0^{\tau_{rec}} d\tau \frac{1}{H + \Delta H}$$

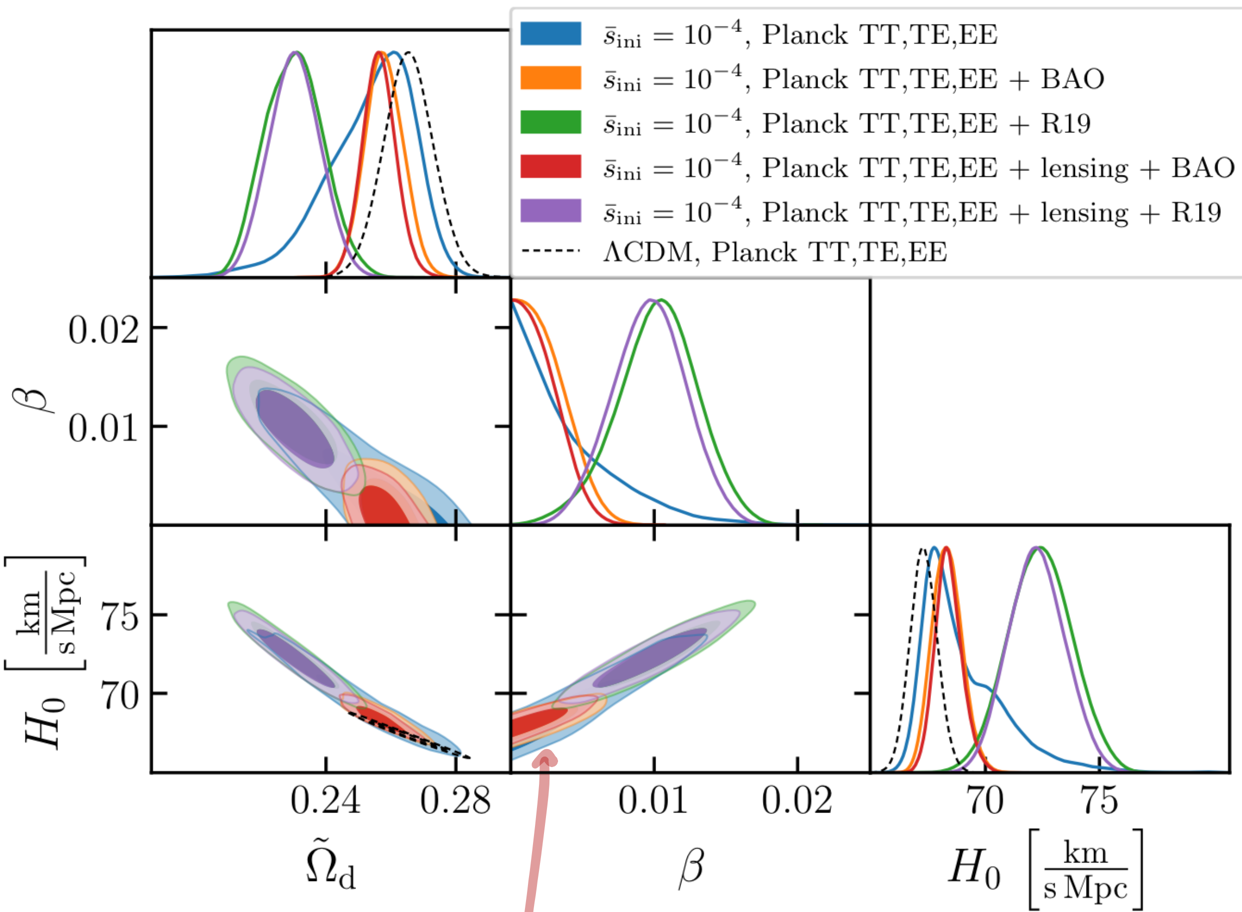
Matter Power Spectrum



Featureless increase of power

$$\sim \beta \log\left(\frac{a_{eq}}{a}\right)$$

LINEAR THEORY CONSTRAINTS ON 5th FORCES



$\beta < 5 \cdot 10^{-3}$

Can we extract new information by testing matter correlators @

$k > k_{LINEAR}$?

Theory predictions with EFT of LSS

$$k_{NL} > k > k_{LINEAR}$$

k_{NL} is the scale where the variance of the power spectrum becomes large: $\frac{k_{NL}^3 P_L(k_{NL})}{2\pi^2} \geq 1$

$$k_{NL} \sim 0.3 \; h\,\mathrm{Mpc}^{-1}$$

NOVEL OBSERVABLE : BISPECTRUM

$$\langle \delta_A(k_1)\,\delta_A(k_2)\,\delta_B(k_3) \rangle = (2\pi)^3\, \delta^3(\bar{k}_1 + \bar{k}_2 + \bar{k}_3)\, B(k_1, k_2, k_3)$$

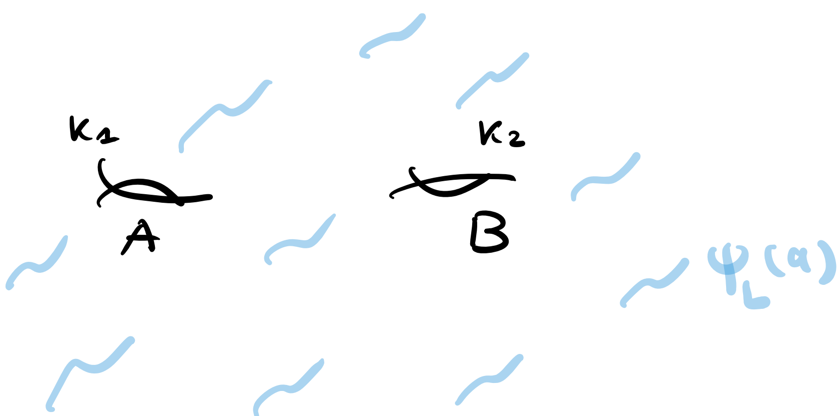
5th FORCES will appear in the BISPECTRUM as IR POLE signalling the violation of the equivalence principle

2 EFFECTS: RELATIVE DENSITIES $\delta r \sim \beta$

RELATIVE VELOCITIES $\delta \theta \sim \beta$

$\sim$ GALILEO EXPERIMENT

PICTORIALLY :



$$\langle \delta_q \, \delta^A_{k_1} \, \delta^B_{k_2} \rangle \underset{q \to 0}{\simeq} \tilde{m}^2 \beta \, \frac{k \cdot q}{q^2} \, P_m(q) \, P_m(k)$$

Creminelli et al. 1312.6074 + many others

A SLIDE OF LSS NOMENCLATURE

We have to deal with galaxy density contrast:

$$\delta_g(x,\eta) \equiv \frac{\delta n_g(x,\eta)}{\bar{n}_g}$$

* @ large scales we expand this in terms of DM, baryon fluctuations (BIAS)

$$\delta_g = b_1 \delta_m + b_r \delta_r + b_\theta \delta\theta + \ldots$$

arbitrary parameters fitted with data

* We account that we measure galaxies in redshift space

* - - - - -

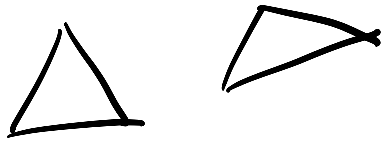
CAN WE TEST EP DIRECTLY IN THE BISPECTRUM GIVEN THE BOUNDS FROM LINEAR COSMOLOGY?

$$\# \, \beta \, \frac{K_{max}}{K_{min}} \quad \text{vs} \quad \beta \log\left(a_{eq}/a\right) \#$$

THERE IS ROOM BUT IT DEPENDS ON THE BIAS PARAMETERS...

CAN we do more?

* FULL BISPECTRUM



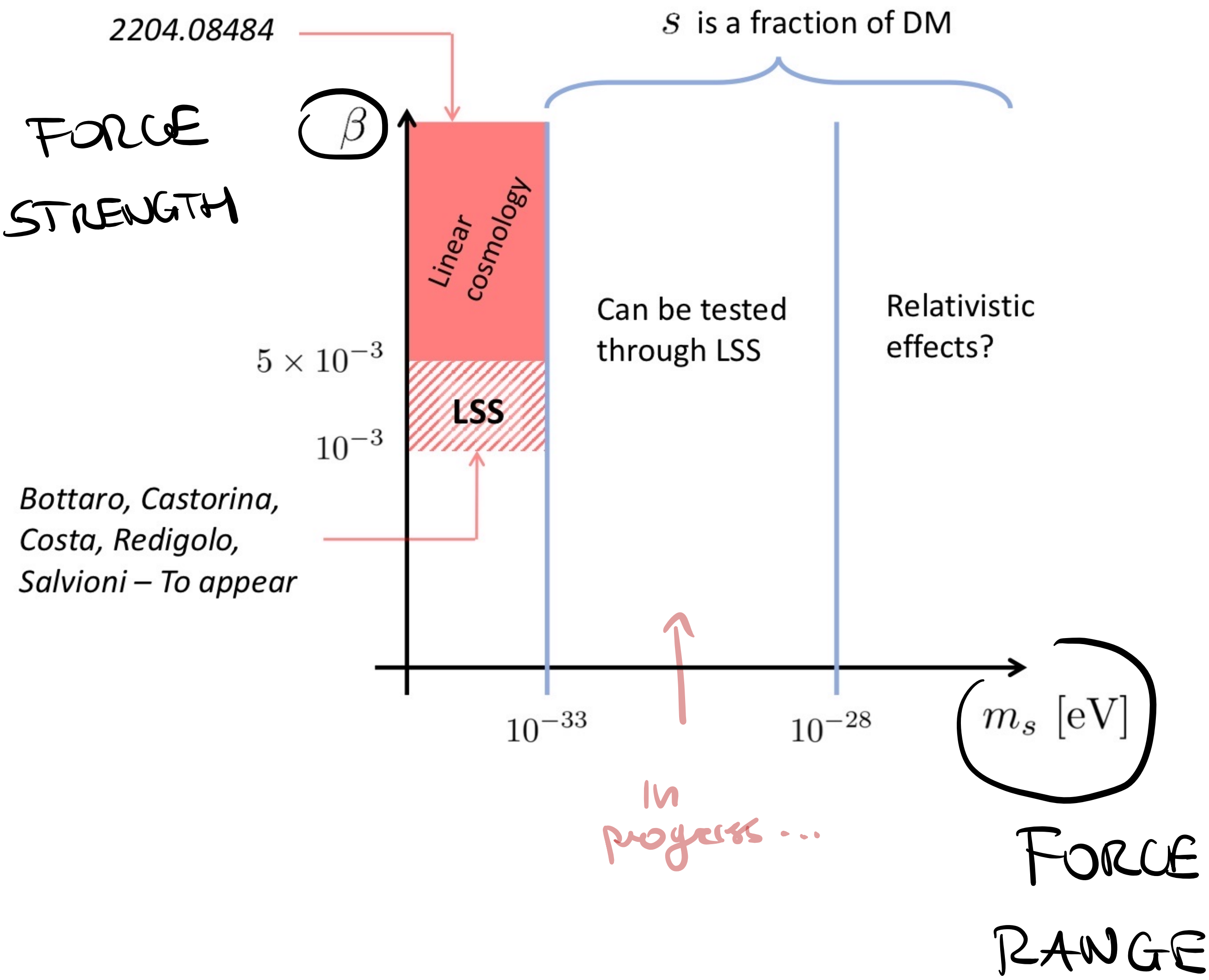
* FULL POWER SPECTRUM

The consistency relation is violated @ order $\sim (\beta \tilde{m}^2)^2$

The expected combined limit (marginalized over biases) for EUCLID

WE EXPECT ~ 1 ORDER OF MAGNITUDE IMPROVEMENT w.r.t CMB + BAO

Testing DM self-interactions with cosmology just started...



KEEP LOOKING

For opportunities

IN

THE DARK