Title: Large scale structures and dark fifth forces

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Collection: Dark Matter, First Light

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Abstract: Cosmology can give insights on the self-interactions of Dark Matter. In this talk we analyze how long range forces acting solely in the Dark Sector imprint on the distribution of galaxies, the so-called Large Scale Structure (LSS).

First we show how BOSS data can complement CMB information and give the strongest constraint on the strength of the self interaction.
In particular we discuss how the long range force affects the galaxy power spectrum and how the theory of LSS is changed in its presence.

Finally we forecast that data from future surveys (Euclid, MegaMapper) can improve the bound by roughly one order of magnitude.
We also mention how higher point statistics can potentially contain relevant information on the enhanced clustering.

# LSS and dark fifth forces
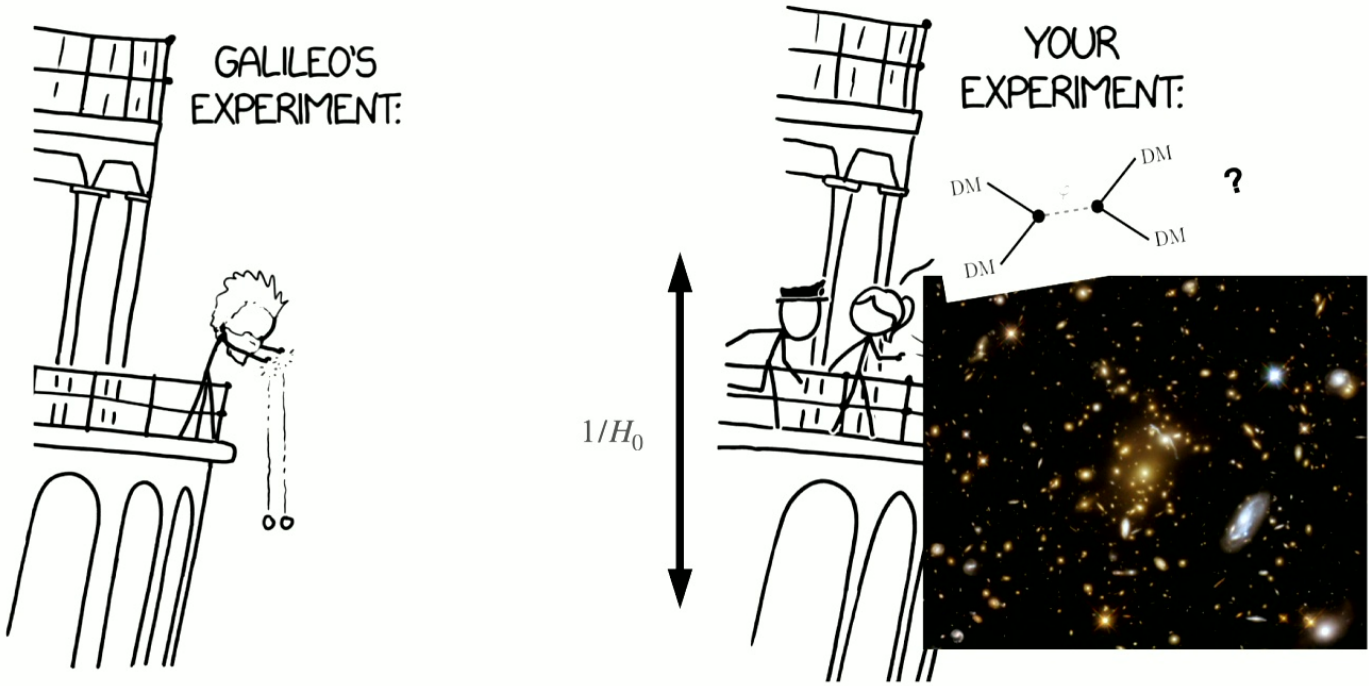
## Results from galaxy surveys

Based on   Archidiacono, Castorina, Redigolo, Salvioni 2204.08484
Bottaro, Castorina, MC, Redigolo, Salvioni 2309.11496

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# Dark fifth forces and EP



credit: R.Munroe

GALILEO'S EXPERIMENT:

YOUR EXPERIMENT:

$1/H_0$

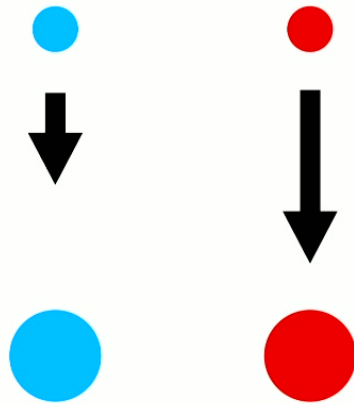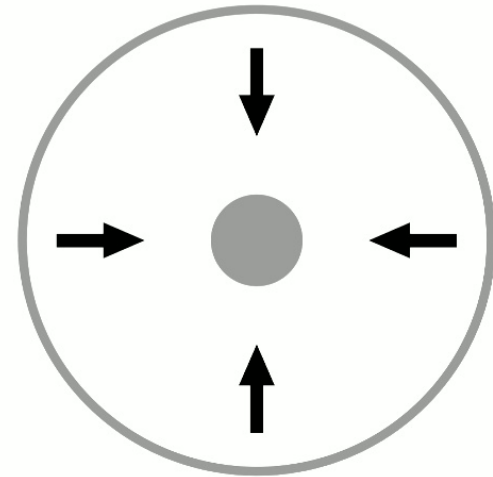**Marco Costa** (Perimeter Institute),    27 Feb 2024

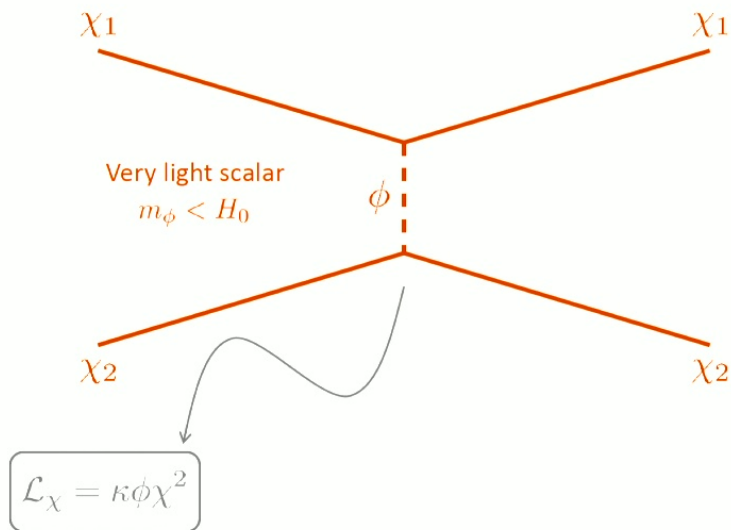# What should I change?

$$\delta_r \equiv \delta_\chi - \delta_b$$

$$\delta_m = f_\chi \delta_\chi + f_b \delta_b$$



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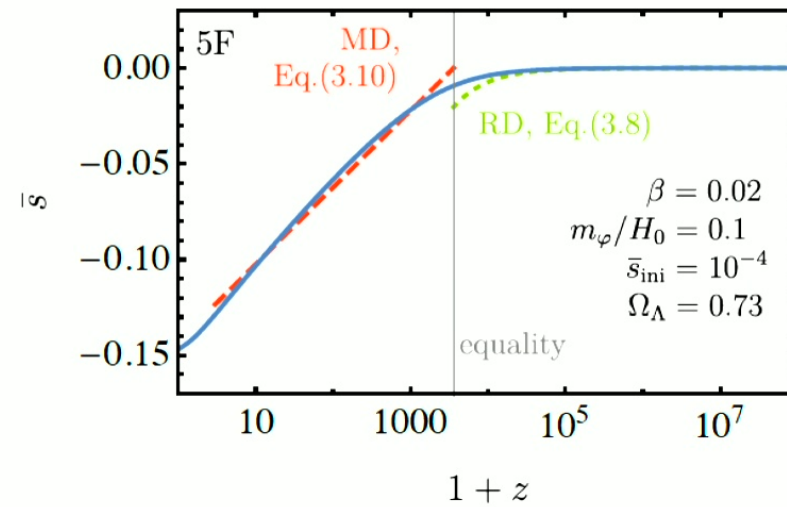
# Fifth force model

## Yukawa interaction

$$s \equiv \kappa\phi/m_\chi^2$$

$$\bar{s} \simeq -2\beta f_\chi \log(\tau/\tau_{\text{eq}})$$

$\chi_1$     $\chi_1$

Very light scalar
$m_\phi < H_0$

$\phi$

$\chi_2$     $\chi_2$

$\mathcal{L}_\chi = \kappa\phi\chi^2$



5F    MD, Eq.(3.10)

RD, Eq.(3.8)

$\beta = 0.02$
$m_\varphi/H_0 = 0.1$
$\bar{s}_{\text{ini}} = 10^{-4}$
$\Omega_\Lambda = 0.73$

equality

$1+z$

$$m_\chi^2 = m_{\chi,0}^2(1 + 2s)$$

$$\beta \equiv (\kappa/m_\chi^2)^2/4\pi G_N$$

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# Side effect of UV completion
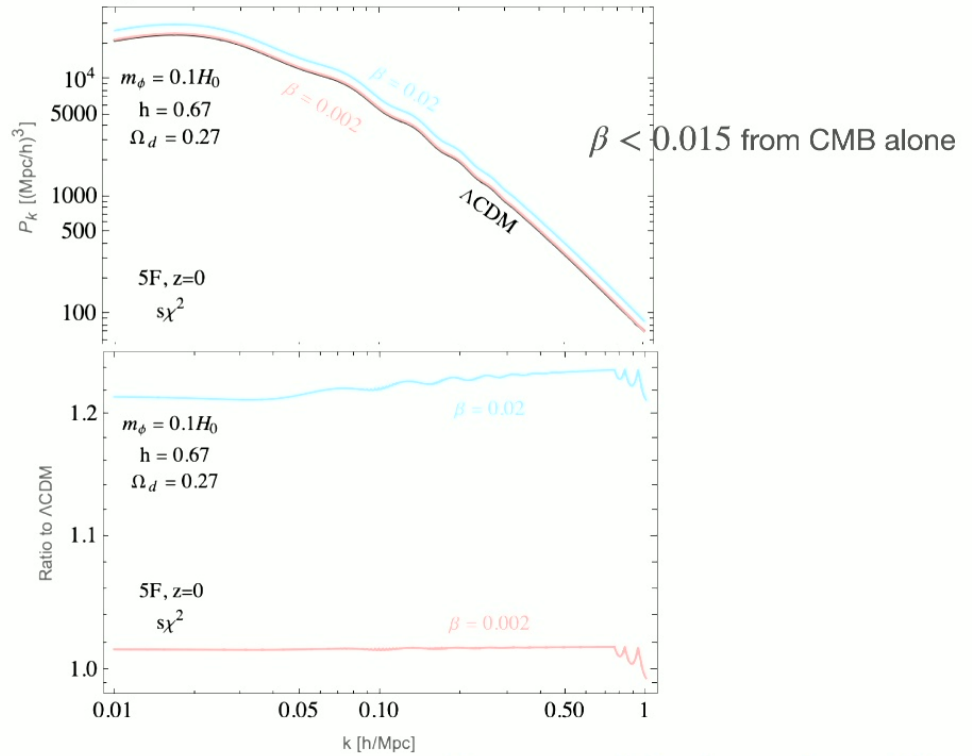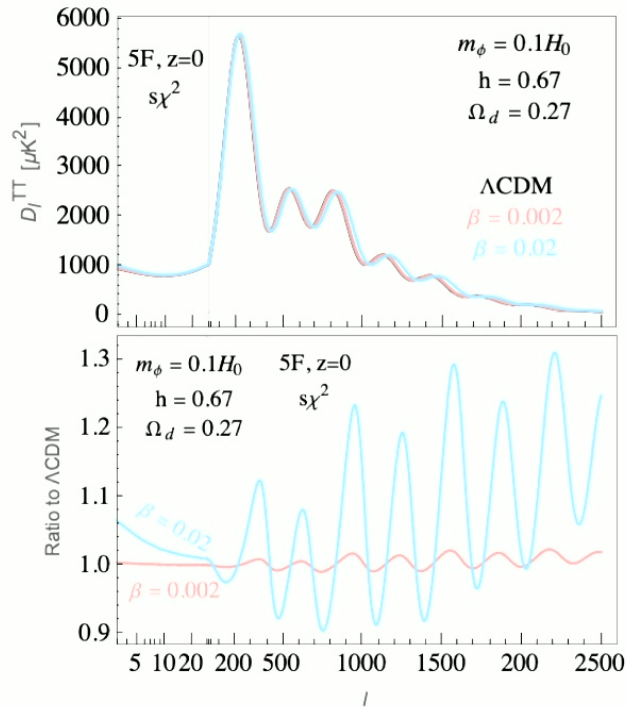
**Can we exploit enhanced growth?**

# LSS Observables

## Galaxy Power Spectrum

$$\boxed{P_g(\vec{k}, z) \sim \langle \delta_g(\vec{k}, z)\, \delta_g(-\vec{k}, z)\rangle}$$

**Galaxy over density :
"Composite" Field**

**Fundamental fields:**

$$\delta_m \equiv f_\chi \delta_\chi + (1 - f_\chi)\delta_b = \left(1 + \frac{6}{5}\beta f_\chi^2 \log(z_{\mathrm{eq}}/z)\right) D_{1m}^{\mathrm{CDM}}(z)\delta_0(k)$$

$$\delta_r \equiv \delta_\chi - \delta_b = \beta f_\chi D_{1m}^{\mathrm{CDM}}(z)\delta_0(k)$$

**Negligible feature if**
$$f_\chi > \log z_{\mathrm{eq}}/z \simeq 1/8$$

**Bias expansion:** based on symmetries of theory

$$\delta_g = b_1\delta_m + b_r\delta_r + b_\theta\theta_r + \frac{b_2}{2}\delta_m^2 + b_s(K_{ij}\delta_m)^2 \; \ldots$$

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# Computing Non-linearities

<div style="border: 2px solid #1a9de0; padding: 10px;">

**Also at non-linear level (loop, EFTofLSS)**
**Dark force = CDM symmetries at**

$$\mathcal{O}(\beta f_\chi^2 \log) \quad ( \text{ if } f_\chi \gtrsim 1/8 )$$

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- Can use existing pipeline as **PyBird** for **BOSS** $P_g$ w. RSD and **FishLSS** for Fisher Forecast

- (Also RSDkernel is the same at $\mathcal{O}(\beta \log)$!)

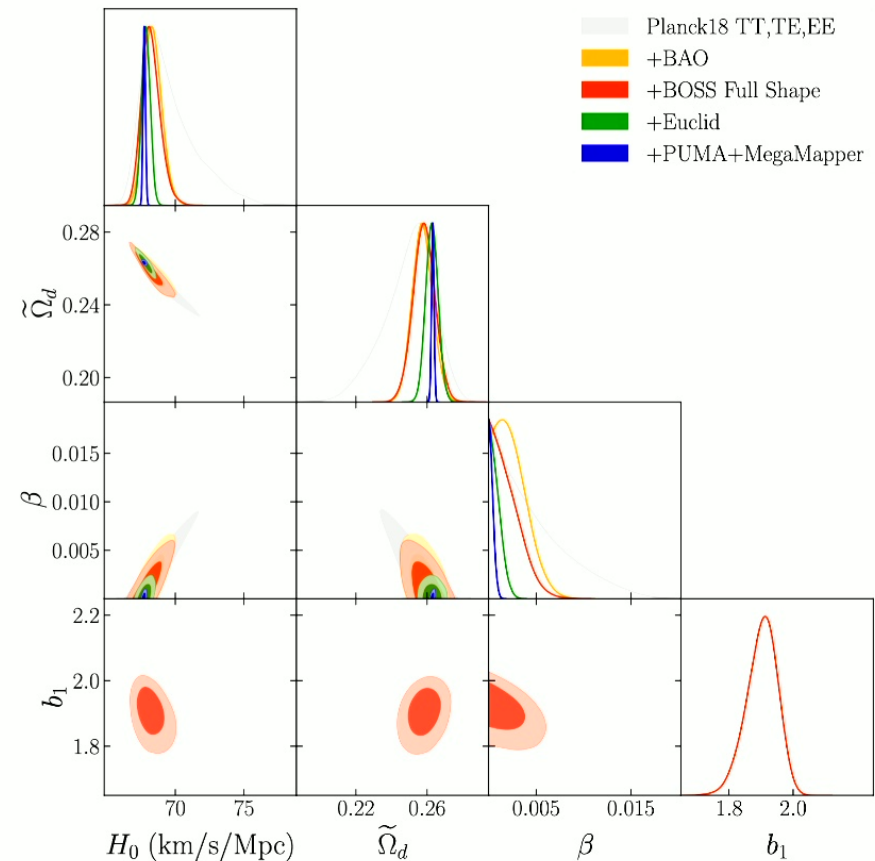Sailer Castorina Ferraro White 21

D'Amico Senatore Zhang 20

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# Results

## FS@1-loop+EFT, RSD

- **CMB only**: $\beta \lesssim 0.015$ @ 95%

- **+ BAO** (w.reco): $\beta \lesssim 5 \times 10^{-3}$

- **+ BOSS FS** no improvement: strong degeneracies between $\beta, b$

- Future surveys FS will improve bound!

  - **+Euclid**: $\beta \lesssim 2 \times 10^{-3}$

  - **+ PUMA+MM**: $\beta \lesssim \times 10^{-3}$

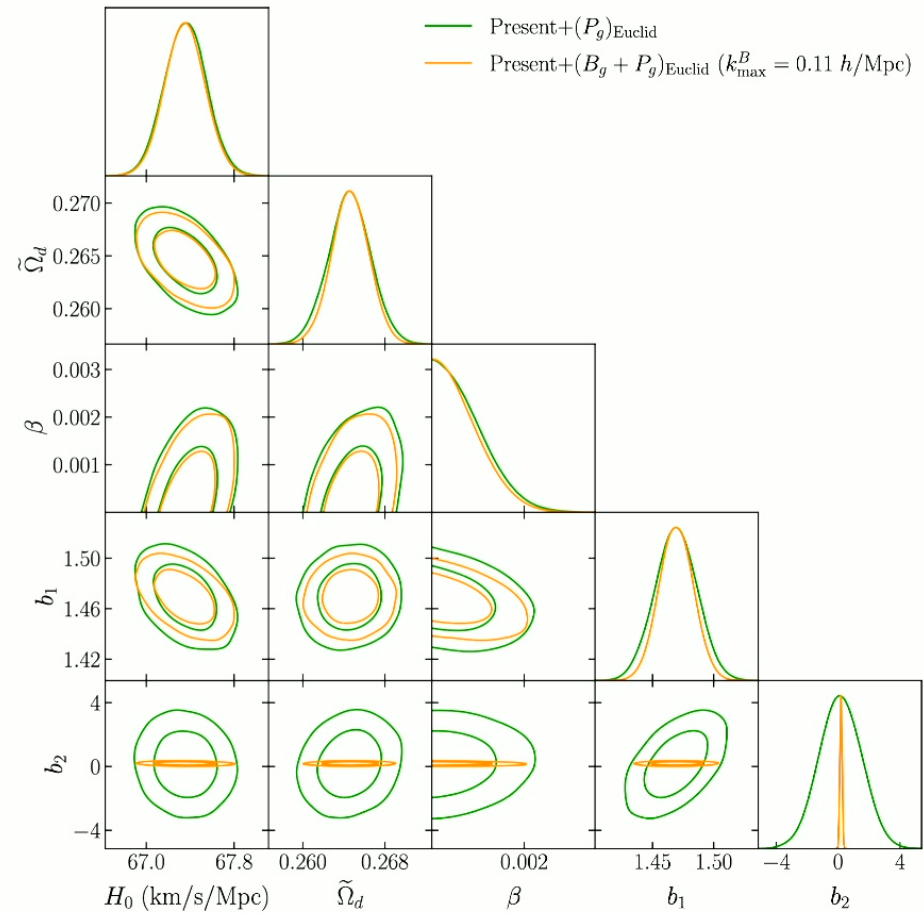**Marco Costa** (Perimeter Institute),   27 Feb 2024

# Bispectrum
## Real Space, Tree level

$$B_g(k_1, k_2, k_3) \sim \langle \delta_g(k_1)\, \delta_g(k_2)\delta_g(k_3)\rangle$$

- Potentially more modes!

- For linear modes, improve only NL bias

- Violation of EP: squeezed limit pole (different infall rate in long mode bkg):

$$\left.\frac{B_g^{AAB}(\vec{p}, \vec{p}_1, \vec{p}_2)}{P^{\mathrm{CDM}}(p)^{\mathrm{CDM}}(p_1)}\right|_{p \to 0} \sim \beta f_\chi \frac{\vec{p} \cdot \vec{p}_1}{p^2}\Delta b^{AB}$$

- Still subleading for $f_\chi \sim 1$…

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# Conclusions

- Future galaxy surveys offer useful observables as $P_g, B_g$

- **Structure of 5th Force = CDM** at $\mathcal{O}(\beta f_\chi^2 \log)$ for $f_\chi \gtrsim 1/8$

- **BOSS FS**: no improvement over $\beta < 5 \times 10^{-3}$   (**CMB+BAO**)

- \+ **Euclid FS**: $\beta \lesssim 2 \times 10^{-3}$,   \+ **PUMA+MegaMapper FS**: $\beta \lesssim 10^{-3}$

- **Bispectrum**: no improvement on cosmo pars @ tree lvl, better measurement of non-linear biases. Potentially interesting pole structure for multitracers.

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# Thanks for the attention!

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