TEL AVIV UNIVERSITY

Dark Forces vs LSS 1

Model and Perturbative Structure

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Based on 2204.08484 and 2309.11496

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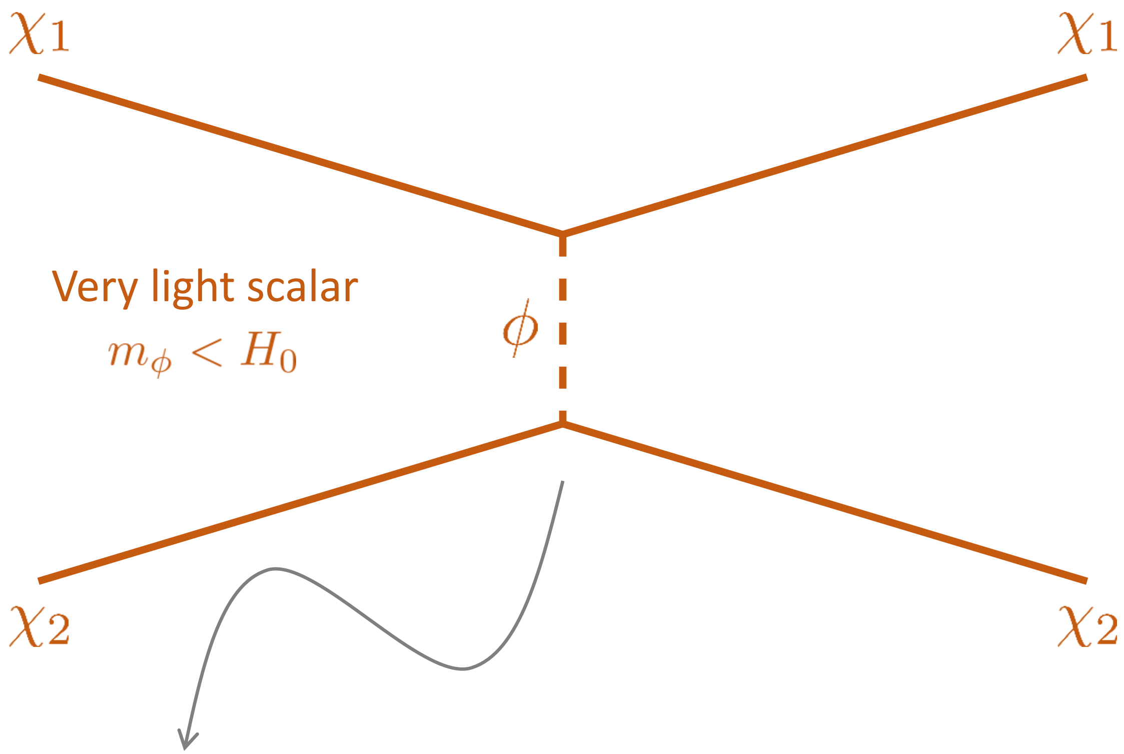
Introduction

Already all the information we have about Dark Matter (existence, abundance…) comes from astrophysical and cosmological observations.

Can we get additional information on DM dynamics from cosmology?

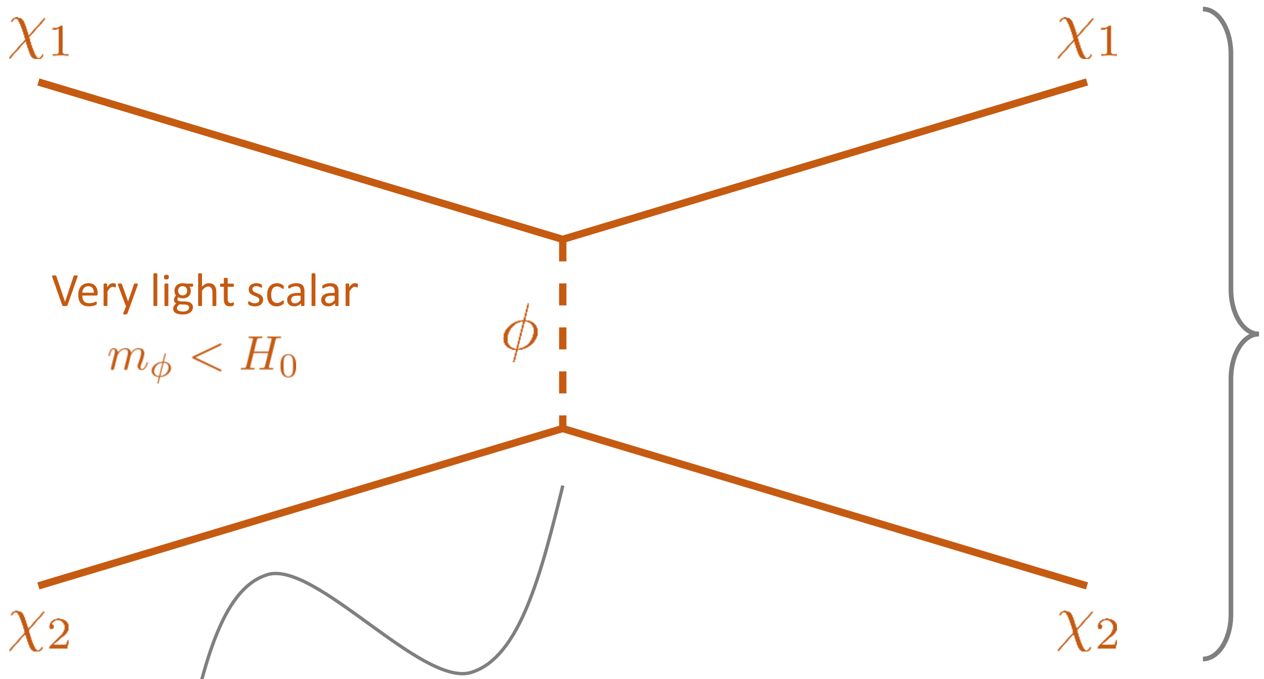
Can we exploit new data from galaxy surveys?

Dark fifth forces – Minimal model



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

Dark fifth forces – Minimal model



Testable only through cosmology!

$$\beta = \frac{\kappa^2}{4\pi m_\chi^4 G_N}$$

$$V_\chi = -4\pi G_N \beta \frac{m_1 m_2}{r} e^{-m_\phi r}$$

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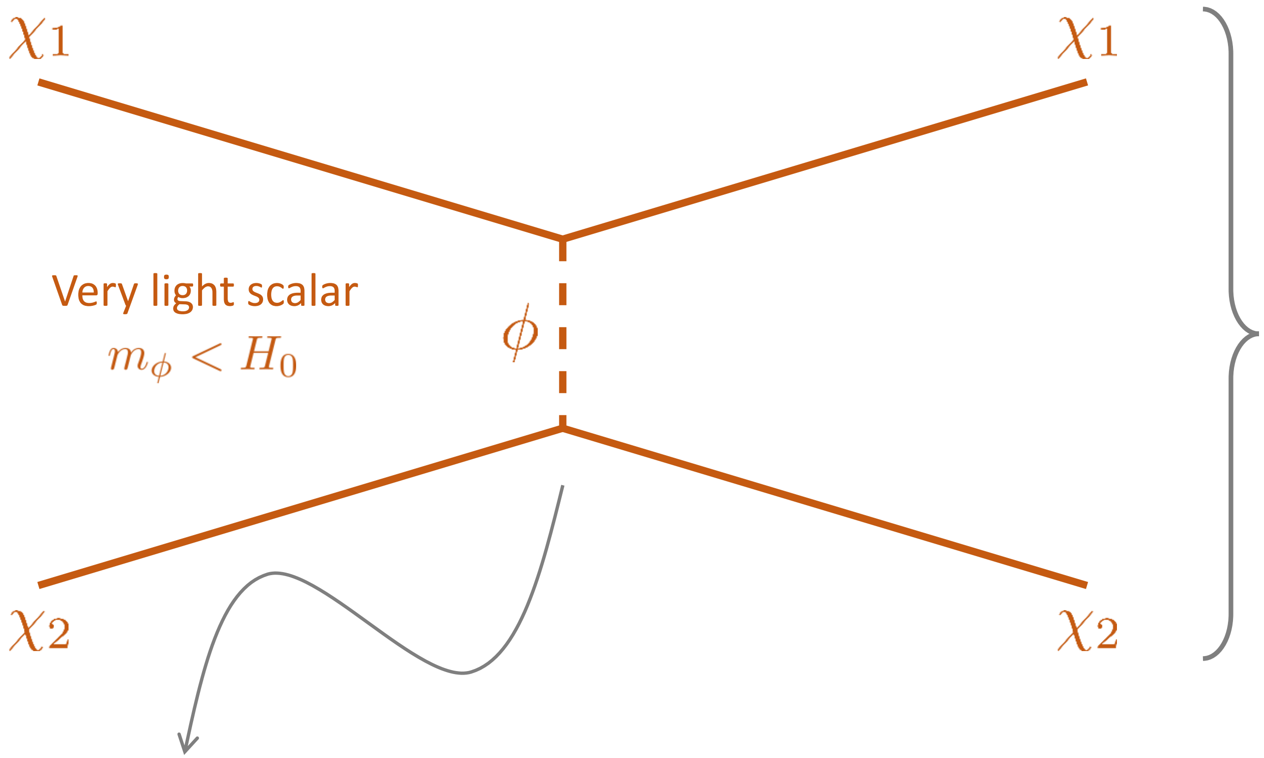

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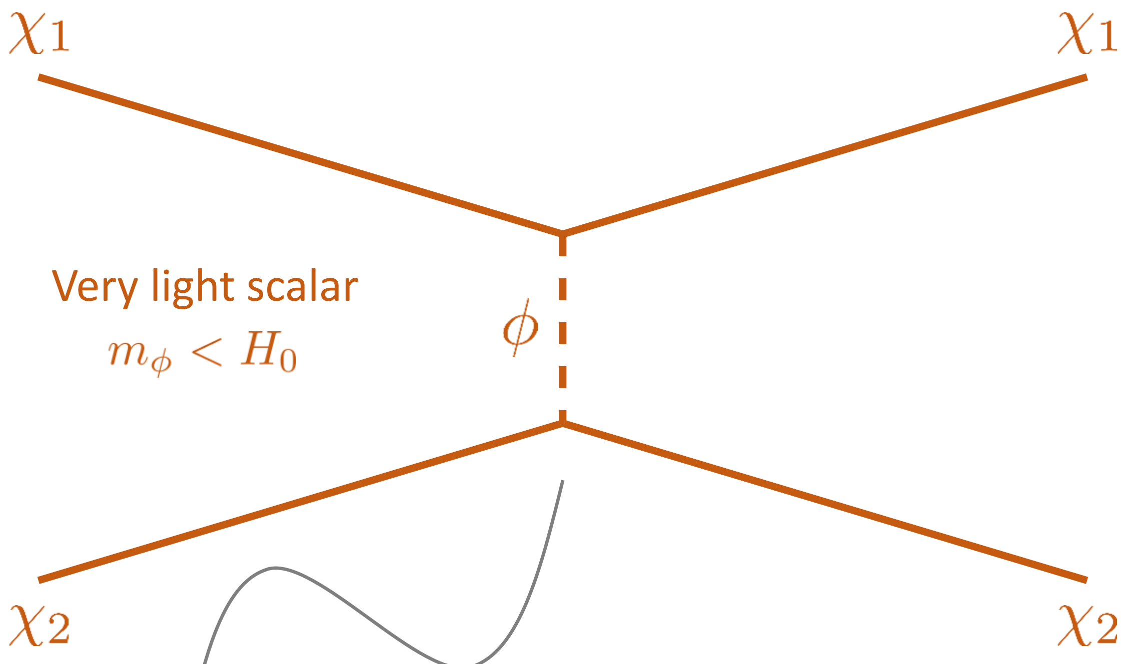

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Effect on cosmological perturbations

Different Newton constant for DM!

$$\mathcal{L}_\chi = \kappa \phi \chi^2 \longrightarrow \mathcal{L}_\chi = \kappa \langle \phi \rangle \chi^2 \equiv m_\chi(\phi)\chi^2$$

Time dep. mass!

Background effect

EQUIVALENCE PRINCIPLE VIOLATION

Background dynamics

Starting point: Klein-Gordon equation for ϕ

$$\bar{s}'' + 2\mathcal{H}\bar{s}' + 4\pi\beta G_N a^2 \bar{\rho}_\chi \frac{\partial \log m_\chi(s)}{\partial s} = 0 \qquad s = \frac{\kappa}{m_\chi^2}\phi$$

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Scalar evolution sourced by DM

$$\bar{s}'' + 2\mathcal{H}\bar{s}' + \boxed{4\pi\beta G_N a^2 \bar{\rho}_\chi \frac{\partial \log m_\chi(s)}{\partial s}} = 0 \qquad s = \frac{\kappa}{m_\chi^2}\phi$$

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Solution in MD

$$\bar{s} = \bar{s}_{\rm eq} - 2\beta \frac{\partial \log m_\chi(s)}{\partial s} f_\chi \log \frac{\tau}{\tau_{\rm eq}}$$

DM redshifs differently!

Correction to Hubble!

$$\dot{\rho}_\chi = \dot{m}_\chi n_\chi + m_\chi \dot{n}_\chi \implies \Omega_\chi \propto a^{-3}\left(1 - \beta f_\chi \frac{\partial \log m_\chi(s)}{\partial s} \log \frac{a}{a_{\rm eq}}\right)$$

$$\mathcal{H} = \mathcal{H}_{\Lambda\rm CDM}\left(1 - \beta f_\chi^2 \frac{\partial \log m_\chi(s)}{\partial s}\right)$$

Cosmological perturbations

$$\delta_m = f_\chi \delta_\chi + (1 - f_\chi)\delta_b$$
$$\delta_r = \delta_\chi - \delta_b$$

Boltzmann equations

$$\delta'_m + \theta_m = -\nabla_i(\delta_m v^i_m)$$

$$\theta'_m + \left(\mathcal{H} + f_\chi \frac{\partial \log m_\chi(s)}{\partial s}\bar{s}'\right)\theta_m = k^2 \frac{\partial \log m_\chi(s)}{\partial s} f_\chi \delta s + k^2 \Psi - \nabla_i(v^j_m \nabla_j v^i_m)$$

$$\delta'_r + \theta_r = -\nabla_i(\delta_m v^i_r + \delta_r v^i_m)$$

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Fifth force

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Perturberd Klein-Gordon equation ⟶ Poisson equation $k^2 \delta s = -\frac{3}{2}\Omega_m \mathcal{H}^2 \beta f_\chi \frac{\partial \log m_\chi(s)}{\partial s}\delta_m$

Cosmological perturbations

Linear solution

$$\delta_m^{(1)}(\vec{k}) = \overbrace{D_{1m}^{\Lambda\text{CDM}}\left(1+\frac{3}{5}\beta f_\chi^2\frac{\partial\log m_\chi(s)}{\partial s}\log\frac{a}{a_{\text{eq}}}+\frac{3}{5}\beta f_\chi^2\frac{\partial\log m_\chi(s)}{\partial s}\log\frac{a}{a_{\text{eq}}}\right)}^{\equiv D_{1m}}\delta_0(\vec{k})$$

$$\delta_r^{(1)}(\vec{k}) = D_{1m}^{\Lambda\text{CDM}}\left(1+\frac{2}{3}\right)\beta f_\chi\frac{\partial\log m_\chi(s)}{\partial s}\delta_0(\vec{k})$$

- Background corrections enhance the growth
- No new spatial features in δ_m at linear level
- Logarithmically enhanced growth of δ_m
- Growing relative perturbations
- Different scalings with the DM fraction

Cosmological perturbations

Linear solution

Fifth force $\equiv D_{1m}$ Background correction

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$$\delta_m^{(n)}(\vec{k}) = D_{1m}^n \int \prod_{i=1}^n \frac{\mathrm{d}^3 q_i}{(2\pi)^3} \delta_0(\vec{q}_i)(2\pi)^4 \delta^{(4)}\left(\vec{k} - \sum_{i=1}^n \vec{q}_i\right)\left(F_n^{\Lambda\mathrm{CDM}}(\{\vec{q}\}) + \beta f_\chi \Delta F_n(\{\vec{q}\})\right)$$

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- Same ansatz as in $\Lambda\mathrm{CDM}$
- Same $\Lambda\mathrm{CDM}$ kernels at $\mathcal{O}(\beta f_\chi^2 \log a)$
- New kernels arise at at $\mathcal{O}(\beta f_\chi) \longrightarrow$ relevant if $f_\chi \lesssim 1/8$

Conclutions

Modified background
- Affects physical distances
- Enhances growth of perturbations

Linear dynamics
- Log enhanced growth of matter perturbations
- Growing relative modes

Dark fifth forces

Non-linear dynamics
- Larger power at non-linear scales
- New spatial features prominent for small DM fractions