Cosmological Measurements of Massive Light Relics

Cosmology From Home 2021

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with Nick Deporzio, Julian Muñoz, & Cora Dvorkin

[2006.09395, 2006.09380 & Ongoing work]

Harvard University

Introduction

Matter content of the universe

- "Light" : Visible, ordinary particle content $\sim 15\%$
- "Dark" : Invisible, feebly-interacting particle content $\sim 85\%$

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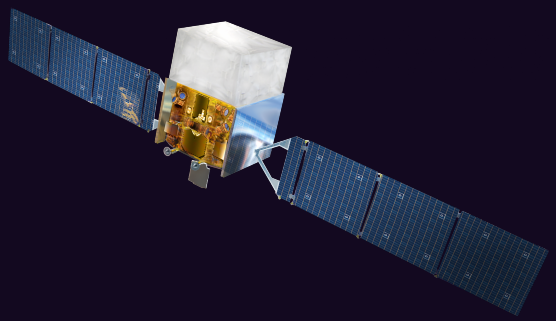

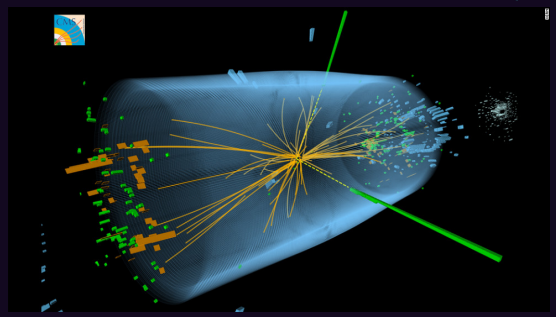

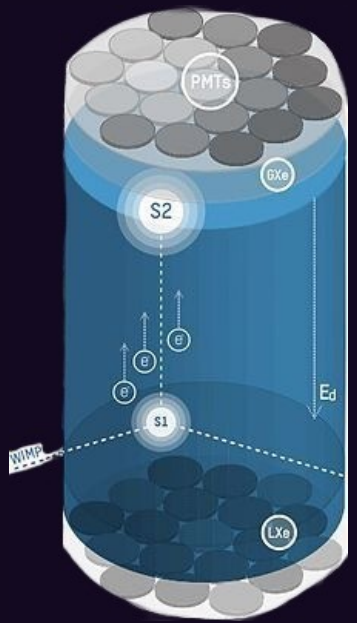

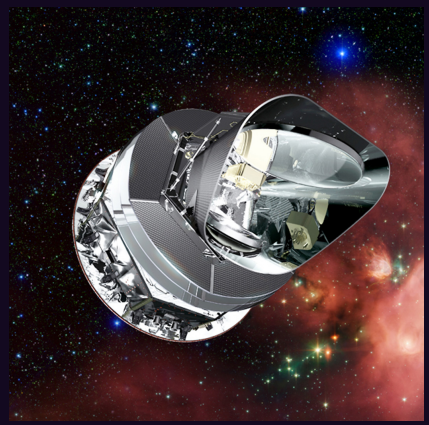

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  - Some fraction can be not that
    - Neutrinos definitely exist, other light relics might too
    - We stand a chance to detect them

Light but Massive Relics

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- Not Neutrinos (LiMRs)
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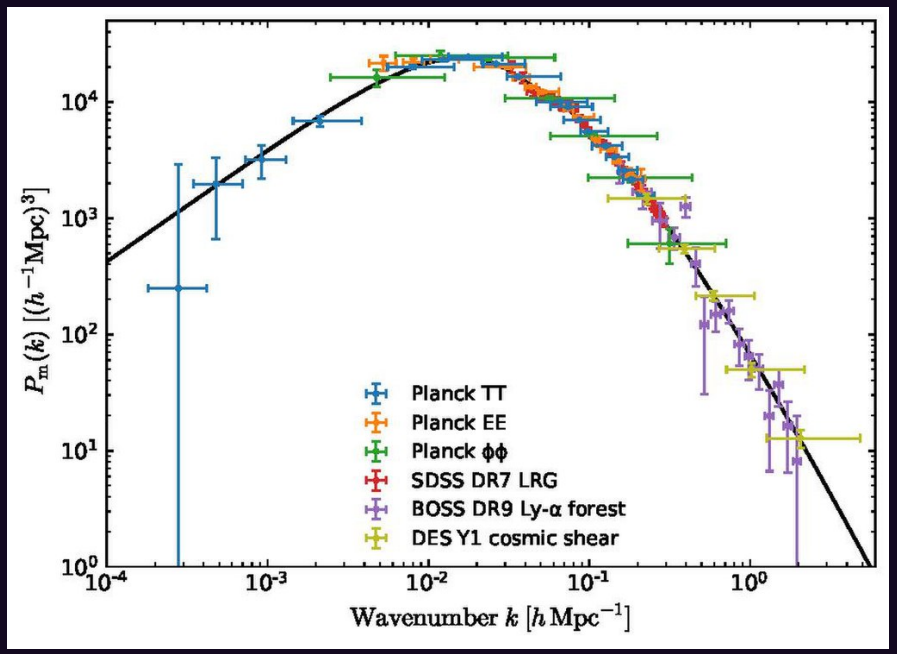
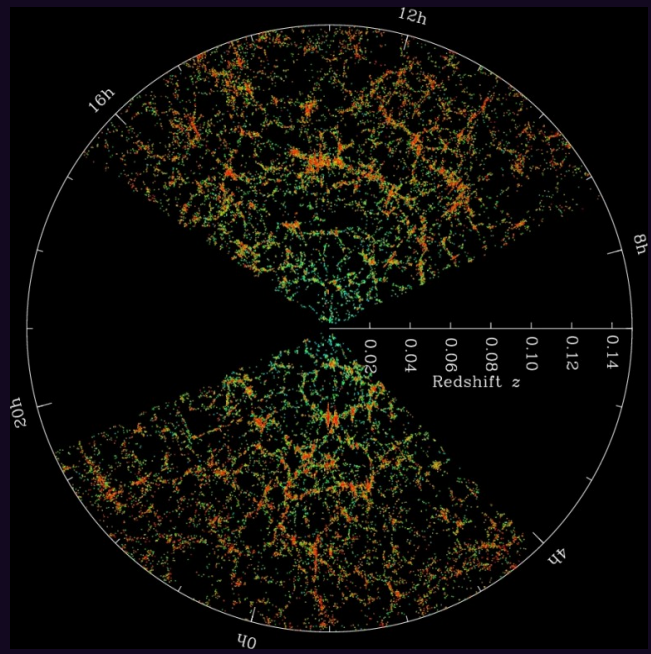
Large-Scale Structure

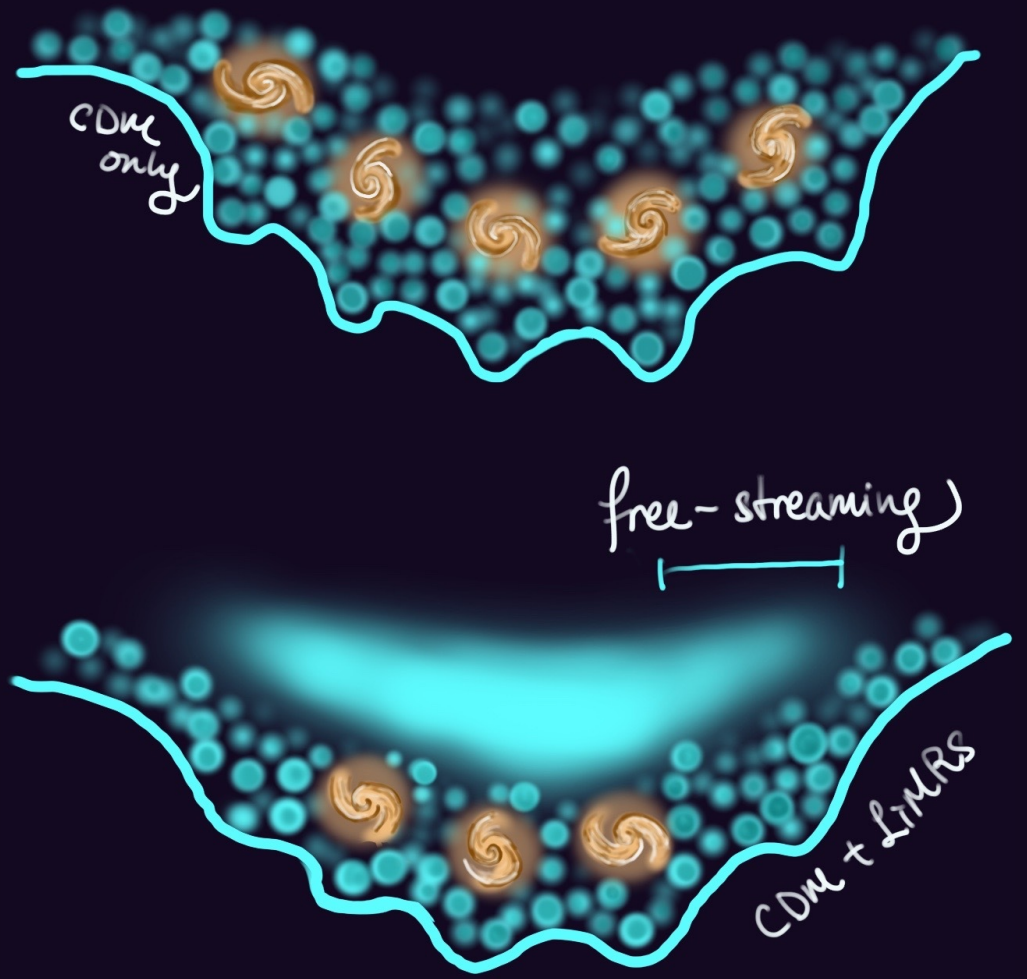




The big picture

CDM clusters at all scales, LiMRs do not

- Independent of any present-day interactions



Massive Light Relics: The basics

A relic X is characterized by its

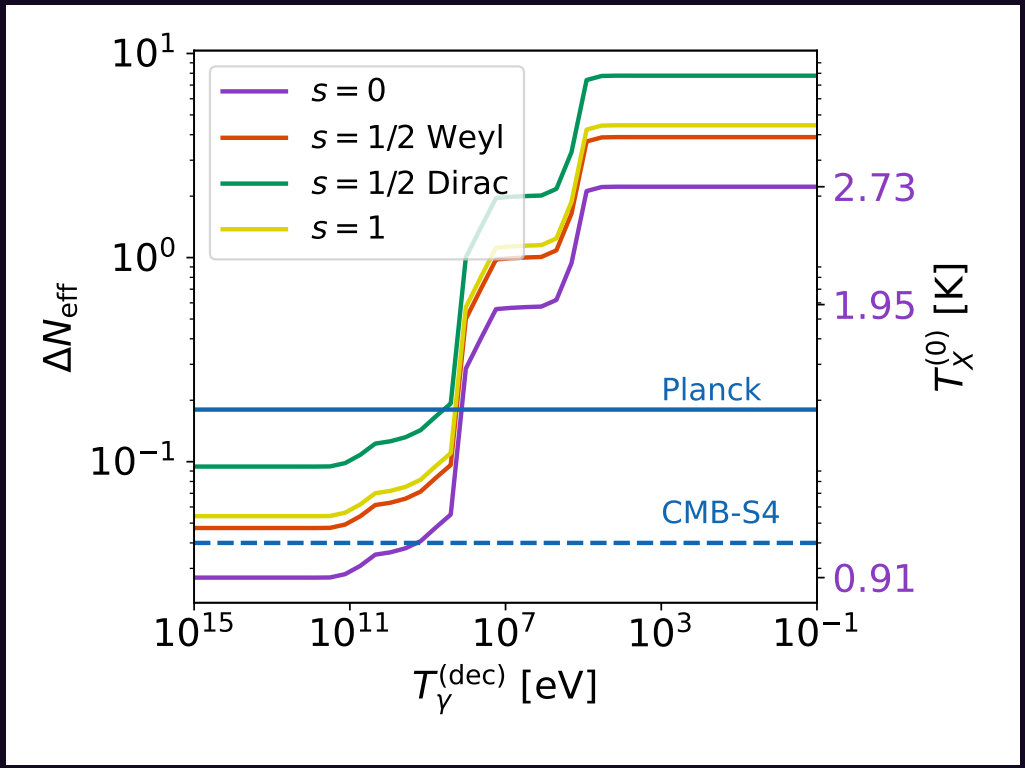
- Mass m_X
- (present-day) Temperature $T_X^{(0)}$
- Thermalized* dofs g_X (bosonic or fermionic)

*Higher-spin particles have effective $g_X = 2$

Massive Light Relics: The basics

Free Parameters: $\{m_X, T_X^{(0)}, g_X\}$

$$g_{*S}^{(dec)} \propto (T_X^0)^{-3}$$



[Deporzio, WLX, Mũnoz, Dvorkin 2006.09380]

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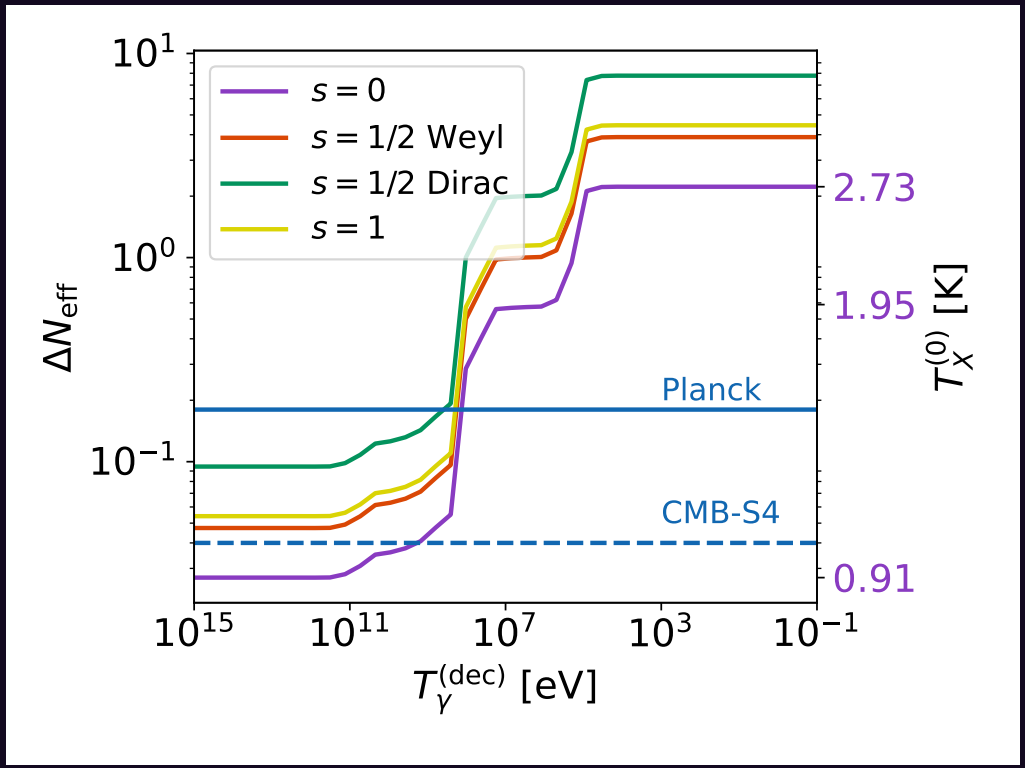


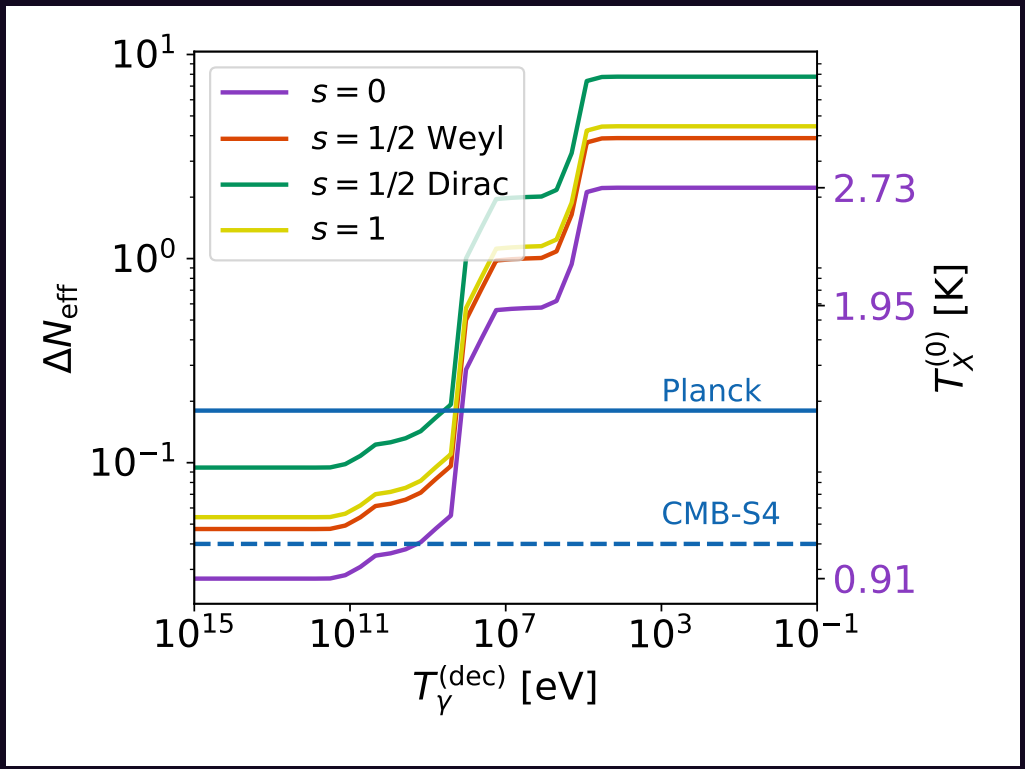
Minimal extensions $\implies T_X^0 \geq 0.91$ K.

[Deporzio, WLX, Mũnoz, Dvorkin 2006.09380]

Key Quantities

- While relativistic, contributes to $\Delta N_{\rm eff}$

$$\Delta N_{\rm eff} \propto g_X (T_X^0)^4$$



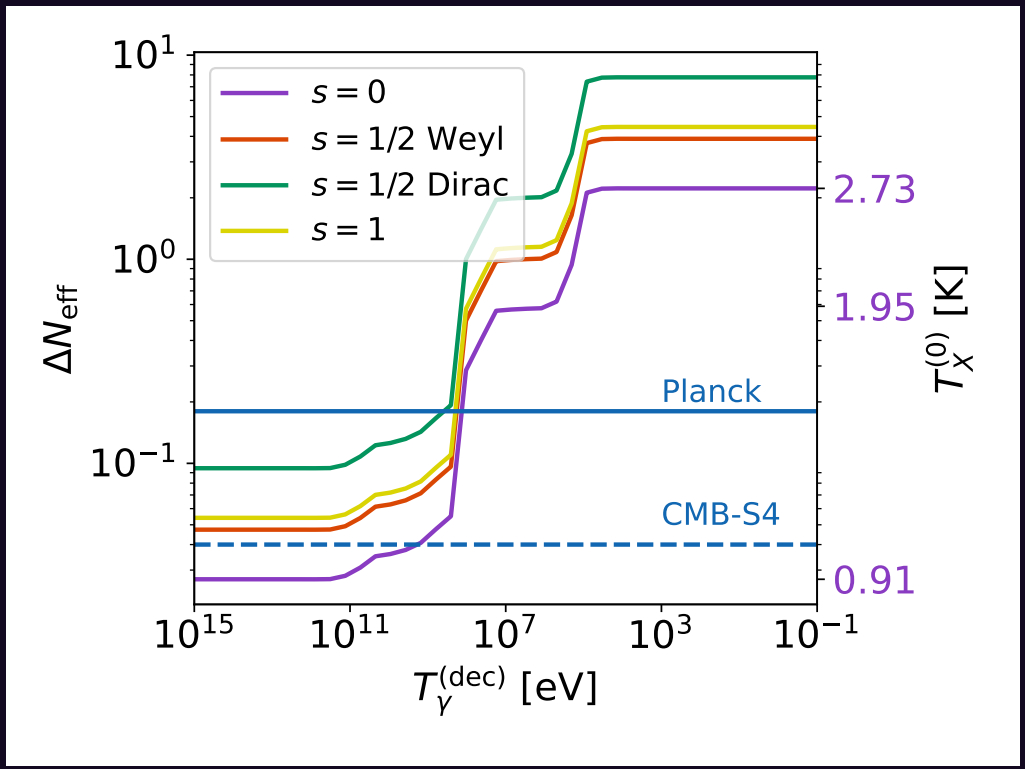
[Deporzio, WLX, Mũnoz, Dvorkin 2006.09380]

Key Quantities

- While relativistic, contributes to $\Delta N_{\rm eff}$

$$\Delta N_{\rm eff} \propto g_X (T_X^0)^4$$

If relativistic during recombination ($m_X \lesssim 0.1$ eV),
Planck $\Delta N_{\rm eff} \leq 0.36$ (95% CL) $\implies T_X^0 \leq 1.5$ K for X Weyl



[Deporzio, WLX, Muñoz, Dvorkin 2006.09380]

Key Quantities

- Transition from radiation to matter $\rightarrow$ free-streaming $k_{\mathrm{fs},X}$

$$k_{\mathrm{fs},X} \propto \frac{m_X/T_X^{(0)}}{\sqrt{1+z}}$$

Key Quantities

- As matter today, present-day abundance ω_X

$$\omega_X \propto g_X m_X (T_X^{(0)})^3$$

Imprint on Large-Scale Structure

Galaxies are biased tracers of matter

$$P_g \propto bP_m(k,z) \qquad \delta_m = \delta_{cb} + \delta_\nu + \delta_X$$

Stuff that clusters $\leftrightarrow$ Stuff that expands

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Imprint on Large-Scale Structure

Galaxies are biased tracers of clustering matter

$$P_g \propto b\cancel{P_m}P_{cb}(k,z) \qquad \delta_m = \delta_{cb} + \delta_\nu + \delta_X$$

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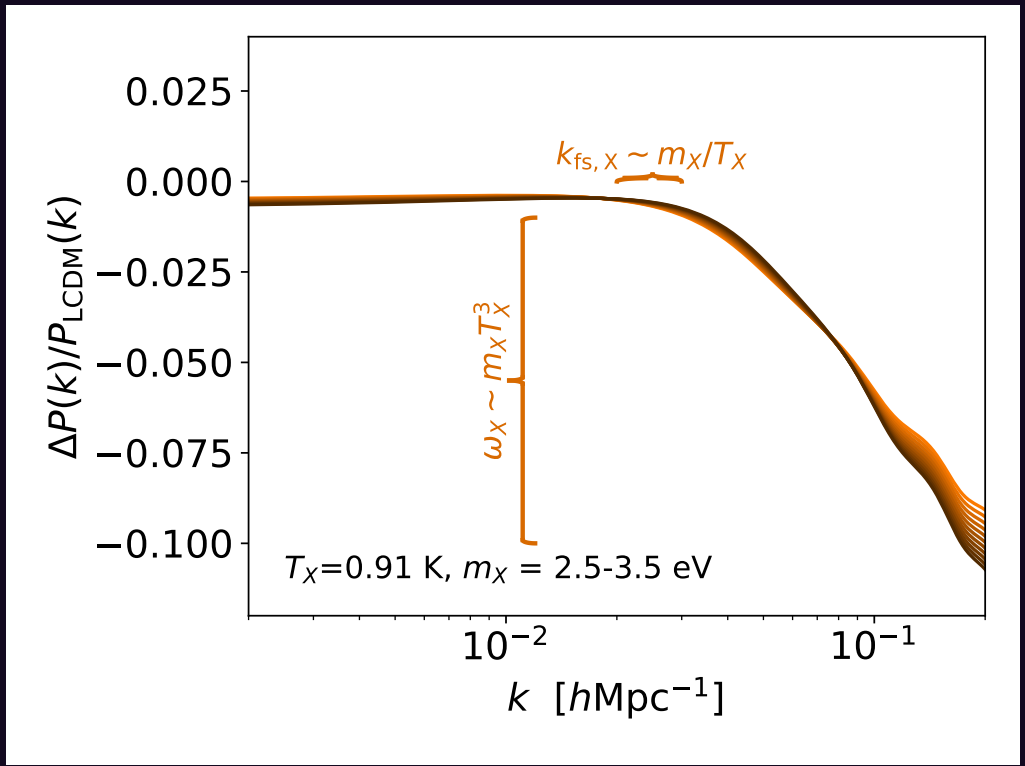
Neutrinos & LiMRs

Imprint on matter fluctuations

Stuff that clusters $\leftrightarrow$ Stuff that expands

Neutrinos & LiMRs



[Deporzio, WLX, Mũnoz, Dvorkin 2006.09380]

Data/Experiments

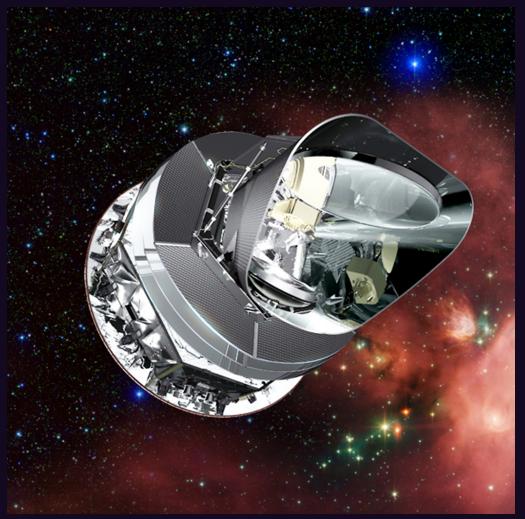
- Markov Chain Monte Carlo

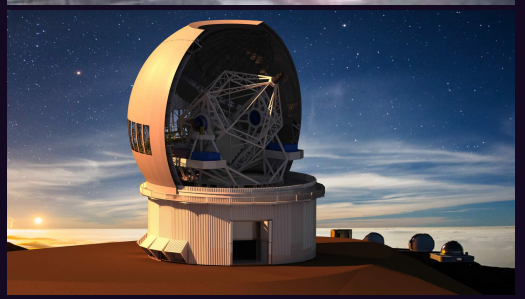
  $\{\omega_b, \omega_{cdm}, h, n_s, A_s, \tau, \sum m_\nu\}$

  $+\{m_X, T_X^{(0)}\}$

- {Scalar, Weyl, Vector, Dirac}

- Planck 2018 TT+TE+EE +Lensing
- CFHTLens
- BOSS DR 12





Results

So, are there LiMRs in our universe?

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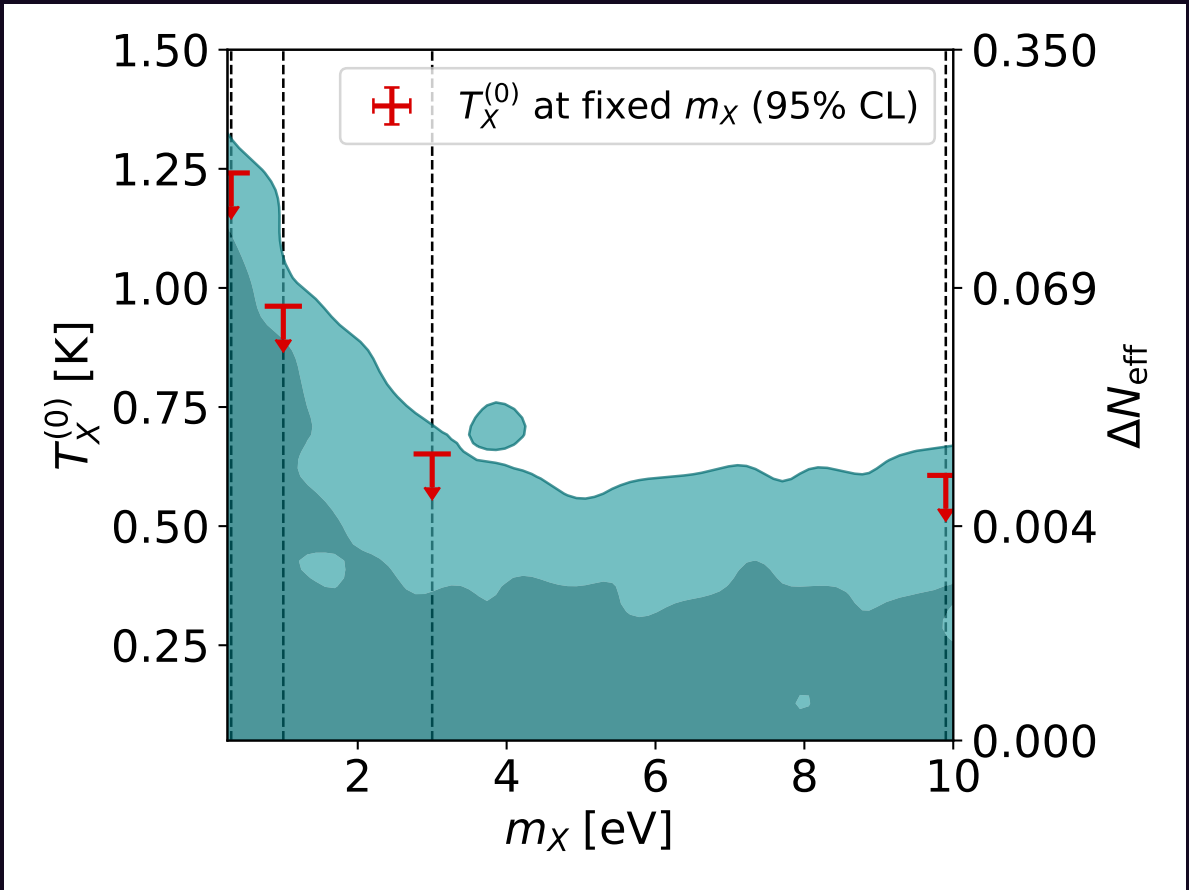
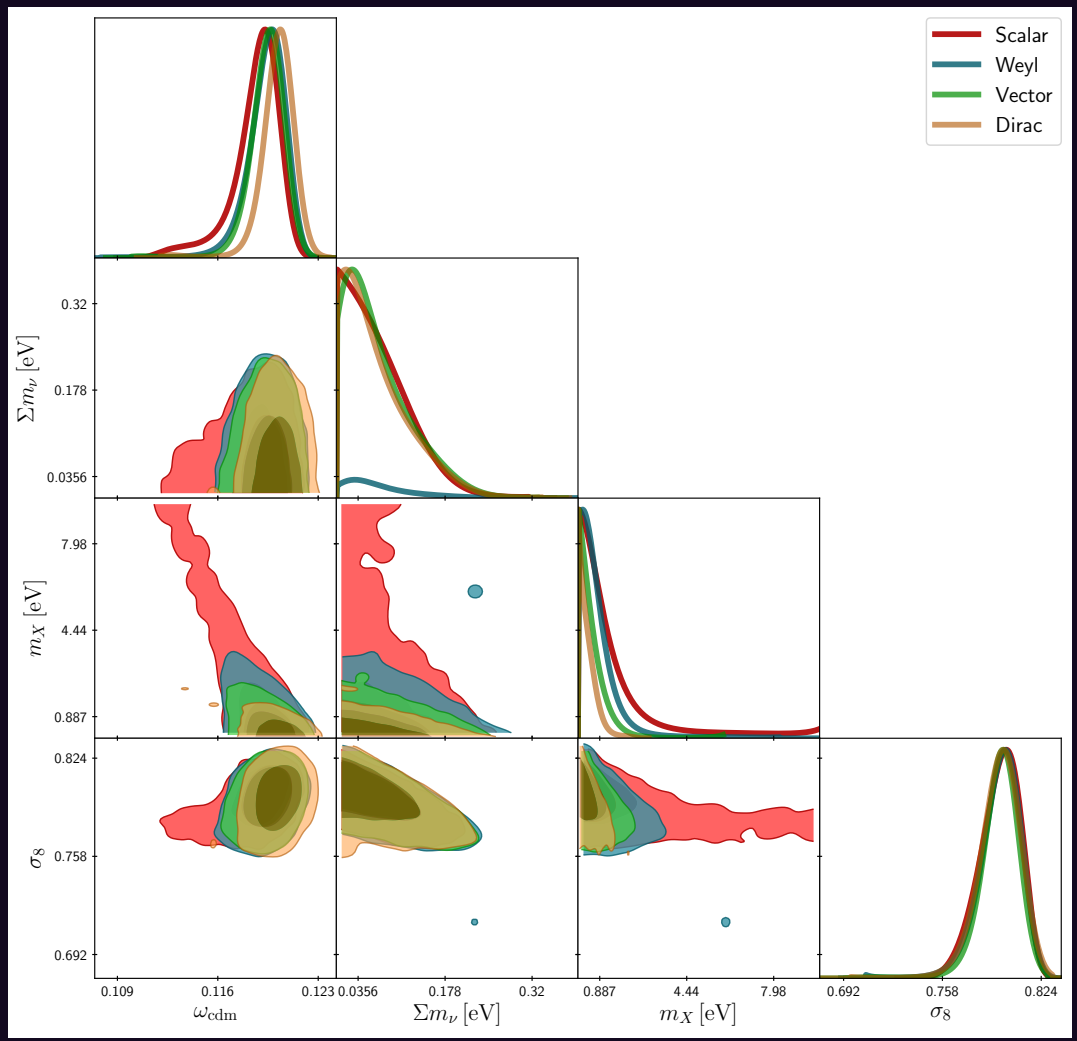


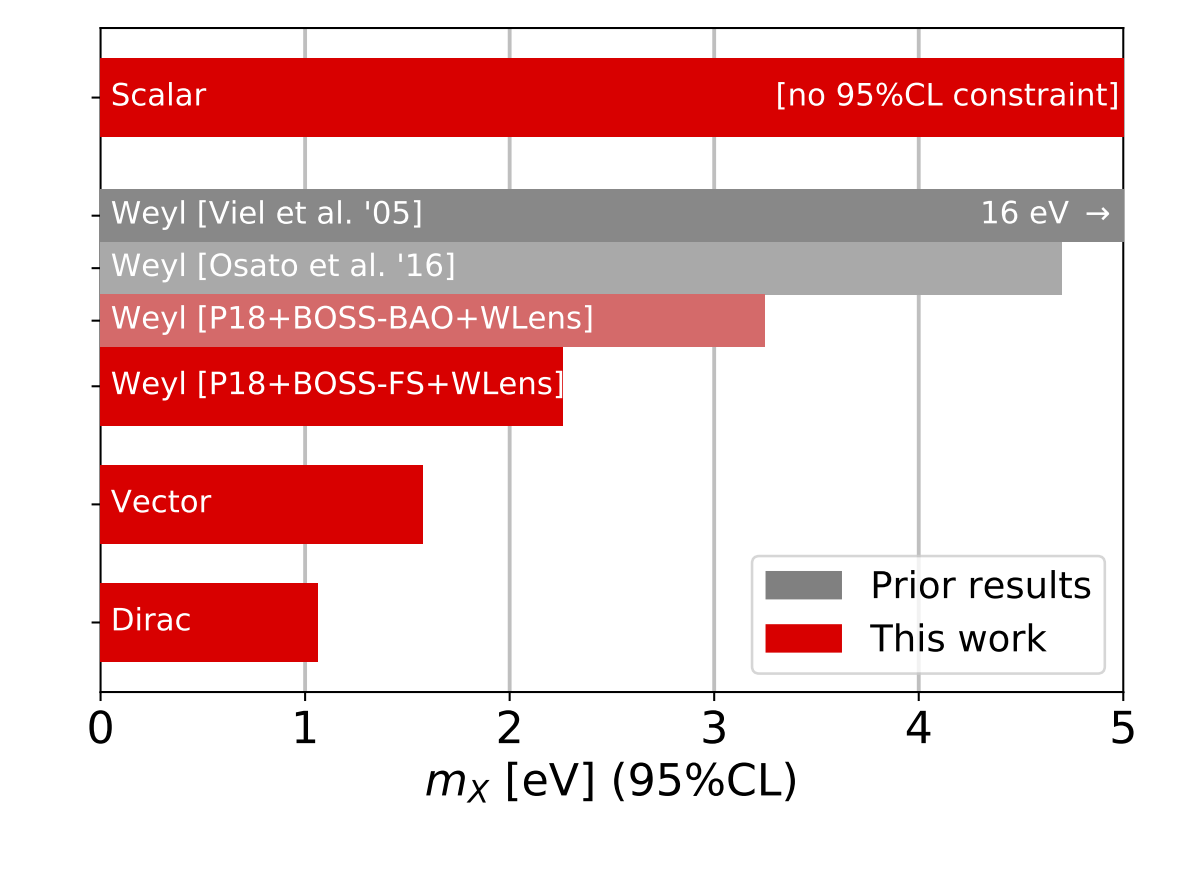
Results

m_X [eV] (95% CL)	
Scalar	–
Weyl	2.26
Vector	1.58
Dirac	1.06



[Minimum temperature $T_X = 0.91$ K]

Results


Scalar
[no 95%CL constraint]
Weyl [Viel et al. '05]
16 eV →
Weyl [Osato et al. '16]
Weyl [P18+BOSS-BAO+WLens]
Weyl [P18+BOSS-FS+WLens]
Vector
Dirac
Prior results
This work
0
1
2
3
4
5
m_X [eV] (95%CL)

Results
& what we can learn from it

Light gravitinos in gauge-mediated SUSY breaking

$$m_X = \frac{\Lambda^2}{\sqrt{3} M_{pl}}, \quad T_X = 0.91K, \quad g_{X,\mathrm{eff}} = 2$$

$$m_X \leq 2.26 \text{ eV} \implies \Lambda \leq 69.1 \text{ TeV}$$

Results
& where we have landed

Dark sectors are worth studying, in whole or in part

- There are reasons to care about LiMRs
- If so, cosmological data is uniquely powerful
- Nontrivial constraints now, better data coming soon!

Thank you!

[Estella Lin, 2021]