Cosmological Constraints on Light (but Massive) Relics

AstroDark 2021

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with Nick DePorzio, Julian Muñoz[†], & Cora Dvorkin

Harvard [†][- Smithsonian CfA]

[2006.09395, 2006.09380 & 2107.09664]

  

Introduction

Matter content of the universe

- "Light" : Visible, ordinary particle content $\sim 15\%$
- "Dark" : Invisible, feebly-interacting particle content $\sim 85\%$
  - Most of it needs to be mostly cold and collisionless

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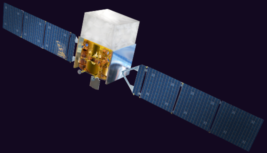

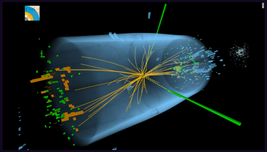

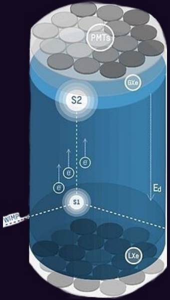

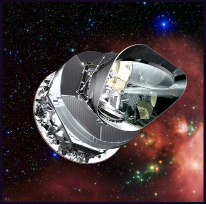

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  - Some fraction can be not that
    - Neutrinos definitely exist, other light relics might too
    - We stand a chance to detect them

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  - Ubiquitous in SM extensions

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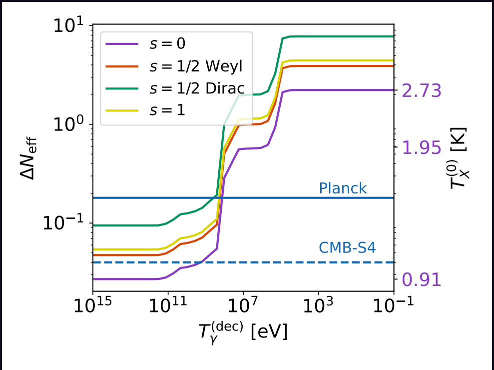
Light but Massive Relics (LiMRs)

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

LiMRs : the Light part

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



[Deporzio, WLX, Mũnoz, Dvorkin 2006.09380]

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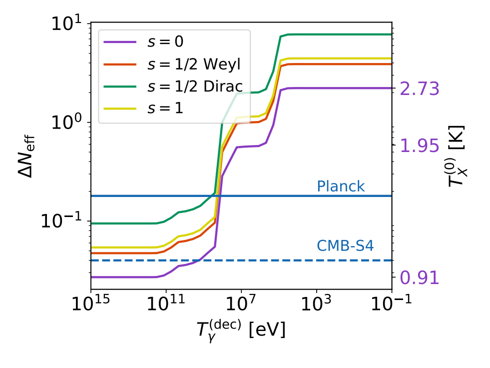
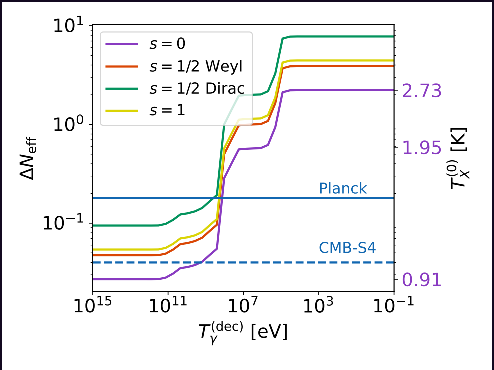


Minimal extensions $\implies T_X^0 \geq 0.91$ K.

[Deporzio, WLX, Mũnoz, Dvorkin 2006.09380]

LiMRs : the Light part

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



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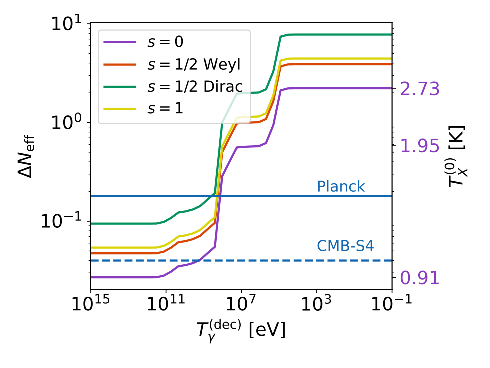


Planck $\Delta N_{\text{eff}} \leq 0.36 \implies T^0_{\text{Weyl}} \leq 1.5$ K

CMB-S4 $\Delta N_{\text{eff}} \leq 0.06 \implies T^0_{\text{Weyl}} \leq 0.96$ K

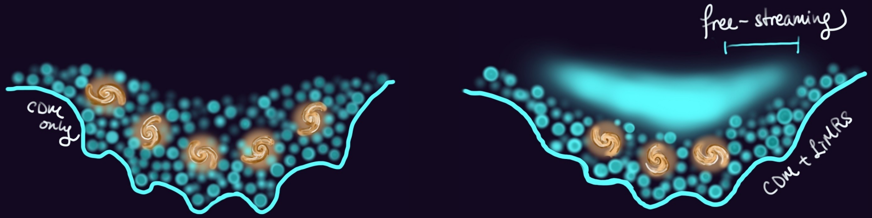
[95% CL]

[Deporzio, WLX, Mũnoz, Dvorkin 2006.09380]

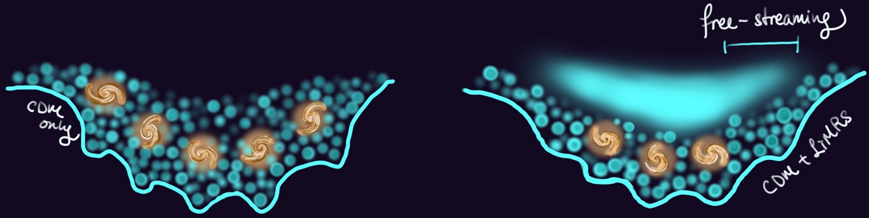
LiMRs : the Massive part

Stuff that clusters ↔ Stuff that expands

Neutrinos & LiMRs



LiMRs : the Massive part



Galaxies are biased tracers

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

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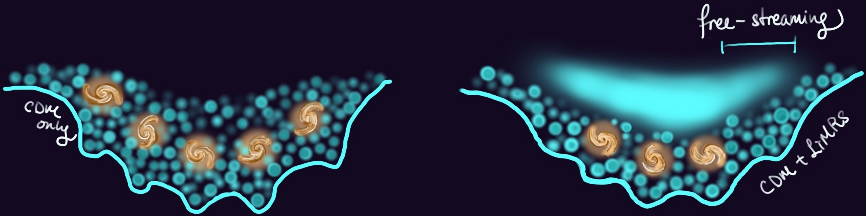
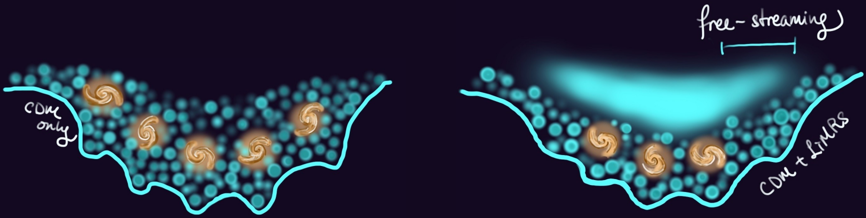


Galaxies are biased tracers of clustering matter

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

LiMRs : the Massive part



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

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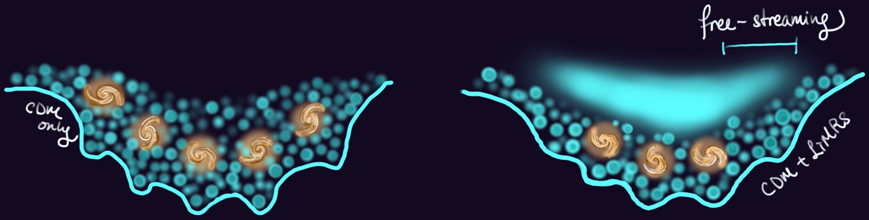

$$\omega_X \propto g_X m_X (T_X^{(0)})^3 \qquad k_{\mathrm{fs},X} \propto \frac{m_X / T_X^{(0)}}{\sqrt{1+z}}$$

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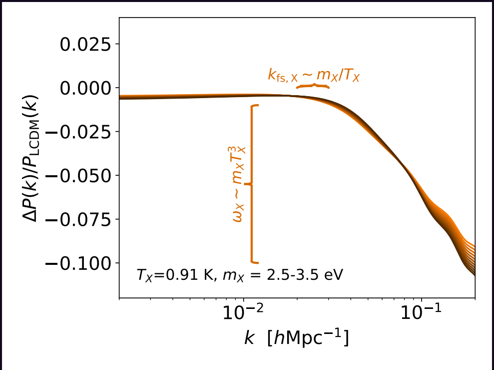
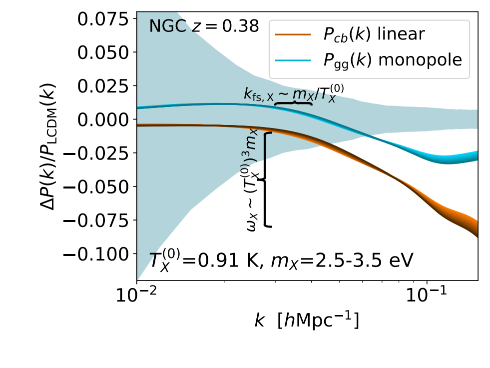


[WLX, Mũnoz, Dvorkin 2107.09664]

LiMRs : the Massive part

$$\delta_g \equiv b_1 \delta_{cb} + b_2 \delta_{cb}^2 + b_{\mathcal{G}_2} \mathcal{G}_2 \qquad \delta_{cb} = (1 - f_\nu - f_X)\delta_m$$



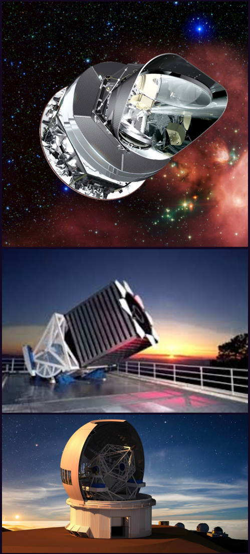
Data/Experiments

- 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 (CLASS-PT)



[Chudaykin, Ivanov, Philcox, Simonović, 2004.10607]

Results

So, have we found anything?

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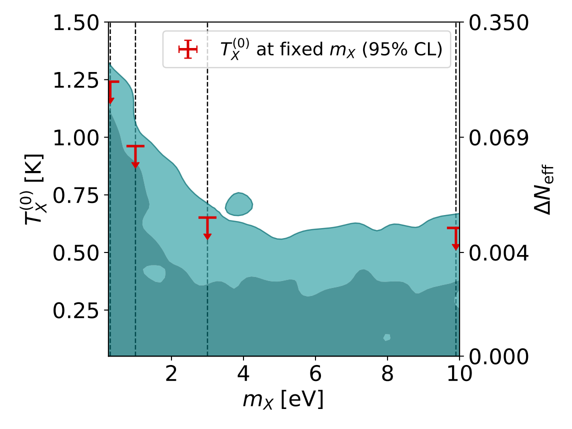
No(t yet), but...

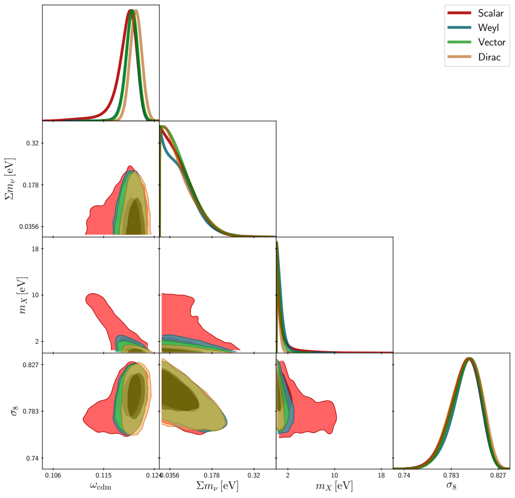


[WLX, Mũnoz, Dvorkin 2107.09664]

Results

$T_X = 0.91$ K

m_X (95% CL)	
Scalar	11.2 eV
Weyl	2.26 eV
Vector	1.58 eV
Dirac	1.06 eV



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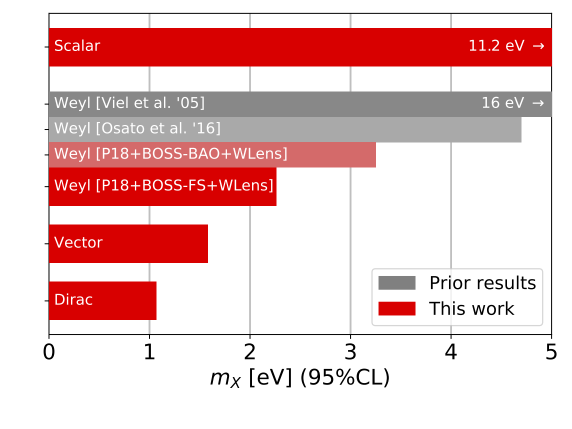

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A Quick Pitch

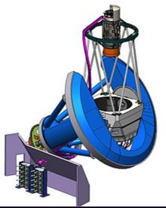
Light gravitinos in gauge-mediated SUSY breaking

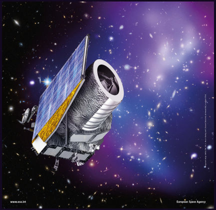
$$m_{3/2} = \frac{\langle F \rangle}{\sqrt{3} M_{pl}}, \quad T_{3/2} \approx 0.95 \text{ K}, \quad g_{3/2,\text{eff}} = 2$$

$$m_{3/2} \leq 1.91 \text{ eV} \implies \sqrt{\langle F \rangle} \leq 63.5 \text{ TeV}$$

Where we're going next

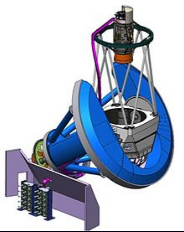
Better data coming soon!

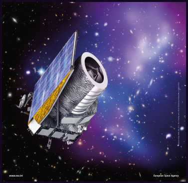




Data/Experiments: Round 2

- Fisher Forecasts
- $\{\omega_b, \omega_{cdm}, h, n_s, A_s, \tau, \sum m_\nu\}$ $+ g_X$, fixed $\{m_X, T_X^{(0)}\}$
- {Scalar, Weyl, Vector, Dirac}
- 10 meV $\leq m_X \leq 10$ eV, 0.91 K $\leq T_X^{(0)} \leq 1.5$ K





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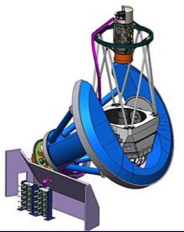
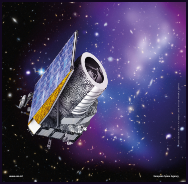
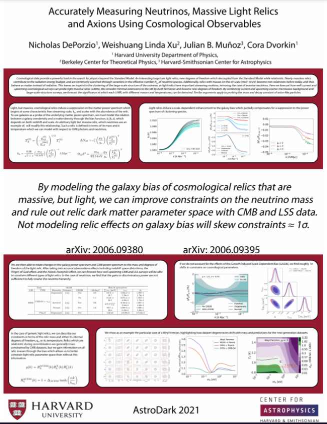
- Planck, CMB-S4 $+\tau$
- LSS Single Tracers:
  - BOSS $\mathcal{O}(100)/\Delta z/\text{deg}^2$ LRGs
  - DESI $\mathcal{O}(1000)/\Delta z/\text{deg}^2$ ELGs
  - Euclid $\mathcal{O}(5000)/\Delta z/\text{deg}^2$ Hαs





Accurately Measuring Neutrinos, Massive Light Relics and Axions Using Cosmological Observables



Nick DePorzio

[2006.09380, 2006.09395, Ongoing work]

Results: to look forward to

$T_X = 0.91$ K

m_X (95% CL)		
BOSS + Planck	Constraints	Forecast
Scalar	11.2 eV	9.6 eV
Weyl	2.26 eV	1.90 eV
Vector	1.58 eV	1.37 eV
Dirac	1.06 eV	0.86 eV

Results: to look forward to

$T_X = 0.91$ K

m_X (**99**% CL)		
	DESI + Planck	DESI + CMB-S4
Scalar	1.96 eV	1.14 eV
Weyl	1.20 eV	0.78 eV
Vector	0.90 eV	0.58 eV
Dirac	0.61 eV	All masses

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Also: 3σ discovery potential for GMSB gravitinos at
$m_{3/2} \geq 0.77$ eV or $\sqrt{F} \geq 40$ TeV
2σ at *all* masses

Some Landing Points

Dark sectors are worth studying, in whole or in part

- Compelling reasons to care about LiMRs
- If so, cosmological data is uniquely powerful
- The first set of comprehensive constraints
  + better things to come

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What's next?

- Generalize the framework (+ annihilations, decays...)
- Develop model applications + follow-up plans
  - what are the compelling targets to search for?
  - how do we identify them if we detect something?

Thank you!

[Estella Lin, 2021]