

Title: Probing Dark Matter Particle Properties with Ultra-High-Resolution CMB Lensing

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Abstract: I will discuss a novel and powerful way to probe dark matter particle properties using deep, high-resolution cosmic microwave background (CMB) gravitational lensing measurements. These measurements can distinguish between cold dark matter and alternative dark matter models that can explain observational puzzles of small-scale structure. I will also discuss a new experiment being developed, called CMB-HD, that can achieve this science and also open new windows on the early Universe, gas and galaxy evolution, planetary studies, and the transient sky.

What is Dark Matter?

- all evidence from gravitational interaction
- other interactions tightly constrained

Uncovering its identity is one of the most important goals in particle physics today

Cold, collisionless Dark Matter passes
an enormous number of tests...

A simulated Milky-Way CDM Halo

[Diemand et.al.]

Via Lactea II
Simulation

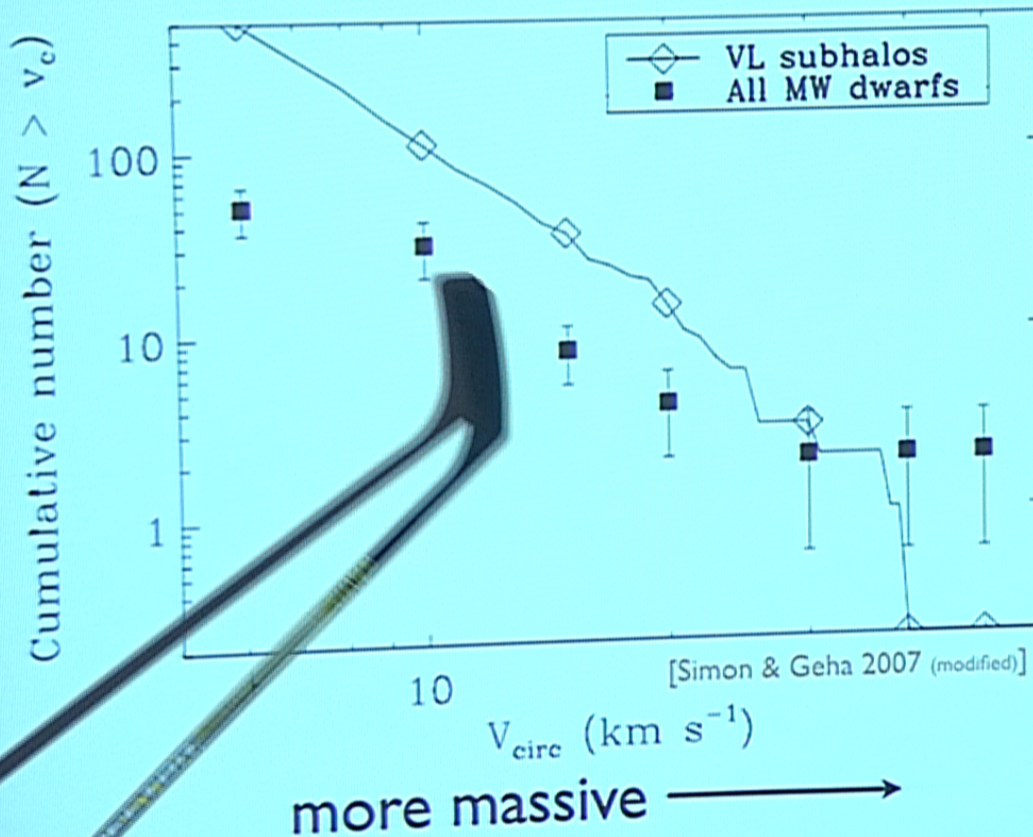
(only DM, no baryons)



1.6 Mega-light-yrs cube

Missing Satellites Problem

e.g. Klypin et al. 1999; Moore et al. 1999



many subhalos
("dwarfs")
predicted...

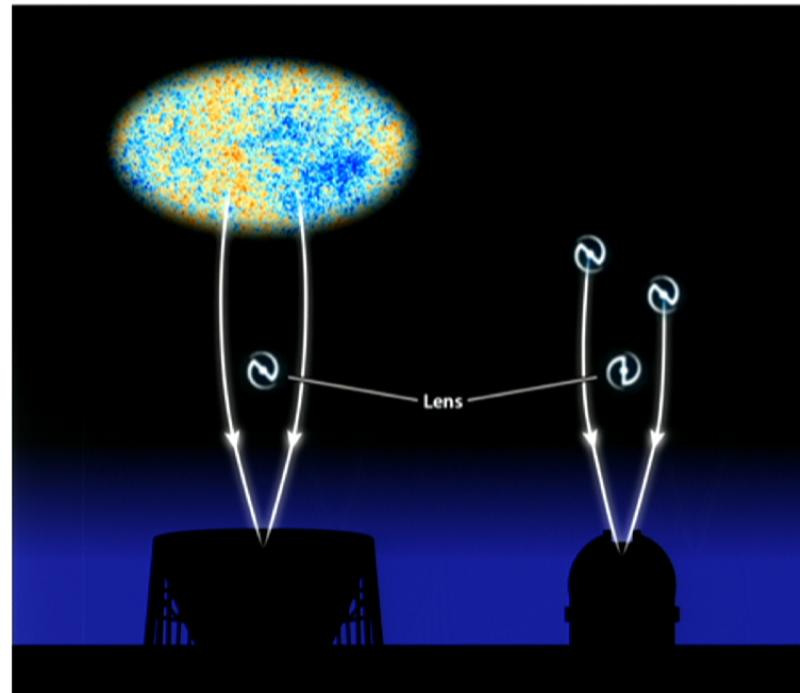
not enough
are observed!

Small-Scale CDM Problems?

- CDM works well on scales larger than 10 kpc, but seems to fail on smaller scales (maybe):

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Gravitational Lensing of the Cosmic Microwave Background



Advantage of CMB Lensing to Probe Small-Scale Structure

1. Directly sensitive to dark matter via gravitational lensing
2. Source light is at well-defined redshift

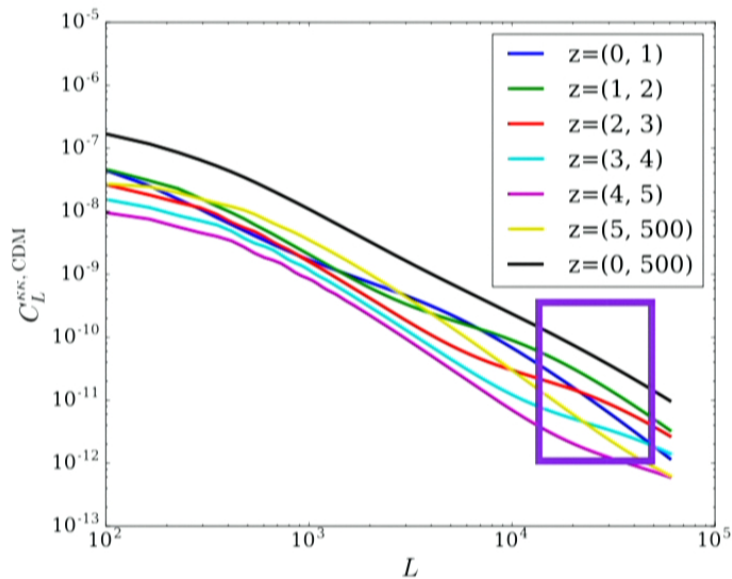
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CMB Lensing Power Spectrum



at these scales sensitive to structure at $z \sim 1-3$

CMB Lensing Power Spectrum
is matter power spectrum
convolved with window

$$C_L^{\phi\phi} = \frac{9\Omega_{m0}^2 H_0^4}{c^4} \int_0^{\chi_s} d\chi \left(\frac{\chi_s - \chi}{\chi^2 \chi_s} \right)^2 \frac{(1+z)^2 P_m(k, z(\chi))}{k^4}$$

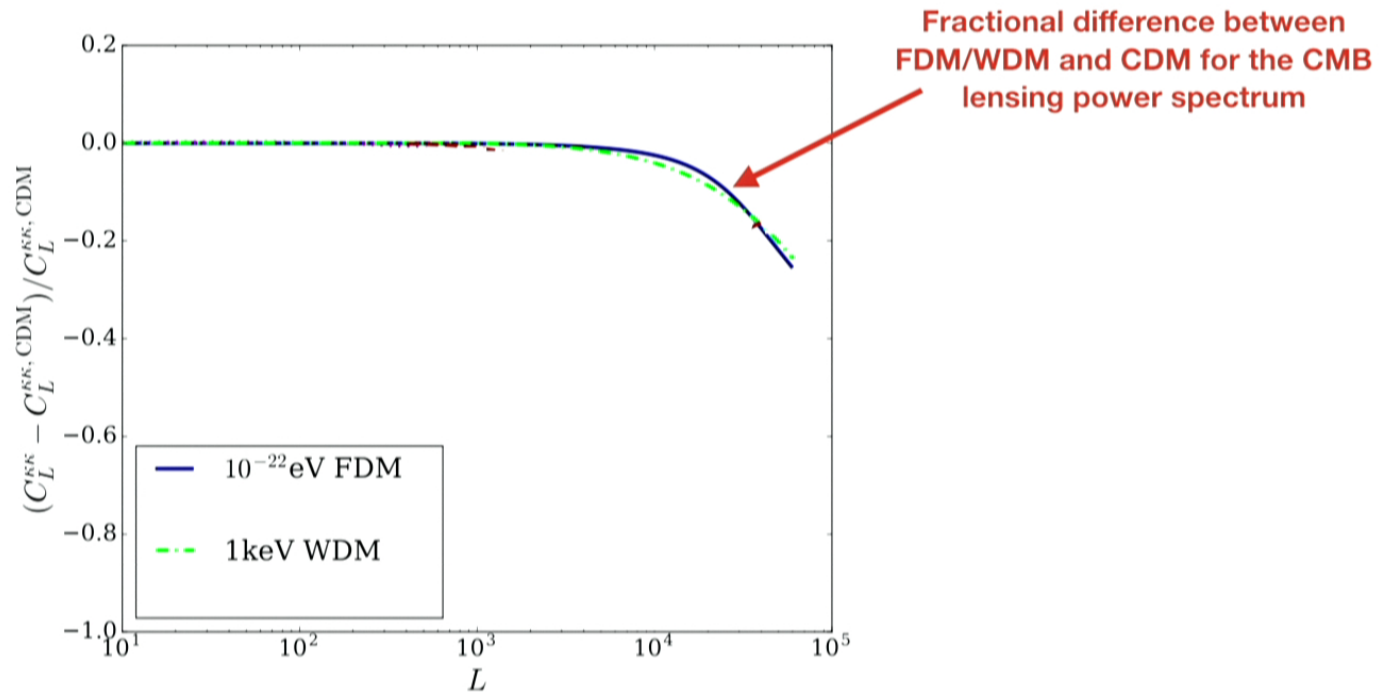
$$C_L^{\kappa\kappa} = \frac{[L(L+1)]^2 C_L^{\phi\phi}}{4}$$

Measured on scales $L < 3000$
so far ($k < 1 \text{ Mpc}^{-1}$)

Want to measure scales $L \sim 30,000$
($k \sim 10 \text{ Mpc}^{-1}$ and $M < 10^9 \text{ Msun}$)

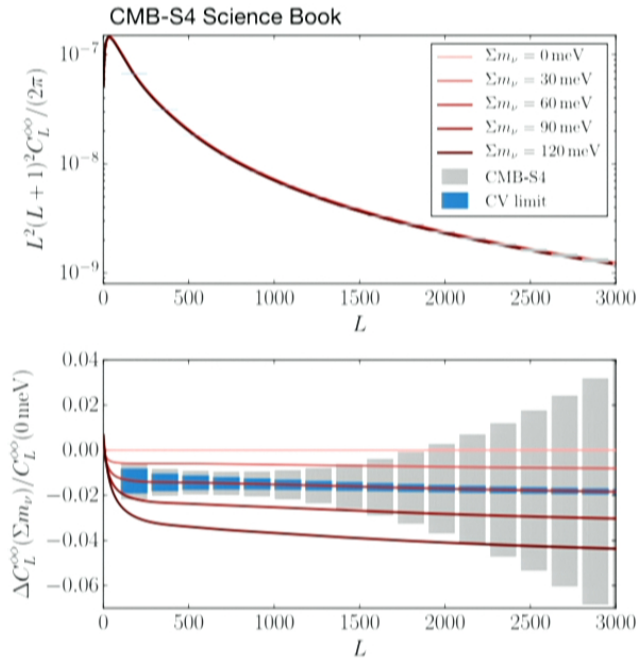
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CMB Lensing Power Spectrum for CDM Versus FDM/WDM



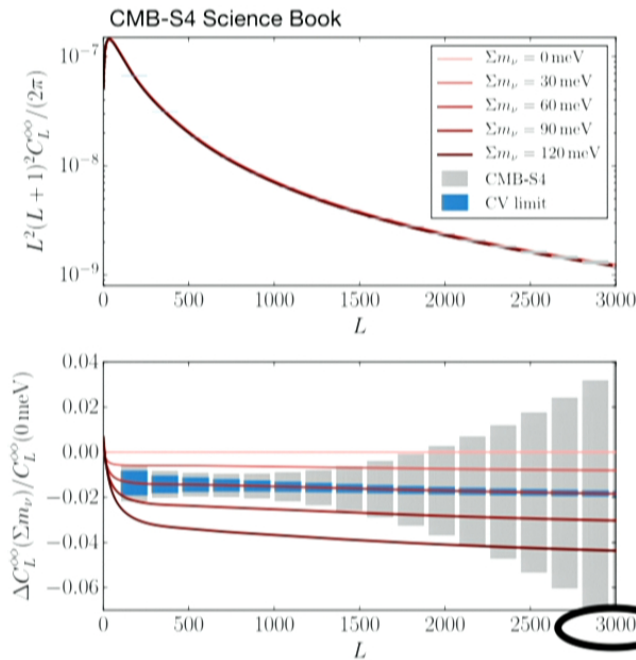
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Dark Matter Constraints Not Degenerate with Neutrino Mass

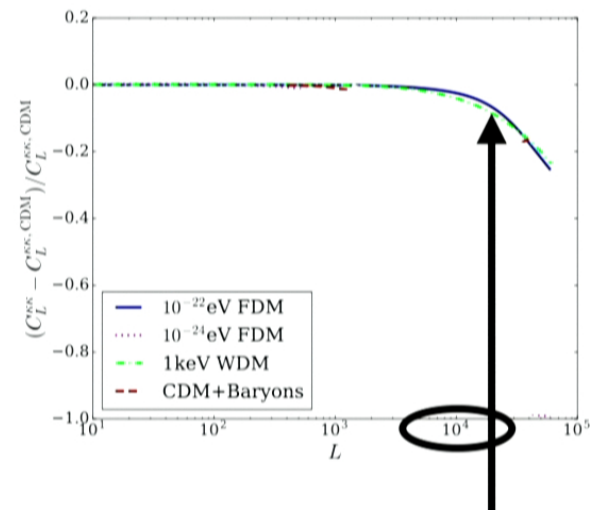


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Dark Matter Constraints Not Degenerate with Neutrino Mass



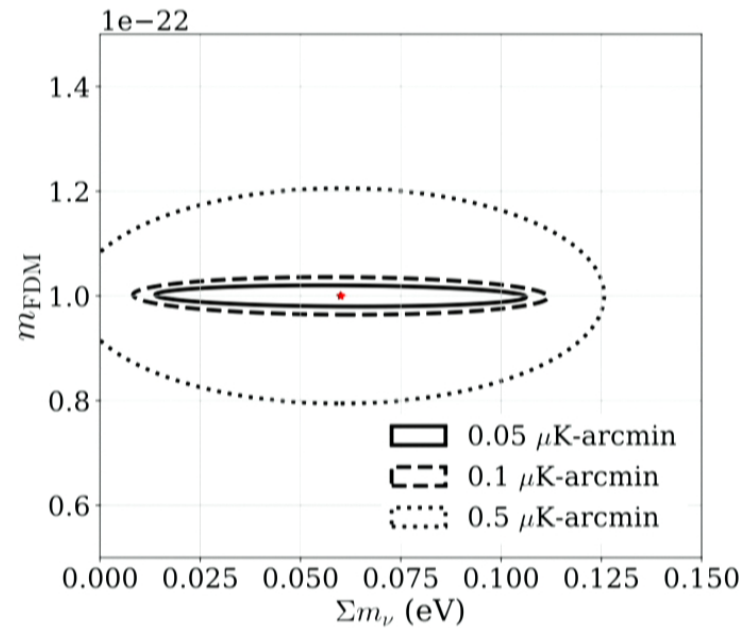
CMB lensing is known for its potential to constrain the sum of the neutrino masses



Alternative DM models of interest suppress power on much smaller scales

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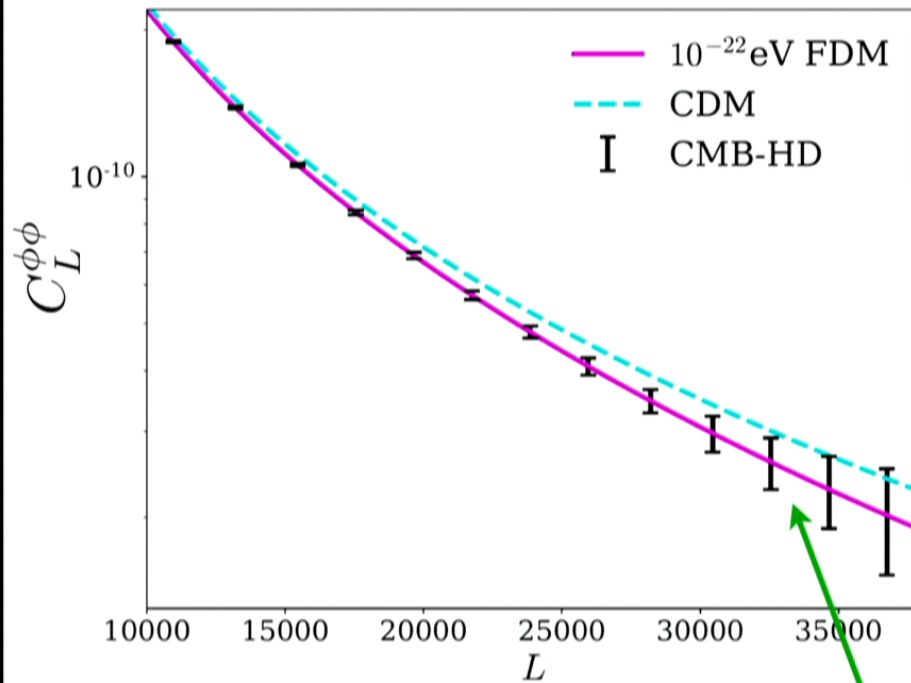
Dark Matter Constraints Not Degenerate with Neutrino Mass



Ho Nam Nguyen, NS, Mathew Madhavacheril, 2019, PRD

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Dark Matter Forecasts Using Ultra-Small-Scale CMB Lensing



8-sigma preference for FDM over CDM

Ho Nam Nguyen, NS, Mathew Madhavacheril, 2019, PRD
NS et al., 2019, arXiv:1903.03263

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Instrument Path

Two new 30-meter mm-wave telescopes in Atacama Desert
with total sensitivity 3 times deeper than CMB-S4 == CMB-HD



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CMB-HD Probe of Light Particles

Table 1: Summary of CMB-HD key science goals in fundamental physics

Science	Parameter	Sensitivity
Dark Matter	S/N: Significance in Differentiating FDM/WDM from CDM ^a	S/N = 8
New Light Species	N_{eff} : Effective Number of Relativistic Species ^b	$\sigma(N_{\text{eff}}) = 0.014$
Inflation	f_{NL} : Primordial Non-Gaussianity ^c	$\sigma(f_{\text{NL}}) = 0.26$
Inflation	A_{lens} : Residual Lensing B-modes ^d	$A_{\text{lens}} = 0.1$

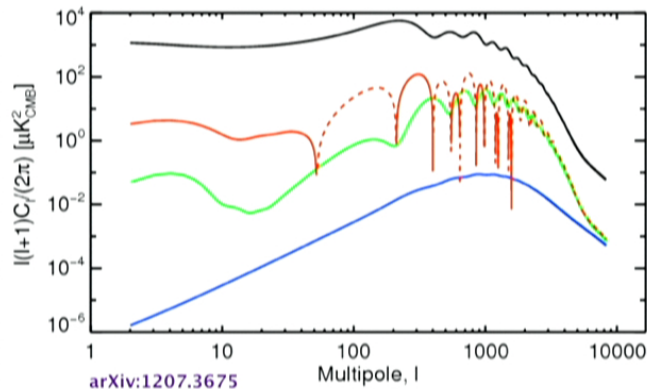
NS et al. 2019, CMB-HD APC White Paper for Astro2020 Decadal (arXiv:1906.10134)

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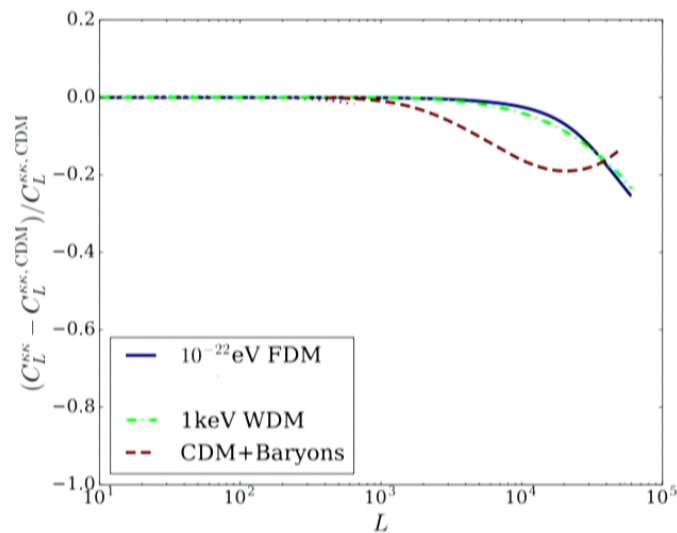
NS et al. 2019, CMB-HD APC White Paper for Astro2020 Decadal (arXiv:1906.10134)



Theory Questions

Degeneracy between baryons impacting matter
and alternatives to CDM

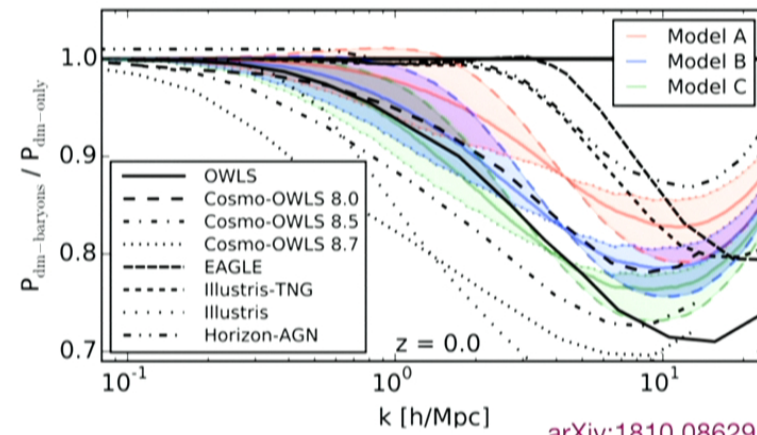
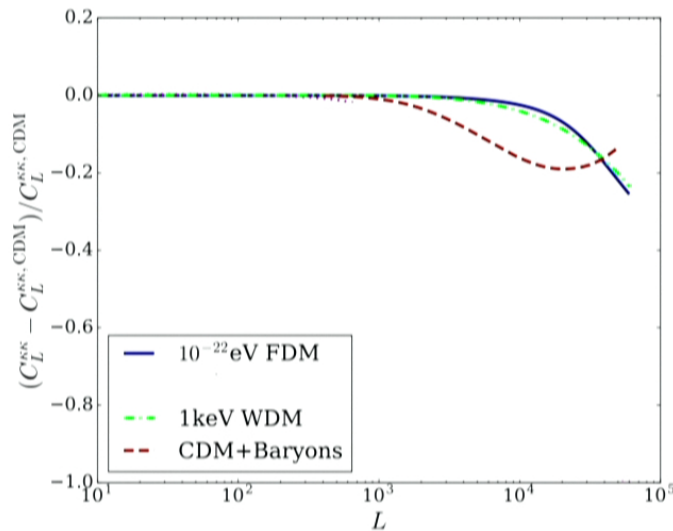
Use difference in shape



Theory Questions

Degeneracy between baryons impacting matter and alternatives to CDM

Use difference in shape



Quantifying baryon effects on the matter power spectrum and the weak lensing shear correlation

Aurel Schneider, Romain Teyssier, Joachim Stadel, Nora Elisa Chisari, Amandine M. C. Le Brun, Adam Amara, Alexandre Refregier

Summary

- Key question: what do matter fluctuations look like on small scales?
- Multiple techniques to measure this are proposed, each with different challenges and systematics
- Another complementary, potentially powerful technique, with different systematics, is to **use ultra-deep, high-resolution CMB lensing to measure the matter power spectrum**
- Requires two 30-meter mm-wave telescopes with total sensitivity 3 times deeper than proposed CMB-S4