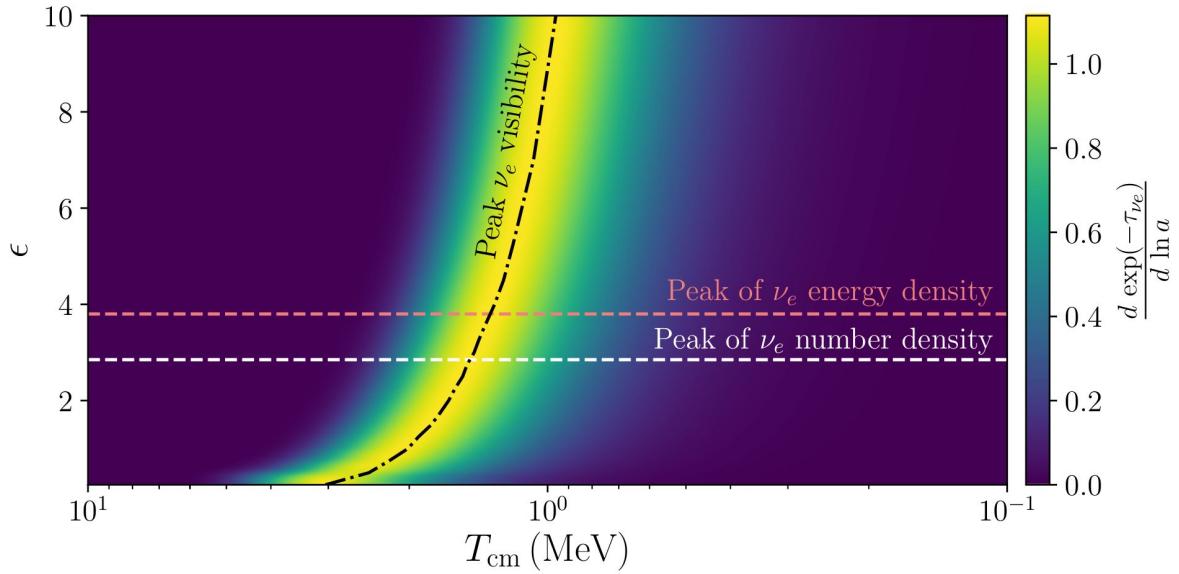
Light Relics with CMB-S4

Joel Meyers

CMB-S4 Collaboration Meeting
May 9-13, 2022

Cosmic Neutrinos as Standard Model Light Relics

Neutrino Differential Visibility



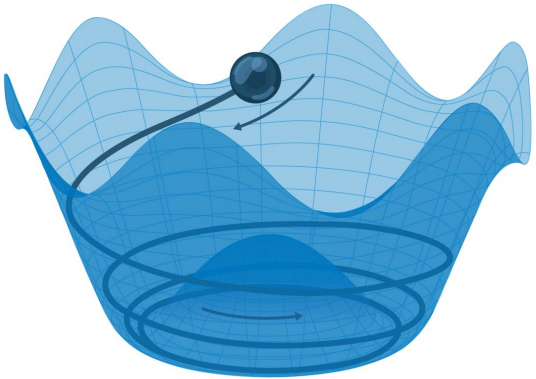
The energy density of the cosmic neutrino background can be calculated precisely, including the effects of non-instantaneous weak decoupling

$$N_{\rm eff} = \frac{8}{7}\left(\frac{11}{4}\right)^{4/3}\frac{\rho_\nu}{\rho_\gamma}$$

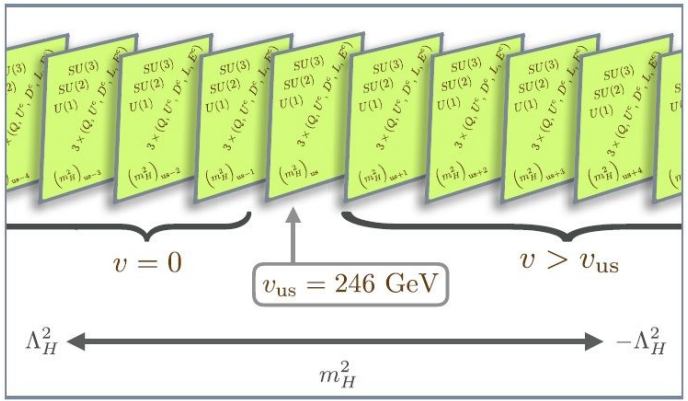
$$N_{\rm eff}^{\rm SM} = 3.044(1)$$

Escudero Abenza (2020); Akita, Yamaguchi (2020); Froustey, Pitrou, Volpe (2020); Bennett, et al (2021); Bond, Fuller, Grohs, JM, Wilson (In Prep.)

New Light Species are Ubiquitous in Standard Model Extensions



Axions and Axion-Like Particles



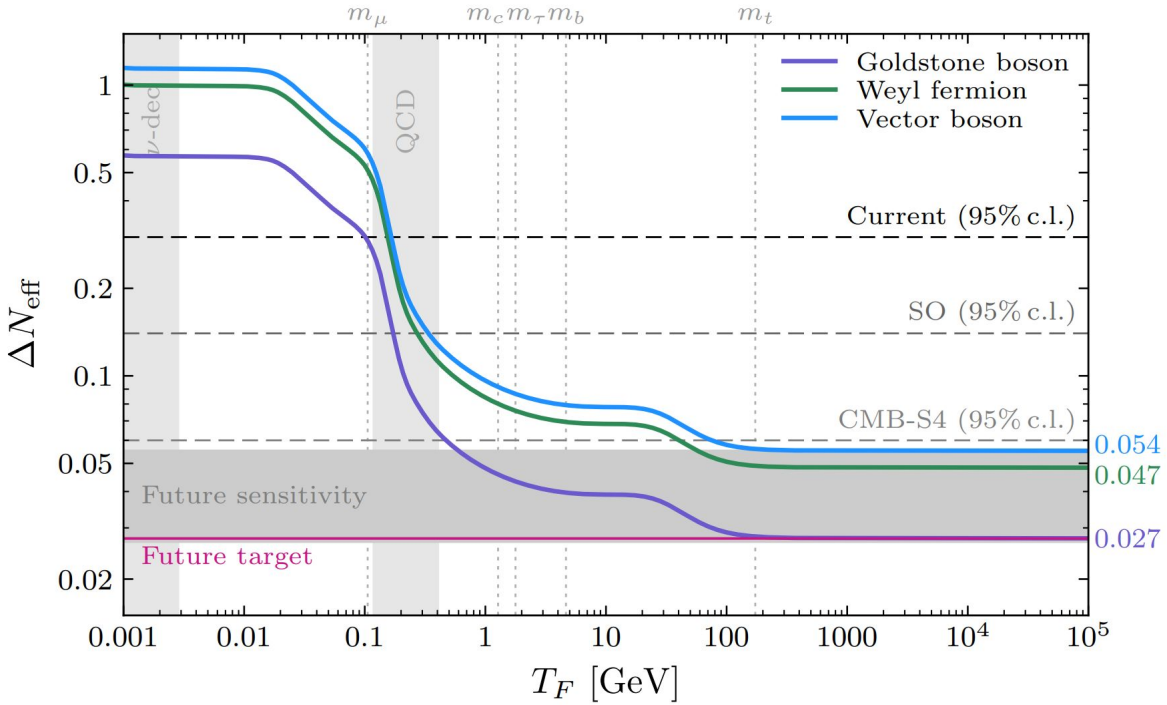
Complex Dark Sectors

Sterile Neutrinos

… and many more

Green, Amin, JM, Wallisch, et al (2019); Dvorkin, JM, et al (2022)
Image Credits: Quanta Magazine; Arkani-Hamed, et al (2016); Symmetry Magazine

Light Thermal Relics Set Useful Targets



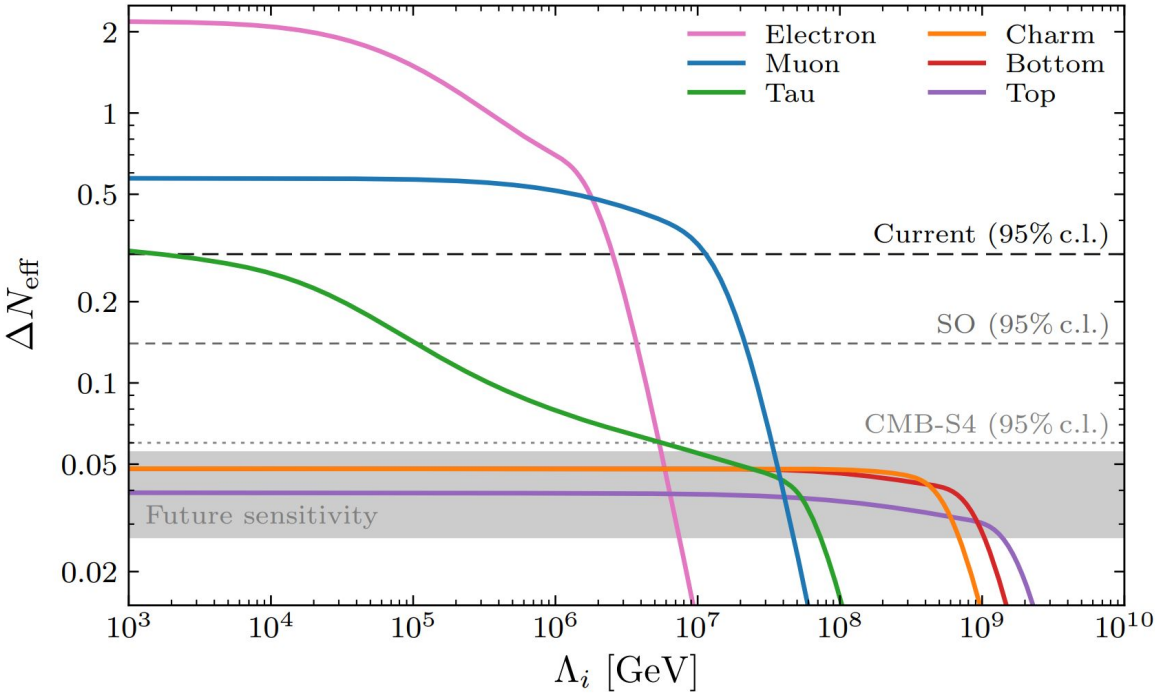
The relic density of any new light species that was ever in thermal equilibrium with the Standard Model plasma can be computed from its spin and decoupling temperature, setting clear targets for future surveys

Freeze-out occurs when production rate falls below Hubble rate

$$\Gamma \sim \frac{T^{2n+1}}{\Lambda^n} \qquad H \sim \frac{T^2}{M_{\rm pl}}$$

CMB-S4 (2016); Green, Amin, JM, Wallisch, et al (2019); Dvorkin, JM, et al (2022)

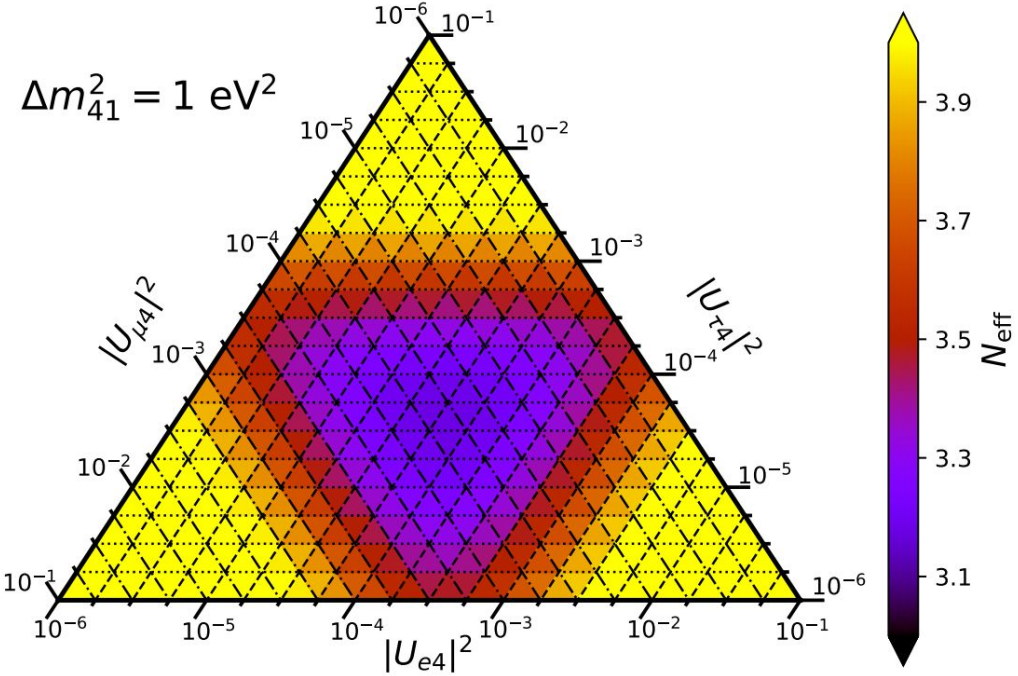
Rethermalization of Light Relics



Light species whose interaction rates decrease more slowly than the expansion rate may thermalize at late times, leading to larger contributions to $N_{\rm eff}$

Green, Guo, Wallich (2021); Dvorkin, JM, et al (2022)

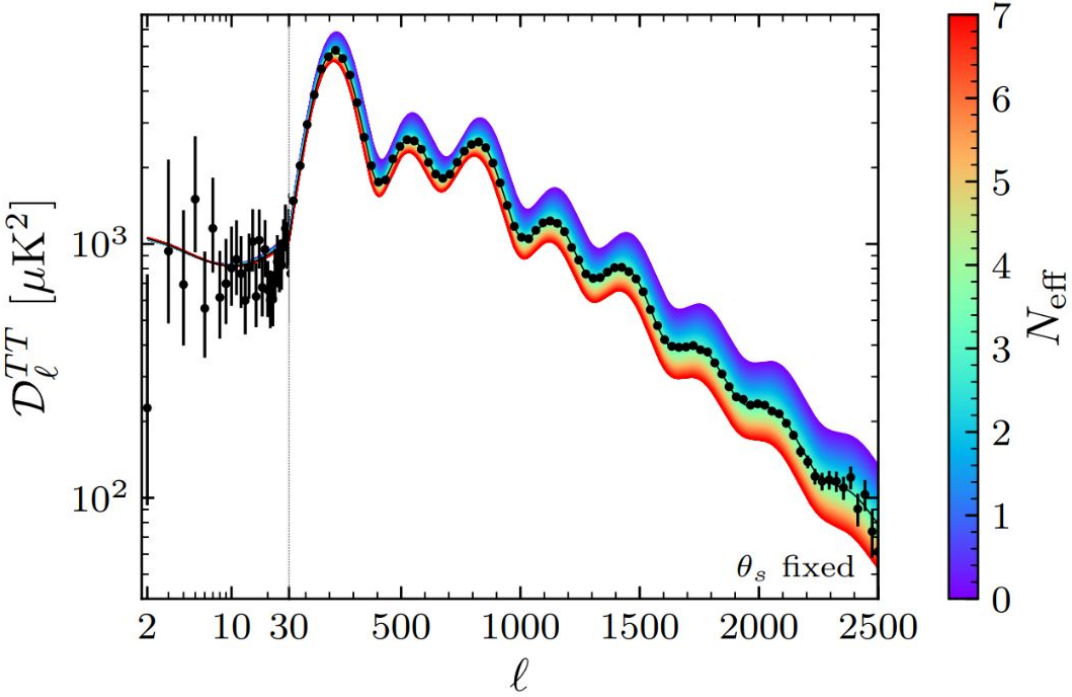
Light Relics from Mixing - Sterile Neutrinos



Sterile neutrinos may not be thermalized, but can be produced through mixing with active neutrinos that are produced in thermal equilibrium

Gariazzo, de Salas, Pastor (2019); Dvorkin, JM, et al (2022)

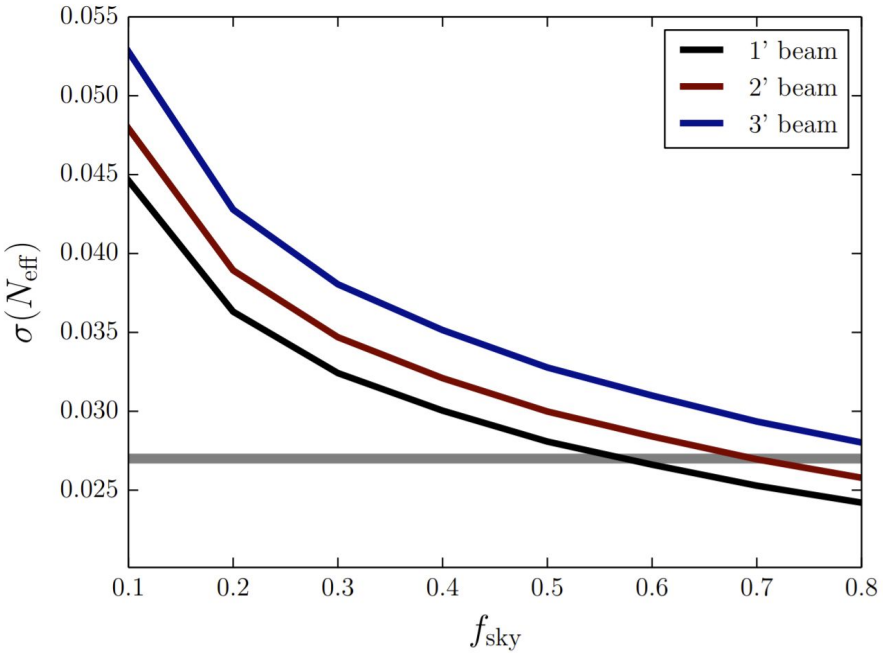
Light Relics Affect CMB Damping Scale



The mean density of light relics affects the expansion rate in the early universe and therefore impacts the damping scale of CMB anisotropies

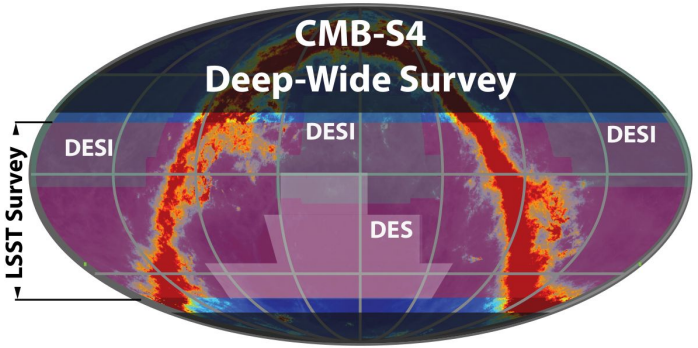
Image Credit: Wallisch (2018)

Light Relics Measurements Favor Wide Surveys



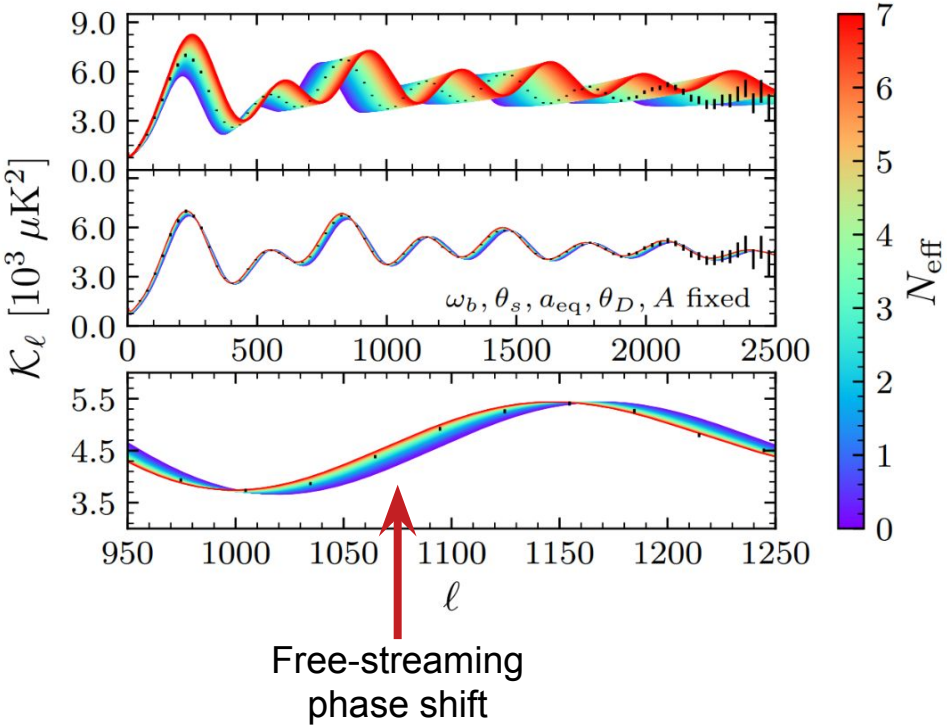
Forecasted errors at fixed effort, normalized to 1μK-arcmin at f_{sky}=0.4

Light relics are best measured with the CMB damping tail, meaning that at fixed effort, more unique modes are available in a wide survey compared to a deep survey - we designed the CMB-S4 wide survey scan strategy to maximize sky coverage in order meet our target for light relics

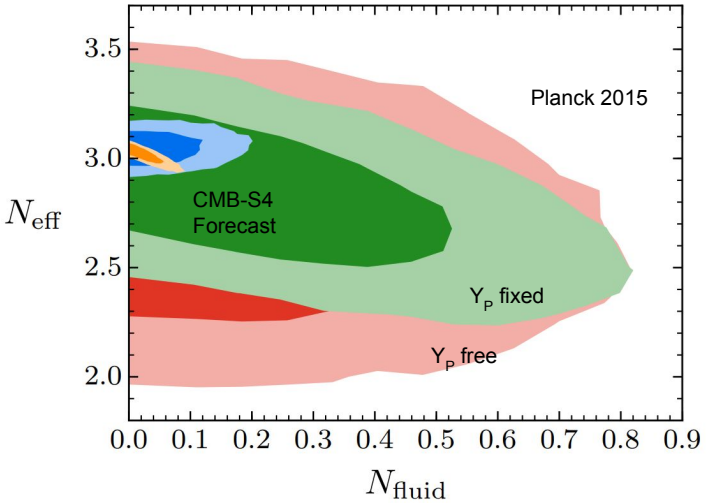


CMB-S4 (2016); CMB-S4 (2019)

Free-Streaming Light Relics and the Phase Shift

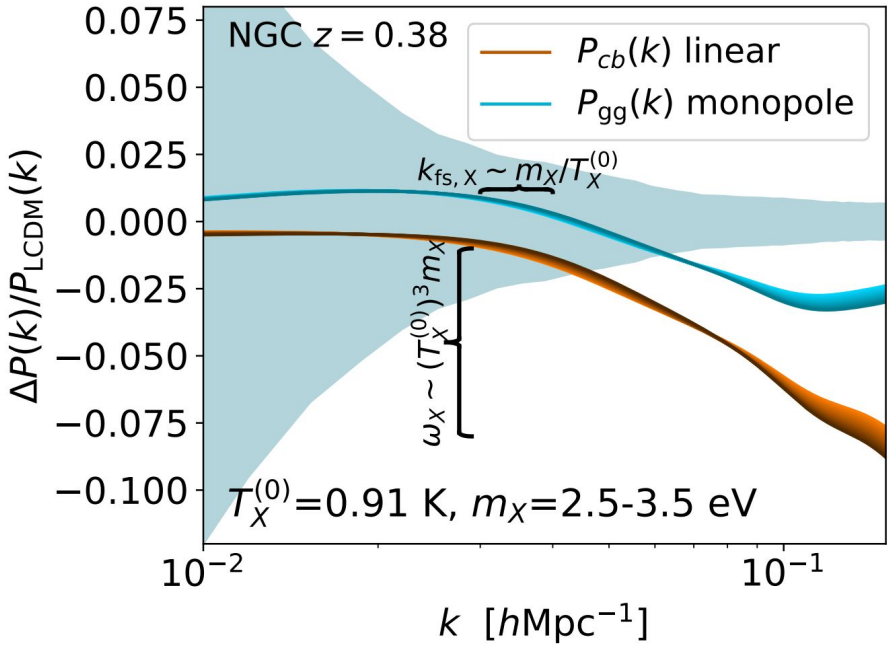


Fluctuations in the density of free-streaming light relics lead to a phase shift of the CMB acoustic peaks, allowing them to be distinguished from fluid-like radiation

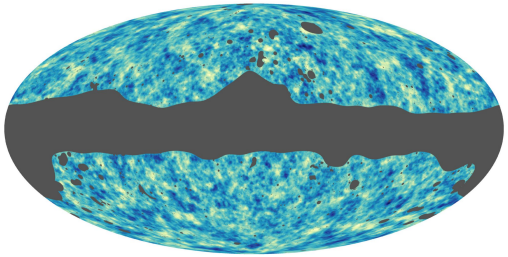


Bashinsky, Seljak (2004); Baumann, Green, JM, Wallisch (2016); Image Credit: Wallisch (2018)

Light But Massive Relics Suppress Matter Clustering



Light relics with non-vanishing mass have large thermal velocities, but are non-relativistic today, and therefore act as hot dark matter, suppressing clustering of matter on scales smaller than their free-streaming length, which is observable in CMB lensing spectrum



Planck (2018); Xu, Muñoz, Dvorkin (2021); Dvorkin, JM, et al (2022)

Snowmass White Paper

The Physics of Light Relics

Cora Dvorkin*[1], Joel Meyers†[2], Peter Adshead[3], Mustafa Amin[4], Carlos A. Argüelles[1], Thejs Brinckmann[5,6], Emanuele Castorina[7], Timothy Cohen[8], Nathaniel Craig[9], David Curtin[10], Francis-Yan Cyr-Racine[11], Peizhi Du[12], Lloyd Knox[13], Bohua Li[14,15], Marilena Loverde[16], Kaloian Lozanov[3], Julian B. Muñoz[17], Katelin Schutz[18], Paul Shapiro[19], Benjamin Wallisch[20,21], Zachary J. Weiner[16], and Weishuang Linda Xu[22]

arXiv:2203.07943