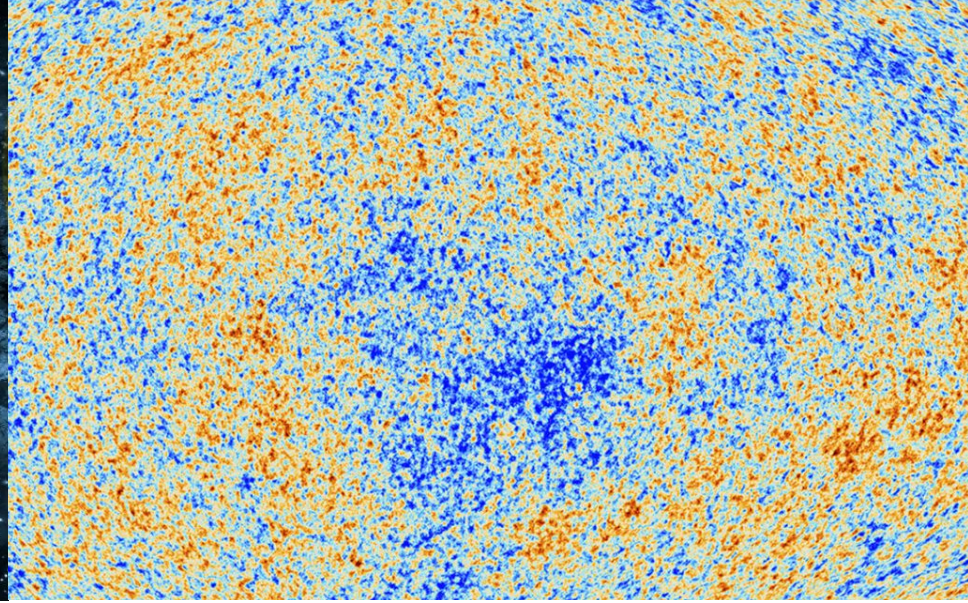
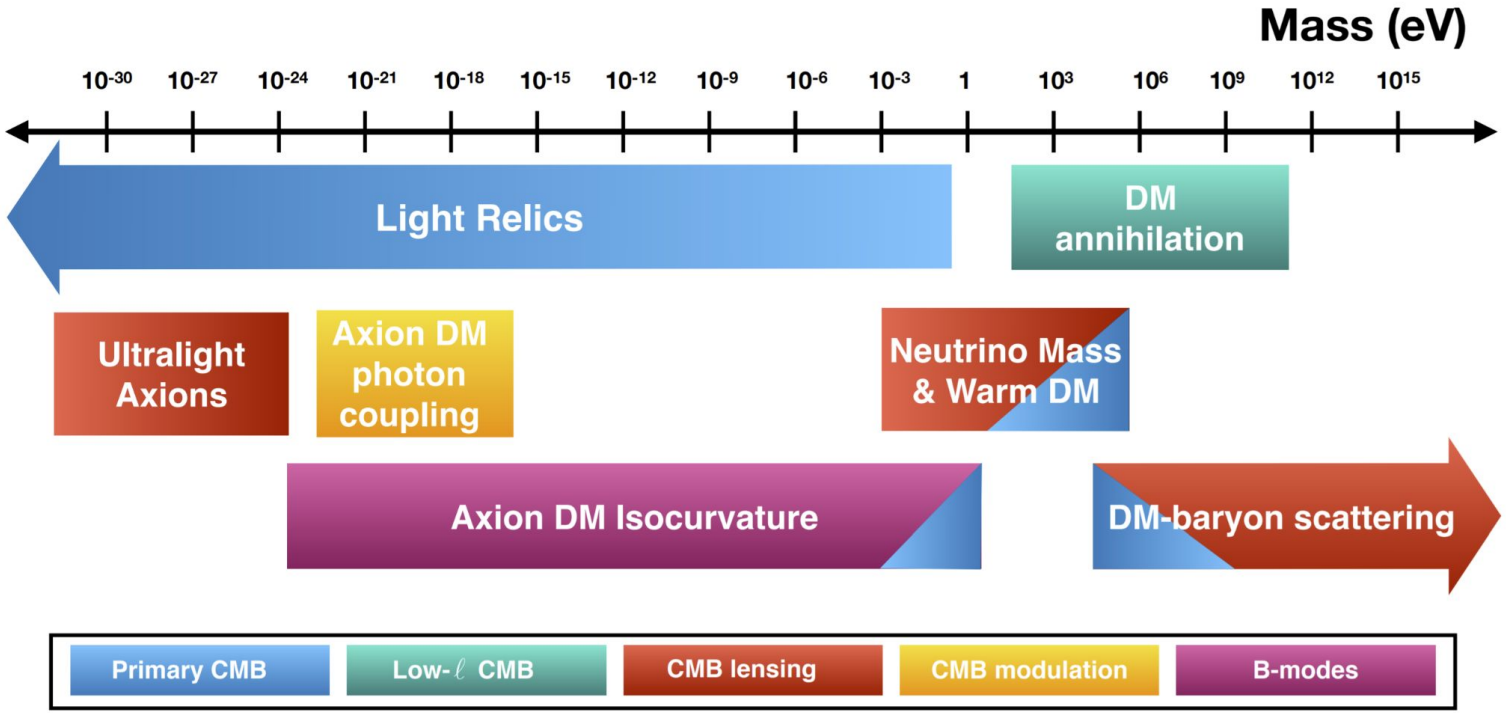


Messengers from the Early Universe with CMB-S4

Joel Meyers
SMU

CMB-S4 Collaboration Meeting
August 10, 2021

CMB Probes of the Dark Sector



CMB-S4 DSR (1907.04473)

Early Universe Messengers in the Standard Model: Cosmic Neutrinos

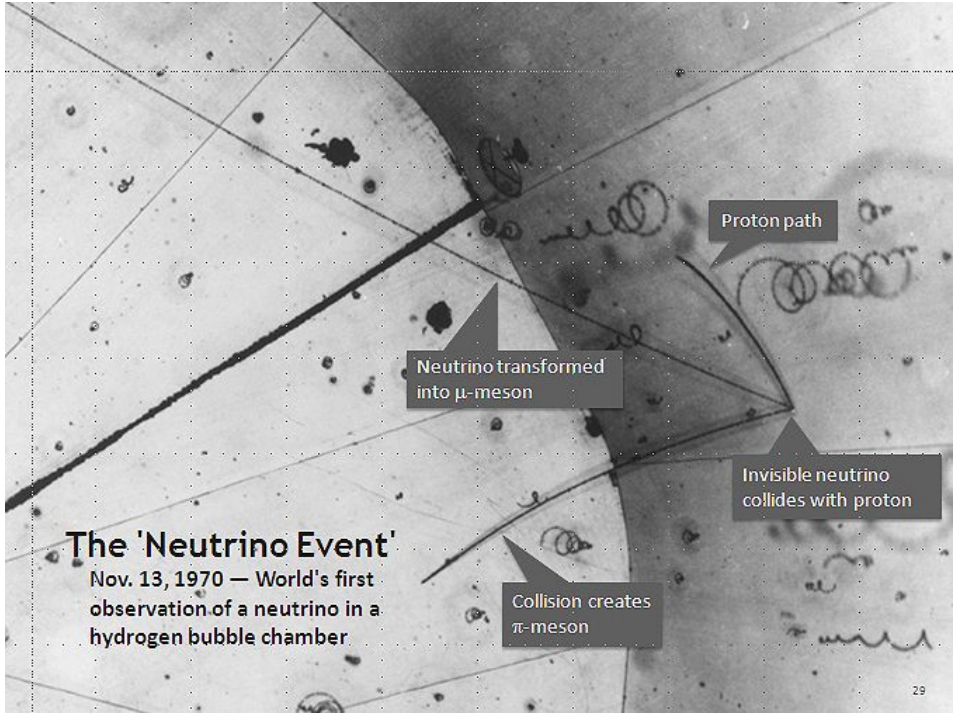
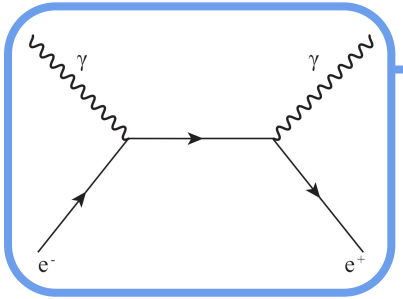


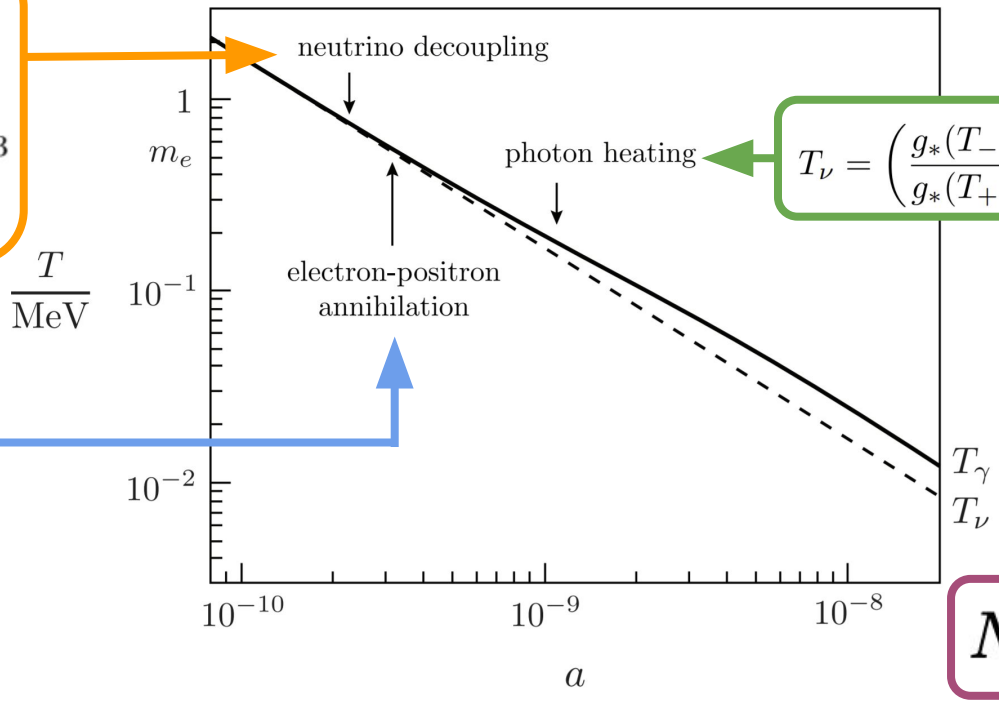
Image Credit: Argonne National Laboratory

Cosmic Neutrino Decoupling

$$\sigma \sim \left| \times \right|^2 \sim G_F^2 T^2$$

$$\frac{\Gamma}{H} \sim \frac{\alpha^2 M_{\rm pl} T^3}{M_W^4} \sim \left(\frac{T}{1\,\text{MeV}}\right)^3$$



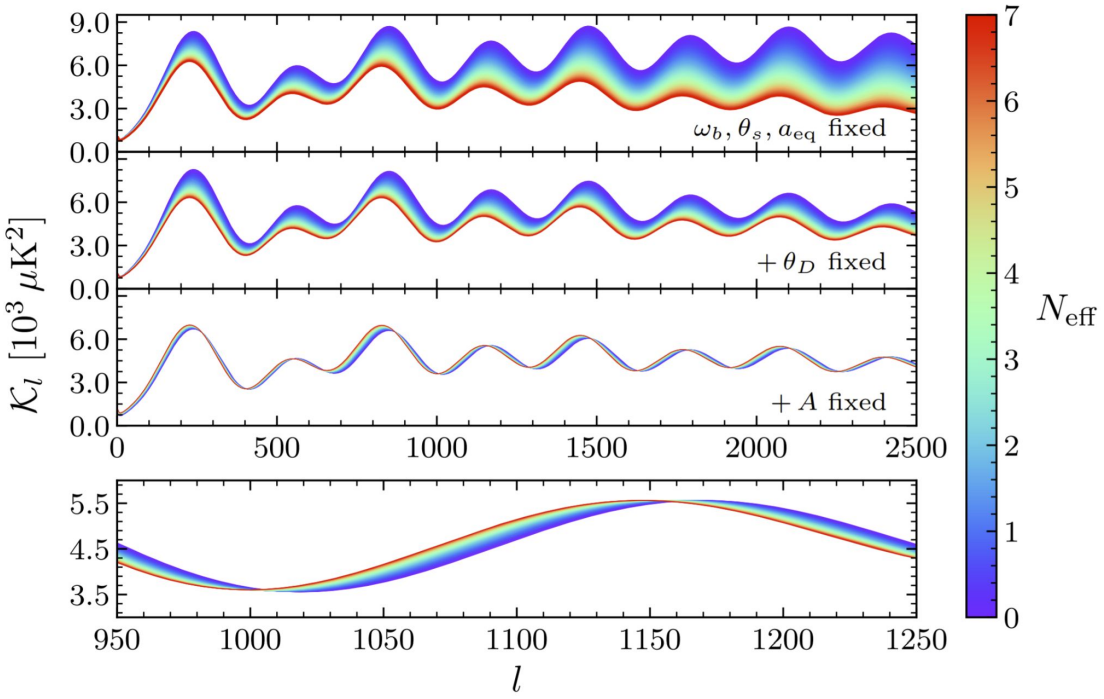


$$T_\nu = \left(\frac{g_*(T_-)}{g_*(T_+)}\right)^{1/3} T_\gamma = \left(\frac{4}{11}\right)^{1/3} T_\gamma$$

$$N_{\rm eff}^{\rm SM} = 3.044$$

Baumann (1807.03098); Akita, Yamaguchi (2005.07047)

Effects of Light Relics on the CMB Power Spectrum



Damping

Amplitude Shift

Phase Shift

Baumann, Green, Wallisch (1712.08067)

Constraints on the Light Relic Density

Current Constraint

$$N_{\rm eff} = 2.92^{+0.36}_{-0.37}$$
(95 %, *Planck* TT,TE,EE+lowE)

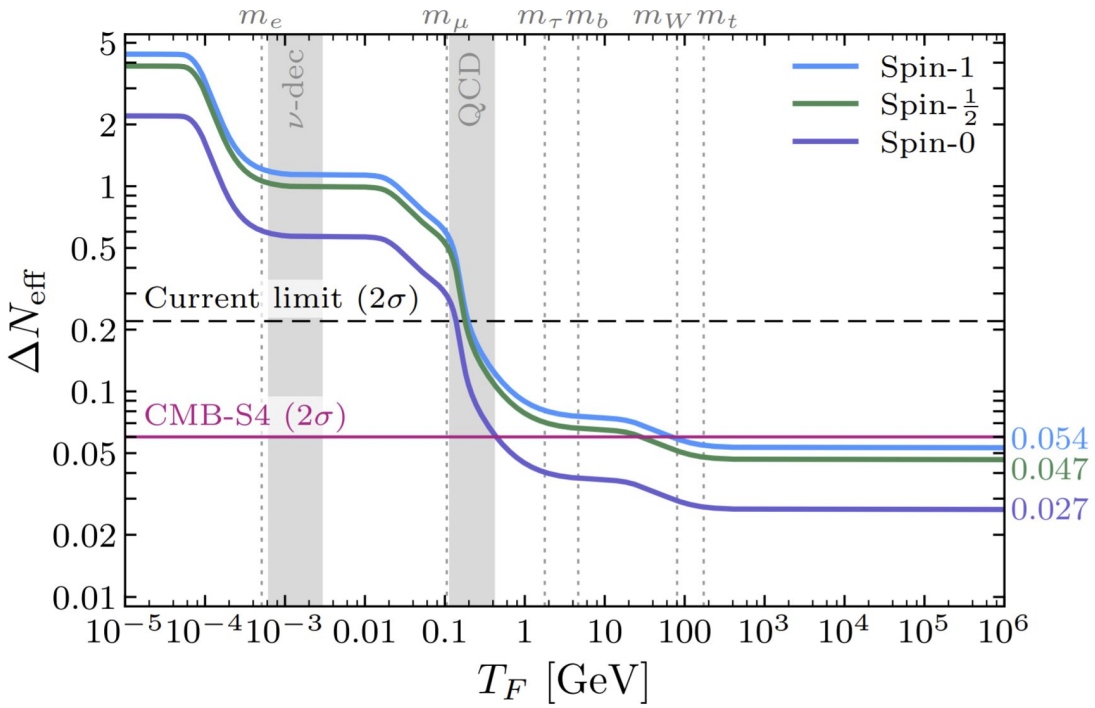
CMB-S4 Target

$$\Delta N_{\rm eff} \leq 0.060\ (95\%)$$

CMB-S4

Planck (1807.06209), CMB-S4 DSR (1907.04473)

Thermal Relic Freezeout

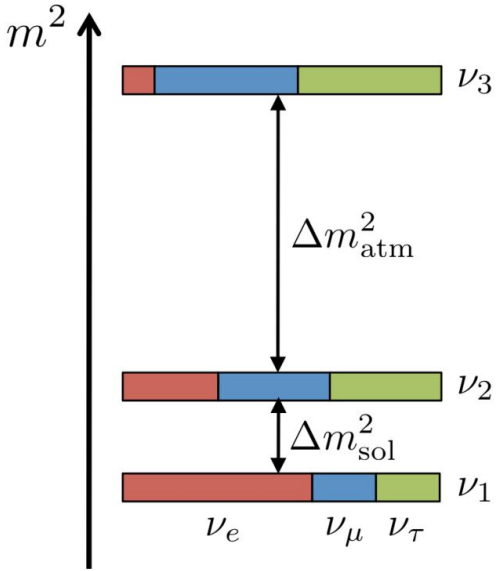


$$\Delta N_{\rm eff} = \frac{4}{7} g_s \left(\frac{43/4}{g_\star(T_{\rm F})} \right)^{4/3}$$

CMB-S4 DSR (1907.04473), Green, Amin, JM, Wallisch (1903.04763)

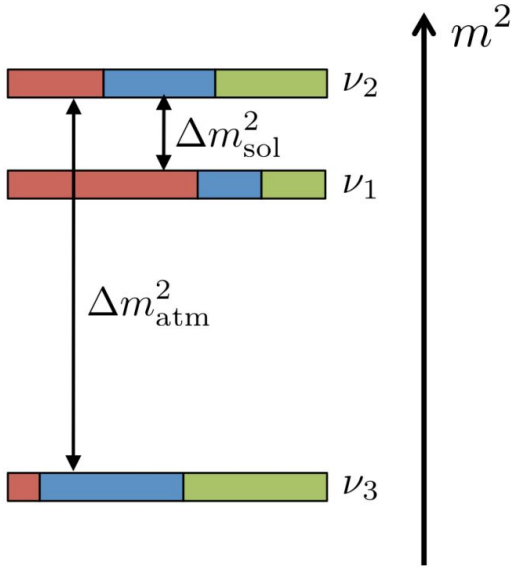
Neutrino Mass

normal hierarchy (NH)



$$\sum m_\nu \gtrsim 58 \text{ meV}$$

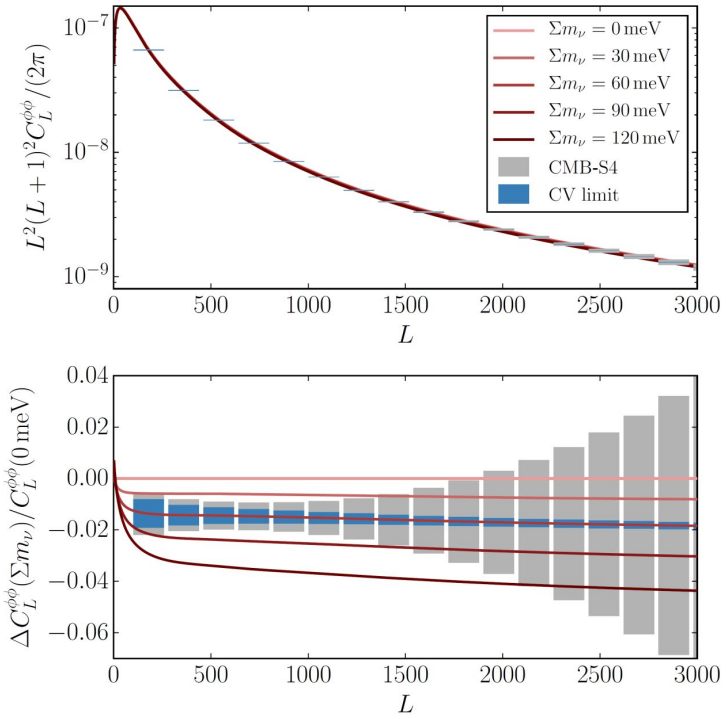
inverted hierarchy (IH)



$$\sum m_\nu \gtrsim 105 \text{ meV}$$

CMB-S4 Science Book (1610.02743)

Effect of Neutrino Mass on CMB Lensing



CMB-S4
Forecast

$$\sigma\left(\sum m_\nu\right) \simeq 20\ \mathrm{meV}$$

Limited by
Optical Depth
Degeneracy

CMB-S4 Science Book (1610.02743)

Summary

- CMB-S4 will measure the primary CMB spectra and the CMB lensing spectrum at exquisite precision allowing for broad insights into dark sector physics
- Cosmic neutrinos provide a useful example of early universe relics within the Standard Model
- Any particles with sufficiently strong coupling to Standard Model particles are abundantly produced in the early universe and leave observable imprints on the CMB due to gravitational effects
- Join parallel session for a broader discussion of CMB probes of the dark sector!

Parallel Session Agenda

- Cosmological Constraints on Light (but Massive Relics) - Linda Xu
- CMB-S4 Gatekeeper of Dark Complexity - David Curtin
- CMB and BBN Constraints on Light Thermally Coupled WIMPS - Rui An
- Modulating Fields and the CMB - JiJi Fan
- Probing Axion Couplings to Matter with N_{eff} Measurements - Benjamin Wallisch
- The Cosmic Axion Background - Nicholas Rodd

Plus lots of time for discussion