Funded by the European Union
European Research Council
Established by the European Commission
INFN Istituto Nazionale di Fisica Nucleare

External constraints on matter components

Massimiliano Lattanzi - INFN Ferrara

CosmoForward Meeting, Feb 10th, 2026, Tenerife

external → non cosmological (mostly lab)

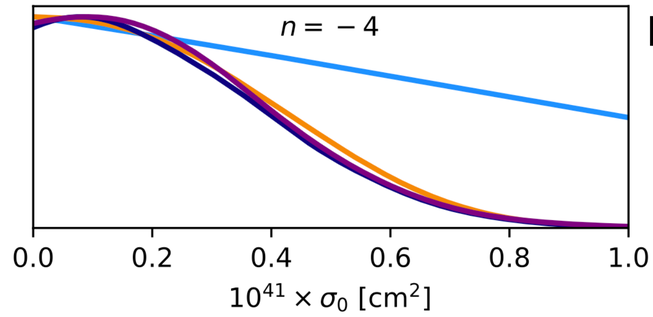
matter components → dark matter, light relics

- Many dark matter and light relics candidates. External constraints depend on the model.
- Choice of models is arbitrary and somehow dictated by my taste/interests.
- (which does not necessarily means things I have worked on)
- Comparison between cosmology and laboratory (or astrophysical) constraints usually requires assumption - I will do my best to made them explicit

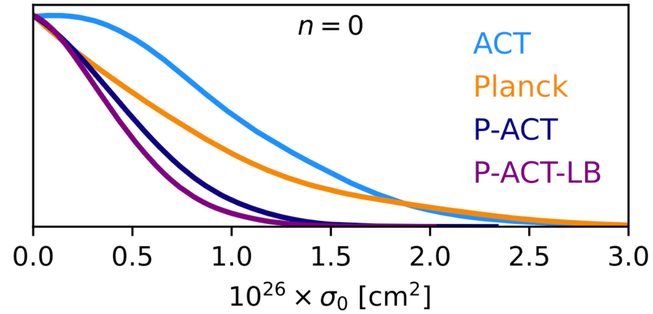
DM-baryon interactions

Dark matter - baryon interactions

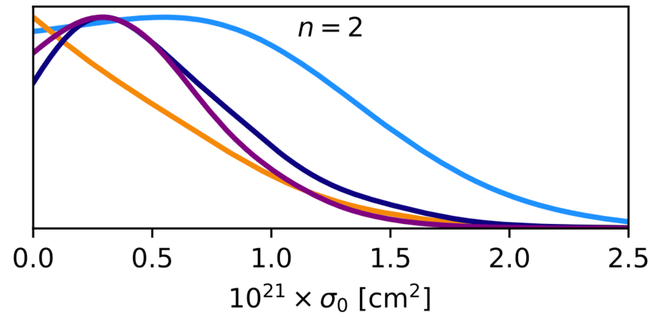
- Cross section $\sigma = \sigma_0 \mathrm{v}^n$
- Cosmology typically sensitive to momentum transfer
  $R \propto \sigma_0 (m_{\mathrm{DM}} + m_H)^{-1} f_n(T_X/m_X, T_b/m_b)$
- DM inertia in acoustic oscillations, suppression of small-scale structure
- Analysis typically restricted to masses < 1 GeV to avoid direct detection constraints
- m_{DM}=1MeV in the plots on the right



Millicharged DM (Coulomb)



"WIMP" (contact)



?

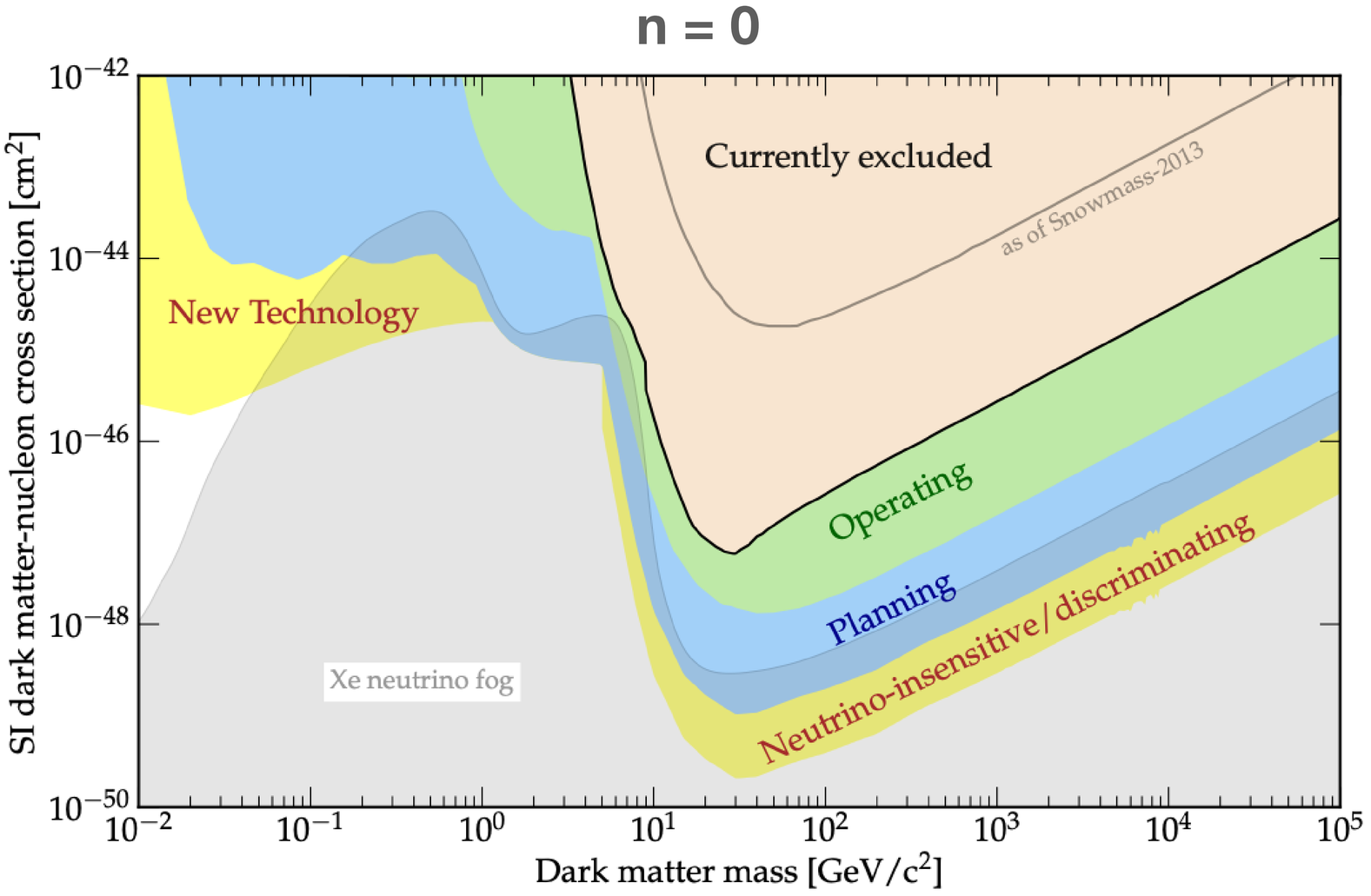
plot from Calabrese et al. (ACT coll) arXiv 2503.14454

Direct detection of dark matter

- Exploits large detector masses and long exposure times to detect DM-nucleon scattering
- Measures target recoil energy
- Nuclear recoil energy becomes undetectable for m_{DM} below ~1 GeV…
- … but electron recoils can probe smaller masses
- Sensitivity goes like $1/m_{DM}$ (for fixed DM density)

Direct detection of dark matter

Current constraints and future sensitivity

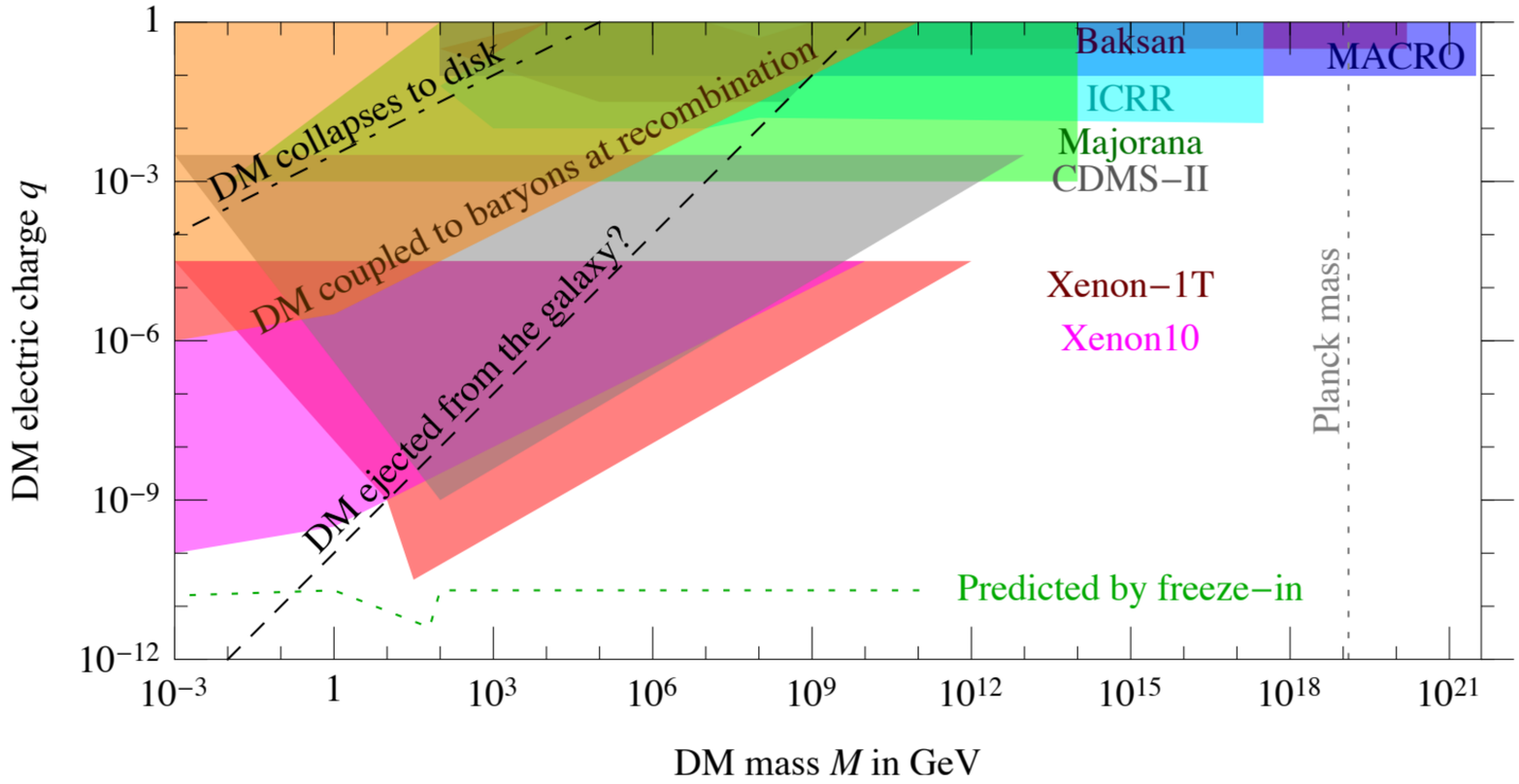


plot from Yu, arXiv 2506.05234

Direct detection of dark matter

Milli-charged DM

n = -4

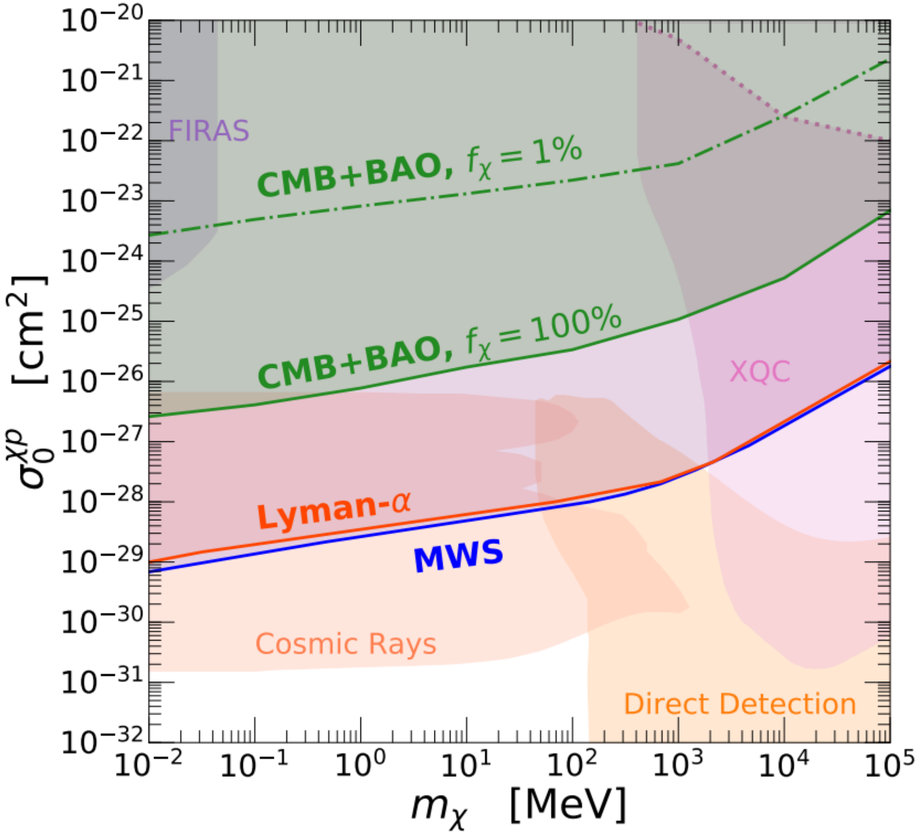


Cirelli et al. arXiv 2406.01705

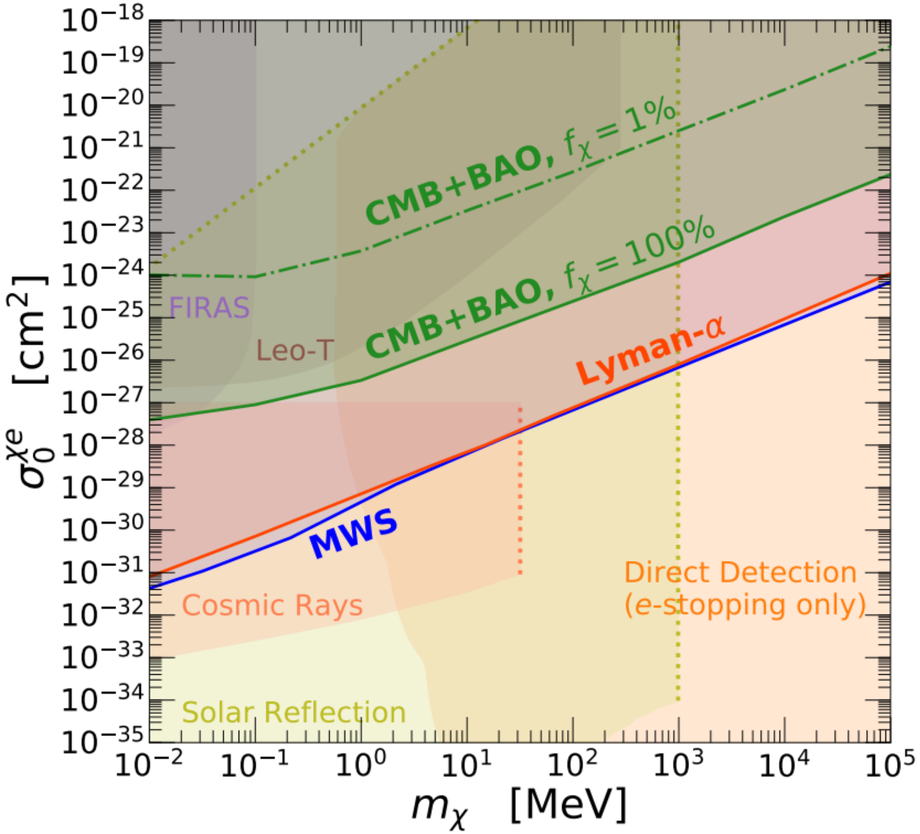
DM-baryon interactions

Constraints for velocity independent (n=0) interactions

nucleons



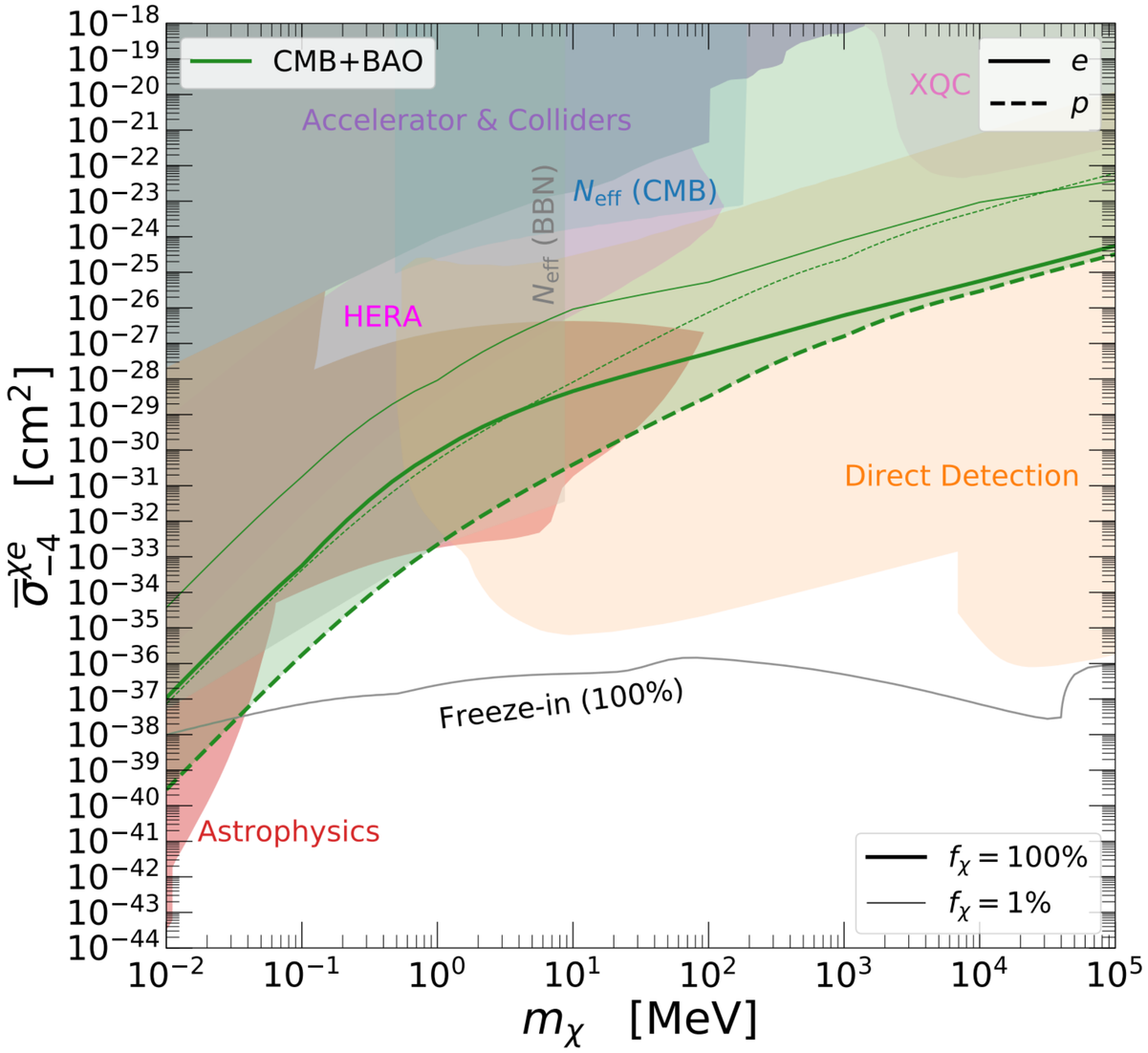
electrons



Buen-Abad et al., arXiv 2107.12377

DM-baryon interactions

Constraints for Coulomb-like (n=-4) interactions



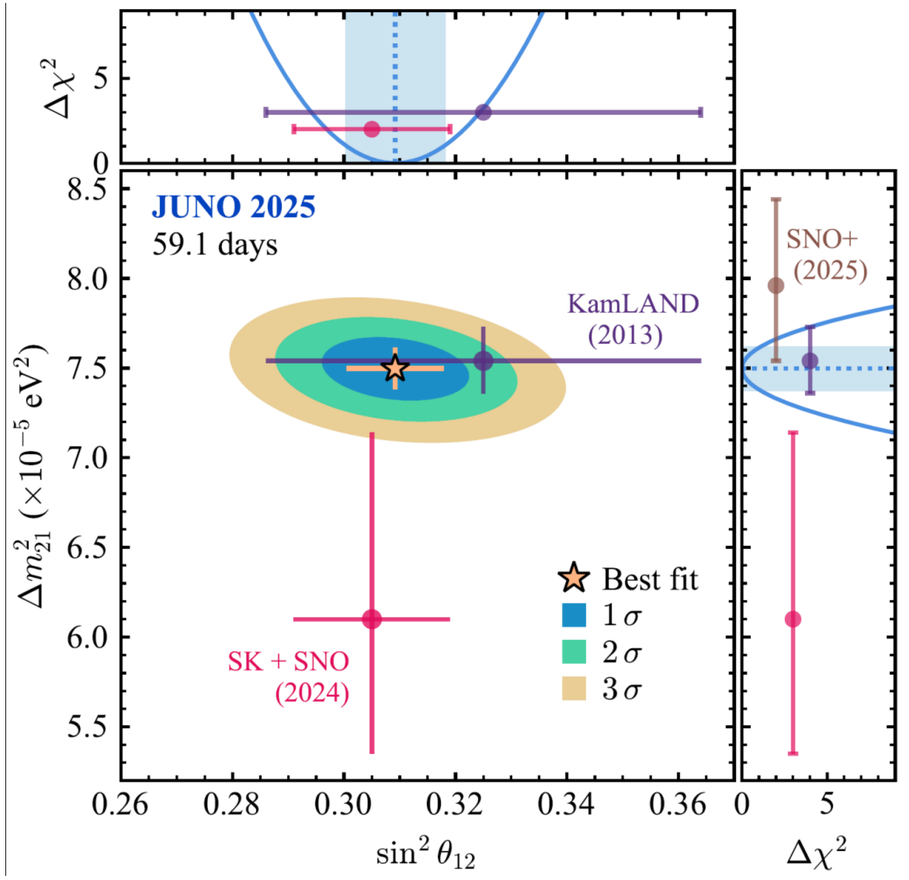
Light mediator n = -4

Buen-Abad et al., arXiv 2107.12377

Active neutrinos in the SM

Neutrino properties

- In the SM, neutrino sector is described by 3 masses and a mixing matrix (3 angles, 1 + 2 phases)
- Flavour oscillation experiments precisely measure (squared) mass differences and mixing angles (5 parameters)
- Still unknown: mass ordering, Dirac phase, absolute mass scale, Dirac vs Majorana

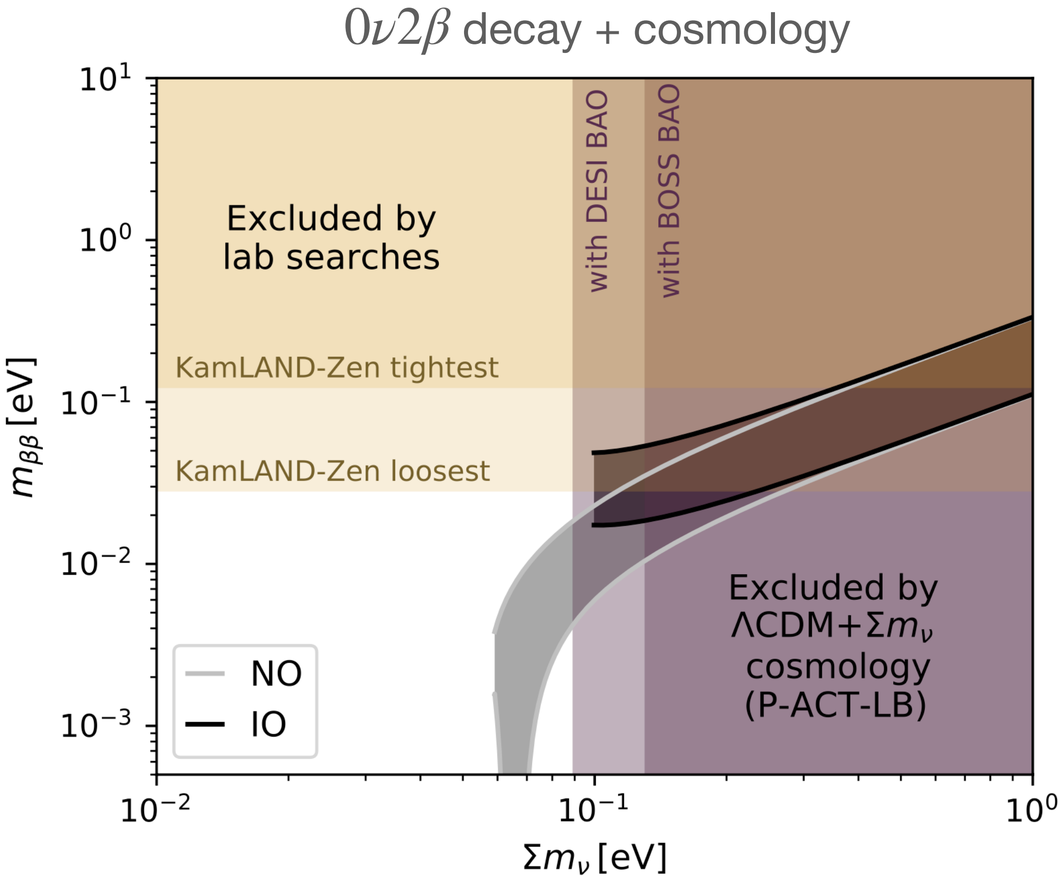


Juno collaboration, arXiv 2511.14593

Neutrino mass parameters: present status

3 ways to probe the absolute mass scale (measure different combinations of the masses and mixing angles)

- “standard” (single) beta decay: less sensitive but very robust
- neutrinoless double decay: requires neutrino to be a Majorana particle, nuclear physics uncertainties, model dependent
- cosmology: model dependent (e.g. dynamical DE; nonzero curvature; but please *not* Alens)



+ single β (KATRIN): $\Sigma m_\nu \leq 1.35\,\mathrm{eV}$

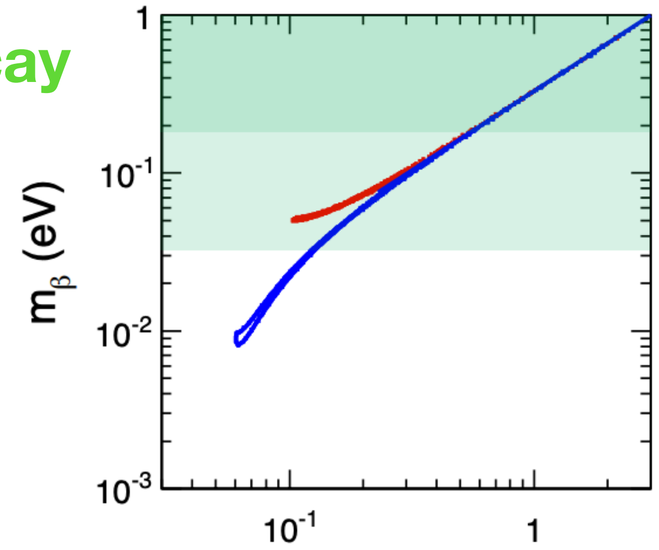
plot from Calabrese et al. (ACT coll) arXiv 2503.14454

Neutrino mass parameters: future (5-10yrs) sensitivities

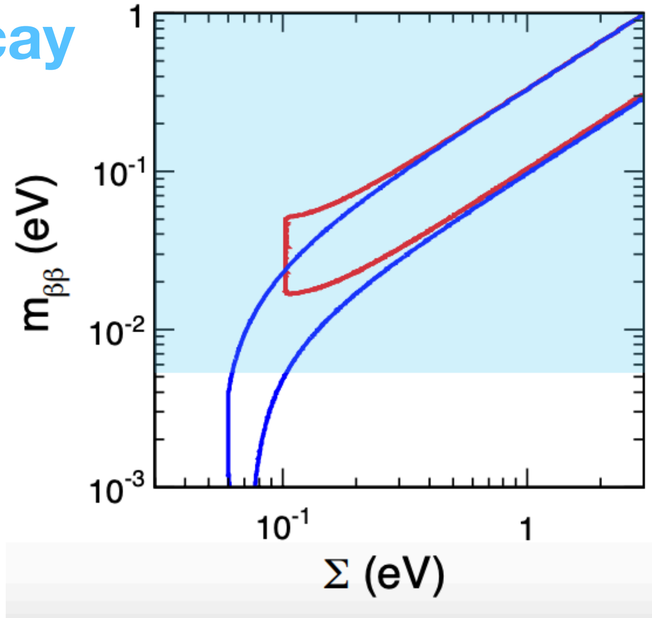
Great way to cross-check: basically 3 observables for 1 parameter

- An inconsistency in m_β vs Σm_ν would likely point to a problem with cosmology
- An inconsistency in $m_{\beta\beta}$ vs Σm_ν might originate from both cosmology and/or $0\nu2\beta$

β decay



$0\nu2\beta$ decay

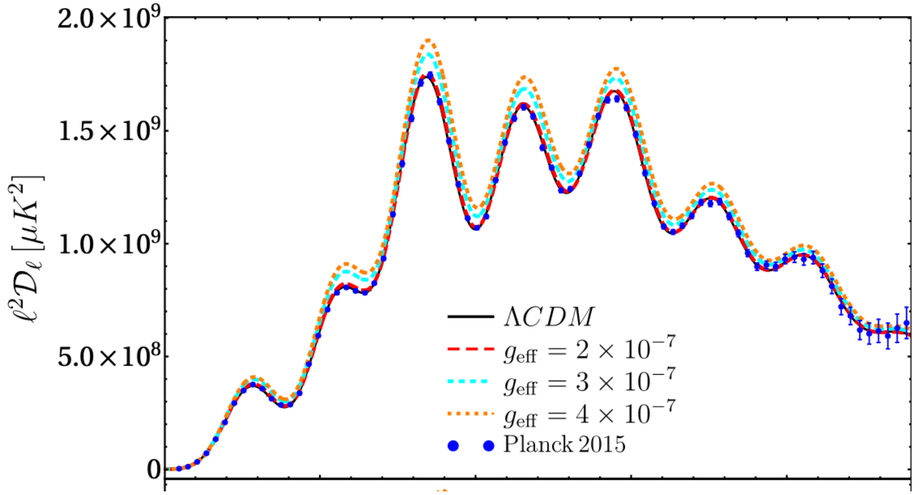


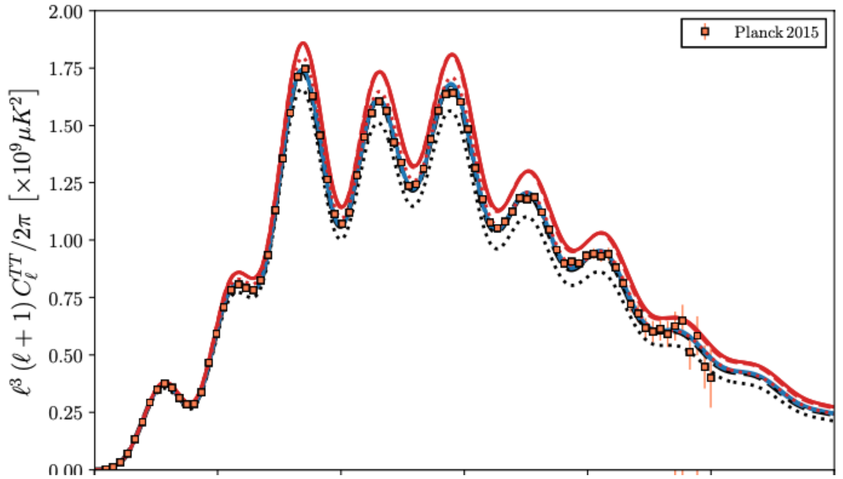
Plots courtesy E. Lisi from Capozzi et al. arXiv 2503.07752
See also Snowmass white paper on synergy between cosmology and laboratory probes of neutrino masses
Gerbino, Grohs, Lattanzi (editors) et al., arXiv 2203.07377

Active neutrinos and BSM physics

Neutrino non-standard interactions (vNSI)

- Arise in a variety of particle physics models (e.g. Majoron models)
- Controlled by dimensionless coupling g
- In principle, coupling can be flavor-dependent and couple different flavors
- Can induce neutrino-neutrino scattering in cosmological settings
- Cosmology effectively constraints the scattering rate
- Boost+shift over a range of scales



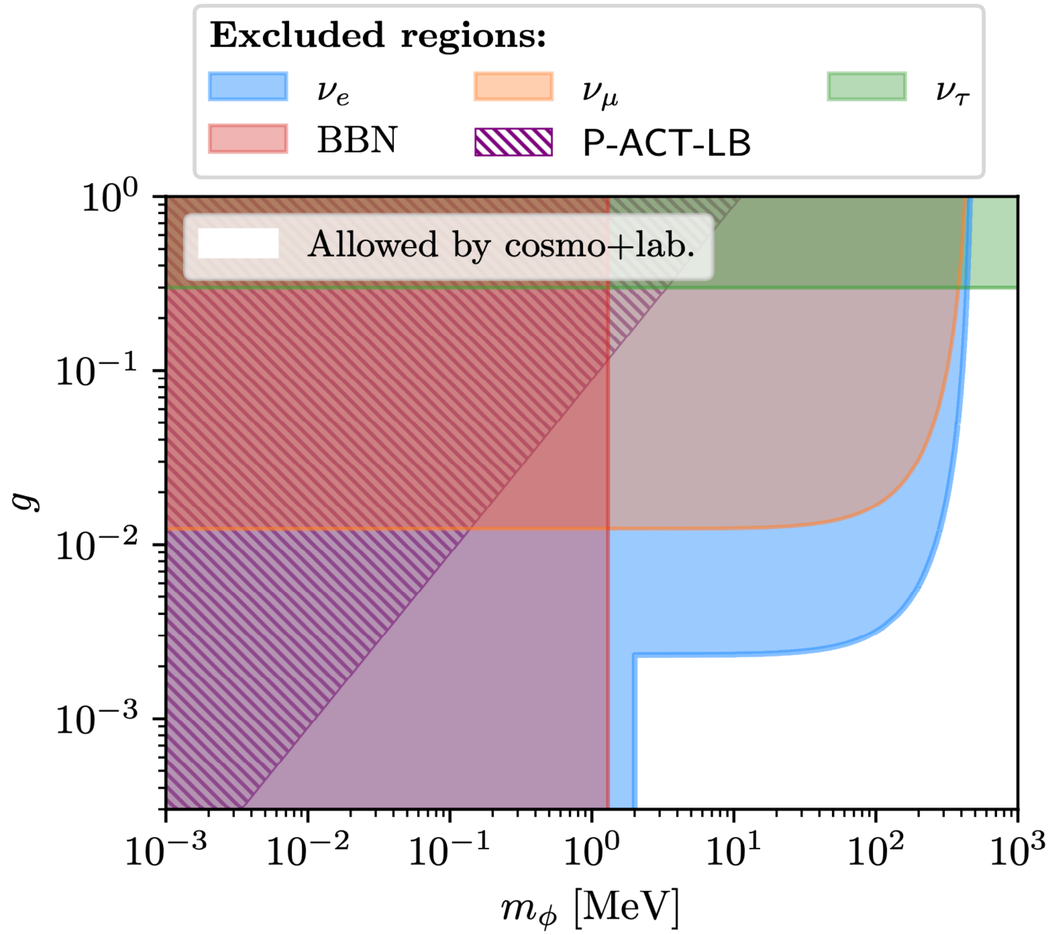


Plot from Forastieri et al., arXiv 1904.07810

Neutrino non-standard interactions (vNSI)

Heavy mediator

- Scattering rate $\Gamma \propto \left(g/m_X\right)^4 T^5$
- Can be constrained by
  - neutrinoless beta decay
  - rare decays of heavy mesons and leptons
- Lab bounds are flavor-dependent

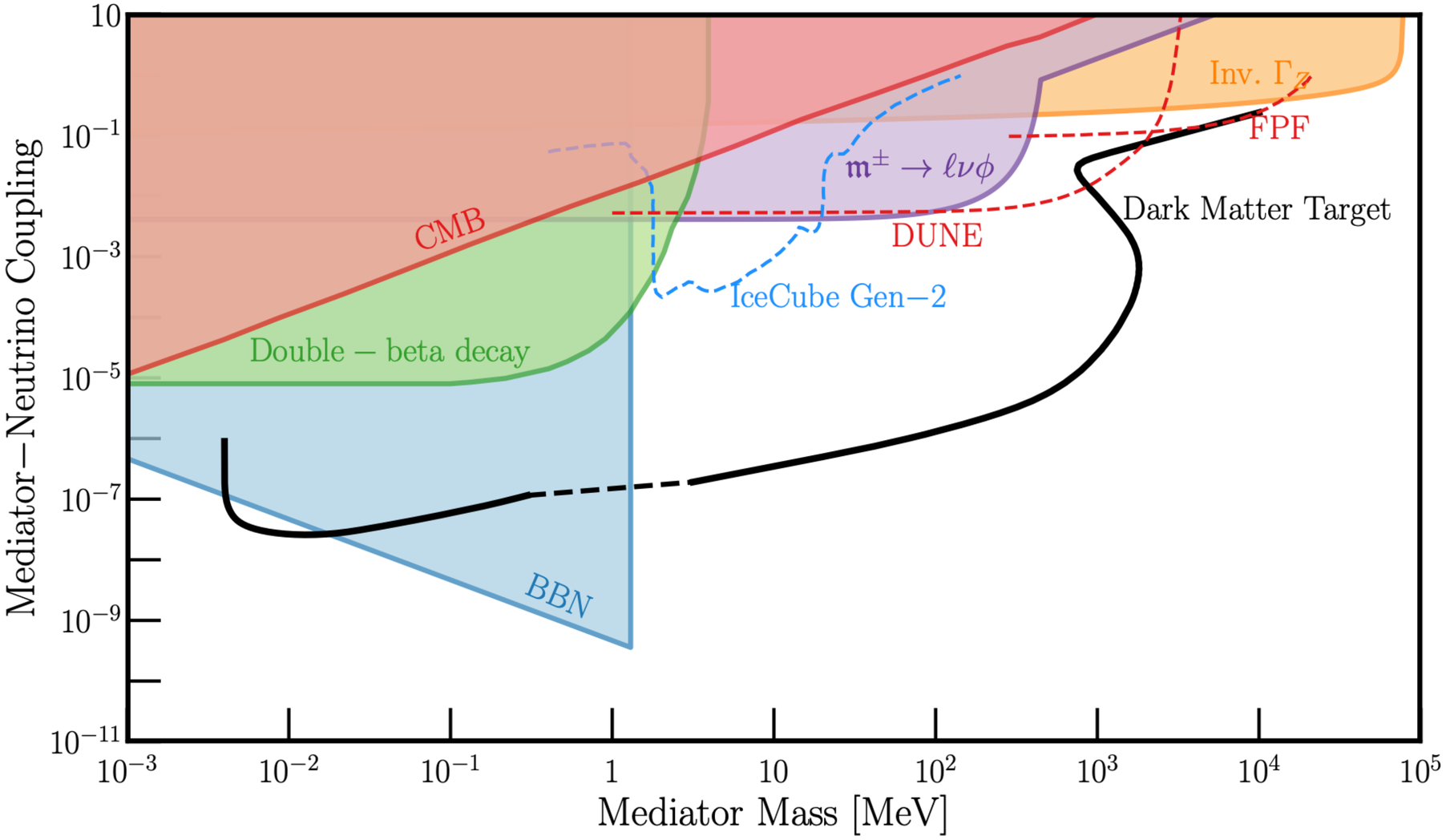


plot from Calabrese et al. (ACT coll) arXiv 2503.14454

Neutrino Self-Interactions: A White Paper

Snowmass white paper on neutrino self-interactions
arXiv:2203.01955

Editors: Nikita Blinov, Mauricio Bustamante, Kevin J. Kelly, Yue Zhang

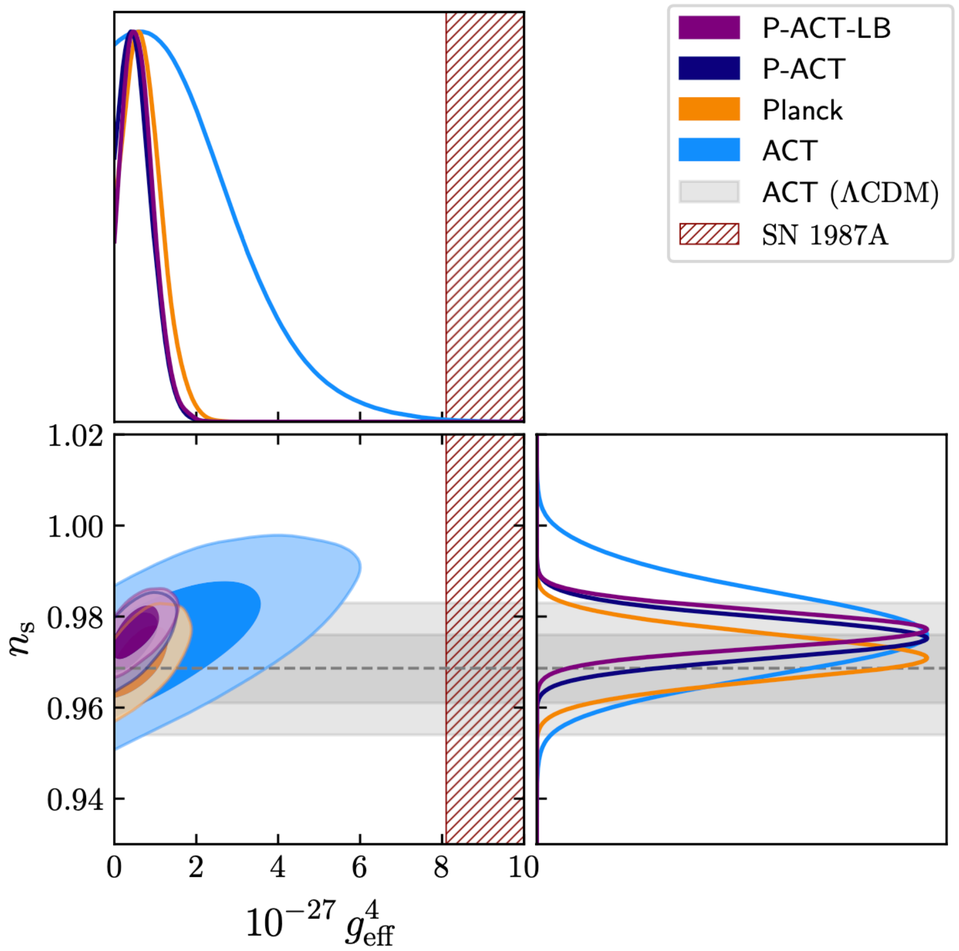


(plot assumes universal coupling)

Neutrino non-standard interactions (vNSI)

Light mediator

- Scattering rate $\Gamma \propto g^4 T$
- Can be constrained by
  - neutrinoless beta decay (for electron neutrinos, $|g_{ee}|$ < (0.4-0.9)x 10^{-5})
  - core-collapse SN - see plot

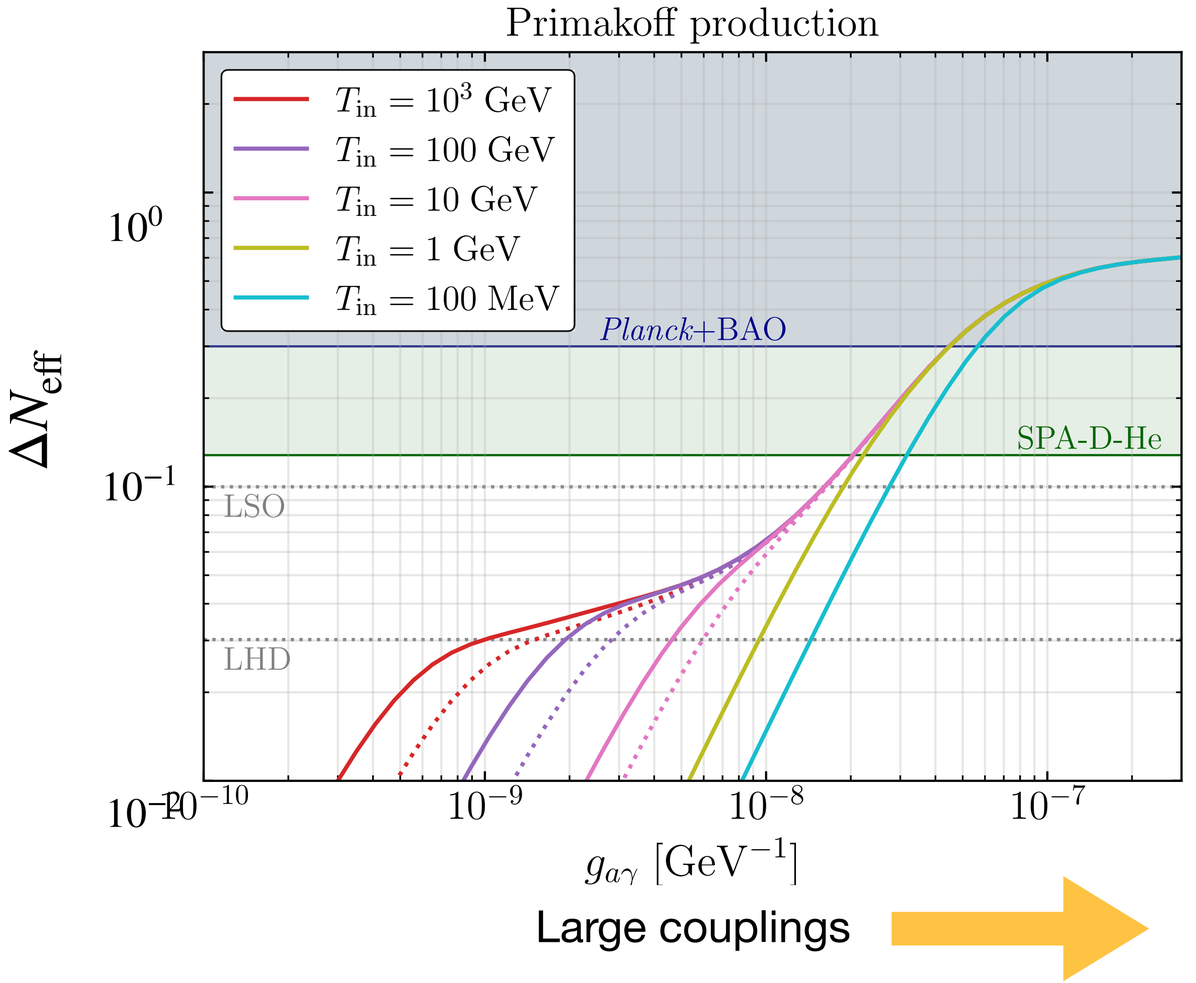


plot from Calabrese et al. (ACT coll) arXiv 2503.14454

Axion-like particles (ALPs)

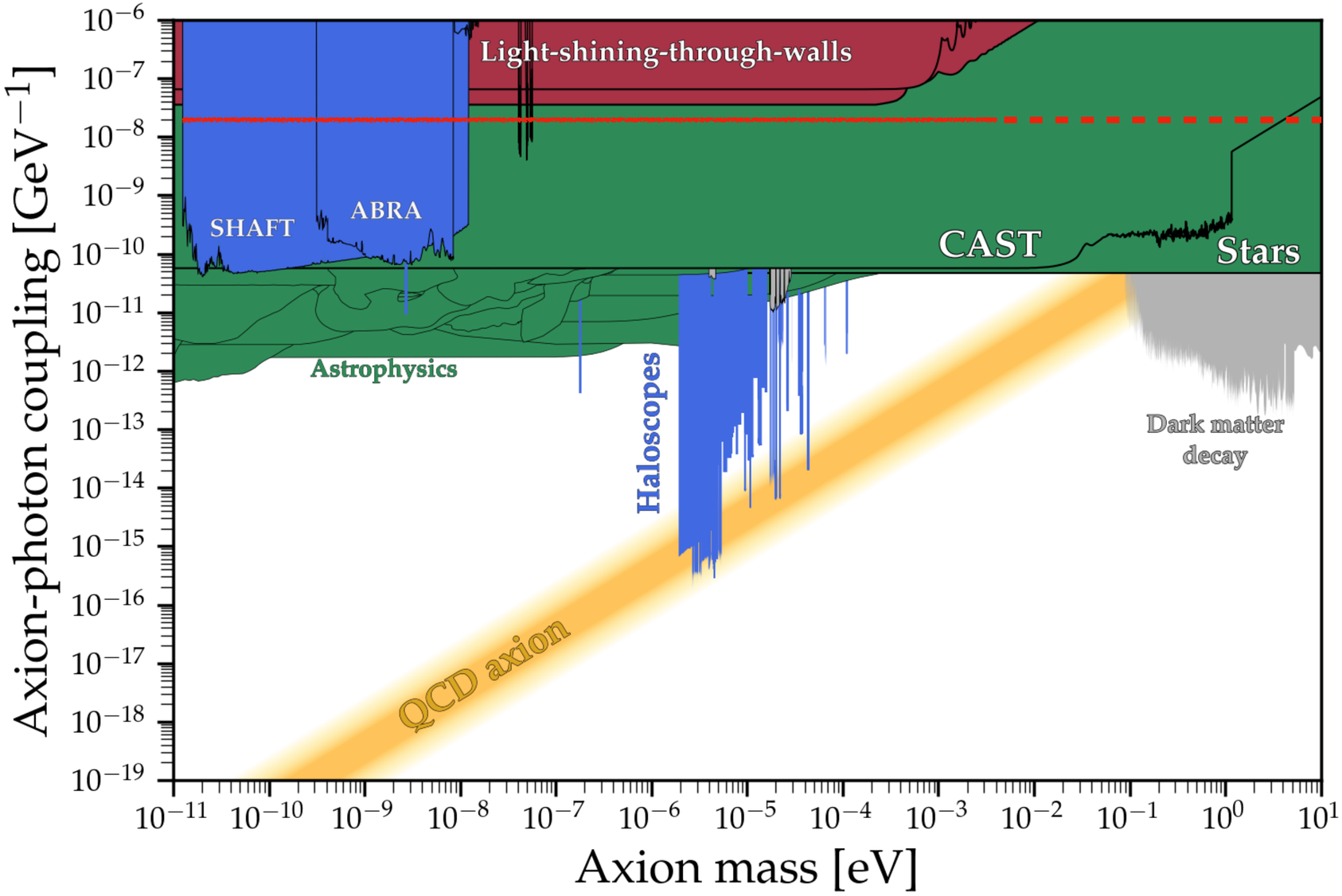
ALPs

- ALPs can be produced in the early Universe through their interaction e.g. with photons or leptons…
- … giving a contribution to Neff



Barbieri et al. , to appear **very** soon

Constraints on ALPs-photon coupling

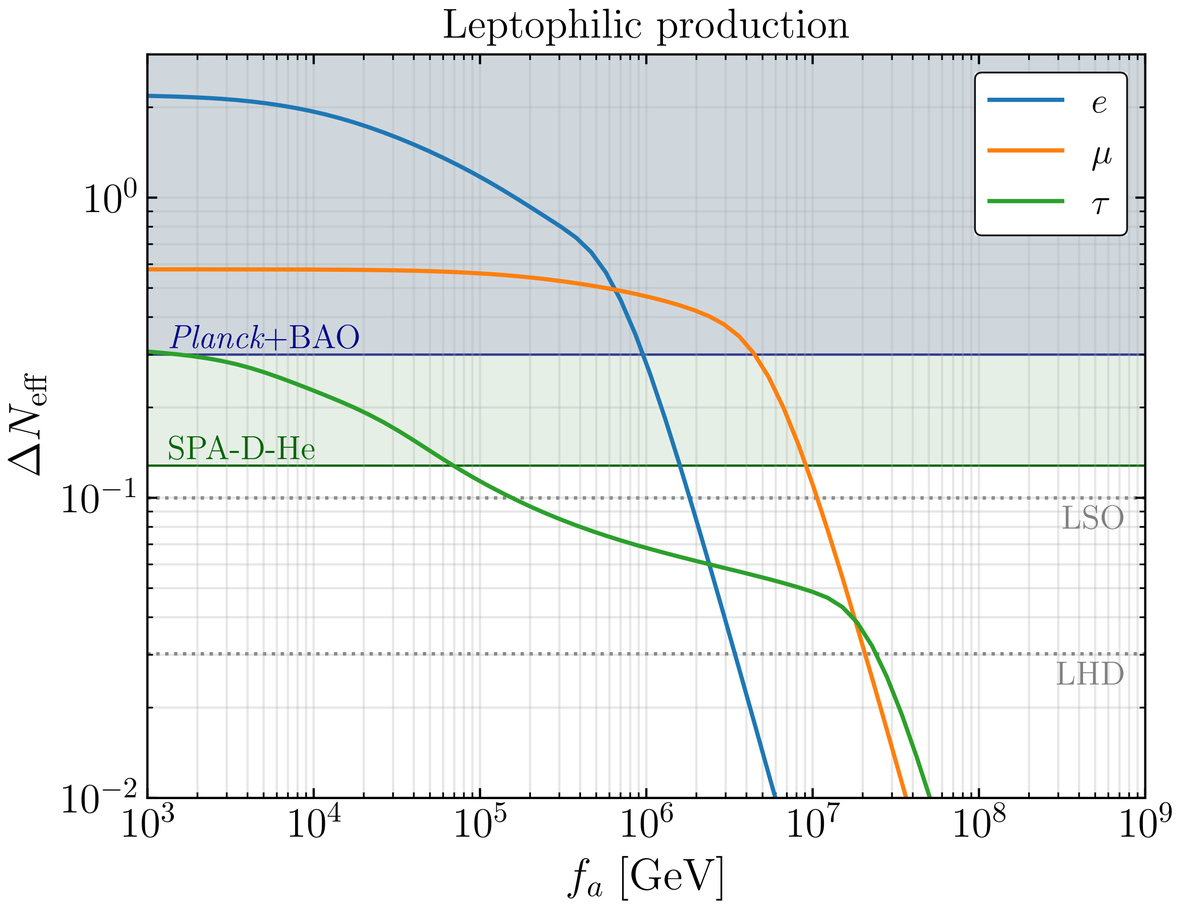


Current CMB + BBN
See Caloni et al
arXiv:2205.01637;
Barbieri et al to appear **very** soon.

plot produced from https://cajohare.github.io/AxionLimits/

ALPs

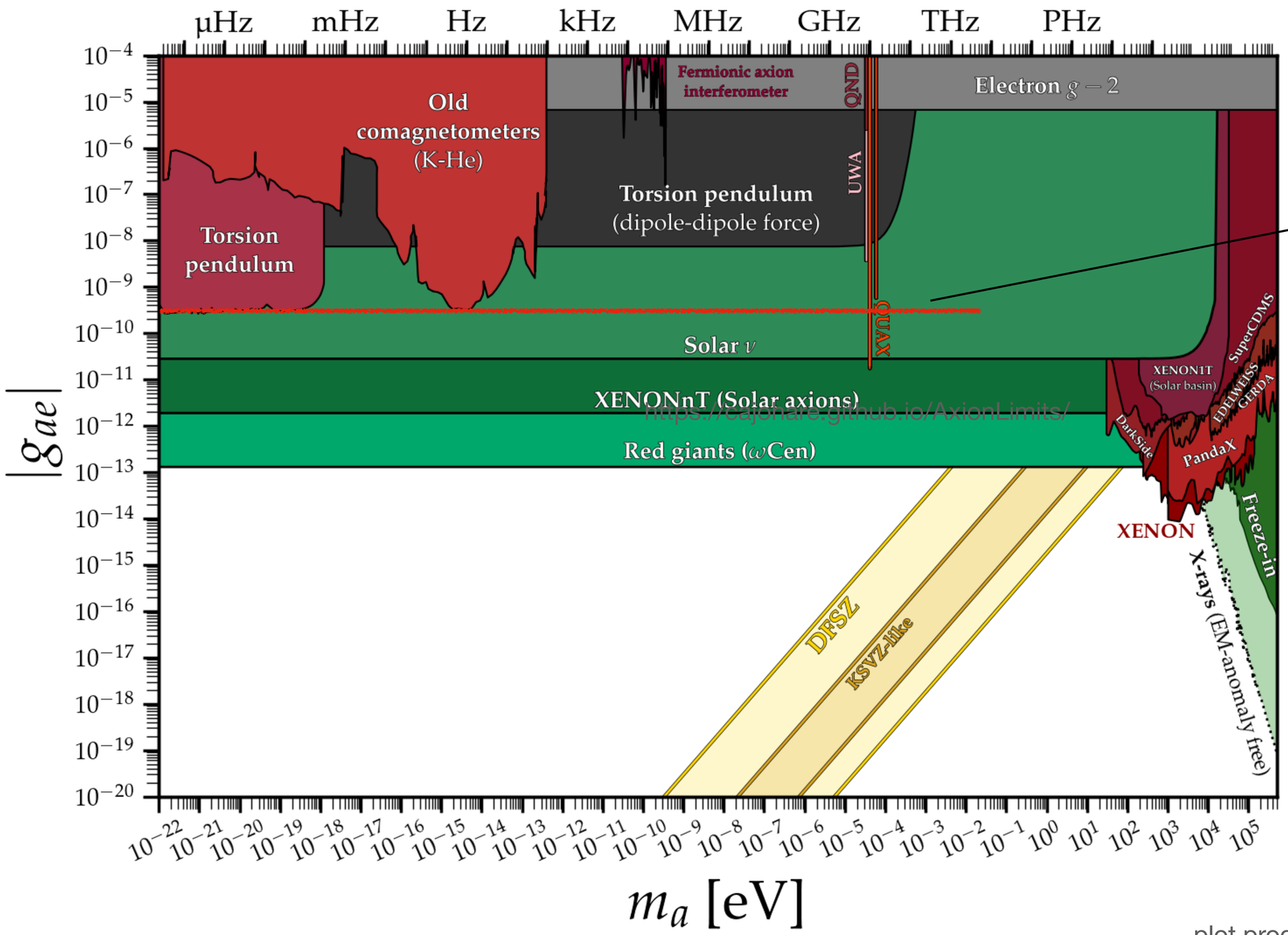
- ALPs can be produced in the early Universe through their interaction e.g. with photons or leptons…
- … giving a contribution to Neff



Large couplings

Barbieri et al. , to appear **very** soon

Constraints on ALPs-electron coupling



Current CMB + BBN
Barbieri et al to appear **very** soon.

plot produced from https://cajohare.github.io/AxionLimits/

Thank you!