NEUTRINO PROPERTIES FROM COSMOLOGY

Cosmology 2018 in Dubrovnik
26 October 2018

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Neutrino cosmology

BOOKS:

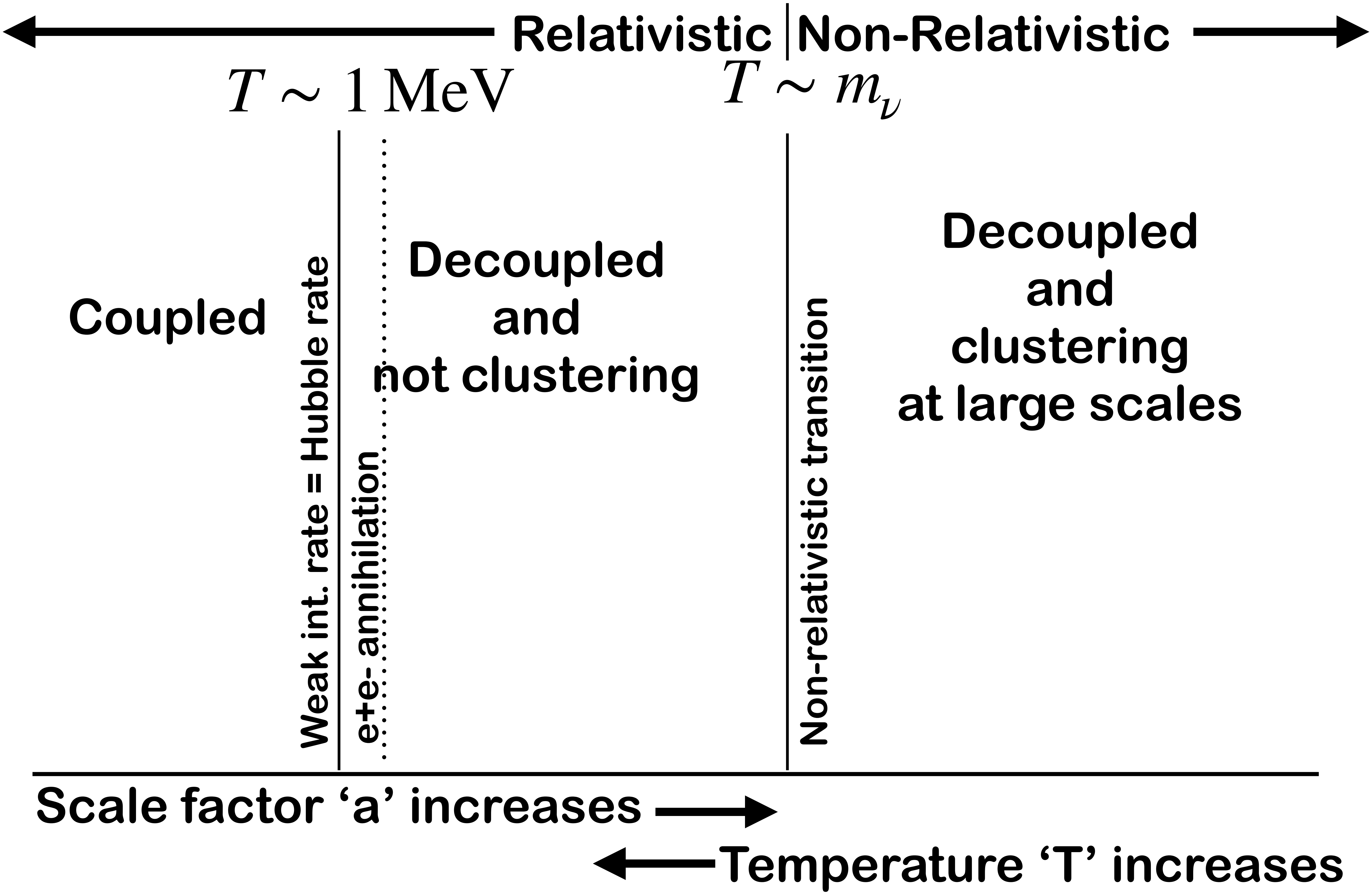
- Lesgourgues, Mangano, Miele, Pastor, 'Neutrino Cosmology', Cambridge U.Press, 2013
- Giunti&Kim, 'Fundamentals of Neutrino Physics and Astrophysics', Oxford U. Press, 2007

REVIEWS:

- Gerbino&Lattanzi, 2017
- PDG Review on Neutrinos, Lesgourgues&Verde, 2017
- Wong, 2011
- Lesgourgues&Pastor, 2006
- …

This talk based on work with S.Vagnozzi, E.Giusarma, M.Lattanzi, O.Mena, S.Ho, K.Freese, Planck collaboration, SO collaboration

Basics of neutrino cosmology



Basics of neutrino cosmology

Relativistic Non-Relativistic

T~m_nu

$$\rho_\nu \propto N_{\rm eff}$$

$$\rho_\nu \propto \Sigma m_\nu$$

$$N_{\rm eff} = \frac{\rho_{\rm rad} - \rho_\gamma}{\rho_\nu^{\rm st}} = 3.045$$

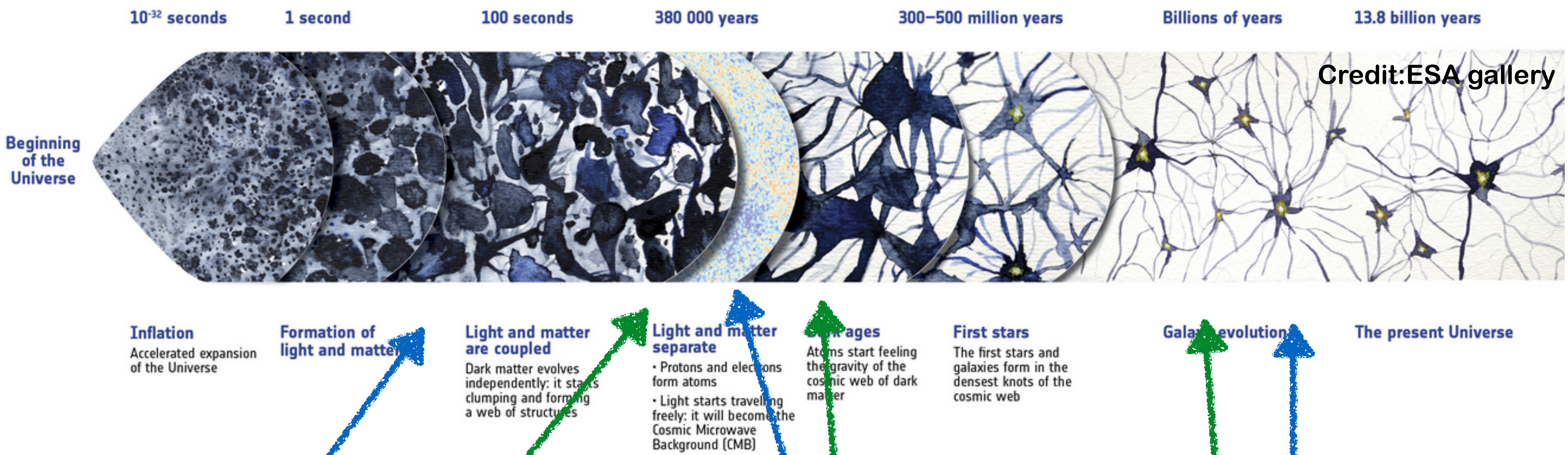
$$\Sigma m_\nu = \Sigma_{i=1,2,3} m_{\nu,i}$$

Distorsions due to non-inst decoupling
radiative corrections,
flavour oscillations
Dolgov, 1997, Mangano+,2005
deSalas&Pastor,2016

Scale factor ‘a’ increases →

← Temperature ‘T’ increases

Basics of neutrino cosmology



Contribution to early expansion

Slow down of early growth of structures

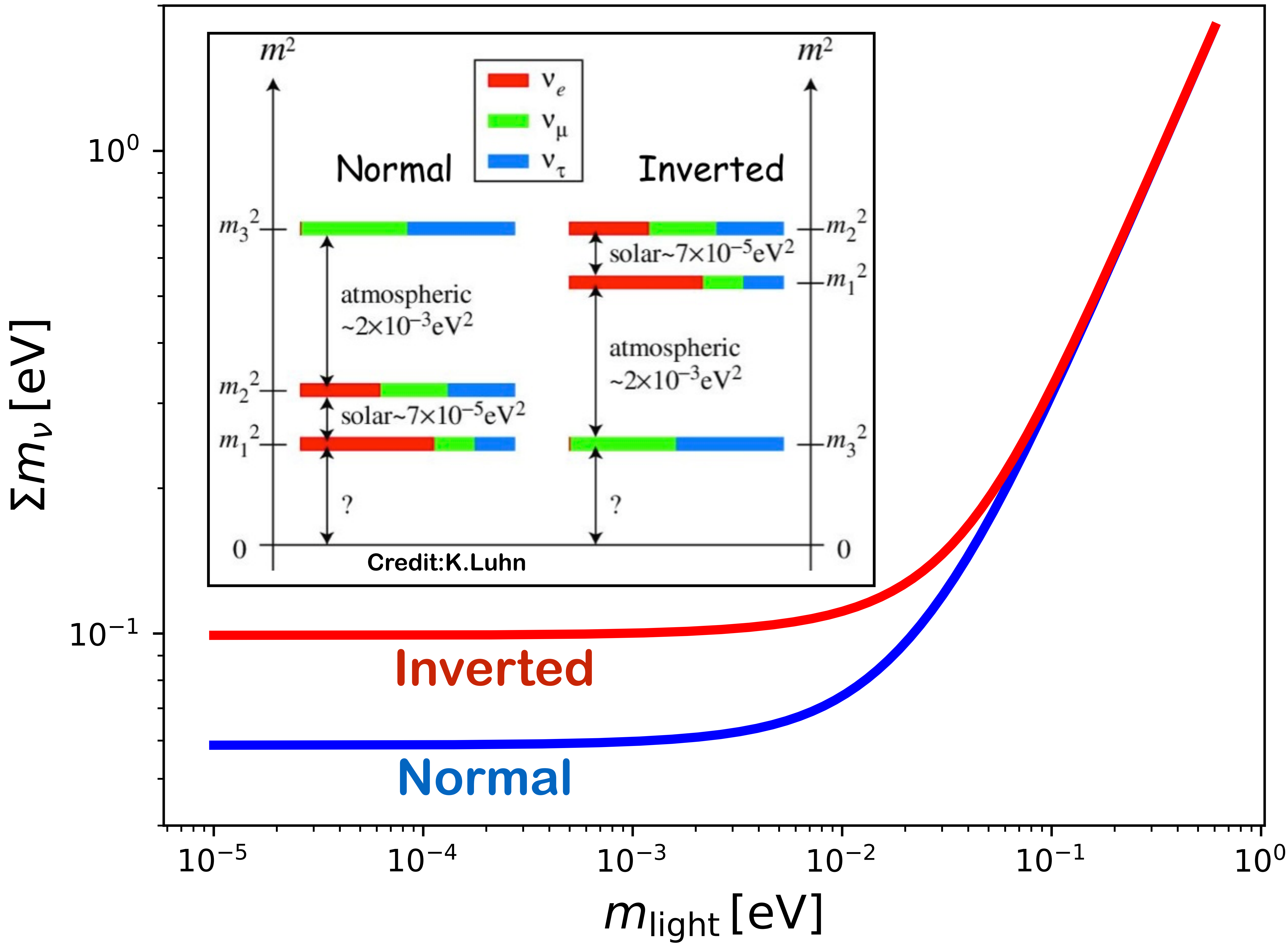
Contribution to metric fluctuations (early ISW)

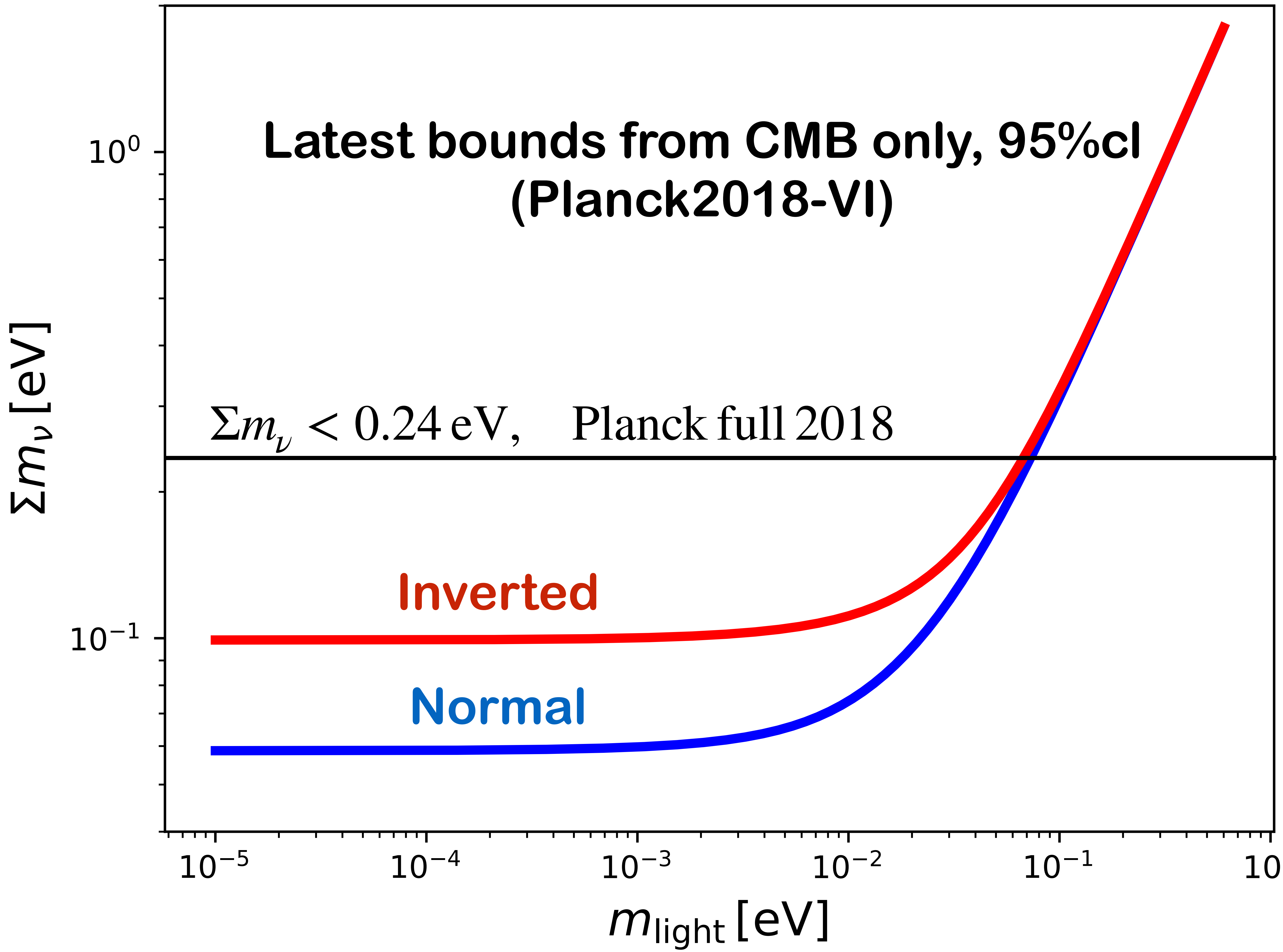
Free-streaming and power suppression

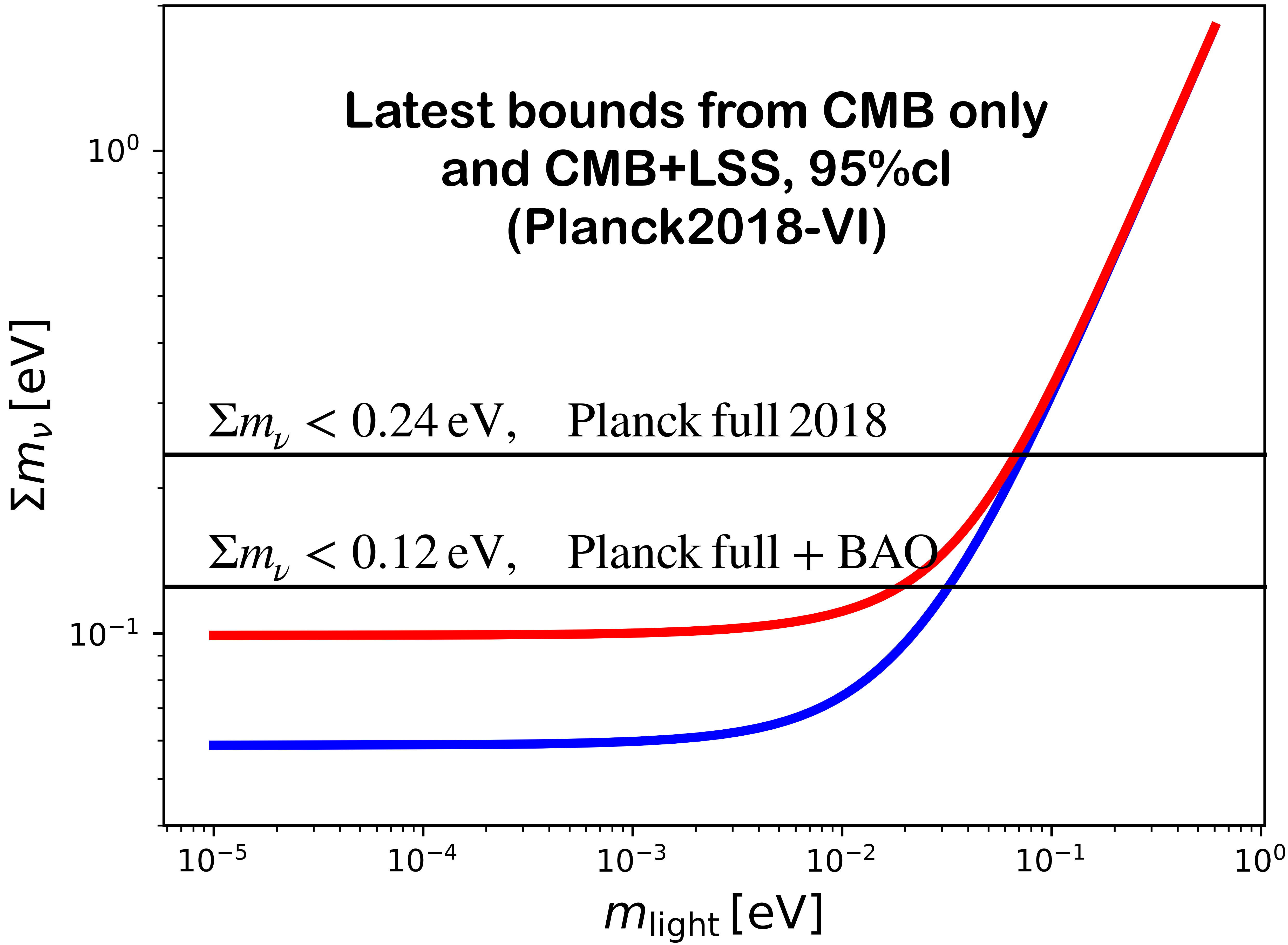
Contribution to late expansion

Slow down of late growth of structures

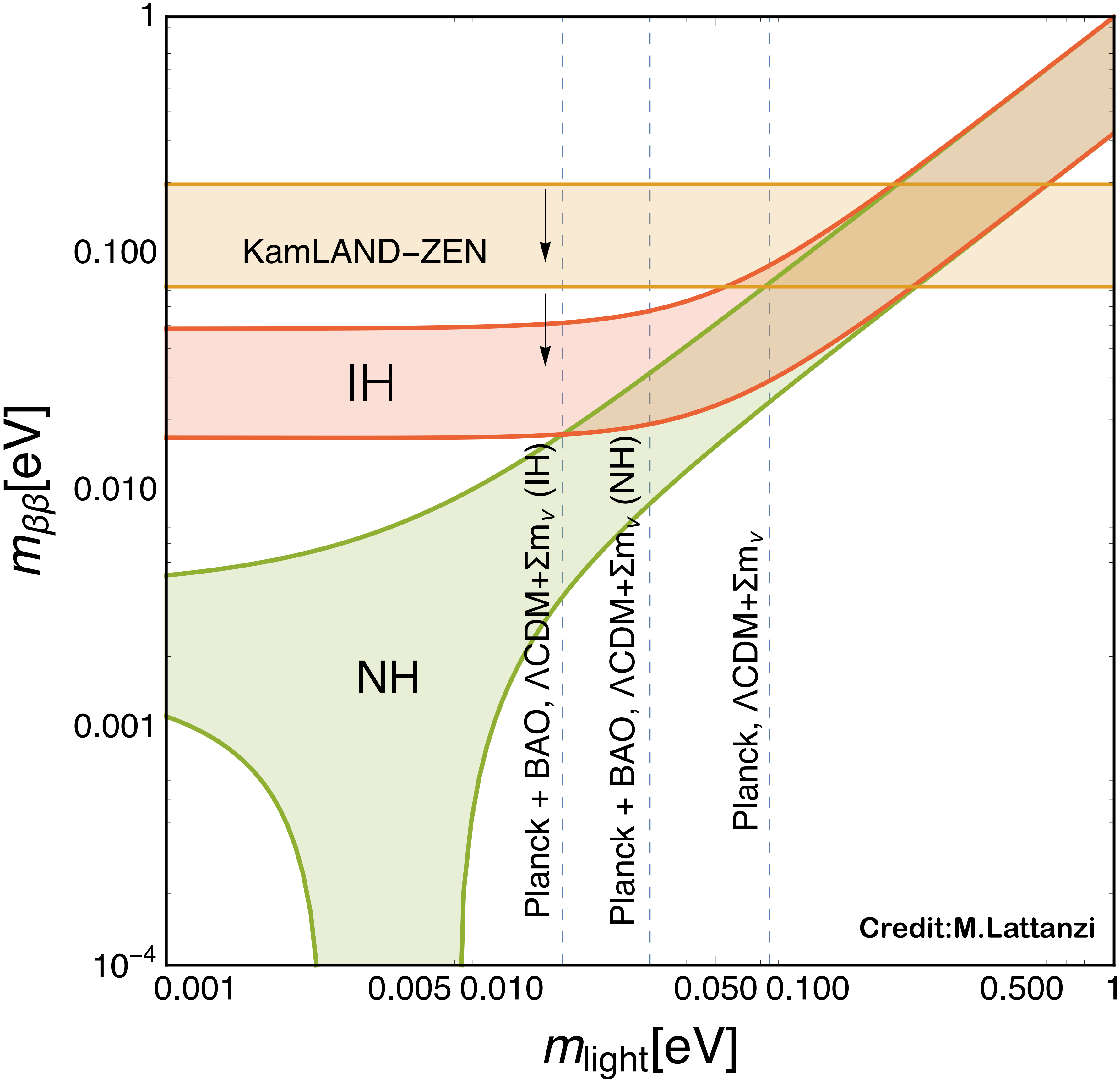
Slide adapted from J.Lesgourgues, talk@Neutrino2018


m^2
ν_e
ν_μ
ν_τ
Normal
Inverted
m_3^2
m_2^2
m_1^2
atmospheric ~2×10^{-3}eV^2
solar~7×10^{-5}eV^2
?
0
Credit:K.Luhn
Inverted
Normal
10^0
10^{-1}
Σm_ν [eV]
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
m_{light} [eV]

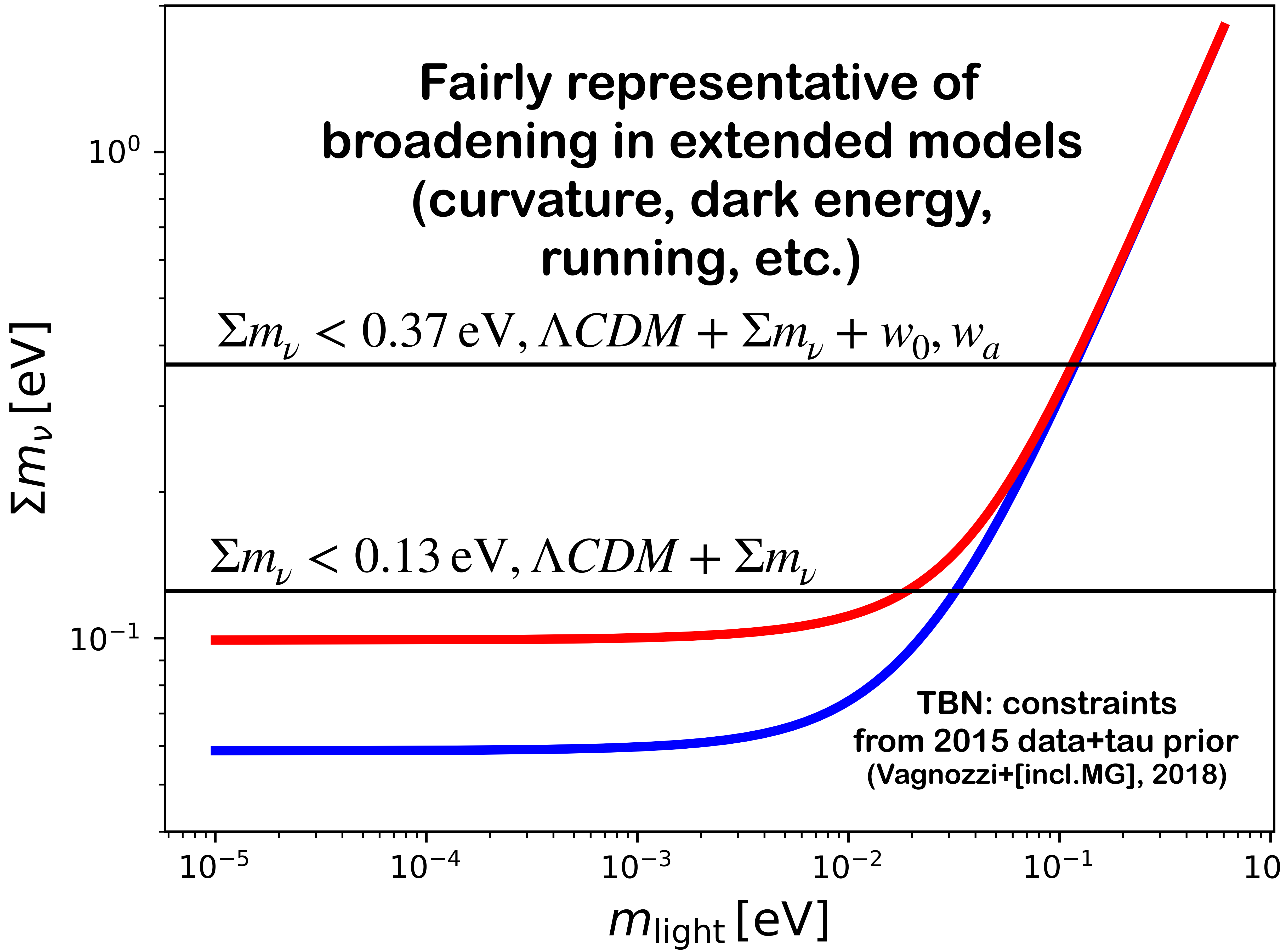

Latest bounds from CMB only, 95%cl
(Planck2018-VI)
$\Sigma m_\nu < 0.24\,\mathrm{eV}$, Planck full 2018
Inverted
Normal
10^0
10^{-1}
Σm_ν [eV]
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
m_{light} [eV]


Latest bounds from CMB only
and CMB+LSS, 95%cl
(Planck2018-VI)
$\Sigma m_\nu < 0.24\,\mathrm{eV}$, Planck full 2018
$\Sigma m_\nu < 0.12\,\mathrm{eV}$, Planck full + BAO
10^{0}
10^{-1}
$\Sigma m_\nu\,[\mathrm{eV}]$
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
$m_{\mathrm{light}}\,[\mathrm{eV}]$

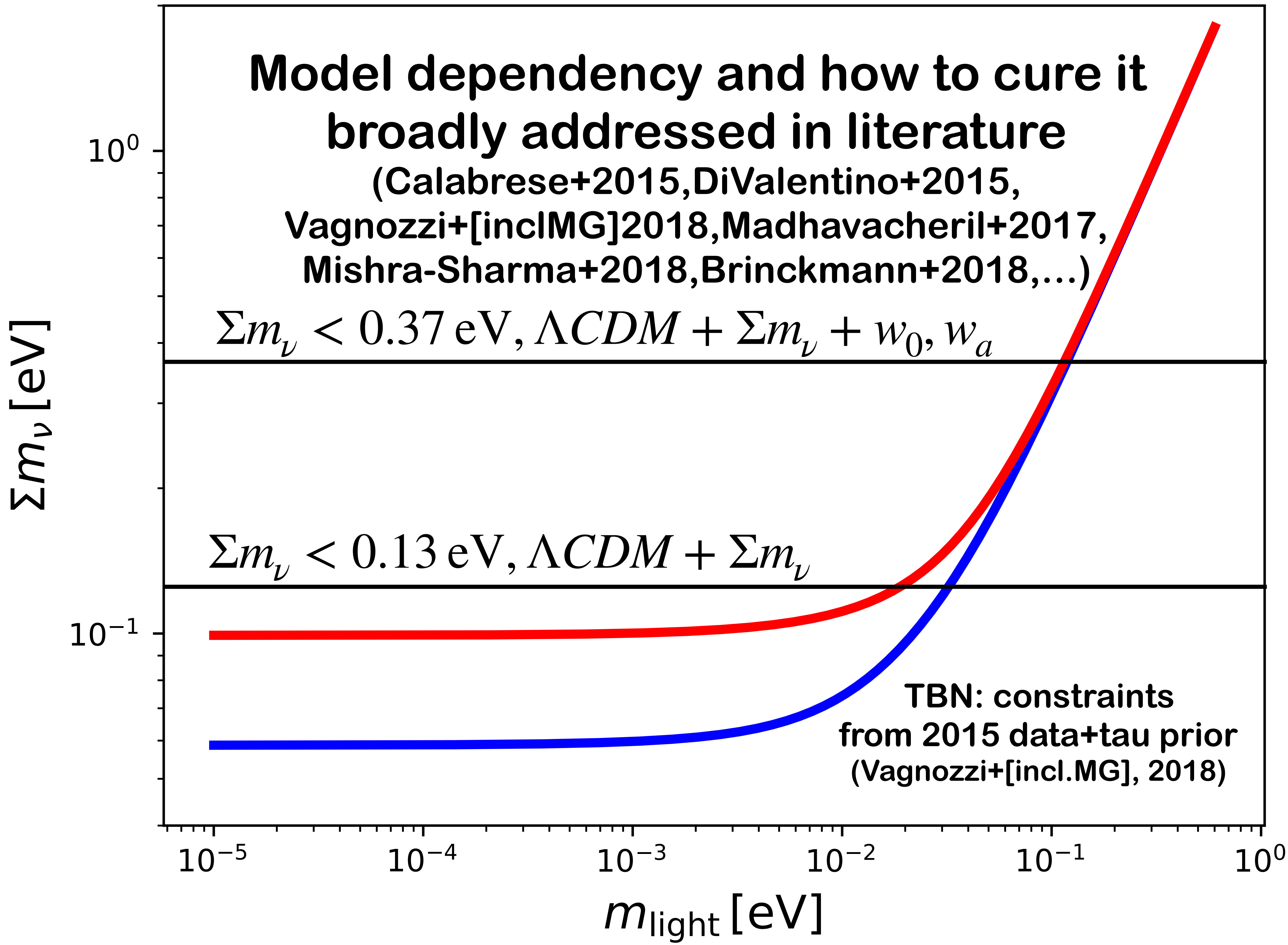
Majorana effective mass
probed by neutrinoless double-beta decay



Lightest neutrino mass state



Fairly representative of
broadening in extended models
(curvature, dark energy,
running, etc.)
$\Sigma m_\nu < 0.37\,\mathrm{eV}, \Lambda CDM + \Sigma m_\nu + w_0, w_a$
$\Sigma m_\nu < 0.13\,\mathrm{eV}, \Lambda CDM + \Sigma m_\nu$
TBN: constraints
from 2015 data+tau prior
(Vagnozzi+[incl.MG], 2018)
Σm_ν [eV]
m_{light} [eV]
10^0
10^{-1}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0



Model dependency and how to cure it
broadly addressed in literature
(Calabrese+2015,DiValentino+2015,
Vagnozzi+[inclMG]2018,Madhavacheril+2017,
Mishra-Sharma+2018,Brinckmann+2018,...)
$\Sigma m_\nu < 0.37\,\mathrm{eV}, \Lambda CDM + \Sigma m_\nu + w_0, w_a$
$\Sigma m_\nu < 0.13\,\mathrm{eV}, \Lambda CDM + \Sigma m_\nu$
TBN: constraints
from 2015 data+tau prior
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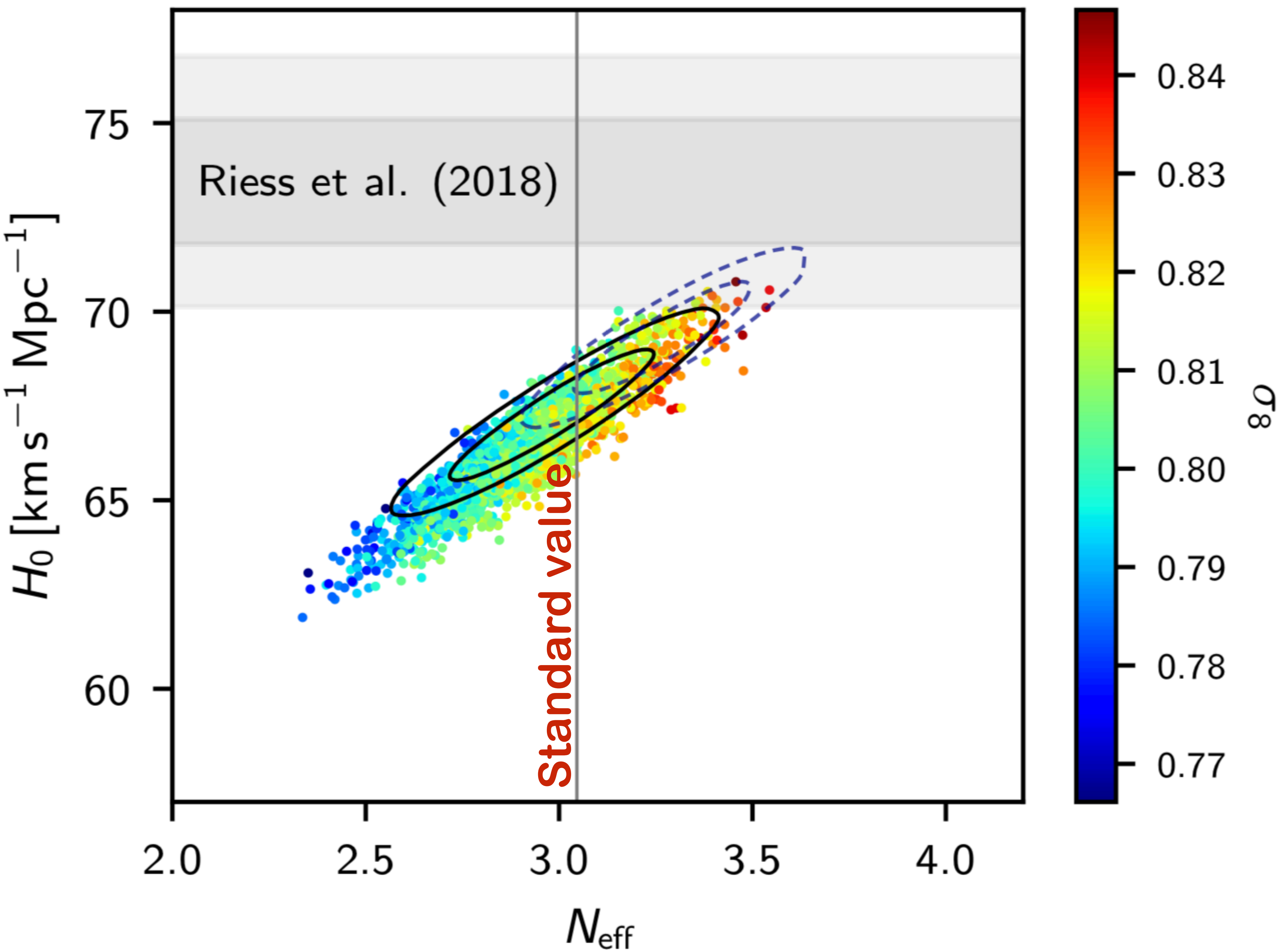
10^0
10^{-1}
Σm_ν [eV]
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
$m_{\rm light}$ [eV]

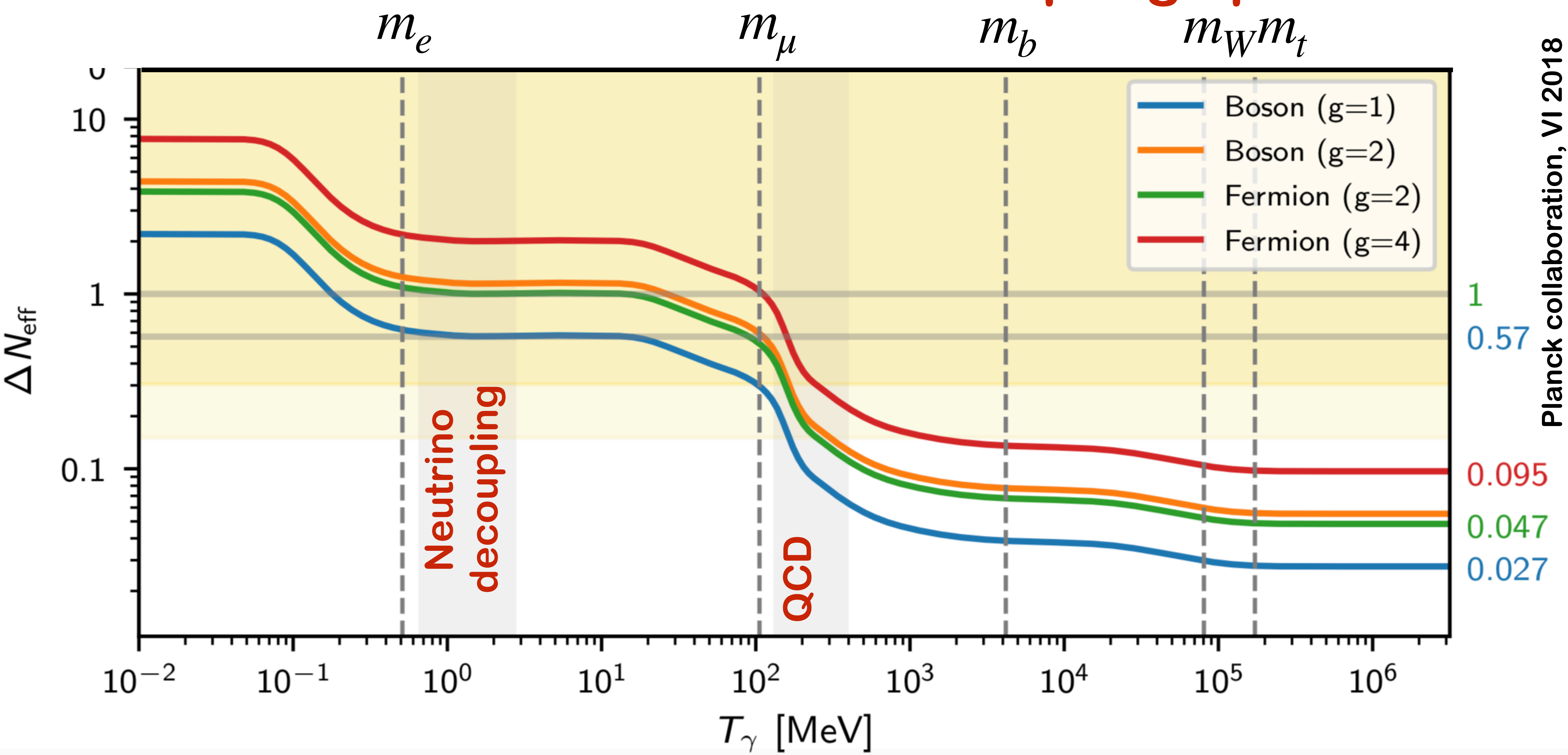
Current limits on Neff

$$N_{\rm eff} = 2.99^{+0.34}_{-0.33}, 95\,\%\,c.l., \text{Planck2018 + BAO}$$



Planck collaboration, VI 2018

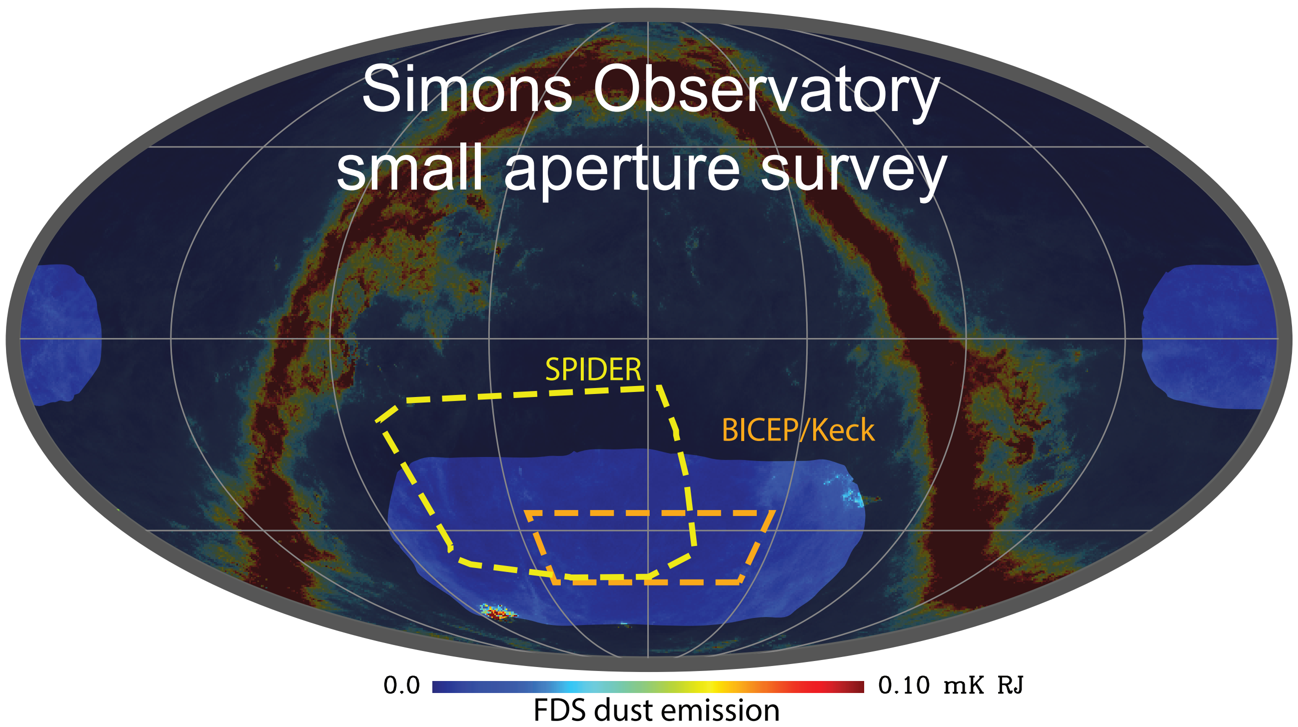
Contribution to Neff from decoupling species

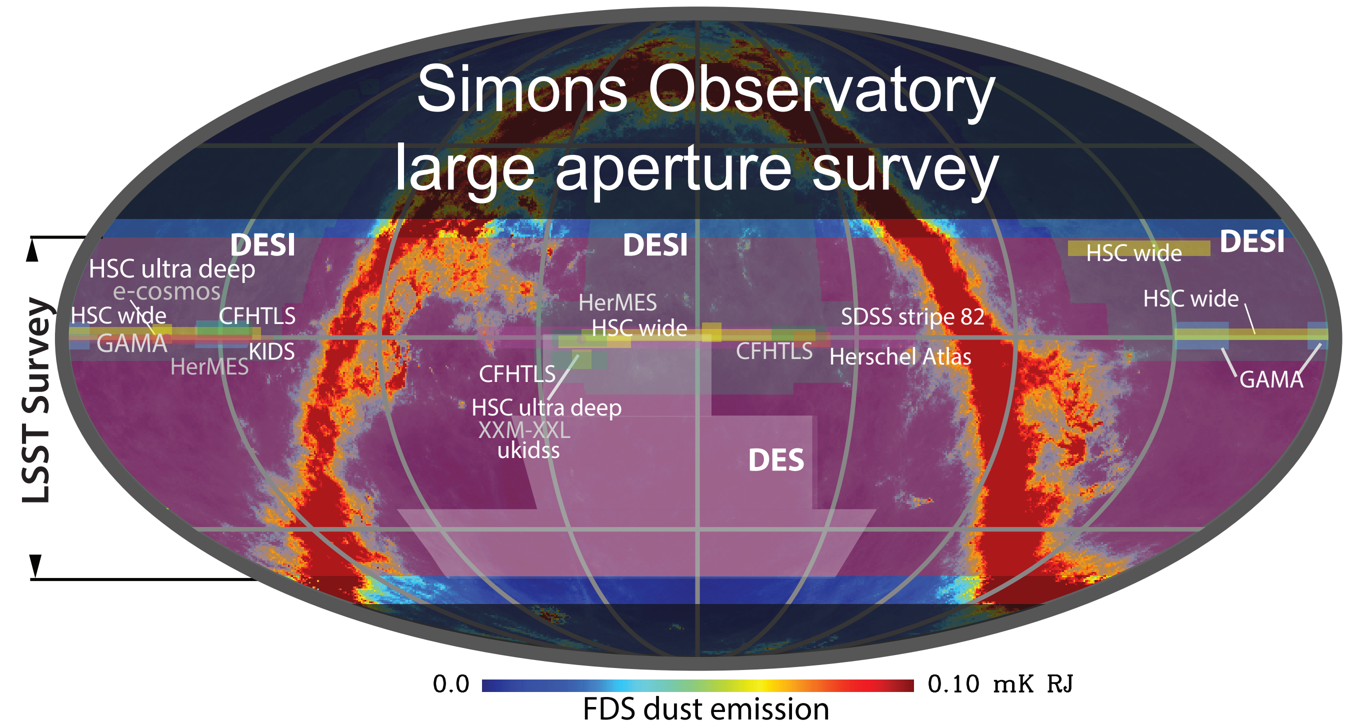


Presence of additional fully thermalised species decoupling after QCD phase transition excluded at 95%c.l.

~eV thermalised sterile neutrino excluded at 7sigma
Non-standard models needed to make SBL compatible with cosmology

Simons Observatory (SO) in a nutshell





- **Multi-frequency CMB experiments observing from Cherro Toco (Chile)**
- **Start observing from ~2020. Initial configuration:**
  - ✳ **3 small-aperture telescopes devoted primarily to primordial tensor-to-scalar ratio measurements**
  - ✳ **1 large-aperture telescope devoted primarily to damping tail, gravitational lensing, bispectrum, Sunyaev–Zel'dovich effects, and delensing science**

Forecast paper is out: arXiv:1808.07445 [astro-ph.CO]

data products: https://www.simonsobservatory.org/publications.php

Route to robust neutrino mass bounds

- CMB lensing from SO combined with DESI BAO

$$\sigma(\Sigma m_\nu) = 0.04\,\mathrm{eV}\ [0.03\,\mathrm{eV}]$$

- Sunyaev-Zeldovich cluster counts from SO calibrated with LSST weak lensing

$$\sigma(\Sigma m_\nu) = 0.04\,\mathrm{eV}\ [0.03\,\mathrm{eV}]$$

- thermal SZ distortion maps from SO combined with DESI BAO

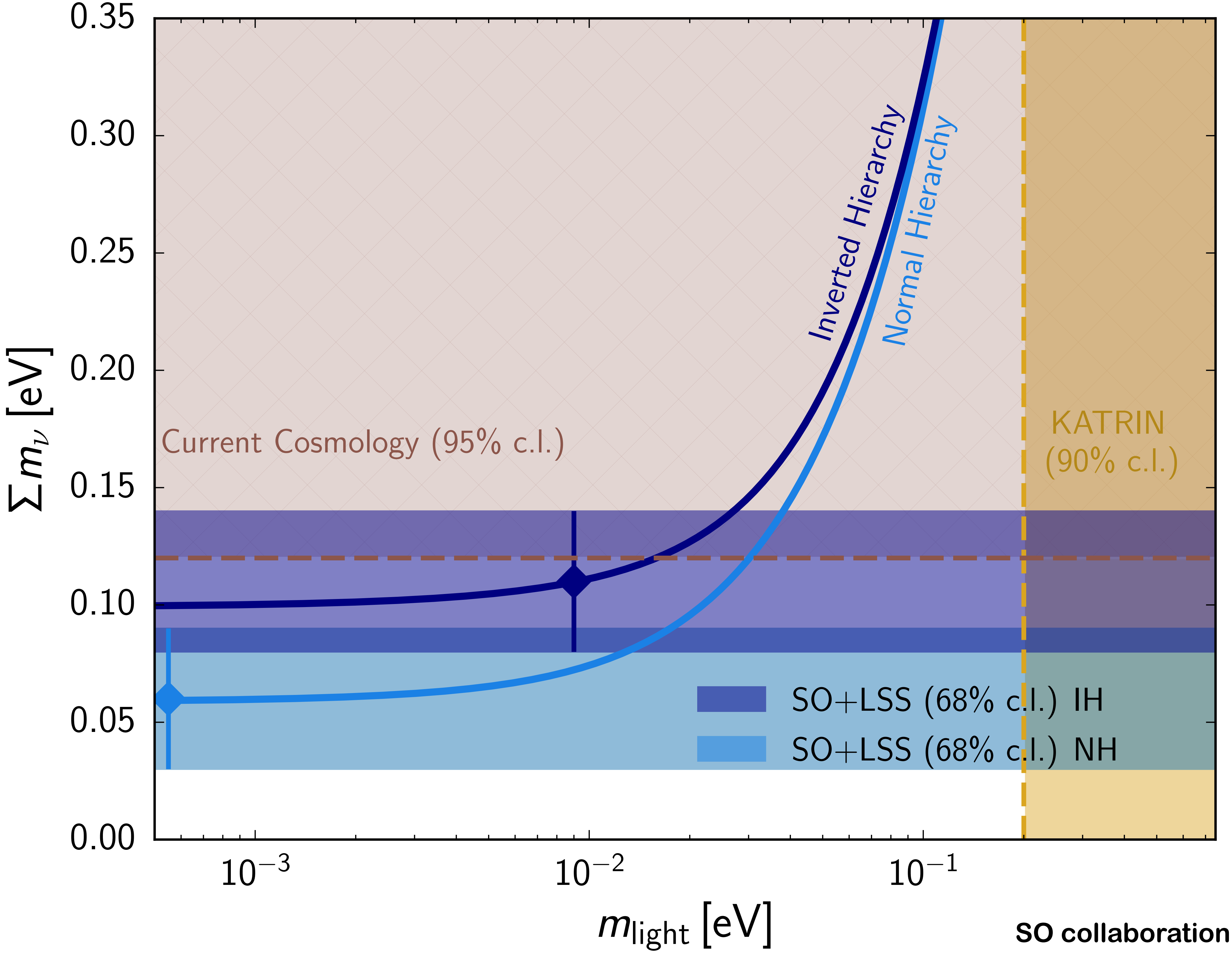
$$\sigma(\Sigma m_\nu) = 0.05\,\mathrm{eV}\ [0.04\,\mathrm{eV}]$$

- legacy SO dataset combined with cosmic-variance-limited measurement of reionization optical depth τ

$$\sigma(\Sigma m_\nu) = 0.02\,\mathrm{eV}$$

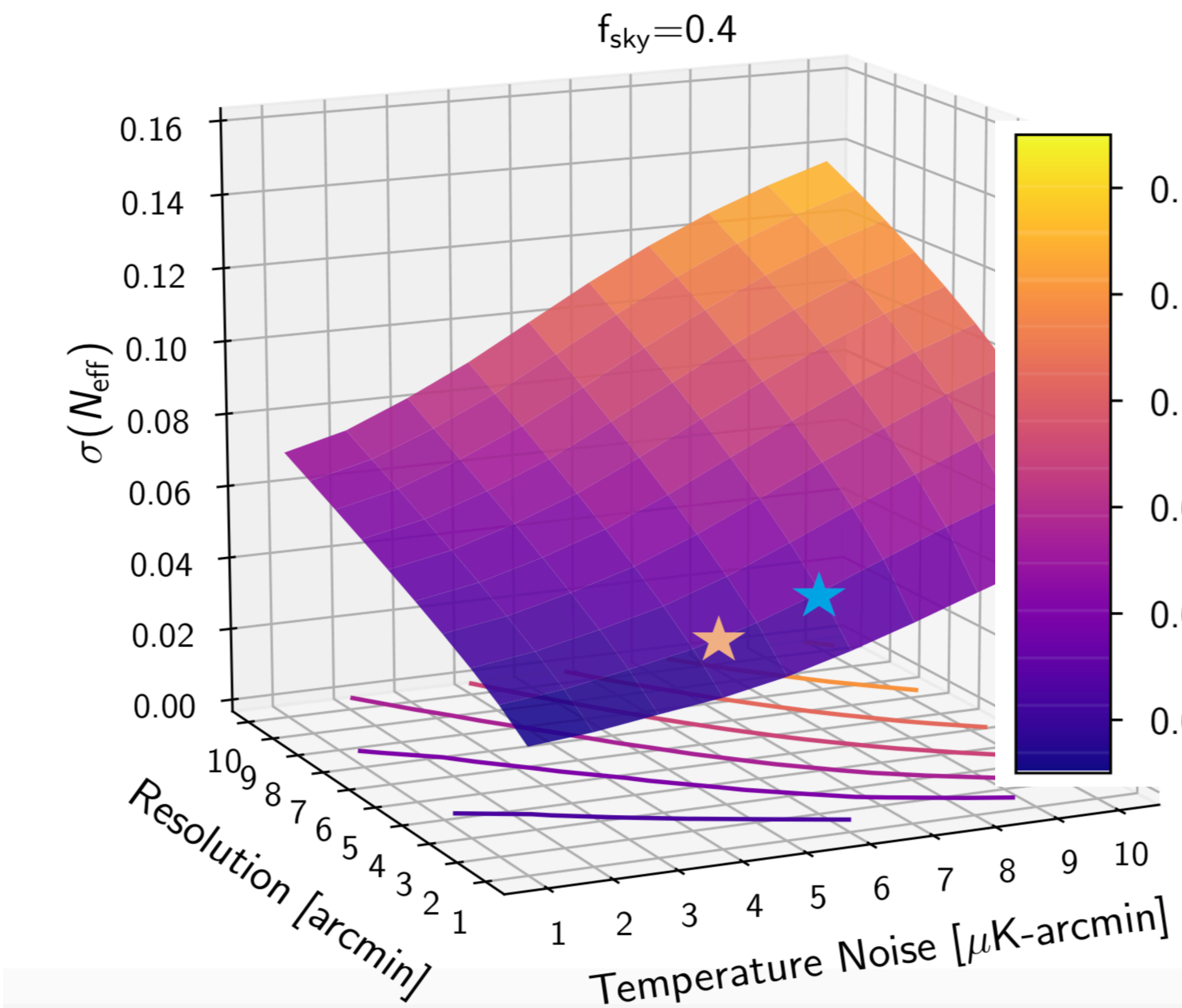
SO collaboration, 2018

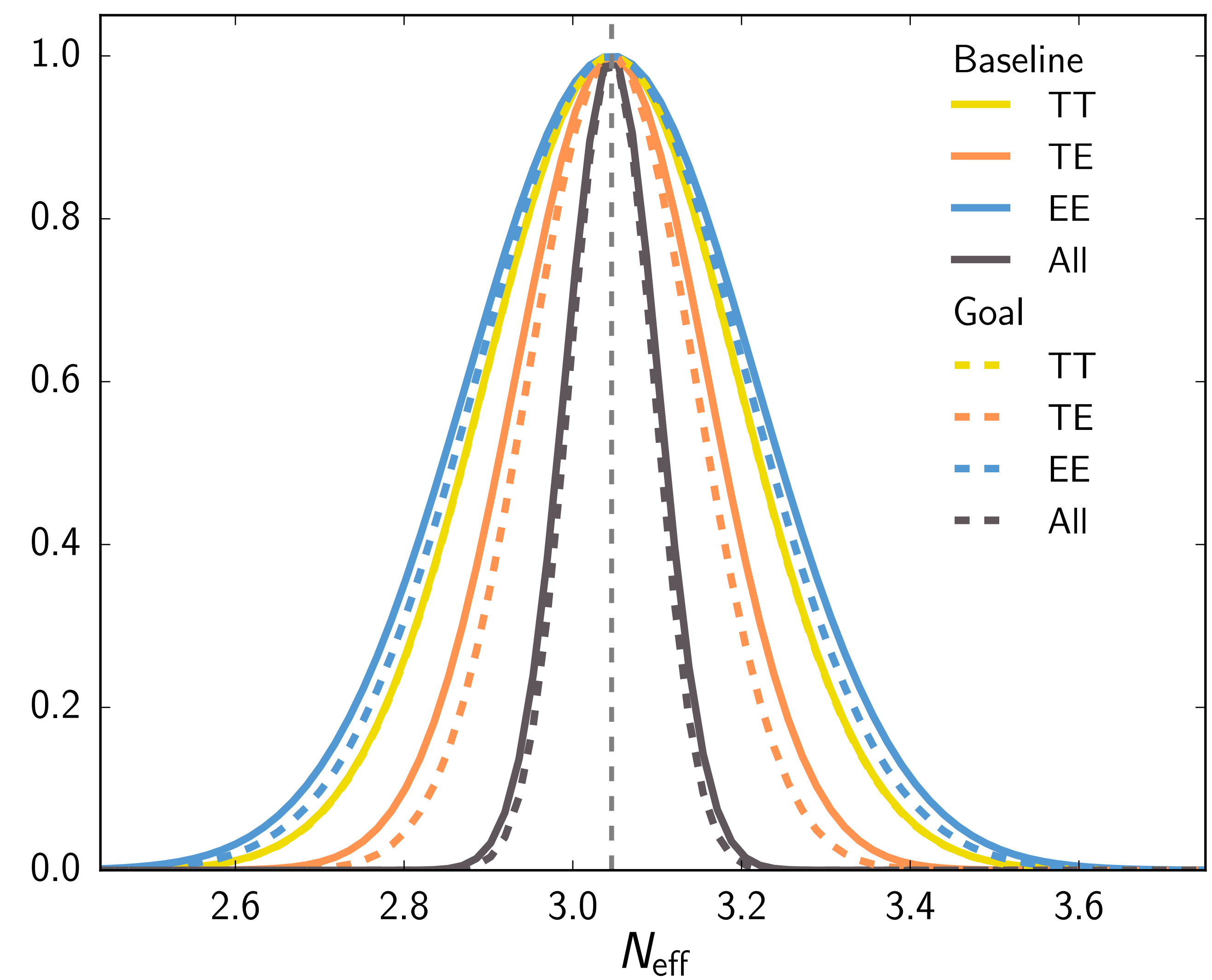
Route to robust neutrino mass bounds



SO collaboration, 2018

Route to improved bounds on Neff



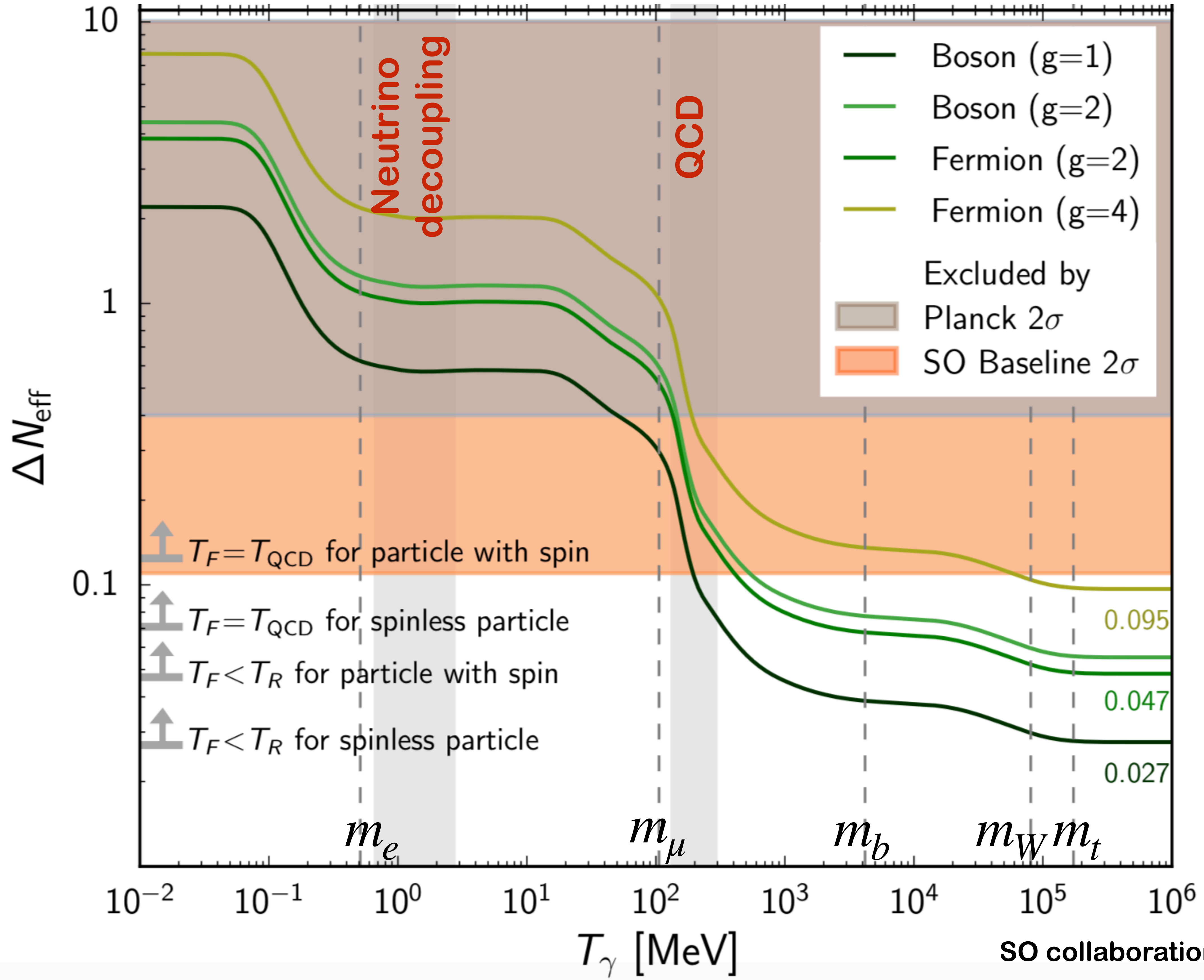


Primary CMB temperature and polarization power spectra from SO

$$\sigma(N_{\rm eff}) = 0.07\ [0.05]$$

SO collaboration, 2018

Route to improved bounds on Neff



SO collaboration, 2018

CONCLUSIONS

Determine CnB properties from neutrino peculiar effects on cosmological observables

Strong and robust constraints from cosmology

Neutrino masses: getting closer to cornering inverting hierarchy
Neff: no preference for an additional thermalised species

Next generation surveys would probe the physics of non-instantaneous decoupling and detect the neutrino mass scale with high statistical significance