Neutrino mass measurements with current and future surveys

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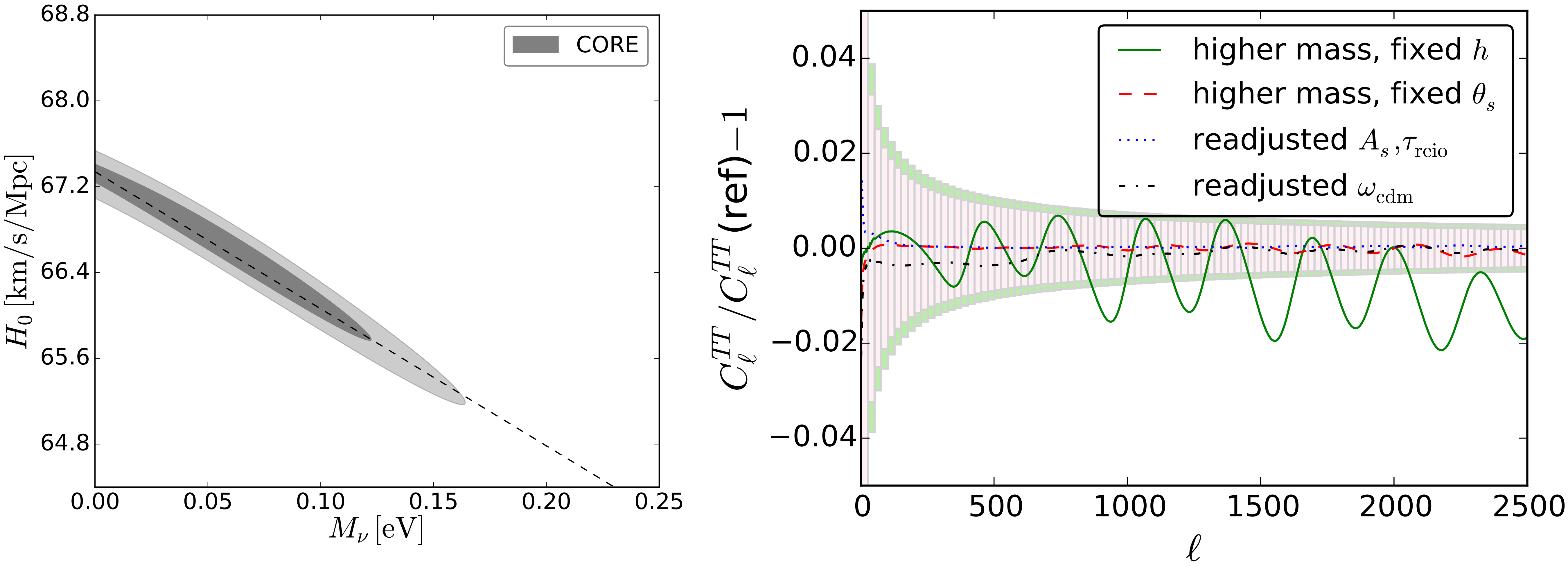
Based on
TB & Lesgourgues, in prep
Archidiacono, TB, Poulin, Lesgourgues arXiv:1610.09852

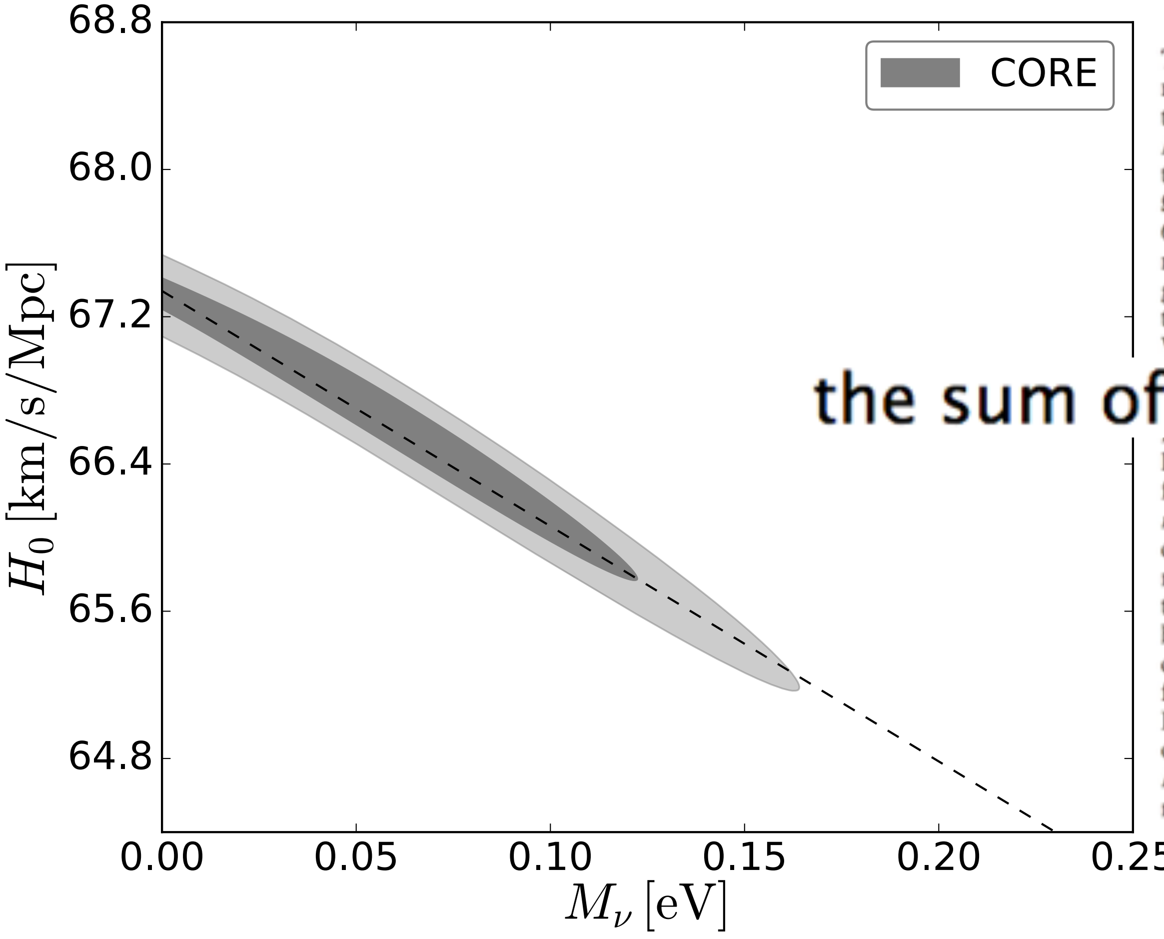
COSMO17, Paris, 28/08/17

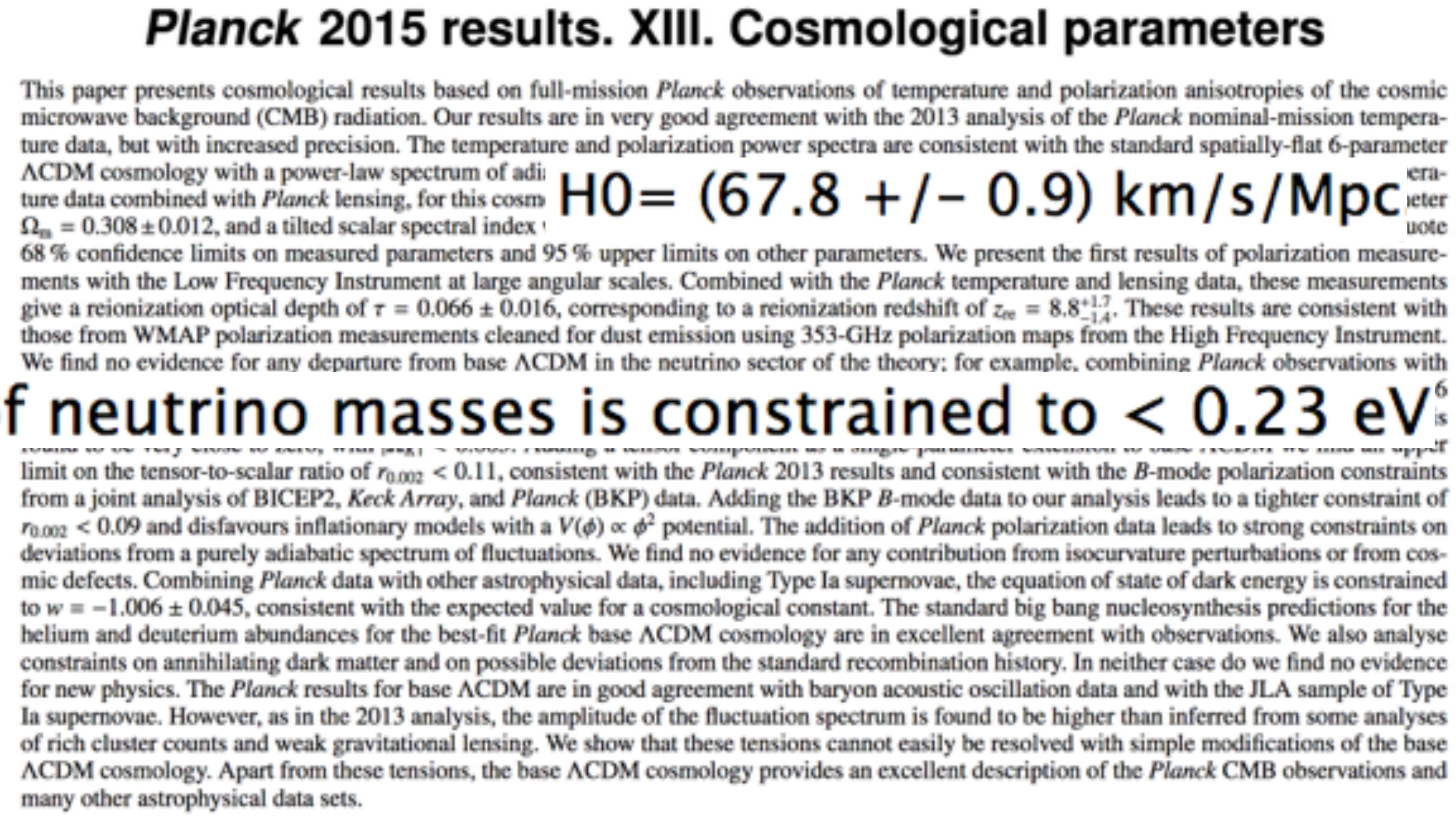
Parameter degeneracies



- Ability of one parameter to imitate the effect of another
- Example: $H_0 - M_\nu$ degeneracy

Parameter constraints in cosmology





Planck 2015 results. XIII. Cosmological parameters

This paper presents cosmological results based on full-mission *Planck* observations of temperature and polarization anisotropies of the cosmic microwave background (CMB) radiation. Our results are in very good agreement with the 2013 analysis of the *Planck* nominal-mission temperature data, but with increased precision. The temperature and polarization power spectra are consistent with the standard spatially-flat 6-parameter ΛCDM cosmology with a power-law spectrum of adi… era-
ture data combined with *Planck* lensing, for this cosm… eter
$\Omega_m = 0.308 \pm 0.012$, and a tilted scalar spectral index … uote
68 % confidence limits on measured parameters and 95 % upper limits on other parameters. We present the first results of polarization measurements with the Low Frequency Instrument at large angular scales. Combined with the *Planck* temperature and lensing data, these measurements give a reionization optical depth of $\tau = 0.066 \pm 0.016$, corresponding to a reionization redshift of $z_{re} = 8.8^{+1.7}_{-1.4}$. These results are consistent with those from WMAP polarization measurements cleaned for dust emission using 353-GHz polarization maps from the High Frequency Instrument. We find no evidence for any departure from base ΛCDM in the neutrino sector of the theory; for example, combining *Planck* observations with
…
limit on the tensor-to-scalar ratio of $r_{0.002} < 0.11$, consistent with the *Planck* 2013 results and consistent with the *B*-mode polarization constraints from a joint analysis of BICEP2, *Keck Array*, and *Planck* (BKP) data. Adding the BKP *B*-mode data to our analysis leads to a tighter constraint of $r_{0.002} < 0.09$ and disfavours inflationary models with a $V(\phi) \propto \phi^2$ potential. The addition of *Planck* polarization data leads to strong constraints on deviations from a purely adiabatic spectrum of fluctuations. We find no evidence for any contribution from isocurvature perturbations or from cosmic defects. Combining *Planck* data with other astrophysical data, including Type Ia supernovae, the equation of state of dark energy is constrained to $w = -1.006 \pm 0.045$, consistent with the expected value for a cosmological constant. The standard big bang nucleosynthesis predictions for the helium and deuterium abundances for the best-fit *Planck* base ΛCDM cosmology are in excellent agreement with observations. We also analyse constraints on annihilating dark matter and on possible deviations from the standard recombination history. In neither case do we find no evidence for new physics. The *Planck* results for base ΛCDM are in good agreement with baryon acoustic oscillation data and with the JLA sample of Type Ia supernovae. However, as in the 2013 analysis, the amplitude of the fluctuation spectrum is found to be higher than inferred from some analyses of rich cluster counts and weak gravitational lensing. We show that these tensions cannot easily be resolved with simple modifications of the base ΛCDM cosmology. Apart from these tensions, the base ΛCDM cosmology provides an excellent description of the *Planck* CMB observations and many other astrophysical data sets.

H0= (67.8 +/- 0.9) km/s/Mpc

the sum of neutrino masses is constrained to < 0.23 eV

- Constraints are often quoted for a best-case scenario
- But constraints are always model dependent!
- And change when considering extended models

Overview

Introduction

- Parameter degeneracies
- Parameter constraints in cosmology

Neutrino mass constraints from data

- Constraints given extended models

Sensitivity forecasts

- Effect on sensitivity from combining surveys
- Joint sensitivity forecast

Experimental setup (data)

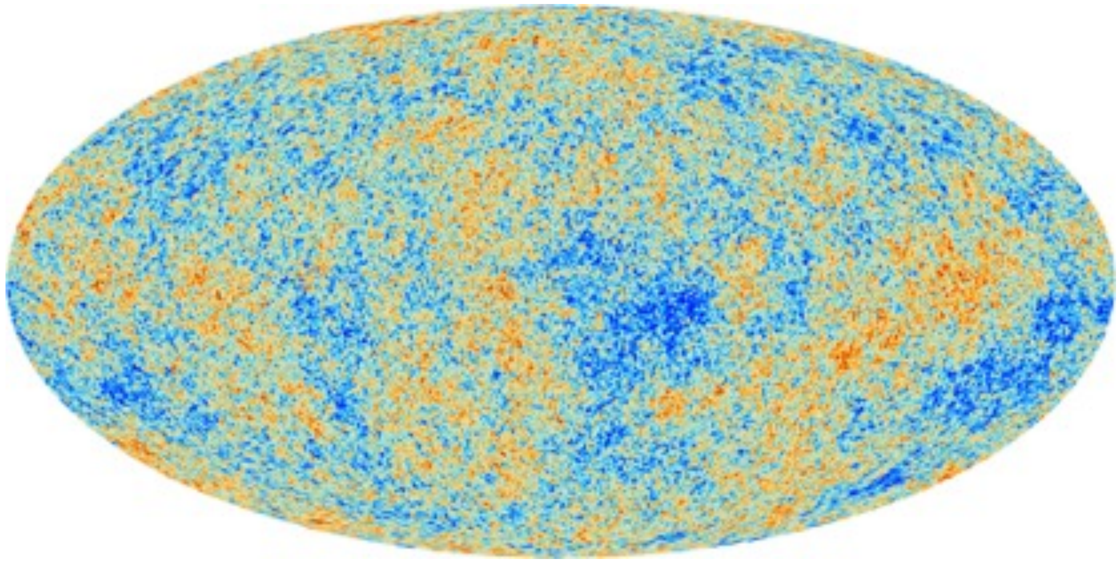
- Method: MCMC
- Codes: MontePython and CLASS
  (1210.7183, 1104.2933)

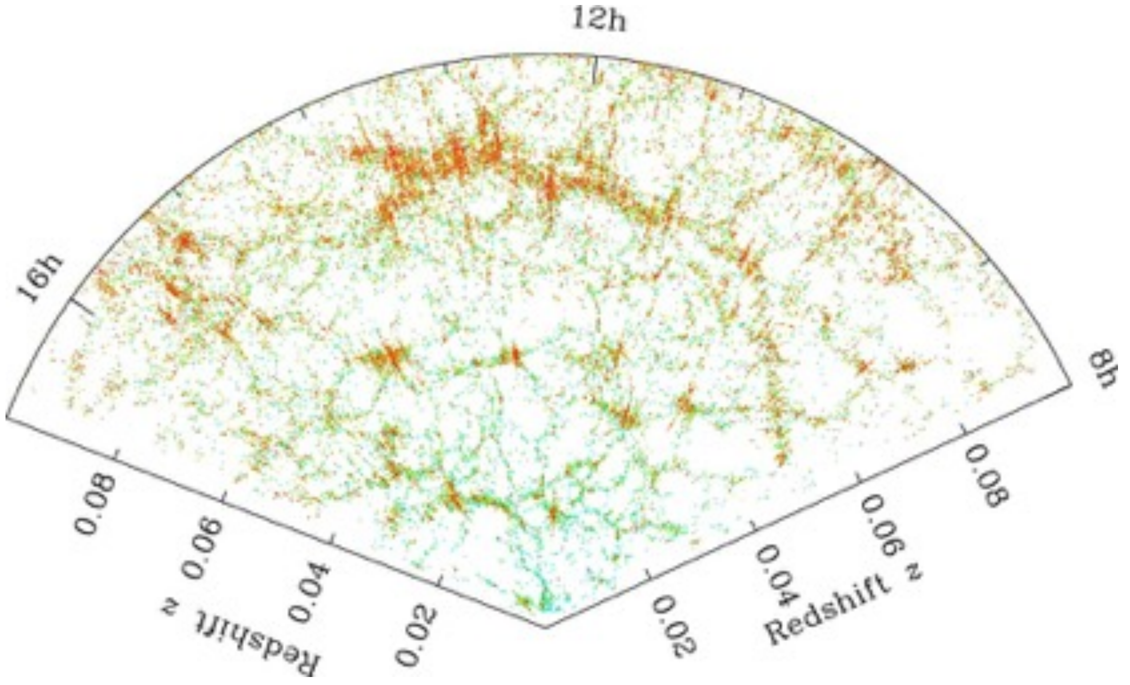
CMB (1507.02704)

- Planck highℓ TT, TE, EE
- Planck lensing
- Prior on τ_{reio} (Planck simlow 1605.02985)

Large-scale structure

- P(k): SDSS DR7 LRG
  (Reid et al. 0907.1659)
- BAO: 6dFGS, MGS, BOSS DR12
  (0907.1659, 1409.3242,1607.03155)

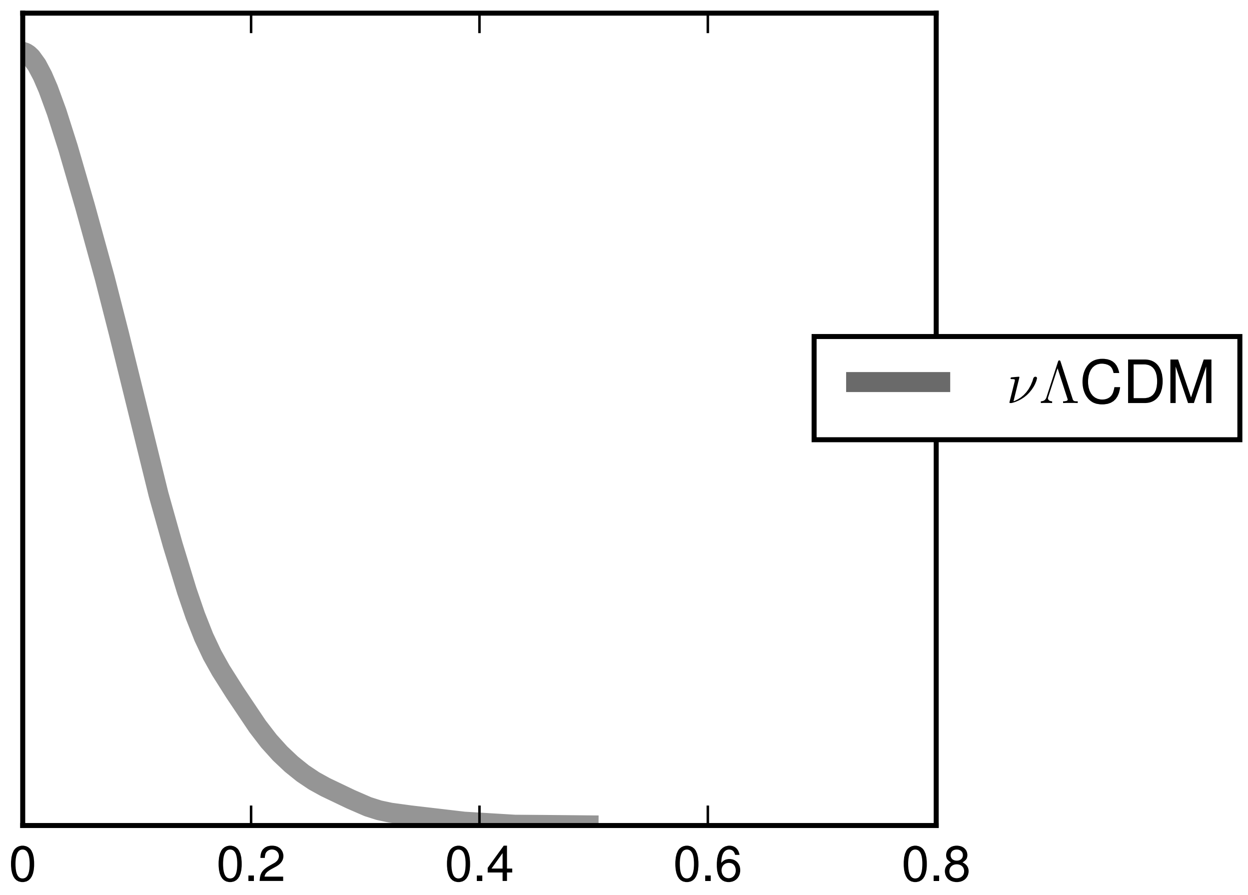




$\sum m_\nu$ constraints for ext. models

- *ΛCDM* + $\sum m_\nu$
- Adding extra free parameters changes the posterior dist.

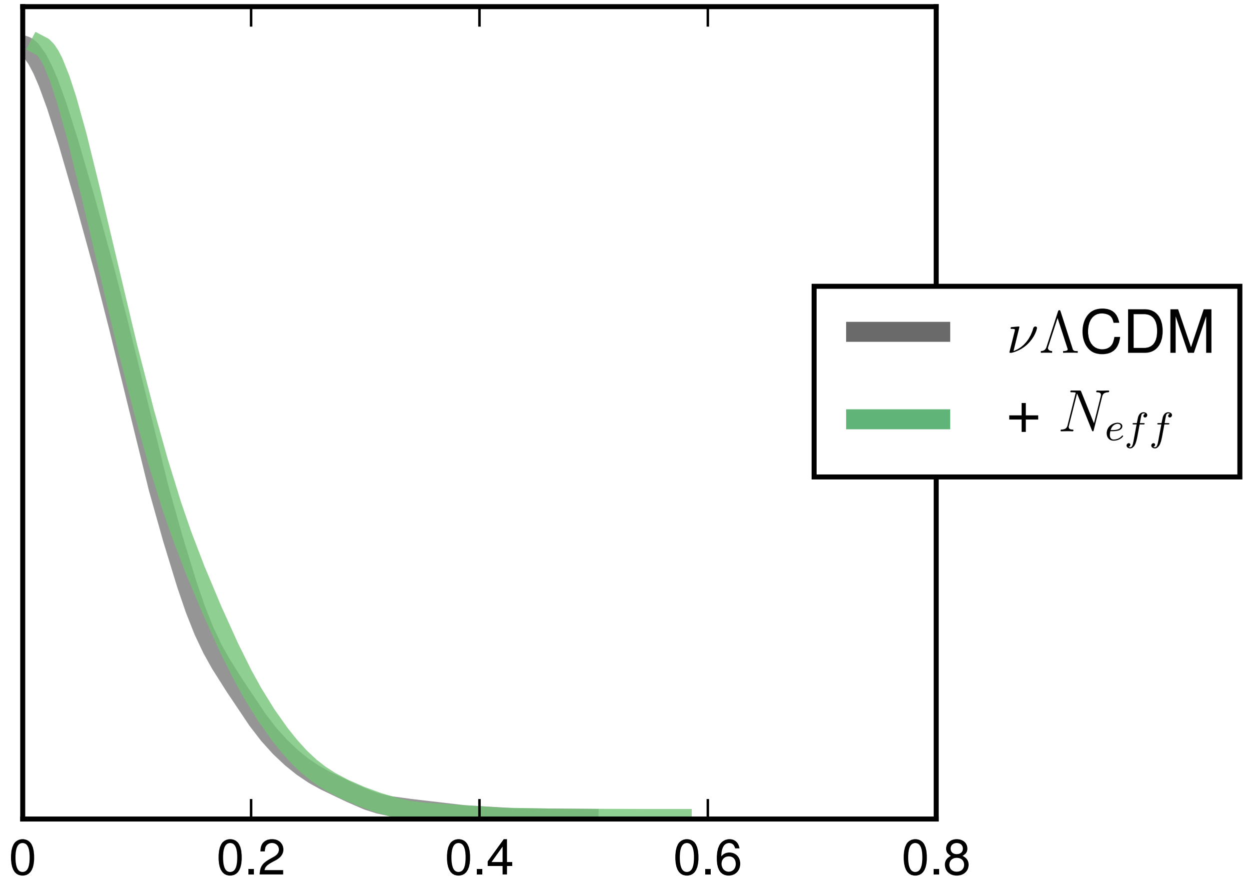
$M_{tot} < 0.223\ eV$ (95% CL)



$\sum m_\nu$ constraints for ext. models

- $\Lambda CDM + \sum m_\nu + N_{eff}$
- Adding extra free parameters changes the posterior dist.
- In some cases not much

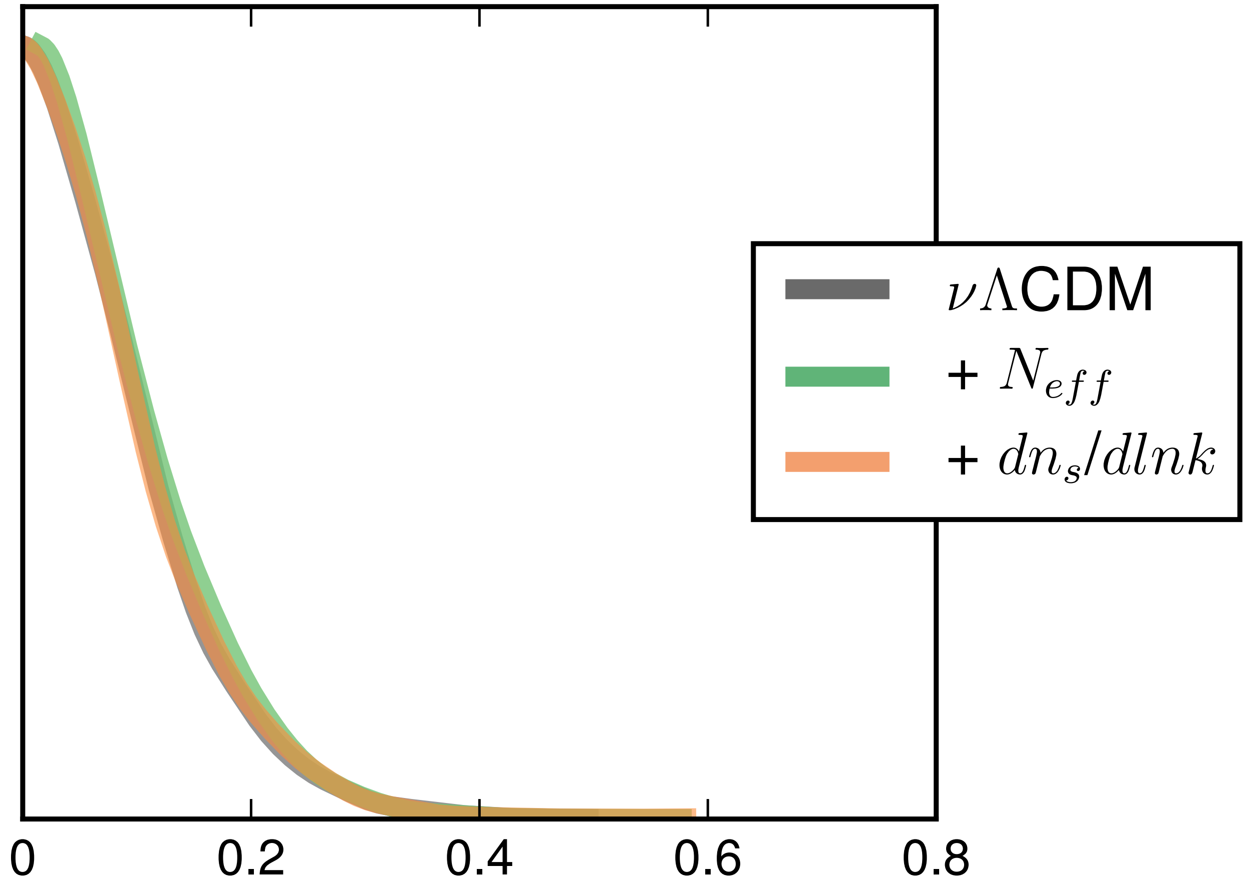
$M_{tot} < 0.221\ eV$ (95% CL)



$\sum m_\nu$ constraints for ext. models

- $\Lambda CDM + \sum m_\nu + dn_s/d\ln k$
- Adding extra free parameters changes the posterior dist.
- In some cases not much
- But some parameters are degenerate with $\sum m_\nu$

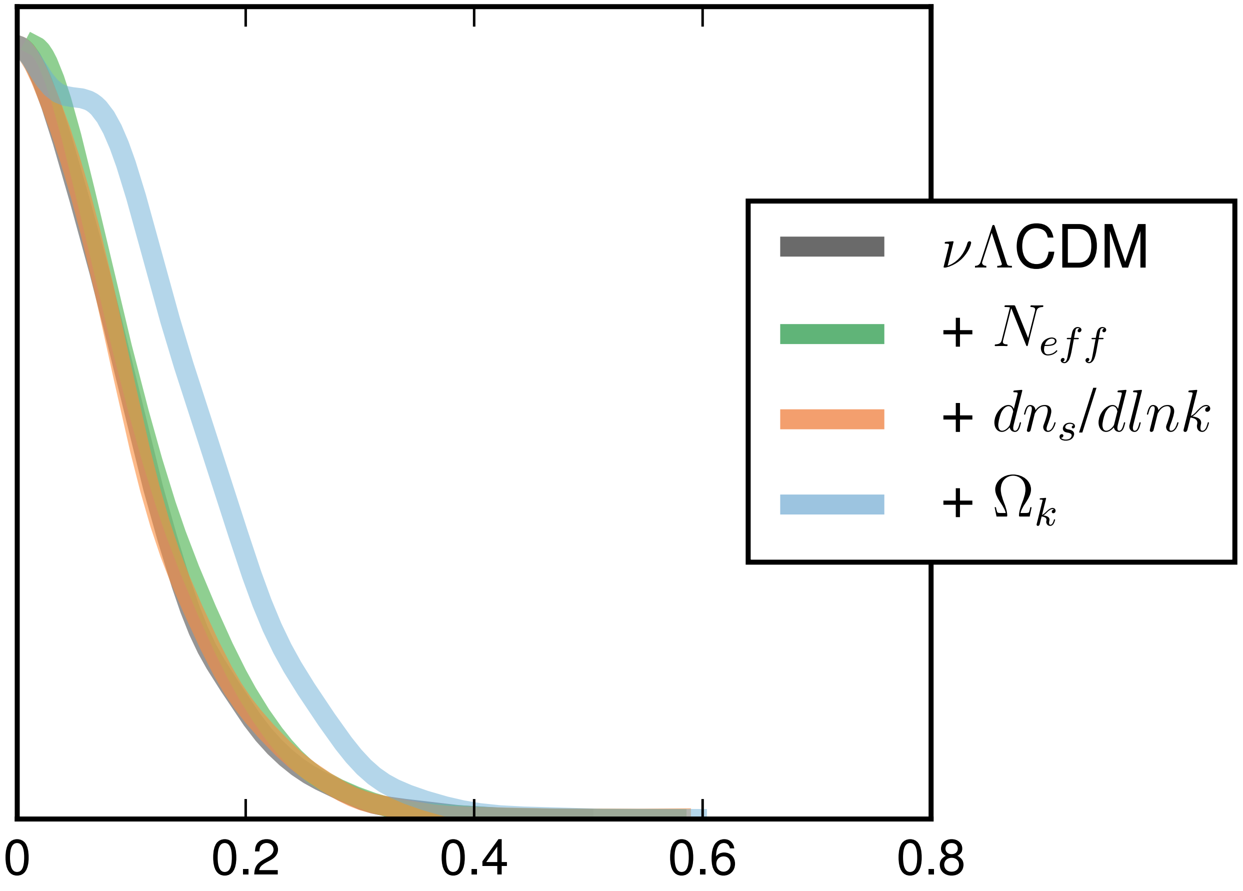
$M_{tot} < 0.225\ eV$ (95% CL)



$\sum m_\nu$ constraints for ext. models

- $\Lambda CDM + \sum m_\nu + \Omega_k$
- Adding extra free parameters changes the posterior dist.
- In some cases not much
- But some parameters are degenerate with $\sum m_\nu$
- Especially: Ω_k

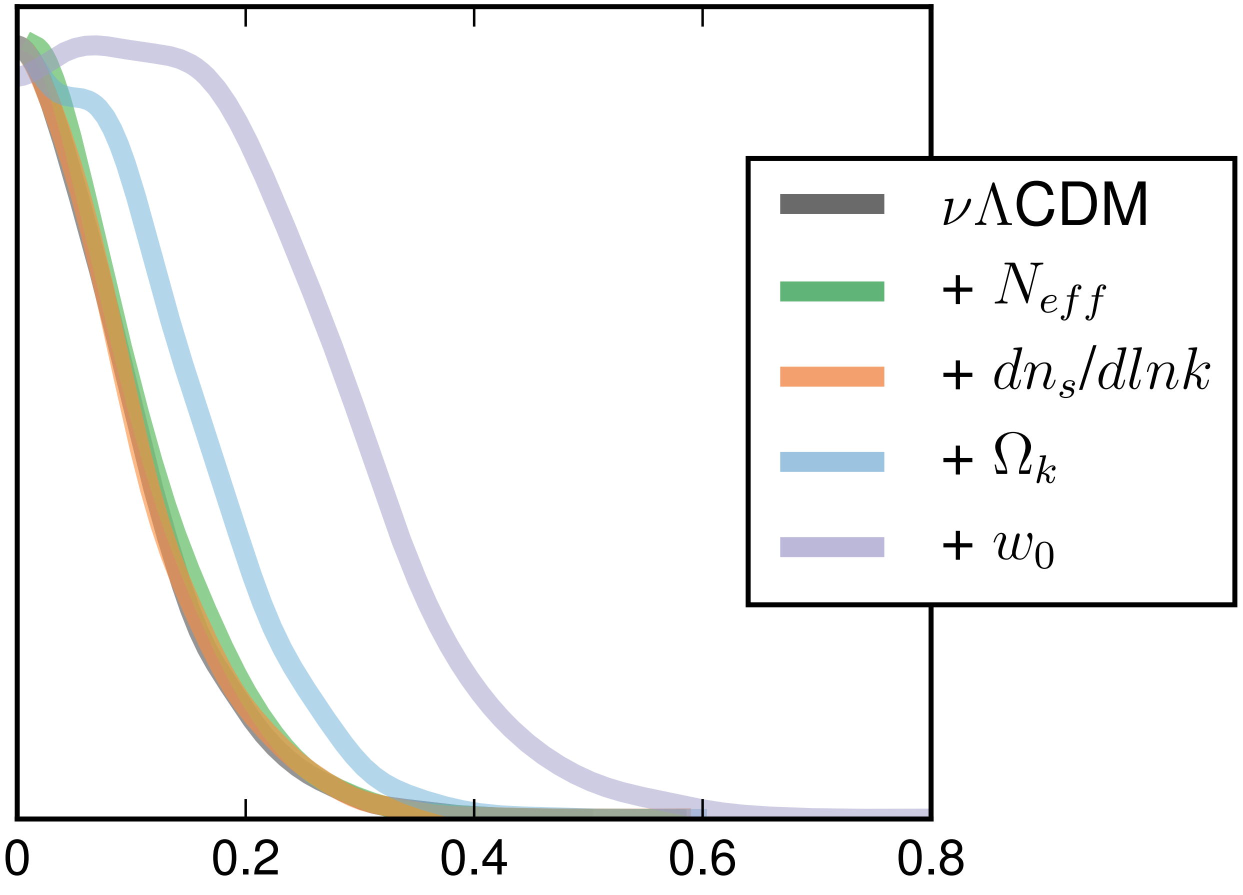
$M_{tot} < 0.259\ eV$ (95% CL)



$\sum m_\nu$ constraints for ext. models

- *CDM* + $\sum m_\nu$ + w_0
- Adding extra free parameters changes the posterior dist.
- In some cases not much
- But some parameters are degenerate with $\sum m_\nu$
- Especially: Ω_k, w_0

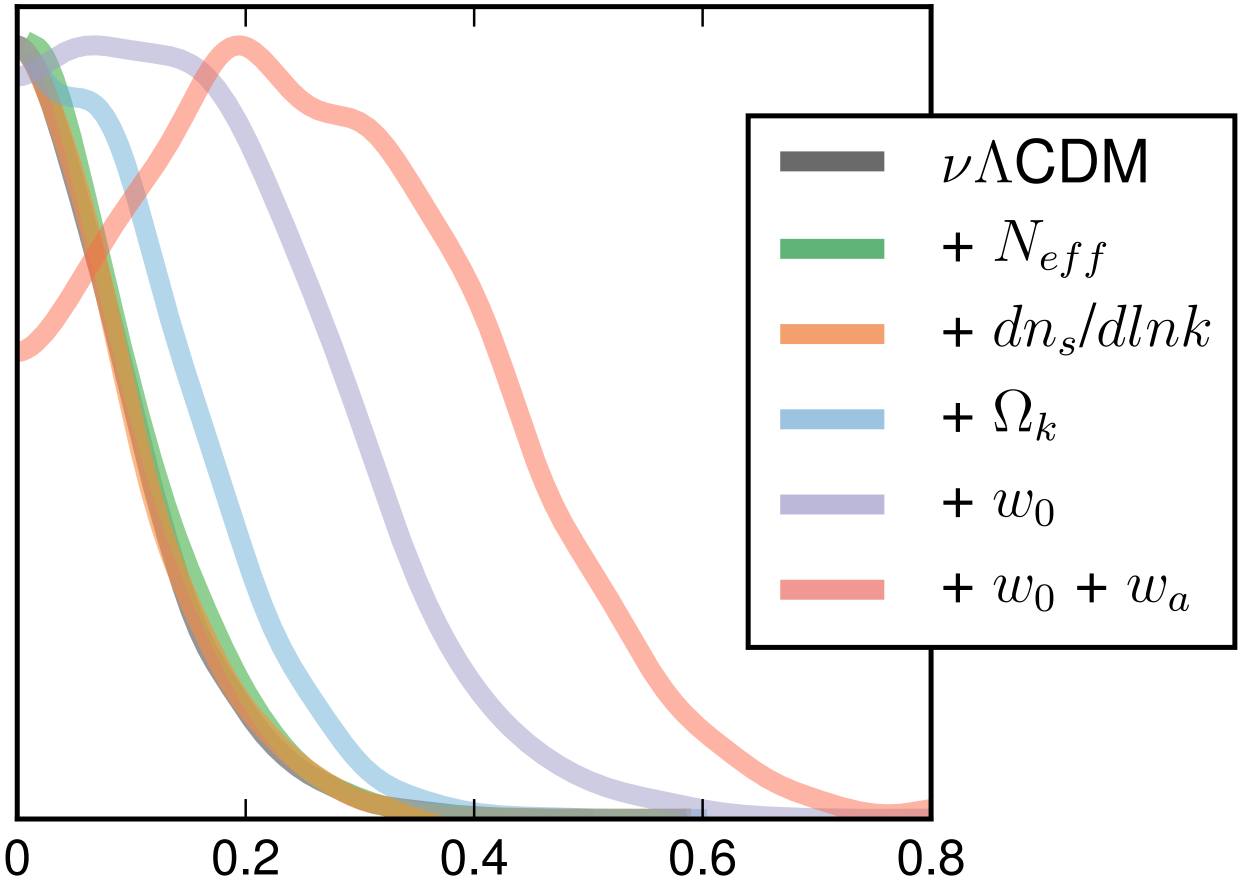
$M_{tot} < 0.394\ eV$ (95% CL)



$\sum m_\nu$ constraints for ext. models

- *CDM* + $\sum m_\nu$ + w_0 + w_a
- Adding extra free parameters changes the posterior dist.
- In some cases not much
- But some parameters are degenerate with $\sum m_\nu$
- Especially: Ω_k, w_0, w_0 + w_a

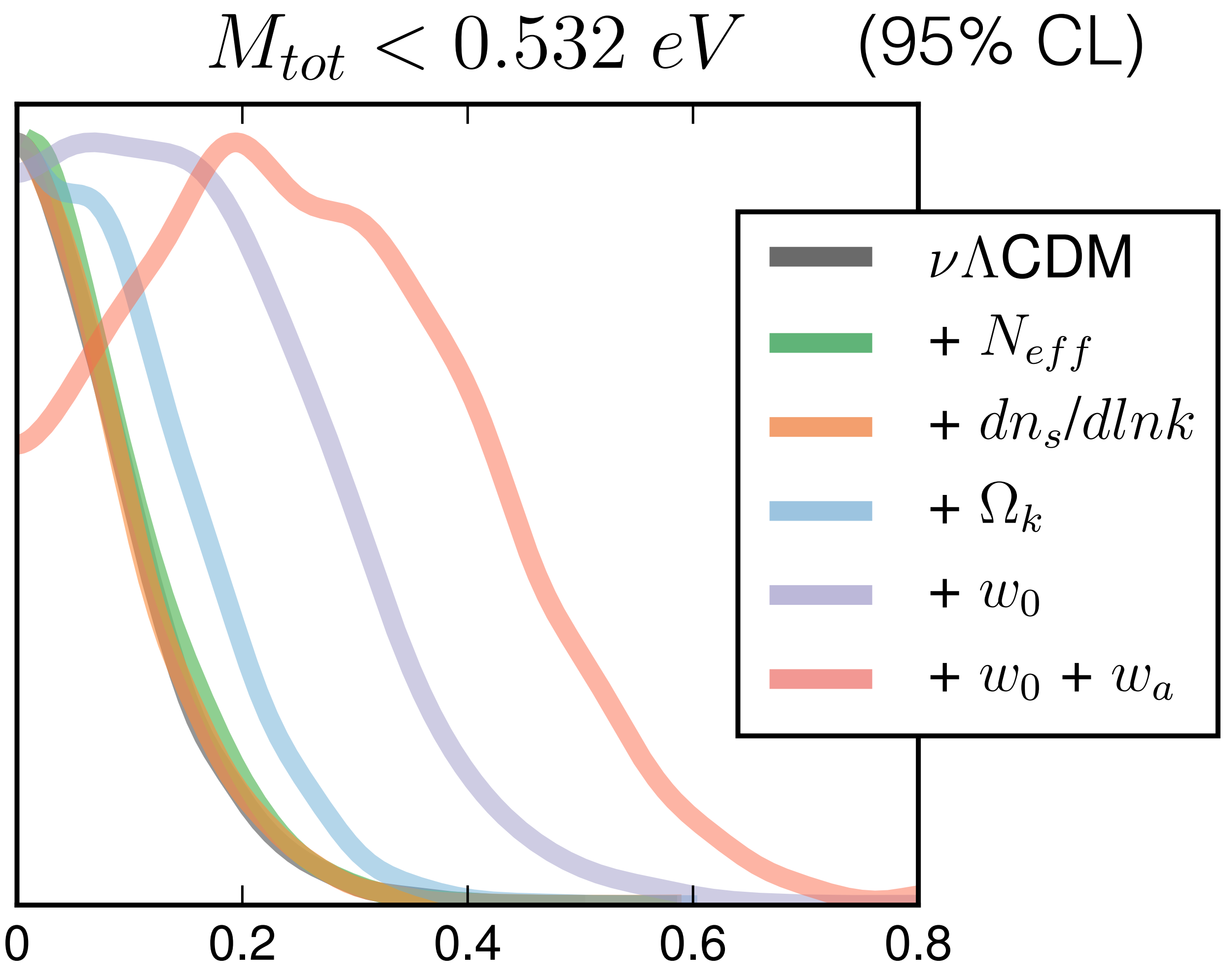
$M_{tot} < 0.532\ eV$ (95% CL)



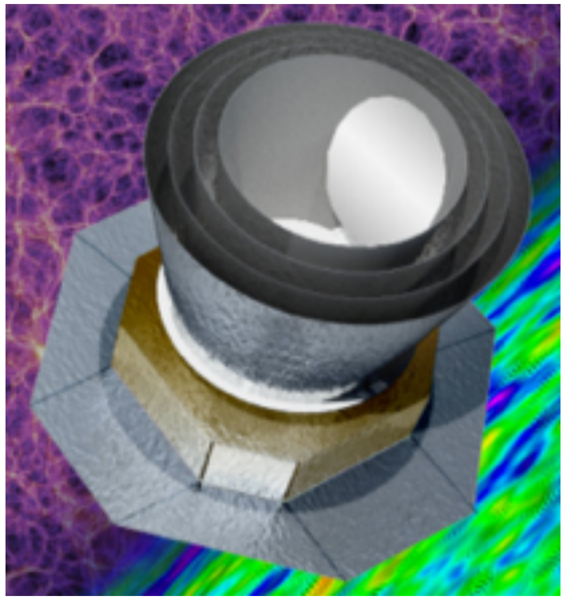
$\sum m_\nu$ constraints for ext. models

Putting it all together (95% CL)

- $\Lambda CDM + \sum m_\nu$: $\sum m_\nu <$ ***0.223 eV***
- $\Lambda CDM + \sum m_\nu + N_{eff}$: $\sum m_\nu <$ ***0.221 eV***
- $\Lambda CDM + \sum m_\nu + dn_s/dlnk$: $\sum m_\nu <$ ***0.225eV***
- $\Lambda CDM + \sum m_\nu + \Omega_k$: $\sum m_\nu <$ ***0.259 eV***
- $CDM + \sum m_\nu + w_0$: $\sum m_\nu <$ ***0.394 eV***
- $CDM + \sum m_\nu + w_0 + w_a$: $\sum m_\nu <$ ***0.532 eV***



Experimental setup (forecasts)

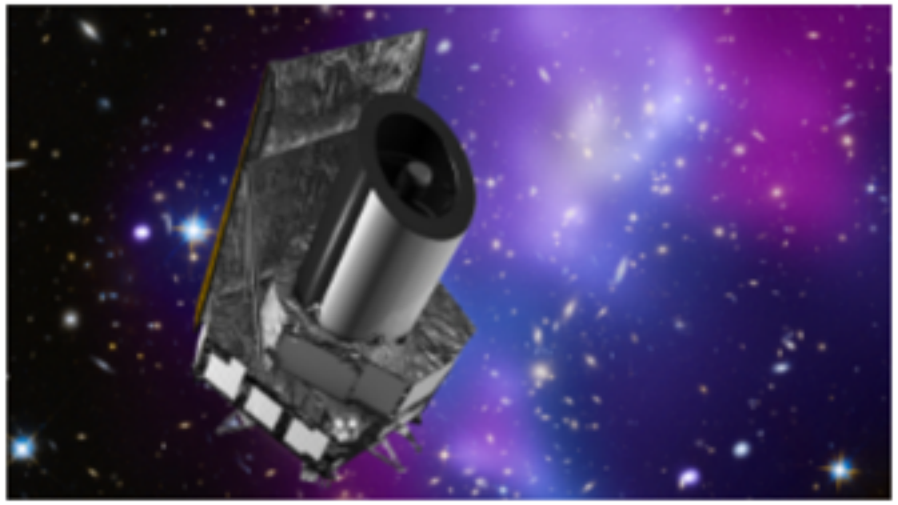


CMB – CORE-like mission
(Di Valentino, TB, Poulin, Gerbino et al. 1612.00021)

- TT, TE, EE, $\phi\phi$
  $\ell_{\mathrm{max}} = 3000$

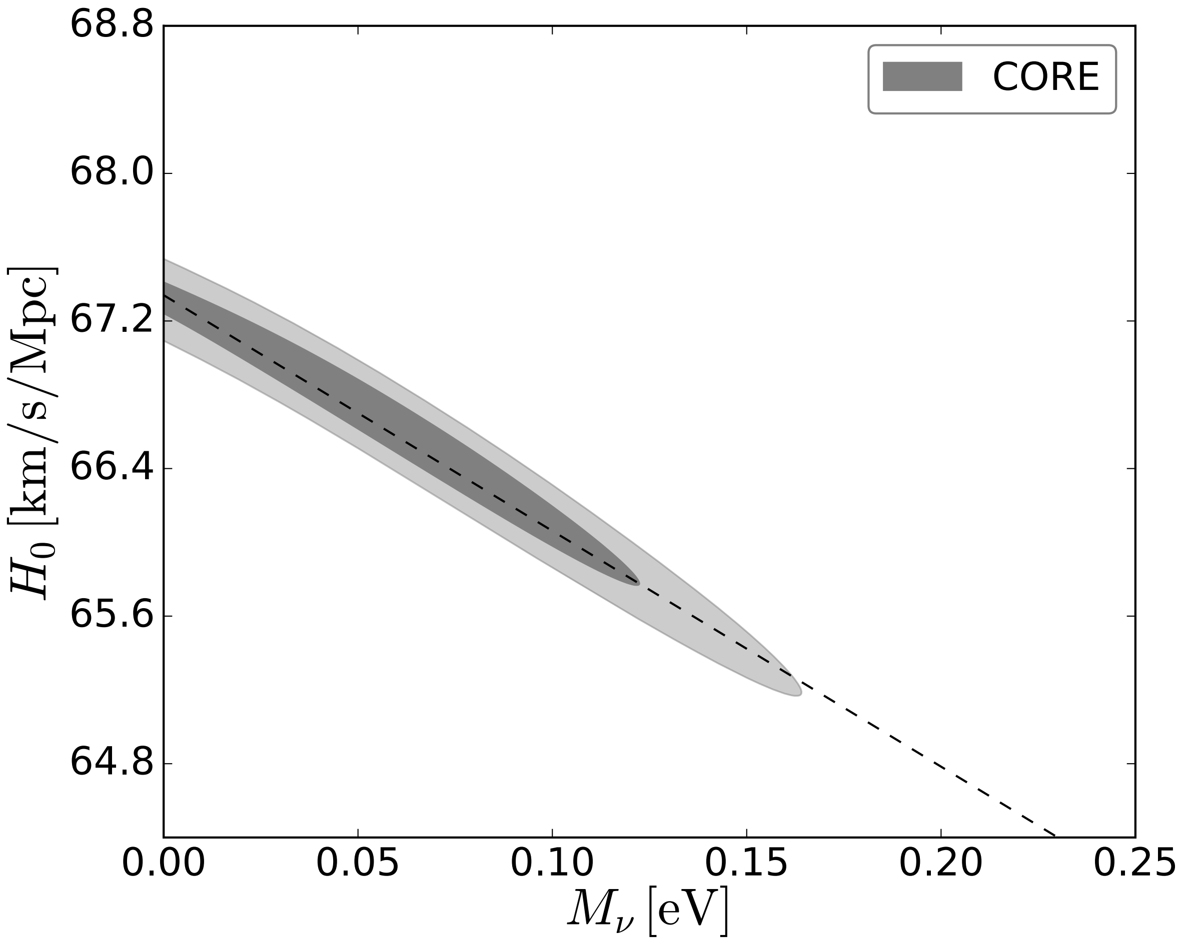
LSS – Euclid satellite
(Audren et al. 1210.2194)

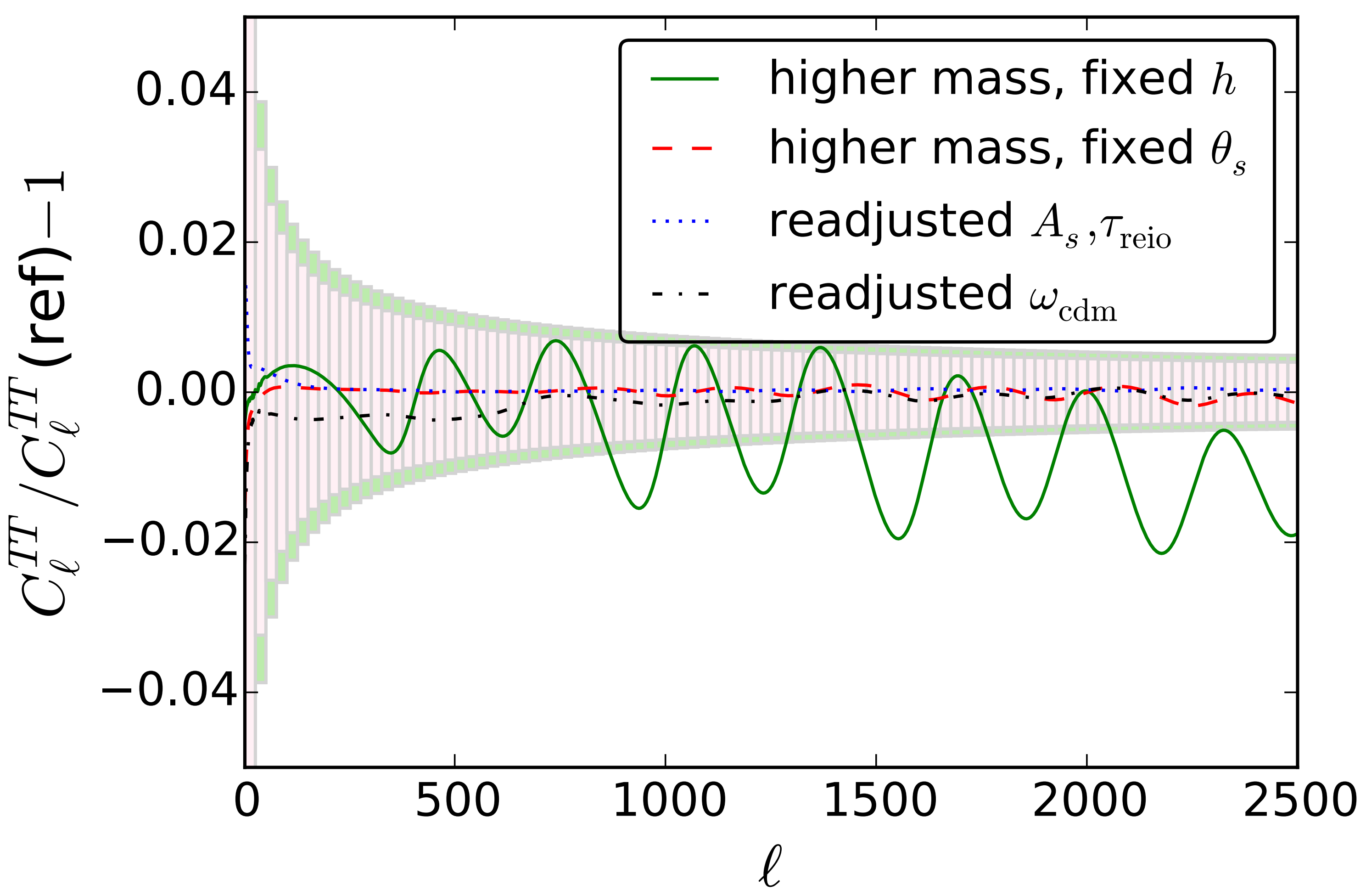
- Cosmic shear
  $\ell_{\mathrm{max}} = 2000$ + theoretical error
- Galaxy clustering P(k)
  $k_{\mathrm{max}} = 0.6$ h/Mpc + theoretical error



Artist's impression of the Euclid spacecraft.
Credit: ESA/C. Carreau

Parameter degeneracies: CMB-only





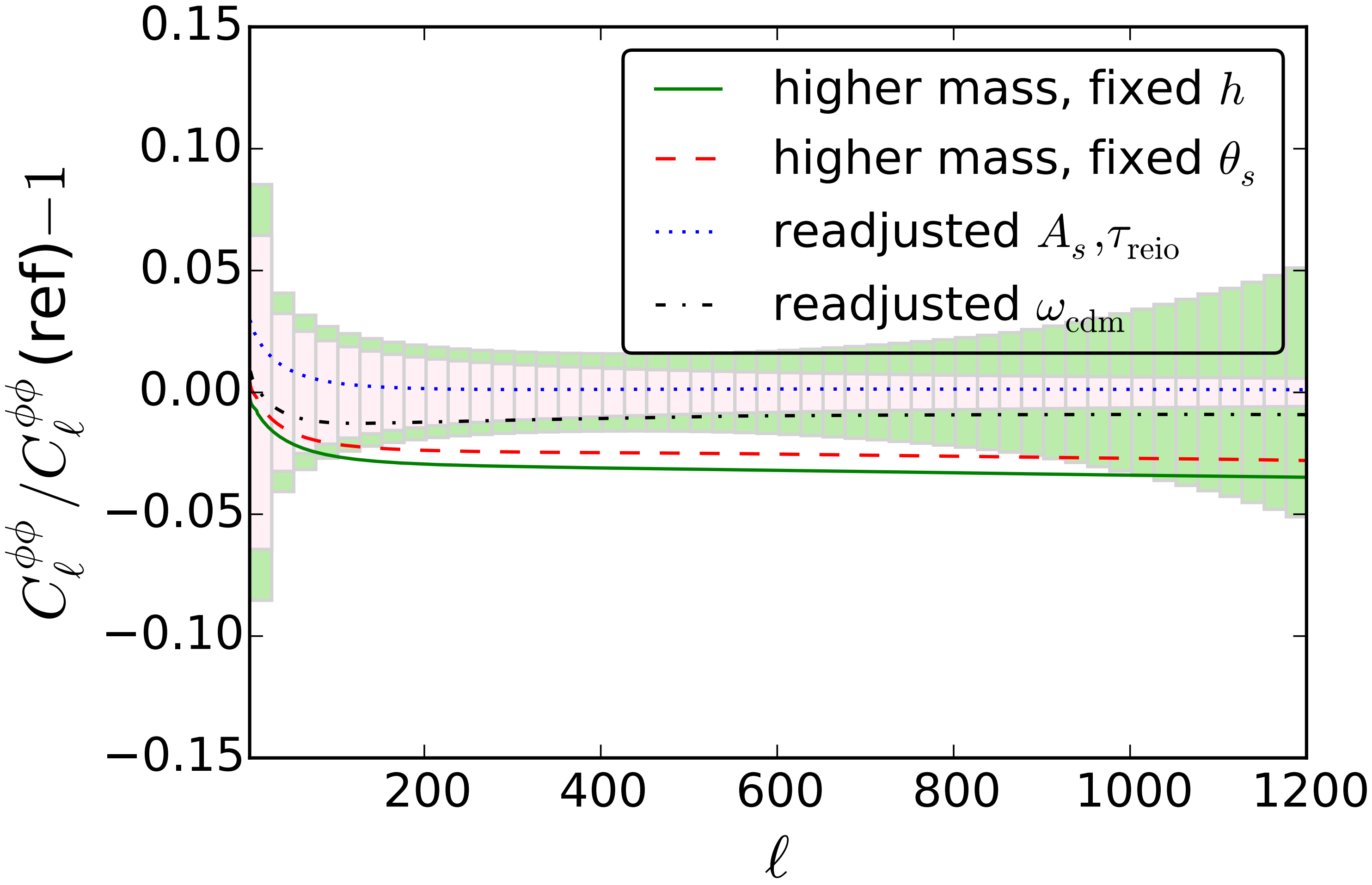
- Already discussed H_0 – M_ν degeneracy
- M_ν ↑ changes $d_A(z_{dec})$, H_0 ↓ to compensate

Parameter degeneracies: CMB-only

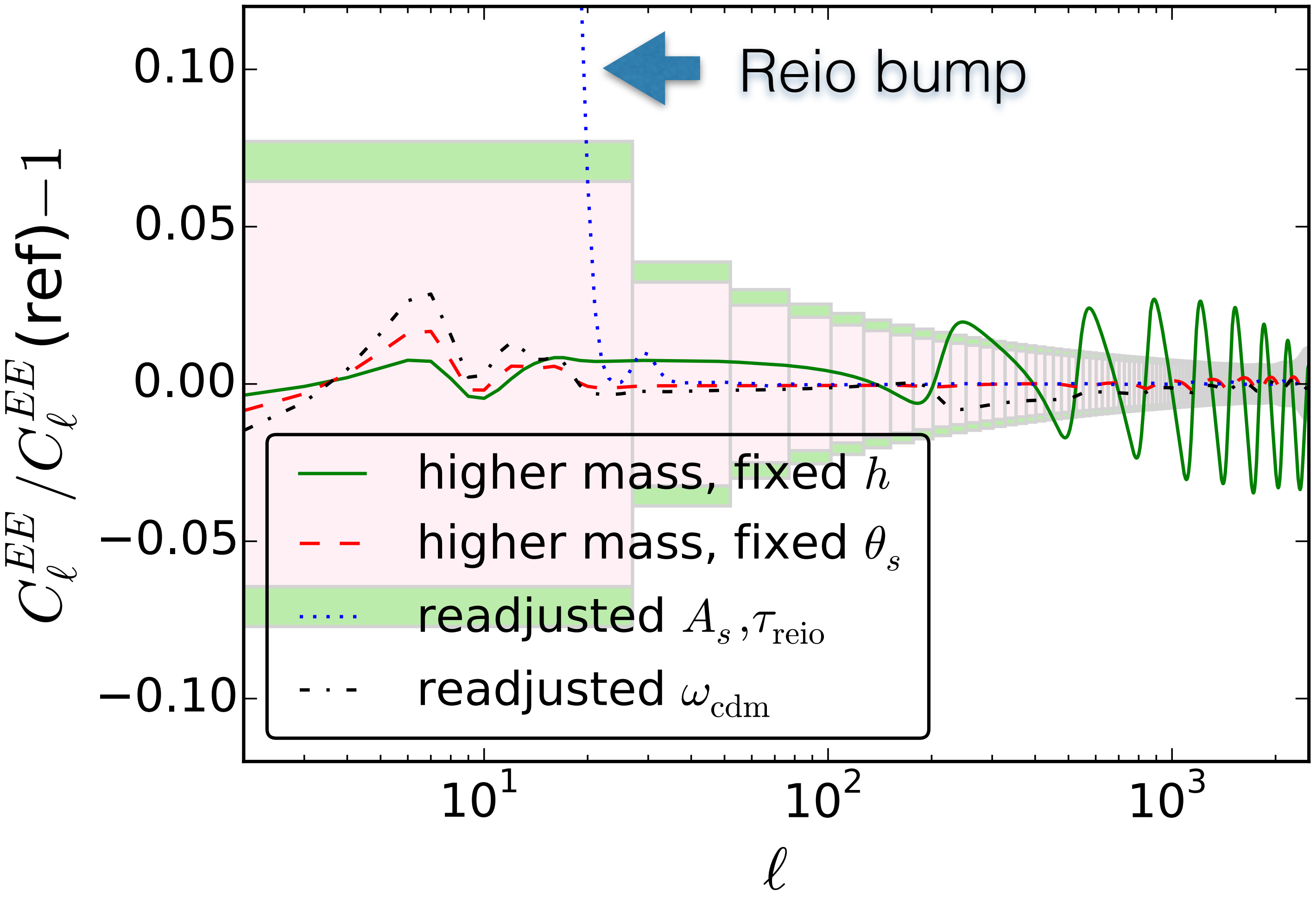
- $M_\nu \uparrow$ decreases amplitude of lensing spectrum
- Option 1: $A_s \uparrow$, $\tau_{\rm reio} \uparrow$

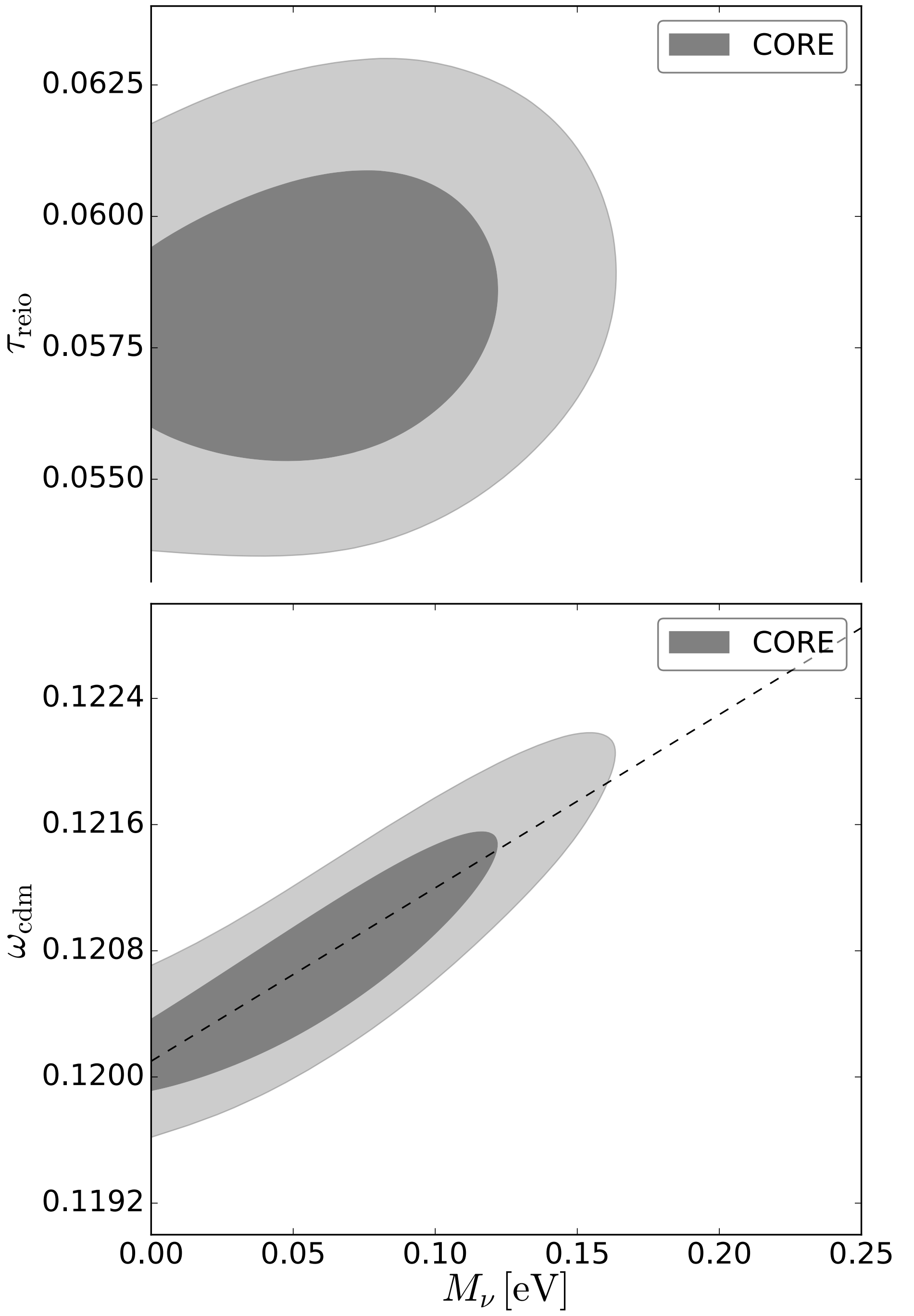
  Lensing: $C_\ell \propto A_s$

  TT, EE: $C_\ell \propto A_s \exp(-2\tau_{\rm reio})$
- Option 2: $\omega_{\rm cdm} \uparrow$



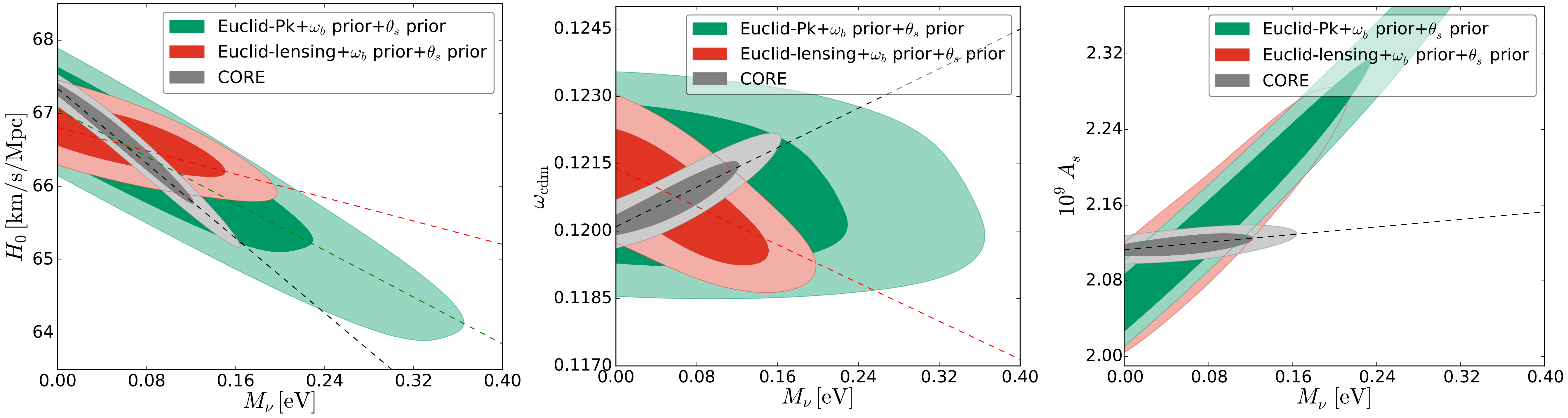
Parameter degeneracies: CMB-only





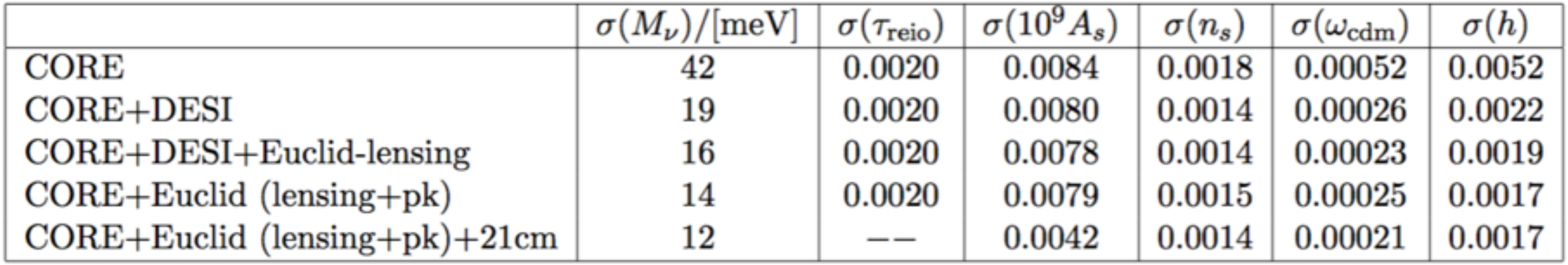
- M_ν ↑ will decrease amplitude of lensing spectrum
- Option 1: A_s ↑, also requires $\tau_{\rm reio}$ ↑
- Option 2: $\omega_{\rm cdm}$ ↑
- CMB-only prefers **option 2**: $\omega_{\rm cdm} - M_\nu$ degeneracy

Parameter degeneracies: adding LSS



- Experiments are sensitive to different effects at different epochs
- E.g. massive neutrinos behave rel. at early times, but non-rel. at late times
- Combining experiments allow us to break degeneracies
- Great prospects for improving constraints by exploiting complementarity

Sensitivity of future surveys



	$\sigma(M_\nu)/[\mathrm{meV}]$	$\sigma(\tau_{\mathrm{reio}})$	$\sigma(10^9 A_s)$	$\sigma(n_s)$	$\sigma(\omega_{\mathrm{cdm}})$	$\sigma(h)$
CORE	42	0.0020	0.0084	0.0018	0.00052	0.0052
CORE+DESI	19	0.0020	0.0080	0.0014	0.00026	0.0022
CORE+DESI+Euclid-lensing	16	0.0020	0.0078	0.0014	0.00023	0.0019
CORE+Euclid (lensing+pk)	14	0.0020	0.0079	0.0015	0.00025	0.0017
CORE+Euclid (lensing+pk)+21cm	12	−−	0.0042	0.0014	0.00021	0.0017

Combing possible future surveys:

- CORE-like CMB satellite
- Euclid weak lensing & galaxy clustering
- 21cm: a τ_{reio} prior inspired by radio surveys like HERA or SKA
  (Liu et al. 1509.08463)

By exploiting complementarity between future surveys:

- We expect to be able to measure the sum of neutrino masses to 5-sigma
- Even if the true mass is 60meV (≈ minimum mass in normal hierarchy)

Summary

Cosmology and parameter degeneracies

- Parameter degeneracies complicate measurements
- Cosmological constraints are model dependent
- Relevant to consider constraints given an array of extended models
- Complementarity between surveys at different epochs, probing different effects can break degeneracies and improve constraints

The future is bright!

- Cosmology should measure the neutrino mass sum in the next decade