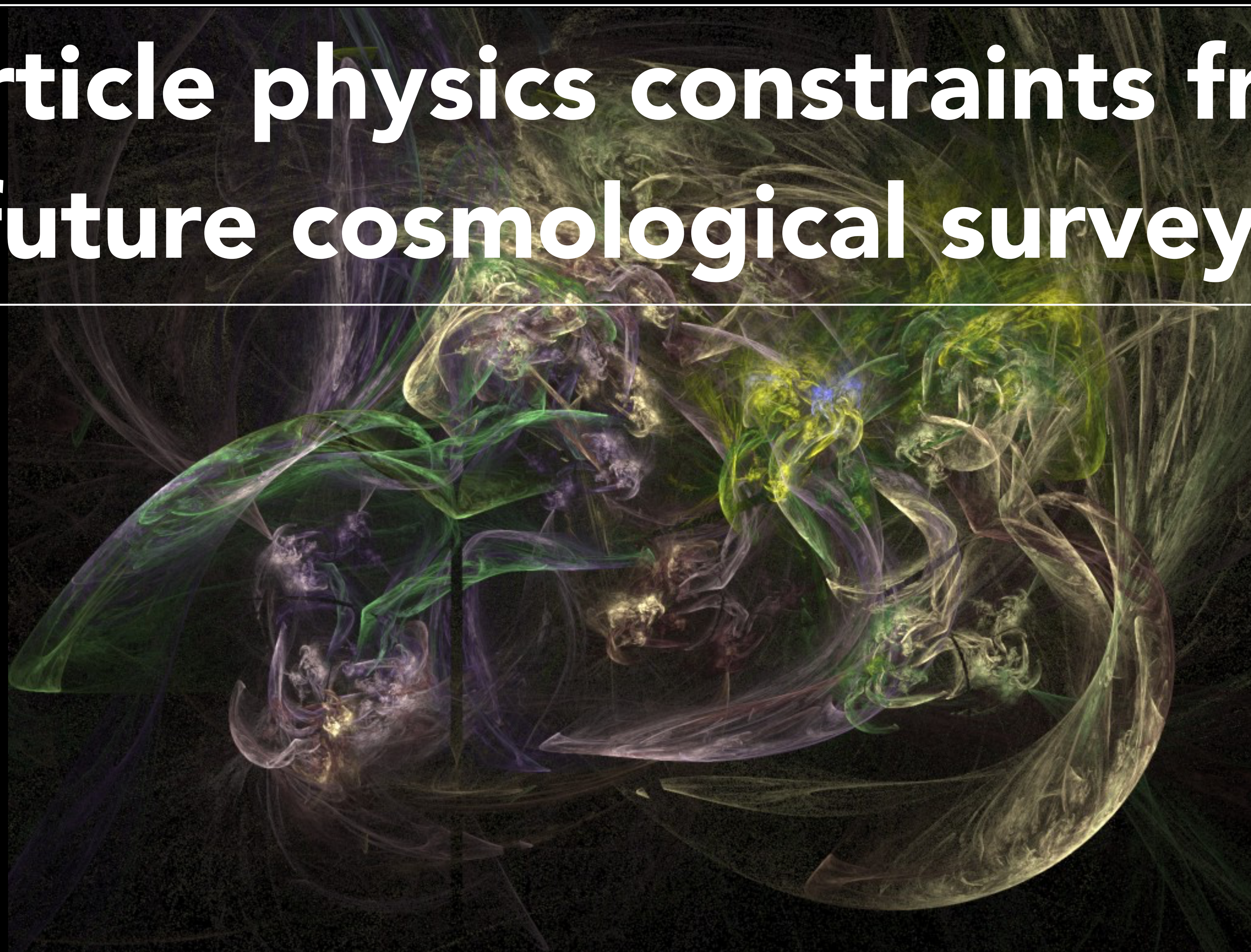
MPI für Kernphysik, 16.01.2017

Particle physics constraints from future cosmological surveys



J. Lesgourgues
Institut für Theoretische Teilchenphysik und Kosmologie (TTK), RWTH Aachen University

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Particle physics constraints from future cosmological surveys

Neutrinos mass

Extra light relics

DM annihilation, decay

J. Lesgourgues

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Particle physics constraints from future cosmological surveys

based mainly on

1606.02073, 1610.09852, 1610.10051, 1612.00021

in collaboration with

M. Archidiacono, T. Brinckmann, D. Hooper, V. Poulin, P. Serpico

J. Lesgourgues

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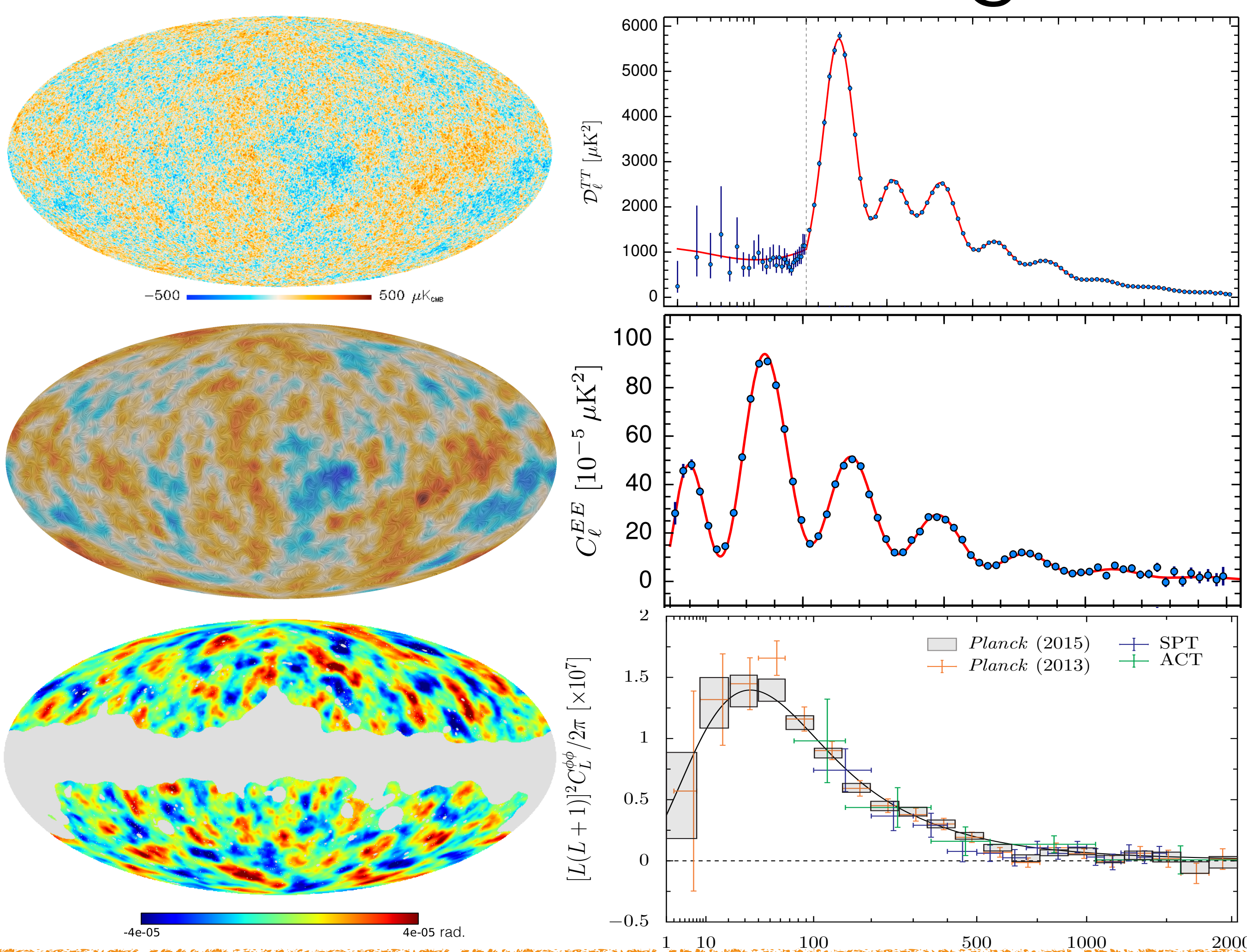
Theoretical cosmology

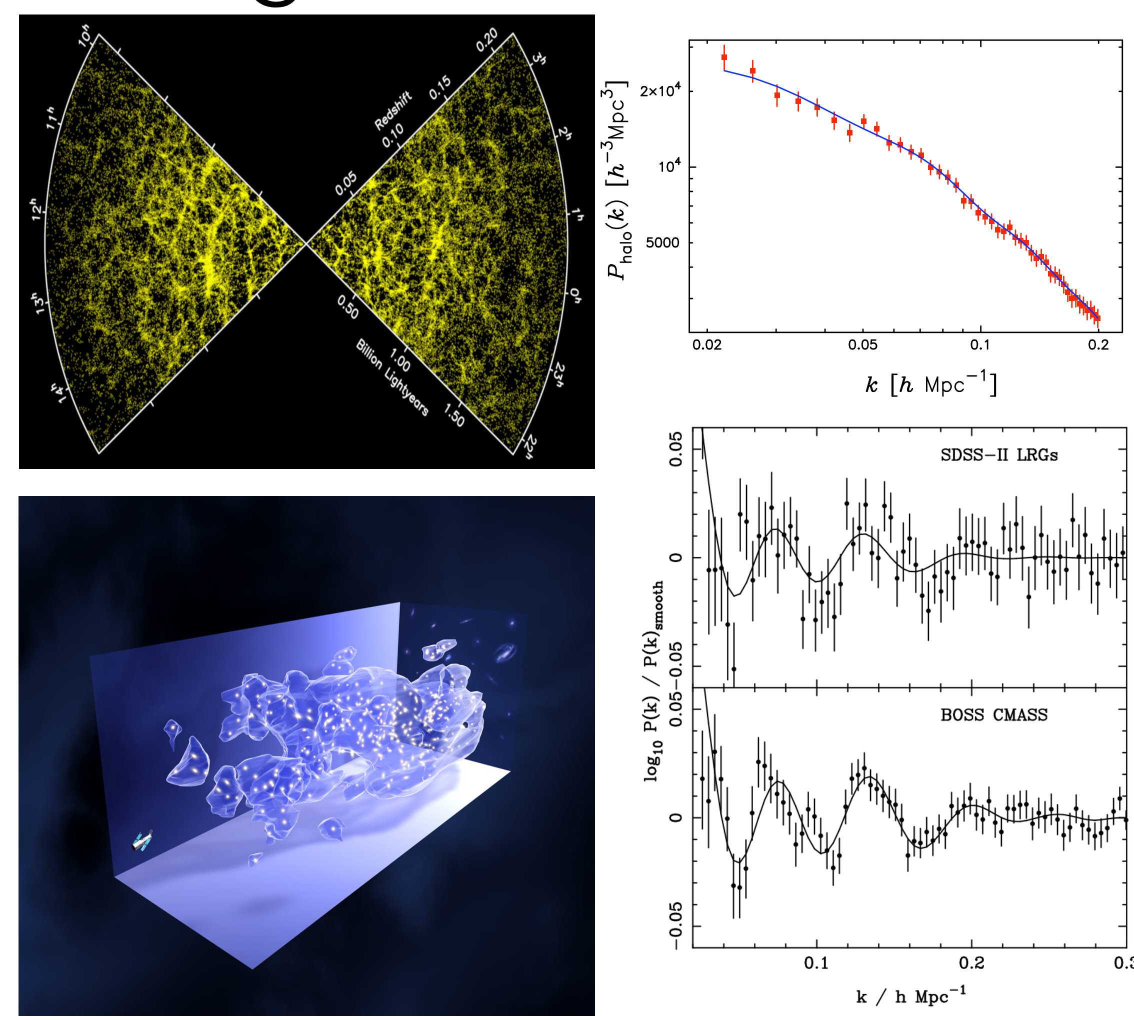
Theory of cosmological perturbations

(high-precision calculation in linear regime, computational challenge in non-linear regime)

Cosmic Microwave Background



Large Scale Structure



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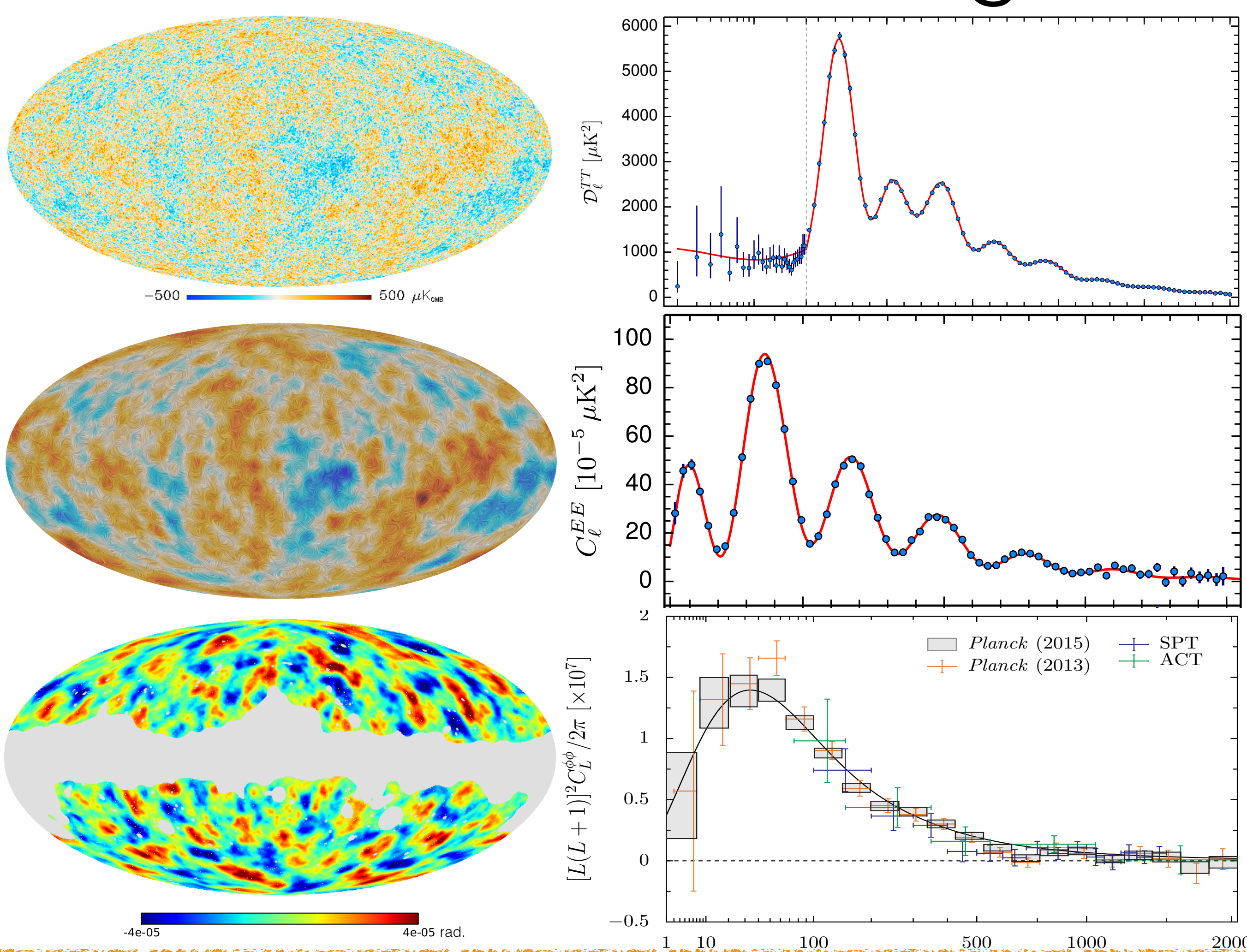
CLASS + MontePython, CAMB + CosmoMC

Cosmic Microwave Background



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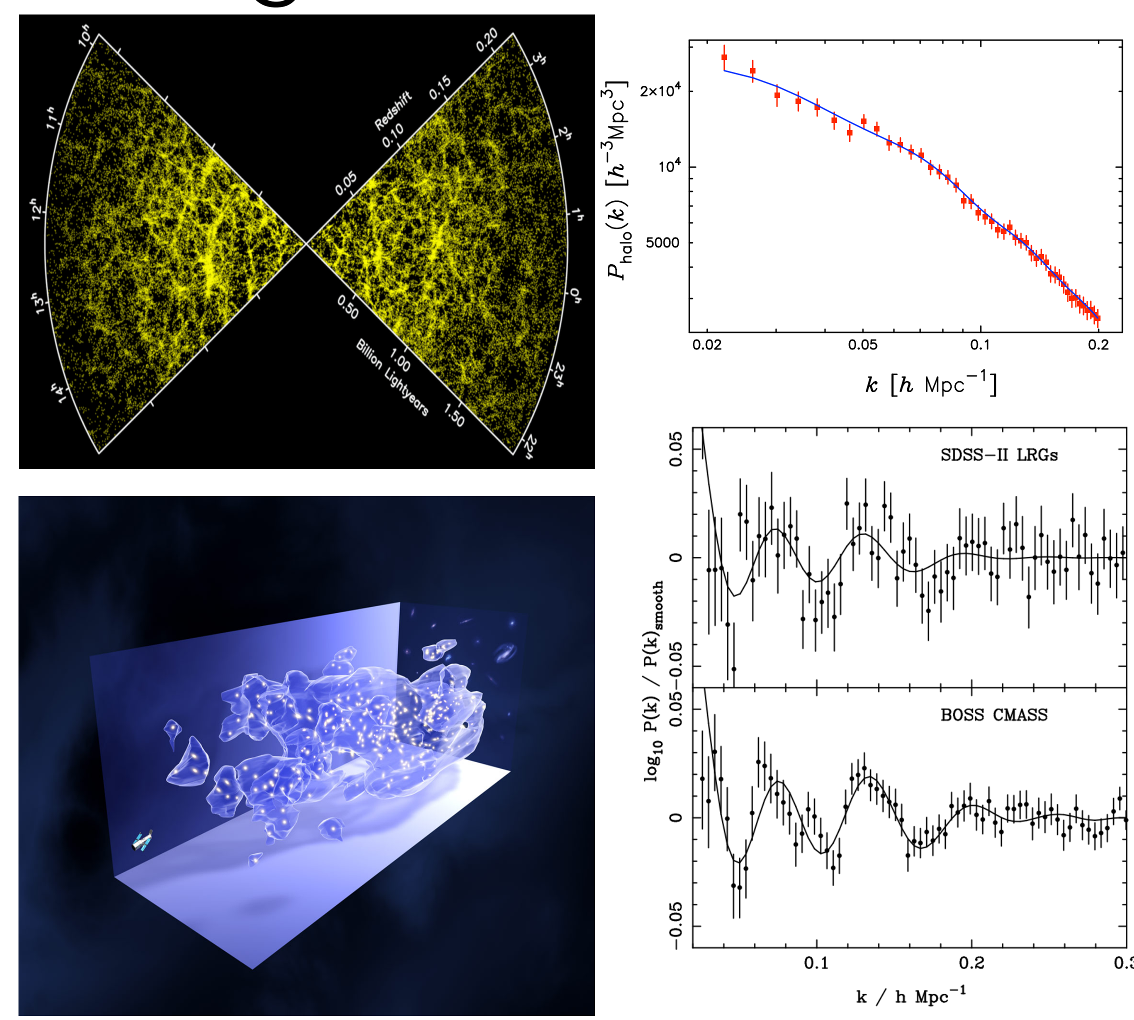
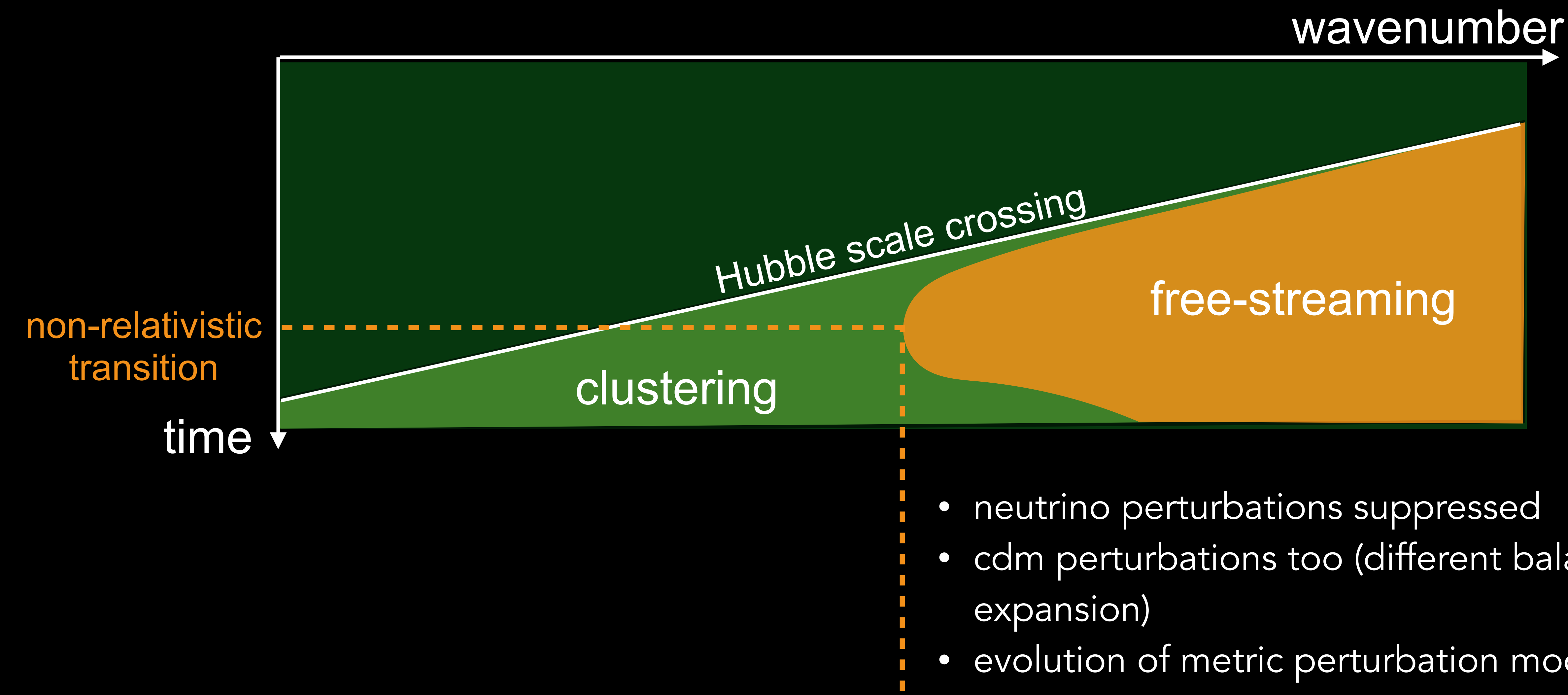


Neutrino masses



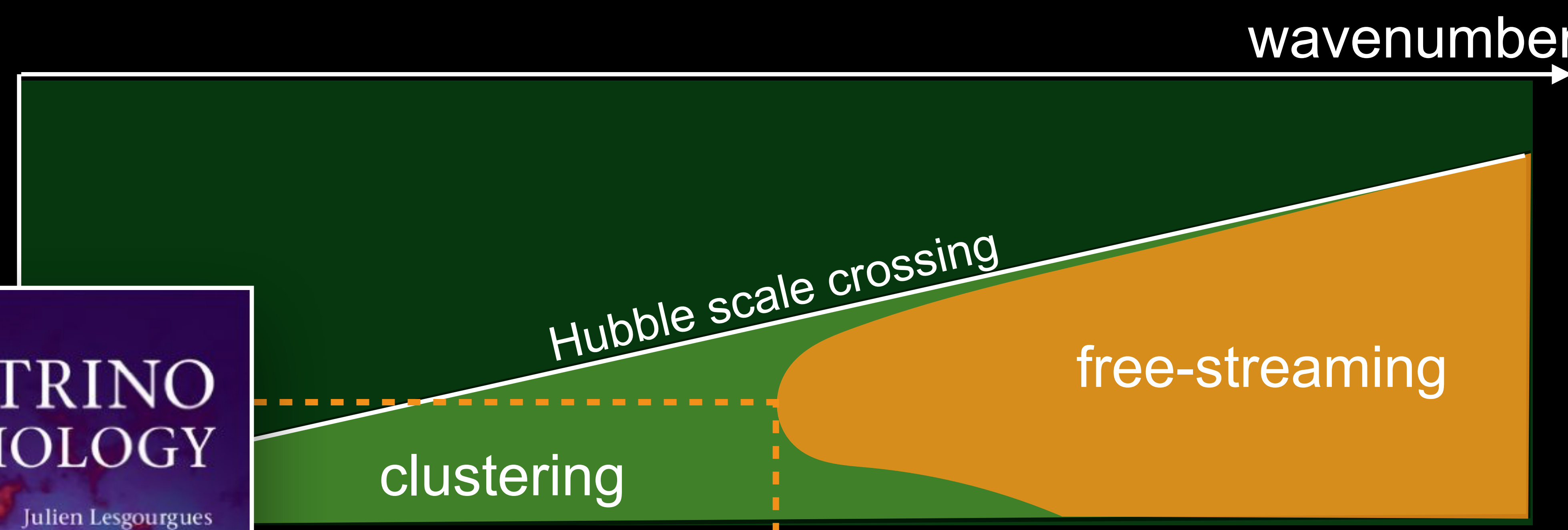
- neutrino perturbations suppressed
- cdm perturbations too (different balance gravity/expansion)
- evolution of metric perturbation modified

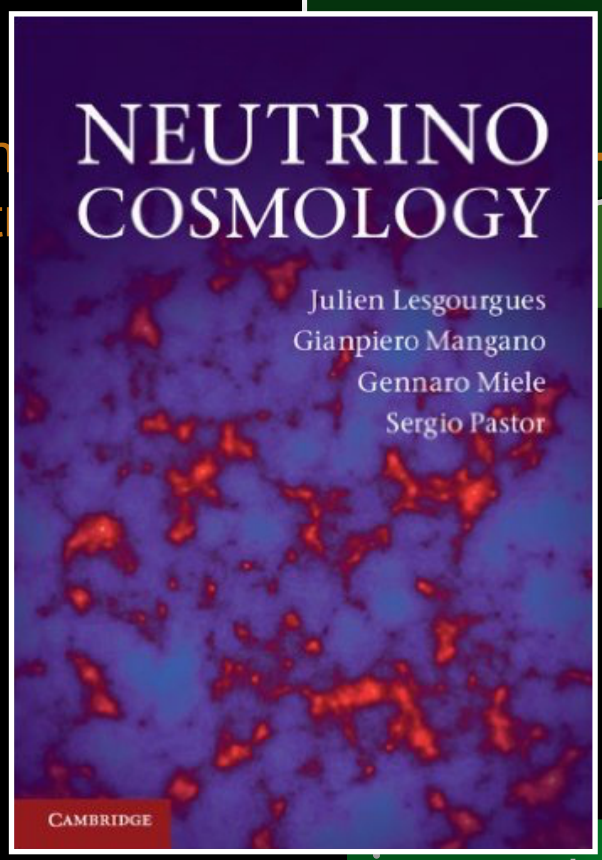
impact on LSS (matter power spectrum, galaxy lensing)

and

CMB (integrated Sachs-Wolfe, CMB lensing)

Neutrino masses





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Neutrino masses

Current status:

- **Very conservative:**

Planck 2015 high-l TT + new 2016 low-l TT,TE,EE:
M_ν < **590 meV** (95%CL)
[Planck col.] 1605.02985

- **More aggressive:**

Planck 2015 high-l TT,TE,EE + new 2016 low-l TT,TE,EE + lensing:
M_ν < **140 meV** (95%CL)
[Planck col.] 1605.02985

Planck 2013 + Lyman-α from BOSS:
M_ν < **120 meV** (95%CL)
Palanque-Delabrouille et al. 1506.05976

These bounds assume minimal ΛCDM+M_ν, but bounds for extended models hardly weaker

Neutrino masses

Future prospects:

New CMB data

- Ground based (ongoing → CMB-S4)
- Satellite? CORE [M5 proposal to ESA], LiteBird [proposal to JAXA]

New measurements of matter power spectrum shape

- Cosmic shear of galaxies
- Clustering of Galaxies and cluster

DES, eBOSS, LSST, DESI, Euclid, WFIRST…

New measurements of Baryon Acoustic Oscillation (BAO) scale

DES, eBOSS, LSST, DESI, Euclid, WFIRST…

21cm Hydrogen-line surveys

- Reionisation history
- Matter clustering in Dark Ages

HERA, SKA, …

Neutrino masses

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Cosmic complementarity

New measurements of Bary Acoustic Oscillation (BAO) scale

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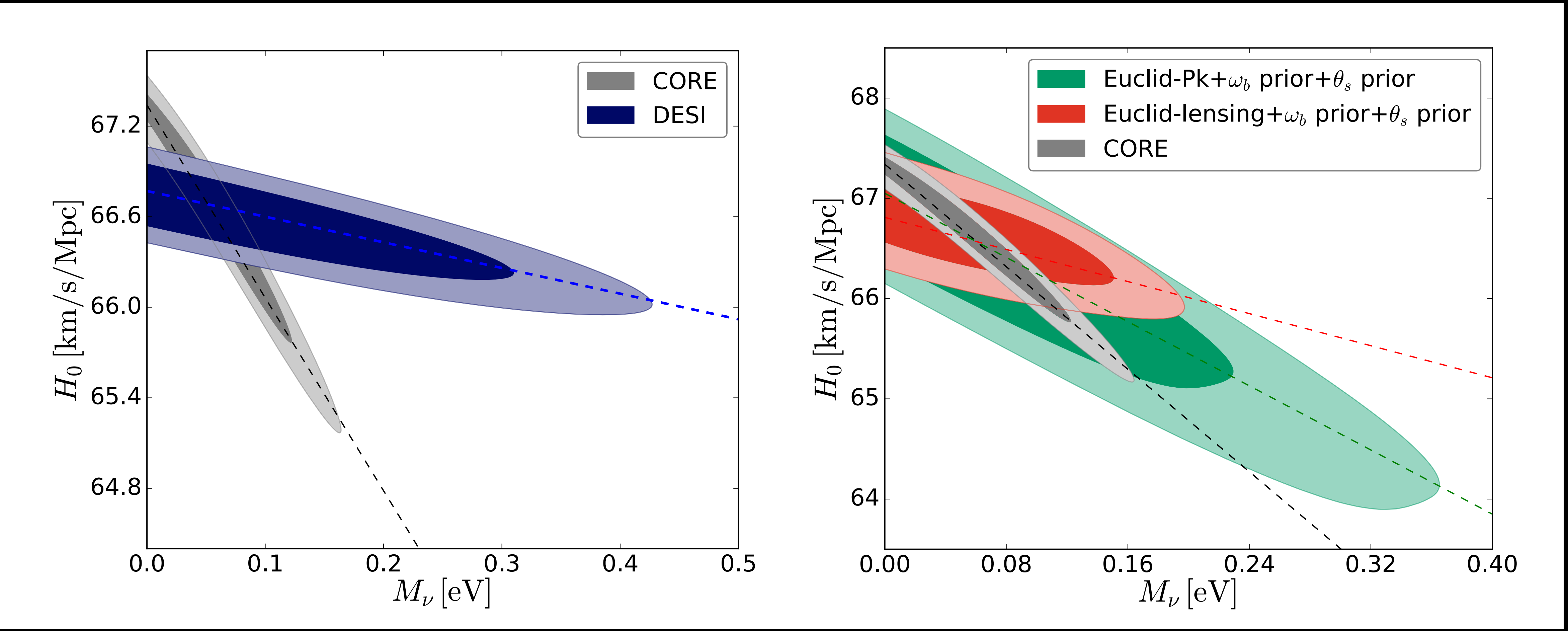
Neutrino masses

Complementarity of future CMB, BAO, LSS:

Archidiacono et al. 1610.09852



(M_ν, h) : geometrical degeneracy related to angular diameter distance, probed at different redshifts by CMB, BAO, LSS…

Neutrino masses

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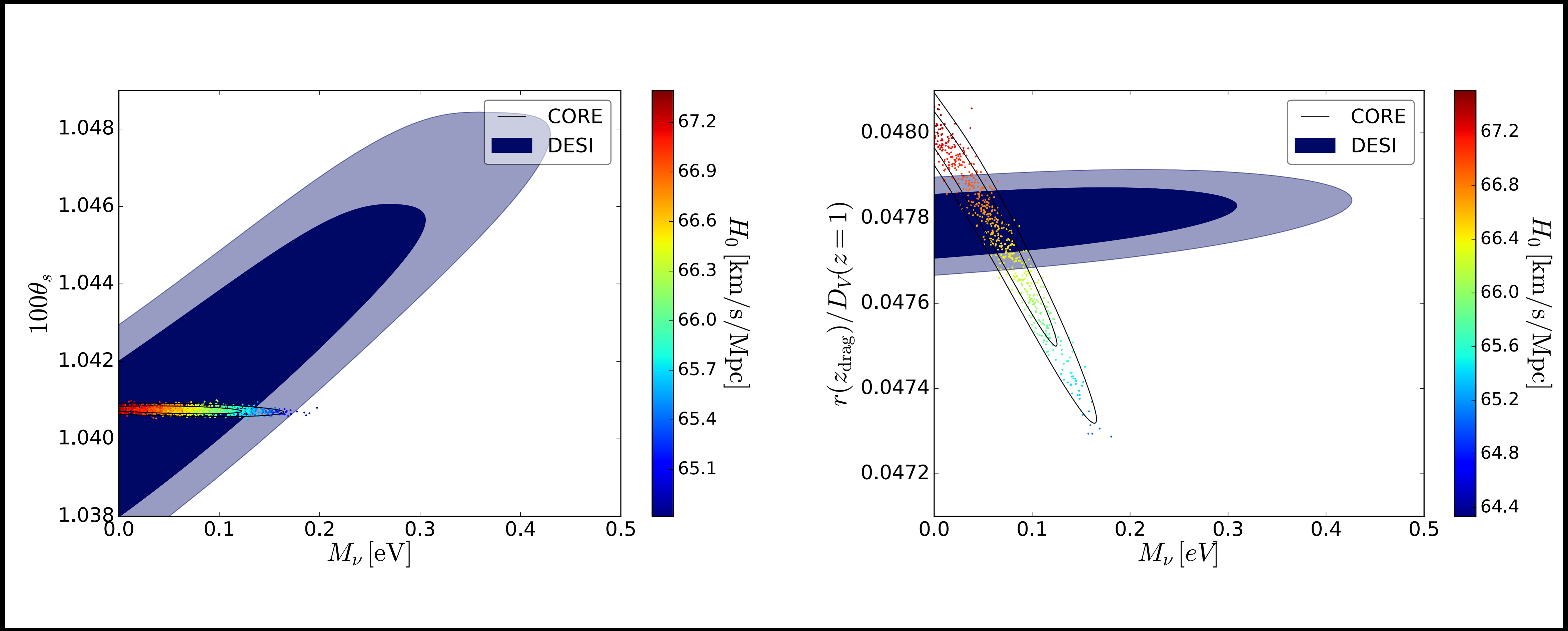

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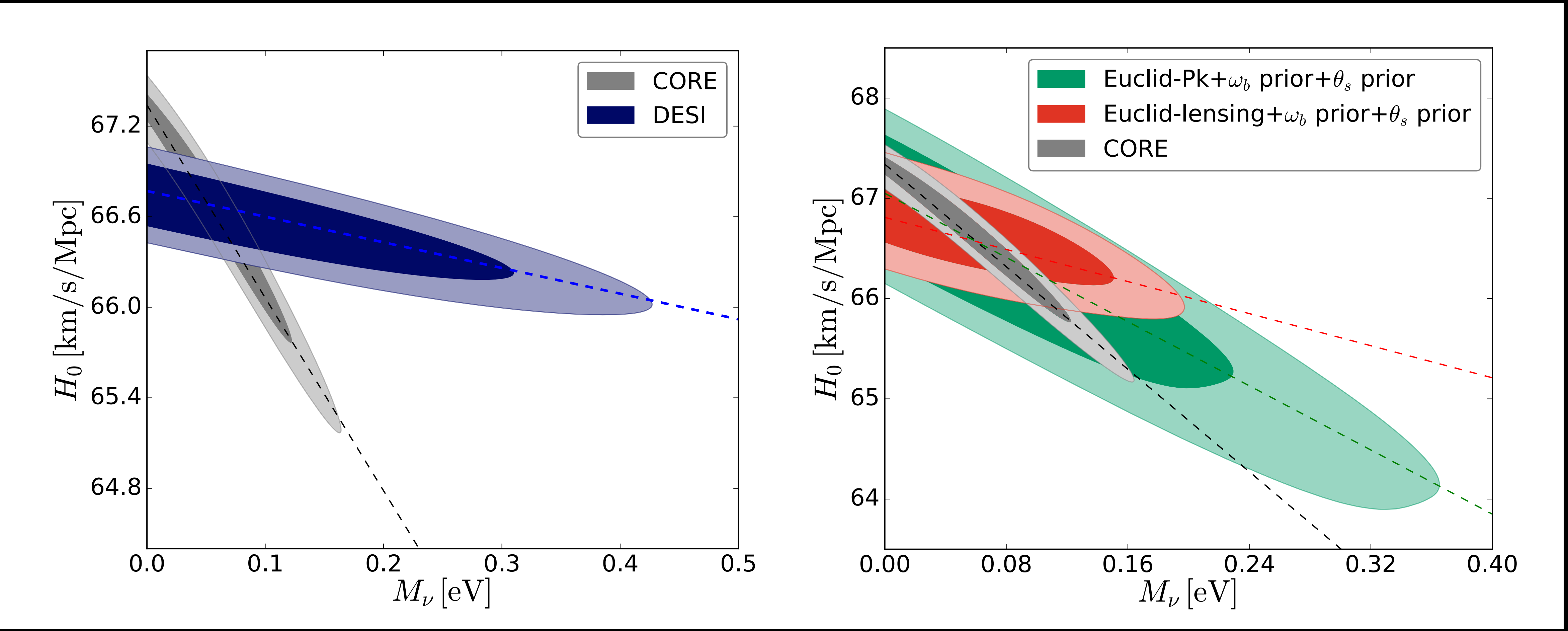

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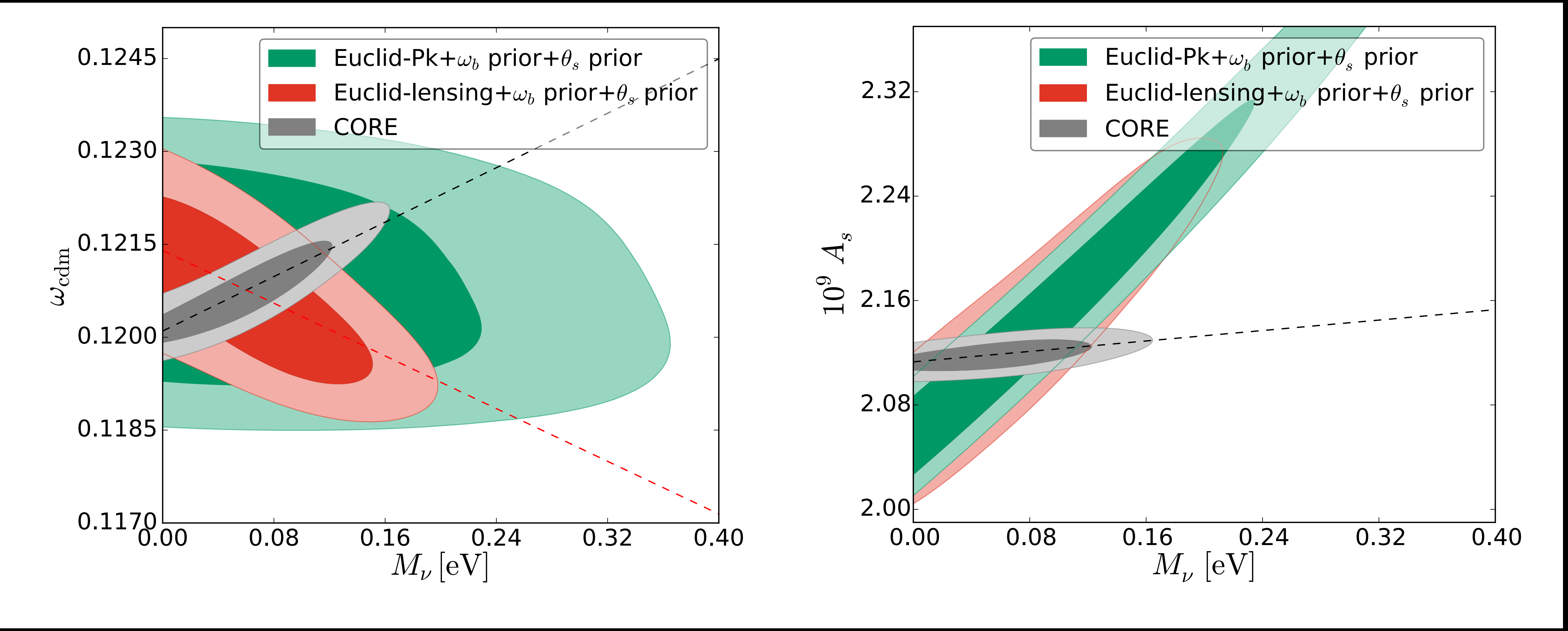
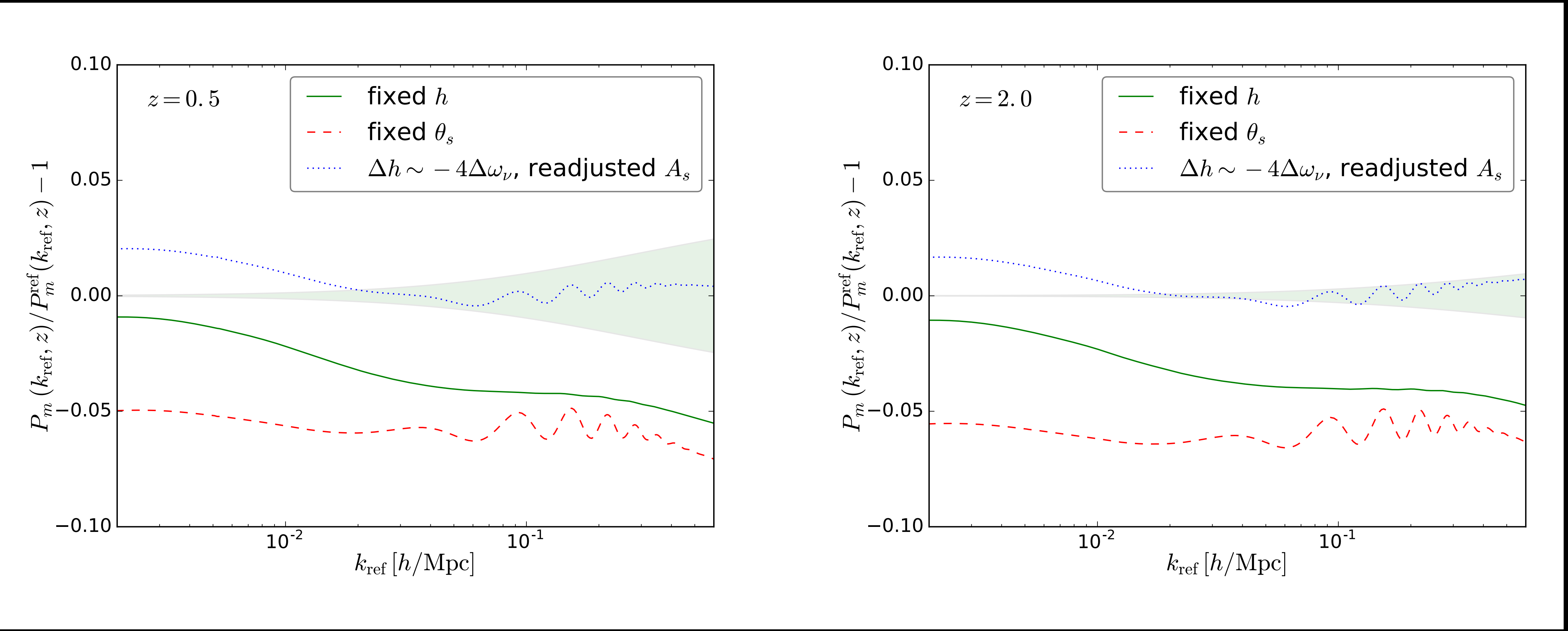


(M_ν, ω_{cdm}) and (M_ν, A_s) : degeneracy related to CMB lensing, and to the shape and amplitude of the matter power spectrum

Neutrino masses

Complementarity of future CMB, BAO, LSS:

Archidiacono et al. 1610.09852



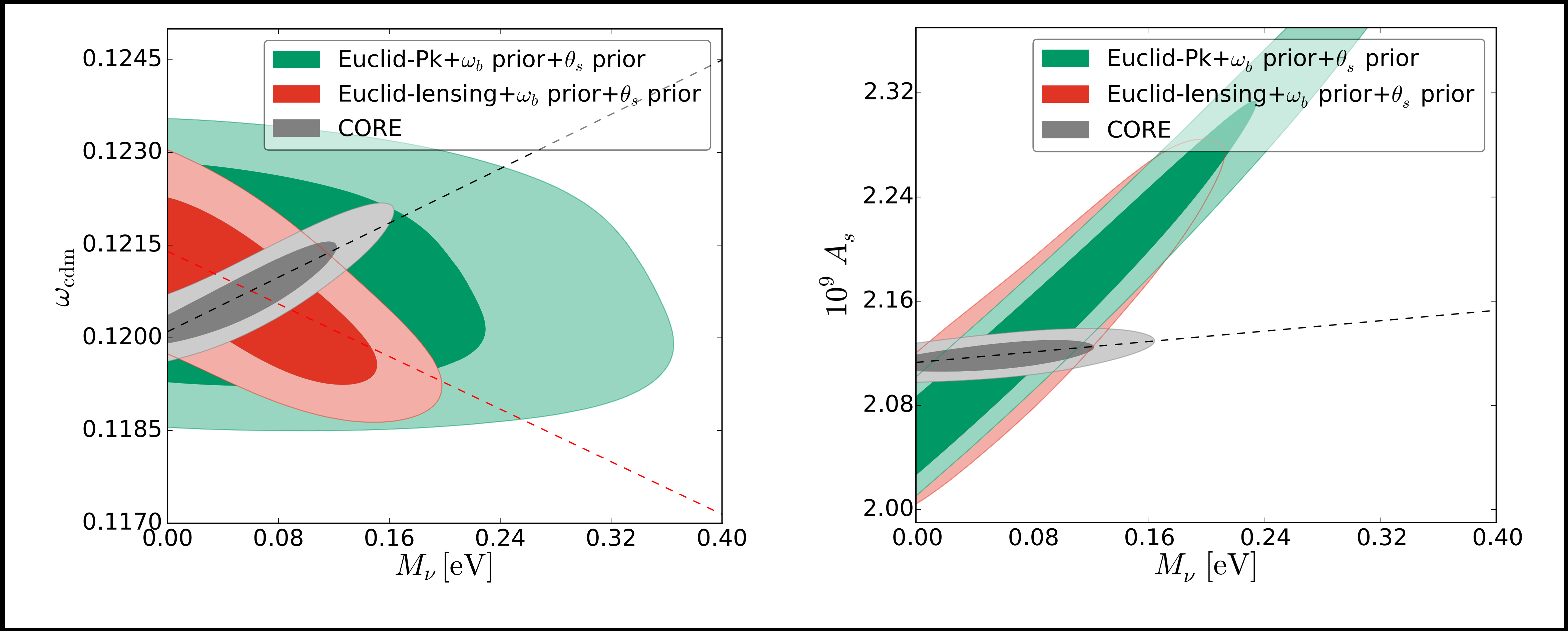
M_ν effect on matter power spectrum:

- **with fixed params including ω_{dm} : usual step-like suppression**
- **with CMB peak scale : nearly constant**
- **with A_s readjusted : nearly degenerate**

Neutrino masses

Complementarity of future CMB, BAO, LSS:

Archidiacono et al. 1610.09852



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Neutrino masses

Complementarity of future CMB, BAO, LSS:

Archidiacono et al. 1610.09852

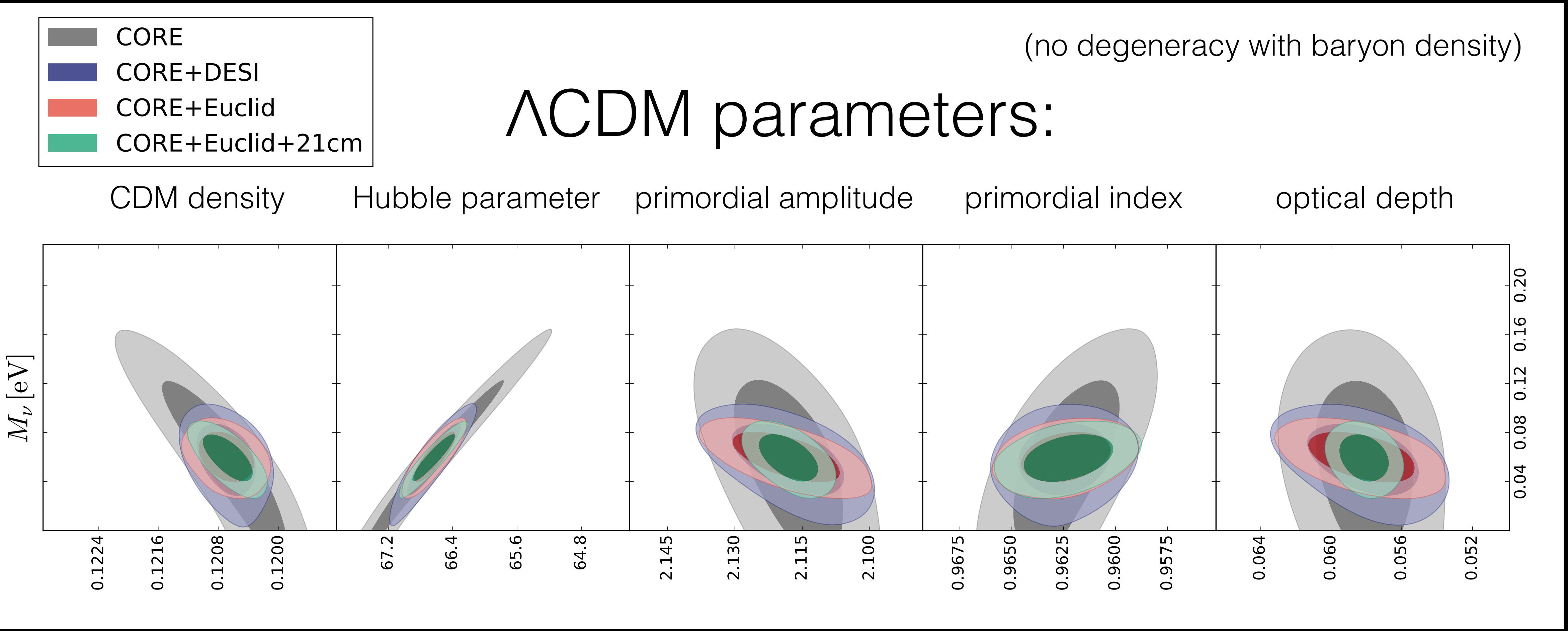
Future experiments	$\sigma(M_\nu)/[\mathrm{meV}]$
CORE	42
CORE+DESI	19
CORE+DESI+Euclid-lensing	16
CORE+Euclid (lensing+pk)	14

- **at least 4σ detection**
- **valid in ΛCDM and most of its extensions**
- **possible dangerous degeneracies: with w_{DE}**

Neutrino masses

Complementarity of future CMB, BAO, LSS:

Archidiacono et al. 1610.09852



- **future 21cm like HERA, SKA may achieve independently Δ(τ)=0.001 (x9 better than Planck) and lead to possible 5σ detection even in minimal hierarchy:**

	$\sigma(M_\nu)/[\mathrm{meV}]$
CORE+Euclid (lensing+pk)+21cm	12

Neutrino masses

Conclusions:

- 5σ detection of M_ν possible even if M_ν = 60 meV
- Error forecasts robust even for non-minimal cosmological assumptions
- More sensitive than β- and double-β- decay (KATRIN, GERDA, …), works for Dirac and Majorana
- Complementary to β-decay which contains independent information (on phases, angles, Dirac/Majorana…)
- No direct test of NH versus IH like PINGU or ORCA, but if measured mass is close to 60 meV, IH could be excluded at 4 to 5σ…

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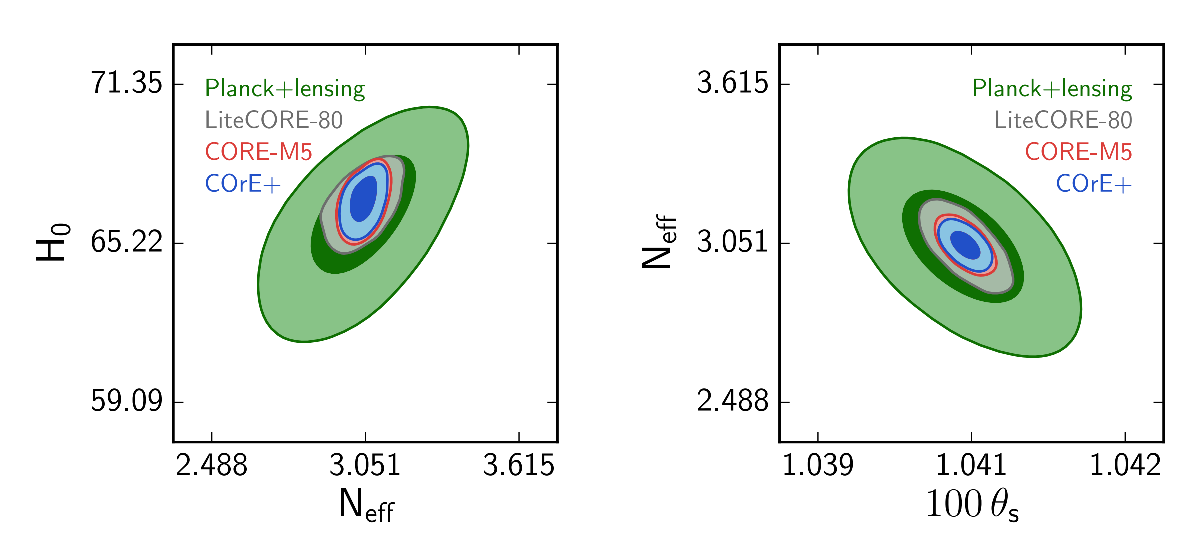
Extra relics (massless case)

Current an future bounds on density of relativistic relics beyond photons (standard model: $N_{eff} = 3.046$)

CORE beats degeneracy with H_0 (redshift of equality) and is limited by determination of peak scale angle (neutrino drag effect)

Planck 2015 (TT,TE,EE + lowP + lensing)	CORE alone CORE collaboration [1612.00021]
$N_{eff} = 3.04 \pm 0.18$ (68%CL)	$\sigma(N_{eff}) = 0.041$

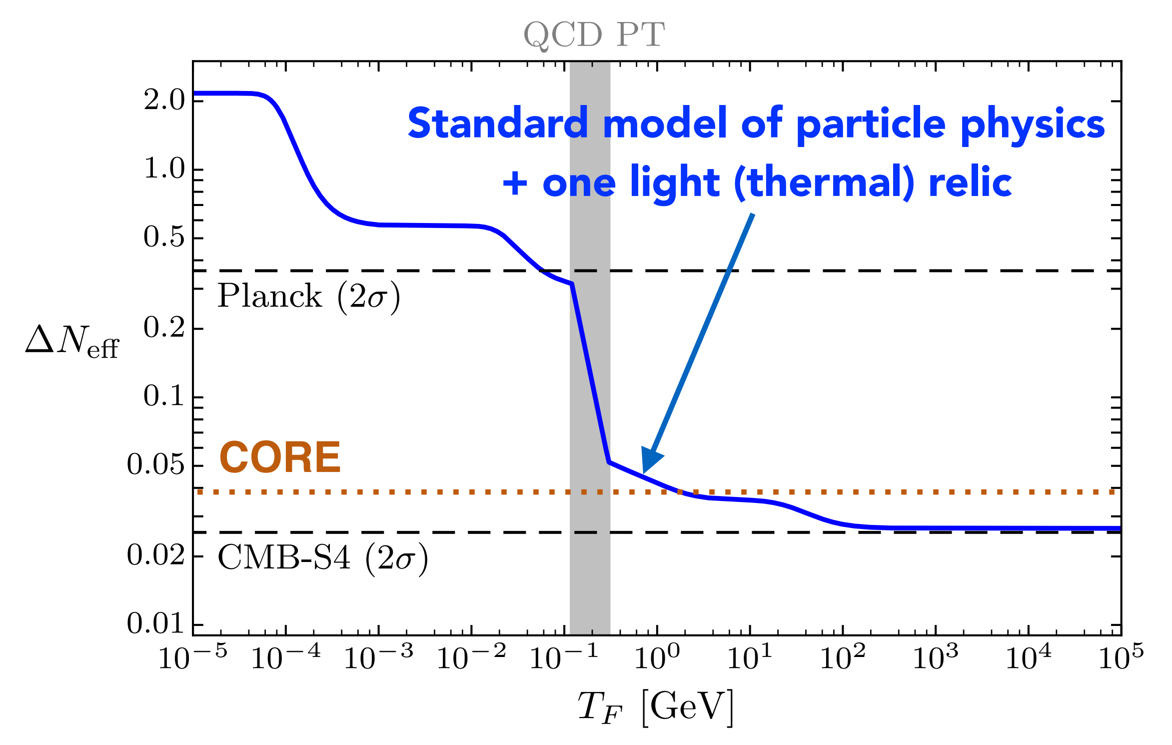


Extra relics (massless case)

Current an future bounds on density of relativistic relics beyond photons (standard model: $N_{eff} = 3.046$)

Test of non-thermal or early decoupled thermal relics (Axion-Like Particles, …), low-temperature reheating models, neutrino NSI (non-standard interactions…)

Planck 2015 (TT,TE,EE + lowP + lensing)	CORE alone CORE collaboration [1612.00021]
$N_{eff} = 3.04 \pm 0.18$ (68%CL)	$\sigma(N_{eff}) = 0.041$



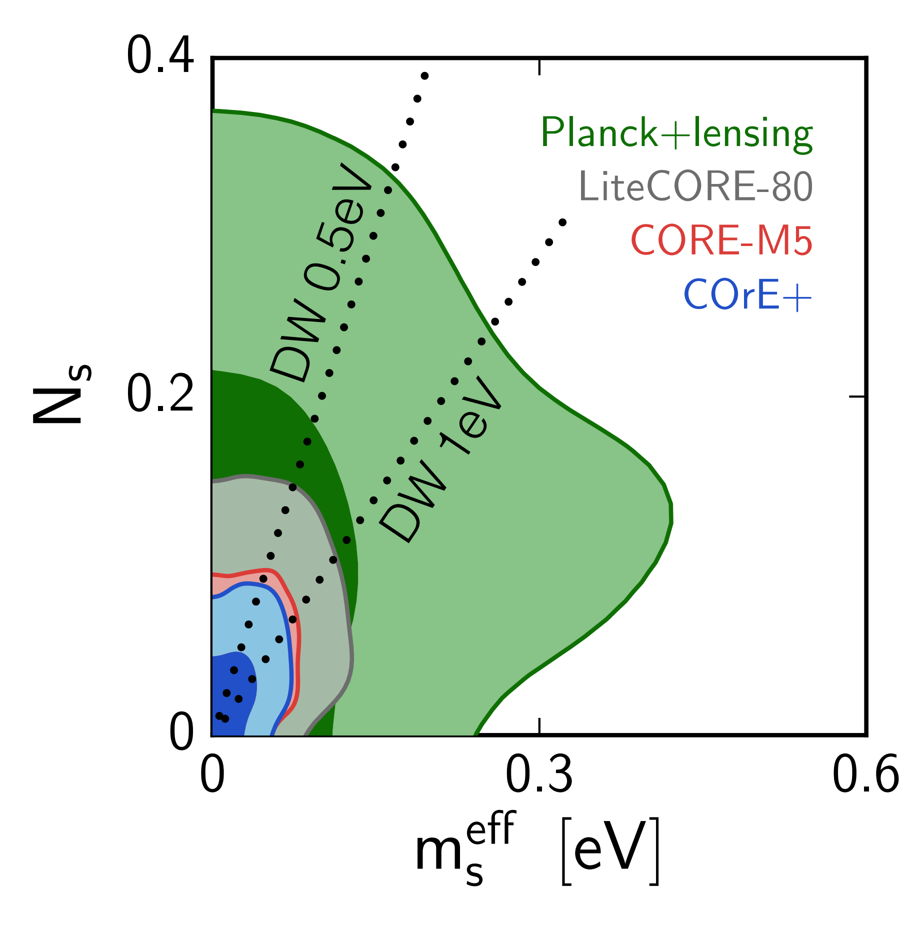
Bauman et al. 1604.08614

Extra relics (small mass case)

Current an future bounds on one early-decoupled or non-thermalized extra light species (e.g. sterile neutrino)

Effective density parameters	Planck 2015 (TT+lowP +lensing) + BAO	CORE + DESI + Euclid CORE collaboration [1612.00021]
ΔN_{eff} (extra contribution to density *before* NR transition)	<0.7 (95%CL)	2σ ~ 0.10
m_{eff} (extra contribution to density *after* NR transition)	< 400 meV (95%CL)	2σ ~ 66 meV

For Dodelson-Widrow neutrinos, physical mass $m = m_{eff}/\Delta N_{eff}$



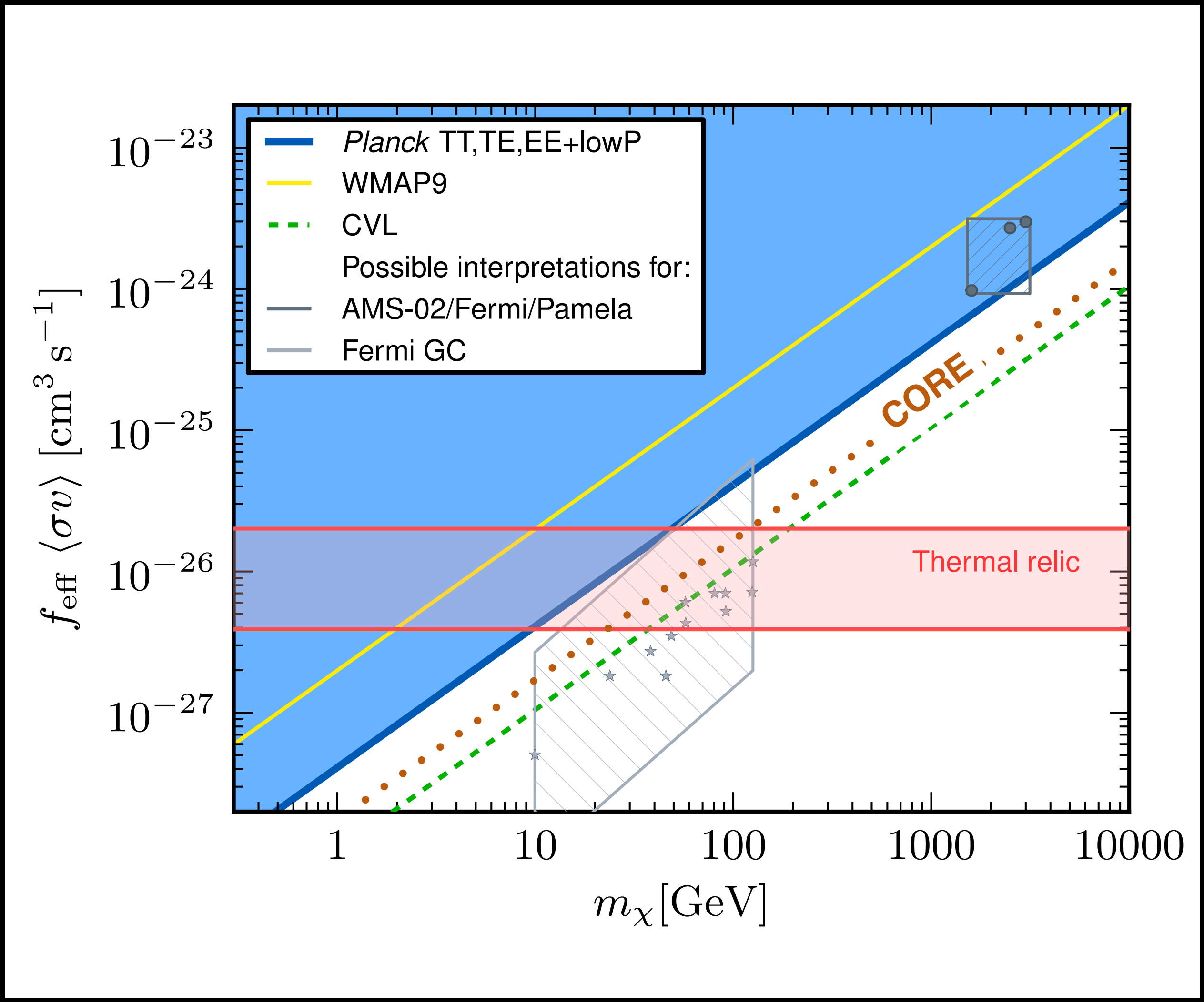
CORE et al. 1612.00021

(forecasted errors obtained while simultaneously varying — and measuring — active neutrino mass scale)

DM annihilation cross-section (WIMPs, etc.)

Current an future bounds from CMB only (due to heating, ionization and excitation of thermal plasma [Slatyer et al. 2012-2016])

Effective annihilation parameter	Planck 2015 (TT,TE,EE + lowP+ lensing)	CORE CORE collab. [1612.00021]
$p_{ann} = \langle\sigma v\rangle / m_{DM}$ x {branching-ratio-dependent factor} [cm^3/s/GeV]	< 3.4 10^{-28} (95%CL)	< 1.4 10^{-28} (95%CL)
m_{DM} assuming thermal WIMP cross-section, and ≠ branching ratios, from $\tau\tau$ to ee	> 10 to 50 GeV (95%CL)	> 25 to 120 GeV (95%CL)

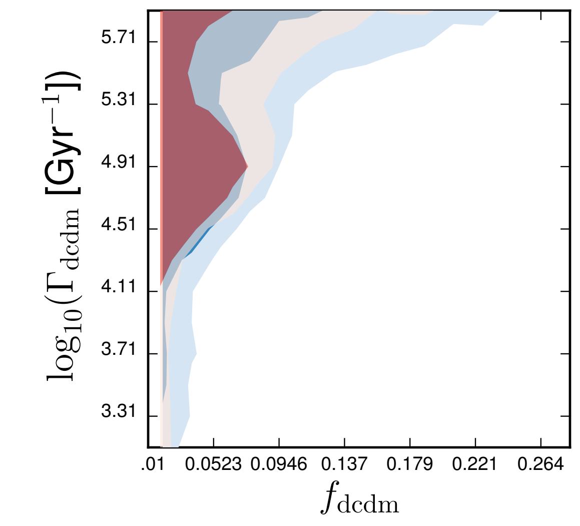


Planck 2015 collaboration 1502.01589

DM lifetime (gravitational effects)

Current and future bounds on lifetime from CMB only (DM decaying into neutrinos or extra relativistic relics; non trivial CMB effects, especially on *CMB lensing* and *late Integrated Sachs Wolfe effect, etc.*)

	+ Planck 2015 (TT,TE,EE lowP+ lensing) Poulin et al. 1606.02073	CORE alone CORE collab. [1612.00021]
100% of CDM = decaying particles	> 160 Gyr (95%CL)	> 330 Gyr (95%CL)
fraction *f* of CDM = decaying particles	• long-lived: *same / f* • short-lived: 4.2% of CDM may decay completely between photon decoupling and today (even more may decay earlier)	←

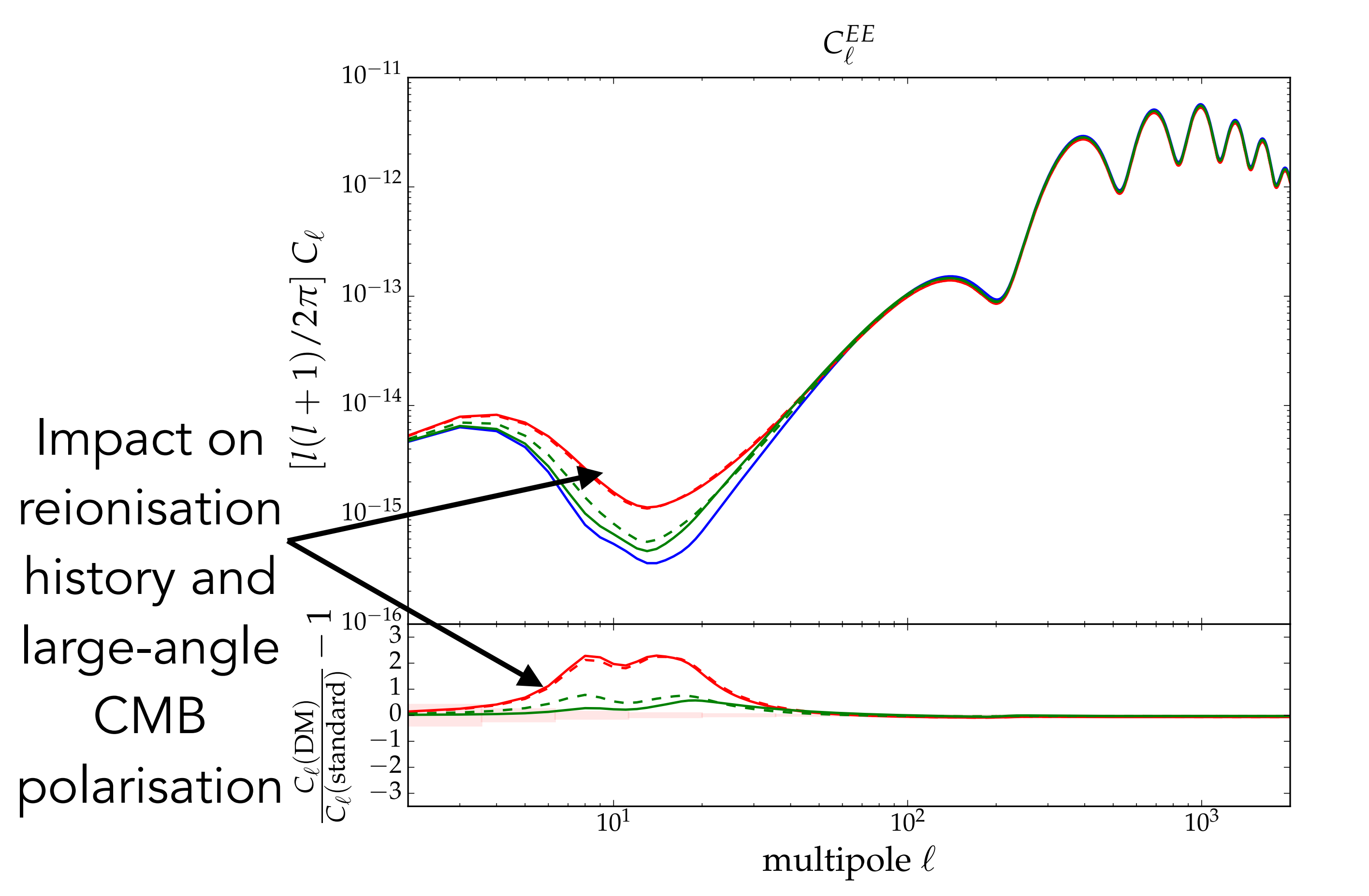


DM lifetime (electromagnetic effects)

Current and future bounds on decay rate from CMB only (DM decaying into SM particles other than neutrinos, heating/ionization/excitation of thermal plasma [Slatyer et al. 2012-2016])

- **If 100% of CDM** is of decaying nature and all decay energy ends up in γ, e^+, e^- :

Planck 2015 (TT,TE,EE + lowP+ lensing) Oldengott et al. 1605.03928 Poulin et al. 1610.10051	CORE alone CORE collab. [1612.00021]
< 5.3 10^{-26} s^{-1} (95%CL)	< 5.6 10^{-27} s^{-1} (95%CL)



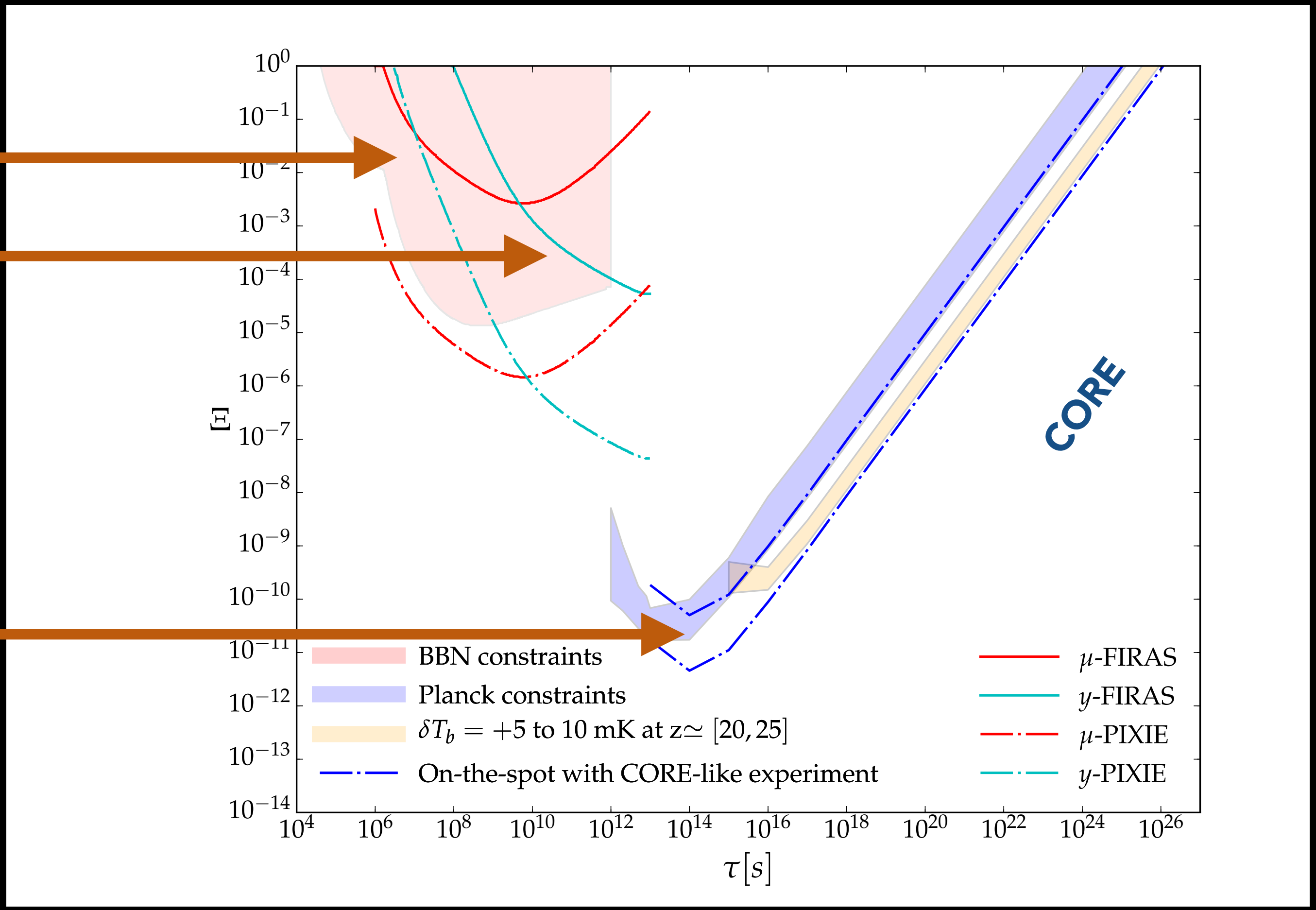
DM lifetime (electromagnetic effects)

Current and future bounds on decay rate from CMB only (DM decaying into SM particles other than neutrinos, heating/ionization/excitation of thermal plasma)

- **If fraction Ξ of CDM** is of decaying nature and ends up in γ, e^+, e^- :

complementarity:
with **BBN**
with **CMB spectral distorsions**
(also with **cosmic rays** at large τ)

maximum CMB sensitivity when lifetime ~ z=300



Poulin et al. 1610.10051

see also Slatyer & Wu 2016

DM lifetime (electromagnetic effects)

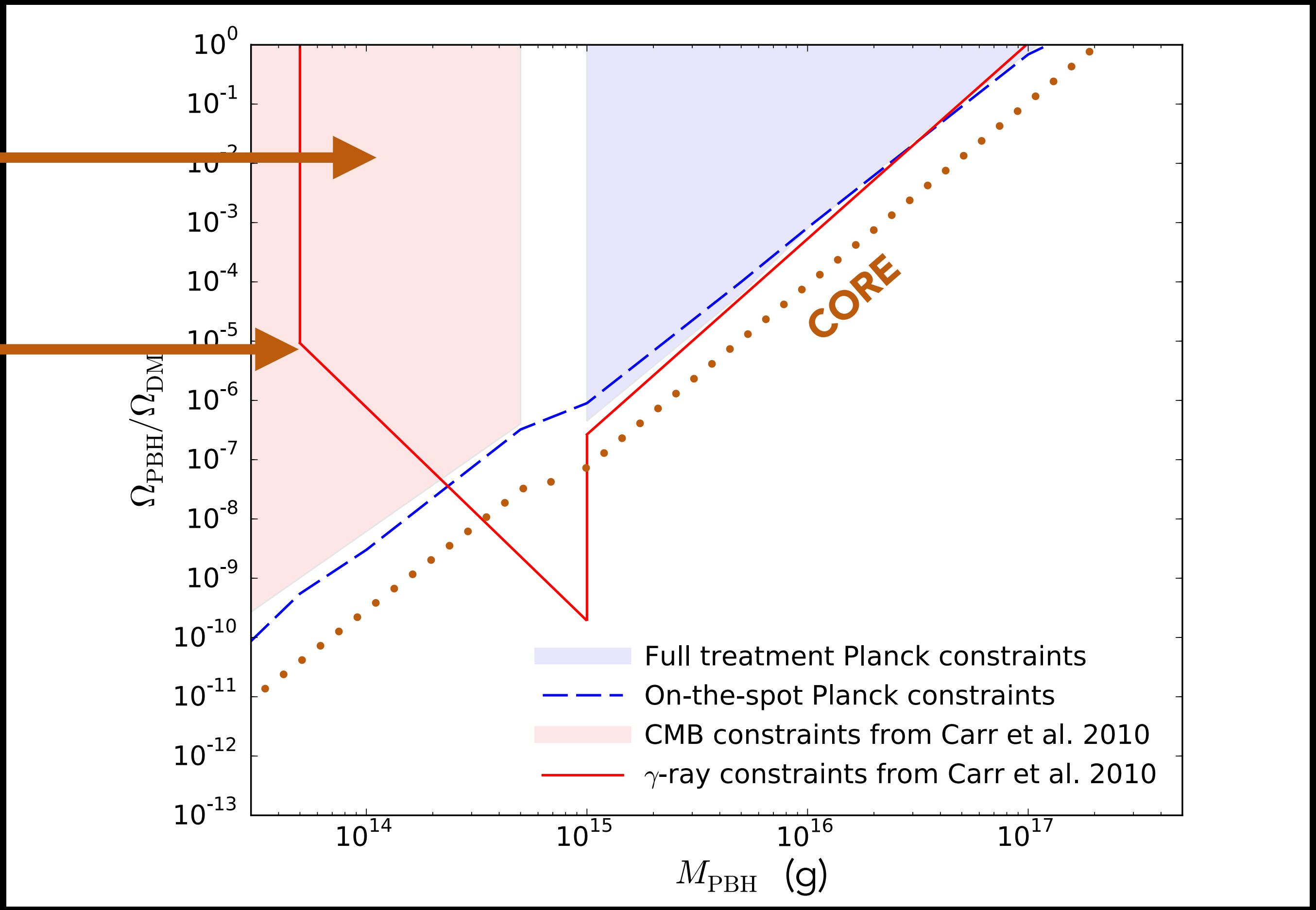
Current and future bounds on decay rate from CMB only (DM decaying into SM particles other than neutrinos, heating/ionization/excitation of thermal plasma)

- **Application** to **Primordial Black Holes** of mass 10^{14}-10^{18}g = fraction of DM

complementary to
CMB spectral distorsions

and γ-ray background

(Hawking evaporation
in different channels,
depending on $T_{BH} \sim M^{-1}$)

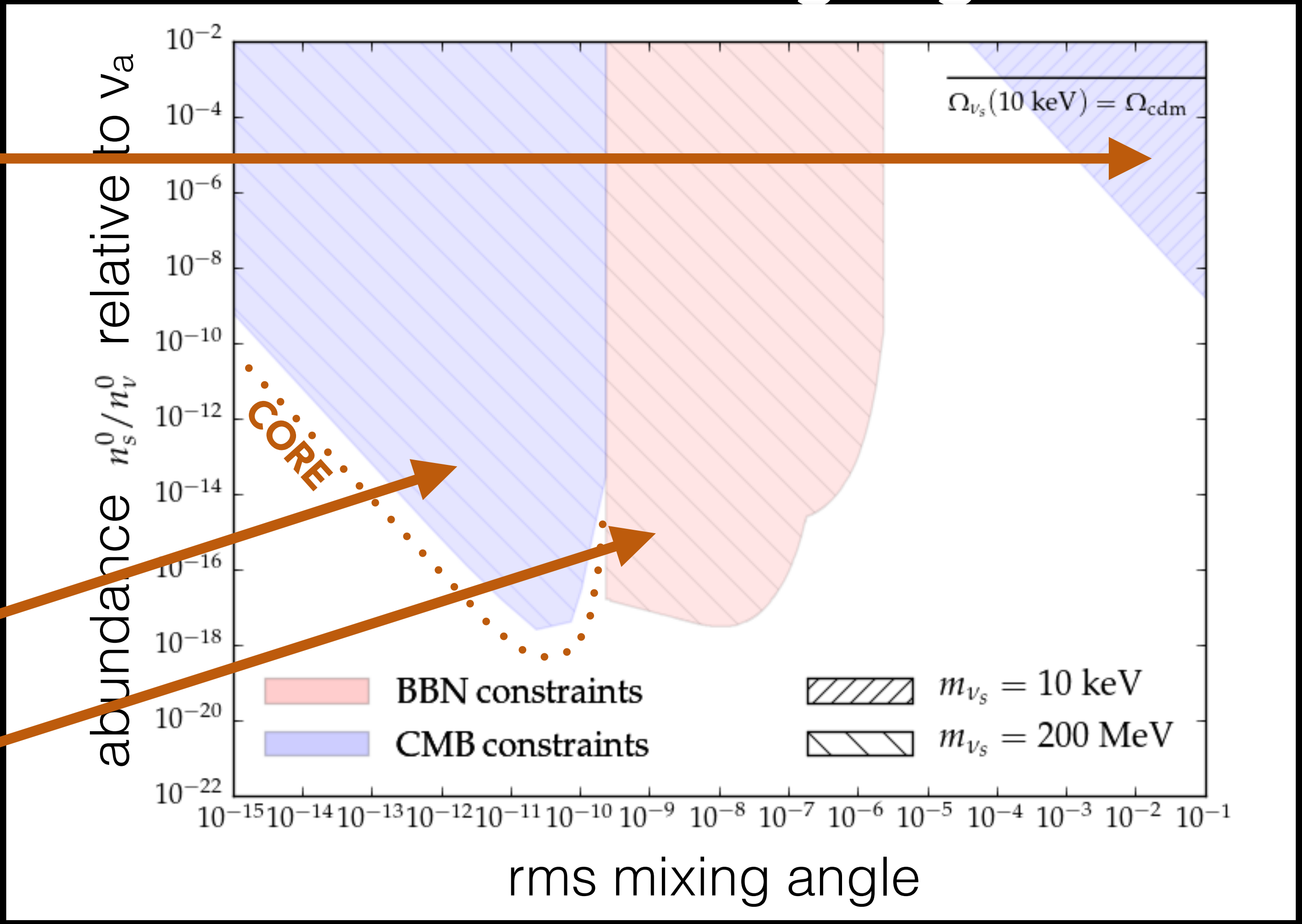


Poulin et al. 1610.10051

DM lifetime (electromagnetic effects)

Current and future bounds on decay rate from CMB only (DM decaying into SM particles other than neutrinos, heating/ionization/excitation of thermal plasma)

- **Application to sterile neutrinos decaying in $3\nu_a$, $\nu_a+\gamma$, $\nu_a+e^+e^-$: thanks to latter channels Ξ is function of mass and mixing angle**
- **M = 10 keV (DM candidate): weaker than X-ray**
- **competitive with X-ray for large M, small mixing, small relic density (e.g. 200 MeV)**
- **BBN complementarity**



Poulin et al. 1610.10051

DM interactions

Not treated here, but well studied for many (although not all) cases

- DM self-interactions
- DM scattering on SM particles
- DM scattering on possible Dark Radiation / other Dark Sector particles

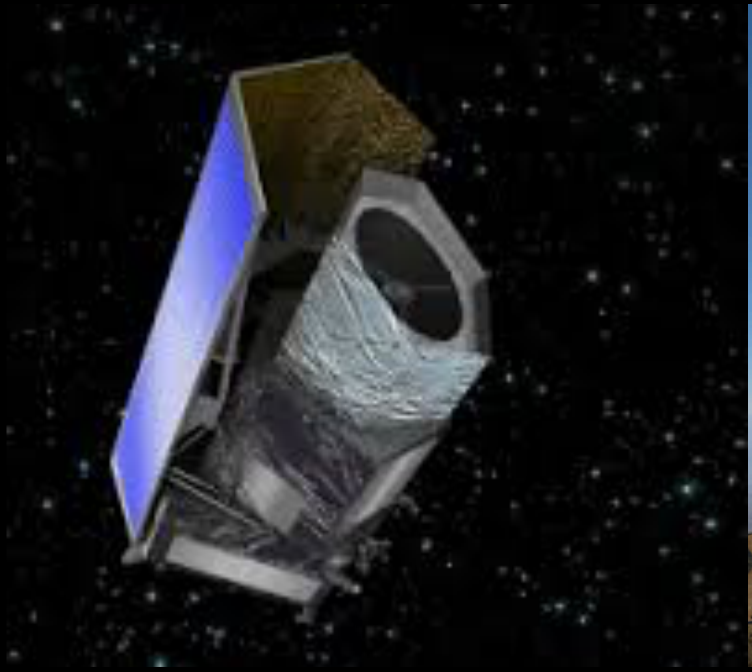
May alter structure formation at early or late time, leave imprint on matter power spectrum, solve tensions with H_0 or σ_8...

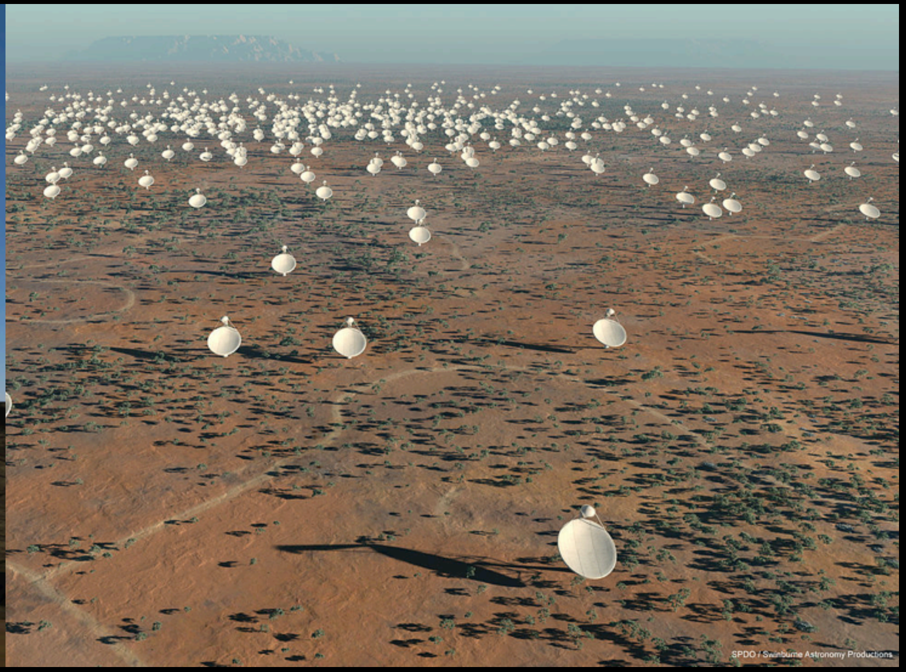
Cosmological bounds complementary to direct detection experiments (goes beyond scattering on quarks, applies to very wide range of dark matter masses)

Wilkinson et al. 1309.7588, 1401.7597; Dvorkin et al. 1311.2937; Cyr-Racine et al. 1310.3278; Buen-Abad et al. 1505.03542; Cyr-Racine et al. 1512.05344; …

Conclusions

- **After Planck:** still a very bright future for cosmology with **strong connections to particle physics**
- **Many of previous experiments already on-going or approved** (Euclid, LSST, SKA…)





- **Cross fingers for the other proposals** (COrE+, LiteBird, PIXIE…)

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