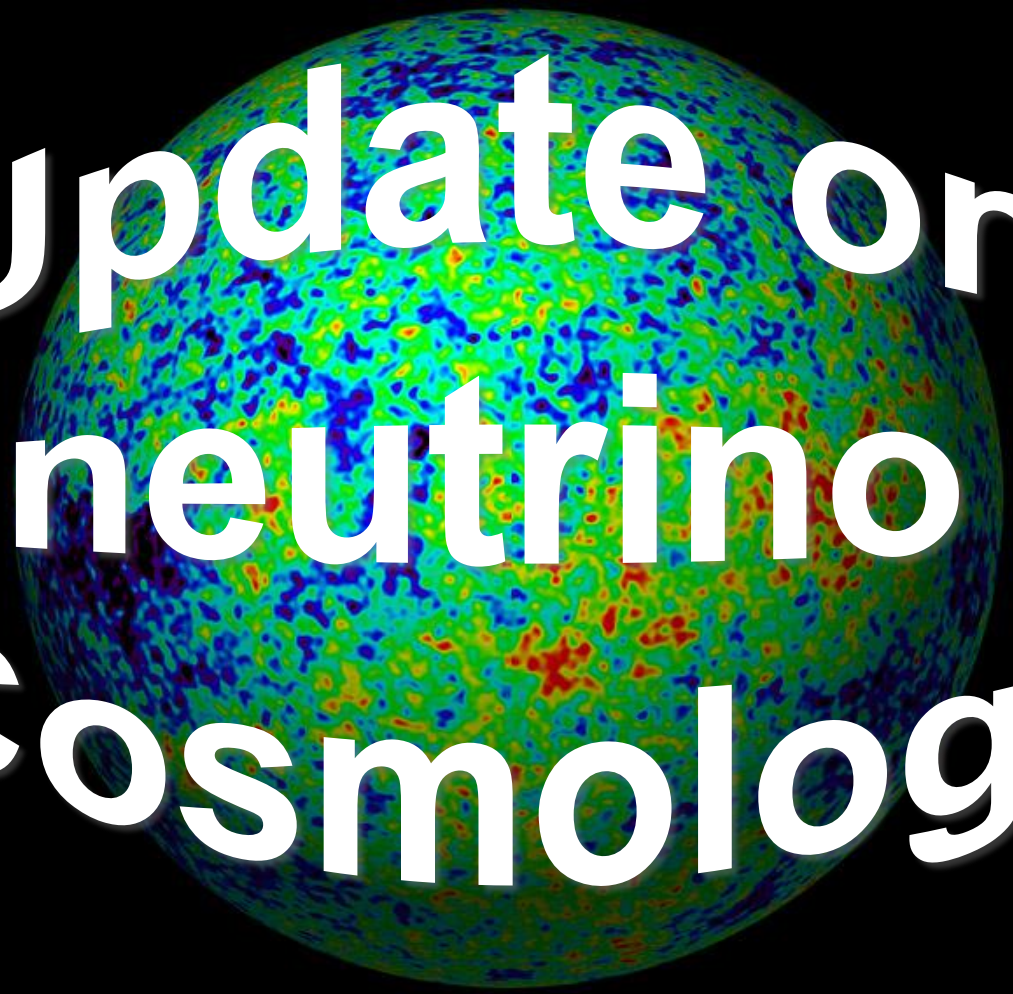


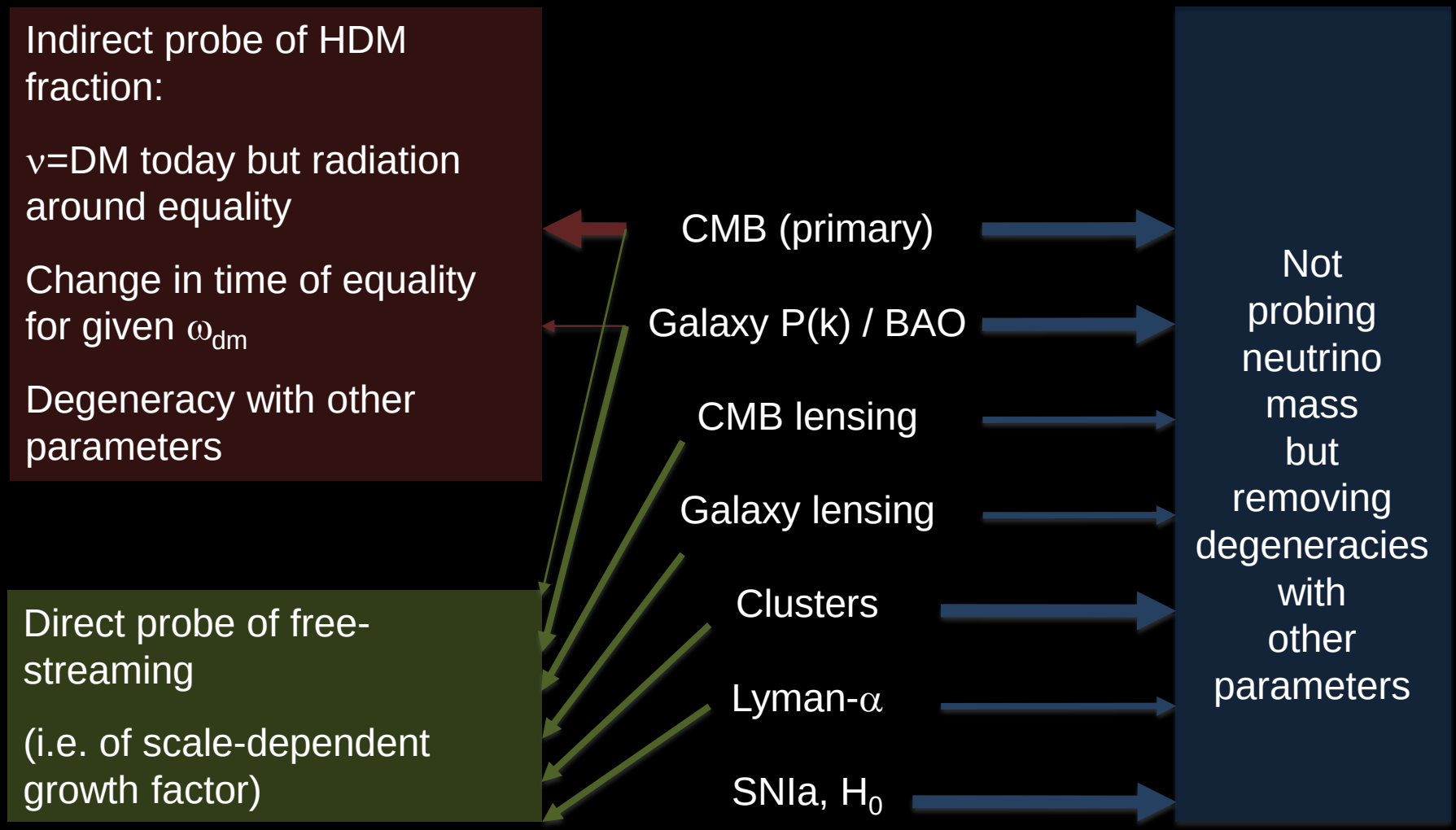
Update on neutrino Cosmology

CHIPP meeting
Leysin, 2.09.2011

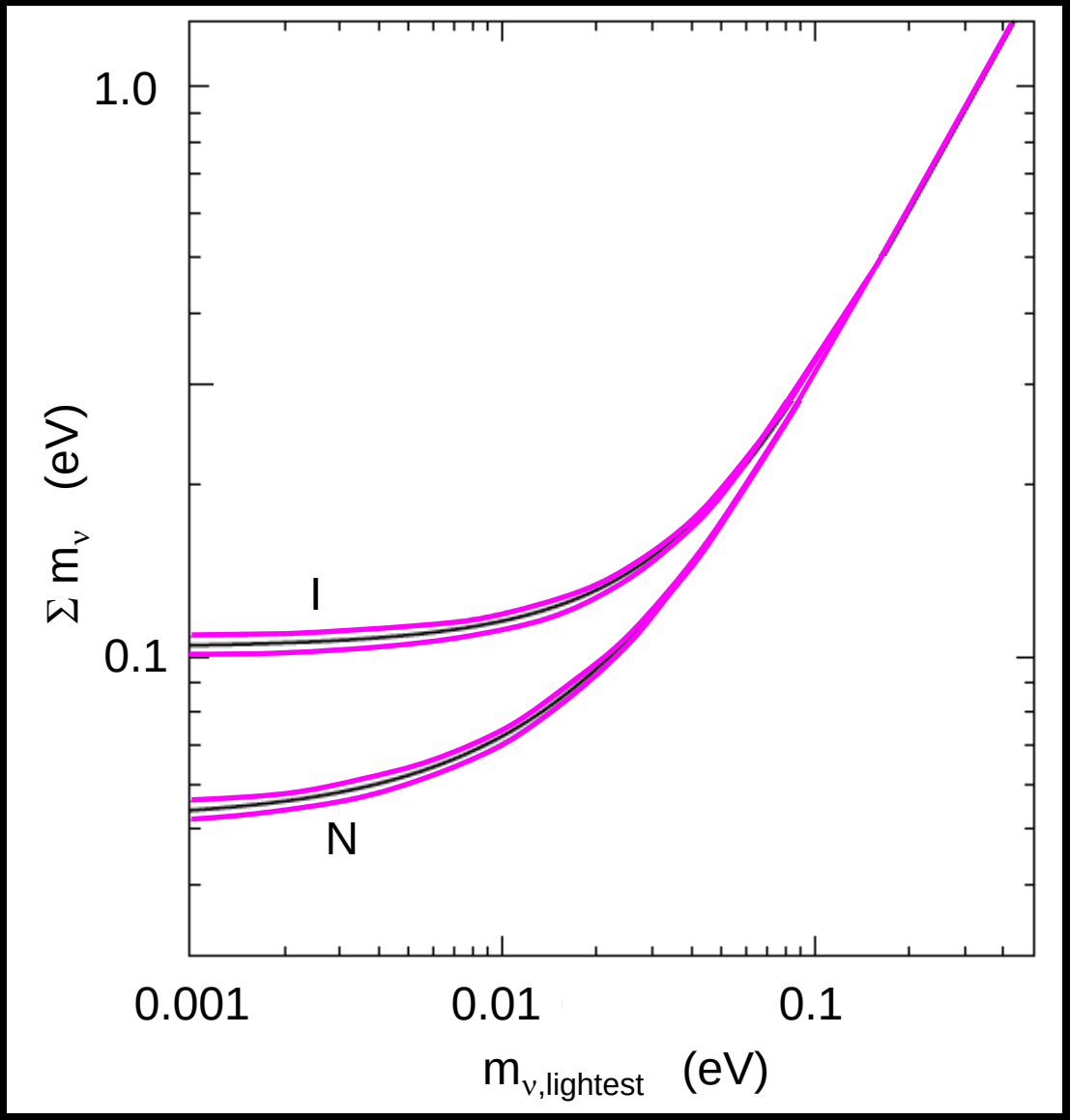
Julien Lesgourgues (CERN&EPFL)

neutrino masses

- Neutrino masses: current limits



- Neutrino masses: current limits (95% C.L., ΛCDM+m_ν)



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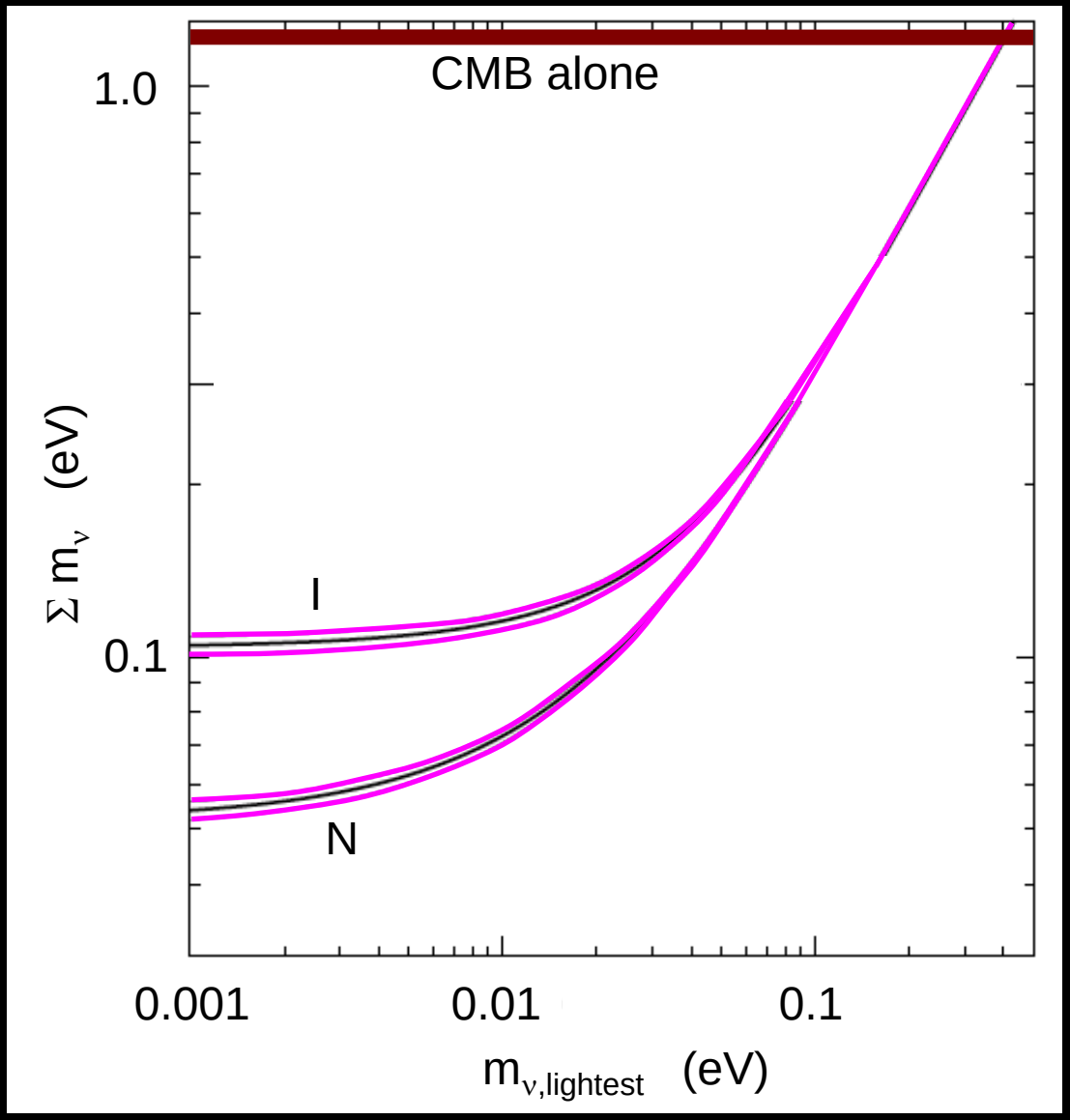

Larson et al. 10

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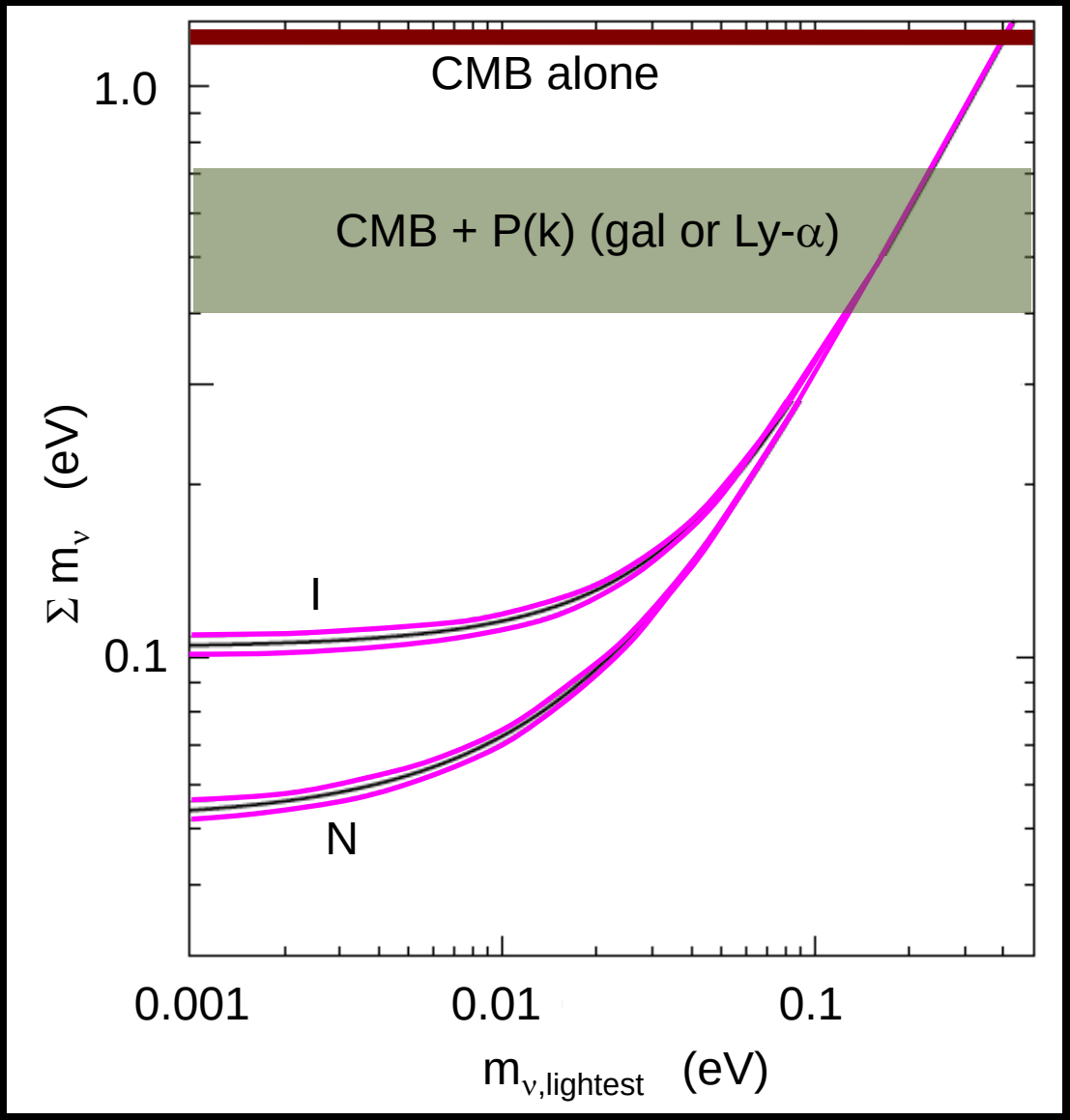

Larson et al. 10

Thomas et al. 10
Hamann et al. 10
Viel et al. 10
Swanson et al. 11

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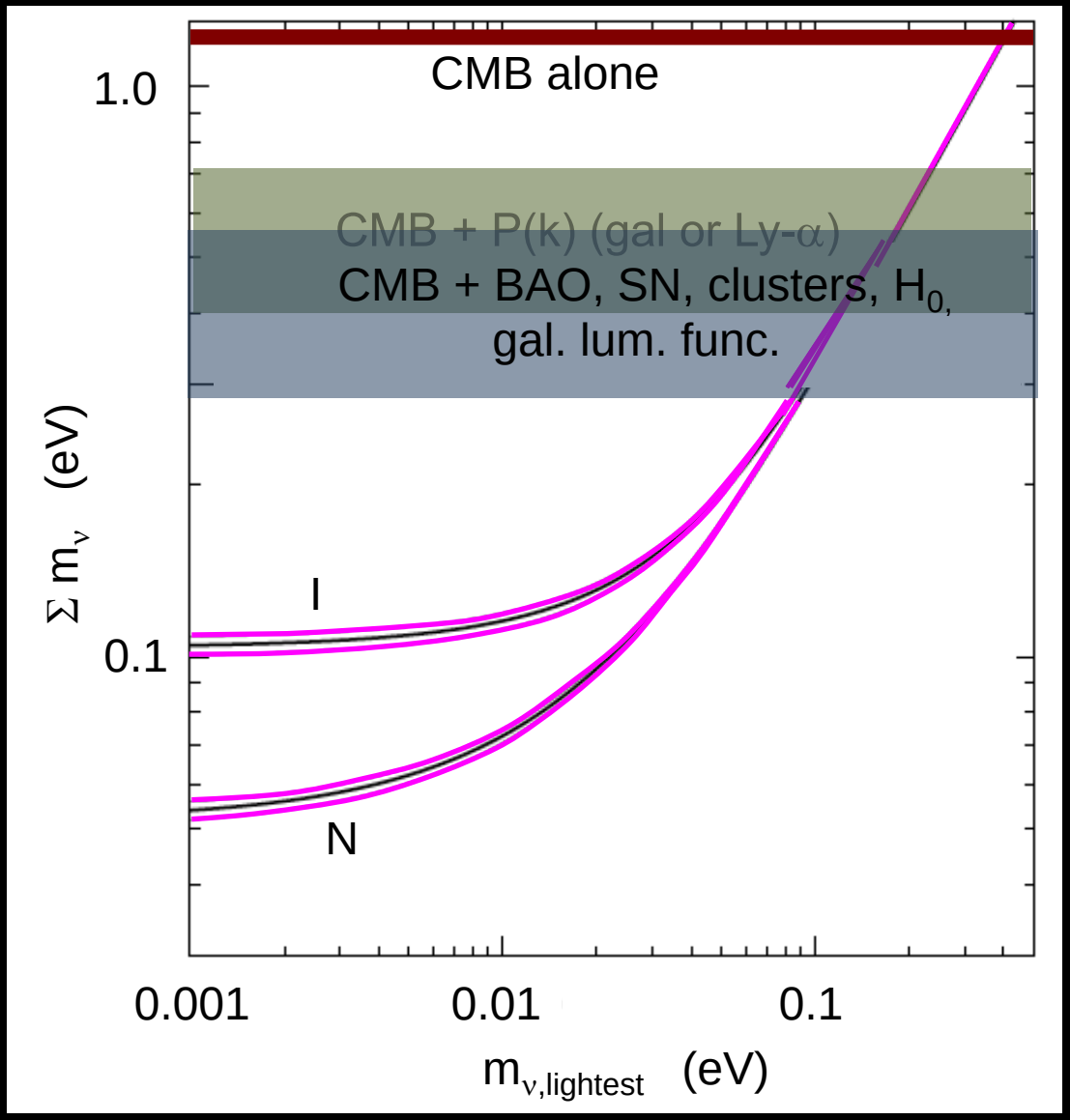

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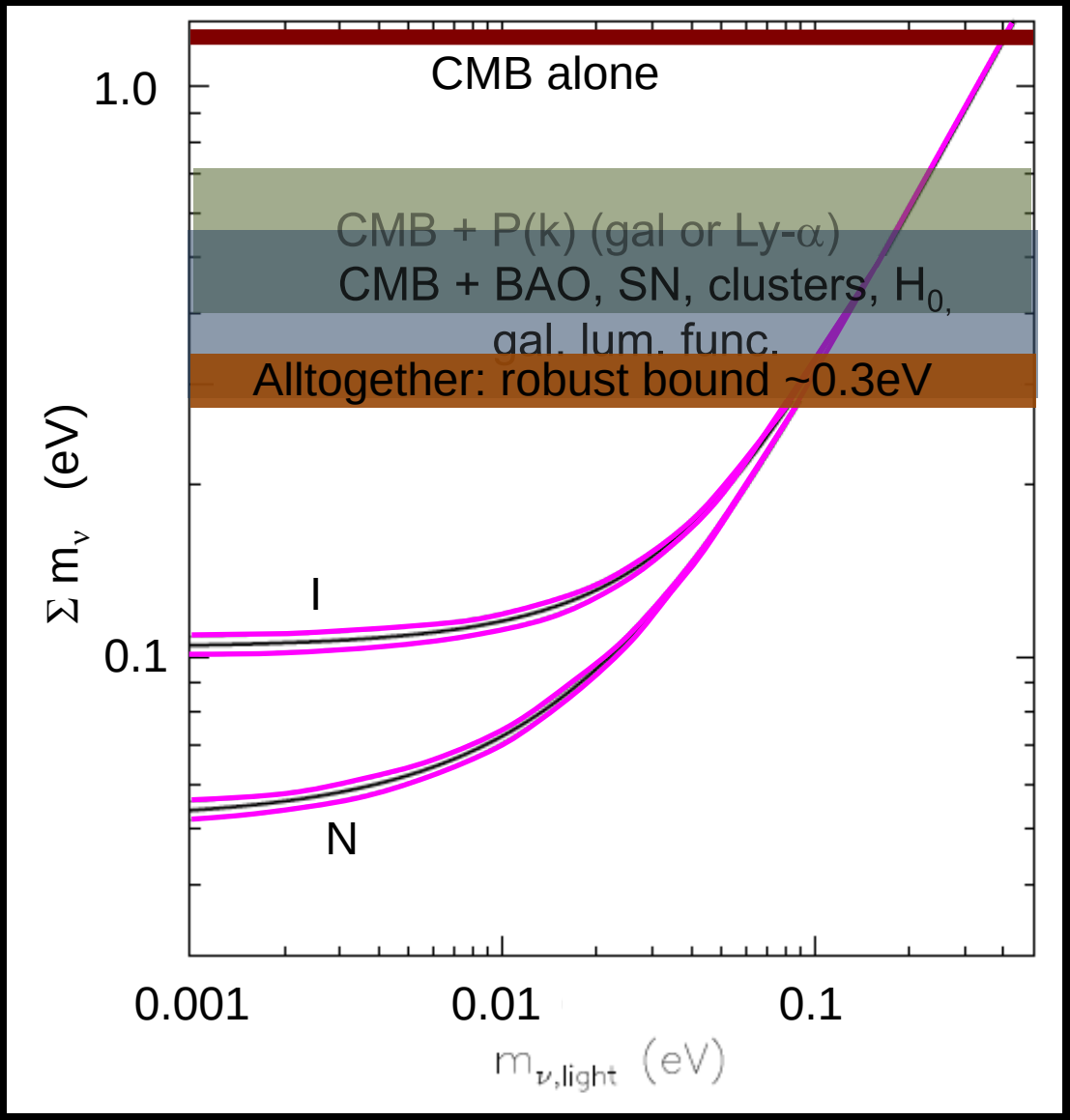

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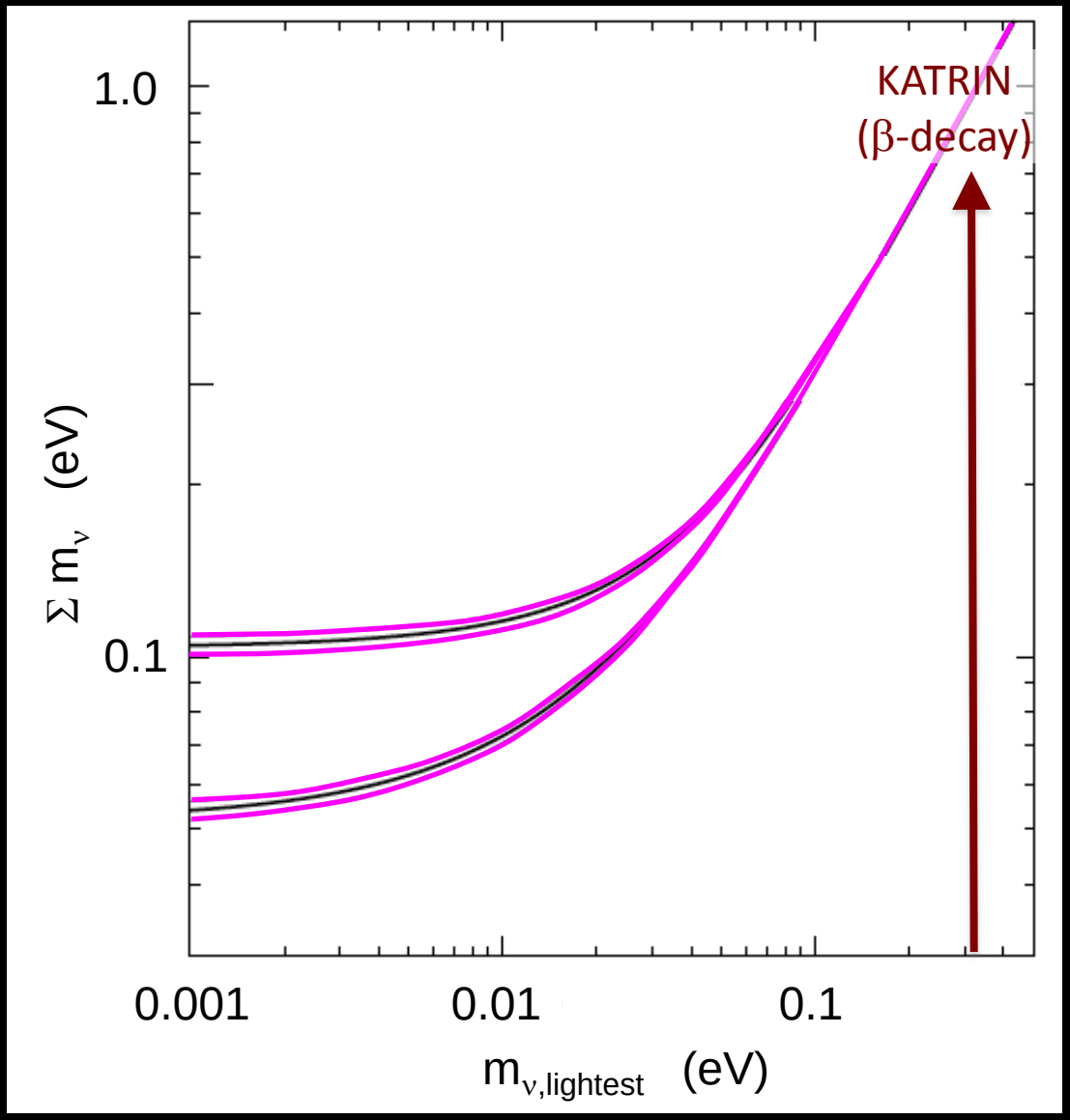

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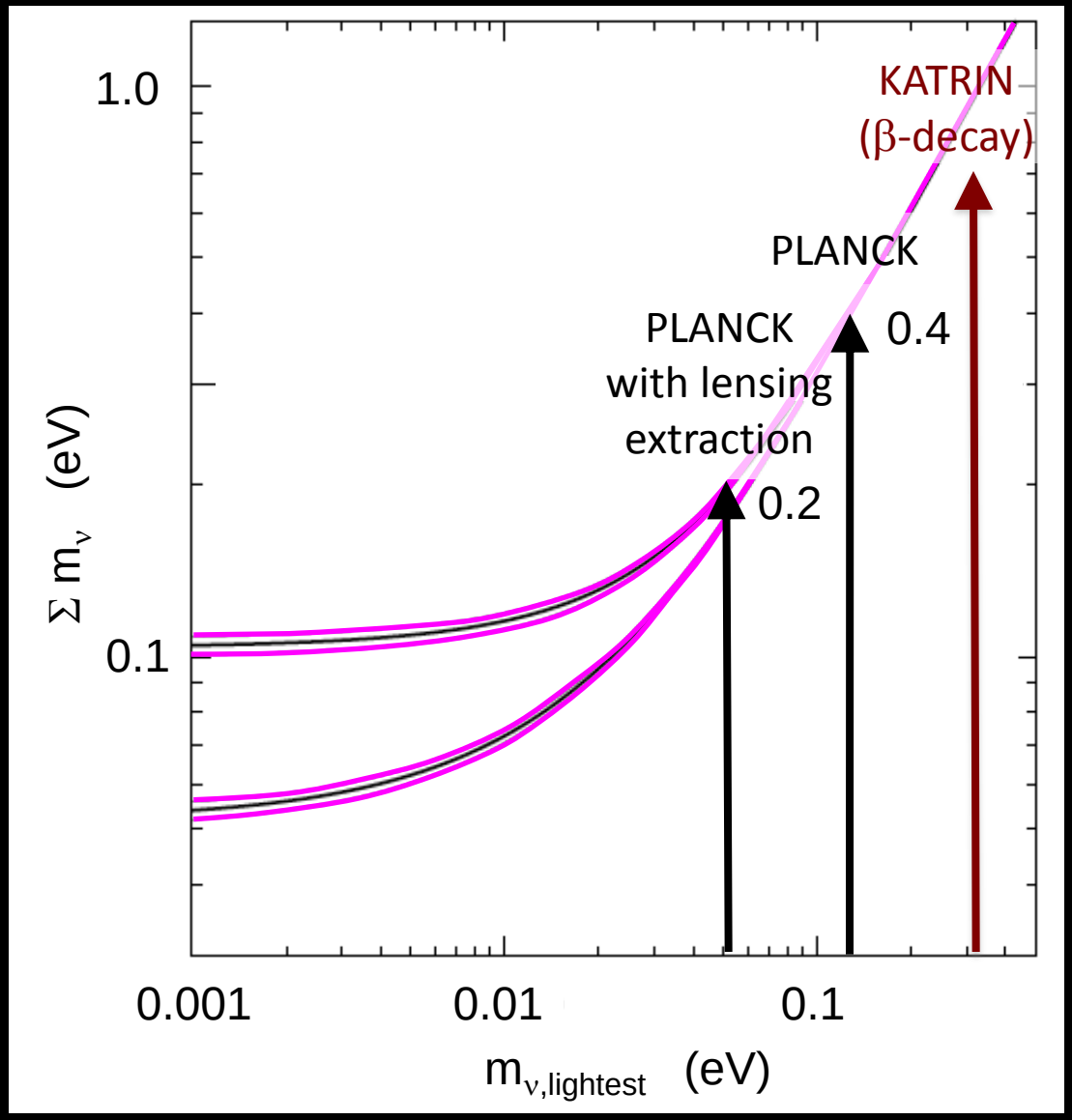

Perotto et al. 06

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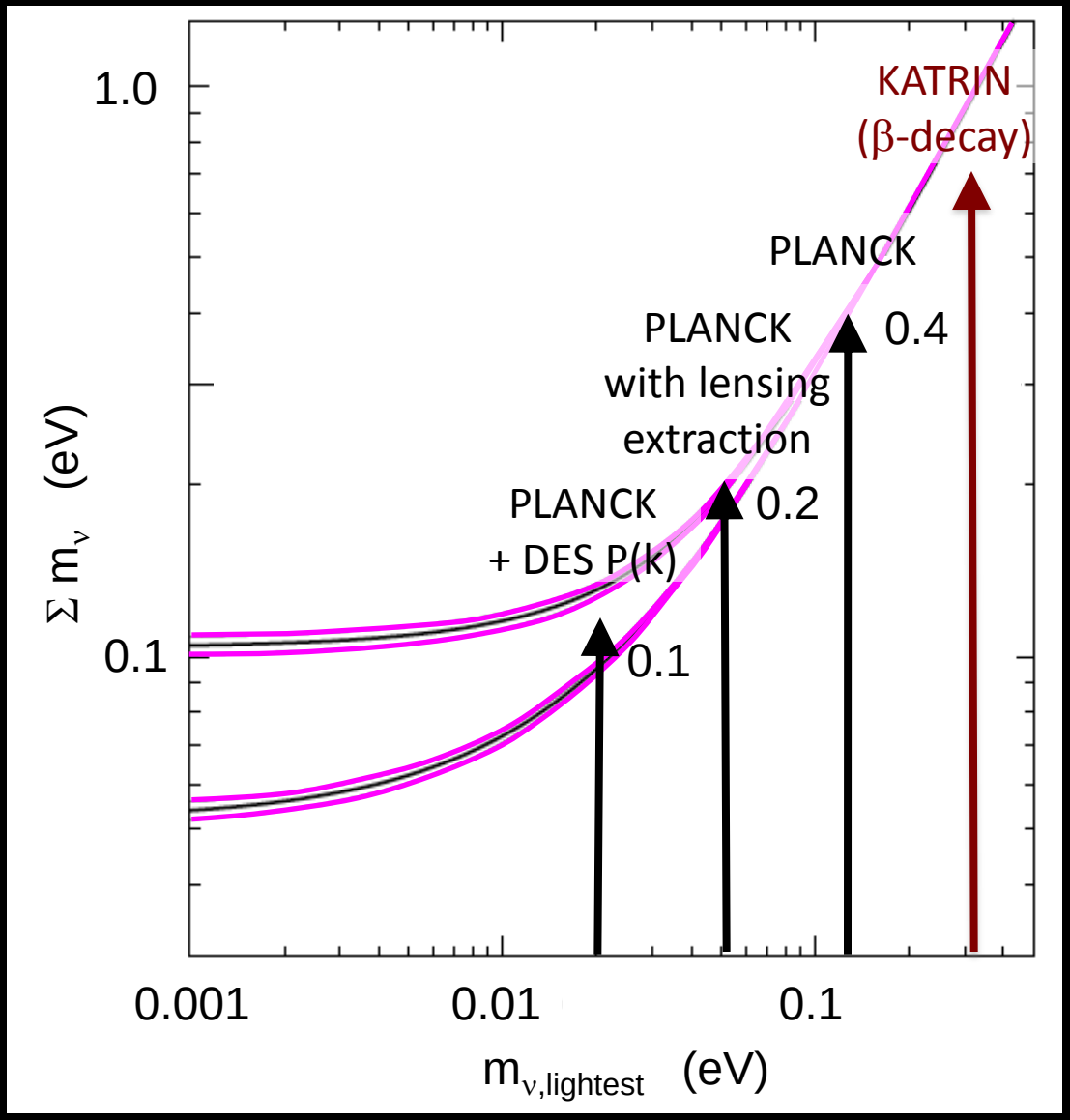

Perotto et al. 06

Lahav et al. 10

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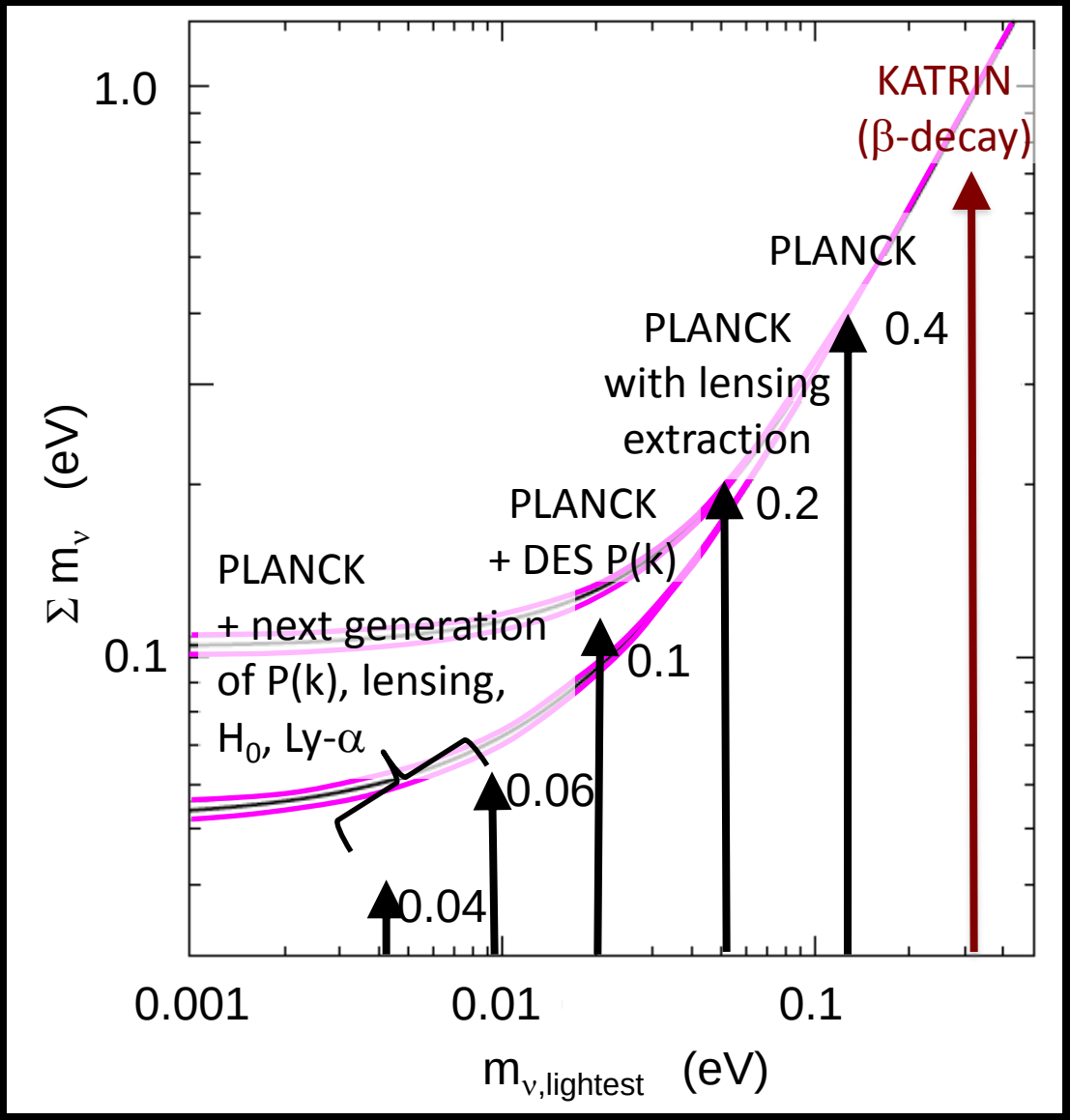


Perotto et al. 06

Lahav et al. 10
…
Gratton et al. 07,
Kitching et al. 08,
Namikawa et al. 10
Sekiguchi et al. 10,
Carbone et al. 11,
…

Reviews:
JL & Pastor 06
Hannestad 10
Abazajian 11

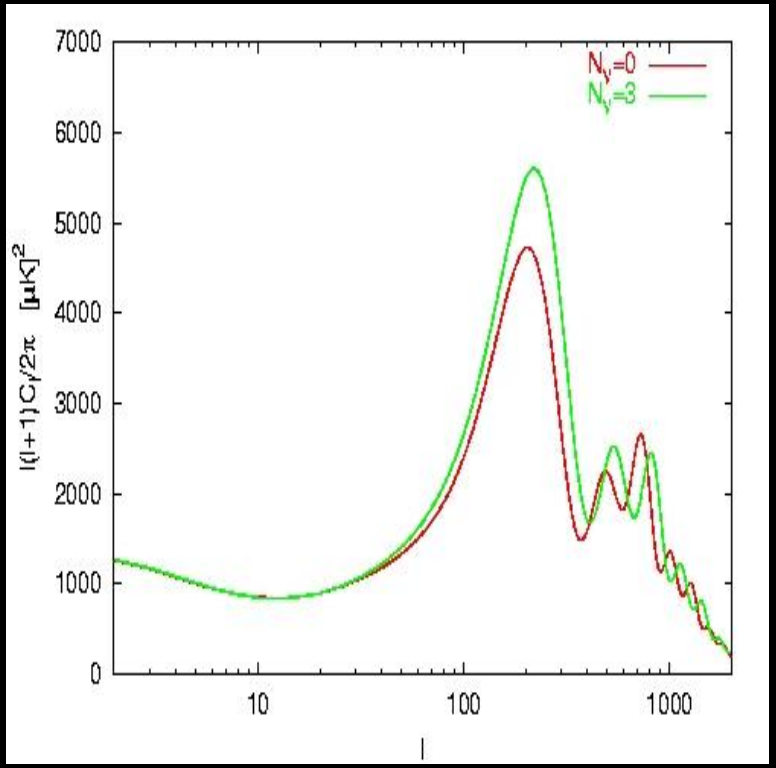
extra light relics

- N_{eff} definition:
  - Radiation density: $\omega_r = \omega_\gamma \left[1 + N_{eff} \times 7/8 \times (4/11)^{4/3} \right]$
  - Standard model: $N_{eff}=3$ in instantaneous decoupling limit, 3.046 in precise calculation
  - Since few years, marginal but increasing evidence that $N_{eff}>3.046$

- N_{eff} impacts CMB in 3 different ways :

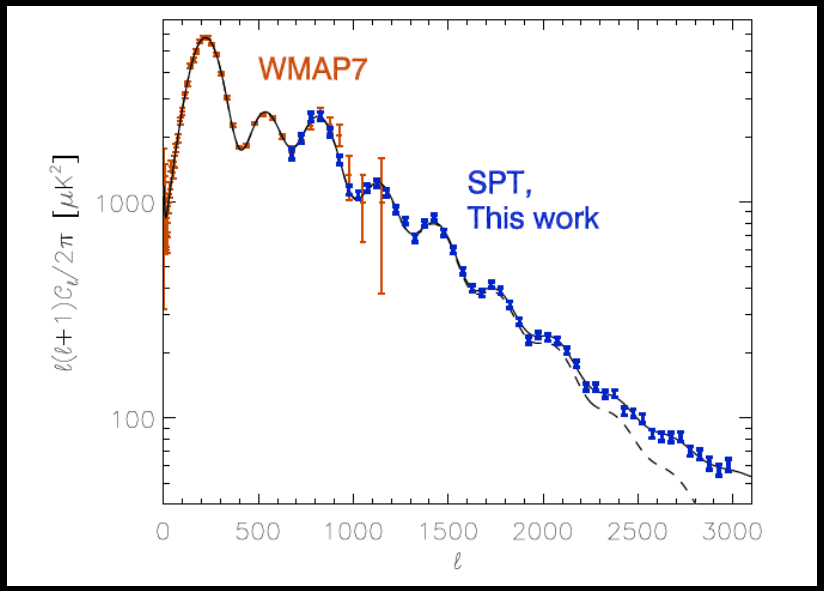
Bashinsky & Seljak 08

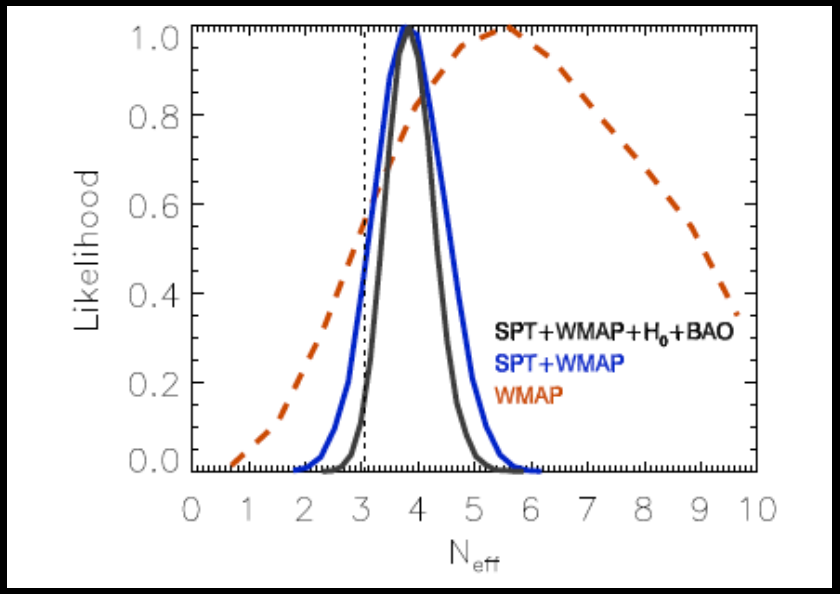
1) Effect on time/redshift of equality (z_{eq})
2) Effect of perturbations of extra species in $\delta T_{\mu\nu}$
3) Effect on Silk damping tail even for fixed z_{eq}



- N_{eff} impacts CMB in 3 different ways :

Recent constraints:





WMAP7 + SPT + BAO + H_0 : Keisler et al. 11 : $N_{eff} = 3.86 \pm 0.42$ (68%CL)

1.9σ above 3.046

weakens with running, but remains

- N_{eff} impacts CMB in 3 different ways :

Conclusion: marginal evidence for $N_{eff} > 3.046$

Disclaimer on statistical significance in Gonzalez-Morales et al. 11

Planck alone in extended cosmology:

$\sigma(N_{eff}) \sim 0.3$

Perotto et al. 2006

- Why would N_{eff} exceed standard value ?

1) Extra light/massless relics, not necessarily related to neutrinos : axions, majorons, dark radiation, early quintessence, …. (future: 2nd effect of N_{eff} may help discriminating)

2) Light sterile neutrinos : (right-handed) neutrinos sharing mass-mixing matrix with active ones : standard assumption, but are some of them light enough / mixed enough to participate to N_{eff}?

3) Leptonic asymmetry in active neutrinos : cannot account for large N_{eff}, because BBN limits $\mu_{\nu e}$, and $\mu_{\nu i}$ cannot be very different from each other due to oscillations in early universe: up to N_{eff}~3.04

- Why would N_{eff} exceed standard value ?

2) Light sterile neutrinos :

- Topic around since LSND anomaly : $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ conversion rate requires ~1eV mass sterile (3+1 scenario)

Aguilar et al. 01

- MiniBoone : latest data (2010) confirms $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ anomaly but does not find same signal in $\nu_\mu \rightarrow \nu_e$: need for CP violation

Aguilar-Arevalo et al. 10

  - 3+2 scenario : mixing matrix incorporates CP violating phase

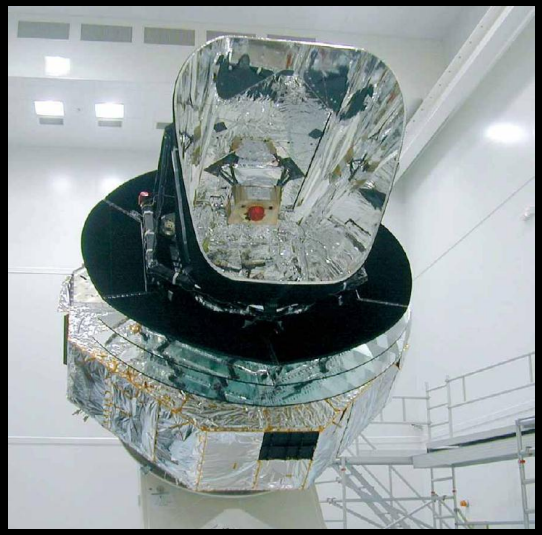
Kopp, Maltoni & Schwetz et al. 11

  - 3+1 scenario : require NSI

Akhmedov & Schwetz et al. 10

- Latter scenario predict N_{eff}=5 only if sterile νs acquire thermal distribution through mixing (not guaranteed: low-T reheating, leptonic assymetry); Conflict with BBN? Latest Helium data also favors high N_{eff}…

- Both scenario need M_ν~1eV; conflict with CMB+LSS? Not if N_{eff} large…



Planck + DES results will come soon !

- first hints for/against inverted hierarchy
- chance to confirm $N_{eff}>3$, to test 3+2 model, to check L_ν

Other programs like LSST approved;

EUCLID: ESA decision early October !