What cosmology can tell us about neutrinos

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RWTH Aachen University

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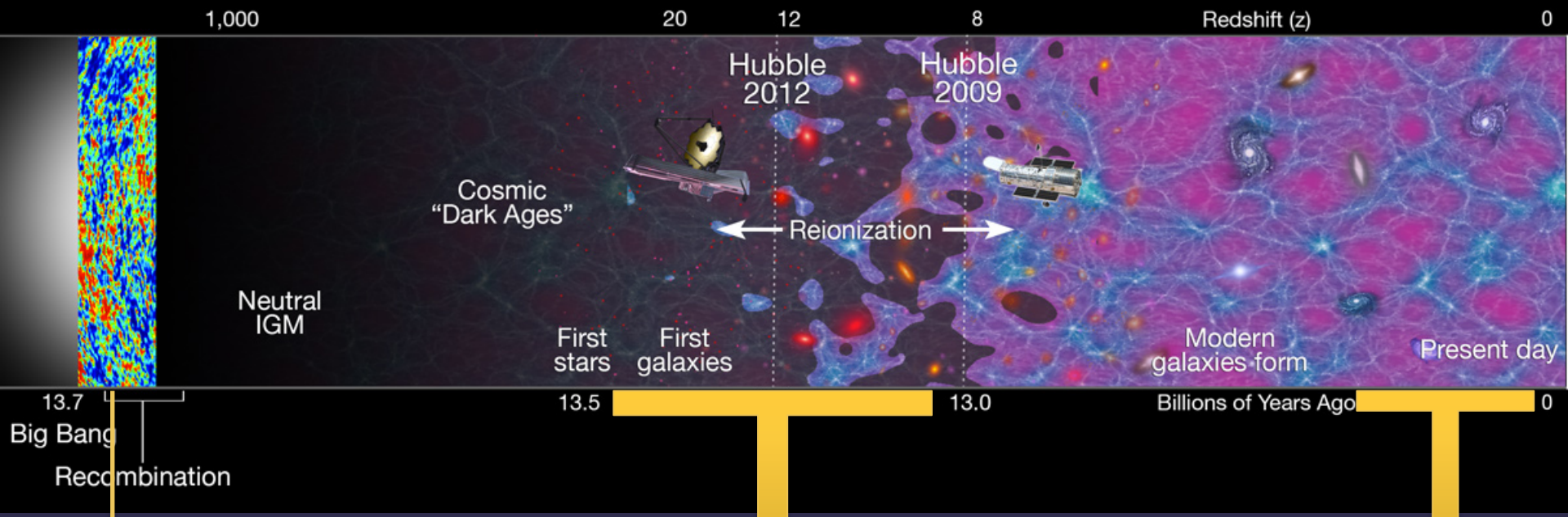
Prologue

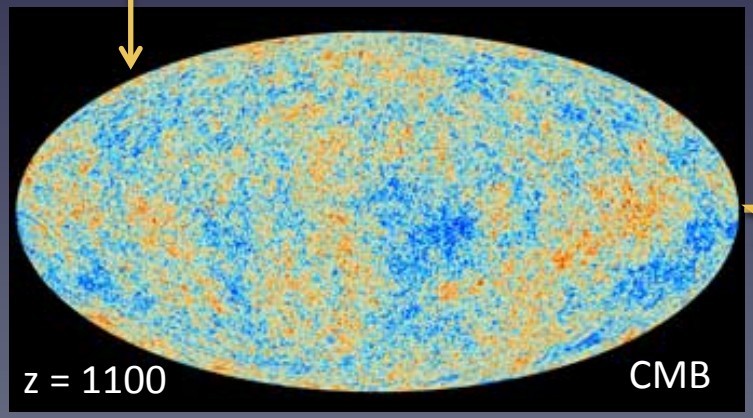
- Neutrino mass sum: more precise than β (KATRIN) and double β decay (GERDA), but more model dependent. Not sensitive to Dirac vs Majorana, mixing angles, phases …
- Hierarchy: not specifically sensitive to the hierarchy like NOνA, DUNE, PINGU, ORCA, Hyper-K, but the IH might be ruled out.
- Effective number of relativistic degrees of freedom, N_{eff}, (~Neutrino number)

Outline

- Neutrino mass sum:
  - State of the art: observables and current bounds
  - Future prospects of constraining the neutrino mass sum and possibly the hierarchy
- N_{eff}:
  - Sterile neutrinos

Observables

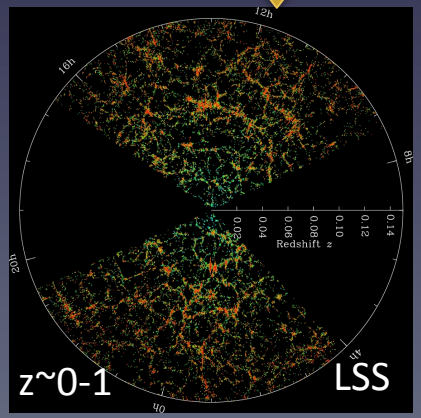




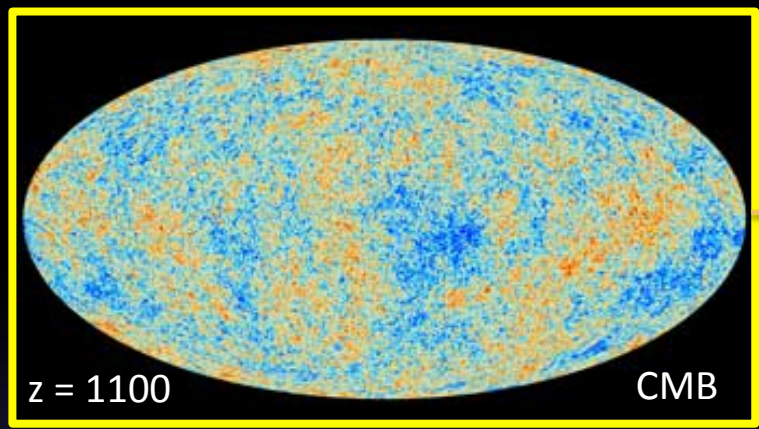
z=13
ν = 1.4 GHz

z=0
ν = 100 MHz

21cm SKA



CMB: TT, EE, TE, lensing



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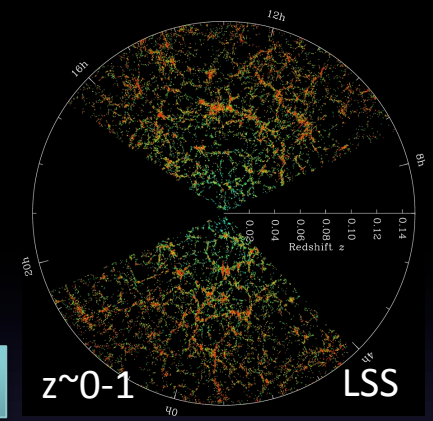
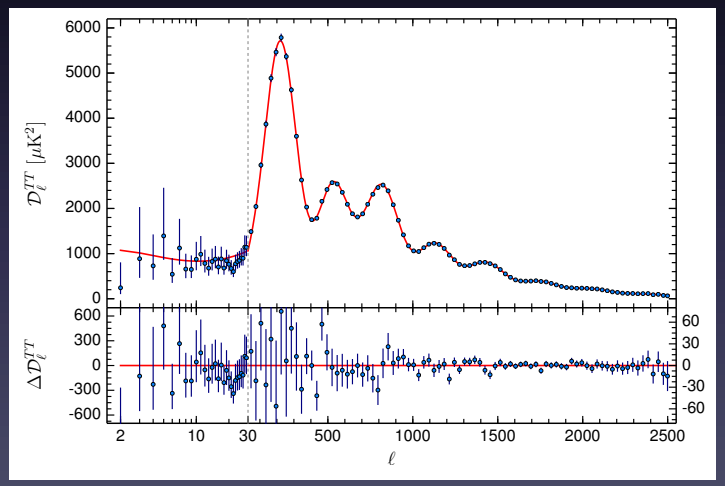
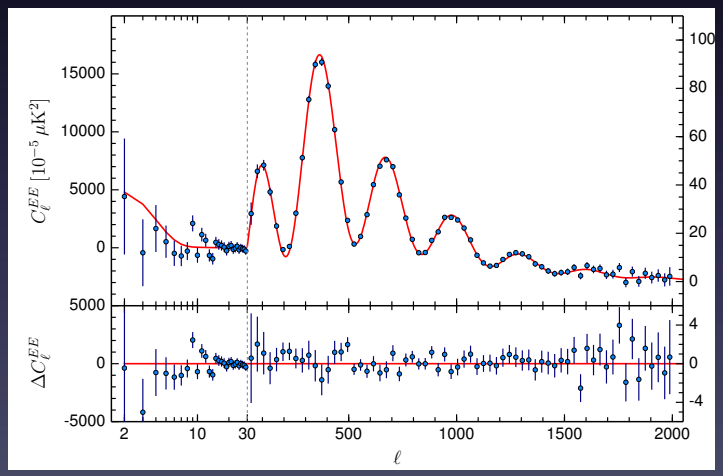




Bkg. effects only at late times: late ISW

Perturb. effects: early ISW.



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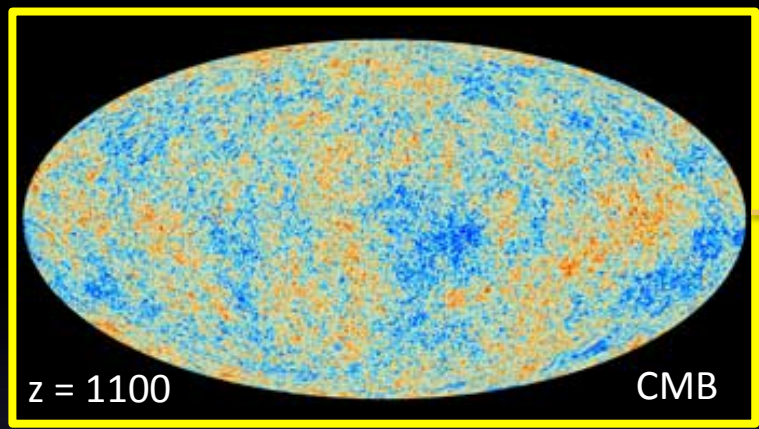

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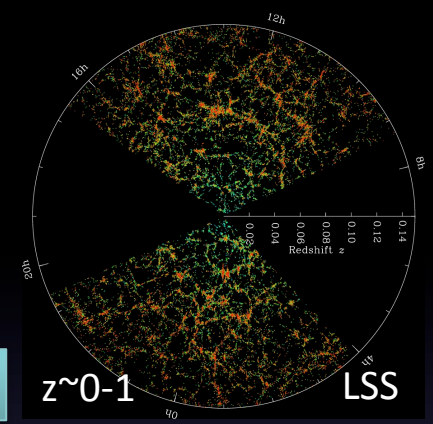

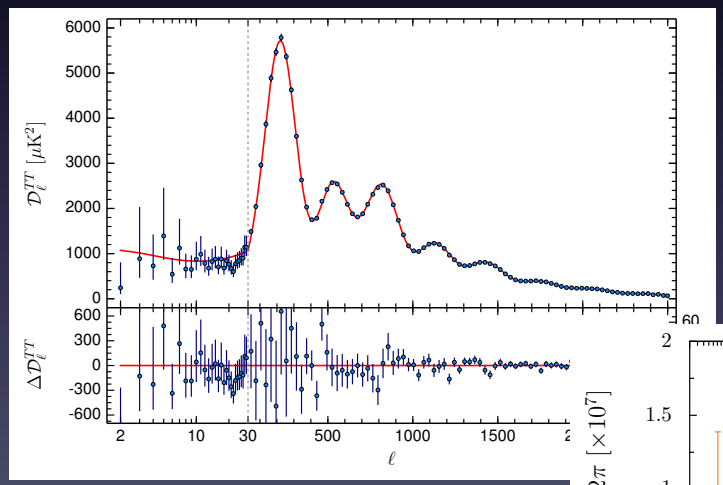

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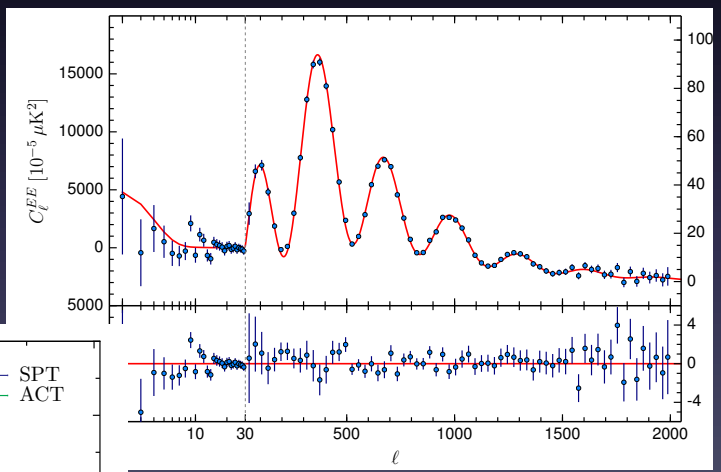
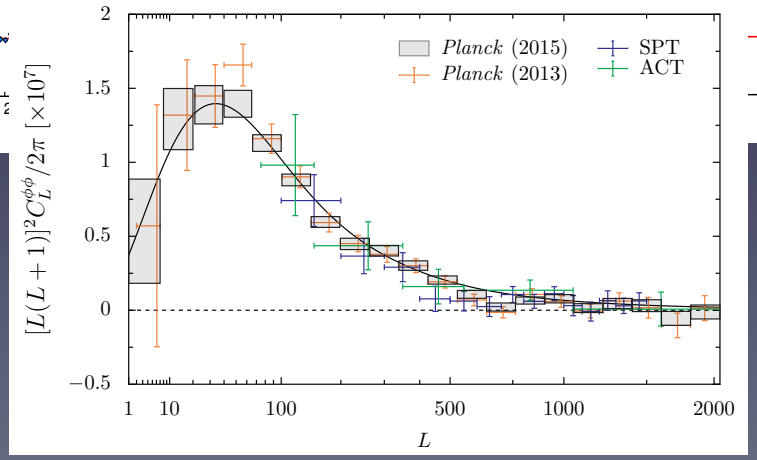


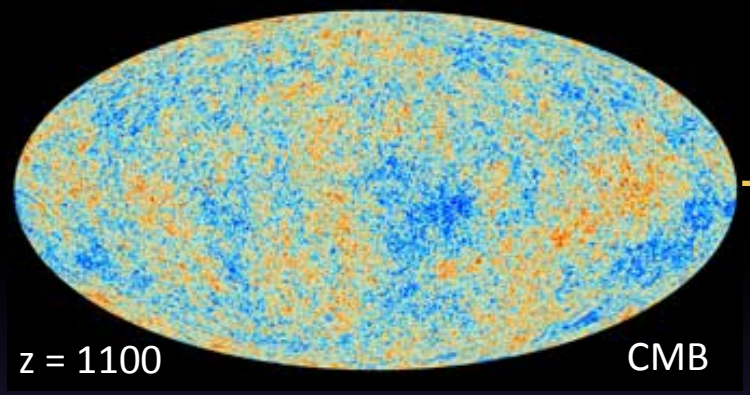
Suppression of lensing potential



$$\sum m_\nu < 0.59 \ eV \ \ 95\%cl$$

Planck15

LSS: BAO, galaxy clustering



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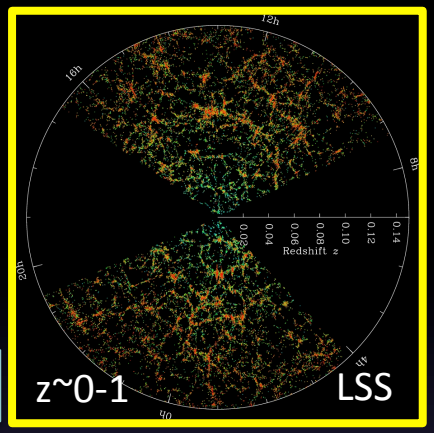
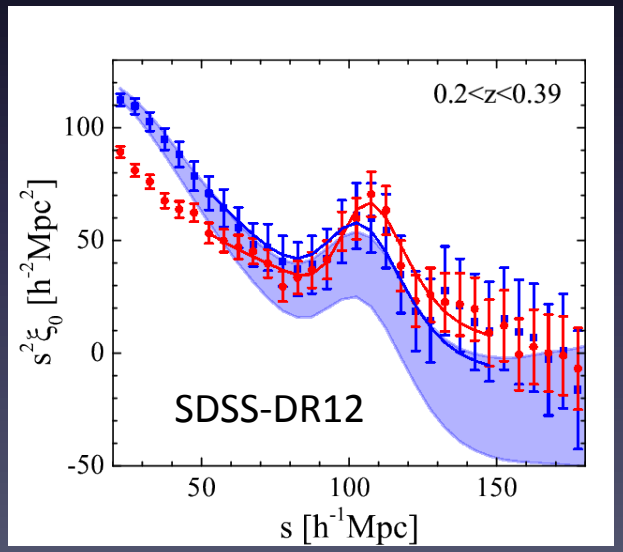
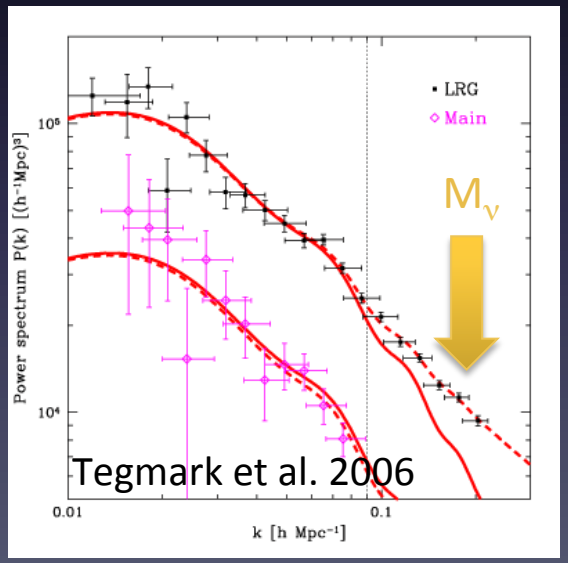




BAO geometric information



P(k) shape information: more powerful, but, at the same time, more affected by systematics

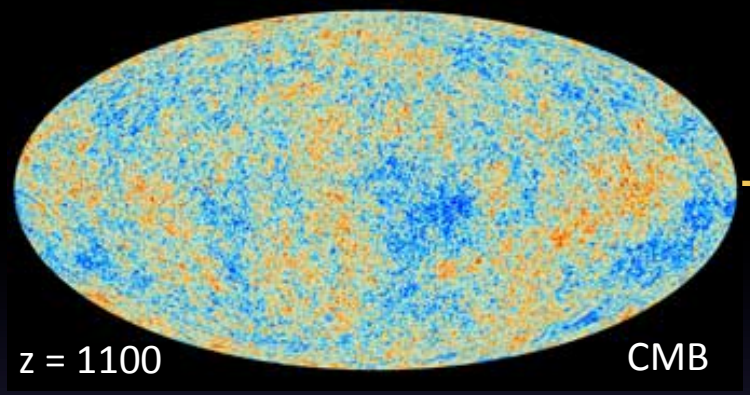
$P_m(k,z) = b^2 P_g(k,z)$

Planck15(TT+TE+EE+lowP)+
SDSS-DR7-P(k)+BAO

$$\sum m_\nu < 0.13\ eV\ \ 95\%cl$$

Cuesta, Niro, Verde,
Phys. Dark Univ (2016)

LSS: galaxy lensing



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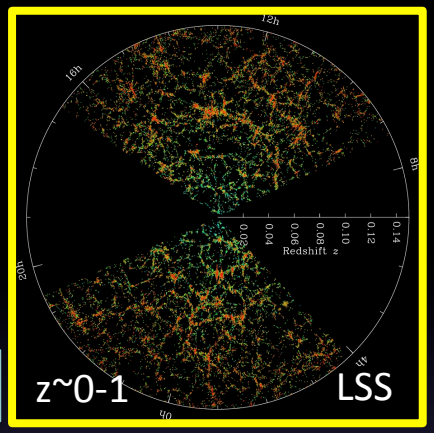
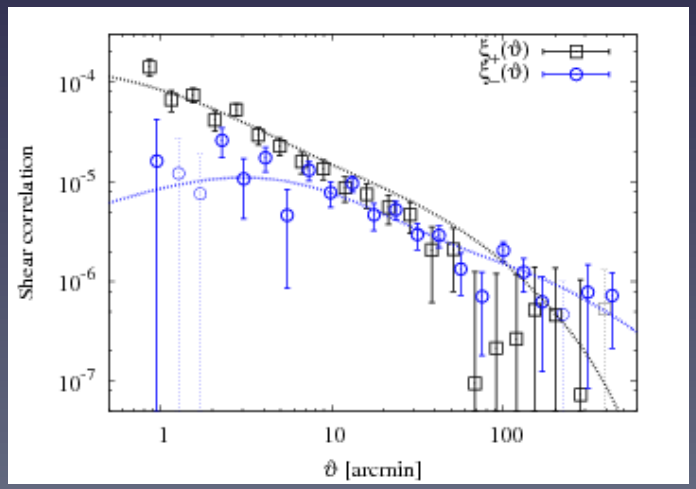


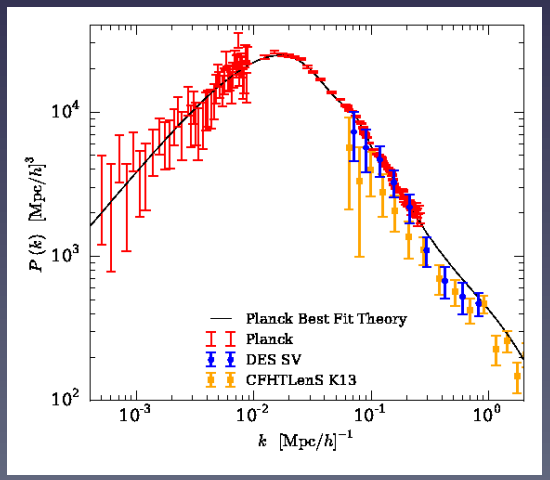
Distortion of distant galaxy images by intervening matter



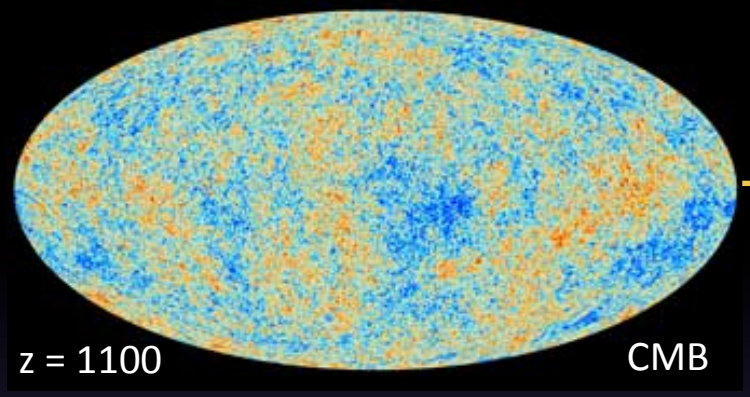
Planck13+CMB-lensing+
BAO+CFHTLens

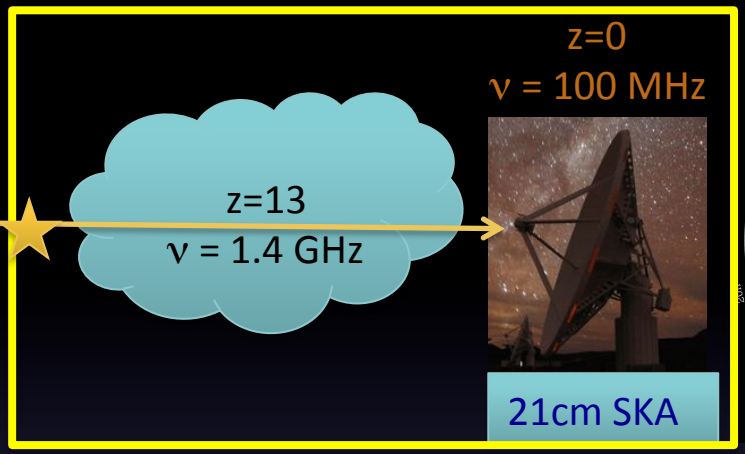
$$\sum m_\nu < 0.30 \ eV \ \ 95\%cl$$

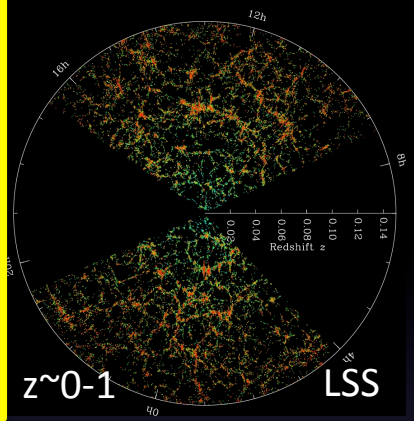
Beutler et al., BOSS Collaboration, MNRAS (2014)
Leistedt, Peiris, Verde, PRL (2014)

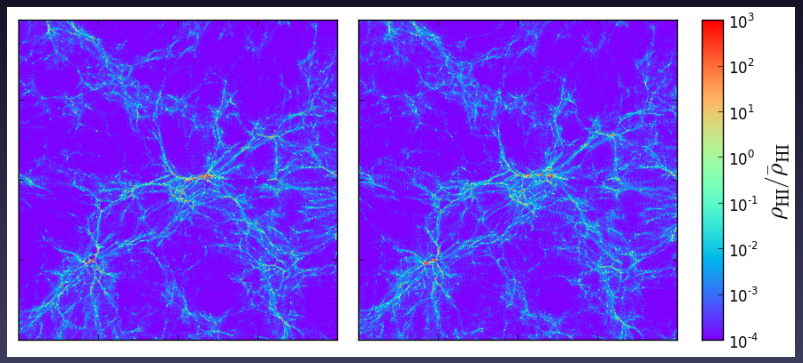


21cm survey

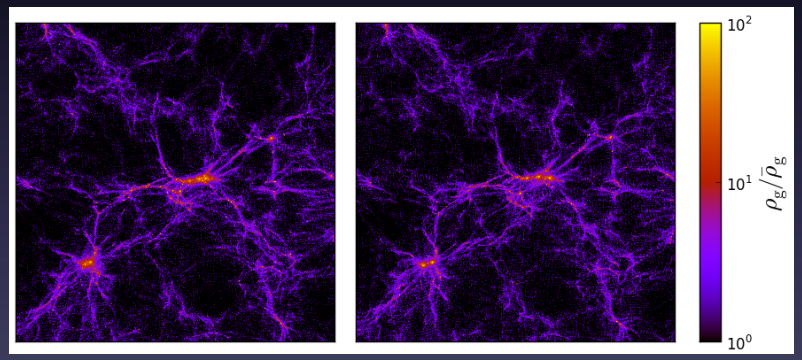








HI and galaxy density contrast in simulations with and without M_ν

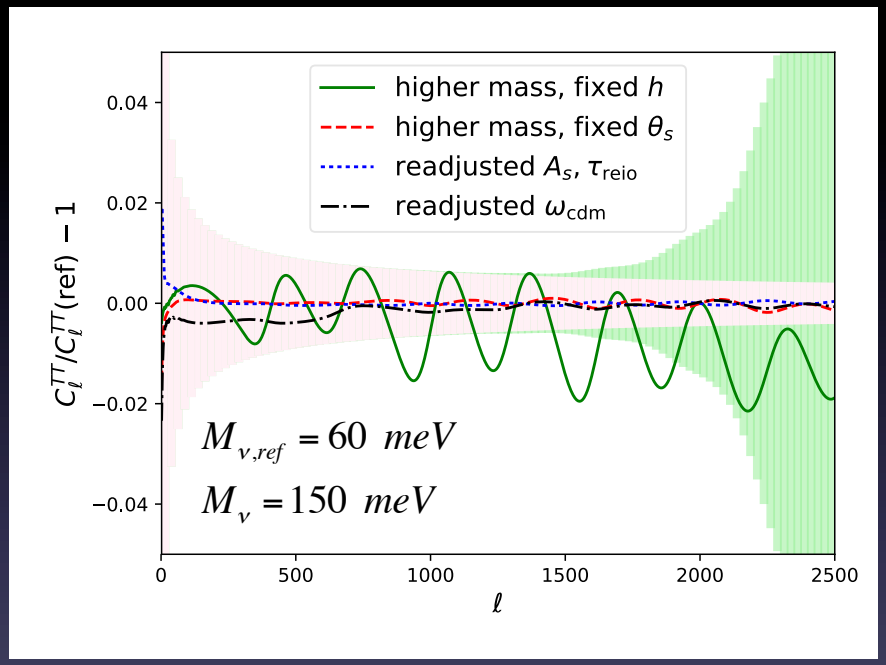


$P_{21}(k,z) = T_b^2 P_m(k,z)$, where $T_b = T_b(\omega_b, \omega_m, x_{HI})$

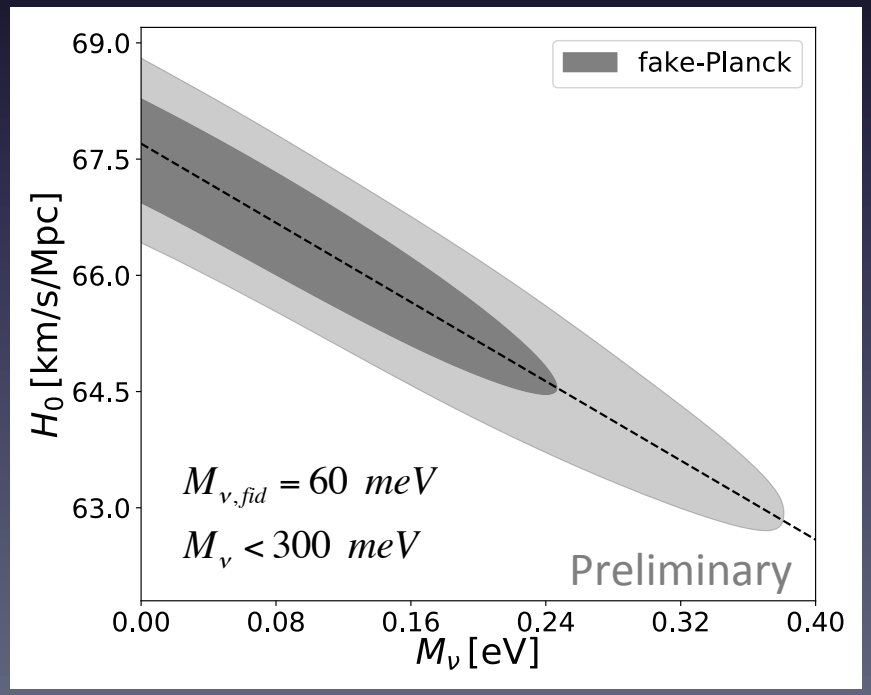
$\sigma(M_\nu) = 56\ meV$ Planck+SKA

Villaescusa-Navarro, Bull, Viel, ApJ (2015)
Mao, Tegmark, McQuinn, Zaldarriaga, Zahn, PRD (2008)
Furlanetto, Oh, Briggs, Phys.Rept. (2006)

Current M_ν constraints CMB



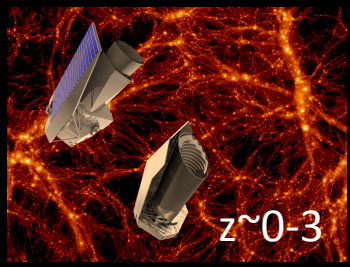
The sensitivity is affected by degeneracies, even in the minimal 6+1 parameter model.

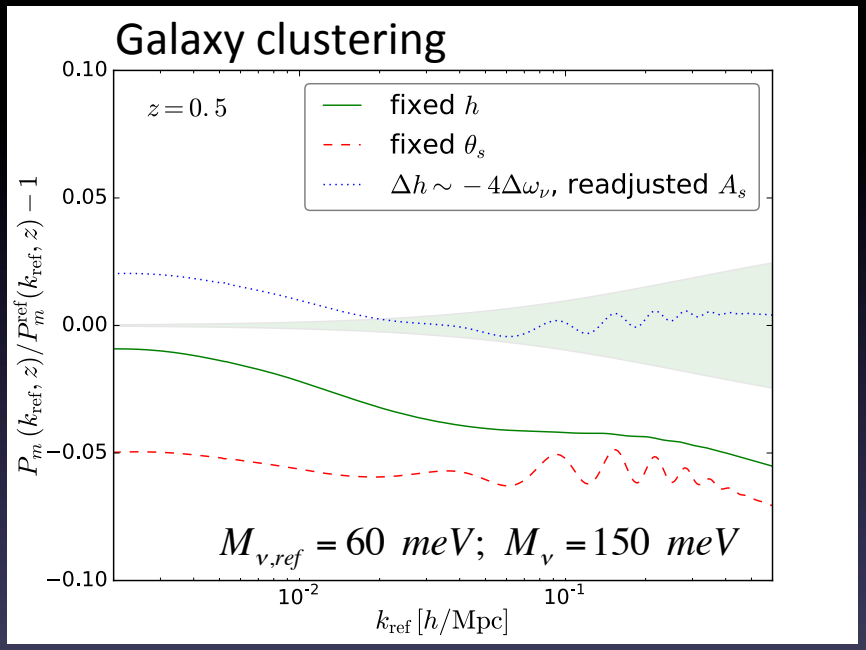


- Model dependence of cosmological results.
- Combining different probes at different redshift will provide robust results.

Archidiacono, Brinckmann, Lesgourgues, Poulin, JCAP (2017)
Archidiacono, Brinckmann, Clesse, Lesgourgues, in preparation

Future M_ν constraints
LSS: Euclid





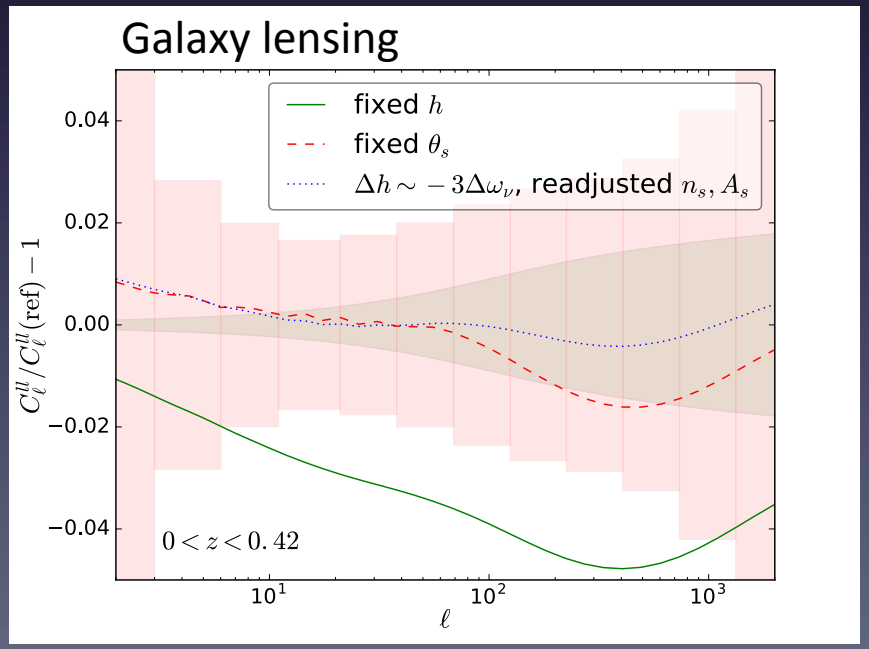
$$P(k,z) = \left\langle \left|\delta_m(k,z)\right|^2 \right\rangle$$

$$\delta_{cdm} \propto a$$

$$\delta_{cdm} \propto a^{1-3/5 f_\nu}$$

$$f_\nu = \omega_\nu / \omega_m$$

Observational + theoretical error



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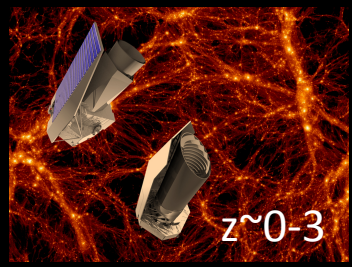

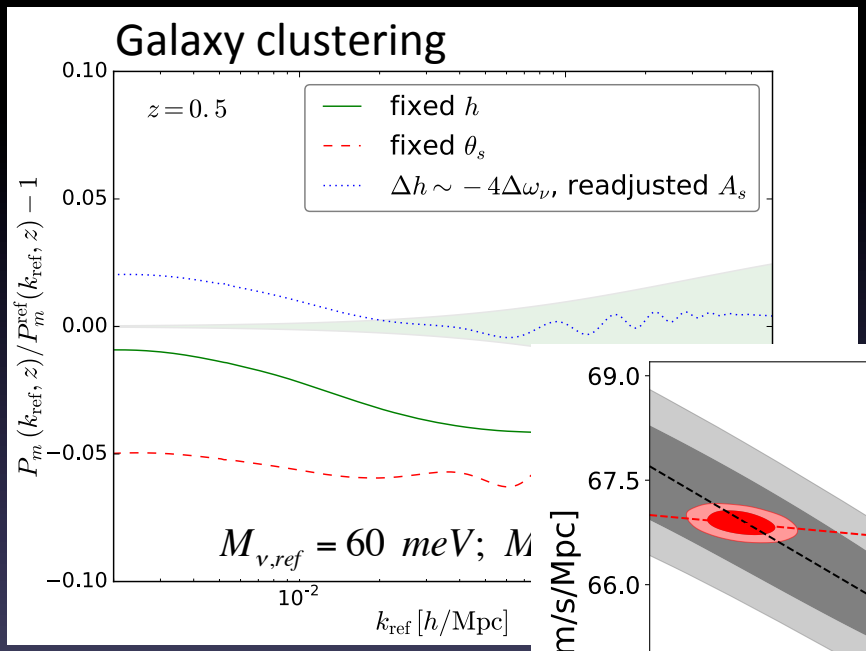

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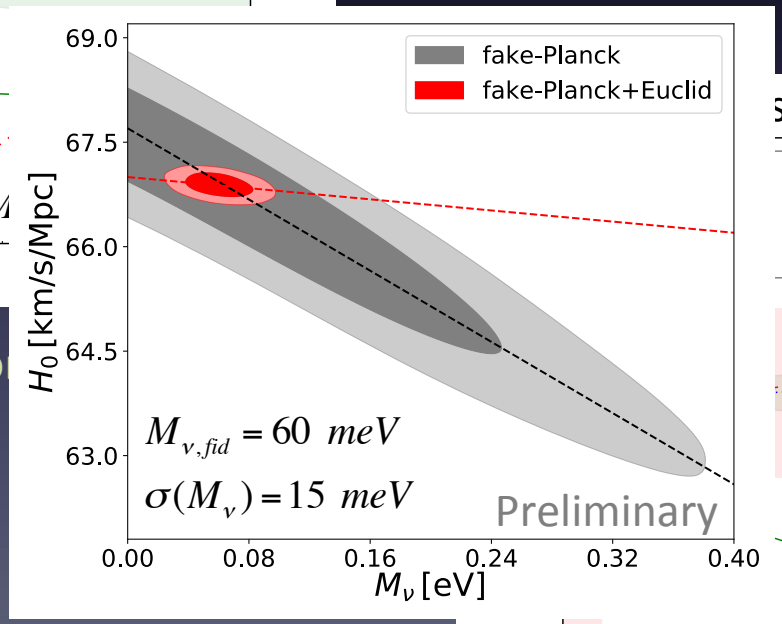

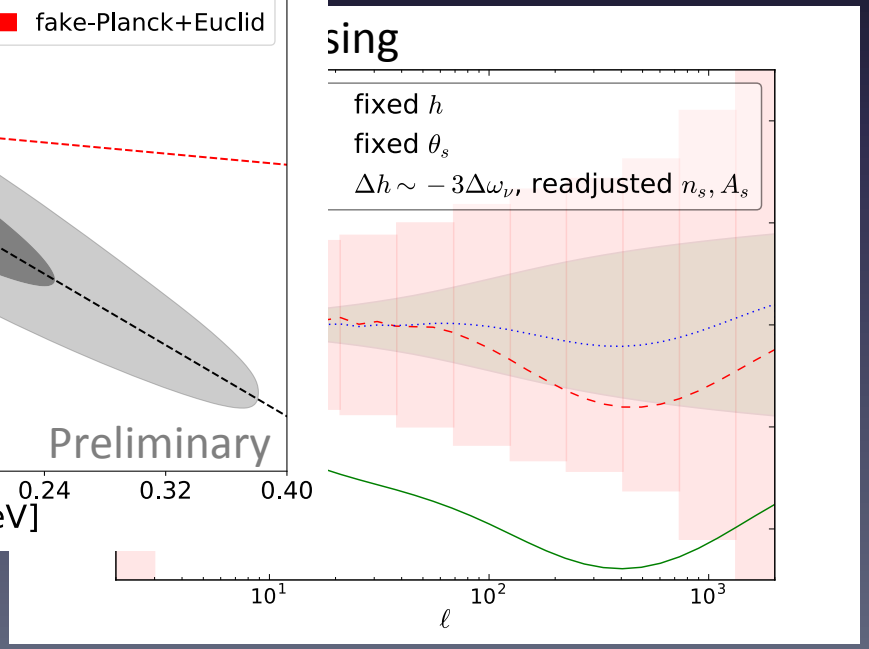

Observational + theo

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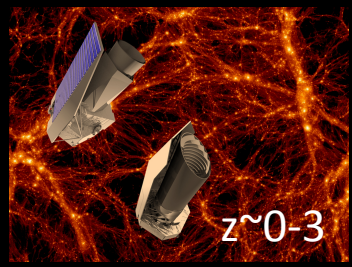

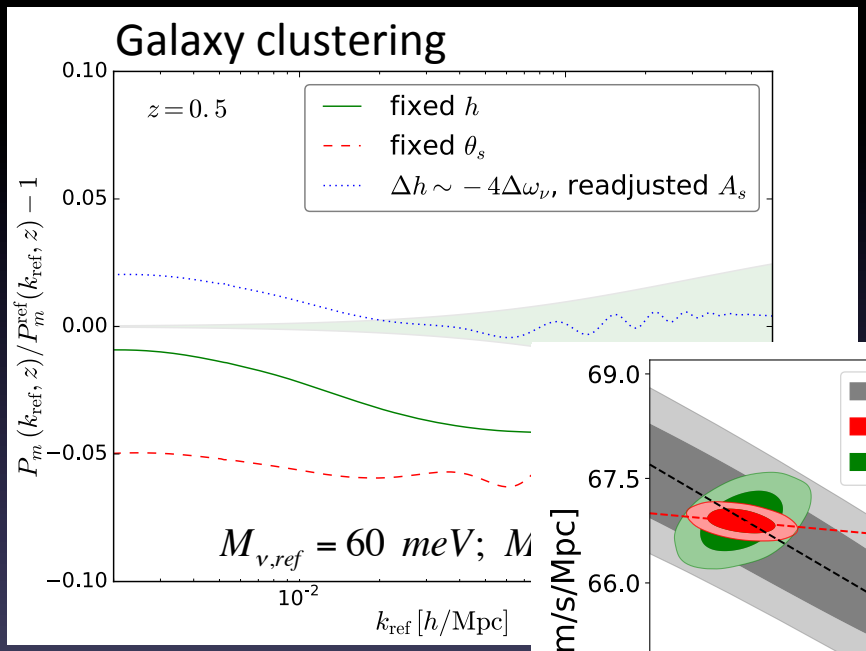

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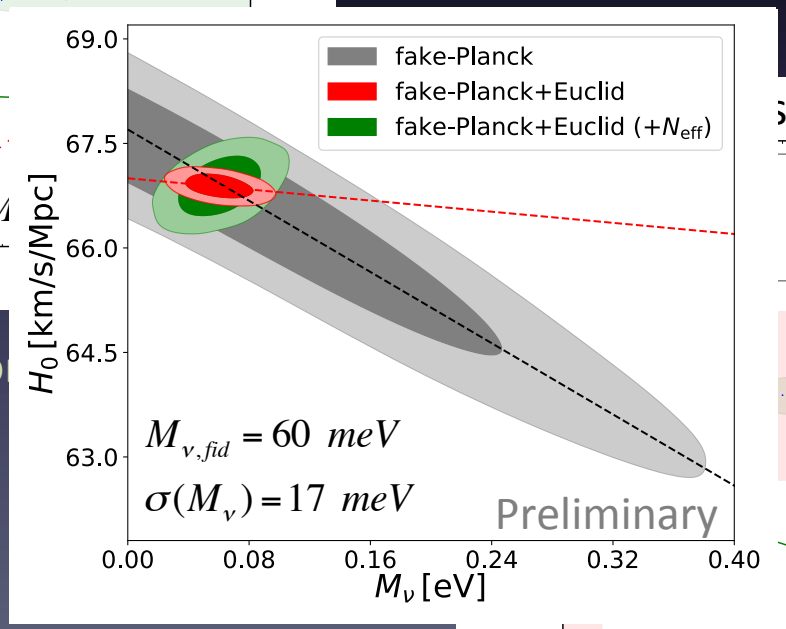

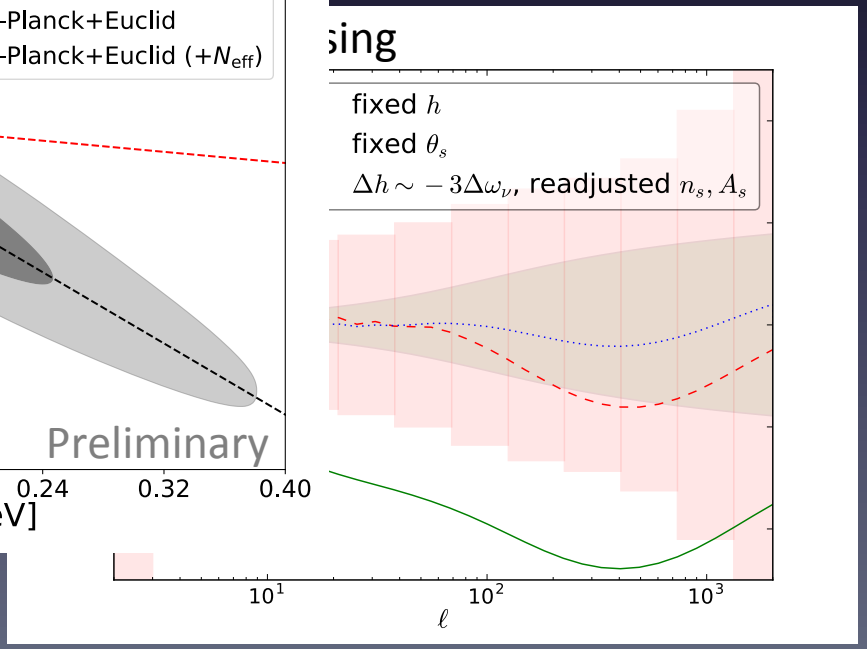

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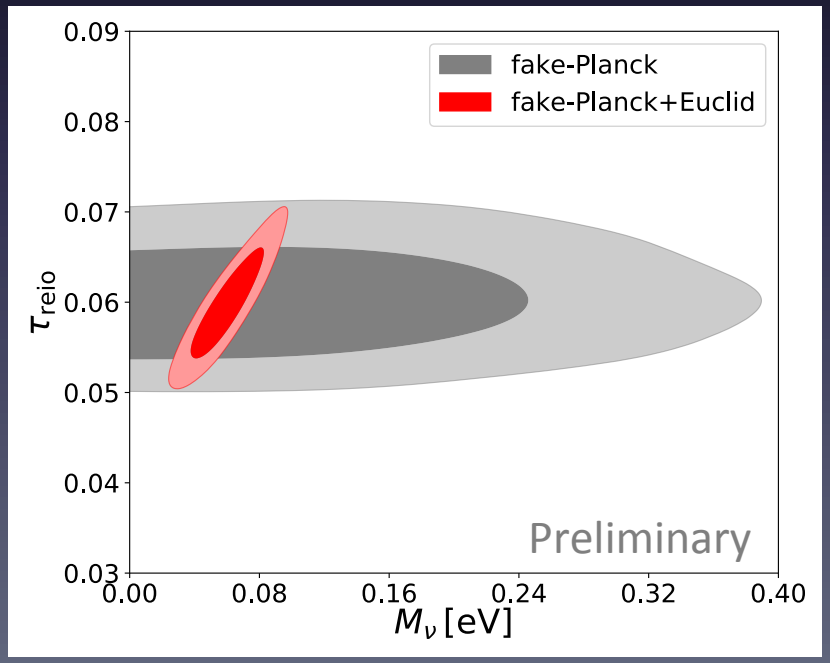
Archidiacono, Brinckmann, Clesse, Lesgourgues, in preparation

Future M_ν constraints 21cm SKA

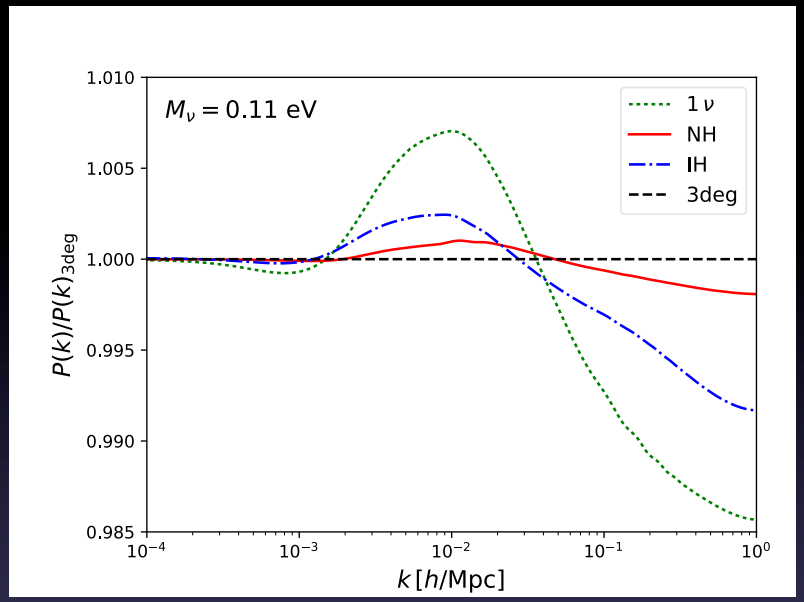
The independent measurement of the epoch of reionization by 21cm surveys may break the degeneracy between the neutrino mass and τ_{reio} which appears in combined analyses of future CMB+LSS data.

However, the measurement of the optical depth at reionization τ_{reio} by 21-cm surveys will be subject to uncertainties coming from the detailed modelling of very non-linear astrophysical processes, and it is currently difficult to predict the sensitivity of future experiments to this parameter.



Villaescusa-Navarro et al., ApJ (2015)
Liu et al., PRD (2016)

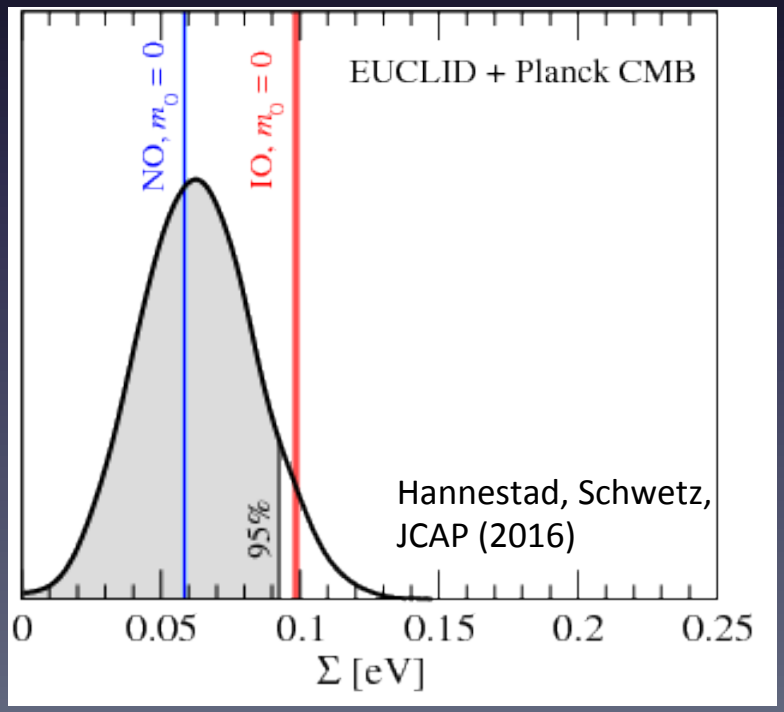
M_ν Hierarchy



$$k > k_{nr} = 0.018\left(\frac{m_\nu}{eV}\right)^{1/2} \Omega_m^{1/2} h / Mpc$$

The scale of the non-relativistic transition depends on the single neutrino mass.

If nature has chosen the neutrino mass sum to be close to the minimum value allowed by oscillation experiments in the normal hierarchy M_ν = 60 meV, then future cosmological data will detect this value at 4-5σ c.l. This would put some pressure on the inverted hierarchy.



Hannestad, Schwetz, JCAP (2016)

N_{eff} from Planck

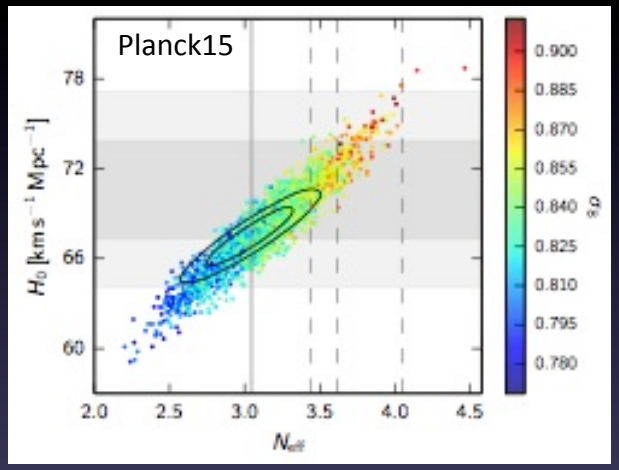
- ΛCDM + N_{eff} ($N_{eff}^{standard}$ = 3.046)

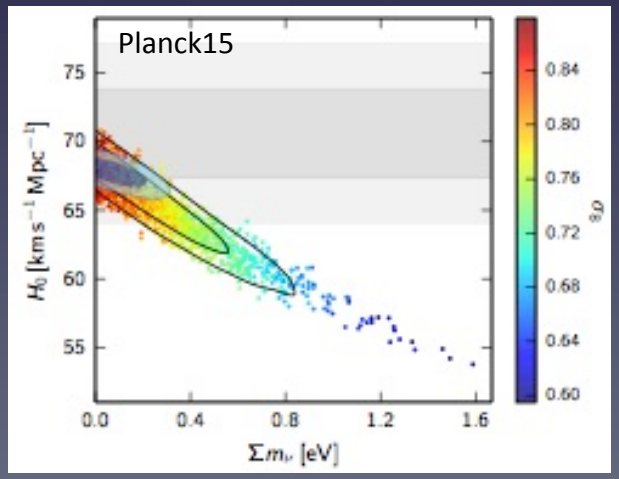
  N_{eff} = 3.04 ± 0.18 (68%c.l.) (Planck+BAO)

- H_0 = (67.31 ± 0.96) km/s/Mpc 0.18 (68%c.l.) (Planck)

  H_0 = (73.24 ± 1.74) km/s/Mpc 0.18 (68%c.l.) (HST, Riess et al., Apj (2016))

- σ_8 tension between Planck and CFHTLens (Kilbinger at al., MNRAS(2013)), alleviated by DES (Abbott at al., PRD(2016))





N_{eff}+$m^{eff}_{\nu,\,s}$ from Planck

ΛCDM + N_{eff} + $m^{eff}_{\nu,\,sterile}$

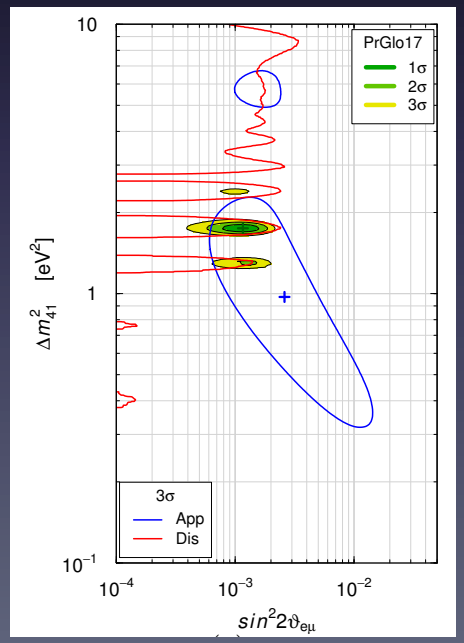
N_{eff} < 3.7 & $m^{eff}_{\nu,\,sterile}$ < 0.38 eV (95%c.l.)

(Planck + BAO)

Planck tension with HST (CFHTLens) does

not represent an escape route!

- χ^2 does not improve
- Tension with SBL



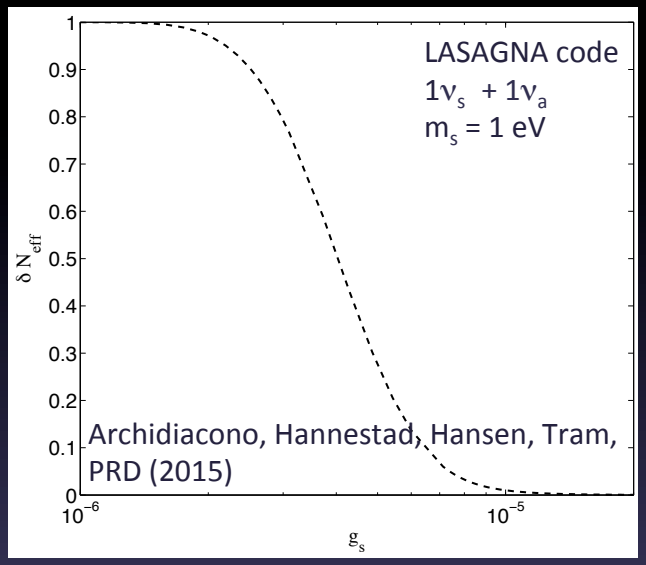
Gariazzo, Giunti, Liu, Global fit (2017)

Talk by C. Giunti

Talk by P. Guzowski

Non-standard sterile neutrino self-interactions

- N_{eff} : Secret interactions induce an additional MSW-like potential. If the potential is dominating at T ≥ 1 MeV, the in medium mixing angle is suppressed and the sterile neutrino production is delayed until after the active neutrino collisional decoupling. The distribution of sterile neutrinos turns out to be partially non thermal.



- M_ν : Since the collisional term is proportional to T, while $H \sim T^2$, sterile neutrinos and light pseudoscalars will re-couple. After the non-relativistic transition, sterile neutrinos will start annihilating into pseudoscalars; the process will last until the final decoupling.

Scalar: Archidiacono, Gariazzo, Giunti, Hansen, Laveder, Tram, JCAP (2015)
Archidiacono, Hannestad, Hansen, Tram, PRD (2016)
Archidiacono, Gariazzo, Giunti, Hannestad, Hansen, Laveder, Tram, JCAP (2016)
Vector: Mirizzi, Mangano, Pisanti, Saviano, PRD (2014) & PRD (2015)
Chu, Dasgupta, Kopp, JCAP (2015)

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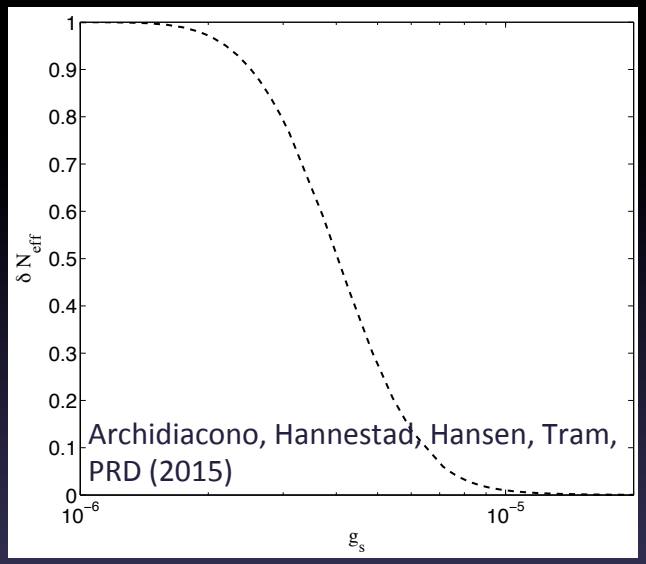

- M_ν : Since the collisional term is proportional to T, while $H \sim T^2$, sterile neutrinos and light pseudoscalars will re-couple. After the non-relativistic transition, sterile neutrinos will start annihilating into pseudoscalars; the process will last until the final decoupling.

Pseudoscalar: Archidiacono, Gariazzo, Giunti, Hannestad, Hansen, Laveder, Tram, JCAP (2015)
Archidiacono, Hannestad, Hansen, Tram, PRD (2016)
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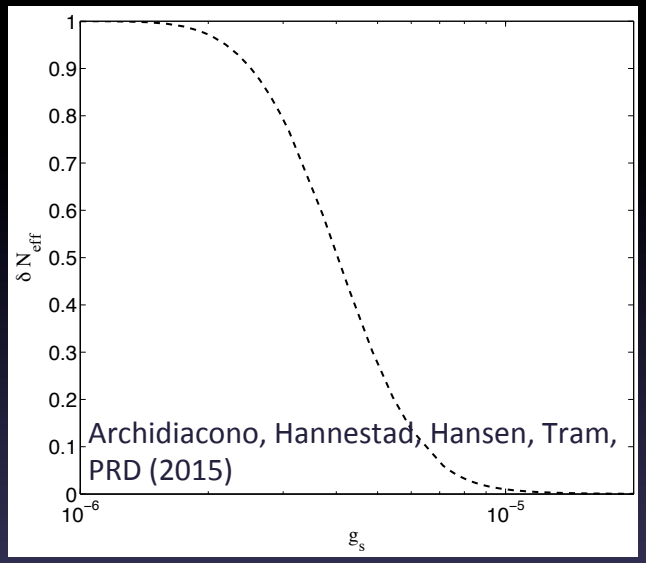

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Conclusions

- Future galaxy and hydrogen surveys will be able to pin down the neutrino mass sum in the minimal extension of the ΛCDM.

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- Take-home message: data tension ➔ model extension!

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Vanilla
ΛCDM
model