

G. Rossi

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# JOINT CONSTRAINTS ON NEUTRINO MASS AND $N_{\text{eff}}$ FROM COSMOLOGY

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# 3 MESSAGES

## JOINT CONSTRAINTS ON $N_{\text{eff}}$ AND $\sum m_\nu$

- $N_{\text{eff}} = 2.91^{+0.21}_{-0.22}$  and  $\sum m_\nu < 0.15$  eV (all at 95% CL) → CMB + Lyman- $\alpha$
- $N_{\text{eff}} = 2.88^{+0.20}_{-0.20}$  and  $\sum m_\nu < 0.14$  eV (all at 95% CL) → CMB + Lyman- $\alpha$  + BAO

- Novel suite of hydrodynamical simulations with massive neutrinos + innovative technique to handle dark radiation models
- Sterile neutrino thermalized with active neutrinos ruled out at more than  $5\sigma$  → one of the strongest bounds to date
- $N_{\text{eff}} = 0$  rejected at more than  $14\sigma$  → robust evidence for the CNB from  $N_{\text{eff}} \sim 3$

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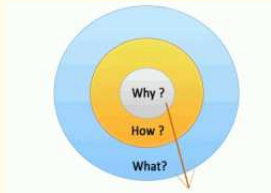
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# OUTLINE

- **Why?** Neutrino Science
- **How?** Tools & Technique
- **What?** Results



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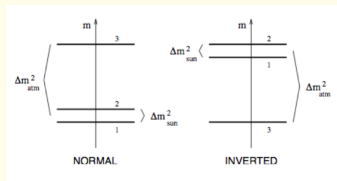
RESULTS

## MAIN REFERENCES

- **G. Rossi** et al. (2015), PRD, 92, 063505
- **G. Rossi** et al. (2014), A&A, 567, A79

# WHY?

- Total neutrino mass?
- Neutrino mass hierarchy?
- Number of effective neutrino species?



- Neutrino mass scale and hierarchy important for **Standard Model** → leptogenesis, baryogenesis, right-handed neutrino sector + several cosmological implications

# HOW → DATASETS



- One-dimensional Ly $\alpha$  forest flux power spectrum derived from the Data Release 9 (DR9) of the Baryon Acoustic Spectroscopic Survey (BOSS) quasar data
- Planck (2013) temperature data from the March 2013 public release (both high and low- $\ell$ )
- High- $\ell$  public likelihoods from the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT)
- Some low- $\ell$  WMAP polarization data
- Baryon Acoustic Oscillation (BAO) scale in the clustering of galaxies from the BOSS Data Release 11 (DR11)

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# HOW → SIMULATIONS

## A suite of 48 hydrodynamical simulations with massive neutrinos

- Typical set (3 sims.) → (a)  $100 h^{-1} \text{Mpc}/768^3$ , (b)  $25 h^{-1} \text{Mpc}/768^3$ , (c)  $25 h^{-1} \text{Mpc}/192^3$
- With splicing technique → equivalent of  $100 h^{-1} \text{Mpc}/3072^3$
- Full snapshots at a given redshift ( $z = 4.6 - 2.2$ ,  $\Delta z = 0.2$ )
- 100,000 quasar sightlines per redshift interval per simulation

**Group I**

Simulation Set	$M_\nu$ [eV]
BG a/b/c	0
NUBG a/b/c	0.01
NU01 a/b/c	0.1
NU01-norm a/b/c	0.1
NU02 a/b/c	0.2
NU03 a/b/c	0.3
NU04 a/b/c	0.4
NU04-norm a/b/c	0.4
NU08 a/b/c	0.8
NU08-norm a/b/c	0.8

**Group II**

Simulation Set	$M_\nu$ [eV]
$\gamma$ +NU08 a/b/c	0.8
$H_0$ +NU08 a/b/c	0.8
$n_s$ +NU08 a/b/c	0.8
$\Omega_m$ +NU08 a/b/c	0.8
$\sigma_8$ +NU08 a/b/c	0.8
$T_0$ +NU08 a/b/c	0.8

- **Group I** → Best-guess and neutrino runs
- **Group II** → Cross-terms

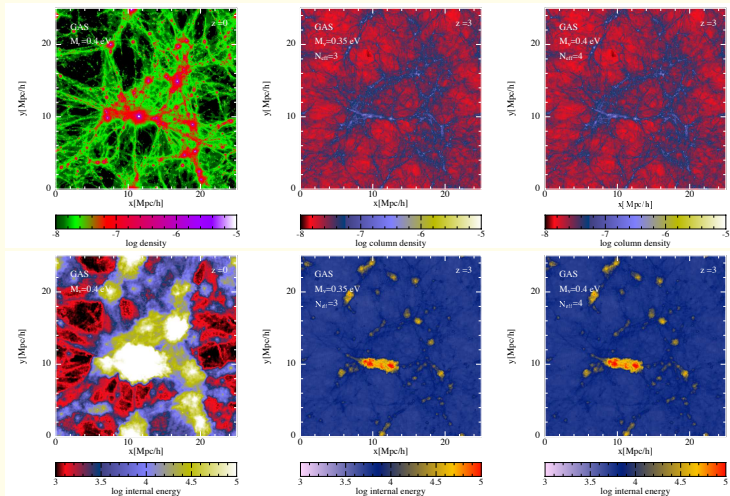
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## VISUALIZATIONS



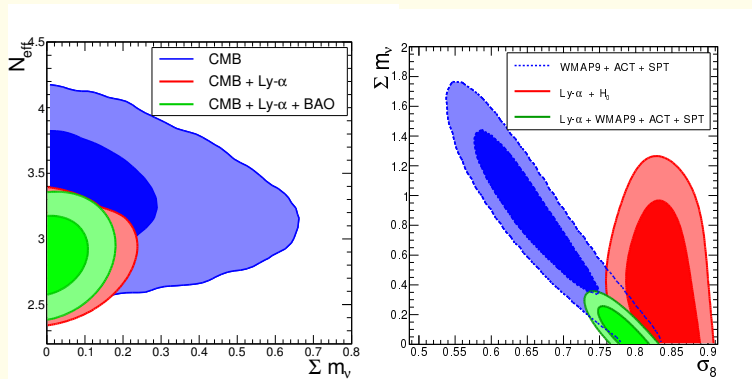
Rossi (2014), Rossi et al. (2014, 2015)

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WHAT  $\rightarrow$  JOINT CONSTRAINTS

Rossi et al. (2015), Palanque-Desabrouille et al. (2015)

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CMB + Lyman- $\alpha$

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