Implications on neutrino masses from the study of the large scale structure with X-ray galaxy clusters

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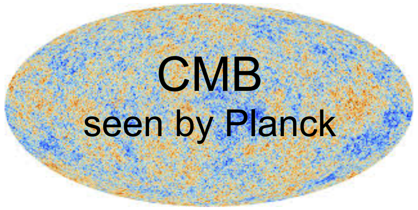
Standard Cosmological Model

Initial conditions:
Gaussian seed fluctuations from inflation

... calibrated by Planck (~300 000 yr a. BB.)

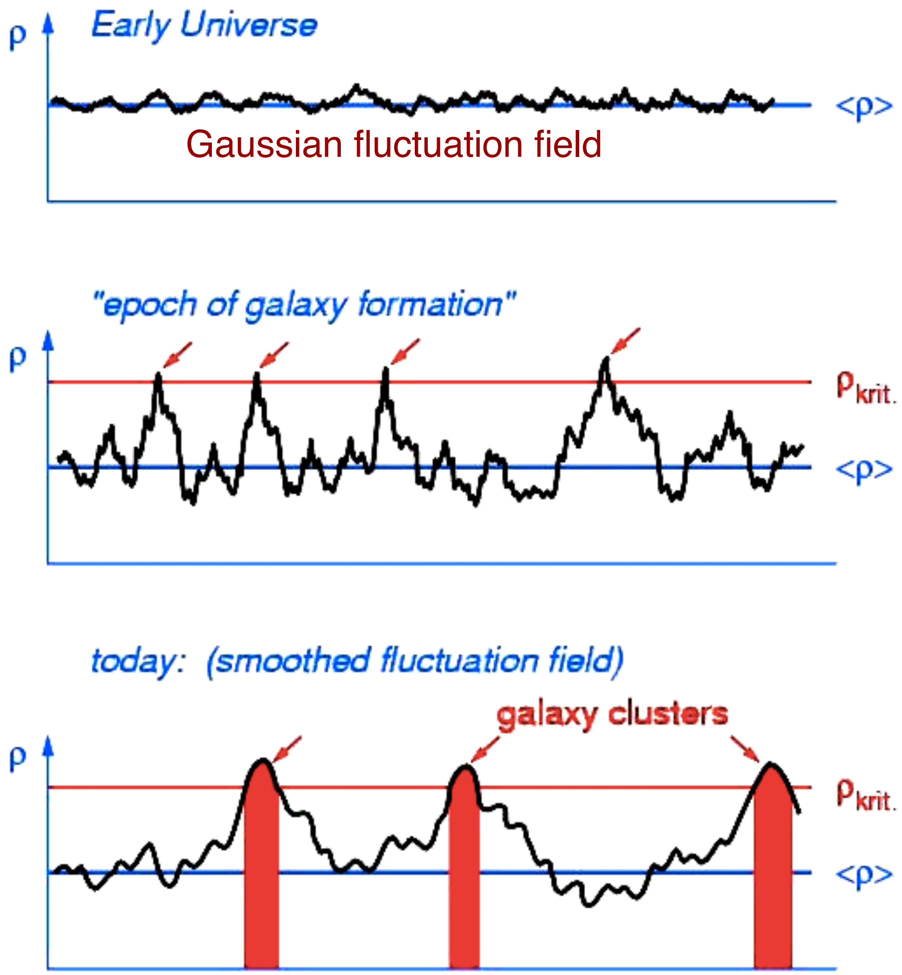


Expansion of the Universe: H_0, Ω_m, Λ, w

Structure growth: Ω_m, Λ, w, and nature of Dark Matter (including neutrinos)

Large scale structure seen today
e.g. galaxy cluster distribution

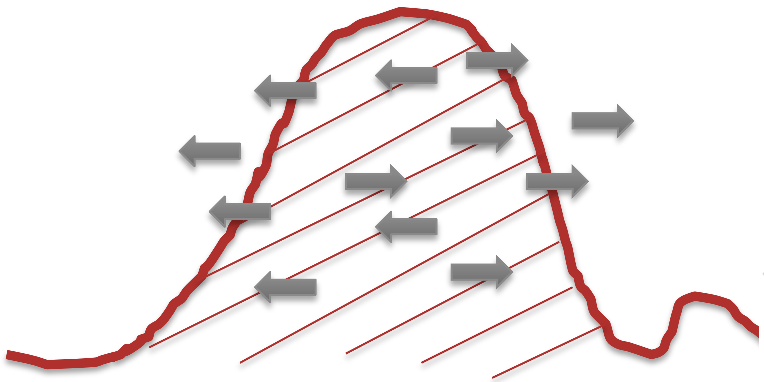
Galaxy clusters in the hierarchy of the large-scale structure



mass of galaxy clusters ~ 10^{14} – 10^{15} M_{sun}

- Galaxy clusters are the largest (10^{14} – 10^{15} M_{sun}) well described structures in the Universe
- As large-scale high amplitude peaks, they are very sensitive probes of the density fluctuation field

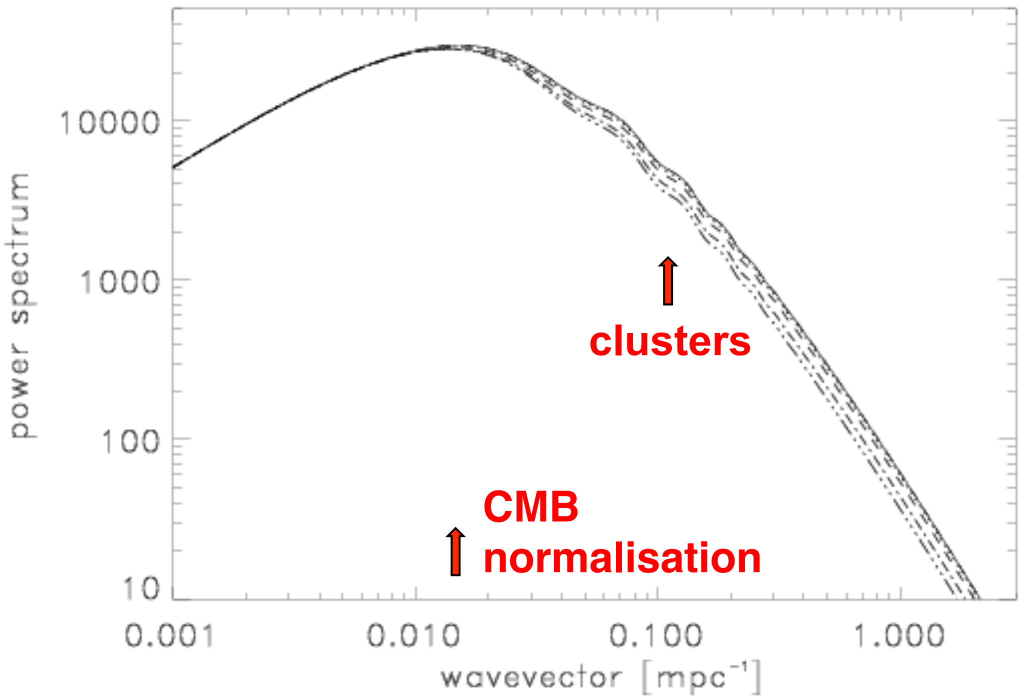
Damping of density fluctuations by relativistic neutrinos



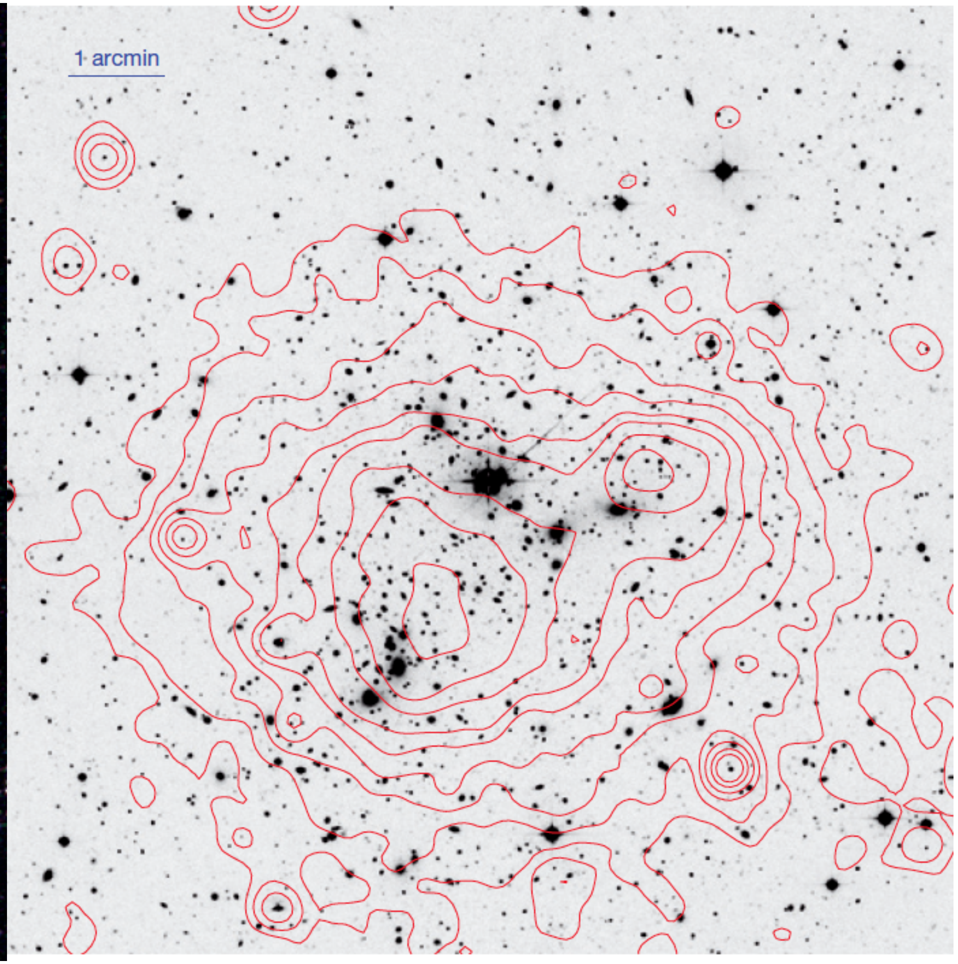
Relativistic neutrinos can diffuse out off the density fluctuation

matter power spectrum

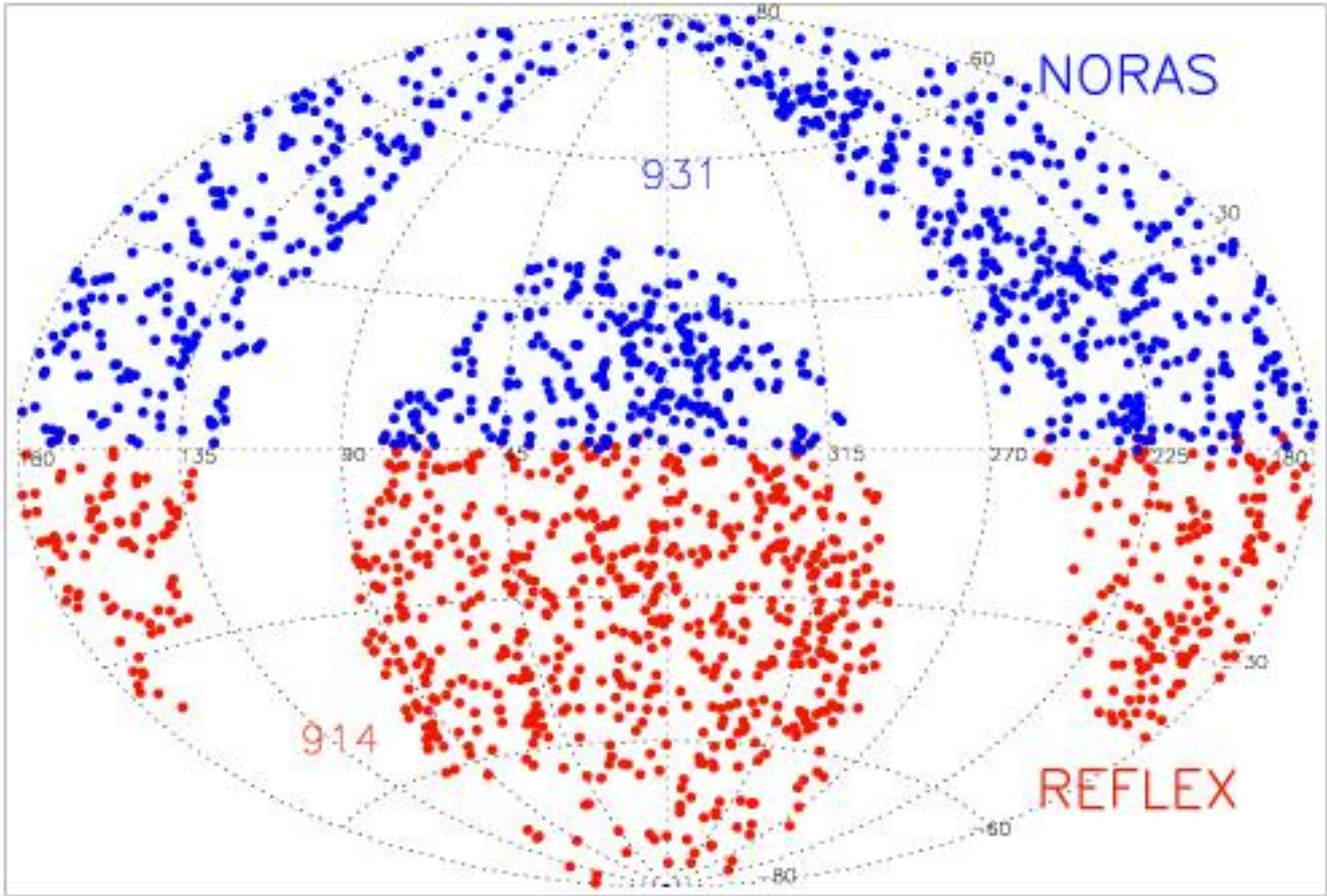
Neutrino mass M_ν = 0, 0.06, 0.17, 0.4, 0.6 eV



Abell 2744, z = 0.3 , Optical and X-ray Images



REFLEX & NORAS Cluster Survey

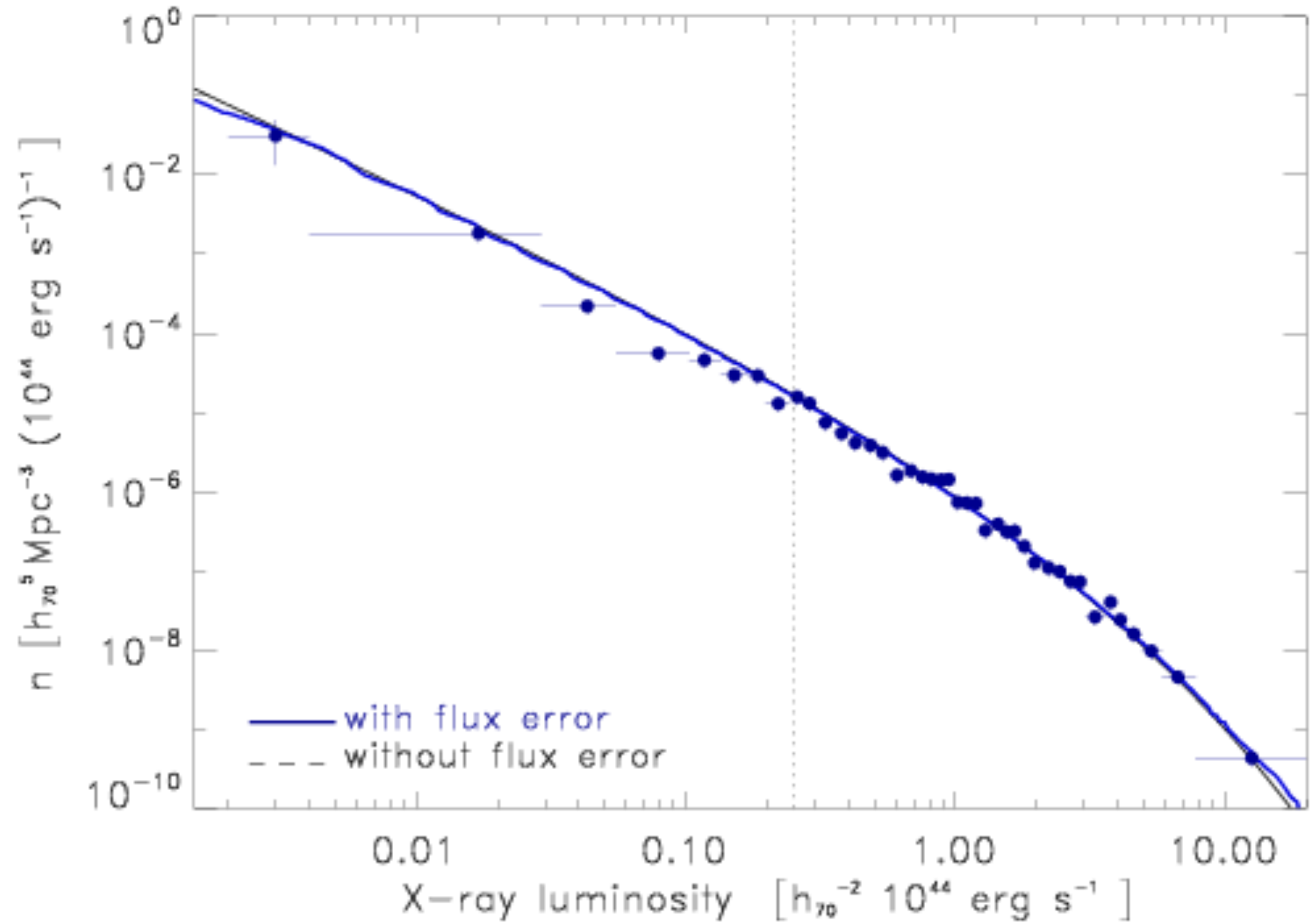


REFLEX II 915 clusters, NORAS II 882 clusters F > 1.8 10^{-12} erg s^{-1} cm^{-2}

Sample description: Böhringer et al. 2000, 2001, 2004, 2013, 2014 Chon & B. 2012

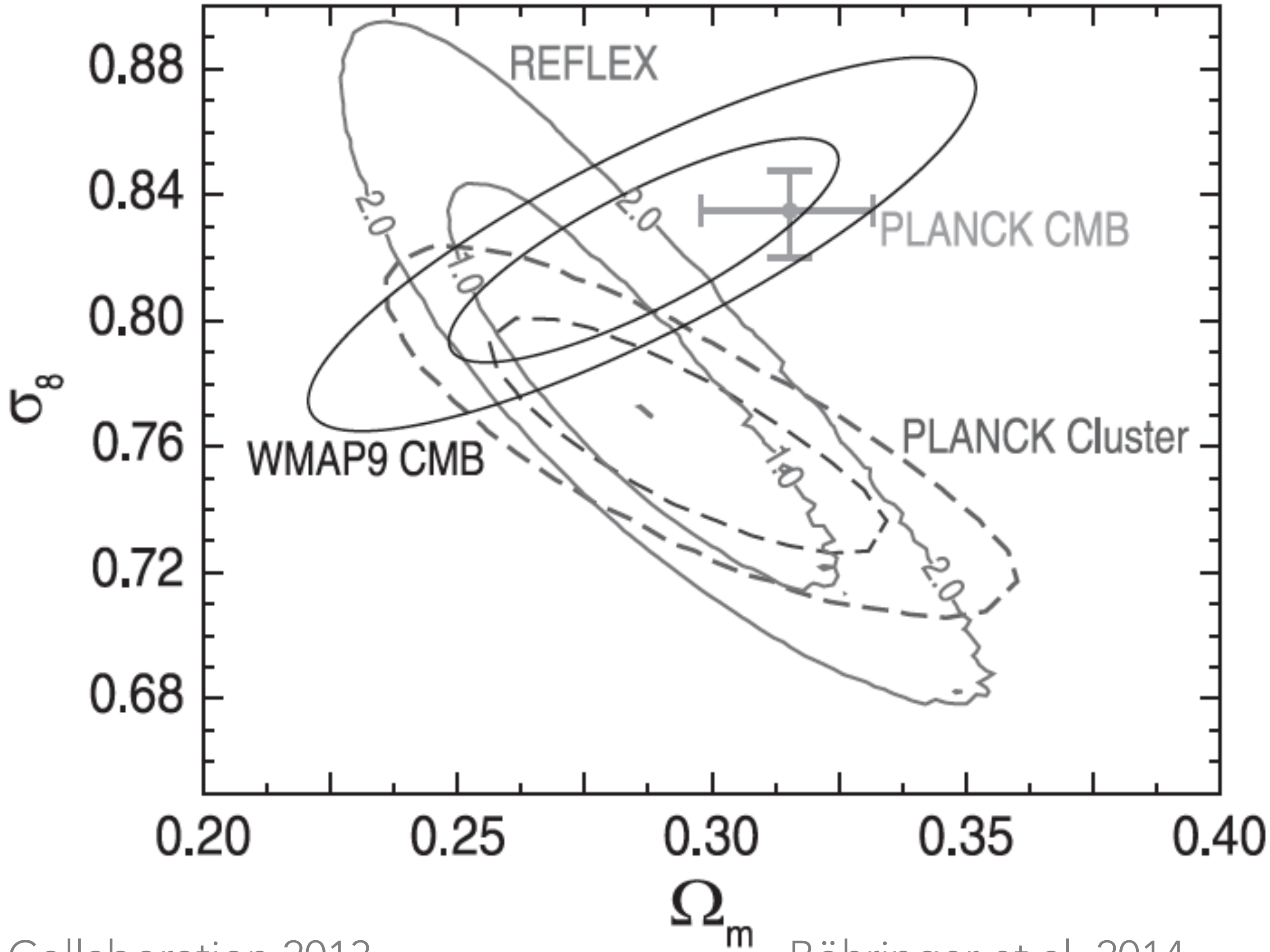
Observed and predicted X-ray luminosity function

Prediction for a flat ΛCMD model $\Omega_m = 0.27$ and $\sigma_8 = 0.80$



Böhringer et al. 2014

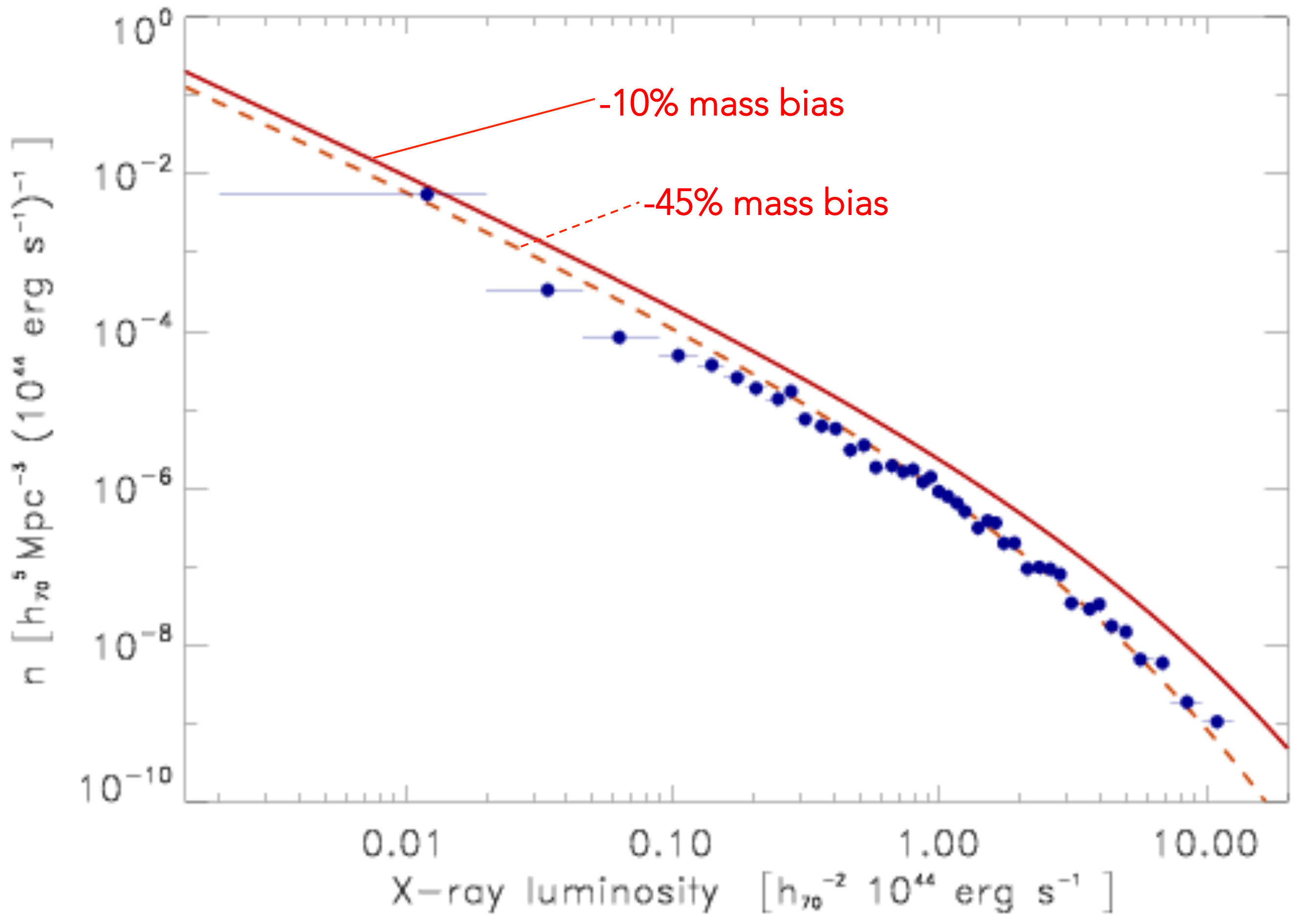
REFLEX and PLANCK cluster and PLANCK and WMAP CMB constraints



Planck Collaboration 2013
Hinshaw et al. 2013

Böhringer et al. 2014

Prediction for PLANCK CMB cosmology



Böhringer et al. 2014

Hydrostatic mass bias calibration with weak lensing

Cluster weak lensing studies

$$M_{HE} = M_{true} \cdot (1-b)$$

CCCP project [Mahdavi et al. 2013] : 1-b ~ **0.90**
[Hoekstra et al. 2015] : 1-b = **0.76** (+-0.05 +- 0.06)

LoCuSS [Martino et al. 2014, Smith & Okabe 2015]: 1-b = **1.02** +- 0.05

Weighting the Giants [von der Linden et al. 2014]: 1-b = **0.698** +- 0.062

PLANCK and ACT clusters [Gruen et al. 2014] … << 20% bias

400d cluster sample [Israel et al. 2014] : no significant bias

CLASH clusters agrees with LoCuSS

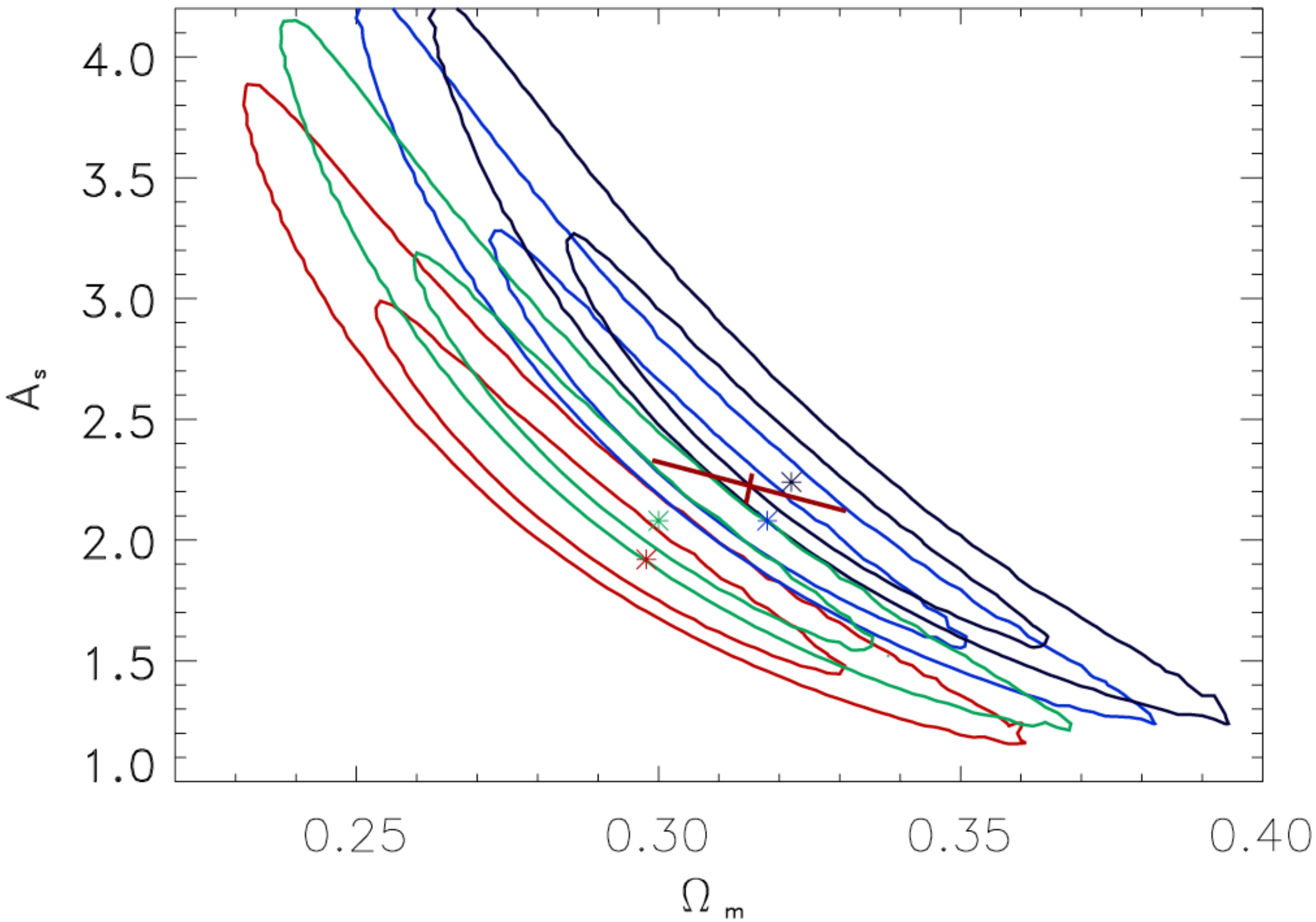
Comparison of X-ray masses and CMB lensing masses

Melin & Bartlett 2015 1-b = **0.98** +- 0.13

We allowed for 1-b = 0.76 – 1.04

Effect of massive neutrinos

Constraints on A_s and Ω_m for M_ν = 0, 0.17, 0.4, 0.6 eV



Formal consistency for M_n = 0.45 +- 0.28 eV

Böhringer & Chon 2015

Summary of indications for massive neutrinos

Observed signature: less power in density fluctuations at present than predicted by ΛCDM with PLANCK-"calibration"

Similar results from different studies of low z LSS:

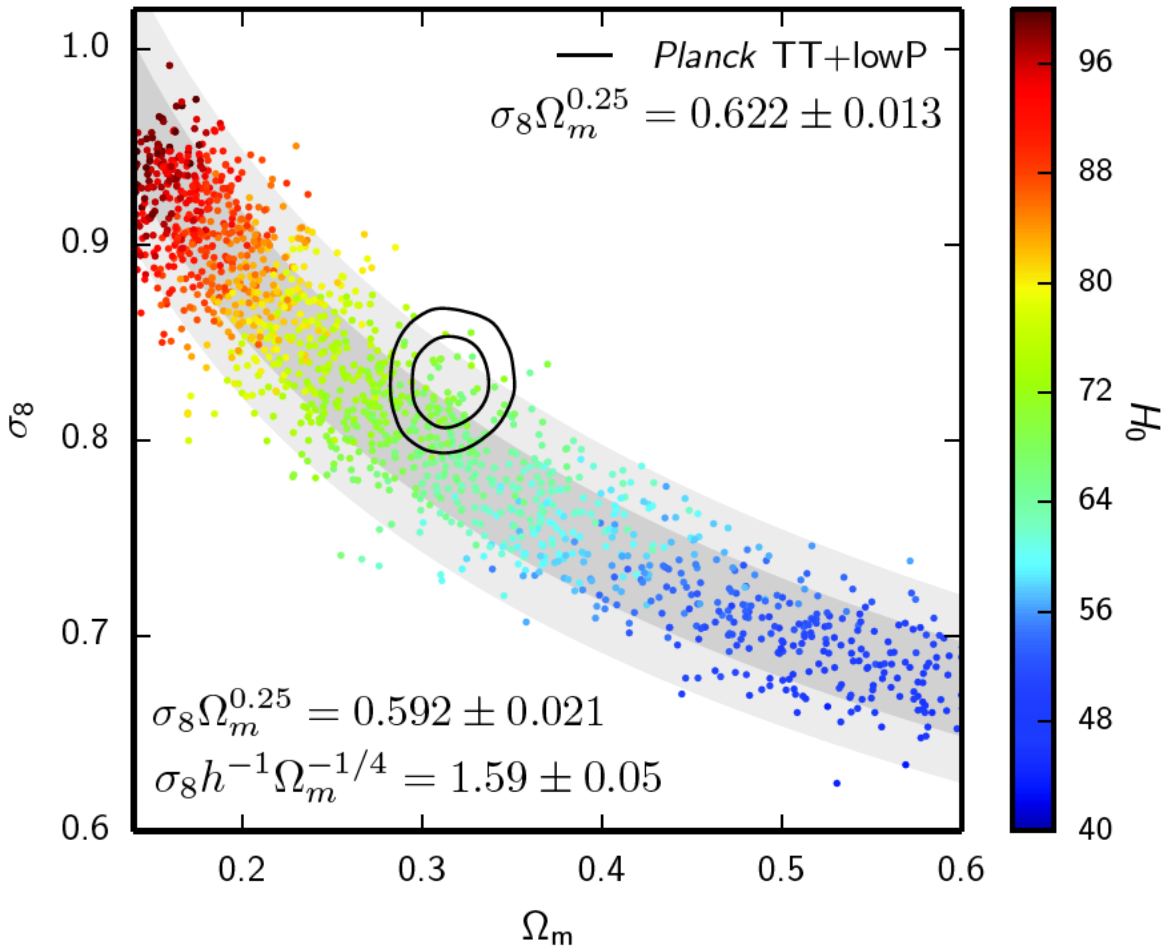
1. **Clusters:** e.g. present work, Planck Collaboration 2014,15 Burenin 2012 - Mantz et al. 2015 reaches different conclusion

2. **Redshift space distortions:** e.g. Beutler et al. 2014, Ruiz & Huterer 2015

3. **LSS lensing shear:** e.g. Hamann & Hasenkamp 2013, Battye & Moss 2014

4. **CMB lensing:** e.g. Planck Collaboration 2015

Planck CMB lensing



Planck Collaboration 2015

Conclusions

- REFLEX clusters provide tight constraints on the growth of cosmic structure and the parameters Ω_m and σ_8
- Clusters and other low z probes of LSS indicate less power in fluctuations than expected from PLANCK and ΛCDM

- The least speculative explanation of this discrepancy are massive neutrinos (with $M_\nu \sim 0.17 - 0.7$ eV)