New Directions

Constraints on neutrino physics and dark matter from cosmology

Neutrino physics from cosmology current status

Signs for neutrino mass from combined cosmological data (Beutler et al. 2014):

$$\sum m_\nu = 0.36 \pm 0.10\,\mathrm{eV}\ \ (68\%\ \mathrm{c.l.})$$

Hints for extra dark radiation from Planck+BICEP2 (Giusarma et al. 2014):

$$N_{\rm eff} = 4.00 \pm 0.41$$

Indication for sterile neutrino from combined cosmological data (Dvorkin et al. 2014):

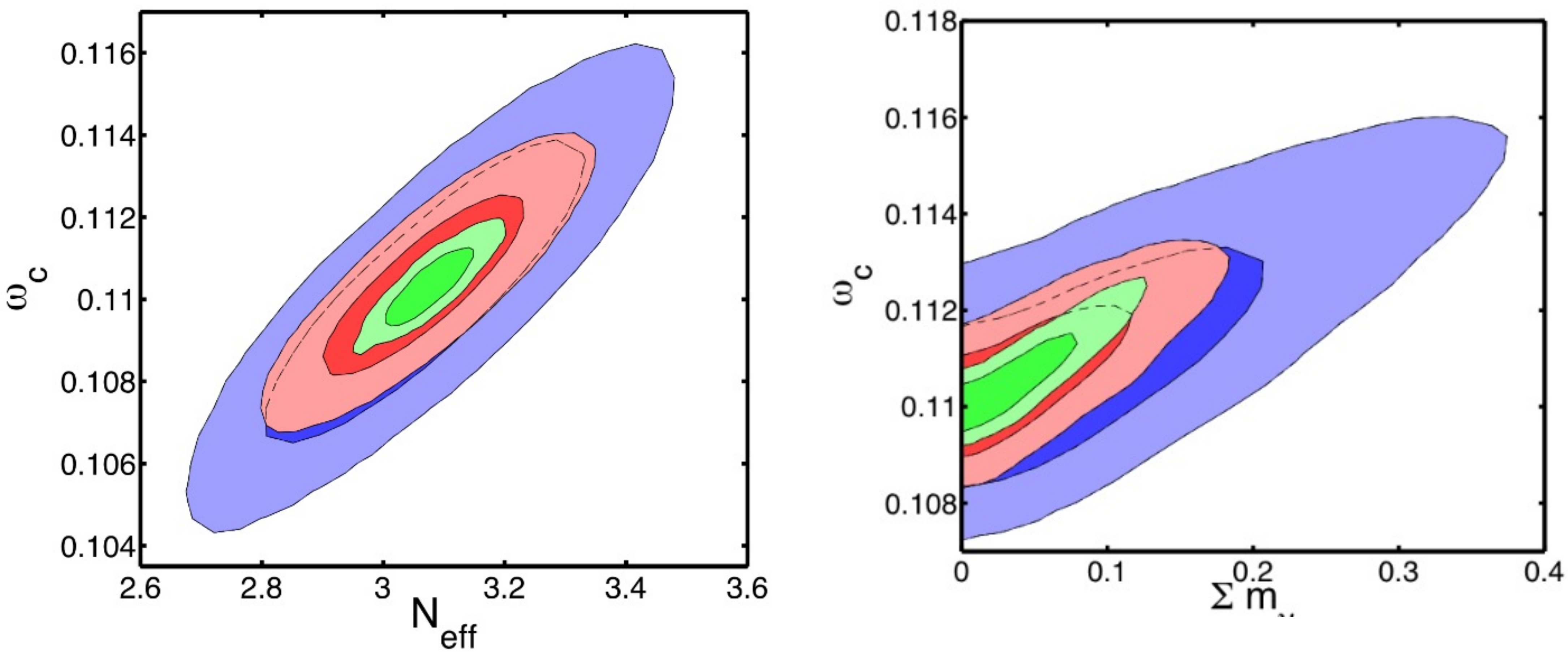
$$m_s = 0.47 \pm 0.13\mathrm{eV} \qquad \Delta N_{\rm eff} = 0.81 \pm 0.25$$

Neutrino Physics from cosmology: caveats

- Constraints are model dependent

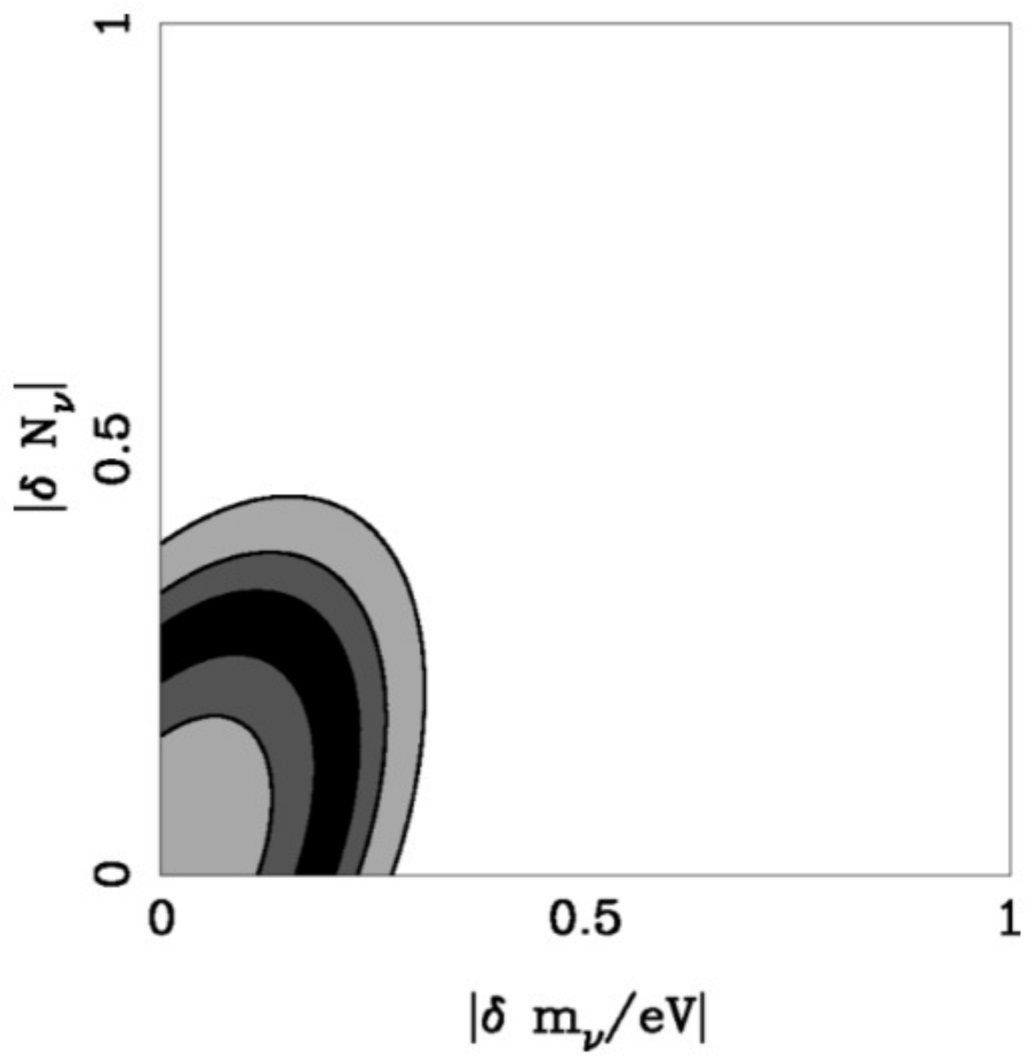
- Indications for extra neutrinos coming from "tensions" between datasets

Neutrino physics from cosmology: forecasts



Blue: Planck 2014, Red: Planck+ACTpol, Green: Next CMB satellite (Galli et al., 2010)

Neutrino physics from cosmology: forecasts



Planck+Euclid
Kitching et al., 2008

$$\Delta m_\nu \sim 0.03 \text{ eV and } \Delta N_\nu \sim 0.08$$

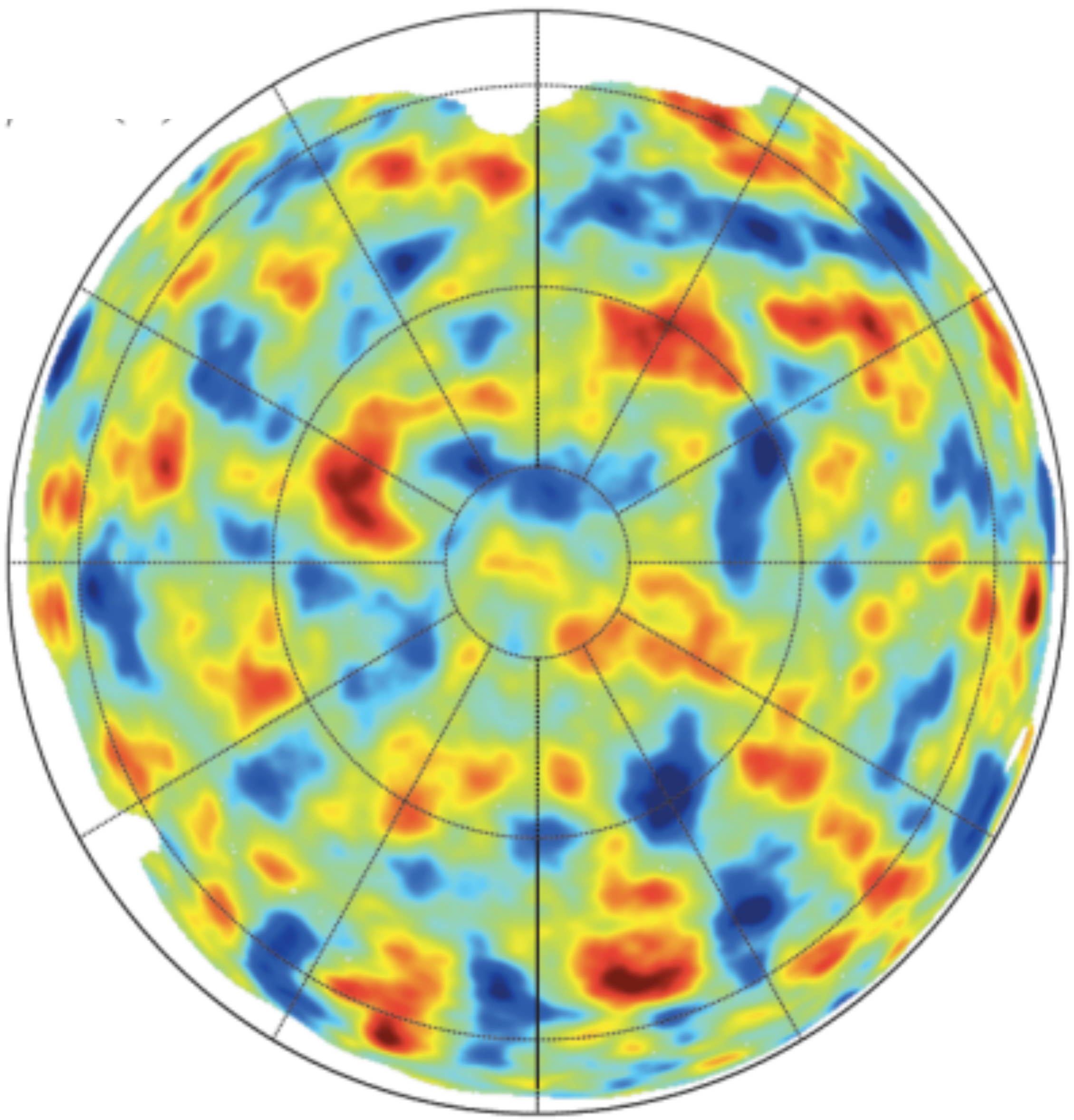
Cosmological constraints on Dark Matter

Constraints

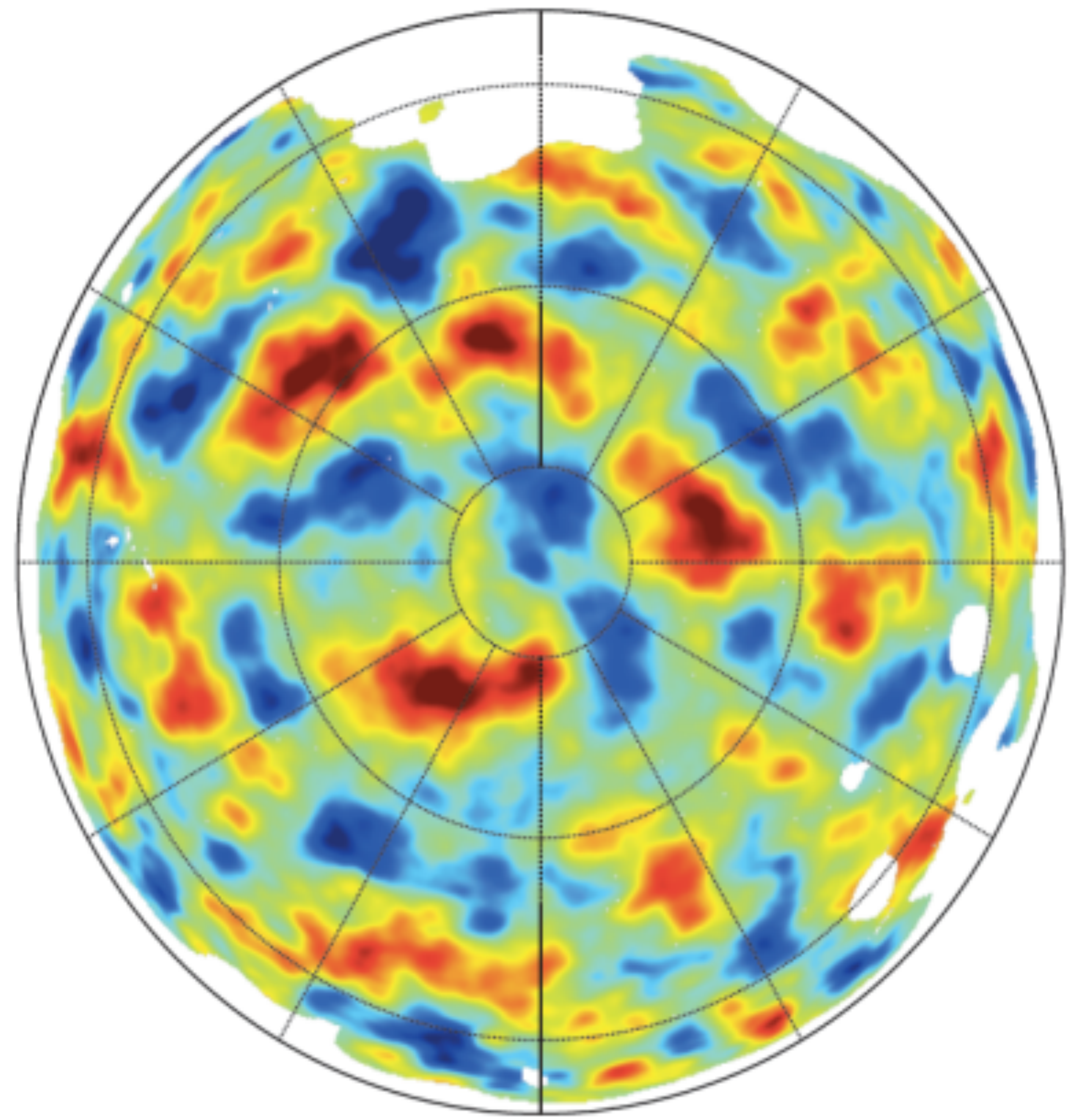
Parameter	*Planck*		*Planck*+lensing		*Planck*+WP	
	Best fit	68% limits	Best fit	68% limits	Best fit	68% limits
$\Omega_b h^2$	0.022068	0.02207 ± 0.00033	0.022242	0.02217 ± 0.00033	0.022032	0.02205 ± 0.00028
$\Omega_c h^2$	0.12029	0.1196 ± 0.0031	0.11805	0.1186 ± 0.0031	0.12038	0.1199 ± 0.0027
$100\theta_{MC}$	1.04122	1.04132 ± 0.00068	1.04150	1.04141 ± 0.00067	1.04119	1.04131 ± 0.00063
τ	0.0925	0.097 ± 0.038	0.0949	0.089 ± 0.032	0.0925	$0.089^{+0.012}_{-0.014}$
n_s	0.9624	0.9616 ± 0.0094	0.9675	0.9635 ± 0.0094	0.9619	0.9603 ± 0.0073
$\ln(10^{10} A_s)$	3.098	3.103 ± 0.072	3.098	3.085 ± 0.057	3.0980	$3.089^{+0.024}_{-0.027}$
Ω_Λ	0.6825	0.686 ± 0.020	0.6964	0.693 ± 0.019	0.6817	$0.685^{+0.018}_{-0.016}$
Ω_m	0.3175	0.314 ± 0.020	0.3036	0.307 ± 0.019	0.3183	$0.315^{+0.016}_{-0.018}$
σ_8	0.8344	0.834 ± 0.027	0.8285	0.823 ± 0.018	0.8347	0.829 ± 0.012
z_{re}	11.35	$11.4^{+4.0}_{-2.8}$	11.45	$10.8^{+3.1}_{-2.5}$	11.37	11.1 ± 1.1
H_0	67.11	67.4 ± 1.4	68.14	67.9 ± 1.5	67.04	67.3 ± 1.2

CMB needs Dark Matter at more than 40 standard deviations !
Caveat: CDM must be non relativistic at recombination.
Masses m>10eV would be OK.

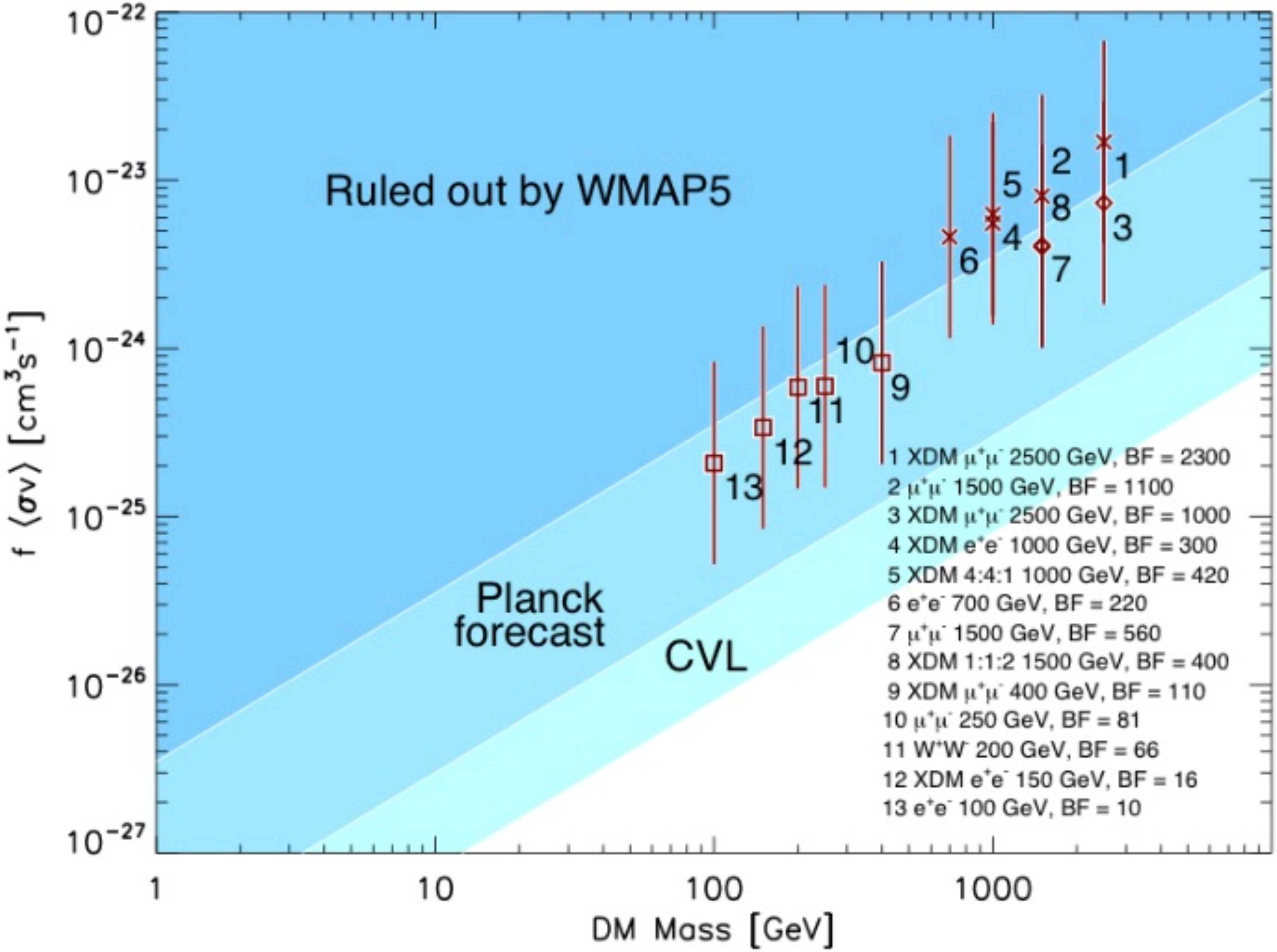
Planck dark matter distribution throught CMB lensing



Galactic North



Galactic South



Ruled out by WMAP5
Planck forecast
CVL
1 XDM μ⁺μ⁻ 2500 GeV, BF = 2300
2 μ⁺μ⁻ 1500 GeV, BF = 1100
3 XDM μ⁺μ⁻ 2500 GeV, BF = 1000
4 XDM e⁺e⁻ 1000 GeV, BF = 300
5 XDM 4:4:1 1000 GeV, BF = 420
6 e⁺e⁻ 700 GeV, BF = 220
7 μ⁺μ⁻ 1500 GeV, BF = 560
8 XDM 1:1:2 1500 GeV, BF = 400
9 XDM μ⁺μ⁻ 400 GeV, BF = 110
10 μ⁺μ⁻ 250 GeV, BF = 81
11 W⁺W⁻ 200 GeV, BF = 66
12 XDM e⁺e⁻ 150 GeV, BF = 16
13 e⁺e⁻ 100 GeV, BF = 10
f ⟨σv⟩ [cm³s⁻¹]
DM Mass [GeV]

Axion cold dark matter in view of BICEP2 results

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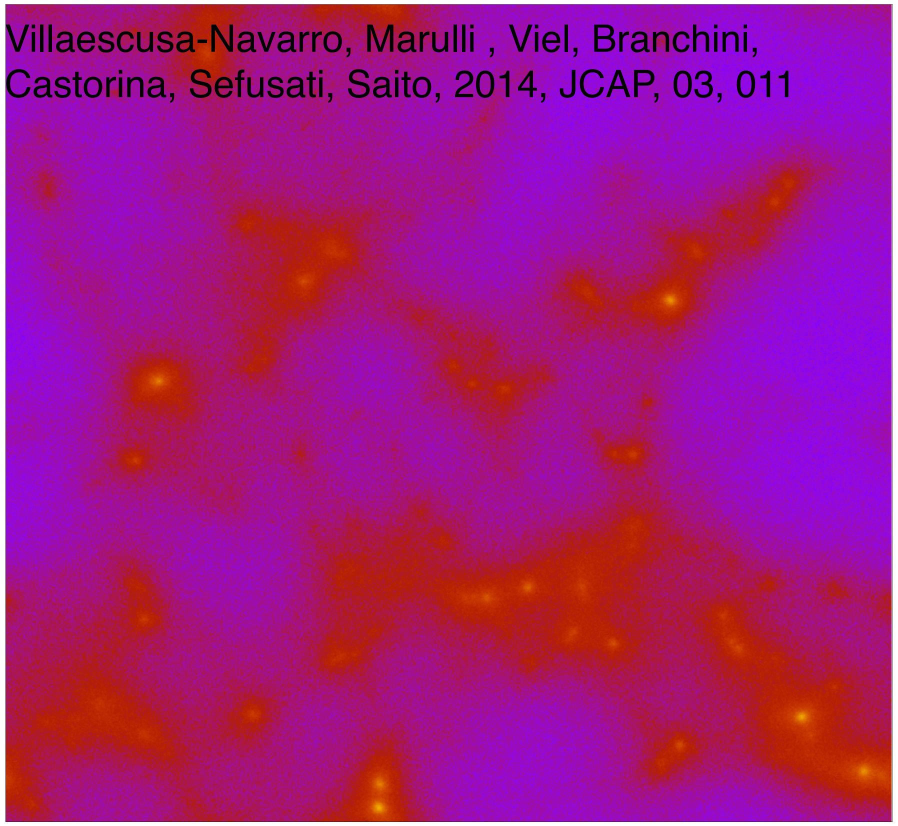
(Dated: March 20, 2014)

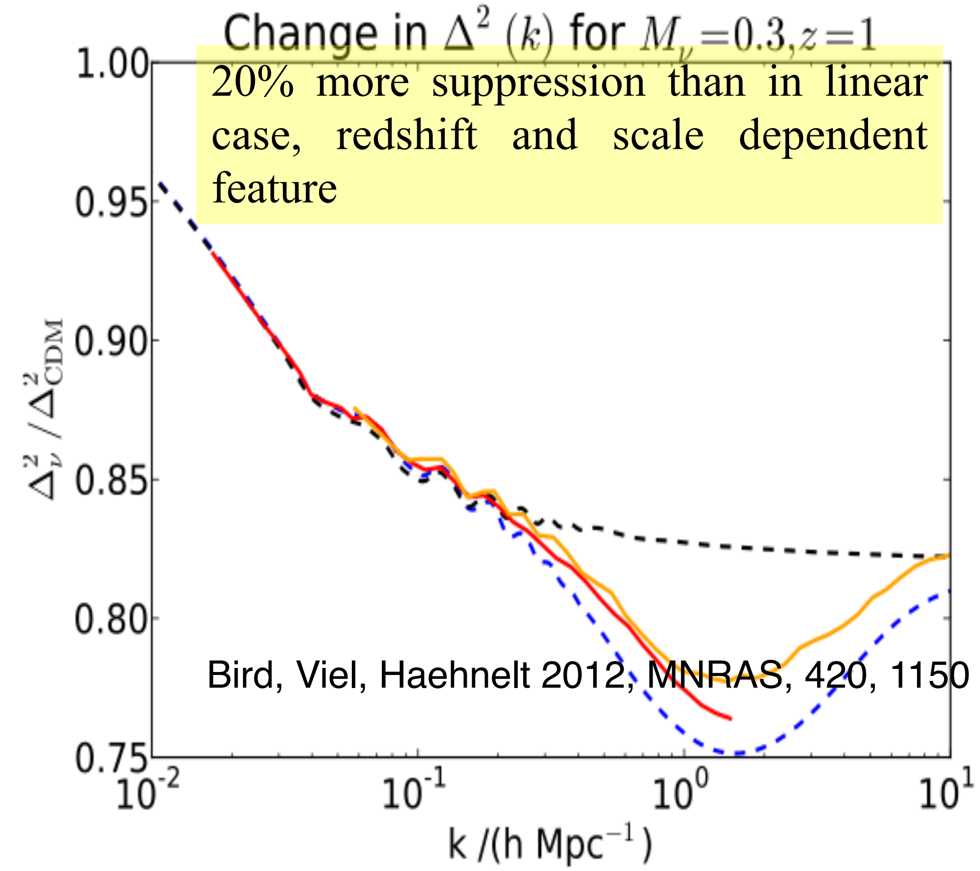
The properties of axions that constitute 100% of cold dark matter (CDM) depend on the tensor-to-scalar ratio r at the end of inflation. If $r = 0.20^{+0.07}_{-0.05}$ as reported by the BICEP2 collaboration, then "half" of the CDM axion parameter space is ruled out. Namely, the Peccei-Quinn symmetry must be broken after the end of inflation, and axions do not generate non-adiabatic primordial fluctuations. The cosmic axion density is then independent of the tensor-to-scalar ratio r, and the axion mass is expected to be in a narrow range that however depends on the cosmological model before primordial nucleosynthesis. In the standard ΛCDM cosmology, the CDM axion mass range is $m_a = (71 \pm 2)\,\mu\text{eV}\,(\alpha^{\text{dec}} + 1)^{6/7}$, where α^{dec} is the fractional contribution to the cosmic axion density from decays of axionic strings and walls.

PACS numbers: 14.80.Mz, 95.35.+d

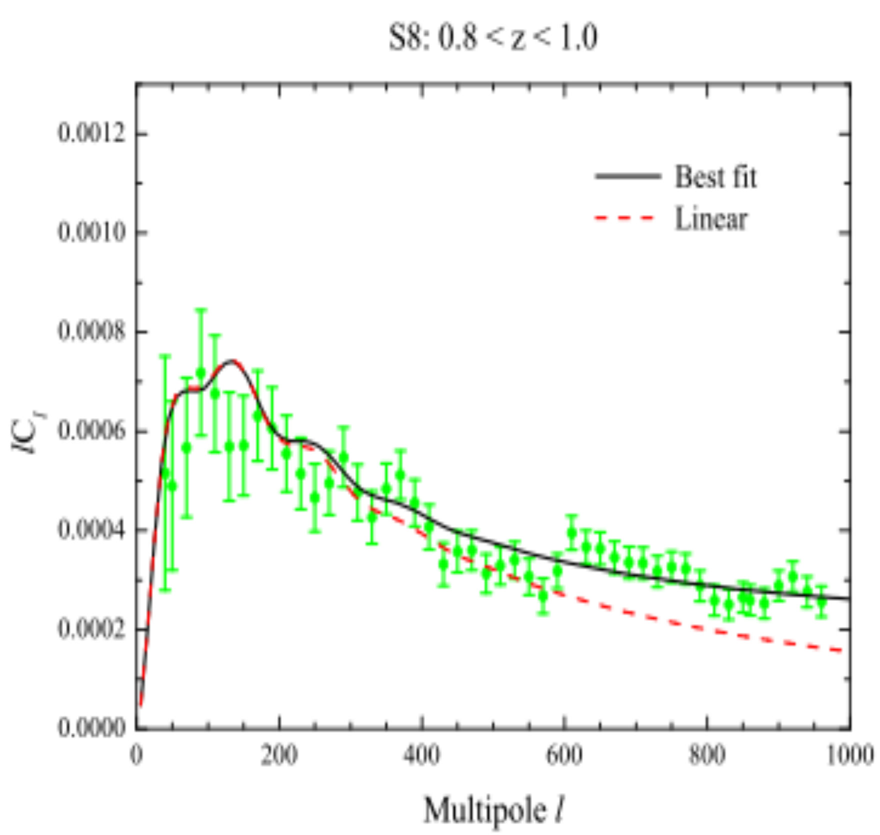
Cosmological Neutrinos



Villaescusa-Navarro, Marulli , Viel, Branchini, Castorina, Sefusati, Saito, 2014, JCAP, 03, 011



Bird, Viel, Haehnelt 2012, MNRAS, 420, 1150



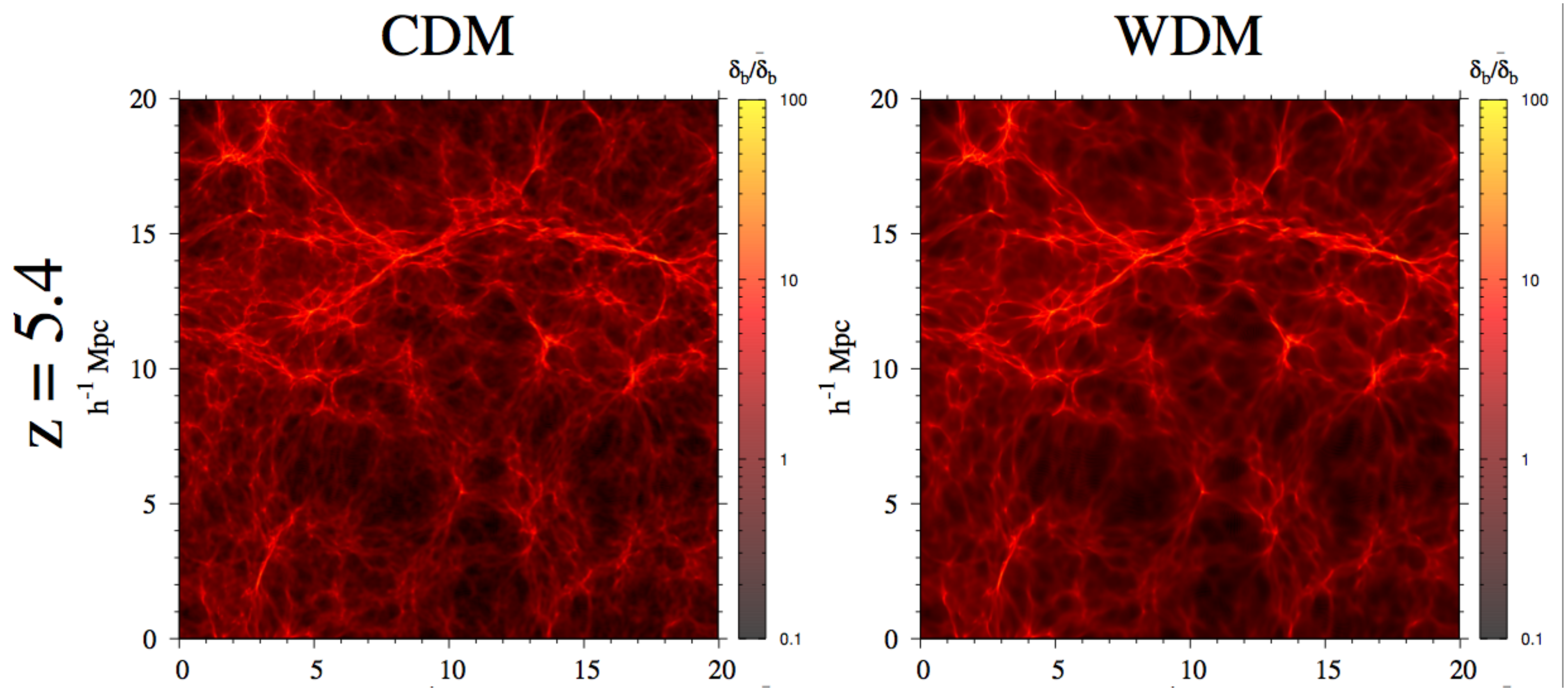
Xia, Granett, Viel, Bird, Guzzo+ 2012 JCAP, 06, 010

Simulations of neutrino clustering (top left) allow to extend the neutrino suppression in the non-linear regime (top right) and to appreciate the importance of non-linearities on existing data (VIPERS+CFHTLS, bottom left).

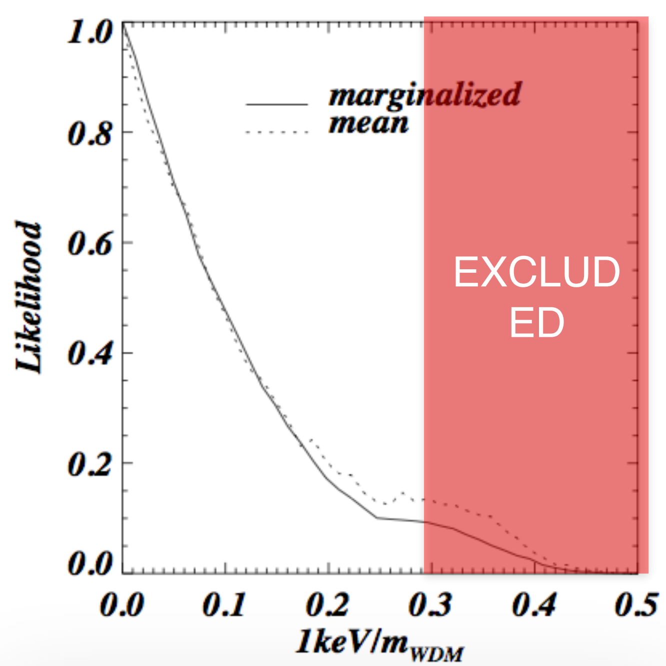
Present contraints from LSS: $\Sigma M_\nu < 0.3$ eV 2σ C.L.

Future directions: address this new regime with
state-of-the-art tools

Dark Matter Coldness



Viel et al. 2014, PRD



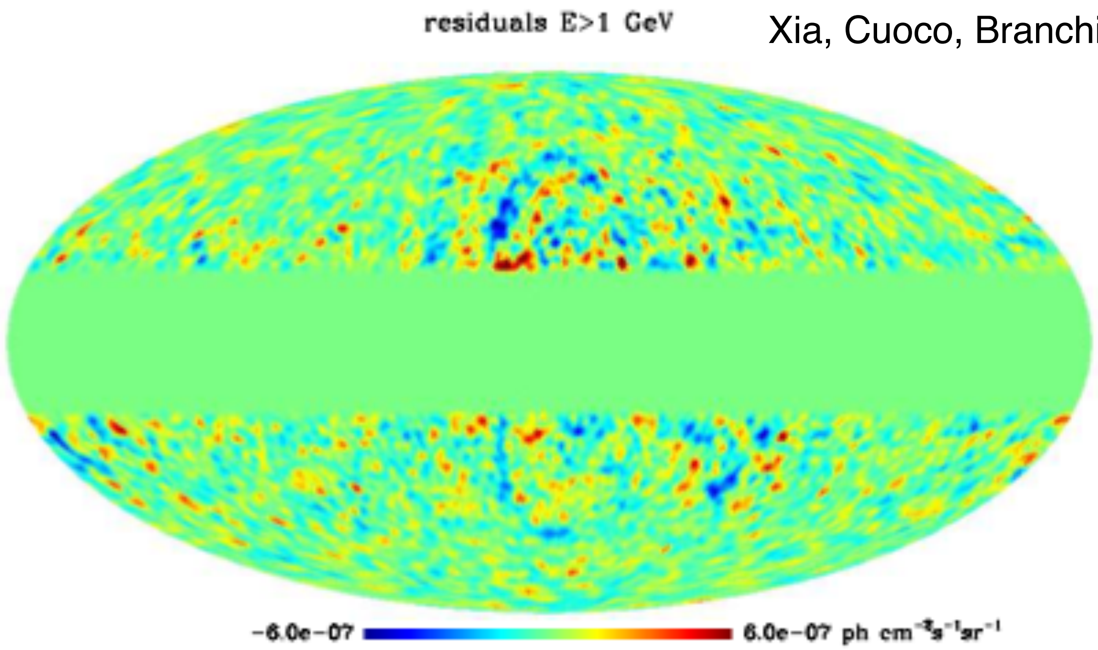
m > 3.3 keV (2σ)

Simulations of the cosmic web in Cold Dark Matter and Warm Dark Matter Cosmologies (top) can be used to put constraints on the mass of a thermal candidate or sterile neutrino using the High redshift regime explored by Lyman-alpha forest data (left).

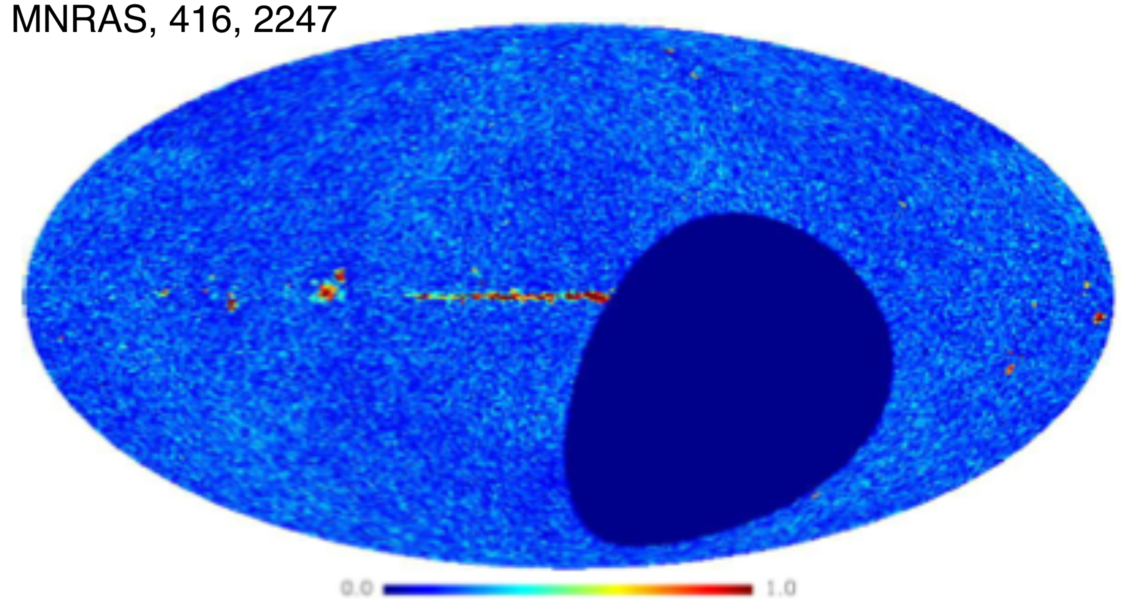
Constraints: so far the tightest have been provided

Future directions: explore wider implications for structure formation

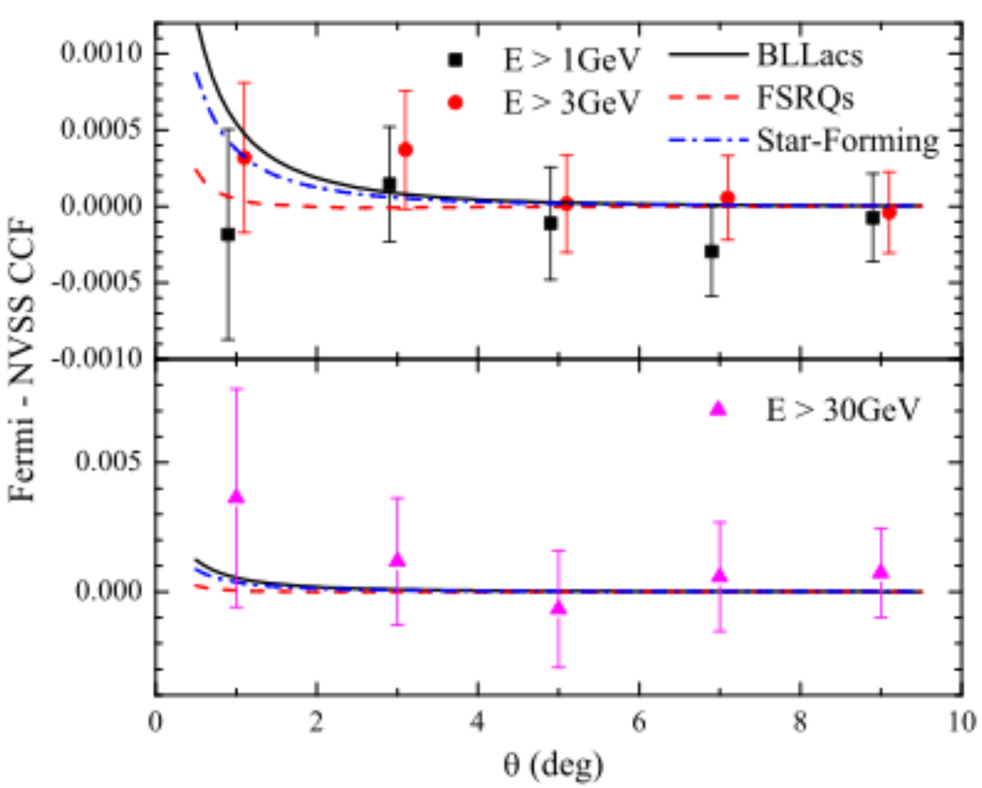
Dissecting the γ-ray background



Xia, Cuoco, Branchini, Fornasa, Viel, 2011, MNRAS, 416, 2247



Xia, Cuoco, Branchini, Viel, 2014, in prep.

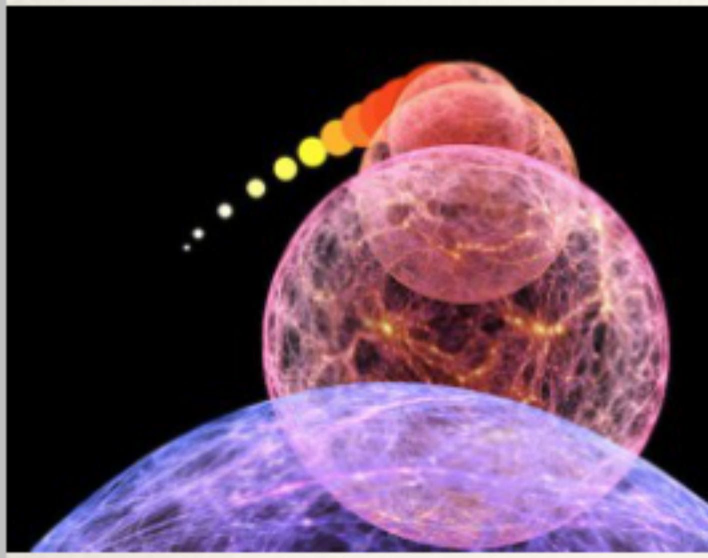


Residuals of γ-ray emission from the Fermi LAT
Satellite (top left, E > 1 GeV, 21 months of data) can be **cross-correlated** (bottom left) with the LSS (top right, NVSS sample) to infer which tracers contribute to the background.

Constraints: No obvious cross-correlation has been found in 2011 but interesting signals are coming up soon.
Future directions: Full characterization of the

Understanding the LSS of the Universe

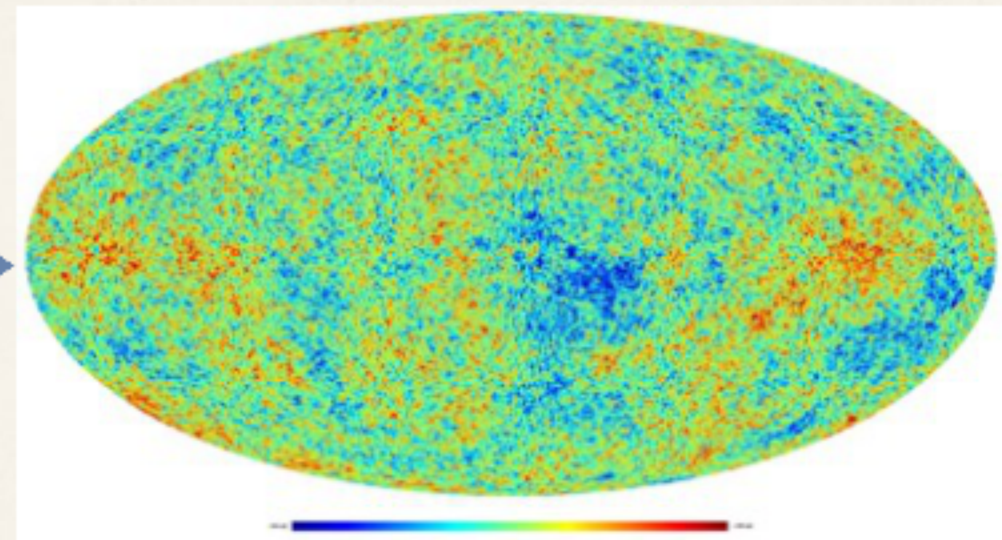
Inflation



Linear, Gaussian

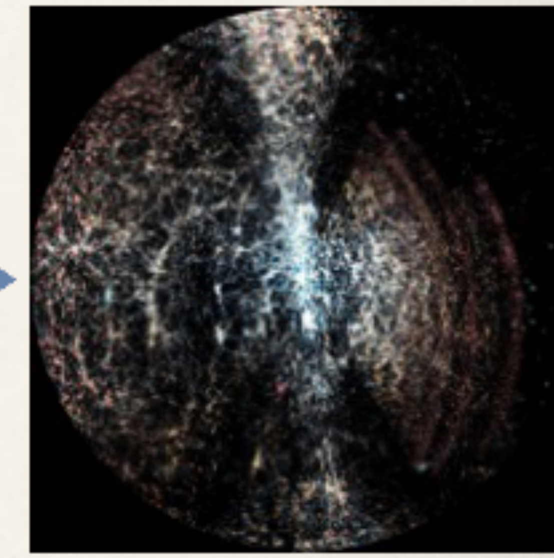
$$\left(\frac{\delta\rho}{\rho} \simeq 10^{-5}\right)$$

Decoupling



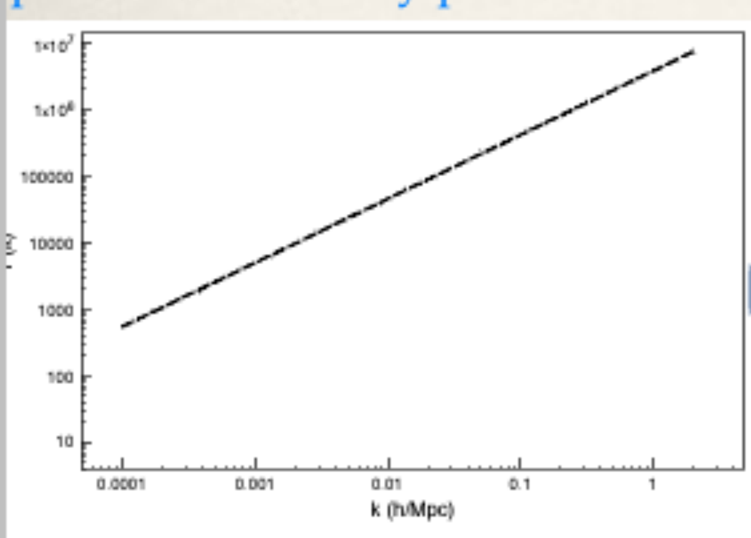
Linear, Gaussian

Today

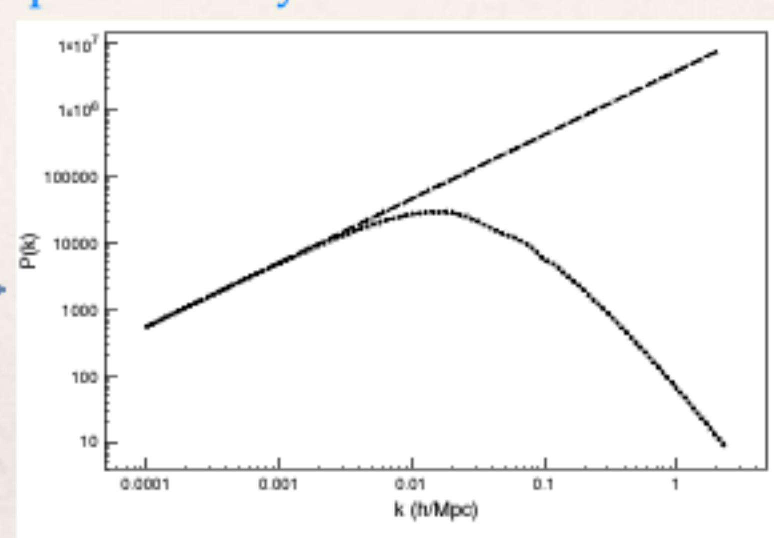


non-Linear,
non-Gaussian

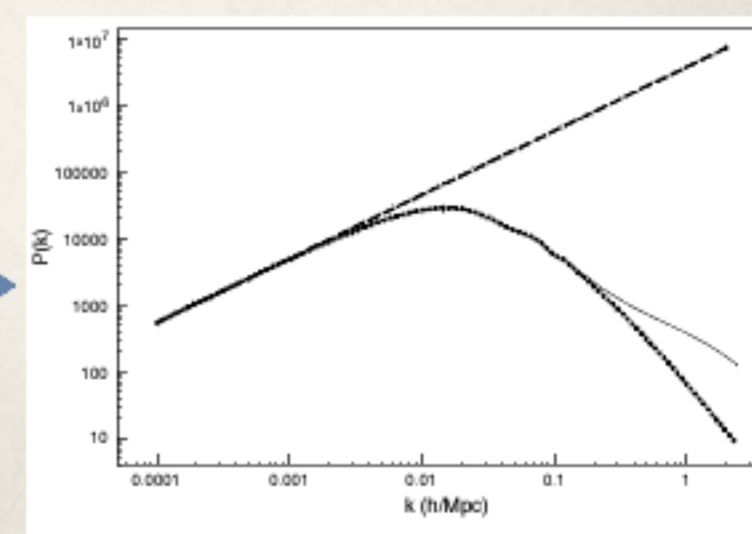
primordial density perturbations



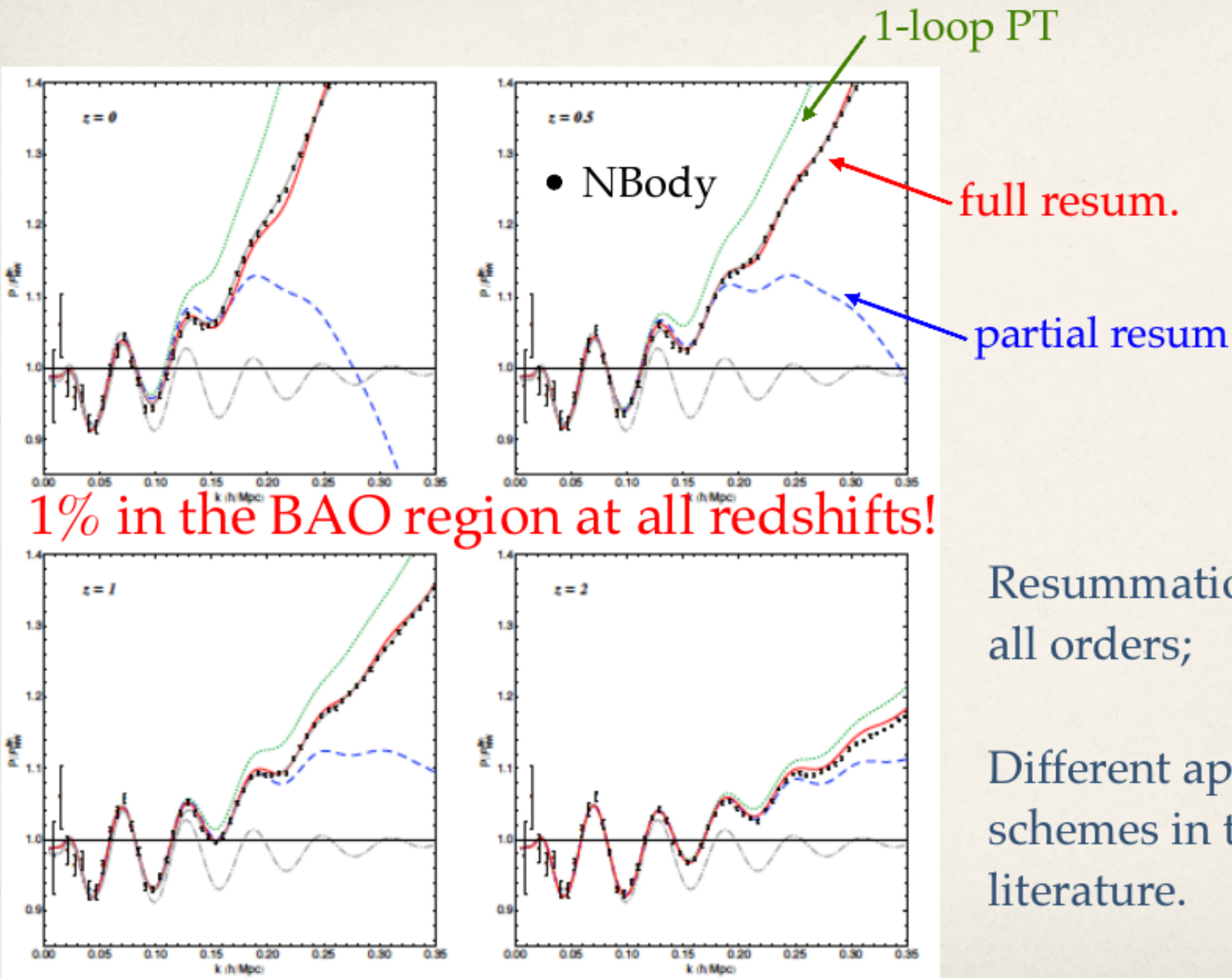
photon-baryon-DM-neutrino....fluid



non-relativistic matter



Resummations - NBody comparison



1% in the BAO region at all redshifts!

Resummation of PT to all orders;

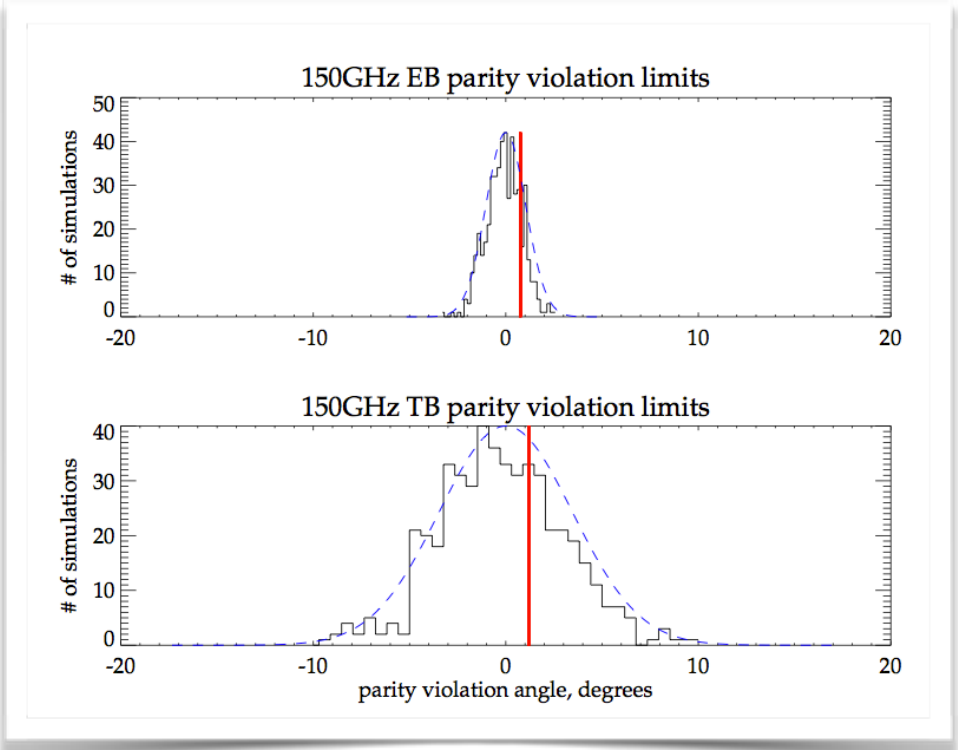
Different approx. schemes in the literature.

S.Anselmi, M.Pietroni 1205.2235

The CMB as a laboratory to probe new physics

- Cosmic birefringence: standard tracer of parity violation in the EM/GW (chiral) sector.
- We look at the photons that achieve the longest possible journey.
- Need high quality CMB polarization datasets.

e.g.:
Gruppuso, Natoli, Mandolesi et al JCAP 2012
Gubitosi et al. JCAP 2012
Gluscevic & Kamionkowski PRD 2010
Cabella, Natoli & Silk PRD 2007



Example: QUAD Wu et al 2008

What Next?

- Exciting physics to dig out. However:
- Need data, in particular high quality CMB polarization data: Planck (ongoing), balloons + ground based, post Planck satellite (ESA/M4 call around the corner)
- Need expertise, in particular phenomenological, data analysis and interpretation. Benefit from Planck experience/legacy.