Cosmic Microwave Background Constraint on Neutrino masses

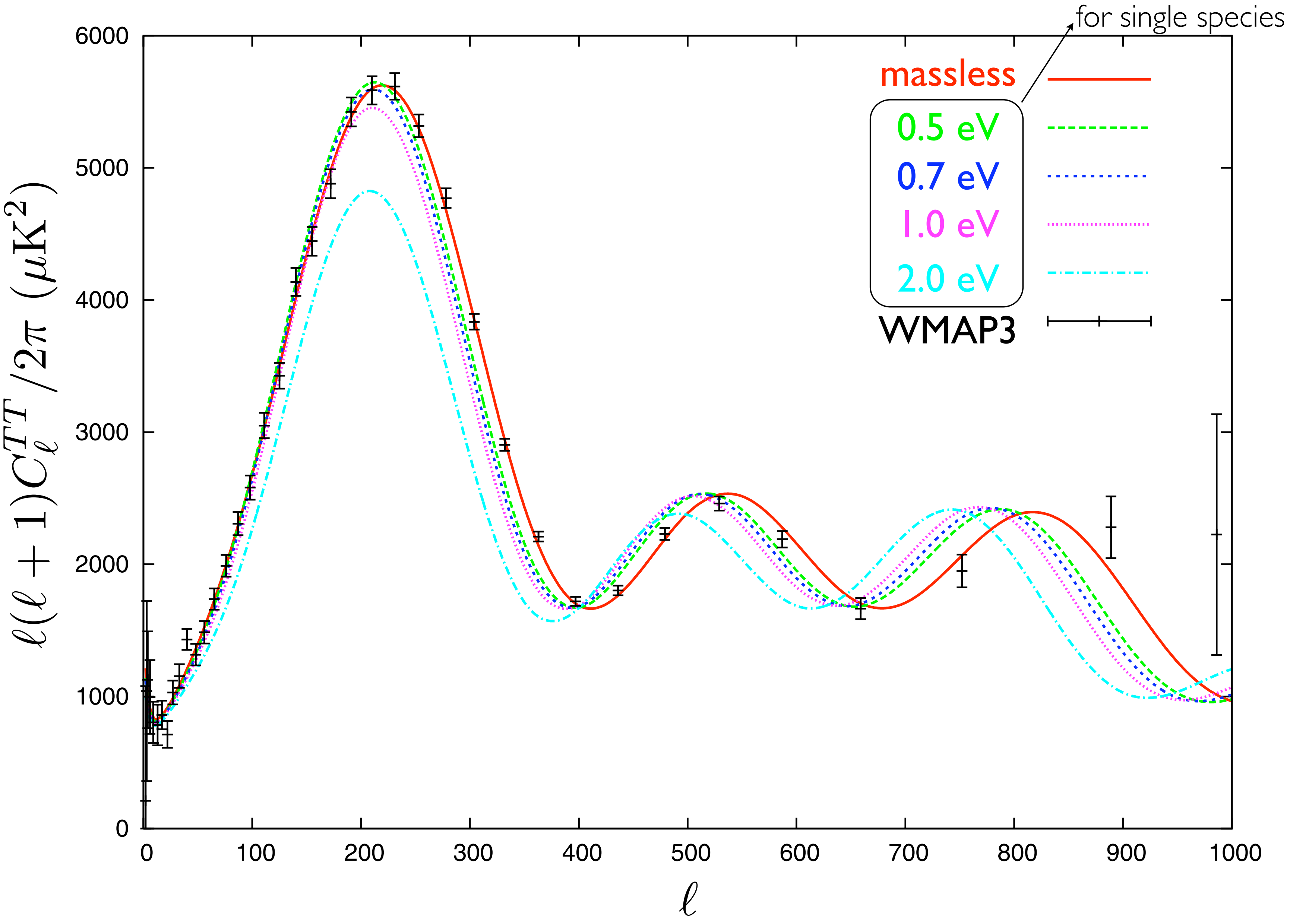
Kazuhide Ichikawa
(Institute for Cosmic Ray Research)

KI, M. Fukugita & M. Kawasaki, PRD71 043001 (2005)
M. Fukugita, KI, M. Kawasaki & O. Lahav, PRD74 027302 (2006)

Progress in Particle Physics 2006,

Yukawa Institute for Theoretical Physics, July 2006

(Equal masses for 3 neutrino species)



Effect of neutrino masses on CMB power spectrum

1. Horizontal shift (to small ell)

$m_\nu \uparrow$ implies smaller Ω_Λ (flatness assumed)

$$\Omega_\nu h^2 = \frac{\sum m_\nu}{94.1\ \mathrm{eV}}$$

1eV corresponds to $\Omega_\nu h^2 \sim 0.03$

⟹ Some fraction of DM or DE

But this effect is absorbed by decreasing Hubble constant.

[Only for $m_\nu \gtrsim 0.6\ \mathrm{eV}$]

2. Relative enhancement of 2nd or higher peaks w.r.t 1st peak

The epoch of recombination z_{rec} ~ 1088 ~ 0.3 eV

→ Massive neutrinos become nonrelativistic before the epoch of recombination if $m_\nu \gtrsim 0.6\ \mathrm{eV}$

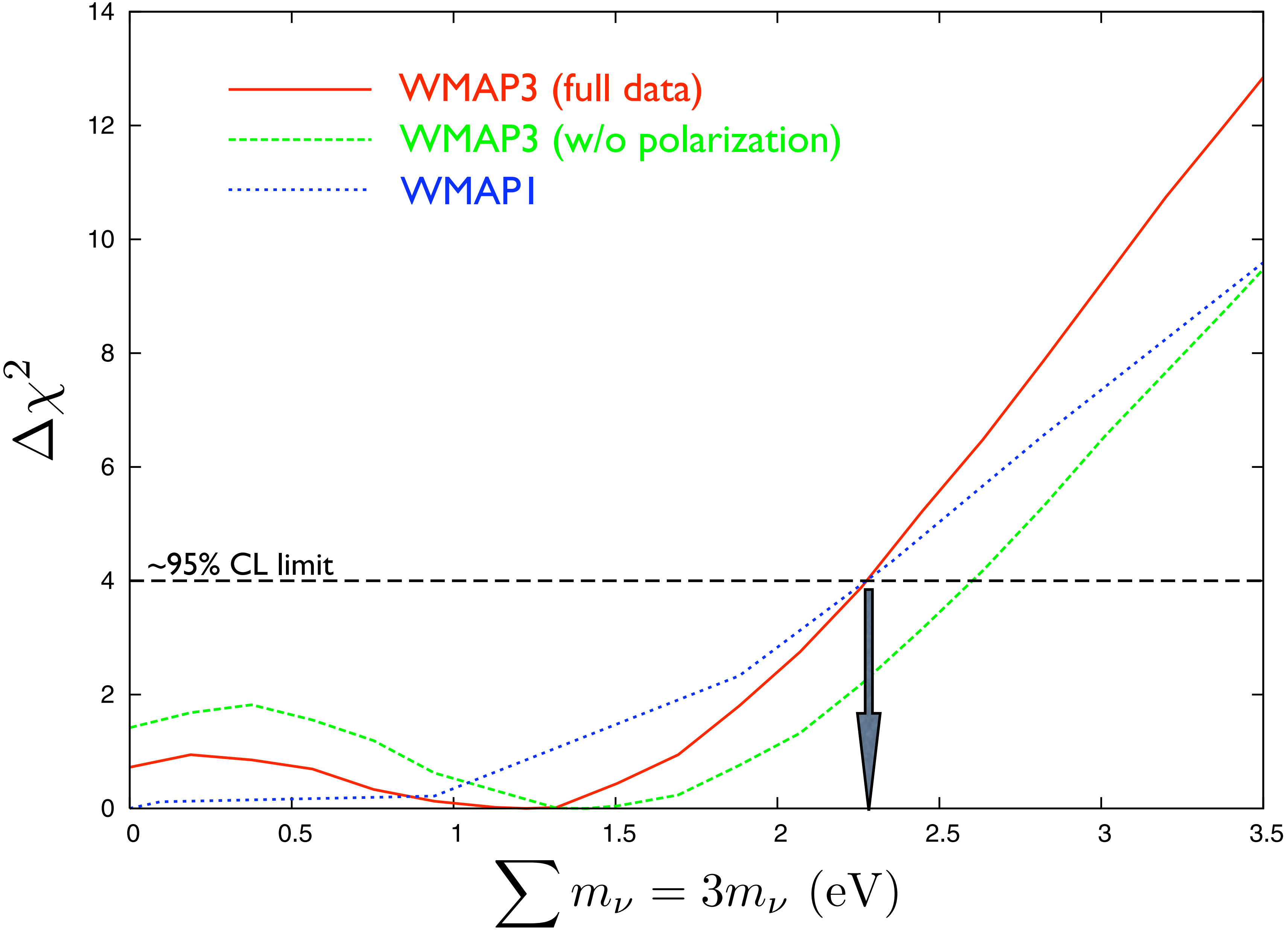
→ In this case, massive neutrinos act like CDM and 3 d.o.f of relativistic component is missed at the epoch of recombination.

Characteristic signals imprinted in acoustic peaks.

χ^2 analysis

(We marginalized over 6 other
LCDM cosmological parameters)

KI, Fukugita & Kawasaki, PRD71 043001 (2005)
Fukugita, KI, Kawasaki & Lahav, PRD74 027302 (2006)



WMAP3 limit (95%CL) : $m_\nu < 0.7\ \mathrm{eV}$

Not improved from WMAP1 limit.

WMAP1 has measured 1st and 2nd peaks well and the massive neutrino signal for >0.6 eV has been already rejected.

The polarization data does not improve neutrino mass constraint much.

Again, 1st and 2nd peaks in CMB TT power spectrum already provide sufficient information to constrain neutrino mass (only for >0.6 eV, however).

Conclusion

We follow up our previous study on constraining neutrino masses from WMAP 1st year data. We obtain 3rd year data limit (95% CL): $m_\nu < 0.7\ \mathrm{eV}$, not improved from the previous one as anticipated.

This limit is quite robust:

1) Obtained from CMB data of WMAP, the cleanest cosmological data.
2) Using only single data set and avoiding to combine different data sets with different systematic errors.
3) Does not suffer from not-well-controlled issues of non-linearity or biasing which appear in e.g. galaxy clustering analysis.

We have to combine other data sets in order to push the limit lower (see the other panel). But proper understanding of systematic errors involved in them is required.

Reference	CMB	LSS	Others	$\sum m_\nu$ 95% limit (eV)
Croft, Hu, Dave (1999)[1]	COBE	Lyα, Cluster abundance	$t_0 > 13.2 \pm 2.9$ Gyr	[1]5.5
Fukugita, Liu, Sugiyama (2000)[2]	COBE	Cluster abundance	$t_0 > 11.5$ Gyr,	
			$\Omega_{m+\nu} < 0.4$, $h < 0.8$	
			$n_s = 1$	2.6
			$n_s = 1.2$	5.4
Wang, Tegmark, Zaldarriaga (2002)[3]	pre-WMAP	PSCz, Lyα	—	4.2
Elgarøy et al. (2002)[4]	—	2dF1	BBN, SNIa, HST,	
			$n_s = 1.0 \pm 0.1$	2.2
Hannestad (2002)[5]	pre-WMAP	2dF1	—	3
			BBN, SNIa, HST	2.5
Lewis, Bridle (2002)[6]	pre-WMAP	2dF1	BBN, SNIa, HST	0.9
Spergel et al. (2003)[7]	WMAP1, CBI, ACBAR	2dF1(galaxy+bias)	—	0.63
		+Lyα	—	0.68
Hannestad (2003)[8]	WMAP1	2dF1	—	2.12
	+Wang comp.		—	1.20
			SNIa, HST	1.01
Allen, Schmidt, Bridle (2003)[9]	WMAP1, CBI, ACBAR	2dF1	X-ray cluster	[2]$0.56^{+0.30}_{-0.26}$
				[3]$0.32^{+0.29}_{-0.15}$
Tegmark et al. (2004)[10]	WMAP1	—	—	10.6
		SDSS	—	1.74
Barger, Marfatia, Tregre (2004)[11]	WMAP1	2dF1, SDSS	—	0.75
Crotty, Lesgourgues, Pastor (2004)[13]	WMAP1, ACBAR	2dF1, SDSS	—	1.0
			SNIa, HST	0.6
				[4]1.0-1.5
Seljak et al. (2005)[14]	WMAP1	SDSS(galaxy+bias)	—	0.54
				[5]0.72
				[6]1.37
Seljak et al. (2005)[15]	WMAP1	SDSS(galaxy)	—	1.54
		+SDSS(Lyα)	—	0.54
		+SDSS(bias)	SNIa	0.42
				[7]0.66
				[8]0.84

Ichikawa, Fukugita, Kawasaki (2005)[16]	WMAP1	—	—	2.0
Hannestad (2005)[17]	WMAP1	SDSS	SNIa, HST	0.65 [9]1.48
MacTavish et al. (2005)[18]	WMAP1, DASI, VSA, ACBAR, MAXIMA, CBI, B03	—	—	3.0
		2dF1, SDSS	—	1.2
		+bias ($b = 1.0 \pm 0.1$)	—	0.48
Sánchez et al. (2006)[19]	WMAP1, ACBAR, VSA, CBI	—	—	2.09
		2dFfinal	—	1.16
		SDSS	—	1.27
Goobar, Hannestad, Mortsell, Tu (2006)[20]	WMAP3, B03	SDSS(gal), 2dFfinal	HST, SNIa(SNLS)	0.70
		+SDSS(BAO)		0.48
		+Lyα		0.27
		SDSS(gal), 2dFfinal, Lyα		0.35
Spergel et al. (2006)[21]	WMAP3	—	—	2.0 (1.8)
		SDSS (gal + [$b = 1.03 \pm 0.15$])	—	0.91 (1.3)
		2dFfinal	—	0.87 (0.88)
		SDSS, 2dFfinal	SNIa(gold+SNLS)	0.68 (0.66)
Seljak, Slosar, McDonald (2006)[22]	WMAP3, B03, CBI, VSA, ACBAR	SDSS(gal+BAO+Lyα), 2dFfinal	SNIa(gold+SNLS)	0.17 [10]0.26
Fukugita, Ichikawa, Kawasaki, Lahav (2006)[23]	WMAP3	—	—	2.0 [11]2.4
Feng, Xia, Yokoyama, Zhang, Zhao (2006)[24]	WMAP3	2dFfinal, SDSS	SNIa(gold)	0.90 [12]0.76
Cirelli, Strumia (2006)[25]	WMAP3	—	—	2.2
	+ACBAR, B03, CAPMAP, CBI, DASI, VSA	SDSS(gal+BAO), 2dFfinal	SNIa(gold+SNLS), HST	0.52
		+Lyα		0.40 (99.9%)

[1] Single massive species.

[2] 68.3% confidence limit, inc. tensor mode (n_T and r).

[3] 68.3% confidence limit, w/o tensor mode.

[4] When $N_{\rm eff}$ is left free.

[5] With running α_s and tensor r.

[6] 3 massless + 1 massive, no running.

[7] With running α_s and tensor r.

[8] 3 massless + 1 massive, no running.

[9] w is varied.

[10] 3 massless + 1 massive.

[11] TT data only.

[12] With running α_s.