Neutrino mass constraint from CMB and its degeneracy with other cosmological parameters

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

TAUP 2007, Sendai, Sept. 2007

Introduction

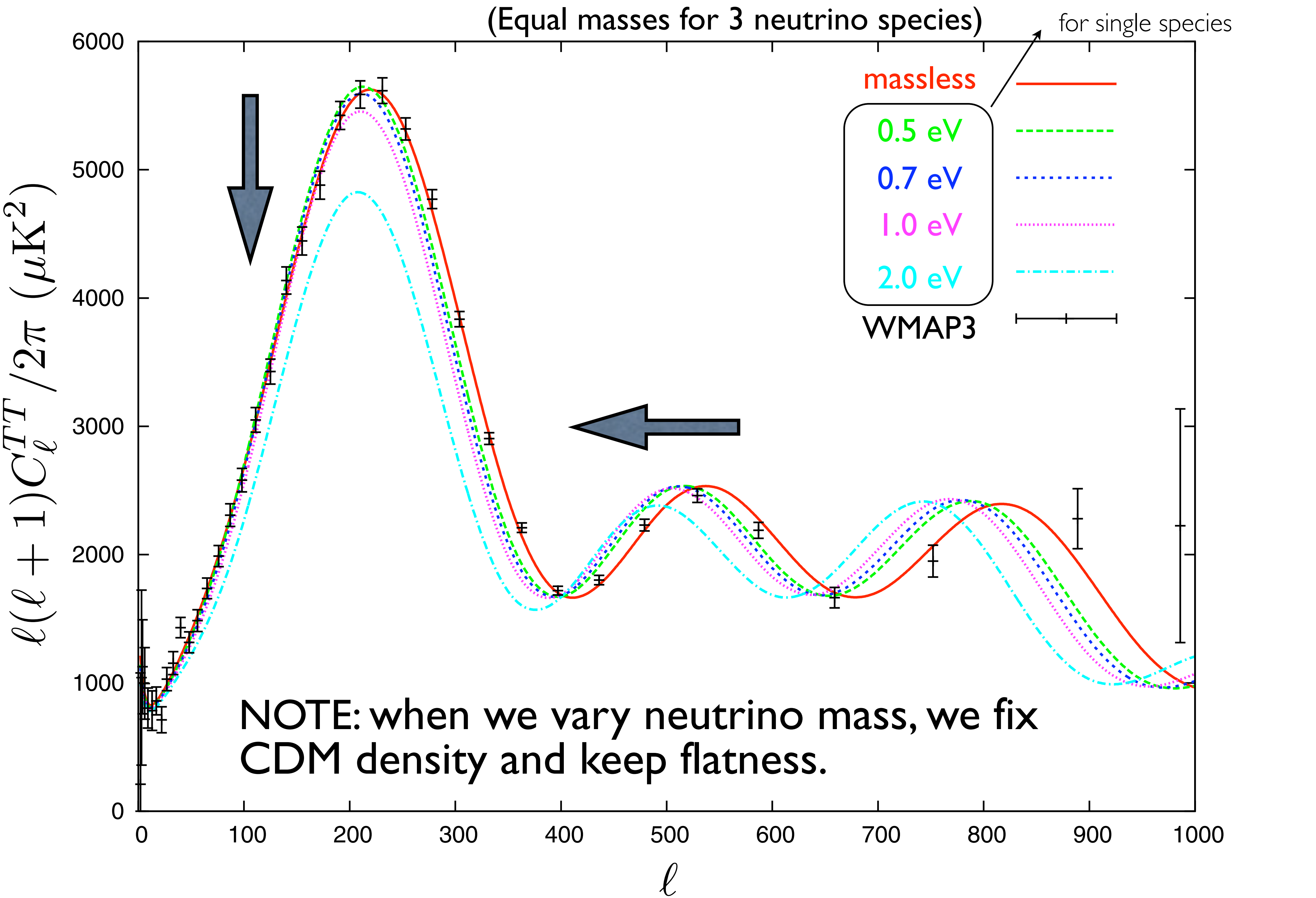
Tritium beta decay experiments: $m_{\nu_e} < 2$ eV

Cosmological bounds:

Spergel et al. [WMAP collaboration]	WMAP1 +2dFGRS	$m_\nu < 0.2$ eV
Tegmark et al. [SDSS collaboration]	WMAP1 +SDSS (main sample)	$m_\nu < 0.6$ eV (3.8 eV for WMAP only) ?
Ichikawa, Fukugita & Kawasaki	WMAP1	$m_\nu < 0.7$ eV

Our results are confirmed by : Hannestad, hep-ph/0602058
Lesgourgues & Pastor, astro-ph/0603494

Effect of neutrino masses on CMB power spectrum



1. Horizontal shift (to smaller multipoles)

$m_\nu \uparrow$ makes the distance to the last scattering surface smaller.

$$\Omega_\nu h^2 = \frac{\sum m_\nu}{94.1 \text{ eV}}$$ ⟹ 1eV corresponds to $\Omega_\nu h^2 \sim 0.03$

But this effect is absorbed by decreasing the Hubble constant.

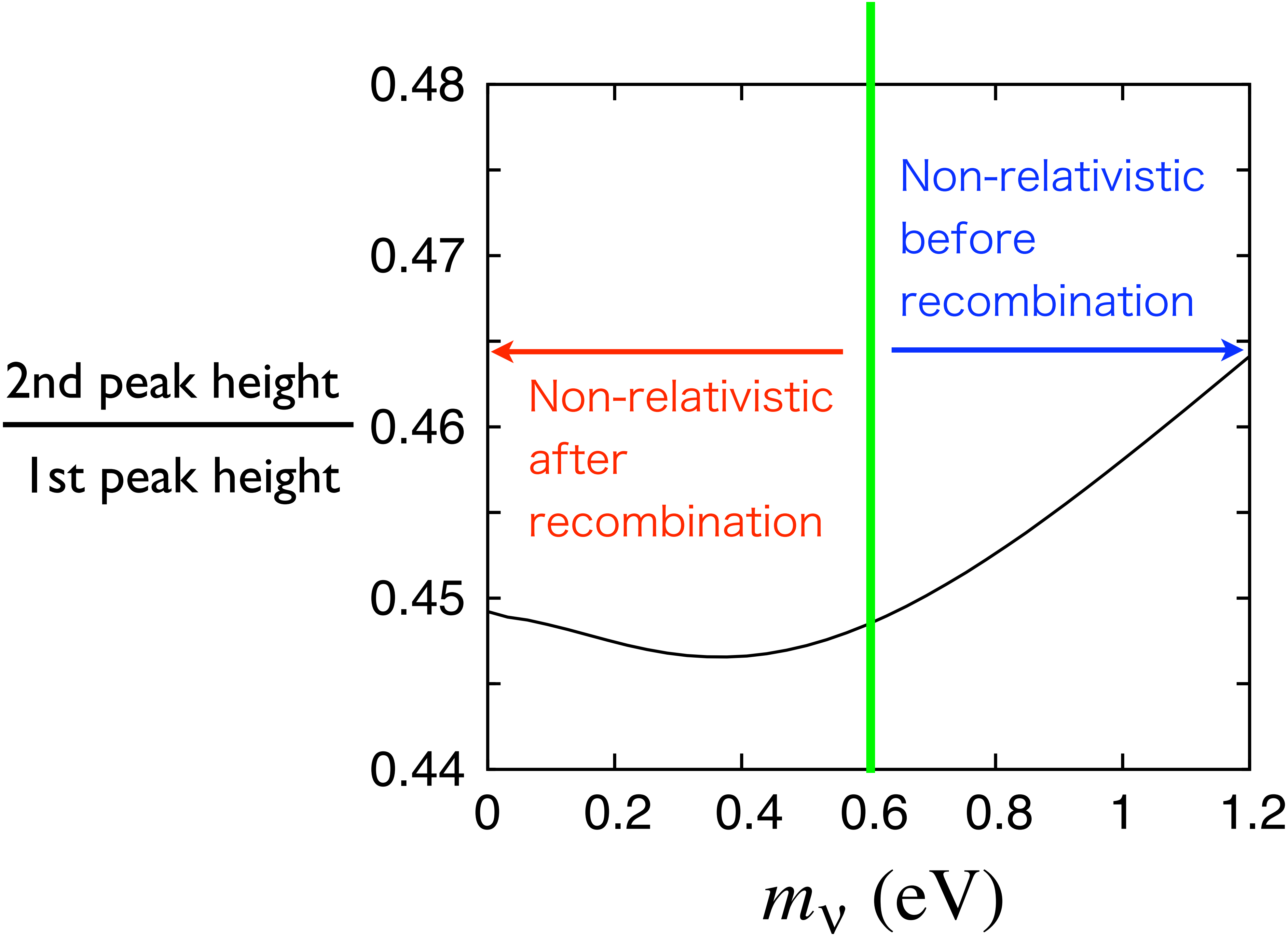
[Only for $m_\nu \gtrsim 0.6 \text{ eV}$]

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

The epoch of recombination $z_{rec} \sim 1088 \sim 0.3$ eV

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

Characteristic signals imprinted in acoustic peaks.



0.48
0.47
0.46
0.45
0.44
0
0.2
0.4
0.6
0.8
1
1.2
2nd peak height
1st peak height
m_ν (eV)
Non-relativistic
before
recombination
Non-relativistic
after
recombination

We assume flat Lambda CDM model (6 parameters) + neutrino mass

- baryon density
- CDM density
- Hubble constant
- amplitude of fluctuation
- epoch of reionization
- a slope for the scalar perturbation

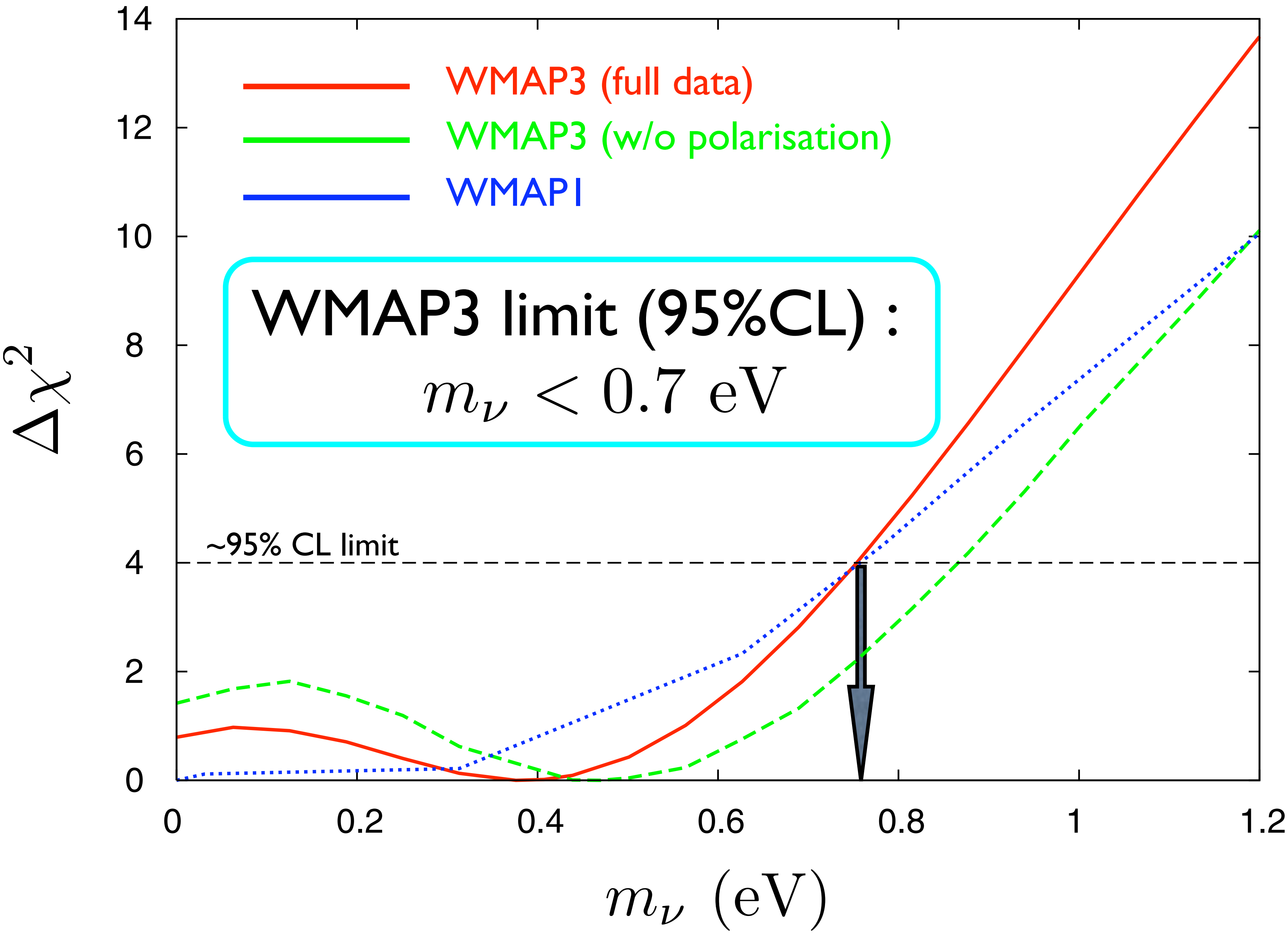
Hubble constant (expansion rate at present): H_0

$$H_0 = 100\,h\,\mathrm{km/s/Mpc}$$

χ^2 analysis

(We minimised 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.

Conclusion for WMAP alone limit

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:

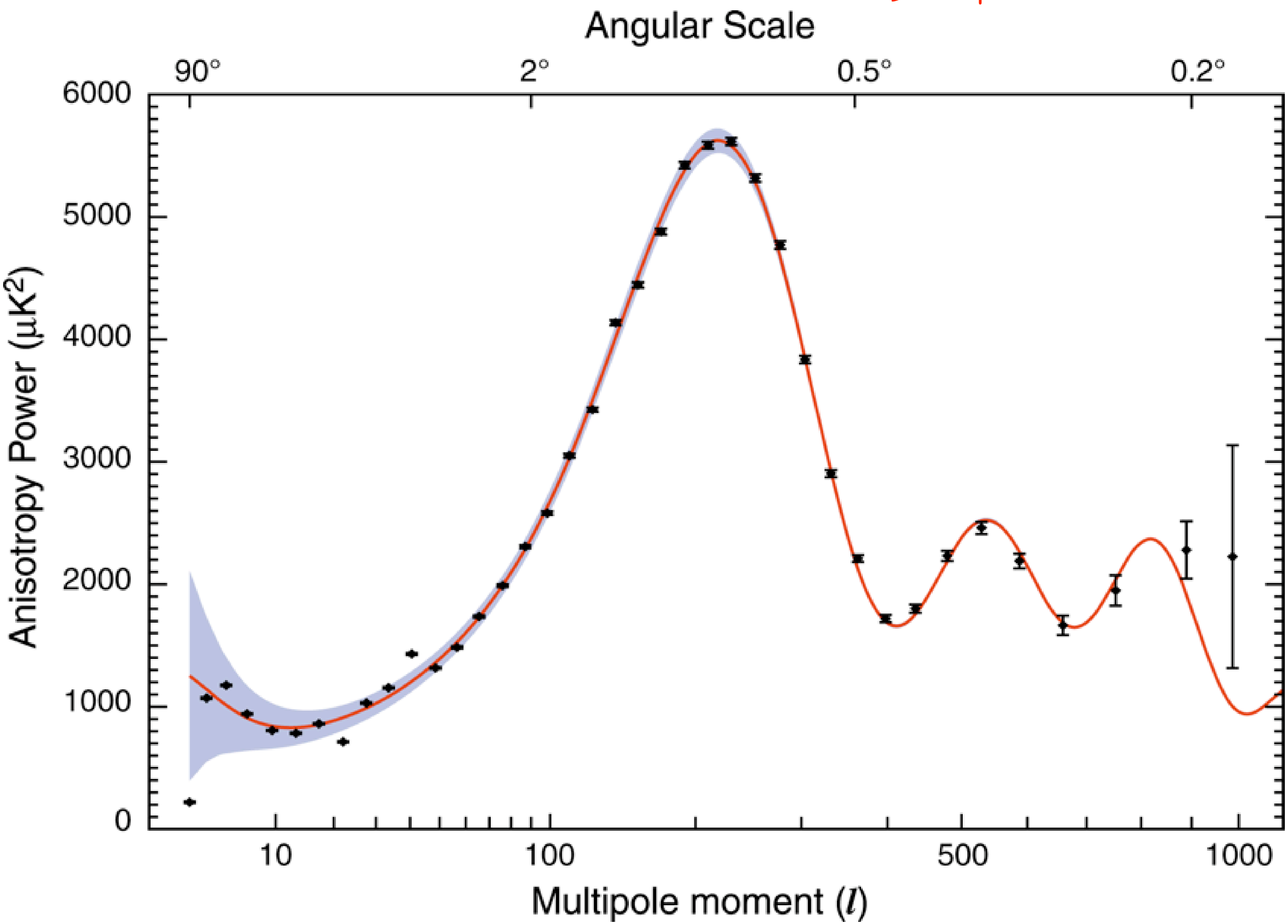
1) Obtained from CMB data of WMAP, the cleanest cosmological data.
2) Using only single data set and avoiding to combine different data sets with different systematic errors.
3) Does not suffer from not-well-controlled issues of non-linearity or biasing which appear in e.g. galaxy clustering analysis.

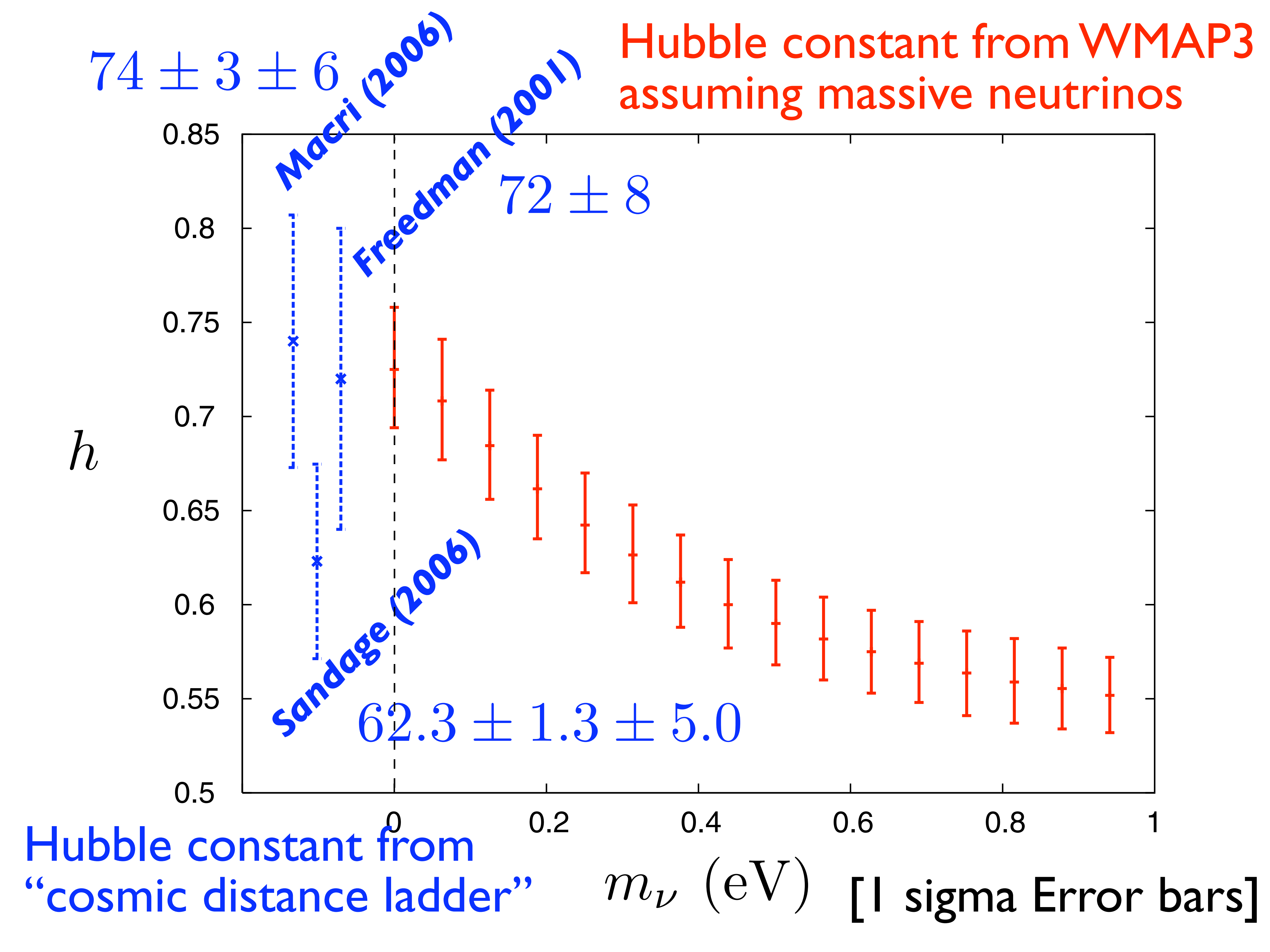
We have to combine other data sets in order to push the limit lower. But proper understanding of systematic errors involved in them is required.

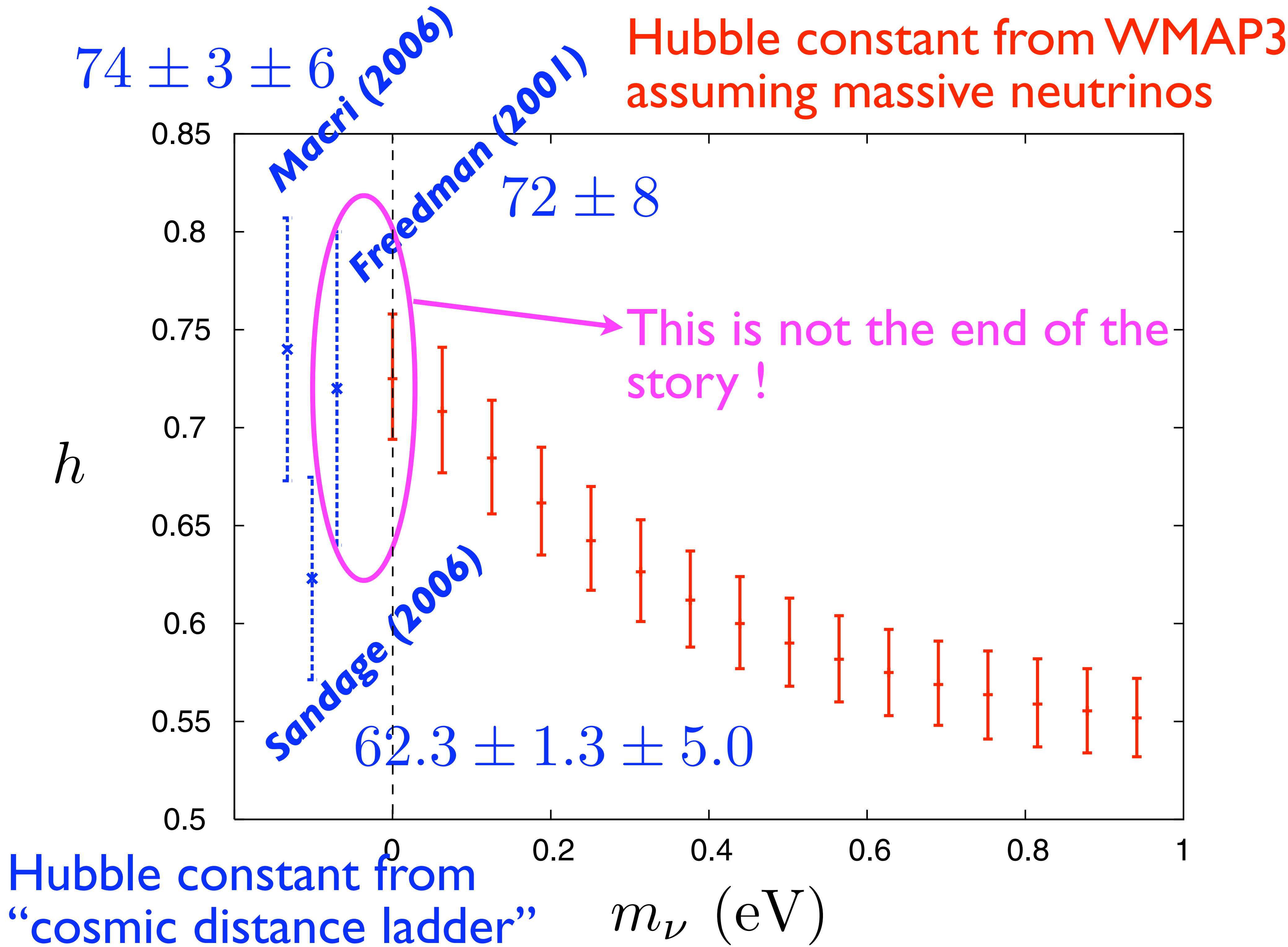
$m_\nu - H_0$ degeneracy

$\longrightarrow H_0 \downarrow$

$\longleftarrow m_\nu \uparrow$




Hubble constant from WMAP3
assuming massive neutrinos
$74 \pm 3 \pm 6$
Macri (2006)
Freedman (2001)
72 ± 8
Sandage (2006)
$62.3 \pm 1.3 \pm 5.0$
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
h
0
0.2
0.4
0.6
0.8
1
m_ν (eV)
Hubble constant from
"cosmic distance ladder"
[1 sigma Error bars]



Hubble constant from WMAP3
assuming massive neutrinos
$74 \pm 3 \pm 6$
Macri (2006)
Freedman (2001)
72 ± 8
This is not the end of the story !
Sandage (2006)
$62.3 \pm 1.3 \pm 5.0$
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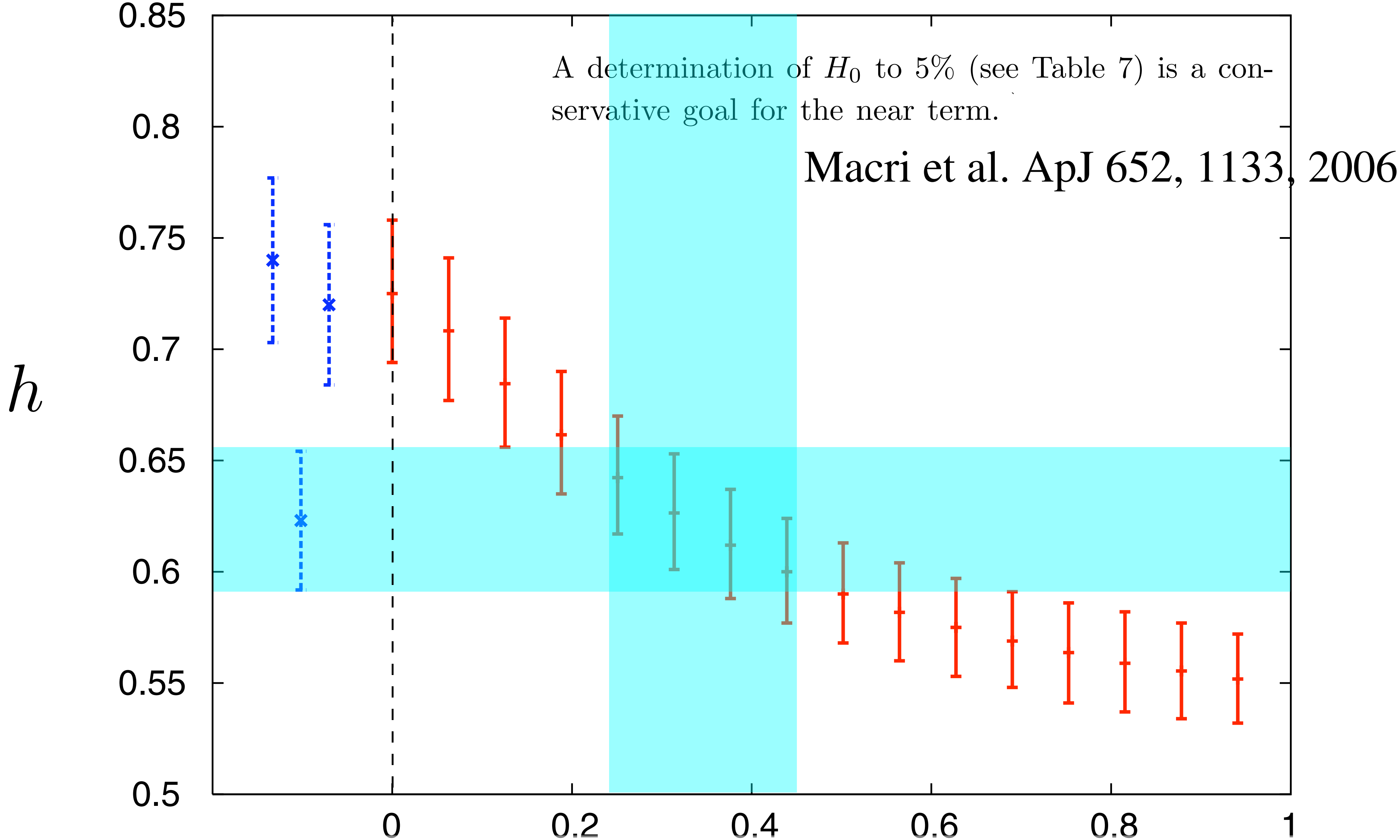
m_ν (eV)
Hubble constant from
"cosmic distance ladder"

Assume h is measured with a total uncertainty of 5%



KATRIN: from 2010 to 2015~16

"a neutrino mass of 0.35 eV could be determined with 5 sigma."

Conclusion

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

- Degeneracy between m_ν and H_0 .

  Uncertainty of m_ν is one of the largest systematic errors for estimating cosmological parameters from CMB.

  If neutrino mass is detected to be m_ν > 0.3 eV, it would be more consistent with the people claiming a small Hubble constant < 65.