Do available cosmological data favor

neutrino mass AND COUPLING BETWEEN DARK MATTER & DARK ENERGY ?

How to get rid of ΛCDM

References:
* LVG , S. Bonometto & Colombo L.P.L.
  arXiv:0810.0127 & NewAstr. 14 (2009) 435
  "Higher neutrino mass allowed if CDM & DE are coupled"
* LVG, Kristiansen J.R., Colombo L.P.L., Mainini R. & S. Bonometto
  arXiv: 0902.2711 & JCAP 04 (2009) 2007
  "Do WMAP data favor neutrino mass & a coupling between CDM & DE?"
* Kristiansen J.R., LVG, Colombo L.P.L., Mainini R. & S. Bnometto
  arXiv: 0902.2737 & New Astr. accepted
  "Coupling between CDM & DE from neutrino mass experiments"
* S.Bonometto, LVG, Kristiansen J.R., Colombo L.P.L., Mainini R.
  arXiv: 0911.3486 and Proc. 'Invisible Universe International Conference' Paris 2009
  "Do WMAP data favor neutrino mass & a coupling between CDM & DE?"

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Frascati, 23 Giugno 2010

Summary

- ν mass laboratory constraints
- ν mass cosmology constraints
- Why & how

  improving ΛCDM: dynamical DE & coupled DE

  vs. fine tuning & coincidence
- Limits on ν mass in Mildly Mixed Coupled (MMC) cosmologies

Spectral effects of coupling & ν mass not just compensating

Their sum favors MMC in respect to ΛCDM

- **Even more when using recent WMAP7 outputs**
- **In case of experimental mass detection**

DM-DE coupling performs much better than w<-1

ν-mass experiments

Neutrino oscillation — solar, reactor experiments — $\Delta m^2_{21} \approx 8 \times 10^{-5}\,\mathrm{eV}^2$

Neutrino mass eingenstates different from flavor eigenstates — atmospheric, accel. beam — $|\Delta m^2_{31}| \approx 3 \times 10^{-3}\,\mathrm{eV}^2$

Tritium β-decay

- MAINZ & TROISZK (1997 - 2005) — $m(\nu_e) < 2\text{-}3$ eV
- KATRIN (from 2012) — sensitivity 0.2 eV

Double β-decay

Assume neutrino to be a Majorana spinor

		τ / y >	τ / y =
Heidelberg-Moskow	$^{76}Ge \rightarrow {}^{76}Se$	1.9e25	(0.69-4.18)e25 Klapdor et al.
Cuoricino / Cuore	$^{130}Te \rightarrow {}^{130}Xe$	2.9e24	
NEMO	$^{82}Se \rightarrow {}^{82}Mo$		
GERDA			

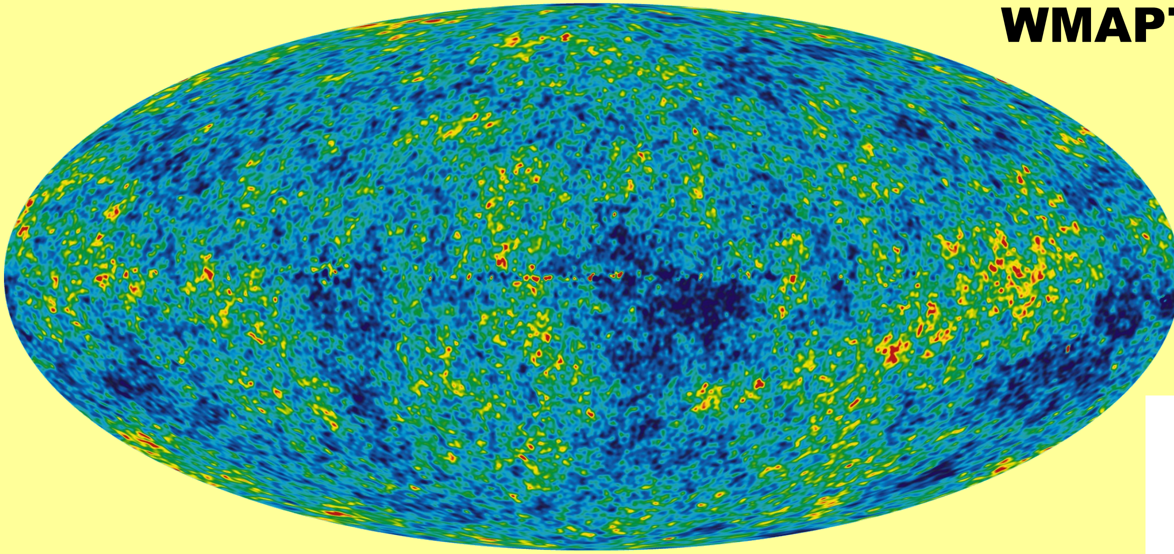
To repeat Heidelberg-Moskow

$$\frac{1}{\tau} = G(Q,Z)\,|M_{nucl}|^2\, m_\nu^2$$

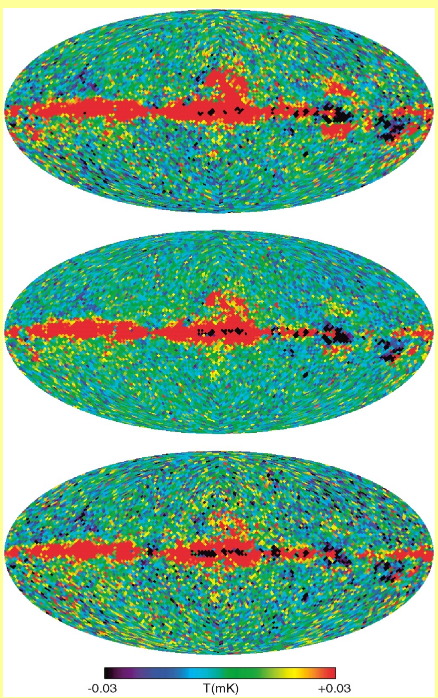
→ $m(\nu_e) = (0.1\text{-}0.9)$ eV (3σ)

Cosmological data

(WMAP5)
WMAP7: no major changes



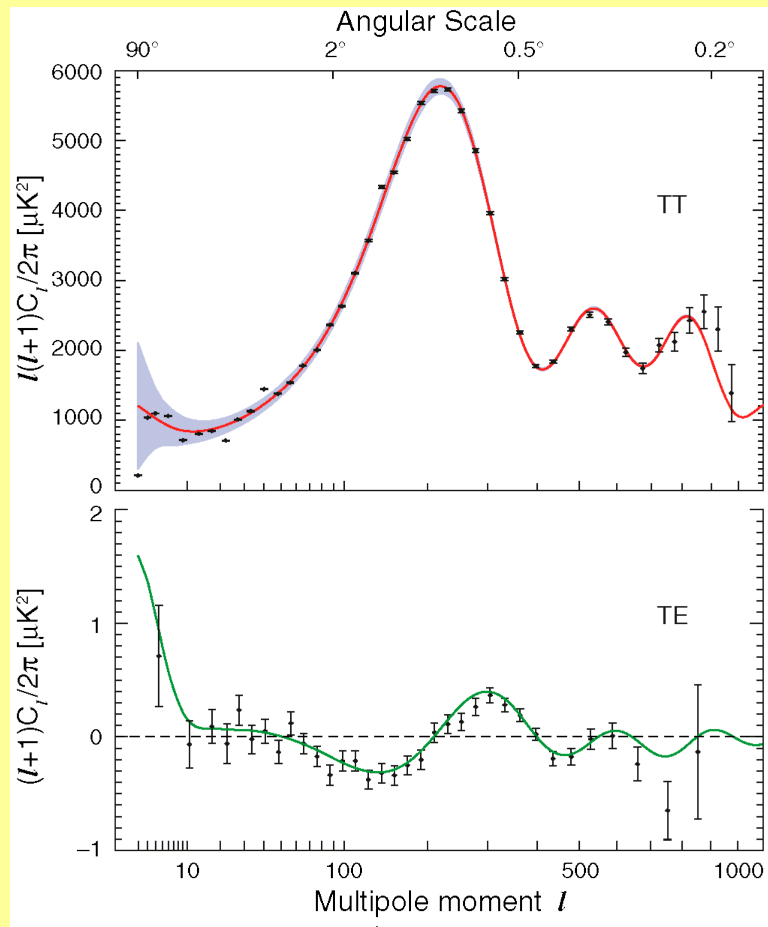
CMB

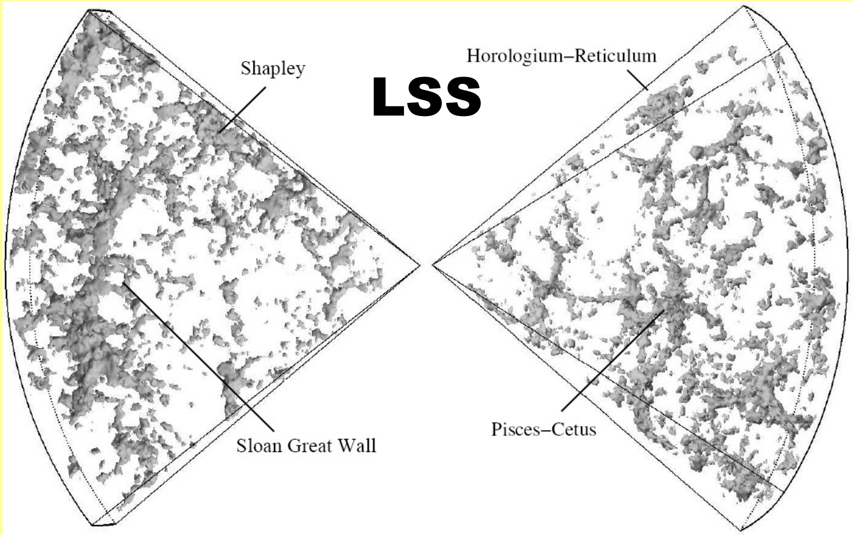


Q band

V band

W band

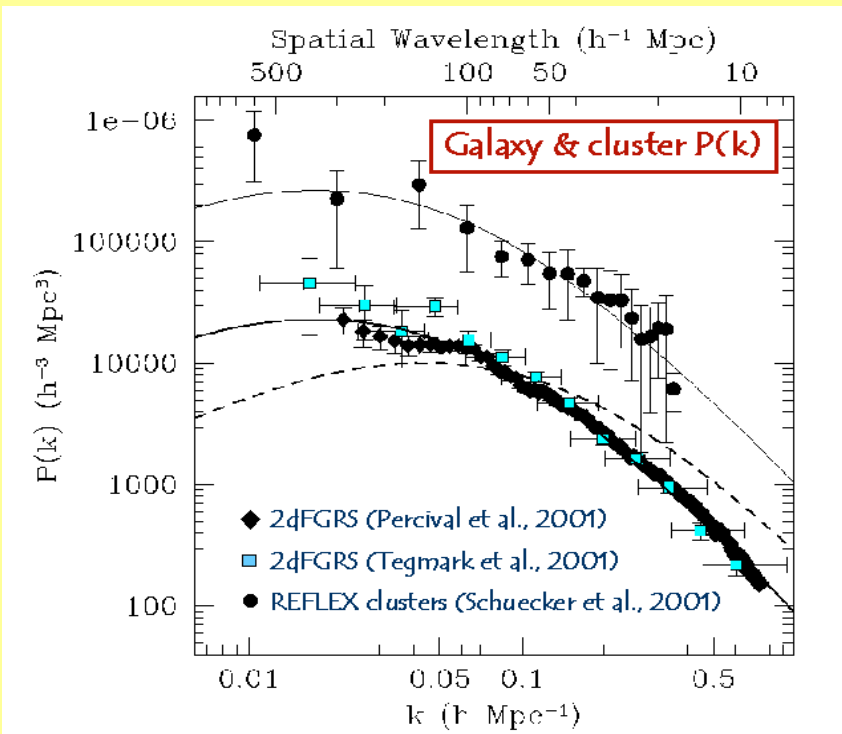


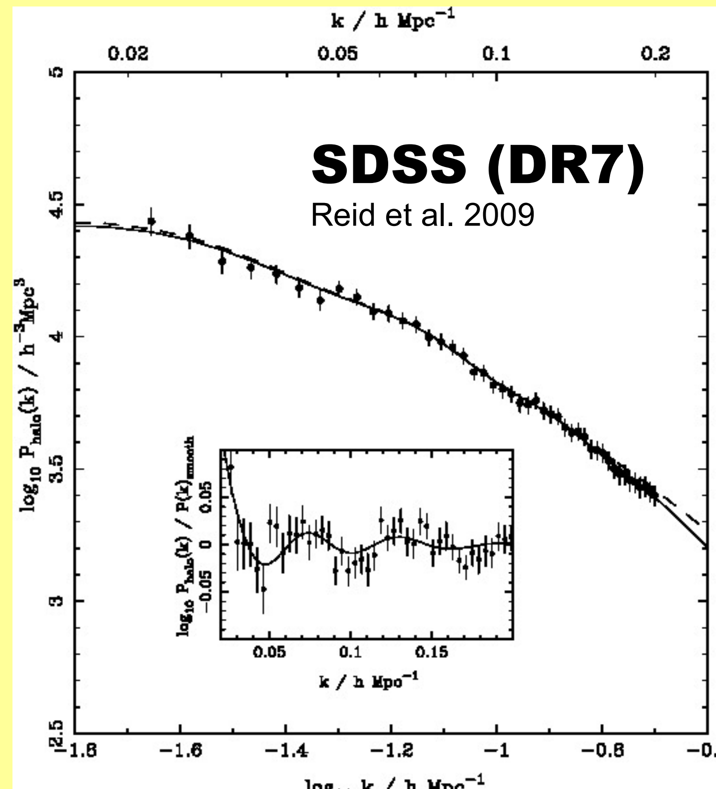


+ **BAO data**
from 2dFGRS and SDSS

e.g.,
Eisenstein et al., 2005
Percival et al., 2009

2dF galaxy redshift survey



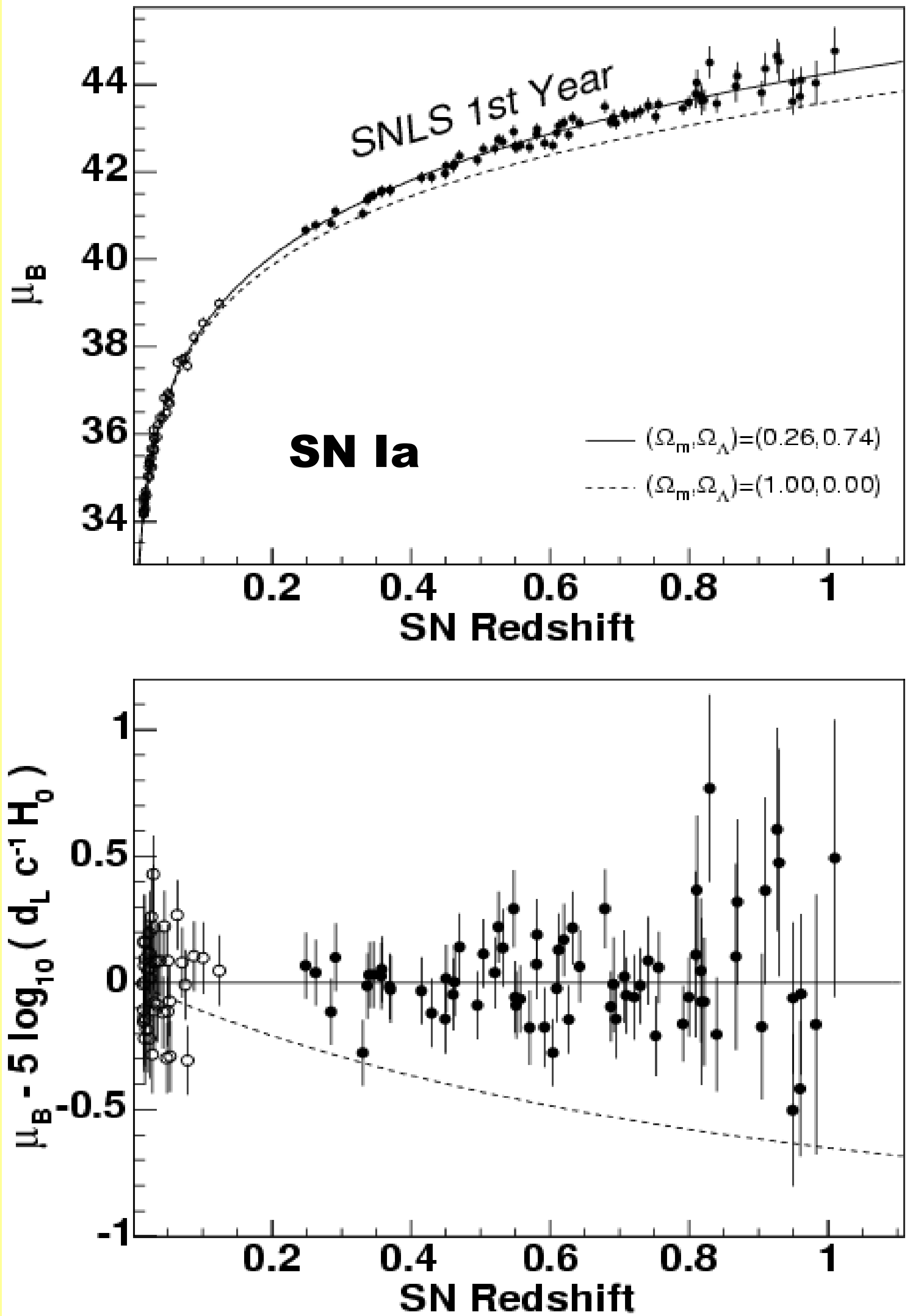


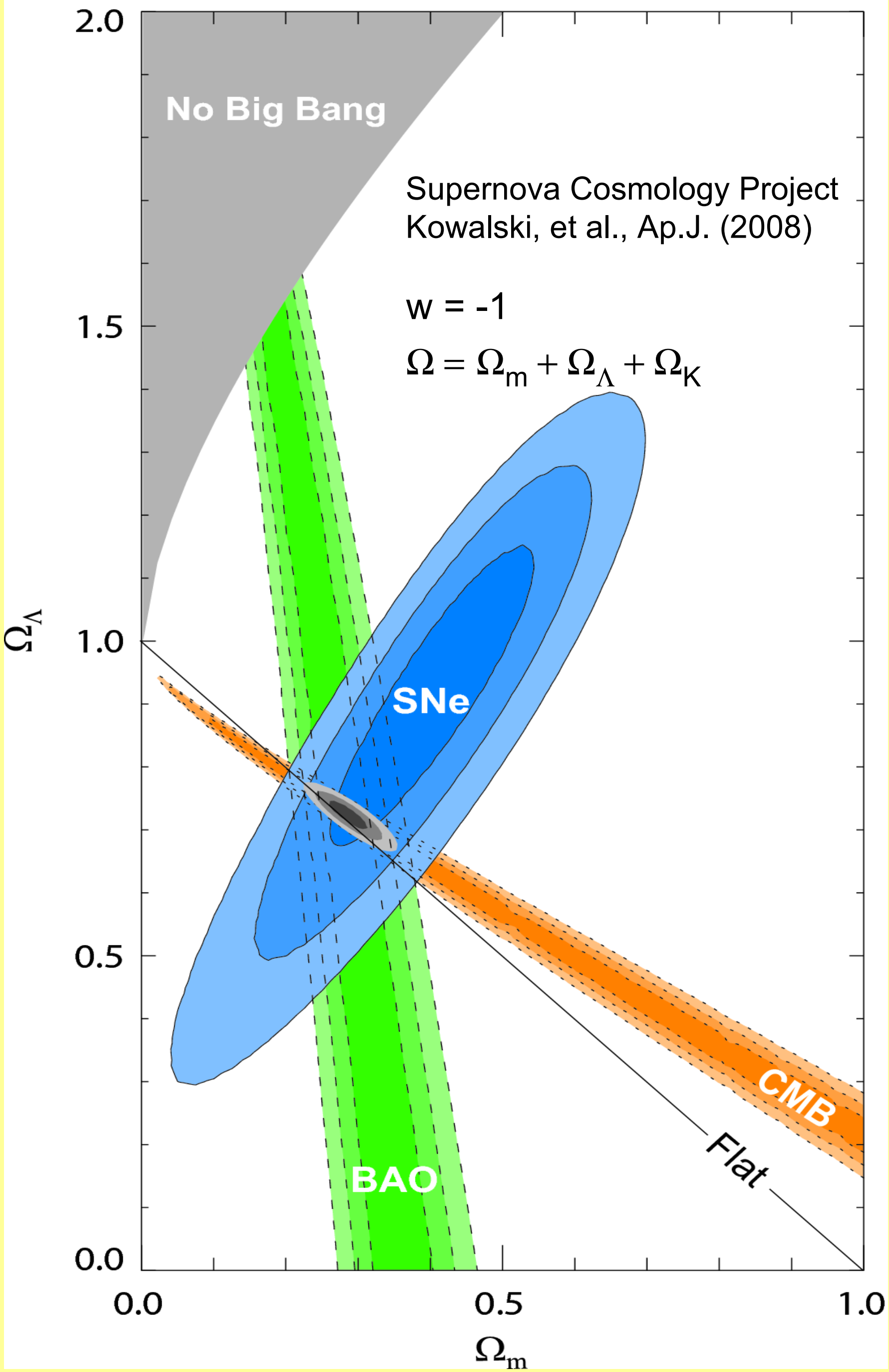
Other priors:

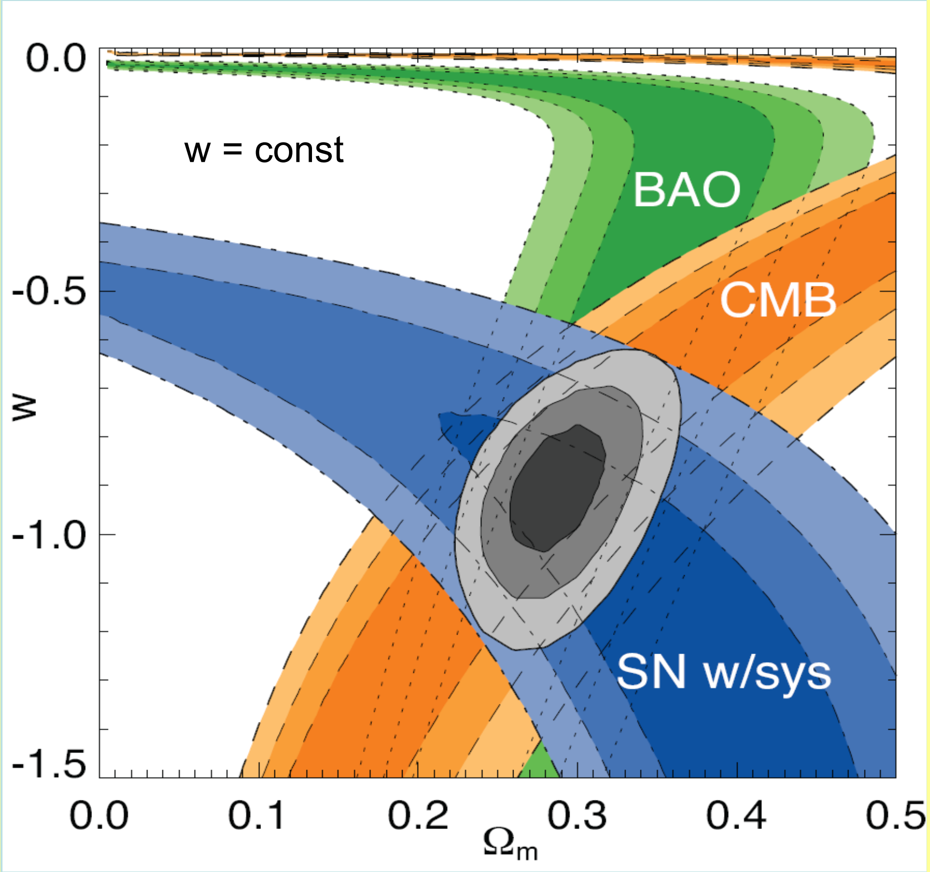
$$H_o = 74 \pm 3.6$$ Riess et al. (2009)

$$\Omega_b h^2 = 0.022 \pm 0.002$$

Burles, Nollet, Turner, 2001, PRD 63
Cyburt, 2004, PRD 70
Serpico et al., 2004, JCAP 0412







ΛCDM

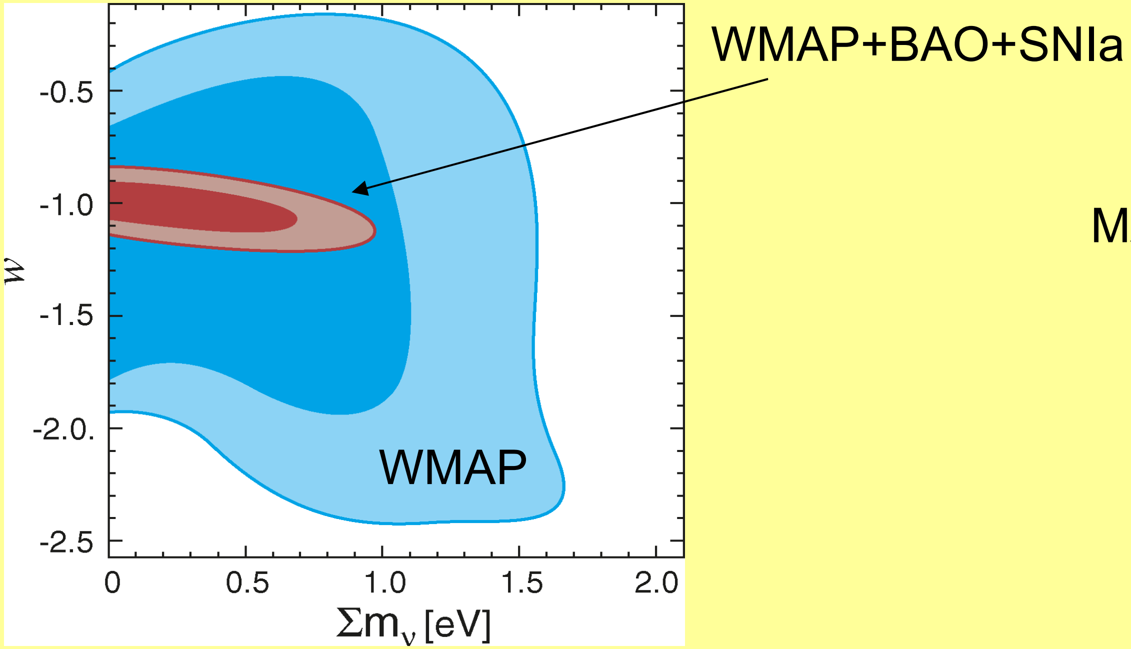
assume

$\Omega = \Sigma\Omega_i = 1$, w = -1

(negligible neutrino mass)

Upper limits on neutrino mass

$M_\nu = \Sigma m_\nu$ (95% CL)	w = -1	w = const ≠ -1
WMAP	1.3 eV	1.6 eV
WMAP+BAO+HST	0.58 eV	1.3 eV
WMAP+LRG+HST	0.44 eV	0.71 eV
WMAP+BAO+SNIa	0.71 eV	0.91 eV



Upper limits on
$M_\nu = \Sigma\, m_\nu$ (95% C.L.)

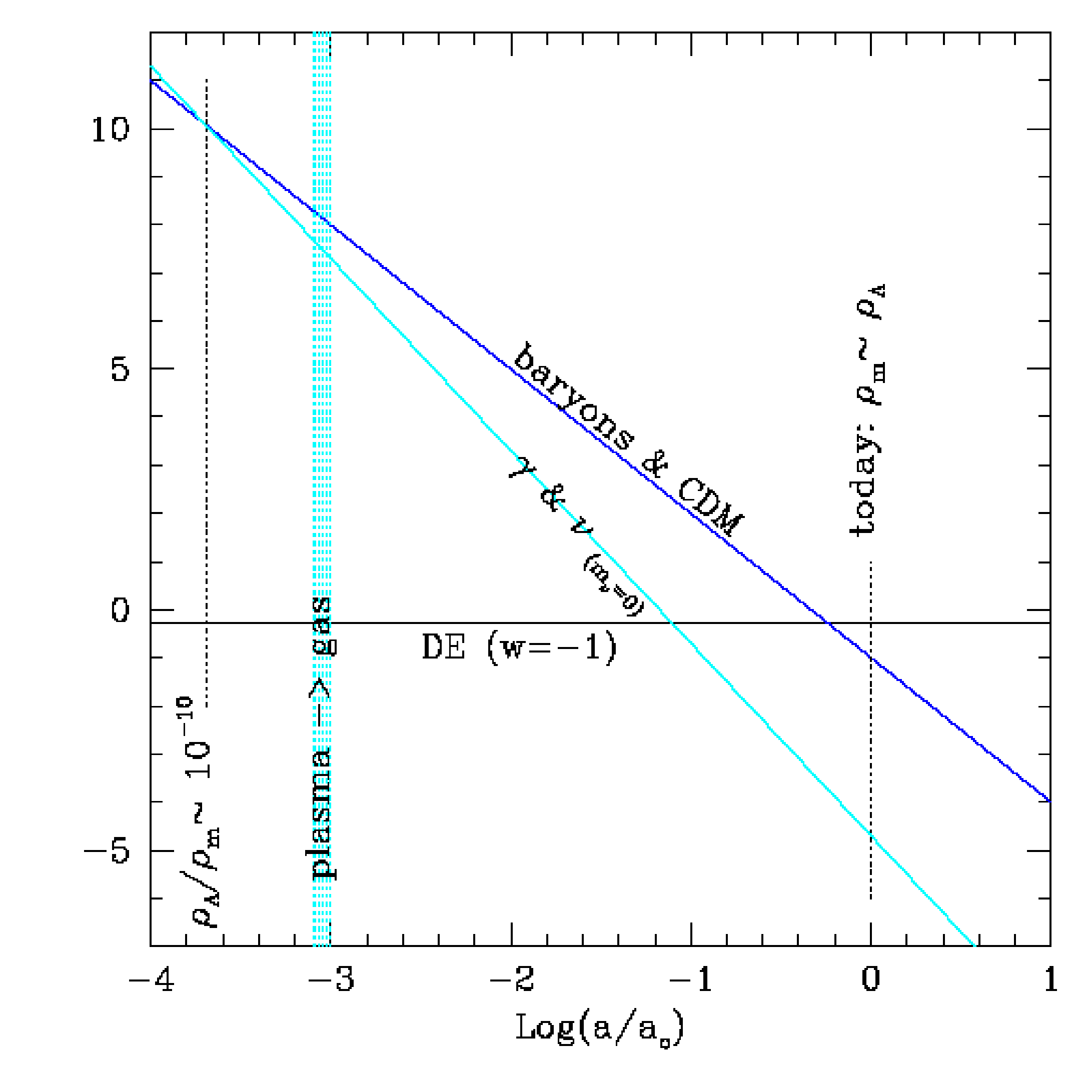
$$\Omega_\nu h^2 = \frac{\sum m_\nu}{93\,\mathrm{eV}}$$

ΛCDM problems

Scale dependence of
different cosmic components
in a ΛCDM model

- Coincidence paradox:
  why now?
  if earlier… no structure would form

- Vacuum fine tuning paradox
  $\sim 1{:}10$^56 at EW transition



w ≠ -1 and dynamical DE:

DE as a self-interacting scalar field
(Wetterich 1988, Ratra & Peebles 1988)

$\Lambda \approx$ GeV

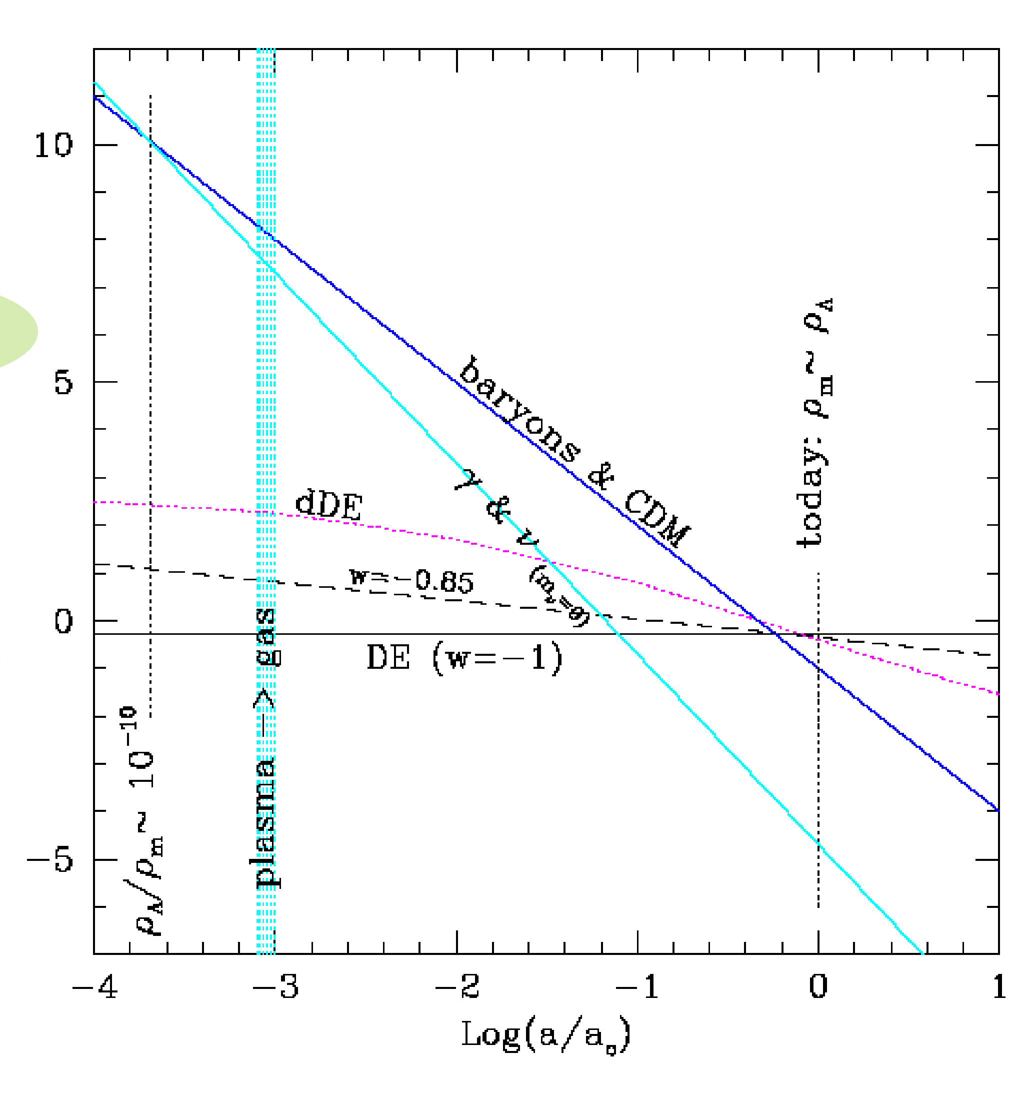
$$V(\varphi) = \frac{\Lambda^{4+\alpha}}{\varphi^{\alpha}} \quad RP$$

$$V(\varphi) = \frac{\Lambda^{4+\alpha}}{\varphi^{\alpha}} \exp\left(\frac{4\pi\varphi^2}{m_P^2}\right) \quad SUGRA$$

Brax & Martin
1999, 2001

$$\rho = \frac{\dot{\varphi}^2}{2a^2} + V(\varphi)$$

$$p = \frac{\dot{\varphi}^2}{2a^2} - V(\varphi)$$



These potentials admit
tracker solutions:
NO dependence on initial condition on the field

$$\Gamma = \frac{V V_{,\varphi\varphi}}{\left(V_{,\varphi}\right)^2} > 1$$

Fine tuning eased (may be...)
Coincidence still a problem

Coupled DE case

Wetterich C. 1995, Amendola L., 2000, etc.

Energy flow from CDM to DE:

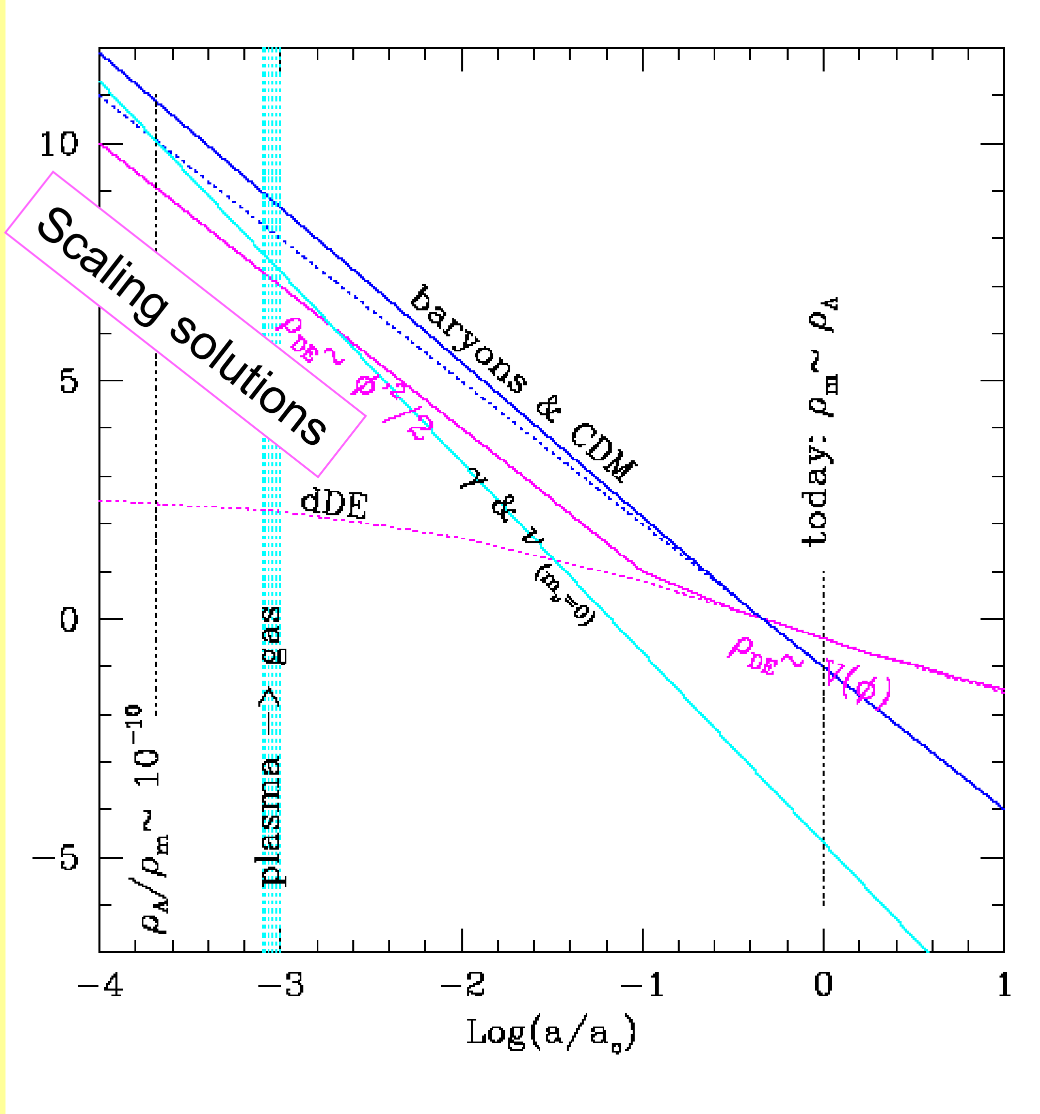
$$T^{(de)\ \mu}_{\ \nu;\mu} = +CT^{(c)}\phi_{,\nu}$$
$$T^{(c)\ \mu}_{\ \nu;\mu} = -CT^{(c)}\phi_{,\nu}\ ,$$

$$\beta = (3/16\pi)^{1/2} m_p C$$

High z :
DE density is purely kinetical dilutes rapidly, but it continues to be fed

Low z :
DE field attains values making the potential term dominant:
Then it overcomes matter density and causes cosmic acceleration

$$\ddot\phi + 2\frac{\dot a}{a}\dot\phi + a^2 V'_\phi = +Ca^2\rho_c$$
$$\dot\rho_c + 3\frac{\dot a}{a}\rho_c = -C\rho_c\dot\phi$$

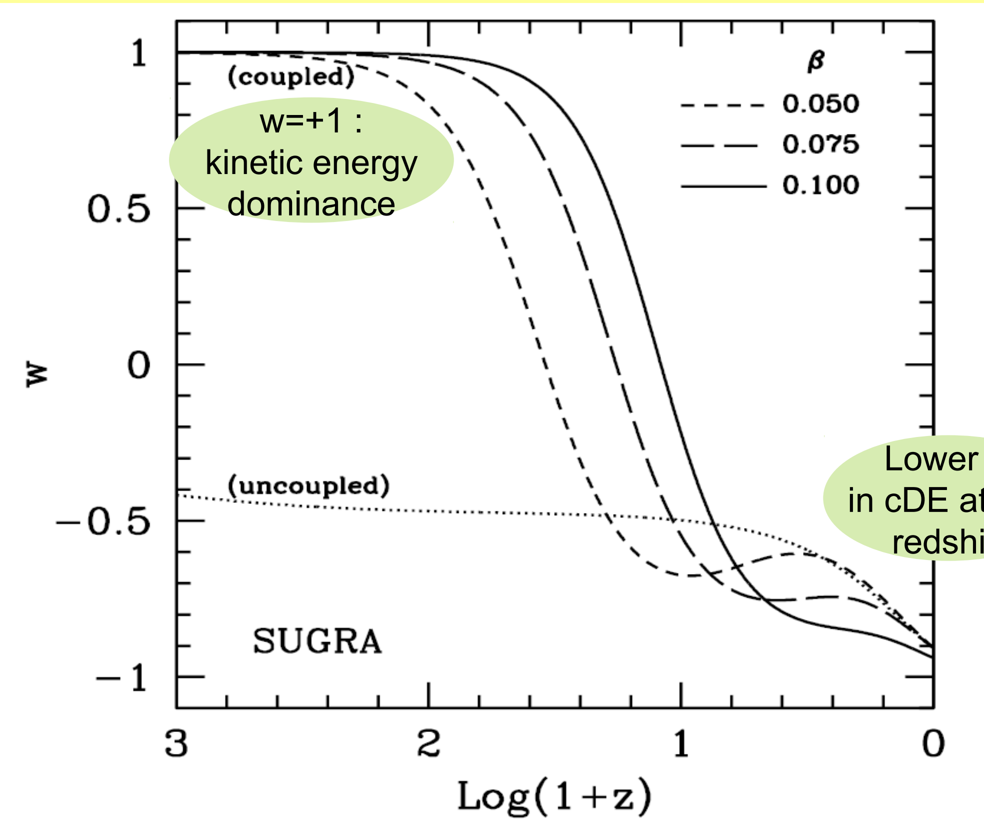


Coincidence eased as well

Different approaches:
* Neutrino DE (Wood-Vasey et al arxiv:0701040, Hung P.Q. arxiv:0010126, Blatt J.R. et al:0812.1895v1, etc. But see: Bjaelde & Hannestad, arXiv:0806.2146v1)
* Coupling with T(de): Gavela M.B. et al, arxiv:0901.1611 (focused on ν mass constraints)

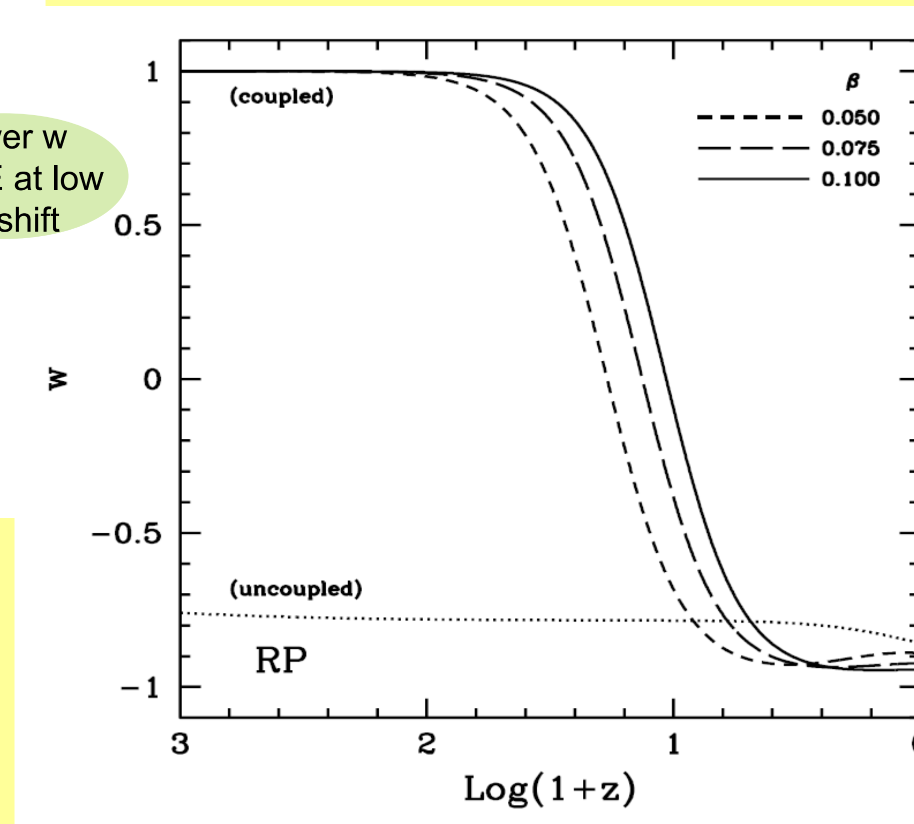
Variable state parameter
in dDE & cDE models

$$w = \frac{p}{\rho} = \frac{\frac{\dot{\varphi}^2}{2a^2} - V(\varphi)}{\frac{\dot{\varphi}^2}{2a^2} + V(\varphi)}$$



w=+1 : kinetic energy dominance

Lower w in cDE at low redshift

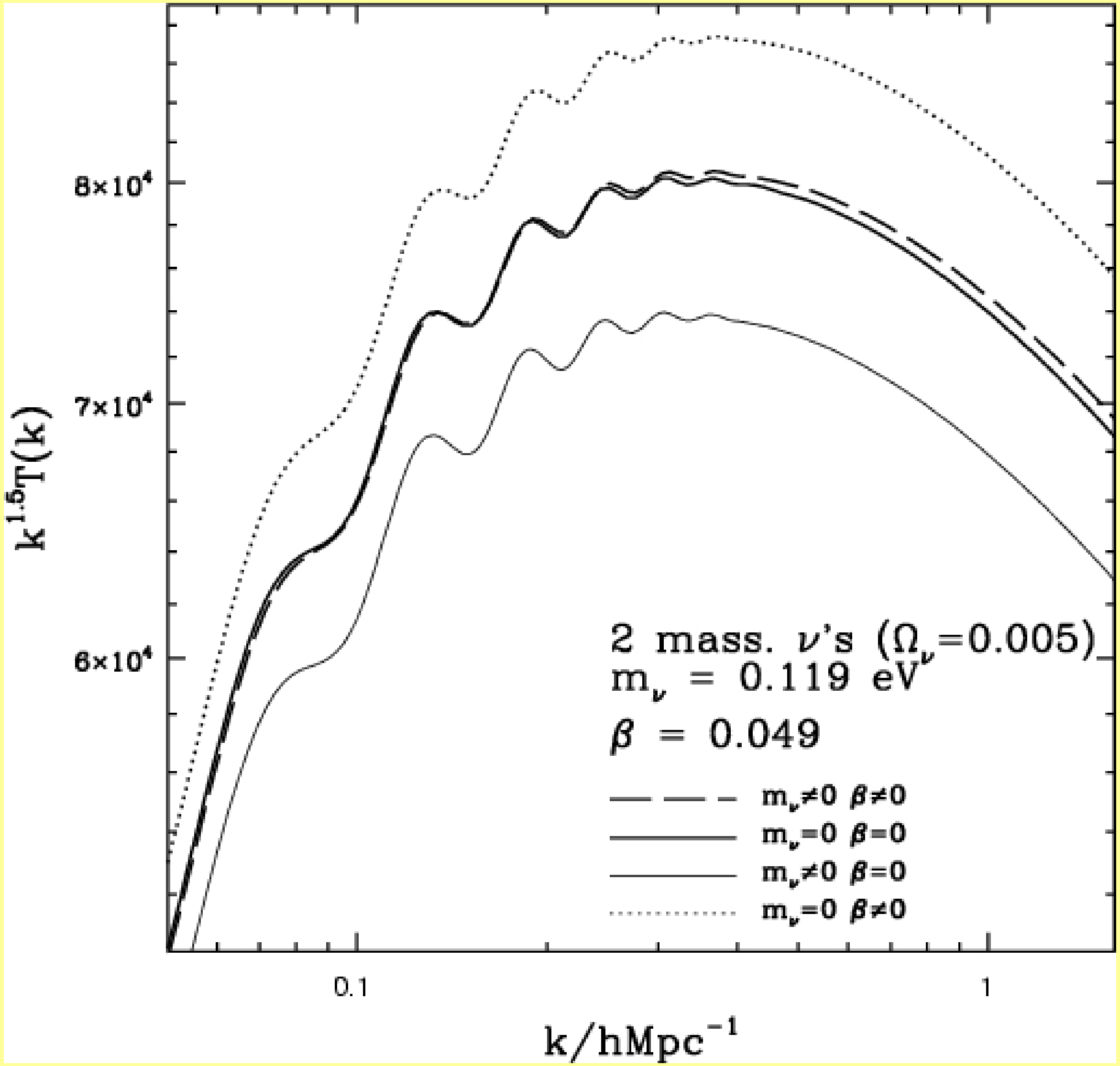


Results obtained with ALLde (Mainini et al.)

MMC models: Matter fluctuations – transfer functions
(Mildly Mixed Coupled)

ANTISYMMETRIC EFFECTS OF NEUTRINO MASS & CDM-DE COUPLING

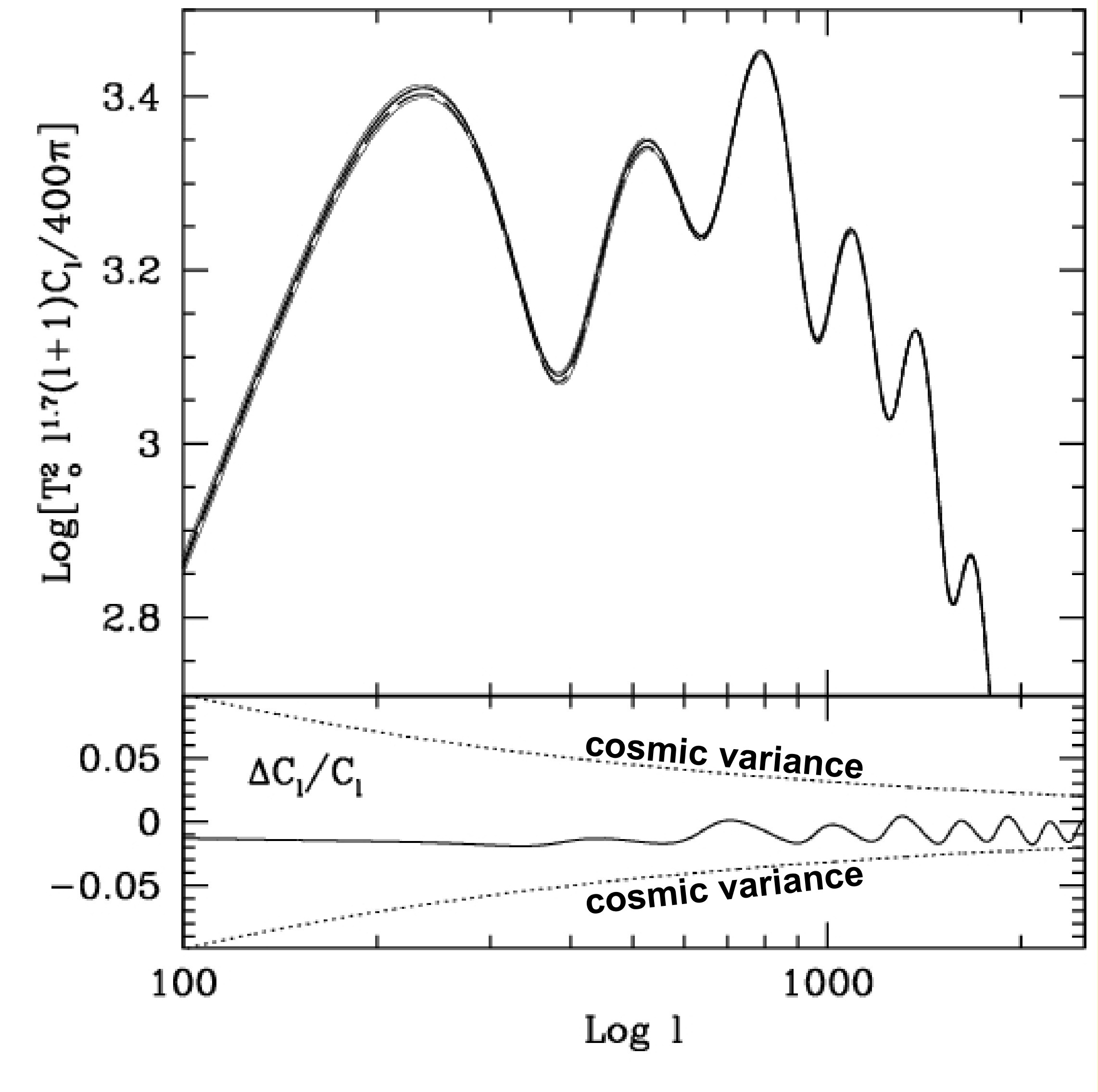
(Other parameters fixed)



MMC models: CMB angular fluctuation spectrum
(Mildly Mixed Coupled)

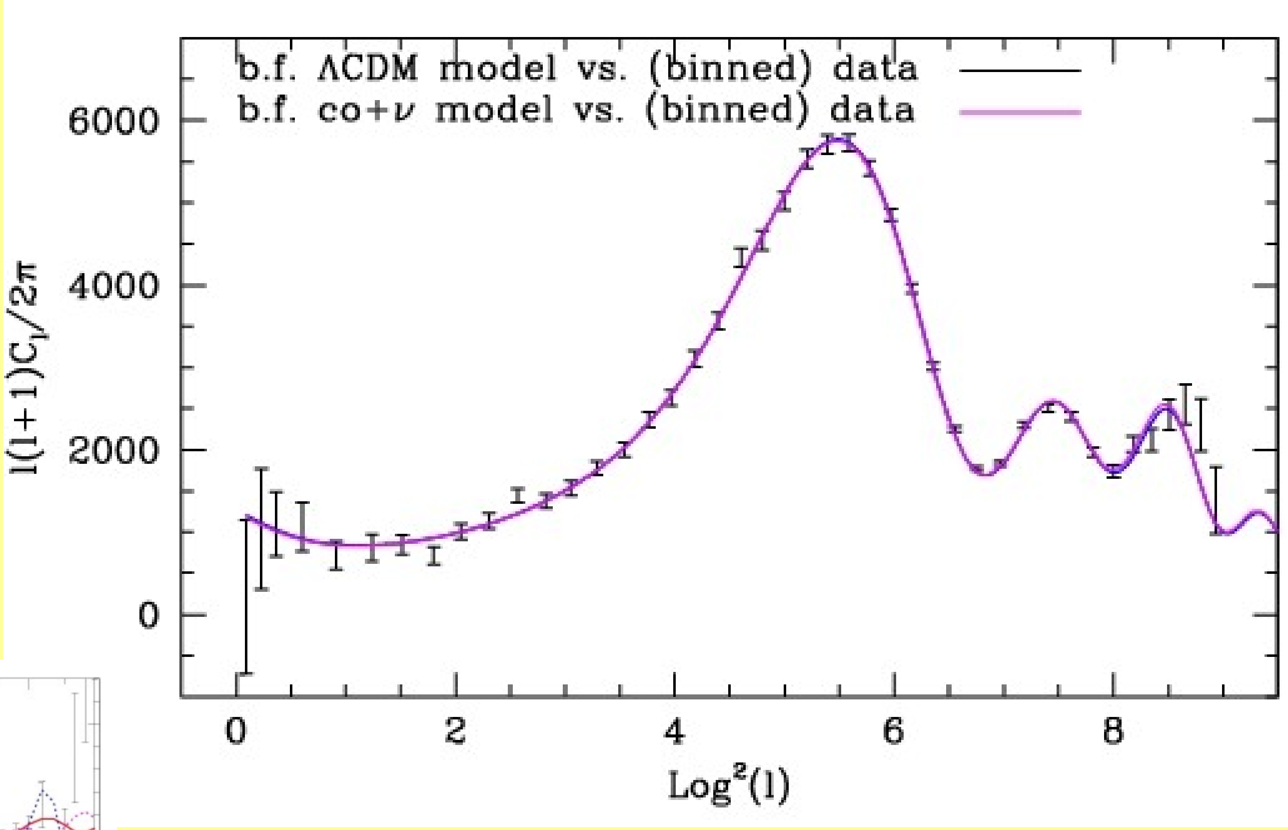
ANTISYMMETRIC EFFECTS OF NEUTRINO MASS & CDM-DE COUPLING

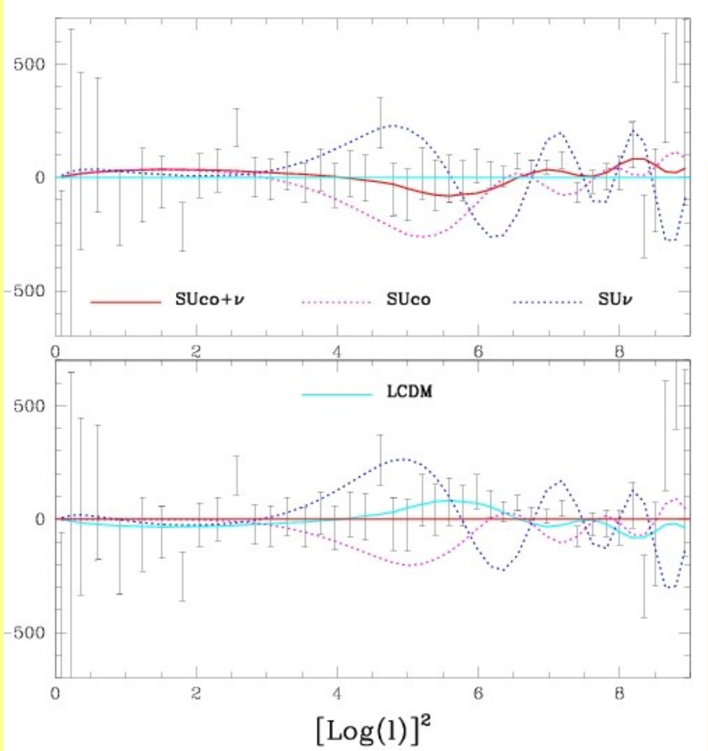
Same parameter values as in the previous slide



BEST FIT
LCDM
vs
(nearly)
BEST FIT
MILDLY-MIXED
COUPLED
SUGRA

see below





3 ν's yielding
$M_\nu \cong 0.9$ eV
$\beta \cong 0.1$

Best-fit parameter values for various models

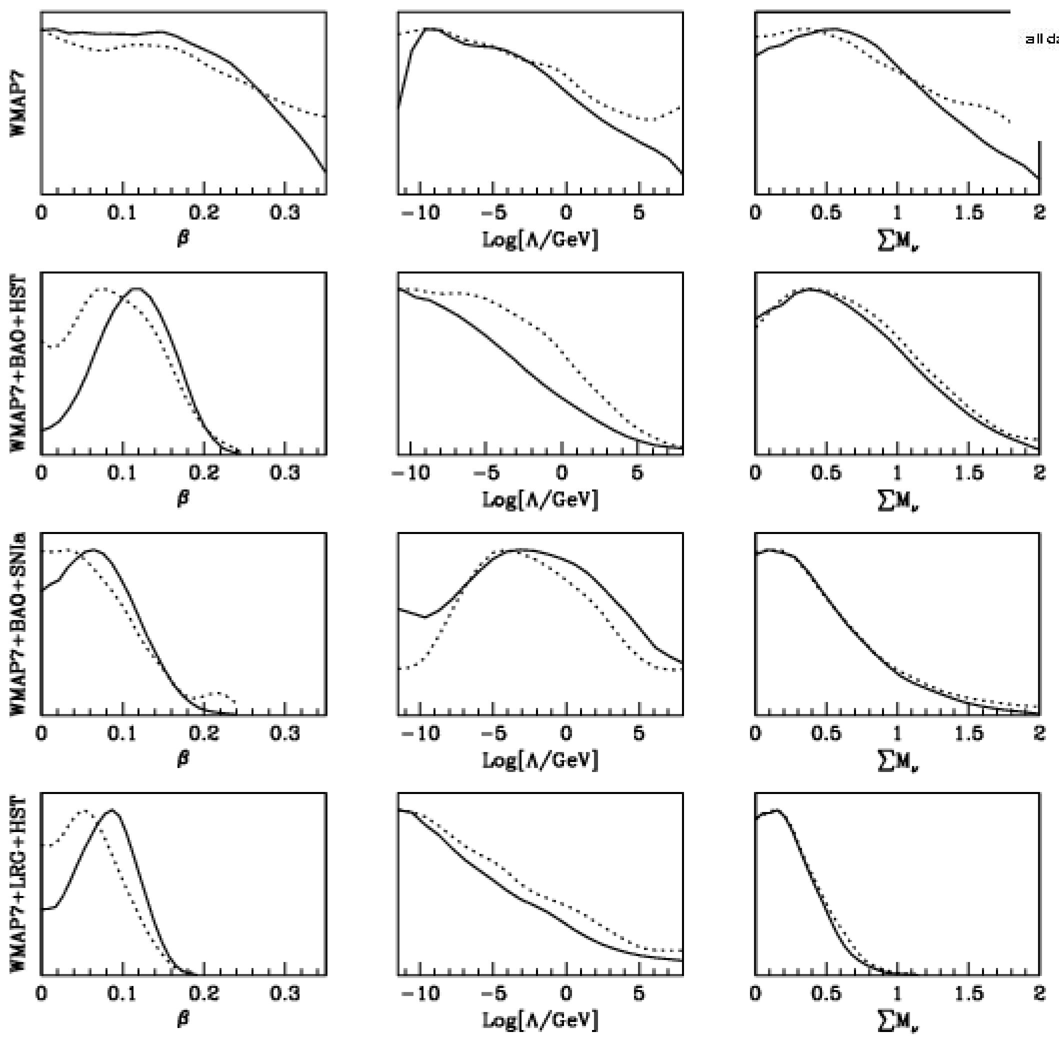
modified COSMOMC & modified CAMB + Likelihood software from WMAP team

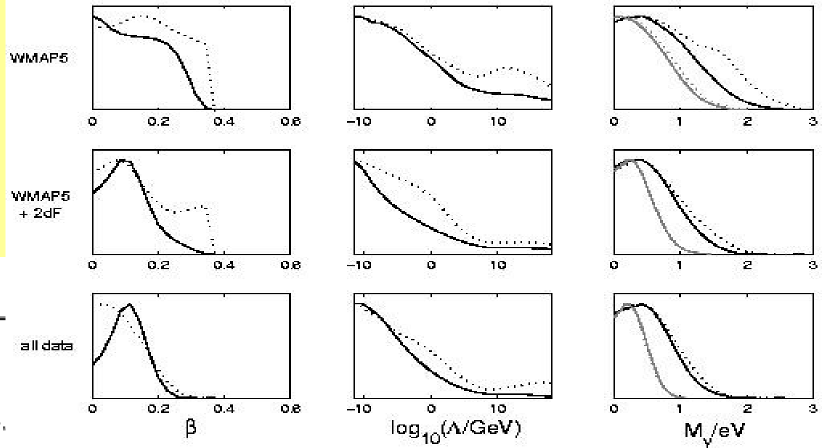
WMAP5, 2dFGRS, H0, ecc.

Parameter	ΛCDM + ν's WMAP only	ΛCDM + ν's all data	w = const. all data	cRP + ν's all data	cSUGRA + ν's all data
$10^2\,\omega_b$	2.244 $\pm$ 0.066	2.258 $\pm$ 0.061	2.247 $\pm$ 0.062	2.260 $\pm$ 0.061	2.260 $\pm$ 0.065
ω_c	0.1156 $\pm$ 0.0078	0.1098 $\pm$ 0.0040	0.1132 $\pm$ 0.0069	0.1039 $\pm$ 0.0062	0.1042 $\pm$ 0.0084
$10^2\theta$	1.0401 $\pm$ 0.0030	1.0401 $\pm$ 0.0030	1.0402 $\pm$ 0.0030	1.0401 $\pm$ 0.0029	1.0406 $\pm$ 0.0030
τ	0.085 $\pm$ 0.017	0.087 $\pm$ 0.017	0.085 $\pm$ 0.017	0.087 $\pm$ 0.016	0.088 $\pm$ 0.017
M_ν (eV) (95% C.L.)	$<$ 1.20	$<$ 0.66	$<$ 0.94	$<$ 1.13	$<$ 1.17
β (95% C.L.)	–	–	–	$<$0.17	$<$0.18
$\log_{10}(\Lambda/\text{GeV})$ (95% C.L.)	–	–	–	$<$ -4.2	$<$ 6.3
n_s	0.955 $\pm$ 0.017	0.962 $\pm$ 0.014	0.958 $\pm$ 0.015	0.969 $\pm$ 0.015	0.970 $\pm$ 0.018
$\ln(10^{10}A_s)$	3.053 $\pm$ 0.043	3.045 $\pm$ 0.040	3.049 $\pm$ 0.040	3.055 $\pm$ 0.040	3.057 $\pm$ 0.041
σ_8	0.691 $\pm$ 0.075	0.713 $\pm$ 0.056	0.711 $\pm$ 0.059	0.723 $\pm$ 0.062	0.717 $\pm$ 0.069
H_o (km/s/Mpc)	67.0 $\pm$ 4.4	70.1 $\pm$ 2.1	69.7 $\pm$ 2.2	71.8 $\pm$ 2.5	71.9 $\pm$ 2.7
-2 $\ln(\mathcal{L})$	1329.39	1407.25	1407.38	1407.44	1407.33

Table 2: Best fit values and 1–σ error bars. In all fits we allow for ν masses. The first 9 lines concern primary parameters. Only upper limits on M_ν, β and Λ are shown. These variables are discussed more thoroughly in forthcoming 2–D plots. Likelihood values are almost model independent.

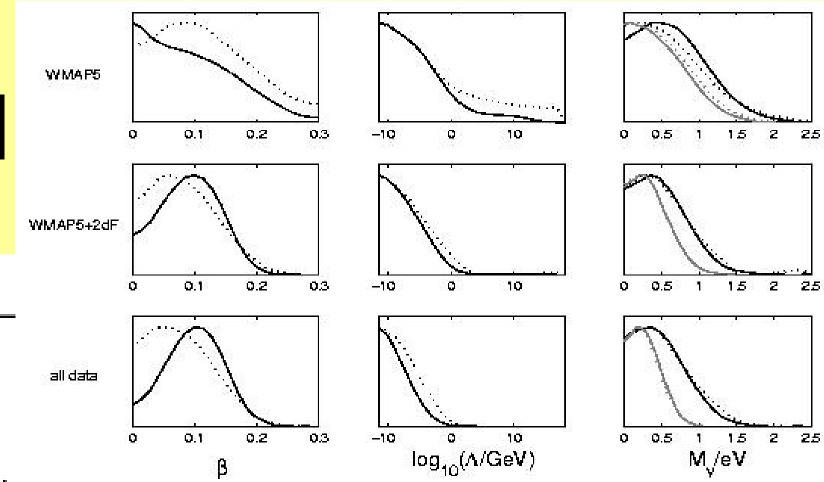
SUGRA potential

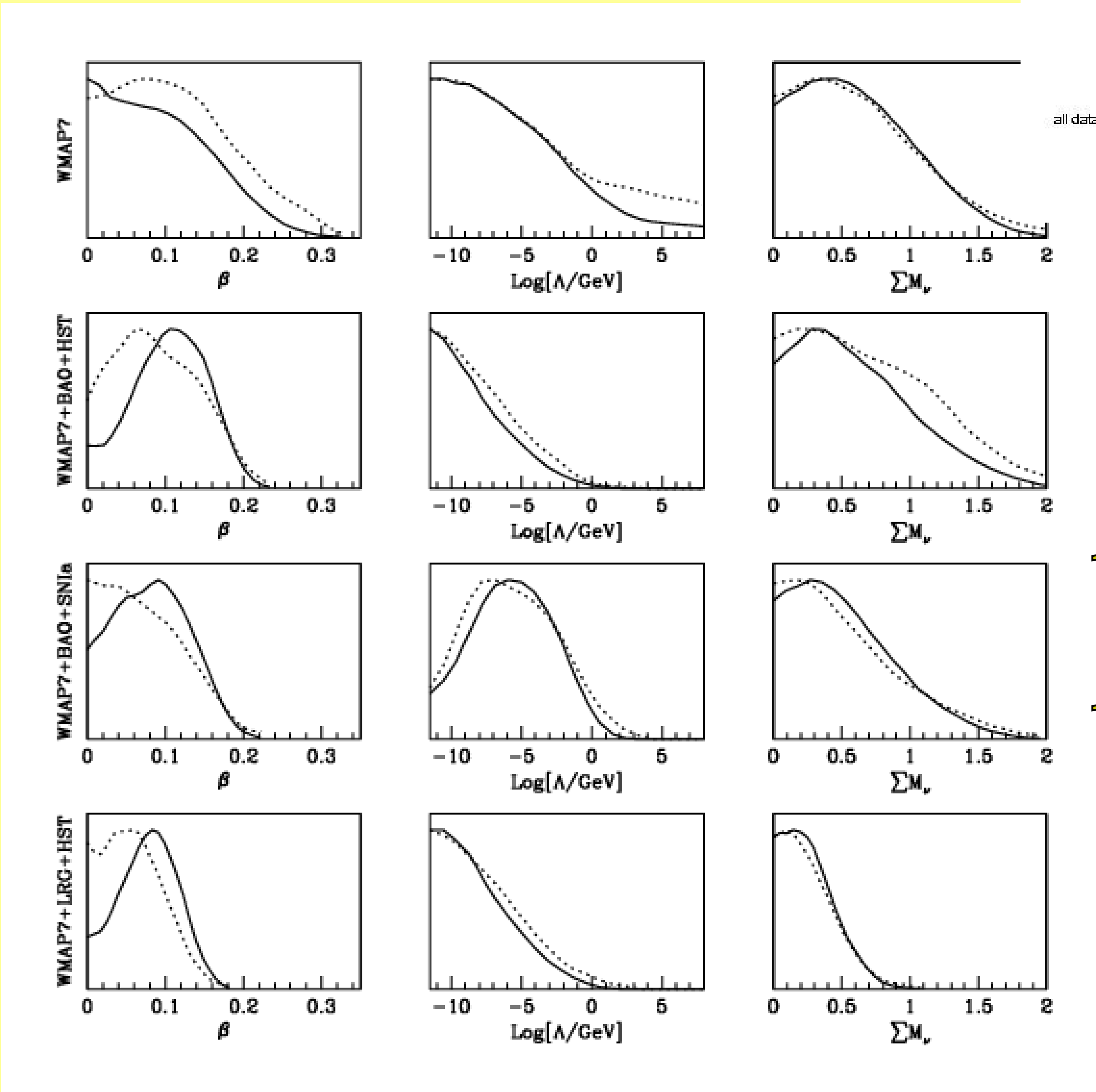




Preliminary

Ratra-Peebles potential

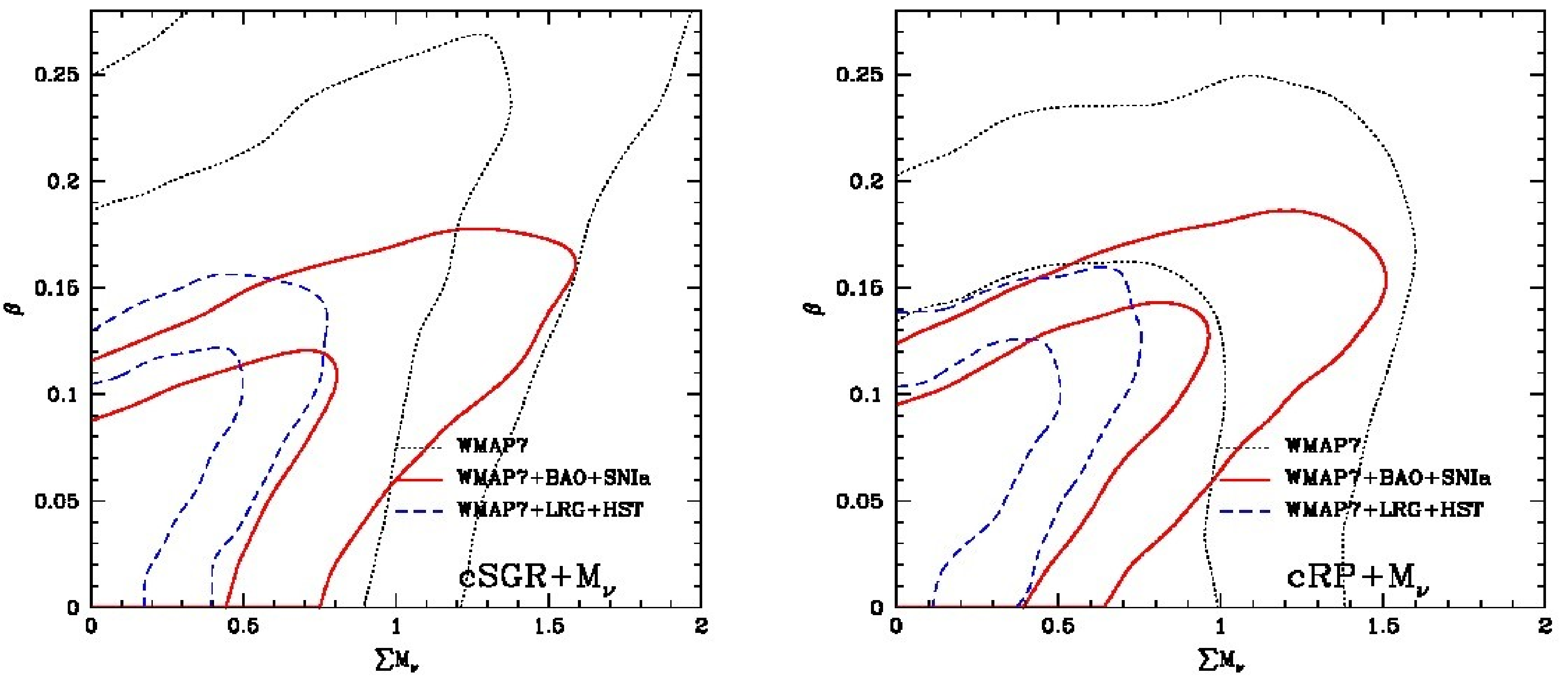


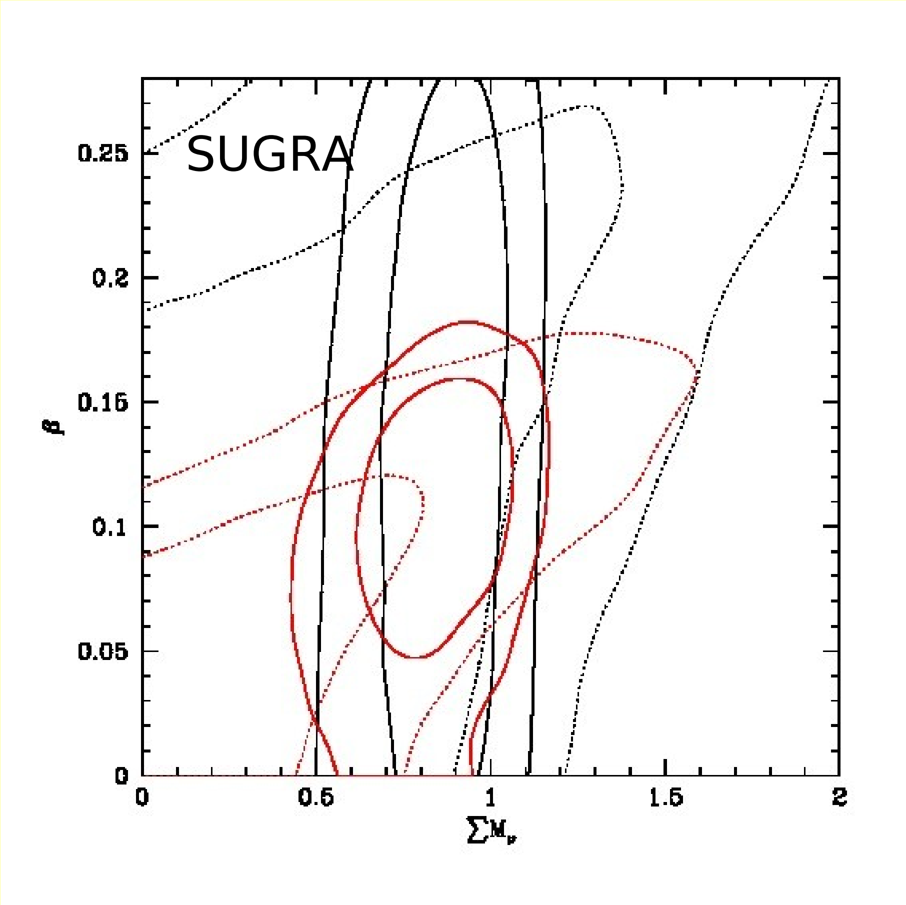


Preliminary

SUGRA

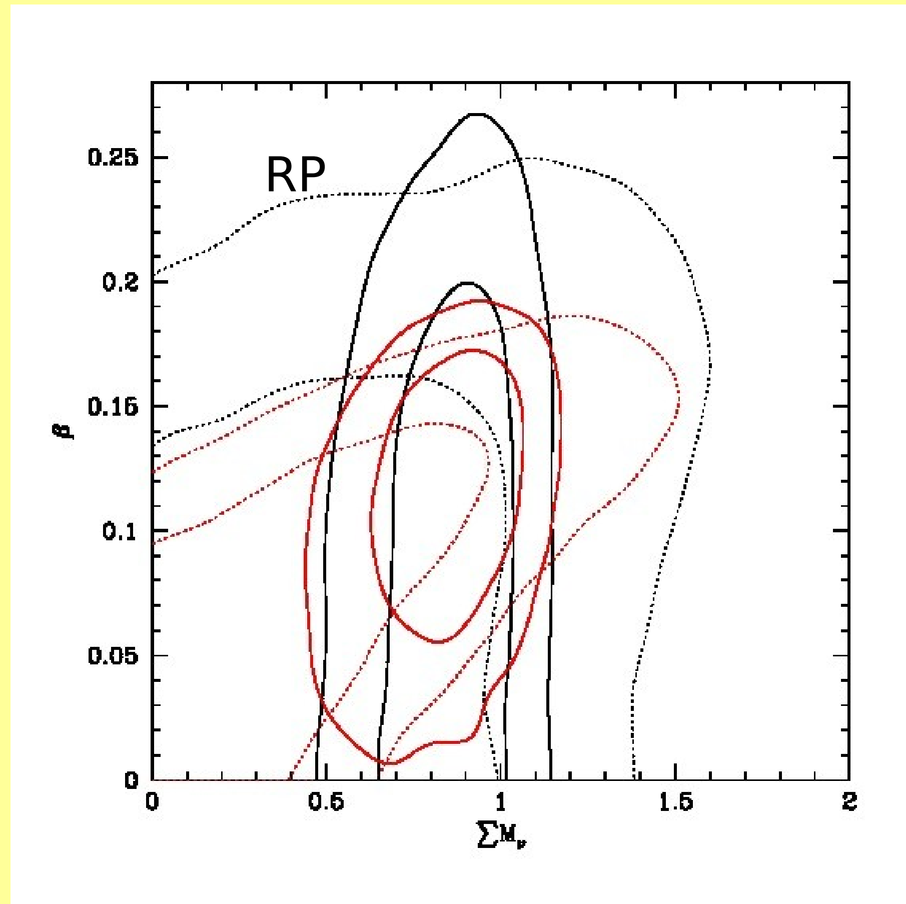
RP



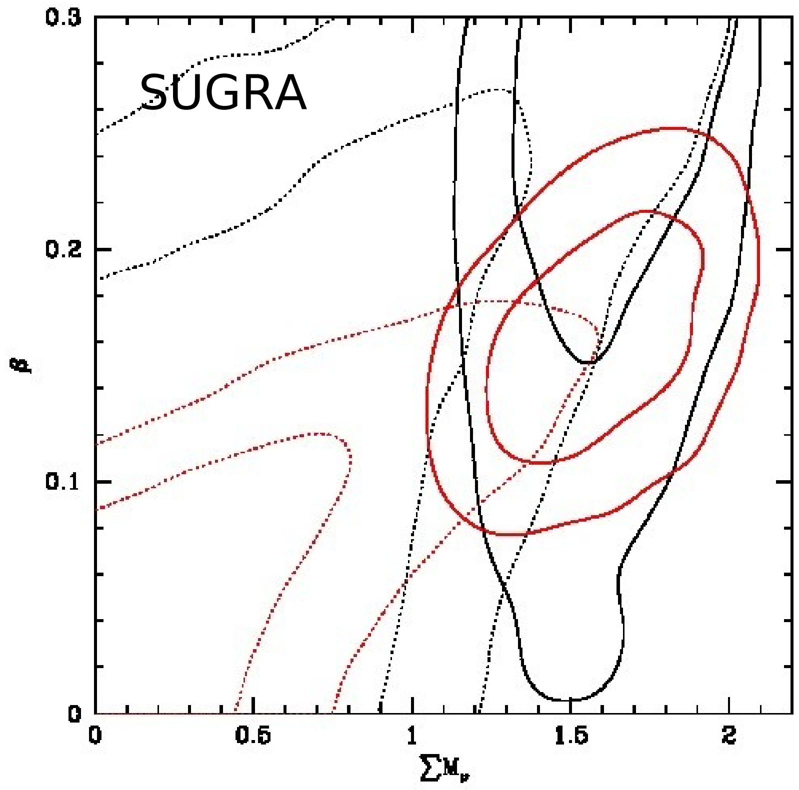


+Katrin neutrino mass prior

$m(\nu_e)\approx$ ۰.۹±۰.۱۶ eV

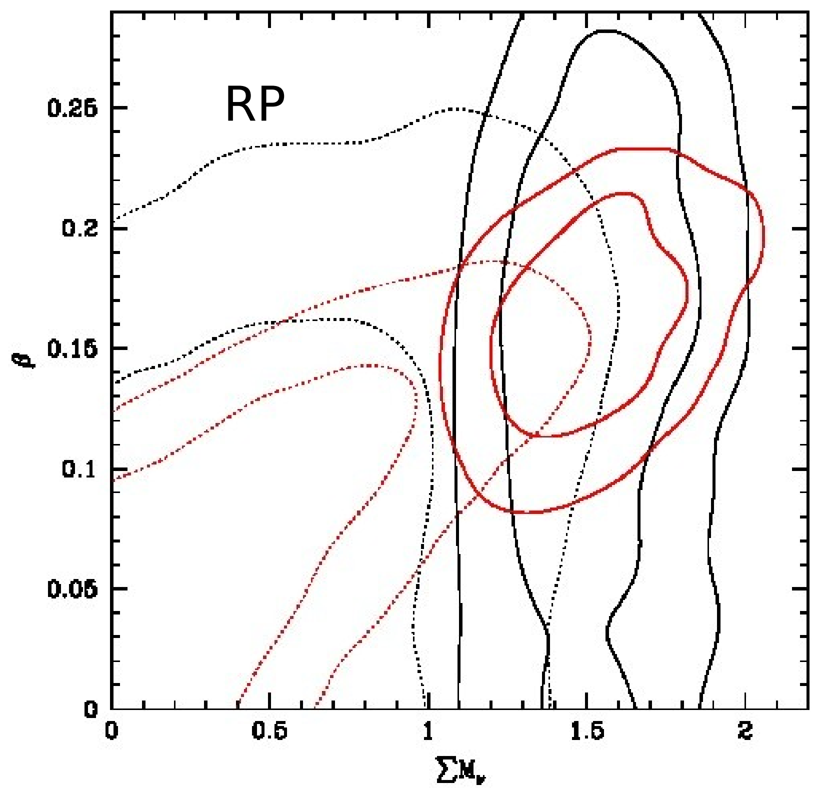


Preliminary



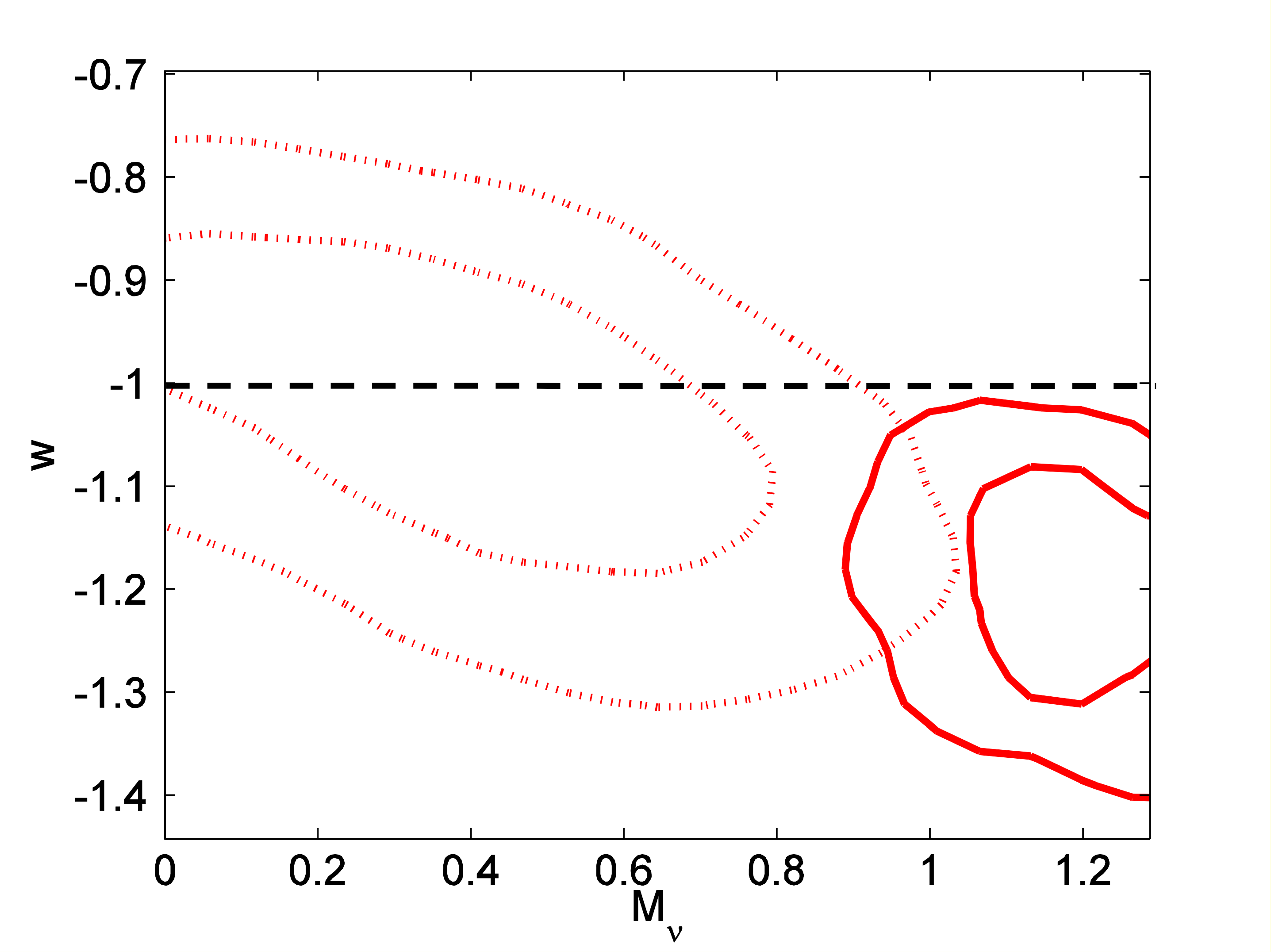
+Klapdor et al. neutrino mass prior

$m(\nu_e) \approx (0.1 \div 0.9)$ eV (3σ)

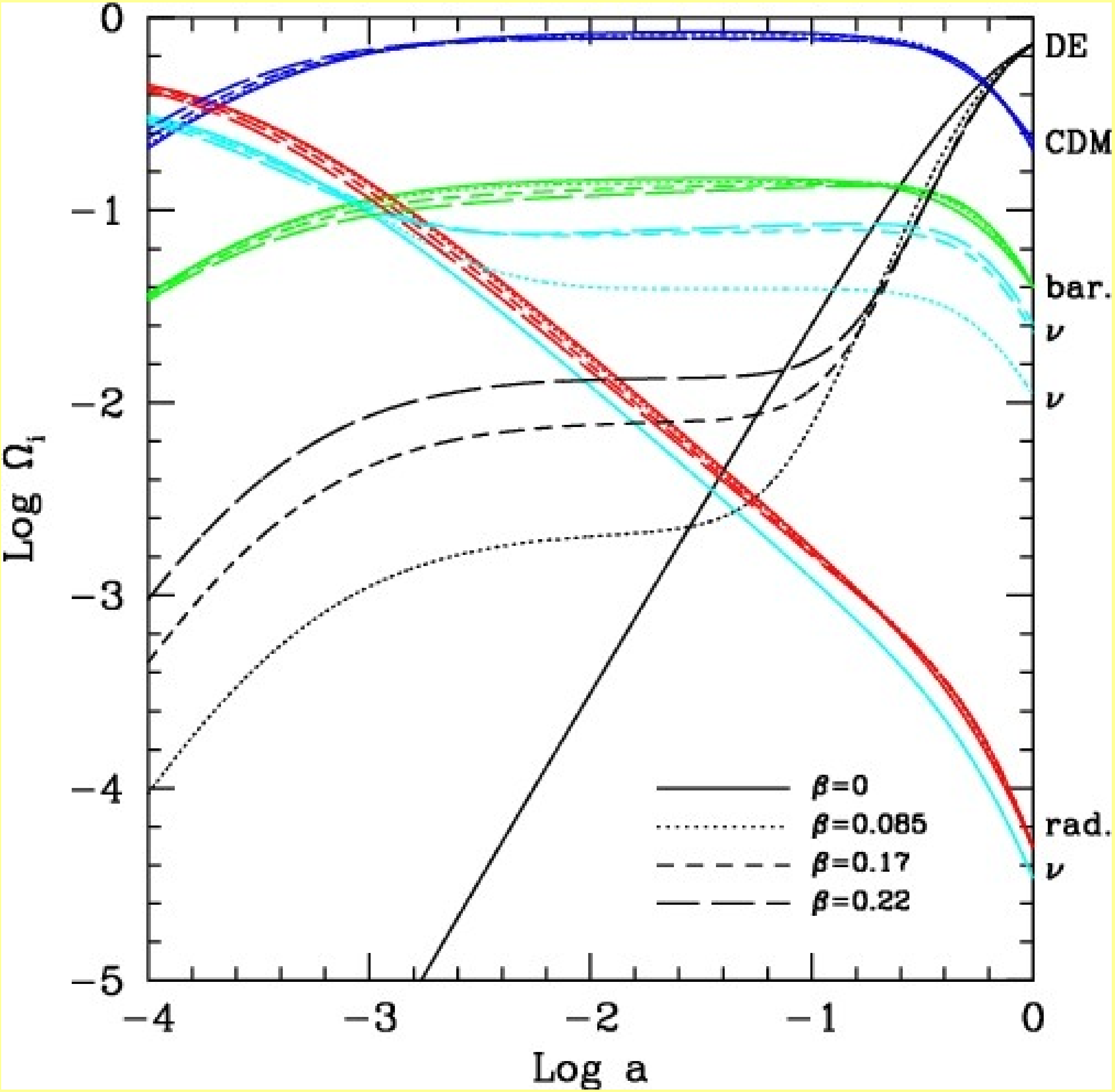


Preliminary

MMC vs wCDM+M_ν



Density parameter evolution in MMC SUGRA models



Some conclusions

- ΛCDM fits available data:
  once ΛCDM was just a counter-example for simulations...

- Coupled DE models ease ΛCDM paradoxes, but... do not fit data

- Coupled DE + neutrino mass fit “better” than ΛCDM

- “signal” is O(1 sigma) ...

- But... KATRIN detection of neutrino mass
  would apparently imply also CDM-DE coupling

- If so: also KATRIN would detect a signal on neutrino mass

Work in progress:

1. New algorithm for MCMC with new data release for various observables: WMAP7, SDSS, extended SN catalogue, more stringent HST prior

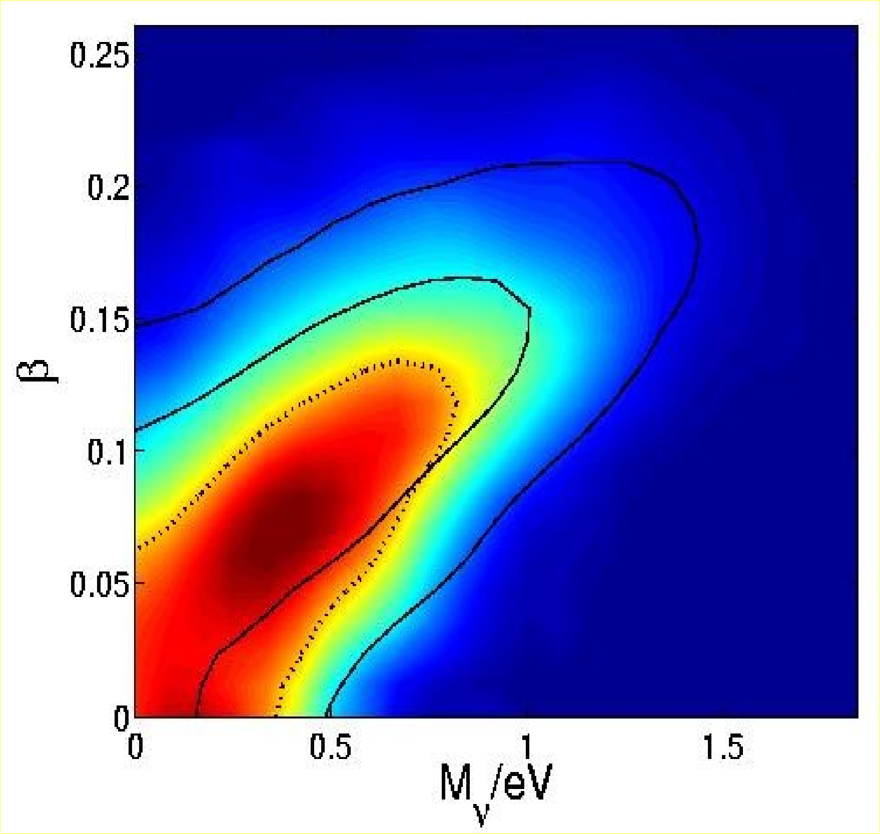
2. Testing how far PLANCK will be constraining

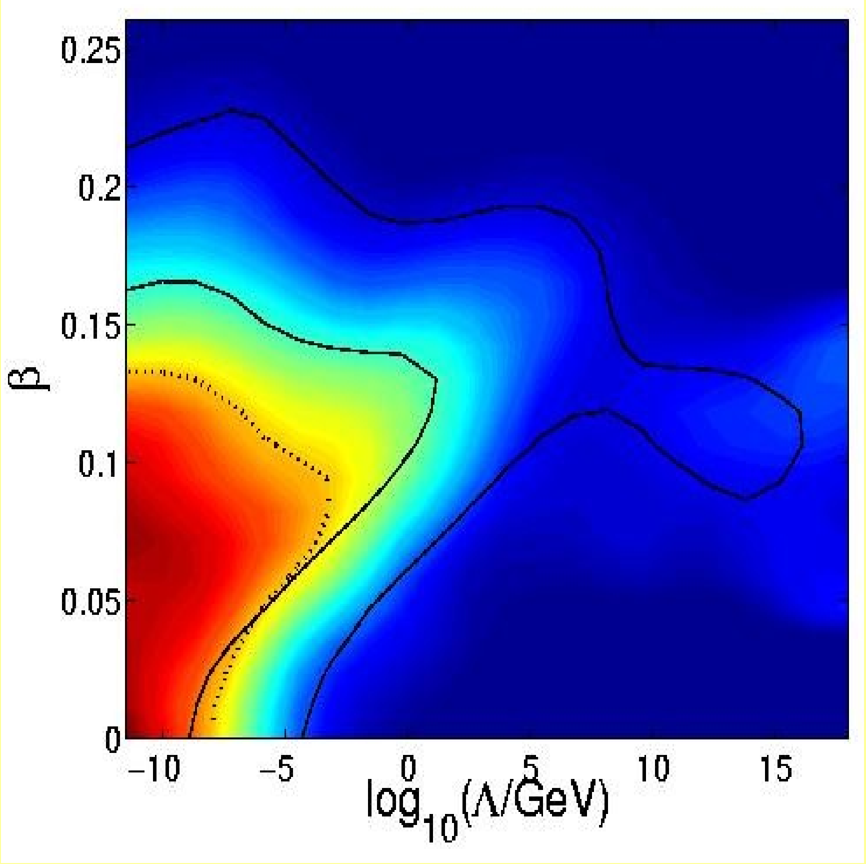
- Build mock data for MMC models
- Deduce model parameter by using PLANCK “outputs”
- Consider cosmic shear observables (EUCLID project)
- How more constraining can they be in fixing
    - DE state equation
    - neutrino masses (?)

3. Probing lower scales: spherical overdensity collapse

Thanks for your attention!

SUGRA potential – all data (WMAP5 + LSS + SNIa)





Ratra-Peebles potential – all data (WMAP5 + LSS + SNIa)