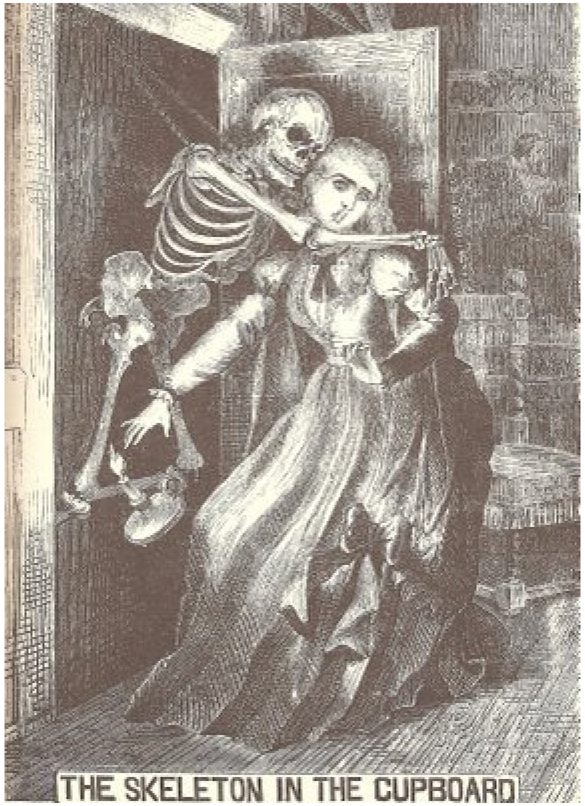

A skeleton in the cupboard: can ^{7}Li come back?

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GLV, A. Valotti & S. A. Bonometto (2011) *in prep.*

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Osservatorio Astronomico di Trieste – March 23rd, 2011

Summary

- Big Bang Nucleosynthesis (BBN)
  - BBN predictions & measurements
  - ^{7}Li problem

- Dark Energy (DE)
  - LCDM: problems & some alternatives
  - DE and massive neutrino

- ^{7}Li: looking for agreement
  - $\Omega_b h^2$ vs. w
  - M_ν vs. w
  - ^{7}Li and MMC

- Conclusions

Highlights of the Big Bang Nucleosynthesis

- **T > 1MeV (~10^10 K), t < 1s** : after baryogenesis, n & p in thermodynamic equilibrium

$n+\nu_e \leftrightarrow p+e \quad n+\bar{e} \leftrightarrow p+\bar{\nu}_e$ (collision) $\quad n \rightarrow p+e+\bar{\nu}_e$ (beta-decay)

$\nu+\bar{\nu} \leftrightarrow e+e^+$ (annihilation) $\quad \nu+e^\pm \leftrightarrow \nu+e^\pm$ (elastic)

- **T ~ 1MeV (~10^10 K), t ~ 1s** : ν decouple,

T ~ Δm(n,p), n/p equilibrium freezing at 1/6, only n decay

Still too hot for ^{2}H=D to survive, high baryon to γ ratio:

$$\eta \equiv \frac{n_b}{n_\gamma} \cong 2.7\times10^{-8}\Omega_b h^2 \qquad \eta_{10} \equiv 10^{10}\eta$$

- **T ~ 80keV (~10^9 K), t ~3min** : *Deuterium bottleneck* opens, 4He production

$$p+n \rightarrow D+\gamma$$

$$D+D \rightarrow {}^3He+n \qquad {}^3He+D \rightarrow {}^4He+p$$

$$D+D \rightarrow {}^3H+p \qquad {}^3H+D \rightarrow {}^4He+n$$

$$D+D \rightarrow {}^4He+\gamma \quad \textit{less frequent}$$

radiative channels

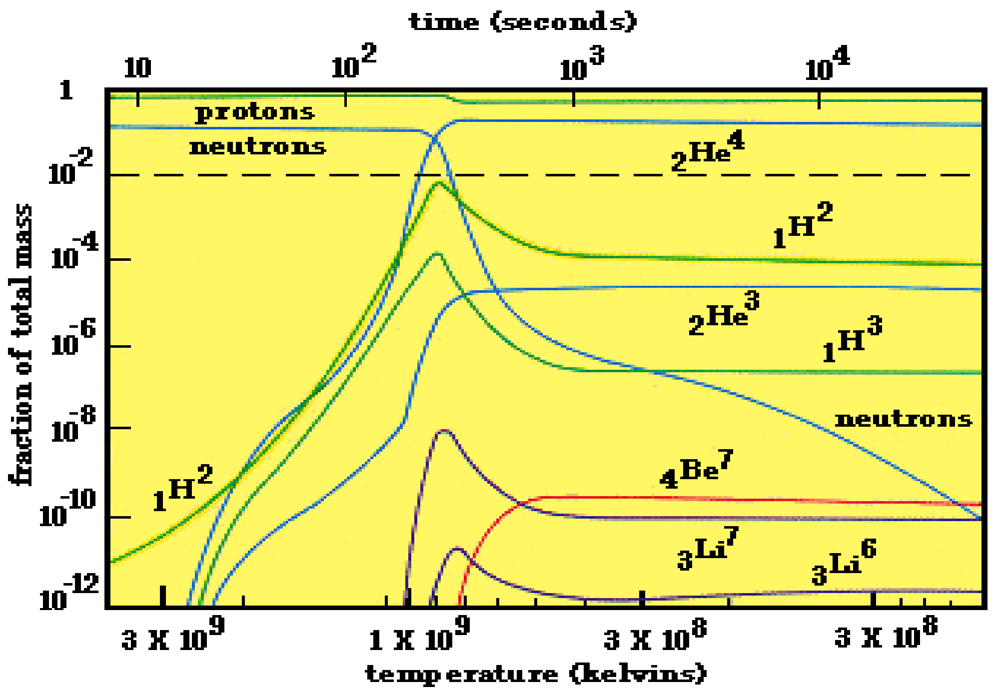
$$p+D \rightarrow {}^3He+\gamma \qquad {}^3He+D \rightarrow {}^4He+p$$

$$n+D \rightarrow {}^3H+\gamma \qquad {}^3H+p \rightarrow {}^4He+\gamma \quad \textit{etc...}$$

$${}^4He+{}^3He \rightarrow {}^7Be+\gamma \qquad {}^7Be+e \rightarrow {}^7Li+\nu \qquad \Omega_b h^2 > 10^{-2}$$

$${}^4He+{}^3H \rightarrow {}^7Li+\gamma \qquad \Omega_b h^2 < 10^{-2}$$

$$p+{}^7Li \rightarrow 2\,{}^4He \qquad \Omega_b h^2 << 1$$



http://aether.lbl.gov/www/tour/elements/early/early_a.html

BBN predictions & measurements

Particle Data Group: Fields & Sarkar (2010)

In principle, abundances measured in low-metal astrophysical sites:

D/H = (2.82±0.21)x10^-5

Y_p = 0.249±0.009

^{7}Li/H = (1.7±0.06±0.44)x10^-10

^{3}He/H intrinsically model dependent

$$X_i \equiv \frac{n_i}{n_B} \qquad i = p, {}^2H, {}^3He, \ldots$$

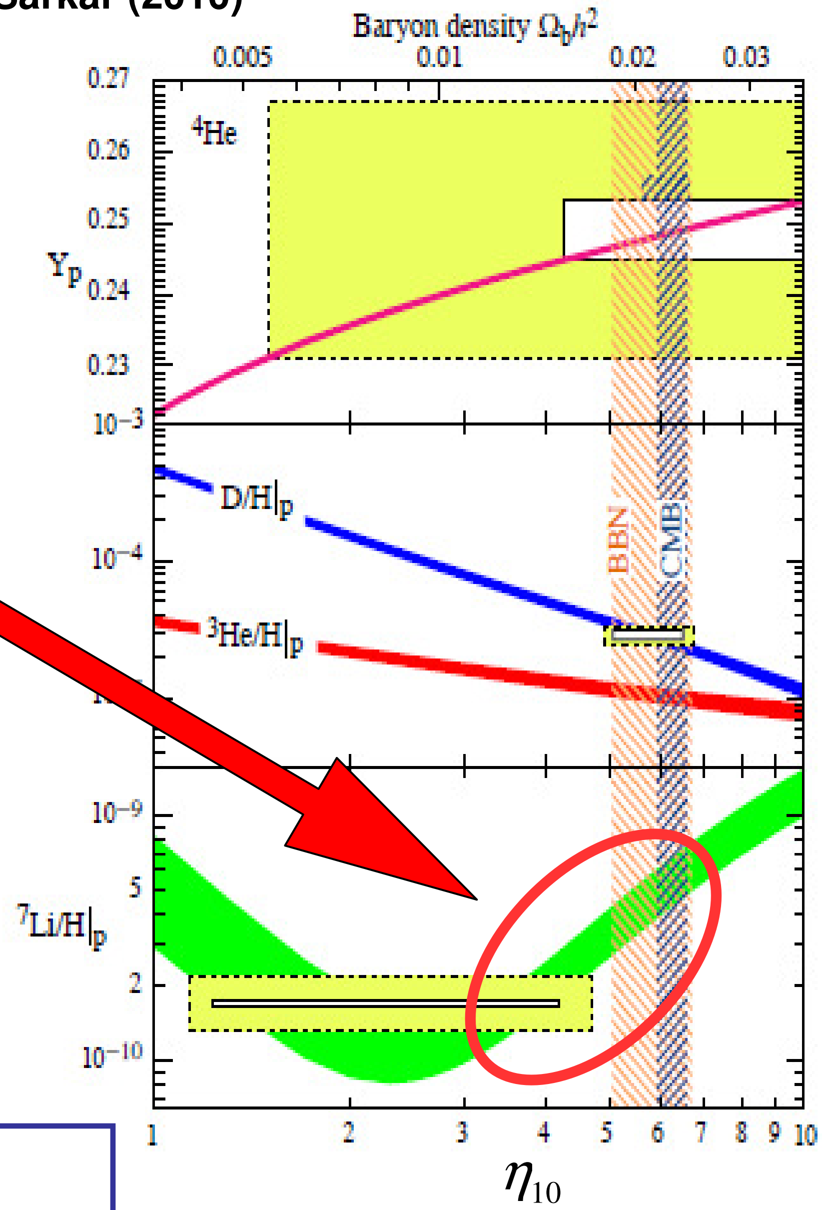
$${}^2H/H \equiv X_{{}^2H}/X_p, \ldots, \quad Y_p \equiv 4X_{{}^4He}$$

overlap region at (95% CL) for D and ^{4}He

$$5.1 < \eta_{10} < 6.5 \quad or \quad 0.019 < \Omega_b h^2 < 0.024$$

WMAP5 (ΛCDM)

$$6.06 < \eta_{10} < 6.40 \quad or \quad 0.02211 < \Omega_b h^2 < 0.02335$$



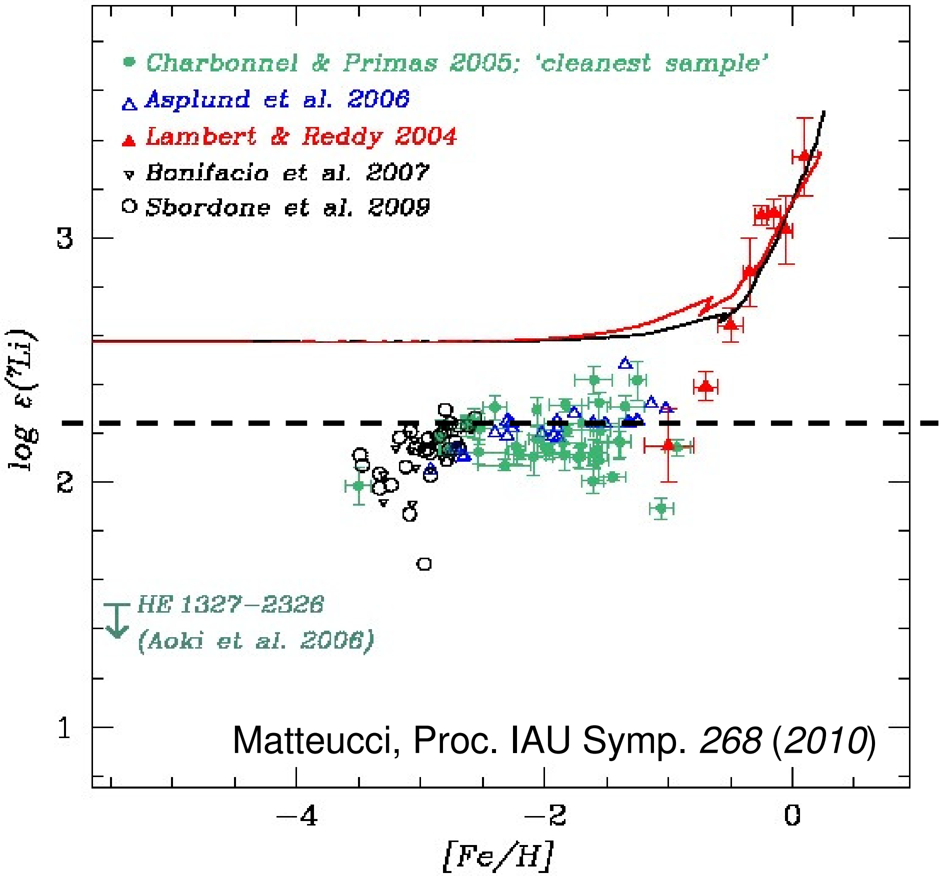
$$\eta \equiv \frac{n_b}{n_\gamma} \cong 2.7\times10^{-8}\,\Omega_b h^2 \qquad \eta_{10} \equiv 10^{10}\eta$$

^{7}Li problem

^{7}Li/H abundance measurement discrepant with the CMB at ~7σ

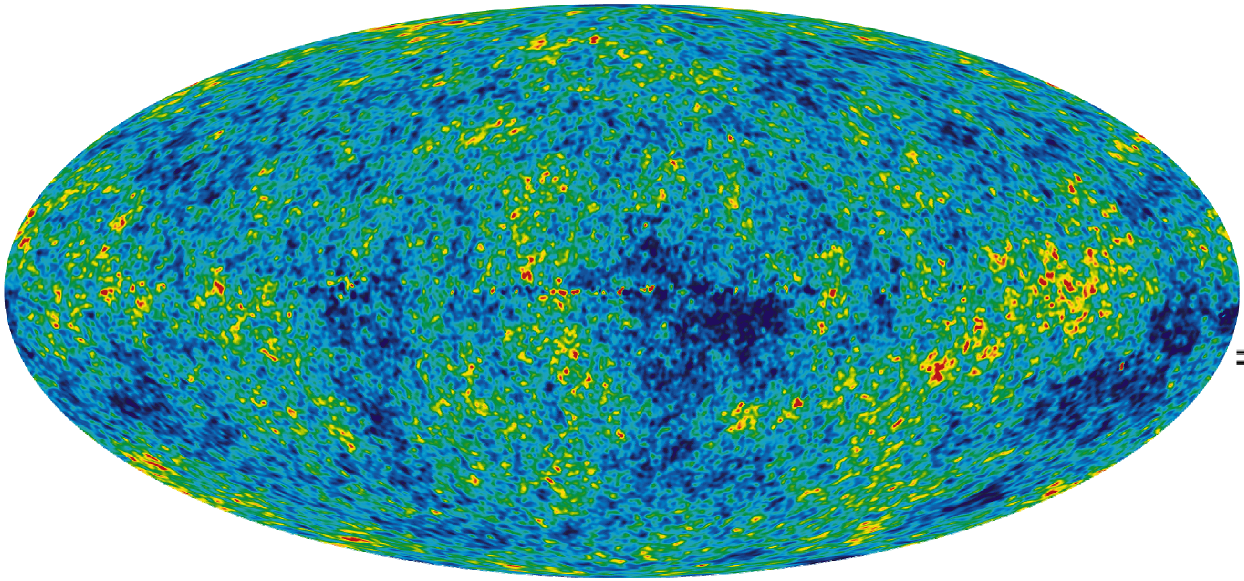
1. Systematic errors in the observed abundances?
2. Theoretical uncertainties in stellar astrophysics?
3. New physics during BBN? (^{6}Li abundance ~10^4 times higher than expected)

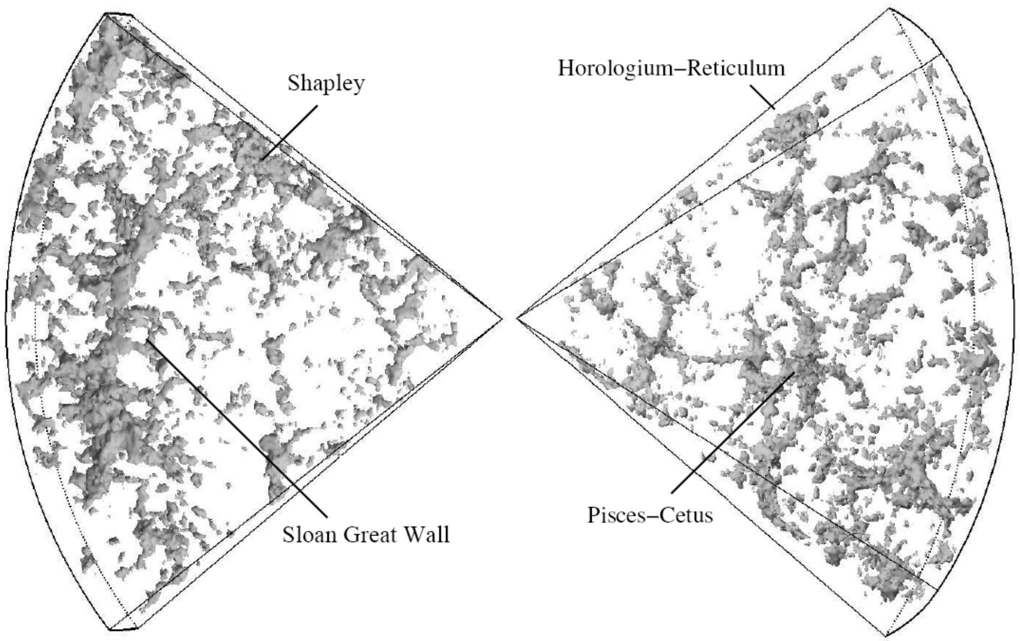
$$Log\,\varepsilon(^7Li) = Log(^7Li/H) + 12$$

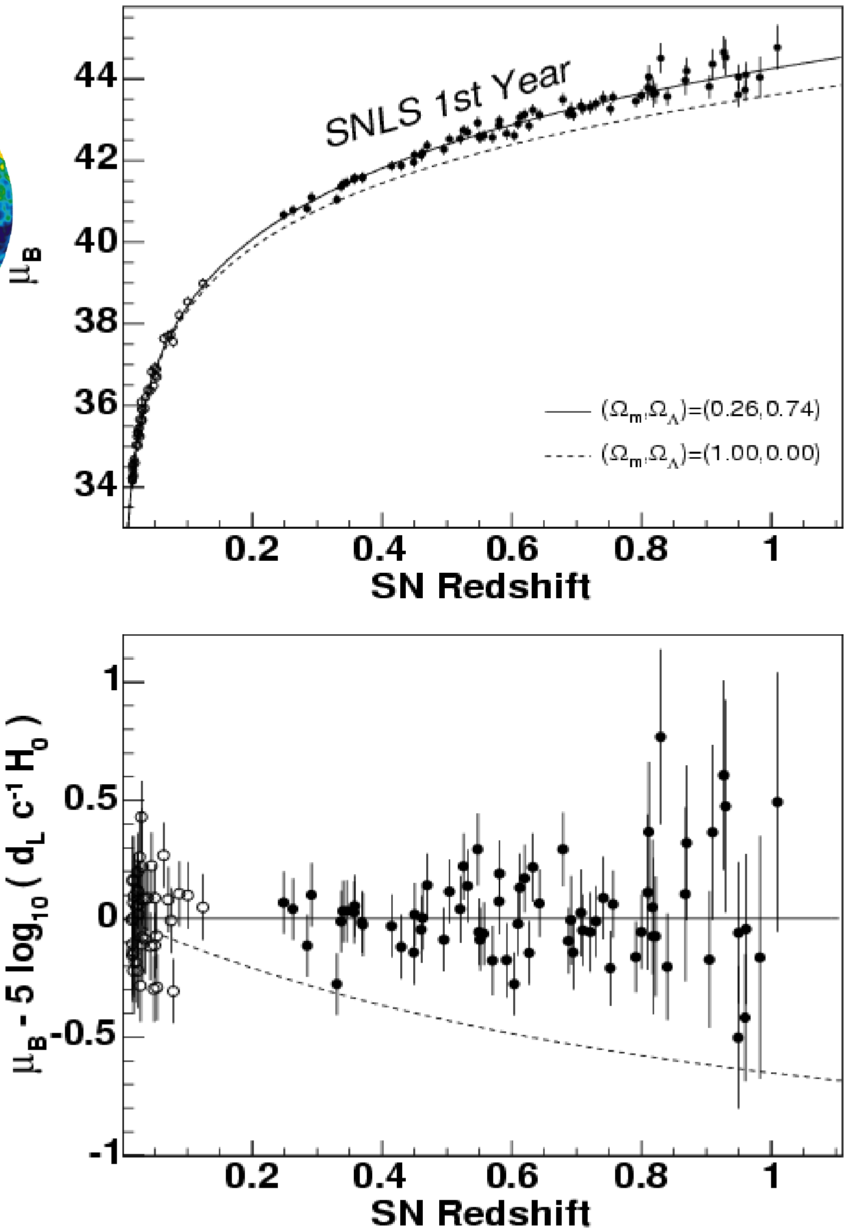


Matteucci, Proc. IAU Symp. *268* (*2010*)

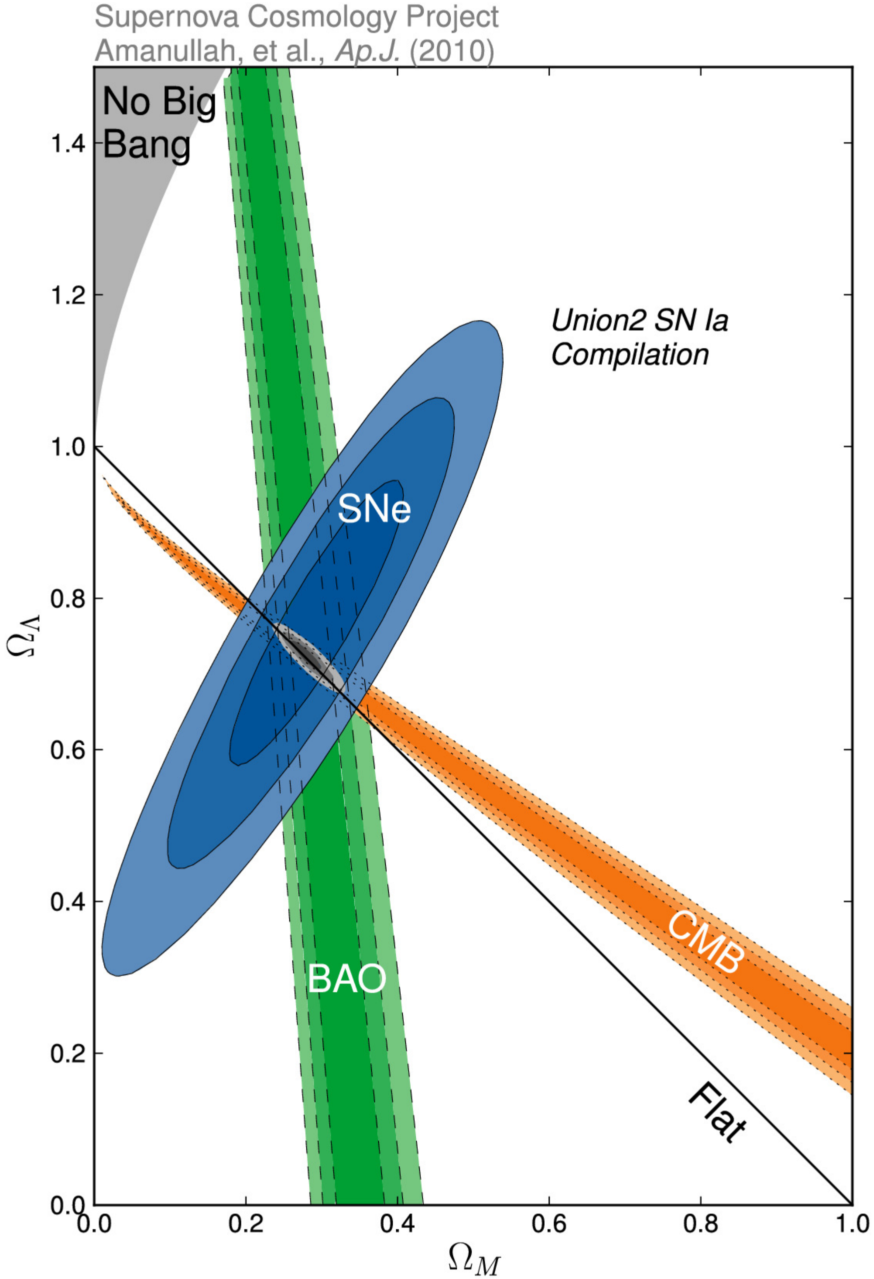
Dark Energy (1)

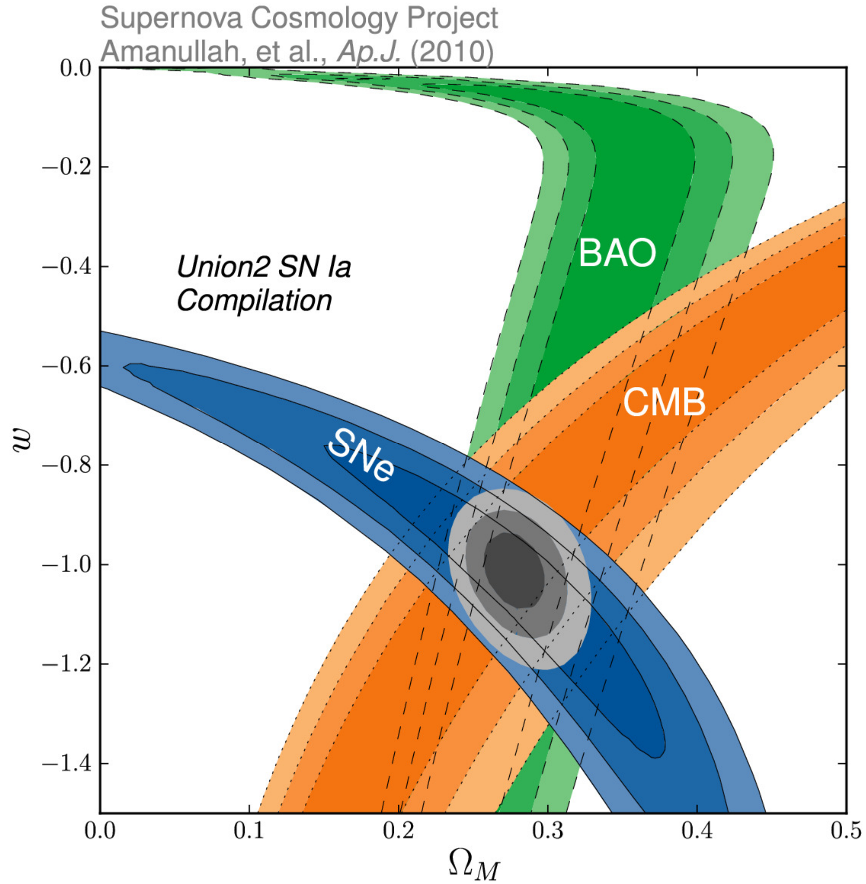






Dark Energy (2)





ΛCDM

assume Ω(tot)=1,

DE: w=p/ρ ~ -1, non clustering fluid

DE: some alternatives

Standard cosmology:
GR gravitational equations + FRW metric

Modify energy-momentum tensor:
i.e. scalar field quintessence, coupled DE,
K-essence, phantom models, Chaplygin gas, …

Modify field equations:
i.e. modified gravity f(R), scalar-tensor theories,
braneworlds, …

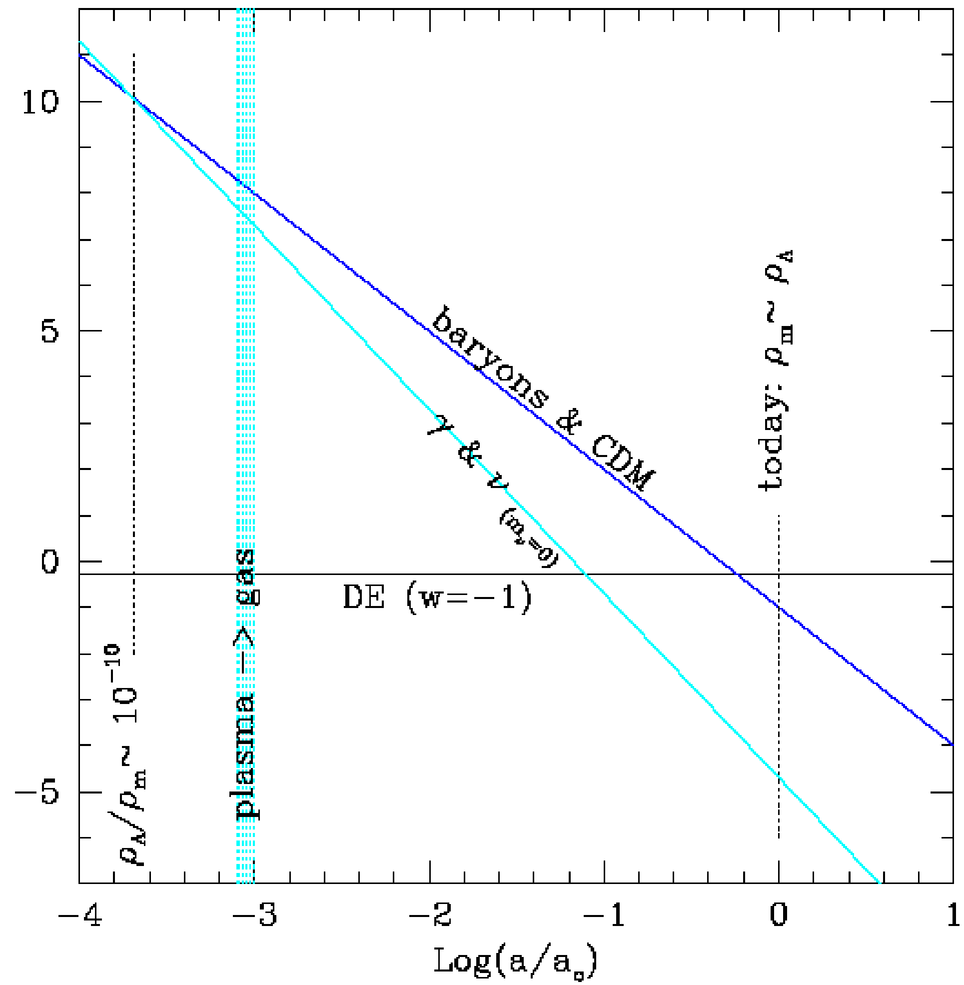
Modify the metric:
i.e. inhomogeneous models, …

ΛCDM: the other side of the coin

Scale dependence of
different cosmic components
In a ΛCDM model

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

- Vacuum fine tuning paradox
~1:10^56 at EW transition



wCDM & dynamical DE

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

$$V(\phi) = \frac{\Lambda^{4+\alpha}}{\phi^{\alpha}} \qquad RP$$

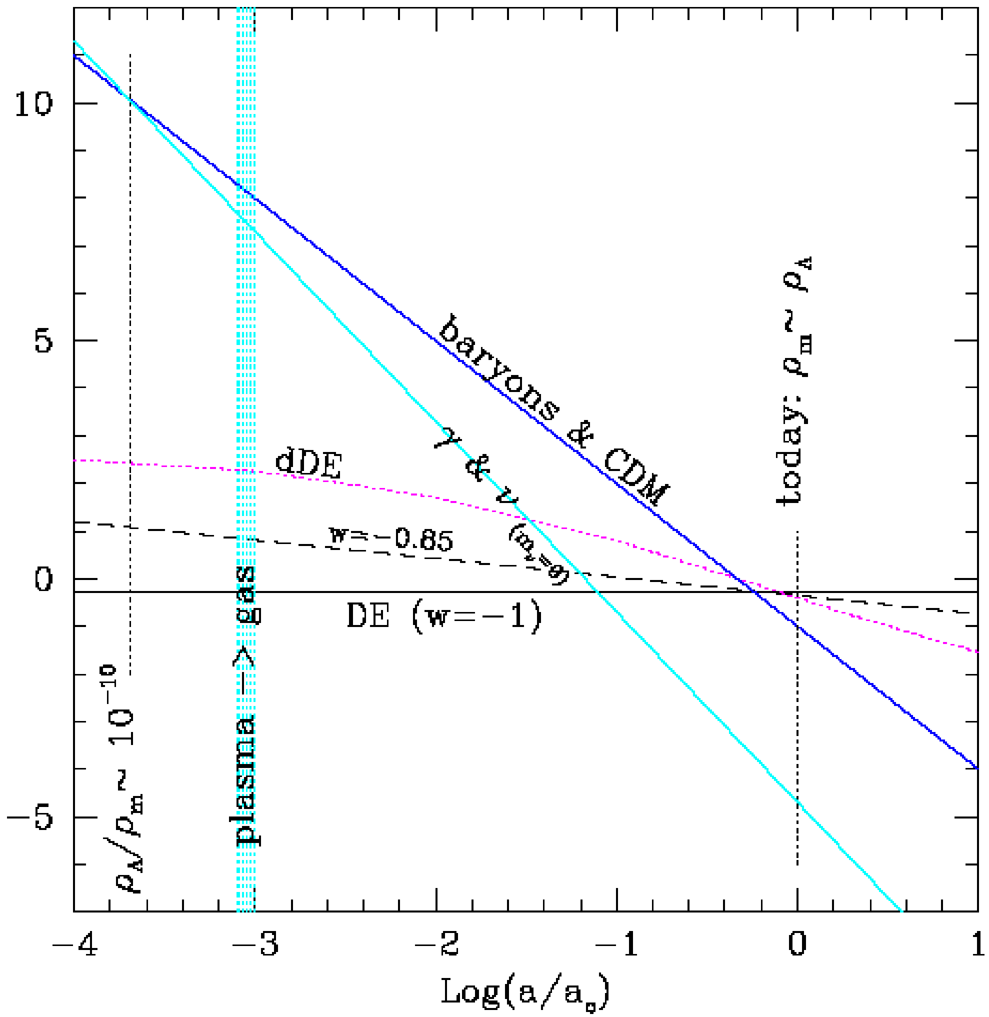
$\Lambda \approx$ GeV

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

Brax & Martin
1999, 2001

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

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



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

Coupled DE

Energy flow from CDM to DE:

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

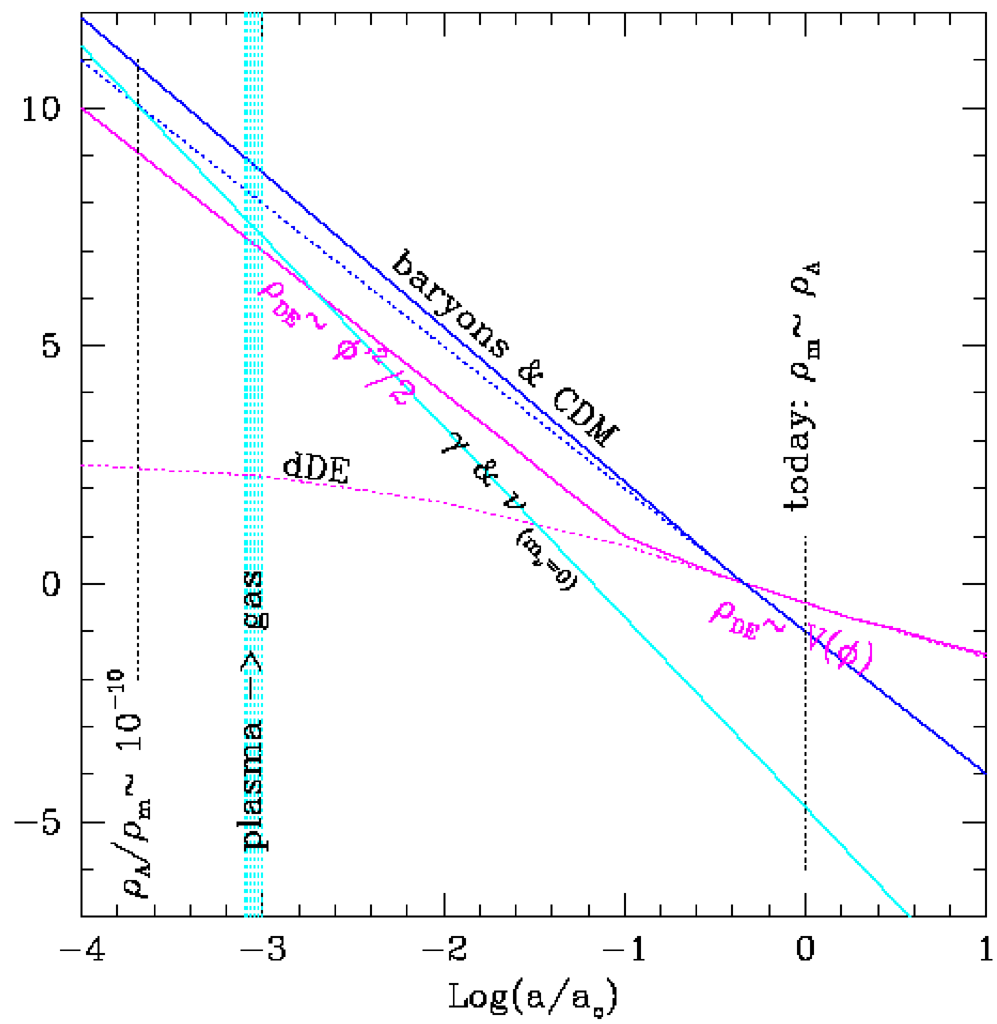
$$\beta = (3/16\pi)^{1/2} m_p C$$

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

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

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

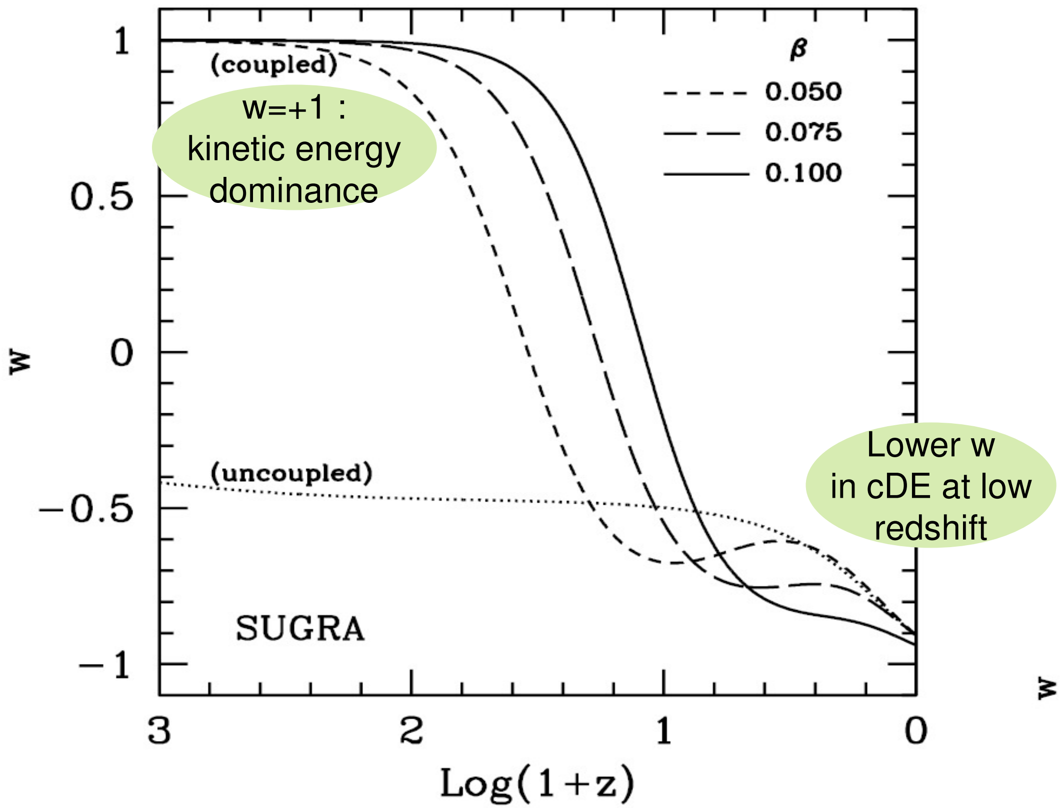


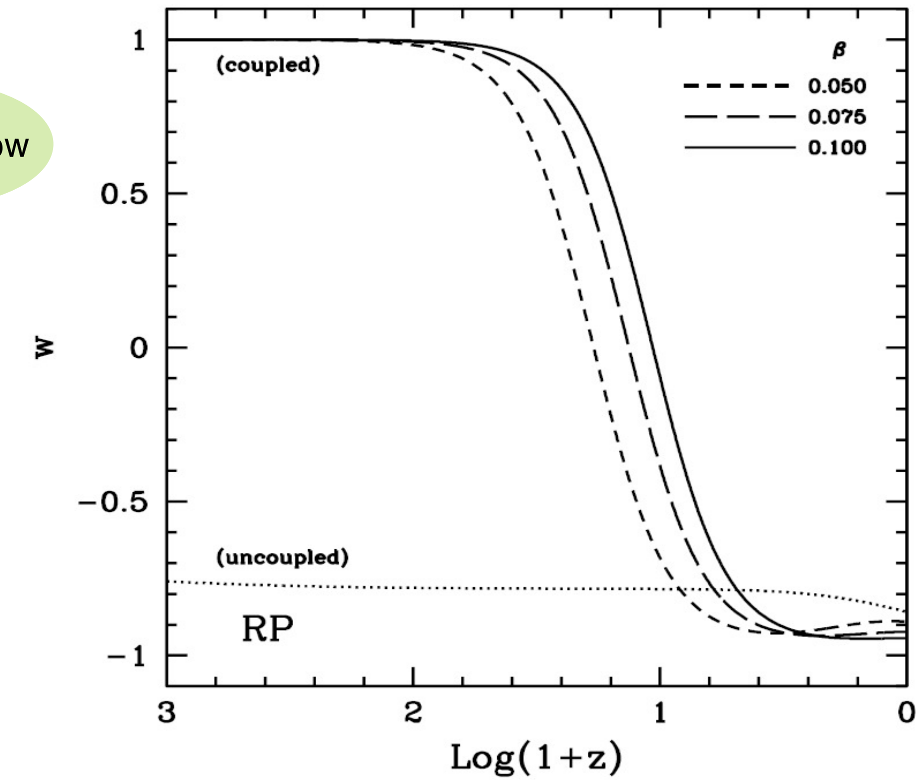
Coincidence eased as well

<u>Different approaches</u>:
* 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)

Equation of state of dDE and cDE

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





Results obtained with ALLde (Mainini et al.)

^{7}Li: looking for agreement

WMAP7+BAO+H$_0$ (ΛCDM)

$\Omega_b h^2 = 0.02260 \pm 0.00053$

$\eta_{10} = 6.18 \pm 0.14$

From nuclide data only (^{2}H, ^{7}Li), general agreement at 1.3σ for

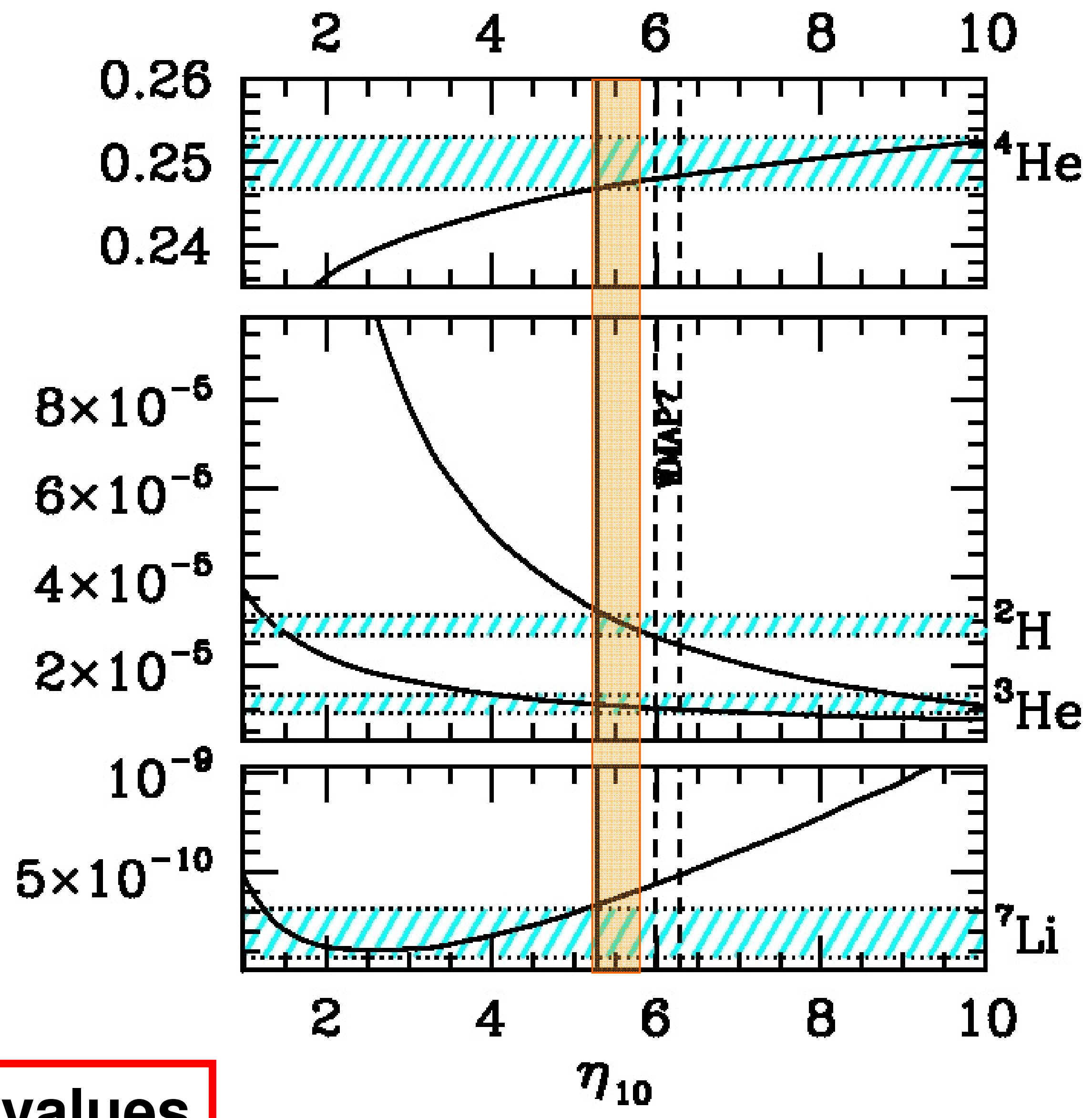
$\Omega_b h^2 = 0.01963, \quad \eta_{10} = 5.37$

Interval with 99% probability to match all nuclides

$0.0192 < \Omega_b h^2 < 0.0212$

$5.25 < \eta_{10} < 5.80$

Pointing to lower η_{10} ($\Omega_b h^2$) values



Abundances as in Iocco et al. 2008

LCDM vs wCDM(+M_ν)

WMAP7+BAO+H_0	$\Omega_b h^2$	η_{10}	w	M_ν(eV, 95%CL)
ΛCDM	0.02260±0.00053	6.18±0.14	-1	0
wCDM	0.02246±0.00058	6.14±0.16	-1.10±0.14	0
wCDM+Mnu	0.02202±0.00060	6.02±0.16	-1.44±0.27	<1.3

Komatsu et al. (2010)

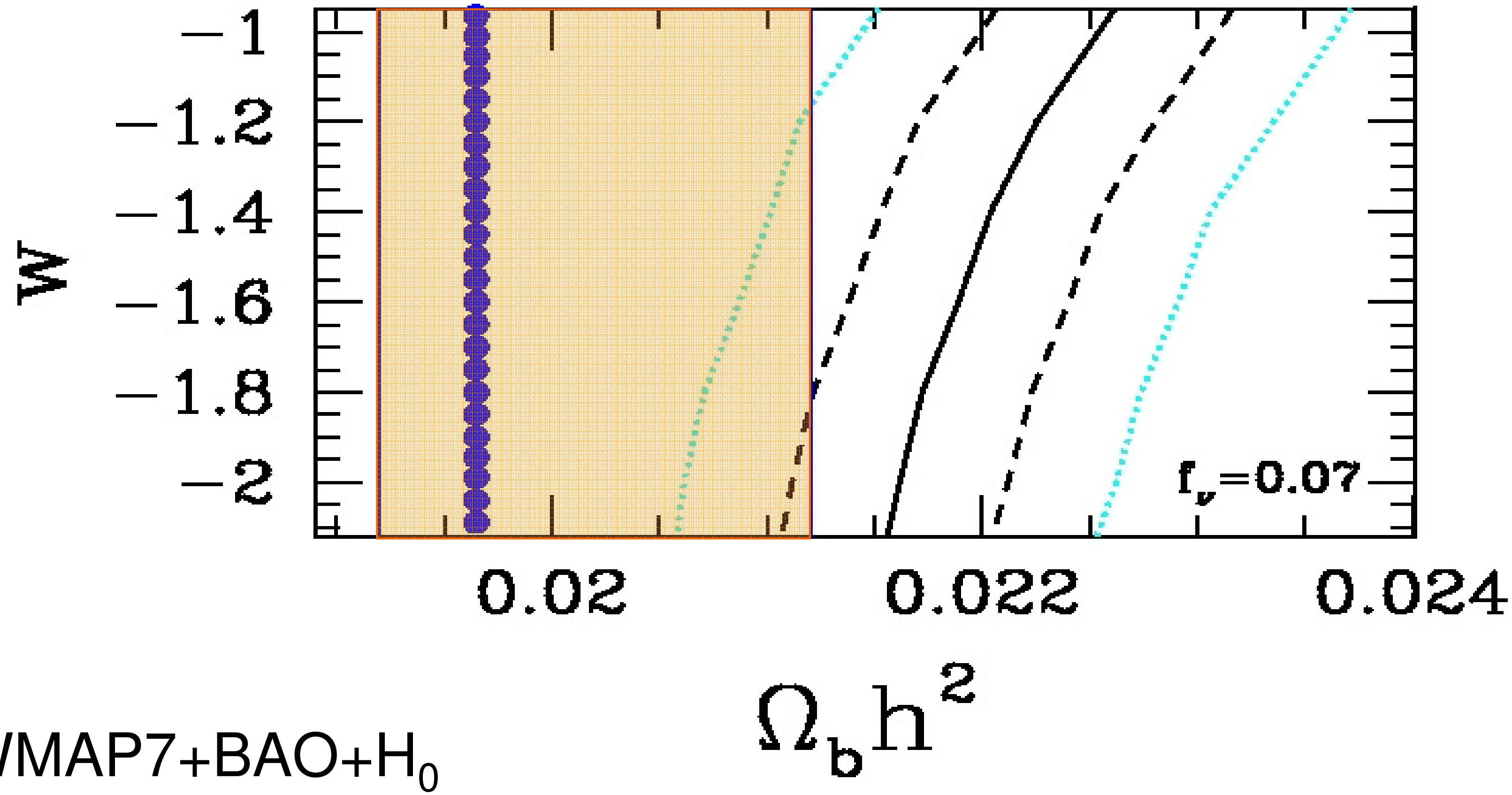
$$M_\nu \equiv \sum m_\nu$$

- The lower w, the lower $\Omega_b h^2$
- Neutrino mass degeneracy with w favors the lowering of w and $\Omega_b h^2$

$\Omega_b h^2$ vs. w

$0.0192 < \Omega_b h^2 < 0.0212$

$5.25 < \eta_{10} < 5.80$

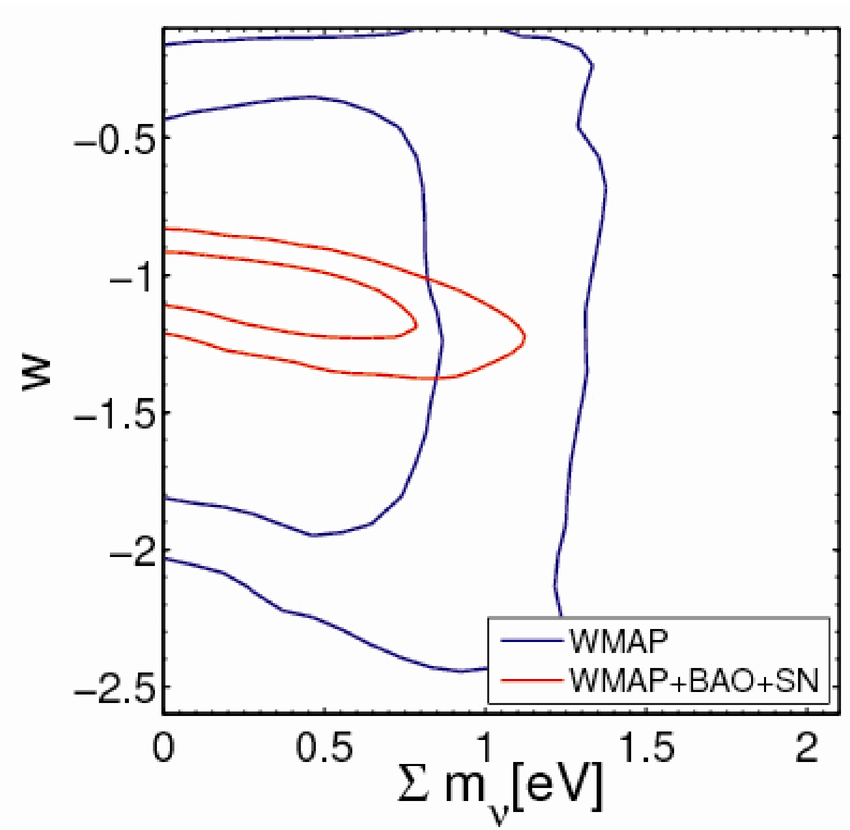


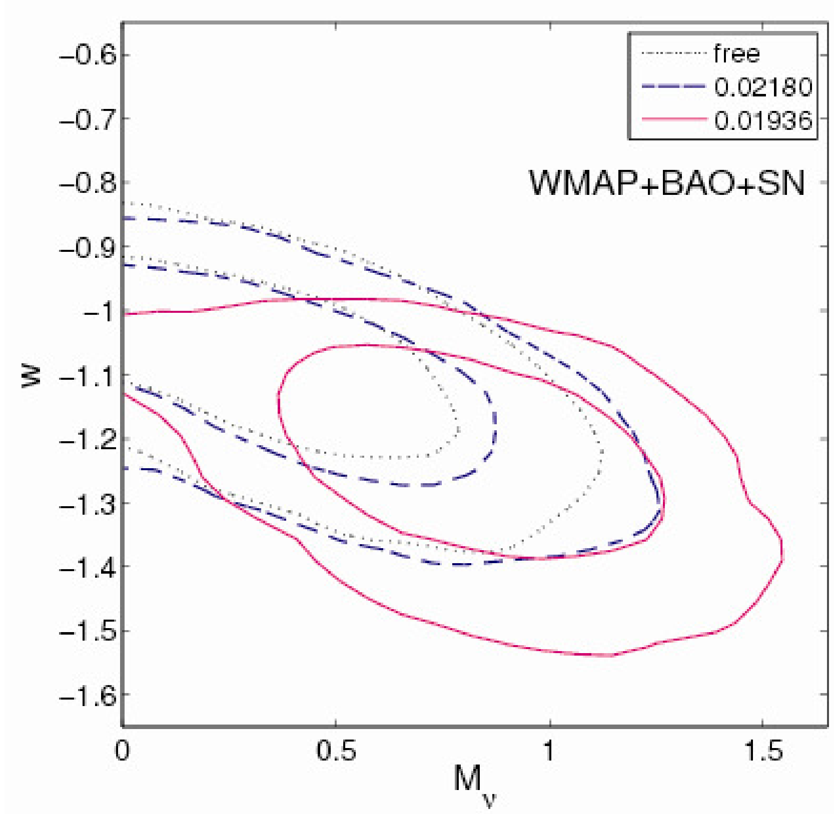
WMAP7+BAO+H_0

M_ν vs. w

Komatsu et al. (2010)

WMAP7+BAO+SN	$\Omega_b h^2$	η_{10}	w	M_ν(eV, 95%CL)
ΛCDM	0.02249±0.00053	6.15±0.14	-1	0
wCDM	0.02250±0.00055	6.15±0.15	-1.020±0.053	0
wCDM+Mnu	0.02236±0.00057	6.11±0.15	-1.040±0.068	<0.91





^{7}Li and MMC

$$w = \frac{p}{\rho} = \frac{E_{kin} - V(\phi)}{E_{kin} + V(\phi)}$$

$$E_{kin} = \dot{\phi}^2 / 2a^2$$

- w > -1 quintessence models
- w < -1 phantom DE, Caldwell 2002 ($-V(\phi) < E_{kin} < 0$), plagued by severe instabilities

An interaction between DM and DE generically results in an effective dark energy equation of state of w<-1.
Das, Corasaniti & Khoury 2006

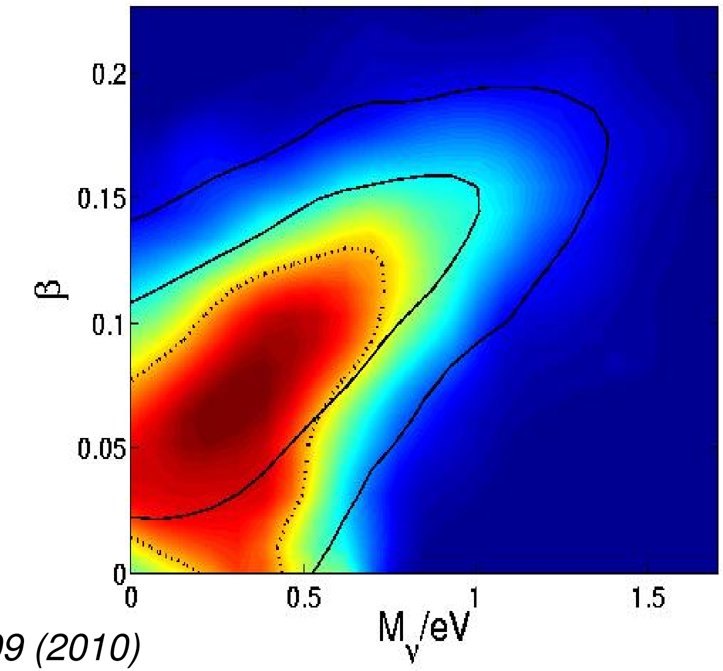
$$\rho_{\rm DE}^{\rm eff} \equiv \frac{\rho_{\rm DM}^{(0)}}{a^3}\left[\frac{f(\phi/M_{\rm Pl})}{f(\phi_0/M_{\rm Pl})} - 1\right] + \rho_\phi\,,$$

w < -1 favored by ^{7}Li data

↕

CDM-DE coupling favored by ^{7}Li data

Mildly Mixed Coupled (MMC) models



GLV et al. JCAP 0904, 007 (2009)
Kristiansen et al., New Astron. 15, 609 (2010)

Conclusions

- ^{7}Li extra constraint to cosmological parameters
- Lower value of $\Omega_b h^2$ favored
- models with w<-1 and M_ν < 1.6eV needed
- strong prior on $\Omega_b h^2$ to better constrain w and M_ν

an evidence in favor of MMC?

(work in progress)

Thank you for you attention!