Interacting Dark Energy in light of PLANCK experiment results

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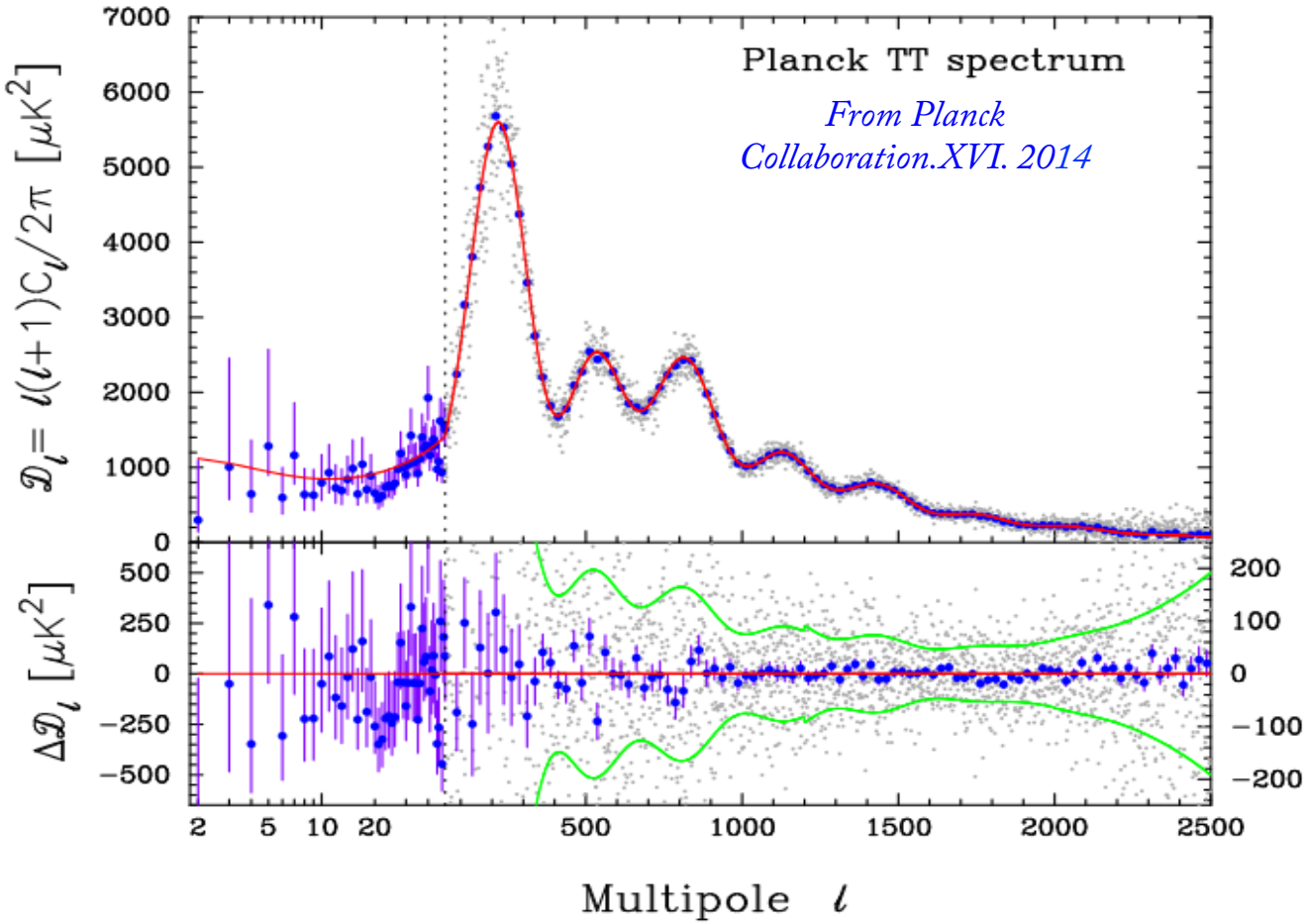
Cosmology on the beach, Cabo San Lucas, Mexico

14 January 2014

Planck results (1st release)



Standard cosmological model in good agreement with data but …

Hubble constant tension

… some tensions exist!

- Hubble Constant value

Measurement from Planck (assuming standard cosmology)

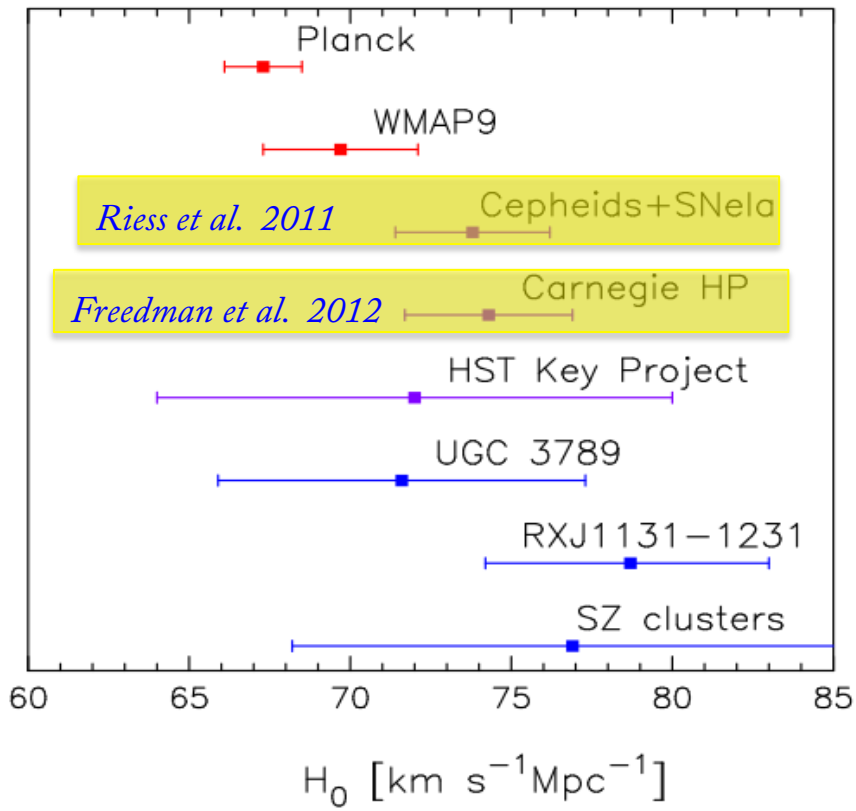
$$H_0 = 67.3 \pm 1.2 \text{ km/s/Mpc}$$

Local measurement from Hubble Space Telescope

$$H_0 = 73.8 \pm 2.4 \text{ km/s/Mpc}$$

AN HINT FOR NEW PHYSICS ???

From Planck Collaboration.XVI. 2014 arXiv:1403.5076



Dark matter-Dark energy interacting models

Models where we allow an energy-momentum transfer between fluids

$$\nabla_\mu T^\mu_{(\mathrm{dm})\nu} = Q_\nu \qquad \nabla_\mu T^\mu_{(\mathrm{de})\nu} = -Q_\nu$$

Tantalizing scenario to investigate!

- ALLOWED BY OBSERVATIONS
  (only the interaction with ordinary matter is strongly constrained)
- CAN ALLEVIATE THE COINCIDENCE PROBLEM
- POSSIBLE EXPLANATION TO THE TENSION BETWEEN LOCAL AND HIGH-REDSHIFT MEASUREMENTS OF THE HUBBLE CONSTANT

Energy Momentum Transfer frame

2 alternatives frames to define the energy-momentum exchange

DEvel

$$Q_\nu = Q u_\nu^{(\mathrm{de})}/a$$

- No momentum transfer to the DE frame
- Change in DM peculiar velocity
- "Fifth force" effect → Effectively modified gravity models

DMvel

4-velocity

$$Q_\nu = Q u_\nu^{(\mathrm{dm})}/a$$

Interaction rate

Scale factor

- No momentum transfer to DM frame
- No violation of the weak equivalence principle

Background evolution

(in a flat universe)

Modified background equations

$$\dot{\rho}_{dm} + 3\mathcal{H}\rho_{dm} = Q \qquad \mathcal{H} = \dot{a}/a$$
$$\dot{\rho}_{de} + 3\mathcal{H}\rho_{de}(1+w) = -Q$$

- The background evolution does not depend on the frame
- If Q<0 DM passes energy to DE, that implies $\rho^0_{\rm dm}|_{\rm Q<0} < \rho^0_{\rm dm}|_{\rm Q=0}$

Effective equations of state

$$w^{\rm eff}_{\rm dm} = -\frac{Q}{3\mathcal{H}\rho_{\rm dm}} \qquad w^{\rm eff}_{\rm de} = w + \frac{Q}{3\mathcal{H}\rho_{\rm de}}$$

- Coupling imitates dynamical dark energy even if w is constant
- Q<0 yields to more negative effective w
- Q<0 acts as a positive pressure in the dark matter EoS

Linear Perturbation theory

(Newtonian gauge)

$\delta \equiv \delta\rho/\rho \qquad \theta \equiv \partial_i v^i$

Baryons not coupled → equations do not change

$$\dot{\delta}_{\rm dm} = -(\theta_{\rm dm} - 3\dot{\Phi}) + \frac{Q}{\rho_{\rm dm}}\left(\frac{\delta Q}{Q} - \delta_{\rm dm} + \Psi\right)$$

$$\dot{\theta}_{\rm dm} = -\mathcal{H}\theta_{\rm dm} + k^2\Psi + (1-\underline{b})\frac{Q}{\rho_{\rm dm}}(\theta_{\rm de} - \theta_{\rm dm})$$

$$\dot{\delta}_{\rm de} = -(1+w)(\theta_{\rm de} - 3\dot{\Phi}) - 3\mathcal{H}\left(\hat{c}^2_{s\,\rm de} - w\right) \times$$
$$\left[\delta_{\rm de} + \mathcal{H}\left(3(1+w) + \frac{Q}{\rho_{\rm de}}\right)\frac{\theta_{\rm de}}{k^2}\right] - \frac{Q}{\rho_{\rm de}}\left(\frac{\delta Q}{Q} - \delta_{\rm de} + \Psi\right)$$

$$\dot{\theta}_{\rm de} = -\mathcal{H}\left(1 - 3\hat{c}^2_{s\,\rm de} - \frac{\hat{c}^2_{s\,\rm de}+b}{1+w}\frac{Q}{\mathcal{H}\rho_{\rm de}}\right)\theta_{\rm de} + \frac{k^2}{1+w}\hat{c}^2_{s\,\rm de}\delta_{\rm de} + k^2\Psi - b\frac{Q}{\rho_{\rm de}}\frac{\theta_{\rm dm}}{1+w}$$

$$b = 0 \quad \text{if} \quad Q_\nu \propto u_\nu^{(\rm de)}$$
$$b = 1 \quad \text{if} \quad Q_\nu \propto u_\nu^{(\rm dm)}$$

Euler equation only changes in DEvel models)

A model to be tested

DMvel frame

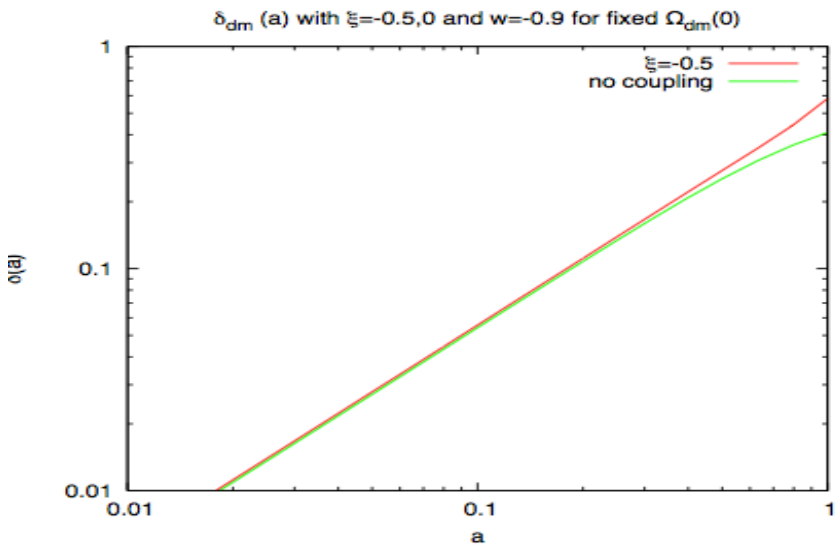
$$Q_\nu = \xi \mathcal{H} \rho_{\rm de} u_\nu^{dm}$$

Dimensionless coupling parameter

MODEL "PROS" :

M.B.Gavela et al. JCAP 0907:034,2009

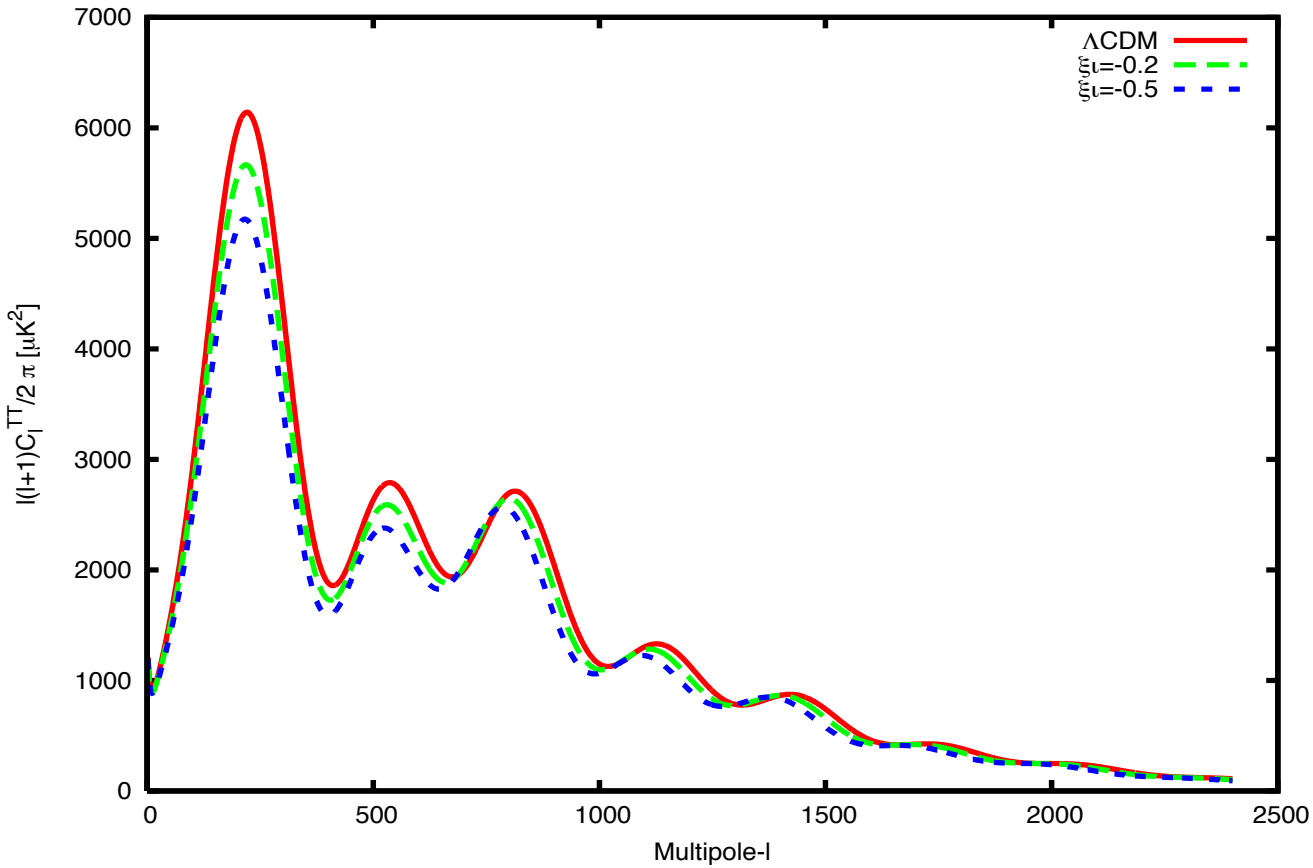
- Viable scenario
- No instabilities (**if Q<0 and w>-1**)
- Analytic form of H(z)
- Changes in background and growth evolution ($\rho_{dm}(z)$ not $\propto (1+z)^3$)



Credits to Laura Lopez-Honorez

Effects on the TT power spectrum

- Decreased amplitude of the spectrum
- Peaks shifted towards lower multipoles

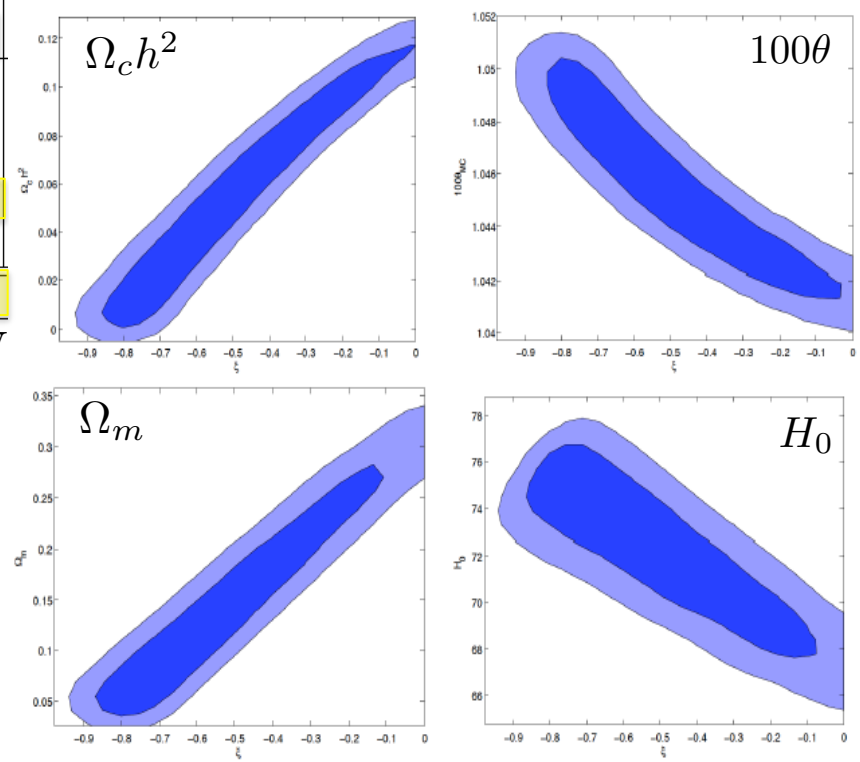


PLANCK Constraints

	PLANCK + ΛCDM		PLANCK+ ξ	
Parameters	Best fit	68% limit	Best fit	68% limit
$\Omega_b h^2$	0.02203	0.02205 ± 0.00028	0.02204	0.02200 ± 0.00027
$\Omega_c h^2$	0.1204	0.1199 ± 0.0027	0.0664	< 0.074
100θ	1.04119	1.04131 ± 0.00063	1.0445	1.0456 ± 0.0026
τ	0.093	$0.089^{+0.012}_{-0.014}$	0.0867	$0.087^{+0.012}_{-0.014}$
n_s	0.9619	0.9603 ± 0.0073	0.9543	0.9580 ± 0.0071
$\log(10^{10} A_s)$	3.098	$3.089^{+0.024}_{-0.027}$	3.090	$3.083^{+0.023}_{-0.025}$
ξ	——	——	-0.46	$-0.49^{+0.19}_{-0.31}$
Ω_m	0.318	$0.315^{+0.016}_{-0.018}$	0.177	$0.155^{+0.050}_{-0.11}$
Ω_Λ	0.682	$0.685^{+0.018}_{-0.016}$	0.823	$0.845^{+0.11}_{-0.050}$
z_{re}	11.4	11.1 ± 1.1	10.9	10.9 ± 1.1
H_0[km/s/Mpc]	67.0	67.3 ± 1.2	71.0	$72.1^{+3.2}_{-2.3}$
Age/Gyr	13.824	13.817 ± 0.048	13.747	$13.733^{+0.062}_{-0.065}$
$\chi^2_{\rm min}/2$	4902.95		4902.45	

$A_L = 1 \quad w = -0.999 \quad N_{eff} = 3.046 \quad \sum m_\nu = 0.06$ eV

VS, A. Marchini, L.Lopez-Honorez, O.Mena, Phys. Rev. D 88, 024531 (2014) astro-ph/1404.7119



- An interacting scenario is compatible with data and not disfavoured
- The degeneracy between H_0 and ξ favours larger values for H_0, the tension with HST is solved

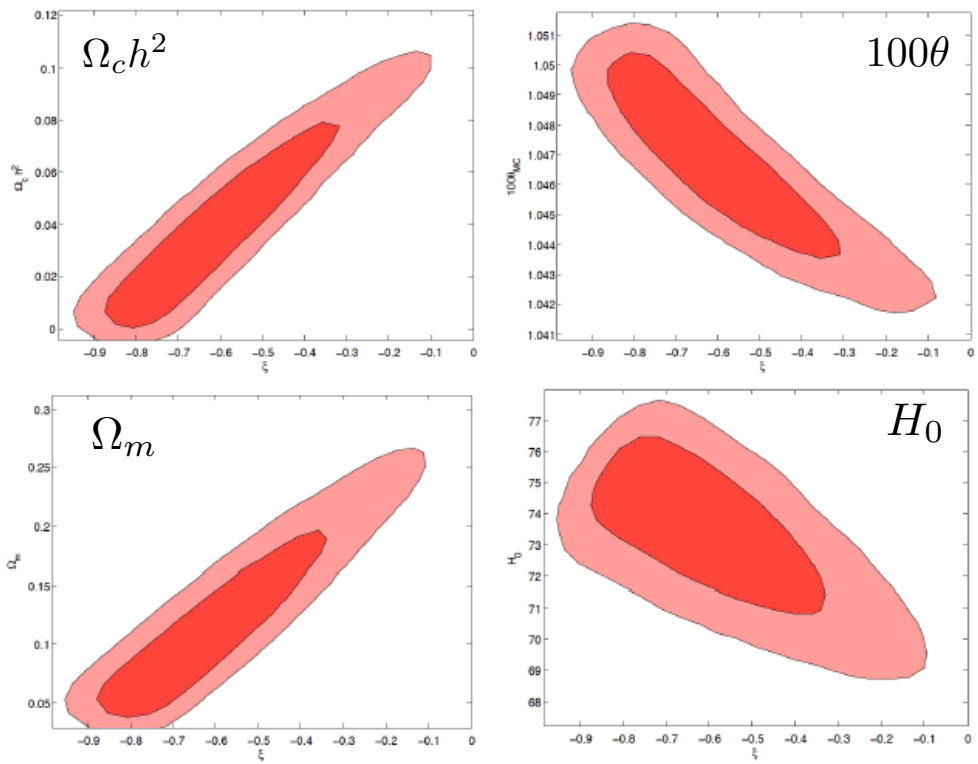
PLANCK+HST constraints

	PLANCK+ HST+ ξ	
Parameters	Best fit	68% limit
$\Omega_b h^2$	0.02201	0.02203 ± 0.00027
$\Omega_c h^2$	0.0450	< 0.056
100θ	1.0461	1.0466 ± 0.0021
τ	0.080	$0.088^{+0.017}_{-0.014}$
n_s	0.9586	0.9589 ± 0.0070
$\log(10^{10} A_s)$	3.070	$3.084^{+0.024}_{-0.027}$
ξ	-0.58	$-0.58^{+0.090}_{-0.22}$
Ω_m	0.127	$0.122^{+0.033}_{-0.070}$
Ω_Λ	0.873	$0.878^{+0.070}_{-0.033}$
z_{re}	10.2	10.9 ± 1.1
H_0[km/s/Mpc]	73.0	$73.3^{+2.0}_{-1.6}$
Age/Gyr	13.720	$13.711^{+0.051}_{-0.046}$
$\chi^2_{\rm min}/2$	4902.52	

VS, A. Marchini, L.Lopez-Honorez, O.Mena, Phys. Rev. D 88, 024531 (2014) astro-ph/1404.7119

Hubble Space Telescope prior

$$H_0 = 73.8 \pm 2.4\,\mathrm{km/s/Mpc}$$



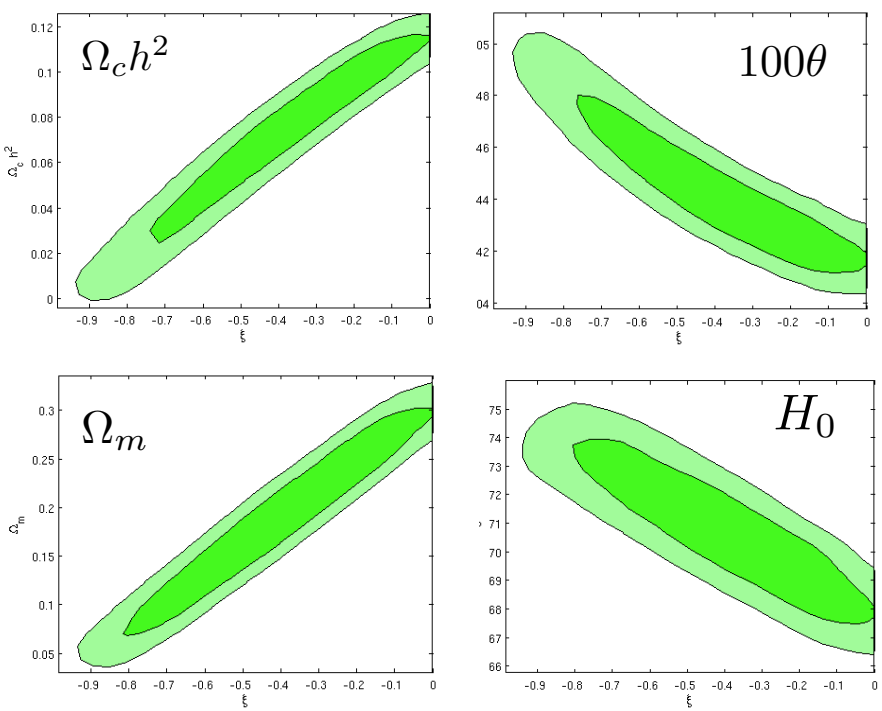
- If we include the HST prior a zero coupling is excluded at 95% c.l.

PLANCK+BAO constraints

	PLANCK+ BAO+ ξ	
Parameters	Best fit	68% limit
$\Omega_b h^2$	0.02195	0.02192 ± 0.00025
$\Omega_c h^2$	0.096	$0.069^{+0.040}_{-0.022}$
100θ	1.0427	1.0445 ± 0.0021
τ	0.090	$0.085^{+0.012}_{-0.013}$
n_s	0.9596	0.9556 ± 0.0060
$\log(10^{10} A_s)$	3.090	$3.082^{+0.023}_{-0.026}$
ξ	-0.22	$-0.42^{+0.29}_{-0.21}$
Ω_m	0.246	$0.187^{+0.085}_{-0.063}$
Ω_Λ	0.754	$0.813^{+0.063}_{-0,085}$
z_{re}	11.2	10.7 ± 1.1
H_0[km/s/Mpc]	69.3	$70.8^{+1.9}_{-2.1}$
Age/Gyr	13.785	13.765 ± 0.044
$\chi^2_{\rm min}/2$	4902.71	

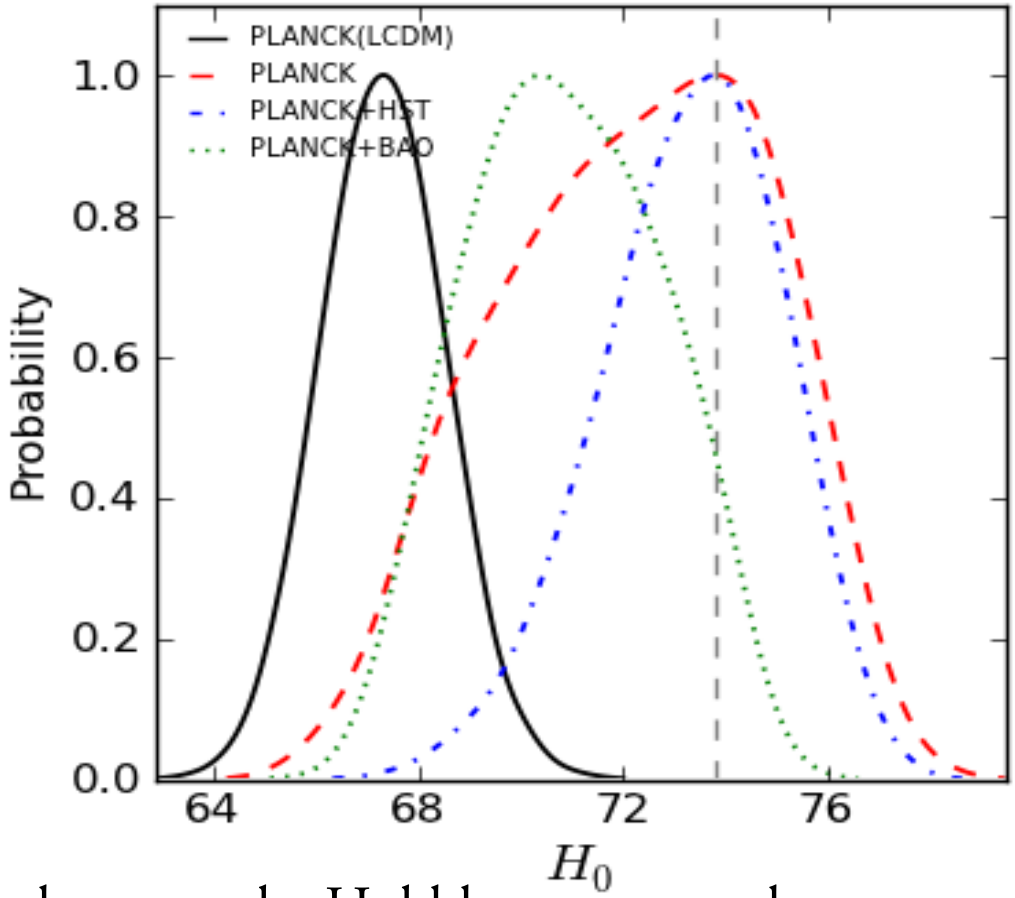
VS, A. Marchini, L.Lopez-Honorez, O.Mena, Phys. Rev. D 88, 024531 (2014) astro-ph/1404.7119

BAO measurements from 6DF, SDSS,BOSS surveys



- If we include BAO a zero coupling is excluded at 68% c.l and the H0 tension is alleviated

Is the H0 tension an evidence for coupling?



The tension between the Hubble constant value measured by the Hubble Space Telescope and measured by PLANCK is solved in this dark coupled scenario.

To summarize

For the interacting dark energy scenario that we have investigated we can conclude that :

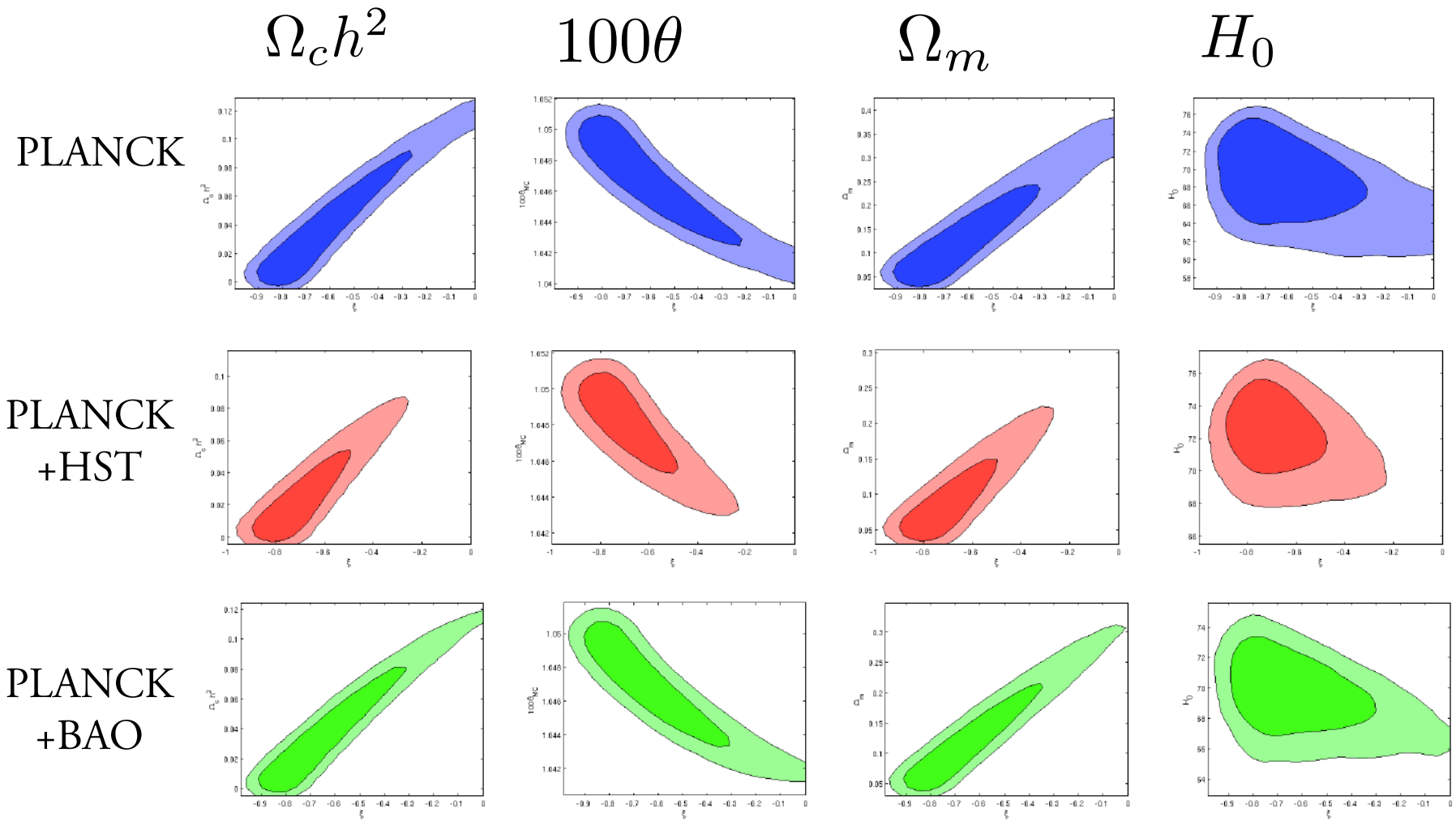
- it is compatible with PLANCK and with PLANCK combined with low redshift measurements
- it can solve the tension between PLANCK and HST measurements of the Hubble constant value
- a null interaction is excluded at 95% c.l. if we consider the combined constraint from PLANCK+HST

Thank you!

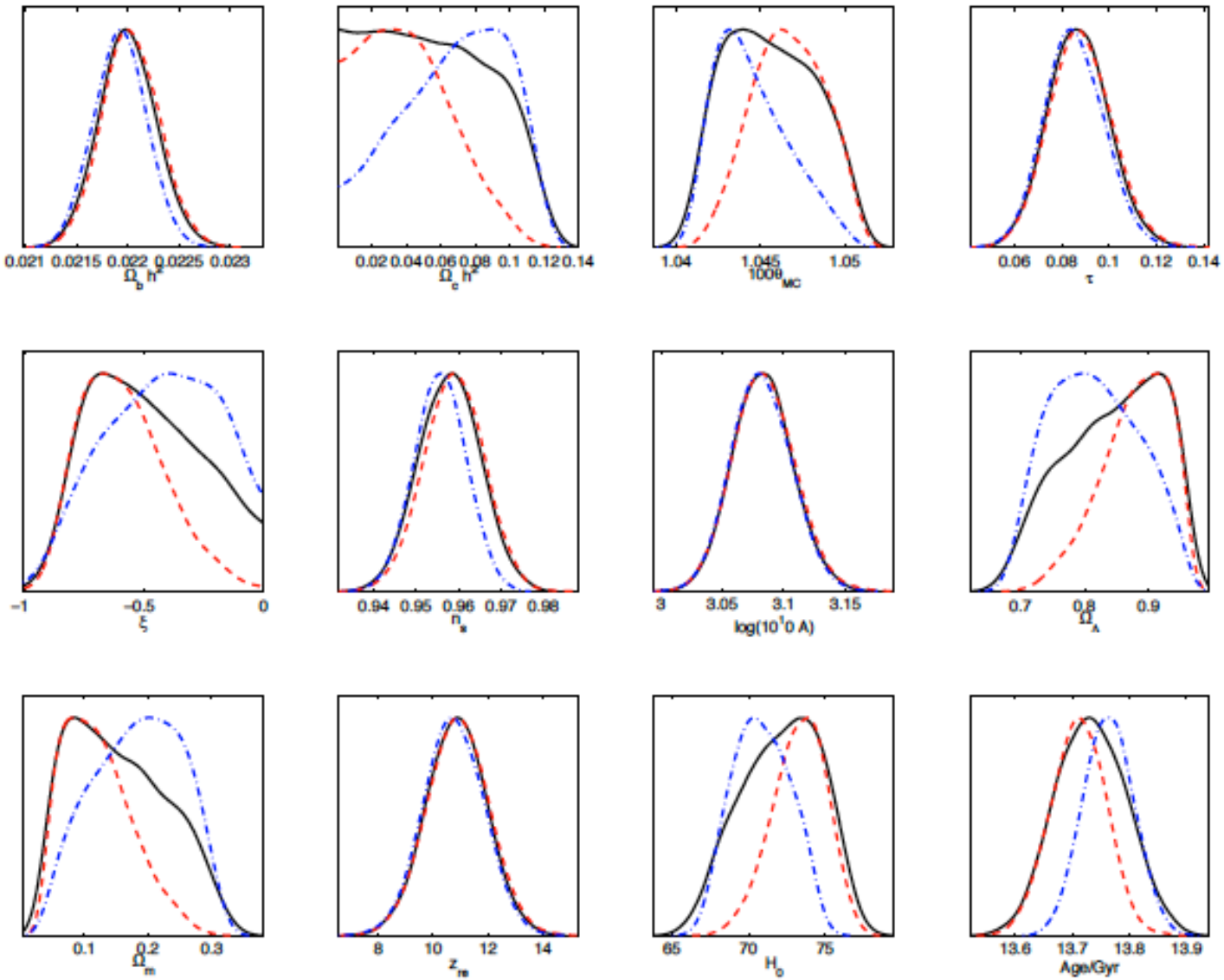
For questions or comments:
valentina.salvatelli@uniroma1.it

Coupling Constraints varying w

VS, A. Marchini, L.Lopez-Honorez, O.Mena, Phys. Rev. D 88, 024531 (2014) astro-ph/1404.7119

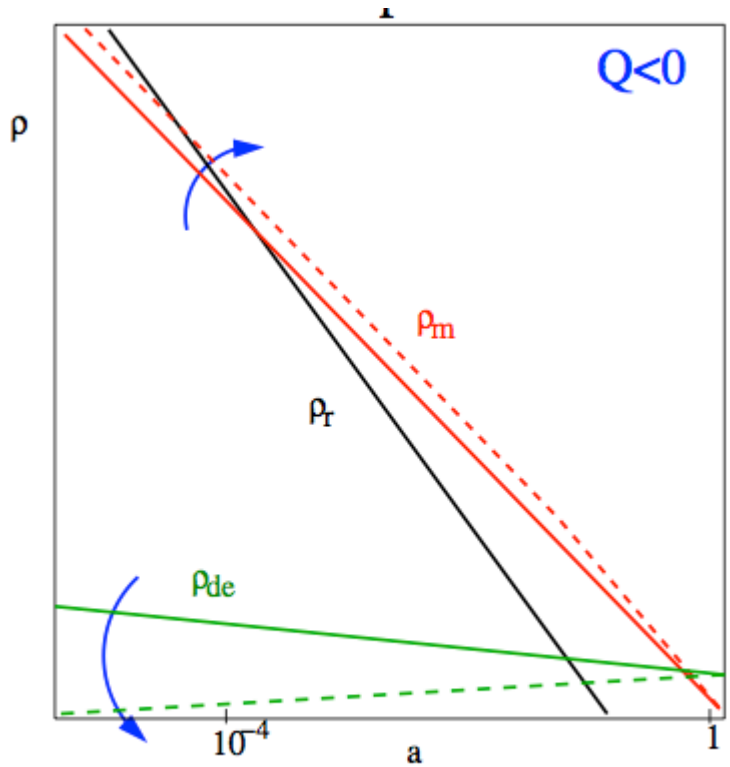


Coupling Posterior distributions



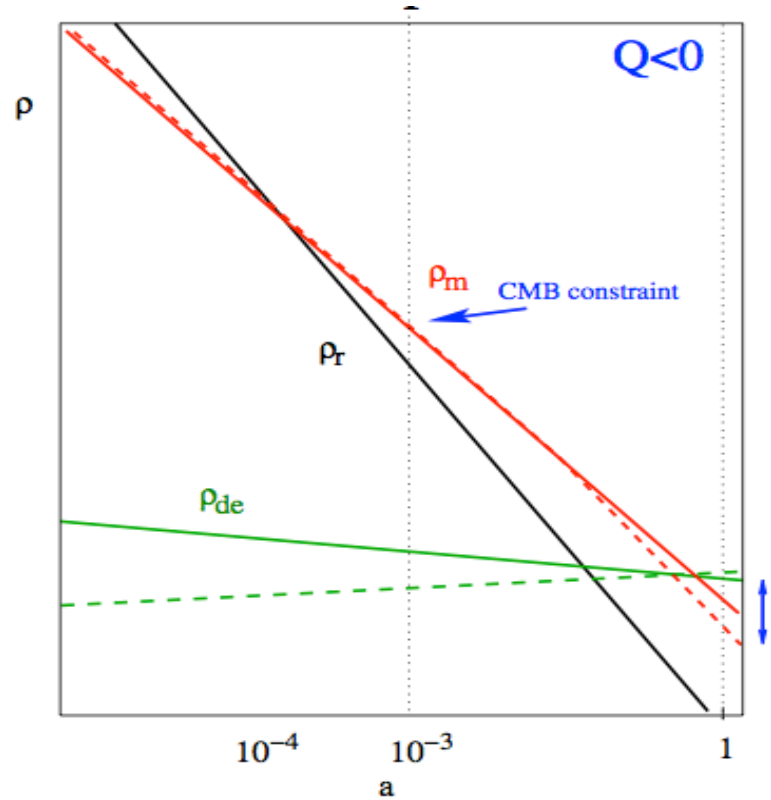
Evolution of energy densities in interacting scenarios

Credits to Laura Lopez-Honorez



$w_{de} = -0.9$ and $Q < 0$

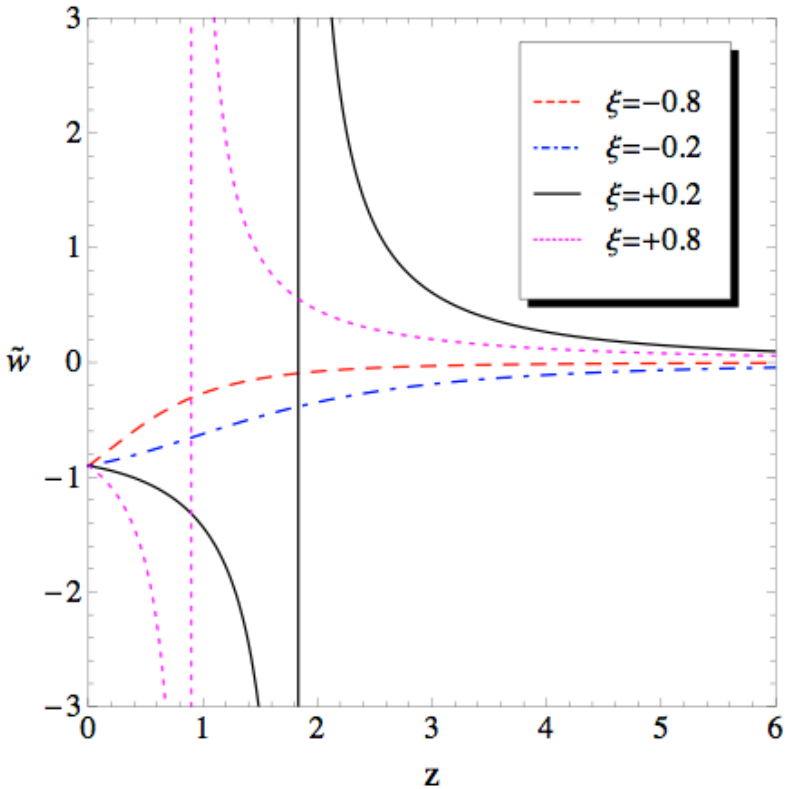
Fine tuning problem is worsened in this case



$w_{de} = -0.9$ and $Q < 0$

CMB is sensitive to densities at recombination

Further indication from Supernovae

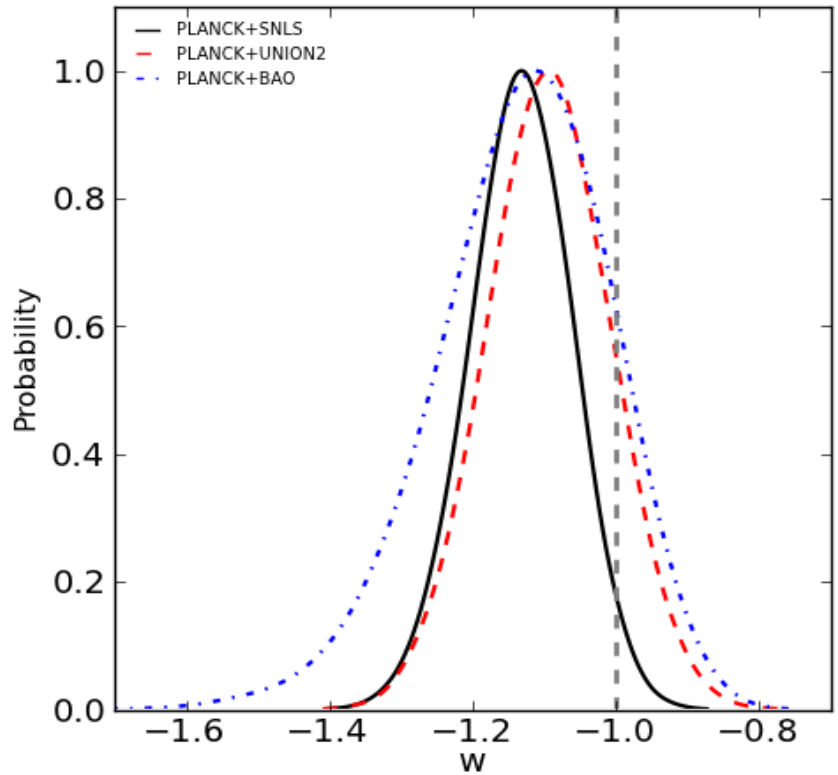


Reconstructed dark energy equation of state if the real universe is coupled and we use standard equations

Combined constraints from CMB and Supernovae

PLANCK+WP+SNLS

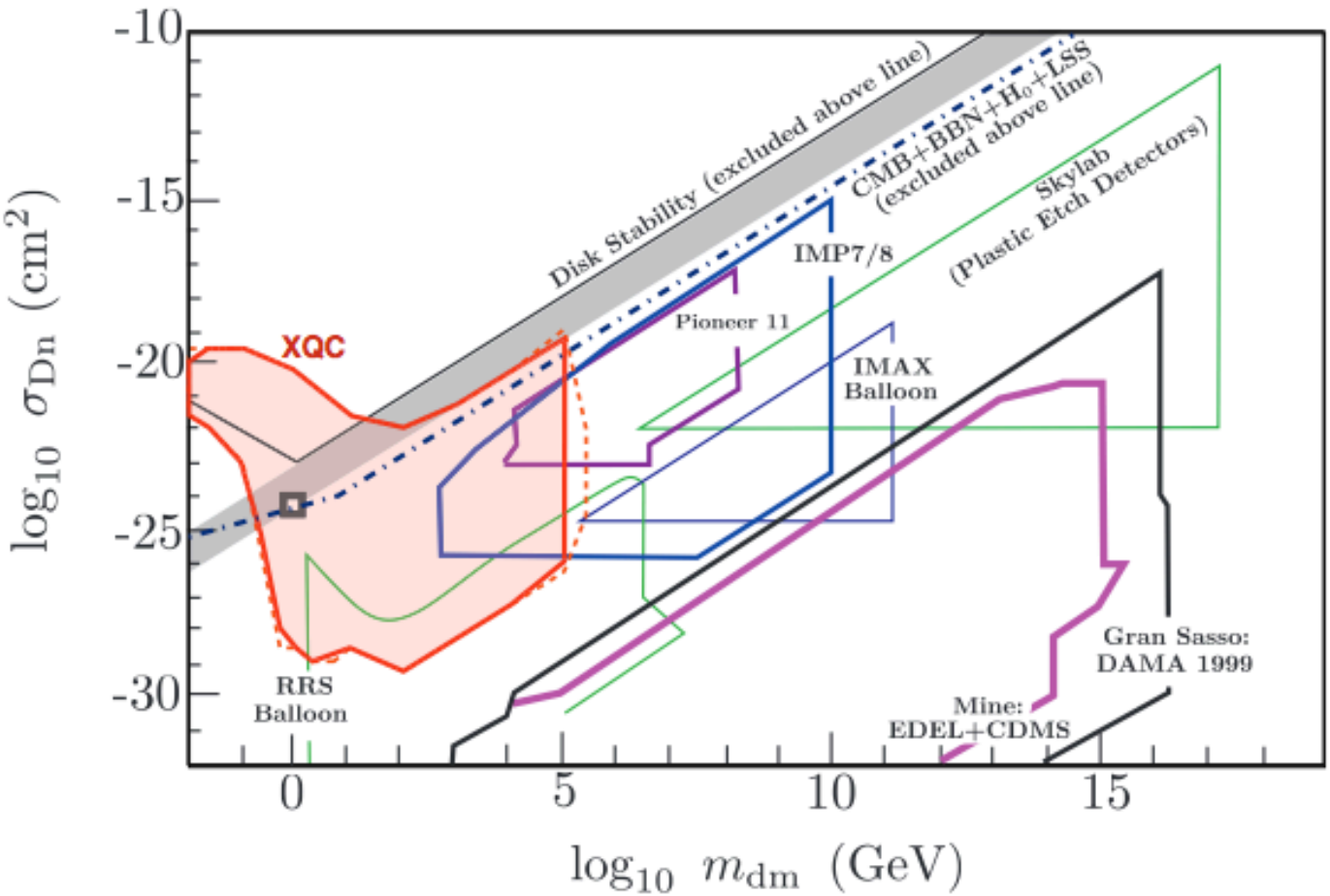
$w = -1.13^{+0.13}_{-0.14}$ 95% c.l.



Constraints on DM-baryons interactions

A. Erickcek et al. Phys.Rev.D76:042007,2007

Cross section for DM particles and nucleons



Values inside the coloured contours are ruled out!

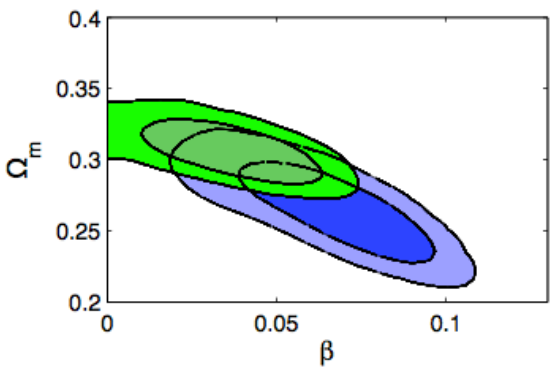
Coupled Quintessence Constraints

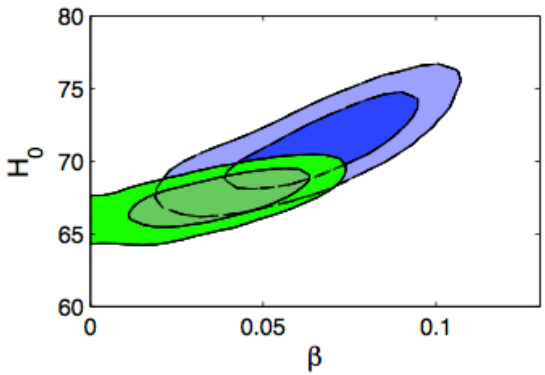
Models in the DEvel frame

$$Q = -\beta \rho_c \phi' \,,$$

V.Pettorino
astro-ph.CO:1405.7457

Parameter	PlanckWP +BAO	PlanckWP +HighL + BAO	PlanckWP +HST	PlanckWP +HighL + HST
$\Omega_b h^2$	0.02204 ± 0.00028	0.0221 ± 0.000269	0.0220 ± 0.00029	0.0221 ± 0.000281
$\Omega_c h^2$	0.1165 ± 0.0019	0.1169 ± 0.00197	0.1114 ± 0.00332	0.1121 ± 0.00338
θ_s	1.0415 ± 0.000579	1.0415 ± 0.000576	1.0418 ± 0.000595	1.0418 ± 0.000611
τ	0.09037 ± 0.0132	0.0904 ± 0.01267	0.0913 ± 0.0135	0.0936 ± 0.0126
n_s	0.9629 ± 0.0062	0.9603 ± 0.00583	0.9677 ± 0.00673	0.9655 ± 0.00678
β	0.0364 ± 0.01626	0.0346 ± 0.0155	0.0660 ± 0.0182	0.0611 ± 0.0188
β	$0.03132^{+0.0360}_{-0.0266}$	$0.0146^{+0.0494}_{-0.0103}$	$0.0564^{+0.0409}_{-0.0292}$	$0.0708^{+0.0235}_{-0.0514}$
σ	0.2895 ± 0.1052	0.2837 ± 0.105	0.2932 ± 0.1055	0.2681 ± 0.0996
Ω_{de}	0.6935 ± 0.0141	$0.6910^{\pm}0.0144$	0.7339 ± 0.0219	0.7295 ± 0.0223
H_0	67.437 ± 1.250	67.267 ± 1.247	71.123 ± 2.109	70.737 ± 2.093





Green=Planck+WP+BAO

Blue = Planck+WP+HST