Coupled DE-DM: treatment and constraints

Laura Lopez Honorez

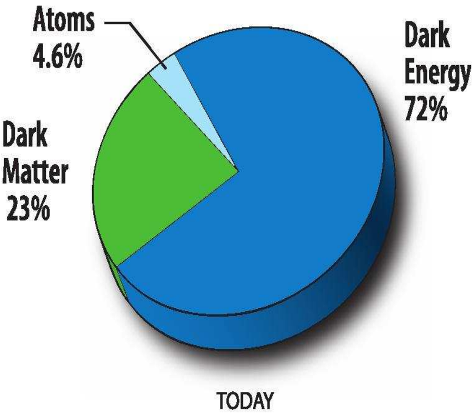
Universidad Autónoma de Madrid

based on

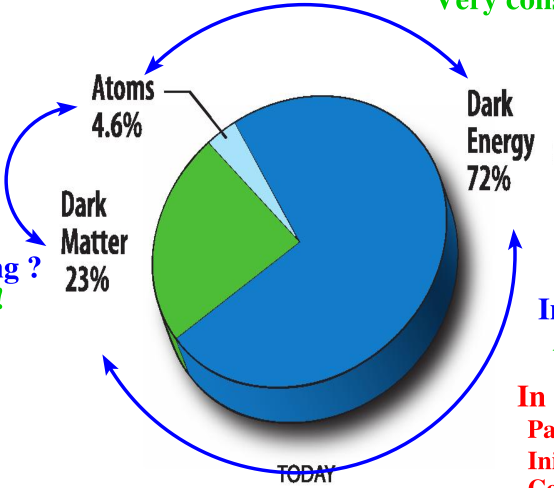
`Dark Coupling`: JCAP 0907:034
`Dark Coupling and Gauge Invariance`: astro-ph/1005.0295

in collaboration with B. Gavela, D. Hernandez, O. Mena, S. Rigolin

Plank 2010 - CERN (Geneva)


Atoms
4.6%
Dark
Energy
72%
Dark
Matter
23%
TODAY

Interacting ?
Very constrained!



Interacting ?
Allowed!

Interacting ?
Allowed!

In this TALK!
Parametrizations
Initial conditions
Cosmological constraints

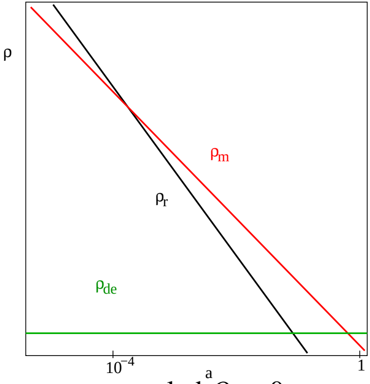
Energy exchange - Background

- Evolution equations for a Interacting DM-DE System :

$$\dot{\rho}_{dm} + 3H\rho_{dm} = aQ$$
$$\dot{\rho}_{de} + 3H\rho_{de}(1+w) = -aQ$$

$Q < 0 \equiv$ DM decaying into DE

ΛCDM model $w_{de} = -1$



uncoupled $Q = 0$

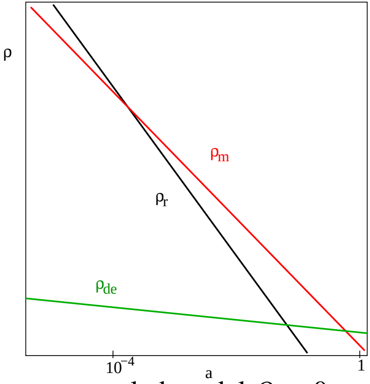
Energy exchange - Background

- Evolution equations for a Interacting DM-DE System :

$$\begin{aligned} \dot{\rho}_{dm} + 3H\rho_{dm} &= aQ \\ \dot{\rho}_{de} + 3H\rho_{de}(1+w) &= -aQ \end{aligned}$$

$Q < 0 \equiv$ DM decaying into DE

DE model $w_{de} = -0.9$



uncoupled model $Q = 0$

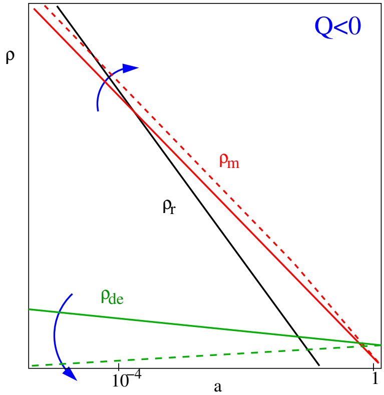
Energy exchange - Background

- Evolution equations for a Interacting DM-DE System :

$$\begin{aligned} \dot{\rho}_{dm} + 3H\rho_{dm} &= aQ \\ \dot{\rho}_{de} + 3H\rho_{de}(1+w) &= -aQ \end{aligned}$$

$Q < 0 \equiv$ DM decaying into DE

DE-dm Coupled model



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

Energy exchange - Background

- Evolution equations for a Interacting DM-DE System :

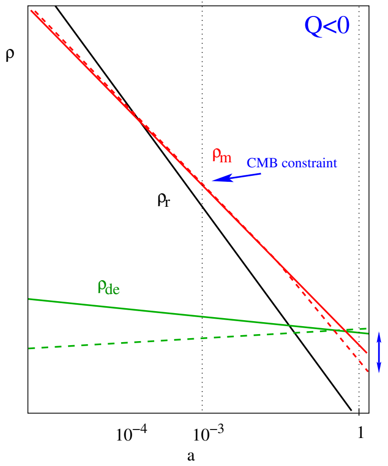
$$\dot{\rho}_{dm} + 3H\rho_{dm} = aQ$$
$$\dot{\rho}_{de} + 3H\rho_{de}(1+w) = -aQ$$

$Q < 0 \equiv$ DM decaying into DE

- Hint of cosmological constraints : CMB data constrains *e.g.* $\rho_{dm}(a_{\rm rec})$

$\rightsquigarrow \rho_{dm}(a_0)|_{Q<0} < \rho_{dm}(a_0)|_{Q=0}$
more dark matter in the past

DE-dm Coupled model



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

Energy-momentum exchange -Perturbations

At the level of the stress tensor : $\nabla_\mu T^\mu_{(dm,de)\nu} = \pm Q_\nu$

Energy-momentum exchange -Perturbations

At the level of the stress tensor : $\nabla_\mu T^\mu_{(dm,de)\nu} = \pm Q_\nu$

$$
\begin{aligned}
\dot{\Delta}_{dm} &= -k\mathcal{H}\,V_{dm} + \frac{Q}{\bar{\rho}_{dm}}\left[\Delta_Q - \Delta_{dm} + \mathcal{A}(\Psi_B, \Phi_B)\right] \,, \\
\dot{V}_{dm} &= -\mathcal{H}V_{dm} + k^2\Psi_B + \frac{Q}{\bar{\rho}_{dm}}\left[V_Q - V_{dm}\right] \,,
\end{aligned}
$$

Energy-momentum exchange -Perturbations

At the level of the stress tensor : $\nabla_\mu T^\mu_{(dm,de)\nu} = \pm Q_\nu$

$$\begin{aligned}\dot{\Delta}_{dm} &= -k\mathcal{H}\, V_{dm} + \frac{Q}{\bar{\rho}_{dm}}\left[\Delta_Q - \Delta_{dm} + \mathcal{A}(\Psi_B, \Phi_B)\right] \;, \\ \dot{V}_{dm} &= -\mathcal{H} V_{dm} + k^2 \Psi_B + \frac{Q}{\bar{\rho}_{dm}}\left[V_Q - V_{dm}\right] \;,\end{aligned}$$

- Momentum exchange :

$Q_\nu = Q\, u_\nu^{(dm)} \rightsquigarrow V_Q = V_{dm}$ (Valiviita & all'08)

$Q_\nu = Q\, u_\nu^{(de)} \rightsquigarrow V_Q = V_{de}$ i.e. modified Euler equation

Energy-momentum exchange -Perturbations

At the level of the stress tensor : $\nabla_\mu T^{\mu}_{(dm,de)\nu} = \pm Q_\nu$

$$\dot{\Delta}_{dm} = -k\mathcal{H}\,V_{dm} + \frac{Q}{\bar{\rho}_{dm}}\left[\Delta_Q - \Delta_{dm} + \mathcal{A}(\Psi_B, \Phi_B)\right] \,,$$

$$\dot{V}_{dm} = -\mathcal{H}V_{dm} + k^2\Psi_B + \frac{Q}{\bar{\rho}_{dm}}\left[V_Q - V_{dm}\right] \,,$$

- Momentum exchange :

  $Q_\nu = Q\,u_\nu^{(dm)} \rightsquigarrow V_Q = V_{dm}$ (Valiviita & all'08)

  $Q_\nu = Q\,u_\nu^{(de)} \rightsquigarrow V_Q = V_{de}$ i.e. modified Euler equation

- Energy exchange :

  $Q \propto \rho_{dm} \rightsquigarrow$ Non adiabatic instabilities for w cst (Valiviita'08, He'08)

  $Q \propto \rho_{de} \rightsquigarrow$ free from instabilities with $Q < 0$ and constant $w > -1$

  (He'08, Gavela'09,Jackson'09)

Analytical treatment of Perturbations

$$Q_\nu = Q\, u_\nu^{(dm)} \text{ with } Q = \xi H \rho_{de}$$

no fith force effects and $\xi < 0$ with $w > -1$ to avoid instabilities

Analytical treatment of Perturbations

$$Q_\nu = Q\, u_\nu^{(dm)} \text{ with } Q = \xi H \rho_{de}$$

no fith force effects and $\xi < 0$ with $w > -1$ to avoid instabilities

- Gauge invariant formalism $\rightsquigarrow$ δH must be included in Δ_Q

Analytical treatment of Perturbations

$$Q_\nu = Q\, u_\nu^{(dm)} \text{ with } Q = \xi H \rho_{de}$$

no fith force effects and $\xi < 0$ with $w > -1$ to avoid instabilities

- Gauge invariant formalism $\rightsquigarrow$ δH must be included in Δ_Q
- Derive initial conditions

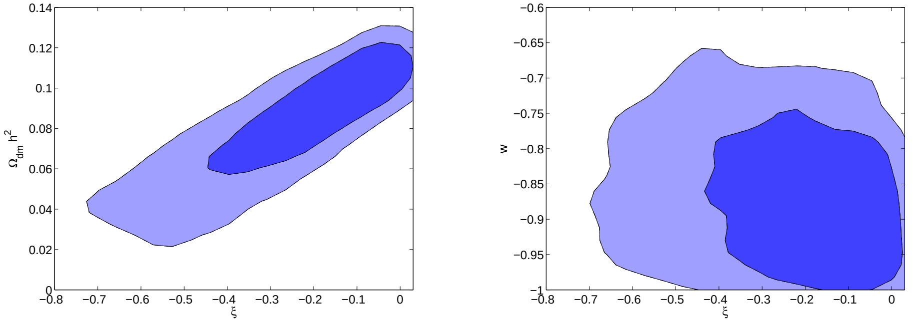
Imposing adiabatic initial conditions $S_{ab} \equiv \frac{\Delta_a^0}{\dot{\rho}_a/\rho_a} - \frac{\Delta_b^0}{\dot{\rho}_b/\rho_b} = 0$ for dm, b, γ, ν, automatically implies :

$$\rightsquigarrow \Delta_{de}^0 = \frac{3}{4}\left(1 + w + \frac{\xi}{3}\right)\Delta_\gamma^0$$

Adiabatic initial conditions for dark energy (depend on ξ ! !)

for uncoupled Doran'03, for coupled also Majerotto'10

Data Constraints : Numerical treatment of the model



Using WMAP7, HST, $H(z)$, SN and LSS

Conclusions

- We have studied a Coupled model with $Q_\nu = \xi H \rho_{de}$
  $\rightsquigarrow$ no fith force effect and no instabilities
- Perturbations in Gauge invariant formalism :
  $\rightsquigarrow$ adiabatic initial conditions also for DE
- both w and ξ are not very constrained from data.
  large values for both parameters, near -0.5, are easily allowed ! !

This is the End

Thank you for your attention ! !

Backup

Growth equation - Doom factor - Instability

$$\delta_i'' = A_i \frac{\delta_i}{a^2} + B_i \frac{\delta_i'}{a} + \mathcal{F}(\rho_j, \delta_j, \delta_j'; j \neq i)$$

leads when A,B negligible

Exponential Growth or Oscillations

(Anti)Damping

Growth equation - Doom factor - Instability

leads when A,B negligible

$$\delta_i'' = A_i \frac{\delta_i}{a^2} + B_i \frac{\delta_i'}{a} + \mathcal{F}(\rho_j, \delta_j, \delta_j'; j \neq i)$$

Exponential
Growth or Oscillations

(Anti)Damping

In the Strongly Coupled case of $\nabla_\mu T^\mu_{(de)\nu} = -Q\, u_\nu^{(dm)}/a$ (*i.e.* when $|\mathbf{d}| > 1$)
at large scale-early time in an unstable scenario :

$$\delta_{de}'' \simeq 3\,\mathbf{d}\,(\hat{c}^2_{s\,de} + 1)\left(\frac{\delta_{de}'}{a} + 3\frac{\delta_{de}}{a^2}\frac{(\hat{c}^2_{s\,de} - w)}{\hat{c}^2_{s\,de} + 1} + \frac{3(1+w)}{a^2}\delta[\,\mathbf{d}\,]\right) + \ldots$$

Growth equation - Doom factor - Instability

leads when A,B negligible

$$\delta_i'' = A_i \frac{\delta_i}{a^2} + B_i \frac{\delta_i'}{a} + \mathcal{F}(\rho_j, \delta_j, \delta_j'; j \neq i)$$

Exponential Growth or Oscillations

(Anti)Damping

In the Strongly Coupled case of $\nabla_\mu T^\mu_{(de)\nu} = -Q\, u_\nu^{(dm)}/a$ (*i.e.* when $|\mathbf{d}| > 1$) at large scale-early time in an unstable scenario :

$$\delta_{de}'' \simeq 3\,\mathbf{d}\,(\hat{c}^2_{s\,de} + 1)\left(\frac{\delta_{de}'}{a} + 3\frac{\delta_{de}}{a^2}\frac{(\hat{c}^2_{s\,de} - w)}{\hat{c}^2_{s\,de} + 1} + \frac{3(1+w)}{a^2}\delta[\mathbf{d}]\right) + \ldots$$

Assuming $\hat{c}^2_{sde} > 0$: $\mathbf{d} > \mathbf{1} \rightsquigarrow$ Non adiabatic source of instability

see also Valiviita - Majerotto - Maartens '08 & He - Wang - Abdalla '08 & Jackson - Taylor - Berera '09

What would be $\tilde{w}(z)$ reconstructed

...from $H(z)$ data assuming no coupling and dynamical DE :

$$R_H(z) = \frac{H^2(z)}{H_0^2} = \Omega_{dm}^{(0)}(1+z)^3 + \Omega_{de}^{(0)} \exp\left[3\int_0^z dz' \frac{1+\tilde{w}(z')}{1+z'}\right]$$

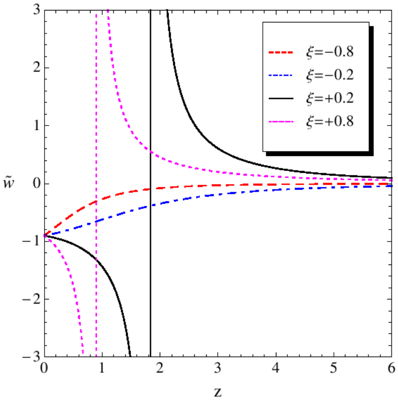
$$\Rightarrow \tilde{w}(z) = \frac{1}{3}\,\frac{R_H'(1+z) - 3R_H}{R_H - \Omega_{dm}^{(0)}(1+z)^3}\,.$$

However in presence of dark couplings :

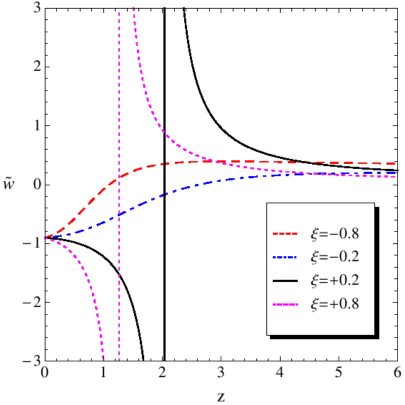
$$R_H(z) = f(w, Q, \Omega_{dm}^{(0)}, \Omega_{de}^{(0)})$$

Reconstructing $\tilde{w}(z)$ as a function of w and ξ

For $Q = \xi H \rho_{de}$



For $Q = \xi H \rho_{dm}$



$\rightsquigarrow$divergent $\tilde{w}(z)$ for $\xi > 0$

Similar behaviour in f(R) cosmologies see *e.g.* Amendola & Tsujikawa '07

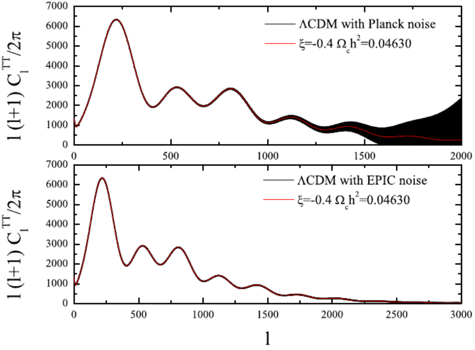
Future Constraints : from CMB lensing Martinelli'10

Lensing deflection $d = \nabla\Phi$ whit Φ the lensing potential. In harmonic space, multipoles follows $d_l^m = -i\sqrt{l(l+1)}\phi_l^m$,

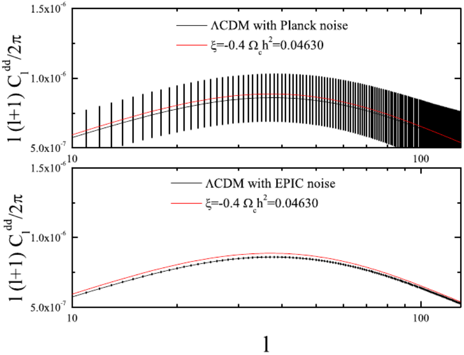
For $C_l^{dd} \equiv \langle d_l^m d_l^{m*} \rangle$ and $C_l^{\phi\phi} \equiv \langle \phi_l^m \phi_l^{m*} \rangle$, we have $C_l^{dd} = l(l+1)C_l^{\phi\phi}$.

$\rightsquigarrow$ breaking of $\Omega_{dm} - \xi$ degeneracy with EPIC that will greatly reduce its noise on CMB lensing

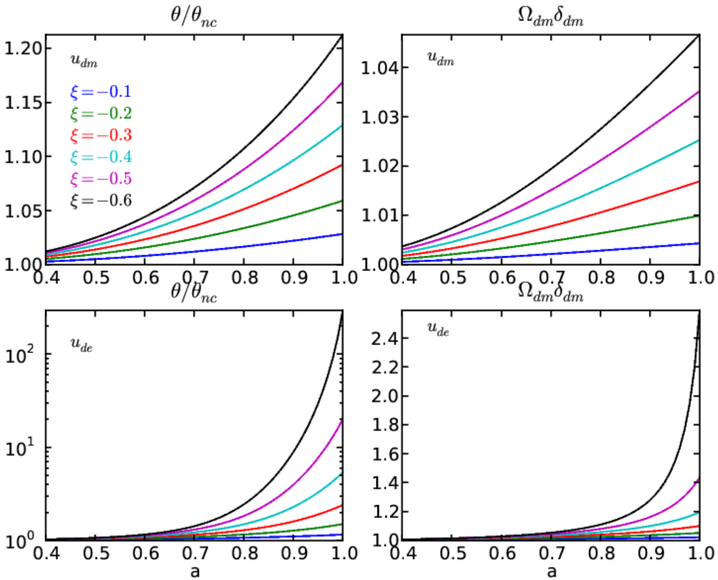
Temperature power spectra



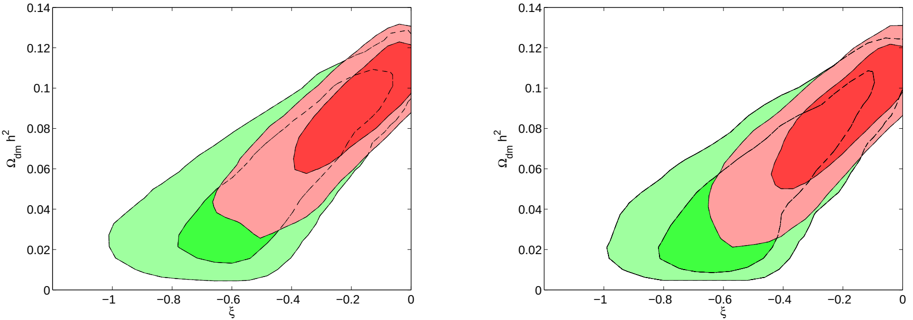
Lensing deflection power spectra



$Q = \xi H \rho_{de} case$



u_{dm} versus u_{de}



Using WMAP5, HST, $H(z)$, SN and LSS

relative acceleration for u^{μ}_{de} case