Interacciones Cosmológicas con cambios de signo

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27 de marzo de 2015

Outline

Cosmology in the context of General Relativity

Einstein Field Equations

$$R_{\mu\nu} - \frac{1}{2}R\ g_{\mu\nu} = \kappa T_{\mu\nu}$$

$g_{\mu\nu}$ is the metric, $R_{\mu\nu}$ is the Ricci tensor, R is the Ricci scalar $T_{\mu\nu}$ is the energy momentum tensor.

Cosmological Principle

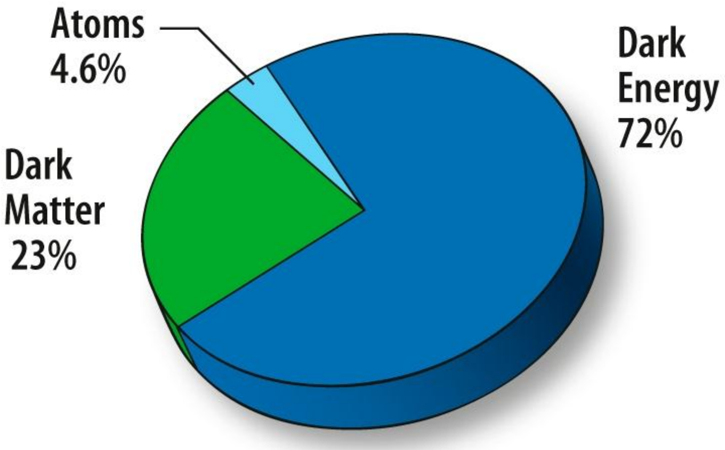
The Universe is homogeneus and isotropic. The most general metric that fulfills this is the **Friedmann-Robertson-Walker (FRW)** metric

$$ds^2 = dt^2 - a(t)^2\left(\frac{dr^2}{1-kr^2} + r^2\left(d\theta^2 + \sin^2\theta d\phi^2\right)\right)$$

$a(t)$ is the scale factor, (r, θ, ϕ) are the spatial coordinates and t is the cosmic time.

Idealized Matter Content

$$T_{\mu\nu} = (\rho + p)u_\mu u_\nu - p\ g_{\mu\nu}$$



TODAY

We consider a Cold Dark Matter (CDM) component with no pressure and a Cosmological constant component Λ. We choose $p_m = 0$ and $p_\Lambda = -\rho_\Lambda$ to represent this assumption.

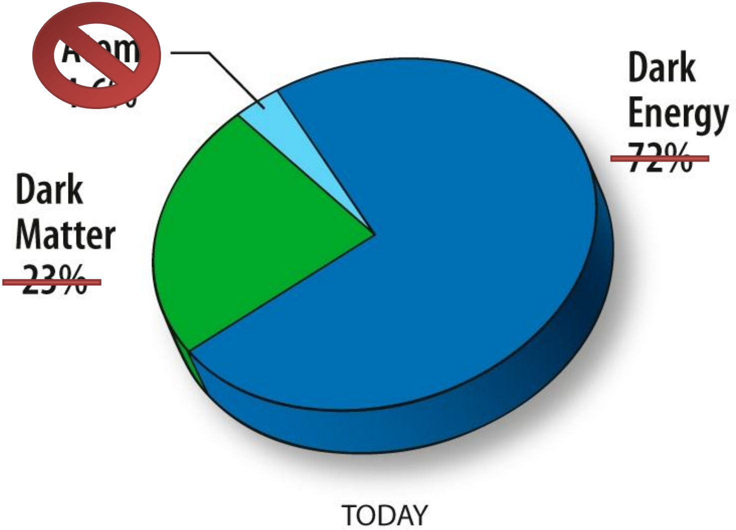
$$\dot{\rho}_{DM} + 3H\rho_{DM} = 0 \rightarrow \rho_{DM} = \rho^0_{DM} a^{-3}$$
$$\dot{\rho}_\Lambda = 0 \rightarrow \rho_\Lambda = \rho^0_\Lambda$$

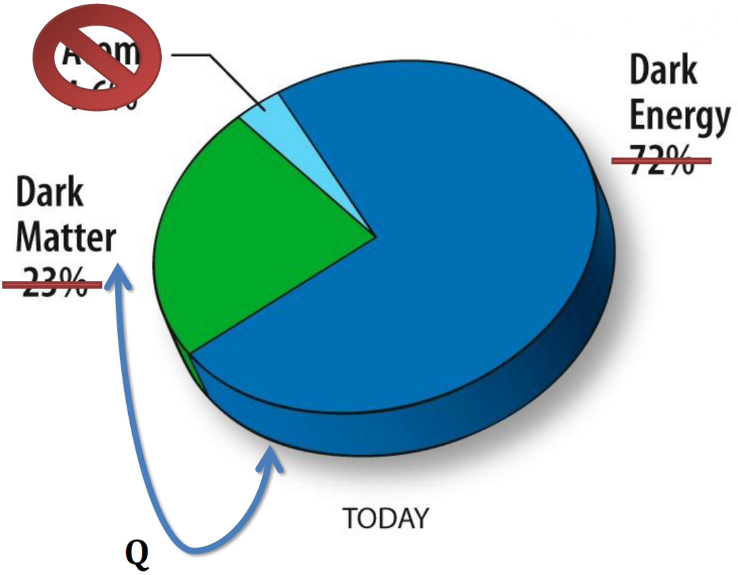
Defining $\Omega^0_i = \frac{\rho^0_i}{3H_0^2}$

$$r_0 = \frac{\Omega^0_{DM}}{\Omega^0_\Lambda} \approx O(1)$$

Problems of λCDM

- Why Λ is small and possitive?
- Why there is a Cosmic Coincidence?


Dark Energy
~~72%~~
Dark Matter
~~23%~~
TODAY


Atom
Dark Energy ~~72%~~
Dark Matter ~~23%~~
Q
TODAY

Two component interacting model

We consider and interacting flat model with ρ_{DE} the dark energy component and the pressure p_{DE} and ρ_{DM} the pressureless dark matter component.

$$\begin{aligned} 3H^2 &= \rho_{DE} + \rho_{DM}, \\ \dot{H} + H^2 &= -\frac{1}{6}(\rho_{DM} + \rho_{DE} + 3\omega_{DE}\rho_{DE}), \end{aligned}$$

where $H = \dot{a}/a$ is the Hubble parameter and $\omega_{DE} = p_{DE}/\rho_{DE}$ is the dark energy Equation of State (EoS), which can be a function of t.
Considering that dark energy exchanges energy with dark matter through a phenomenological coupling function Q

$$\dot{\rho}_{DE} + 3H(\rho_{DE} + \omega_{DE}\rho_{DE}) = -Q, \tag{1}$$

$$\dot{\rho}_{DM} + 3H\rho_{DM} = Q. \tag{2}$$

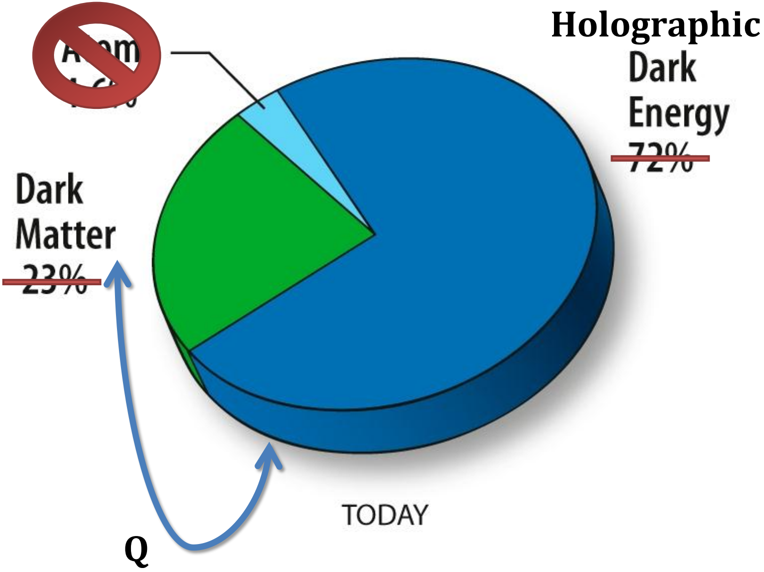
Types of interactions in the literature

$Q(t)$	analítico	numérica	WEC	SD	datos	r	ref
$\alpha H \rho_{DM}$	✓	-	✓	-	-	cte	2001 [39]
$\lambda(\rho_{DE}^{\alpha} \rho_{DM}^{\beta})$	-	✓	-	-	-	-	2002 [40]
$\alpha H(\rho_{DM} + \rho_{DE})$	✓	-	-	✓	✓	var	2003 [41]
$\lambda\ \rho_{DM}/H$	-	✓	-	✓	-	-	2008 [42]
$H(-\alpha\rho_{DM} + \beta\rho_{DE})$	✓	-	-	-	-	cte	2008 [43]
$\alpha H \rho_{DE}$	✓	-	-	-	✓	var	2009 [44]
$Q(\rho, \rho', \rho'')$	✓	-	-	✓	-	var	2010 [45]
$\alpha \rho_{DM} \rho_{DE}$	-	✓	-	✓	✓	var	2010 [46]

Sign change interaction

There are few cases of change sign for Q

- Cai and Su [5], without choosing a special form of interaction Q, they proposed a new squeme in which $Q = 3H\delta(z)$ is partioned in the whole redshift range and $\delta(z)$ is constant in each partition. Fitting with observational data found that δ probably crosses the non-interacting line ($\delta(z) = 0$). The authors suggest that there shoud be studied more general interaction term.
- The authors Li Zhang [6] proposed a phenomenological interaction of the form $Q(a) = 3b(a)H_0\rho_0$, such that the function $b(a)$ is variable. The sign change manifests for early times when fitted with data.
- The authors of [7] study an interaction $Q \sim q$. Because of the sign change from a decelerated universe to an accelerated one, a sign change is presented in the interaction.


Holographic
Dark Energy
~~72%~~
Dark Matter
~~23%~~
Q
TODAY

Model I: Ricci-like holographic dark energy

For the dark energy density ρ_{DE} we consider the holographic model type Ricci [1, 2, 3, 4]

$$\rho_{_{DE}} = 3(\alpha H^2 + \beta \dot{H})$$

Equivalent to $p_{_{DE}} = -\frac{2}{3\beta}\rho_{_{DE}} + H^2\left(2\alpha - 3\beta\right)/\beta$. We obtain a differential equation for the Hubble parameter in terms of the EoS parameter ω_{DE},

$$\dot{H} = -3\left(\frac{1+\alpha\ \omega_{_{DE}}}{2+3\ \beta\ \omega_{_{DE}}}\right)H^2, \tag{3}$$

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$$\dot{H} = -3\left(\frac{1 + \alpha\ \omega_{DE}}{2 + 3\ \beta\ \omega_{DE}}\right)H^2, \tag{3}$$

The holographic type RDE takes the form

$$\rho_{DE} = 3H^2\left(\frac{2\alpha - 3\beta}{2 + 3\beta\omega_{DE}}\right) \longrightarrow (2\alpha - 3\beta)/(2 + 3\beta\omega_{DE}) > 0 \tag{4}$$

with WEC. The cosmic coincidence parameter r can be written as

$$r = \rho_{DM}/\rho_{DE} = 3H^2/\rho_{DE} - 1 = \left(2 + 3\beta\omega_{DE}\right)/(2\alpha - 3\beta) - 1. \tag{5}$$

The case for constant ω_{DE} would result in a constant r for all time.

Interaction in Ricci-like holographic dark energy

The sign of the interaction function can be visualized as

$$Q = 3H^3 \frac{r}{(1+r)^2}\left(-3\omega_{_{DE}} + a\frac{r'}{r}\right), \tag{6}$$

Replacing the HDE in (1), we obtain a term of interaction on r,

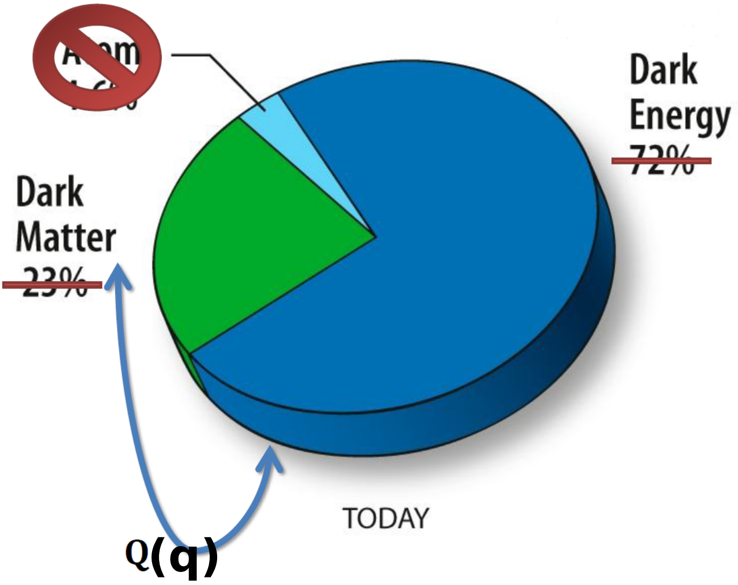
$$Q = 3H^3 \frac{\left((2-2\alpha+3\beta)r + (3\beta-2\alpha)r^2 + \beta a r'\right)}{\beta(1+r)^2}. \tag{7}$$

It is equivalent to study (7) or to study the interaction as a function of the state parameter $\omega_{_{DE}}$

$$Q = 9H^3(2\alpha-3\beta)\frac{\left(-\omega_{_{DE}}(2-2\alpha+3\beta+3\beta\omega_{_{DE}}) + a\beta\omega'_{_{DE}}\right)}{(2+3\beta\ \omega_{_{DE}})^2}. \tag{8}$$

or as a function of the deceleration parameter

$$Q \;=\; 3H^3\left[3\left(1-\alpha\right)-\left(q+1\right)\left(2-3\beta-2\alpha-2\beta q\right)\right]+\;3H^2\beta\;\dot{q}. \tag{9}$$


Dark Energy
~~72%~~
Dark Matter
~~23%~~
TODAY
Q(q)

Model II: q-interaction in Cosmology

Summary of interactions involving the deceleration parameter q

	$\mathbf{Q(q)}$	$\mathbf{Q}(\rho,\rho')$
I	$\beta q \rho$	$-\beta\left(\rho+\frac{3}{2}\rho'\right)$
II	$\frac{q}{3H}\beta\dot{\rho}$	$-\beta\left(\rho'+\frac{3}{2}\frac{\rho'^2}{\rho}\right)$
III	$\beta q \rho_m$	$\beta\left(\gamma_x\rho+(1+\frac{3}{2}\gamma_x)\rho'+\frac{3}{2}\frac{\rho'^2}{\rho}\right)/\Gamma_{-}$
IV	$\beta q \rho_x$	$-\beta\left(\gamma_m\rho+(1+\frac{3}{2}\gamma_m)\rho'+\frac{3}{2}\frac{\rho'^2}{\rho}\right)/\Gamma_{-}$
V	$\frac{q}{3H}(\alpha\dot{\rho}+3\beta H\rho)$	$-\left(\beta\rho+(\alpha+\frac{3}{2}\beta)\rho'+\frac{3}{2}\alpha\frac{\rho'^2}{\rho}\right)$

using $' = d/d\eta$ and for $\gamma_i = 1 + w_i$

$$q = -\left(1+\frac{3}{2}\,\rho'/\rho\right), \quad \rho_m = -\frac{\gamma_x\rho+\rho'}{\Gamma_{-}}, \quad \rho_x = \frac{\gamma_m\rho+\rho'}{\Gamma_{-}}, \qquad (10)$$

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I	$\beta q\rho$	$-\beta\left(\rho+\frac{3}{2}\rho'\right)$
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IV	$\beta q\rho_x$	$-\beta\left(\gamma_m\rho+(1+\frac{3}{2}\gamma_m)\rho'+\frac{3}{2}\frac{\rho'^2}{\rho}\right)/\Gamma_-$
V	$\frac{q}{3H}(\alpha\dot{\rho}+3\beta H\rho)$	$-\left(\beta\rho+(\alpha+\frac{3}{2}\beta)\rho'+\frac{3}{2}\alpha\frac{\rho'^2}{\rho}\right)$

using $' = d/d\eta$ and for $\gamma_i = 1 + w_i$

$$q=-\left(1+\frac{3}{2}\,\rho'/\rho\right),\quad \rho_m=-\frac{\gamma_x\rho+\rho'}{\Gamma_-},\quad \rho_x=\frac{\gamma_m\rho+\rho'}{\Gamma_-},\qquad (10)$$

The q-interaction can be generalized as

$$Q=\left(c_1\rho+c_2\rho'+c_3\rho'^2/\rho\right)/\Gamma_-. \; (11)$$

With $\Gamma_{+} = \gamma_m + \gamma_x$ and $\Gamma_{\times} = \gamma_m \gamma_x$ the interacting equations are equivalent to

$$\rho'' + \Gamma_{+}\rho' + \Gamma_{\times}\rho = Q\,\Gamma_{-}, \quad (12)$$

Its solution is

$$\rho(a) = \left(\sum c_{\pm}\; a^{\frac{3}{2}\left(-b_1 \pm \sqrt{b_1^2 - 4b_3(1+b_2)}\right)} \right)^{1/(1+b_2)} . \quad (13)$$

$(\mathbf{b_1}, \mathbf{b_2}, \mathbf{b_3})$	$\rho(\mathbf{a})$
I $\left(\Gamma_{+} + \frac{3}{2}\beta\Gamma_{-}, 0, \Gamma_{\times} + \beta\Gamma_{-}\right)$	$\sum c_{\pm} a^{\frac{3}{4}\left(-3\beta\Gamma_{-} - 2\Gamma_{+} \pm 2\sqrt{\left(\Gamma_{+} + \frac{3\beta}{2}\Gamma_{-}\right)^2 - 4(\beta\Gamma_{-} + \Gamma_{\times})}\right)}$
II $\left(\Gamma_{+} + \beta\Gamma_{-}, \frac{3}{2}\beta\Gamma_{-}, \Gamma_{\times}\right)$	$\left(\sum c_{\pm} a^{\frac{3}{2}\left(-\beta\Gamma_{-} - \Gamma_{+} \pm \sqrt{\left(-\beta\Gamma_{-} - \Gamma_{+}\right)^2 - 2(3\beta\Gamma_{-} + 2)\Gamma_{\times}}\right)}\right)^{\frac{2}{2-3\beta}}$
III $\left(\Gamma_{+} - \beta\left(\frac{3}{2}\gamma_x + 1\right), -\frac{3}{2}\beta, (\gamma_m - \beta)\gamma_x\right)$	$\left(\sum c_{\pm} a^{\frac{3}{4}\left(\beta(3\gamma_x + 2) - 2\Gamma_{+} \pm \lvert\beta(3\gamma_x - 2) + 2\Gamma_{-}\rvert\right)}\right)^{\frac{2}{2-3\beta}}$
IV $\left(\Gamma_{+} - \beta\left(\frac{3}{2}\gamma_m + 1\right), -\frac{3\beta}{2}, (\gamma_x - \beta)\gamma_m\right)$	$\left(\sum c_{\pm} a^{\frac{3}{2}\left(\beta - \Gamma_{+} + \frac{3}{2}\beta\gamma_m \pm \frac{1}{2}\lvert(-2\Gamma_{+} + \beta(3\gamma_m - 2))\rvert\right)}\right)^{\frac{2}{2-3\beta}}$
V $\left(\Gamma_{+} - \frac{3\beta}{2} - \alpha, -\frac{3\alpha}{2}, \Gamma_{\times} - \beta\right)$	$\left(\sum c_{\pm} a^{\frac{3}{4}\left(3\beta - 2\Gamma_{+} + 2\alpha \pm 2\sqrt{\left(\alpha + \frac{3\beta}{2} - \Gamma_{+}\right)^2 + 2(2-3\alpha)\left(\beta - \Gamma_{\times}\right)}\right)}\right)^{\frac{2}{2-3}}$

Cuadro : Analytical solutions to the cosmological q-interactions are presented. We simplified solutions considering $\gamma_x \leq 2/3 < \gamma_m$.

Observational Constraints

To estimate the value of the parameters in each case we will use late universe observational data set $(0{,}1 < z < 1{,}4)$, Supernovae type I Union 2 [8]. We adjust the $N = 4$ parameters and we marginalize over H_0 [14]. With H we have the theoretical luminosity distance $d_L(theo)$ and compare it with luminosity distance

$$\chi^2 = \sum_i \frac{\left(d_L^{theo} - d_L^{obs}\right)^2}{\sigma^2} \tag{14}$$

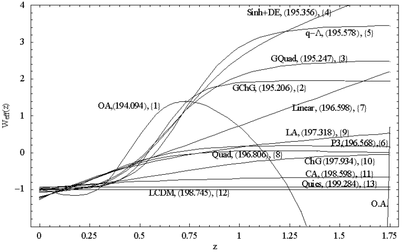
where σ is the error asociated to the compilation. The function χ^2 depends on the parameters and not the redshift z. The parameters of the model that better adjust the data are obtain minimizing χ^2, whose minimum value is χ^2_{min}. We defined reduced χ^2 as

$$\chi^2_* = \frac{\chi^2_{min}}{n - N}, \tag{15}$$

where n is the number of data and N is the number of parameters. A good adjustment is when $(\chi^2_* \sim 1)$.

Model I: Ansatzes on ω_{DE}

We consider different Ansatzes for the dark energy parameter ω_{DE} in order to study in detail the system described by (3).



A comparison of cosmological models using recent supernova data

S. Nesseris and L. Perivolaropoulos*
Department of Physics, University of Ioannina, Greece
(Dated: February 2, 2008)

We study the expansion history of the universe up to a redshift of z=1.75 using the 194 recently ublished SnIa data by Tonry et. al. and Barris et. al. In particular we find the best fit forms of everal cosmological models and $H(z)$ ansatze, determine the best fit values of their parameters and ank them according to increasing value of χ^2_{min} (the minimum value of χ^2 for each $H(z)$ ansatz). We

Ansatz	ω_{DE}
Case I	$\omega_0 + \eta(1-a)$
Case II	$\omega_0 + \eta(1-a)/a$
Case III	$\omega_0 + \eta(a^{-3\delta}-1)$

Table 1

Model	$H(z)$, $(\Omega_{0m}=0.3)$	χ^2_{min}	Best Fit Parameters
OA (1)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + a_1\cos(a_2 z^2 + a_3)$ $+(1 - a_1\cos(a_3) - \Omega_{0m})]$	194.1	$a_1 = -3.36\ ^{+0.93}_{-0.76},\ a_2 = 2.12\ ^{+0.93}_{-0.76}$ $a_3 = -0.06\pi \pm 0.01\pi$
GCG (2)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + (1-\Omega_{0m})\sqrt{A + (1-A)(1+z)^\alpha}]$	195.2	$A = 0.9998\ ^{+0.0001}_{-0.0004},\ \alpha = 17.68\ ^{+0.02}_{-0.04}$
GQ (3)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + a_1(1+z)^{3(1+w_1)} + a_2(1+z)^{3(1+w_2)}$ $+(1 - a_1 - a_2 - \Omega_{0m})]$	195.2	$w_1 = -1.13 \pm 0.24,\ w_2 = 2.49 \pm 0.02$ $a_1 = 0.57\ ^{+0.03}_{-0.02},\ a_2 = 0.003^{+0.0003}_{-0.0002}$
Sinh+DE (4)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + a_1(1+z)^{3(1+w_1)} + a_2\sinh(w_2 z)$ $+1 - \Omega_{Om} - a_1]$	195.4	$w_1 = -0.81\ ^{+0.1}_{-0.3},\ w_2 = 5.90\ ^{+0.93}_{-3.13}$ $a_1 = -0.50\ ^{+0.1}_{-0.3},\ a_2 = 0.026\ ^{+0.005}_{-0.015}$
q-Λ (5)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + a_1(1+z)^{3(1+w_1)} + (1 - \Omega_{0m} - a_1)]$	195.6	$w_1 = 3.44\ ^{+0.44}_{-0.78},\ a_1 \simeq 5\ 10^{-4}\ ^{+0.4\ 10^{-4}}_{-0.9\ 10^{-4}}$
P3 (6)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + a_3(1+z)^3 + a_2(1+z)^2 +$ $a_1(1+z) + (1 - a_1 - a_2 - a_3 - \Omega_{0m})]$	196.6	$a_1 = -2.55 \pm 0.12$ $a_2 = 0.50\ ^{+0.07}_{-0.05},\ a_3 = 0.36 \pm 0.06$
Linear (7)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + (1-\Omega_{0m})$ $(1+z)^{3(1+w_0-w_1)}e^{3w_1 z}]$	196.6	$w_0 = -1.25 \pm 0.09,\ w_1 = 1.97\ ^{+0.08}_{-0.01}$
Quad (8)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + a_1(1+z) + a_2(1+z)^2$ $+(1 - a_1 - a_2 - \Omega_{0m})]$	196.8	$a_1 = -4.05\ ^{+1.16}_{-1.27},\ a_2 = 1.79\ ^{+0.79}_{-0.63}$
LA (9)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + (1-\Omega_{0m})(1+z)^{3(1+w_0+w_1)}$ $e^{3w_1(\frac{1}{1+z}-1)}]$	197.3	$w_0 = -1.29 \pm 0.10,\ w_1 = 2.84 \pm 0.05$
CG (10)	$H^2(z) = H_0^2[\Omega_{0m}(1+z)^3 + (1-\Omega_{0m})\sqrt{A + (1-A)(1+z)^6}]$	197.9	$A = 0.96 \pm 0.03$

Case I

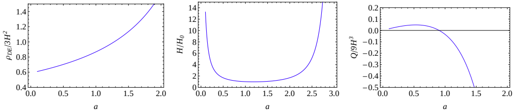
In this case we use the Chevalier-Polarski parametrization $\omega_{DE} = \omega_0 + \eta(1 - a)$ [10, 11]. The system is determined

$$H(a) = H_0 \ a^{-3\frac{(1+\alpha(\eta+\omega_0))}{(2+3\beta(\eta+\omega_0))}} \left(\frac{-2 + 3(a-1)\eta\beta - 3\omega_0\beta}{-2 - 3\omega_0\beta} \right)^{-\frac{2\alpha - 3\beta}{\beta(2+3(\eta+\omega_0)\beta)}} . \quad (16)$$

Considering the Weak Energy Conditions we obtain a range for the parameters resumed in the following inequalities

$$\frac{\beta}{\alpha} < \frac{2}{3} , \quad \beta < -\frac{2}{3\omega_0} , \quad \beta < -\frac{2}{3(\omega_0+\eta)} , \quad \alpha < -\frac{1}{\omega_0+\eta}. \quad (17)$$

parameters	
ω_0	-1.001
η	0.999
α	0.86
β	0.23
χ^2_*	0.982



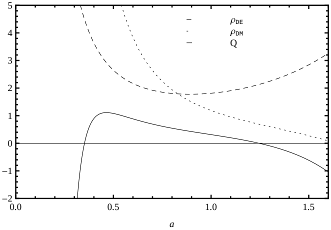
Case II

With the parametrization $\omega_{DE} = \omega_0 + \eta(1-a)/a$ [12]. The system is determined, the (3) can be integrated and leads to

$$H(a) = H_0 a^{\frac{-\alpha}{\beta}} \left(\frac{(2+3\omega_0\beta - 3\beta\eta)a + 3\beta\eta}{2+3\beta\omega_0} \right)^{\frac{3-2\alpha/\beta}{3\beta(\eta-\omega)-2}} . \tag{18}$$

There is a singularity $a_s = 3\beta\eta/(2+3\omega_0\beta - 3\beta\eta)$. There also a value $a_c = 3\beta\eta/\left(2\alpha - 2 - 3\beta(1+\omega_0-\eta)\right)$, for when $r(a_c) = 0$.

parameters	WEC
ω_0	-1.29
η	0.47
α	0.73
β	0.38
χ^2_*	0.9817

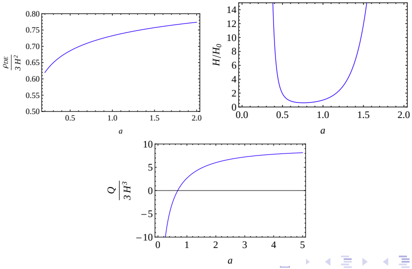


Case III

We consider an Ansatz for the coincidence parameter of the form $r = r_0 a^{-3\delta}$ [13] where $r_0 \equiv \rho_{DM0}/\rho_{DE0}$ is the value today for r and δ is a positive constant. Given that there is arelation between r and ω_{DE} given by the equation (3), this is equivalent to use the Ansatz $\omega_{DE} = \omega_0 + \eta(a^{-3\delta} - 1)$

$$H(a) = H_0 a^{\frac{1}{\beta}(1-\alpha)} \left(\frac{r_0 a^{-3\delta} + 1}{r_0 + 1} \right)^{\frac{1}{3\beta\delta}} . \tag{19}$$

parametros	$r_0 < 0{,}5$
δ	0,107
r_0	0,365
α	0,714
β	0,050
χ^2_*	0.9814



Model II

Case	α	β	γ_x	γ_m	Ω_x	χ^2_{min}	χ_*	$\tilde{\omega}_{eff}$	z_{acc}
	0.000	0.000	-0.010	*1.000	0.719	562.224	0.973	-1.010	0.722
I	0.000	0.160	-0.115	*1.000	0.645	562.253	0.974	-0.942	0.698
II	0.278	0.000	0.050	*1.000	0.766	562.203	0.974	-0.960	0.729
III	0.273	$\alpha\gamma_x$	0.040	*1.000	0.758	562.205	0.974	-0.960	0.722
IV	-0.210	$\alpha\gamma_m$	0.059	*1.000	0.779	562.222	0.974	-1.197	0.747
V	0.102	-0.048	0.038	*1.000	0.757	562.213	0.976	-1.001	0.728

Cuadro : Best fit parameters for SnIa data. Priors are indicated with an asterisk. The last two columns correspond to derived quantities, the effective value of the asymptotic state parameter and the redshift of the transition in the deceleration parameter.

Case	α	β	γ_x	γ_m	Ω_x	χ^2_{min}	χ_*	$\tilde{\omega}_{eff}$	z_{acc}
	0.000	0.000	0.017	1.027	0.741	562.232	0.974	-0.983	0.718
I	0.000	-0.070	-0.0006	1.003	0.745	562.277	0.976	-1.073	0.705
II	0.280	0.000	-0.007	0.933	0.708	562.195	0.976	-1.005	0.753
III	0.243	$\alpha\gamma_x$	-0.003	0.929	0.703	562.207	0.976	-1.003	0.769
IV	-0.267	$\alpha\gamma_m$	-0.024	0.904	0.698	562.219	0.976	-1.432	0.794
V	-0.025	-0.163	0.019	0.945	0.740	562.209	0.978	-1.154	0.756

Cuadro : Best fit parameters for SnIa data. The last two columns correspond to derived quantities, the effective value of the asymptotic state parameter and the redshift of the transition in the deceleration parameter.

Model II

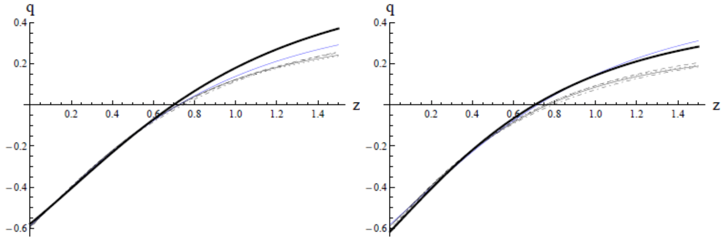
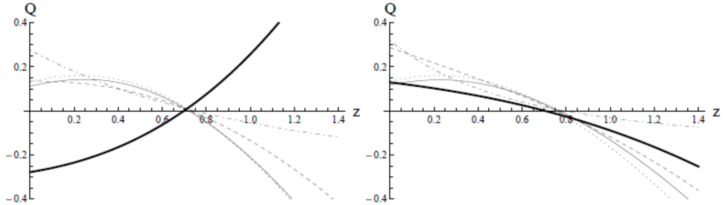
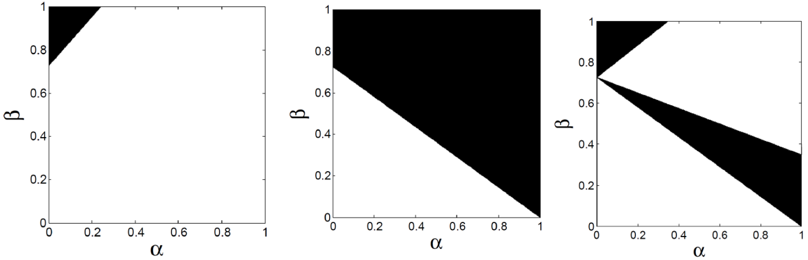


Figure 1: The deceleration parameter is shown. Left panel corresponds to $\gamma_m = 1$ and right panel to a fitted γ_m. The blue line corresponds to the case without interaction. Thick line corresponds to interaction type I; dotted, solid, dot dashed and dashed to types II, III, IV and V respectively.



What about thermodynamics?



Final Remarks

- The holography type Ricci ($\beta \neq 0$) has a change of sign in the interaction function Q.
- In Ricci-like holography there is a equivalence in postulating Ansatz in the coincidence parameter r, desaceleration parameter q and the EoS ω_{DE} and they determine Q.
- The integrability of the q-interaction equations of motions can also be seen in Eq. (12), where any interaction that is a linear function of q has a direct solution.
- Table 15 could indicate that other interactions presented as new in the literature could be equivalent to previous scenarios and moreover, interactions proposed from alternative theories that seem difficult to incorporate could take advantage of simpler integration methods.
- ¿What is the physical nature of a interaction that changes sign?

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Acknowledgments

This work has been supported by Comision Nacional de Ciencias y Tecnologia through Fondecyt Grant 3130736 (FA).

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Acknowledgments

This work has been supported by Comision Nacional de Ciencias y Tecnologia through Fondecyt Grant 3130736 (FA).

¡¡Thanks for your attention!!