Extended Quintessence with exponential coupling

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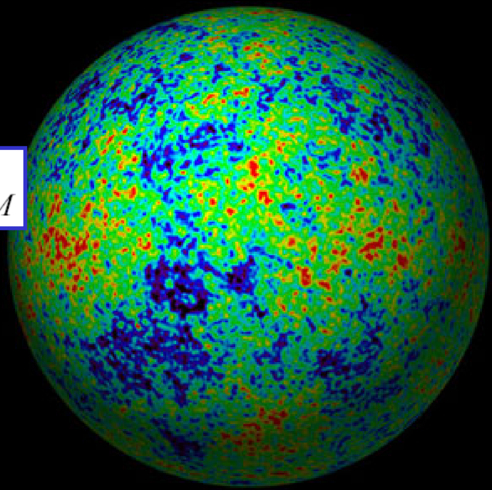
Modern cosmology

CMB

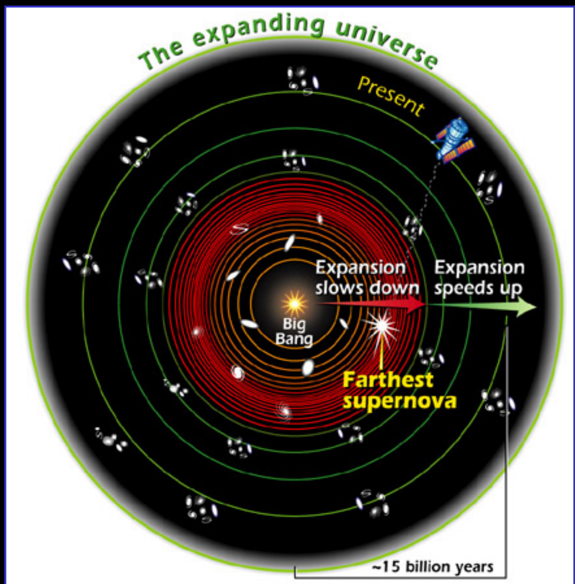
$$\Omega_\Lambda \approx 1 - \Omega_M$$



Large Scale Structures

Supernovae Ia

$$\Omega_\Lambda \approx 1.4\Omega_M + 0.2$$



HST

Content of the Universe

$$\Omega_{tot} = 1$$

$$\Omega_b = 0.045$$

$$\Omega_{DM} = 0.225$$

$$\Omega_{DE} = 0.73$$

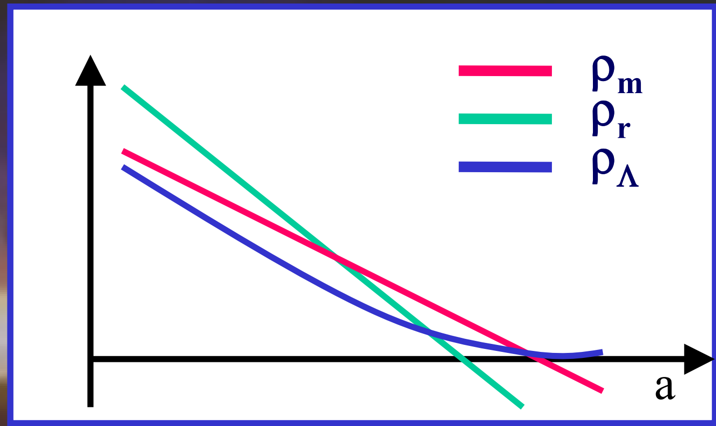
Part of the energy in the universe which does not cluster.

Dark Energy scalar field

Cosmological constant

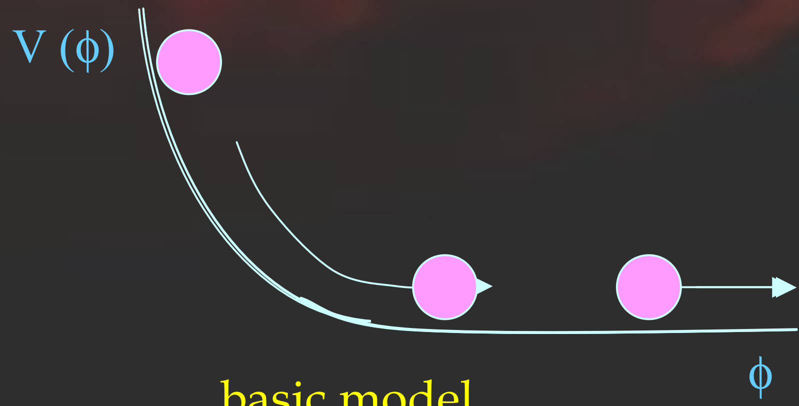
Constant energy contribution

Why so small?
Why same order right now?



Dark energy

Dynamical energy contribution



basic model

DE and tracker fields

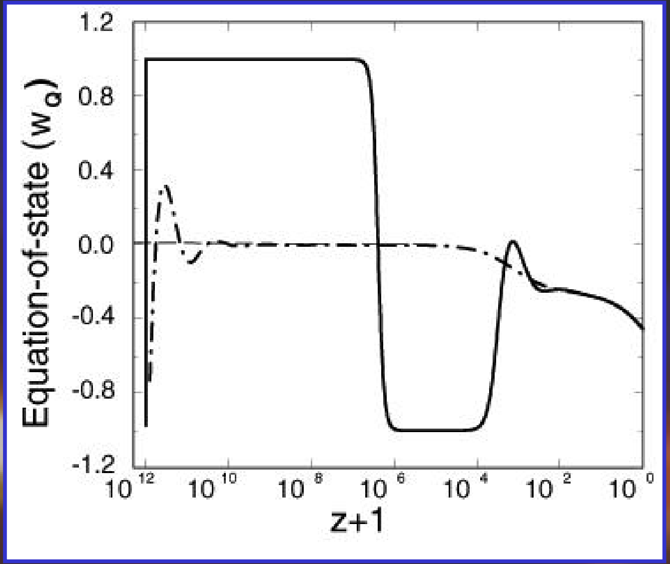
Cosmological constant

⇩

Dark Energy

⇩

Tracker fields

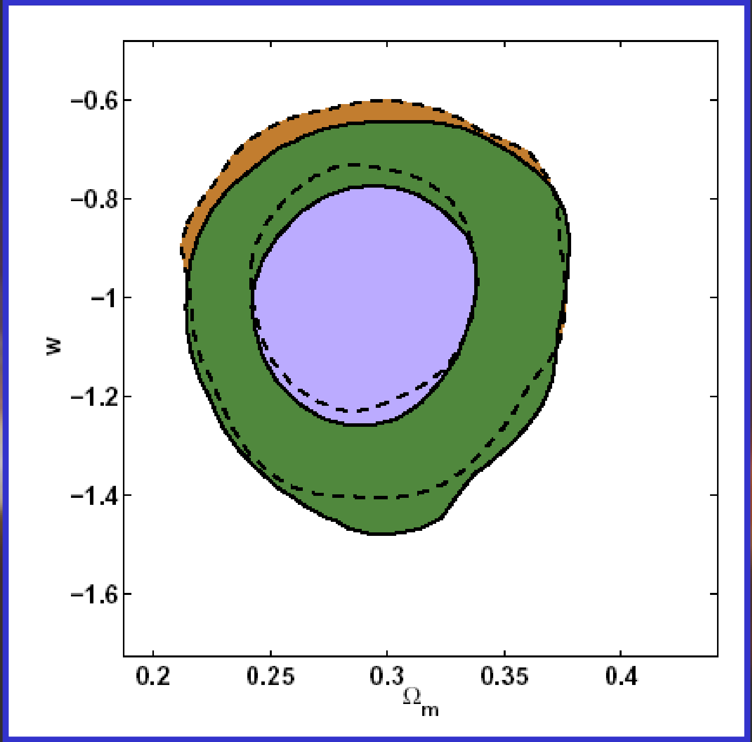


A subclass of Quintessence models admits a useful property: any solution within a wide range of initial conditions converges to an attractor solution, providing the amount of energy density required today.

Liddle & Scherrer, Steinhardt et al

w_Q and tracker fields

In most tracker models w_Q today is predicted to be too different from – 1 to be allowed by observations. The potential V needs to be flattened, thus shrinking the range of initial conditions.



LSS CMB H Sup Ia

↓

$w_Q < -0.78$ at 95%

Spergel et al 2003

$w_Q = -0.91^{+0.13}_{-0.15}$

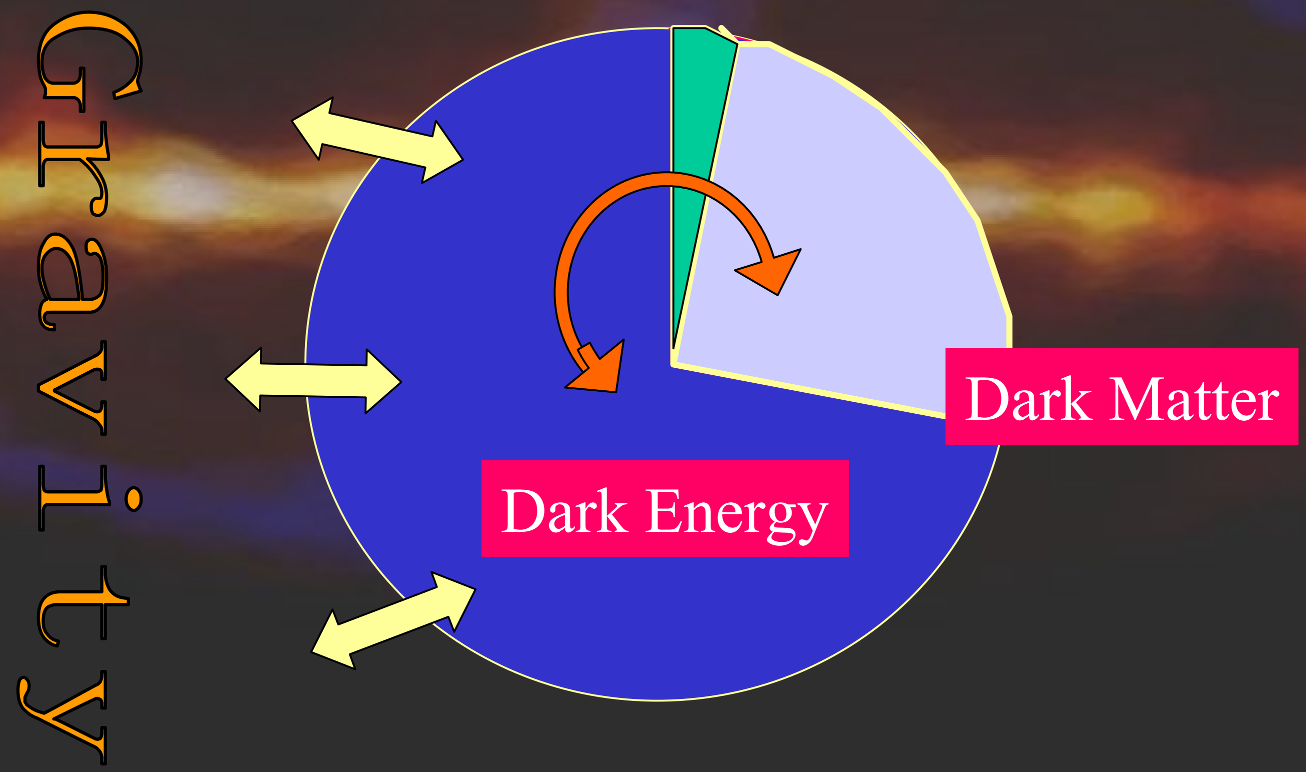
Tegmark 2004

Weller & Lewis 2003

As the allowed range shrinks, tracker fields become less appealing.

Coupling Dark energy

Essential to understand how Dark Energy interacts with other entities



Dark energy

Cosmological constant

↓

Dark energy

↙ ↘

Non coupled DE | Coupled DE

Non coupled DE → Tracker fields

Perrotta Baccigalupi Matarrese 2000

Coupled DE → Dark energy & Gravity; Dark Energy & Dark Matter

Extended Quintessence

Amendola 2000

V.P. Mangano, Miele 2002

Scalar tensor theories

Scalar field

Ricci scalar

$$S = \int d^4x \sqrt{-g} \left[\frac{1}{2\kappa} f(\phi, R) - \frac{1}{2}\omega(\phi)\phi^{;\mu}\phi_{;\mu} - V(\phi) + \mathcal{L}_{\text{fluid}} \right]$$

$= 1$

$$\frac{f(\phi, R)}{2\kappa} = F(\phi)R$$

The coupling

Scalar tensor theories of gravity

Induced Gravity (IG)	Non minimal Coupling (NMC)	Exponential Coupling
$F(\phi)R = \xi\phi^2 R$	$F(\phi)R = \dfrac{R}{16\pi G} + \xi\phi^2 R$	$F(\phi)R = \dfrac{R}{16\pi G}\exp(\xi\phi)$

Exponential Coupling: Dilatonic-inspired coupling

Cosmological expansion

In a FRW space, the relevant equations change

...both for the background...

$$\mathcal{H}^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3F}\left(a^2 \rho_{fluid} + \frac{1}{2}\dot{\phi}^2 + a^2 V - 3\mathcal{H}\dot{F}\right)$$

$$\ddot{\phi} + 2\mathcal{H}\dot{\phi} - \frac{\xi}{16\pi a}\rho_{m_0} + a^2 V_{\phi} = 0$$

...and for the field

Where we have used

$$R \simeq \frac{1}{F}\frac{\rho_{m_0}}{a^3}$$

$$\tilde{\rho}_{\phi} = \frac{1}{2a^2}\dot{\phi}^2 + V(\phi) - \frac{3\mathcal{H}\dot{F}}{a^2}$$

Observational constraints

Time variation of the gravitational constant

$$\left|\frac{G_t}{G}\right| = \left|\frac{F_t}{F}\right|$$

$$< 10^{-11} / yr$$

Local laboratories and solar system experiments

Effects on the J.B.D. parameter

(Bertotti et al. Nature 2004)

$$\xi = \sqrt{\frac{16\pi}{\omega_{JBD}}}$$

$$\omega_{JBD} \equiv \frac{F}{F_\phi^2}$$

$$\geq 4 \times 10^4$$

Effects induced on photon trajectories from G variation

Nucleosynthesis

$$-1.4 \leq \Delta N \leq 0.6 \rightarrow -0.1 \leq \xi\phi \leq 0.3$$

This bound guaranties a value for ^{4}He and Deuterium in concordance with recent extimates.

$$0.228 \leq Y_p \leq 0.256$$

$$2.4\times10^{-5} \leq D/H \leq 3.2\times10^{-5}$$

R-boost

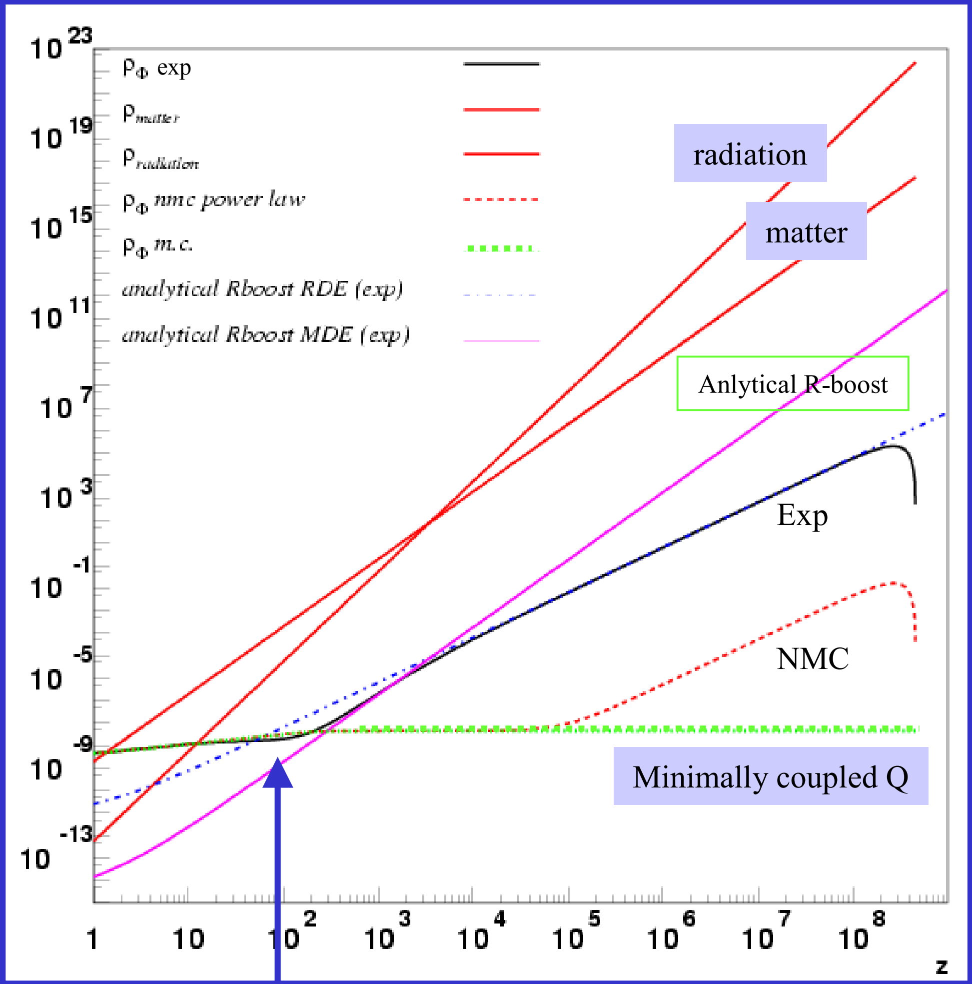
The coupling generates a new purely gravitational effect called R-boost

$$\ddot{\phi} + 2H\dot{\phi} - \frac{a^2 F_\phi R}{2} + a^2 V_\phi = 0$$

When $R \cong \frac{1}{F}\frac{\rho_{m_0}}{a^3} \neq 0$ there is an effective gravitational potential acting on the field

Baccigalupi Matarrese Perrotta 2000

Energy density behaviour



$\dot{\phi}_{beg} = 0$

$\omega_{JBD} = 10^5$
$\xi = 1.6\times10^{-2}$

The RDE is dominated by the R-boost

$$2H\dot{\phi} \approx \frac{a^2 F_{\phi} R}{2}$$

slow roll

The minimally coupled solution is equivalent to a cosmological constant in RDE. It moves only recently, when it reaches the tracker solution

V becomes important: end of slow-roll; ρ_ϕ reaches the required value today

RDE & MDE

Analytical solutions of the K.G. equation

RDE $a \propto \tau$

$$\phi(\tau) = \frac{\xi}{4}\rho_{m_0}\sqrt{\frac{3}{8\pi\rho_{r_0}}}\tau + \phi_{beg}$$

$$\frac{1}{2}{\phi_t}^2 = \frac{1}{2}\frac{\dot{\phi}^2}{a^2} = \frac{3}{32}\frac{{\rho_{m_0}}^2}{\rho_{r_0}}\frac{\xi^2}{8\pi}(1+z)^2$$

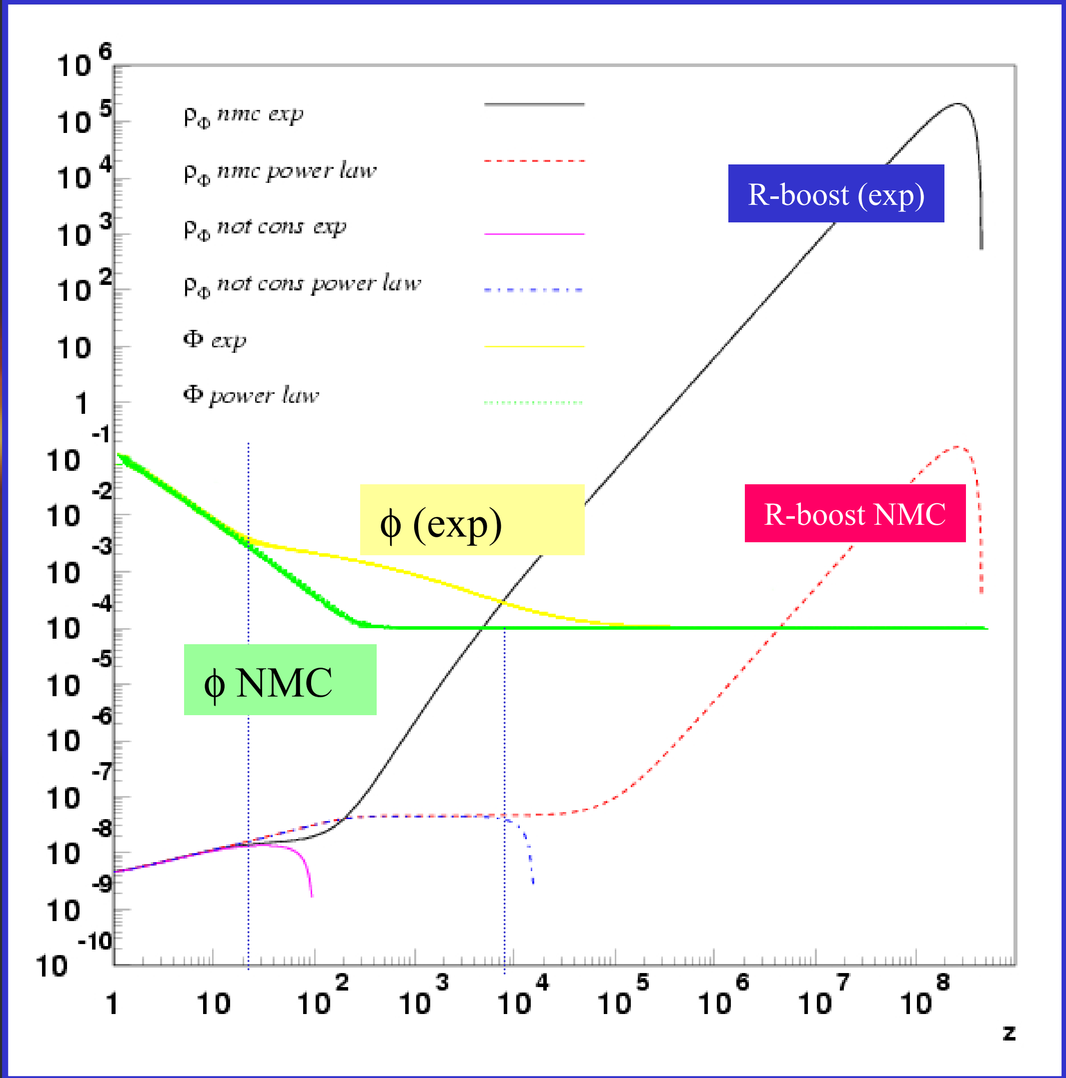
MDE $a \propto \tau^2$

$$\phi(\tau) = \frac{3}{16\pi}\xi \log\tau + const$$

$$\frac{1}{2}{\phi_t}^2 = \frac{1}{2}\frac{\dot{\phi}^2}{a^2} = \frac{3}{256\pi}\xi^2\rho_{m_0}(1+z)^3$$

Independent of ϕ_{beg}

R-boost effects



Stability

If we look for scaling solutions of the K.G. equation:

$$\rho_\phi \propto a^{-n}$$

when the background is:

$$\rho \propto a^{-m}$$

we find that the R-boost solution is given by:

$$\phi_e = \phi_0 \left(\frac{t}{t_0}\right)^{-\frac{n}{m}+1}$$

and F must be:

$$\frac{F_\phi}{F} = A\phi^B$$

B(m,n) = 0 for exp coupling

ϕ_e is an attractor

Conclusions

- The coupling generates a purely gravitational effect called R-boost.

- The R-boost dynamics is the most relevant effect during the initial motion of the field, dominated by kinetic energy.

- The R-boost is an attractor, independently of V, that restores a large basin of attraction even if the true potential is flat.

- The exponential coupling gives a stronger effect than the power law NMC model both on ρ_ϕ and on ϕ.

- The exponential coupling, of dilatonic-inspiration, is the simplest expression for the coupling to give scaling solutions to K.G. equation.

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