

Review on dark energy and alternatives

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Introduction

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- At low energies? At large scales?

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- What is it?

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- What is the phenomenological picture of gravity?
Minkowski?

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 - ★ Set/constrain a model
 - ★ Where does it come from?

DE as a scalar field

- Minimally coupled scalar field, quintessence

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- Mass of quintessence field, $m_\phi \sim 10^{-33}$ eV.
- In general difficult to accomodate in particle physics
[Frieman et al 1995; Hall et al 2005]

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- In FLRW universe, $ds^2 = -dt^2 + a(t)^2 d\mathbf{x}^2$, $H = \dot{a}/a$

$$3M_P^2 H^2 = \rho_\phi + \rho_m,$$

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0,$$

$$\dot{\rho}_m + 3H\rho_m = 0$$

$$\rho_\phi \equiv \frac{1}{2}\dot{\phi}^2 + V; \rho_\phi - p_\phi = 2V,$$

Constraints from data

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- Structure formation, Lensing . . .

Quintessence: thawing models

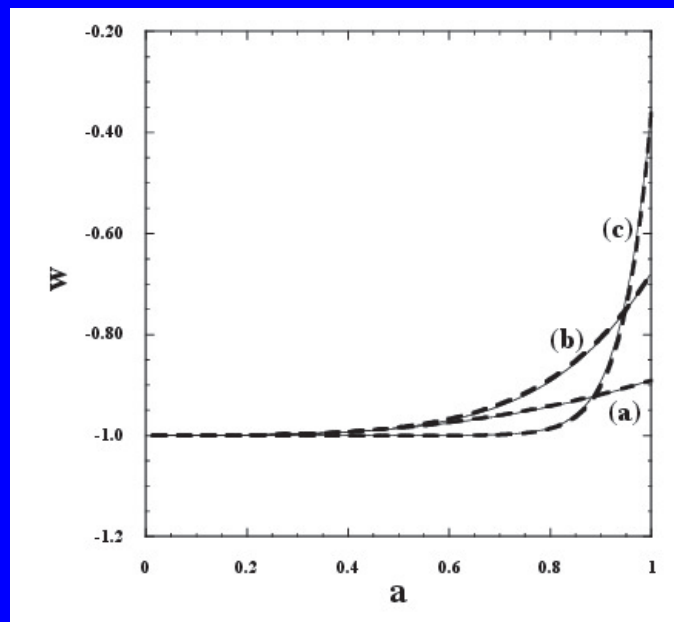
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Quintessence: freezing models

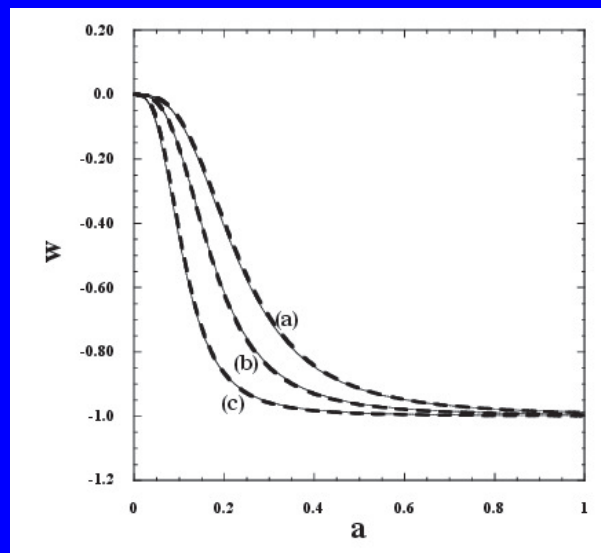
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- *Scaling Freezing*: $w \rightarrow 0 \rightarrow -1$
- Typical example $V = \mu(e^{\lambda_1\phi} + \lambda_3 e^{\lambda_2\phi})$



Tracker freezing models

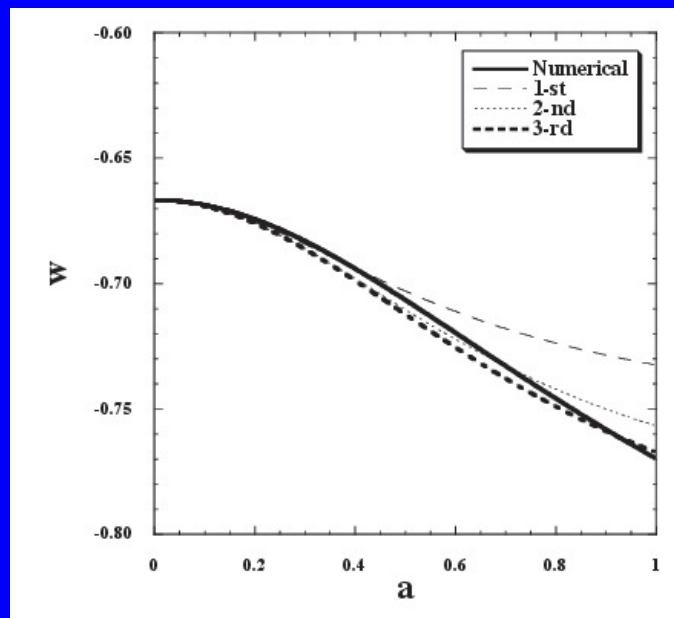
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- Extra-dimensions

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- Working toy models appeared: $f' > 0$, $f'' > 0$, $f(0) = 0$

$$f = R - \mu R_c \left[\frac{(R/R_c)^{2n}}{1 + (R/R_c)^{2n}} \right], \text{ [Hu et al 2007]}$$

$$f = R - \mu R_c \left[1 - \left(1 + R^2/R_c^2 \right)^{-n} \right], \text{ [Starobinsky 2007]}$$

$$f = R - \mu R_c \tanh(R/R_c). \text{ [Tsujiikawa 2008]}$$

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- See my review [ADF, Tsujikawa: Liv. Rev. in Rel. 2011]

$R + f(G)$ gravity

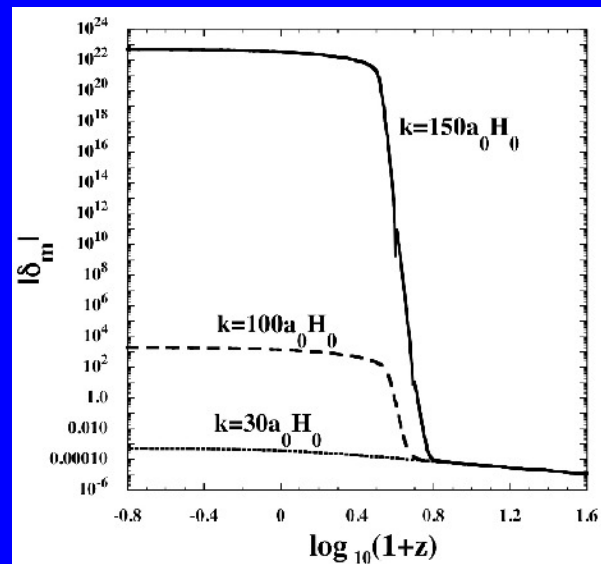
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- Unviable DE models: FLRW unstable [ADF et al, 2011]



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- Unviable DE models: a scalar ghost always present in FLRW [ADF, Tanaka, 2011]

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- Model of brane-bending mode
- Vainshtein mechanism
- Excluded at $2\text{-}\sigma$ by ΛCDM , $\Delta(\chi^2) \sim 20$ [ADF, Tsujikawa: PRL 2011][ADF et al 2012]

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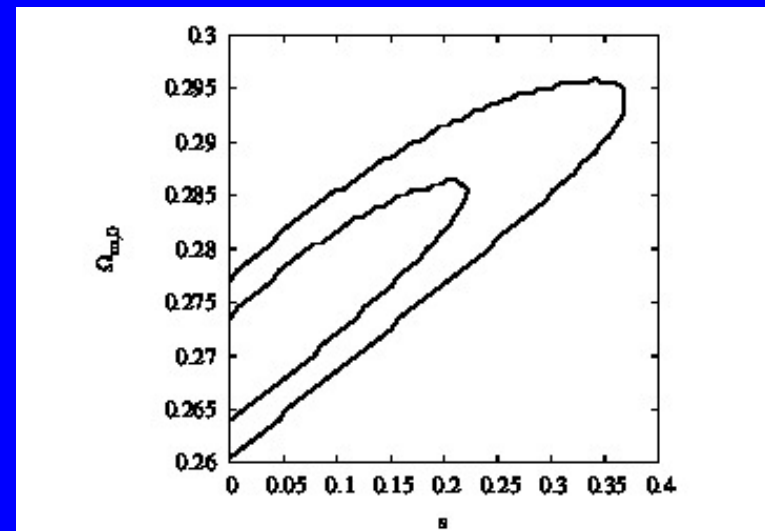
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- General model of DE-induced by extra-dimensions

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- Interesting phenomenology



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- Presence of a non-linear ghost (not spin-2) on FLRW
[ADF et al 2012]

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- Properties of DE: time evolution, eos