2nd Azores School on Observational Cosmology
june, 3rd 2014

Probing non-standard gravity with the growth index of cosmological perturbations

Dark Energy
Brane-word cosmology
clustering quintessence
PPF
Λ
Modified Gravity
scalar field
DGP
LTB
f(*R*)
vacuum energy
Quintessence
k-essence
Cosmological constant

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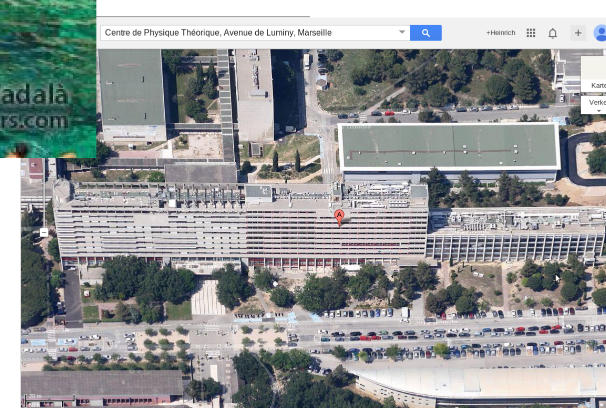

talk by
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H. Steigerwald, J. Bel, C. Marinoni, (2014) [arXiv:1403:0898]   (accepted by JCAP)

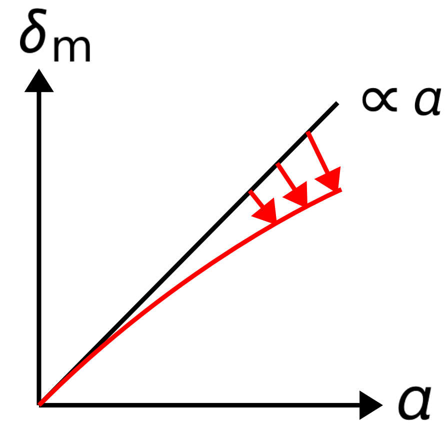
Context

- The problem is <u>not</u> the lack of theories to explain cosmic acceleration
- The simplest model – the ΛCDM model – is doing well with observations (CMB, SNIa, LSS, …)
- Why worry about more complicated models, what can we win?
  1) Either constrain away a large number of theories
  2) Or maybe discover new physics
  3) ΛCDM is unsatisfactory until the microscopic origin of Λ is known (my opinion)
- Even though all accelerating models are tuned to fit the background evolution, their respective predictions for LSS are very different
- Consistency tests of specific models are abundant, what we would like is a model independant ananlysis

First order matter perturbations

$$\rho_\mathrm{m}(t,\mathbf{x}) = \bar{\rho}_\mathrm{m}(t)(1+\delta_\mathrm{m}(t,\mathbf{x}))$$

$$\ddot{\delta}_\mathrm{m} + 2\nu H\dot{\delta}_\mathrm{m} - 4\pi\mu G\rho_\mathrm{m}\delta_\mathrm{m} = 0$$



(matter only)

(matter + Λ)
damping because H
is higher in the past!

In more sophisticated models,
we have additional source μ and damping ν
In ΛCDM, $\mu = \nu = 1$

Introduce the growth rate $f = \frac{d\ln\delta_\mathrm{m}}{d\ln a}$

$$f' + f^2 + (1 + \nu + \frac{H'}{H})f - \frac{3}{2}\mu\Omega_\mathrm{m} = 0$$

What is the general solution?

- f depends on kinematics : $\frac{H'}{H}, \Omega_\mathrm{m}$ (SNIa, CMB, ...)
- f depends on dynamics : μ, ν (LSS)

growth index

Common definition : $f = \Omega_\mathrm{m}^\gamma$

new ansatz : $$\gamma = \sum_n \gamma_n \frac{(\ln\Omega_\mathrm{m})^n}{n!}$$

[arXiv:1403:0898]

→ very precice for models 'close' to ΛCDM
→ growth indexes γ_n are analytic

Data analysis technique

Growth data (2014)

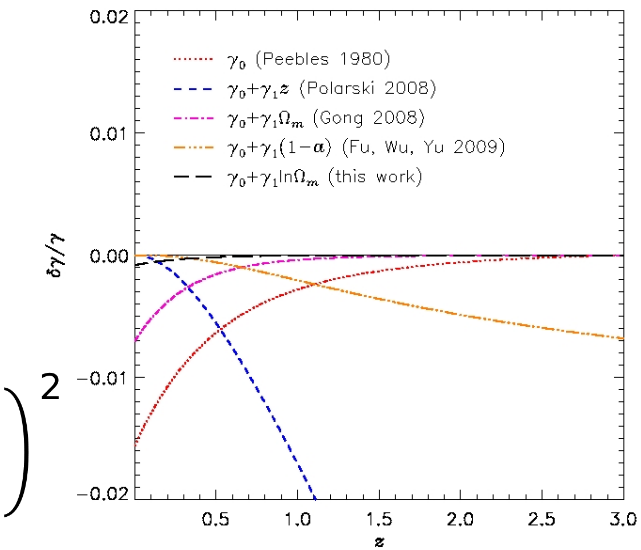
Label	Reference	z	$f\sigma_8$
THF	Turnbull *et al.* (2012)	0.02	0.40 ± 0.07
DNM	Davis *et al.* (2011)	0.02	0.31 ± 0.05
6dFGS	Beutler *et al.* (2012)	0.07	0.42 ± 0.06
2dFGRS	Percival *et al.* (2004) , Song & Percival (2009)	0.17	0.51 ± 0.06
2SLAQ	Ross *et al.* (2007)	0.55	0.45 ± 0.05
SDSS	Cabré *et al.* (2009)	0.34	0.53 ± 0.07
SDSS II	Samushia *et al.* (2012)	0.25	0.35 ± 0.06
		0.37	0.46 ± 0.04
BOSS	Reid *et al.* (2012)	0.57	0.43 ± 0.07
WiggleZ	Contreras *et al.* (2013)	0.20	0.40 ± 0.13
		0.40	0.39 ± 0.08
		0.60	0.40 ± 0.07
		0.76	0.48 ± 0.09
VVDS	Guzzo *et al.* (2008) , Song & Percival (2009)	0.77	0.49 ± 0.18
VIPERS	De la Torre *et al.* (2013)	0.80	0.47 ± 0.08

Theory

$$f(\boldsymbol{\gamma}, \mathbf{p}, z) = \Omega_m(\mathbf{p}, z)^{\sum_n \gamma_n \left(\ln \Omega_m(\mathbf{p},z)\right)^n / n!}$$

$$\sigma_8(\boldsymbol{\gamma}, \mathbf{p}, z) = \sigma_{8,0}\, e^{\int_0^z \frac{f(\boldsymbol{\gamma},\mathbf{p},z')}{1+z'} dz'}$$

$$\chi^2(\boldsymbol{\gamma}, \mathbf{p}) = \sum_{i=1}^{N} \left(\frac{(f\sigma_8)_{\mathrm{obs}}(z_i) - f(\boldsymbol{\gamma}, \mathbf{p}, z_i)\sigma_8(\boldsymbol{\gamma}, \mathbf{p}, z_i)}{\sigma_i} \right)^2$$



$$\mathbf{p} = (\sigma_{8,0}, \Omega_{m,0}, w_0, w_a)$$

background parameters (except for $\sigma_{8,0}$)

$$\boldsymbol{\gamma} = (\gamma_0, \gamma_1, \ldots)$$

perturbation parameters

- Plot the likelihood contours $\mathcal{L} = \exp(-\frac{1}{2}\chi^2) = 68\%, 95\%$
- This constrains gravity, given that we know exactly the background evolution
- However, $w = -1.13 \pm 0.25$ (*Planck*+WP+BAO), etc.

Remapping growth indexes into the fiducial background

- Fix a fiducial background $\bar{\mathbf{p}} = (\bar{\sigma}_{8,0}, \bar{\Omega}_{\mathrm{m},0}, \bar{w}_o, \bar{w}_a)$
- Analyse the growth data in the fiducial background
- Remap the model growth indexes into the fiducial background

Example: wCDM model:

Growth indexes:

$$\gamma_0 = \frac{3(1-w)}{5-6w}$$

$$\gamma_1 = -\frac{3(1-w)(2-3w)}{2(5-12w)(5-6w)^2}$$

Model parameters

$$\mathbf{p} = (0.835, 0.315, w, 0)$$

$$f(\boldsymbol{\gamma}^*, \bar{\mathbf{p}}, z) = f(\boldsymbol{\gamma}, \mathbf{p}, z)$$

z in [0,2]

Fiducial model parameters

$$\bar{\mathbf{p}} = (0.835, 0.315, -1, 0)$$

$$\boldsymbol{\gamma}^* = (\gamma_0^*, \gamma_1^*)$$

Effective growth indexes

- Errors are of order 0.3% for Euclid and 3% for current data (and the most extreme models)

Results : current growth data vs theories