Theoretical and Observational Aspects of Coupled Dark Energy

Andresa Campos, Rogerio Rosenfeld
IFT-Unesp, ICTP-SAIFR

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I - Introduction

Standard Cosmological Model - ΛCDM

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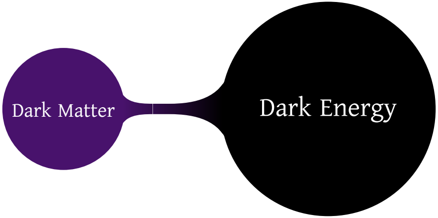

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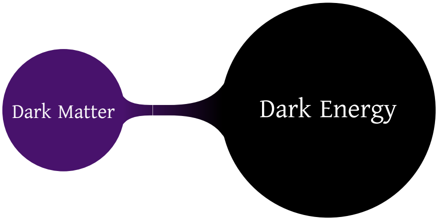

Coupled Quintessence

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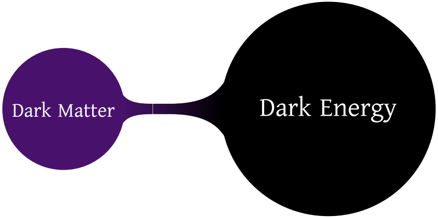


Coupled Quintessence **Phenomenological Fluids**

II - Coupled Dark Energy (Phen. Approach)

- Energy-momentum tensor:

$$\nabla_\nu T^{\nu}_{(\alpha)\mu} = Q_{(\alpha)\mu},$$

with the constraint

$$\sum_\alpha Q_{(\alpha)\mu} = 0.$$

- The choice of $Q_{(\alpha)\mu}$ specifies the strength of the coupling.

$$Q = 3\mathcal{H}\lambda\rho_d.$$

λ: **new parameter**

Other choices can be made!!

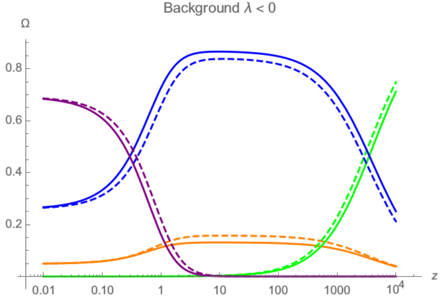
Recall $T^{\nu}_{(\alpha)\mu} = (\rho_\alpha + p_\alpha)u_\mu u^\nu + p_\alpha \delta^\nu_\mu$ where $u_\mu = (-a, 0, 0, 0)$ and $w_\alpha \equiv p_\alpha/\rho_\alpha$.

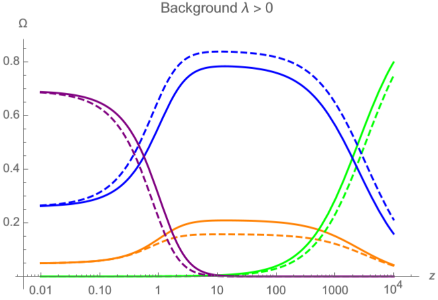
III - Background

Conservation equations

$$\dot{\rho}_d + 3\mathcal{H}\rho_d(1+w_d) = -3\mathcal{H}\lambda\rho_d$$
$$\dot{\rho}_c + 3\mathcal{H}\rho_c = +3\mathcal{H}\lambda\rho_d$$

- $\lambda < 0$: DM $\longrightarrow$ DE
- $\lambda > 0$: DE $\longrightarrow$ DM





IV - Perturbations

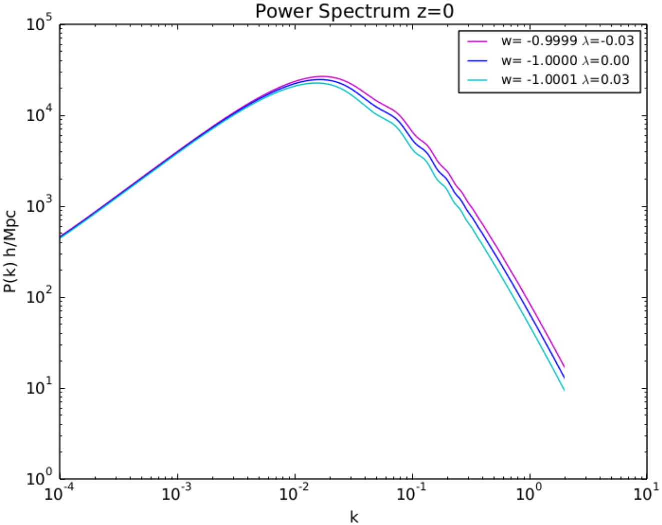
Linear perturbations in synchronous gauge

$$
\begin{aligned}
\dot{\delta}_c &= -(kv_c + \dot{h}/2) + 3\mathcal{H}\lambda(\delta_d - \delta_c)\rho_d/\rho_c, \\
\dot{v}_c &= -\mathcal{H}v_c(1 + \lambda\rho_d/\rho_c), \\
\dot{\delta}_d &= -(1+w)(kv_c + \dot{h}/2) \\
&+ 3\mathcal{H}[(w - c_e^2) - 3\mathcal{H}(c_e^2 - c_a^2)(1+w+\lambda)v_d/k], \\
\dot{v}_d &= -\mathcal{H}(1 - 3c_e^2)v_d + \frac{3\mathcal{H}}{1+w}(1+c_e^2)\lambda v_d + kc_e^2\frac{\delta_d}{1+w}.
\end{aligned}
$$

CAMB, CLASS, CMBFAST etc.

V - Modified CAMB

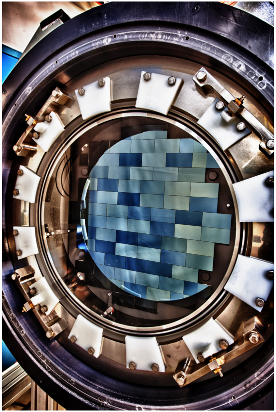
We use a modified version of CAMB† to solve these equations.



- *Shift in the matter-radiation equality;*
- *Change in location and amplitude of the BAO;*
- *Change in velocity of perturbation growth.*

† *Andre Costa, Xiao-Dong Xu, Bin Wang, and Elcio Abdalla. (ArXiv:1605.04138)*

VI - Dark Energy Survey



Photometric Galaxy Survey

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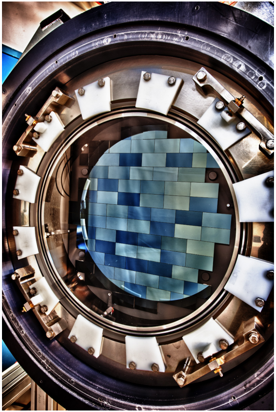

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High redshift

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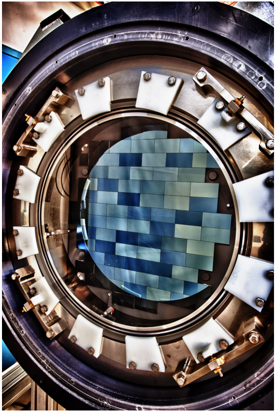

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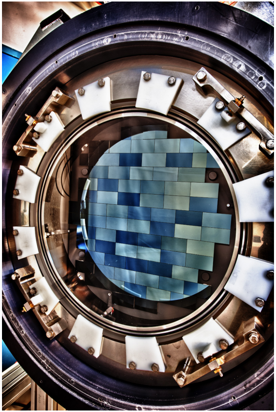

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- High redshift
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Standard approach: split the data into redshift bins and use $\omega(\theta)$ or C_ℓ .

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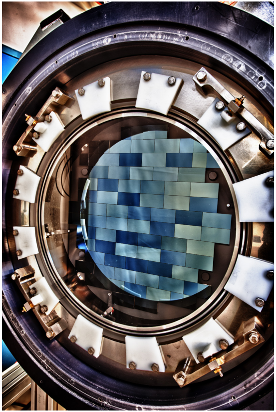

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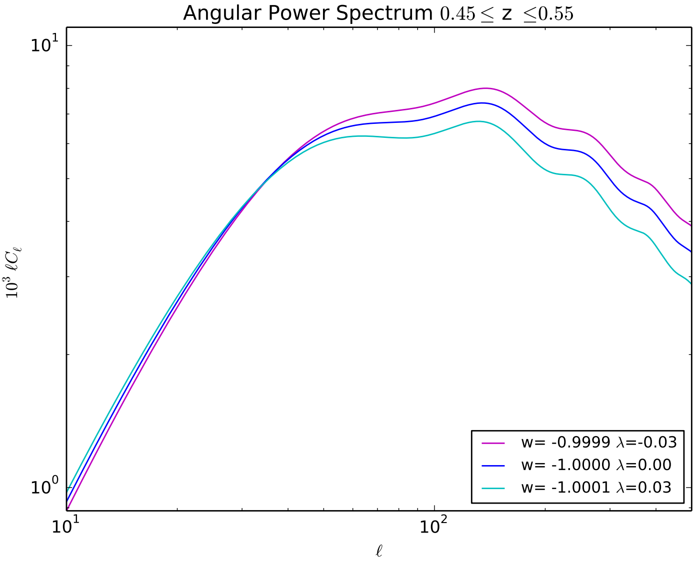
$$C_{\ell,Limber} = \int \mathrm{d}z \phi^2(z) P\left(\frac{\ell + 1/2}{r(z)}\right) \frac{1}{r^2(z)}.$$

VI - Angular Matter Power Spectrum



VII - Fisher Information Matrix

Assuming a Gaussian likelihood, the Fisher matrix elements are given by

$$\mathcal{F}_{\alpha\beta} = \sum_i \frac{1}{\sigma_i^2} \frac{\partial X_i}{\partial \theta_\alpha} \frac{\partial X_i}{\partial \theta_\beta}$$

$X_i \rightsquigarrow C_\ell$

$\theta \rightsquigarrow \lambda$ and w

$\lambda_{fid} = 0$ and $w_{fid} = -1.0001$

The variance in the C_ℓ's can be estimated as $\sigma_\ell^2 \approx \dfrac{2\, C_\ell^2}{f_{sky}(2\ell + 1)}$.

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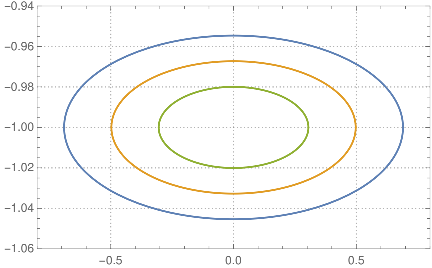
$$[\mathcal{F}]^{-1} = \mathbf{C} = \begin{pmatrix} \sigma_\lambda^2 & \sigma_\lambda \sigma_w \\ \sigma_\lambda \sigma_w & \sigma_w^2 \end{pmatrix}$$

Preliminary results!



Next

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- Beyond Limber
- Redshift-space distortions
- Photo-z error
- More redshift bins
- Binning in ℓ

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Data from first year of observations of Dark Energy Survey

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Thank you!

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