Constraining Modified Gravity and Dark Energy Models with Weak Lensing

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Outline

- Motivation
- Why lensing?
- Importance of non-linear modelling
- Predictions for modified gravity
- Predictions for coupled dark energy

Motivation

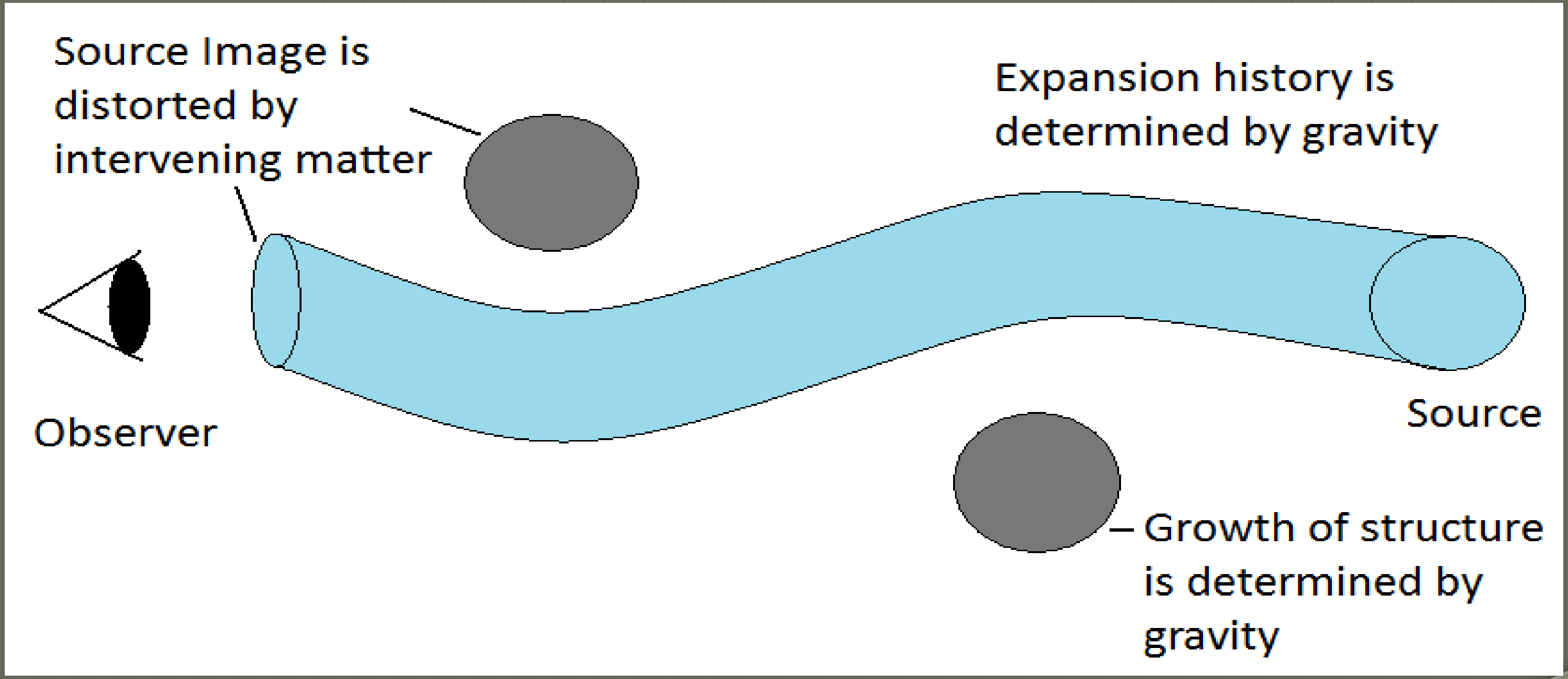
Problems with ΛCDM

- Fine tuning problem
- Coincidence problem

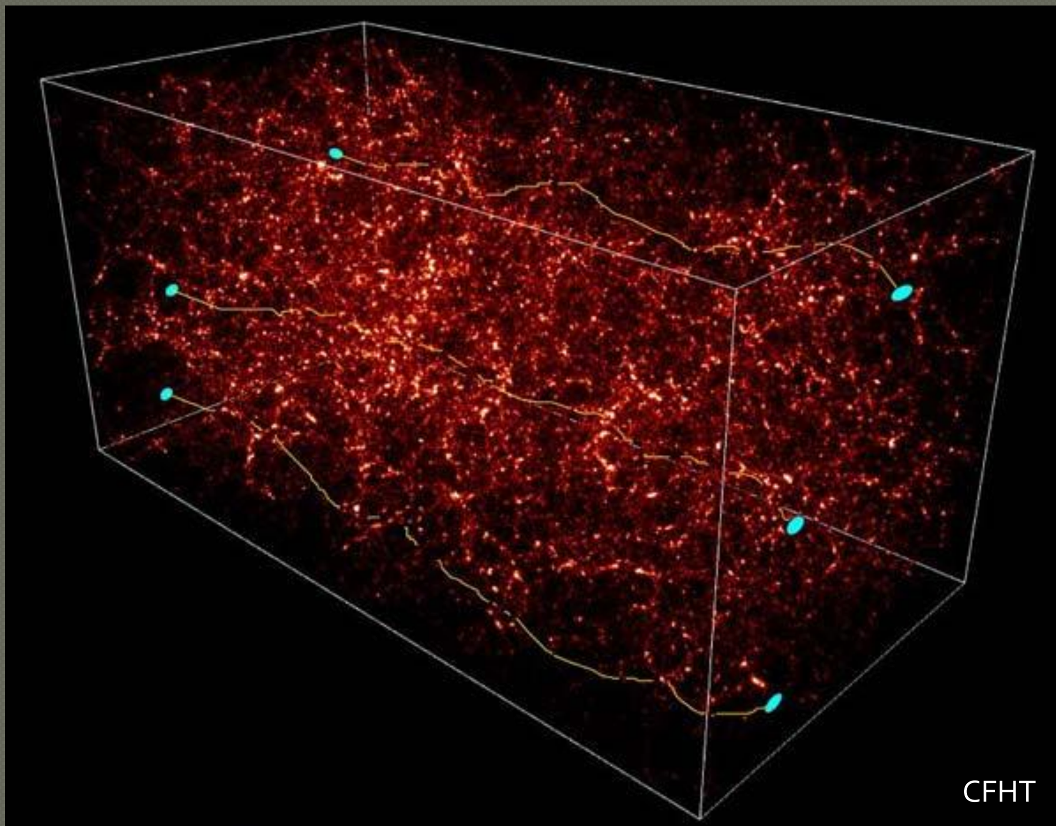
- Two main alternative ways of explaining accelerated expansion
  - Dynamical dark energy
  - Modified Gravity

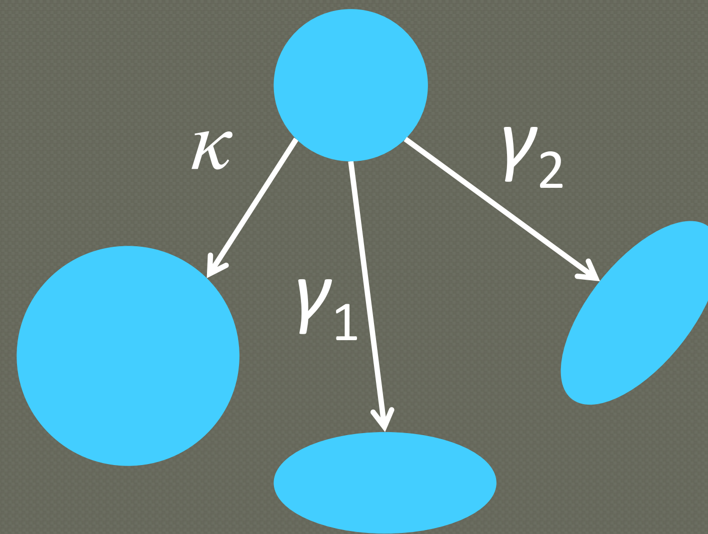
Why lensing?

- Some current observations only probe the expansion history
- Weak lensing probes growth history and expansion history



Weak Lensing





- Light bundles are distorted by

$$\begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

Weak Lensing

- Calculate correlation of observed distortions to overcome intrinsic shape noise

$$C_\gamma(\theta) = \langle \gamma_a \gamma_b \rangle$$

- Changes in matter power spectrum → changes in shear correlation function

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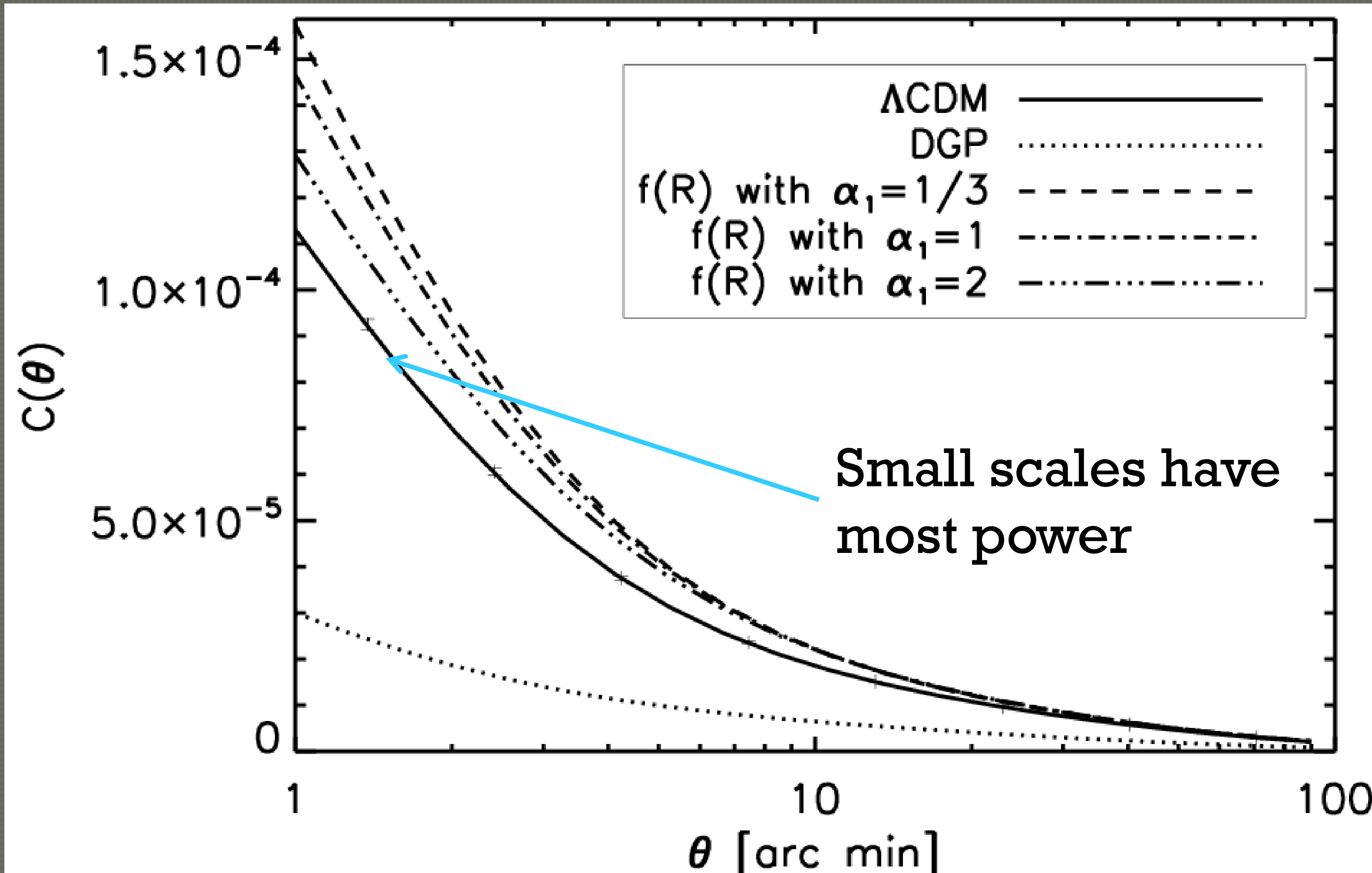
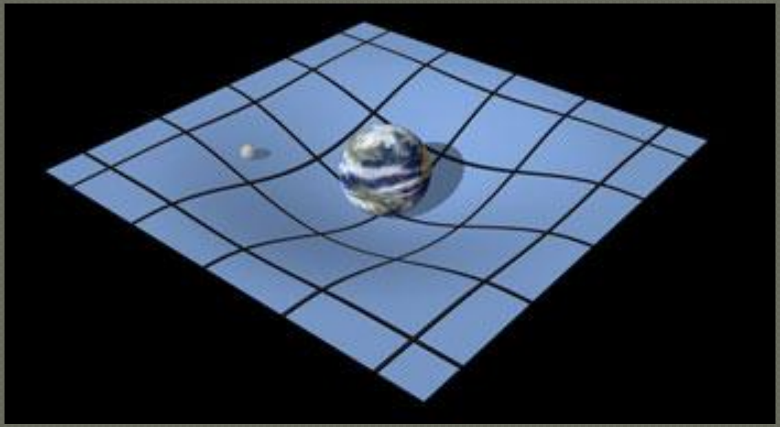
Lensing at non-linear scales



Modified Gravity

- Alternative to DE
- Gravity can be modified to fit expansion history however produces a distinct growth rate of structure



- DGP: 5D braneworld model where
  $r<r_c$ 4D gravity
  $r>r_c$ 5D gravity
- *f(R):* changes relationship between energy-density and spacetime

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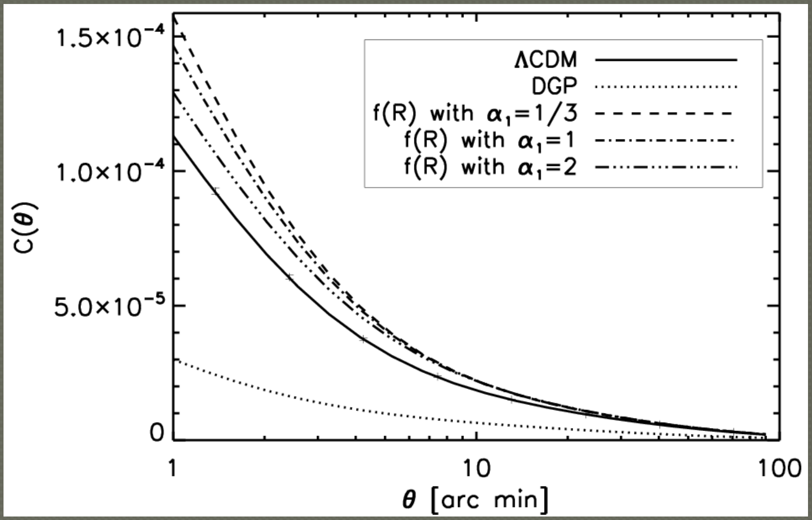
Beynon et al. 2010
MNRAS, 403, 353

Modified Gravity

- MG must asymptote to GR at small scales to fit Solar system observations
- Fitting proposed by Hu & Sawicki 2007 – Interpolate between MG non-linear PS and GR non-linear PS



Fiducial Model	Modified gravity	Ground-based $\Delta\chi^2$	Euclid $\Delta\chi^2$
ΛCDM	DGP	6×10^3	7×10^4
	$f(R)$, $\alpha_1 = 1/3$	600	8×10^3
	$f(R)$, $\alpha_1 = 1$	300	3×10^3
	$f(R)$, $\alpha_1 = 2$	60	1×10^3
QCDM	DGP	0.5	5

- At least an order of magnitude increase in χ^2 when comparing to ΛCDM against using linear alone
- Not including this asymptote falsely increases discriminatory power by up to 90%

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Beynon et al. 2012
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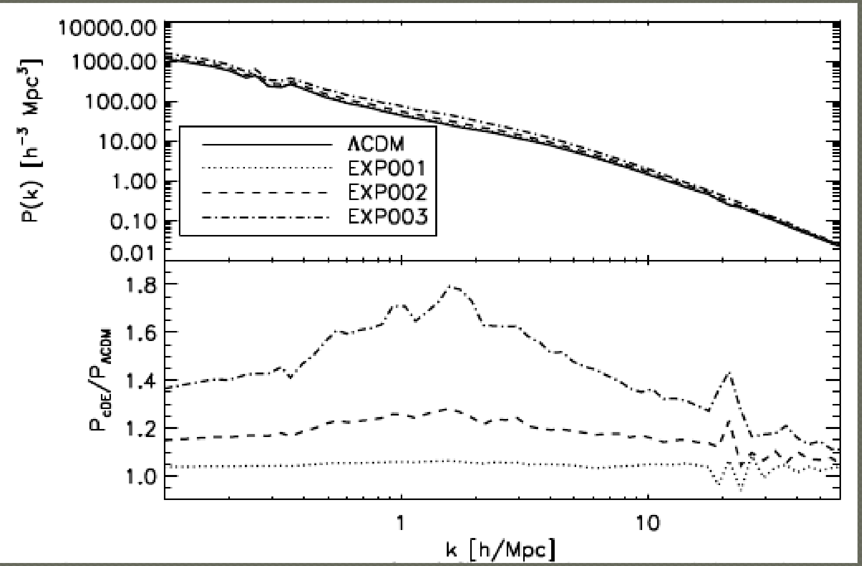
Coupled Dark Energy

- Alternative to Λ is evolving DE
- Baryon interactions tightly constrained by observations but can couple dark sector

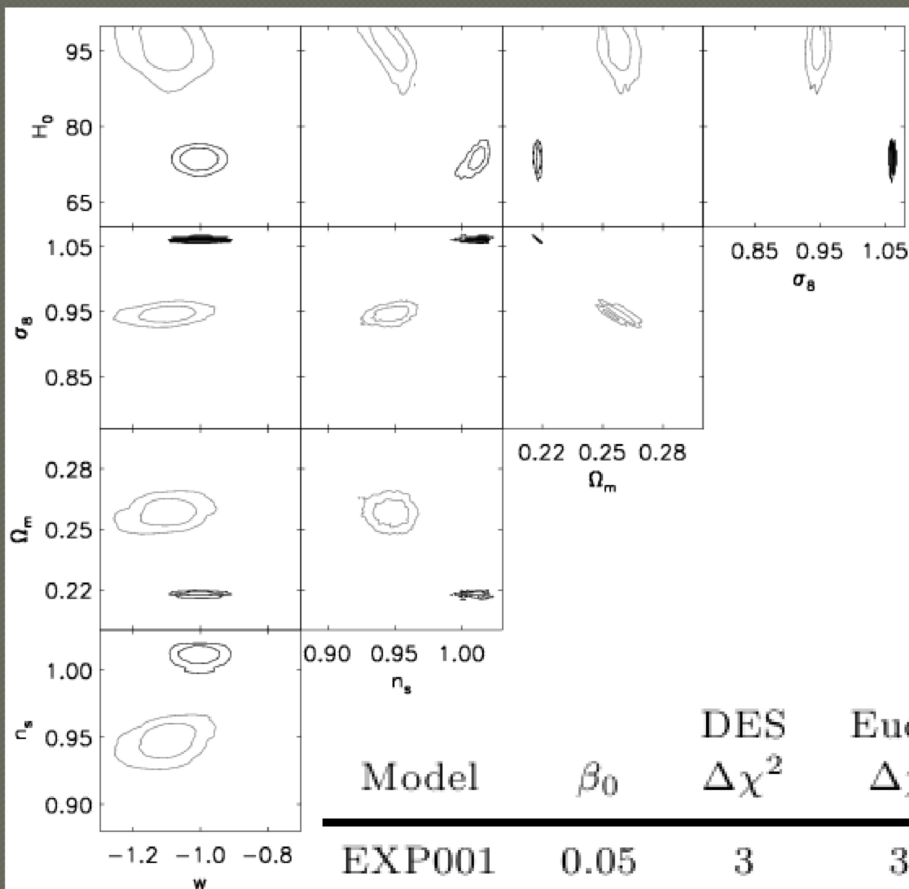


$$\rho_c' + 3H\rho_c = -\beta(\phi)\rho_c\phi'$$

$$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = \beta(\phi)\rho_c$$

- Use Baldi 2011 CoDECs N-body simulations to obtain non-linear

Coupled Dark Energy



Model	β_0	DES $\Delta\chi^2$	Euclid $\Delta\chi^2$
EXP001	0.05	3	30
EXP002	0.1	48	480
EXP003	0.15	340	3300

- Important to use full covariance matrix as off diagonal elements change best fit
- $\beta_0 \leq 0.1$ at 4σ confidence level for DES
- $\beta_0 \leq 0.05$ at 5σ confidence level for Euclid

Summary

- Lensing is a powerful discriminant between different gravity and DE models
- It's necessary to be careful about the GR limit of modified gravities to get the right lensing predictions
- We now have lensing predictions for MG and cDE
- DES and Euclid will be able to substantially constrain these models