Constraining modified gravity theories with weak gravitational lensing

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CAUSTIC

Conventional And Unconventional Studies & Tools In Cosmology

INFN Istituto Nazionale di Fisica Nucleare

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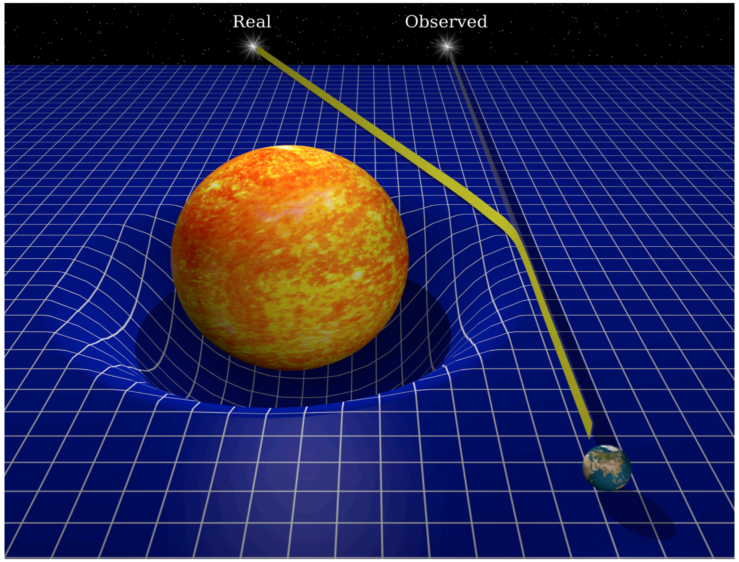
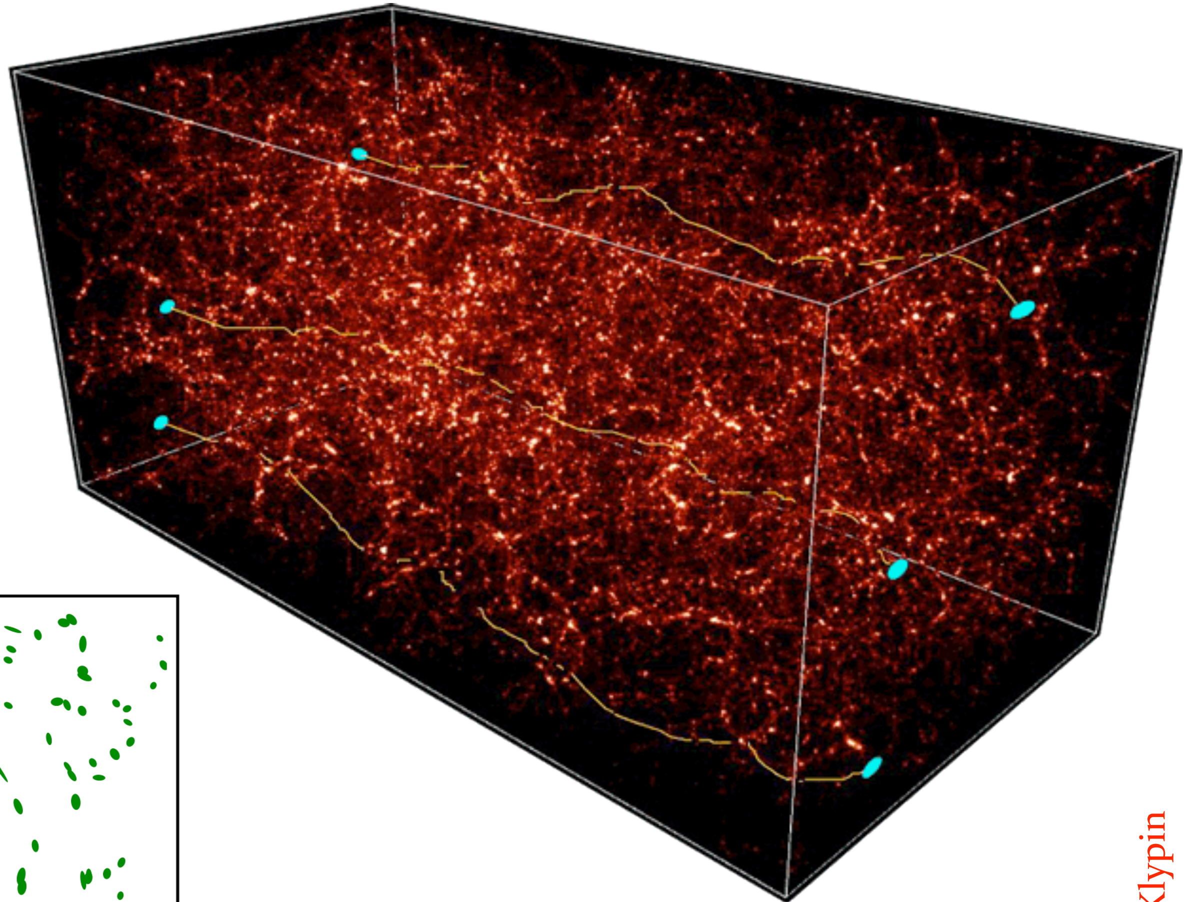
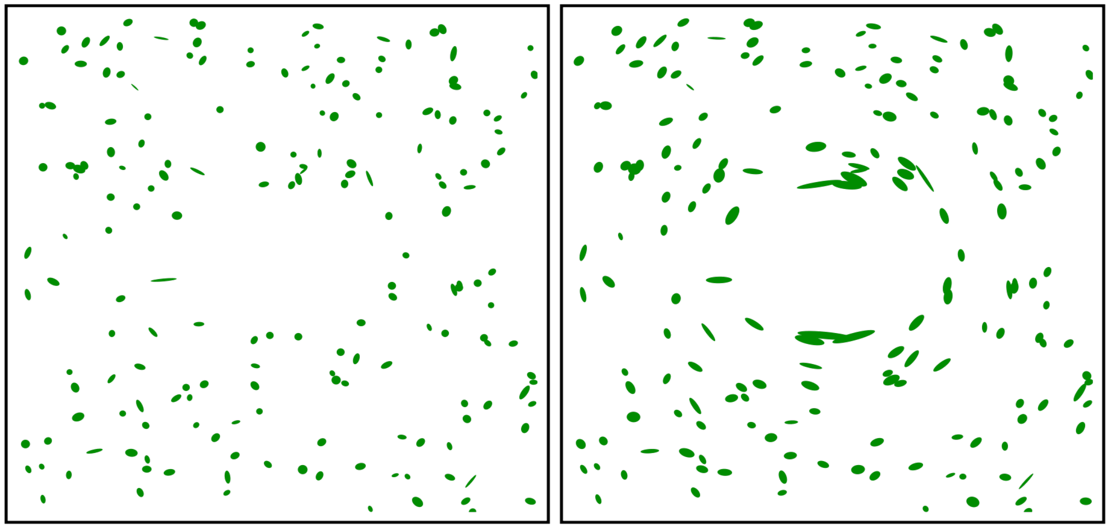
Outline

- Weak gravitational lensing
  - Next future missions and surveys
- Modified gravity theories
  - Unified DM and DE models
  - Brane-world cosmologies
  - Modified-action theories
- Conclusions

Weak gravitational lensing

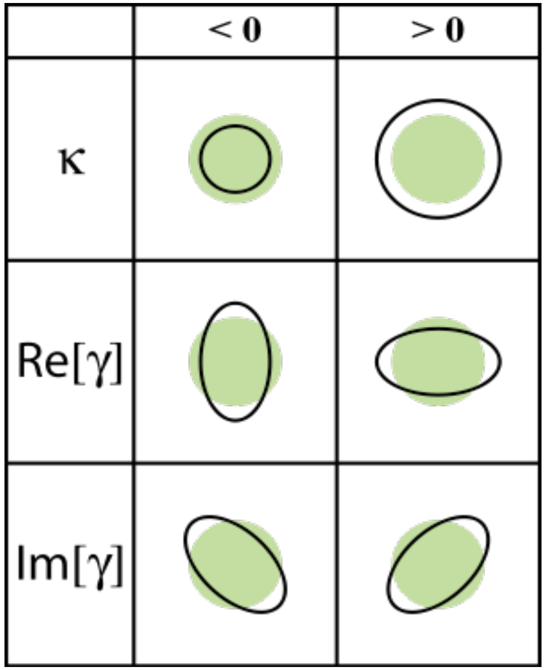






Kravtsov & Klypin

Weak gravitational lensing



Distorsion tensor:

$$\psi_{ij} \equiv \begin{pmatrix} \kappa + \mathrm{Re}[\gamma] & \mathrm{Im}[\gamma] \\ \mathrm{Im}[\gamma] & \kappa - \mathrm{Re}[\gamma] \end{pmatrix} = \int_0^{\chi} \mathrm{d}\chi' \, \chi' W(\chi') \left[\frac{\mathbf{\Psi} - \mathbf{\Phi}}{2} \right]_{,ij}$$

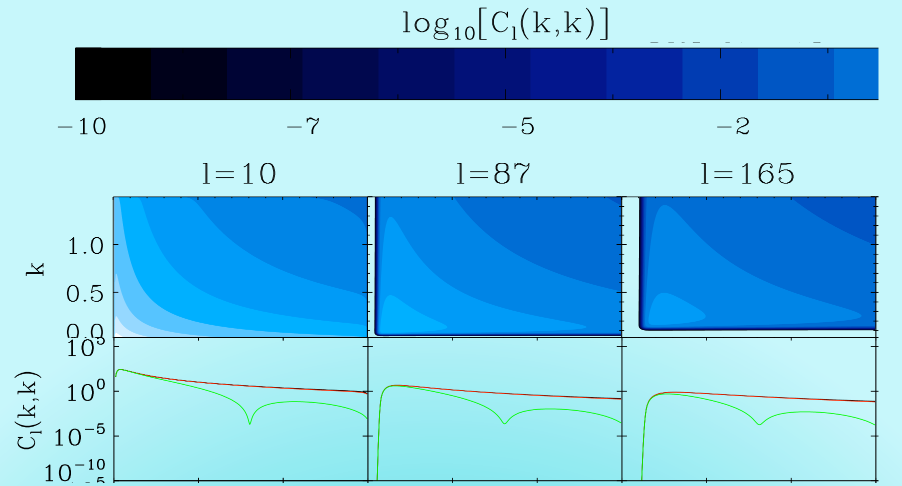
- $\chi(z)$ radial comoving distance
- $W[\chi(z)]$ window function
- **Φ**=-**Ψ** Newtonian potential (in General Relativity)

Linear theory of scalar perturbations: $\mathrm{d}s^2 = -(1 + 2\mathbf{\Phi})\,\mathrm{d}t^2 + a^2(t)\,(1 + 2\mathbf{\Psi})\,\mathrm{d}\mathbf{x}^2$

Weak gravitational lensing

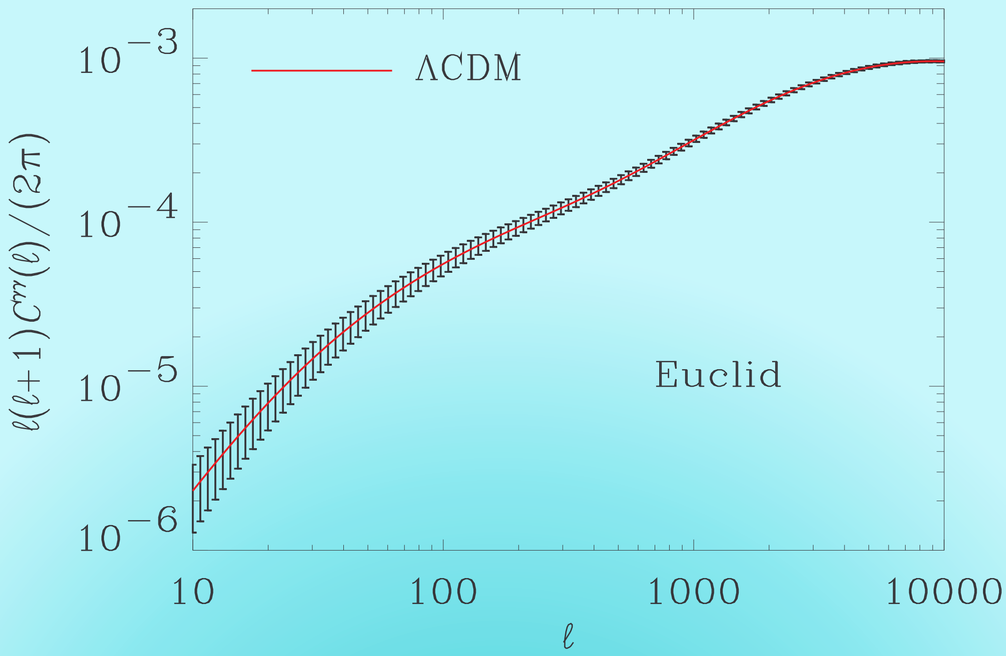
3D shear signal

$$C^{\gamma\gamma}(k_1,k_2;\ell)=\frac{\ell^4}{\pi^2}\int\prod_{i=1}^{2}\mathrm{d}\chi_i\mathrm{d}k\,k^2\frac{\Phi_{k_i}(\chi_i)}{\Phi_{k_i}(0)}W(\chi_i)j_\ell(k_i\chi_i)P^\Phi(k,0)$$



Limber's approximation

$$C^{\gamma\gamma}(\ell)=\frac{\ell^4}{4}\int\mathrm{d}\chi\,\frac{W^2(\chi)}{\chi^6}P^\Phi\left(\frac{\ell}{\chi},\chi\right)$$



Weak gravitational lensing

Pan-STARRS

Pan–STARRS is an innovative design for a wide–field imaging facility being developed at the University of Hawaii's Institute for Astronomy. By combining relatively small mirrors with very large digital cameras we will be able to develop and deploy an economical observing system that will be able to observe the entire available sky several times each month.

Euclid is an ESA mission to map the geometry of the dark Universe. The mission will investigate the distance–redshift relationship and the evolution of cosmic structures by measuring shapes and redshifts of galaxies and galaxy clusters out to a look–back time of 10 billion years. It will therefore cover the entire period over which DE played a significant role in accelerating the expansion of the Universe.

Modified gravity theories

$$\mathscr{L} = \frac{R}{16\pi G} + \mathscr{L}_{m/r} + \mathscr{L}_{\rm DM} + \mathscr{L}_\Lambda$$

UDM models	DGP brane worlds	*f(R)* theories
DM and DE as two aspects of one exotic "dark fluid"	Accelerated expansion via leakage of gravity into extra dimension(s)	DE (and even DM) as curvature effects
$\mathscr{L} = \frac{R}{16\pi G} + \mathscr{L}_{m/r} + \mathscr{L}_{\rm UDM}$	$\mathscr{L} = \frac{R^{(5)}}{16\pi G_{(5)}} + \frac{R^{(4)}}{16\pi G} + \mathscr{L}_{m/r} + \mathscr{L}_{\rm DM}$	$\mathscr{L} = \frac{f(R)}{16\pi G} + \mathscr{L}_{m/r}\,[+\mathscr{L}_{\rm DM}]$

Unified DM and DE models

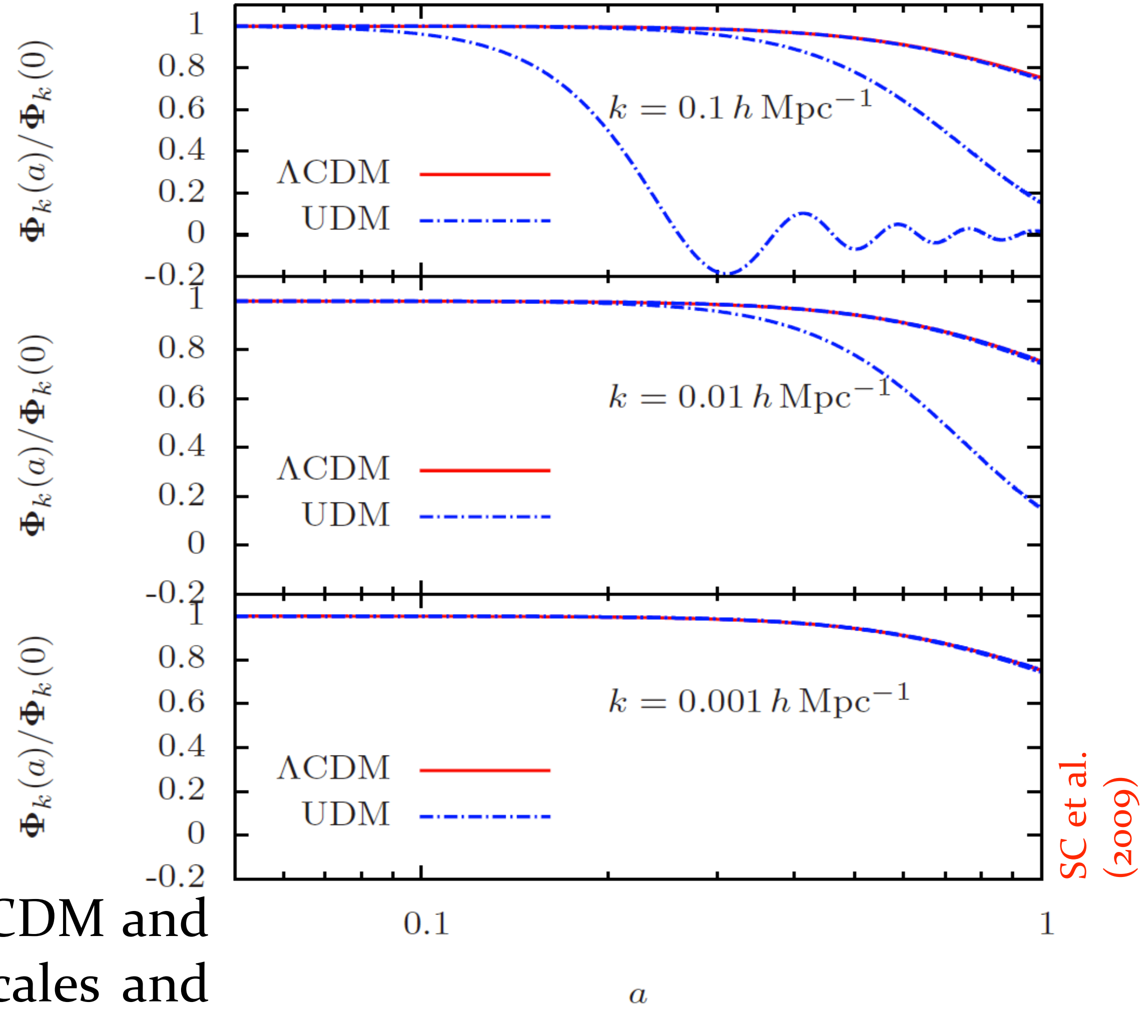
In Unified Dark Matter (UDM) models there is only one exotic component, a scalar field which can mimic both DM and DE:

$$\rho_{\mathrm{UDM}}(t) = \rho_{\mathrm{DM}}(t) + \rho_{\Lambda}(t)$$

$$H(z) = H_0\sqrt{\Omega_m\,(1+z)^3 + \Omega_r\,(1+z)^4 + \Omega_\Lambda}$$

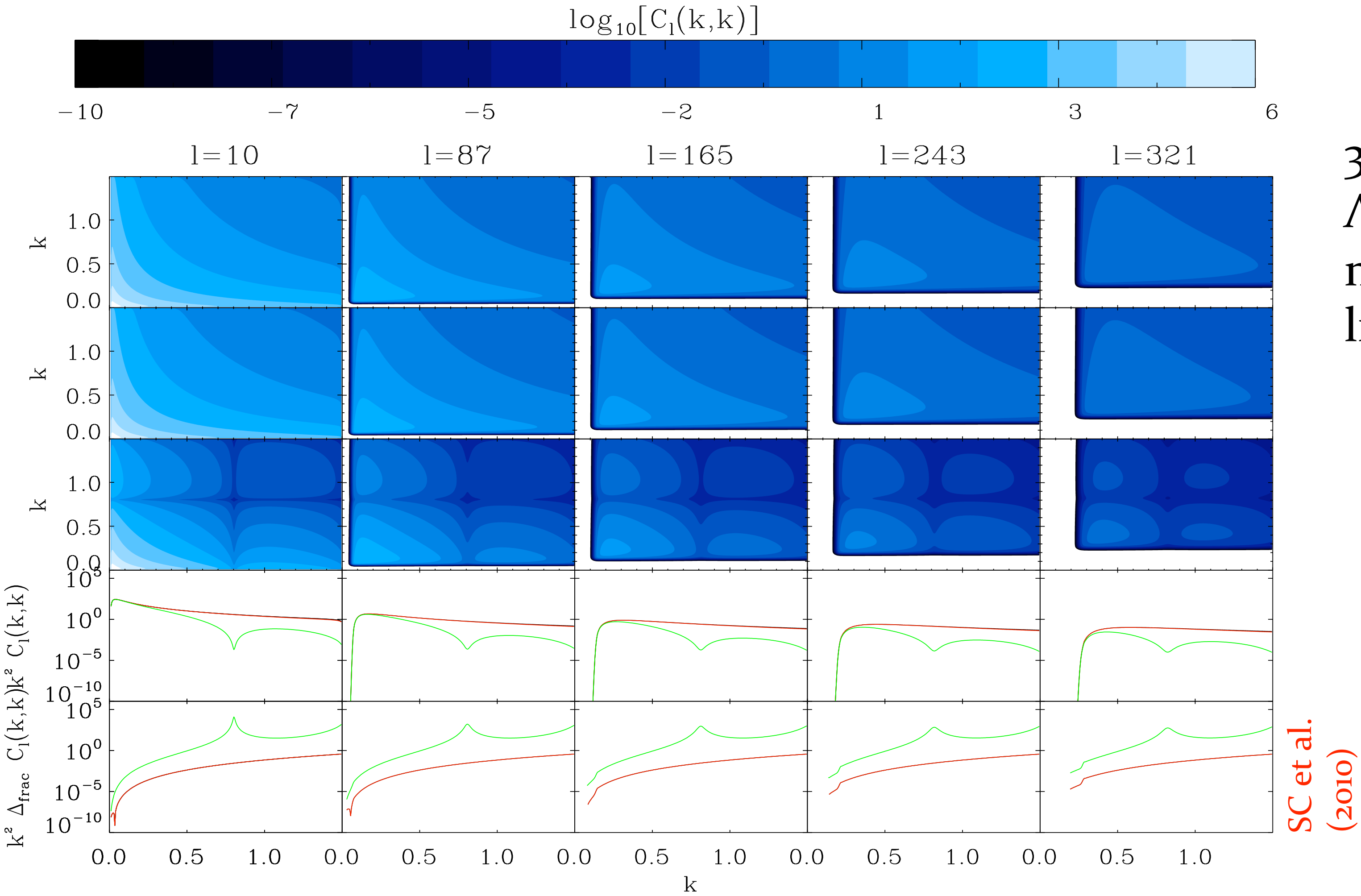
$$\Omega_m = \Omega_b + \Omega_{\mathrm{DM}}$$

$$c_s{}^2(z) = \frac{\Omega_\Lambda {c_\infty}^2}{\Omega_\Lambda + (1-{c_\infty}^2)\,\Omega_{\mathrm{DM}}\,(1+z)^3}$$



Grativational potential in ΛCDM and UDM models at different scales and for different values of c_∞

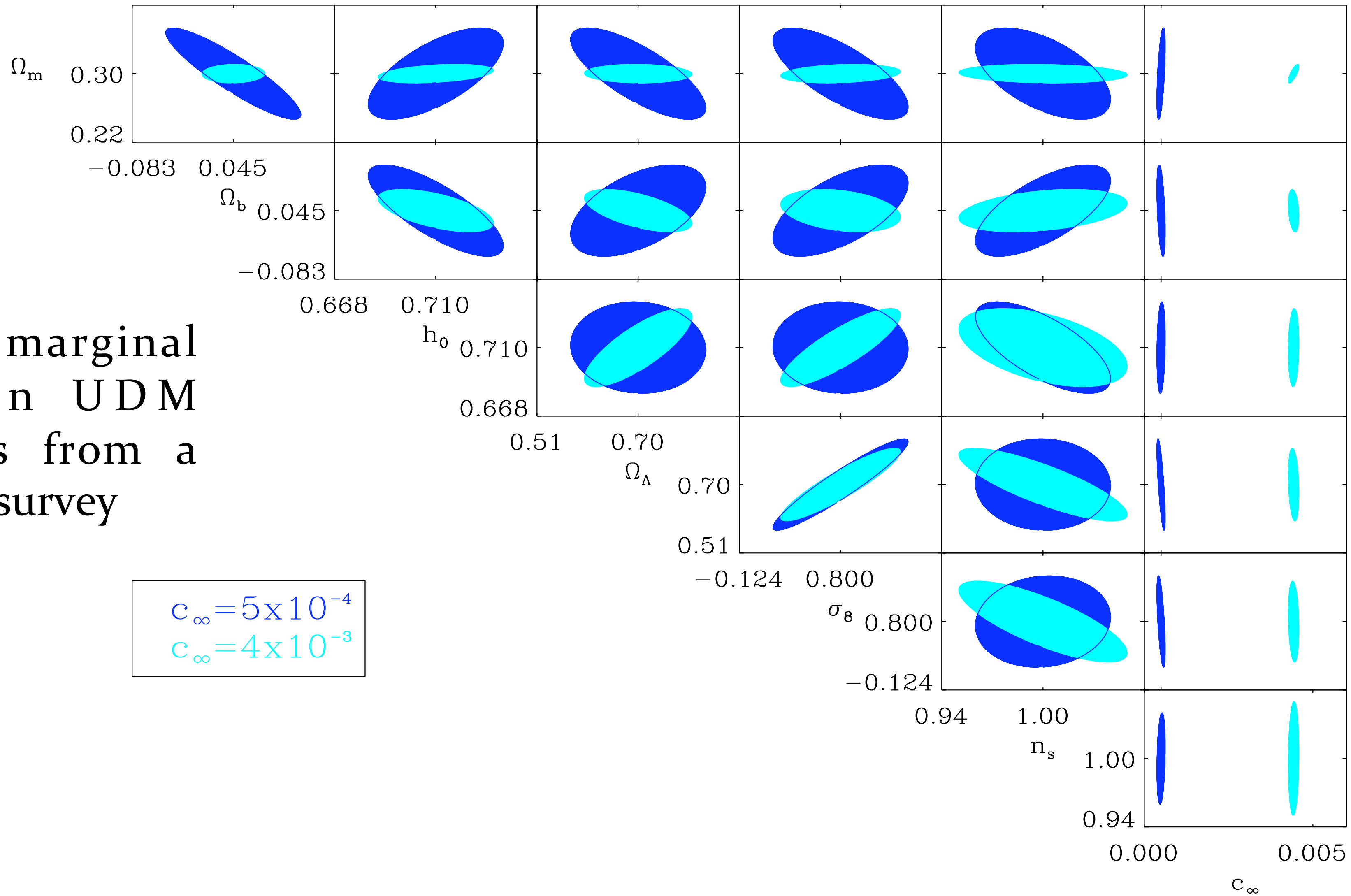
Unified DM and DE models



3D shear signal in ΛCDM and UDM models for a Euclid-like survey

Unified DM and DE models

Expected marginal errors on UDM parameters from a Euclid-like survey



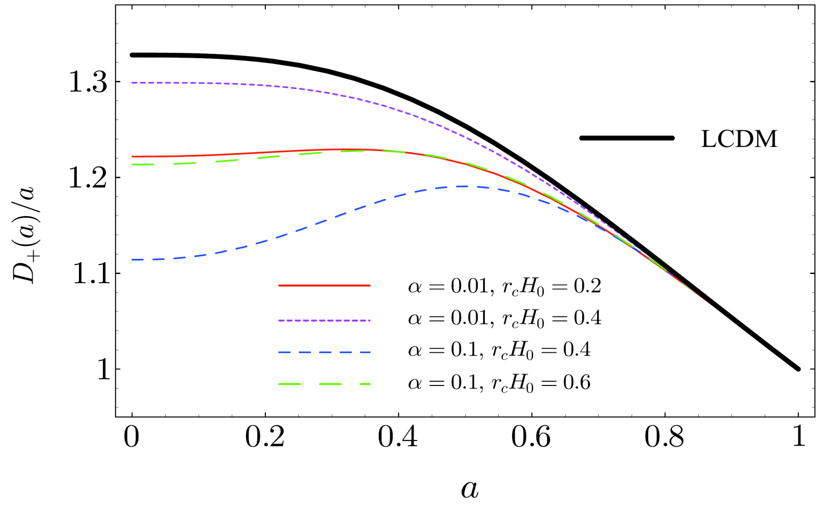
SC et al. (2010)

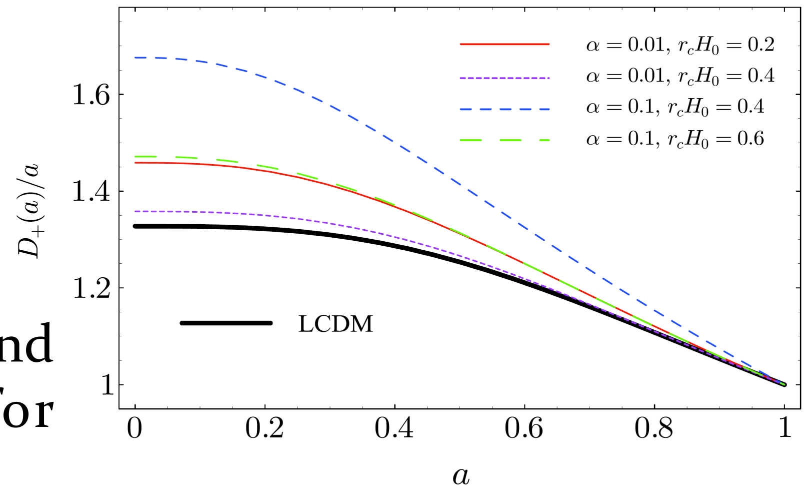
Brane-world cosmologies

In the Dvali-Gabadadze-Porrati (DGP) model and its extensions the Universe is a 4D brane embedded in an higher dimensional bulk.

$$H^2 \pm \frac{H^{2\alpha}}{{r_c}^{2(1-\alpha)}} = H_0 \left(\Omega_m (1+z)^3 + \Omega_r (1+z)^4 + \Omega_\Lambda\right)$$

$$\nabla^2 \left[\frac{\Psi - \Phi}{2}\right] = 4\pi \mathscr{G}(k,a)\rho$$

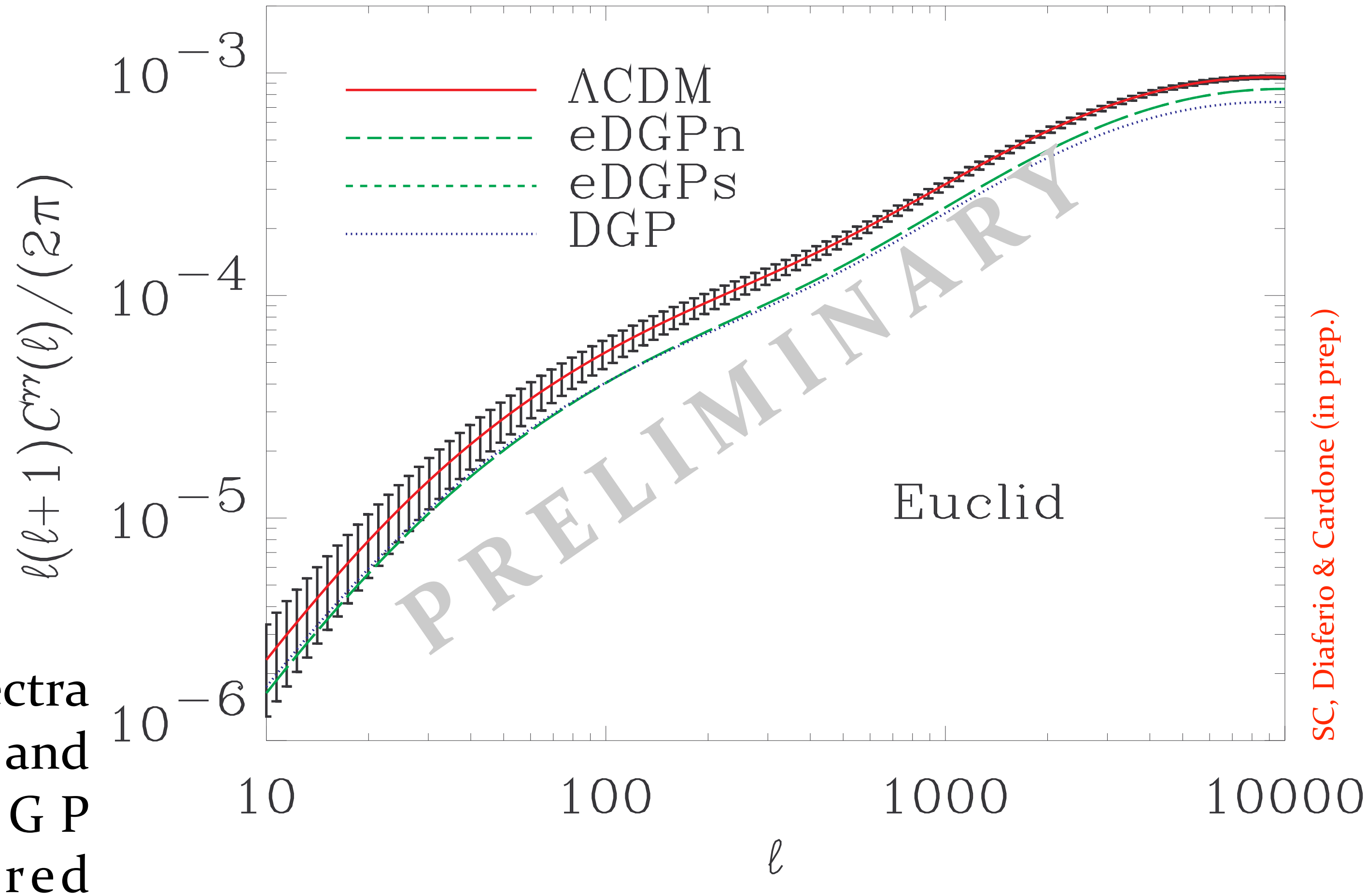




Kobayashi & Tashiro (2009)

Growth factor in ΛCDM and extended DGP models for different values of r_c and α

Brane-world cosmologies



SC, Diaferio & Cardone (in prep.)

Shear power spectra for ΛCDM, DGP and extended DGP models compared with Euclid errorbars

Modified-action theories

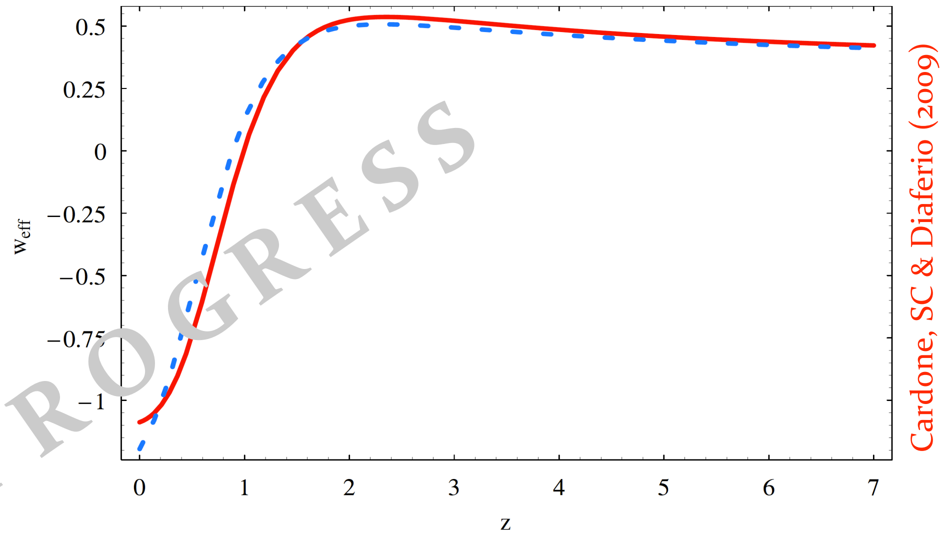
In $f(R)$ theories, the Hilbert-Einstein Lagrangian is replaced by a more general function of Ricci's scalar:

$$\mathscr{L}_{\rm HE} = \frac{1}{16\pi G} f(R)$$

$$H^2 = H_0\left(\Omega_m (1+z)^3 + \Omega_r (1+z)^4 + \Omega_{\rm curv}(a)\right)$$

$$w_{\rm curv} = -1 + \frac{\ddot R f_{,RR} + \dot R\left(\dot R f_{,RRR} - H f_{,R}\right)}{(f - R f_{,R}/2) - 3H\dot R f_{,RR}}$$

WORK IN PROGRESS



Equation of state parameter in two viable $f(R)$ theories

Conclusions

- The concordance cosmological model excellently reproduces current observational data; however it presents some interpretative problems (e.g. DM and DE)
- Weak gravitational lensing can powerfully investigate the LSS of the Universe, thus constraining the nature of DM & DE and of the gravitational interaction
- Modified gravity theories furnish viable alternatives to DM and/or DE by modifying the behaviour and the nature of gravity

Thanks