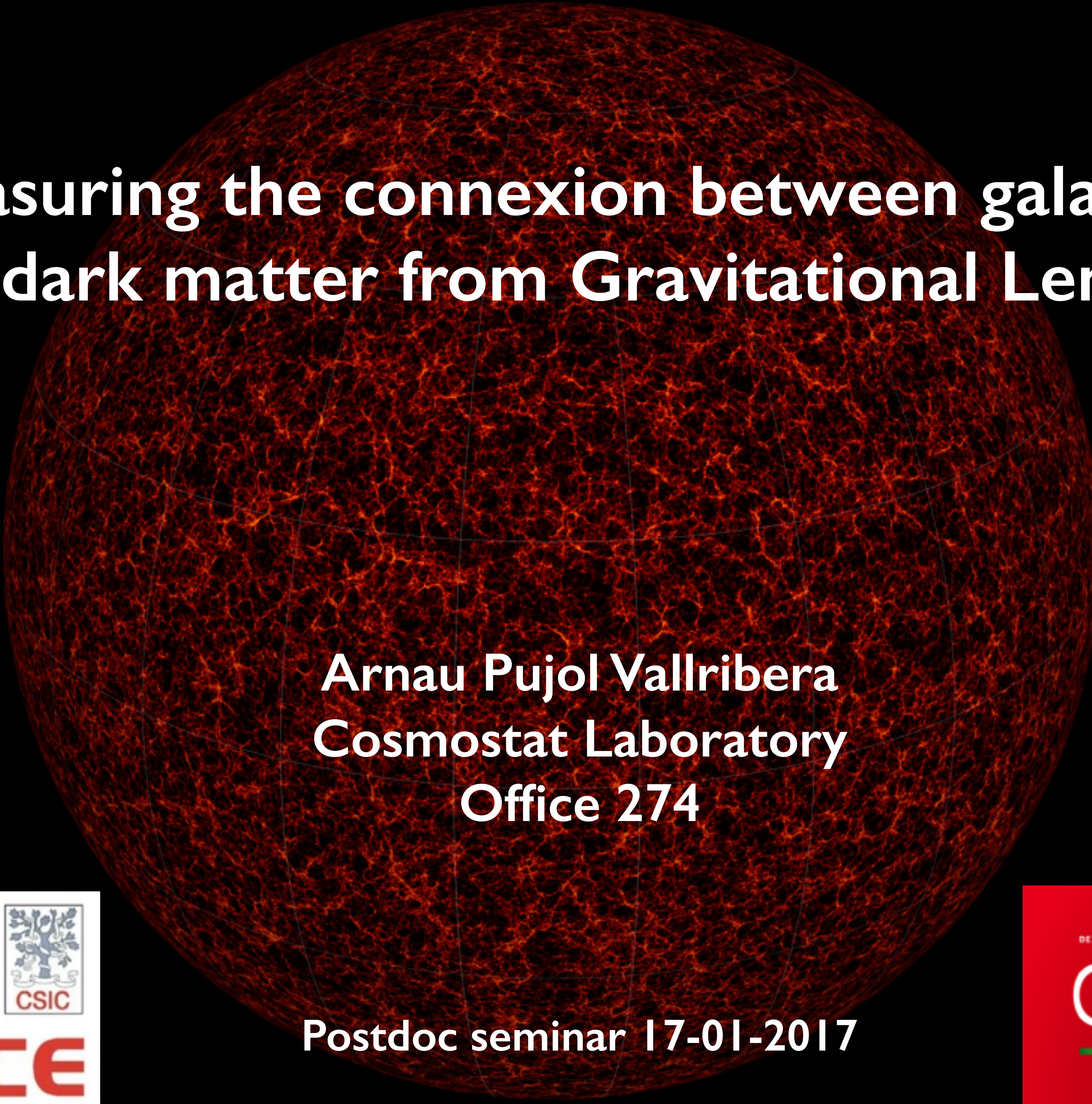

Measuring the connexion between galaxies and dark matter from Gravitational Lensing

Arnau Pujol Vallribera
Cosmostat Laboratory
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Postdoc seminar 17-01-2017

INSTITUT D'ESTUDIS ESPACIALS DE CATALUNYA
IEEC
CSIC
INSTITUTO DE CIENCIAS DEL ESPACIO
ICE

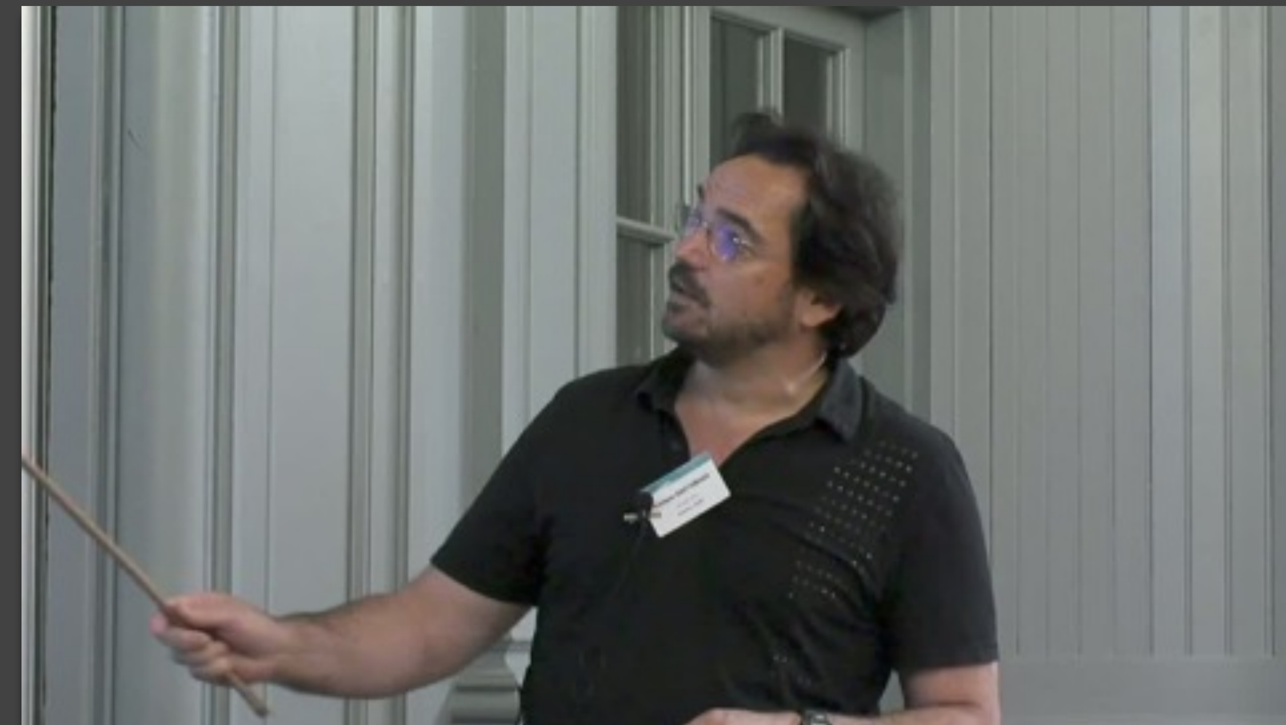
DE LA RECHERCHE À L'INDUSTRIE
cea

Barcelona, Catalonia/Spain

Arnau Pujol Vallribera

PhD 2016
Cosmology with galaxy surveys

Supervised by Enrique Gaztañaga



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Overview

Introduction to Cosmology and galaxy bias

Introduction to Gravitational Lensing

New method to measure bias from GL

Conclusions

Work at CEA

MICE Simulations

Introduction

Goal of Cosmology: study the origin, nature, evolution and content of the Universe as a whole

$\Lambda\mathrm{CDM}$ model is the actual standard model of Cosmology

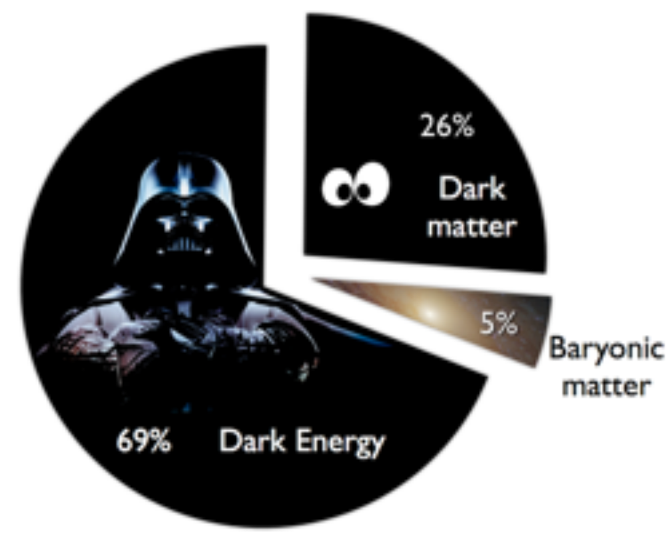
It assumes:

Big Bang

+

General Relativity

+



Presence of dark matter and dark energy

And follows the Friedmann equation:

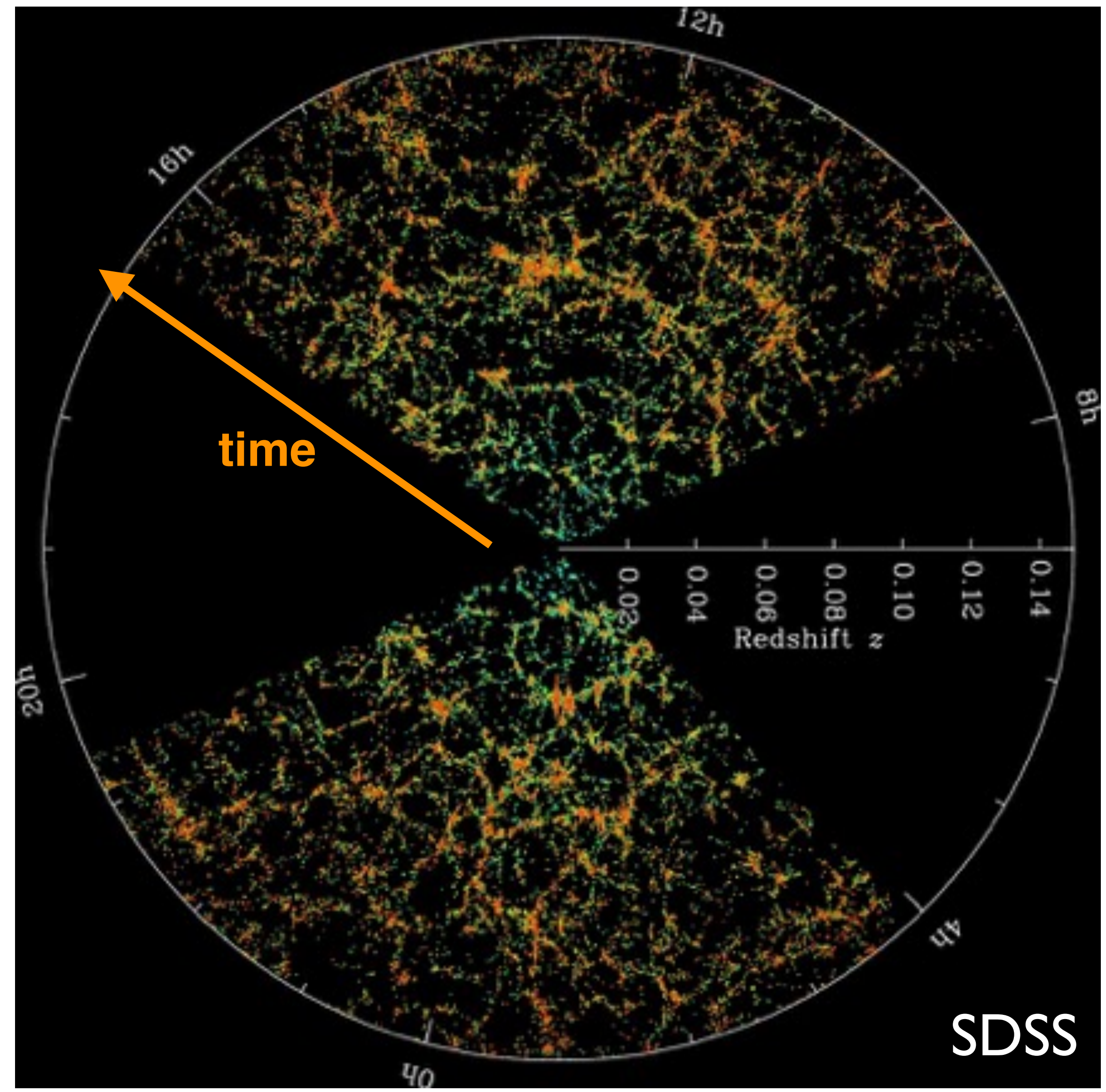
$$H^2(a) = H_0^2[\Omega_m a^{-3} + \Omega_r a^{-4} + \Omega_k a^{-2} + \Omega_\Lambda]$$

Introduction

Galaxy surveys allow us to study cosmology from the distribution of galaxies

The actual state of the Universe depends on:

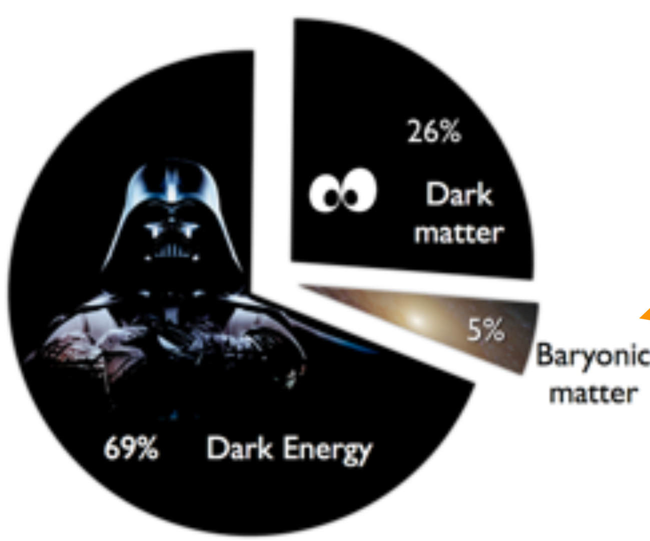
- Initial conditions (Big Bang)
- Physics of the Universe (GR, QM…)
- Content of the Universe

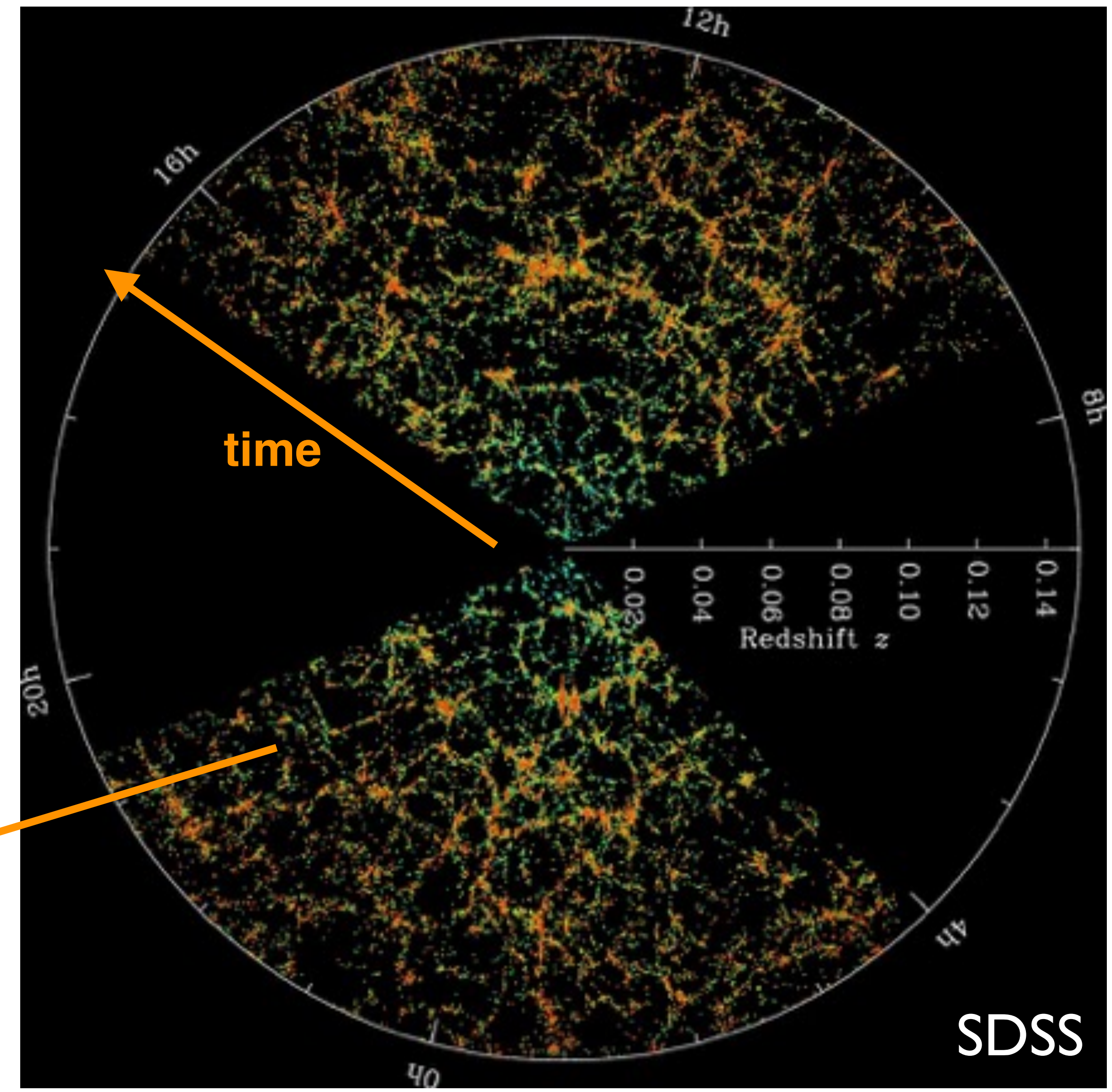


The study of the structures of the Universe allow us to understand all this, but…

Introduction

Galaxy surveys allow us to study cosmology from the distribution of galaxies





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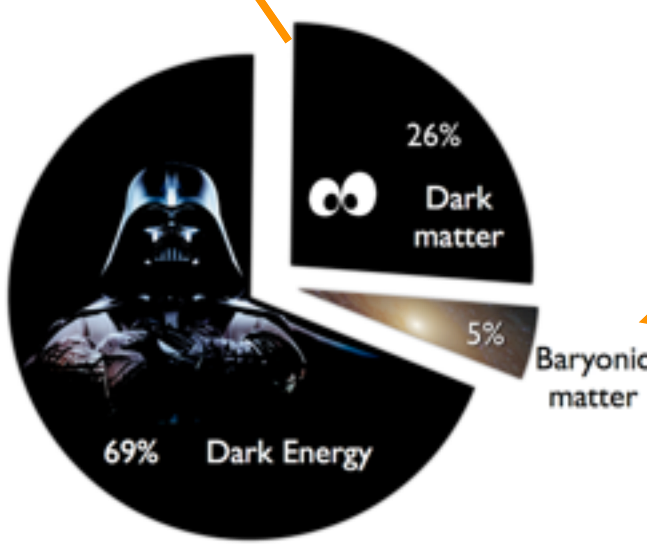
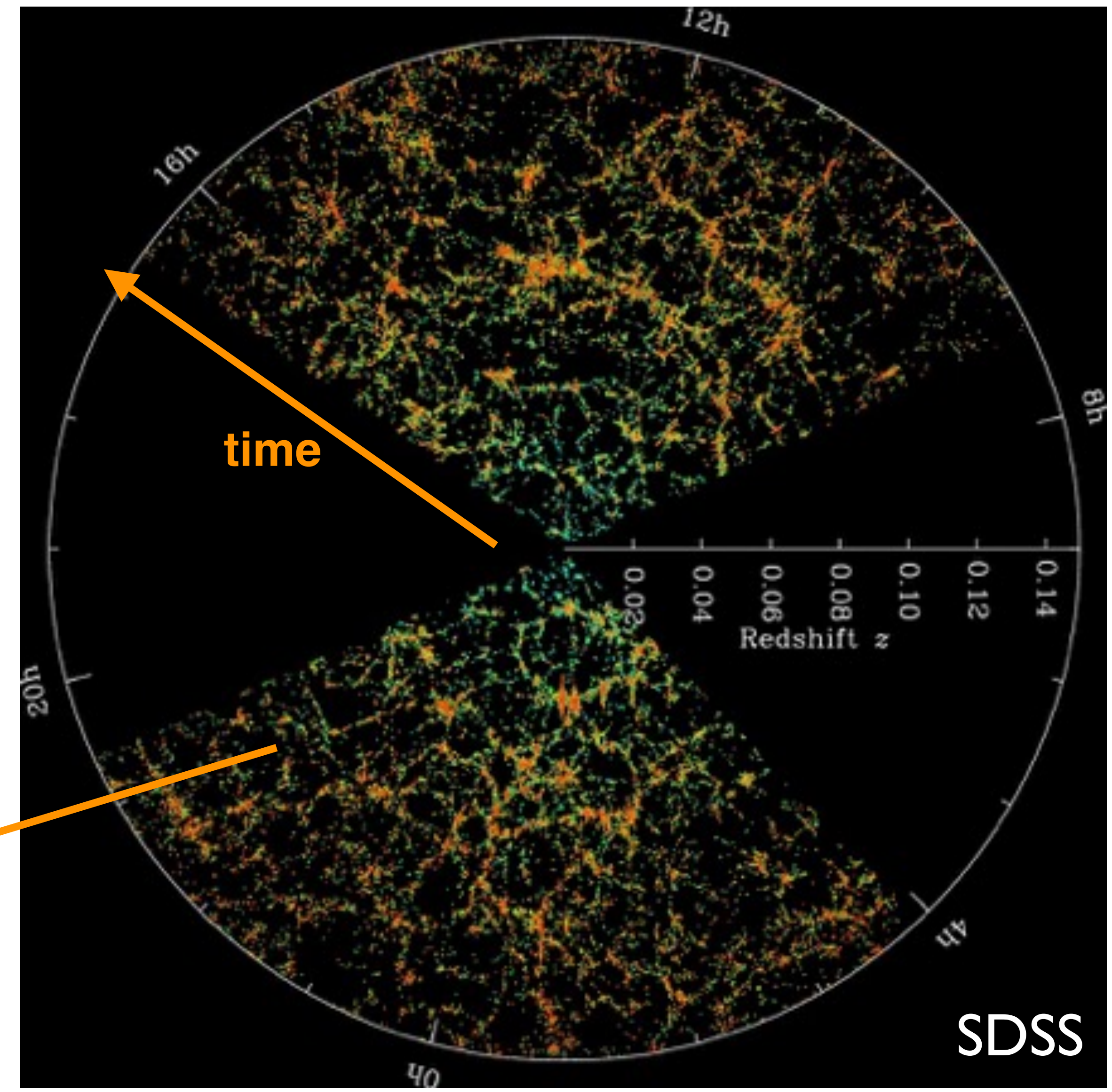




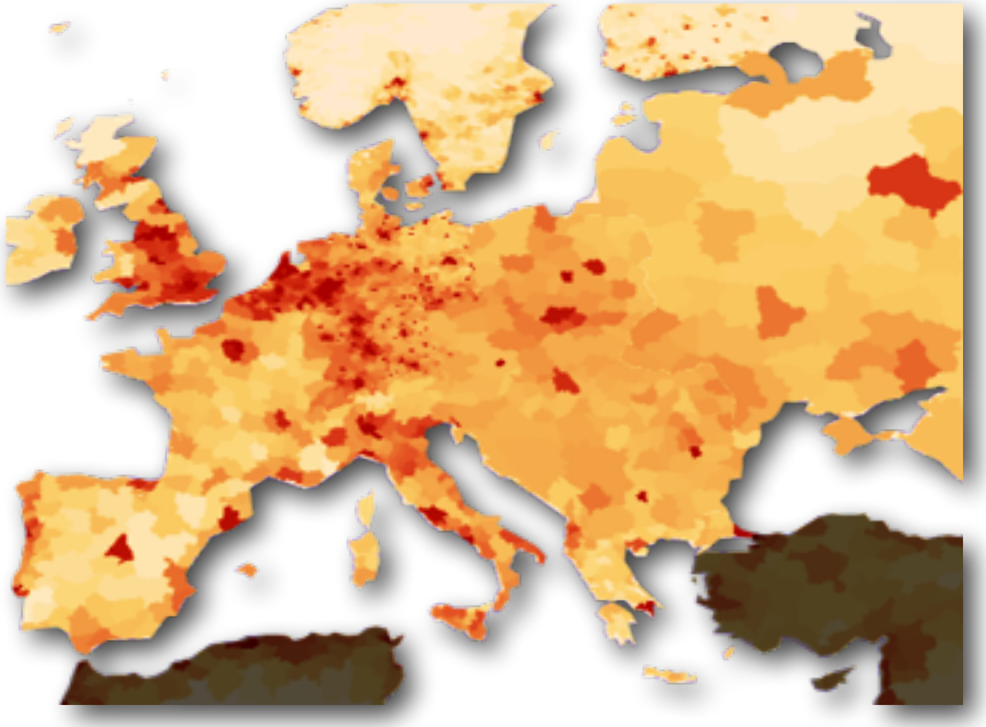
We must know the connection between galaxies and dark matter to study the Universe in detail

Introduction

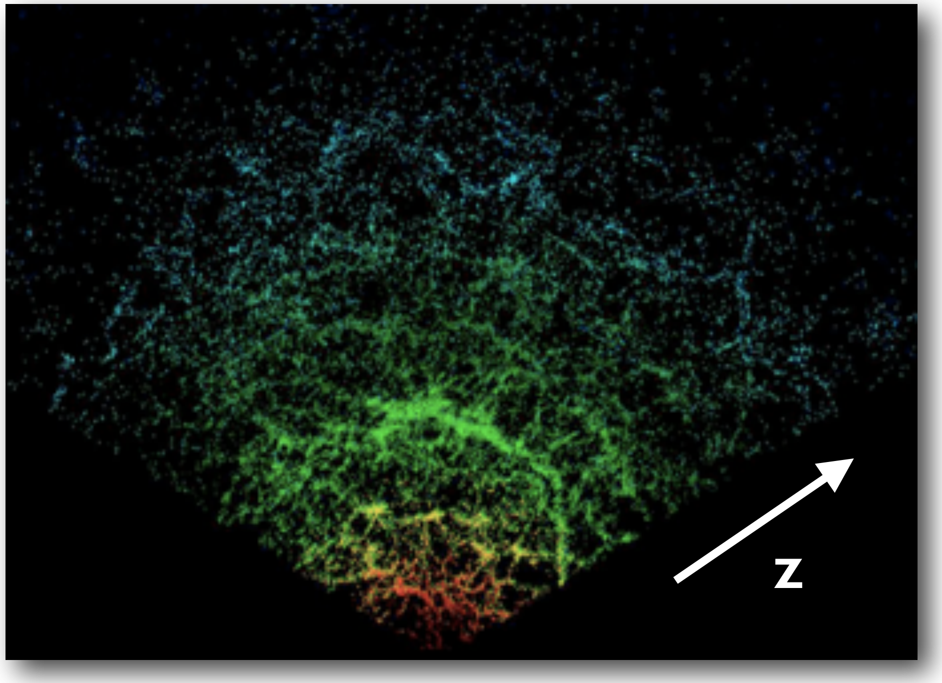
Light traces population

Europe at night

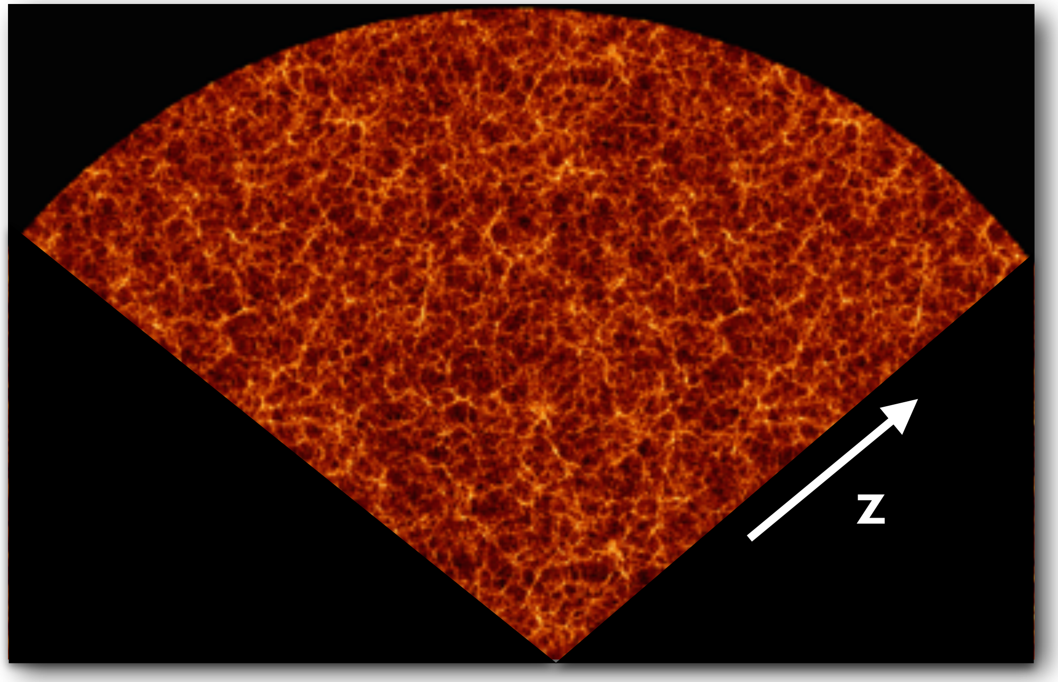
Europe population



Light (of galaxies) traces matter



Galaxy distribution from galaxy survey (SDSS)



Dark matter distribution from simulation

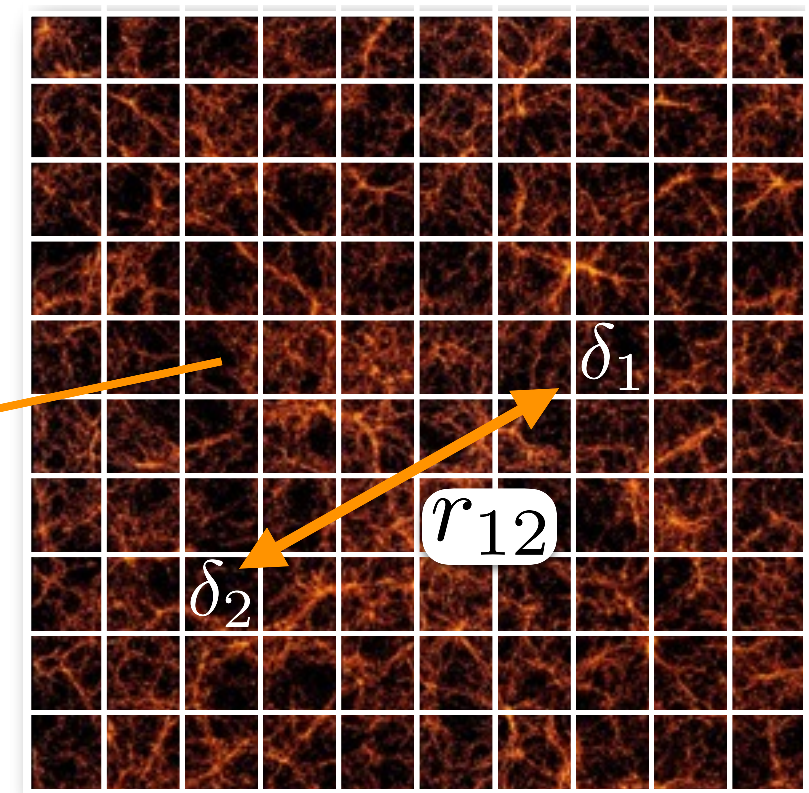
Introduction

Two-point correlation function (2PCF): it gives information about the correlations in densities separated a given distance

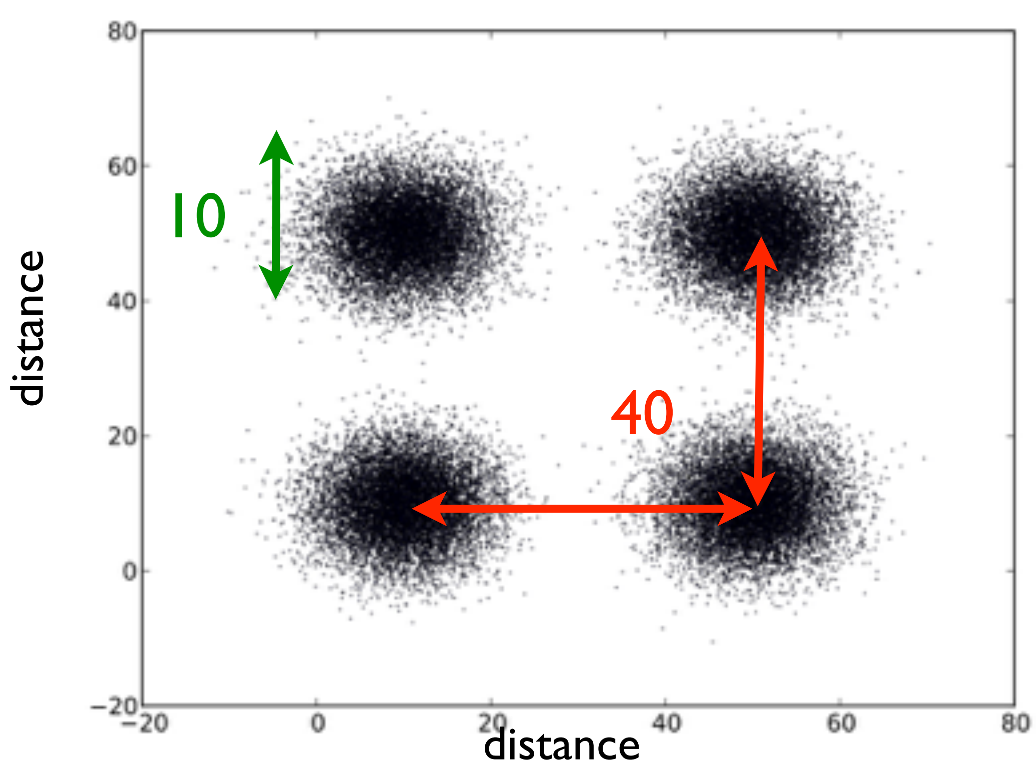
$$\xi(r_{12}) = \langle \delta_1(r_1)\delta_2(r_2) \rangle$$

$$\delta = \frac{\rho - \bar{\rho}}{\bar{\rho}}$$

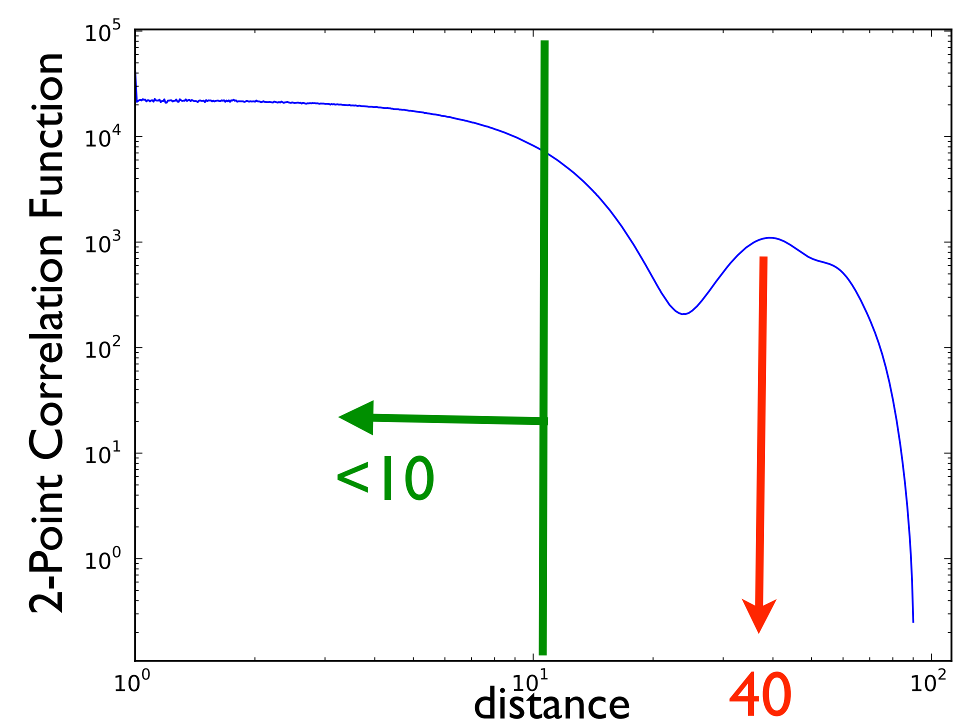
Dark matter distribution (Millennium Simulation)



Toy distribution



Toy 2PCF



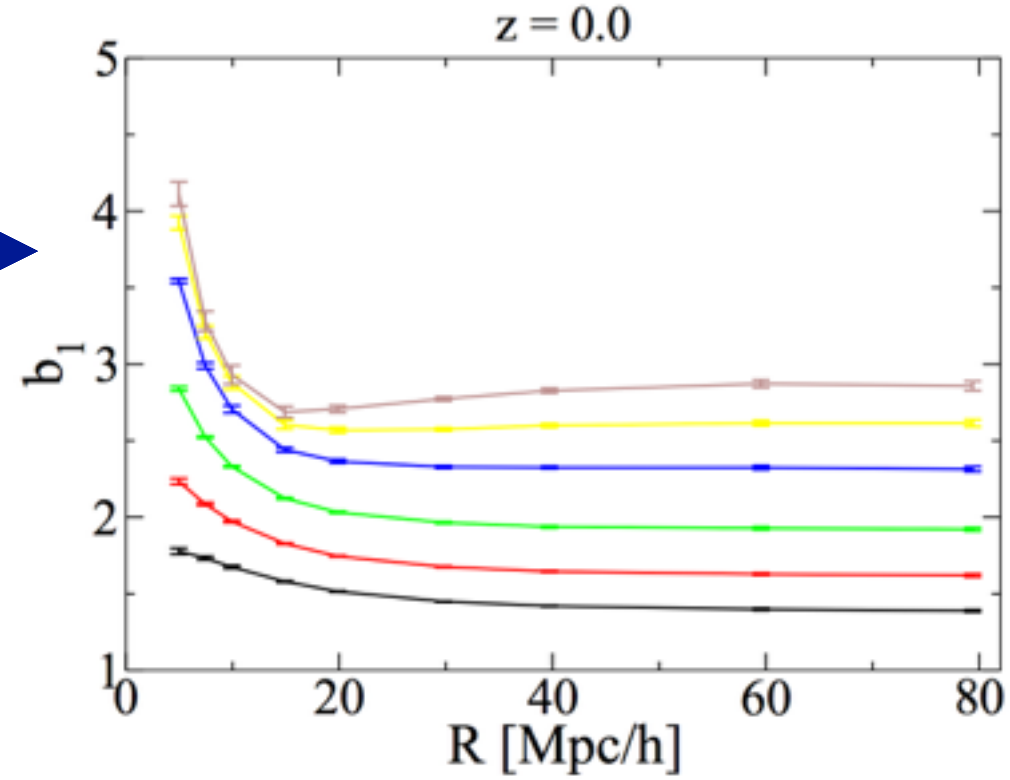
Introduction

Linear bias

Galaxy bias is defined as the ration between the galaxy and matter 2 Point Correlation Function (2PCF)

$$b(r) = \sqrt{\frac{\xi_g(r)}{\xi(r)}}$$

Bias at large scales is constant



Manera & Gaztañaga 2011

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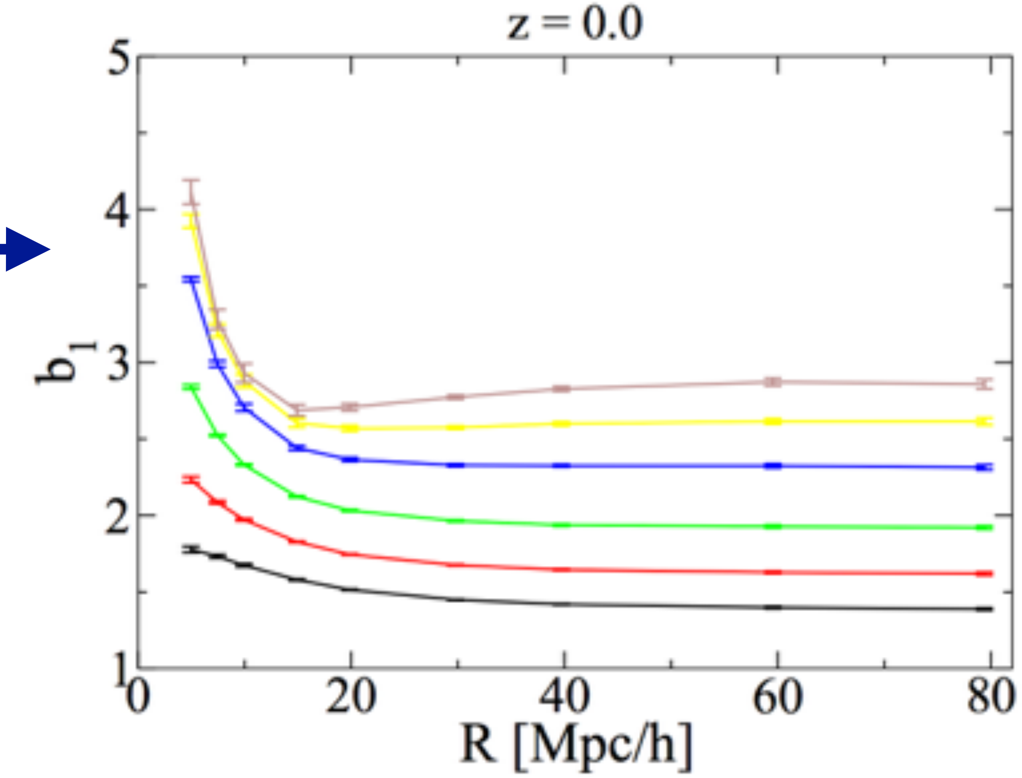
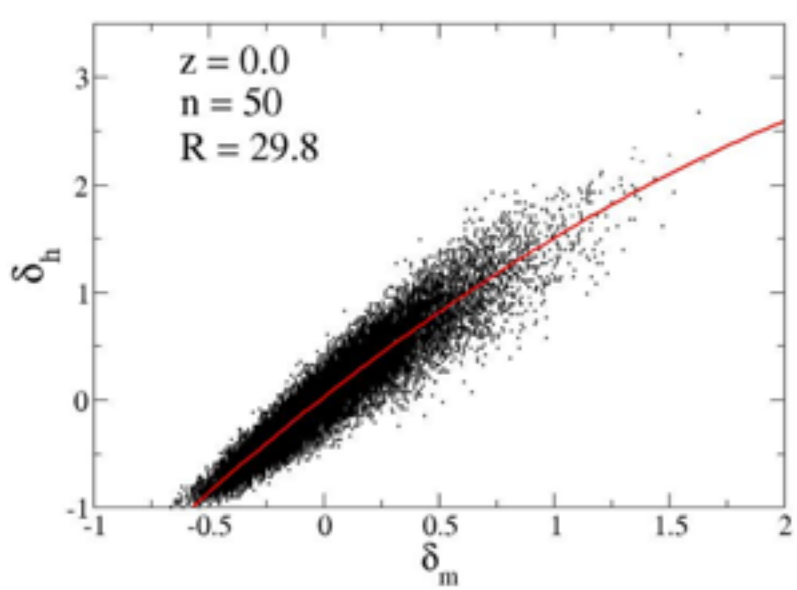
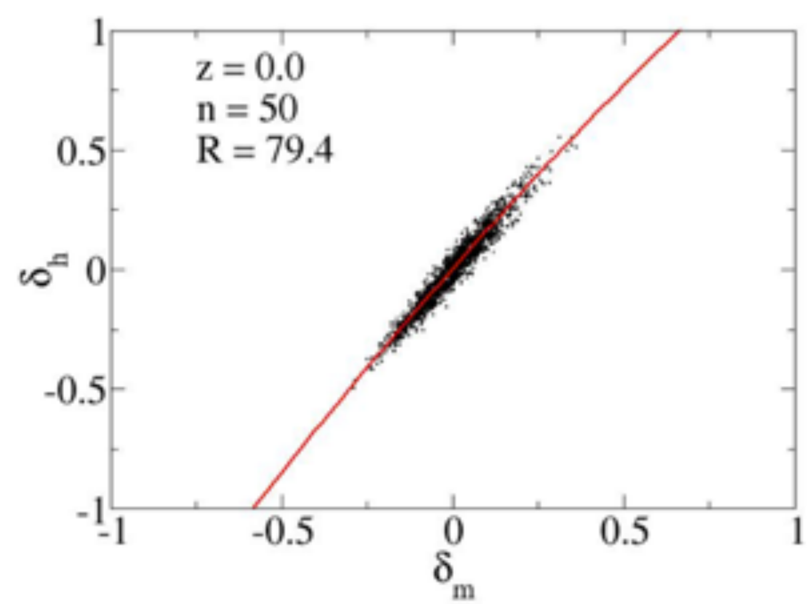


Manera & Gaztañaga 2011

Linear bias approximation

$$\delta_g(\vec{x}) \simeq b\delta(\vec{x})$$





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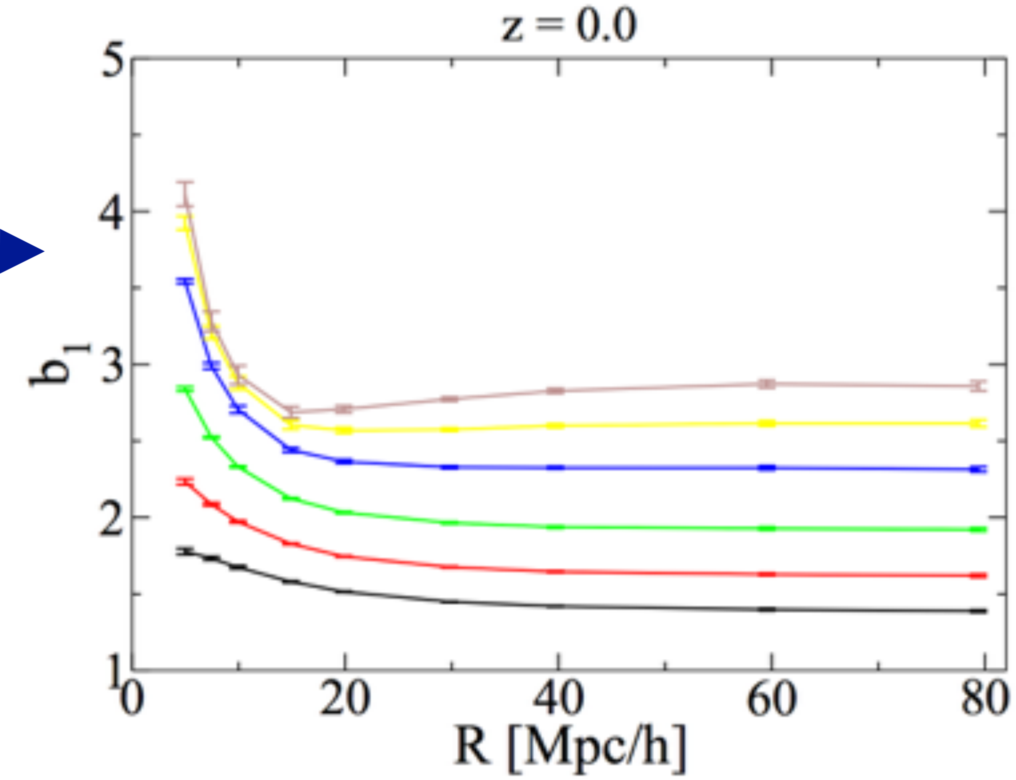

Manera & Gaztañaga 2011

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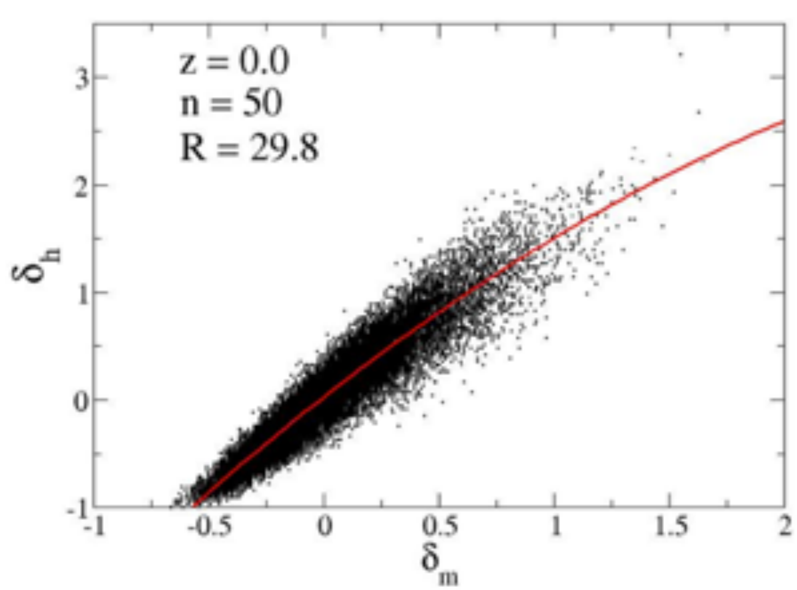
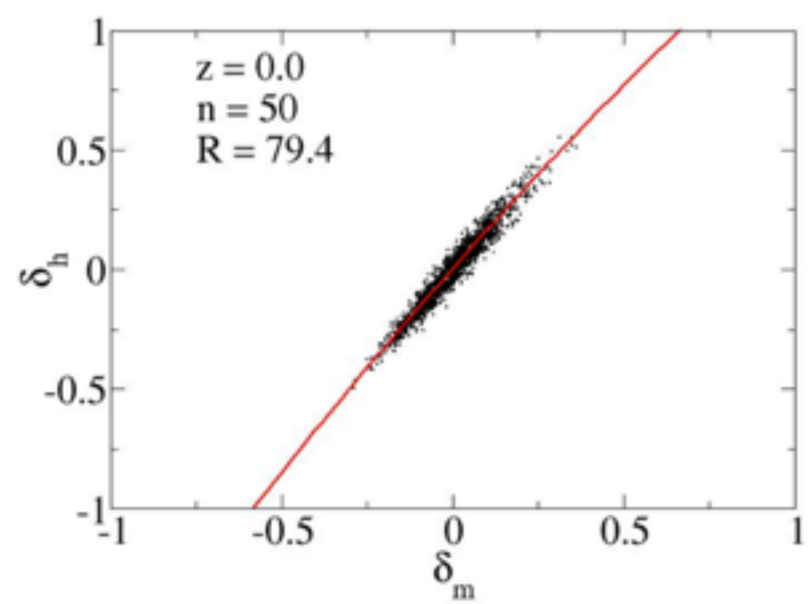
We can measure it from galaxy surveys





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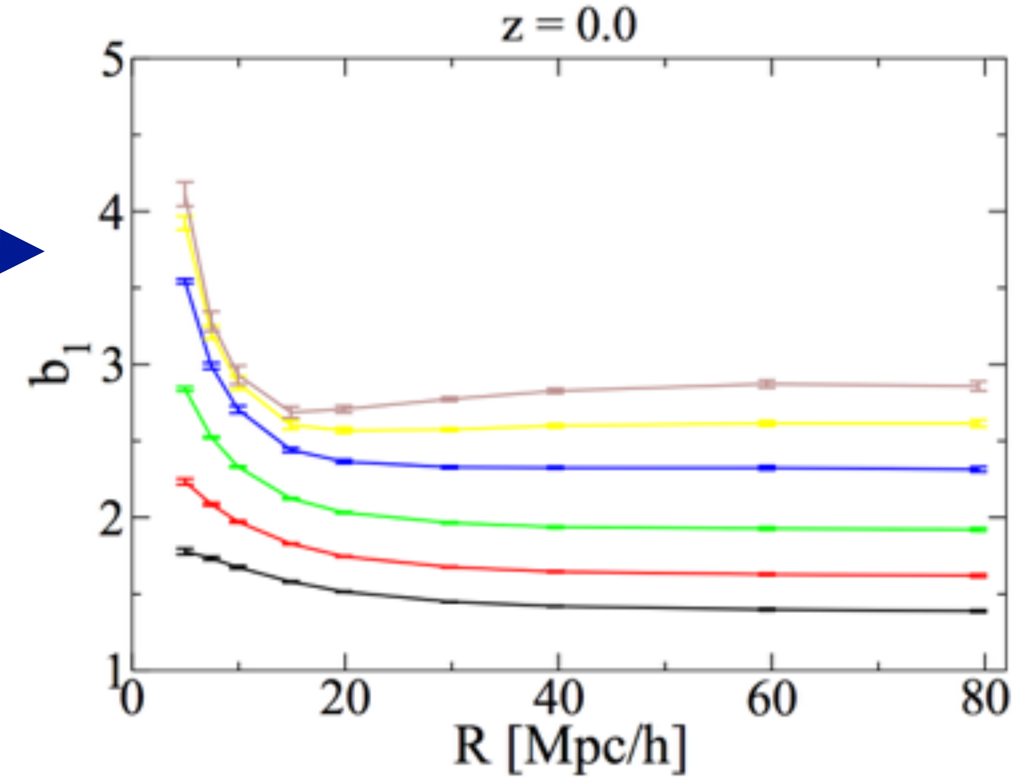

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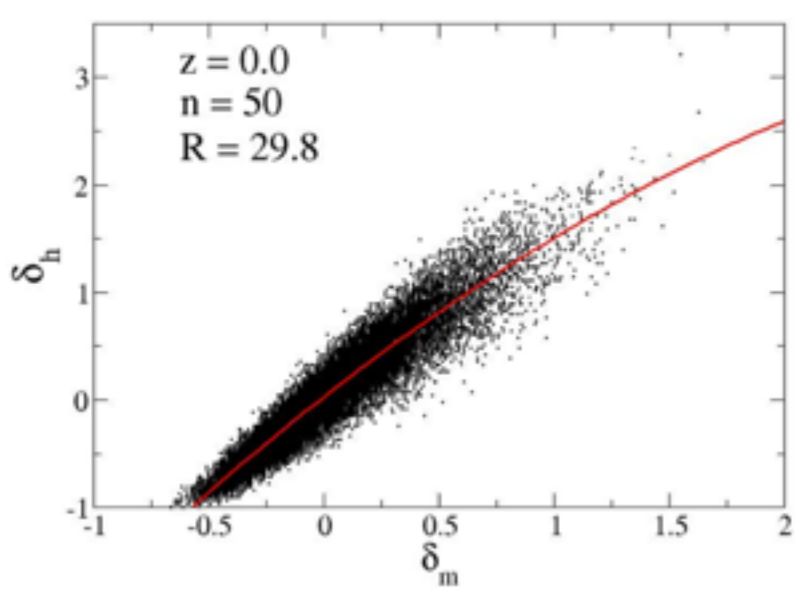
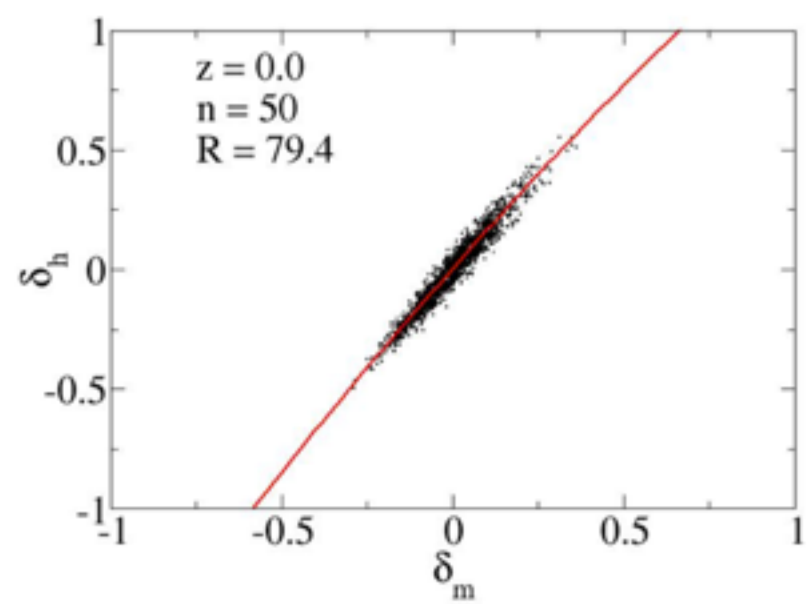
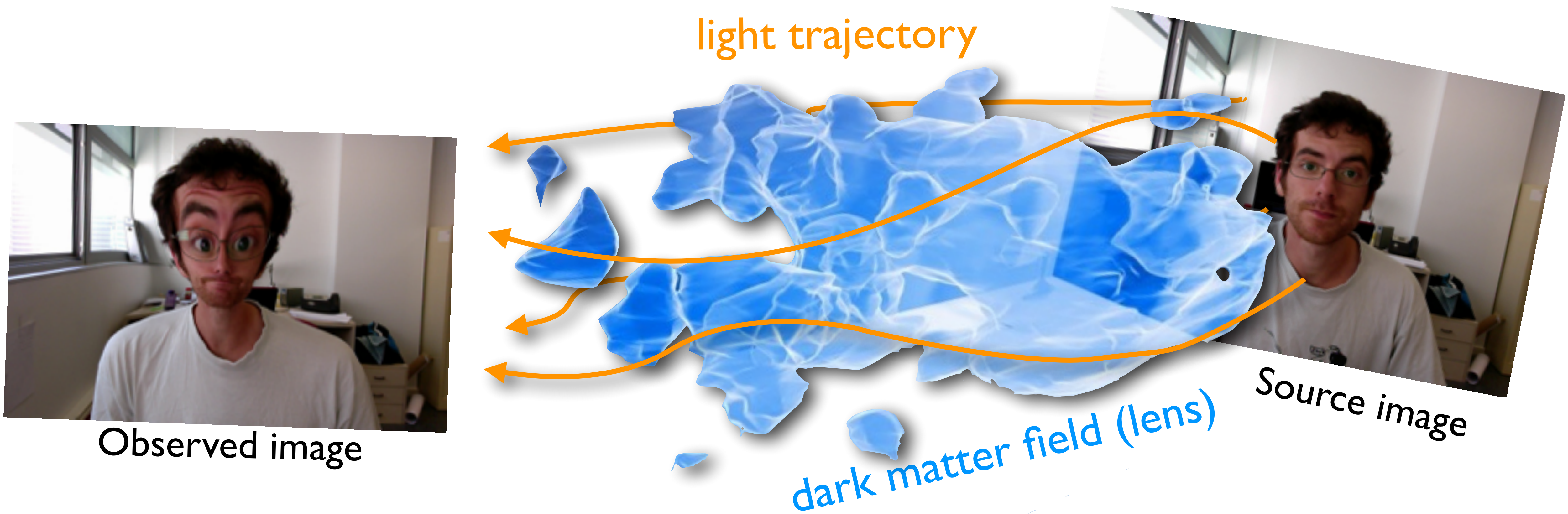




Manera & Gaztañaga 2011

Gravitational Lensing



The light is deflected when travelling throw a gravitational field (or a mass fluctuation)
Then, galaxy images are affected by the foreground mass distribution

Images from HST

Einstein Ring

Happy Universe

Space Invader

Gravitational Lensing

Weak Gravitational Lensing (WL)

WL studies the small distortions of galaxy images due to the foreground mass distribution

The lensing field is described by:

- Shear

$$\gamma = \gamma_1 + i\gamma_2 = \frac{1}{2}(\psi_{,11} - \psi_{,22}) + i\psi_{,12},$$

$$(\psi_{,ij} = \partial_i \partial_j \psi)$$

- Convergence

$$\kappa = \frac{1}{2}\nabla^2 \psi$$

$$\kappa(\theta, \chi) = \frac{3H_0^2 \Omega_m}{2c^2} \int_0^{\chi_s} d\chi \frac{\chi(\chi_s - \chi)}{\chi_s} \frac{\delta(\theta, \chi)}{a(\chi)}$$

$$= \int_0^{z_s} q(z)\delta(\theta, z) dz$$

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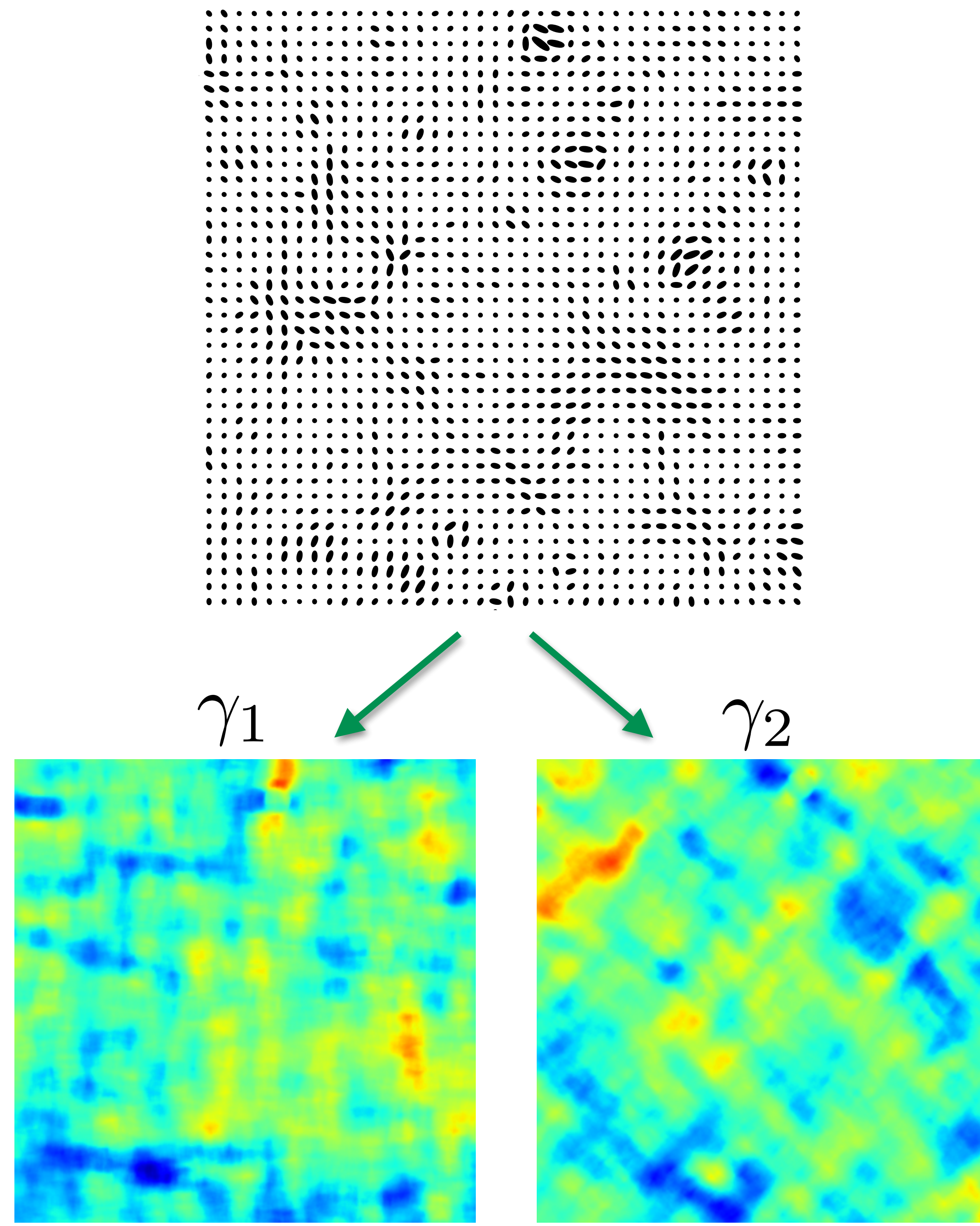

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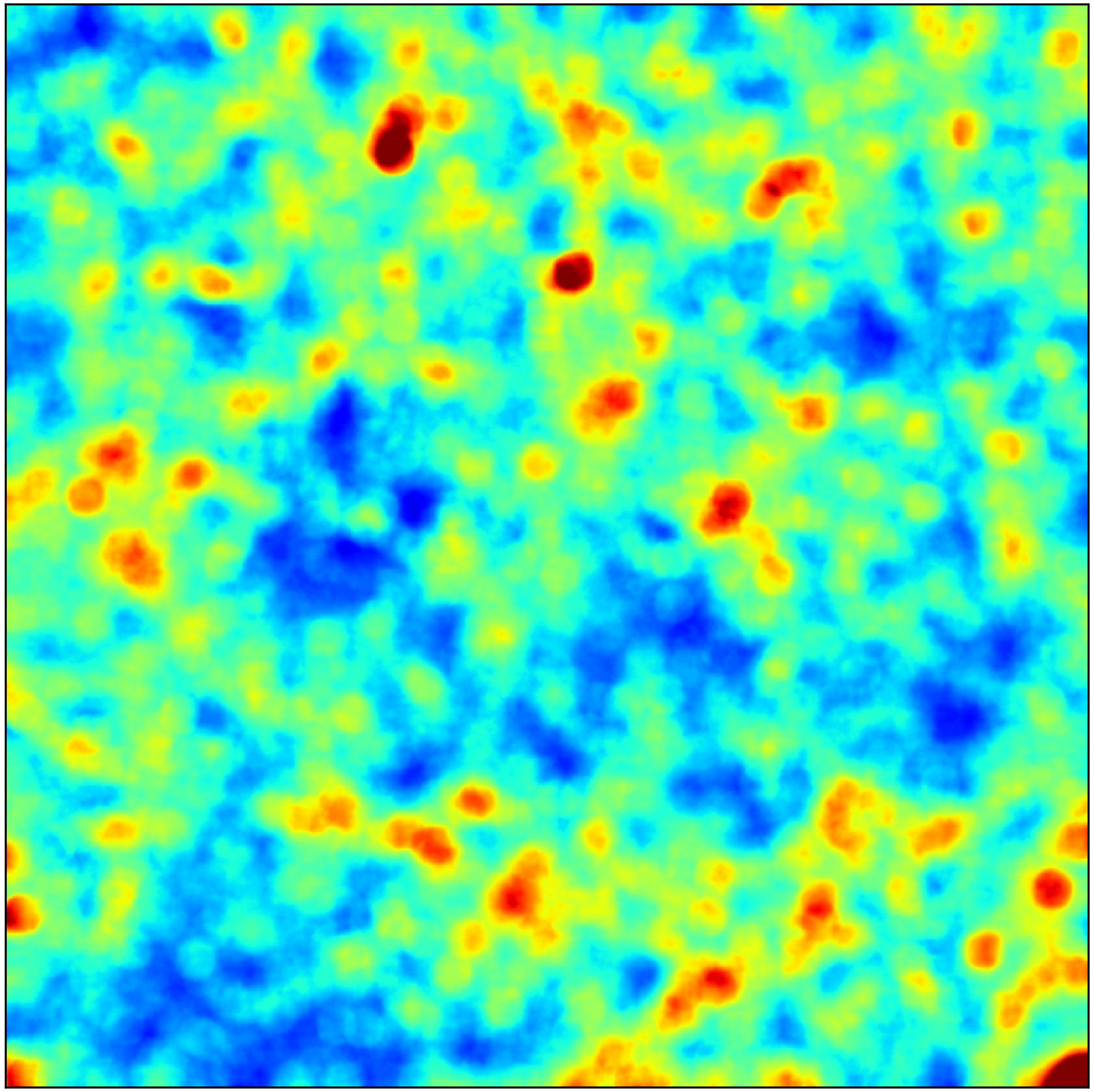

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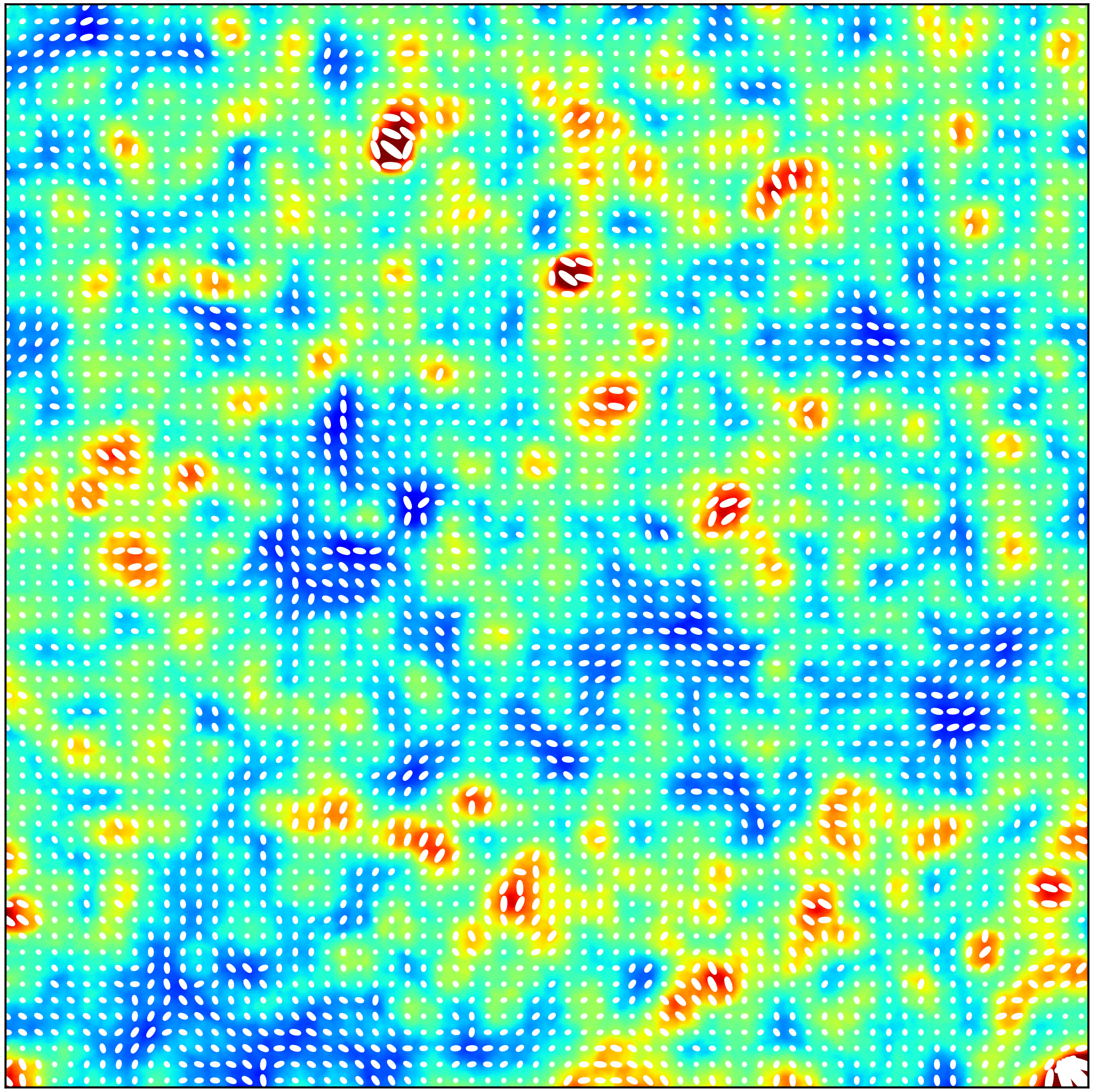

Methodology

Assuming linear bias

$$\delta_g(\theta) = b(z)\delta(\theta)$$

We construct a biased version of κ:

$$\kappa_g(\theta) = \int_0^{z_s} q(z)\delta_g(\theta)dz = b(z)\kappa(\theta)$$

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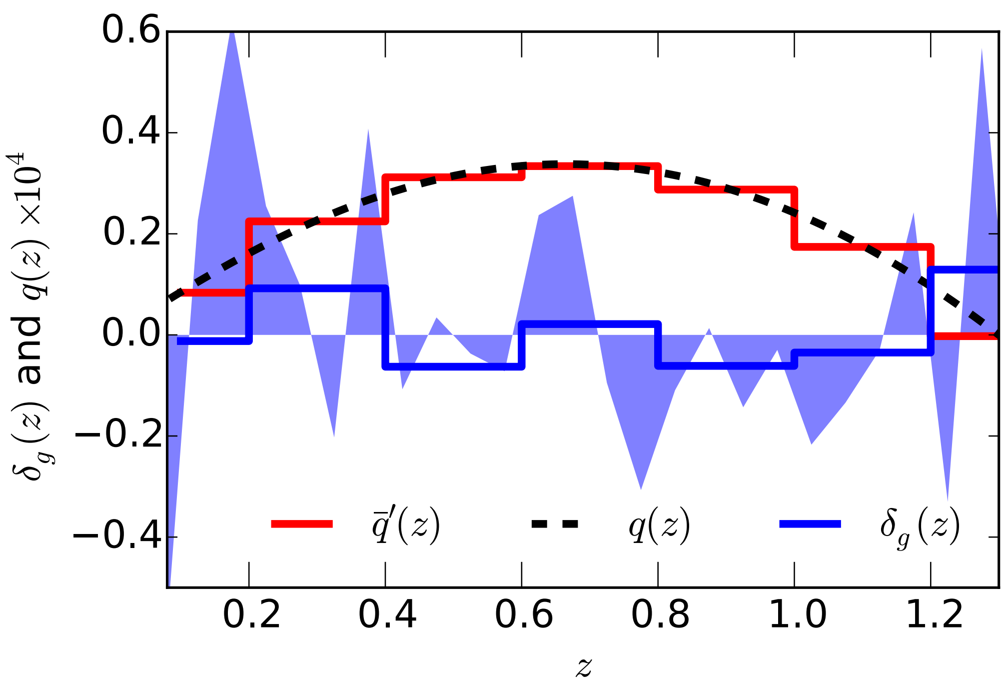

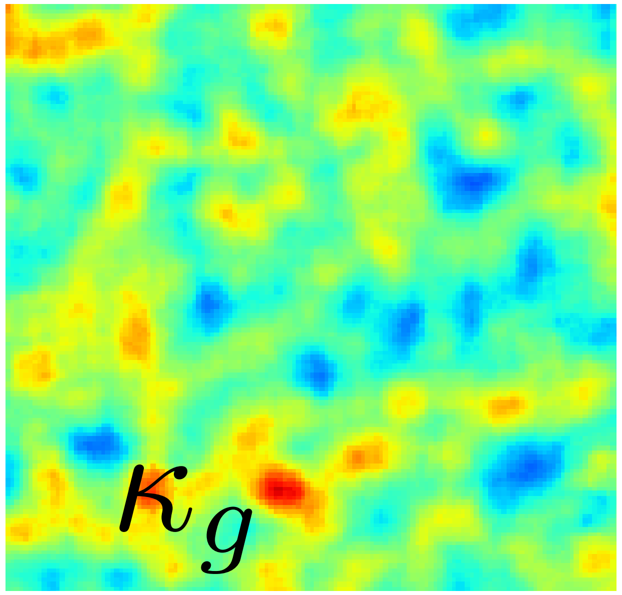

Pujol et al. 2016

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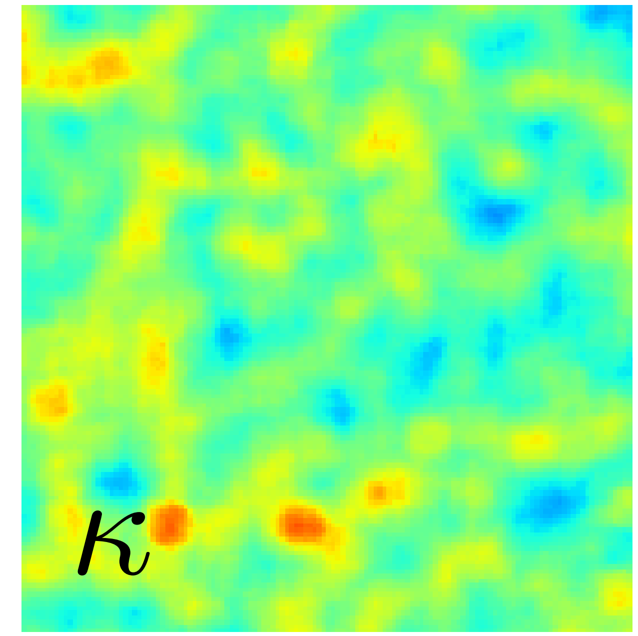

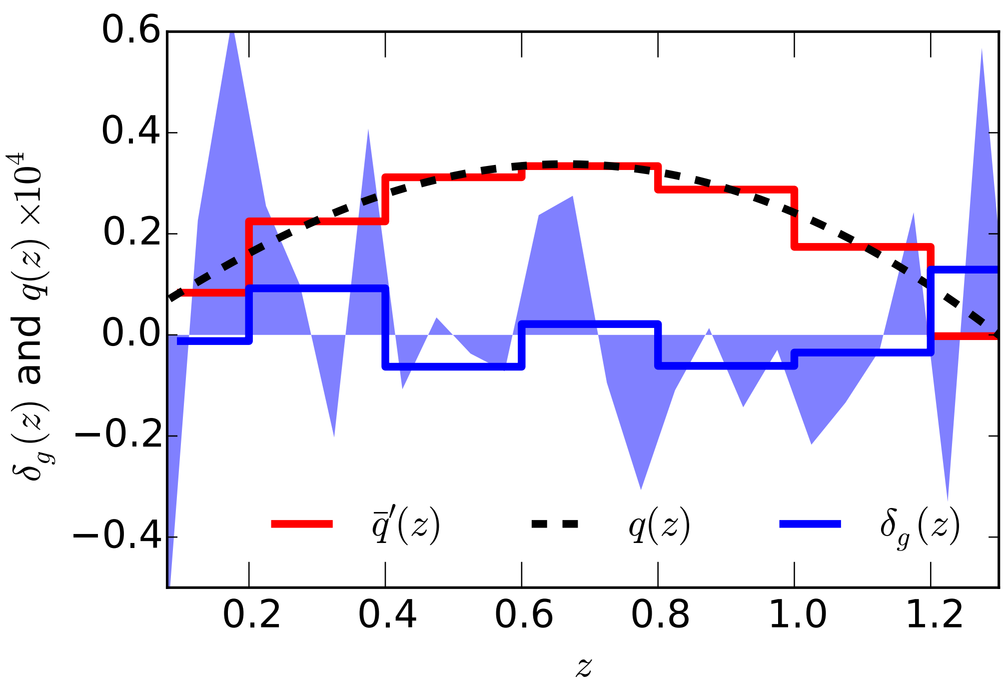

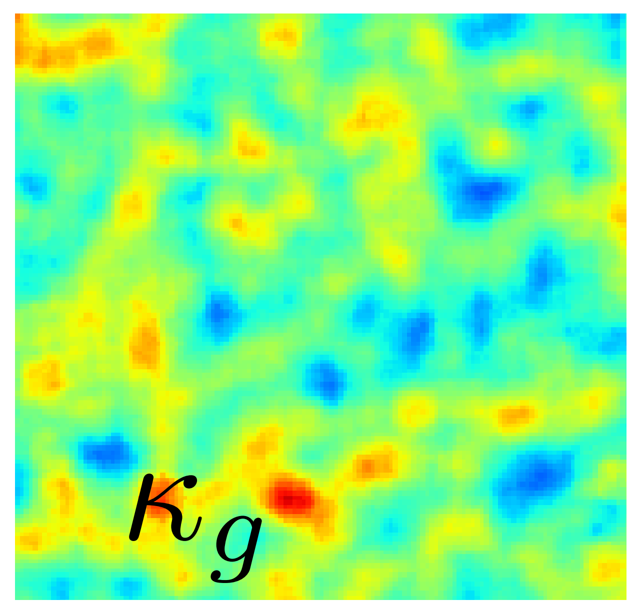

Pujol et al. 2016

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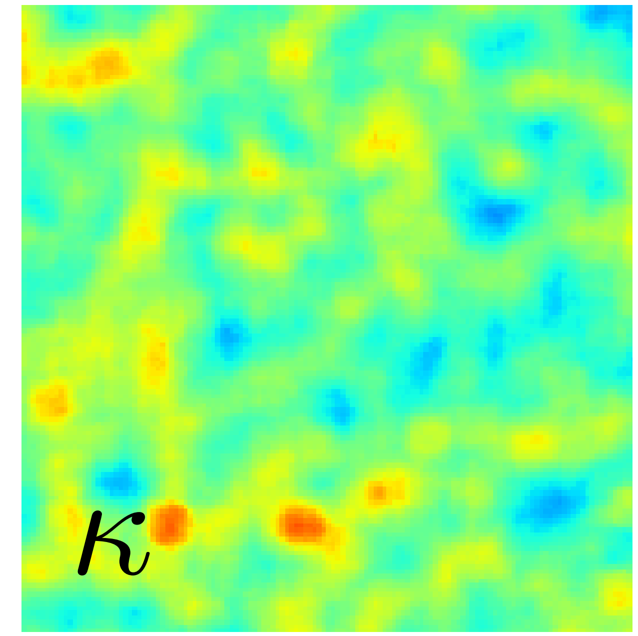
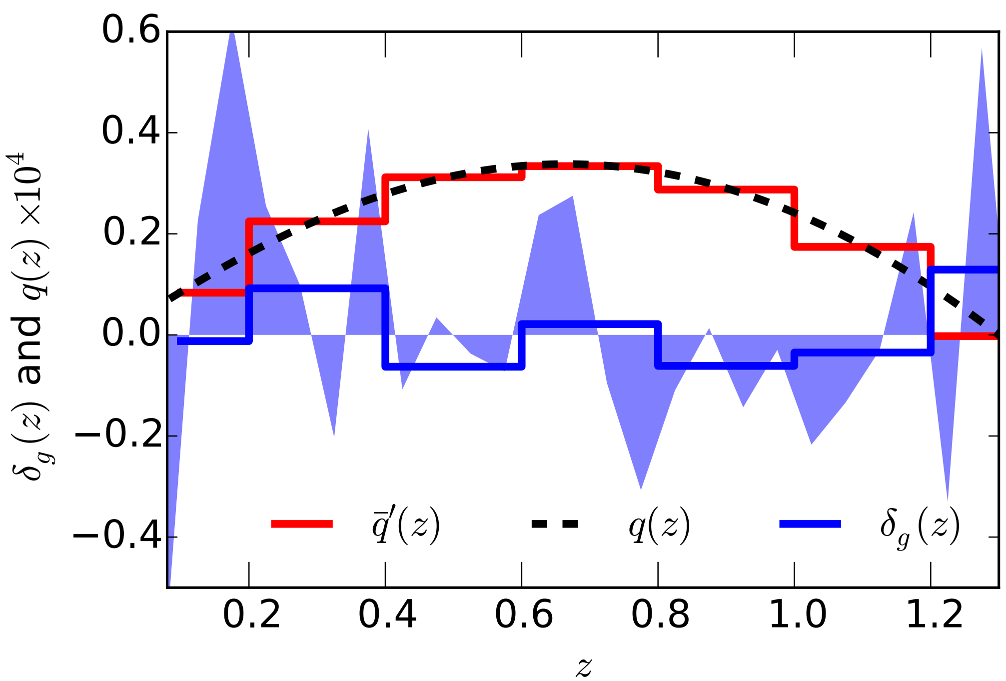
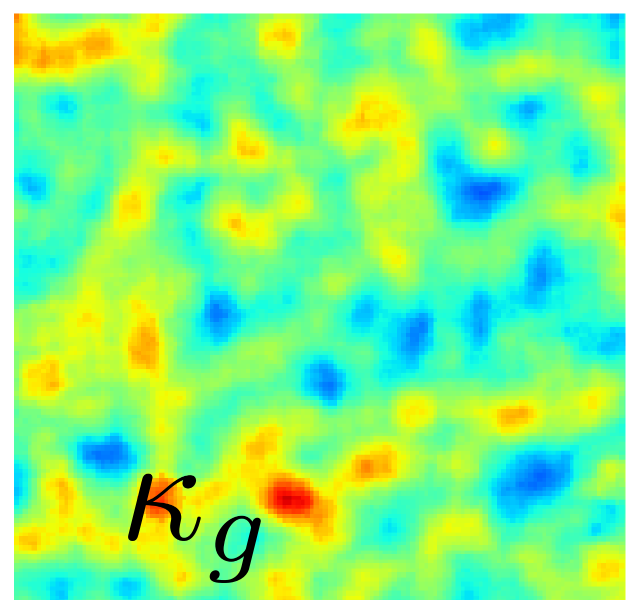




Pujol et al. 2016



Measure galaxy bias from

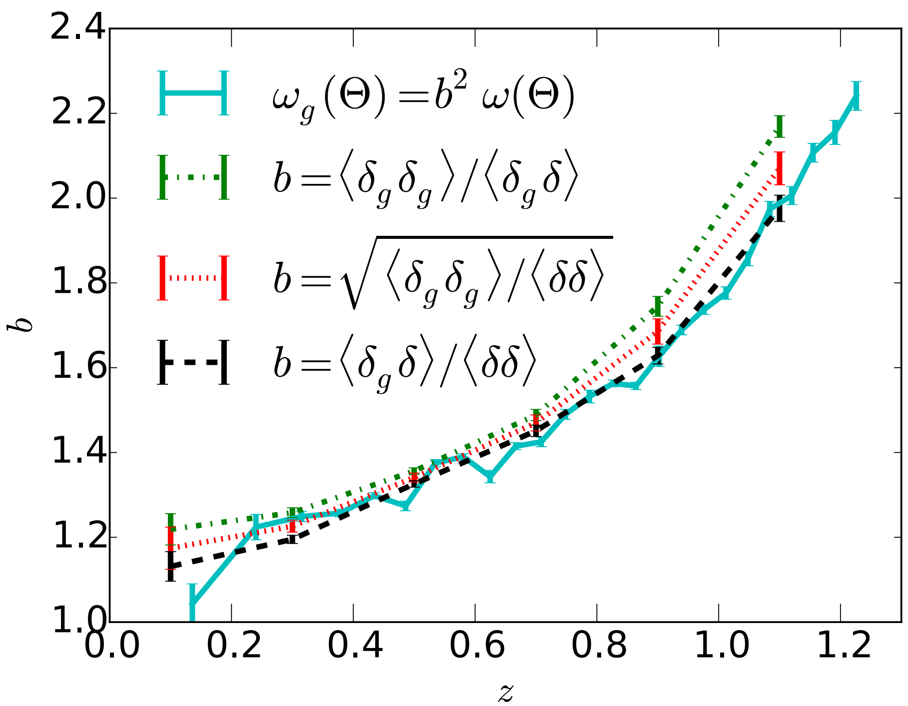
$$b = \frac{\langle \kappa_g \kappa \rangle}{\langle \kappa\kappa \rangle - \langle \kappa^N \kappa^N \rangle}$$

$$b = \frac{\langle \kappa_g \kappa_g \rangle - \langle \kappa_g^N \kappa_g^N \rangle}{\langle \kappa_g \kappa \rangle}$$

Methodology

Redshift dependence

Galaxy bias depends on redshift!



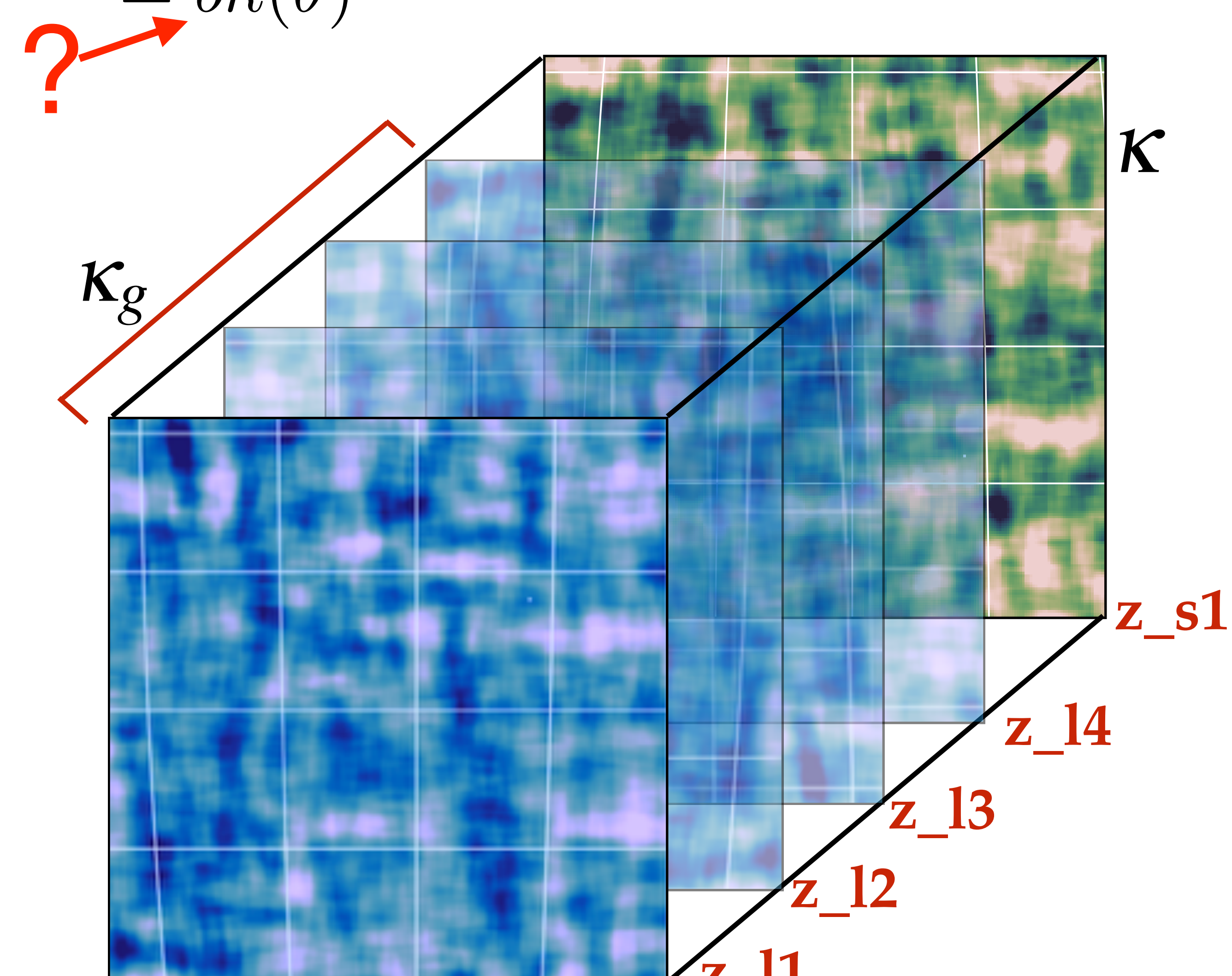
Pujol et al. 2016

Solution adopted: measure galaxy bias in **tomographic bins**, restricting the galaxies inside each bin and assuming that bias does not change inside the bin

We are measuring a weighted mean of the redshift dependent bias

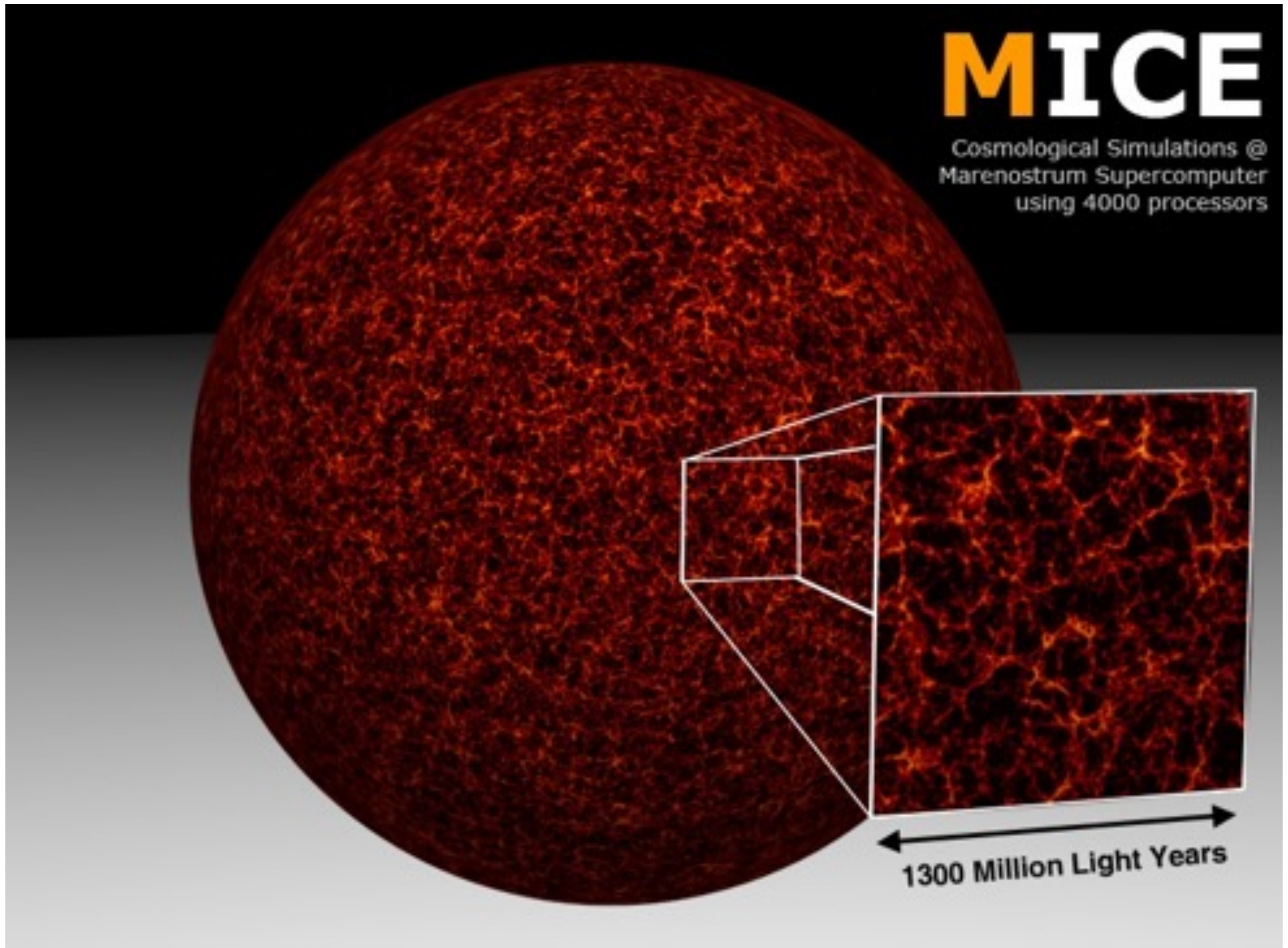
$$\kappa_g(\theta) = \int_0^{z_s} q(z)\delta_g(\theta)dz = \int_0^{z_s} q(z)b(z)\delta(\theta)dz$$

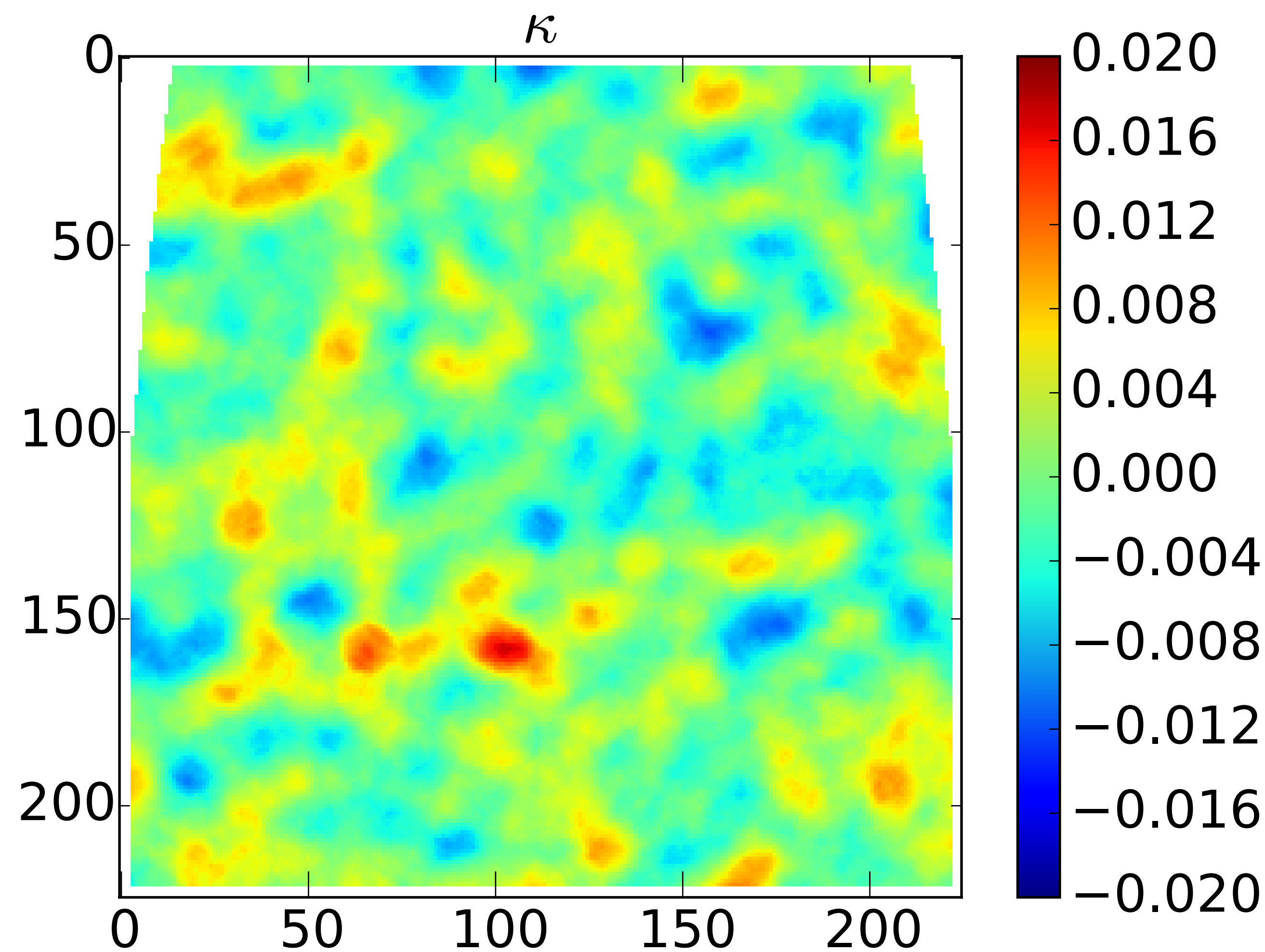
$$= b\kappa(\theta)$$



Methodology

MICE Simulation





Convergence map of MICE

$\Lambda\mathrm{CDM}$ lightcone up to z = 1.4

$\Omega_m = 0.25 \quad h = 0.7$

$\Omega_b = 0.044 \quad n_s = 0.95$

$\Omega_\Lambda = 0.75 \quad \sigma_8 = 0.8$

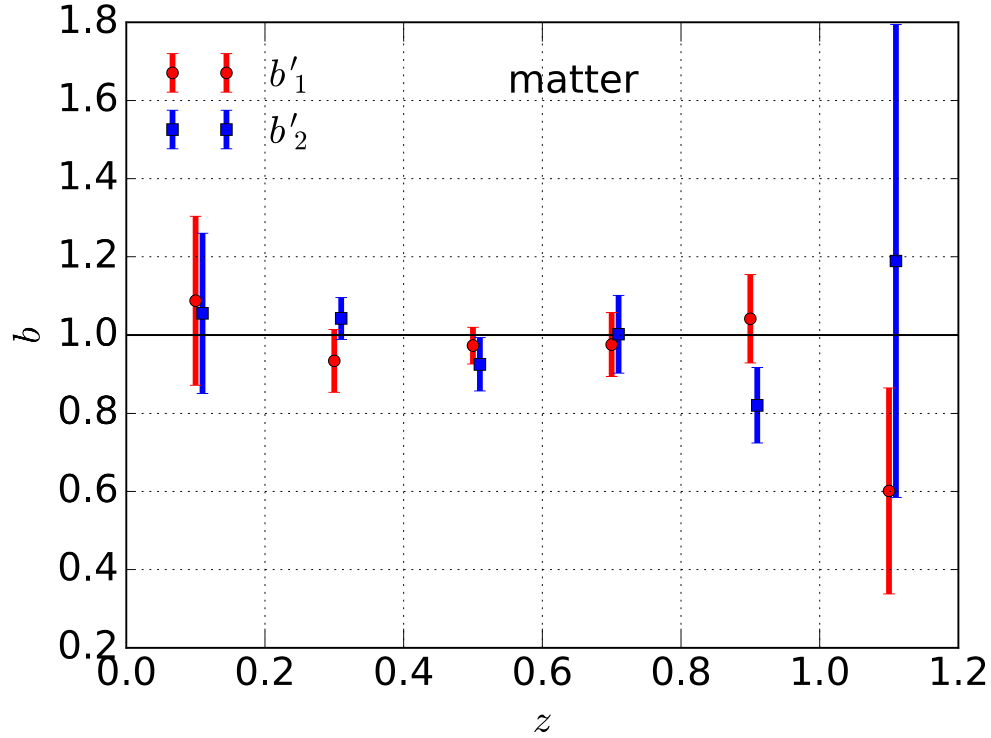
~200 million galaxies over 5000 sq.deg

~3 million CPU hours

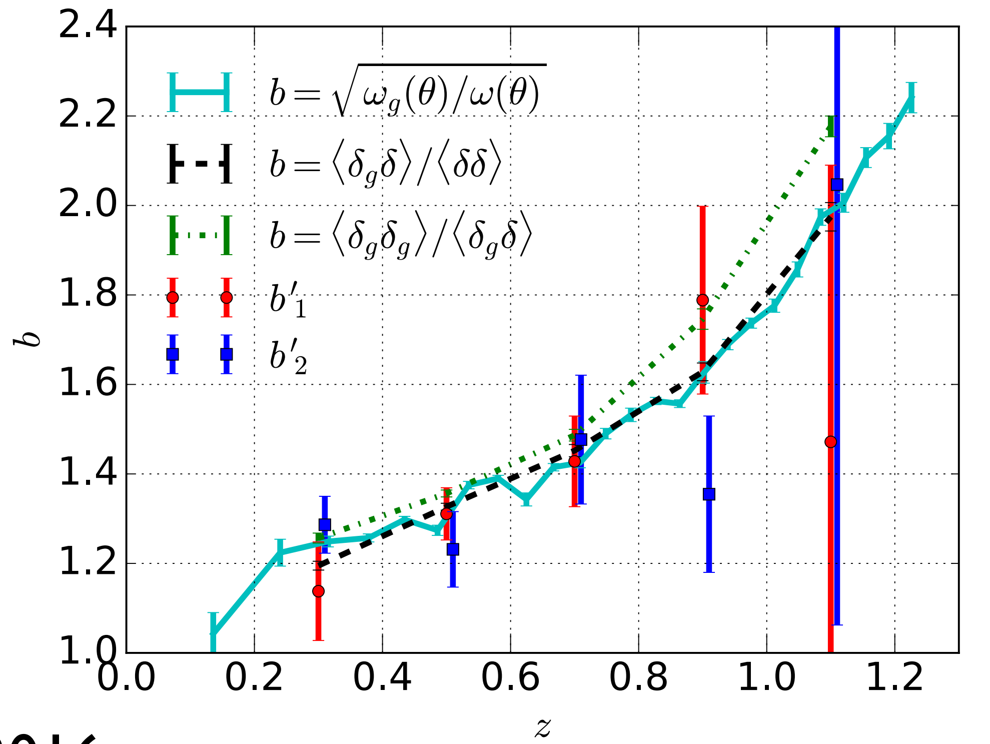
~3Gpc size

MICE provides lensing catalogues (Fosalba et al. 2015), galaxy catalogues (Carretero et al. 2015), dark matter field particles

Results



- Dark matter bias measured
- Consistent with unity



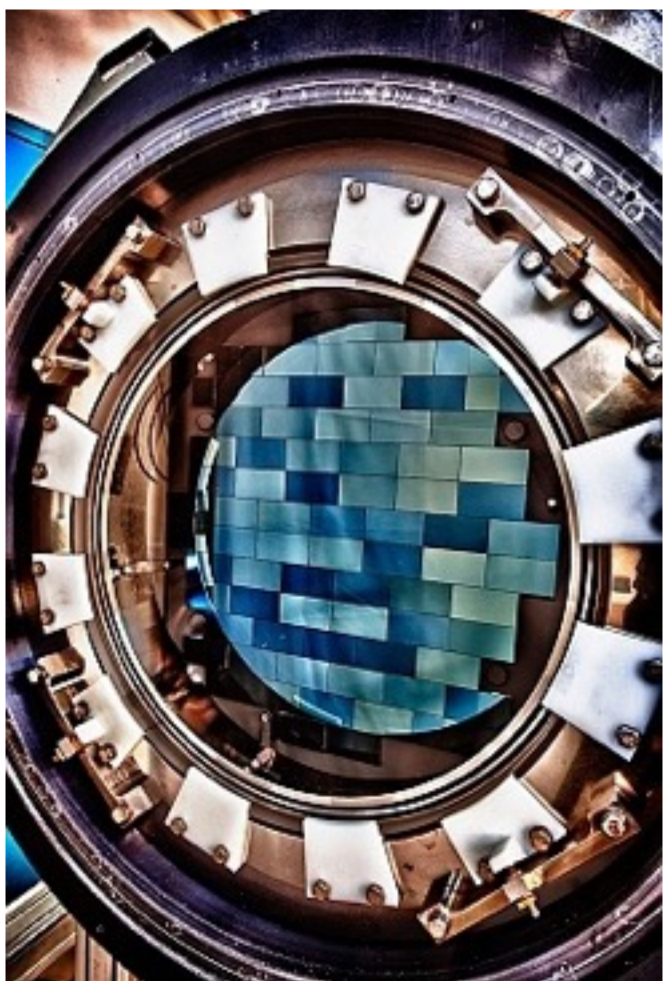
- Galaxy bias measured in MICE for galaxies with i < 22.5
- Consistency between our method and other methods to measure galaxy bias
- Optimal for intermediate redshifts
- This method only depends on Ω_m

Pujol et al. 2016

Application to data

Dark Energy Survey (DES)

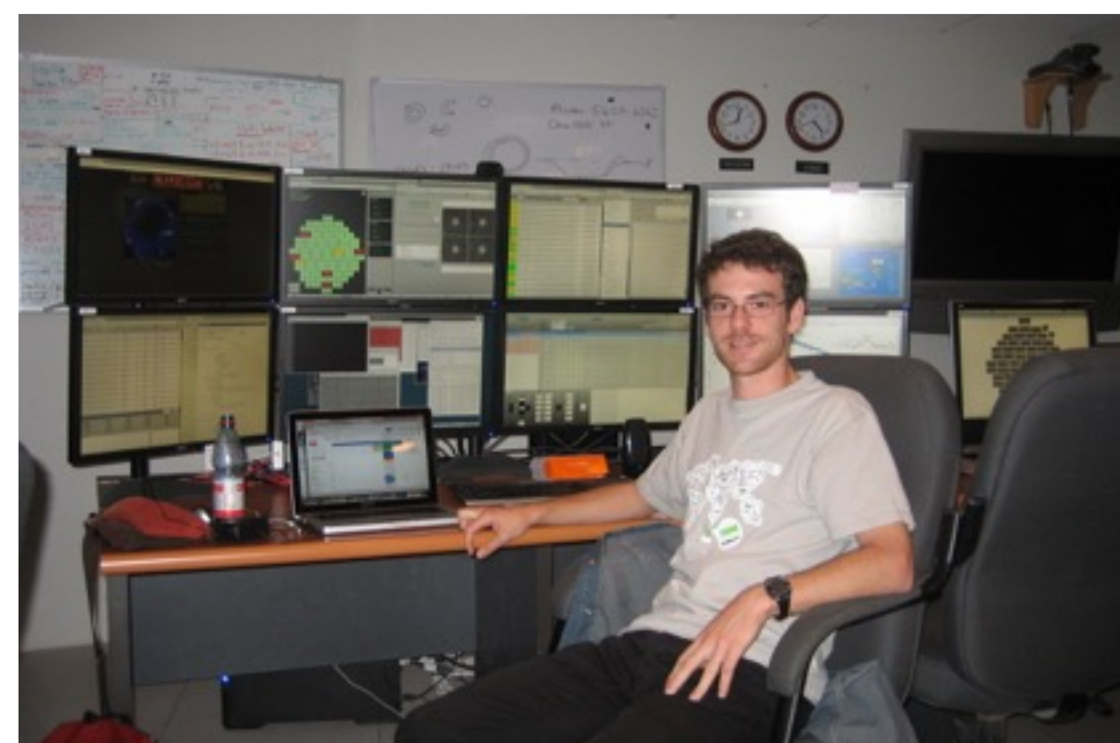
- 4m Blanco Telescope at Cerro Tololo (Chile)
- 5,000 square degrees
- 300 million galaxies up to z = 1.4
- Collaboration of 25 institutions



DECam

- 570 Megapixel camera (DECam)
- 74 CCDs
- 5 optical filters
- 525 nights
- Photo-z survey

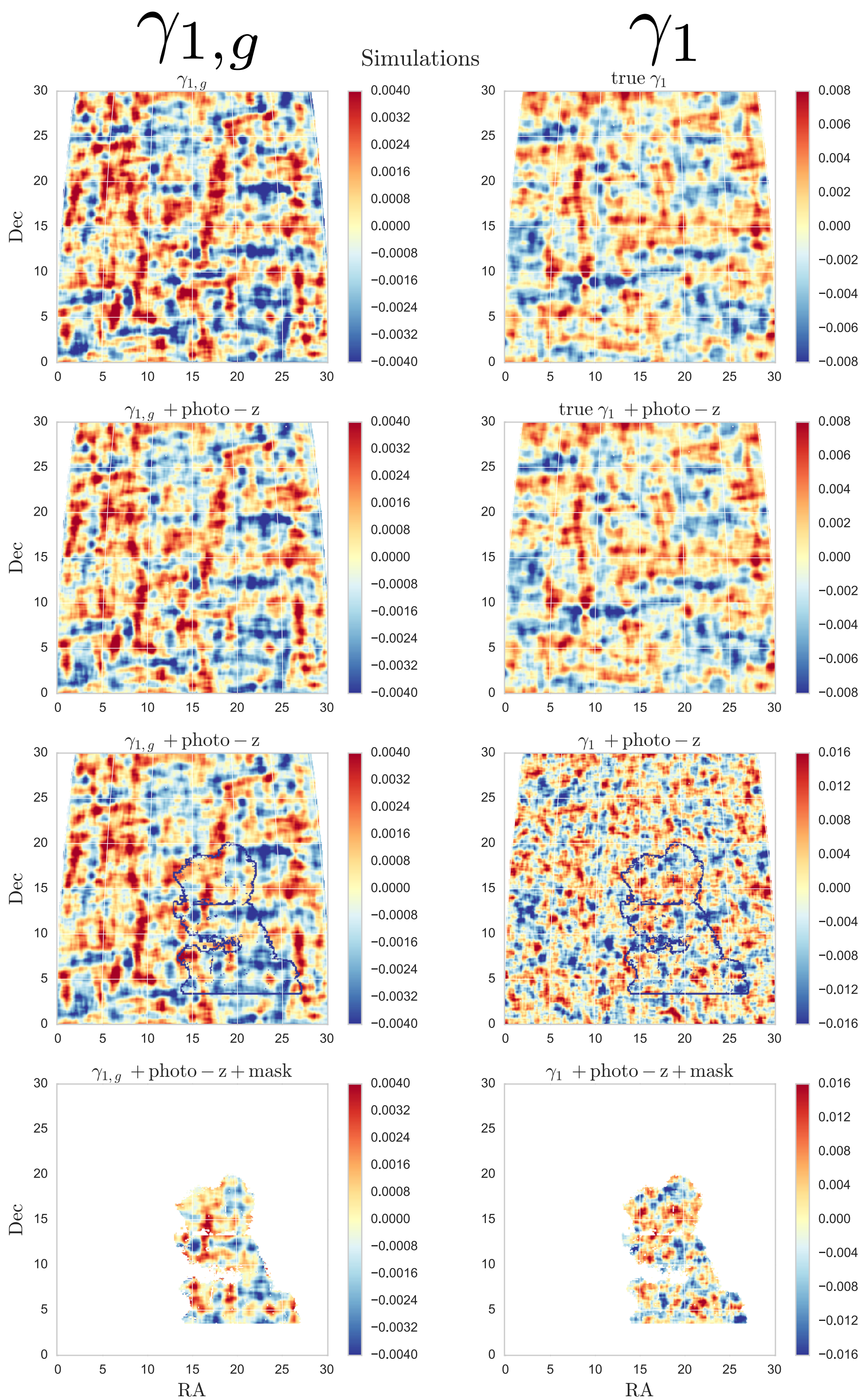
Cerro Tololo



Cool observer being distracted

Application to data

Further simulation tests in MICE

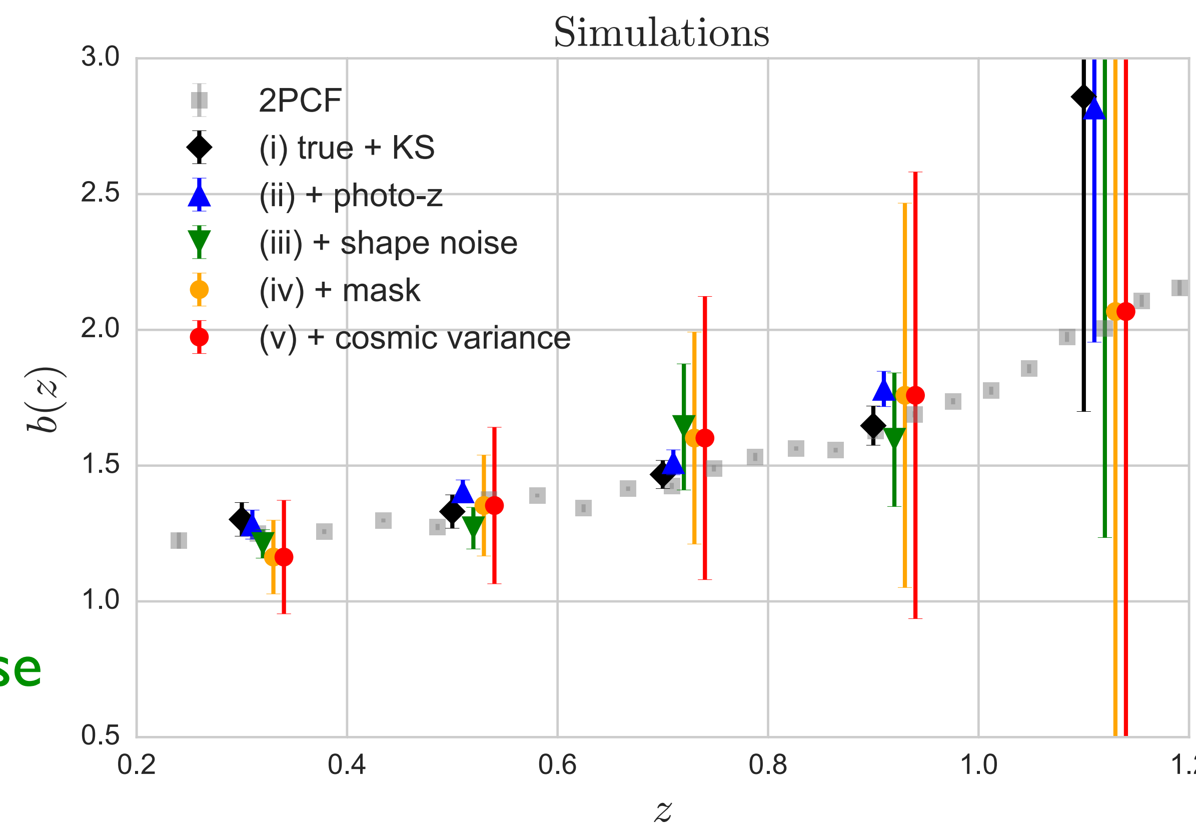


Using shear instead of convergence

applying photo-z errors

applying shear noise

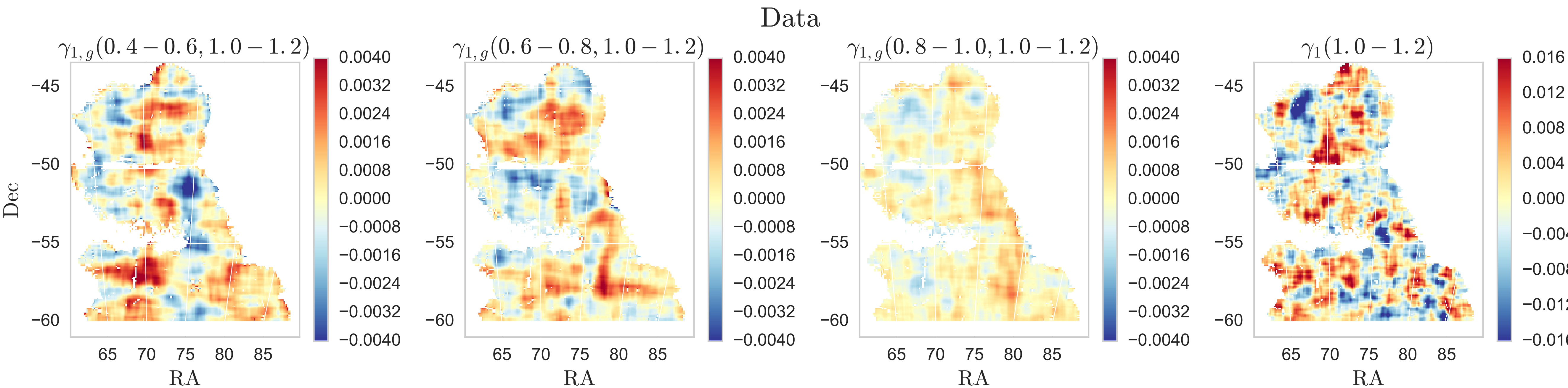
applying SV mask

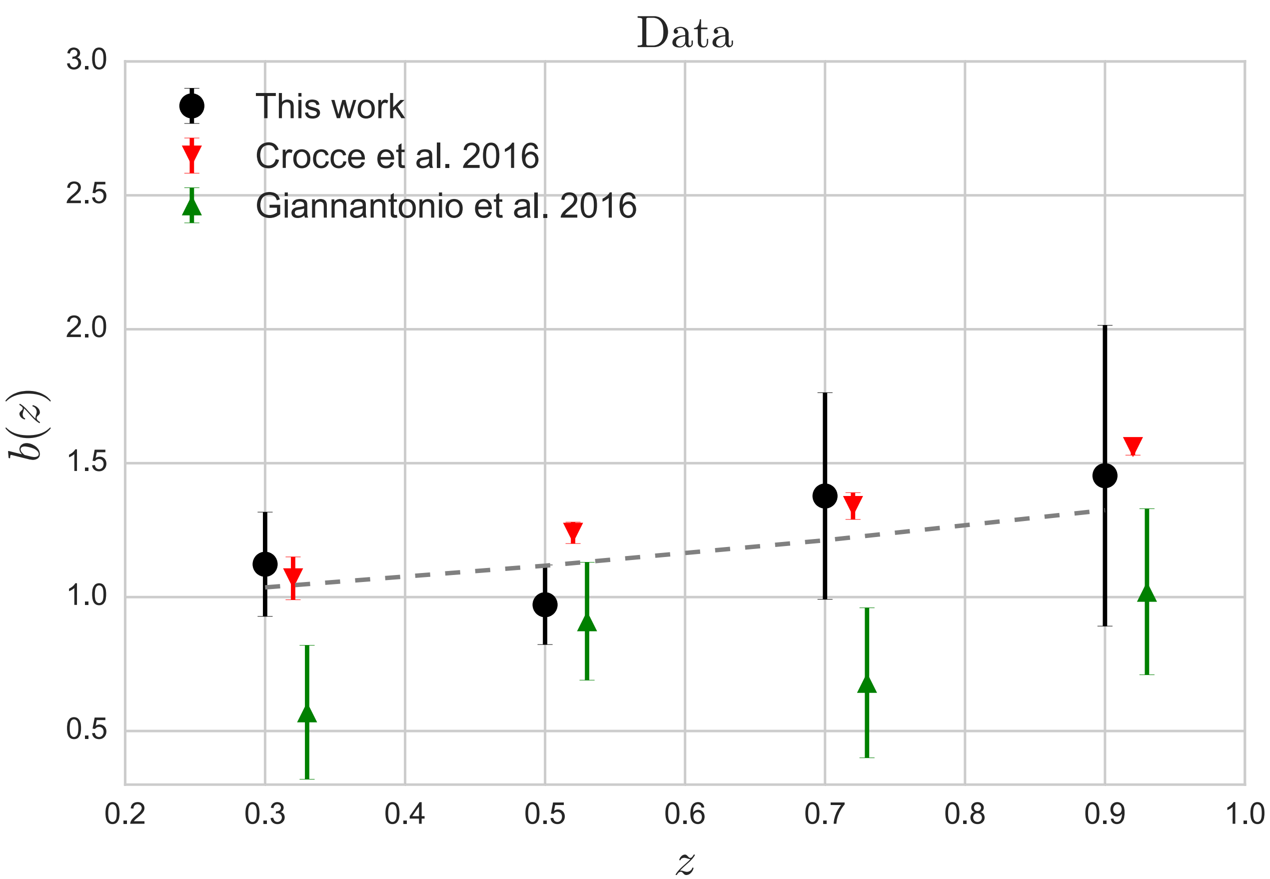


Chang et al. 2016

Application to data

Results for DES SV data





- Galaxy bias for the benchmark galaxy sample (i < 22.5)
- Consistent results with other estimations of bias
- Linear fit show slight increase of bias in redshift

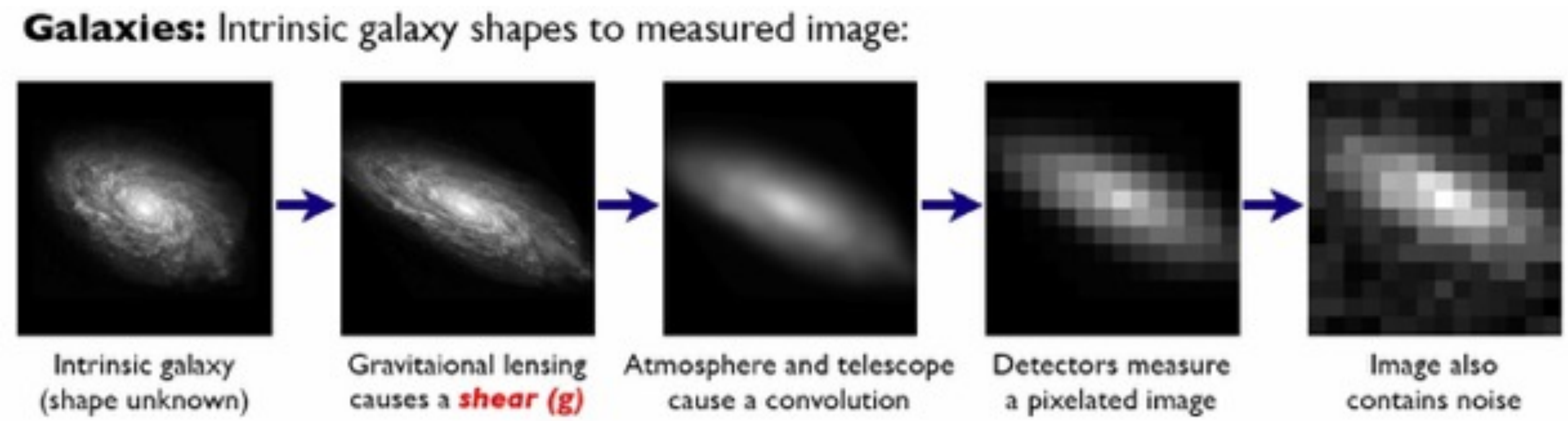
Chang et al. 2016

Conclusions

- Study Large Scale Structures and clustering is useful for cosmology
- Galaxy Bias describes the connexion between galaxy and dark matter distribution, important to improve our precision in cosmology studies
- Gravitational Lensing is a very useful tool to measure the mass distribution, baryonic and dark matter
- New method to measure galaxy bias from WL and density fields
- Method applied to DES SV data, planning to apply it to Y1

Work at CEA

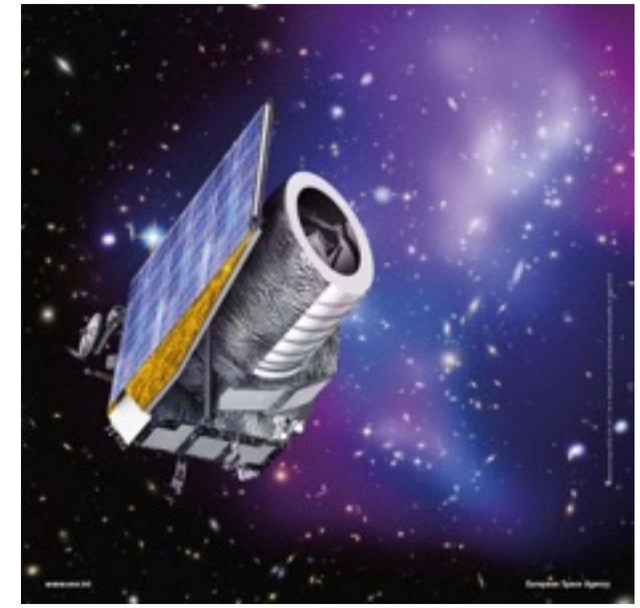
Many processes affect the galaxy images that we obtain



+ Specific instrumental systematics form CCD, telescope, electronics, Point Spread Function, overlap between galaxies, etc.

And when we estimate the galaxy shapes many other aspects can bias our results:

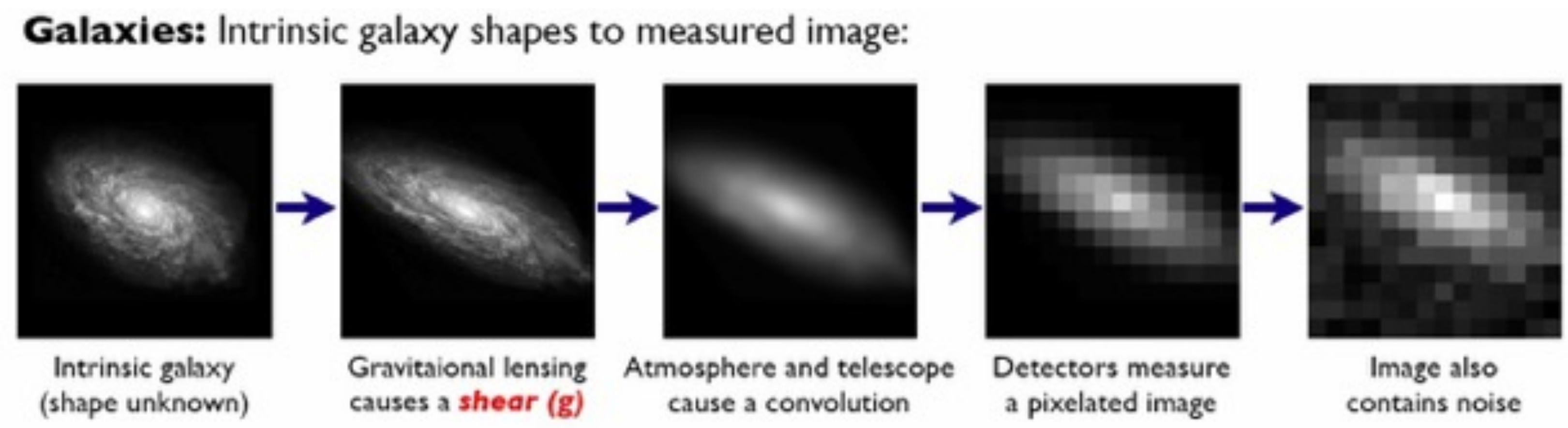
- Pixelization
- Galaxy morphology
- Truncation
- The use of a wrong model
- Neighbour galaxies
- …



Euclid Mission

Work at CEA

Many processes affect the galaxy images that we obtain



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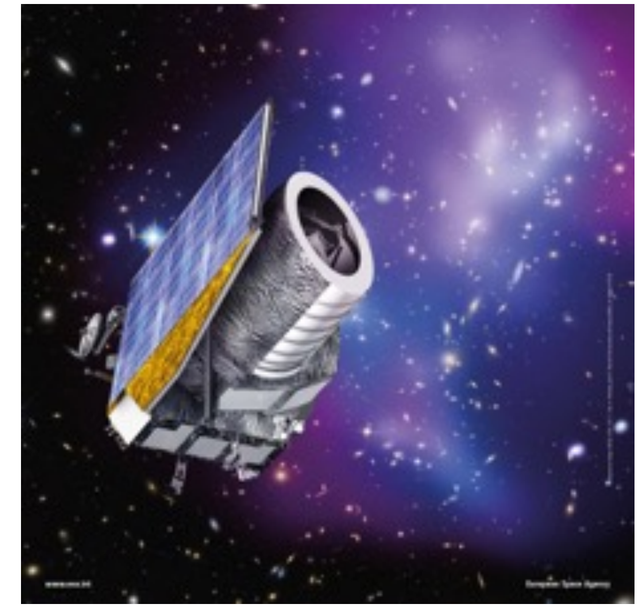

Euclid Mission

And with all these issues we want to measure lensing statistics with unprecedented precision!

Goal of my work: study the biases produced in the estimation of galaxy shapes and how to calibrate them


Thanks!