I.S. InDark. Report 2016

The goal of InDark is to investigate crucial aspects of the standard cosmological model and their connection with fundamental physics.

Main topics are: inflation in the Early Universe, the nature of Dark Matter and of Dark Energy and modified gravity models. Particular emphasis is given to the present-day and future observations of CMB radiation, the study of the Large-Scale Structure (LSS) of the Universe through present and future surveys.

InDark Nationwide

The InDark project is carried out in 8 INFN sections: Bologna (11 people), Ferrara (6), LNGS (4) Padua (12), RM2 (4), RM3(3), Turin (6) and Trieste (16).

National Coordinator: Nicola Bartolo (Pd)

InDark@ RM3

Local Coordinator (E. Branchini)

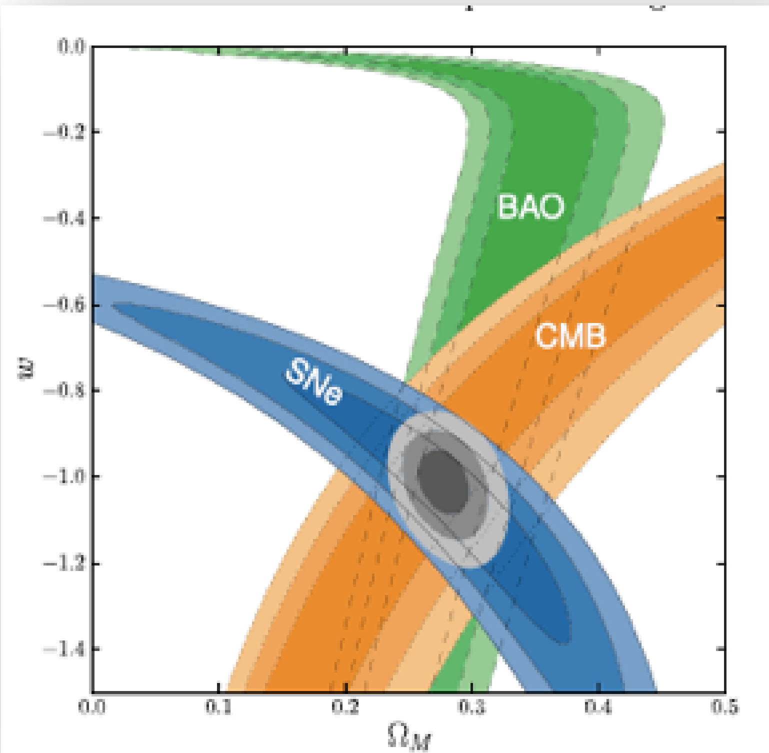
Members: A. Balaguera-Antolínez (Postdoctoral Fellow), Adriana Postiglione (PhD. student)

InDark@ RM3: Research Topics

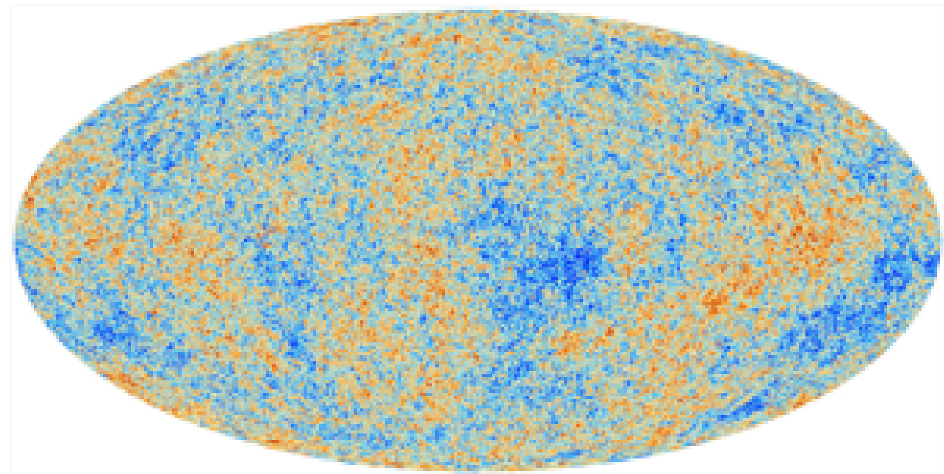
1. Indirect Dark Matter searches. DM features in the γ-ray sky observed by Fermi-LAT. Method: x-correlation with Large Scale Structure [LSS]. Results: constraints on DM mass and annihilation x-section.
2. Search for missing baryons in the intergalactic medium. Method: X-ray observations from space. Results: new observational strategies to detect this missing component with next generation x-ray satellites.
3. Nature of Dark Energy and deviations from General Relativity. Method: analysis of the spatial distribution of galaxies in large surveys. Results: preparation activities for the Euclid Satellite Mission.

The Euclid Satellite Mission

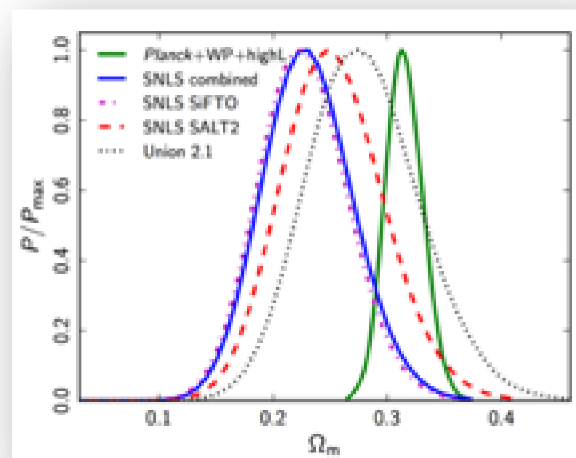
An accelerating Λ–dominated Universe: “concordance”, but with a few crucial open questions…



Amanullah et al. 2010 (Union Supernovae)



Planck Collaboration 2013, paper XVI



Euclid key question 1

Is cosmic acceleration produced by a cosmological constant or by an evolving scalar field?

Evolving equation of state of DE:
e.g.

$$w(a) = w_0 + w_a(1 - a)$$

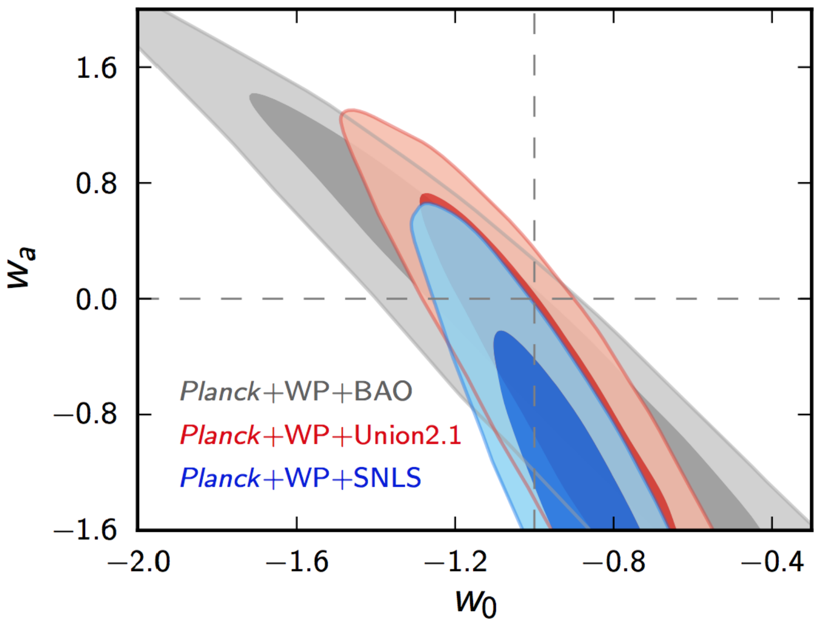
DETF (Albrecht et al. 2006): characterize experiments through a Figure of Merit in ($\boldsymbol{w_0}$, $\boldsymbol{w_a}$) plane (or similar):

$$\mathrm{FoM} = 1/(\Delta w_0 \times \Delta w_a)$$

But this reflects chosen parameterization

→ FoMs should be taken with a big grain of salt (e.g. NASA/DOE/ESA FoMSWG report, Albrecht et al. 2009): there is much more science in a galaxy survey

Parameterizing our ignorance

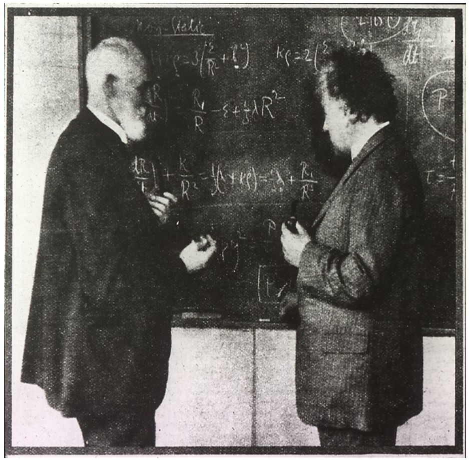


Planck Collaboration 2013, XVI

Does General Relativity still work on cosmological scales?

A story with two sides…

$$\mathcal{R}_{\mu\nu} - \frac{1}{2} g_{\mu\nu}\mathcal{R} = 8\pi G_{\mathrm{N}}\mathcal{T}_{\mu\nu} - \Lambda_{\mathrm{b}} g_{\mu\nu}$$



Modify gravity theory [e.g. ***R* → *f(R)***]

→ Distinguish by measuring both background expansion H(z) and growth rate of structure f(z)

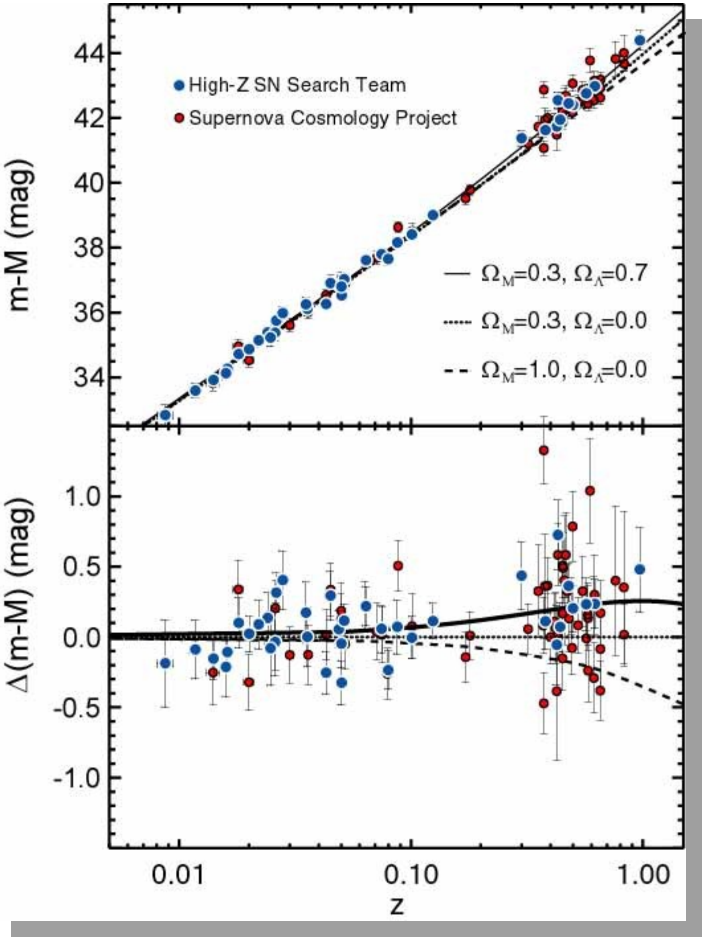
Euclid goal: answer both questions

1. Measure ***the expansion history H(z)*** to high accuracy, as to detect percent variations of DE *equation of state* w(z) with robust control of systematics:

   Achieve this through **two probes**:

   A. Using the scale of Baryonic Acoustic Oscillations (BAO) in the clustering pattern of galaxies as a standard rod

   B. Using shape distortions induced by Weak Gravitational Lensing



Euclid: answer both questions

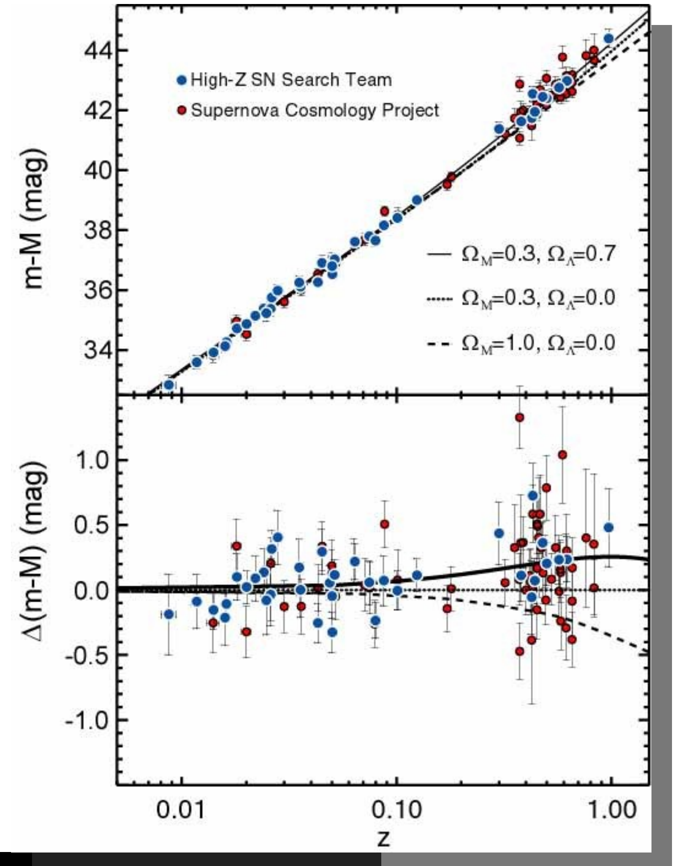
1. Measure the expansion history H(z) to high accuracy, as to detect percent variations of DE *equation of state* w(z) with robust control of systematics.

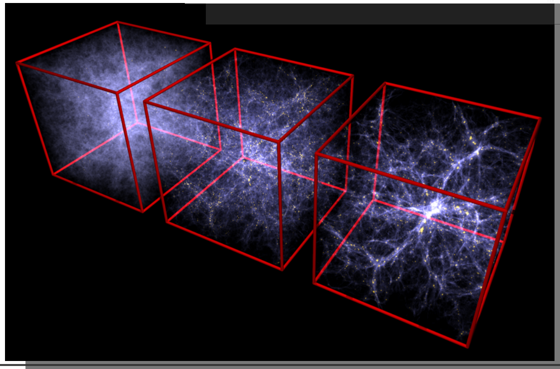
2. Measure at the same time ***the growth rate of structure*** from the same probes, to detect modifications of gravity:

    1. **Clustering redshift-space distortions (RSD)**

    2. **Weak Lensing (WL) Tomography**

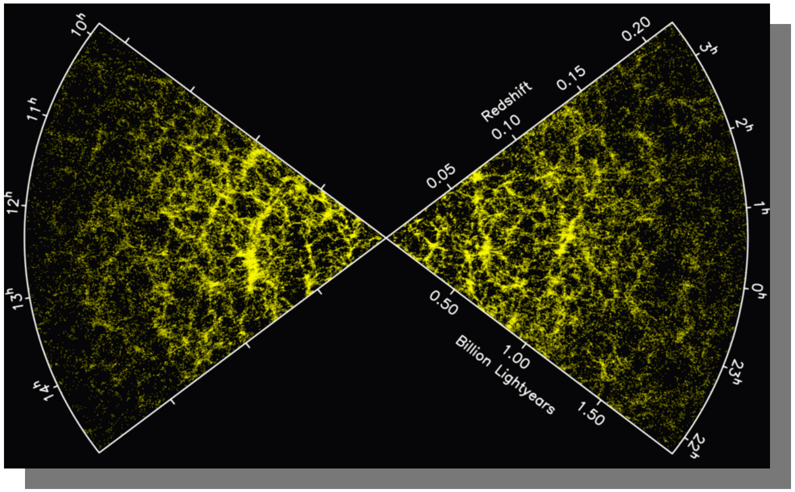
    → These two probes are differently sensitive to the Ψ and Φ potentials of the perturbed metric, i.e. to deformations of time and space



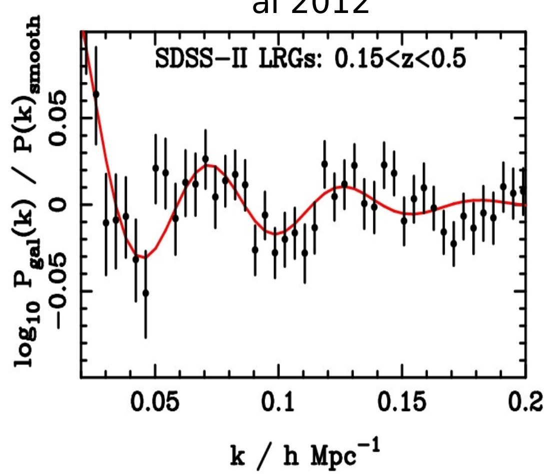


Baryonic Acoustic Oscillations: a cosmological ruler

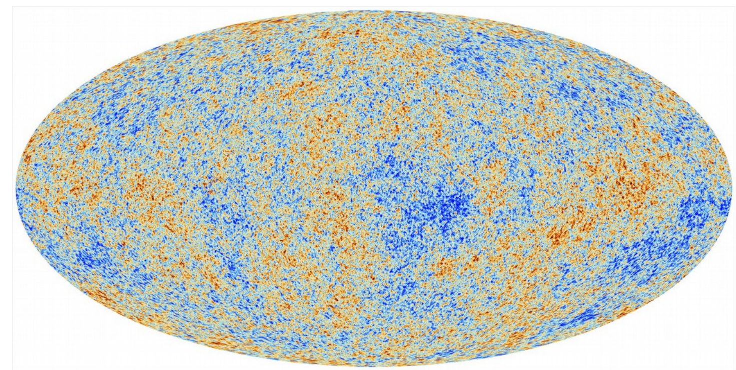
Galaxies



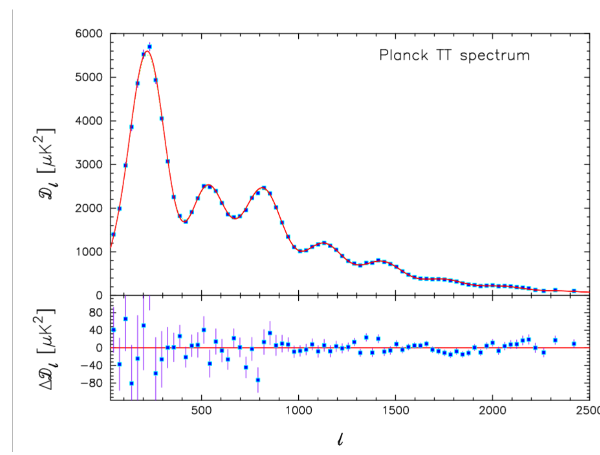
Percival et al. (2007, 2009, 2010); Anderson et al 2012



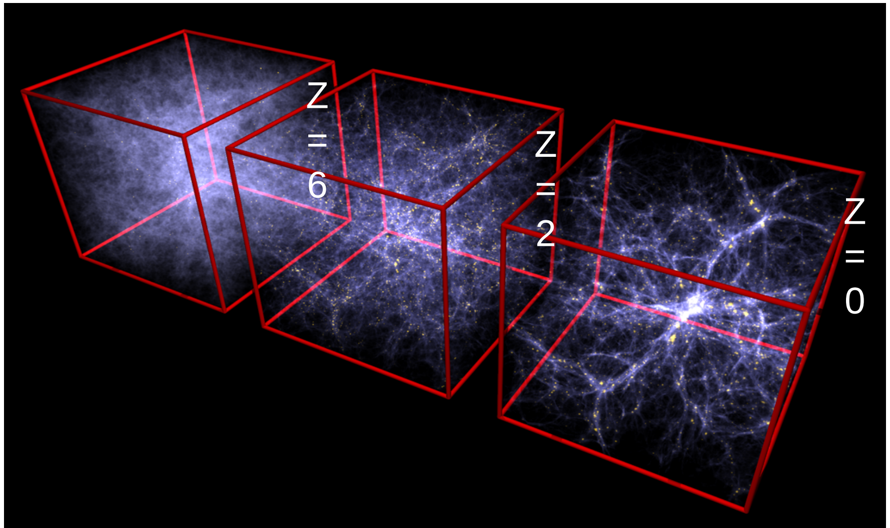
Microwave background

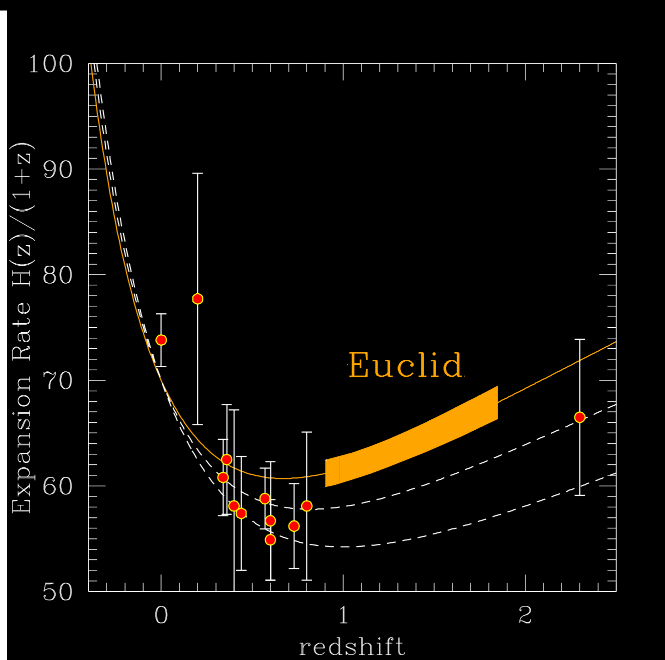


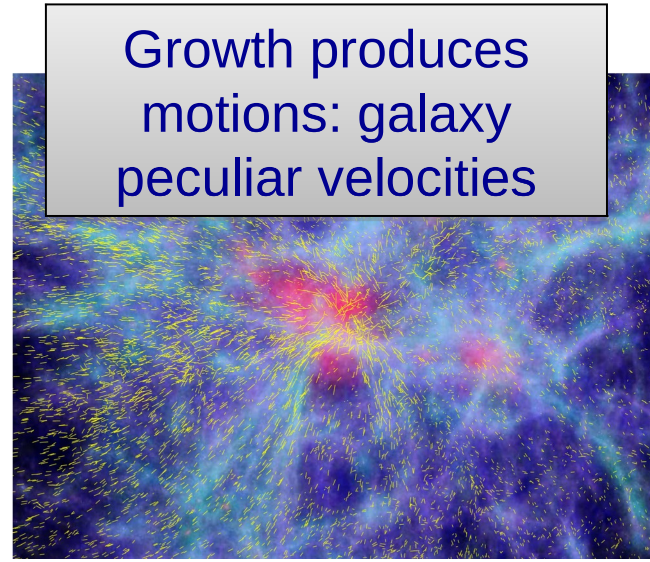
Planck 2013, XVI: Cosmological results

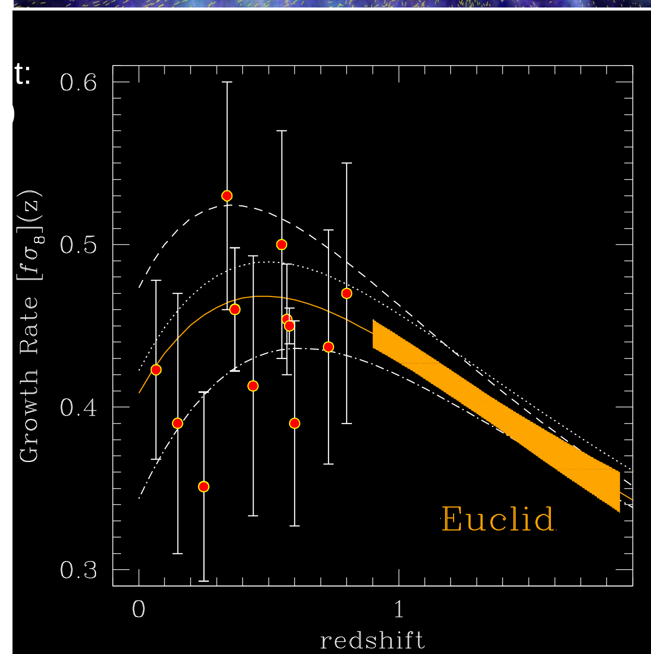


Expansion history H(z) from BAO and SnIa & Growth rate





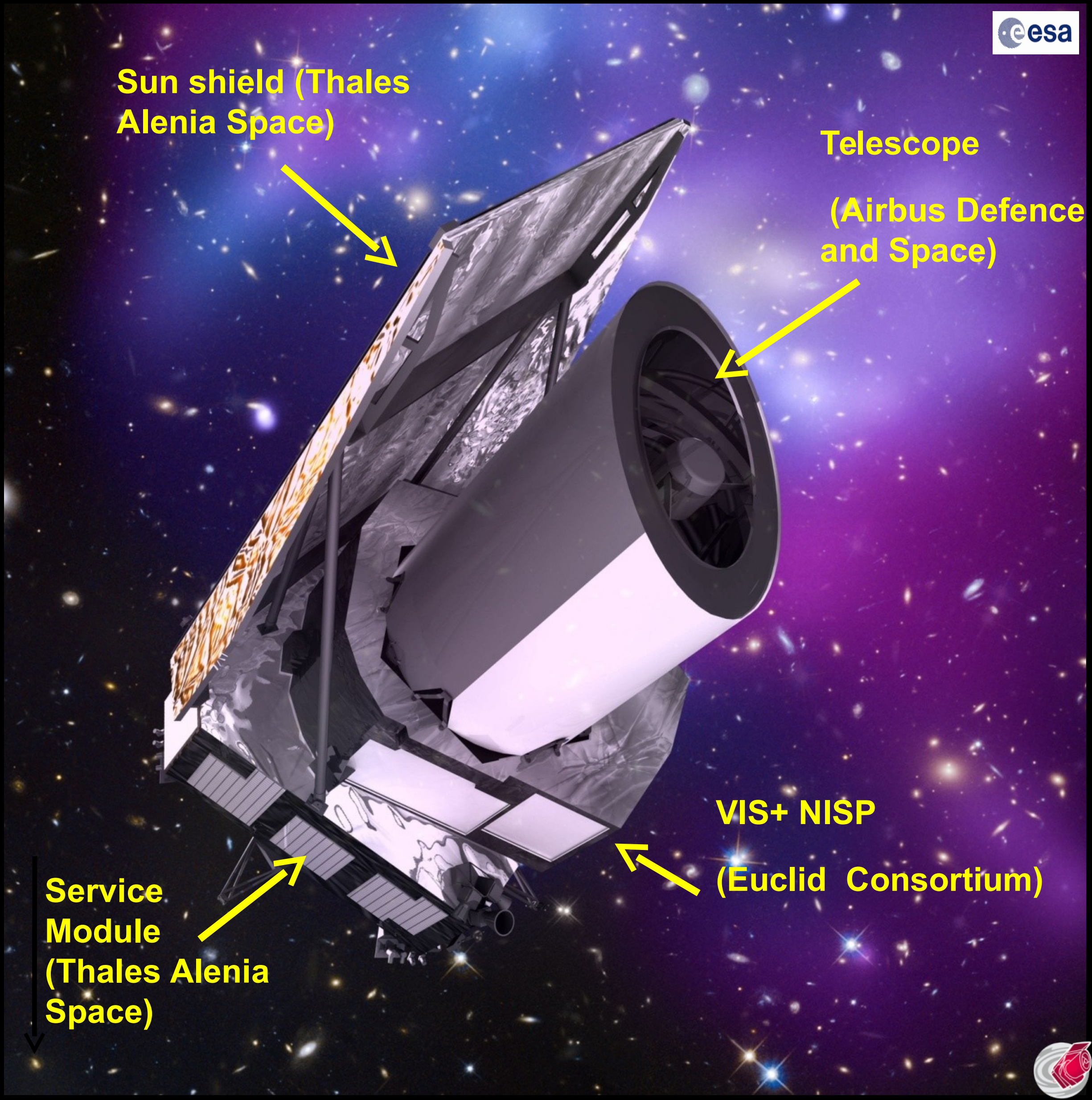




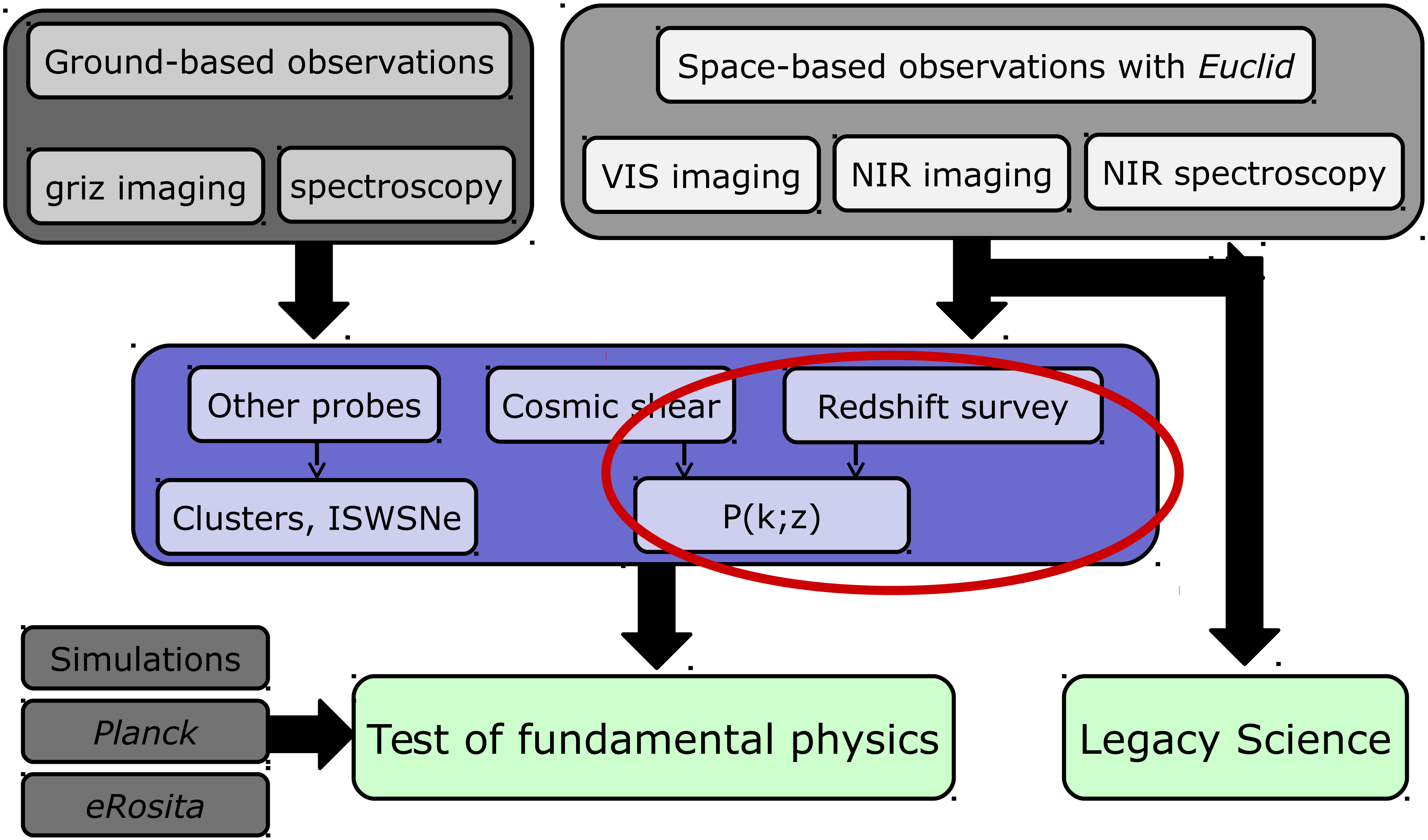
ESA Euclid mission

The legacy of SPACE (Italy-led, PI Cimatti) and DUNE (France-led, PI Refregier) Cosmic Vision proposals: →France and Italy main contributors to Euclid

- Mirror size: 1.2 m Korsch
- Total mass satellite : 2 200 kg
- Dimensions: 4,5 m x 3 m
- Launch: end 2020 by a Soyuz rocket from the Kourou space port
- Placed in L2
- Survey: 6 years,



How to do this with Euclid

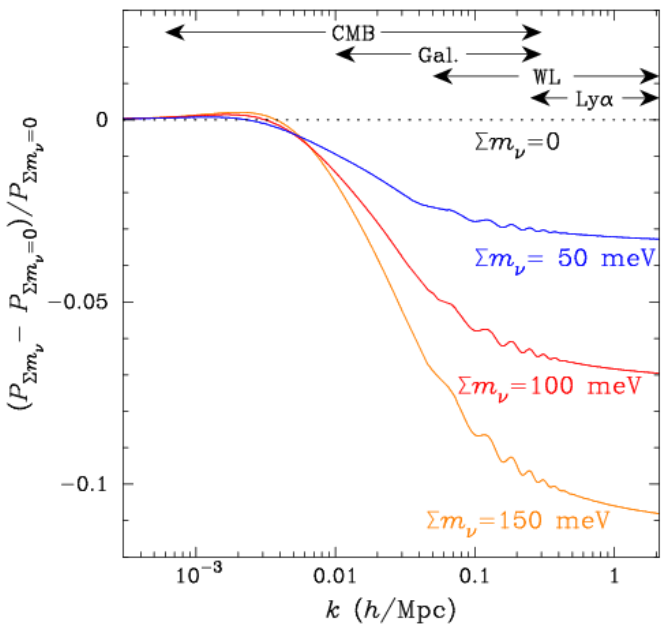


Some forecasts

- 12 billion of stars and galaxies
- 50 millions spectra/redshifts
  - Statistics: = a SDSS @ 1<z<3
  - Rare objects
  - High res. imaging of the extragalactic sky,
  - NIR: cool, obscured and high-z sources
    - Wide:15,000 deg^2, YJH_{AB}=24
    - Deep: 40 deg^2, YJH_{AB}=26

Neutrinos and relativistic species

Abazajian et al 2015



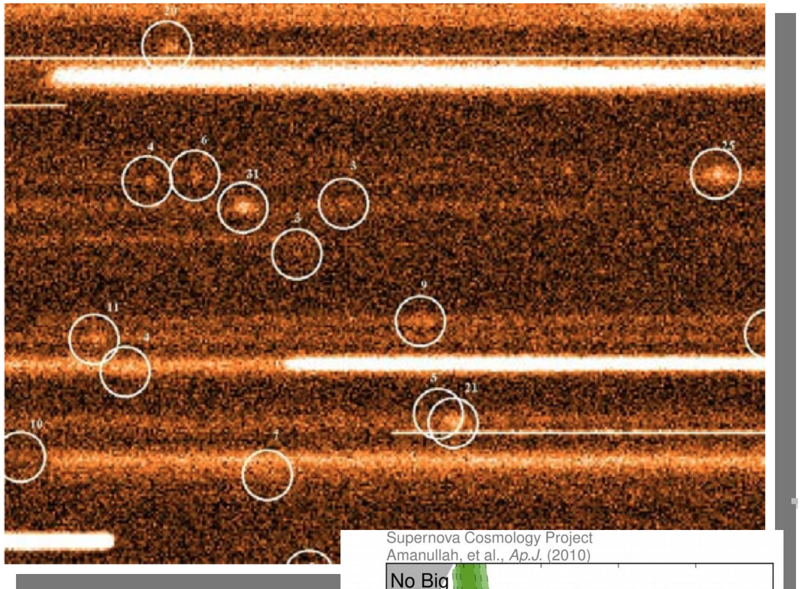
Forecast for primary probes

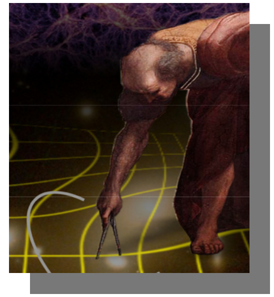
	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν /eV	f_{NL}	w_p	w_a	FoM
Euclid primary (WL+GC)	0.010	0.027	5.5	0.015	0.150	430
Euclid all probes	0.009	0.020	2.0	0.013	0.048	1540
Current (2009)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Ref: Euclid RB arXiv:1110.3193 from Euclkid SWGs
More detailled forecasts given in Amendola et al arXiv:1206.1225

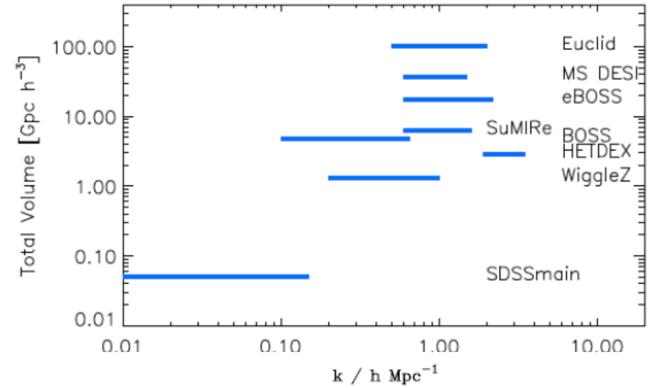
The long way from raw data to cosmology

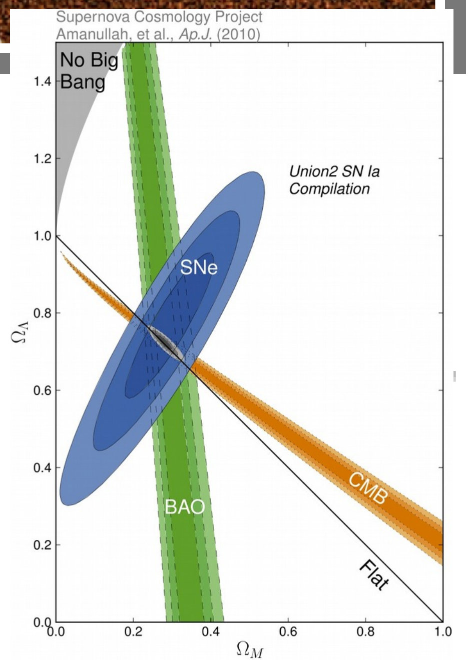
Euclid Consortium

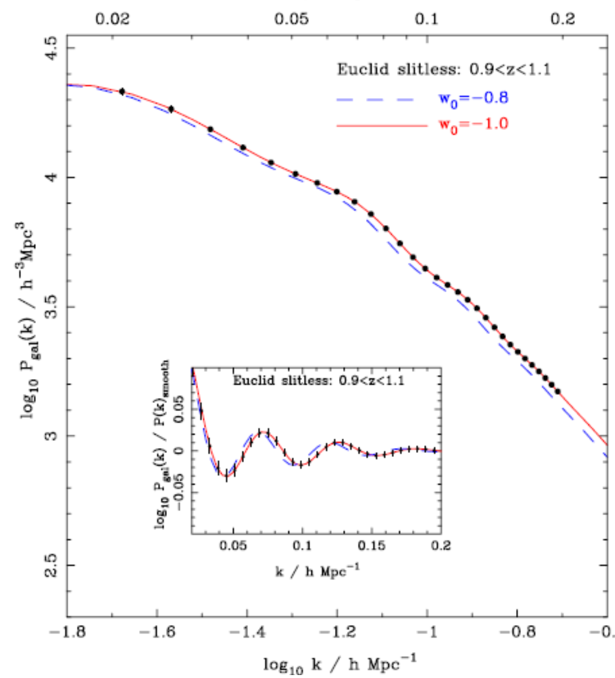




Euclid Theory Review, arXiv 1206.1225 & Living Reviews in Relativity







- Percentage difference [*expected* – *measured*] power spectrum: recovered to 1% .

- **Science comes from overdensities**
  - Need galaxy catalogue
  - Need galaxy mask:
    - angular completeness
    - radial completeness
    - radial/angular fluctuations
- 2-point statistics of δ field contain most, but not all of the information
  - *Power spectrum*

    $$\langle \delta(\boldsymbol{k}) \delta^*(\boldsymbol{k}') \rangle_{\rm en} = (2\pi)^3 \delta_D^3(\boldsymbol{k} - \boldsymbol{k}') P(\boldsymbol{k}').$$

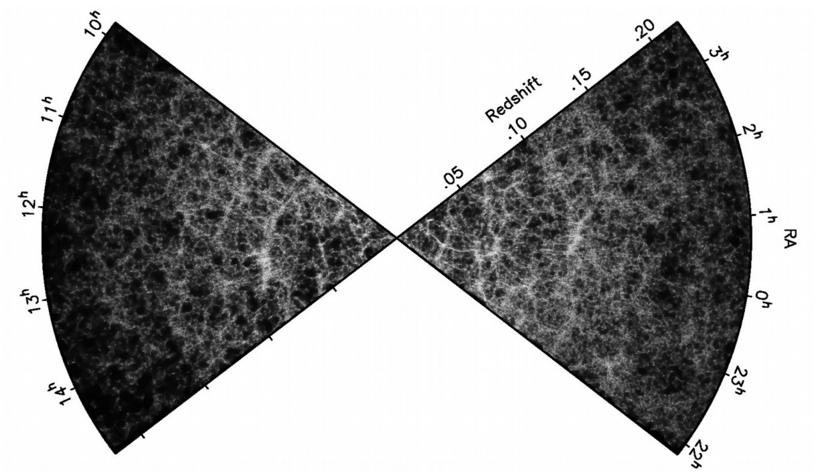
  - *Correlation function*

    $$\xi(\mathbf{r}, \mathbf{r}') \equiv \langle \delta(\mathbf{r}) \delta(\mathbf{r}') \rangle = \xi(|\mathbf{r} - \mathbf{r}'|)$$

  - *Angular power spectrum*
  - *Higher order statistics* (e.g., bispectrum)

$$\delta(\mathbf{r}, t) = \frac{\rho(\mathbf{r}, t) - \langle \rho(\mathbf{r}, t) \rangle}{\langle \rho(\mathbf{r}, t) \rangle}$$

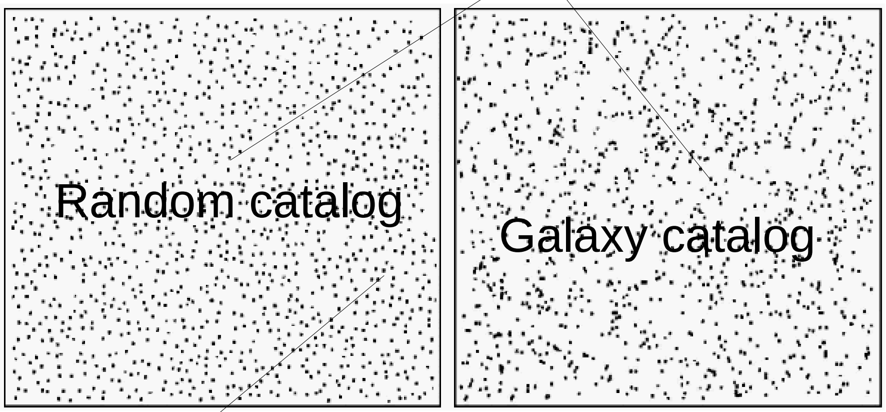
Need to know where we **could** have seen galaxies in the Universe, had they existed



Our contribution: 3D Power Spectrum

Development of a C++ code to measure two-point statistics in Fourier space (e.g, 3D power spectrum, angular power spectrum)

$$F(\mathbf{r}) \equiv \frac{w(\mathbf{r})}{N}\left(n_g(\mathbf{r}) - \alpha n_s(\mathbf{r})\right)$$



$$\hat{P}(k) \equiv \frac{1}{V_k}\int_{V_k} |F(\boldsymbol{k})|^2 \mathrm{d}^3k - S(0)$$

Shot noise

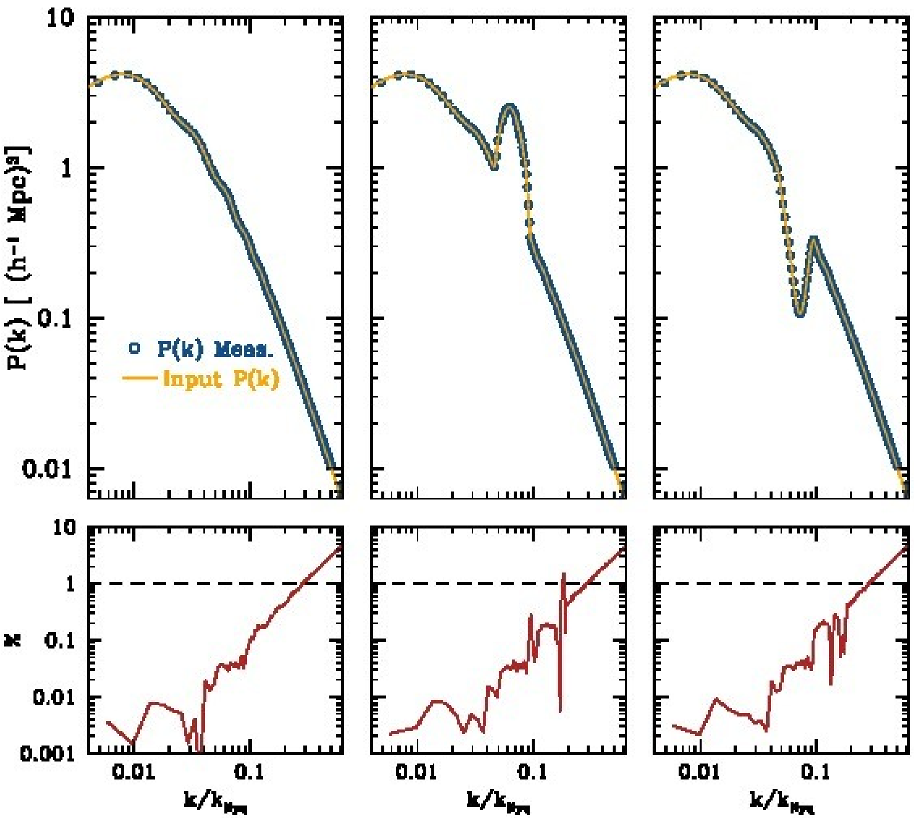
$$\langle \hat{P}(\boldsymbol{k})\rangle = \int \frac{\mathrm{d}^3k'}{(2\pi)^3} P(\boldsymbol{k}')|W(\boldsymbol{k}' - \boldsymbol{k})|^2$$

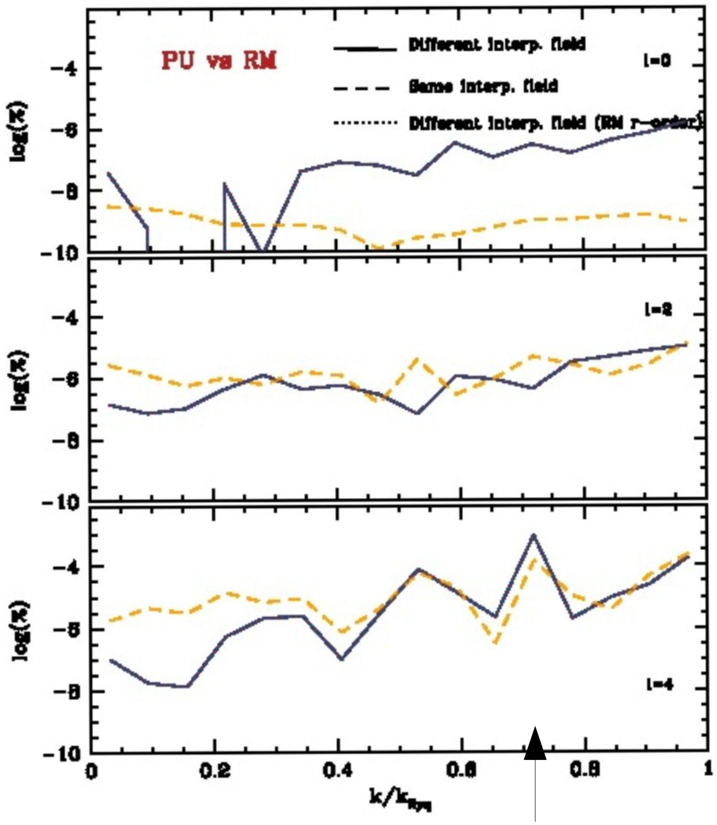
Underlying galaxy power spectrum

Window function

Our contribution: 3D Power Spectrum

Libraries undergoing tests of accuracy and precision. To be included within the EUCLID processing pipelines





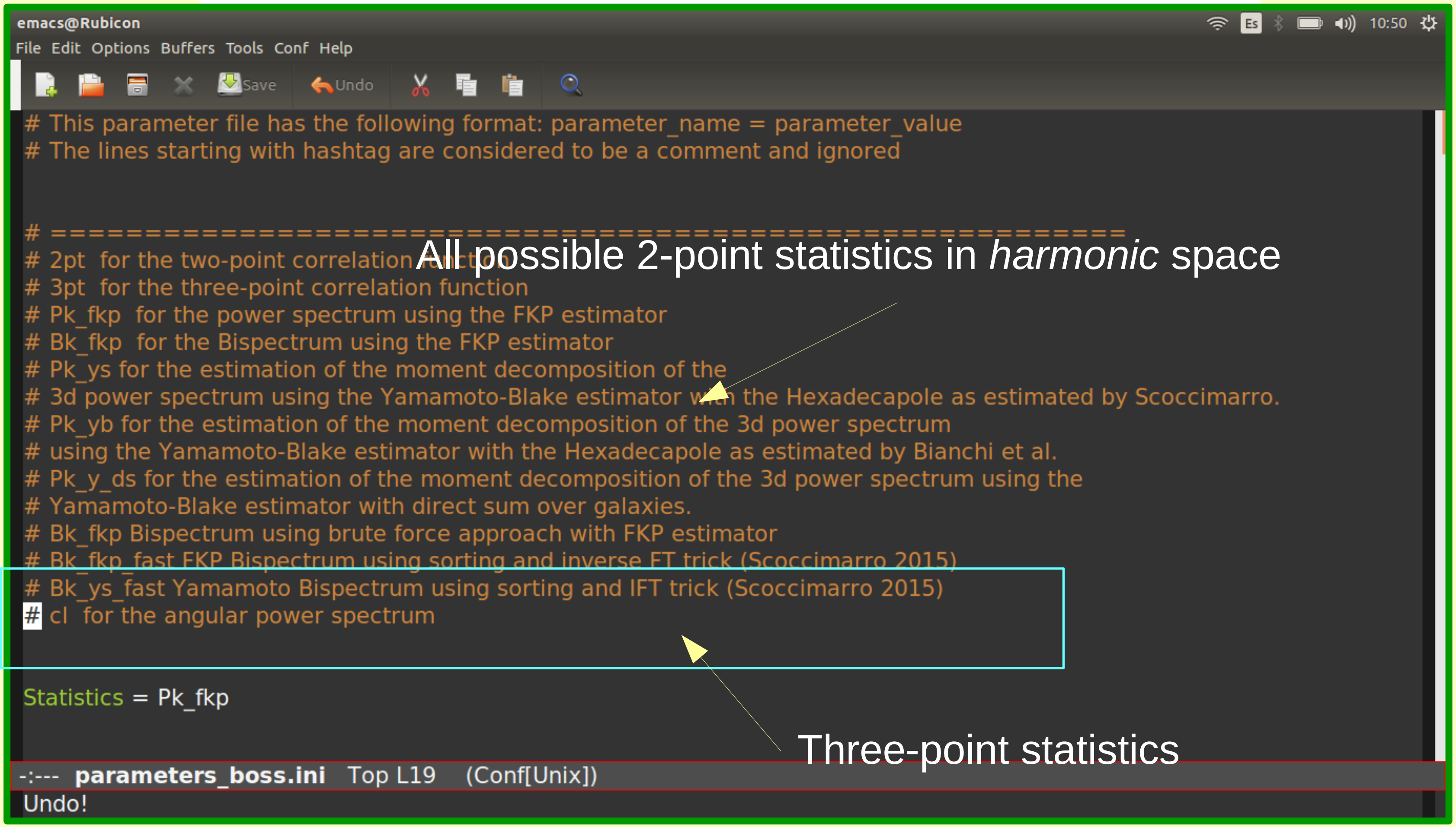
Compared against independent codes

Accuracy tests

Our contribution: 3D Power Spectrum

Processing Functions for the estimates of 3D power spectrum (PK-GC) in EUCLID

Developers: Andrés Balaguera-Antolínez, Federico Marulli



```
# This parameter file has the following format: parameter_name = parameter_value
# The lines starting with hashtag are considered to be a comment and ignored


# ==================================================
# 2pt  for the two-point correlation function
# 3pt  for the three-point correlation function
# Pk_fkp  for the power spectrum using the FKP estimator
# Bk_fkp  for the Bispectrum using the FKP estimator
# Pk_ys for the estimation of the moment decomposition of the
# 3d power spectrum using the Yamamoto-Blake estimator with the Hexadecapole as estimated by Scoccimarro.
# Pk_yb for the estimation of the moment decomposition of the 3d power spectrum
# using the Yamamoto-Blake estimator with the Hexadecapole as estimated by Bianchi et al.
# Pk_y_ds for the estimation of the moment decomposition of the 3d power spectrum using the
# Yamamoto-Blake estimator with direct sum over galaxies.
# Bk_fkp Bispectrum using brute force approach with FKP estimator
# Bk_fkp_fast FKP Bispectrum using sorting and inverse FT trick (Scoccimarro 2015)
# Bk_ys_fast Yamamoto Bispectrum using sorting and IFT trick (Scoccimarro 2015)
# cl  for the angular power spectrum


Statistics = Pk_fkp

-:---  parameters_boss.ini   Top L19    (Conf[Unix])
Undo!
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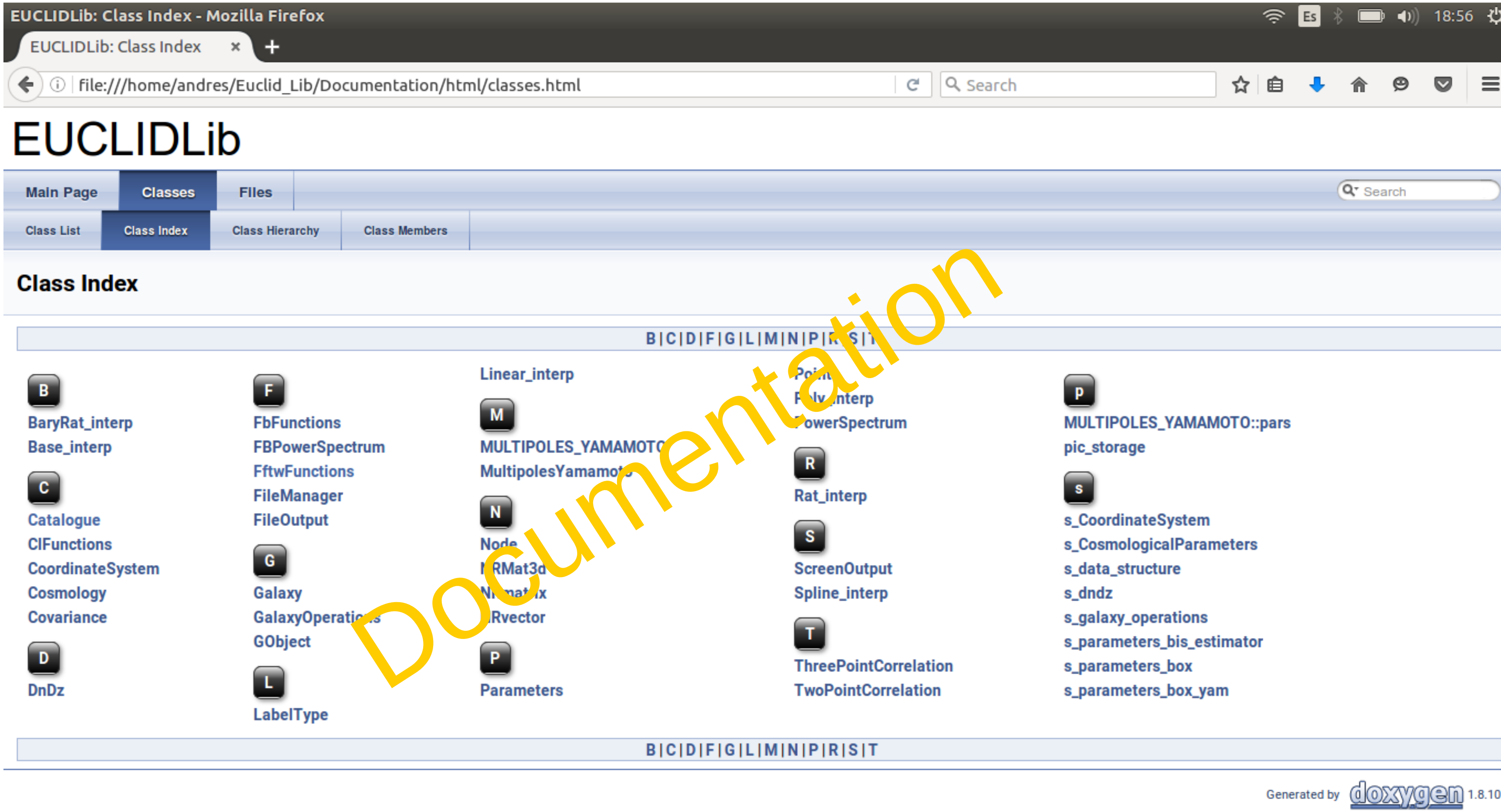
Our contribution: 3D Power Spectrum



Our contribution: other statistics

Other statistics included:

Correlation function (3D, 2D) (with E. Branchini, F. Marulli and M. Moresco @Bologna)

Covariance matrix (lead by P. Monaco @ Trieste and A. Sánchez@Munich)

Angular power spectrum (with E. Branchini, A. Postiglione @RomaTre)

Bispectrum (with J. Pollack@Porstmouth and C. Porciani@ Bonn)

International team aiming at developing Euclid
algorithms for
Galaxy clustering
Lead @RomaTre!

SUMMARY

InDark activities

Large scale structure of the Universe based on recently published catalogs as 2MPZ:

Angular power spectrum from the 2MPZ sample (Adriana Postiglione Phd Project)

and on future missions: EUCLID:

Develpment of algorithms to characterize the spatial distribution of galaxies (from 2013)