The MICE simulations for cosmological surveys: DES, PAU, DESI & Euclid

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on behalf of many collaborators

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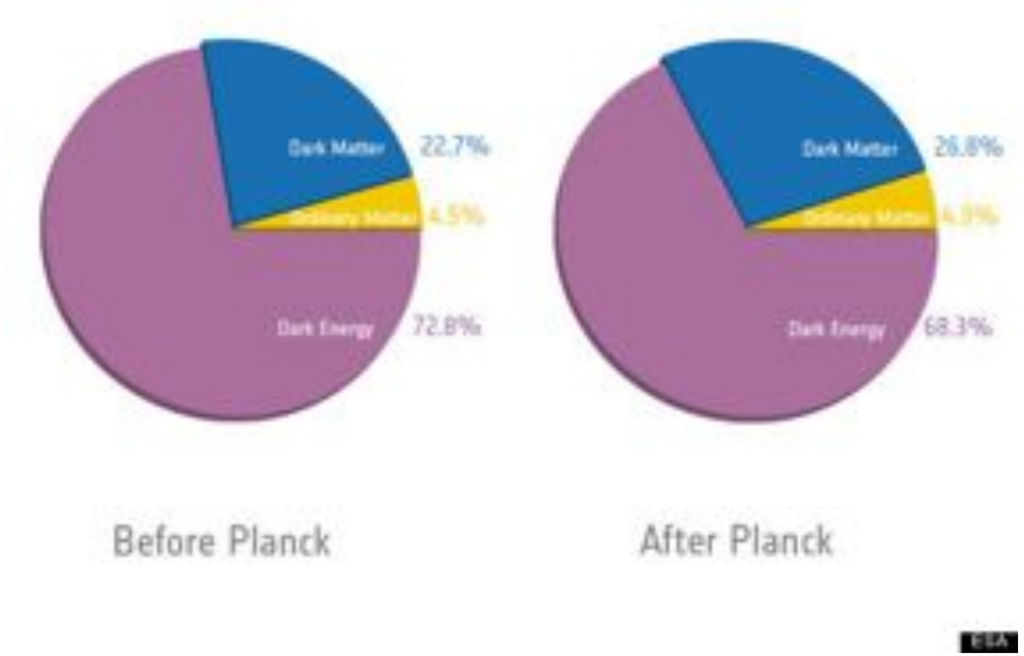
Questions in Cosmology

- What is the physical cause of cosmic acceleration?
  - Dark Energy or modification of General Relativity?
    - If Dark Energy, is it Λ (the vacuum) or something else?
      - What is the DE equation of state parameter *w*?



Probing Cosmology

- Cosmology is probed mainly measuring the expansion rate of the universe H(z), the rate growth of structure g(z)

$$H^2(z) = H^2_0 \ [\ \underbrace{\Omega_M (1+z)^3}_{\text{matter}} + \underbrace{\Omega_R (1+z)^4}_{\text{radiation}} + \underbrace{\Omega_K (1+z)^2}_{\text{curvature}} + \underbrace{\Omega_{DE} (1+z)^{3(1+w)}}_{\text{dark energy}}\ ]$$

g(z) a function of cosmological parameters

Probing Cosmology

- Geometric test: integrals over $H(z)$:

Comoving distance		$r(z) = \int dz/H(z)$
Standard Candles	Supernovae	$D_L(z) = (1+z)\, r(z)$
Standard Rulers	Baryon Oscillations	$D_A(z) = (1+z)^{-1}\, r(z)$
Standard Population	Clusters	$dV/dzd\Omega = r^2(z)/H(z)$

- Growth of Structure test: $g(z)$

  Clusters, Weak lensing, clustering, redshift space distortions

- Matter distribution: $P(k,z)$ and higher orders

  Galaxy clustering

Dark Energy Task Force

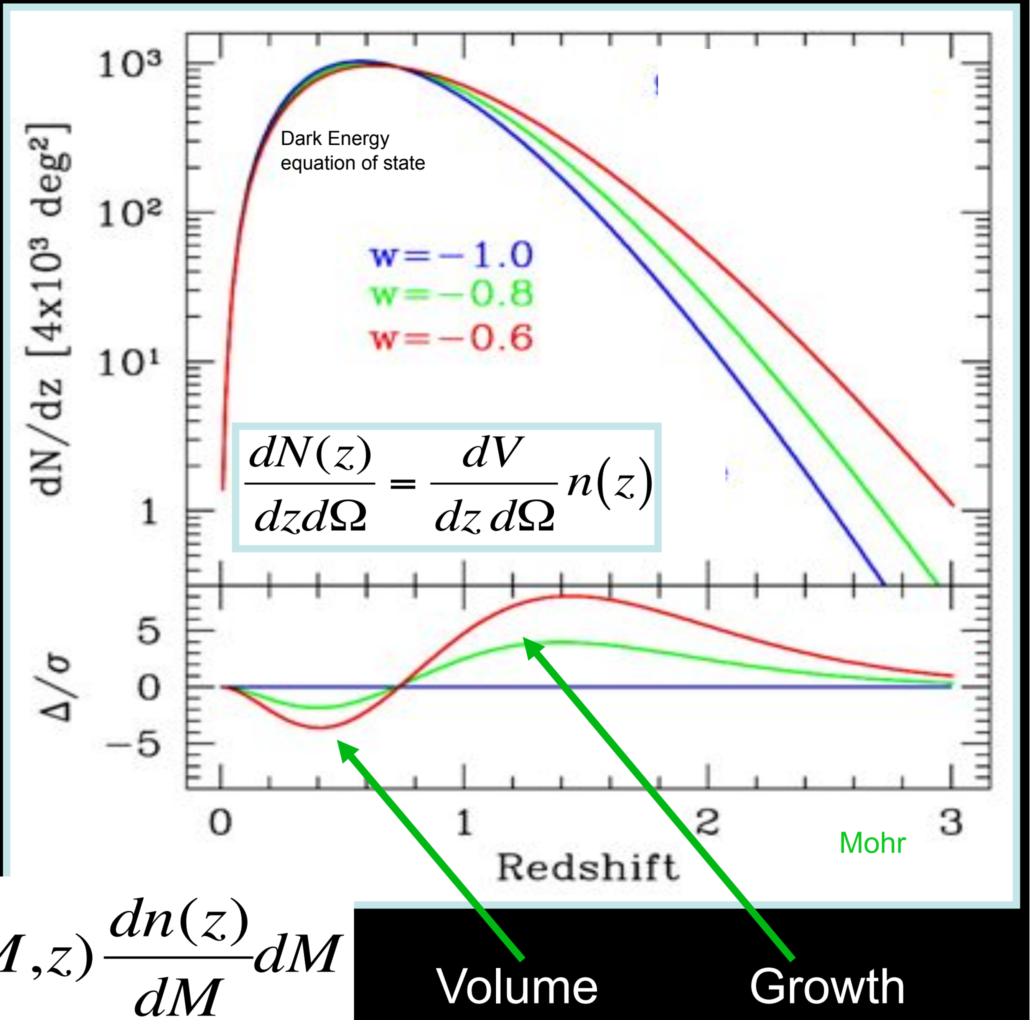
Best observational probes

- Weak lensing (geometrical & growth)
- Baryon acoustic oscillations (geometrical)
- Supernovae (geometrical)
- Clusters of galaxies (growth & geometrical)

I. Clusters

- Elements of the Method:
  - Abundance tracers: measure evolution of density: numbers (growth) / volume (geometry)
  - Clusters are proxies for massive halos whose abundance evolution is sensitive to cosmology
  - Can be detected relatively easy and their z can be estimated (e.g., colours)
  - Observable proxies for cluster mass: optical richness (optical), SZ flux decrement (radio), weak lensing mass (optical), X-ray flux (x-rays)
  - Cluster spatial correlations help calibrate mass estimates

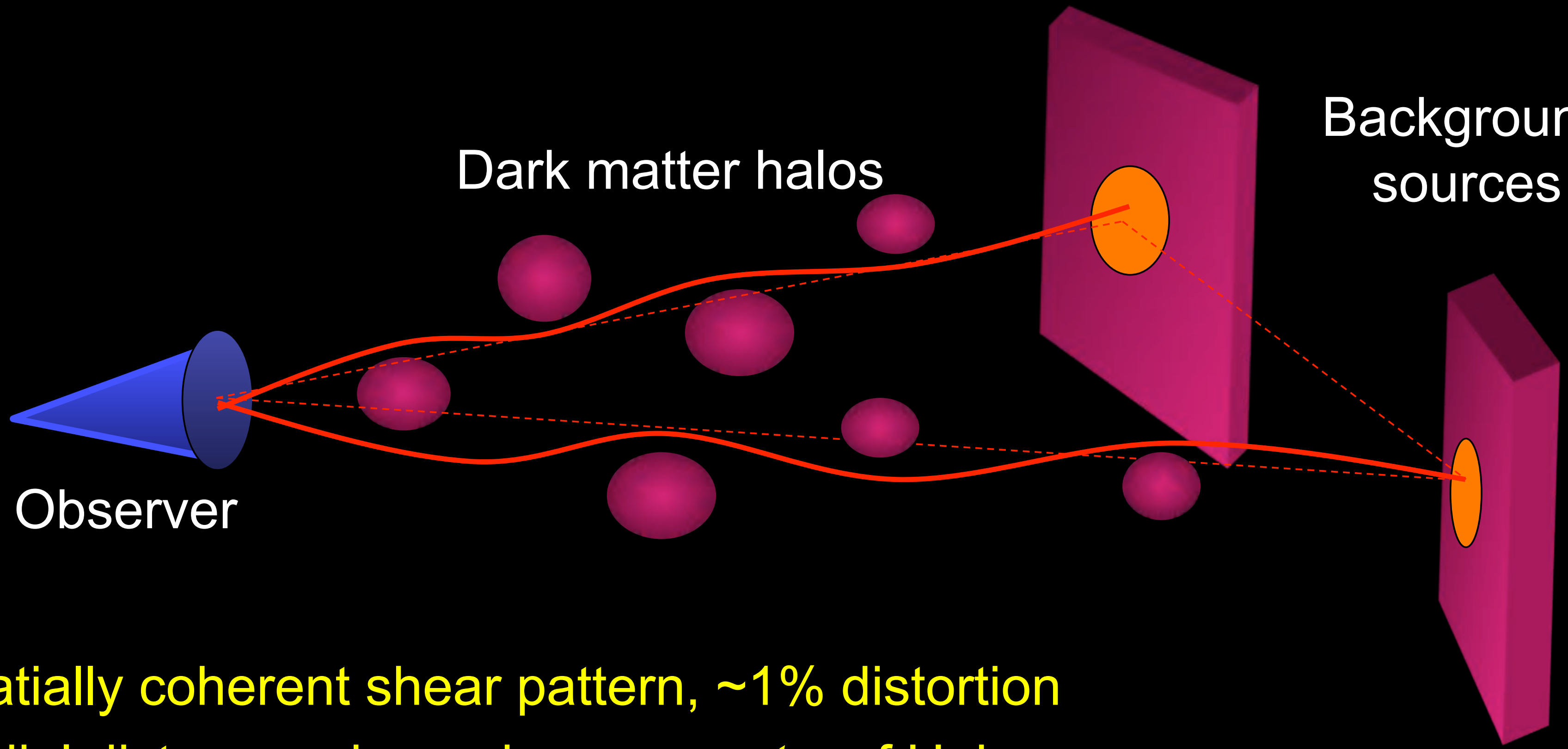
Number of clusters above mass threshold



$$\frac{dN(z)}{dz\,d\Omega} = \frac{dV}{dz\,d\Omega} n(z)$$

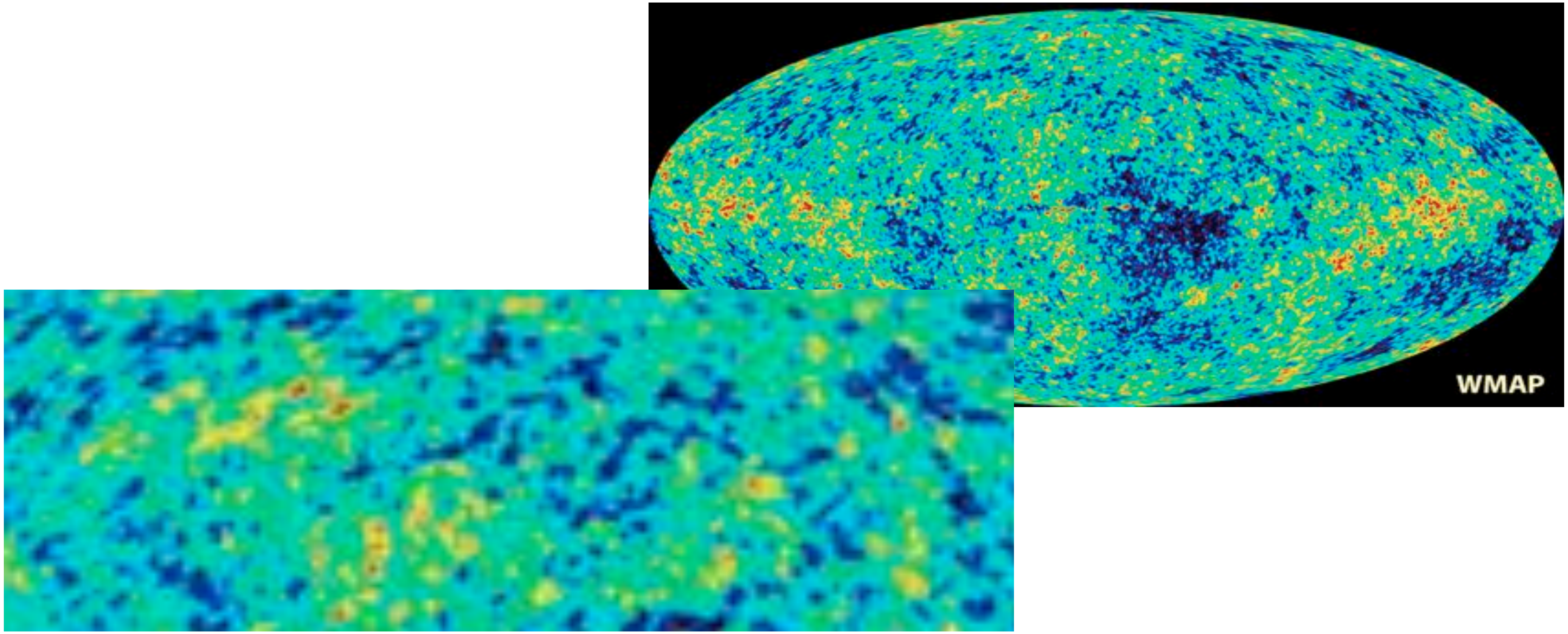
$$\frac{d^2N}{dz d\Omega} = \frac{r^2(z)}{H(z)} \int f(O,z) dO \int p(O \mid M,z) \frac{dn(z)}{dM} dM$$

II. Weak Lensing: Cosmic Shear



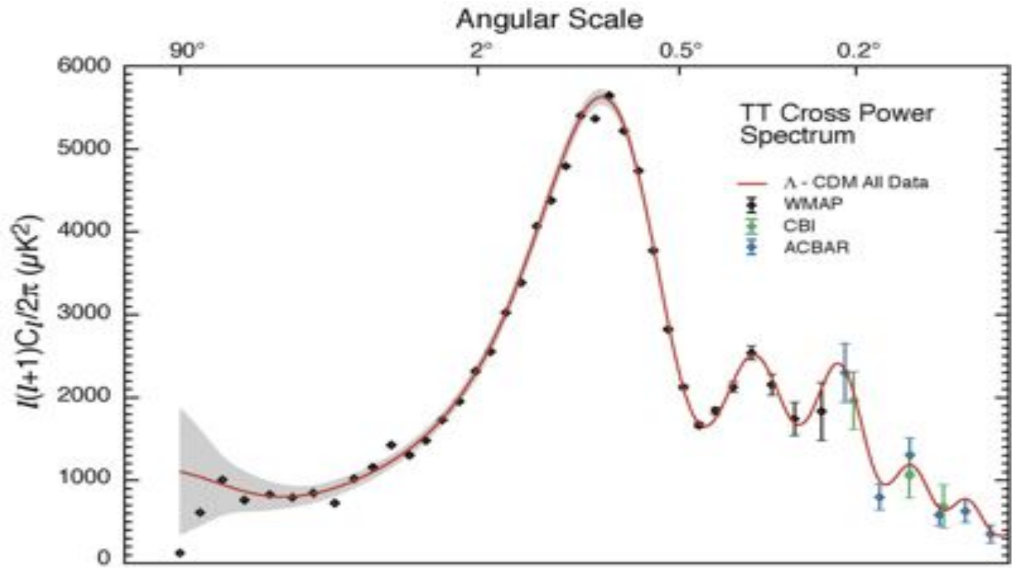
- Spatially coherent shear pattern, ~1% distortion
- Radial distances depend on *geometry* of Universe
- Foreground mass distribution depends on *growth* of structure

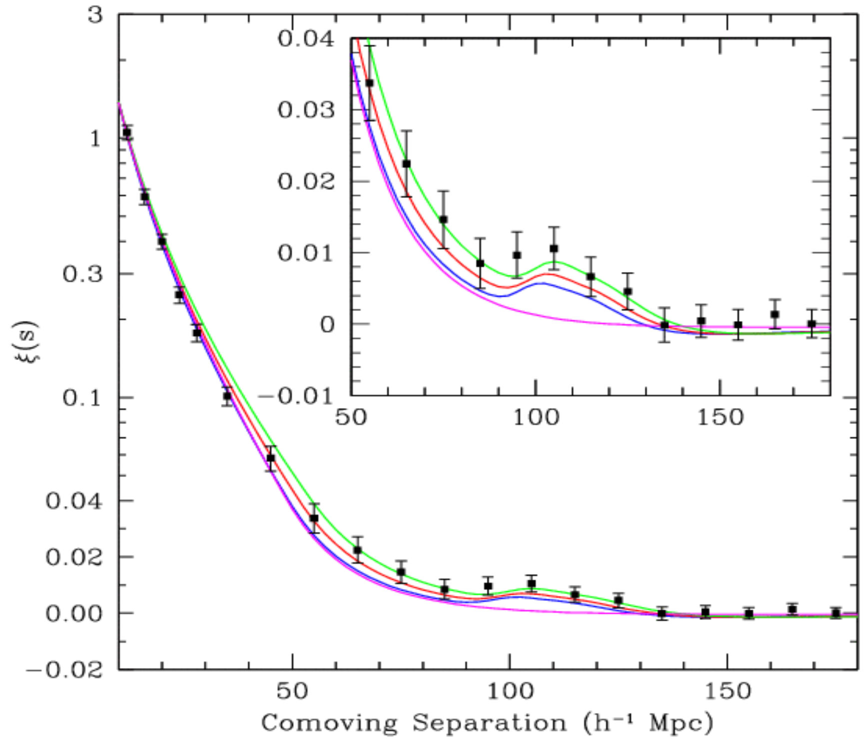
Baryon Acoustic Oscillations (BAO) in the CMB



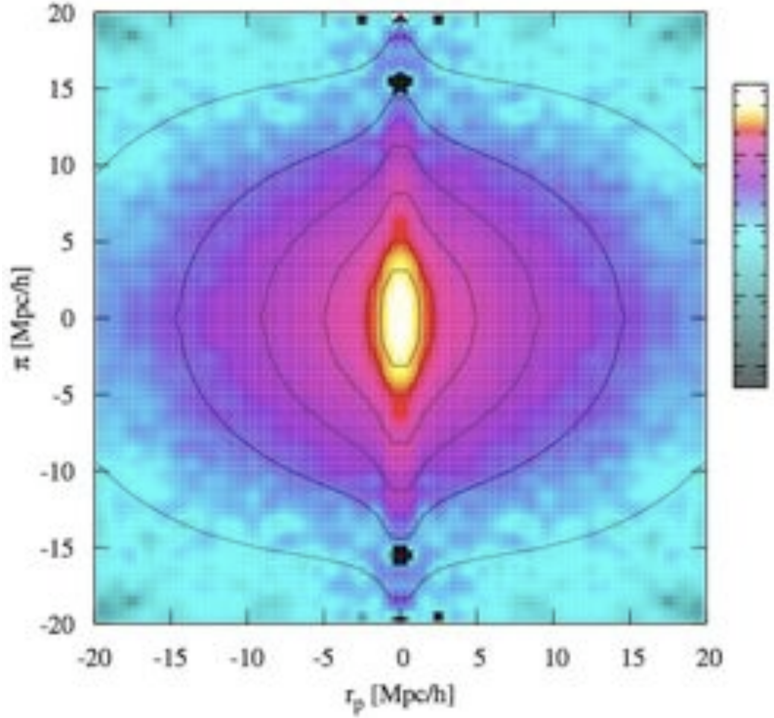
- Characteristic angular scale set by sound horizon at recombination: standard ruler (geometric probe).

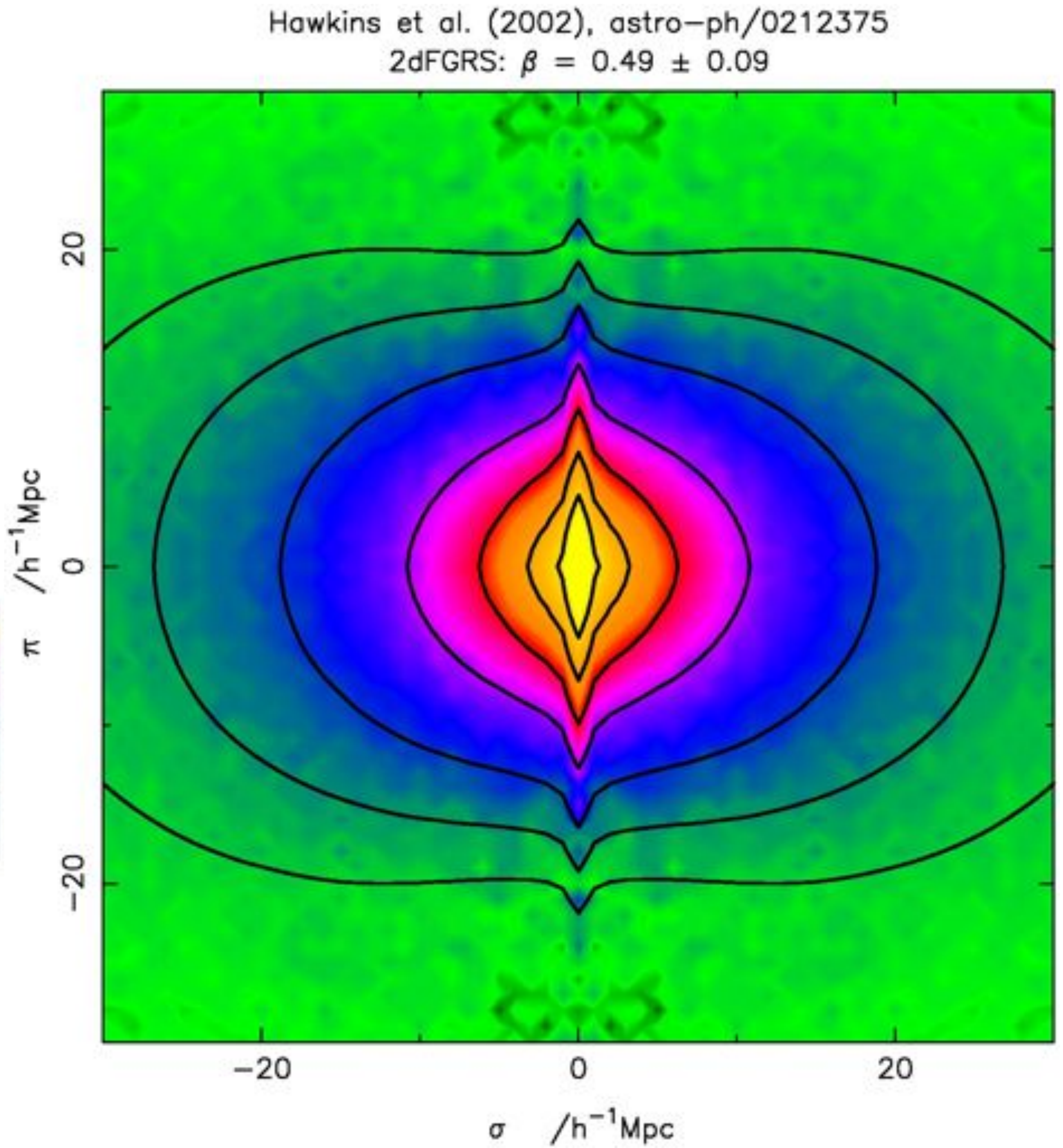
Baryon Acoustic Oscillations: CMB & Galaxies





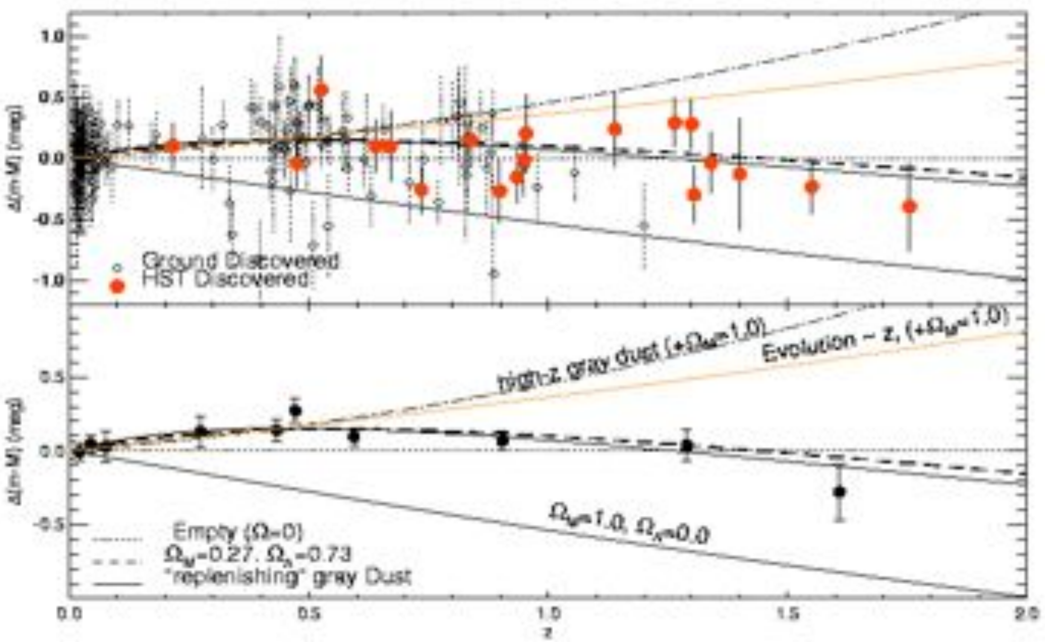
Redshift Space Distortions

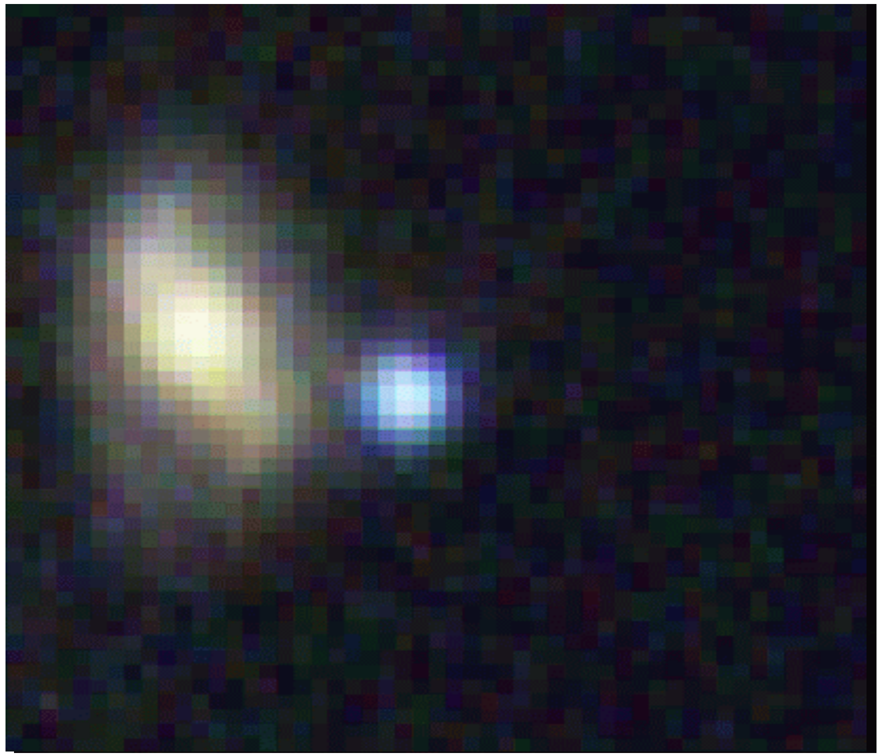




Supernovae

- Measure luminosity distance
- Geometric Probe of Dark Energy





Requirements for cosmology survey

- sample large volumes
- sample enough (many) tracers
- measure distances
- measure shapes
- time sampling

Dark Energy Task Force

Survey design optimization: Figure of Merit

- Inverse of the marginalized errors
- Higher FoM => smaller errors
- Fisher matrices approach

Observational surveys

- Imaging => DES
- Photo-z survey => PAU
- Spectroscopy => DESI
- Space => Euclid

The Dark Energy Survey

Status and First Results

DES Science summary

DARK ENERGY SURVEY

4 Probes of Dark Energy

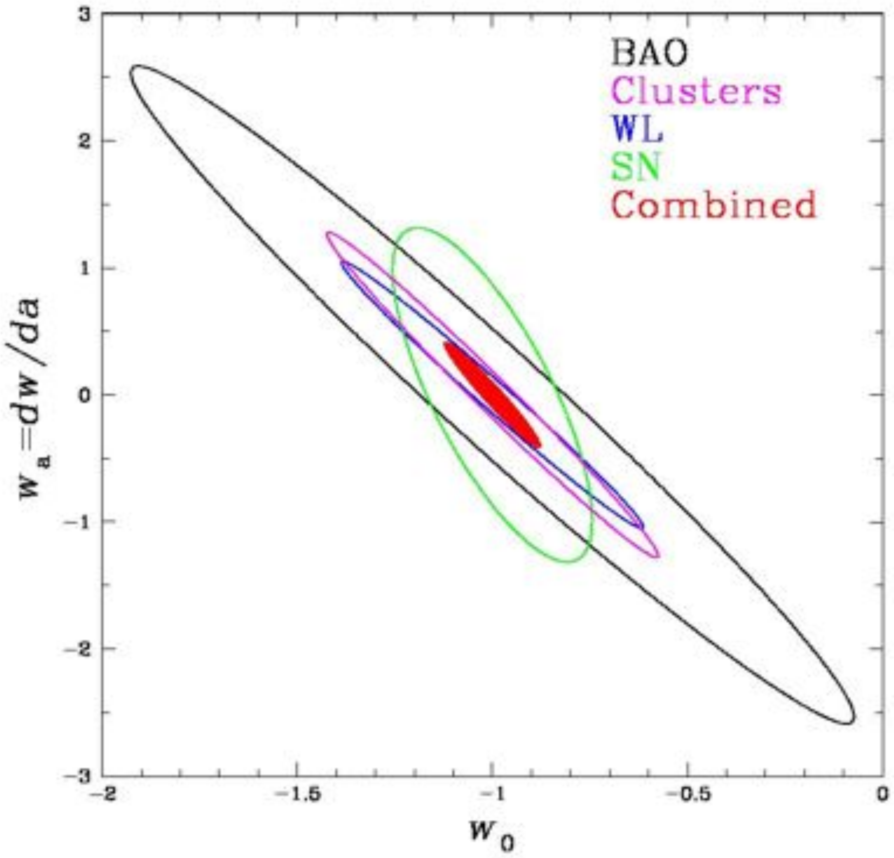
Galaxy Clusters (distance & structure growth)
Tens of thousands of clusters to z~1 (10^5)
Synergy with SPT, VHS

Weak Lensing (distance & structure growth)
Shape and magnification measurements of 200 million galaxies

Baryon Acoustic Oscillations (distance)
300 million galaxies to z~1.4 and i < 24

Supernovae (distance)
3500 well-sampled SNe Ia to z~1

It is the largest survey of its kinds.



The Dark Energy Survey

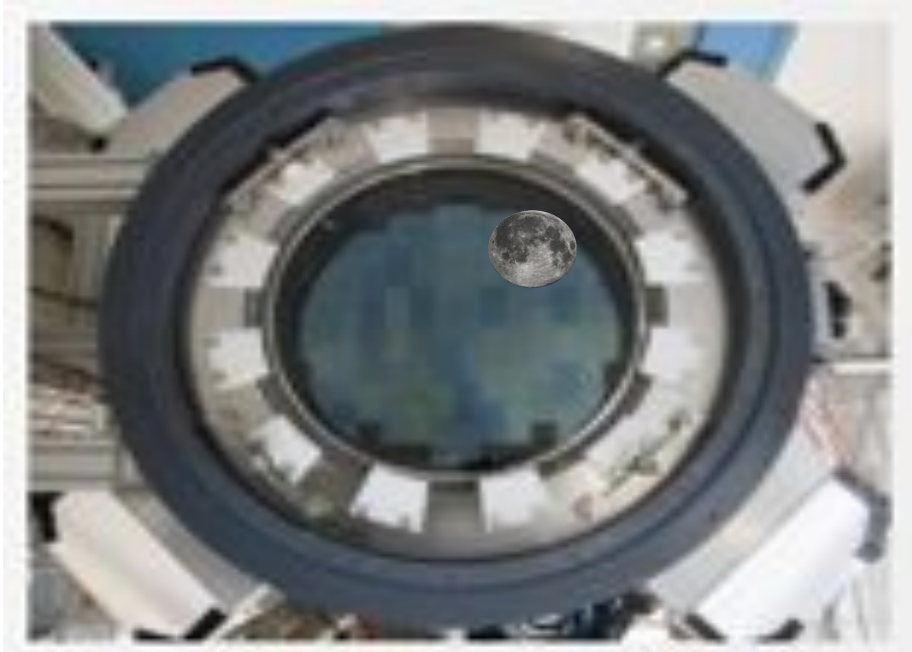
DARK ENERGY SURVEY

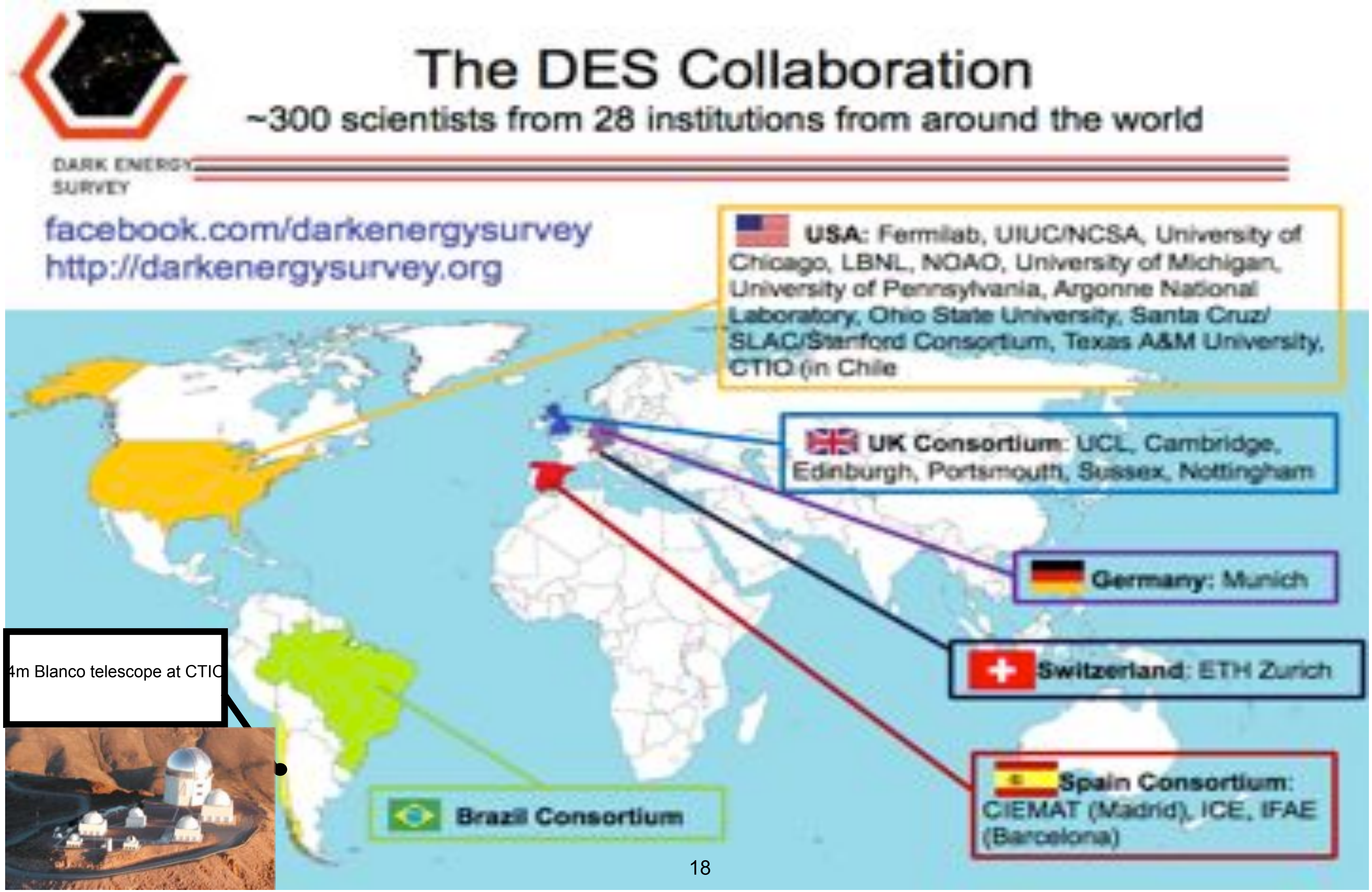
Optical imaging survey with the Blanco 4m telescope at Cerro Tololo Inter-American Observatory(CTIO) in Chile

5000 sq-deg (1/8 of the sky) in grizY bands (2500 sq-deg overlapping with SPT survey) + 30 sq-deg time-domain griz (SNe)

New 570 Mpx camera with 3 sq-deg FoV, DECam

Up to 24th magnitude (z~1.5)

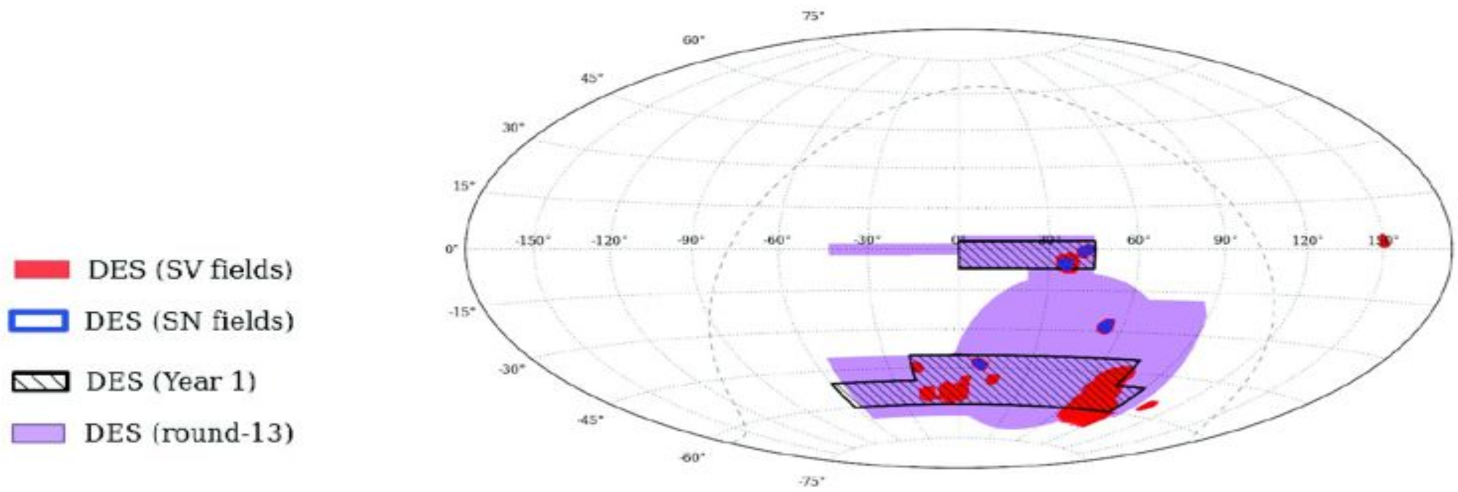




4m Blanco telescope at CTIO

DES Timeline

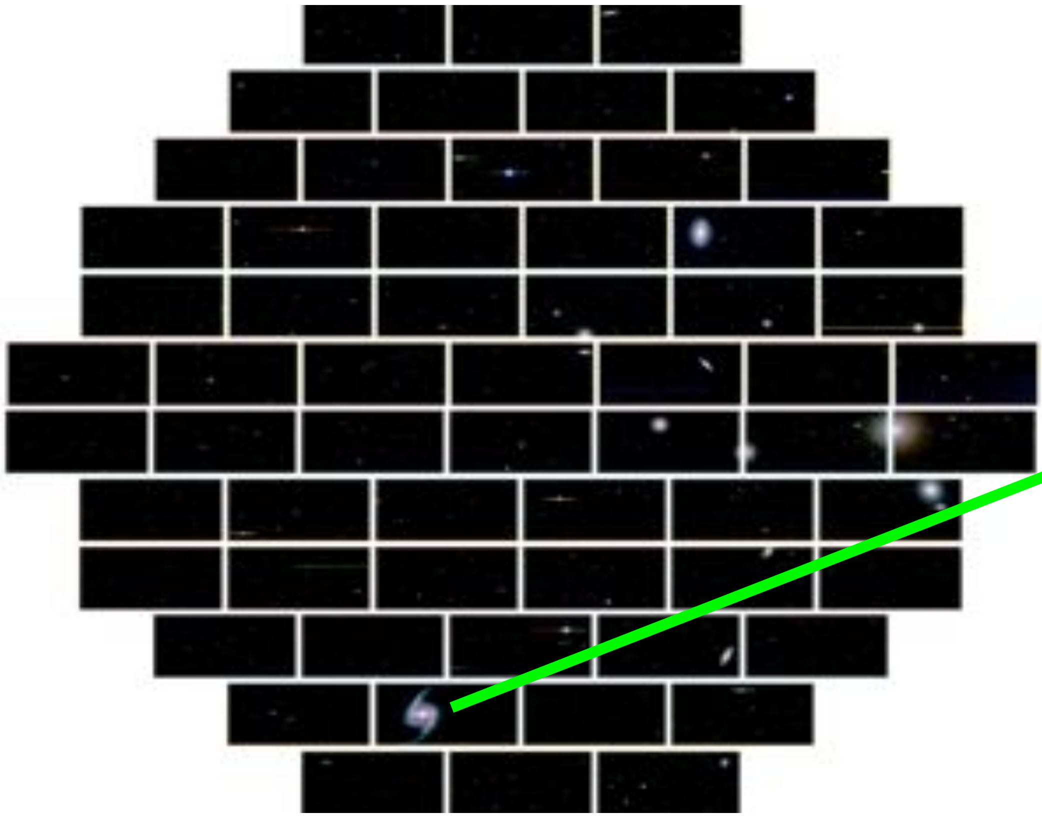
2003	Project start
2004-8	R&D
2008-11	DECam construction
2012 [Sept]	Installation
2012 [Sept-Oct]	Commissioning and first light



DARK ENERGY SURVEY

First Light: 12 september 2012

Fornax galaxy cluster



NGC 1365

DES Timeline

2003	Project start
2004-8	R&D
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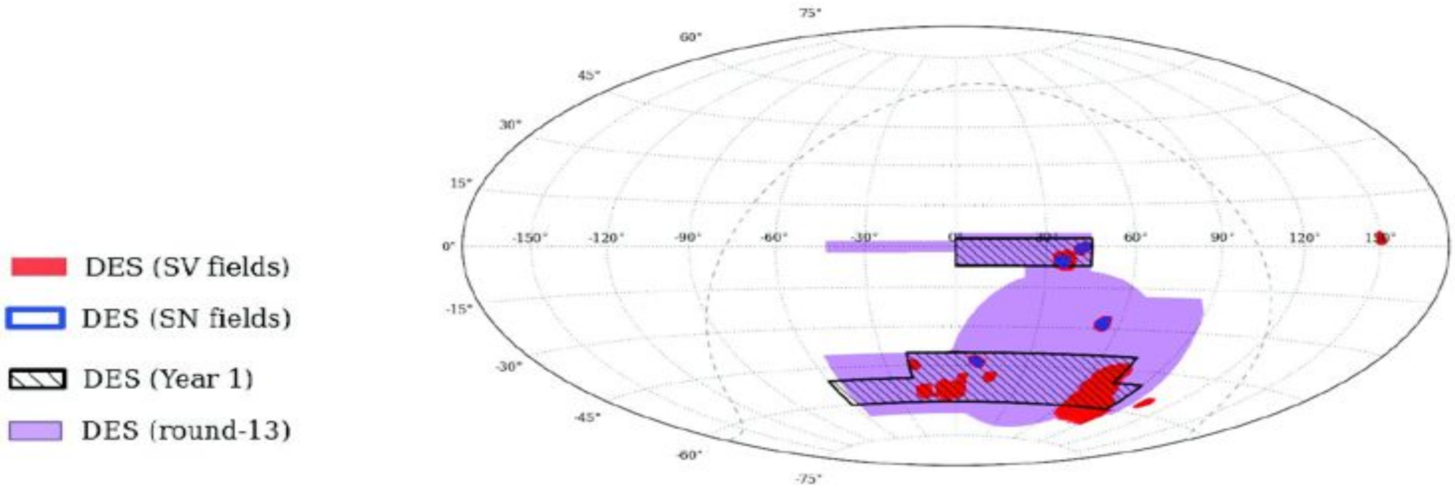
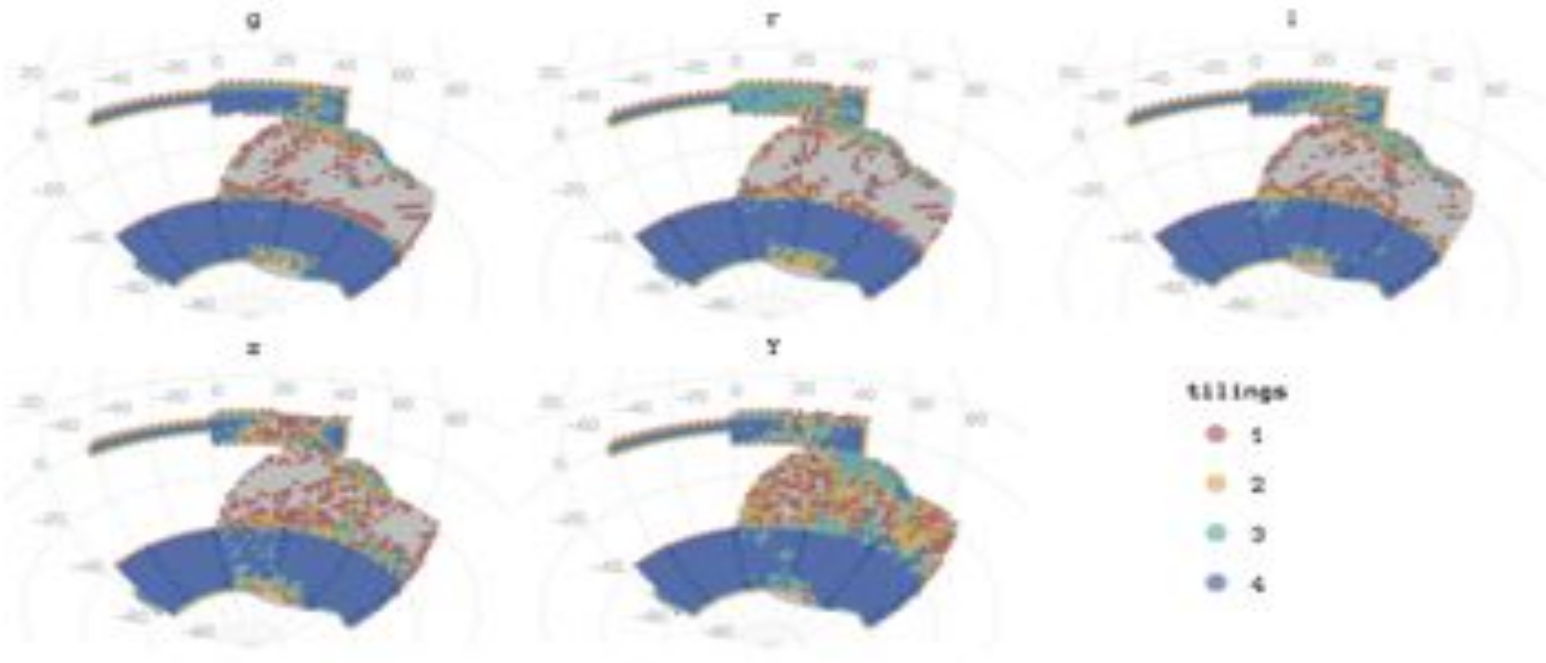
2012 [Sept]	Installation
2012 [Sept-Oct]	Commissioning and first light
Nov 2012- Feb 2013	Science Verification
Aug 31 2013 -9 Feb 2014	First Season (Year 1)
2014-2018	Second-Fifth Seasons



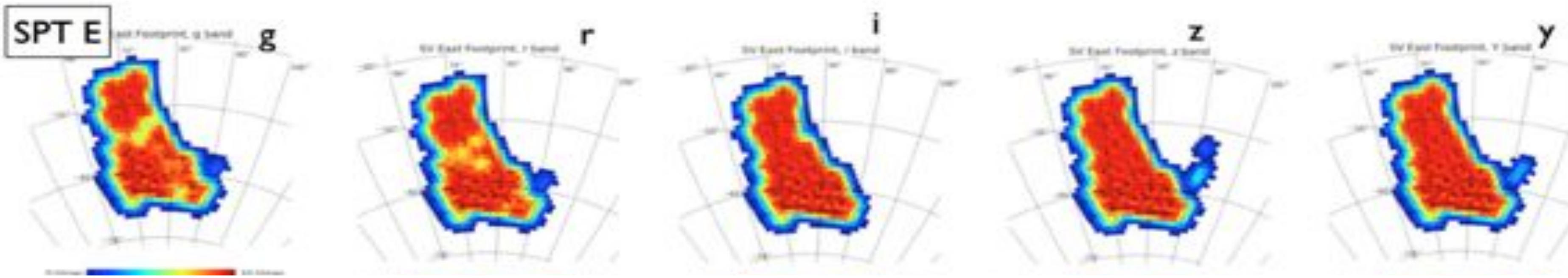
DARK ENERGY SURVEY

DES Timeline



Current wide-survey exposures completed

First Results: DECam performance has been extremely good



The next scientific results are based on these data (~157 sq-deg, 15+ million galaxies i < 24, 2000 clusters)

Main Goals: Exercise downstream analyses (DESDM) and determine whether quantities derived from image data are meeting DES requirements

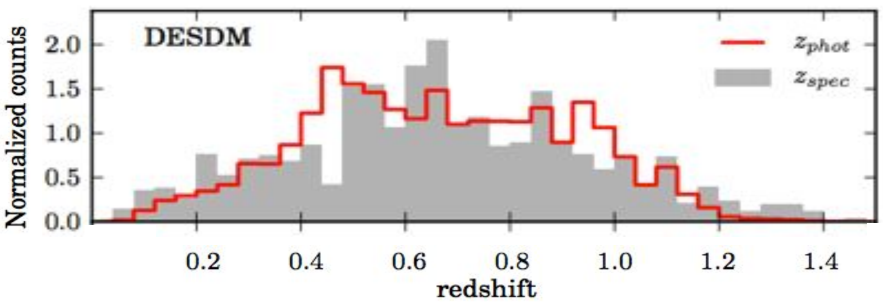
Photometric redshift performance
arXiv:1406.4407

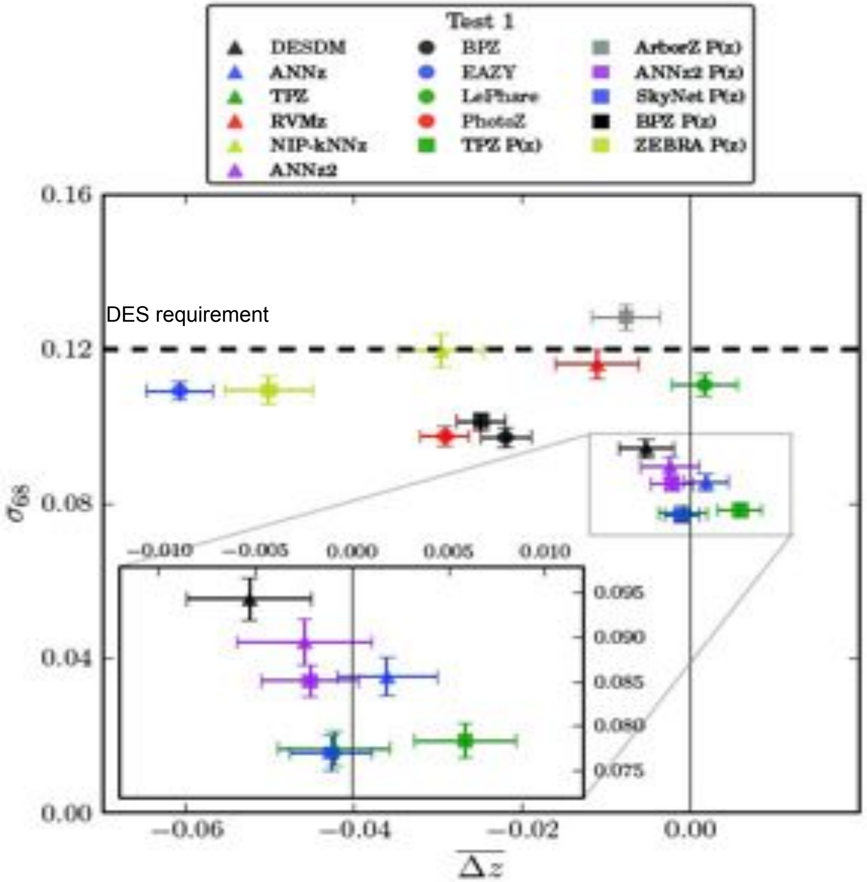
DARK ENERGY SURVEY

Use 15000 galaxies with spectroscopic determination of the redshift (from several previous surveys) for testing and calibrating photoz

Most of the codes meet the DES science requirements, already at this early stage

This paper proves that DES can measure photometric redshifts

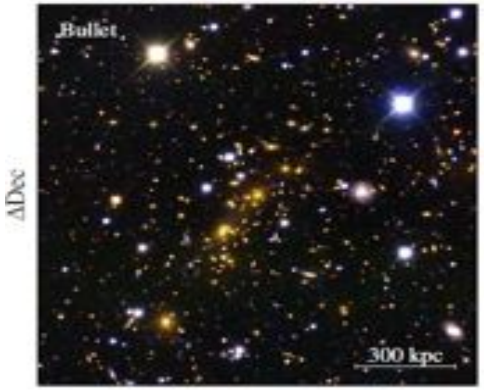




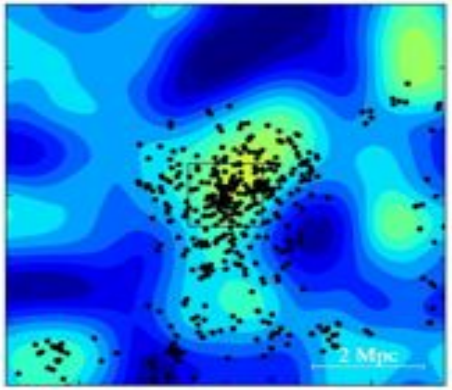
Testing Weak Lensing: Masses of 4 galaxy clusters
(arXiv:1405.4285)

DARK ENERGY SURVEY

Multi-color image of the inner 5 arcmin



Map of WL aperture mass significance overlaid with gals inner 30 arcmin



- Measure the masses and redshifts of four known massive galaxy clusters
- Background galaxies identified using photo-z
- Cluster member galaxies identified using photo-z and RedMaPPer
- Weak lensing analysis using im3shape code

Results in very good agreement with previously known measurements

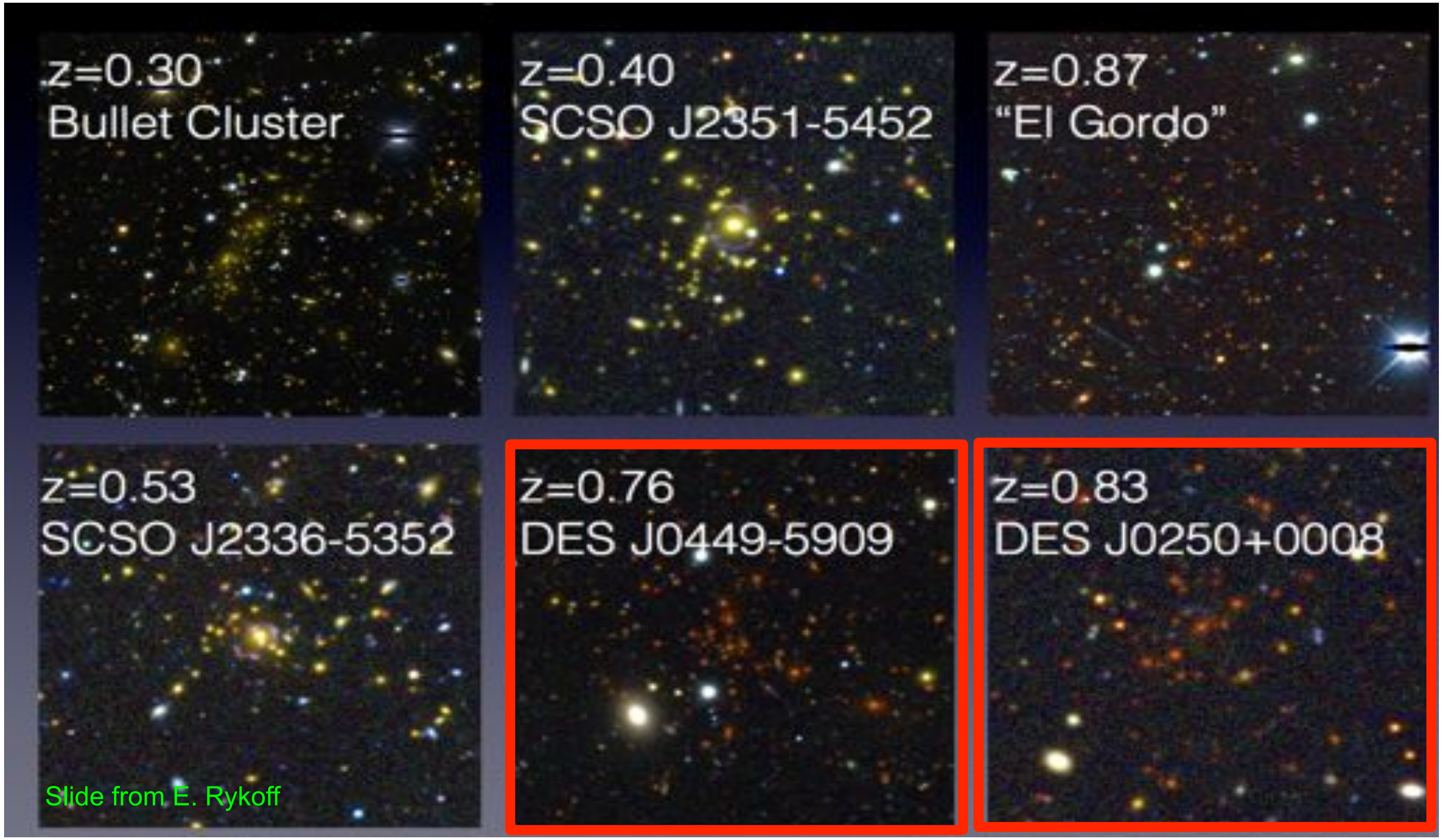
Table 4. Weak lensing masses M_{200c} in units of $10^{14} M_{\odot}$ (with a flat prior on c_{200c}), redMaPPer richness λ and redshift estimate z_{λ}, and their statistical errors (see Section 3.2 and Section 5.1 for details). The literature mass estimates are derived from weak lensing, galaxy dynamics (D) or optical richness (R).

Cluster name	M_{200c}	λ	z_{λ}	Literature value M_{200c}
RXC J2248.7-4431	$17.6^{+4.5}_{-4.0}$	203 ± 5	0.346 ± 0.004	$22.8^{+6.6}_{-4.7}$ (Gruen et al. 2013b), 20.3 ± 6.7 (Umetsu et al. 2014), 16.6 ± 1.7 (Merten et al. 2014)
1E 0657-56	$14.2^{+10.0}_{-6.1}$	277 ± 6	0.304 ± 0.004	17.5 (Clowe et al. 2004)[i], 12.4 (Barrena et al. 2002, D)
SCSO J233227-535827	$10.0^{+3.7}_{-3.4}$	77 ± 4	0.391 ± 0.008	$11.2^{+3.0}_{-2.7}$ (Gruen et al. 2013a), $4.9 \pm 3.3 \pm 1.4$ (High et al. 2010, R)
Abell 3261	$8.6^{+8.6}_{-3.9}$	71 ± 3	0.216 ± 0.003	—

[i] We converted the measured r_{200c} from Clowe et al. (2004), which lacks an error estimate, to M_{200c} using the critical density in our adopted cosmology.

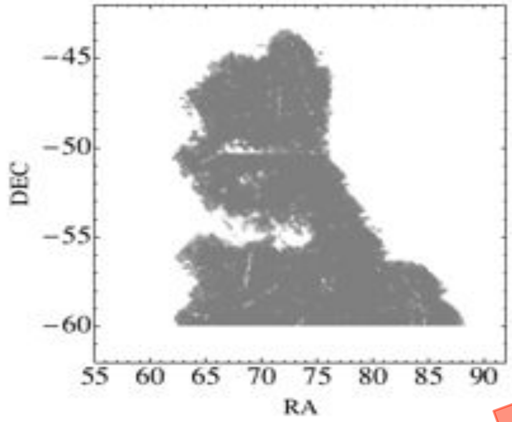
DES can measure galaxy shapes, even in the SV preliminary data set

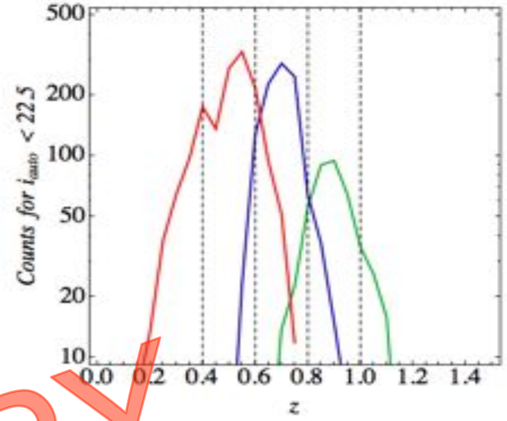
Galaxy clusters from DES:
New clusters at high redshift (z>0.7!)

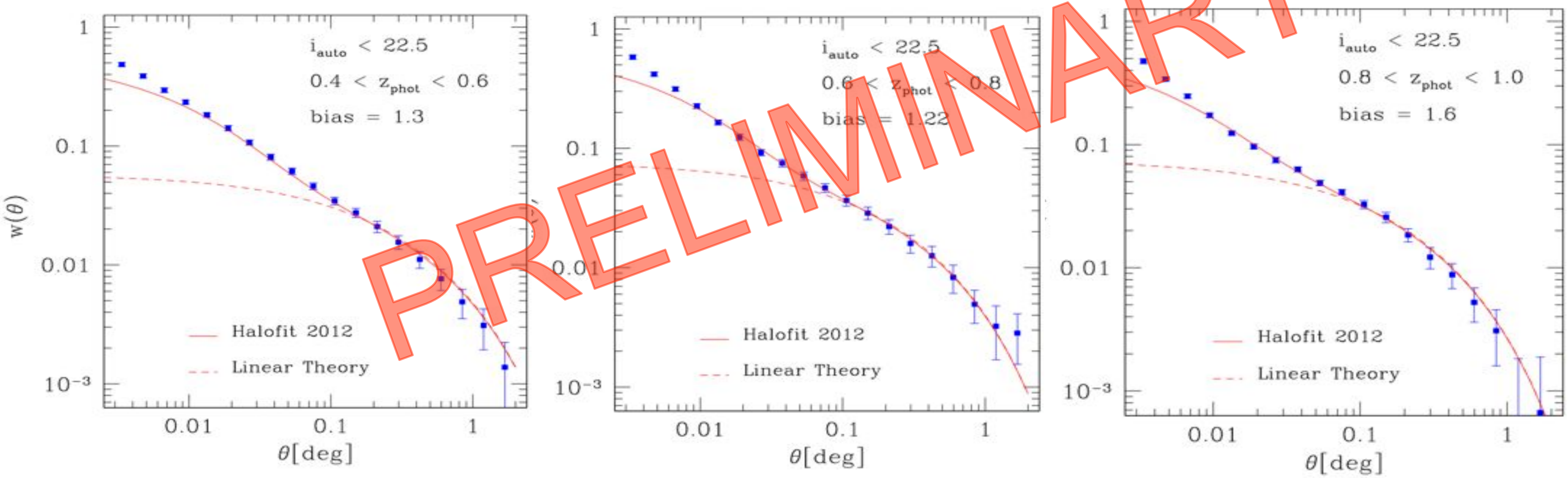


Galaxy Clustering

- Galaxy Clustering in few photo-z bins for an observed magnitude sample (i_{auto}<22.5)
- About 130 sq deg with roughly half a million galaxies each







Galaxy Clustering
ongoing LSS projects and cross-correlations

DARK ENERGY SURVEY

- HOD and comparison with CFHTLS

- Cross-correlations with CMB lensing (from SPT and Planck)

- GG Lensing + LSS to measure bias and stochasticity (or growth)

- Cross correlations with clusters to get N(z). Cluster clustering

DARK ENERGY SURVEY

Galaxy Clustering

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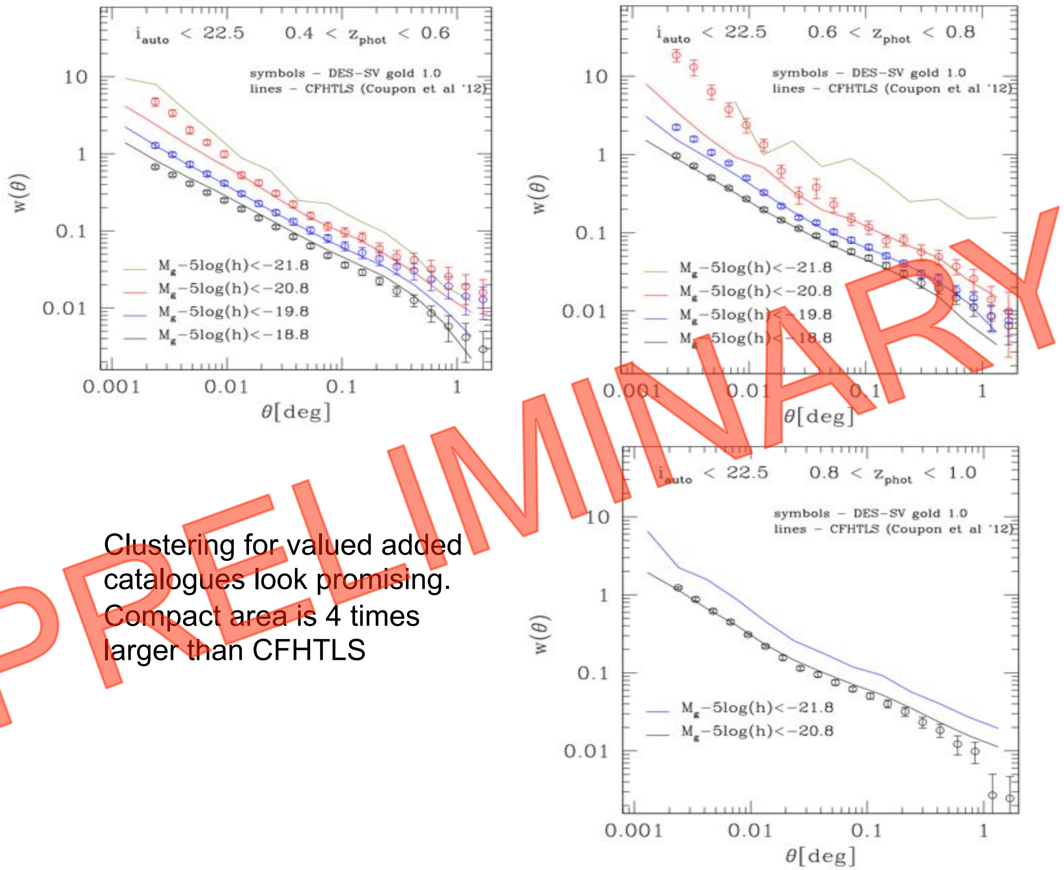

Clustering for valued added catalogues look promising. Compact area is 4 times larger than CFHTLS

Galaxy Clustering

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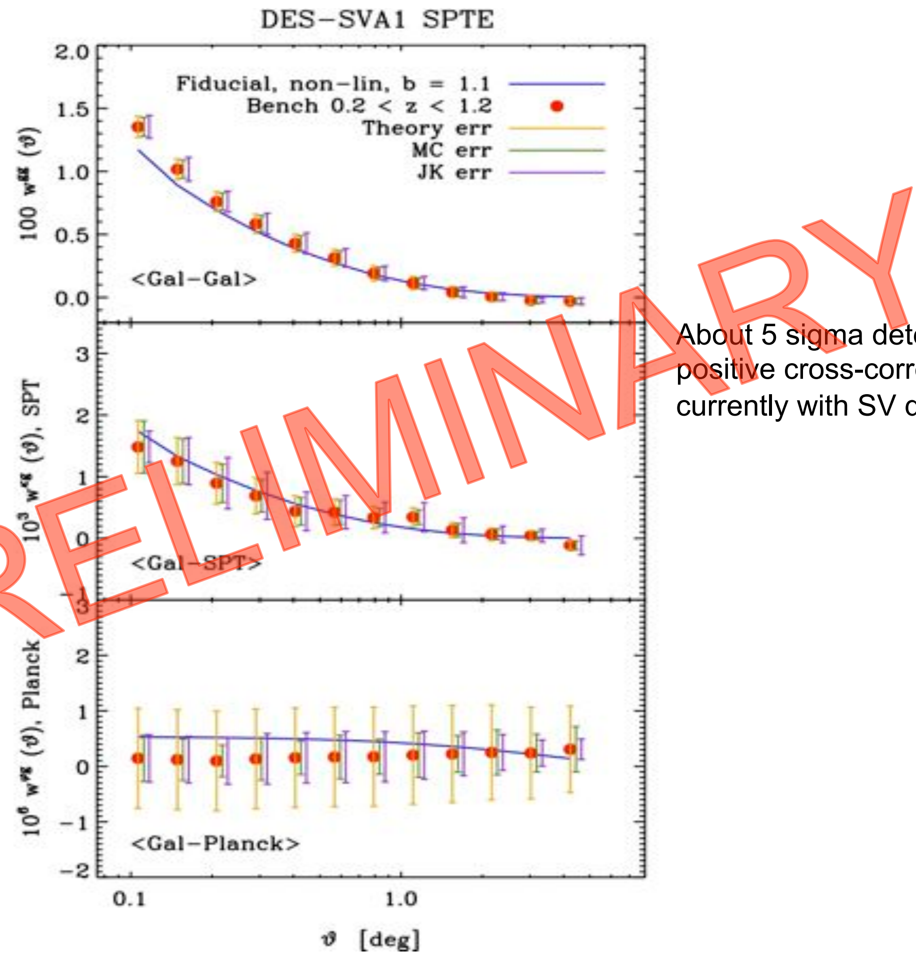

About 5 sigma detection of positive cross-correlation currently with SV data

Galaxy Clustering

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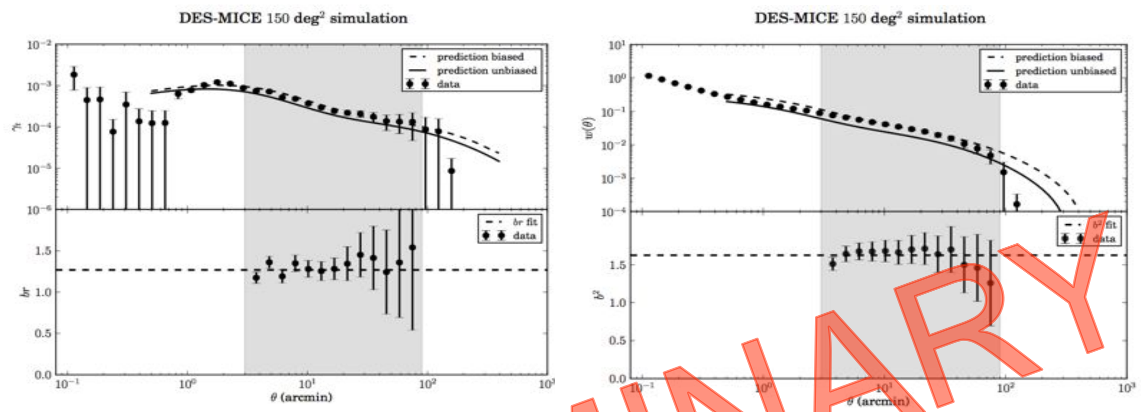
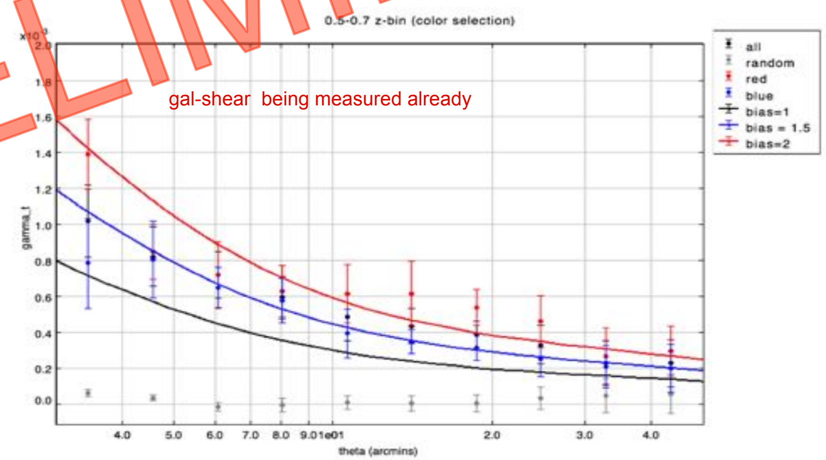


combine gal-shear with gal-gal to get b and r and with shear-shear to get also growth



Many other interesting results in the pipeline, that will be published soon

DARK ENERGY SURVEY

Galaxy clustering and validation against CFHTLS

DES SV galaxies cross-correlated with CMB lensing

SPT-SZE signatures of DES SV RedMaPPer clusters

Joint Optical and near infrared photometry from DES and VHS

Galaxy populations within SPT selected clusters

DES/XCS: X-ray properties of galaxy clusters in DES SV

The DES SV shear catalogue: Pipeline and tests

Calibrated ultra fast image simulations for DES

DES13S2cmm: The first super-luminous supernova from DES

The DES supernova survey: Search strategy and algorithm

Wide-field mass mapping with the DES SV data

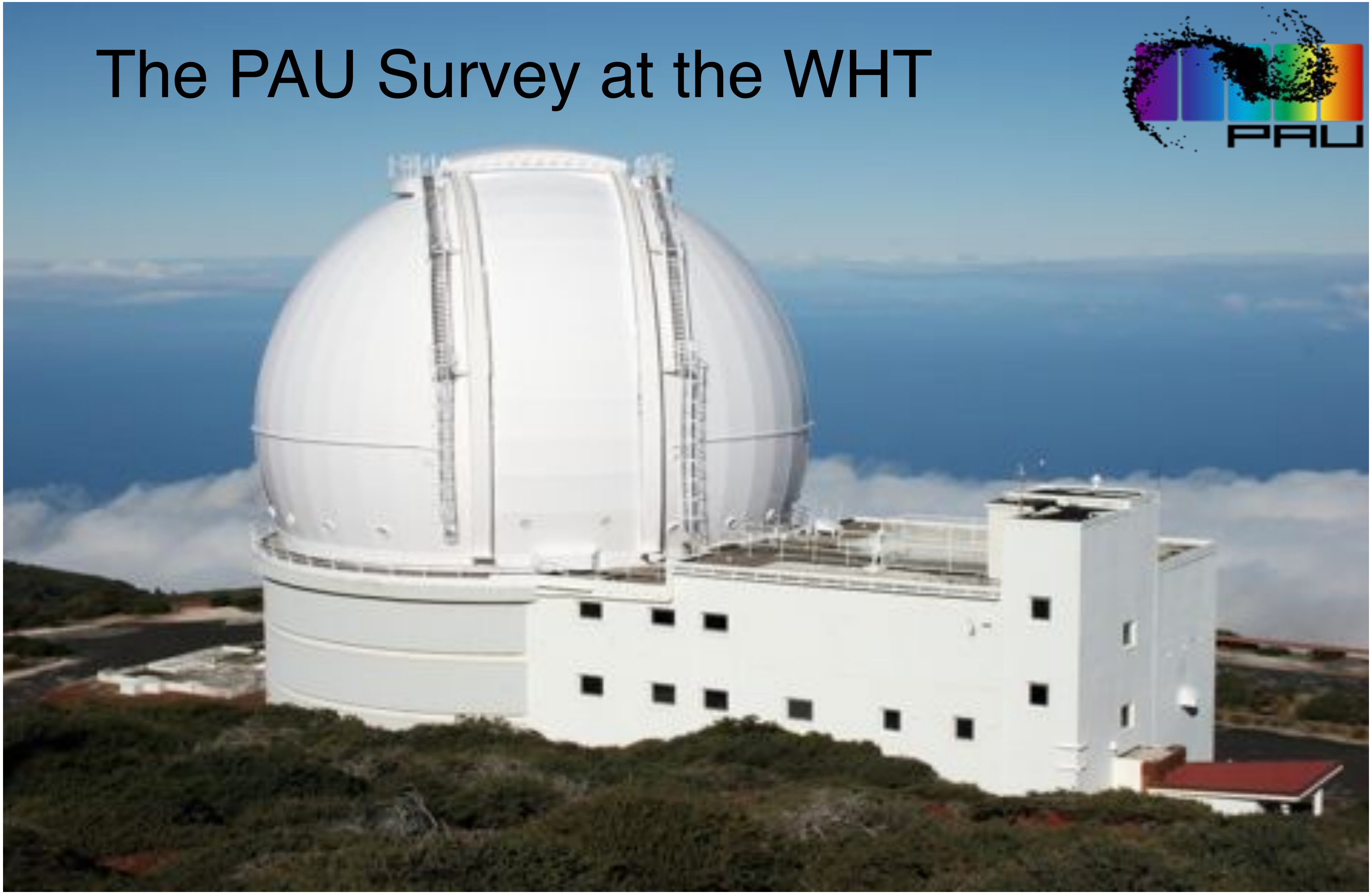
DARK ENERGY SURVEY

Summary

- DES **started survey operations** in august 2013
- SV data are of high quality, are currently being analyzed, and **first papers** have been already **submitted**
  - Photo-z required precision reached
  - DES is able to measure galaxy shapes around clusters
  - Clustering as a function of redshifts matching CFHTLS
  - Many results in the pipeline…
- The data quality and quantity of DES as a whole will be a major step beyond this
- **First season data** are being processed. Second season ending
- First Dark energy results expected from 2 first seasons of data.

STAY TUNED!!!

The PAU Survey at the WHT



PAU survey

Main ideas:

•To prepare for conducting a large photometric red-shift survey.
•Emphasis in measuring Dark Energy probes
•Well suited to study the weak lensing intrinsic alingment case
•Very useful for galaxy evolution
•Serve for preparation of future targeting (DESI)

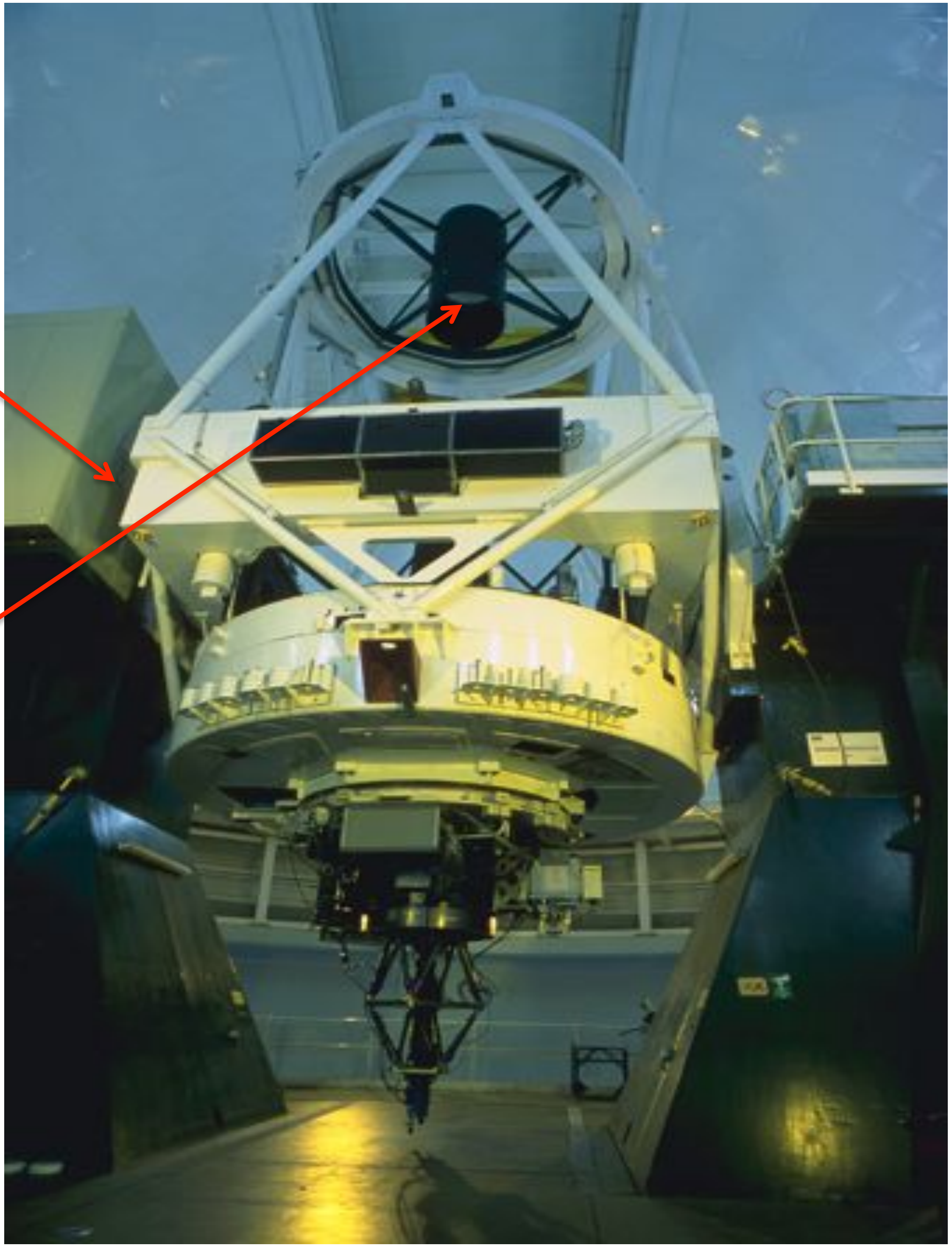
PAUCam at WHT

WHT Telescope

- Diameter: 4.2 m
- Prime focus: 11.73 m
- Focal ratio: f/2.8
- FoV: 1 deg ∅, 40’ unvignetted
- Scale: 17.58’’/mm ⇔ 0.26”/pixel

PAUCam will be mounted at the prime focus:

Strong limitation in the weight: **max. 235 kg**.



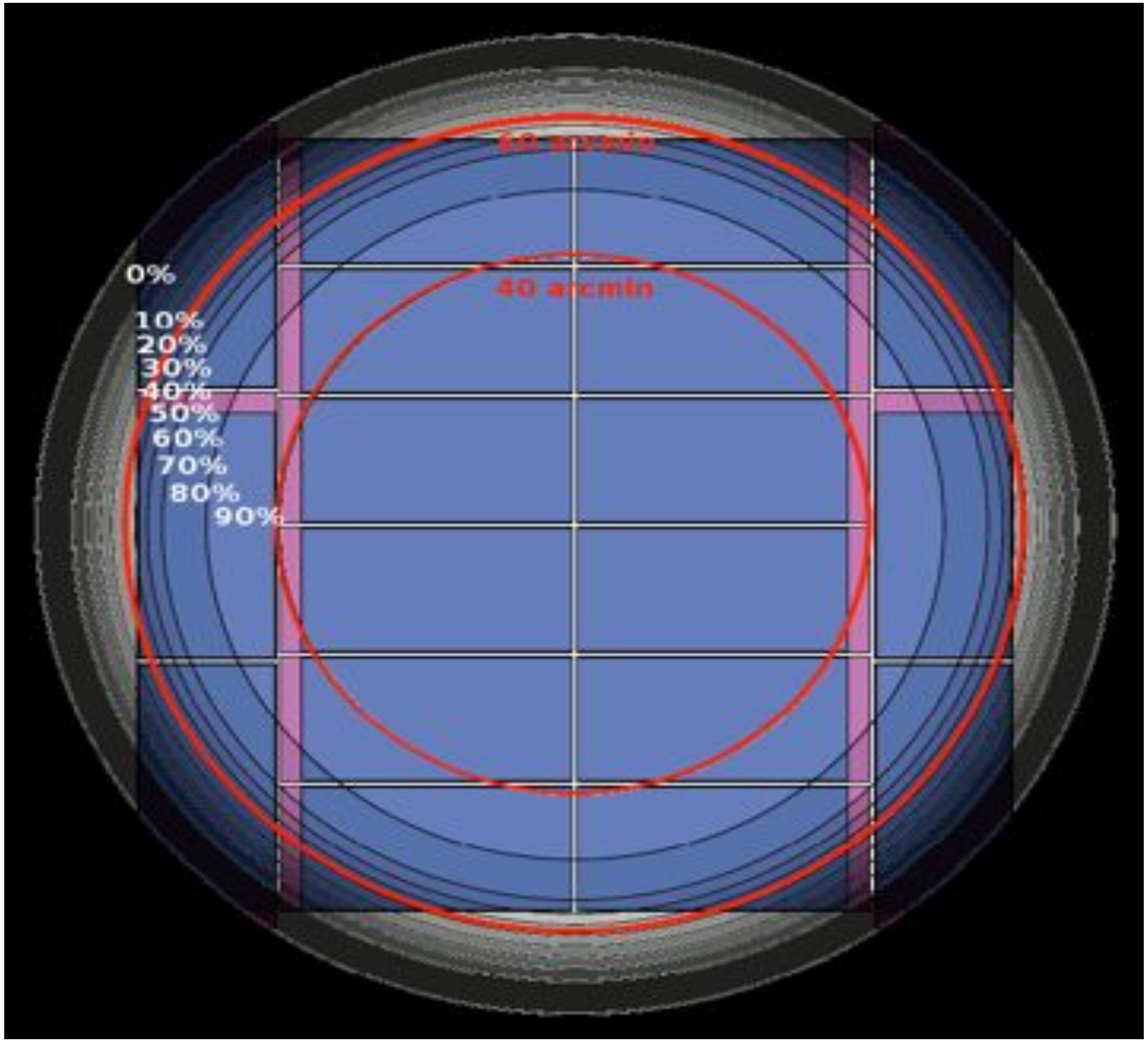
PAUCam focal plane

8 central CCDs with almost 100% exposure for imaging.

Rest of the CCDs:
2 for guiding
8 for additional photons

40 narrow band (10nm) filters covering the range ≈ 450-850 nm
6 BB filters u.g.r.i.z.Y.

Optimization: central CCDs will have 8 NB, others BB



PAU Survey Strategy

- Each central CCDs covers the whole survey area twice.

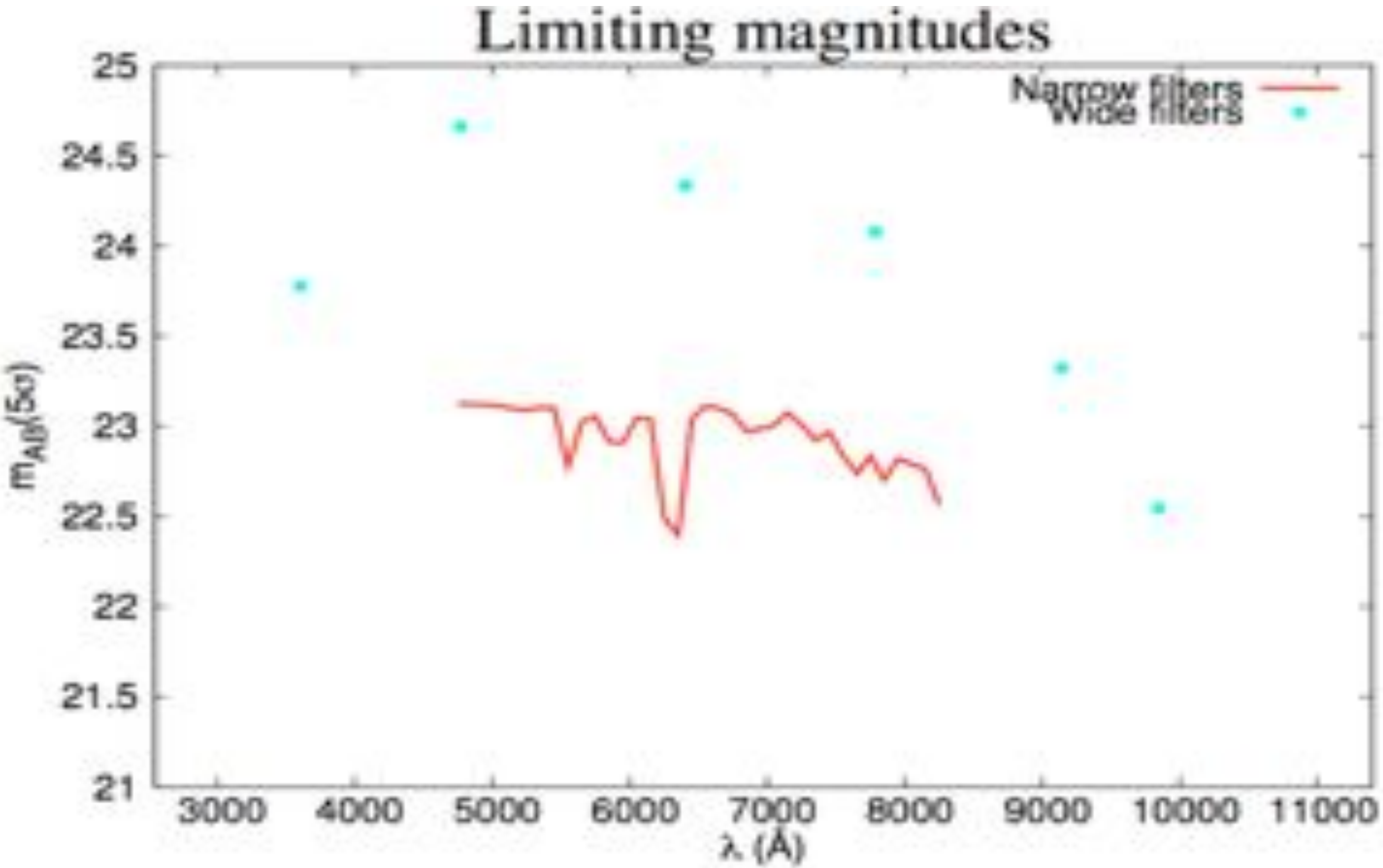
- Broad bands reach ≈1.4 magnitudes deeper than narrow bands.

- Objects detected in the BB, and flux obtained in the NB.

- Exposure times depend on tray: ≈ 100 s. for bluest, ≈250 s. for reddest.

- Surveying capability: sample 2 deg2 / night to $i_{AB} < 22.7$ magnitude in all NBs, and $i_{AB} < 24.1$ in all BBs ➜ 30000 galaxies, 5000 stars, 1000 quasars /night.

PAU Survey Strategy



PAUS (PAU-Survey) Scientific Goals

We expect to obtain ≈ 100 nights during the 4-year period 2015-2019. This implies ≈200 deg^2.

Scientific goals for PAU/WHT will focus on measuring

- Red-shift Space Distortions (RSD)
- Weak Lensing Magnification (MAG),

simultaneously over the same sky area, but by making use of two galaxy samples:

- A bright galaxy sample (B) ($i_{AB} < 22.5$) with high redshift resolution of $\sigma_z = 0.0035\,(1+z)$.
- A faint sample (F) $22.5 < i_{AB} < 24$ with $\sigma_z = 0.05\,(1+z)$.

The scientific case, has been published in
(ref. E. Gaztañaga et al. 2012, MNRAS)

The paper explores several possibilities:

B

F

F + B (different areas)

F x B (same area) ← substantial improvement.

B can be seen as a spectroscopic follow-up of a photo-z F sample.

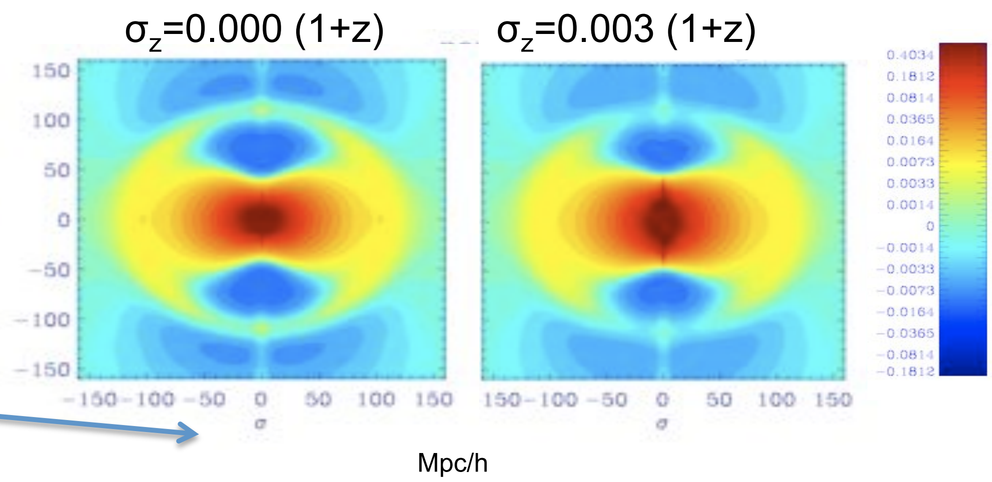
- **Weak-lensing magnification**
  - Lensing changes area of background image ➔ density fluctuations correlated with density fluctuations in the foreground lenses.
  - Very precise photo-z's in foreground lenses allow to perform galaxy-galaxy cross-correlations between well-defined and narrow redshift bins (bin width ≈ 4 times the resolution of the B sample; not critical).

- **Red-shift Space Distortions.**
  - The Hubble relation between redshift and distance in the radial direction is modified by the peculiar velocity of galaxies.
  - Large structures give rise to bulk motions which affect the z-r maps. Galaxies behind over-dense regions will appear nearer, while galaxies in front of dense regions will appear farther ➔ squashing of matter distribution in radial direction at large scales.

PAU photo-z resolution particularly well-suited for this measurement over bright sample.

Radial

Perpendicular



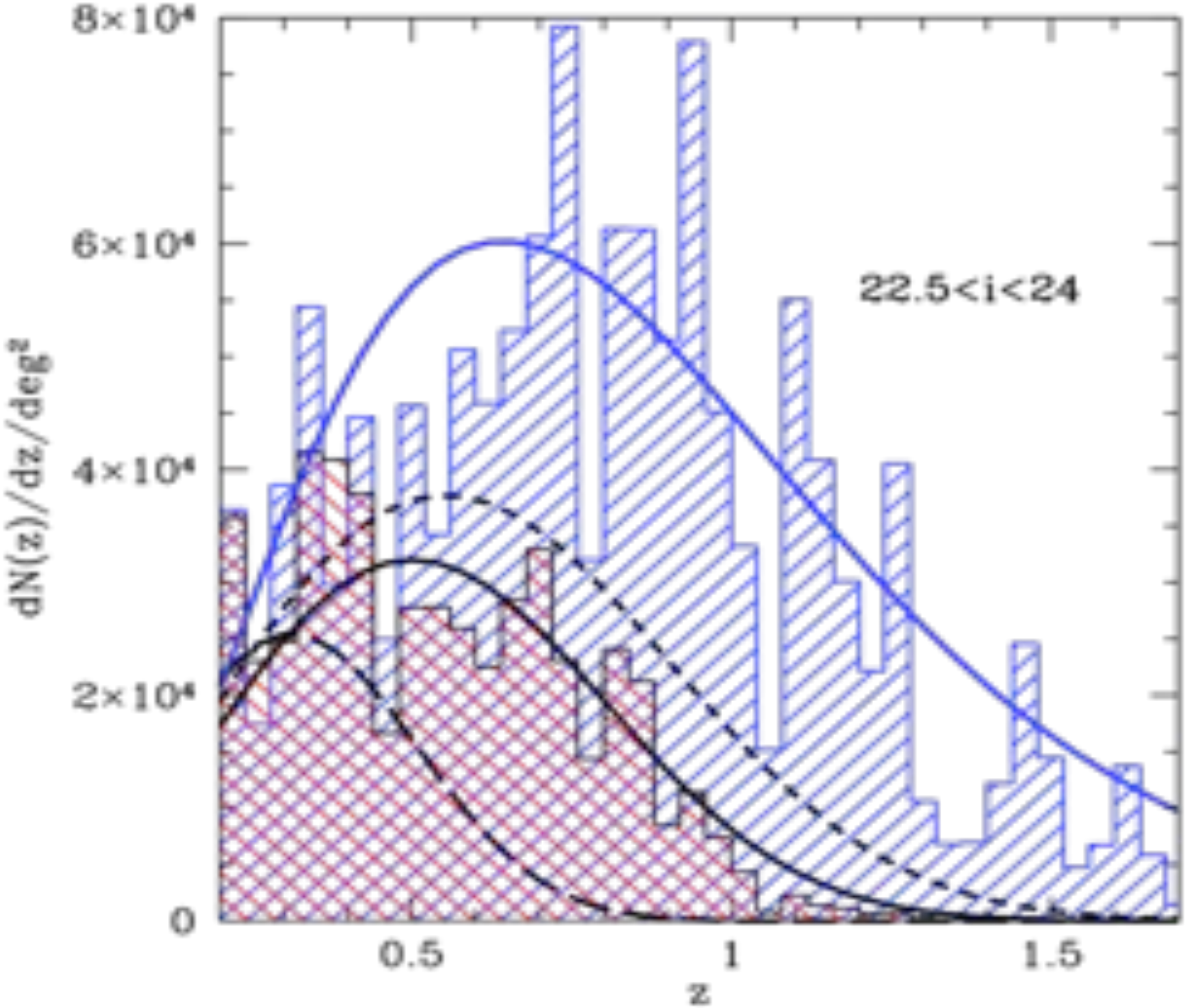
PAUS (PAU-Survey) Scientific Goals

dN(z)/dz /deg^2 for
FAINT (F) and
BRIGHT (B) samples.

6 x 10^6 B galaxies
2 x 10^6 F galaxies
(after 50% efficiency)

F → for W.L. MAG
and/or shear

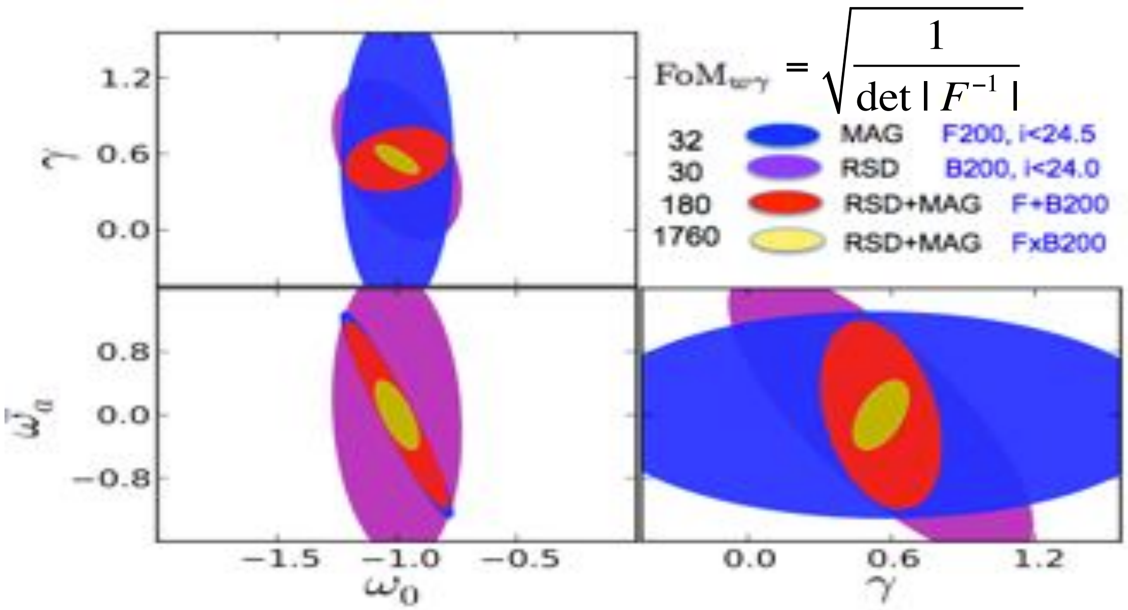
B → for RSD



PAU at the WHT

Effects (MAG and RSD) are sensitive to both the equation of state parameter, w = w0 + wa (1-a), and structure growth γ.

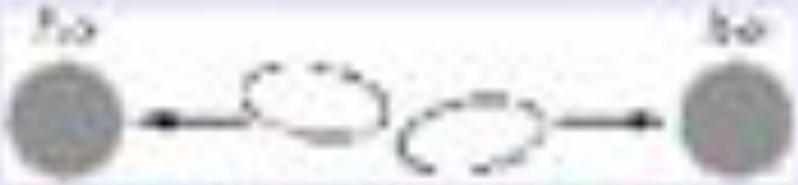
The combination of RSD and MAG in the same dataset is very powerful in breaking degeneracies between cosmological parameters
➔A unique advantage of PAU.

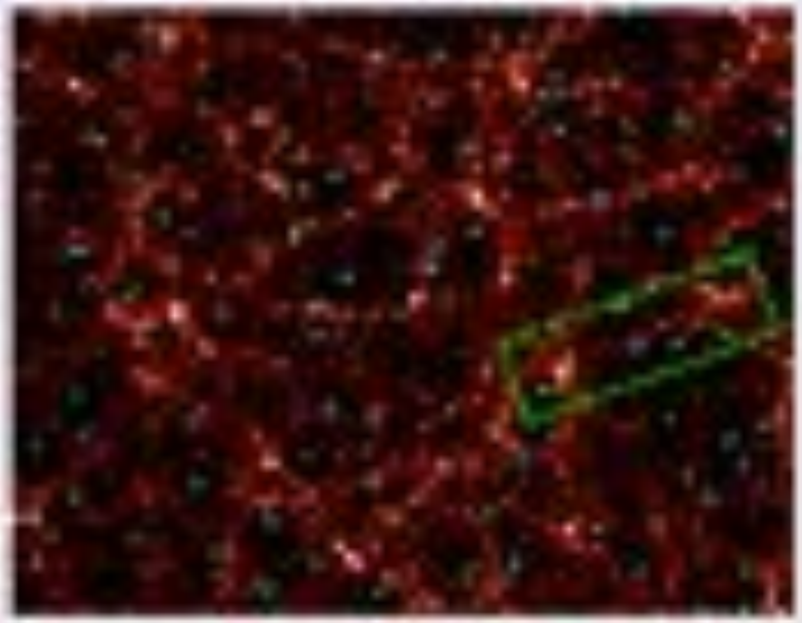


Gaztañaga, Eriksen, Crocce, Castander, Fosalba, Martí, Miquel, Cabré, MNRAS, 422,2904G (2012)

PAU at the WHT

2pt correlation: $$\underbrace{\langle \epsilon_i \epsilon_j \rangle}_{\text{observed}} = \underbrace{\langle \gamma_i \gamma_j \rangle}_{\text{GG}} + \underbrace{\langle \epsilon^s_i \epsilon^s_j \rangle}_{\text{II}} + \underbrace{\langle \gamma_i \epsilon^s_j \rangle + \langle \epsilon^s_i \gamma_j \rangle}_{\text{GI}}$$





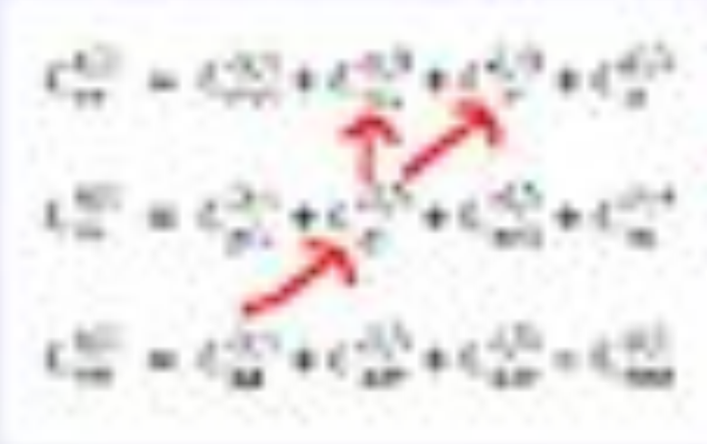
tidal gravitational field generates torques & shear forces

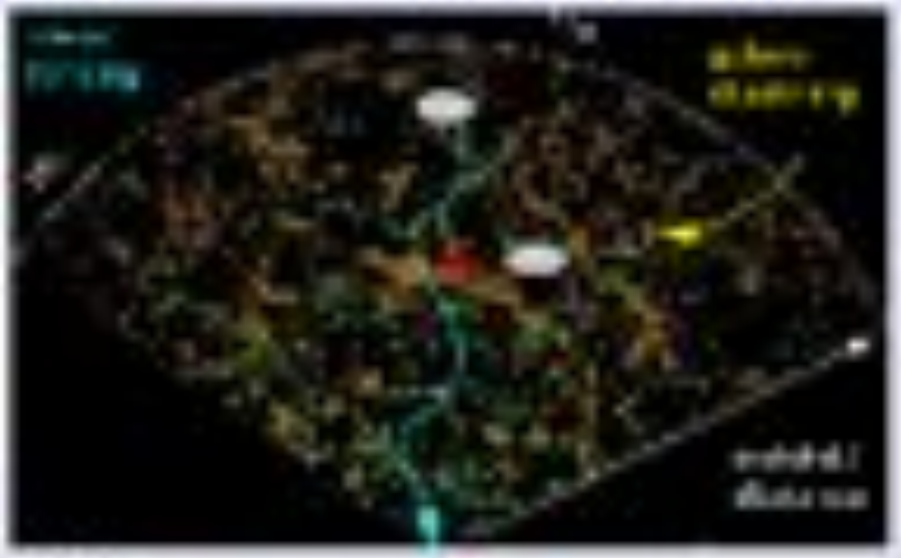
→ angular momenta & shapes of haloes become correlated

→ galaxy ellipticities become correlated

PAU at the WHT

Ansatz: Use additional correlations available from weak lensing surveys





G: gravitational shear
I: intrinsic shear
g: intrinsic number densities
m: magnification effects

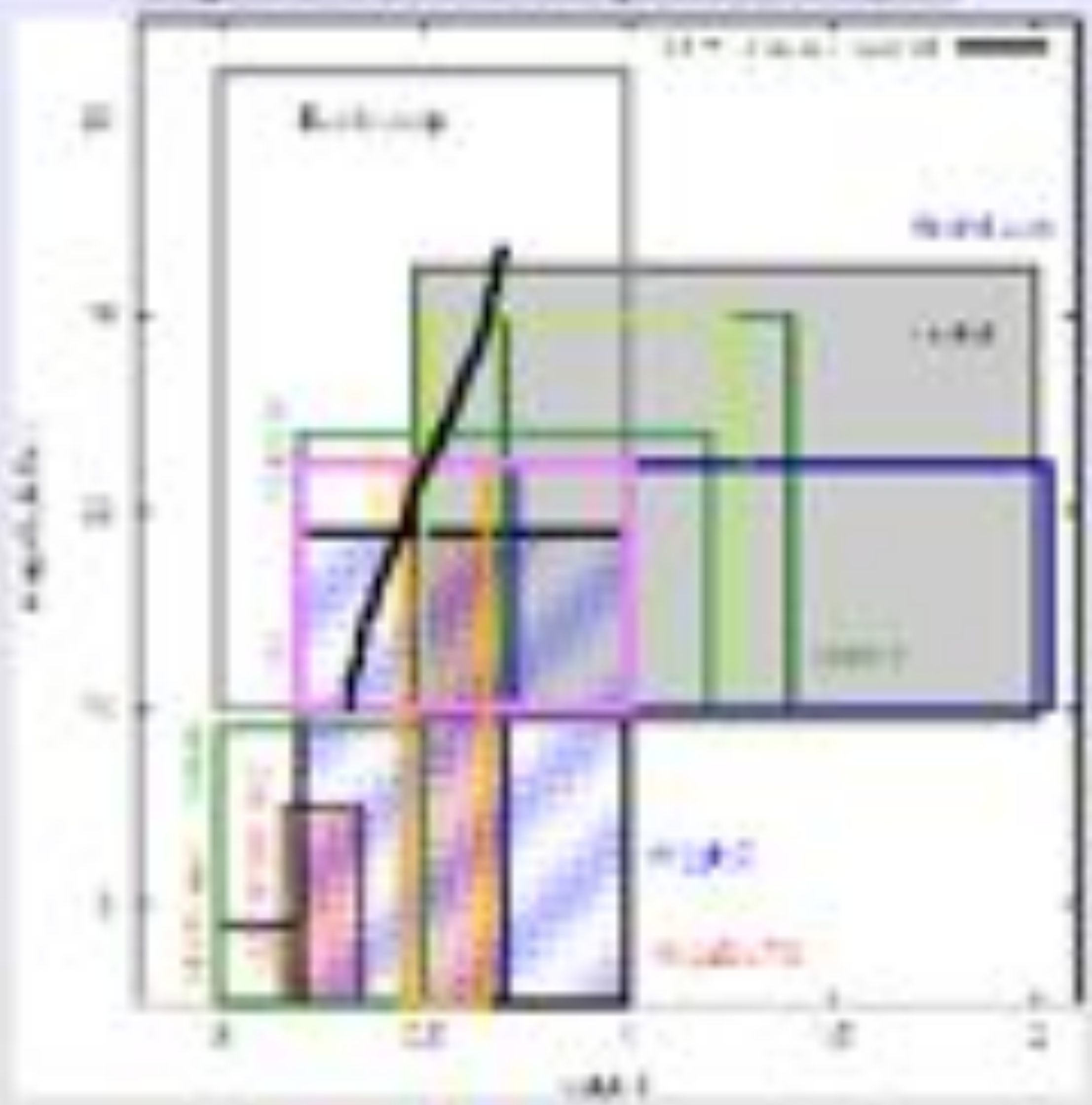
Goal:
Calibrate GI signal via cross-correlation with galaxy clustering

Procedure: *(Bernstein 2009, Joachimi & Bridle 2010)*

- include galaxy number density correlations
- introduce generic flexible parametrisation for IA and galaxy bias
- marginalise over all IA and galaxy bias parameters

→ **External priors on IA essential to meet Euclid requirements**

PAU at the WHT



hatched: existing
open: planned
grey: to be calibrated

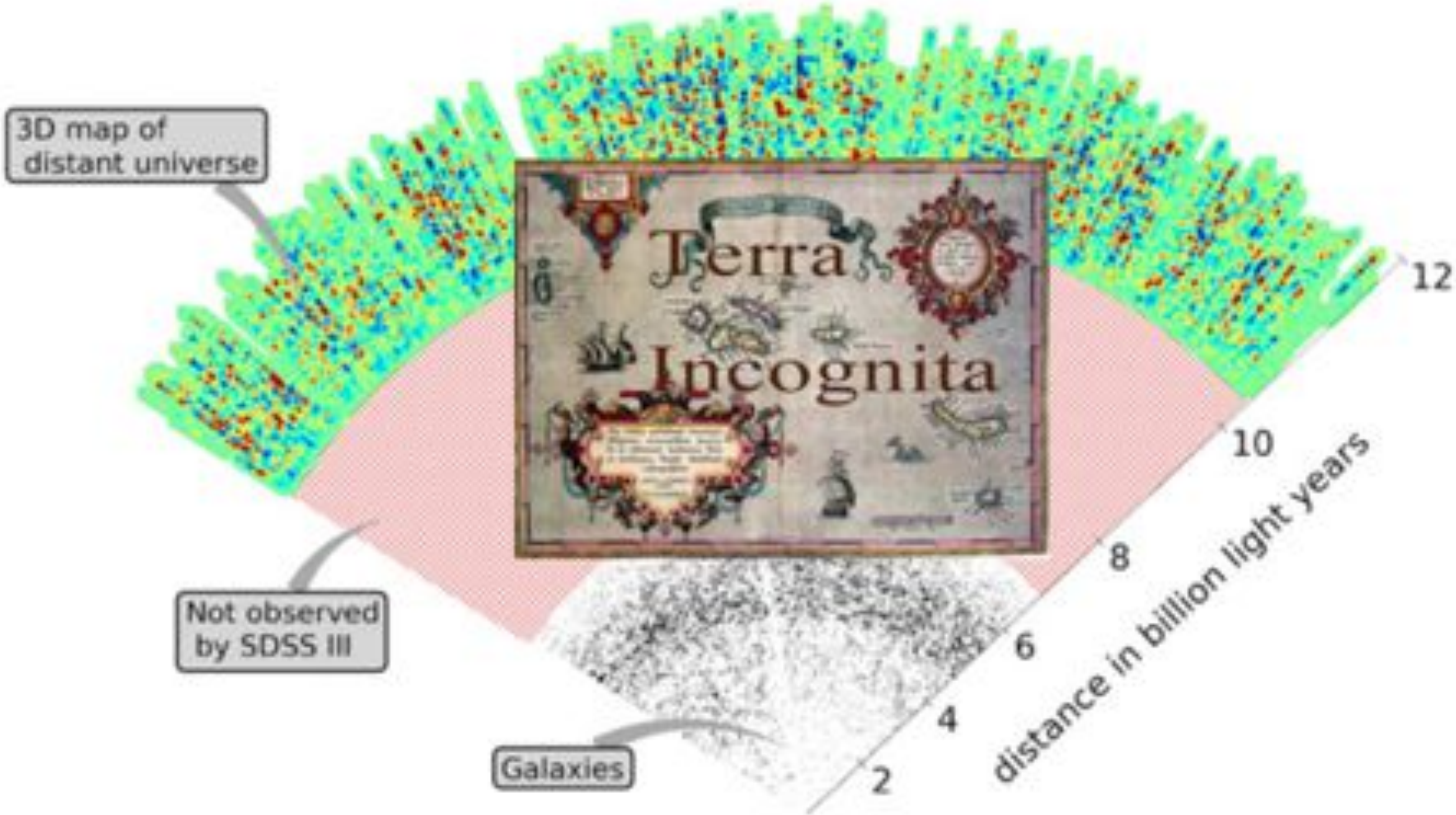
reddish: red samples
bluish: blue samples
greenish: both

assume measurement via position-shape correlations to constrain GI

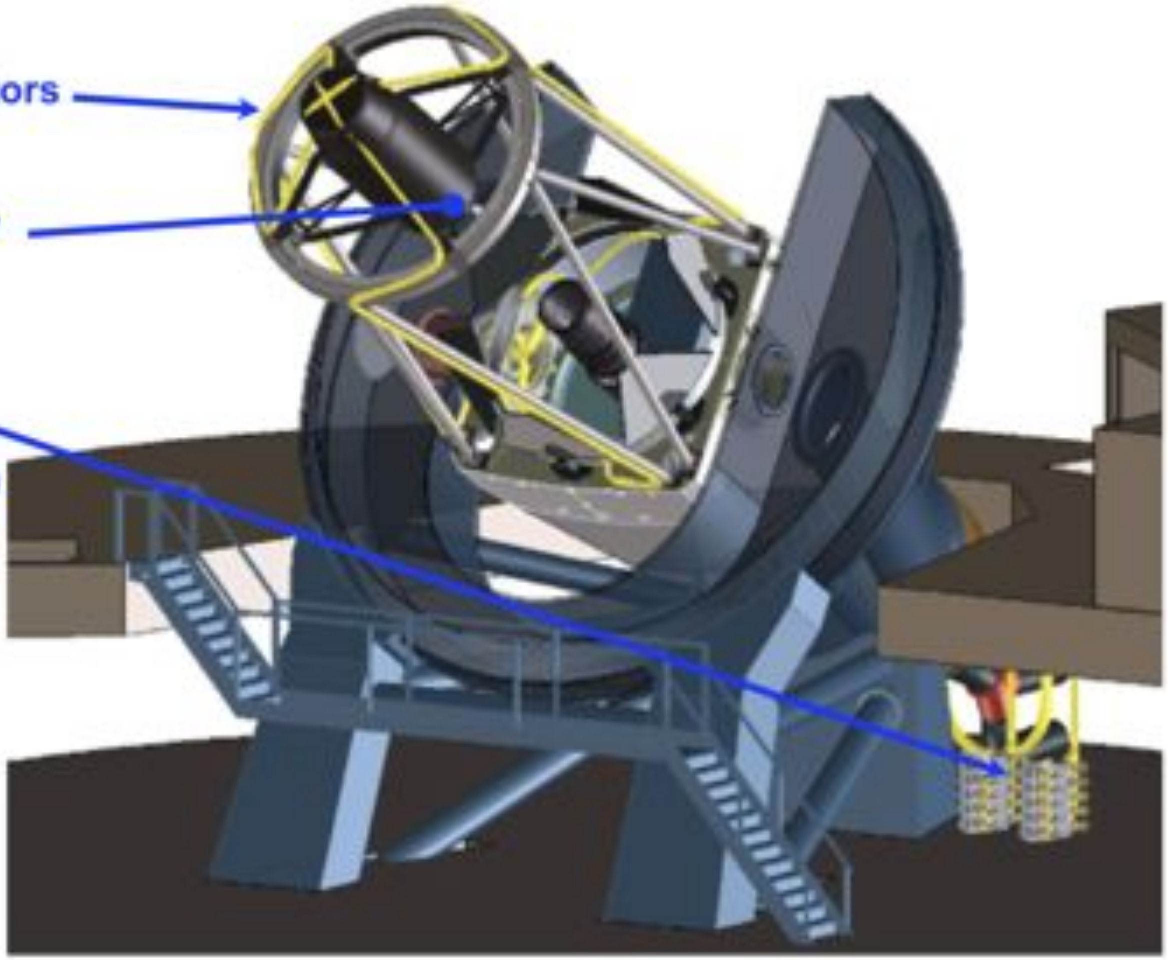

DESI
Borrowed from D. Schlegel

Where are we with SDSS-III/BOSS ?

SDSS-III/BOSS completed on April 1, 2014
1.5 million redshifts spanning ~5 $h^{-3}Gpc^3$



DESI Instrument



What is the DESI survey?

1. An imaging (targeting) survey over 14,000 deg^2

g-band to 24.0 mag

r-band to 23.6 mag

z-band to 23.0 mag

2. A spectroscopic survey over 14,000 deg^2

4 million Luminous Red Galaxies

23 million Emission Line Galaxies

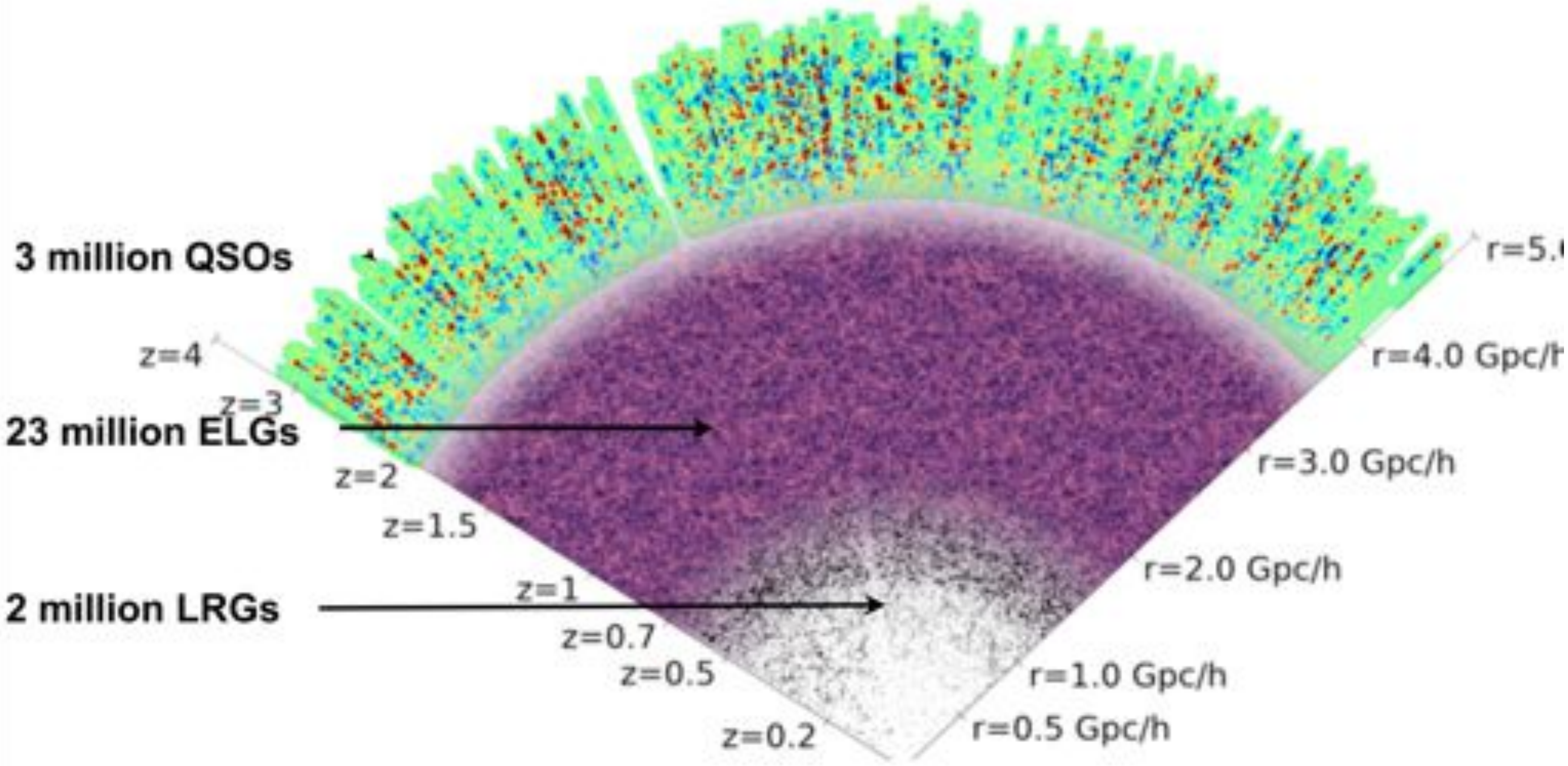
1.4 million quasars

0.6 million quasars at $z>2.2$ for Lyman-alpha-forest

What is the DESI survey?

The largest spectroscopic survey for dark energy

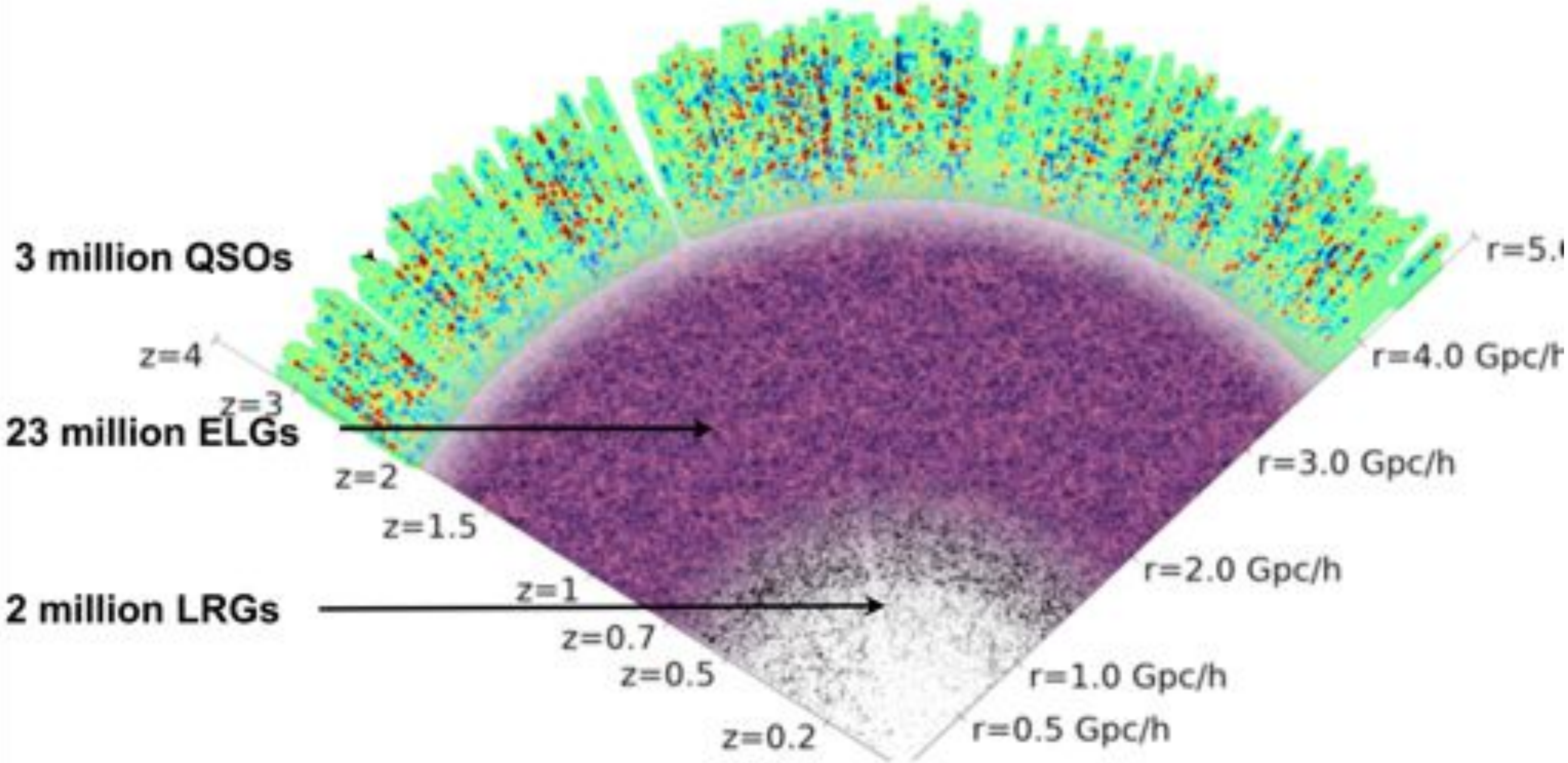
SDSS ~2h^{-3}Gpc^3 ⇨ BOSS ~6h^{-3}Gpc^3 ⇨ DESI 50h^{-3}Gpc^3



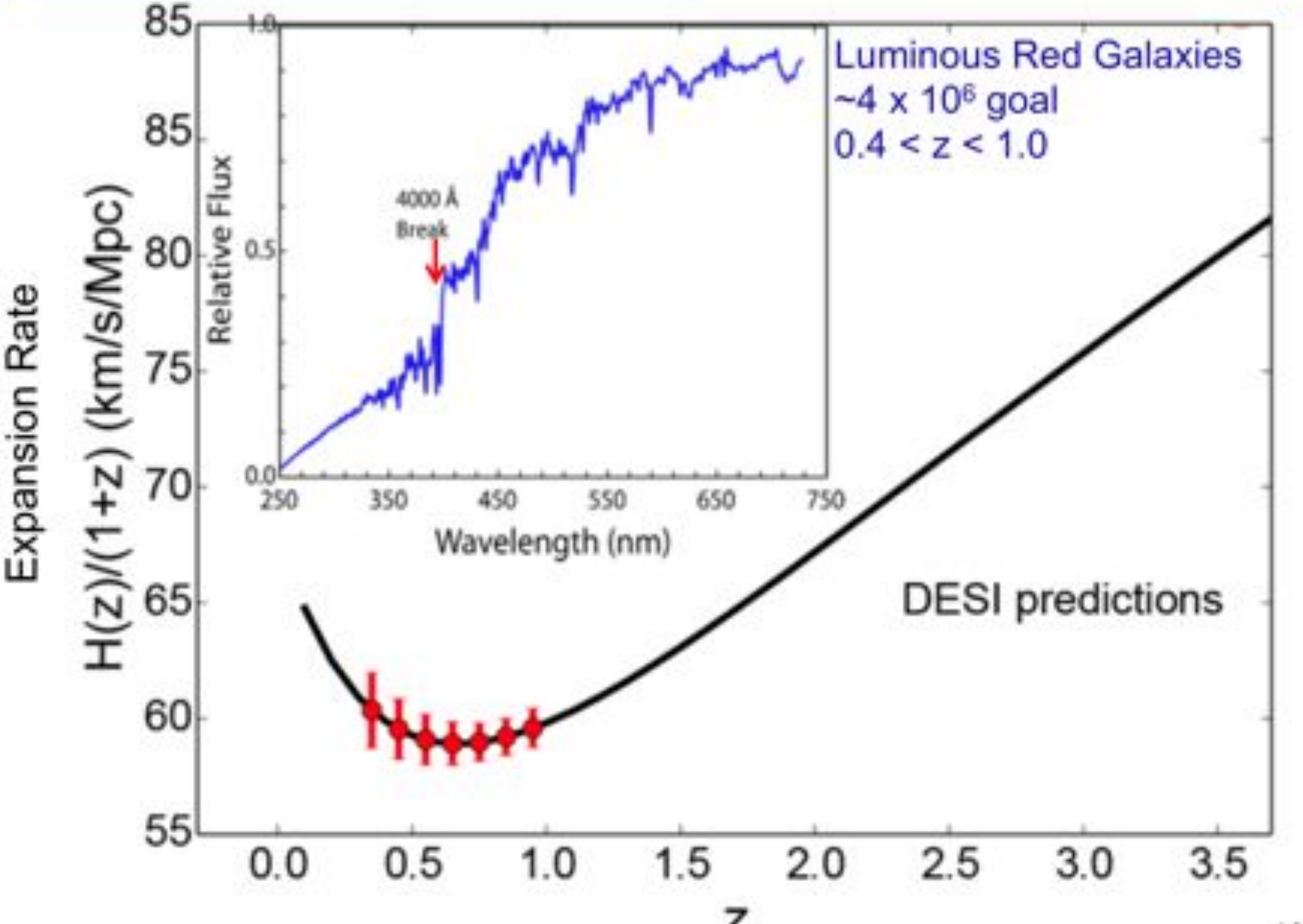
What is the DESI survey?

Four target classes spanning redshifts z=0 → 3.5

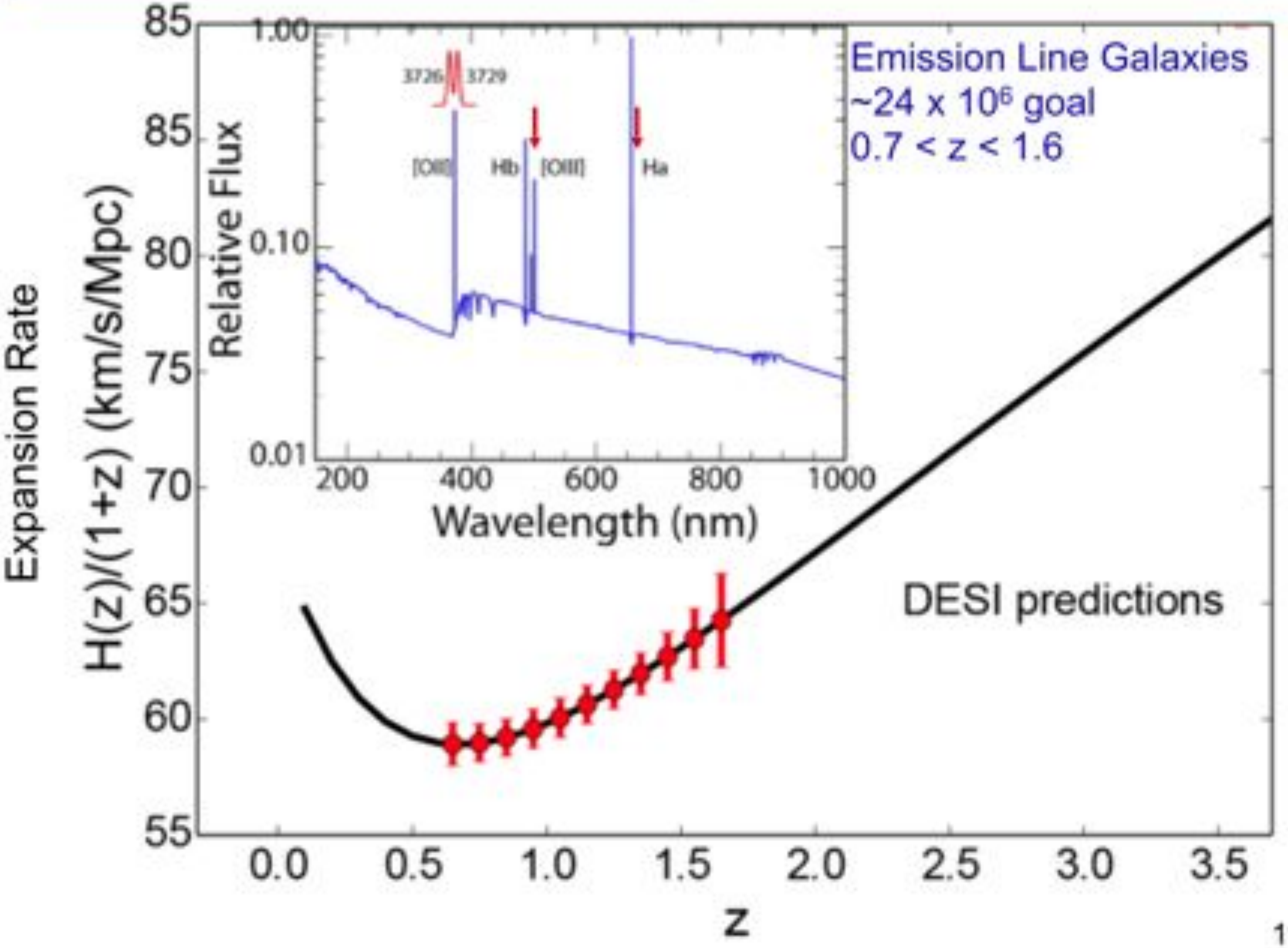
Includes all the massive black holes in the Universe (LRGs + QSOs)



LRG Targets

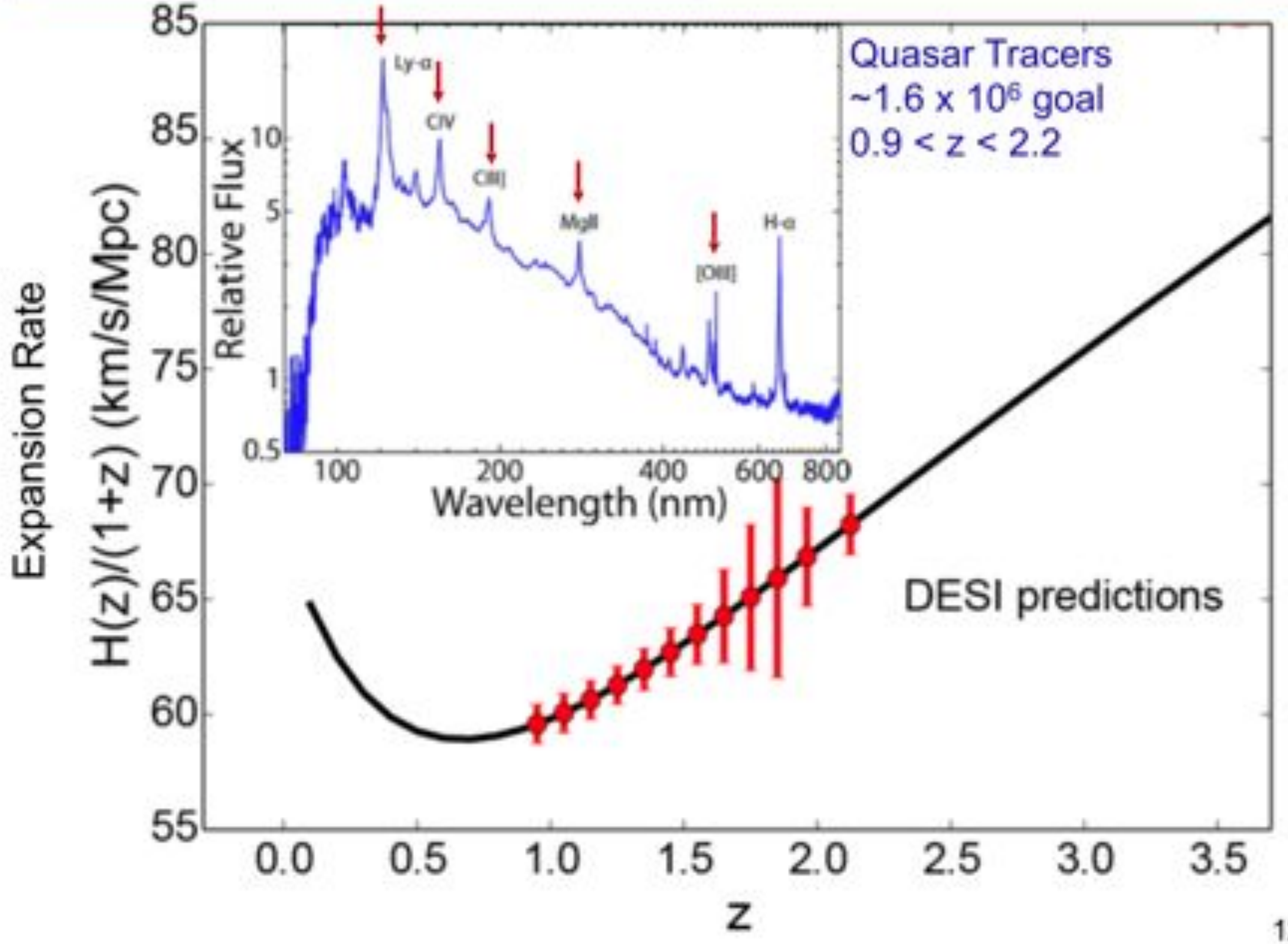

Luminous Red Galaxies
~4 x 10^6 goal
0.4 < z < 1.0
DESI predictions
Expansion Rate
H(z)/(1+z) (km/s/Mpc)
z
85
85
80
75
70
65
60
55
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Relative Flux
Wavelength (nm)
4000 Å
Break
1.0
0.5
0.0
250
350
450
550
650
750

ELG Targets

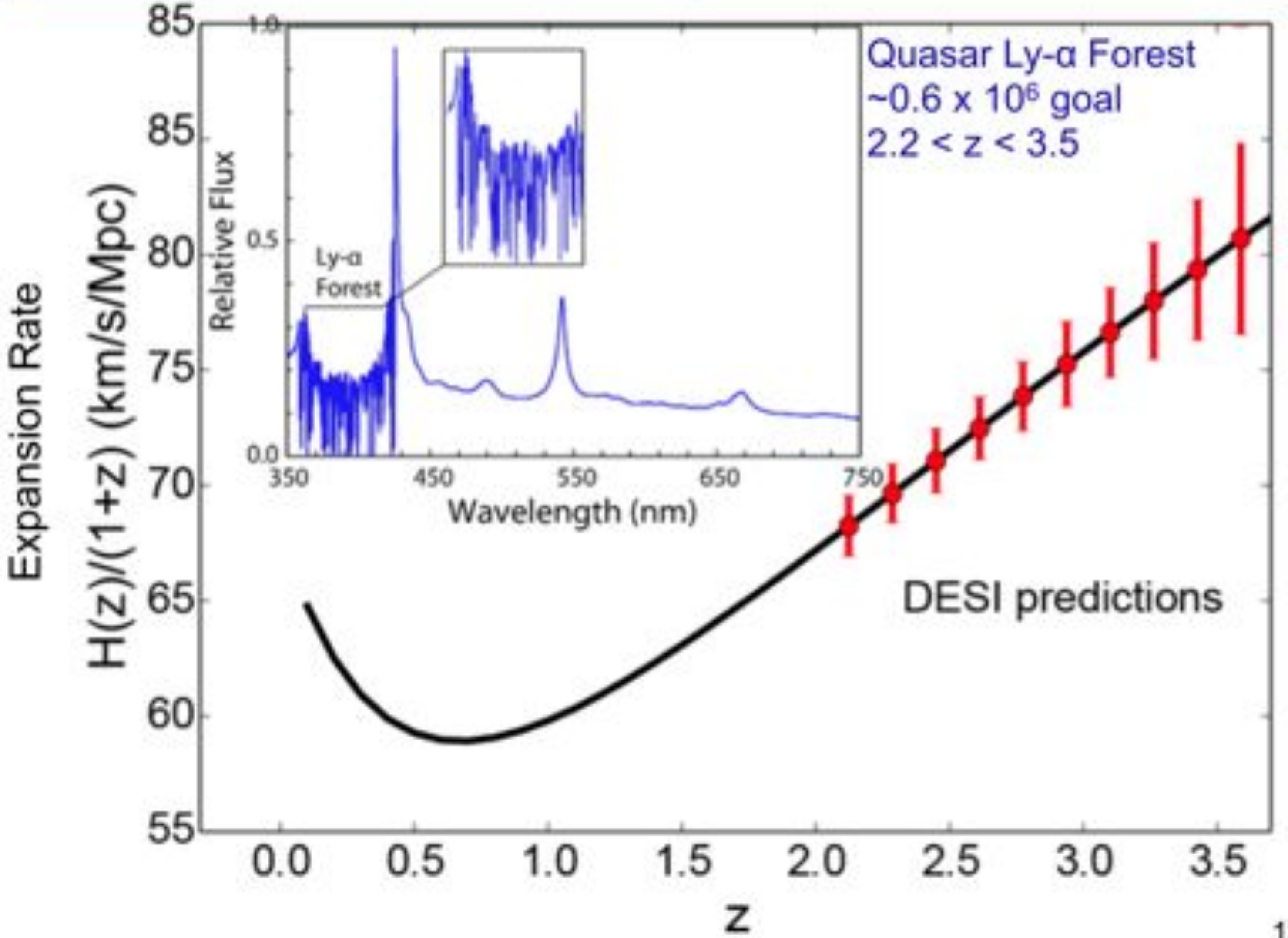


Emission Line Galaxies
~24 x 10^6 goal
0.7 < z < 1.6
Relative Flux
Wavelength (nm)
3726
3729
[OII]
Hb
[OIII]
Ha
Expansion Rate
H(z)/(1+z) (km/s/Mpc)
z
DESI predictions

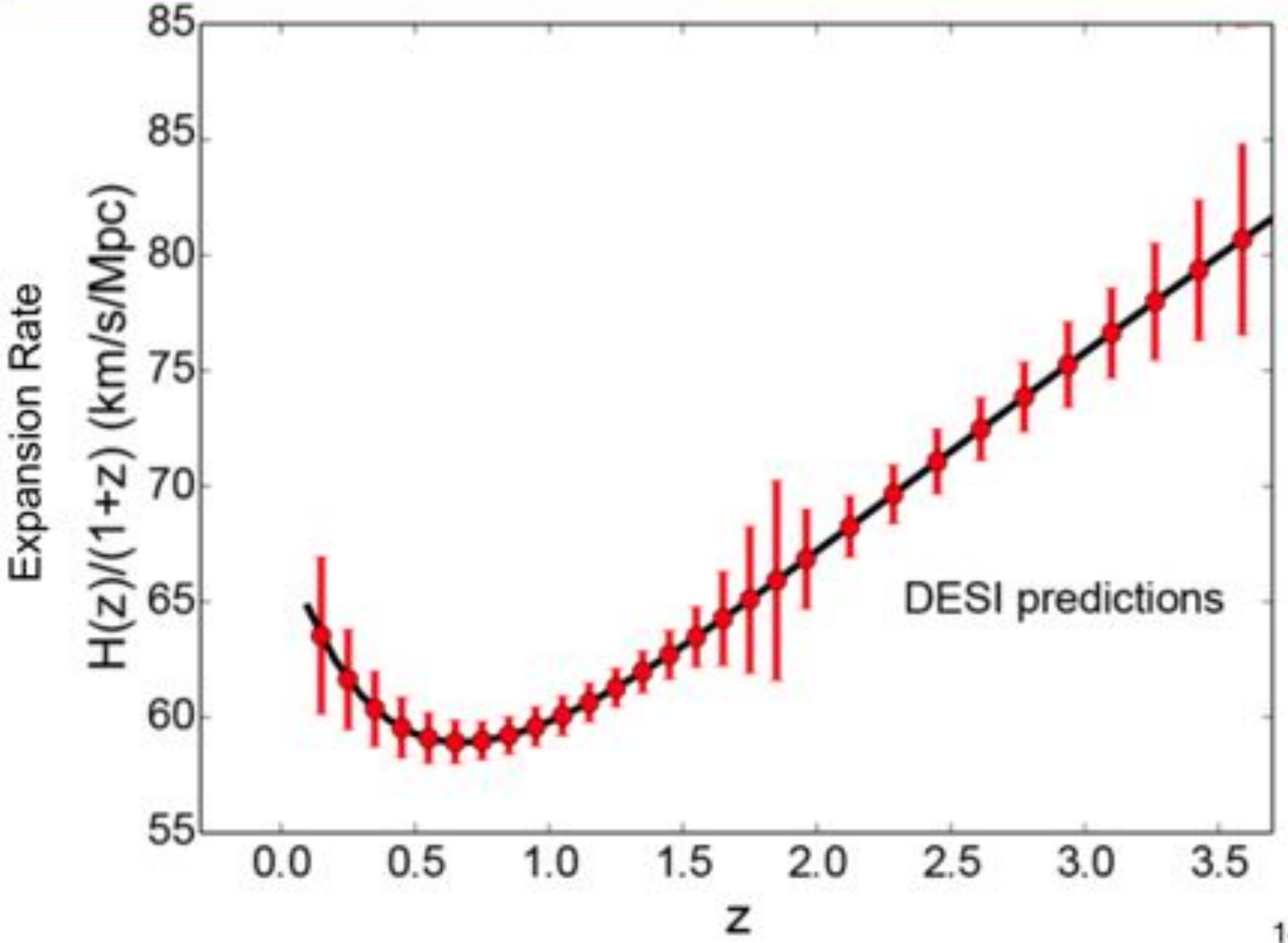
QSO Targets


Quasar Tracers
~1.6 x 10^6 goal
0.9 < z < 2.2
DESI predictions
Expansion Rate
H(z)/(1+z) (km/s/Mpc)
z
85
85
80
75
70
65
60
55
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Relative Flux
Wavelength (nm)
Ly-α
CIV
CIII]
MgII
[OIII]
H-α
10
5
1
0.5
100
200
400
600
800

Ly-α Forest QSO Targets



DESI on the Hubble Diagram



DESI Key Project goals

Defined in Science Requirements Document (SRD)

- **Distance-redshift relation**
  - — Measure distance scale to <0.3% between $0.0 < z < 1.1$
  - — Measure distance scale to <0.3% between $1.1 < z < 1.9$
  - — Measure the Hubble parameter to < 1% in the bin $1.9 < z < 3.7$
- **Gravitational growth growth**
  - — Constrain the growth factor at ~ a few percent level up to z=1.5
- **Beyond Dark Energy**
  - — Constrain spectral index of primordial perturbations and its running to < 0.4%
  - — Measure the neutrino masses to < 0.017 eV

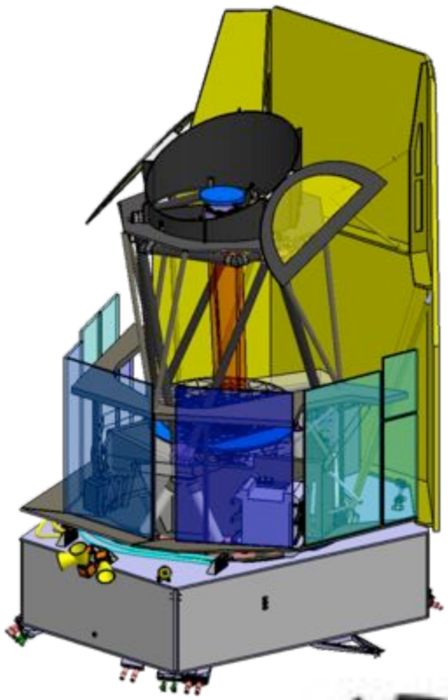

Euclid

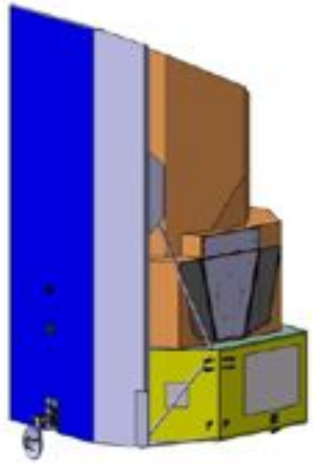
Euclid Science Objectives

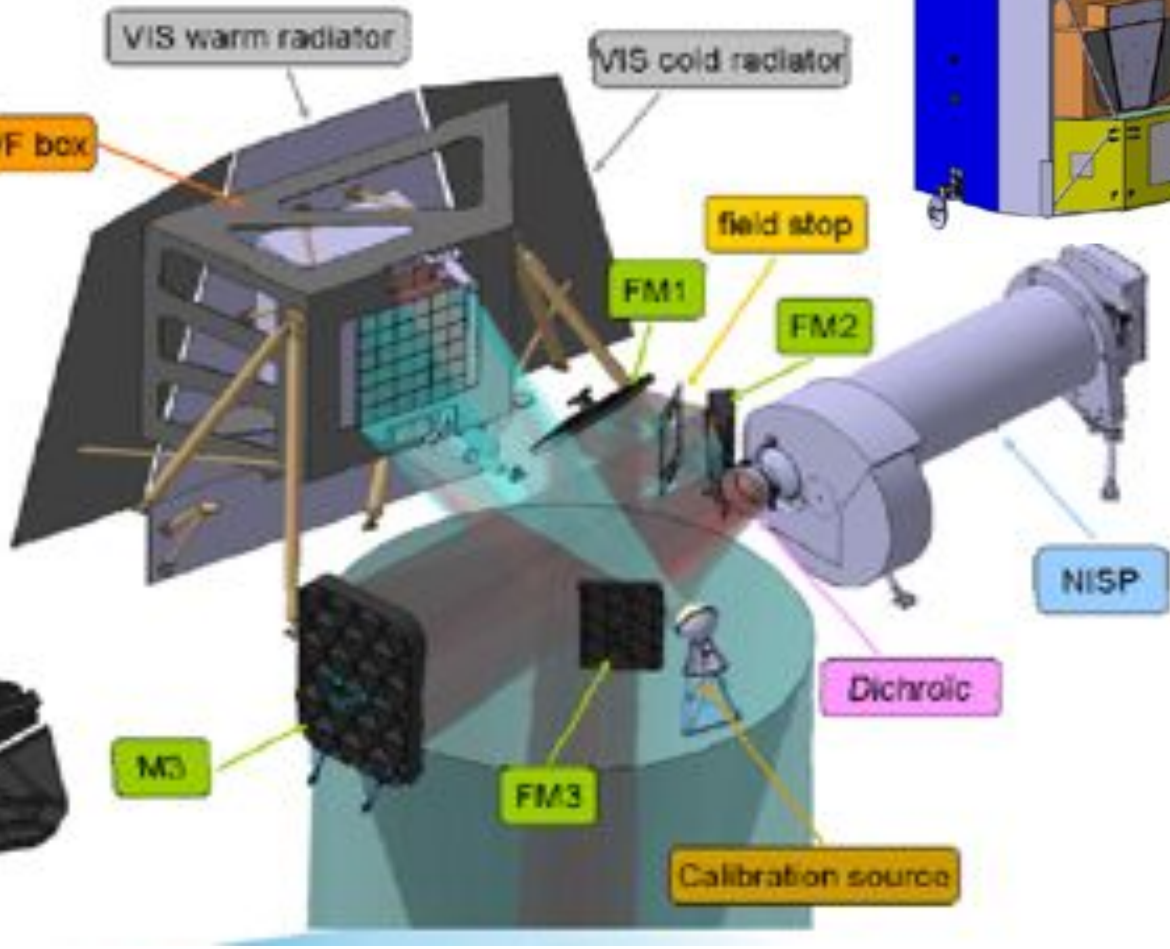
Issue	Euclid's Targets
What is Dark Energy	**Measure the Dark Energy equation of state parameters** w_p and w_a to a precision of 2% and 10%, respectively, using both expansion history and structure growth.
Beyond Einstein's Gravity	**Distinguish General Relativity from modified-gravity theories**, by measuring the galaxy clustering growth factor exponent γ with a precision of 2%.
The nature of dark matter	**Test the Cold Dark Matter paradigm** for structure formation, and measure the sum of the neutrino masses to a precision better than 0.04eV when combined with Planck.
The seeds of cosmic structure	**Improve by a factor of 20 the determination of the initial condition parameters** compared to Planck alone. n (spectral index), σ_8 (power spectrum amplitude), f_{NL} (non-gaussianity)

Euclid Payload

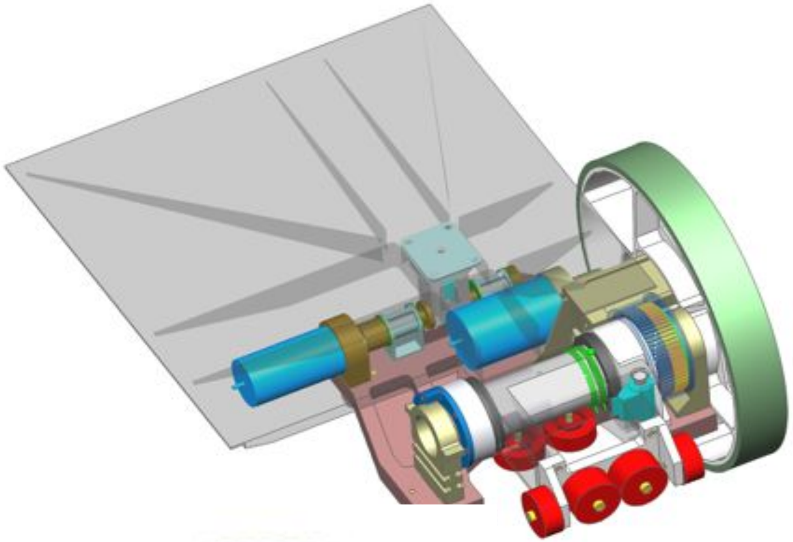
EUCLID CONSORTIUM

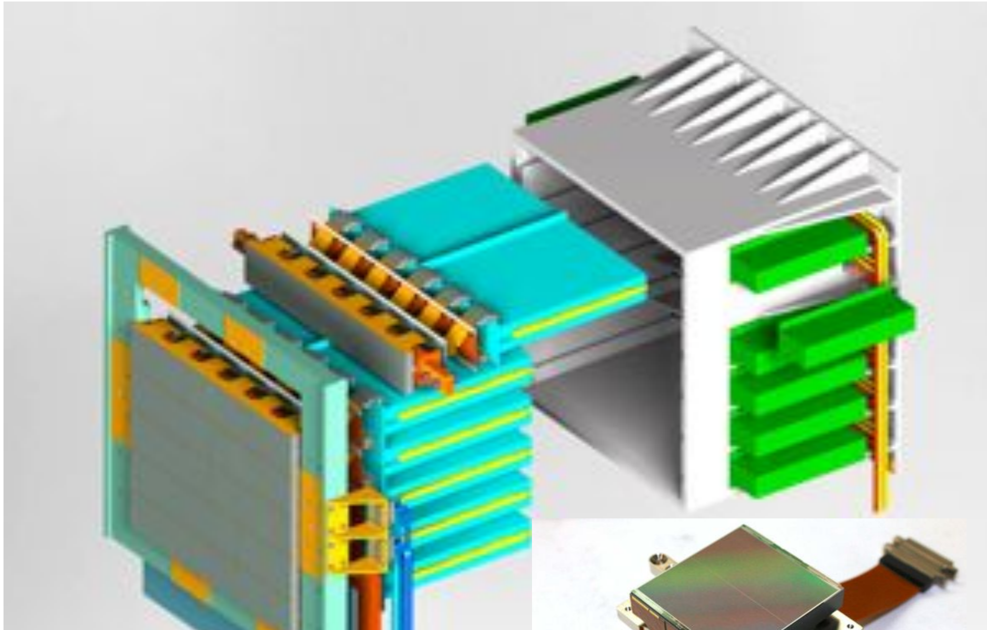


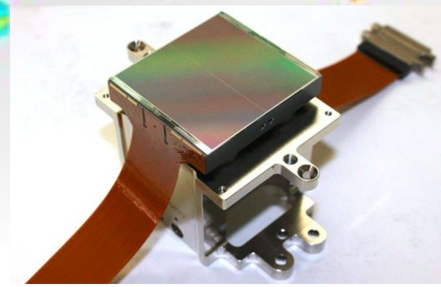


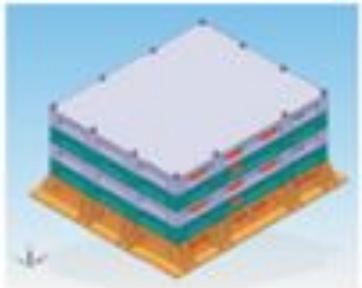


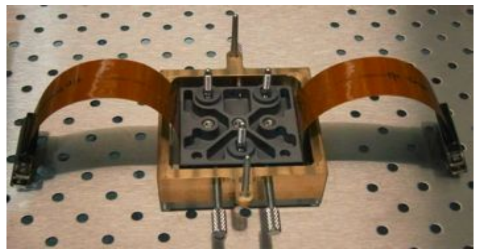
Brazed baseplate



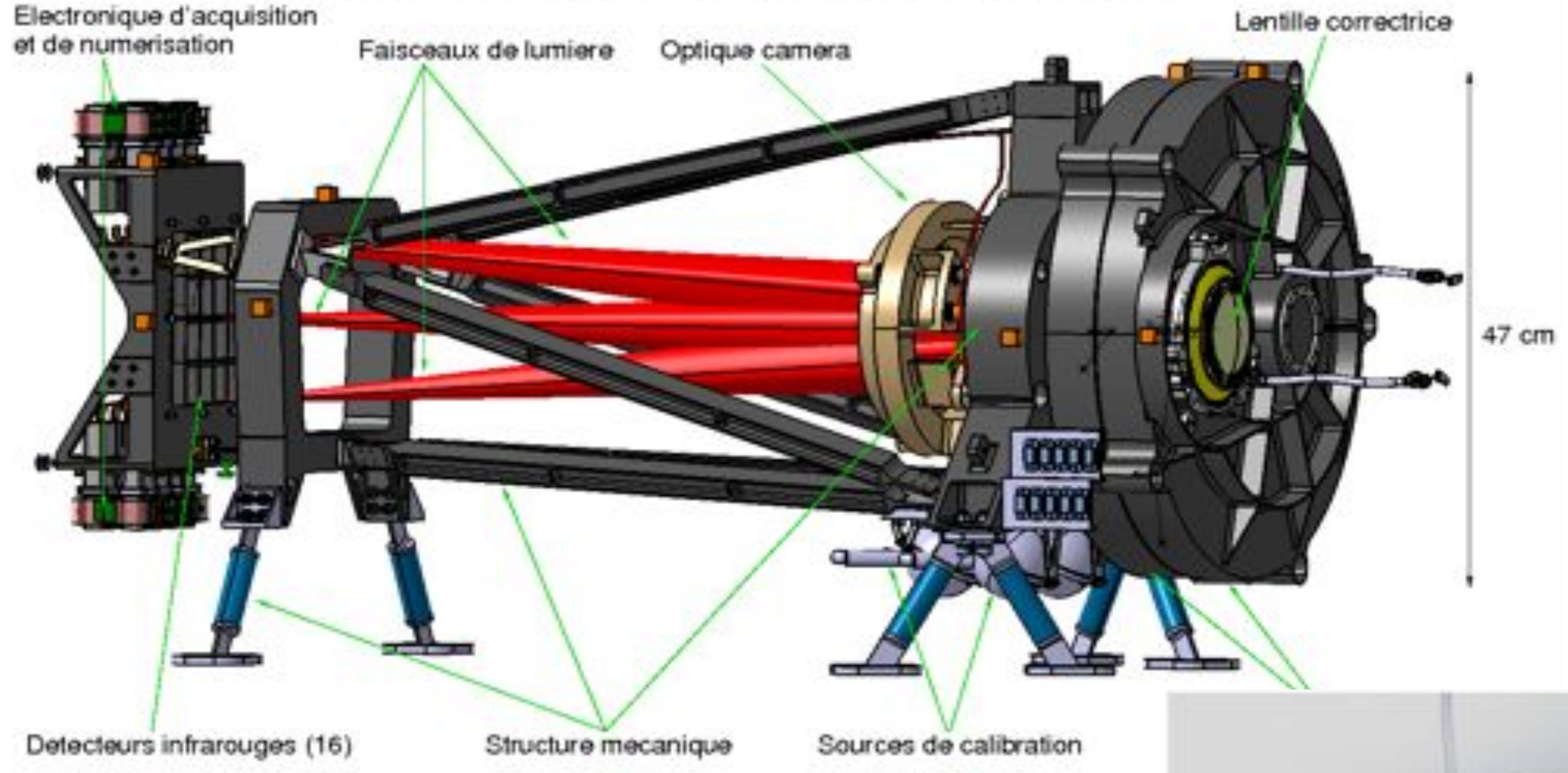








The NISP instrument: Near Infrared Spectrometer and Photometer



Euclid Focal planes

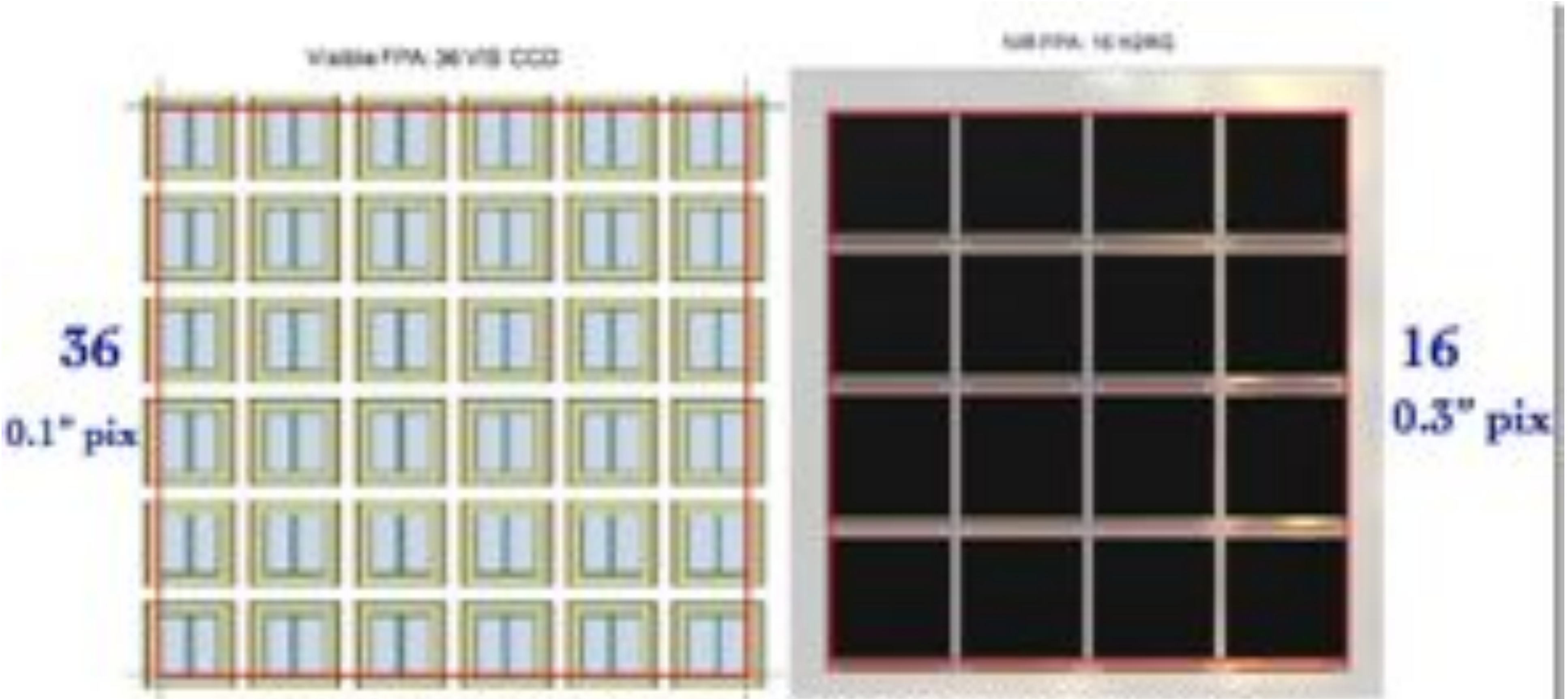


Figure 6-1: VIS (left red ensquared area) and NISP (right red ensquared area) Geometrical FoV.

Euclid Exposure sequence

4 exposures ~1 full field -0.5 sq deg- / 1.25 hr (~ 19/day ≈10 sq deg/day)

Observing sequence for each field + move to next one ~4500 s

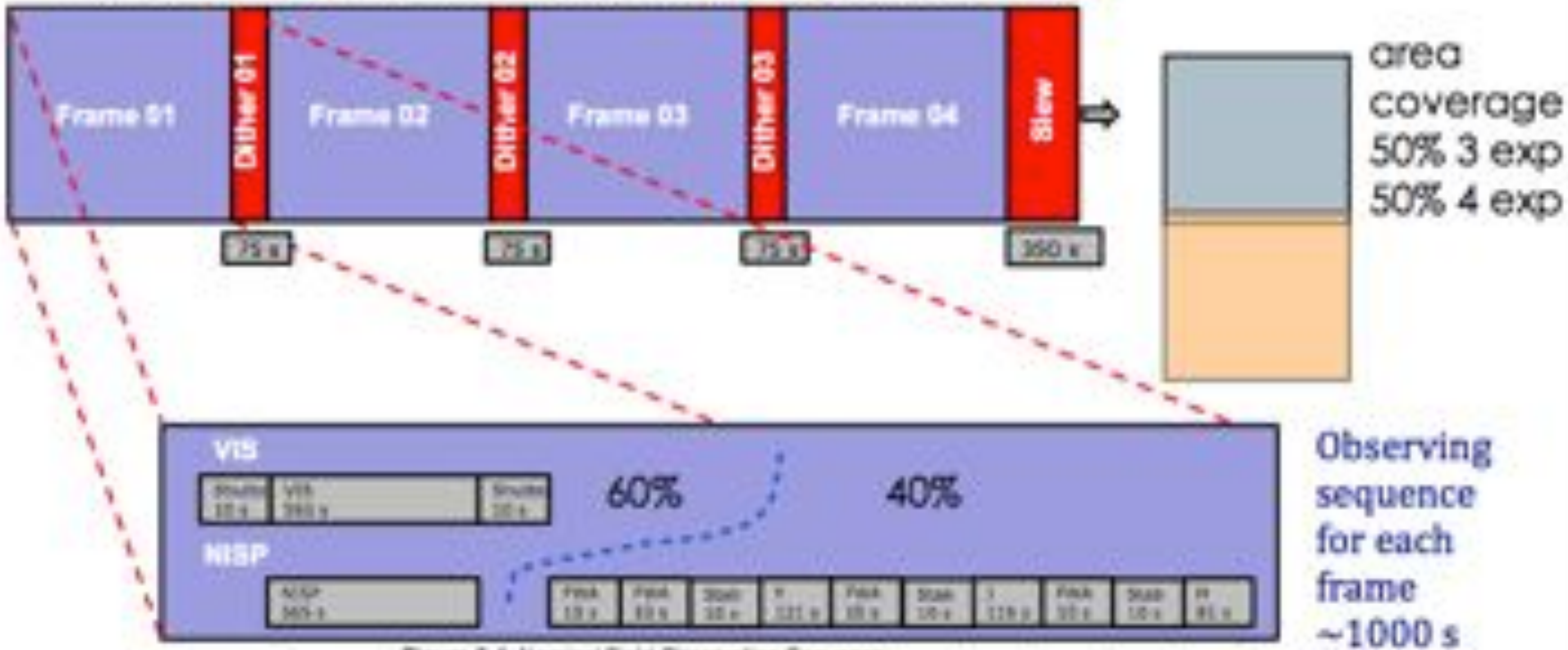


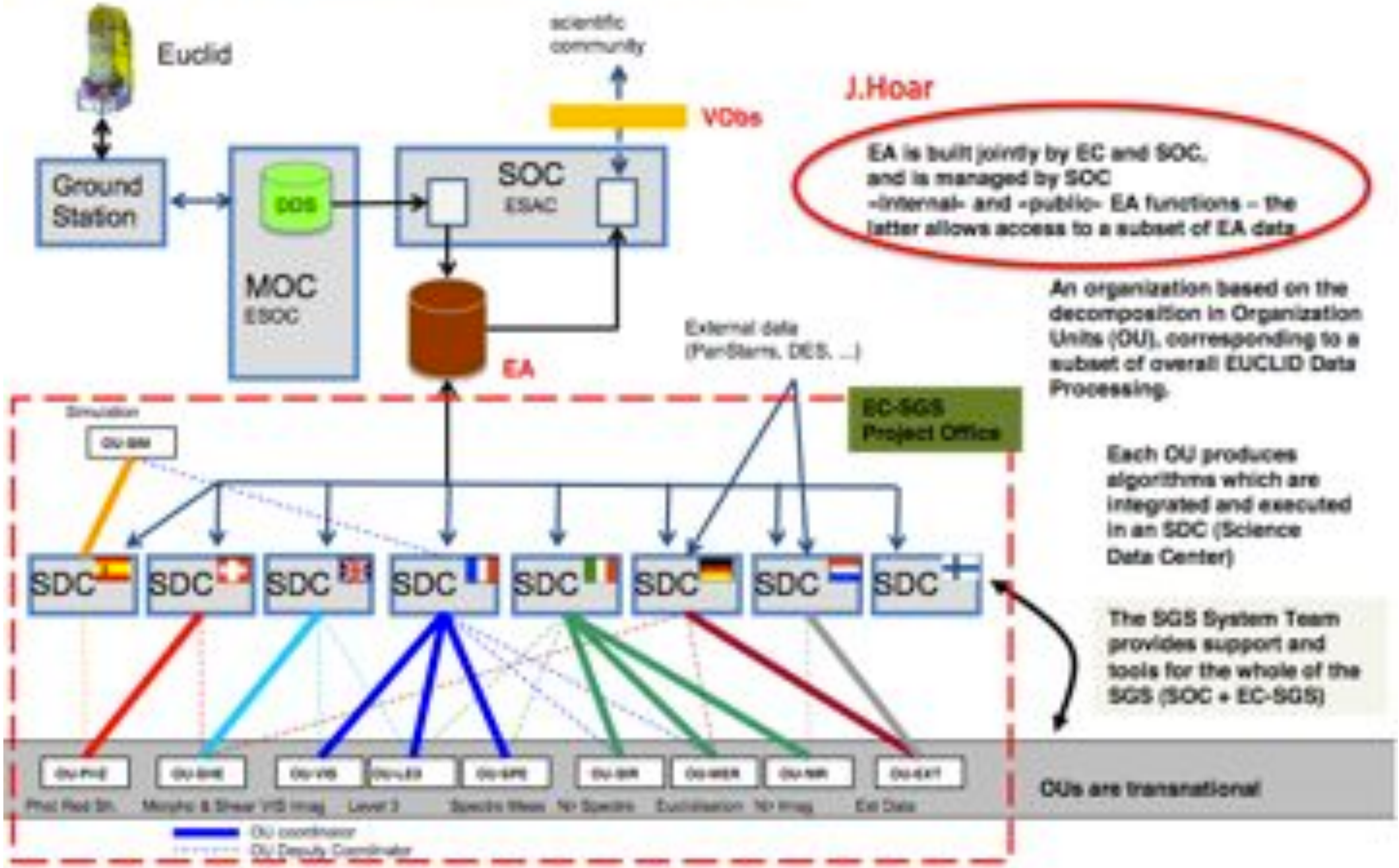
Figure 5-4 Nominal Field Observation Sequence

NIR: first spectroscopy contemporarily to VIS, then imaging (filter/grism wheel motion perturbs VIS)

Slitless: Blue, then Red grism, then again at 90 degs (--> 4 dithers)

Euclid Ground Segment

EUCLID CONSORTIUM



Euclid Mission concept

- Optimize the mission for galaxy clustering and weak lensing, two dark energy complementary probes
- Two instruments: optical imager (VIS) and near-infrared spectrophotometer (NISP)
- Minimum survey area of 15000 deg2 → 6 years nominal mission

Weak Lensing: → VIS imager + NIR photometer

- Shapes and shear of galaxies with a density of >30 galaxies/arcmin^2.
- Very high image quality, high stability
- Minimum Systematics $\sigma_{sys} < 10^{-7}$
- Redshift accuracy dz/z ~ 0.04, down to z~2

Galaxy clustering → NIR slitless spectrometer

- Redshifts for >3500 galaxies/deg^2
- Redshift range $0.7 < z < 2.05$
- Redshift accuracy dz/z < 0.001 in same volume as WL
- Line Flux limit < $3\ 10^{-16}$ erg cm^{-2}s^{-1}

Euclid Surveys

Two Survey Strategy

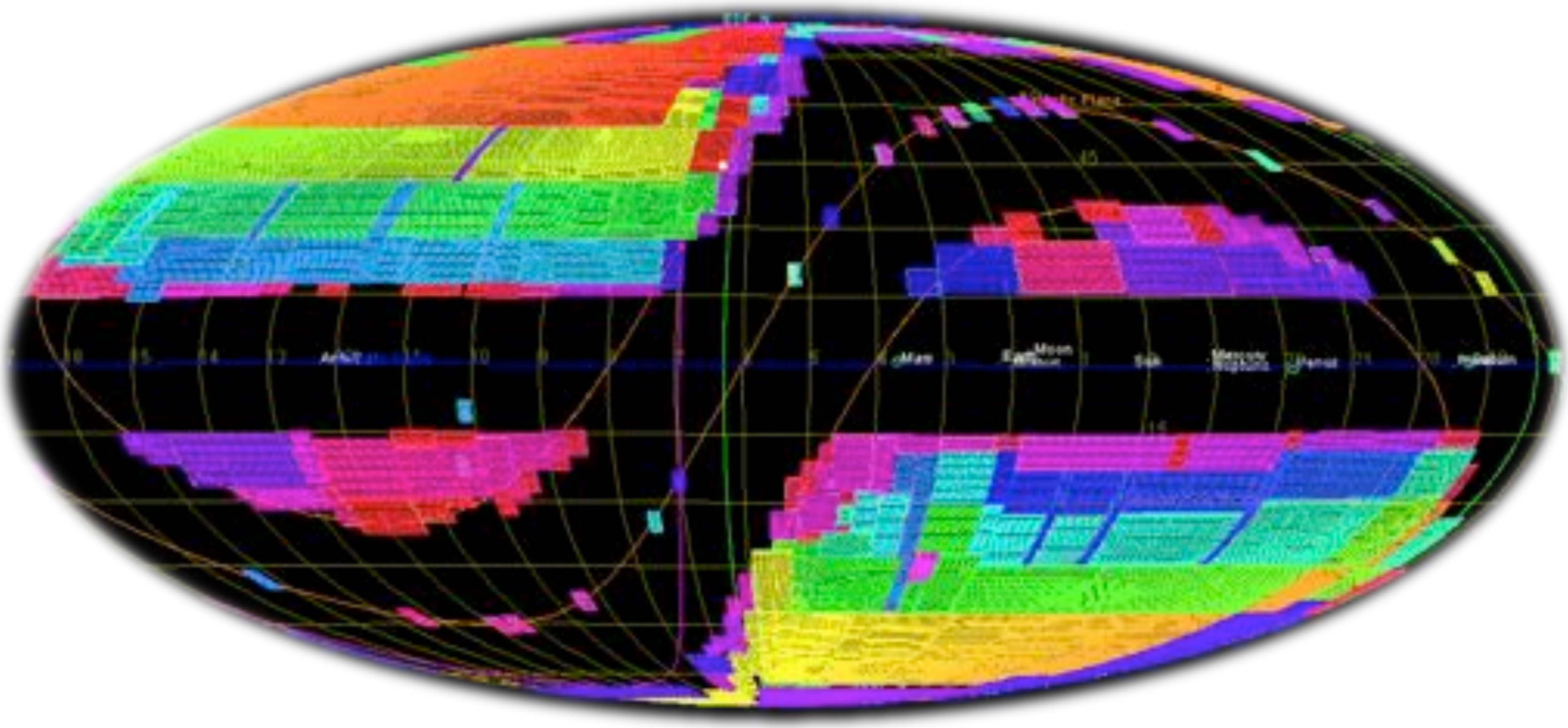
Wide Survey

- Area: 15000 deg^2; goal 20000 deg^2
- Avoid galactic plane, ecliptic plane and high extinction
- Imaging depth: $RIZ_{AB} = 24.5$ at 10σ; NIR (Y_{AB},J_{AB},H_{AB}) = 24.0 at 5σ
- Spectroscopic depth: $3\ 10^{-16}$ erg cm^{-2} s^{-1}

Deep Survey

- Area: 40 deg^2, in two pointing
- Location TBD, but most likely in ecliptic poles
- Depth: 2 magnitudes deeper than wide survey

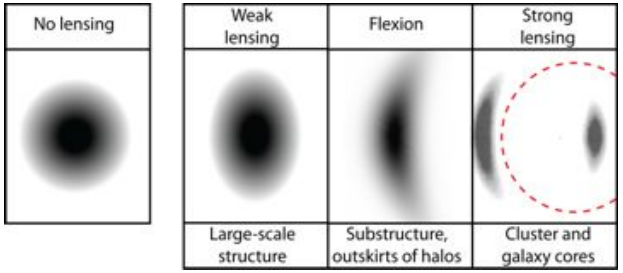
Euclid Sky coverage

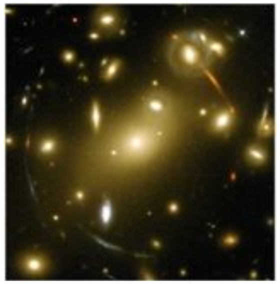


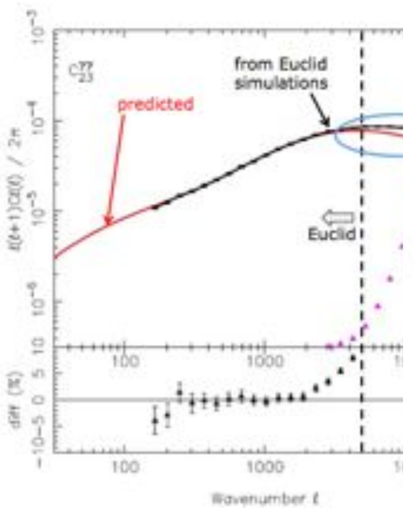
- Ecliptic plane avoided (zodiacal light, $|\beta|<15$ deg) and low ($|b|<25$ deg) galactic latitudes and high extinction regions $E(B-V) < 0.08$
- Different colours indicate different survey years
- Calibration fields along the galactic plane

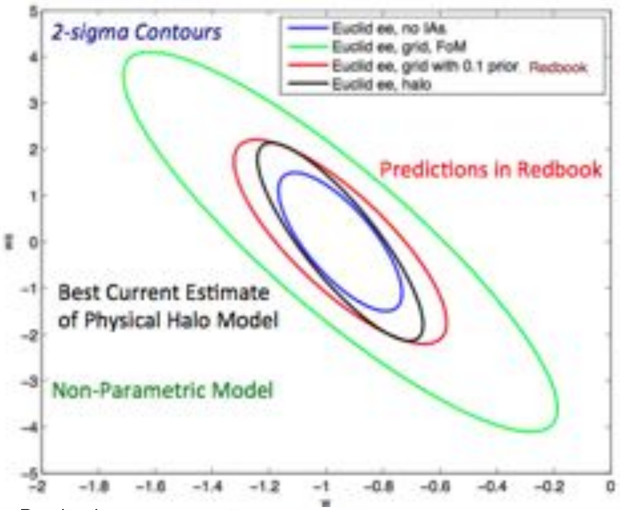
Euclid Weak Lensing

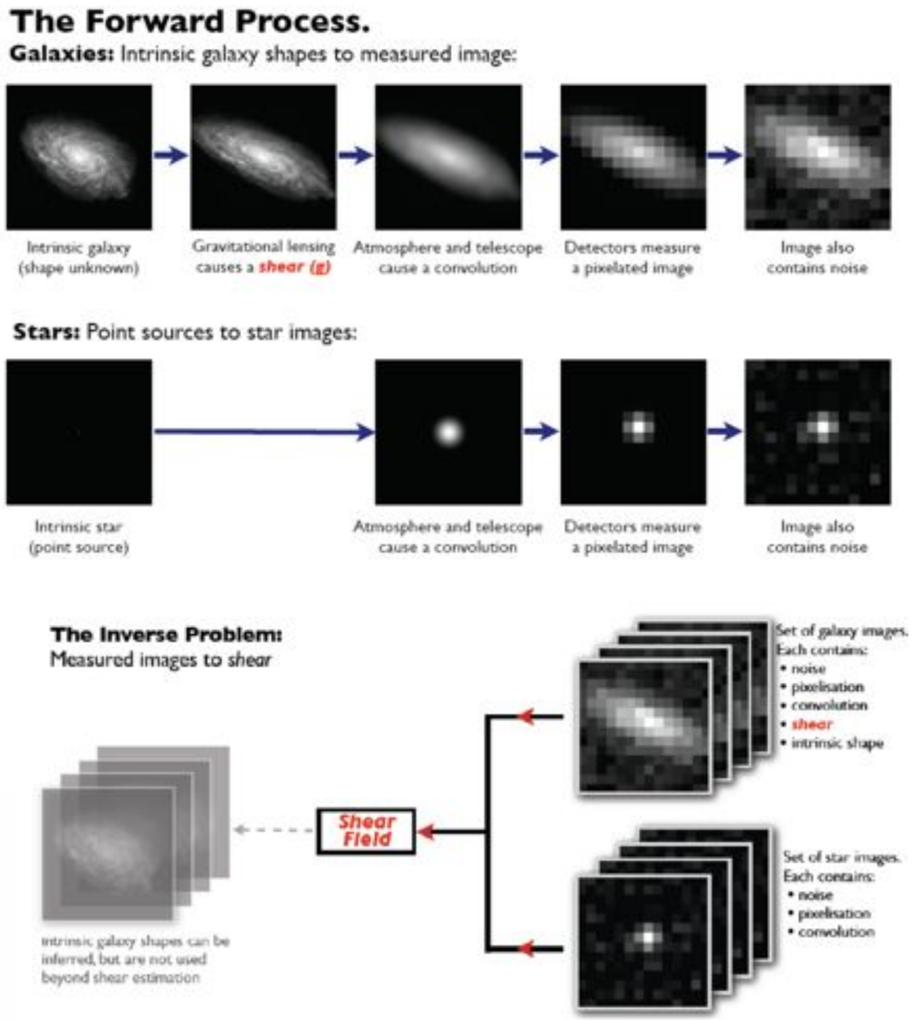
EUCLID CONSORTIUM

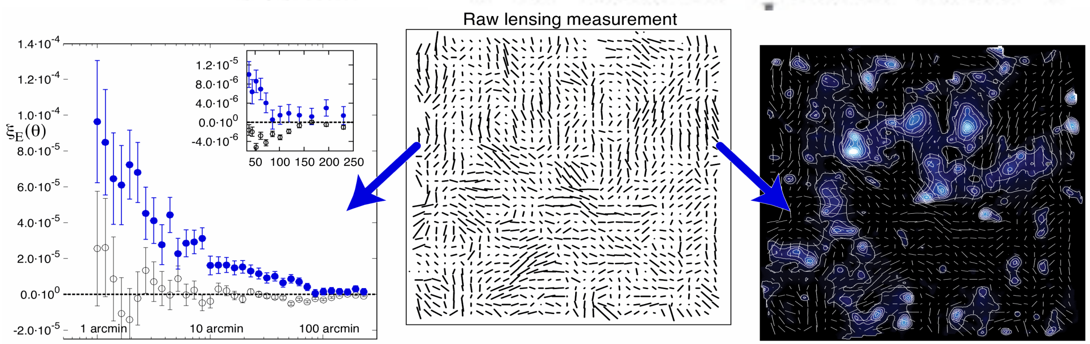










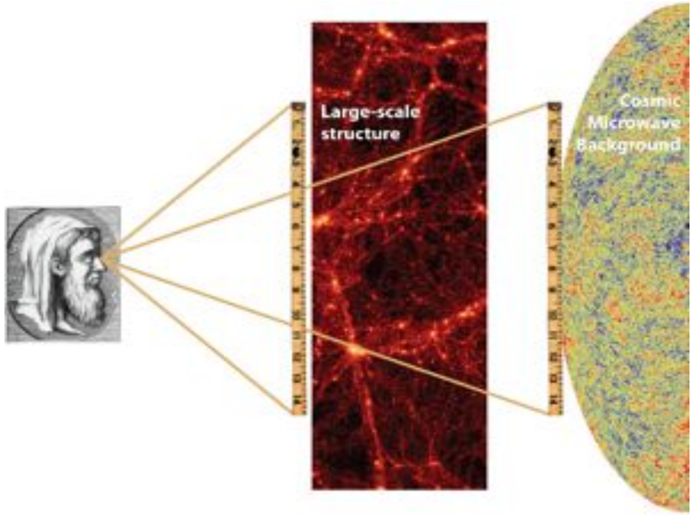


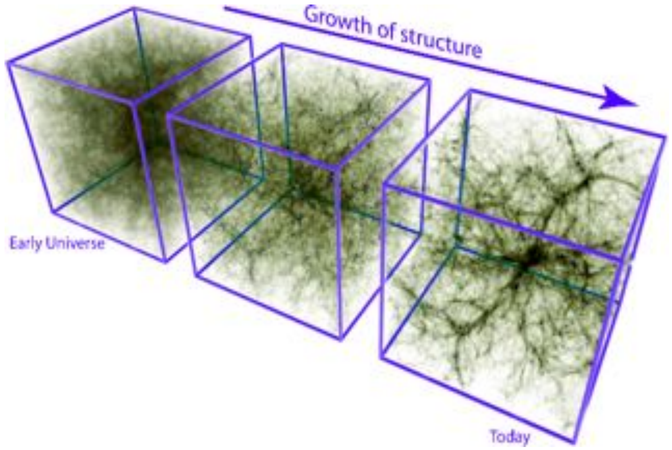
Correlation function

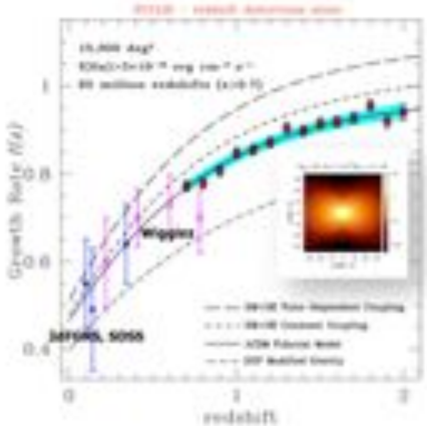
Dark matter distribution

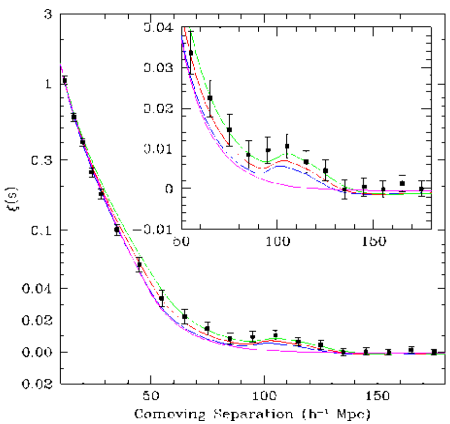
Euclid Galaxy clustering

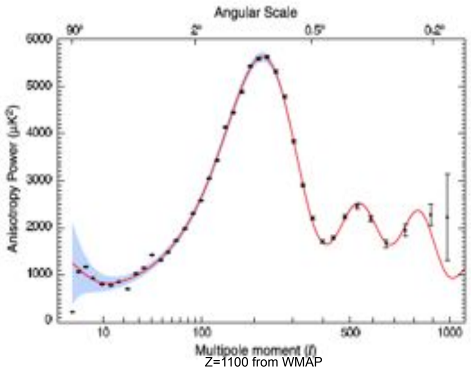
EUCLID CONSORTIUM

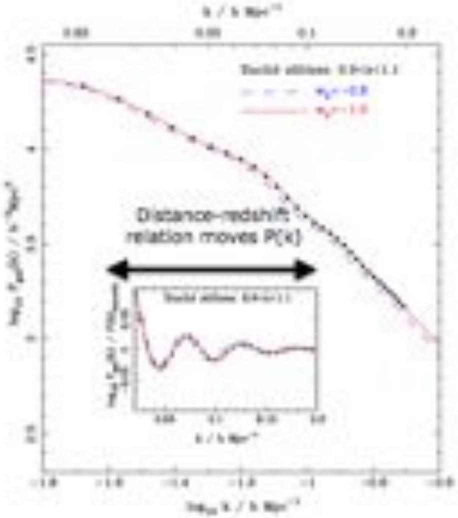


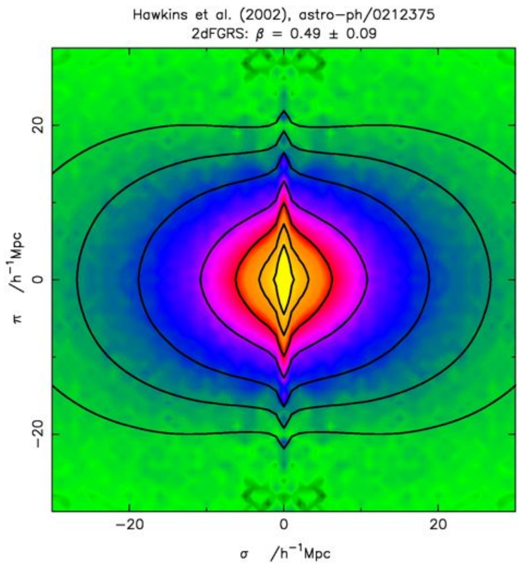










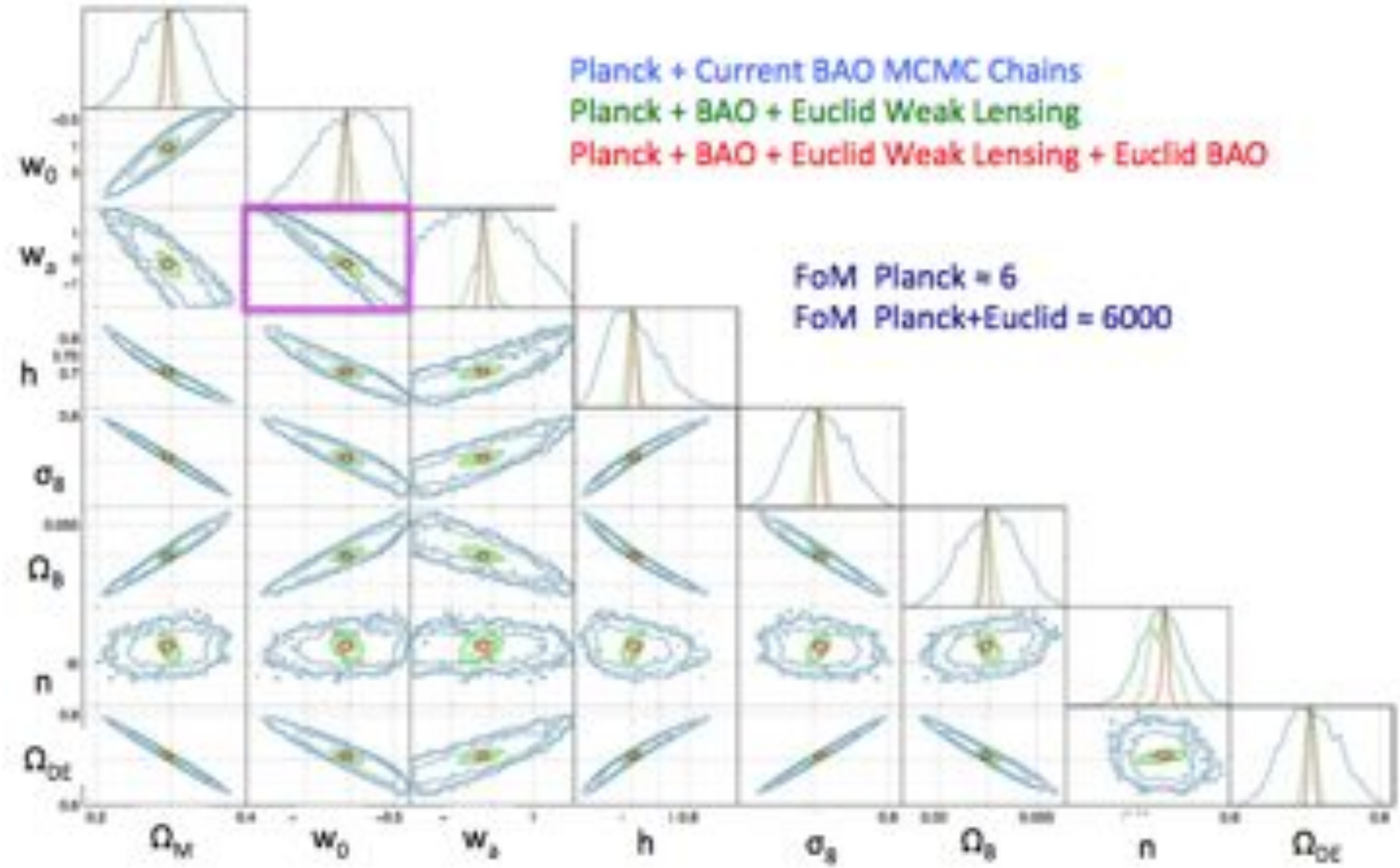


Euclid Science Prediction

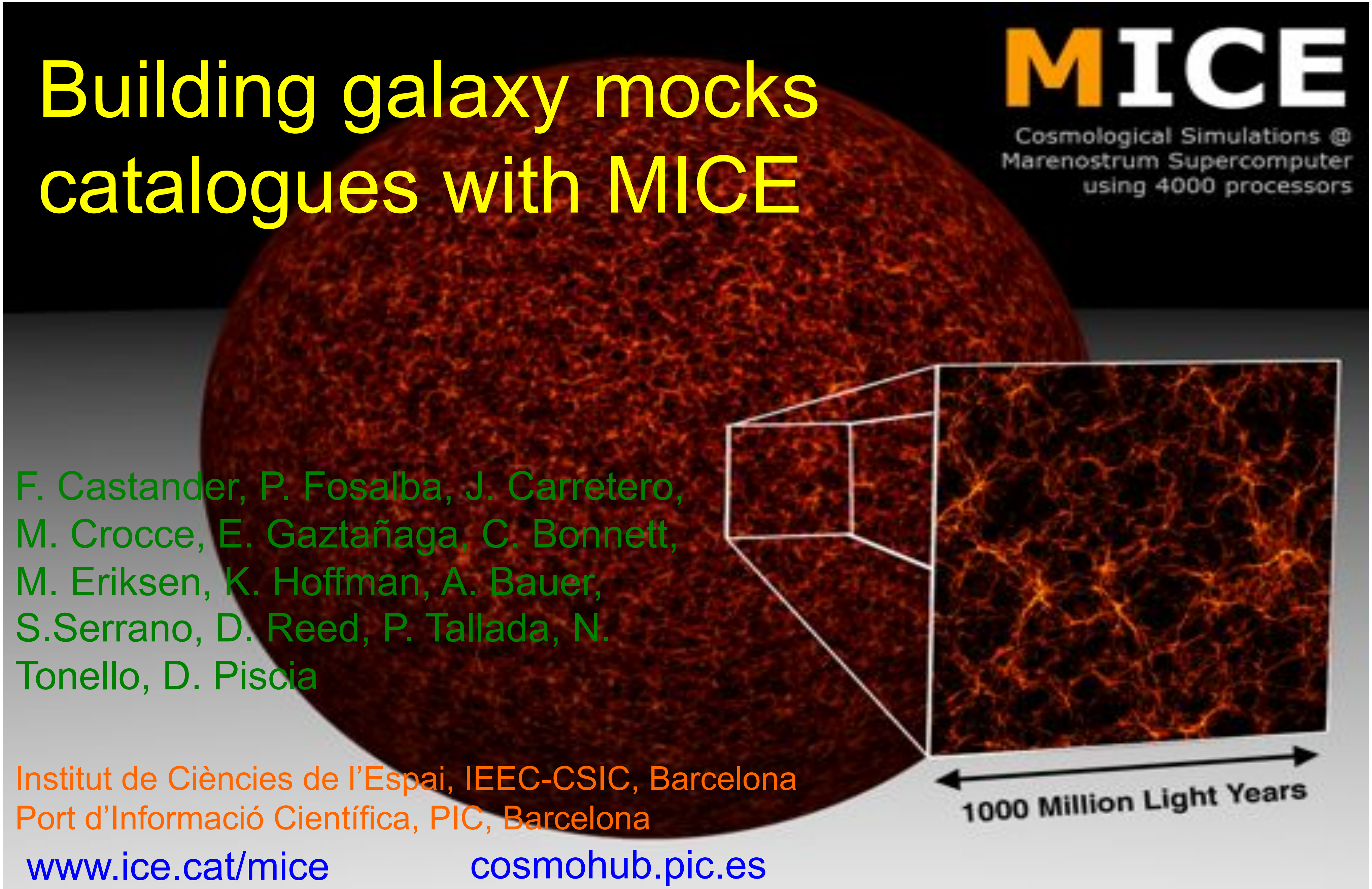
Red Book Predictions

	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν/eV	f_{NL}	w_p	w_a	FoM
Euclid Primary	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>50**	**>300**

Euclid Science prediction



Building galaxy mocks catalogues with MICE



F. Castander, P. Fosalba, J. Carretero, M. Crocce, E. Gaztañaga, C. Bonnett, M. Eriksen, K. Hoffman, A. Bauer, S.Serrano, D. Reed, P. Tallada, N. Tonello, D. Piscia

Institut de Ciències de l'Espai, IEEC-CSIC, Barcelona
Port d'Informació Científica, PIC, Barcelona

www.ice.cat/mice cosmohub.pic.es

MICE

Marenostrum Institut de Ciències de l'Espai Simulations

MICE simulations

www.ice.cat/mice

Cosmological surveys

- Probe large volumes: wide area & z range
- determine tracers (galaxies) positions (redshifts)
- determine the expansion rate and growth of structure

MICE simulations

- Provide mocks for cosmological surveys: DES, PAU, Euclid, DESI
- help plan and optimize surveys
- analyze and exploit cosmological data
- understand errors and covariances

MICE

Marenostrum Institut
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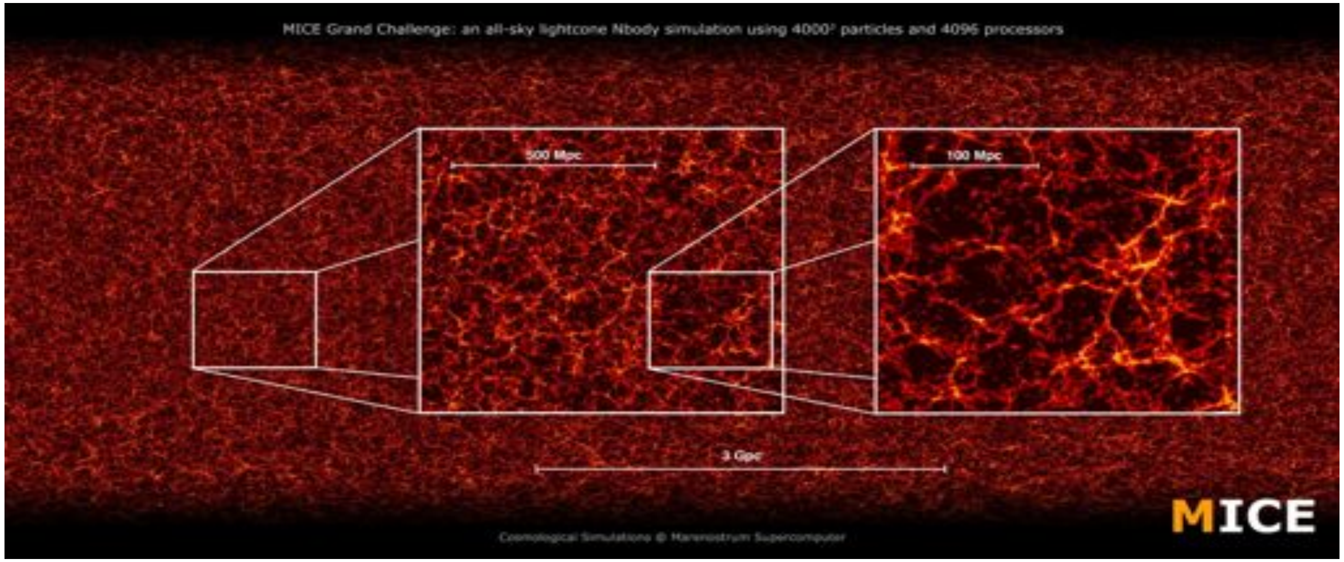
Simulations

MICE simulations

www.ice.cat/mice

Simulation process

- Generate large dark matter simulation
- Produce lightcones
- All-sky lensing maps
- generate halo catalogues
- produce galaxy catalogues



MICE

Marenostrum Institut
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Simulations

MICE simulations

www.ice.cat/mice

MICE

Products

- Comoving and lightcone outputs
  - dark matter
  - halo catalogues
  - lensing catalogues
  - galaxy catalogues

Properties

- Clustering
- Lensing
- Galaxy properties

MICE

Marenostrum Institut de Ciències de l'Espai Simulations

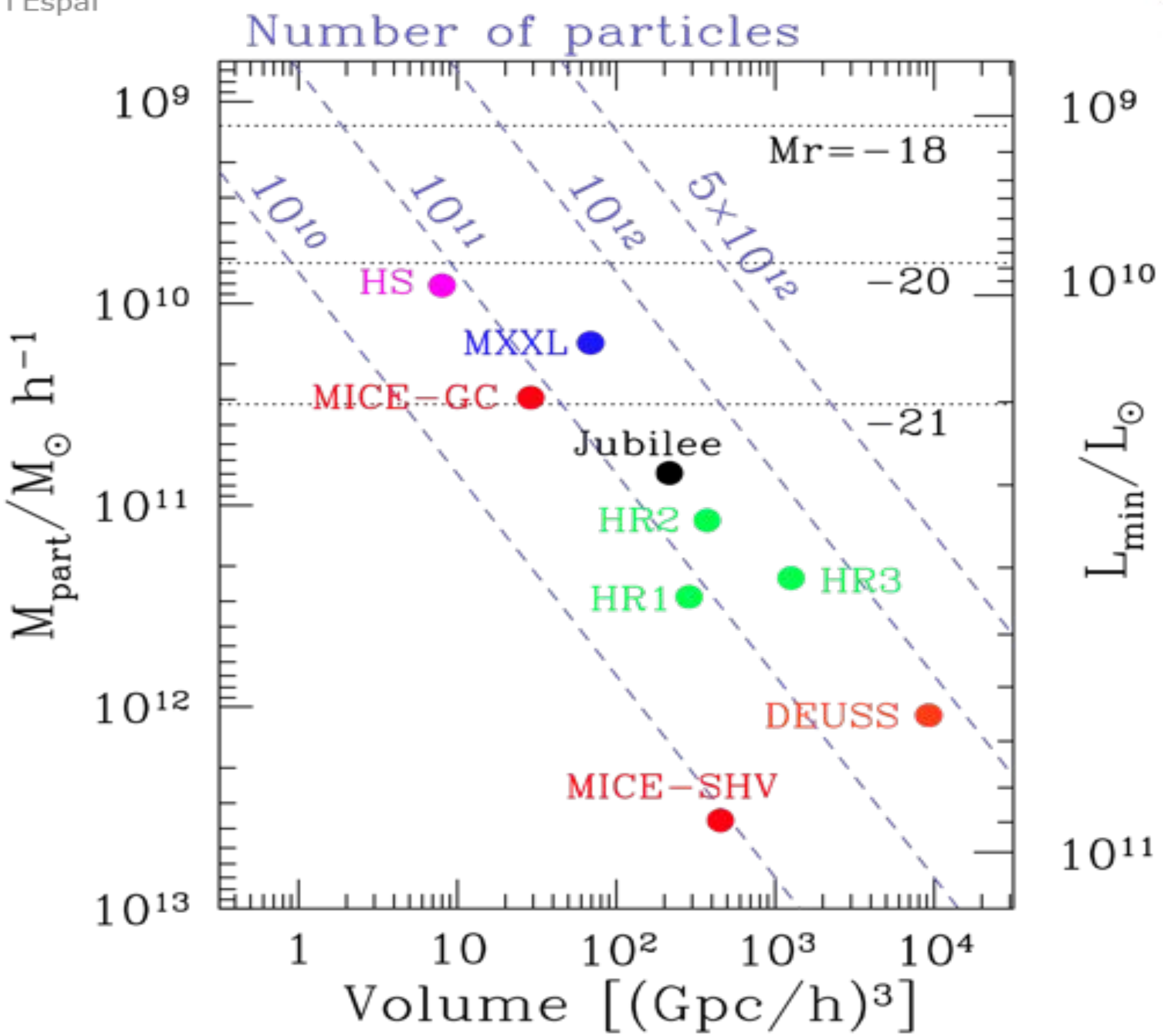
MICE galaxy catalogue

- Run at BSC Marenostrum
- Uses MICE Grand Challenge simulation: 4096^3 = 70 billion particles, 3 Gpc/h box, mp=$3\text{x}10^{10}$ $M_{\odot}$
- Lightcone without repetition to z=1.4
- FoF halos with b=0.2 (1.2 billion, $n_{part} \geq 10$)
- All-sky lensing maps
- 1 octant (5000 deg^2) filled with HOD+SHAM galaxies
- Apply lensing properties to all galaxies

Box Size (Mpc/h)	Number of Particles	Particle Mass ($\text{x}10^{10}$ Msun/h)	PMGrid size	Initial conditions	Initial redshift	l_{soft} (kpc/h)	MaxSize Timestep
3072	4096^3	2,927	4096^3	ZA	100	50	0,02

MICE GC simulation

MICE
Marenostrum Institut de Ciències de l'Espai Simulations



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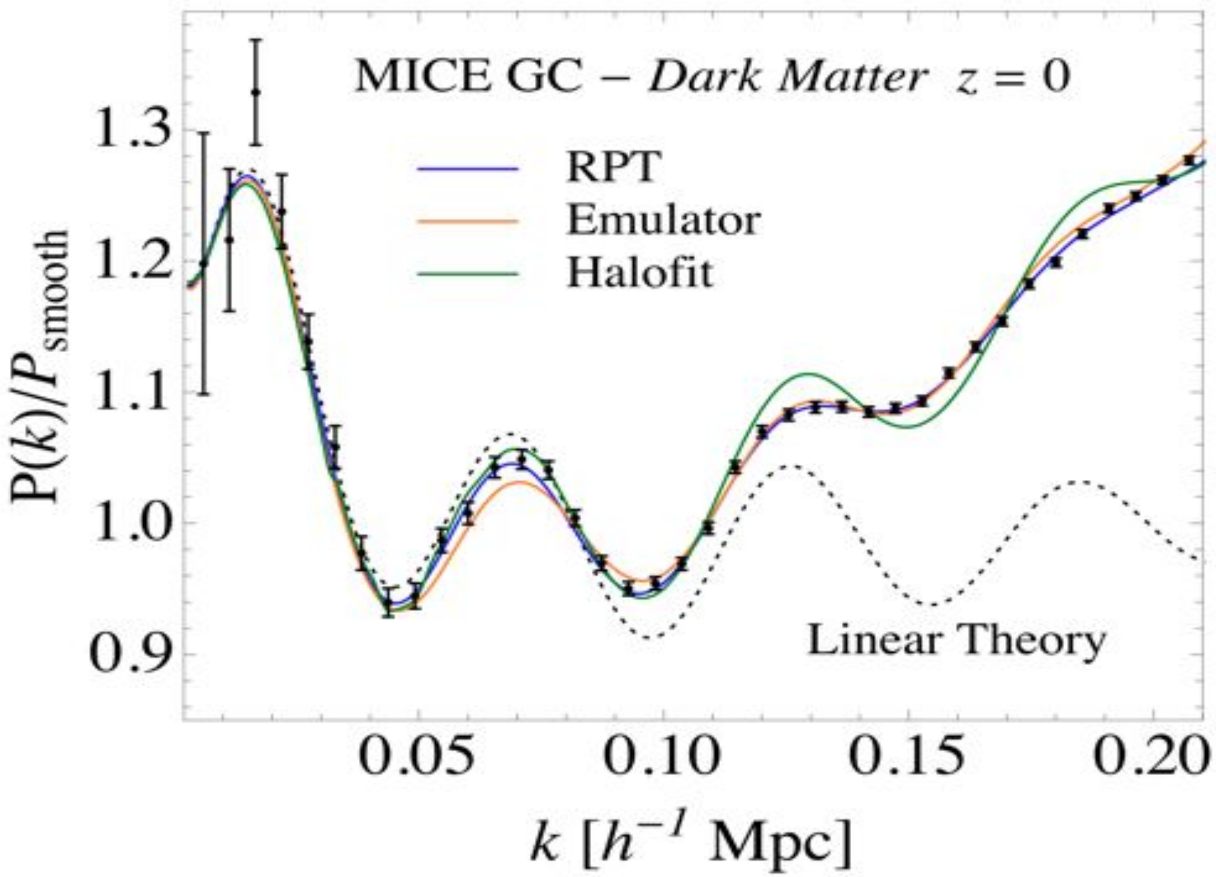
MICE simulations

Dark Matter



MICE simulations

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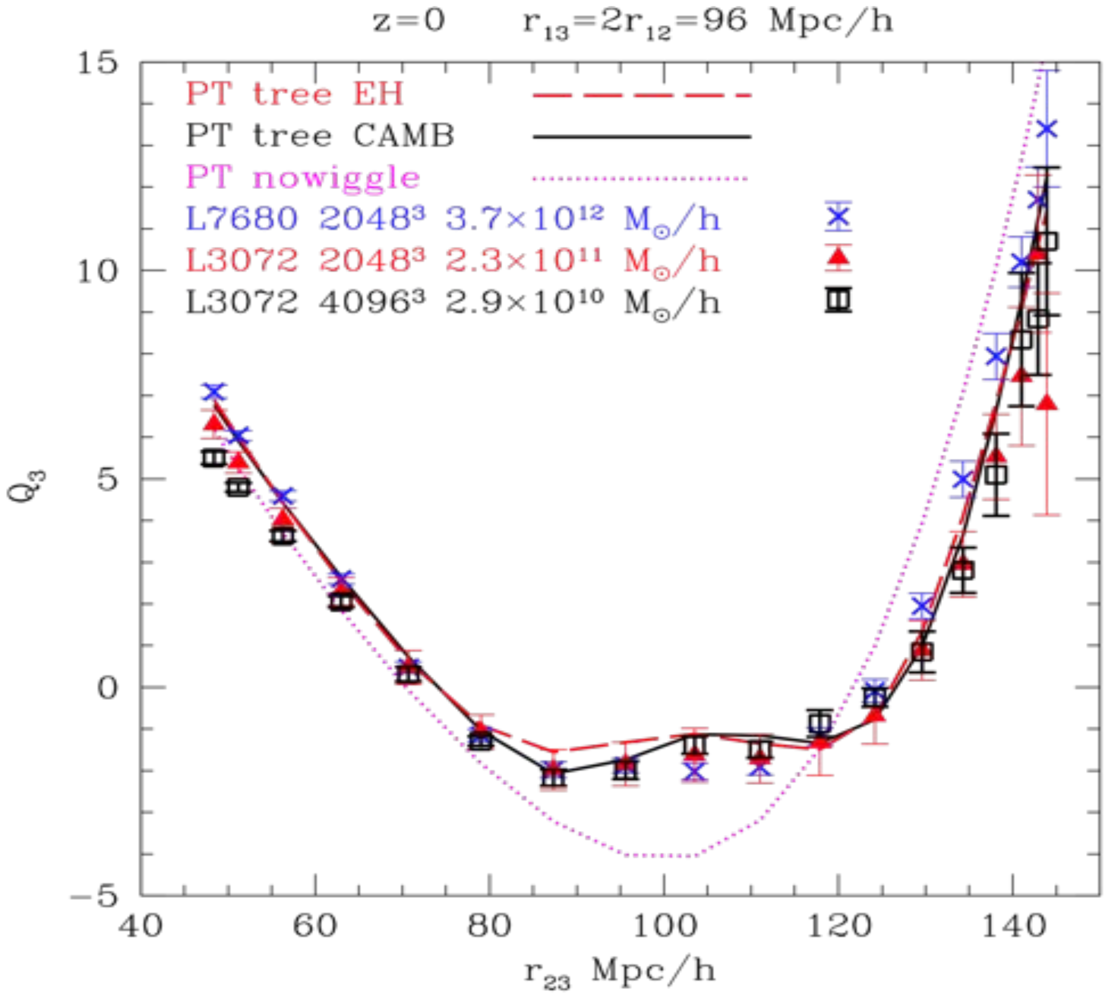
Simulations

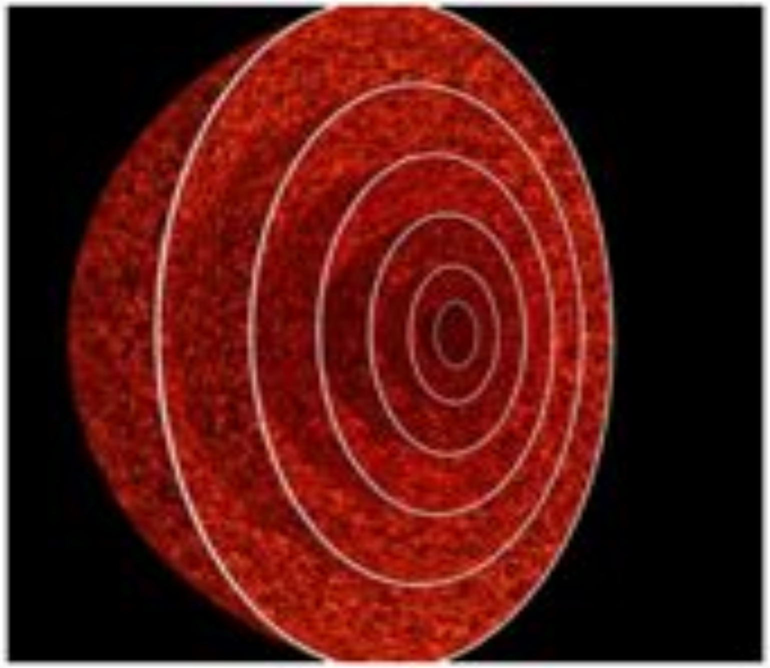
Dark Matter



MICE simulations

All sky lensing maps

" The onion universe: all sky light-cone simulations in spherical shells "
Fosalba et al, MNRAS, **391**, 435 (2008)



- Split data in thin shells
- Interplate into (healpix) pixels
- Combine to produce convergence maps

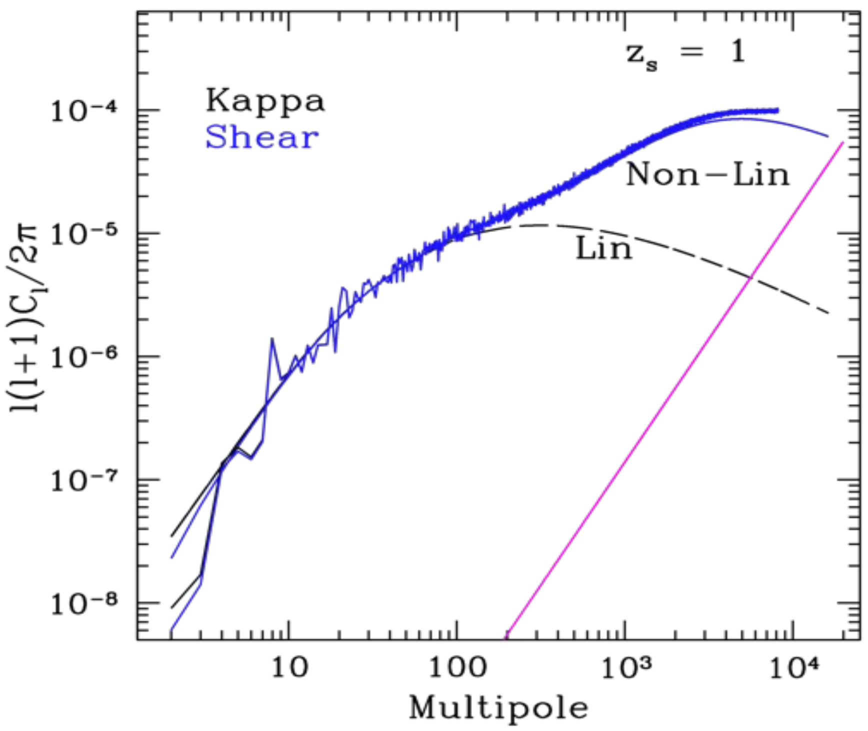
$$\kappa(\theta) = \frac{3H_0^2\Omega_m}{2c^2} \int dr \; \delta(r,\theta) \frac{(r_s - r)r}{r_s \; a}$$

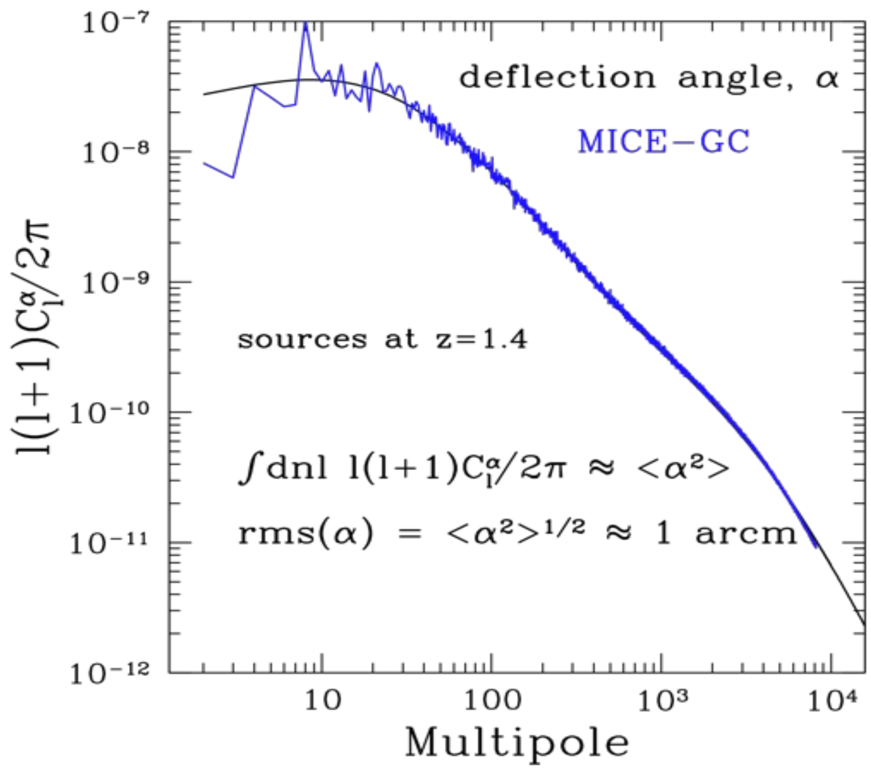
$$\kappa(i) = \frac{3H_0^2\Omega_m}{2c^2} \sum_j \delta(i,j) \frac{(r_s - r_j)r_j}{r_s a_j} \; dr_j$$

- From this it is possible to obtain other lensing observables, e.g. shear, magnification, flexion, etc *in the Born approximation*

MICE simulations

All sky lensing maps

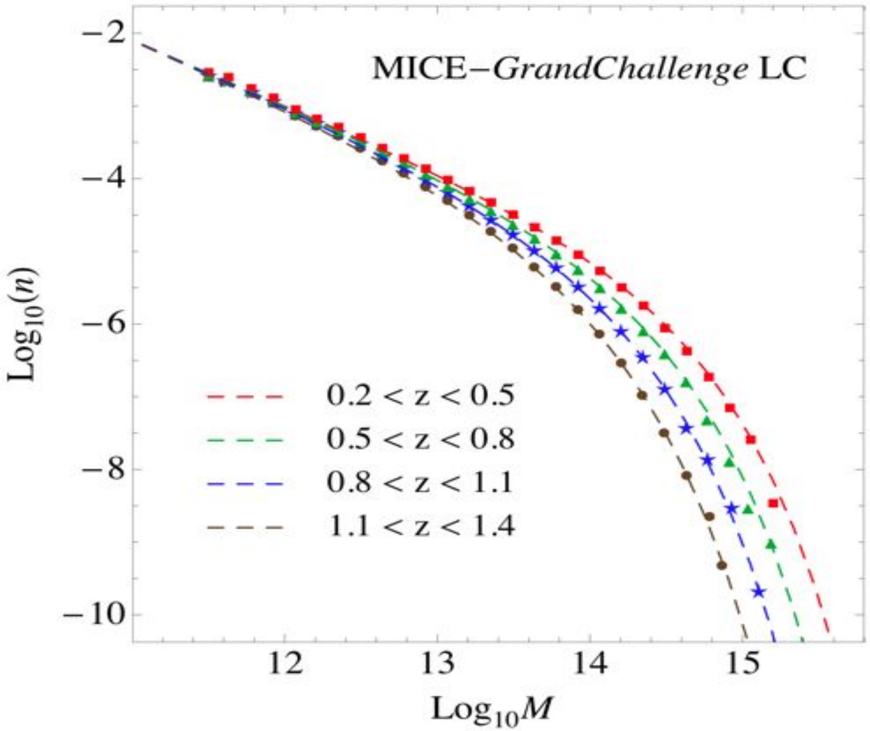


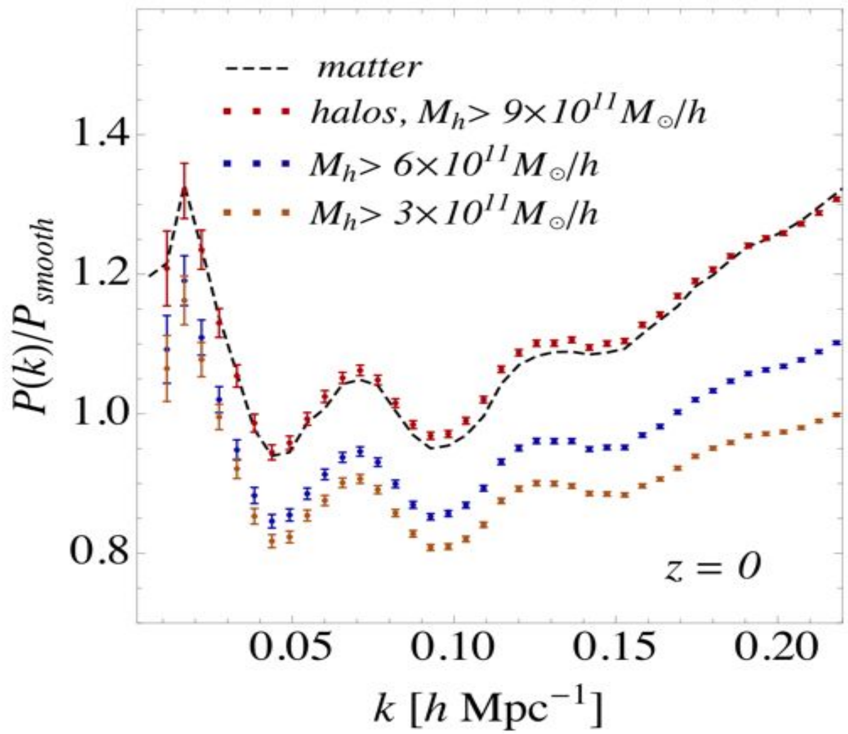


MICE simulations

Halo catalogue

- Select halos with FoF b=0.2; Crocce et al 2010





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MICE simulations

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Galaxy Catalogues

- Build mock galaxy catalogues from N-body halos using HOD & SHAM prescriptions
- Generate: positions, luminosities, colours, SEDs and lensing
- Start at z=0 where constraints more stringent
- Constraints
    - luminosity function
    - colour-magnitude diagram
    - clustering as a function of luminosity and colour
- Implement recipes to higher redshifts

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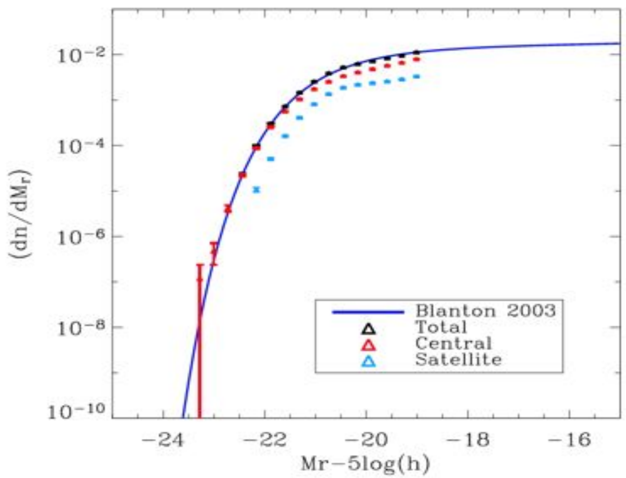
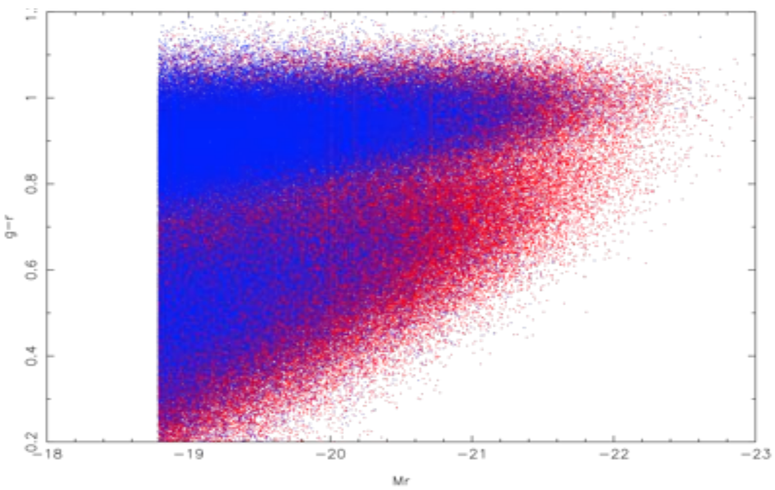
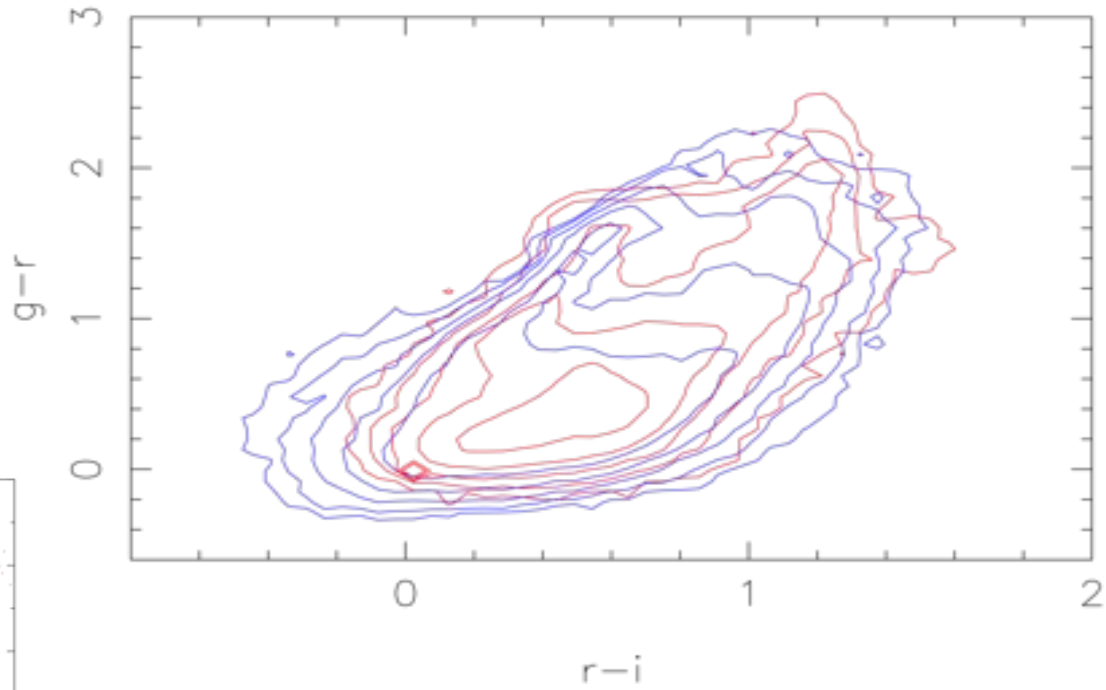
Galaxy catalogue: photometric properties







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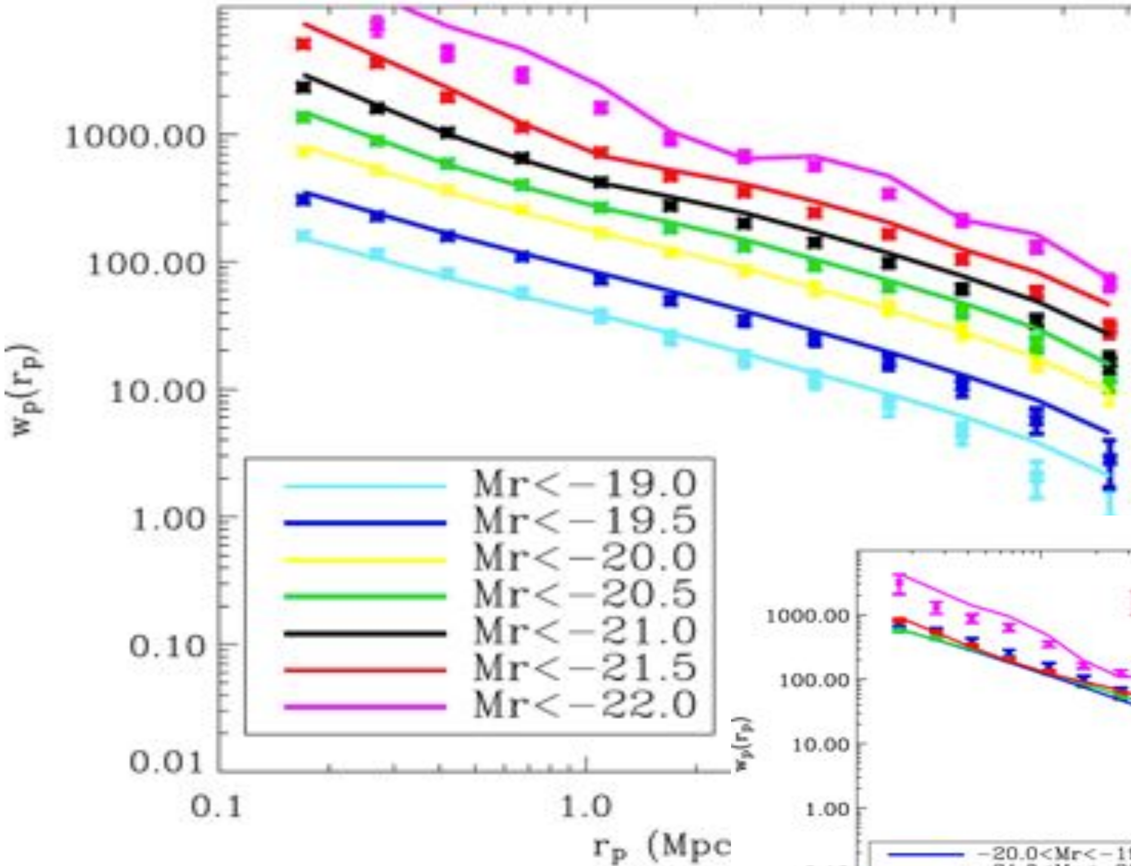
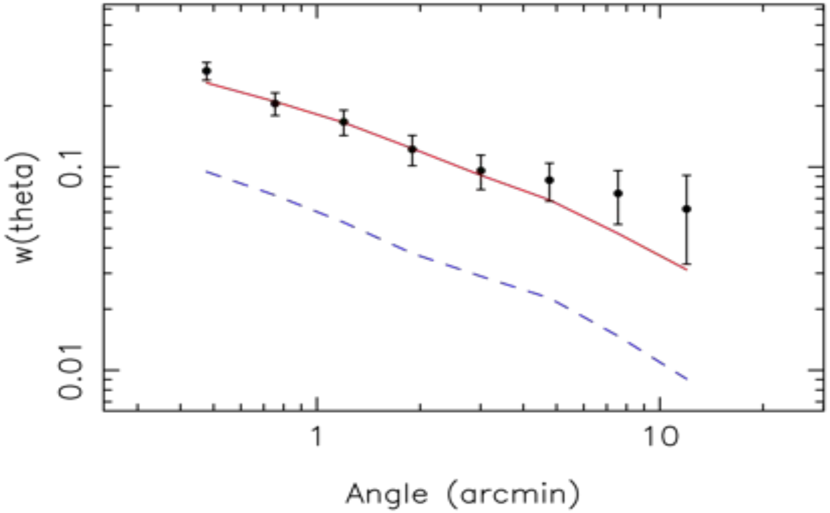
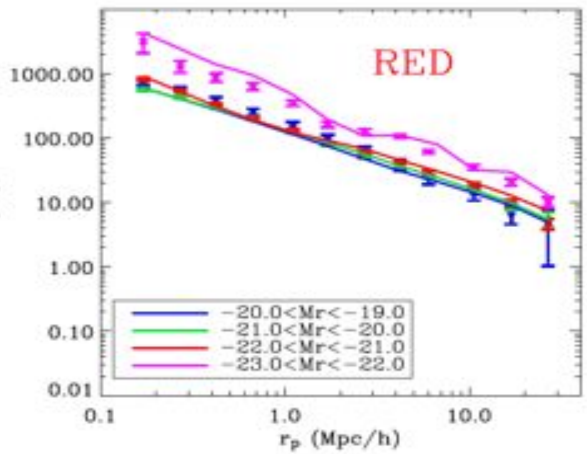
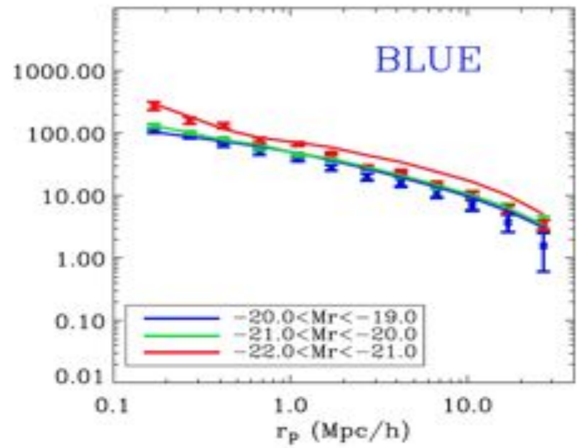
Mock galaxy catalogues

Galaxy Catalogue: clustering









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Mock galaxy catalogues

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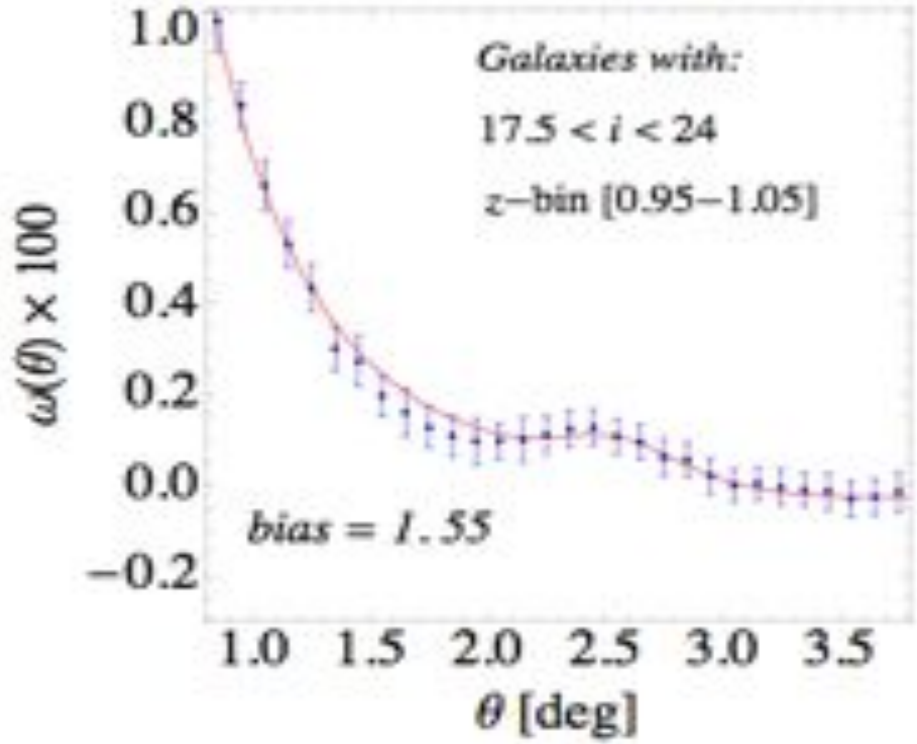
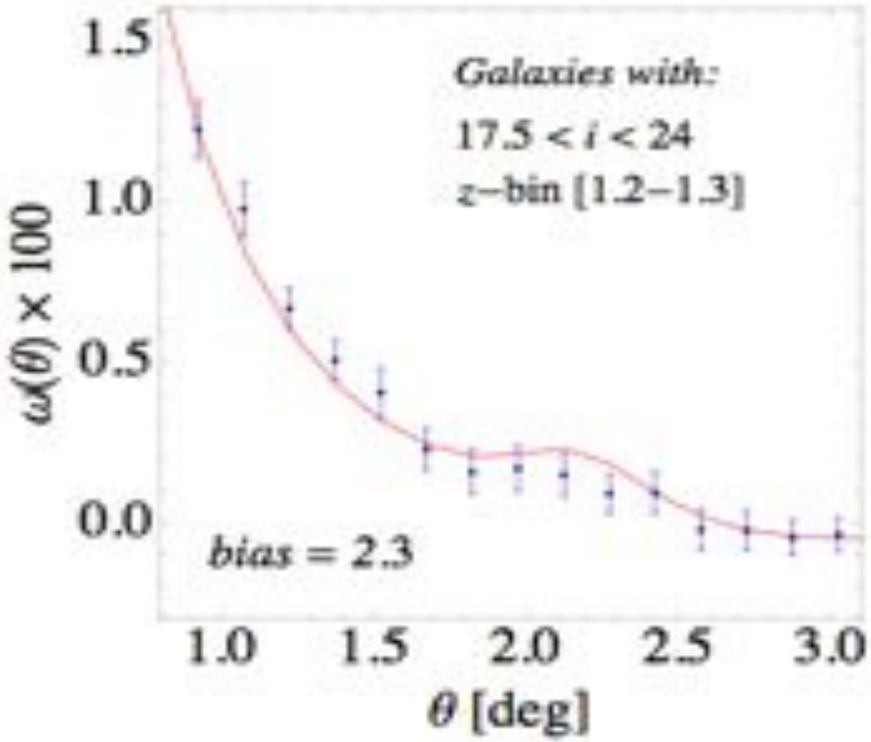
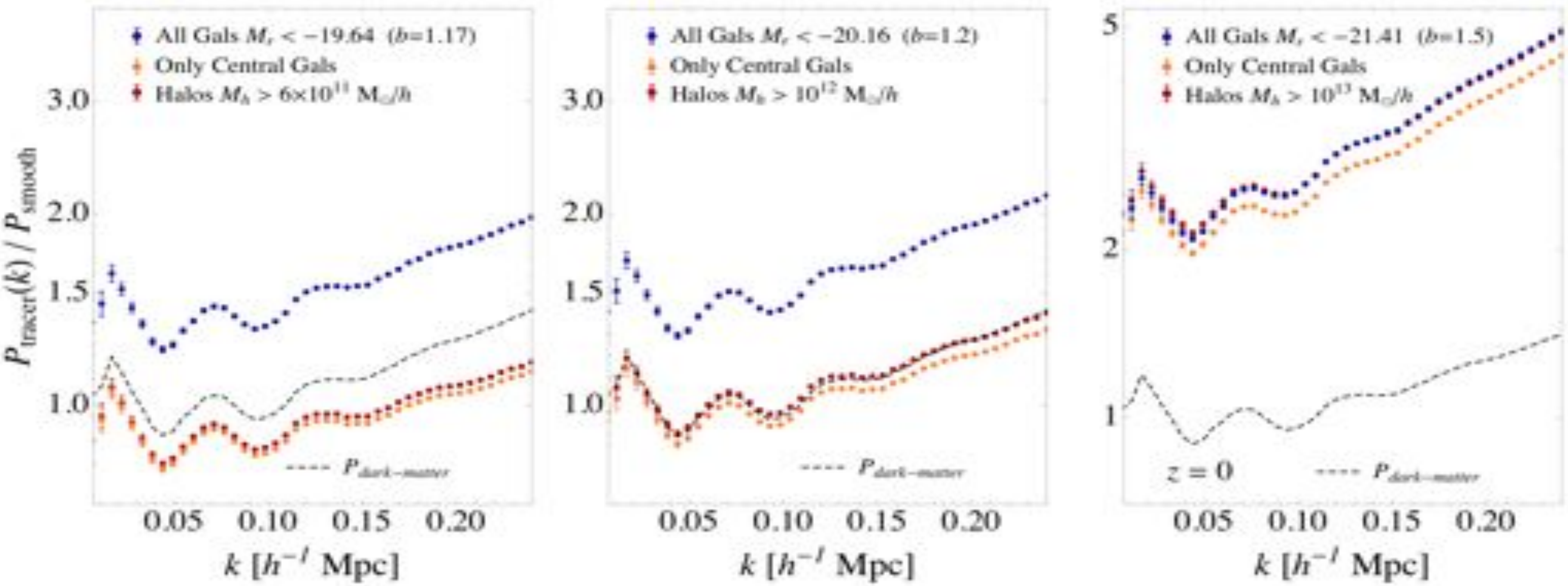
Galaxy catalogues: clustering





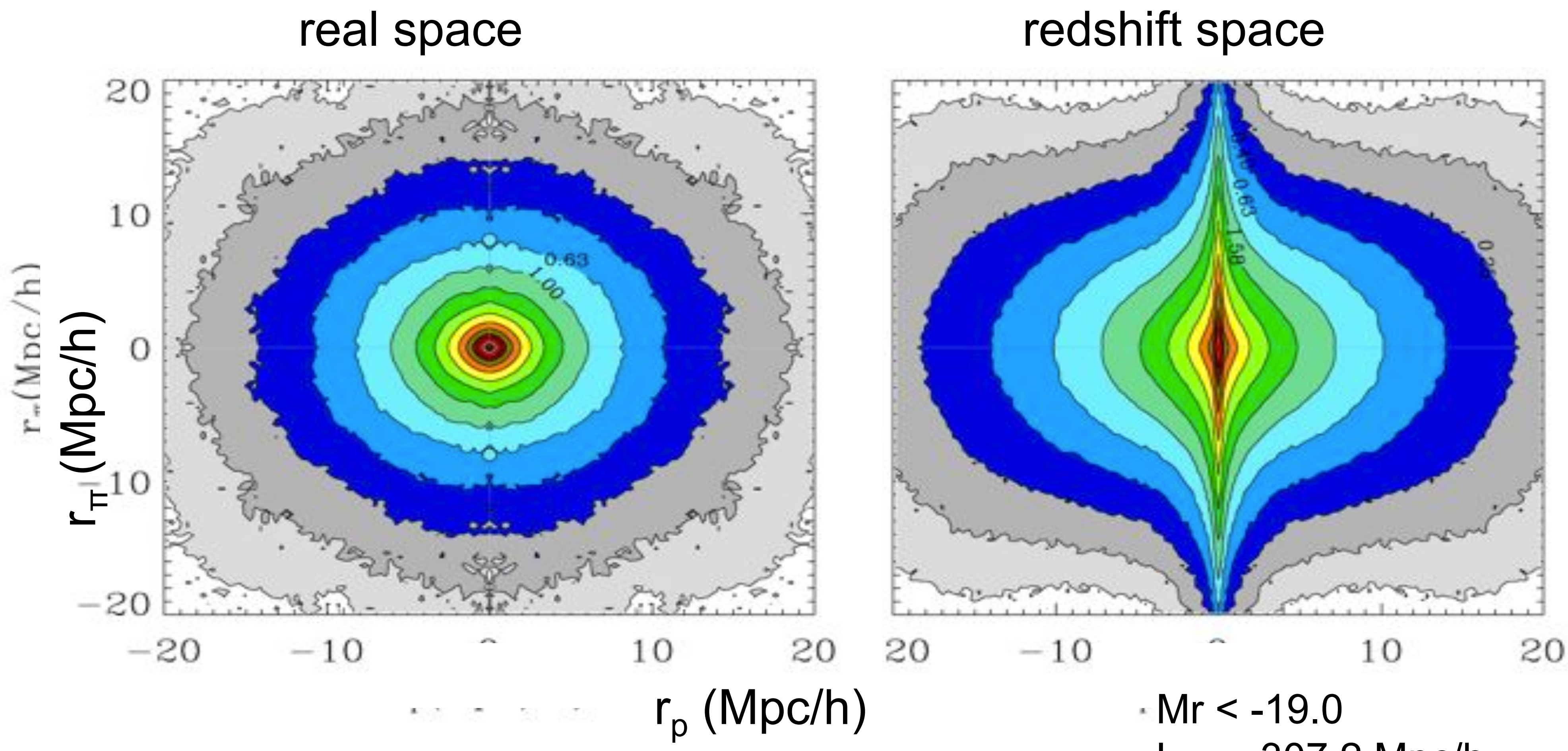
MICE simulations

Halo & galaxy catalogue



Mock galaxy catalogues

Galaxy Catalogue: Redshift Space Distortions

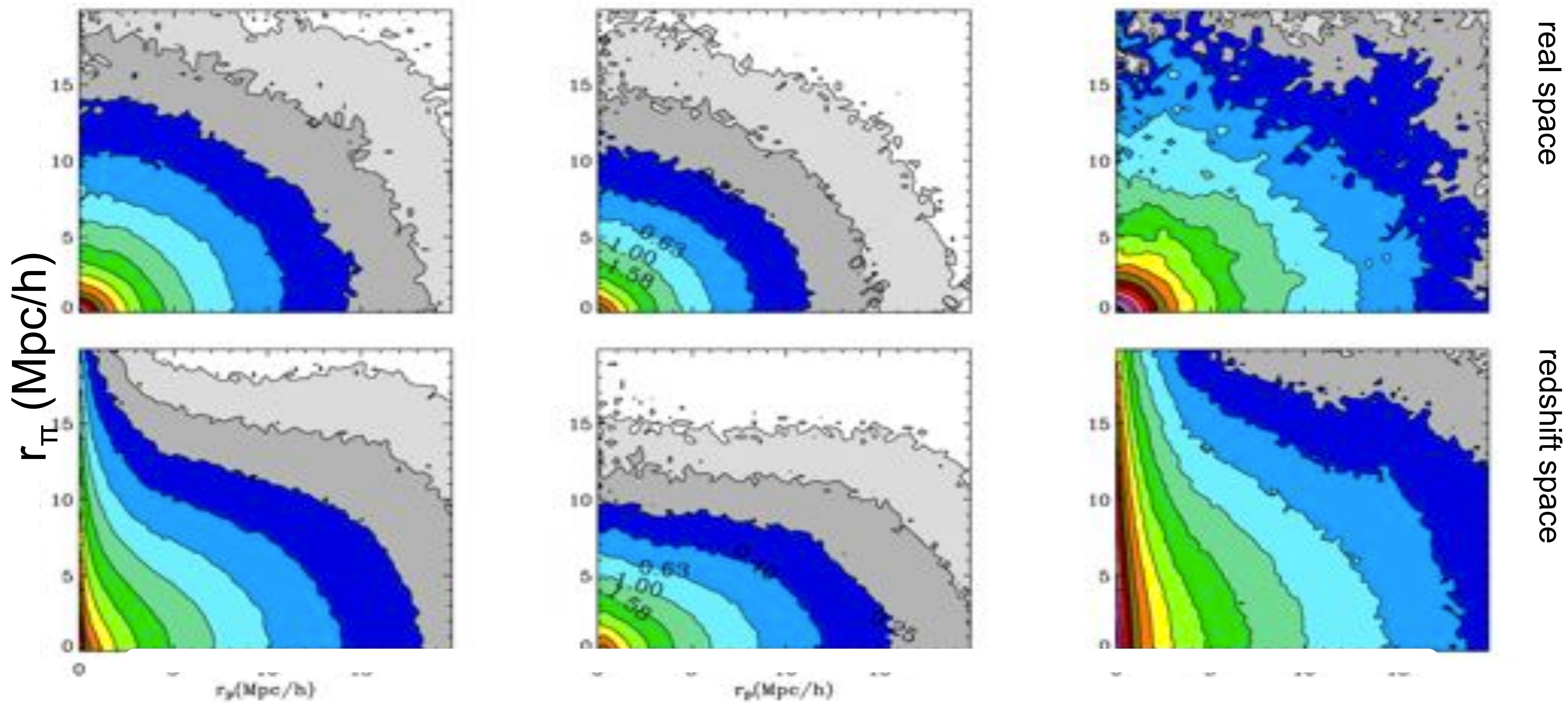


Mr < -19.0
L_{BOX}=307.2 Mpc/h

Mock galaxy catalogues

Galaxy Catalogue: Redshift Space Distortions

TOTAL CENTRAL SATELLITE



r_p (Mpc/h)

$M_r < -19.0$ $L_{BOX}=307.2$ Mpc/h

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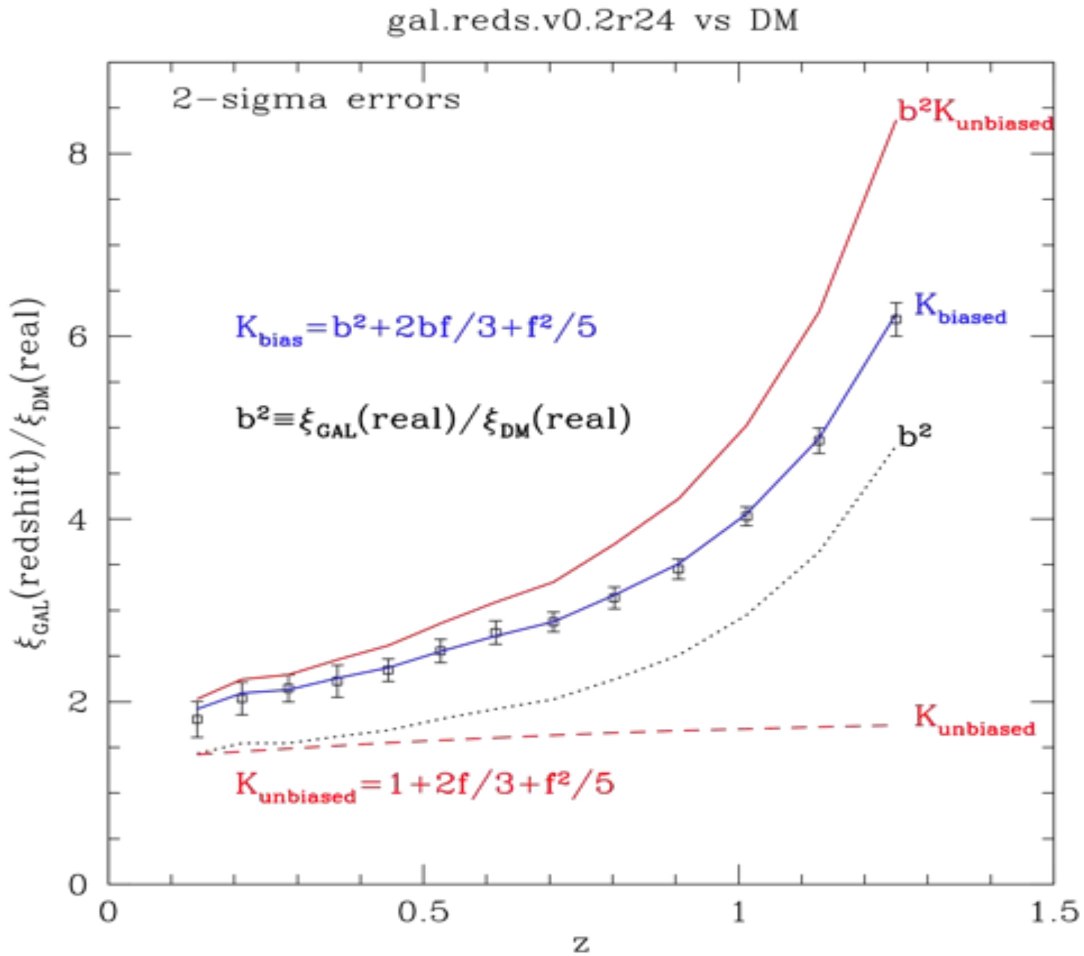
Mock galaxy catalogues

Galaxy Catalogue: Redshift Space Distortions

$$\delta_G(k,\mu) = (b + f\mu^2)\delta_m(k)$$

$$P_{gg}(k,\mu) = <\delta_G^2(k)> = (b + f\mu^2)^2 P(k)$$

$$\xi_{gg} = K(z)\,\xi_{mm}$$
$$K(z) \equiv b(z)^2 + \frac{2}{3}b(z)f(z) + \frac{1}{5}f(z)^2 b(z)^2$$



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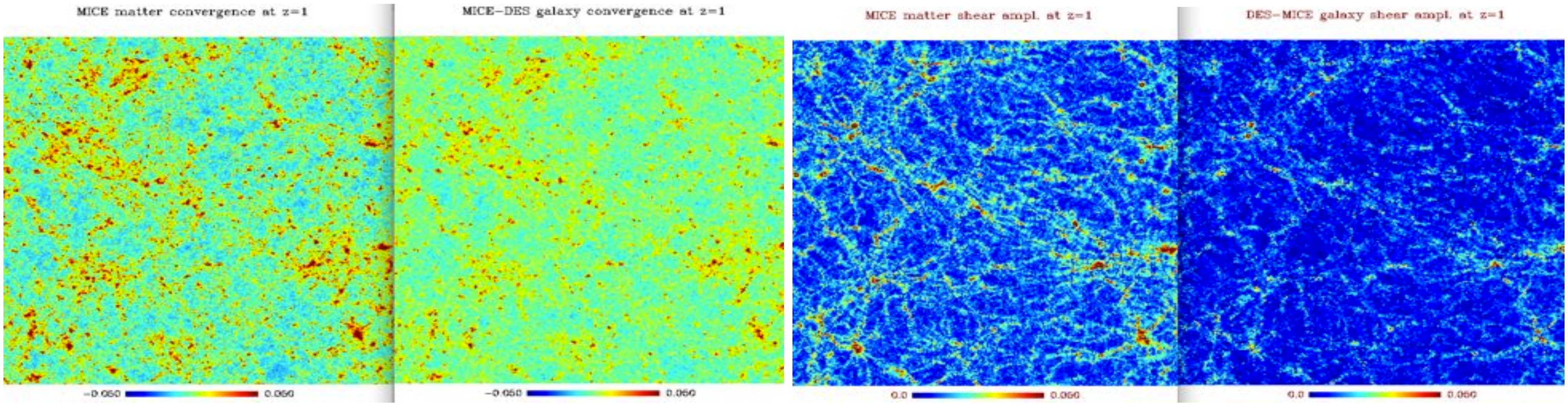
MICE simulations

Galaxy catalogue: lensing

- All-sky convergence maps computed in 3D in the LC
- Compute shear in this 3D grid
- Assign convergence and shear to galaxies



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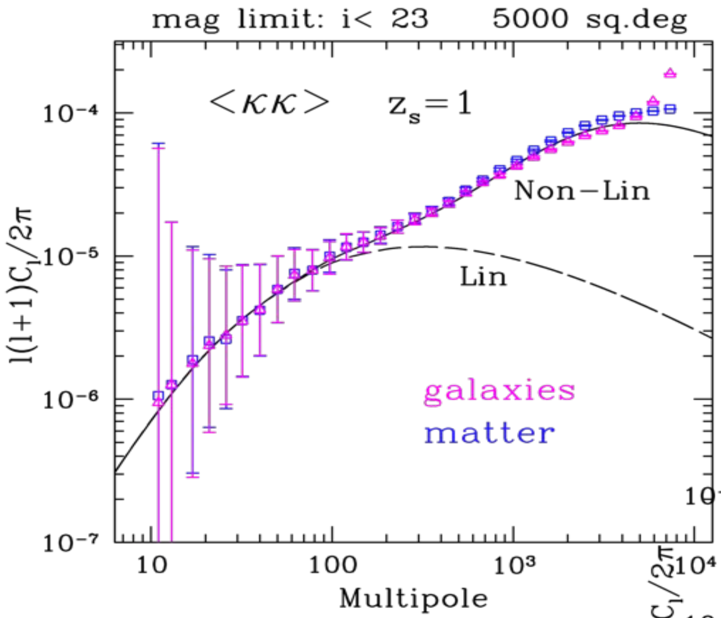
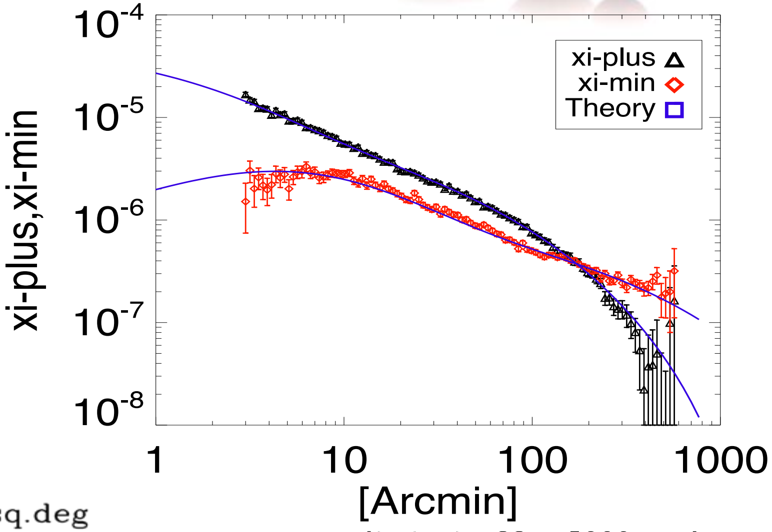
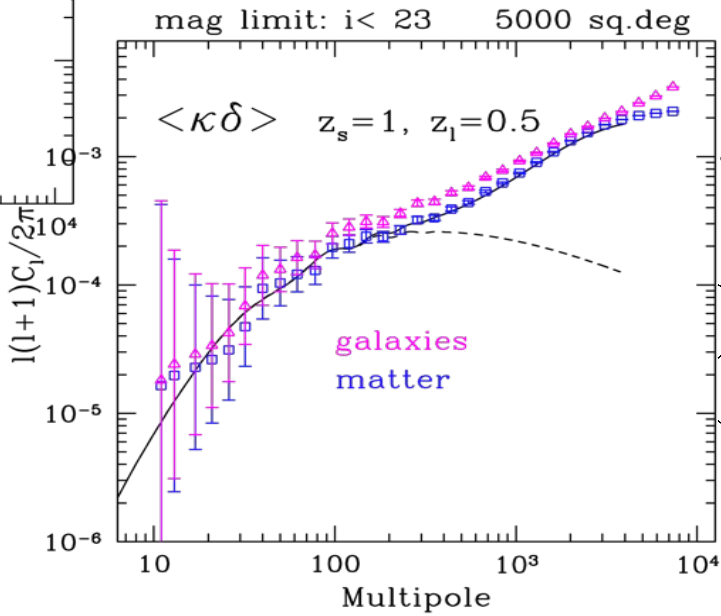
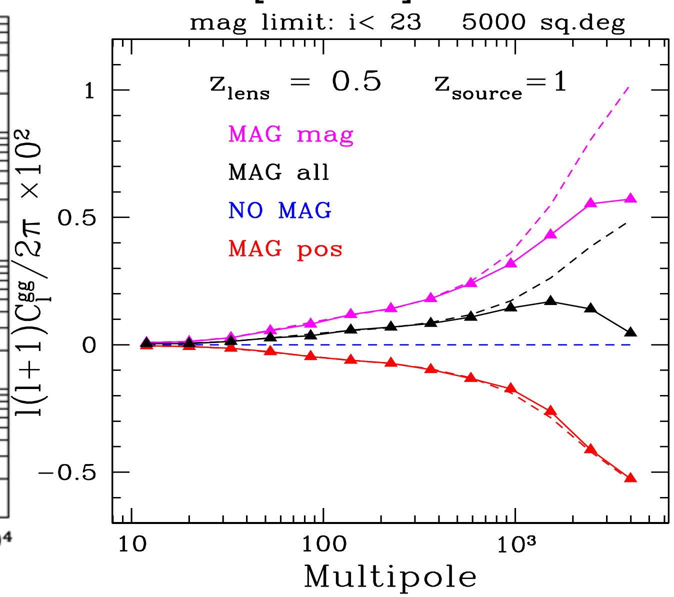
Galaxy catalogue: lensing









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MICE simulations

www.ice.cat/mice

New Releases

- MICECAT v2.0
  - includes 500 million galaxies
  - now complete to $i<24$ and $0<z<1.4$
  - lensing resoltion improved
  - New properties added: shapes, stellar masses, metallicities, emission lines
  - access to data: cosmohub.pic.es

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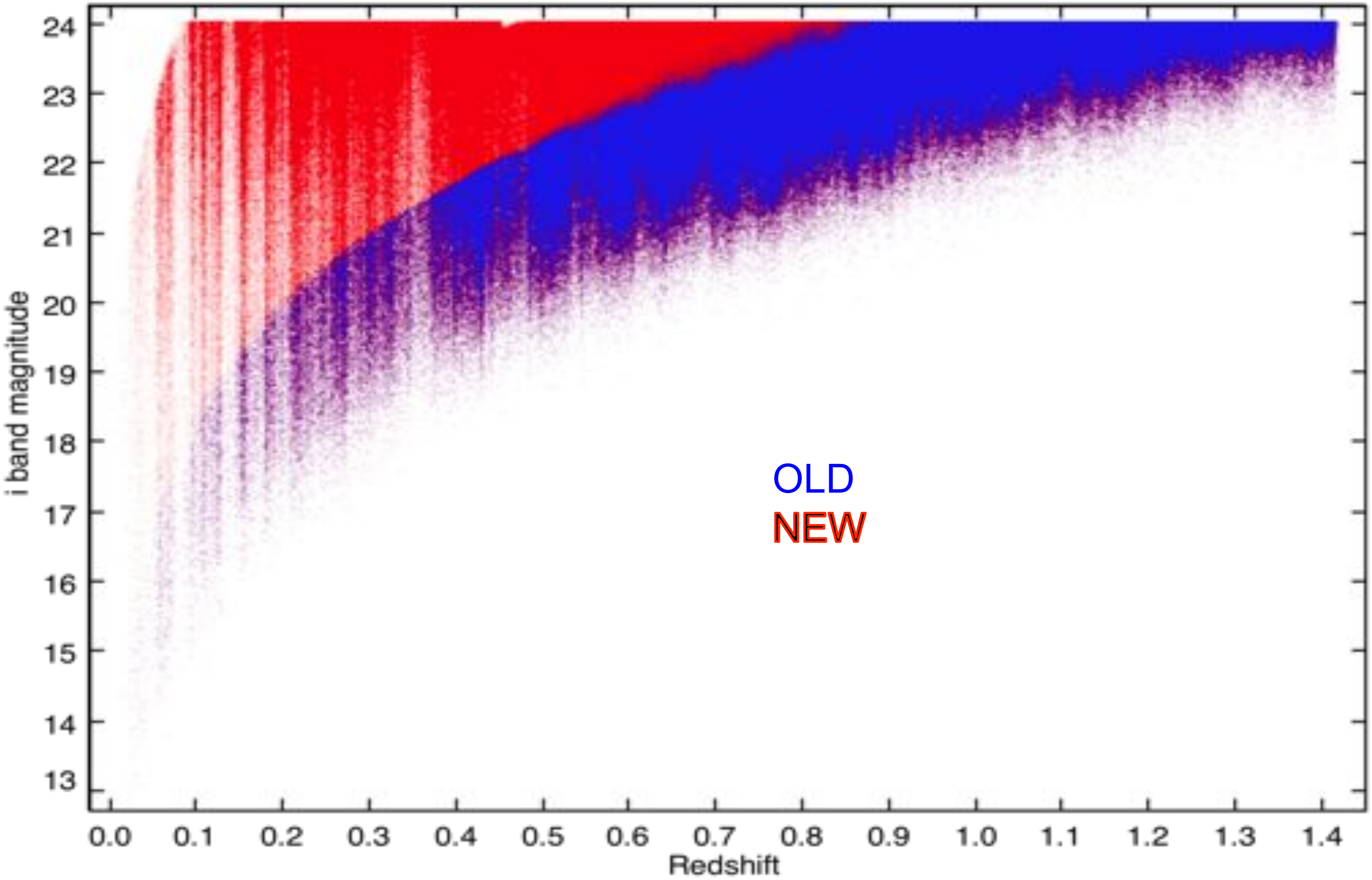
MICE simulations

New catalogue



MICE simulations

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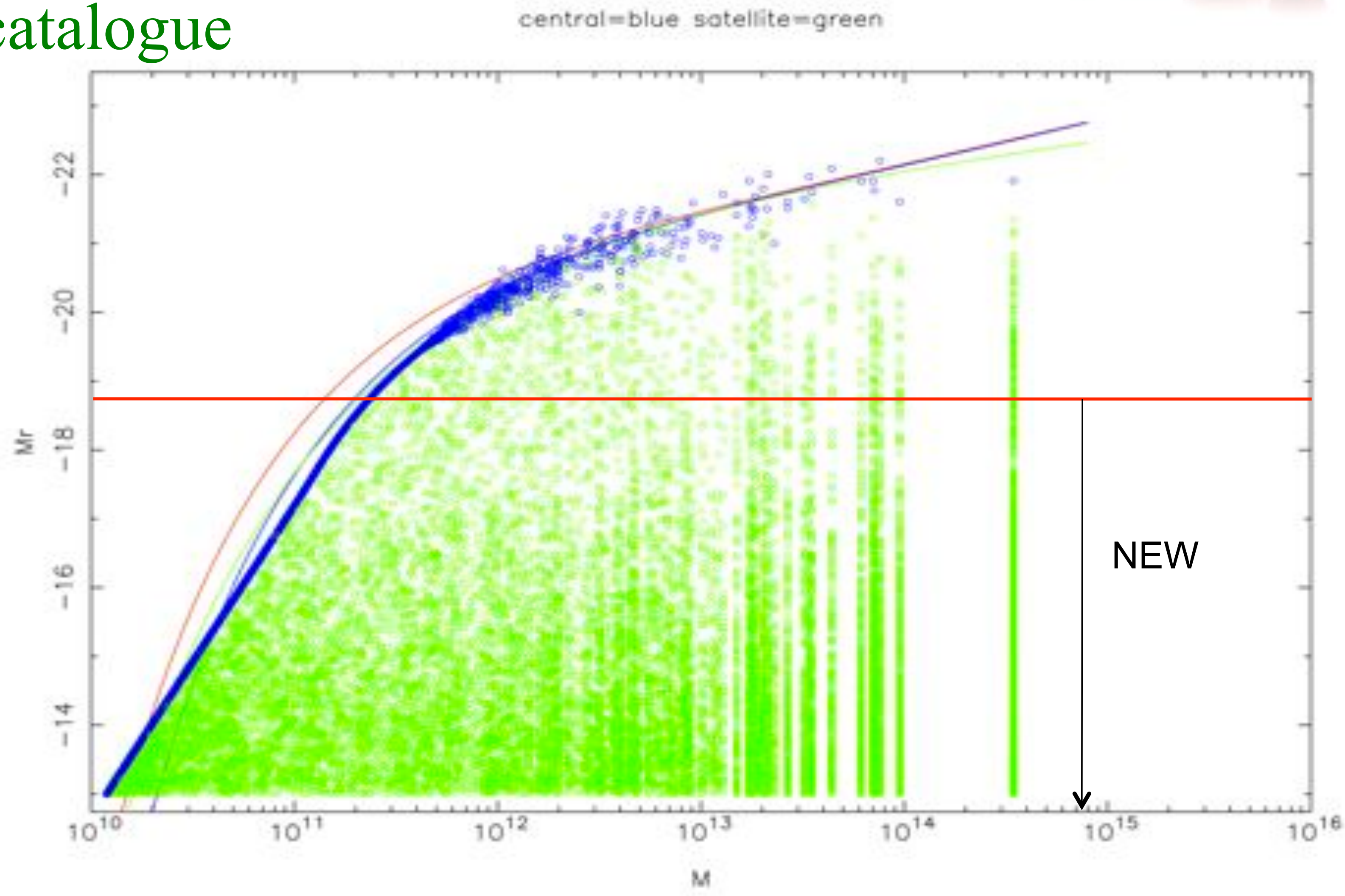
New catalogue



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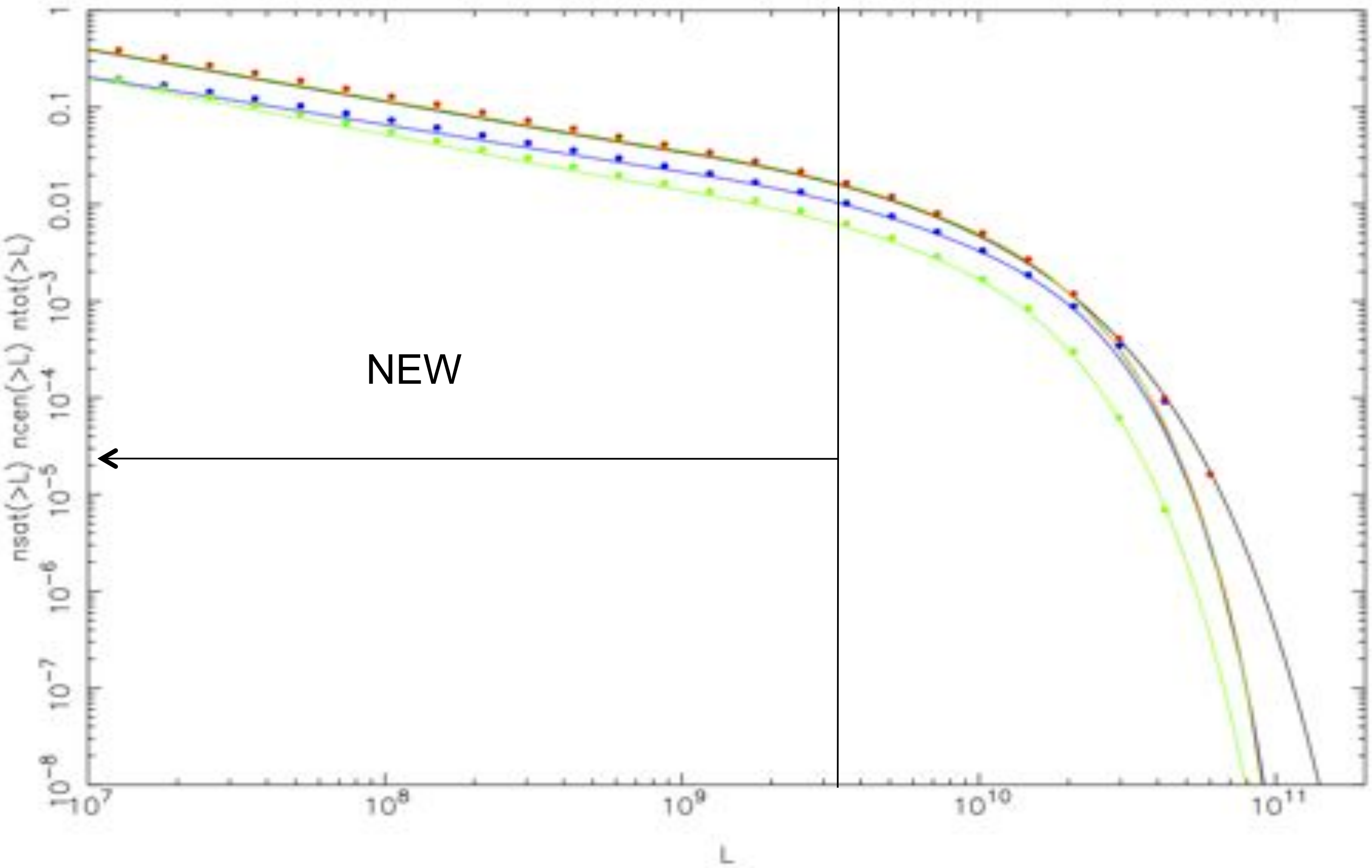
New catalogue



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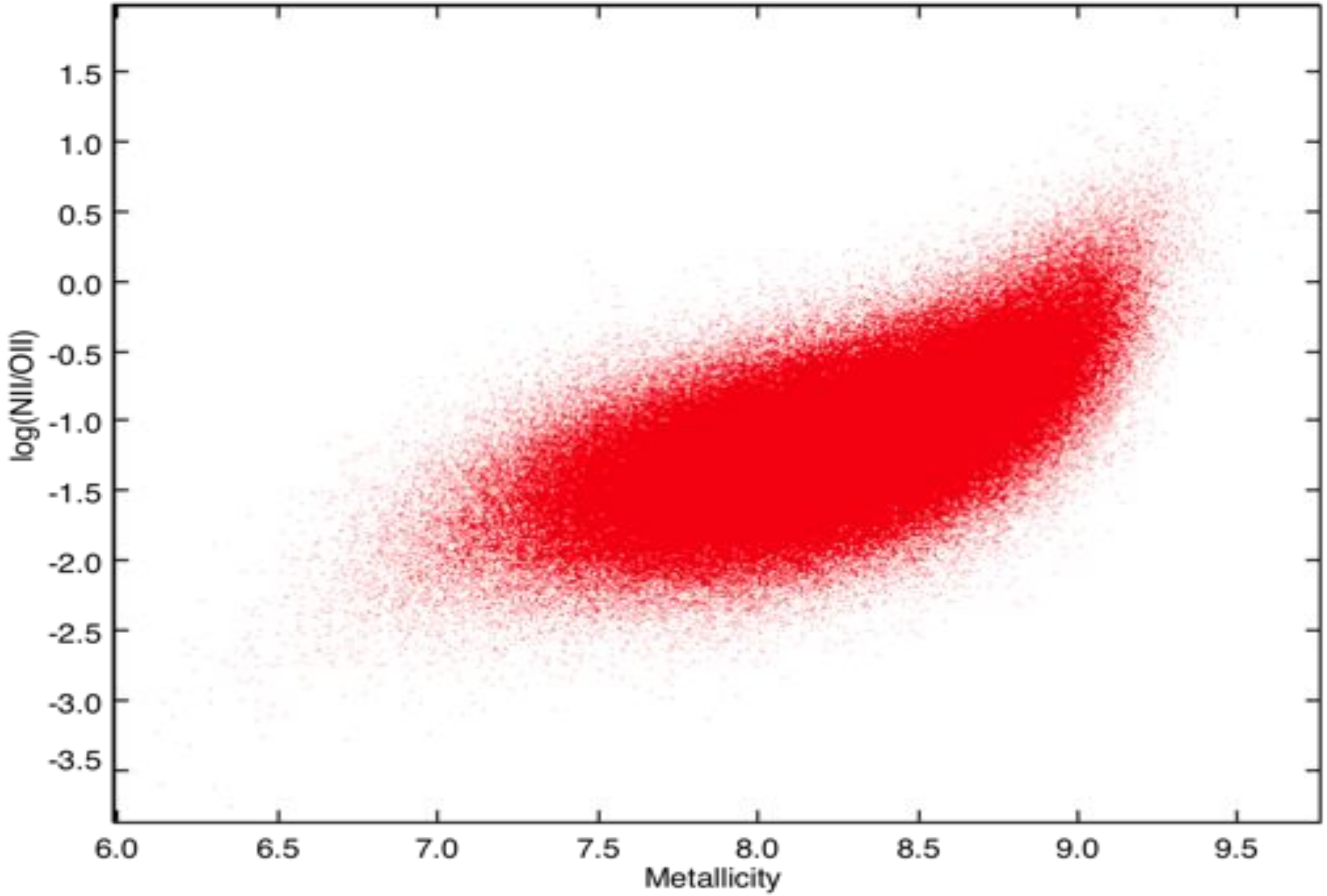
New catalogue



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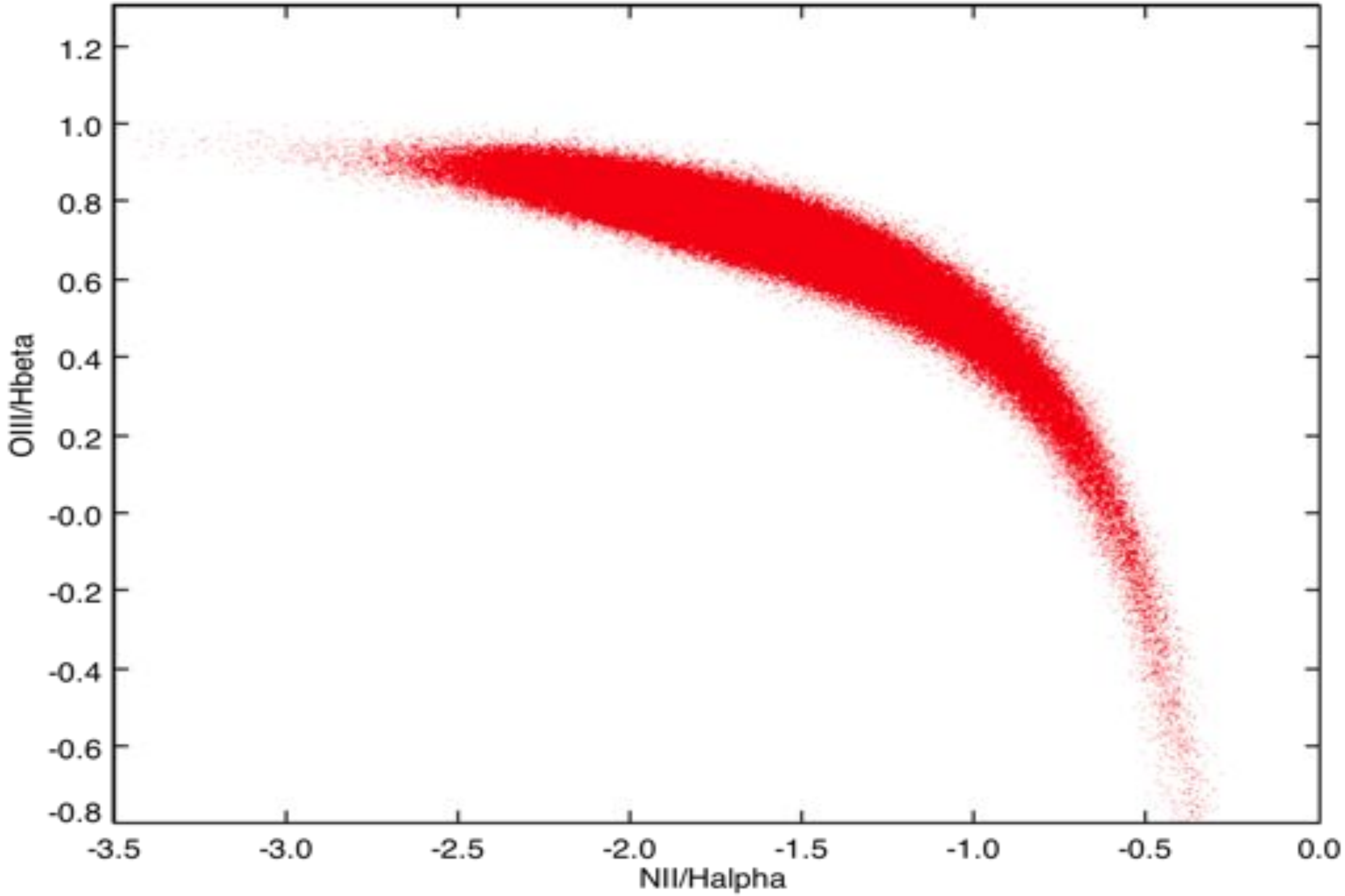
New catalogue



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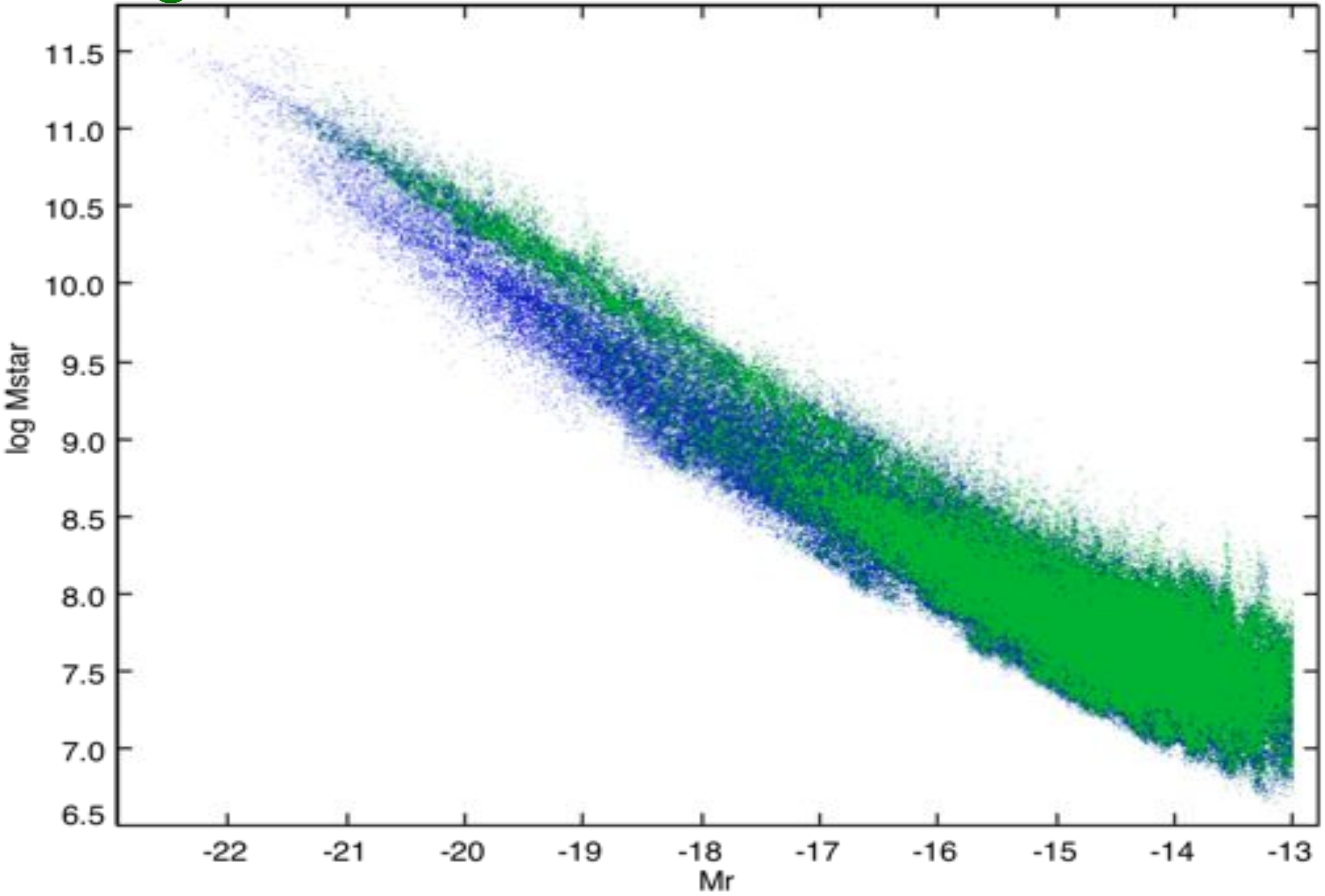
New catalogue



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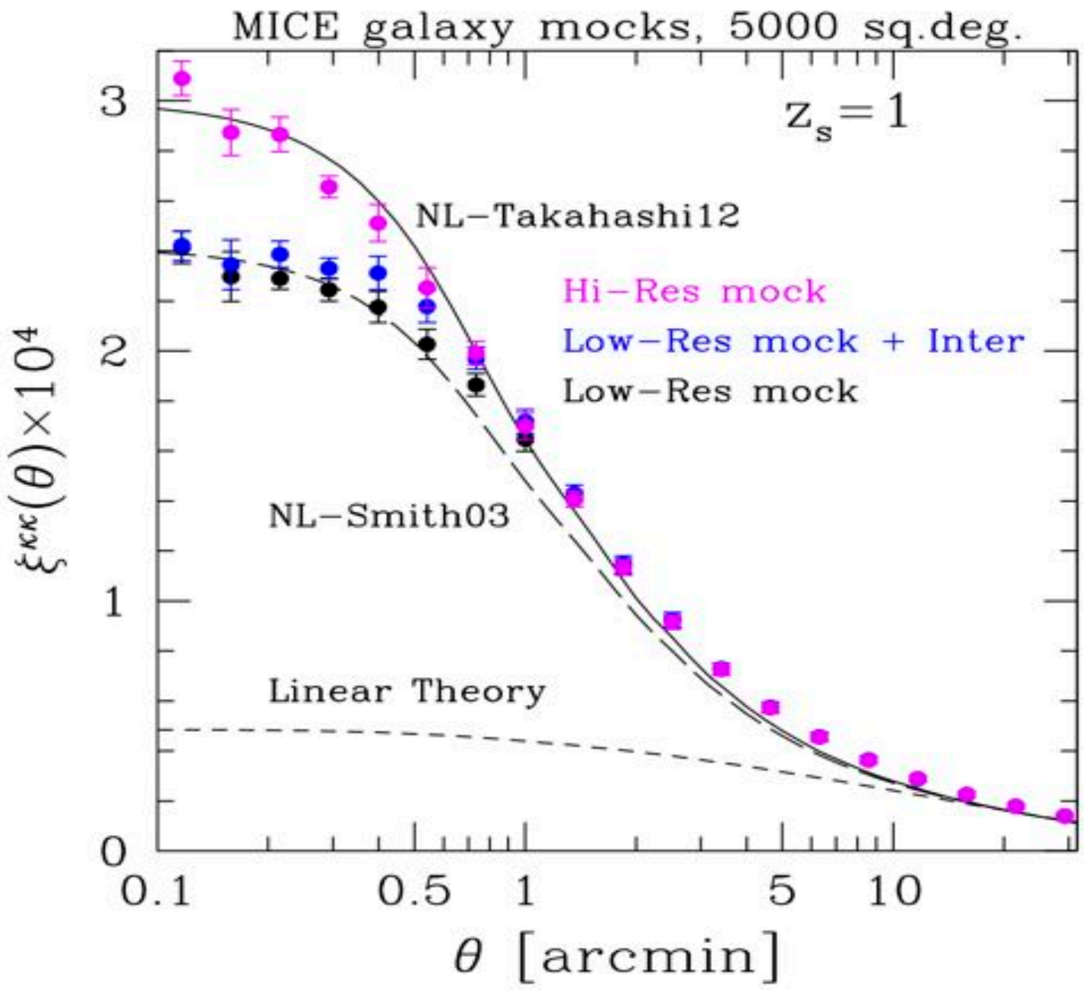
MICE simulations

WL on small-scales

MICECAT v1.0 assigns galaxy lensing properties using DM healpix maps at Nside=4096 (pix_scale=0.85', **"Low-Res mocks"**)
Data at cosmohub.pic.es

Bi-linear interpolation of **Low-Res mock** increases power by ~8% on 0.5'

MICECAT v2.0 Hi-Res mock (Nside=8192, pix_scale=0.42') agrees with recent fits to high-mass resolution Nbody (Takahashi et al. 2012) down to pix_scale



Convergence 2PCF

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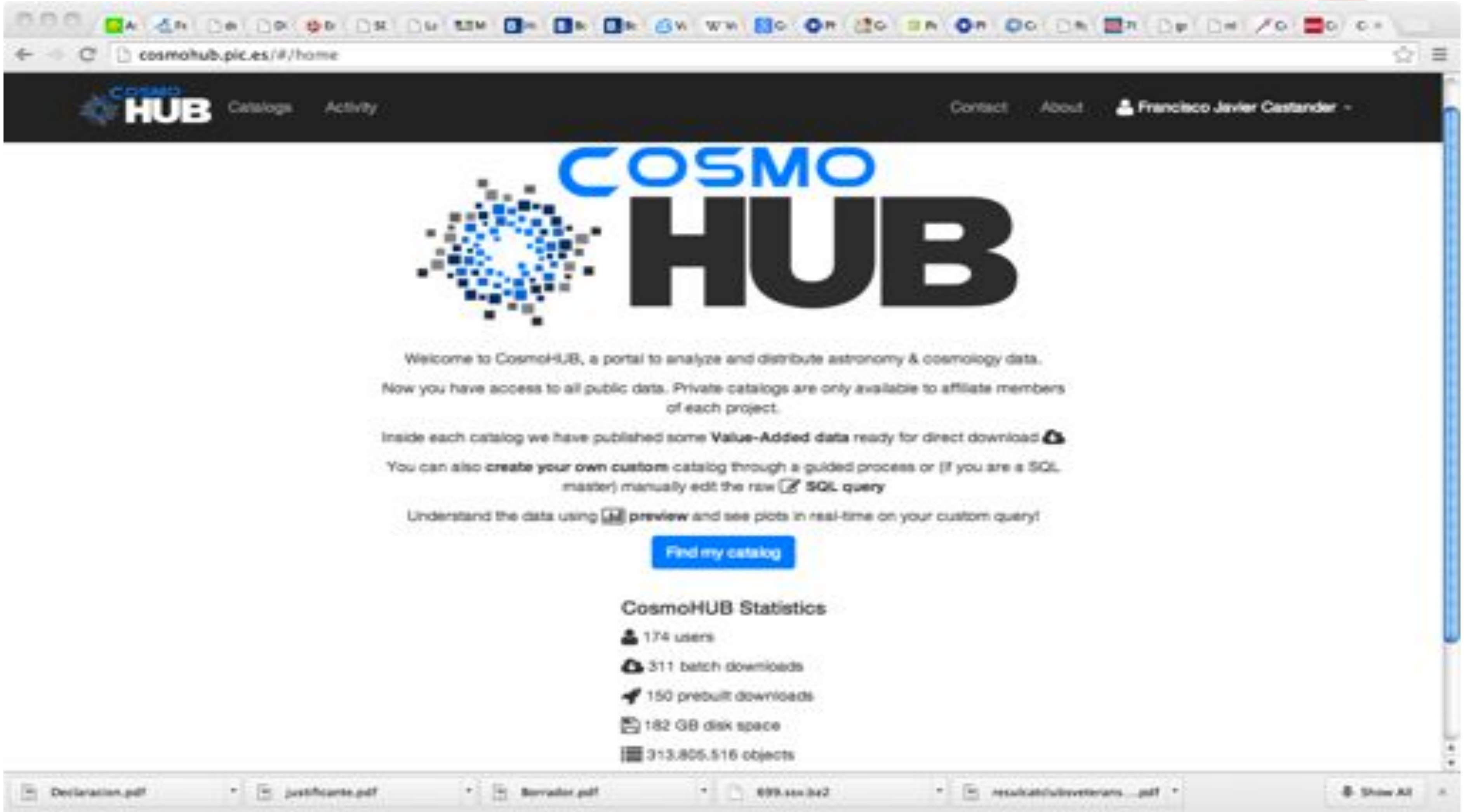
Mock galaxy catalogues

cosmohub.pic.es



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Description of mocks

- Fosalba et al 2013: arXiv: 1312.1707 Dark Matter
- Crocce et al 2013: arXiv: 1312.2013 Halo & Galaxy Catalogue
- Fosalba et al 2013: arXiv: 1312.2947 Lensing
- Hoffmann et al 2014: arXiv: 1403.1259 High order clustering
- Carretero et al 2015, MNRAS, 447, 646 galaxy mock method I
- Castander et al 2015, in prep galaxy mock method II