Image: Dark Energy Camera, from http://darkenergydetectives.org

Introduction to Cosmology 3: Dark Energy and the Future

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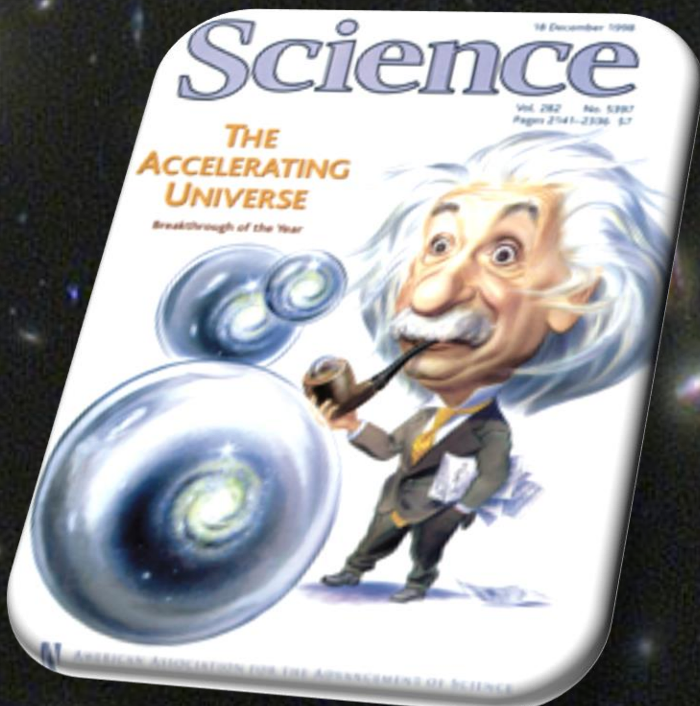
THE DARK ENERGY



What is dark energy?

The Discovery of the accelerated expansión of the Universe (1998) was a huge surprise, since the expectation was exactly the opposite due to thgarevity action (attractive and non repulsive)

<u>The dark energy is the mechanism that causes the accelerated cosmic expansion</u>

Einstein´s Cosmological Constant

A new force field ("quintessence")

Modifications to General Relativity

WHAT DO WE KNOW ABOUT DARK ENERGY?

1)It emits no electromagnetic radiation

2)It has large and negative pressure

3)Its distribution is homogeneous. Dark energy does not cluster significantly with matter on scales at least as large as galaxy clusters

Dark energy is qualitatively very different from dark matter. Its pressure is comparable in magnitude to its energy densisty (it is energy-like) while matter is characterized by a negligible pressure

Dark energy is a diffuse, very weakly interacting with matter and very low energy phenomenon. Therefore, it will be very hard to produce it in accelerators. As it is not found in galaxies or clusters of galaxies, the whole universe is the natural (and perhaps the only one) laboratory to study dark energy.

No well-motivated theoretical explanations for dark energy

Very likely, progress will come from improving observational constraints

The Cosmological Constant Case

All current observations are compatible with dark energy being the cosmological constant. This is the most plausible and the most puzzling dark energy candidate.

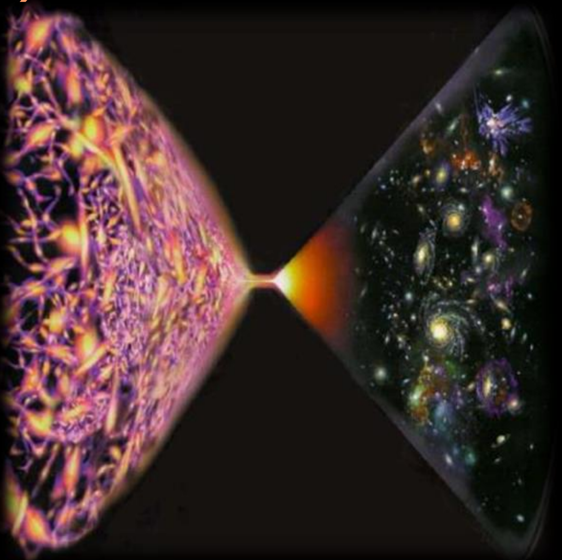
w= -1 with ~10% precision assuming flat universe and constant w

There is no physical explanation for Λ from the particle theory. If it is the vacuum energy

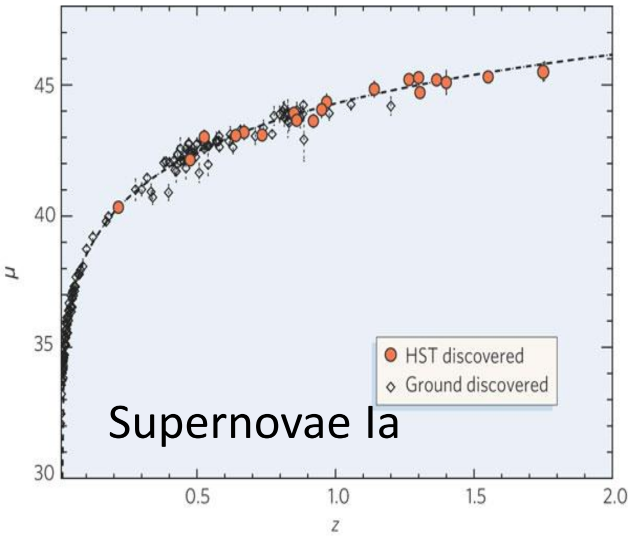
$$\Omega_\Lambda \sim 0.7 \quad \longrightarrow \quad \rho_\Lambda \sim (10\ \text{meV})^4$$

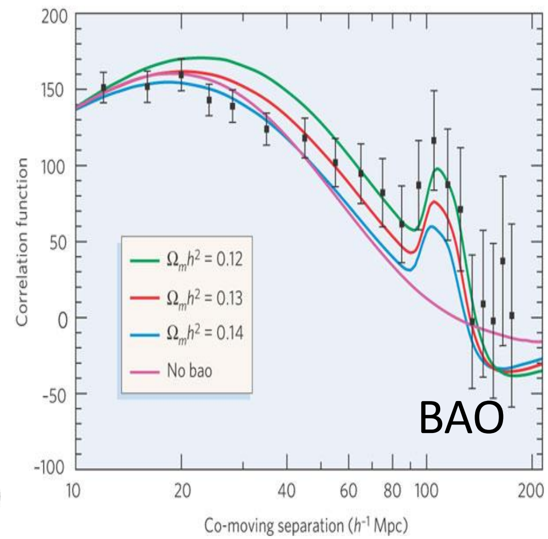
While the estimate from QFT is

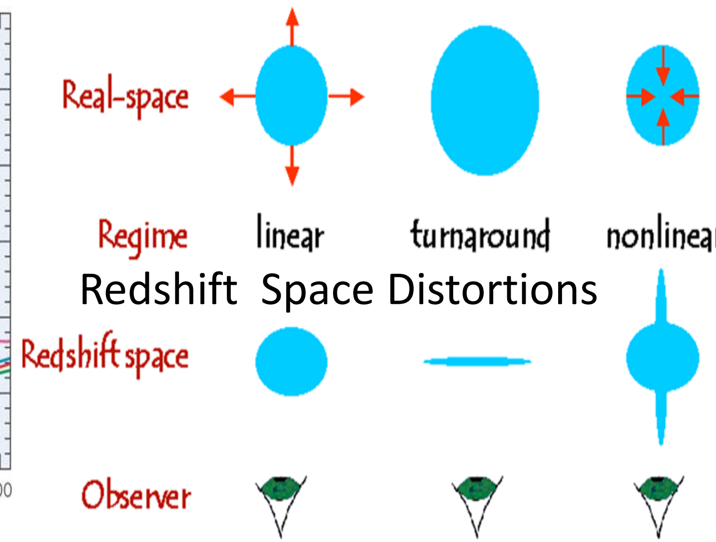
$$\rho_\Lambda \sim M^4_{Planck} \sim 10^{120} \times (10\ \text{meV})^4$$

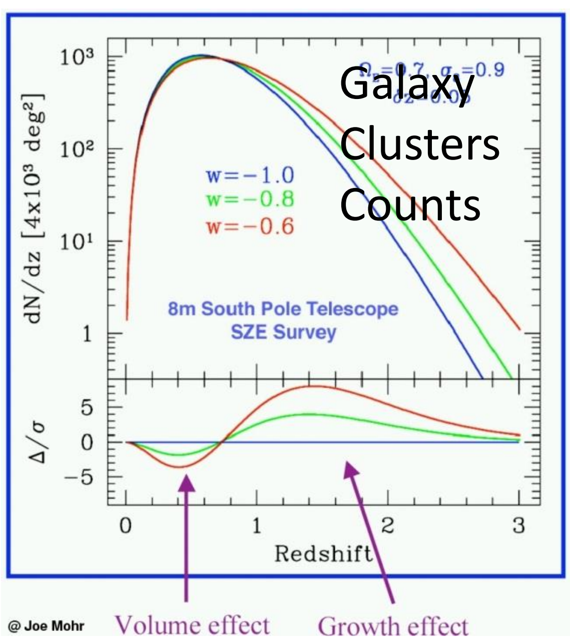


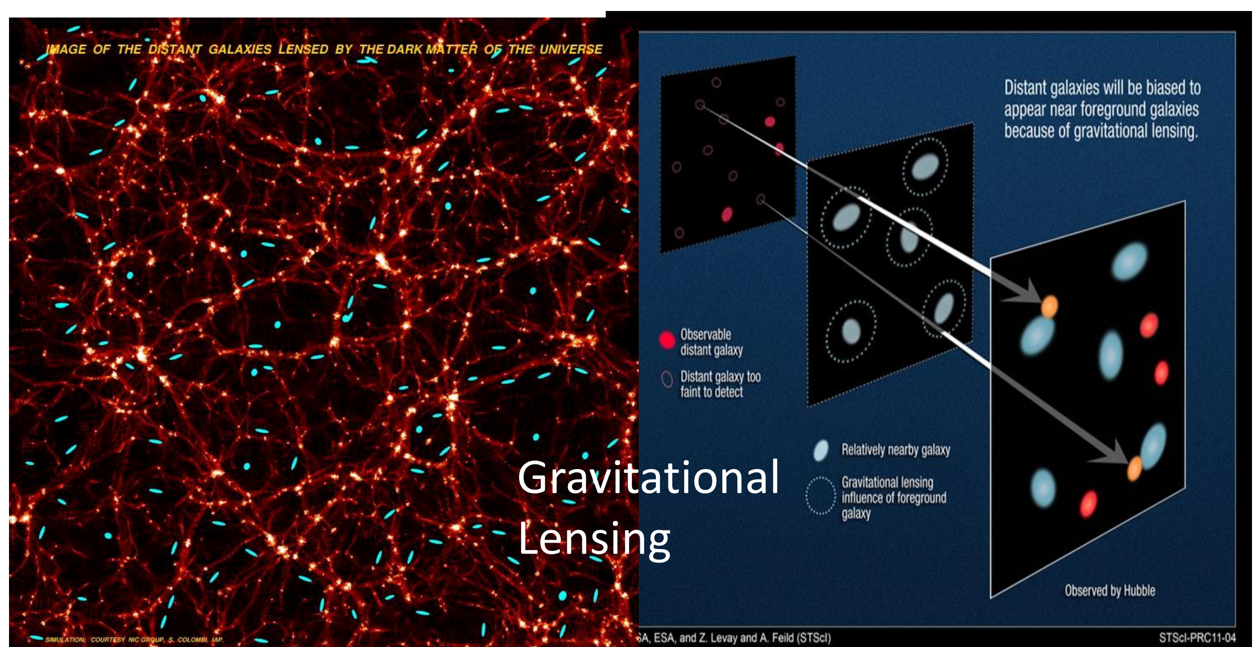
Methods to study dark energy





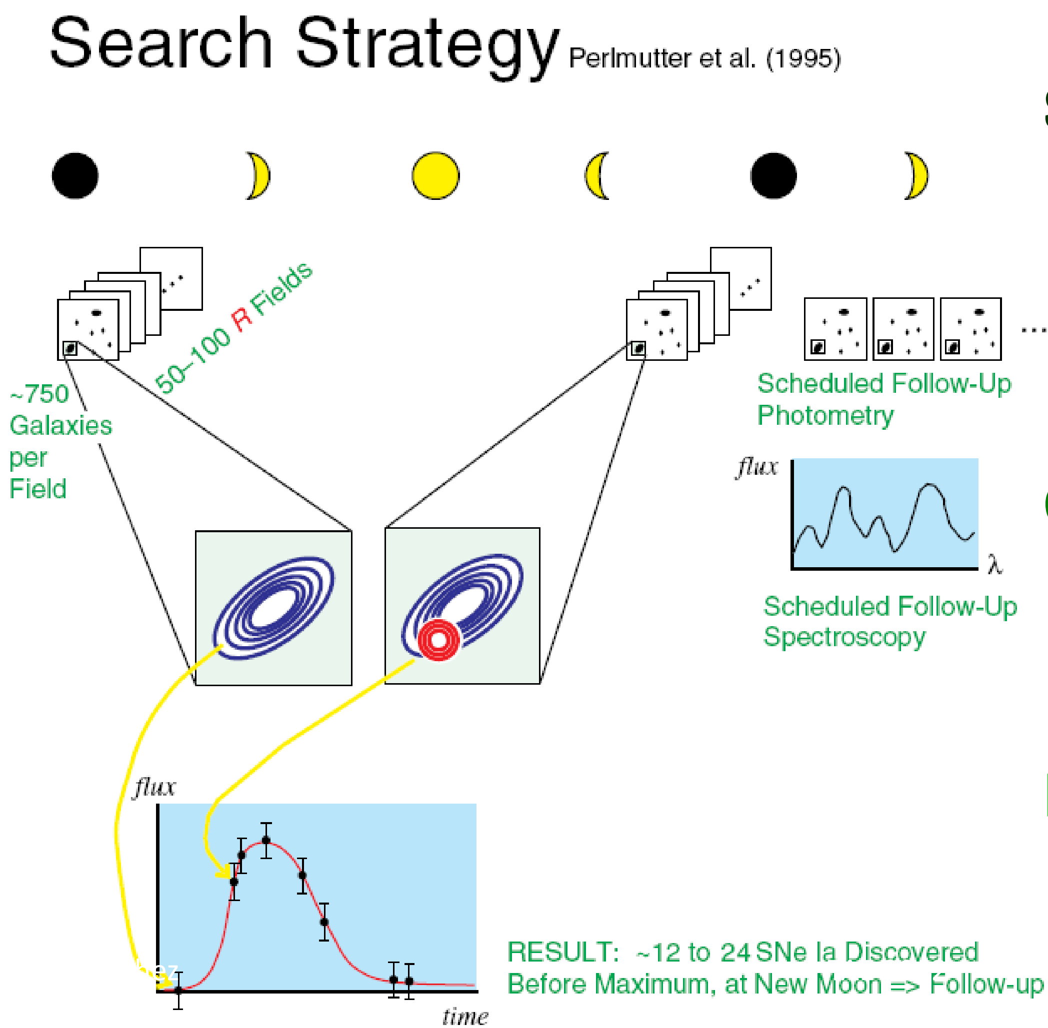






Supernovae Ia

The dark energy was discovered with this technique.
It is still the best controlled method
SN Ia are EXCELLENT DISTANCE INDICATORS



Searching Strategy

Rolling Search

Observing systematically the same sky area

Clasification

Spectra and colors of the supernovae

Light Curves

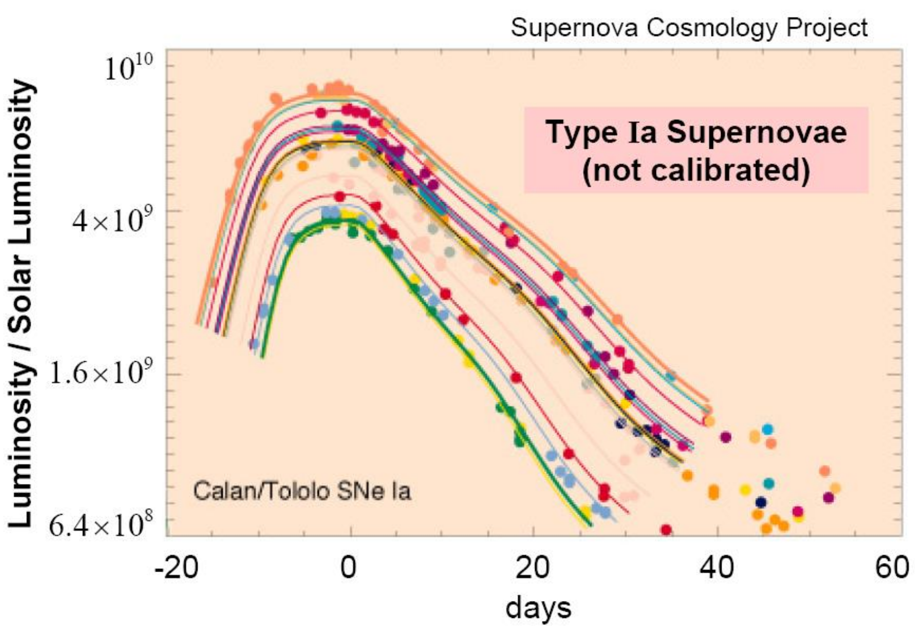
In many colors

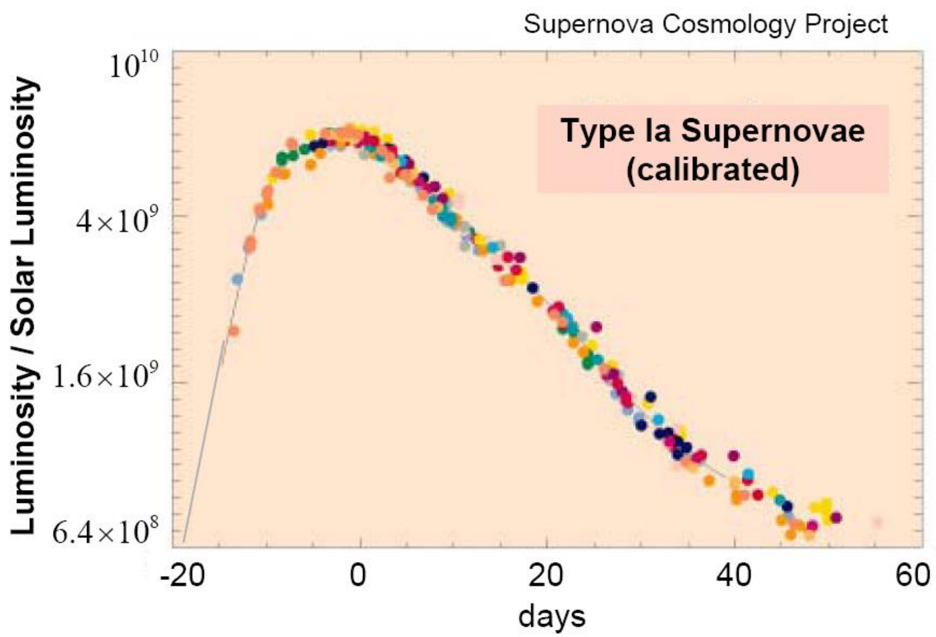
Supernovae Ia

SN Ia are GOOD DISTANCE INDICATORS

Not real standard candles, but standarizable

Calibrated with nearby supernovae, cepheids and theoretical models





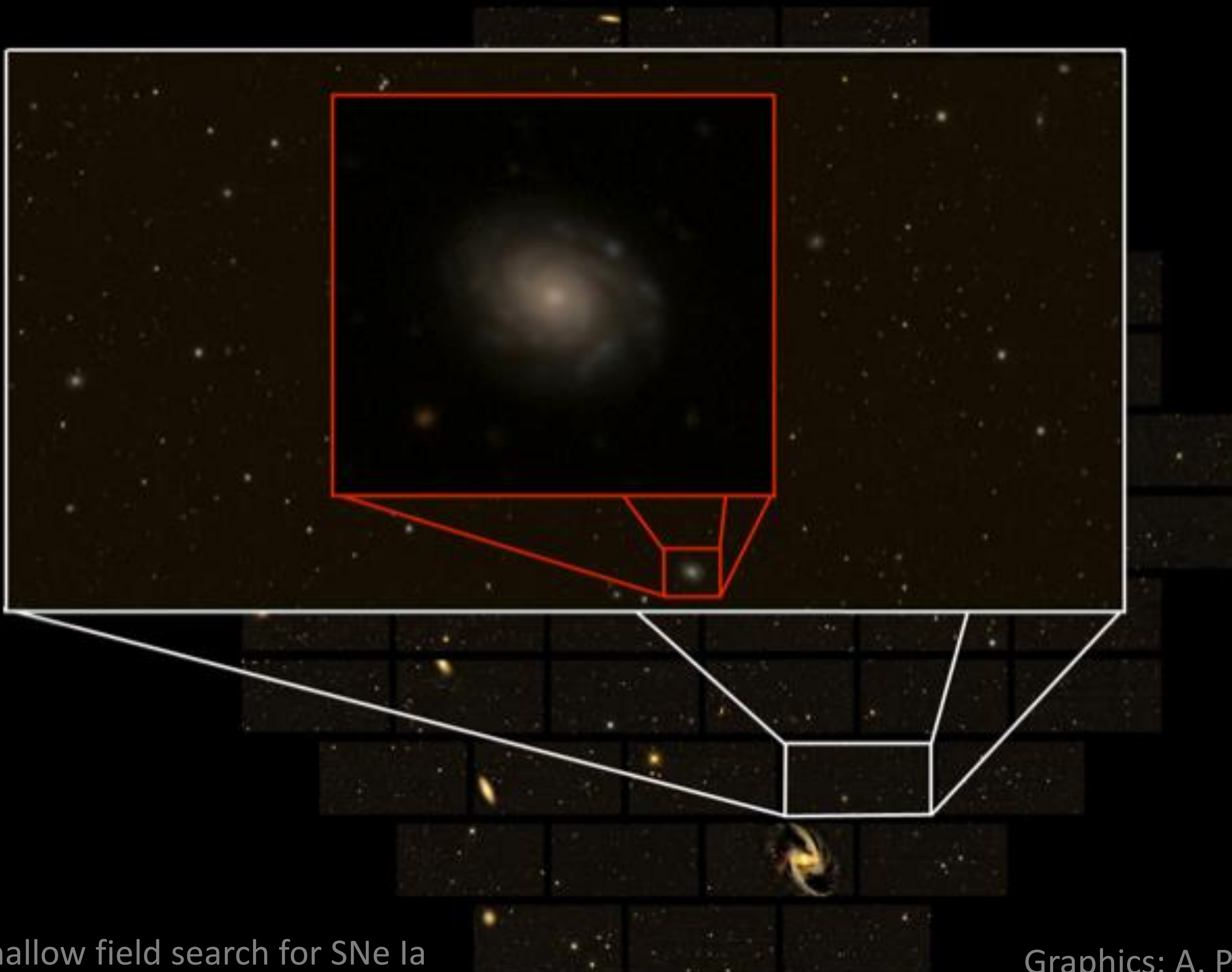
The shape of the light curve is related to the luminosity: Several very precise models (SALT2, MLCS2k2…) that allow fitting all the SN characteristics

THE DARK ENERGY SURVEY

THE DARK ENERGY SURVEY

Shallow field search for SNe Ia

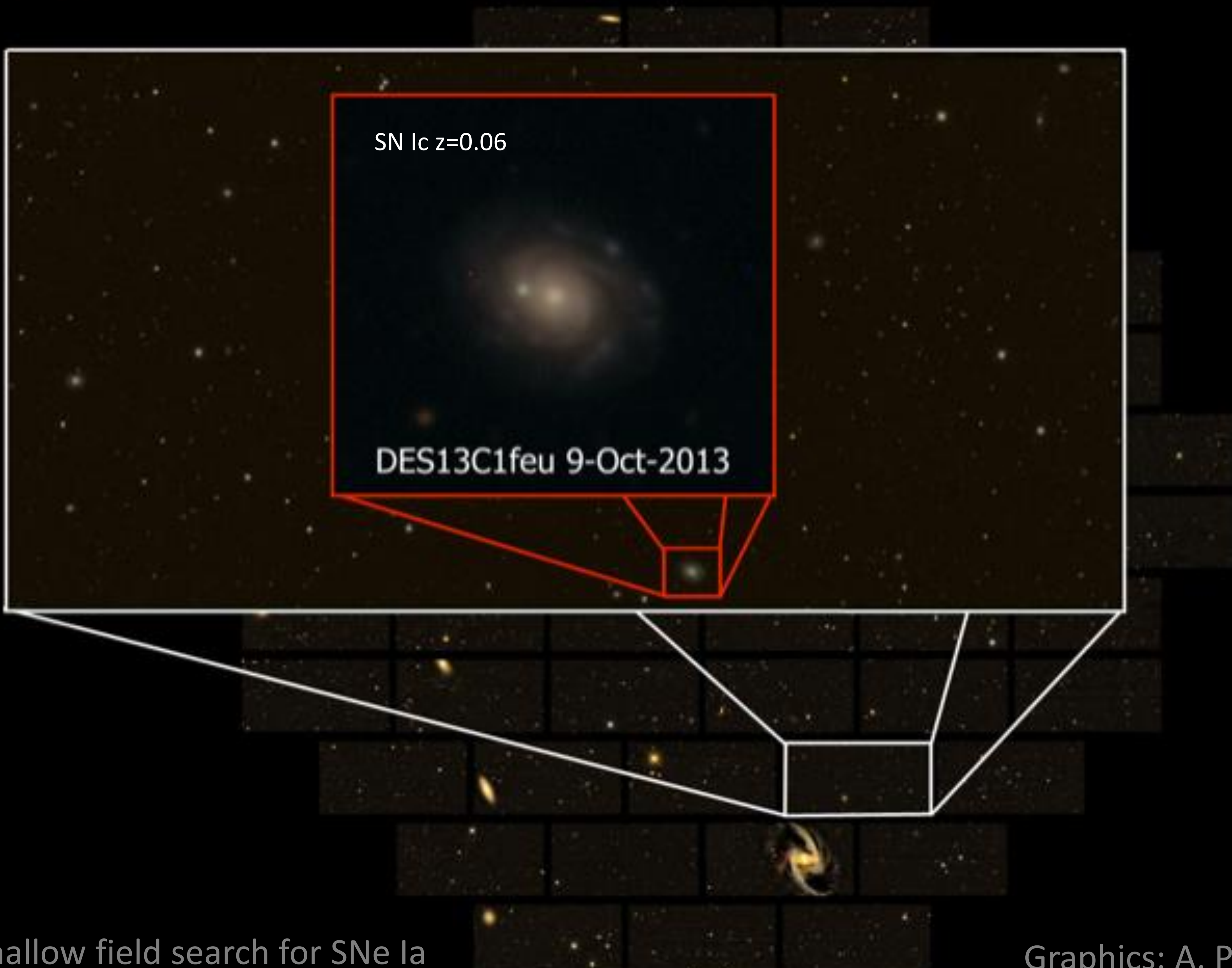
Graphics: A. Papadopoulos



Shallow field search for SNe Ia

Graphics: A. Papadopoulos

THE DARK ENERGY SURVEY



Shallow field search for SNe Ia

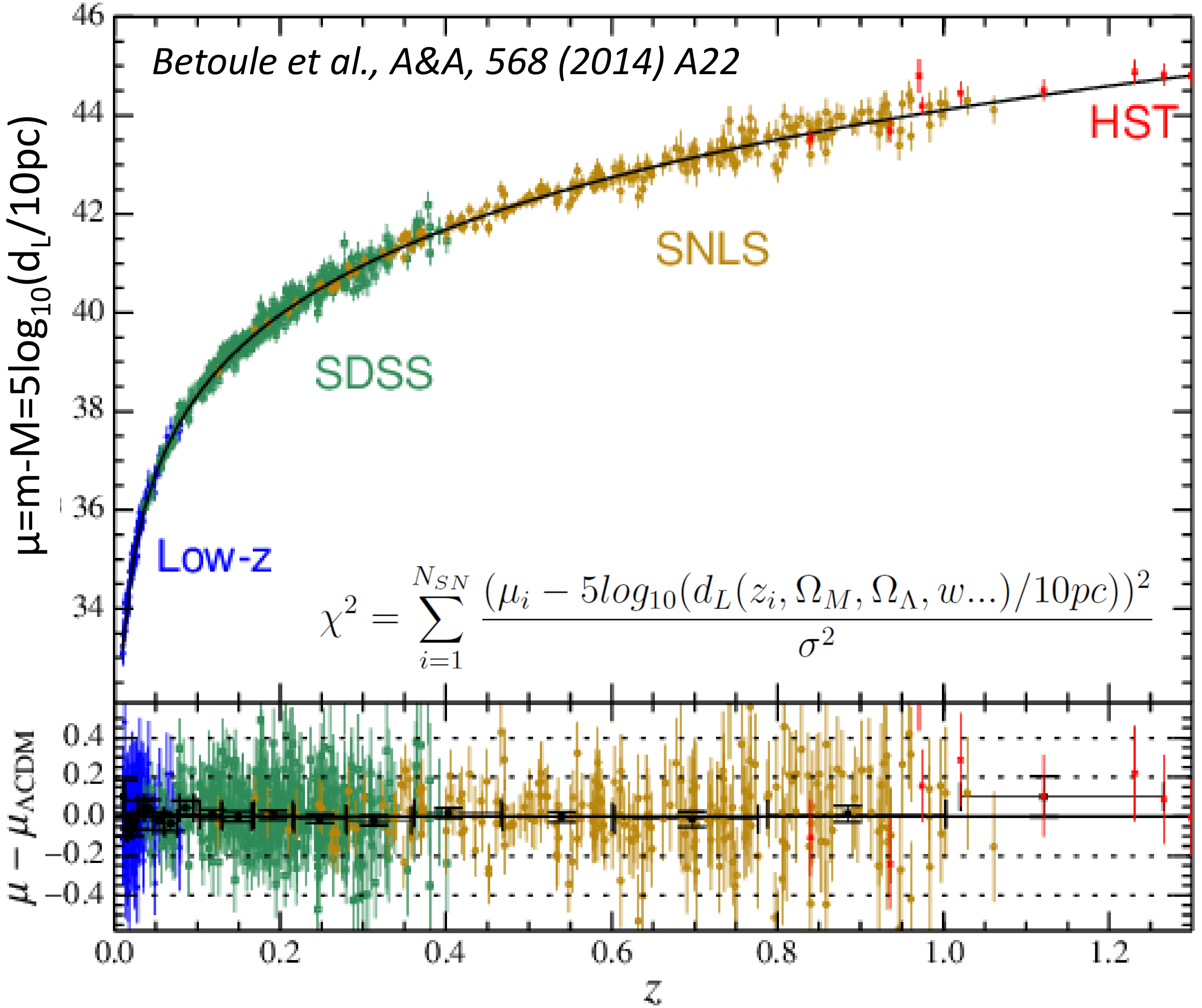
Graphics: A. Papadopoulos

Supernovae Ia

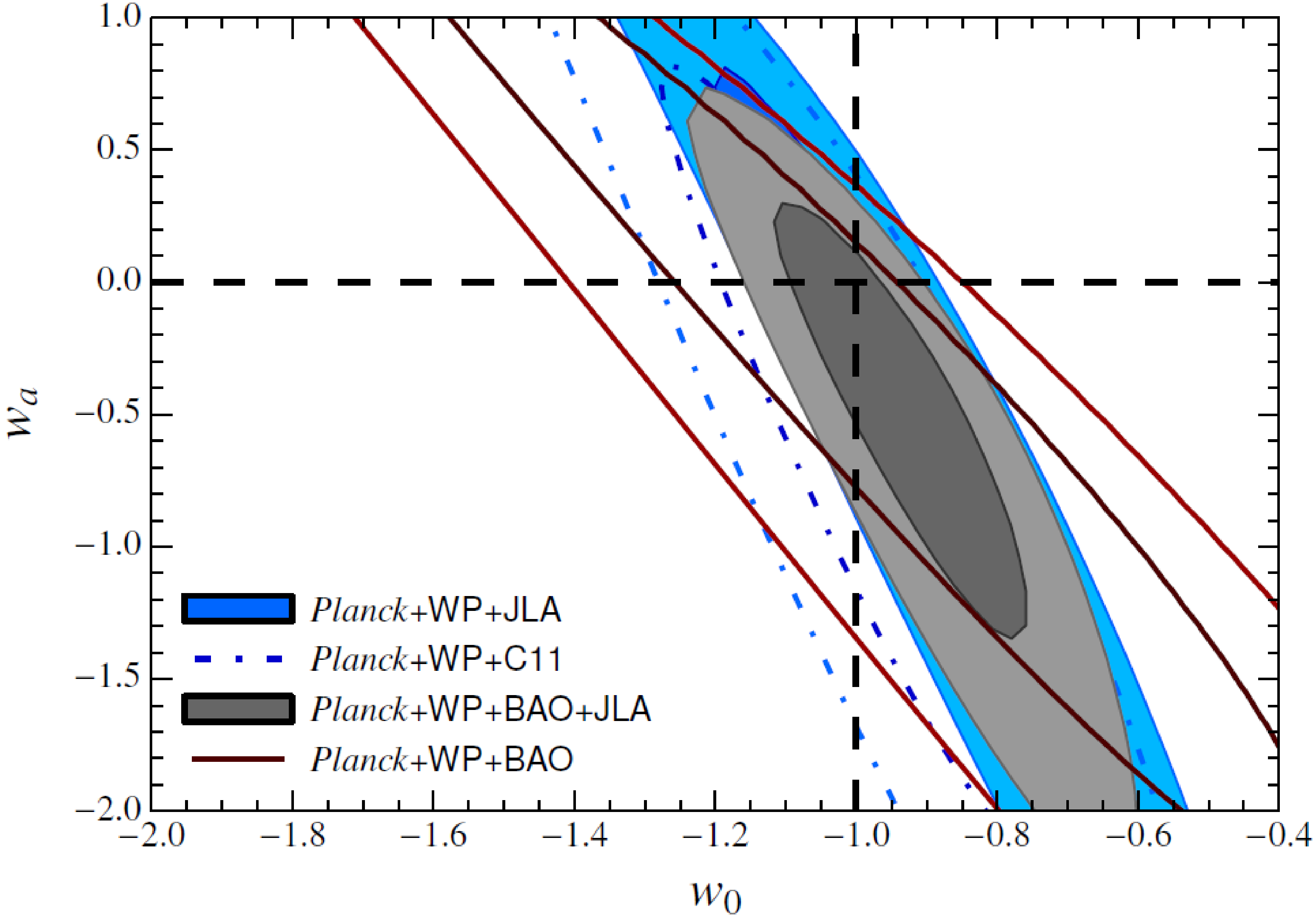
Once the magnitudes are measured, build the Hubble diagram

And fit the cosmological parameters

M = Absolute Magnitude (known for standard candles),
m = apparent magnitude (measured for each supernova)



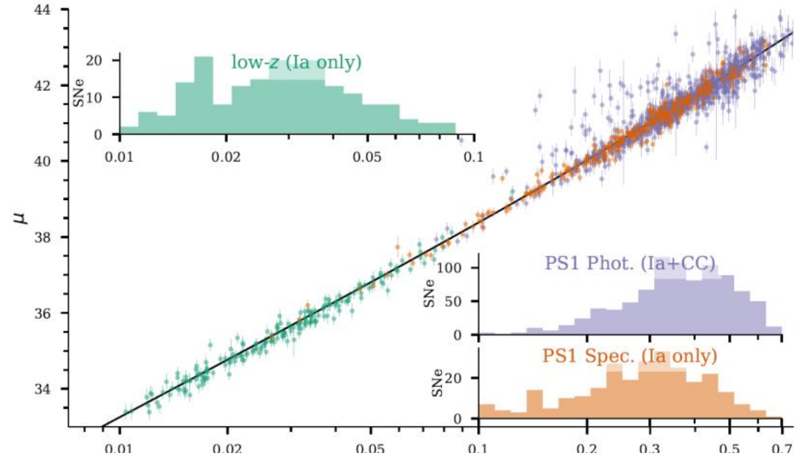
Betoule et al., A&A, 568 (2014) A22

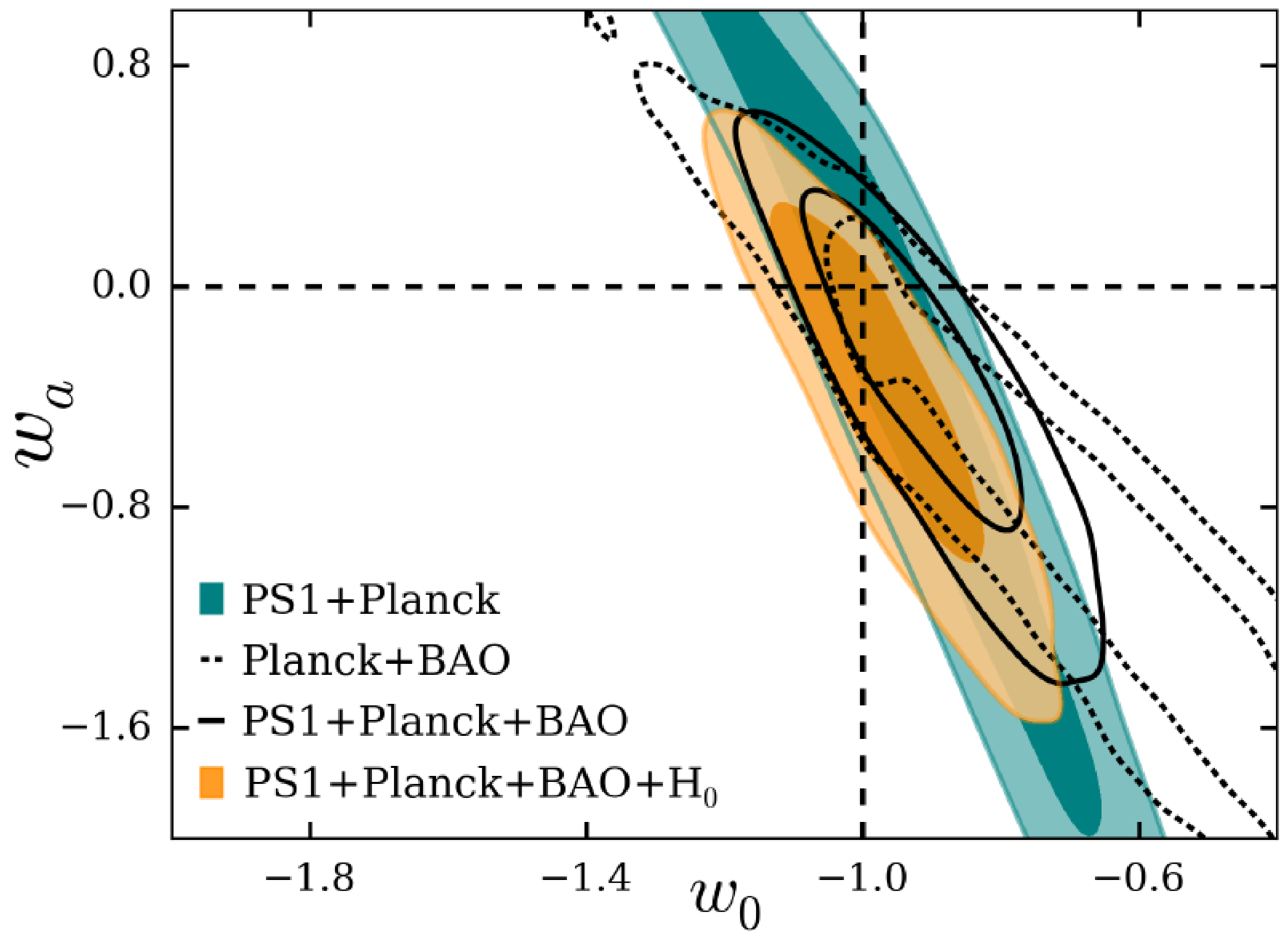


Latest results (2017)

More than 1000 supernovae

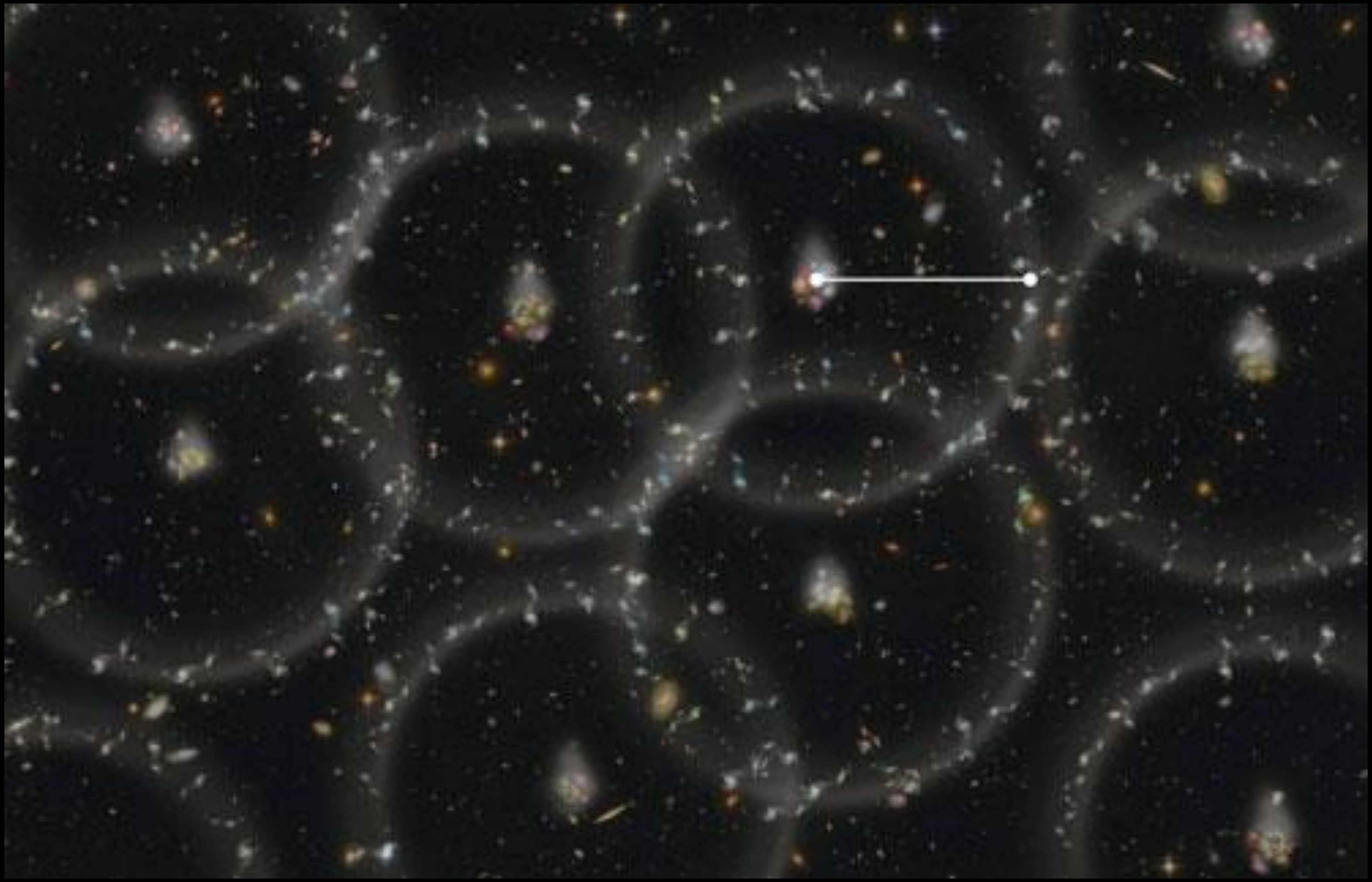
The cosmological constant remains a good fit to the data





D. O. Jones et al.,
ApJ 857 (2018) 51
arXiv 1710.0084 [astro-ph]

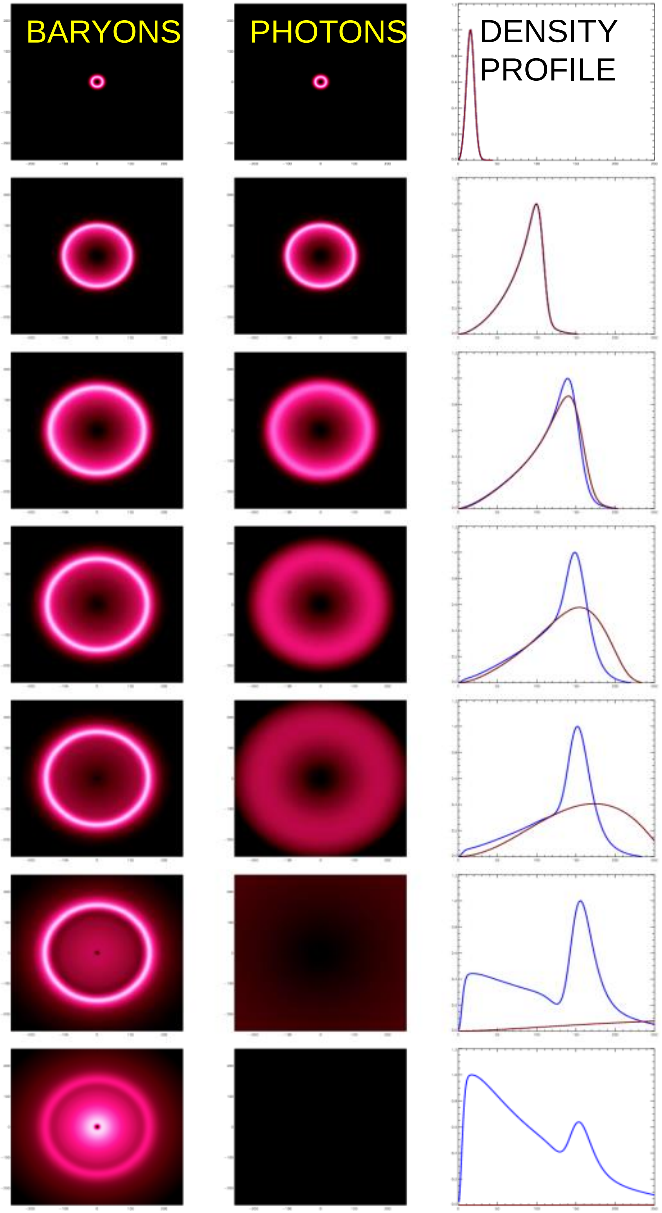
Baryon Acoustic Oscillations (BAO)



The early Universe was a strongly coupled gas of photons and charged particles (and neutrinos and dark matter)

Overdensities make overpressures and a sound wave in the gas → BAO

BAO



For *z*>>1000 the universe was a strongly coupled gas of photons and charged particles (and neutrinos and dark matter)

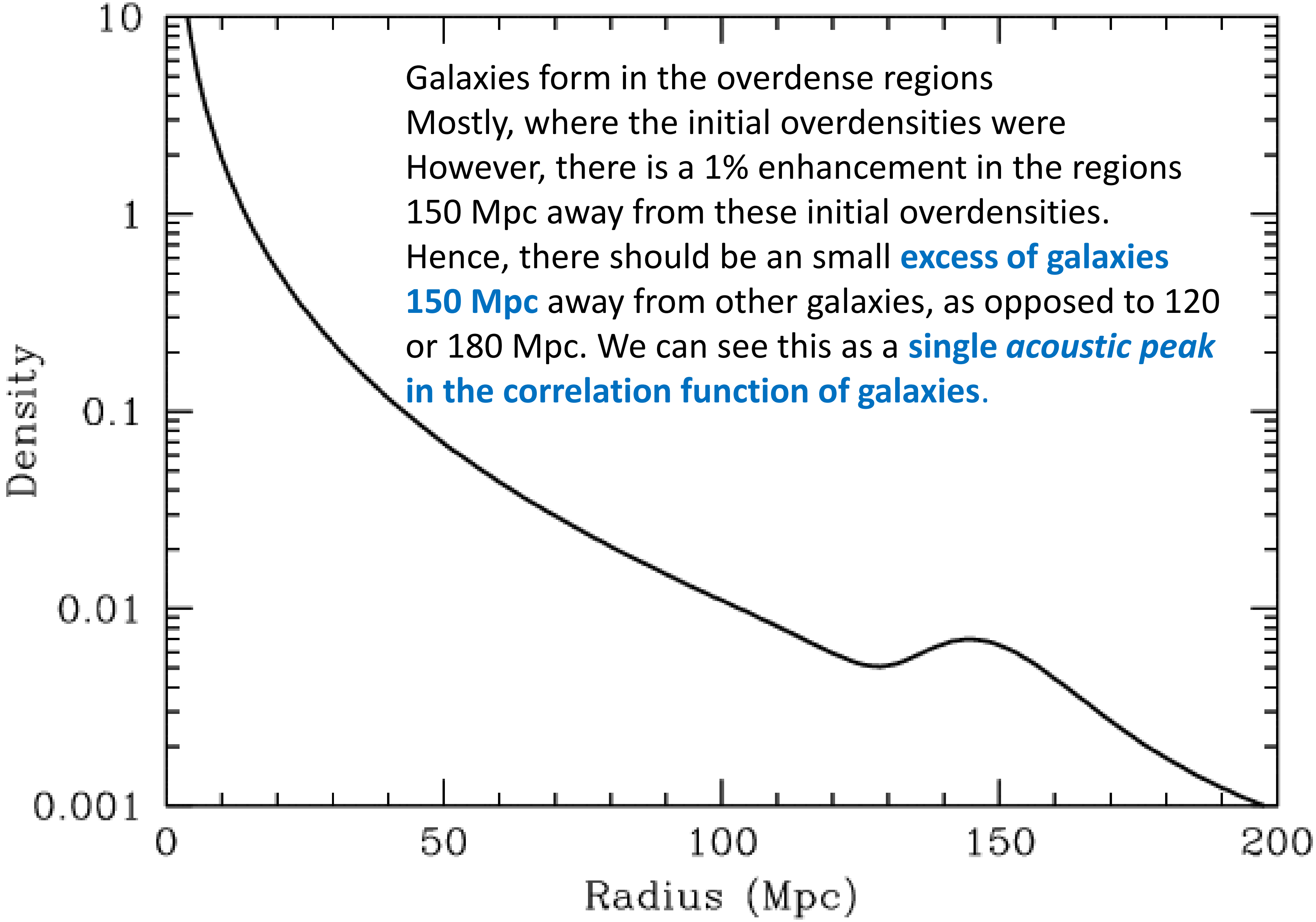
Overdensities make overpressures and a sound wave in the gas, wich propagates with velocity $c/\sqrt{3}$

For *z* ~ 1100 (*t* ~ 350 000 yr), temperature is low enough (3000 K) for the formation of hydrogen. Photons decouple and propagate freely (CMB)

Photons quickly stream away, leaving the baryon peak stalled at ~150 Mpc.

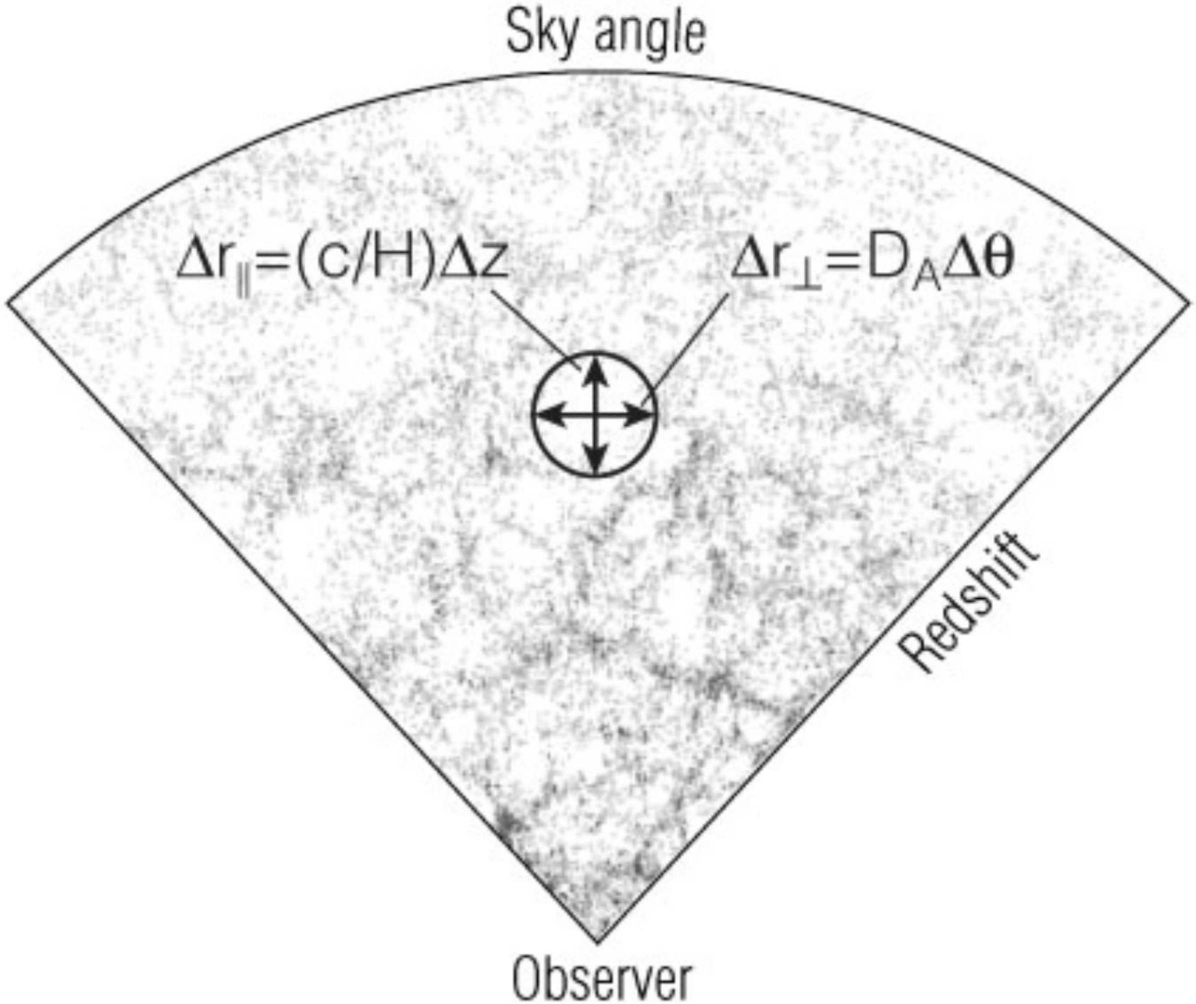
There is a special separation between galaxies: 150 Mpc, that can be used as a STANDARD RULER

Plotting the density profile we see that the peak is indeed very weak, but measurable



Galaxies form in the overdense regions
Mostly, where the initial overdensities were
However, there is a 1% enhancement in the regions 150 Mpc away from these initial overdensities.
Hence, there should be an small **excess of galaxies 150 Mpc** away from other galaxies, as opposed to 120 or 180 Mpc. We can see this as a **single *acoustic peak* in the correlation function of galaxies**.

https://www.cfa.harvard.edu/~deisenst/acousticpeak/acoustic_physics.htm



Measuring 2 distances with standard rulers:

Angular diameter distance → $D_A(z; \Omega_M, \Omega_B, \Omega_\Lambda, w\ldots)$

Expansion rate (along the LoS) → $H\ (z; \Omega_M, \Omega_B, \Omega_\Lambda, w\ldots)$

Different sensitivity and systematic errors

Cosmological distances

The comoving distance to a light source at redshift z is:

$$d_A = \frac{d_M}{1+z}$$

$$d_M = \begin{cases} d_H \frac{1}{\sqrt{\Omega_k}} \sinh\left(\sqrt{\Omega_k} d_C / d_H\right) & \Omega_k > 0 \\ d_C & \Omega_k = 0 \\ d_H \frac{1}{\sqrt{|\Omega_k|}} \sin\left(\sqrt{|\Omega_k|} d_C / d_H\right) & \Omega_k < 0 \end{cases}$$

$$d_C(z) = \chi(z) \equiv c \int_0^z \frac{dz'}{H(z')}$$

$$d_H \equiv \frac{c}{H_0}$$

$$H(z) = H_0 \left[\Omega_m (1+z)^3 + \Omega_k (1+z)^2 + \Omega_\gamma (1+z)^4 + \Omega_\Lambda (1+z)^{3(1+w_0+w_a)} e^{-3w_a \frac{z}{1+z}}\right]$$

For a Euclidean Universe, the angular diameter distance is : $d_A = r(z)/(1+z)$

Therefore, from a set of standard ruler measurements at different redshifts, we will have many values of r(z), and we can fit the cosmological parameters

$$\Delta\theta = \frac{s_\perp}{d_A}$$

Standard ruler size

$$H(z) = \frac{c\Delta z}{s_\parallel}$$

The concrete expressions in the BAO case are

$$r_s(z_{dec}) = \frac{c}{\sqrt{3}} \int_0^{1/(1+z_{dec})} \frac{da}{a^2 H(a) \sqrt{1 + (3\Omega_b/4\Omega_\gamma)a}} \ \mathrm{Mpc\ h}^{-1}$$

$$z_{dec} = 1291 \frac{(\Omega_m h^2)^{0.251}}{1 + 0.659(\Omega_m)^{0.828}} \left[1 + b_1 \left(\Omega_b h^2\right)^{b_2}\right]$$

$$b_1 = 0.313 \left(\Omega_m h^2\right)^{-0.419} \left[1 + 0.607 \left(\Omega_m h^2\right)^{0.674}\right]$$

$$b_2 = 0.238 \left(\Omega_m h^2\right)^{0.223}$$

The observable quantities are angles and redshifts

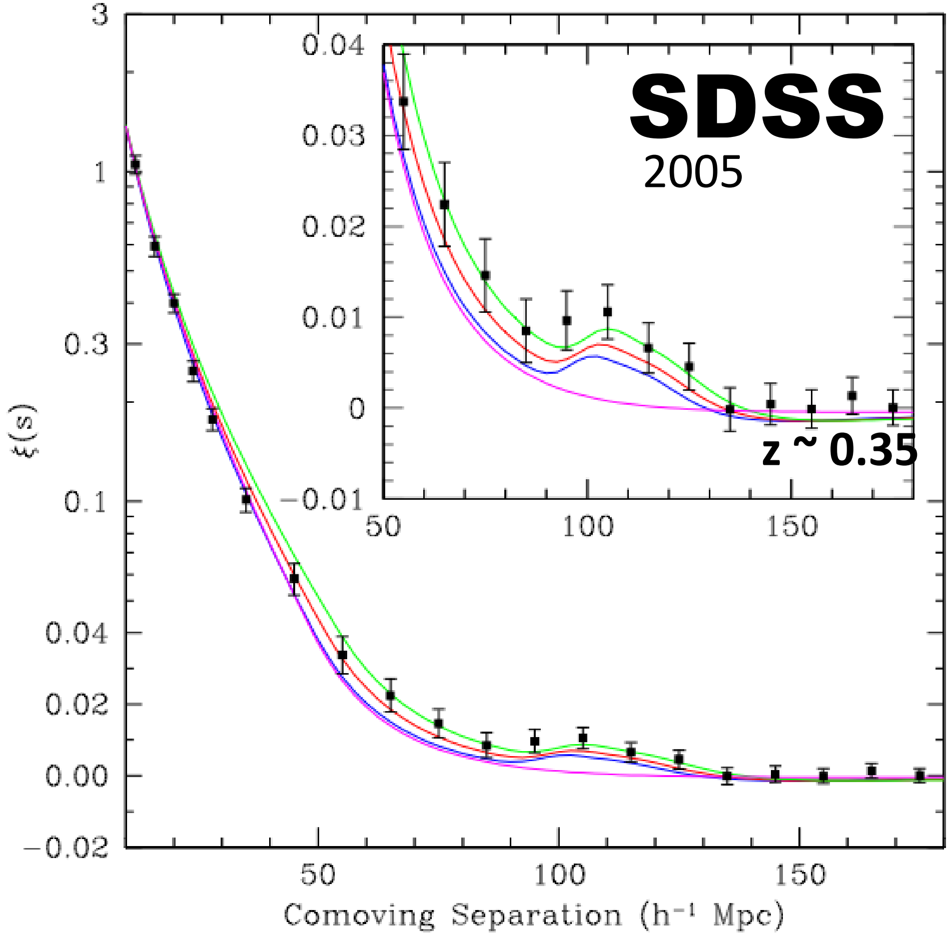
$$\theta_{BAO} = \frac{r_S(\Omega_M, w_0, w_a \ldots)}{(1+z)\ d_A(z, \Omega_M, w_0, w_a \ldots)}$$

$$\Delta z_{BAO} = H(z) r_s$$

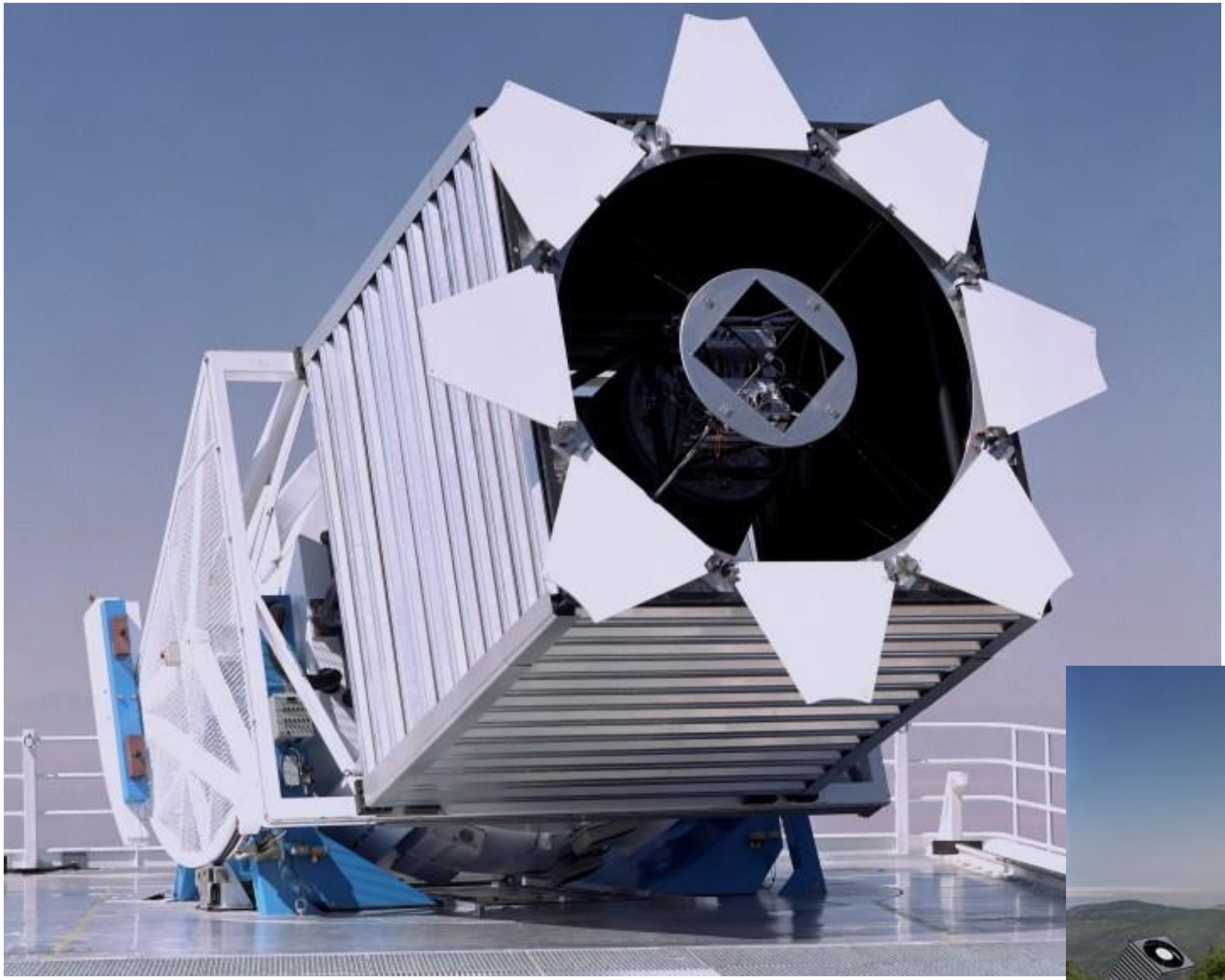
Baryon Acoustic Oscillations

Measure position and redshift of the galaxies, compute the correlation function (or power spectrum) and locate the excess

Very robust technique. Not affected by astrophysical systematic effects



Redshift survey: BOSS (SDSS-III)



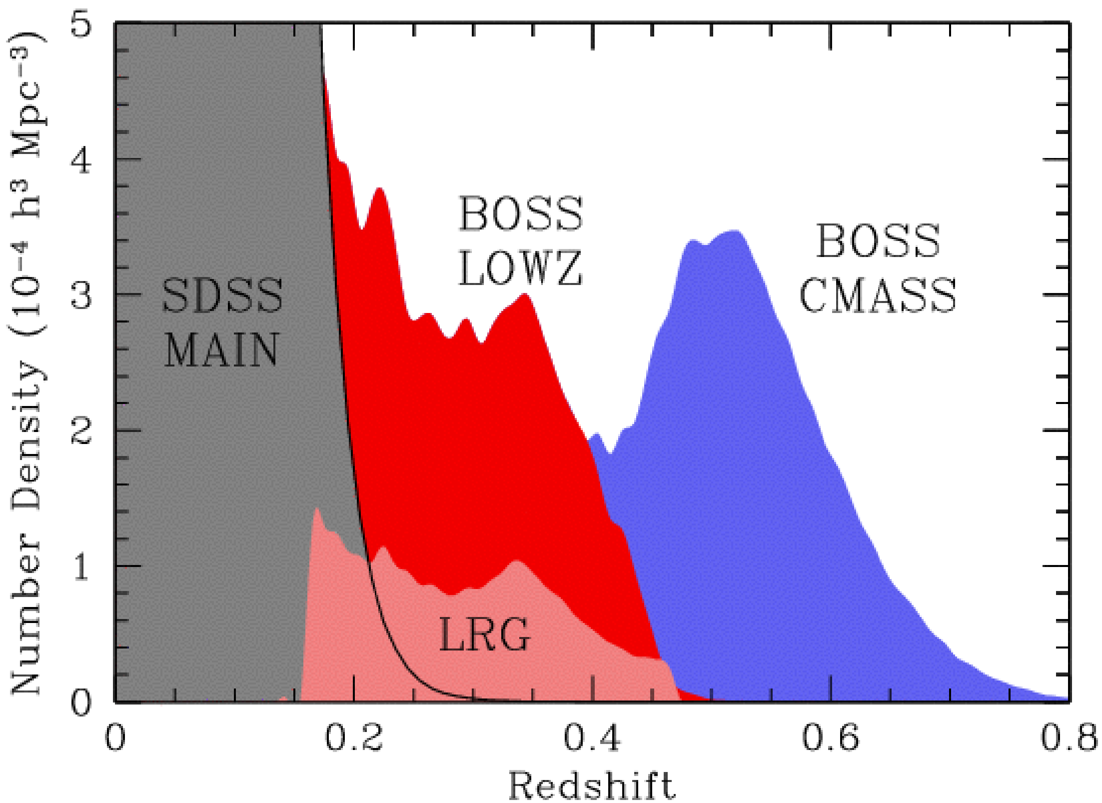
Apache Point Observatory

Dedicated 2.5m Telescope

1000 spectra simultaneously

BOSS took data from 2008 to 2014

There is currently a SDSS-IV phase, with the survey eBOSS (extended BOSS)

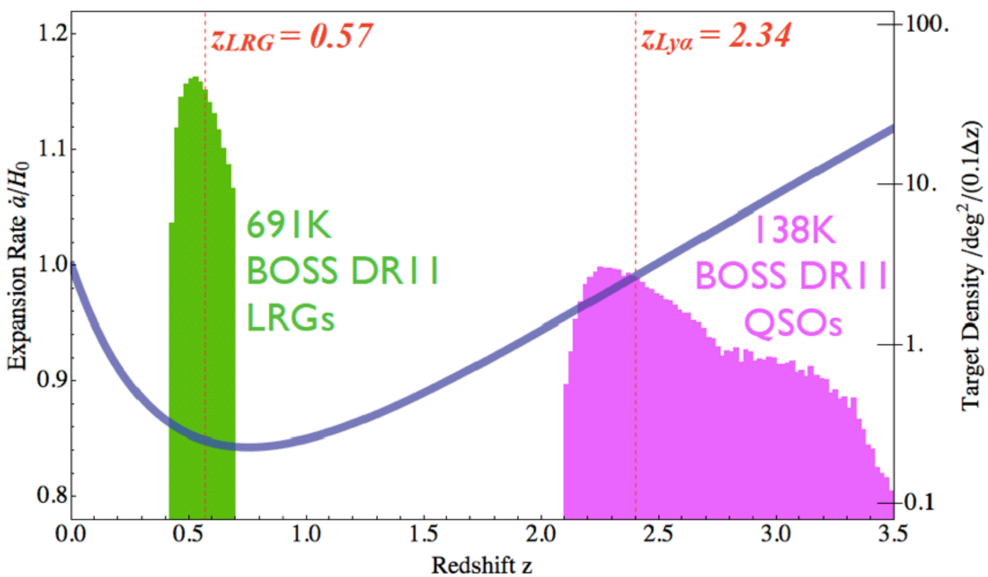


Several Galaxy samples, selected to map different redshift ranges

Luminous Red Galaxies (z < 0.4) → Brightest and reddest galaxies

CMASS Galaxies (0.4 < z < 0.7) → More luminous and massive galaxies

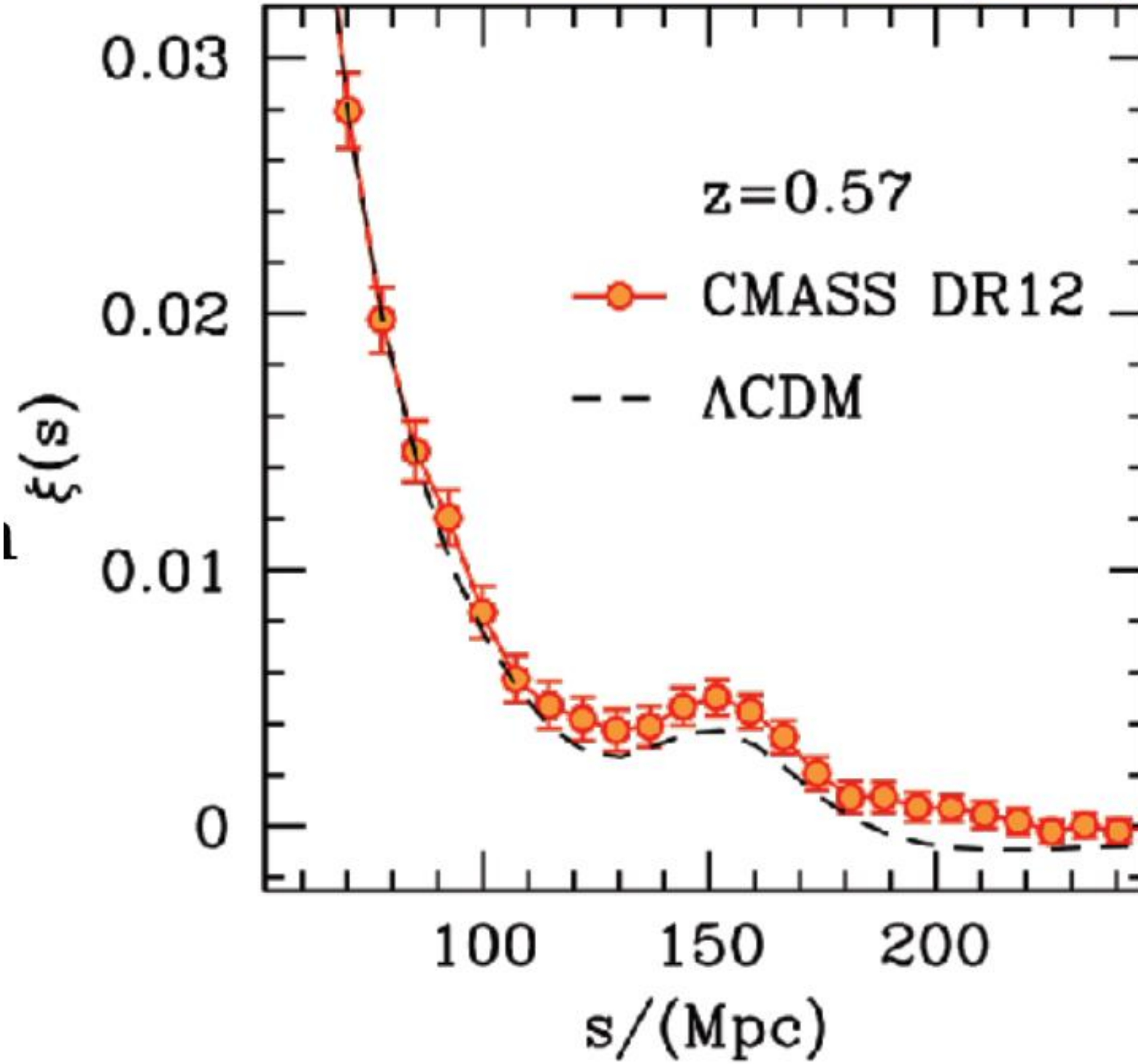
In addition, a quasar sample that covers the redshift range 2.15 < z < 3.5, to use the Ly-α forest as a cosmological probe



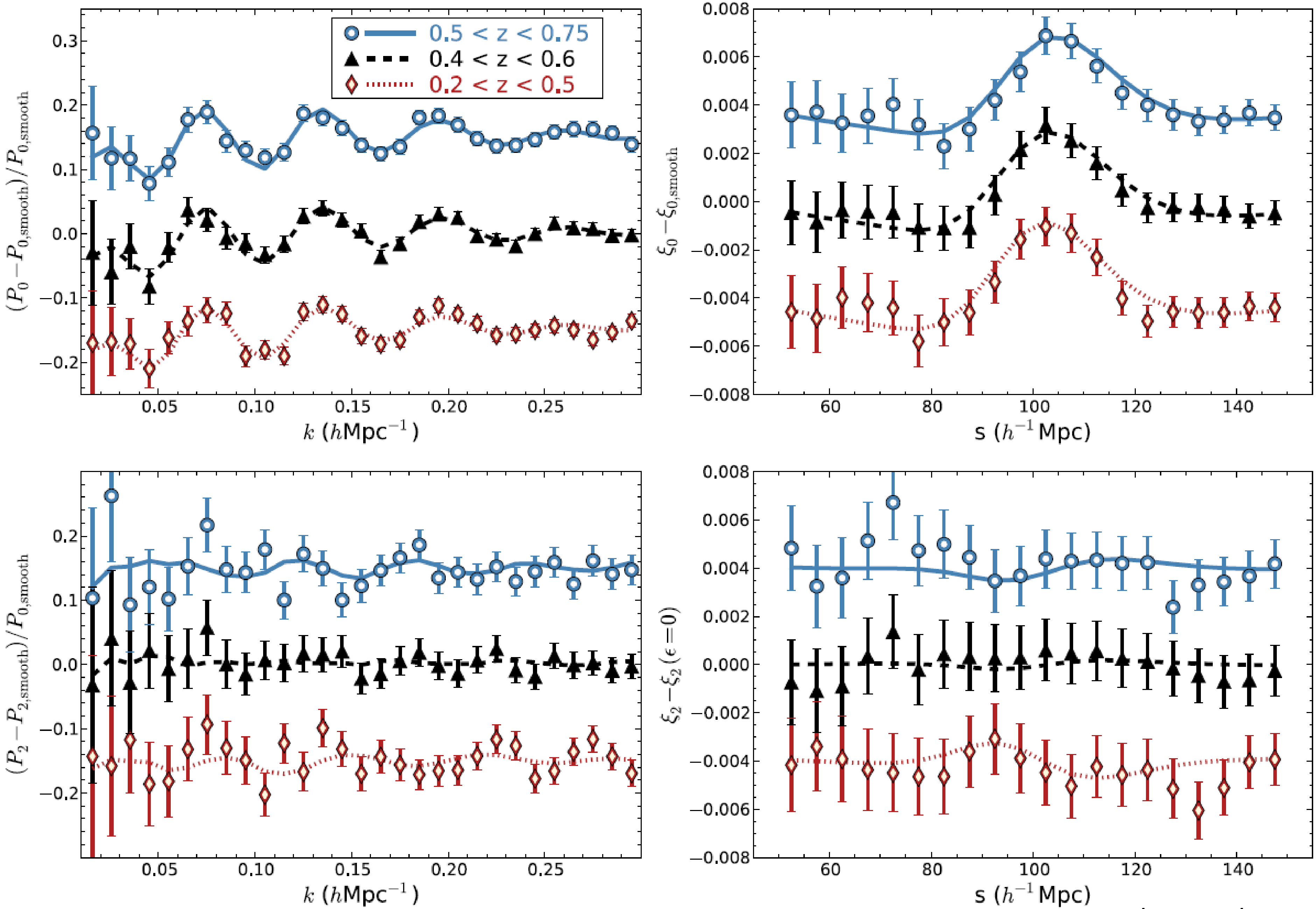
For each of these samples, compute the correlation function.

Identify and fit the BAO peak position

Sánchez et al. (2017)

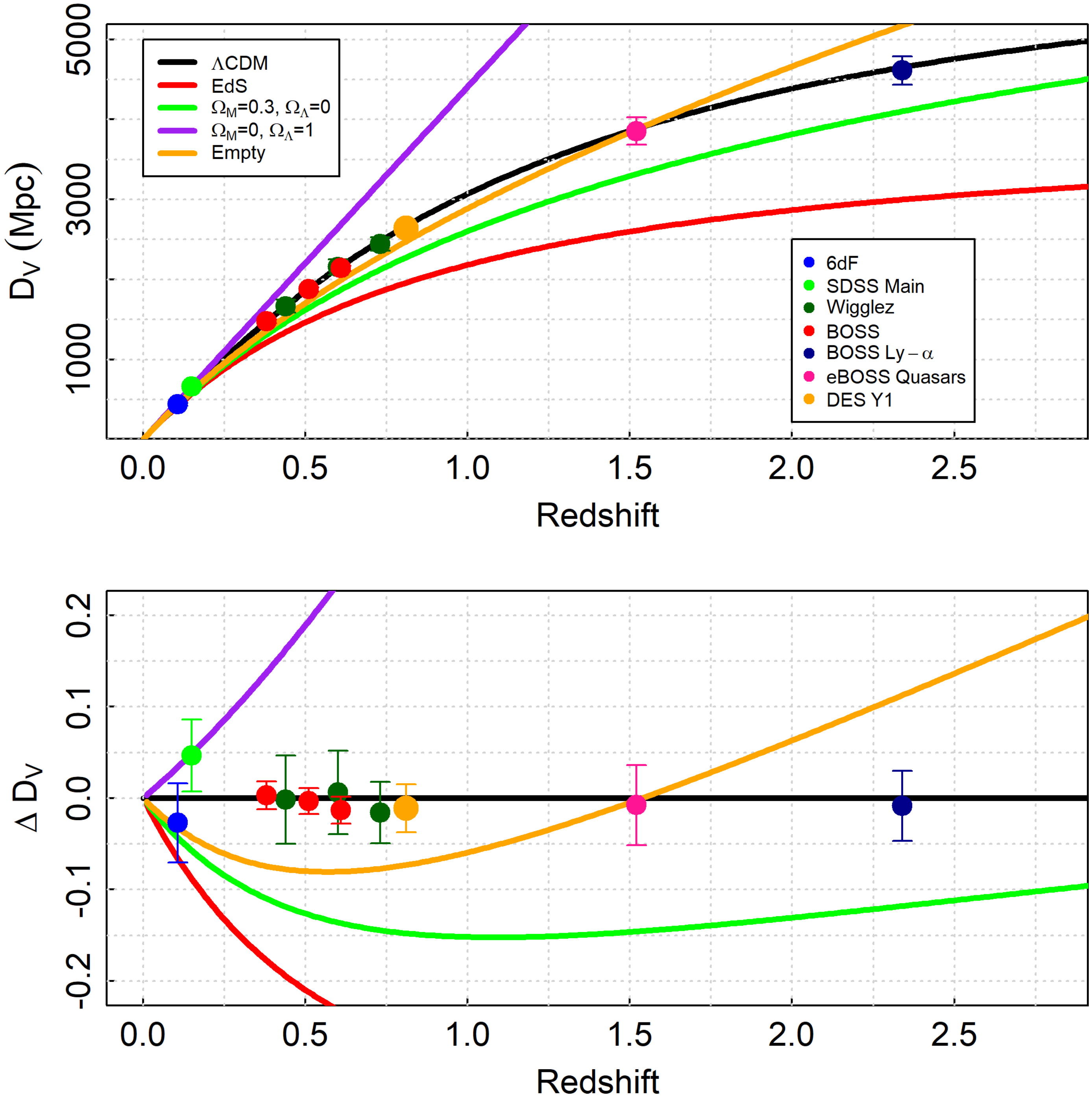


BOSS Final Results



Alam et al. 2017

Current Hubble Diagram using BAO angular distances



Perfectly described by ΛCDM, but not by other cosmological models

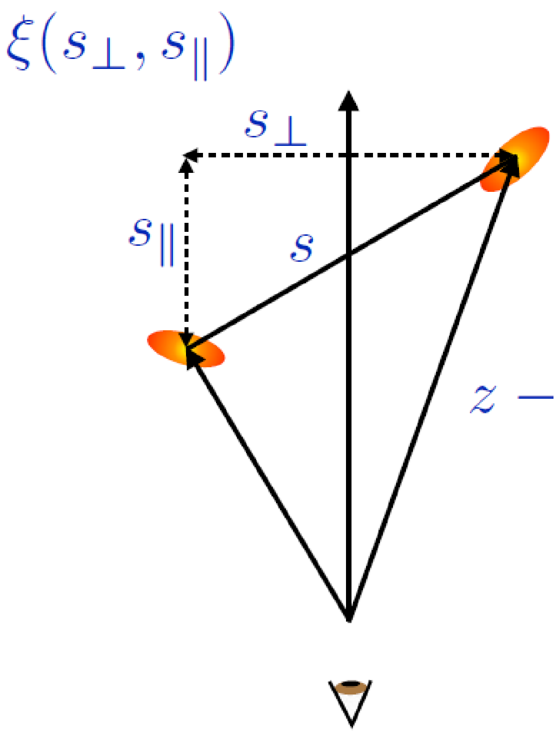
Precisions of the percent order

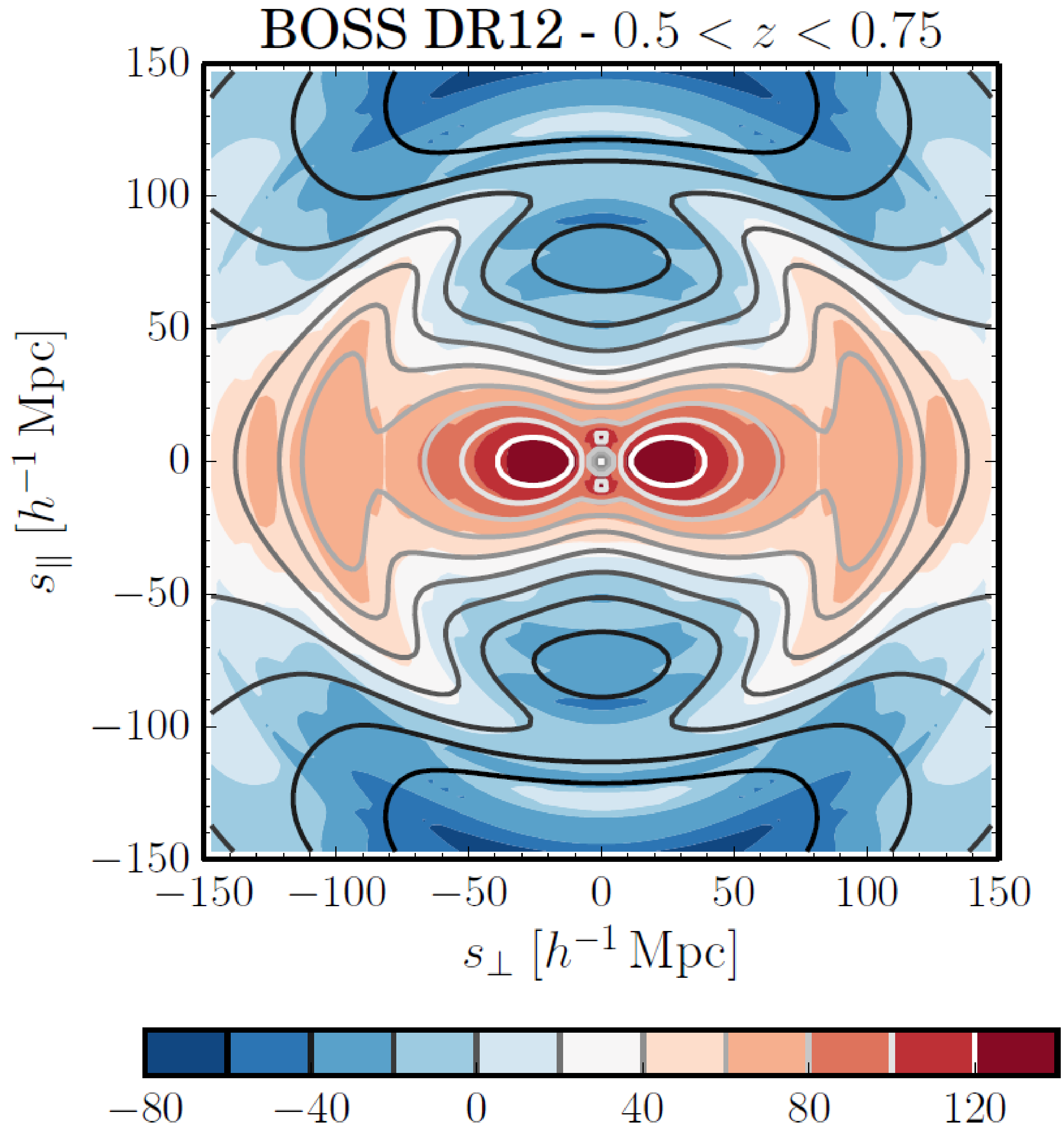
The full BAO power

Anisotropic clustering

Measuring angular and radial BAO separately

Redshift space distortions





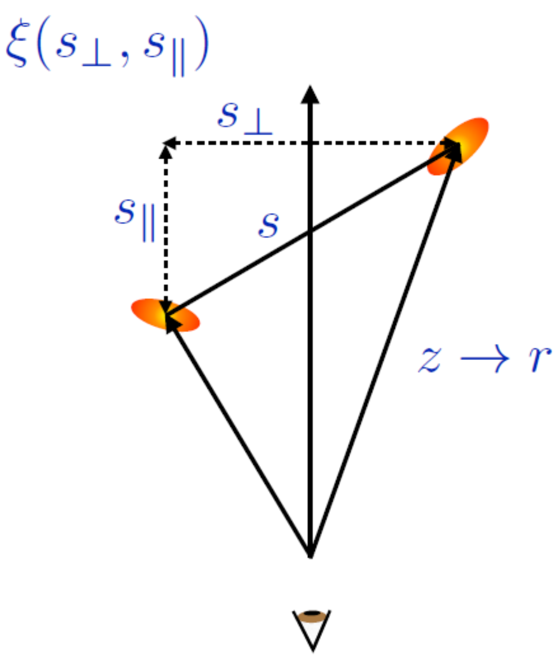
The full BAO power

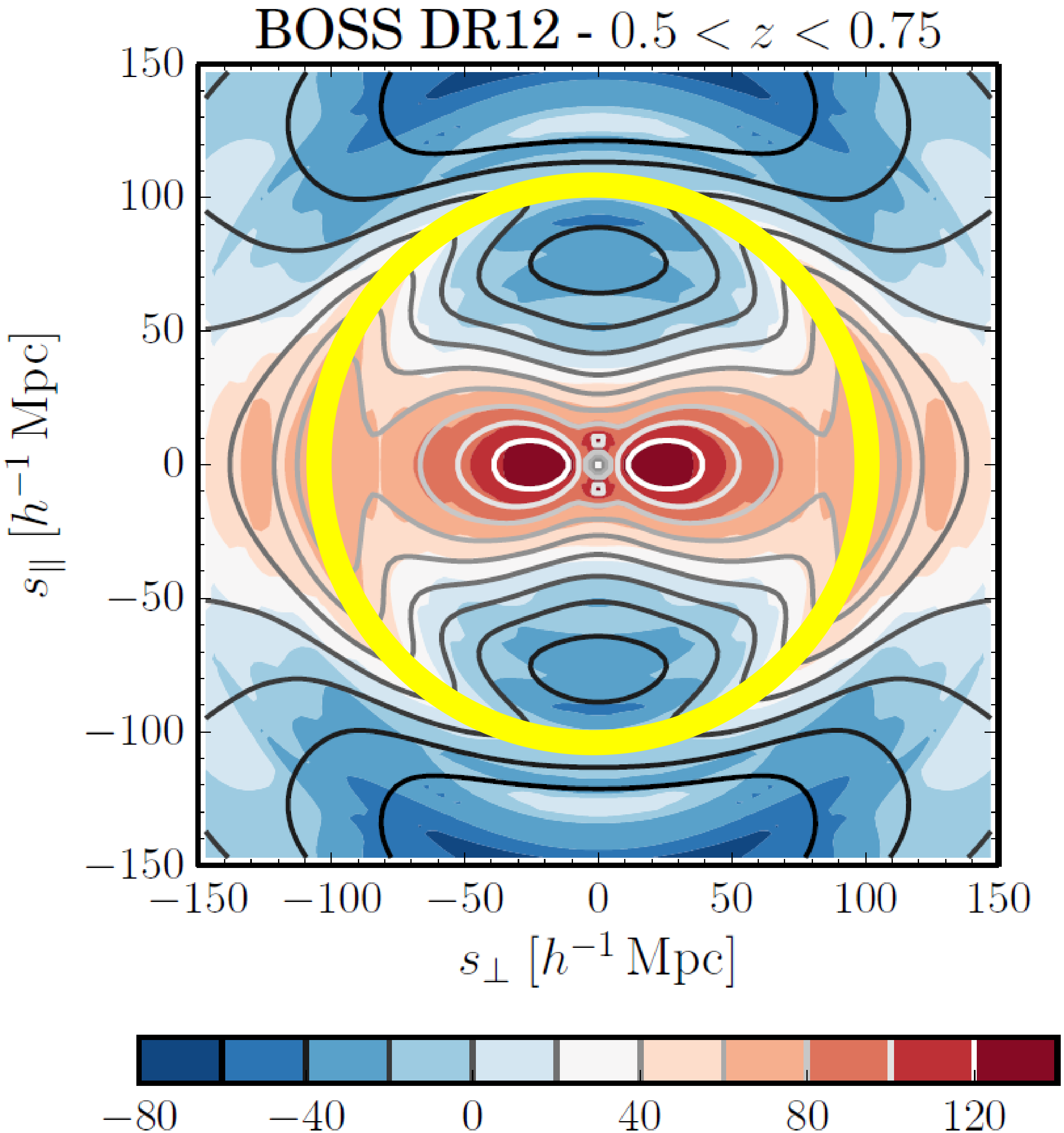
BOSS DR12 anisotropic correlation function

The BAO signal appears as a ring at s=110 Mpc/h

RSD distort the contours, which deviate from perfect circles

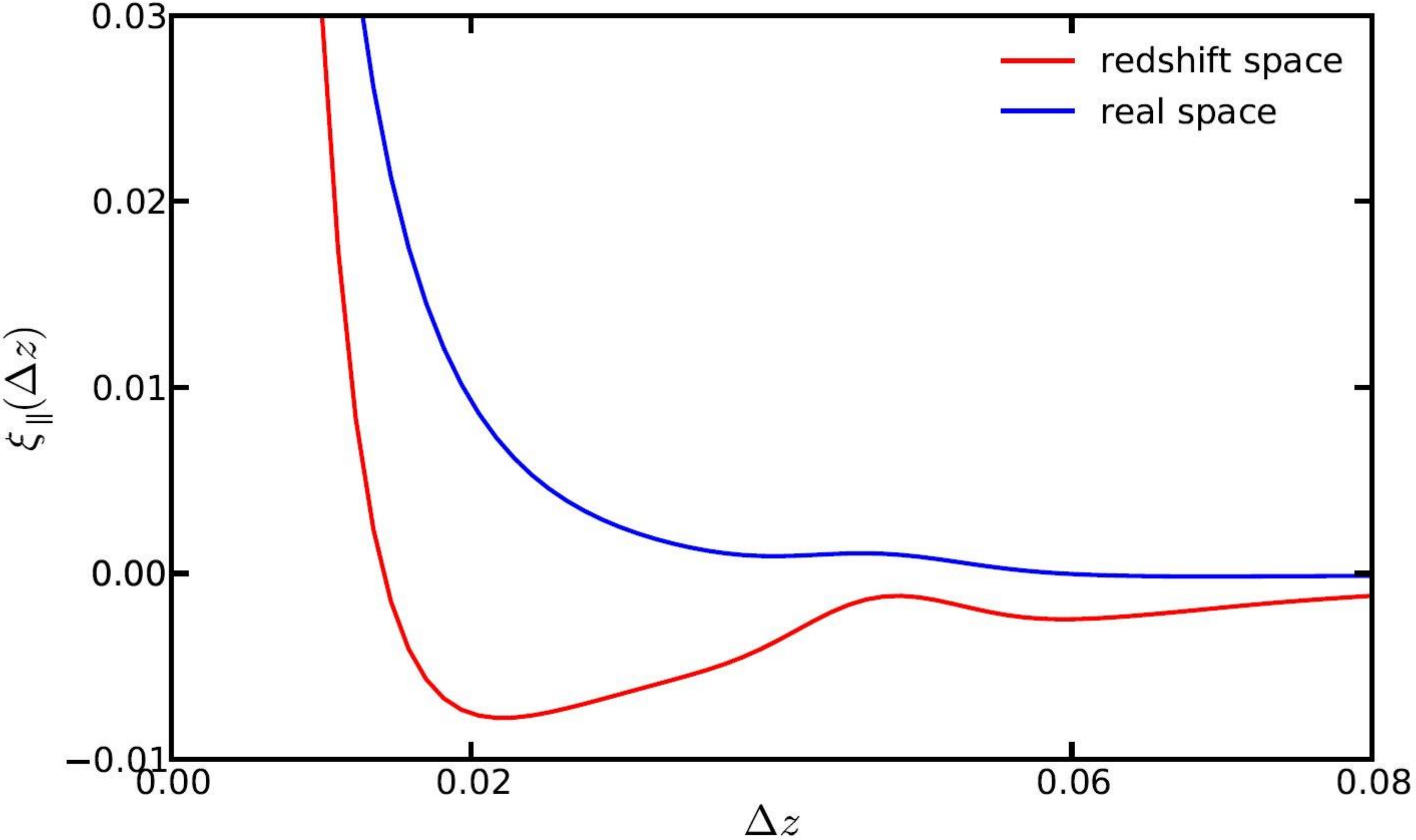
Usable for cosmology





Redshift Space Distortions (RSD)

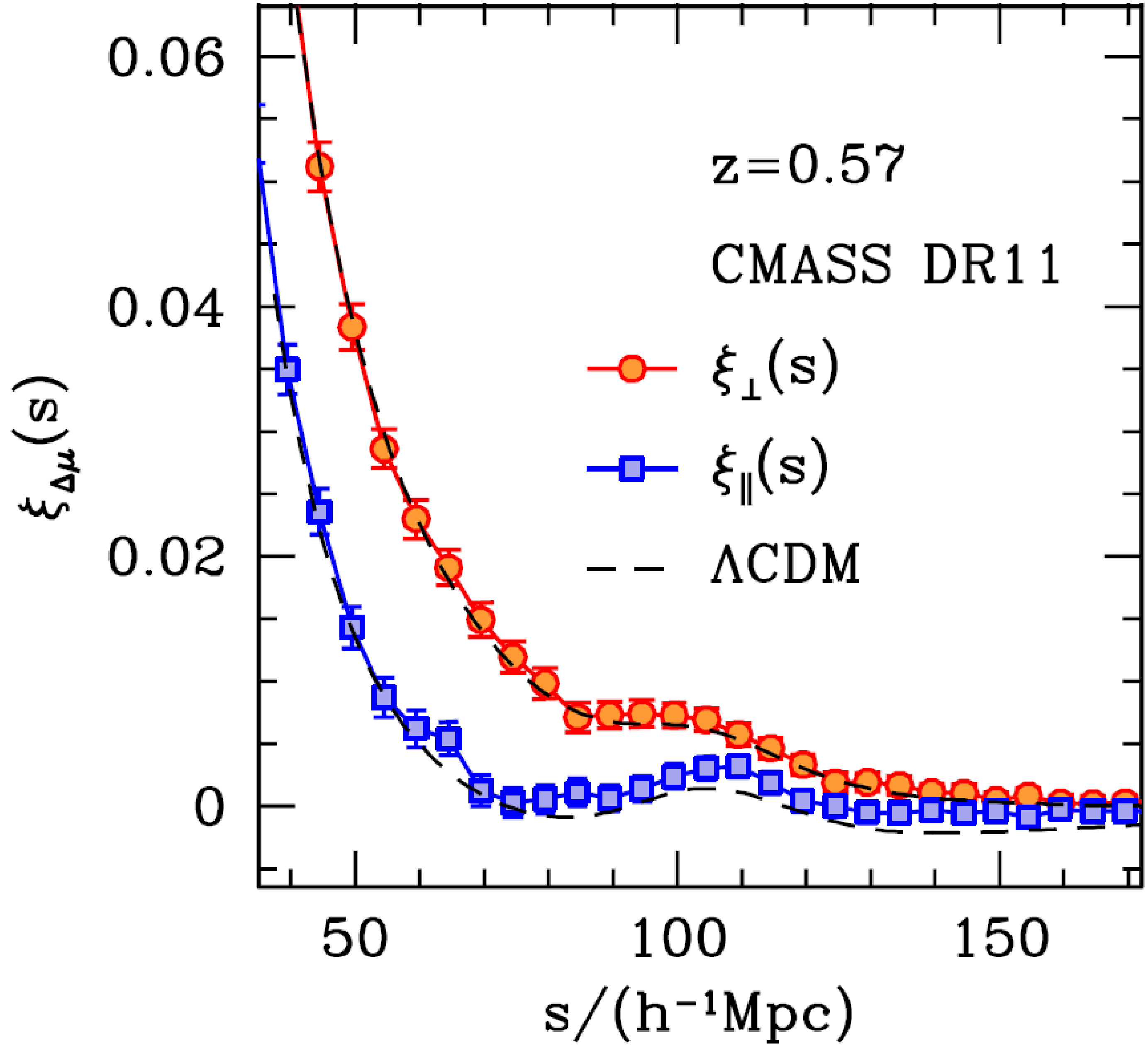
The shape of the correlation function changes dramatically when RSD are included
However the BAO peak position does not change
BAO is very robust against systematic errors

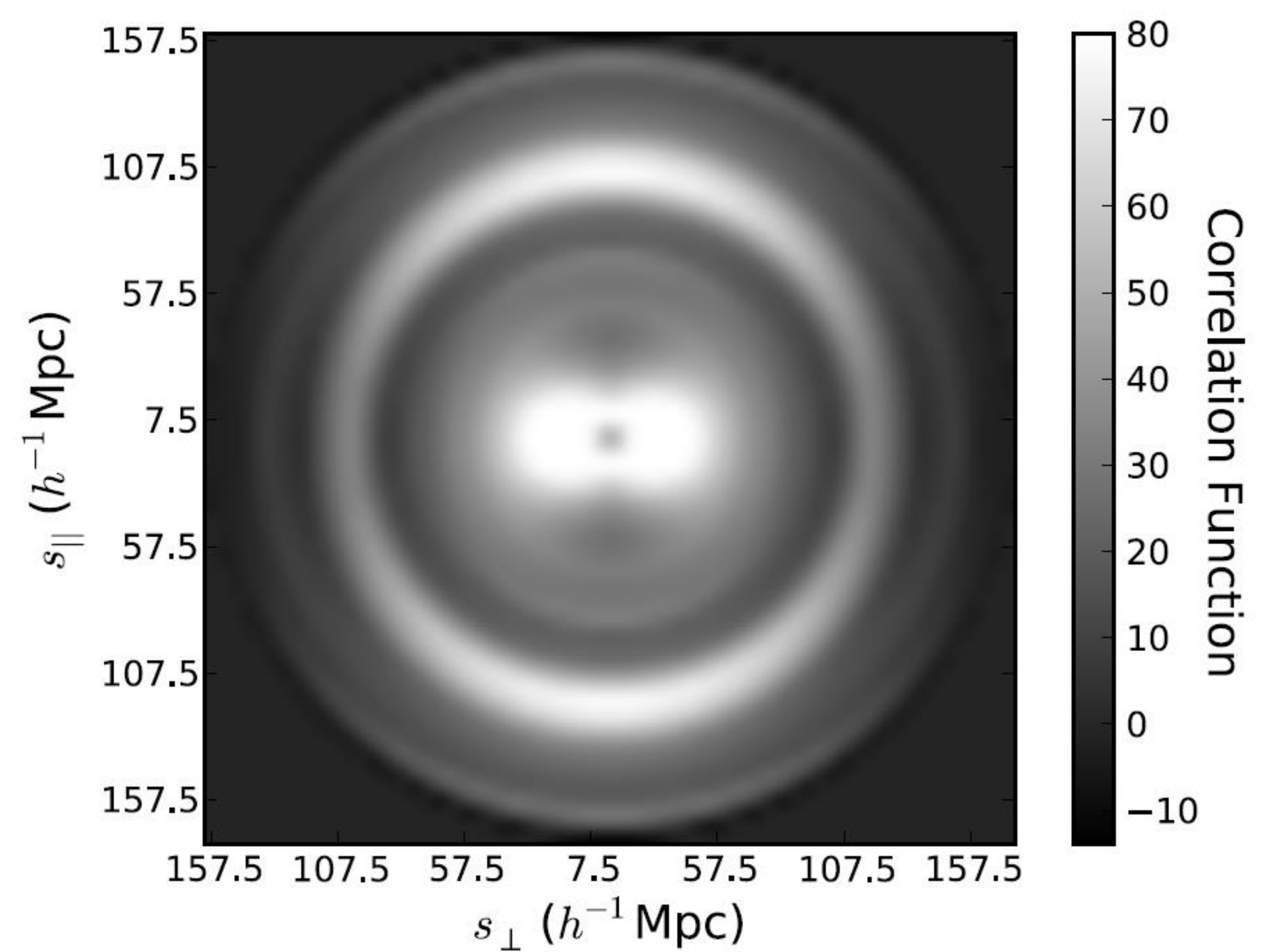


RSD have been measured in real data

Spectroscopic surveys are sensitive to RSD, since the radial distances are not measured directly, but using the Galaxy redshift

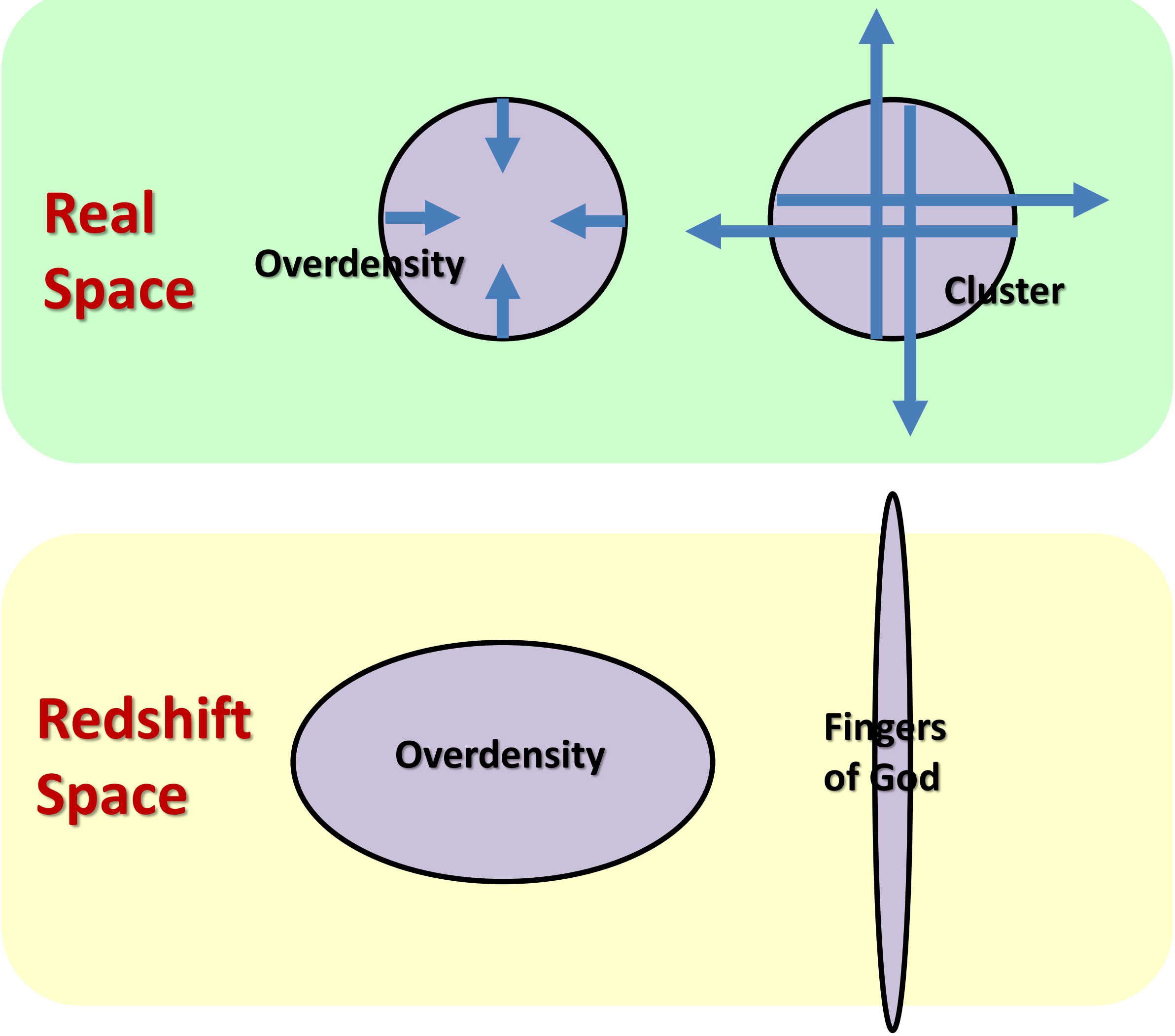
They are affected by the peculiar velocity of the galaxy

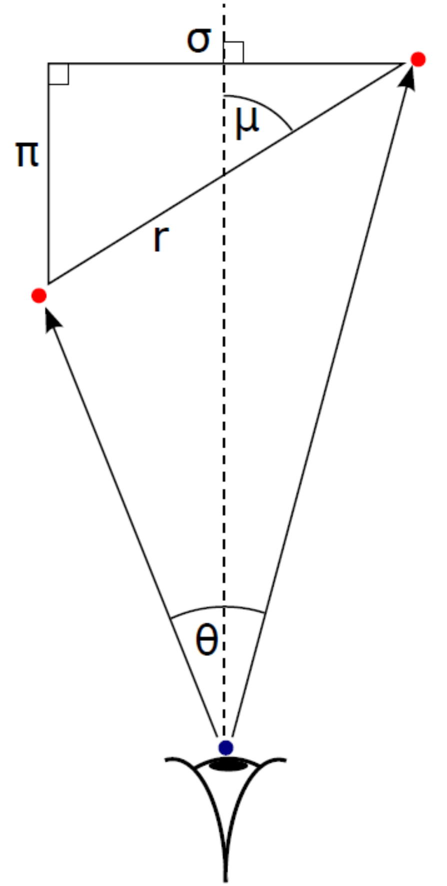



157.5
107.5
57.5
7.5
57.5
107.5
157.5
$s_{||}$ (h^{-1} Mpc)
157.5
107.5
57.5
7.5
57.5
107.5
157.5
$s_\perp$ (h^{-1} Mpc)
80
70
60
50
40
30
20
10
0
−10
Correlation Function

Why RSD?

They are a consequence of peculiar velocities coming from structure
They carry very valuable information about cosmology





RSD change the shape of the power spectrum and the correlation function: Kaiser effect

Assuming peculiar velocities are small, the observed redshift of an object z_o is altered from its comoving redshift z (the shift due only to the expansion) by $z_o = z + v_z$, where v_z is the projection of the object's peculiar velocity along the line of sight (in units of c). Thus, this object will be assigned a radial comoving distance given by

$$\chi_s \equiv \chi(z + v_z) \simeq \chi_r + \frac{v_z}{H(z)}$$

The power spectrum (and the correlation function) becomes asymmetric. The radial and angular directions become different

$$P_s(k, \mu_{\mathbf{k}}, z) = (1 + \beta(z)\, \mu_{\mathbf{k}}^2)^2\, P_r(k, z)$$

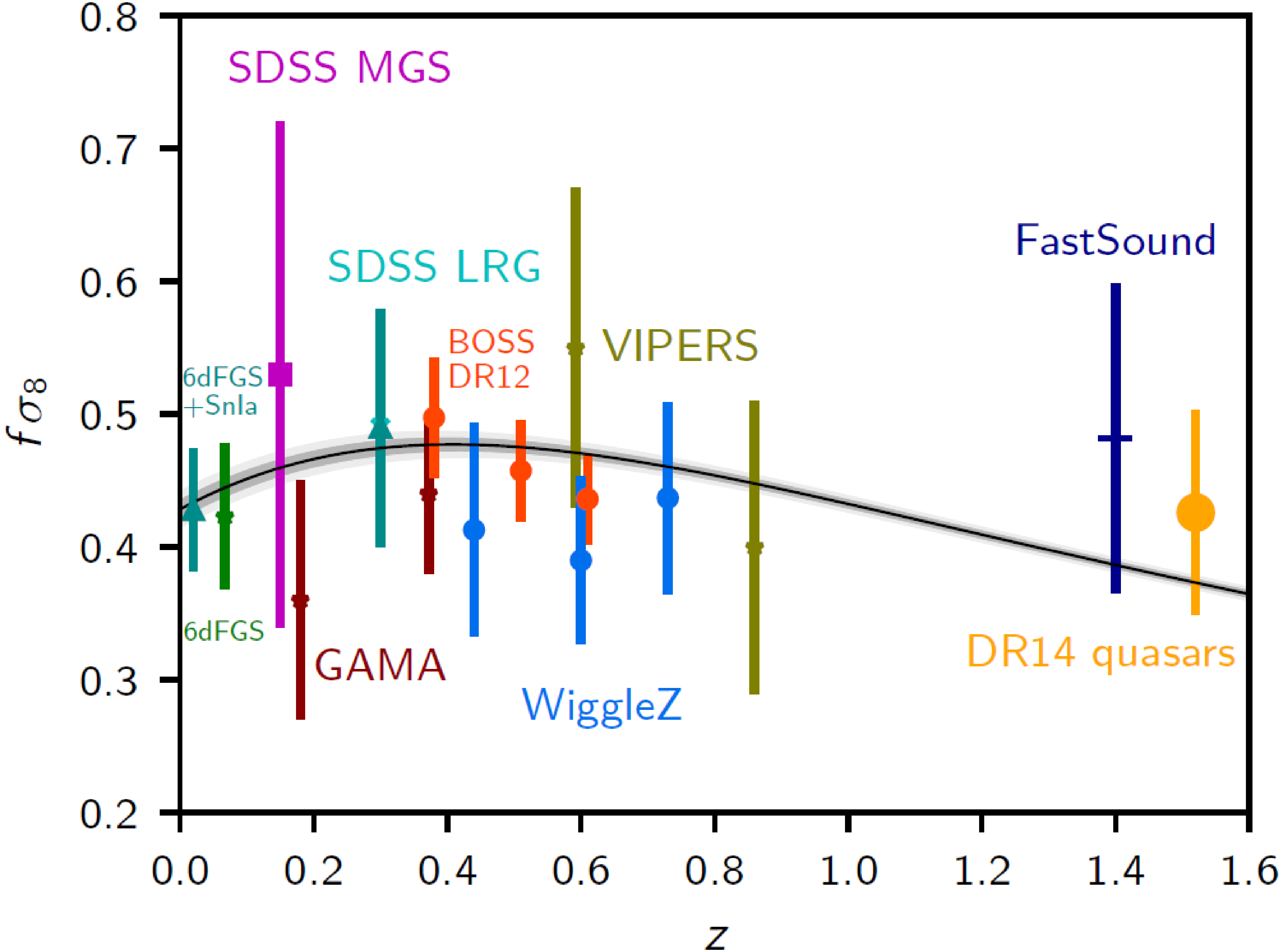
$$\beta \equiv f/b \qquad \mu_{\mathbf{k}} \equiv \mathbf{k} \cdot \hat{\mathbf{n}}_z / k$$

$$f \equiv \frac{d\ln(\delta_{\mathbf{k}})}{d\ln(a)}$$

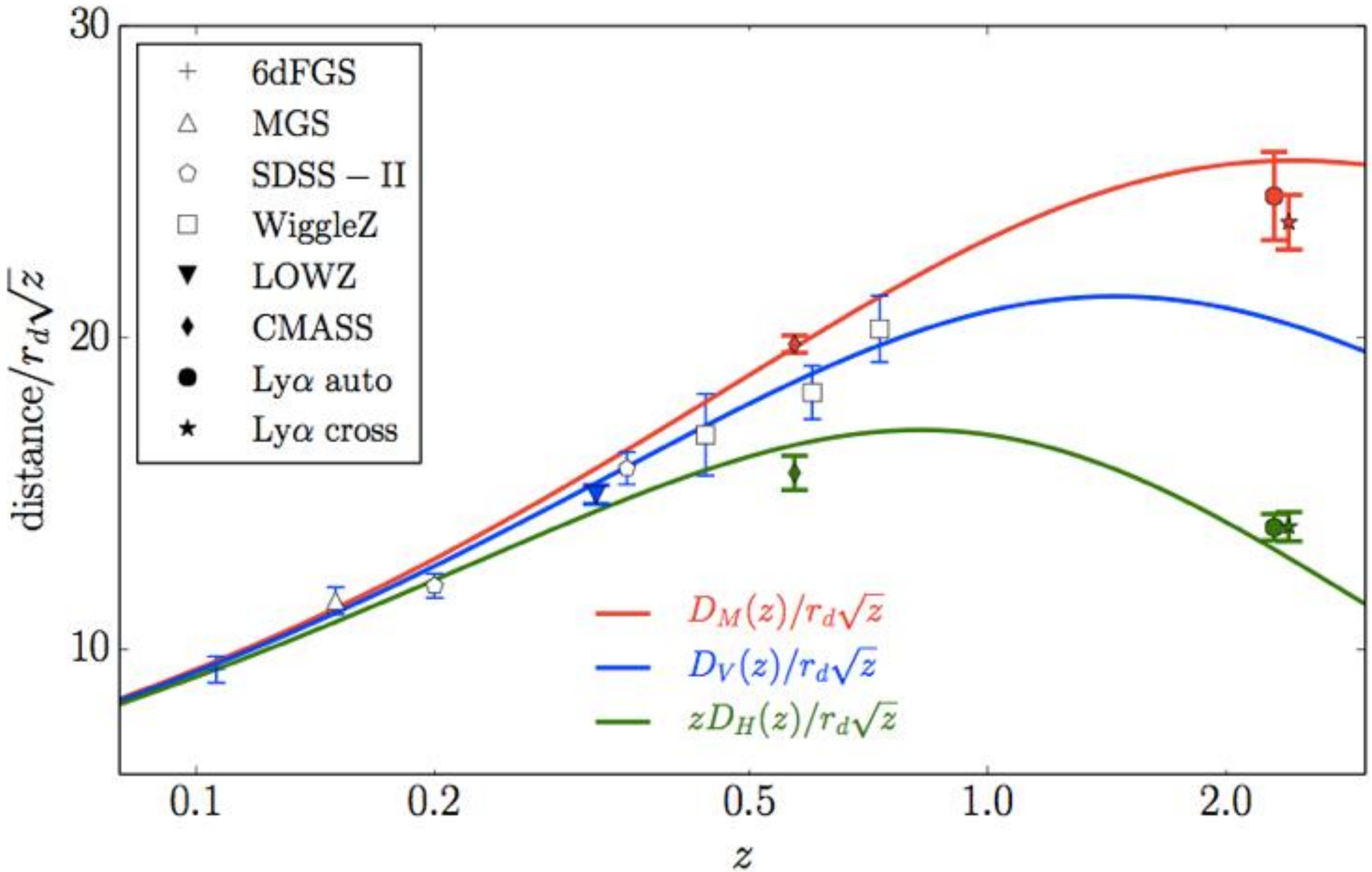
$$f(a) = \Omega_{\mathrm{M}}(a)^{\gamma}$$

f is the Growth rate and γ is the growth index.
For GR γ ~ 0.55

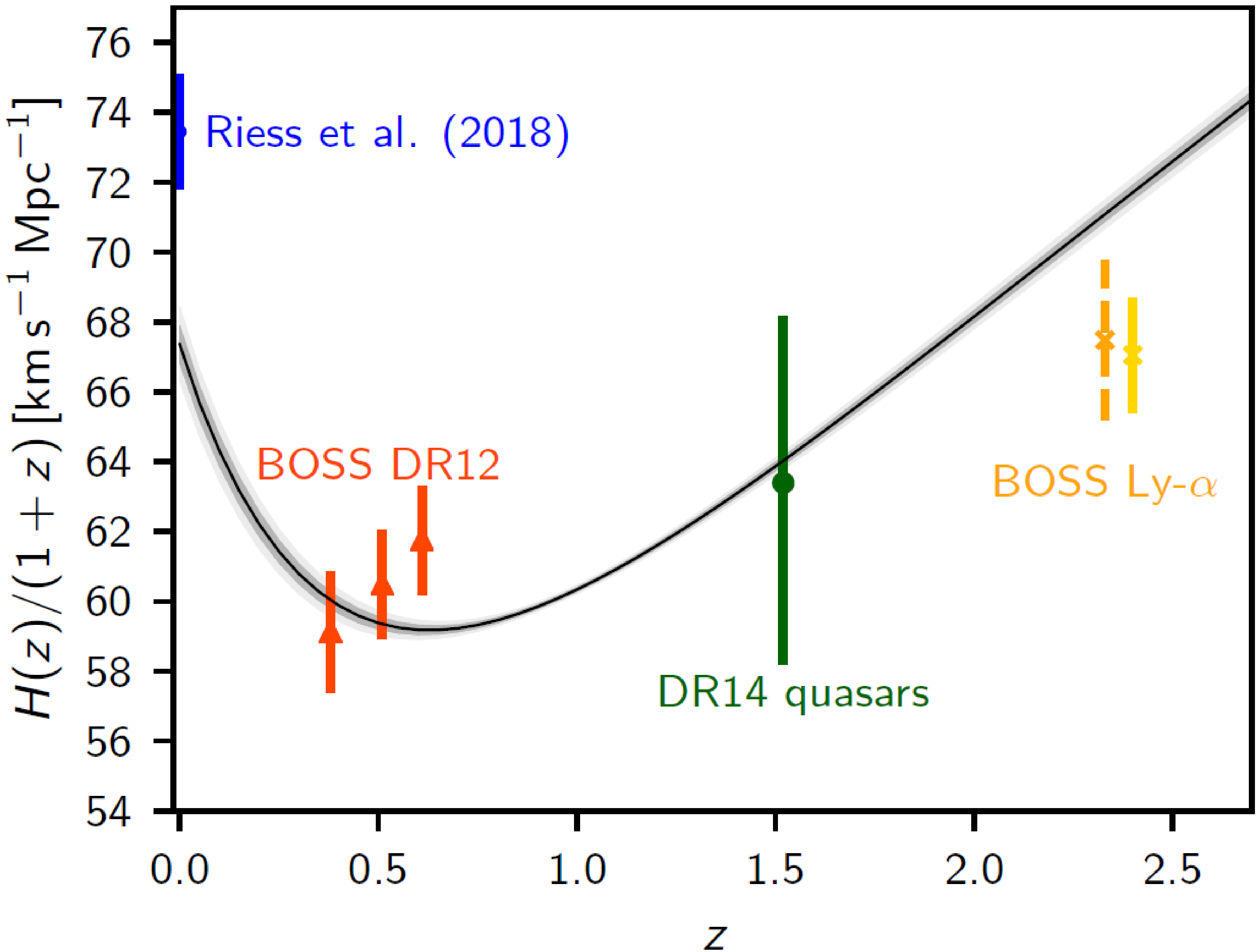
Current status of Growth Factor Measurements



BAO Hubble diagram for different definitions of Distances



Current Hubble Parameter Measurements using BAO Standard Ruler

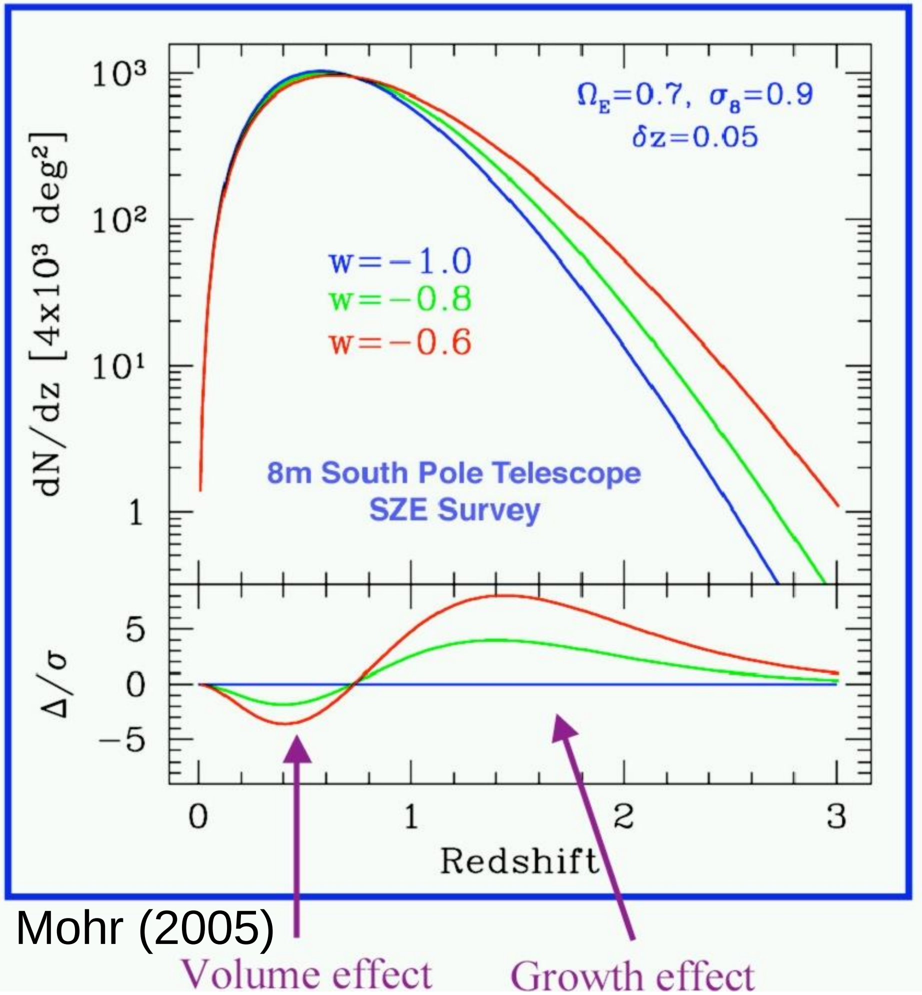


Number of Galaxy clusters

The number of Galaxy clusters as a function of redshift is very sensitive to the cosmological parameters (including dark energy properties)

Sensitive to distances and structure growth

$$\frac{dN}{d\Omega\, dz} = \frac{dV}{d\Omega\, dz} \int_{M_{min}}^{\infty} dM\, \frac{dn}{dM}$$



Mohr (2005)

Number of Galaxy clusters

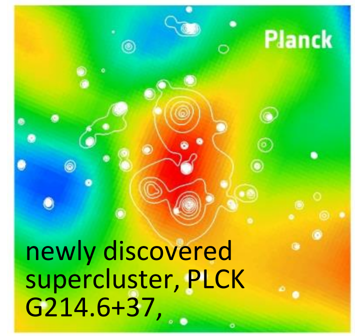
Identify and measure the Galaxy clusters:

Sunyaev Zel'dovich
X Rays
Optical Images
Gravitational Lensing

Measure the mass and the redshift of the cluster

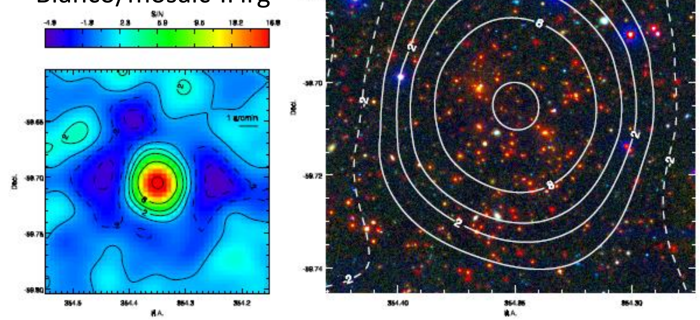
Mass from SZ, X rays or/and lensing
z from optical images and spectra

PLANCK Data release (16/01/2011)

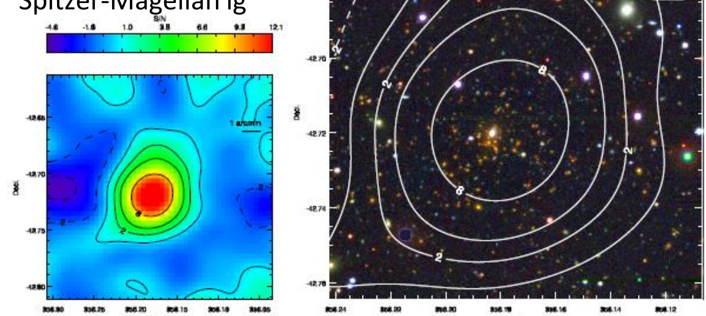


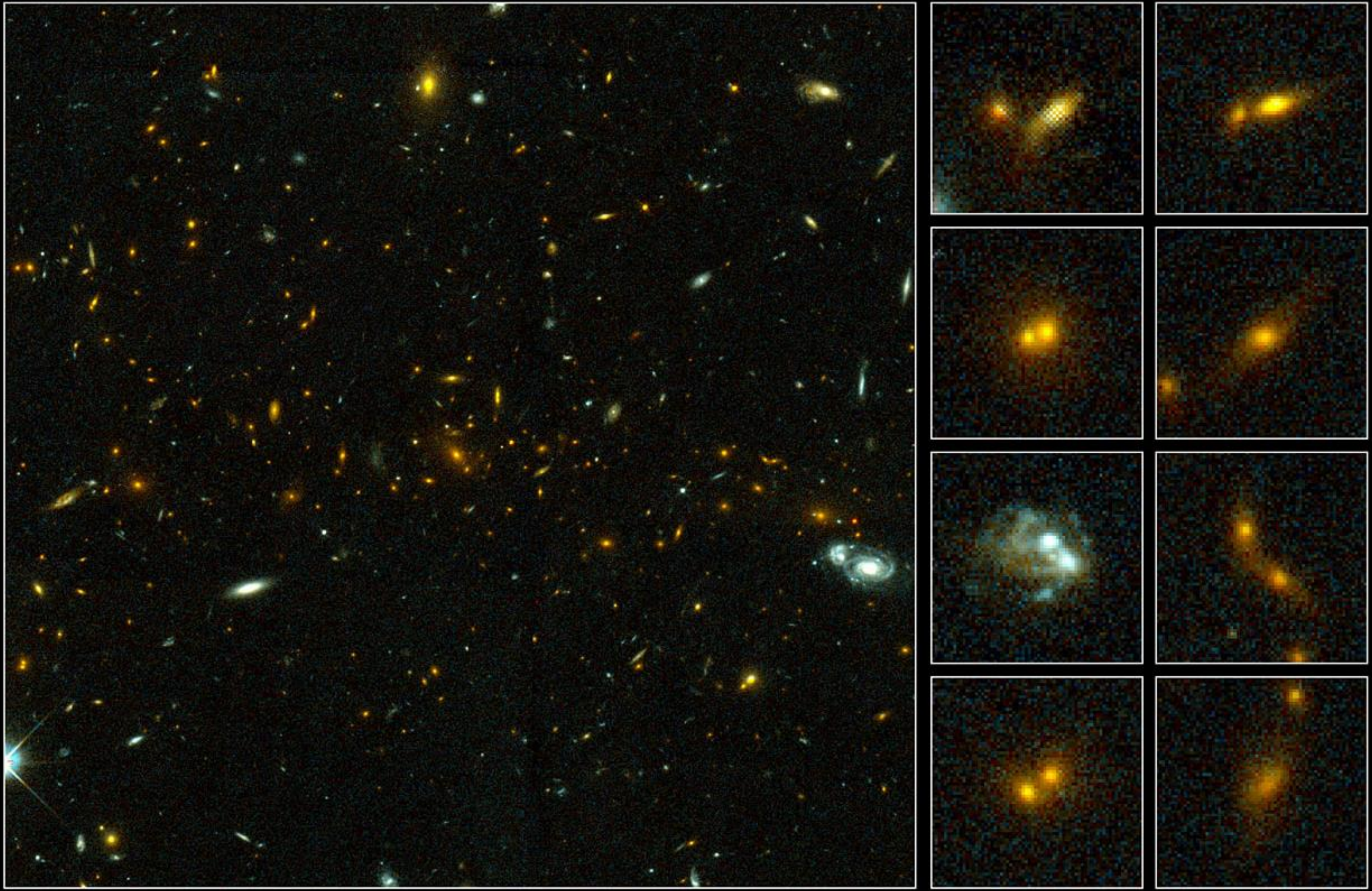
SPT Results
R. Williamson et al., arXiV:1101.1290 astro-ph (2011)

SPT-CL J2344-4243
Z=0.62
Blanco/mosaic-II irg



SPT-CL J2337-5942
Z=0.775
Spitzer-Magellan ig





Galaxy Cluster MS1054-03

Hubble Space Telescope • Wide Field Planetary Camera 2

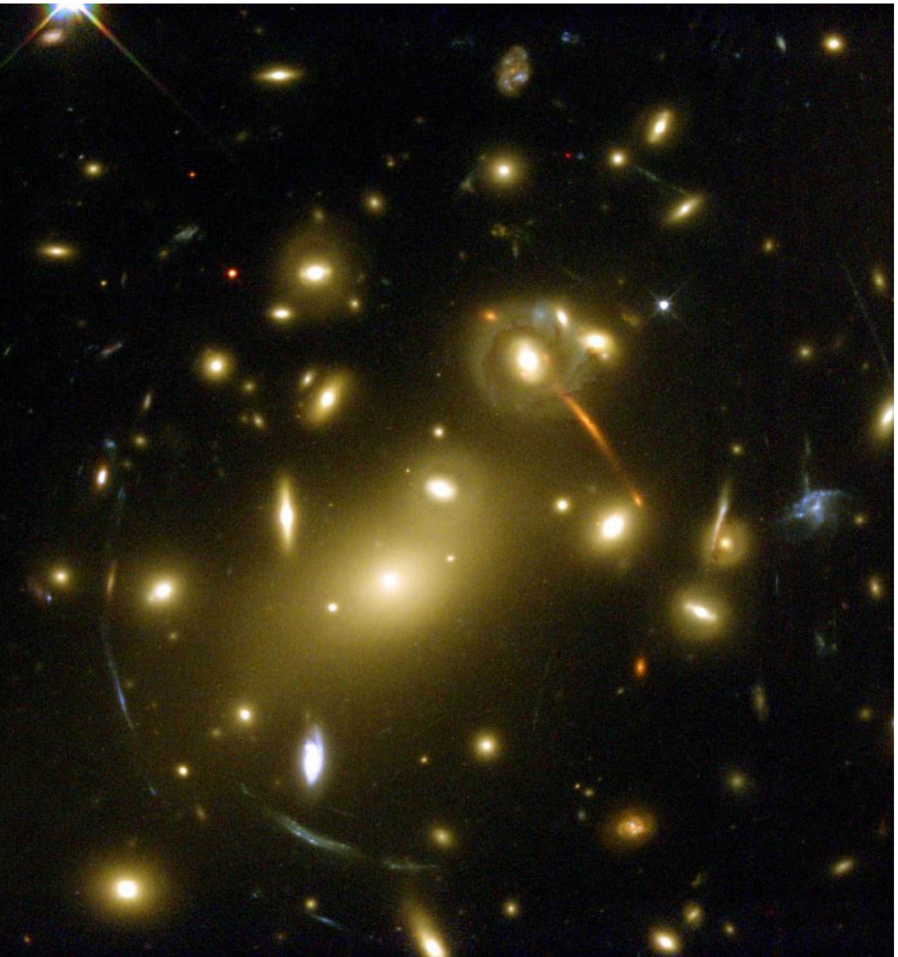
PRC99-28 • STScI OPO • P. van Dokkum (University of Groningen), ESA and NASA

Weak Gravitational Lensing

Radiation is deflected in gravitational fields → Image distortion

Since the effect comes from the gravitational field, it is sensitive to all matter/ energy, including dark matter and dark energy

STRONG LENSING

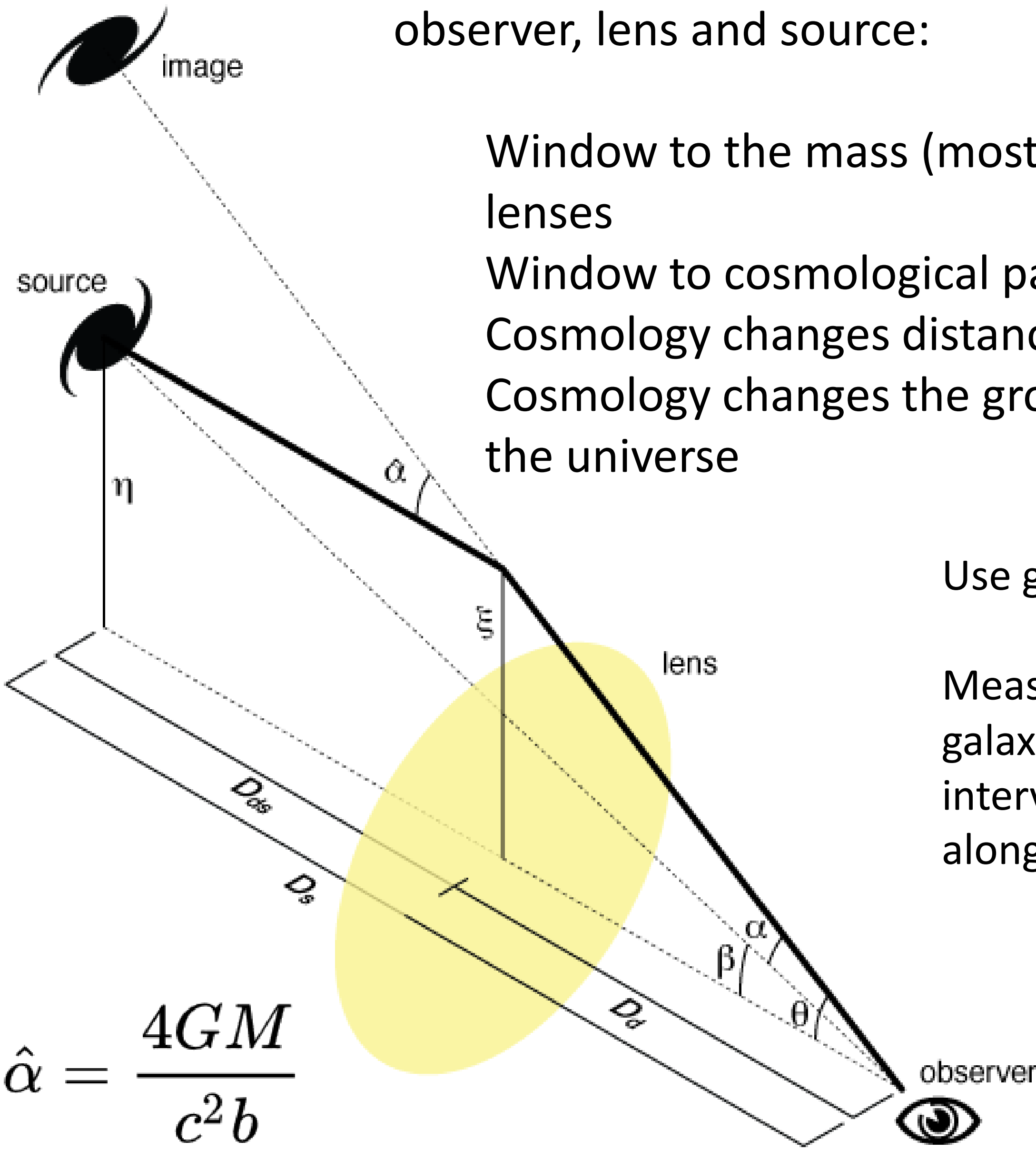


WEAK LENSING

Weak Gravitational Lensing

The effect depends on the lens mass and the distances between observer, lens and source:

Window to the mass (mostly dark matter) distribution in the lenses
Window to cosmological parameters:
Cosmology changes distances **Dd, Ds, Dds**
Cosmology changes the growth rate of mass structures in the universe



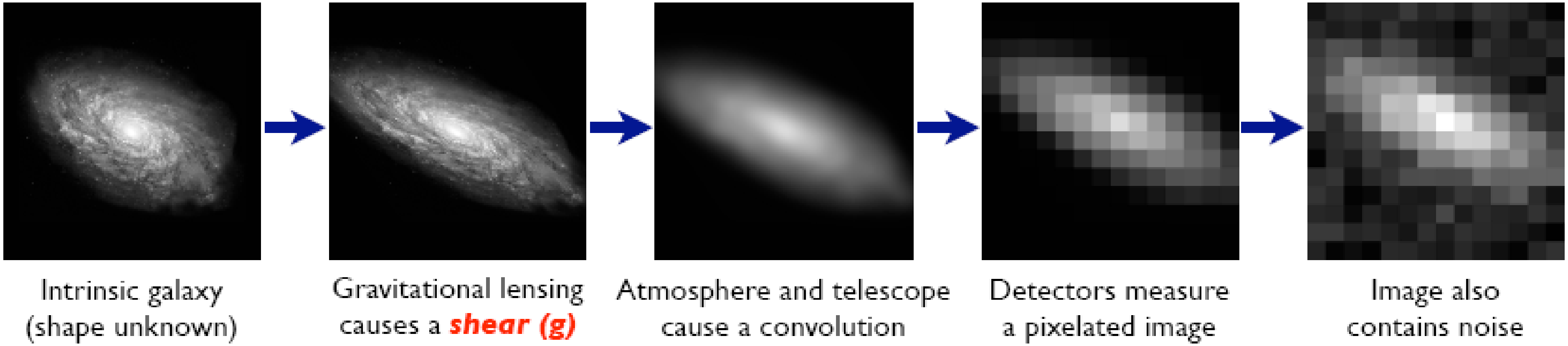
Use galaxies as tracers

Measure the shapes of background galaxies → Galaxy shapes are distorted by intervening mass → Infer mass integrated along the line of sight

$$\hat{\alpha} = \frac{4GM}{c^2 b}$$

Weak Gravitational Lensing

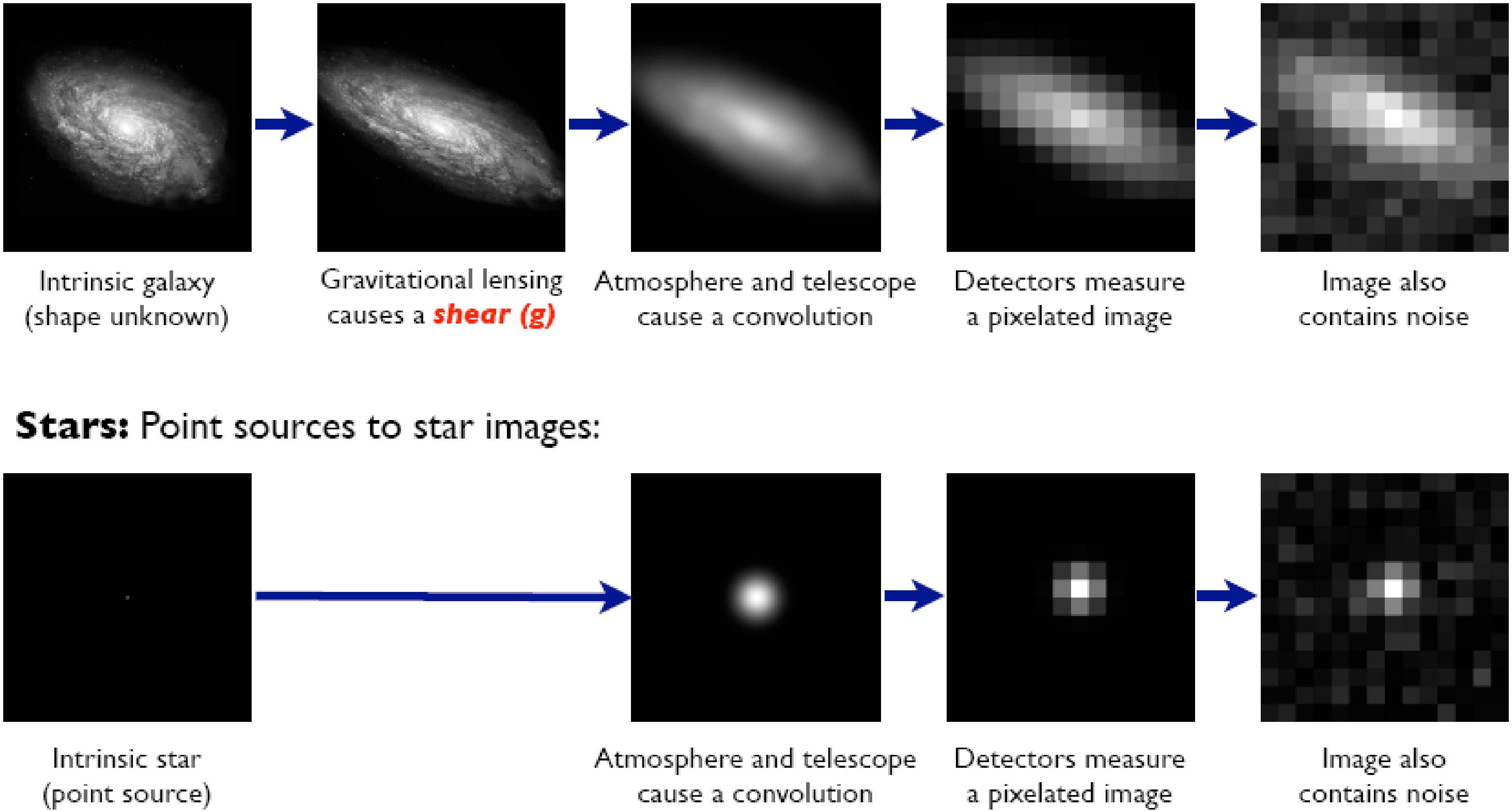
Effect exagerated by x20



Small and difficult to measure effect, but observable

Weak Gravitational Lensing

Effect exagerated by x20

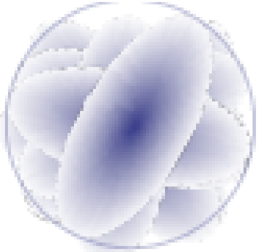


Small and difficult to measure effect, but observable

Control the measurement using known pointlike objects → stars

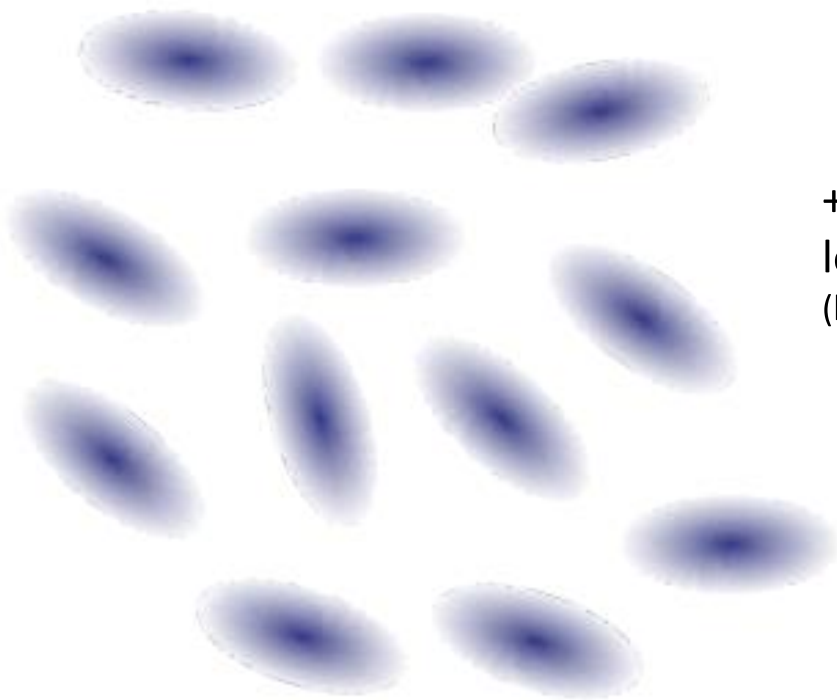
Weak Gravitational Lensing

small patch on sky filled with (elliptical) galaxies
(unrelated objects with different redshifts)

=> the average shape will be circular: 

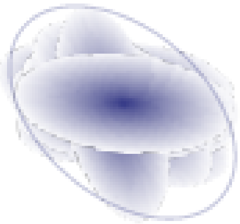
Weak Gravitational Lensing

small patch on sky filled with (elliptical) galaxies
(unrelated objects with different redshifts)

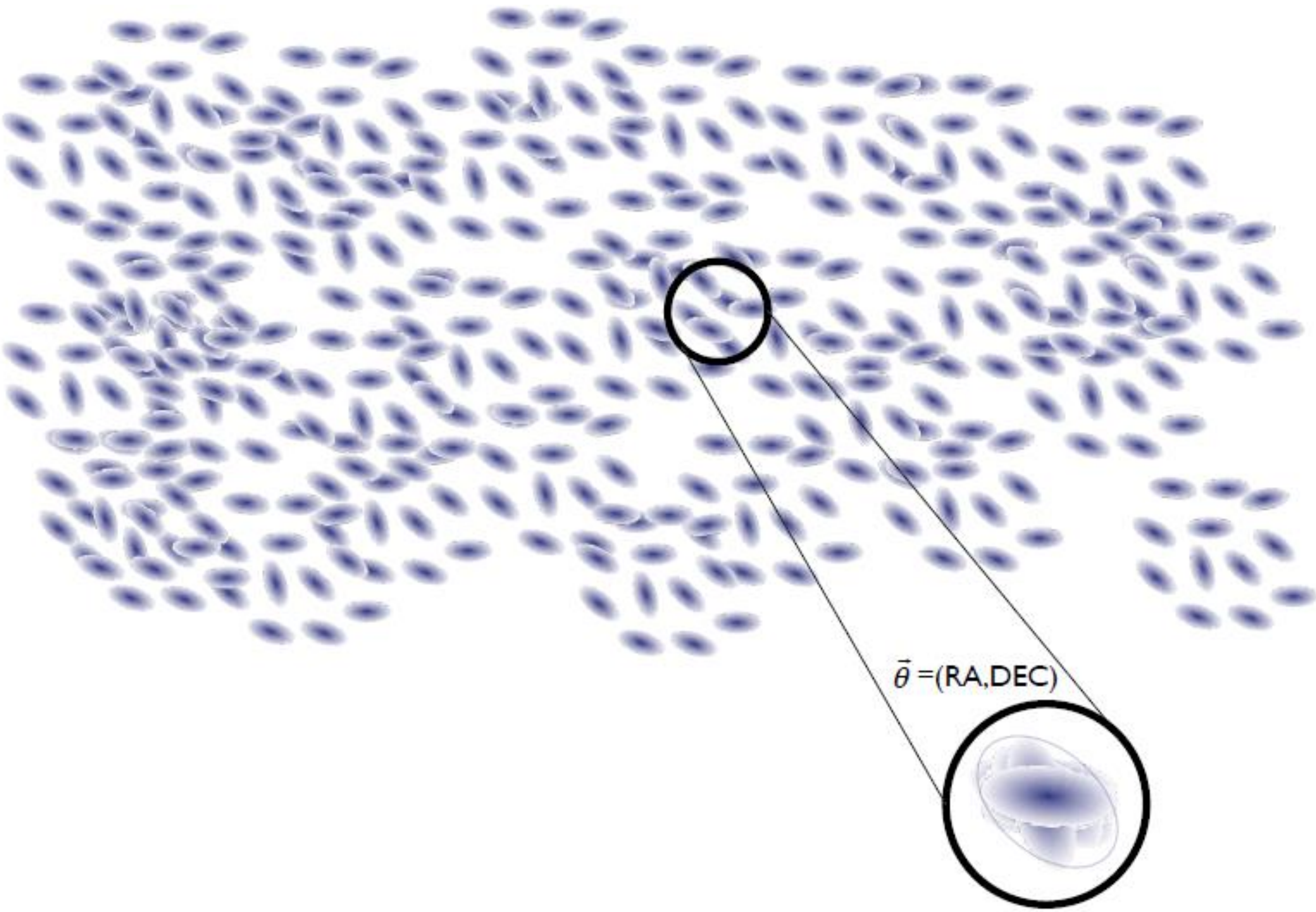


+ weak gravitational lensing!
(lightpaths become related)

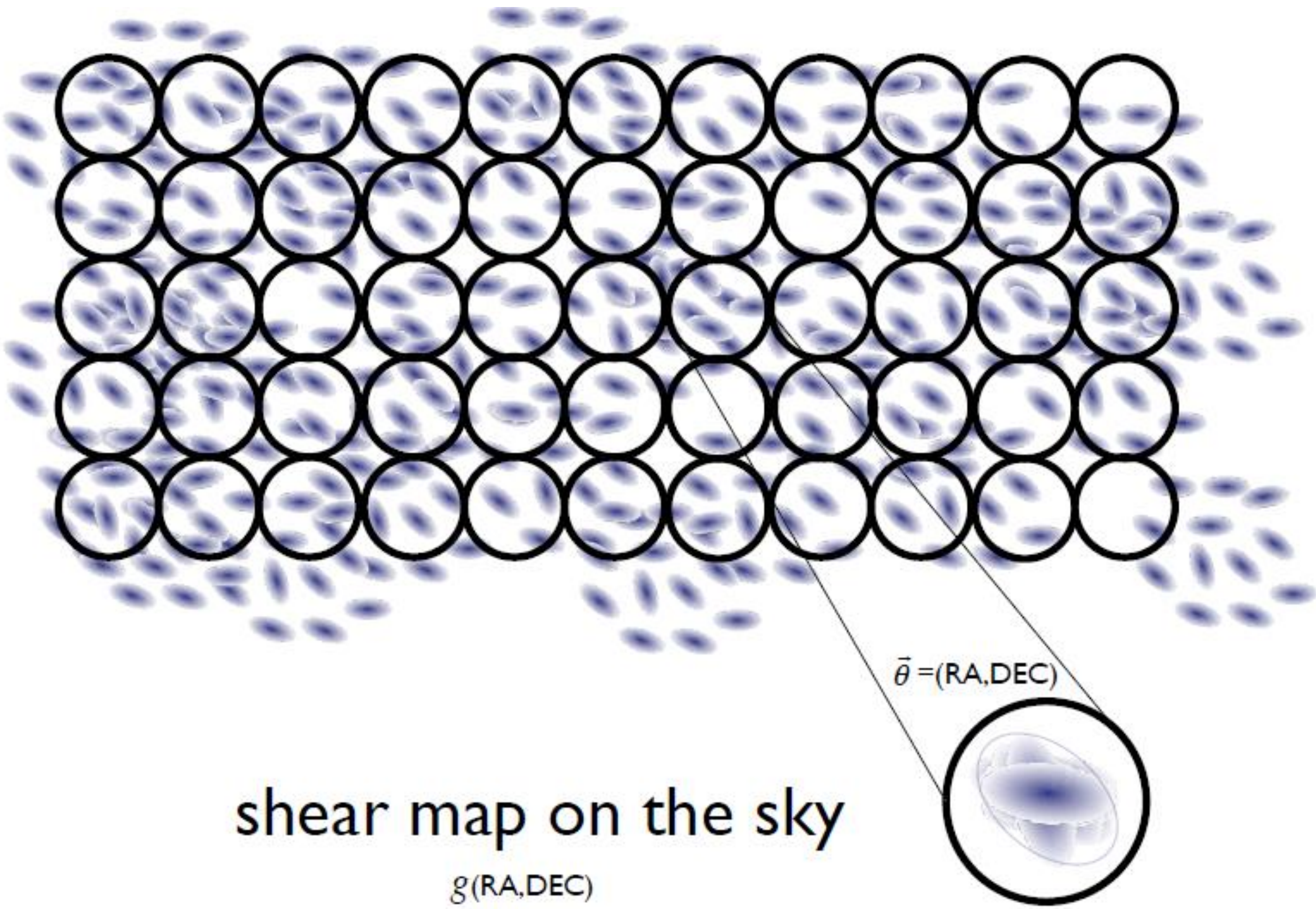
=> the average shape will be elliptical:



Weak Gravitational Lensing

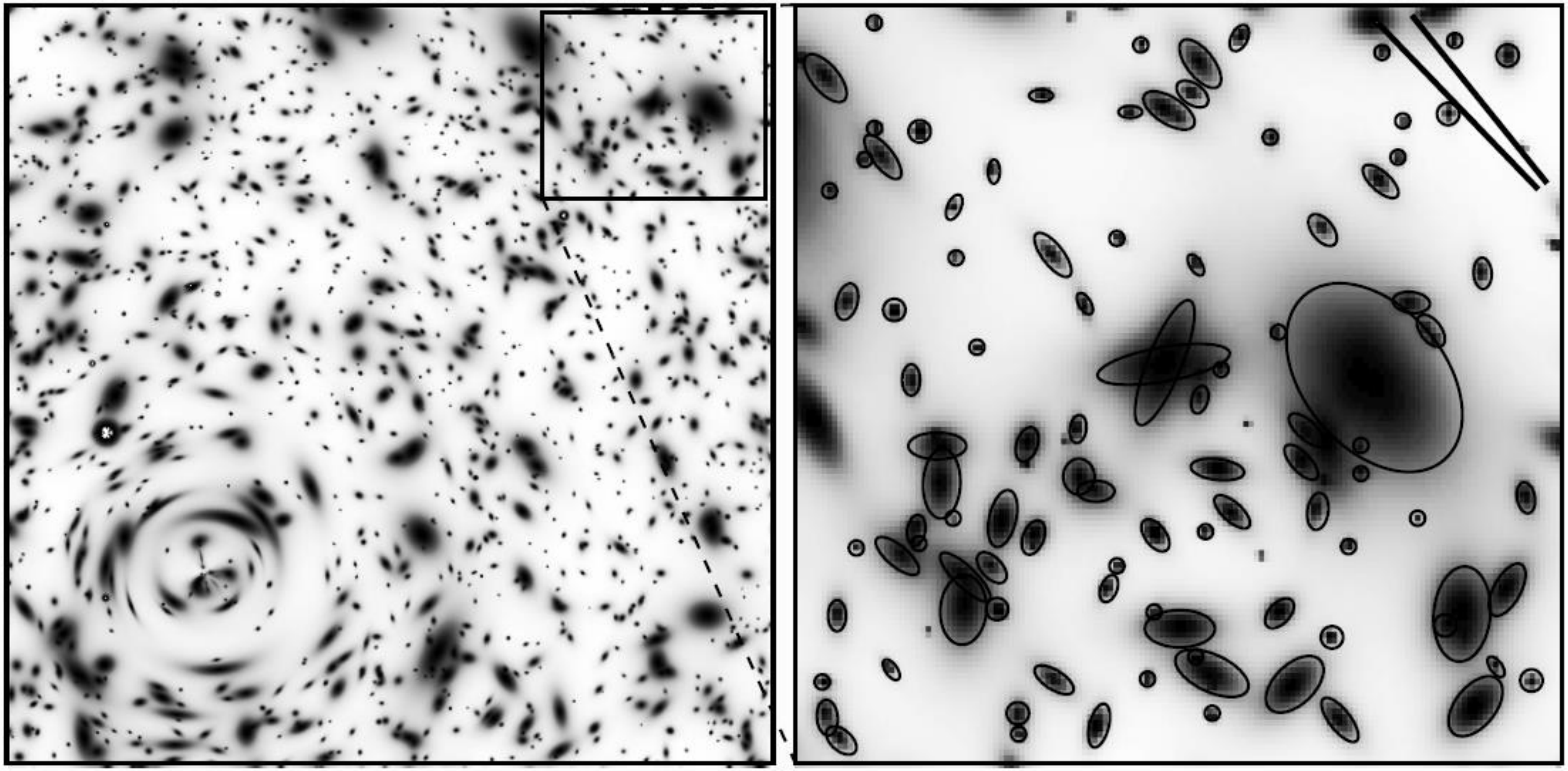


Weak Gravitational Lensing



Weak Gravitational Lensing

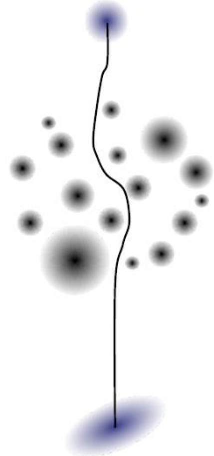
Ellipticity and local shear



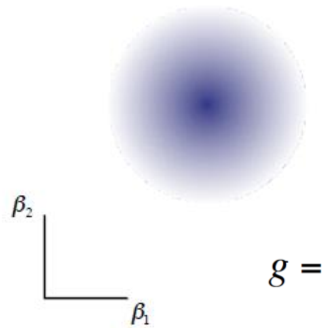
[from Y. Mellier]

Galaxy ellipticities are an estimator of the local shear.

Weak Gravitational Lensing

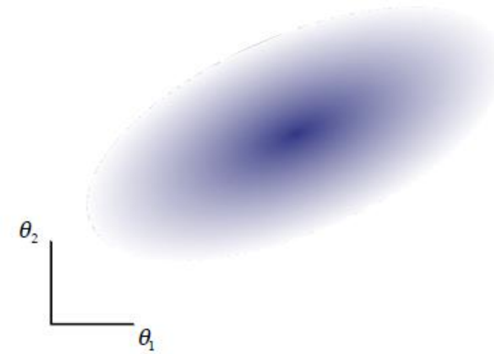


The distortion matrix



$$g = \frac{\gamma}{1-\kappa} = \langle \varepsilon(\theta) \rangle$$

is observable!



$$\kappa(\theta) = \frac{3H_0^2\Omega_0}{2c^2} \int n_s(z_s) \int \frac{D_{LS} D_L}{D_S} \frac{\delta(\theta, z)}{a(z)} dz\, dz_s$$

$$A_{ij} = (1-\kappa)\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} - \begin{pmatrix} \gamma_1 & \gamma_2 \\ \gamma_2 & -\gamma_1 \end{pmatrix}$$

Growth of structure: Density contrast

Geometry: Comoving distance to lens, source and scale factor

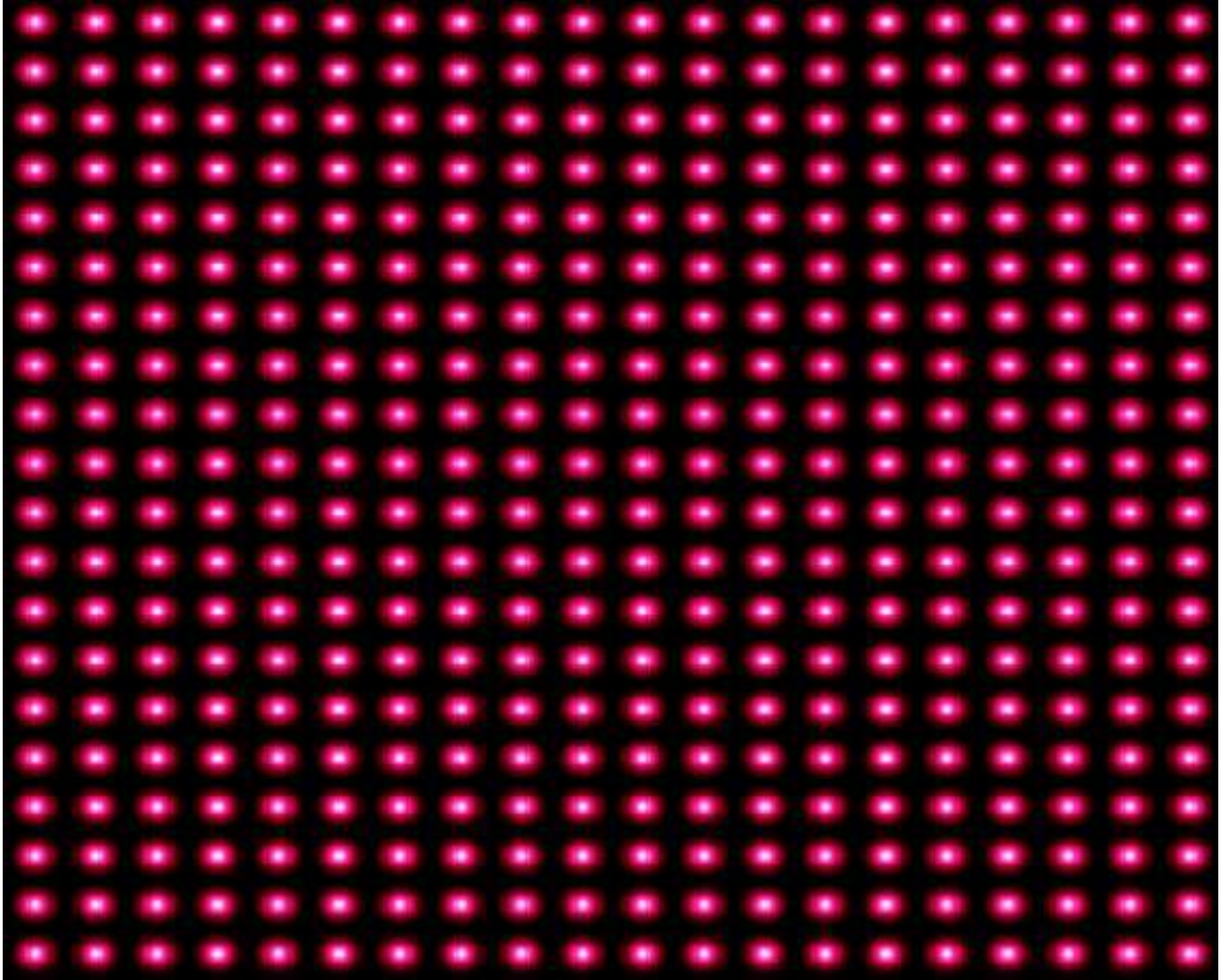
$$\kappa_{lm} = \int d\hat{\mathbf{n}}\, \kappa(\hat{\mathbf{n}}, \chi)\, Y^*_{lm}(\hat{\mathbf{n}})$$

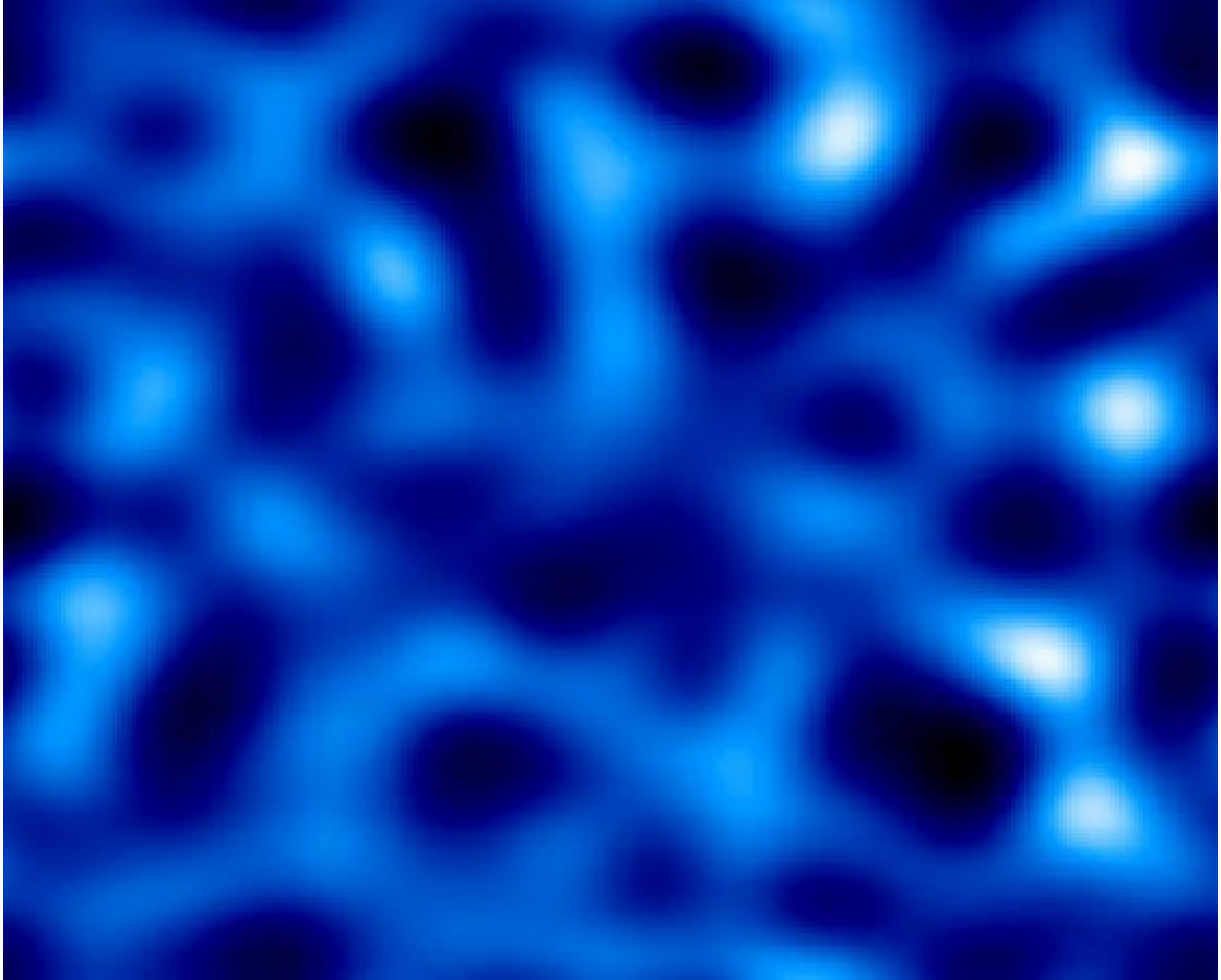
$$\langle \kappa_{\ell m} \kappa_{\ell' m'} \rangle = \delta_{\ell \ell'}\, \delta_{m m'}\, P^{\kappa}_{\ell}$$

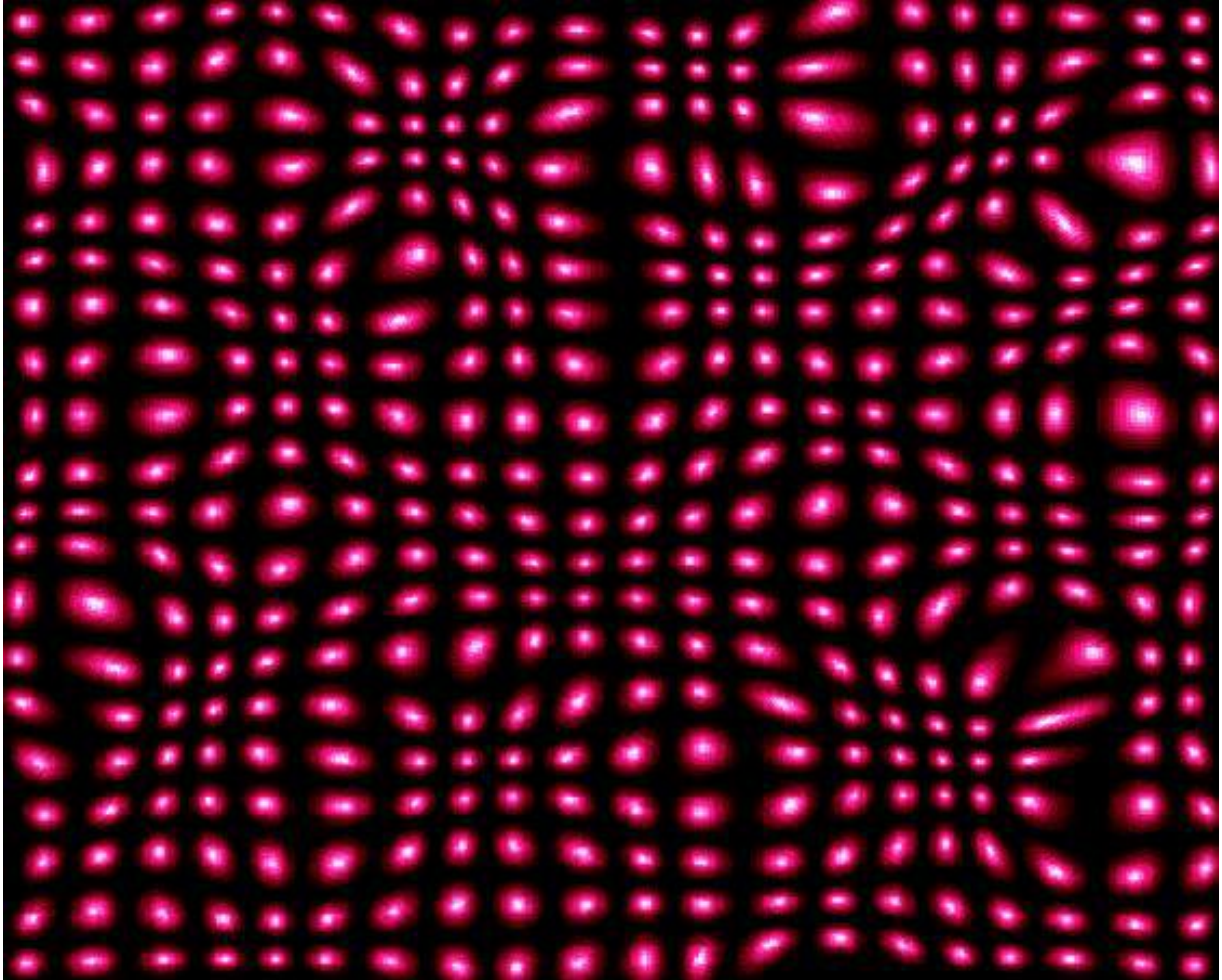
$$W(\chi) = \frac{3}{2} \Omega_M\, H_0^2\, g(\chi)\, (1+z)$$

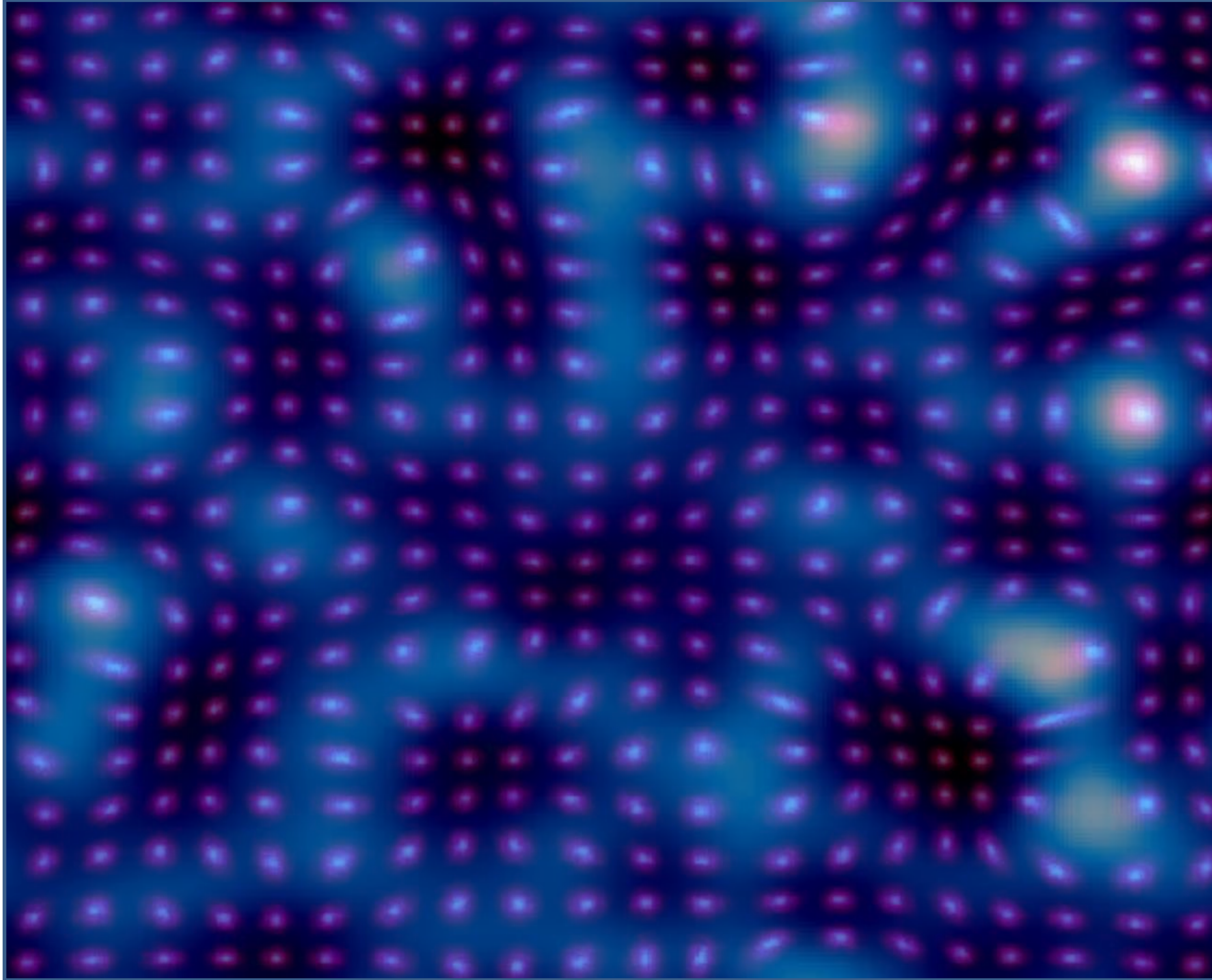
$$P^{\gamma}_{\ell}(z_s) \simeq P^{\kappa}_{\ell}(z_s) = \int_0^{z_s} \frac{dz}{H(z) d_A^2(z)} W(z)^2 P\left(k = \frac{\ell}{d_A(z)}; z\right)$$

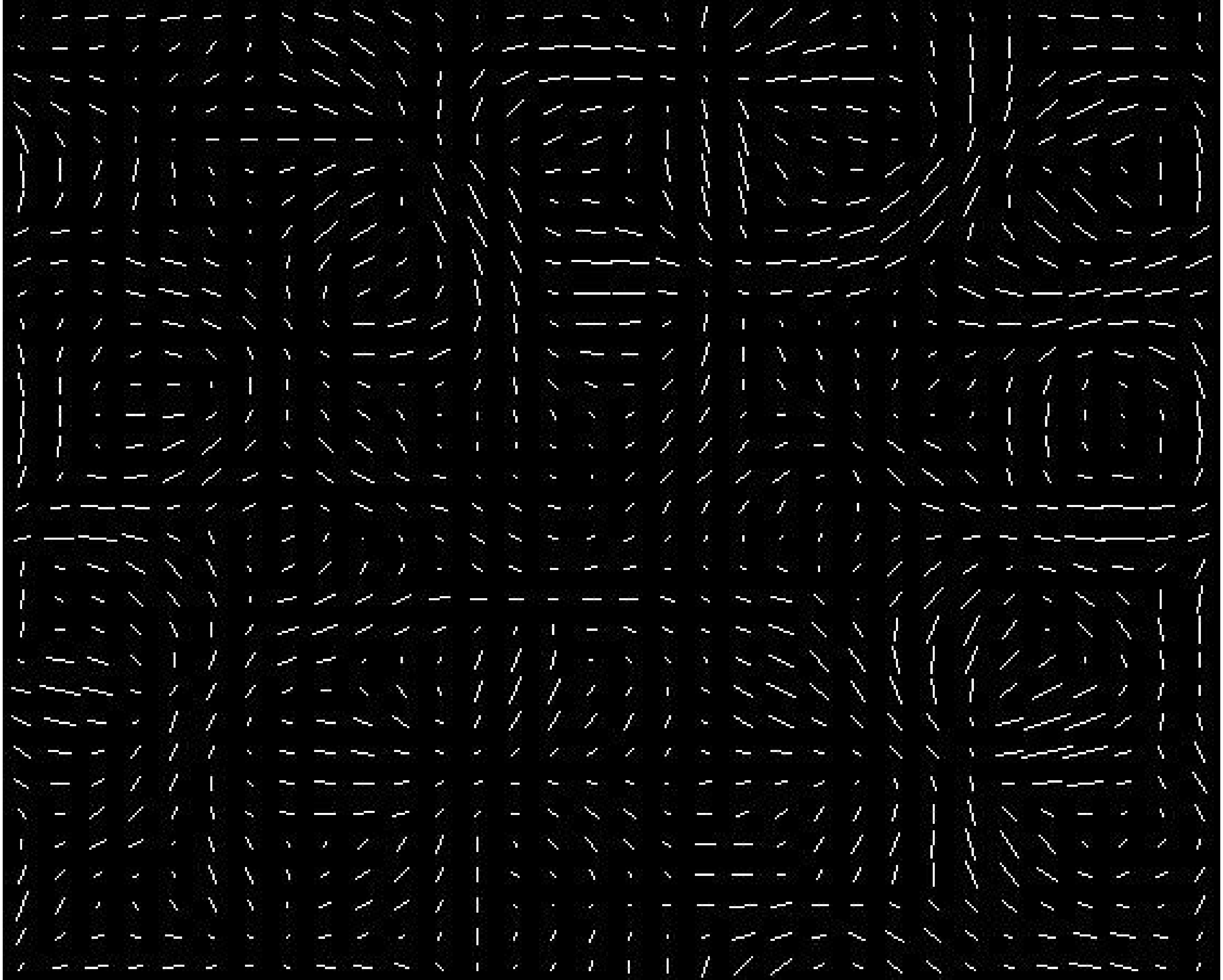
Great potential for cosmology

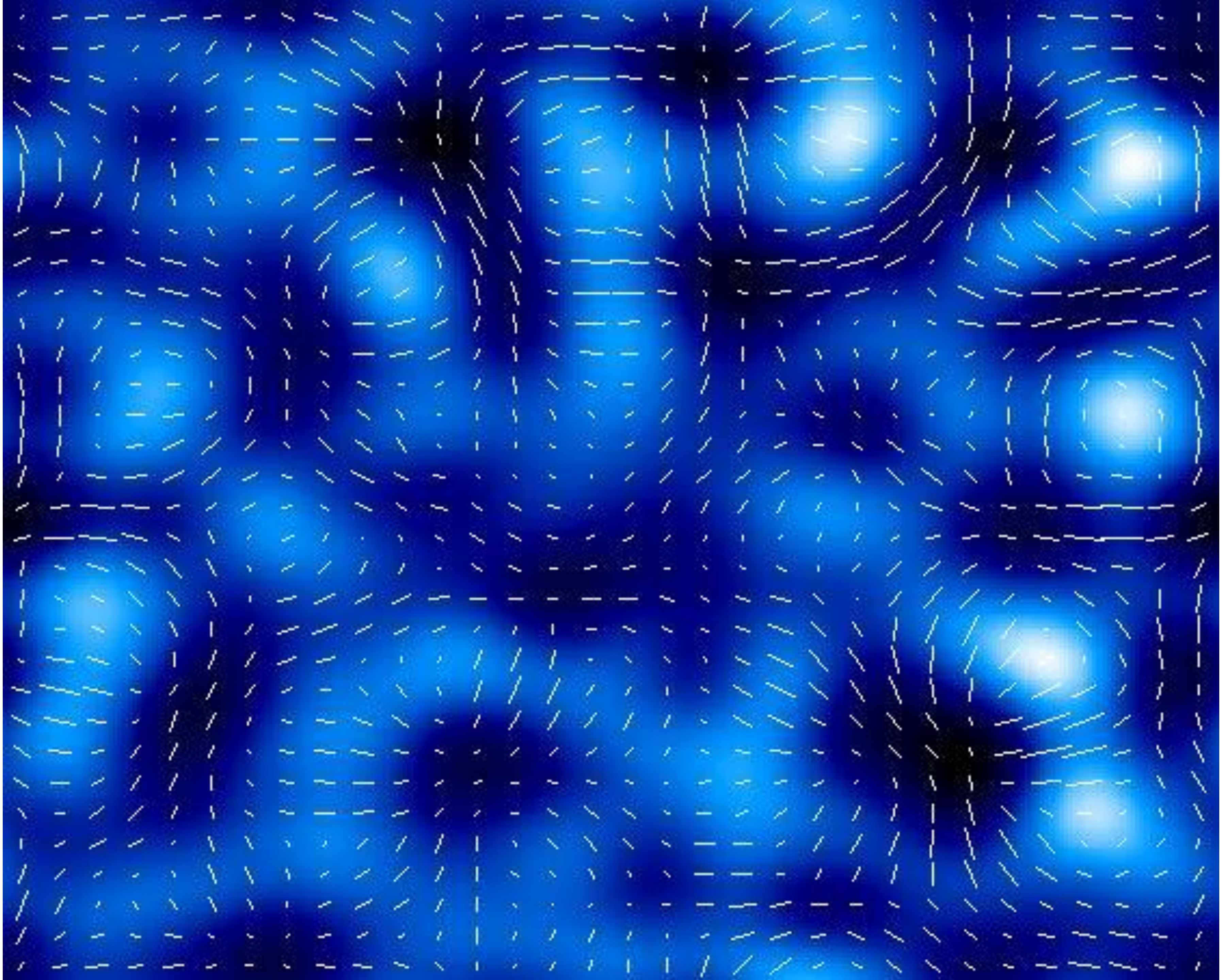


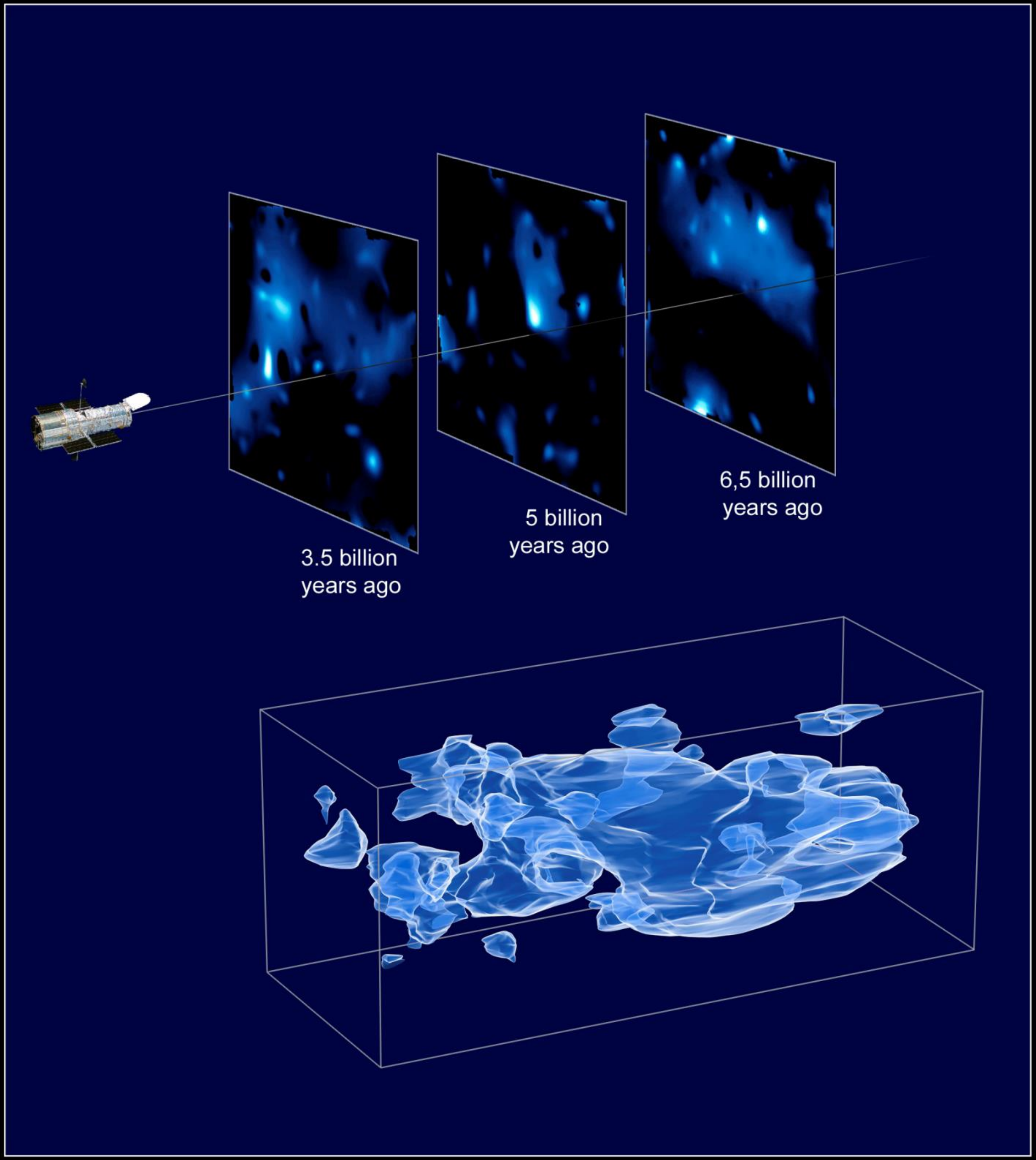











3.5 billion years ago
5 billion years ago
6,5 billion years ago

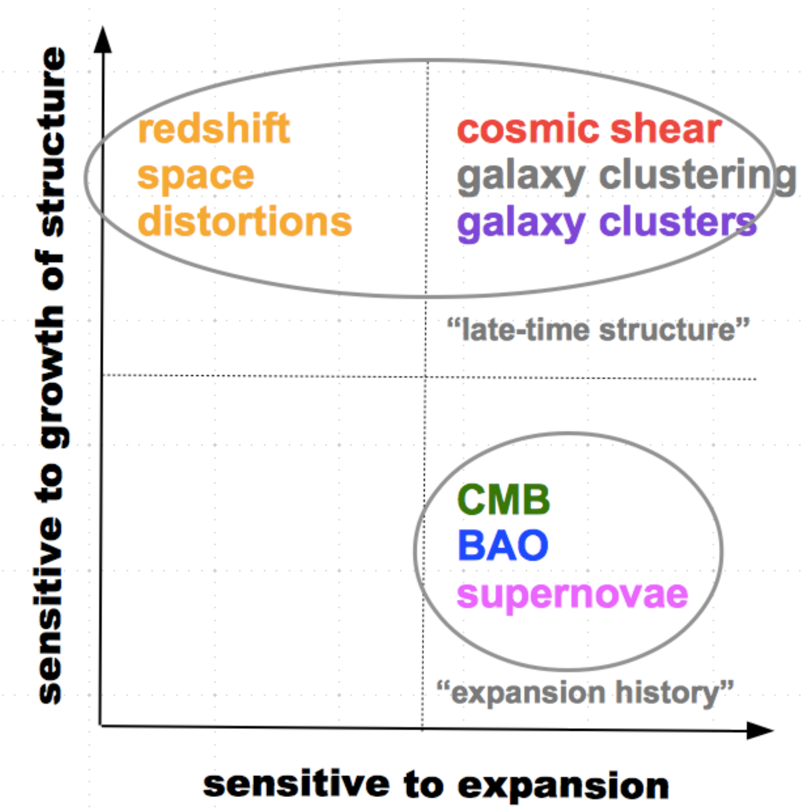
Beyond individual probes

There are many observational probes for dark energy:

__Distance probes__: SN1a, BAO, CMB, weak lensing, Galaxy clusters…
__Growth of structure probes__: CMB, RSD, weak lensing, clusters…

No single technique is sufficiently powerful to improve the current knowledge on dark energy by one order of magnitude →

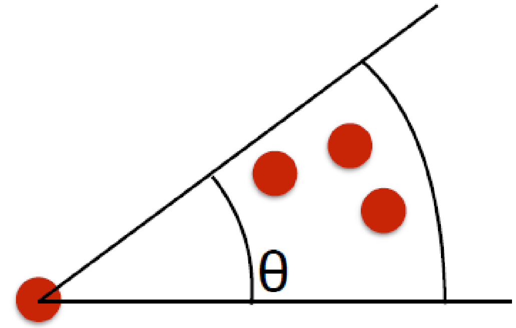
COMBINATION OF TECHNIQUES



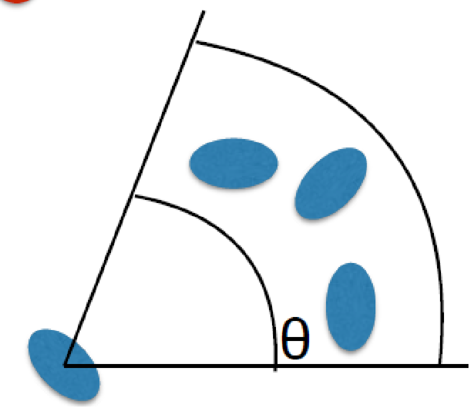
Beyond individual probes

We can measure more properties of galaxies than only their positions: Colors, spectra, shape and we can correlate them

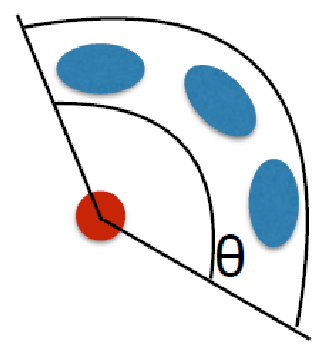
Correlations



- $w(\theta)$
  Galaxy density (position) correlation function

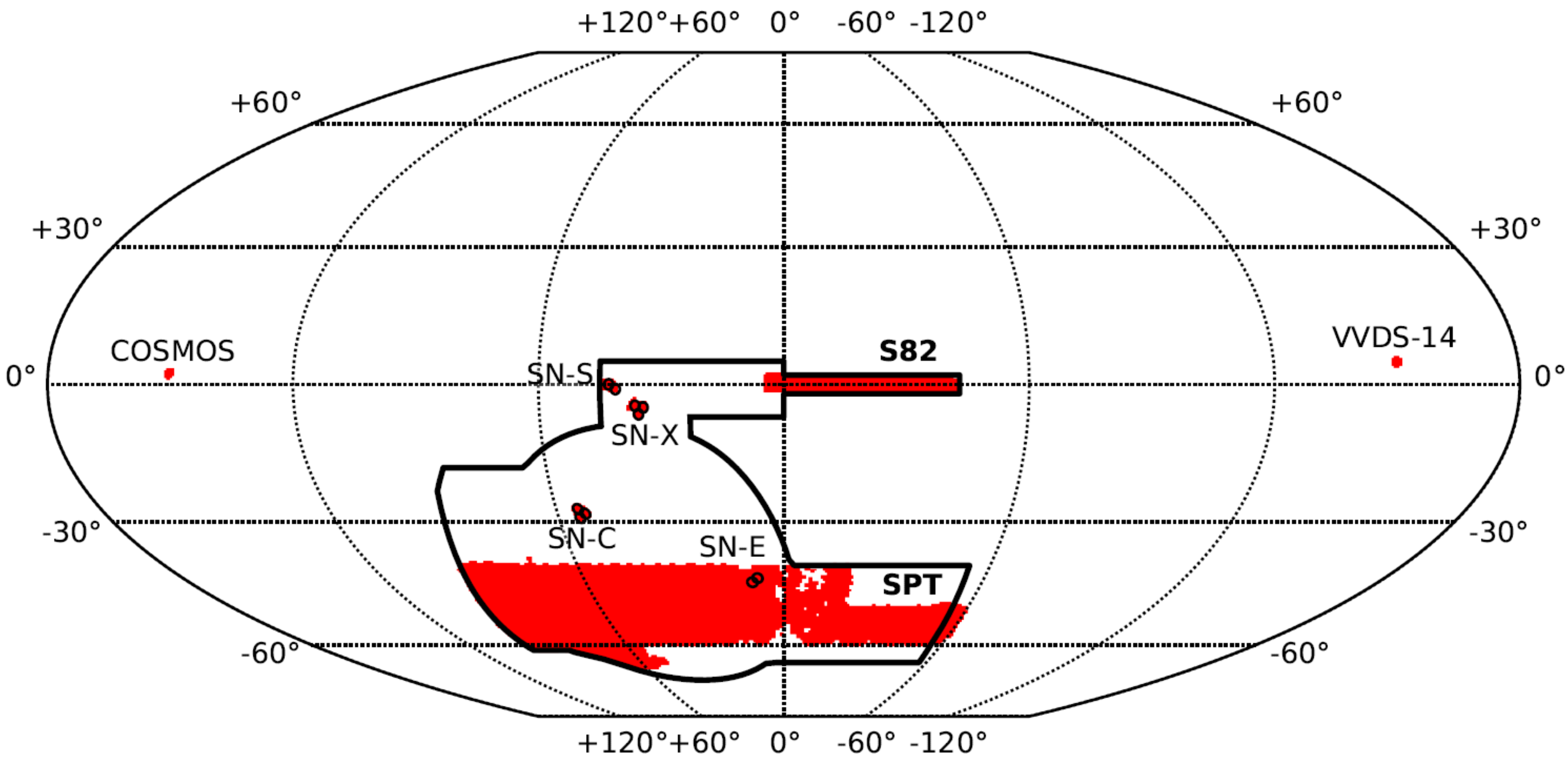


- $\xi_{+}(\theta)$, $\xi_{-}(\theta)$
  Shear (shape) correlation functions



- $\gamma_T(\theta)$
  Shear around galaxies
  (galaxy-galaxy lensing)

Example: Cosmology from clustering AND weak lensing from DES Y1 Data



The Dark Energy Survey

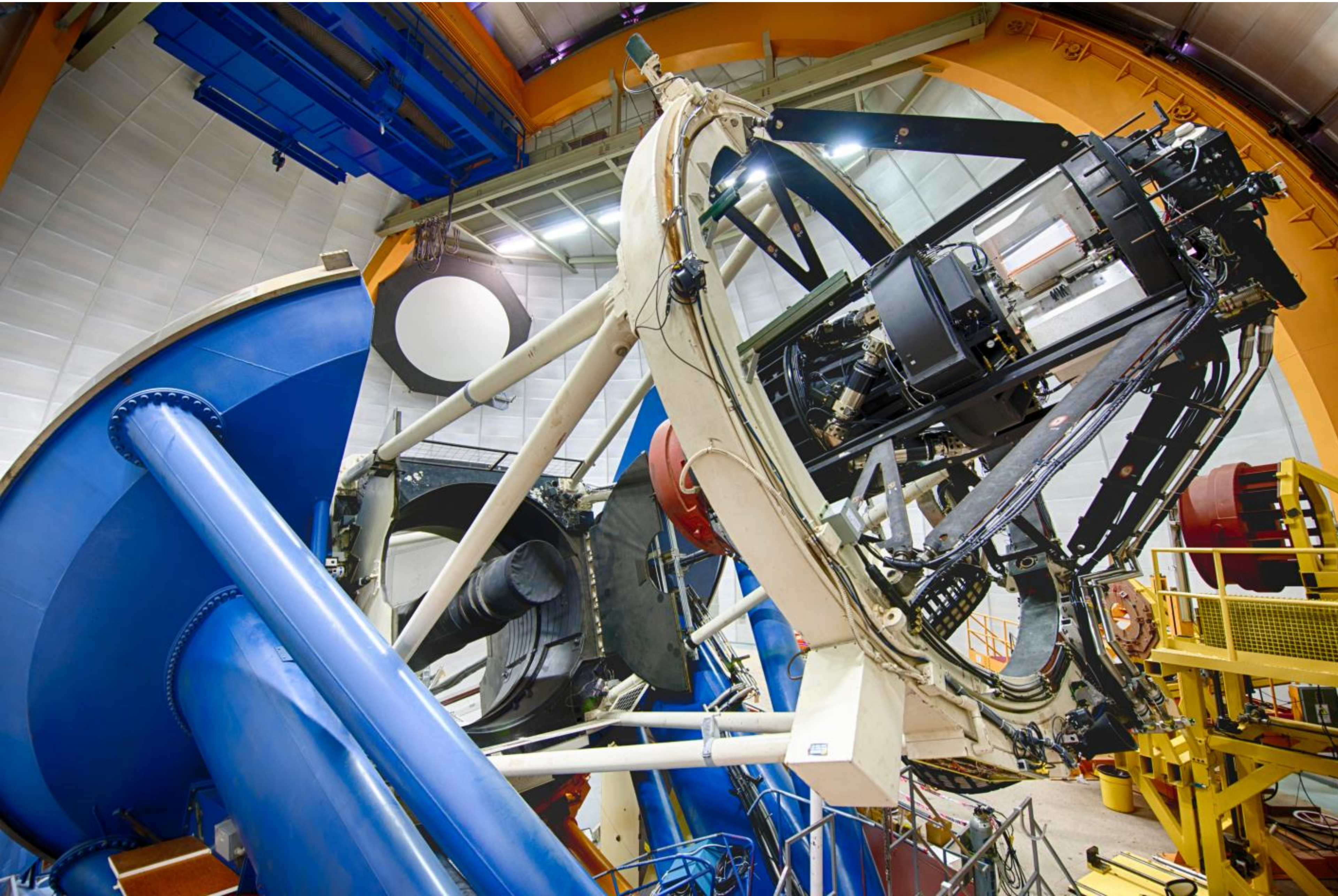
Optical/IR imaging survey with the Blanco 4m telescope at Cerro Tololo Inter-American Observatory(CTIO) in Chile

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)

Up to i_{AB} ~ 24th magnitude at 10 σ (z~1.5)

570 Mpx camera with 3 sq-deg FoV, DECam

Installed on Blanco since 2012



NGC 1365

NGC 1365 (the Great Barred Spiral Galaxy) is a barred spiral galaxy about 56 million light-years away in the constellation Fornax. (DECam, DES Collaboration)

NGC 1566

NGC 1566 (the Spanish Dancer) is a spiral galaxy in the constellation Dorado. (DECam, DES Collaboration)

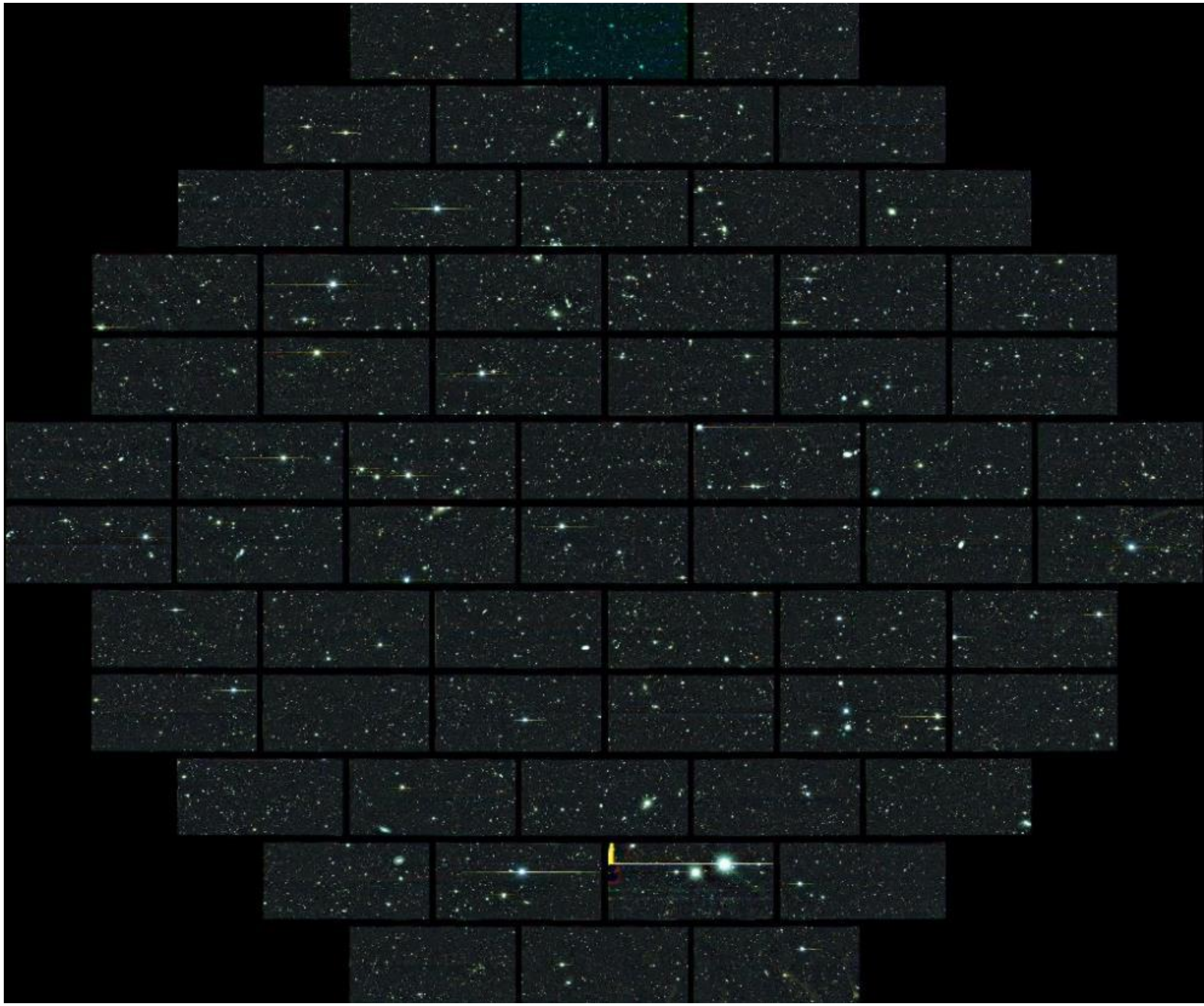
DECam

74 CCD chips (570 Mpx/image) (62 2kx4k image, 8 2kx2k alignment/focus, 4 2kx2k guiding)

Red Sensitive CCDs
QE>50% @ 1000 nm
250 microns thick

3 sq-deg FoV
Excellent image quality
0.27´´/pixel

Low noise electronics (<15 e @ 250 kpx/s)



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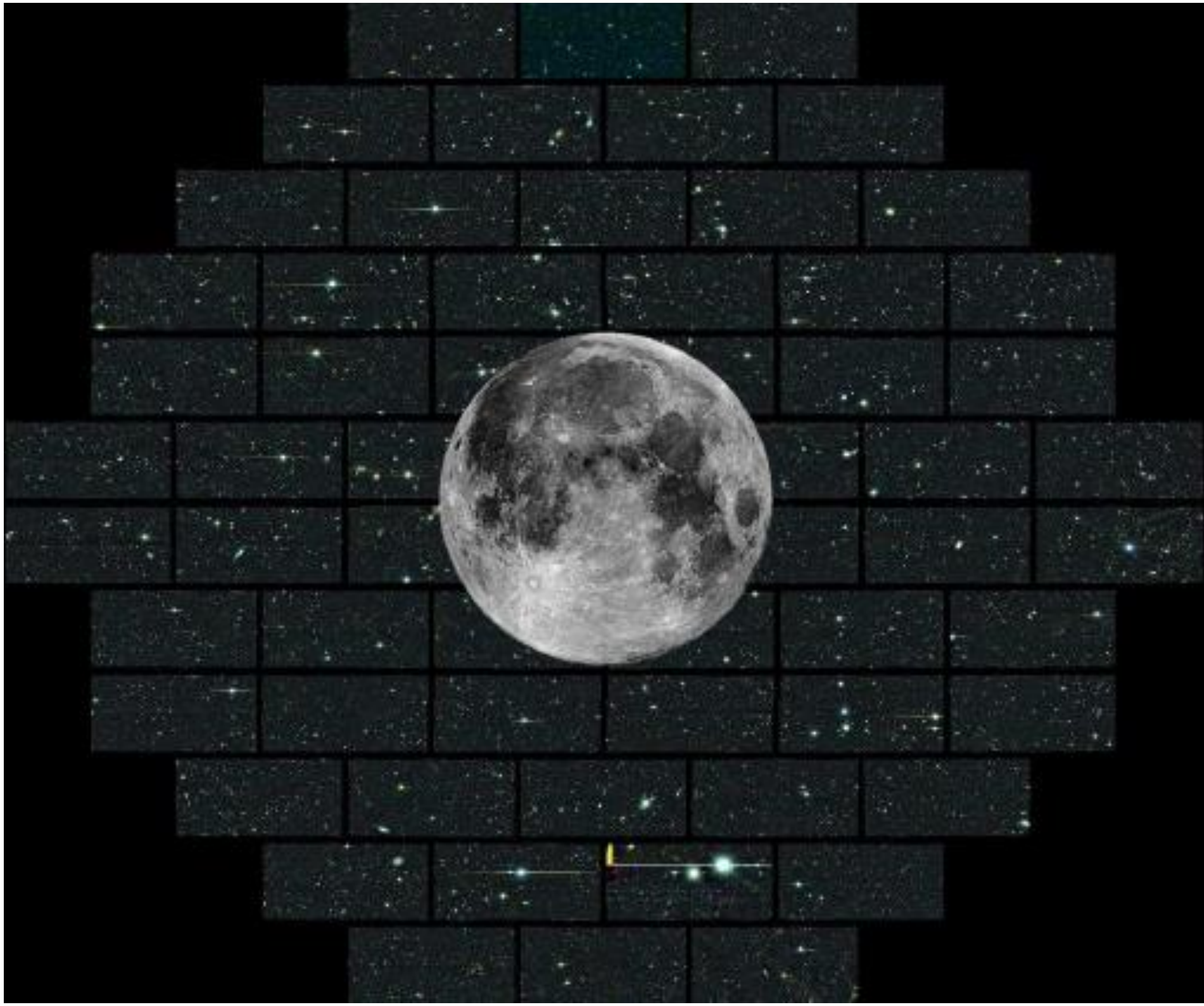


DES Science Summary

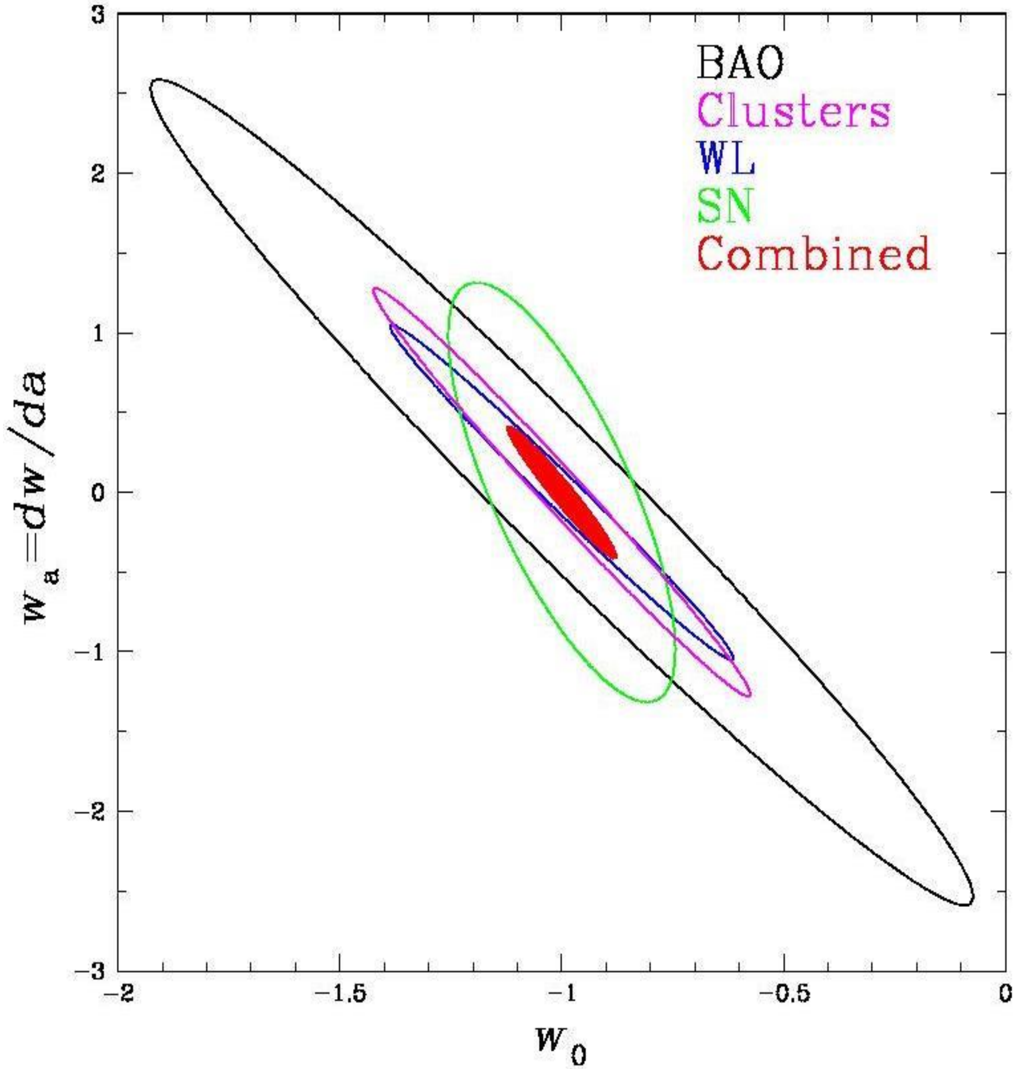
4 Probes of Dark Energy

Galaxy Clusters (dist & struct)
Tens of thousands of clusters to z~1
Synergy with SPT, VHS

Weak Lensing (dist & struct)
Shape and magnification measurements of 200 million galaxies

Baryon Acoustic Oscillations (dist)
300 million galaxies to z~1.4

Supernovae (dist)
3500 well-sampled Sne Ia to z~1



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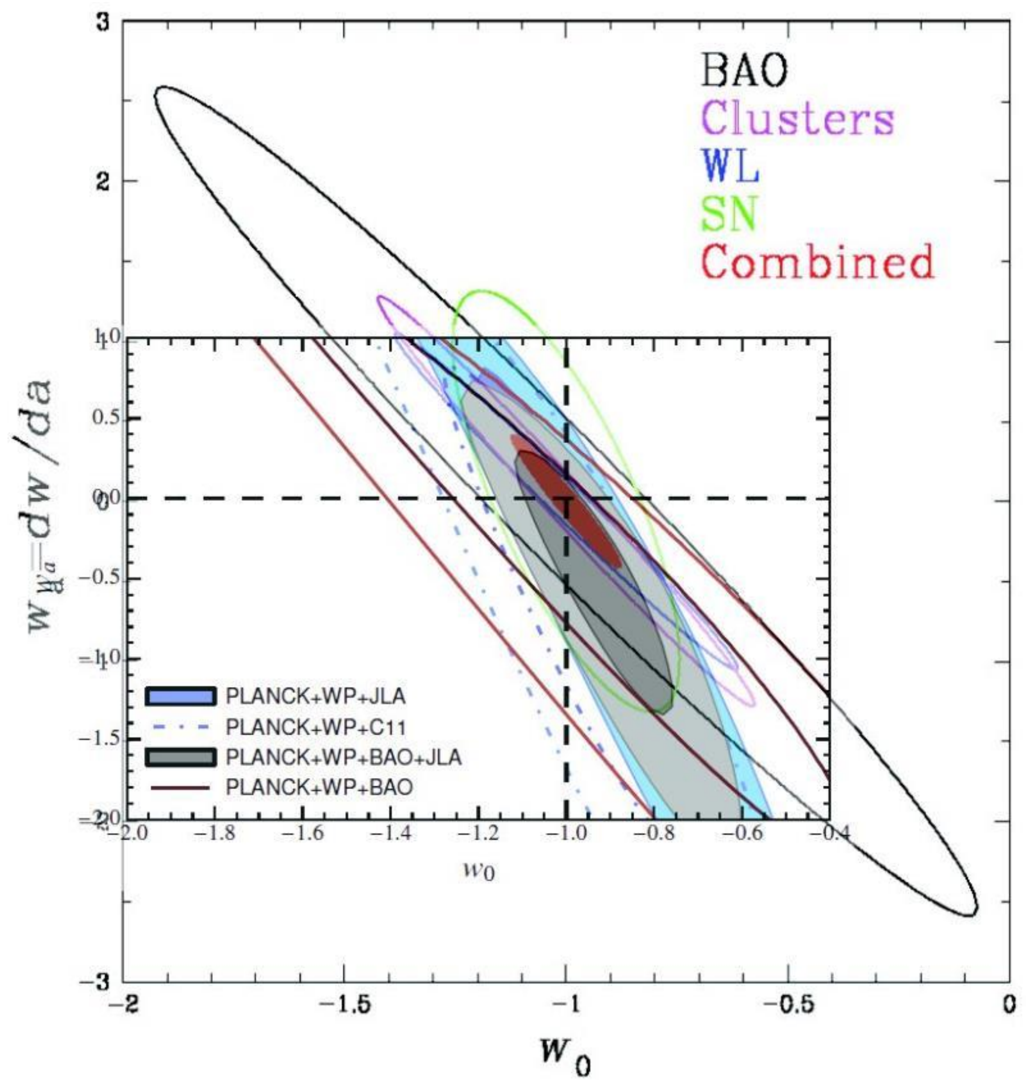
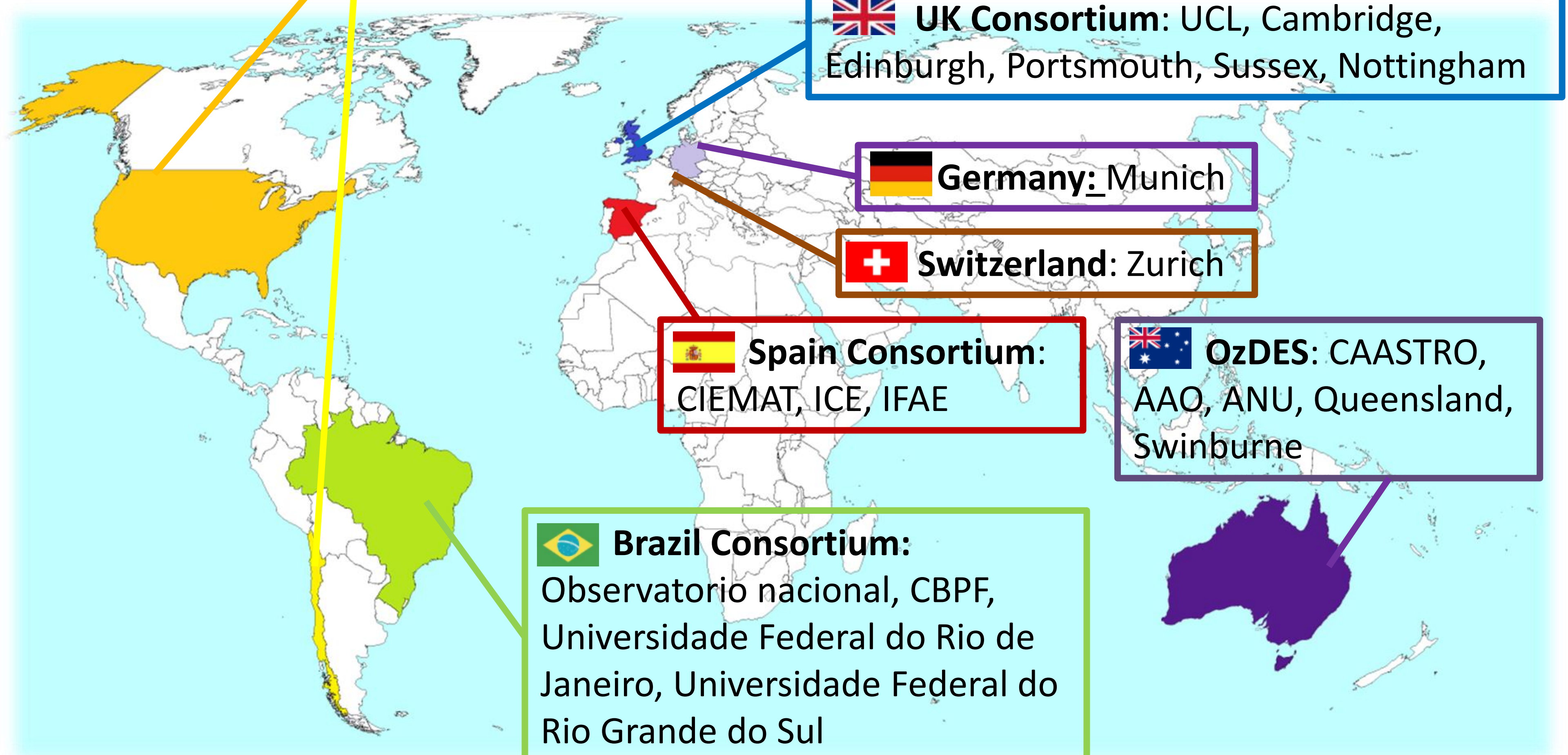


DES Collaboration

~500 scientists from
25 institutions in 7 countries
darkenergysurvey.org
Facebook.com/darkenergysurvey

DARK ENERGY SURVEY

USA: Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of pennsylvania, Argonne National Laboratory, Ohio State University, Santa Cruz/SLAC Consortium, Texas A&M University , CTIO (in Chile)



UK Consortium: UCL, Cambridge, Edinburgh, Portsmouth, Sussex, Nottingham

Germany: Munich

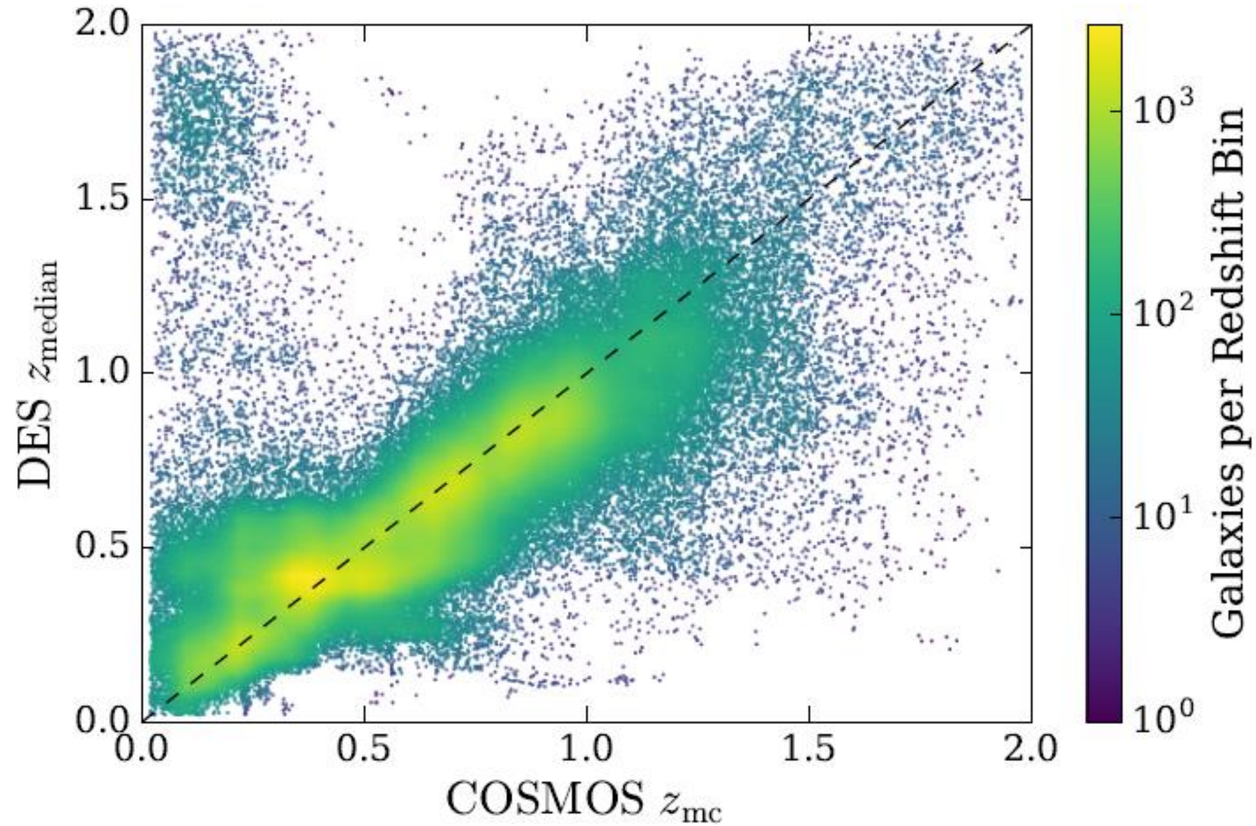
Switzerland: Zurich

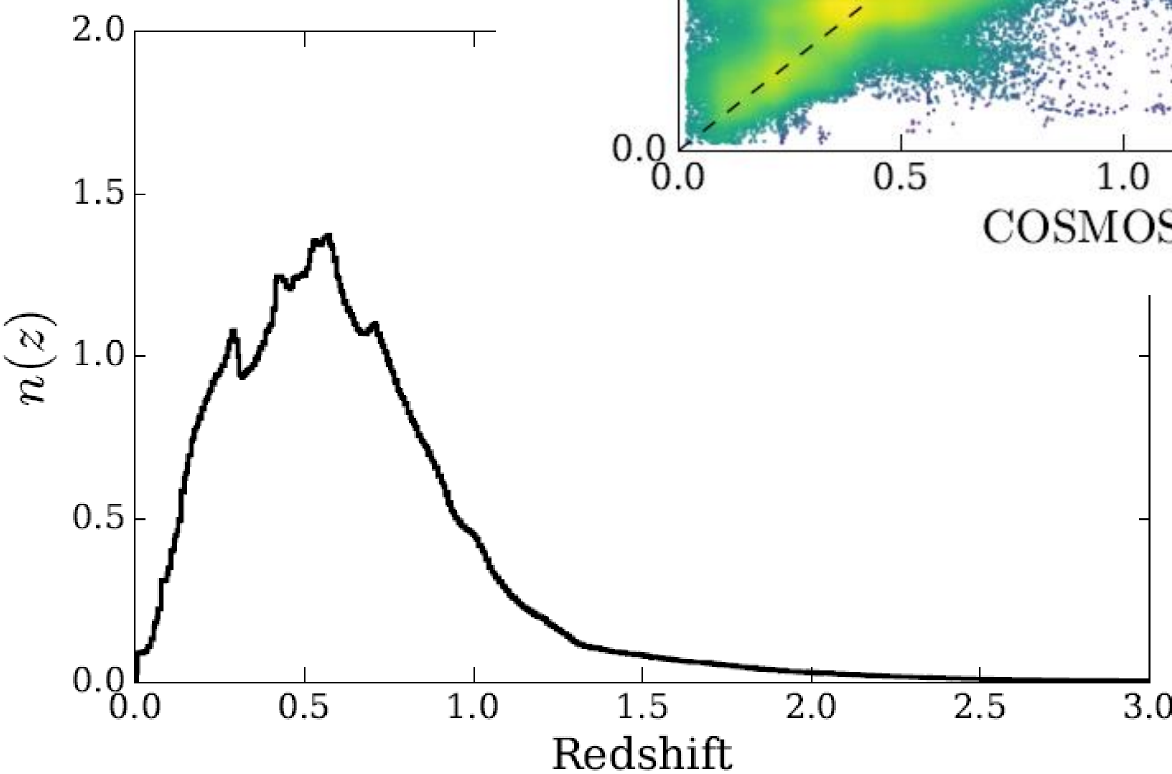
Spain Consortium: CIEMAT, ICE, IFAE

OzDES: CAASTRO, AAO, ANU, Queensland, Swinburne

Brazil Consortium: Observatorio nacional, CBPF, Universidade Federal do Rio de Janeiro, Universidade Federal do Rio Grande do Sul

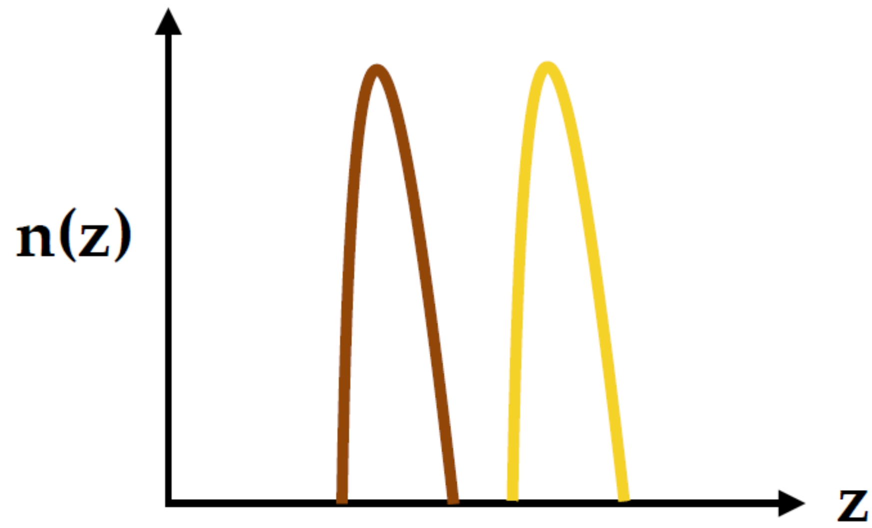
Redshift distribution of galaxies within DES Y1 data





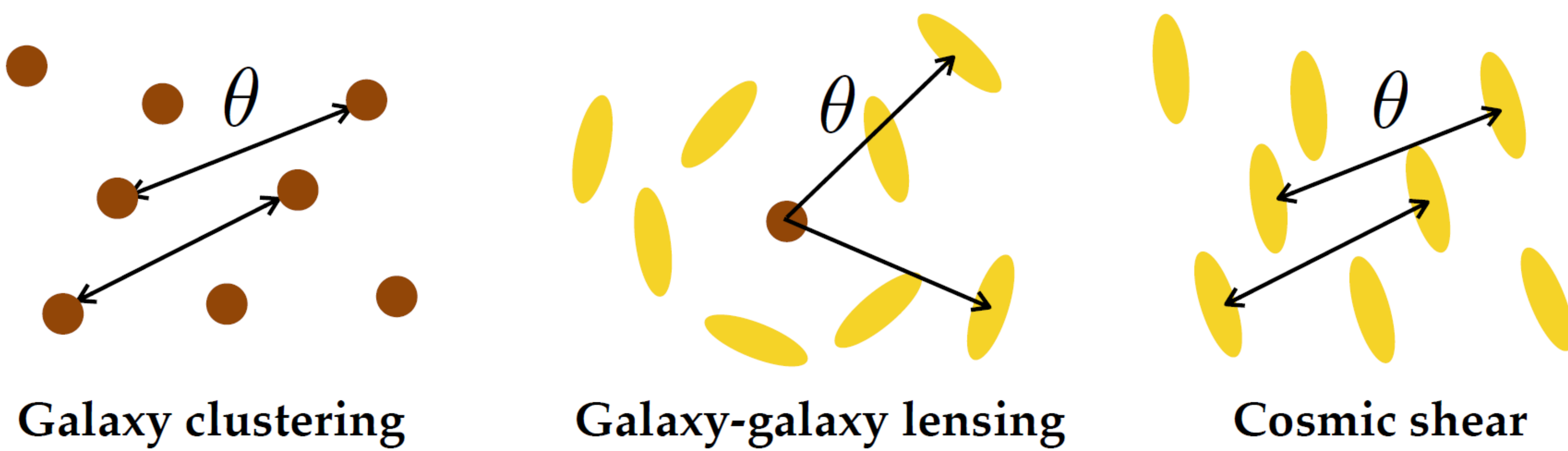
DES Y1 3x2pt Cosmology

2 samples of galaxies: **"lens"** and **"sources"**



Combine the auto and cross-correlation of

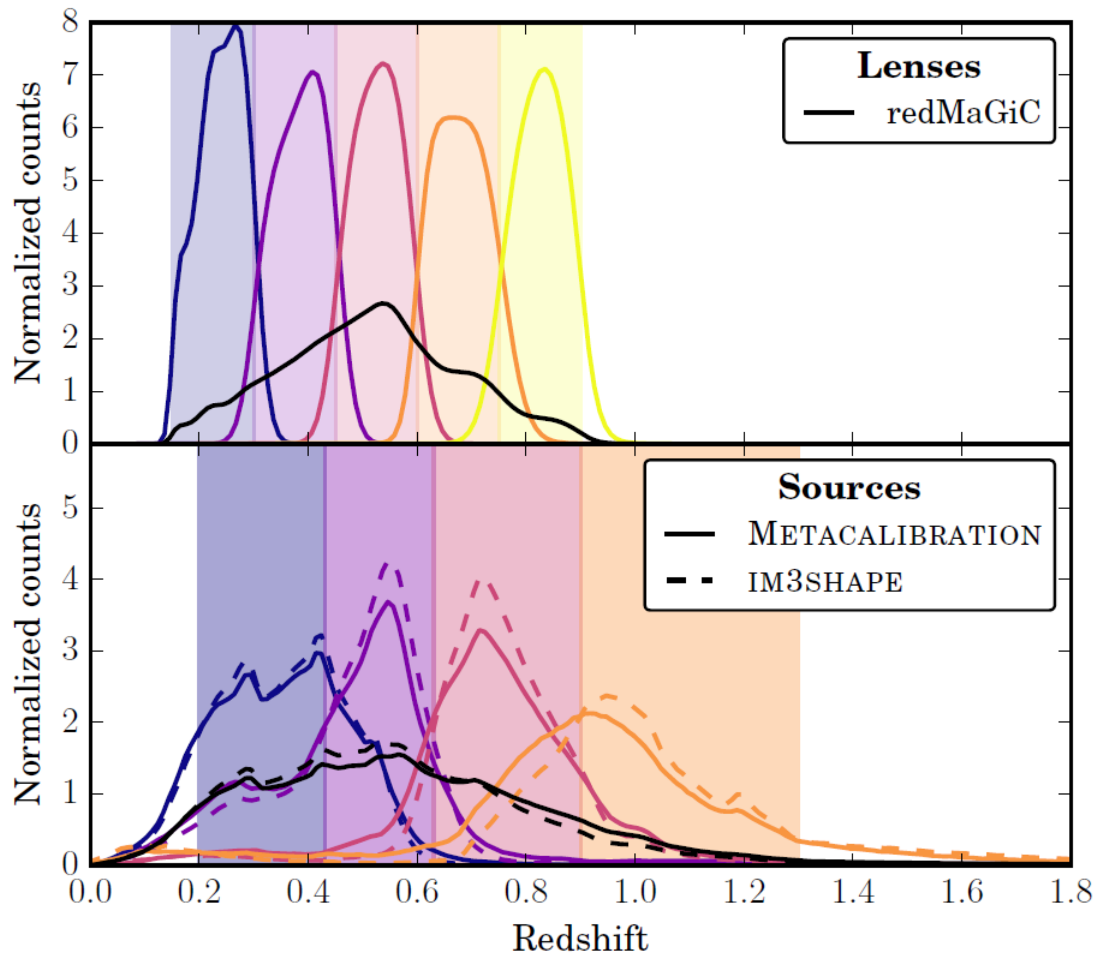
1. **positions** of the lens galaxi
2. **shapes** of the source galax



DES Y1 3x2pt Cosmology

This is a very demanding measurement:

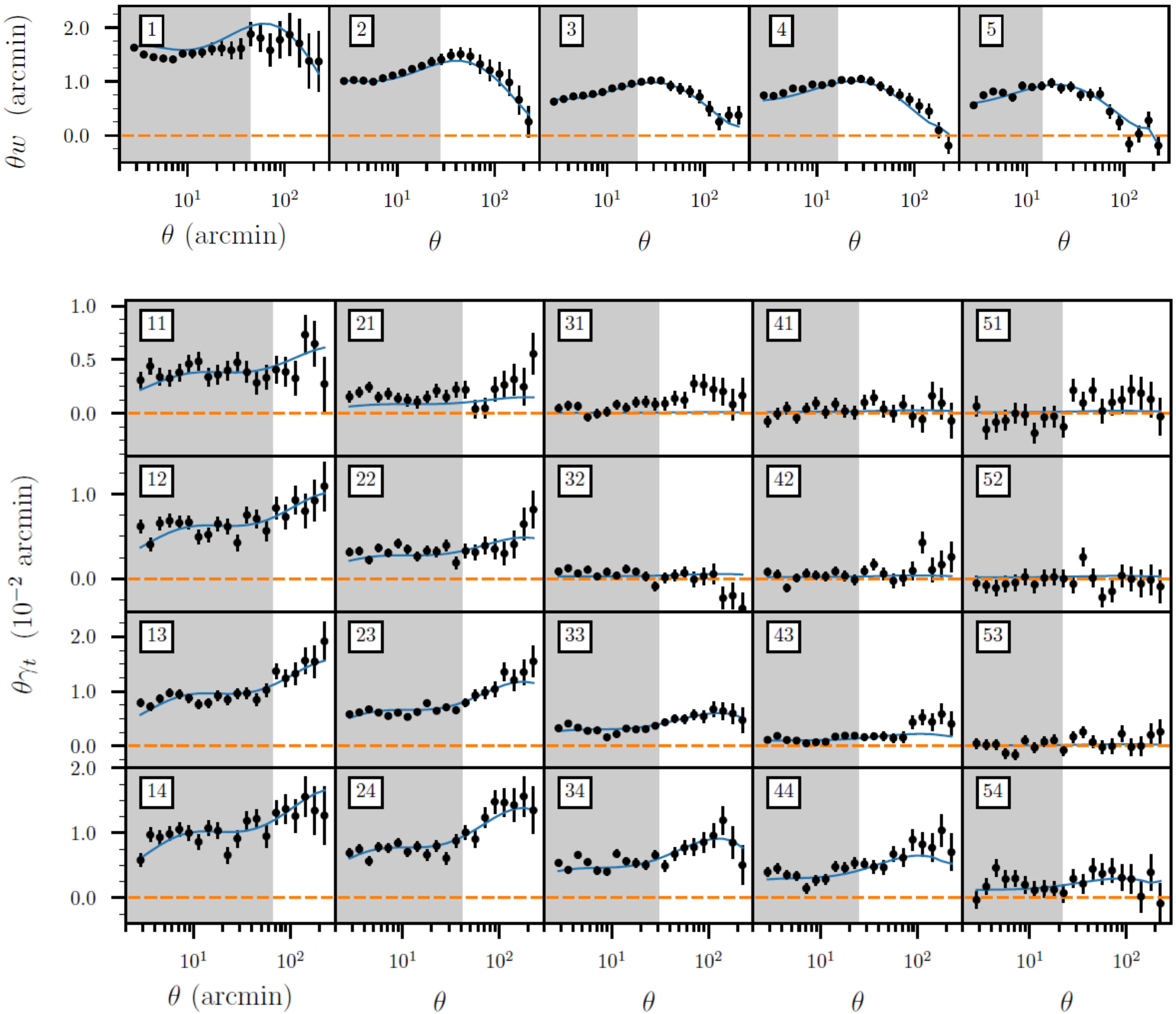
- **Manage a large dataset**
- **Compute correlation functions (3 types)**
- **These measurements are not independent → Compute and verify the covariance matrix**



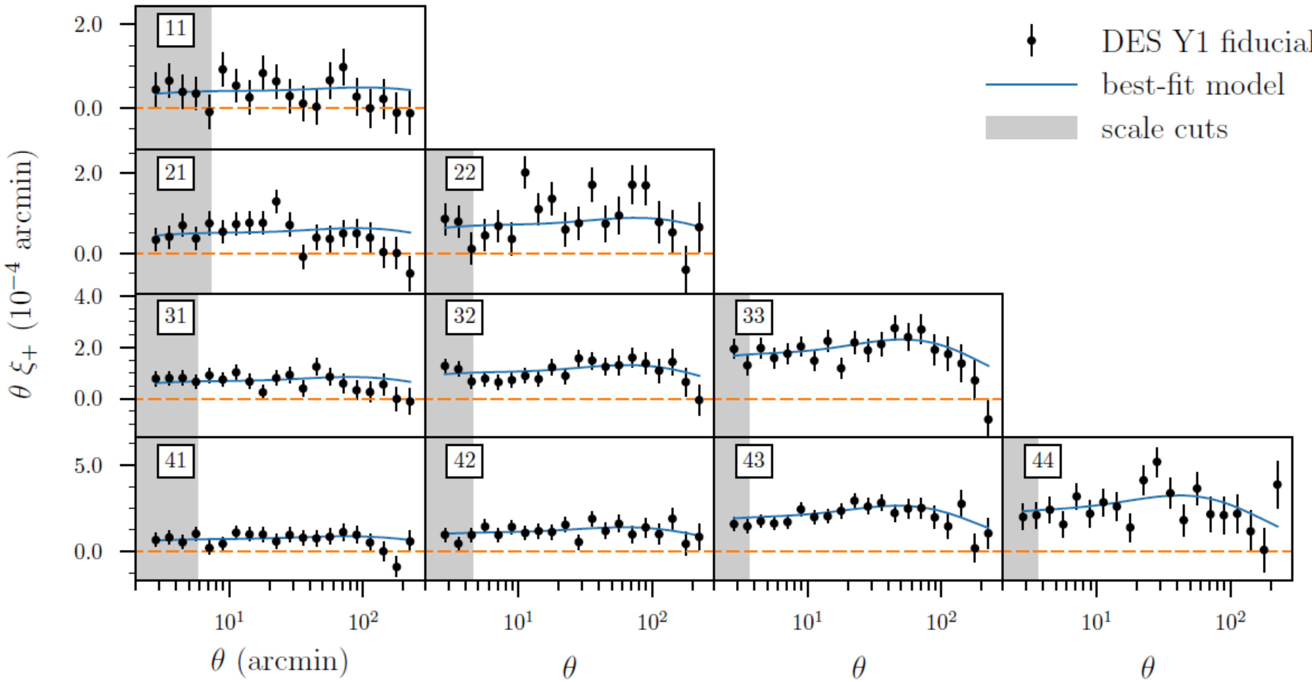
DES Y1 3x2pt Cosmology

Galaxy-Galaxy correlations (lens – lens)

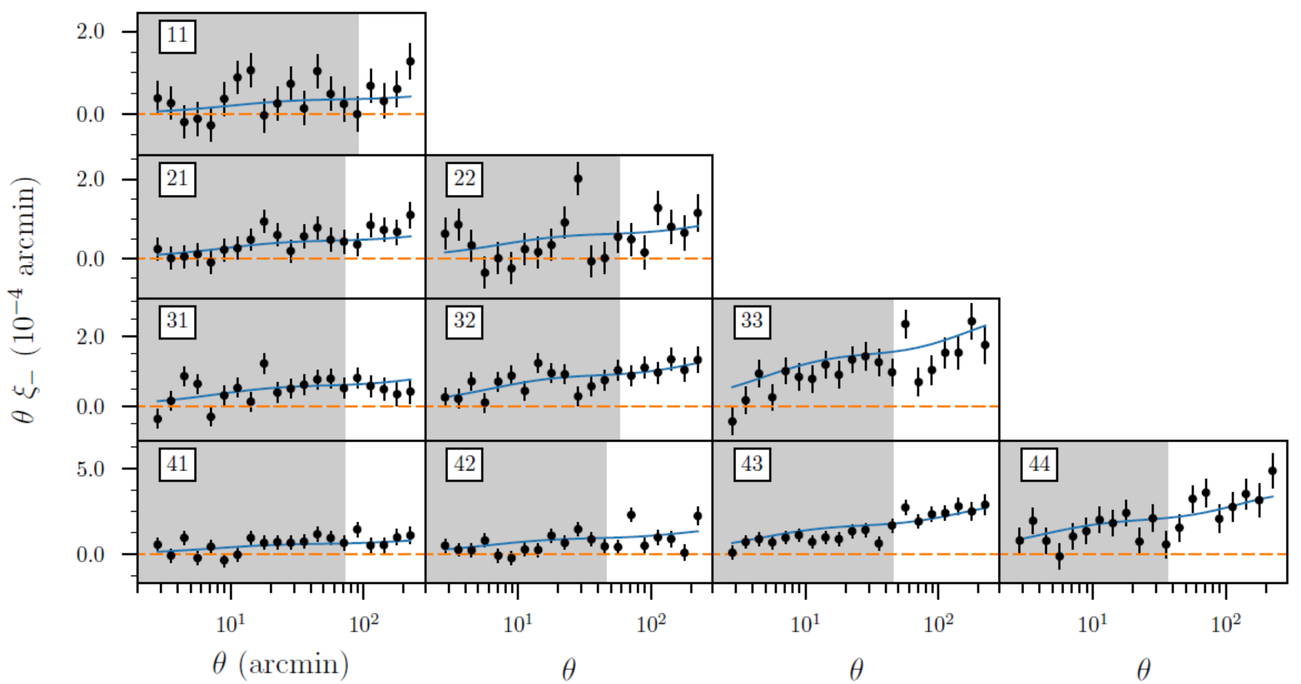
Galaxy-Shear correlations (lens – source)



DES Y1 3x2pt Cosmology



Shear-Shear correlations (source – source)



DES Y1 3x2pt Cosmology

$$w^i(\theta) = \left(b^i\right)^2 \int \frac{dl\, l}{2\pi} J_0(l\theta) \int d\chi \times \frac{\left[n_1^i(z(\chi)\right]^2}{\chi^2 H(z)} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

Galaxy Clustering
Correlation position-position

$$\gamma_{\rm t}^{ij}(\theta) = b^i(1+m^j) \int \frac{dl\, l}{2\pi} J_2(l\theta) \int d\chi n_1^i(z(\chi)) \times \frac{q_s^j(\chi)}{H(z)\chi^2} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

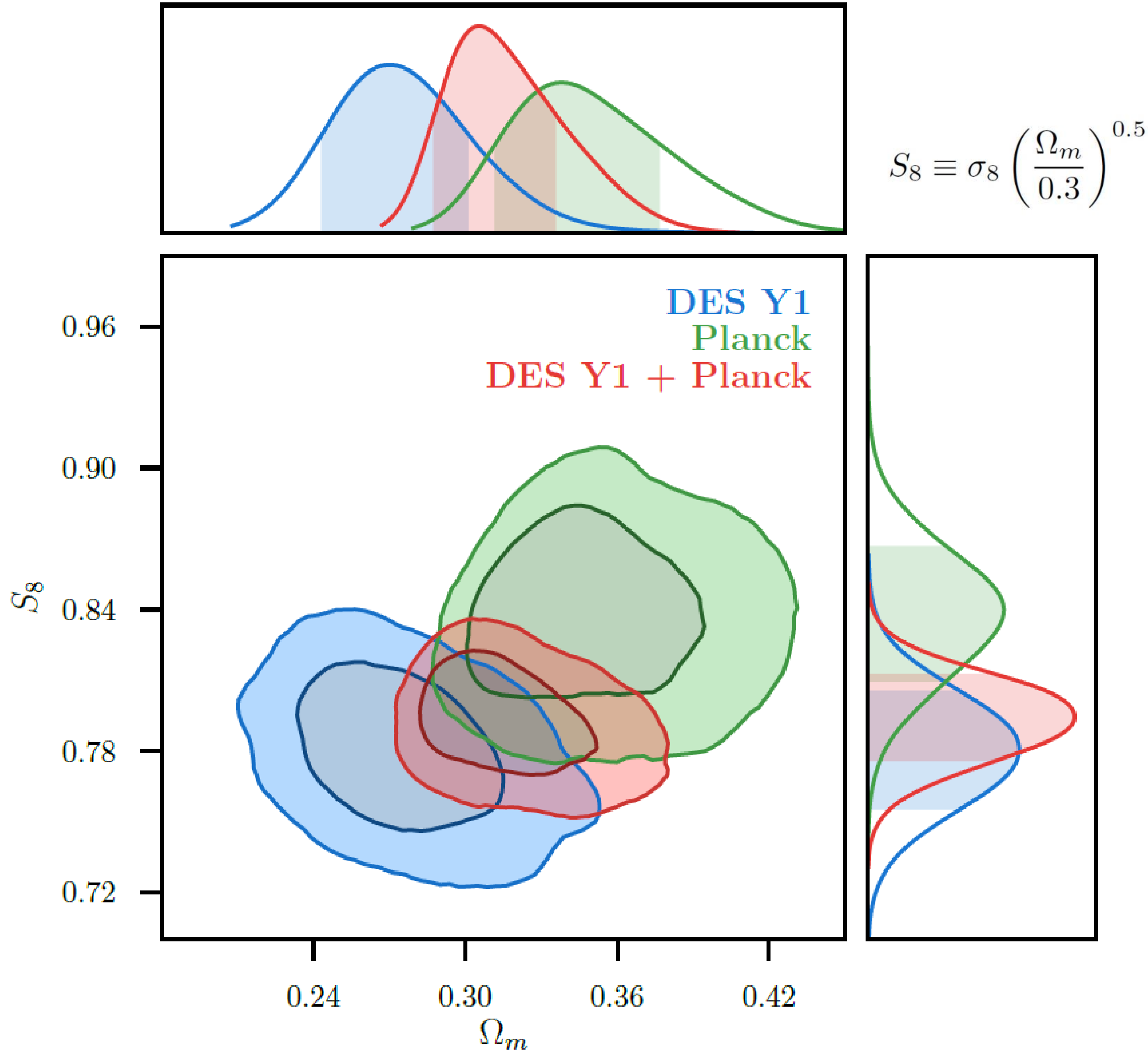
Galaxy-Glaxy Lensing
Correlation position-shape

$$q_s^i(\chi) = \frac{3\Omega_m H_0^2}{2} \frac{\chi}{a(\chi)} \int_\chi^{\chi(z=\infty)} \mathrm{d}\chi' n_s^i(z(\chi')) \frac{dz}{d\chi'} \frac{\chi'-\chi}{\chi'} \tag{IV.3}$$

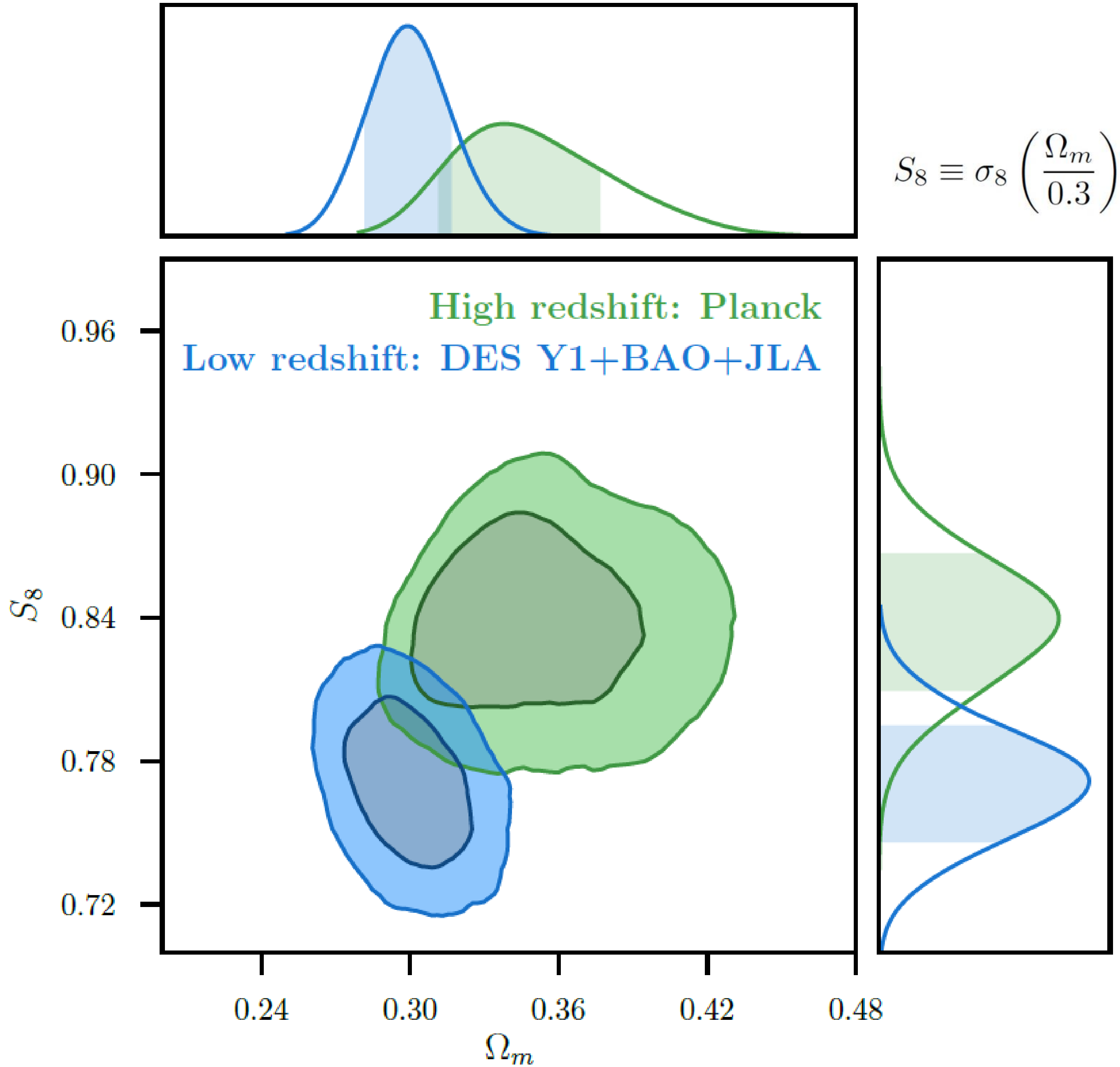
$$\xi_{+/-}^{ij}(\theta) = (1+m^i)(1+m^j) \int \frac{dl\, l}{2\pi} J_{0/4}(l\theta) \int d\chi \times \frac{q_s^i(\chi) q_s^j(\chi)}{\chi^2} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

Cosmic Shear
Correlation shape-shape

DES Y1 3x2pt Cosmology

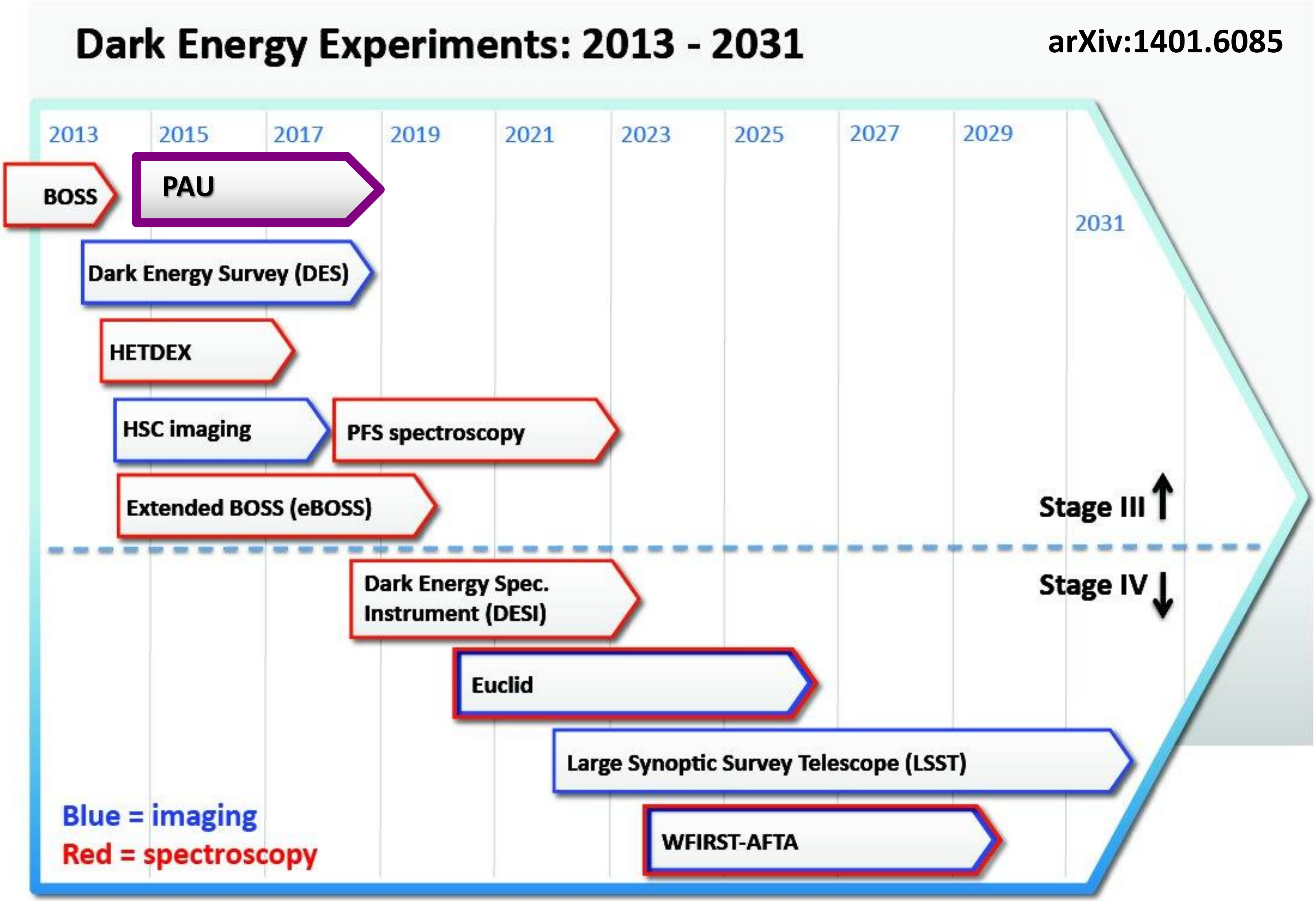


DES Y1 3x2pt Cosmology



$$S_8 \equiv \sigma_8 \left(\frac{\Omega_m}{0.3}\right)^{0.5}$$

Future Projects about Dark Energy

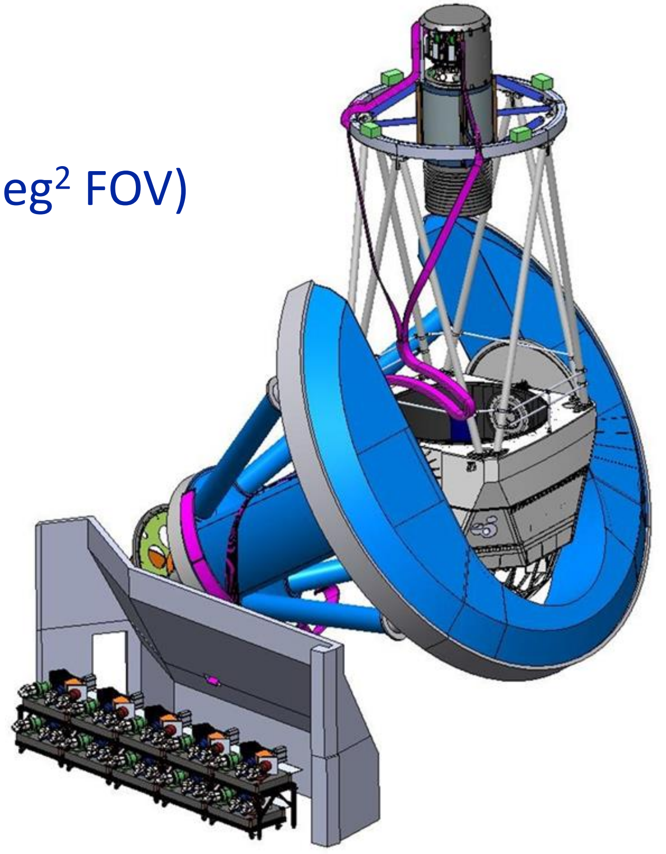


Future Projects: DESI

DESI (Dark Energy Spectroscopic Instrument)

The DESI collaboration is building:

A new corrector for the Mayall telescope at Kitt Peak (8 deg^2 FOV)
A new top ring, barrel and hexapod
A focal plane with 5000 robots fiber positioner
10 espectrographs, following the BOSS design
Instrument control and data proccess systems



DESI will start the data taking in 2019

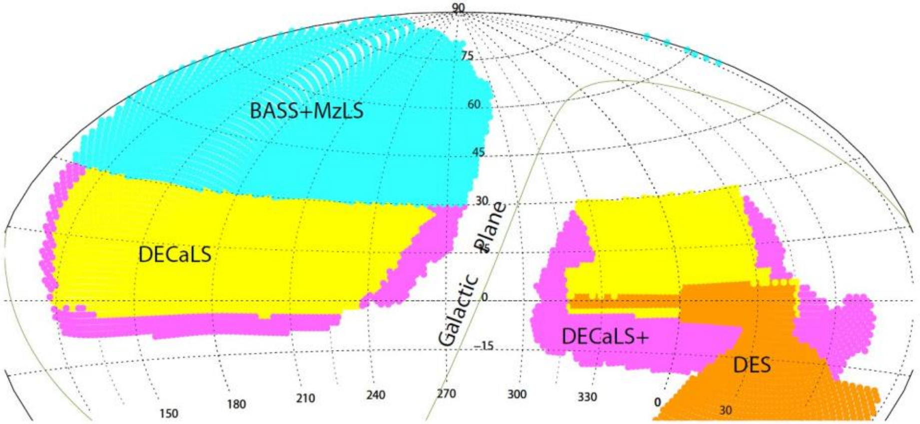
Future Projects: DESI

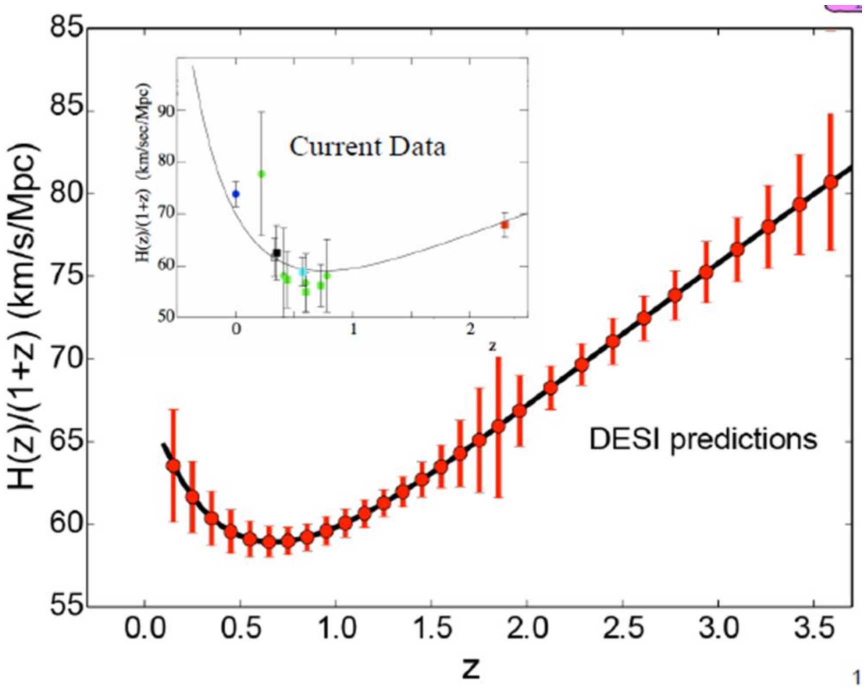
Scientific potential

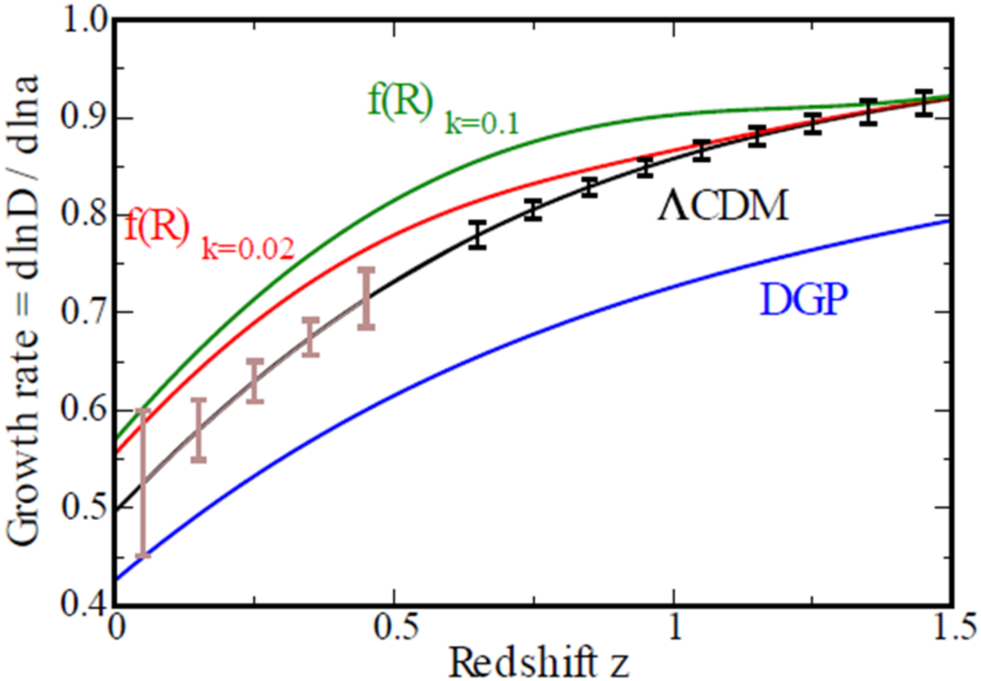
Distances with BAO better than 0.3%

Growth factor better than 1% → GR test

Sum of neutrino masses better than 20 meV







Future Projects: Euclid & LSST

Euclid Consortium

FoM ~ 1500 , -4000 (all)

Main probes: WL & Galaxie clustering (BAO,RSD) (spectro))

European lead project / ESA

Participation of NASA

~ 1000 members

Space telescope / 1.2 m mirror

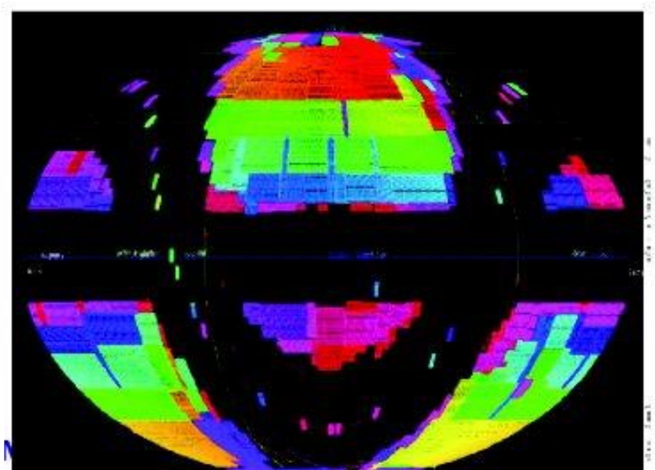
Launch : **Q4 2020**

Mission length : 6 years

1 exposure depth : 24 mag

Survey Area : 15 000 sq deg (.36 sky)

Filters : 1 Visible(550-900nm)+ 3 IR (920-2000 nm) + NIR spectroscopy (1100 – 2000 nm)



LSST Large Synoptic Survey Telescope

FoM > 800

Main probes : **WL, CL, SN, BAO (photo)…**

US lead project / NSF-DOE

Participation of France/In2P3

~ 450 Core members + 450 to come

Ground Telescope / 6.5 m effective mirror

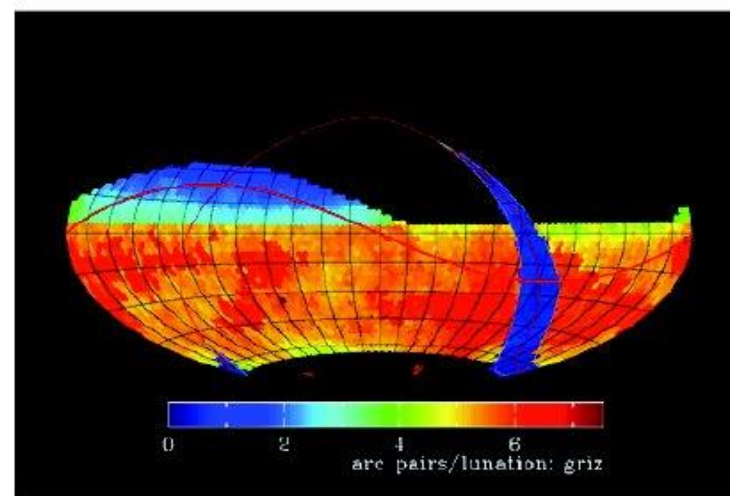
1st light : **2021**

Observation length : 10 years

1 exposure depth : 24 mag (i)

Survey Area : 20 000 sq dg (.48 sky)

Filters : 6 filters (320-1070 nm)



Conclusions

Cosmology is in a golden era

All current data are consistent with LCDM: 70% cosmological constant, 25% of dark matter (of unknown nature) and 5% of ordinary matter

Some open problems that affect the whole picture: Dark energy, dark matter, inflation, baryogenesis → Require new physics

Probing the expansión history of the Universe and the growth of structure with much better precisión can provide a strong boost to the current knowledge

A number of large projects are under way or planned for the future, and hopefully, will bring significant progress

Dark matter, dark energy, baryogenesis and inflation are very important questions both for cosmology and for particle physics, since the unveiling of their physical nature can bring us to a revolution in our understanding of the cosmos