Modeling the galaxy halo occupation distribution of Hα emitters in new-generation spectroscopic surveys

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esa

ESAC, 18 May 17

Outline

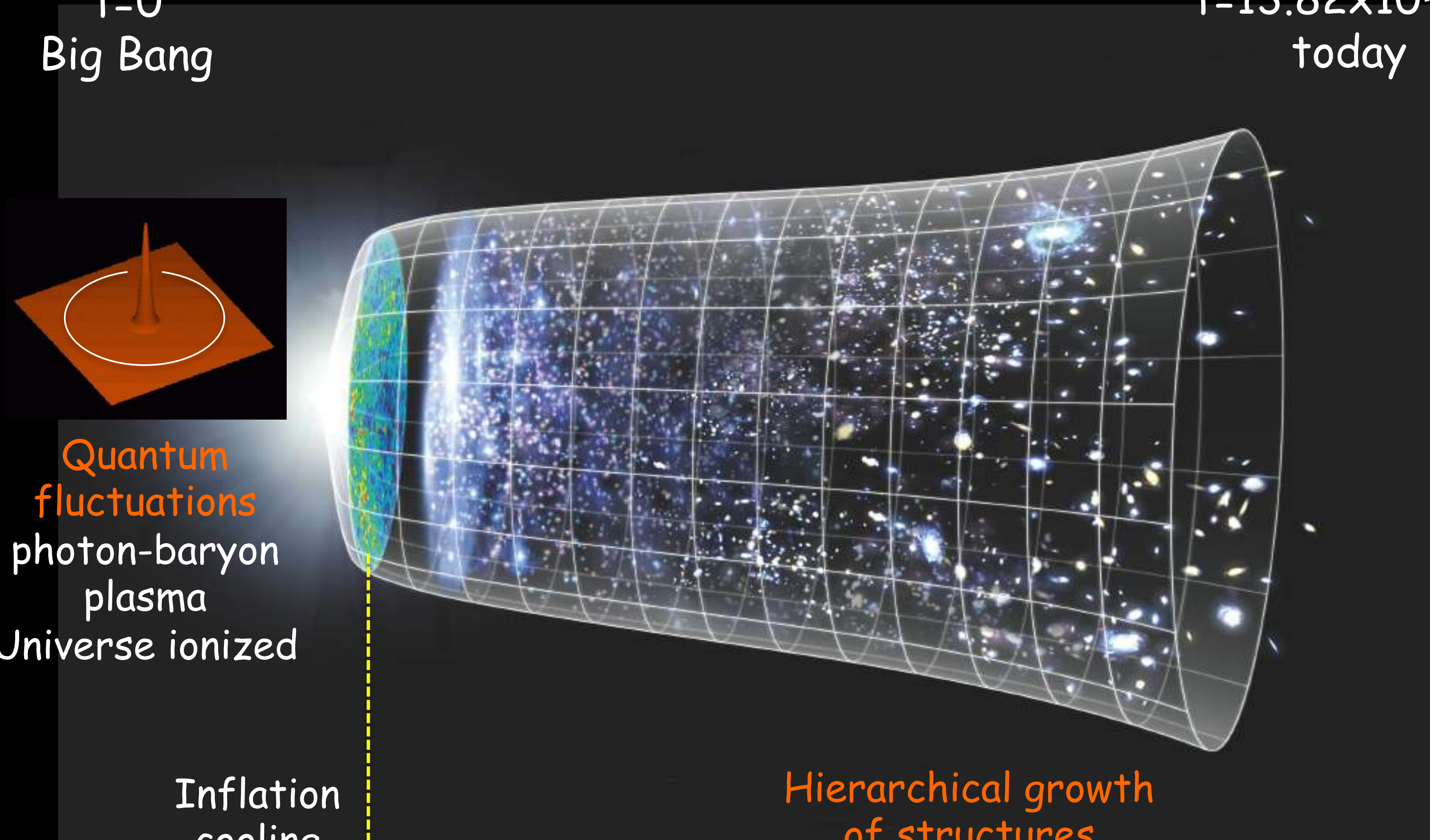
- Cosmological framework
- Large-volume spectroscopic surveys
- Galaxy clustering measurement as cosmological probe: data & models
- Results:

  I. Clustering properties of *g*-selected galaxies at z~0.8 (Favole et al. 2016a)

  II. Galaxy clustering dependence on [OII] emission line luminosity at z~0.1 (Favole et al. 2016b)

  III. WISP/3D-HST Hα emitters in preparation to Euclid

- Summary and future prospects



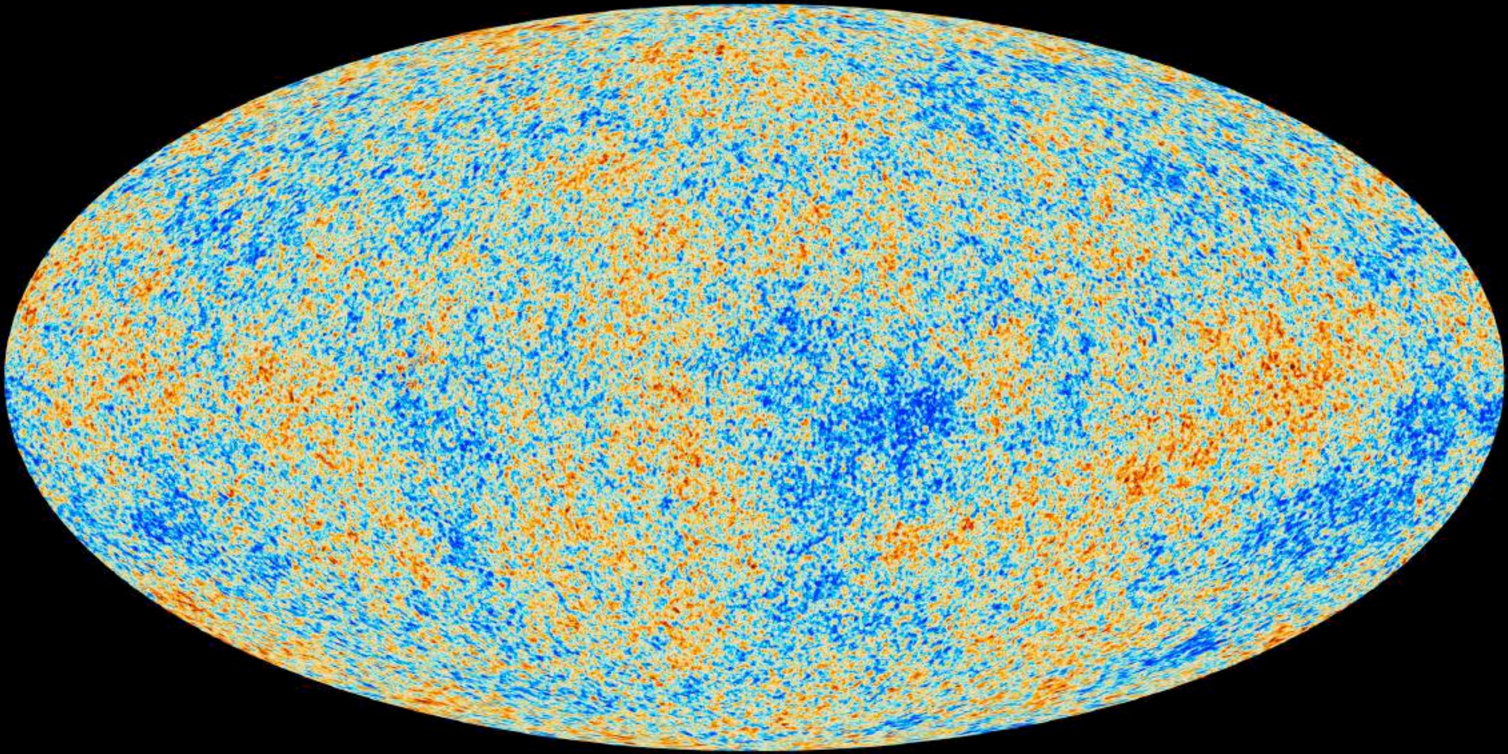
Accelerated expansion

Dark energy?

First light: 380,000 yrs
CMB radiation
Universe neutral and transparent

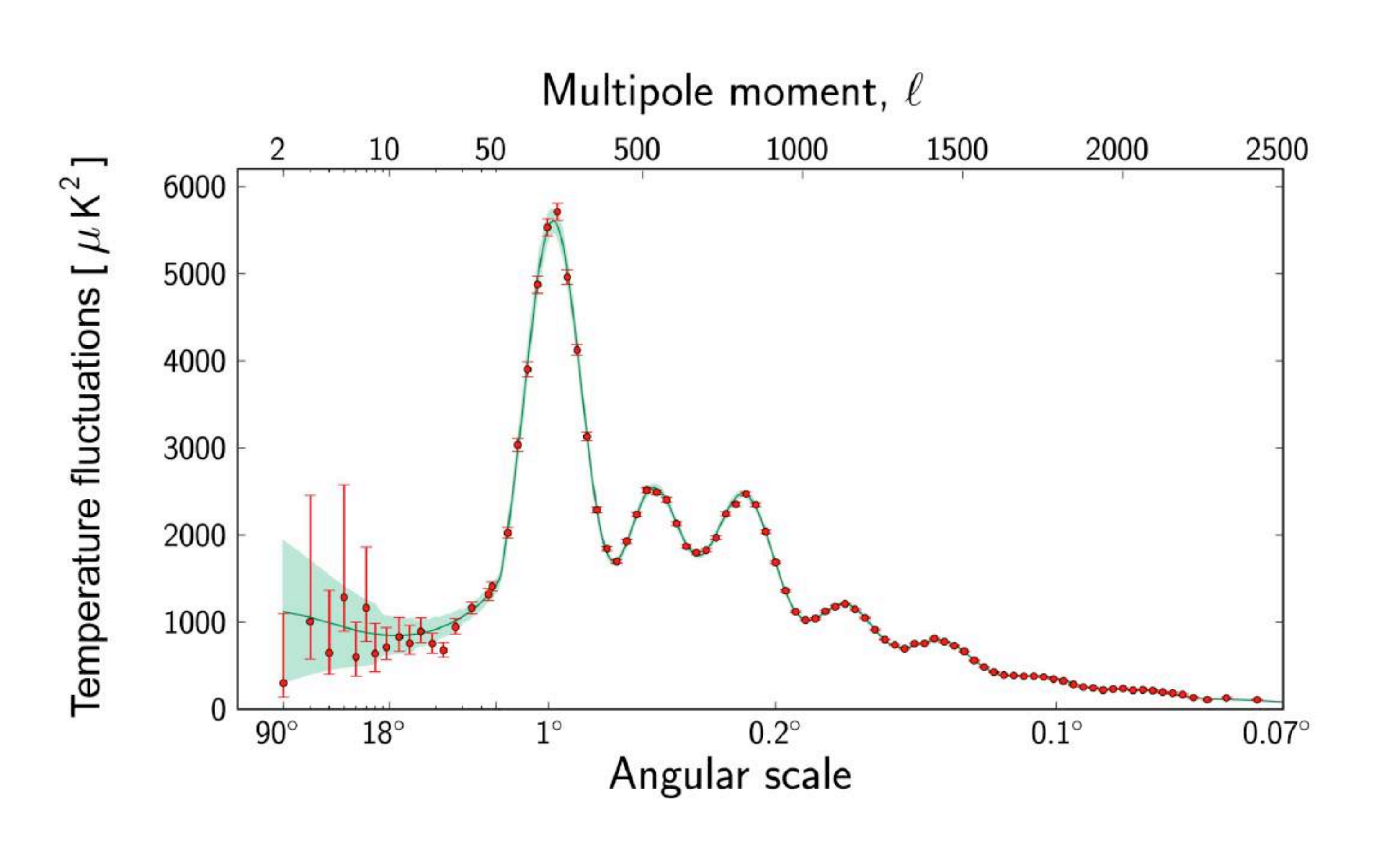
Primordial fluctuations propagate as sound waves
leaving their imprint in the CMB

Seeds of the large scale structure we see in the Universe today



ESA Planck Collaboration, 2013

Temperature power spectrum

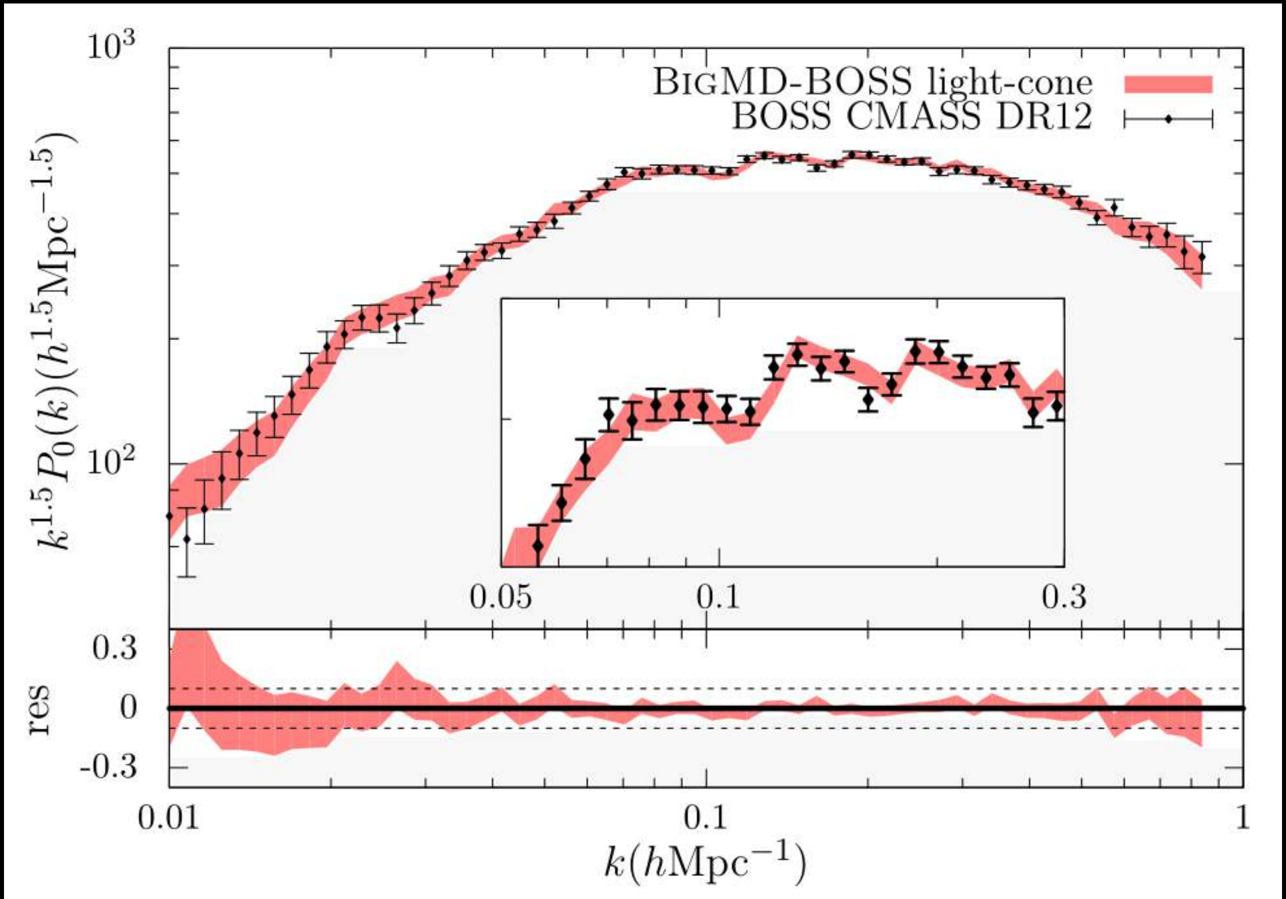


ESA Planck Collaboration, 2013

Galaxy power spectrum

$$P(k) = \langle|\delta_k|^2\rangle = Ak^n$$

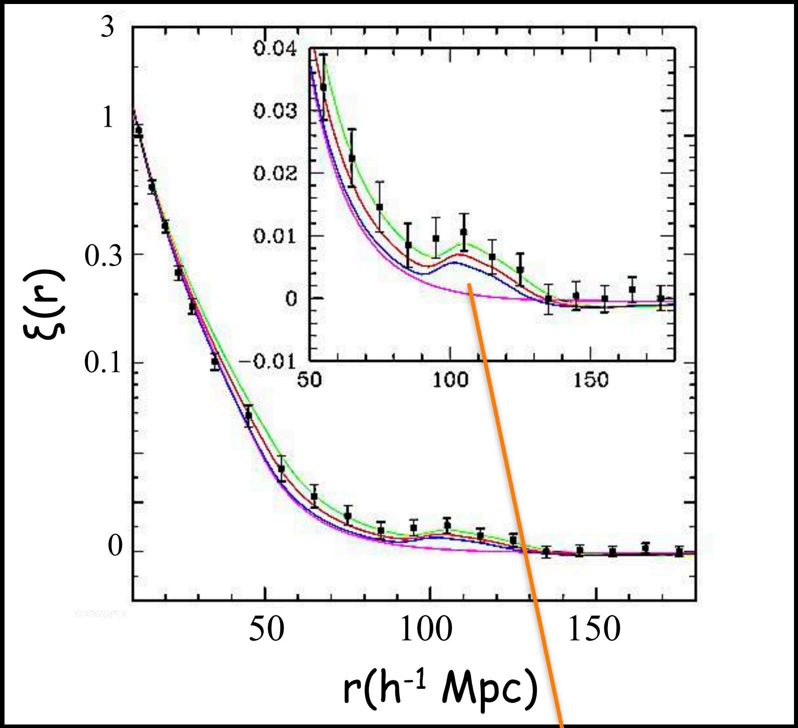
Fourier transform of the primeval density fluctuations



Rodríguez-Torres ++, Favole et al., 2016 MNRAS.40.1173R

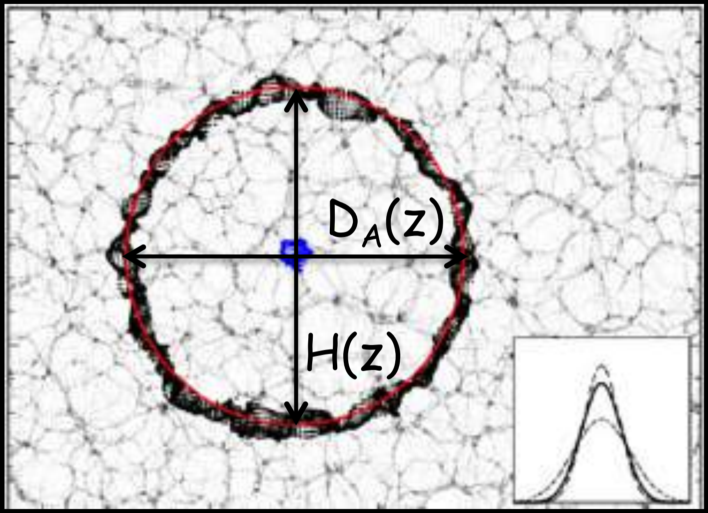
Galaxy two-point correlation function

$$dP = n^2[1+\xi(r)]\, dV_1 dV_2$$



Eisenstein et al., 2005, ApJ.633.560E

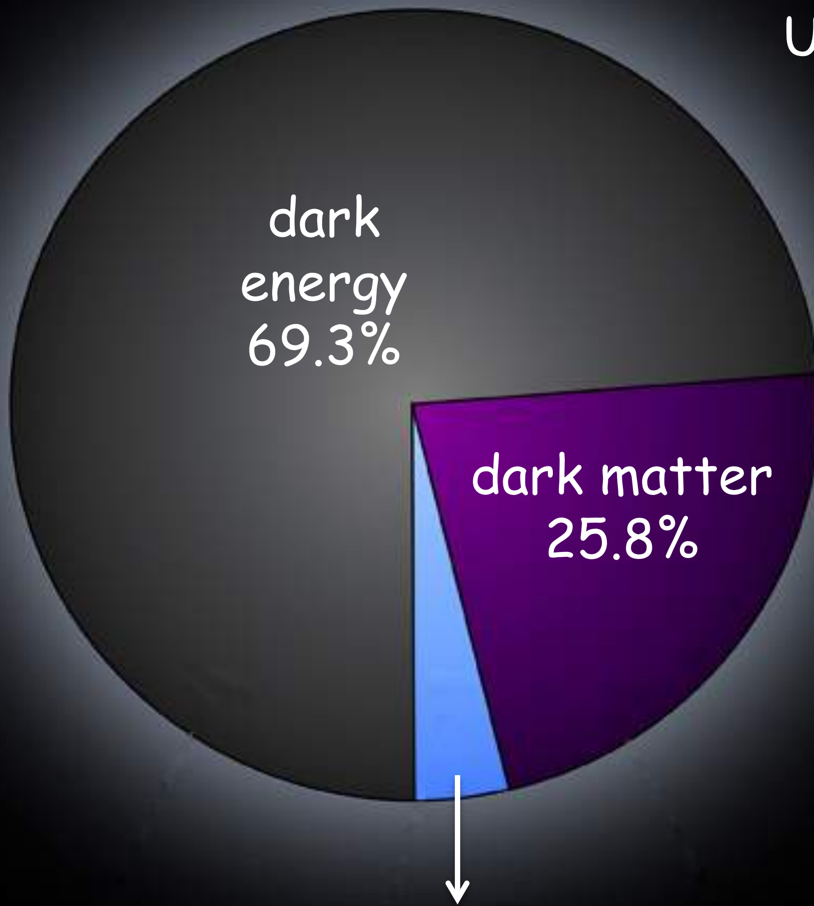
preferential radial and transverse scales:



Baryon Acoustic Oscillation (BAO) peak is a "standard ruler" for cosmological distances from which we infer the growth rate of structures

The energy content of the Universe today

Mysterious component still unknown



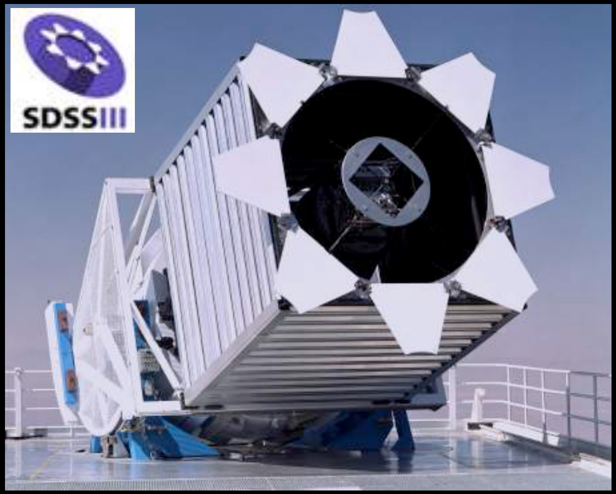
negative pressure accelerating the Universe expansion?

Everything else, including all stars, planets, us … 4.9%

Large-volume spectroscopic surveys: past

SDSS-I/II (2003-2009) and SDSS-III/BOSS (2009-2014)

2.5-m telescope, Apache Point Observatory, NM
10,000 deg^2 sky coverage
ugriz photometric bands



sdss3.org

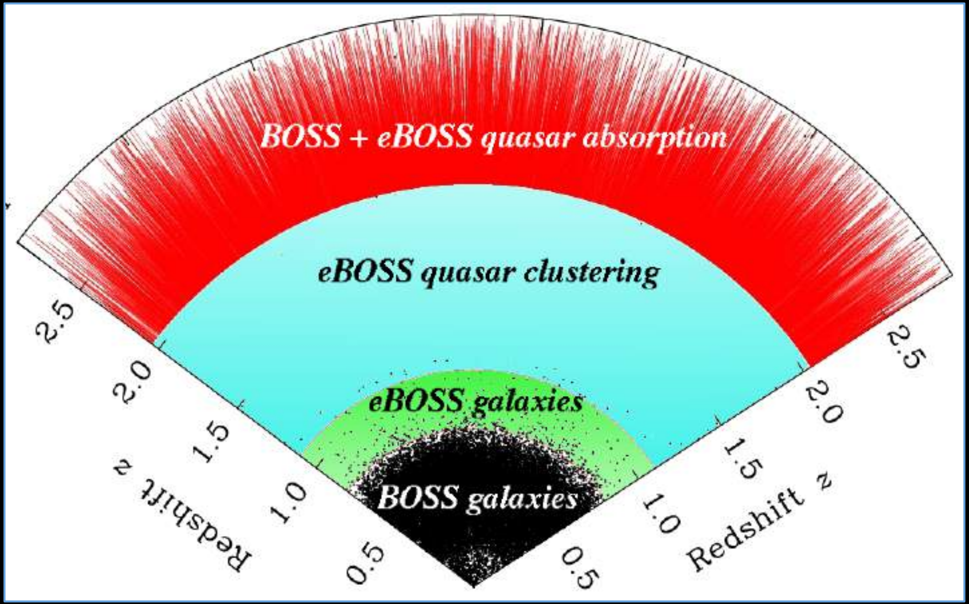
1.5M spectra of Luminous Red Galaxies (LRGs) at $z<0.7$
in two galaxy samples: LOWz at $z<0.43$ and CMASS in $0.43<z<0.7$
(Anderson et al. 2014)

160,000 Lyman-α forest quasars in $2.2<z<3$

ongoing

SDSS-IV/eBOSS (2014-2020)

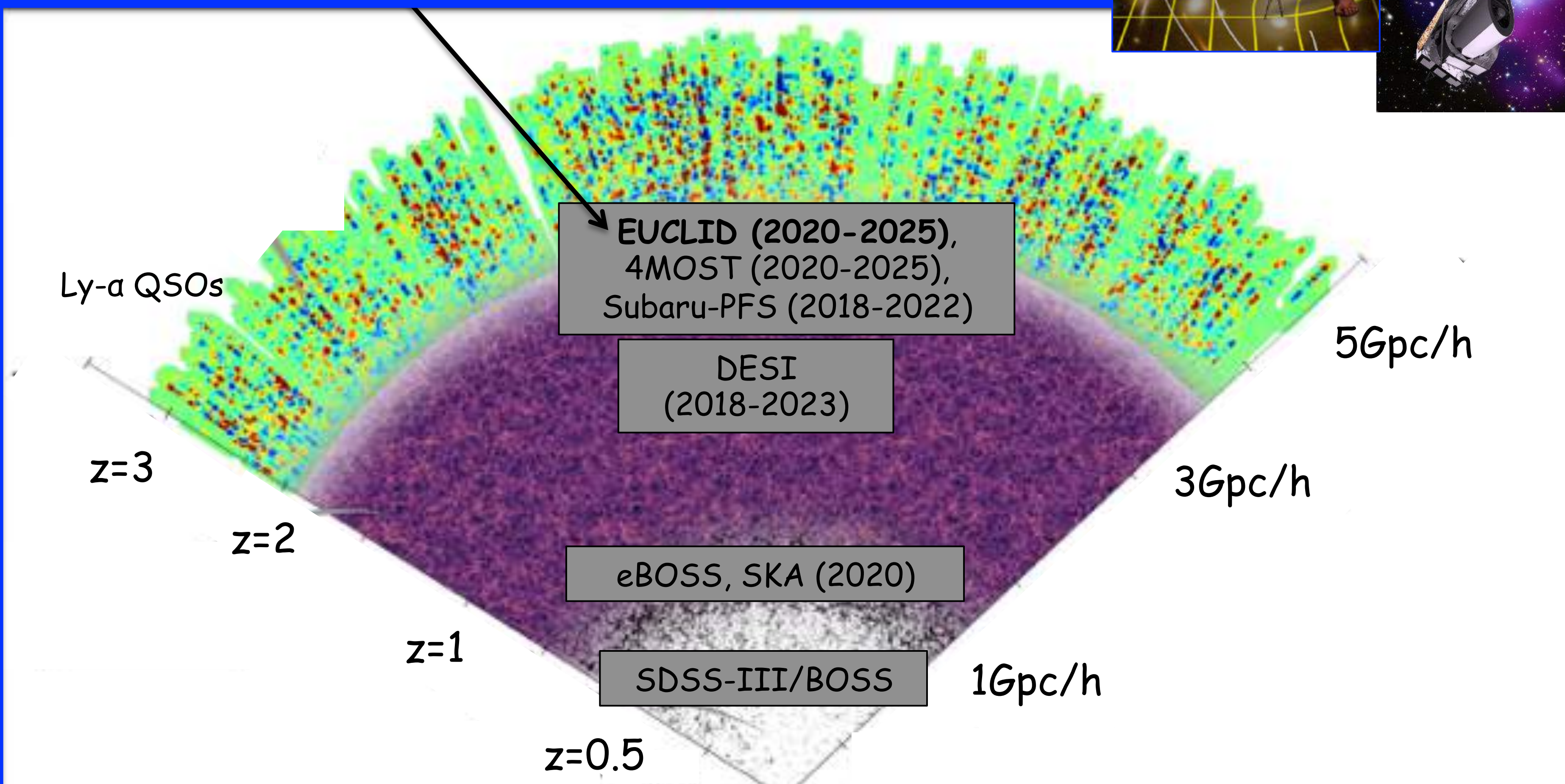
7500 deg^2
375,000 LRGs in $0.6<z<0.8$
260,000 Emission Line Galaxies (ELGs) in $0.6<z<1$
740,000 QSOs $z<2$ and Lyman-α forest $z<3.5$
(Dawson et al. 2016)



http://www.sdss.org/surveys/eboss/

Slitless near-IR spectroscopy
15,000 deg^2, 1.2m telescope
50M galaxy spectra
Ha ELGs up to z=2

future



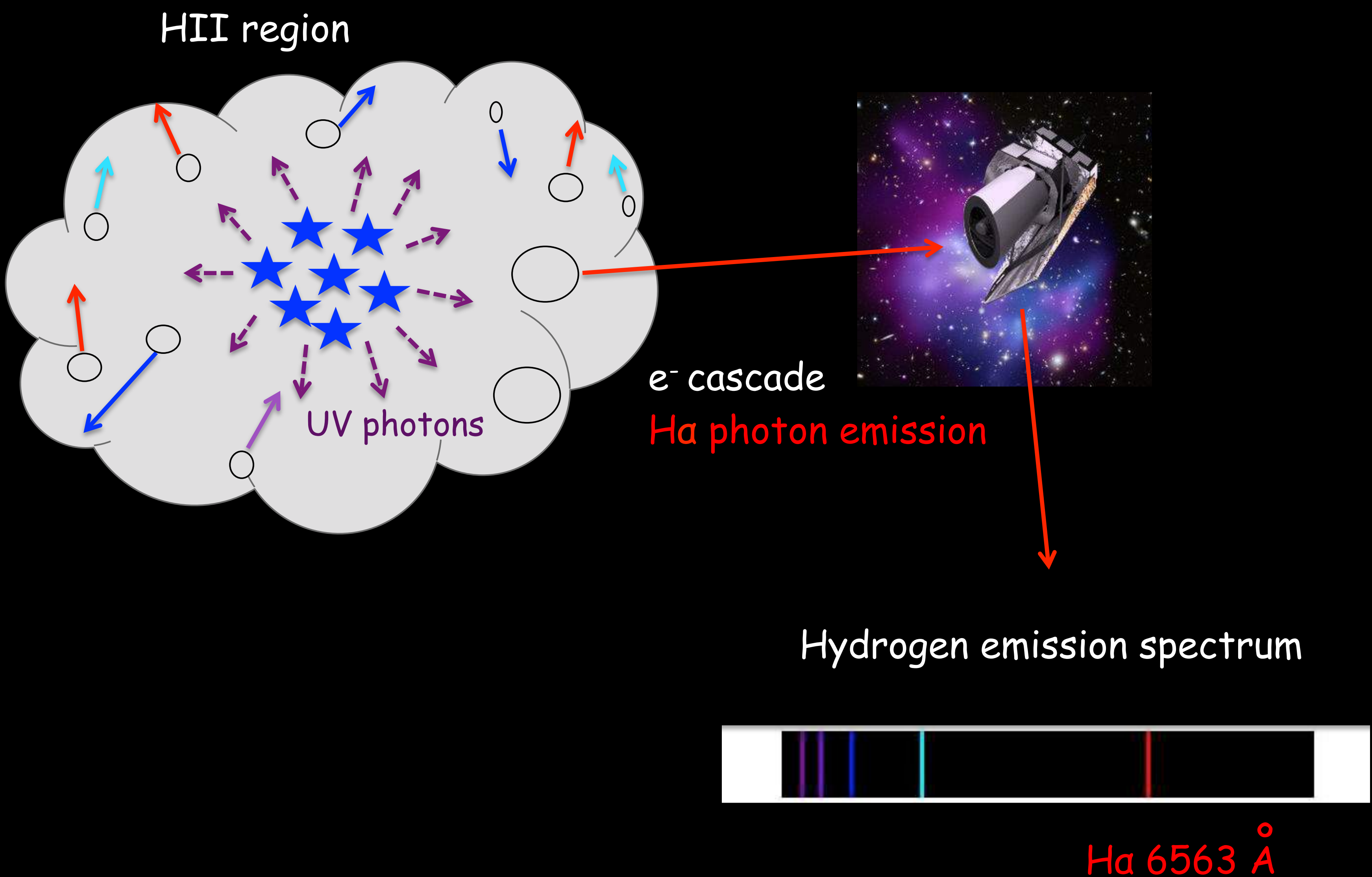
Future surveys aim to:

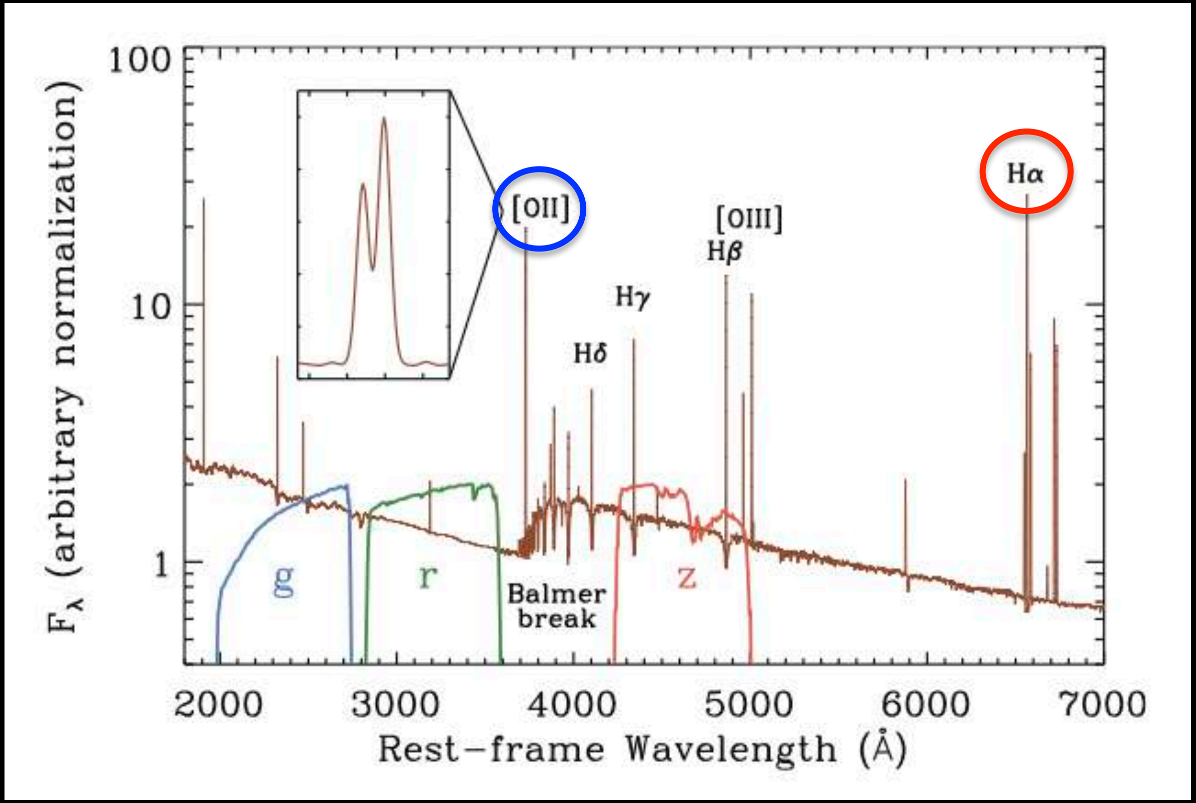
- Detailed 3D maps of the Universe to probe its expansion history
- Unveil dark matter, dark energy
- Measure BAO as standard ruler for distances

by targeting Emission-Line Galaxies (ELGs) up to z=2

Observing ELGs, modeling their clustering properties and understanding how they populate their host dark matter halos are key issues for future experiments

Emission-line galaxies

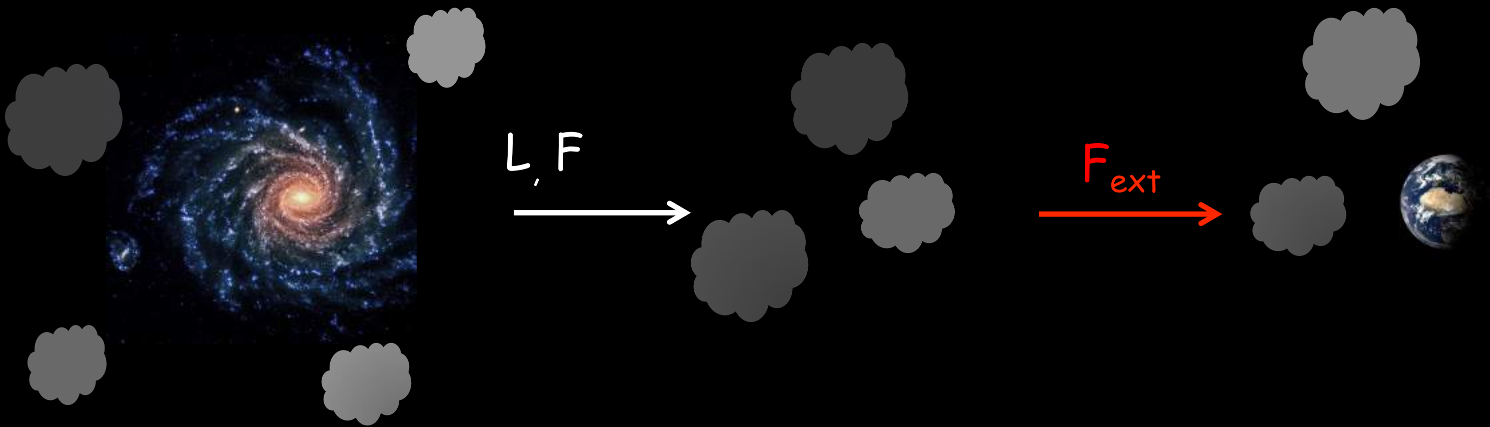




http://desi.lbl.gov/tdr/

Hα is the strongest line to trace star formation

The [OII] doublet is the most prominent feature in the spectra of faint blue galaxies



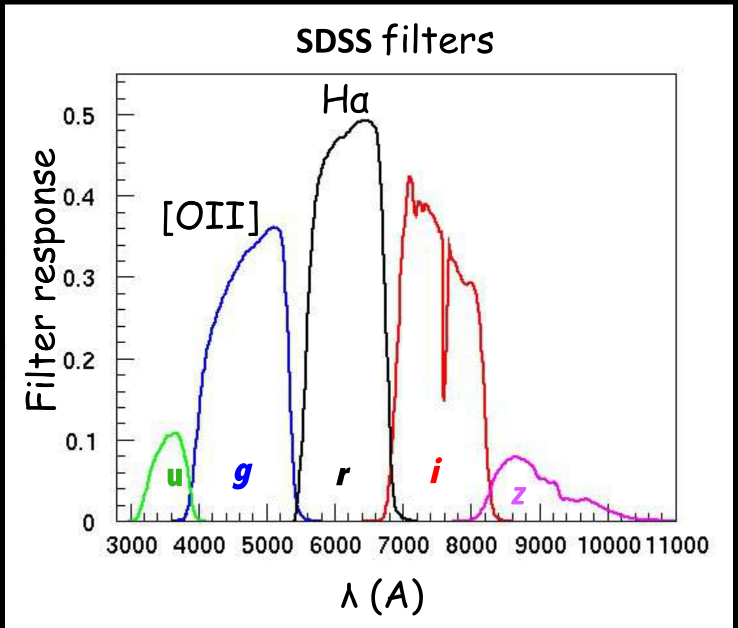
Reconstruct Lum from Flux correcting for extinction:

$$F = F_{ext} \times 10^{-0.4\,E(B-V)\,k(\lambda_{obs})}$$

$$L = 4\pi D_L^2\, F\, 10^{-0.4\,(mp-mfib)}$$

↓

fiber aperture correction: SDSS < 3″



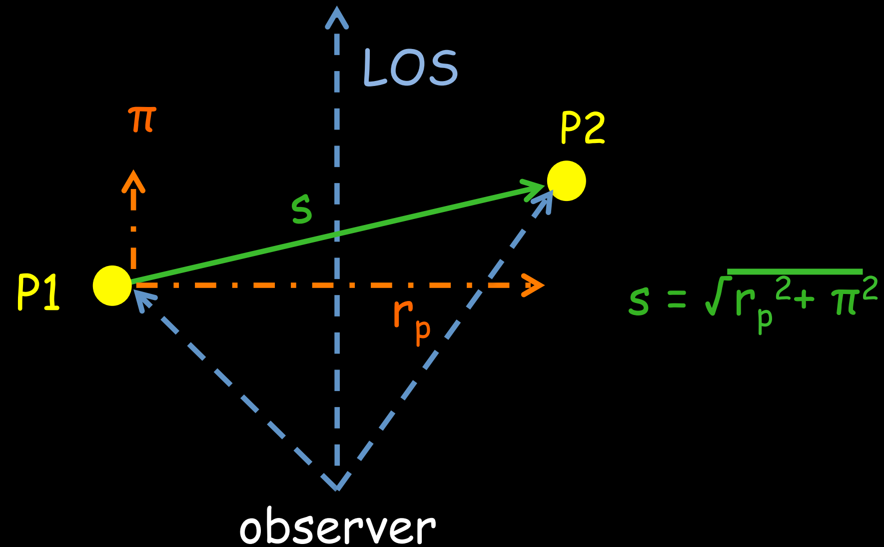
Two-point correlation function (2PCF)

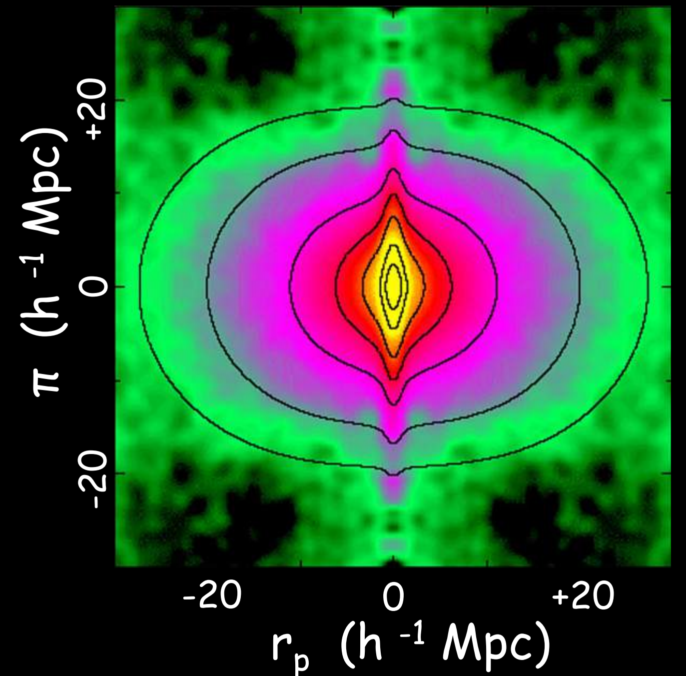
Excess probability over random to find two galaxies in the volume elements dV_1 and dV_2 separated by a distance r with mean galaxy number density n:

$$dP = n^2[1+\xi(r)]\, dV_1 dV_2$$

Landy & Szalay (1993) estimator:

$$\xi(r_p,\pi) = \frac{DD(r_p,\pi) - 2DR(r_p,\pi) + RR(r_p,\pi)}{RR(r_p,\pi)}$$





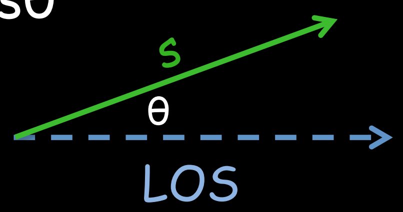
Expand the redshift-space 2PCF in multipoles using the Legendre polynomials:

$$\xi_l(r) = \frac{2l+1}{2} \int_{-1}^{+1} \xi(r_p, \pi)\, P_l(\mu)\, d\mu$$

l=0 monopole

l=2 quadrupole

$\mu = \cos\theta$



Integrate along the line of sight to mitigate the peculiar velocity contribution responsible of the finger-of-god elongation

$$w_p(r_p) = 2 \int_0^{\infty} \xi(r_p, \pi)\, d\pi$$

projected 2PCF

N-body cosmological simulations

Computationally expensive: solve the equation of motion of N particles interacting only gravitationally

I. DARK-MATTER ONLY

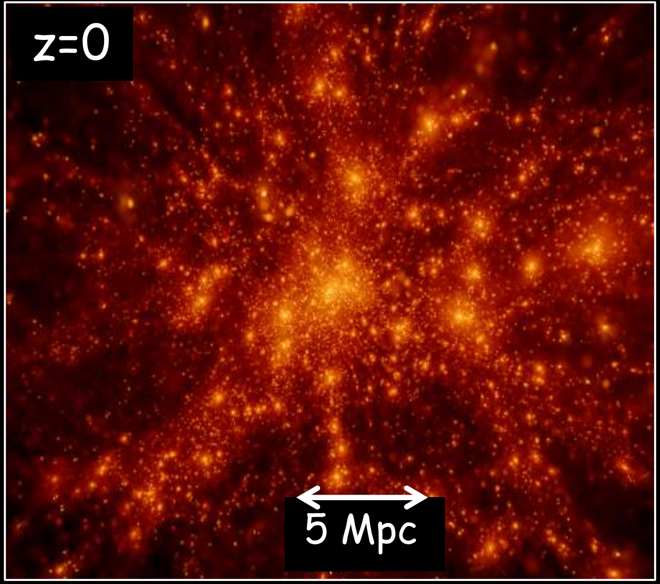
No baryons, collisionless cold dark matter particles

MultiDark Planck (Klypin et al., 2016)

$L = 1\ h^{-1}$Gpc, 3840^3 particles

$1.51\times10^9\ h^{-1}\ M_\odot$ mass resolution

Halo finders: BDM, ROCKSTAR, FoF



www.multidark.org

II. HYDRO (DM+Baryons)

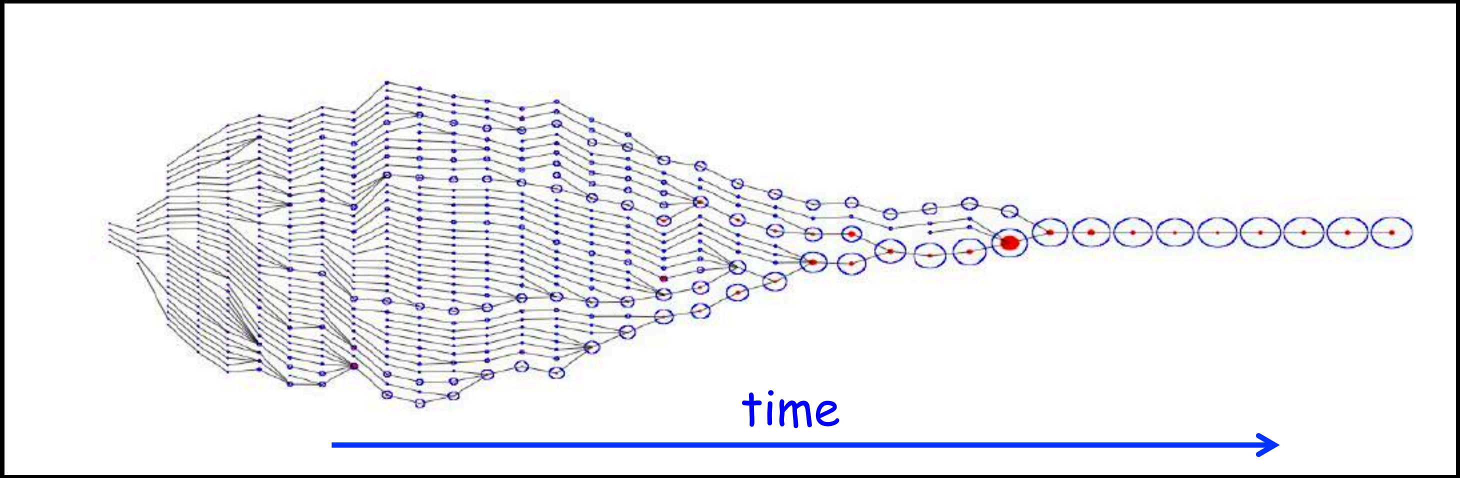
Include baryons (gas, stars, …) as a fluid

CURIE, ILLUSTRIS

III. Semi-analytic models of galaxy formation (SAMs)

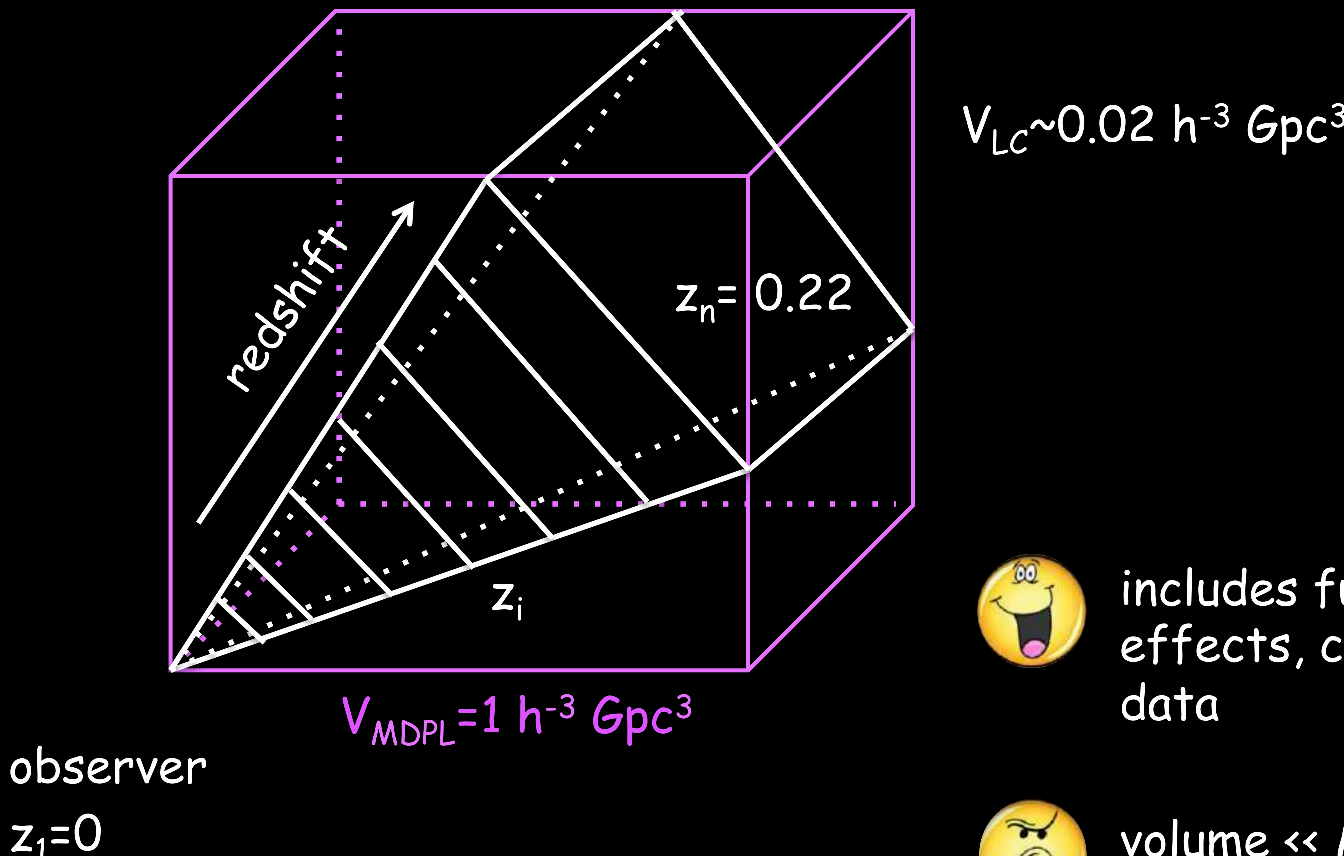
Approximate analytic models to simulate the formation of galaxies including merger trees, gas infall and cooling, SN and AGN feedback, chemical evolution

Now in development: SAG, SAGE, Galacticus, GALFORM, MultiDark galaxies



MultiDark Light-cones

Survey Generator (SUGAR; Rodríguez-Torres et al. 2016) algorithm applied to MultiDark Planck 1Gpc/h simulation snapshots



- includes full z evolution, volume effects, cosmic variance as real data
- volume « MDPL box

The halo-galaxy connection: statistical methods

Galaxies are biased tracers of the underlying dark matter distribution. We populate DM halos with galaxies using their spatial properties

I. (Sub)Halo Abundance Matching – SHAM

Conroy et al., 2006, 2009; Behroozi et al., 2010; Trujillo-Gomez et al., 2011; Nuza et al., 2013

II. Halo Occupation Distribution – HOD

Cooray et al., 2002; Berlind & Weinberg 2002; Kravtsov et al., 2004; Zheng et al., 2007

SHAM

Monotonic correspondence, with some scatter σ, between halo and galaxy number densities

$$n_{gal}(<M_r) = n_h(>V_{max})$$

$$V_{max} = \max\left[\sqrt{GM_{vir}(<r)/r}\right]$$

More luminous galaxies reside in more massive halos

straightforward, only one physically motivated parameter: σ

only works with complete galaxy samples

ELGs are INCOMPLETE in stellar mass (Comparat et al. 2014), thus a modification is required

Modified SHAM for ELGs

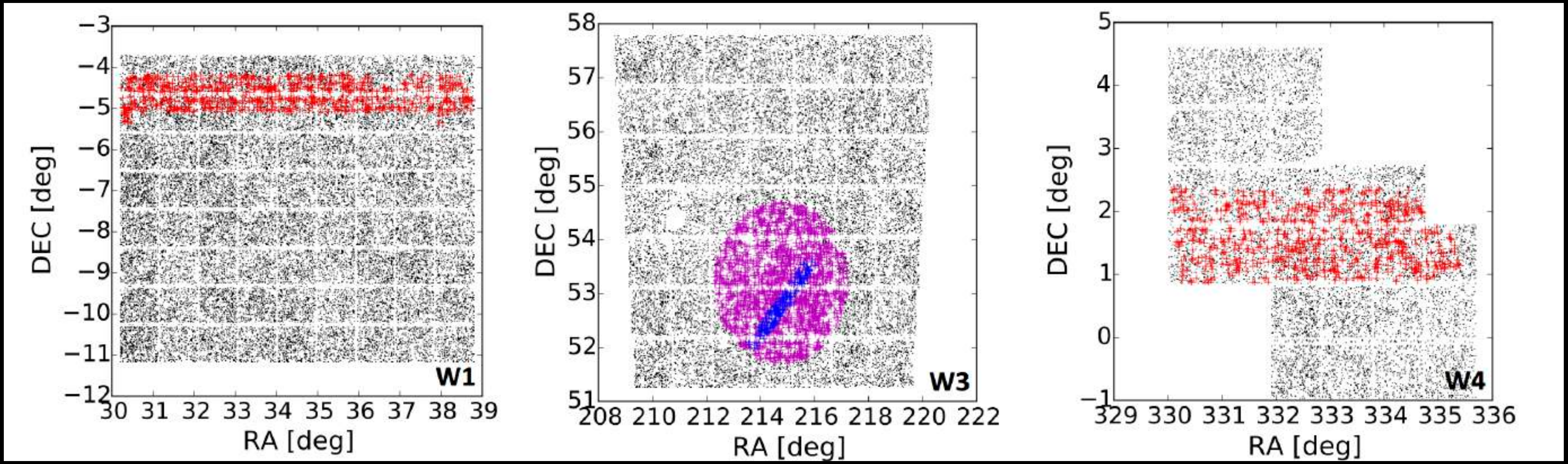
Apply SHAM to a MultiDark light-cone drawing central and satellite halos through a Gaussian selection function with M_h or V_{max} as halo proxy and vary the satellite fraction to optimize the small-scale clustering fit.

$$P(M_h, M_{mean}, \sigma_M, f_{sat}) = f_{sat}\, G_{sat}(M_h, M_{mean}, \sigma_M, f_{sat}) + (1-f_{sat})\, G_{cen}(M_h, M_{mean}, \sigma_M, f_{sat})$$

I. Clustering properties of g-selected galaxies at z~0.8

About 4000 spectra of [OII] ELGs from BOSS, DEEP2, VIPERS in the CFHT-LS Wide photometric fields

Clustering + weak lensing measurements to constrain ELG halo masses and satellite fraction

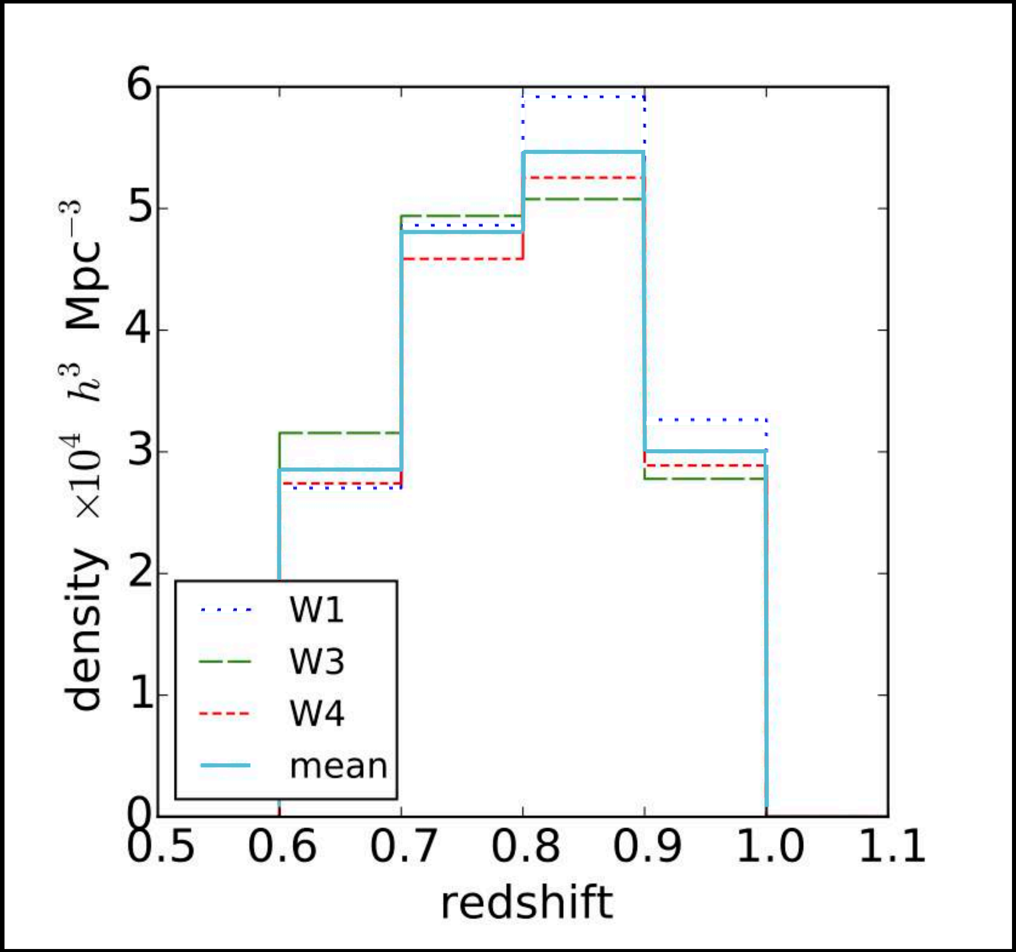


Favole et al. 2016a, MNRAS461.3421F

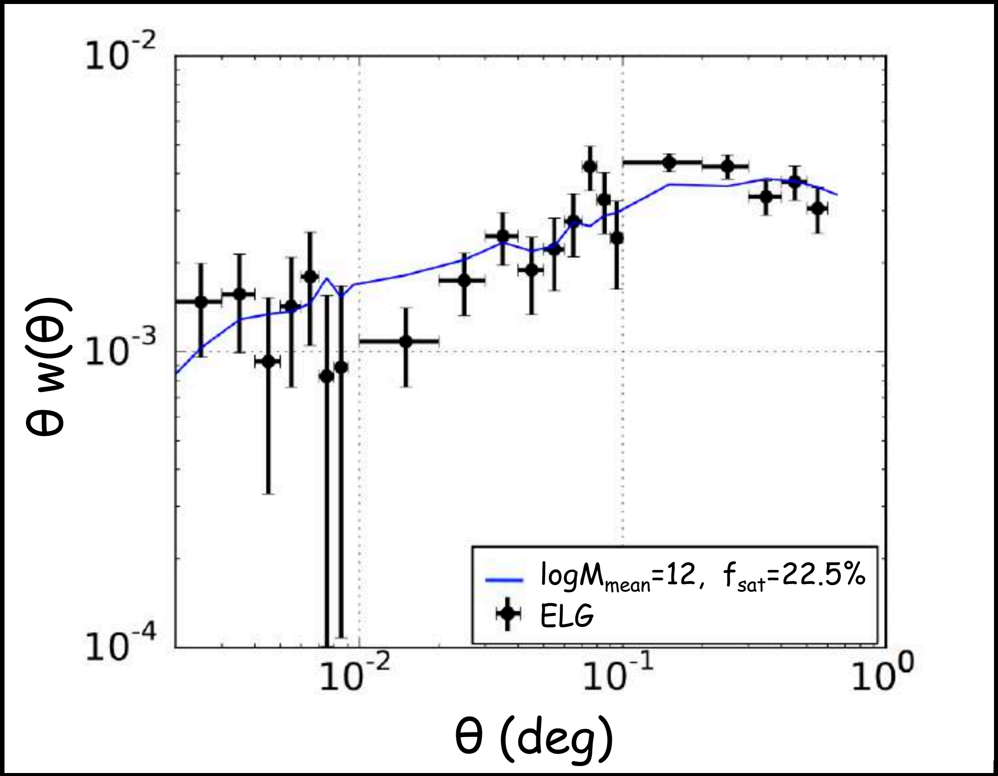
VIPERS: 5.478 deg^2 in W1; 5.120 deg^2 in W4
BOSS: 6.67 deg^2 in W3
DEEP2: 0.5 deg^2 in W3

Select galaxies with bright emission lines and low dust in 0.6<z<1:

20 < g < 22.8; i < 22.5; -0.5 < (u-r) < 0.7(g-i)+0.1

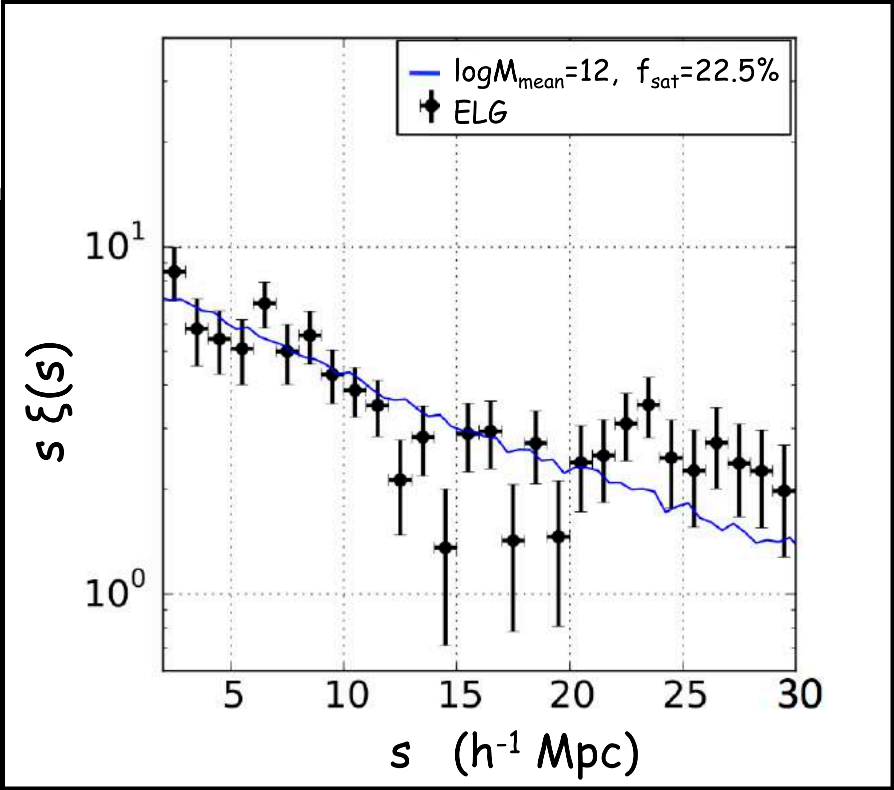


Favole et al. 2016a, MNRAS461.3421F

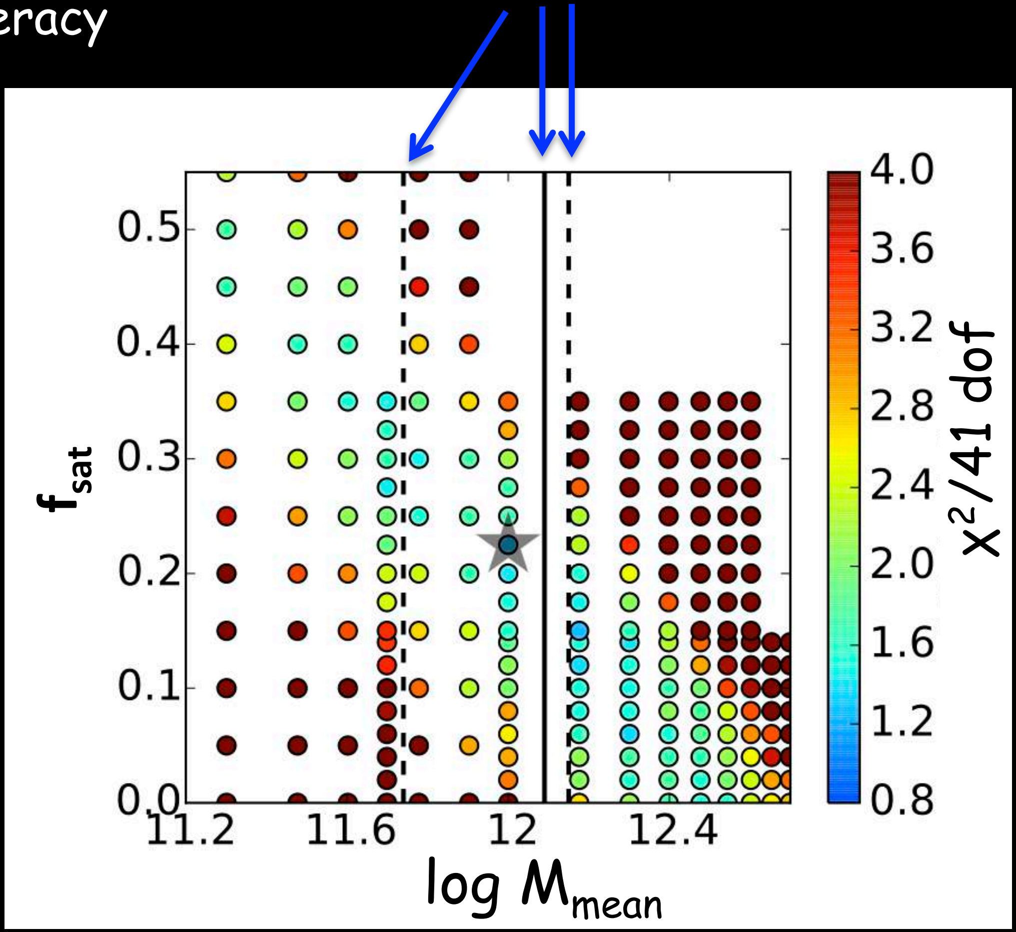


Errors from mock re-sampling

Favole et al. 2016a, MNRAS461.3421F



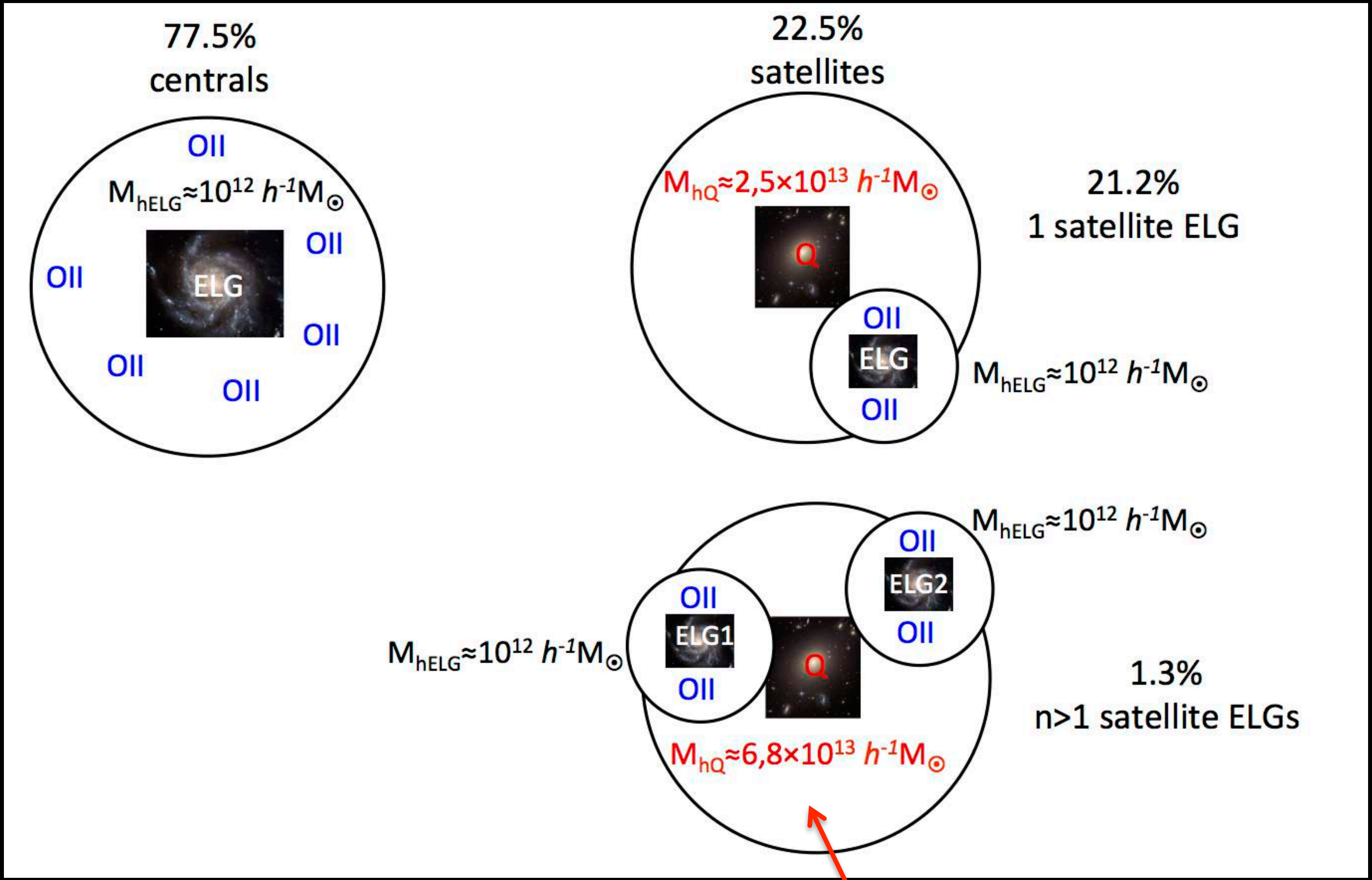
Galaxy-galaxy lensing: measure tangential shear around photometric ELGs as a function of the distance from the lenses. This additional constraints help to break the degeneracy



Favole et al. 2016a, MNRAS461.3421F

ELGs at z~0.8 live in halos of $M_{mean} = 10^{12}\ h^{-1}\ M_{\odot}$ and 22.5% of them are satellites belonging to larger halos whose central galaxies are quiescent.

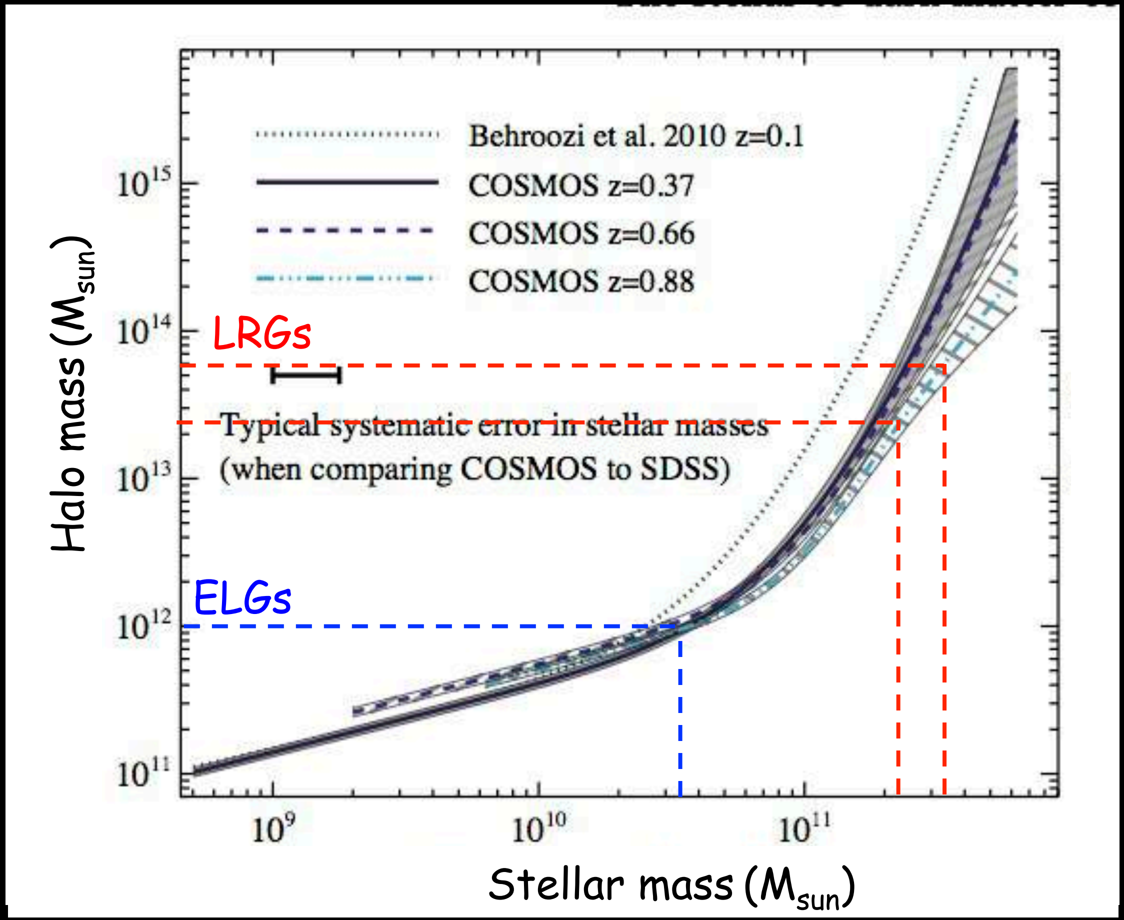
[OII] ELG configuration at z~0.8:



Favole et al. 2016a, MNRAS461.3421F

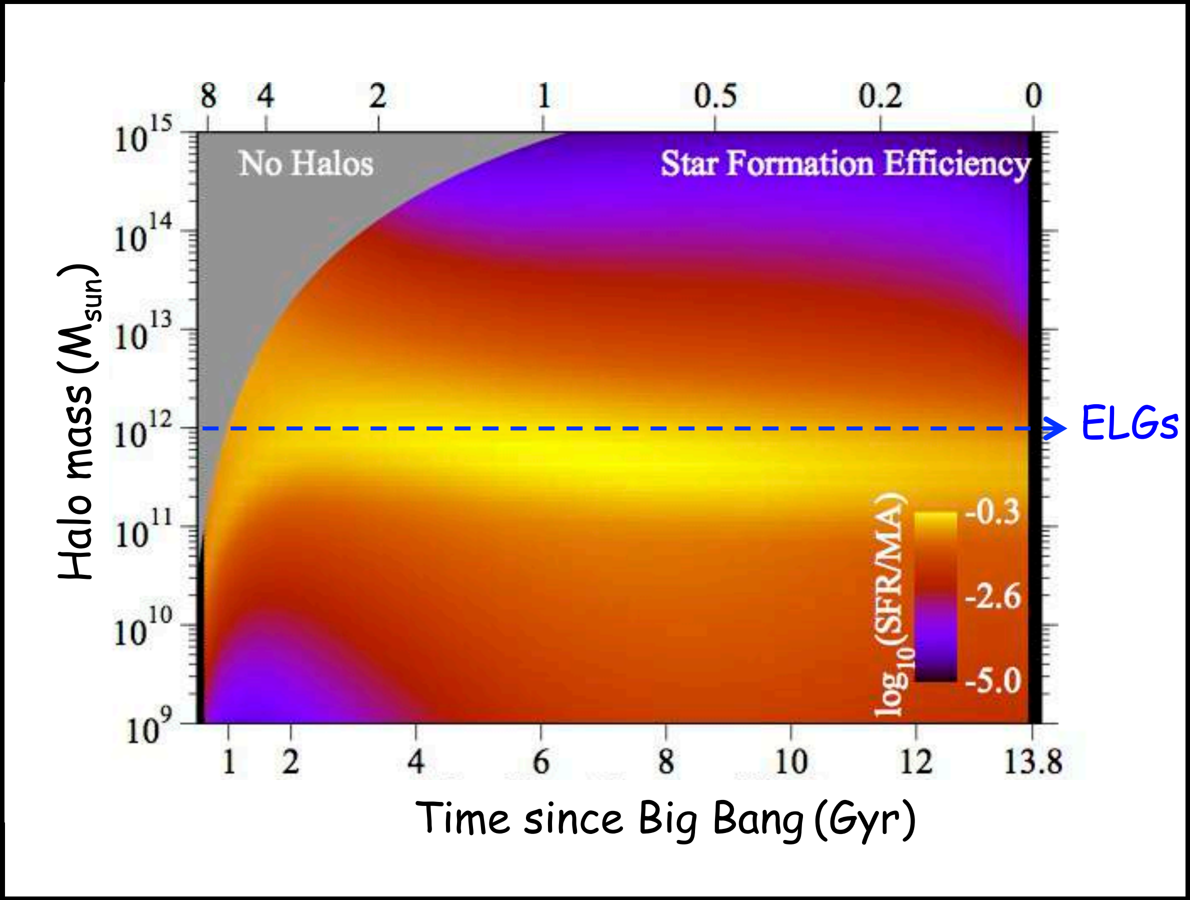
The quiescent central galaxies are NOT included in the sample !

ELGs at z~0.8 with typical halo masses of 10^{12} h^{-1} $M_\odot$ have stellar masses of about $3.5\times10^{10} h^{-1}$ $M_\odot$



Leauthaud et al. 2012

The SFR reveals that we are sampling those halos that most efficiently form stars

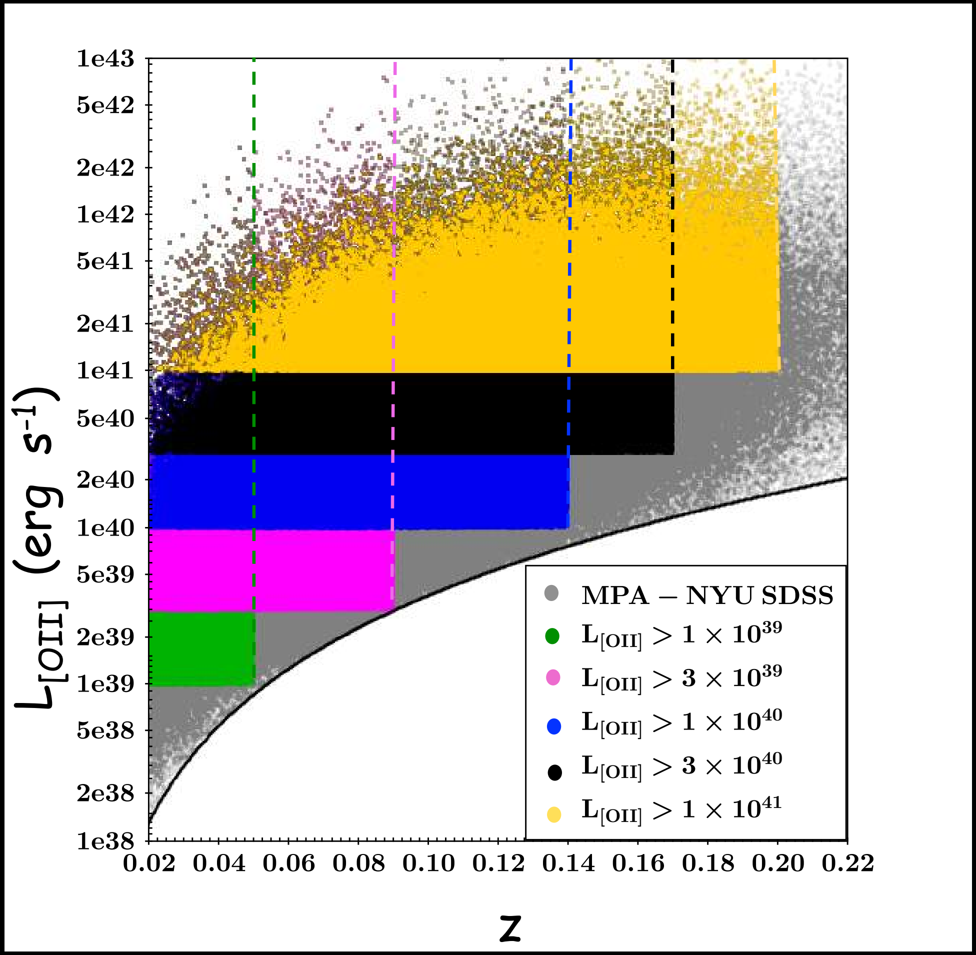


Behroozi et al. 2013

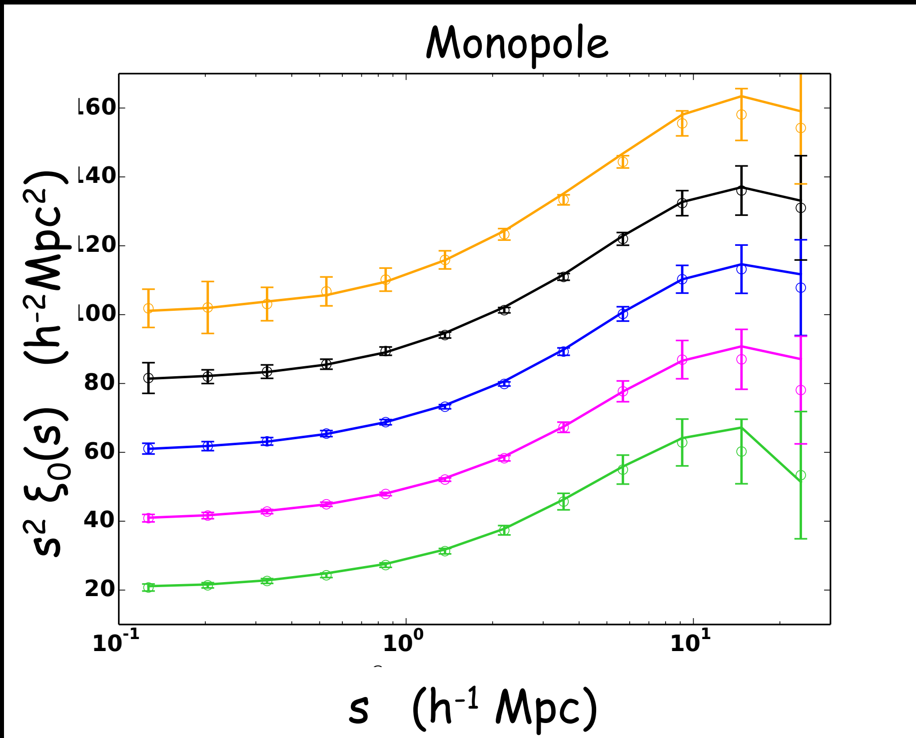
II. Galaxy clustering versus $L_{[OII]}$ at z~0.1

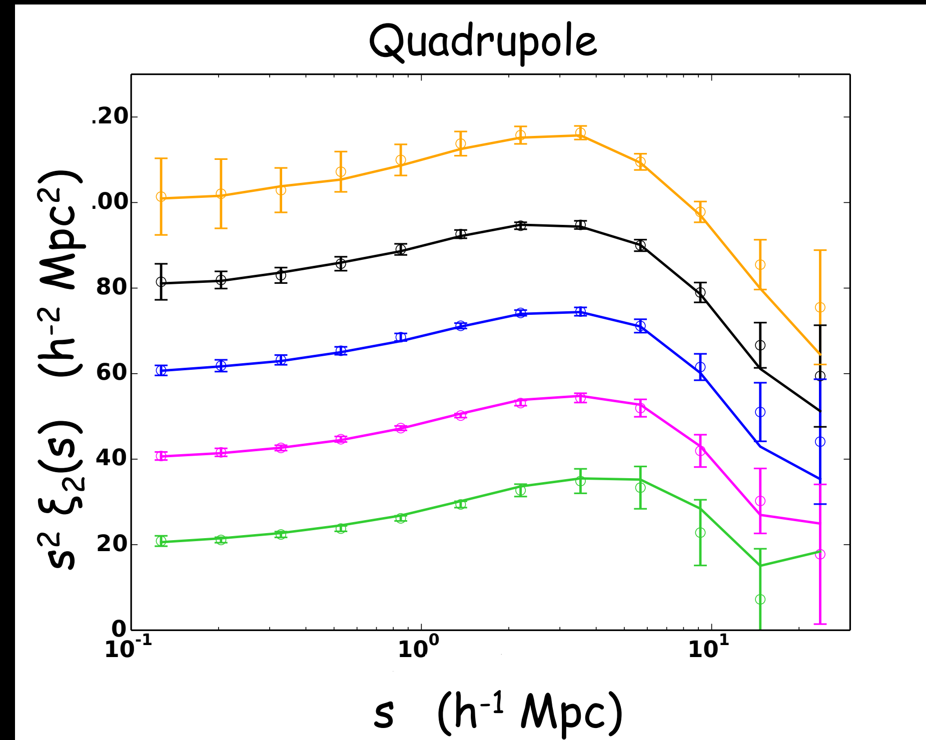
SDSS DR7 main galaxy sample (Strauss et al. 2002): 7300 deg^2 in 0<z<0.22
[OII] emission lines from MPA-JHU DR7 spectrum release.

Spectroscopic matching: 433,000 ELGs with [OII] Flux > 3x10^{-16} erg cm^{-2} s^{-1}



Favole et al. 2016b, arXiv: 16110545F



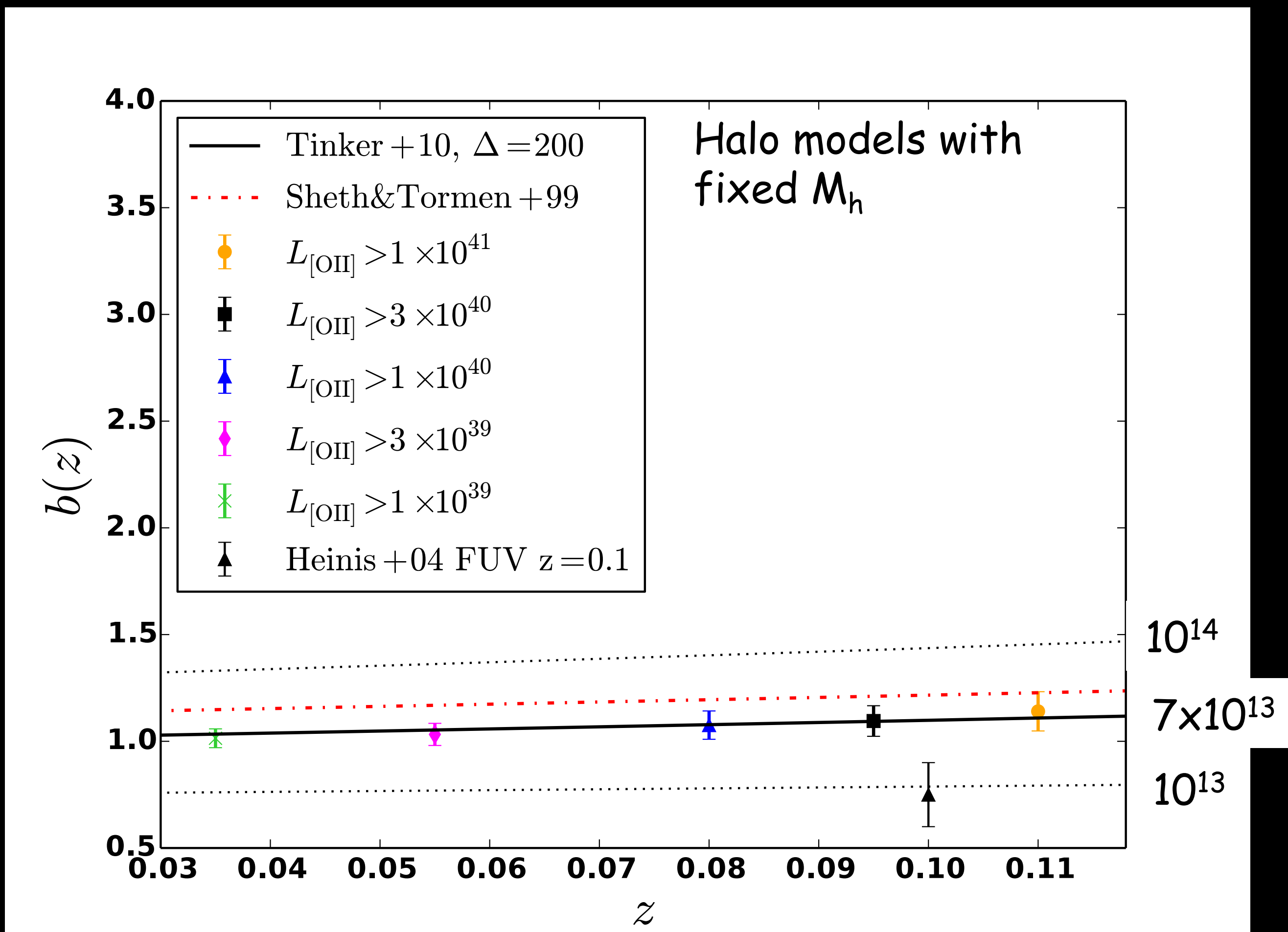


The more luminous, the more clustered, the higher V_{peak} and M_h, the lower f_{sat}

	$L_{[OII]}$ (erg/s)	V_{peak} (km/s)	M_h (M_{sun}/h)	f_{sat} (%)
	>1e+39	127±58	$(3.17\pm0.19)\times10^{11}$	33.4±0.1
	>3e+39	177±53	$(6.64\pm0.41)\times10^{11}$	27.9±0.4
	>1e+40	201±86	$(1.54\pm0.09)\times10^{12}$	22.5±0.7
	>3e+40	283±117	$(2.92\pm0.18)\times10^{12}$	19.4±0.4
	>1e+41	341±140	$(5.49\pm0.34)\times10^{12}$	18.1±0.5

Linear galaxy bias correlates with [OII] luminosity and increases with redshift

$$b(r_p) = \sqrt{w_p(r_p)/w_p^m(r_p)}$$



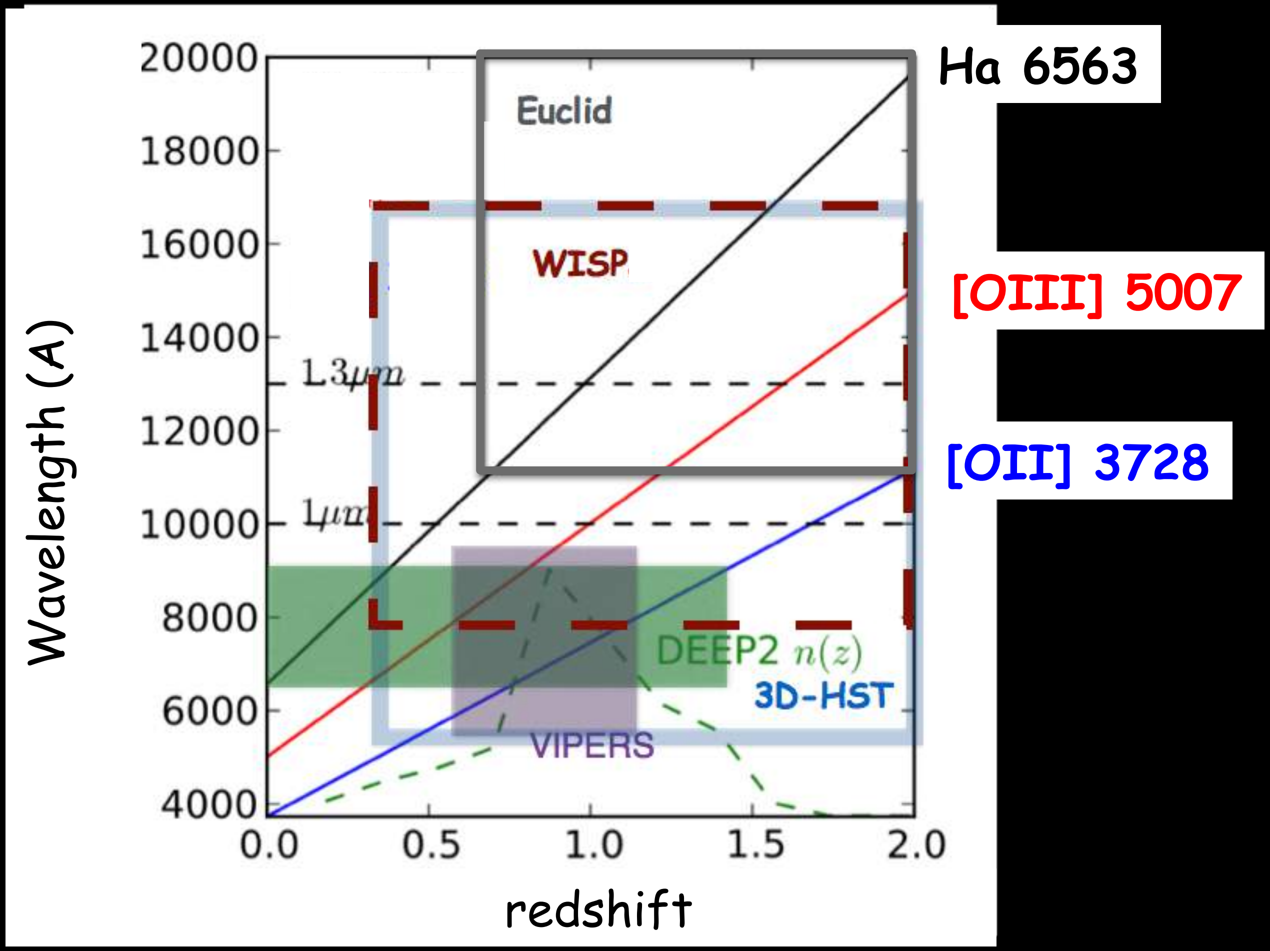
bias driven by mean parent halo mass !

What we learn from SDSS and SDSS-III/BOSS:

- How to build straightforward galaxy clustering models based on N-body cosmological simulations
- How to modify the standard SHAM model to account for the ELG incompleteness
- How to generate light-cones using SUGAR (Rodríguez-Torres et al., 2016) to include the full redshift evolution

III. WISP/3D-HST Ha emitters

Ha ELG sample for clustering studies using WISPS and 3D-HST in preparation to Euclid. Detection window determined by z, wavelength coverage:



Comparat et al. 2013; Newmann et al. 2013

Ongoing near-IR, slitless HST programs

WISP

WFC3 pure parallel program, 483 reduced fields

Total coverage ~ 1330 $arcmin^2$ (~ 0.34 deg^2)

Grisms:
WFC3/G102 (0.8-1.17μm, R~210)
WFC3/G141 (1.11-1.67μm, R~130)

Imaging in J,H bands with broadband filters F110W, F140W, F160W.

ELG targets: [OII], [OIII], Hα in 0.3<z<1.5

3D-HST

HST treasury program

~ 600 $arcmin^2$ (~ 0.17 deg^2) in 5 extragalactic fields

Grisms:
WFC3/G141
ACS/G800L (0.55-1.05μm, R~130)

Imaging filters:
WFC3/F140W
ACS/F814W

ELG targets: [OII], [OIII], Hα in 0.3<z<1.5.

Ha ELG clustering sample completeness:

C (Ha flux, EW, size) + geometry – bad fields = survey mask

Simulate fake Ha ELGs with aXesim and include them in WISP pipeline.

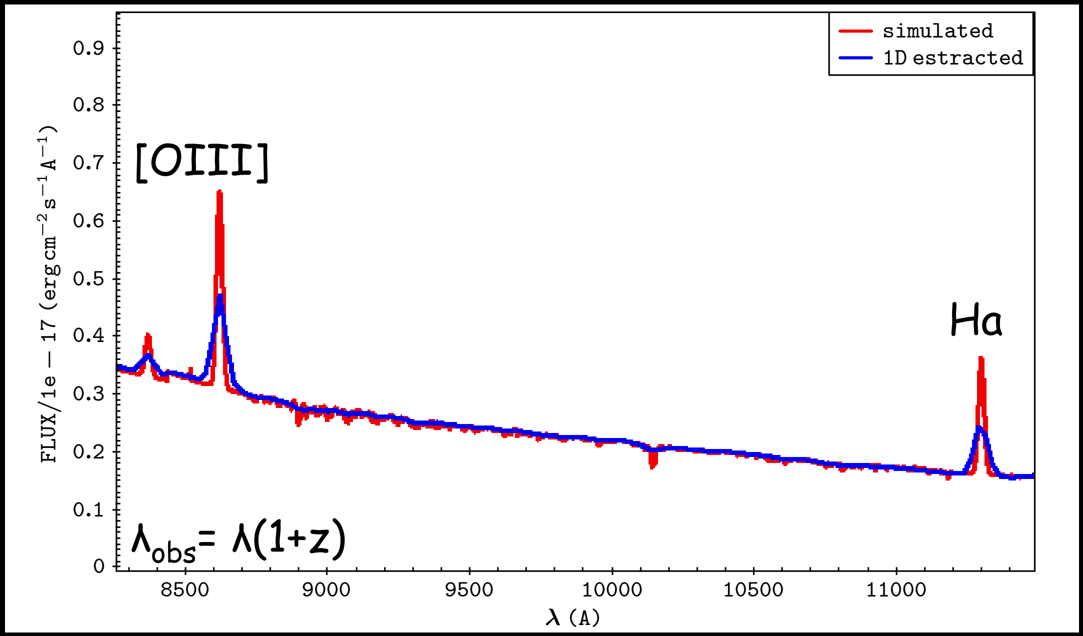
5 bins in each property, 20 galaxies per bin:

- 2e-17< Ha flux < 1e-15 erg cm^{-2} s^{-1}
- 20 < EW< 700 A
- 0.05"< a < 1.2" ; 0.03"< b < 0.8" to match 3D-HST in z range down to H=26

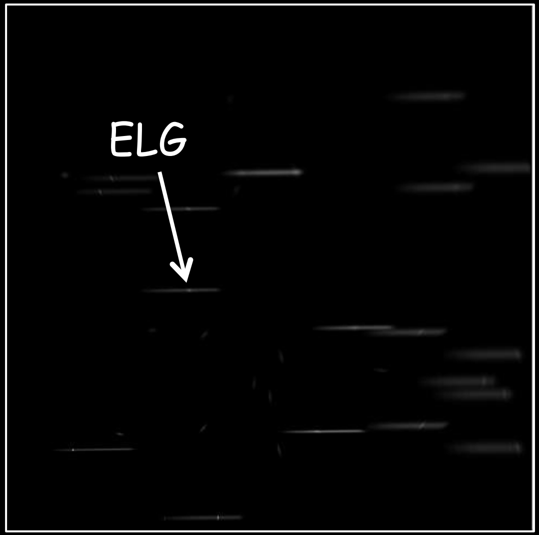
2 deep fields: WFC3/G102 with F110W and WFC3/G141 with F160W

Bruzual & Charlot 2003 (BC03) spectral templates, Chabrier IMF

Add gaussian emission lines



Slitless image



Place fake ELGs in the field, run pipeline, line-finder algorithm, inspection

Estimate completeness, draw polygon mask, eliminate bad fields

Finally measure & model galaxy clustering !

Summary & future prospects

Complementing EUCLID measurements with data from ground-based spectroscopic/photometric surveys and modeling with high-resolution cosmological simulations, we will be able to:

- push clustering analysis r << $1h^{-1}$ Mpc
- precisely measure & model galaxy clustering, bias, z-space distortions
- accurately predict the galaxy halo occupation distribution
- study correlation clustering – SFR – emission line strength
- probe Universe LSS and expansion history, unveil dark energy
- improve BAO measurement & errors


Thank you!