Modeling the clustering of emission line galaxies using light-cones

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In collaboration with

J. Comparat, S. Rodríguez-Torres, F. Prada, D. Croton

September 26, La Plata

Outline

- **Introduction**

  The importance of emission line galaxies (ELG)

  Past, ongoing and near-future spectroscopic surveys

- **Modeling the ELG clustering using MultiDark light-cones**

  The BOSS [OII] ELG sample at z≈0.8 - Favole et al. 2016, arXiv:1507.04356

  The SDSS [OII] ELG sample at z≈0.1 - Favole et al. 2016, in prep.

- **Building mocks with semi-analytic models (SAMs) of galaxy formation**

  Tests on TAO/SAGE clustering models

- **Summary and future plans**

  How do ELG luminosity, clustering and star formation rate correlate?

Emission line galaxies (ELGs)

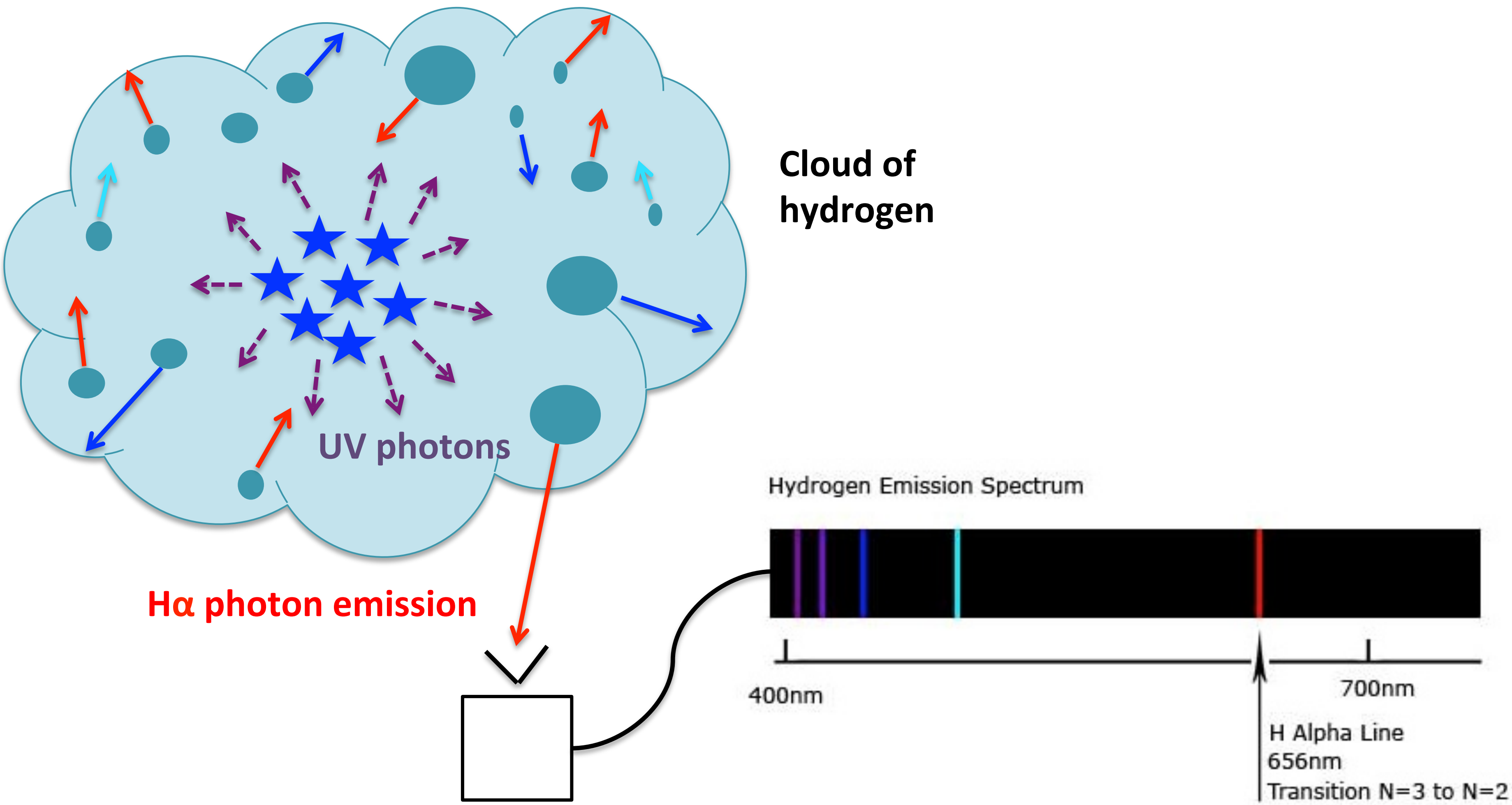
New-generation spectroscopic surveys (SDSS-IV/eBOSS; DESI; 4MOST; EUCLID; Subaru-PFS) will target emission line galaxies in the attempt to trace the baryon acoustic oscillation (BAO) feature up to redshift z=2.

↓

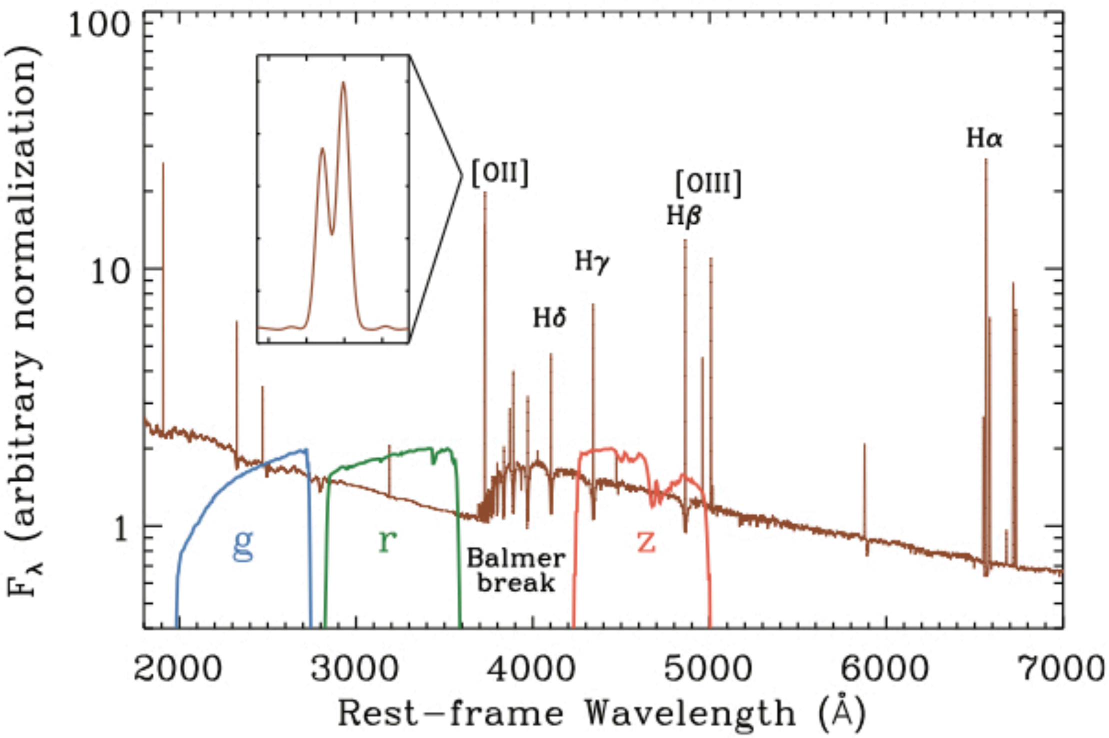
Learning how to correctly measure and model the ELG clustering properties and how they populate their host halos are fundamental points for near-future experiments.

HII regions are emission nebulae, composed primarily of hydrogen, created when young, massive stars ionize nearby gas clouds with high-energy UV radiation

The excited particles of the gas emit photons, which are visible in the hydrogen spectrum



Typical flux of star-forming galaxies whose spectra exhibit nebular emission lines:

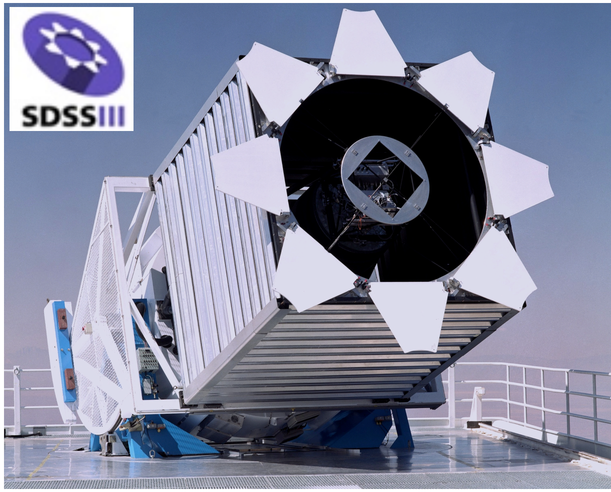


http://desi.lbl.gov/tdr/

The Hα λ6563 Balmer line is the strongest feature to trace star formation (SF)

The [OII] λ3726-3729 doublet is the most prominent feature in the spectra of faint galaxies in the blue

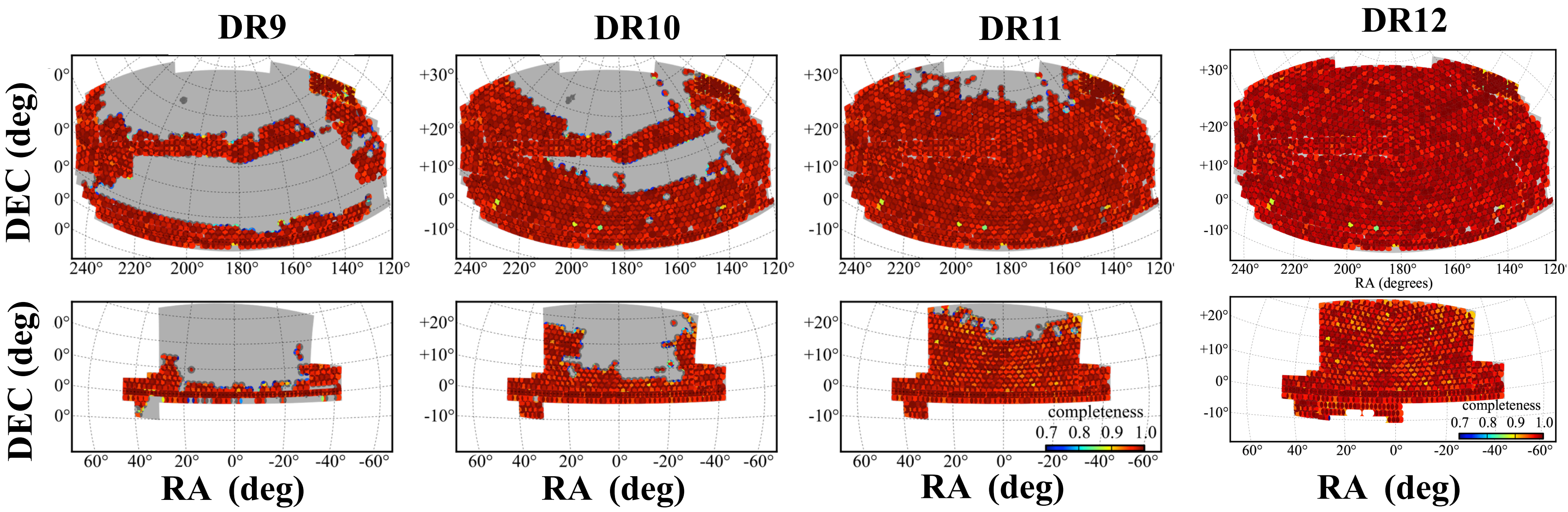
SDSS-III/BOSS



www.sdss3.org

Activity: **2009-2014**
wide field 2.5-m telescope, Apache Point Observatory, NM
10,000 deg^2 sky coverage, North + South galactic caps
ugriz photometric bands

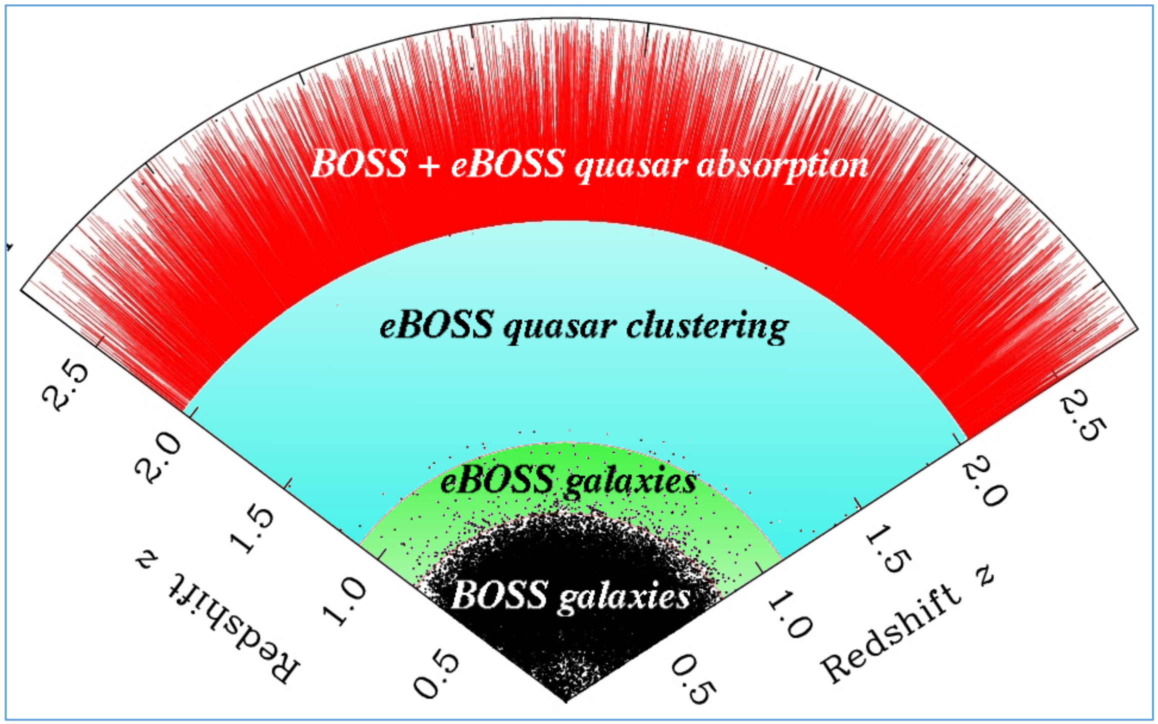
Targets used as **BAO tracers**:
1.5M spectra of **luminous red galaxies at z<0.7**
160,000 Lyman-α forest **quasars out to z=3**



Anderson et al. 2014

SDSS-IV/eBOSS

Activity: **2014-2020**
7500 deg^2
375,000 **LRGs in 0.6<z<0.8**
260,000 **Emission-Line Galaxies 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/

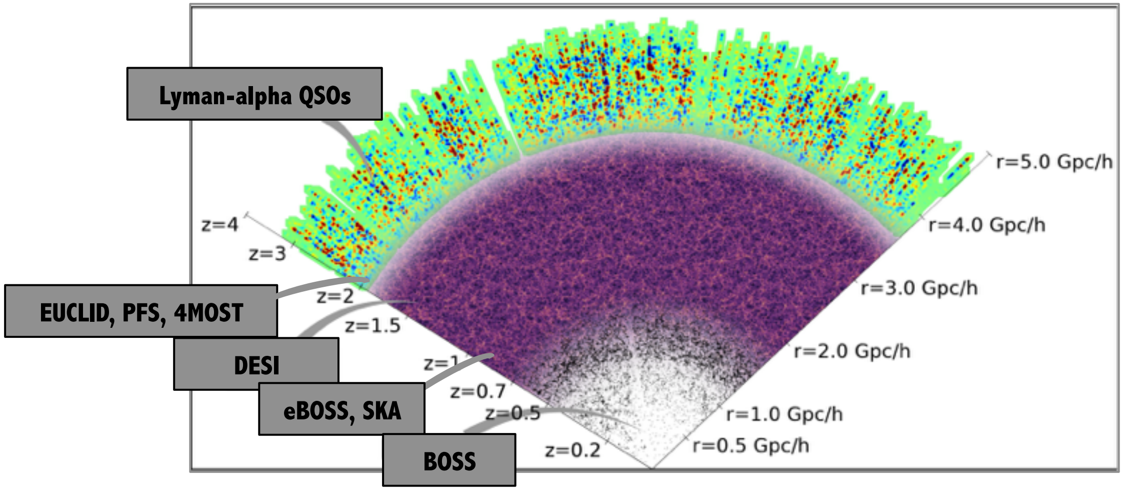
Near-future spectroscopic surveys

DESI (2018-2023)

4m Mayall telescope, Kitt Peak
14,000 deg^2 sky, 10M spectra
LRGs at z<1
ELGs in 0.5<z<1.7
QSOs 1.2<z<3.5
desi.lbl.gov

Prime Focus Spectrograph (2018-2022)

optical/near-IR multi-fiber spectrograph
8.2m Mauna Kea telescope
ELGs up to z=2
(Smee et al. 2014)

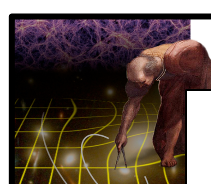


4MOST (2020-2025)

4m VISTA telescope, Paranal
Simultaneously spectra over 4deg^2
1M AGN z<5
[OII] ELGs at z<2
(de Jong et al. 2012)

EUCLID (2020-2025)

near-IR slitless spectroscopy
15,000 deg^2, 1.2m telescope
VIS + NISP deep instruments
50M galaxy spectra
Hα ELGs up to z=2
(Laurejis et al. 2011; Sartoris et al. 2015)



SKA (starting 2020)

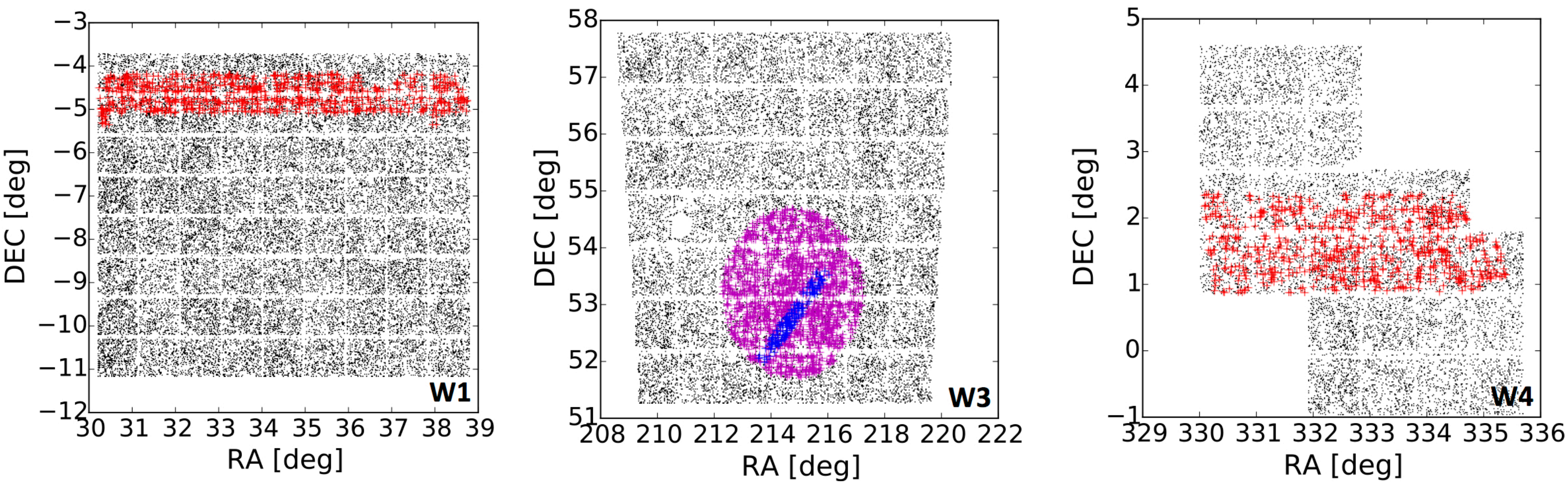
Fastest radio telescope ever built
Australia+South Africa
total area 1km^2
Galaxy clusters with
21-cm HI emission at z>1
www.skatelescope.org

The BOSS [OII] ELG sample at z≈0.8

SDSS-III/BOSS UV-selected star forming galaxies at z≈0.8

About **4000 spectra** from **BOSS DR12, DEEP2, VIPERS** in the CFHT-LS Wide photometric fields

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



Favole et al. 2016, arXiv:1507.04356

VIPERS: 5.478 deg^2 in W1; 5.120 deg^2 in W4

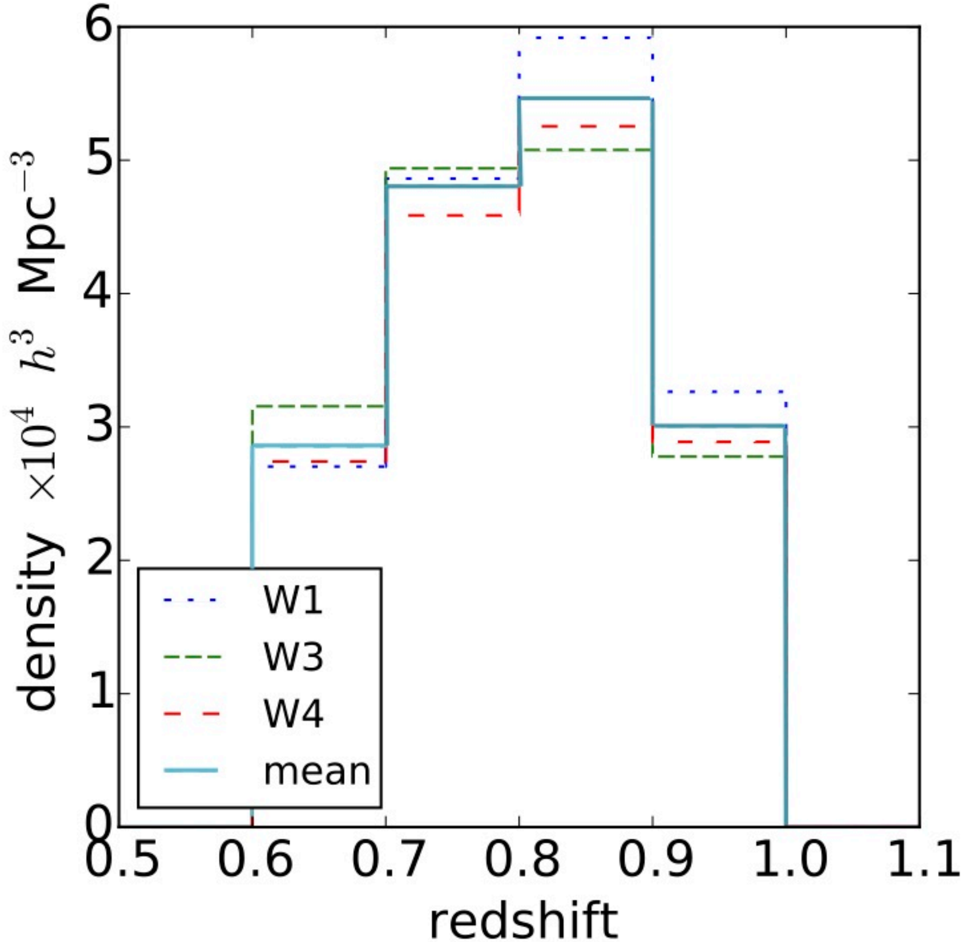
BOSS: 6.67 deg^2 in W3

DEEP2: 0.5 deg^2 in W3

Color cuts to 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. 2016

The MultiDark cosmological simulation

MultiDark Planck MDPL *(Klypin et al., 2016)*

L = 1 h^{-1}Gpc

3840^3 particles

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

Planck cosmology:

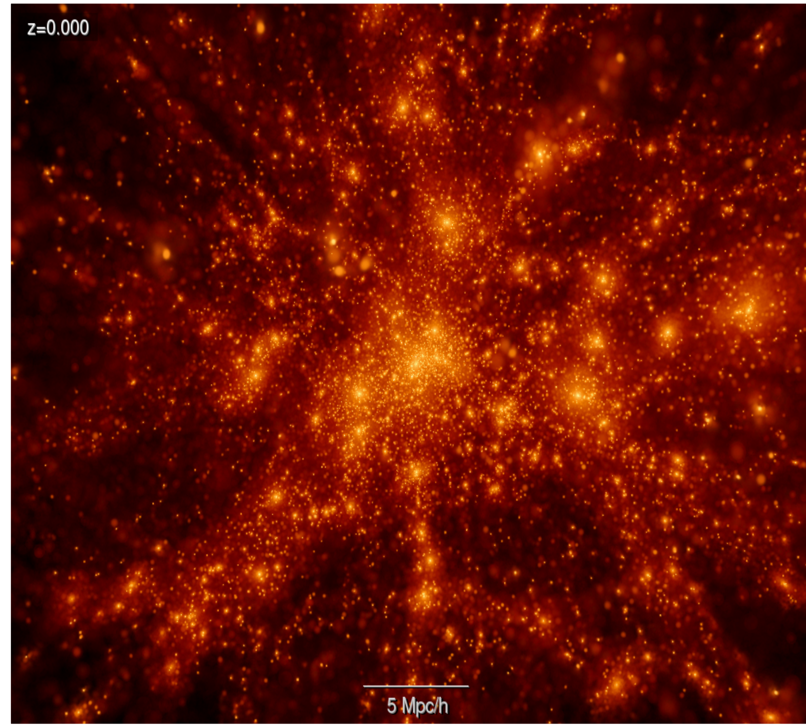
Ω_Λ=0.693, Ω_m=0.307, σ_8=0.82, n=0.96

Halo finders: BDM, ROCKSTAR, FoF

MultiDark
Multimessenger Approach
for Dark Matter Detection

GERMAN ASTROPHYSICAL GAVO VIRTUAL OBSERVATORY

AIP



www.multidark.org

Mapping galaxies to halos:
(Sub)Halo Abundance Matching - SHAM

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

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

$$V_{max} = max[(GM_{vir}/r)^{1/2}]$$

More luminous galaxies reside in more massive halos

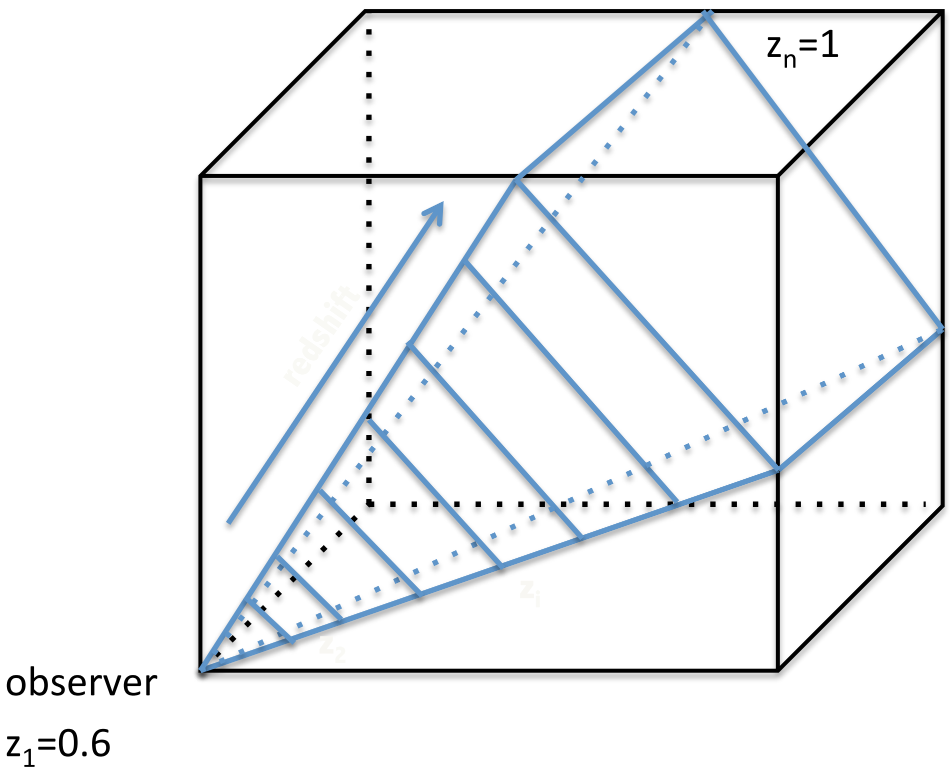
Straightforward method with only one physically motivated parameter: σ

SHAM works only with complete galaxy samples !

ELG clustering model

Modified HAM to account for the ELG stellar mass incompleteness:

1. Generate a MultiDark Planck light-cone using the **Survey GenerAtoR algorithm** (SUGAR; Rodríguez-Torres et al., 2016)



PROS:

LC includes full redshift evolution and volume effects as cosmic variance present in the data

CONS:

Small volume compared to MDPL box

2. Apply SHAM to the light-cone drawing halos through the Gaussian selection function:

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

Favole et al. 2016

virial mass (M_{bound} for subhalos)

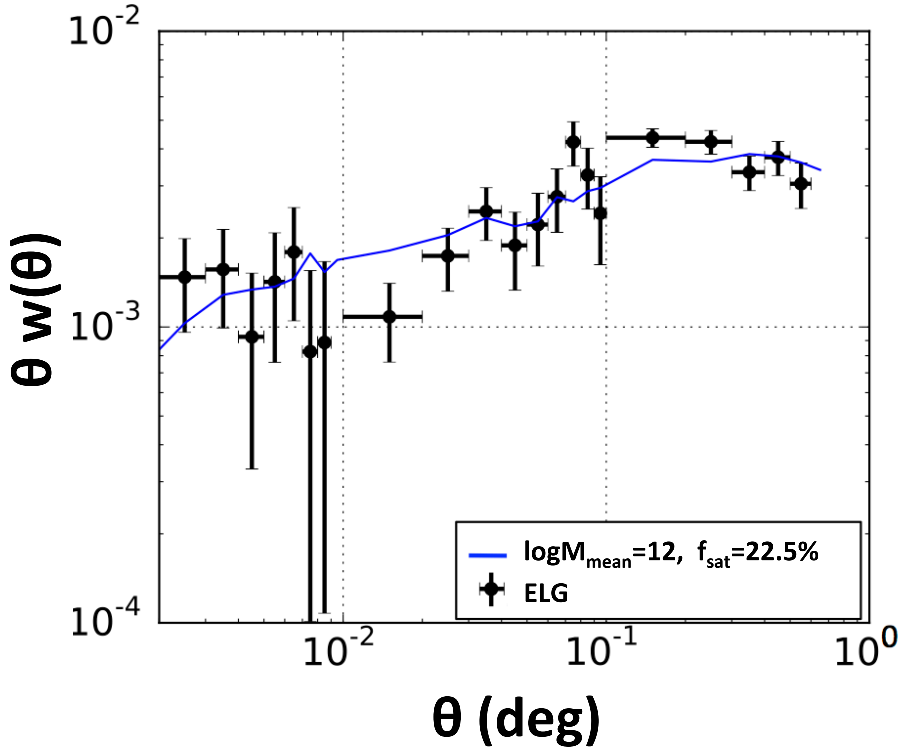
mean halo mass of the sample

dispersion around M_{mean}

satellite fraction

Halo mass as main proxy to be consistent with weak lensing measurements

Clustering results

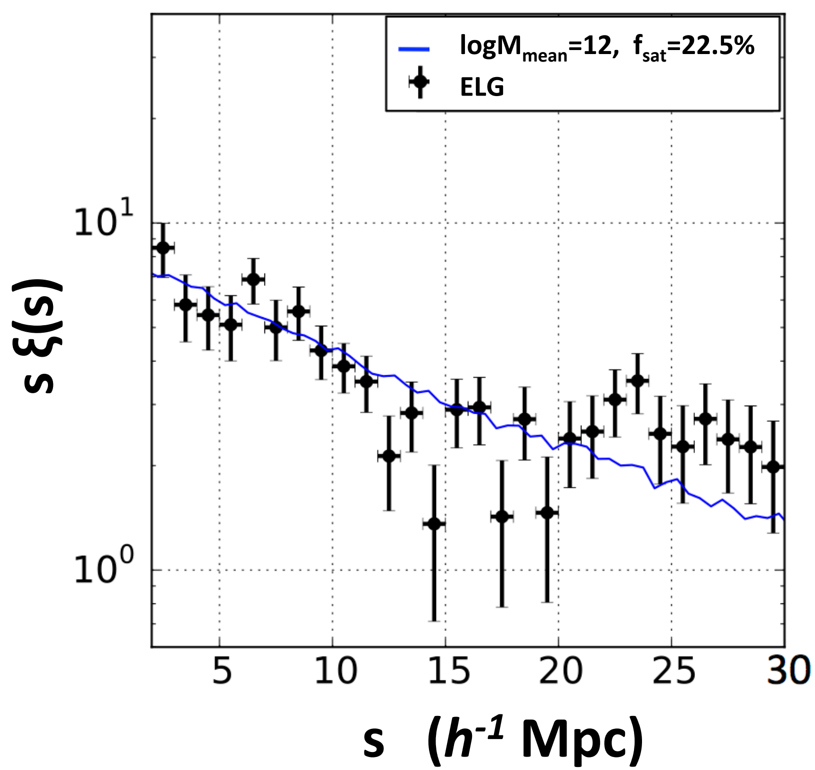


Favole et al. 2016

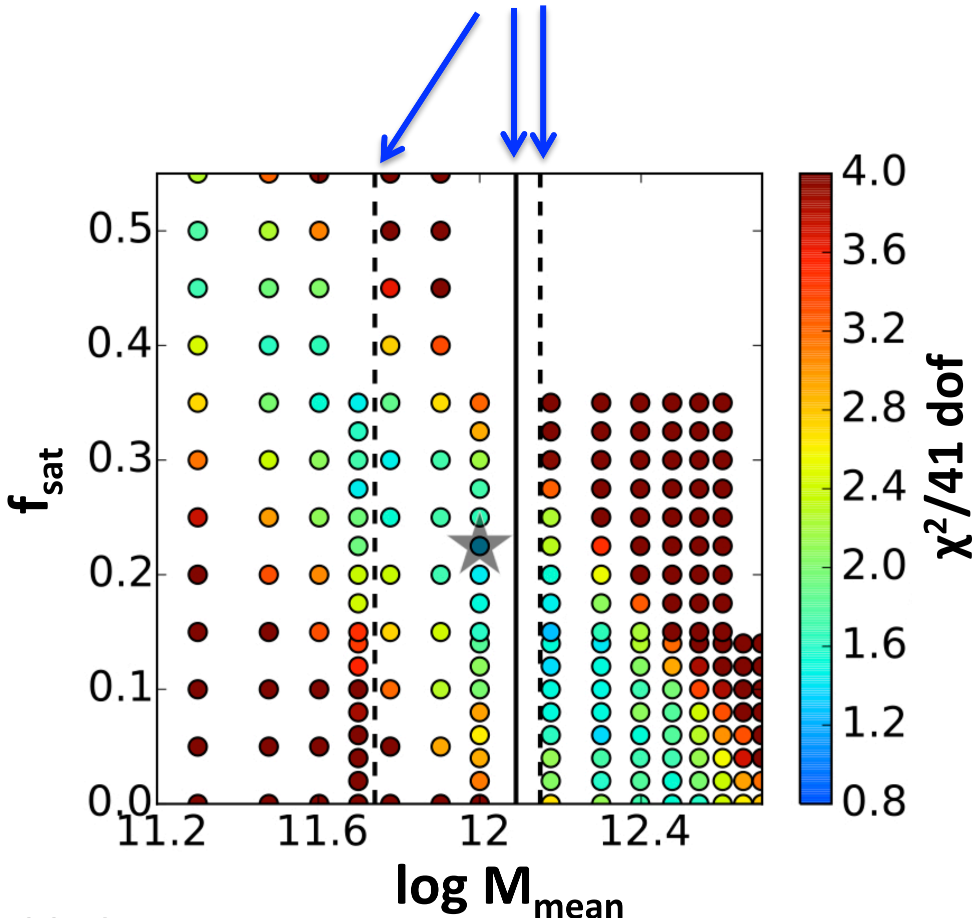
$$\sigma_\xi = \sqrt{\sigma^2_{poiss} + \sigma^2_{jack}}$$

↓

Errors from MDPL light-cone re-sampling:
8 photometric + 24 spectroscopic samples



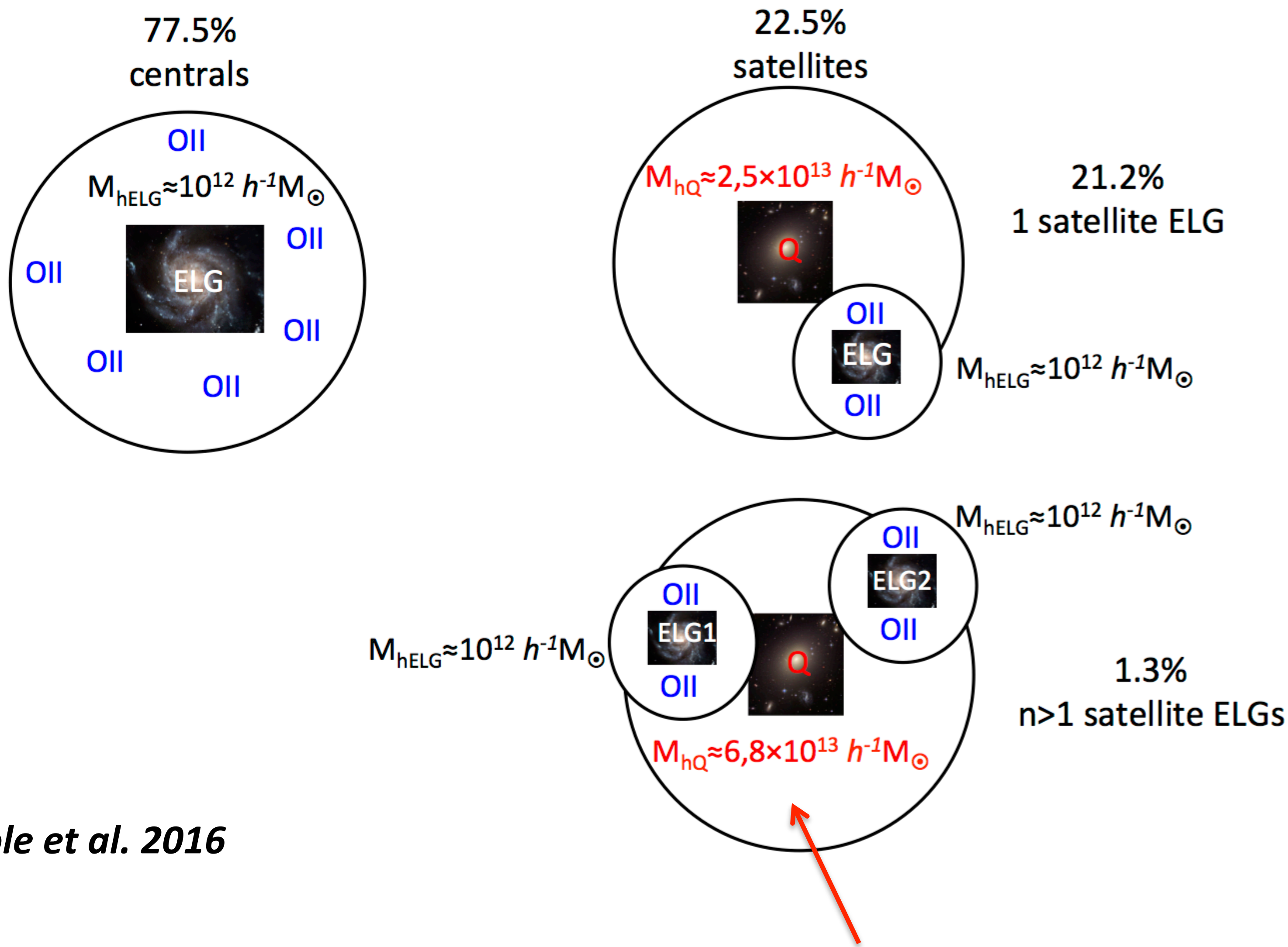
The weak lensing constraints help to break the degeneracy



Favole et al. 2016

ELGs at z≈0.8 live in halos of $\mathbf{M_h = (1 \pm 0.5) \times 10^{12}}$ h^{-1} $\mathbf{M_\odot}$ and (**22.5±2.5)% of them are satellites** belonging to larger halos whose central galaxies are quiescent.

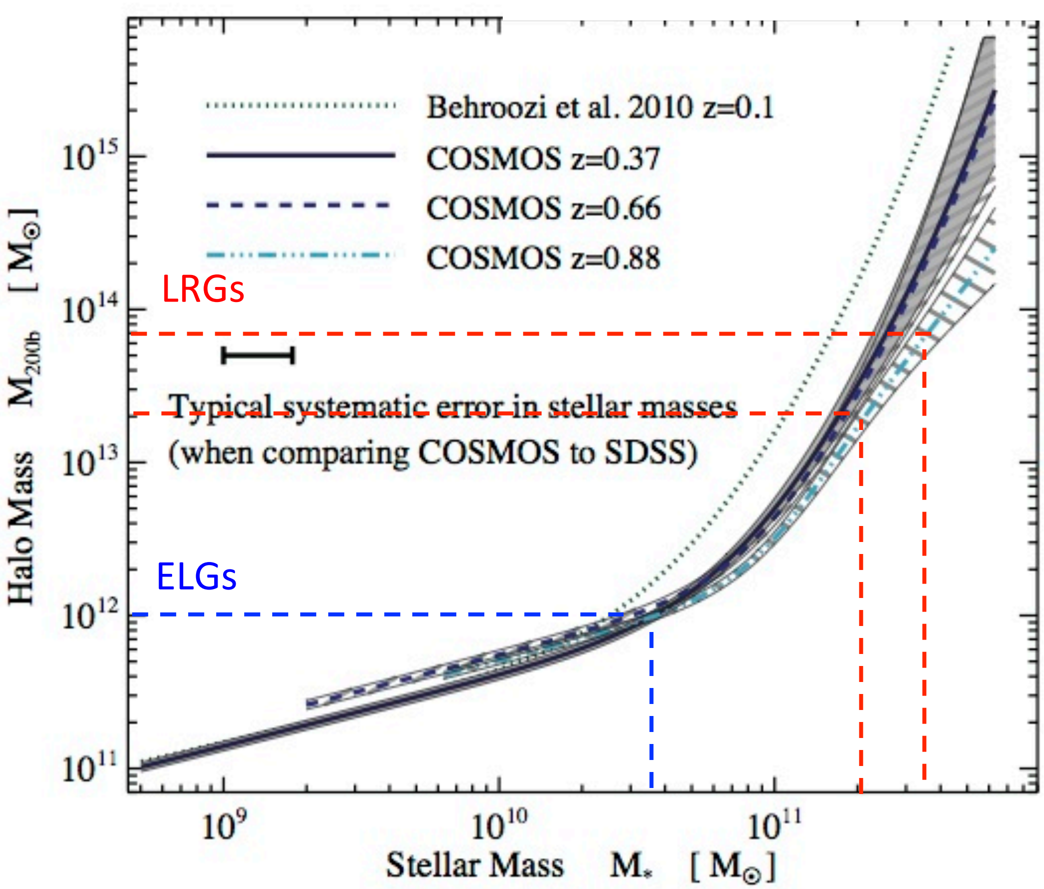
[OII] ELG configuration at z≈0.8 in BOSS DR12:



Favole et al. 2016

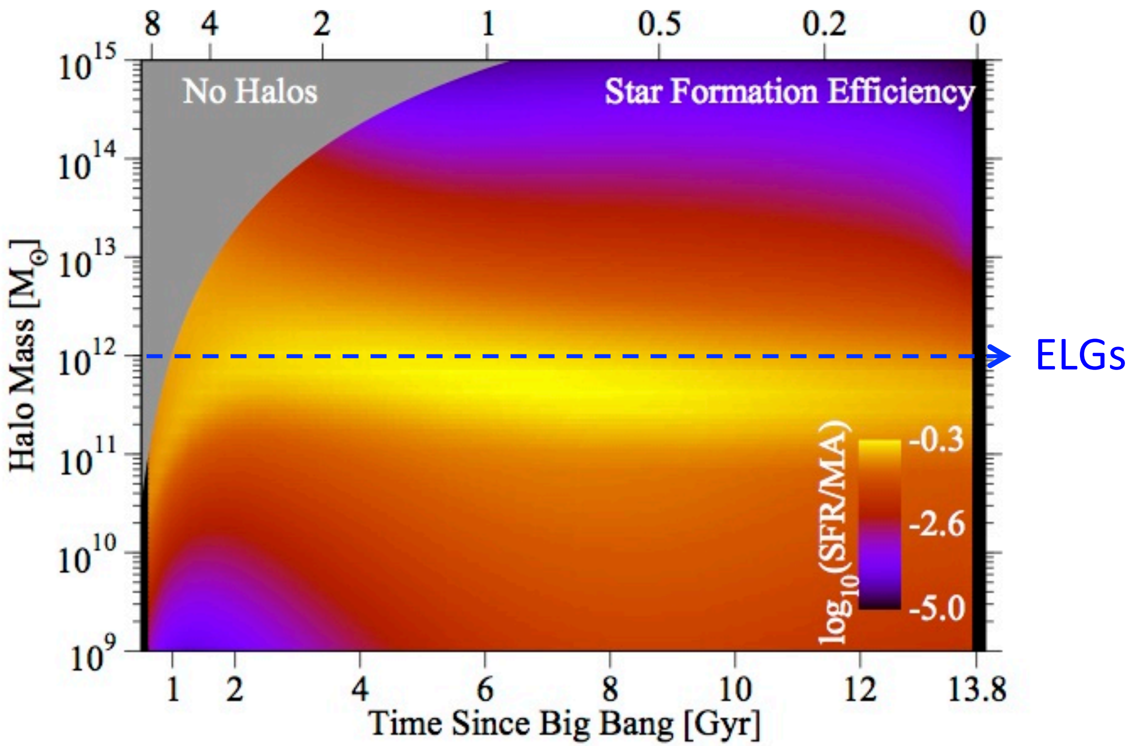
The quiescent central galaxies are NOT included in our sample !

ELGs at z≈0.8 with typical halo masses of $10^{12}\,h^{-1}\,M_\odot$ have **stellar masses** of about **$3.5\times10^{10}h^{-1}\,M_\odot$** according to the stellar-to-halo-mass relation (SHMR)



Leauthaud et al. 2012

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

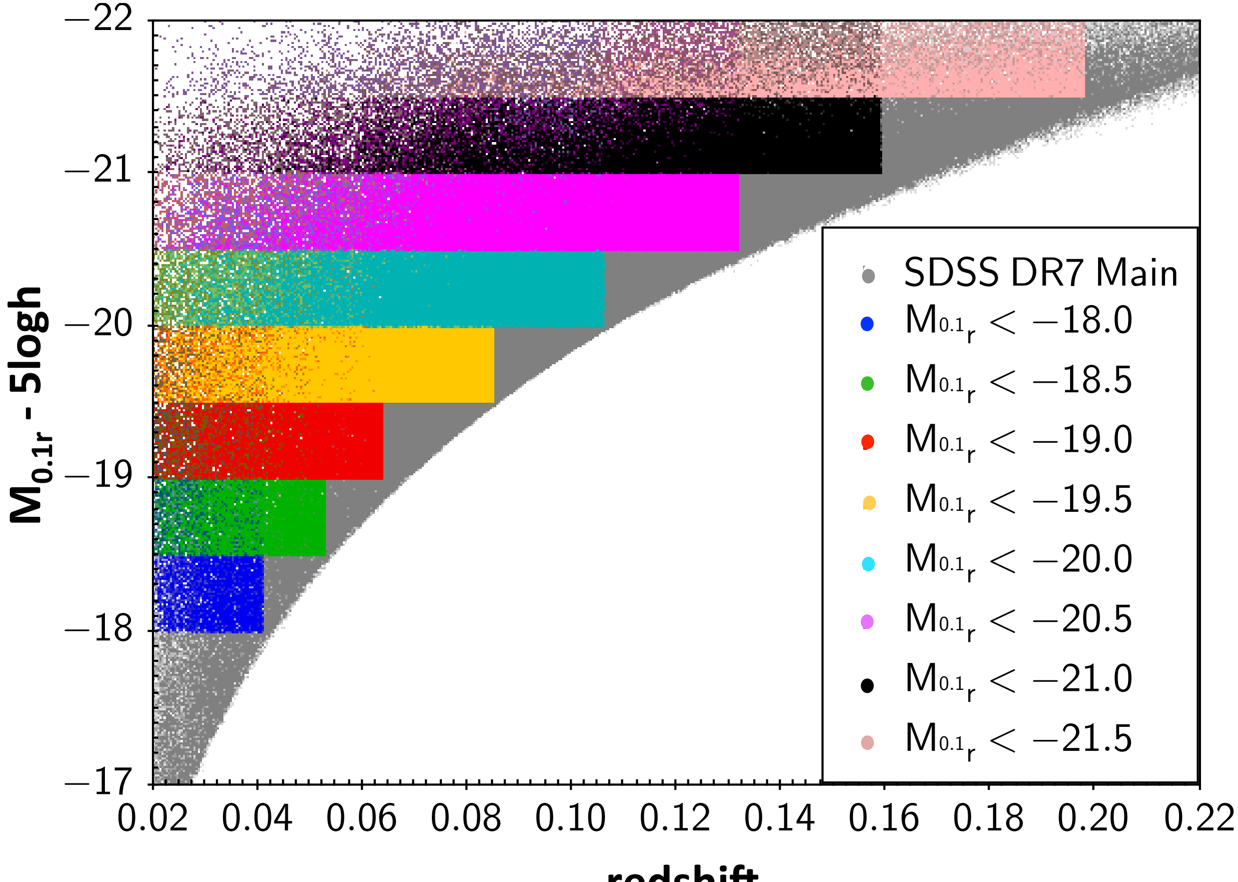


Behroozi et al. 2013

The SDSS [OII] ELG sample at z≈0.1

From the NYU-Value Added Galaxy Catalog we select the **SDSS Main galaxy sample**: 520,000 galaxies in 7300 deg^2 and 0<z<0.22 with r-band absolute magnitude

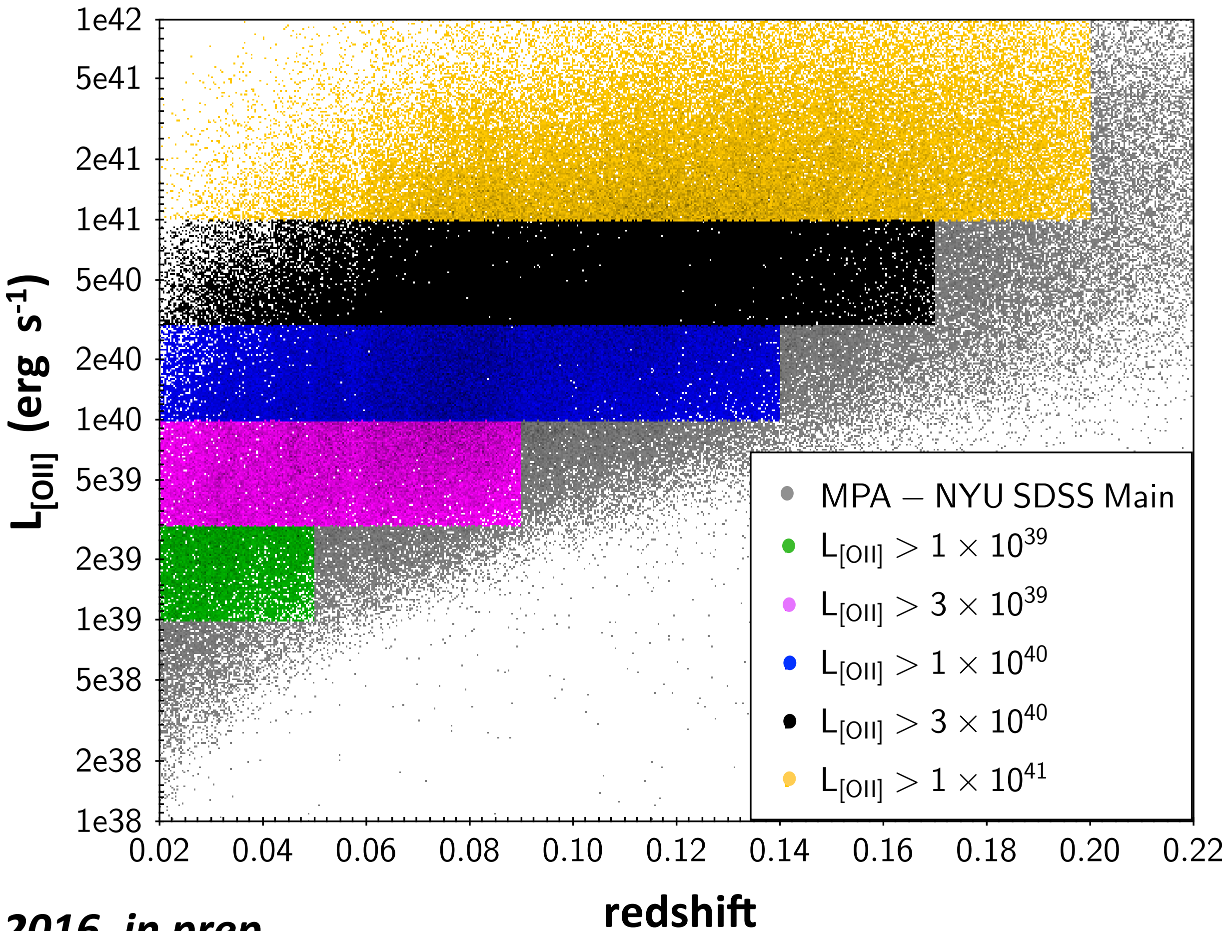
$$M_{0.1r} - 5\log h = m_r - DM(z, \Omega_m, \Omega_\Lambda, h=1) - K_{0.1rr}(z)$$



Favole et al. 2016, in prep.

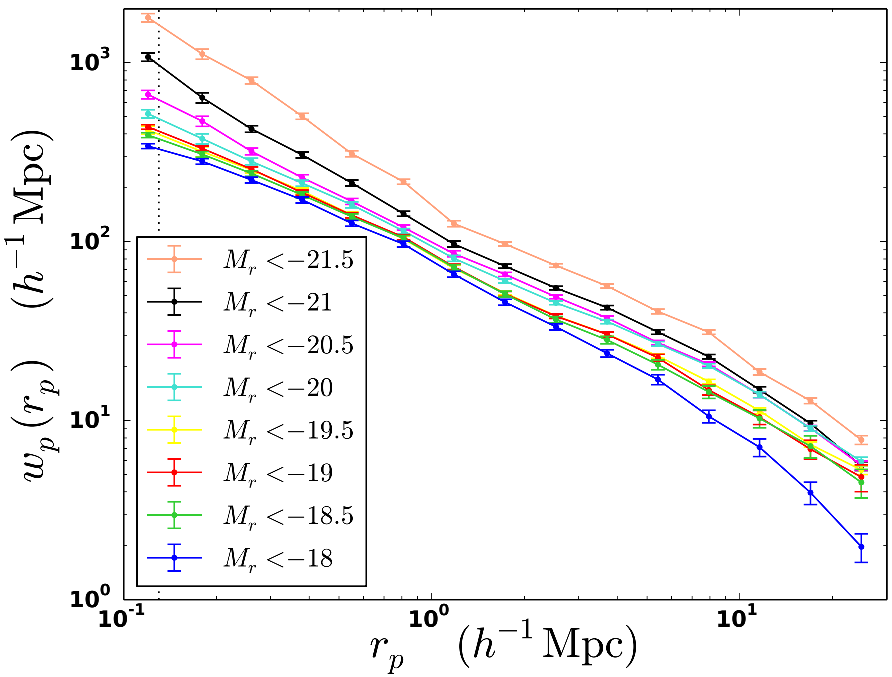
Spectroscopic matching between the SDSS Main DR7 galaxy sample and the MPA-JHU DR7 release of spectrum measurements **https://wwwmpa.mpa-garching.mpg.de/SDSS/DR7/** to assign emission line luminosities.

433,000 ELGs with [OII] Flux > 10^{-16} erg cm^{-2} s^{-1}

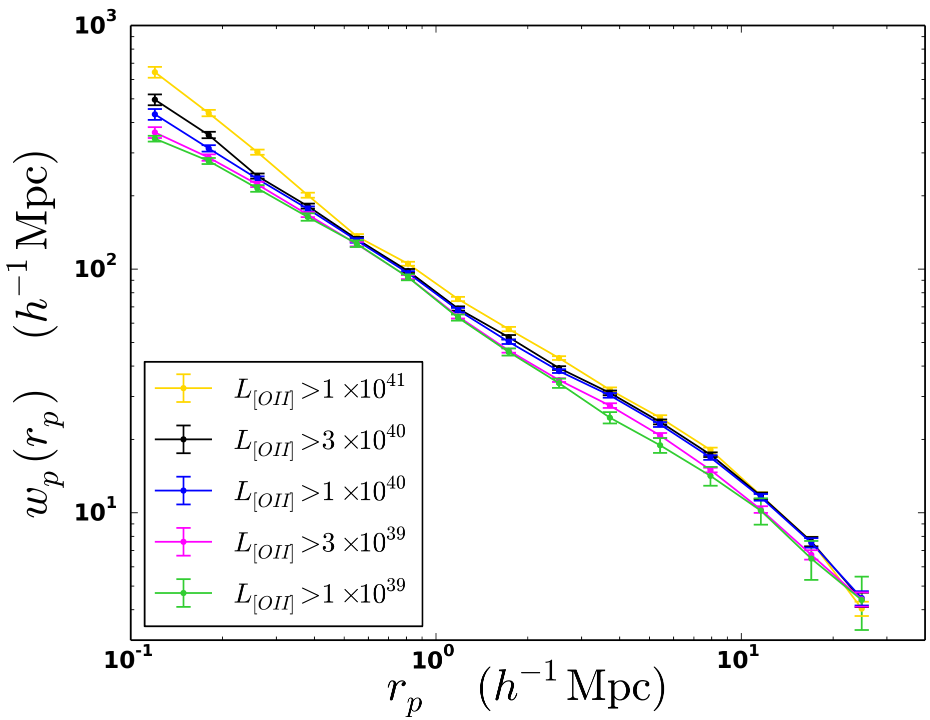


Favole et al. 2016, in prep.

Clustering versus $L_{[OII]}$ and M_r

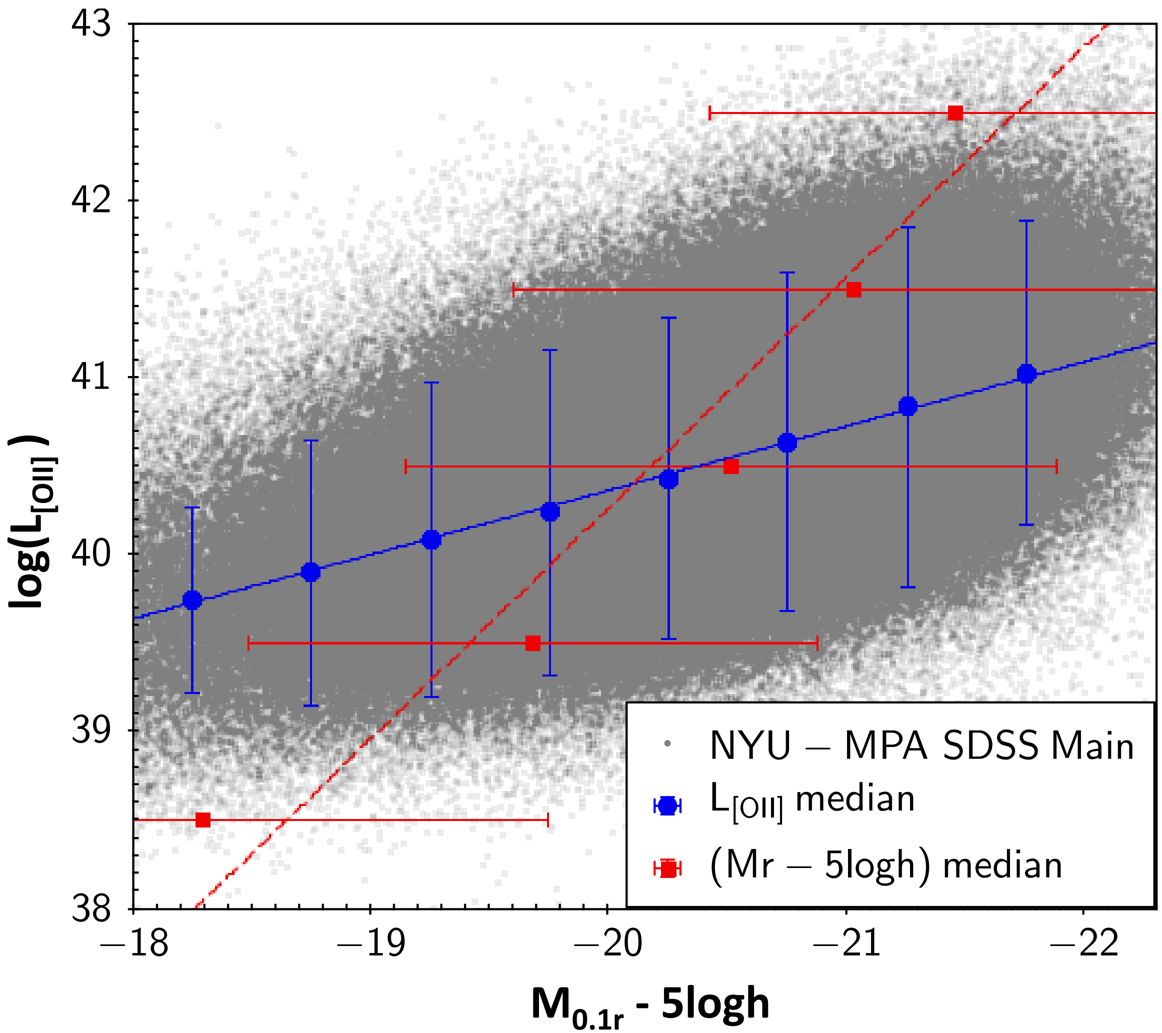


M_r and $L_{[OII]}$ are correlated:
the more luminous the more clustered



Favole et al. 2016, in prep.

How can we describe such a correlation?



$\log(L_{[OII]}) = A\,(M_{0.1r} - 5\log h) + B$ with $A=-0.4\pm0.2$, $B=33.1\pm4.5$

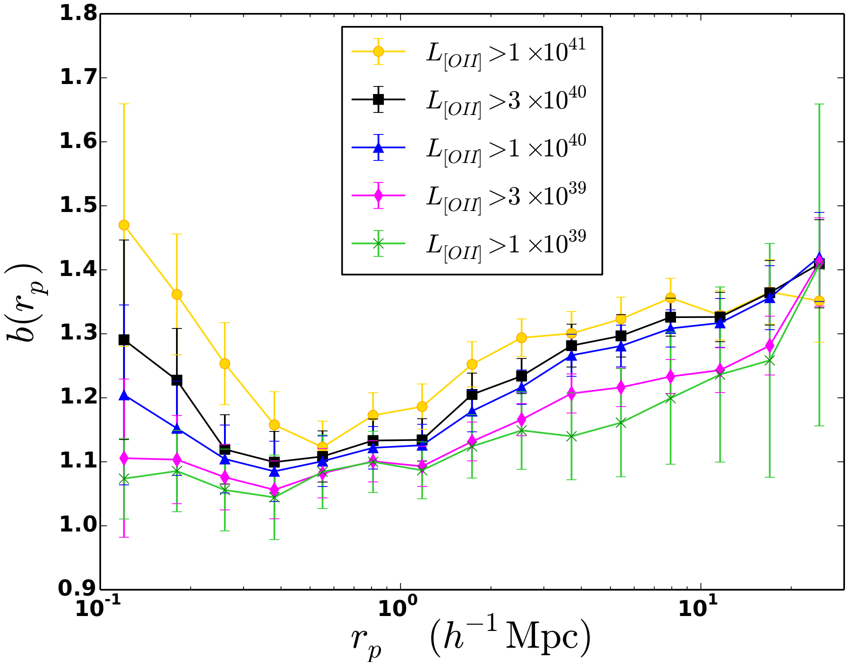
$(M_{0.1r} - 5\log h) = C\,\log(L_{[OII]}) + D$ with $C=-1.3\pm0.5$, $D=14.2\pm10.5$

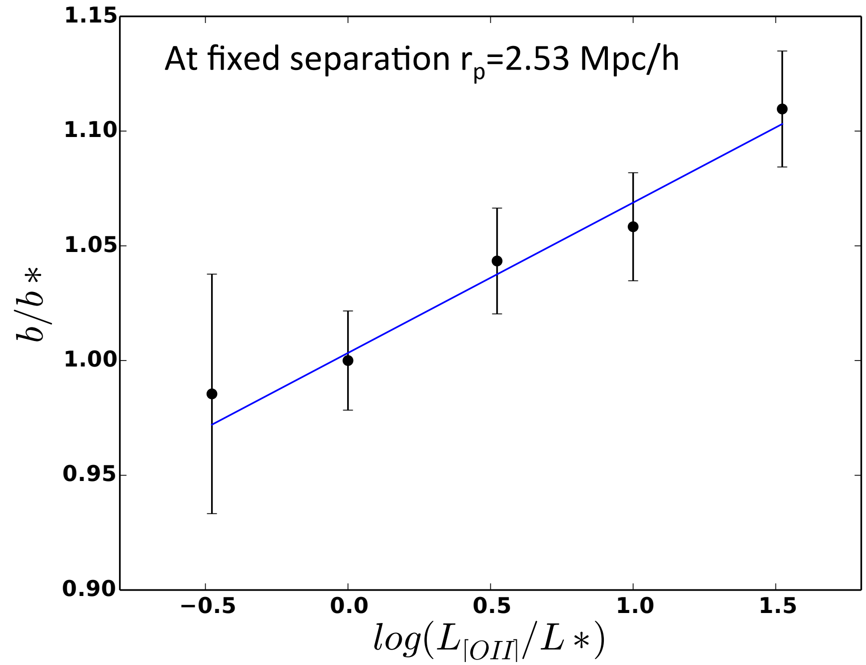
Favole et al. 2016, in prep.

Galaxy bias

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

matter 2PCF





Favole et al. 2016, in prep.

$$b/b^* = a \log(L_{[OII]}/L^*) + c$$

with a=0.065±0.018, c=-1.58±0.76

The more luminous the more biased

Summary, so far

These results open the path to study **the correlation between clustering** , the **strength of emission lines** and the **star formation rate (SFR)**.

We have learned how to measure and model the SDSS-III/BOSS ELG clustering at z≈0.8 in terms of the **halo mass** and **satellite fraction** using a **MDPL light-cone + SHAM approach**.

Using this method we can measure and model the SDSS DR7 Main galaxy **clustering** at z≈0.1 **as a function of r-band luminosity** and **$L_{[OII]}$,** which are **correlated** quantities. The **clustering** signal **and** the **bias correlate with both luminosities.**

Next goals

1. **Extend** this analysis **to Hα emitters in Euclid up to z=2.**

2. Combine this method with **semi-analytic models (SAMs)** of galaxy formation to study the **correlation between clustering,** the **ELG luminosity** and the **SFR indicator.**

The Theoretical Astrophysical Observatory (TAO)

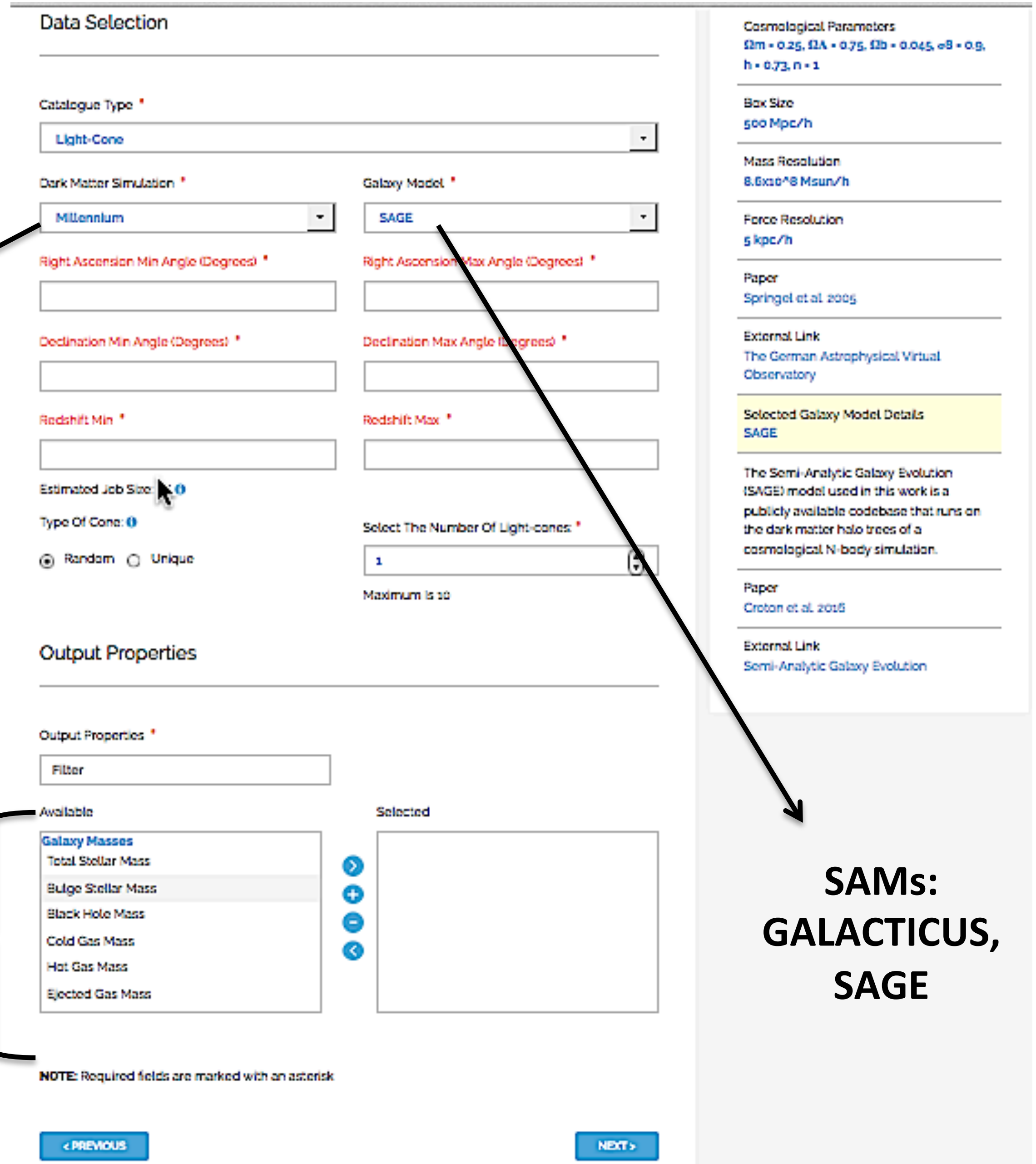
TAO | THEORETICAL ASTROPHYSICAL OBSERVATORY

ASVO

The Theoretical Astrophysical Observatory at CAS, Swinburne, is a virtual observatory that allows you to **build your own light-cone** (or single snapshot) running different **galaxy formation models** (SAGE, Croton et al. 2006; GALACTICUS, Benson 2012) on **multiple cosmological simulations** (Millennium, mini-Millennium, Bolshoi).

See Darren's talk on Wednesday!

Build your own light-cone (or single snapshot)



Simulations:
Millennium - 500Mpc/h,
mini-Millennium - 62.5Mpc/h,
Bolshoi - 250 Mpc/h

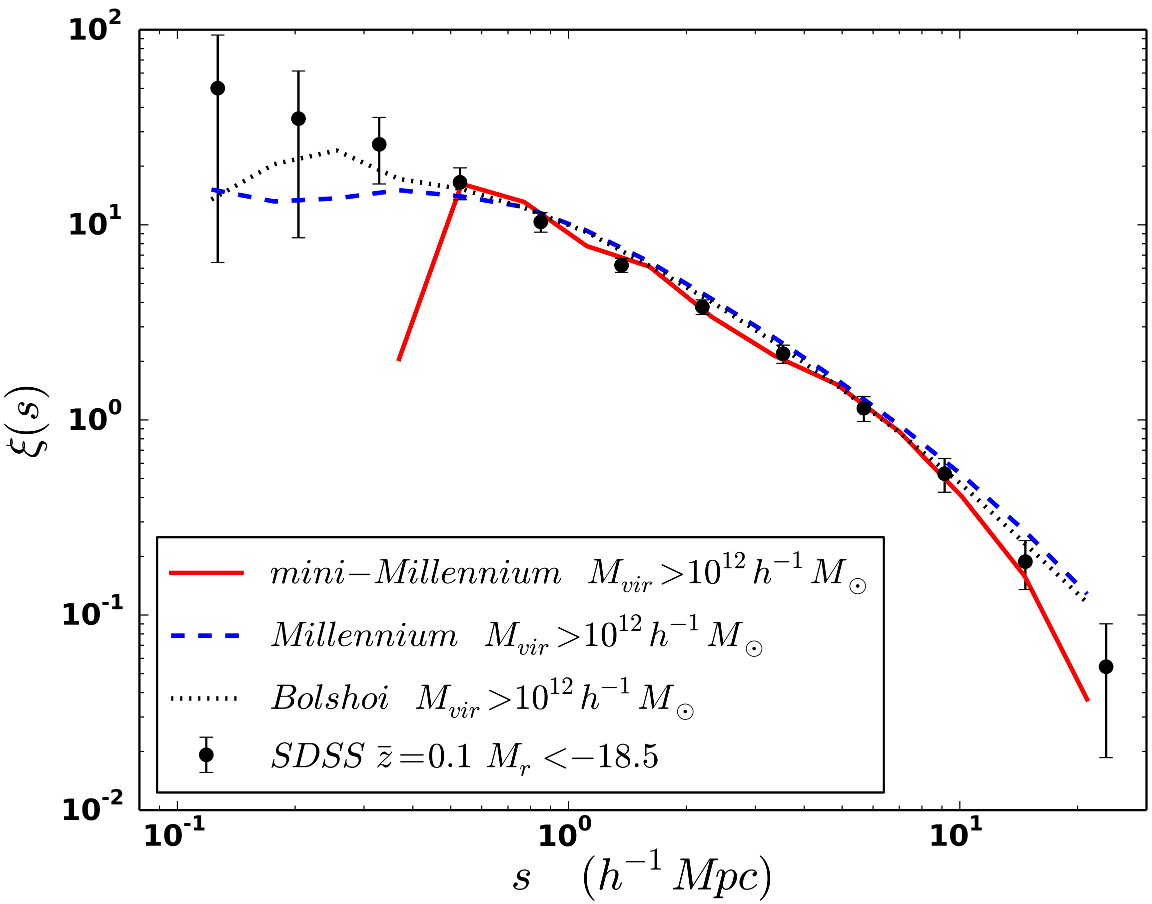
Select halo and galaxy output properties: M_{vir}, M_{star}, spatial properties, SDSS mags, SFR …

SAMs: GALACTICUS, SAGE

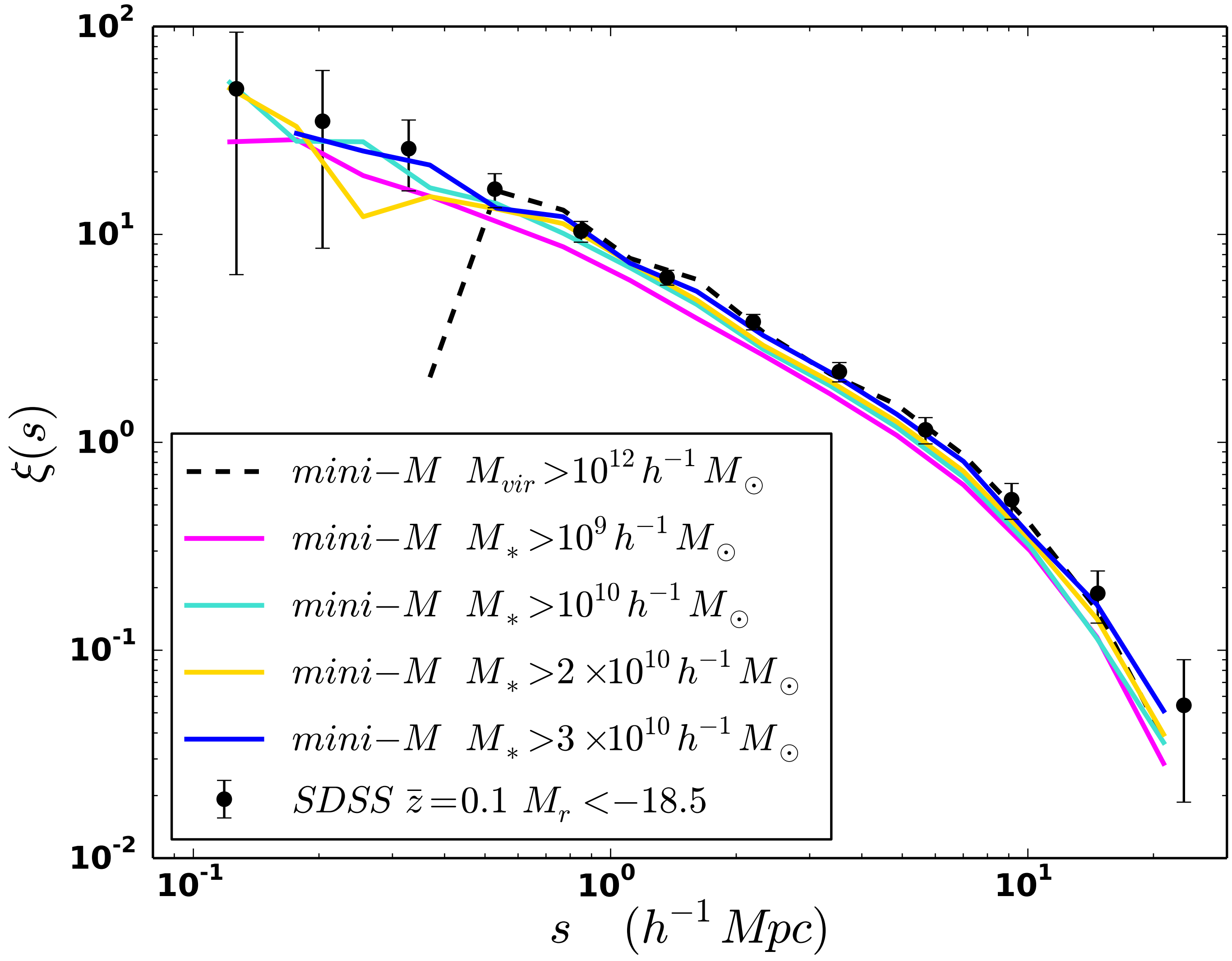
Preliminary checks on single snapshots

We produced several TAO SAGE realizations using different simulations and checked their properties (SDSS r-band absolute mag, halo mass, stellar mass…) by comparing their clustering with the observed **SDSS Main galaxy sample** signal at mean redshift **z=0.1**.

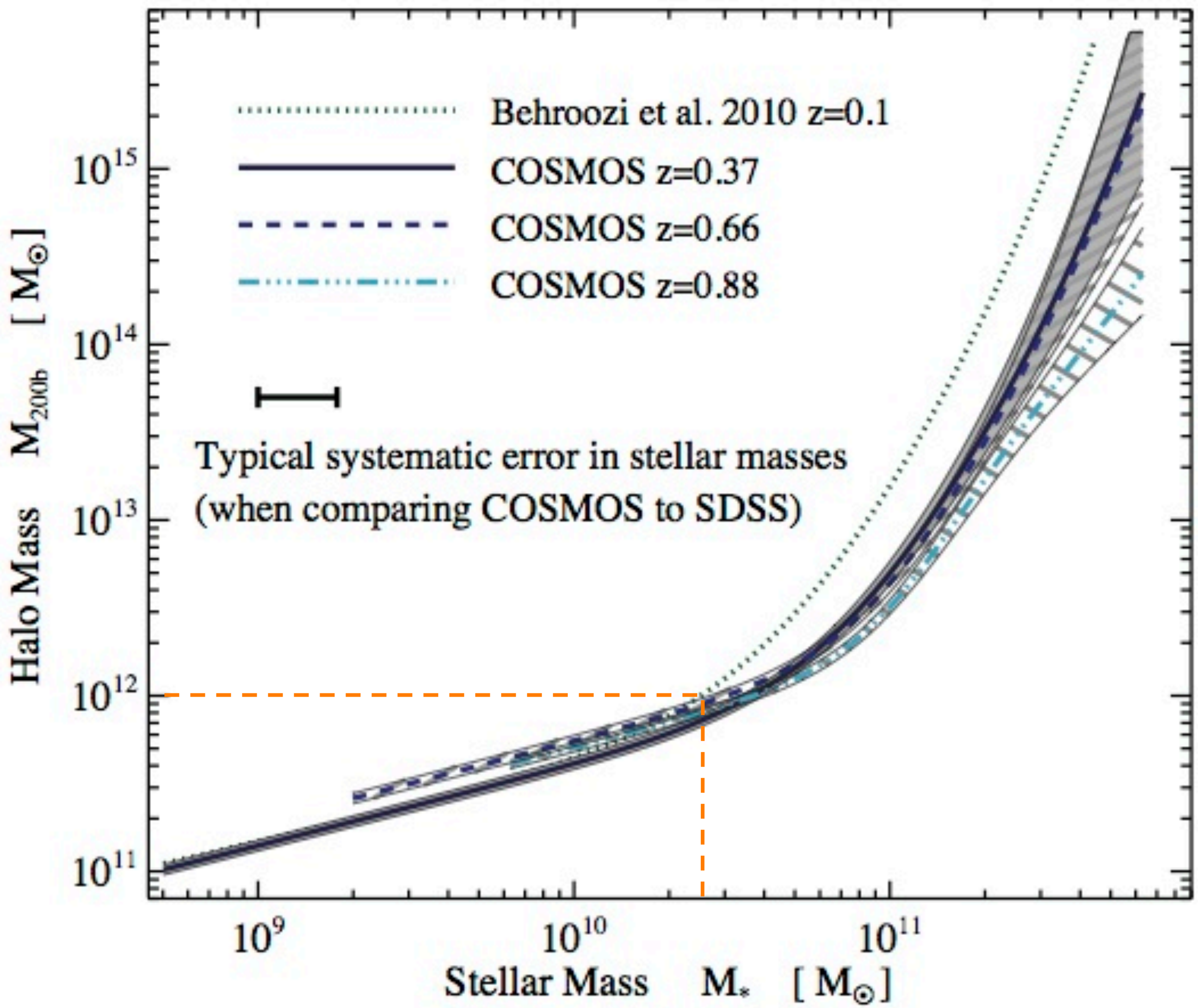
By selecting halos with $\mathbf{M_{vir} > 10^{12}\ \mathit{h}^{-1}\ M_{\odot}}$, we find agreement:



Halos with $\mathbf{M_{vir} > 10^{12}}$ $\boldsymbol{h^{-1}}$ $\mathbf{M_\odot}$ have typical stellar masses of $\mathbf{M_{star} = (2\text{-}3) \times 10^{10}}$ $\boldsymbol{h^{-1}}$ $\mathbf{M_\odot}$



… consistent with the stellar-to-halo mass ratio:



Leauthaud et al. 2012

What's next

- Clustering analysis with TAO/SAGE Millennium light-cone in progress …
- Better characterize the correlation of the SDSS r-band luminosity with ELG luminosity using SAMs
- Understand how the **ELG luminosity correlates with the SFR indicator** and use this latter to select star-forming galaxies, in particular ELGs.
- Observations versus theory:
  Can we **retrieve** the observed **ELG sample** by **selecting in SFR** instead of luminosity?