ALHAMBRA novel analysis techniques: correlations at the smallest scales

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ALHAMBRA
SURVEY

Outline

1. The ALHAMBRA Survey
2. Galaxy segregation by luminosity and spectral type
3. Galaxy clustering at the smallest scales

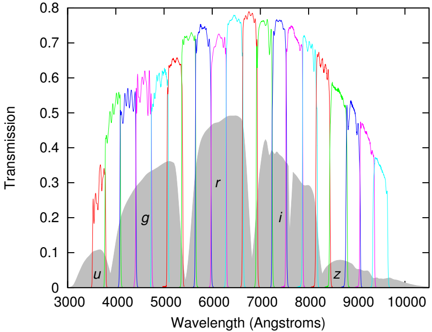
ALHAMBRA

Advanced, Large Homogeneous Area, Medium-Band, Redshift Astronomical survey

A pencil-beam, multi-band photometric survey with the aim of providing a *cosmic tomography* to study cosmic evolution

- Exploit photo-z techniques at maximum
- Precursor and ideal testbench for J-PAS and PAU@WHT

- 20 optical filters + JHK_s
- Catalogue (I-band selected): Molino et al. (2014)
  - Photo-z: $\sigma_z \leq 0.014(1+z)$ (to $I < 24.5$)
  - $z_{\rm med} = 0.75$
- Total effective area: $\sim 2.4\,\text{deg}^2$, distributed in 7 separate fields



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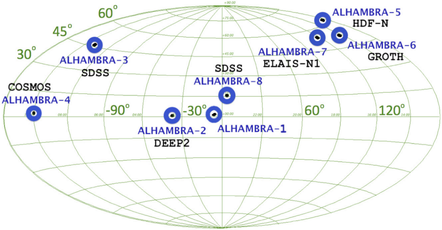
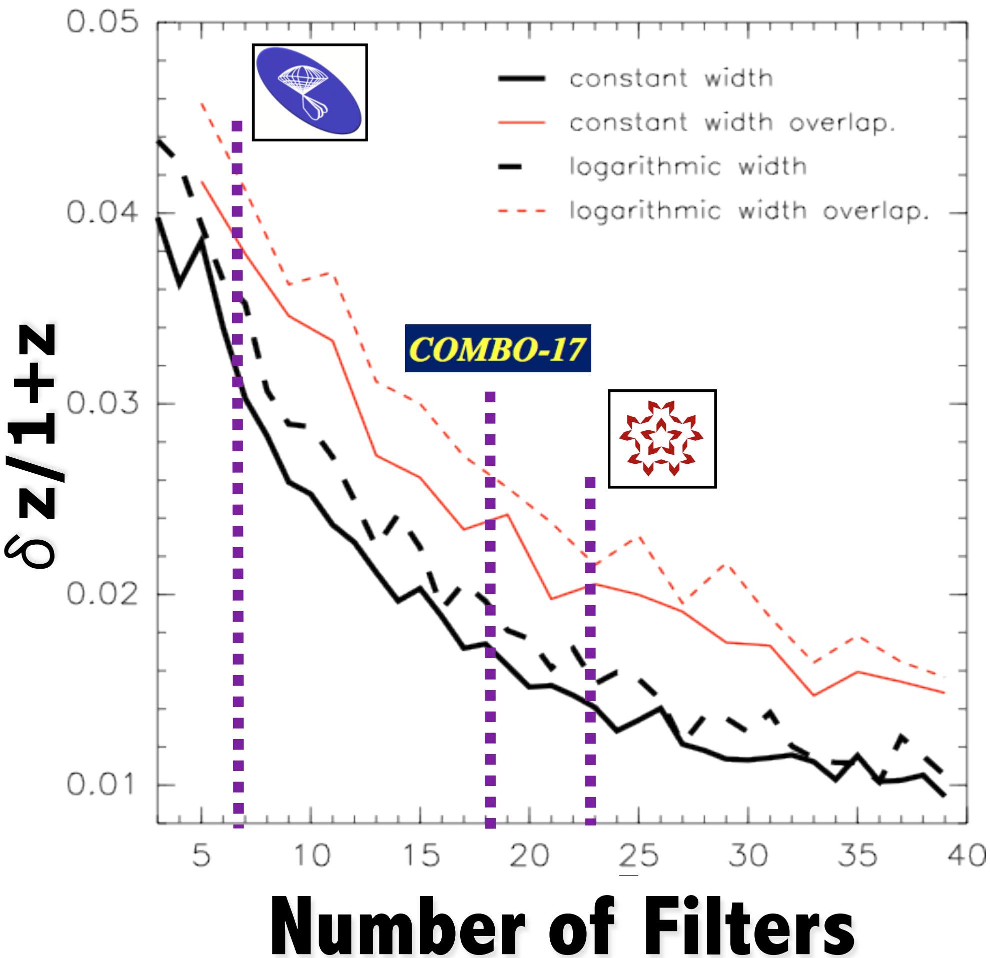
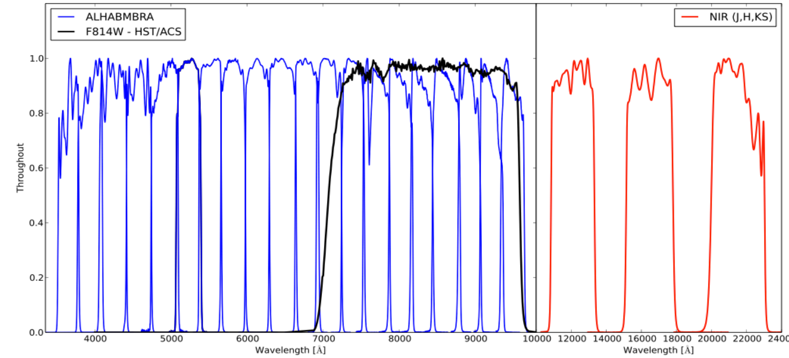


Why so many filters?

Number of filters vs Accuracy

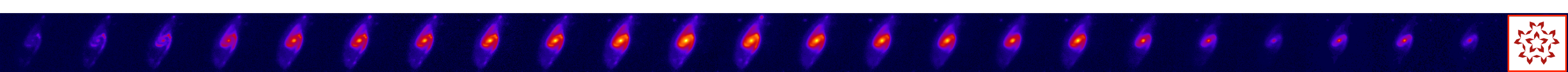
Benítez et al. 2009

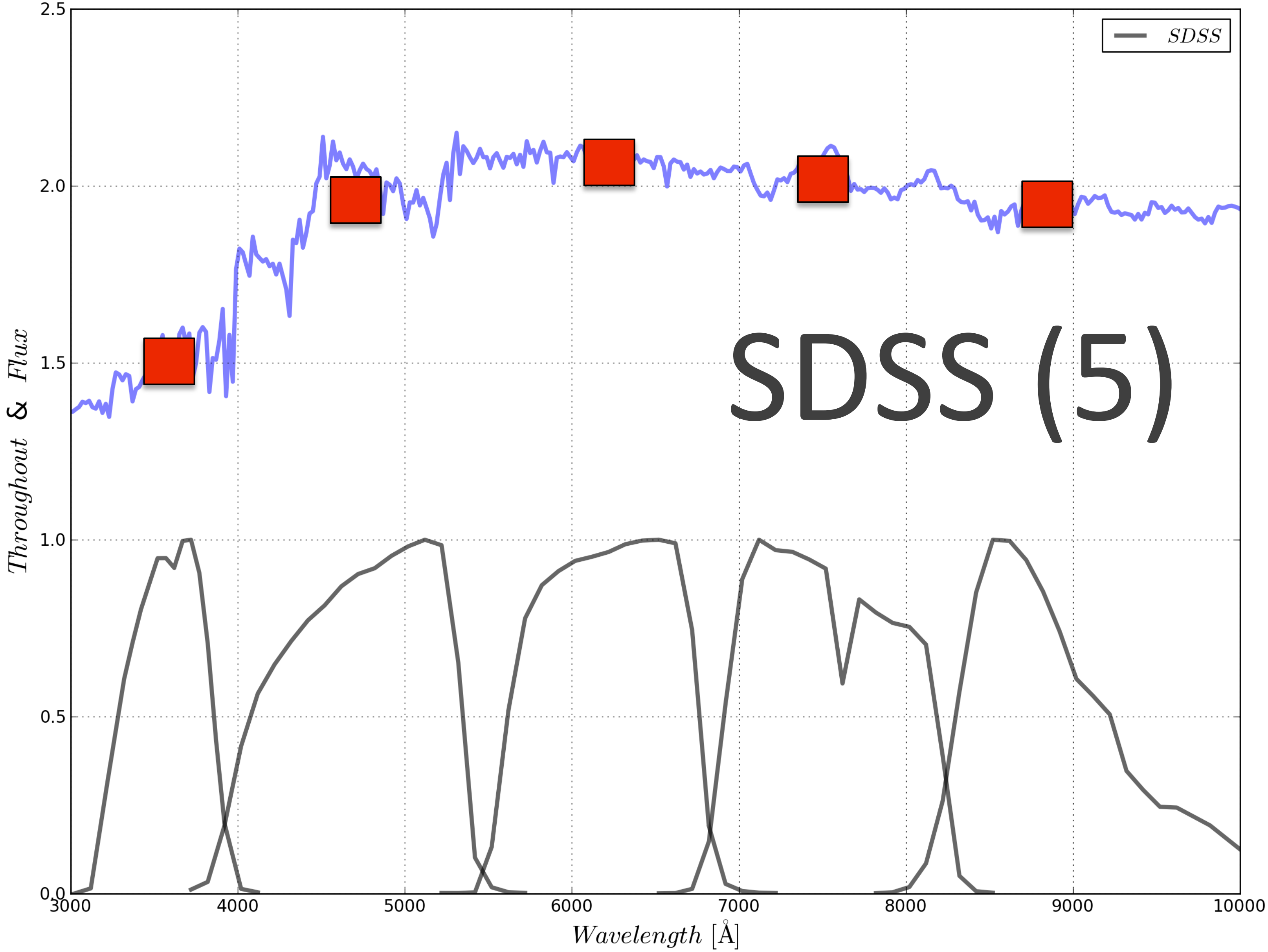


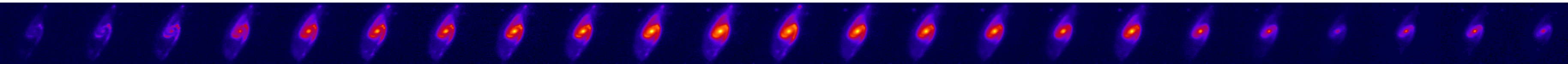


Photometric Redshift surveys

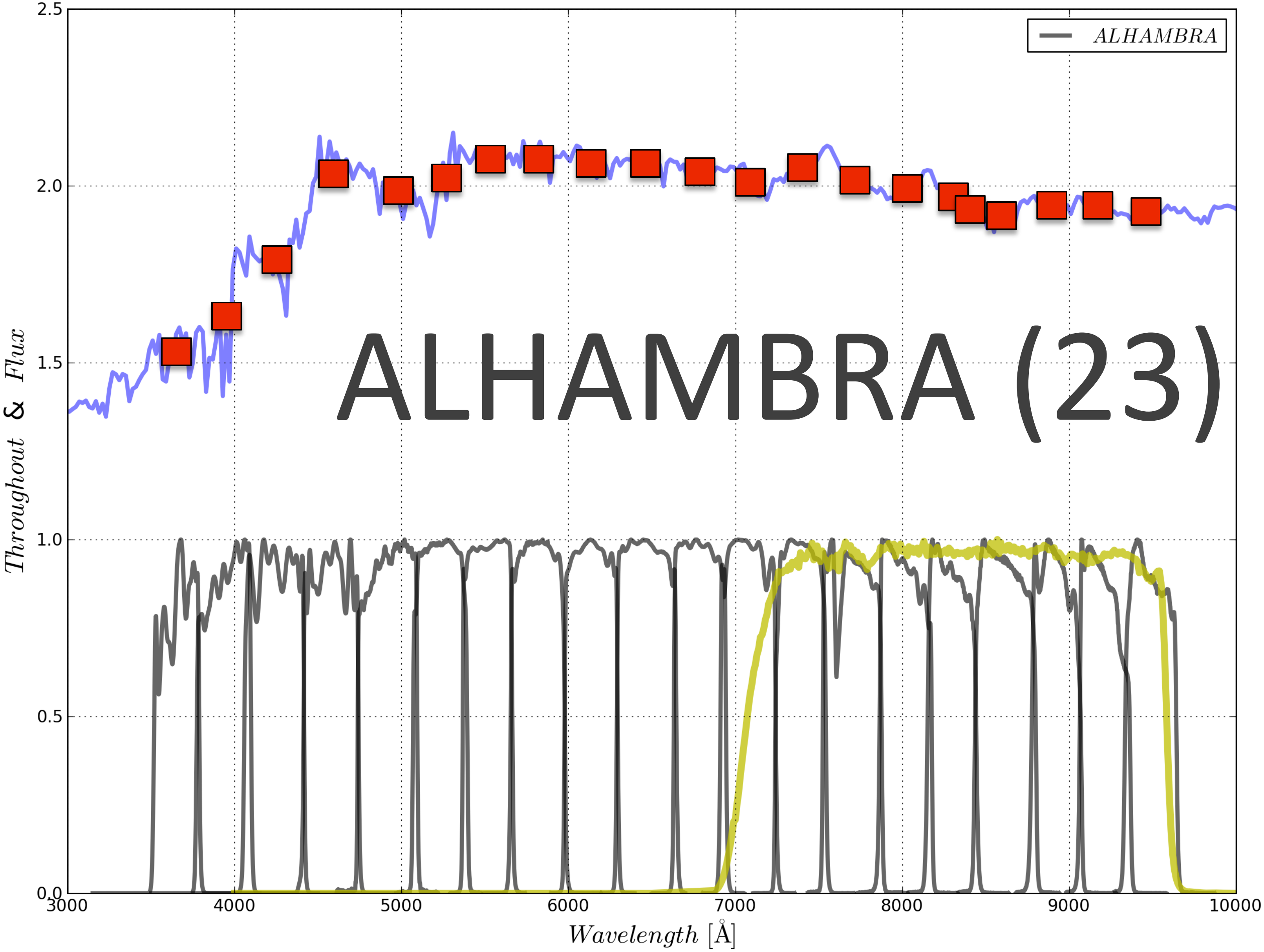
survey	Reference	Bands	$\delta_z/(1+z)$
HDF	Sawicki (1997)	4	0.080
SDSS/DR6	Csabai (2003)	5	0.035
SWIRE	Rowan-Robinson (2008)	5	0.035
HUDF	Coe (2006)	6	0.040
HDF	Fernández-Soto (1999)	7	0.060
CFHTLS	Ilbert (2006)	9	0.030
GOODS	Dahlen (2010)	12	0.040
CLASH	Molino (2013, prep.)	16	0.025
COMBO-17	Wolf (2004)	17	0.020
ALHAMBRA	Molino (this work)	23	0.013
COSMOS	Ilbert (2009)	30	0.007
MUSYC	Cardamone (2010)	32	0.007
JPAS	Benítez (2009a, 2013, prep.)	59	0.003

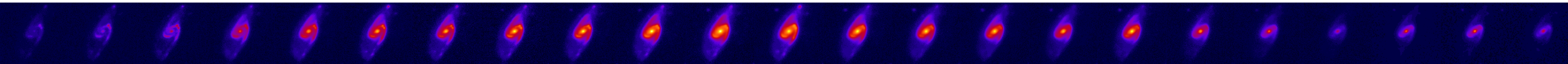


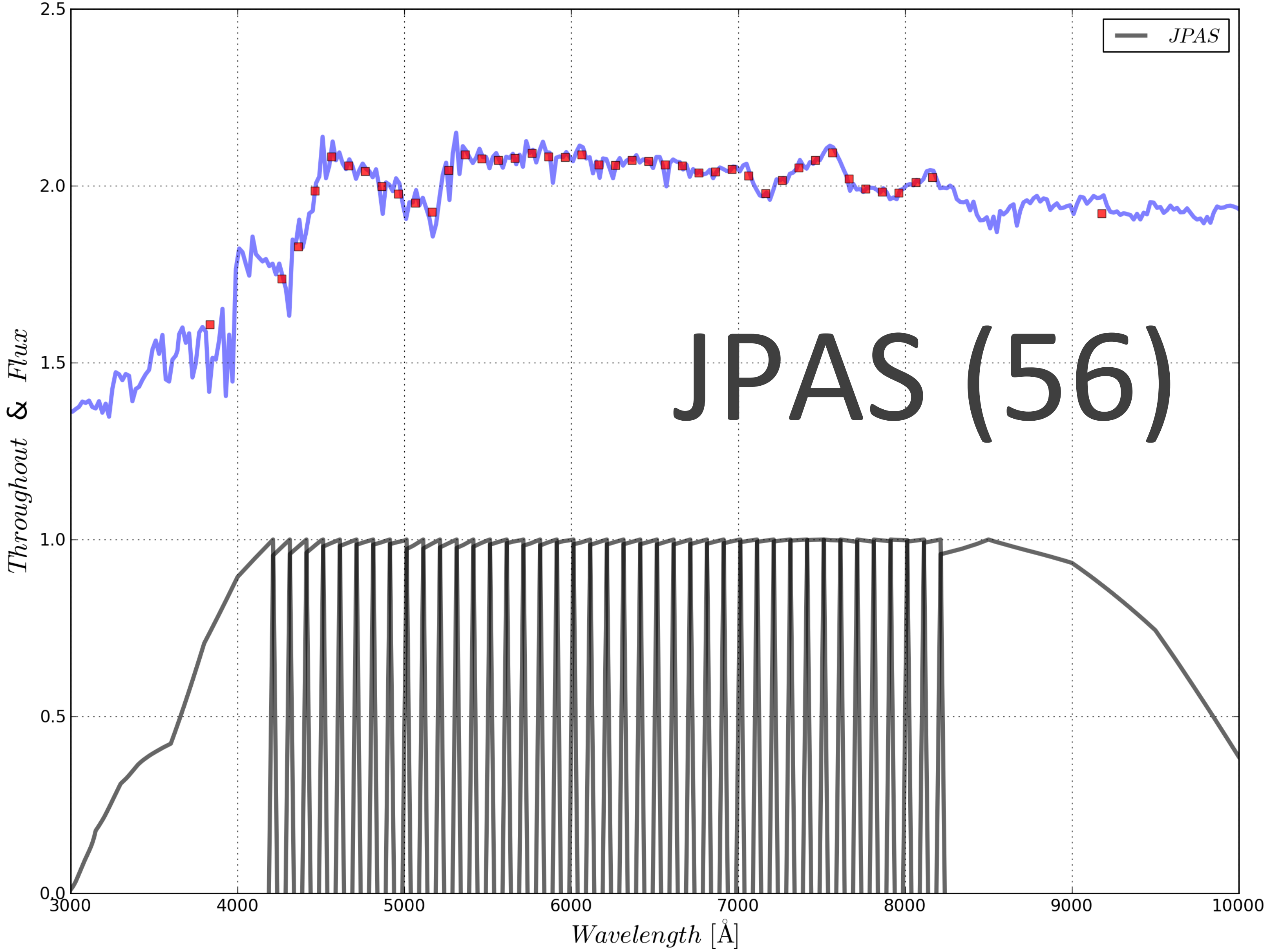

SDSS (5)
SDSS
Throughout & Flux
Wavelength [Å]
2.5
2.0
1.5
1.0
0.5
0.0
3000
4000
5000
6000
7000
8000
9000
10000



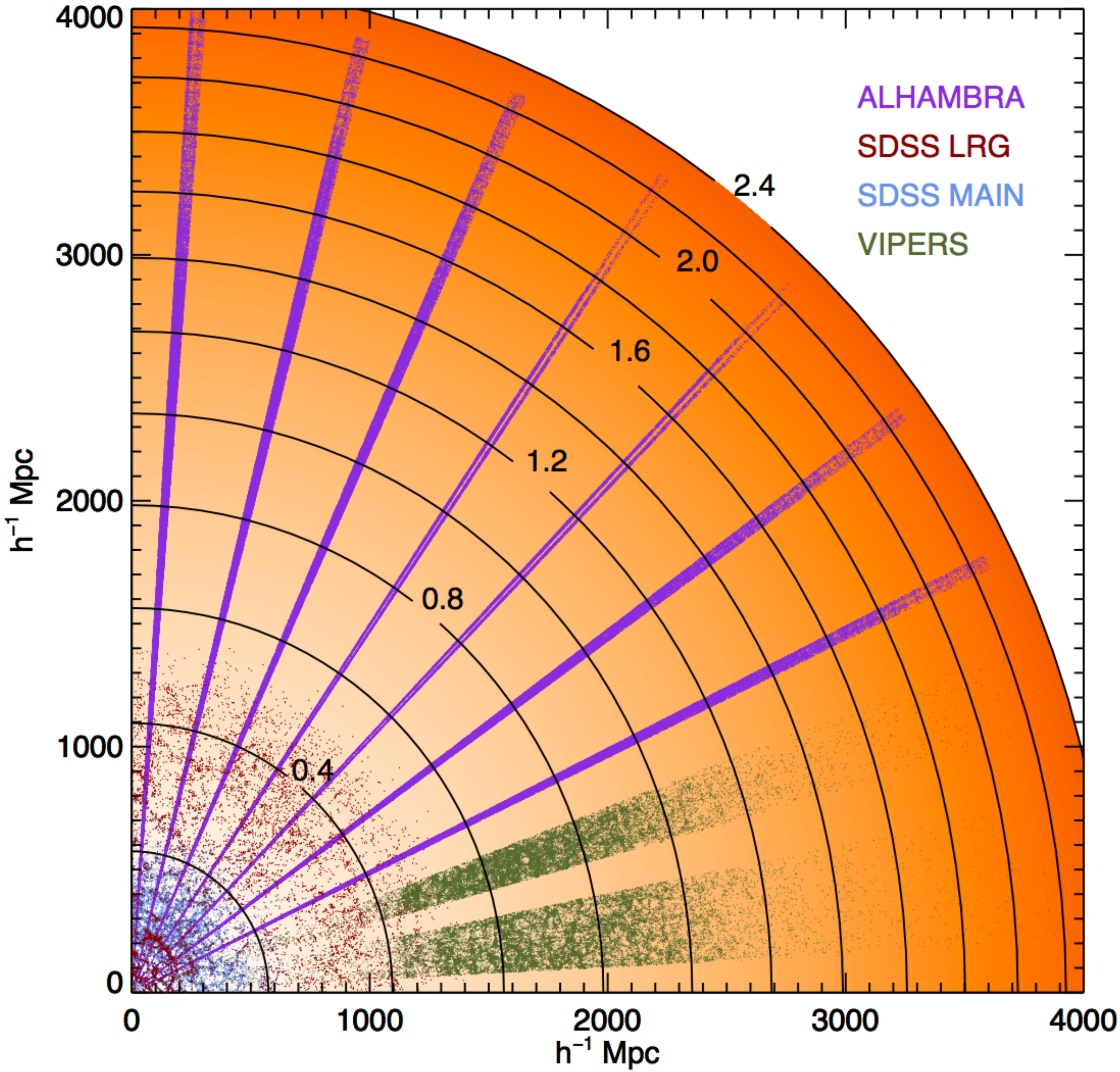
ALHAMBRA (23)


ALHAMBRA
Throughout & Flux
Wavelength [Å]
2.5
2.0
1.5
1.0
0.5
0.0
3000
4000
5000
6000
7000
8000
9000
10000

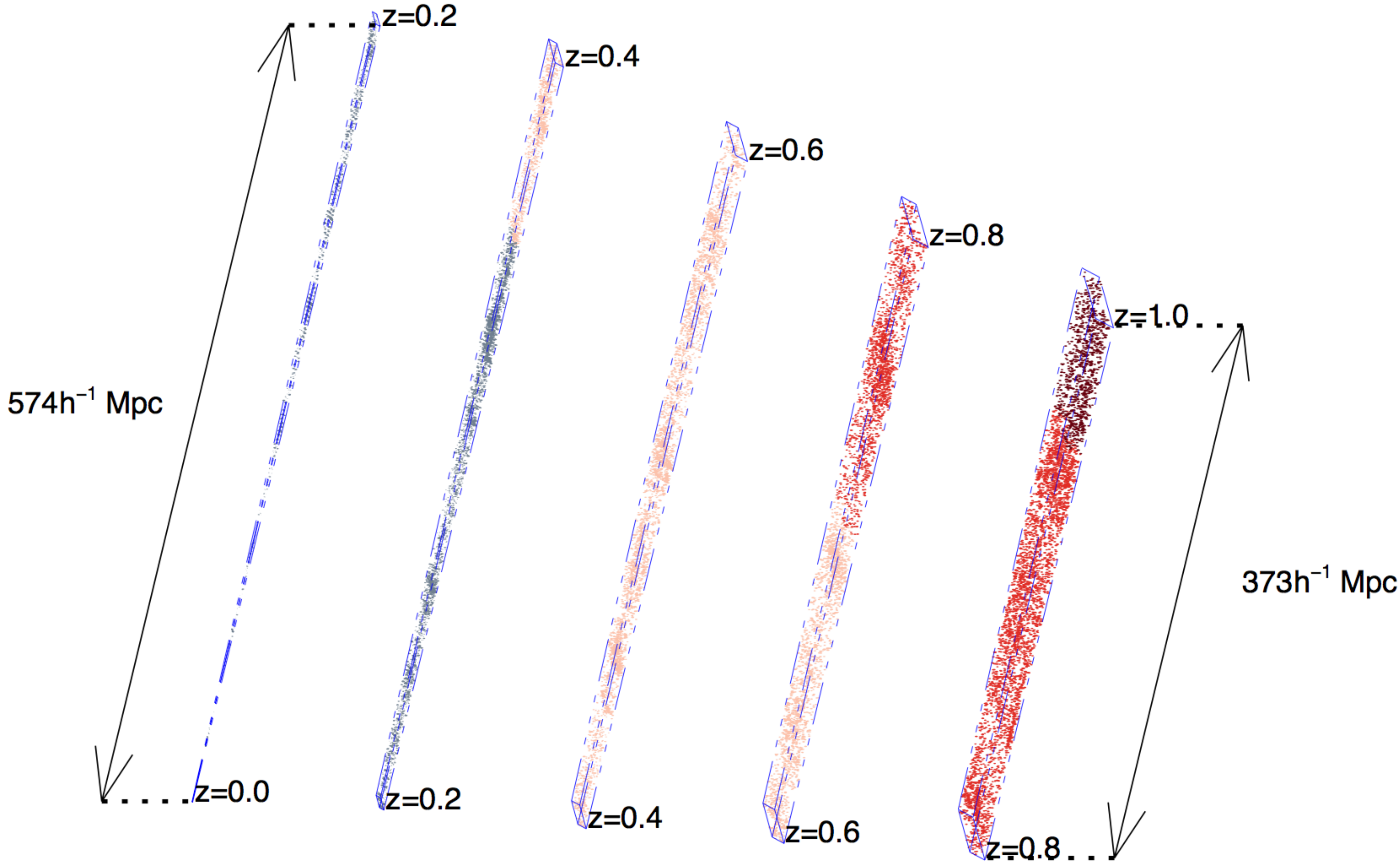




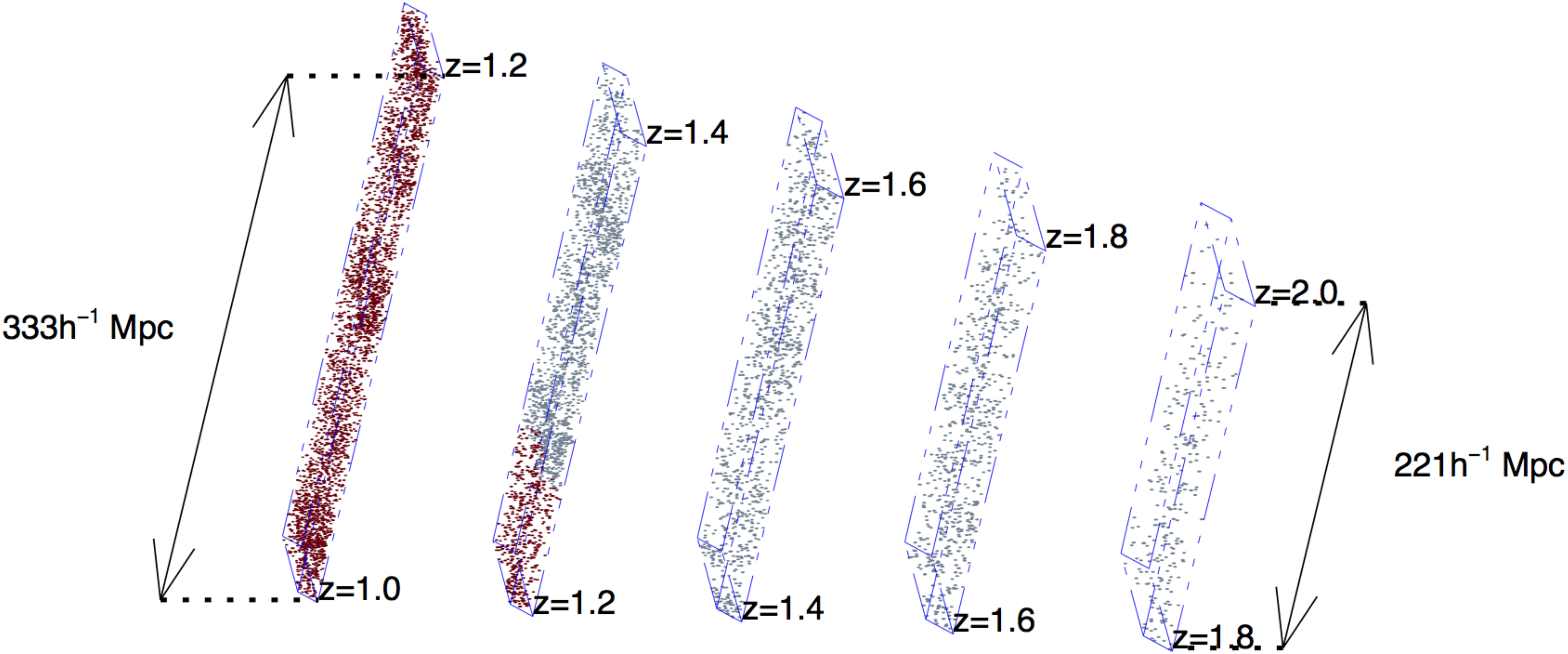
JPAS
JPAS (56)
Throughout & Flux
Wavelength [Å]
0.0
0.5
1.0
1.5
2.0
2.5
3000
4000
5000
6000
7000
8000
9000
10000



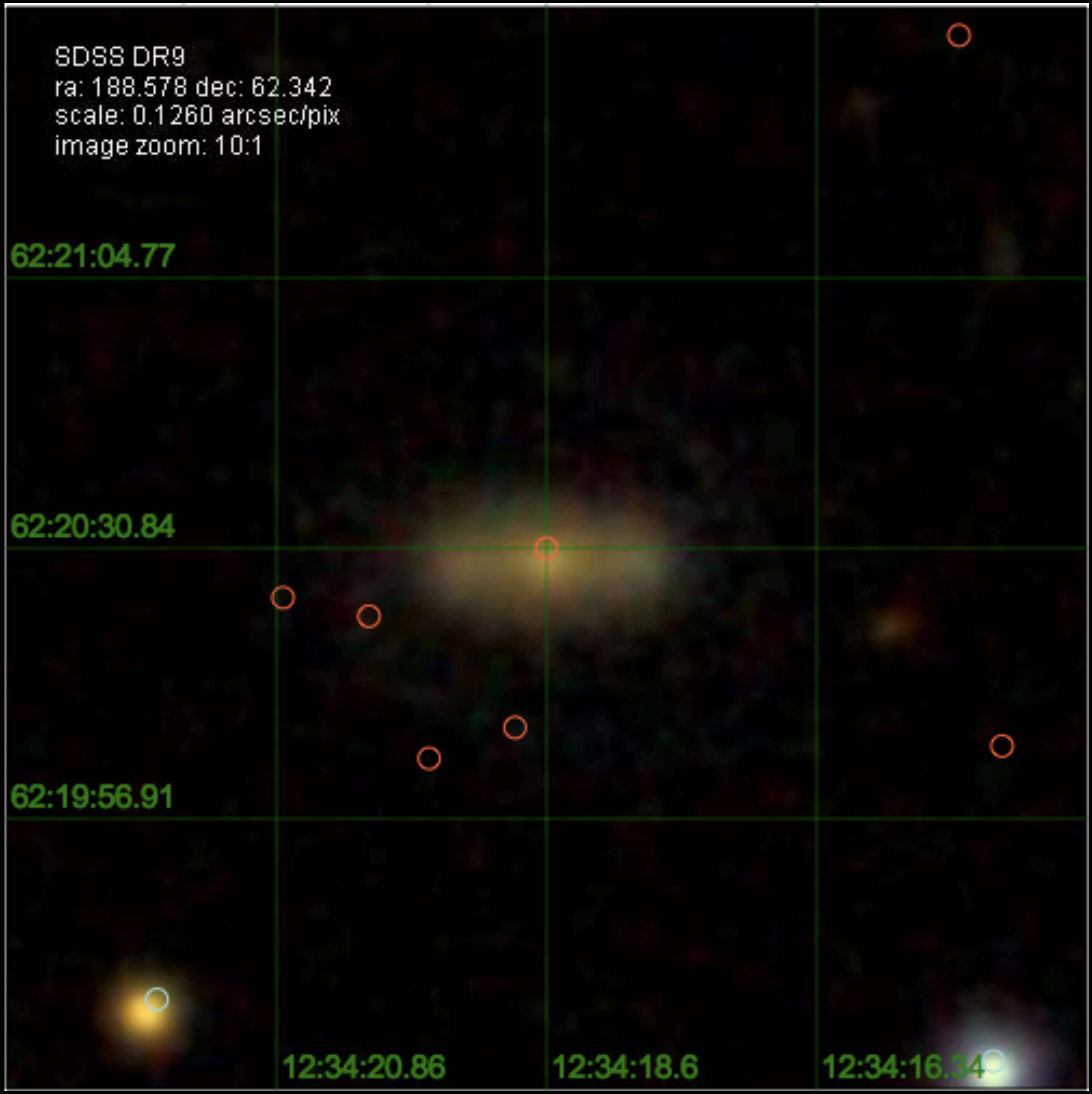
ALHAMBRA
SDSS LRG
SDSS MAIN
VIPERS
0.4
0.8
1.2
1.6
2.0
2.4
h⁻¹ Mpc
h⁻¹ Mpc
0
1000
2000
3000
4000

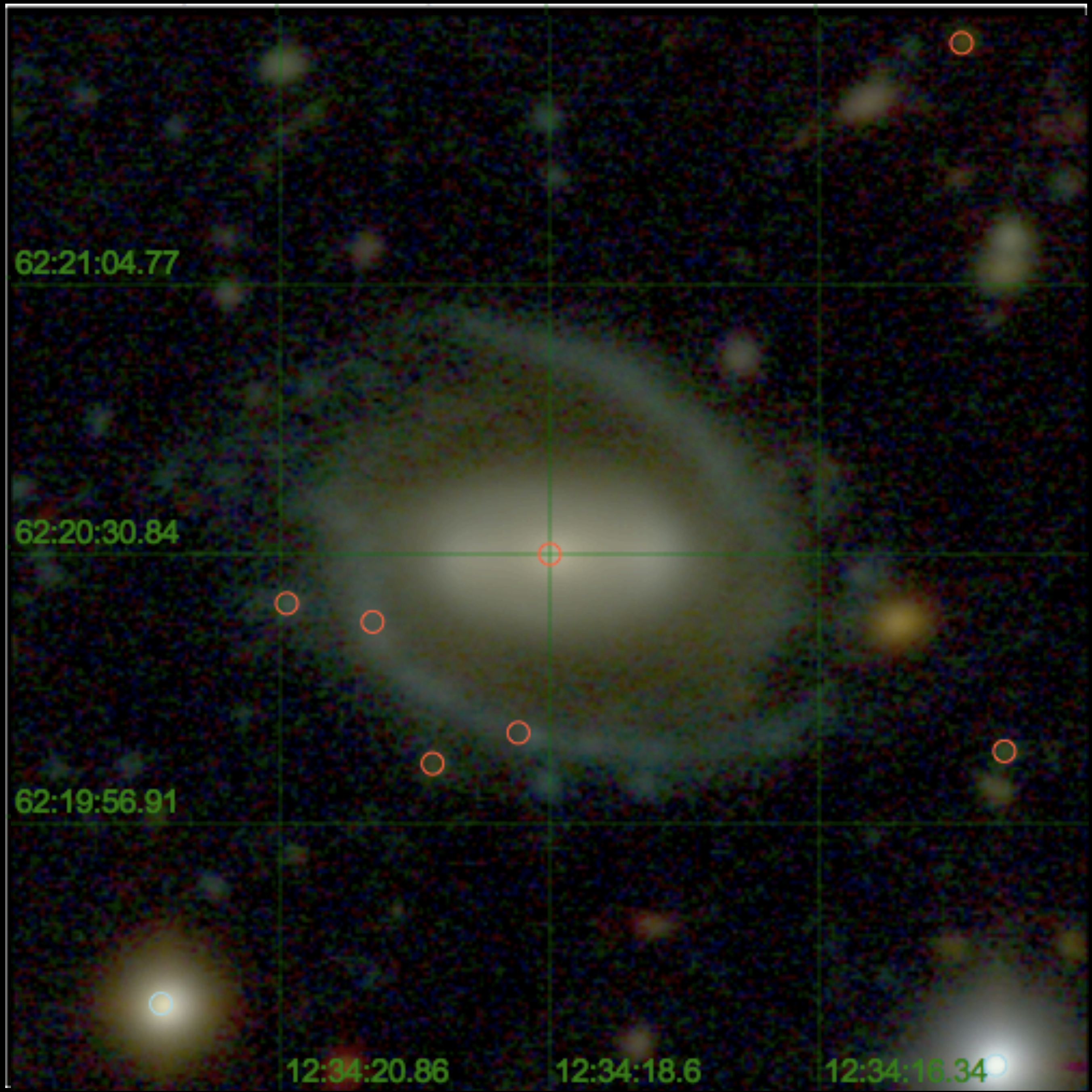


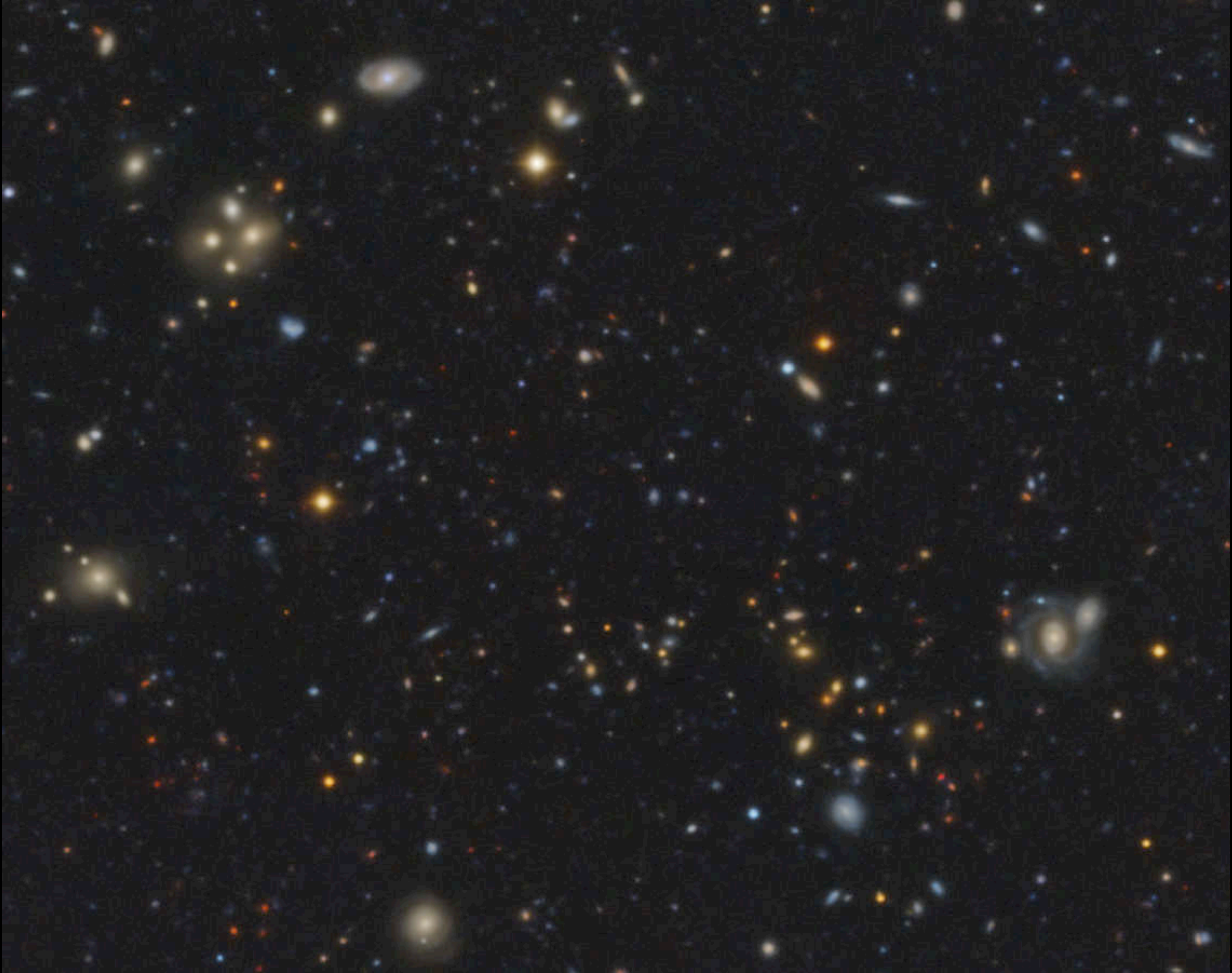
z=0.2
z=0.4
z=0.6
z=0.8
z=1.0
574h^{-1} Mpc
373h^{-1} Mpc
z=0.0
z=0.2
z=0.4
z=0.6
z=0.8



z=1.2
z=1.4
z=1.6
z=1.8
z=2.0
333h^{-1} Mpc
221h^{-1} Mpc
z=1.0
z=1.2
z=1.4
z=1.6
z=1.8


SDSS DR9
ra: 188.578 dec: 62.342
scale: 0.1260 arcsec/pix
image zoom: 10:1
62:21:04.77
62:20:30.84
62:19:56.91
12:34:20.86
12:34:18.6
12:34:16.34

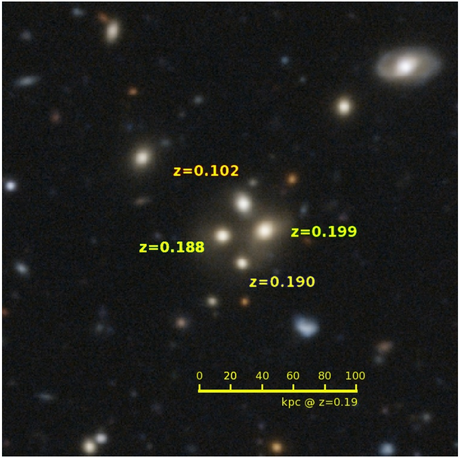

62:21:04.77
62:20:30.84
62:19:56.91
12:34:20.86
12:34:18.6
12:34:16.34



Clustering at the smallest scales: the 1-halo term

ALHAMBRA ideal to study clustering at the smallest scales

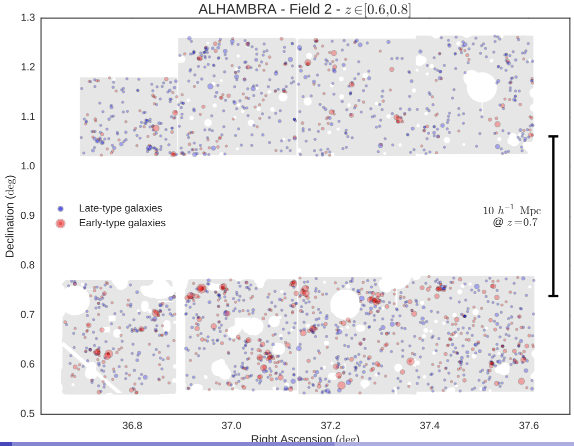
- Depth $\leftrightarrow$ number density
- Have 'pseudo-spectrum' for every object in the sky: no fiber collisions, undersampling
- Small scale limit set by seeing: $\langle FWHM \rangle = 1.1'' \rightarrow$ $r_p \gtrsim 10 - 20\, h^{-1}\,$kpc



ALHAMBRA

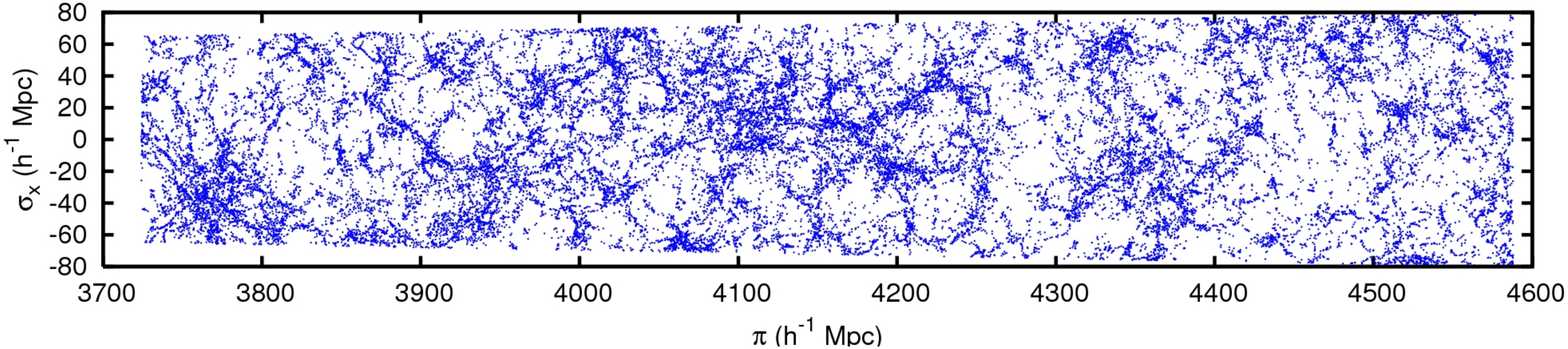
- Depth, photo-z quality: ideal dataset for study of clustering at scales $\lesssim 10\,h^{-1}$ Mpc and its evolution in $z \sim [0.3 - 1.2]$
- Probes the overall growth of structures + evolution of the relation between galaxies and Dark Matter haloes

Use the 2-point projected correlation function $w_p(r_p)$ (adapted for the photo-z data)



Mock photometric redshift catalogues.

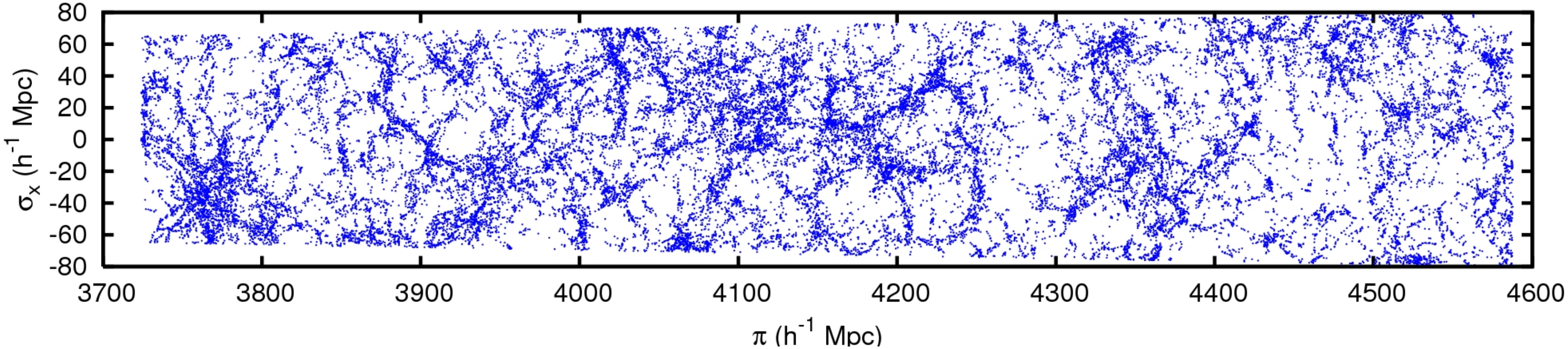
- Effect of Δz: projection of the different catalogues on a longitudinal plane



Real-space catalogue

Mock photometric redshift catalogues.

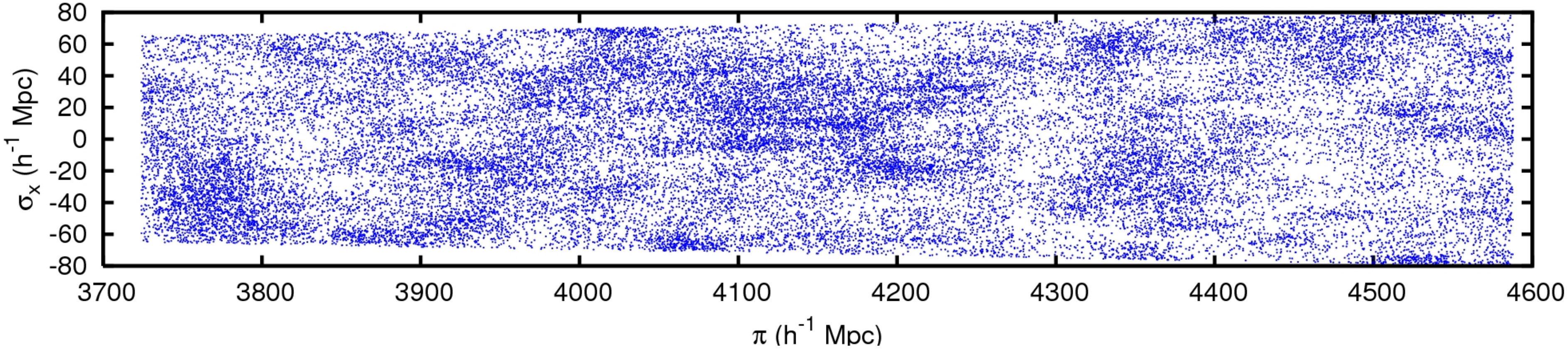
- Effect of Δz: projection of the different catalogues on a longitudinal plane



Redshift space

Mock photometric redshift catalogues.

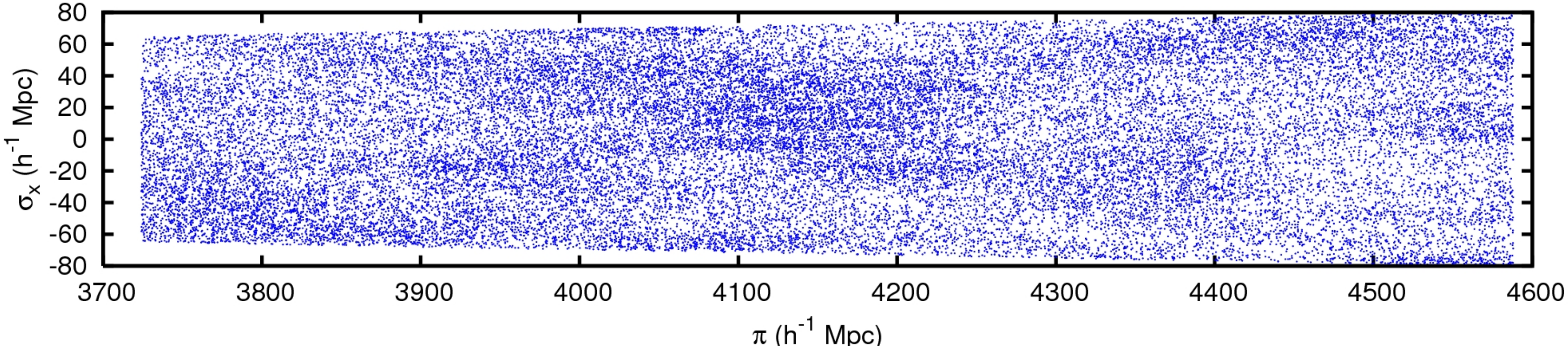
- Effect of Δz: projection of the different catalogues on a longitudinal plane



$\Delta z = 0.005(1+z)$ mock catalogue

Mock photometric redshift catalogues.

- Effect of Δz: projection of the different catalogues on a longitudinal plane



$\Delta z = 0.015(1+z)$ mock catalogue

Correlation function

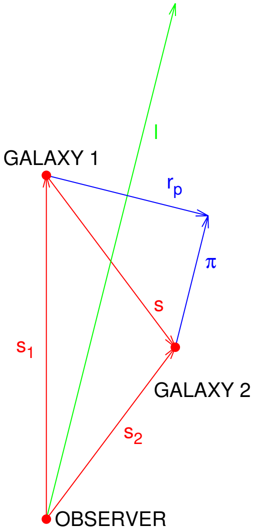
Projected correlation function. Correction due to the use of photo-z to estimate distances. We integrate the pair correlation function along the line of sight:

$$\hat{\xi}_{LS}(r_p,\pi) = 1 + \left(\frac{N_R}{N_D}\right)^2 \frac{DD(r_p,\pi)}{RR(r_p,\pi)} - 2\frac{N_R}{N_D}\frac{DR(r_p,\pi)}{RR(r_p,\pi)}$$

$$w_p(r_p) \equiv 2\int_0^\infty \xi_{LS}(r_p,\pi)\mathrm{d}\pi$$

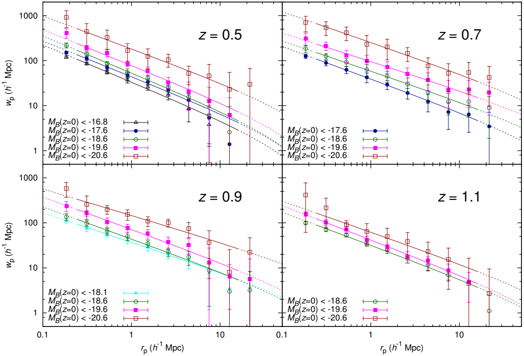
where

$$\pi \equiv \frac{|\mathbf{s}\cdot\mathbf{l}|}{|\mathbf{l}|}\,,\; r_p \equiv \sqrt{\mathbf{s}\cdot\mathbf{s}-\pi^2}$$



Clustering measurements in ALHAMBRA

- Use the 2-point projected correlation function $w_p(r_p)$ (adapted for the photo-z data)
- Scales $r_p \sim 0.1 - 20\, h^{-1}\,\mathrm{Mpc}$ (typical scales probed in LSS surveys)
- Evolution and segregation by luminosity (Arnalte-Mur et al., 2014, MNRAS, 441)
- Segregation by spectral type (Hurtado-Gil et al., 2016, ApJ 818, 174)
- $w_p(r_p)$ measurements in ALHAMBRA well tested



Clustering at the smallest scales: the 1-halo term

Why are small scales $r \sim 0.01 - 1\,h^{-1}\,\mathrm{Mpc}$ interesting?

- These scales probe clustering inside haloes ("1-halo term") $\rightarrow$ study how host haloes are populated by galaxies
- Simplest assumption (works very well at $r \gtrsim 0.1\,h^{-1}\,\mathrm{Mpc}$):
  - DM in haloes follows a NFW radial density profile
  - Satellite galaxies are distributed following same profile as DM
- However:
  - Theoretically, baryonic effects make NFW fail to describe hydrodynamical simulations (too shallow) at very small scales (e.g., Schaller et al., 2015, EAGLE)
  - Can be tested observationally?

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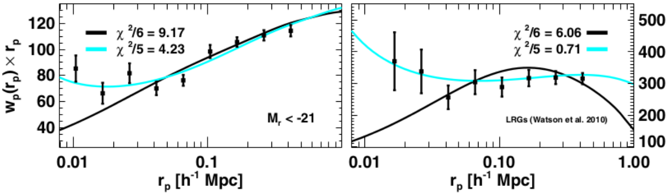
"Baryons and dark matter have different distributions at high redshift"
Will Percival, this morning talk

Observational tests of the NFW assumption

- Watson et al. (2010, 2012): SDSS-Main ($z \sim 0.1$):
  - Found significantly steeper profiles at $r_p \lesssim 50\,h^{-1}$ kpc for brightest samples ($\rightarrow$ most massive haloes)



- Guo et al. (2014): BOSS ($z \sim 0.5$):
  - Found no significant deviation from NFW, except for the reddest sample
- With ALHAMBRA: we aim to continue this type of analysis
  - Photometric survey: avoid problem of fiber collisions
  - Deep survey: can study evolution with z
  - However, much smaller area (larger uncertainty)

HOD modelling of $w_p(r_p)$ in ALHAMBRA

Ingredients of the HOD modelling:

Zheng et al, 2005
Contreras et al, 2013

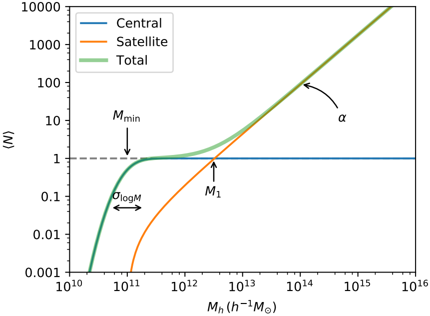
- Properties of halo population (mass function, bias, ...): kept fixed

- HOD: mean no. of galaxies per halo as function of M_h. Use a 4-parameter model:

$$N_{\rm cent}(M) = \frac{1}{2}\left[1 + {\rm erf}\left(\frac{\log M - \log M_{\rm min}}{\sigma_{\log M}}\right)\right]$$

$$N_{\rm sat}(M) = \left(\frac{M - M_{\rm min}}{M_1}\right)^{\alpha}$$

$$N_{\rm tot}(M) = N_{\rm cent}(M) + N_{\rm sat}(M)$$



- Can obtain information about galaxy formation and evolution (mean halo mass, satellite fraction, ...) from the HOD parameters

HOD modelling of $w_p(r_p)$ in ALHAMBRA

Ingredients of the HOD modelling:

- Radial profile for the distribution of satellites (Watson et al.):

NFW profile

- Radial density:

$$\rho_h(r|M) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

- Concentration ($c \equiv r_{\rm vir}/r_s$): $c_{\rm gal} = c_{\rm DM}$

***Generalized* NFW profile**

- Radial density:

$$\rho_h(r|M) = \frac{\rho_s}{(r/r_s)^{\gamma}(1+r/r_s)^{3-\gamma}}$$

- Concentration ($c \equiv r_{\rm vir}/r_s$): $c_{\rm gal} = f_{\rm gal}\, c_{\rm DM}$

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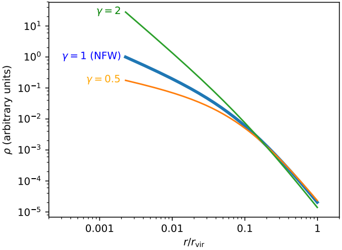
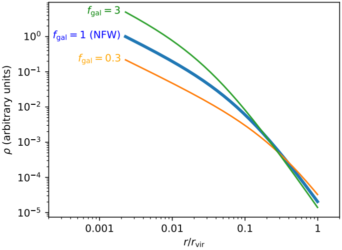
  $c_{\rm gal} = f_{\rm gal}\, c_{\rm DM}$

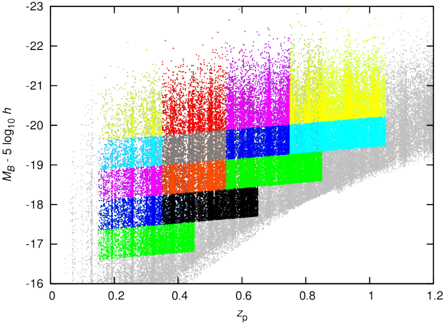
- *Generalized* NFW profile: two extra parameters, γ, $f_{\rm gal}$



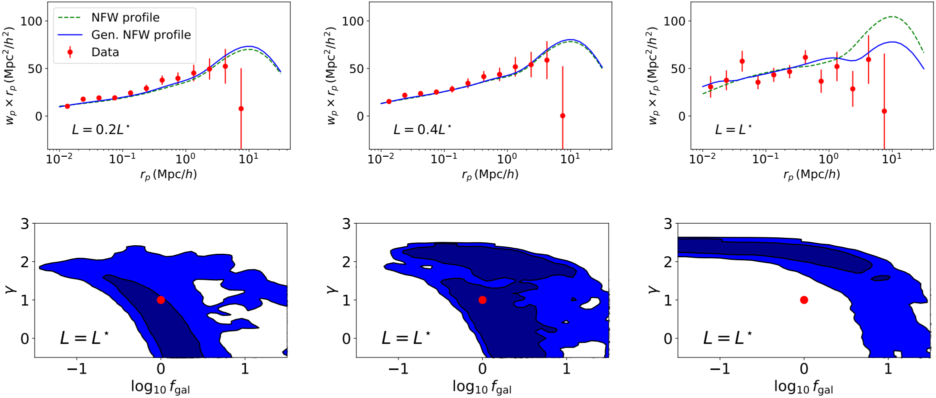


Small-scale $w_p(r_p)$ measurements in ALHAMBRA

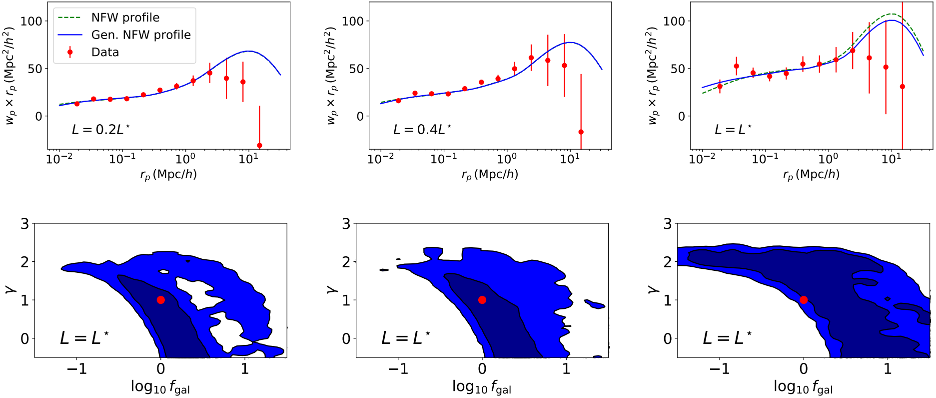
- ALHAMBRA catalogue to $I_{AB} < 24$
- Select samples by B-band absolute magnitude and redshift
- Measure $w_p(r_p)$ in each sample down to smallest r_p allowed by seeing $(10 - 20\,h^{-1}\,\mathrm{kpc})$



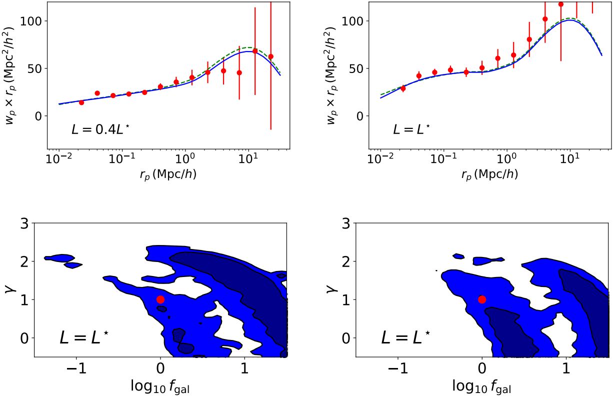
Preliminary results — $z = 0.3$



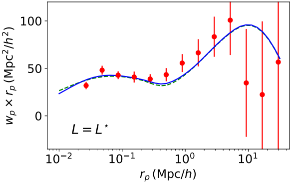
Preliminary results — $z = 0.5$

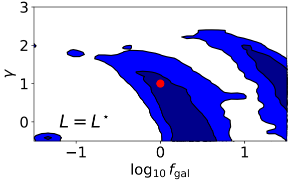


Preliminary results — $z = 0.7$



Preliminary results — $z = 0.9$





Conclusions

- Very good overall agreement of the NFW model with galaxy clustering down to scales $r \sim 10-20\,h^{-1}\,\mathrm{kpc}$ in $z \in [0.2, 1.0]$.
- Exception: brightest sample, $z = 0.3 \rightarrow$ similar to Watson et al.'s results
- Hint of evolution for brightest sample: can explain difference between SDSS-Main and BOSS
- Overall: possible deviation from NFW only for the most massive haloes
- ALHAMBRA limited by cosmic variance: future improved constraints from J-PAS? Could constraint baryonic effects in simulations?
- Also: information about galaxy formation/evolution in the other HOD parameters $\rightarrow$ work in progress

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Muchas Gracias

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