# Galaxy clustering with GAMA

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# Outline

- Introduction: what is galaxy clustering? Why is it interesting? Literature results
- Data & model: our dataset and the semi-analytic models we test
- Methodology: how suitable random catalogues are generated, covariance matrices
- Results
- Summary/future work

# Galaxy Clustering

- Measured by the 2-point correlation function (2PCF). Defined in terms of the density field

$$\xi_{DM}(r) = \langle \rho(x)\rho(x+r) \rangle$$

$$\xi_{gal}(r) = b^2 \langle \rho(x)\rho(x+r) \rangle$$

- The density field mainly depends on cosmology, and can be predicted from simulations
- The measured correlation function is biased (e.g. Cole & Kaiser 1989), this bias describes how galaxies occupy the Dark Matter haloes

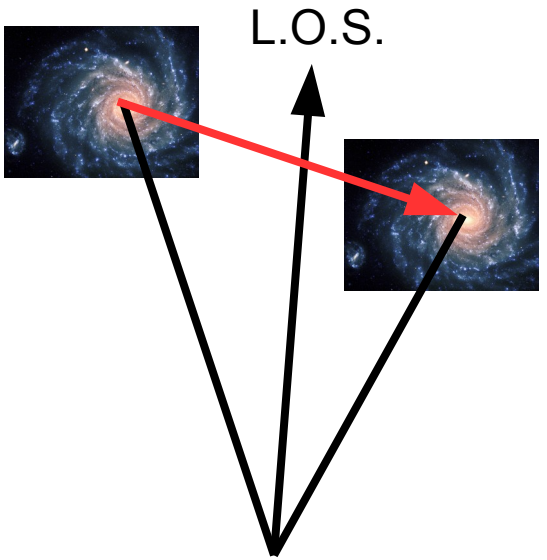
# Pair Counts - I

- Common estimators depend on having a catalogue of random points that fills the volume of the data, accounting for the selection function.

$$\xi(r) = \frac{dd(r)}{rr(r)} - 1 \qquad \xi(r) = \frac{dd(r)\,rr(r)}{(dr(r))^2}$$

# Pair Counts - II

- Count pairs in bins of transverse & perpendicular direction to some defined line-of-sight

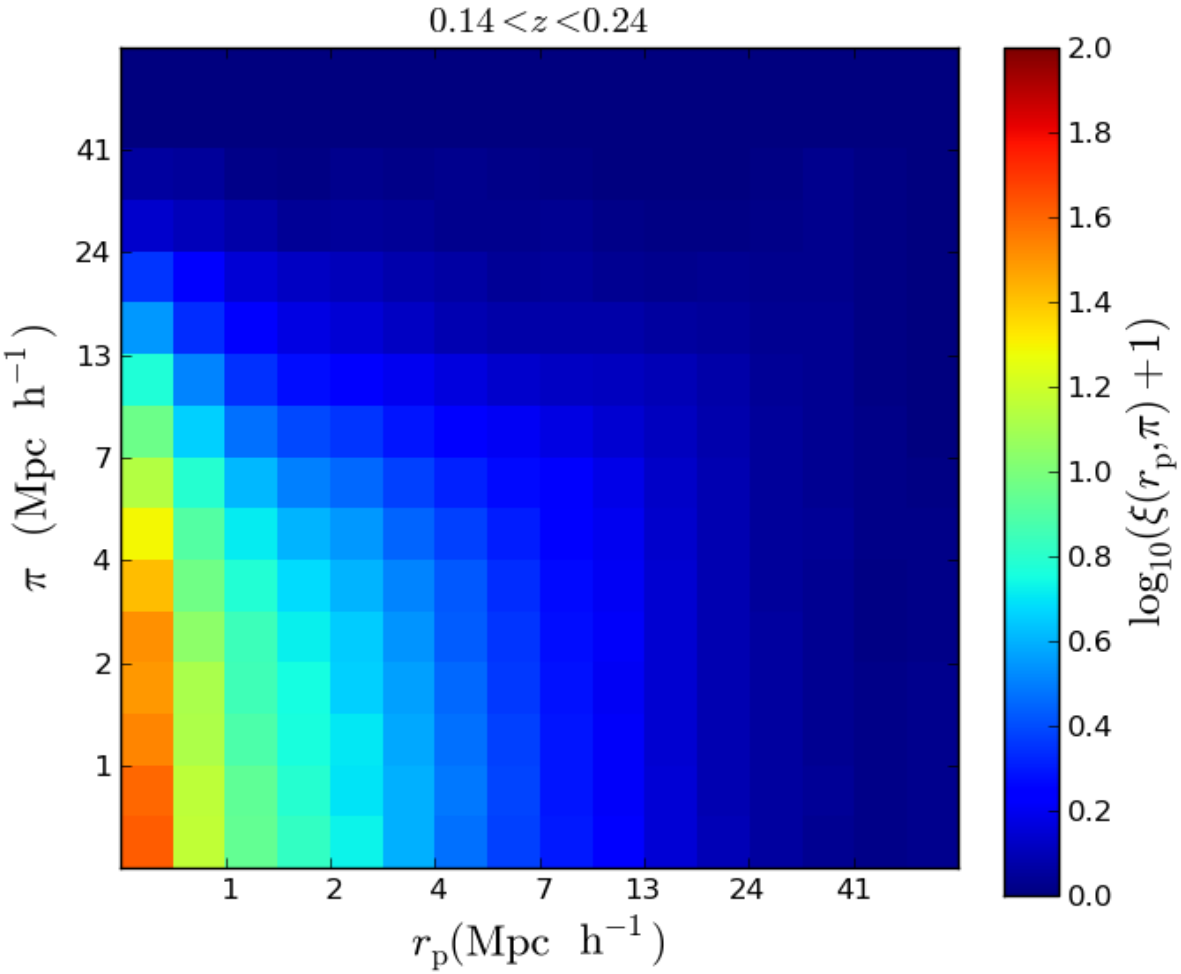



- Π is the projection of the separation (red arrow) on L.O.S (i.e. a dot product)
- Rp is the other side of the triangle of Π & L.O.S.

Galaxy image credit: ESO

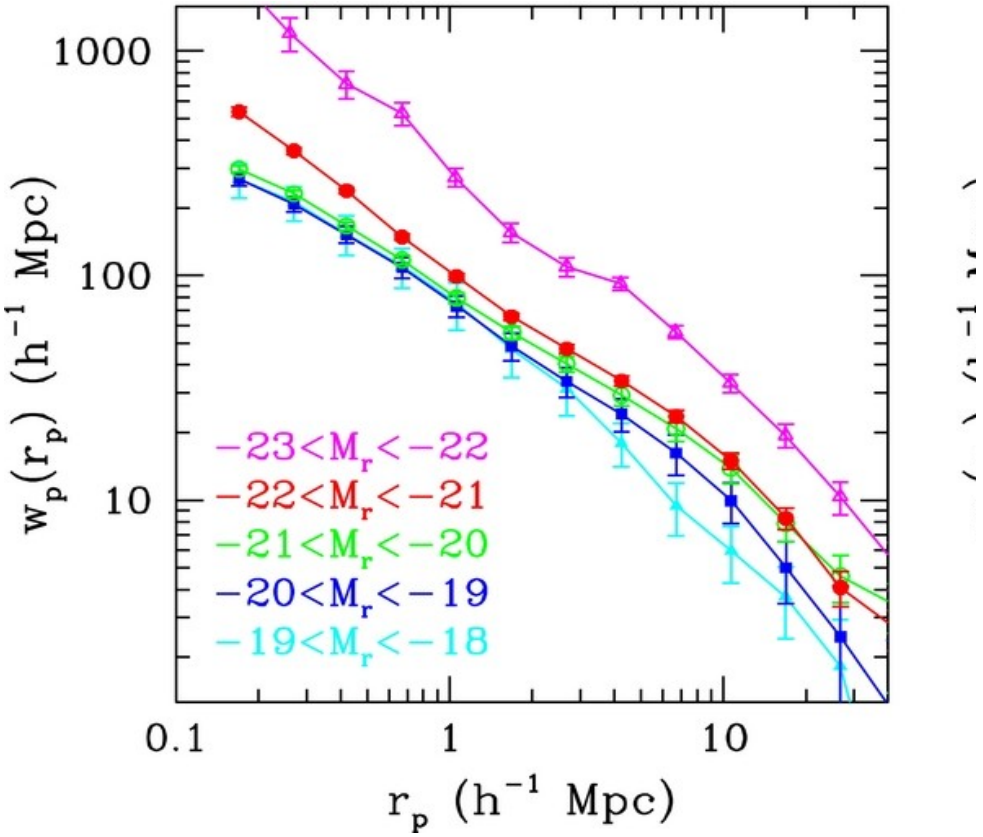
# Galaxy Clustering

- Can plot in 2D, as function of line-of-sight and transverse separation
- Projected correlation function: integrate along line of sight



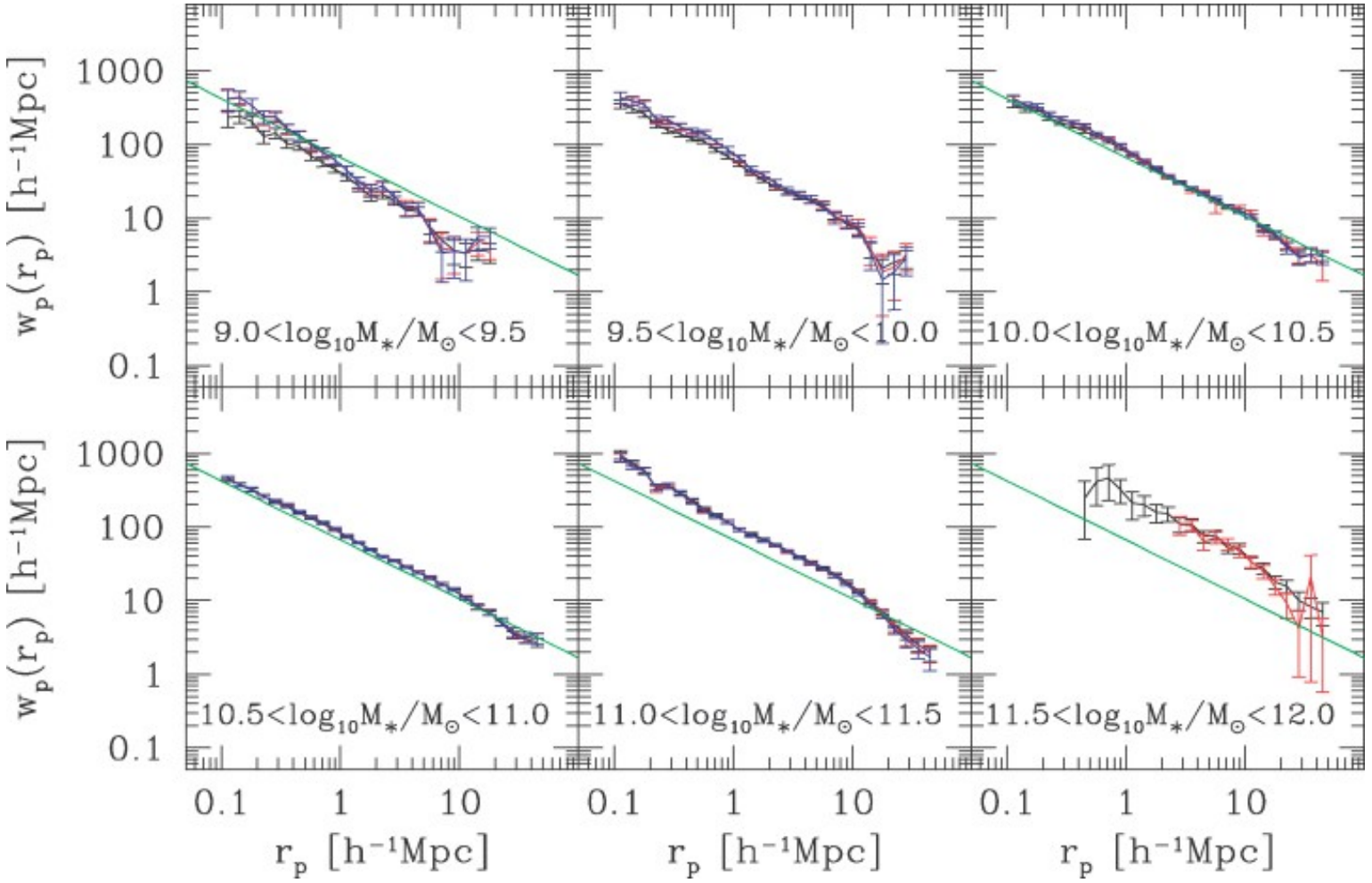
# Literature results (z~0.1)

- SDSS: more massive & brighter galaxies more clustered → live in more massive DM haloes.




Zehavi et al (2011)

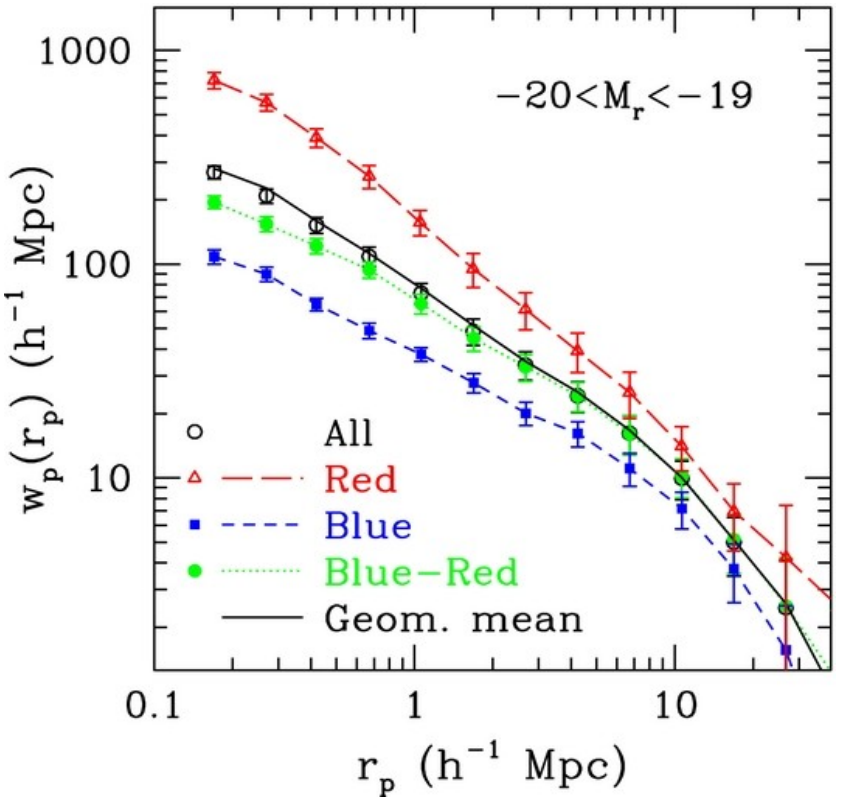
# Literature results (z~0.1)




Li et al (2006)

# Literature results (z~0.1)

- Red galaxies have steeper correlation functions (stronger 1-halo term) with larger amplitudes

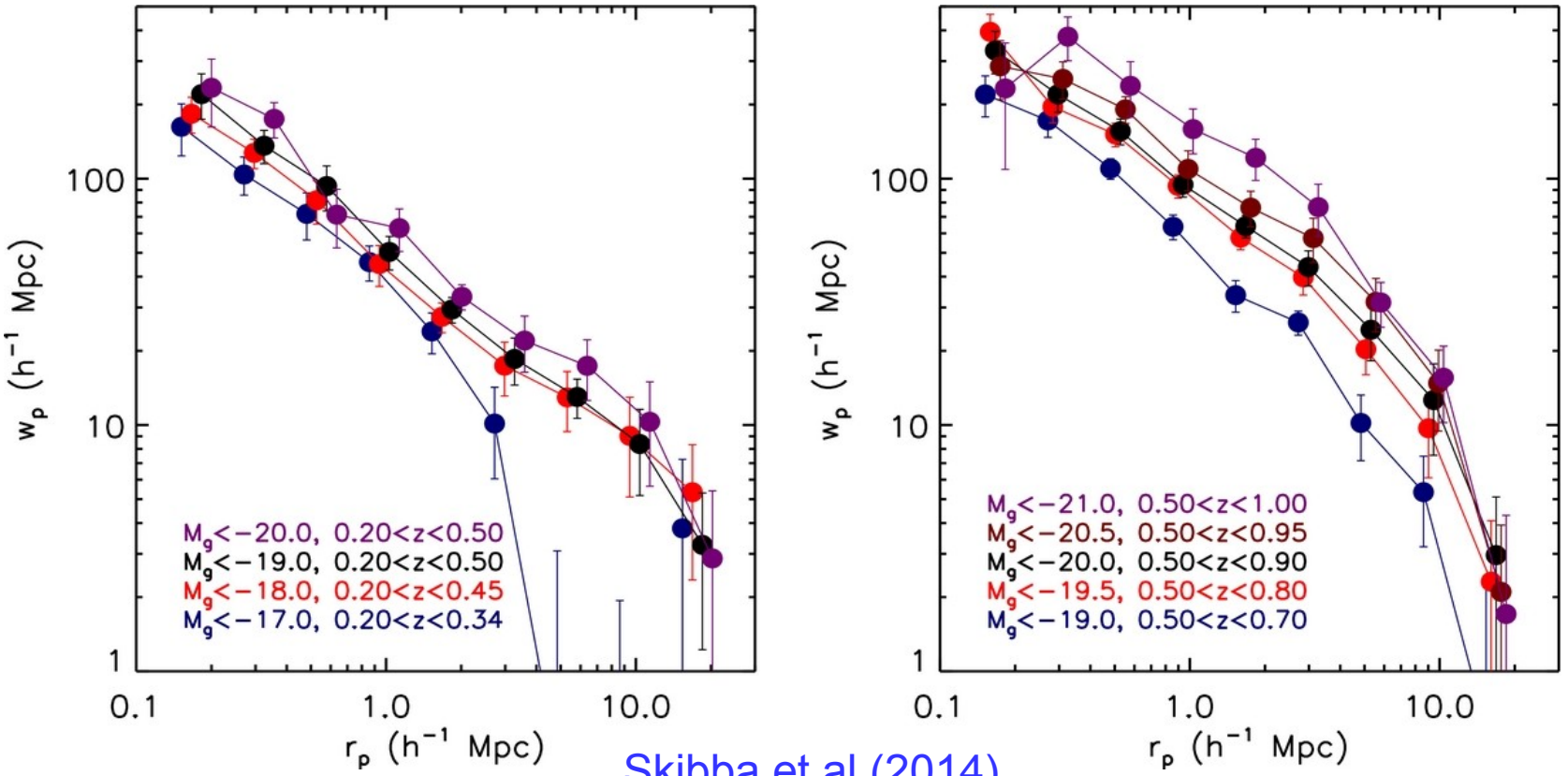



Zehavi et al (2011)

*For more on low-z see also e.g. Norberg+ 2001, 2002; Zehavi+ 2002, 2005; Christodoulou+ 2012 ...*

# Literature results (0.2<z<1.0)

- Small area surveys (a few degrees area or less) have confirmed these trends are in place at higher-z e.g. PRIMUS



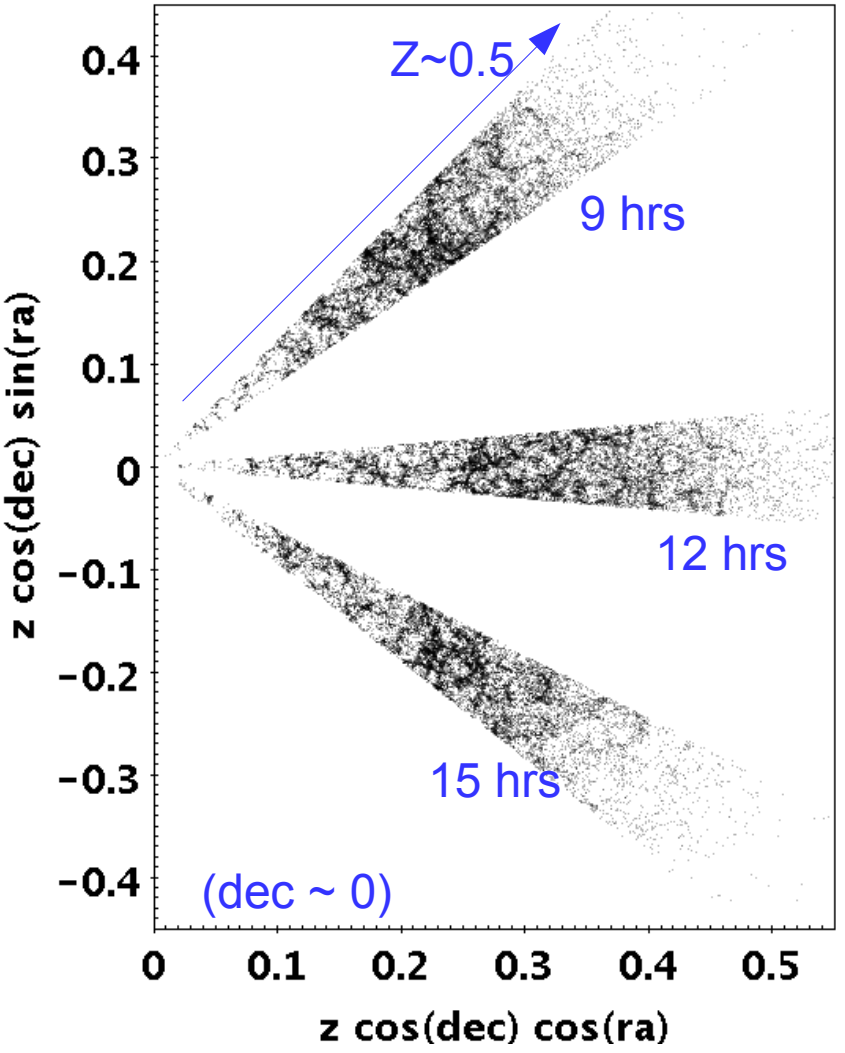

Skibba et al (2014)

*For more on high-z, low area see e.g. Phleps+ 2006; Pollo+ 2006; Brown+ 2008; Coil+ 2008, 2011; Meneux+ 2009; de la Torre+ 2013, Marulli+ 2013 ...*

# Galaxy and Mass Assembly Survey (GAMA)

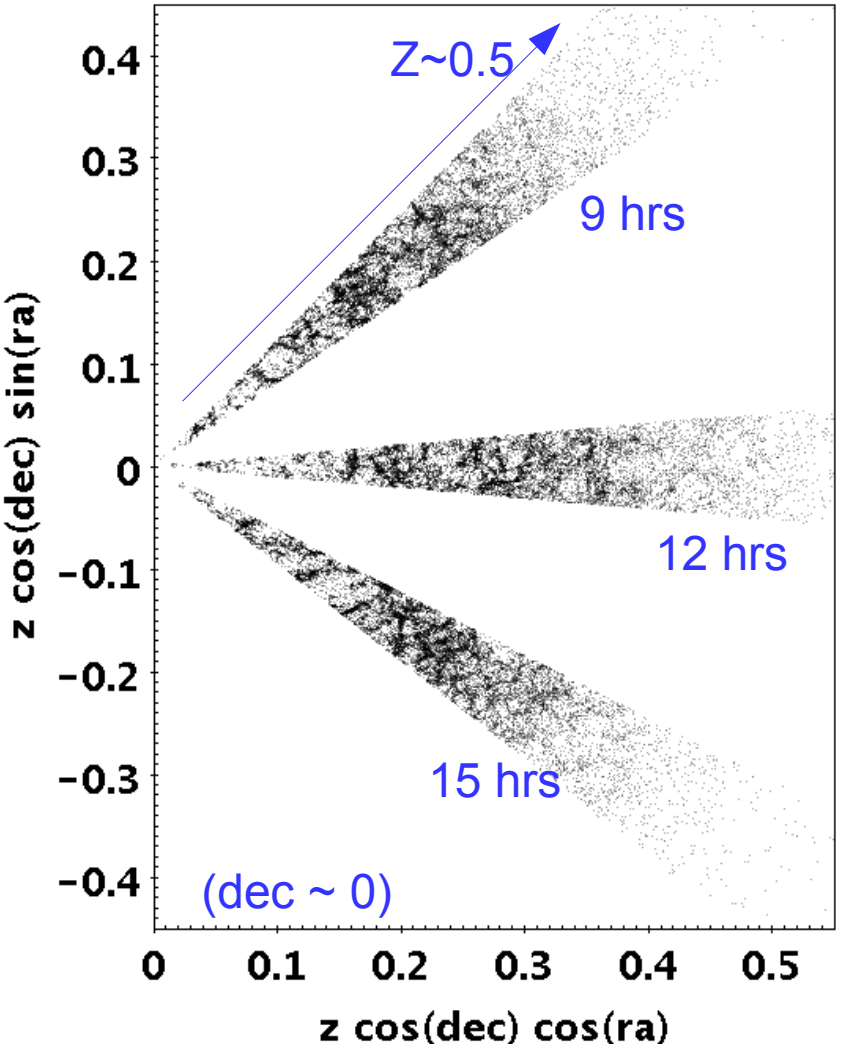
Data

- Spectroscopic redshift survey down to r<19.8, in three fields with a total area of 182 sq. degrees
- Bridges gap between small area, high-z surveys and SDSS
- Multiwavelength measurements (from radio to x-ray)
- Stellar masses from g-i colour (using Taylor+ 2011)



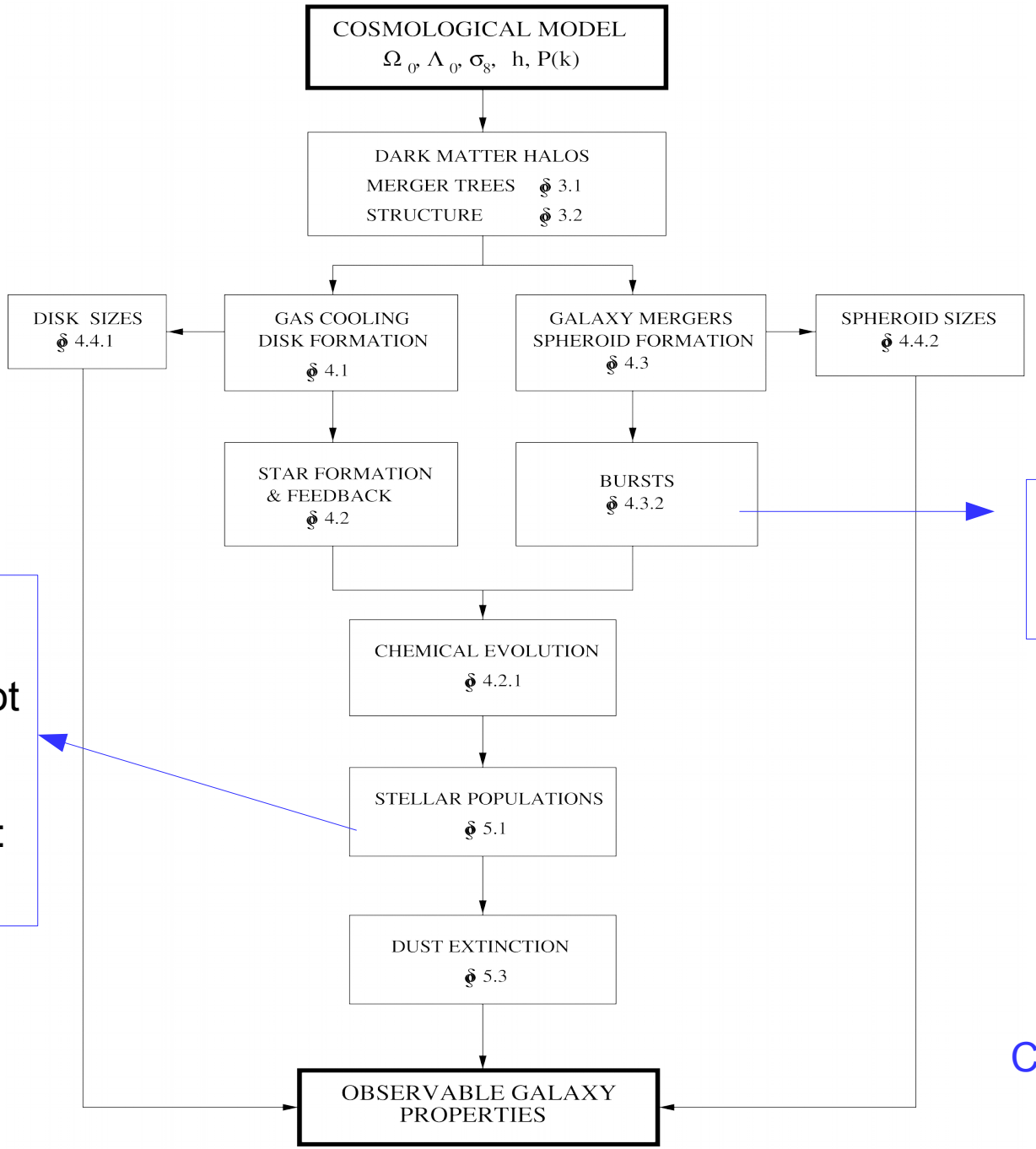
# GAMA mock catalogues

- Produced from the semi-analytic model GALFORM on an N-body simulation with WMAP7 cosmology
- Two different GALFORM versions
- 26 realisations
- Lightcone modelled via Merson+ 2013
- We take stellar masses direct from the mock
- Luminosity functions forced to match



# GALFORM Primer

Model




Lacey+ (in prep): Different IMF in bursts

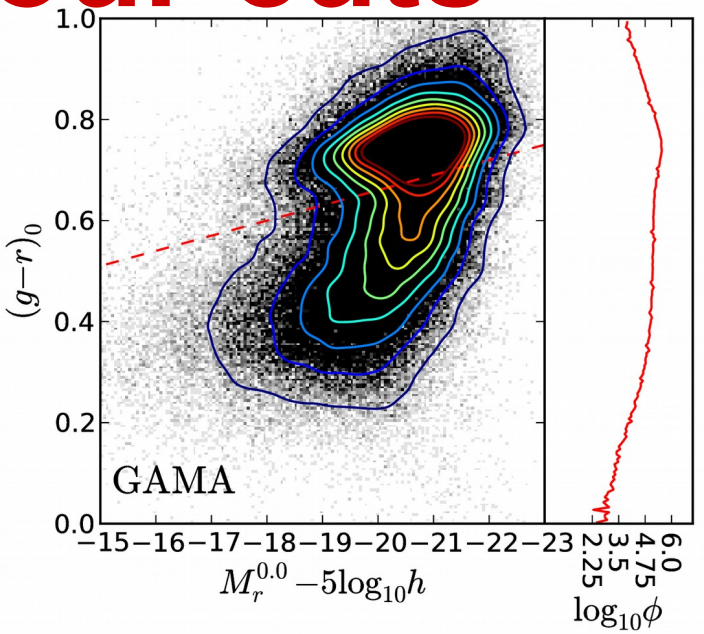
Gonzalez-perez + 2014: Bruzual & Charlot 93

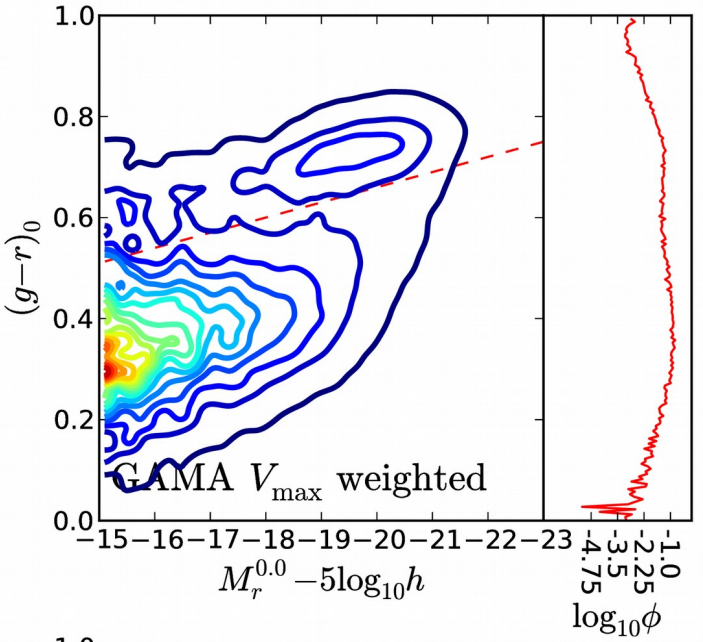
Lacey+ (in prep): Maraston 2005

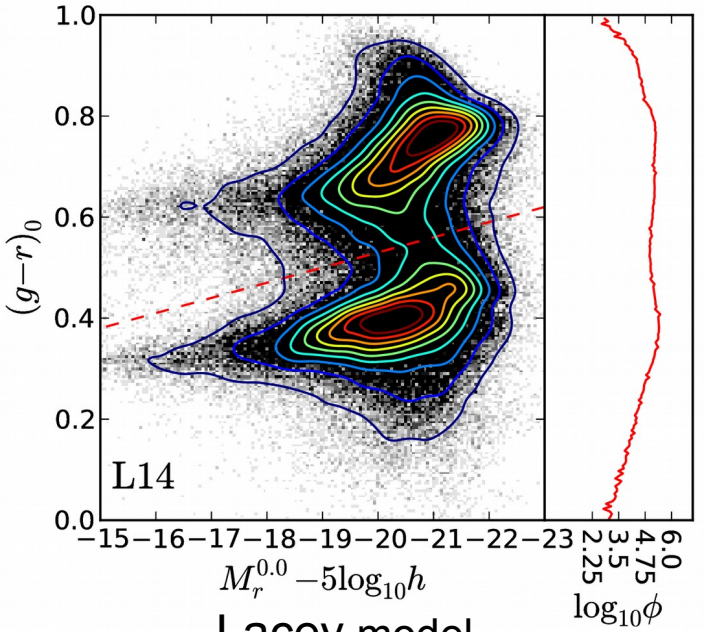
Cole+ 2000

# Colour cuts

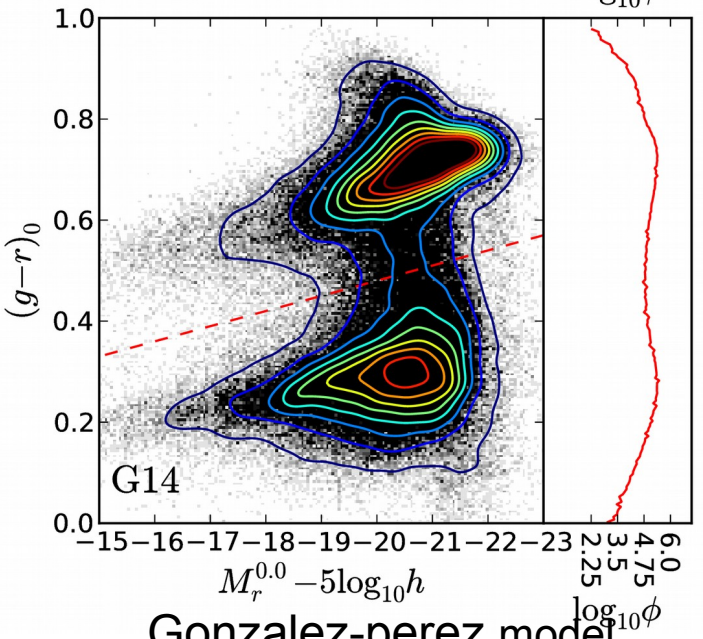
Model




Lacey model




Gonzalez-perez model

# Random catalogues I

- Adapted form of the Cole (2012) method.
- Clone galaxy catalogue, distributing each clone over the galaxies Vmax
- Number of times to clone each galaxy:

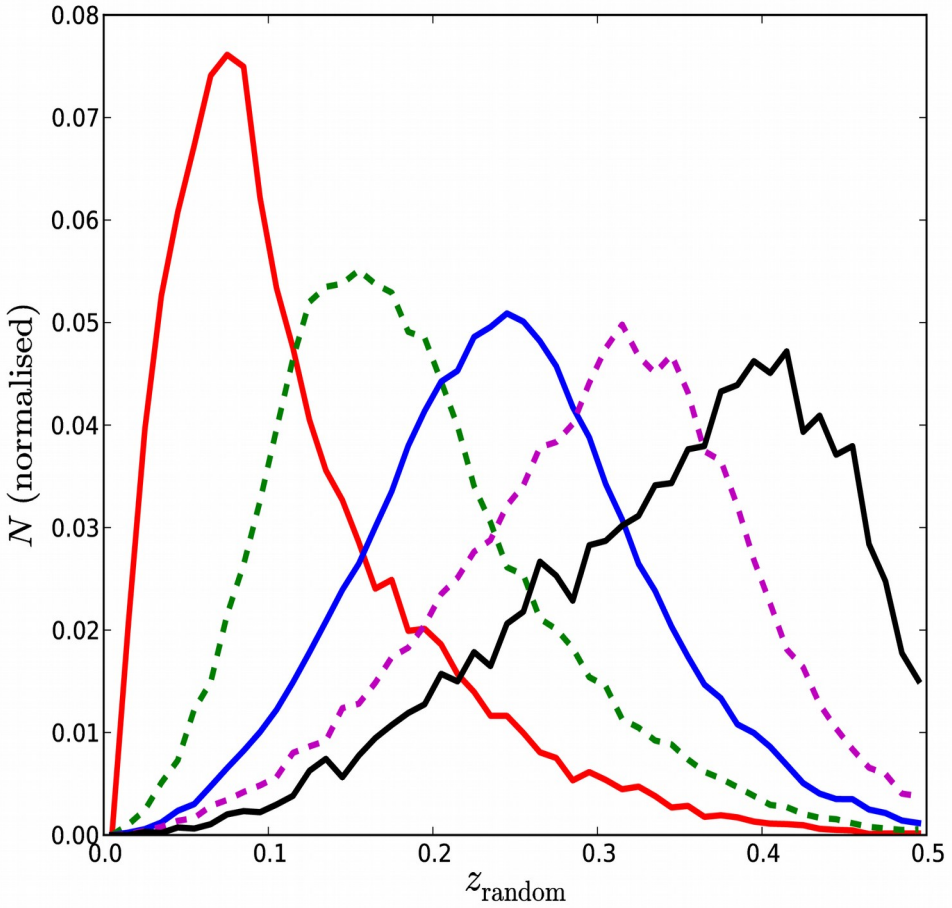
$$n_{clones} = N \frac{V_{max}}{V_{max,dc}}$$

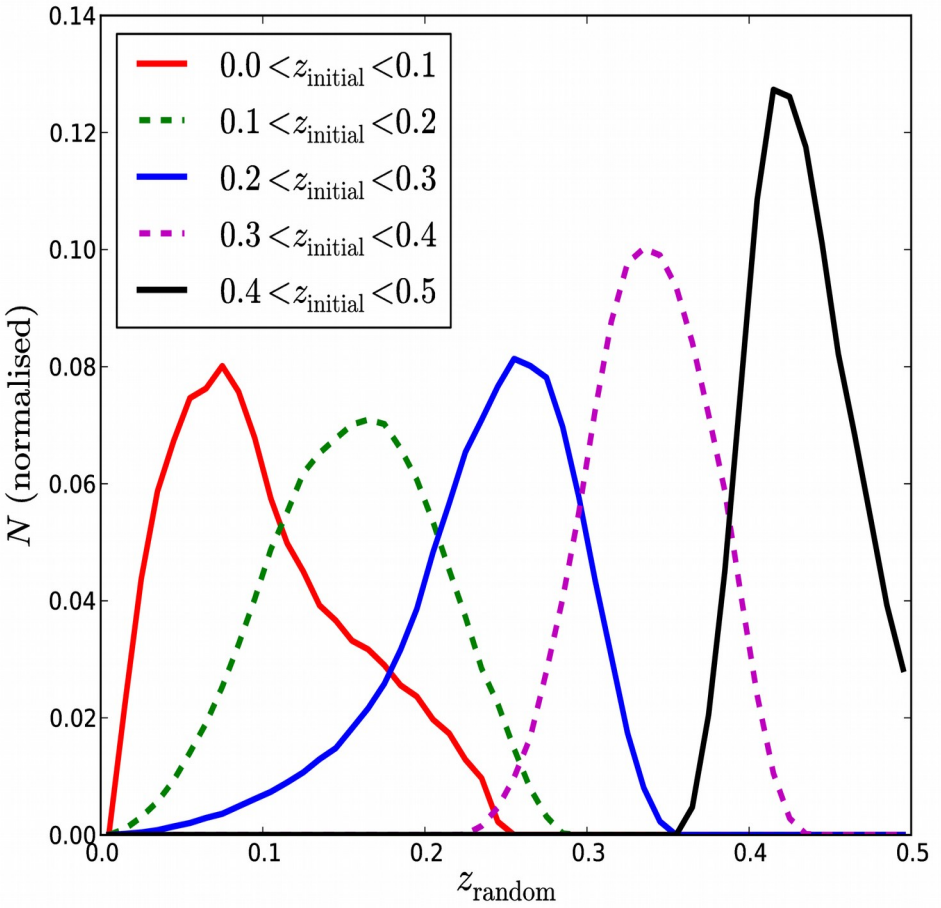
Estimate iteratively from ratio of data n(z) and random n(z)

$$V_{max,dc} = \int \Delta(z) \frac{dV}{dz} dz$$

- Randoms have all the properties of the data!

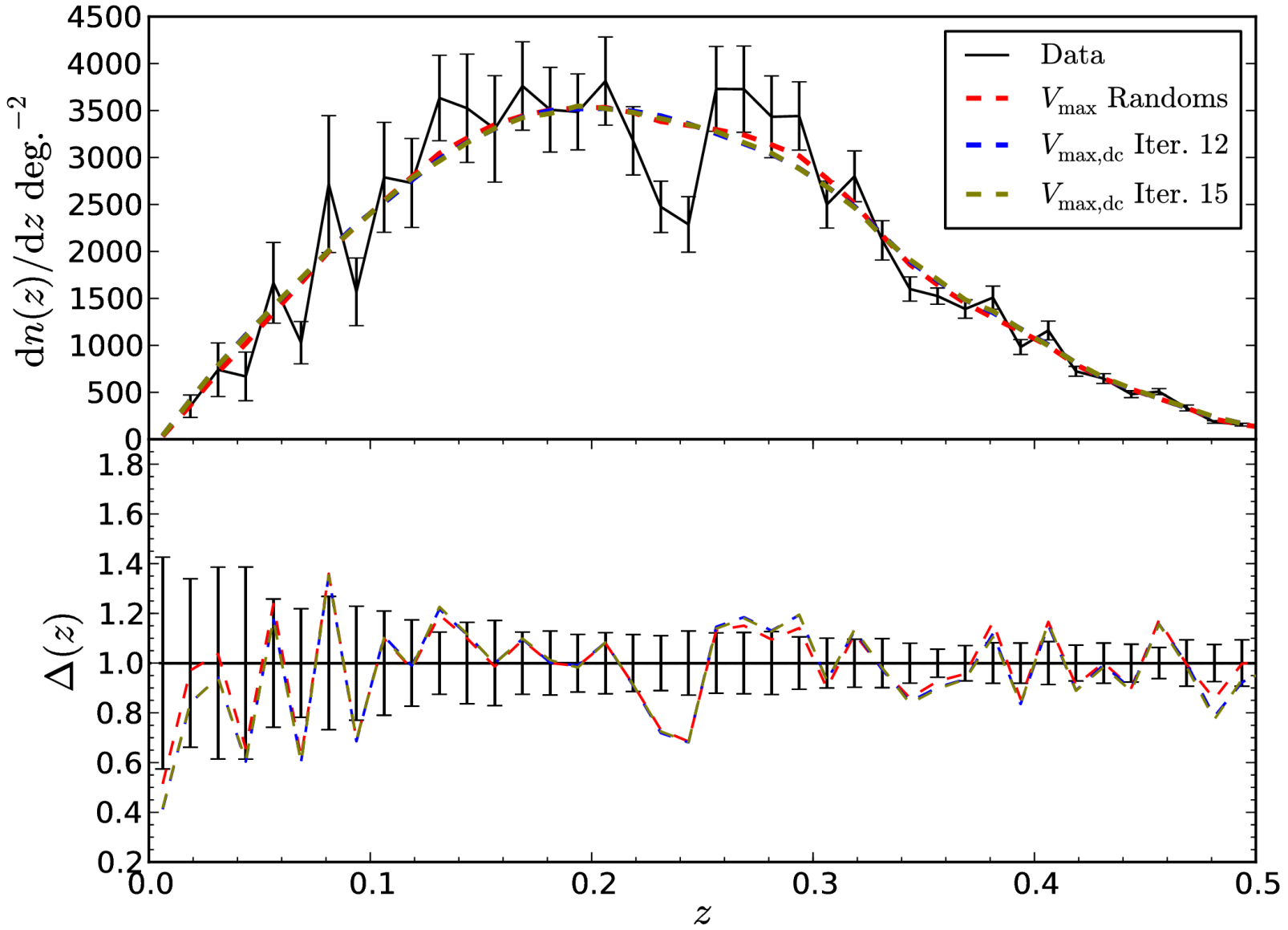
# Random catalogues II



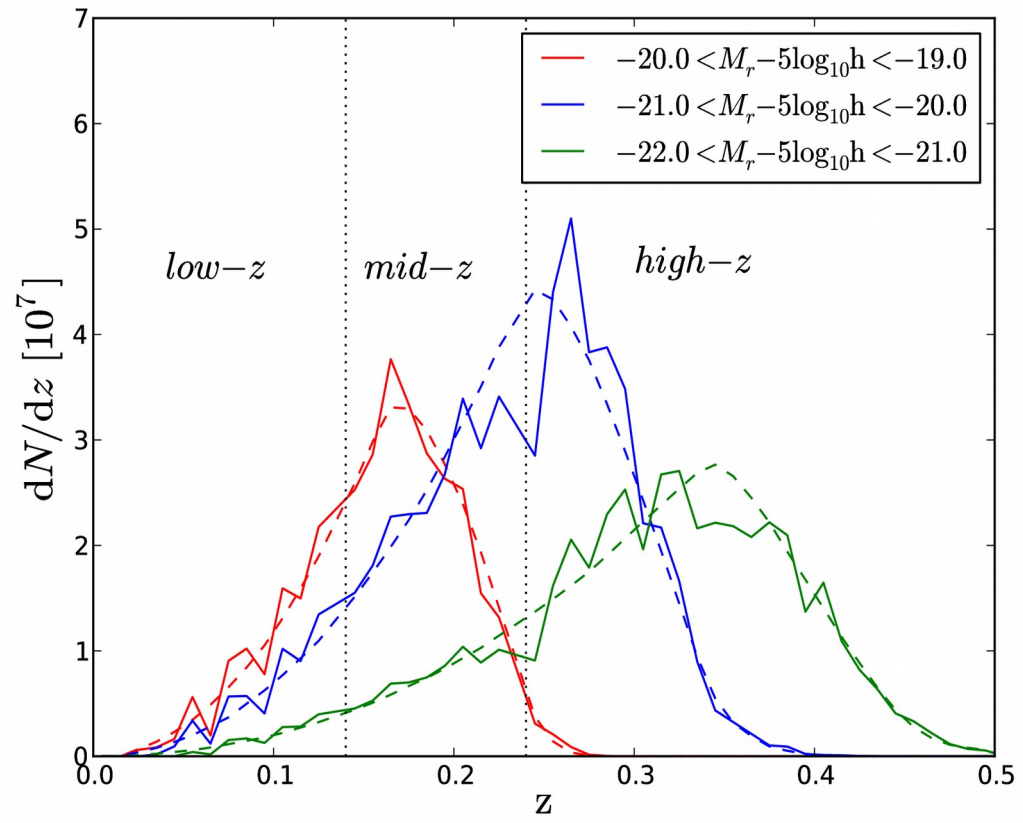



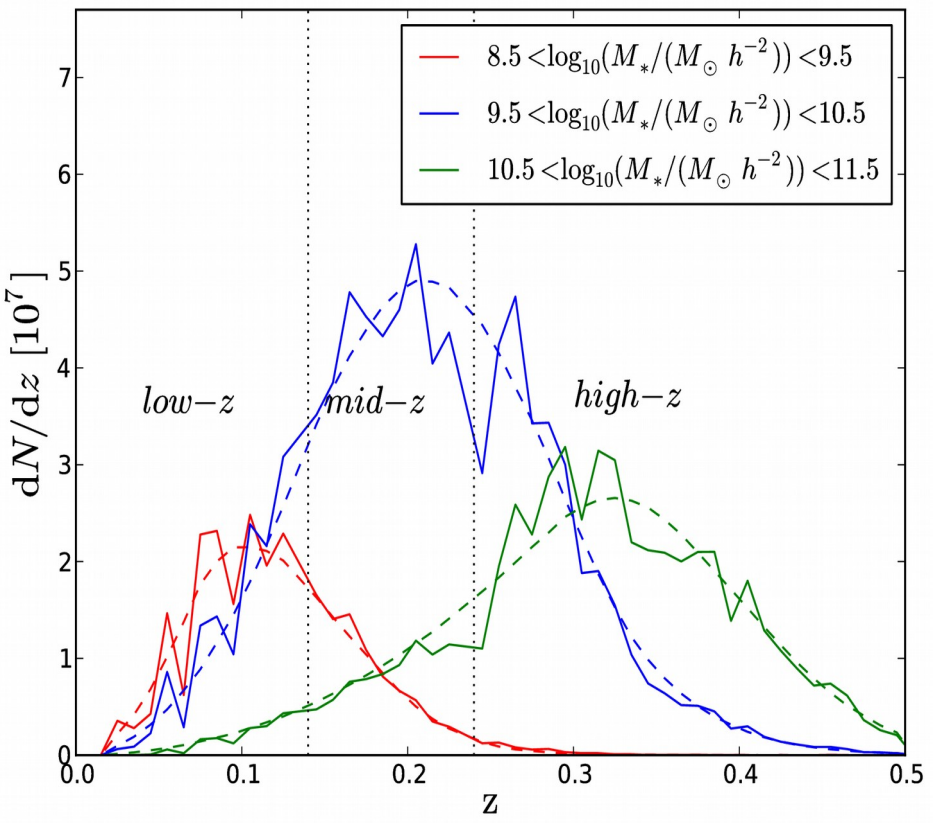

With the windowed randoms, cloned galaxies move less from their original location → limits the impact of unmodelled evolution on the randoms

# Random catalogues III



# Random catalogues IV




Resultant catalogues are an excellent fit to the data over these luminosity ranges. They are being used for a variety of applications related to LSS e.g. Eardley+ 2014

# Covariance Estimates

- Our estimates of the covariance matrix are noisy as they're only based on the scatter between 26 mock catalogues → such matrices can give incorrect results
- Carry out an SVD on the matrix, and only keep the 4 largest terms of the diagnosized matrix

$$\widetilde{C} = \frac{C_{ij}}{\sqrt{\sigma_i \sigma\, j}}$$

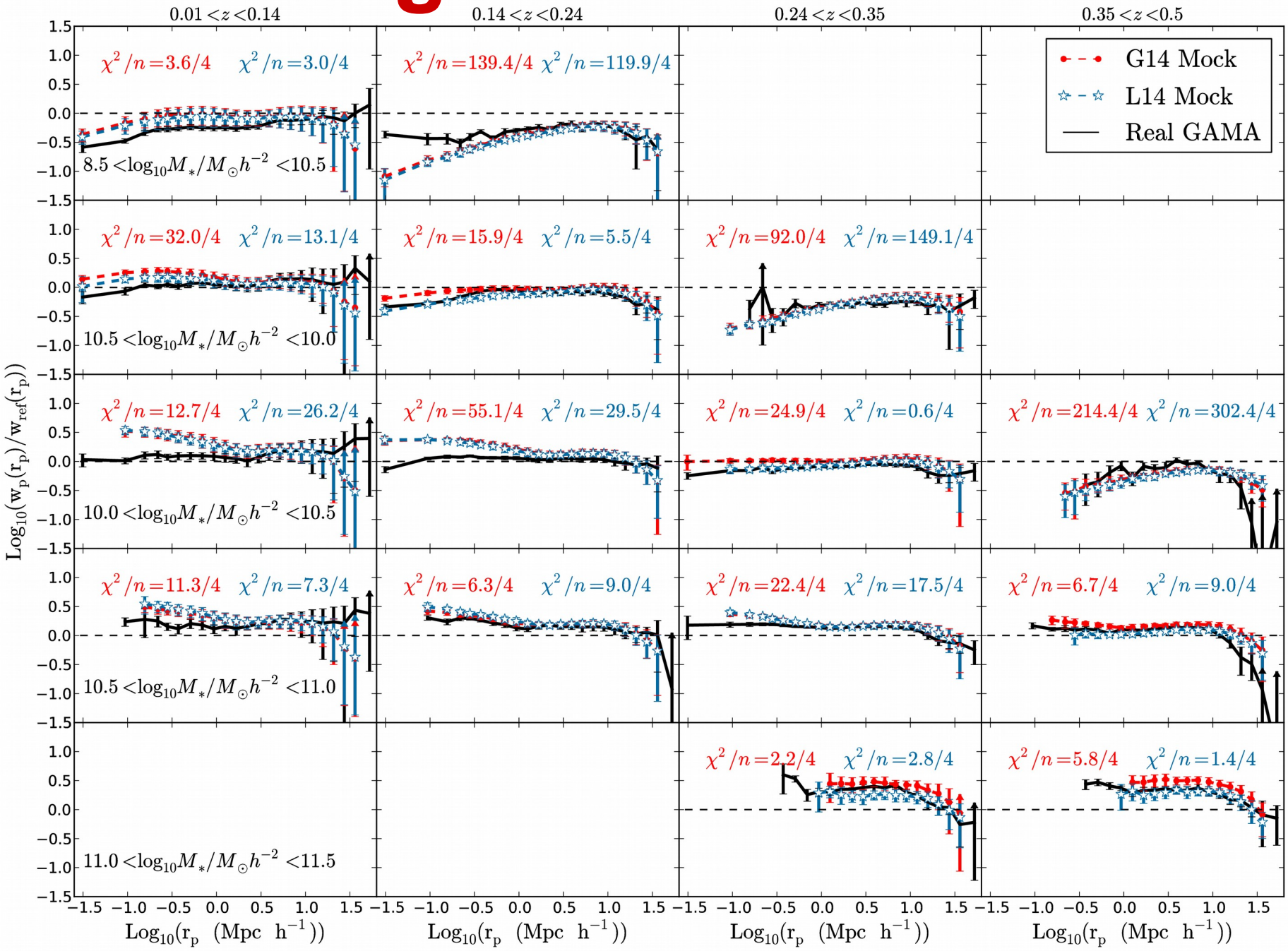
$$\widetilde{C} = R^{-1} \widetilde{C}_{diag} R$$

$$\widetilde{C'^{-1}} = R \widetilde{C}'^{-1}_{diag} R^{-1}$$

Basic method from: Gaztanaga & Scoccimarro (2005), Marn+ (2013)

# Clustering in mass bins





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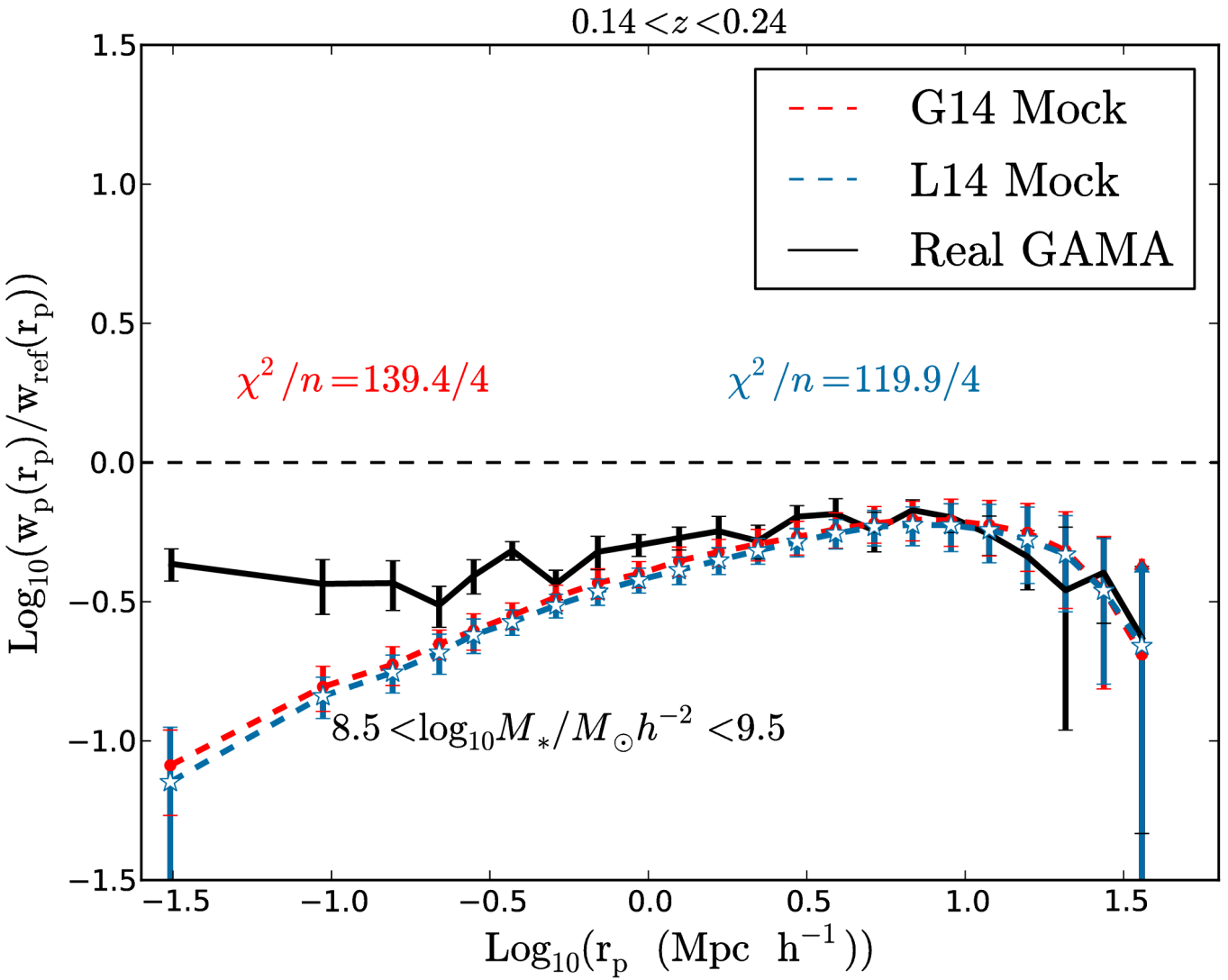

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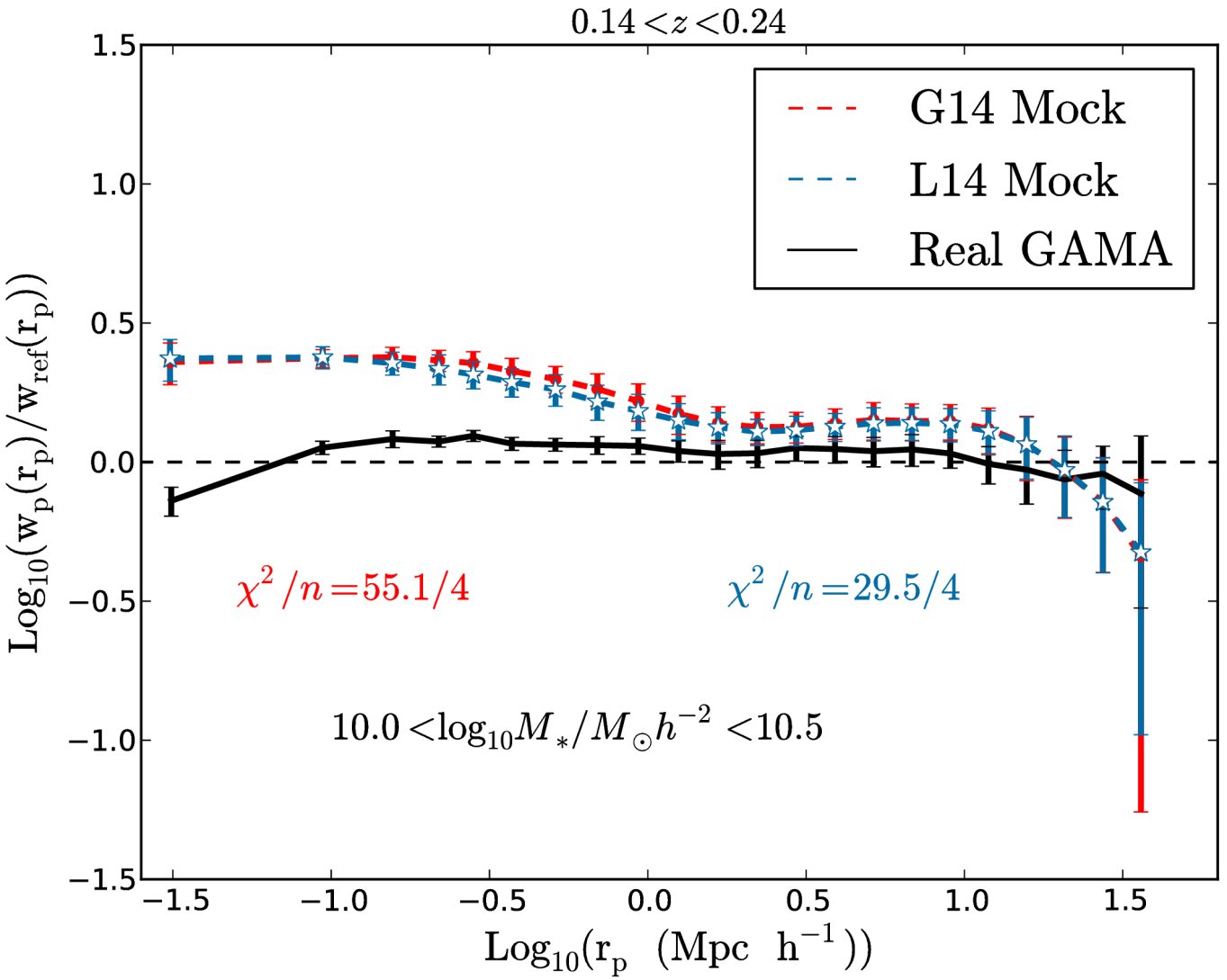

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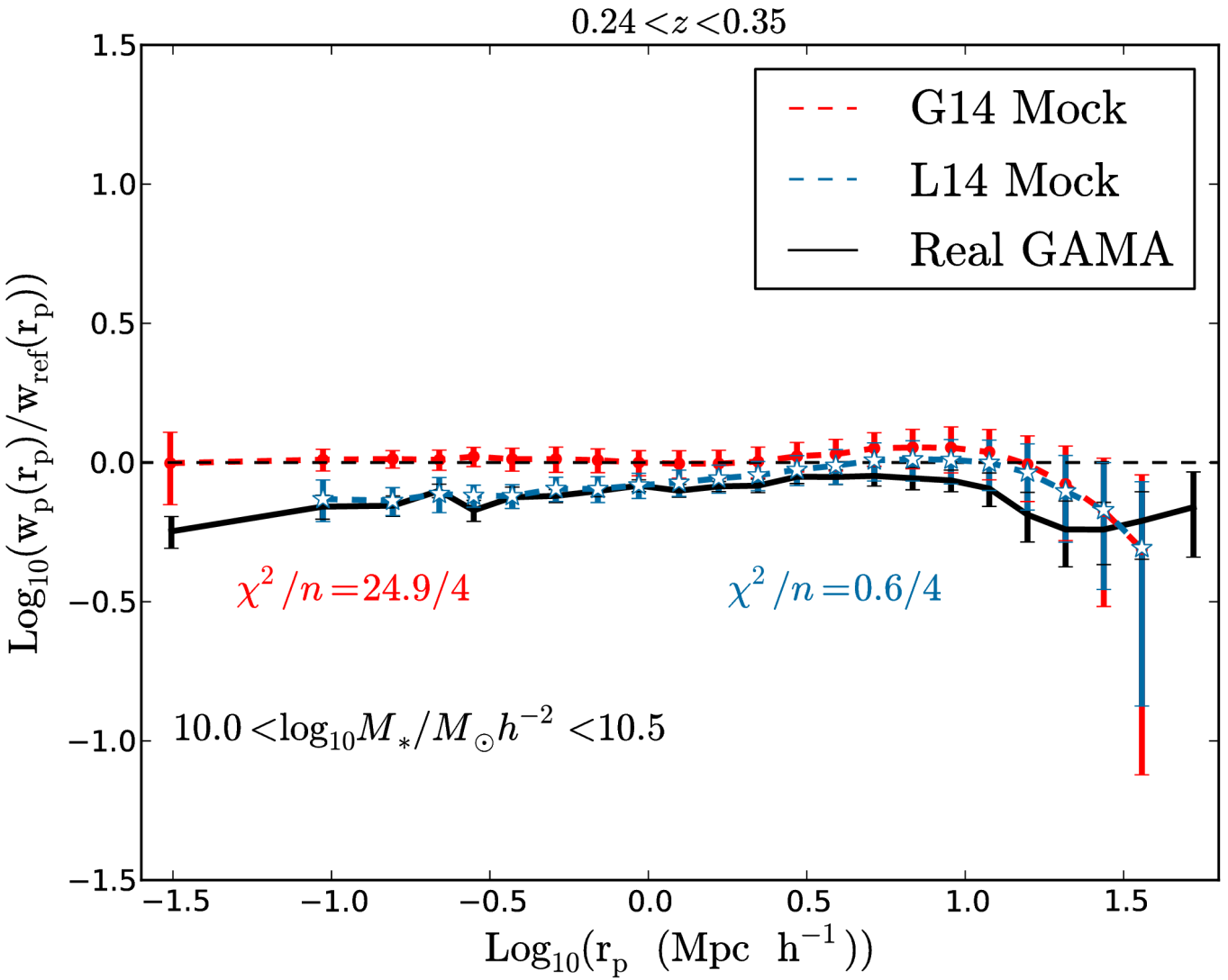
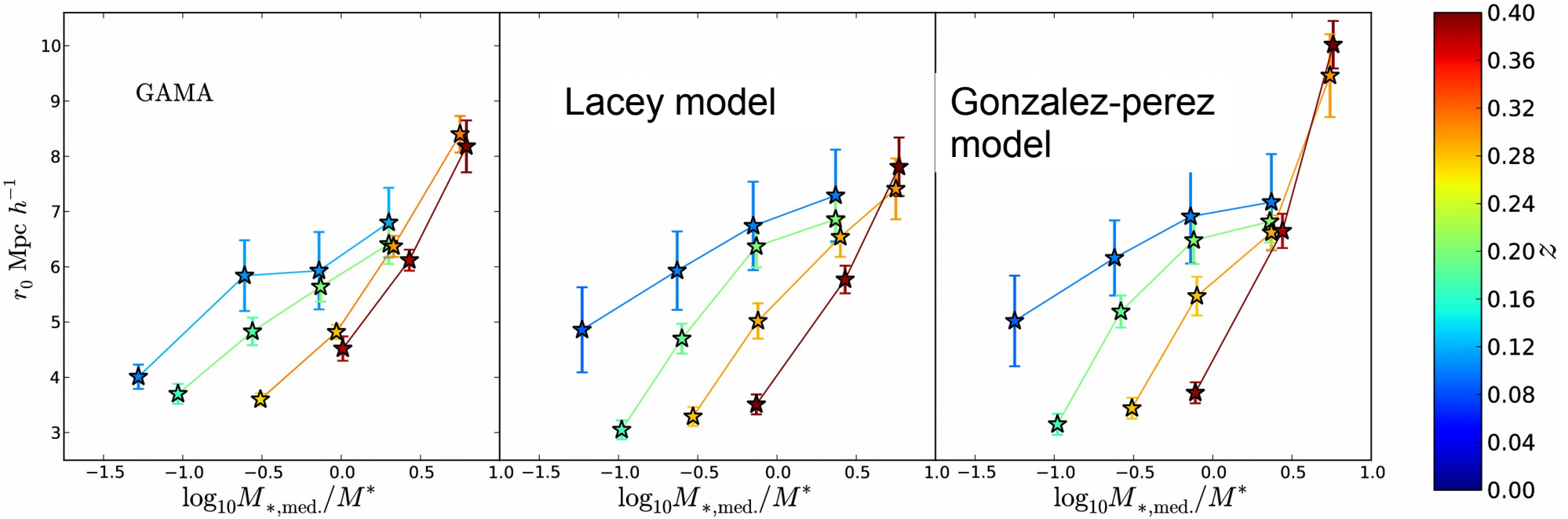
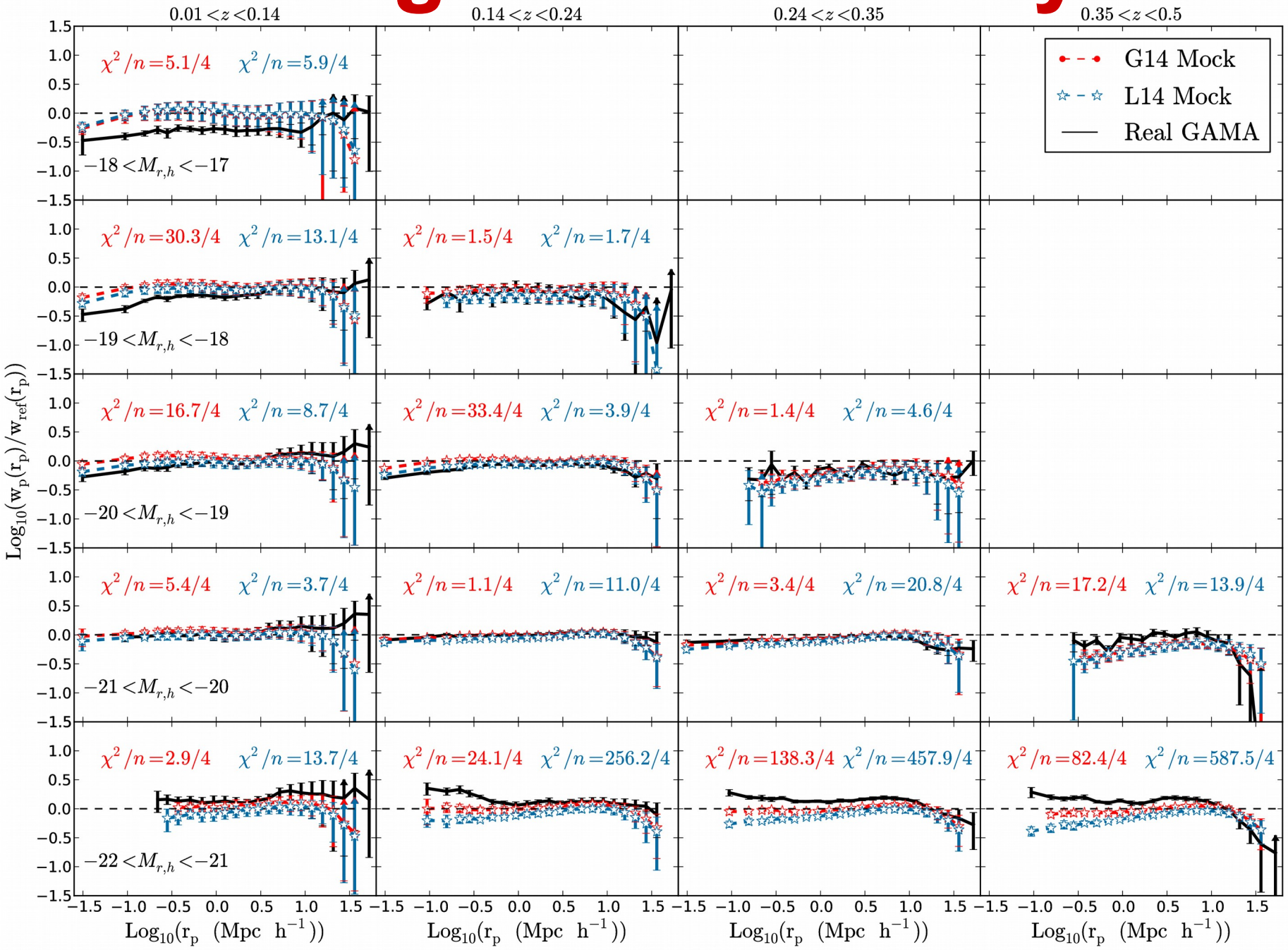


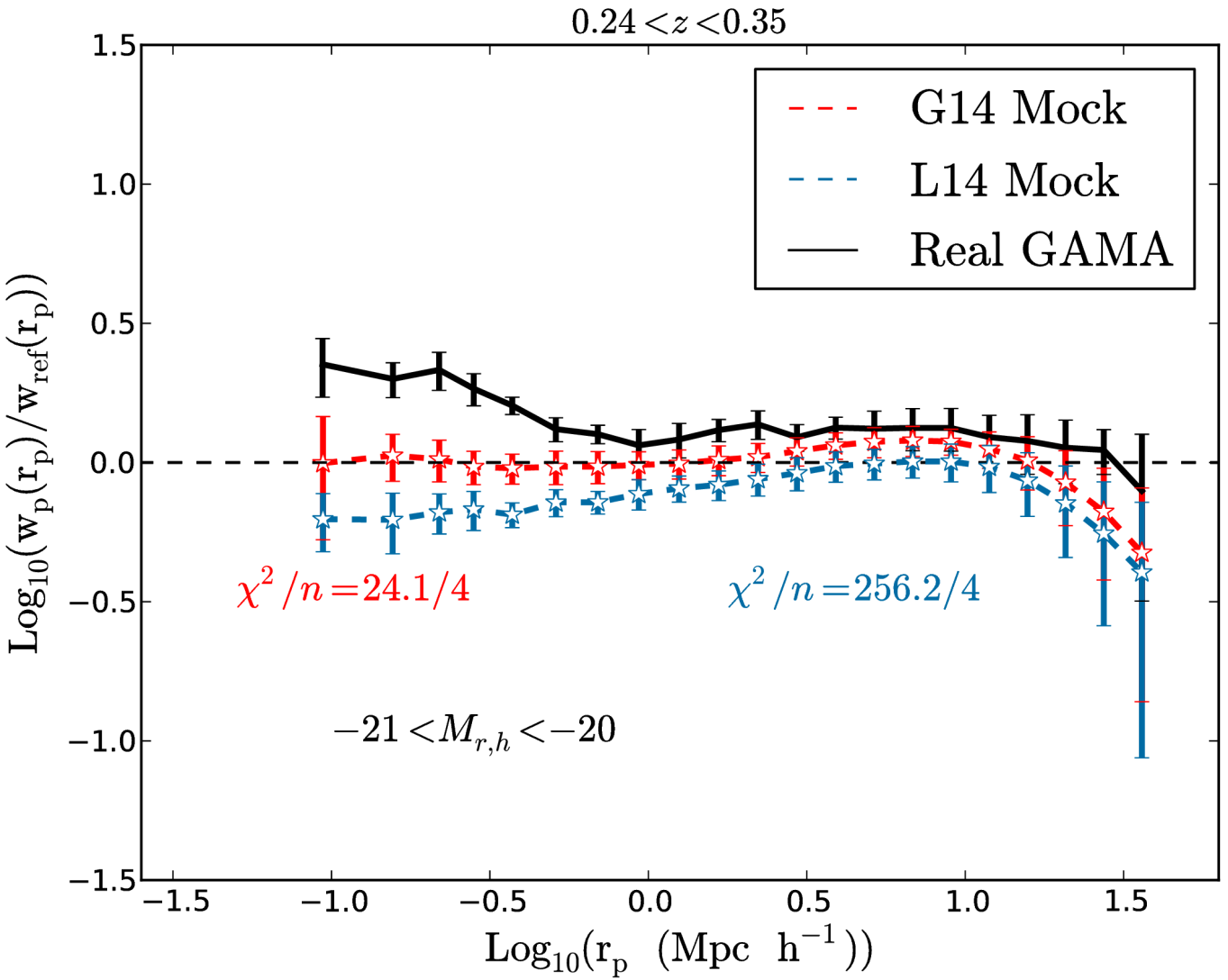
# Trends with mass & z



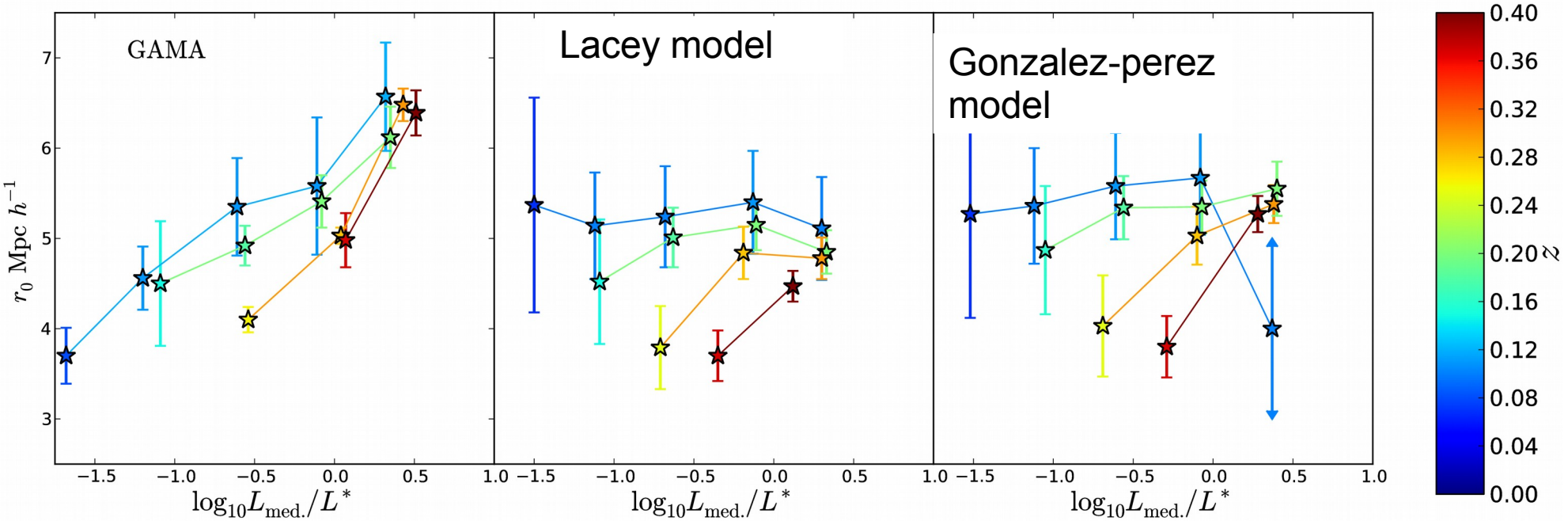
# Clustering in luminonsity bins



# Clustering in luminosity bins

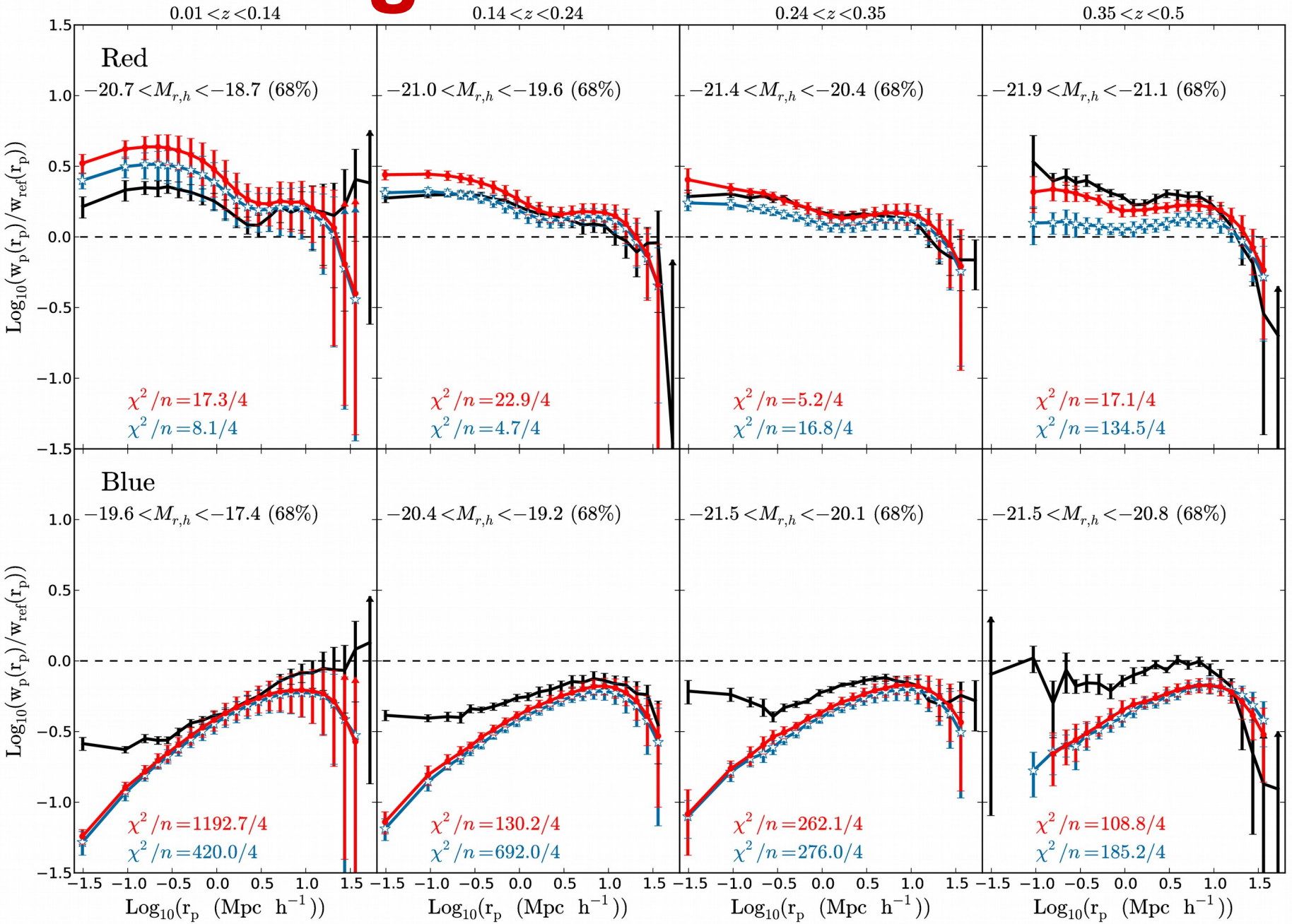


# Trends with luminosity & z



# Clustering versus colour





# Interpretation

- The models reproduce the increase in clustering amplitude with mass, and trends with z
- Neither model reproduces the trends with luminosity
- Both models wrongly predict small scale clustering in mass samples, and underpredict this for blue galaxies and the most luminous galaxies
- Models have too well defined red and blue sequences
- The models make different detailed predictions (particularly on small scales) → but trends are similar
- Satellite galaxy physics can affect all of the descrepancies (see Font+ 2008, Kim+ 2009, Contreras+ 2013)

# Summary/future

- Studied the clustering of galaxies in GAMA
- Created a catalogue of random points, using a modified version of Cole+ 2011 → releasing to GAMA consortium
- Compared to existing models
- New models can be tested with these data, also different ways of looking at existing models (Campbell+ (submitted))
- Extend to other properties (e.g. SFR)
- Paper submitted in a month or so