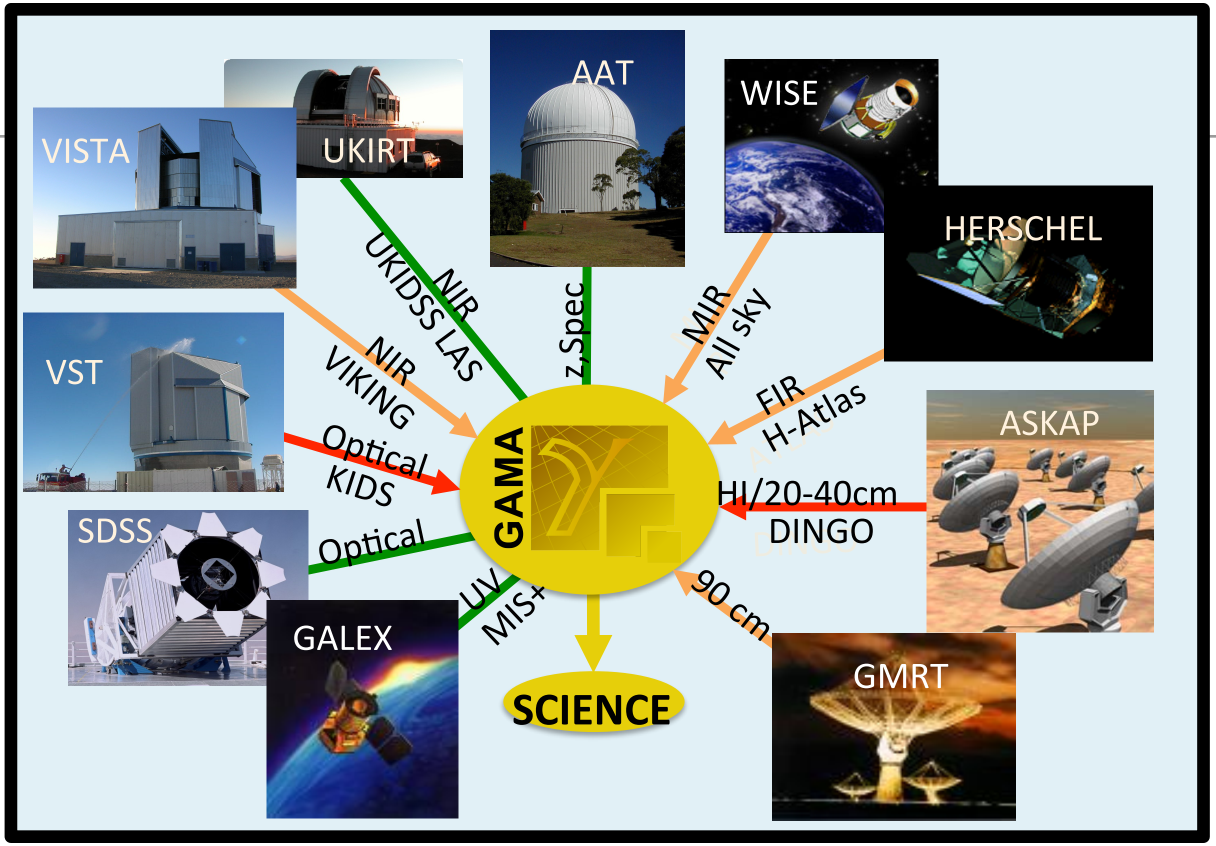
Evolution in the stellar mass function and clustering of galaxies

Jon Loveday
University of Sussex



Outline

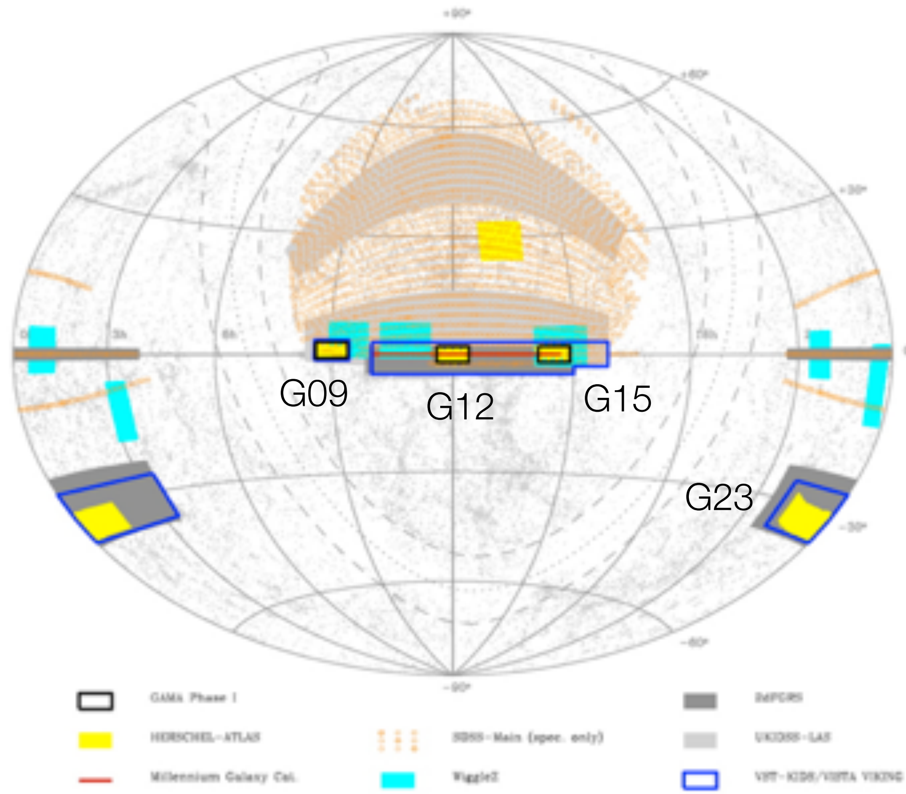
- Motivation
- Quick GAMA overview
- Luminosity/stellar mass function evolution
- Clustering evolution
- Summary

Motivation

- Galaxy formation theories need to explain buildup of stellar mass with cosmic time as a function of environment
- Most easily compared to observations through stellar mass function and clustering of mass-selected samples for a wide range of masses and environments
- Requires surveys of representative volumes to moderate depth
  - Wide-area surveys such as SDSS have the volume but not the depth
  - Pencil-beam surveys such as VIPERS have the depth but not the volume
  - Difficulties with comparing results from heterogeneous sample
- One key goal of the Galaxy and Mass Assembly (GAMA) survey is to address these issues

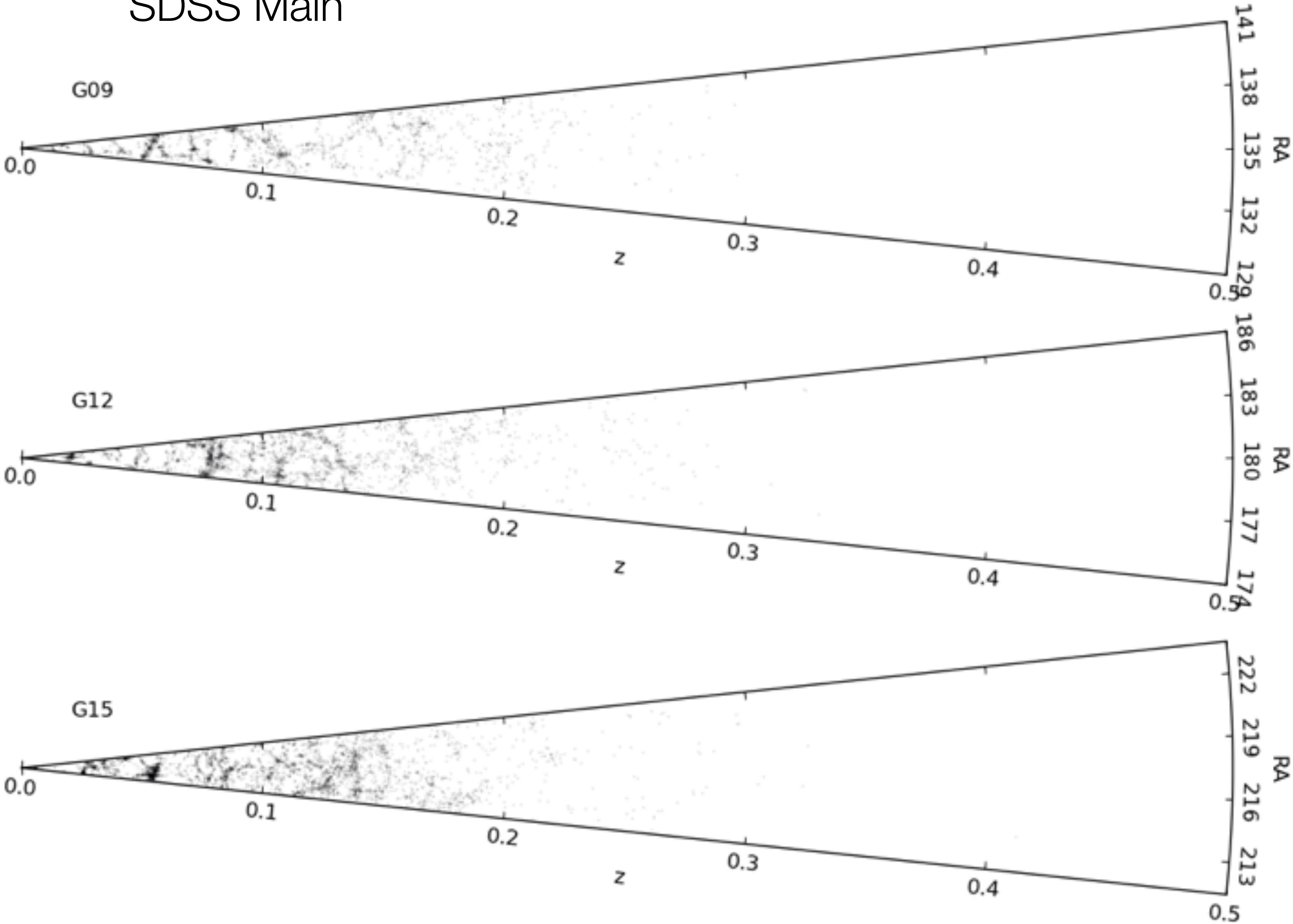
GAMA-II

- Four 12 x 5 deg fields to SDSS r = 19.8: G09, G12, G15, G23
- Target density ~1000/deg^2
- Fully automated redshifts
- We use equatorial regions (G09, G12, G15):
  - 183,010 galaxies with reliable redshifts (96.7% success rate)
  - Mean redshift z = 0.23
- Derived parameters: stellar masses, groups, environment
- Matched-aperture photometry GALEX-SDSS-UKIDSS



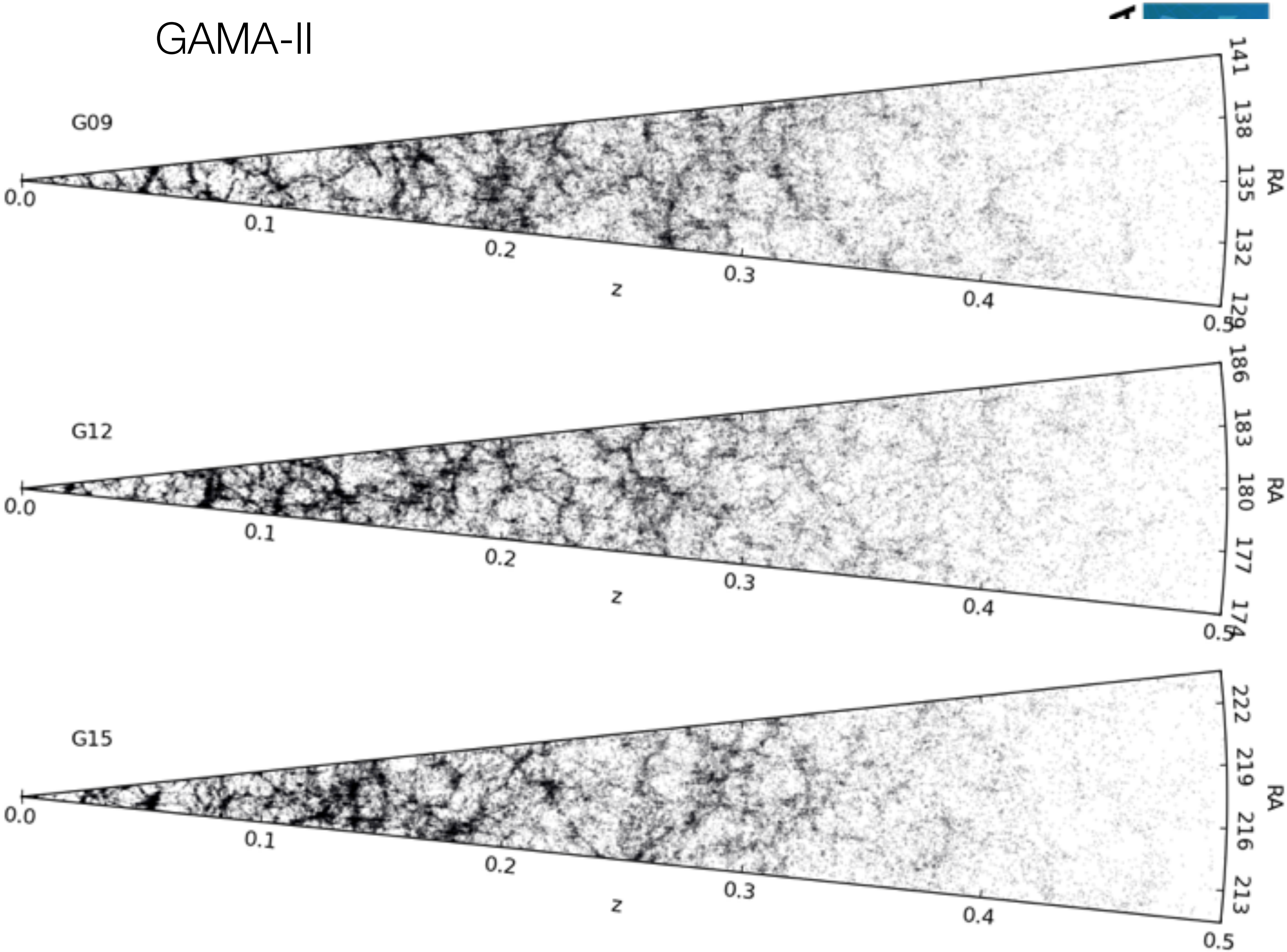
www.gama-survey.org

SDSS Main



G09
0.0
0.1
0.2
0.3
0.4
0.5
z
141
138
135
132
129
RA
G12
0.0
0.1
0.2
0.3
0.4
0.5
z
186
183
180
177
174
RA
G15
0.0
0.1
0.2
0.3
0.4
0.5
z
222
219
216
213
RA

GAMA-II

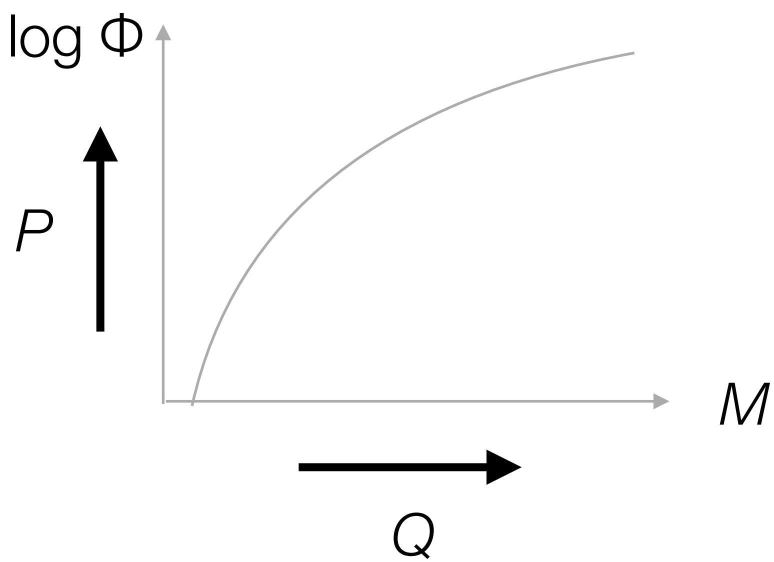

G09
G12
G15
0.0
0.1
0.2
0.3
0.4
0.5
z
RA
141
138
135
132
129
186
183
180
177
174
222
219
216
213

Issues with measuring a luminosity function

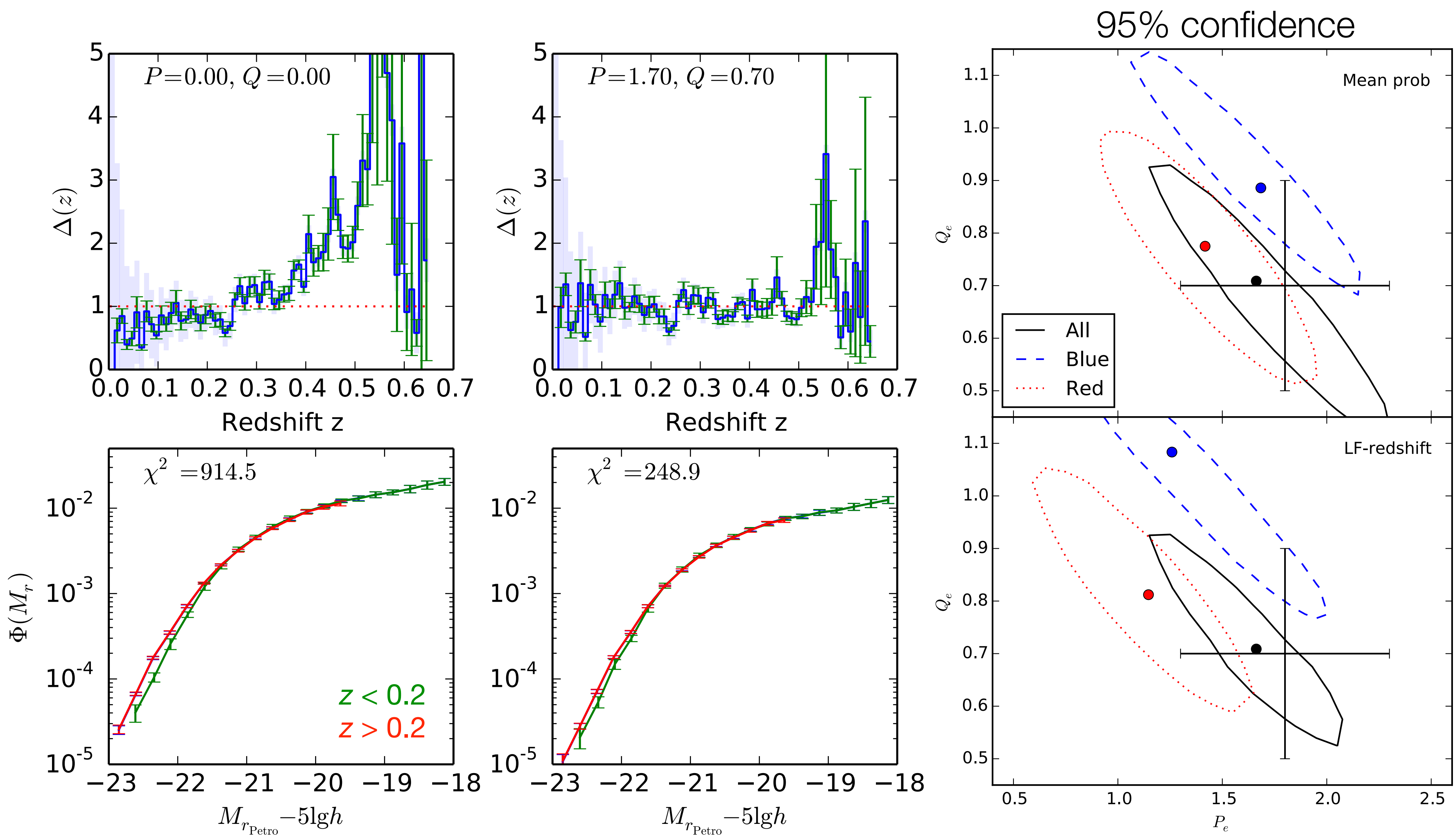
- Standard $1/V_{max}$ estimate (Schmidt 1968) sensitive to radial density variations
  - Can use density-defining population (Baldry+ 2006, 2012) to correct for this
- Maximum likelihood methods (Sandage+ 1979, Efstathiou+ 1988) unaffected by density variations, but must be independently normalised
- All of these methods must either:
  - Be applied to restricted redshift range, or
  - Explicitly allow for evolution in parametric form (e.g. Lin+ 1999)
- Cole (2011) introduced *joint stepwise maximum likelihood* (JSWML) method to simultaneously fit:
  - LF $\Phi(L)$
  - overdensity $\Delta(z)$ in radial shells
  - luminosity and density evolution according to specified parametric model (but not parametric LF)

Evolution model

- Allow for evolution in luminosity (Q) and density (P) using (Lin+ 1999) parametrization:
  - $M_c(z) = M + Qz$
  - $n(z) = n(0) \times 10^{0.4Pz}$
- LF shifts horizontally (by Q) and vertically (by P)
- Search over Q, P to minimise combined χ^2 from LF between redshift bins and deviation of density fluctuations $\Delta(z_i)$ from unity



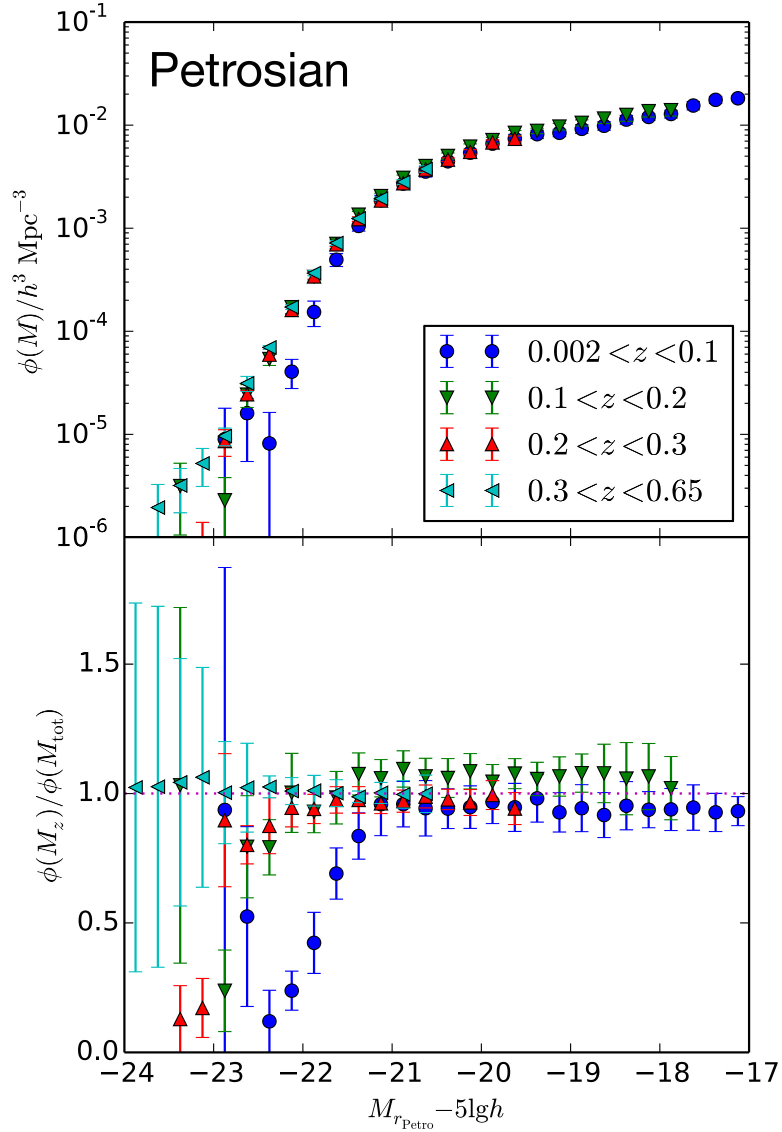
Fitting for evolution (Loveday+ 2015)



How good is evolution model?

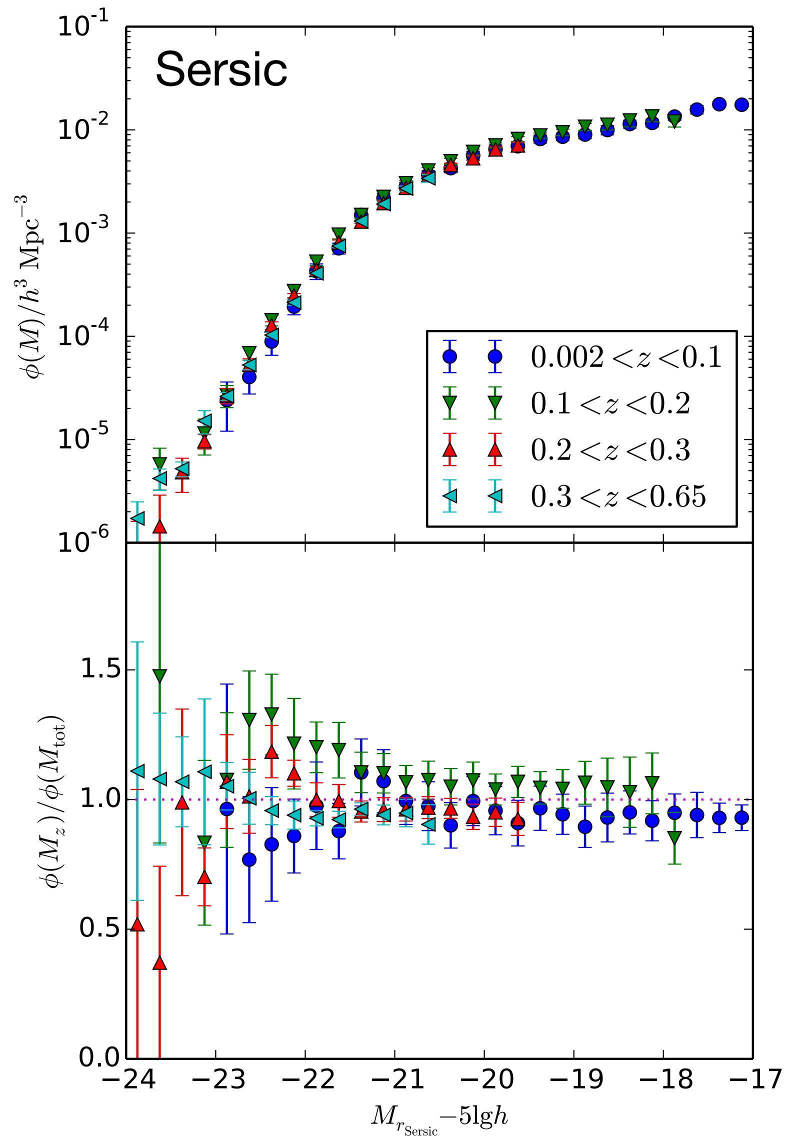
- Upper panel: evolution-corrected Petrosian *r*-band LF in redshift slices
- Lower panel: normalised by fit to whole sample
- Generally good agreement apart from:

1. Lowest (z < 0.1) slice systematically lower in amplitude than 0.1 < z < 0.2 slice
   - more rapid evolution than model at lowest redshifts?
2. Luminous ($M \lesssim$ -21 mag) galaxies at z < 0.1 underdense by ~50%
   - Background over-subtraction and Petrosian mags missing flux of nearby, luminous galaxies?



How good is evolution model?

- Using Sersic magnitudes largely removes bright-end, low-z discrepancy
- Can get slightly better low-z agreement by assuming that log luminosity and density evolve linearly with $z/(1+z)$ (~ lookback time) rather than redshift, but gives slightly larger discrepancies at higher redshifts

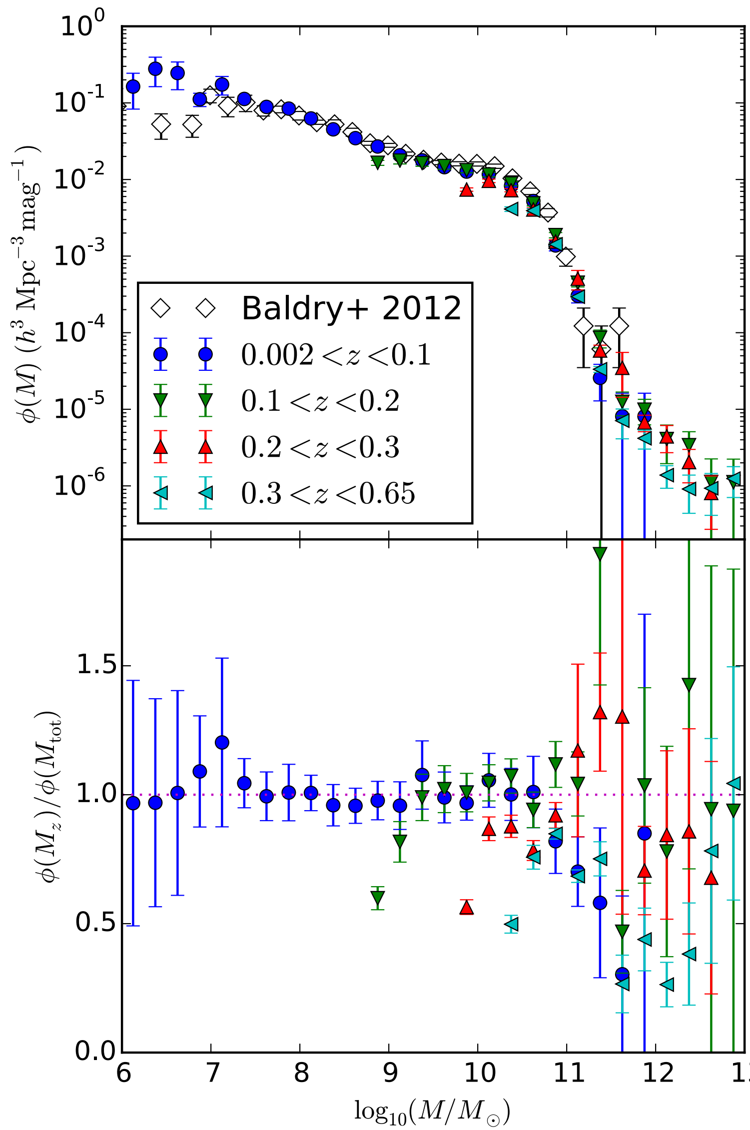


Stellar mass function evolution

- Having fit evolution parameters *P*, *Q* and radial density fluctuations Δ(*z*), one can define a density-corrected $V_{\max}$:

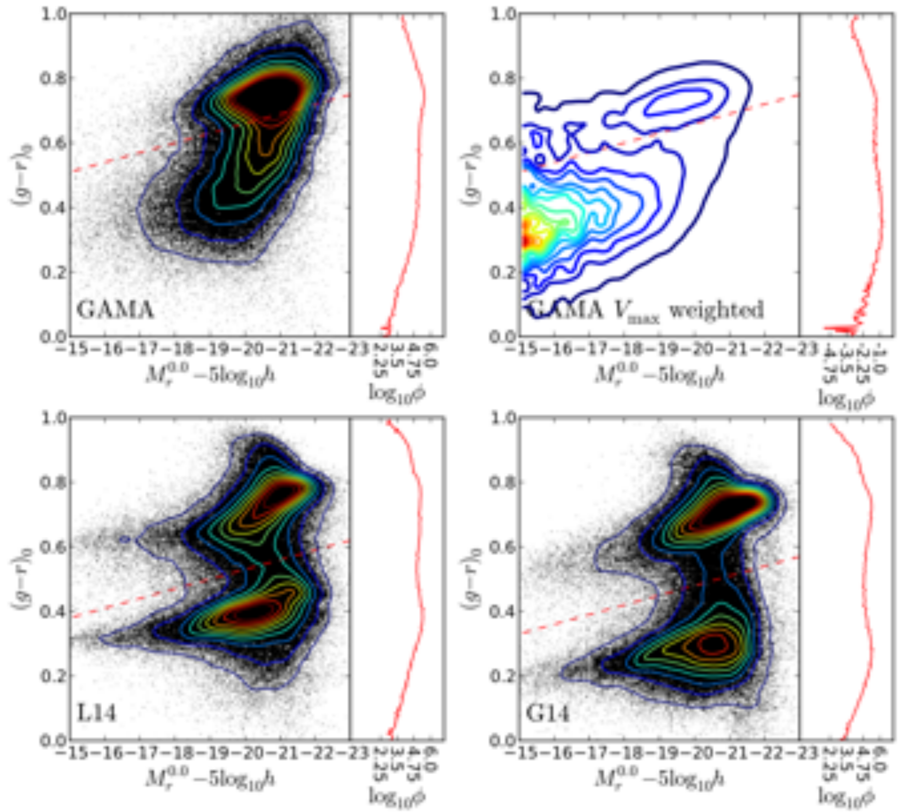
$$V^{\mathrm{dc}}_{\max i} = \int_{z_{\min i}}^{z_{\max i}} \Delta(z) P(z) \frac{dV}{dz} dz$$

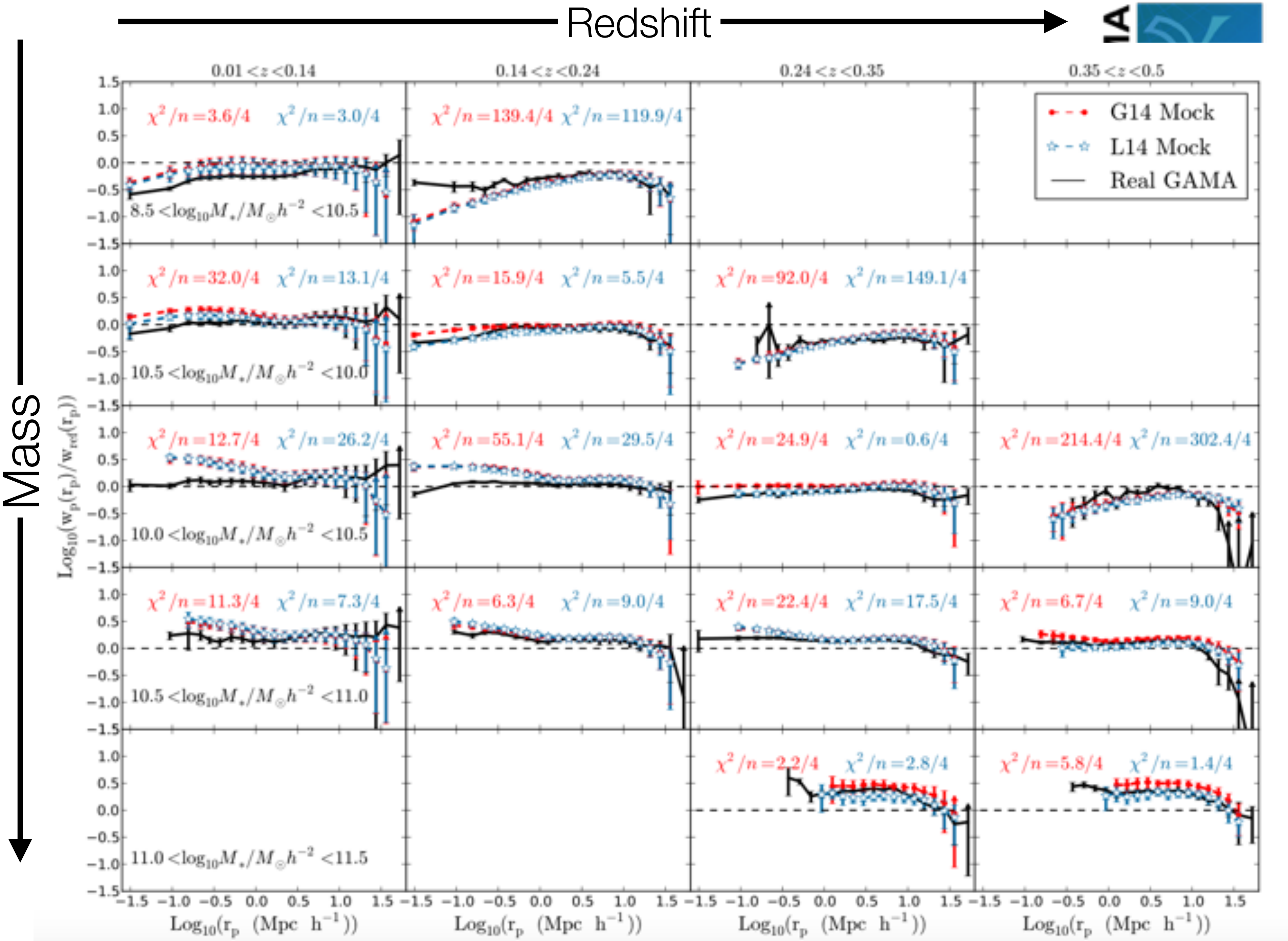
- One can use these to calculate other distribution functions, such as stellar mass function (SMF), for sample selected on *r*-band mag
- Stellar masses from Taylor+ 2011
- No strong evidence for evolution in SMF beyond *r*-band density evolution



Clustering evolution (Farrow et al. in prep)

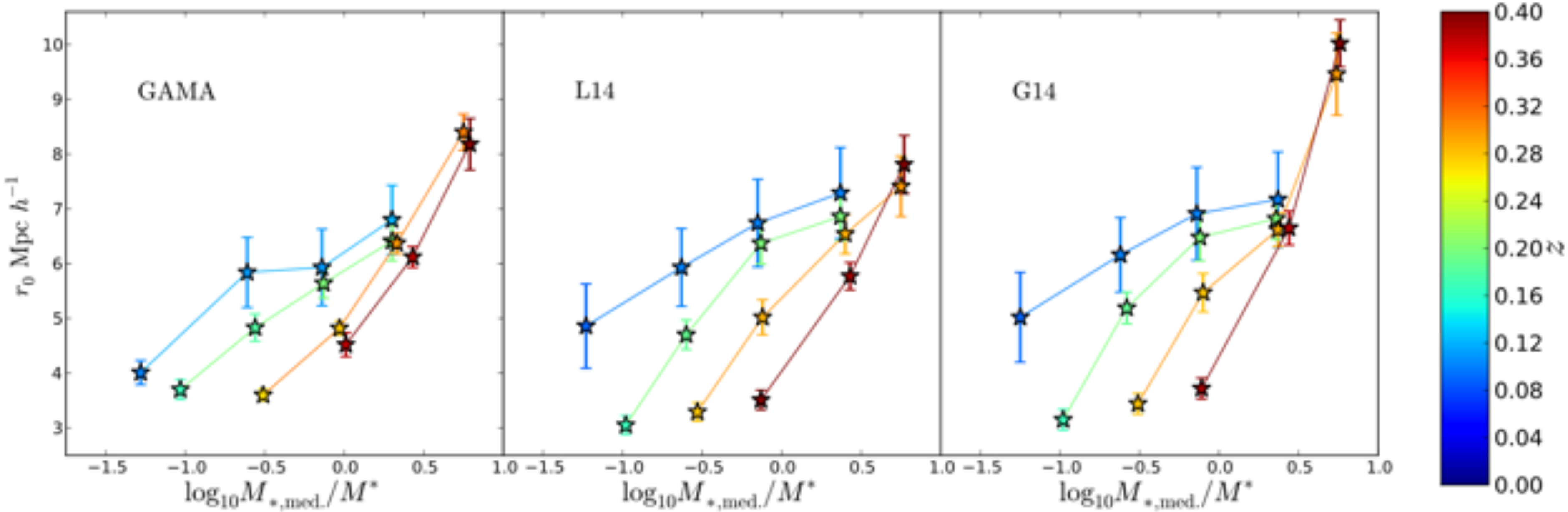
- Measure *projected correlation function* $w_p(r_\perp)$ for a series of mass-selected samples by integrating $\xi(r_\perp, r_\parallel)$ along line of sight, $r_\parallel$
  - Plot $w_p(r_\perp)$ normalised by fiducial power law $\xi(r) = (r/5.33\ h^{-1}\ \mathrm{Mpc})^{-1.81}$
- Compare with GALFORM-based mock catalogues of Gonzalez-Perez et al. (2014; G14) and Lacey et al. (in prep; L14)
  - L14 has top-heavy IMF for starburst galaxies; satellite merging timescale based on Jiang+ 2008, 2014; Maraston 2005 SPS models





Redshift
Mass
0.01 < z < 0.14
0.14 < z < 0.24
0.24 < z < 0.35
0.35 < z < 0.5
G14 Mock
L14 Mock
Real GAMA
χ²/n = 3.6/4
χ²/n = 3.0/4
χ²/n = 139.4/4
χ²/n = 119.9/4
8.5 < log10 M*/M⊙ h⁻² < 10.5
χ²/n = 32.0/4
χ²/n = 13.1/4
χ²/n = 15.9/4
χ²/n = 5.5/4
χ²/n = 92.0/4
χ²/n = 149.1/4
10.5 < log10 M*/M⊙ h⁻² < 10.0
χ²/n = 12.7/4
χ²/n = 26.2/4
χ²/n = 55.1/4
χ²/n = 29.5/4
χ²/n = 24.9/4
χ²/n = 0.6/4
χ²/n = 214.4/4
χ²/n = 302.4/4
10.0 < log10 M*/M⊙ h⁻² < 10.5
χ²/n = 11.3/4
χ²/n = 7.3/4
χ²/n = 6.3/4
χ²/n = 9.0/4
χ²/n = 22.4/4
χ²/n = 17.5/4
χ²/n = 6.7/4
χ²/n = 9.0/4
10.5 < log10 M*/M⊙ h⁻² < 11.0
χ²/n = 2.2/4
χ²/n = 2.8/4
χ²/n = 5.8/4
χ²/n = 1.4/4
11.0 < log10 M*/M⊙ h⁻² < 11.5
Log10(wp(rp)/wred(rp))
Log10(rp (Mpc h⁻¹))

Evolution of correlation length r_0 (fixed slope)



- r_0 increases more rapidly with stellar mass at higher redshifts
- Clustering of massive galaxies evolves more slowly than low-mass, in agreement with previous studies, e.g. White+ 2007, Brown+ 2008, Coil+2008, Meneux+ 2008
- Both variants of mock catalogues reproduce these trends

Summary

- Luminosity/stellar mass function evolution:
  - Over last ~5 Gyr (since z ~ 0.5), galaxies have, subject to degeneracies between luminosity and density evolution:
    - faded in r-band luminosity by about 0.4 mag
    - decreased in comoving number density by a factor ~2
  - Petrosian magnitudes grossly underestimate bright end of LF: Sersic magnitudes recover more flux, but subject to contamination from nearby bright stars
  - No strong evidence for evolution in SMF beyond r-band density evolution
- Clustering evolution:
  - In redshift bins, clustering increases more strongly with stellar mass at at higher redshifts
  - In mass bins, clustering evolves more slowly at higher mass
  - GALFORM-based mock catalogues reproduce these trends
- WAVES-like survey needed to extend these results to lower masses at higher z