Small-scale galaxy dynamics: the pairwise velocity dispersion

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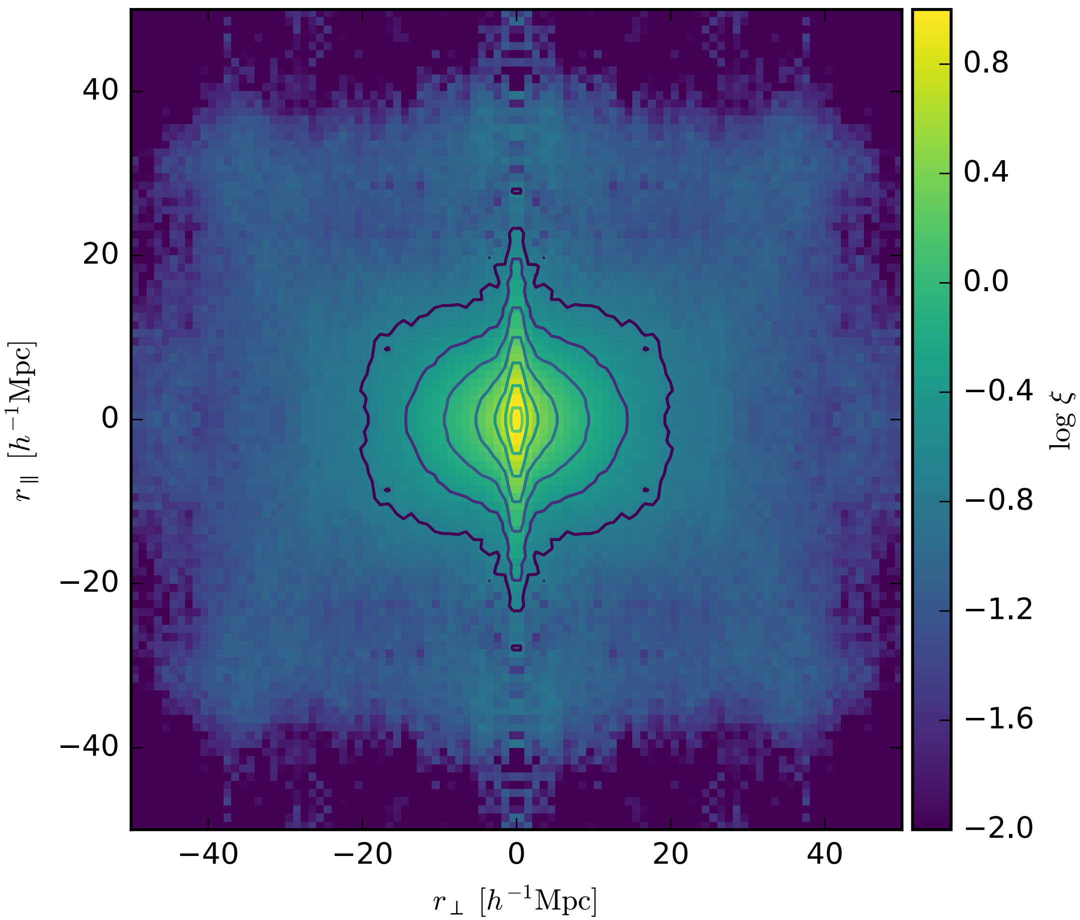

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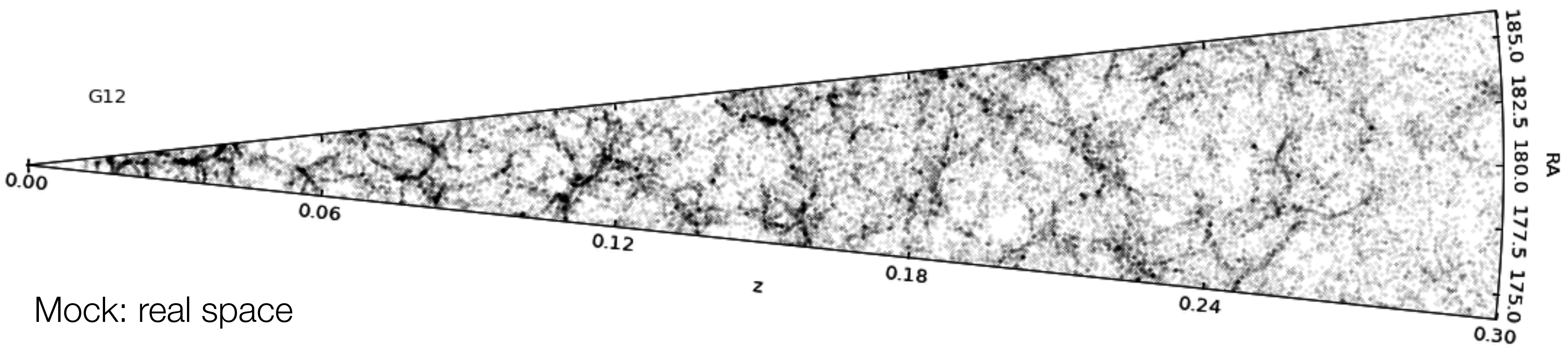
Outline

- RSD overview
- Galaxy pairwise velocity dispersion (PVD)
  - why measure it?
- GAMA data and mocks
- Ways of measuring PVD
- Results: luminosity dependence
- Future work

- See Loveday+ 2018, MNRAS, 474, 3435

Redshift-space distortions

- Redshift space measurements are distorted by *motions* of galaxies relative to Hubble Flow
  - Small scales: random motions → “Fingers of God”
  - Large scales: coherent bulk motions towards high-density regions → growth factor
- Pairwise velocity dispersion (PVD) σ_{12} is the dispersion in relative velocity between pairs of galaxies as a function of projected separation



Mock: real space

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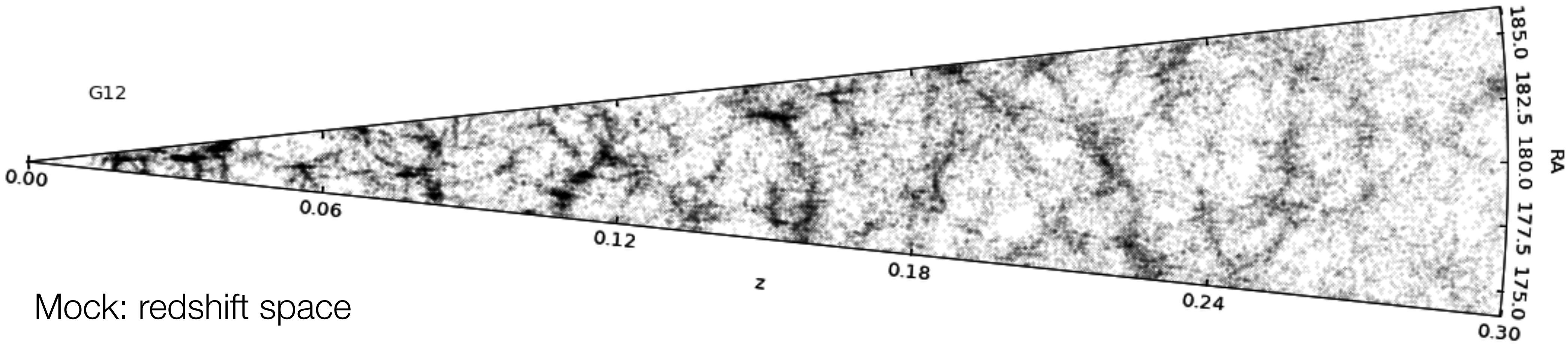
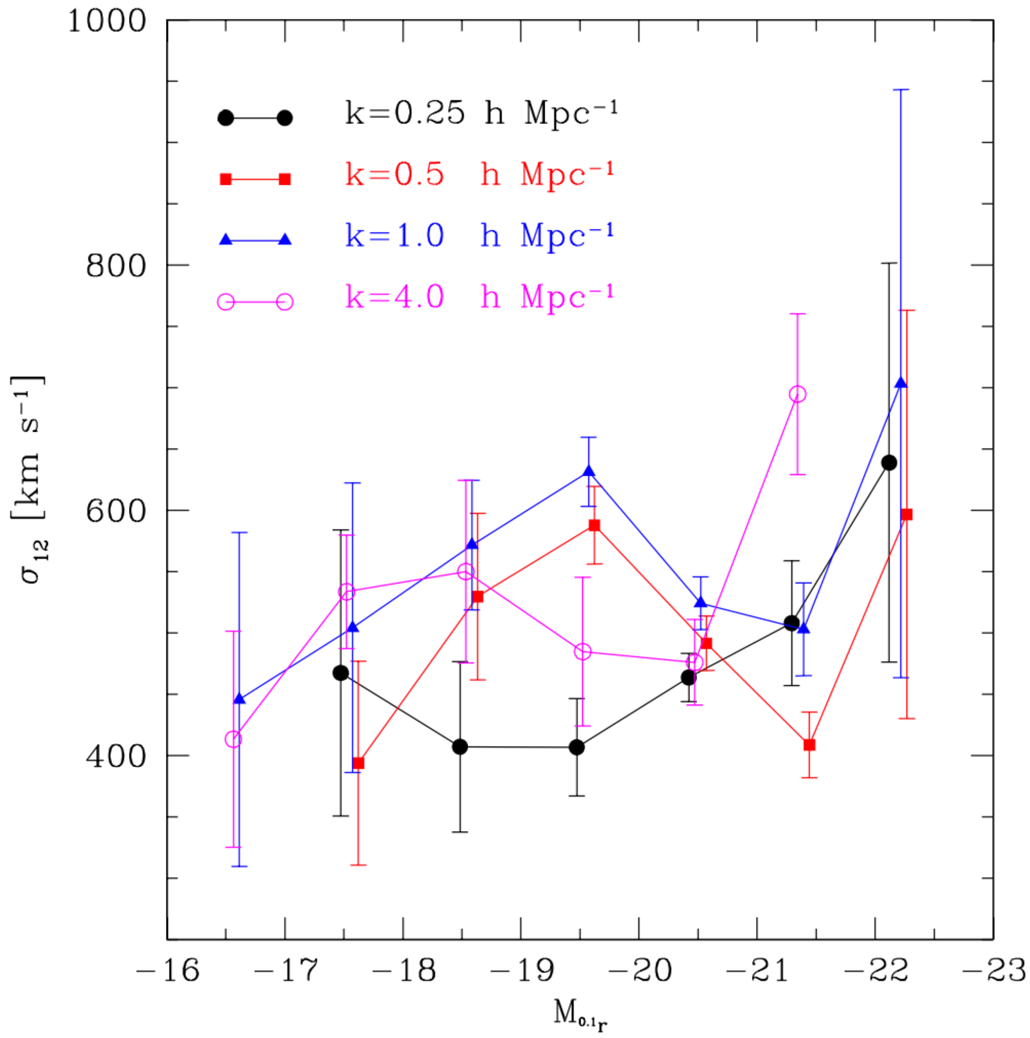


Mock: redshift space

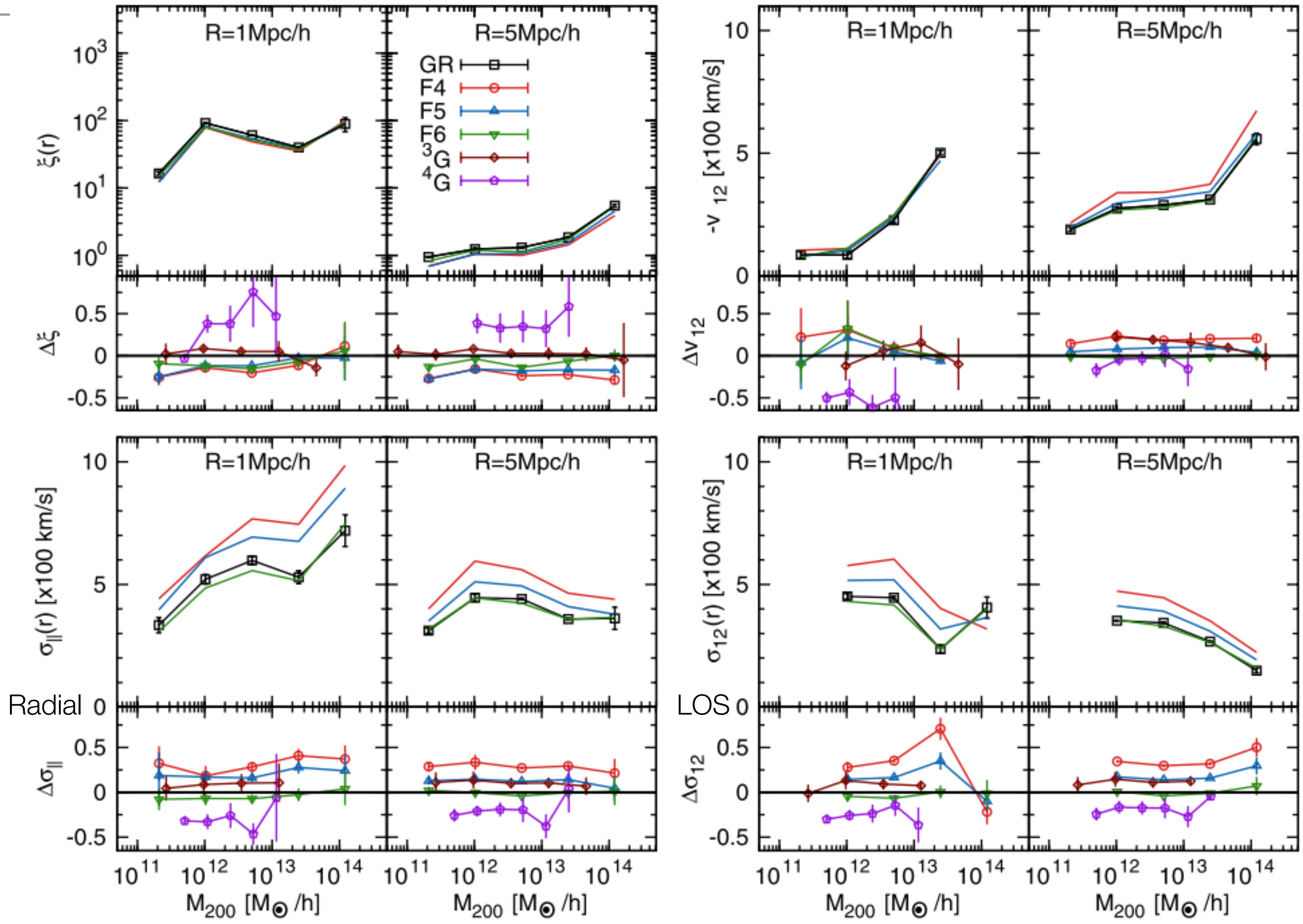
Motivation - why measure PVD?

- Originally used to estimate Ω_m via cosmic virial theorem (Peebles 1976)
  - First evidence for $\Omega_m < 1$
  - However, results are sensitive to presence or absence of rich clusters (Mo+ 1993)
- Quantify FoG effect
  - Needed to model linear infall
- Constrain HOD models (dependence on stellar mass and scale, e.g. Tinker+ 2007)
  - Clarify luminosity-dependence
- Test modified gravity models



Li+ 2006, MNRAS, 368, 1

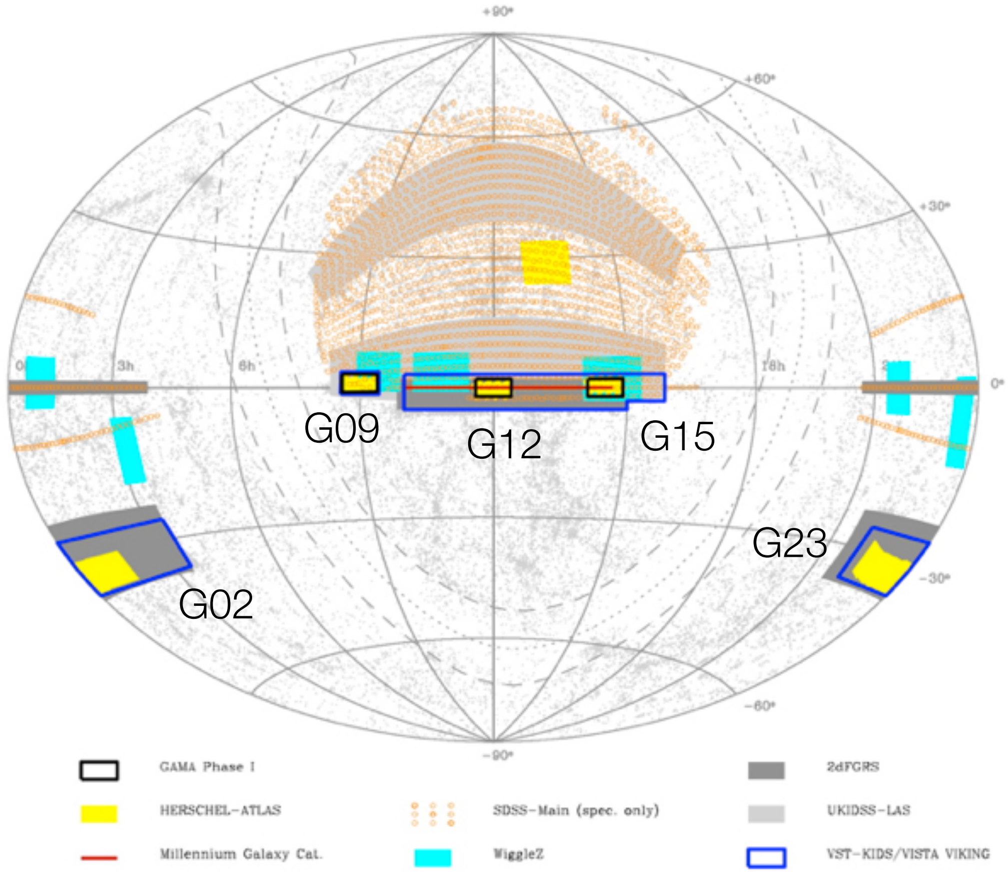
Constraining modified gravity models



Hellwing+ 2014, PRL, 112, 221102

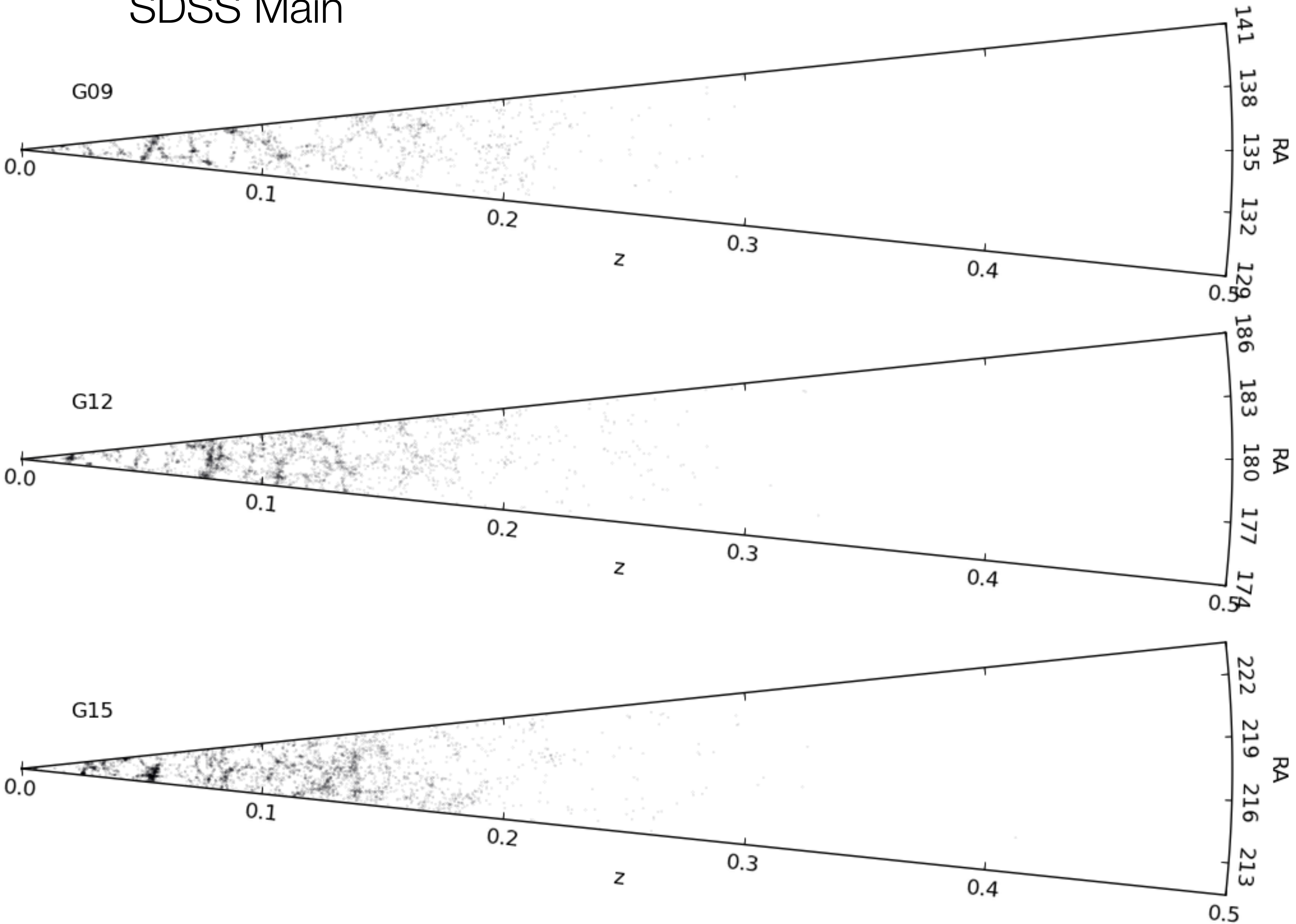
Galaxy and Mass Assembly (GAMA)

- Three 12 x 5 deg equatorial fields to r = 19.8: G09, G12, G15
  - Target density ~1000/deg^2
  - Fully automated redshifts
  - 183,010 galaxies with reliable redshifts (98.5% completeness, inc high-density regions)
  - Mean redshift $\bar{z}$ = 0.23
- Derived parameters: stellar masses, groups, environment
- Matched-aperture photometry GALEX-SDSS-UKIDSS
- Southern fields (G02, G23) less complete



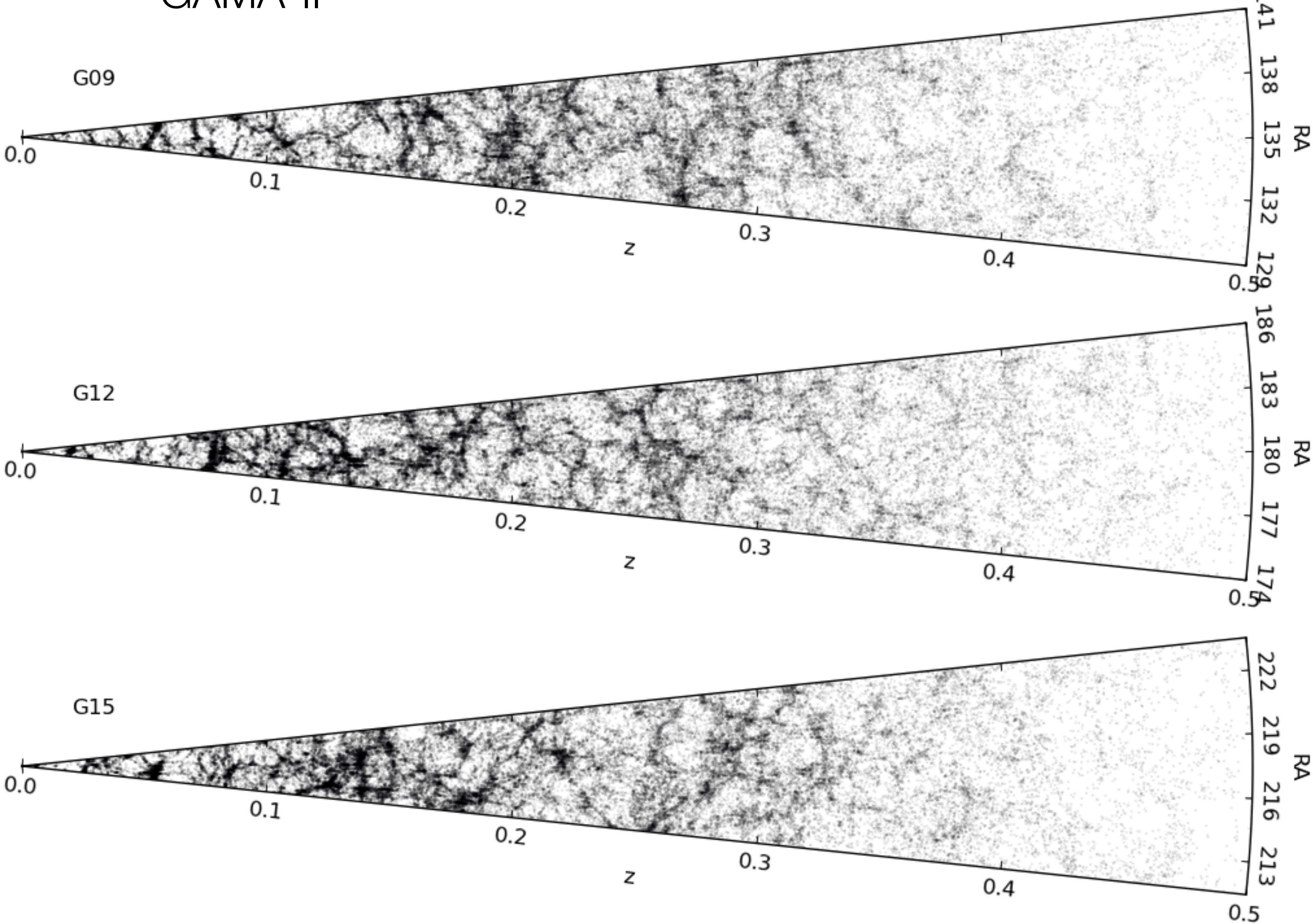
www.gama-survey.org

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
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z
RA
141
138
135
132
129
186
183
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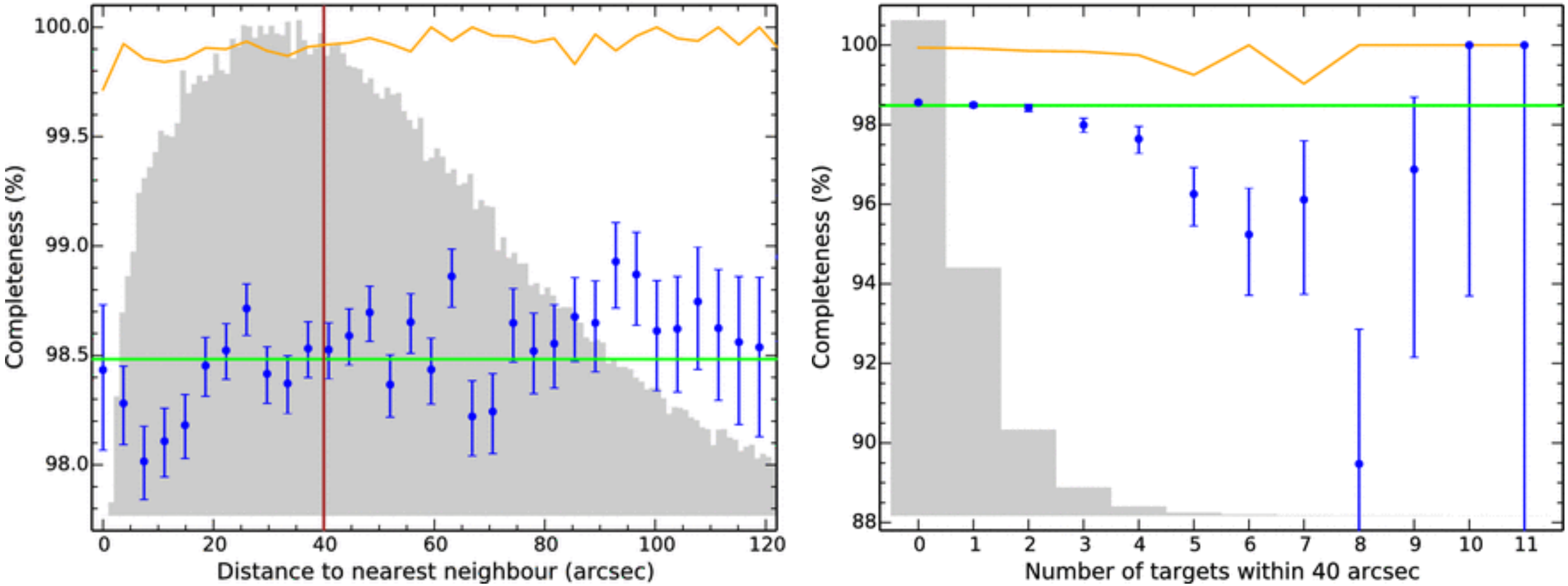
177
174
222
219
216
213

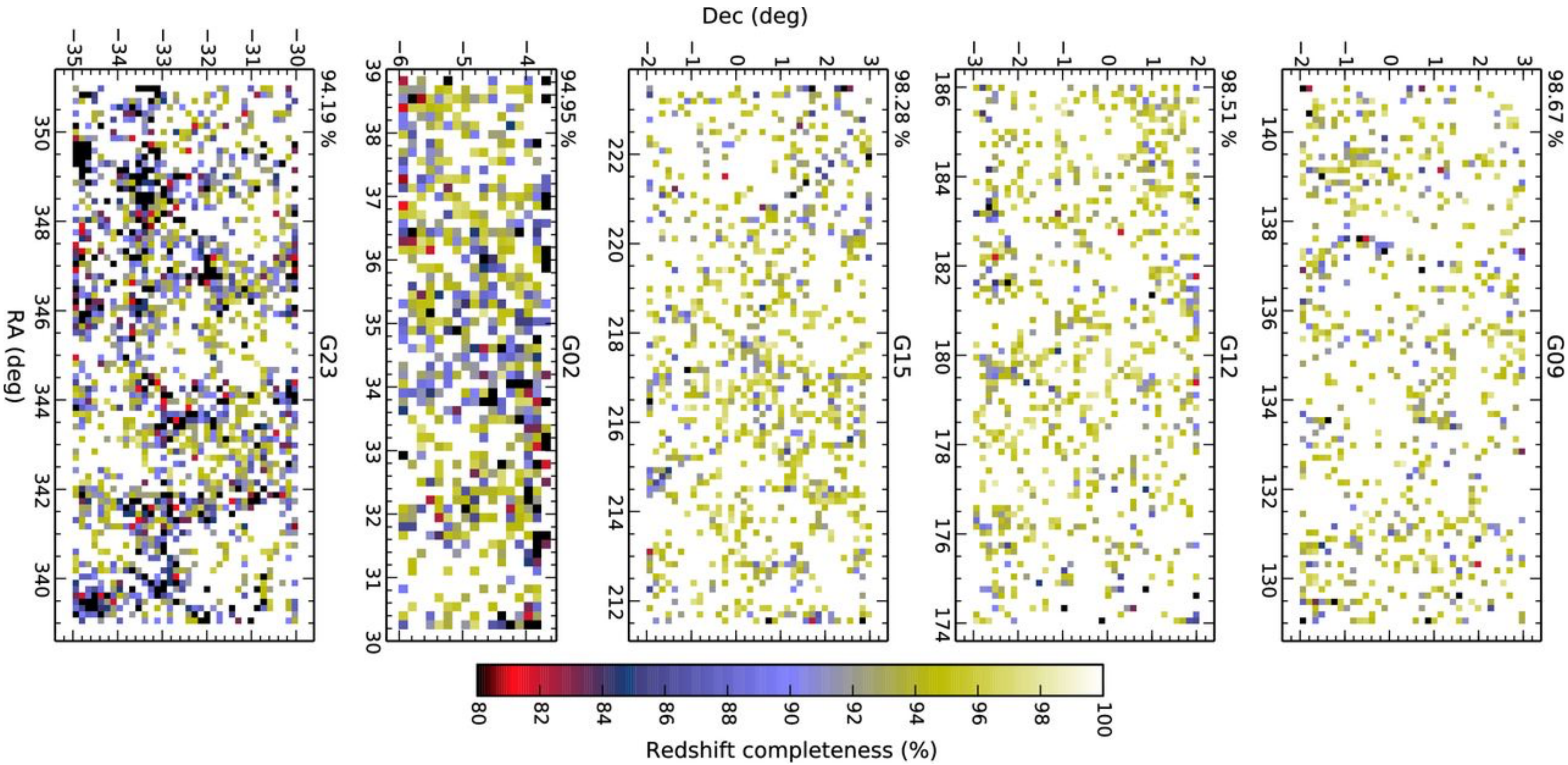
Spectroscopic completeness (eq regions)

Number
Target completeness
Redshift completeness (average)



Liske+ 2015

Redshift completeness maps



Liske+ 2015

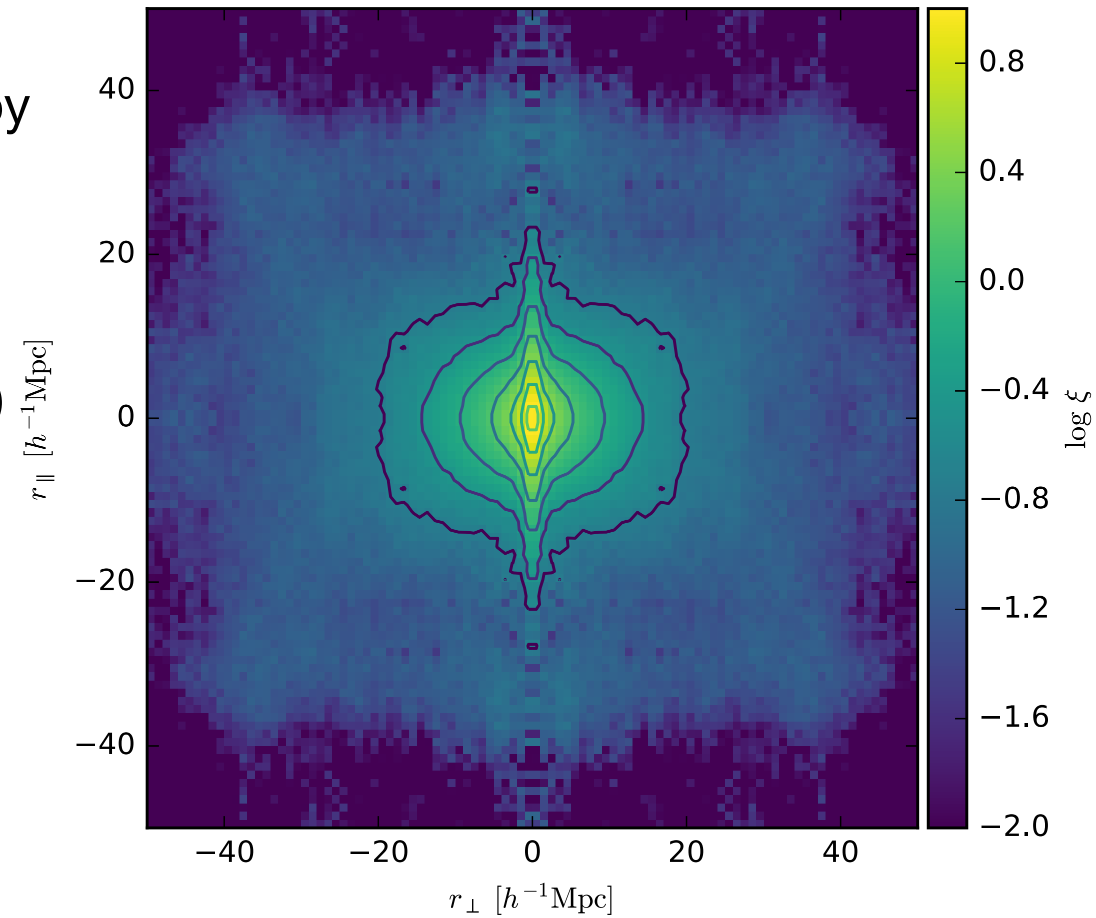
Mock comparison data

- Good test of methods since peculiar velocities known for each galaxy
- Main comparison/testbed:
  - Millennium-WMAP7 Simulation (Guo et al. 2013)
  - Gonzalez-Perez+ 2014 GALFORM model
  - GAMA-like lightcones from Merson et al. 2013
  - 26 realisations: plots show average and standard deviation
  - Use z_{cos} and z_{obs} to measure `true' PVD
  - Compare with estimates using only observable information (RA, dec, z_{obs})

- Also compare with EAGLE hydrodynamical simulation RefL0100N1504 (Crain et al. 2015; Schaye et al. 2015; McAlpine et al. 2016)

Galaxy clustering measurements

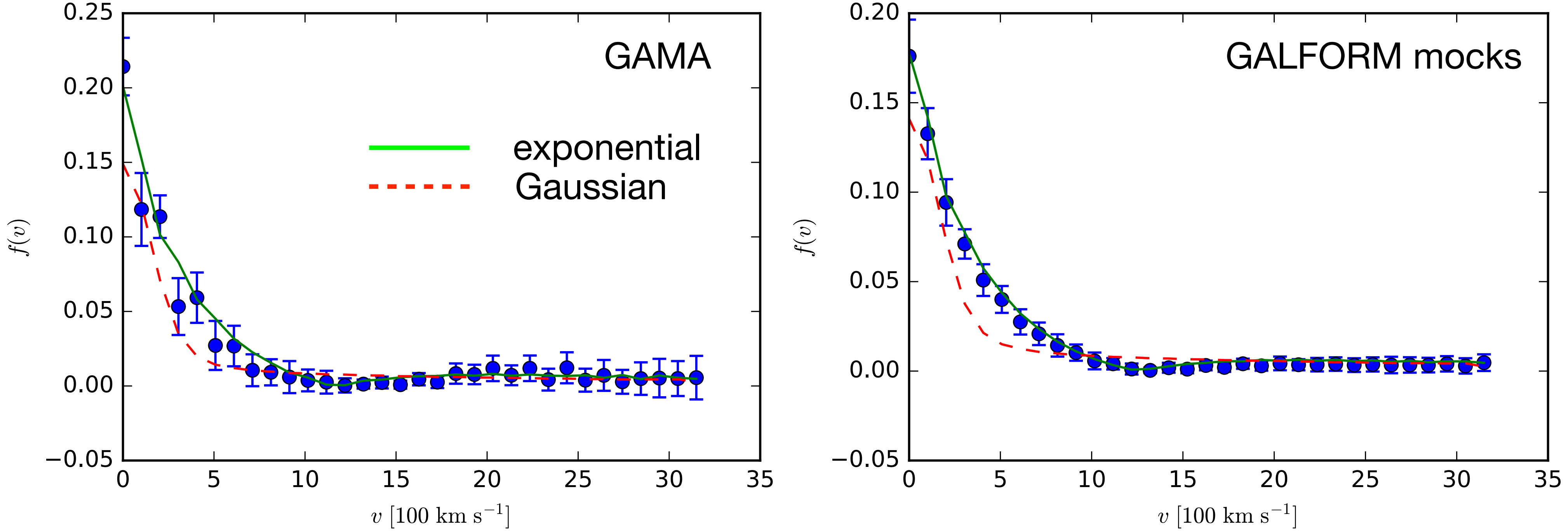
- Two-point correlation function $\xi(r_\perp, r_\parallel)$: excess probability of observing two galaxies separated by distance $r_\perp$ perpendicular to line of sight (LOS), $r_\parallel$ parallel to LOS
- Integrate along LOS to obtain *projected correlation function* $w_p(r_\perp)$
- Invert to obtain real-space $\xi_r(r)$
- PVD then determined via *streaming* or *dispersion* models
- First need to choose model for pairwise velocity distribution function …



Loveday+ 2018

Pairwise velocity distribution function

- Determined via 2-d Fourier transform of $\xi(r_\perp, r_\parallel)$ (Landy+ 1998, 2002)



- Exponential function significantly better fit than Gaussian for both GAMA and mocks, in line with previous work

Loveday+ 2018

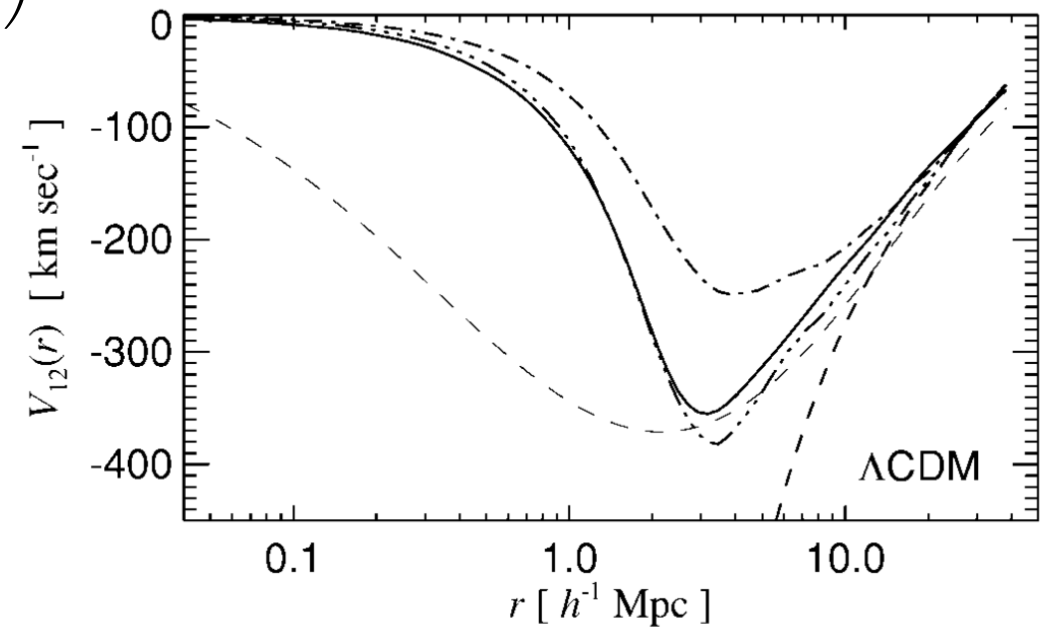
Method 1: Streaming model

- Assumes model for mean streaming velocity $\bar{v}(r)$ (e.g. Peebles 1980, Davis & Peebles 1983, Juszkiewicz+ 1999)
- Predicted 2-d correlation function $\xi(r_\perp, r_\parallel)$ given by convolving $\xi_r(r)$ with $f(v)$:

$$1 + \xi(r_\perp, r_\parallel) = H_0 \int_{-\infty}^{\infty} \left[1 + \xi_r\left(\sqrt{r_\perp^2 + y^2}\right)\right] f(v) dy$$

$$f(v) = \frac{1}{\sqrt{2}\sigma_{12}} \exp\left(-\frac{\sqrt{2}|v - \bar{v}|}{\sigma_{12}}\right)$$

$$v \equiv H_0(r_\parallel - y)$$



Juszkiewicz+ 1999

Method 2: Dispersion model

- Rather than assume mean streaming motion, convolve Kaiser linear infall model with *f*(*v*) centred on zero (Peacock & Dodds 1994, Cole+ 1995)

$$P_s(k,\mu) = P_r(k)(1+\beta\mu^2)^2 D(k\mu\sigma_{12}(k))$$

Kaiser linear infall   Small-scale dispersion

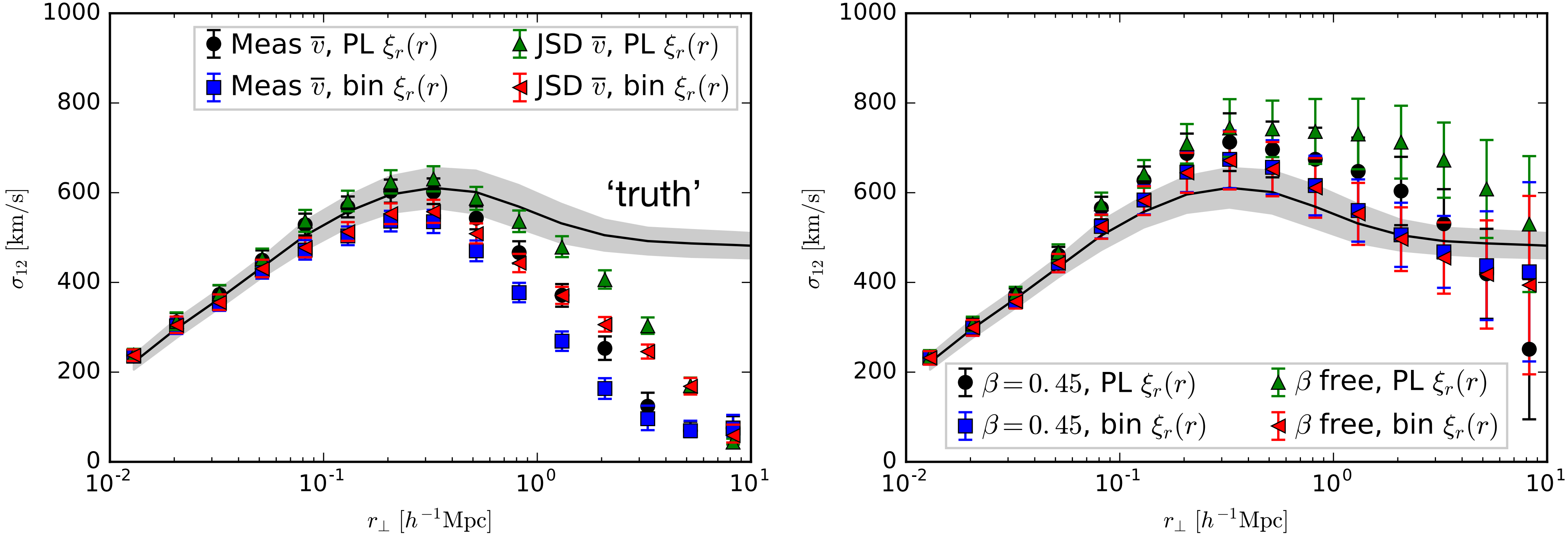
- Kaiser infall in configuration space given by spherical harmonics (Hamilton 1992):

$$\xi'(r_\perp, r_\parallel) = \xi_0(s)P_0(\mu) + \xi_2(s)P_2(\mu) + \xi_4(s)P_4(\mu)$$

- Predicted 2-d clustering given by convolution of ξ′ with *f*(*v*):

$$\xi(r_\perp, r_\parallel) = \int_{-\infty}^{\infty} \xi'(r_\perp, r_\parallel - v_{12}/H_0) f(v) dv$$

Mock tests



Streaming model

Dispersion model

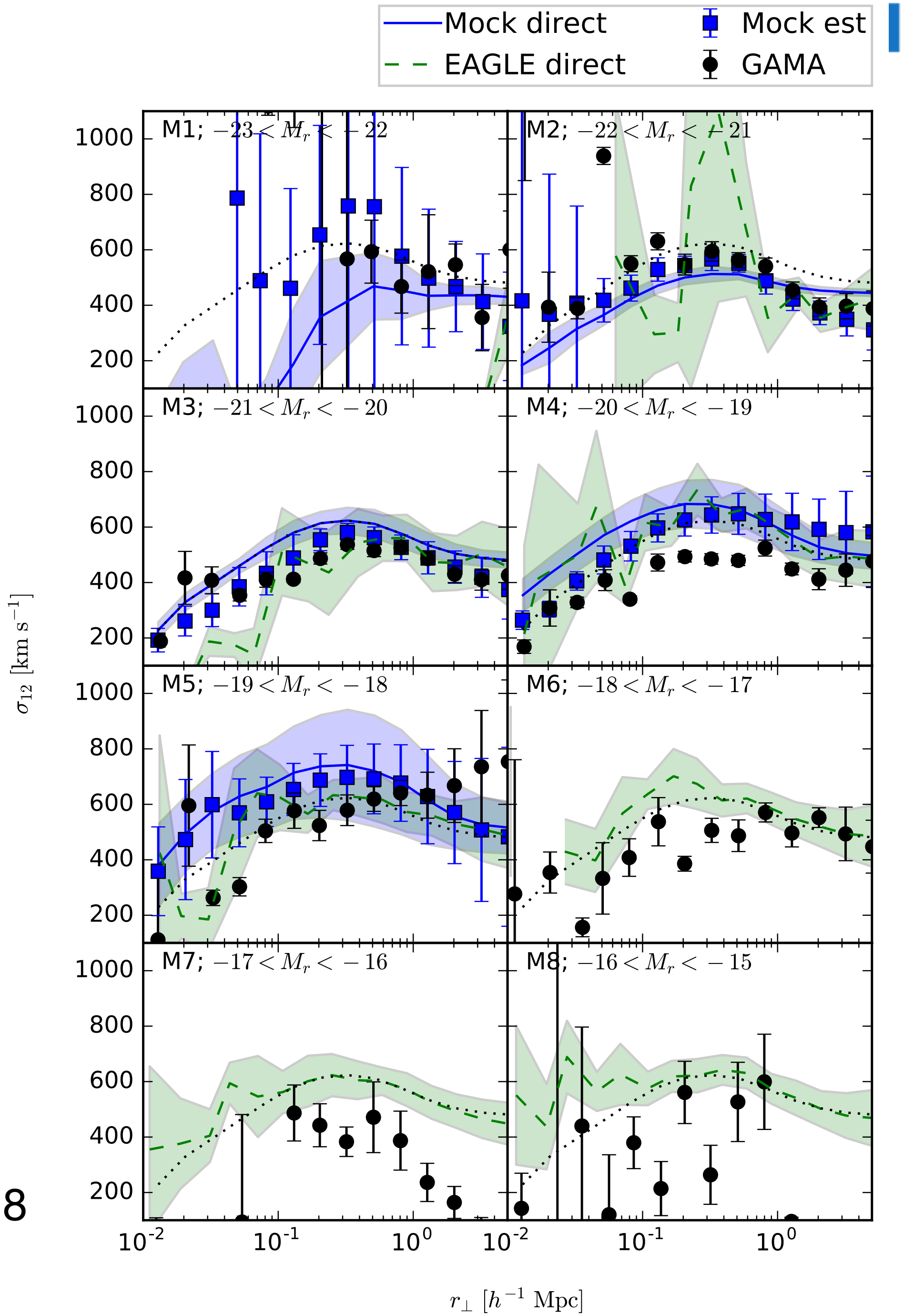
- Streaming model recovers true PVD well on very small scales ($r \lesssim 1\ h^{-1}$ Mpc)
- Dispersion model performs better on larger scales ($r \lesssim 10\ h^{-1}$ Mpc)

Loveday+ 2018

Results:
PVD luminosity dependence

- GALFORM mocks consistent with GAMA for luminous galaxies ($M_r \lesssim -20$)
- Mock PVDs systematically higher for fainter galaxies
- EAGLE simulations largely consistent with GALFORM

Loveday+ 2018

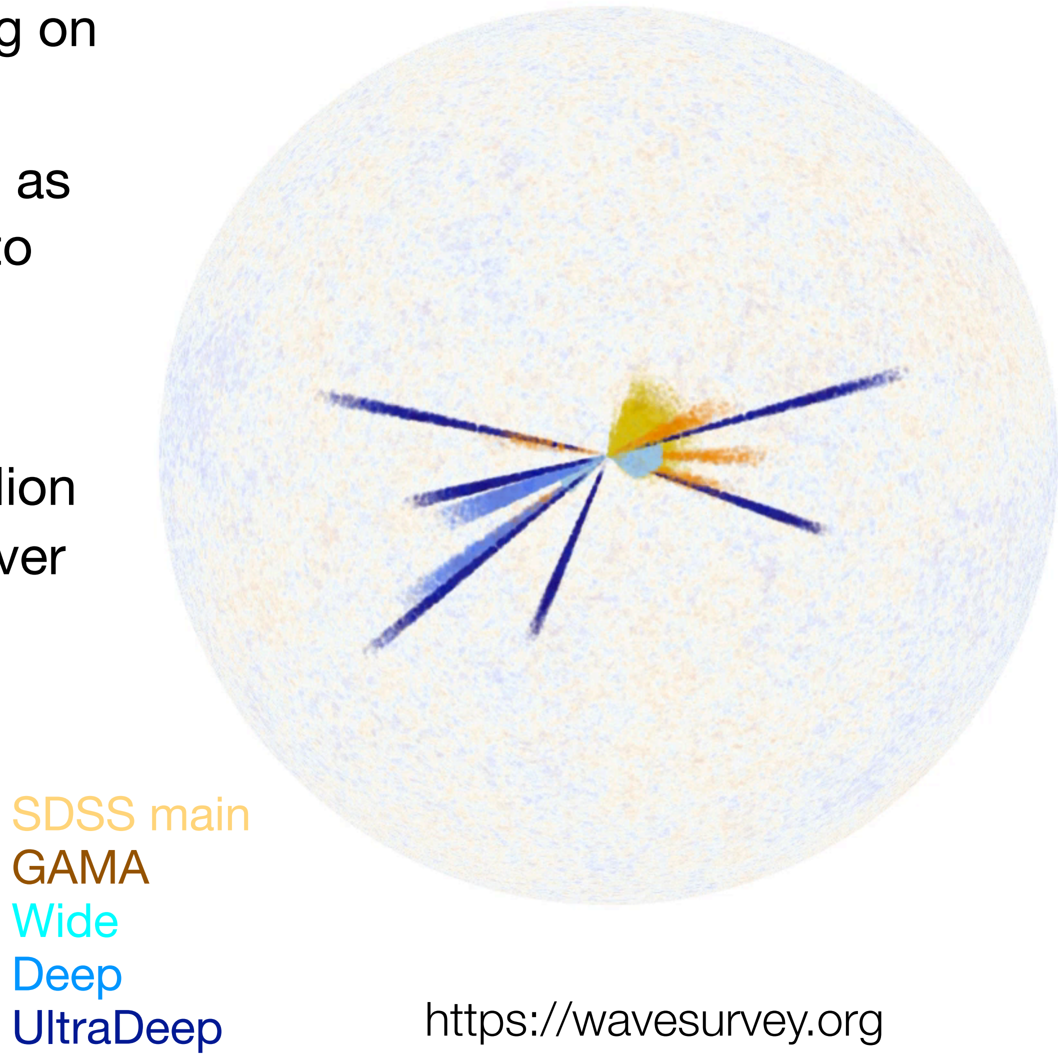


Summary

- PVD measured to ~10 × smaller scales than previous work (e.g. Hawkins et al. 2003, Jing & Borner 2004, Li et al. 2006)
- In agreement with previous work, we find that the pairwise velocity distribution is much better fit by an exponential than a Gaussian function
- The dispersion model can make reliable predictions of the PVD for projected separations 0.01–10 h^{-1} Mpc
- The PVD peaks at $\sigma_{12} \approx 600$ km s^{-1} at projected separations $r_\perp \approx 0.3\ h^{-1}$ Mpc
- On small scales, $r_\perp \lesssim 1\ h^{-1}$ Mpc, the measured PVD for GAMA galaxies declines slightly from ≈ 600 km s^{-1} at high luminosities to ≈ 400 km s^{-1} at low luminosities
- The GALFORM mocks do a good job at matching the observed PVD for luminous galaxies, but overpredict the PVD for fainter objects.

Future prospects

- Greatest challenge for utilising PVD measurements is accurate modelling on non-linear scales
- Galaxy feedback processes, as well as cosmology, will need to be taken into account
- 4MOST WAVES:
  - Wide survey will observe ~ 1 million galaxies to ~10^6 $M_\odot$ to $z \approx 0.2$ over 1600 deg^2
- 4MOST/LSST cross-correlation synergies?



https://wavesurvey.org