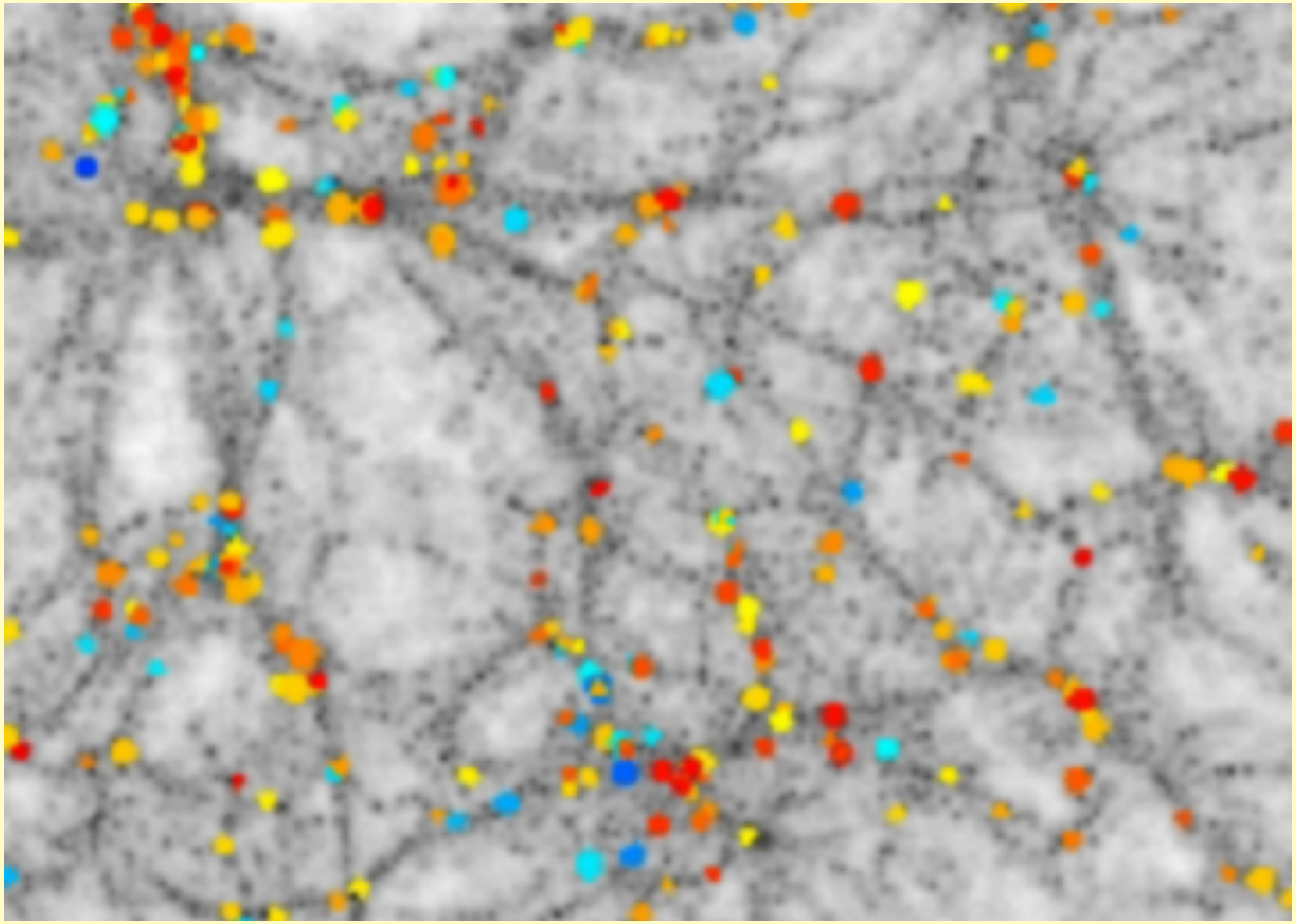
Multiple tracers of cosmological structure

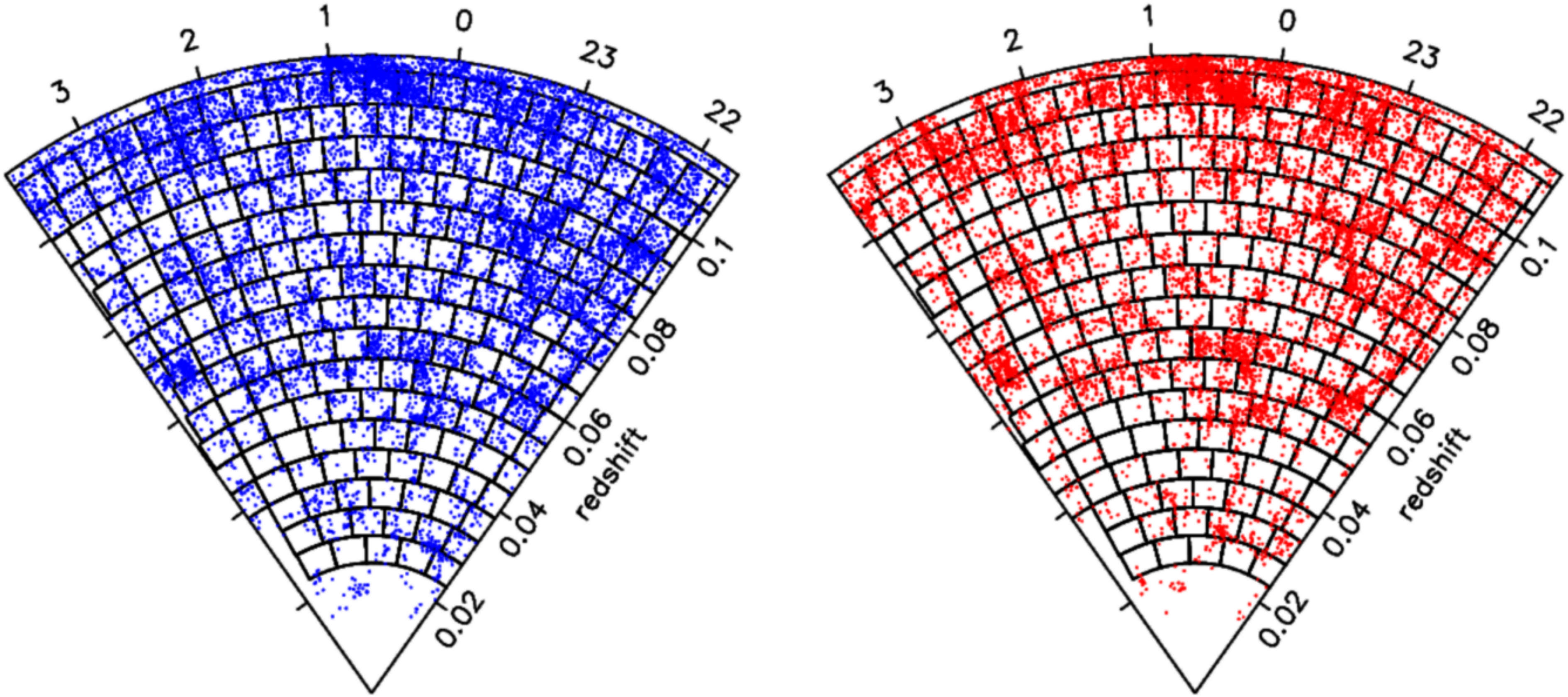


John Peacock Ripples in the Cosmos: Durham 26 July 2013

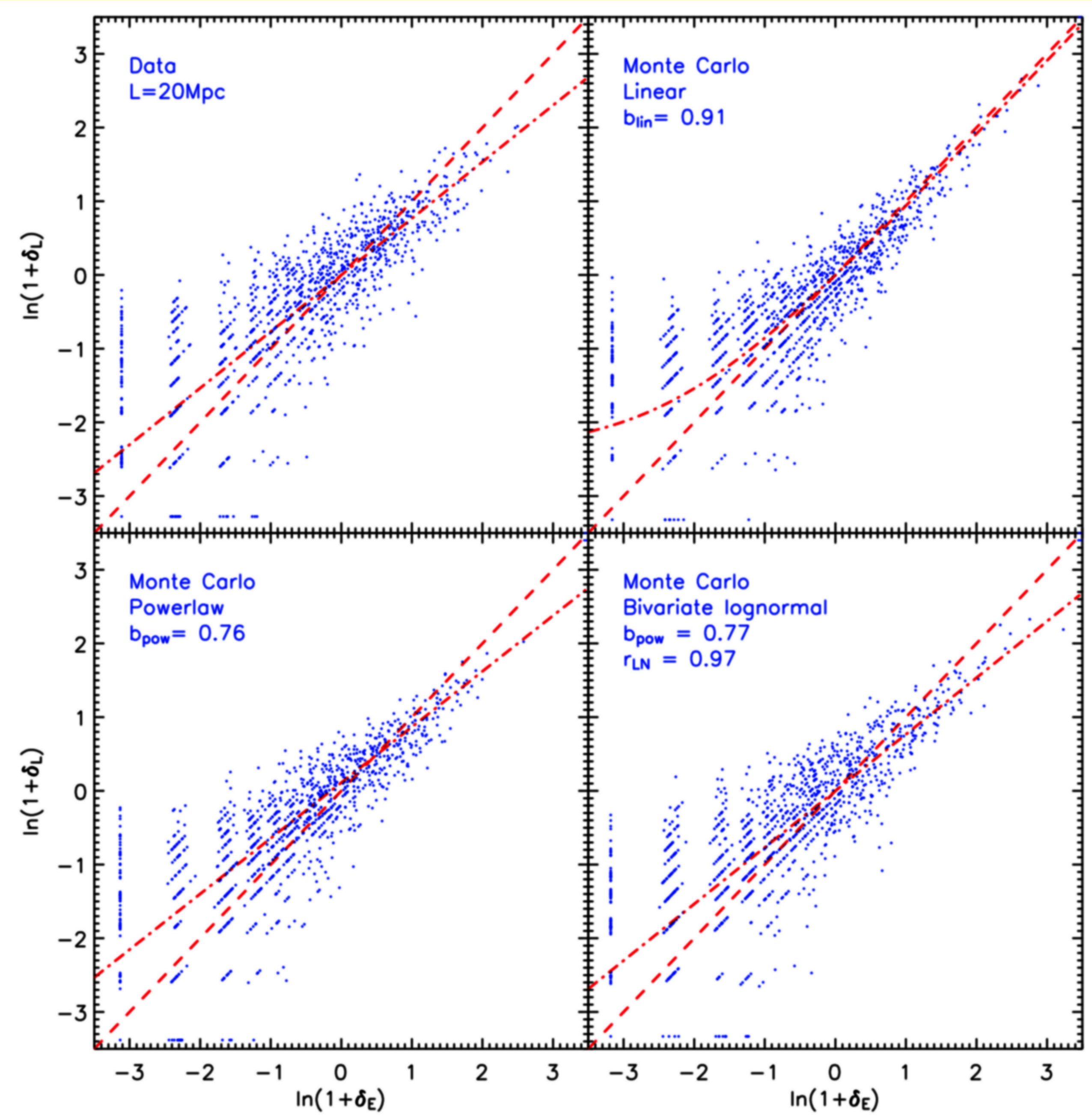
Topics

- Response of different tracers to DM density field
  - Bias, stochasticity and noise
- Information from cross-correlation
  - Exploiting CMB lensing
  - Tomographic photo-z calibration
- Evading cosmic variance
  - GAMA multi-tracer RSD

Stochastic bias in 2dFGRS



Wild et al. (2004): counts-in-cells for different populations



Stochastic bias in 2dFGRS

Extra scatter in blue vs red overdensity beyond Poisson:

r = 1 – few % correlation in density

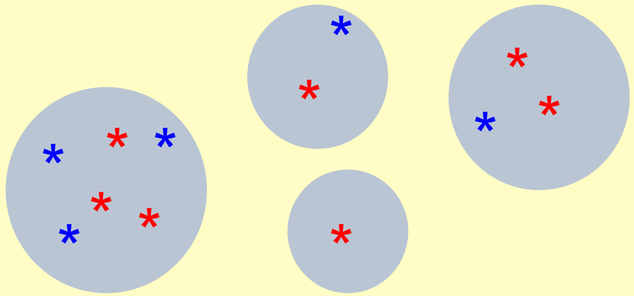
Stochastic bias and discreteness

$$\delta_t(\mathbf{x}) = f(\delta[\mathbf{x}]) + \epsilon(\mathbf{x})$$

– e.g. $f(\delta) = b_0 + b_1\delta + b_2\delta^2/2$ or $1 + \delta_t \propto (1+\delta)^b$

$$\Rightarrow P_t(k) = b^2(k)\,P(k) + P_\epsilon + P_{\rm shot}; \qquad P_{\rm shot} = 1/n$$

Halo model interpretation:



ε field arises mainly from discrete nature of haloes (like shot noise); non-local bias. see Baldauf et al. 1305.2917

But overall density field is sum of haloes, so in principle no shot noise if haloes are weighted by mass (Seljak, Hamaus & Desjacques 0904.2963)

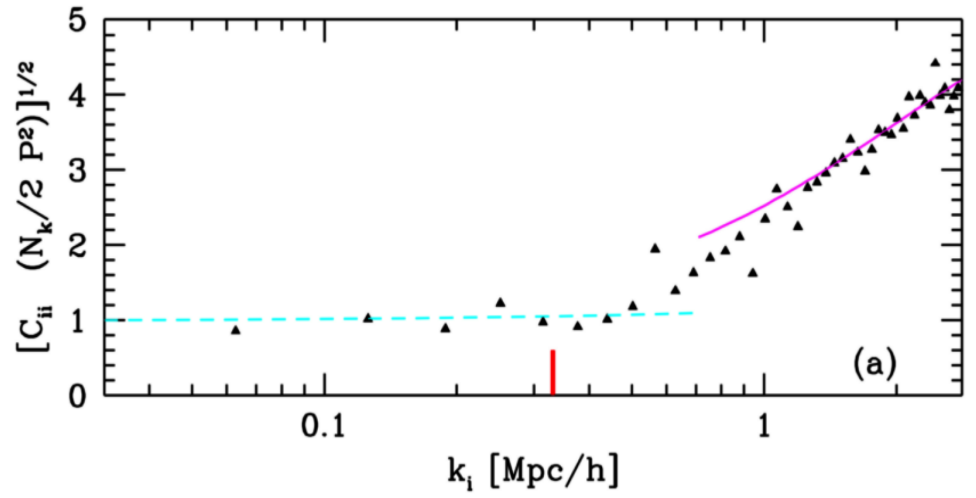
Cosmic variance

Gaussian field: $\delta \ln P = N_{\rm modes}^{-1/2} = \left(\frac{V}{4\pi^2}\, k^3\, d\ln k\right)^{-1/2}$

Halo model: $P_{\rm nonlin} = P_{\rm lin} + P_{1-\rm halo}[+P_{\rm shot}]$
$\simeq P_{\rm lin} + 1/n_{\rm halo}[+1/n_{\rm galaxy}]$

$\Rightarrow \mathrm{Var}(\ln P) \simeq 1/N_{\rm modes}(k) + 1/N_{\rm halo}$
$= \mathrm{Var}(\ln P)_{\rm Gaussian} \times \left(1 + \frac{1}{2}\Delta^2(k)\, d\ln k\right)$

Hence enhanced covariance (and lost signal) beyond NL scale: Scoccimarro et al. (1999); Meiksin & White (1999)



So ultimate limit to precision is number of linear modes?

Cross-correlations

- Natural quantity to consider if you have >1 tracer
- Cross-power affected by cosmic variance in same way as auto-power
- Informative about e.g. stochasticity

$$P_{12} \equiv \delta_1(k)\delta_2^*(k); \qquad r(k) = P_{12}/[P_{11}(k)P_{22}(k)]^{1/2}$$

- Interesting tomographic information from samples with partial overlap

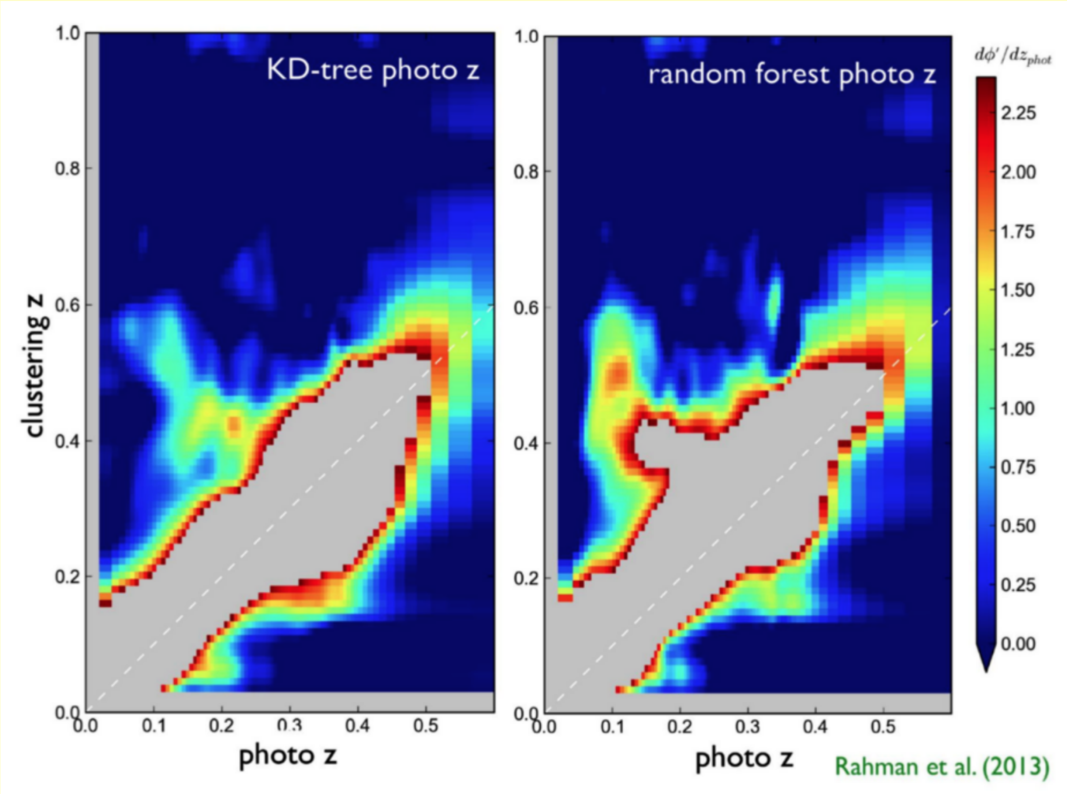
Cross-correlation with photo-z's

$$w_{pt}(\theta, z_p) = \int \frac{b_p(z)}{b_t(z)}\, \xi_t(r[z, z_p, \theta])\, \phi(z|z_p)\, dz$$

So measure $\varphi(z|z_p)$ if bias evolution is known

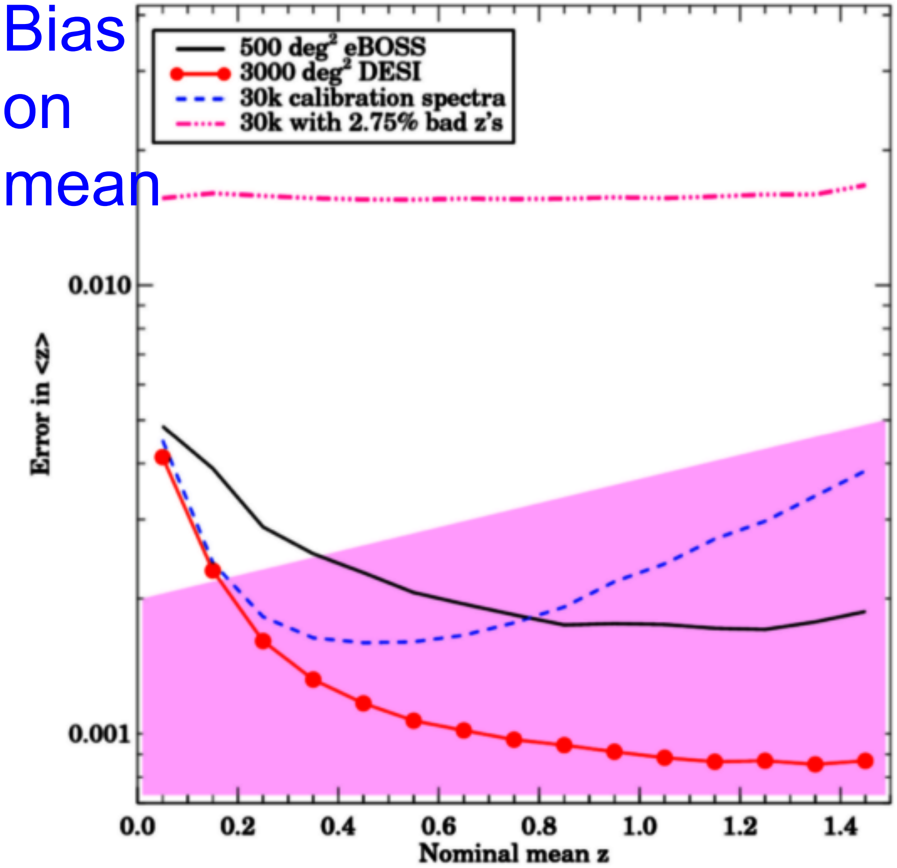
Newman (0804.1409); Schulz (0910.3683); McQuinn & White (1302.0857)

Use bright tracers to calibrate deep photo-z's since complete spectroscopy to requisite depth may be infeasible

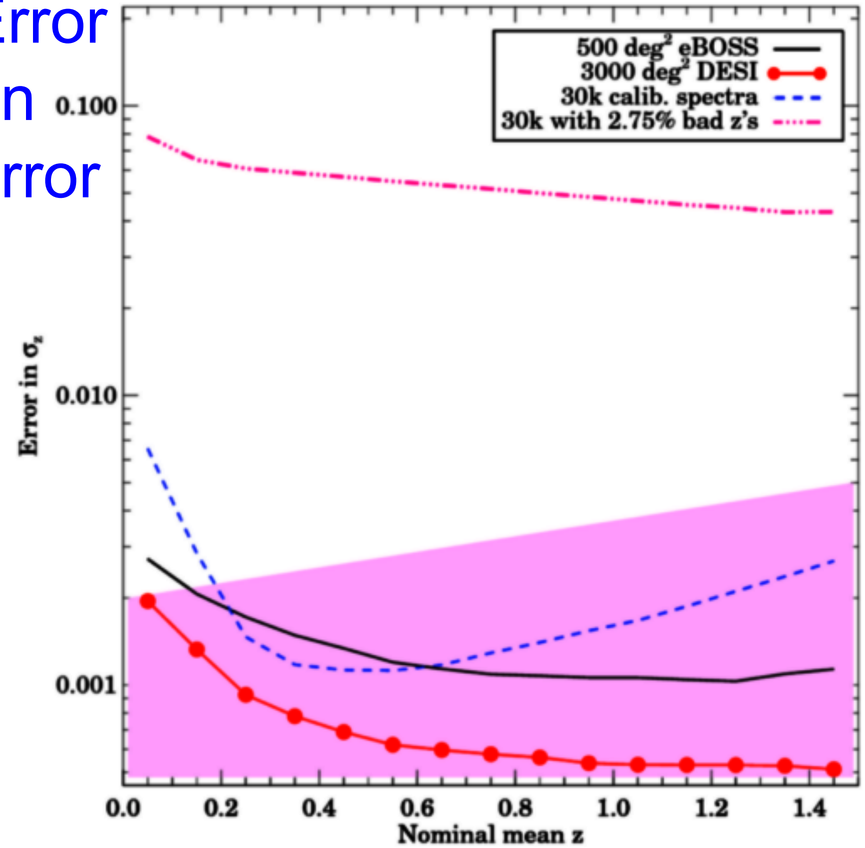


Prospects for LSST

Bias on mean

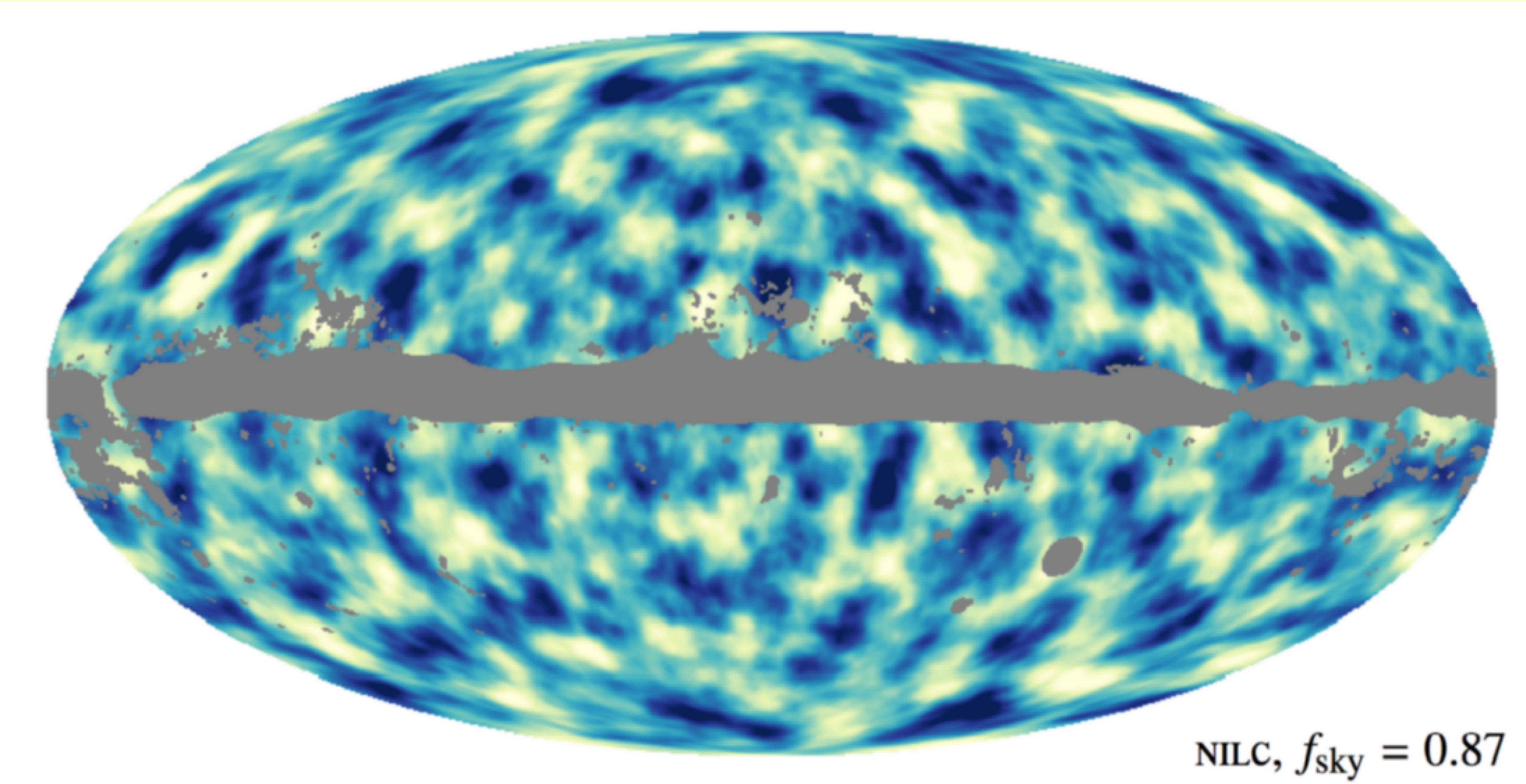


Error on error



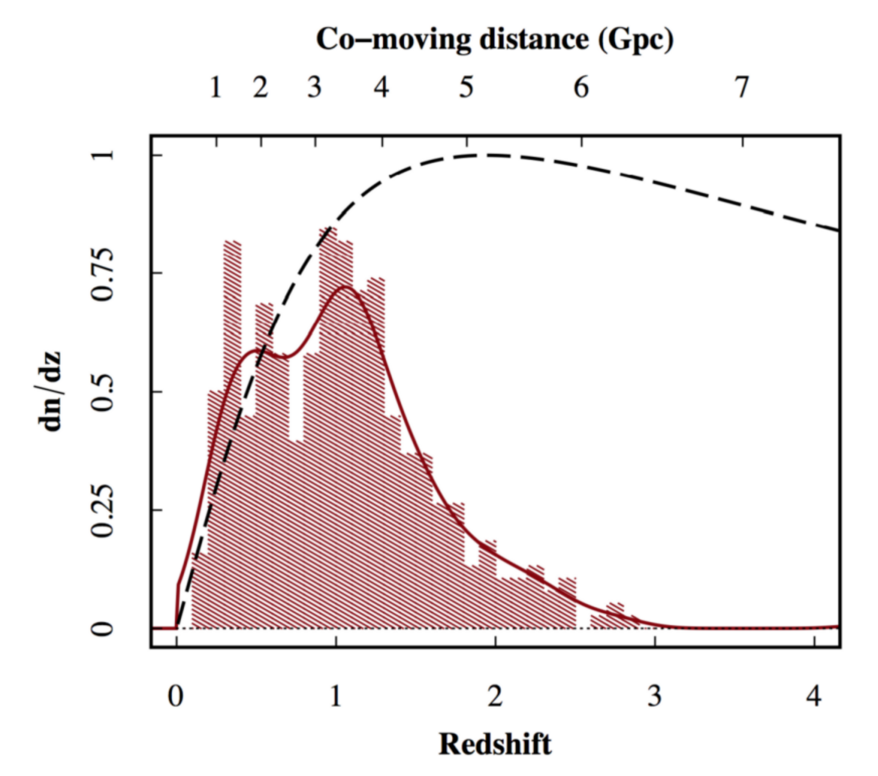
Newman et al. Snowmass 2013

Deprojecting CMB lensing



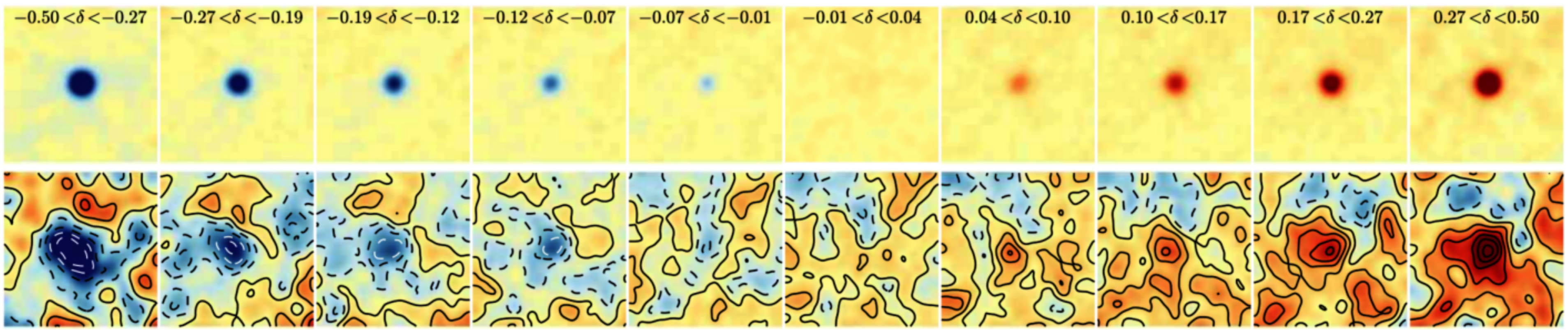
Lensing potential: Planck 2013 paper 17

Deprojecting CMB lensing



Geach et al. 1307.1706: cross-correlate SPT lensing with WISE-selected quasars. Measure b = 1.67 +/- 0.24

Strong calibration test for tomographic weak lensing



Beating cosmic variance

McDonald & Seljak 0810.0323. See also 1003.3238

In limit of linear bias, all populations share same fluctuations in phase and mode amplitude:

$P(>|\delta|) = \exp(-|\delta|^2/\langle|\delta|^2\rangle)$; random phase

Fourier Configuration space:

$$\delta_1 = b_1\delta,\ \delta_2 = b_2\delta \Rightarrow b_2/b_1 = |\delta_2|/|\delta_1|$$

Fourier Redshift space:

$$\delta_1 = (b_1 + f\mu^2)\delta,\ \delta_2 = (b_2 + f\mu^2)\delta \Rightarrow (b_2 + f\mu^2)/(b_1 + f\mu^2) = |\delta_2|/|\delta_1|$$

So can access RSD without limit from mode amplitude and phase if two b factors are different

All the information is in power

$$P_1 = A\bar{P}(1+\alpha) + \Delta P_1$$
$$P_2 = B\bar{P}(1+\alpha) + \Delta P_2,$$

Since $\hat{A} = P_1/\bar{P}$ etc., the covariance matrix is

$$\sigma^2_{AA} = A^2\sigma^2 + \epsilon_1^2/\bar{P}^2$$
$$\sigma^2_{BB} = B^2\sigma^2 + \epsilon_2^2/\bar{P}^2$$
$$\sigma^2_{AB} = AB\sigma^2,$$

where $\sigma^2 \equiv \langle\alpha^2\rangle$, $\epsilon^2 \equiv \langle(\Delta P)^2\rangle$. From this, we get

$$\mathrm{var}(A/B) = (A/B)^2[\epsilon_1^2/A^2\bar{P}^2 + \epsilon_2^2/B^2\bar{P}^2].$$

Cross-correlation (i.e. tracers have same phase) gives no extra information

Getting errors on parameters

Covariance matrix for parameters λ and λ' comes from inverse of Hessian matrix:

$$\sigma^2_{\lambda\lambda'} = (H^{-1})_{\lambda\lambda'}; \quad H_{\lambda\lambda'} \equiv -\frac{\partial^2 \ln \mathcal{L}}{\partial\lambda\partial\lambda'}; \quad \ln \mathcal{L} = D^\dagger \cdot C \cdot D/2$$

Fisher matrix is expectation of Hessian (for error forcasting). For Gaussian likelihood:

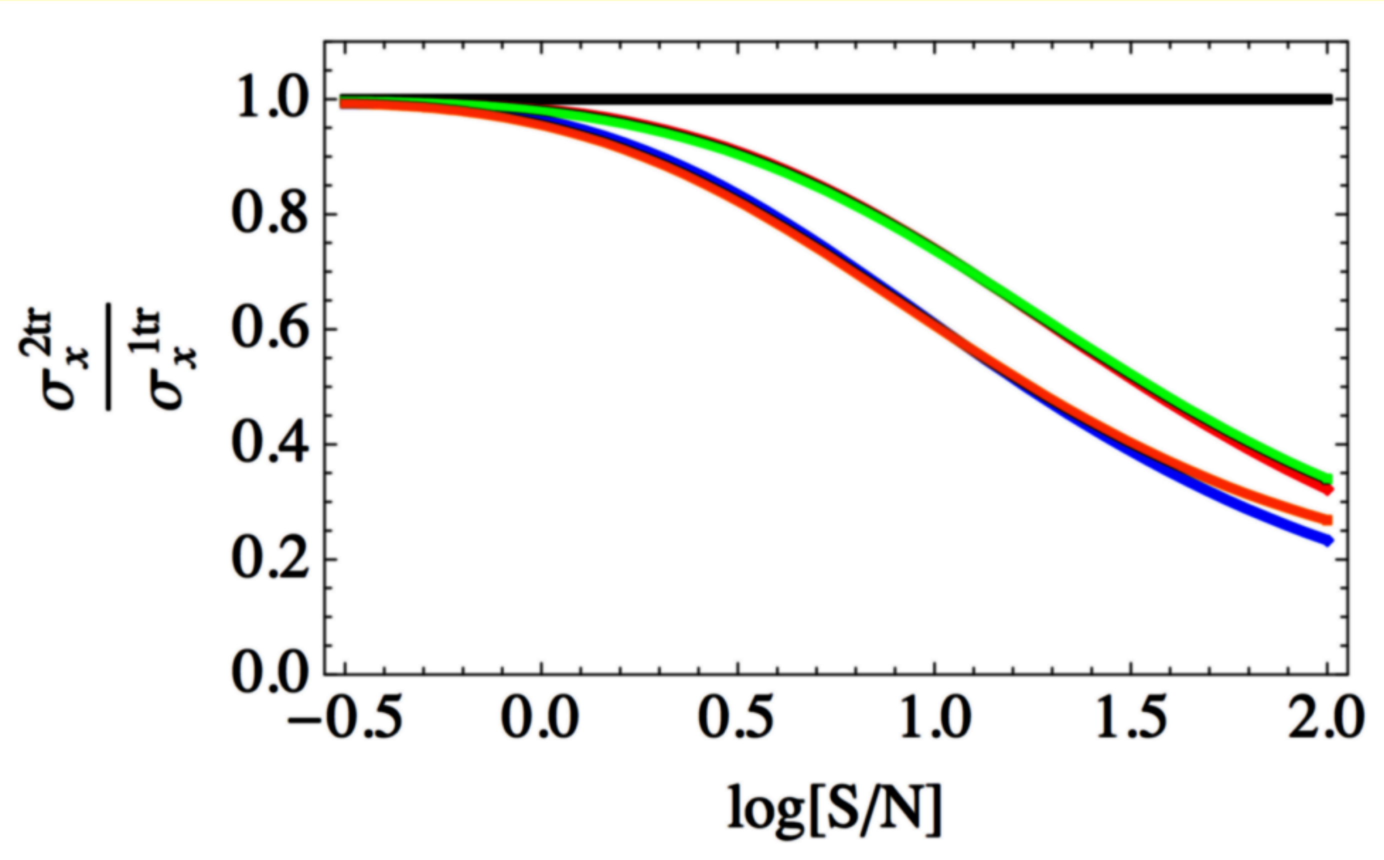
$$F_{\lambda\lambda'} = \frac{1}{2}\mathrm{Tr}\left(C_{,\lambda} C^{-1} C_{,\lambda'} C^{-1}\right)$$

What goes in D (the data)? It doesn't matter

Thus easier in practice to use covariance of density, $C_{ij} = < \delta_1 \delta_2^* >$, rather than covariance of power − just need power spectrum itself.

Gain as f(SNR)

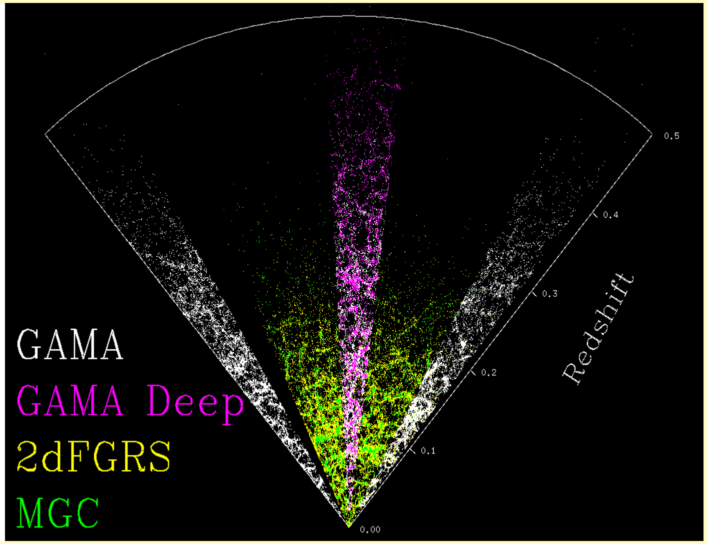
Extent of 2-tracer gain is limited by relative size of shot noise: SNR = P_g / P_{shot}



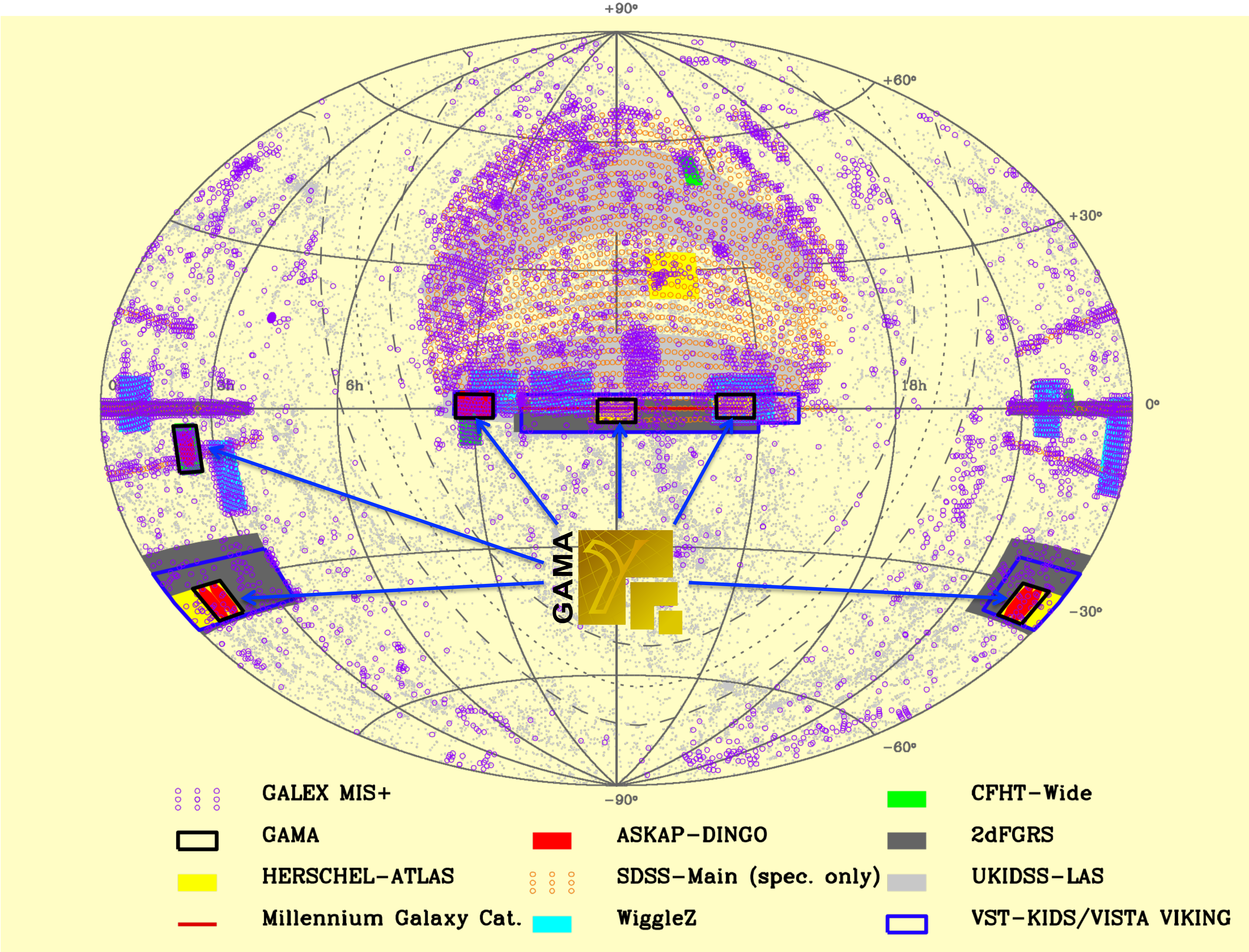
Gil-Marin et al. 1003.3238: b_1=1, b_2 varying

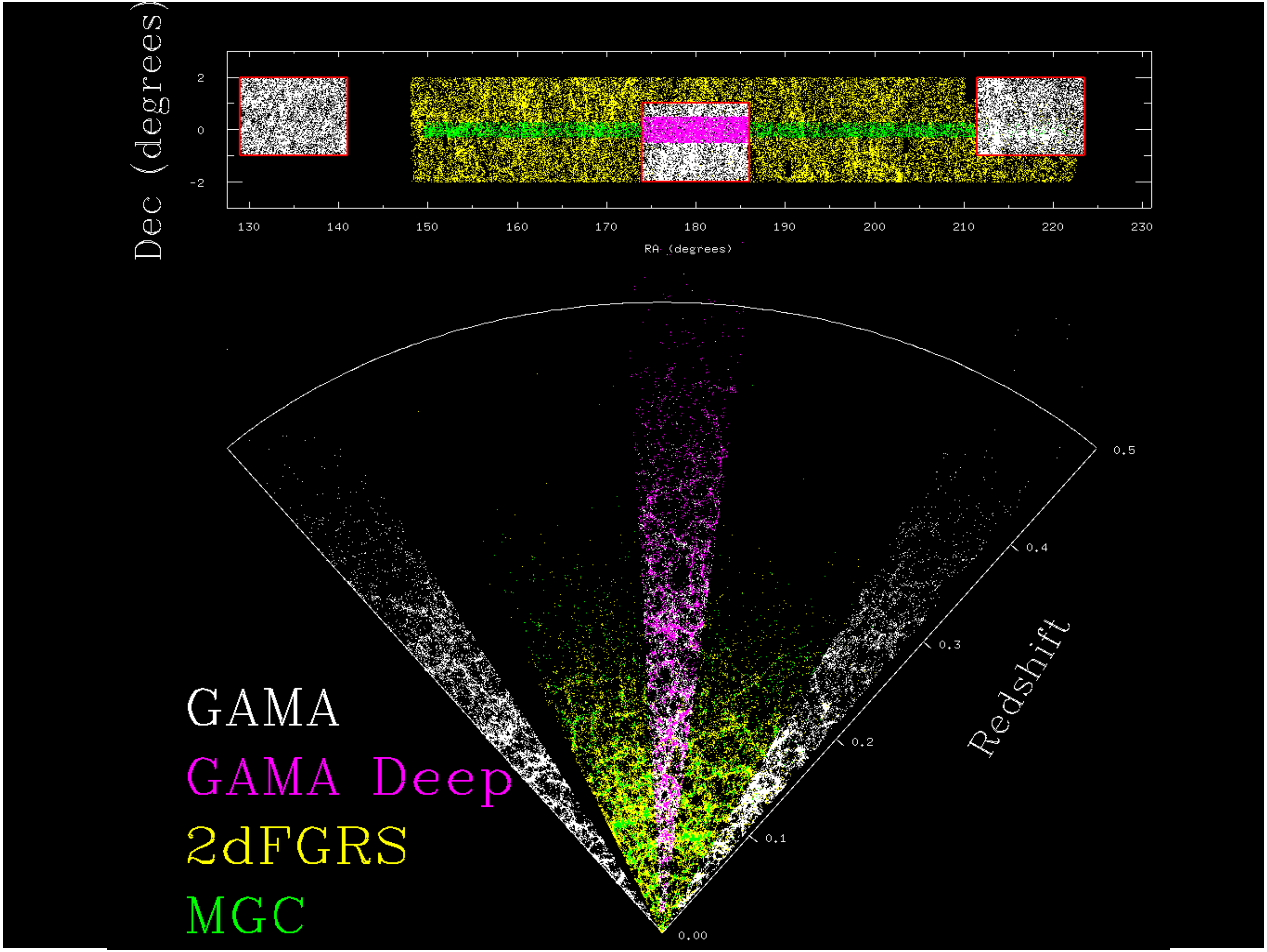
First application: GAMA

Galaxy And Mass Assembly – GAMA



- 300 deg^2 in 6 fields
- to r < 19.4 / 19.8 (GAMA deep) – cf. SDSS 17.8
- Aim for >200,000 redshifts
- First 3 observing seasons (GAMA I; 150 deg^2):
  - 63 AAT nights 08/09/10 – 75% clear
  - 140k new z's; 96% success
  - Over 160k including 2dFGRS/SDSS
  - GAMA-II 2011-14; should reach 400k z's

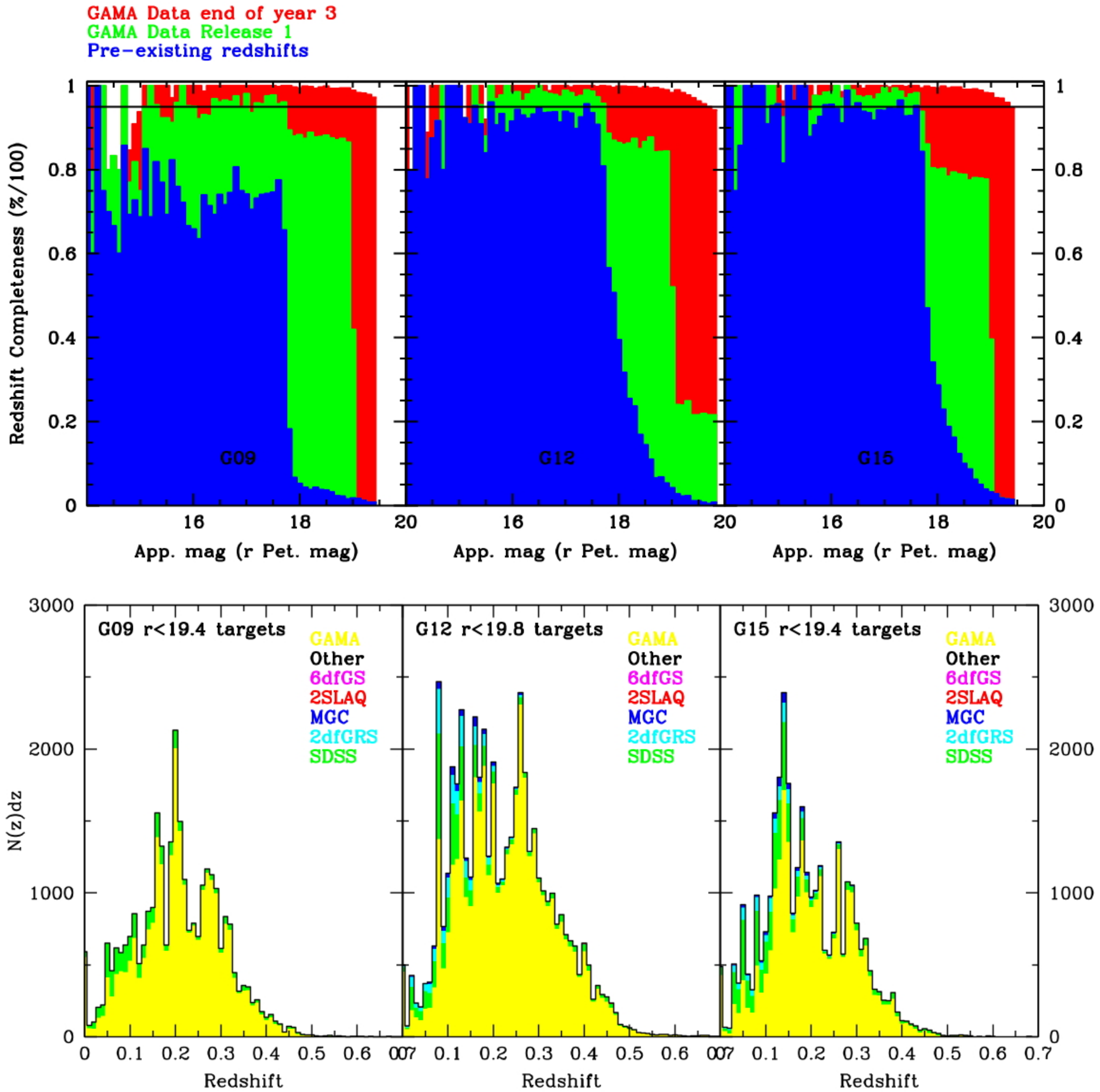

+90°
+60°
+30°
0°
-30°
-60°
-90°
0h
3h
6h
18h
GAMA
GALEX MIS+
GAMA
HERSCHEL-ATLAS
Millennium Galaxy Cat.
ASKAP-DINGO
SDSS-Main (spec. only)
WiggleZ
CFHT-Wide
2dFGRS
UKIDSS-LAS
VST-KIDS/VISTA VIKING



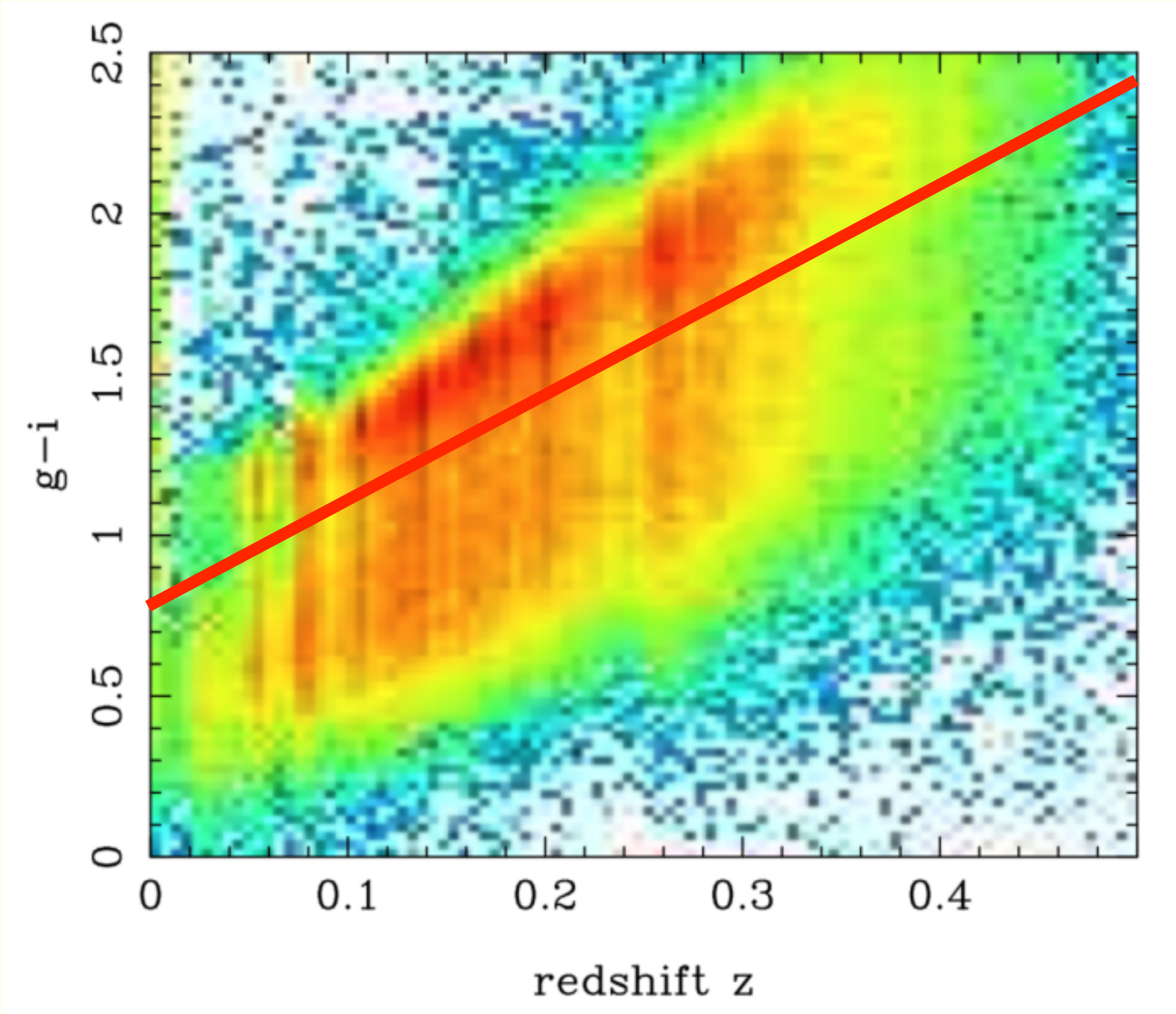
Dec (degrees)
2
0
-2
130
140
150
160
170
180
190
200
210
220
230
RA (degrees)
0.5
0.4
0.3
0.2
0.1
0.00
Redshift
GAMA
GAMA Deep
2dFGRS
MGC

A very complete z-survey: (>96%)

(sampling, not success rate)

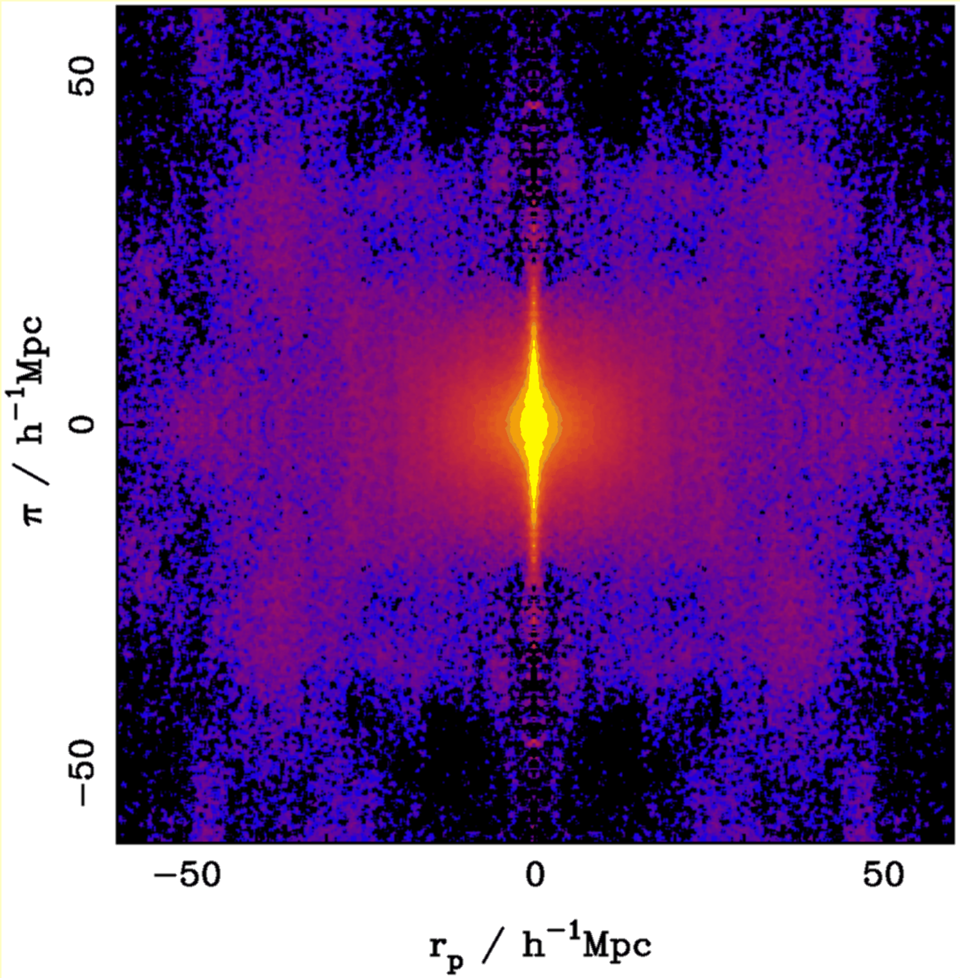


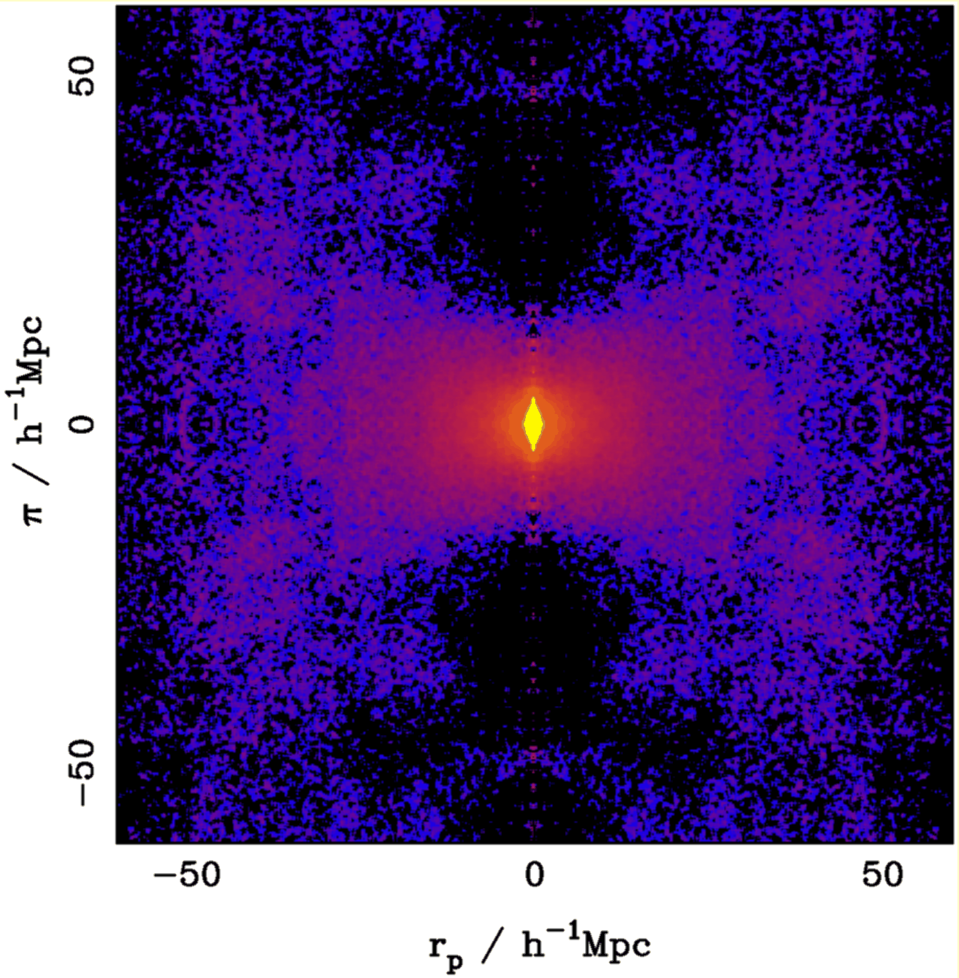
GAMA colour split



Split at g-i = 0.8 + 3.2z

RSD as f(colour) in Fourier space (not)

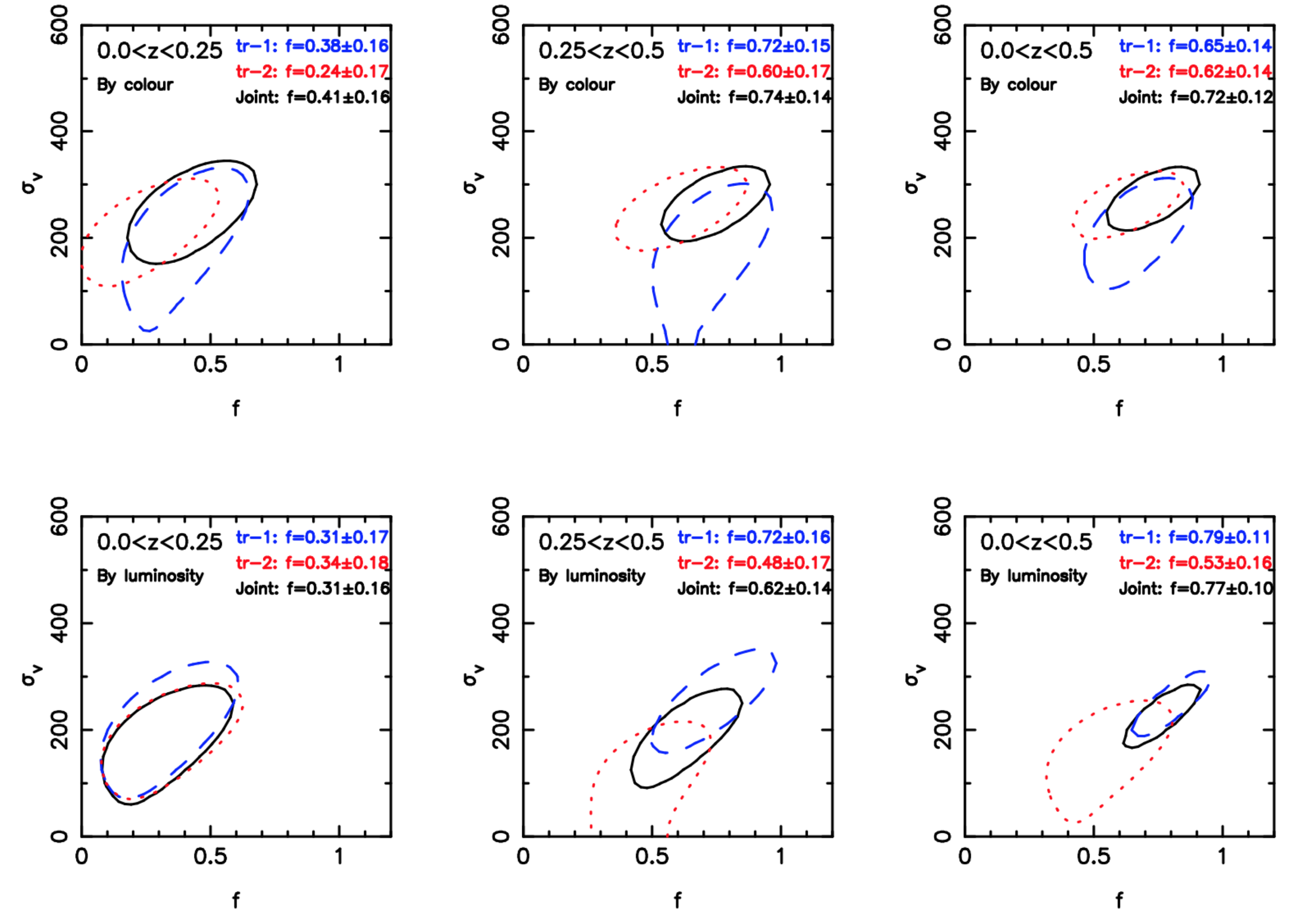




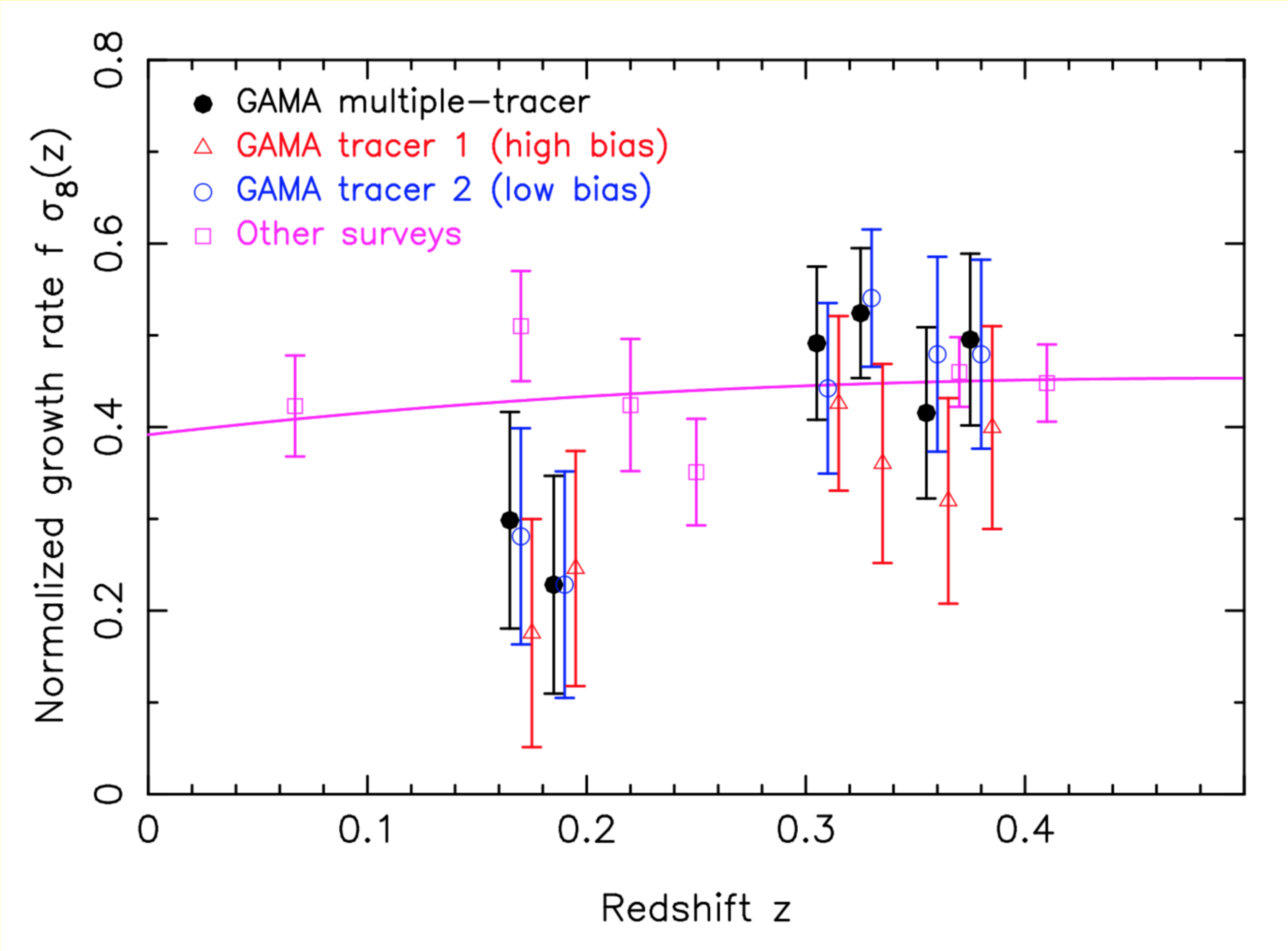
Red **Blue**

GAMA multi-tracer analysis

Blake et al. (2013): ~ 10% improvement on single-tracer f_g error

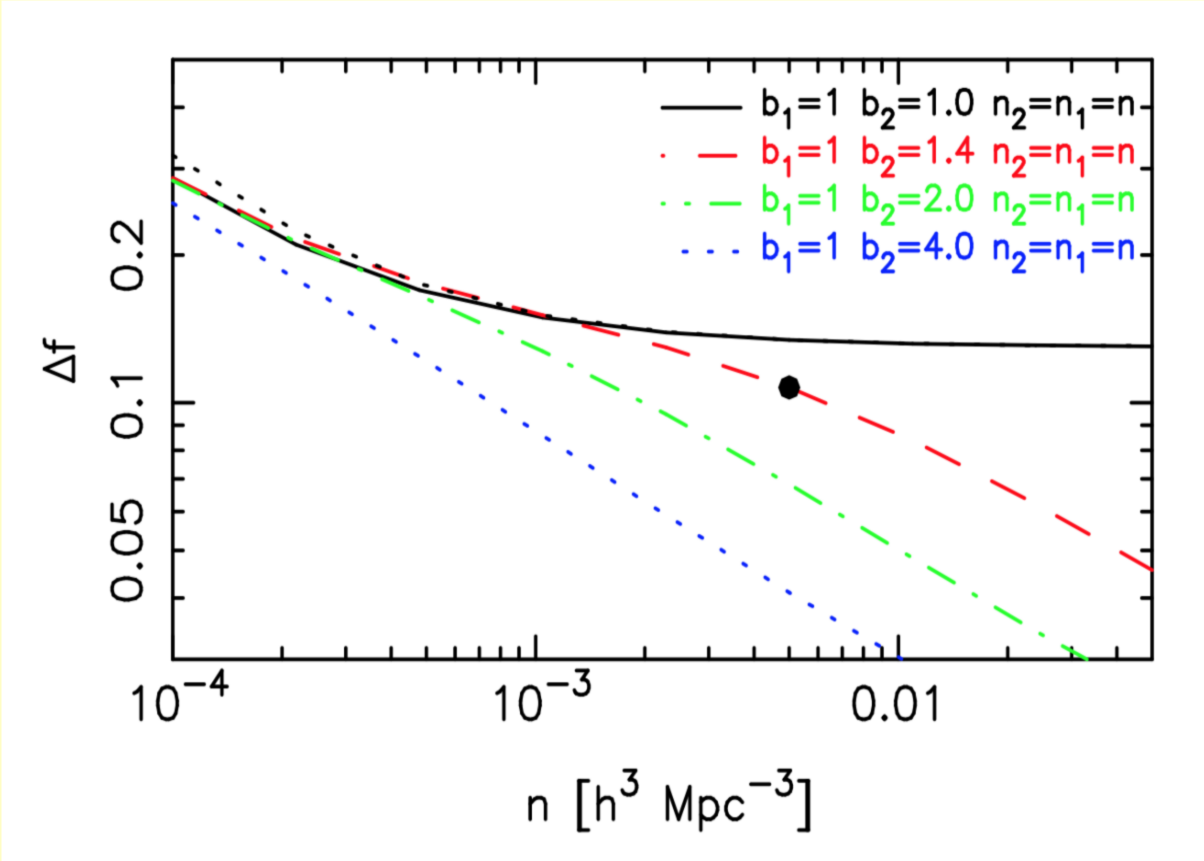


Growth-rate results



cf. BOSS DR9 0.415 +/- 0.034 at z=0.57

Outlook



Gain requires (a) large bias difference; (b) low shot noise. Normally hard to reconcile − but Seljak et al. estimate shot noise (for one tracer) can be reduced X ~10: should allow factor 2 improvement in multi-tracer result.

Summary

- Different tracers have complex relation to mass field
  - But most systematics can be understood via halo model
  - Discreteness noise can be tamed by halo weighting

- Cosmic variance is not the ultimate limit to precision
  - Practical implementation of McDonald-Seljak method
  - Proof of concept applied to GAMA
  - Scope for factor > 2 improvement in BOSS results if suitable subsets can be identified (harder with sparser samples)