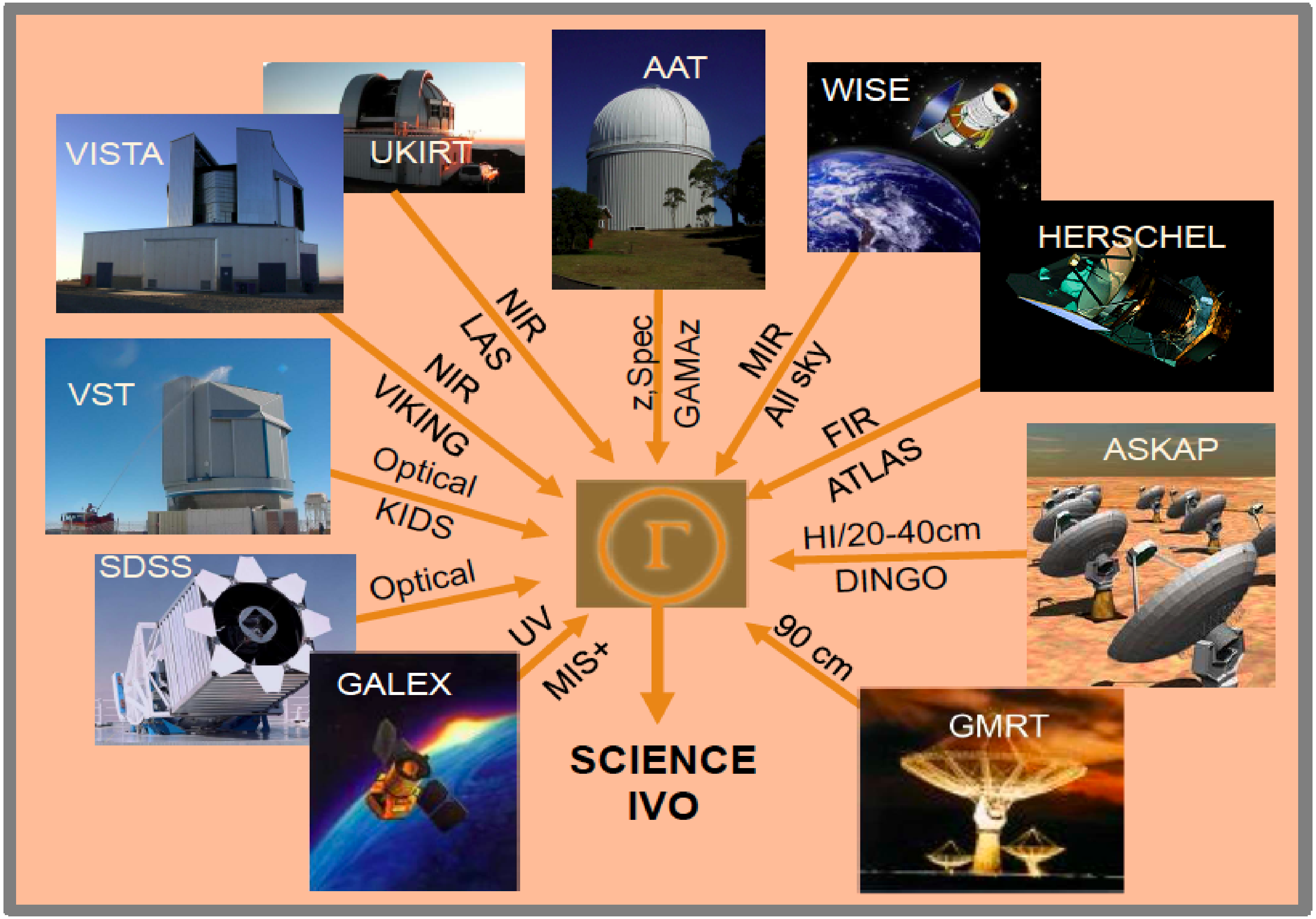
Probing the growth of non-linear structure with the Galaxy And Mass Assembly survey



Peder Norberg

Institute for Astronomy, University of Edinburgh, UK

LSS in the “low”-redshift Universe

A. Probing the growth of non-linear structure with the Galaxy And Mass Assembly survey:

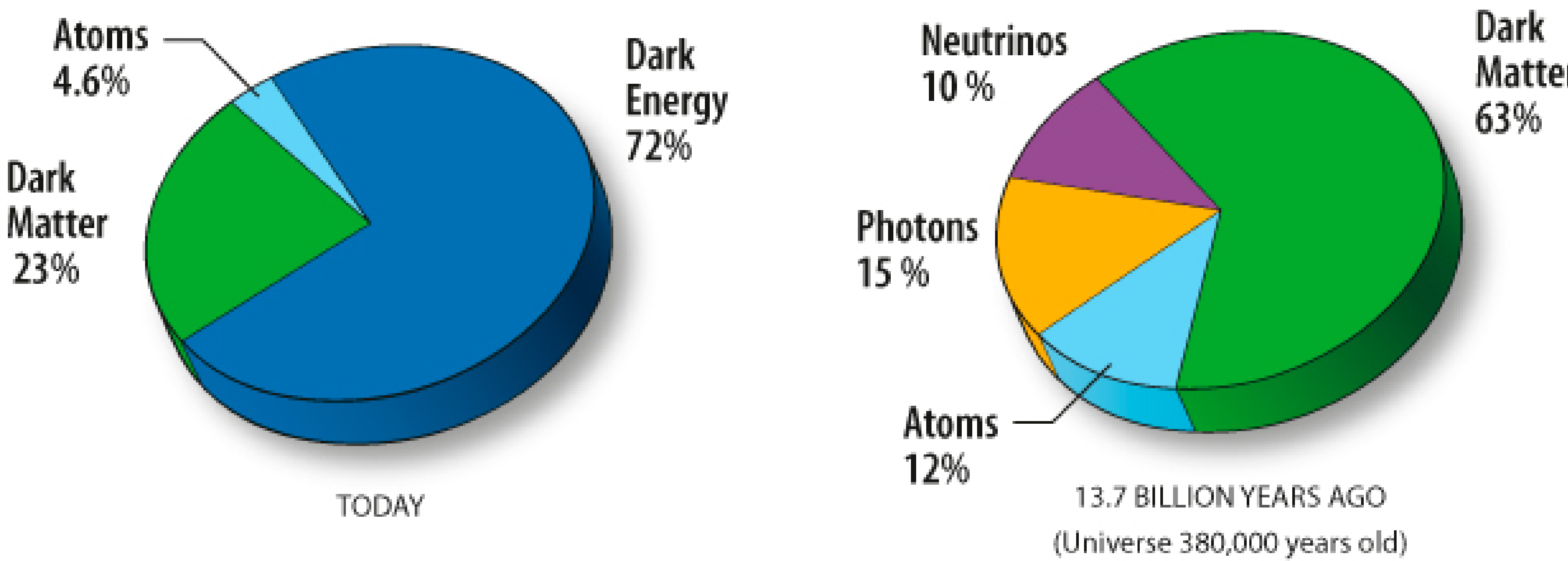
- GAMA: a multi-wavelength redshift survey
- Main LSS goals: DM HMF evolution, growth of structure
- Preliminary results

B. An objective way to quantify the impact of superstructures: [with Baugh, Gaztanaga & Croton]

- Uncertainty in data induced clustering errors
- Our Method
- Results (applied to SDSS DR7)

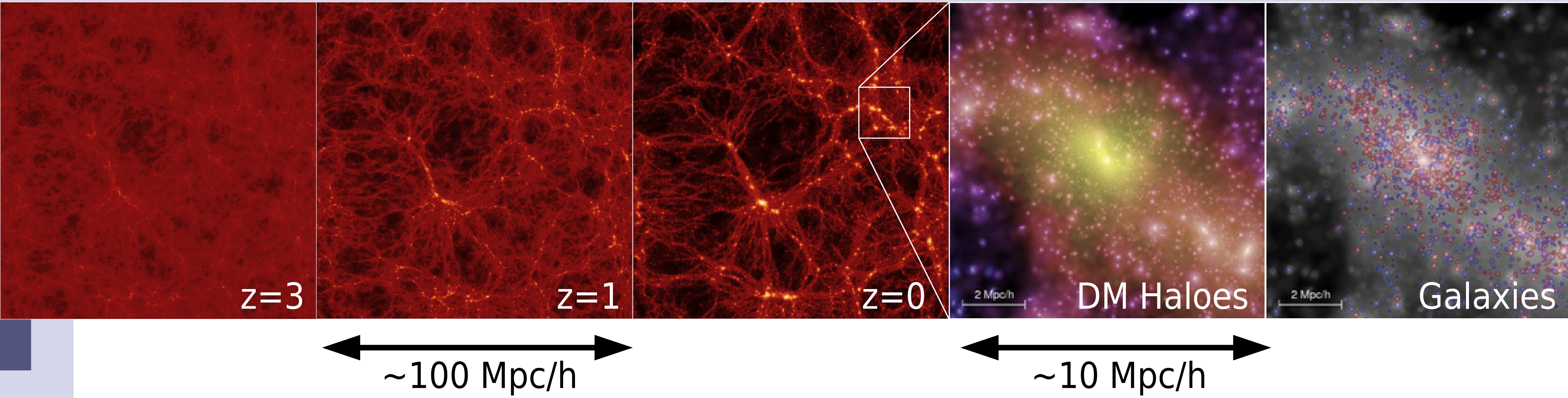
ΛCDM: standard cosmological model

Combined with H_0 & SN Ia measurements, CMB & LSS confirm a standard cosmological picture:



Credit: NASA/WMAP Science Team

Growth of non-linear structure



Structure formation:

- $\Delta\rho_{DM}/\rho_{DM}$ grow under gravity → DM haloes
- Gas cools in DM haloes → stars → galaxies in DM haloes

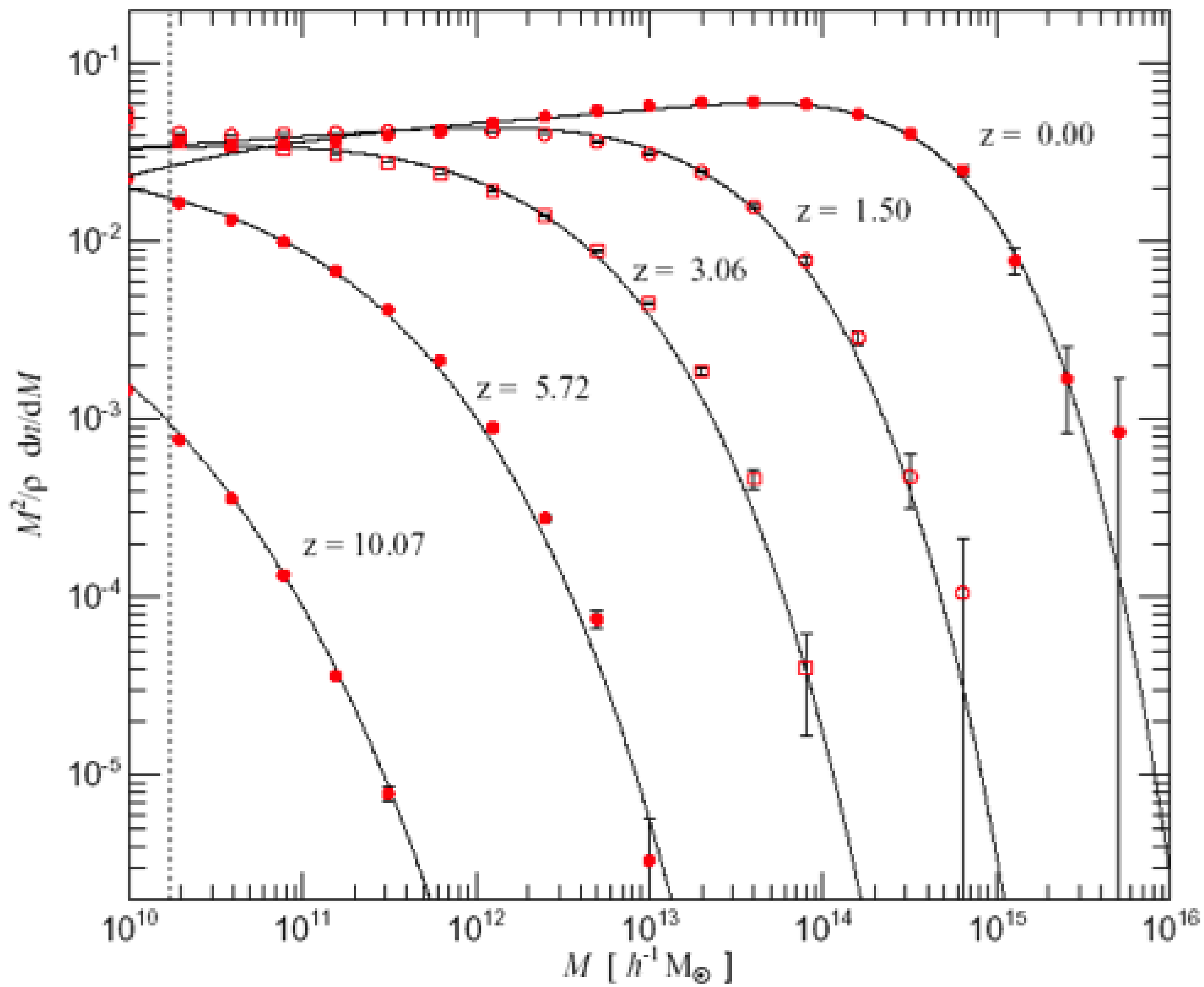
Key questions:

- Is the Cold Dark Matter (CDM) model correct?
- Dark Energy or new gravitational physics?

Fundamental research to our understanding of structure formation and galaxy evolution.

CDM halo mass function

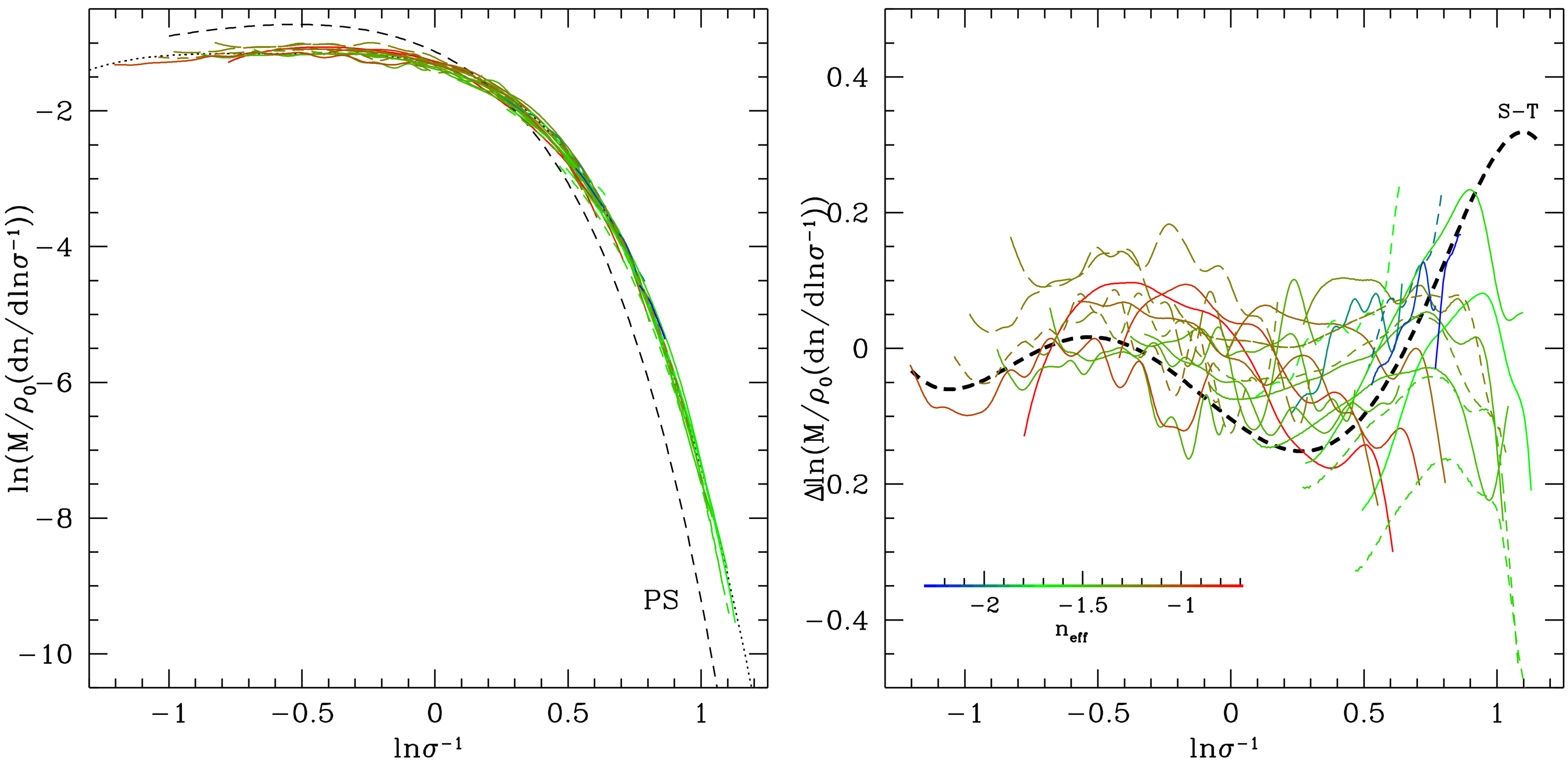
Multiplicity Function



Springel et al. (2005)

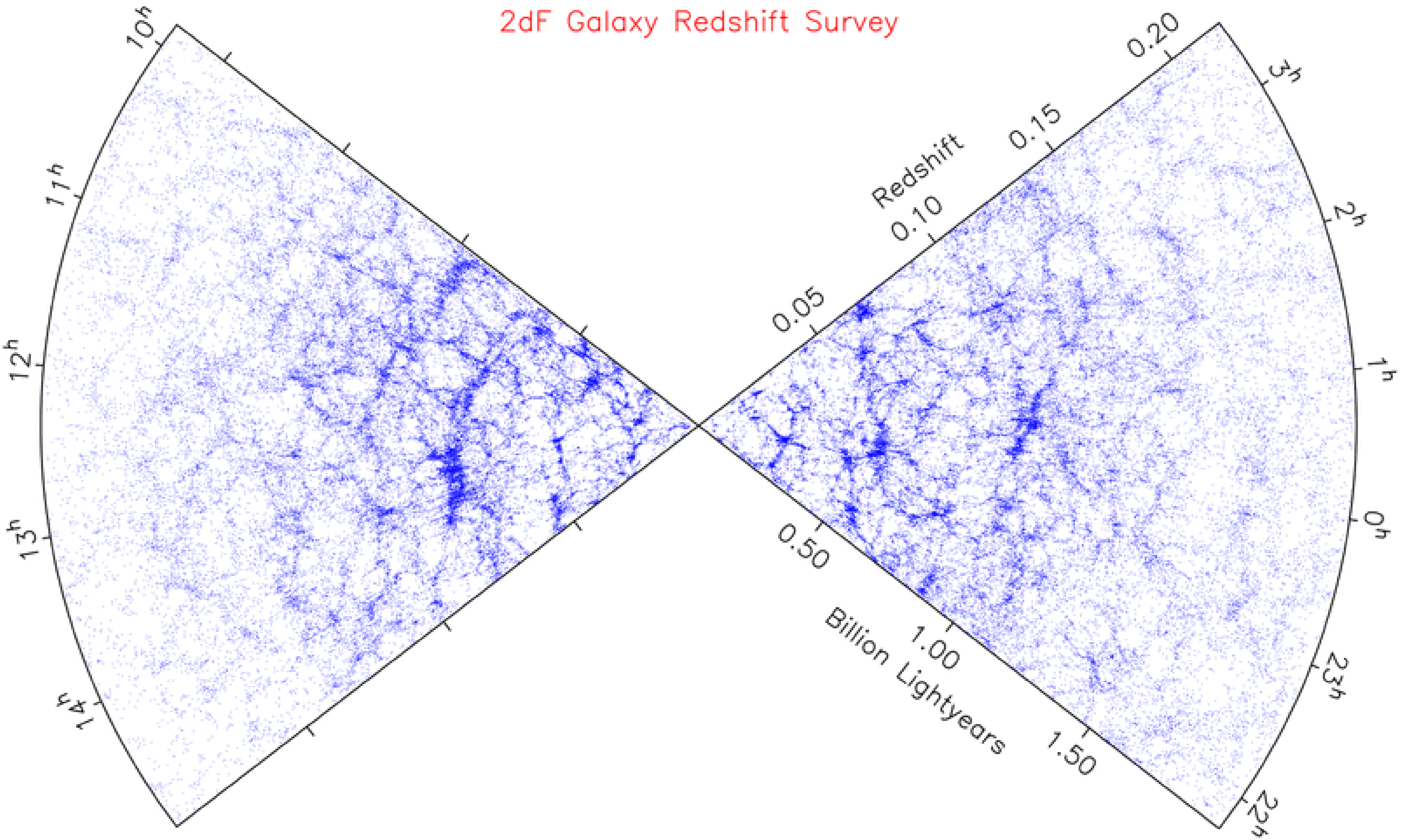
CDM halo mass function

For a given cosmology, the CDM halo mass function is very well predicted (~10% accuracy), but not tested...

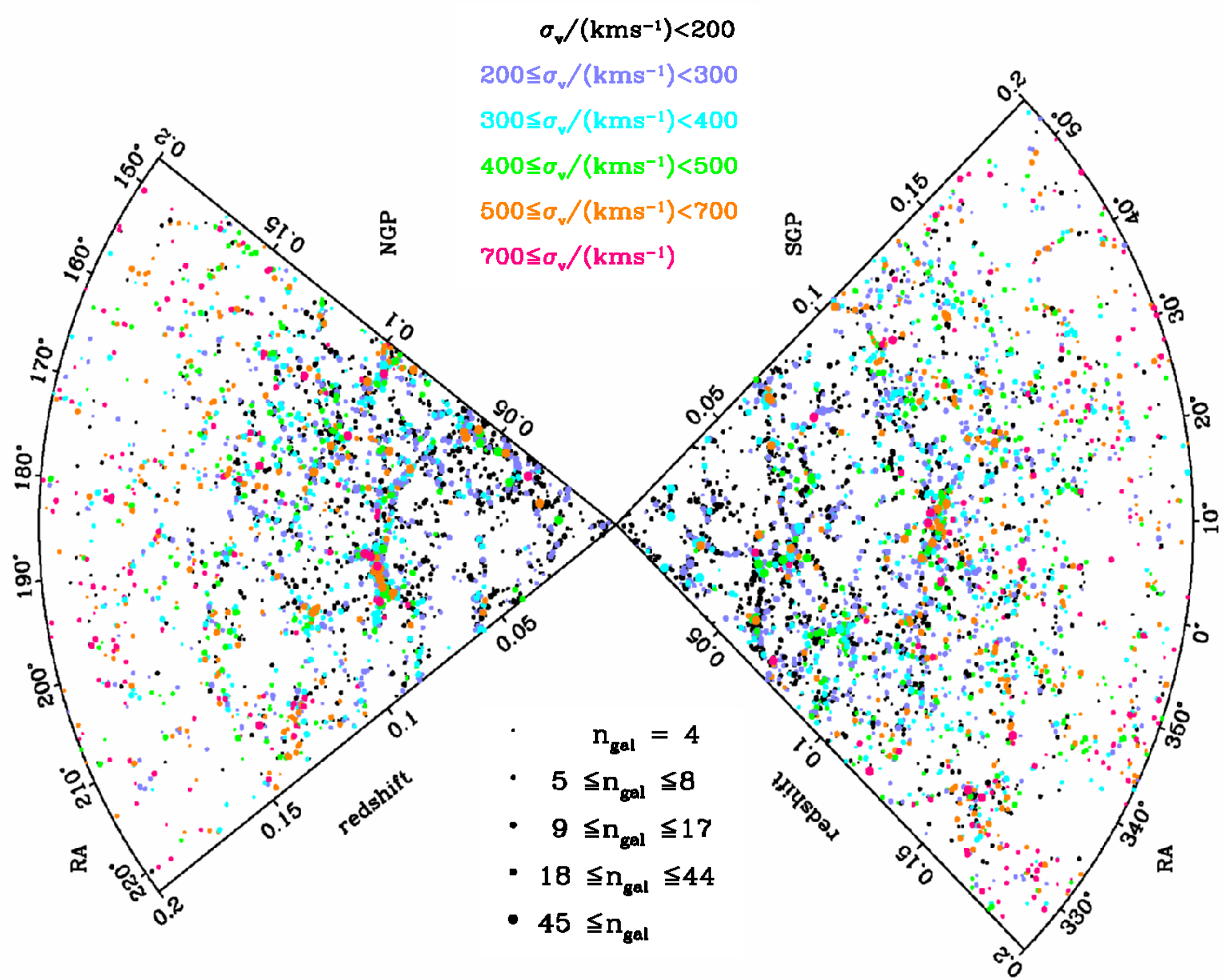


Jenkins et al. (2001)

2dF Galaxy Redshift Survey: a short summary



2dFGRS Percolation Inferred Galaxy Group Catalogue (2PIGG)



Dynamical group mass estimator:

$$\sigma^2=\sigma^2_{gap}\left(\frac{N}{N-1}\right)-\sigma^2_{err}$$

$$M=\frac{0\ r\ \sigma^2}{G}$$

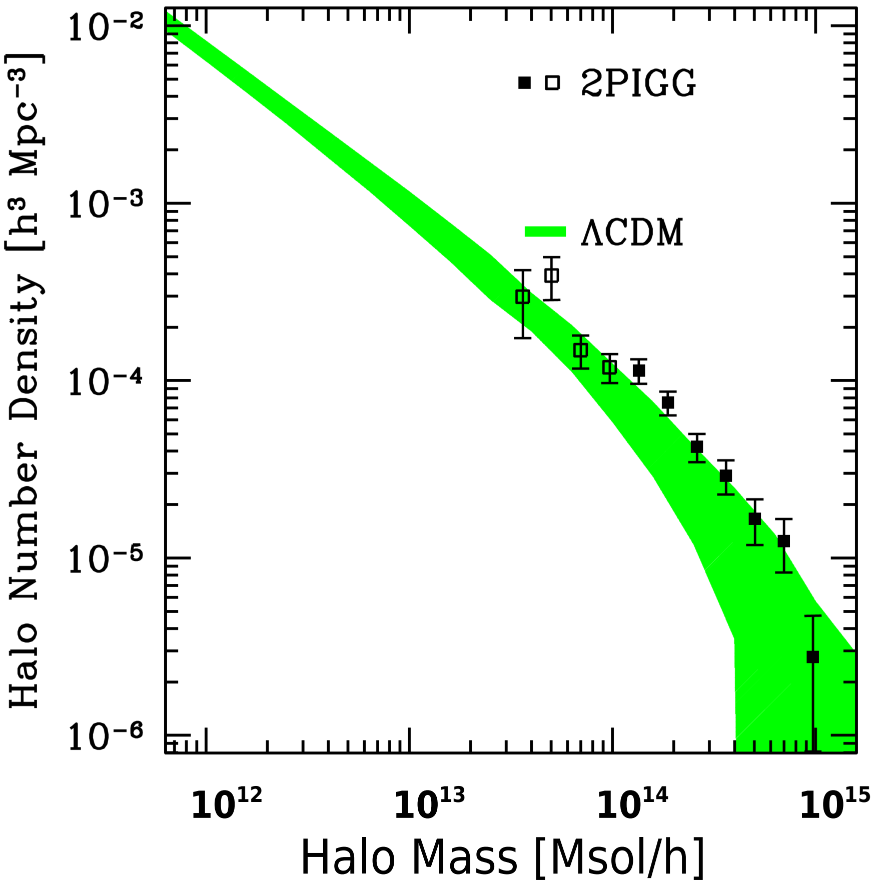
with 5 so as to match DM FOF b=0.2 halo masses. σ_{gap} see Beers, Flynn & Gebhardt (1990).

(Eke et al. 2004)

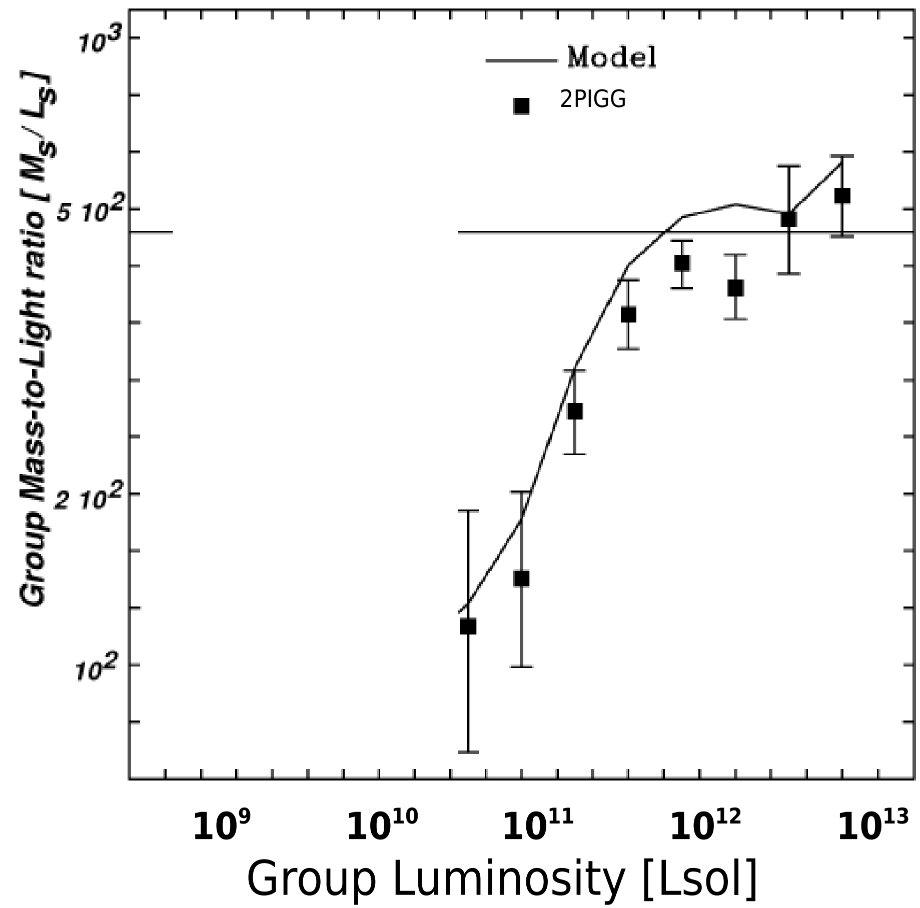
GAMA: la raison d'être

(with predictions from semi-analytic galaxy formation models)

Dark Matter
Halo Mass Function



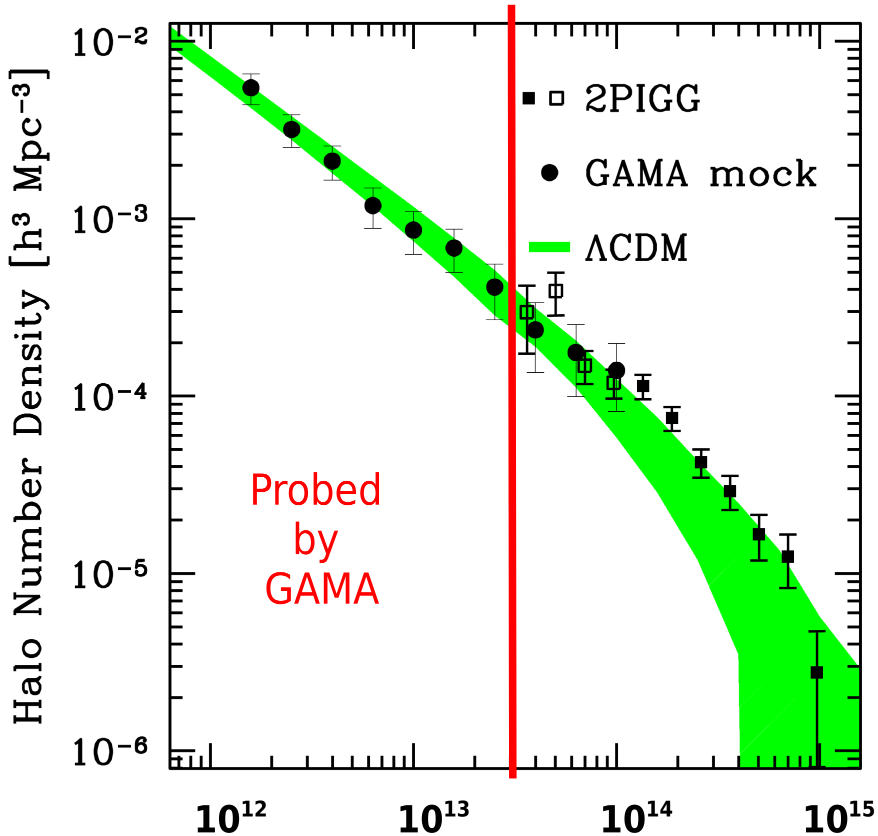
Galaxy Formation
Efficiency



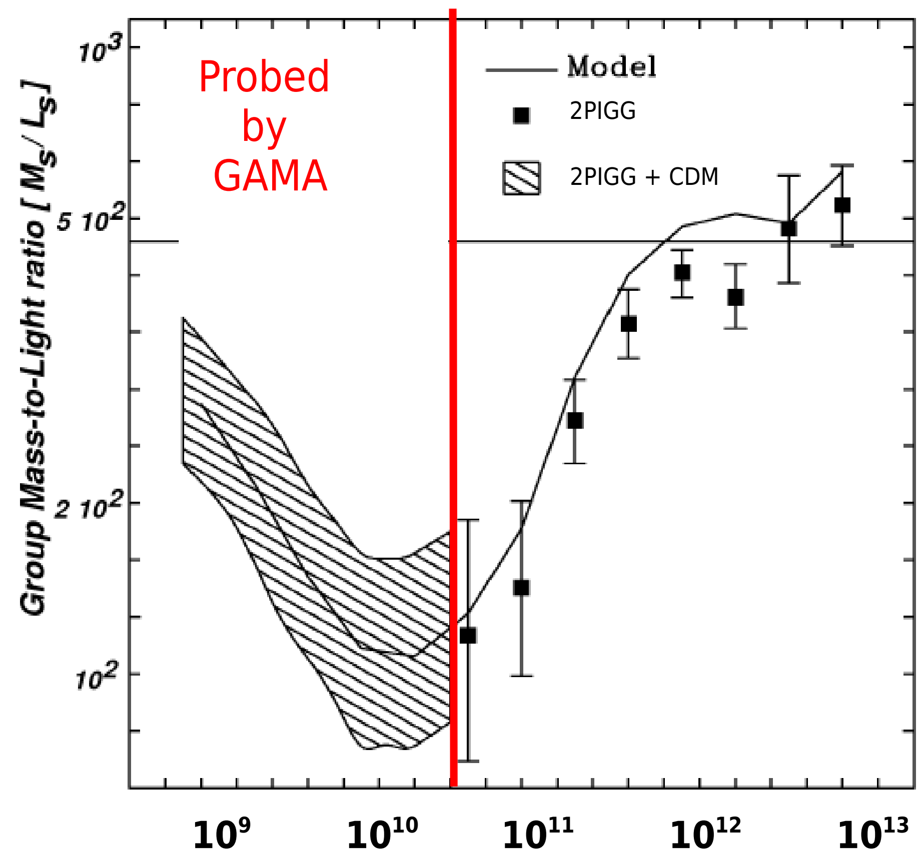
GAMA: la raison d'être

(with predictions from semi-analytic galaxy formation models)

Dark Matter
Halo Mass Function



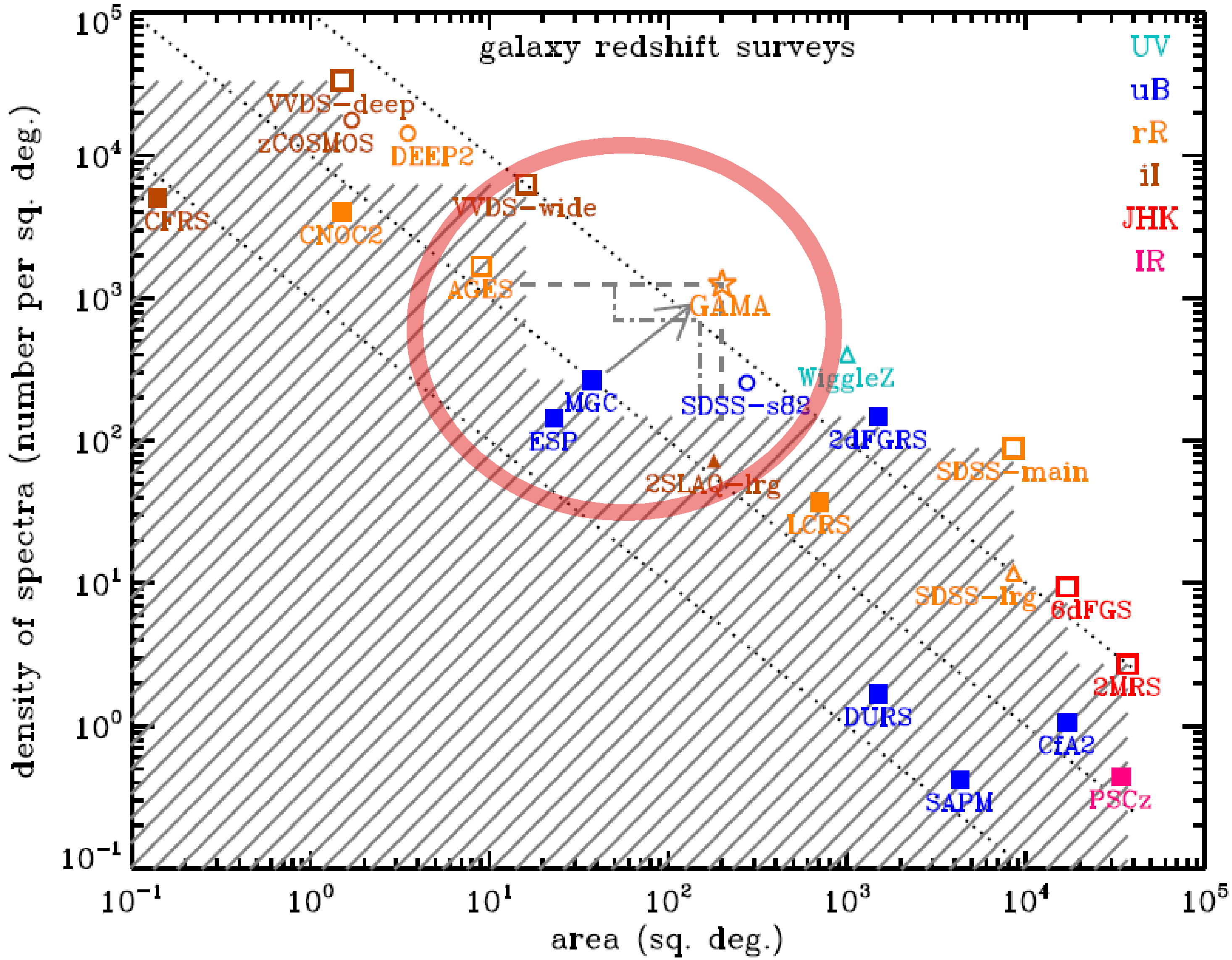
Galaxy Formation
Efficiency



Galaxy And Mass Assembly Survey: Phase I (2008-2010)

- Next generation galaxy redshift survey:
  - ~150,000 galaxy spectra to r_{AB}~19.8:
    - 2 mag. fainter than SDSS => L* at z~0.30 [~3 Gyr]
  - 150 sq. deg. wide, overlapping with SDSS and 2dFGRS
  - 75 nights on AAT with AAOmega over 3 years (2008-2010)
  - GAMA is also K-band limited, with K_{AB}<17.6
- GAMA is a unique survey and fills an essential gap in the current generation of redshift surveys, between the very wide low-z and very narrow high-z.

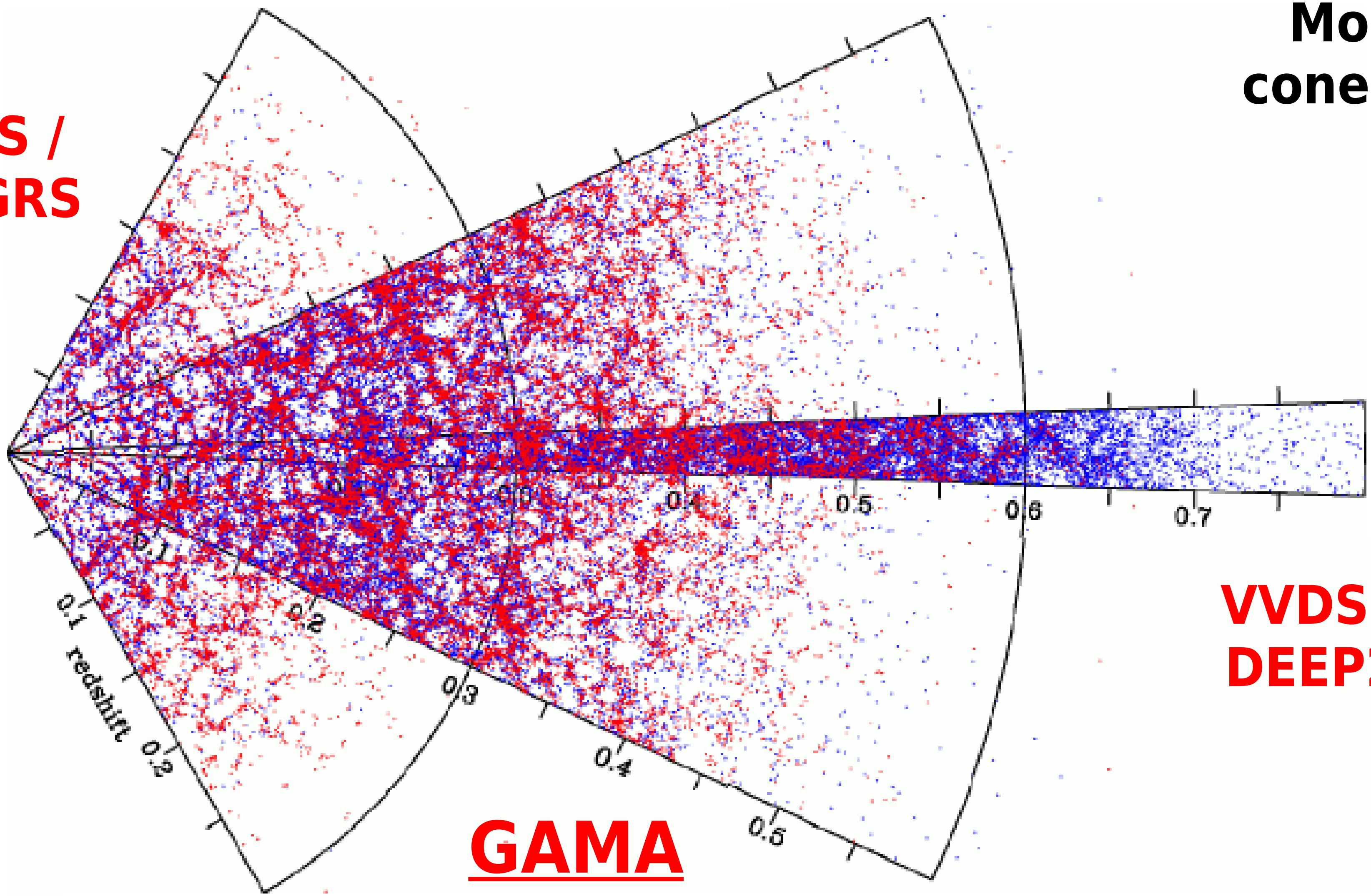
Galaxy And Mass Assembly Survey:
germane connection between shallow-wide & deep-narrow



Galaxy And Mass Assembly Survey:
germane connection between shallow-wide & deep-narrow

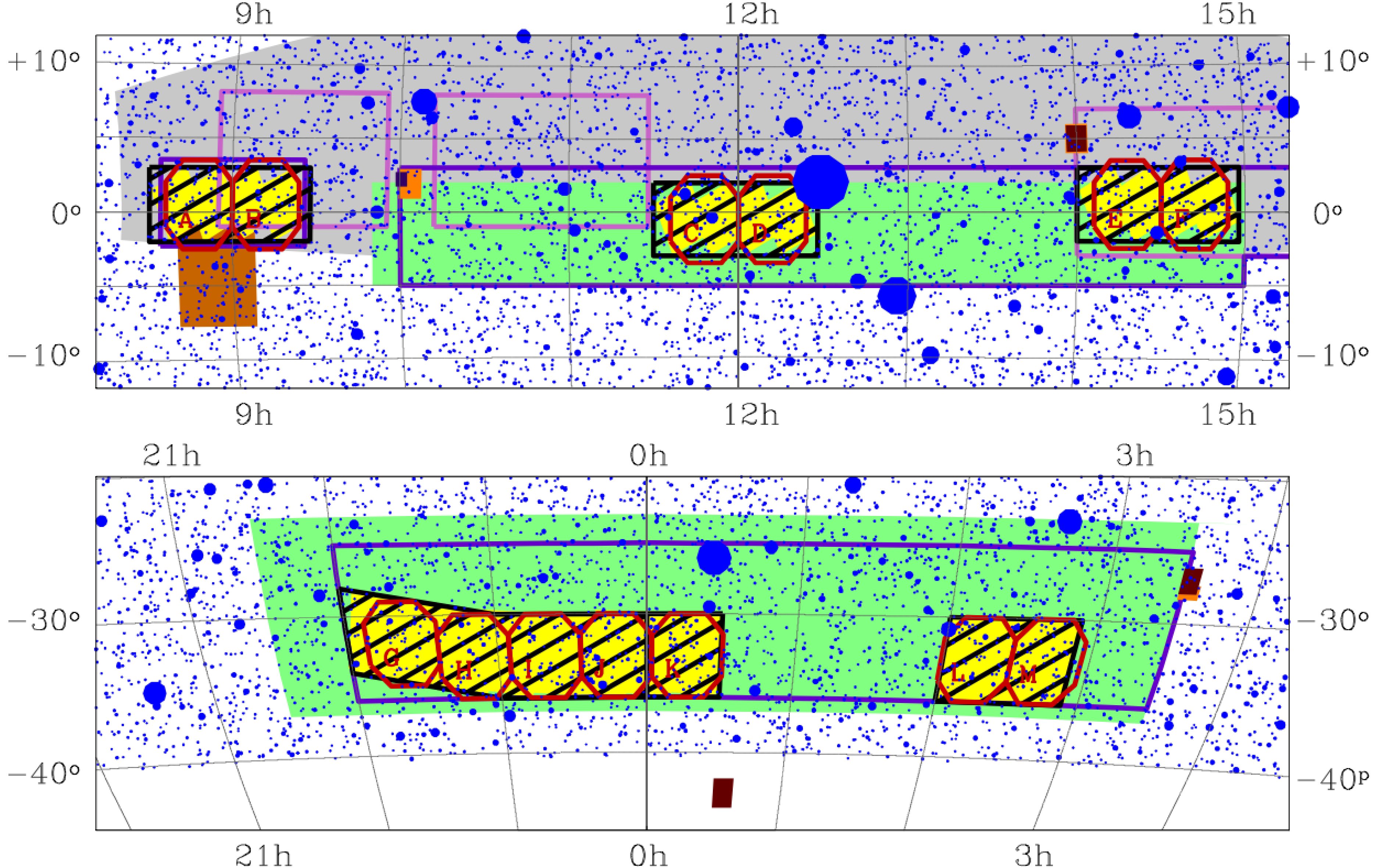
Mock coneplot

SDSS / 2dFGRS

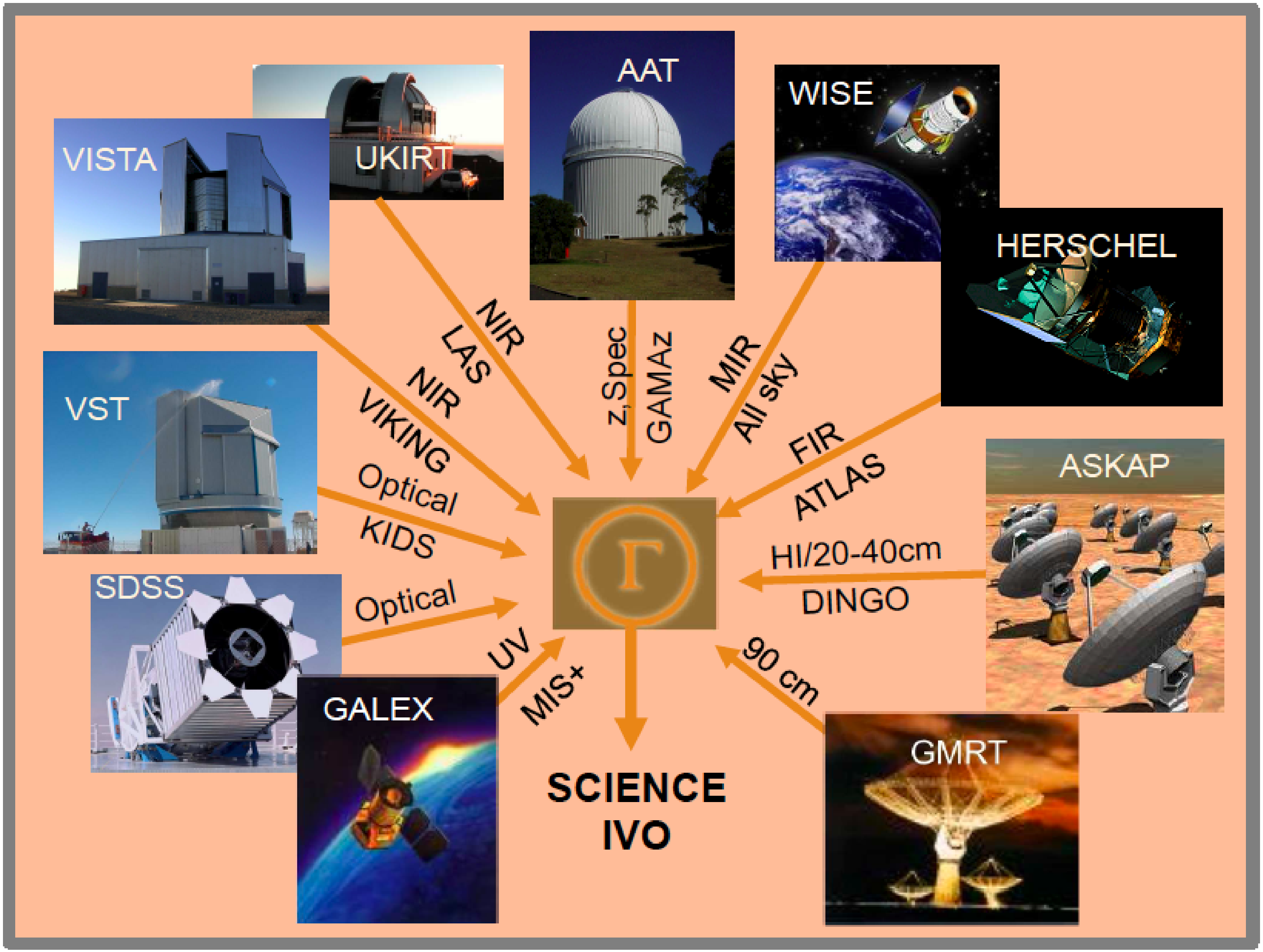


VVDS / DEEP2

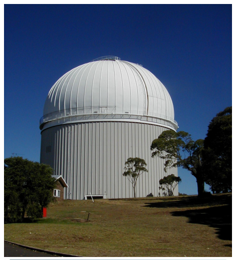
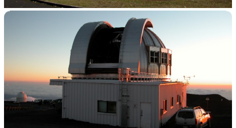
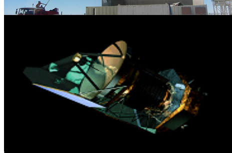
Galaxy And Mass Assembly Survey: where are the fields?



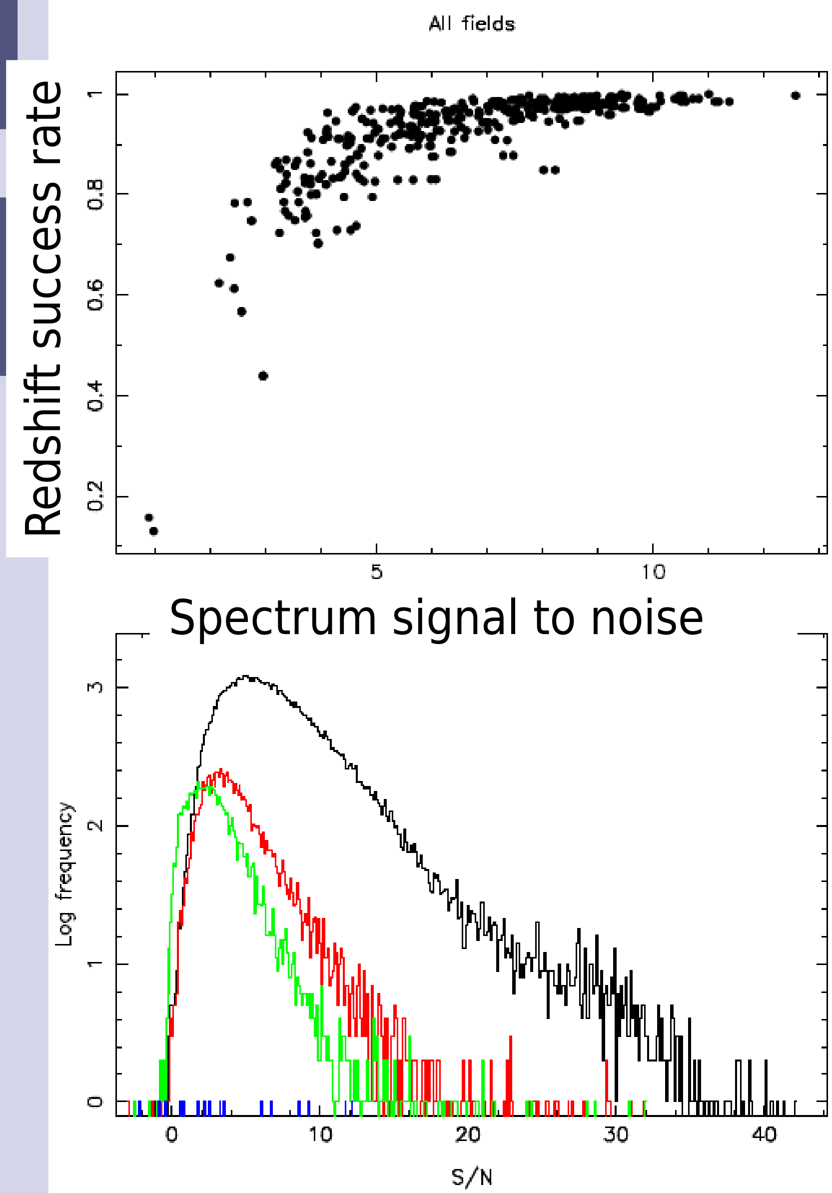
GAMA: Contributing Facilites

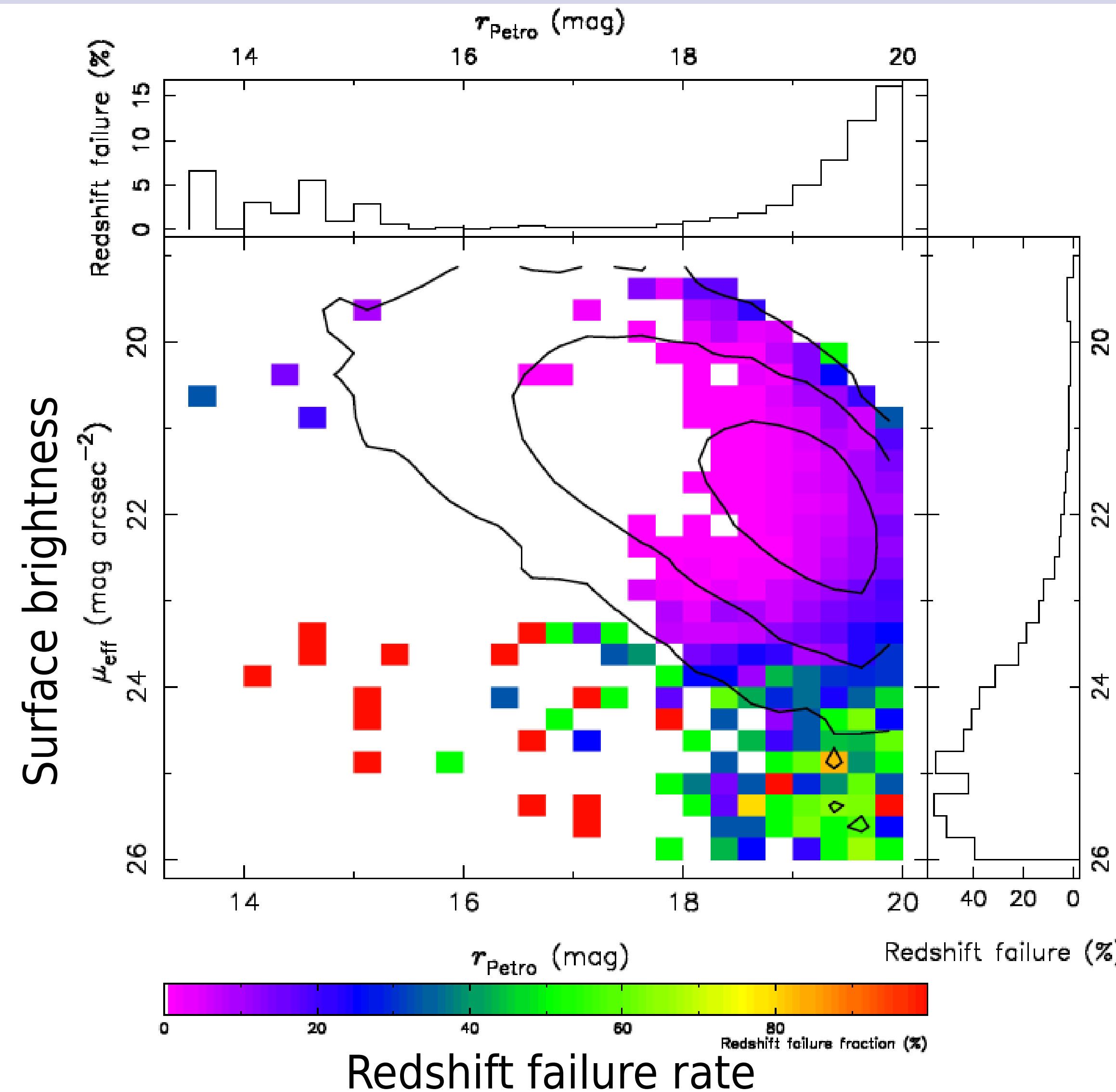


GAMA: (some) follow up observations

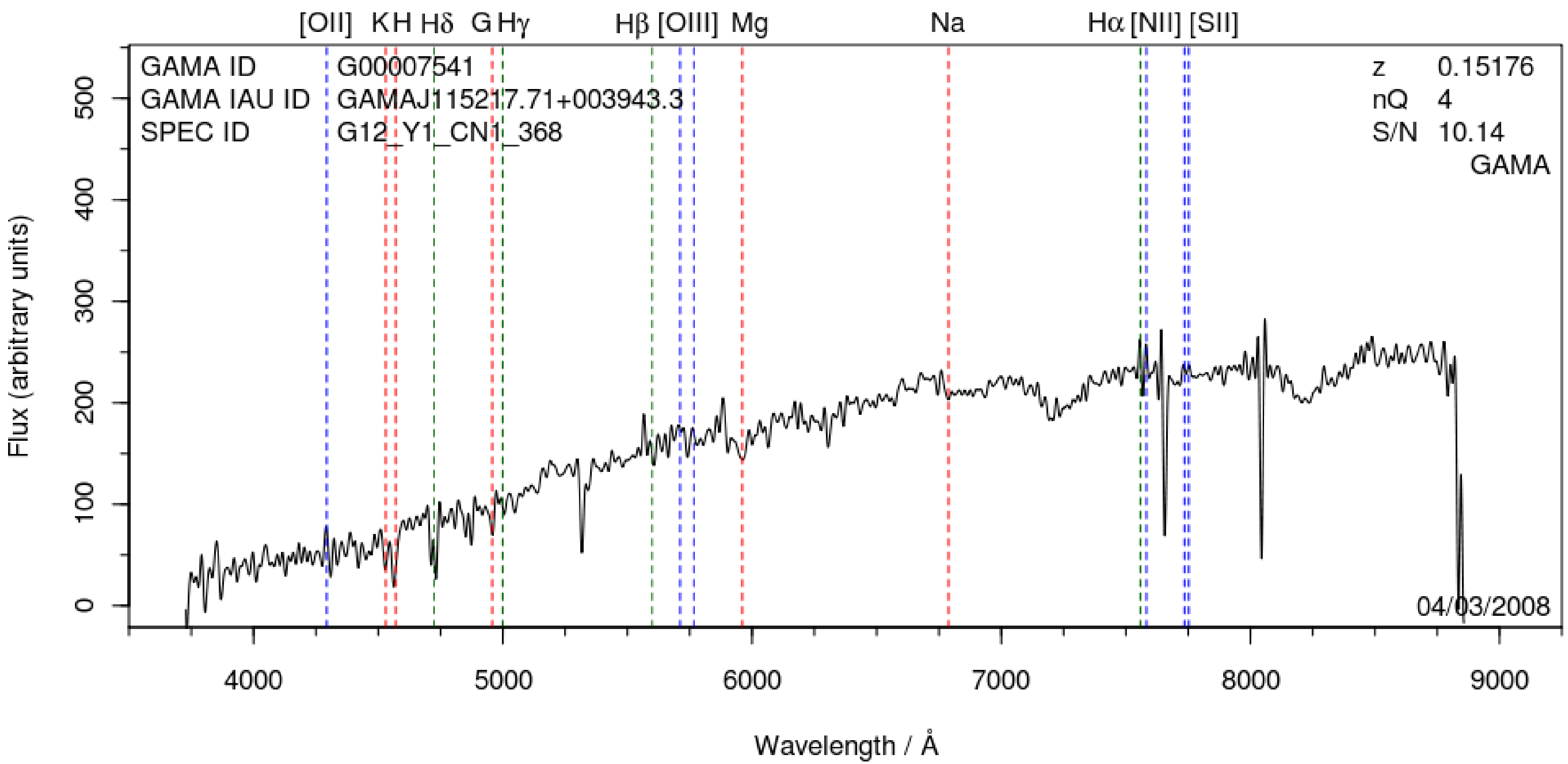
GAMA:	Facility	Wavelength	Time	Depth (on GAMA) (5σ, AB)	Status
	AAT/AAΩ (GAMA I)	Spectra	75nights	r < 19.8, K=17.6 mag	finished
	AAT/AAΩ (GAMA-II)	Spectra	~200nights	r < 19.8, K<17.6 mag	submission (Sept-2010)
	UKIRT (LAS)	Near-IR (YJHK)	35nights	Y=22.0, J=20.9, H=20.2, K=20.4	in progress
	VISTA (VIKING)	Near-IR (YJHK)	75nights	Z=23.8, Y=23.0, J=22.8, K=21.9	in progress
	VST (VST)	Optical (ugriz)	120nights	u=24.8, g=25.4, r=25.2, i=24.2	early 2011
	HERSCHEL (ATLAS)	Far-IR	200hours	100, 160, 250, 350, 500 microns 67, 94, 45, 62, 53 mJy	in progress
	XMM	X-Ray		follow up of GAMA groups	submission (Oct-2010)
	ASKAP (DINGO)	Radio (21cm)	phase-I proposal over 150 sq.deg.		Phase-1 "accepted"

GAMA: Preliminary Results
spectra quality & redshift success rate…



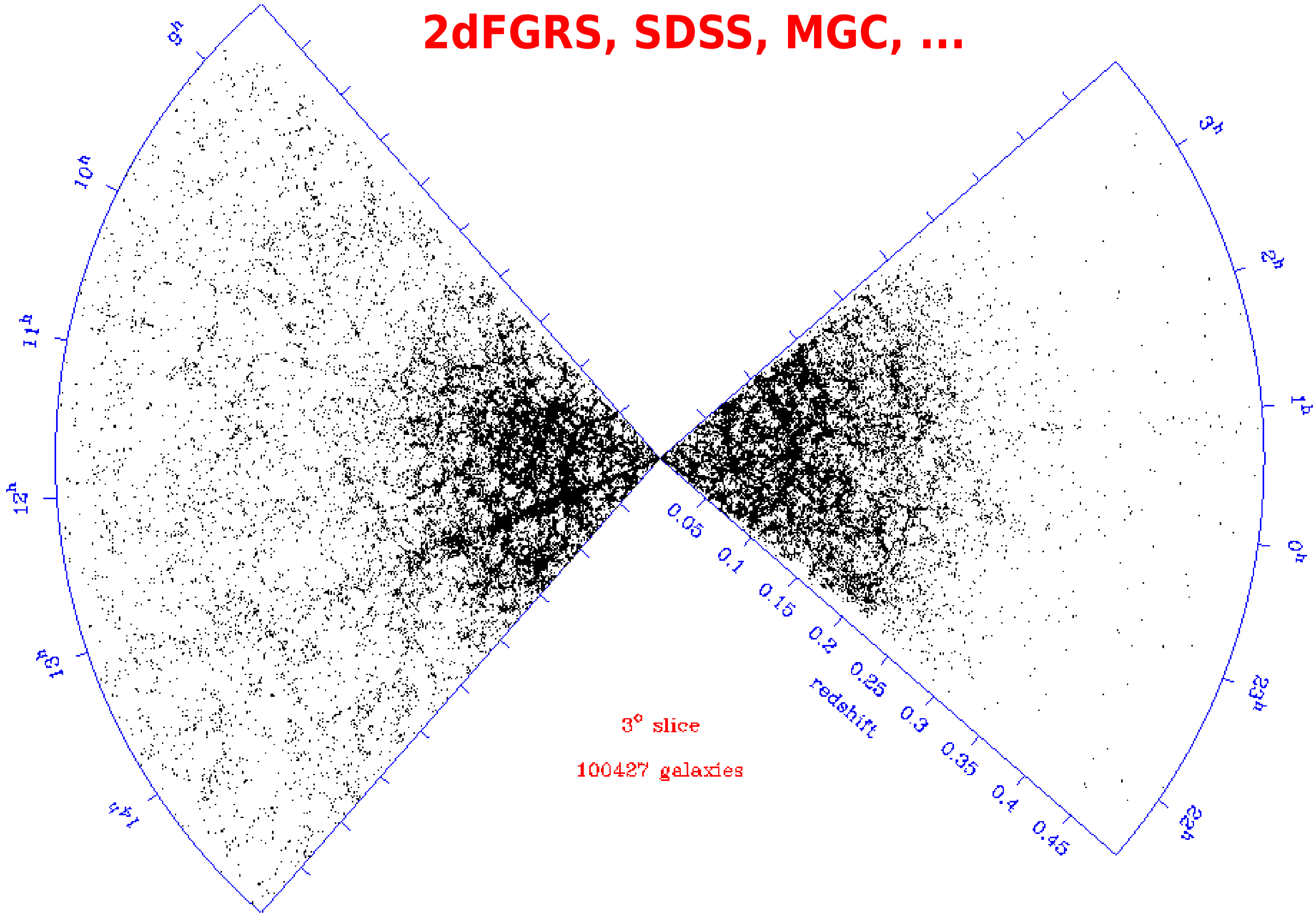


GAMA: example spectra
(improved with PCA sky-subtraction)



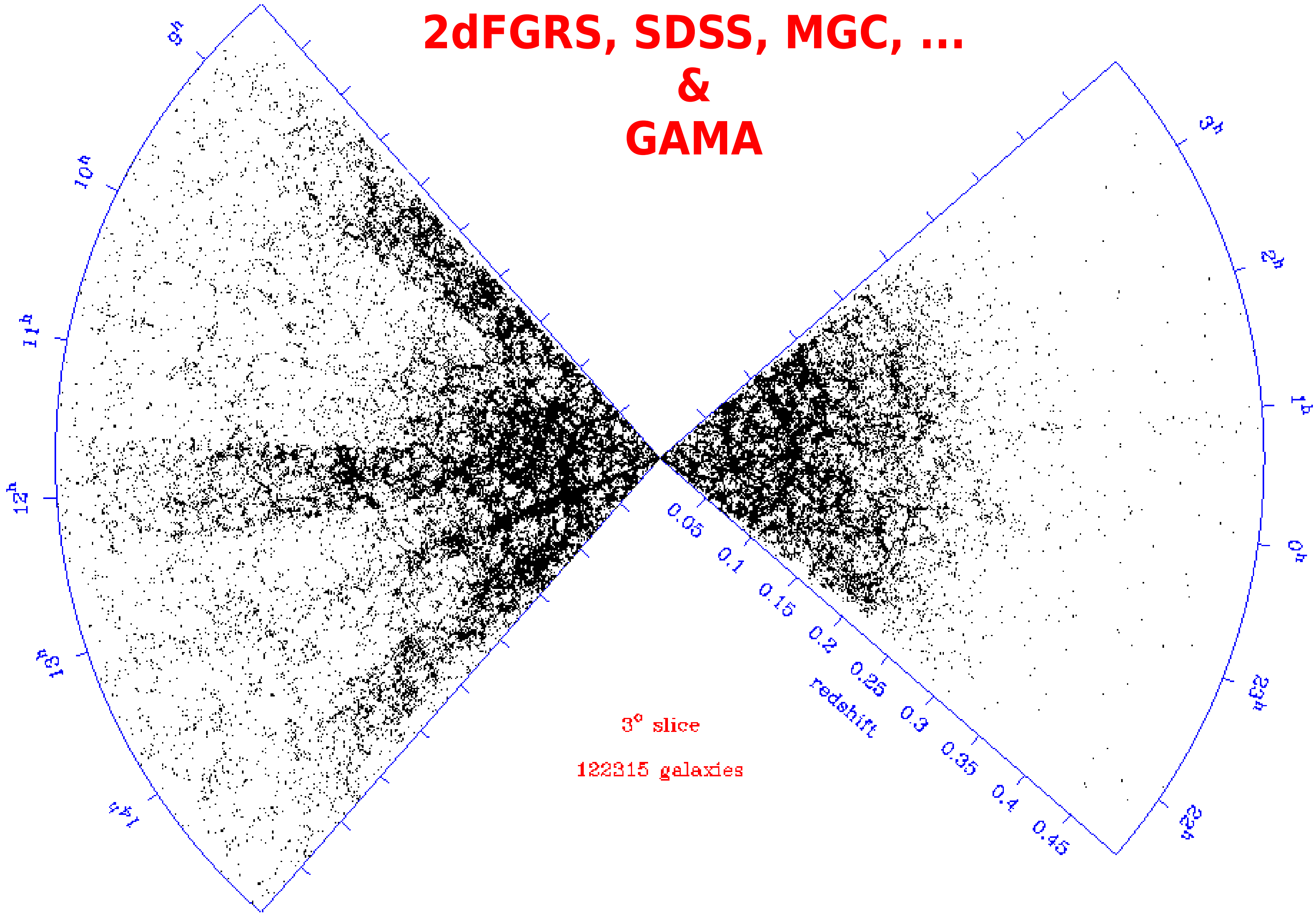
GAMA: Preliminary Results
tracing in detail the large scale structure

2dFGRS, SDSS, MGC, …

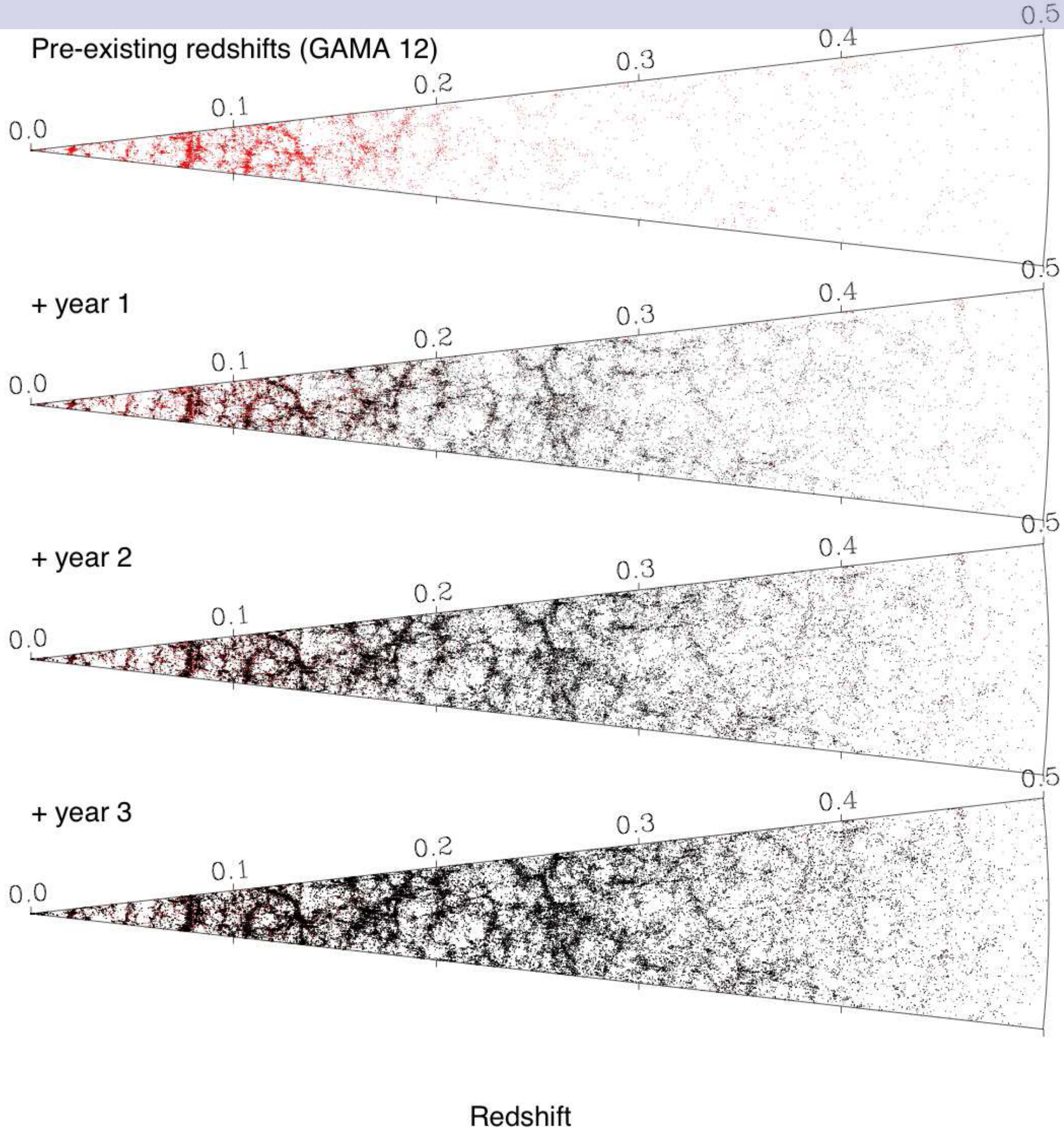


GAMA: Preliminary Results
tracing in detail the large scale structure

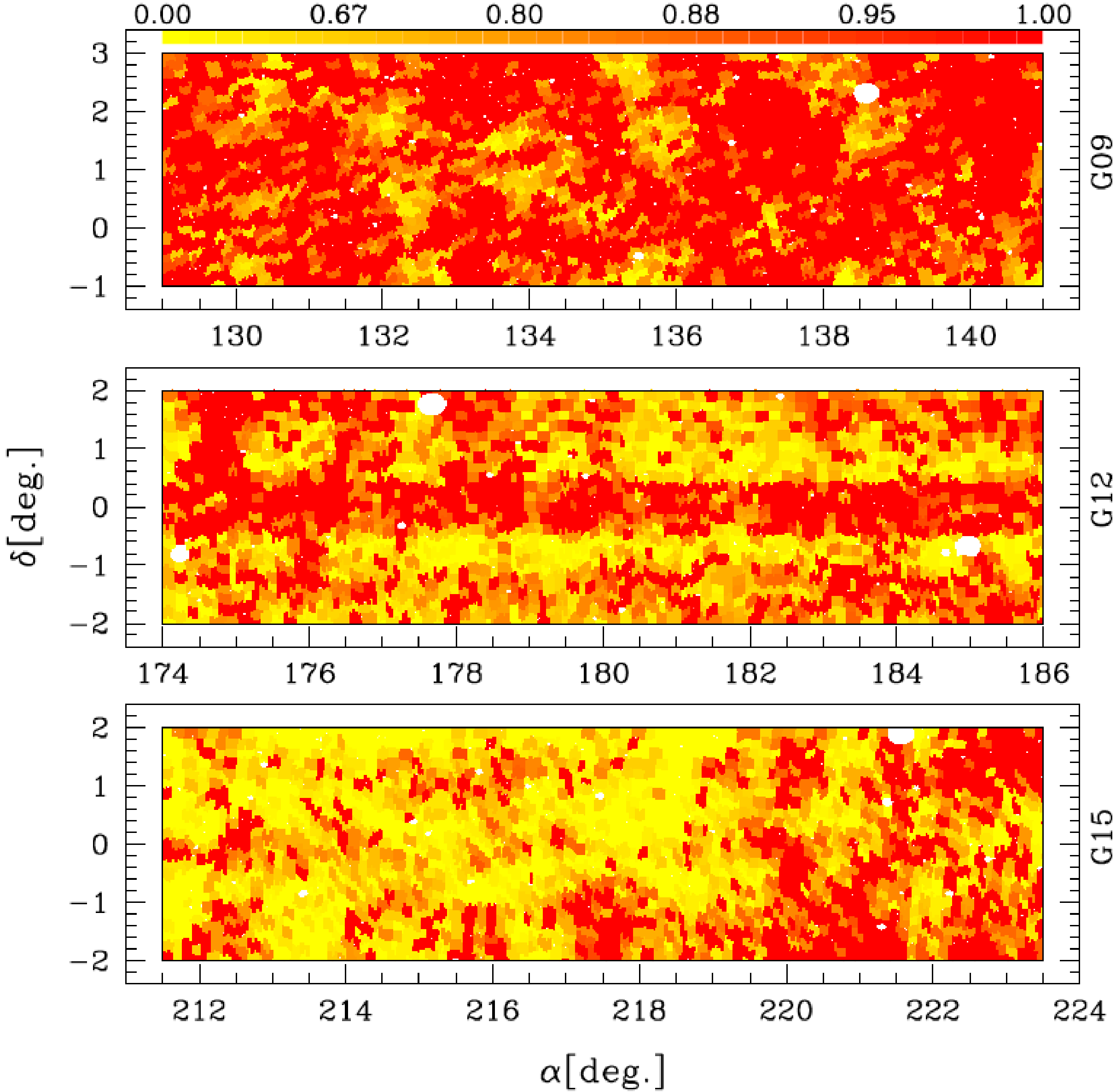
2dFGRS, SDSS, MGC, ...
&
GAMA



GAMA: Preliminary Results
tracing in detail the large scale structure

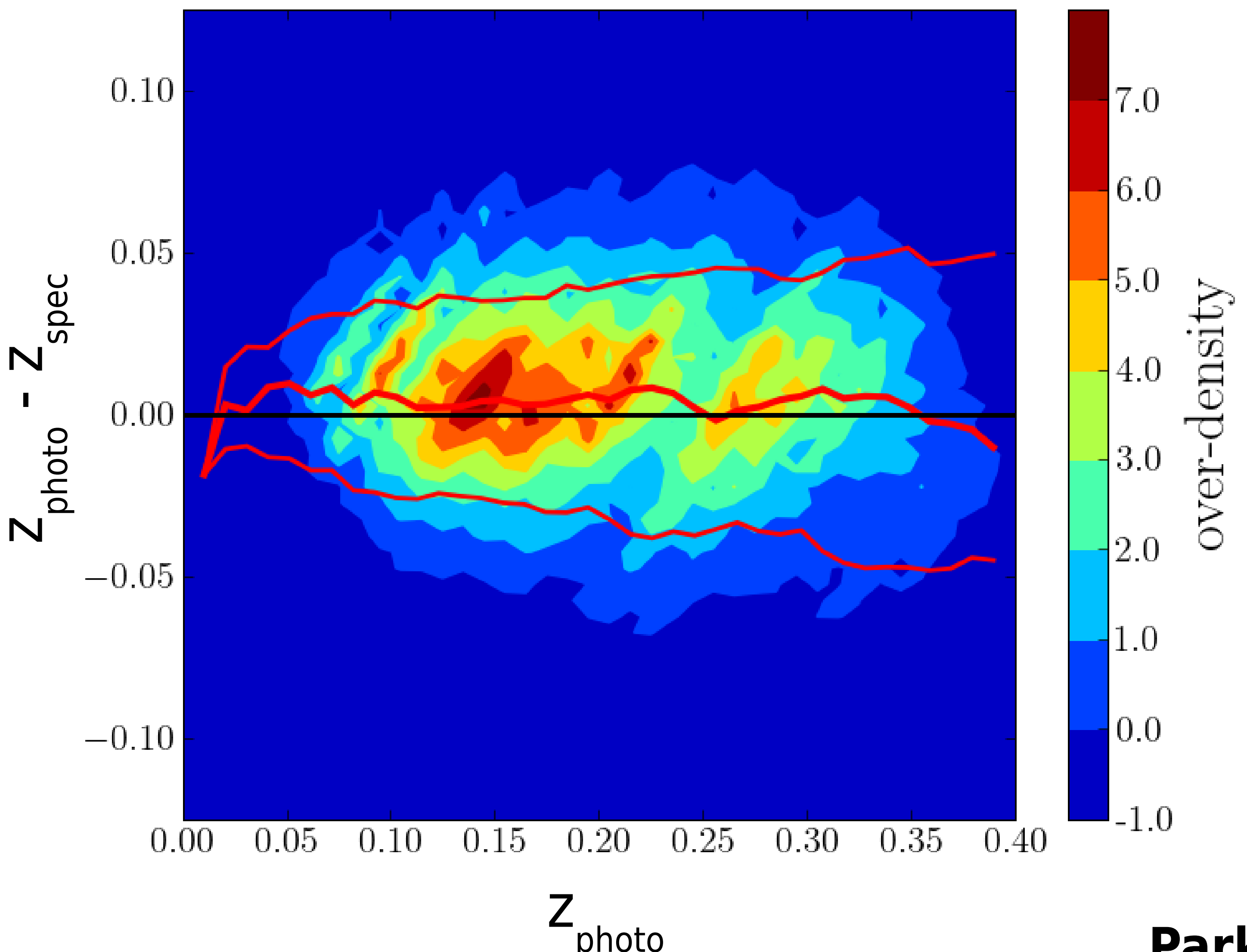


GAMA: Preliminary Results
survey redshift completeness...



$19.0 < r_{AB} < 19.4$

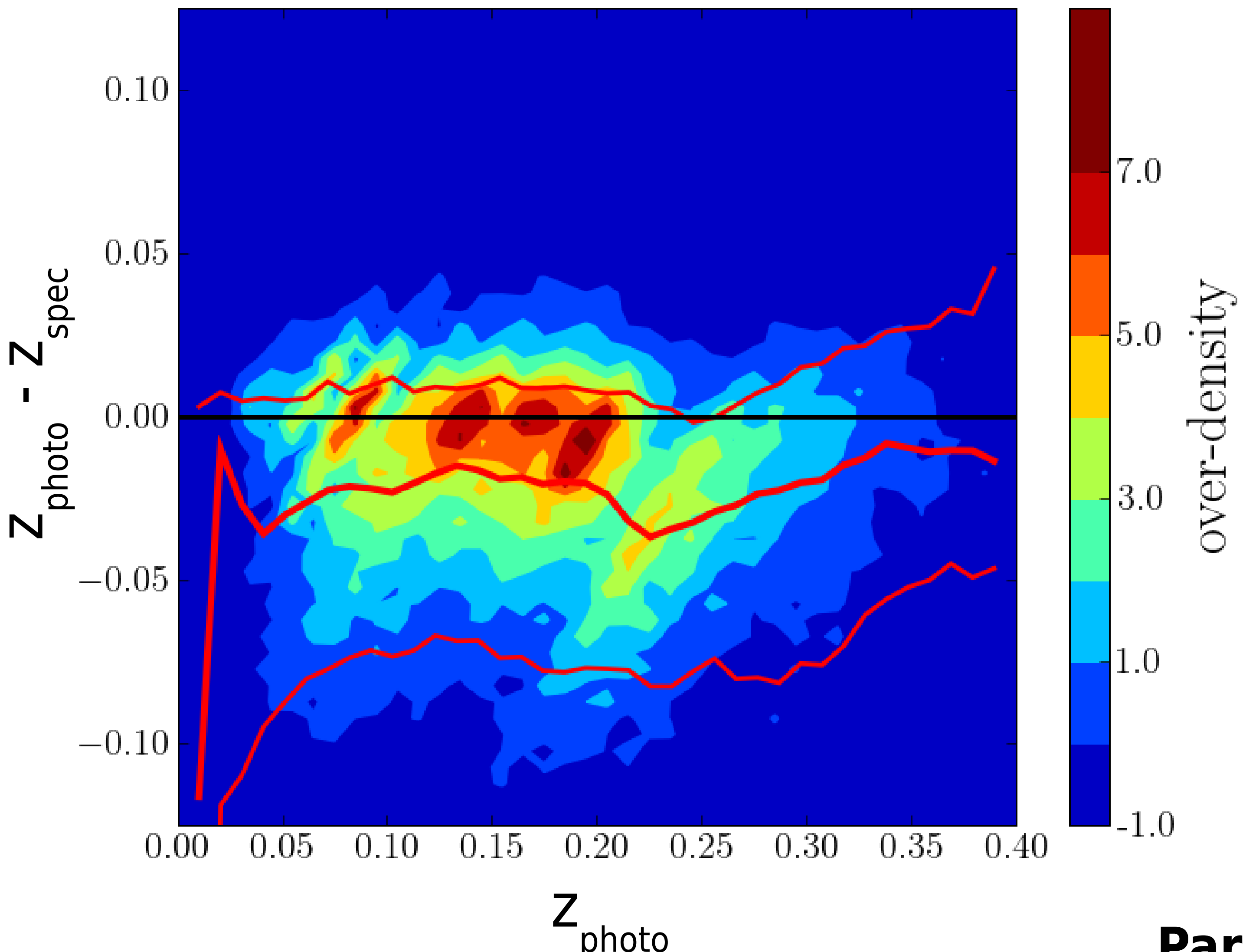
GAMA: Preliminary Results
improved photometric redshifts



GAMA

Parkinson et al.

GAMA: Preliminary Results
improved photometric redshifts

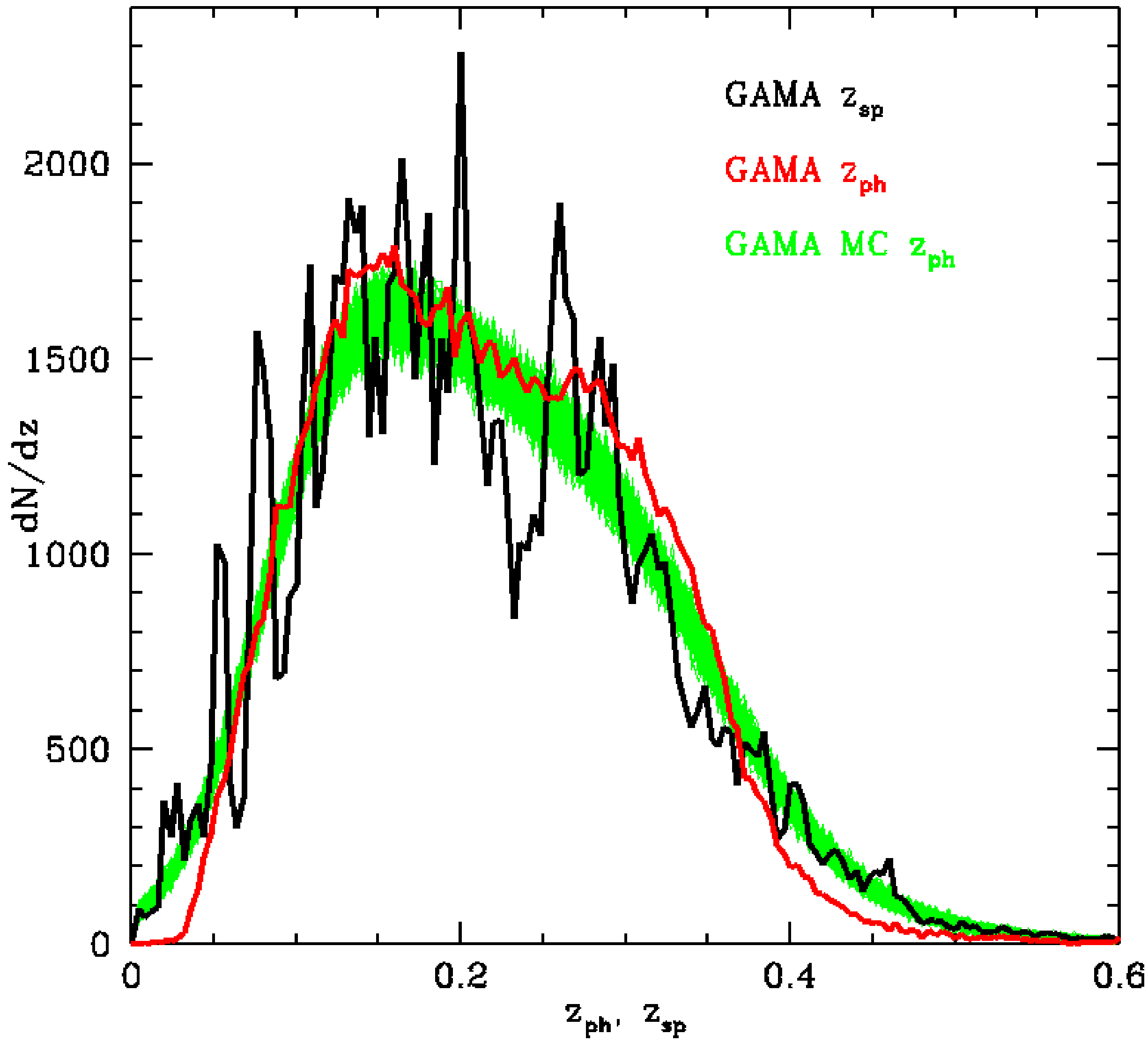


SDSS Photoz

[comparison with Photoz2 in progress]

Parkinson et al.

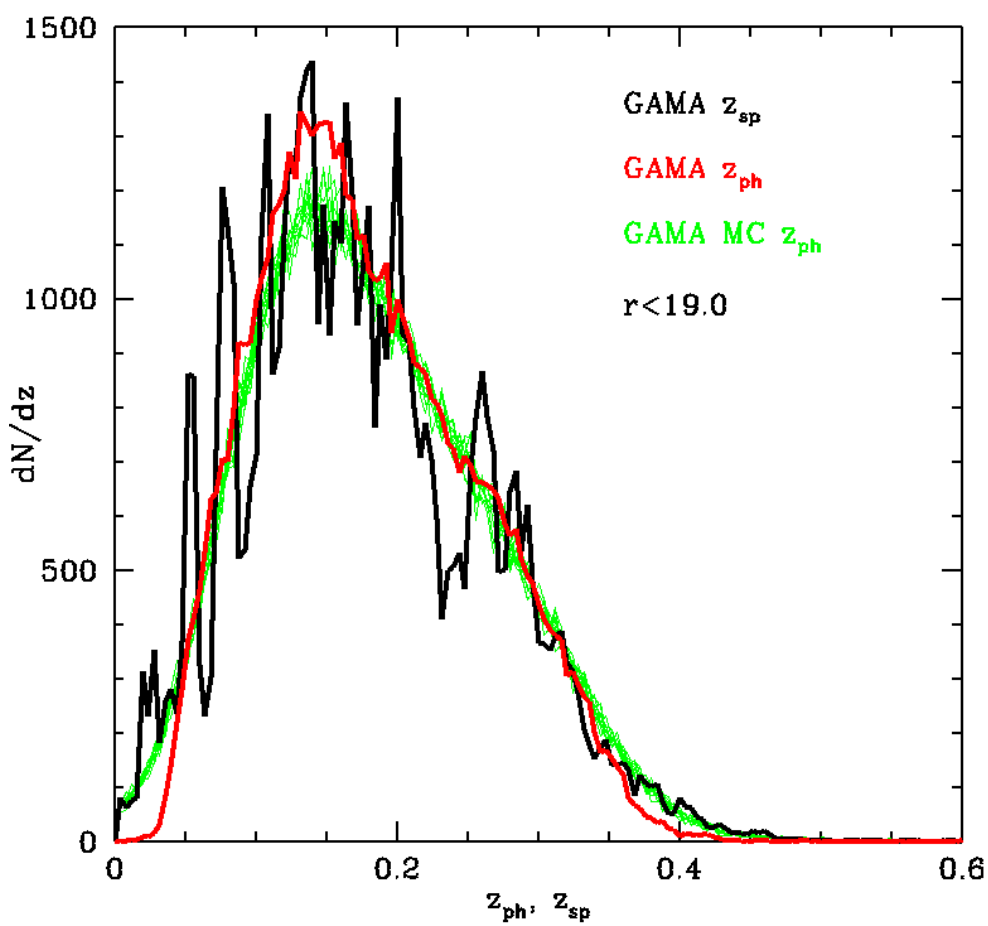
GAMA: Preliminary Results
N(z) for z_{spec} and z_{photo}

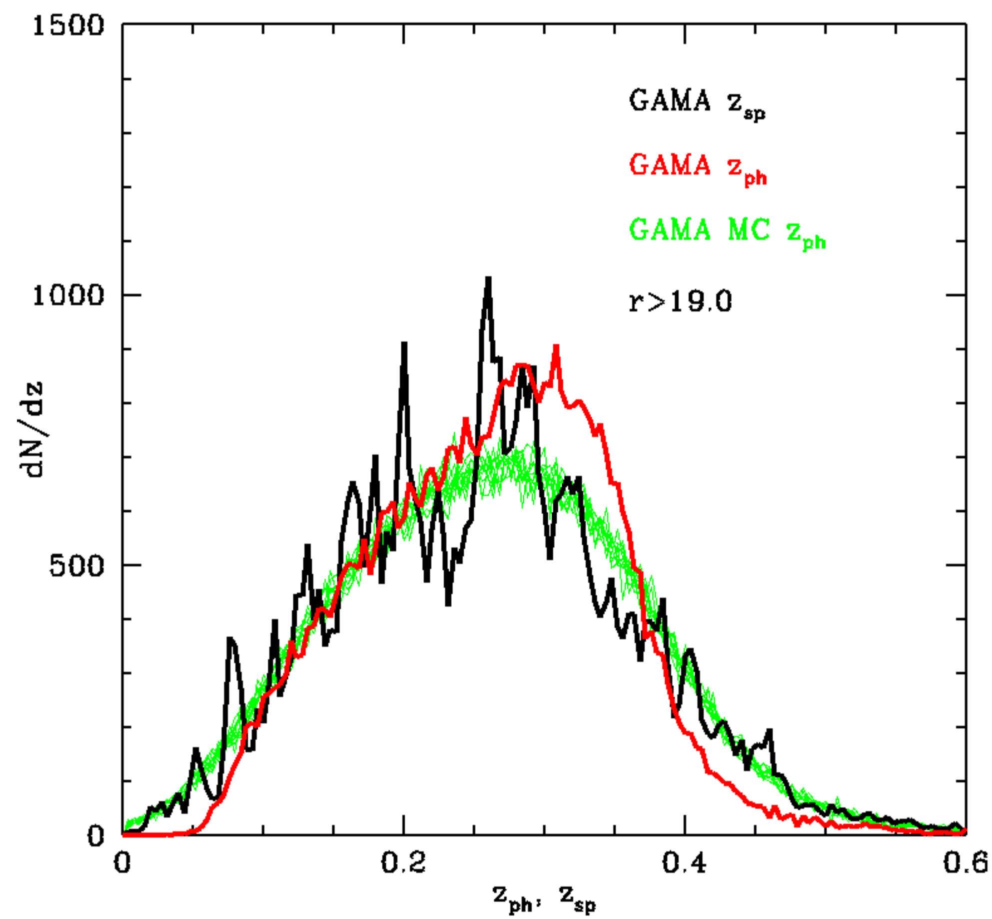


N(z) for the full GAMA sample: Photo-z trained on a representative subset....

Parkinson et al.

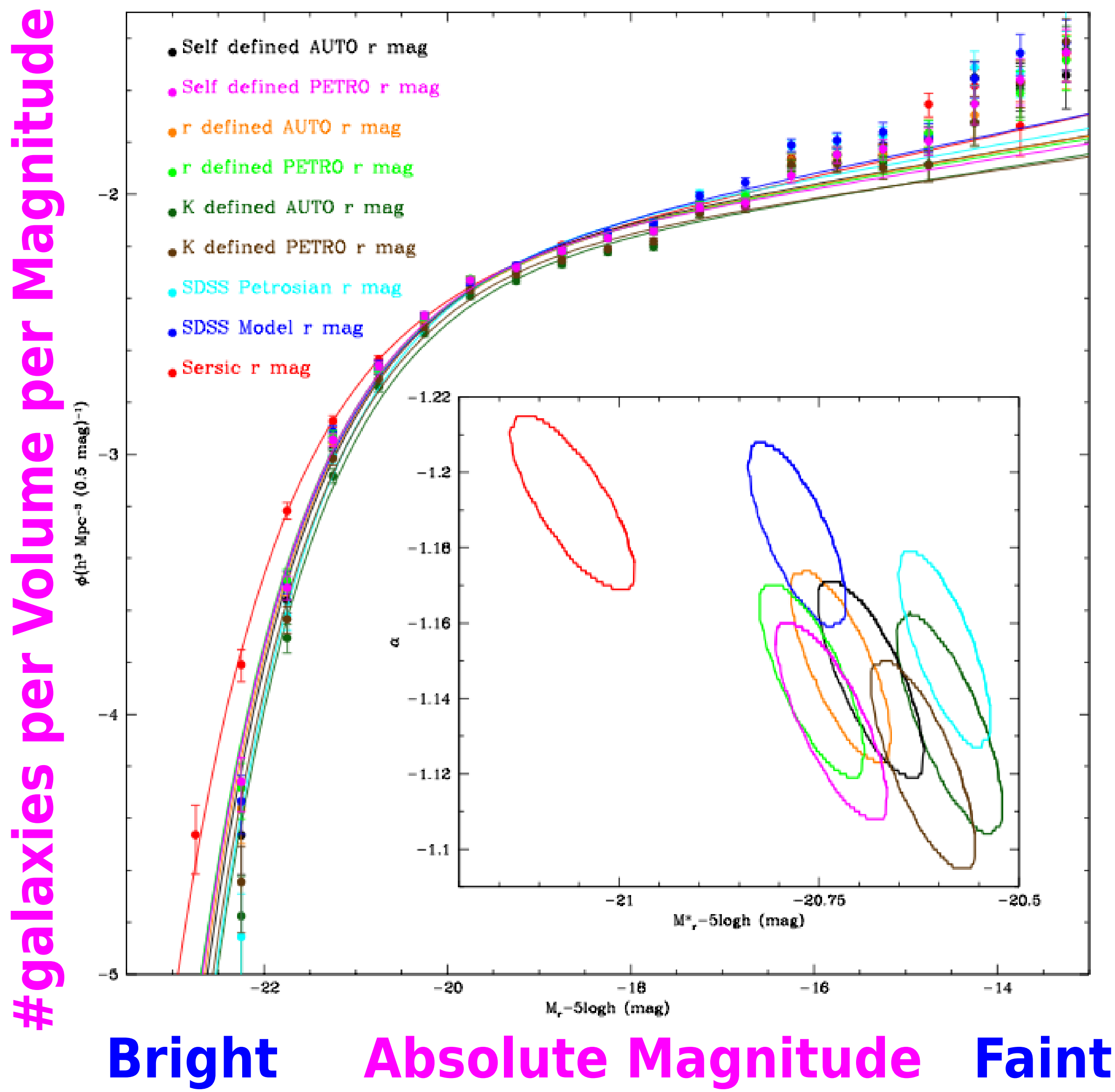
GAMA: Preliminary Results
N(z) for z_{spec} and z_{photo}





Parkinson et al.

GAMA: Preliminary Results
r-band galaxy luminosity function (z<0.1)

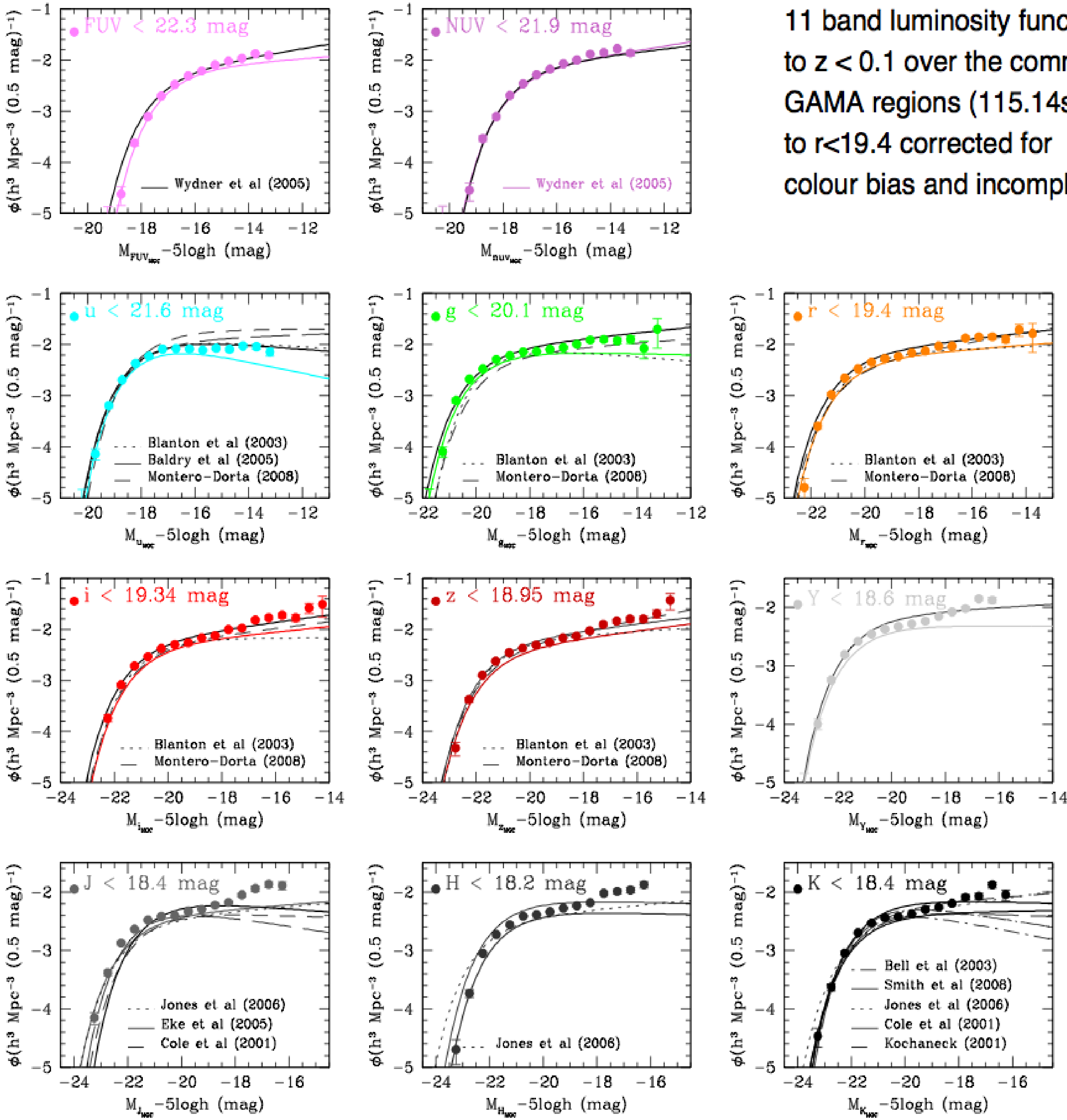


Impact of magnitude definitions

Inset:
schechter function maximum likelihood parameters (α,M*)

Hill et al.

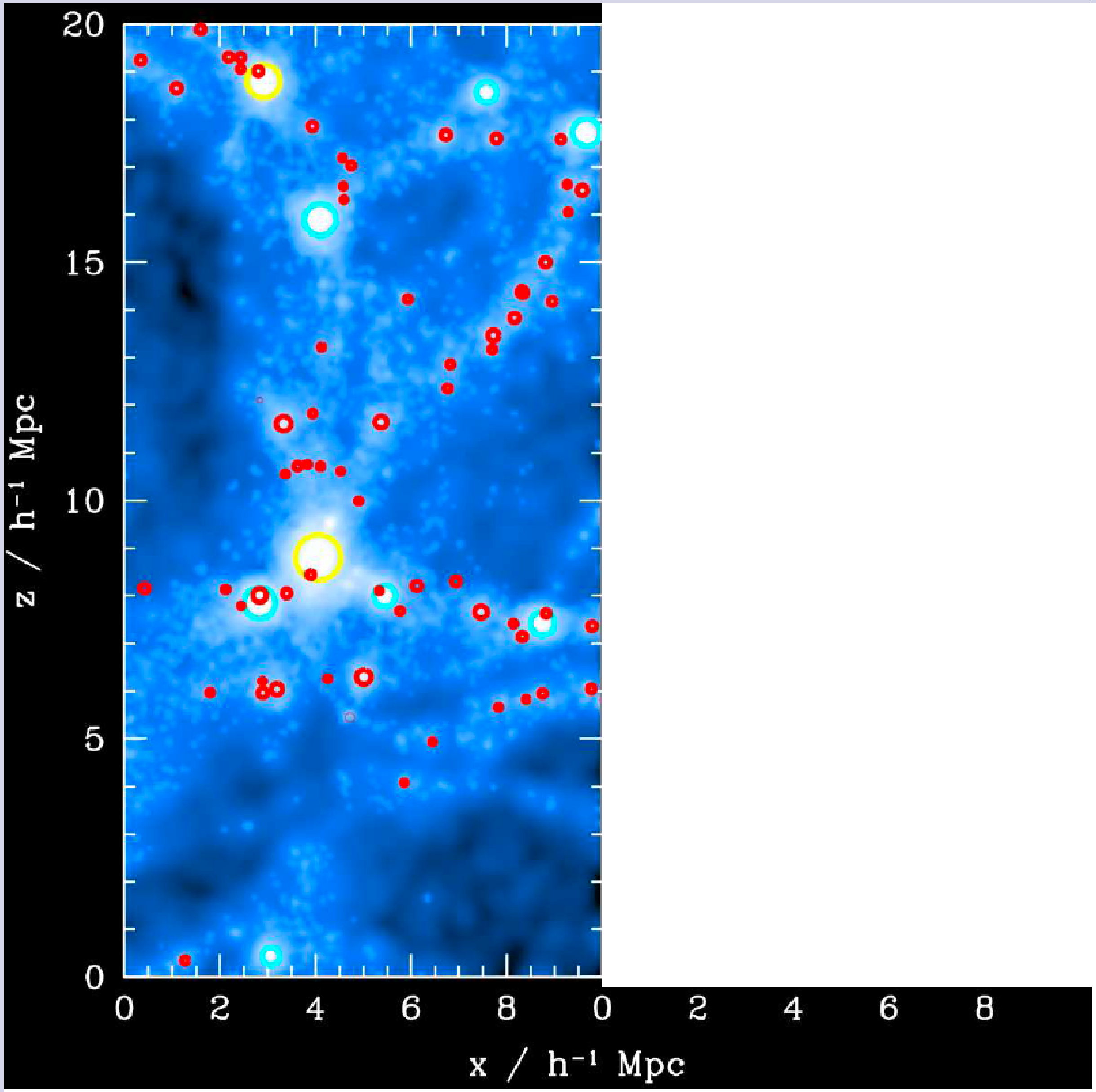
11 band luminosity functions to z < 0.1 over the common GAMA regions (115.14sq deg) to r<19.4 corrected for colour bias and incompleteness



Driver et al.

GAMA: Preliminary Results

Mock GAMA Galaxy Group (G^3) catalogue



Example of a 4 Mpc/h thick slice of a mock GAMA galaxy catalogue:

- HOD/CLF
- modified semi-analytic (Durham/Munich)

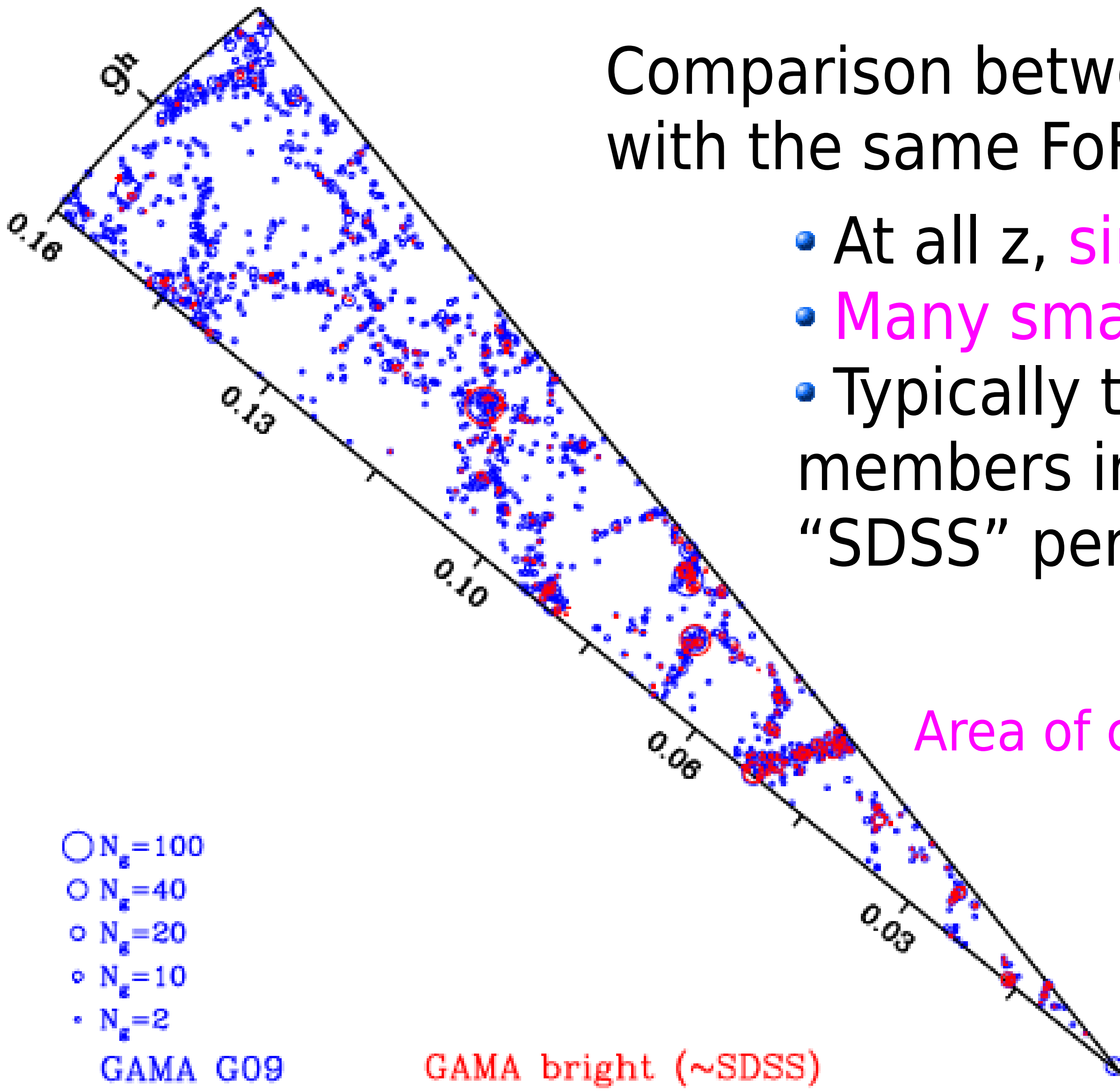
Halo ~ 10^{14} Msol/h

Halo ~ 10^{13} Msol/h

Halo ~ 10^{12} Msol/h

Halo ~ 10^{11} Msol/h

GAMA: Preliminary Results
GAMA Galaxy Group (G^3) catalogue

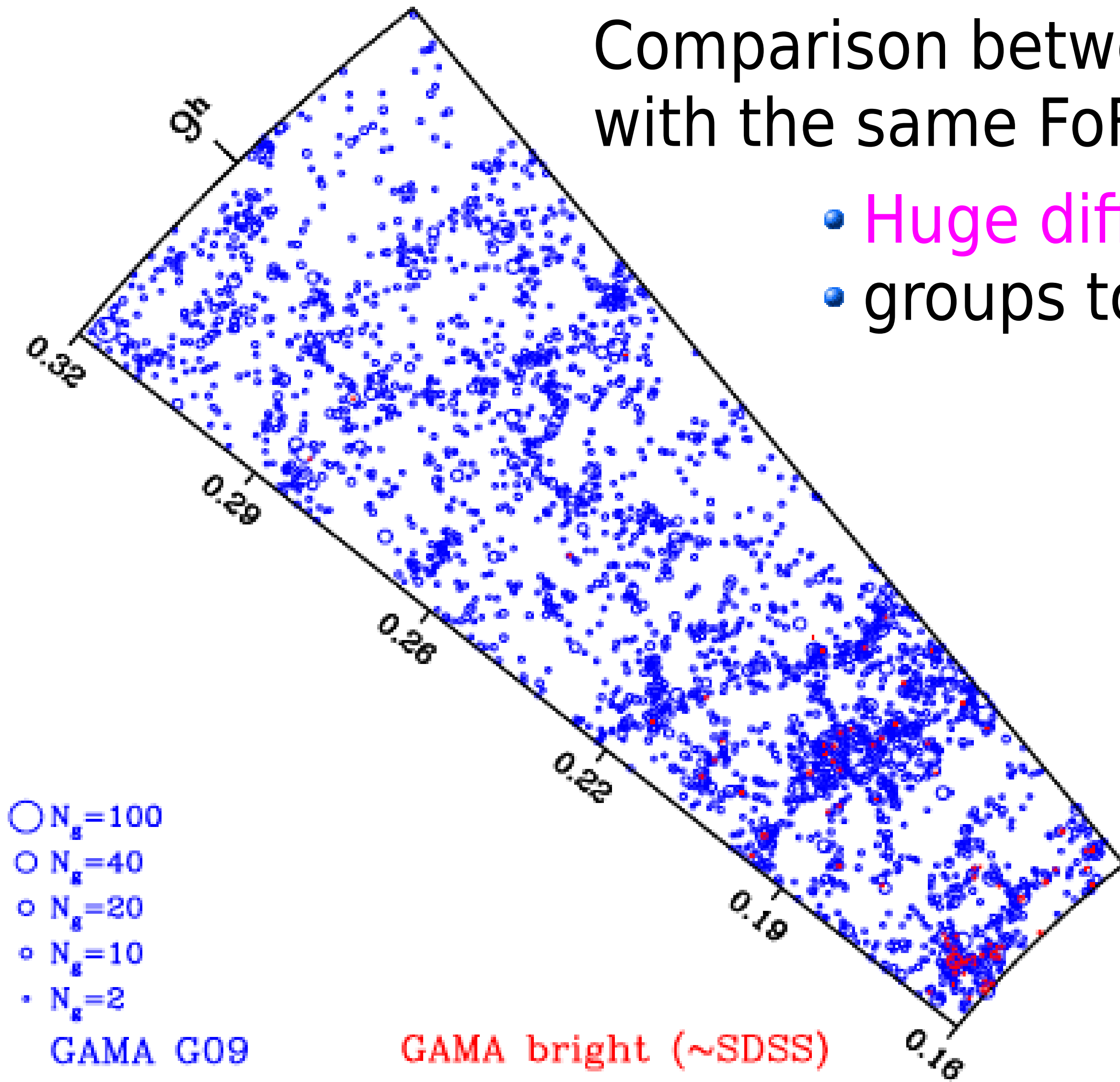


Comparison between GAMA & "SDSS" with the same FoF group finder:

- At all z, similar structures found
- Many smaller groups with GAMA
- Typically twice as many group members in GAMA as with "SDSS" per group.

Area of circle ~ # of group member

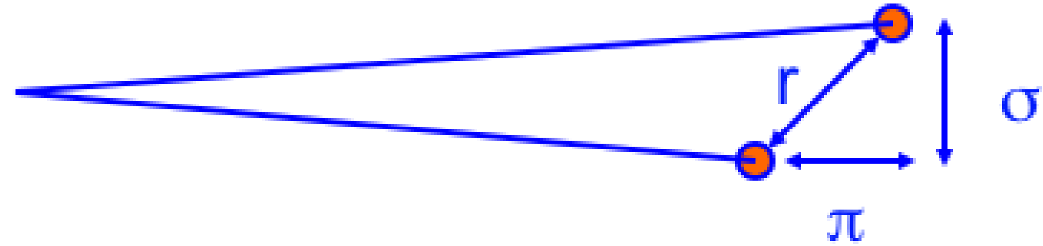
GAMA: Preliminary Results
GAMA Galaxy Group (G^3) catalogue



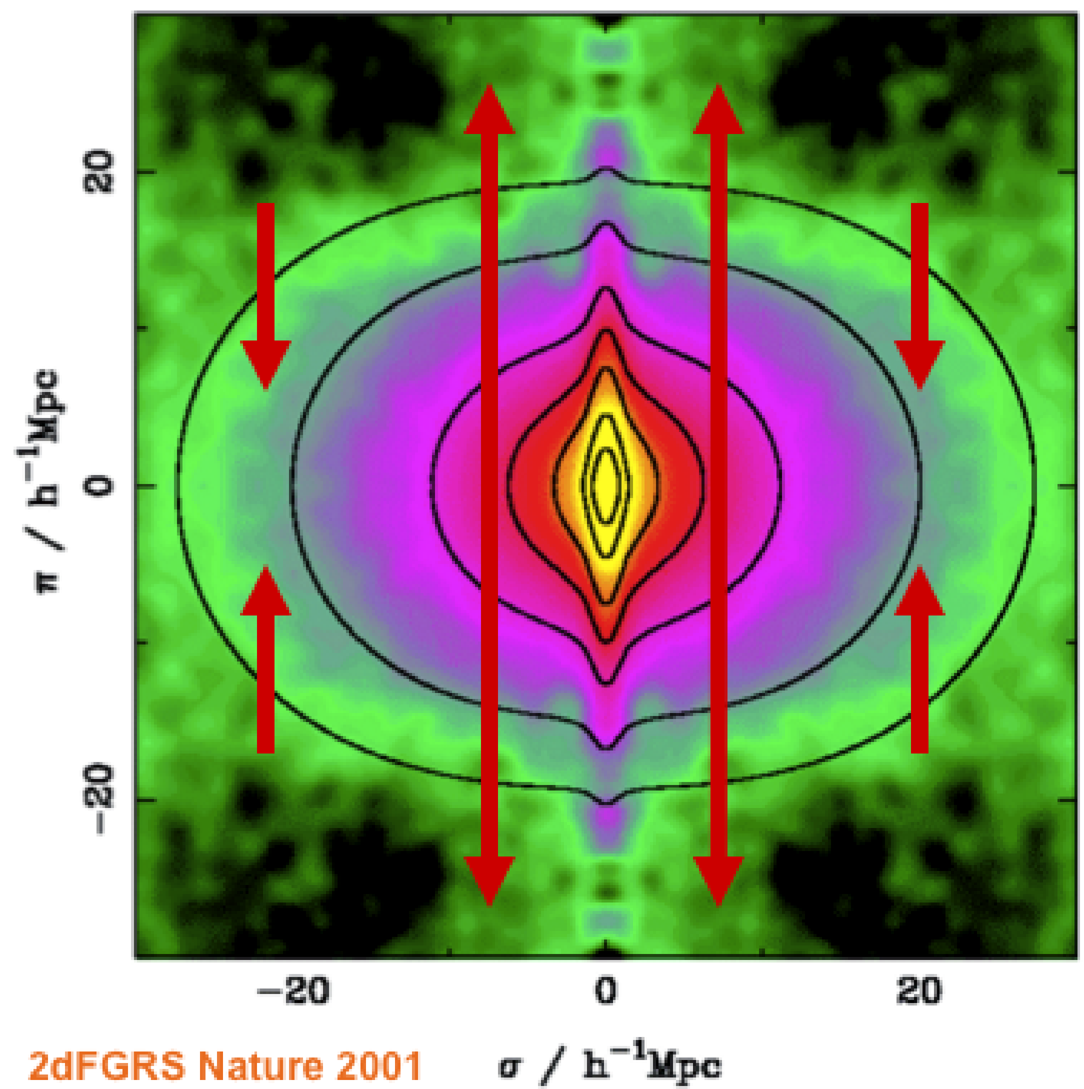
Comparison between GAMA & "SDSS" with the same FoF group finder:

- Huge difference for z>0.15!
- groups to z~0.4 with GAMA.

Redshift-Space Distortions



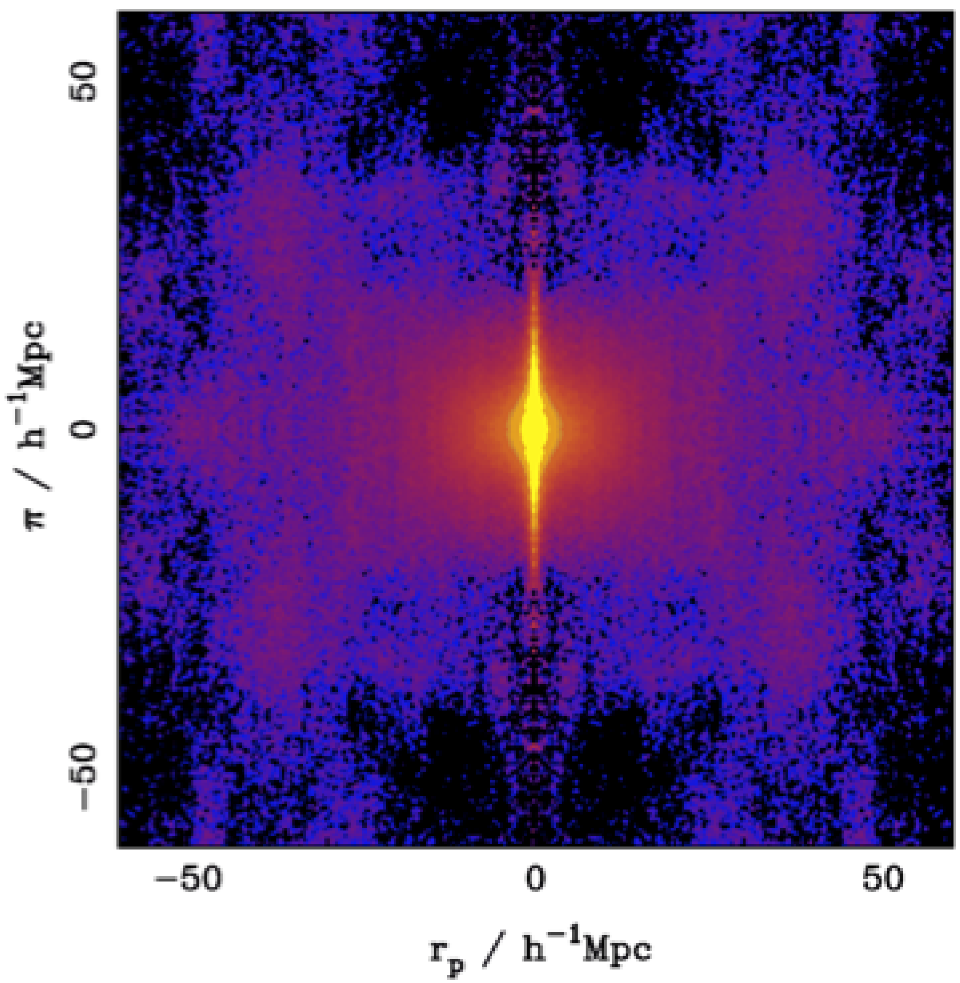
- RSD due to peculiar velocities are quantified by correlation fn $\xi(\sigma,\pi)$.
- Two effects visible:
  - Small separations on sky: 'Finger-of-God';
  - Large separations on sky: flattening along line of sight.



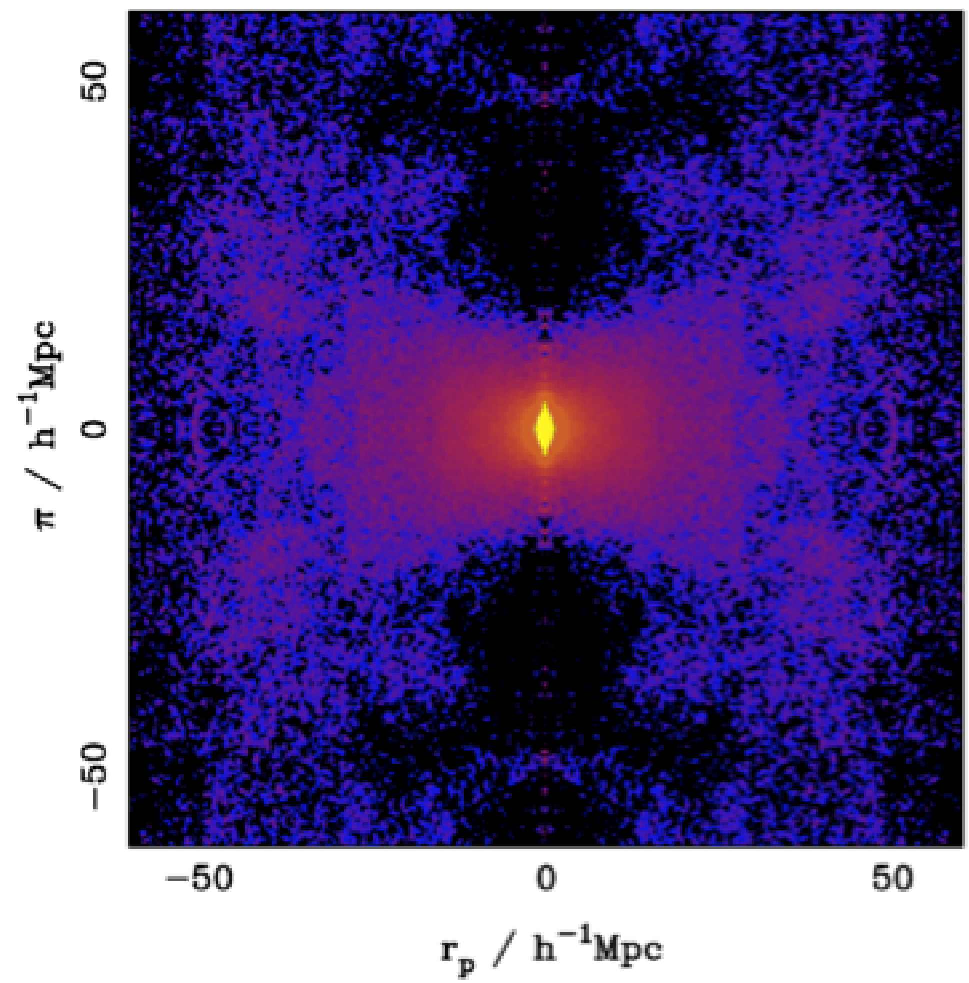
2dFGRS Nature 2001

GAMA: Preliminary Results

Clustering & Redshift Space Distortions



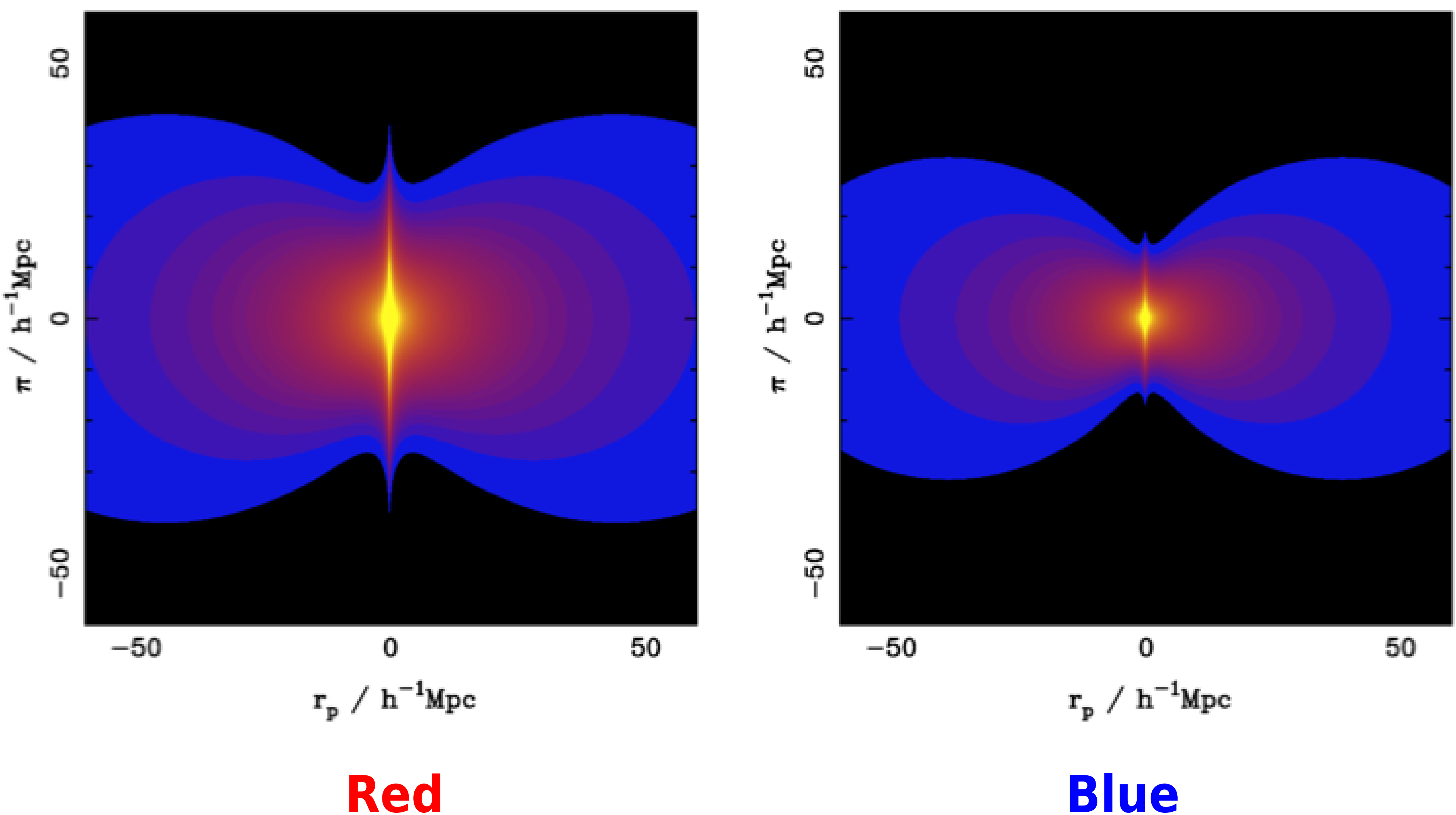
Red



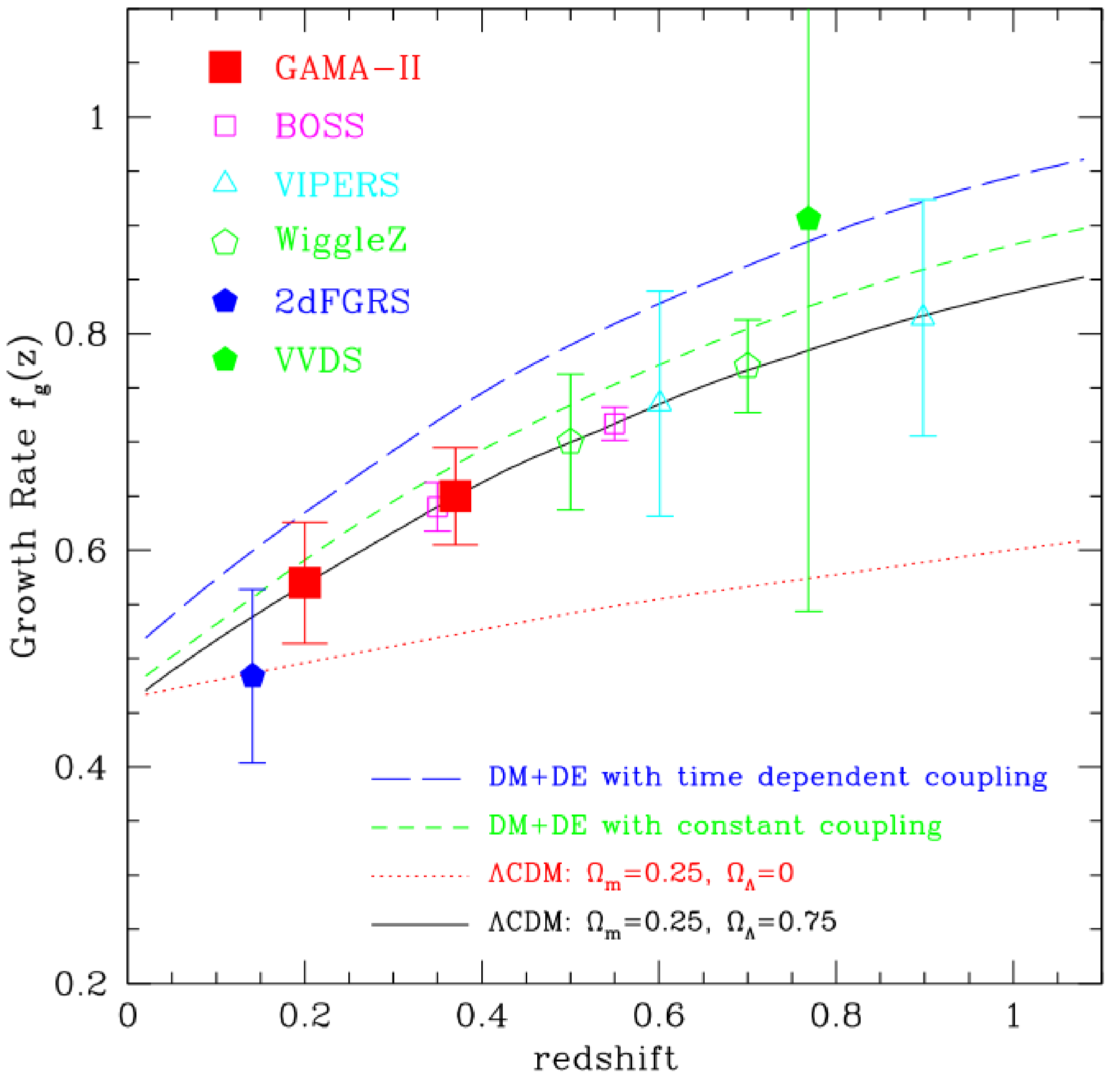
Blue

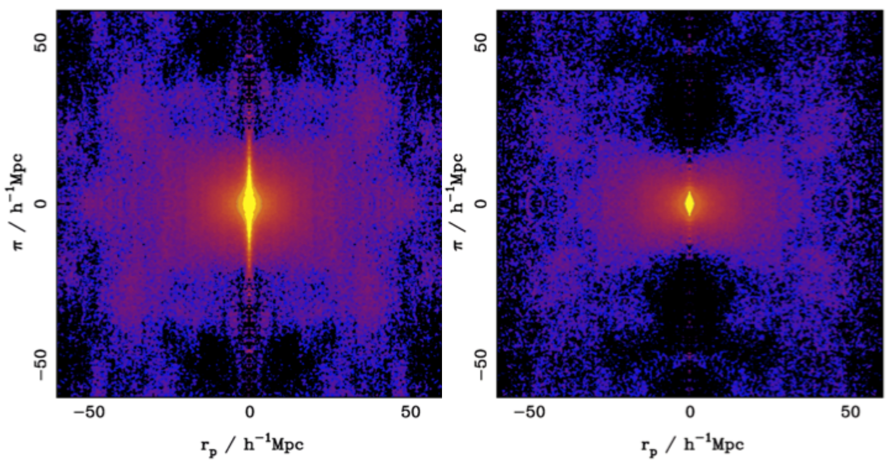
GAMA: Preliminary Results

Clustering & Redshift Space Distortions



Galaxy And Mass Assembly: Growth rate (predictions)





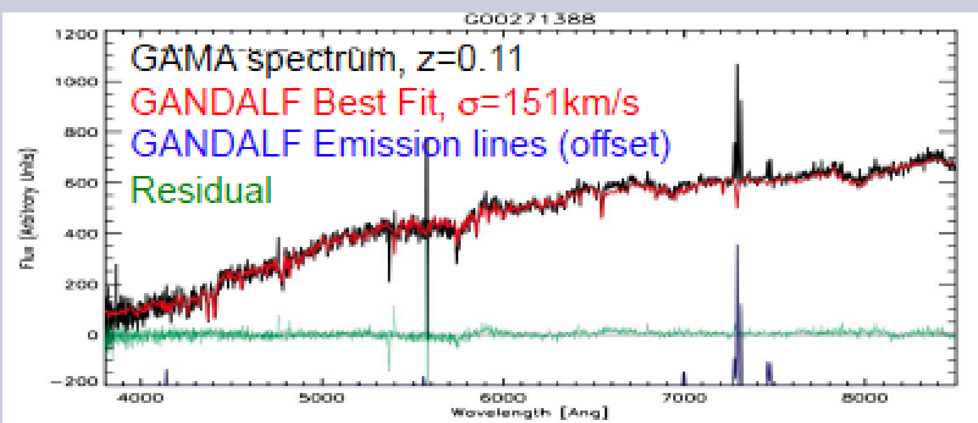
$$f_g(z) = \mathrm{dln}\delta/\mathrm{dln}a \simeq \Omega_m^{\gamma}(z)$$

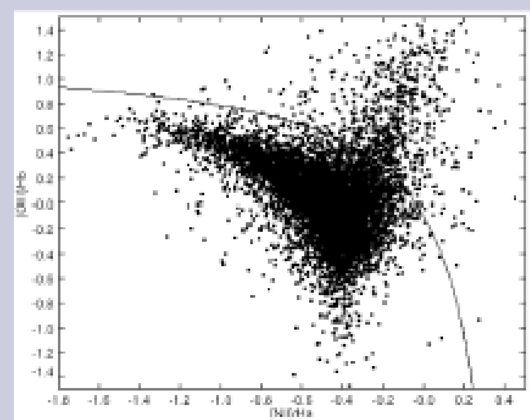
Plot to be updated to:
$f_g(z)\, \sigma_8(z)$

GAMA: THE DATABASE (I)

All (~250k):

- General: GAMA ID : SDSS ID : z (heliocentric) : z quality
- Flux: UV : optical : near-IR : mid-IR : far-IR : Radio (20,rest-21,30,40,90cm)
- Shape: CAS : Sersic index: half-light radii : b/a : PA in *ugrizYJHK*
- Opacity: $\tau_{UV,ugriz,YJHK}$
- Spectral features: Emission: $H\alpha$,$H\beta$,$H\gamma$,$H\delta$,OII,OIII,NII
  Abs.: Dn4000,Ca4227,$H\alpha$,$H\beta$,$H\gamma$,$H\delta$,Mgb,Fe
- SFR: UV : $H\alpha$: far-IR : Radio continuum
- Fossil record: Age : SFH : element abundance
- AGN: BPT diagnostics : type : strength : ionisation state
- Dynamics: σ_{spec} (GANDALF) : W_{21}: HI line profile
- Distances: Tully-Fisher : Faber-Jackson
- Masses: Stellar : SMBH : HI : Dust : Baryon : Dynamical
- Environment/Halo: Local density : Group membership : Group halo mass





GAMA: THE DATABASE (II)

For z<0.1 (~30k):

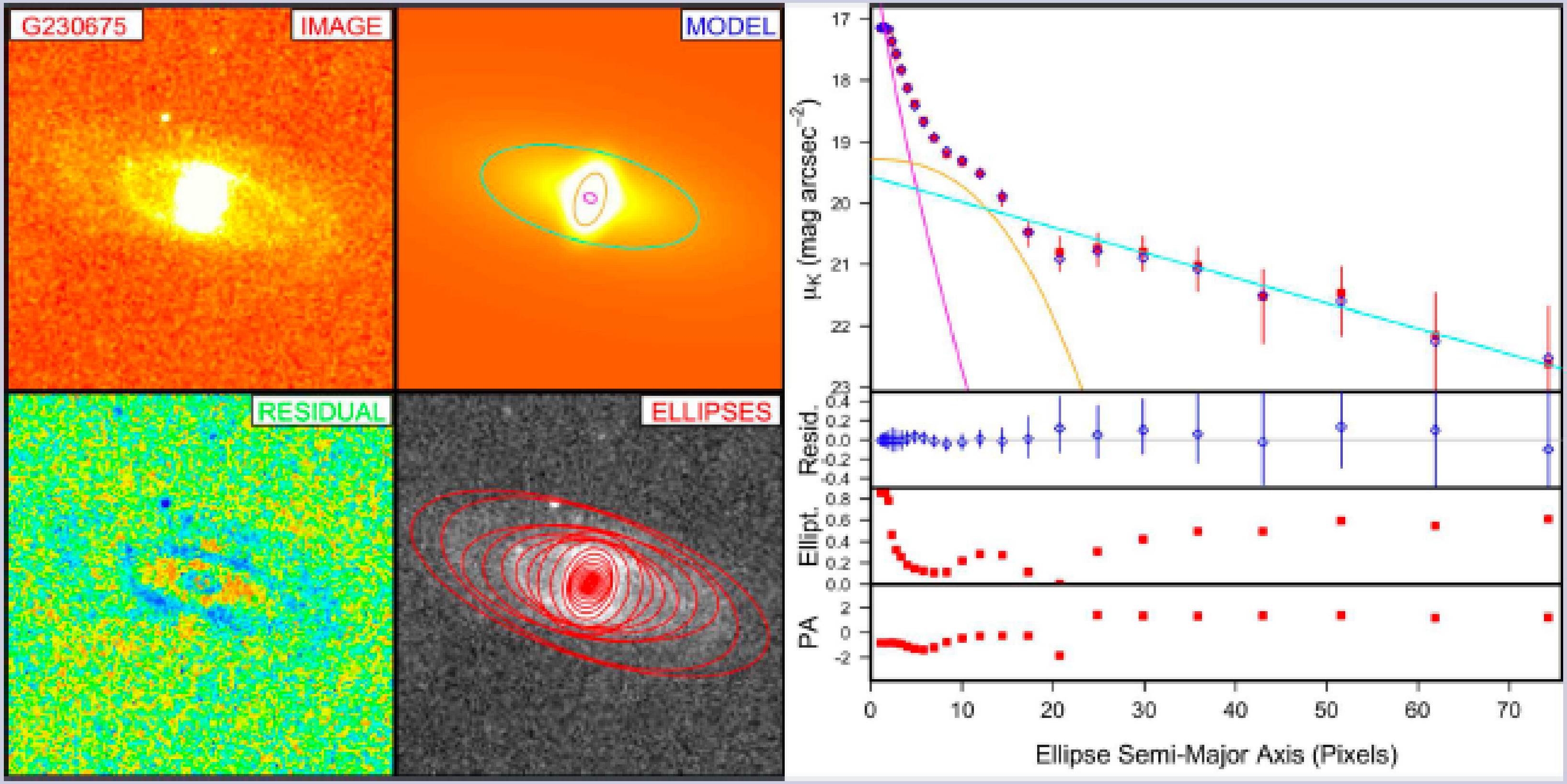
Structural: Bulge/Bar/Disc decomp. in *ugrizYJHK* (GALFIT3)

Bulge: Sersic index, half light radius, Pos. Angle, Ellipticity

Bar: Sersic index, half light radius, scale-length

Disc: Scalelength, PA, b/a

SMBH Mass: via M-σ, M-L , M-n relations



GAMA: Galaxy And Mass Assembly
Team Structure

WORKING GROUPS

SCIENCE	CATS	DATABASE	OBS	MOCK/THEORY	RADIO	SPEC. P.	IMAGE P.
Peacock (ROE)	Baldry (LJMU)	Liske (ESO)	Driver (PI, StA)	Norberg (ROE)	Hopkins (Sydney)	Loveday (Sussex)	Bamford (Nott.)

TEAM MEMBERS (now incomplete...)

Bland-Hawthorn (Sydney)
Croom (Sydney)
Frenk (Durham)
Kuijiken (Leiden)
Nichol (Portsmouth)
Proctor (Swinburne)
Sutherland (QMUL)
Warren (Imperial College)
Cameron (StA, ETH)

Couch (Swinburne)
Cross (ROE)
Graham (Swinburne)
Lahav (UCL)
Phillipps (Bristol)
Sharp (AAO)
Tuffs (MPIK)
Robotham (StA)
Thomas (ICG)

Concelice (Nottingham)
Edmondson (Portsmouth)
Jones (AAO)
Oliver (Sussex)
Popescu (UCLan)
Staveley-Smith (UWA)
van Kampen (Innsbruck)
Ellis (Sydney)
Brough (AAO)....

More than 5 PhD students: Hill & Kelvin (StA), Parkinson (ROE), Prescott (LJMU), Gunawardhana (Macquarie U), Wijesinghe (Sydney)...

TEAM AFFILITATIONS

UKIRT/LAS, VST/KIDS, VISTA/VIKING, HERSCHEL/ATLAS, ASKAP/DINGO, DURHAM ICC

Galaxy And Mass Assembly: The next steps....

- GAMA-II:
  - Galaxy formation and large scale structure survey:
    - ~360 sq. deg.: ~200 sq.deg. at δ~0 (mostly GAMA-I) & ~160 at δ~-30.
    - 2 mags deeper than SDSS & 4 mags deeper than 6dFGS
    - Multi-wavelength: AAT, VST, VISTA, HERSCHEL (XMM, SCUBA II, ASKAP)
  - Comprehensive study of matter and energy on Mpc to kpc scales z < 0.5

- GAMA-II and the large scale structure case:
  - Groups: Halo Mass Function, Galaxy Formation Efficiency, X-ray follow up...
  - Environmental studies: from voids to clusters as function of redshift!
  - Growth rate of structure, $f_g(z)$, and $\gamma(z)$ from the GAMA survey!

- GAMA-II and the multi-wavelength case (~15 bands):
  - SMF, SFH, SFR, ... as function of X...
  - Structural decomposition into bulge, bar, disk, … in multiple (optical) bands
  - Herschel/ATLAS and ASKAP/DINGO fields → Far-IR and H_I Universe

An objective way to quantify the impact of superstructures

Motivation:

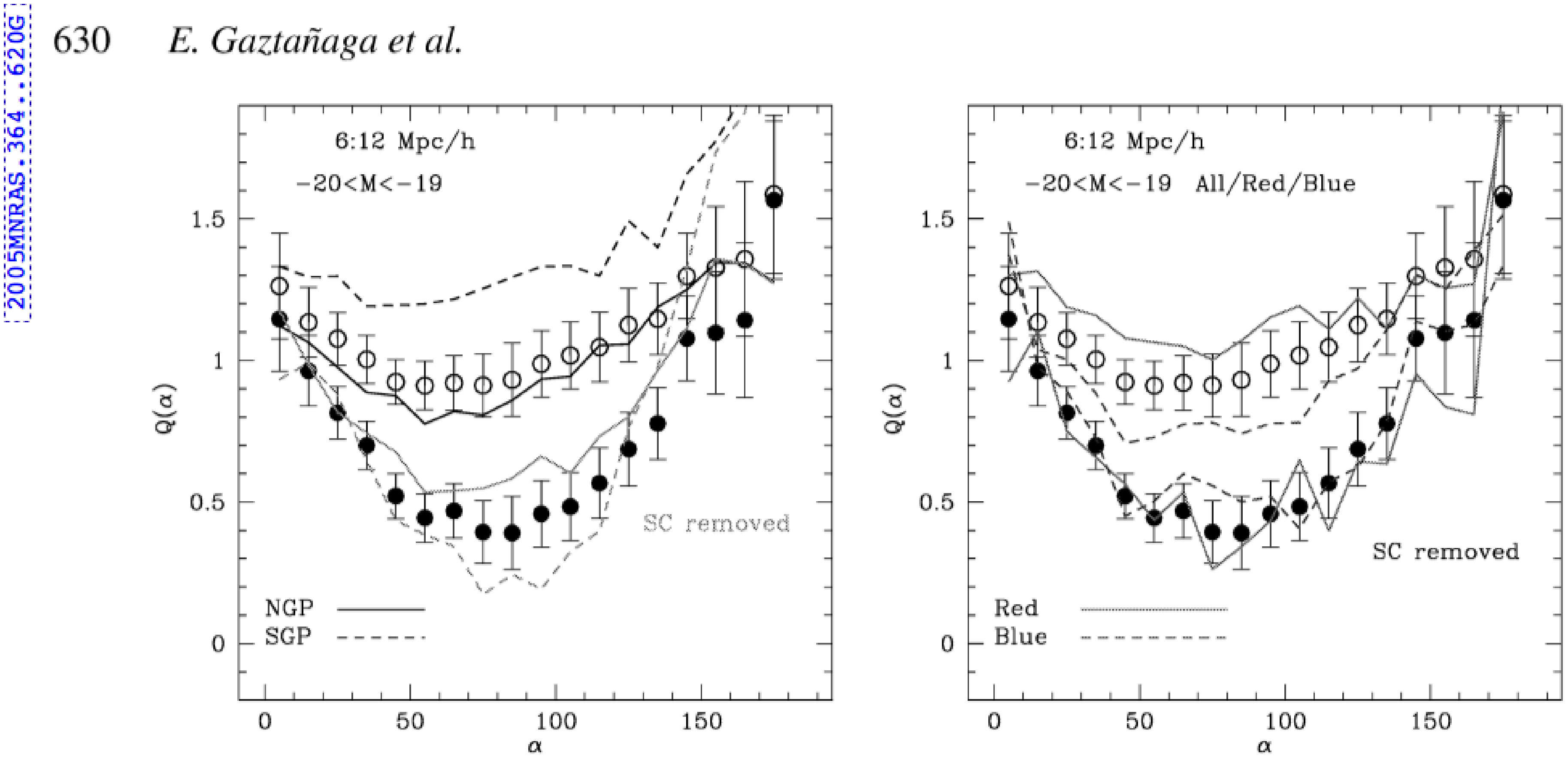
- **coherent large scale structures influence clustering measurement in a non-trivial way**

- **data based methods to infer errors do not put any precise constraint on the sub-region sizes to be used (e.g. bootstrap and Jackknife)**

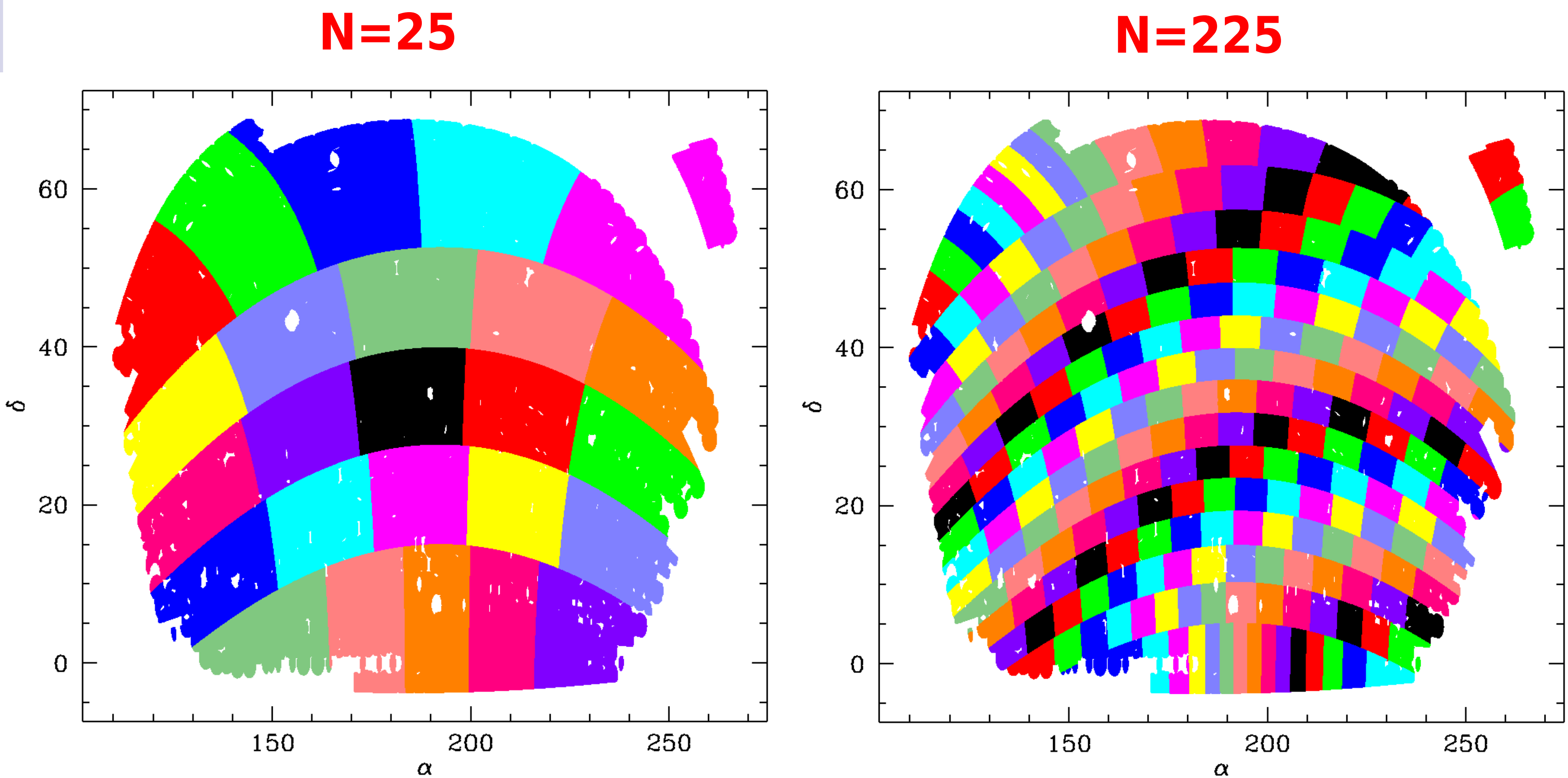
- **Errors on higher order statistics are non-trivial to estimate using mocks → errors from data...**

- **There must be a quantitative & objective way to validate the size of the sub-samples used.**

An objective way to quantify the impact of superstructures



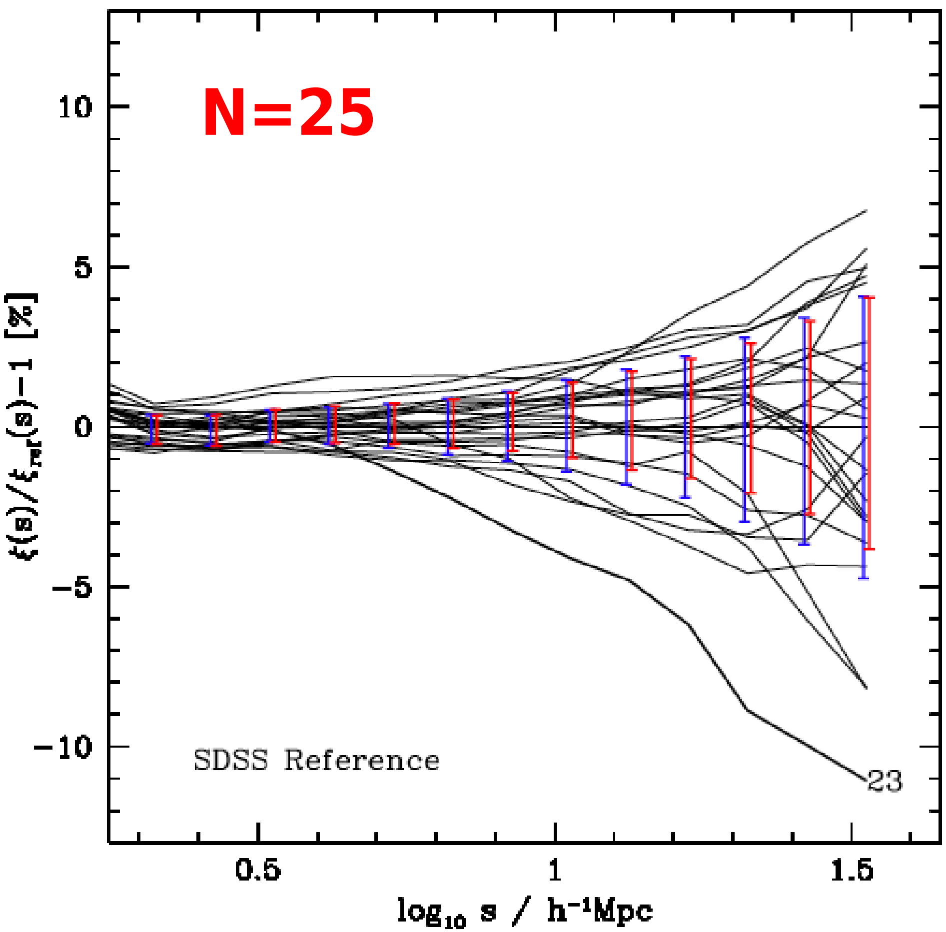
The Jackknife quilts for SDSS DR7



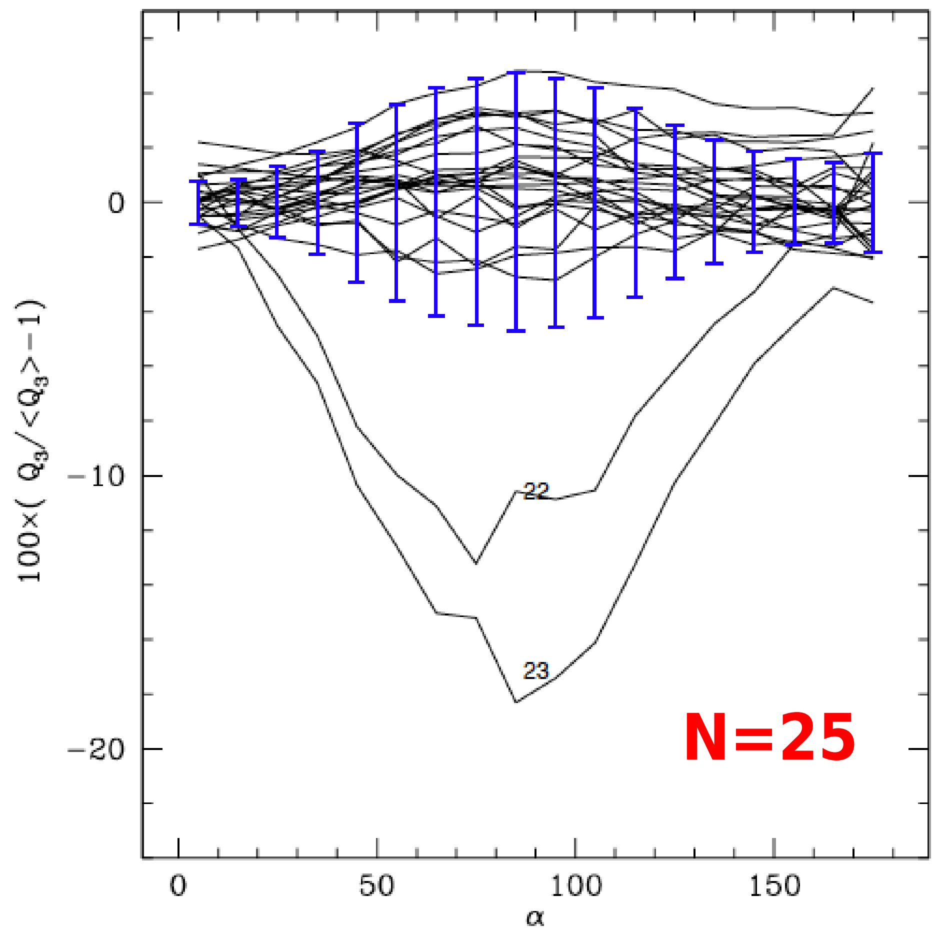
Jackknife method consists in estimating the covariance from N samples, leaving one out each time.

Relative clustering of each JK sample

2-pt correlation



Reduced 3-pt correlation



Sample: SDSS DR7, M*+0.5>M>M*-0.5, V ~ (258 Mpc/h)^3

New statistic: JK ensemble fluctuation

Relative variance 1: $$\sigma^2_{\rm tot} = \frac{1}{N_{sub}} \sum_{i=1}^{N_{sub}} \Delta_i^2$$

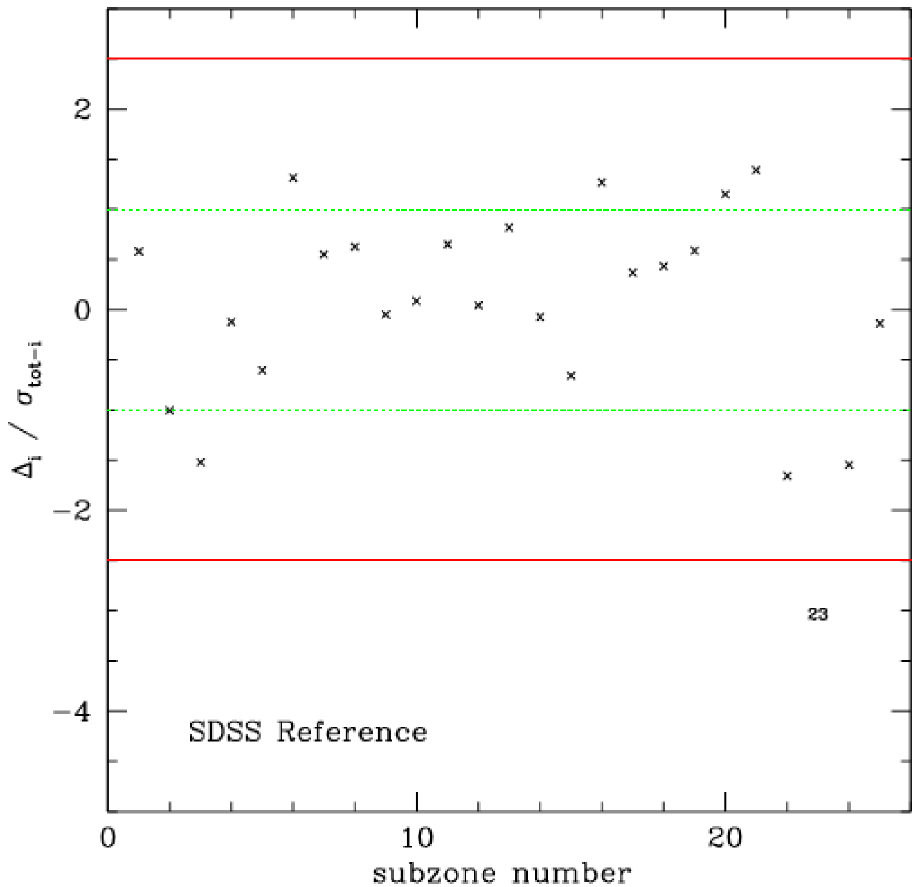
where Δ_i is the relative difference of our measurement in the Jackknife sample (everything minus the i^{th} zone) with respect to the one of the whole sample, using $N=N_{sub}$ samples.

Relative variance 2: $$\sigma^2_{\rm tot-i} = \frac{1}{N_{sub}-1} \sum_{j\neq i}^{N_{sub}-1} \Delta_j^2$$

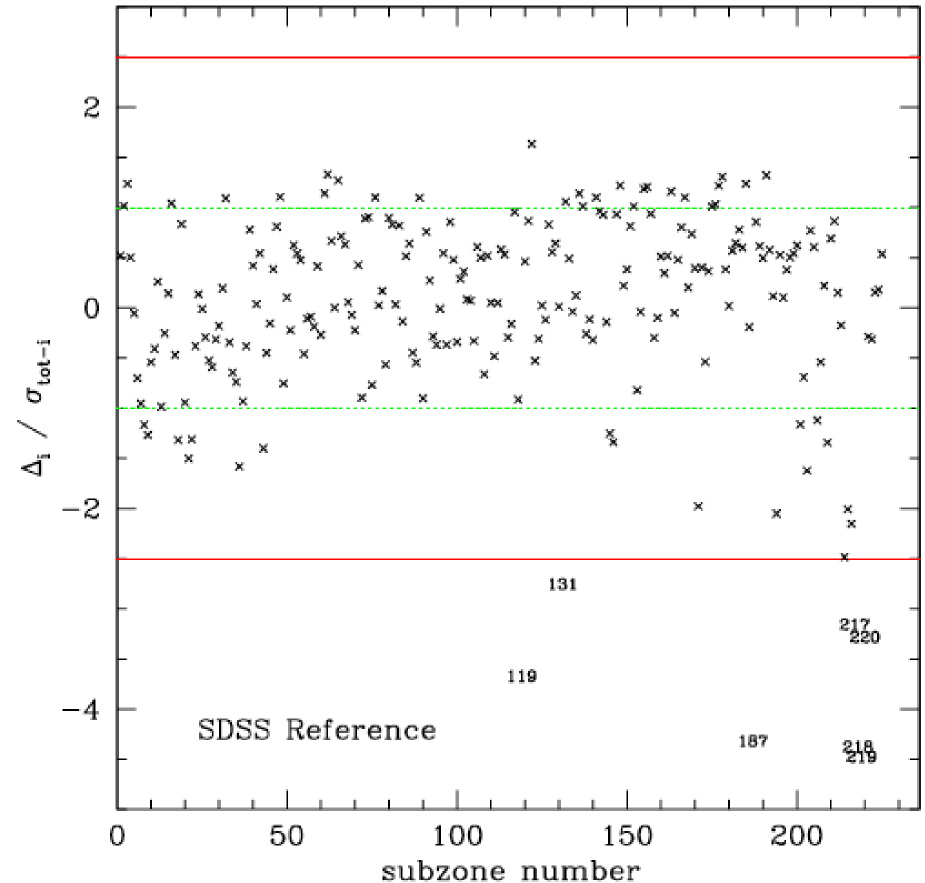
JK ensemble fluctuation: $$\delta^i_{JK} \equiv \frac{\Delta_i}{\sigma_{\rm tot-i}}$$

JK ensemble fluctuation

2-pt correlation (N=25)



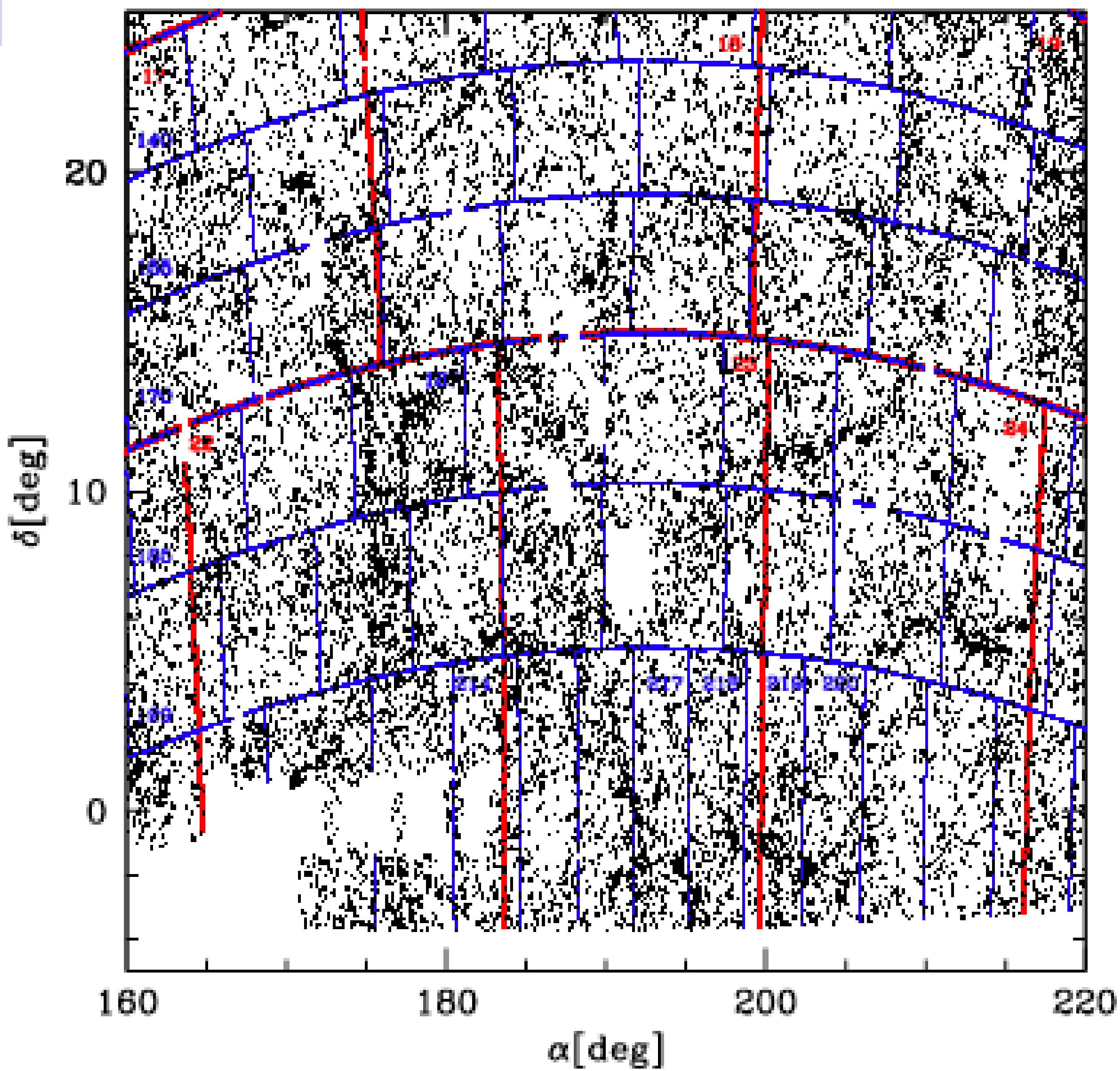
2-pt correlation (N=225)



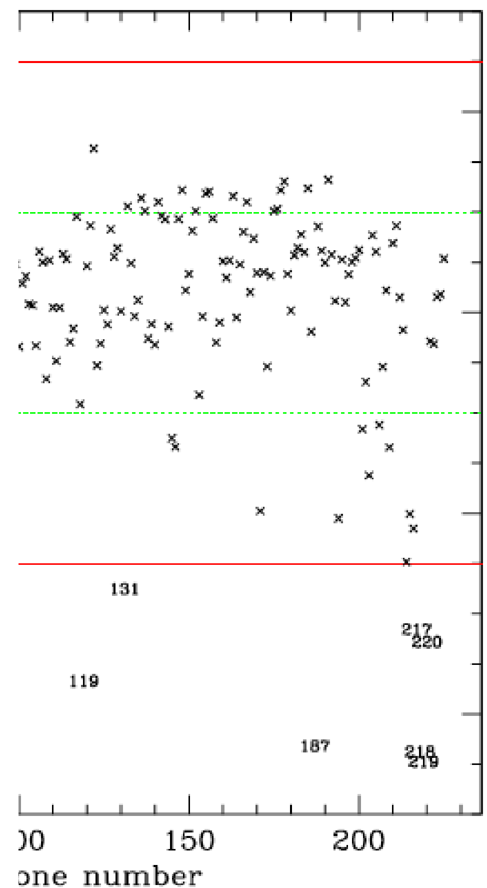
$$\delta^i_{JK} \equiv \frac{\Delta_i}{\sigma_{\mathrm{tot-i}}}$$

$$\sigma^2_{\mathrm{tot-i}} = \frac{1}{N_{sub}-1} \sum_{j \neq i}^{N_{sub}-1} \Delta_j^2$$

n

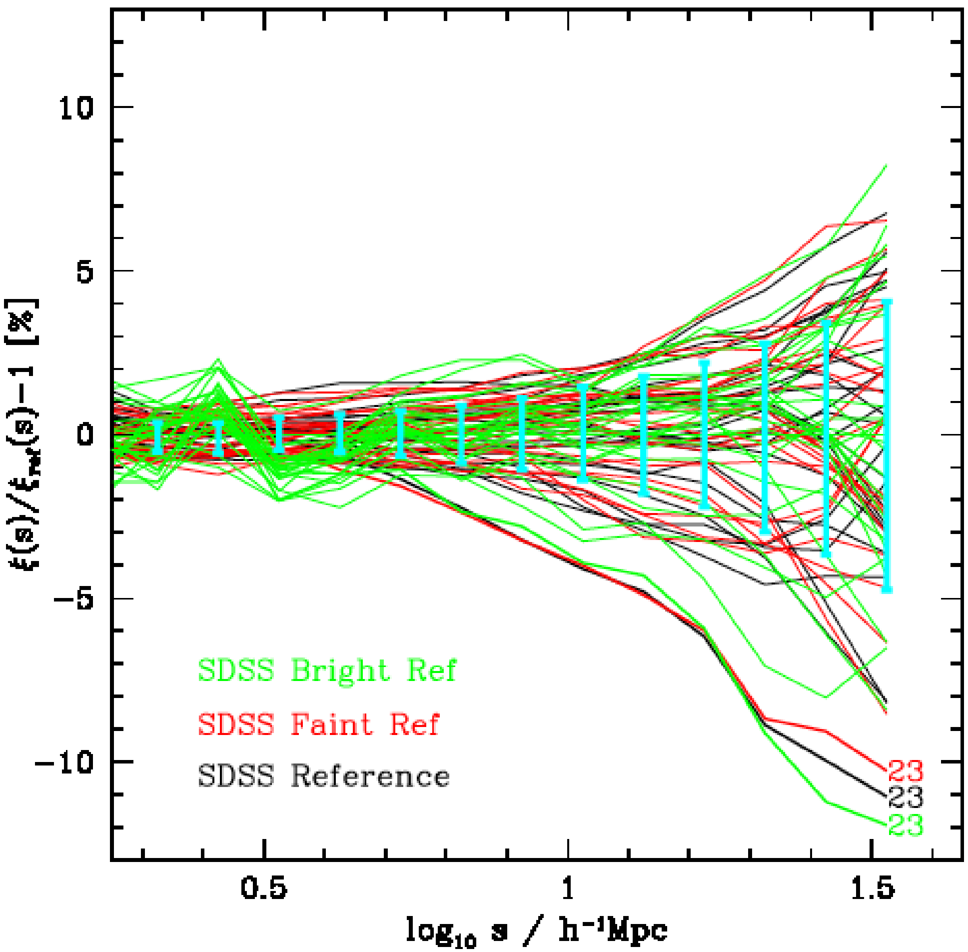


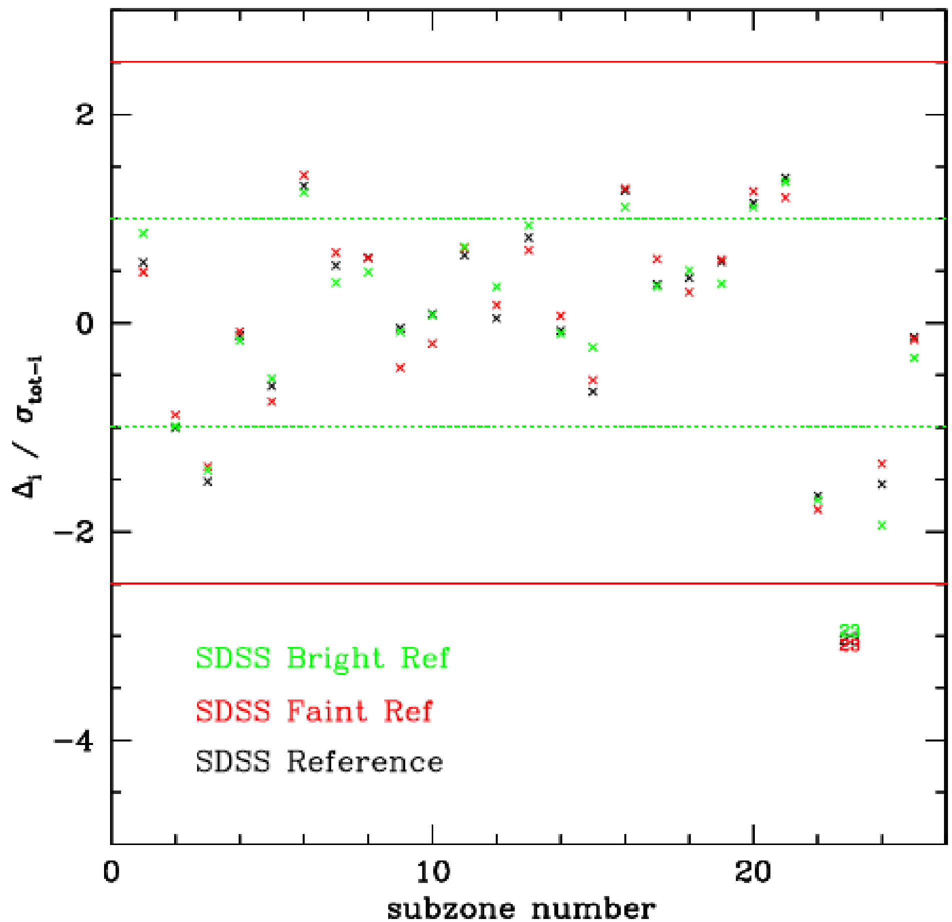
elation (N=225)



$$\frac{1}{{}_{ub} - 1} \sum_{j \neq i}^{N_{sub}-1} \Delta_j^2$$

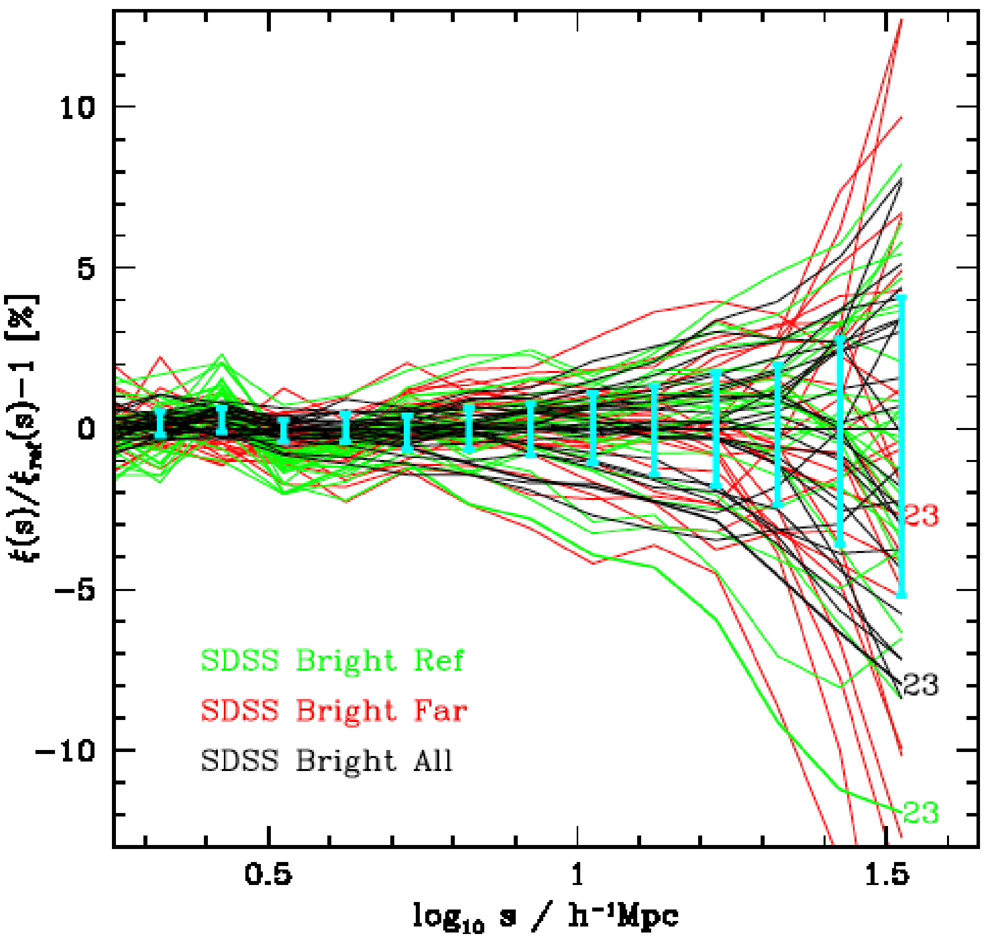
Different galaxies in the same volume

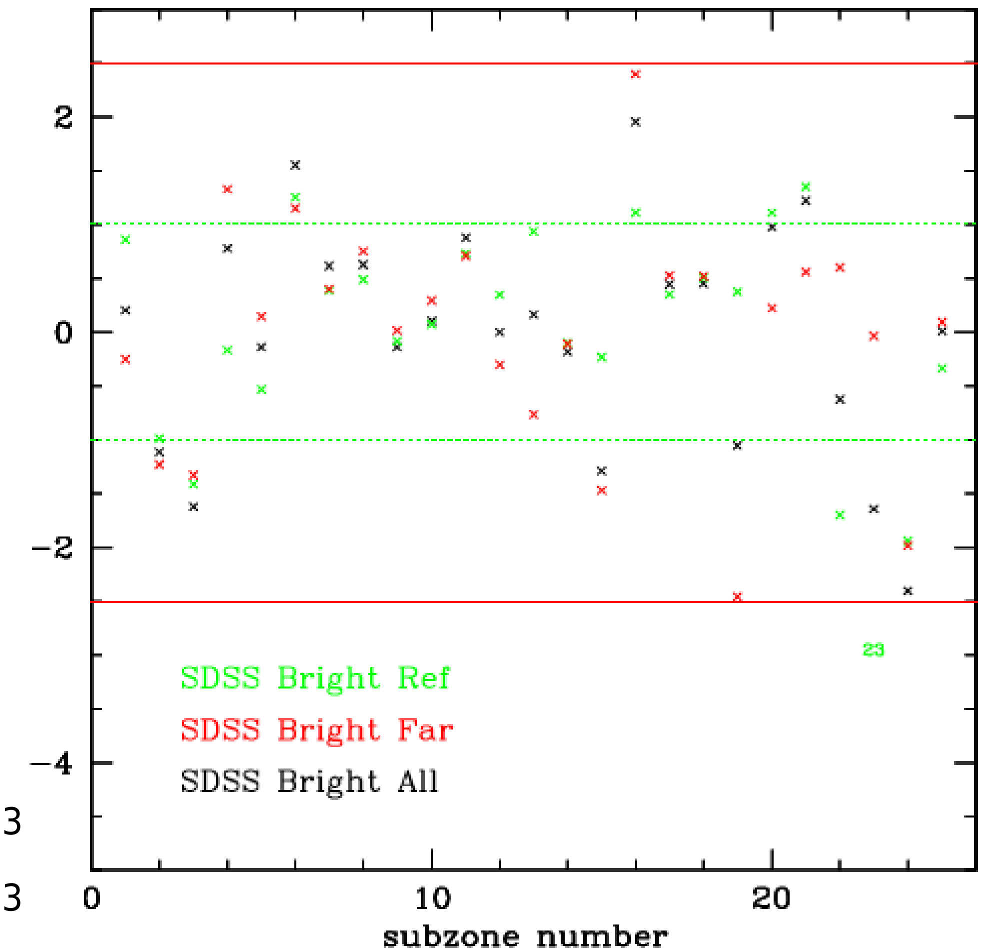




Sample: V ~ (258 Mpc/h)^3
M*+0.5>M>M*
M*>M>M*-0.5

“Same” galaxies in different volumes



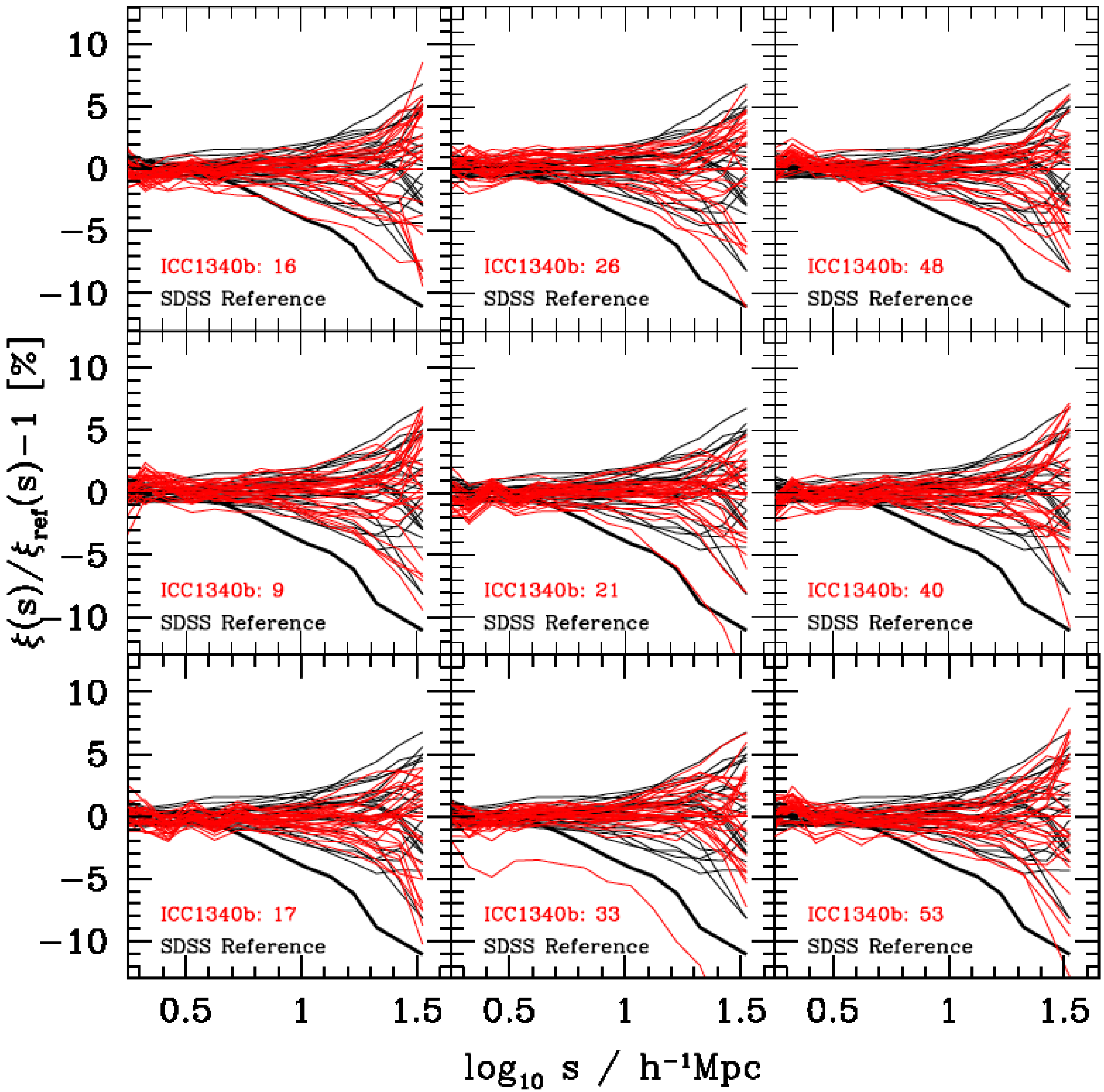


Sample: M*+0.5>M>M*

0.051<z<0.106, V ~ (258 Mpc/h)^3

0.106<z<0.132, V ~ (259 Mpc/h)^3

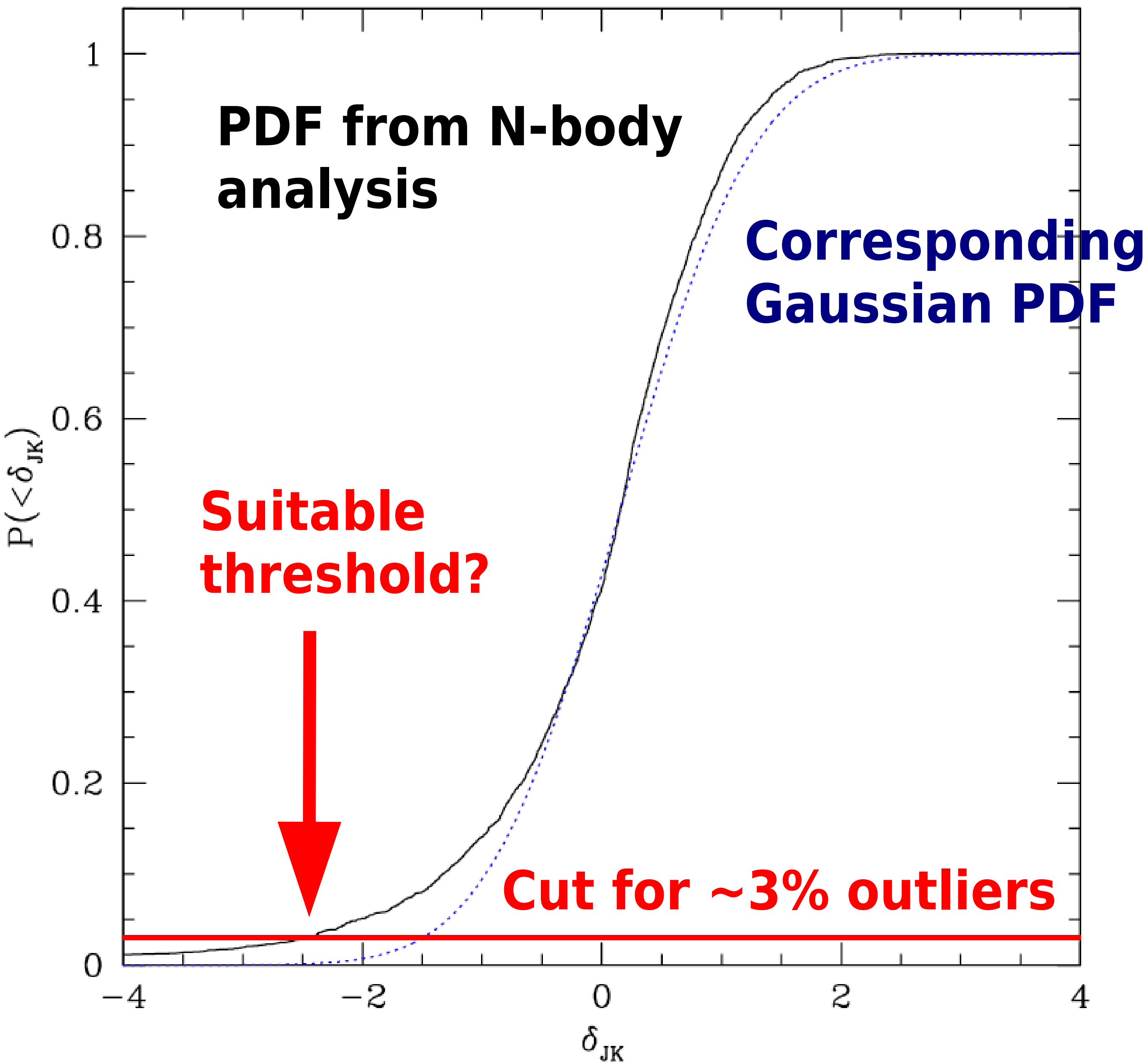
Does this match ΛCDM simulations?



L-BASICC:
50 low-res. N-body
L=1340 Mpc/h
$M_p \sim 10^{12}$ Msol/h
(Angulo et al. 2008)

Extract:
100 SDSS L* volumes
→ 2 from each box, >500Mpc/h apart
→ 99/100 truly independent
Analyse DM only, with M* mean density.
(Norberg et al. 2009)

PDF for JK ensemble fluctuation



JK ensemble fluctuation: conclusion

- an objective way of finding large coherent superstructures, using a standard Jackknife resampling technique.

- a quantitative way of justifying the size of the Jackknife zones to be used for the error analysis of the clustering signal

- a quantitative way to study the influence of large coherent superstructures, even when they dominate the clustering signal.

But most importantly:

It is based on the data alone.
It is easy to compute (so why not do it)