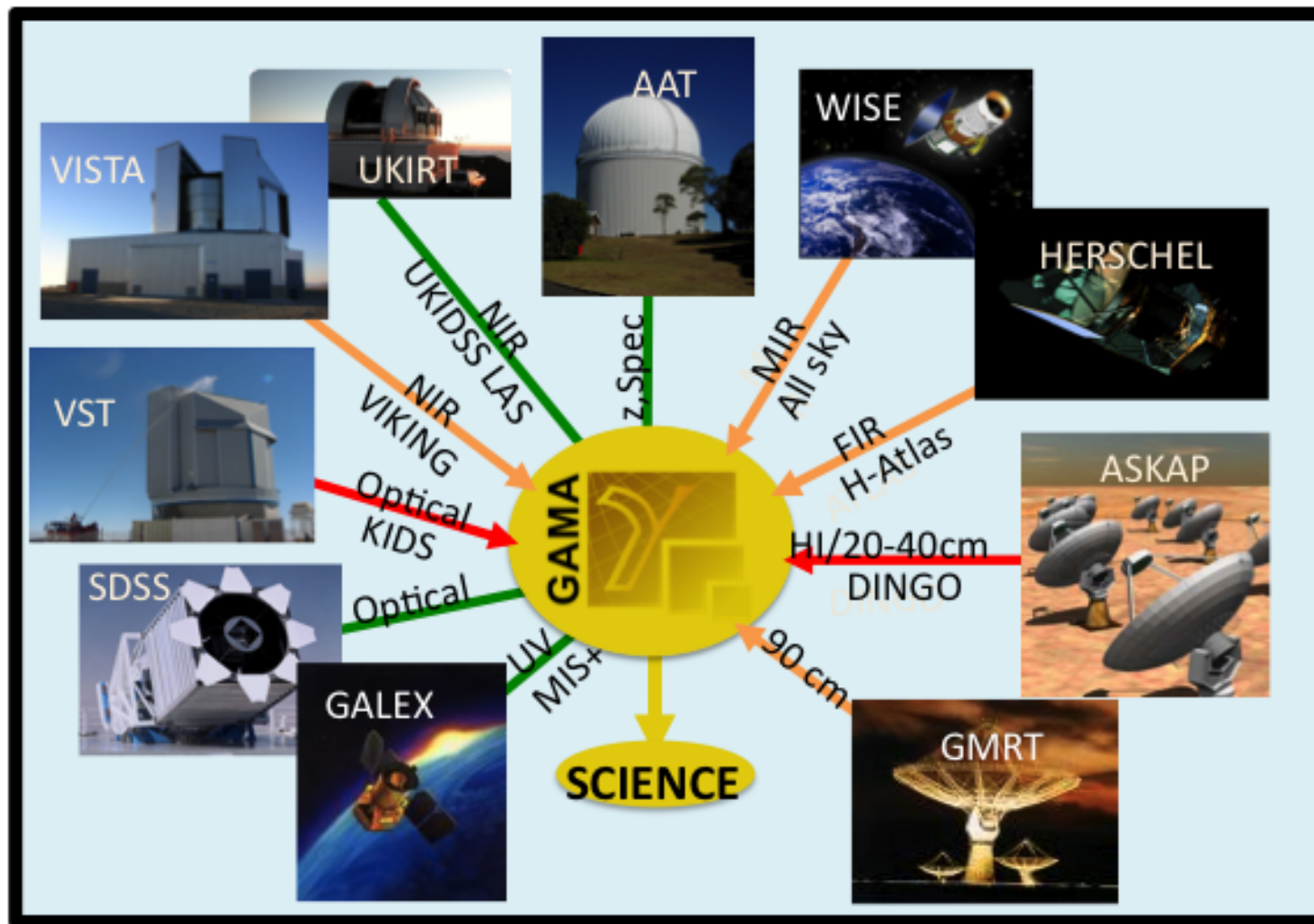# Large scale structure and galaxy formation studies with the Galaxy And Mass Assembly survey

Peder Norberg
ICC, Durham University

EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

erc

European Research Council

A Few Health Warnings

- Real DATA:

  → observe light in many wavelengths [not mass]

  → use galaxies as tracer [not DM nor DM (sub)halos]

  → small scale studies in z-space with scaled dependent biased tracers!

- Basic statistics & cosmology:

  → mainly 1-pt (& 2-pt) functions [no (N>2)-pt functions]

  → in configuration space [no k-space]

  → standard ΛCDM cosmology [no NG, no w(z), no MG,...]

- "Realistic" simulations:

  → non-linear N-body DM simulations with galaxy formation models

- Plenty of systematics in data & models

Talk Overview

- Introduction to GAMA

- LSS with GAMA:

  – Angular clustering with GAMA calibrated z_{ph}
  → sensitivity to data systematics (in SDSS)

  – Redshift space clustering as $f(z, M_*, colour)$
  → test for systematics in f_g modelling

  – Galaxy groups with spatially complete GAMA
  → test of ΛCDM and the halo model

- Beyond LSS with GAMA:

  – why GAMA is "the" galaxy formation survey

GAMA Team/Collaboration

GAMA EXEC
Ivan Baldry
Steven Bamford
Joss Bland-Hawthorn
Sarah Brough (SC)

Michael Brown
Michael Drinkwater
Simon Driver (PI)
Andrew Hopkins (PI)
Joe Liske (PM)

Jon Loveday
Martin Meyer
Peder Norberg
John Peacock
Aaron Robotham (SC)
Richard Tuffs

GAMA Team members

Nicola Agius
Mehmet Alpaslan
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Amanda Bauer
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John Ching
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Matthew Colless
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St Andrews
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UCLAN
Nottingham
LJMU
Bristol
Cardiff
Sussex
Oxford
Durham
Portsmouth
Hertfordshire

Leiden
MPIK
ESO
ETH

UBC
Waterloo
OCIW

U San Paulo
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GAMA Consortium Members

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	Mark Seibert
DINGO	Lister Staveley-Smith
VISTA-VIKING	Will Sutherland
UKIDSS	Steve Warren

GROUND–BASED FACILITIES:
AAT, Siding Springs
SDSS, Apache Point
VST, Paranal
UKIRT, Mauna Kea
VISTA, Paranal
GMRT, Pune
ASKAP, WA
SPACE MISSIONS
Herschel, L2
GALEX, Earth Orbit
WISE, Earth Orbit

ICRAR
UQ
AAO
USyd
Swinburne
UMelb
Monash

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Galaxy And Mass Assembly Survey:
the redshift survey in a nutshell (2008-201?)
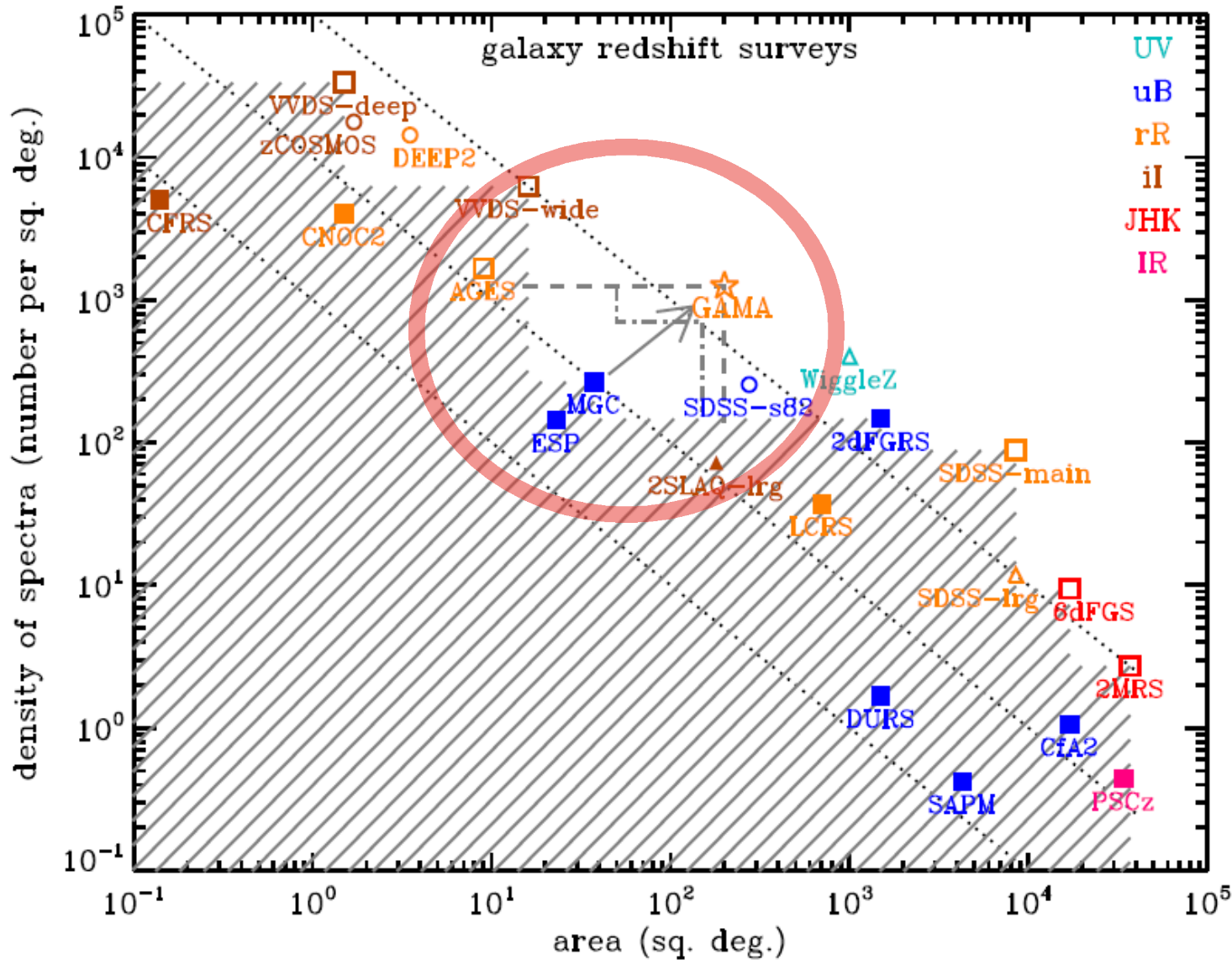
z-survey 2mags
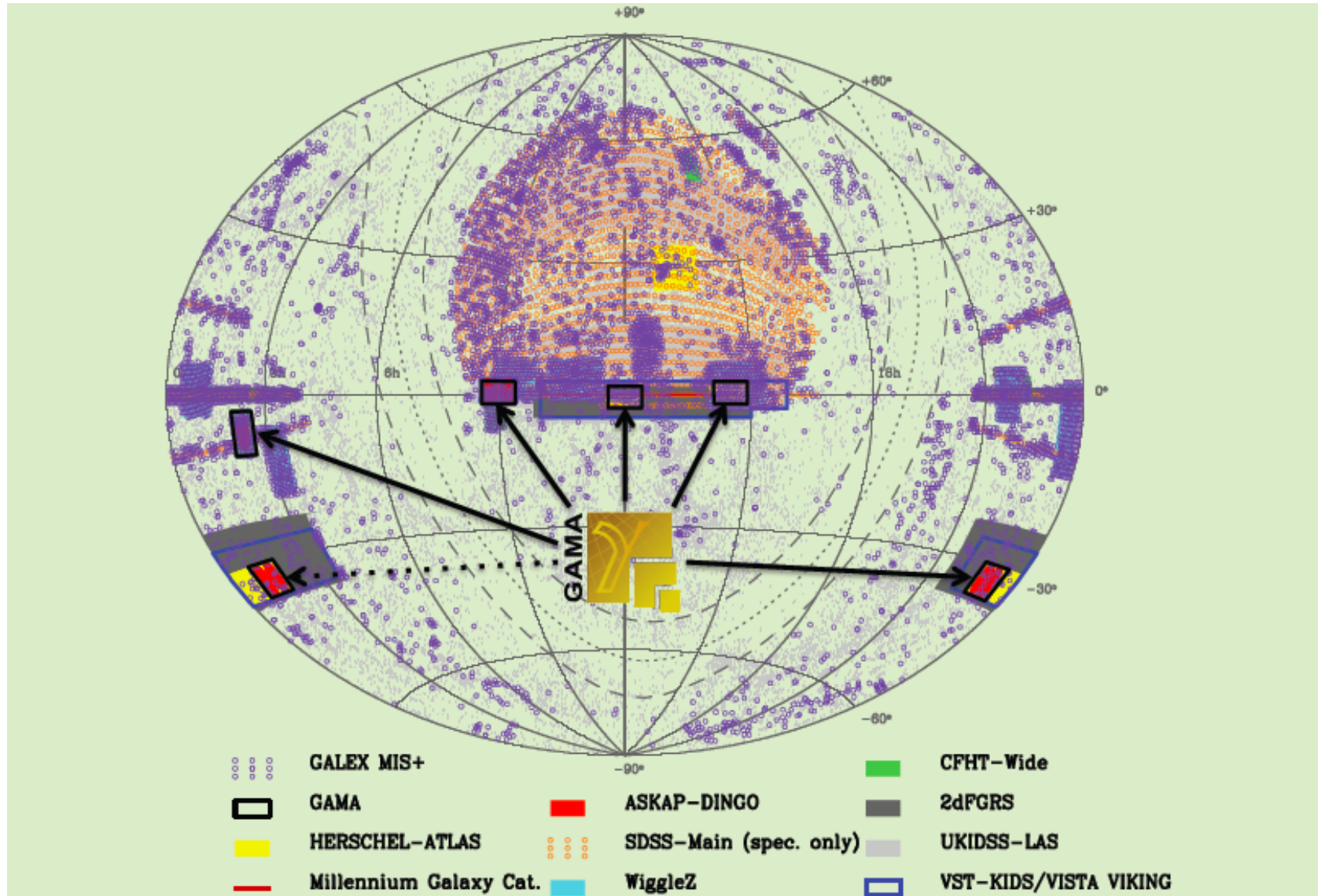deeper than SDSS

5/6 regions all RA

350,000 galaxies

z<0.5

Giants to LMC range

Pre-existing redshifts (GAMA 12)

+ year 1

+ year 2

+ year 3

Redshift

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

Galaxy And Mass Assembly Survey:
where are the fields?

GAMA I

GAMA
zCOSMOS
WiggleZ
MGC
2dFGRS
SDSS-main

GAMA: Contributing Facilites
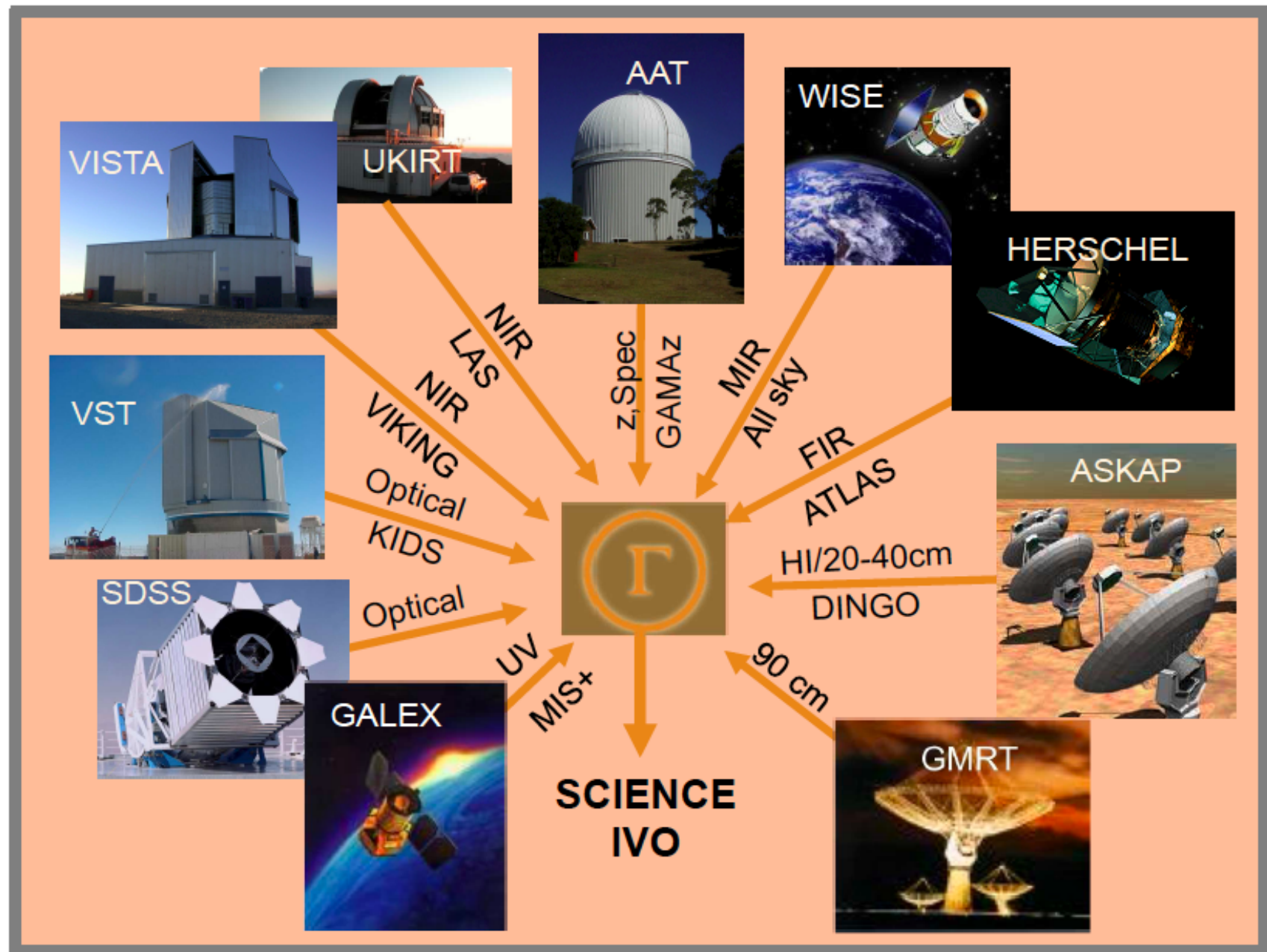
GAMA: redshift accuracy, quality & completeness
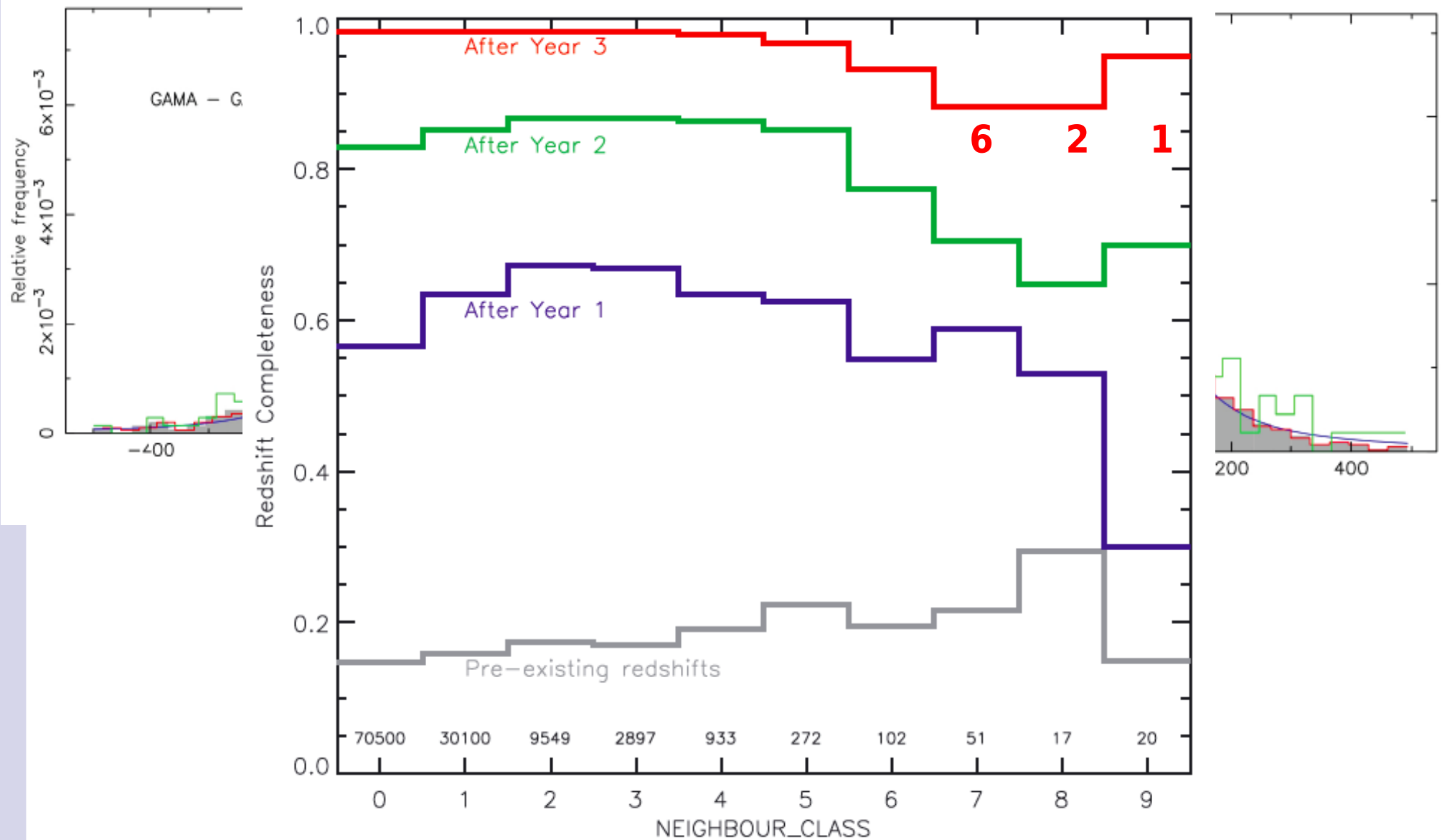
Driver et al. (2011)

GAMA-I: *redshift completeness...~98%!*

GAMA: improved photometric redshifts (r<19.8)

photometric redshifts

GAMA spectroscopic redshifts (G12)
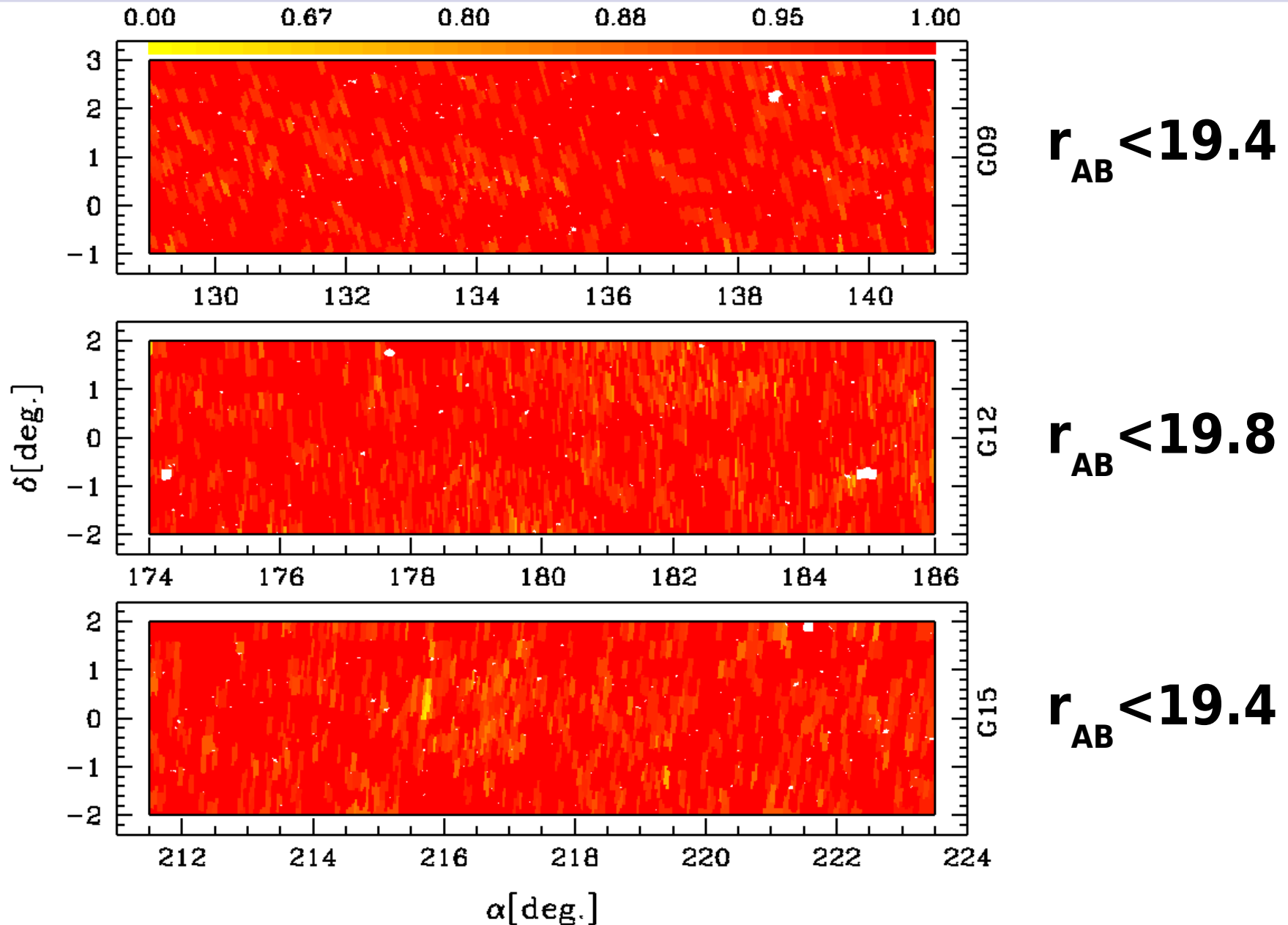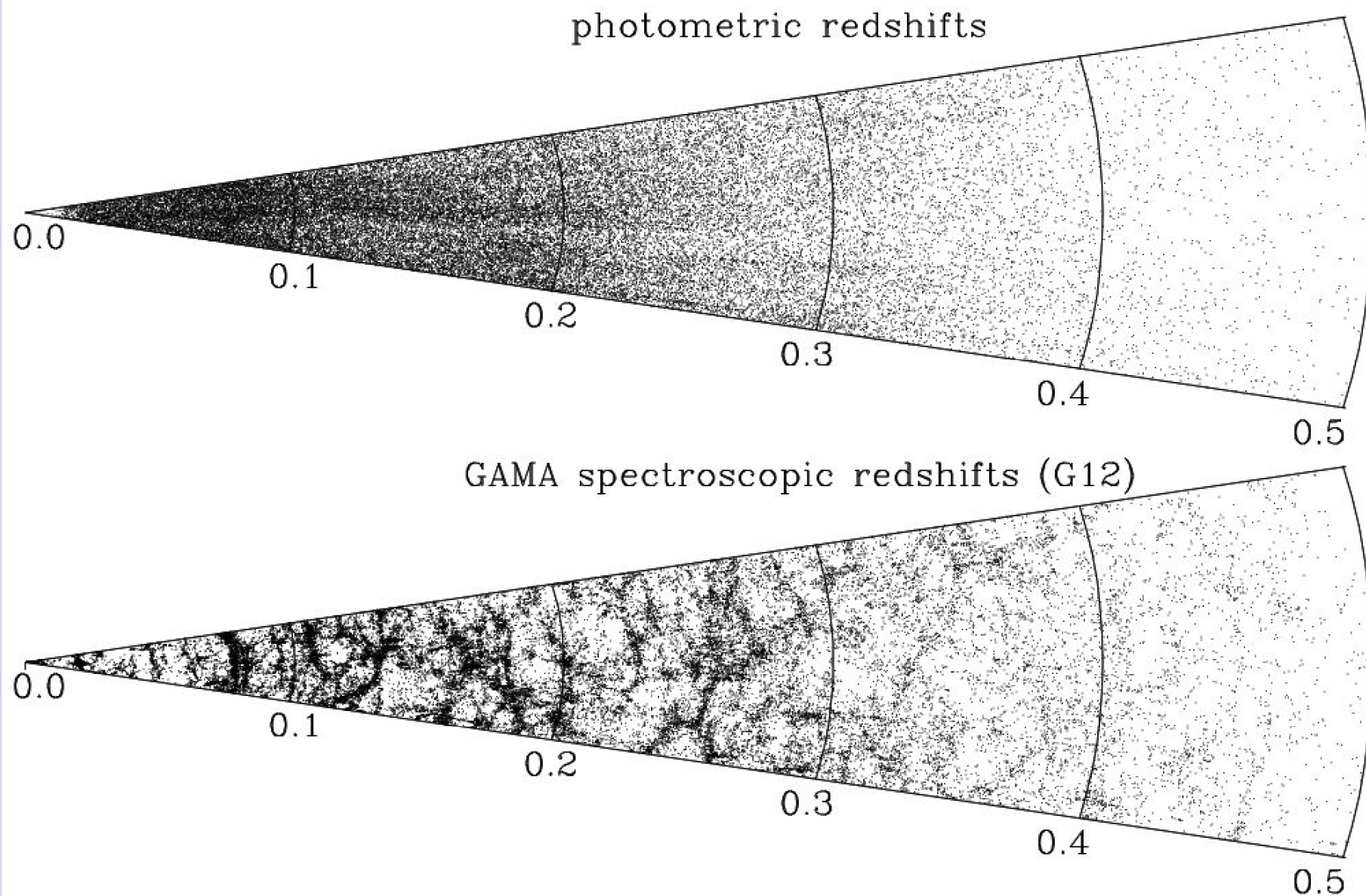
GAMA: improved photometric redshifts (r<19.8)
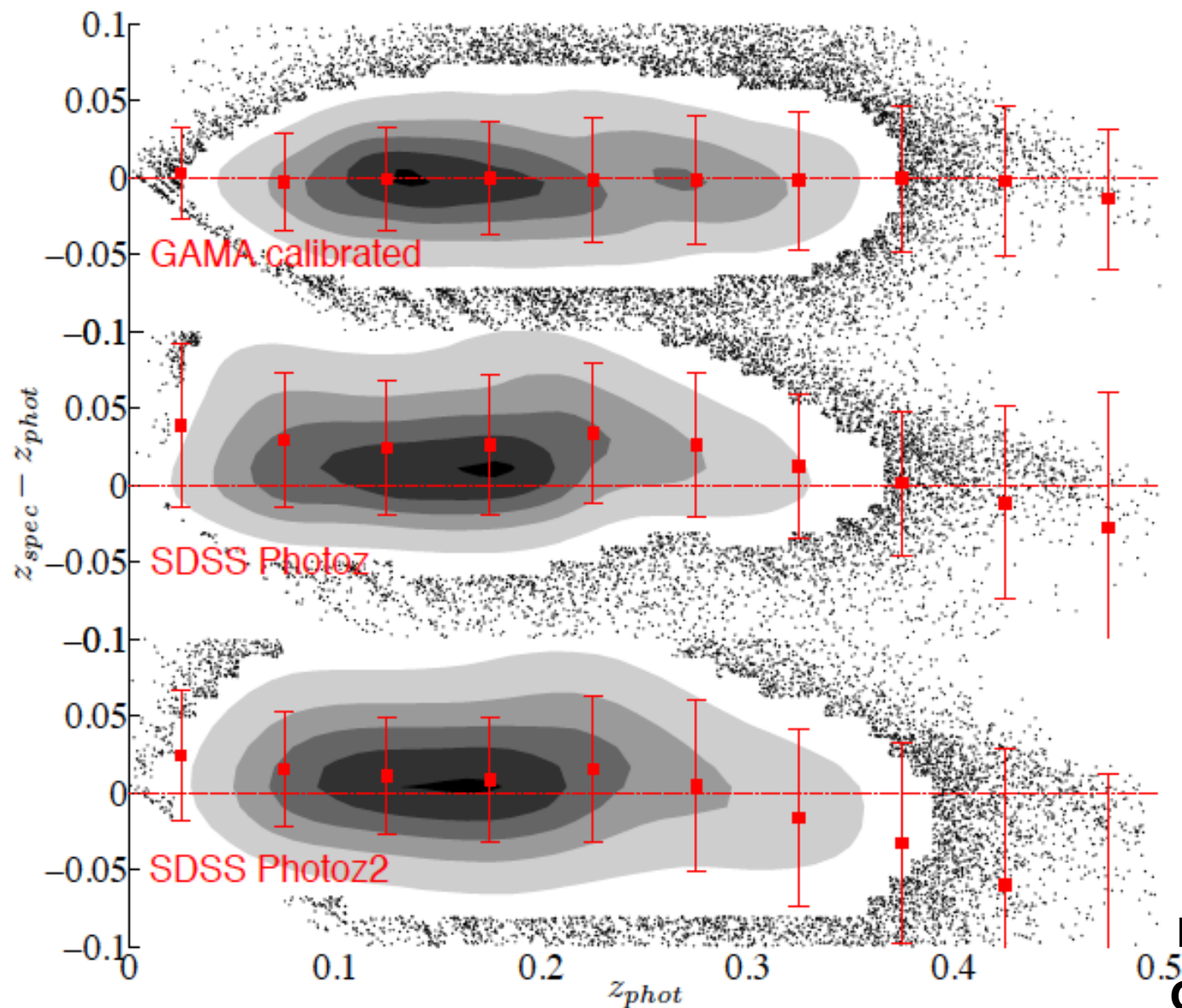
GAMA
vs
SDSS DR7

Photoz
Table 1

&

Photoz
Table 2

Parkinson (in prep)
Christodoulou et al.

GAMA: N(z) for z_{spec} and z_{ph}
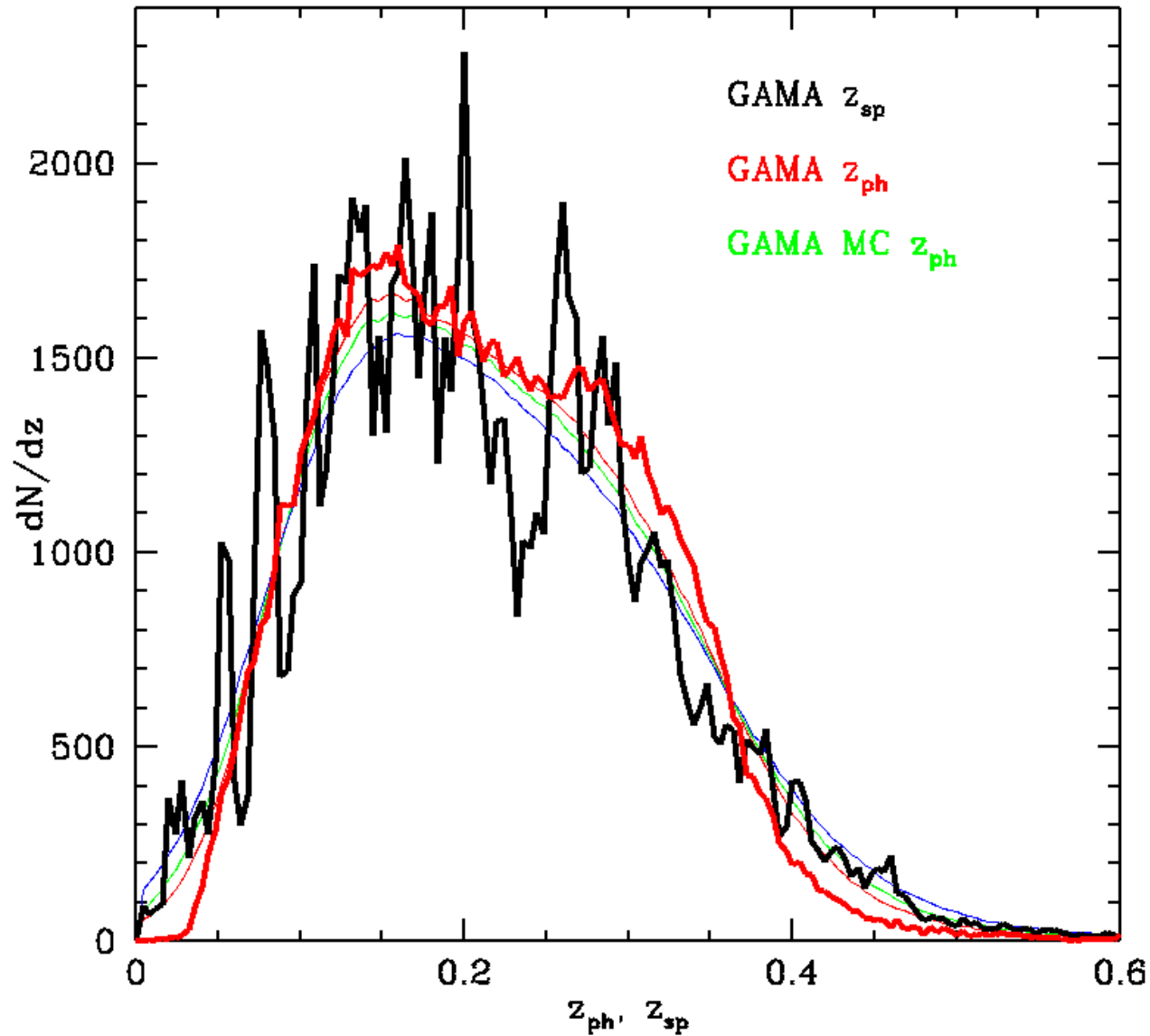
Driver et al. (2011)
Christodoulou et al.

SDSS: clustering split by z_{ph} & $M_r(z_{ph})$

Peder Norberg
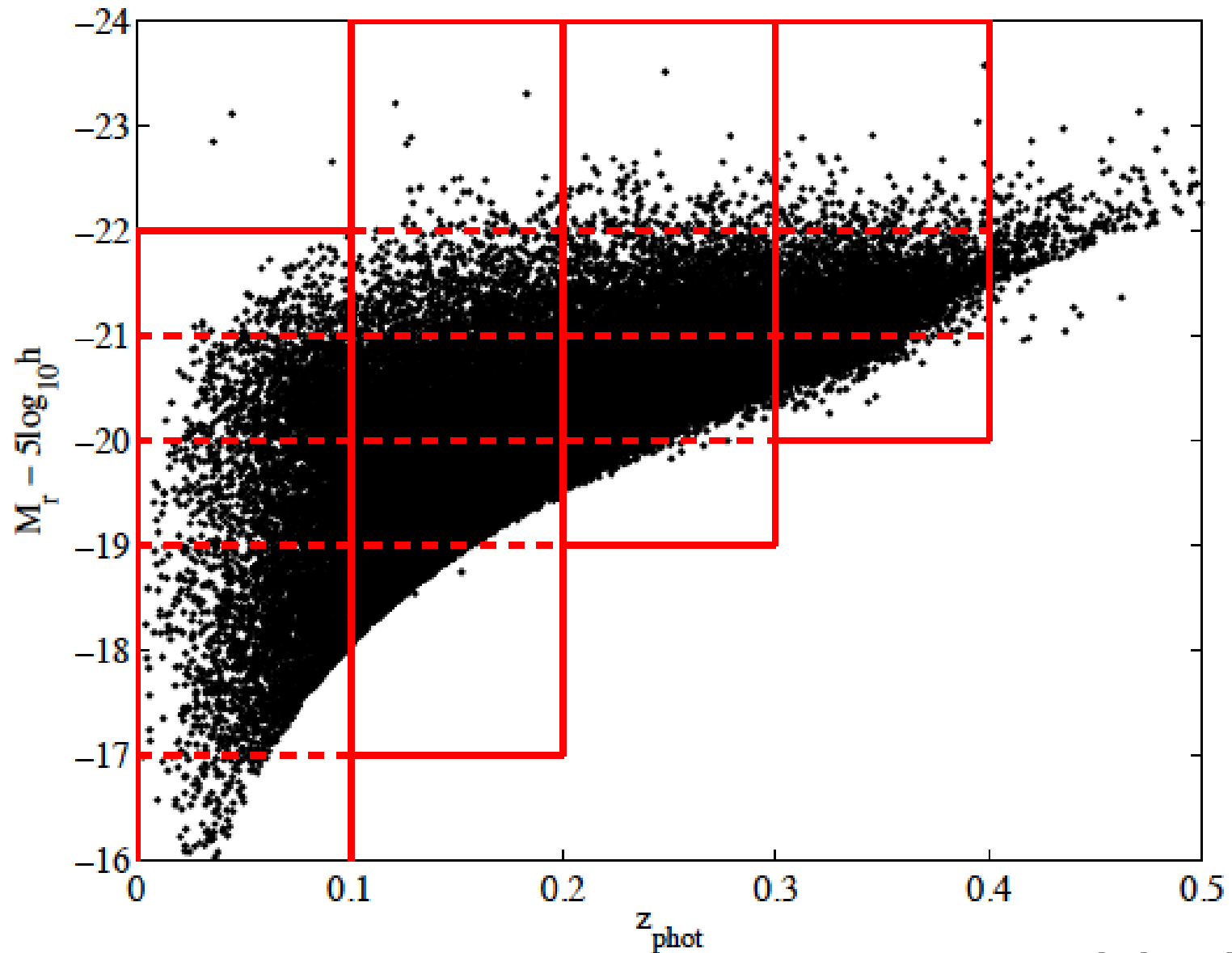
Christodoulou et al.

SDSS: *w(θ) split by z_{ph} & $M_r(z_{ph})$*
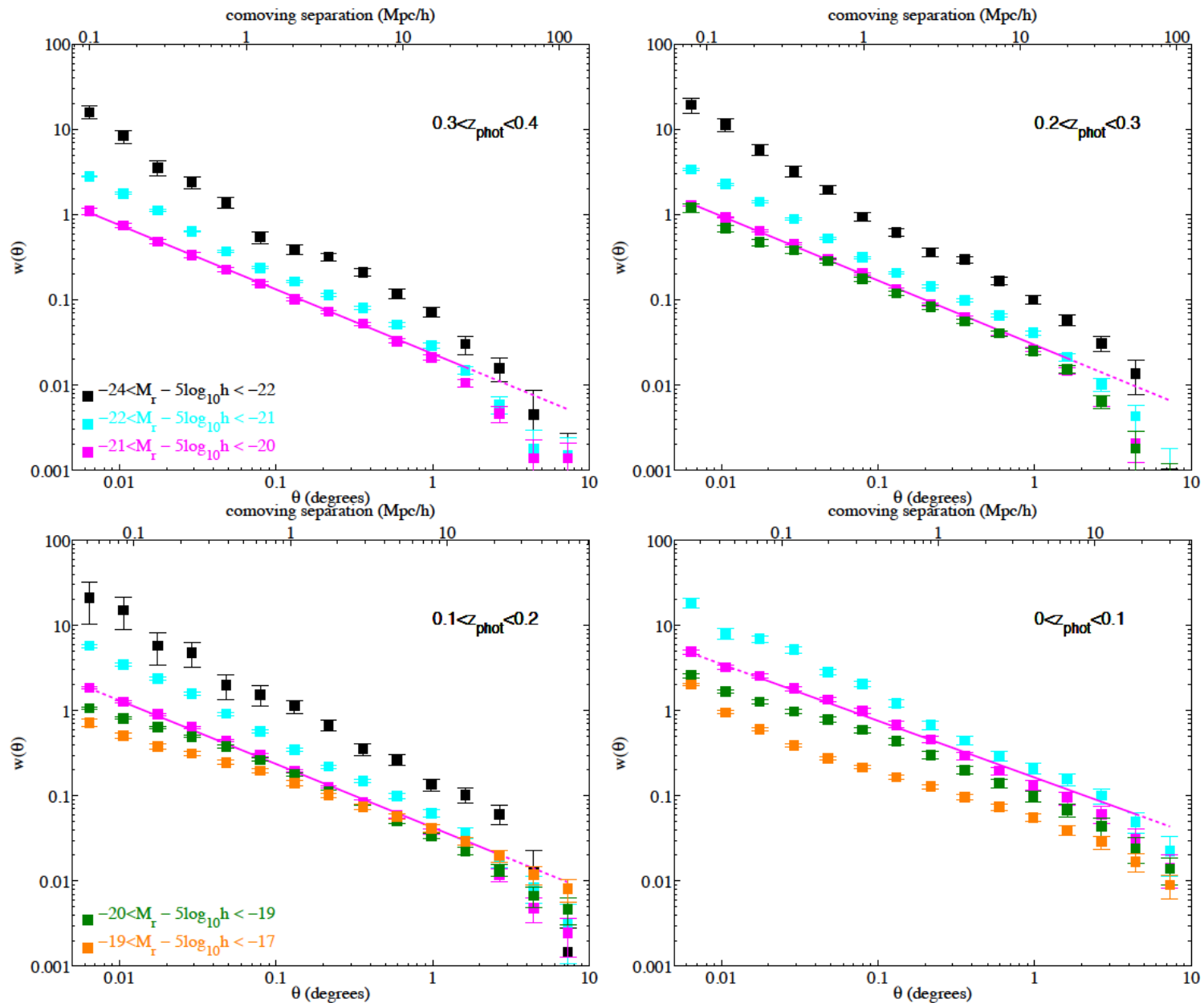
Christodoulou et al.

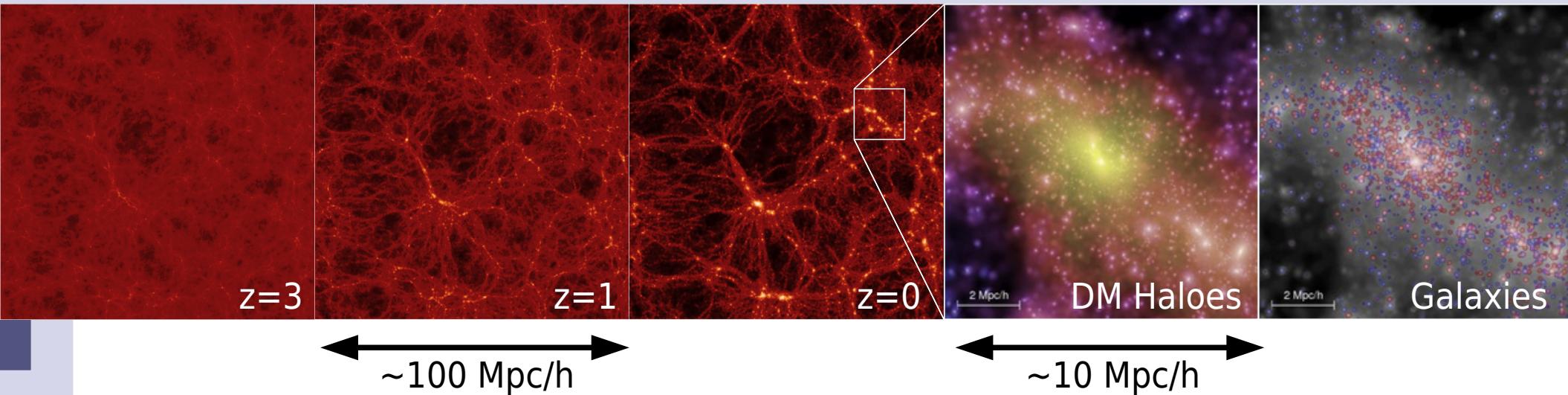# SDSS: $w(\theta)$ for faint galaxies, split by $M_r(z_{ph})$

Christodoulou et al.

N(z) reconstruction
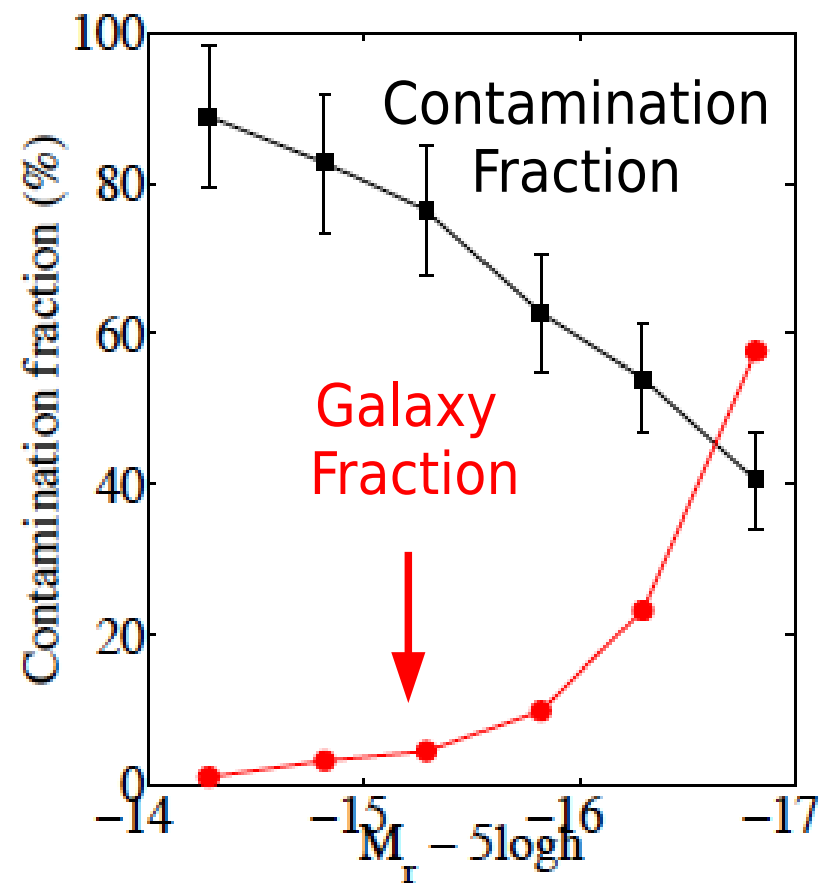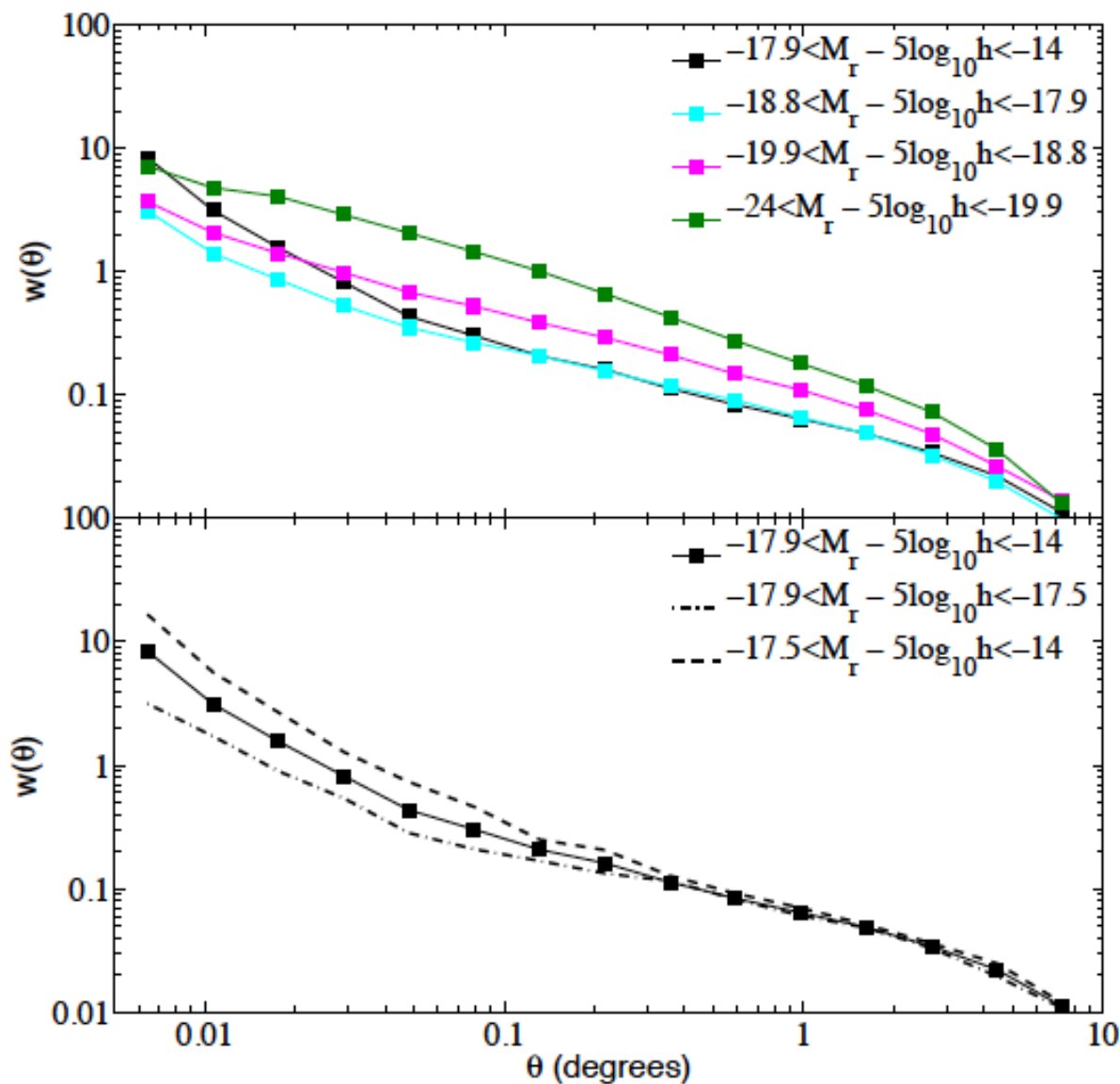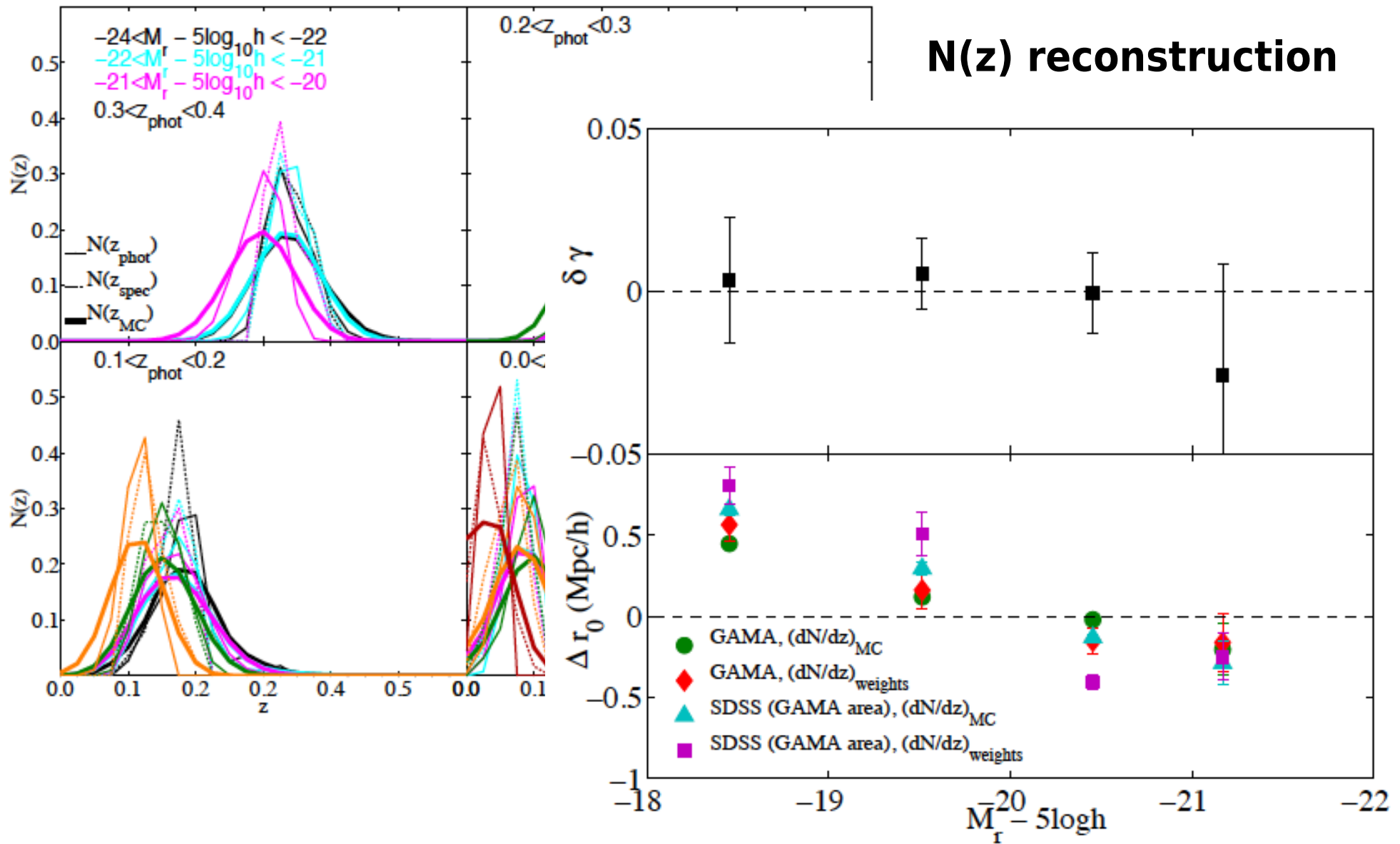
Christodoulou et al.

Growth of non-linear structure

z=3   z=1   z=0   DM Haloes   Galaxies

~100 Mpc/h   ~10 Mpc/h

Structure formation:

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

Key question:

- Do galaxy groups trace DM haloes as predicted (i.e. CDM correct?)
- Is it Dark Energy or gravitational physics?

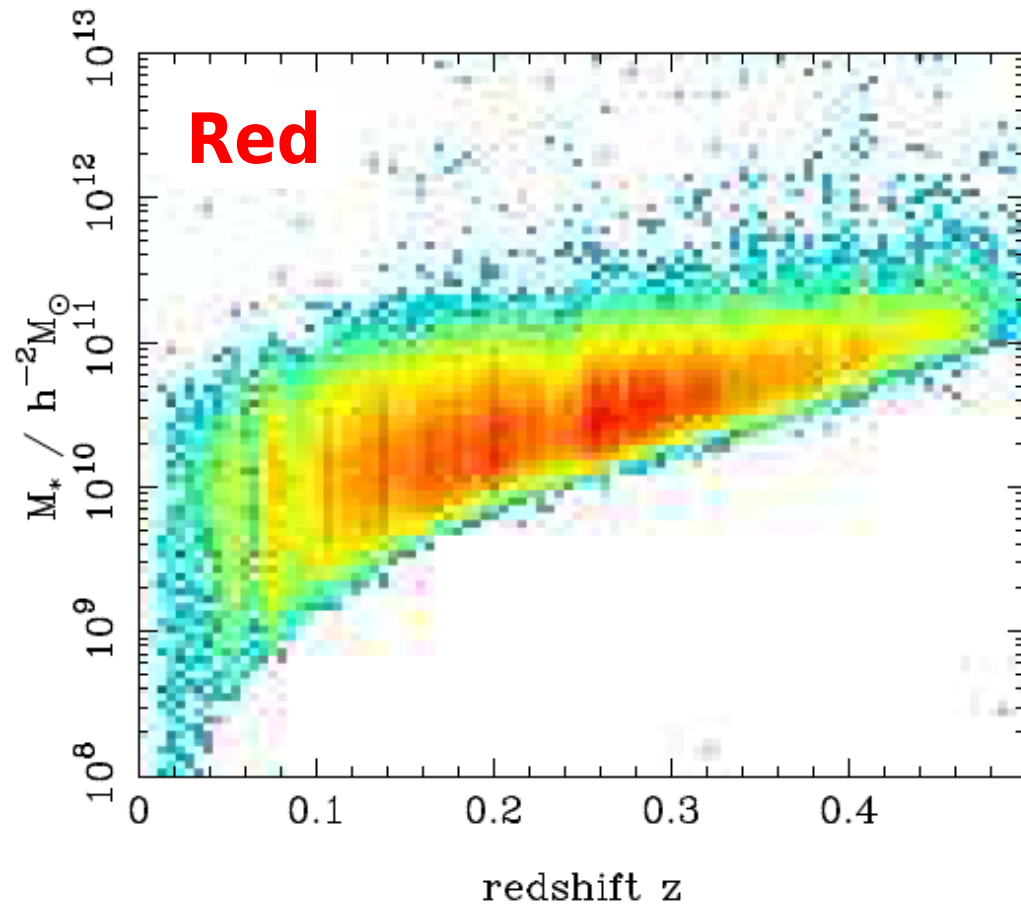Fundamental research to our understanding of structure formation and galaxy evolution.

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';
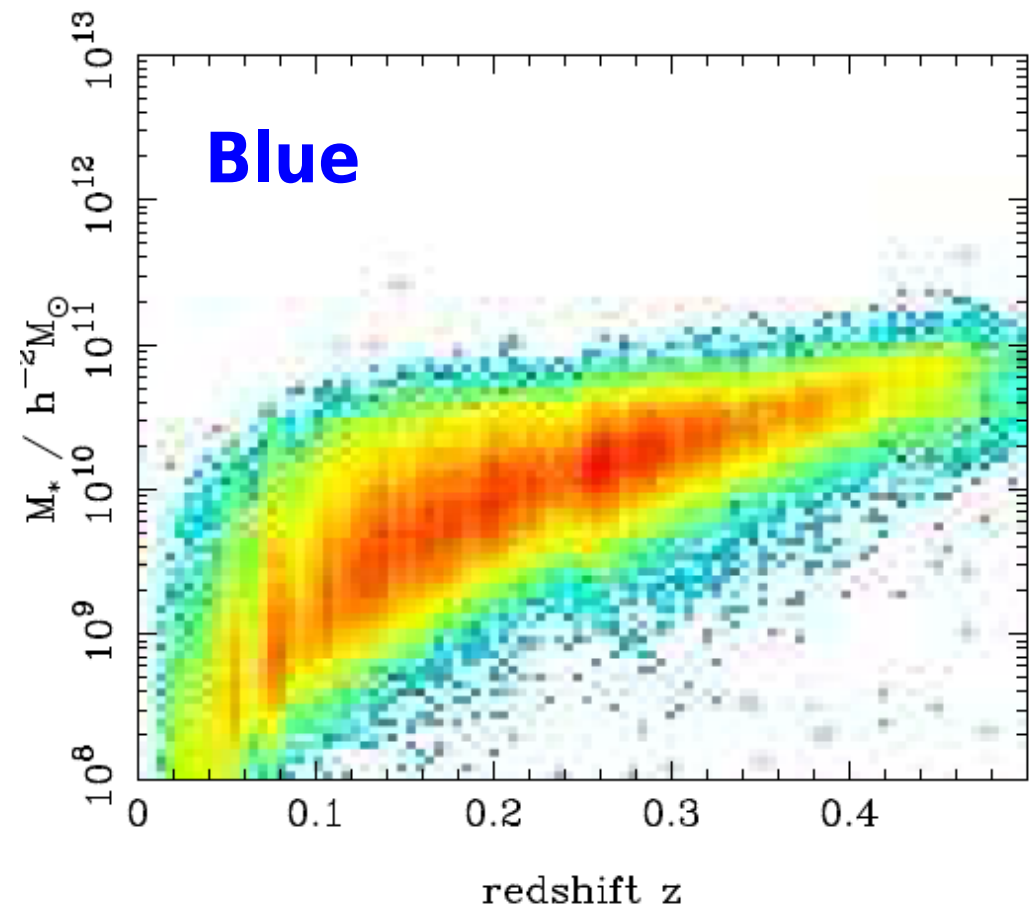 - Large separations on sky: flattening along line of sight.

2dFGRS Nature 2001 σ / $h^{-1}Mpc$
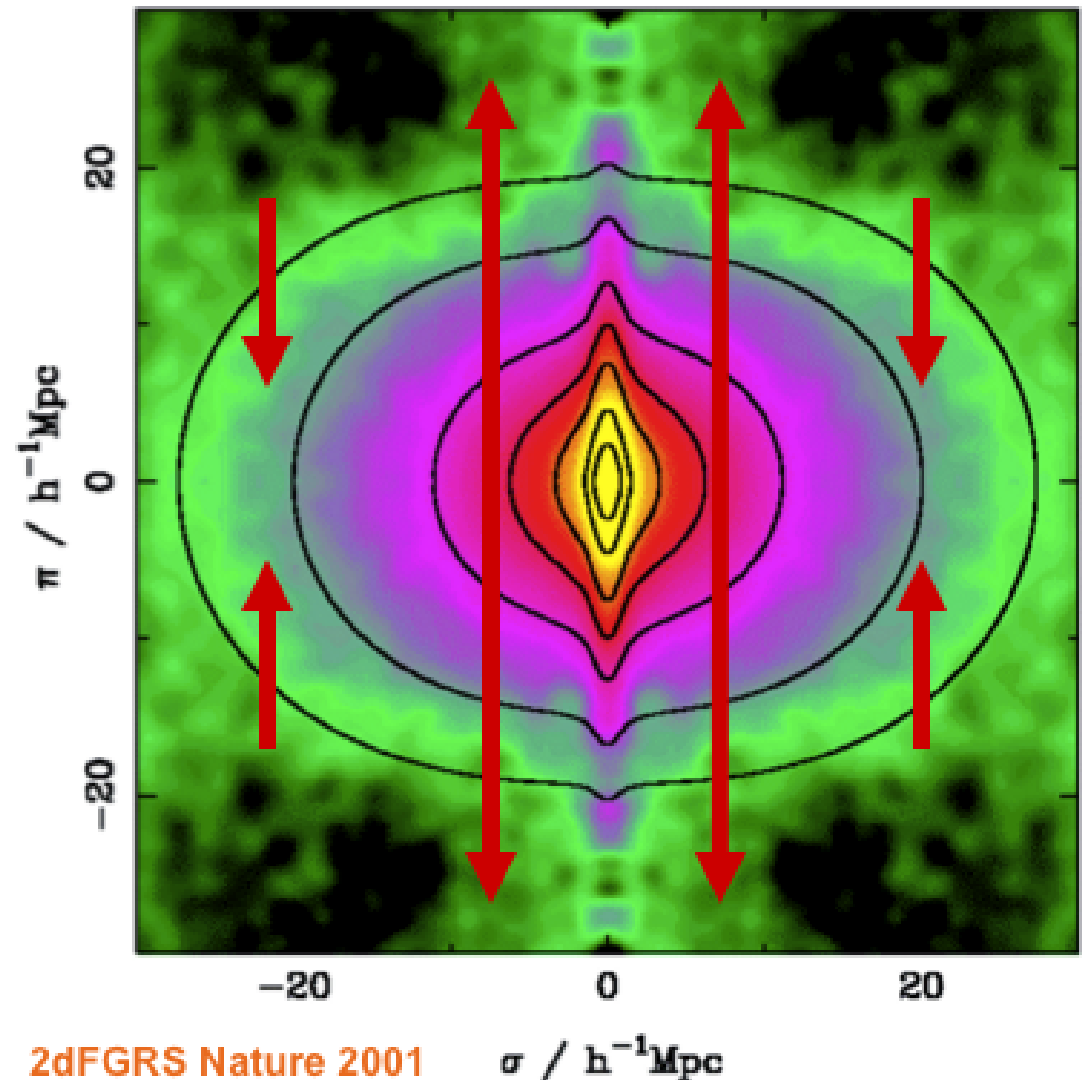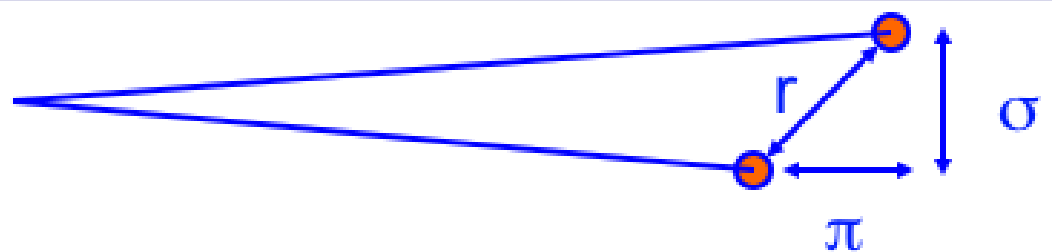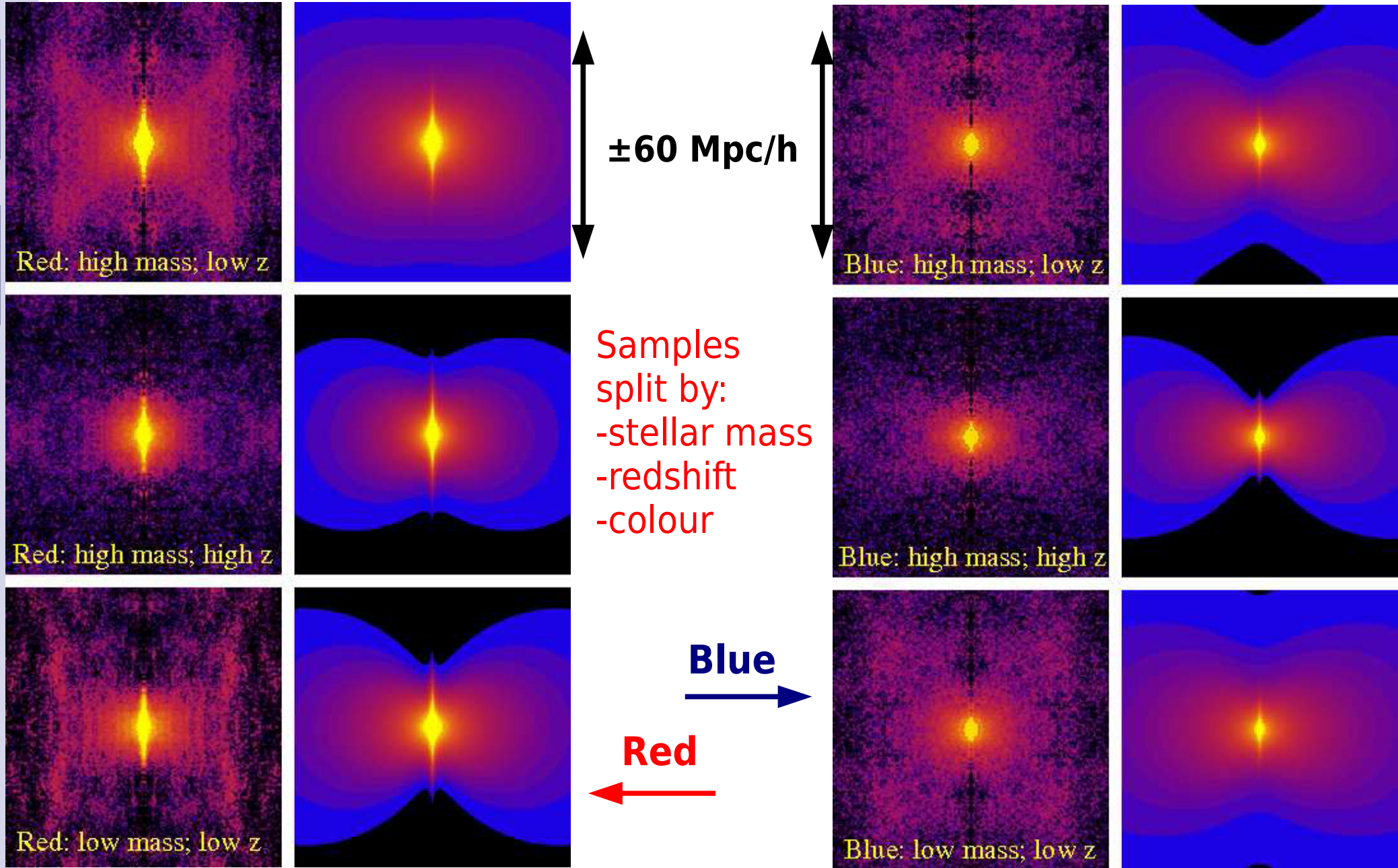
GAMA-I: clustering by colour, stellar mass, redshift

$$\log_{10}(M_*/h^{-2}M_\odot) =$$
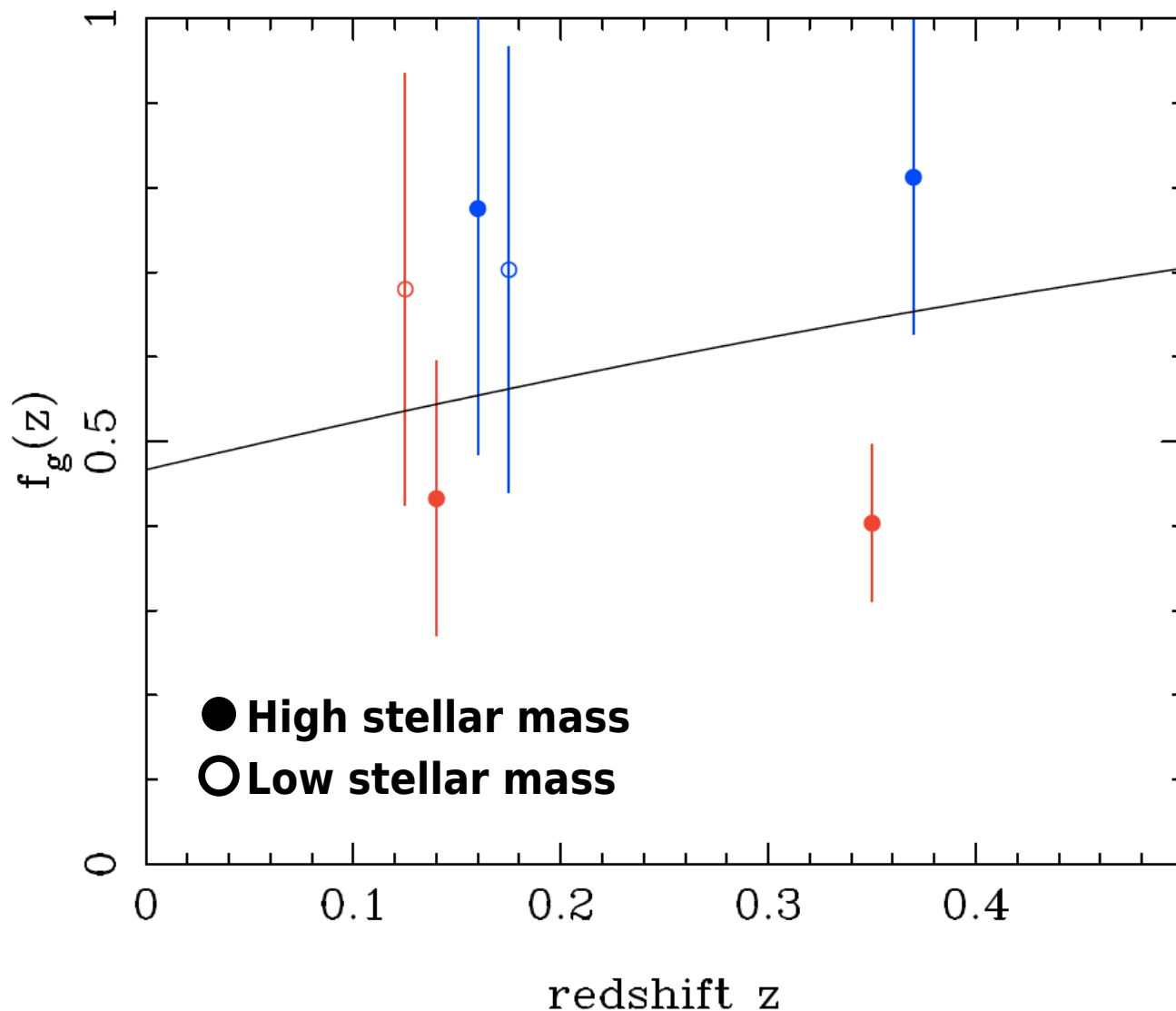$$1.15 + 0.70(M_g - M_i) - 0.4(M_i + 5\log_{10}h)$$

Taylor et al. (2011)

Peacock et al. (in prep)

Peder Norberg   Institute for Computational Cosmology, Durham University   Benasque, August 2012

GAMA-I: Clustering & Redshift Space Distortions

±60 Mpc/h

Samples
split by:
-stellar mass
-redshift
-colour

Blue →

← **Red**

Red: high mass; low z

Blue: high mass; low z

Red: high mass; high z

Blue: high mass; high z

Red: low mass; low z

Blue: low mass; low z

GAMA-I: Growth rate *(assuming Kaiser formalism)....*

$$f_g(z) = \Omega_m^\gamma(z)$$

Tension:
Tracers dependent growth rates....

2 options (at least):
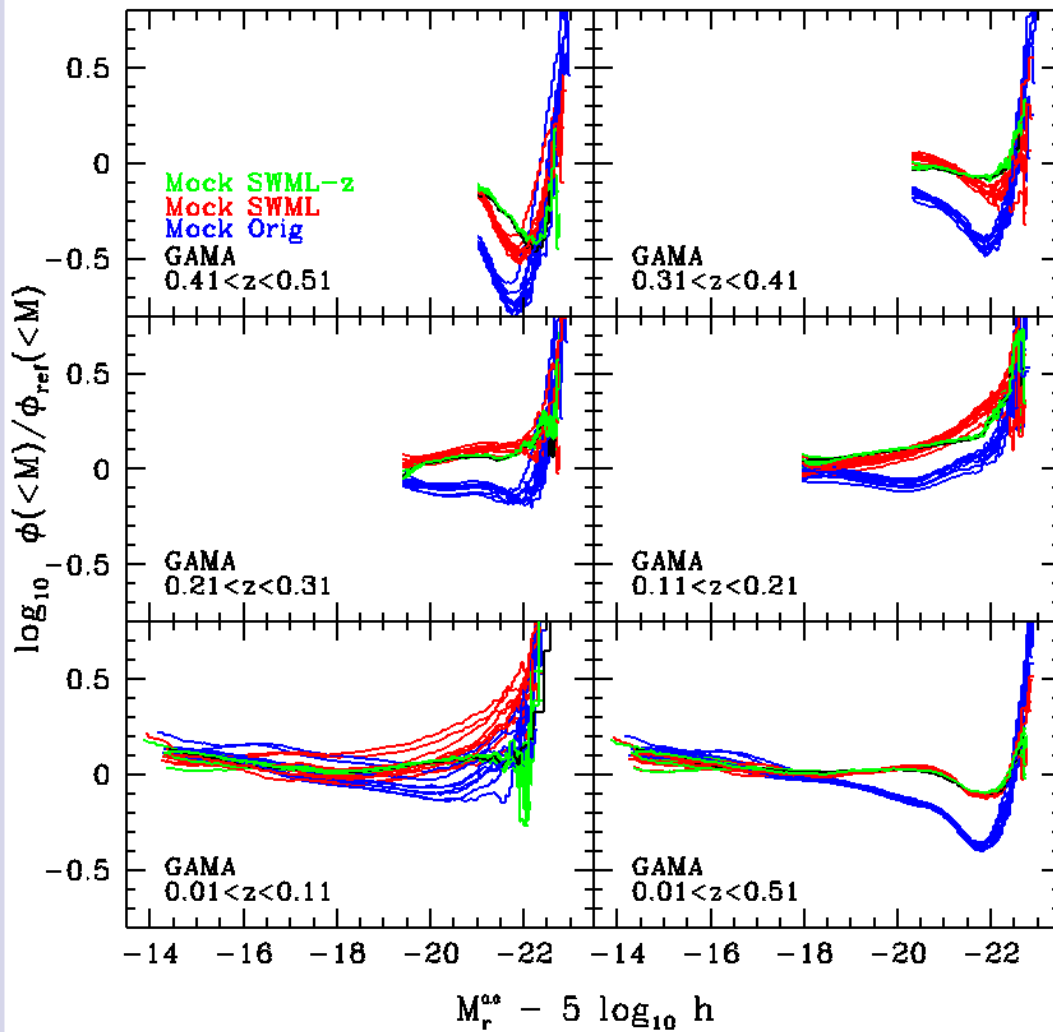a. residual systematics
b. inappropriate f_g modelling

Main suspect: (b)
[Kwan et al. 2011 model seems the way forward...]

Peacock et al. (in prep)

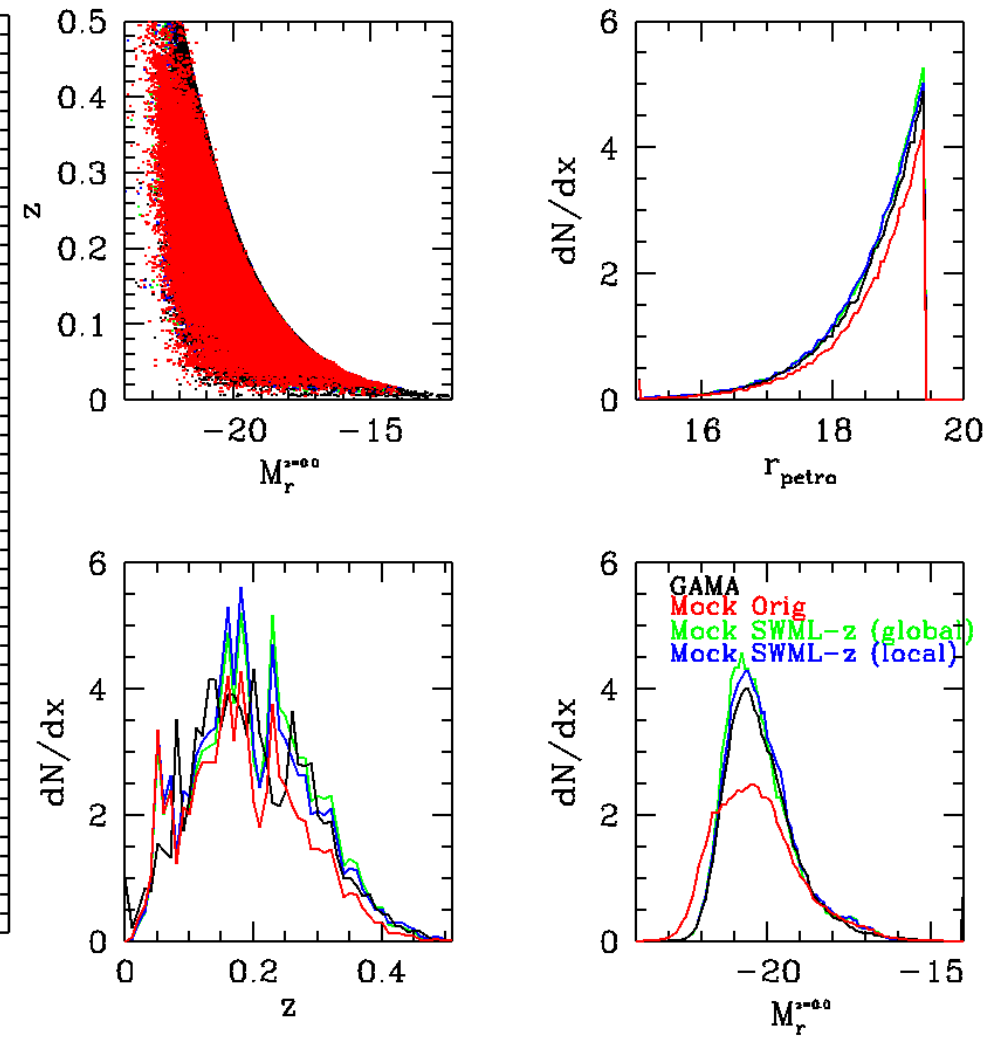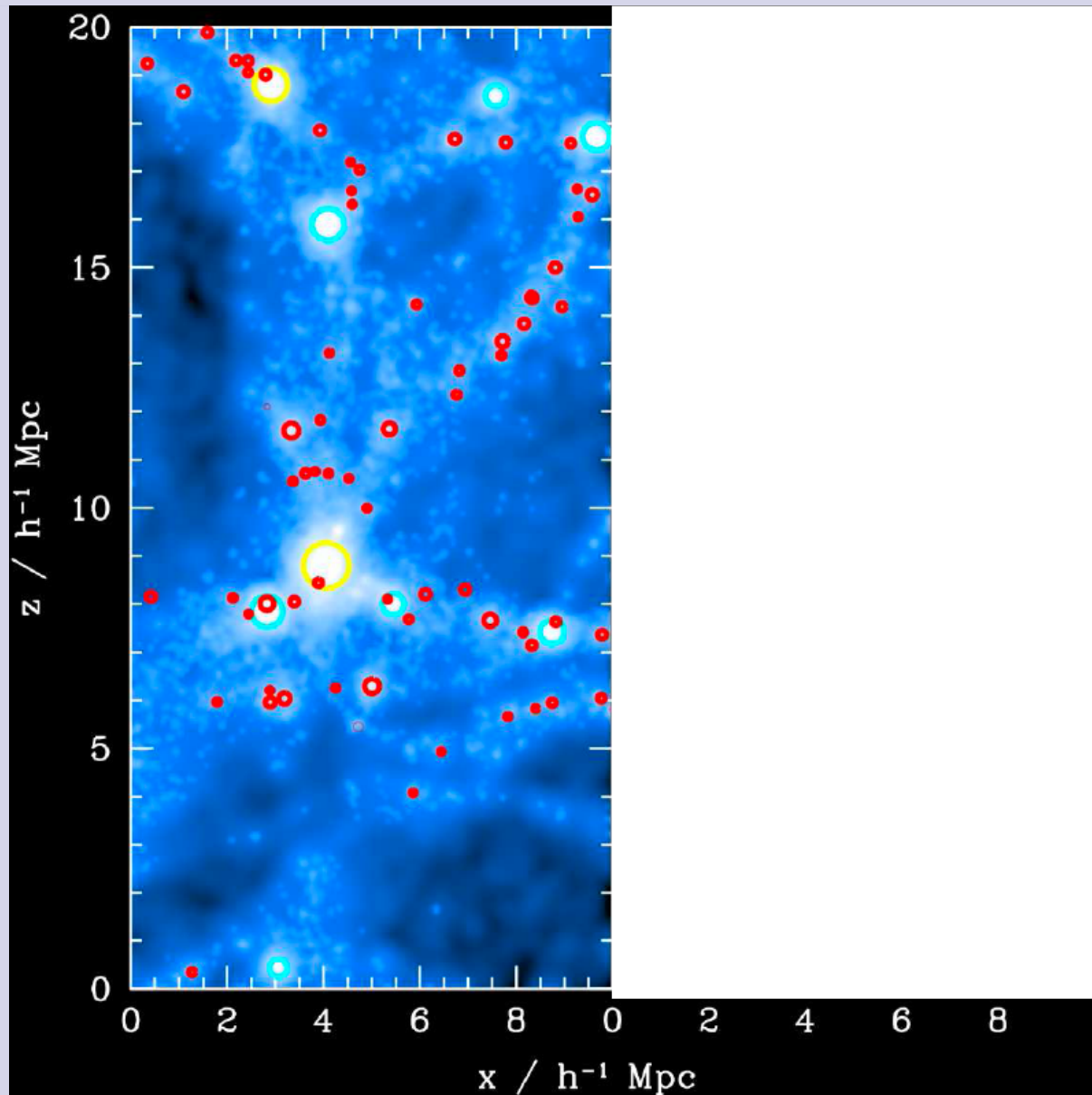# *GAMA: Mock GAMA Galaxy Group Catalogue (G³Cv1)*

CLF ratio: mocks vs GAMA

Global properties

Faint   **Abs. Mag.**   **Bright**

Norberg et al. (in prep)

Peder Norberg   Institute for Computational Cosmology, Durham University   Benasque, August 2012

GAMA: Mock GAMA Galaxy Group Catalogue (G^{3}Cv1)

Example of a 4 Mpc/h thick slice of a mock GAMA galaxy catalogue:
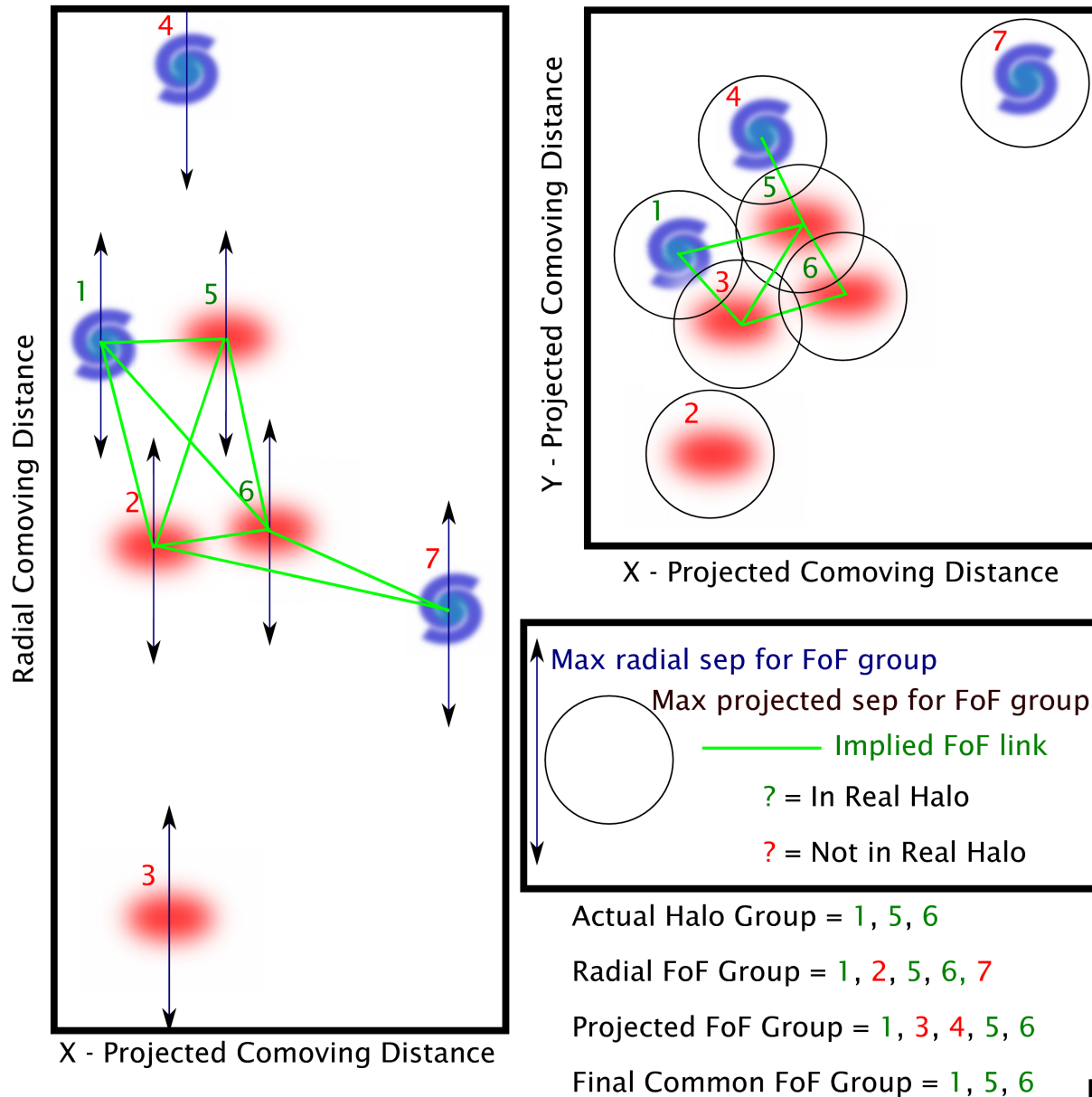- HOD/CLF
- modified semi-analytic (Durham/Munich)

Halo ~ 10^{14} Msol/h
Halo ~ 10^{13} Msol/h
Halo ~ 10^{12} Msol/h
Halo ~ 10^{11} Msol/h

GAMA: Friends-of-Friends (G³Cv1)

X - Projected Comoving Distance

Max radial sep for FoF group
Max projected sep for FoF group
——— Implied FoF link
? = In Real Halo
? = Not in Real Halo

Actual Halo Group = 1, 5, 6
Radial FoF Group = 1, 2, 5, 6, 7
Projected FoF Group = 1, 3, 4, 5, 6
Final Common FoF Group = 1, 5, 6

Two key issues:

- radial & tangential linking lengths

- redshift dependent selection function

Two key ingredients:

- lightcone mocks
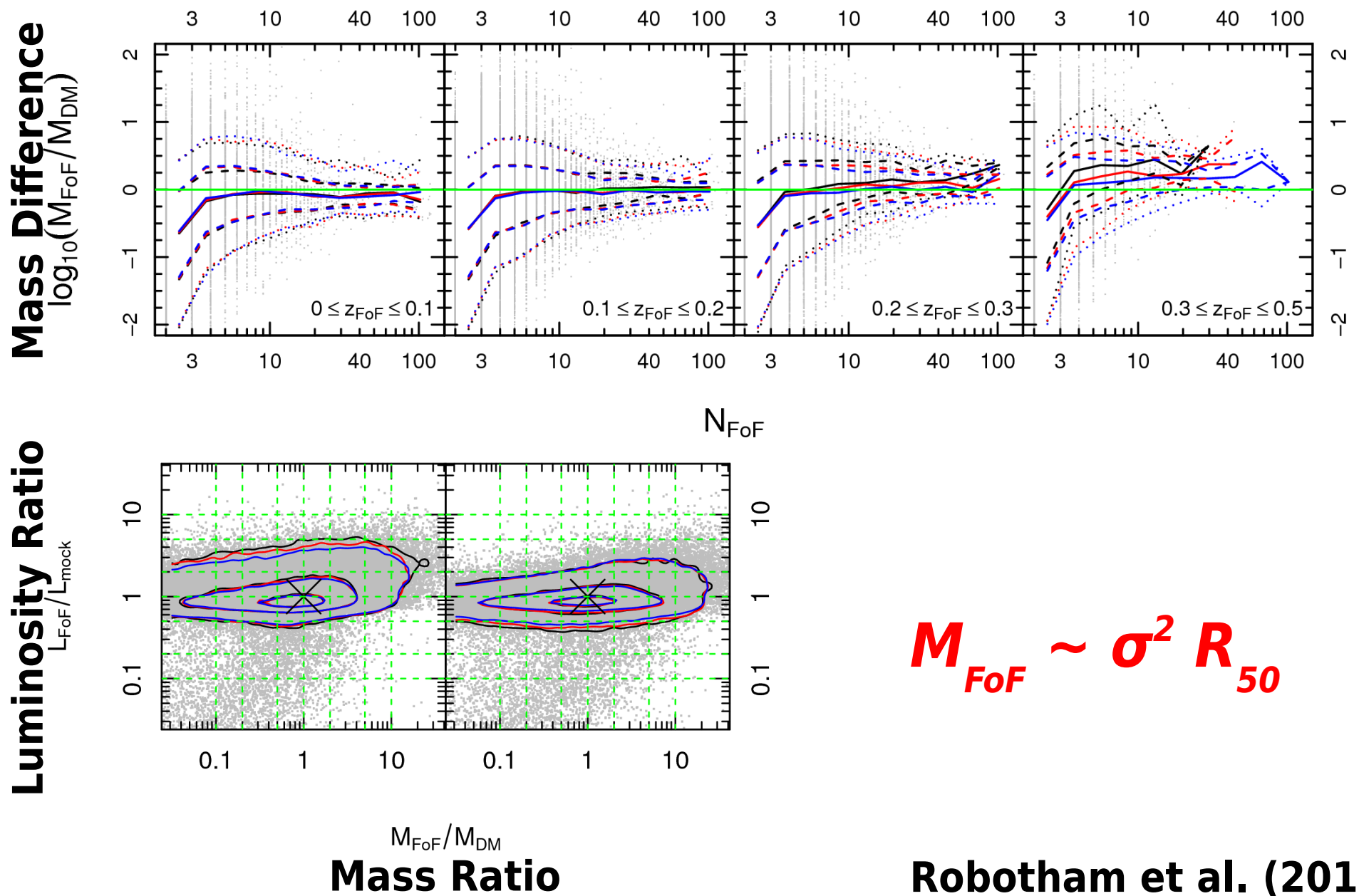
- extensive testing

Robotham et al. (2011)

Peder Norberg   Institute for Computational Cosmology, Durham University   Benasque, August 2012

GAMA: tuning/testing of G³Cv1
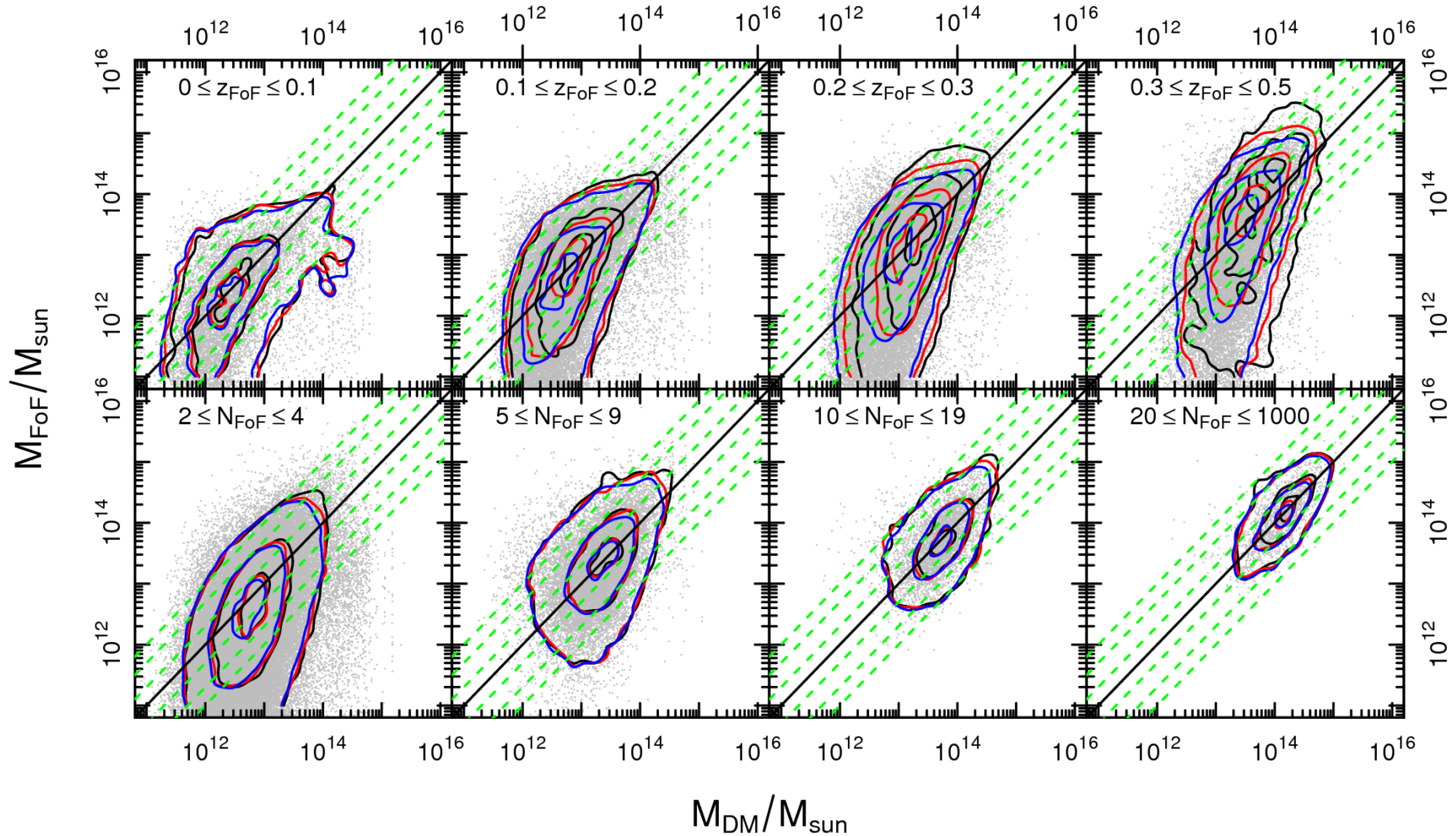
$$\frac{M_{\mathrm{FoF}}}{h^{-1}\,\mathrm{M}_\odot} = \frac{A}{\dfrac{G}{\mathrm{M}_\odot{}^{-1}\,\mathrm{km}^2\,\mathrm{s}^{-2}\,\mathrm{Mpc}}} \left(\frac{\sigma_{\mathrm{FoF}}}{\mathrm{km\,s}^{-1}}\right)^2 \frac{\mathrm{Rad}_{\mathrm{FoF}}}{h^{-1}\,\mathrm{Mpc}}$$

Robotham et al. (2011)

Peder Norberg   Institute for Computational Cosmology, Durham University   Benasque, August 2012

GAMA: tuning/testing of G³Cv1

Mass Difference $\log_{10}(M_{FoF}/M_{DM})$

$0 \leq z_{FoF} \leq 0.1$ $0.1 \leq z_{FoF} \leq 0.2$ $0.2 \leq z_{FoF} \leq 0.3$ $0.3 \leq z_{FoF} \leq 0.5$

N_{FoF}

Luminosity Ratio L_{FoF}/L_{mock}

M_{FoF}/M_{DM}

Mass Ratio

$$M_{FoF} \sim \sigma^2 R_{50}$$

Robotham et al. (2011)

Peder Norberg   Institute for Computational Cosmology, Durham University   Benasque, August 2012

GAMA: G³Cv1 coneplot

- 142 sq.deg. to r=19.4
- 12k $N_g \geq 2$ groups
- 1.5k $N_g \geq 5$ groups

NEWS:
GAMA-II NGP "completed"

→ ~180 sq.deg. to r=19.8
→ ~2x more groups
→ G³Cv2 on its way...

Robotham et al. (2011)
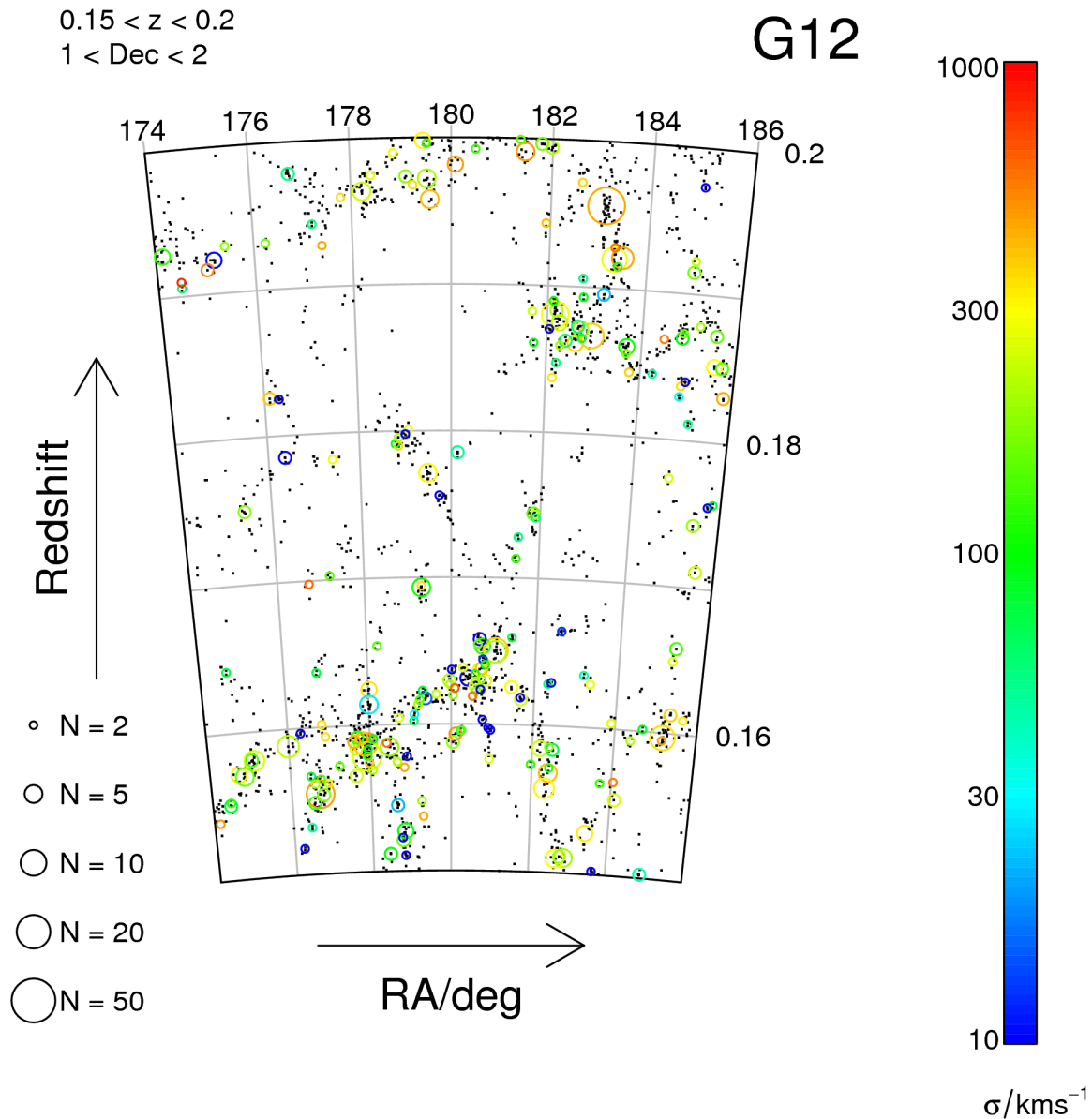
GAMA: G³Cv1 zoom in

0.15 < z < 0.2
−2 < Dec < −1

G12

Robotham et al. (2011)

GAMA: G³Cv1 zoom in

Robotham et al. (2011)
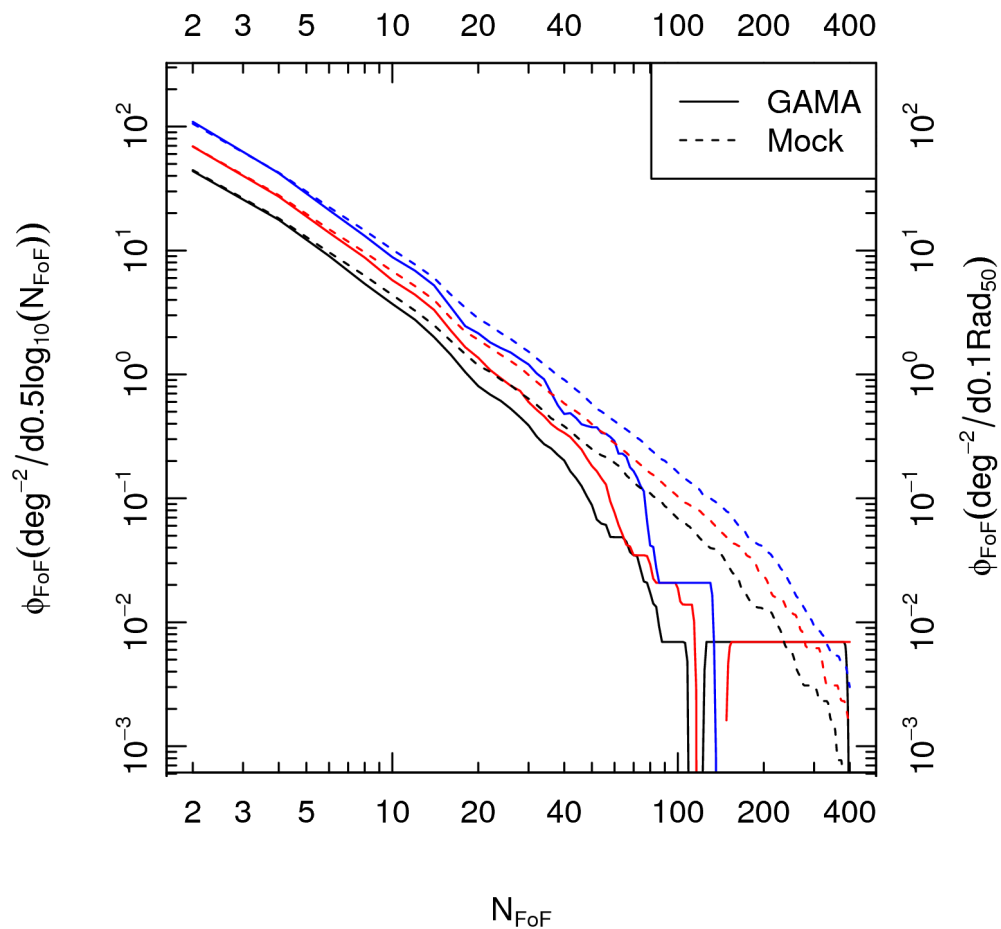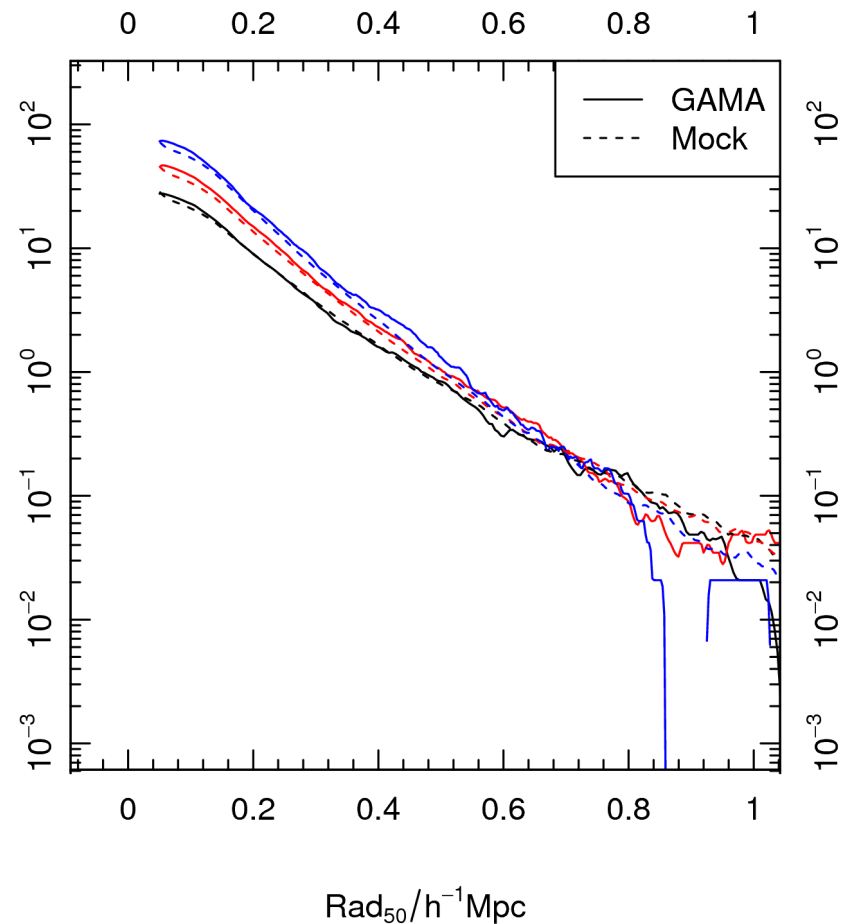
GAMA: G³Cv1 zoom in

Robotham et al. (2011)

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GAMA: G³Cv1 zoom in

0.15 < z < 0.2
1 < Dec < 2

G12

Robotham et al. (2011)

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GAMA: G³Cv1 global properties

Galaxy formation dependent group properties

Multiplicity

Radius

Robotham et al. (2011)

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GAMA: G³Cv1 global properties

CDM dependent group properties
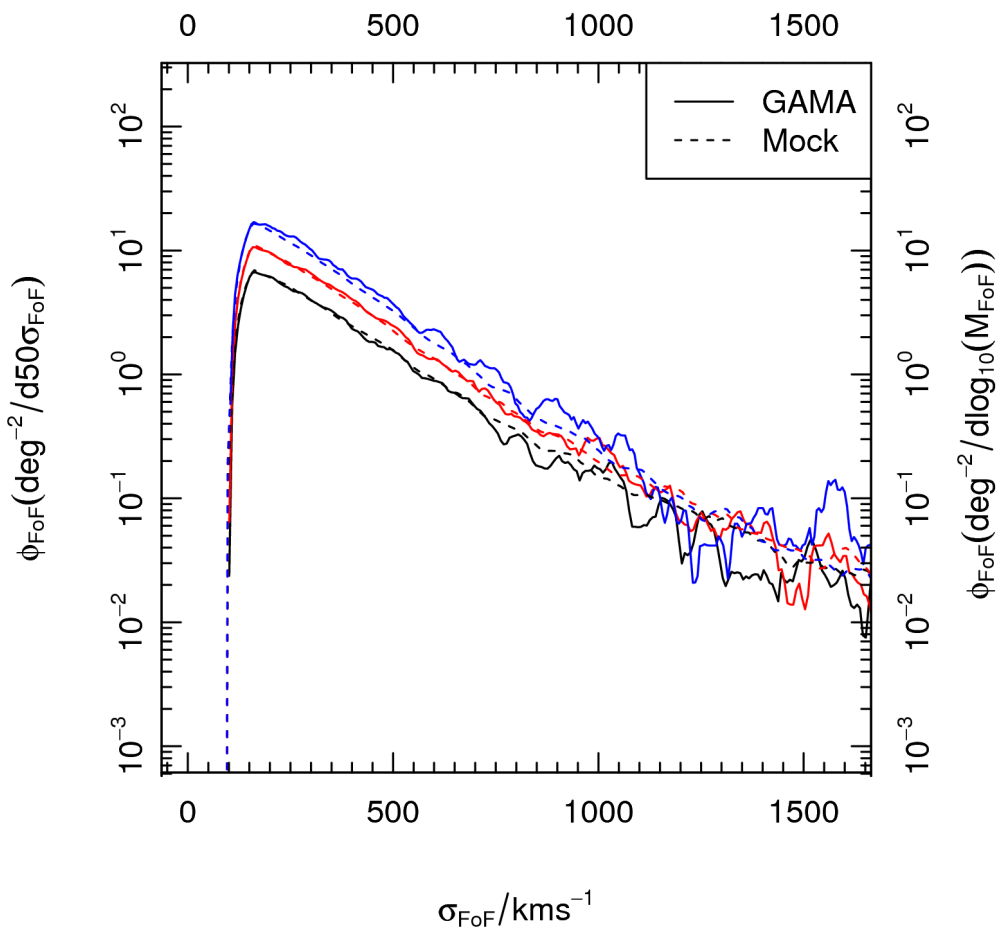
Velocity Dispersion
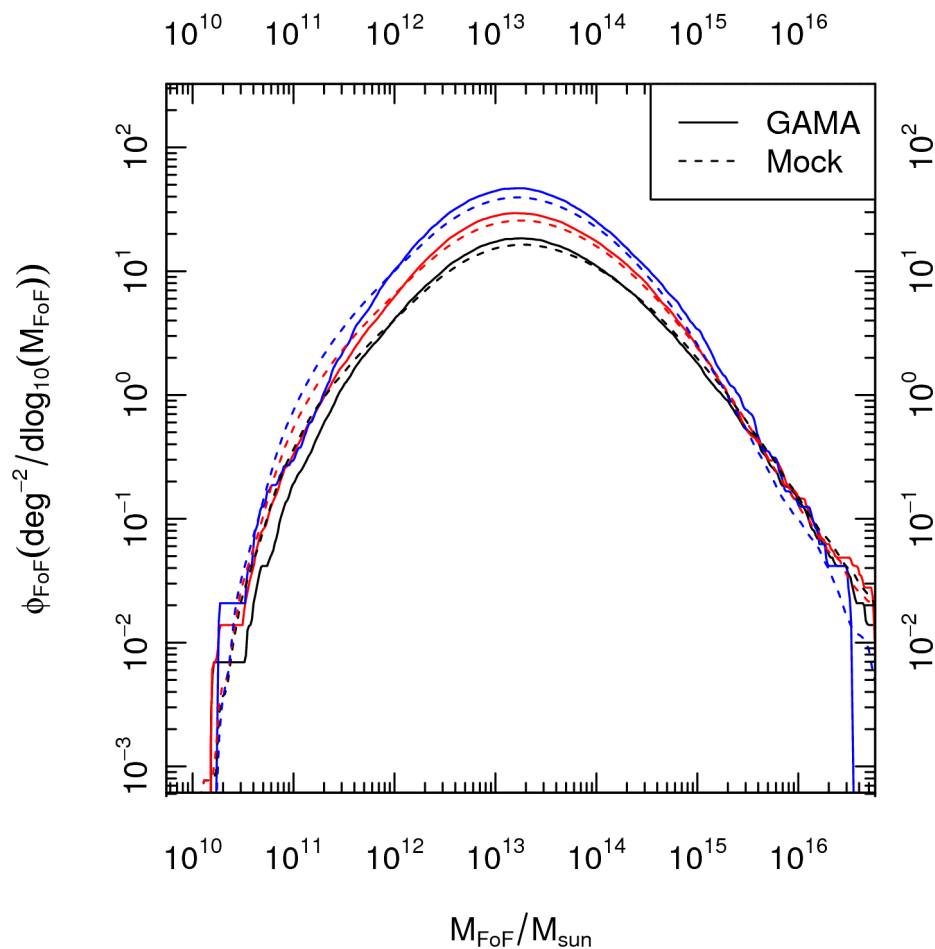
Halo Mass

Robotham et al. (2011)

GAMA: G³Cv1 global properties
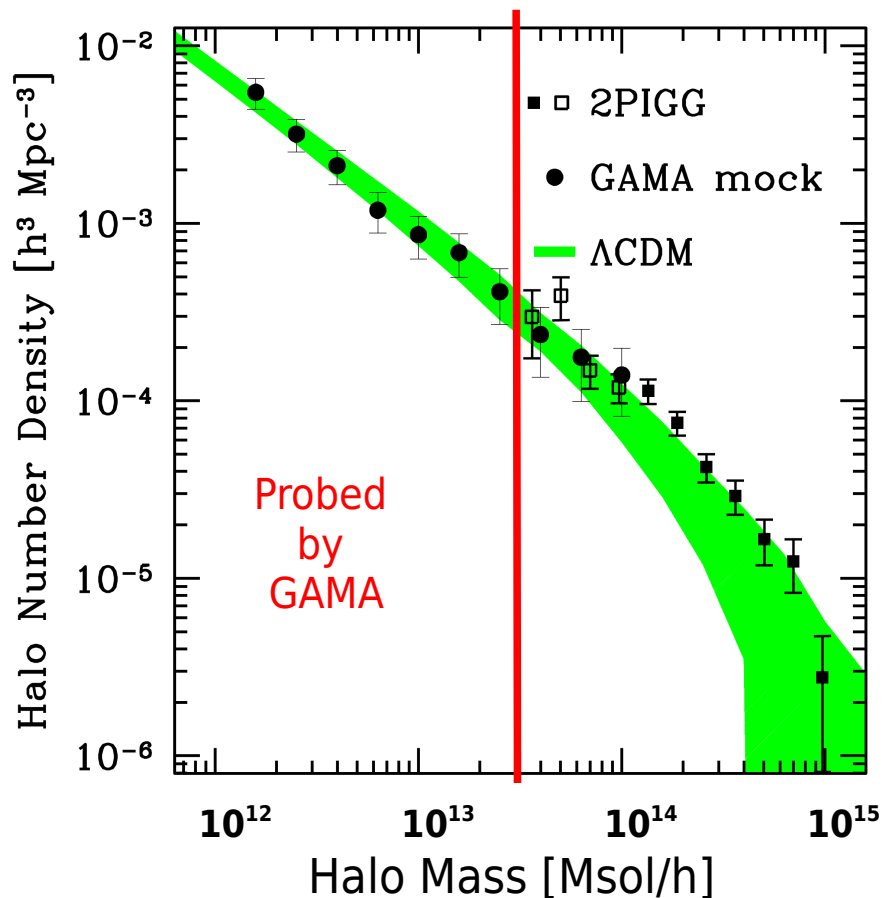
Current limitations of the mocks
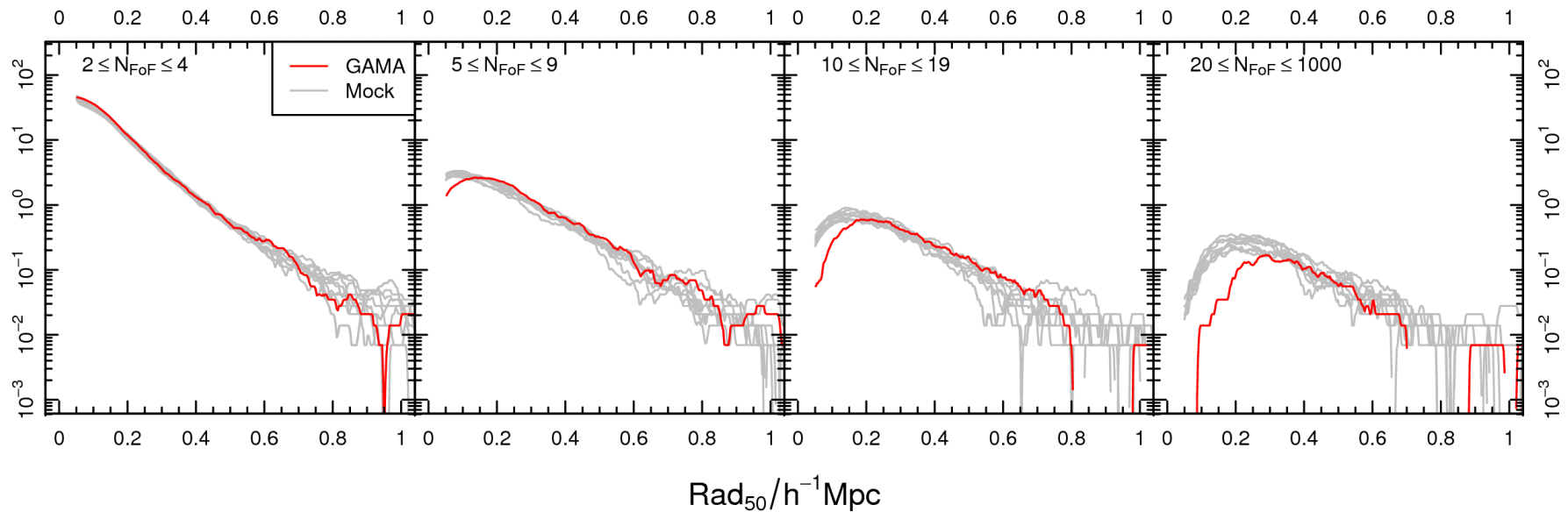
- one set of mocks with one galaxy formation model
- redshift space clustering not perfectly matched
- redshift errors not modelled in detail
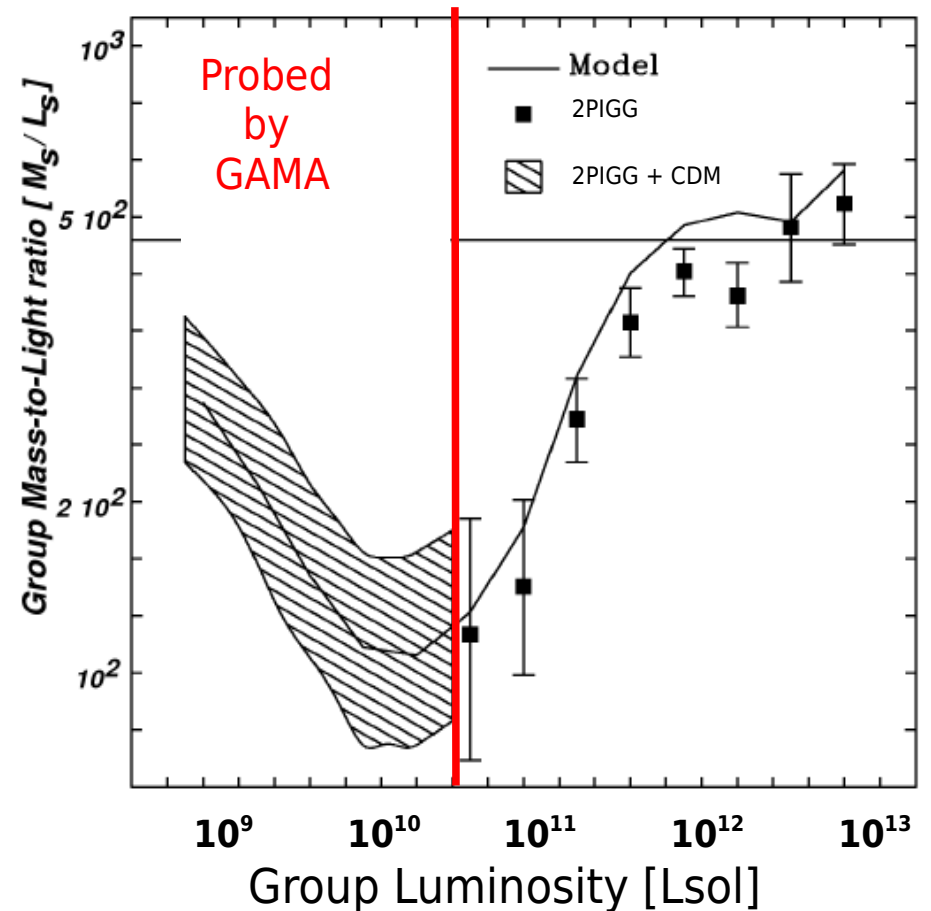- ...

Robotham et al. (2011)

GAMA: *still some way to go towards the final GAMA goal...*
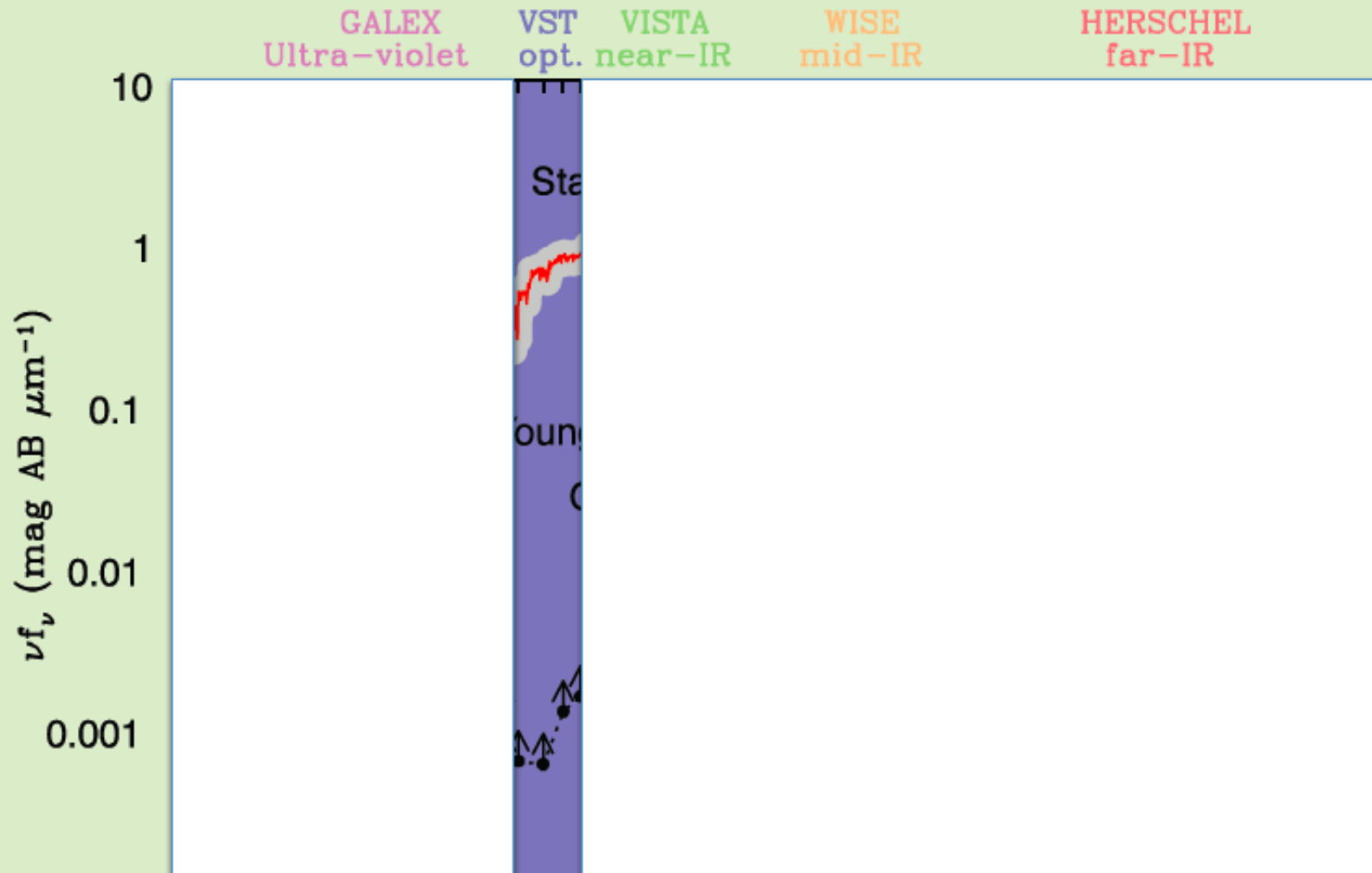

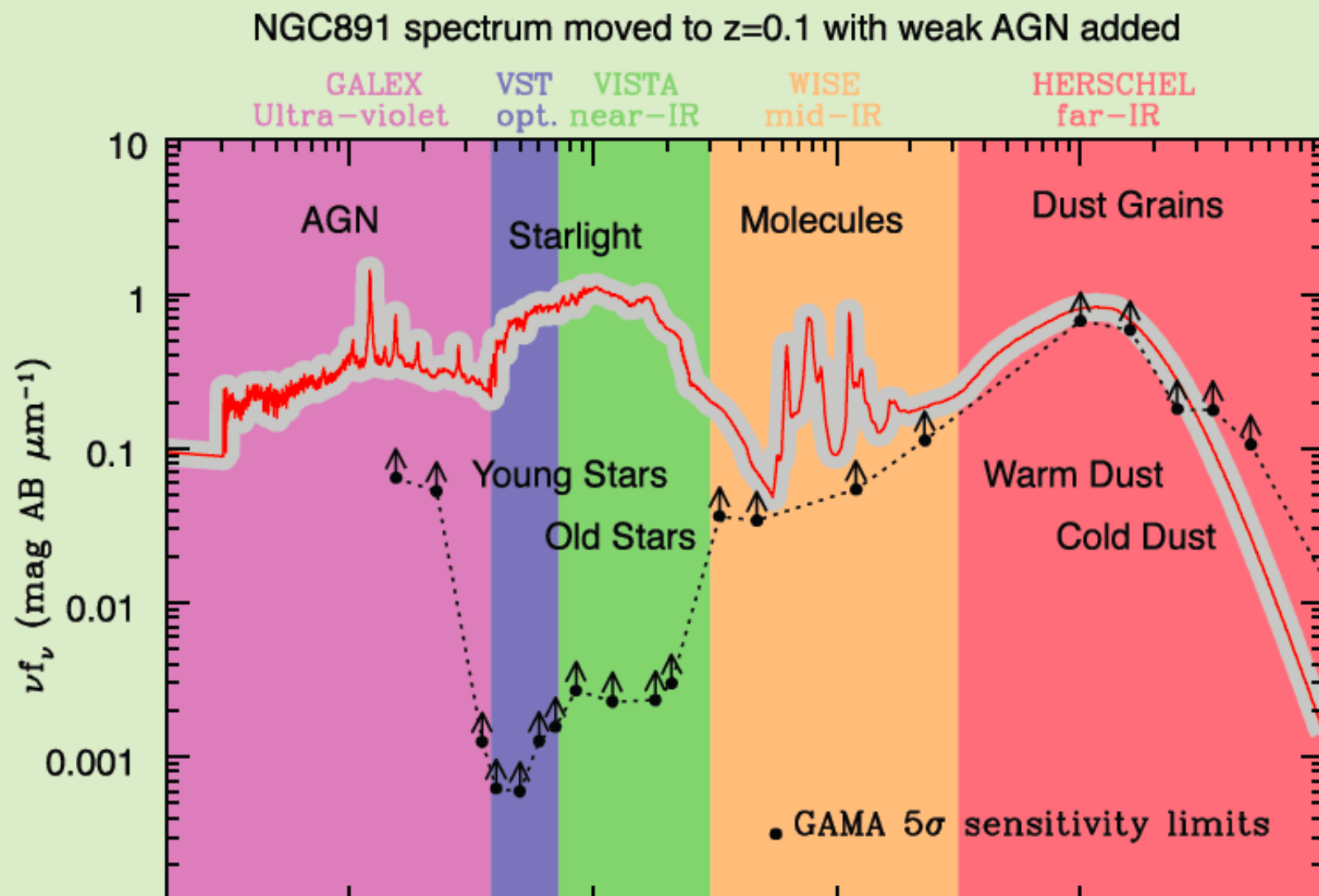Dark Matter Halo Mass Function

Galaxy Formation Efficiency

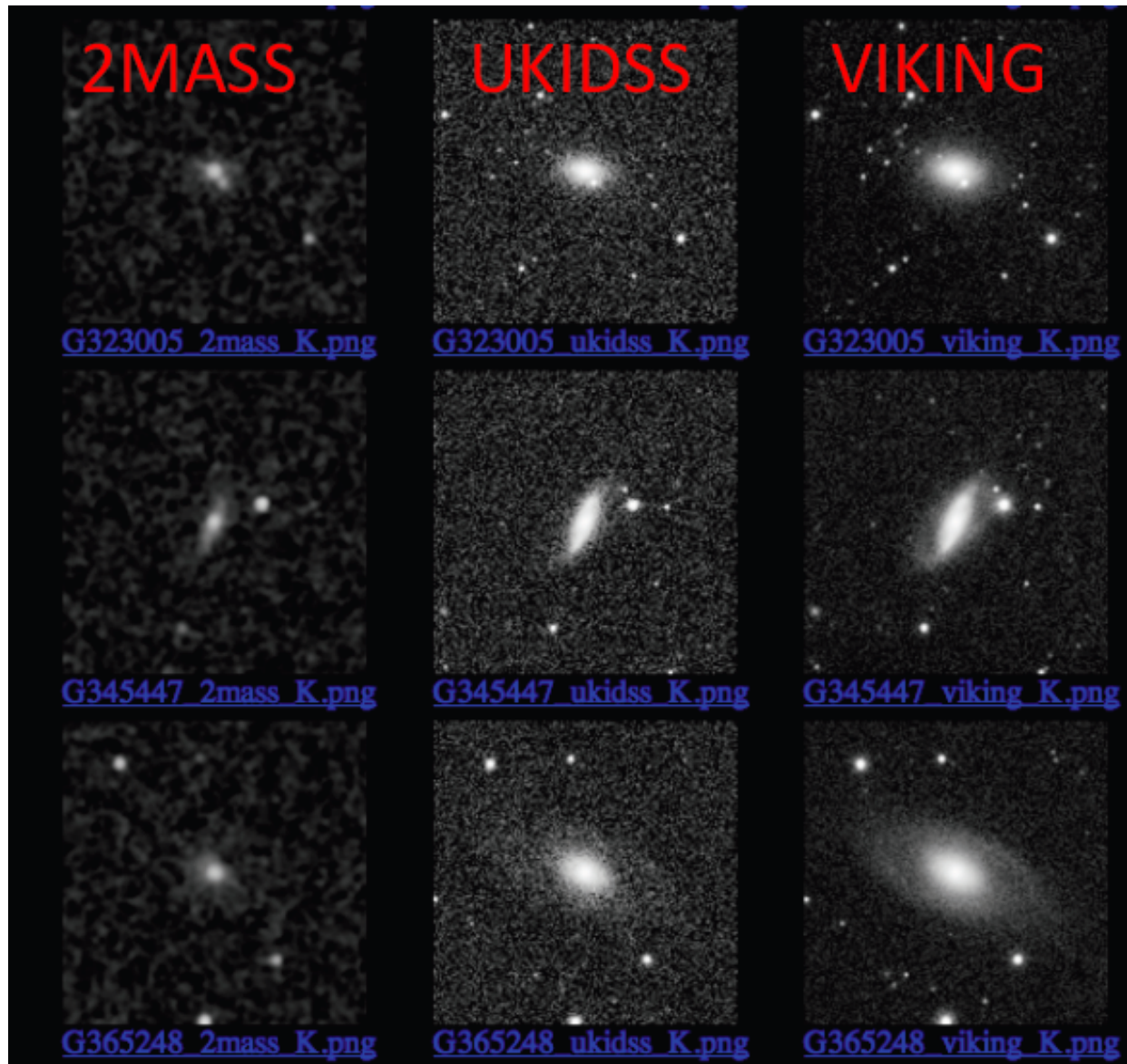# GAMA beyond LSS: 'the' galaxy formation survey with UV to far-IR SEDs

NGC891 spectrum moved to z=0.1 with weak AGN added

GAMA beyond LSS: 'the' galaxy formation survey with UV to far-IR SEDs

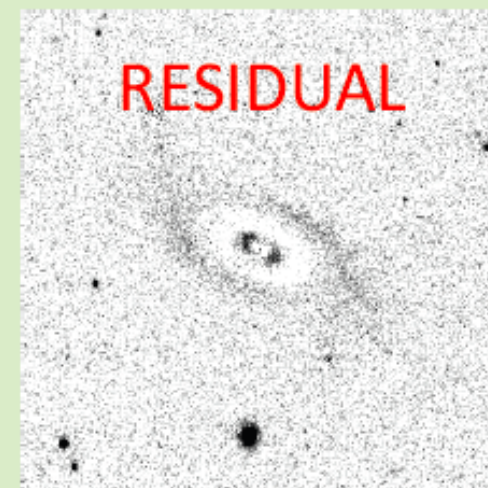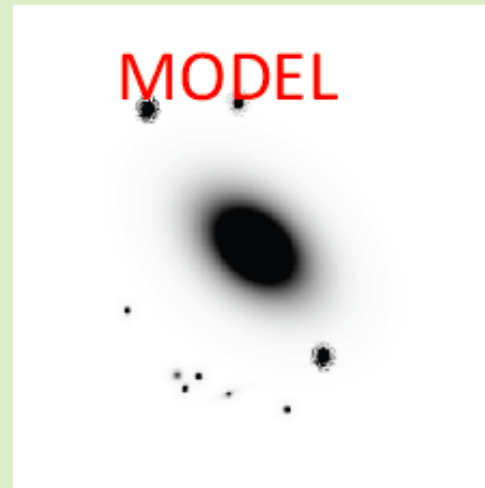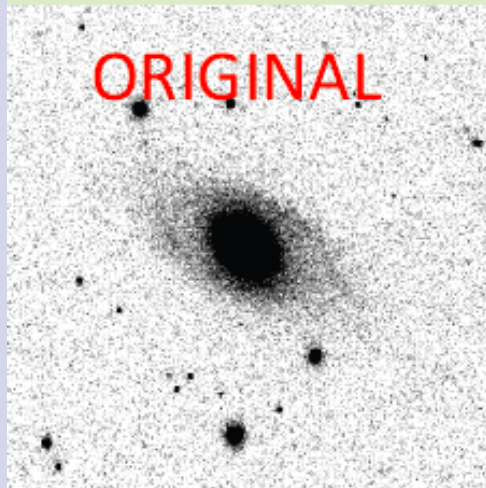NGC891 spectrum moved to z=0.1 with weak AGN added

GAMA beyond LSS: 'the' galaxy formation survey with improved spatial resolution

Peder Norberg   Institute for Computational Cosmology, Durham University   Benasque, August 2012

GAMA beyond LSS: 'the' galaxy formation survey with improved spatial resolution

All z<0.1 galaxies in all bands

ORIGINAL · MODEL · BULGE · DISC · RESIDUAL

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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
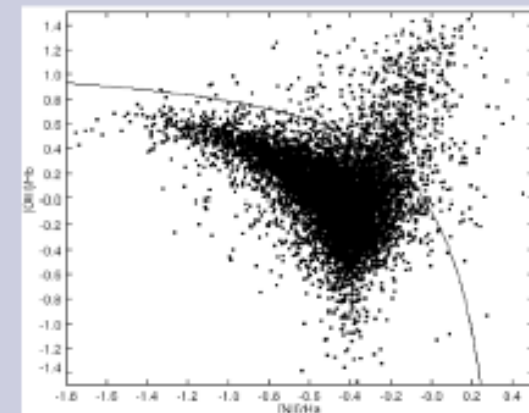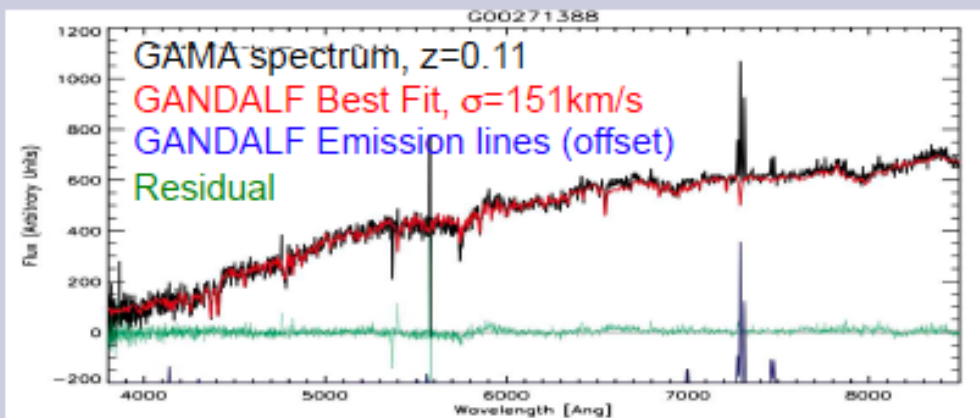
AGN: BPT diagnostics : type : strength : ionisation state

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 spectrum, z=0.11
GANDALF Best Fit, σ=151km/s
GANDALF Emission lines (offset)
Residual

GAMA: THE DATABASE (II)

For z<0.1 (~30k):
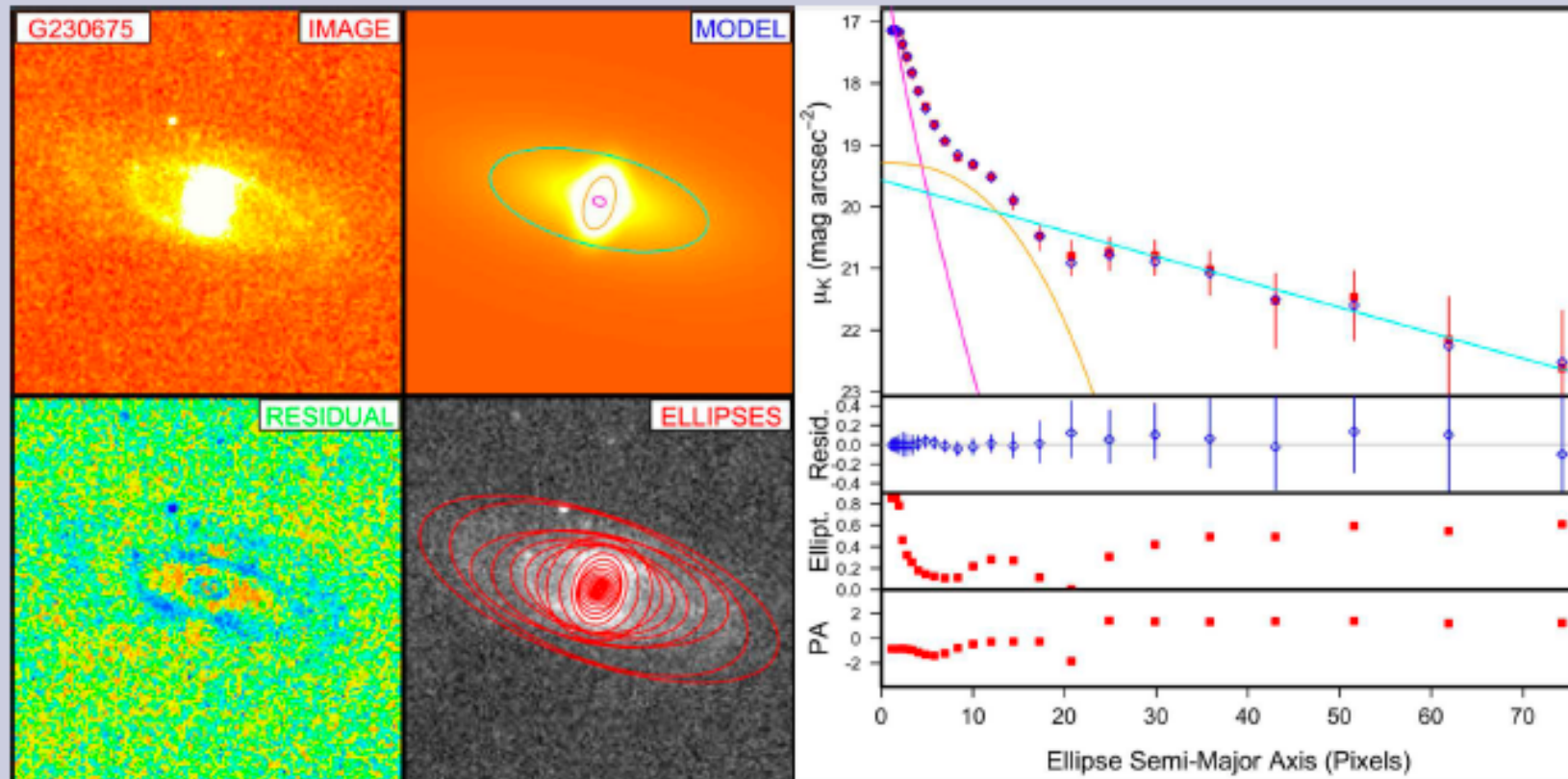
Structural: Bulge/Bar/Disc decomp. in *ugrizYJHK* (GALFIT3)

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

Conclusions

- GAMA is a unique multi-wavelength survey:

    - 200k redshifts so far (aim: 350k over 350 sq.deg)

    - very high z-completeness (~98% to r<19.8)

    - 21 bands (far-UV to far-IR + X-ray + Radio)

- GAMA LSS:

    - ideal to test for key systematics, but statistically limited (culprit: survey volume)

- GAMA G^{3}Cv1:

    - 1.5k groups > 10^{12} M_{sol}

    - Local group analogues (Robotham et al. 2012)

- Main GAMA strength:

    - Test galaxy formation models (far-UV to far-IR)