The lives and times of galaxies in the Cosmic Web

Mehmet Alpaslan
with **Pamela Marcum, Simon Driver, Aaron Robotham,** and many others!

Tuesday April 28th, 2015

GAMA

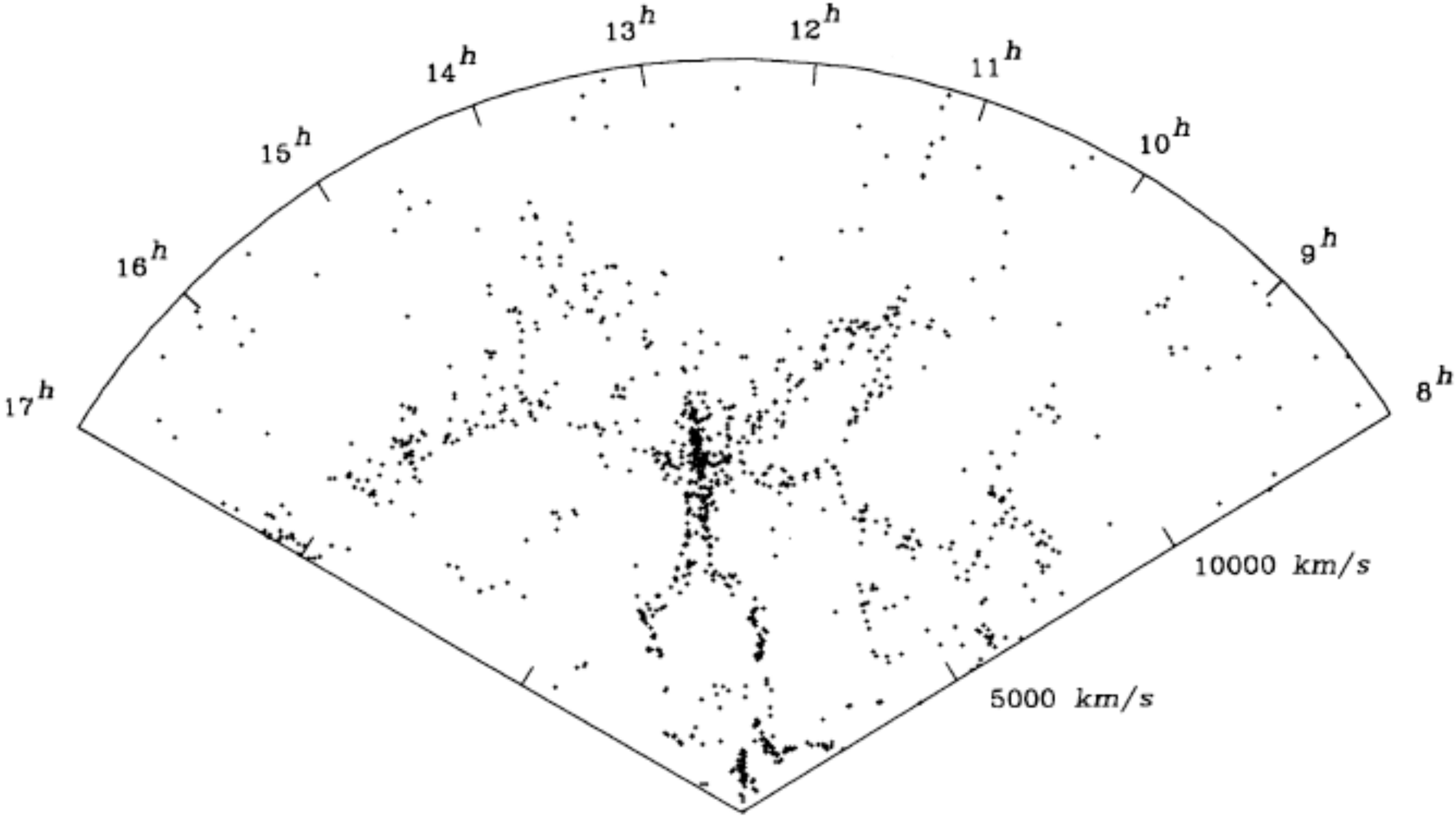
NASA POSTDOCTORAL PROGRAM

Ames Research Center

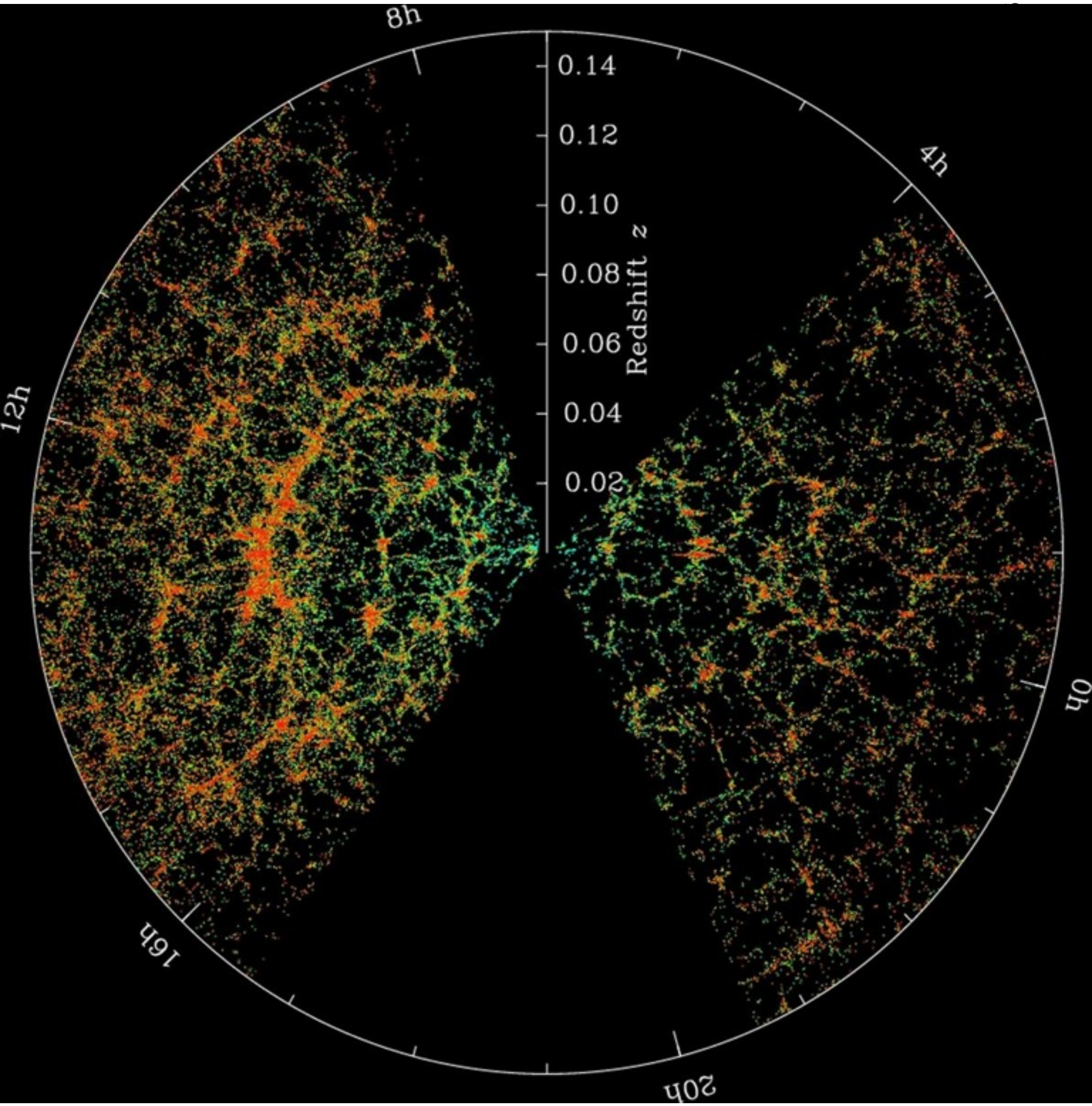
University of St Andrews

ICRAR International Centre for Radio Astronomy Research

It all started with a stick man…



De Lapparent et al. 1986

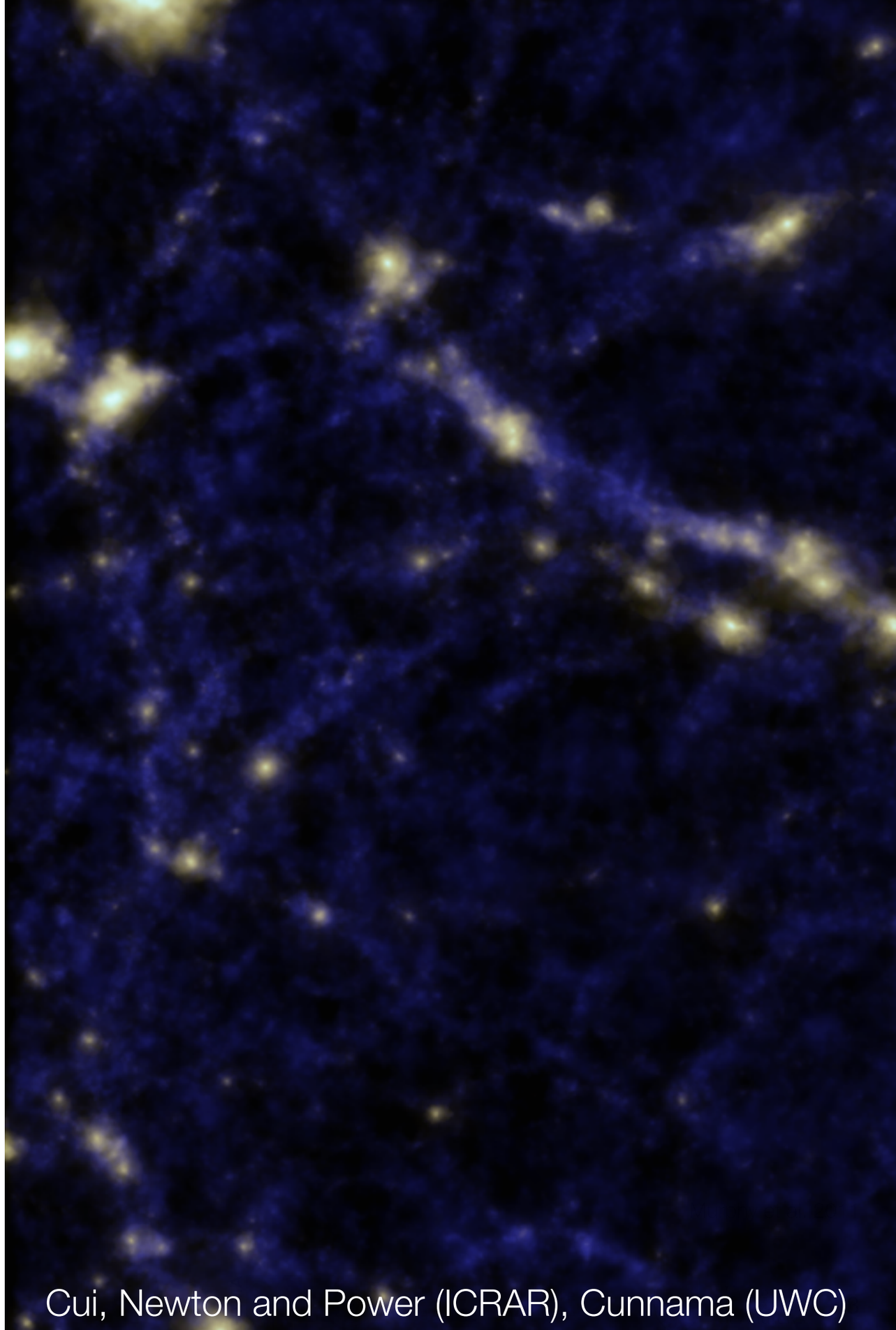

8h
4h
0h
20h
16h
12h
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Redshift z

No galaxy is an island

Galaxies are tightly linked to their environment - the presence of other galaxies has a strong impact on morphology and baryonic content.

This relationship is well understood at local scales; but what role do cosmic filaments play in the assembly of mass? Do galaxies in voids evolve differently to galaxies in clusters?

These fundamental questions require not only detailed observations, but also a thorough catalogue of large scale structure.



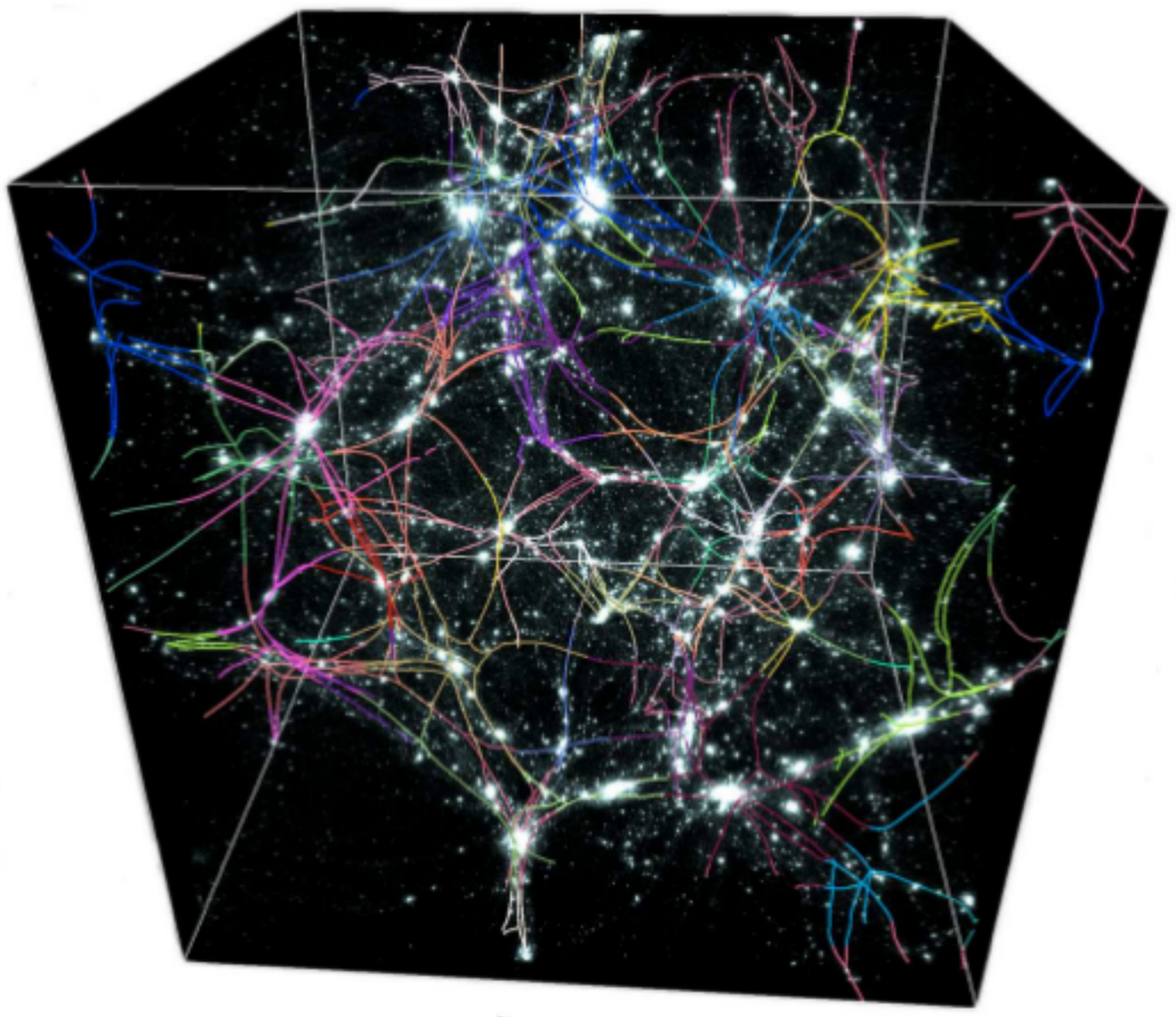
Cui, Newton and Power (ICRAR), Cunnama (UWC)

Filaments and large scale structure

Filaments offer a cosmological test at the largest scales, as well as a measure of the effects of environment on galaxy properties, particularly as a function of density.

Many filament finders exist (e.g. Barrow et al. 1995; Colberg 2007; Sousbie et al. 2008; Stoica et al. 2010; Murphy et al. 2011) and are complemented by void finders (e.g. El-Ad & Piran 1997; Peebles 2001; Hoyle & Vogeley 2004; van de Weygaert 2009).

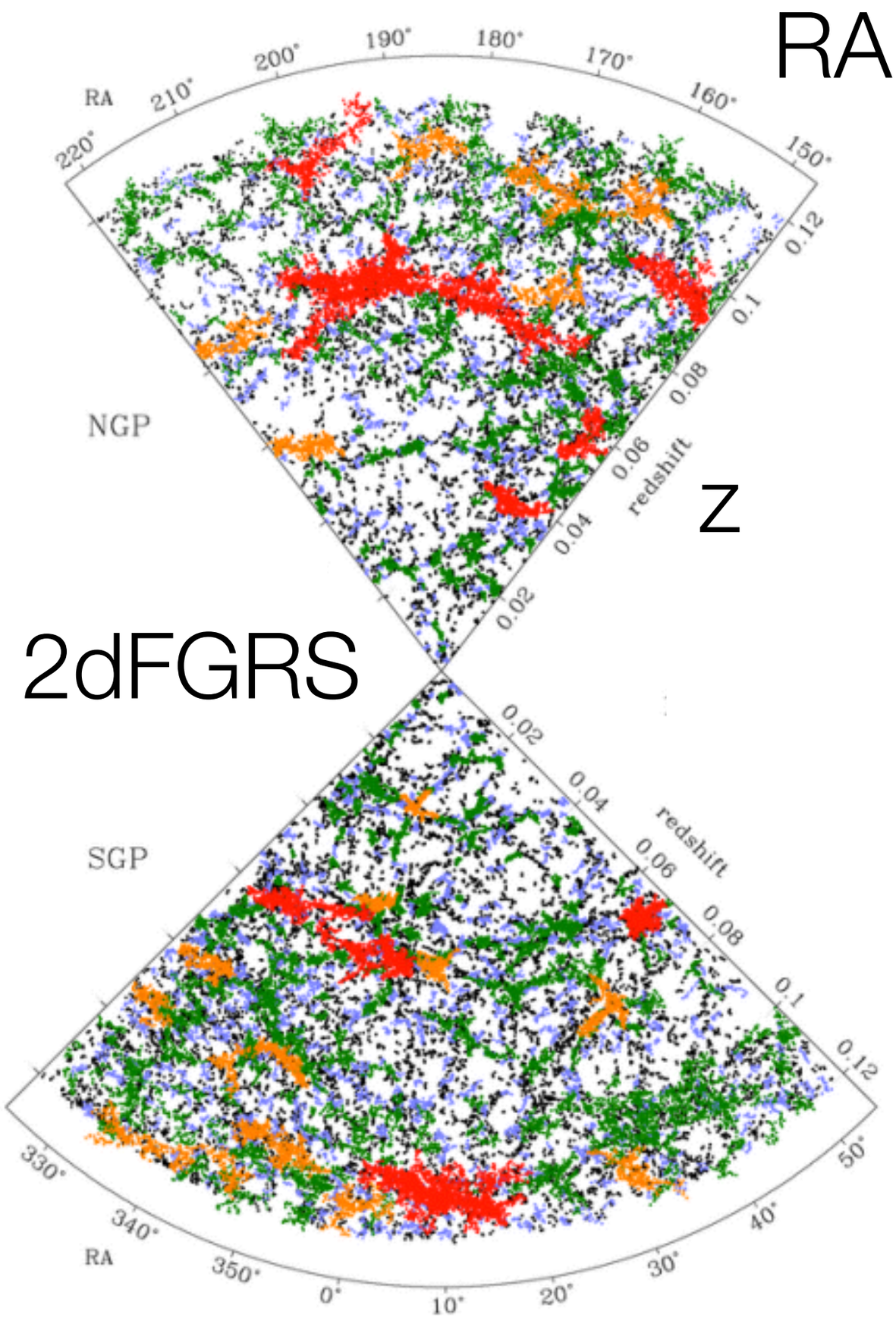
Stoica et al. 2008



What is the question I want to answer?

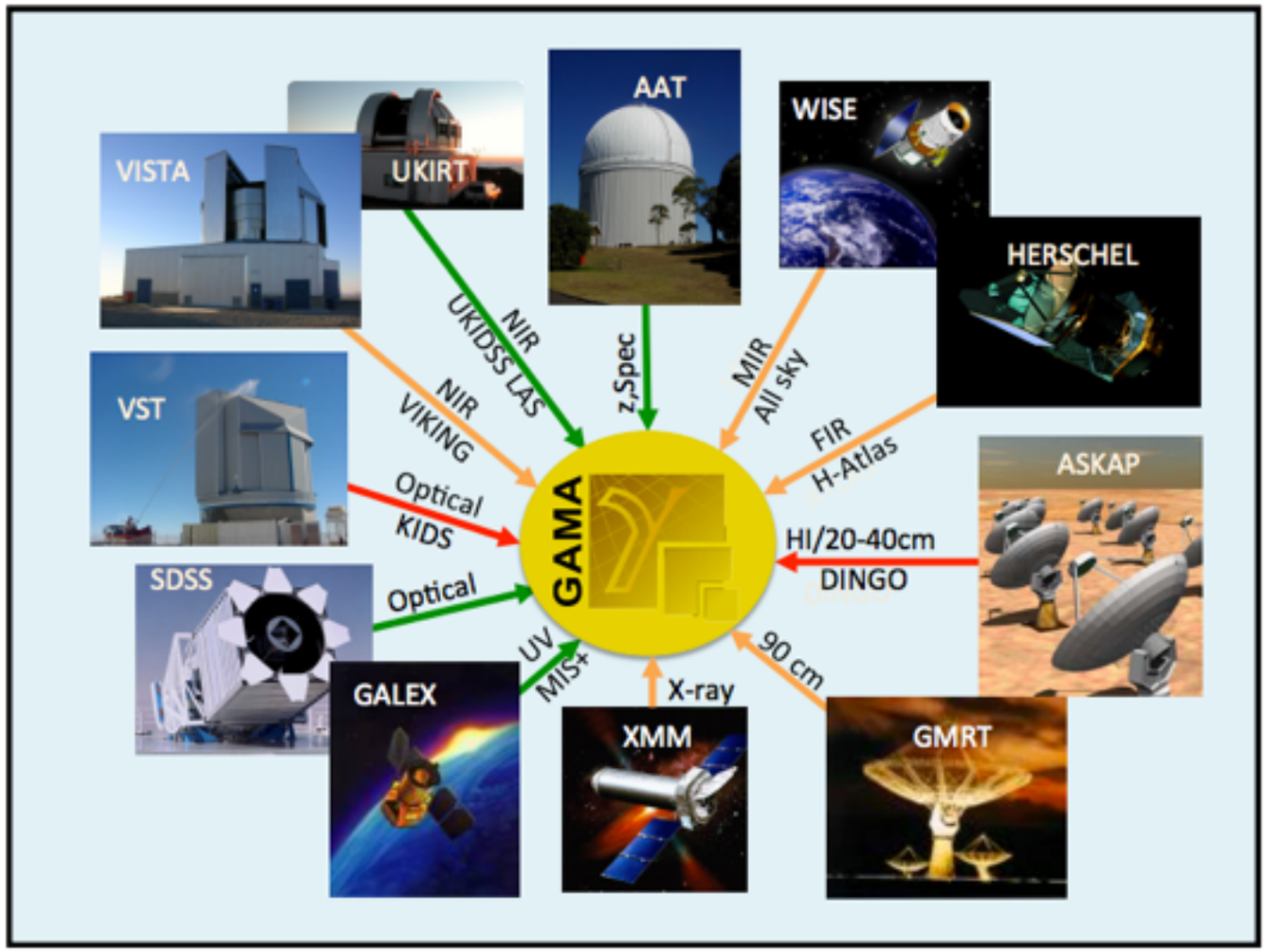
How is the evolutionary fate of a galaxy linked to its large scale environment?

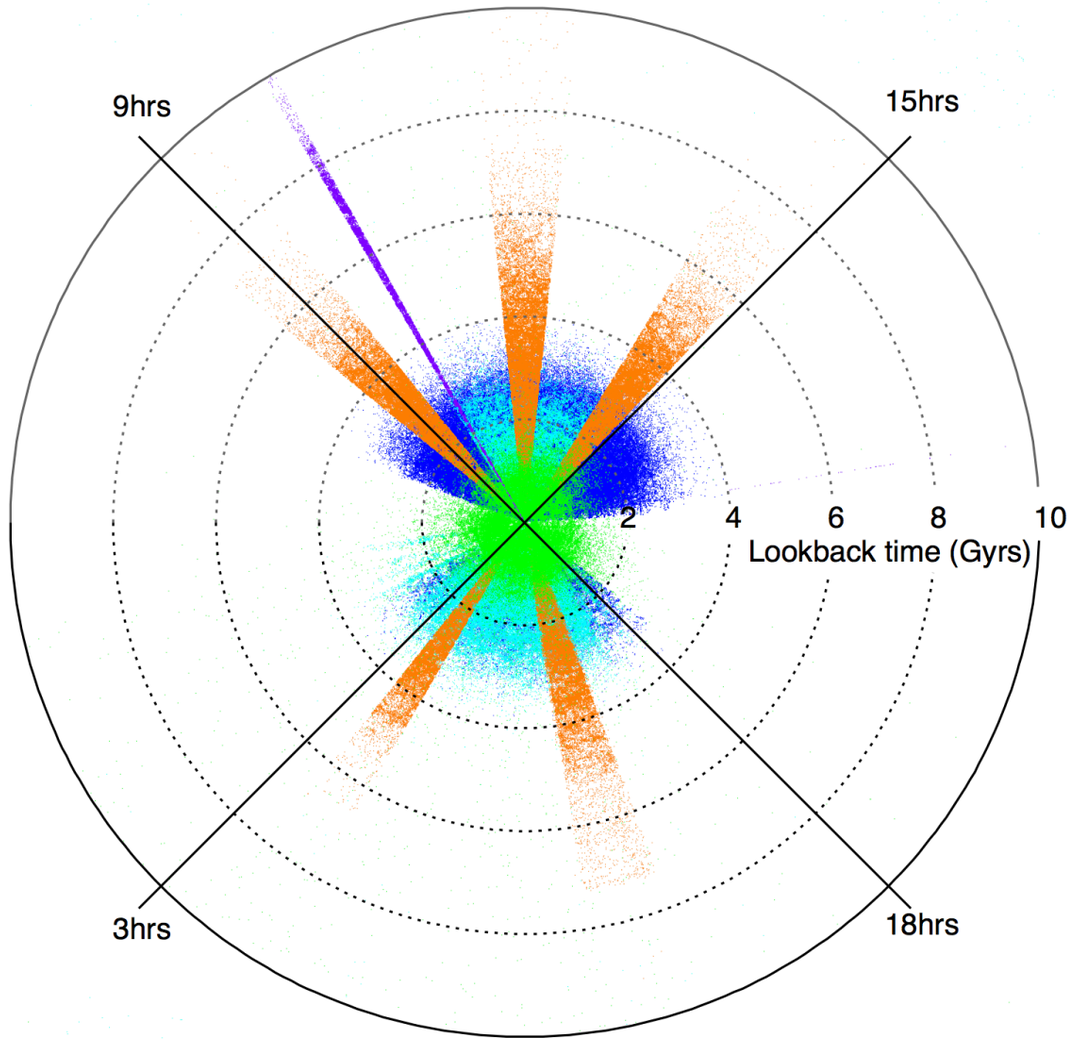
Need a LSS catalogue that is observationally motivated, works on galaxy survey data, and designed to investigate galaxy evolution.



Murphy et al. 2011

Galaxy And Mass Assembly (GAMA)

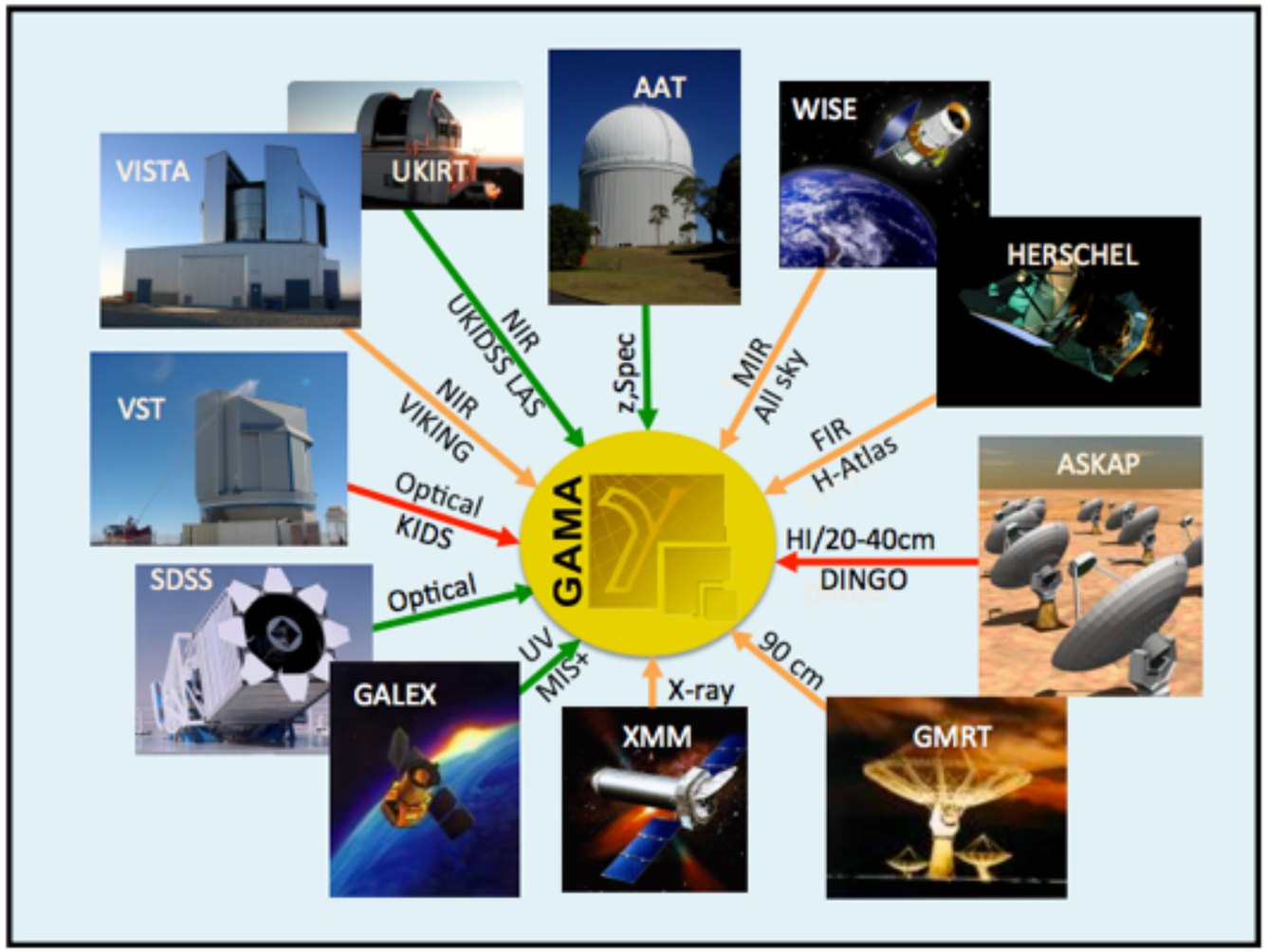


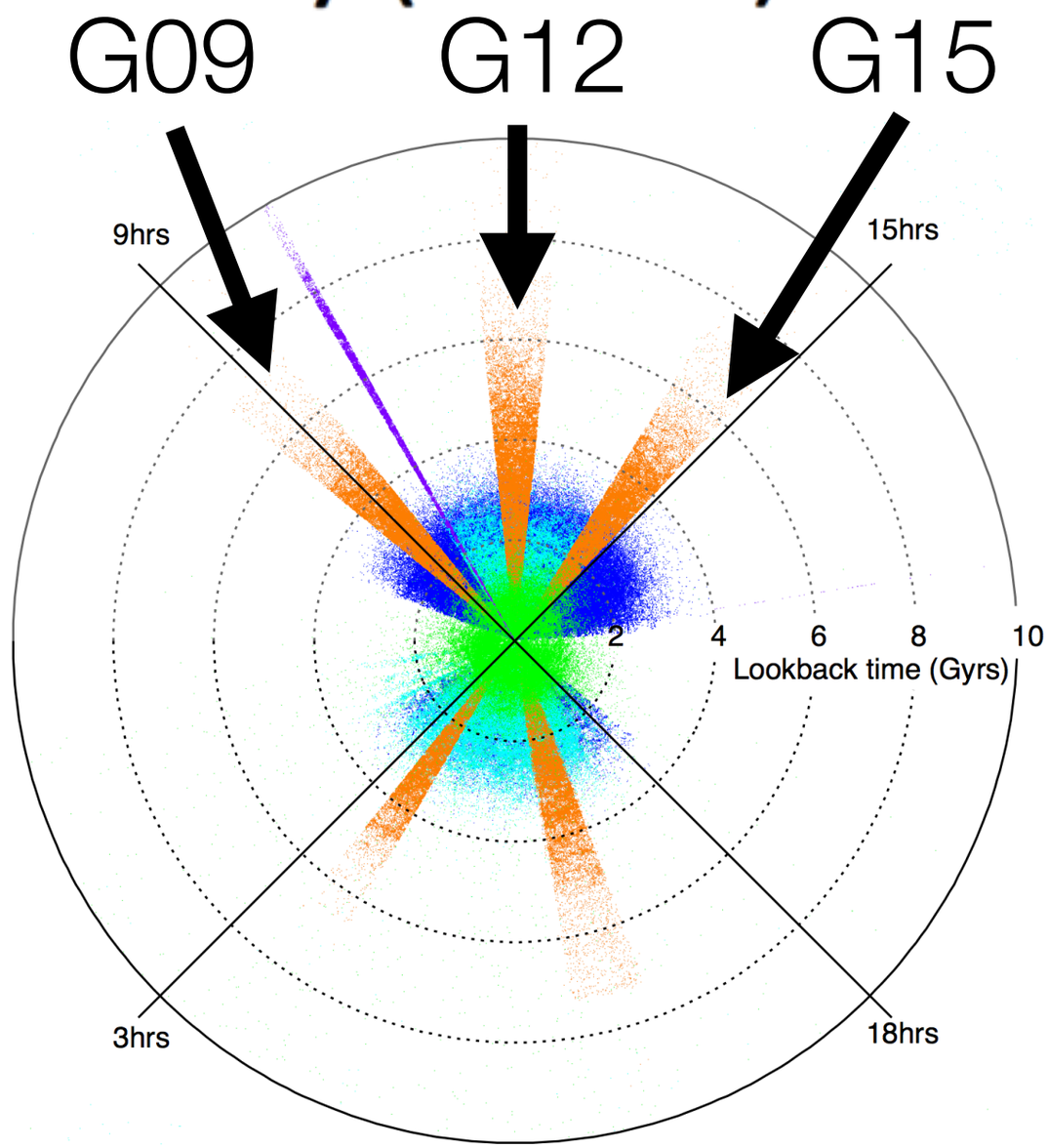


250,000 galaxies to r<19.8mag over five 60 sq deg | 6dfGRS | SDSS DR9 | 2dFGRS | GAMA | zCOSMOS

- catalogue of 25,000 groups (halos) to $10^{12}M_o$
- 21 band photometry + gas (ASKAP) [GALEX+VST+VIKING+WISE+Herschel]
- mass, energy and structure on 1kpc to 100Mpc scales to z~0.2
- Website http://www.gama-survey.org/ Community Data Releases (DR1,DR2,PDR)

Galaxy And Mass Assembly (GAMA)





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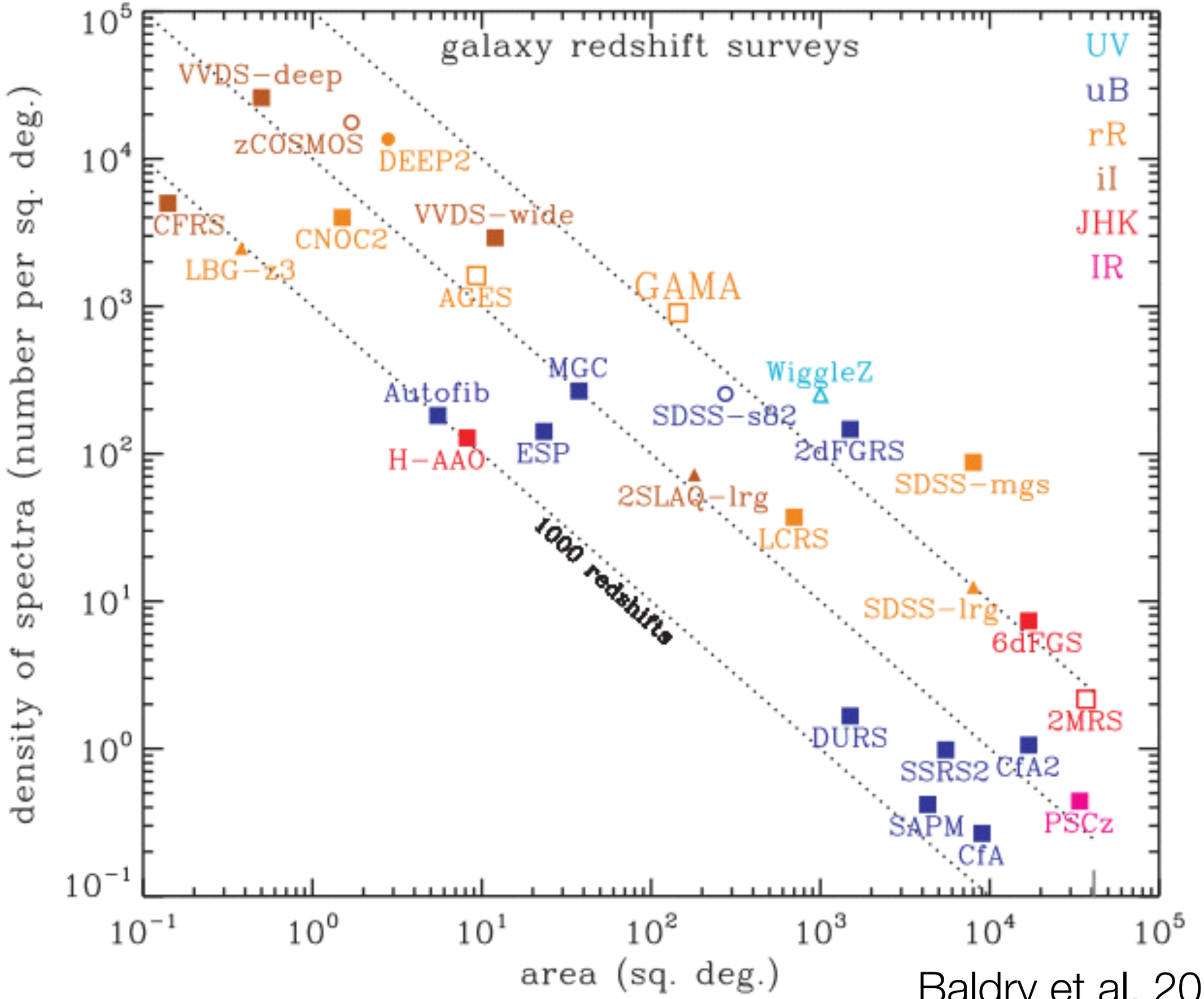
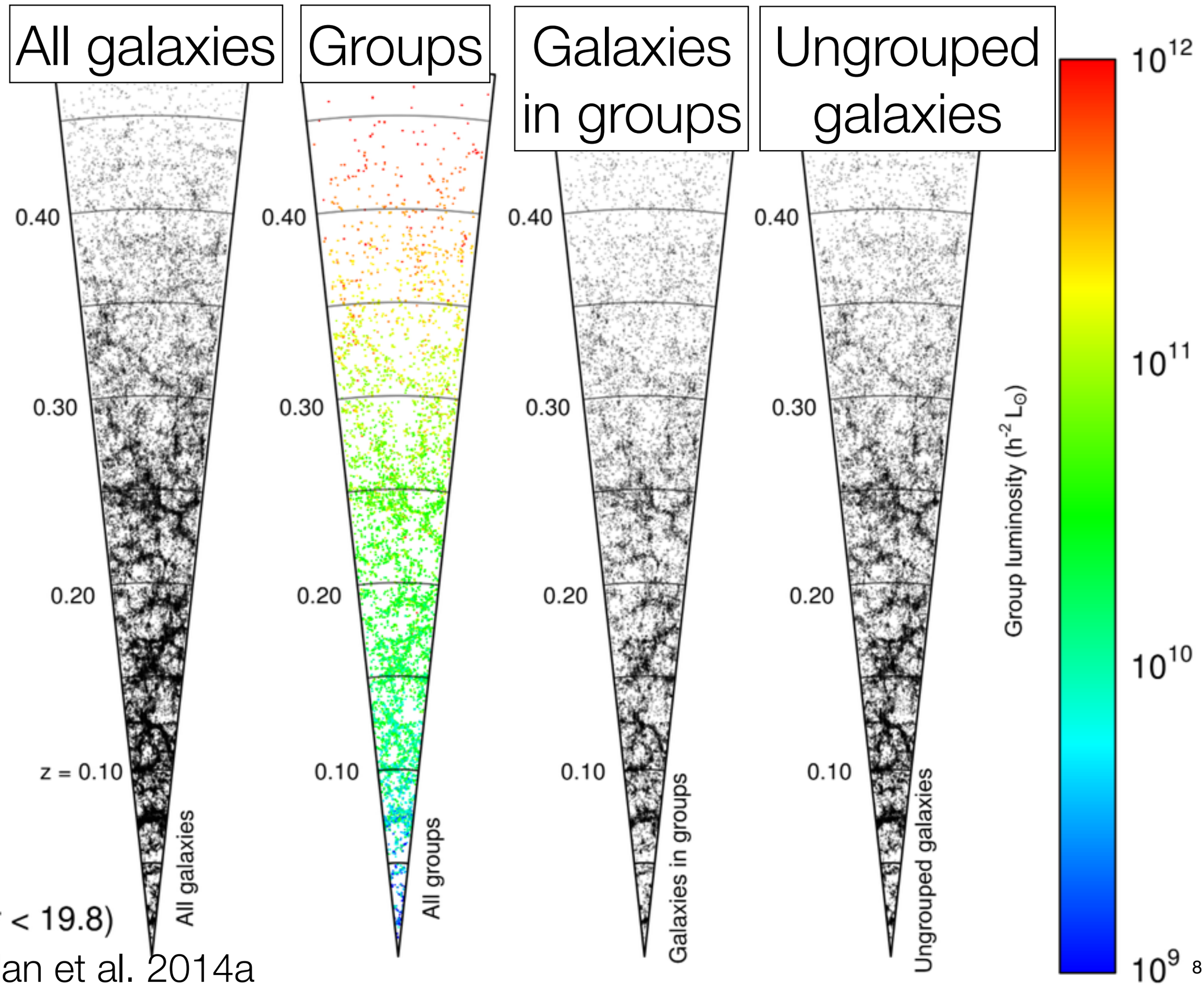


Baldry et al. 2011



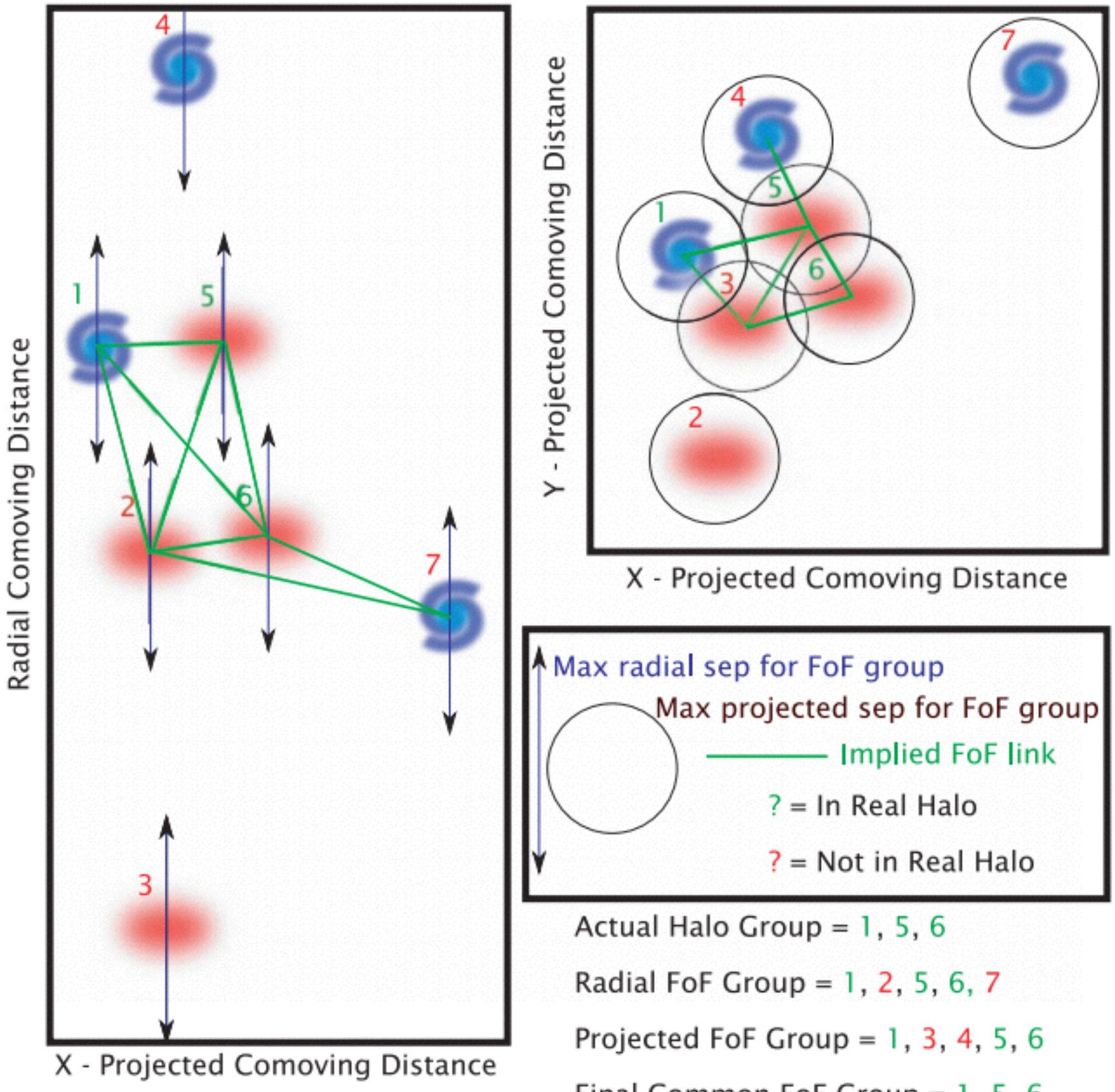
G12 (r < 19.8)

Alpaslan et al. 2014a

The GAMA Group Catalogue

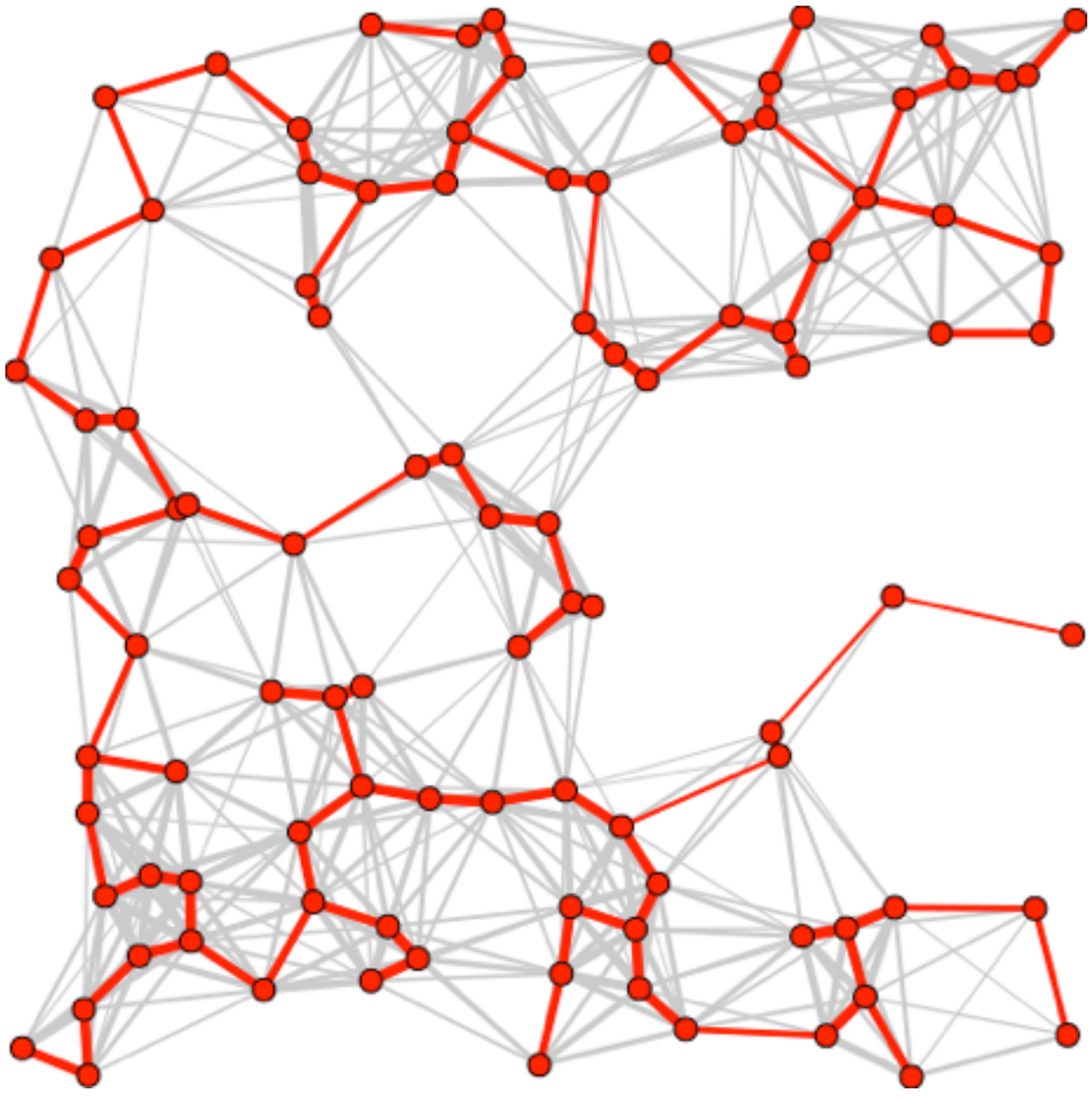
Group catalogue that has been put together using a slightly modified friends-of-friends algorithm that considers galaxies to be in a group if they are grouped both along the line of sight, as well as when projected onto the sky.

This successfully eliminates the fingers of god effect caused by the peculiar velocities of galaxies in groups.



Robotham et al. 2011

Minimal spanning trees (Barrow et al. 1985; Colberg 2007; Doroshkevic et al. 2012)



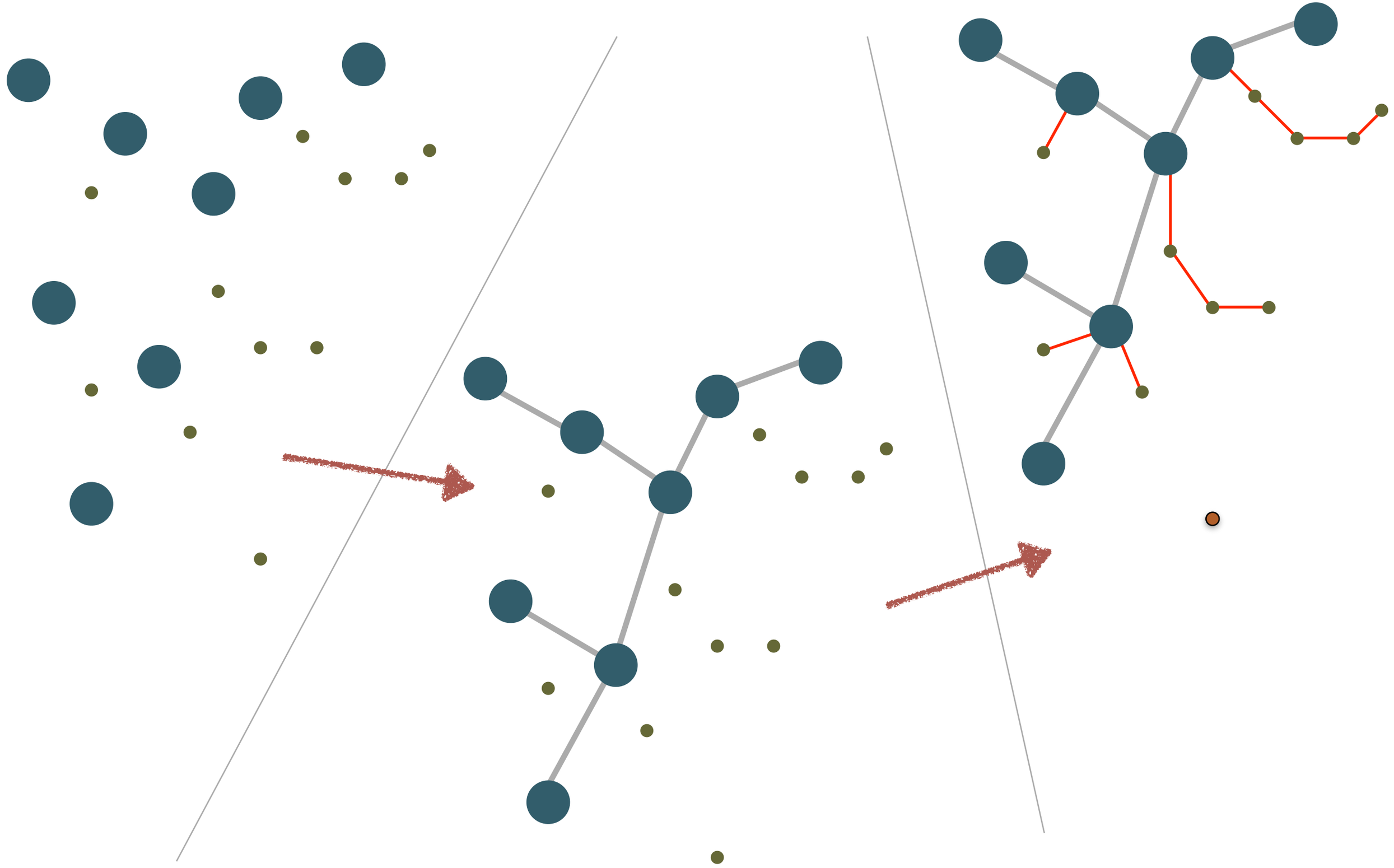
Structure finder based on minimal spanning trees.

Analogous to a friends-of-friends search. Linking length b = maximum allowed edge length.

Ideal at detecting linear structures.

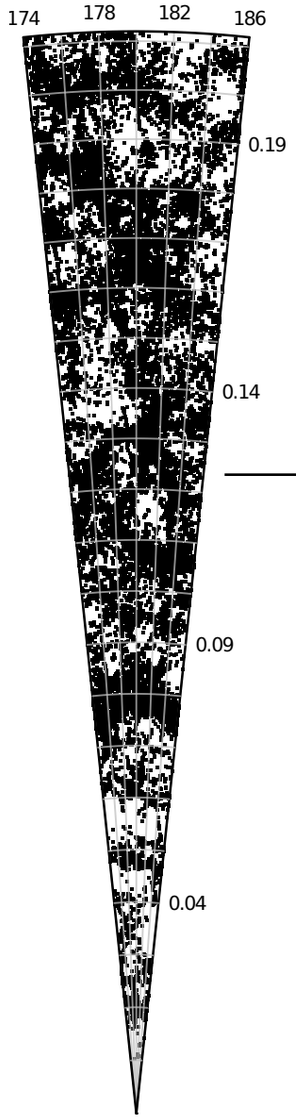
igraph library. Copyright (C) 2003-2012 Gábor Csárdi and Tamás Nepusz

Three pass approach



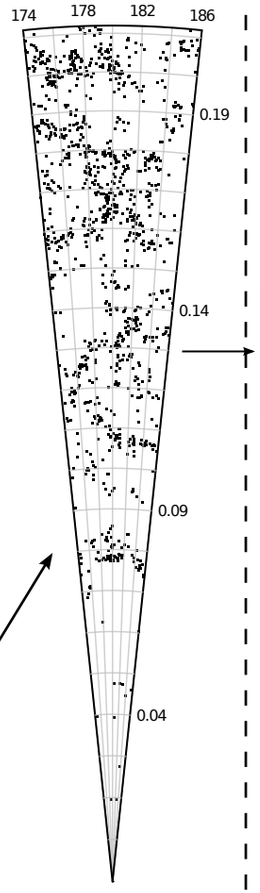
R11

All galaxies



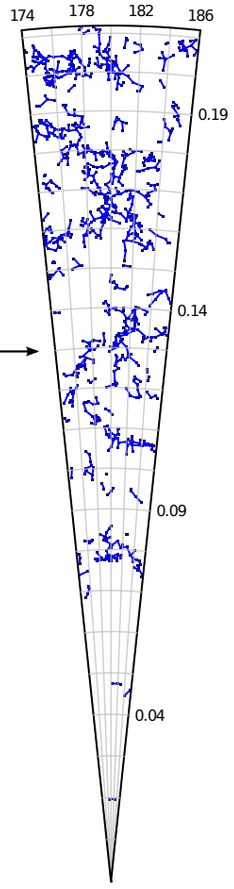
FoF

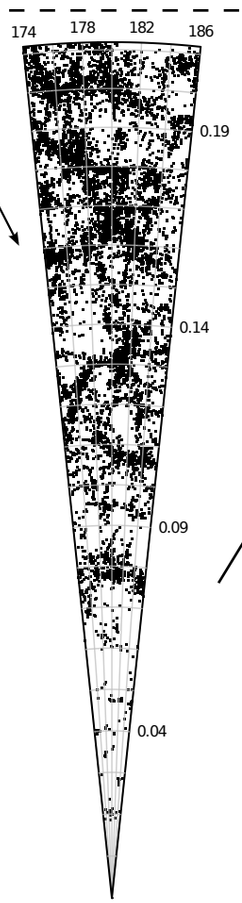
on galaxies



MST

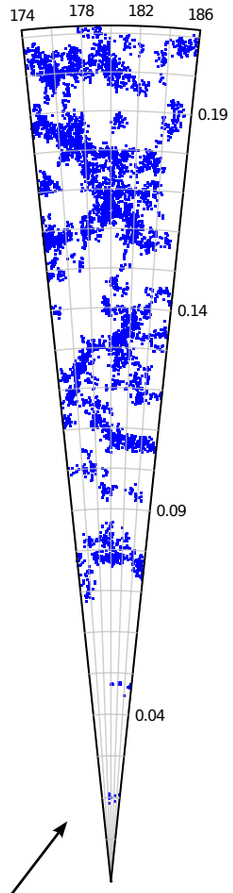
on groups

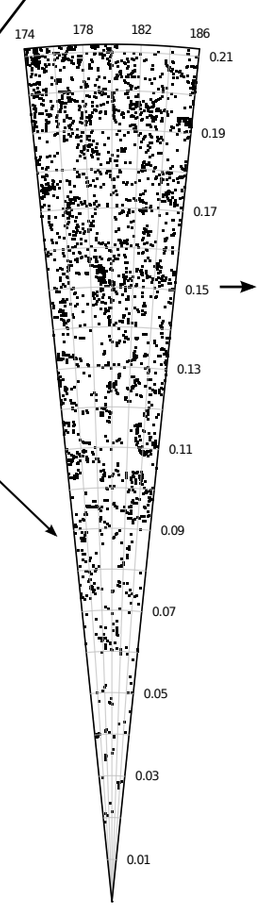




Ungrouped galaxies

Scooper

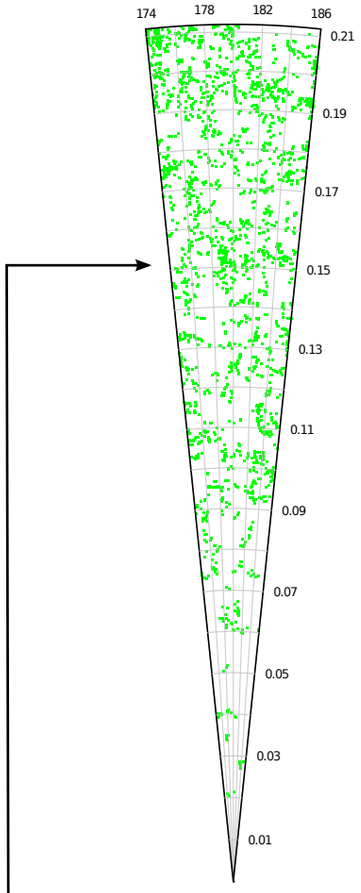


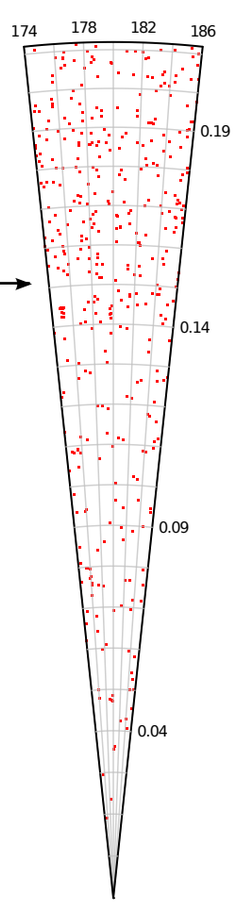


Isolated galaxies

MST

on galaxies





Void galaxies

Alpaslan et al. 2014a

RA (deg)

174 178 182 186

z

0.21 0.19 0.17 0.15 0.13 0.11 0.09 0.07 0.05 0.03 0.01

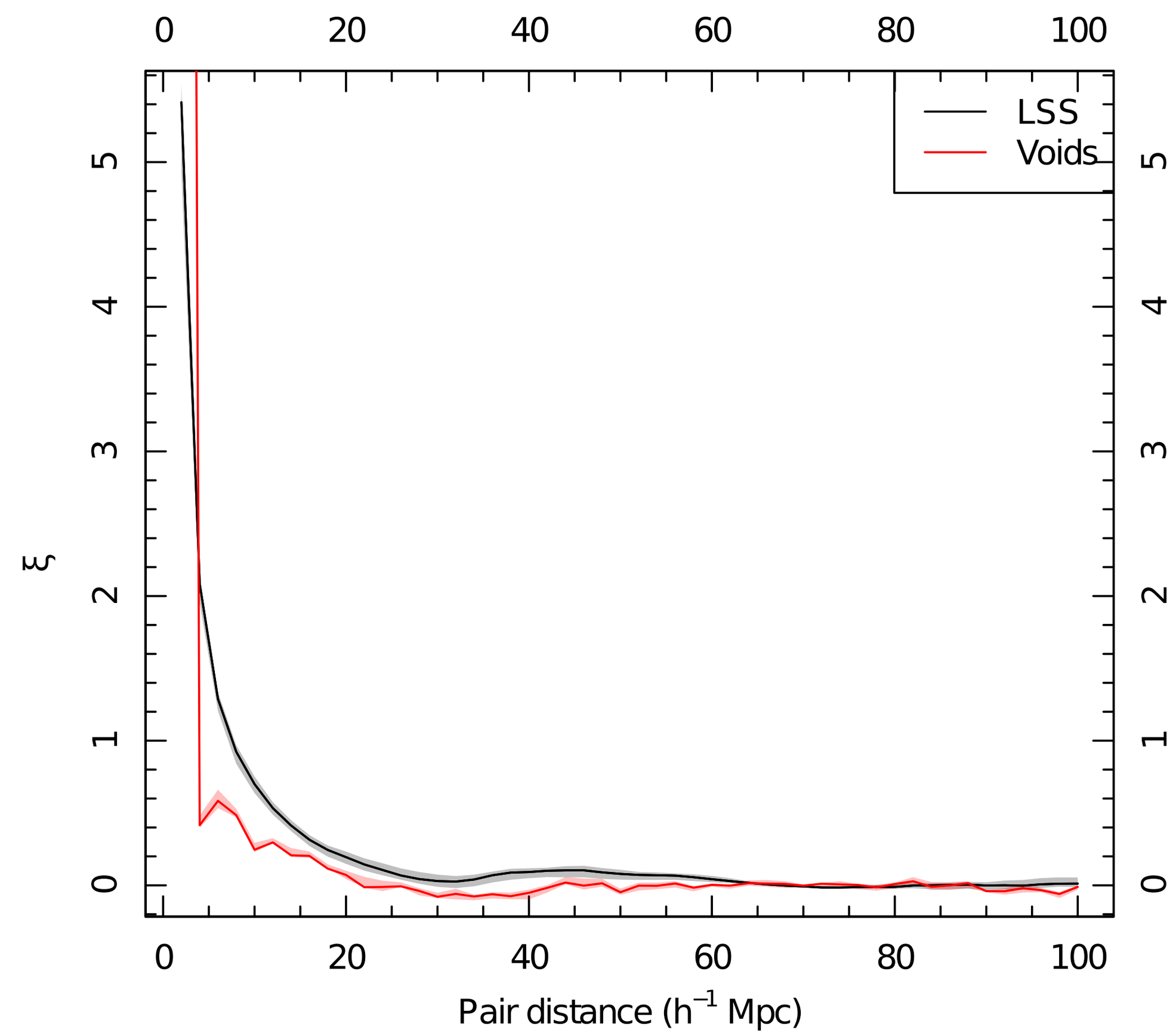
b = 15 h^{-1} Mpc

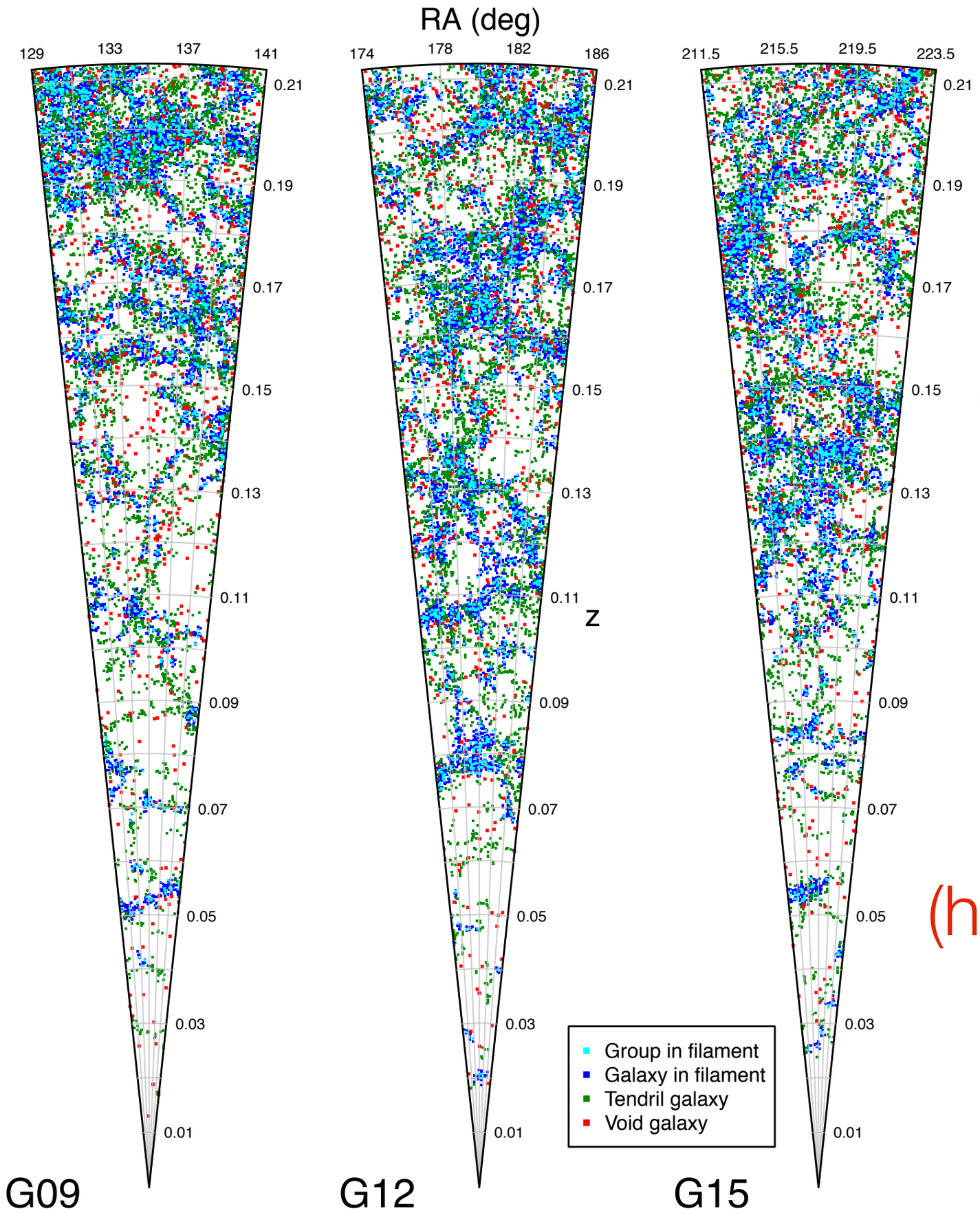
b = 10 h^{-1} Mpc

b = 5.75 h^{-1} Mpc

b = 5 h^{-1} Mpc

b = 1 h^{-1} Mpc


0
20
40
60
80
100
LSS
Voids
ξ
0
1
2
3
4
5
Pair distance (h^{-1} Mpc)



Groups

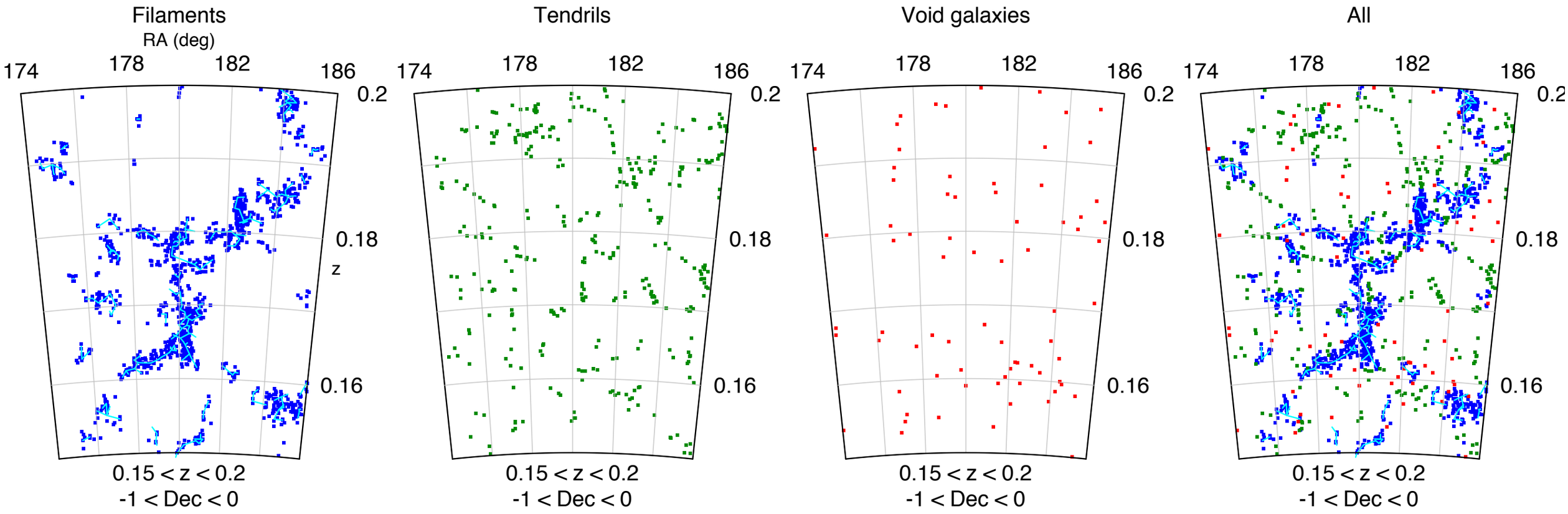
Galaxies in filaments

Tendrils
(structures in voids)

Galaxies in voids
(hyper isolated galaxies)

GAMA II

Alpaslan et al. 2014a



Alpaslan et al. 2014b

Spot the simulation!

Groups

Galaxies in filaments

Tendrils
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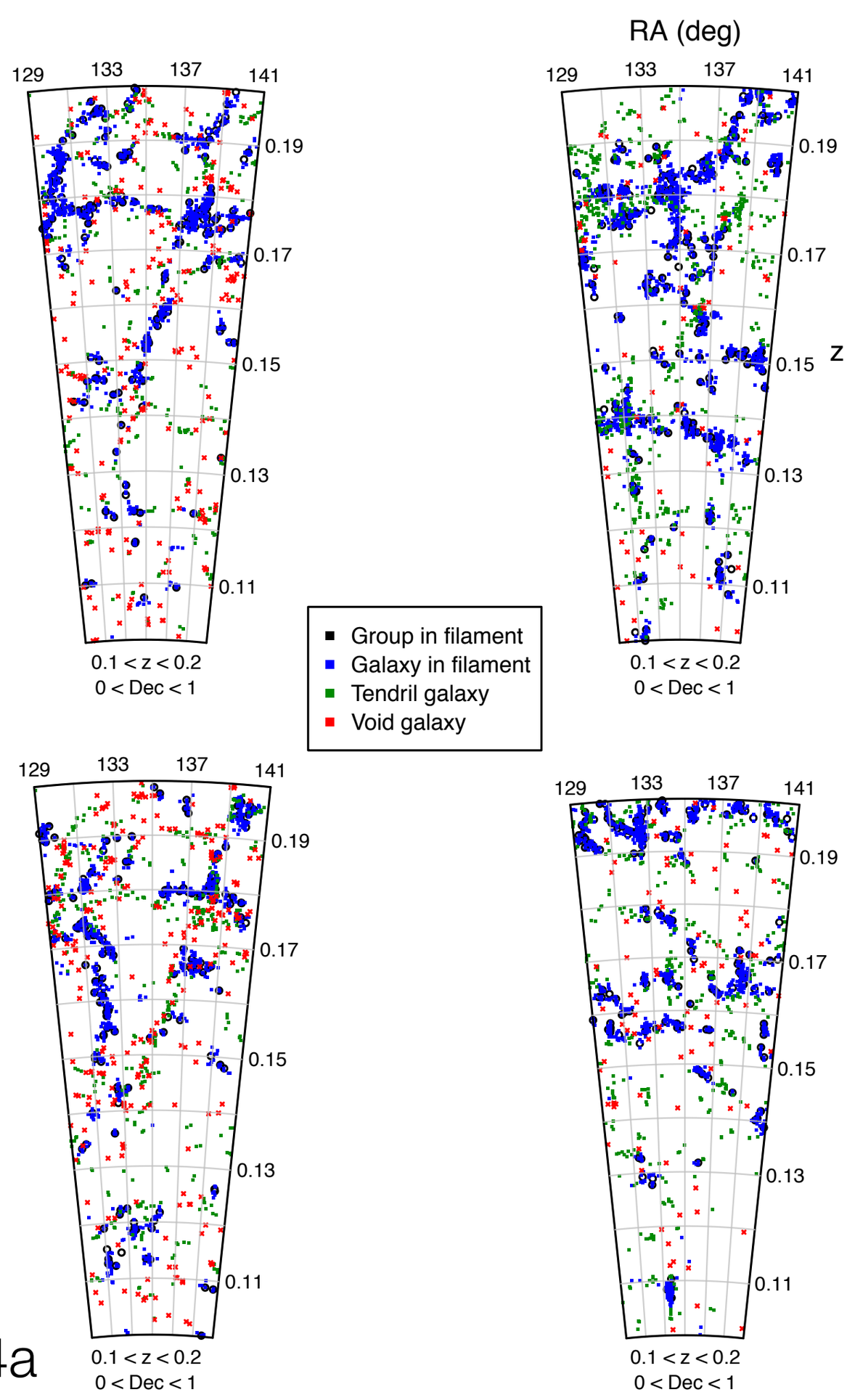


Alpaslan et al. 2014a

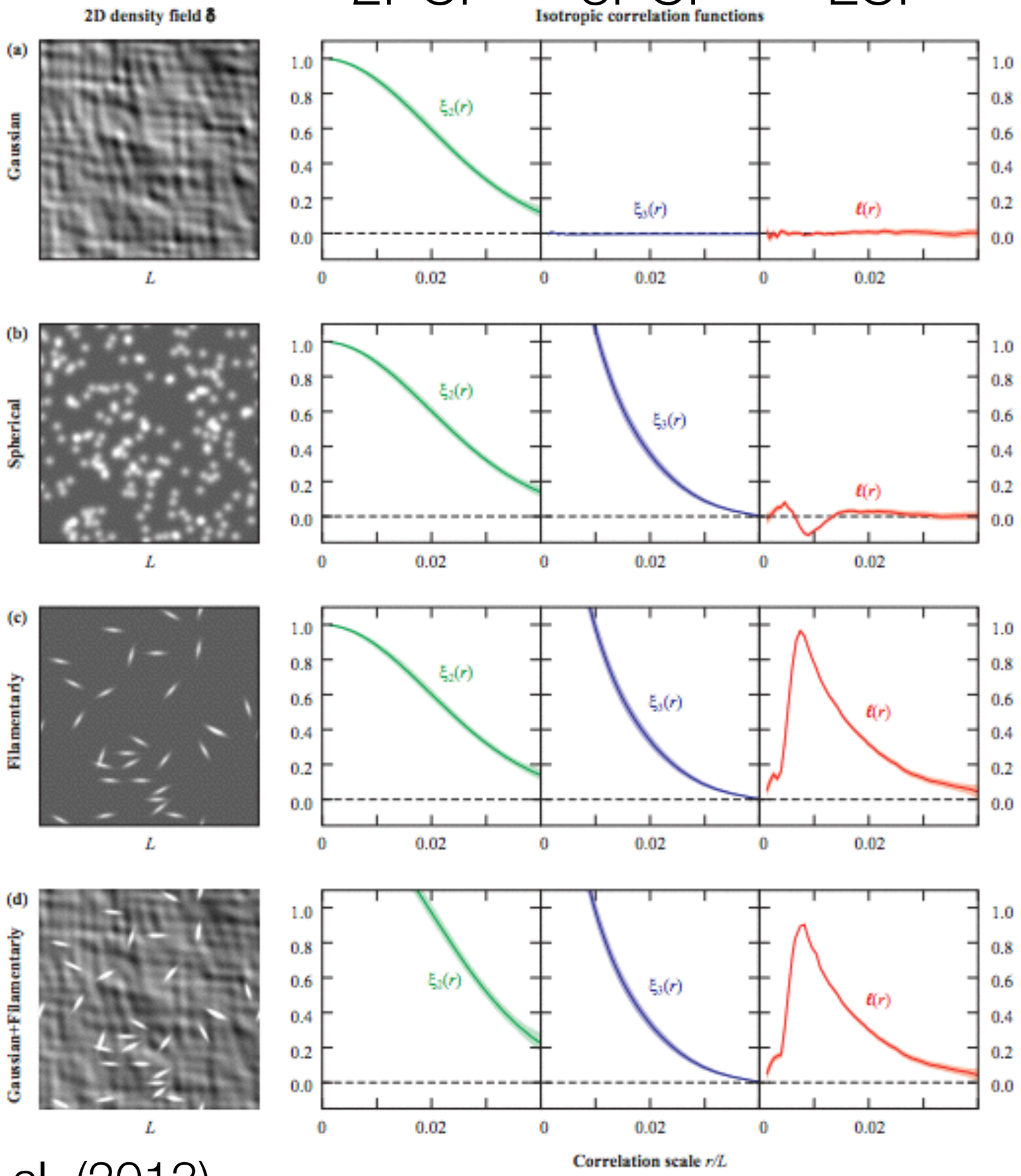
2PCF 3PCF LCF

Noise

Spherical

Filaments

Filaments
+
noise



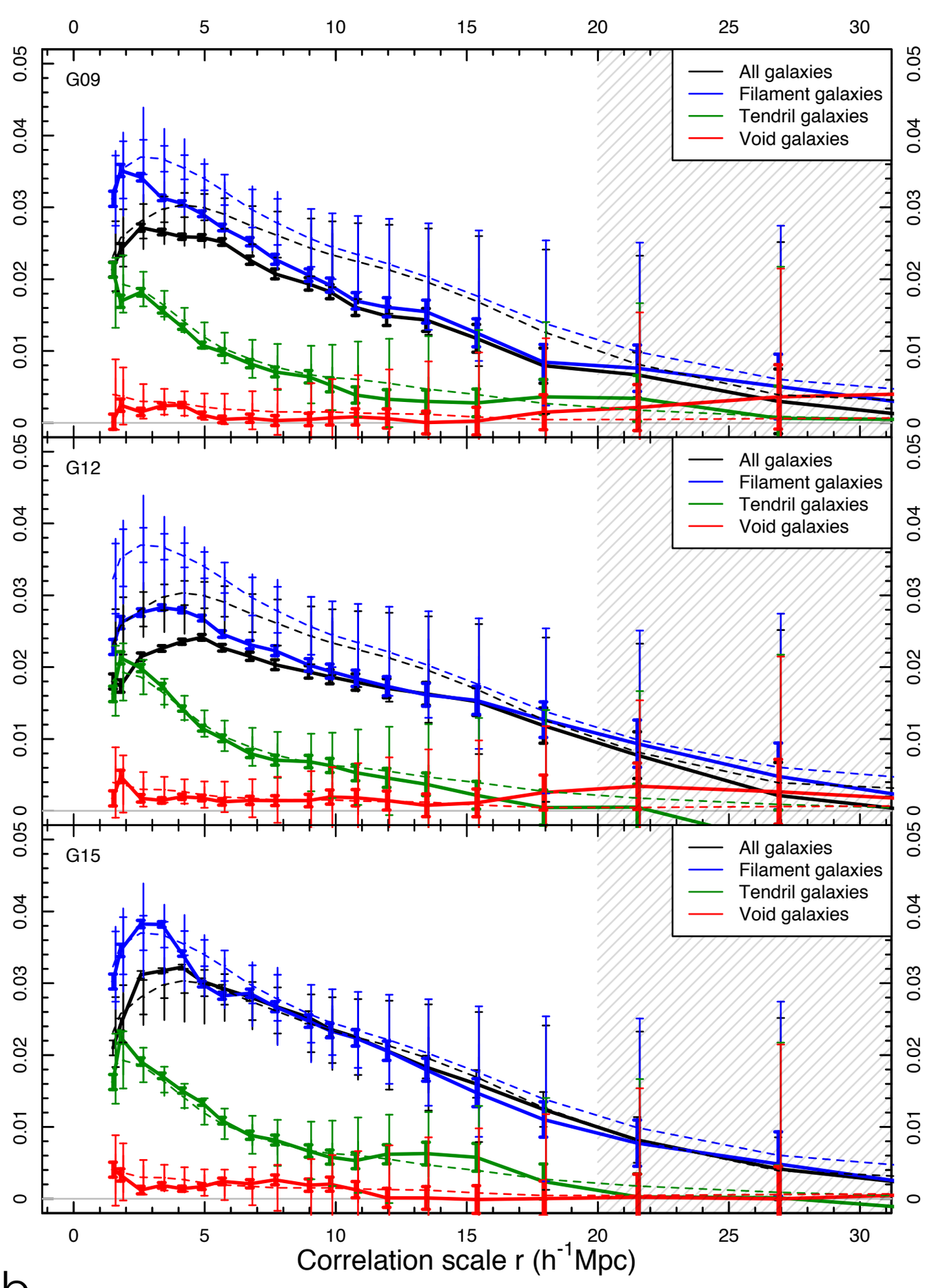
Obreschkow et al. (2013)

Line correlation function

Galaxies in filaments

Tendrils

Galaxies in voids

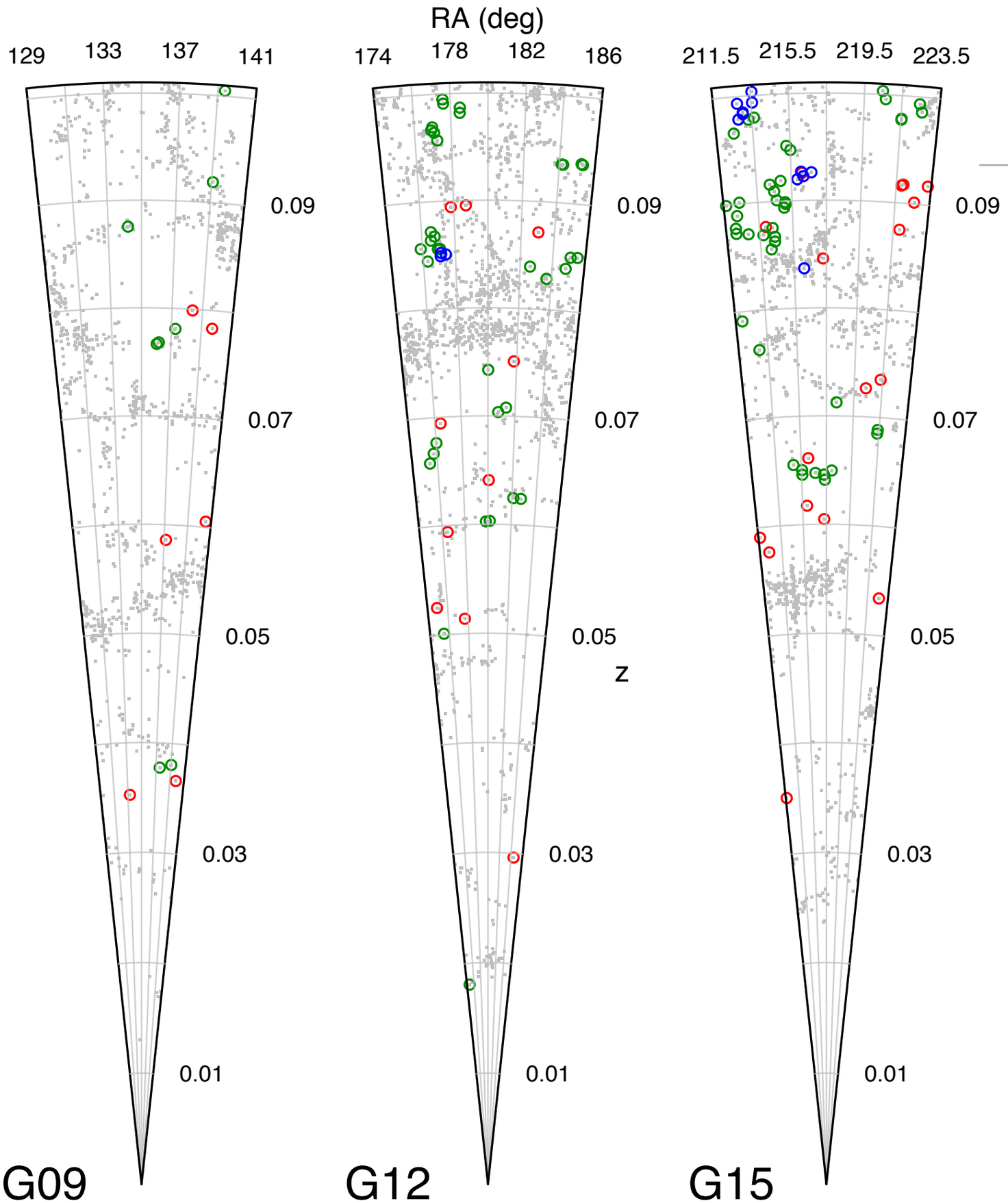


G09

G12

G15

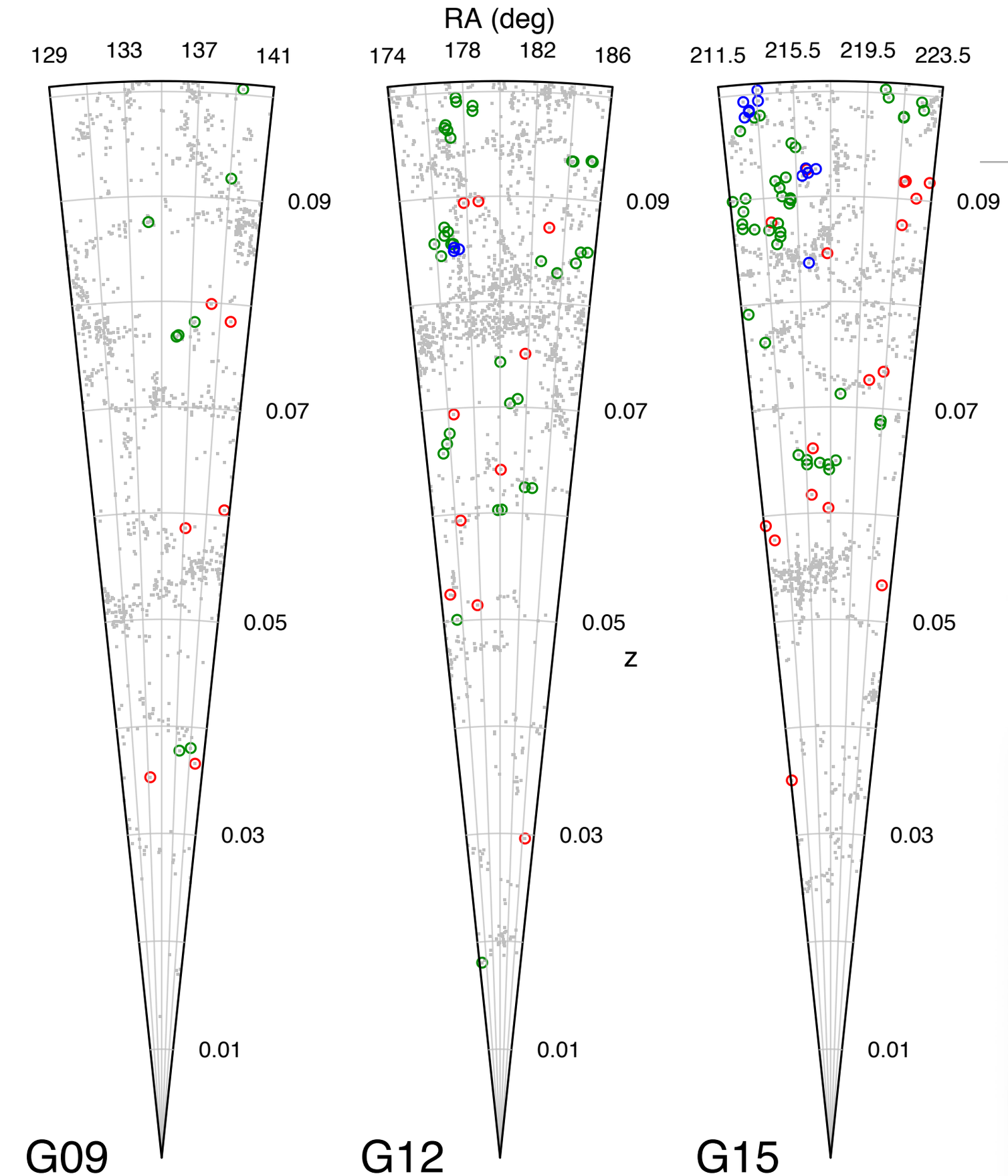
Alpaslan et al. 2014b



Void sizes are sensitive to survey design!

- Voids from SDSS (Pan et al. 2012), galaxies from GAMA.
  - Void galaxies (25%)
  - Tendril galaxies (65%)
  - Filament galaxies (10%)

Alpaslan et al. 2014b



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These aren't the voids you're looking for!

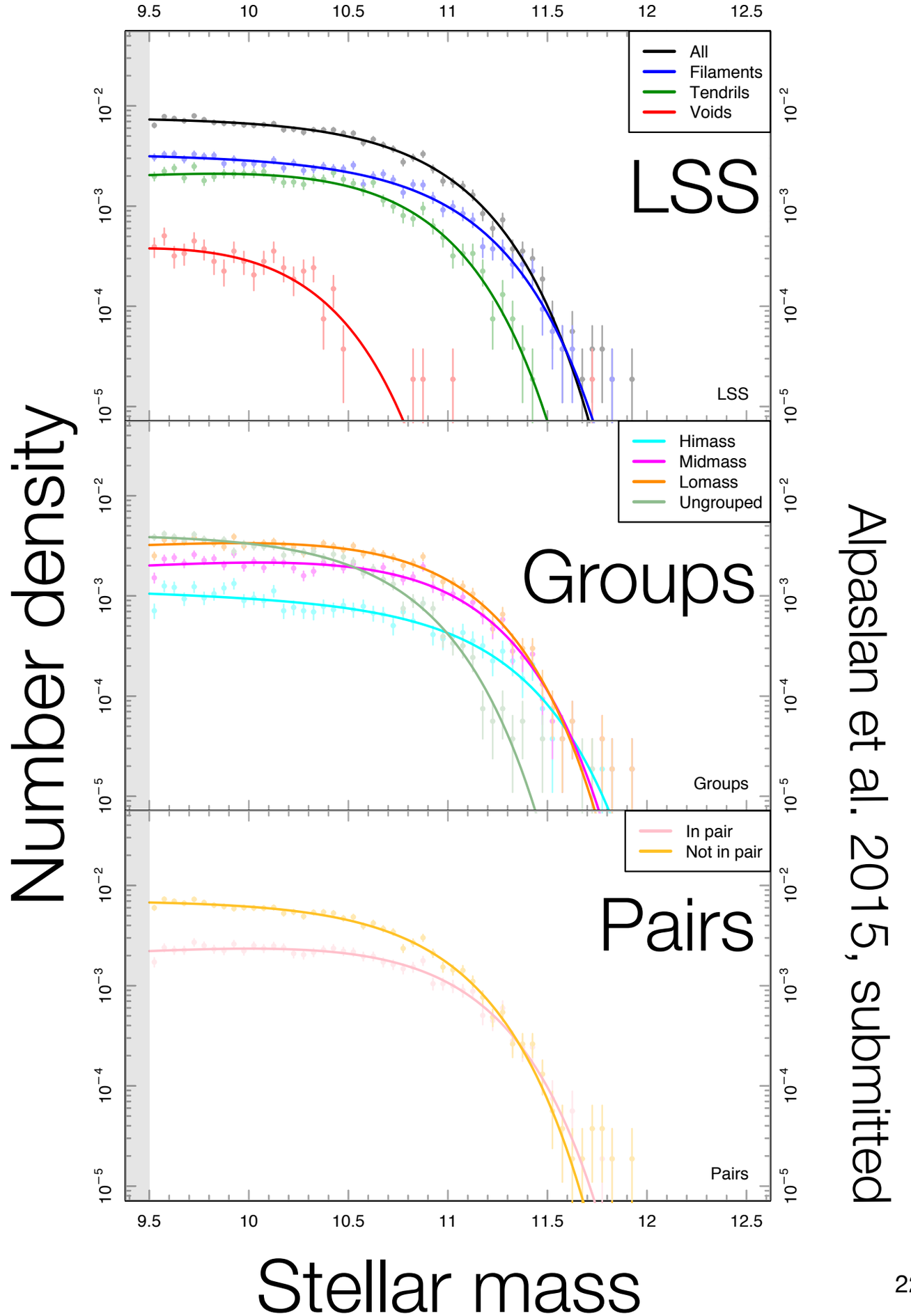
Alpaslan et al. 2014b

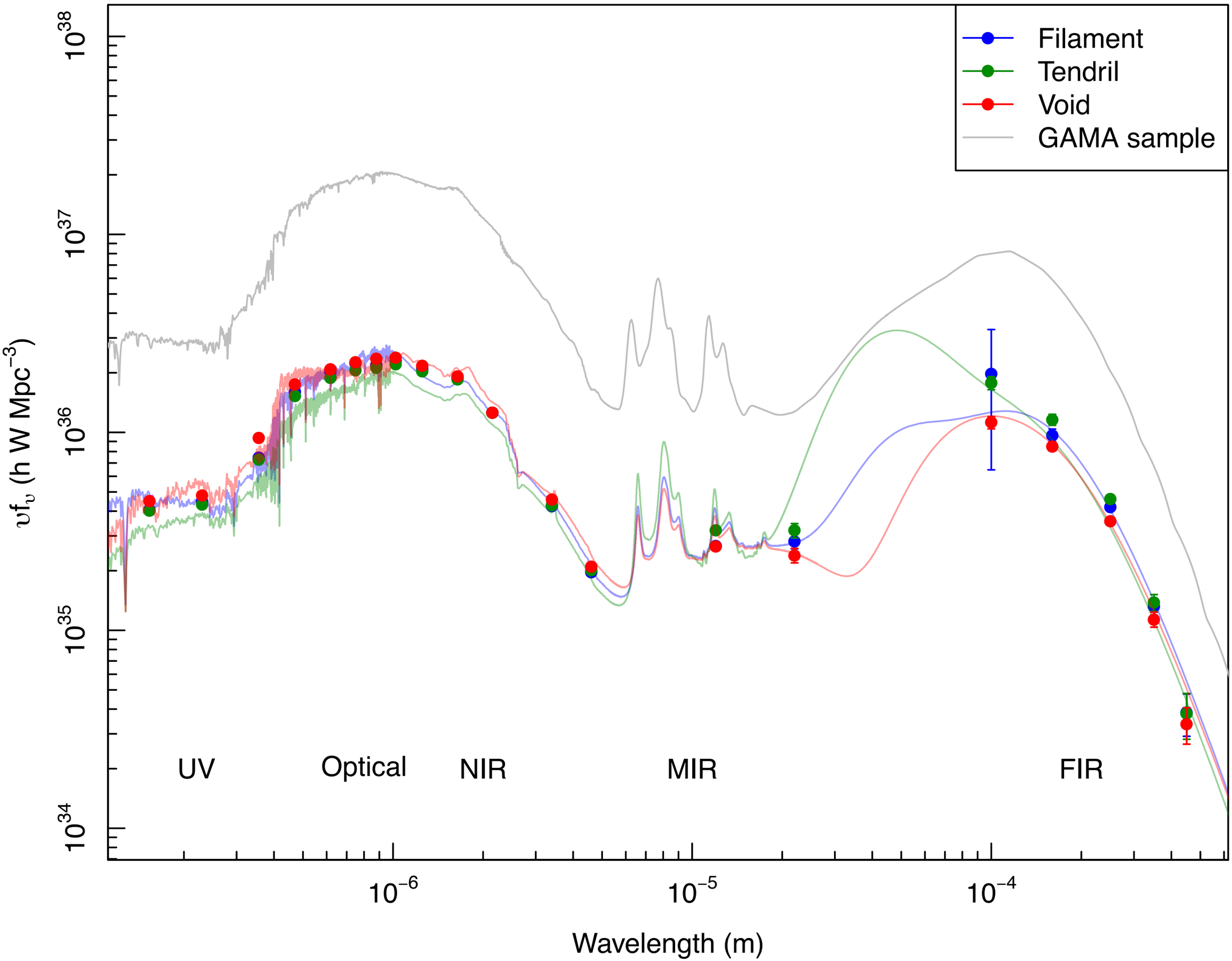
The GAMA Large Scale Structure Catalogue

- Let’s talk if you want to use the data!
- ~45,000 galaxies sorted by LSS (including 2,000 isolated galaxies)
- Some projects using the data include:
  - Properties of ultra-isolated voids (Marcum+, NASA Ames)
  - Analysis of LSS using Minkowski functionals (Schimdt+, LAM)
  - Tracking SFR in Hα along filaments (Bassett+, U. Swinbourne)
  - Frequency of LBS galaxies in LSS (Moffett+, U. Western Australia)
  - Cross-correlation of x-ray gas with LSS (Tuffs+, Heidelberg)

Recent work

- Do galaxies in different environments exhibit different properties?
- The galaxy stellar mass function varies greatly as a function of environment.
- Recently submitted work focuses on looking for trends in morphology and stellar populations across environments.

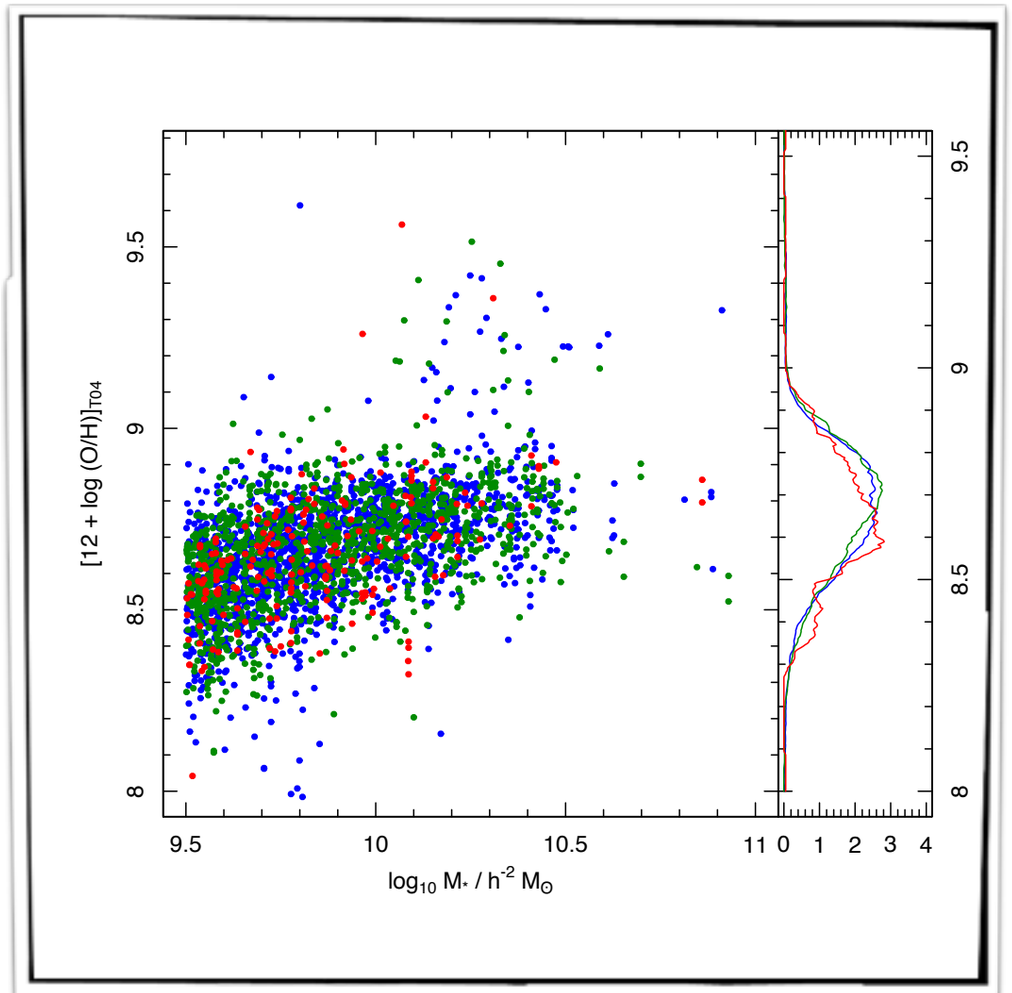


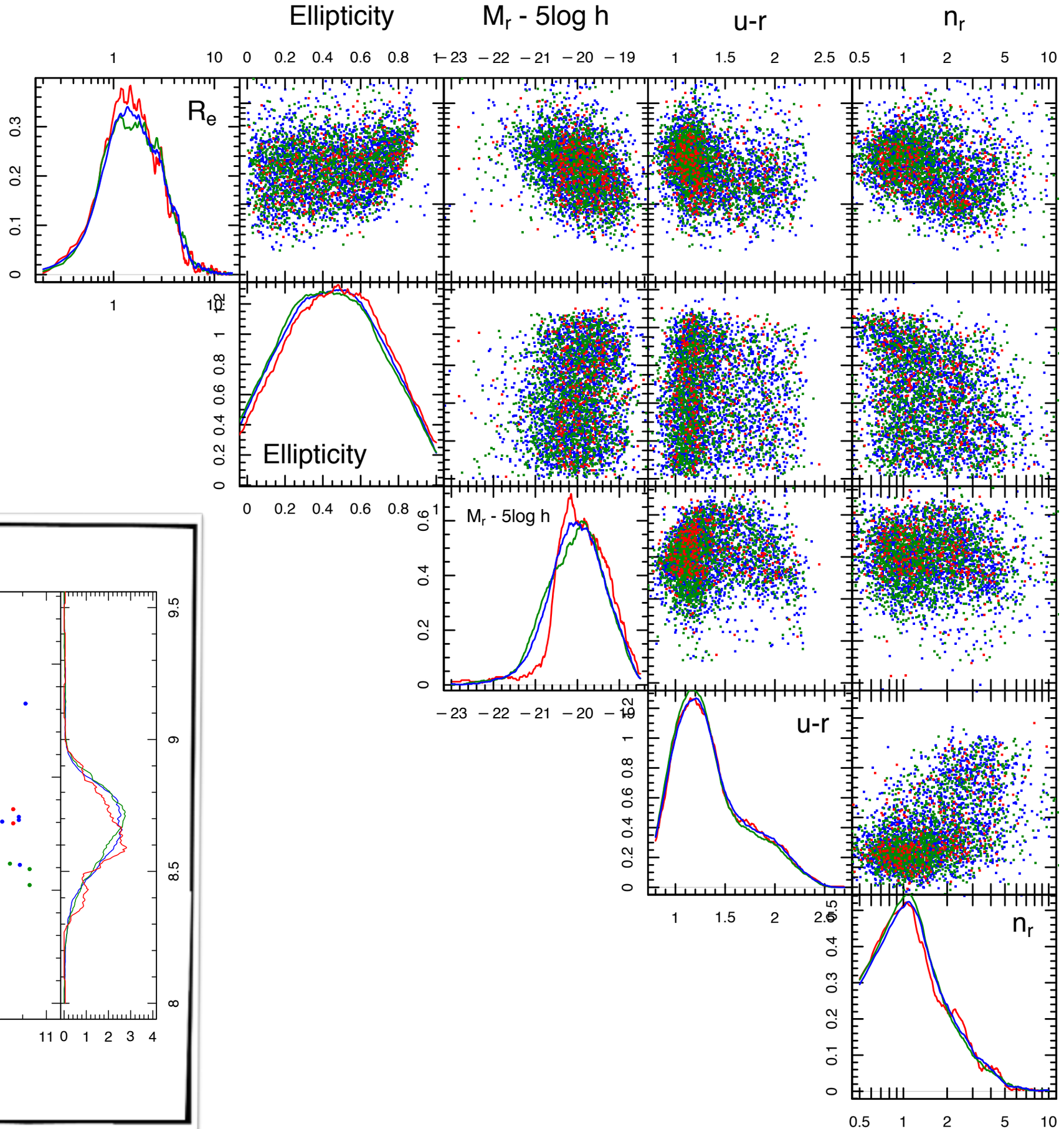

Filament
Tendril
Void
GAMA sample
10^{38}
10^{37}
10^{36}
10^{35}
10^{34}
υf_υ (h W Mpc^{-3})
UV
Optical
NIR
MIR
FIR
10^{-6}
10^{-5}
10^{-4}
Wavelength (m)

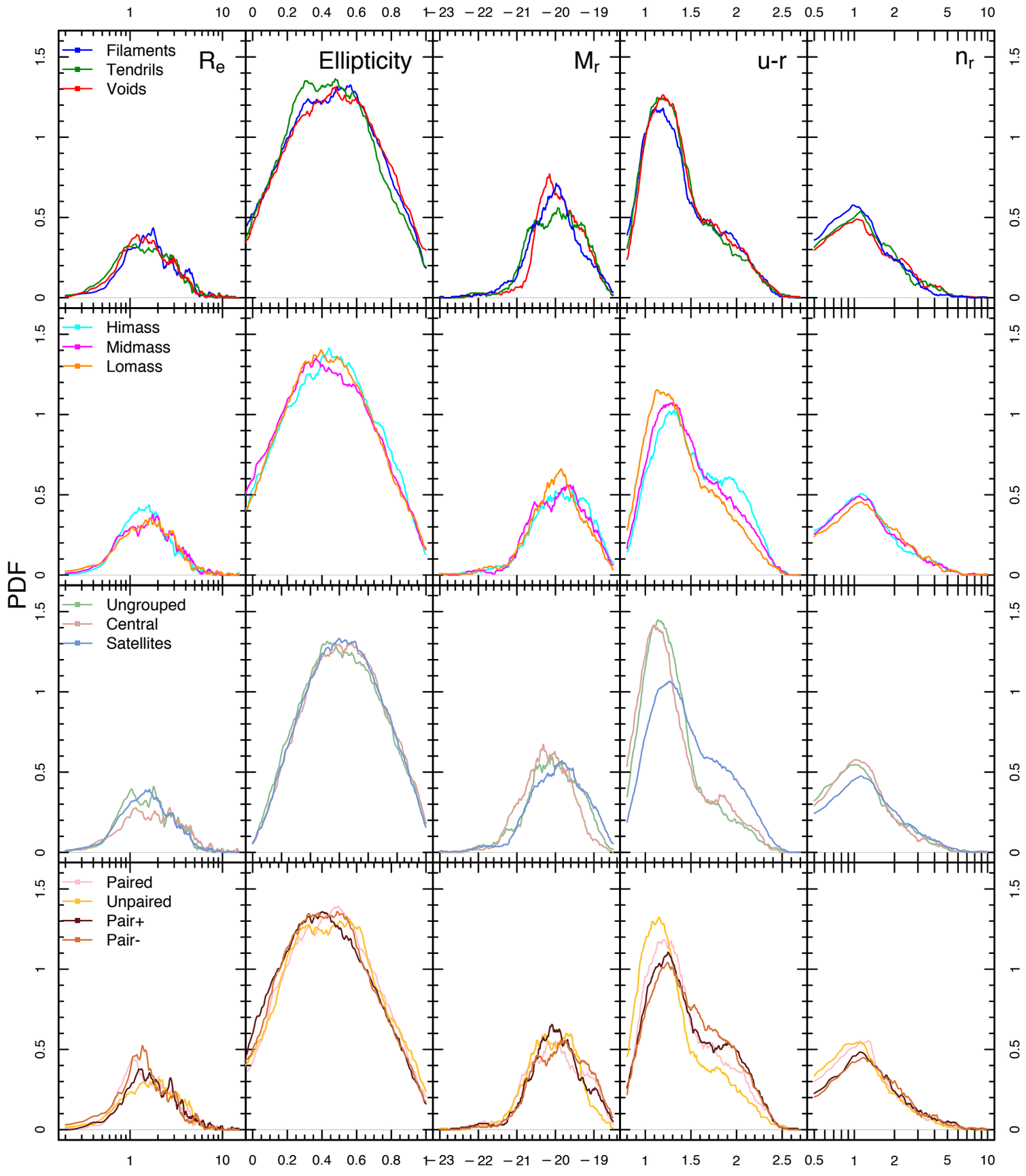
Filaments

Tendrils

Voids

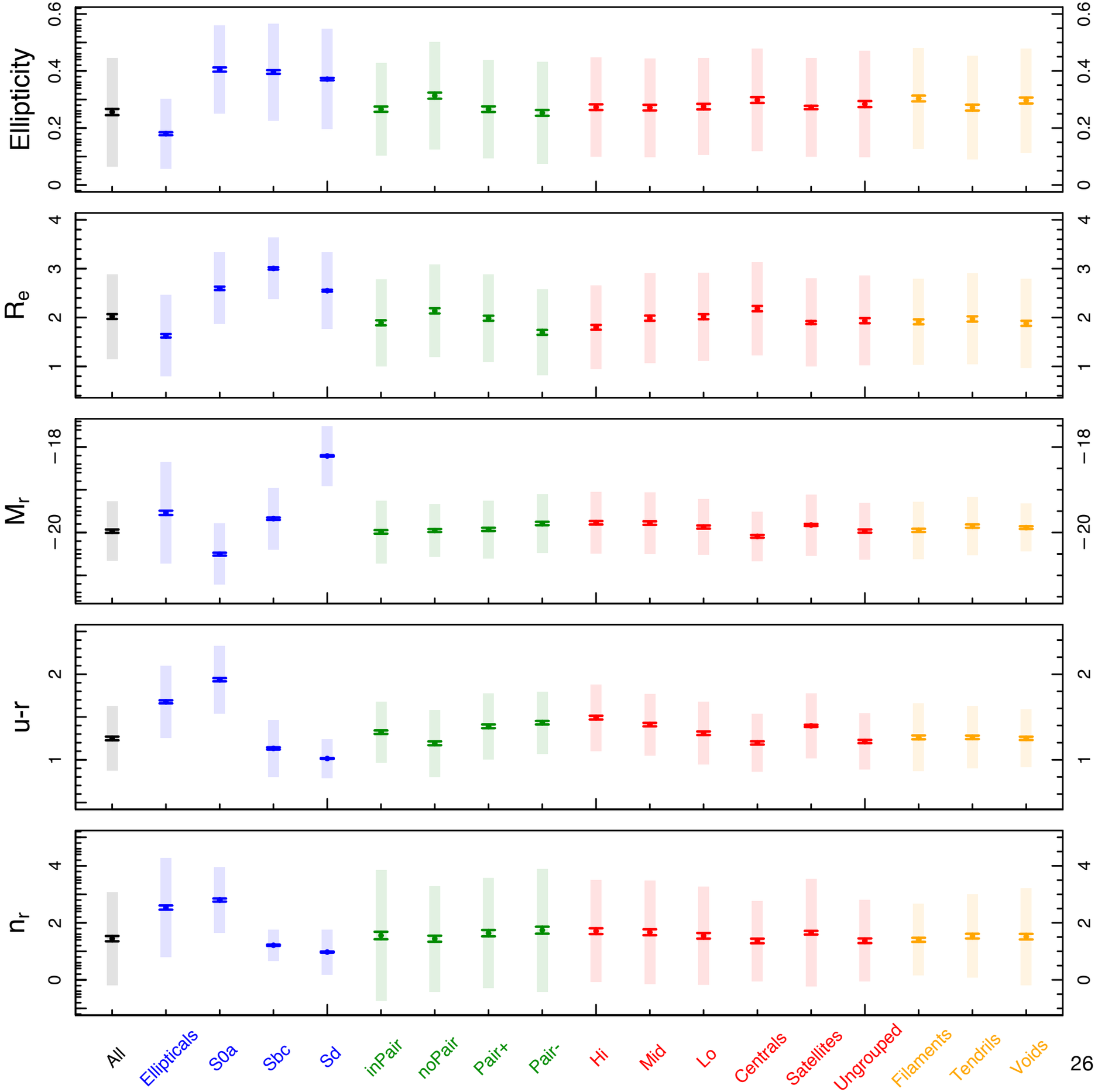






Why stop there? We can extend our analysis to galaxies in groups and pairs.

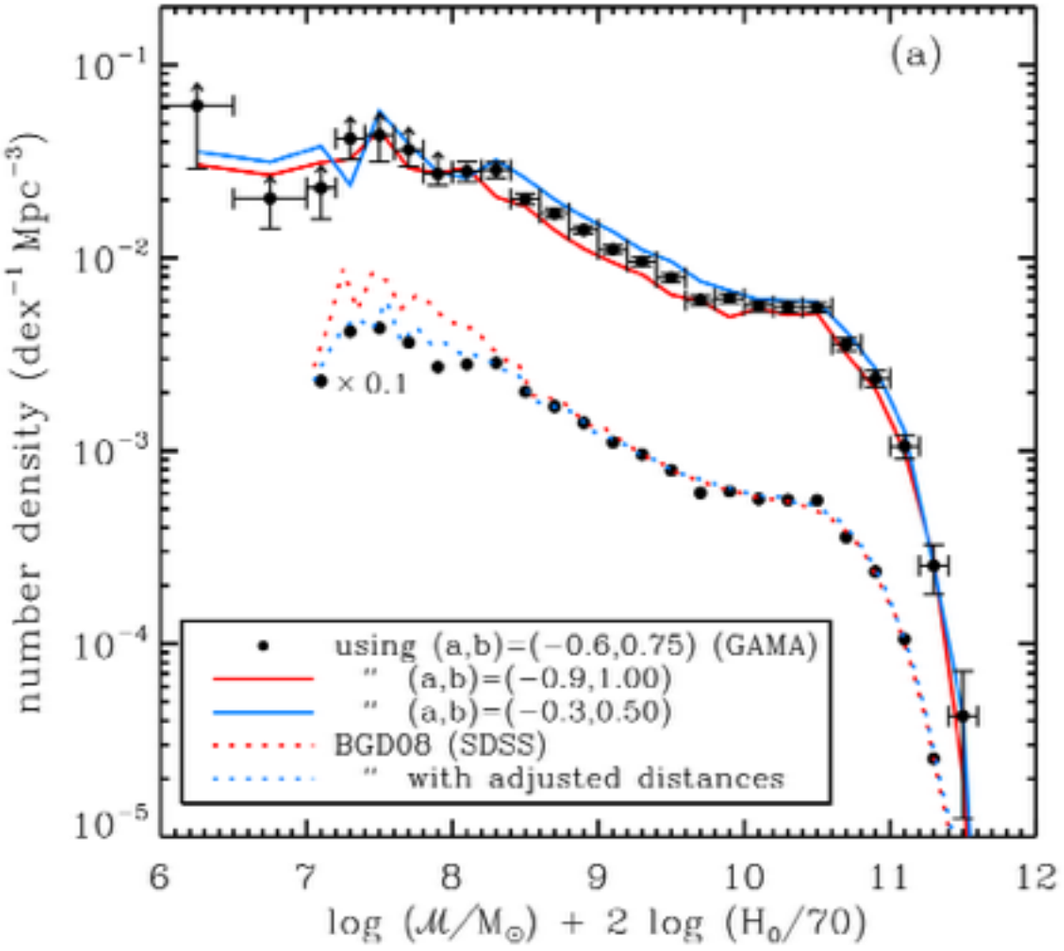
And morphological type…

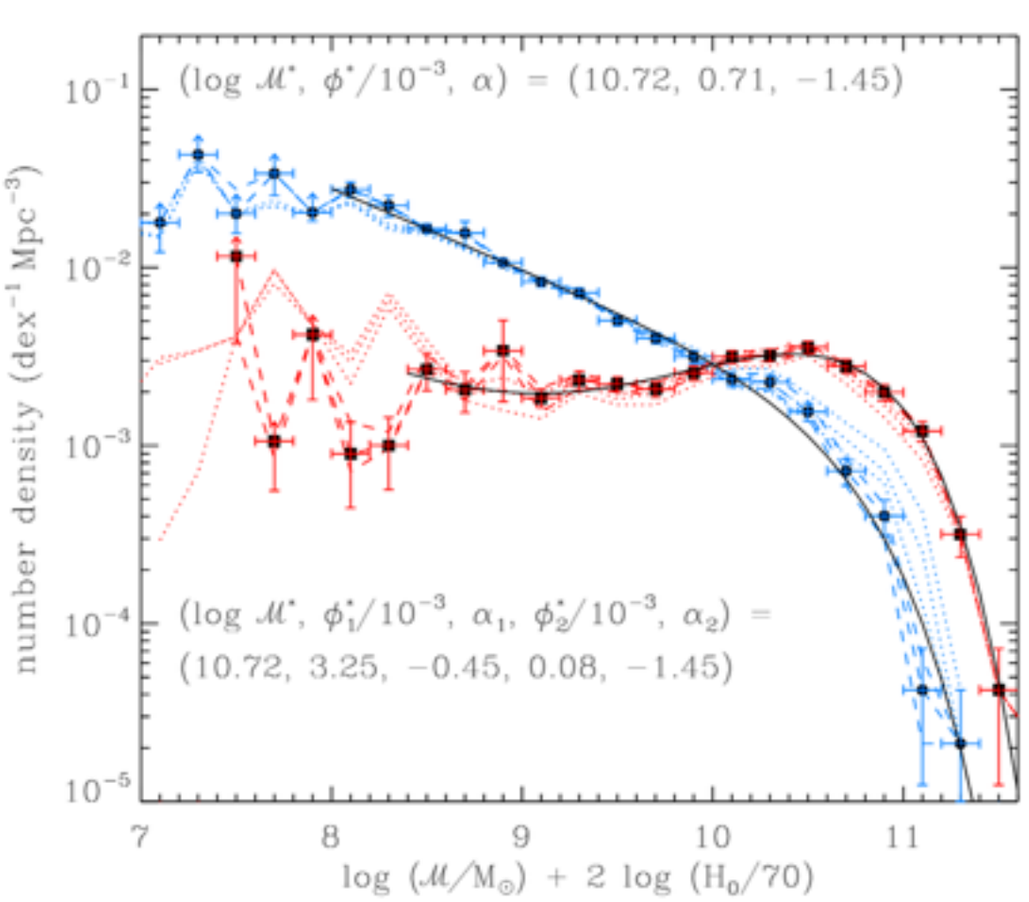


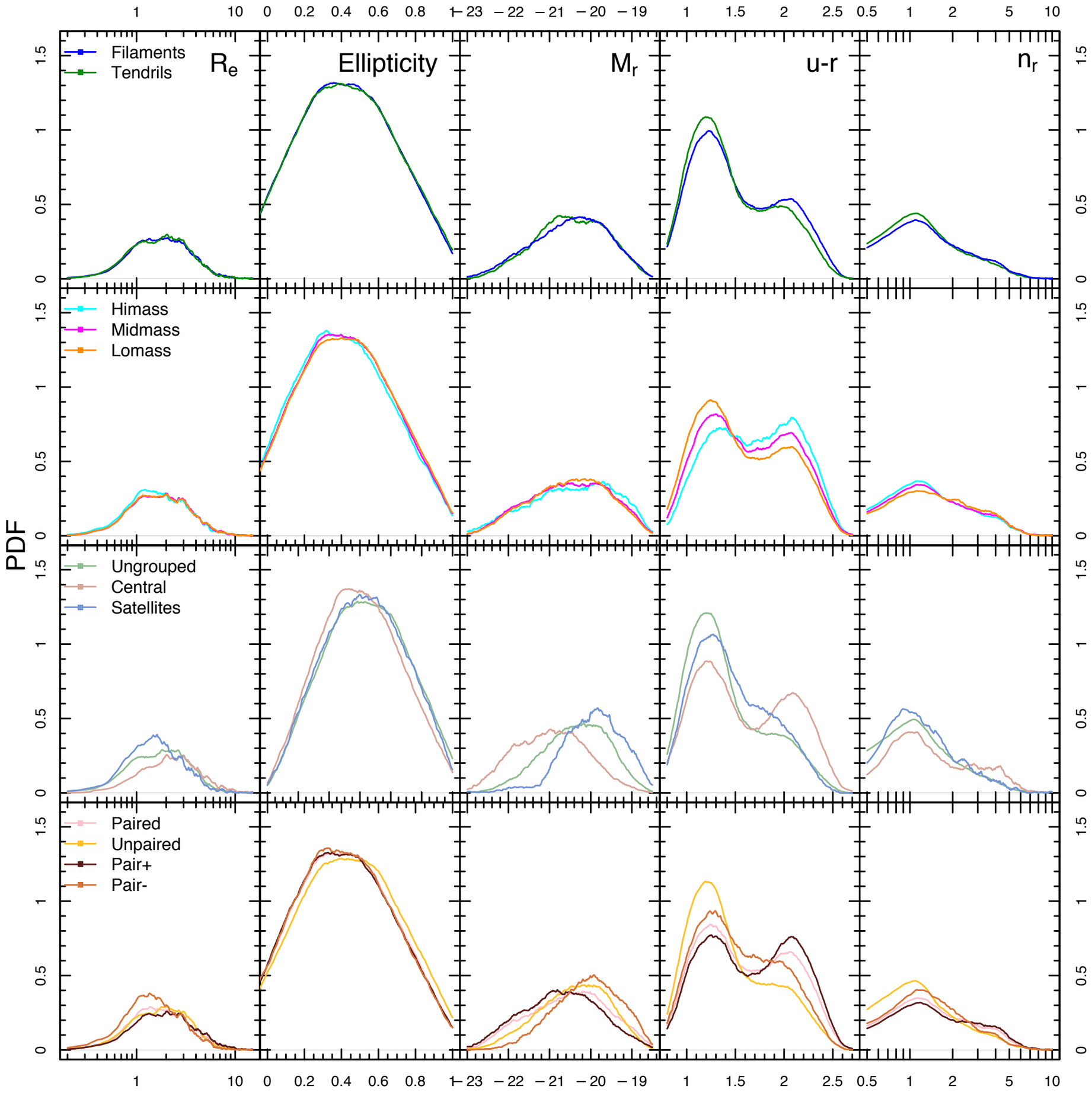
The effects of controlling for stellar mass

- It is evident that when one controls for stellar mass, the properties of galaxies in different structures, particularly large scale ones, look largely the same. How exactly does the mass normalisation affect this?

- We can study this by normalising to the Baldry et al. (2012) GAMA GSMF.






Filaments
Tendrils
R_e
Ellipticity
M_r
u-r
n_r
Himass
Midmass
Lomass
Ungrouped
Central
Satellites
Paired
Unpaired
Pair+
Pair-
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0.8
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−19
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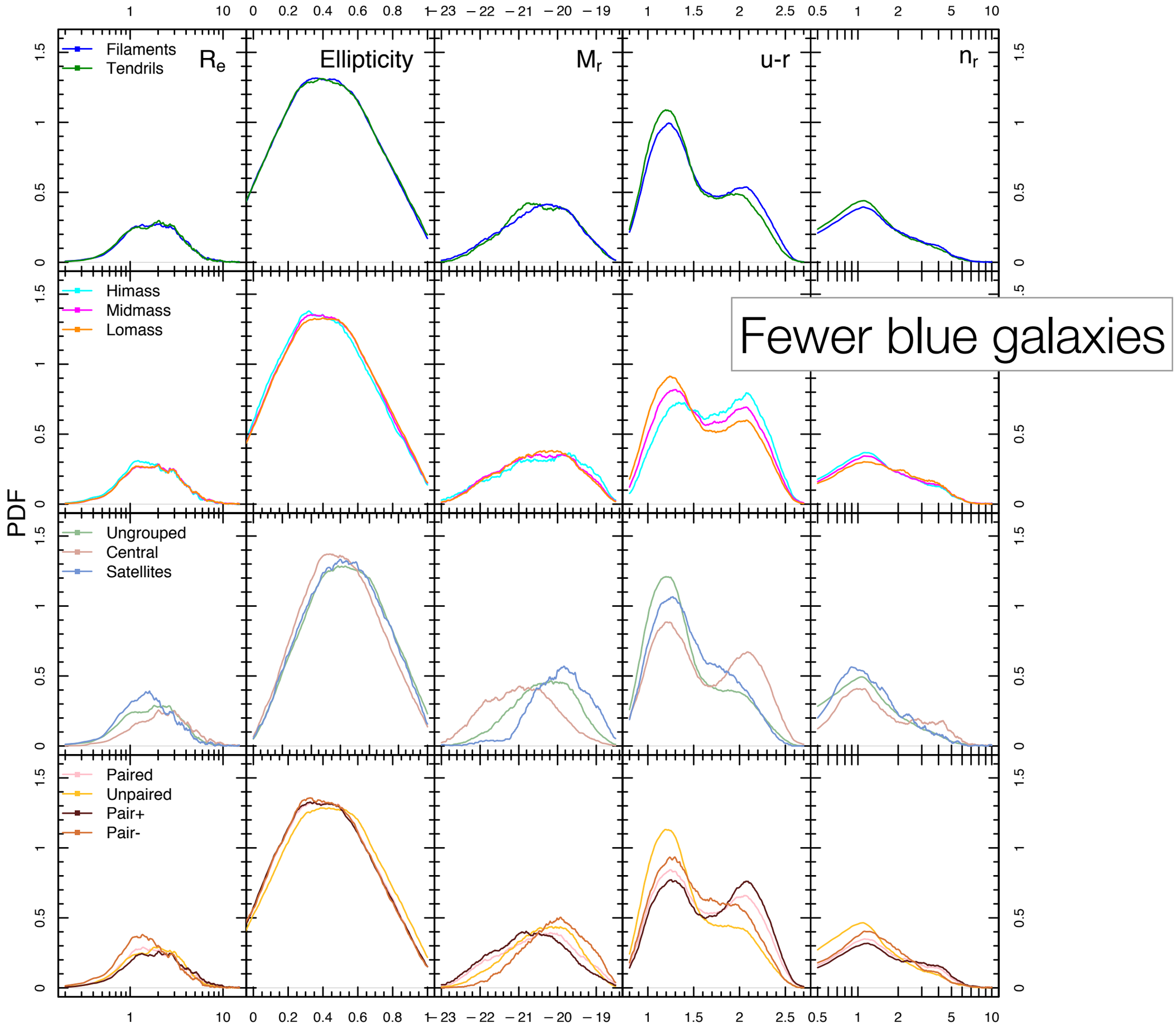
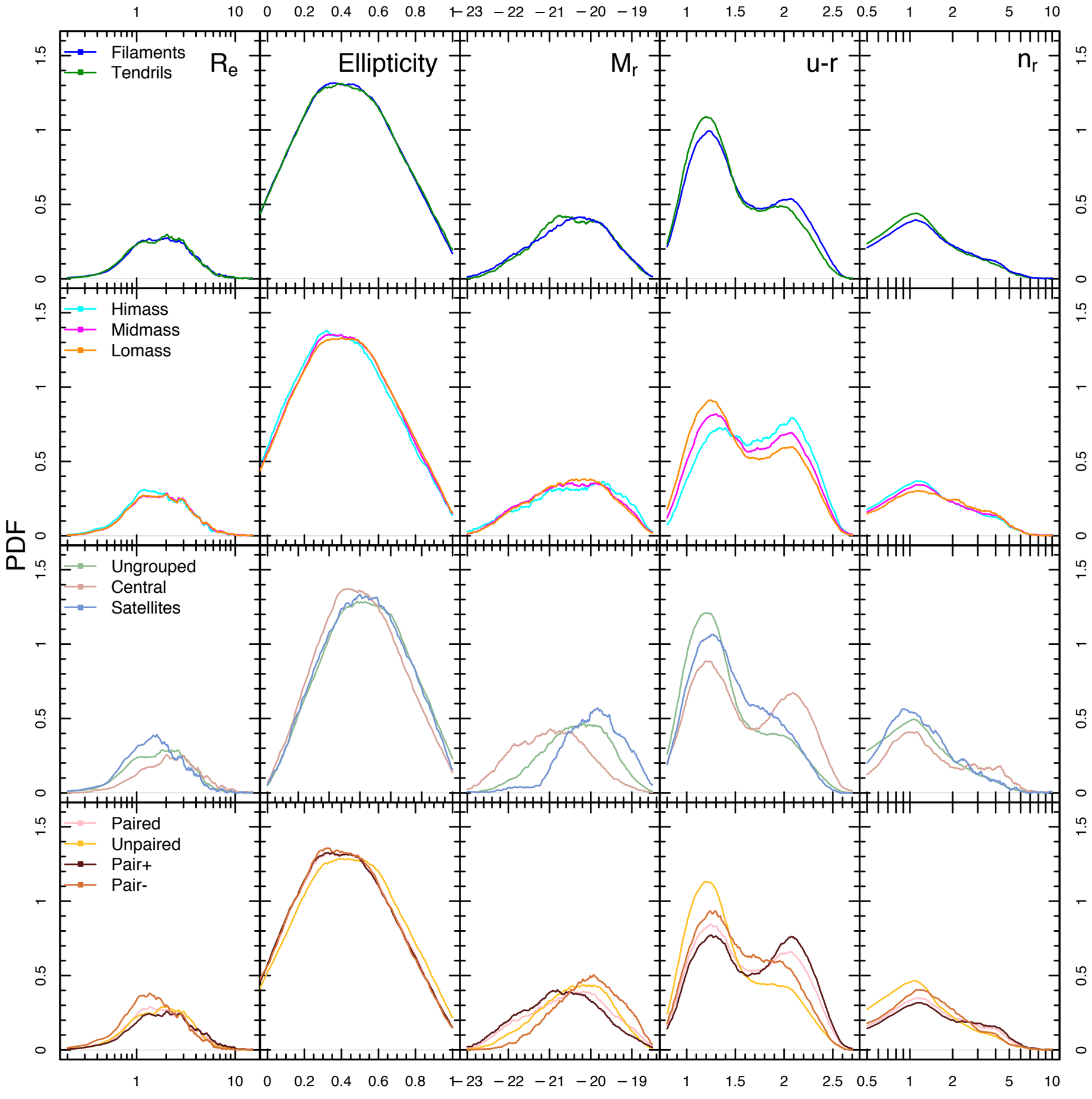

Filaments
Tendrils
R_e
Ellipticity
M_r
u-r
n_r
Himass
Midmass
Lomass
Ungrouped
Central
Satellites
Paired
Unpaired
Pair+
Pair-
PDF
Fewer blue galaxies


Filaments
Tendrils
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Ellipticity
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Himass
Midmass
Lomass
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Central
Satellites
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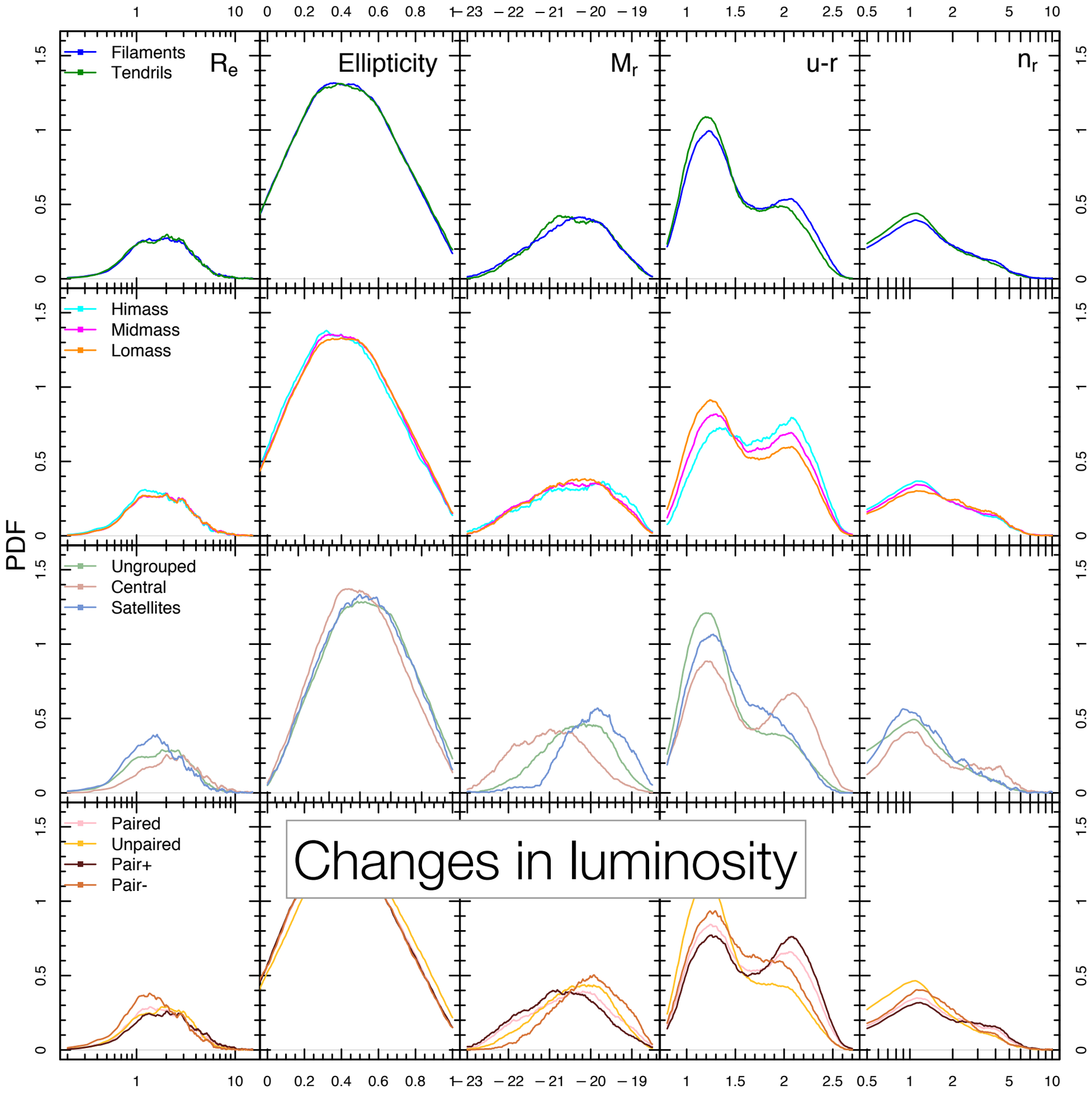
Filaments
Tendrils
R_e
Ellipticity
M_r
u-r
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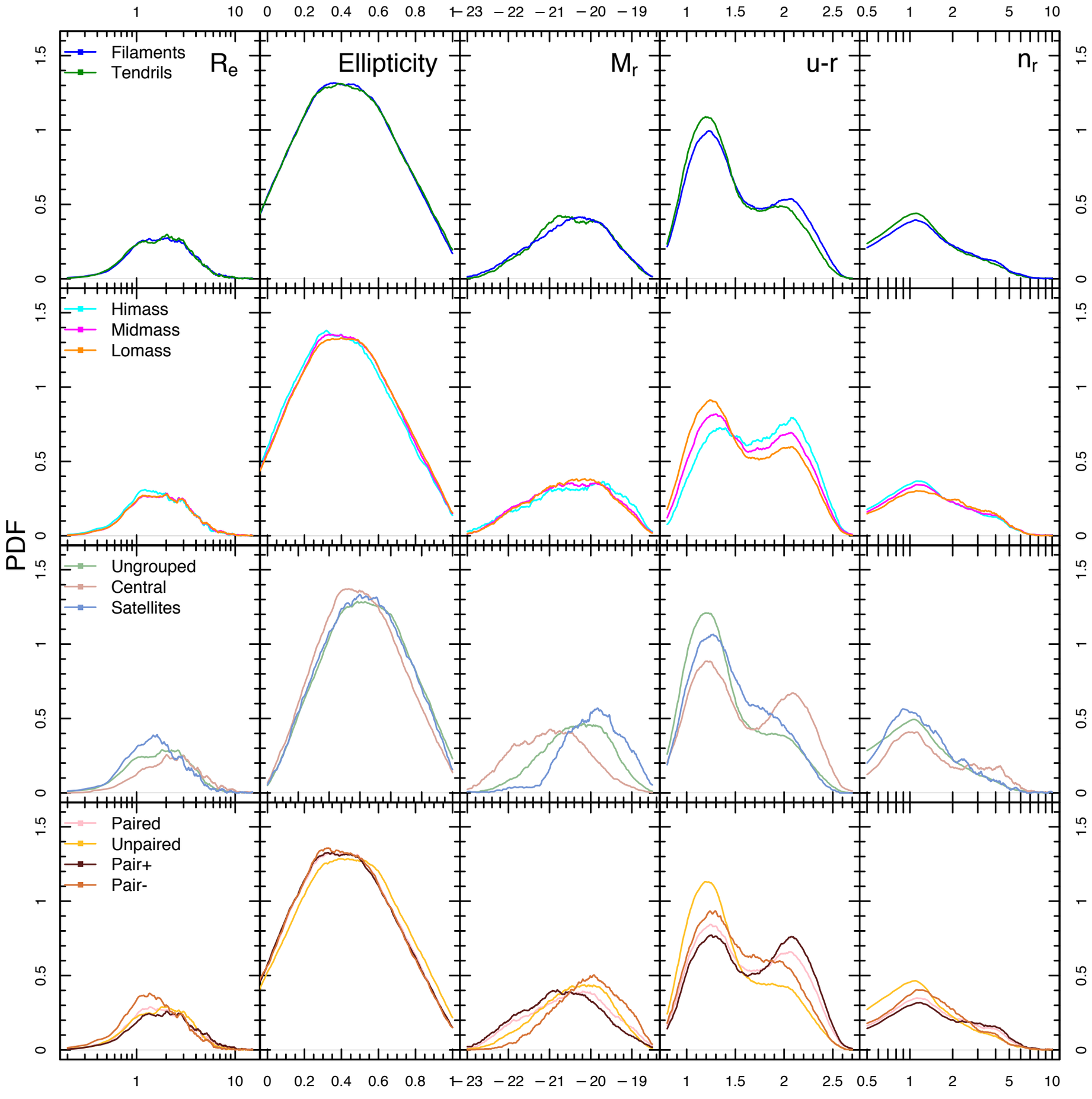
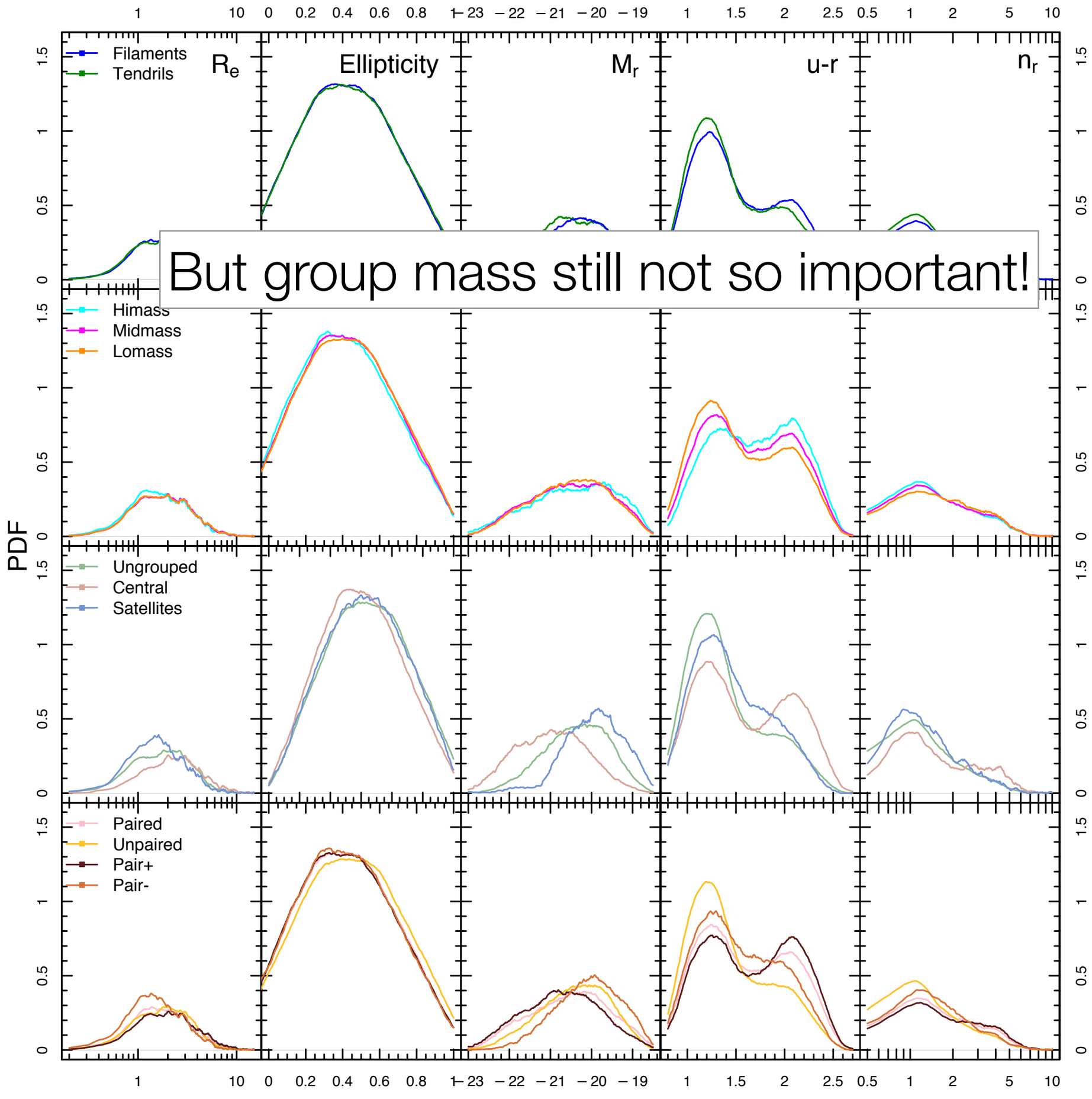
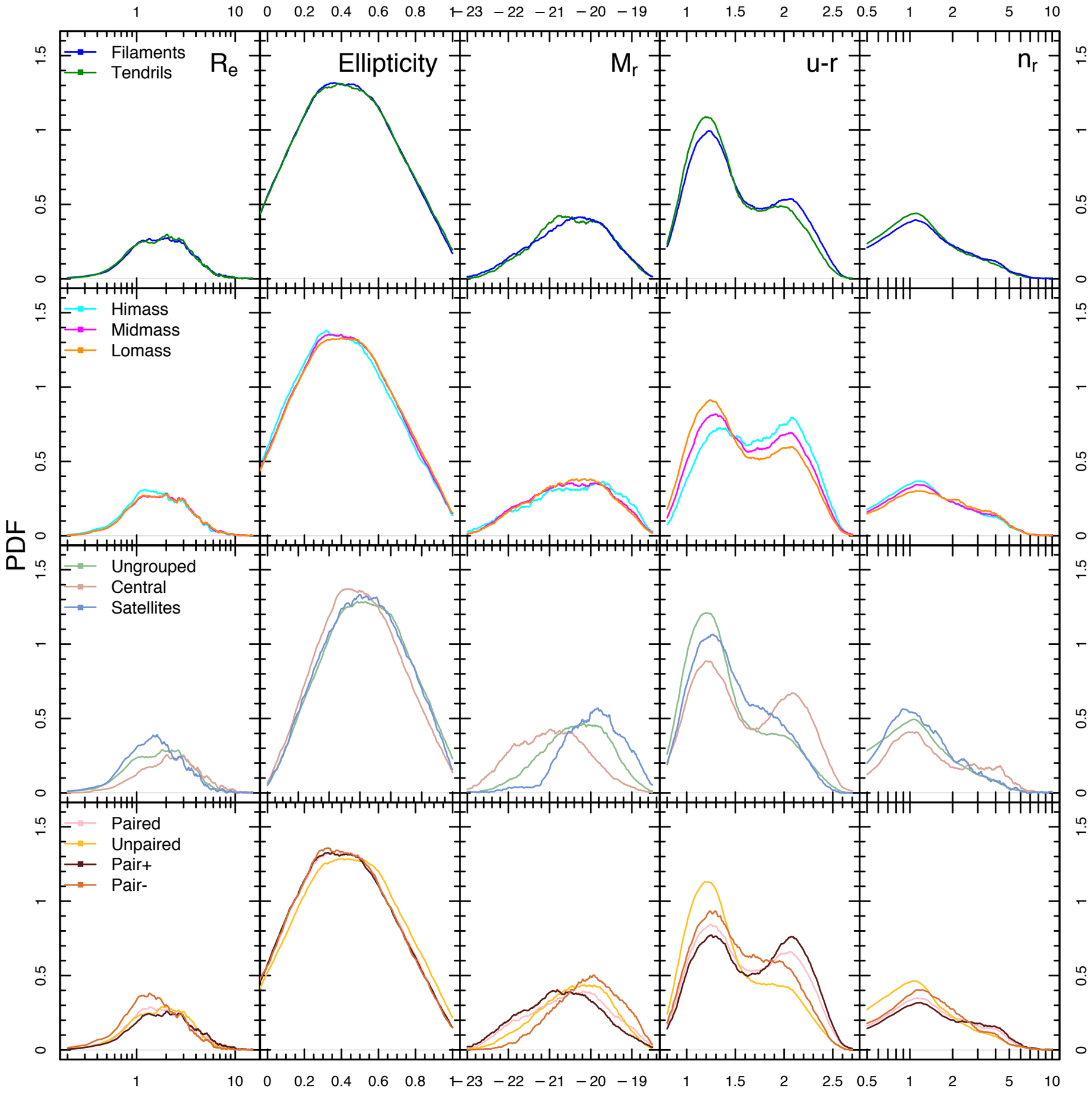
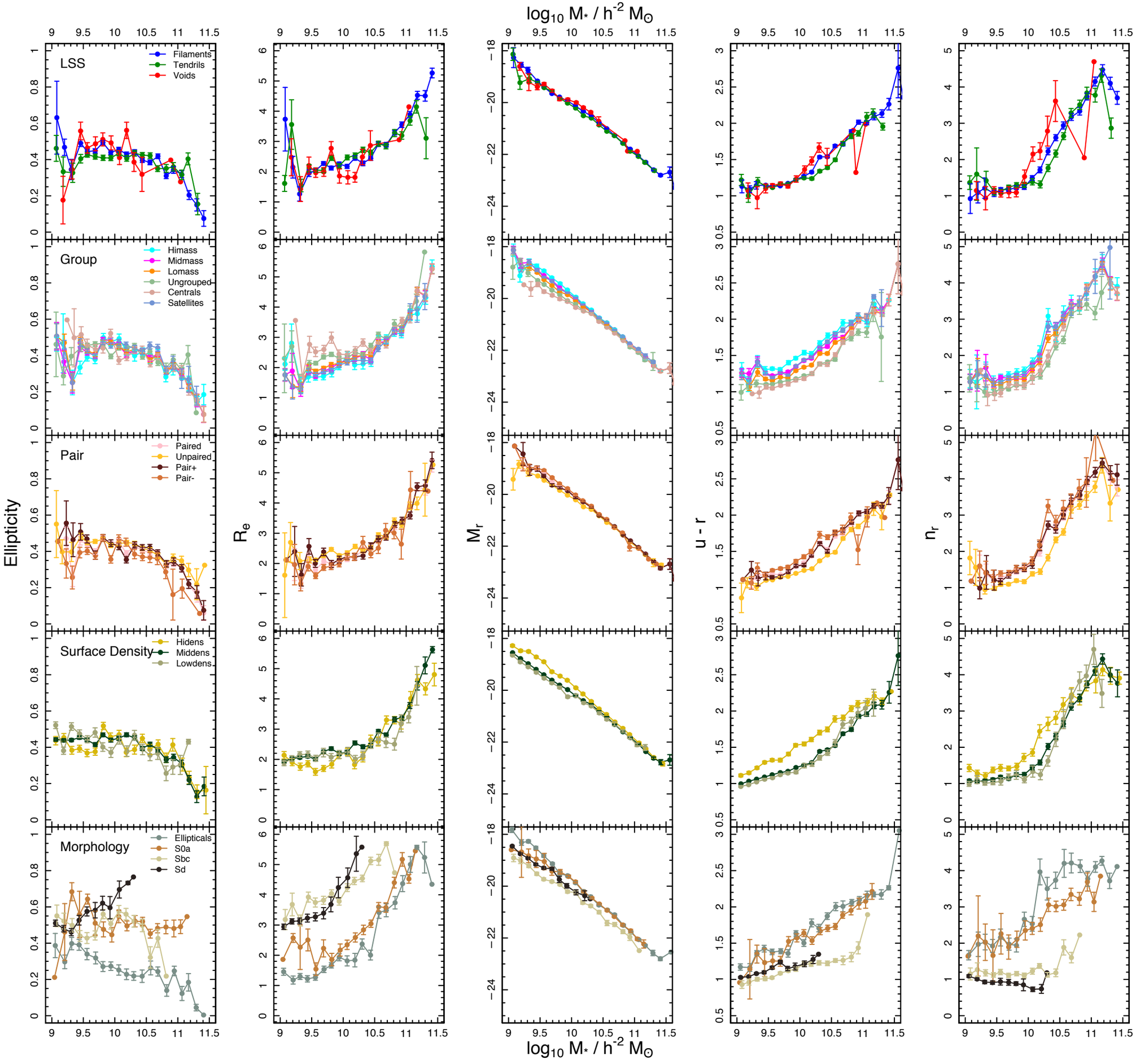
Himass
Midmass
Lomass
Ungrouped
Central
Satellites
Paired
Unpaired
Pair+
Pair-
PDF
Changes in luminosity


Filaments
Tendrils
R_e
Ellipticity
M_r
u-r
n_r
Himass
Midmass
Lomass
Ungrouped
Central
Satellites
Paired
Unpaired
Pair+
Pair-
PDF
1
10
0
0.2
0.4
0.6
0.8
−23
−22
−21
−20
−19
1
1.5
2
2.5
0.5
1
2
5
10
0
0.5
1
1.5


Filaments
Tendrils
R_e
Ellipticity
M_r
u-r
n_r
Himass
Midmass
Lomass
Ungrouped
Central
Satellites
Paired
Unpaired
Pair+
Pair-
PDF
But group mass still not so important!


Filaments
Tendrils
R_e
Ellipticity
M_r
u-r
n_r
Himass
Midmass
Lomass
Ungrouped
Central
Satellites
Paired
Unpaired
Pair+
Pair-
PDF
1
10
0
0.2
0.4
0.6
0.8
−23
−22
−21
−20
−19
1
1.5
2
2.5
0.5
1
2
5
10
0
0.5
1
1.5


log10 M* / h-2 MO
Ellipticity
Re
Mr
u - r
nr
LSS
Filaments
Tendrils
Voids
Group
Himass
Midmass
Lomass
Ungrouped
Centrals
Satellites
Pair
Paired
Unpaired
Pair+
Pair-
Surface Density
Hidens
Middens
Lowdens
Morphology
Ellipticals
S0a
Sbc
Sd

Summary

When controlled for mass, galaxies in dense large scale environments (i.e. filaments) are no more likely to be blue, faint, or disc-like than their counterparts in voids.

Extending our analysis to galaxies in groups and pairs we show that galaxies outside of structures (ungrouped or unpaired) exhibit similar characteristics. We fail to see a strong dependence of halo mass on Sersic index and galaxy luminosity, but do find that it correlates very strongly with colour.

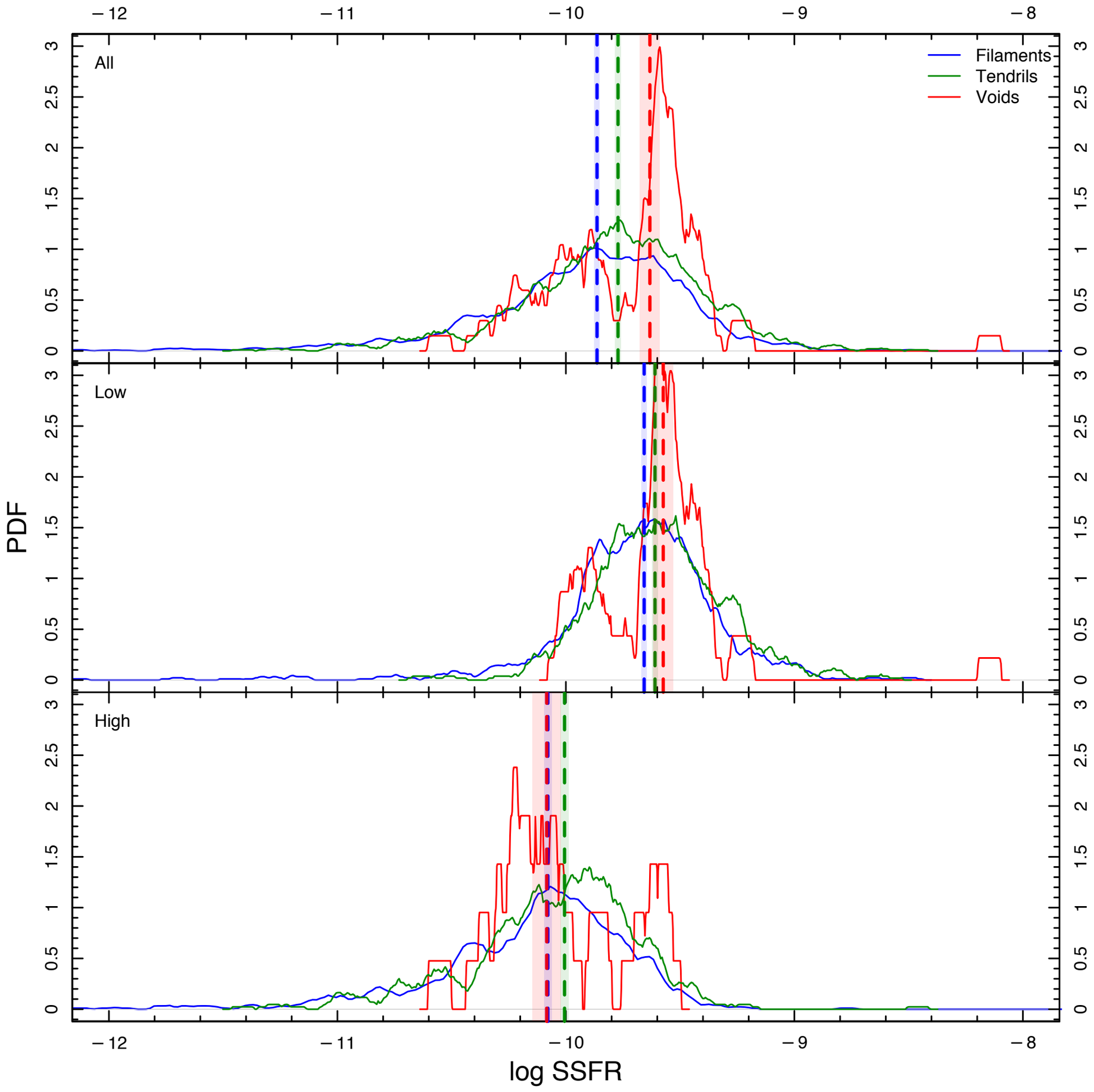
Repeating our analysis for galaxies that have not been mass controlled introduces and amplifies trends in the properties of galaxies in pairs, groups, and large scale structure, indicating that **stellar mass is the most important predictor of galaxy properties followed by local density and group/pair interactions, and finally large scale structure.**

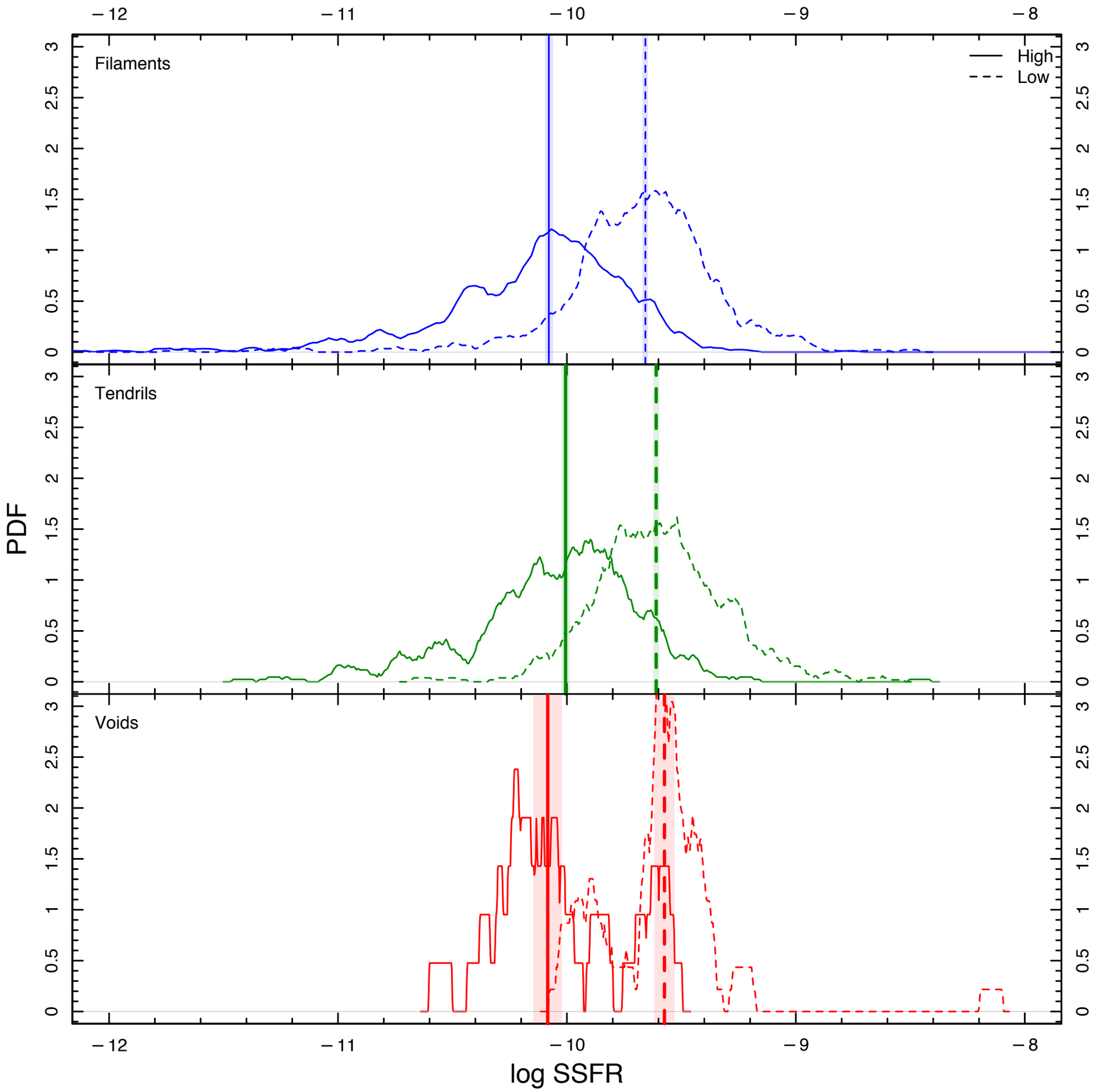
Current, very preliminary work

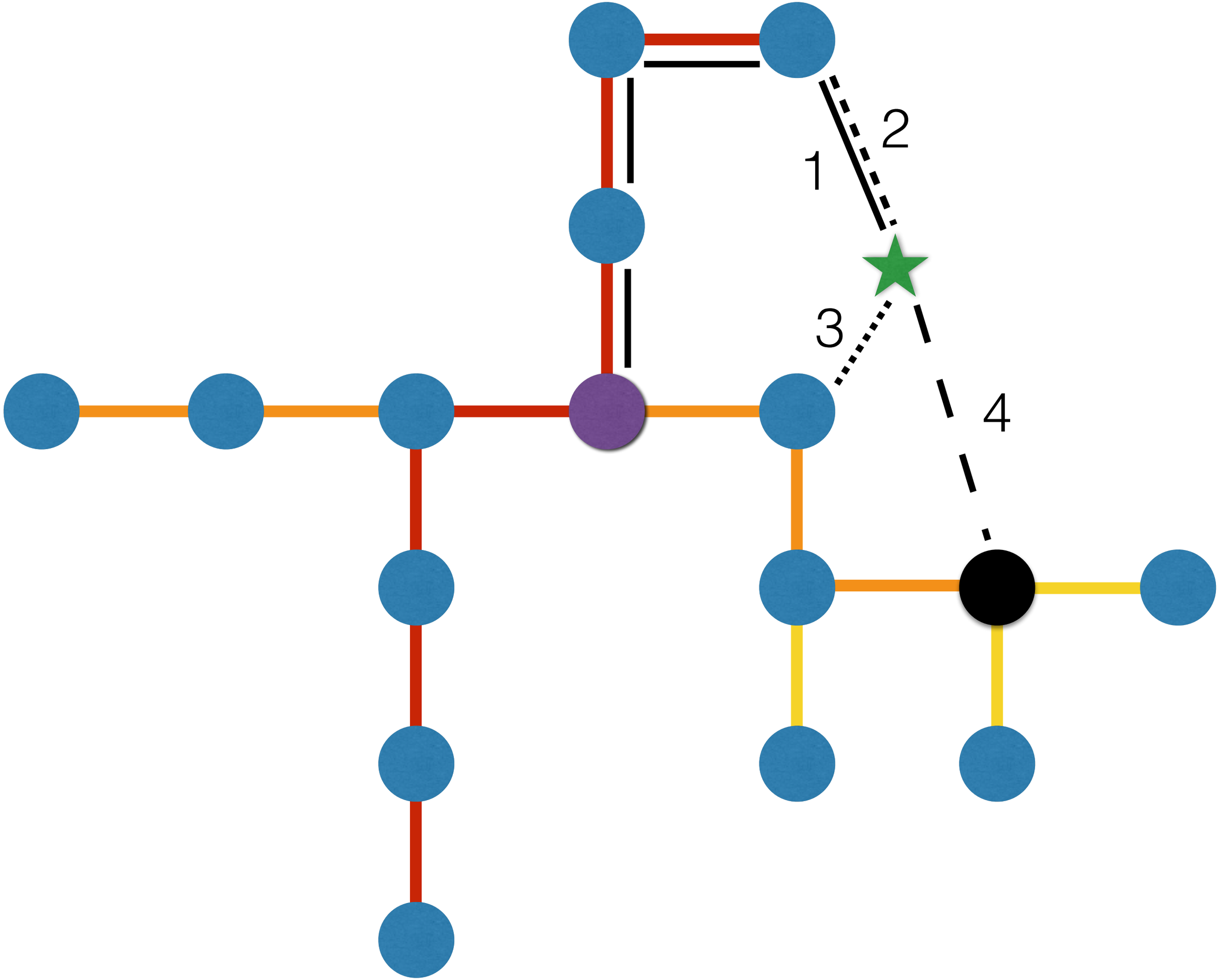
1. **Is it possible to track the mass flow of gas along the Cosmic Web by detecting systematic changes in star formation rates of galaxies in filaments, tendrils, and voids?**

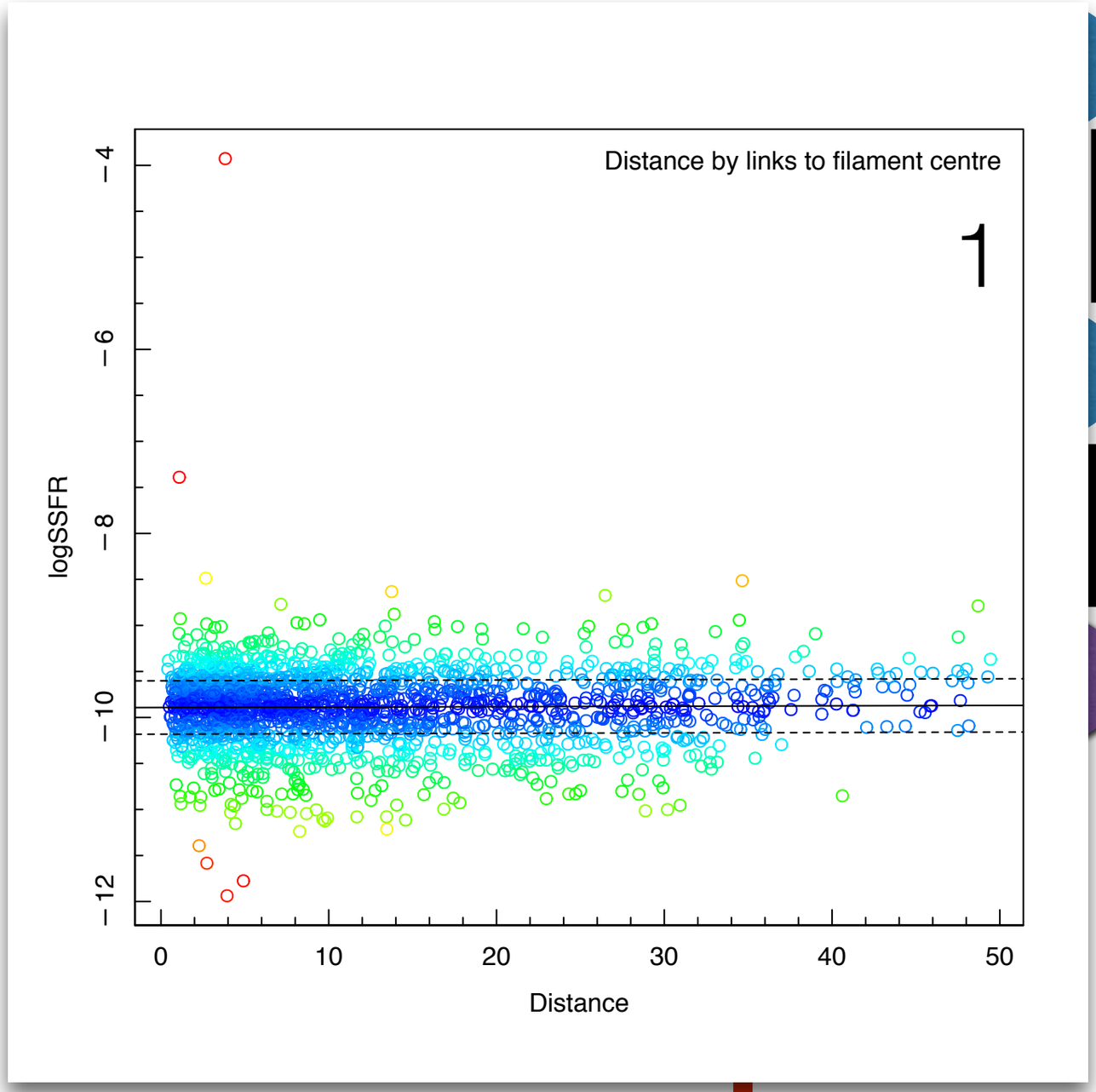
   - The typical expectation is that cold gas flows from voids, through filaments, into large clusters. This gas could provide galaxies with fresh material with which to form stars; however, one must be careful not to simply rediscover star formation suppression caused by local density phenomena (i.e. within groups and pairs).

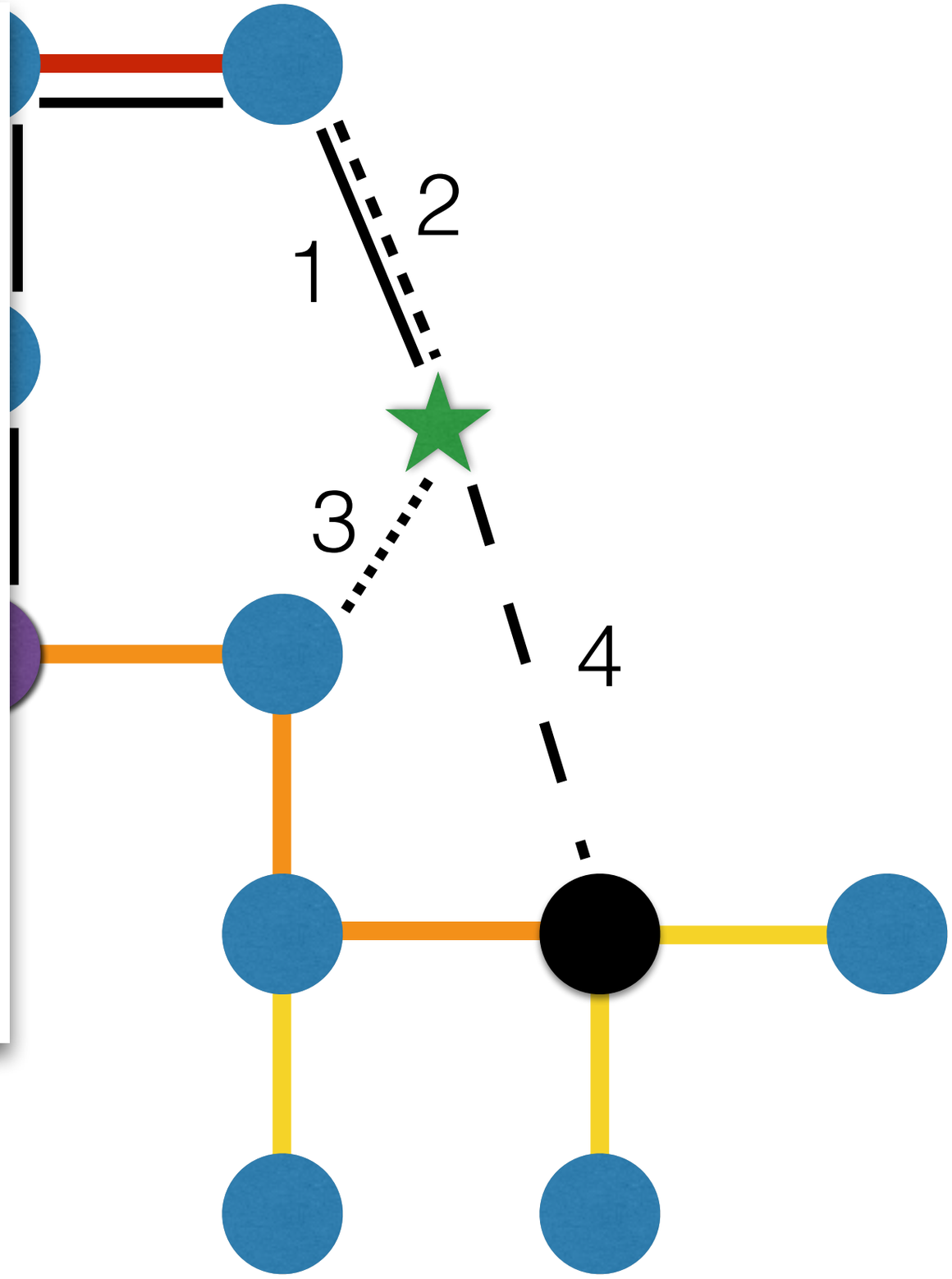
   - Also non-trivial - defining the spatial & geometric shape of a filament, as well as a distance metric!

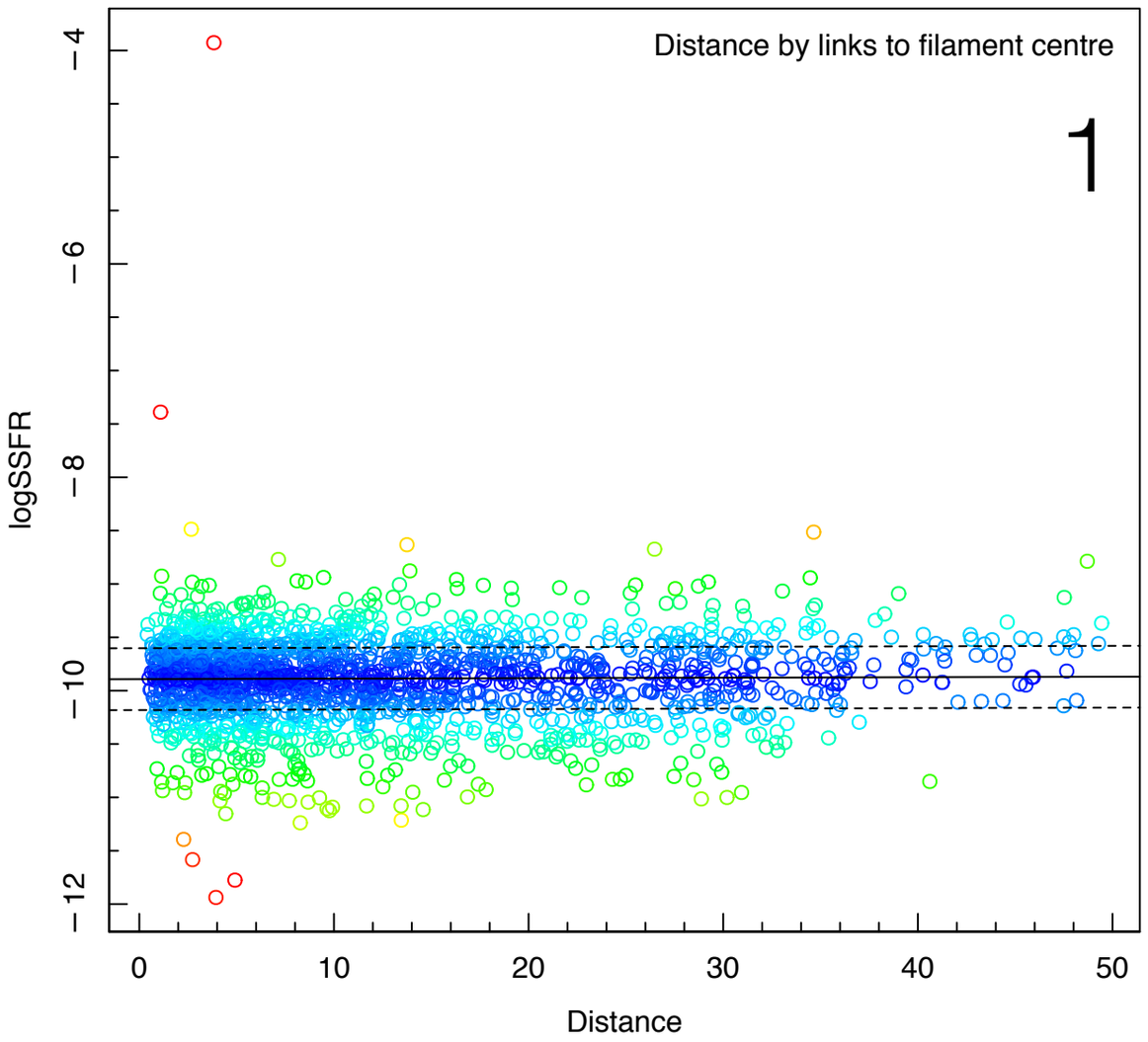

All
Low
High
Filaments
Tendrils
Voids
PDF
log SSFR
−12
−11
−10
−9
−8
0
0.5
1
1.5
2
2.5
3

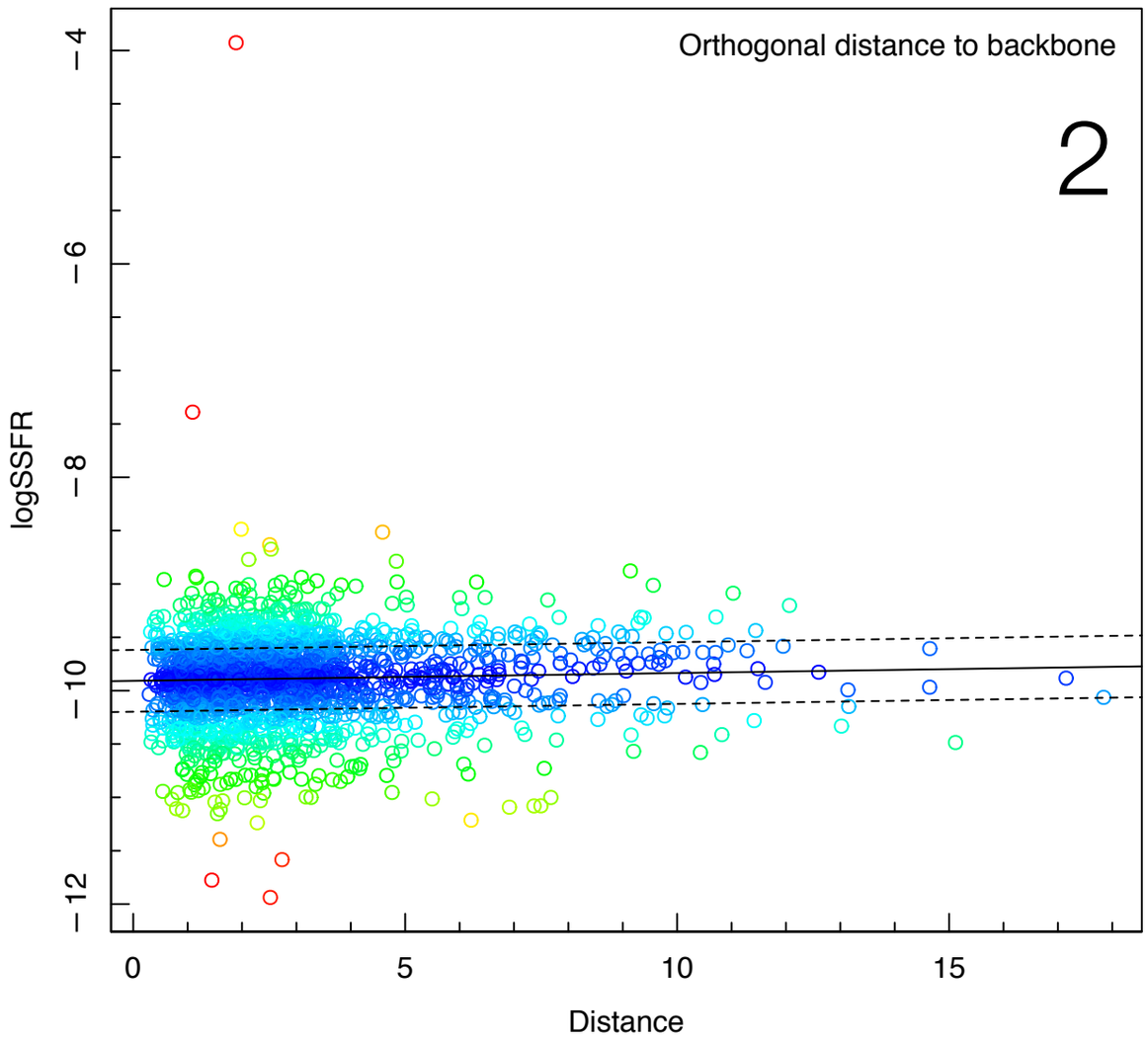

Filaments
High
Low
Tendrils
Voids
PDF
log SSFR
−12
−11
−10
−9
−8
0
0.5
1
1.5
2
2.5
3

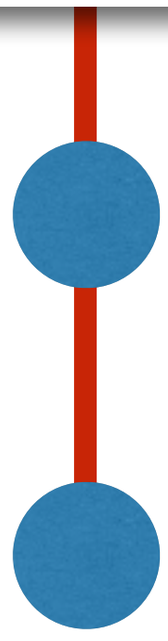

1
2
3
4

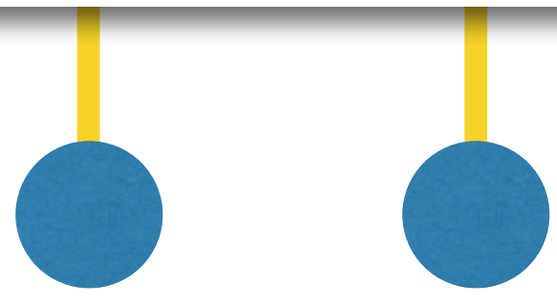

Distance by links to filament centre
1
logSSFR
−4
−6
−8
−10
−12
0
10
20
30
40
50
Distance

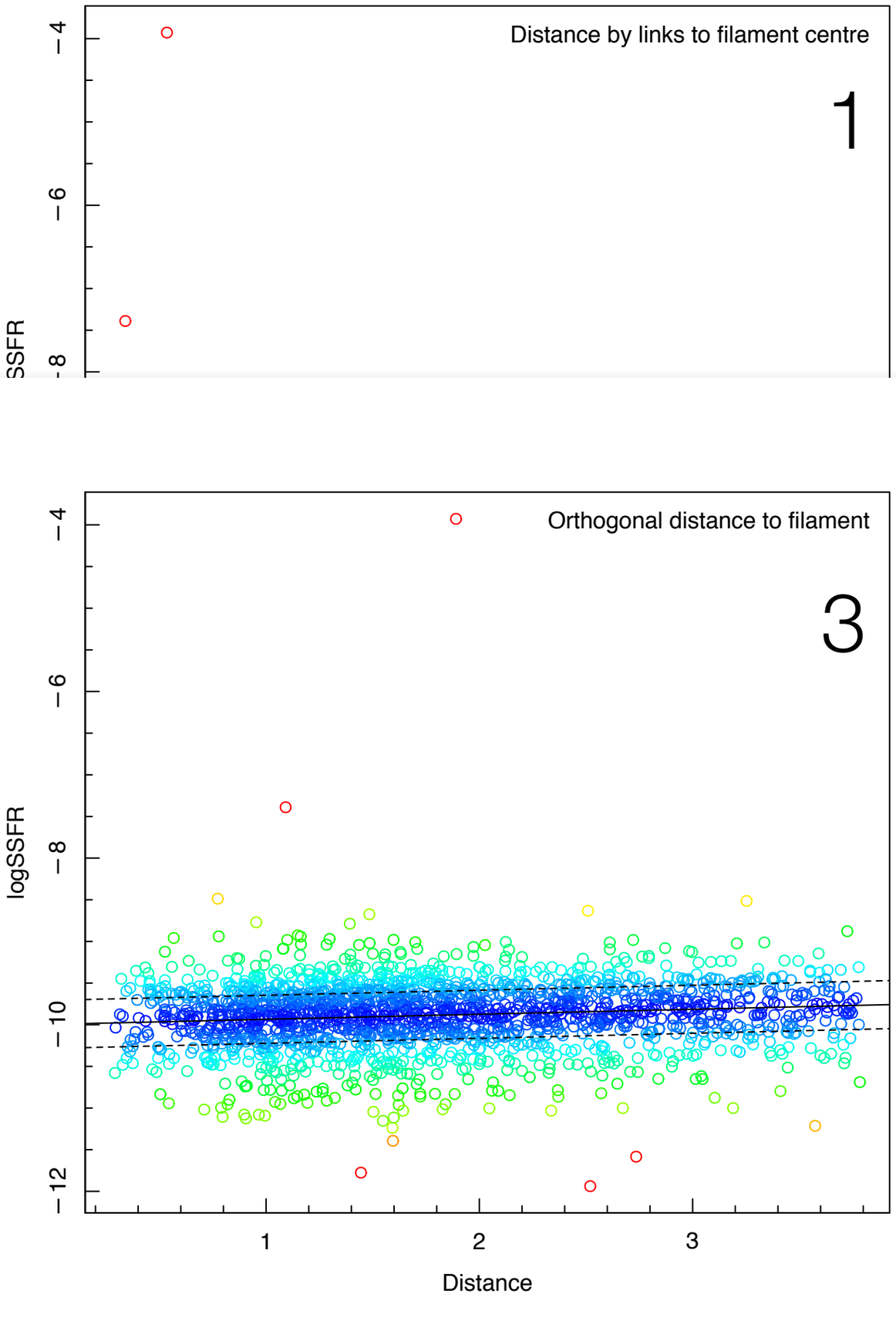

1
2
3
4

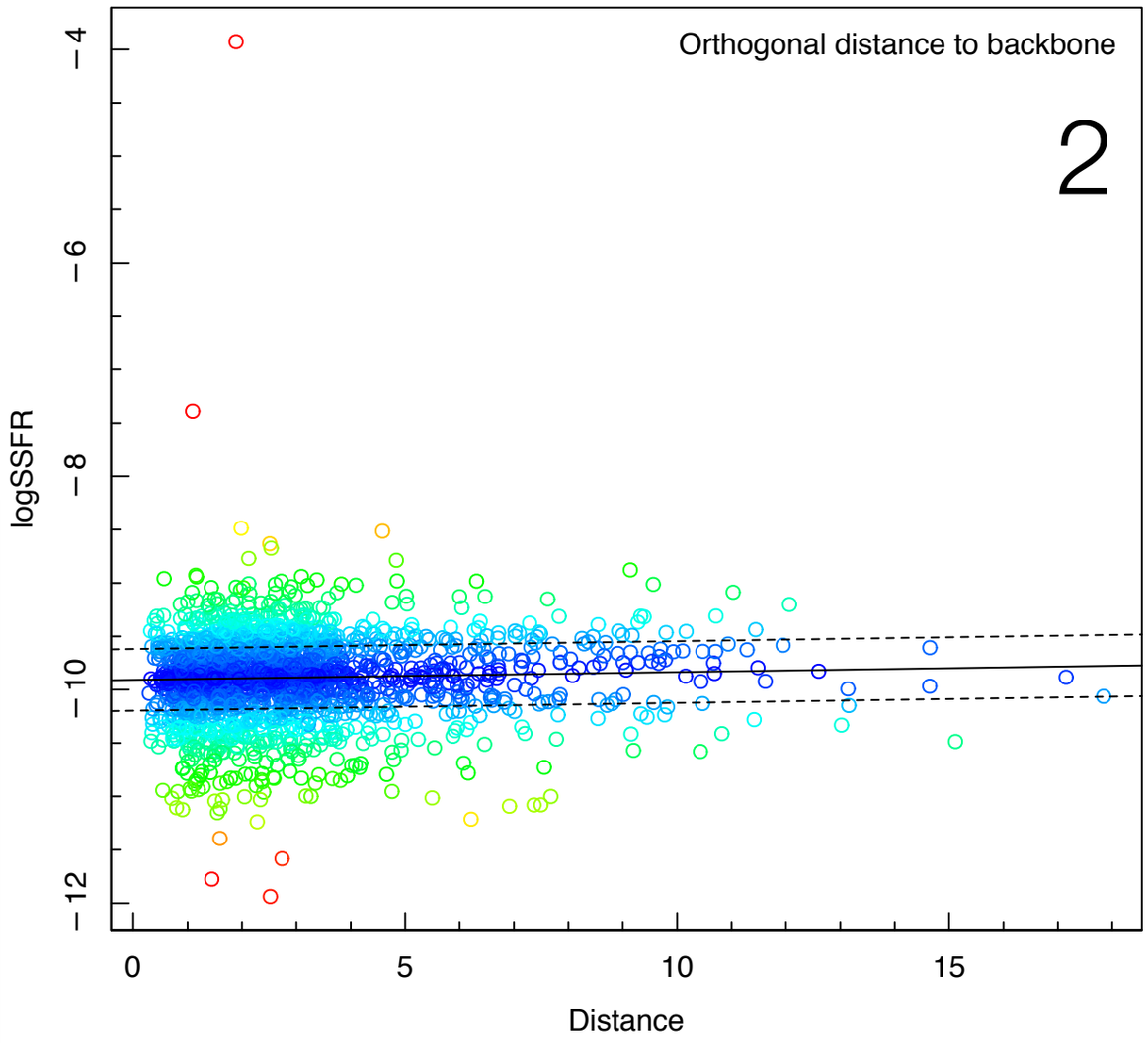

Distance by links to filament centre
1
logSSFR
−4
−6
−8
−10
−12
0
10
20
30
40
50
Distance

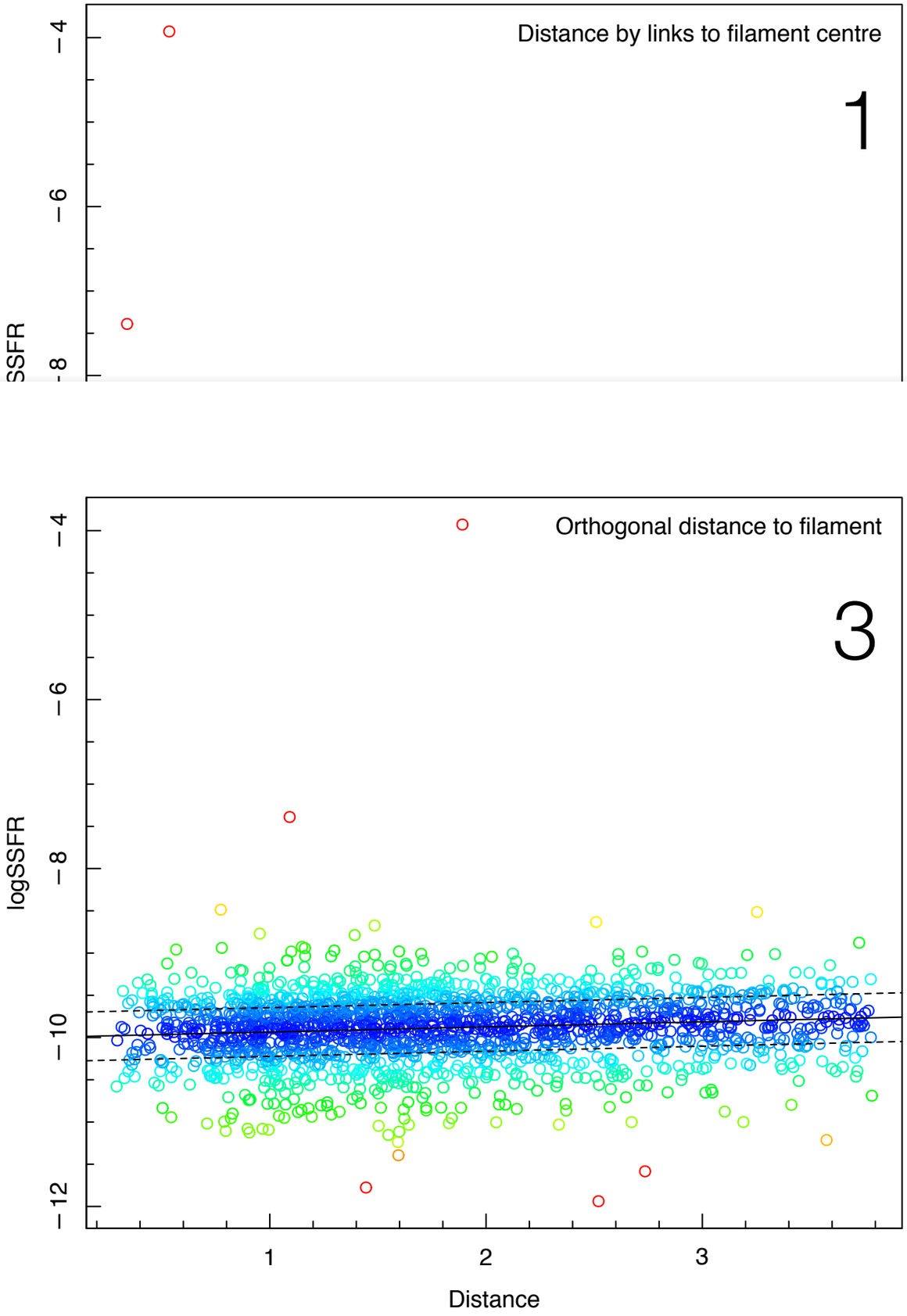

Orthogonal distance to backbone
2
logSSFR
−4
−6
−8
−10
−12
0
5
10
15
Distance

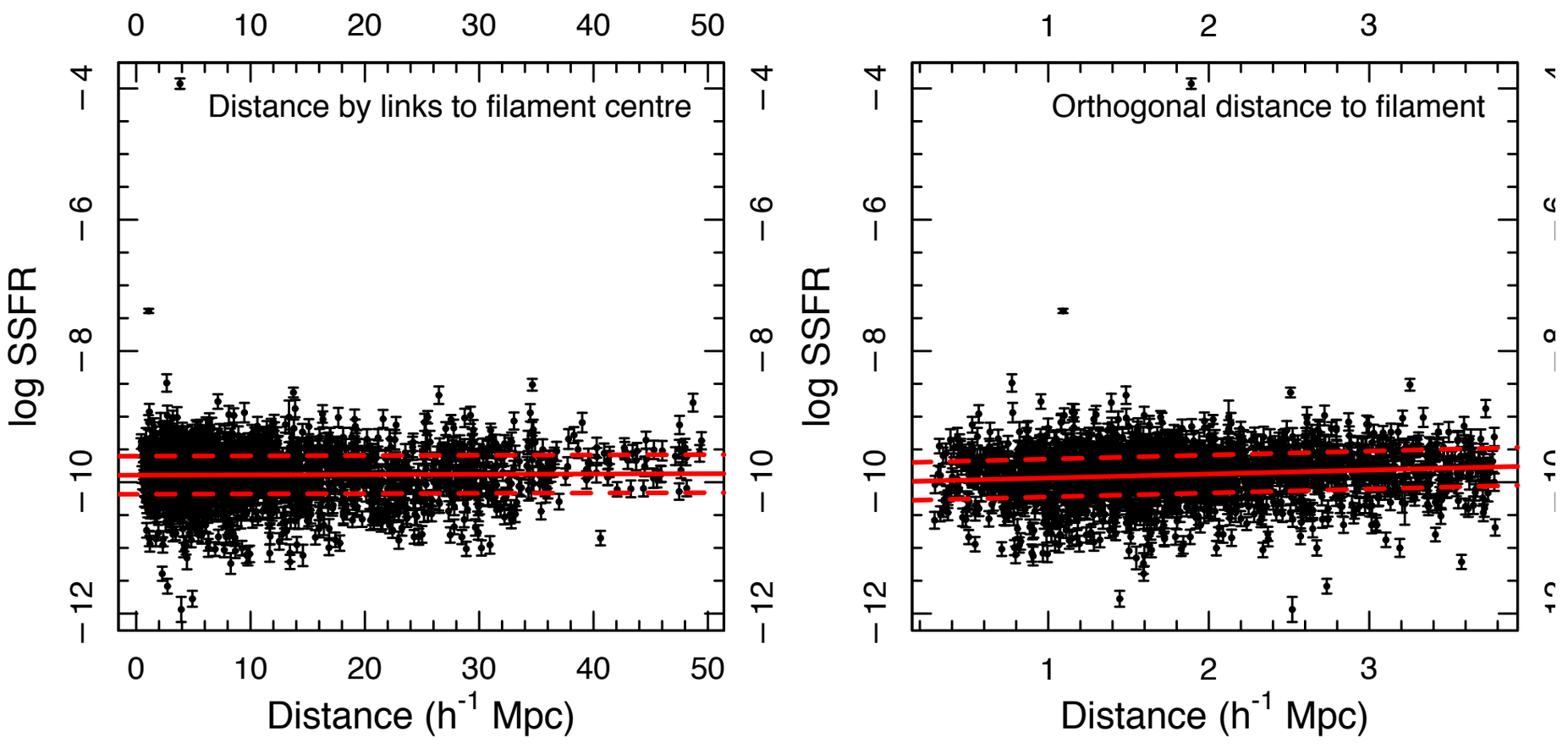


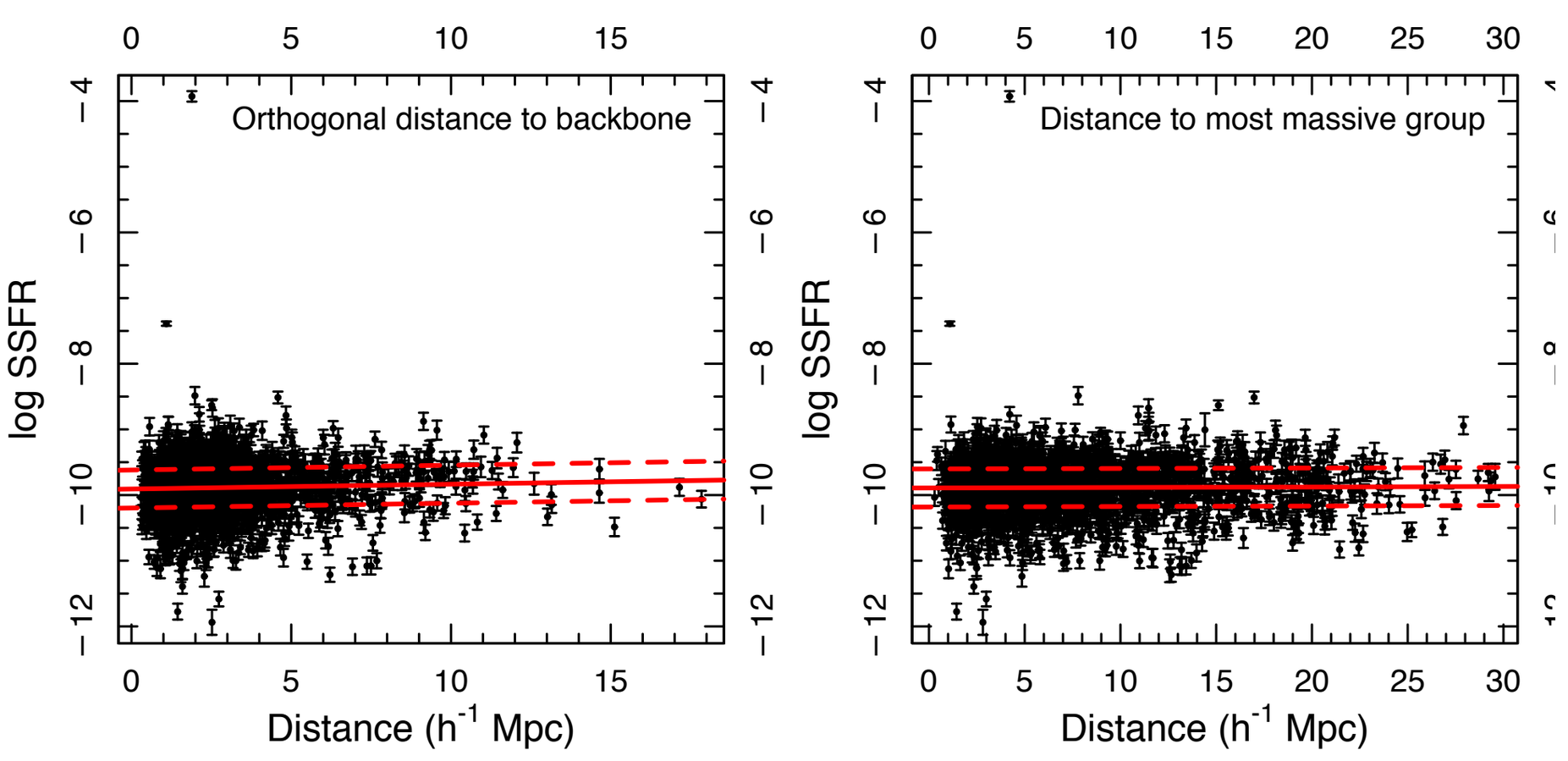



Distance by links to filament centre
1
Orthogonal distance to filament
3
logSSFR
−4
−6
−8
−10
−12
1
2
3
Distance


Orthogonal distance to backbone
2
logSSFR
−4
−6
−8
−10
−12
0
5
10
15
Distance


Distance by links to filament centre
1
Orthogonal distance to backbone
2
Orthogonal distance to filament
3
Distance to most massive group
4
logSSFR
−4
−6
−8
−10
−12
0
5
10
15
20
25
30
Distance


Distance by links to filament centre
Orthogonal distance to filament
log SSFR
Distance (h^{-1} Mpc)

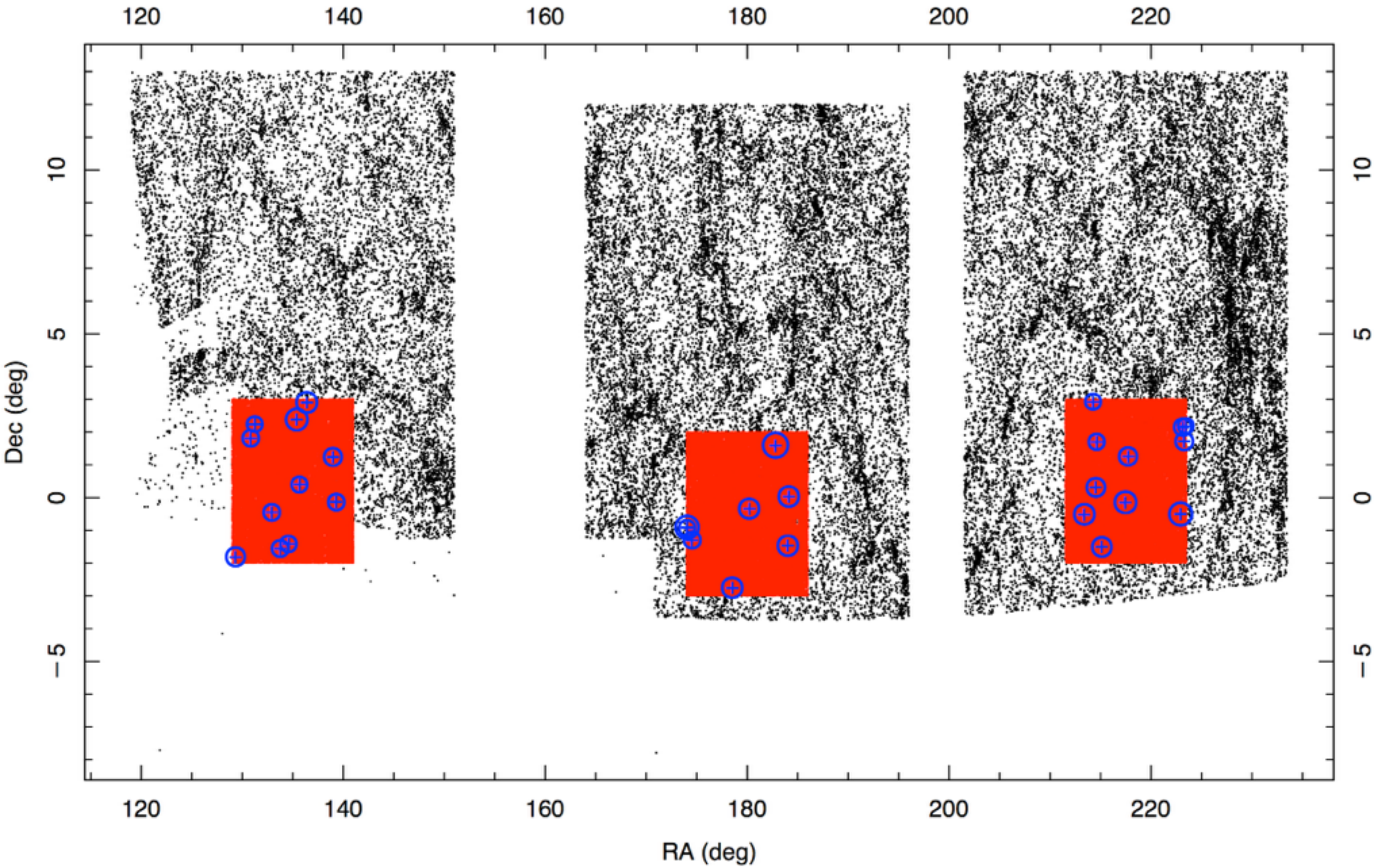

Orthogonal distance to backbone
Distance to most massive group
log SSFR
Distance (h^{-1} Mpc)

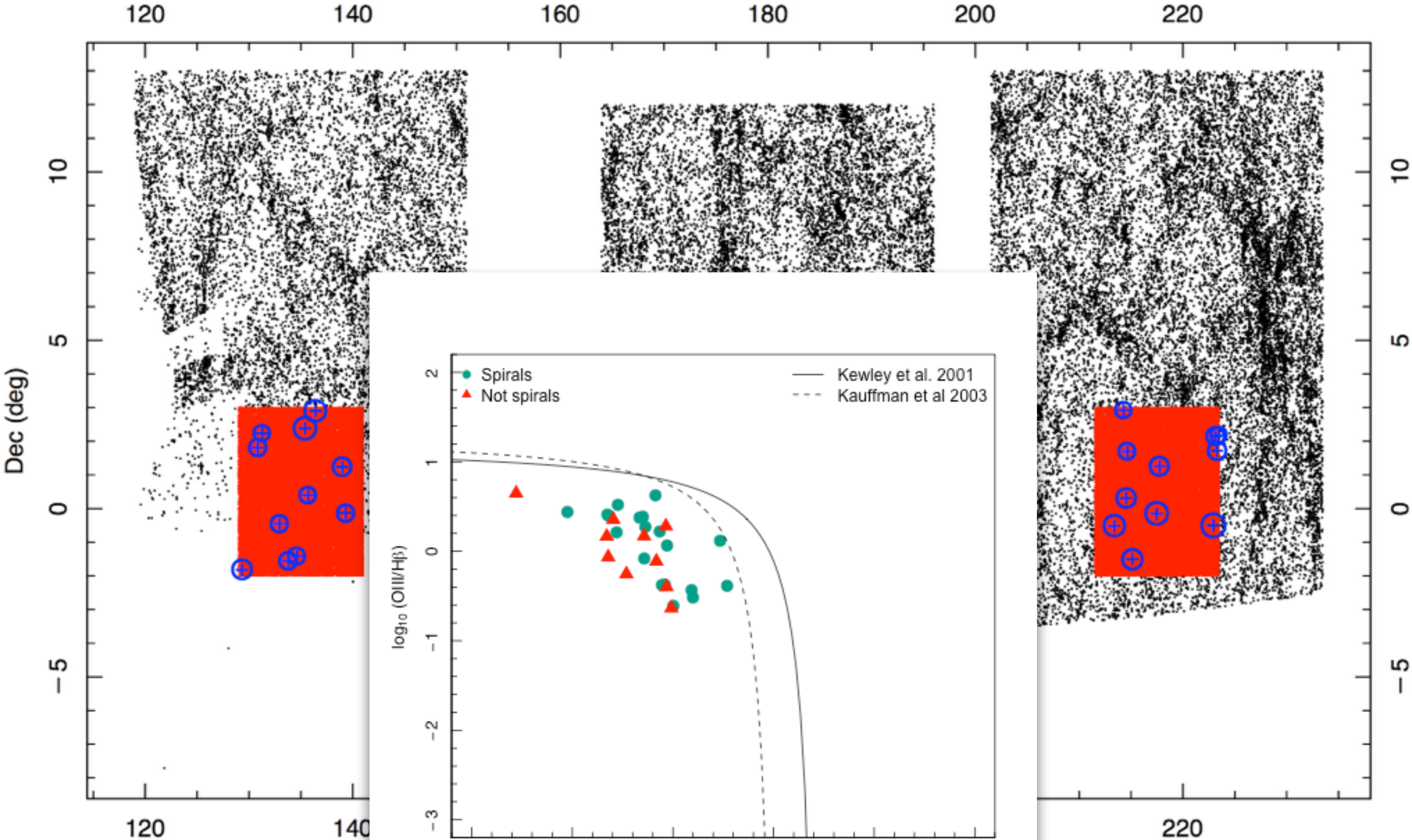
Current, very preliminary work

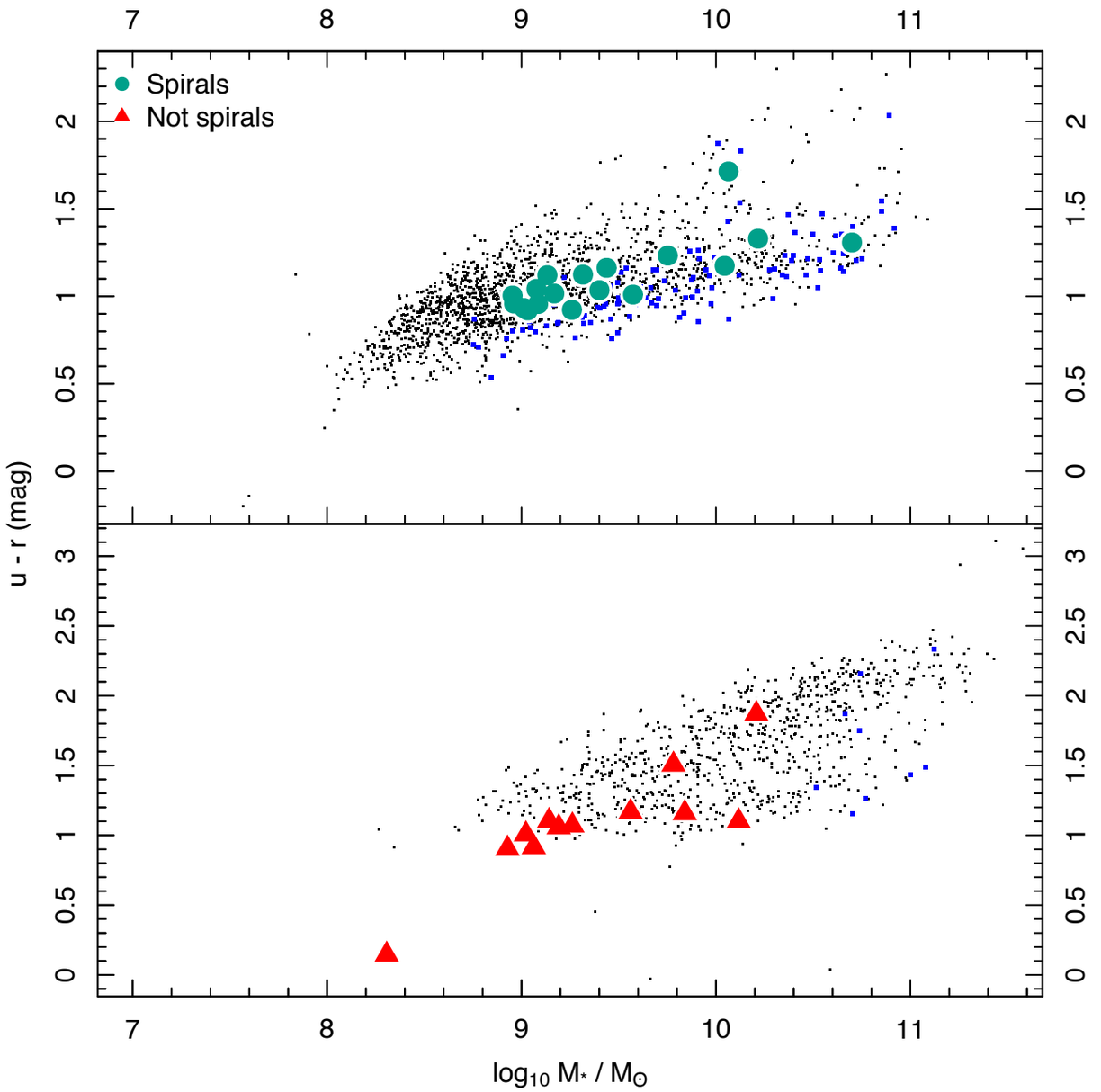
1. Is it possible to track the mass flow of gas along the Cosmic Web by detecting systematic changes in star formation rates of galaxies in filaments?

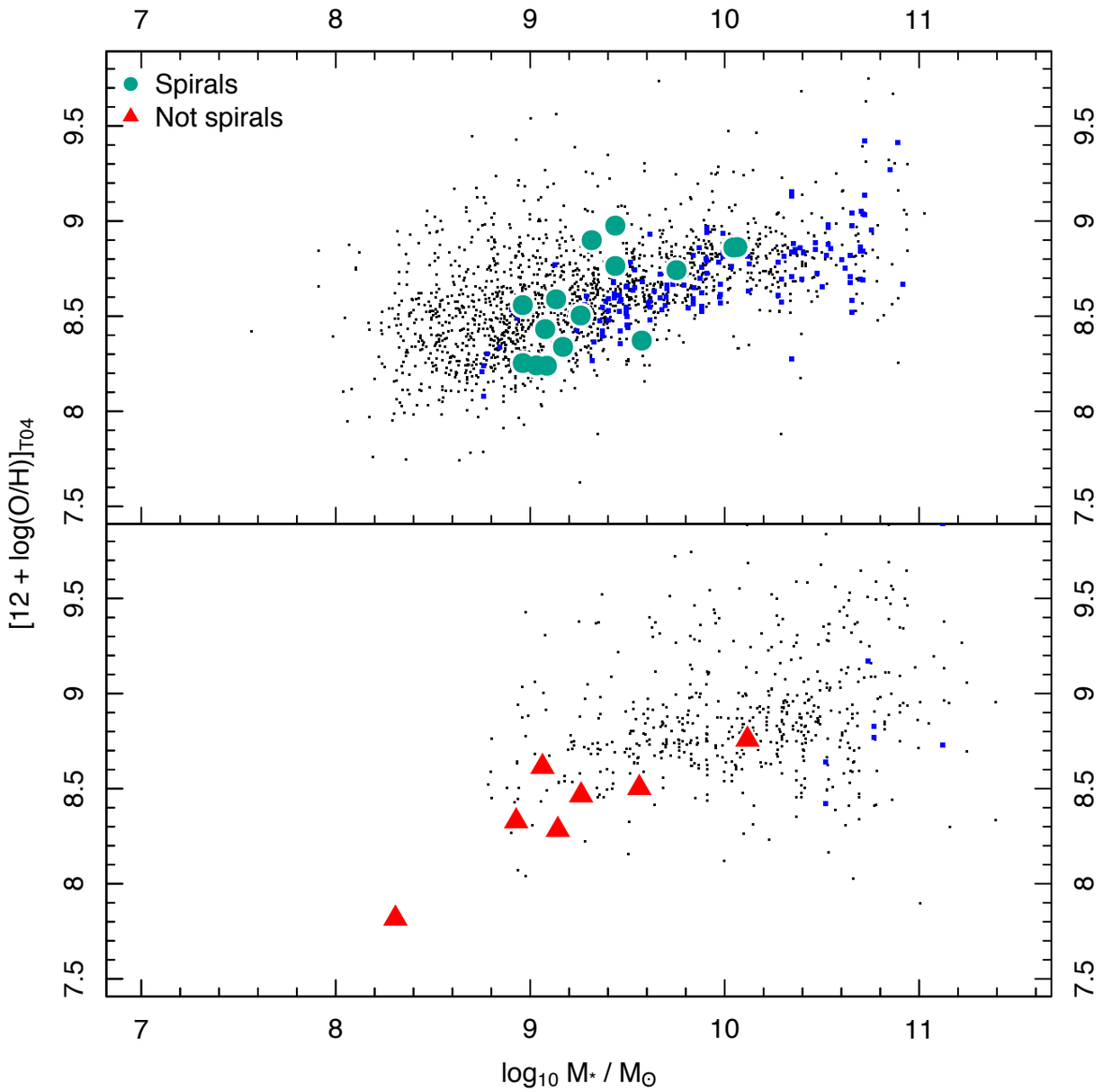
2. **Are the most isolated void galaxies in GAMA any different to their counterparts in more mundane environments?**

- These galaxies have presumably evolved in an extremely isolated environment, meaning that they are less likely to experience the dynamical interactions that most galaxies experience during their evolution. Can we detect this?


120
140
160
180
200
220
10
5
0
−5
Dec (deg)
RA (deg)


120
140
160
180
200
220
10
5
0
−5
Dec (deg)
Spirals
Not spirals
Kewley et al. 2001
Kauffman et al 2003
log10 (OIII/Hβ)
log10 (NII/Hα)
2
1
0
−1
−2
−3





No systematic difference between hyper-isolated void galaxies and their counterparts in more dense environments. Evidence of past mergers in voids?

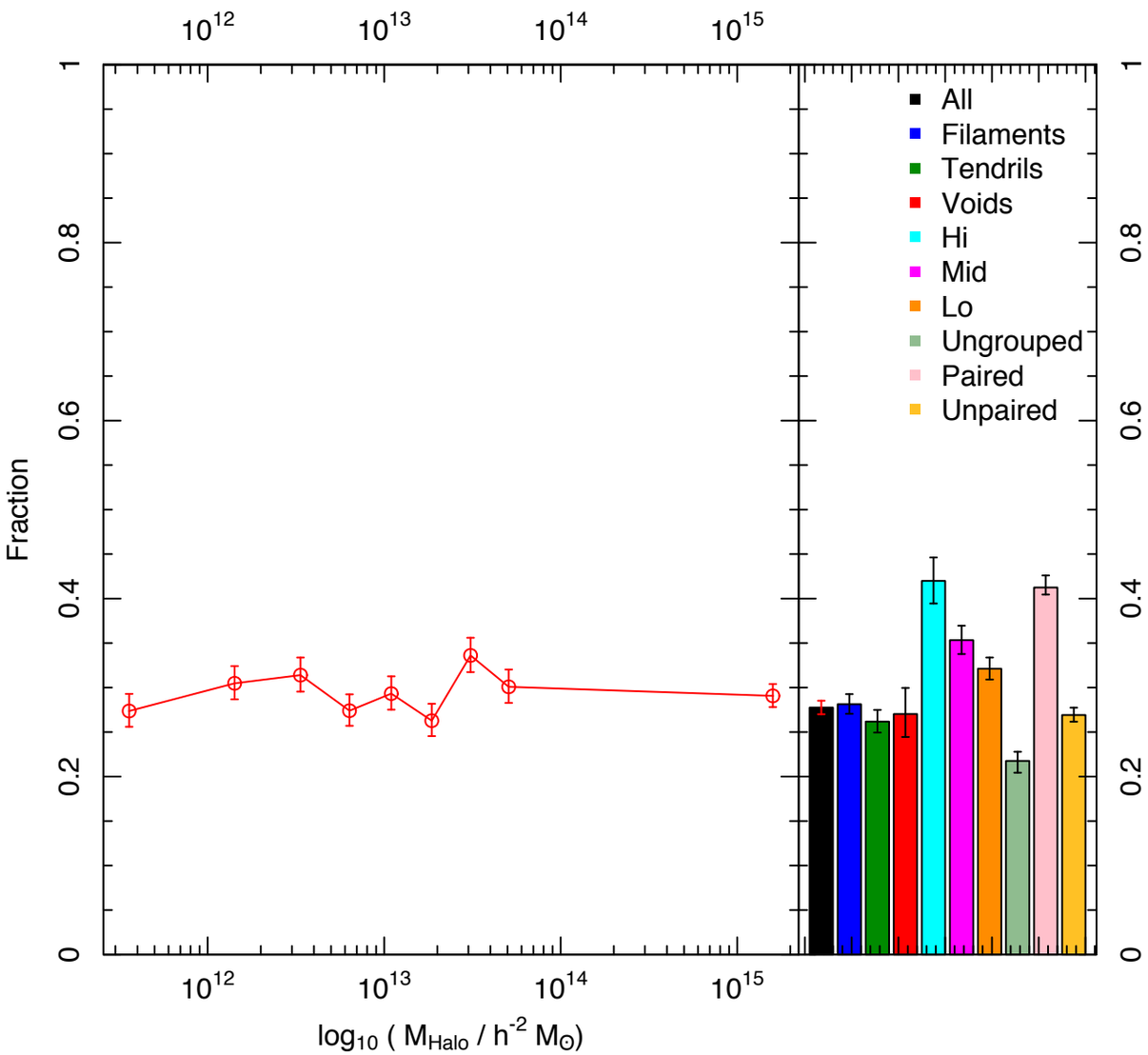
Summary

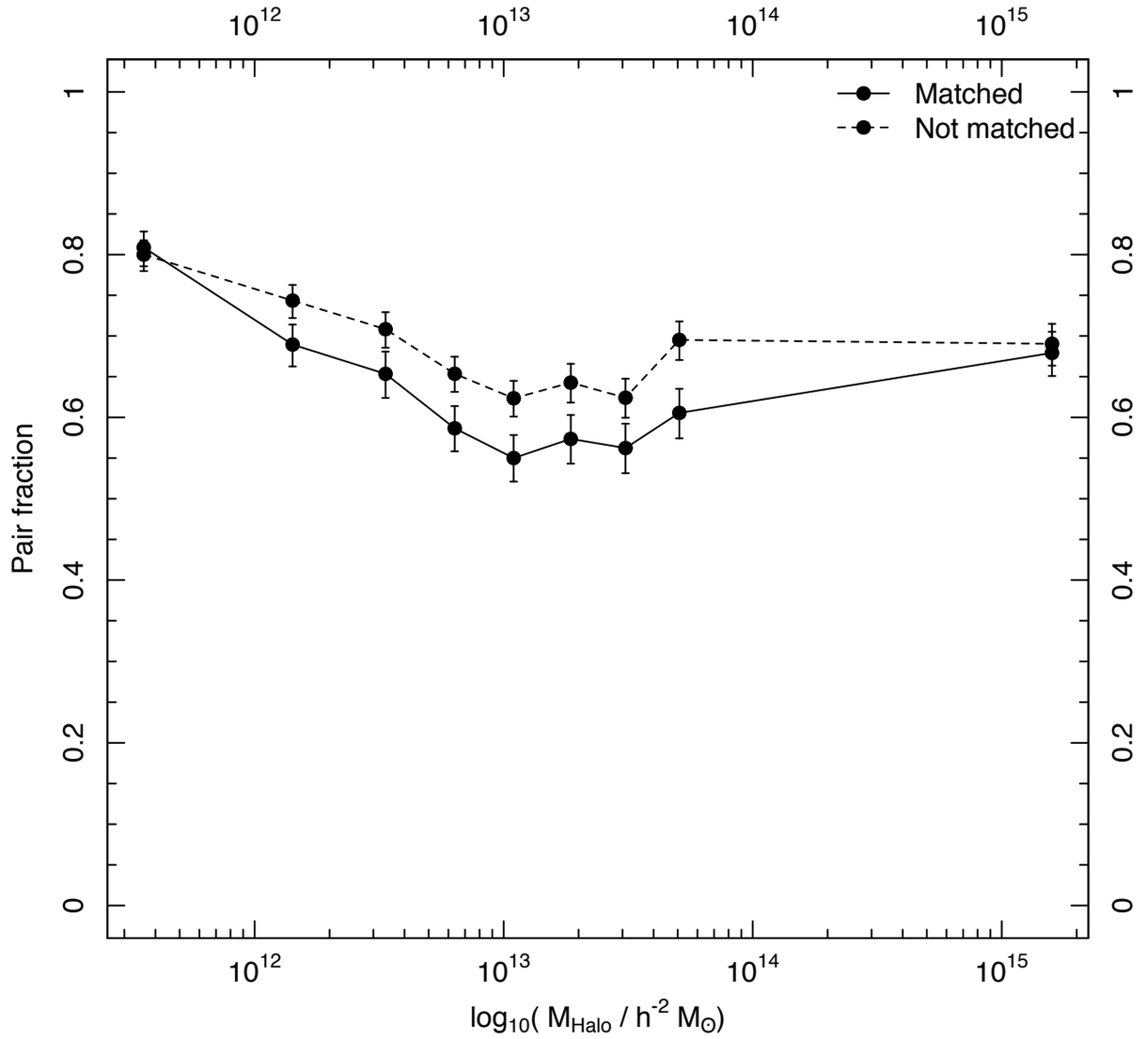
- Current and next generation redshift surveys will continue to shed light on the large scale structure of the Universe - but does it really play a large role in galaxy evolution?

- When controlling for stellar mass, large scale structure does not appear to influence many galaxy properties; but galaxies in different environments do have vastly different stellar masses (particularly voids).

- While we currently do not see a lot of correlation between filamentary structure and star formation rates, these results are preliminary. It would be great to have simulations at low z to compare to!

Spare slides


Fraction
All
Filaments
Tendrils
Voids
Hi
Mid
Lo
Ungrouped
Paired
Unpaired
log10 (MHalo / h-2 MΘ)


Matched
Not matched
Pair fraction
log10(MHalo / h-2 MΘ)