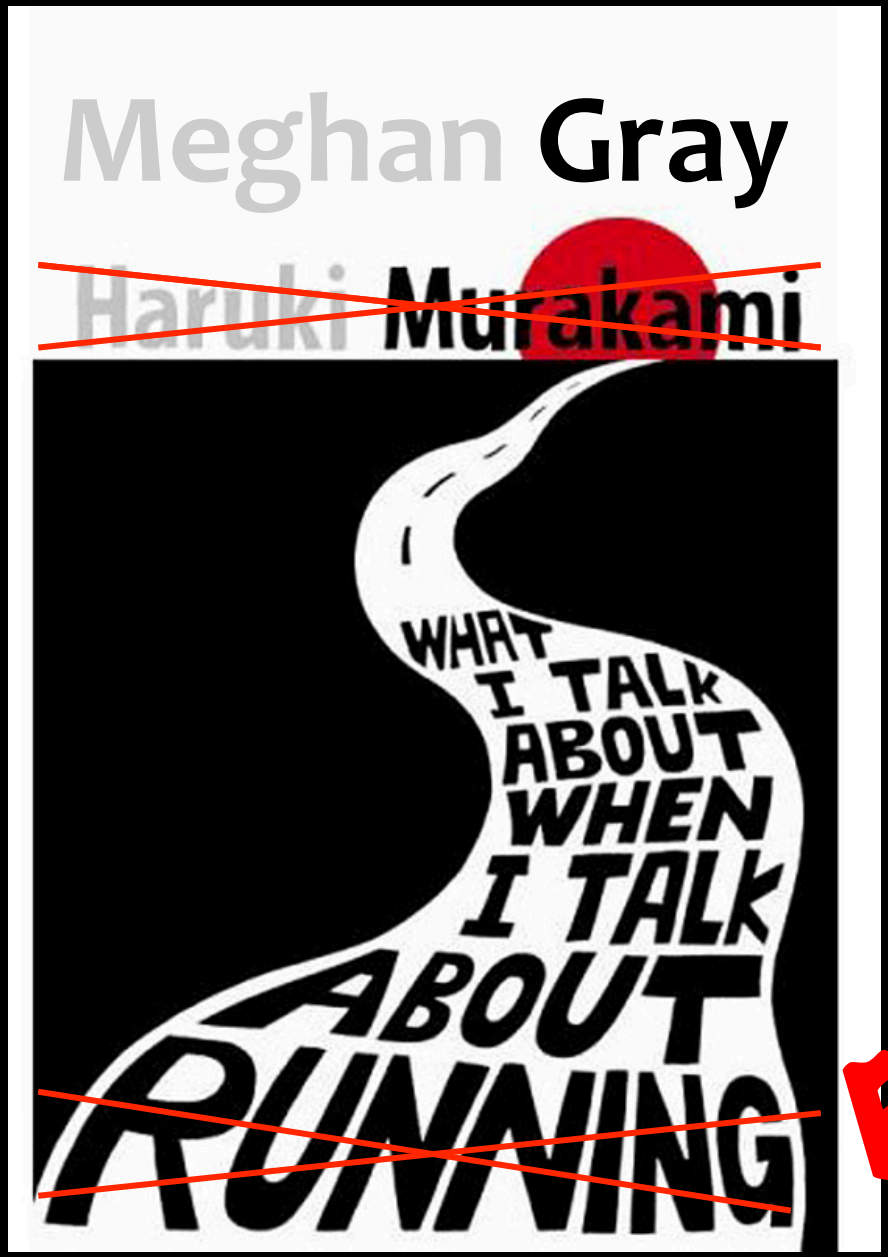


The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

ENVIRONMENT

galaxy evolution and environment

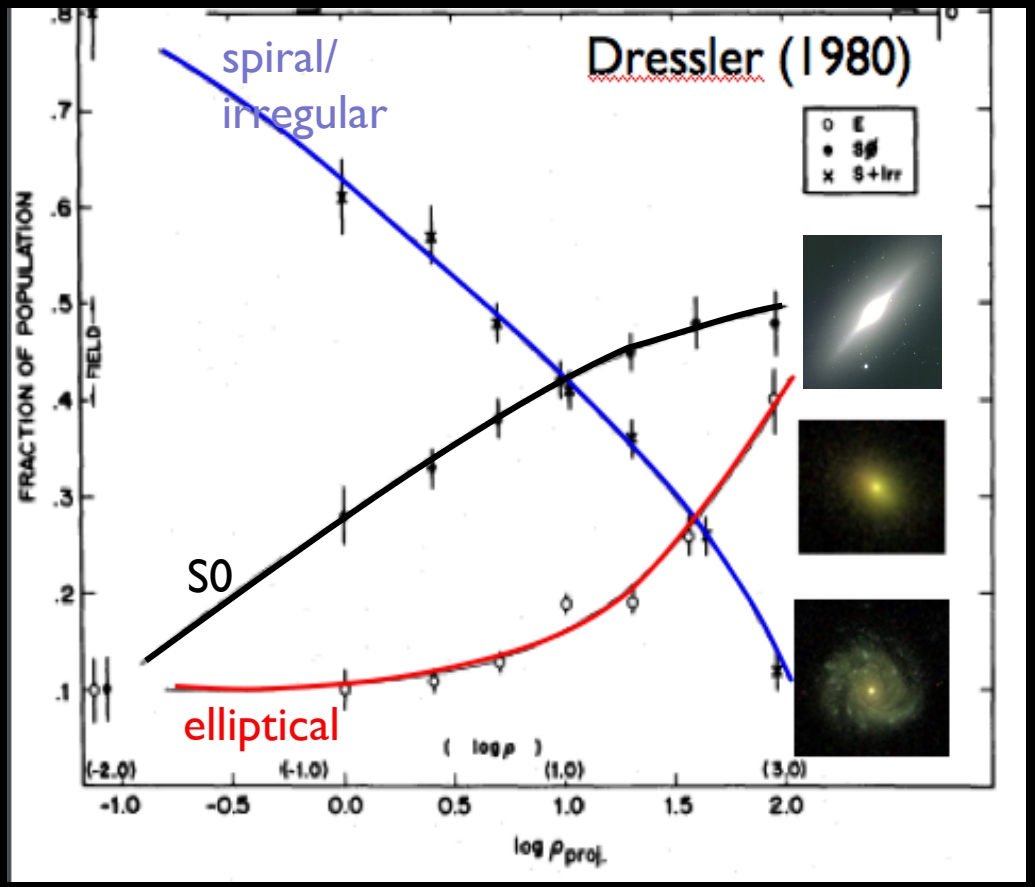
Kuala Lumpur April 2009

Bologna September 2014

Evolving Environments

- where do galaxies live in a hierarchical universe?
- how does this change over time?
- what do we mean by “environment”?
  (and how do we go about measuring it?)

Conference Bingo slide



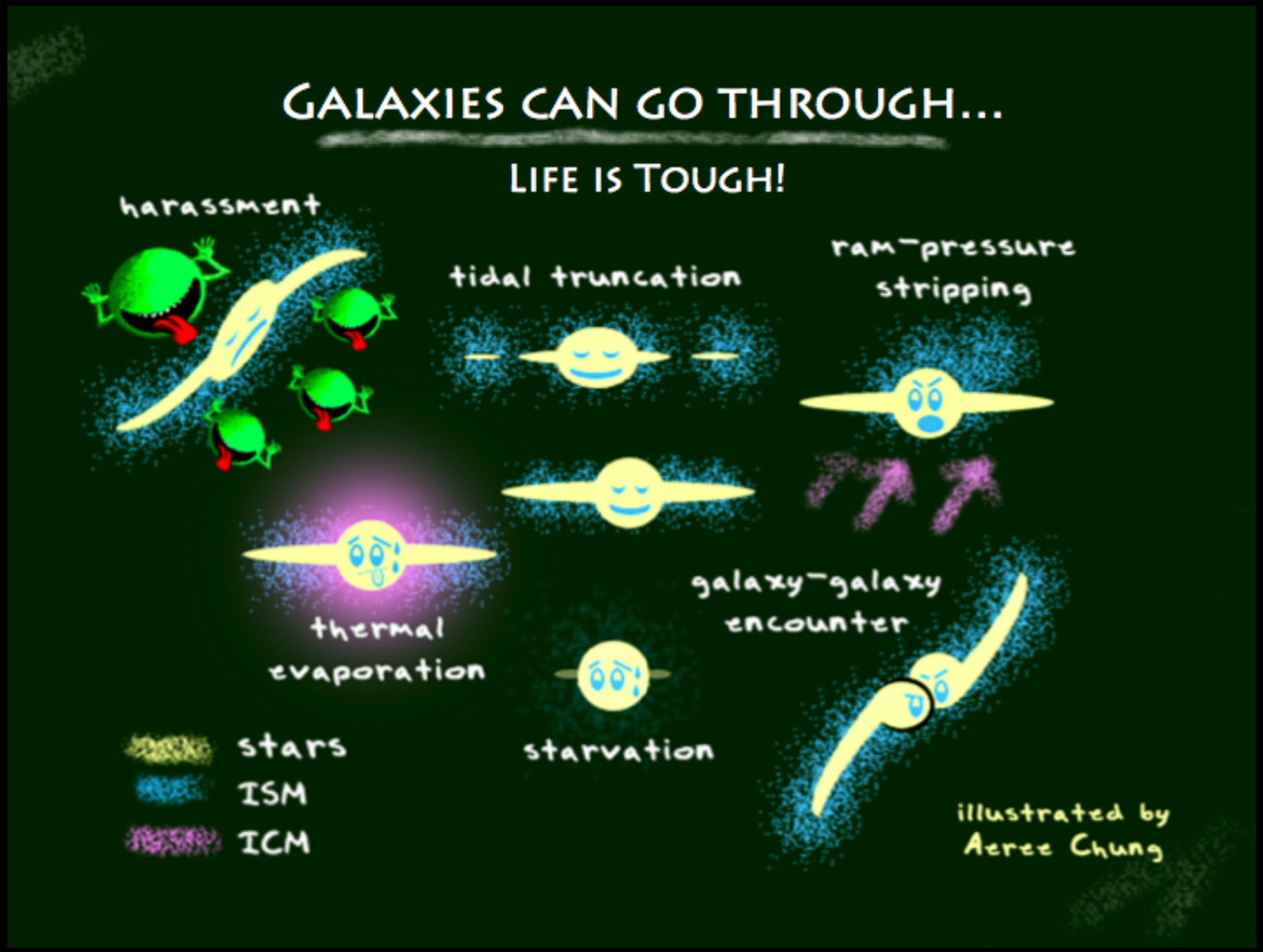
Need to explain

- changes with redshift
  - decline of star-formation rate
  - emergence of Hubble sequence
- changes with environment
  - quenching of star formation
  - morphology-density relation
- changes with galaxy mass
  - bimodality in galaxy properties

"nature vs nurture"?

“nurture”…

see also Boselli+ 2006 review

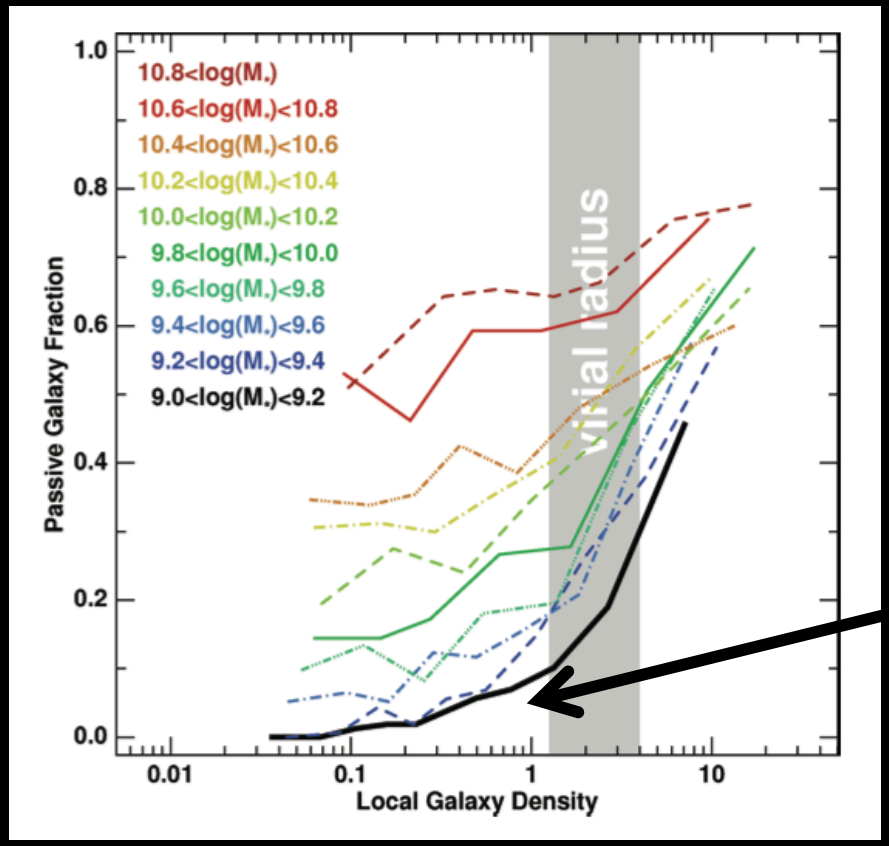


…or nature?

Darren Croton:
“halo mass is king!”

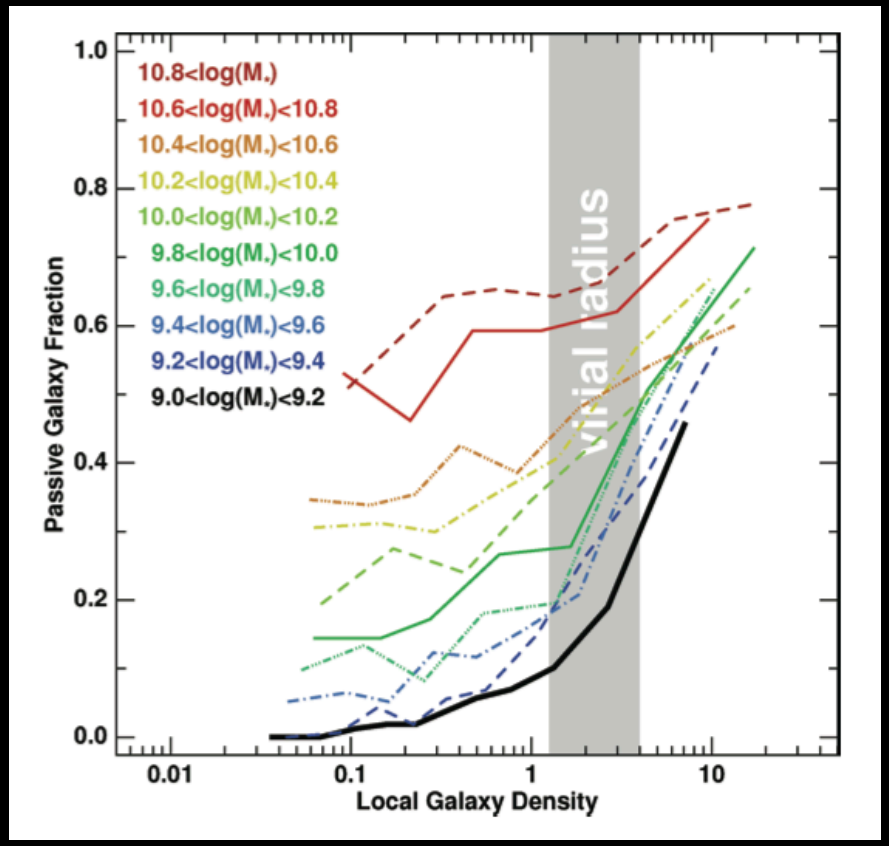
What about galaxy mass?

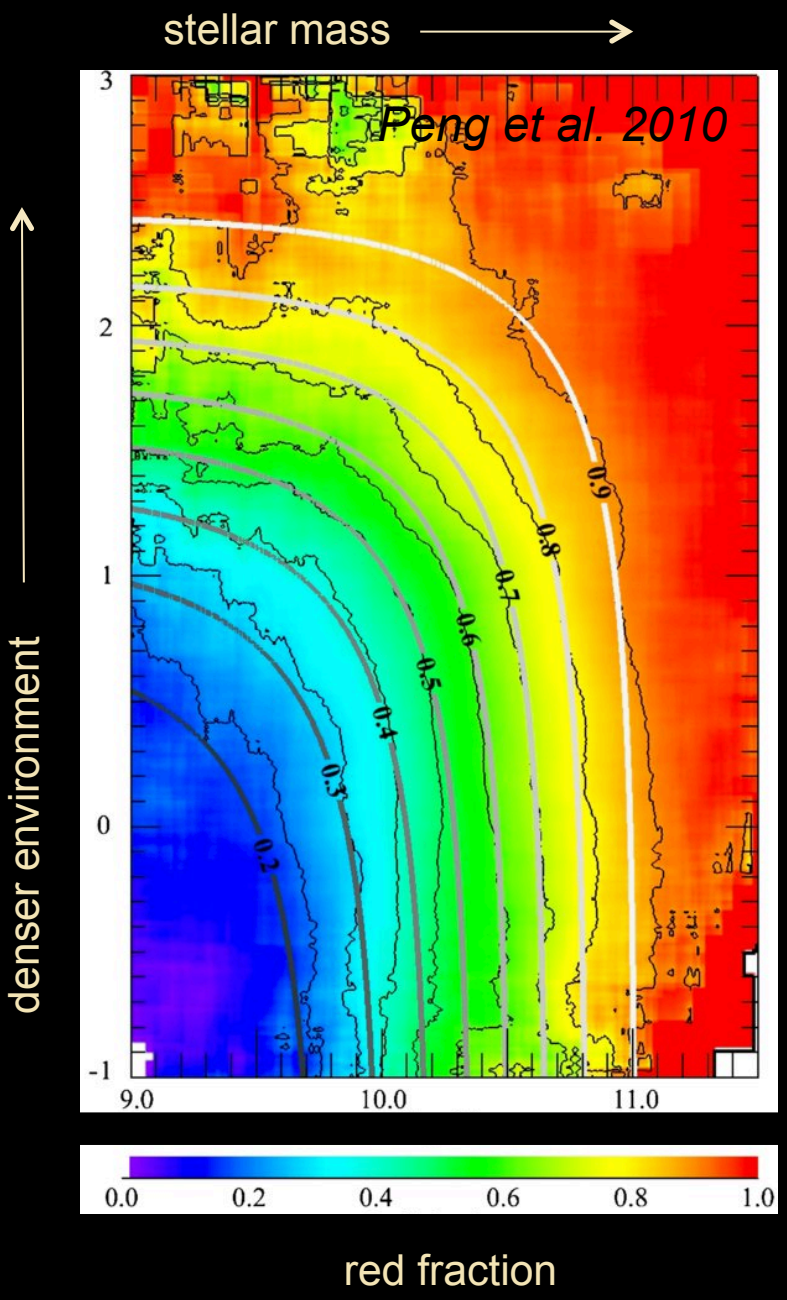
Haines et al. 2007: different processes influence star formation histories of massive and dwarf galaxies



No passive low-mass galaxies in sparse environments!

What about galaxy mass?

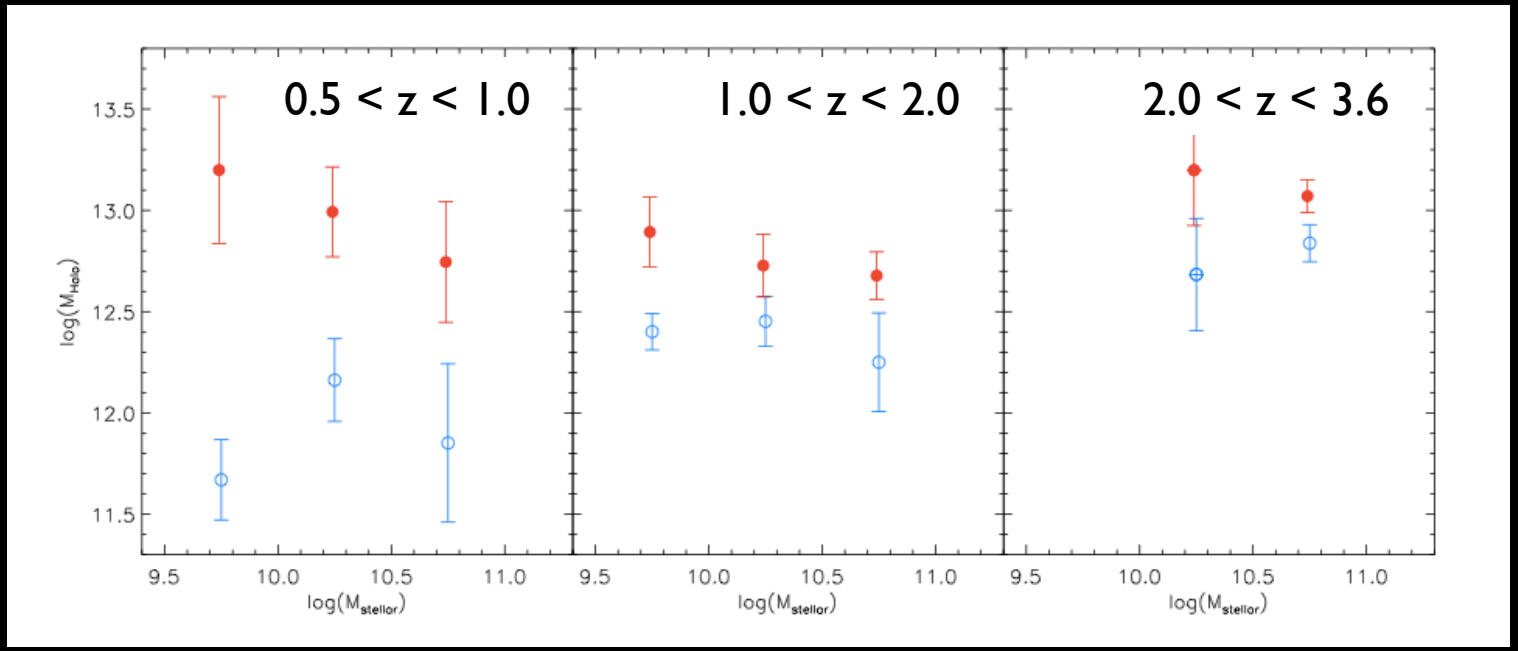




What about redshift?

Hartley et al. 2013

more massive haloes



stellar mass

Clustering studies show that passive galaxies occupied the most massive haloes to at least z=2

"nature vs nurture"

almost certainly an ill-posed question

- inevitably a complicated mix of
  - local environment
  - global environment
  - stellar mass
  - redshift
  - assembly history

Assembly of galaxy environments

Toy model for cluster spherical infall

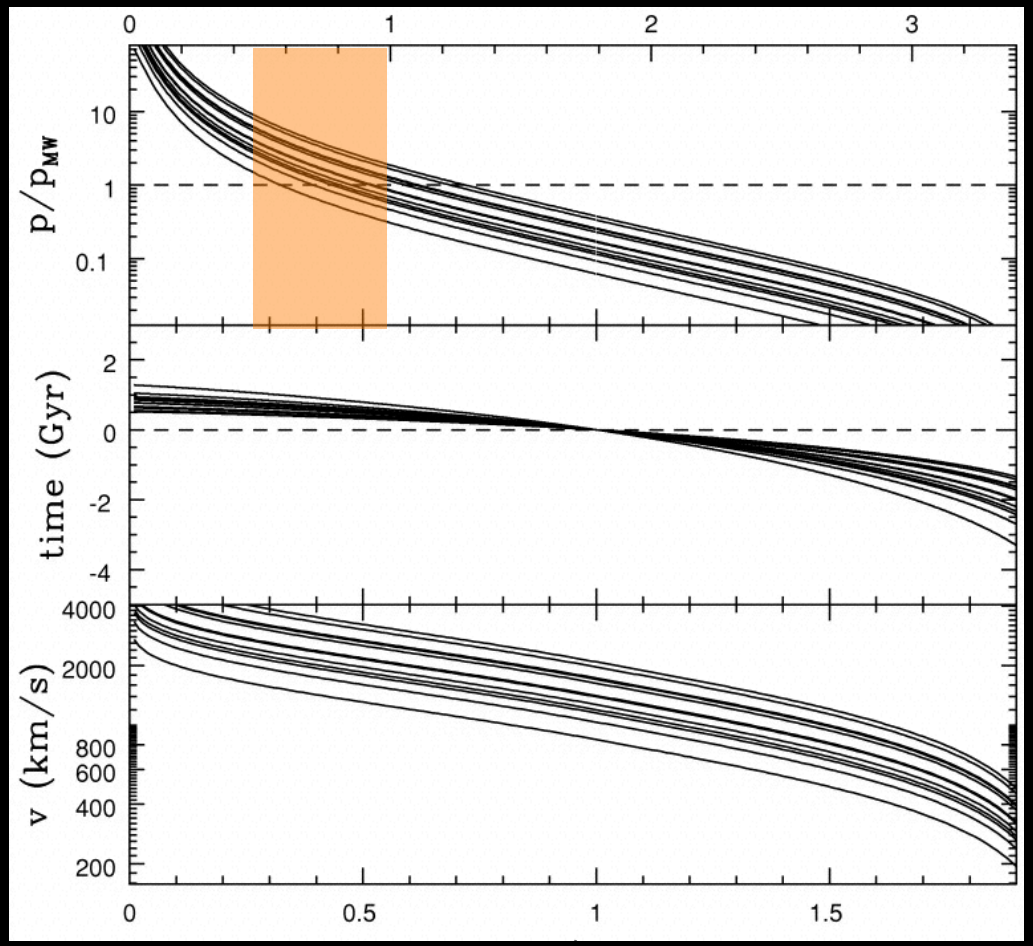
radius (Mpc) →

Treu et al. 2003

ram pressure to strip Milky Way

travel time from the virial radius

velocity of a radially infalling galaxy

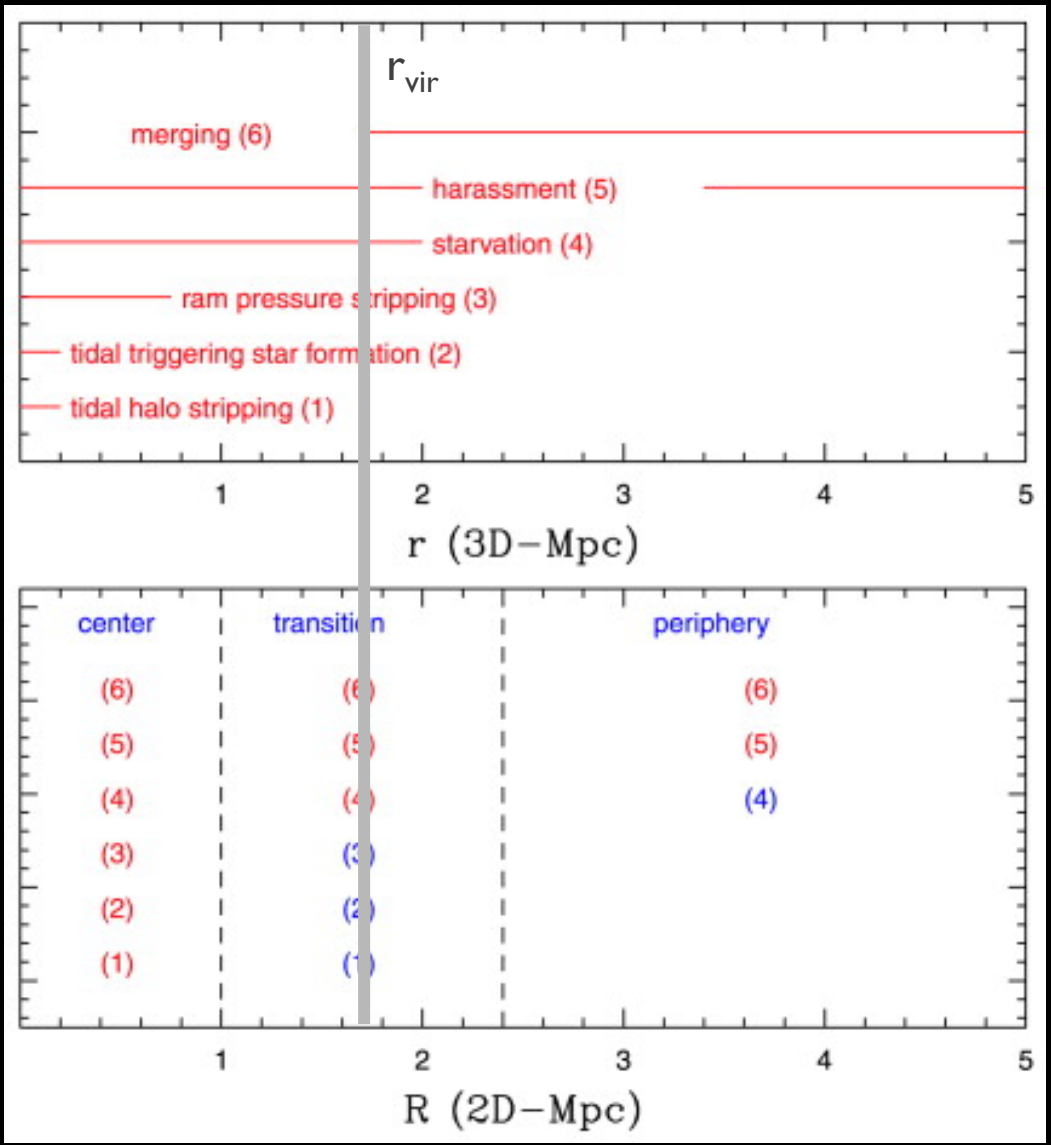


r / r_V →

Toy model for cluster spherical infall

3D space

2D projected space



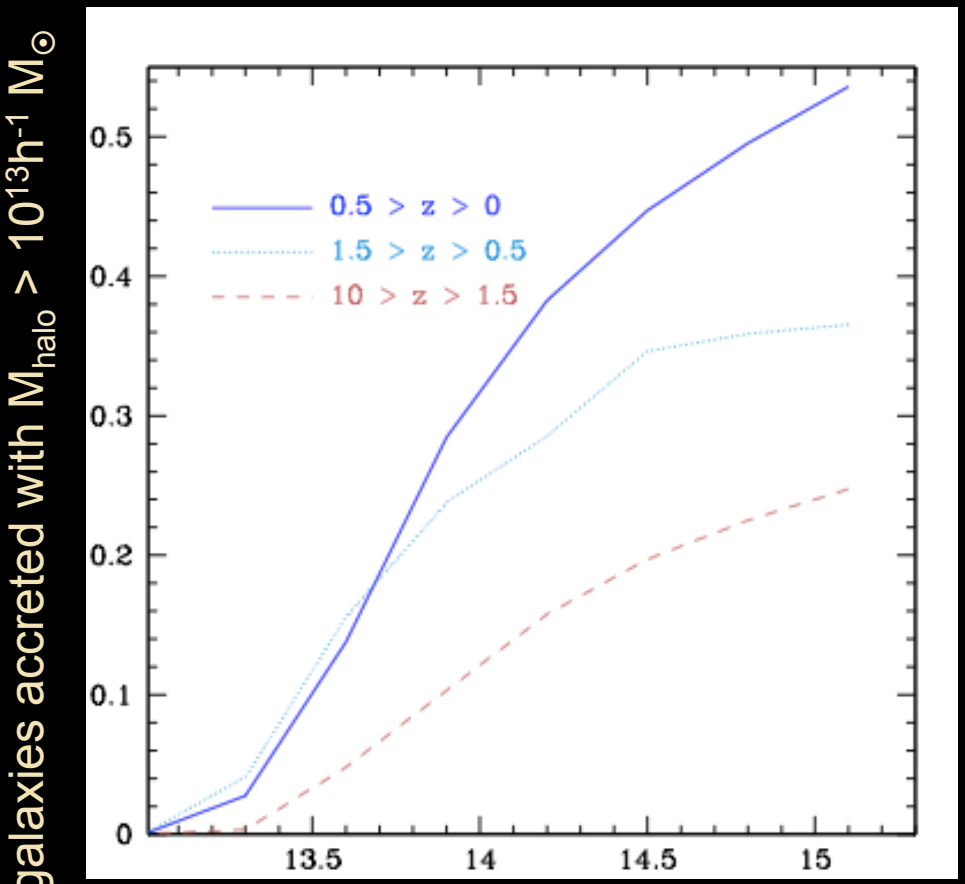
Treu et al. 2003

Hierarchical assembly of structure

Illustrus collaboration; Vogelsburger et al. 2014

Cluster growth via groups

McGee et al. (2009), using Font et al. (2008) model



- $M \sim 10^{14} M_\odot$ clusters accrete 35% of galaxies via groups
- for Coma-like clusters, fraction is 50%.

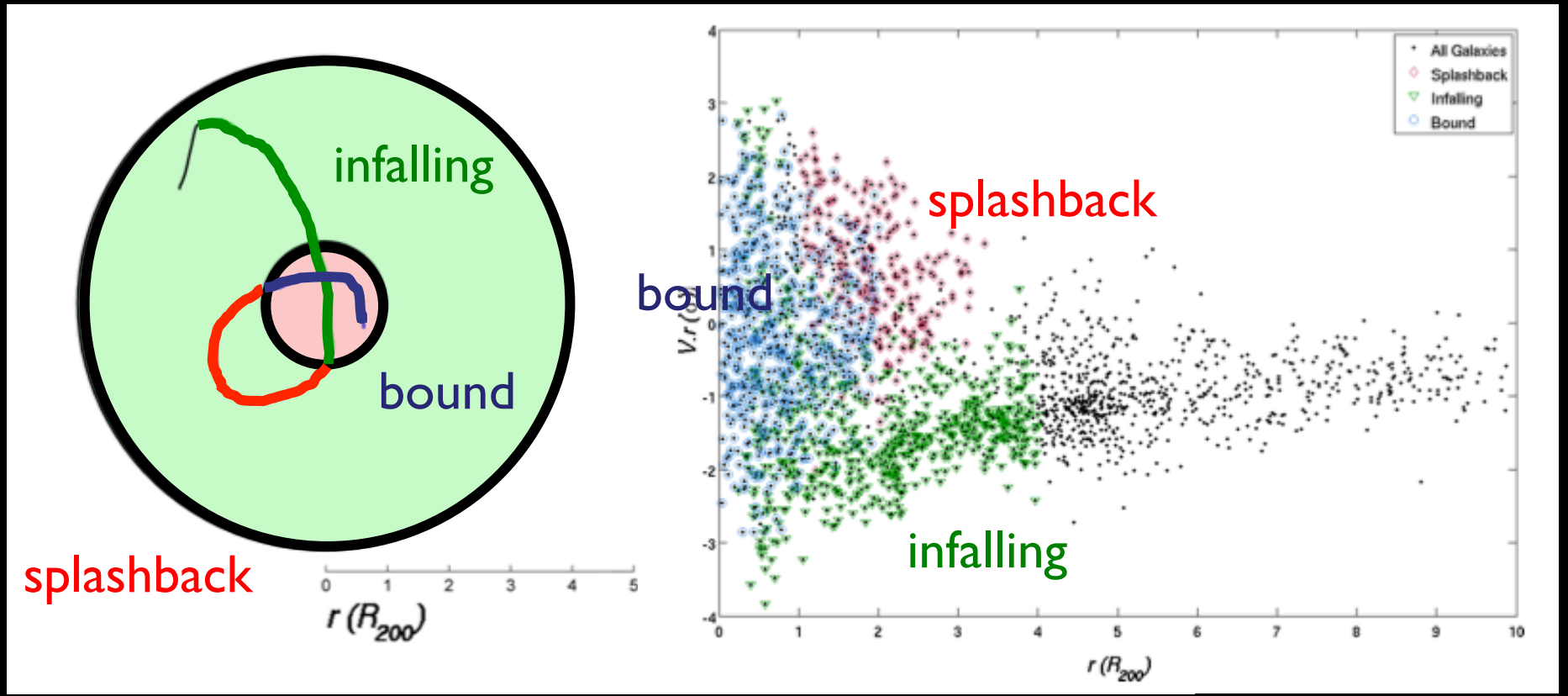
see also Berrier et al. 2009, reconciled by de Lucia et al 2012; Dressler et al. 2013

beyond the toy model

- importance of pre-processing
  - group vs cluster processes
- beyond the virial radius (central/satellite)
  - e.g. PISCES (Kodama et al. 2005), WINGS (Fasano et al 2005), ORELSE (Lubin 2009), ICBS (Dressler et al. 2013)
- orbital histories of satellite galaxies
  - phase space diagrams, splashback populations, crossing times

orbital histories

V.r(σ) vs r(R_{200})

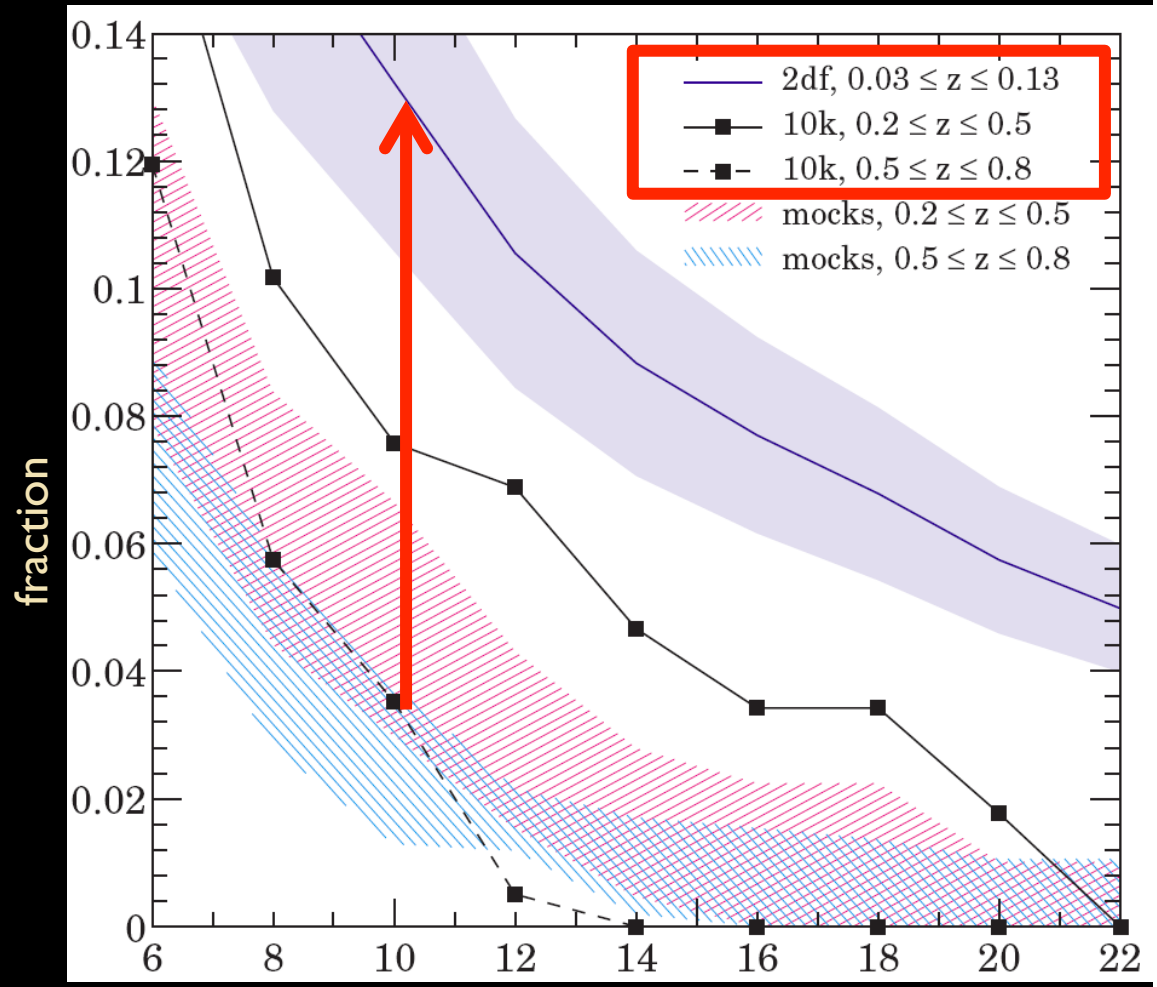


R. Rhodes, PhD thesis, University of Nottingham (2013); see also Oman et al. 2013

Buildup of structure

- Group environment is common
  - *How common? It depends: on what you call a group, on stellar mass fraction*
  - *Knobel et al. 2009*
    Robotham et al. 2011
    de Lucia et al 2012
- Abundance evolves strongly

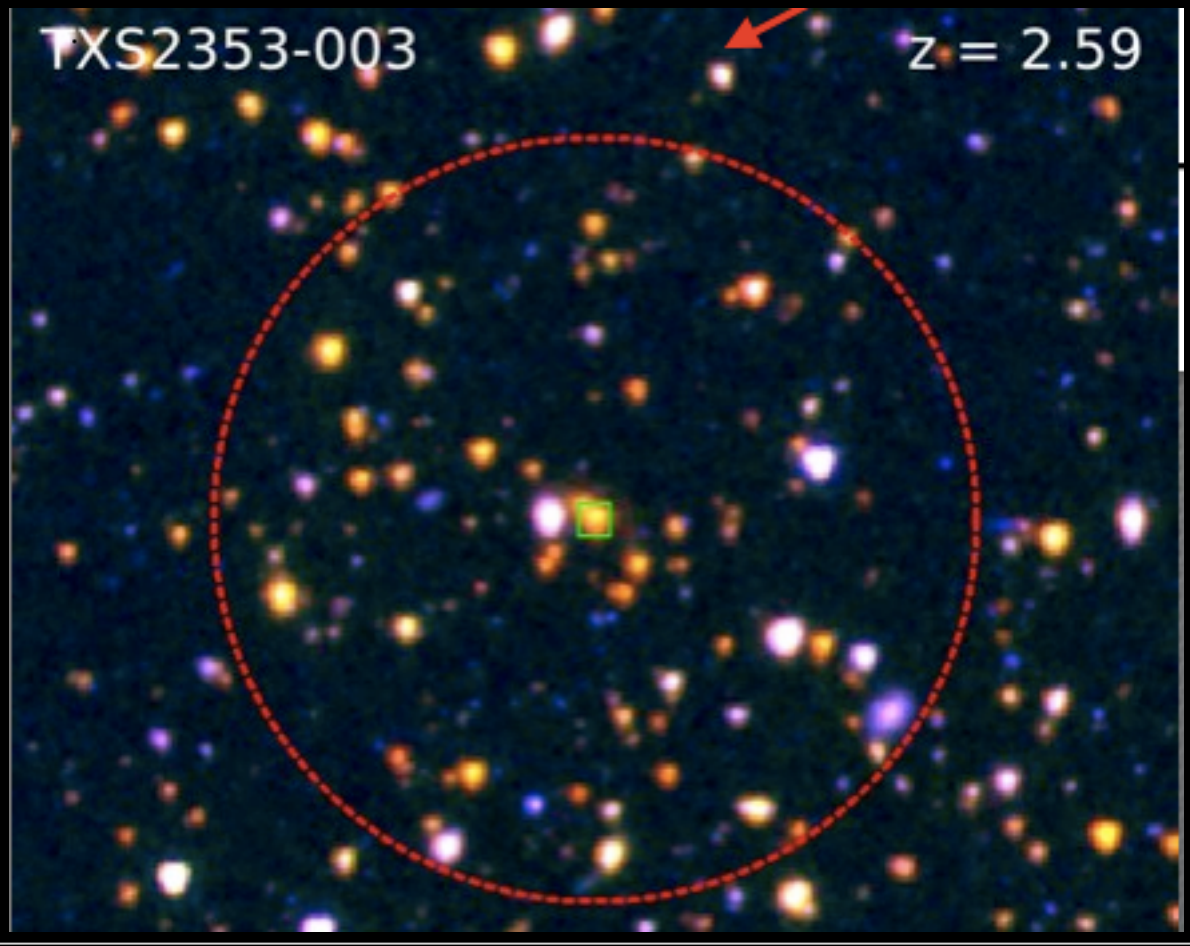
Fraction of galaxies in groups (N>6) increases by about a factor 3 since z=1



Knobel et al. (2009)

Beyond z=1-2: the protocluster regime

large and unvirialized: the progenitors of present-day clusters.



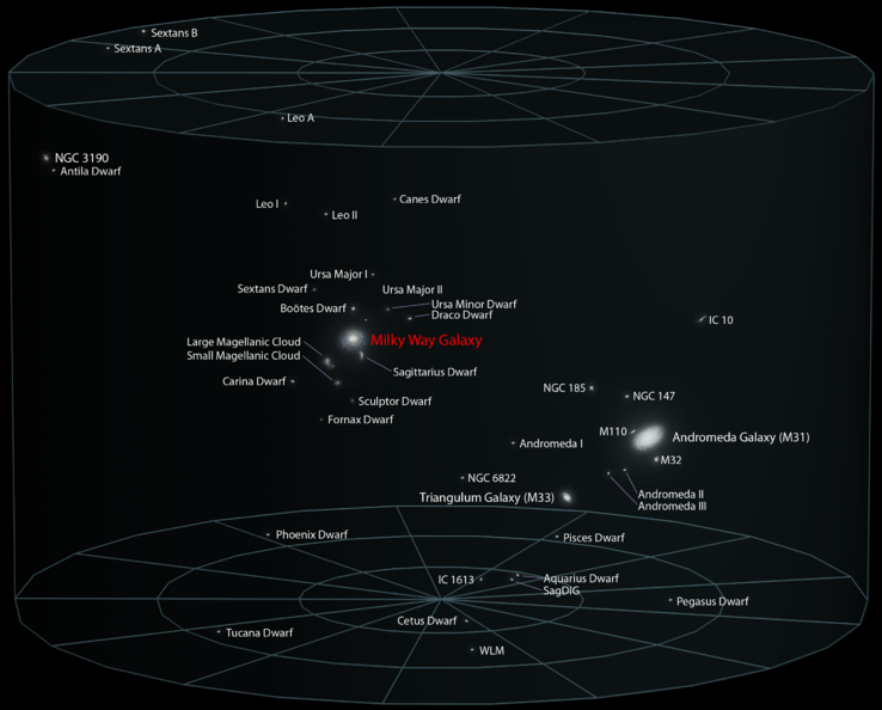
CARLA survey; Wylezalek et al.

But…what do we mean by environment?

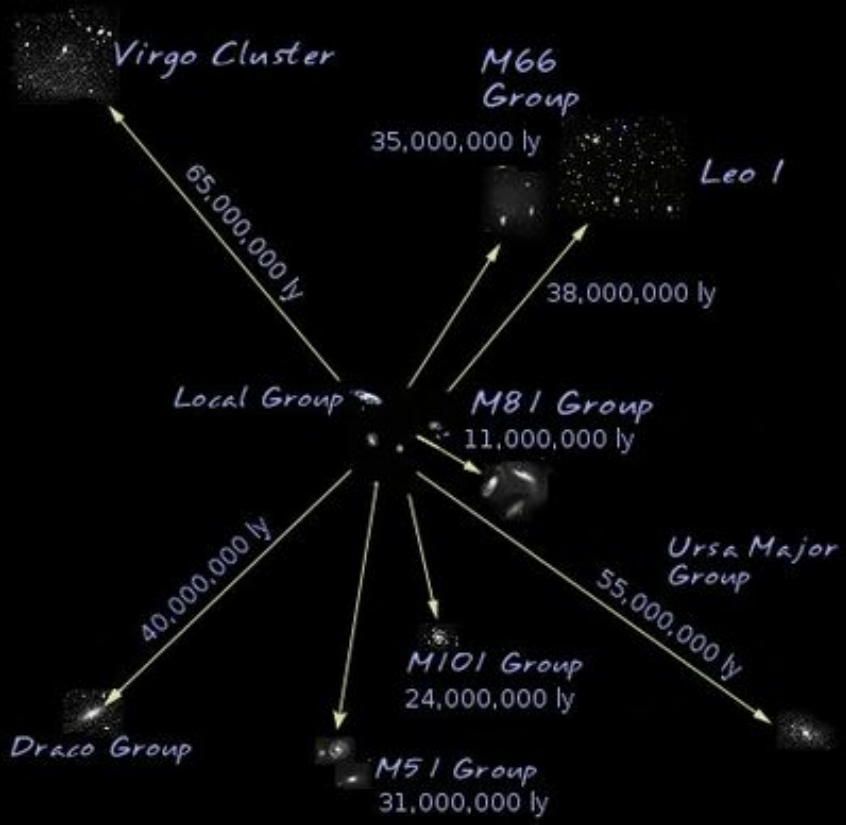
definition

matters

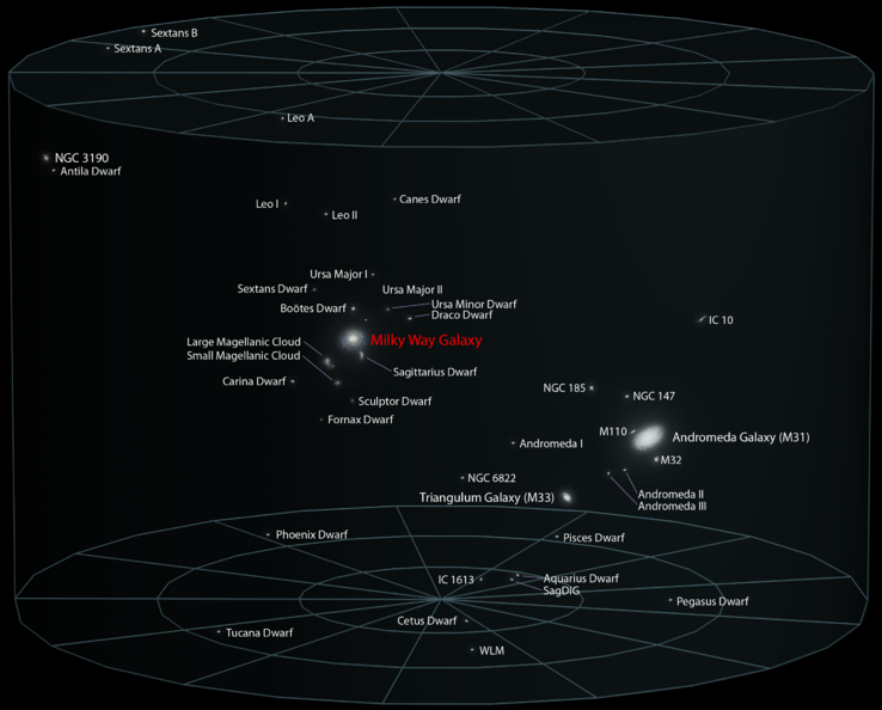
Our own neighbourhood: the Local Group

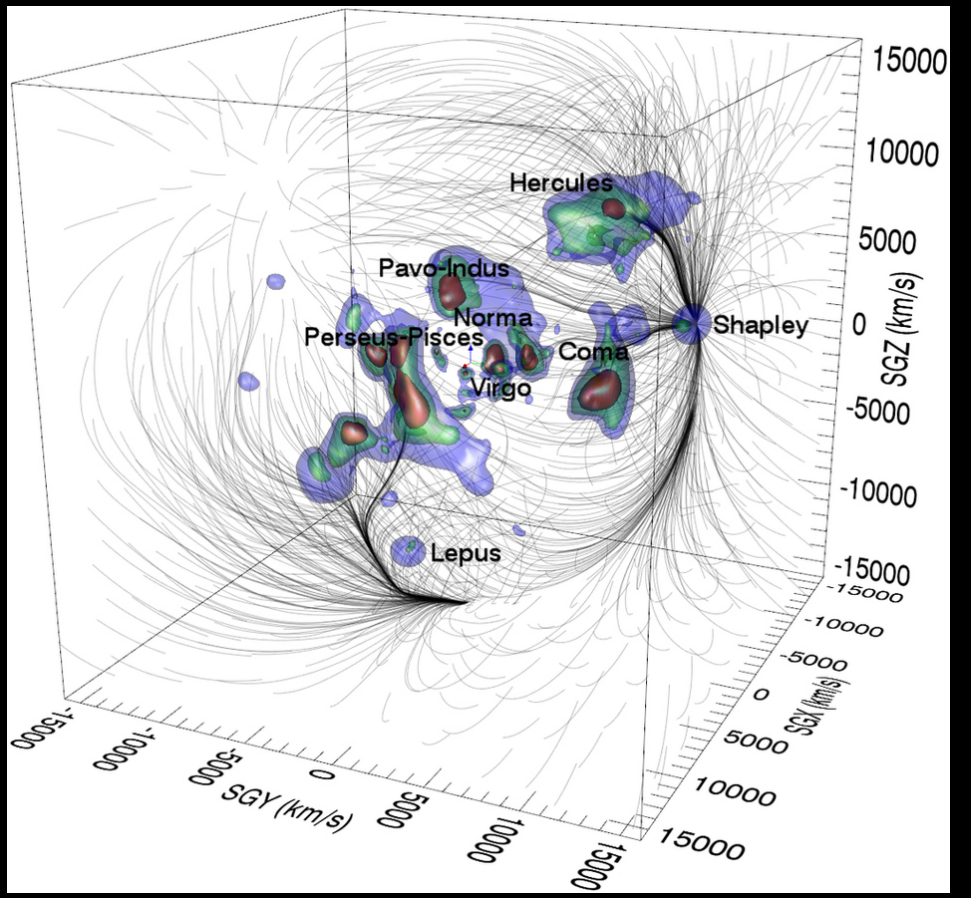


Andrew Z. Colvin



Our own neighbourhood: the Local Group





Tully et al. 2014

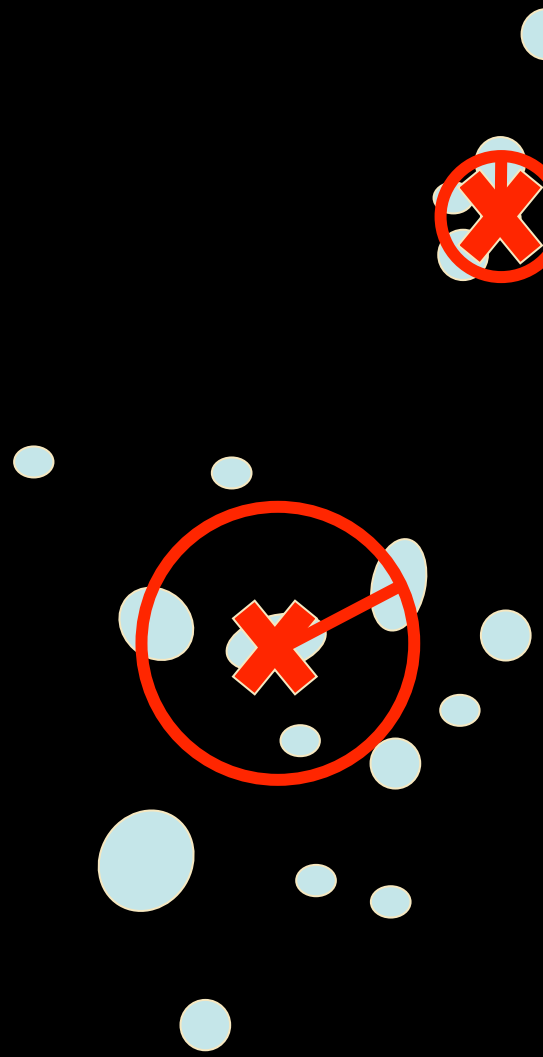
is my high density the same as your high density?

Muldrew et al. 2012,
see also Haas et al. 2012

Num.	Method	Author
	Neighbours	
1	3rd Nearest Neighbour	Muldrew
2	Projected Voronoi	Podgorzec & Gray
3	Mean 4th & 5th Nearest Neighbour	Baldry[1]
4	5 Neighbour Cylinder	Li[2]
5	7th Projected Nearest Neighbour	Ann
6	10 Neighbour Bayesian Metric	Cowan[3]
7	20 Neighbour Smooth Density	Choi & Park[4]
8	64 Neighbour Smooth Density	Pearce
	Aperture	
9	$1\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice[5]
10	$2\,h^{-1}$Mpc ($\pm500\,\mathrm{km\,s^{-1}}$)	Gallazzi[6]
11	$2\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice
12	$2\,h^{-1}$Mpc ($\pm6000\,\mathrm{km\,s^{-1}}$)	Gallazzi[6]
13	$5\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice
14	$8\,h^{-1}$Mpc Spherical	Croton[7]
	Annulus	
15	$0.5-1.0\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
16	$0.5-2.0\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
17	$0.5-3.0\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
18	$1.0-2.0\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
19	$1.0-3.0\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
20	$2.0-3.0\,h^{-1}$Mpc ($\pm1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]

Table 1. List of environment measures used in this study and the authors who implemented them, including references where applicable. See Section 3 for further details. References: 1: Baldry et al. (2006), 2: Li et al. (2011), 3: Cowan & Ivezić (2008), 4: Park et al. (2007), 5: Grützbauch et al. (2011), 6: Gallazzi et al. (2009), 7: Croton et al. (2005) and 8: Wilman, Zibetti & Budavári (2010).

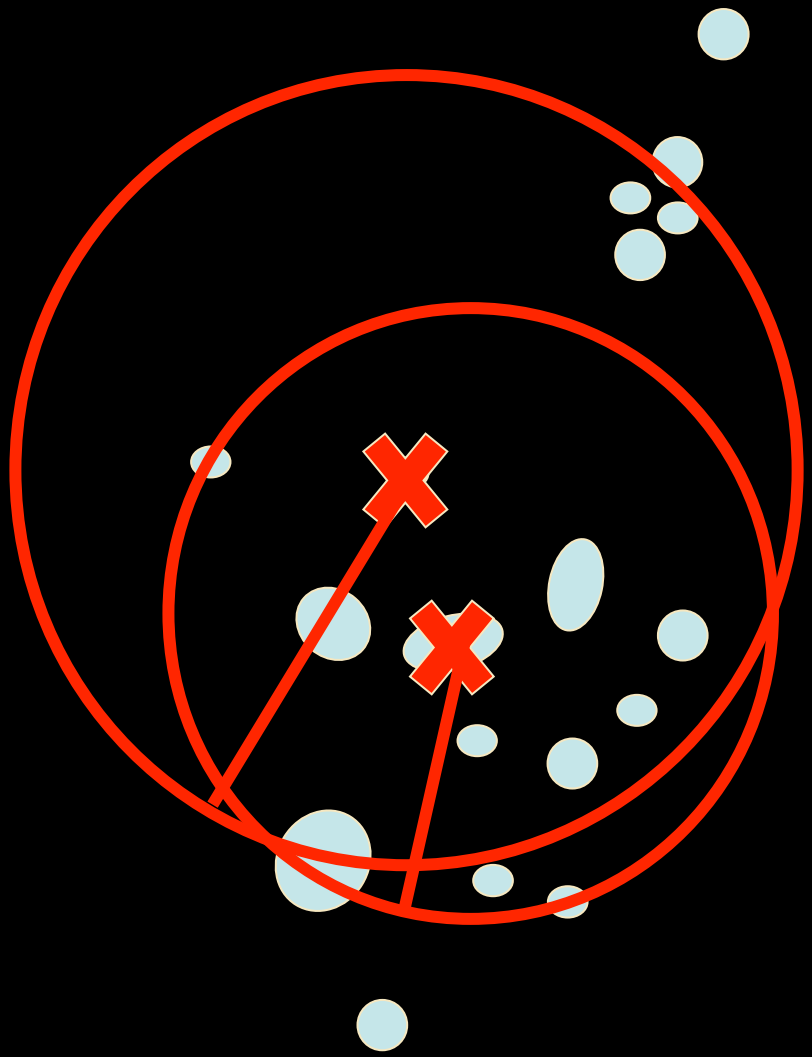
Measuring environment with galaxy density



Examples:

- 3rd nearest neighbour
- 10th nearest neighbour
- fixed aperture/cylinder

Measuring environment with galaxy density



Examples:

- 3rd nearest neighbour
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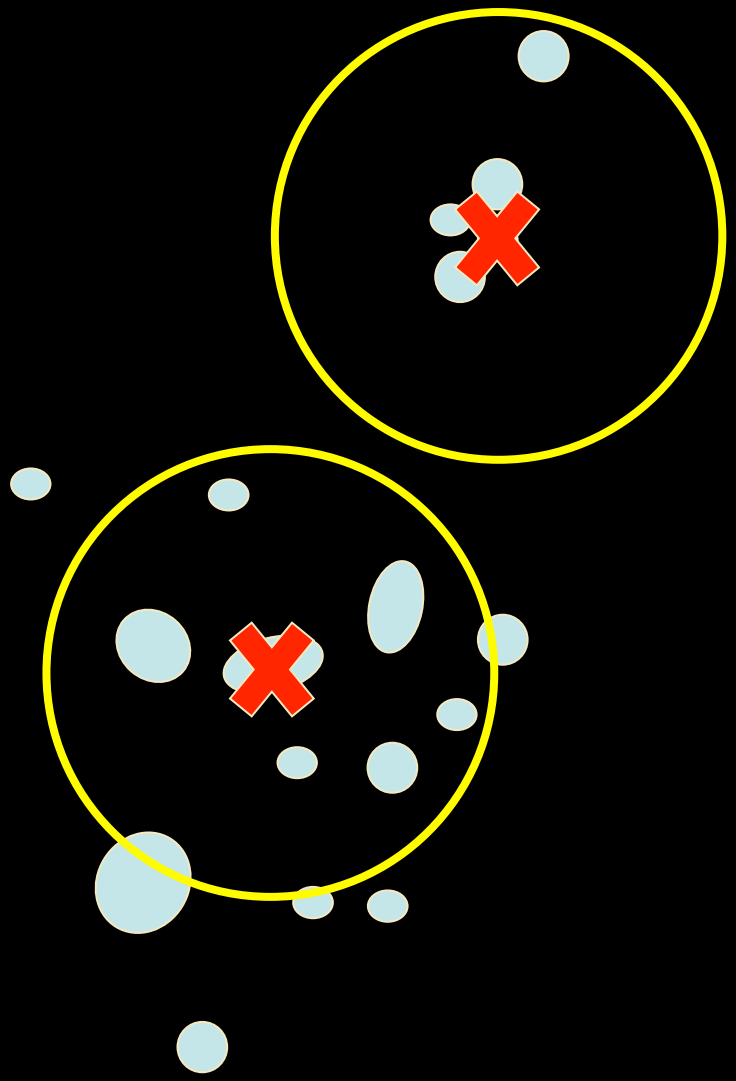
Measuring environment with galaxy density



Examples:

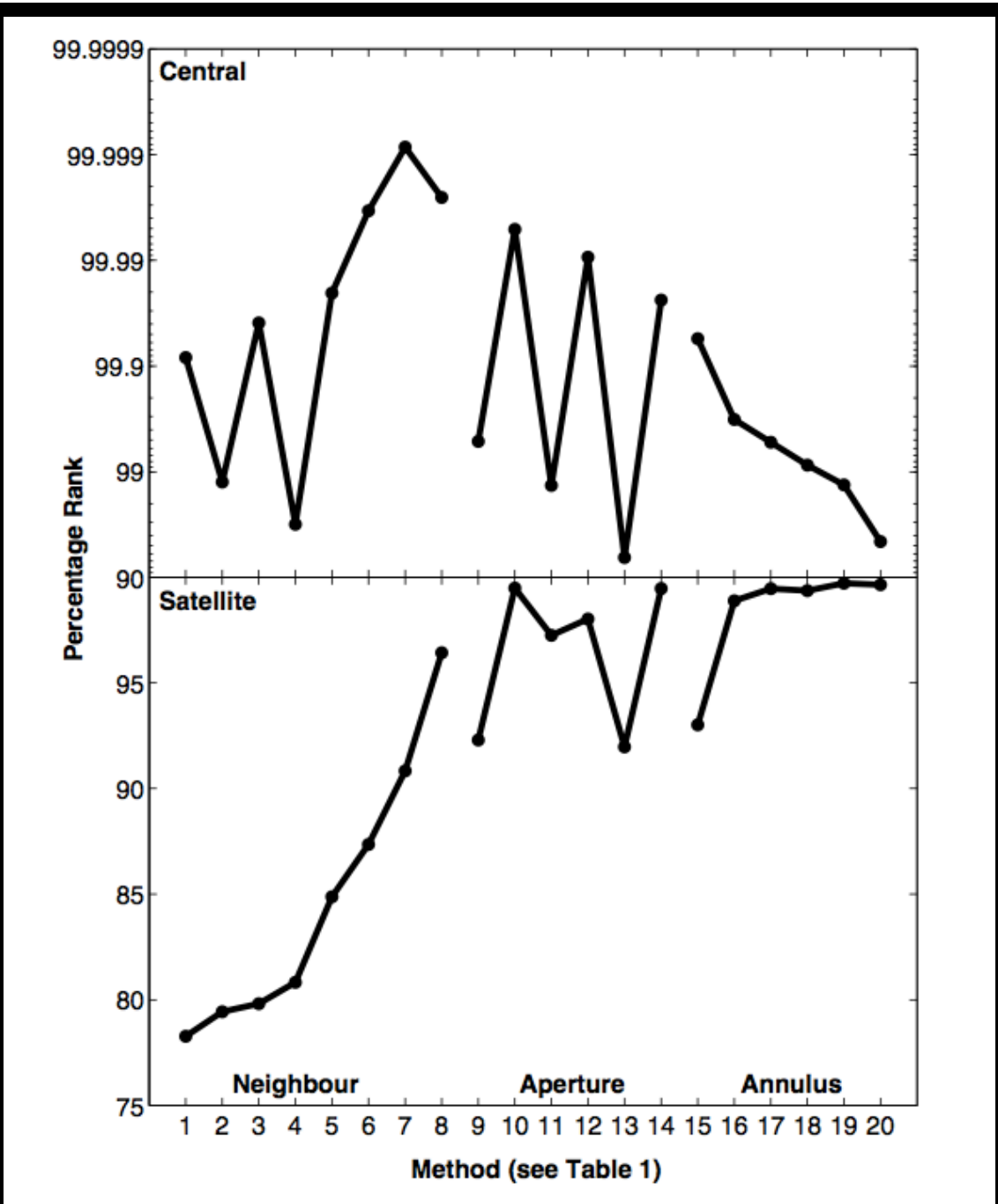
- 3rd nearest neighbour
- 10th nearest neighbour
- fixed aperture/cylinder

Generally:

nearest neighbour best probes local environment

aperture best probes large-scale environment

Muldrew et al. 2012
see also Haas et al. 2012

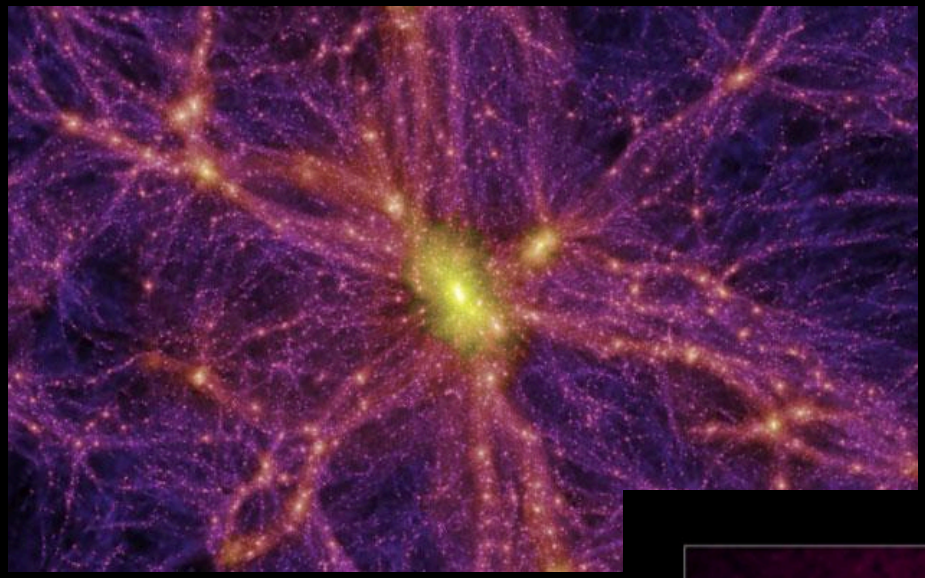


most methods agree for a given massive galaxy

cluster satellite ranking more sensitive to choice of method

Muldrew et al. 2012

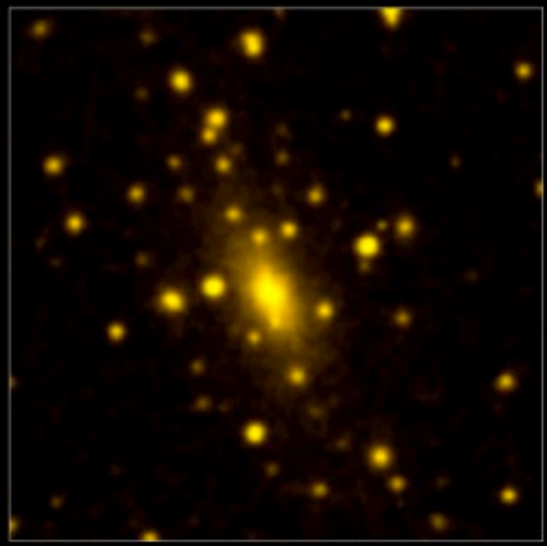
Caution: galaxy density…or proxy for:



dark matter halo mass,
large scale structure,
filaments?

hot X-ray gas?

CHANDRA X-RAY



DSS OPTICAL

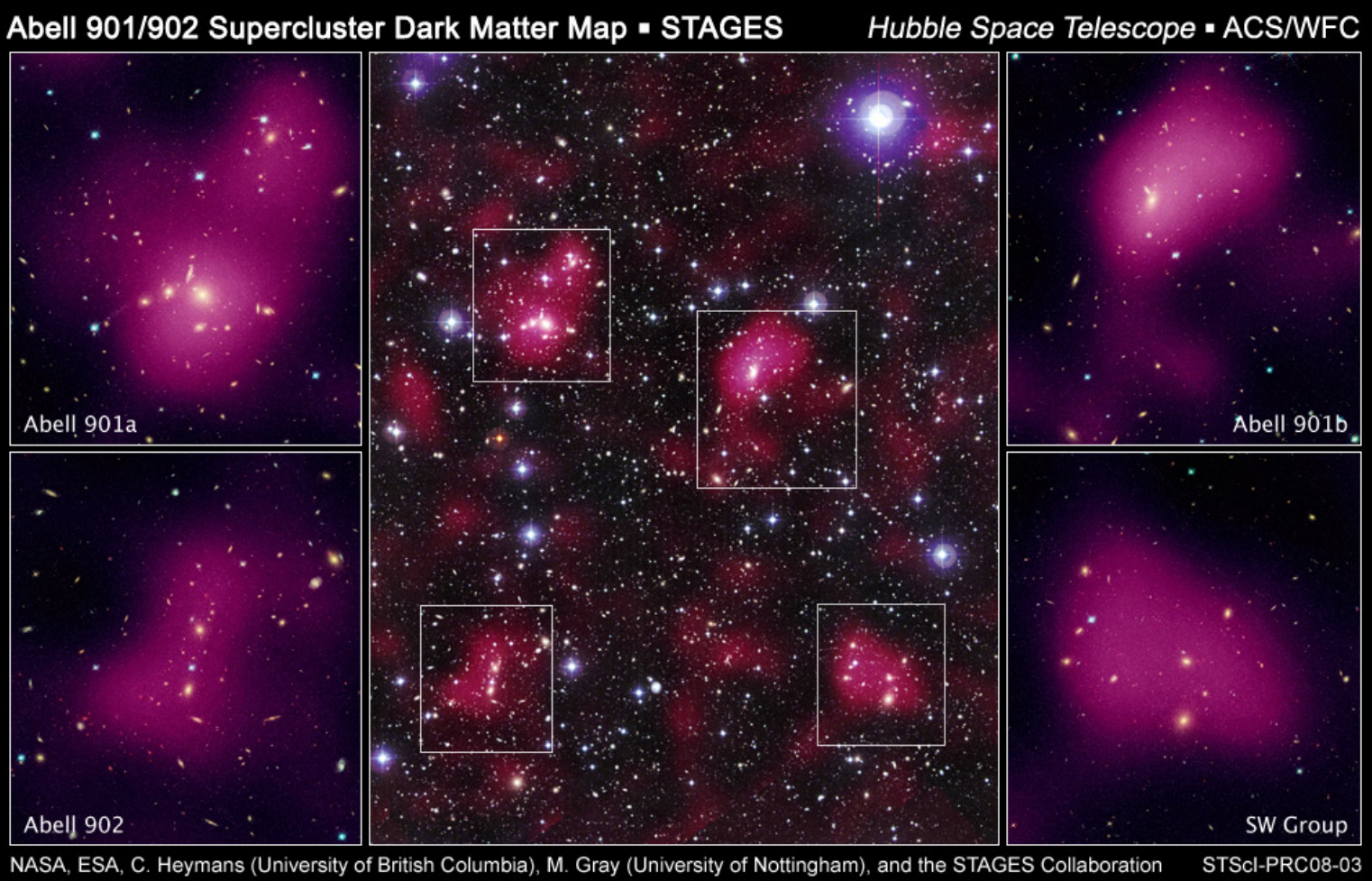
the case study approach

- intensively study a single piece of large-scale structure, e.g.
  - Shapley (z=0) Merluzzi+14
  - STAGES (z~0.2) Gray+09
  - CL0016 (z=0.55) Tanaka+09
  - UKIDSS DXS (z=0.89) Swinbank+07
  - RCS2319+00 (z~0.9) Falloon+13
  - CL1604 (z~0.9) Lubin+00

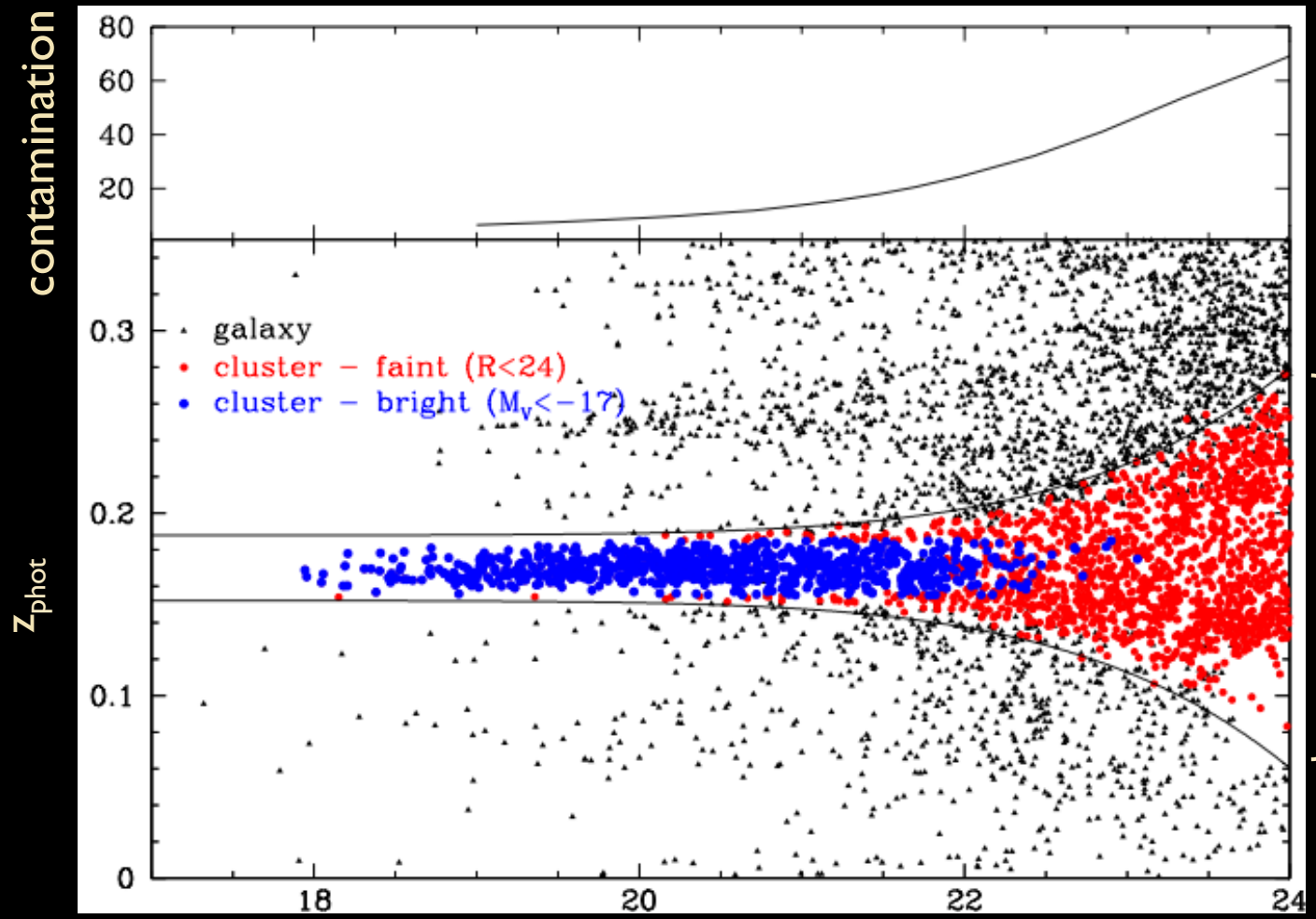
complements approach of the statistical power of large surveys (SDSS, GAMA, zCOSMOS, VIPERS, UDSz, etc etc etc)

STAGES: A901(a,b)/A902 @ z=0.16

Heymans + STAGES 2009



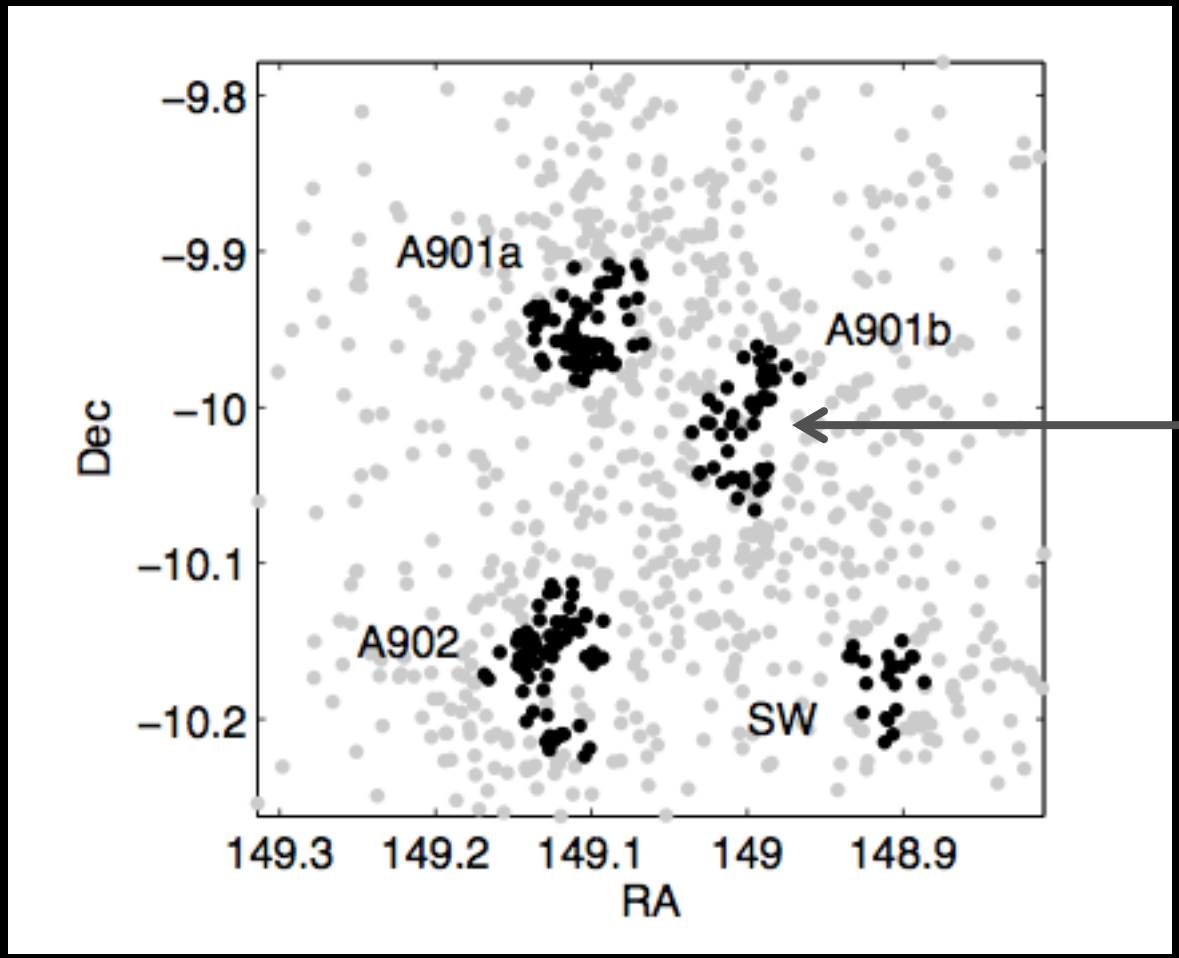
how did we measure environment?



90% complete

Gray et al. 2009

how did we measure environment?



aperture stellar-mass density cut

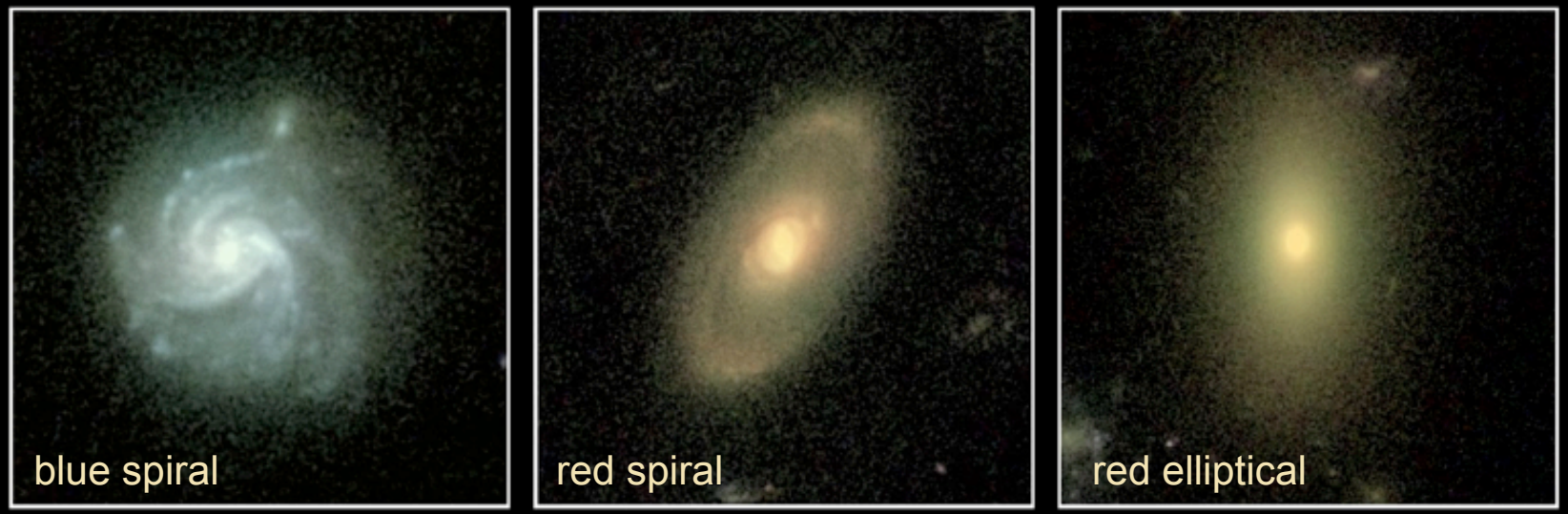
"cluster core" subsample

Maltby et al. 2010, Wolf et al. 2009

"Dusty red galaxies" = passive spirals

mass-dependent quenching of star-formation in cluster infall

Wolf + STAGES (2009)



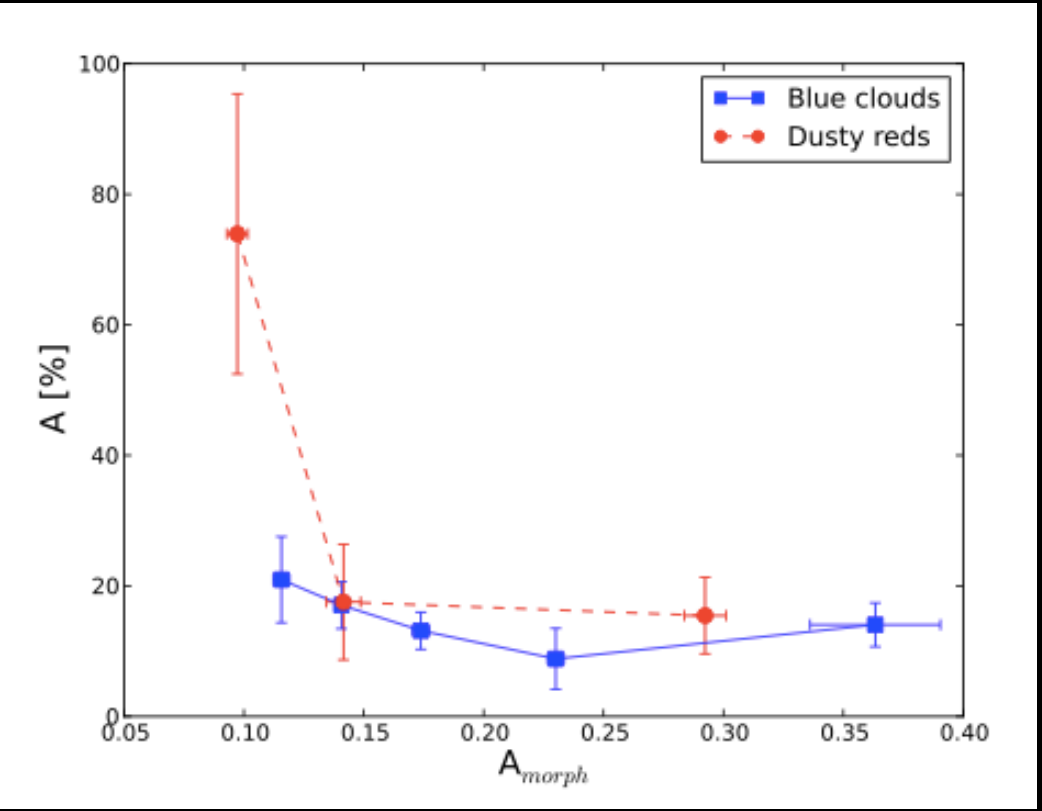
- dusty red galaxies are a cluster-specific phenomenon
- are forming stars but at rate 4x lower than blue spirals at fixed mass

see also Galaxy Zoo (Bamford et al. 2009)

Ram-pressure stripping at work

Boesch, Boehm + STAGES (2013a,b)

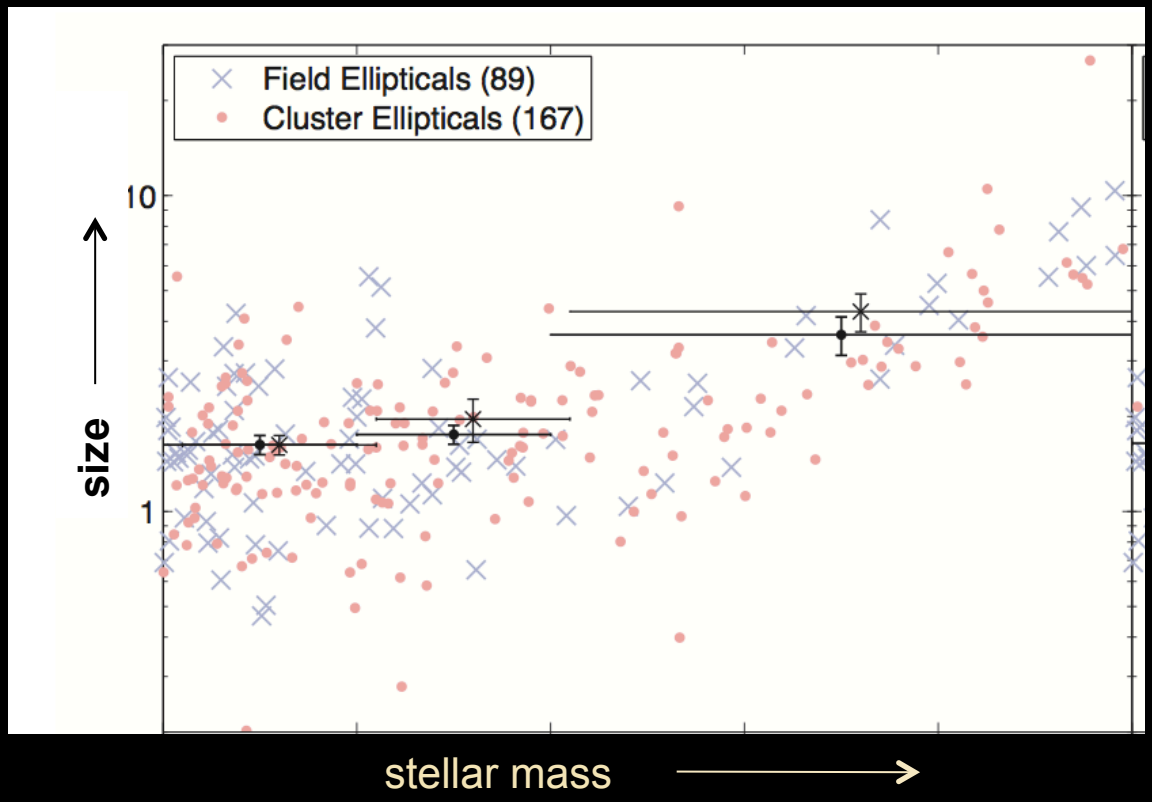
kinematically disturbed disks



morphologically disturbed disks

No change in structural parameters

Maltby + STAGES (2010);
related work in poster by K. Kelkar



No evolution in the stellar mass – size relation between cluster and field

same goes for bars (Marinova et al. 2008); surface brightness profiles (Maltby et al 2012), interactions (Heiderman et al. 2008); boxy/diskiness of ellipticals (Haeussler et al. in prep)

Lessons from STAGES (so far)

- fully characterized environment of a complex system in mass, gas and galaxies

- observe mass-dependent changes in star-formation and AGN activity with environment (infall regions) and find evidence of transitional objects

- morphological/structural transformations much harder to catch in action

see more at www.nottingham.ac.uk/astronomy/stages

Final thoughts

- assembly history, preprocessing important
  - internal processes vs external processes
  - cluster processes vs group processes
  - gas processes vs gravitational processes
- (at least) three axes to consider:
  - stellar mass
  - redshift
  - environment (however you measure it, including dark matter, galaxies, and gas)
- please be specific when you talk about environment!
  - tell us how you measured it, and remember that 'high density' isn't really meaningful
  - different measures will be appropriate to probe different physical regimes