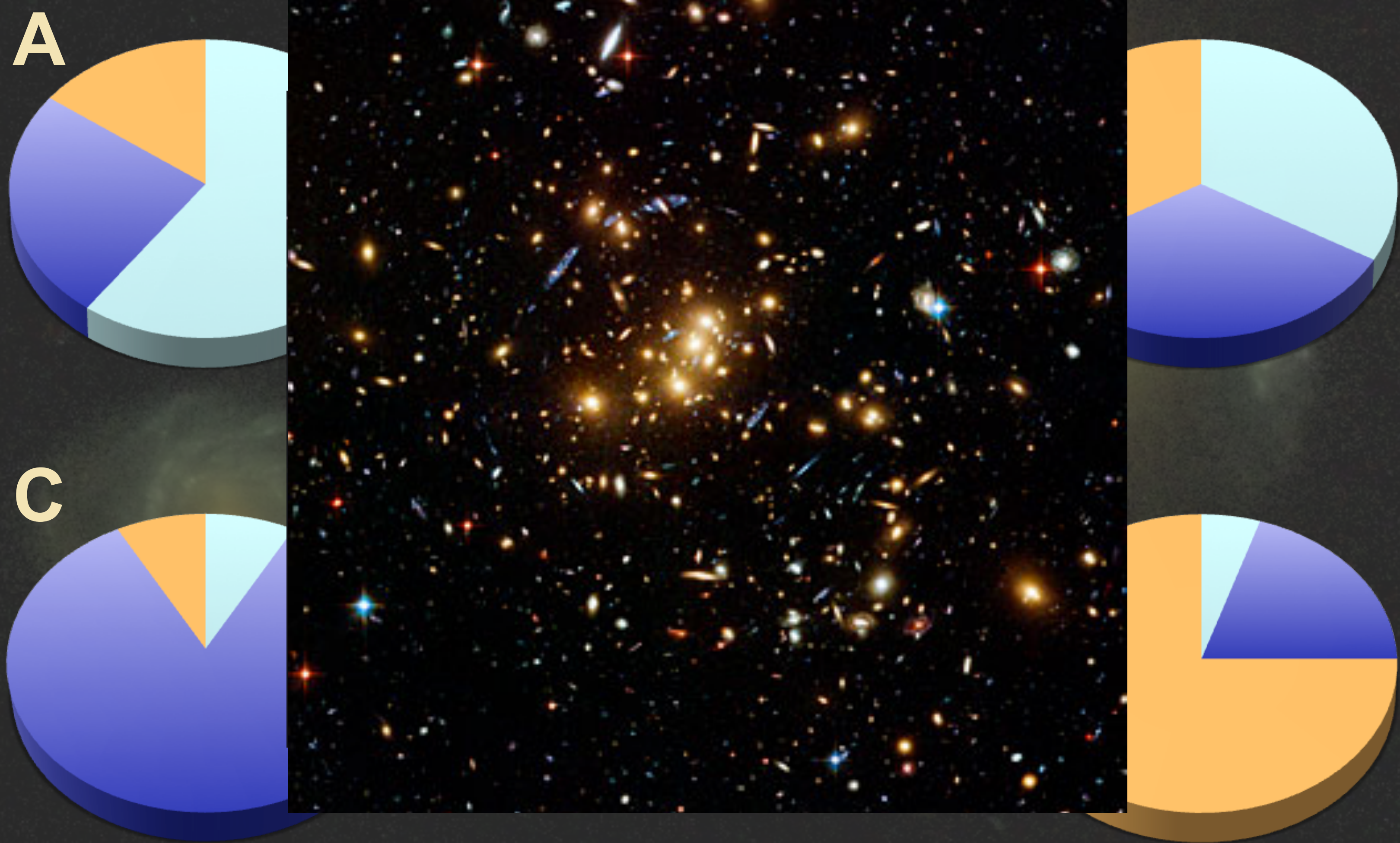
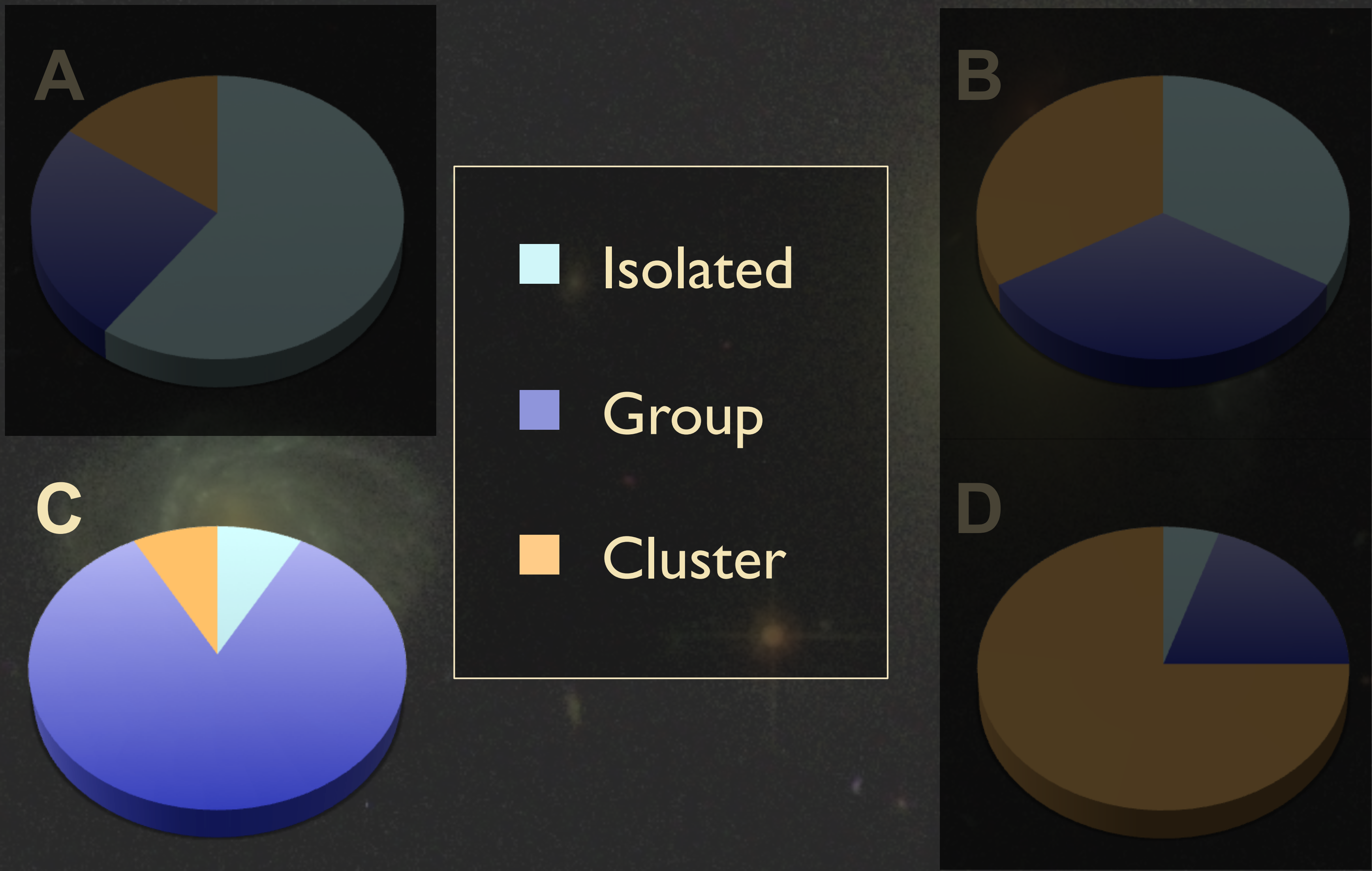
Galaxy evolution and environment

Dr. Meghan Gray,
University of Nottingham
with the STAGES collaboration

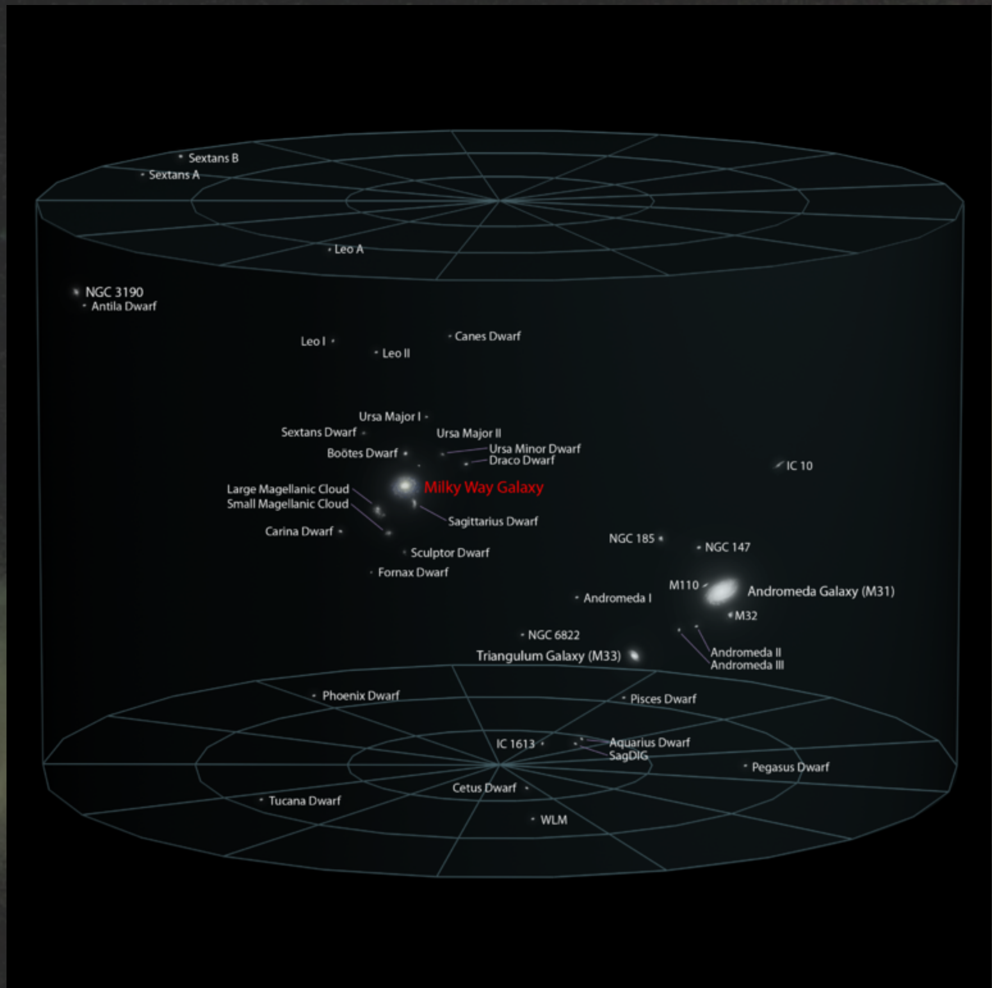
Where do most galaxies in the low-z Universe live?



Where do most galaxies in the low-z Universe live?



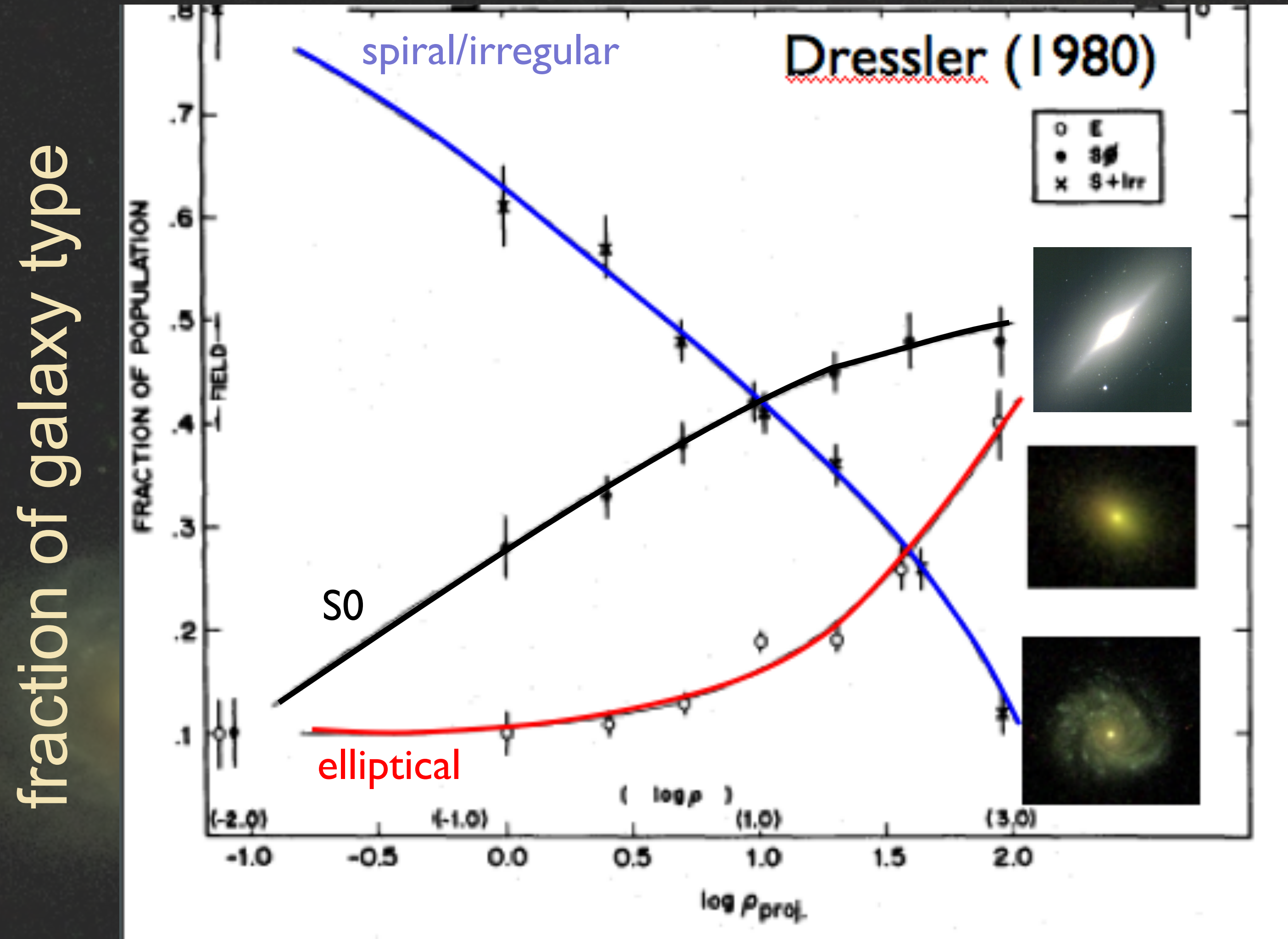
Our own neighbourhood: the Local Group



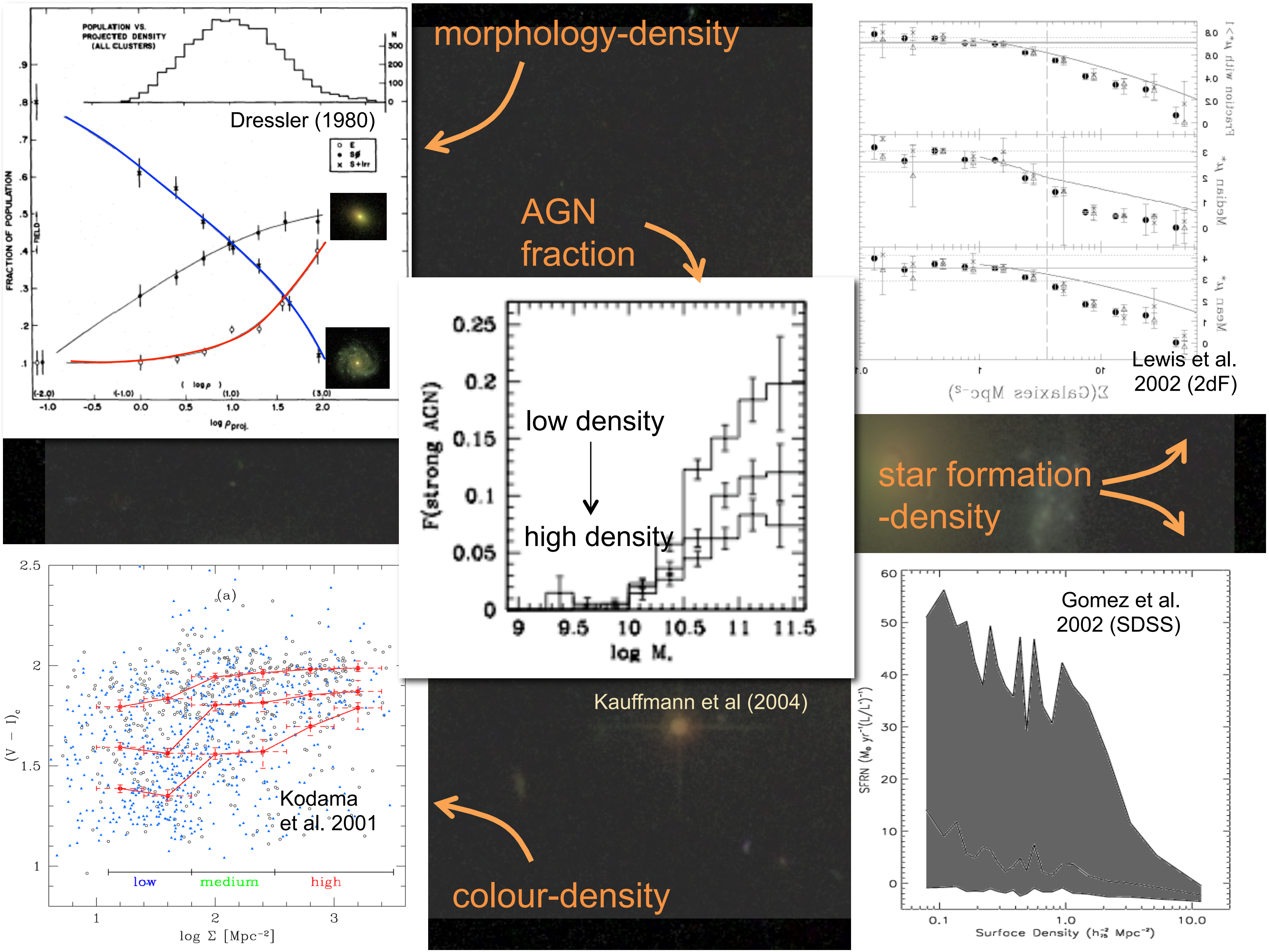
Andrew Z. Colvin

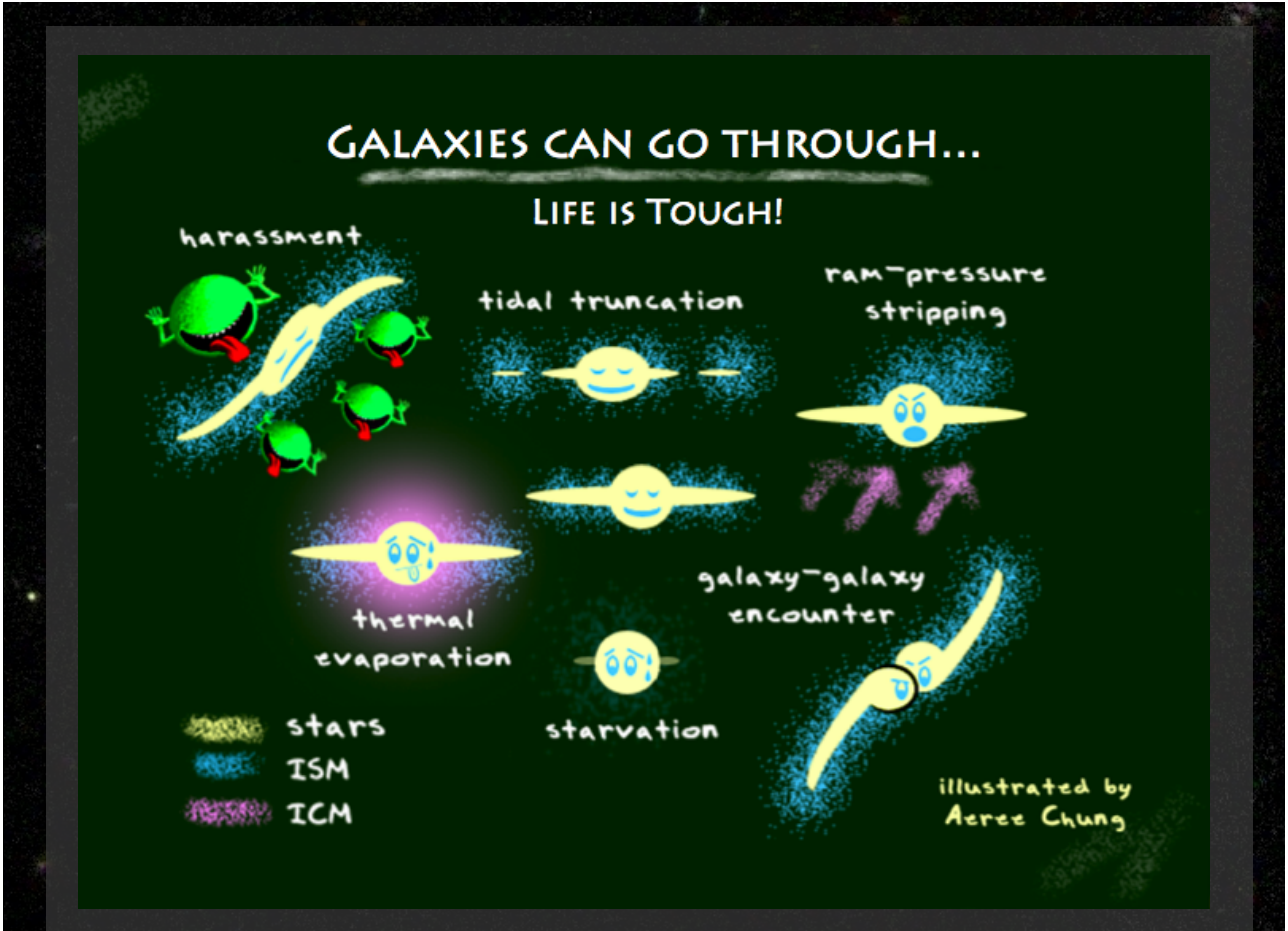
www.nottingham.ac.uk/astrononmy/stages

Morphology-Density relation



less crowded → more crowded


morphology-density
AGN
fraction
star formation
-density
colour-density
Dressler (1980)
POPULATION VS.
PROJECTED DENSITY
(ALL CLUSTERS)
FRACTION OF POPULATION
log ρproj.
E
S0
S+Irr
low density
high density
F(strong AGN)
log M*
Kauffmann et al (2004)
Lewis et al.
2002 (2dF)
Kodama
et al. 2001
(V − I)c
log Σ [Mpc⁻²]
low
medium
high
Gomez et al.
2002 (SDSS)
SFRN (M⊙ yr⁻¹(L/L*)⁻¹)
Surface Density (h₇₅² Mpc⁻²)


GALAXIES CAN GO THROUGH...
LIFE IS TOUGH!
harassment
tidal truncation
ram-pressure stripping
thermal evaporation
starvation
galaxy-galaxy encounter
stars
ISM
ICM
illustrated by Aeree Chung

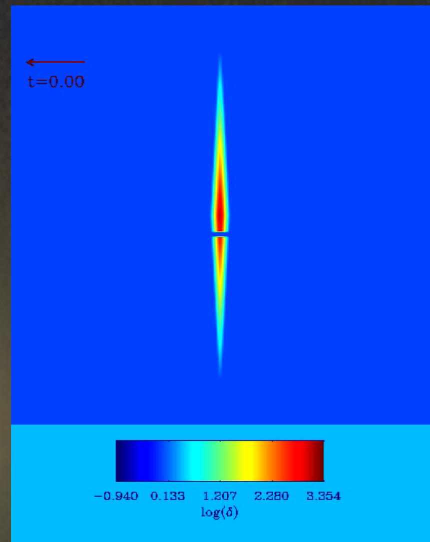
What we know so far about environment

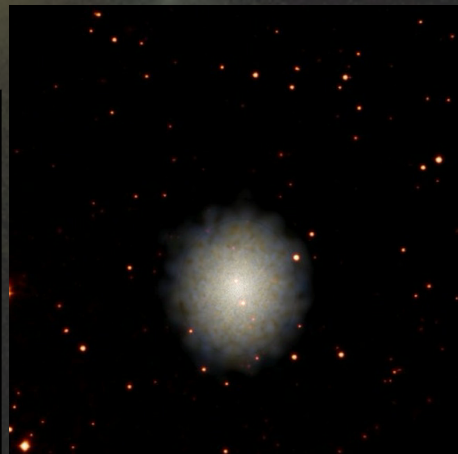
1. Galaxy-cluster gas interactions
   - e.g. ram-pressure stripping

     (Gunn & Gott 1972, Larson et al 1980)
2. Galaxy-cluster gravitational interactions
   - e.g. tidal truncation of galaxy dark matter halos

     (Merrett 1983, 1984)
3. Galaxy-galaxy interactions
   - mergers (low-speed interactions; Bekki 1998);
   - harrassment (high-speed interactions; Moore et al 1999)

Vicent Quilis, Valencia





Volker Springel, MPA

Distinct observational effects on galaxy properties:

- star-formation (induce, truncate, or suffocate)
- AGN activity (modify gas supply to central engine)
- structural parameters (destroy disks, create tidal features)

➔ effective on different timescales and in different regimes

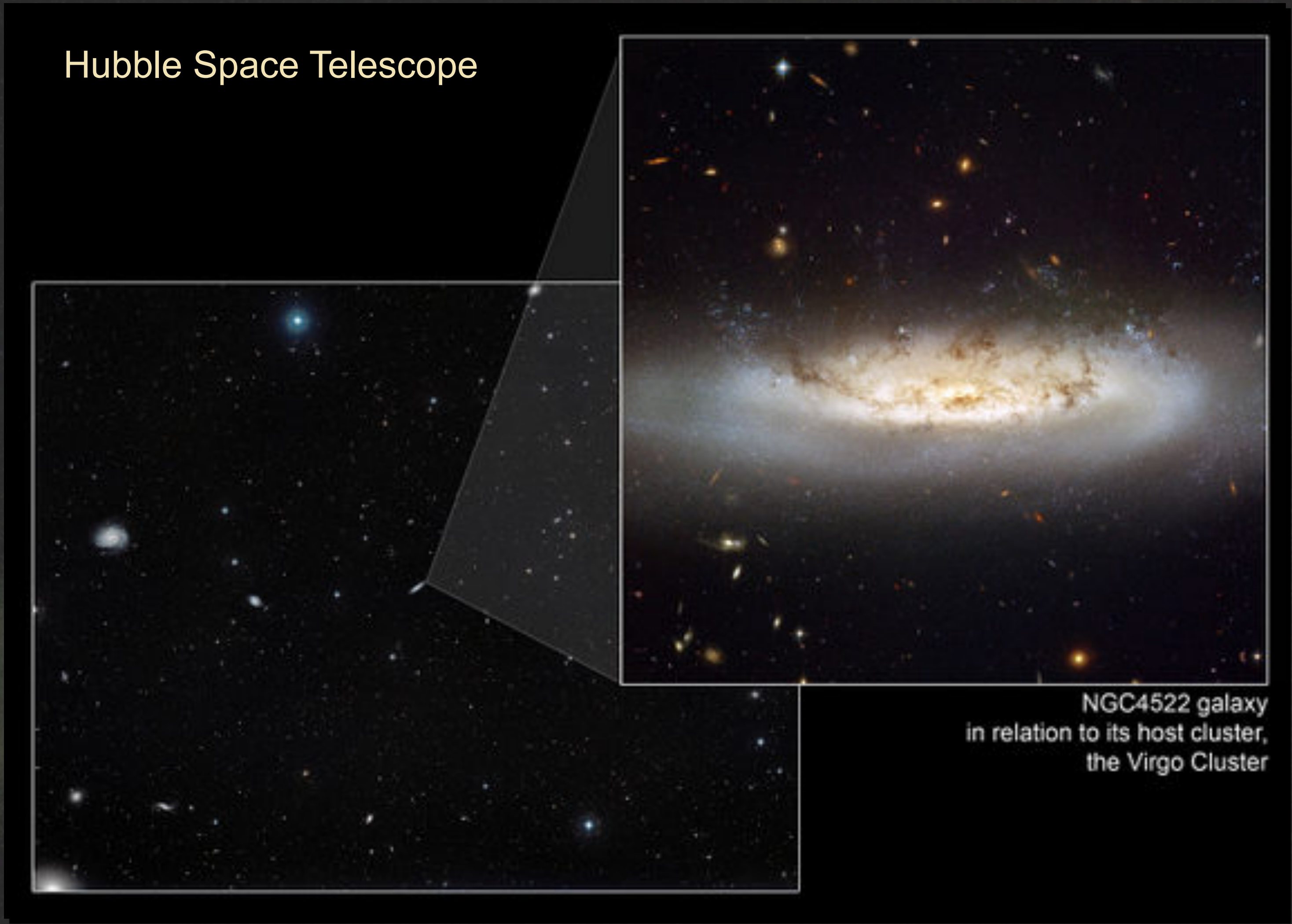
In action: galaxy mergers

the Antennae galaxies

NOAO/AURA/NSF

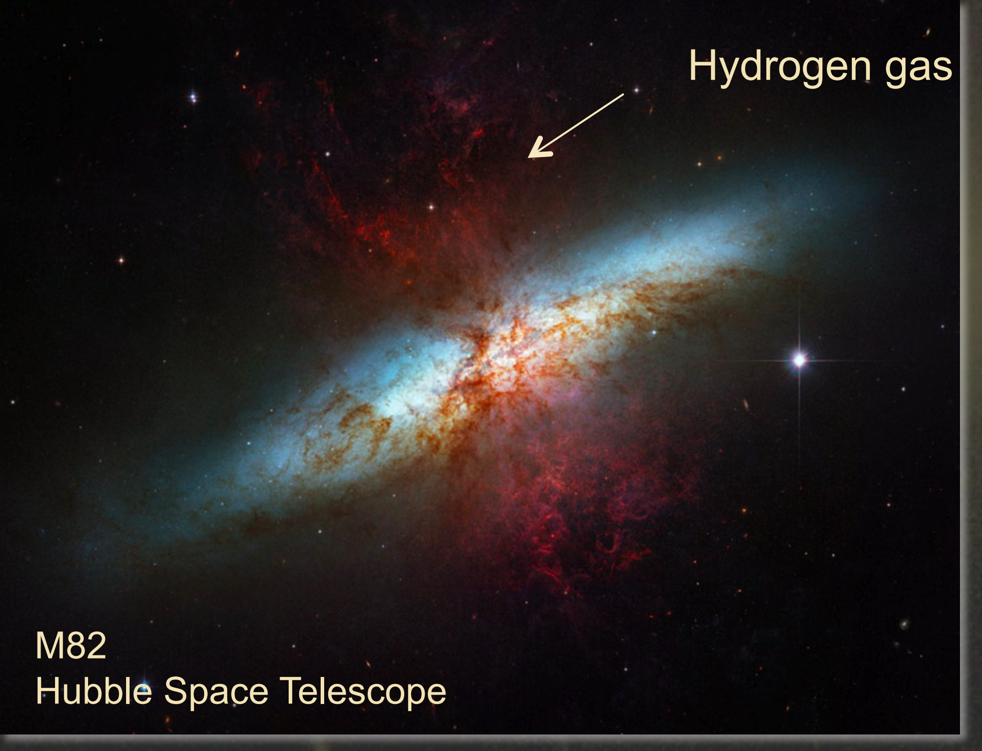
Hubble Space Telescope

In action: ram-pressure stripping



In action: natural causes

- internal process: winds from supermassive black hole, supernova may drive out gas



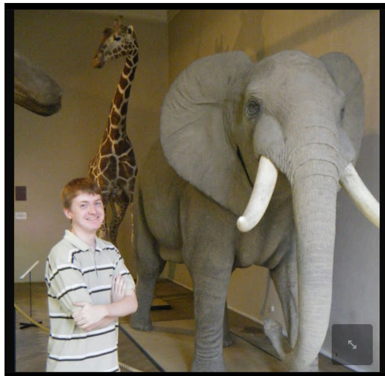
- old age: the galaxies in dense environments may simply have formed first, giving them more time to evolve

Nurture…

…or nature?

Darren Croton:
"halo mass is king!"

But…how do we measure environment?



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 ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice[5]
10	$2\,h^{-1}$Mpc ($\pm 500\,\mathrm{km\,s^{-1}}$)	Gallazzi[6]
11	$2\,h^{-1}$Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice
12	$2\,h^{-1}$Mpc ($\pm 6000\,\mathrm{km\,s^{-1}}$)	Gallazzi[6]
13	$5\,h^{-1}$Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice
14	$8\,h^{-1}$Mpc Spherical	Croton[7]
	Annulus	
15	$0.5 - 1.0\,h^{-1}$Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
16	$0.5 - 2.0\,h^{-1}$Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
17	$0.5 - 3.0\,h^{-1}$Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
18	$1.0 - 2.0\,h^{-1}$Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
19	$1.0 - 3.0\,h^{-1}$Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
20	$2.0 - 3.0\,h^{-1}$Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	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).

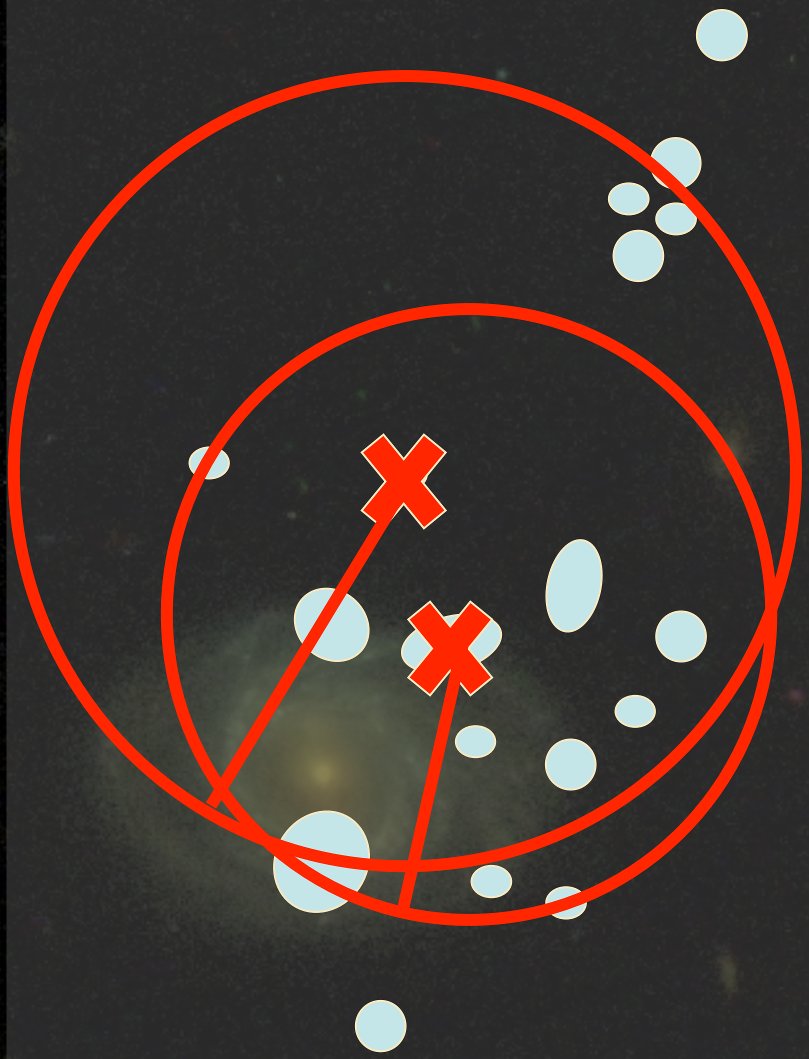
Muldrew et al. 2012

Measuring environment with galaxy density

Examples:

- 3rd nearest neighbour (N gal/Mpc^2)

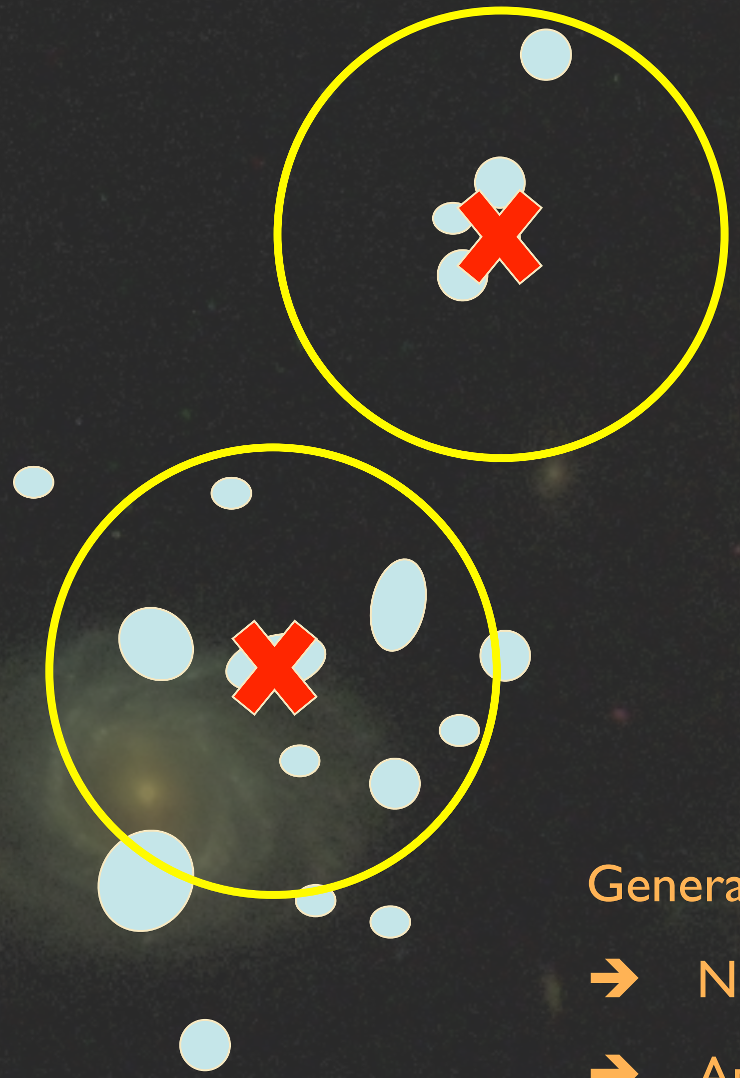
Measuring environment with galaxy density



Examples:

- 3rd nearest neighbour
  (*N* gal/Mpc^2)
- 10th nearest neighbour
  (*N* gal/Mpc^2)

Measuring environment with galaxy density



Examples:

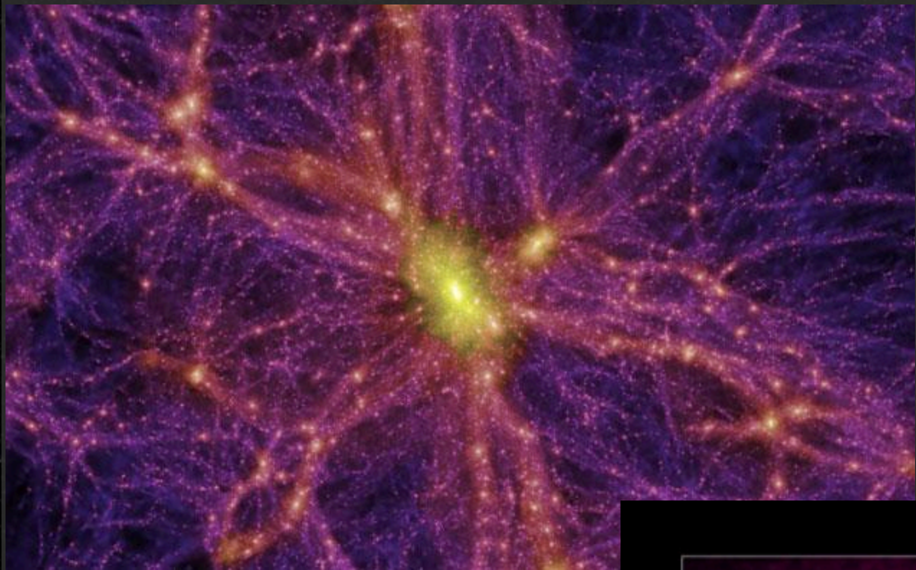
- 3^{rd} nearest neighbour
  (N gal/Mpc^2)
- 10^{th} nearest neighbour
  (N gal/Mpc^2)
- fixed aperture/cylinder

Generally:

➔ Nearest neighbour probes internal halo

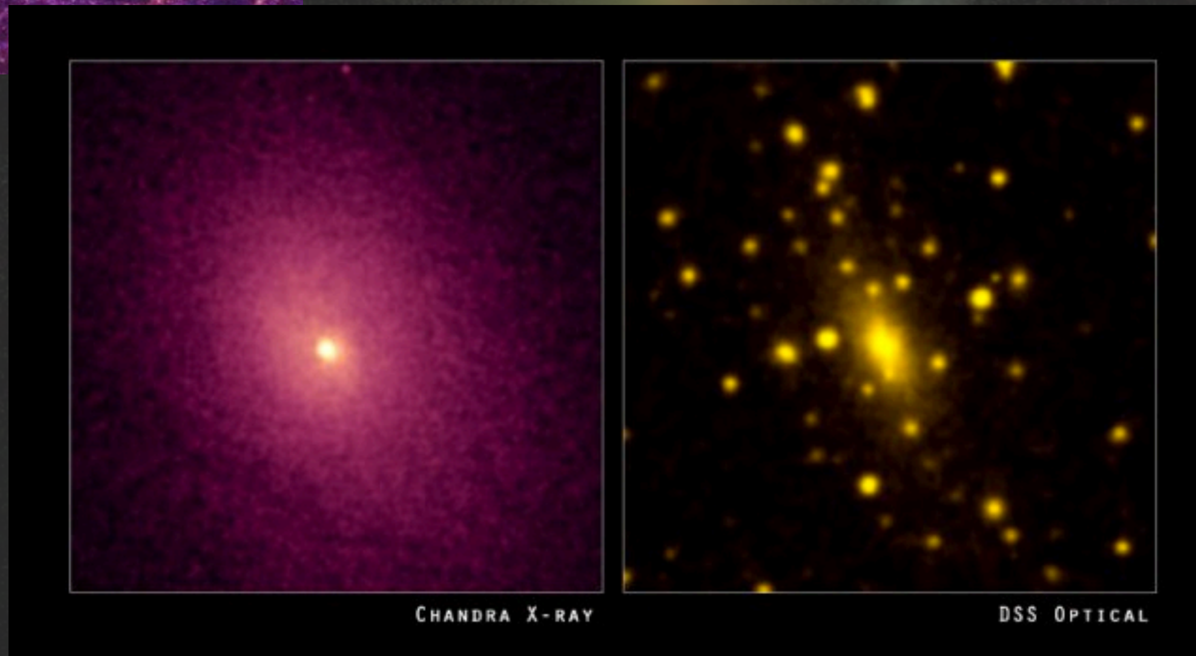
➔ Aperture probes halo as a whole

Caution: galaxy density…or proxy for:



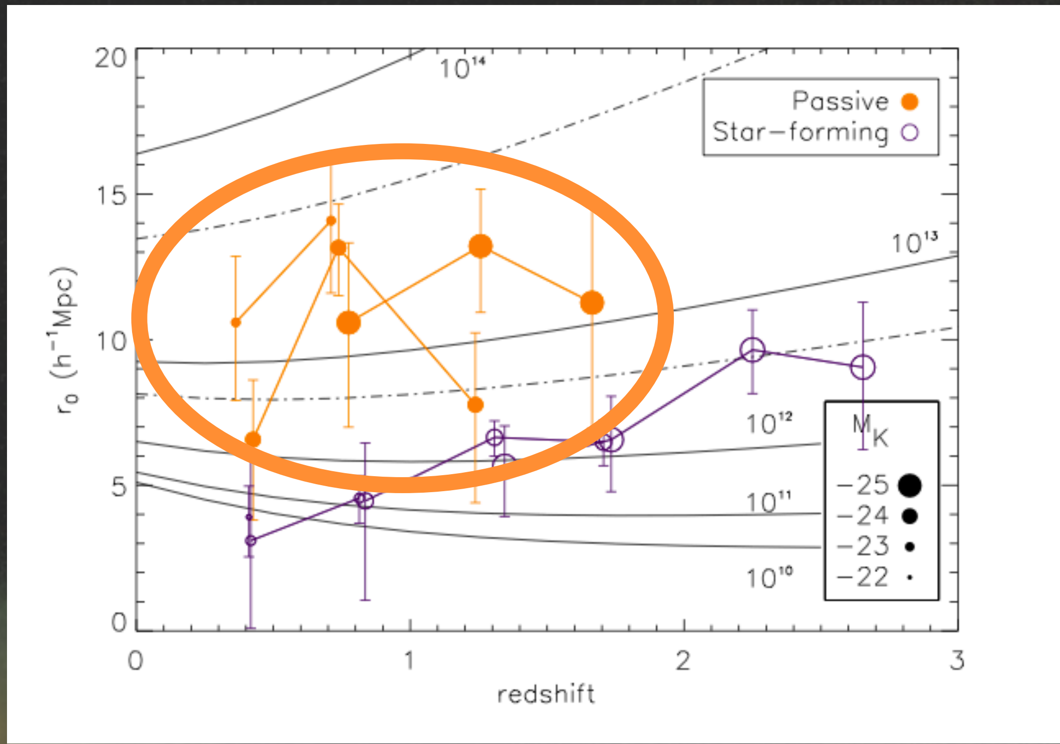
dark matter halo mass?

Hot X-ray gas?



What about redshift?

Hartley et al. 2010



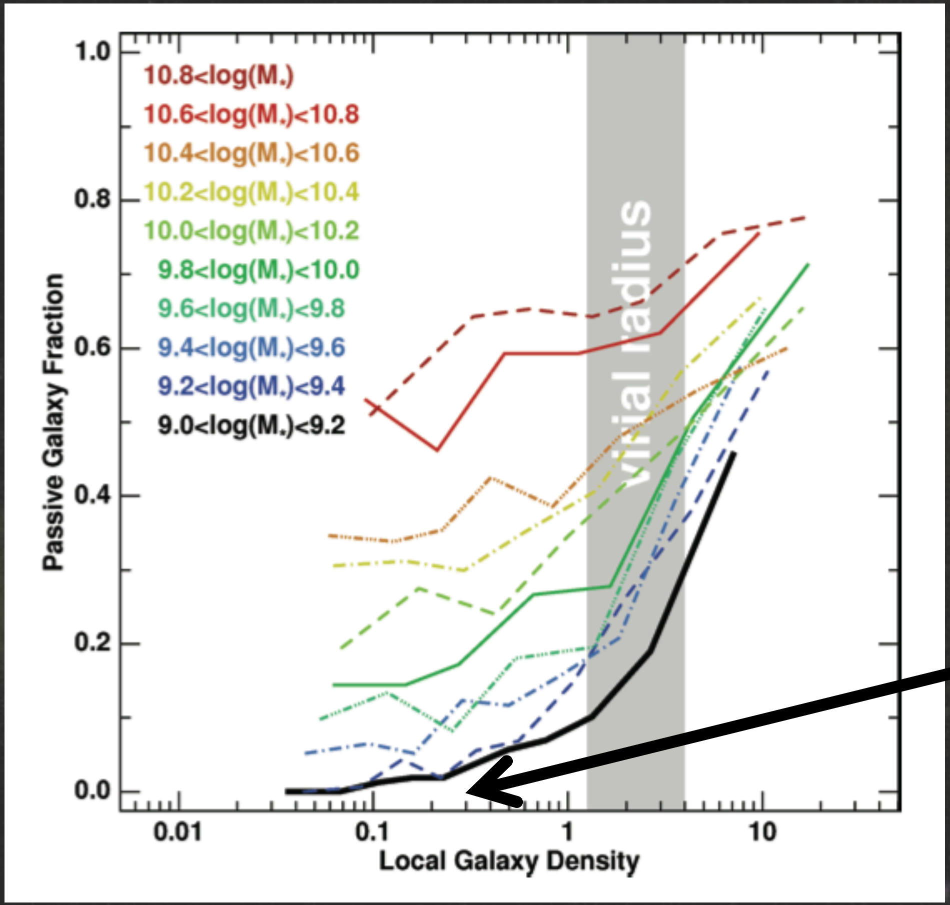
more massive haloes ↑

redshift →

Clustering studies show that passive galaxies occupied the most massive haloes as far back as z=2 (at least)…

What about galaxy mass?

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



fraction of passive galaxies

denser environment

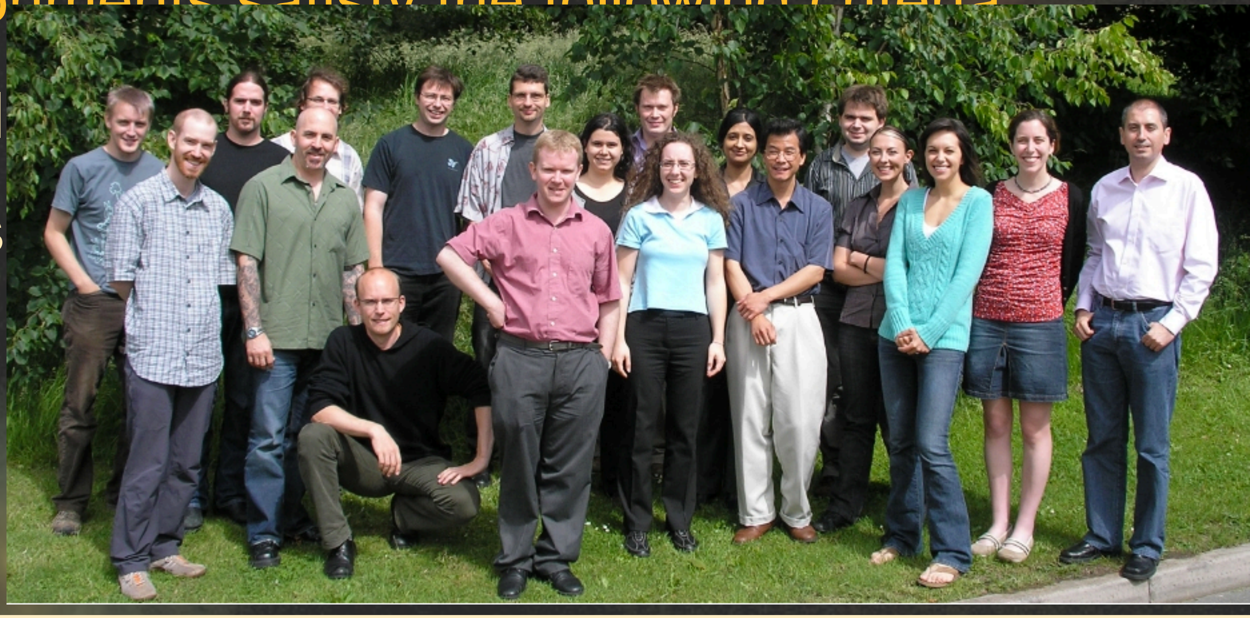
No passive low-mass galaxies in sparse environments!

Galaxy evolution and environment: Relationship status: "it's complicated"

- Who?
  - Which types (e.g. mass, morphology) of galaxies are affected?
- What?
  - What process (if any) is responsible for transformation?
- Where?
  - In which environments do transformations occur?
- When?
  - At what redshift? How quickly does the transformation happen, and how long do effects last?
- How?
  - How are the observable properties of the galaxies affected?
- Why?
  - We can't fully understand growth and assembly of galaxies over cosmic time unless we understand the role of environment.

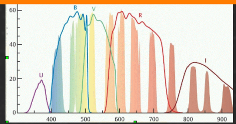
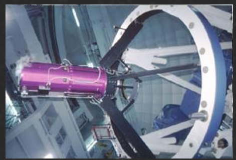
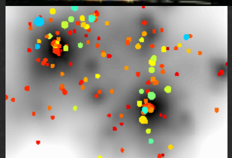
Nature or nurture?

An experiment to understand galaxy evolution in dense environments satisfy the following criteria:

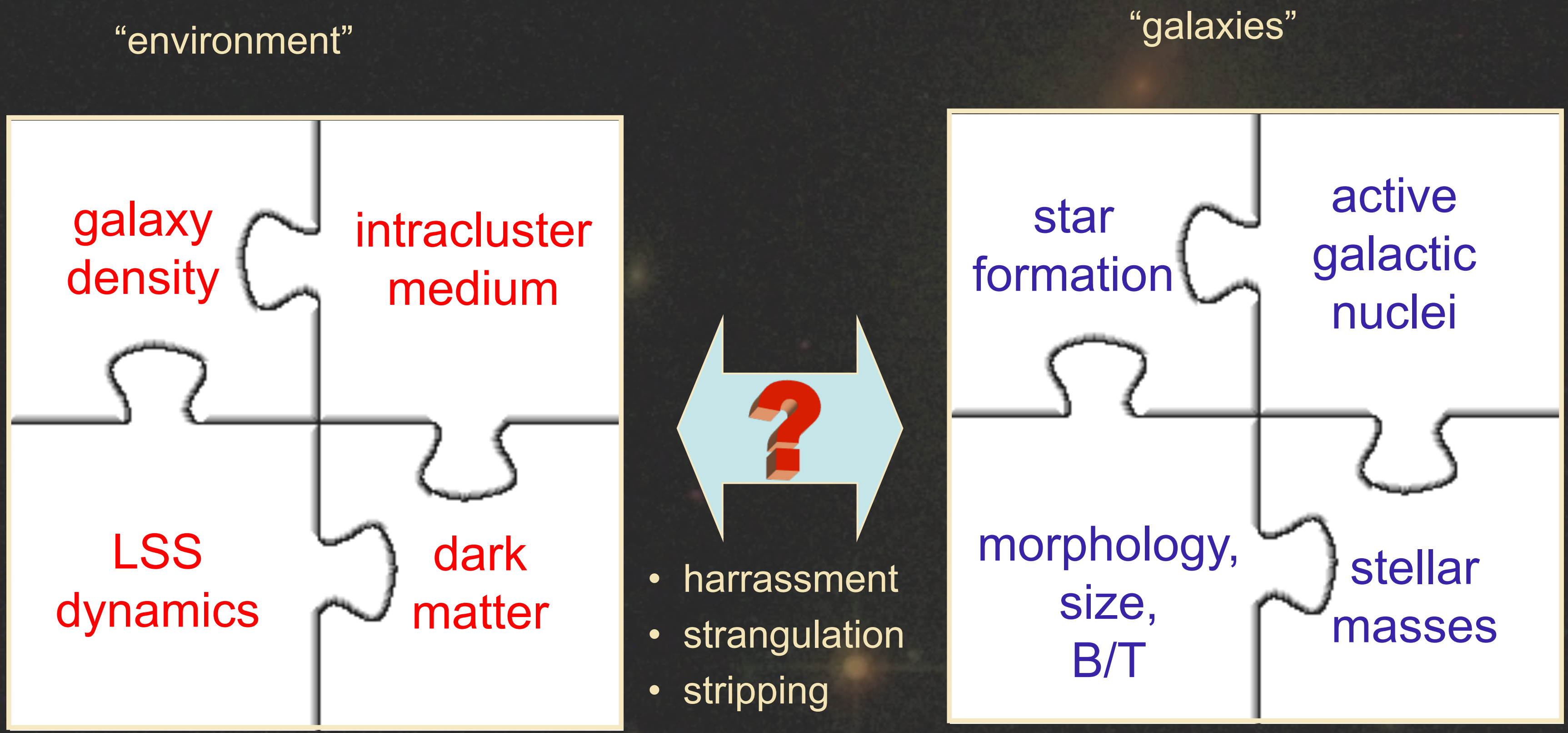


- compl ... axies
- choos
- cover ... s to field
- probe ... and AGN

STAGES: Space Telescope A901/902 Galaxy Evolution Survey (PI: Gray)

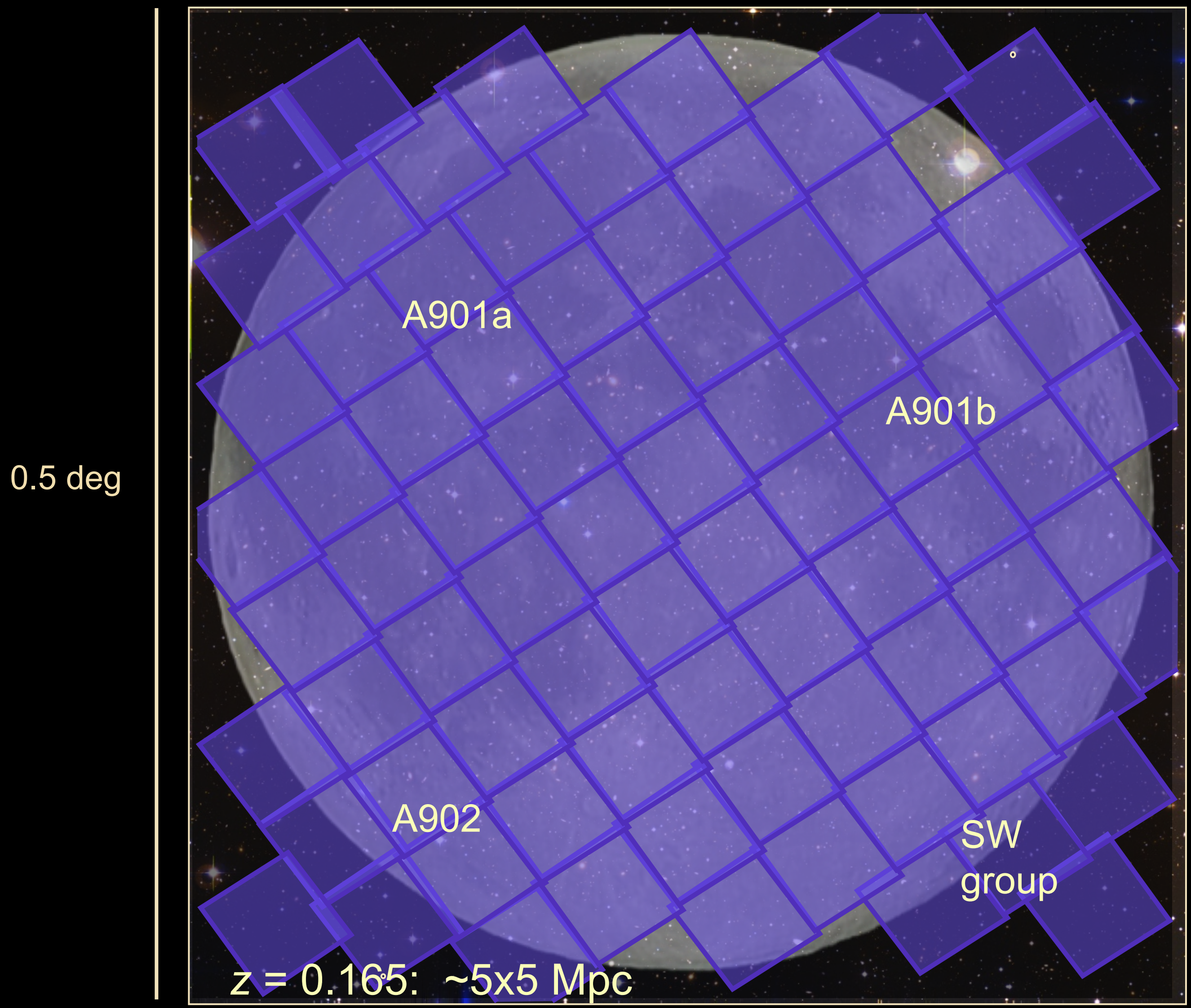
	**Hubble Space Telescope**	**80-orbit mosaic with 3 cameras:** morphologies, weak gravitational lensing
	COMBO-17 survey (Wolf, Meisenheimer++)	17-band optical imaging: photo-zs + SEDs for 15000 objects
	Omega2000 @ Calar Alto (Meisenheimer)	near-infrared extension (Y, J1, J2, H): M*, photo-zs
2dF	2dF spectrograph	spectroscopy of ~300 cluster galaxies: dynamics, star-formation histories
	XMM-Newton	90 ks X-ray imaging/spectroscopy: ICM, AGN
Spitzer Space Telescope	Spitzer (Bell)	infrared imaging (8 and 24 μm): obscured star formation, AGN
	GALEX (GALEX team)	NUV + FUV imaging: unobscured star formation
	GMRT (Green, Beswick, Saikia)	radio imaging (610 and 1400MHz) obscured SF, AGN
	simulations (van Kampen; also Pearce)	N-body + hydro + semi-analytic models dark matter, gas, galaxies

The A901/902 multiple-cluster system:
a laboratory for studying galaxy evolution & environment



- harrassment
- strangulation
- stripping
- tidal truncation
- merging
- …

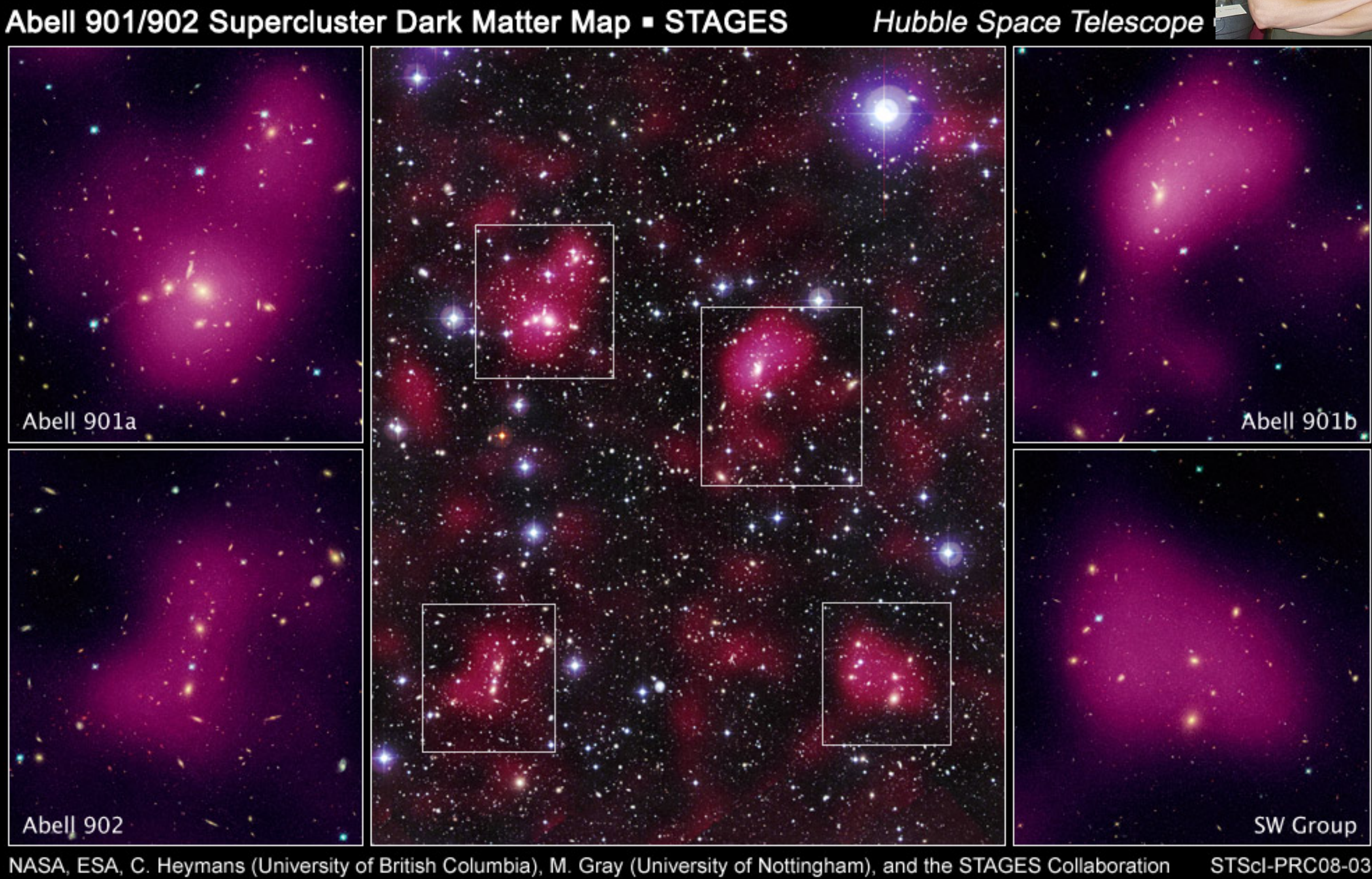
Multiple clusters and groups in one field-of-view



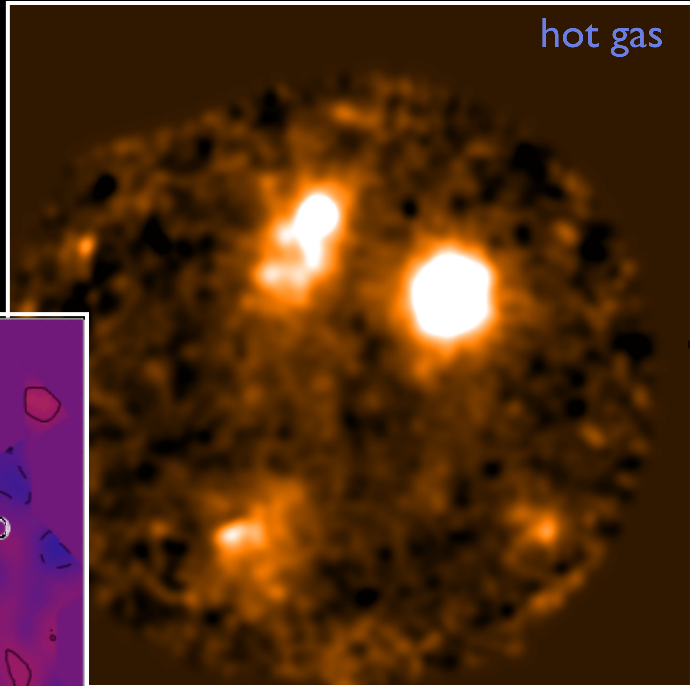
COMBO-17 image

STAGES high-resolution weak lensing map

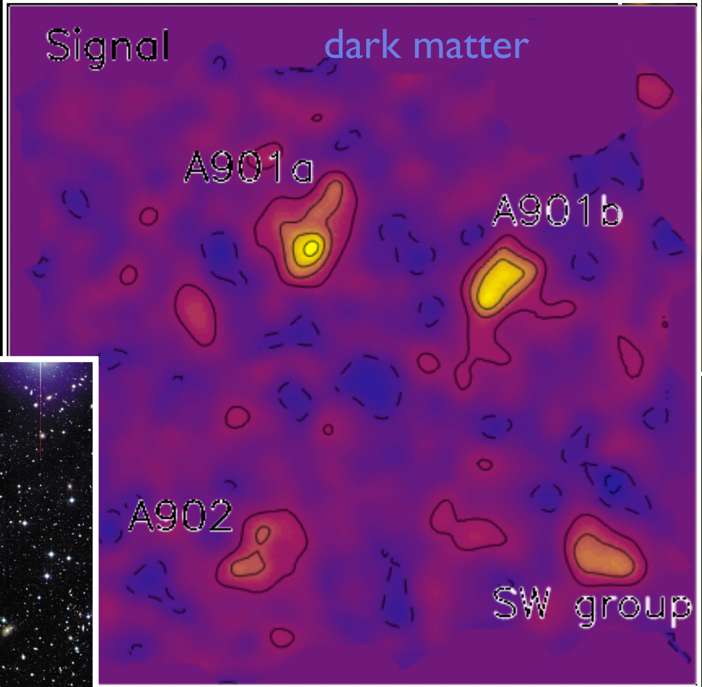
Heymans + STAGES 2009



Dissecting a supercluster



X-ray imaging



gravitational lensing

optical imaging

A complex environment!

Results (I): activity in galaxies

mass-dependent quenching of star-formation in cluster infall

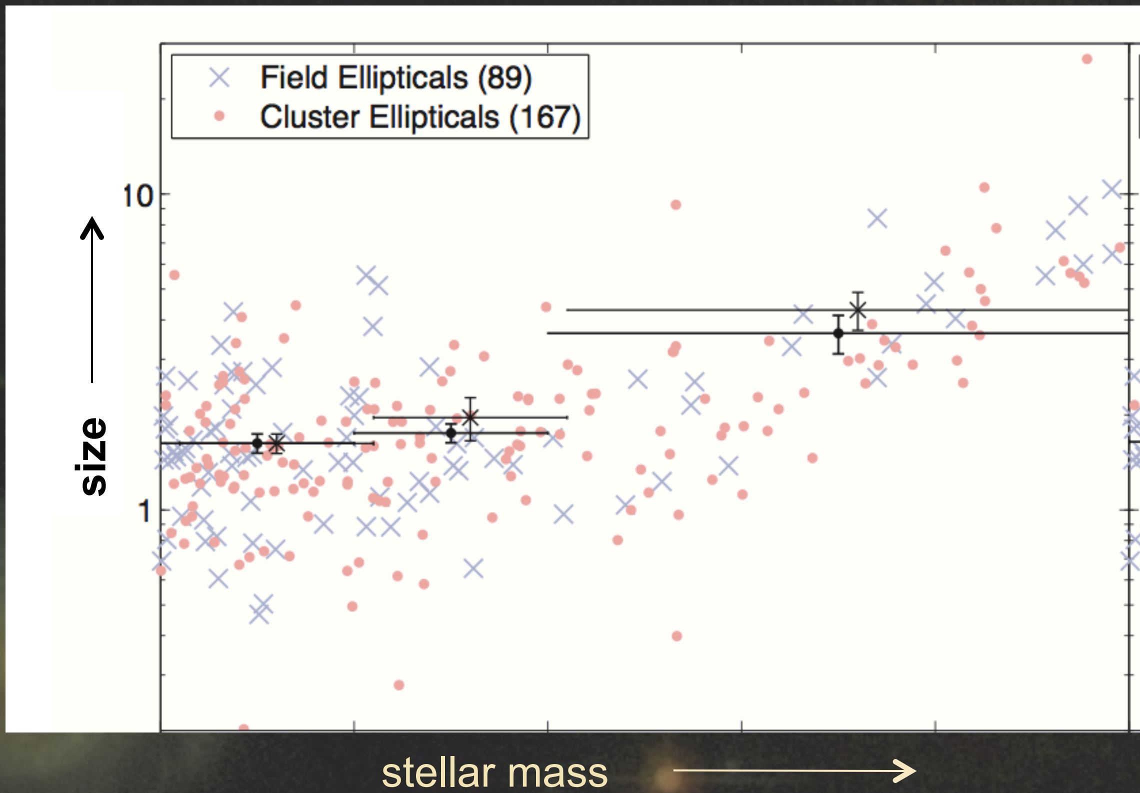
Wolf + STAGES (2009)

- dusty red galaxies are a cluster-specific phenomenon
- are forming stars but at rate 4x lower than blue spirals at fixed mass
- cluster: contains more dusty red than blue galaxies (mostly Sabs)

…see also Galaxy Zoo (Bamford et al. 2009)

Results (II): Structural parameters

Maltby + STAGES (2010)



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

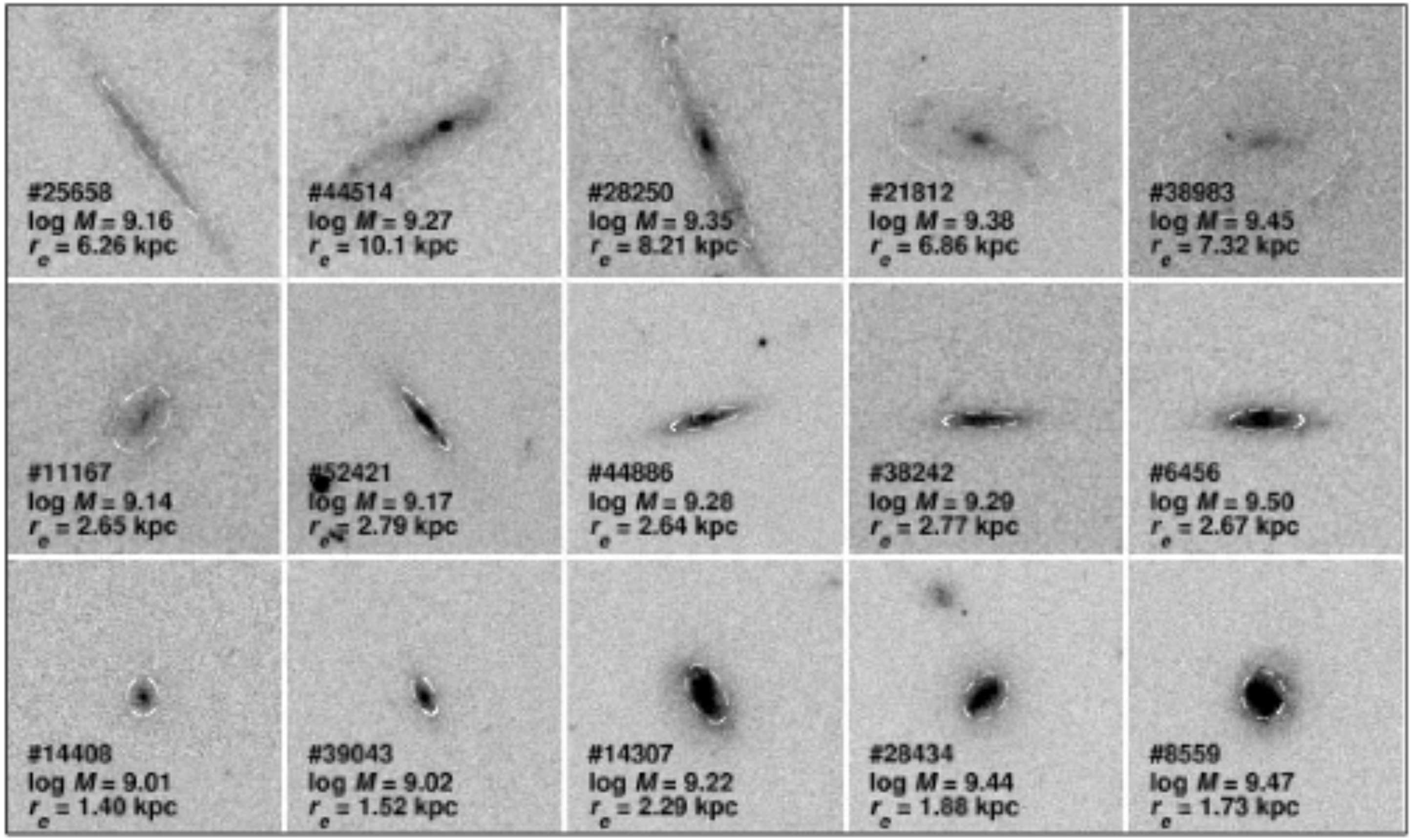
same goes for bars (Marinova et al. 2008); surface brightness profiles (Maltby et al 2012), interactions (Heiderman et al. 2008); boxy/diskiness of ellipticals (Haeussler et al. 2012)

Results (II): Structural parameters (con't)

Maltby + STAGES 2010

field spirals

cluster spirals



Large, low-mass spirals seen in the field but not the cluster

➔ destroyed on infall?

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

Some outstanding questions

- How does star formation get supressed in the cluster environment?
- How do spiral galaxies transform into S0s?
- What drives the morphology density relation?
- At what redshift are the colour-density and morphology-density relations established?
- What is the balance between external and secular evolution, and the dependence on galaxy mass?
- What drives galaxy evolution with redshift?

Lots to do!