Galaxy And Mass Assembly (GAMA): From little blue galaxies to massive red monsters and beyond…

Sarah Brough

& The GAMA team

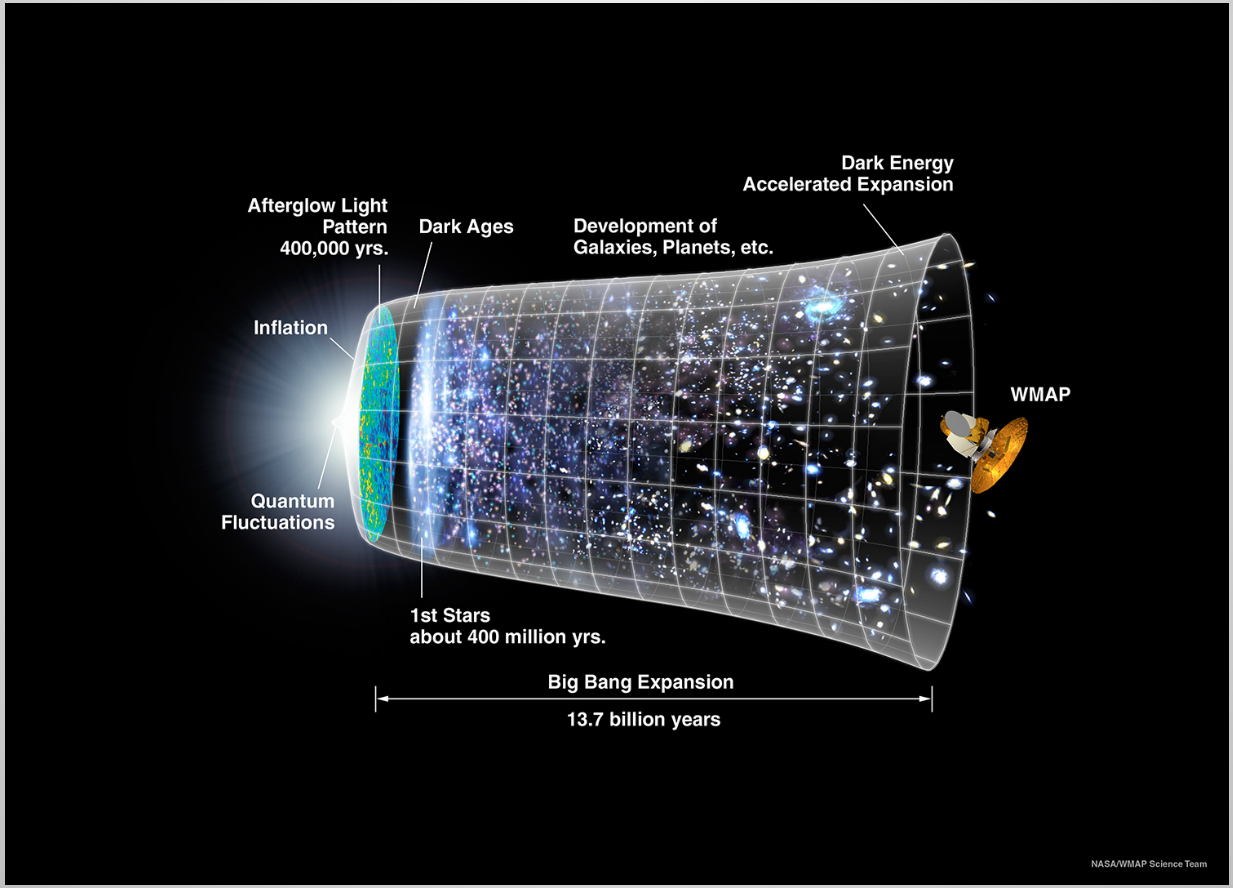
Australian Government
Department of Innovation
Industry, Science and Research

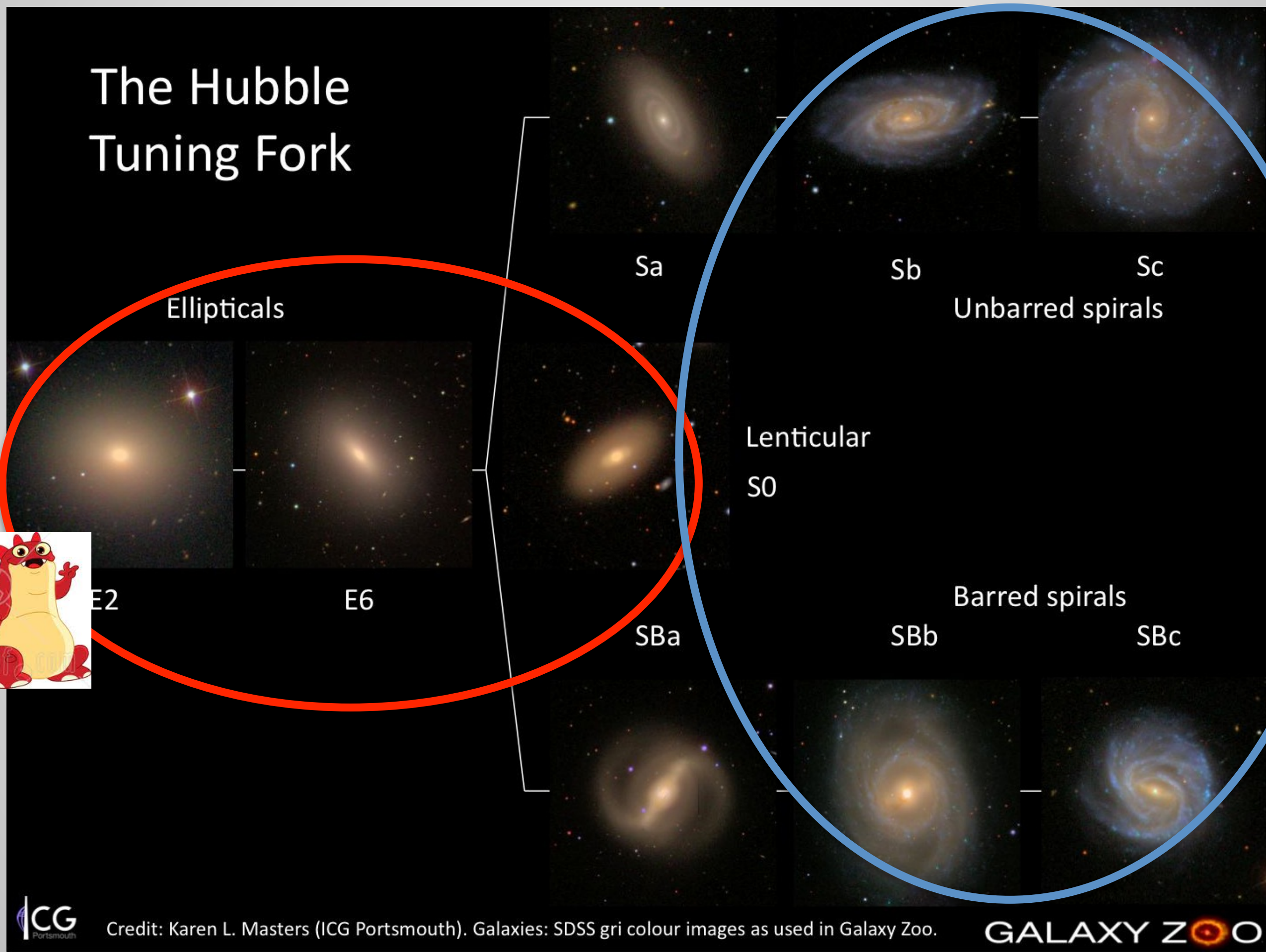
AAO

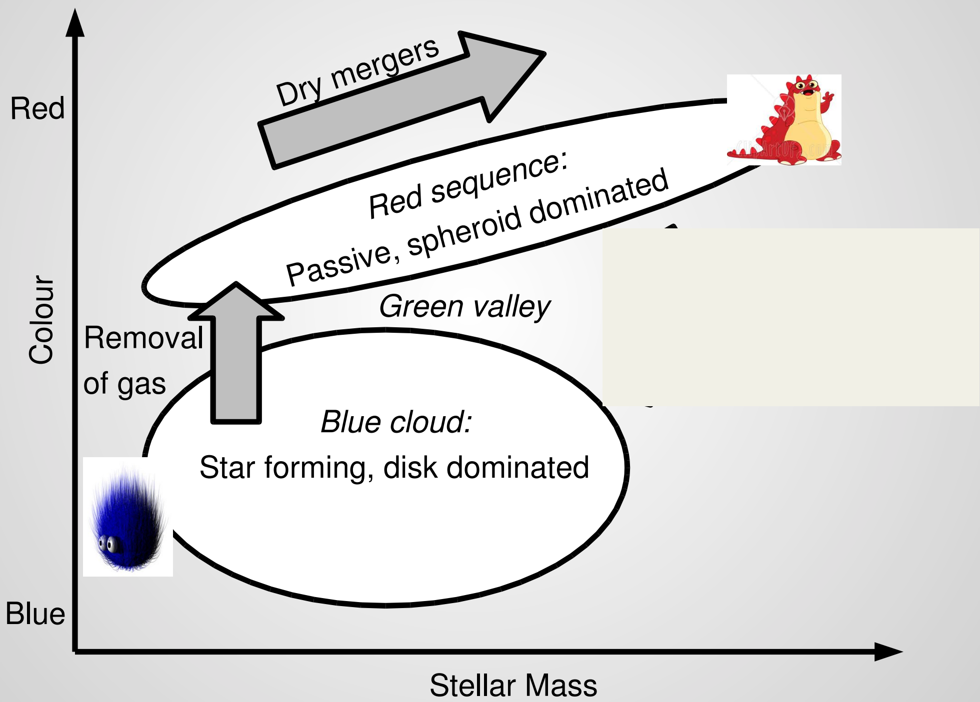

A N T A R C T I C A
SOUTHERN OCEAN
The Hobo Dyer Equal Area Projection
SOUTHERN OCEAN
NEW ZEALAND
AUSTRALIA
ATLANTIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
BRAZIL
ARGENTINA
BOLIVIA
PERU
COLOMBIA
MEXICO
INDONESIA
SOUTH AFRICA
ZAMBIA
ANGOLA
SUDAN
CHAD
NIGER
MALI
NIGERIA
ALGERIA
LIBYA
EGYPT
SAUDI ARABIA
INDIA
IRAN
TURKEY
KAZAKSTAN
CHINA
MONGOLIA
PACIFIC OCEAN
ATLANTIC OCEAN
U. S. A.
C A N A D A
R U S S I A
ARCTIC OCEAN
ATLANTIC OCEAN


Darwin
NORTHERN TERRITORY
Cairns
Broome
Townsville
AAO
Alice Springs
QUEENSLAND
WESTERN AUSTRALIA
SOUTH AUSTRALIA
Brisbane
NEW SOUTH WALES
Perth
Sydney
Adelaide
Canberra
VICTORIA
Melbourne
Swinburne, Monash
TASMANIA
Hobart

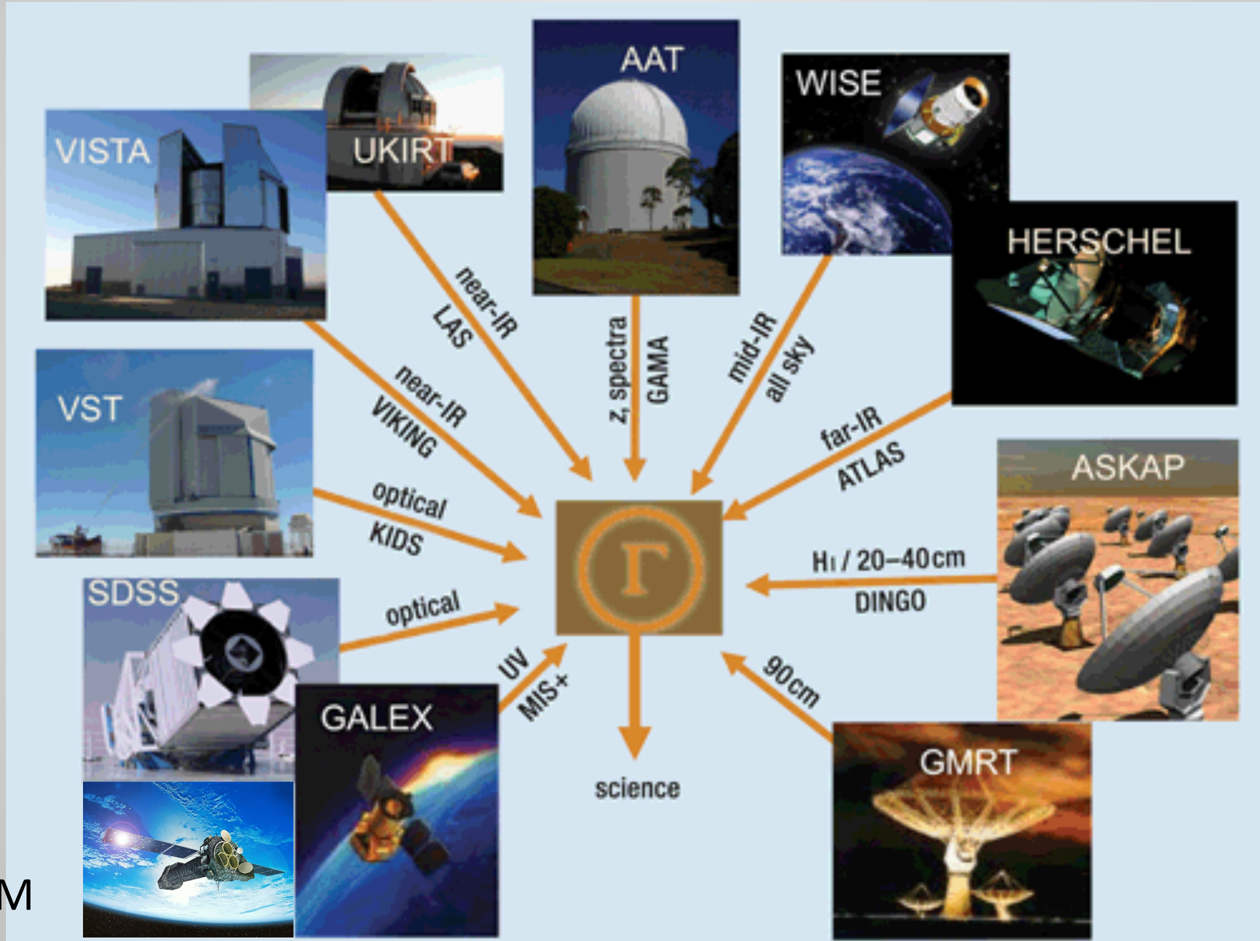
Fundamental Point




The Hubble
Tuning Fork
Ellipticals
E2
E6
Sa
Sb
Sc
Unbarred spirals
Lenticular
S0
Barred spirals
SBa
SBb
SBc
ICG
Credit: Karen L. Masters (ICG Portsmouth). Galaxies: SDSS gri colour images as used in Galaxy Zoo.
GALAXY ZOO



- How do galaxies move around this diagram?
- Environmental effects or feedback?



XMM

Driver et al 2009, A&G, 50, 5.12; Driver et al 2011, MNRAS, 413, 971

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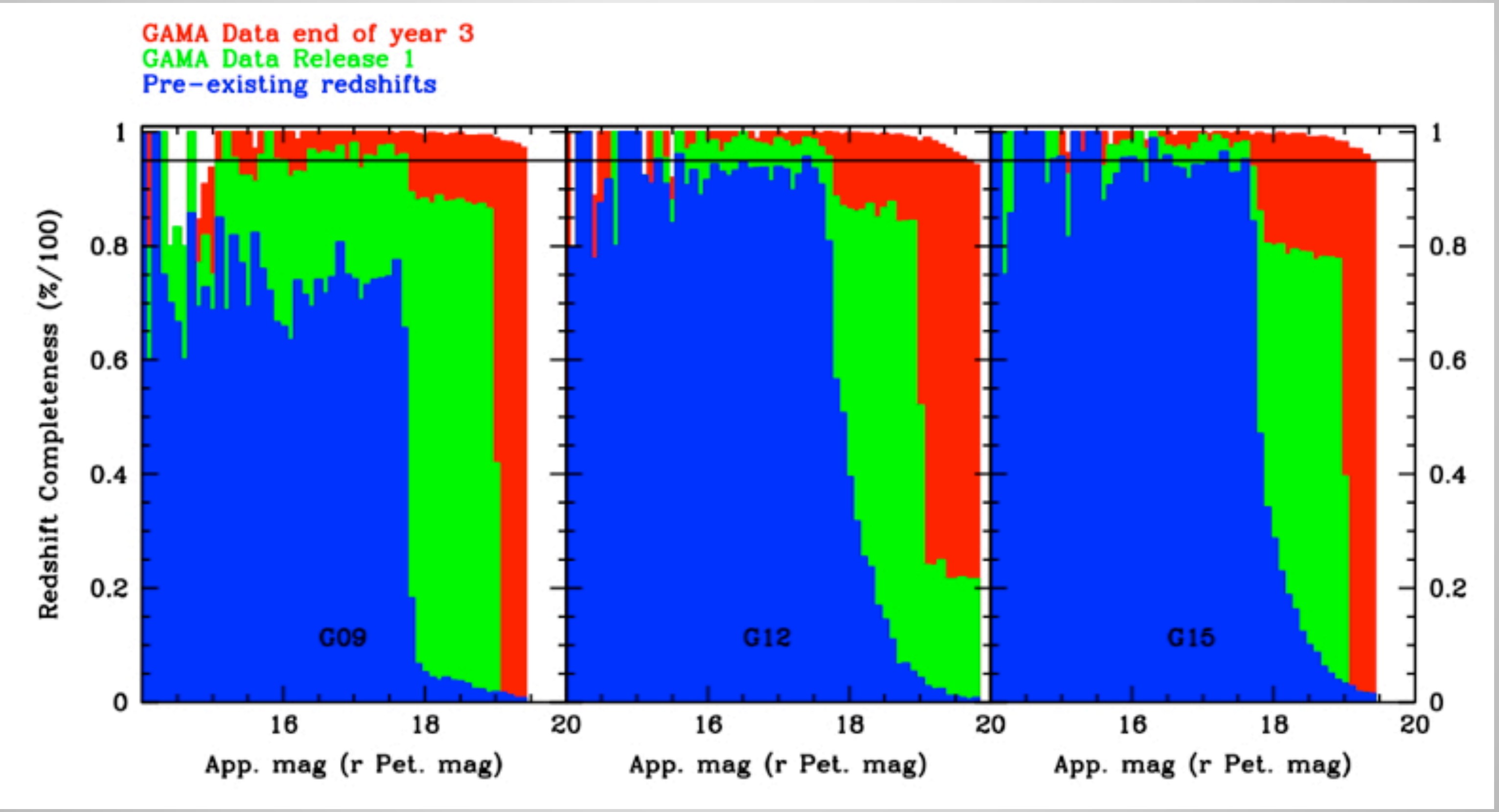
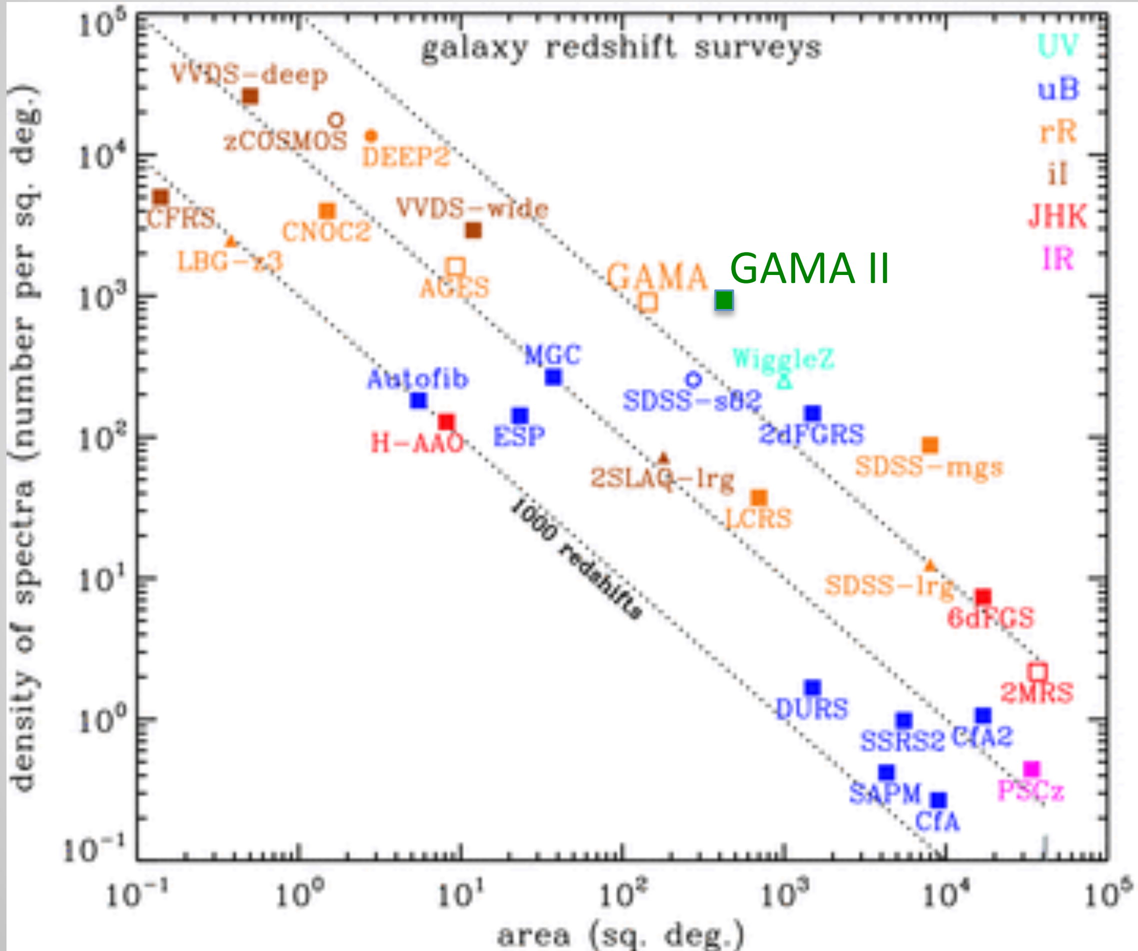
SDSS, Apache Point
VST, Paranal
UKIRT, Mauna Kea
VISTA, Paranal
GMRT, Pune
ASKAP, WA
SPACE MISSIONS
Herschel, L2
GALEX, Earth Orbit
WISE, Earth Orbit
ICRAR
UQ
AAO
USyd
Swinburne
UMelb
Monash

- An r-band selected redshift survey:
  - r < 19.8mag
  - Median z~0.2
  - Six regions each ~5x12 deg
  - ~1000 redshift targets per sq deg (2dFGRS~120, SDSS~70)
  - Testing ΛCDM via halo mass function, galaxy merger rates, and star formation efficiency
  - Total allocation 178 nights

- A multi-wavelength study of galaxies:
  - FUV,NUV,ugrizYJHK,mid-IR,far-IR,20cm,21cm,1m (AGN, stars, gas, dust)
  - 1kpc resolution in ugrizYJHK to z<0.1 (structural analysis)
  - Robust halo masses (internal/external environmental markers)

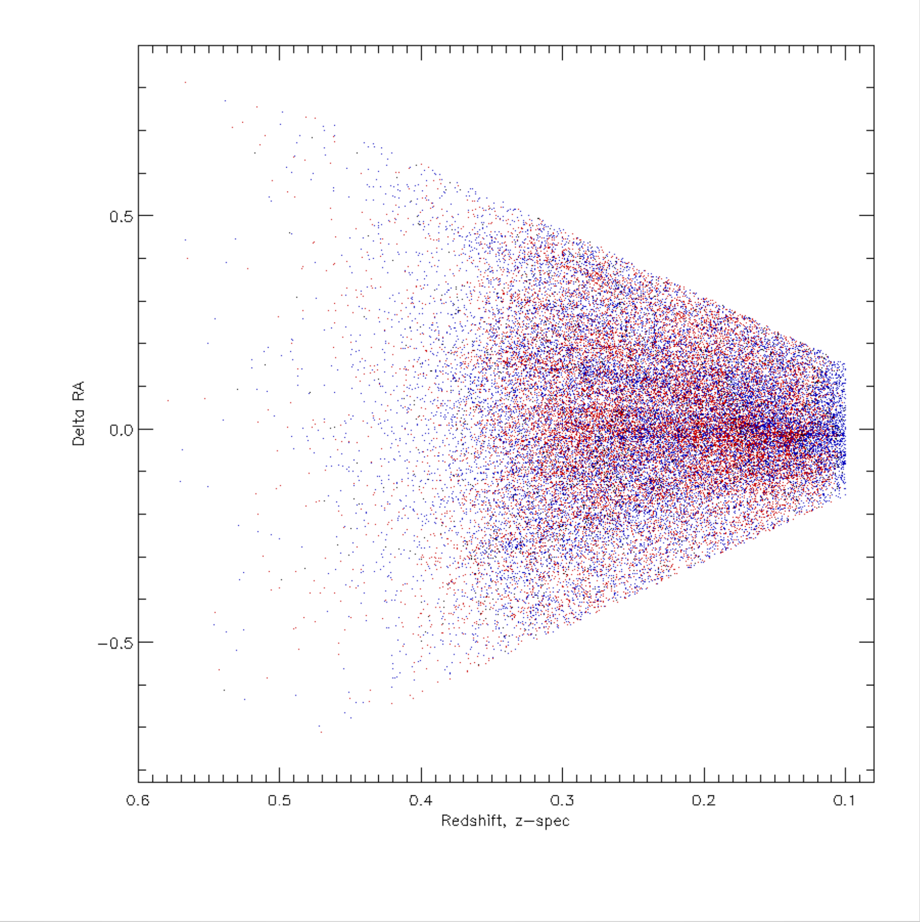


Driver et al. (2011)



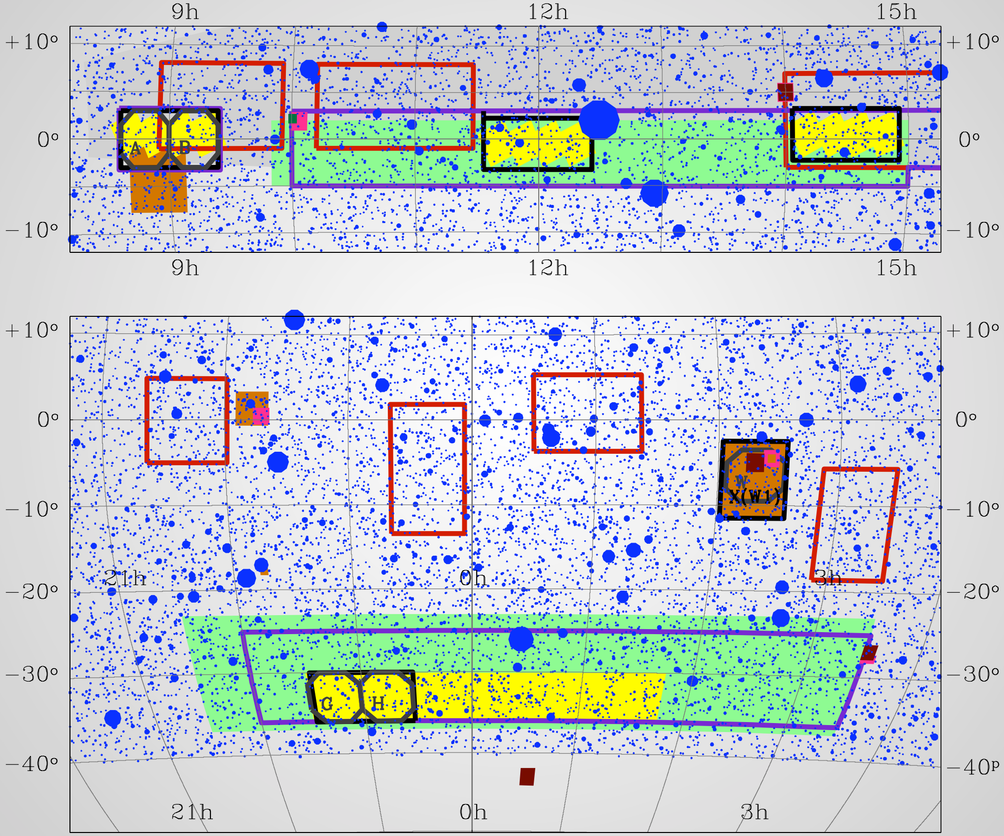
Baldry et al. (2010)

Galaxy And Mass Assembly



Credit: Rob Sharp (Mount Stromlo)

Galaxy And Mass Assembly



The GAMA footprint (black rectangles). 2dFGRS (Green), SDSS (grey), WiggleZ (red), Herschel ATLAS (yellow), and VISTA VIKING (purple). Blue circles are NVSS radio continuum sources.

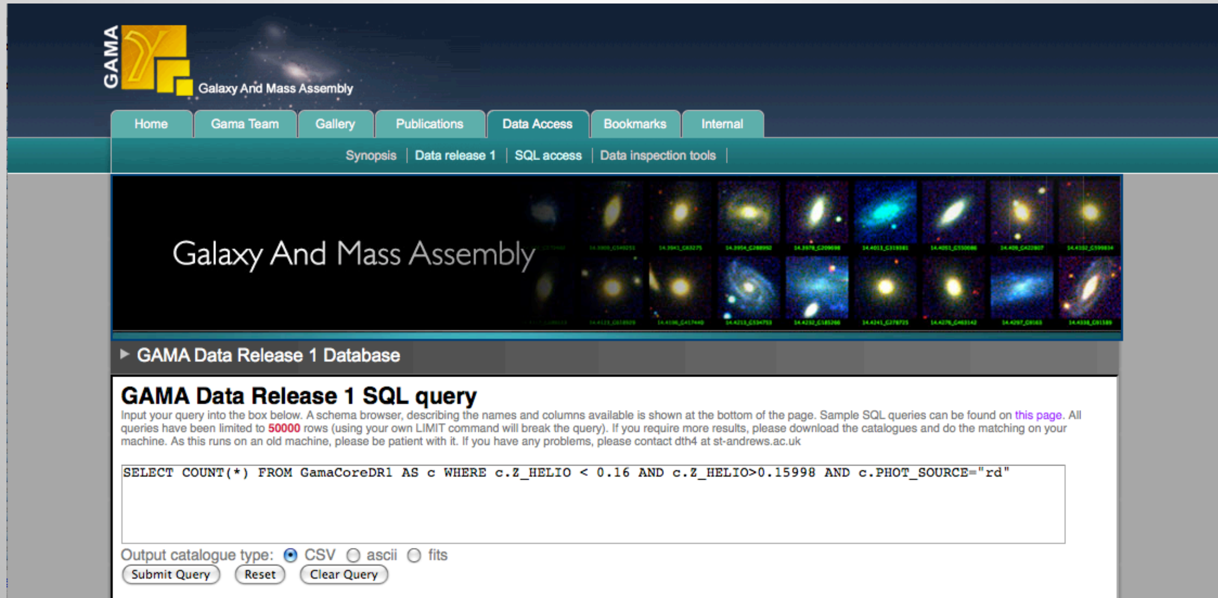
Key Science:

- A measurement of the dark matter halo mass function of groups and clusters using group velocity dispersion measurements. (Robotham et al. 2011, arXiv:1106.1994; Norberg et al. in prep)
- A comprehensive determination of the galaxy stellar mass function to Magellanic Cloud masses to constrain baryonic feedback processes. (Taylor et al. 2011, arXiv1108.0635; Baldry et al. in prep)
- A direct measurement of the recent galaxy merger rates as a function of mass, mass ratio, local environment and galaxy type.

Galaxy And Mass Assembly

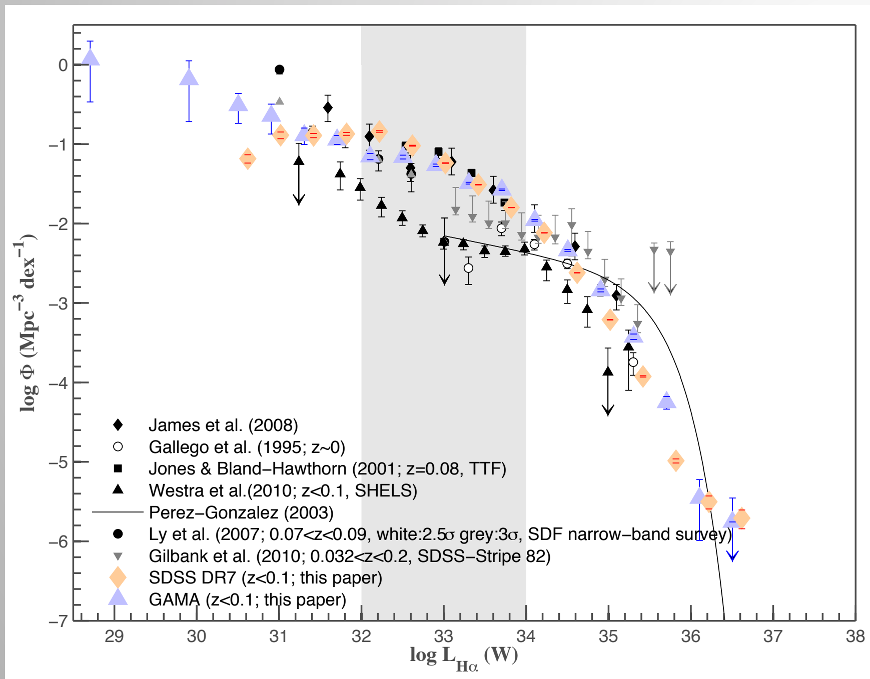
First Data Release (Driver et al., MNRAS, 2011):

- http://gama-survey.org/
- ~110,000 ugrizYHK photometric objects, to r<19.4 and r<19.8
- ~50,000 with redshifts & spectra available in DR1, out to z~0.6 (<z> ~ 0.2)

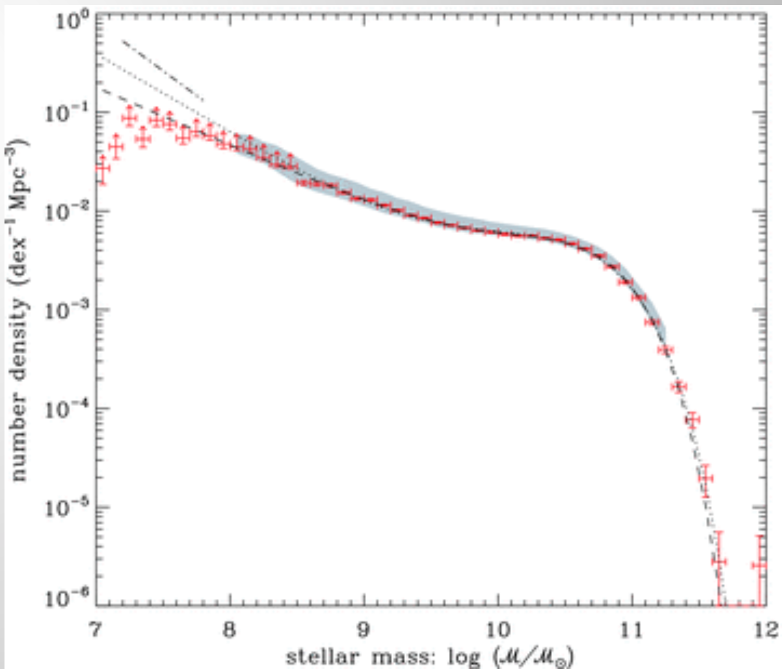


Little Blue Fuzzies

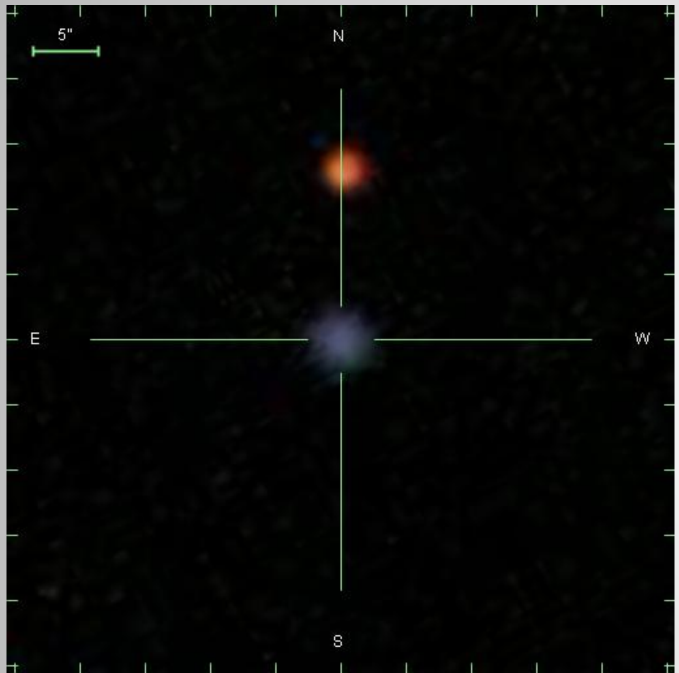
(Galaxies at the faint end of the Hα Luminosity Function)

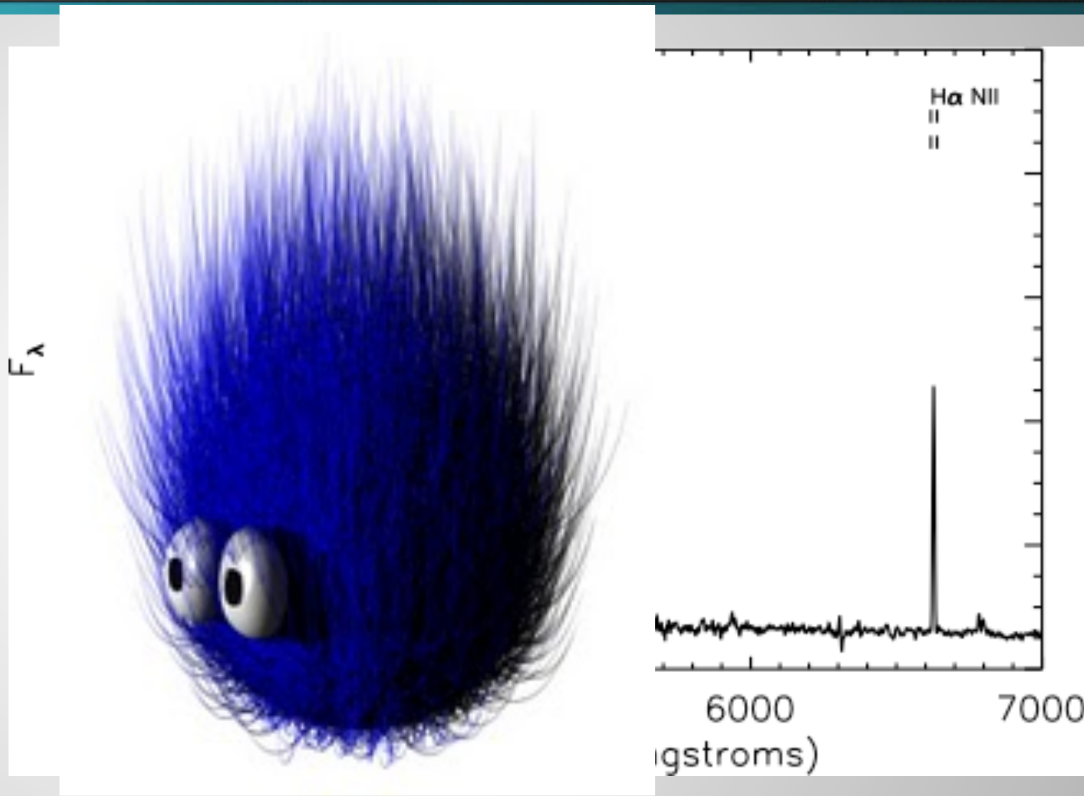


Gunawardhana et al., in prep

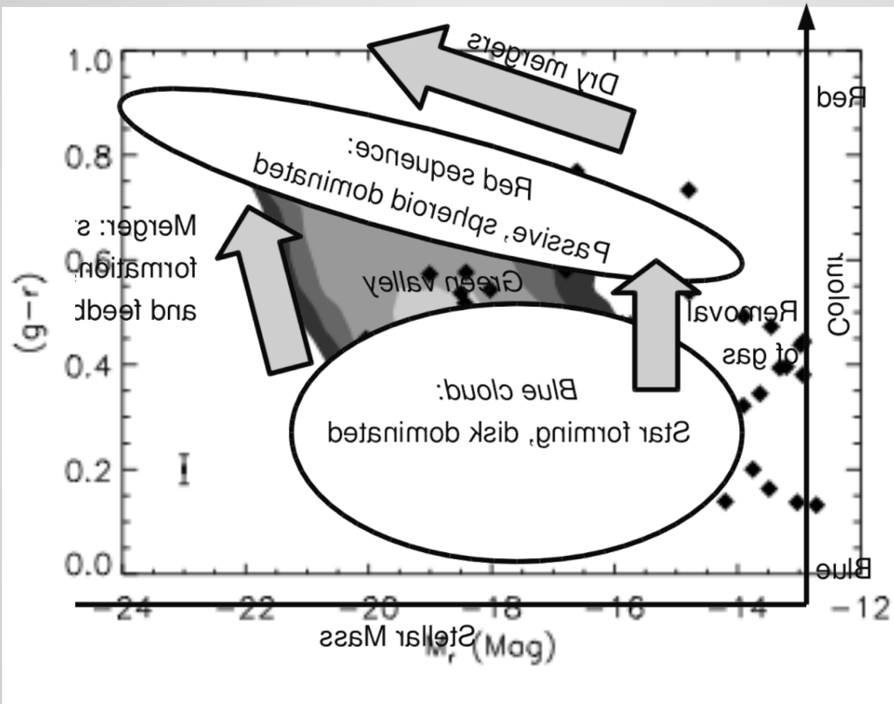


Baldry et al., 2008



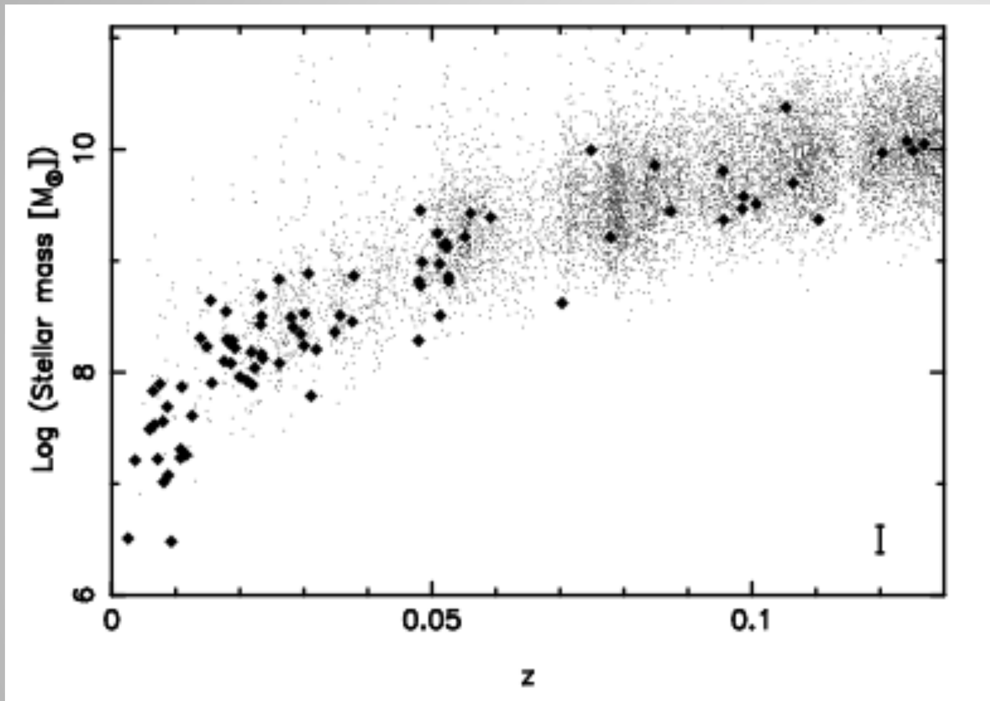


Brough et al. (2011a)

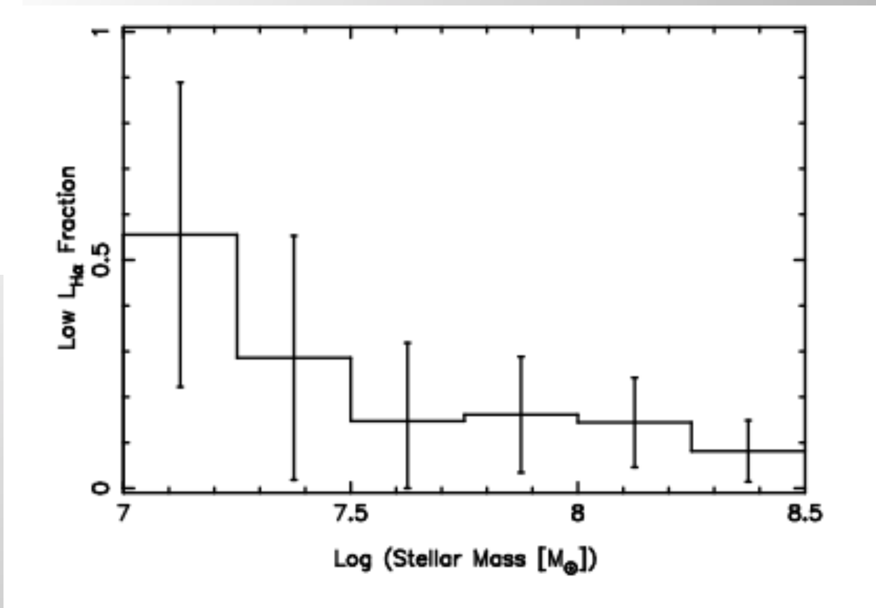


Brough et al. (2011a)

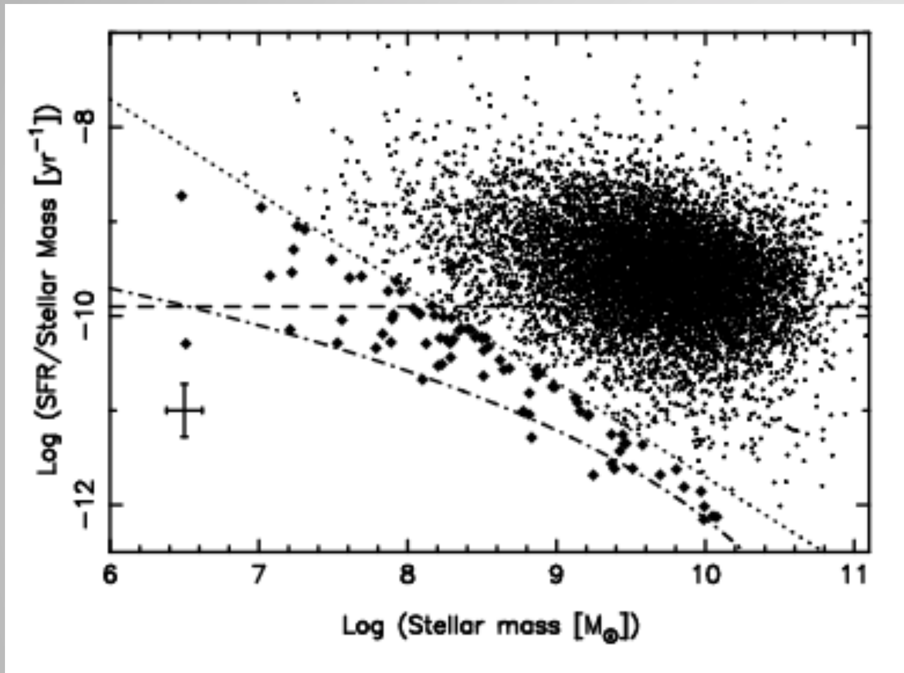
Galaxy And Mass Assembly



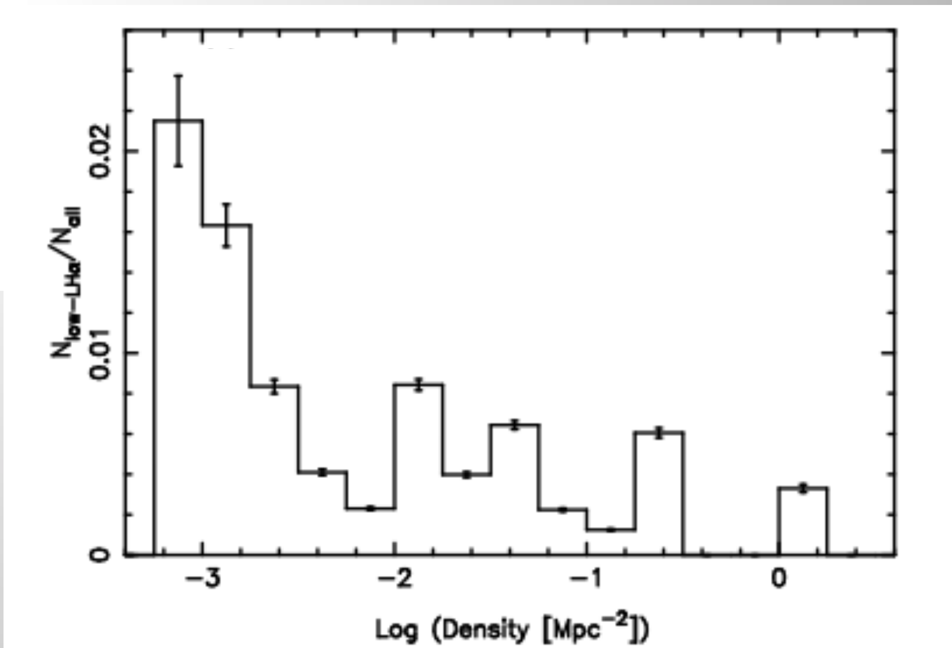
Brough et al. (2011a)



Galaxy And Mass Assembly



Brough et al. (2011a)



•SSFRs are consistent with their having a variety of star formation histories.

•Low-SFR galaxies are in under-dense environments.

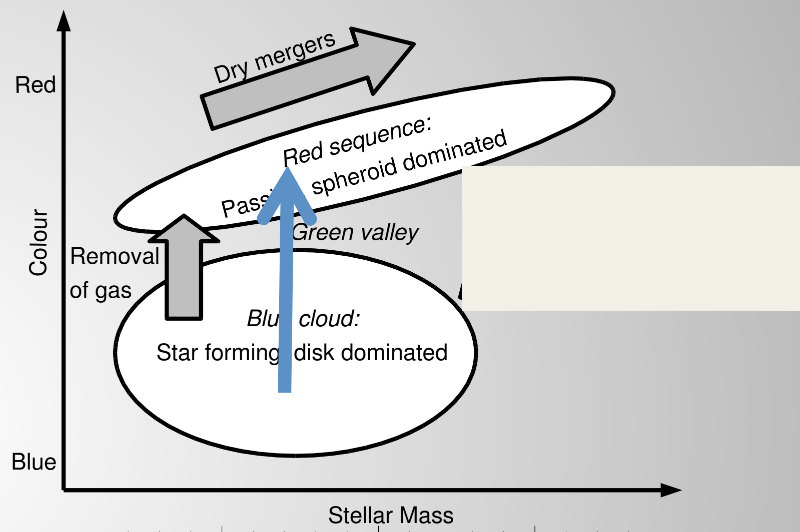
Little Blue Fuzzies Conclusions

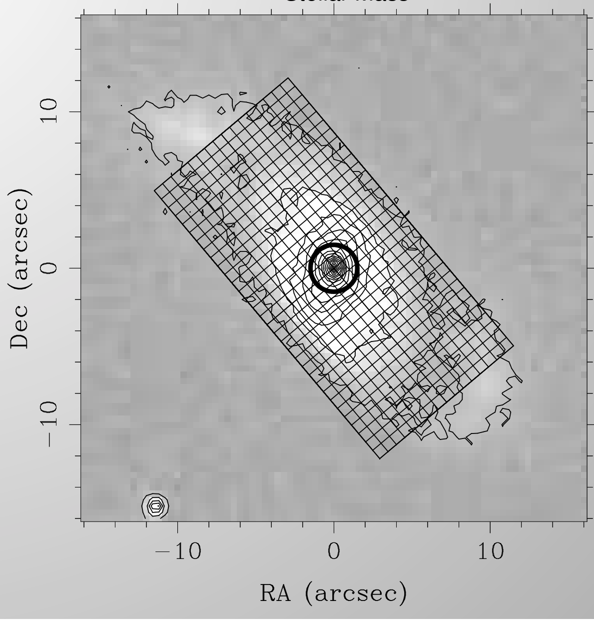
- Most are low-mass galaxies (median stellar mass $=2.5\times10^{8}\ M_{sun}$)
- Similar to local group dwarf irregulars they show a wide range of star formation histories (e.g. Weisz+11)
- Global environment shows that such low-mass, star-forming systems can only remain if they reside sufficiently far from other massive galaxies to avoid being accreted, dispersed through tidal effects or having their gas reservoirs stripped.

And Beyond…

- How do galaxies move from blue cloud to red sequence: Environmental effects or feedback?

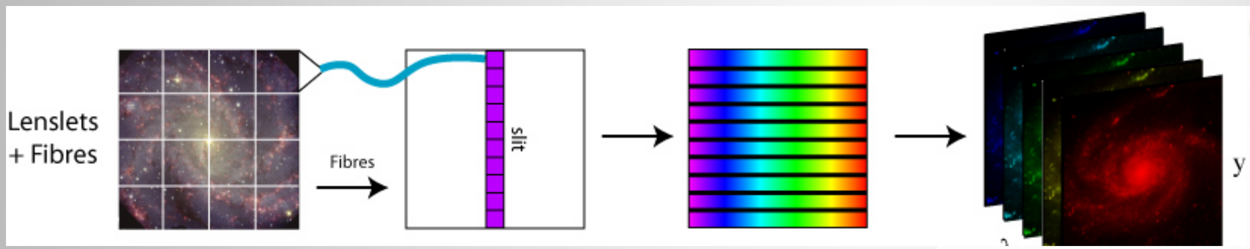
- Much progress made by large surveys BUT single fibre on centre of galaxy gives limited information on spatial properties (e.g. truncation of star formation on outskirts of galaxies)





Integral Field Spectroscopy

- There is another way to look at things, using INTEGRAL FIELD SPECTROSCOPY
- An IFS is an instrument that allows you to gather spectra over a two-dimensional field-of-view.

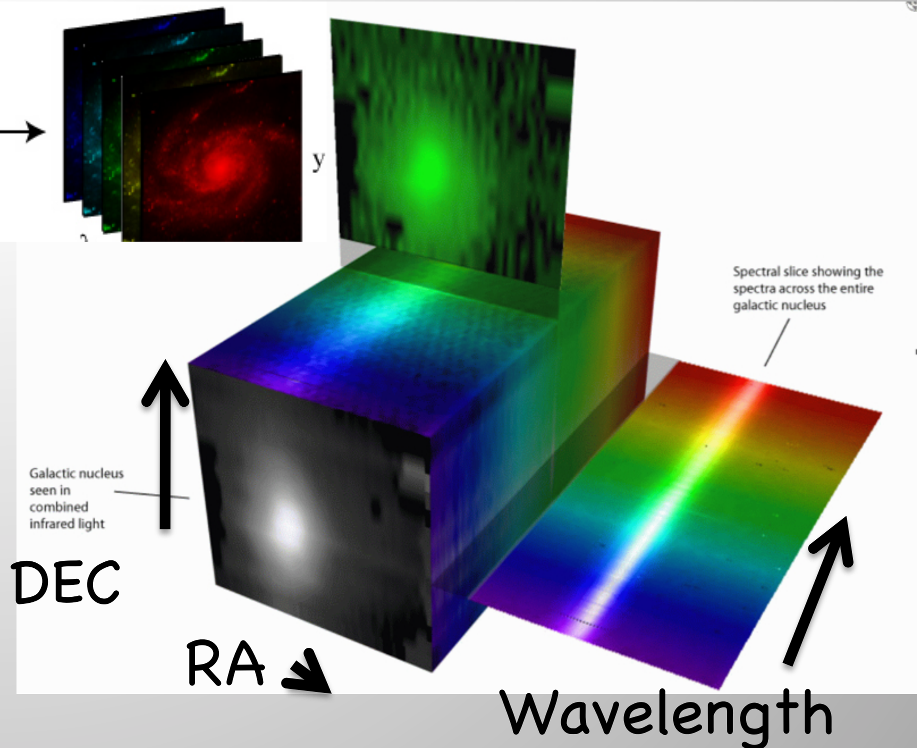


e.g.

SPIRAL on the Anglo-Australian Telescope

VIMOS on the Very Large Telescope

GMOS on Gemini

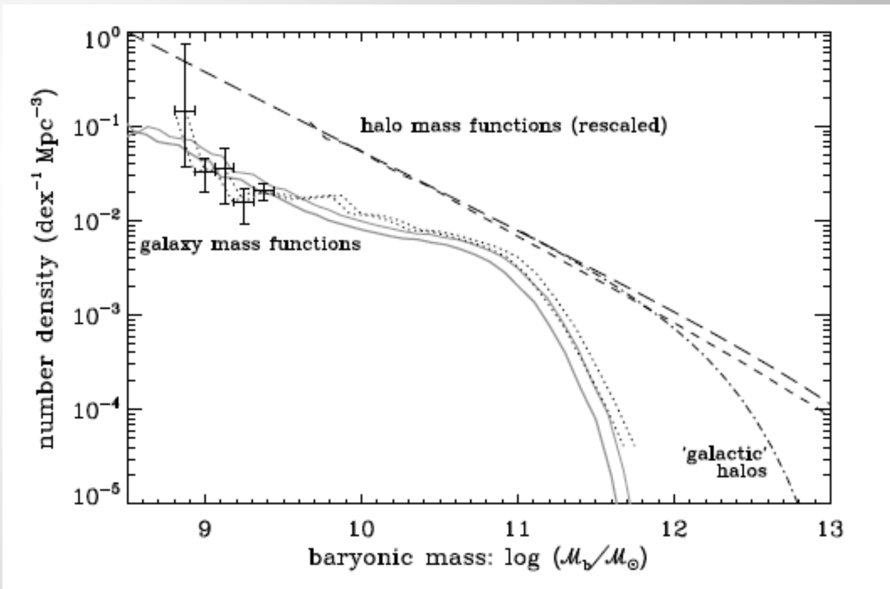


Credit: Stephen Todd (ROE) and Douglas Pierce-Price (JAC)

- IFU observations enable study of:
  - Angular momentum
  - Dynamical mass
  - Stellar Age distributions
  - Stellar and Gas Metallicity distributions
  - Star formation distributions
  - Evidence of mergers through kinemetry

- Lots of research on nearby early-type galaxies (SAURON/ATLAS3D) and distant star-forming galaxies (e.g. SINS/Law+2010/Wisnioski+2011) but not on local star-forming galaxies

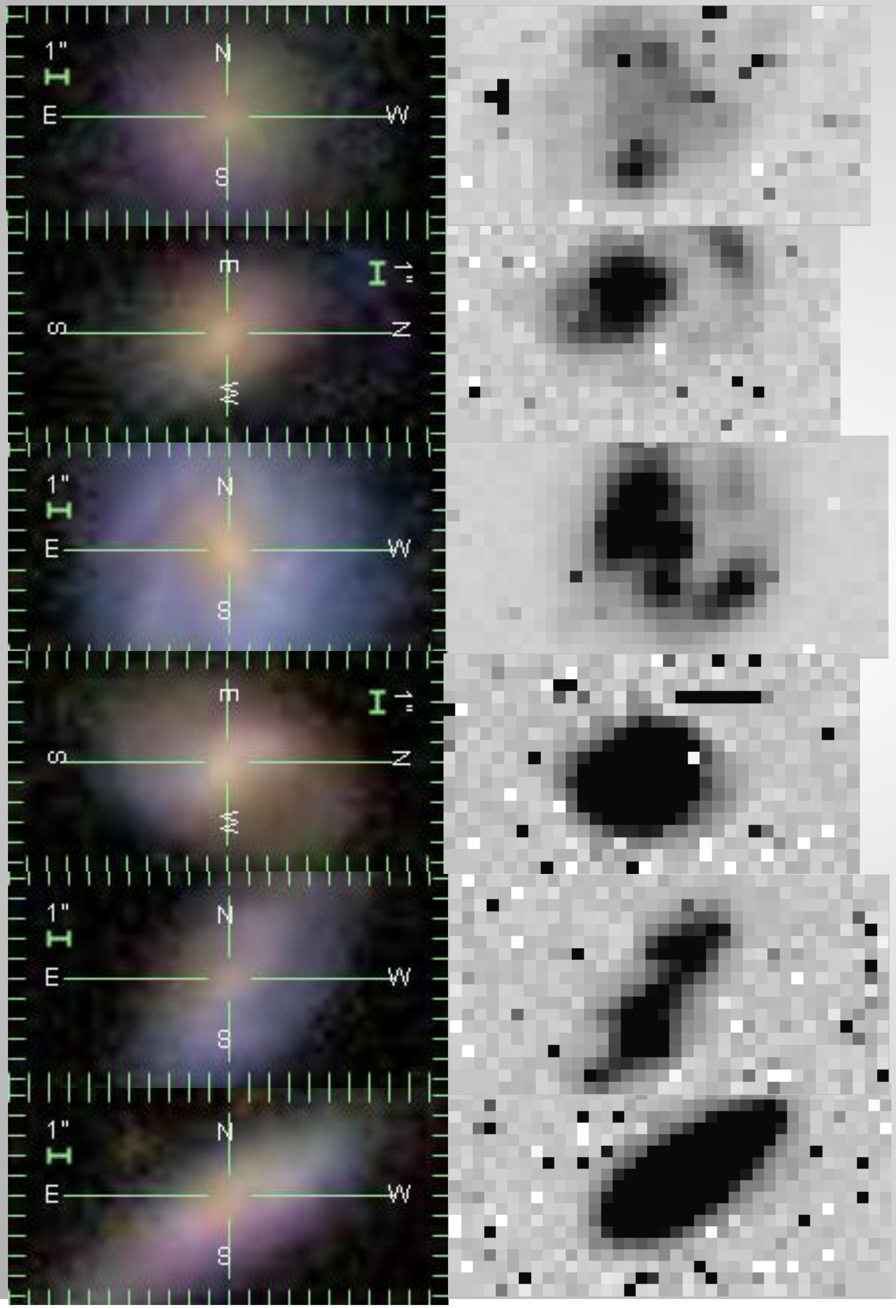
- Observe galaxies in narrow stellar mass slice to remove stellar mass effects: choose 10^{10} M_{sol} as this is the mass at which the stellar mass function is significantly suppressed relative to the dark matter halo mass function (Baldry et al. 2008)



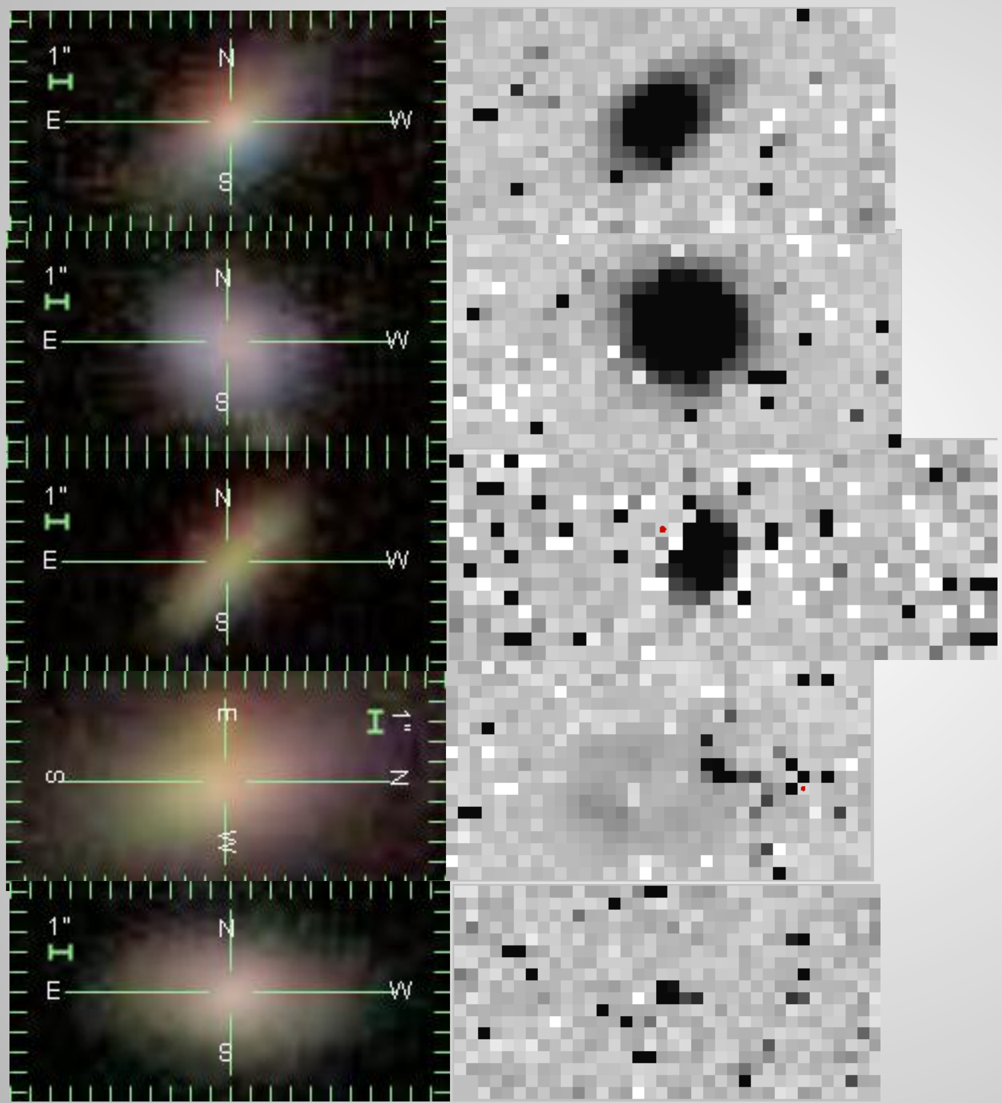
- Selected from GAMA

- Examine effects of environment on spatially resolved properties.

Integrated Hα Emission (Env Density < 0.05 gals/mpc$^{2)}$



Integrated Hα Emission (Env Density ~ 0.5 gals/mpc^{2})



G418448

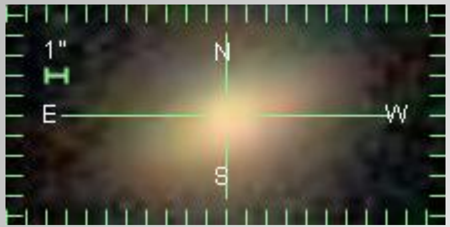
G227962

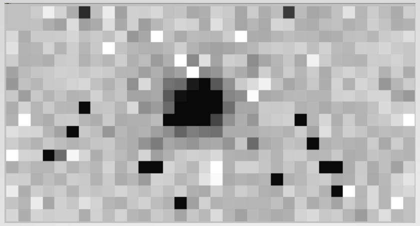
G106252

G92770

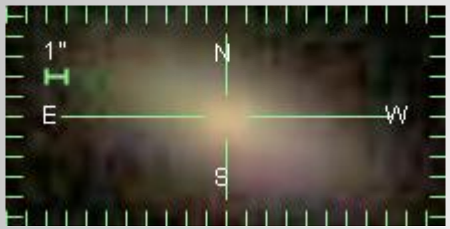
G422359

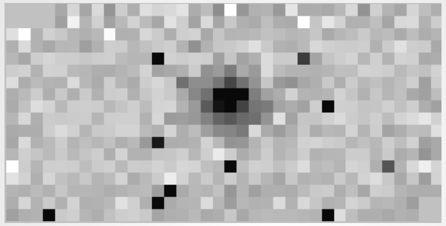
Integrated Hα Emission (Env Density >5 gals/mpc^{2})





G227278



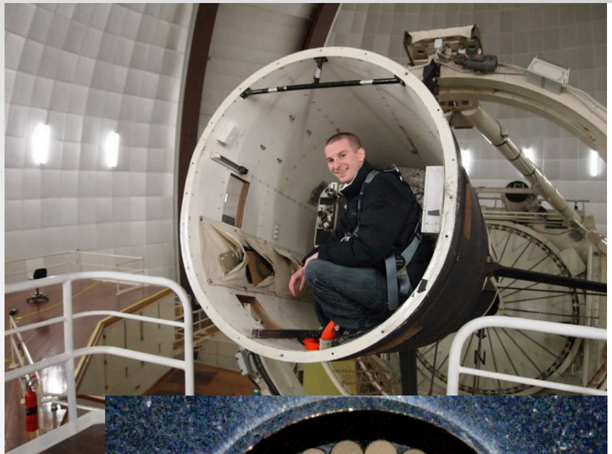


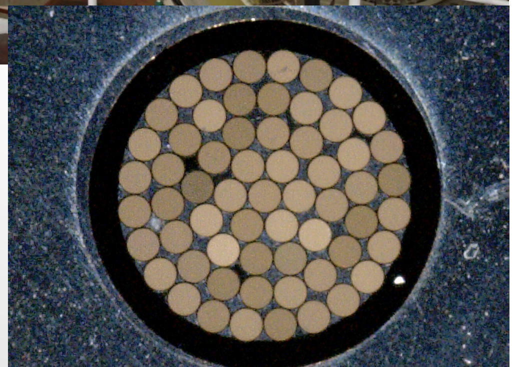
G136880

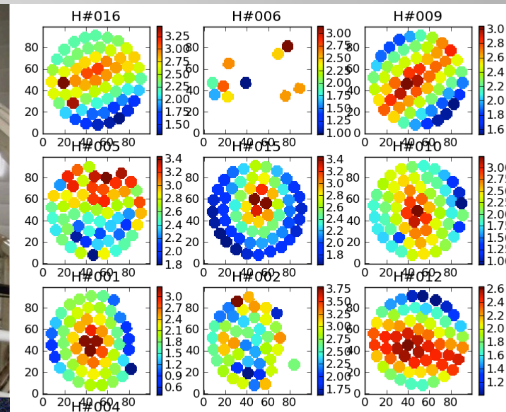
Work in progress so obviously a lot more analysis to be done. But is an interesting start…

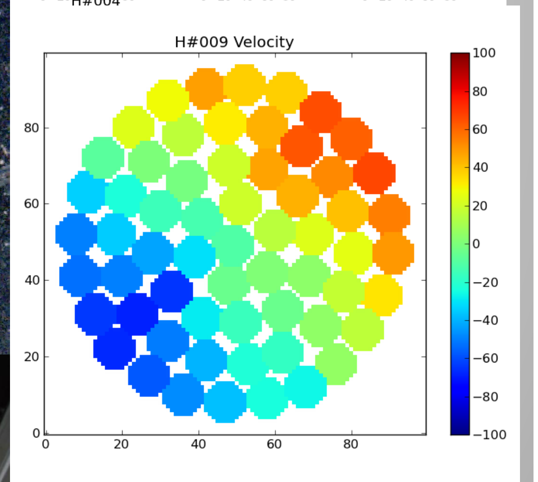
A new AAT Instrument

- SAMI (Sydney AAO MOS IFS)
- 13 deployable "hexabundle" fibres 61 1.7" fibres per bundle and ~14" per bundle across 1 deg field
- Led by Scott Croom (Sydney Uni) and Jon Lawrence (AAO).





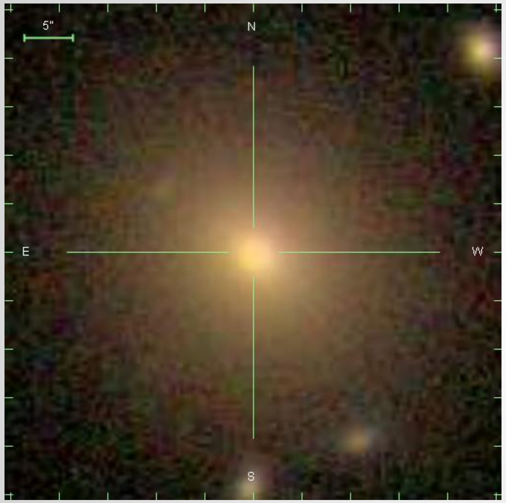


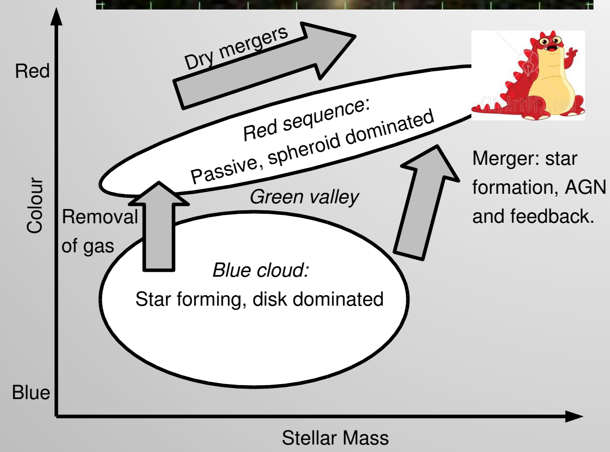


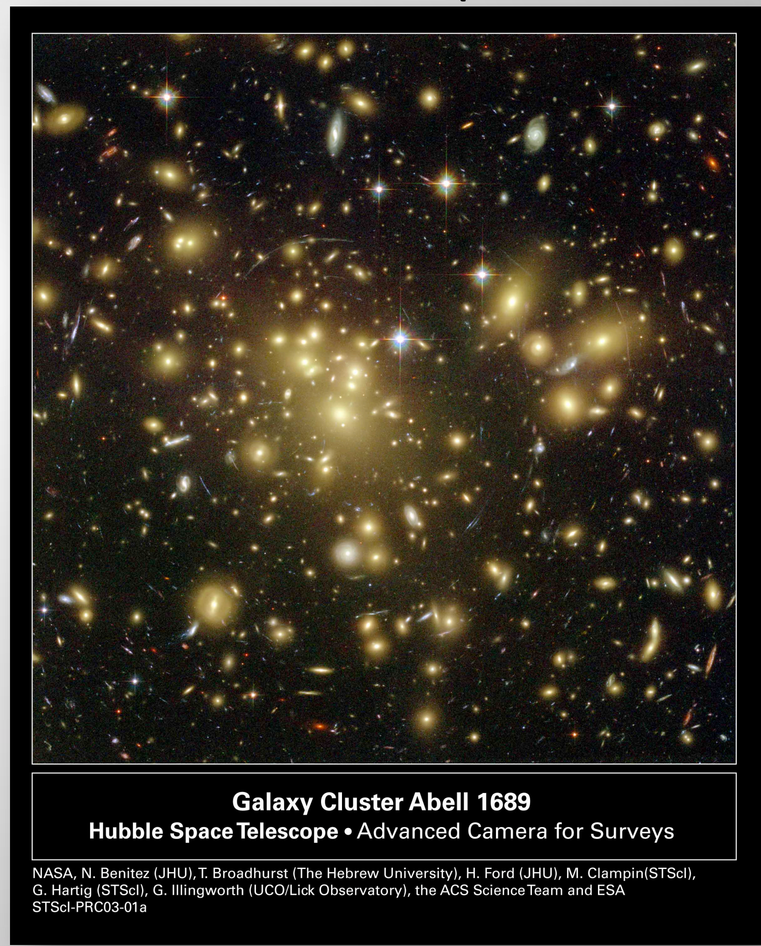
Croom et al. submitted

Massive Red Monsters
Brightest Cluster Galaxies (BCGs)

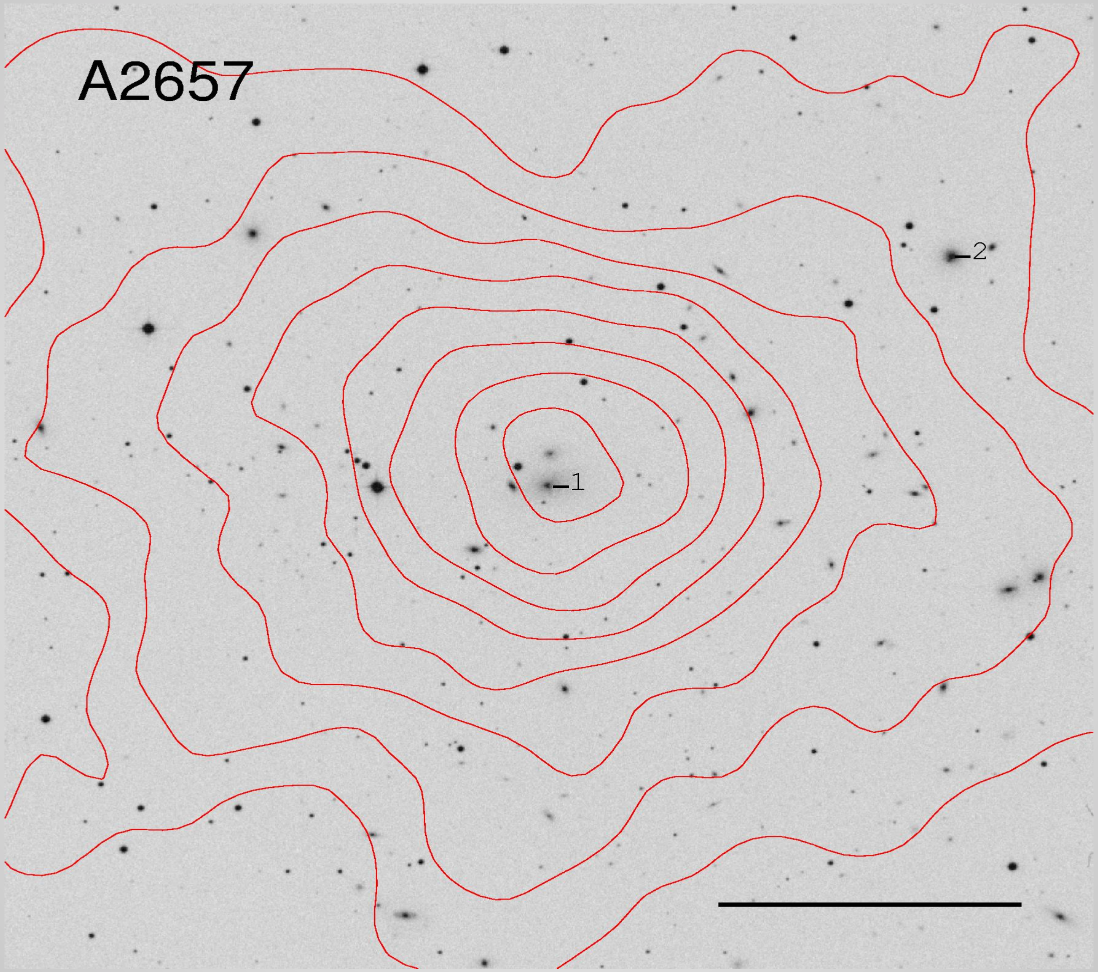
with Kim-Vy Tran (Texas A&M), Rob Sharp (Mount Stromlo) Anja von der Linden (Stanford) and Warrick Couch (Swinburne)





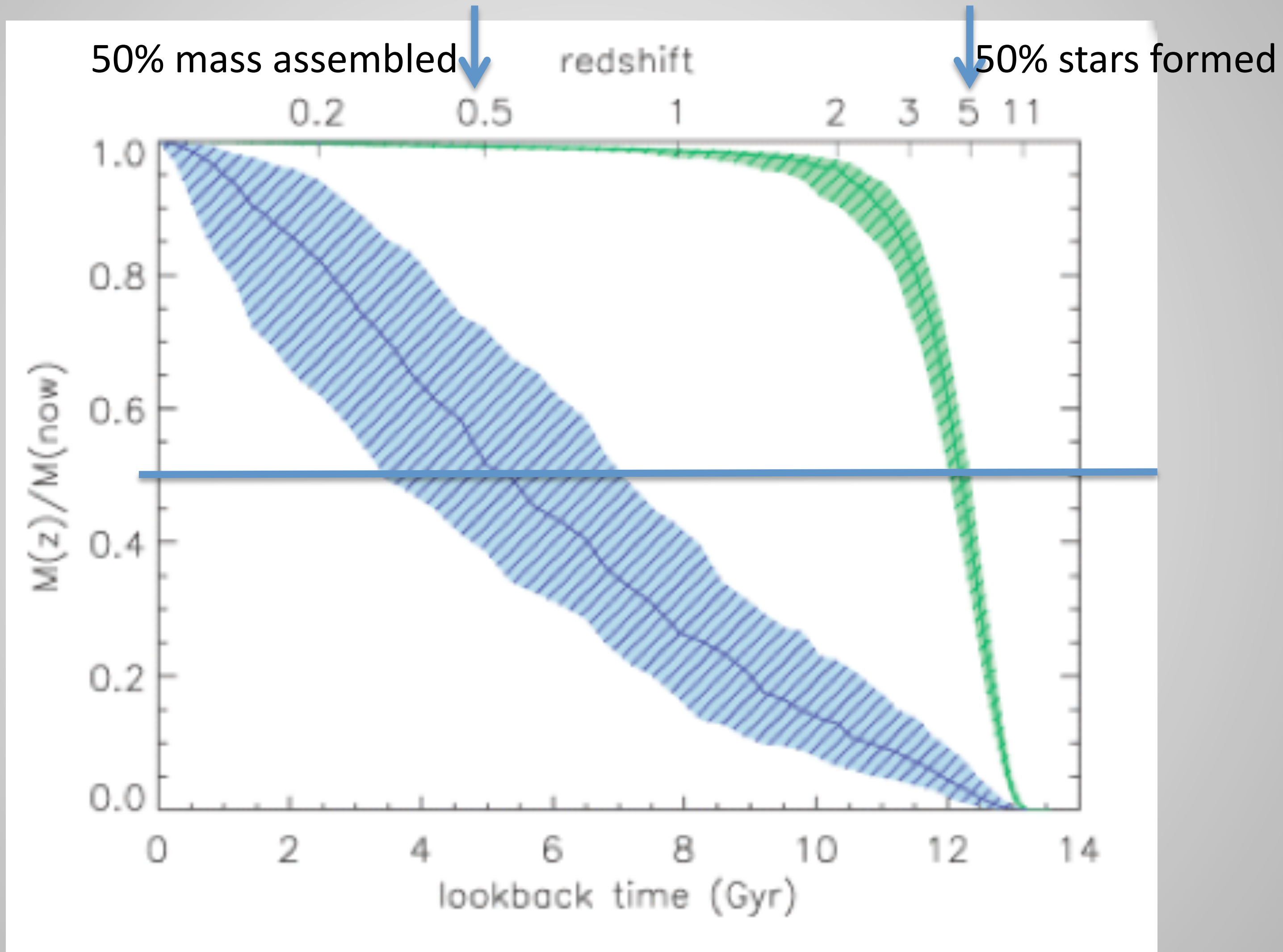


X-ray Image of Galaxy Cluster Abell 2657



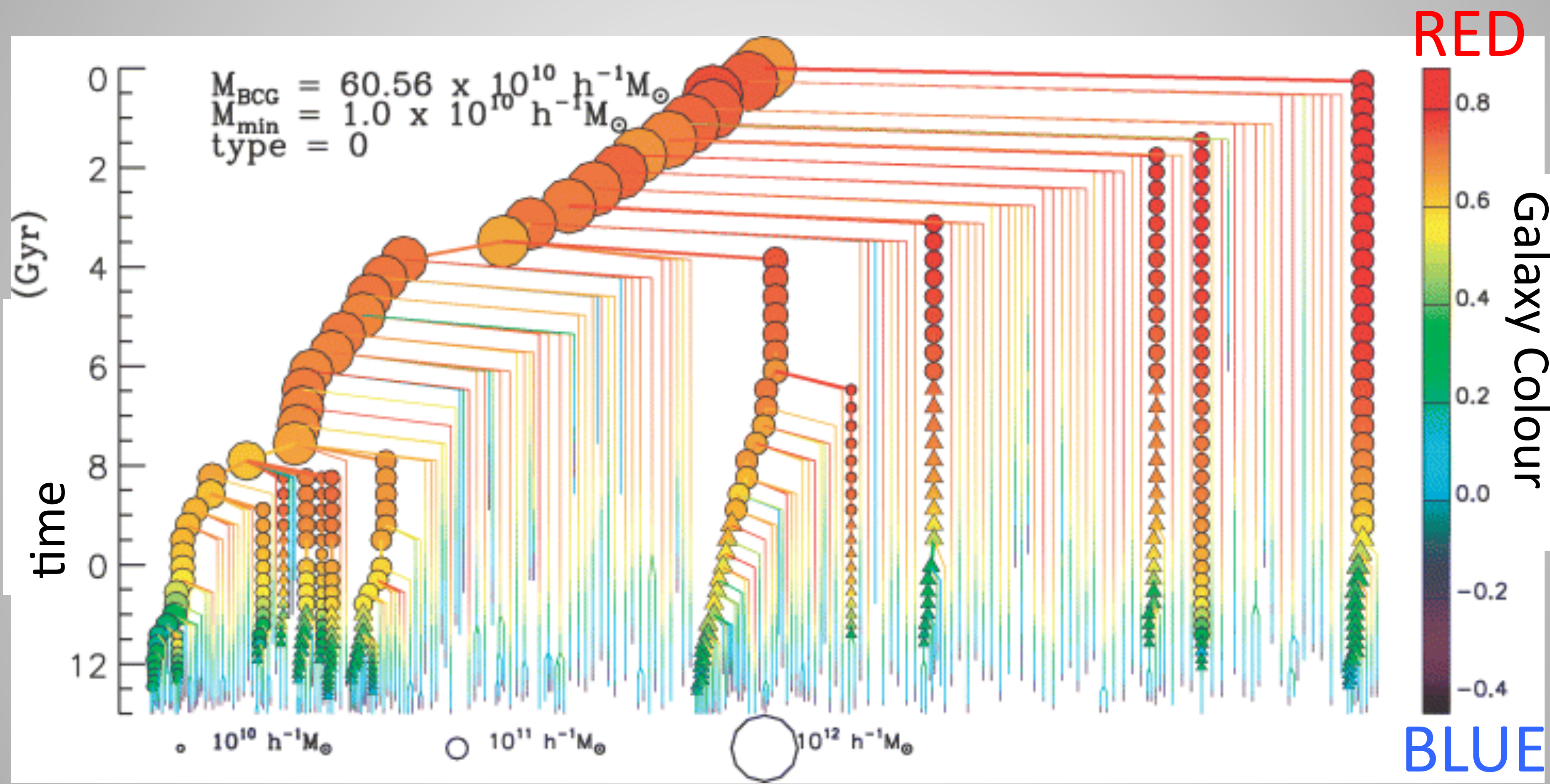
5 arcmin (240 kpc)

HOW DID THEY GET TO BE SO MASSIVE?



de Lucia & Blaizot (2007)

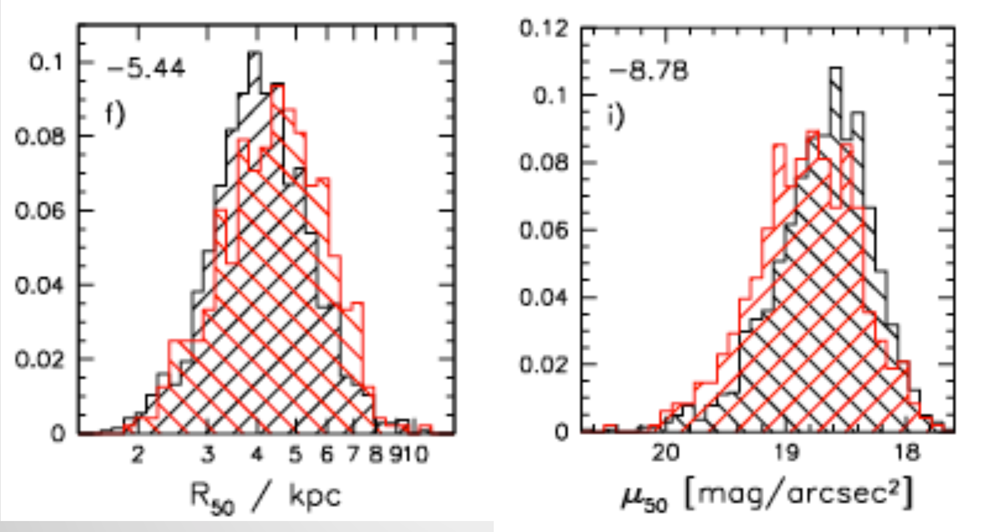
Evolution Path



de Lucia & Blaizot (2007)

1. Shapes

- We can compare the sizes and light profile of BCGs to other galaxies and to models that examine the effects of mergers

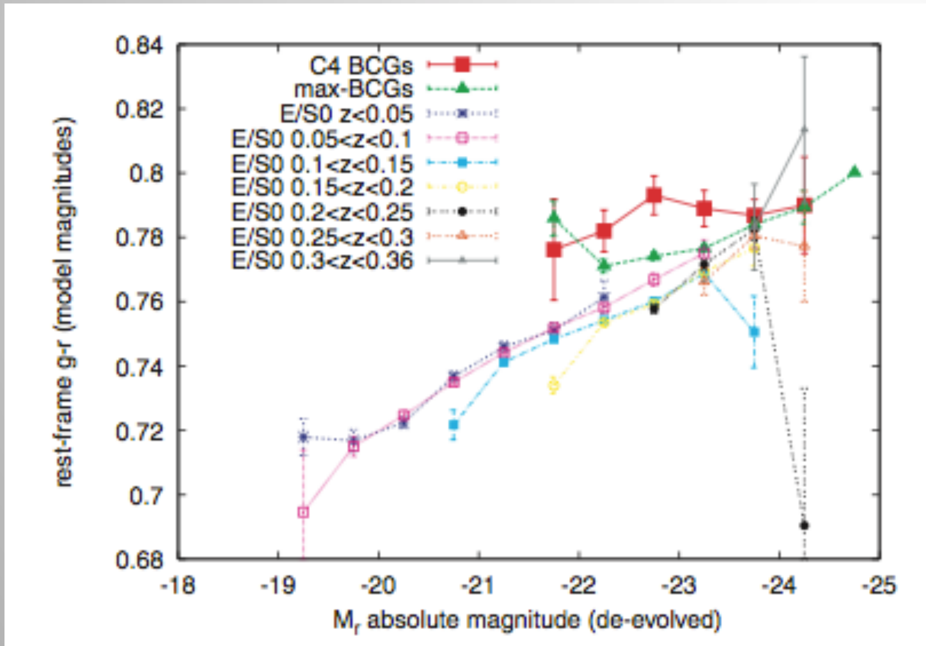


von der Linden et al. 2007

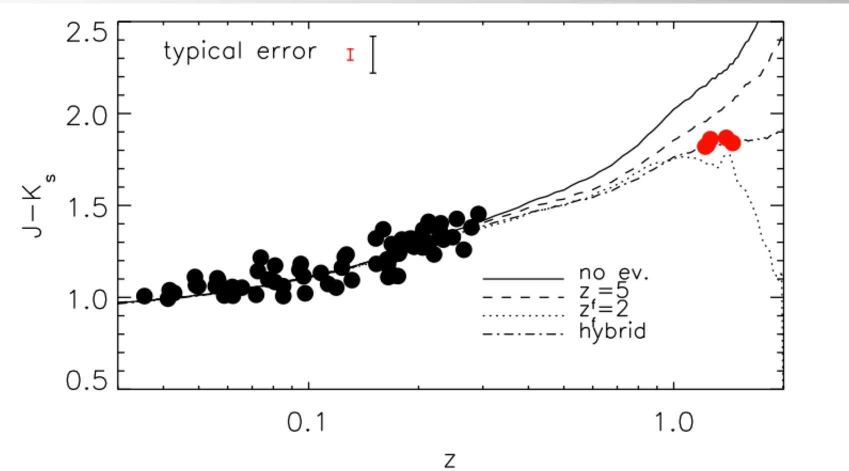
- BCGs have larger sizes and more diffuse light profiles than less massive galaxies – suggesting they are more likely to be gas-less major merger remnants (e.g. Oegerle et al. 1991, Brough et al. 2005, von der Linden et al. 2007, Lauer et al. 2007, Ruszkowski et al. 2009)
- BCG sizes and velocity dispersions may also evolved faster than less-massive early-type galaxies since z~0.3 (Bernardi et al. 2009 but see Stott et al. 2011)

2. Colours

- Their colours are redder than other galaxies and spectra show little sign of star formation



Roche et al. (2010)

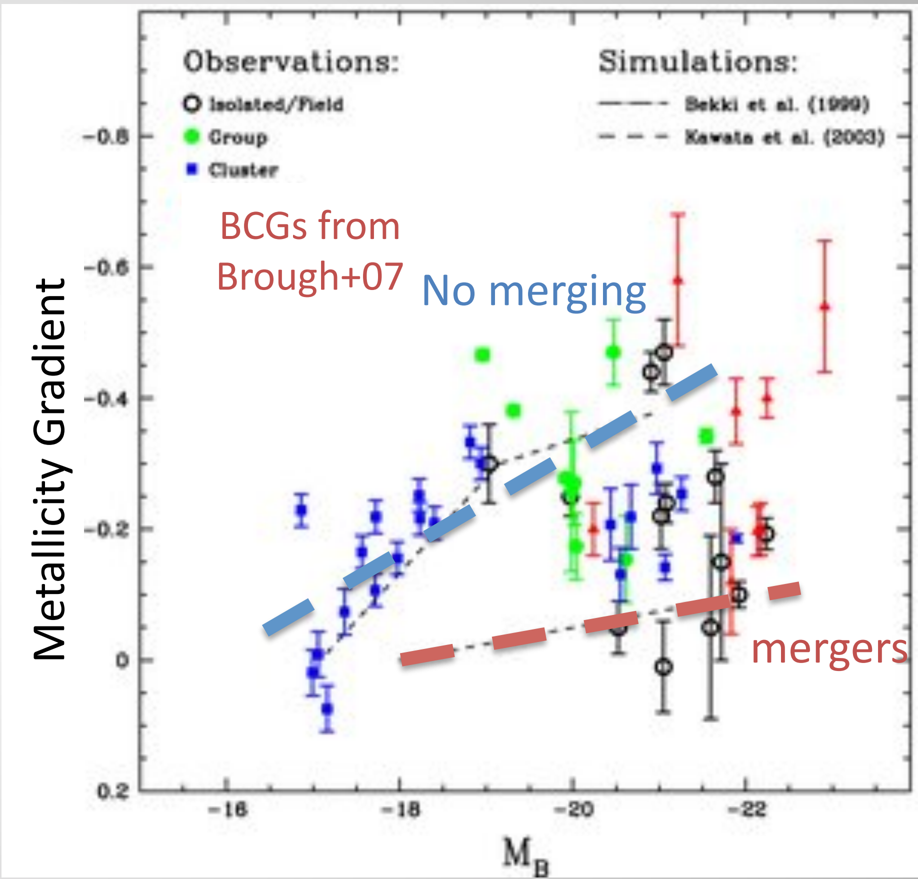


Collins et al. (2009)

3. Stellar populations

- Different modes of galaxy evolution (e.g. many mergers vs none) leave different imprints on the radial distribution of stellar populations, particularly the metallicity gradients.

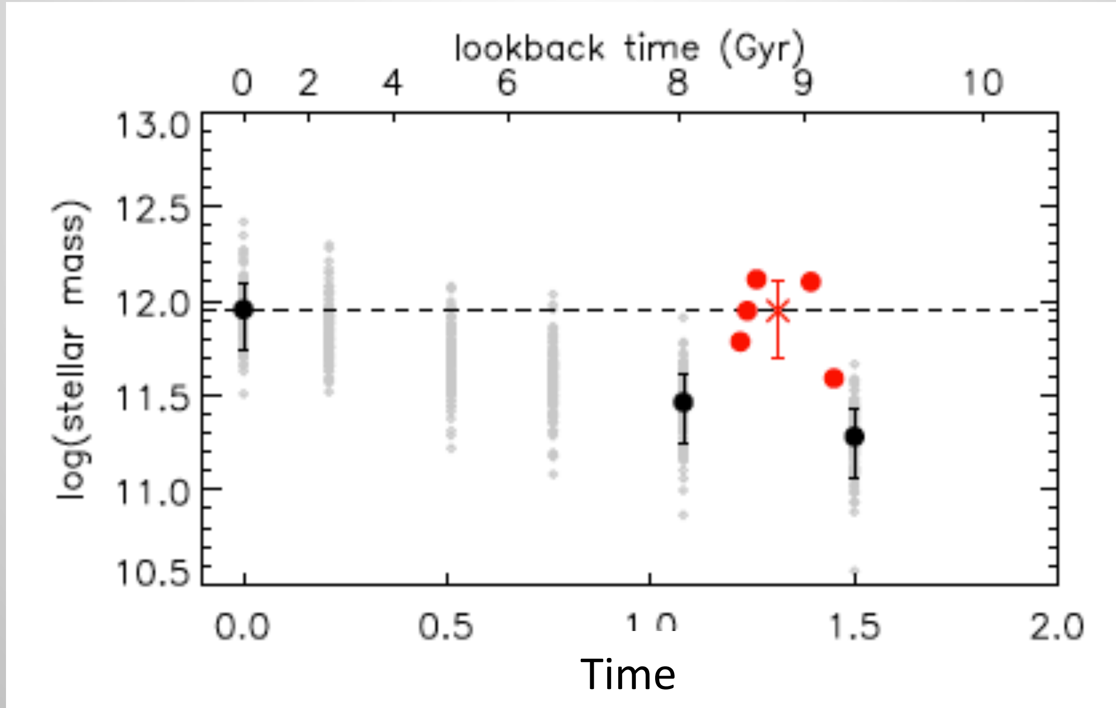
- Some BCG metallicity gradients are steep showing little evidence for recent major mergers (Brough et al. 2007)



Spolaor et al. (2010)

4. Evolution

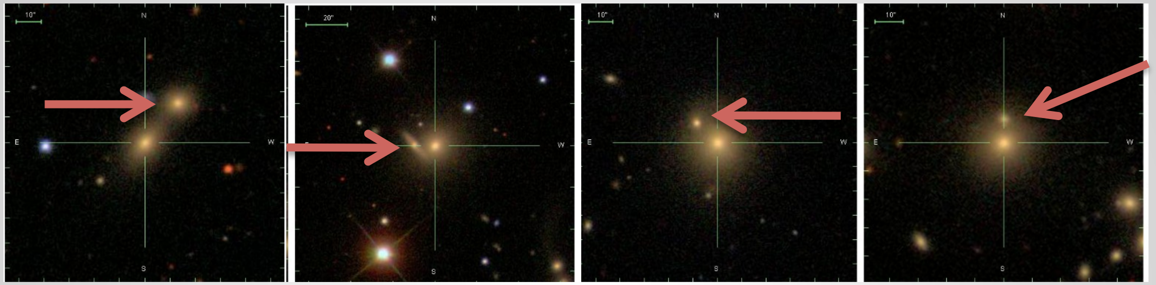
- Studies of BCG luminosities/stellar masses over time show little evolution over last 8-9 Gyrs, certainly not as much as suggested by models



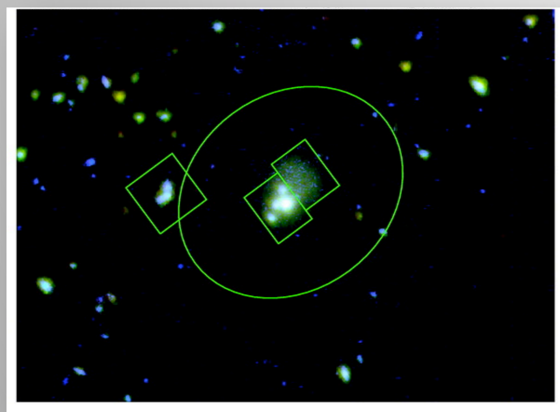
Collins et al. (2009)

5. Fuel?

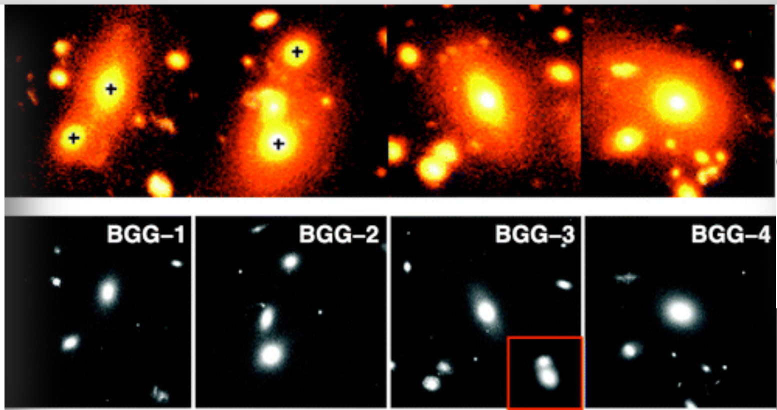
- BCGs are frequently observed to have multiple nuclei:



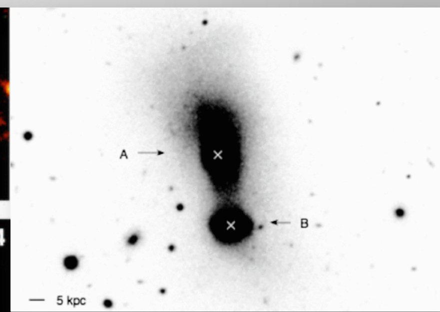
- And, there are some direct observations of BCGs undergoing mergers:



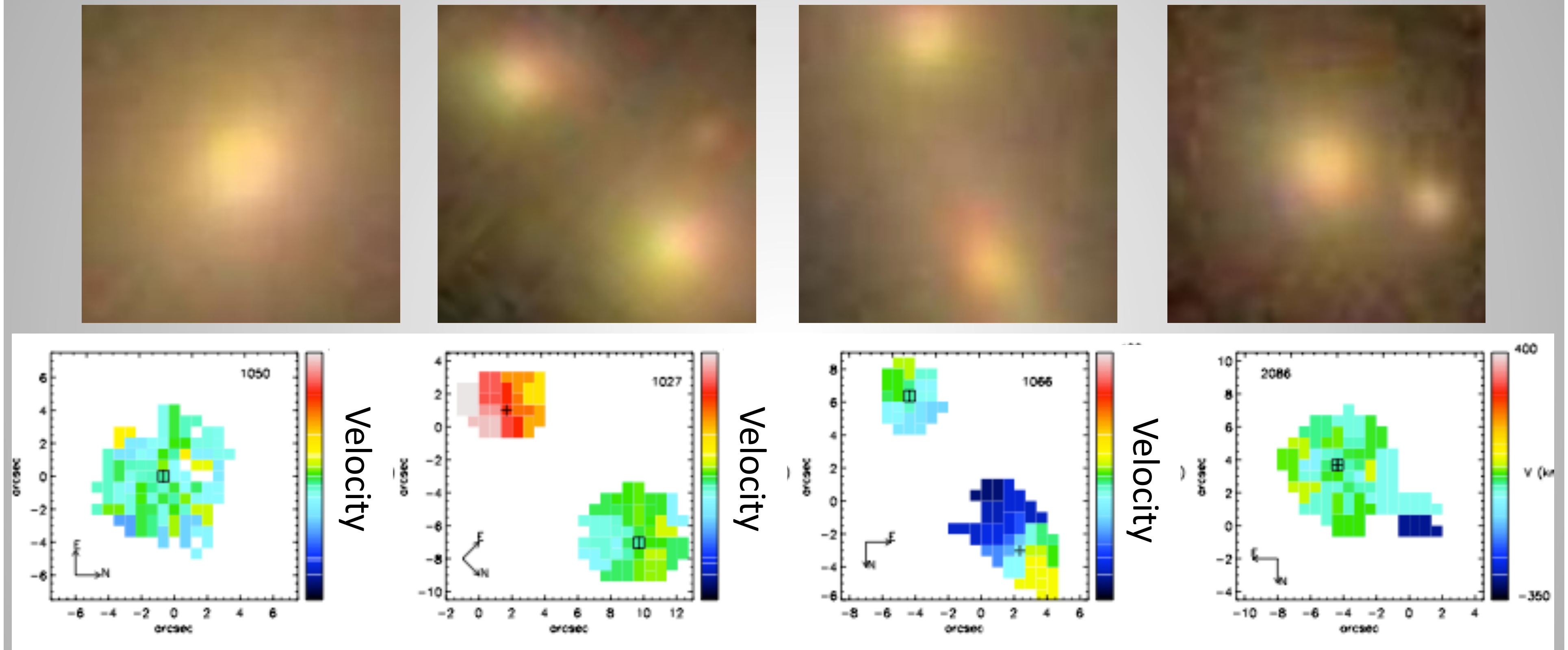
Rines et al (2007)



Tran et al (2008)



Rasmussen et al (2010)



Cluster 1050 Cluster 1027 Cluster 1066 Cluster 2086

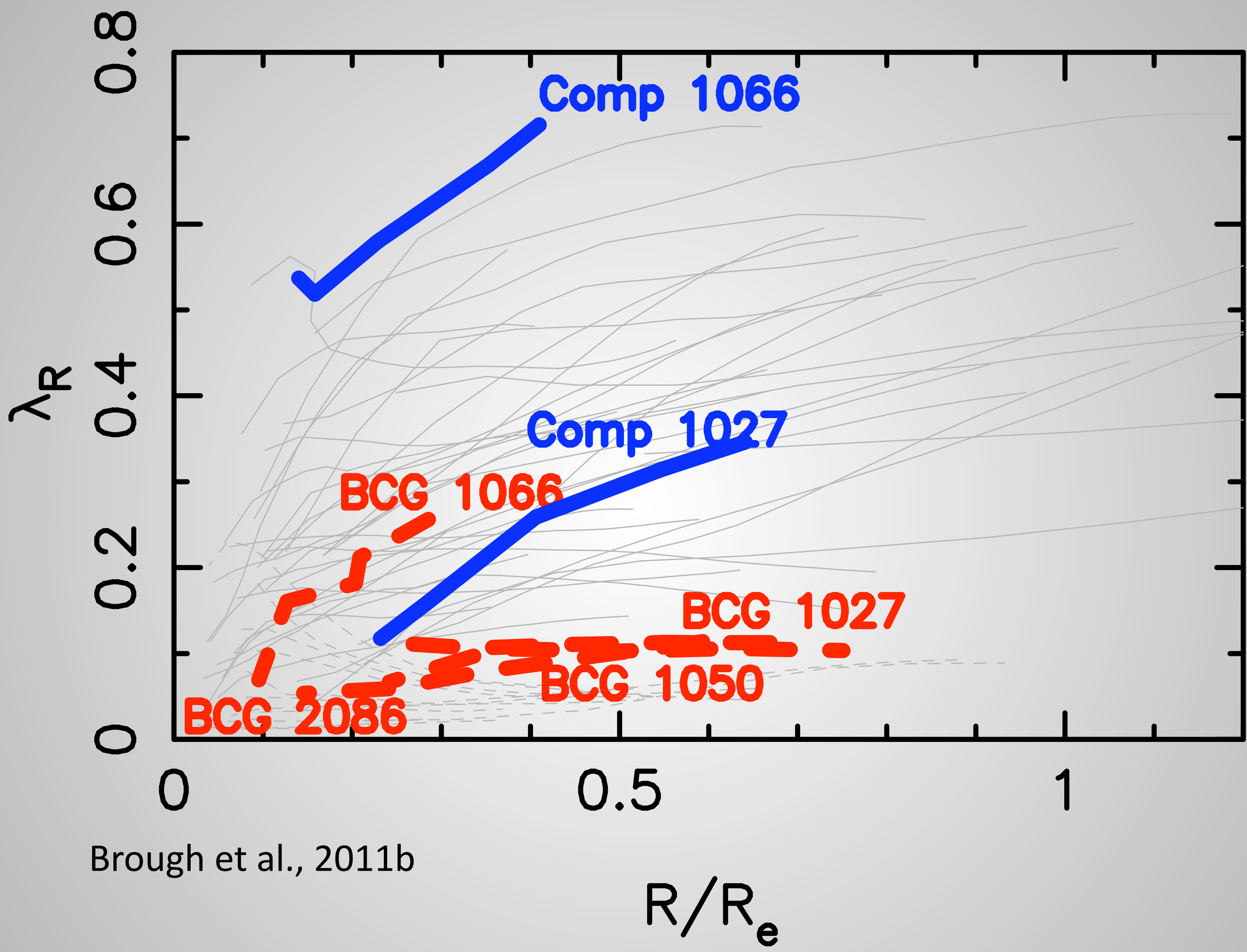
Brough et al. (2011b)

Are the companions bound?

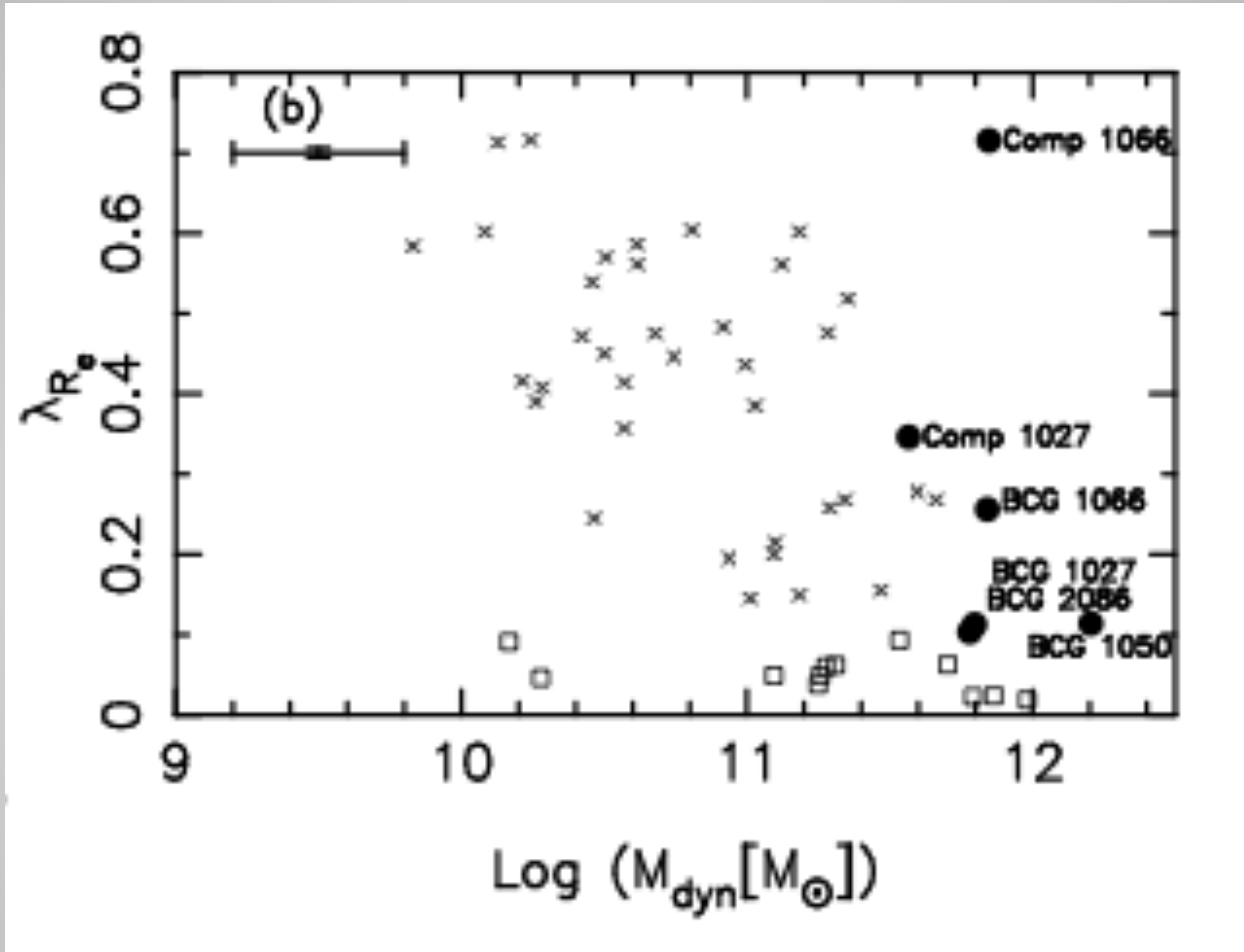
- The 2086 system is likely to be bound at an upper limit of only the 0.1 per cent level
- The 1027 system is likely to be bound at an upper limit of 61 per cent
- The 1066 system is likely to be bound at an upper limit of 98 per cent
- No emission lines therefore dry; nearly equal-mass therefore major mergers.
- Evidence that BCGs continue to grow by major, dry, mergers, even at z~0

6. Angular Momentum

- Λ_R = < R|V| > / < R sqrt($V^2 + \sigma^2$) >, is a proxy for the observed projected stellar angular momentum per unit mass.
- Early-type galaxies are separated into slow and fast rotators, depending on whether they have $\Lambda_{Re} > 0.3\sqrt{\varepsilon_e}$ (Emsellem et al. 2011)
- Provides a new parameter with which to compare BCGs to other early-type galaxies and to models



Brough et al., 2011b



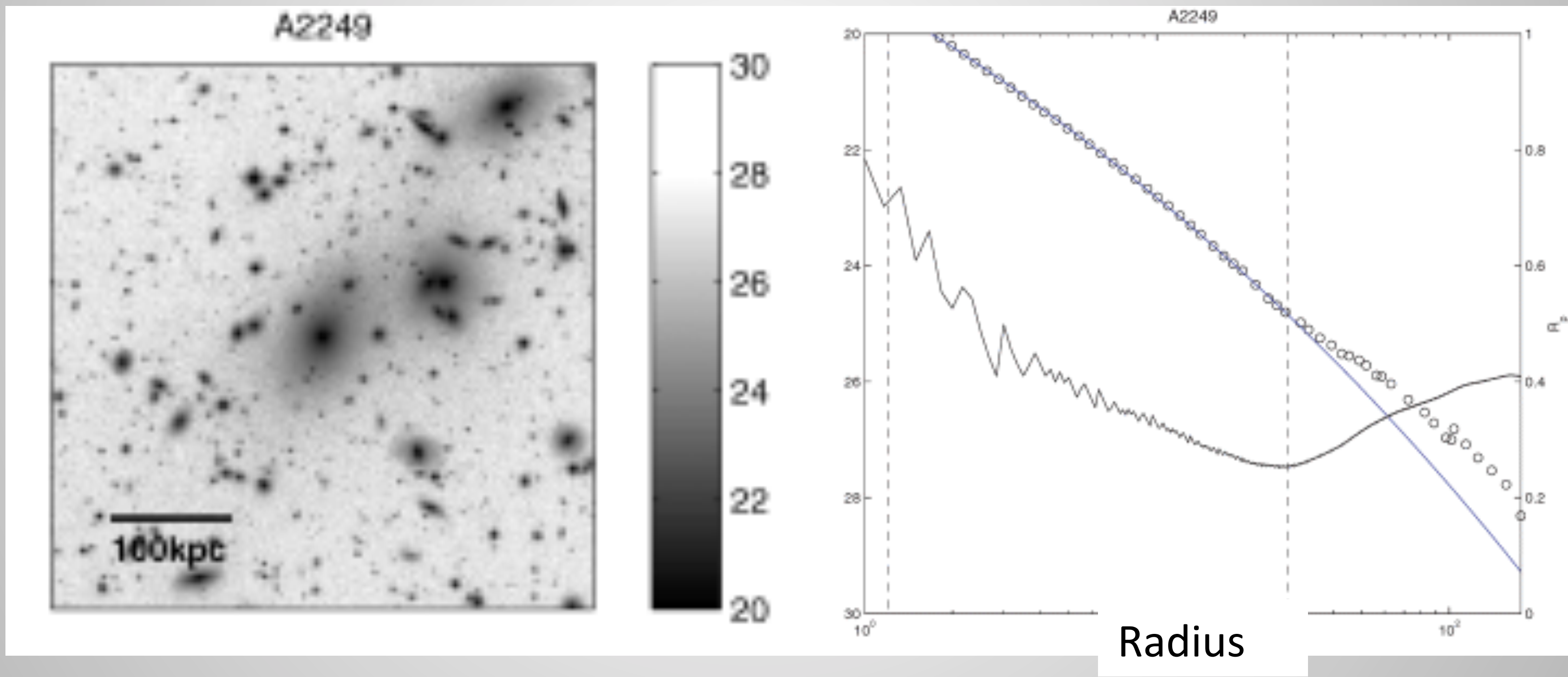
Brough et al., 2011b

In summary:

1. Shapes suggest mergers have happened ☑
2. Colours suggest little/no recent star formation ☑
3. Stellar populations suggest for *some* any significant merger was a very long time ago ☒
4. Little stellar mass increase over 9 Gyrs ☒
5. Major mergers do still occur for *some* ☑
6. Angular Momentum low for *some* ✍

POSSIBLE SOLUTION?

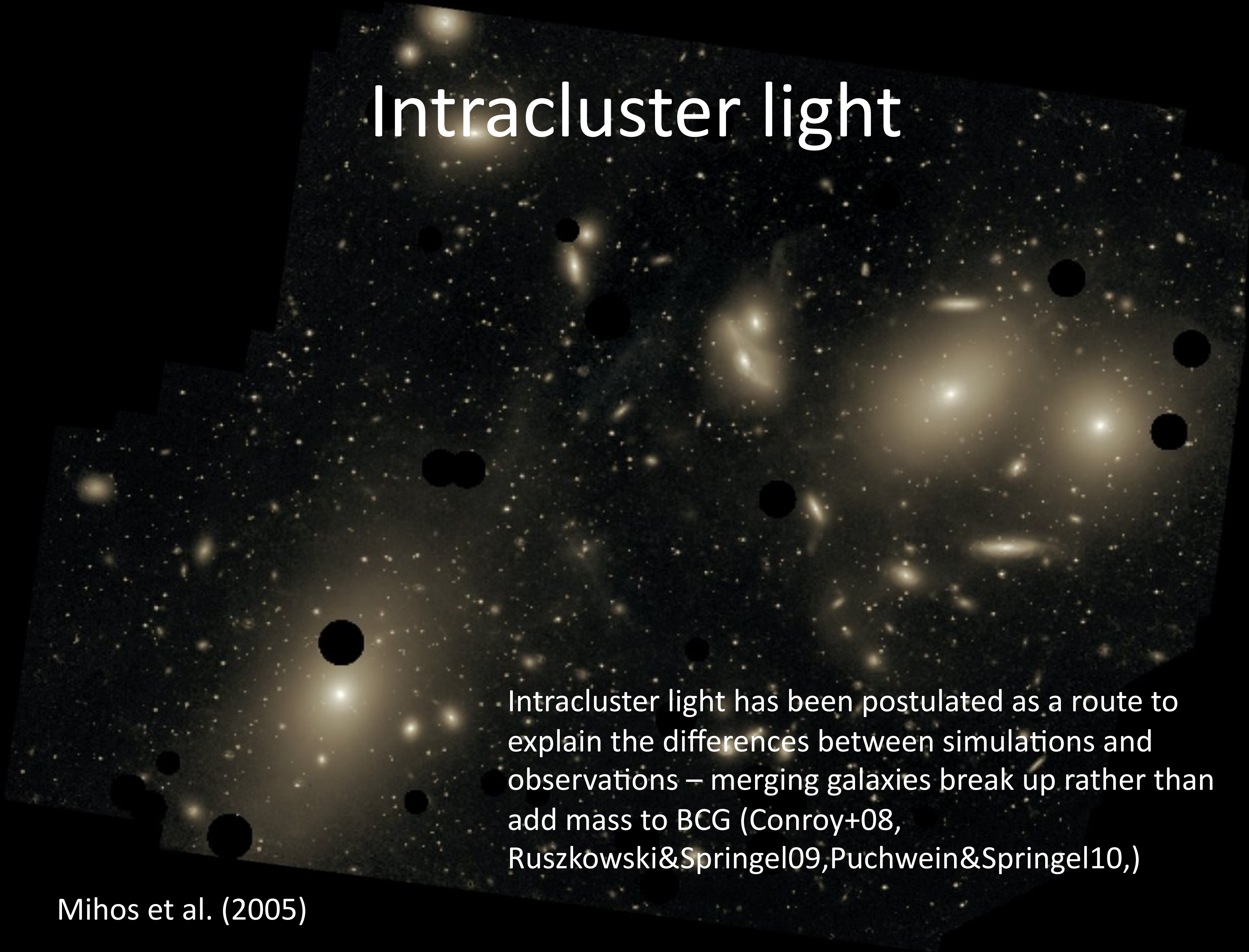
- Many BCGs are observed to have an extended, low surface brightness envelope around them: these are classified as cD galaxies



Patel et al. (2006)

- Make up 10 - 50 per cent of the total optical cluster luminosity (e.g. Kelson+02, Gonzalez +05+07,Patel+06

Intracluster light



Intracluster light has been postulated as a route to explain the differences between simulations and observations – merging galaxies break up rather than add mass to BCG (Conroy+08, Ruszkowski&Springel09,Puchwein&Springel10,)

Mihos et al. (2005)

Where Now?

- Observations still can't prove/disprove models
  - Need to know more about intra-cluster light!
  - Need better estimation of when/what merging
  - Larger samples with stellar population analyses
- Models could be wrong in treatment of merger debris, timescales for merging or input stellar populations or…??
- All very single wavelength…
- Need GAMA and more observations… ☺

More science on its way, keep a look out!