Unraveling the properties of the brightest cluster galaxies

using multi-wavelength data

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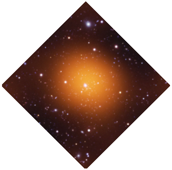

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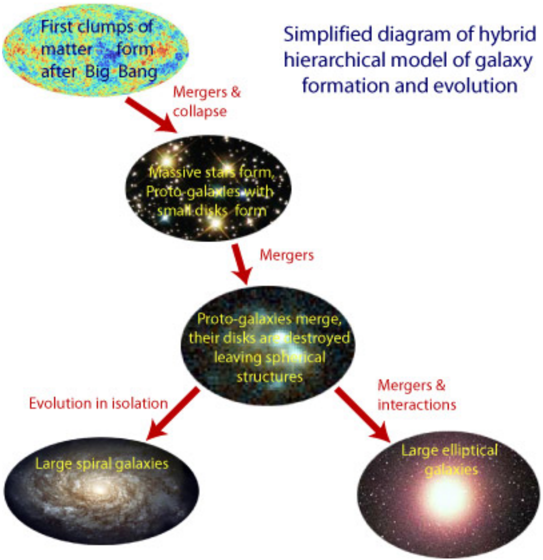
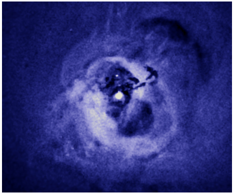
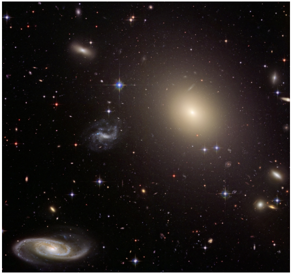
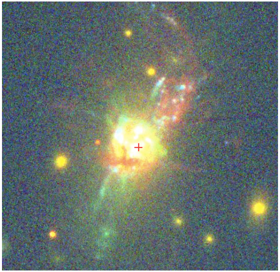

First clumps of matter form after Big Bang
Simplified diagram of hybrid hierarchical model of galaxy formation and evolution
Mergers & collapse
Massive stars form, Proto-galaxies with small disks form
Mergers
Proto-galaxies merge, their disks are destroyed leaving spherical structures
Evolution in isolation
Mergers & interactions
Large spiral galaxies
Large elliptical galaxies

Perseus (NGC1275)







Nearby BCGs exhibit diverse morphologies, stellar populations, and star formation histories – important for understanding:

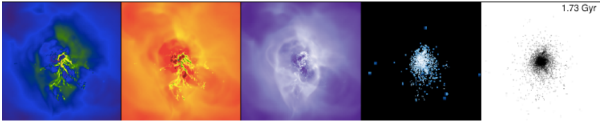
- Mass build-up and evolution of BCGs and host clusters
- Explain the physical mechanisms behind heating and cooling cycle in cool-core clusters

Sample

- 14 MENeaCS $(0.05 < z < 0.15)$ Gemini GMOS & CFHT MegaCam
- 18 CCCP $(0.15 < z < 0.30)$ Gemini GMOS & CFHT MegaCam
- 4 CLASH $(z \sim 0.35)$ SALT RSS & HST

36 BCGs between $0.05 < z < 0.35$

Optical spectra	Imaging	X-ray/Cluster
redshift	stellar light profiles	offset from X-ray peak
rotation	core size and inner slope	centroid shift variance
central vel dispersion	isophote and core shapes	halo mass
vel dispersion slopes	stellar circular vel profiles	cluster vel dispersion
young populations and ages	colour gradients	central entropy
age/metallicity gradients	multiple nuclei	cooling time
stellar M/L ratios	brightness	
	ellipticity	*Hoekstra et al. 2012; 2015*
	effective radius	*Mahdavi et al. 2013*



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rotation

vel dispersion slopes

young populations and ages

stellar M/L ratios

stellar light profiles

core size and inner slope

Spectra and analysis

Gemini & SALT spectra:

- Spatially-resolved long-slit spectroscopy
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Kinematics & Stellar population analysis:

- Vazdekis/MILES high resolution stellar population models
- full-spectrum fitting (3500 – 4900 Å), using a Salpeter IMF
- Identify best-fitting spectrum SSP (t_{SSP}) & the best-fitting composite stellar model (of age $t_{young} < 2$ Gyr superposed on an intermediate/old stellar population with $t_{old} > 2$ Gyr)
- If the $t_{SSP} < 10$ Gyr then the stellar population consists of both an old stellar population as well as intermediate aged stellar population(s).

Loubser, Babul, Hoekstra, Mahdavi, Donahue, Bildfell, Voit, 2016, MNRAS, 456, 1565

Images and analysis

- CFHT r-band & HST F814W (for 4 CLASH BCGs)
- Fit surface brightness profiles *(similar to Bildfell et al. 2008)*

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The envelope profile has the form $I(r) \sim r^{-\beta}$ as $r \rightarrow \infty$, while the inner cusp has $I(r) \sim^{-\gamma}$ as $r \rightarrow 0$; with the transition radial-scale provided by the “break-radius” r_b. The “speed” of transition between the envelope and inner cusp is provided by α.

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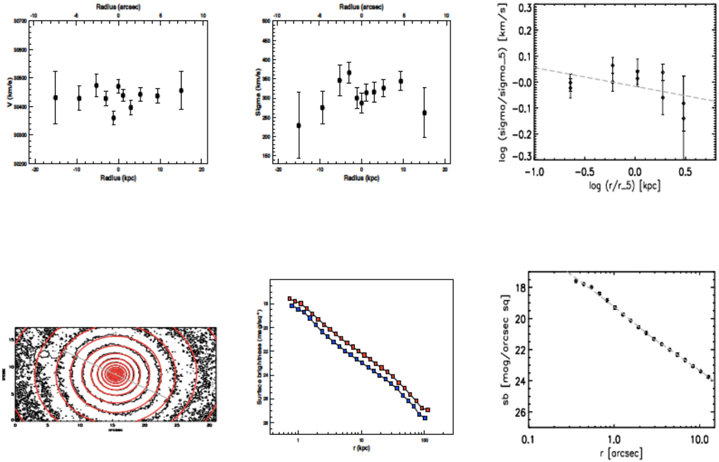
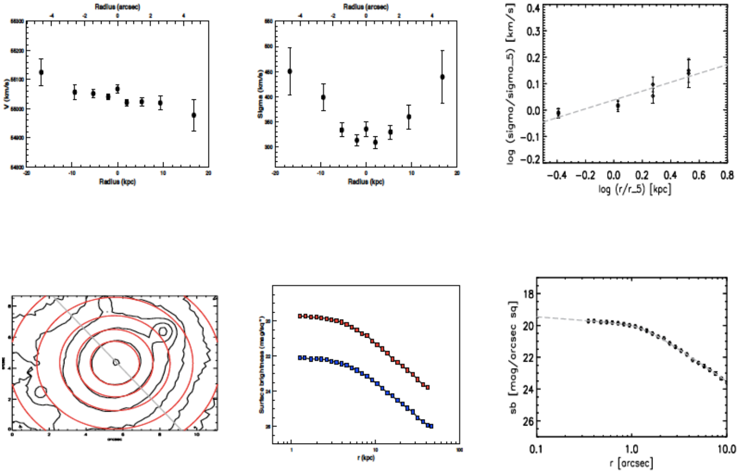
- The deprojected luminosity density, Γ(x, y, z), needed to constrain the stellar gravitational potential, using the multi-Gaussian expansion (MGE) method by Cappellari (2002).


Radius (arcsec)
V (km/s)
Radius (kpc)
Radius (arcsec)
Sigma (km/s)
Radius (kpc)
log (sigma/sigma_5) [km/s]
log (r/r_5) [kpc]
r (kpc)
sb [mag/arcsec sq]
r [arcsec]

Abell 2055


Radius (arcsec)
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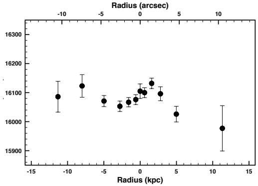
Sigma (km/s)
Radius (kpc)
log (sigma/sigma_5) [km/s]
log (r/r_5) [kpc]
Surface brightness (mag/sq")
r (kpc)
sb [mag/arcsec sq]
r [arcsec]

Abell 1689

Slow rotator/fast rotator?



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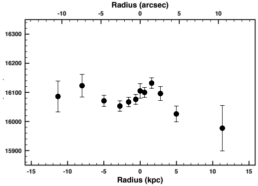

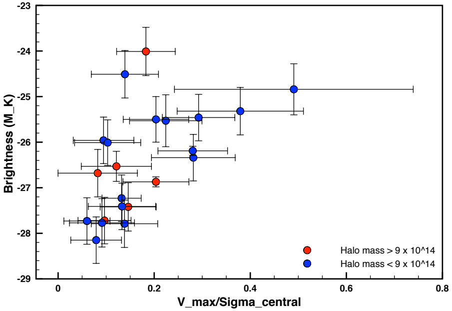

BCGs that show rotation are all fainter than $M_K > -26.5$ in K-band, and located in halo masses below 9×10^{14} solar masses

Velocity dispersion profiles – up/down?

- Rising velocity dispersion profiles: Dressler 1979 (IC1101); Carter et al. 1999, etc.
  Small samples or individual galaxies
- Loubser et al. 2008 – 5/41 BCGs ($z < 0.07$)
- Newman et al. 2013a – 7/7 BCGs ($0.2 < z < 0.3$)

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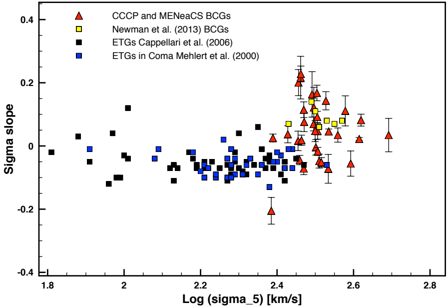
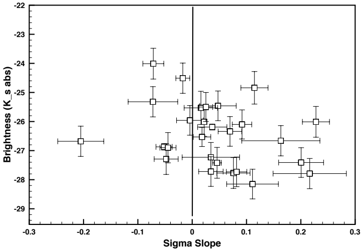
Question of what a rising velocity dispersion tells us about a galaxy. Is it a true reflection of the gravitational potential of the galaxy, the center of the galaxy cluster, or a snapshot of a dynamical system that has not reached equilibrium?

Velocity dispersion profiles





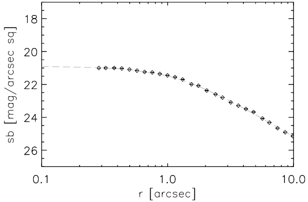
Velocity dispersion profiles

- Sign of the BCG velocity dispersion slope correlates with brightness (and therefore also bias with redshift).
- If sigma traces mass directly, then galaxies in large clusters or groups should see a rise in sigma at large radius. But, because of the degeneracy between mass and radial velocity anisotropy – a falling sigma profile does not necessarily imply the absence of massive dark matter haloes.

Caution: wide variety of profiles challenges aperture correction schemes.

Core/Core-less BCGs?

Abell 2261:



Largest BCG core to date with cusp-radius of 3.2 kpc *(Postman et al. 2012)*

Cusp-radius $r_\gamma = r_b(\frac{1/2-\gamma}{\beta-1/2})^{1/\alpha}$ *(Lauer et al. 2007)*

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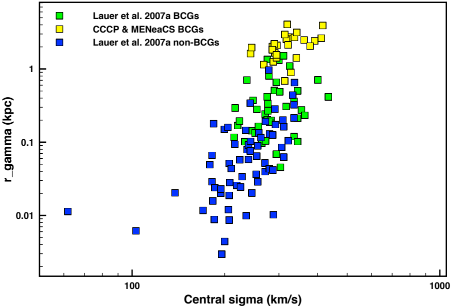

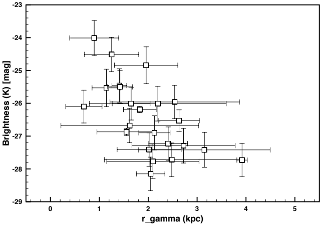

Core/Core-less BCGs?

- No cores in A611, A646, A1835, A2055 and MS14
- 84% BCGs have cores *(88% in Lauer et al. 2007)*
- Before A2261, the largest core was 1.5 kpc in BCG of Abell 2199 (Lauer et al. 2007a). We find several more large cores, e.g. A1689 at $\sim$ 4 kpc.
- Correlations between large cores and massive, brightest BCGs (although core-less $\neq$ fainter BCGs)
- Core-less ellipticals: they may have formed from wet mergers of other ellipticals, and gas moves to centre to form stars, leaving a denser core.

Star forming BCGs?

Identify BCGs with young (< 2 Gyr) components *(see Loubser et al. 2016)*

Use best fitting stellar templates to predict M/L_* (in r-band)

Also identify BCGs with M/L_* that changes with radius from the core (i.e. age gradient)

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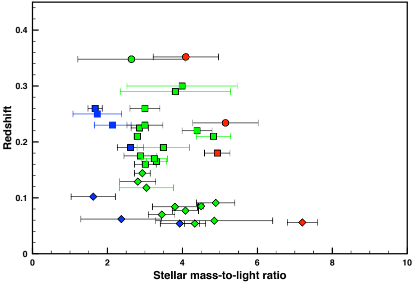

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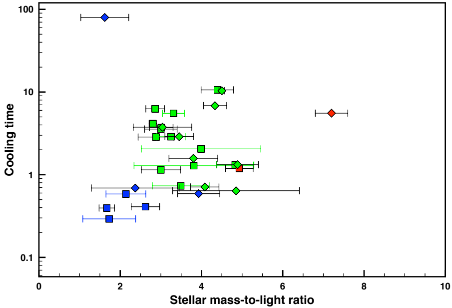

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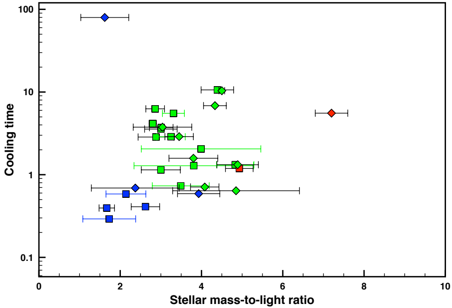

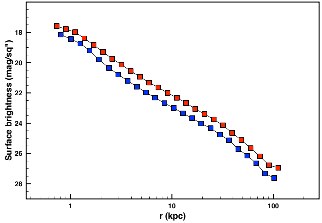

Abell 2055: Optical emission lines, blue colour and young component but long cooling time and no core.
= via dissipative (wet) merger.

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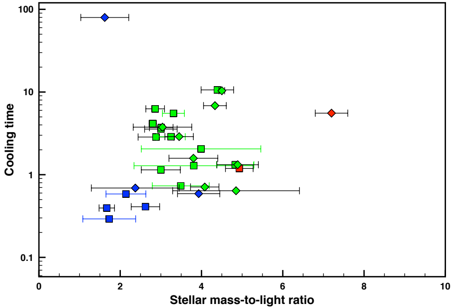

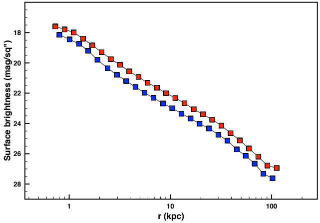

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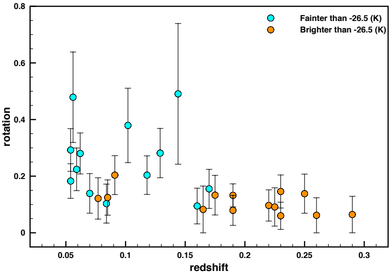
Caution: against assuming constant M/L_* for dynamical modelling

Evolution with redshift?



- Rotation at lower redshift (also fainter BCGs)
- M/L_* larger at low redshift (driven by older ages)

Summary

We have a sample of 36 BCGs between $0.05 < z < 0.35$, with detailed optical imaging and spectroscopy, and with X-ray and lensing data for the clusters.

We uncover a number of trends, but also a very large amount of intrinsic variety amongst BCG properties.

We're using the BCG stellar mass profiles, and velocity dispersion profiles to (simultaneously) fit to X-ray and lensing mass models to constrain the baryon fraction and dark matter distribution in clusters.