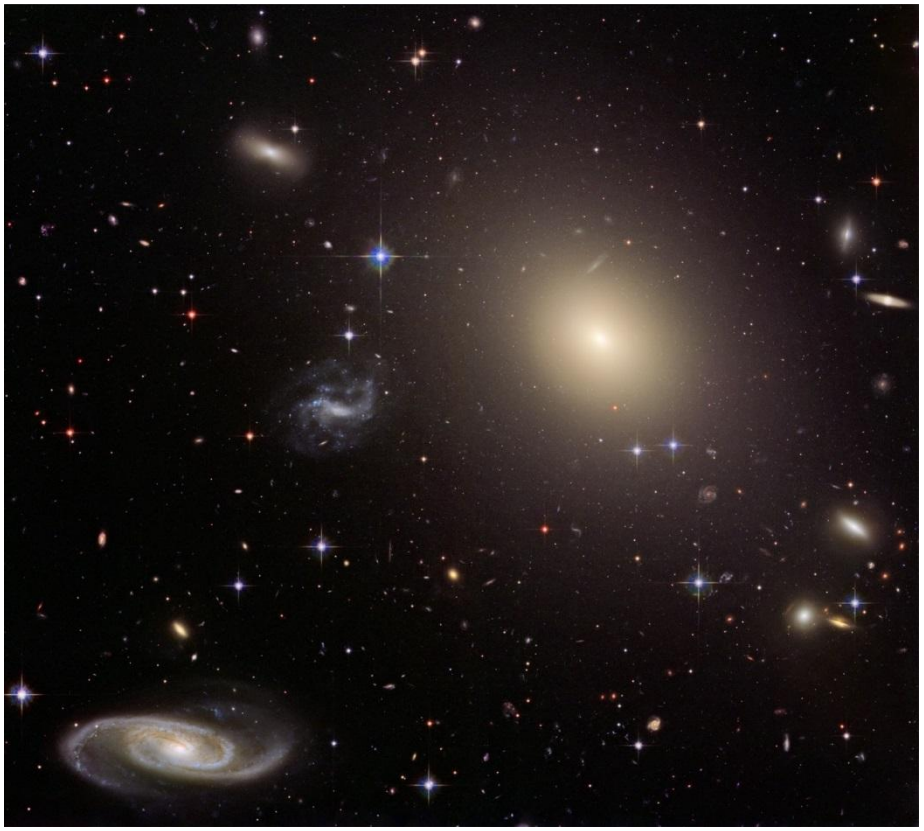
The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

# The formation and evolution of the Brightest Cluster Galaxies



**Dongyao Zhao**

**Alfonso Aragón-Salamanca**

**Christopher Conselice**

*School of Physics & Astronomy*
*University of Nottingham*

# Outline

Brightest cluster galaxies (BCGs) are the most massive and luminous galaxies in the universe

- BCG morphology and structure

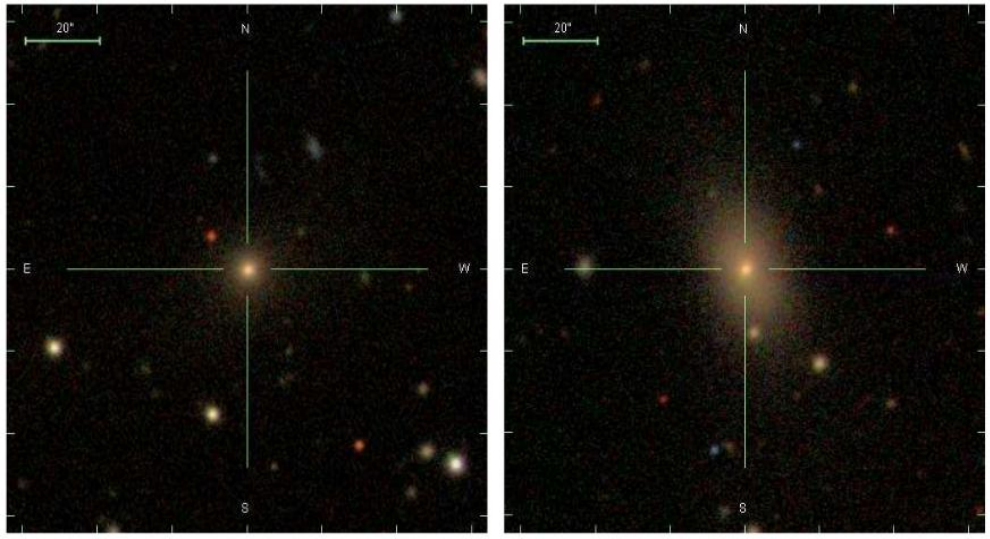
Zhao, Aragón-Salamanca, Conselice (2015a)

- Linking BCG morphology, structure, mass and environment

Zhao, Aragón-Salamanca, Conselice (2015b)

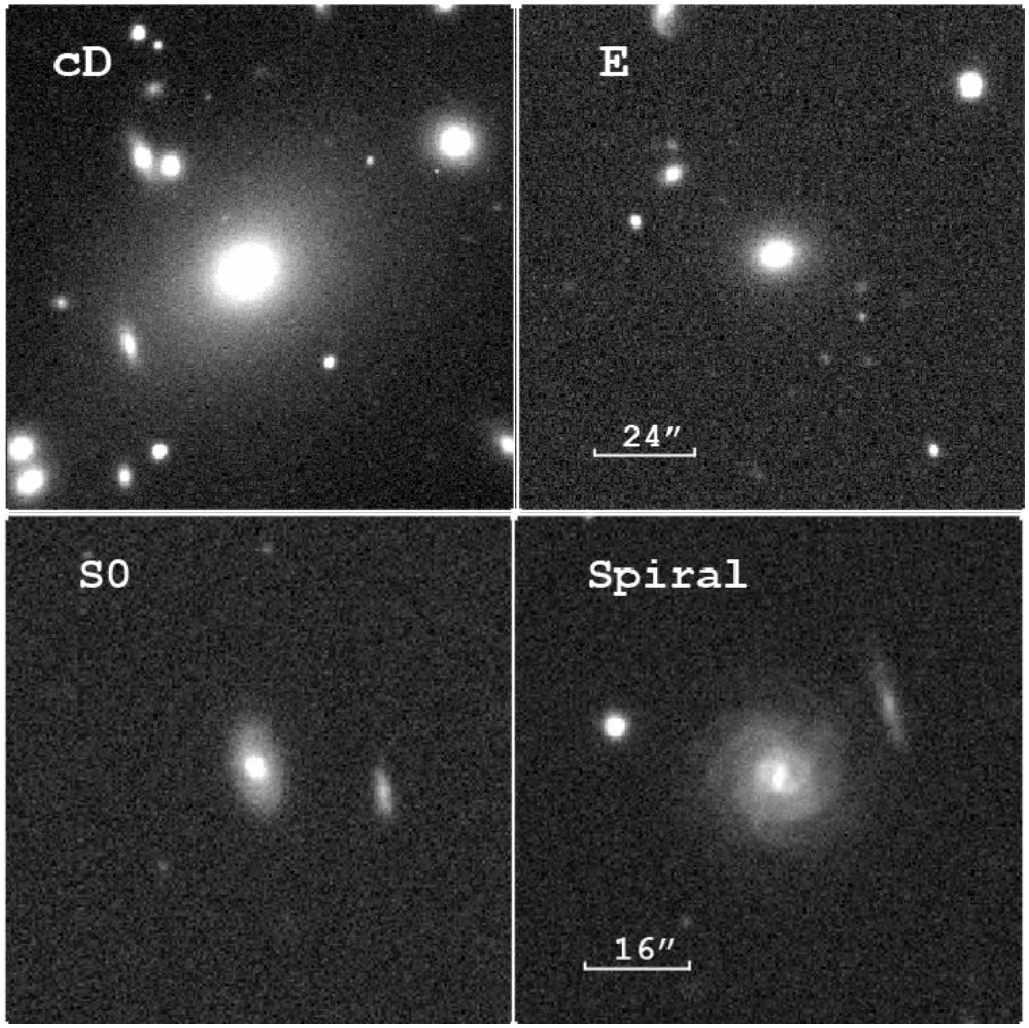
- BCG evolution since z~2

Zhao, Conselice, Aragón-Salamanca (2016)




von der Linden+07

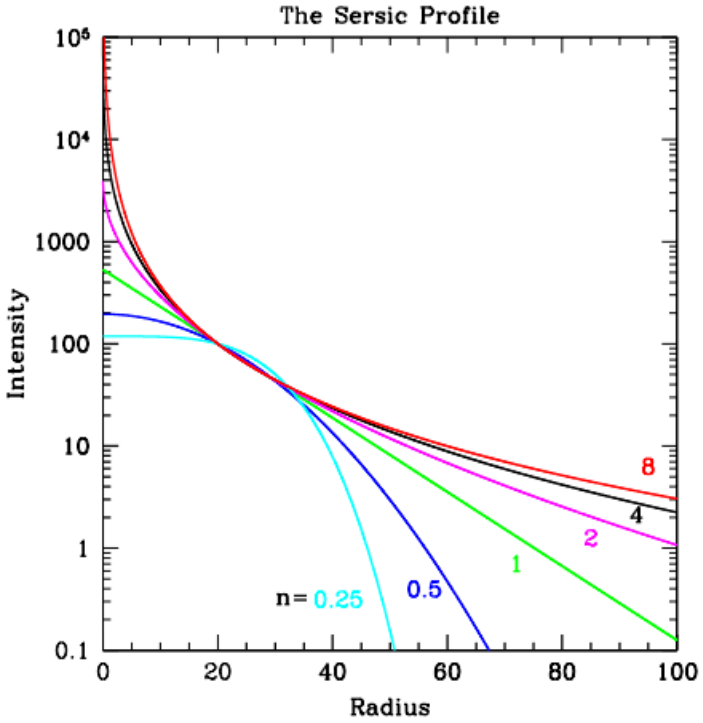
# Visual Classification




SDSS DR7 r-band

- 625 BCGs $0.02 \leq z \leq 0.1$ from von der Linden+07
- Morphologies:
  - cD: 57%
  - cD/E or E/cD: 21%
  - Elliptical: 13%
  - S0s: 3.5%
  - Spirals: 3.8%
  - Mergers: 2%

# Measurements of Structure




Peng+10

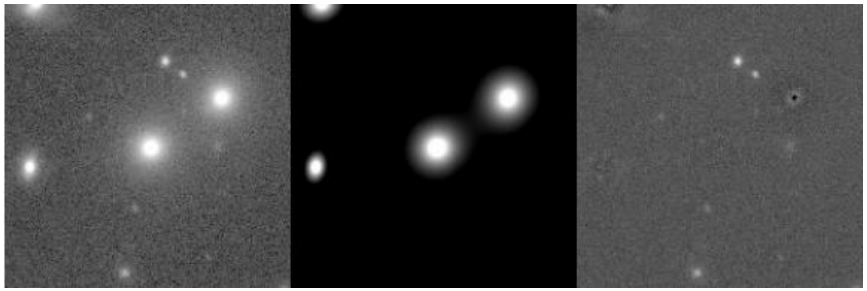
- GALFIT/GALAPAGOS

  Peng+02, Barden+12
- $\mu_{limit} \sim 27$ mag/arcsec$^2$
- Sérsic profile

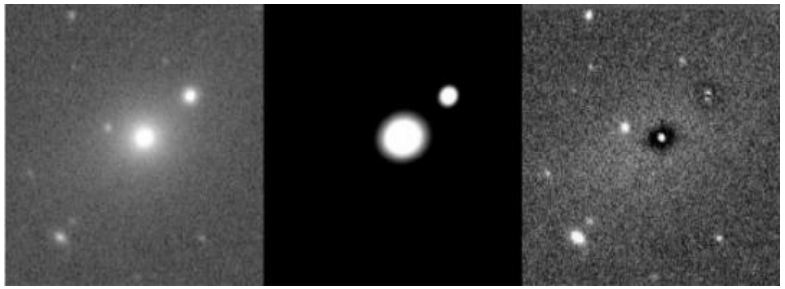
$$\Sigma(r) = \Sigma_e \exp\left[-\kappa\left(\left(\frac{r}{r_e}\right)^{1/n} - 1\right)\right]$$

Sérsic index: galaxy shape

effective radius: size



original model residual



original model residual

# Quality of the fits

Quantify residual images

- residual flux fraction (*RFF*)

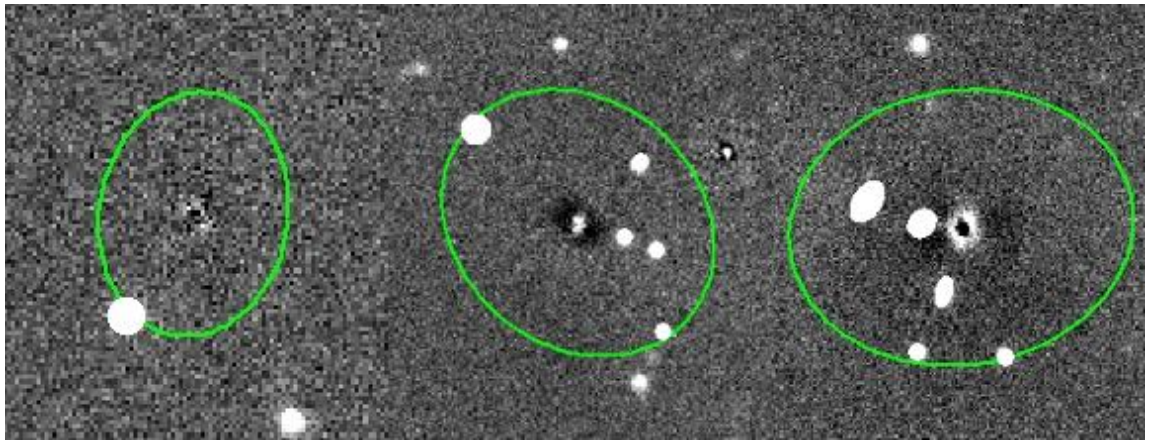
$$RFF = \frac{\sum_{i,j\in A} |I_{i,j} - I^{\rm model}_{i,j}| - 0.8 \times \Sigma_{i,j\in A}\sigma^{\rm bkg}_{i,j}}{\Sigma_{i,j\in A} I_{i,j}}$$

residual flux

- reduced $\chi^2$

$$\chi^2_\nu = \frac{1}{N_{\rm dof}} \sum_{i,j\in A} \frac{(I_{i,j} - I^{\rm model}_{i,j})^2}{\sigma^2_{i,j}}$$

Good fit:
RFF ~ 0.02
$\chi^2$ ~ 1.1

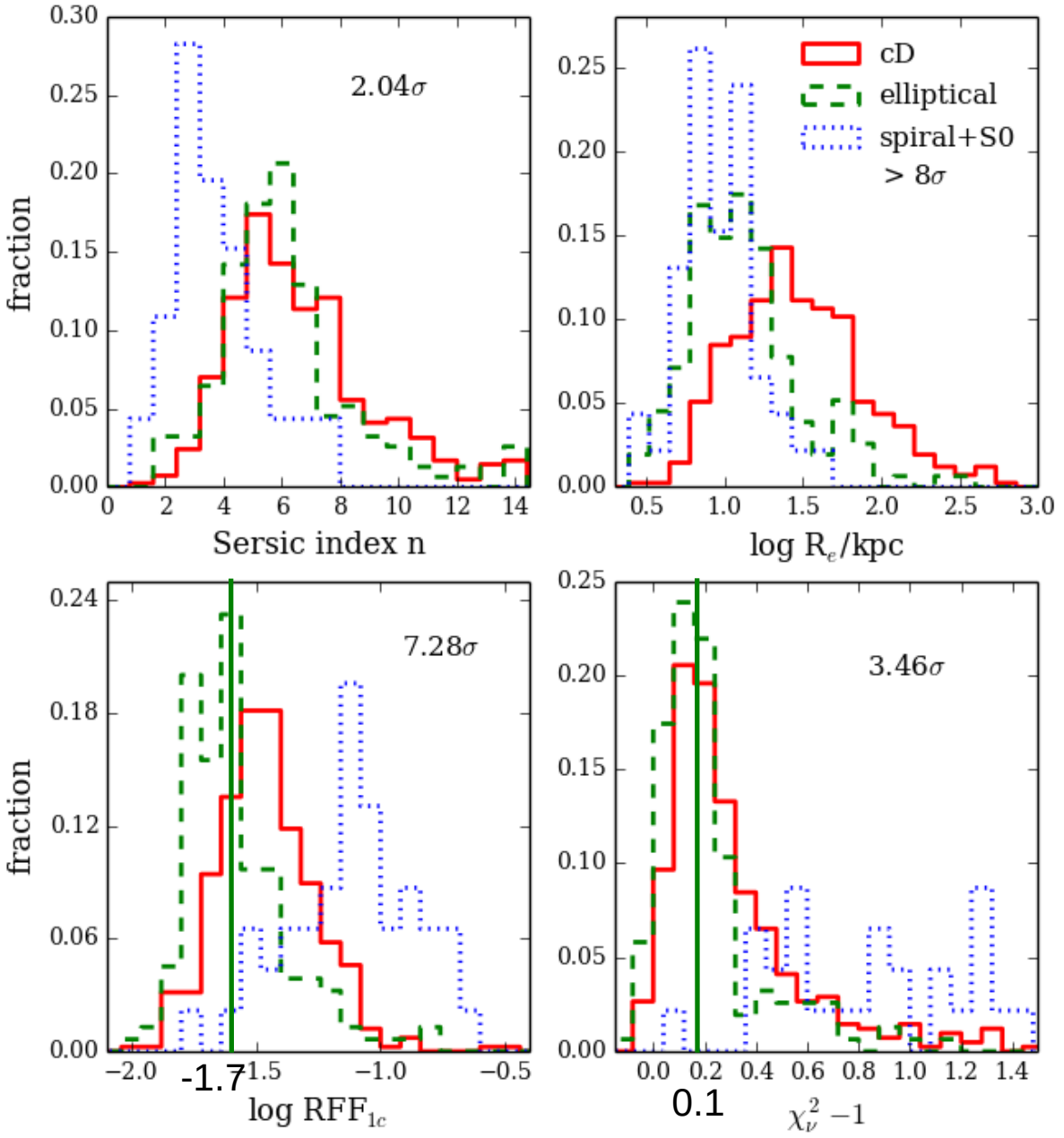


*RFF*=0.015 $\chi^2$=1.052

*RFF*=0.045 $\chi^2$=1.348

*RFF*=0.047 $\chi^2$=1.455

# Linking BCG Morphology and Structure

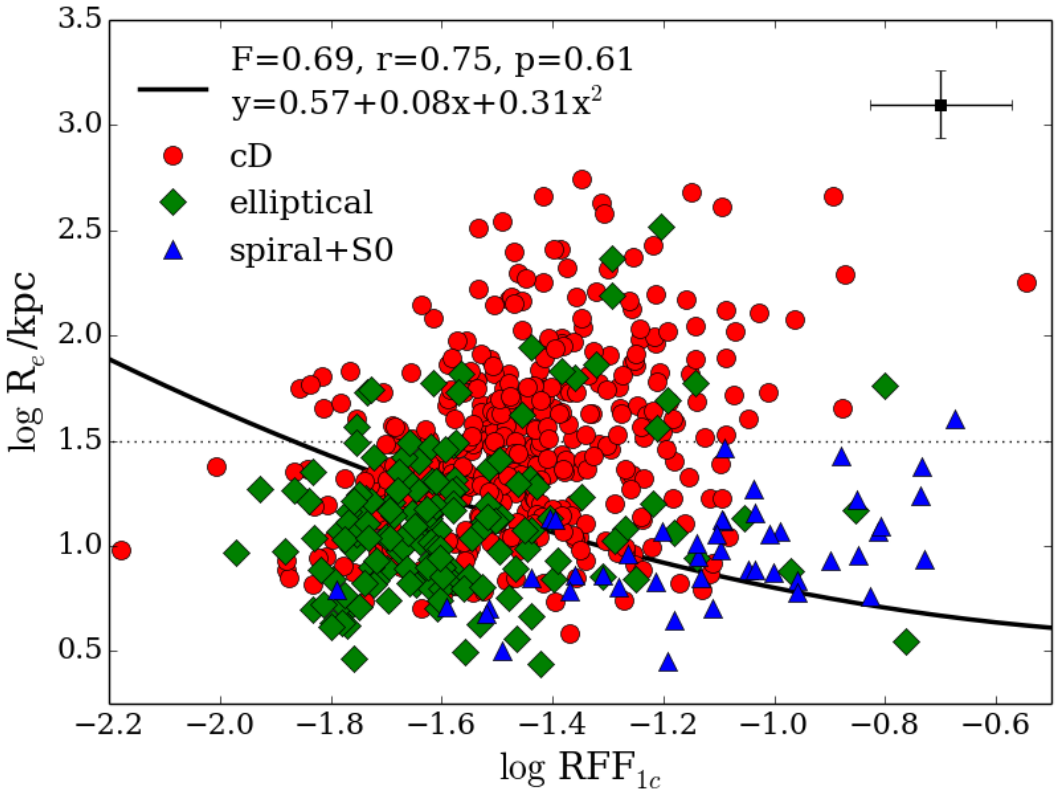



## Single Sérsic profile fits

- cD and elliptical BCGs have similar *n*
- cD galaxies have larger effective radii than ellipticals
- It is harder to fit cD galaxies well with a single Sérsic profile (larger *RFF* and $\chi^2$)

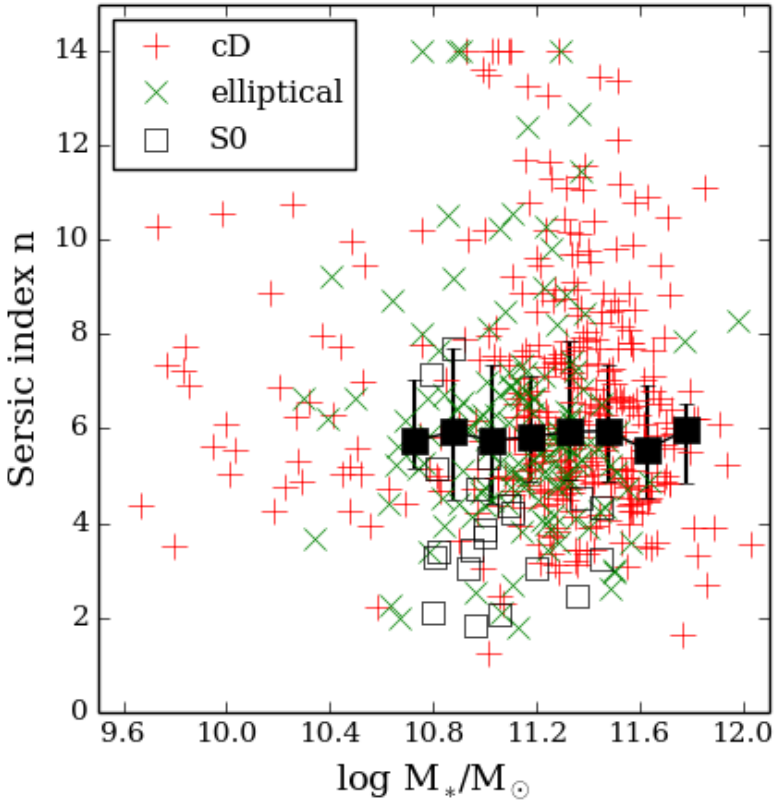
→ Clear link between morphology and structure

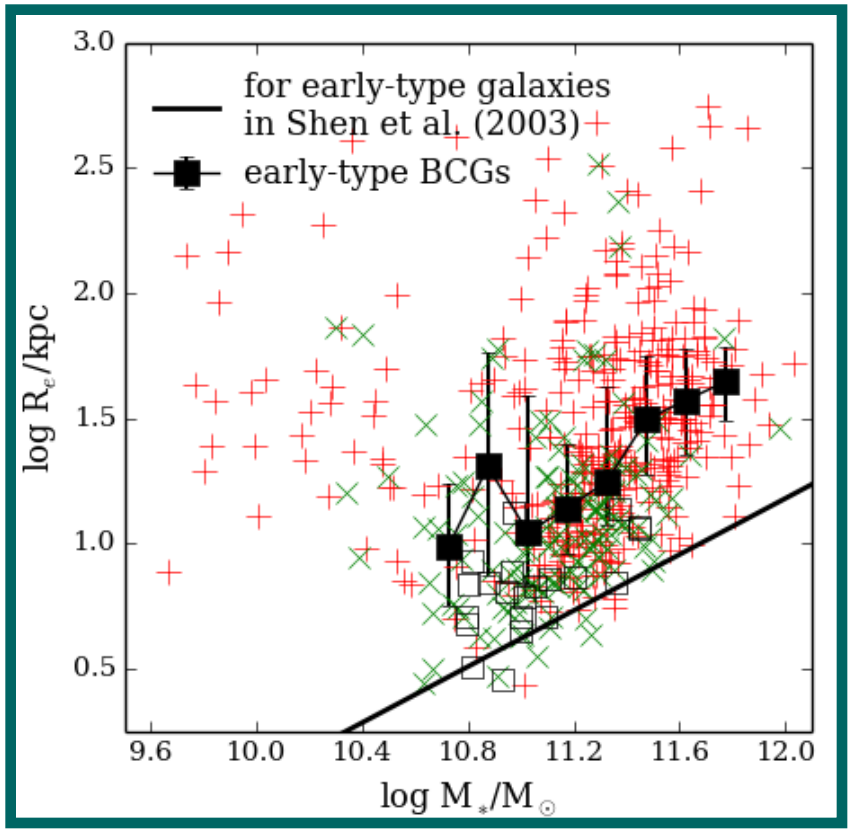
# Automatic Selection of cD Galaxies




- Best border
  - Method from Hoyos+12
  - Selected cDs have high completeness (75%) and low contamination (20%)
  - This method can be applied to future BCG samples

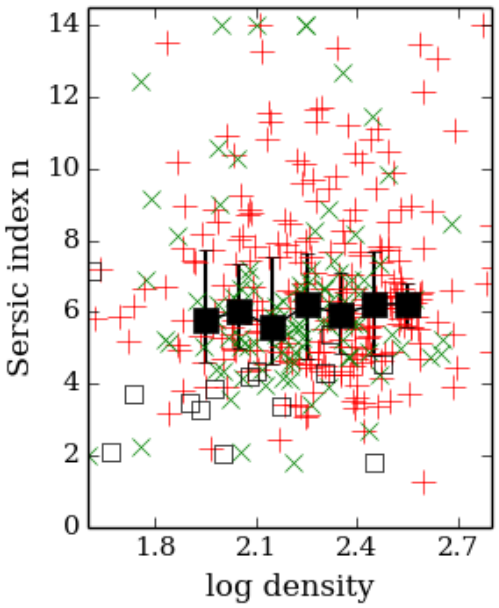
# Stellar Mass

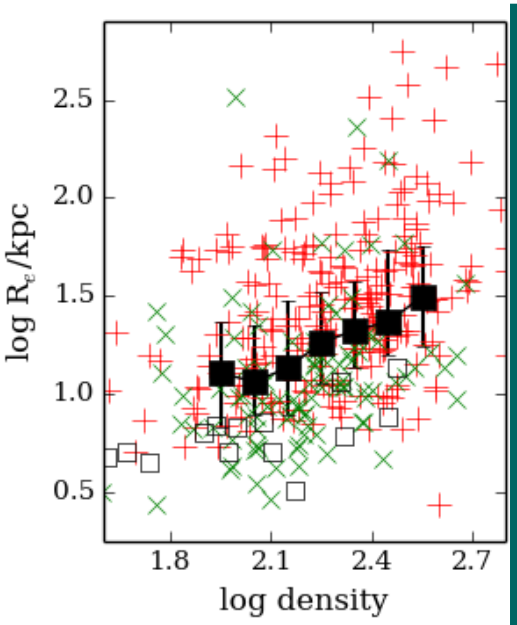


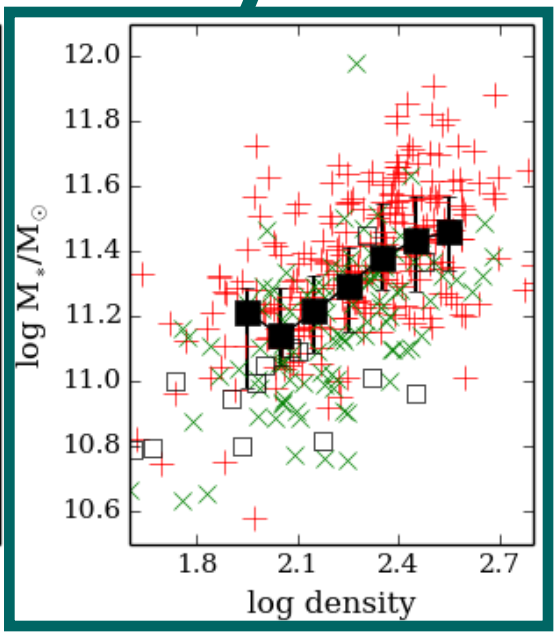




- $M*$ does not correlate with Sérsic index $n$
- $M*$ correlates with effective radius $R_e$

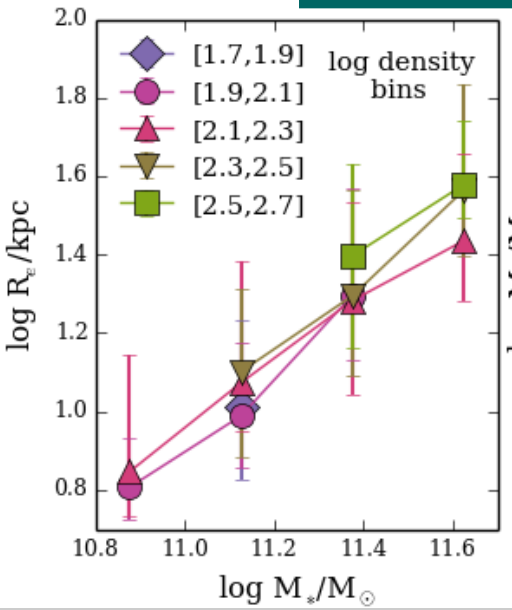
# Environmental Density

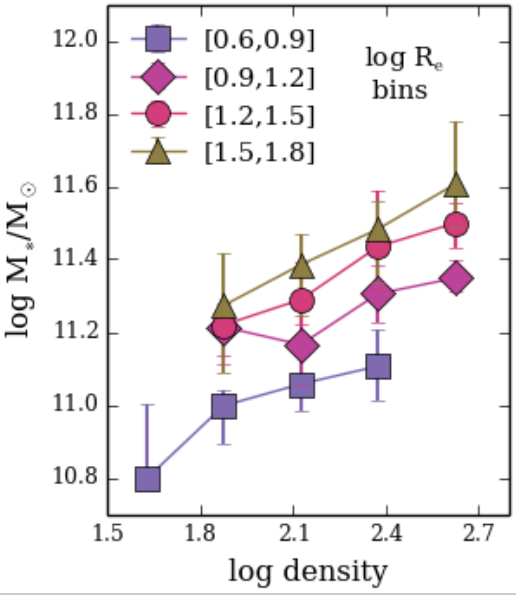


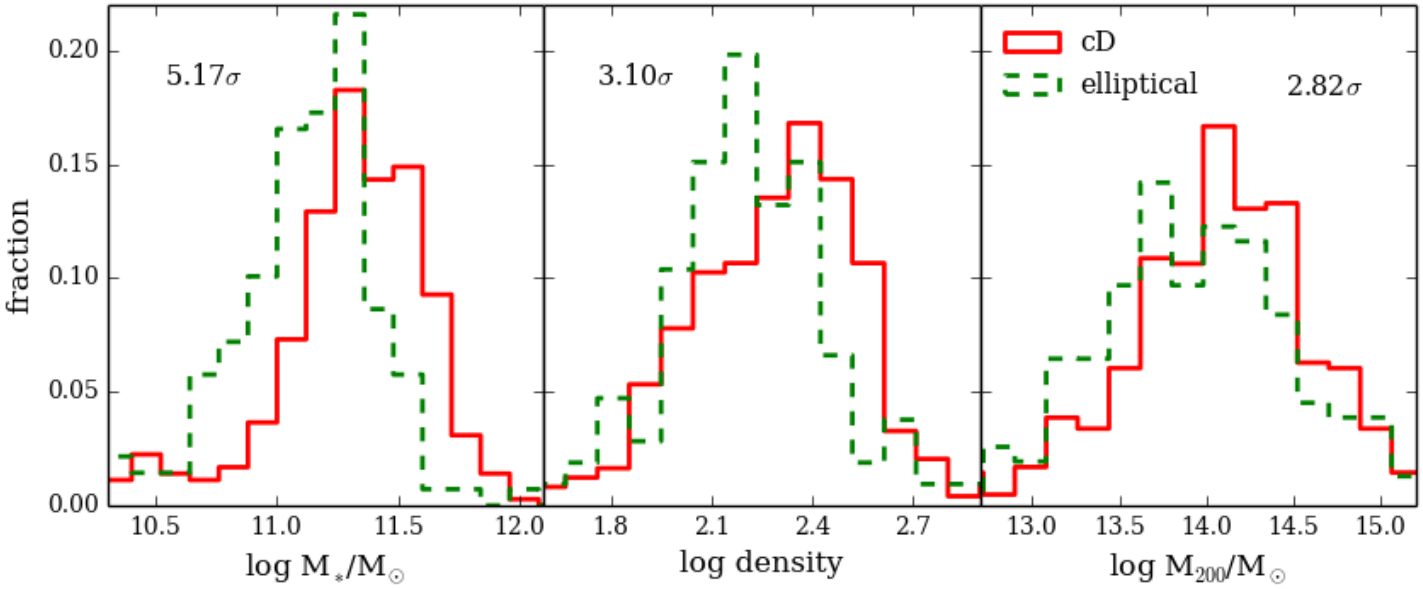




- Density does not correlate with $n$ or $R_e$
- Density correlates with $M_*$



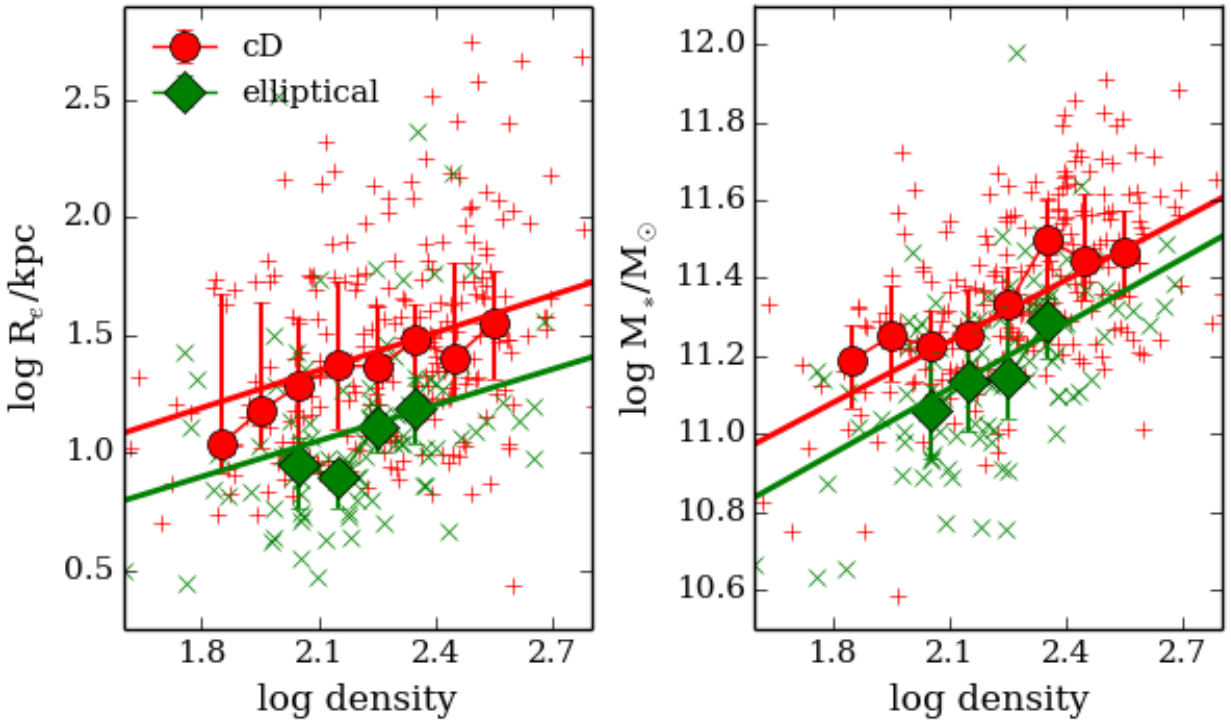



# BCG morphology is linked with $M_*$ and environment



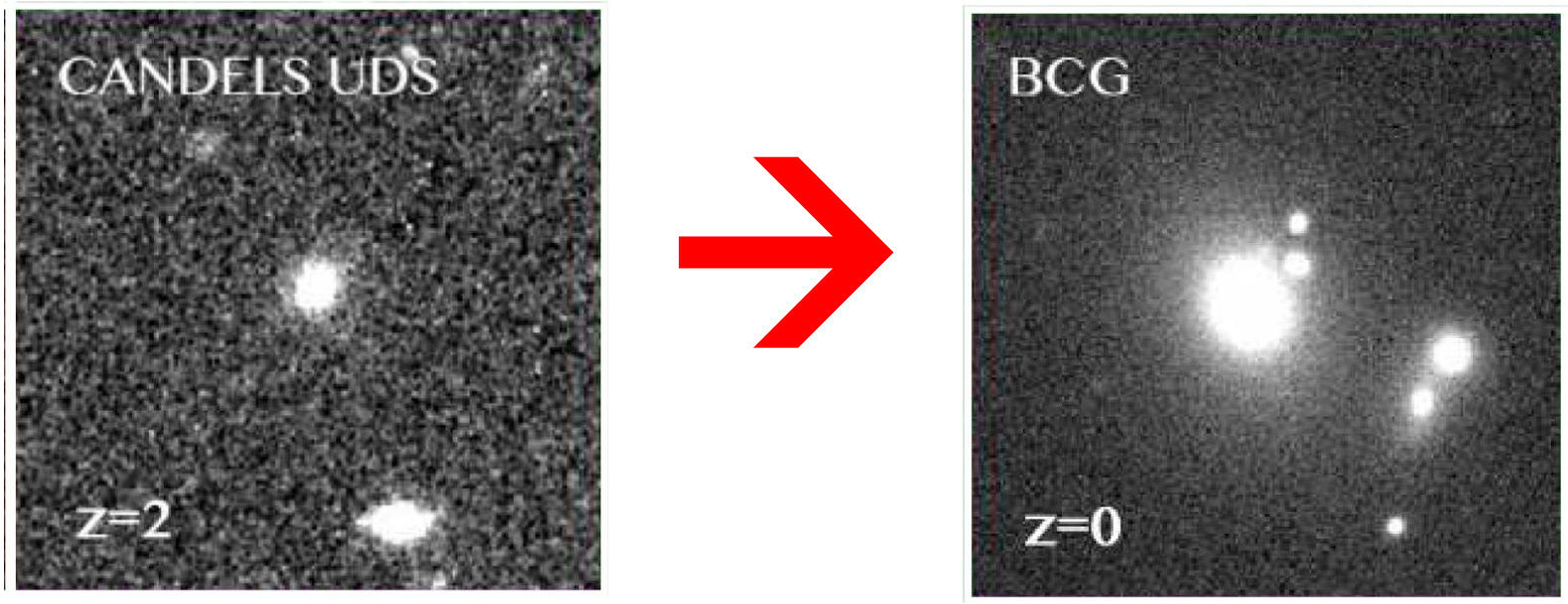

- cDs tend to be more massive than elliptical BCGs
- cDs reside in denser regions than elliptical BCGs
- cDs are hosted by more massive DM haloes than ellipticals

# BCG morphology is linked with $M_*$ and environment




- cDs are larger by a factor of 2 and 60% more massive than elliptical BCGs at the same density
- cDs probable grow from elliptical BCGs through dry (minor) mergers while developing their outer envelope

# The $z \sim 2$ progenitors of today's BCGs




To understand BCG evolution since $z \sim 2$ we need to:

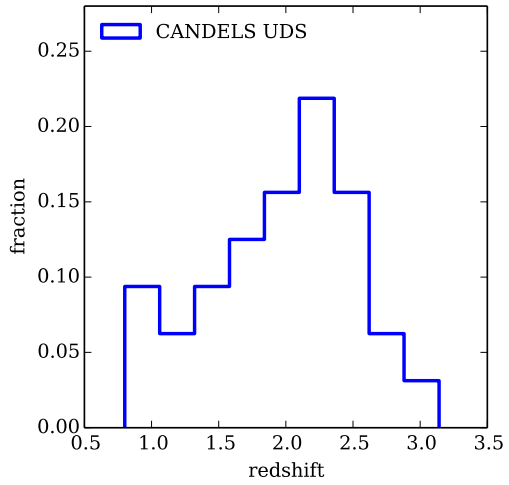
- Select sample of BCG progenitor candidates at $z \sim 2$
- Select matching sample of their descendants at $z \sim 0$
- Compare the structure, morphology, stellar mass, and SFR/sSFR of BCG progenitors and their descendants

→ Implications for BCG evolution

# The $z \sim 2$ progenitors of today's BCGs

BCG number density ~ $10^{-4}\ h^3\ \mathrm{Mpc}^{-3}$

- $z \sim 1$-3: CANDELS UDS + density catalogue (Lani+13)
  - 38 BCG progenitor candidates selected as the **most massive galaxies in the densest regions**



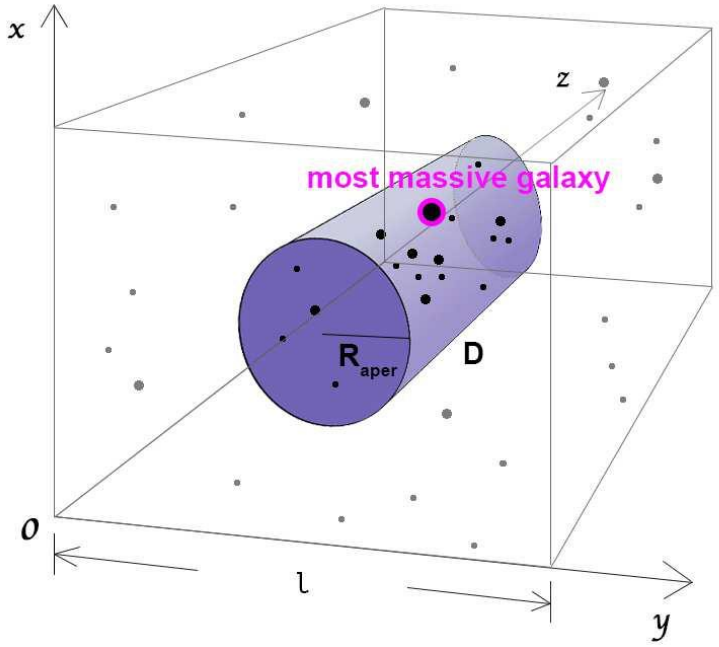

- $z \sim 0$ SDSS BCGs (von der Linden+07)
  - 470 local descendants

# Simulations

**Millennium Simulation + SAM** (De Lucia+07)

Constant number density of $10^{-4}$ $h^3$Mpc$^{-3}$: 8490 galaxies

- ***Z*~0 BCGs:**
  - Select most massive galaxies in most massive DM haloes
  - Trace true BCG progenitors at $z$~2
- ***Z*~2 BCG progenitor candidates:**

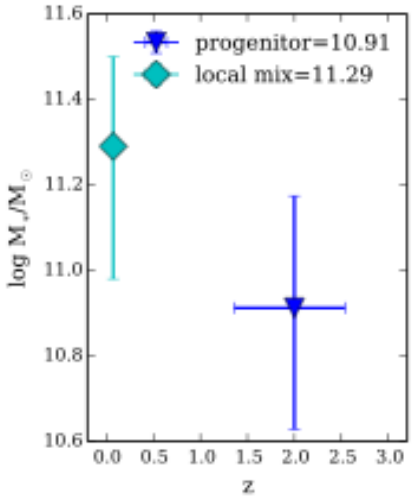


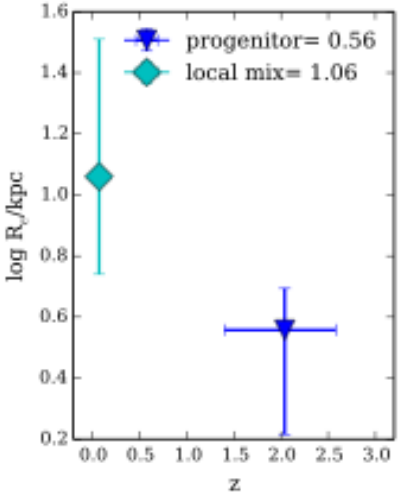

- Select most massive galaxies in densest regions
- Evolve forward to z~0 and check how many become BCGs

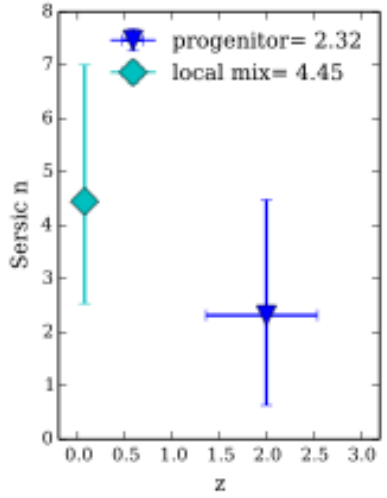
$R_{aper}$ =400 $h^{-1}$kpc

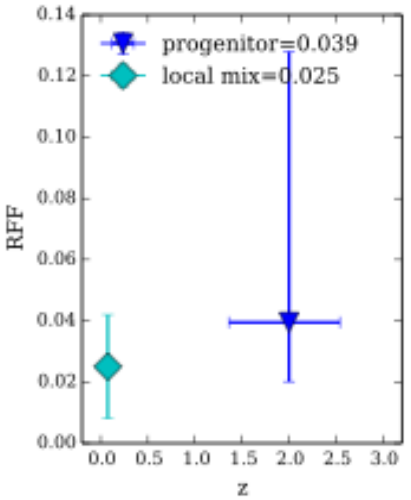
$D$=120 $h^{-1}$Mpc

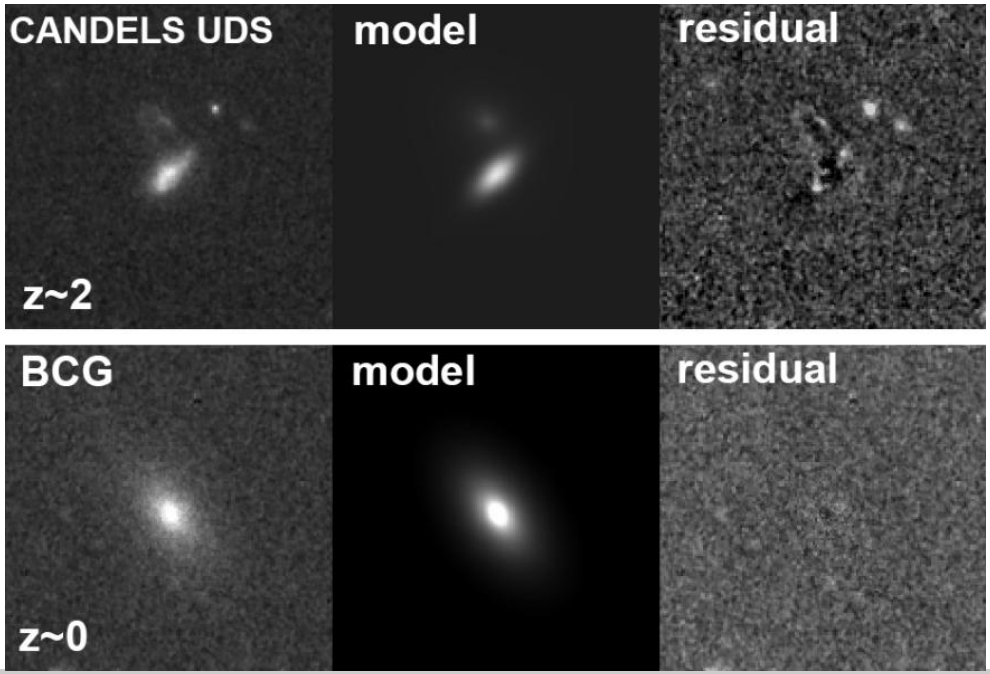
# BCG evolution since $z \sim 2$



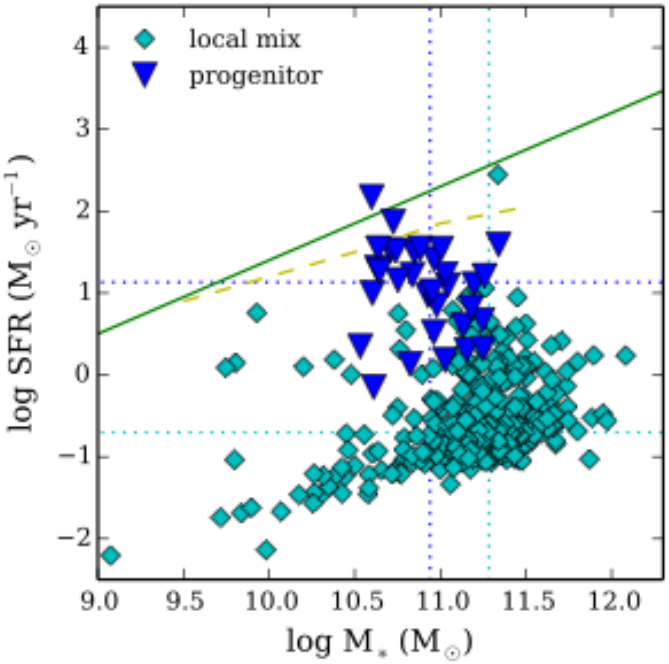



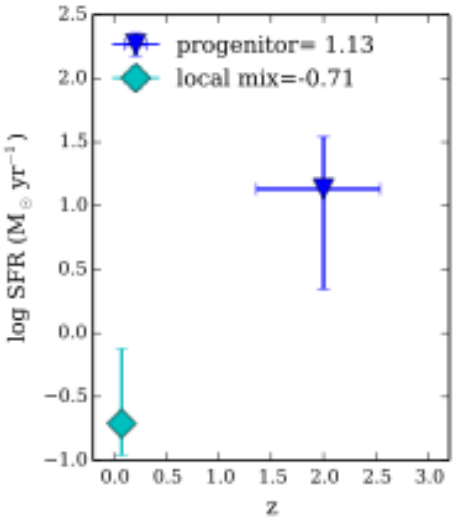



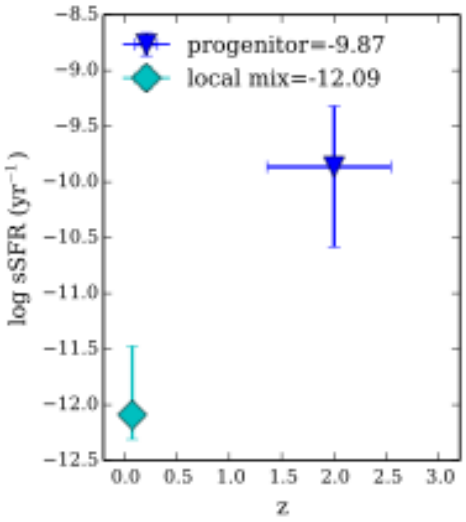




- **Stellar mass has grown by a factor of ~2.5**
- **Size has grown by a factor of ~3.2**
- **BCGs evolve from disturbed disk-like galaxies to smooth ellipticals and cDs**

# BCG evolution since $z \sim 2$




- **SFR is ~70x and sSFR is ~170x larger at $z \sim 2$ than z~0**
- **At $z \sim 1–2$ Star formation contributes ~12% and merging ~9% of the final stellar mass**
- **At z < 1 there is little contribution from star formation and (minor) mergers dominate mass growth**

# Conclusions

- Properties of $z$~0 BCGs:
  - Most local BCGs are cDs or cD/E+E/cD (57%+21%). Only 13% are Es
  - cDs are larger and more massive than elliptical BCGs
  - cDs are harder to fit with single Sérsic profile than elliptical BCGs

    → Automatic selection of cDs
  - Size correlates with stellar mass; stellar mass correlates with density
  - cDs tend to live in denser environments than elliptical BCGs
- BCG evolution:
  - Since $z$~2, BCGs have grown by ~x2.5 in $M_*$ and ~x3.2 in $R_e$
  - The BCG progenitors are more disk-like and more disturbed than local BCGs
  - Merger and star formation contribute similarly to BCG mass growth at high redshift ($z$~1–2). At lower redshift ($z<1$), (minor) mergers dominate

    → cDs evolve from elliptical BCGs, growing the outer envelope through dry minor mergers.

    This process is ongoing but almost finished (most BCGs are cDs)