KMOS-Cluster - Size and Resolved Stellar Mass Distribution of Cluster Galaxies at z ~1.4

Jeffrey Chan
& The KMOS-clusters team
& The KMOS instrument and commissioning team

MPE/USM: Ralf Bender (PI), Alessandra Beifiori, Audrey Galametz, Trevor Mendel, Roberto Saglia, Dave Wilman, Michael Wegner

UK: Roger Davies (co-PI), Ryan Houghton (Oxford), Michele Cappellari (Oxford), Ian Lewis (Oxford), Ray Sharples (Durham), Russell Smith (Durham), John Stott (Durham)

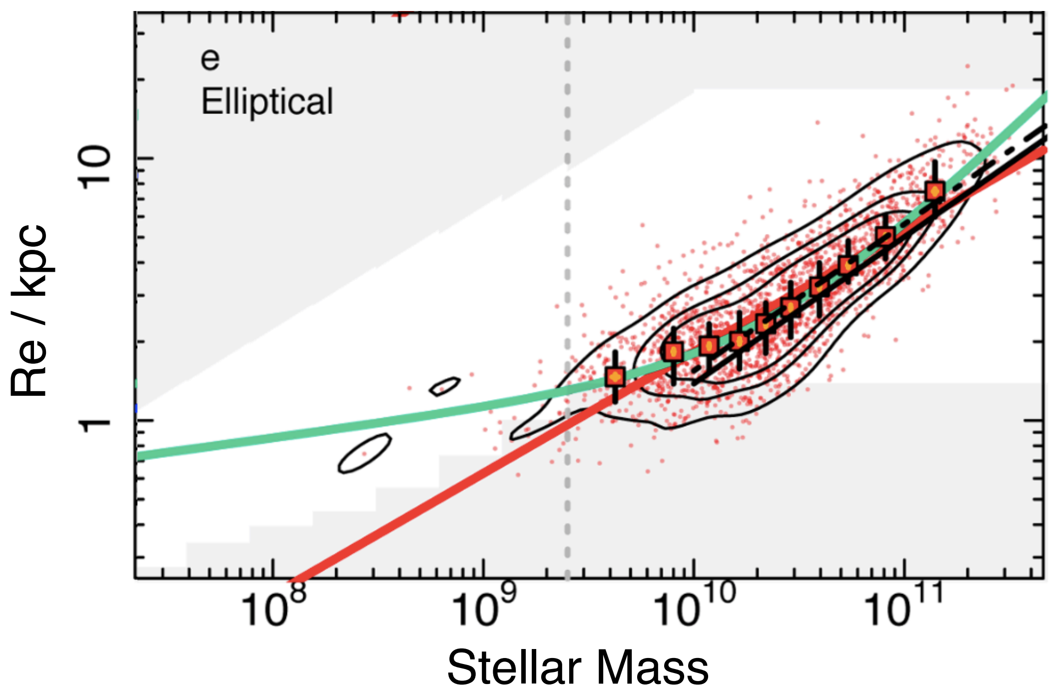
OPINAS seminar 2015

Outline

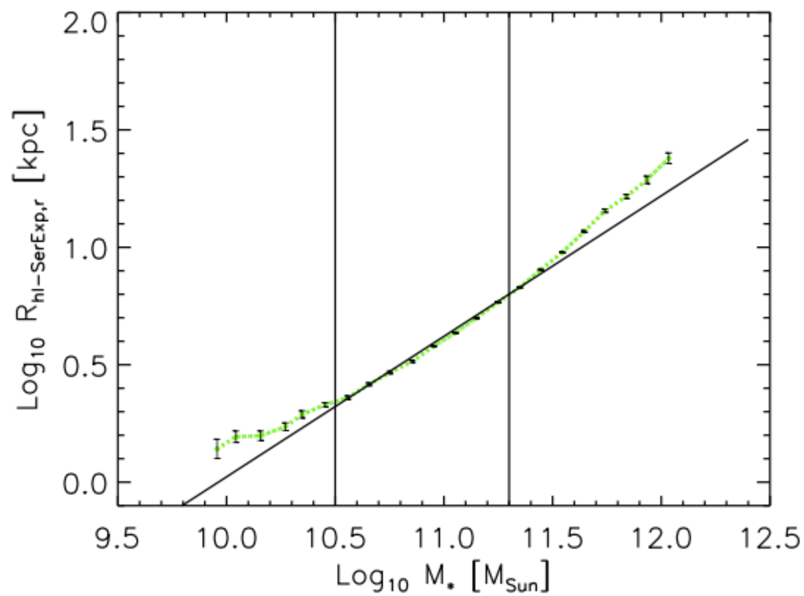
- Background
- KMOS-cluster: the project description
- Motivations and Goals
- Methods and results
  - Light-weighted structural parameters
  - Resolved stellar mass distribution
  - Mass-weighted structural parameters
  - Dependencies of the structural parameters
  - Color and M/L gradients
- Summary

Sizes of Early-type galaxies

- In the local universe, early-type galaxies have long been known to exhibit a correlation between their luminosity-weighted” sizes and stellar masses, the “Mass–Size relation”
- Despite initially formulated as a single power-law, significant deviation is seen on the low & high-mass end (e.g. Shen +03, Bernardi +12)



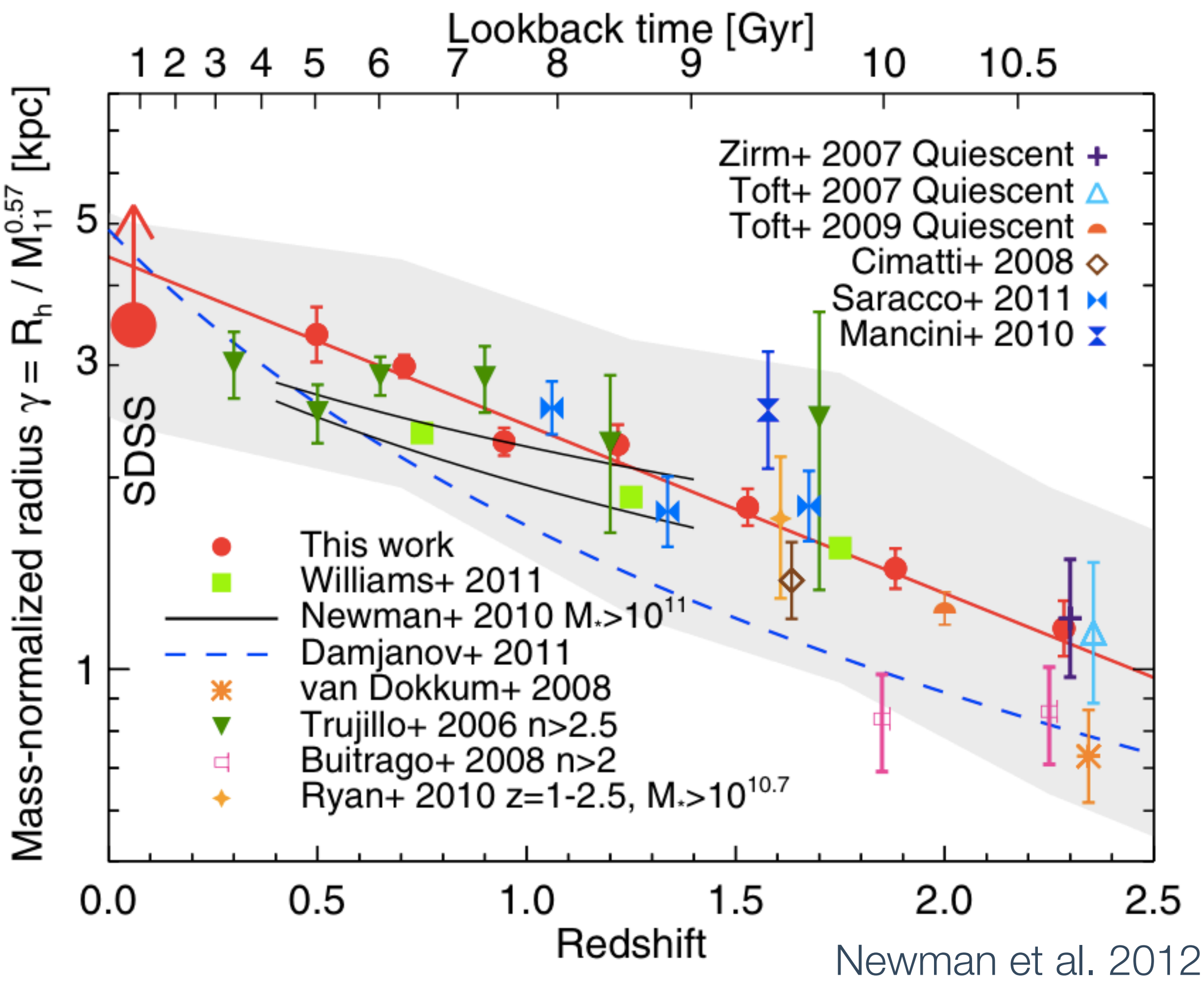
Lange et al. 2015



Bernardi et al. 2012

Size evolution of Early-types

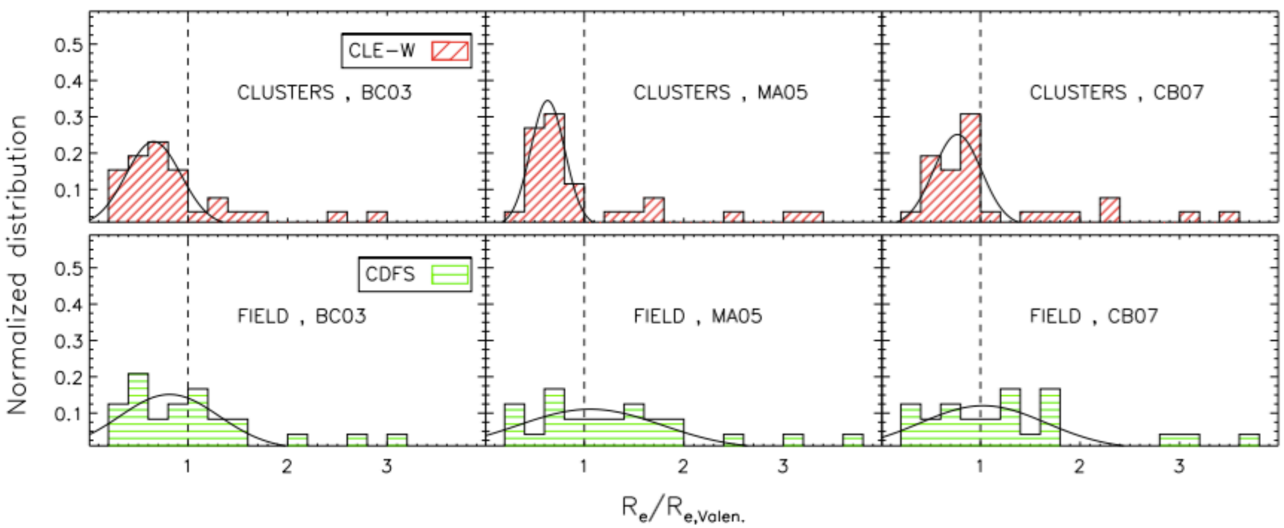
- Early-type galaxies appear to be extremely compact at high-z with Re ~1kpc
- ~2 x smaller at z~1, ~4 x smaller at z~2 (e.g. Daddi +05, Trujillo +06, Cimatti +12, Barro +13, Delaye +13)



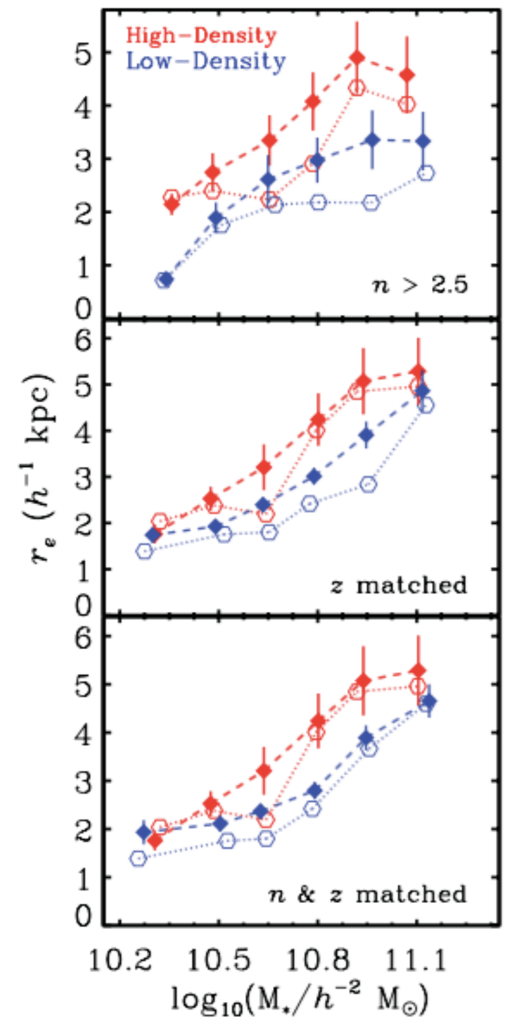
Newman et al. 2012

Environmental effects on the size evolution

- The role of environment to the size evolution have been controversial (cluster ETGs vs. field ETGs)
- In the local universe there seems to be no environmental dependence of sizes (e.g. Weinmann +09, Huertas-company +13)
- At high-z, different studies with different sample selections show opposing trends (e.g. no trend: Rettura +10, C < F: Raichoor +12, C > F: Cooper +12, Lani +13, Strazzullo +13, Delaye +14)



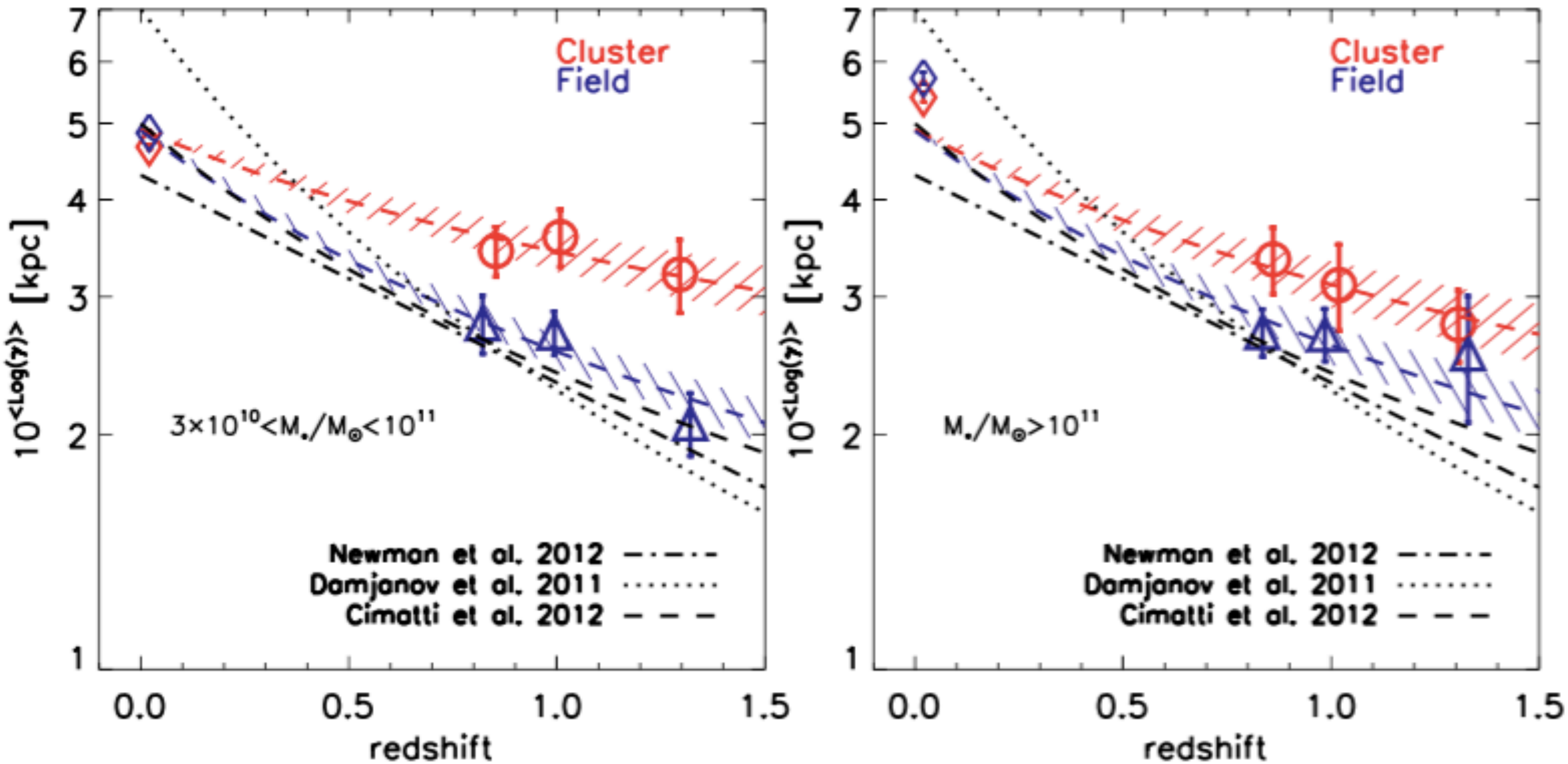
Raichoor et al. 2012



Cooper et al. 2012

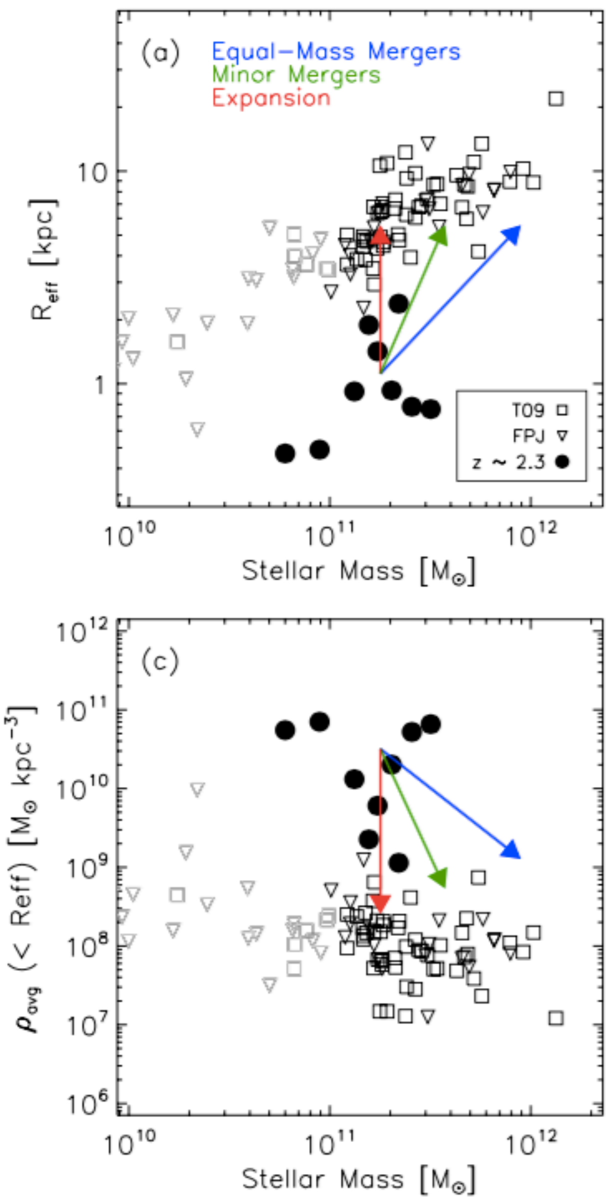
Environmental effects on the size evolution

- Size difference seems to be more pronounced at the lower mass bin 10.5 < M < 11.0 (Delaye +14)
- Due to galaxies being quenched more efficiently in clusters? Morphological mixing?



Delaye et al. 2014

Explaining evolution – the underlying physical process



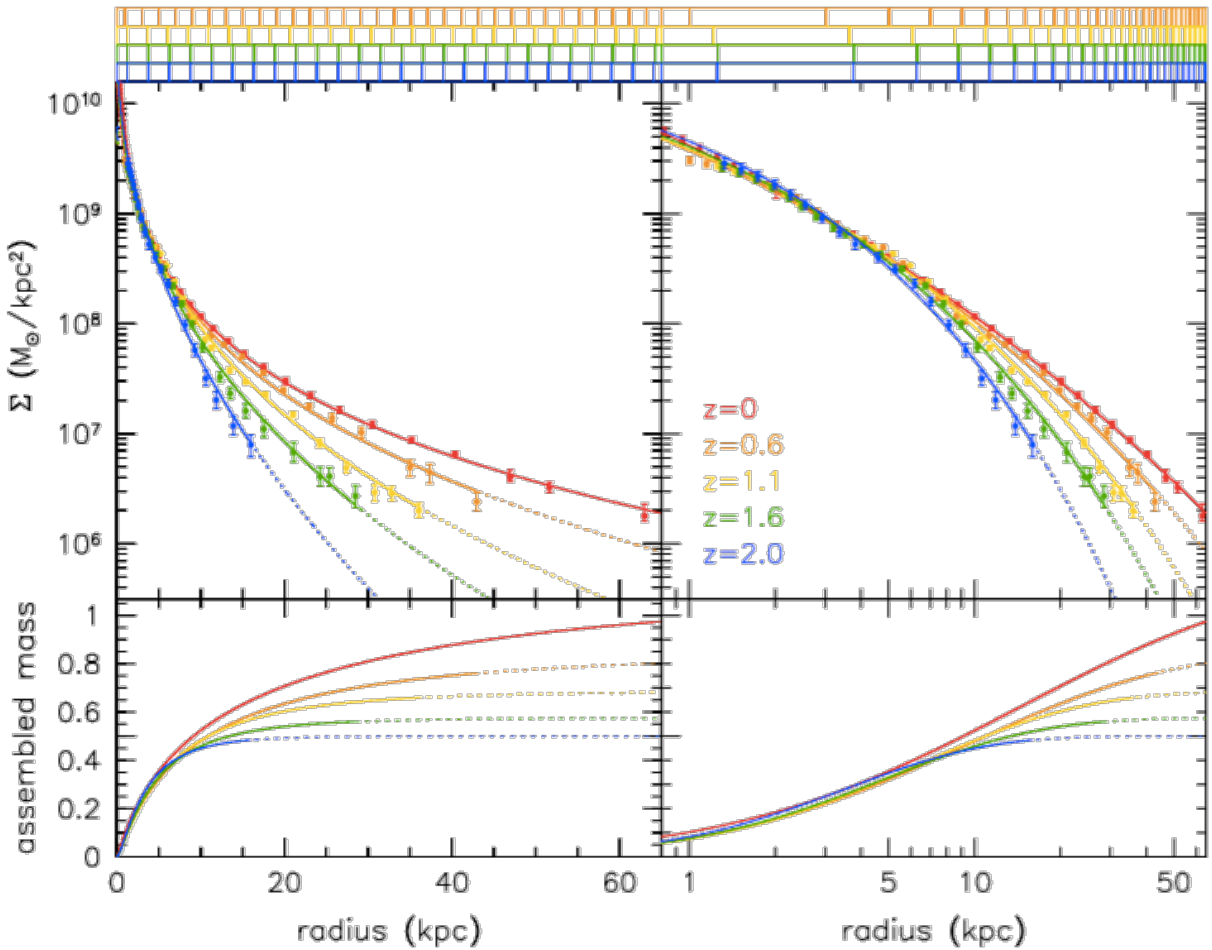
Bezanson et al. 2009

- Best candidates so far:
- "Puffing up" expansion scenario (e.g. Fan +08, Fan +10, Ragone-Figueroa +11)
  - Mass loss due to AGN / supernovae feedback
- Mergers (e.g. Naab +09, Hopkins +10, Shankar +13)
  - Major / Minor dry mergers
- Observational evidence points to both directions (e.g. Ascaso +11, Trujillo +11, Newman +12)

- Unresolved issues:
  - Selection effect and abundance of compact galaxies at z~0 (Valentinuzzi +10, Poggianti +13)
  - Impact of newly quenched ETGs
  - Morphological evolution

“Inside-out” growth

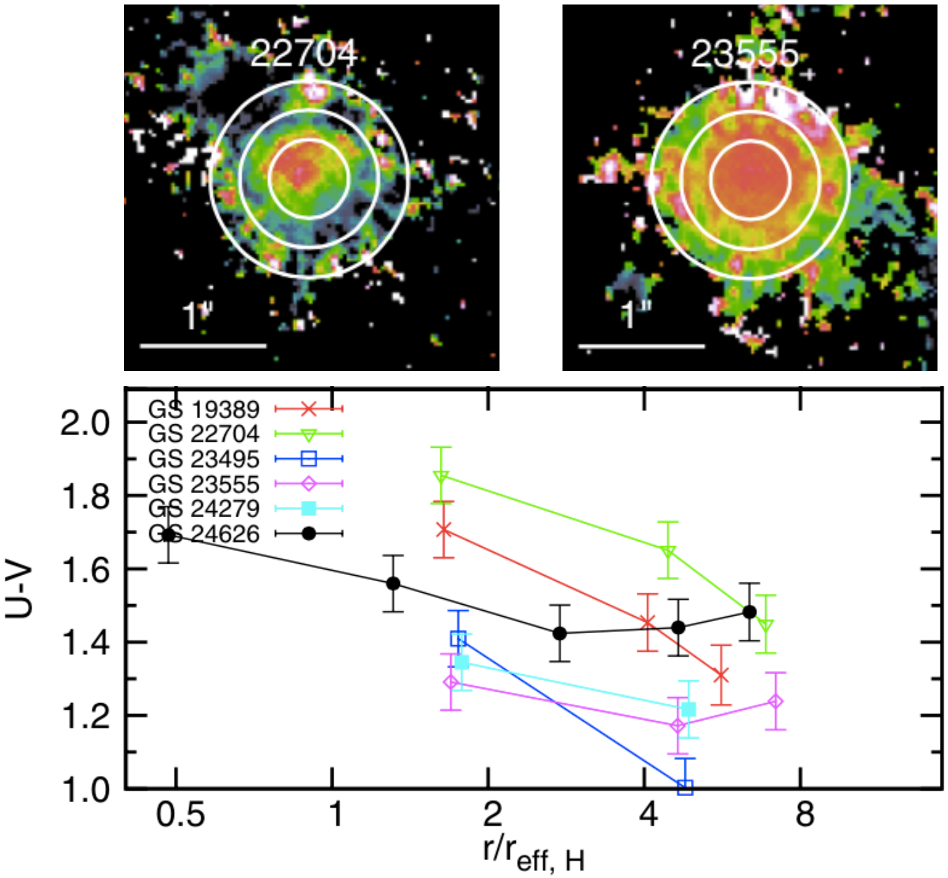
- Central densities of ETGs at high-z comparable to ETGs at z~0
- Compact, dense cores formed early at z~2
- Subsequent growth takes places at outer radii (e.g. van Dokkum +10, Patel +12)



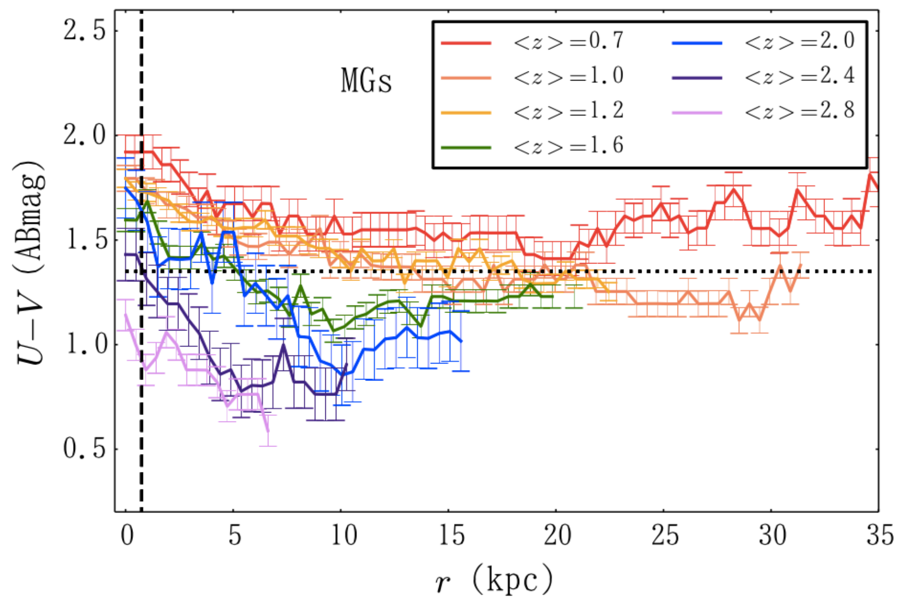
Van dokkum et al. 2010

Color gradients

- Star formation history in inner and outer regions are quite different
- Measure Color gradients at high-z to probe mass-growth and stellar population (e.g. Guo +11, Szomoru +13, Morishita +15)



Guo et al. 2011



Morishita et al. 2015

KMOS-Clusters

PIs: R. Bender (MPE/USM) & R. Davies (Oxford)

Goals

- Derive **Stellar velocity dispersions**, **Sizes, Resolved stellar masses**, **Absorption line indices** of high-z cluster ETGs
- Pioneer FP and dynamical M/L studies at z~1.5 to constrain formation history of early-type galaxies in clusters
- Compare with deep field (e.g. KMOS-VIRIAL (PI: Trevor Mendel)) – identify the effect of environment
- Strong effort in comparison with predictions from models

Alessandra's talk
Next week!

Methods

- Deep IFU spectroscopy in known X-ray selected clusters at $1 < z < 2$, targeting > 20 galaxies in each clusters
- Total: Large sample of **> 80 galaxies** (Rest-frame optical)

KMOS – the instrument

Why KMOS?

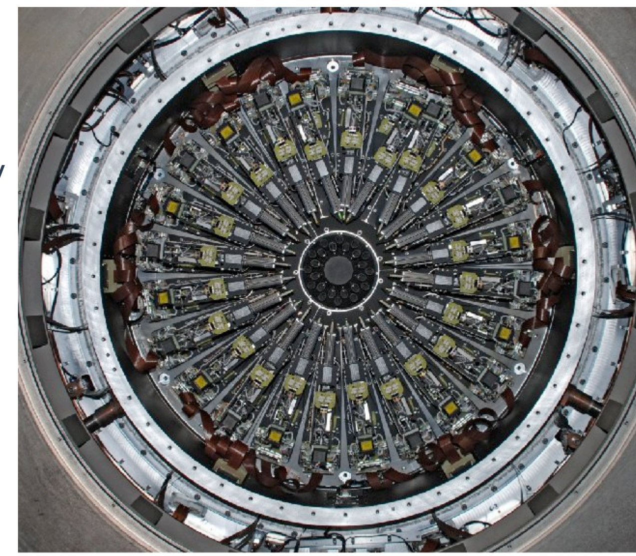
NIR integral-field spectroscopy at z > 1.3

ETGs' strongest spectral features (Ca II H+K, g-band …..) → into NIR (KMOS iz, YJ bands)

Multiplexing capabilities

Simultaneously observe ~20 galaxies

An order-of-magnitude increase in observing efficiency



Perfect instrument size

KMOS patrol field ~ extent of the clusters on the sky

IFU size (2.8" x 2.8") ~ sizes of the ETGs

GTO resources allow a comprehensive study

ETGs at z~2 are faint

GTO allows us to have long integration times (>12 h)

Sizes and Stellar mass distribution of KMOS-Cluster galaxies

Goals

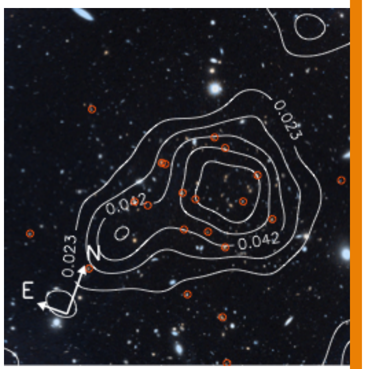
- Measure the **light-weighted structural parameters** of the cluster ETGs
- Derive **mass-size relations** of the KMOS clusters

- Derive the **stellar-mass distributions** of the ETGs
- Measure their **mass-weighted structural parameters**
  - Compare with light-weighted parameters
  - Study their mass-growth
  - Comparison with models predictions
- Derive **Color and M/L profiles and gradients**

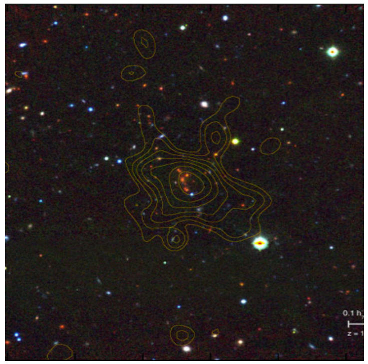
- Compare with local samples – Evolution over redshift

KMOS cluster sample

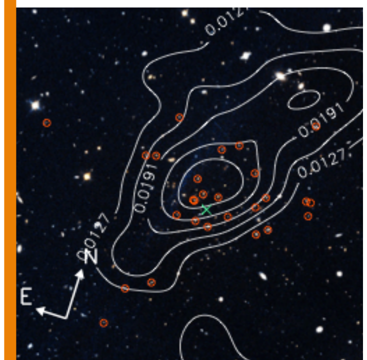
RCS234526-363 2.6 (Jee +11)



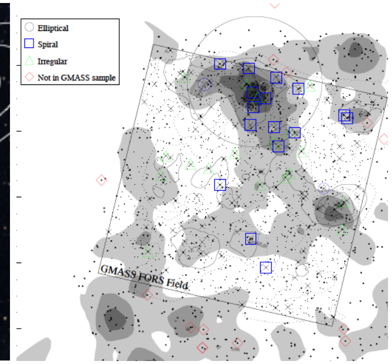
XMMU J2235-2557 (Mullis +05)



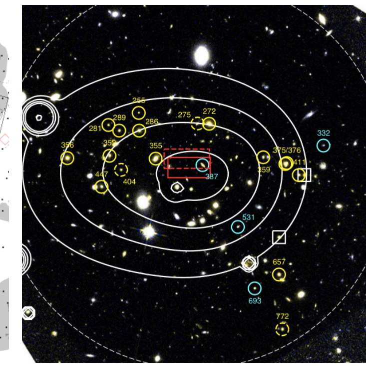
XMMXCSJ2215. 9-1738 (Jee +11)



Cl0332-2742 (Kurk +09)



JKCS 041 (Newman +12)



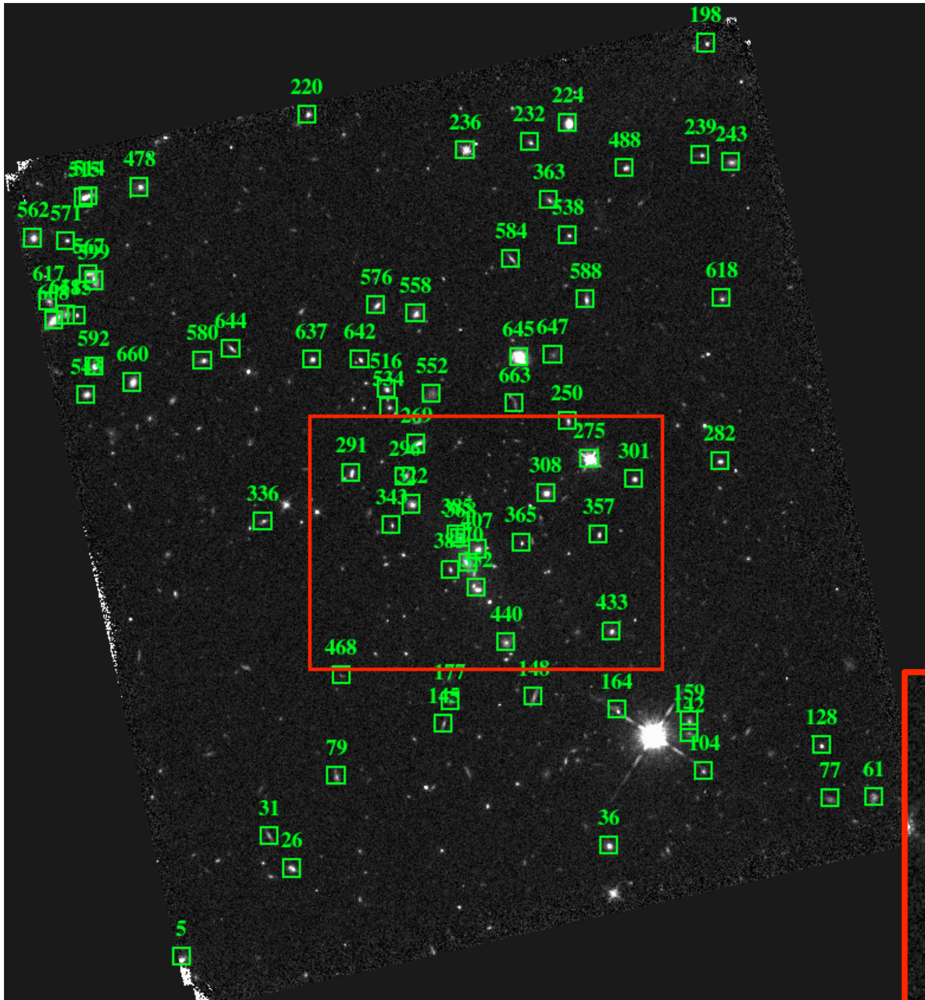
Redshift z

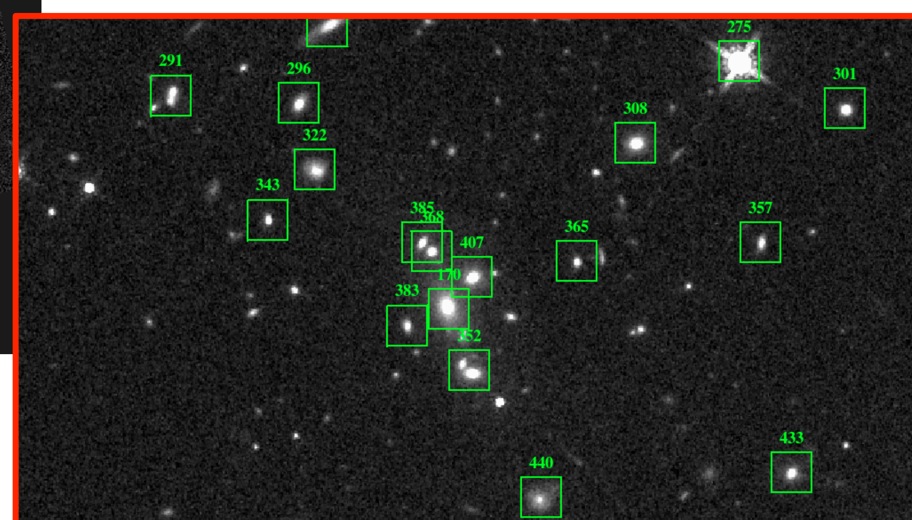
RCS234526-363	XMMU J2235-2557	XMMXCSJ2215.9-1738	Cl0332-2742	JKCS 041
1.04	1.39	1.46	1.61	1.80

KMOS selection requirements

- Multi-band HST photometry - Sizes and morphologies
- Deep ground-based imaging - Red-sequence studies and SED fitting
- Have large number of spectroscopically confirmed members
- Suitable redshifts - key absorption lines (e.g. Balmer, Mg & Fe lines) are uncontaminated from sky emission / telluric absorption

XMMU2235-2557 – Data available

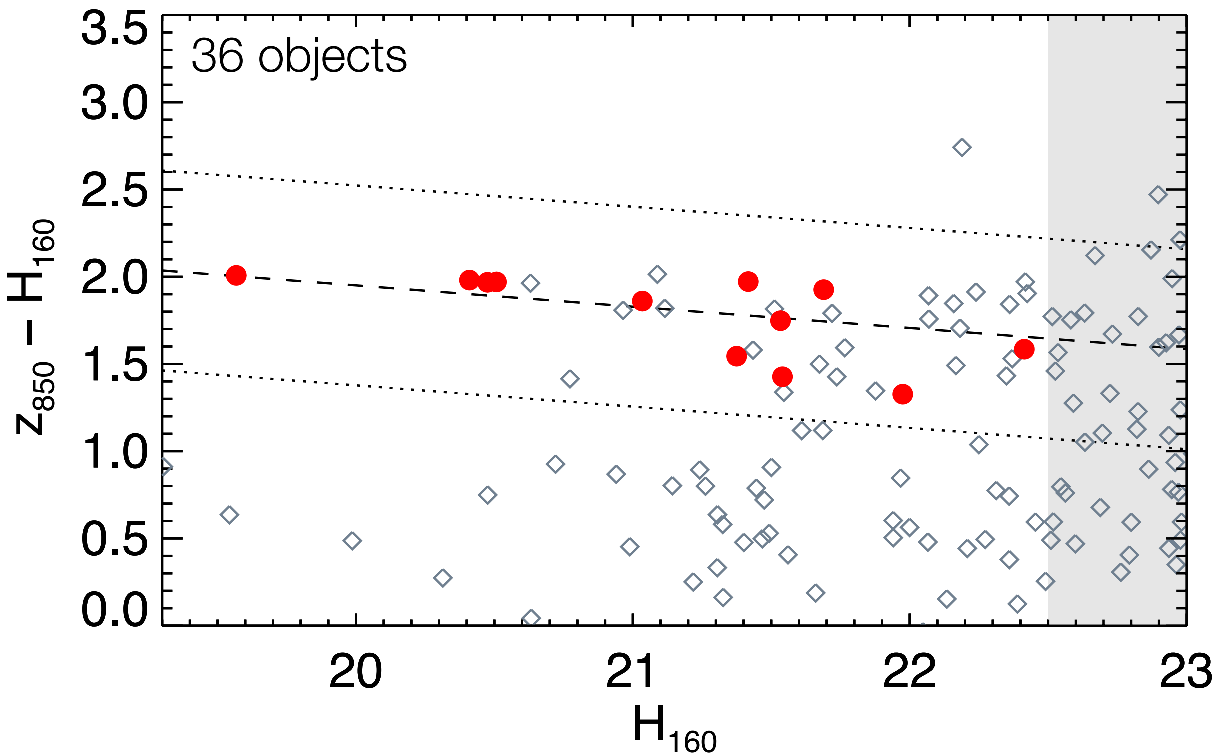




- 6-band HST imaging (PID 10496, 10698, 12051)
  - ACS i775, z850 (u)
  - WFC3 Y105 (B)
  - WFC3 YJ110 (g)
  - WFC3 J125 (V)
  - WFC3 H160 (r)
- Limiting FOV 145” x 126” (~500 kpc from cluster center)
- Photometric catalogue derived using H160 as detection band

Sample selection

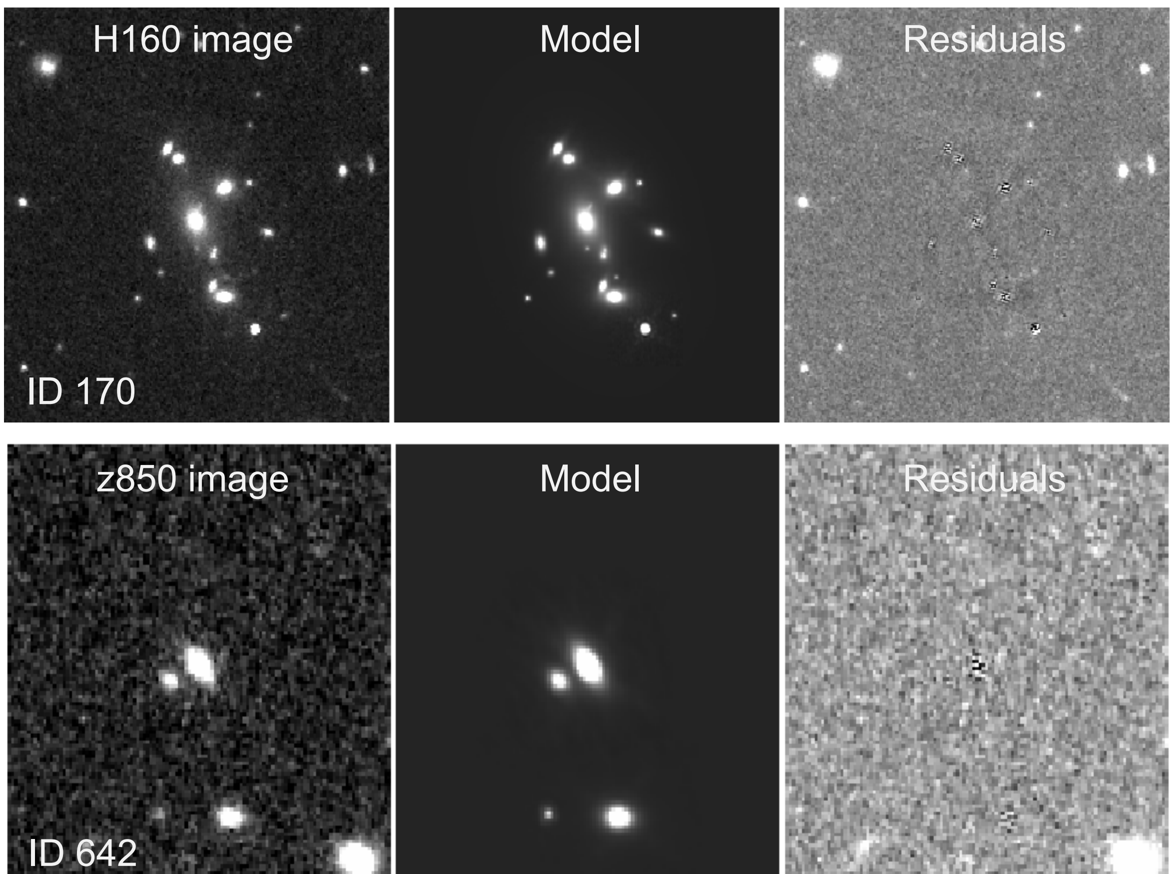
- Identify ETGs through fitting the red sequence from the color-magnitude diagram
- Cross-match existing catalogues to identify spectroscopically confirmed cluster members (Lidman +08, Grutzbauch +12)
- Red sequence galaxies with H < 22.5 are selected as our sample (completeness of ~95%)

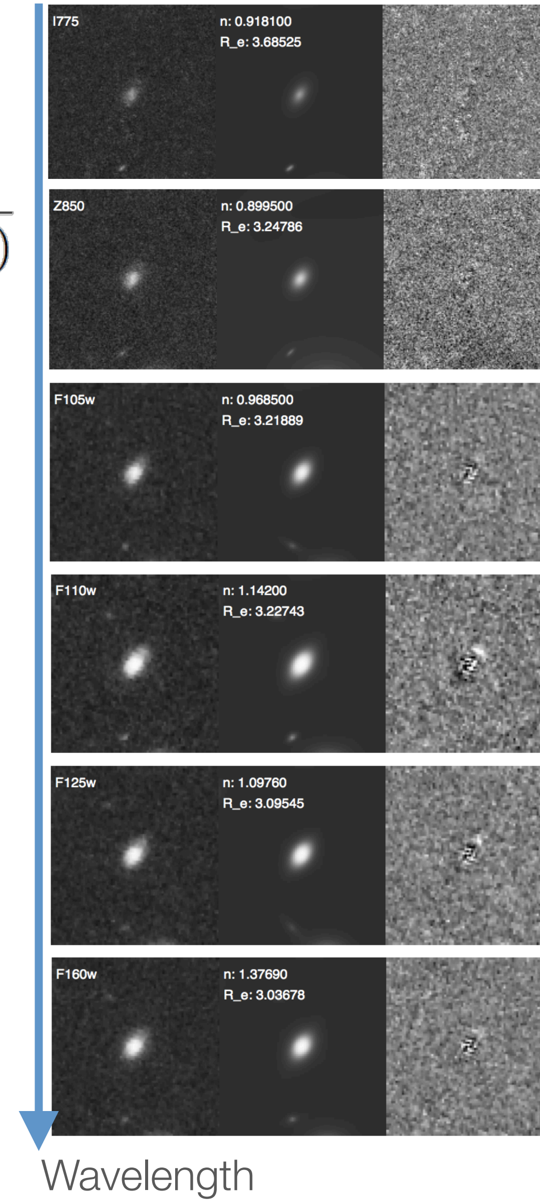


Structural parameters of XMMUJ2235

- Measure galaxy sizes in multiple bands with 2D Sérsic fit using GALAPAGOS (GALFIT) (Peng +02, Barden +12)

$$I(r) = I_e \exp\left[-b_n\left(\left(\frac{r}{r_e}\right)^{1/n} - 1\right)\right] \quad \text{where} \quad I_e = \frac{L_{tot}}{2\pi n q r_e^2\, b_n^{-2n}\,\Gamma(2n)}$$

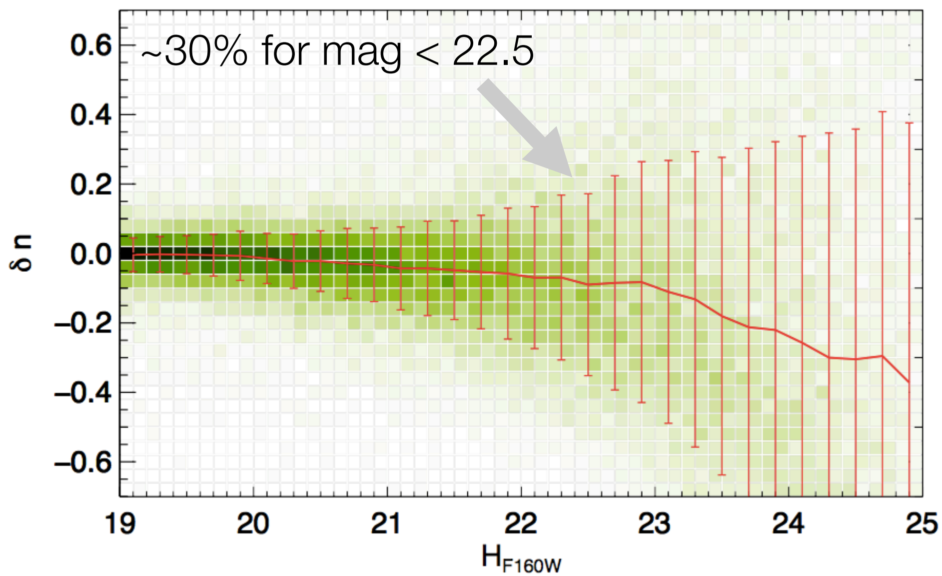


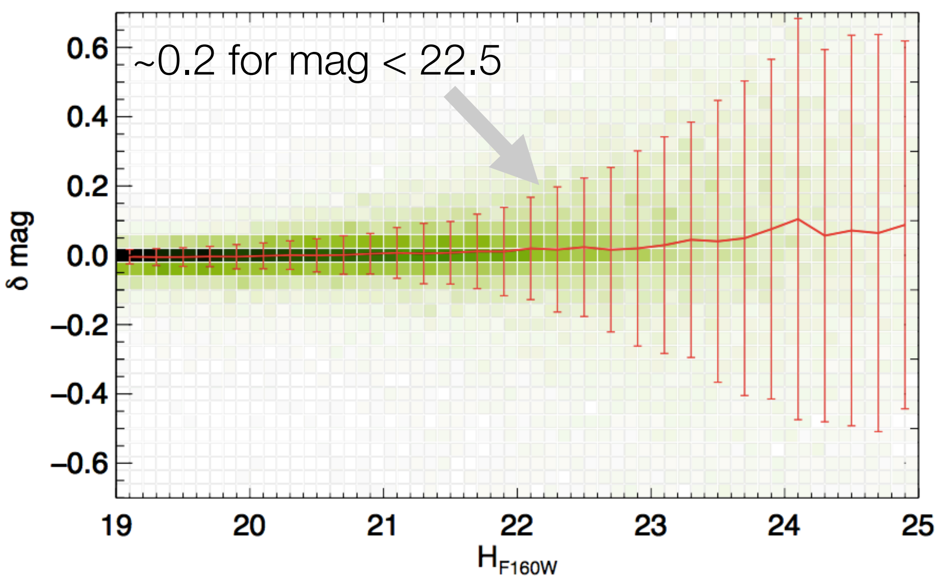


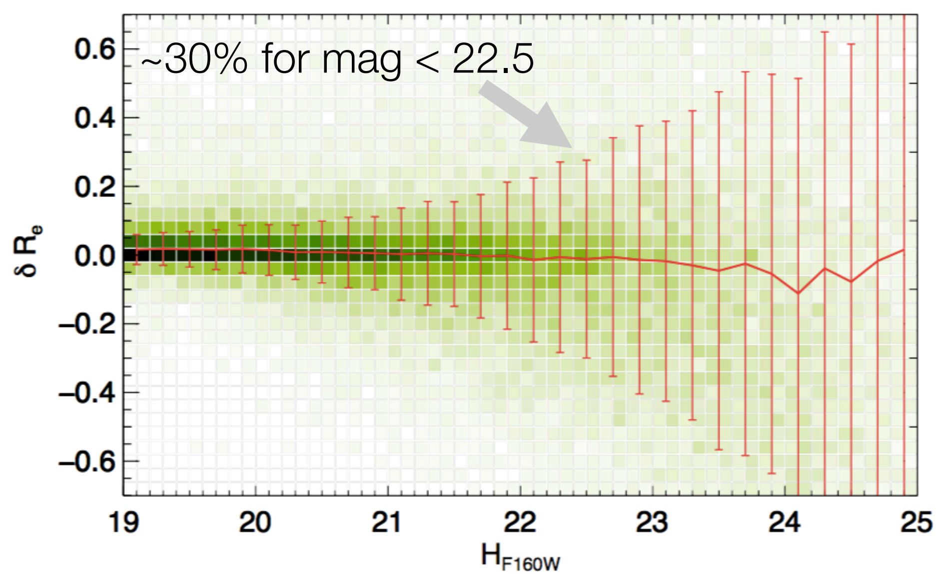
Uncertainty test with artificial galaxies

- Assess the accuracies of our size measurements with simulation

- 50000 simulated galaxies randomly dropped on the image
- $19 < H_{160} < 25$
- Gaussian distribution of n and re following the cluster sample
- Add the uncertainty in quadrature with the error output by GALFIT





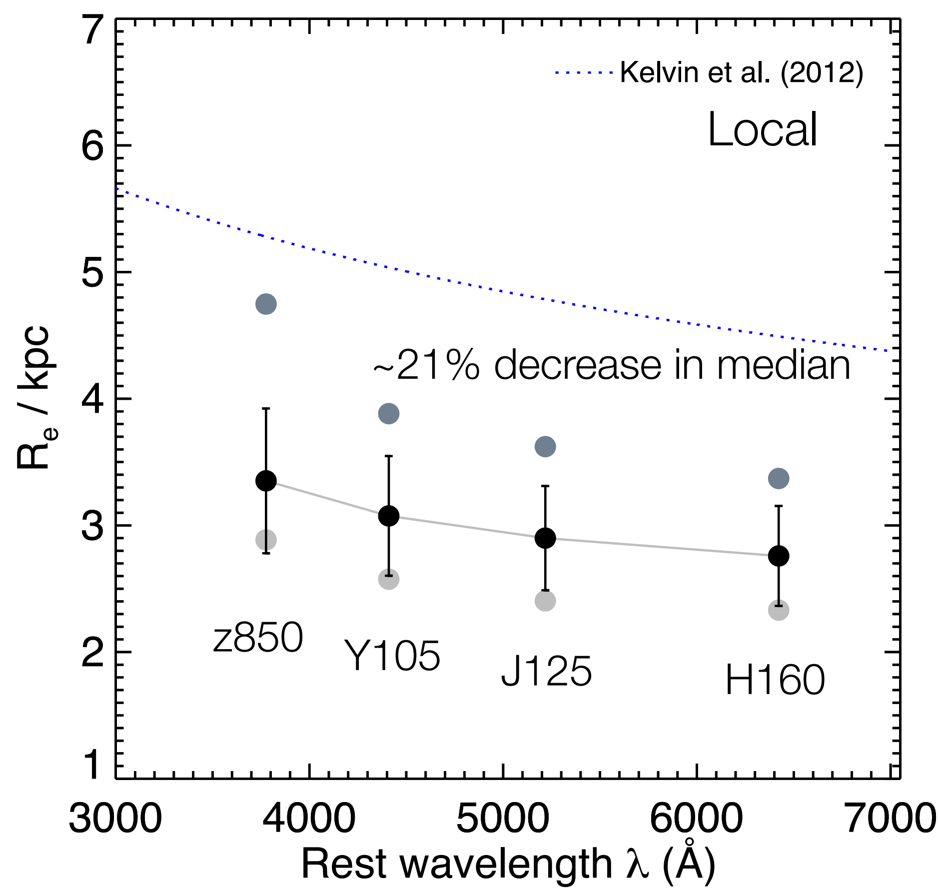


Wavelength dependence of galaxy sizes

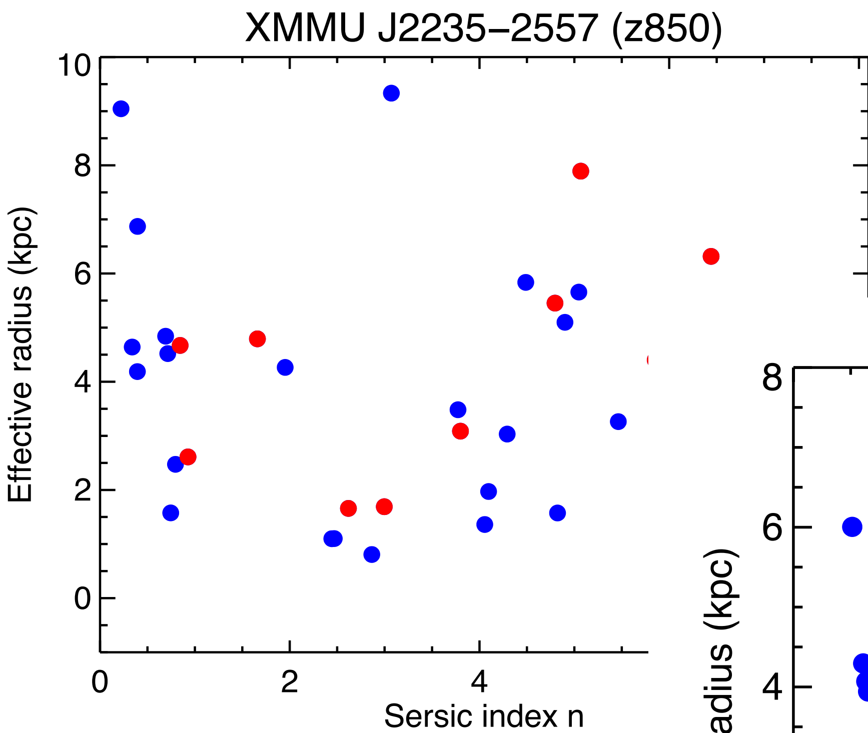
- Galaxy sizes change in wavelength
  - Dust
  - Bulge / disc prominent in different λ
  - Inside-out growth
  - Metallicity gradients

- Wavelength dependence has been studied for local ETGs (La Barbera +10, Kelvin +12, Lange +15)
- Trend consistent with Kelvin +12

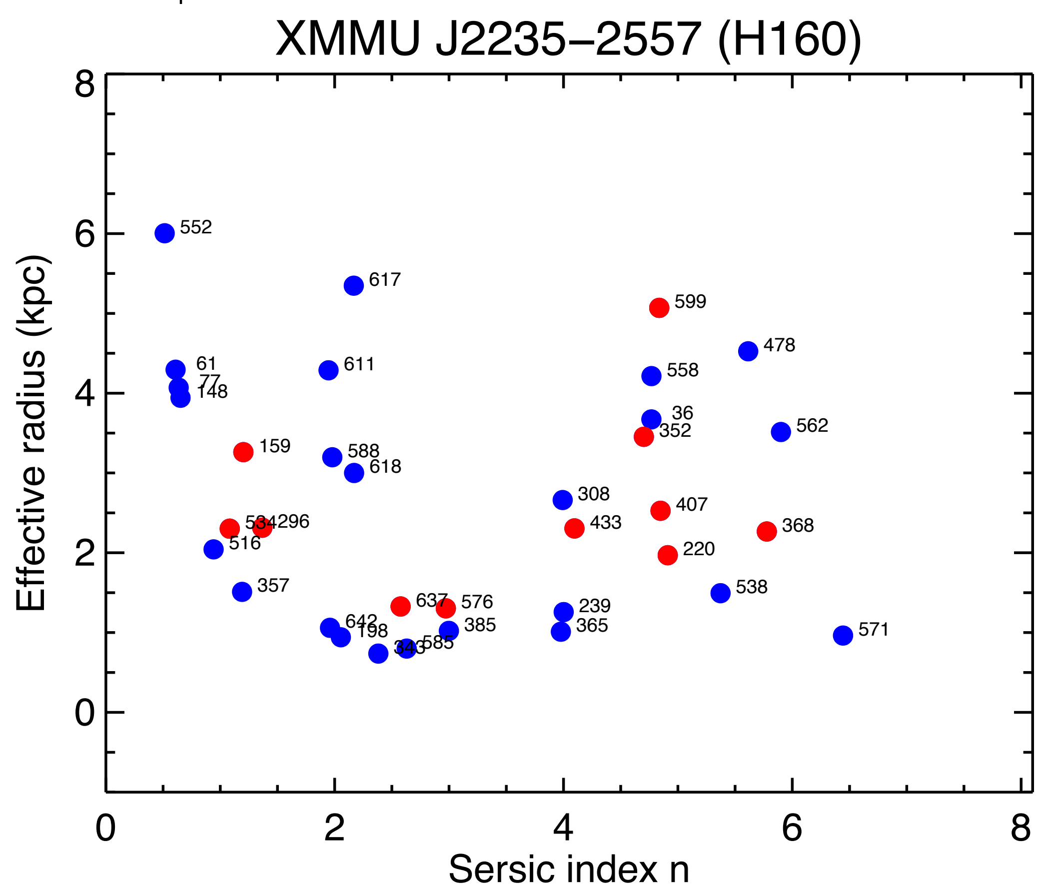
- Useful in interpolating sizes at intermediate wavelength for the KMOS cluster FP measurements



Structural parameters of XMMUJ2235

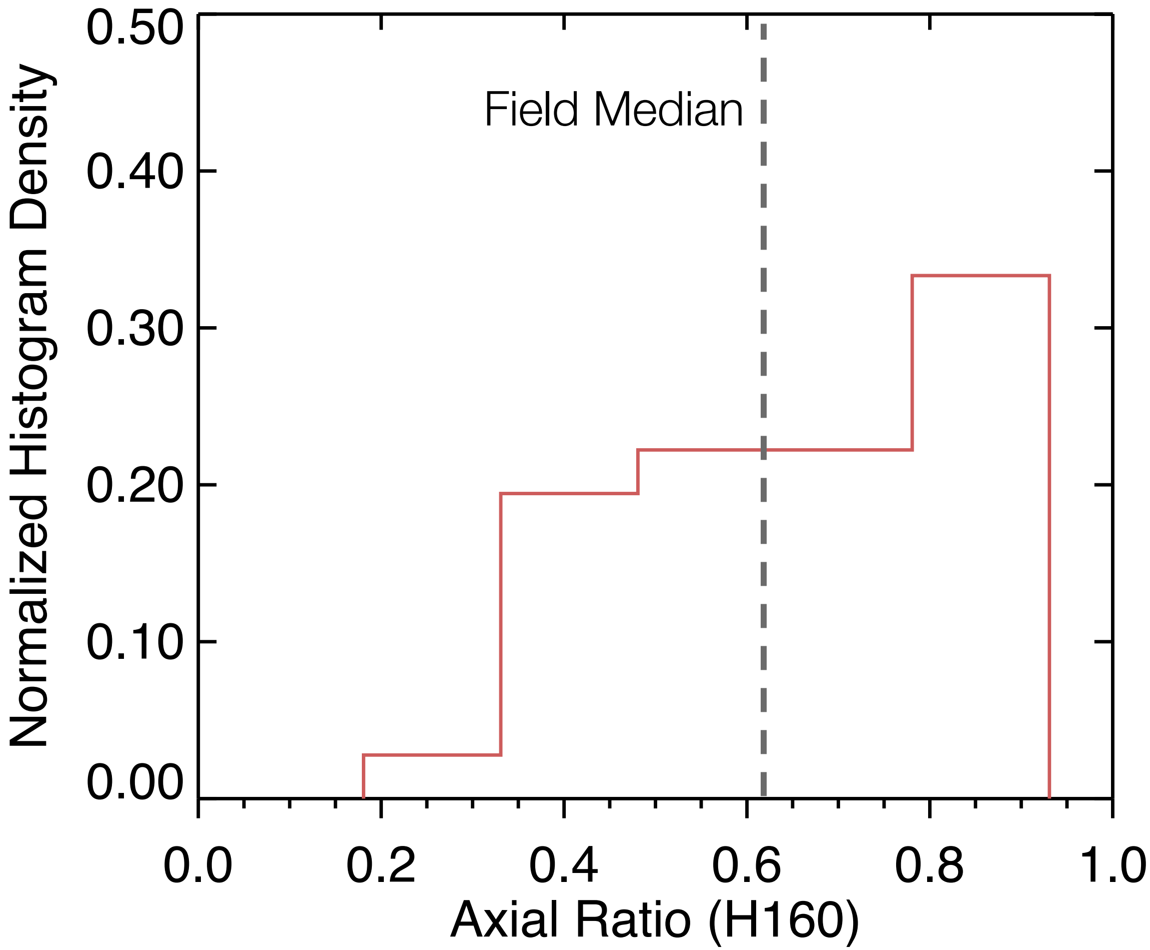


- Spectroscopic confirmed objects - mostly with n > 3 ~ local ETGs
- A population of disky objects (n < 2)
- Entire sample with median n~2.7



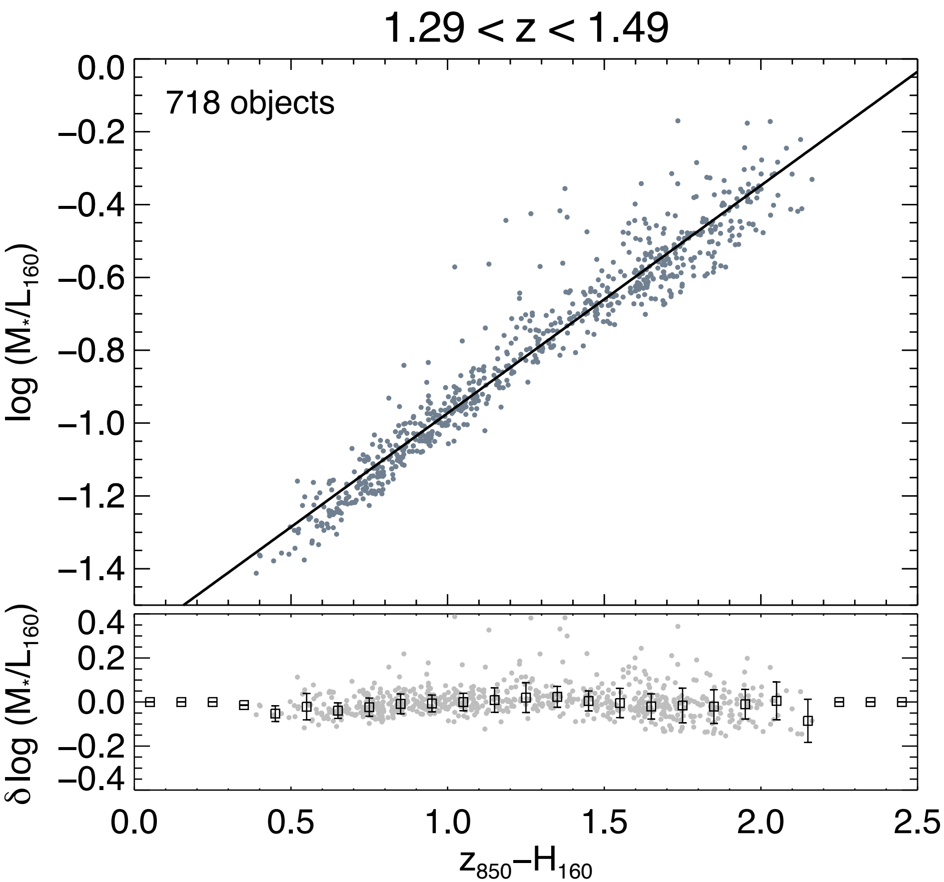
Structural parameters of XMMUJ2235

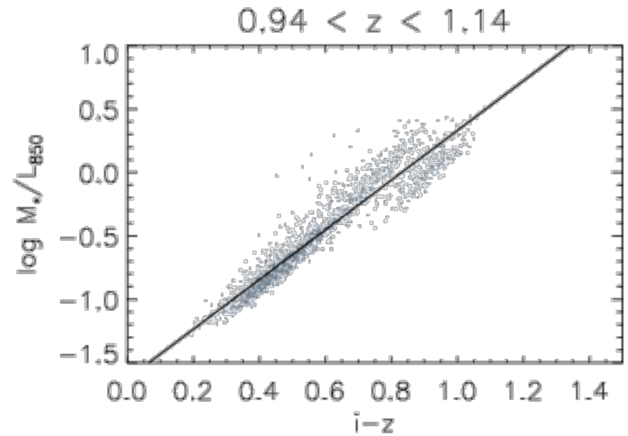
- The distribution of projected axial ratio
- Cluster galaxies are rounder(?) compared to field galaxies (Delaye +14)

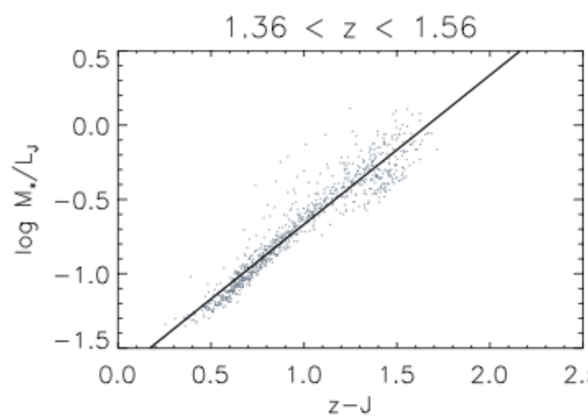


Measuring Stellar masses

- Using Color - M_*/L relation (Bell & de Jong +01, Bell +03)
- Derive our own relations from Newfirm Medium Band Survey (NMBS) catalogue (Whitaker +11)

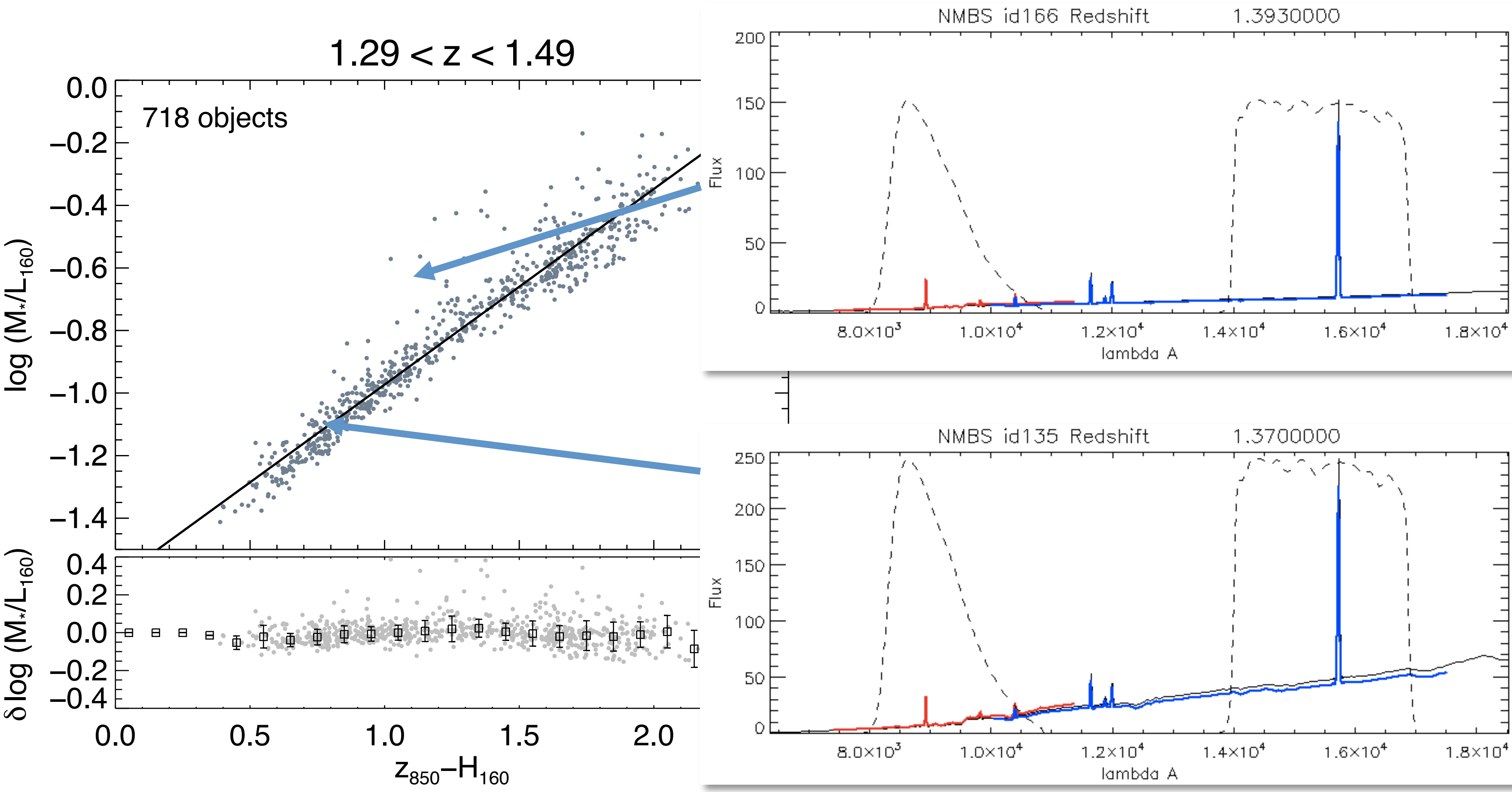






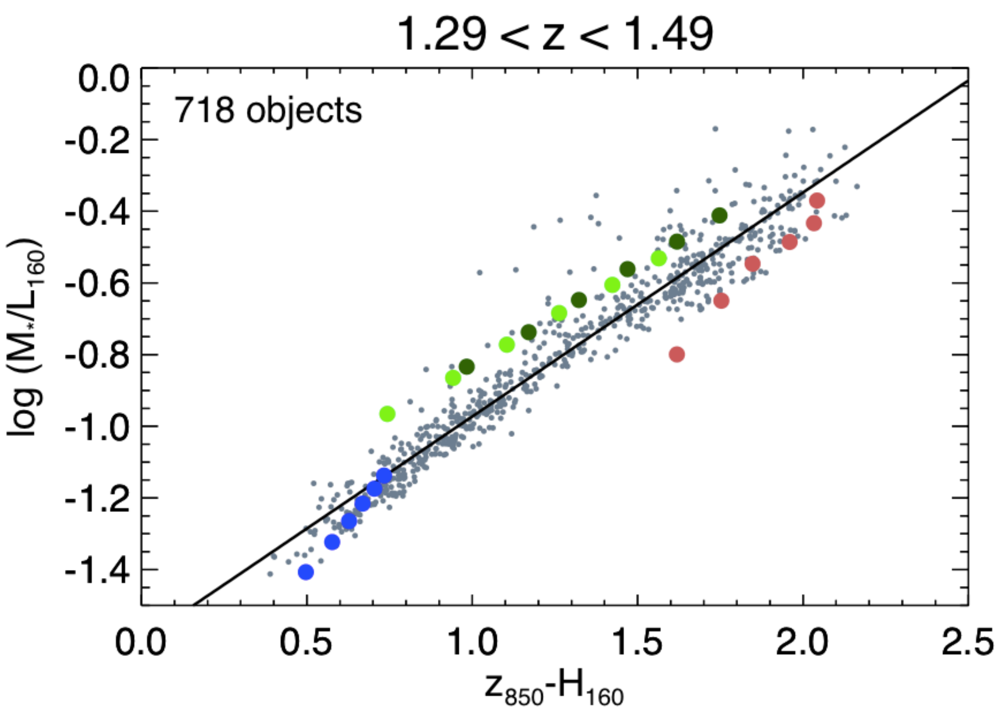
Measuring Stellar masses

- Using Color - M*/L relation (Bell & de Jong +01, Bell +03)
- Derive our own relations from NMBS catalogue (Whitaker +11)
    - Extract best-fit SED from EAZY to the photometry
    - Measure the magnitudes at observer frame



Measuring Stellar masses

- Using Color - M_*/L relation (Bell & de Jong +01, Bell +03)
- Derive our own relations from NMBS catalogue (Whitaker +11)
    - Extract best-fit SED from EAZY to the photometry
    - Measure the magnitudes at observer frame

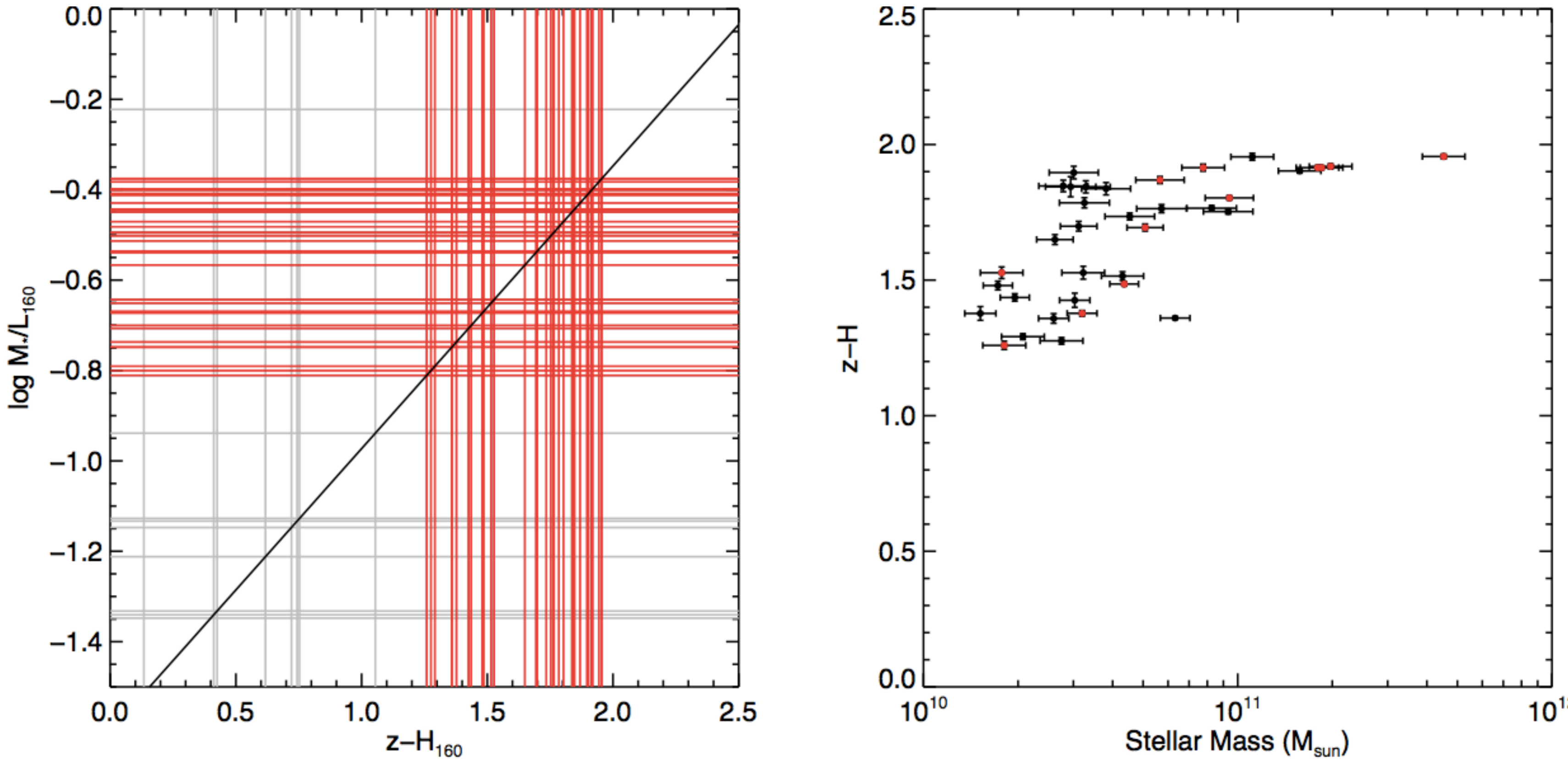


Bruzual & Charlot 2003 models between 1.5 Gyr - 4.0 Gyr:

- Red – Exponential declining SFR ($\tau = 0.1$)
- Green – Exponential declining SFR ($\tau = 1.0$)
- Dark green - Exponential declining SFR ($\tau = 1.0$) + 1Av extinction
- Blue – Constant SFR

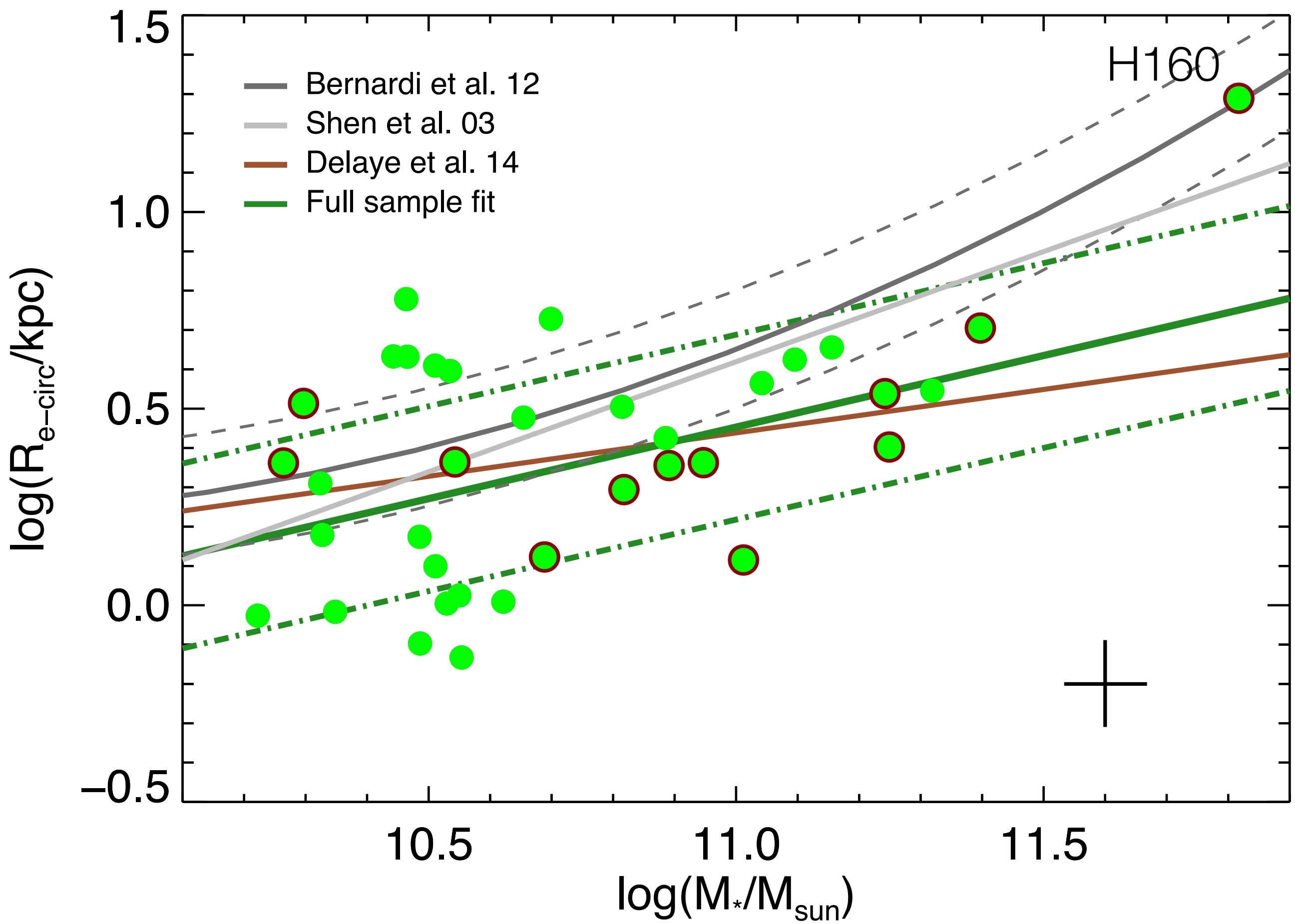
Measuring Stellar masses

- With z850 – H160 aperture color and Sérsic fit total luminosities we obtained the M_*/L of individual cluster galaxies -> integrated masses



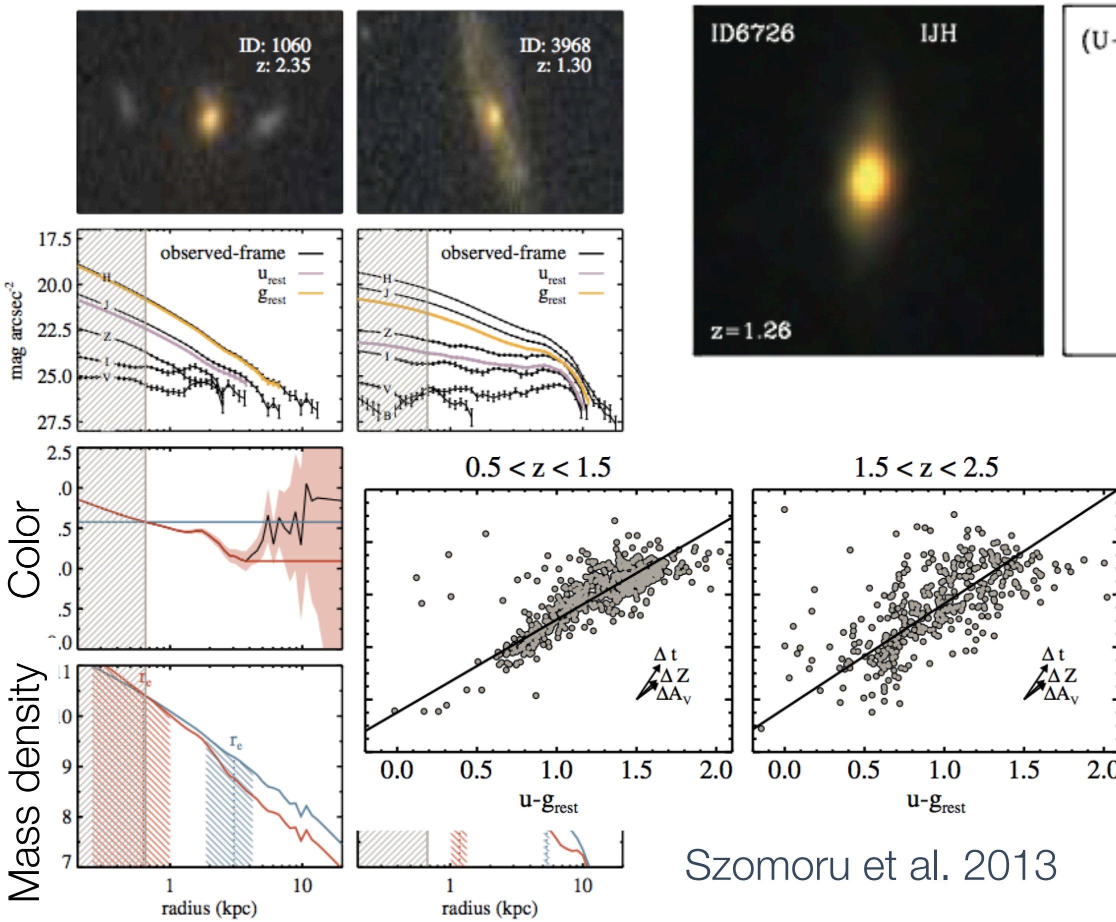
Mass-Size Relation of XMMUJ2235

- H-band sizes of ETGs in this cluster are on average ~40% smaller than those on the local relation with the same mass
- Circularized size - $r_{e-circ} = r_e \times \sqrt{q}$

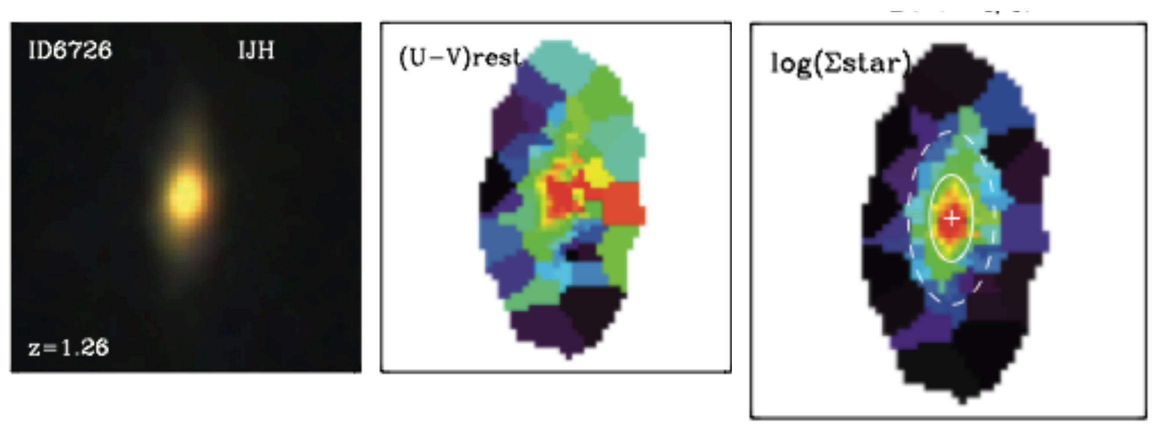


Deriving resolved stellar mass distribution

- Multi-band photometry allows us to reconstruct the distribution of stellar mass
  - Resolved SED fitting (e.g. Wuyts +12, Lang +14)
  - Color - M_*/L relation (e.g. Zibetti +09, Szomoru +13)



Szomoru et al. 2013

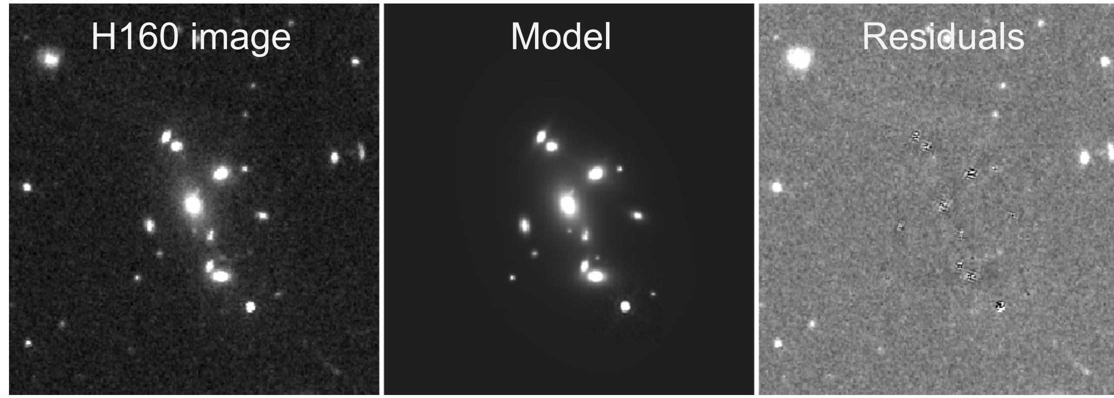


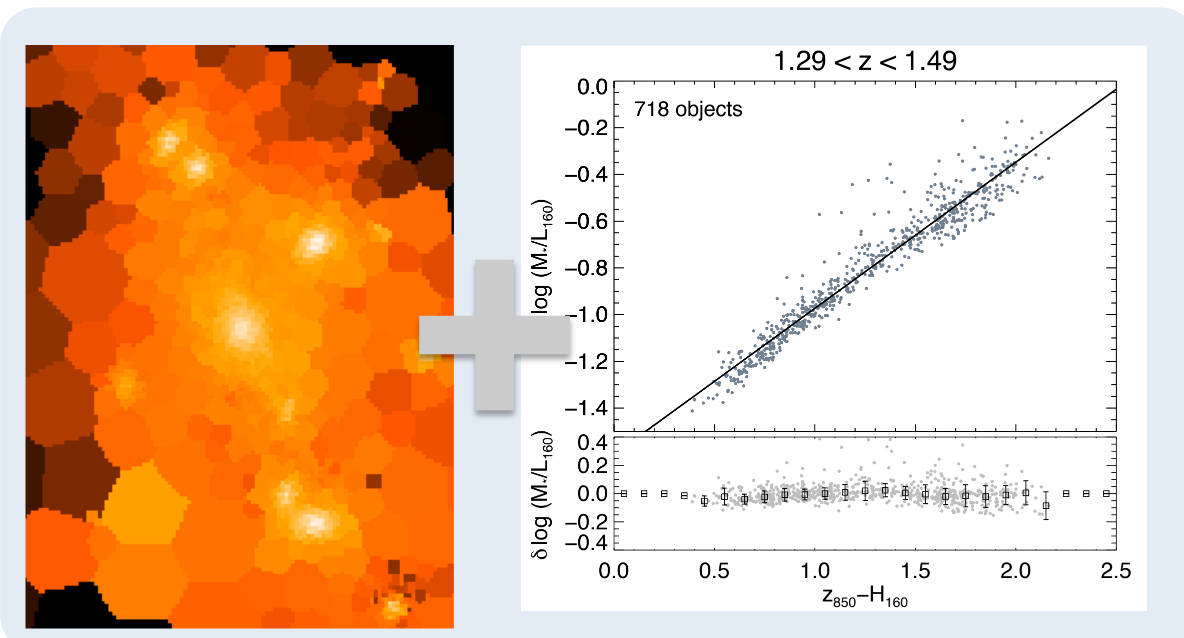
Wuyts et al. 2012

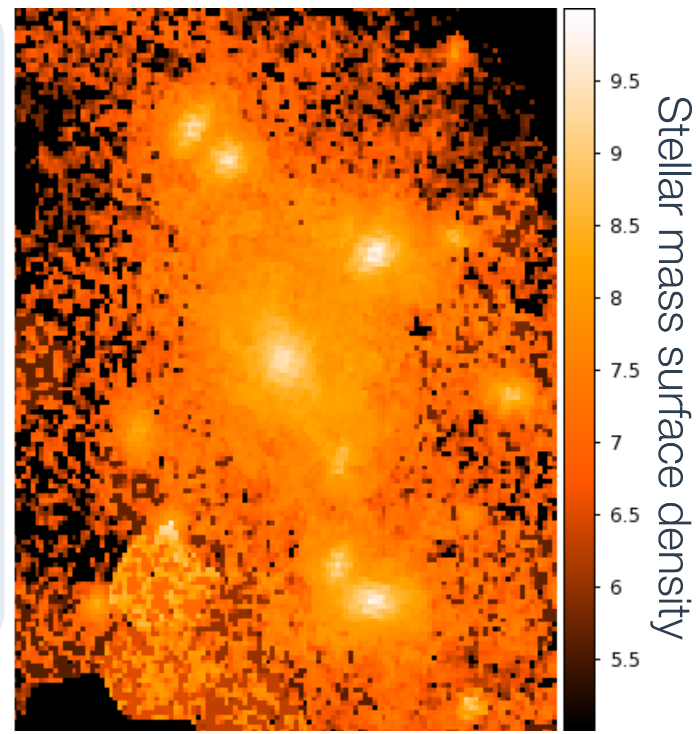
In our cluster sample we only have 2 – 4 bands for each cluster -> **Color - M_*/L relation**
High S/N is required

Resolved stellar mass map from Color - M*/L relation

- From the color- M/L relation, we can derive resolved stellar mass maps
- Apply Voronoi binning with S/N ~10 per bin (Cappellari +03)

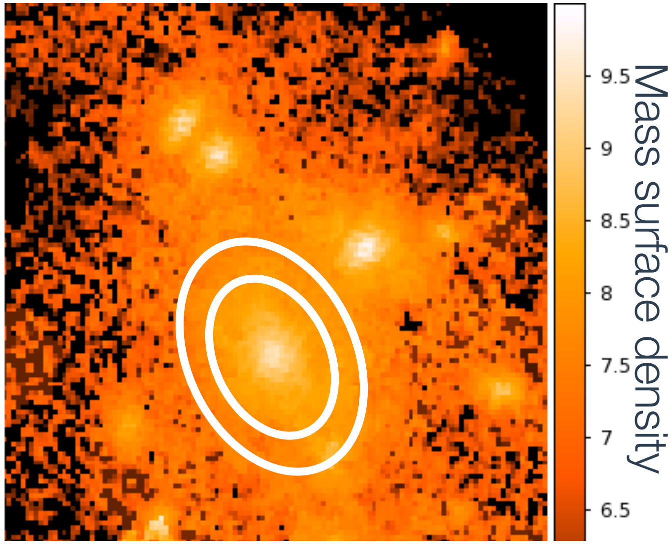


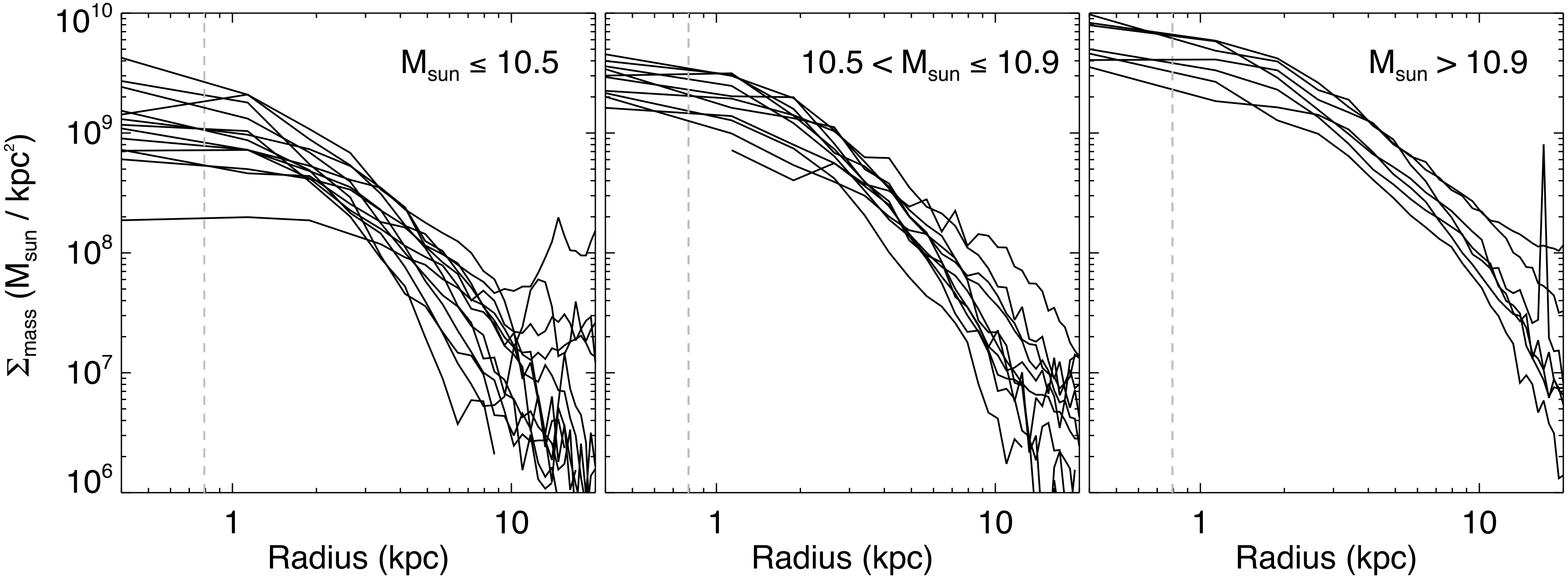




Radial stellar mass surface density

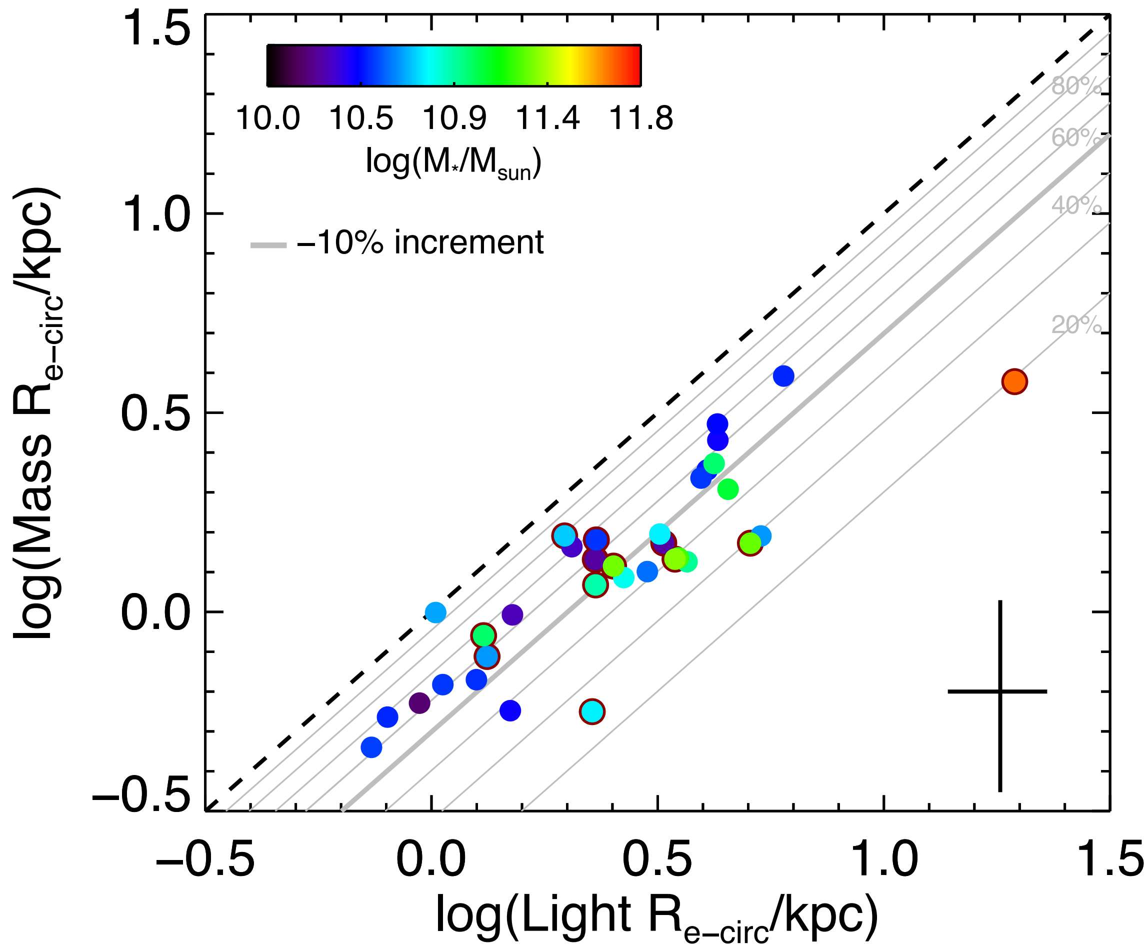
- From 2D resolved mass maps we can also derive 1D mass profiles
- Profile accurate to ~3-4 x effective radius (~10 kpc)
- Also use as quality checks to mass profiles from 1D – in progress





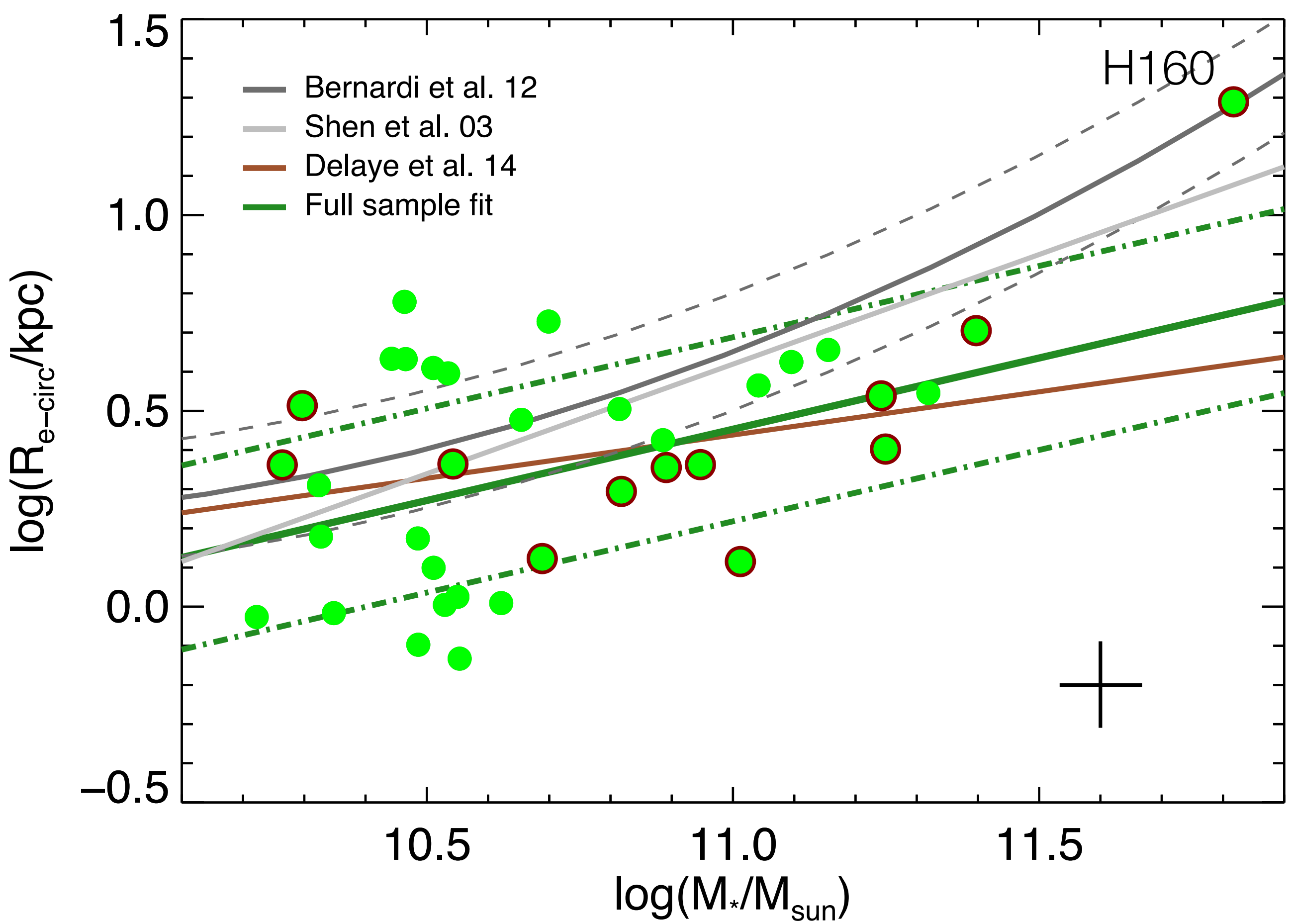
Mass-weighted structural parameters

- Measure mass-weighted galaxy sizes with 2D Sérsic fit using GALFIT
- Compare with light-weighted sizes - ~45% smaller



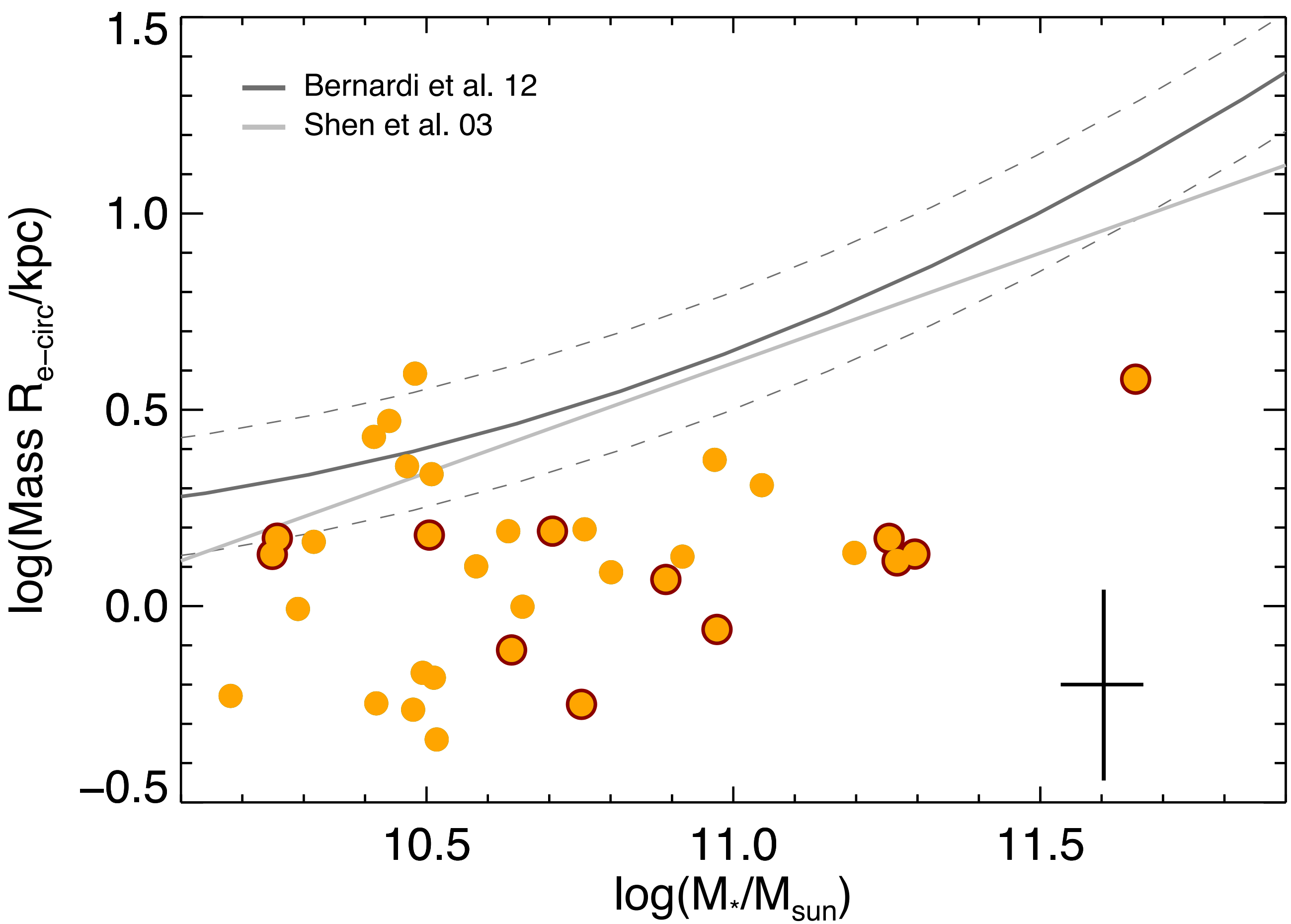
Mass-Size Relation of XMMUJ2235

- H-band sizes of ETGs in this cluster are on average ~40% smaller than those on the local relation with the same mass
- Circularized size - $r_{e-circ} = r_e \times \sqrt{q}$



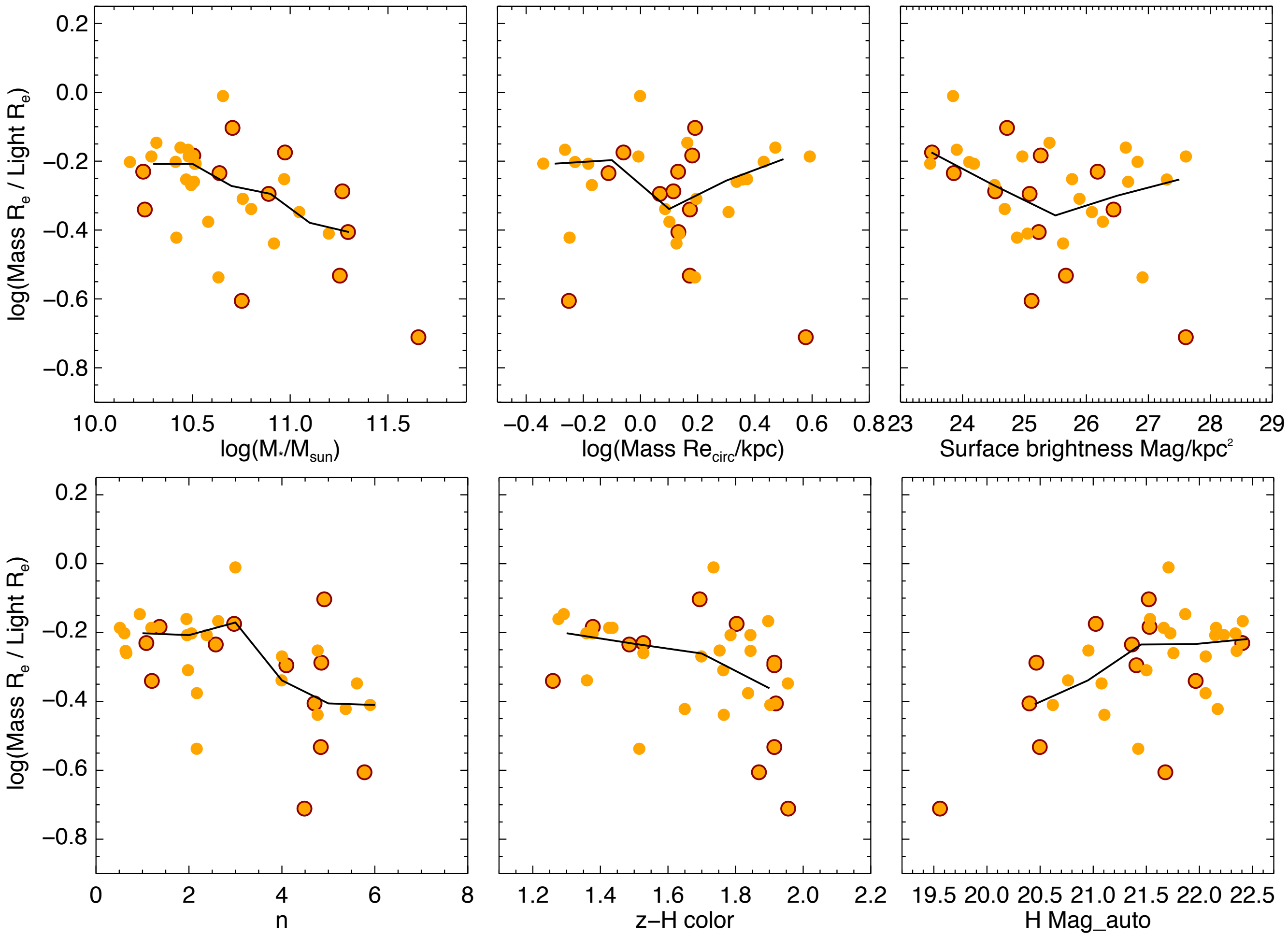
Mass - Mass-weighted-Size Relation of XMMUJ2235

- Mass-weighted size are ~45% smaller than light-weighted sizes
- Possible Change in slope of the relation? – Dependency



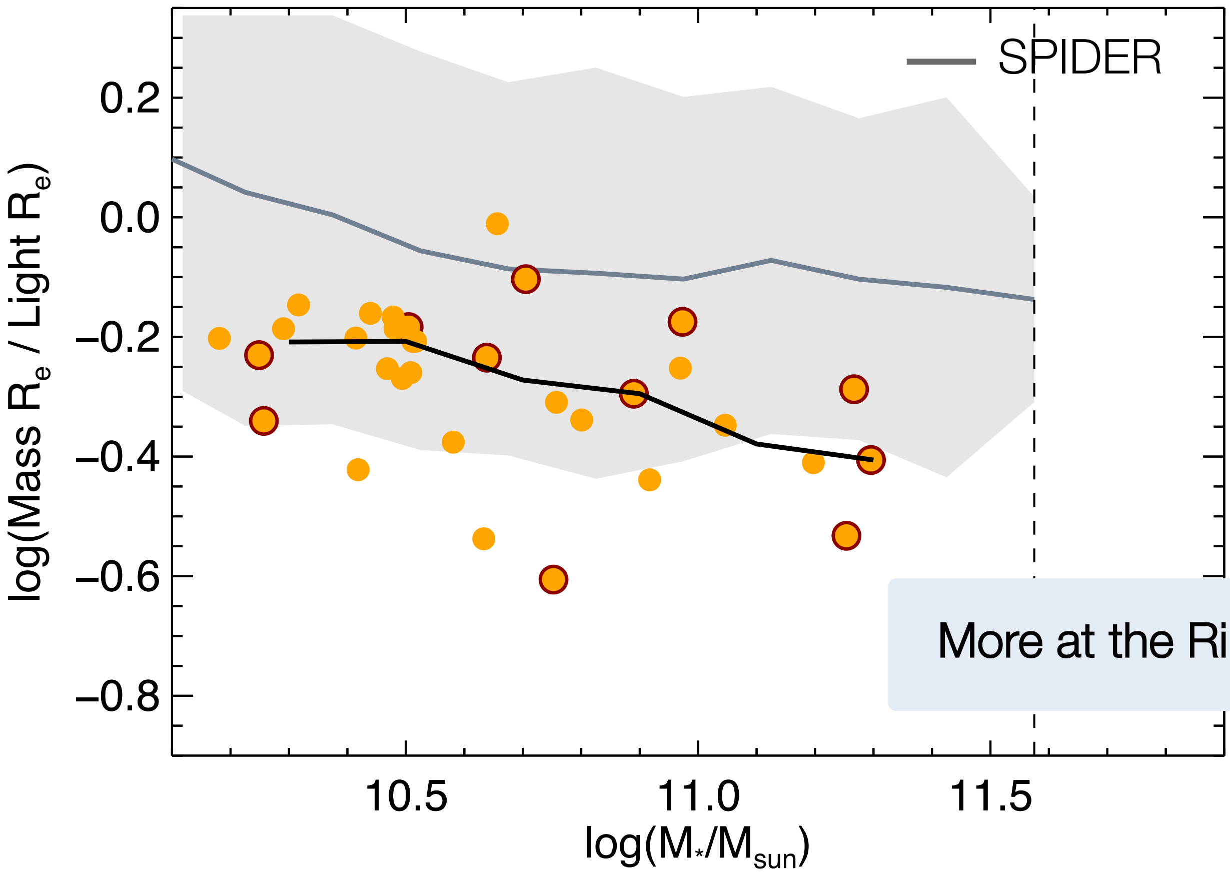
Dependencies of the mass/light size ratio

- Ratio of mass-weighted to light-weighted size seems(?) to show a weak dependence on stellar mass (or ~similarly luminosity) – in progress
- No obvious dependence on the other parameters



Mass dependence? – comparing to the local sample

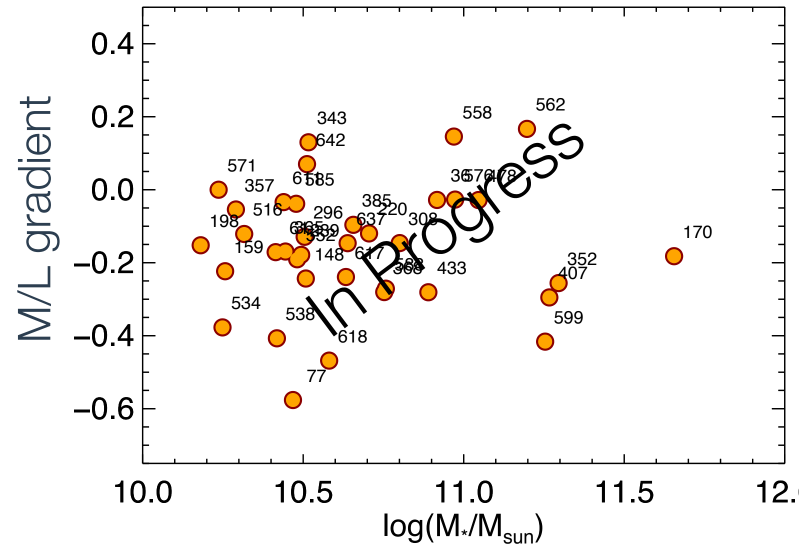
- We derive the same size ratio from the local SPIDER sample (g & r band)
- Mass/Light size ratio much smaller at high-z (~-0.1 i.e. 20% smaller)
- No(?) dependence on mass at z~0



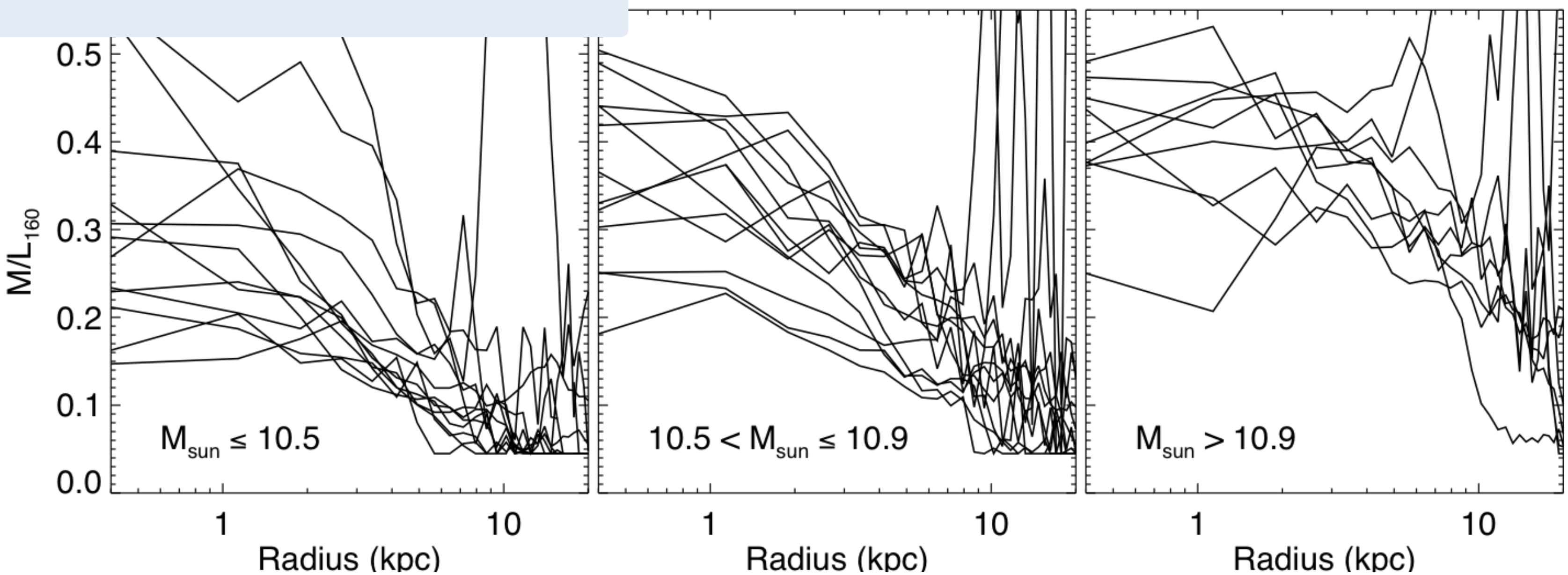
More at the Ringberg meeting!

Color (M/L) gradients

- Can color (M/L) gradient explain this ratio?
- In the sense that galaxies in higher mass have steeper M/L gradient?
- Construct 1D color and M/L profiles and compute M/L gradients
- Current in Progress!



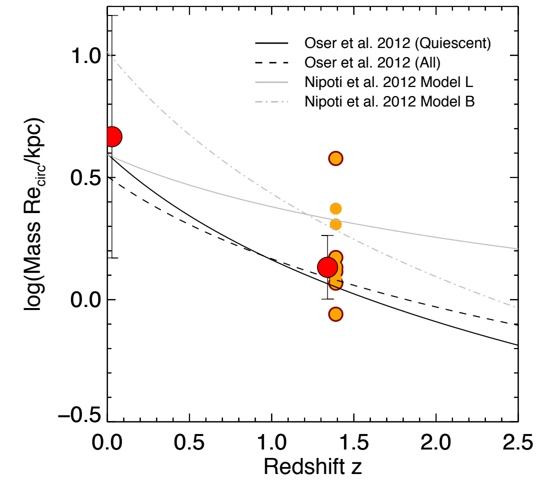
More at the Ringberg meeting!



Summary

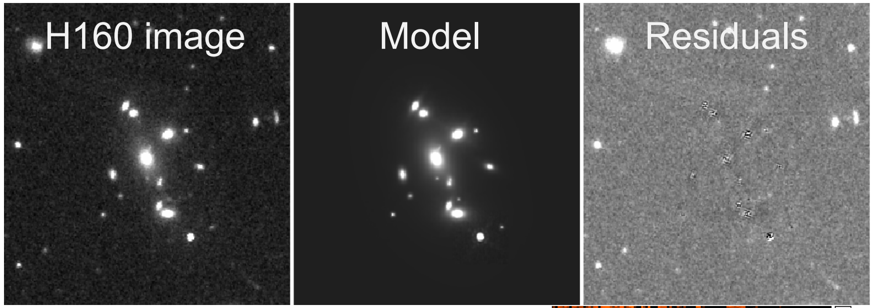
As part of KMOS-cluster, we aim at:

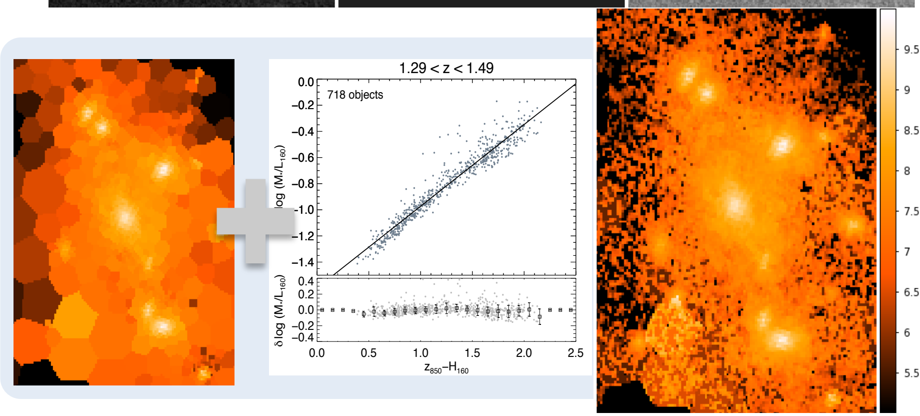
- Derive resolved 2D stellar mass surface density map
- Measure light-weighted and mass-weighted structural parameters
- Study their stellar-mass distribution and mass growth
- Compare with models



We found so far:

- H160 sizes of ETGs at z~1.4 cluster are **~40%** smaller than the local relation
- Mass sizes **~45%** < light sizes
- Ratio of mass to light sizes seems to show weak dependence on mass that is not seen in local universe
- May be explained by the difference in M/L gradient in different mass
- Difference in mass-growth?





More work required and (I hope)
More results at the Ringberg meeting!!