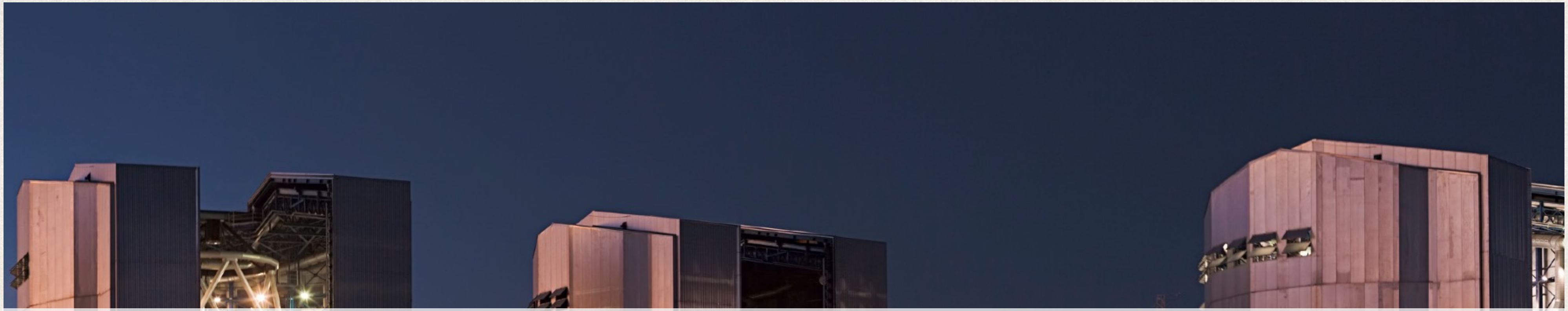


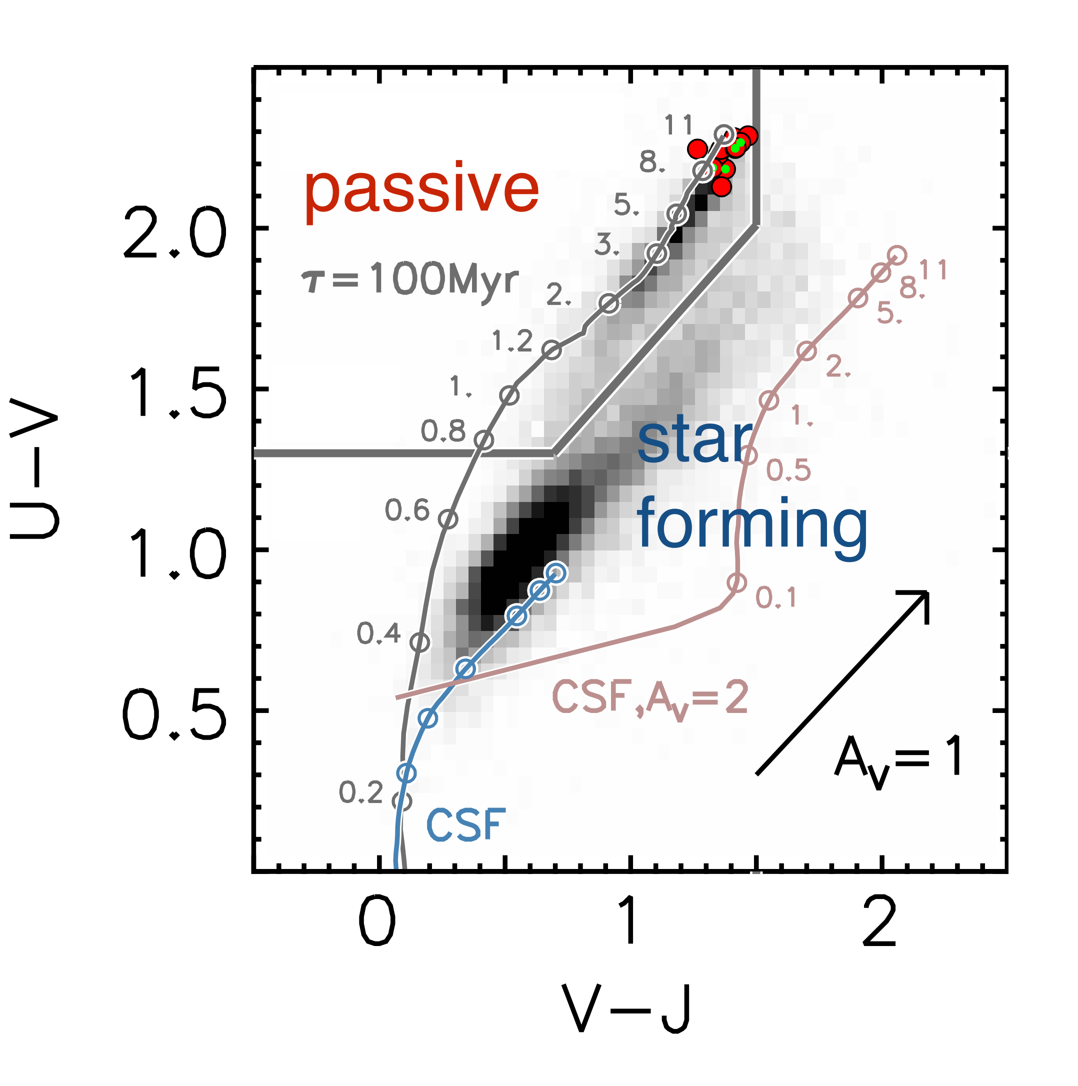
The KMOS Cluster Survey - KCS: Tracing the evolution of passive galaxies in clusters at $1.4<z<1.8$

Alessandra Beifiori (USM/MPE)

&

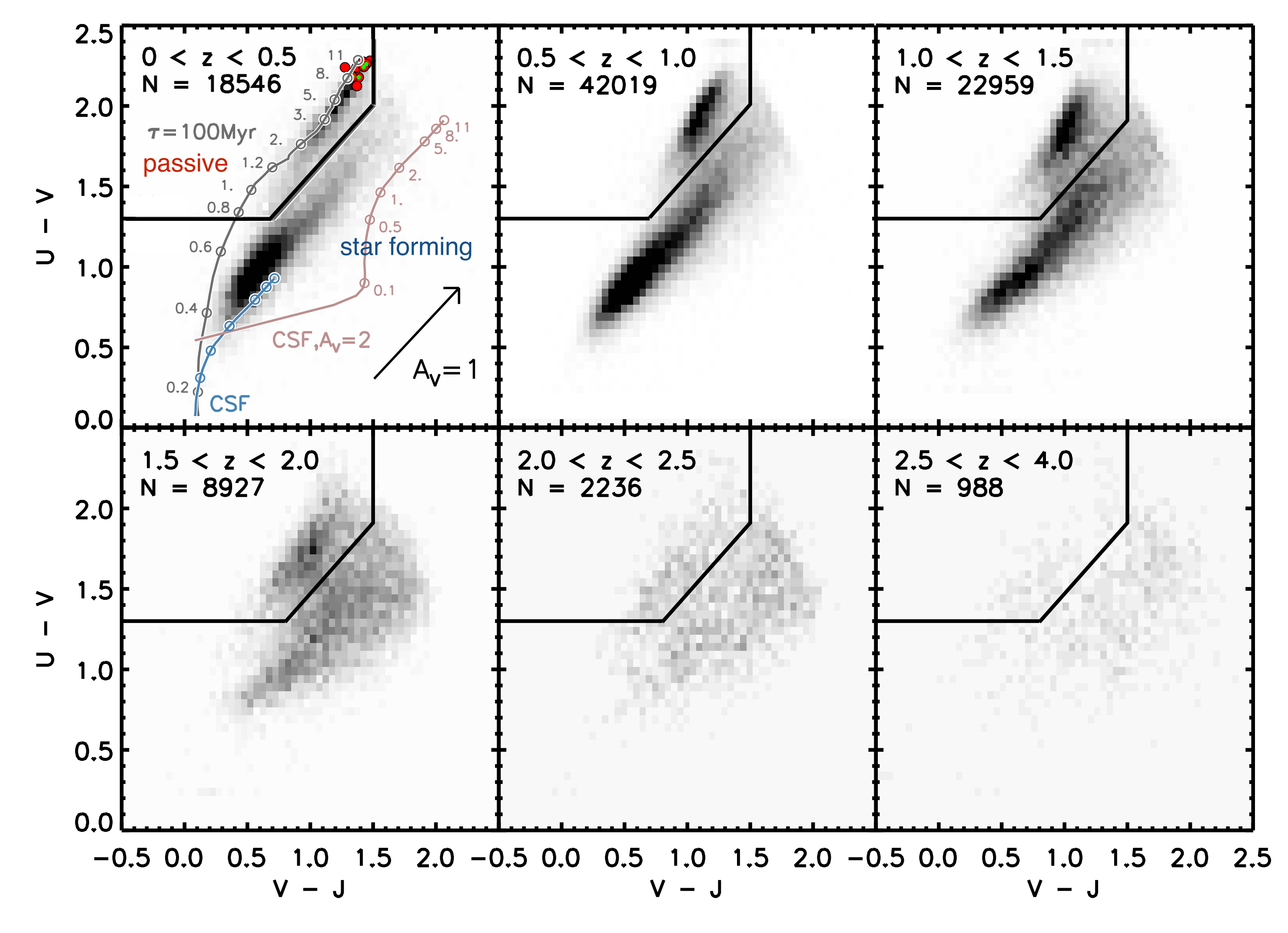
KCS team: **N. Amos**, R. Bender, M. Cappellari, **J. Chan**, R. Davies, A. Galametz, **R. Houghton, T. Mendel**, **K. Mehrgan**, **L. Prichard**, R. Saglia, R. Sharples, R. Smith, **J. Stott**, D. Wilman, I. Lewis, M. Wegner & KMOS instrument, software and commissioning teams

Tracing passive galaxies out to high redshift



Muzzin et al. 2013; Marchesini et al. 2014

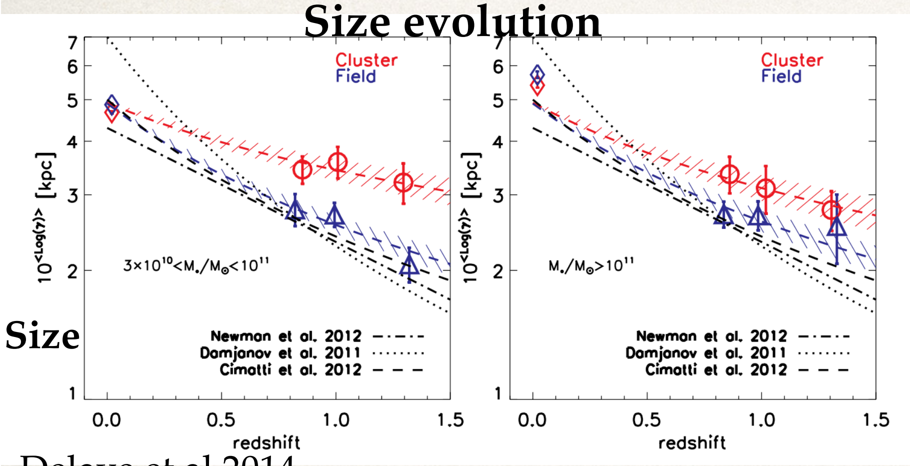
Tracing passive galaxies out to high redshift



Muzzin et al. 2013; Marchesini et al. 2014

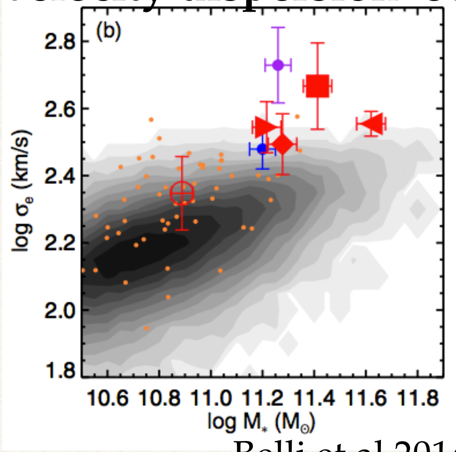
Tracing passive galaxies out to high redshift

Size evolution



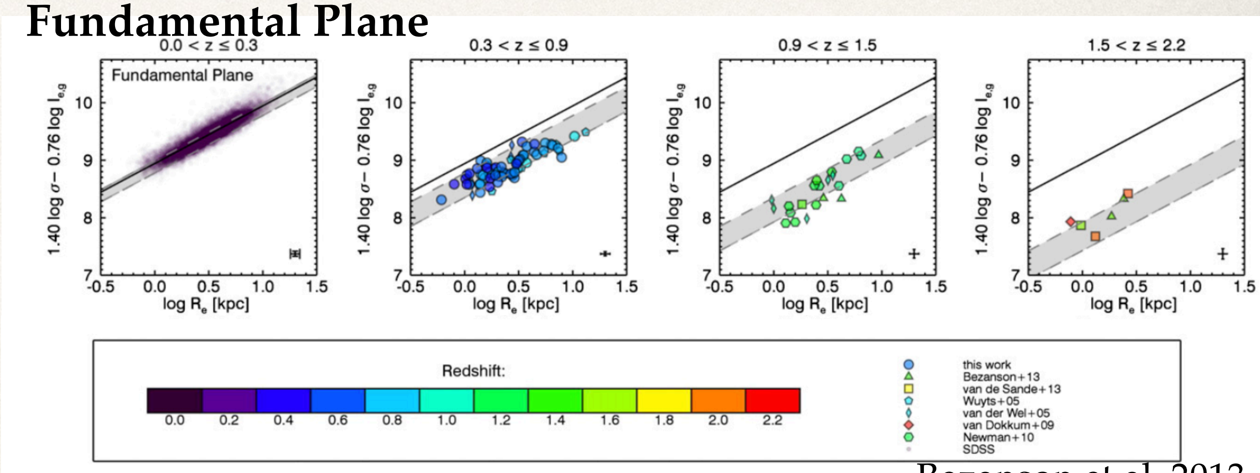
Delaye et al 2014

Stellar velocity dispersion evolution



Belli et al 2014

Fundamental Plane



Bezanson et al. 2013

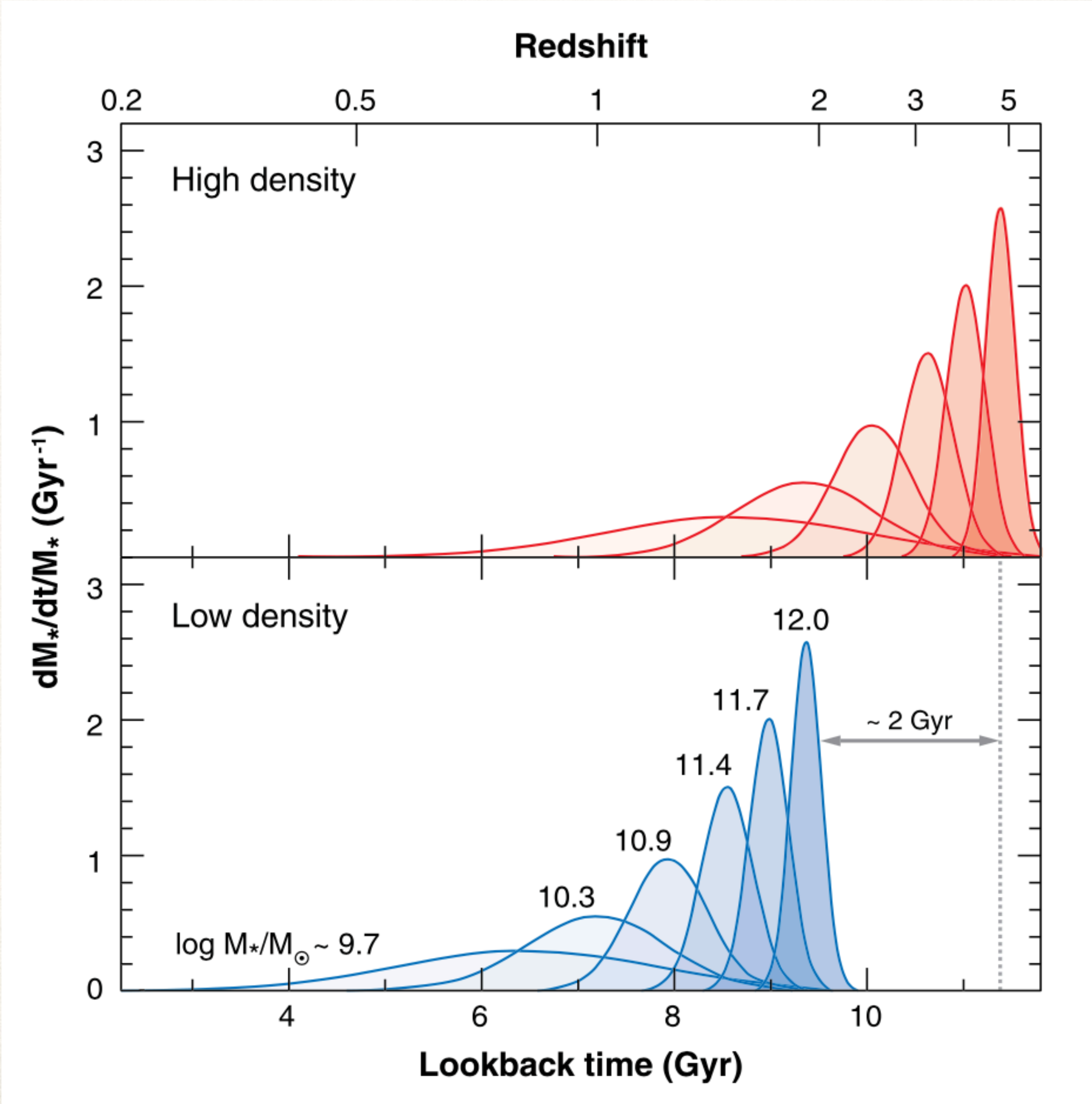
- **What are the properties of massive quiescent galaxies at/near their epoch of formation?**
  - How do they evolve over time?
  - How do they depend on their environment?

5 years ago existing samples of quiescent galaxies at high redshift were small, biased towards the brightest and blue objects, and mostly in the field

Timing the formation of massive passive galaxies in different environments

- When do massive quiescent galaxies form?

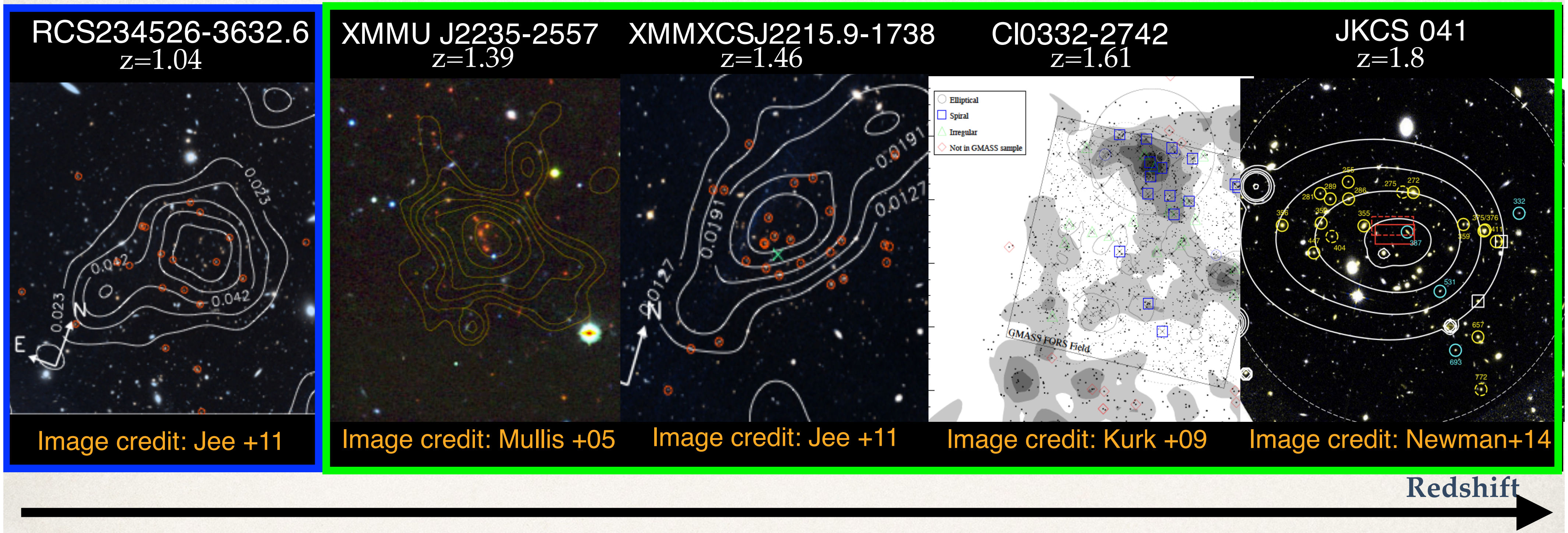
- Do formation times depend on environment?



Thomas et al. 2005, Renzini et al. 2006

The KMOS Cluster Survey - KCS

z~1 cluster - IZ band **Main sample - YJ band**



- **KCS: 30 nights** KMOS GTO program (PI s: R. Bender & R. Davies)
- Primary goal: enlarge existing **spectroscopic samples at z>1.4** ***in dense environments*****. Complementary to VIRIAL.**
- **1.4<z<2: critical epoch** where diversity of the Hubble sequence is established

The KMOS Cluster Survey - KCS

z~1 cluster - IZ band

RCS234526-3632.6
z=1.04

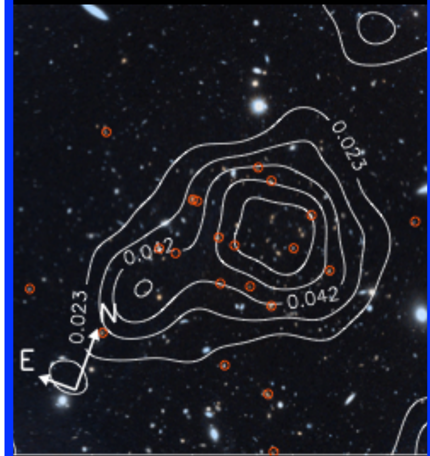


Image credit: Jee +11

Main sample - YJ band

XMMU J2235-2557
z=1.39

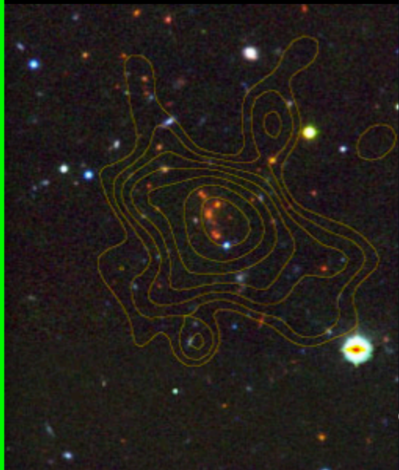


Image credit: Mullis +05

XMMXCSJ2215.9-1738
z=1.46

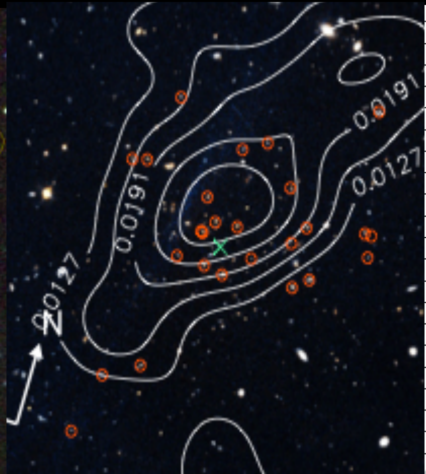


Image credit: Jee +11

Cl0332-2742
z=1.61

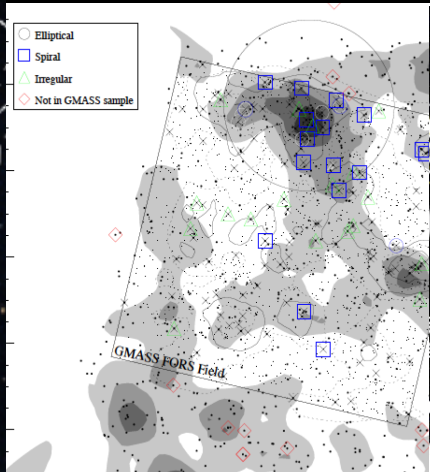


Image credit: Kurk +09

JKCS 041
z=1.8

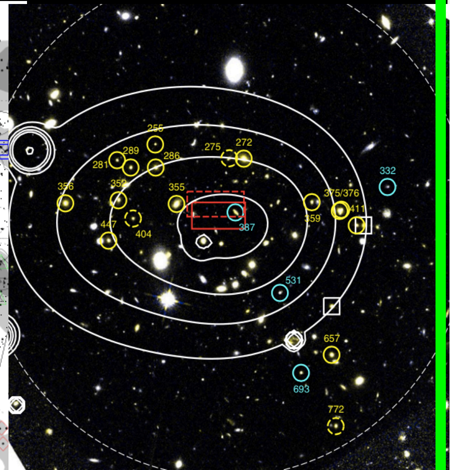
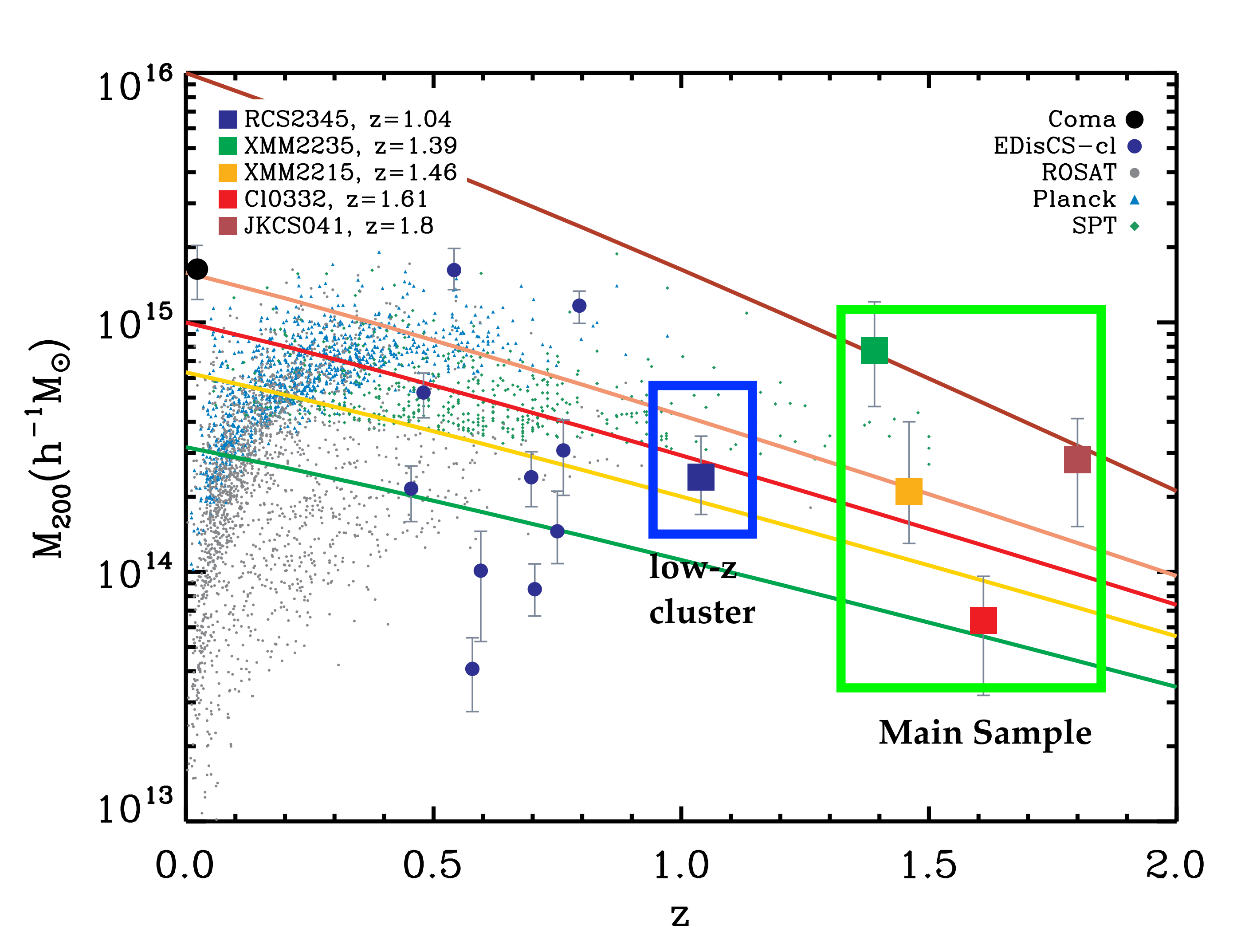


Image credit: Newman+14

Redshift →

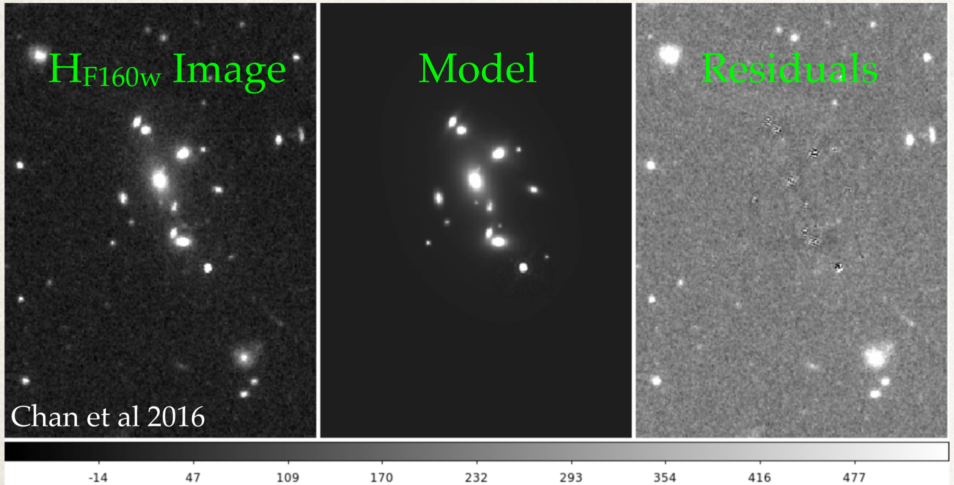
- **Overdensities** with lots of **ancillary data**: spectroscopic **redshifts, HST/ACS&WFC3 imaging (HST Cycle 22 WFC3 images** (PI: A. Beifiori).
- **Passive Galaxies (~85% nights):**
  - **Deep absorption-line spectroscopy** of ≥ **20 passive galaxies** *in each* of **4 main** overdenstities at **1.4<z<1.8 &** in cluster at **z=1.04** to bridge to local studies. Exposure: **20h on source.**
  - **Red-sequence selected**
- **Star-forming galaxies** in **infalling regions @ z~1.4**

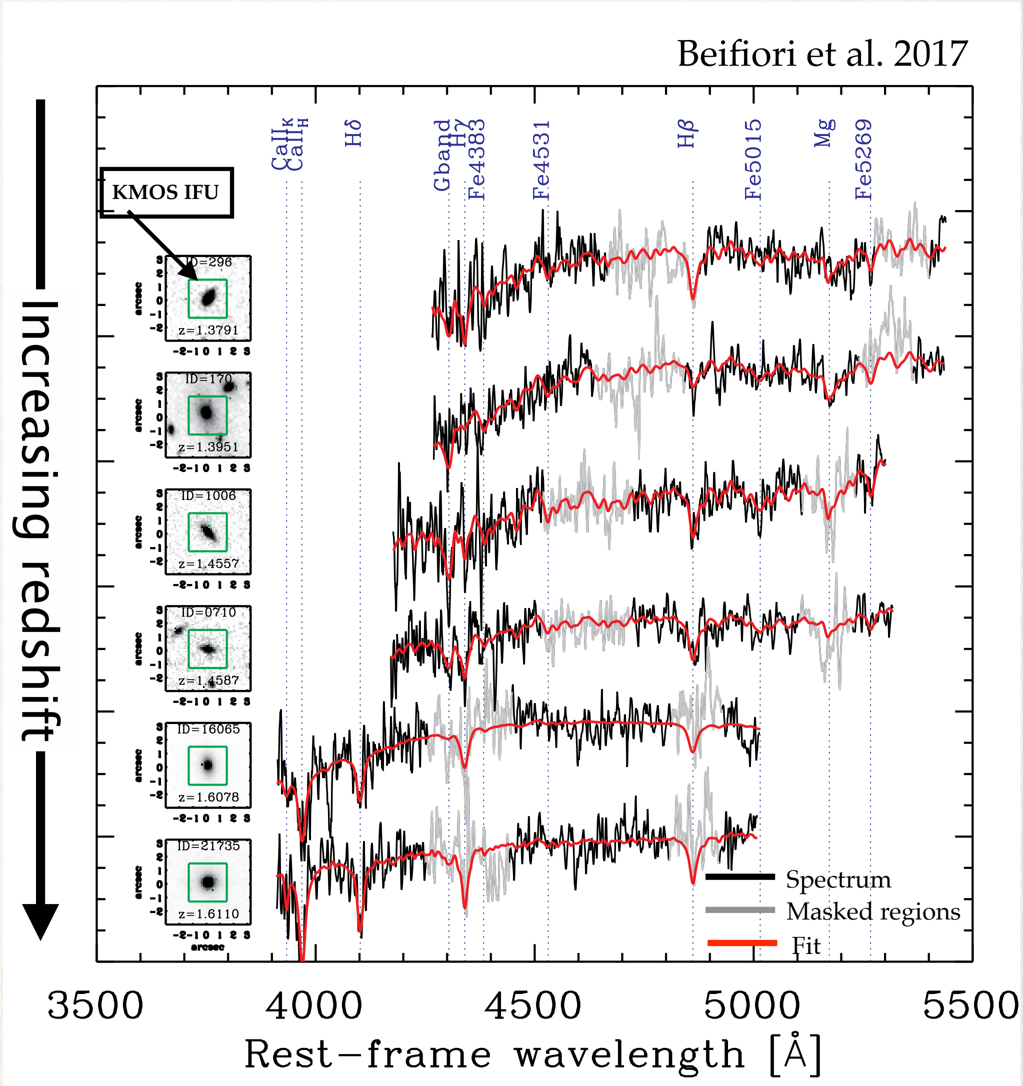
The KMOS Cluster Survey - KCS



Beifiori et al. 2017

The KMOS Cluster Survey - KCS

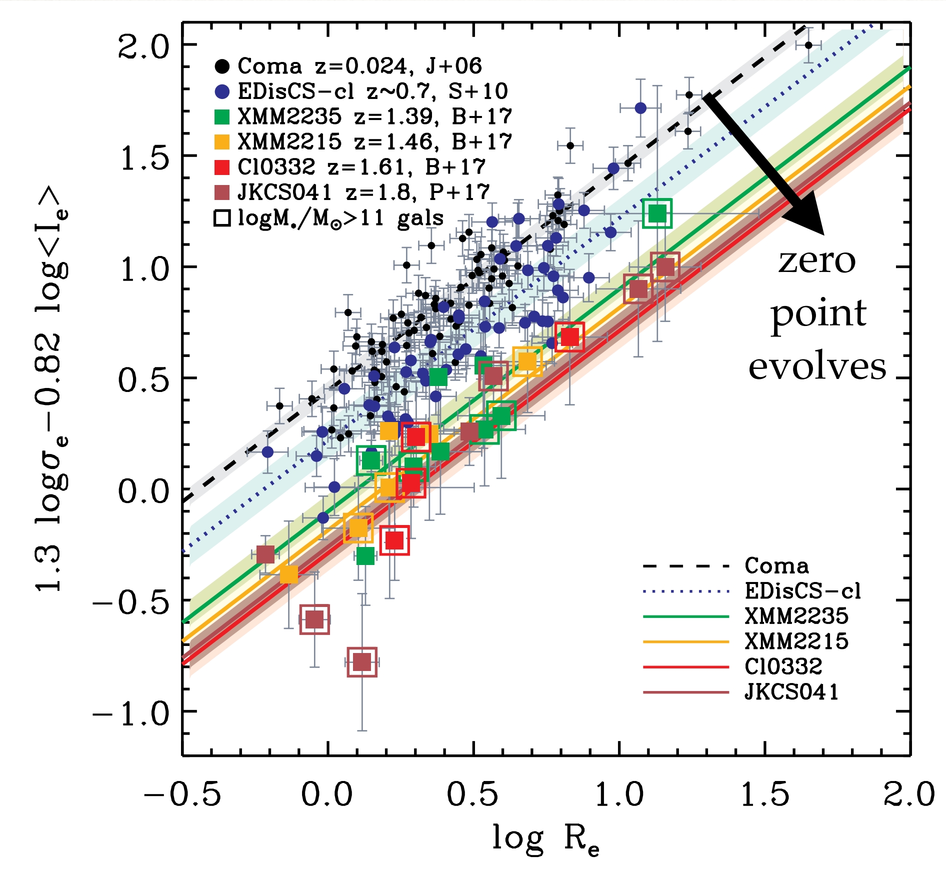




- Structural parameters, i.e. size R_e and surface brightness I_e from HST images in several bands for each cluster (e.g., Chan et al 2016, Chan et al 2018, Prichard et al. 2017)
- **26 new stellar velocity dispersions σ_e** in *dense environments* from KMOS spectra: **19 @ 1.39<*z*<1.61 -** Beifiori et al 2017 **+ 7 @ z~1.8 -** Prichard et al 2017 (+5 new @z=1.04)

Timing the formation of passive galaxies in KCS

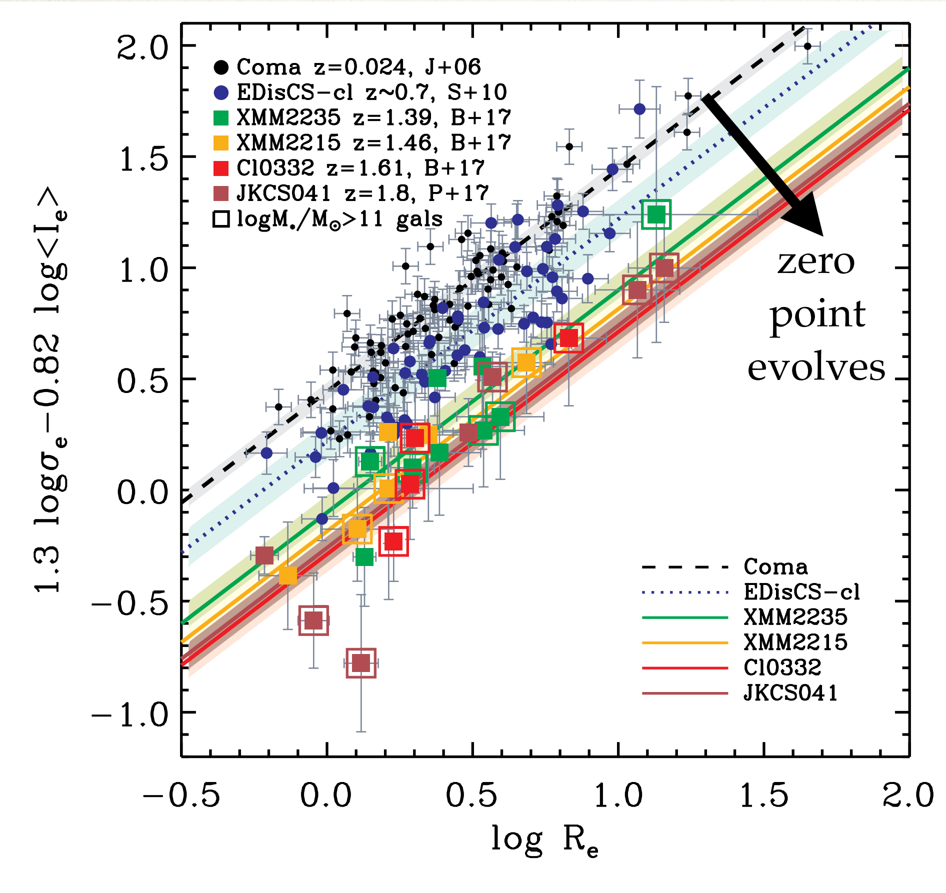
The Fundamental Plane of KCS galaxies @ $1.4 < z < 1.8$

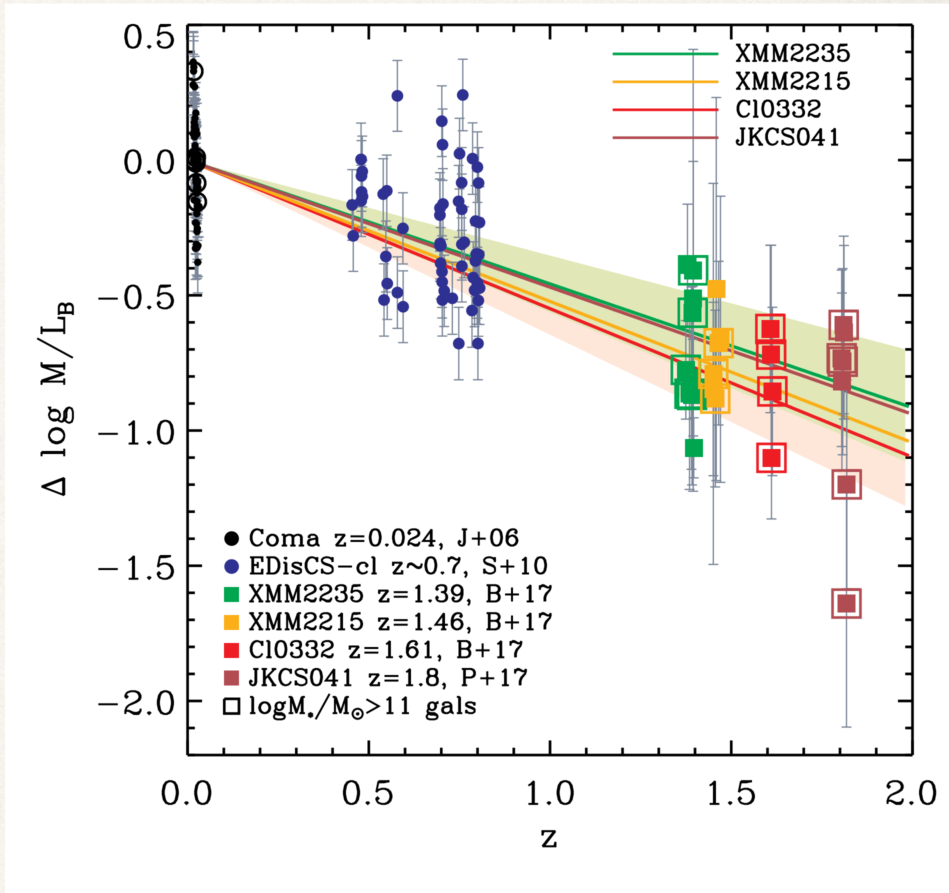


- Adopt FP coefficients from local Coma studies —> trace zero-point evolution

Beifiori et al. 2017, Prichard, Davies, AB et al 2017

The Fundamental Plane of KCS galaxies @ $1.4 < z < 1.8$



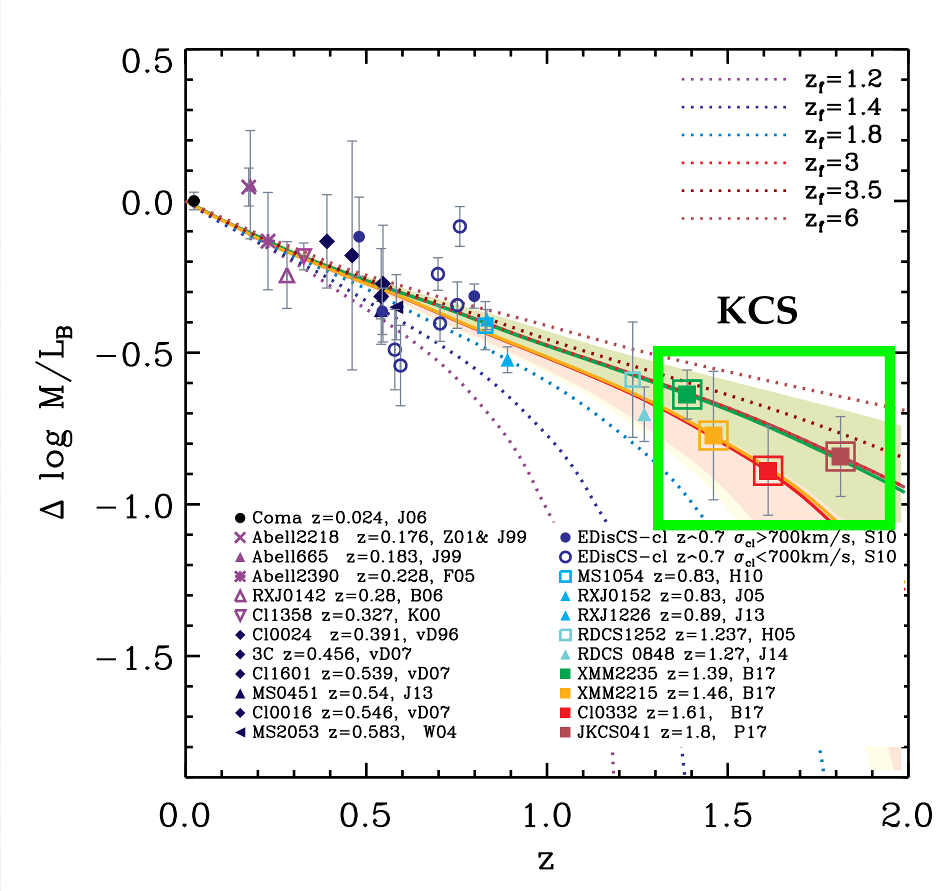


- Adopt FP coefficients from local Coma studies —> trace zero-point evolution
- Zero Point of FP varies as result of evolving M/L with z, i.e. galaxies are getting younger.
- Effects of structural evolution and stellar velocity dispersion evolution account for ~6-35% of ZP evolution

Beifiori et al. 2017, Prichard, Davies, AB et al 2017

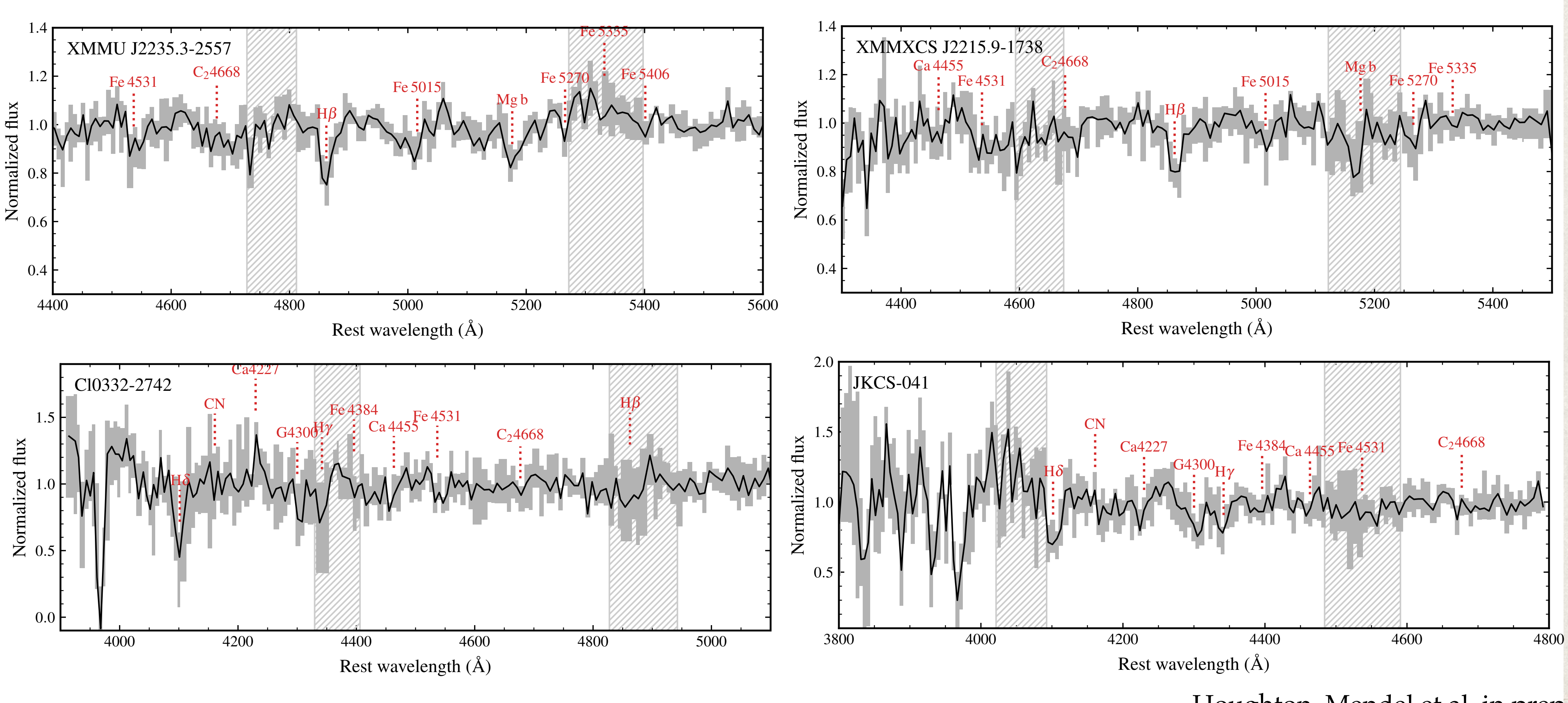
The formation ages of KCS galaxies from the fundamental plane

- KCS expands previous FP studies up to z~1.8 (e.g., Beifiori et al. 2017, Prichard et al 2017).
- From SSPs derive luminosity-weighted ages of $\log M_*/M_\odot>11$ gals—> z_{form}~2.4-3.
- Weak suggestion of older mean ages for **$\log M_*/M_\odot>11$ galaxies** in more evolved clusters (XMM2235 & JKCS041)
- Mean ages for **$\log M_*/M_\odot>11$ galaxies** ~ mean ages from VIRIAL field survey (e.g., Mendel et al 2015), weak suggestion that are older in more evolved cluster



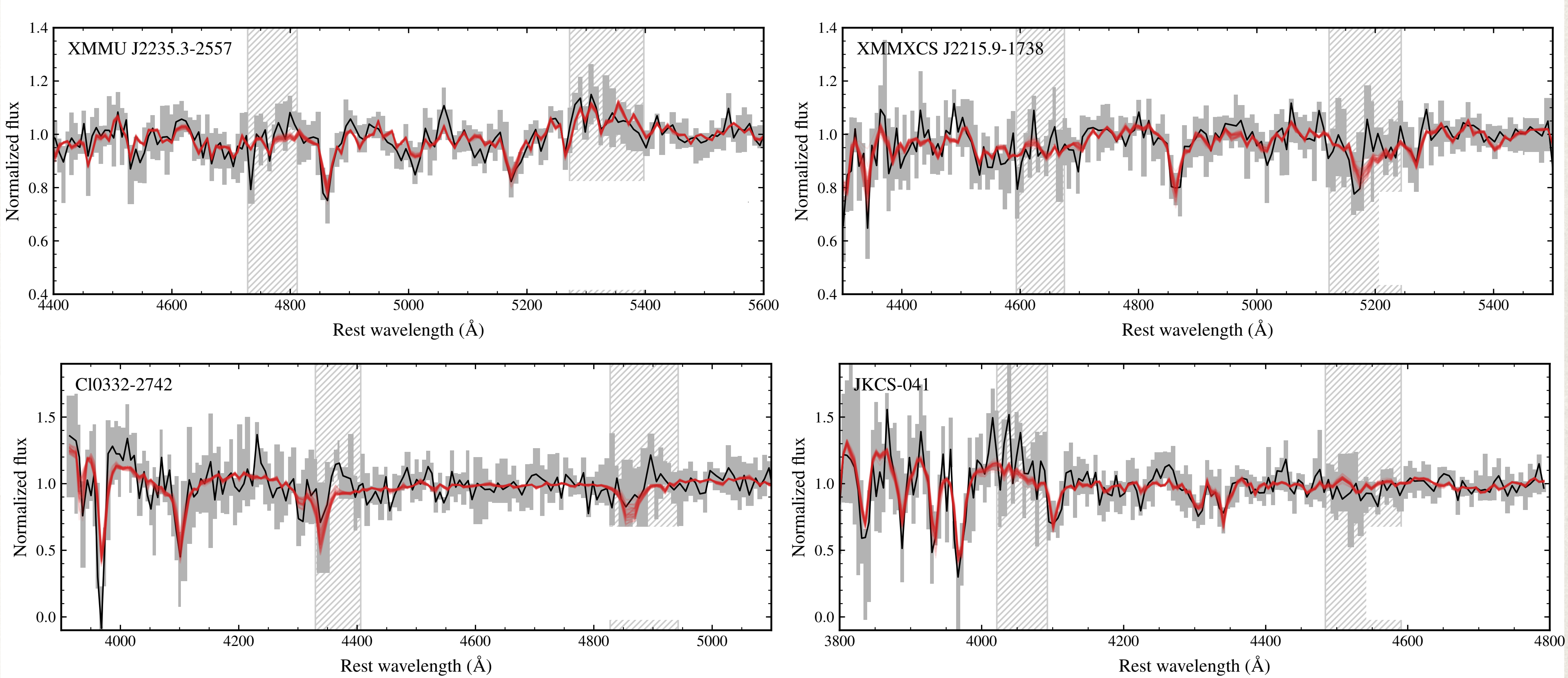
Beifiori et al. 2017, Prichard, Davies, AB et al 2017

Timing the formation of KCS galaxies using stacked spectra



Houghton, Mendel et al, in prep

Timing the formation of KCS galaxies using stacked spectra

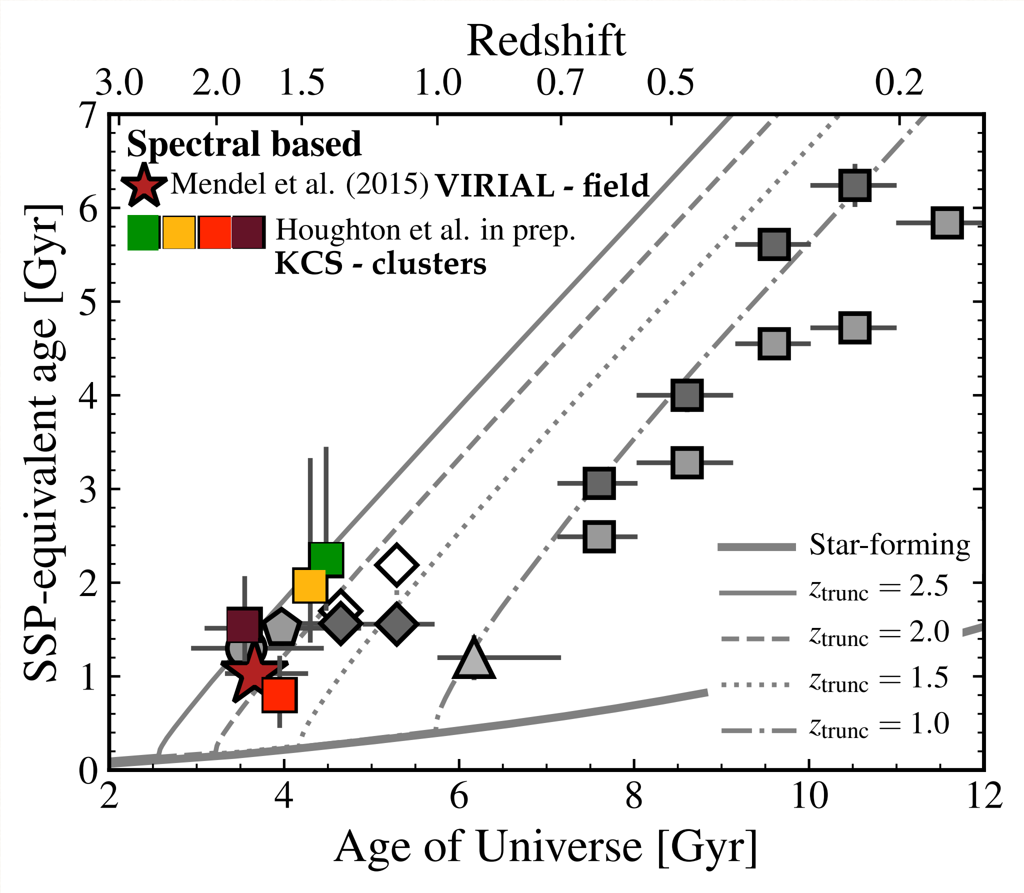


Houghton, Mendel et al, in prep

- Derived formation ages, consistent with fundamental plane ages. Metallicity ~ solar/slightly above solar in lowest redshift cluster. All clusters moderately α-enhanced.

Credit Trevor Mendel

Timing the formation age of KCS galaxies using stacked spectra



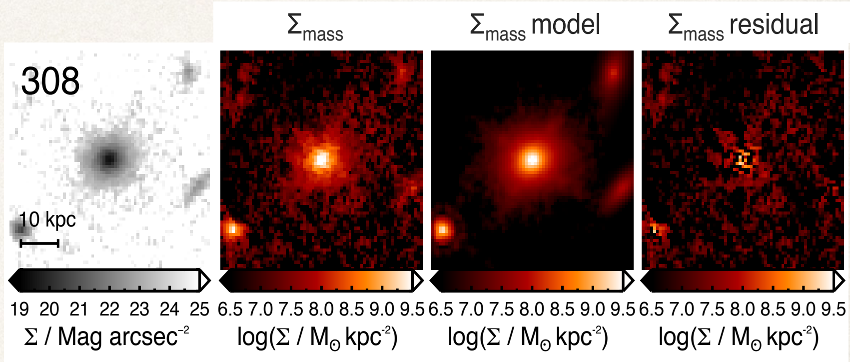
- Weak suggestion of older mean ages of most massive galaxies in the more massive/evolved cluster versus field galaxies (e.g., Mendel et al 2015/KMOS VIRIAL survey)

Credit Trevor Mendel

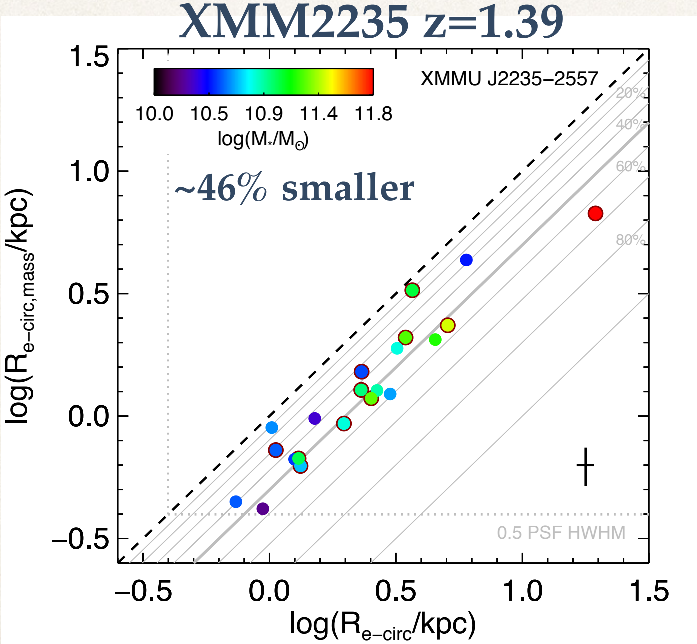
The properties of KCS galaxies from high-z to present

The resolved stellar mass distribution of cluster galaxies at 1.4<z<1.6

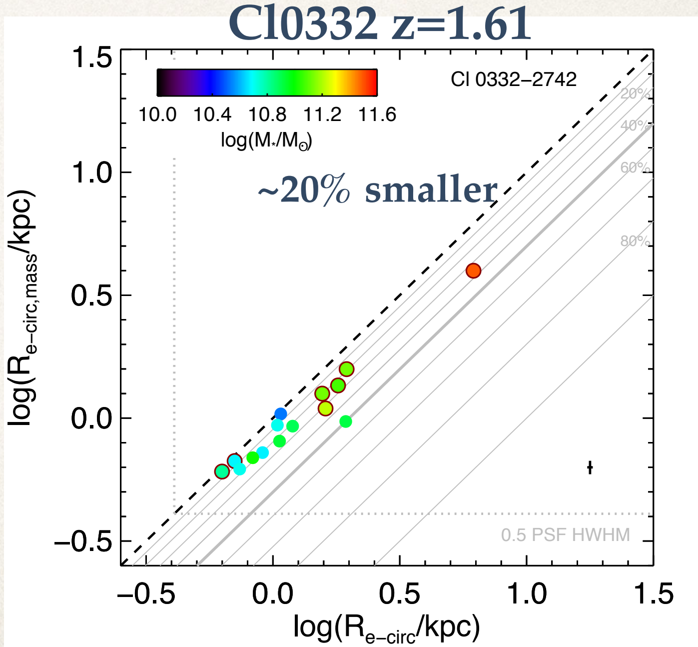
- **Mass-weighted sizes are smaller than R-band rest-frame light-weighted sizes-> variations between clusters.**
- Related to the variation in the colour gradients and M/L gradients —> how mass and light distributed within galaxies



XMM2235 z=1.39

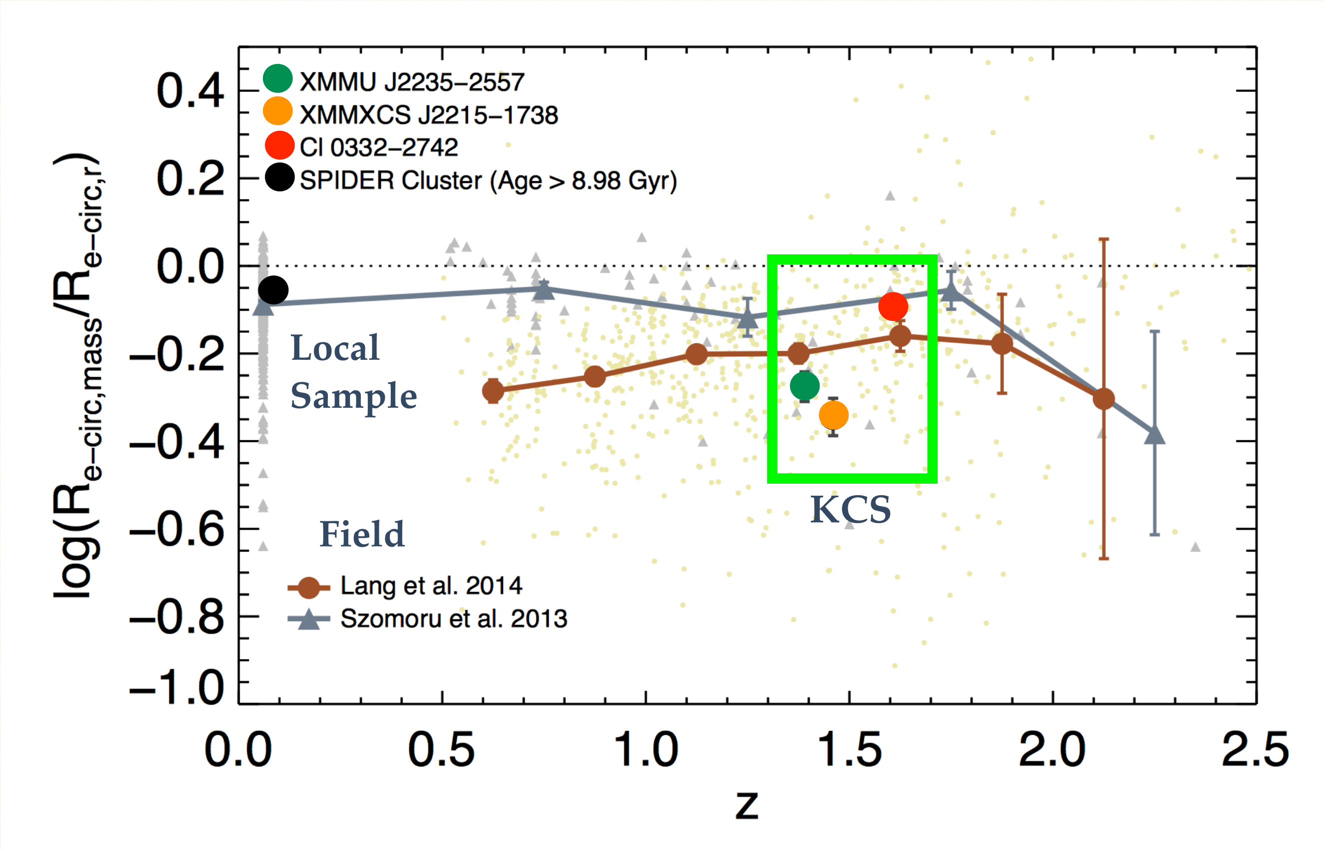


Cl0332 z=1.61



Chan, AB et al 2016, Chan, AB et al. 2018

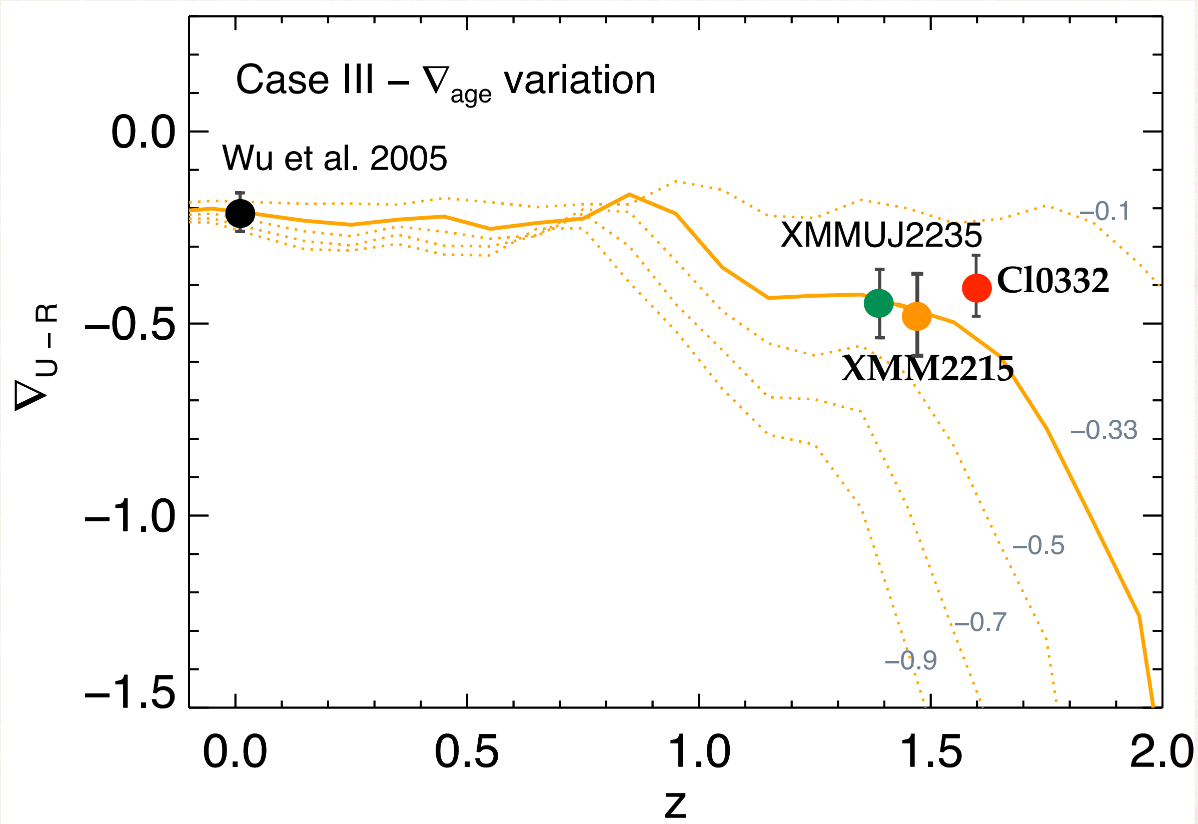
The resolved stellar mass distribution of cluster galaxies at 1.4<z<1.6



- **Ratio** mass-weighted to light-weighted sizes at z~1.5 **smaller than at z~0**
- **Ratio** of mass-weighted to light-weighted sizes in **XMMUJ2235** (z=1.39) and **XMMXCSJ2215(z=1.46) smaller than field samples at similar z ,** Cl0332 (z=1.61) comparable to the field

Chan, AB et al. 2018

The evolution of the color gradients



For **local** passive galaxies: ∇_{age} ~ 0, ∇_Z ~ -0.1 /-0.3

KCS: ∇_{age} ~ -0.3, ∇_Z ~ -0.2 Age difference in/out 0.90 -0.70 Gyr depending on cluster

- Model the evolution of the color gradients with SSPs using age-driven gradient (passive) evolution
- **Colour gradients of galaxies in our sample steeper than local colour gradients: evolving luminosity-weighted age gradients at cluster redshift + fixed metallicity gradient with local early-type value**
- Age gradient consistent with inside-out growth scenario, **via an epoch of enhanced minor merger activity during cluster assembly**

Chan, AB et al 2016, Chan, AB et al. 2018

Future Prospects

The stellar-mass fundamental plane of KCS galaxies at 1<z<1.8

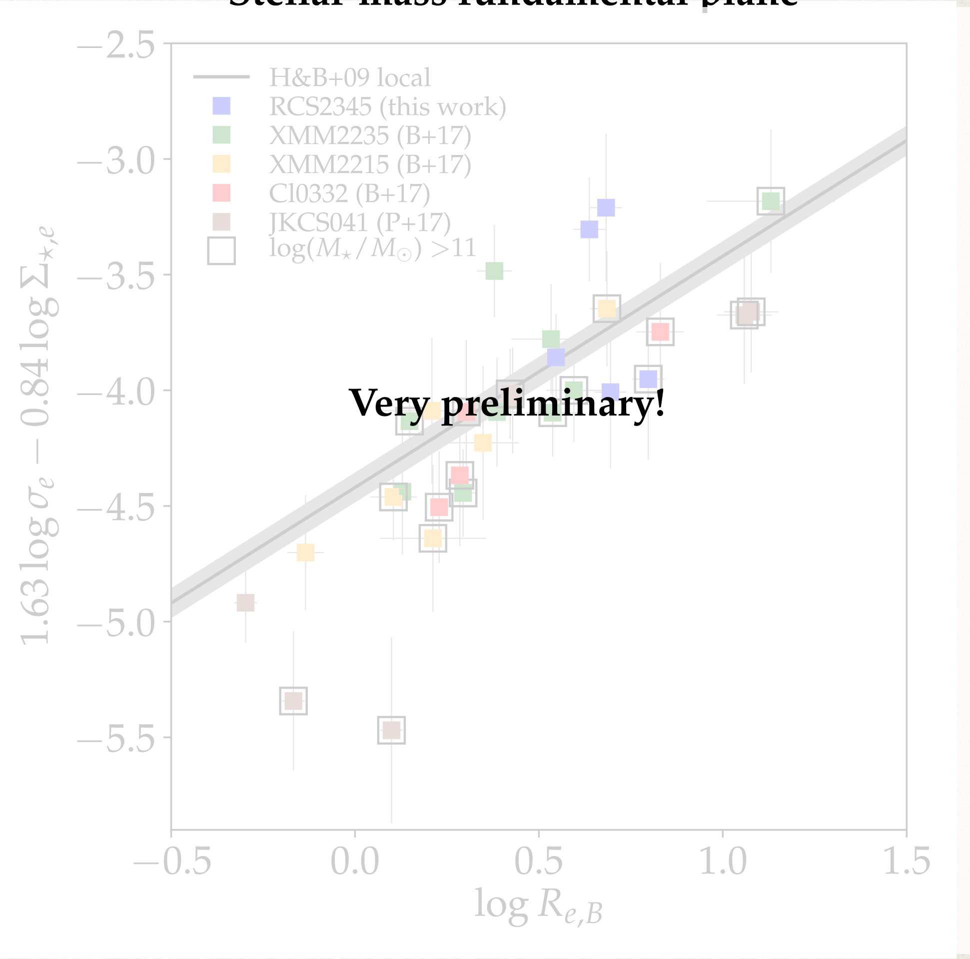
- **Stellar-mass FP**: -> isolate structural and dynamical evolution. Mass FP includes variations of galaxy stellar population

- Tilt of mass FP —> variations of M_{dyn}/M_* within the galaxy population

- **Assumptions**: local Hyde &Bernardi 2009 coefficients. $R_{e,B}$ contains half of the stellar mass…

- Zero point of the stellar-mass FP does not evolve with redshift - consistent with results from field (i.e. Bezanson et al 2013)

Stellar-mass fundamental plane

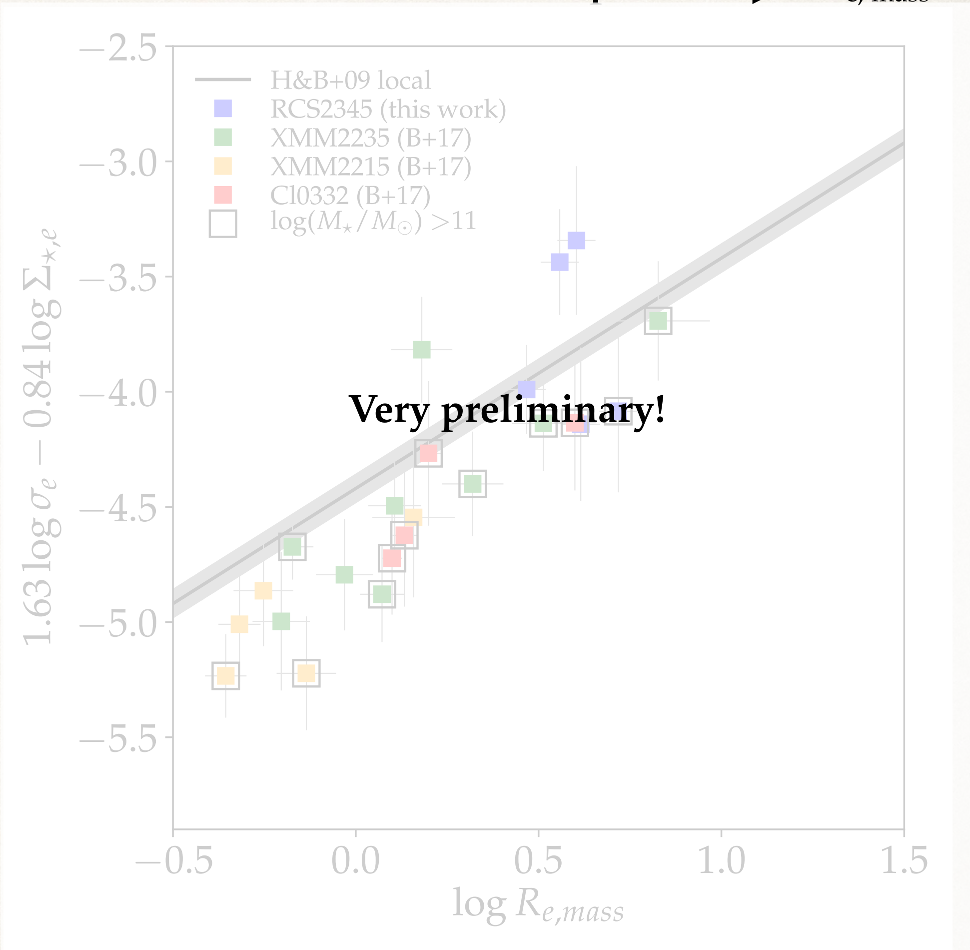


Beifiori, Chan, Mehrgan et al. in prep

The stellar-mass fundamental plane of KCS galaxies at 1<z<1.8

- M/L gradients: better use mass-weighted sizes?
- Working on mass-weighted parameters for cluster @ z=1.8 & local sample….

Stellar-mass fundamental plane ➡ $R_{e,\,mass}$

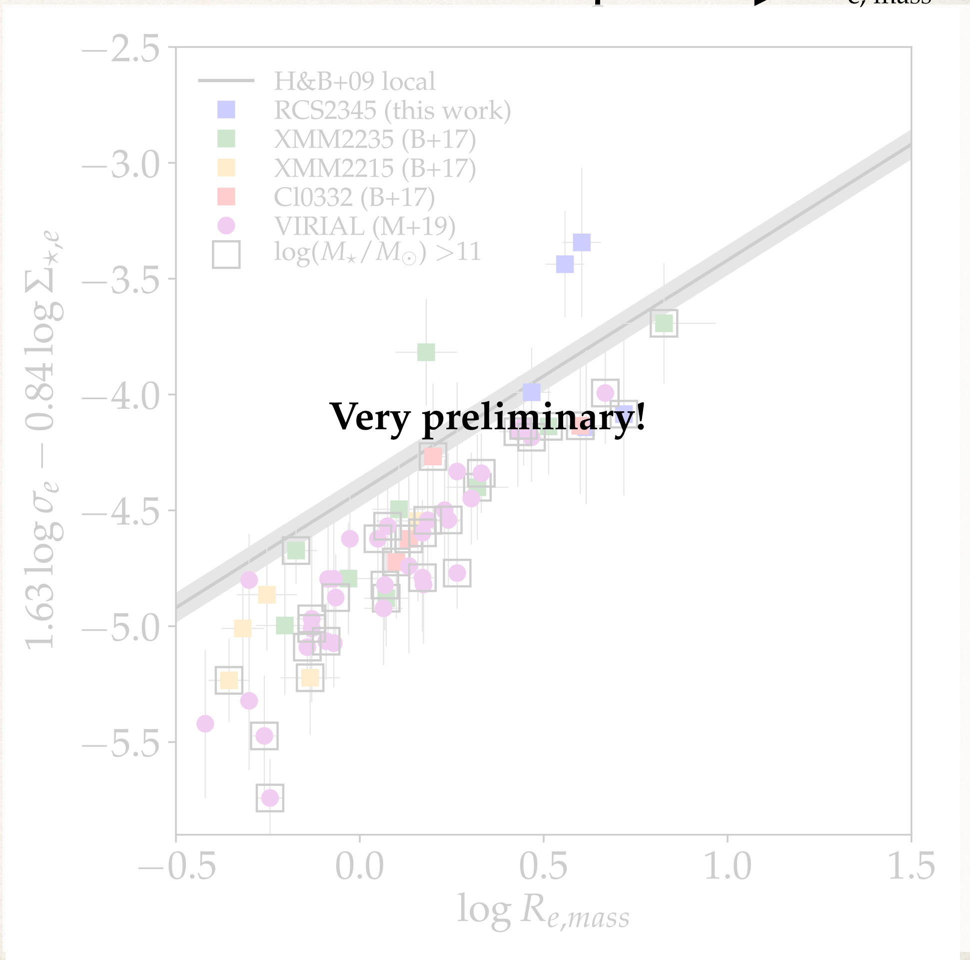


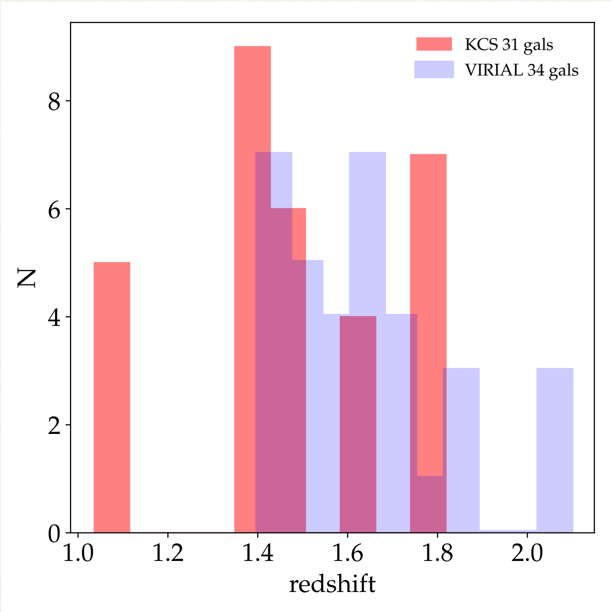
Beifiori, Chan, Mehrgan et al. in prep

The stellar-mass fundamental plane of KCS galaxies at 1<z<1.8

- M/L gradients: better use mass-weighted sizes?
- Working on mass-weighted parameters for cluster @ z=1.8 & local sample….
- Combine KCS & VIRIAL

Stellar-mass fundamental plane ➜ $R_{e,\,mass}$





Beifiori, Chan, Mehrgan et al. in prep

Star-forming galaxies in the infalling regions of KCS clusters @ z~1.4

Emission-line sample:

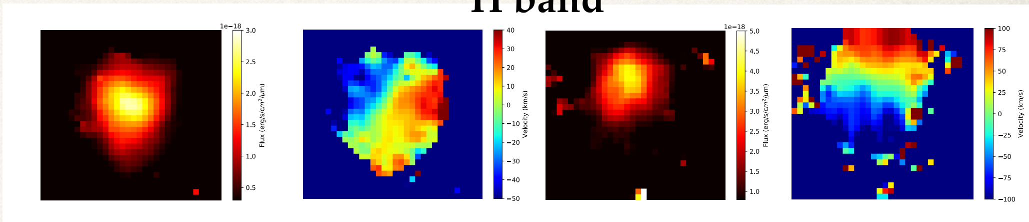
- YJ-band observations of ~**40 emission-line galaxies** for **[OIII] and Hβ** at 1.39<z<1.8

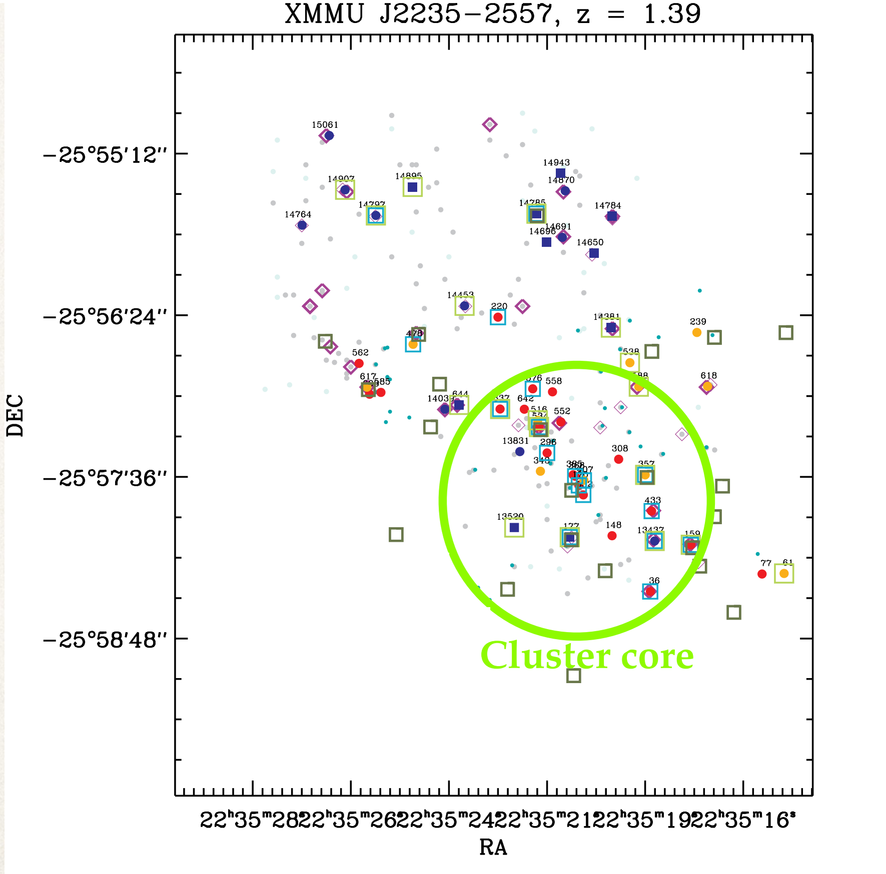
- H-band observations of ~**40 line emitters** for **Hα & [NII]** at 1.39<z<1.46

  - **XMM2215**: Hayashi+2012 NB [OII] emitters

  - **XMM2235**: Grützbauch+2012 NB Hα emitters

- **Science plans:**
  - resolved emission line studies of the star forming galaxies and AGN in the clusters.
  - dynamics and resolved SFR and metallicity
  - **Ongoing: stay tuned!**

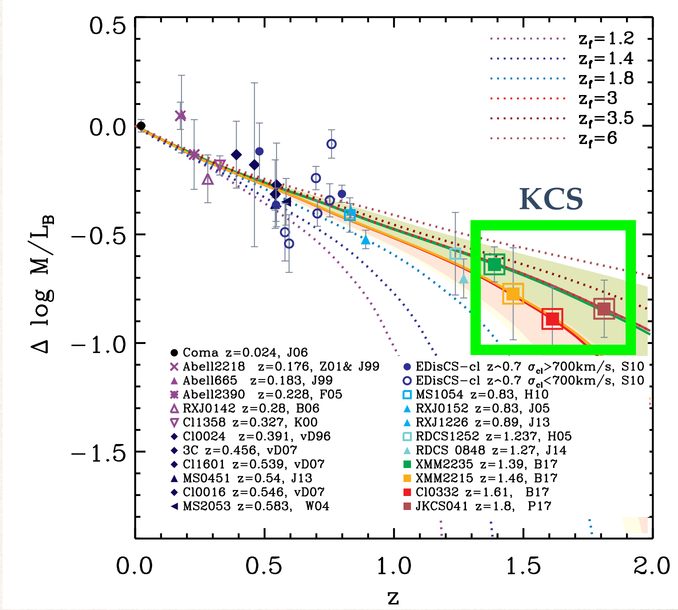




Nick Amos & John Stott et al.

Summary

- **KCS**: Deep (~20h on source) **absorption line spectroscopy** in known **overdensities** at **1.4 <z<1.8** & **emission-line spectroscopy** in the infalling region of 2 clusters at **z~1.4**.

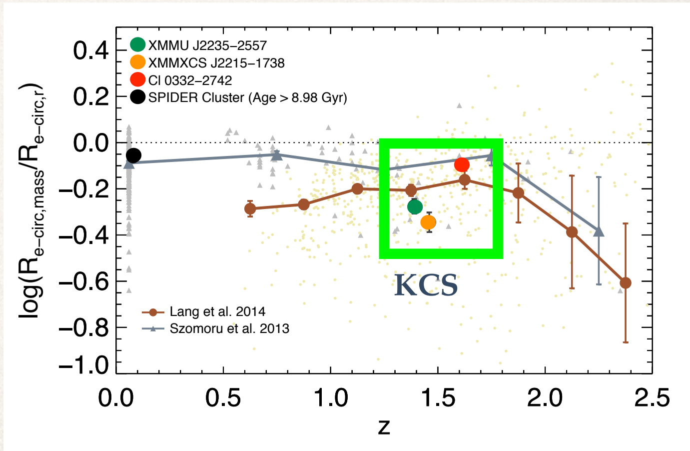


Beifiori et al 2017, Prichard et al 2017

Main Results:

- **Timing the formation of passive galaxies in KCS**:
  - **FP:** Rate of zero-point evolution of the FP consistent with previous work.
  - **FP:** Weak suggestion that **logM>11** galaxies in **more massive/ evolved clusters at 1.4<z<1.8** are **older**, older than field.
  - **Stacked spectra: Ages fairly consistent with FP ages** (Houghton, Mendel et al in prep) suggesting older ages of galaxies in evolved clusters compared to field (e.g., VIRIAL, Mendel et al 2015).

- **The properties of KCS galaxies from high redshift to present**:
  - **Mass-weighted sizes smaller than light-weighted sizes.** Dependence on cluster and redshift.
  - **Colour gradients** much **steeper than local gradients** -> age gradients+metallicity gradients. **Gradual mass-growth mechanism**, i.e. minor mergers, favoured.



Chan, AB et al 2016, Chan, AB et al 2018