A Tale of Dwarfs and Giants: How the Red Sequence in Clusters Grew over the Last 9.5 Gyr

Gregory Rudnick (*Univ. of Kansas*)
&
Kim-Vy Tran (*Texas A&M*)
Casey Papovich (*Texas A&M*)
Christopher Willmer (*U of Ariz.*)
Ivelina Momcheva (*Carnegie, Yale*)

Science Questions

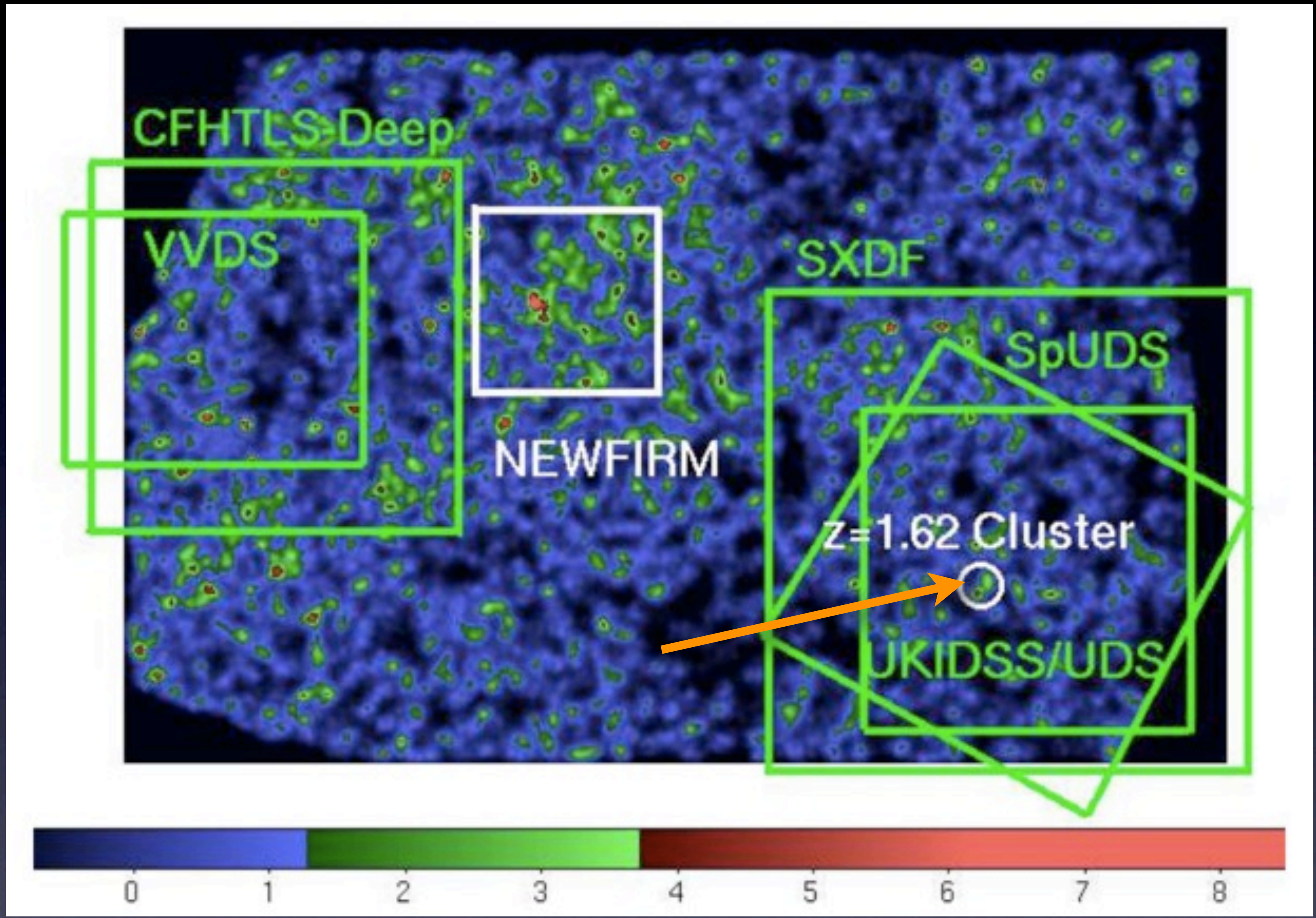
How did the passive population of galaxies in clusters grow over cosmic time?

What physical processes shaped this growth?

How did the dominant processes change over time?

Searching for high redshift clusters

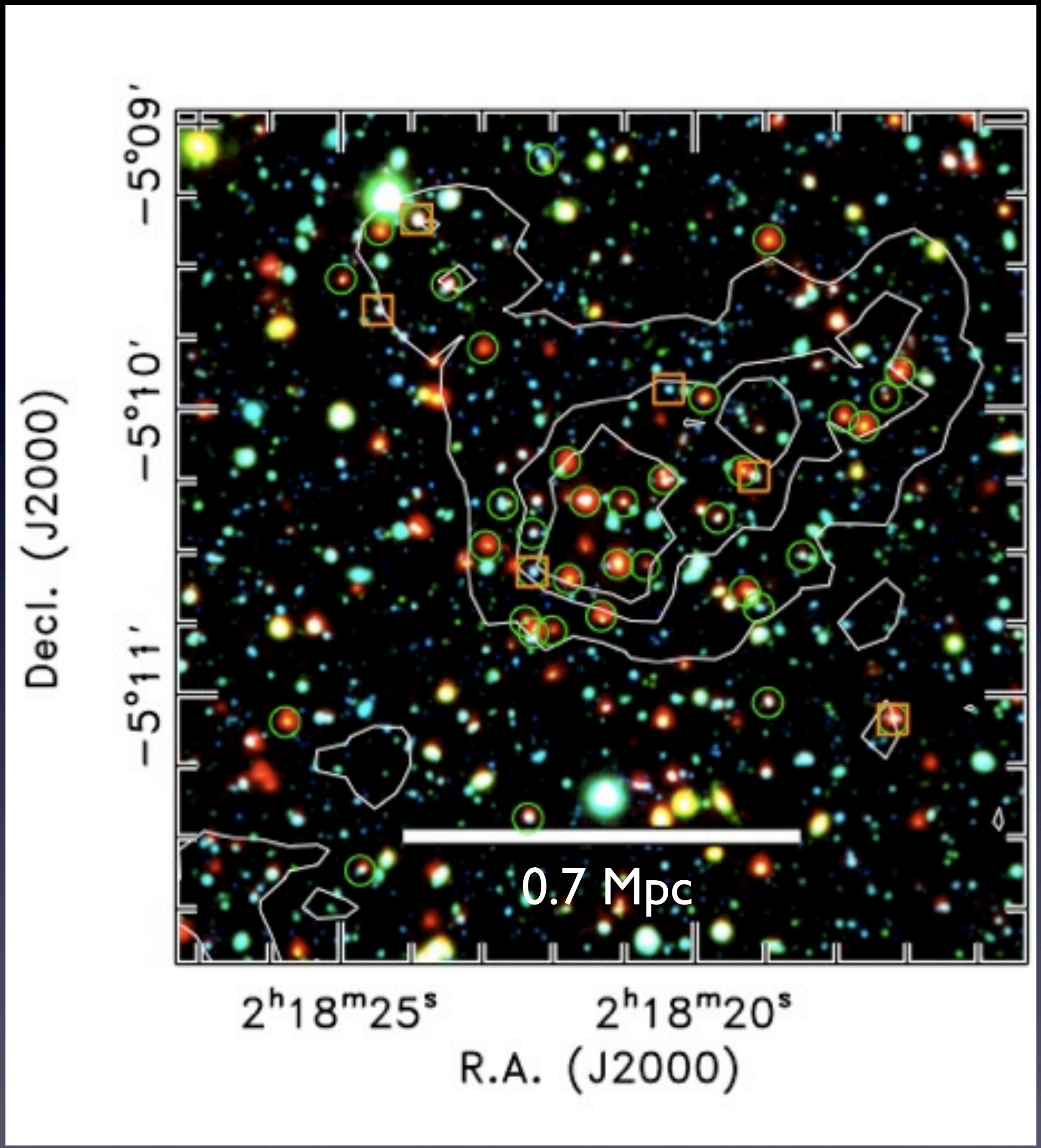
- galaxies are identified by red [3.6]-[4.5] colors
- candidate clusters defined by projected overdensities
- angular clustering of overdensities similar to that of clusters
- Target promising candidates with spectroscopy



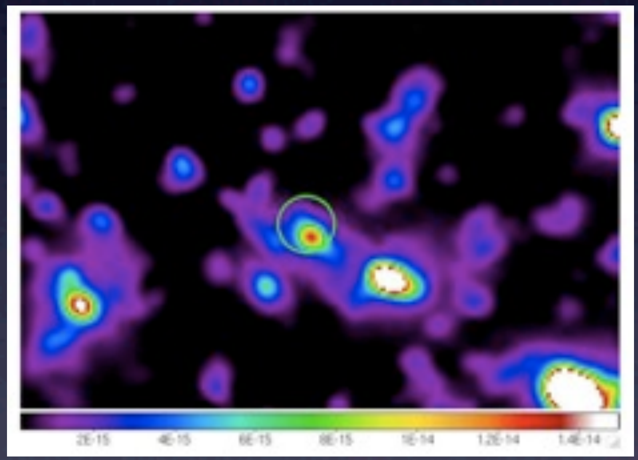
Papovich 2010; Papovich, et al. + Rudnick 2010

Papovich, et al. + Rudnick 2010; Tanaka et al. (2010)

z=1.62 cluster



- 20σ above mean overdensity
- 22 spectroscopically confirmed members
- later confirmed with x-rays

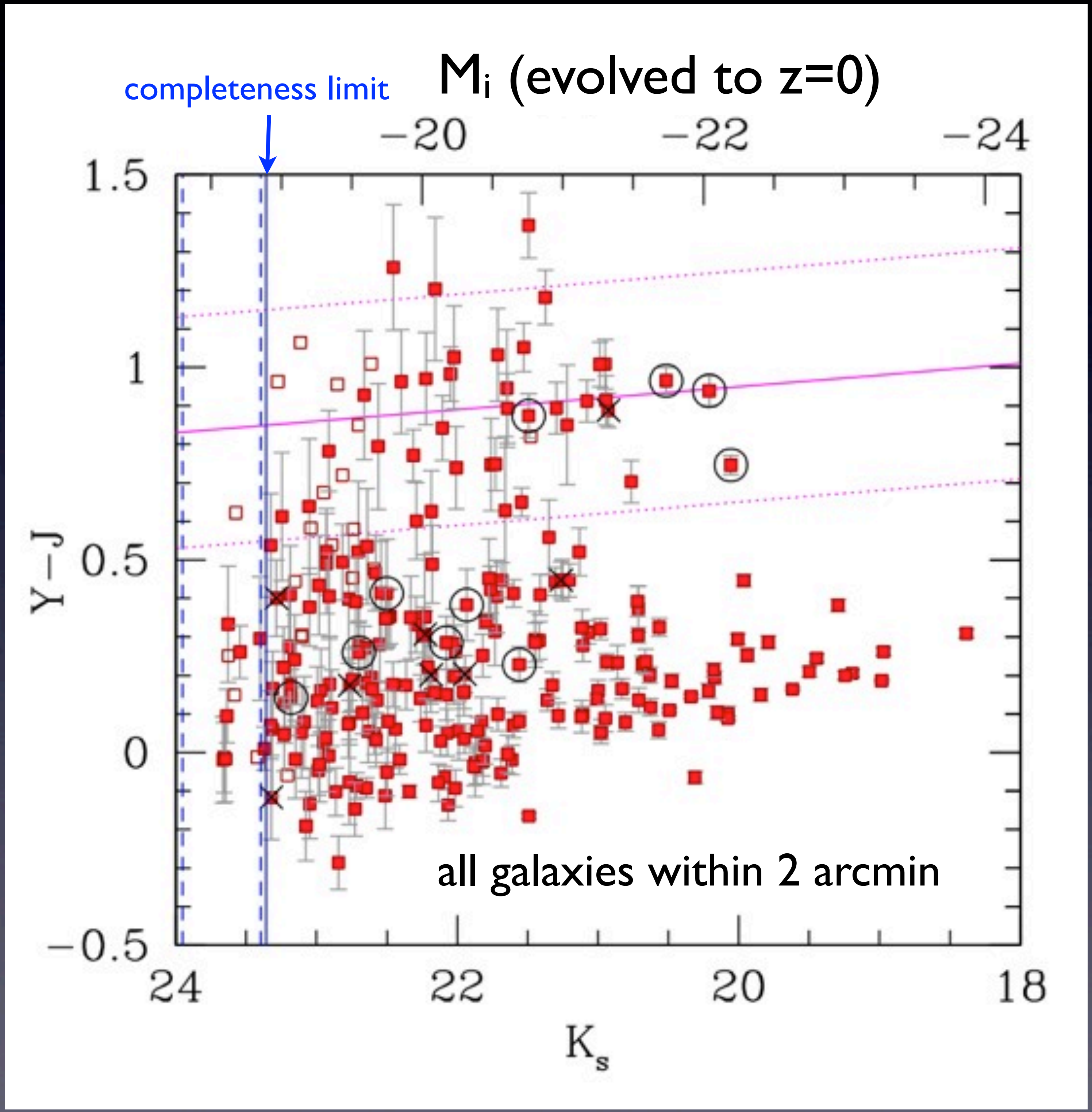


Pierre et al. 2011

- 2.3σ x-ray detection
- $M_{xray} \sim 8 \times 10^{13}$ Msun
- $M_{dyn} \sim 4 \times 10^{14}$ Msun

A clear red sequence at z=1.62 seen with HAWK-I/VLT

- clear red sequence
- rest-frame opt/NIR colors show that >75% of all red galaxies are passive *(Tran et al. 2010; Papovich+,GR 2012)*
- deficit of faint red galaxies
  - not just a completeness effect



Rudnick et al. (2011)

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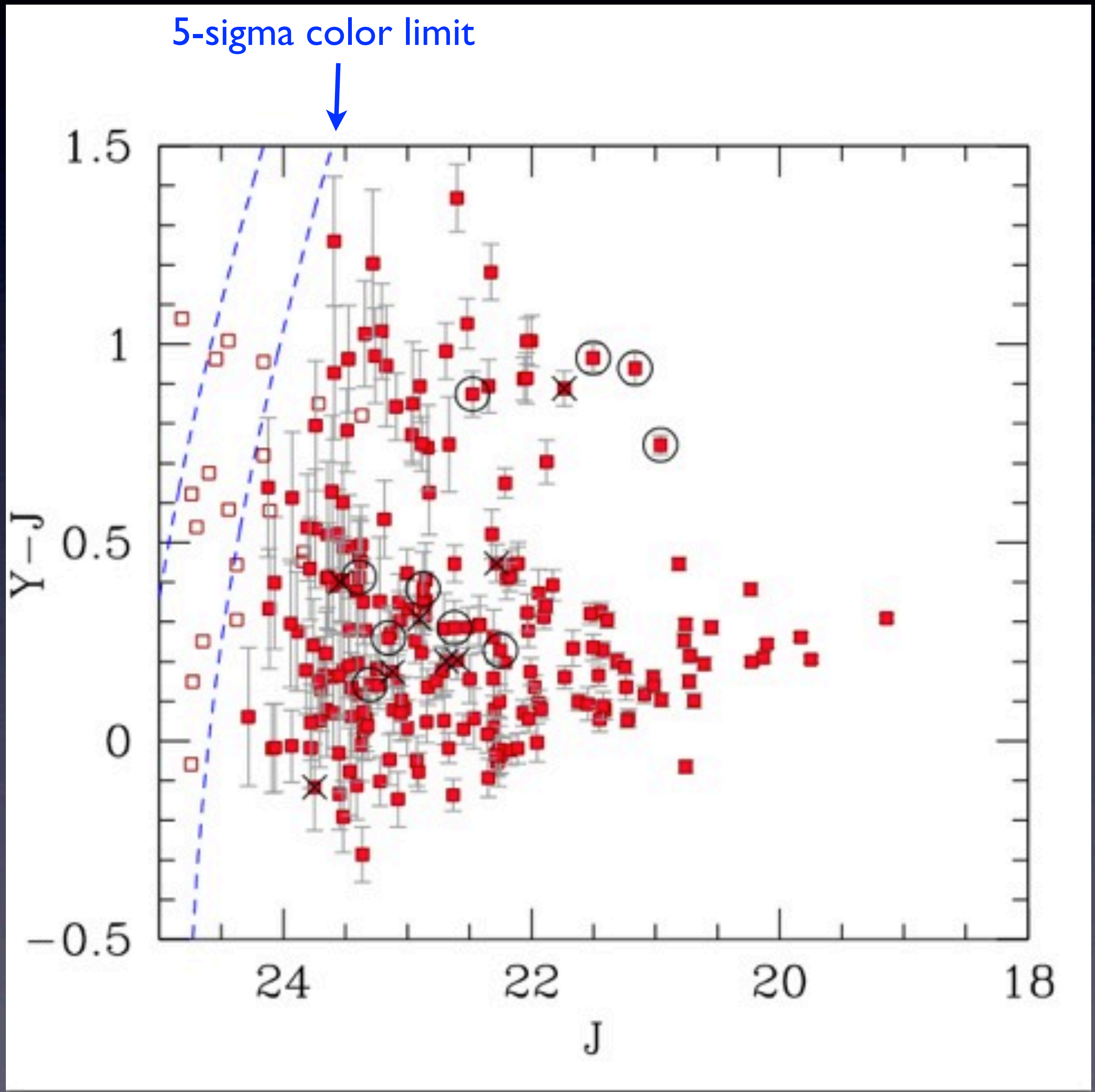

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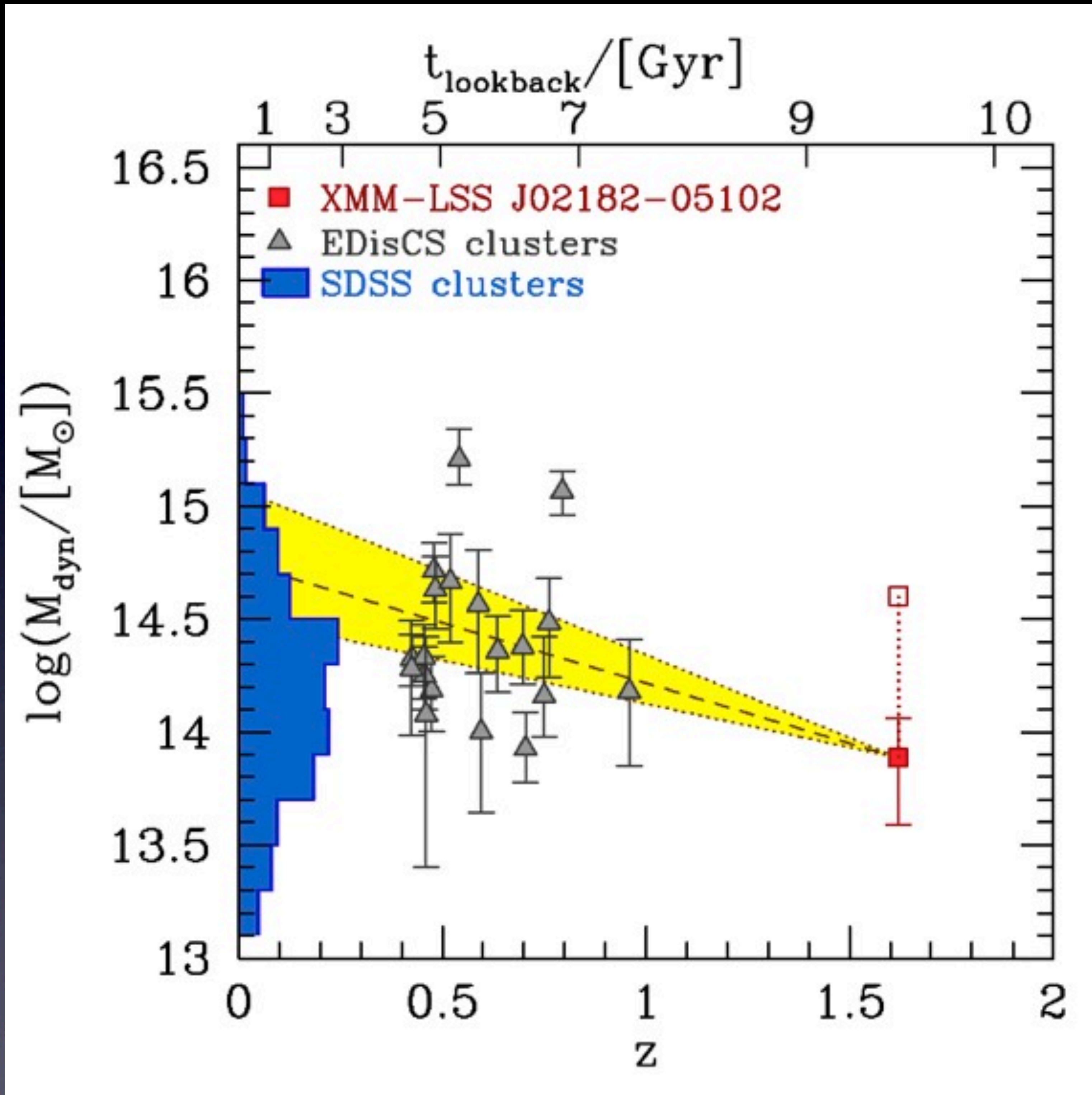
Rudnick et al. (2011)

Predicting the lower redshift descendants

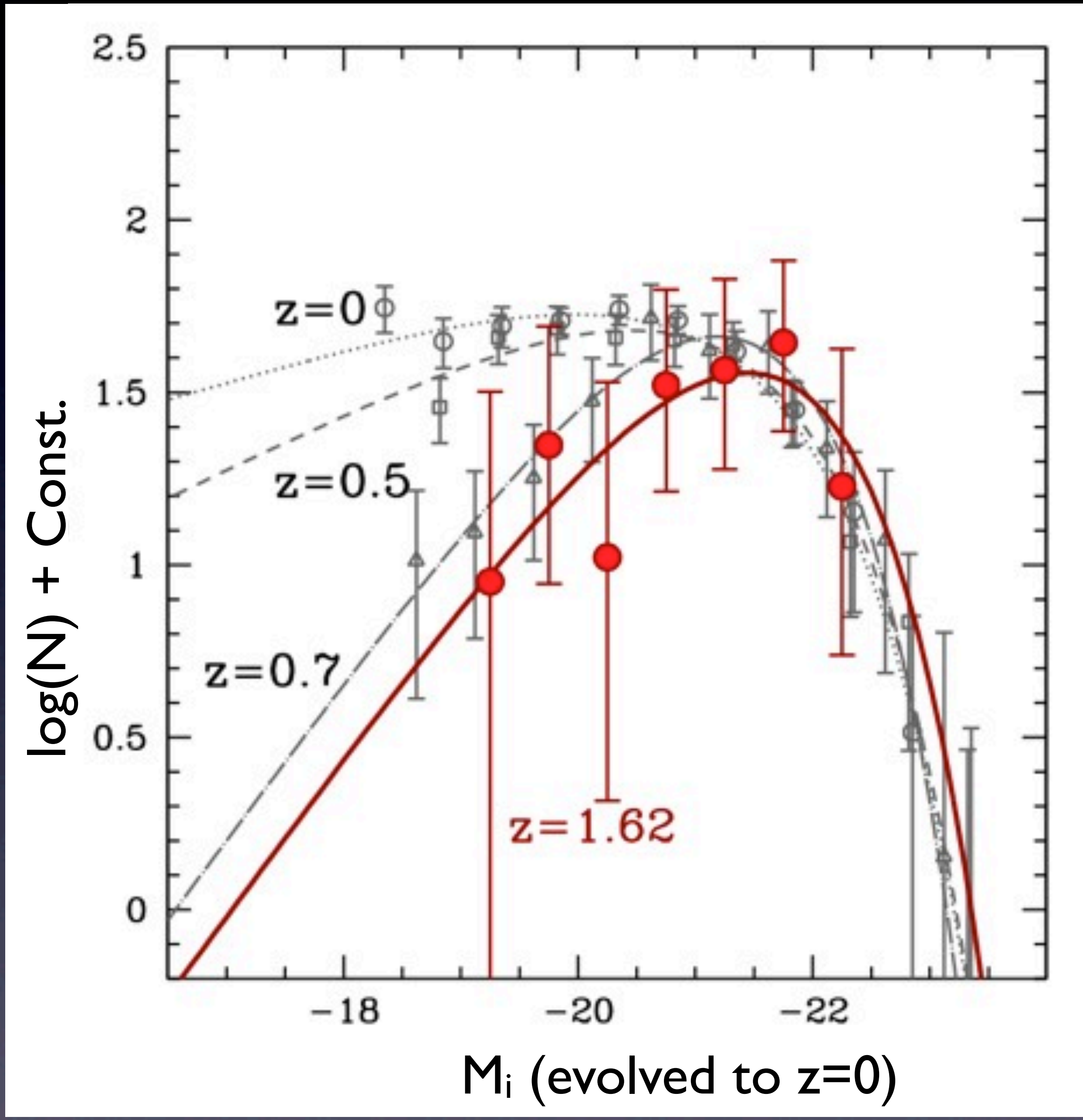


Rudnick et al. (2012)

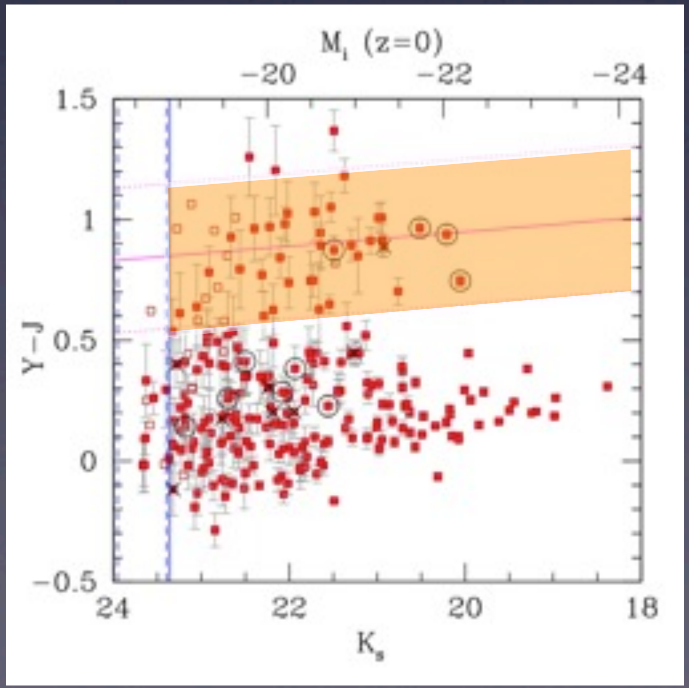
- Track cluster growth by accretion (Bullock et al. 2011; Wechsler et al. 2002)
- Our clusters will evolve into "typical" local clusters.

The luminosity function over 10 Billion Years

- identify members using statistical background subtraction
- no shape evolution from z=1.62 to z=0.7 composite LF from ESO Distant Cluster Survey *(Rudnick et al. 2009)*
- At z<0.7 red sequence LF changes significantly *(De Lucia et al. 2004; Tanaka et al. 2005; Stott et al. 2007; De Lucia et al. 2007; Gilbank et al. 2008; Rudnick et al. 2009;)*



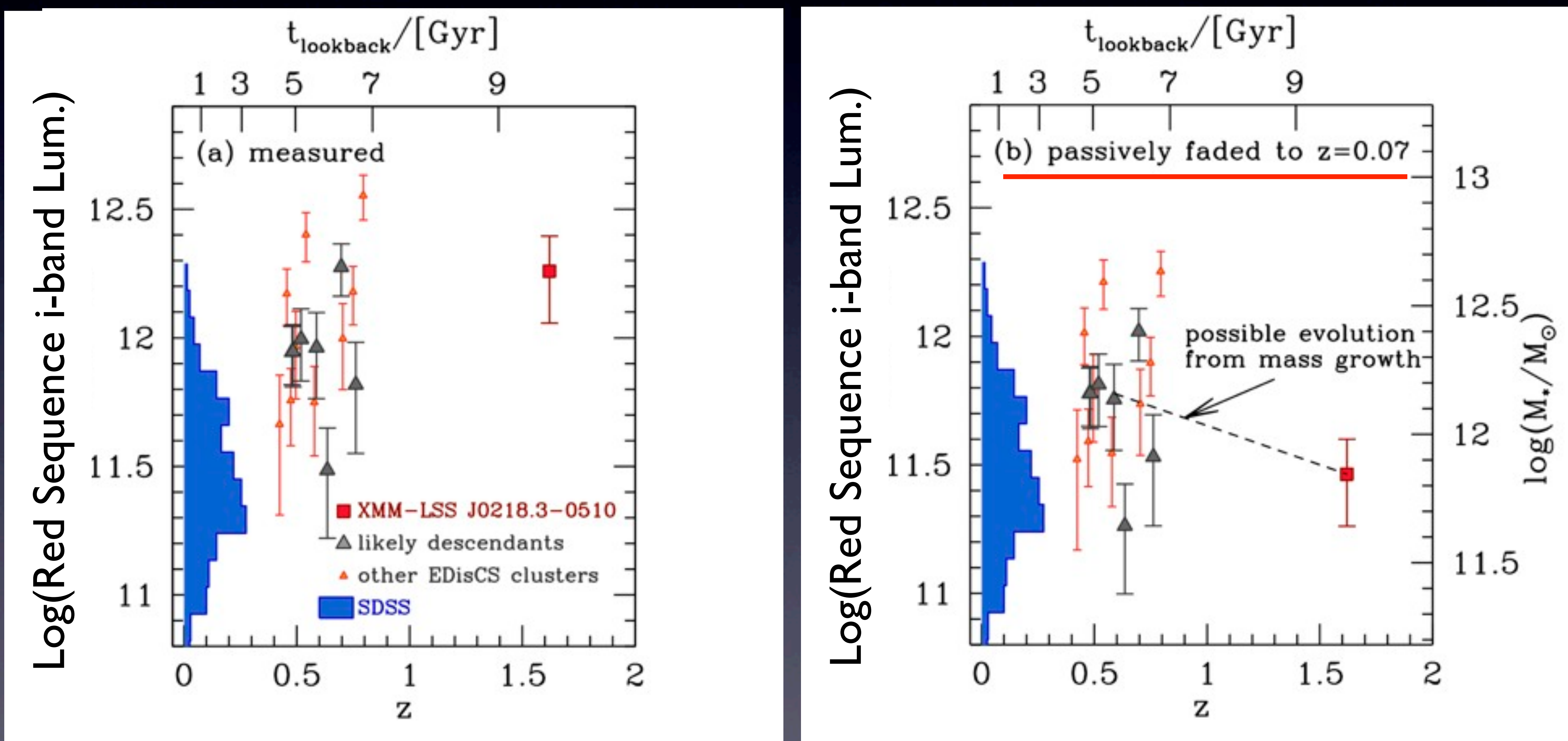
similar to stellar mass



Rudnick et al. (2012)

Evolution in total passive luminosity

- z=1.62 Cluster needs to grow in red sequence light (stellar mass) by a factor of ~2 between z=1.6 and z=0.6.



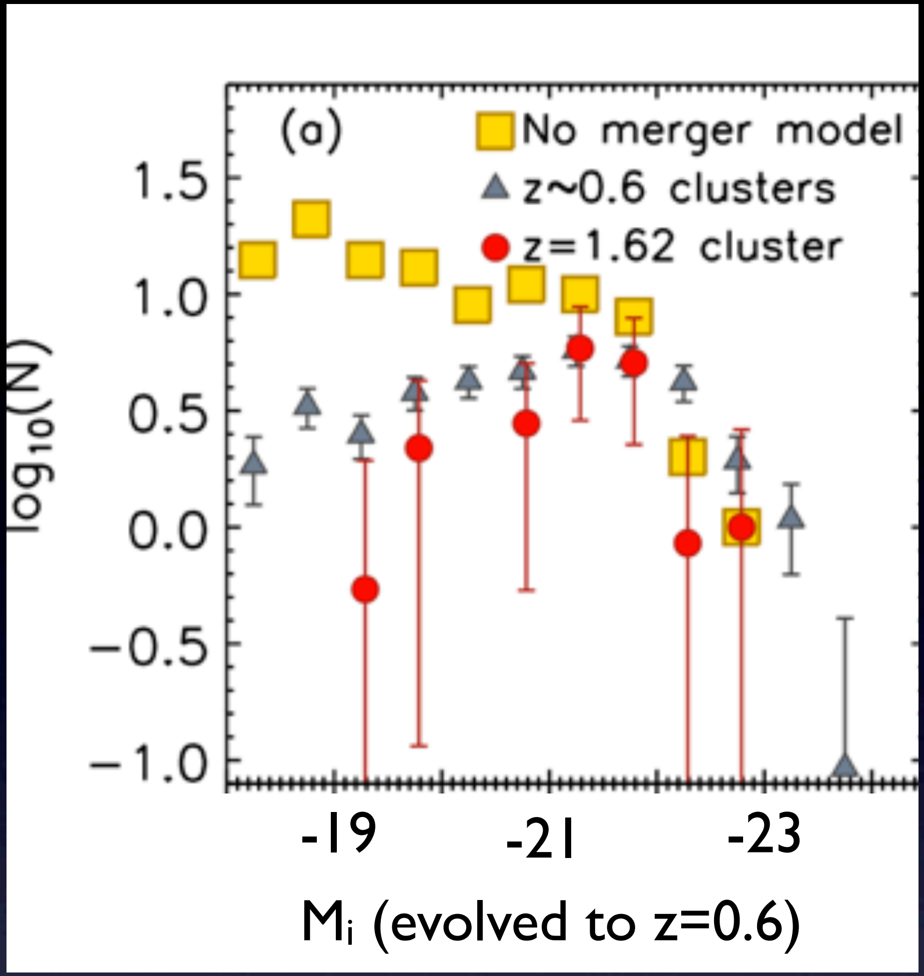
Need to explain following:

- total light grows by factor of ~2 in 4 Gyr between z=0.6 and 1.6
- shape of LF remains same

A toy model:

- Galaxies are added to red sequence from star-forming field population and then have their SFR suppressed.
- No mass dependence of quenching.
- Number of accreted galaxies fixed to match necessary luminosity growth
- Color and luminosity evolution of accreted galaxies consistently tracked
- Suppressed galaxies then merge

•LF evolution cannot be reconciled with pure mass-independent quenching

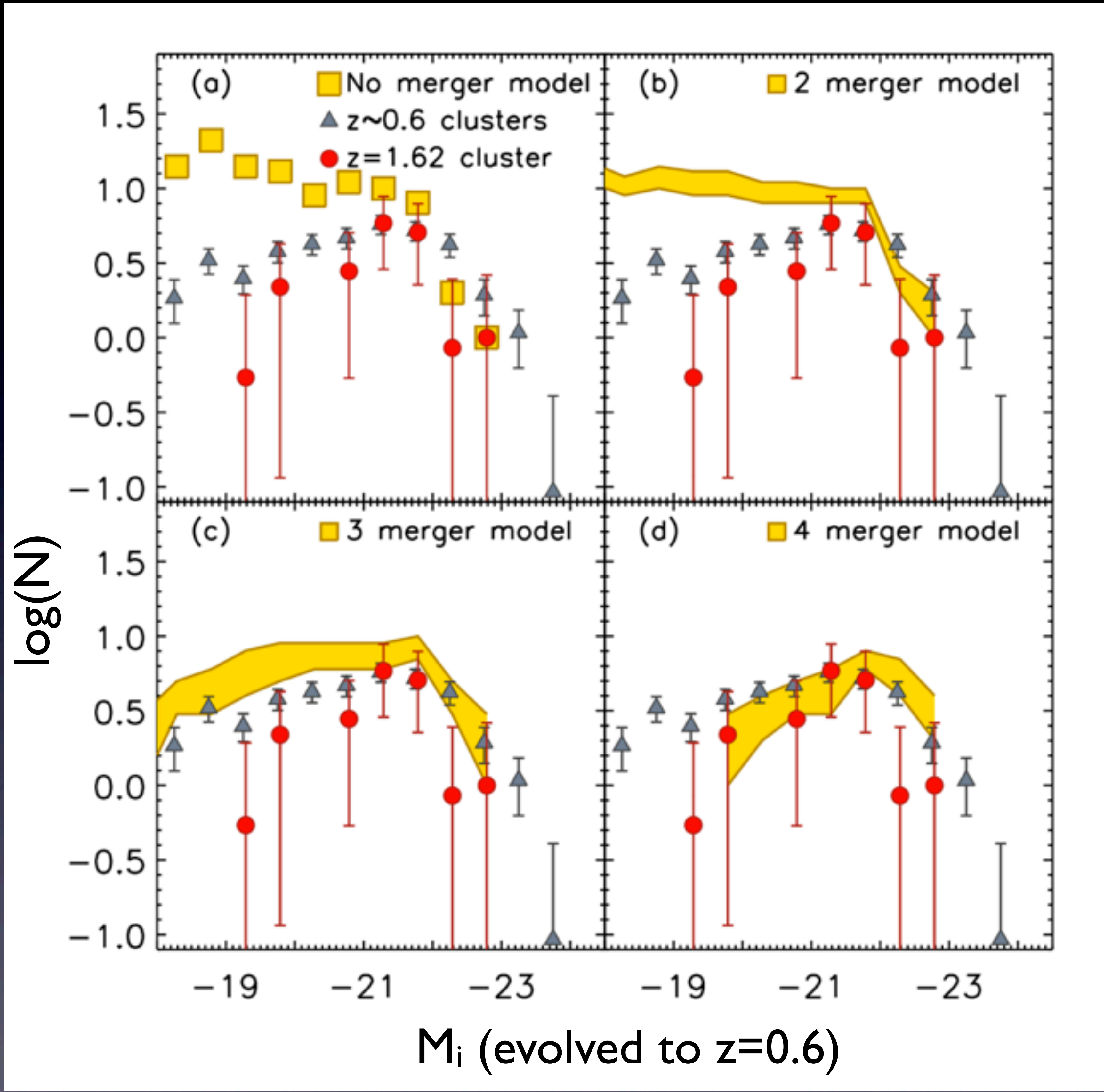


Rudnick et al. (2012)

- ~3-4 mergers between z=1.6 and 0.6 can account for most of the evolution of LF.

- mergers are important for early evolution of cluster passive galaxy population

- Dry mergers in this cluster are required to match size and ellipticity evolution of quiescent galaxies (Papovich+,GR 2012)



Rudnick et al. (2012)

An evolutionary scenario for the growth of the passive population in clusters

- The passive population grows by the suppression of star formation in star-forming field galaxies.
  - Environmental dependence of quenching is not yet known
- Between z=1.6 and 0.6, the passive population grows by a factor of ~2 and the passive LF shape is preserved through repeated mergers between passive galaxies.
  - Understood because of low cluster velocity dispersion and high substructure
- At z<0.6 the passive population grows by a factor of ~2 but the LF shape rapidly evolves → mergers are not necessary
  - Understood because cluster velocity dispersion is high

Summary

- Galaxy clusters are excellent laboratories for studying the growth of the red sequence
- Deep NIR observations are crucial to this endeavor
- The LF of the red sequence reflects the buildup of passive galaxies
- Dry(?) mergers may have played a crucial role in shaping the early cluster galaxy population, but especially at early times ($z>1$)
  - but need more clusters!