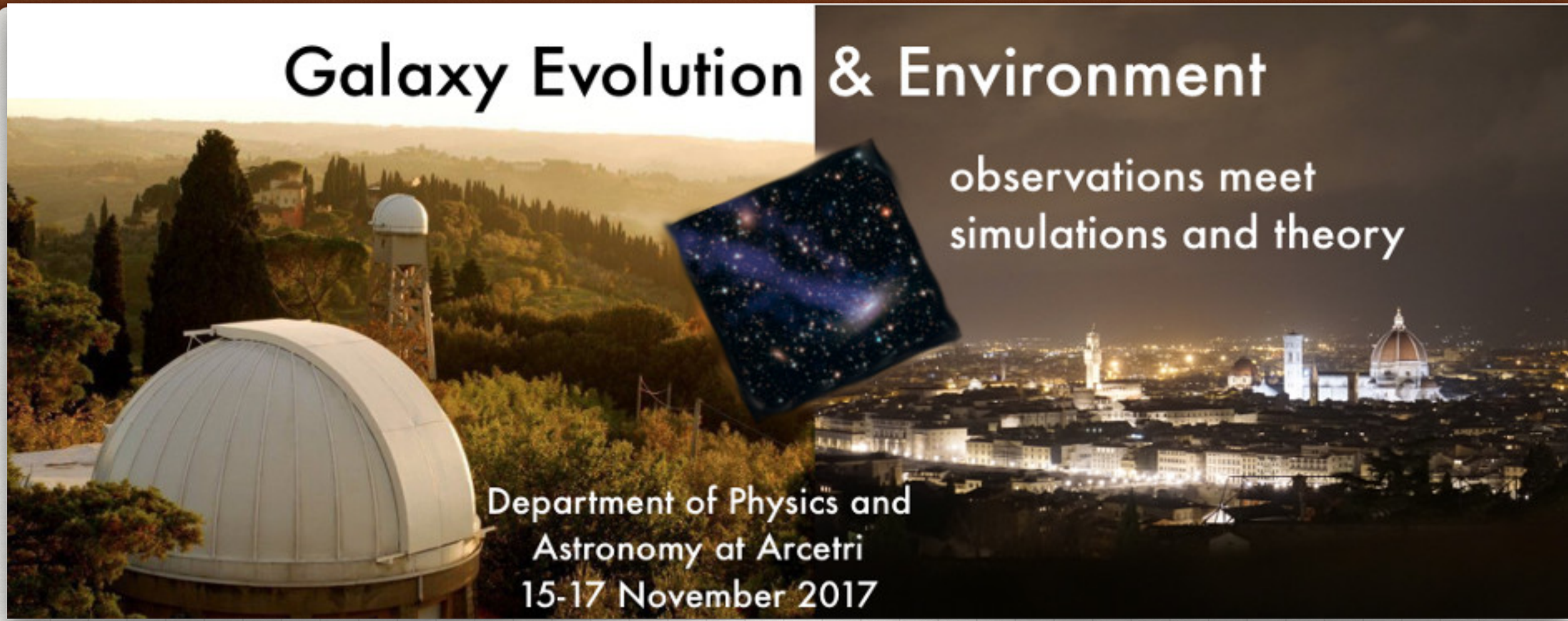
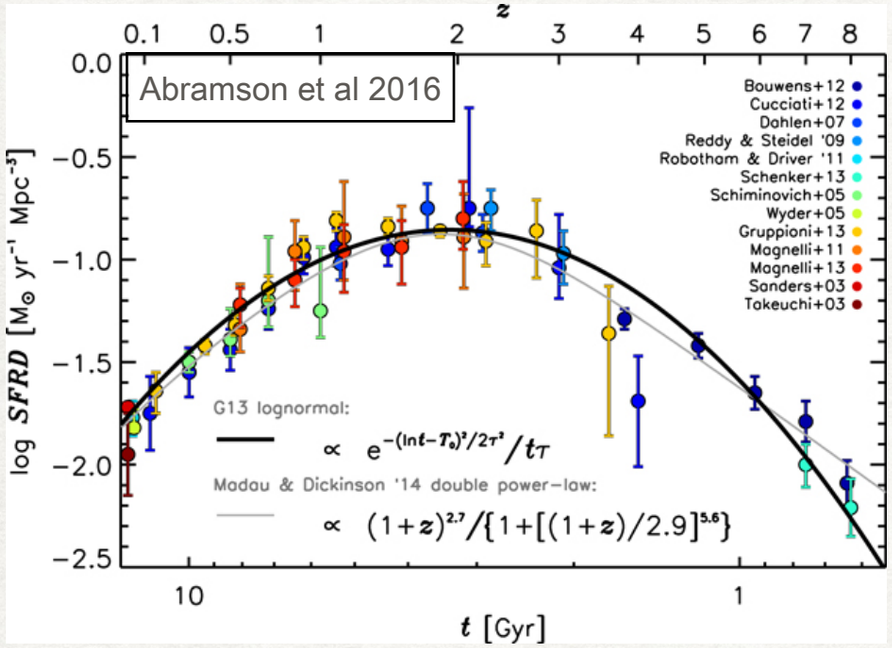


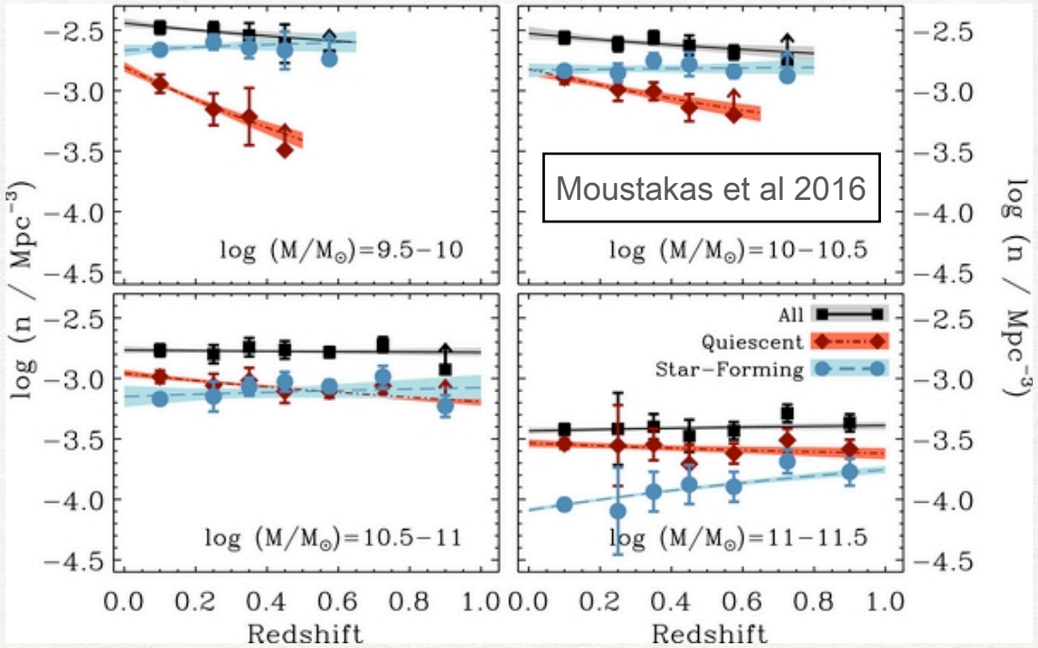
EVOLUTION OF GALAXIES' STELLAR CONTENT SINCE Z~1: PROSPECTS FROM DEEP SPECTROSCOPIC SURVEYS

ANNA GALLAZZI
INAF-Arcetri Astrophysical Observatory

The global SFR density has declined by almost a factor 10 since z~1 (e.g.,Hopkins & Beacom 06, Bell+05, Zheng+07, Karim+11, Cucciati+12, Madau&Dickinson'14, Abramson+16)



different evolution in number density of massive red-sequence galaxies and of massive star-forming galaxies (e.g.,Cimatti+06, Faber+07, Bell+07, Ilbert+10,13, Pozzetti+10, Moustakas+13)



More detailed and complementary insight from stellar populations

- ☐ **MASS, AGE AND CHEMICAL COMPOSITION OF STELLAR POPULATIONS** are the result of the **past history of star formation and chemical evolution**, the recycling of heavy elements into the ISM/IGM, galaxy-environment interactions
- ☐ **"Fossil record"** approach: infer past history from present-day stellar populations
- ☐ **"Direct"** approach: census of galaxy populations at different redshift

apply archaeological approach at different epochs to constrain galaxies star formation and assembly histories

- **high-quality rest-frame optical spectra**
- **modeling that captures complexity of galaxy SFHs**

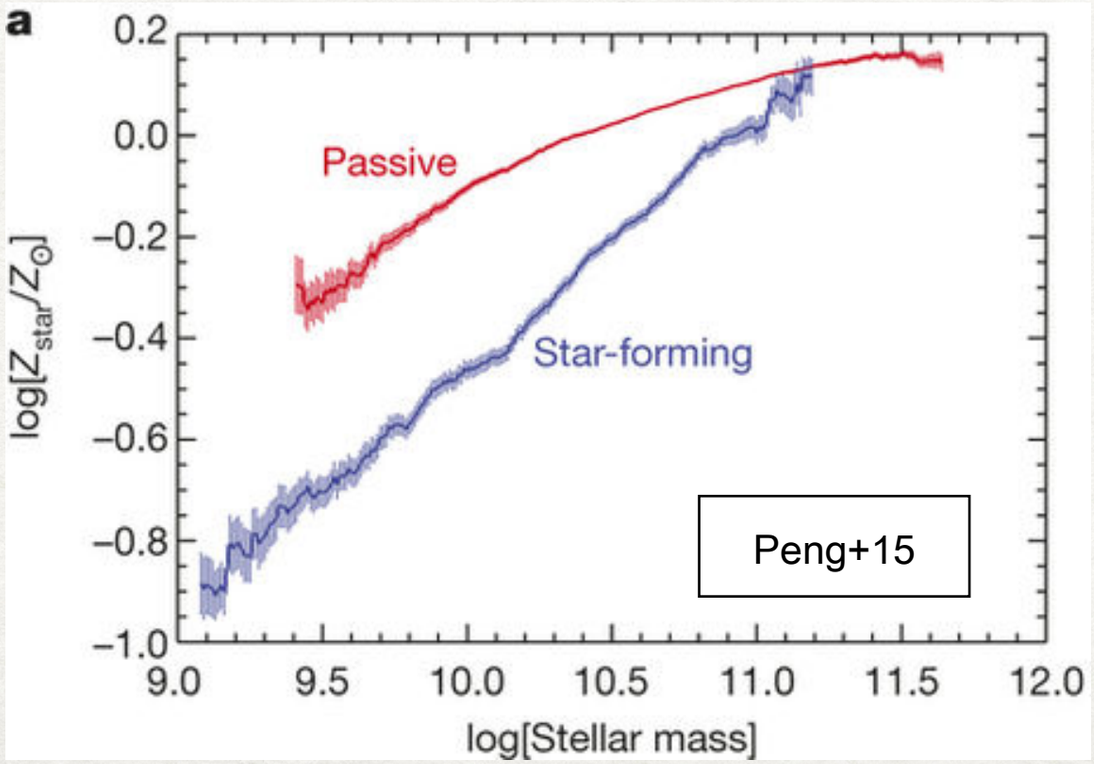
GALAXY POPULATIONS AT Z=0

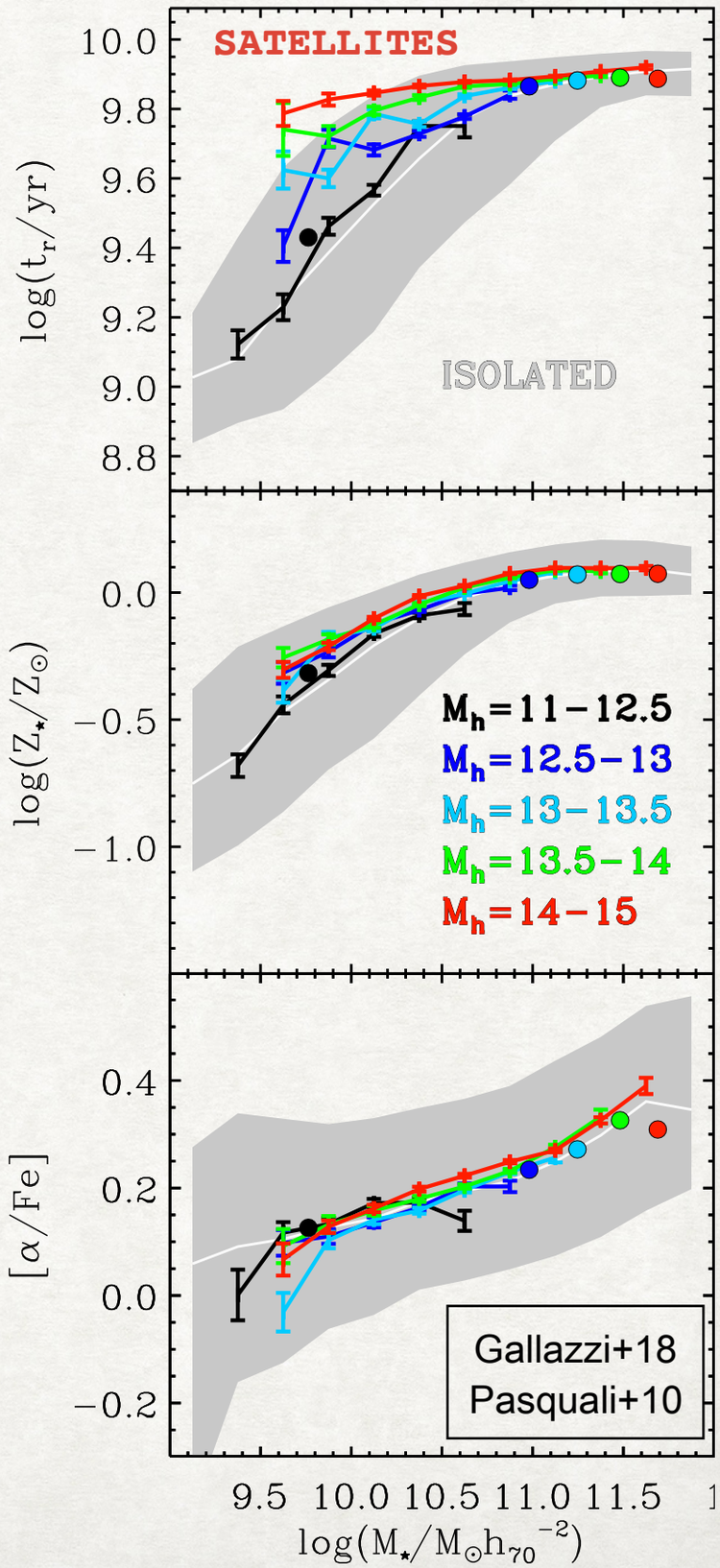
Bimodality in several spectral, structural and physical properties transitioning around a characteristic mass of $3x10^{10}$ $M_\odot$ (e.g. Kauffmann et al 2003, Baldry et al 2004, Gallazzi et al 2005, Mateus et al 2006, Panter et al 2008, Schawinski et al 2014, Gonzalez-Delgado et al 2014)

Stars in more massive galaxies are older and metal-richer than in lower mass galaxies ("chemo-archaeological downsizing" Fontanot et al 2009)

change in slope and scatter around $3x10^{10}$ $M_\odot$ (~ transition mass in MF of “blue” and “red”)

- **scatter** in scaling relations associated to
  - different scaling relations for **quiescent** and **star-forming**
  - **environment**



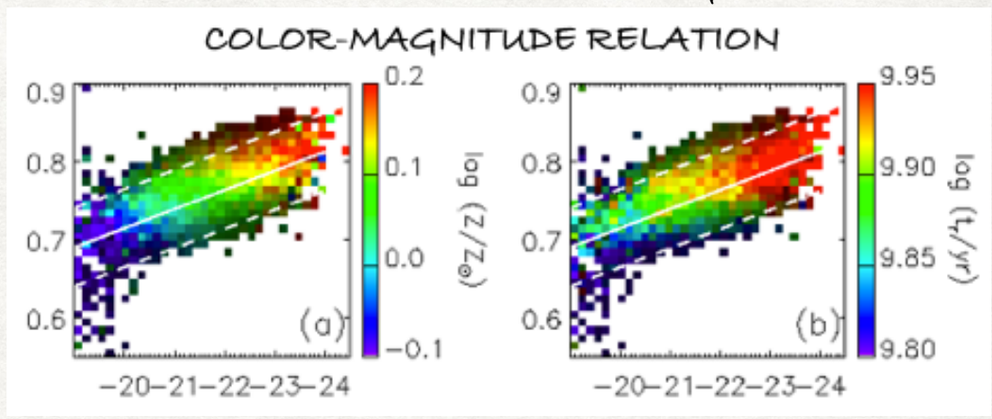


LOCAL QUIESCENT GALAXIES

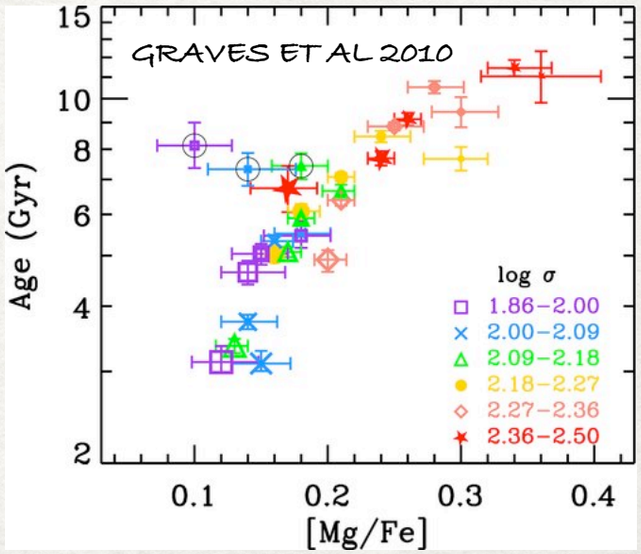
- contain **more than half of the mass and metal mass densities in stars at z=0** (e.g. McDermid+15, Gallazzi+08, Baldry+04, Bell+03)

- **increase in age, total metallicity and α/Fe with mass/velocity dispersion** (e.g. Kuntschner+00, Trager+00, Thomas+05, Gallazzi+06, Nelan+06, Graves+09,10, Arrigoni+10,Spolaor+10, Johansson+12, Harrison+11, McDermid+15)
- correlation between α/Fe and age (Gallazzi+06, Graves+10, Walcher et al 2015) and “half-mass time” (de la Rosa+11)

GALLAZZI+06



- scatter in metallicity and in age increasing at low stellar masses
- Episodic rejuvenation through small burst of SF?
- Continuous build-up of the red-sequence through quenching of SF in blue-cloud galaxies?



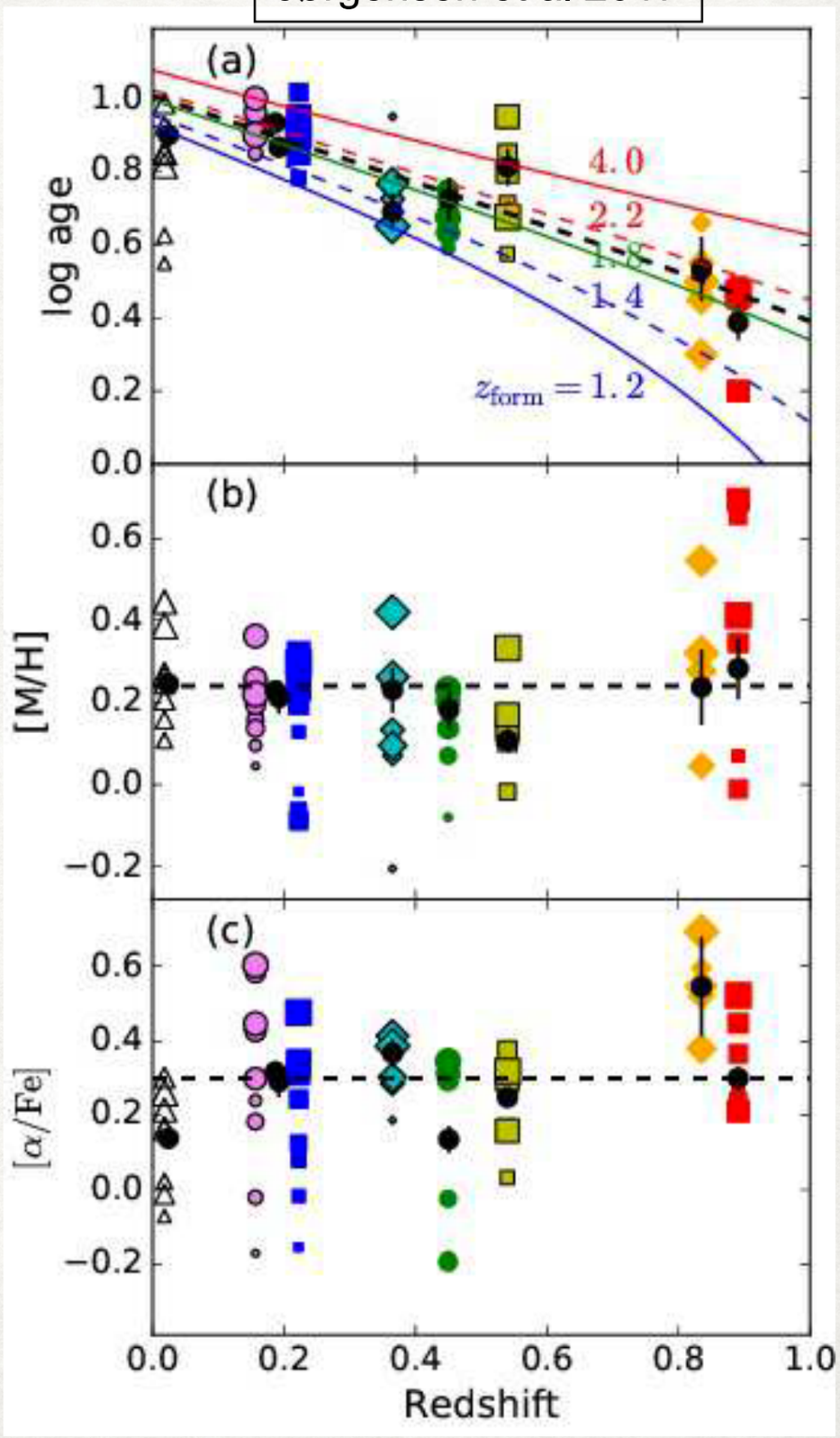
EVOLUTION TO INTERMEDIATE REDSHIFT

- How do scaling relations and their scatter evolve?
- Can we distinguish between EVOLUTION OF INDIVIDUAL RS GALAXIES and EVOLUTION OF THE POPULATION through addition of newly "formed" RS galaxies?
- Can STAR-FORMING GALAXIES provide the necessary population for the observed evolution?
- Is there an ENVIRONMENTAL dependence?

- Age of **massive CLUSTER quiescent galaxies** consistent with **high formation redshift (z~2) and subsequent passive evolution** to z=0 (e.g. Sanchez-Blazquez+09, Jørgensen & Chiboucas 2013, Jørgensen+17).
- **no clear evolution in metallicity nor α/Fe** but cluster-to-cluster variations

quiescent/early-type cluster galaxies (Kelson+06, Sanchez-Blazquez+09, Jorgensen 05, Jørgensen&Chiboucas+13, Ferre'-Mateu+14, Jørgensen+17), quiescent/early-type field galaxies (Schiavon+06, Ferreras+09, Choi+14), mass-selected field galaxies (Gallazzi+14)

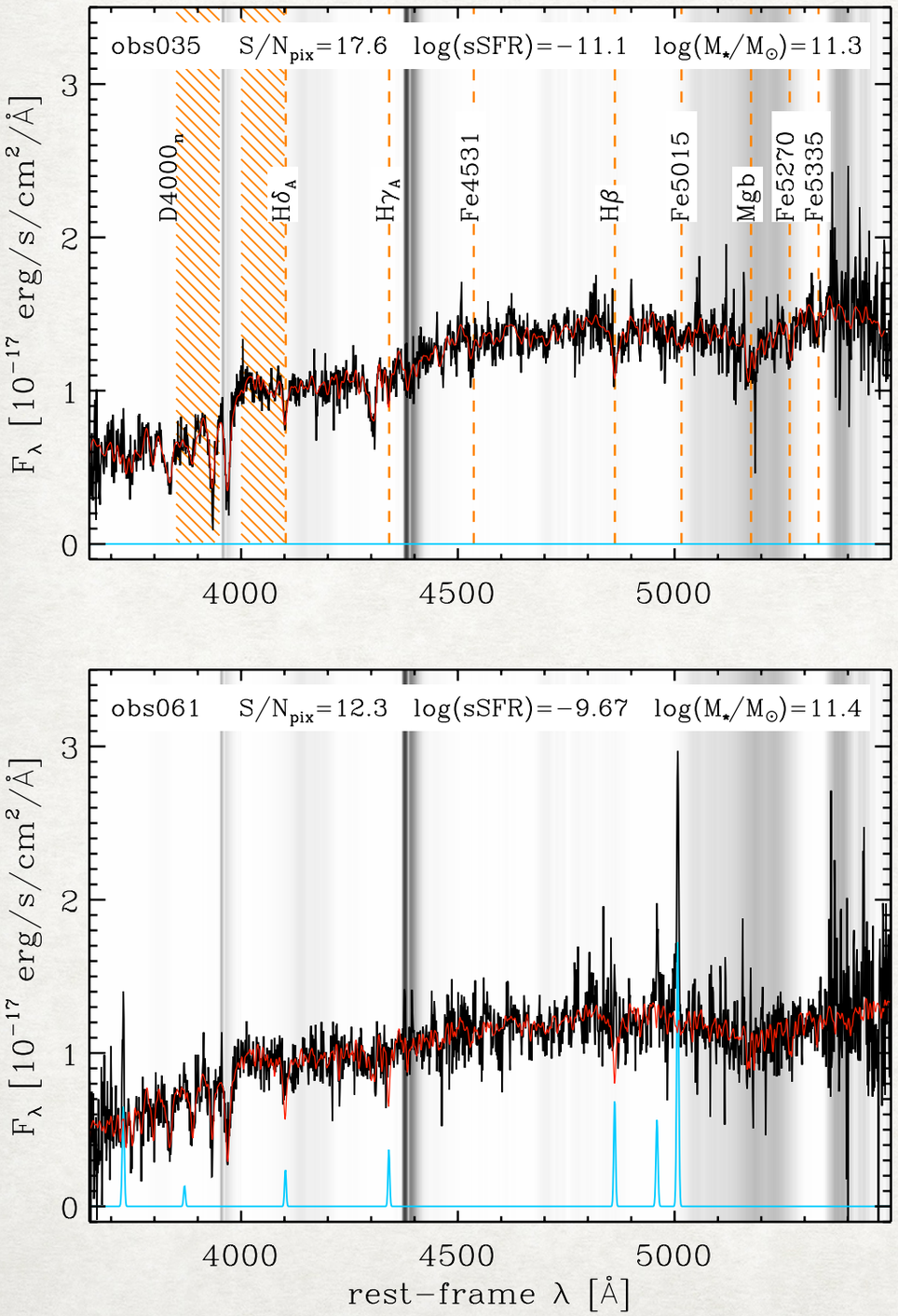
Jørgensen et al 2017

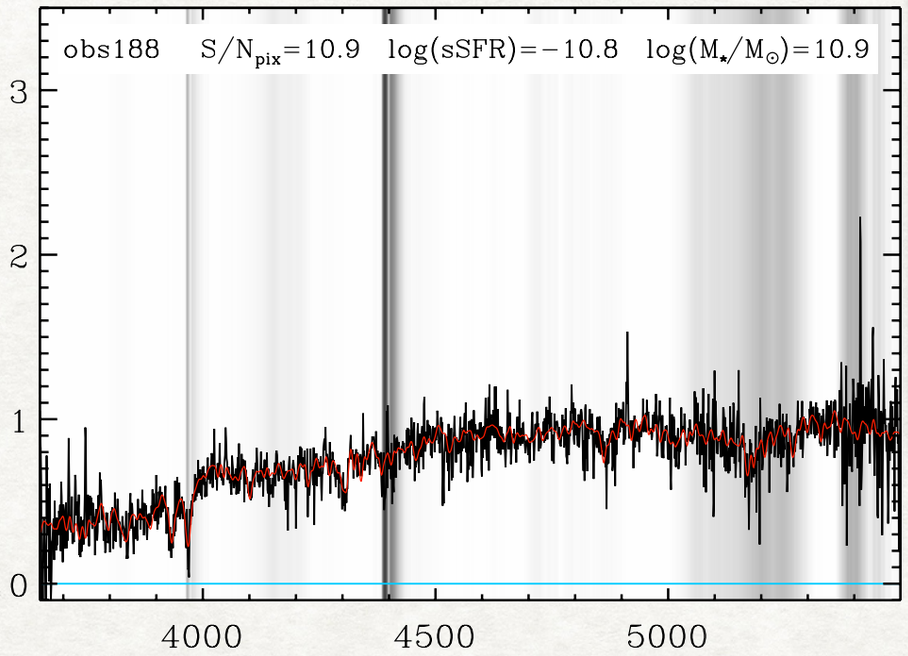


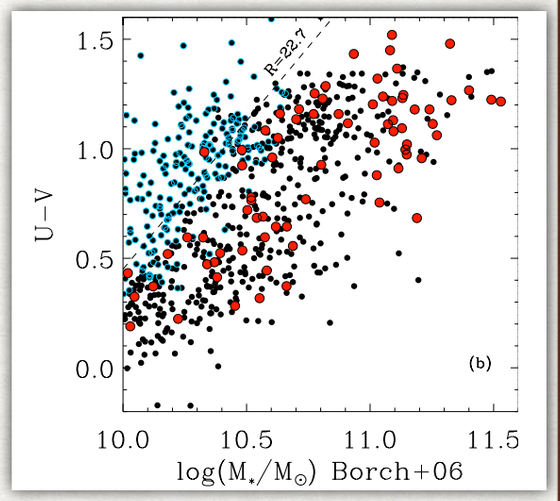
STELLAR POPULATION PROPERTIES AT Z~0.7: OUR FIRST ATTEMPT

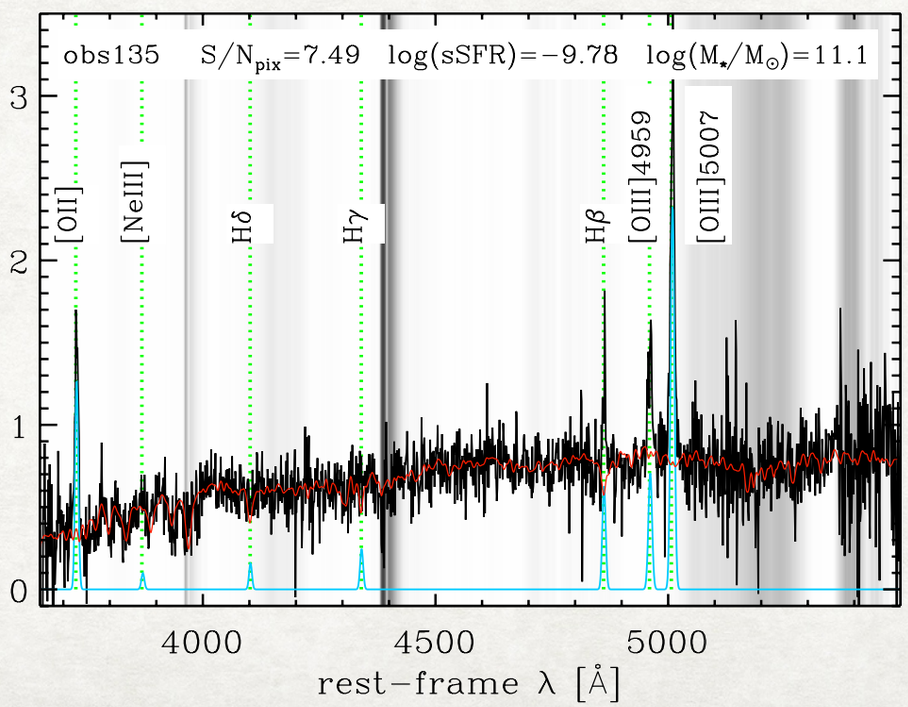
GALLAZZI ET AL 2014

* ≥70 massive galaxies at 0.65<z<0.75 in CDFS
* IMACS spectroscopy, 10hr exposures, 3700-5500Å rest-frame, 3.4Å FWHM resolution

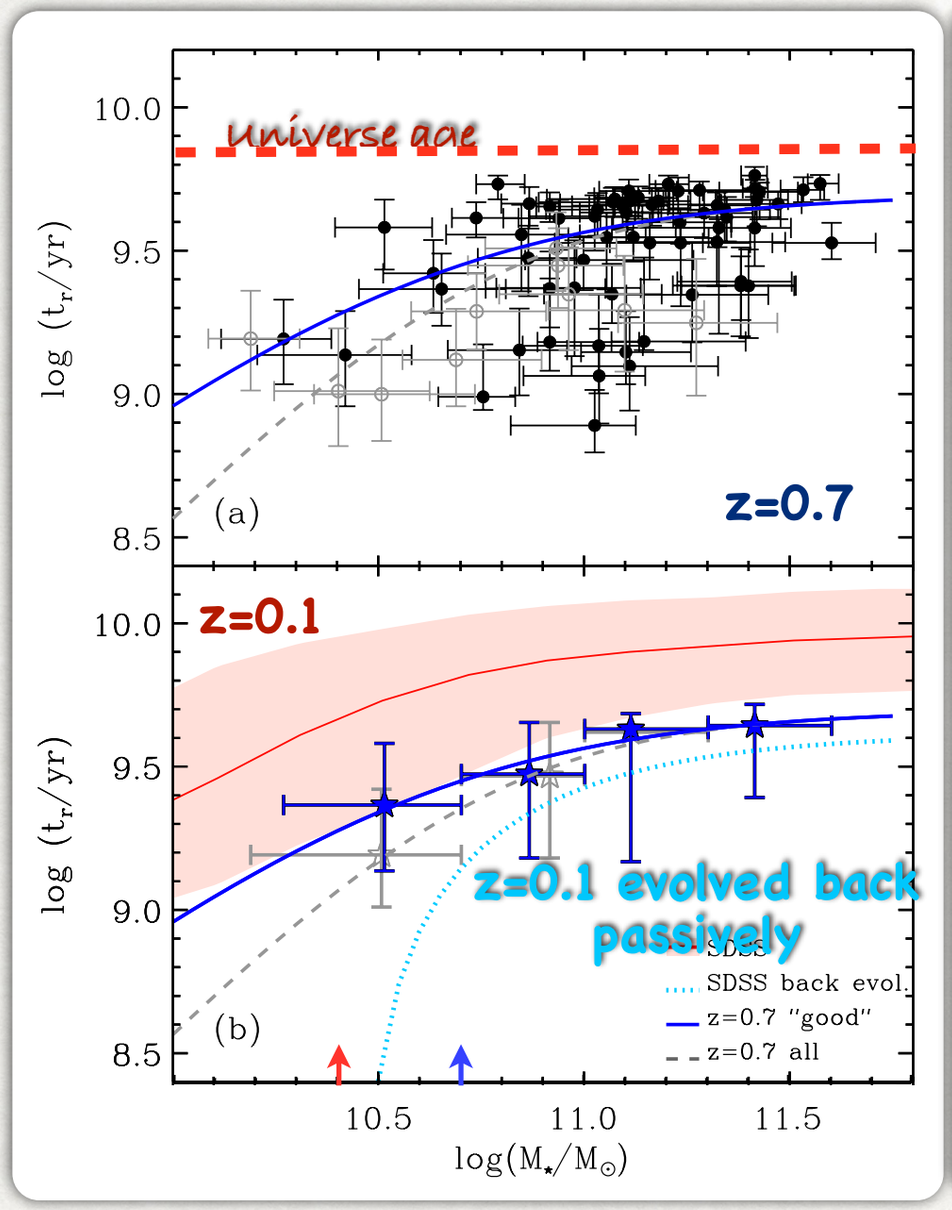


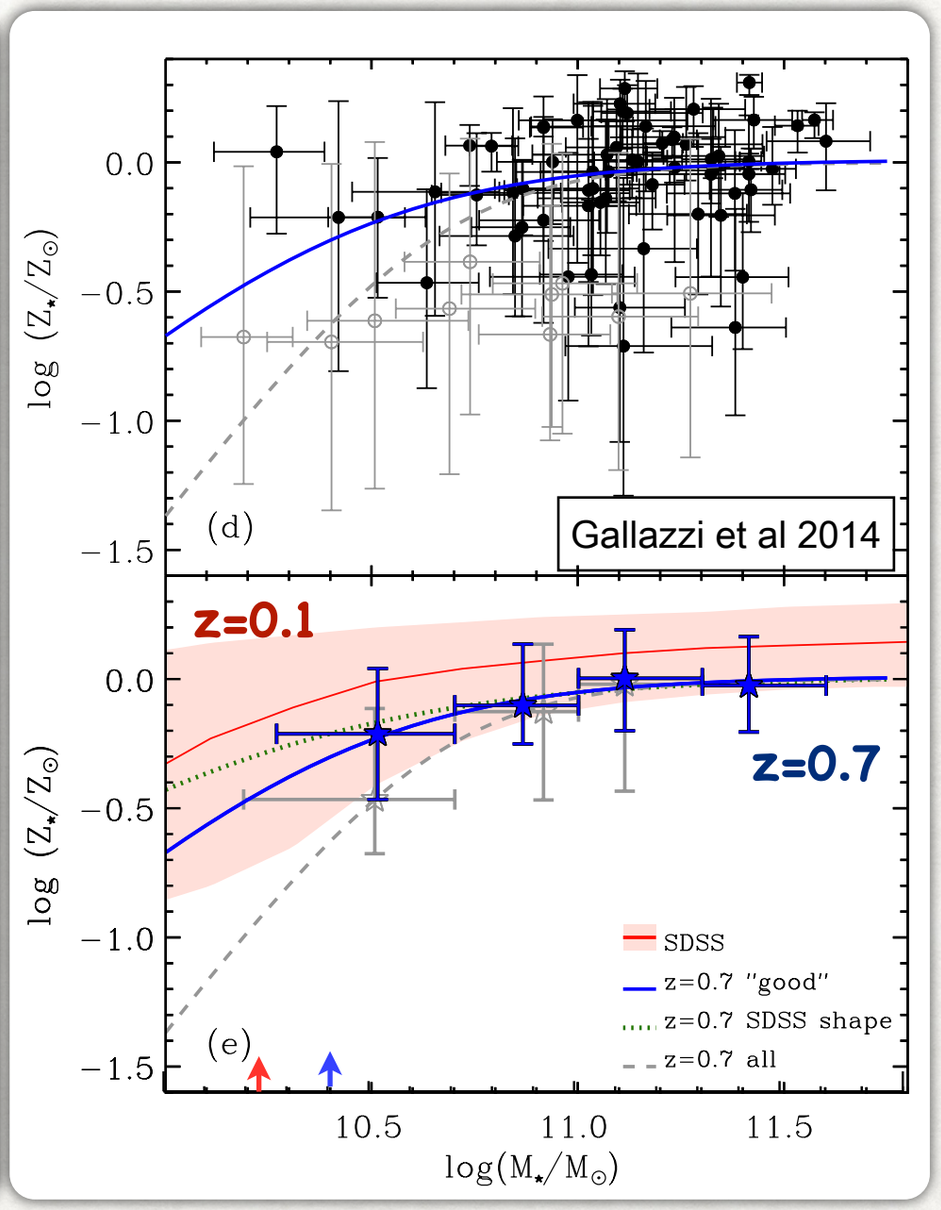






STELLAR POPULATION SCALING RELATIONS FOR ALL GALAXY TYPES





Open questions:

Is there evolution in characteristic stellar mass?
(see e.g. Pannella+09, Pozzetti+10, Muzzin+13)

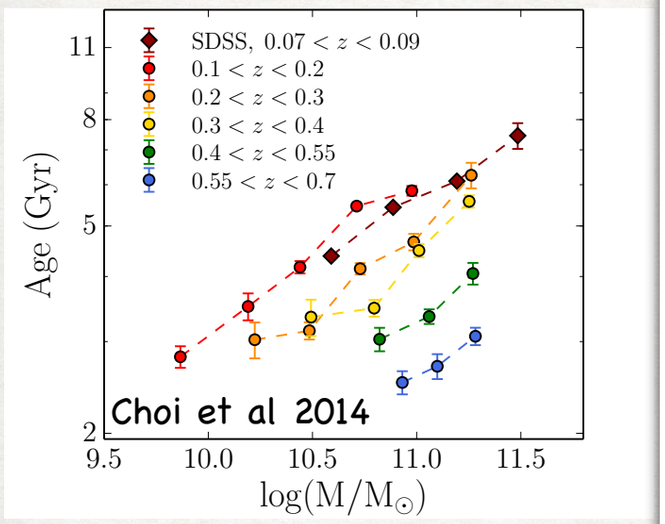
Does stellar metallicity-mass relation steepen at low masses?

~4 Gyr evolution at $10^{11.5}$ $M_\odot$

~0.13 dex evolution at $10^{11.5}$ $M_\odot$

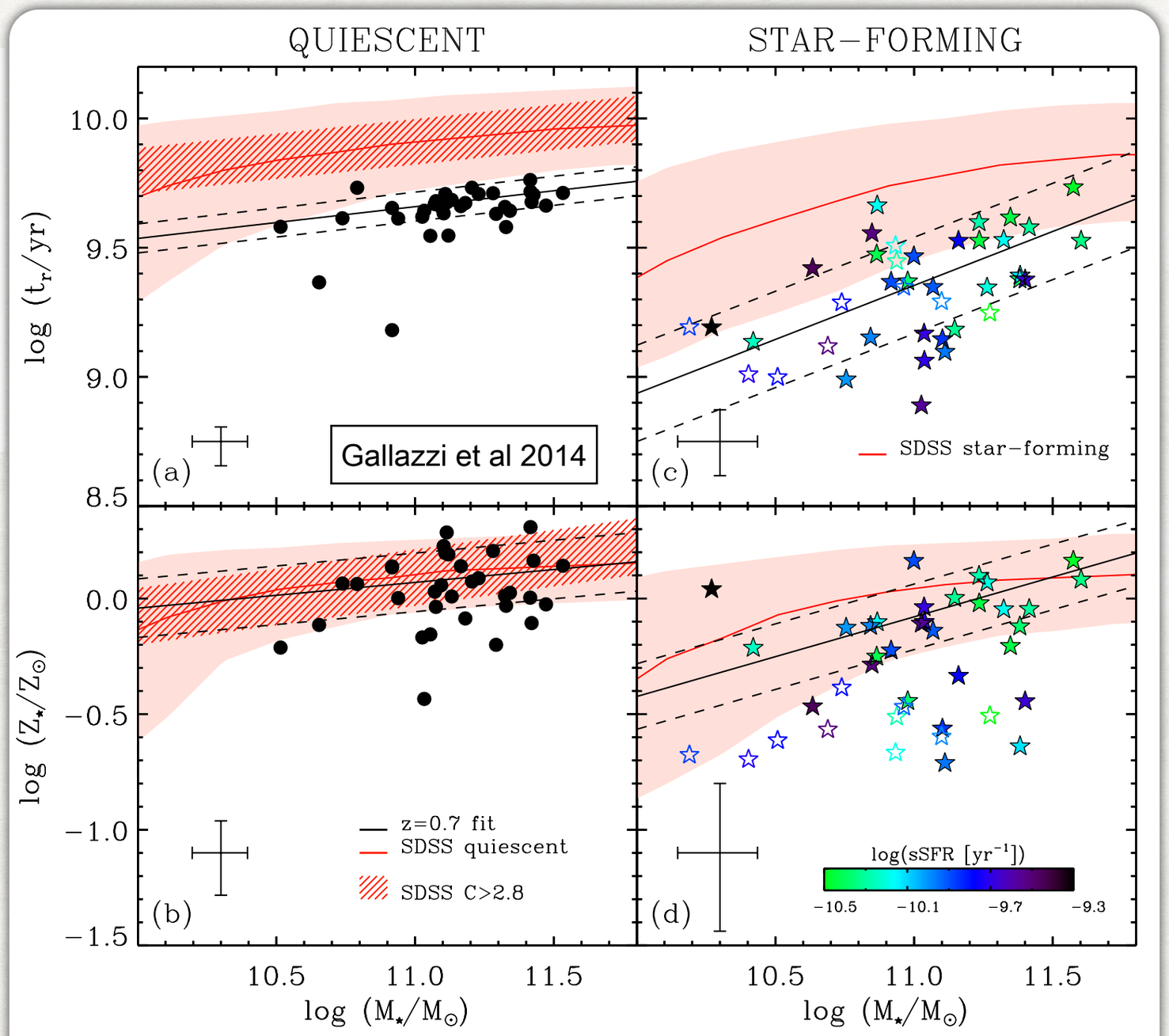
Too shallow and too old :
mass-dependent rate of evolution in age

QUIESCENT AND STAR-FORMING



also Ferreras et al 2009

stellar metallicity-mass relation fully consistent with local quiescent galaxies



median metallicity lower by 0.12 (0.2) dex wrt to local SF (Q) galaxies

Passively evolved Q galaxies consistent with local population, but smaller age scatter

Low fraction of post-SB (~3%) argues against significant SF episodes prior to quenching - Only **small amount of 'frosting'** is allowed

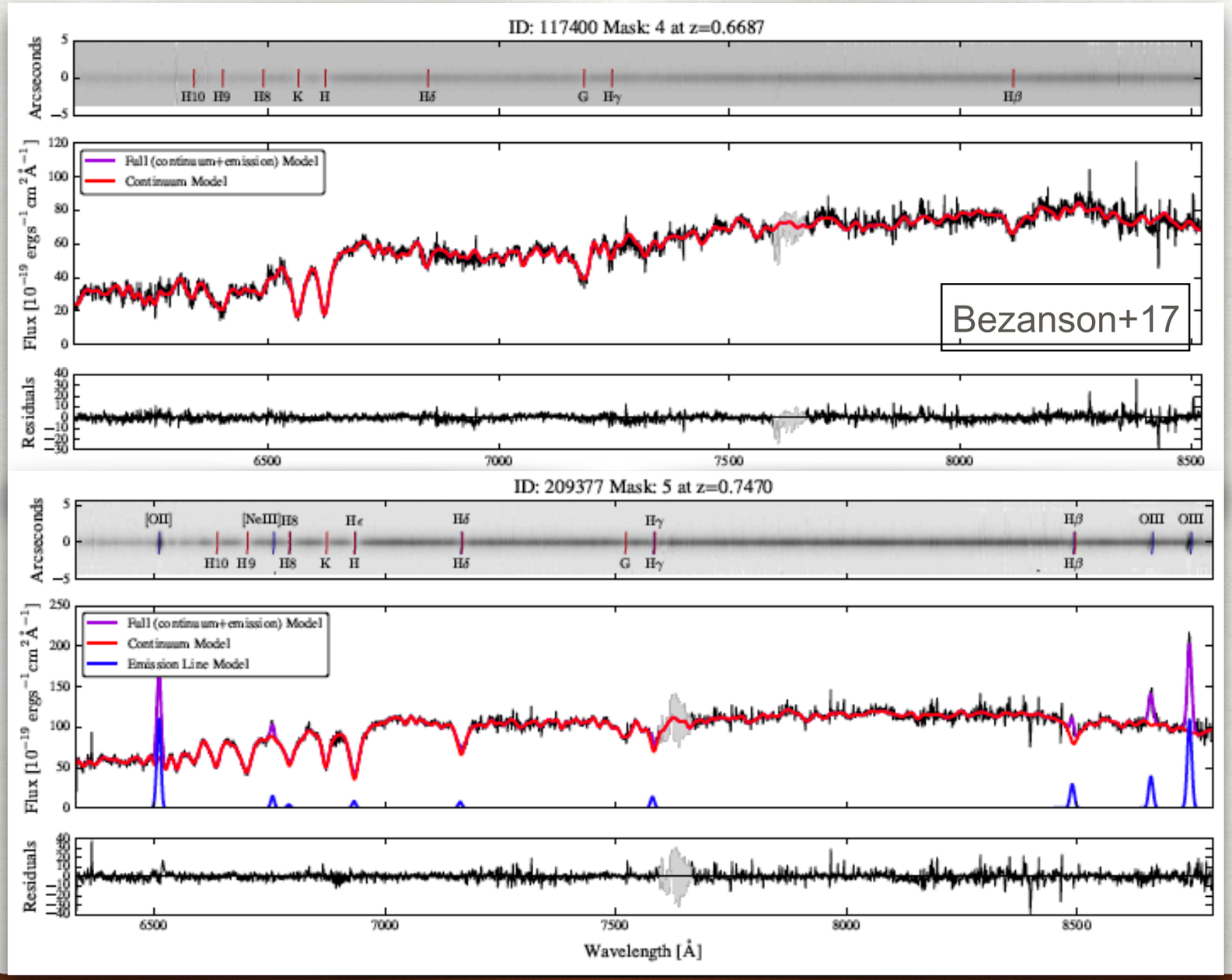
Require **quenching and subsequent passive evolution of (high-metallicity) SF galaxies** to populate the younger portion of local Q galaxies

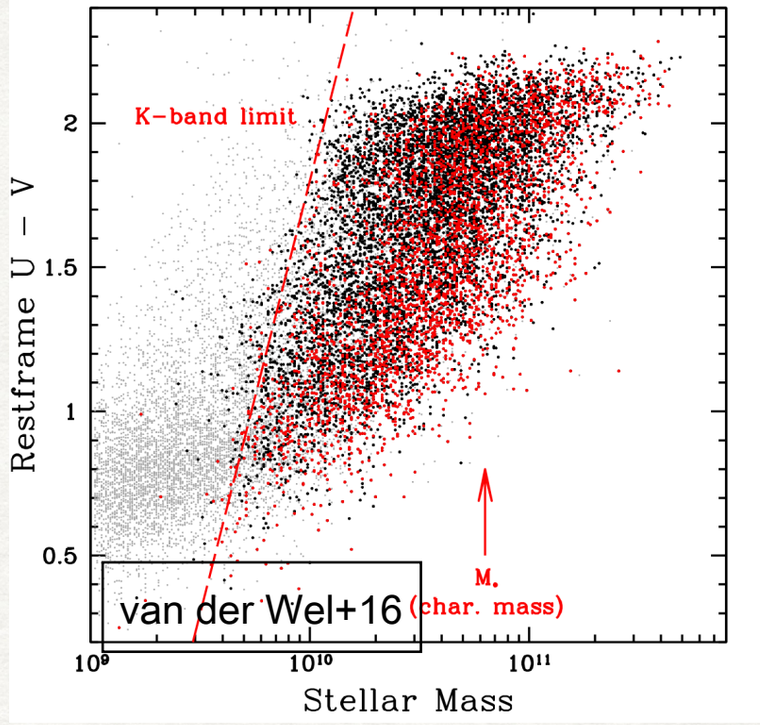
LEGA-C

Public spectroscopic survey with VIMOS @ VLT (van der Wel+2016, Barisic+2017)

PI: Arjen van der Wel, Survey Scientists: Rachel Bezanson, Anna Gallazzi

- 3200 0.6<z<1 targets **K-band selected** (K=21.1@z=0.6, K=20.4@z=1) from UltraVISTA catalog
- 1.3 sq. deg. in COSMOS field
- 20 hr integration: **S/N>10/A for ~2700 galaxies**
- **6300-8800A with R=2500**





DR1 is out (15/9/2016): spectra and redshifts for **865 unique galaxies** over 0.29 sq.deg. **stay tuned for DR2! (~1900 galaxies)**

- **emission lines** and stellar continuum and **absorption features**
- stellar and gas **kinematics** (resolve down 50 km/s)

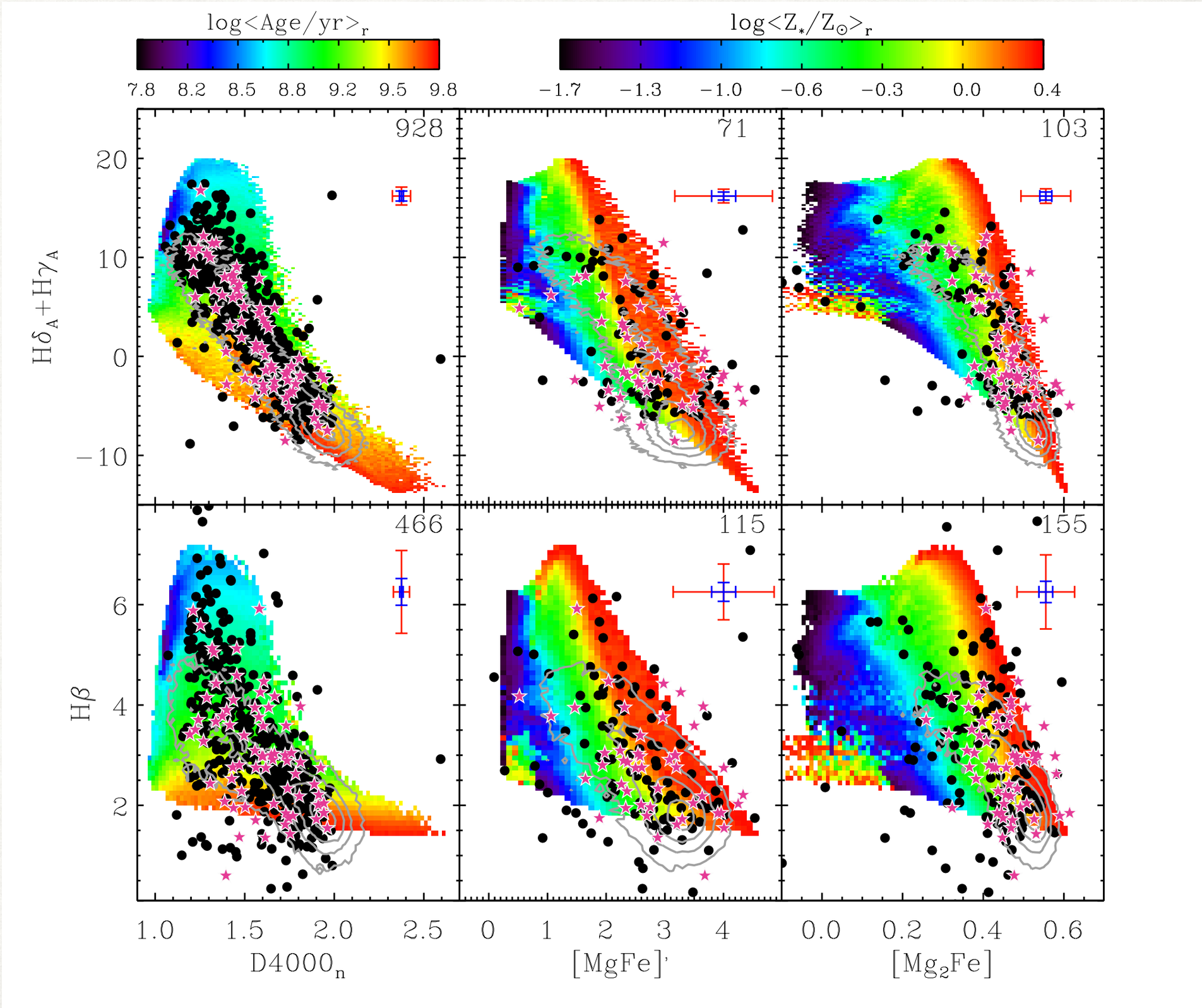
INDEX-INDEX DIAGNOSTICS

LEGA-C

Gallazzi+14

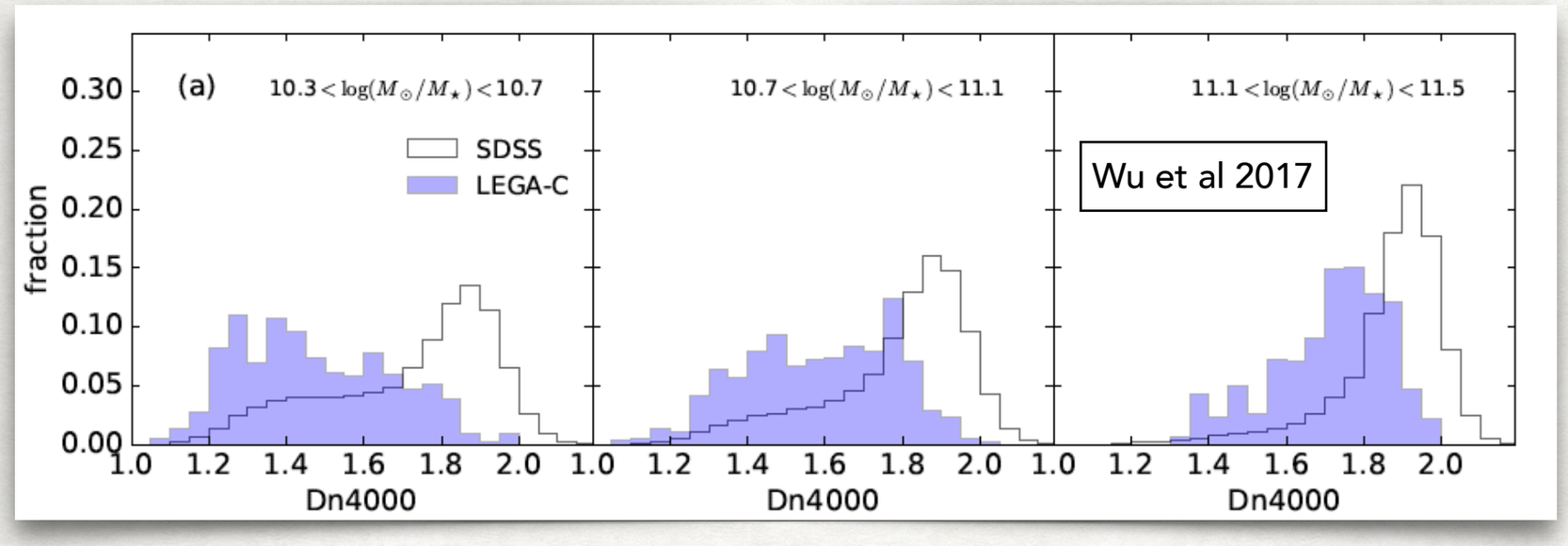
SDSS

SPS models with complex SFHs and metal enrichment



D_N4000-Hd FOR ~1000 Z~1 GALAXIES

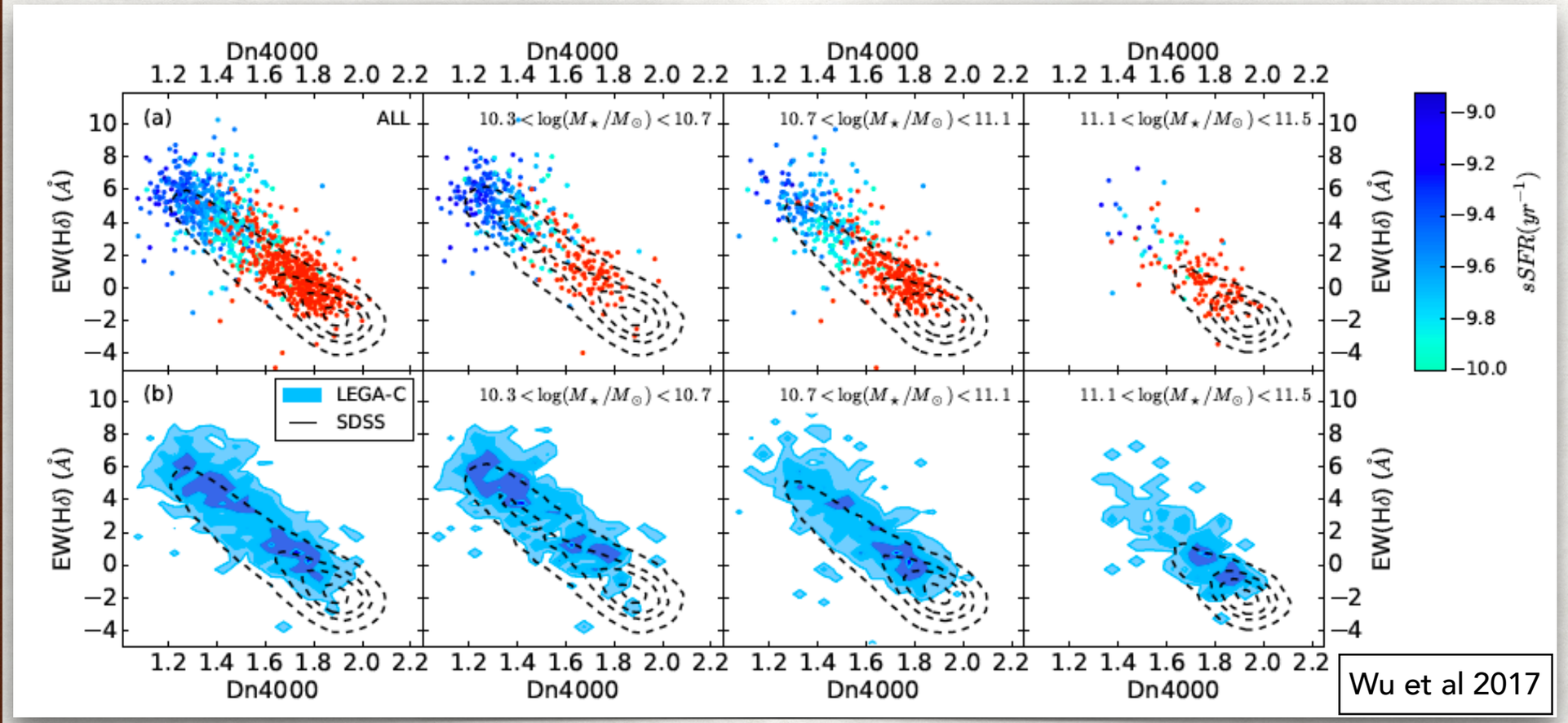
Wu, van der Wel, Gallazzi et al, to be submitted



galaxies at z~0.8 show

- bimodal distribution in D4-Hδ below $10^{11}M_\odot$

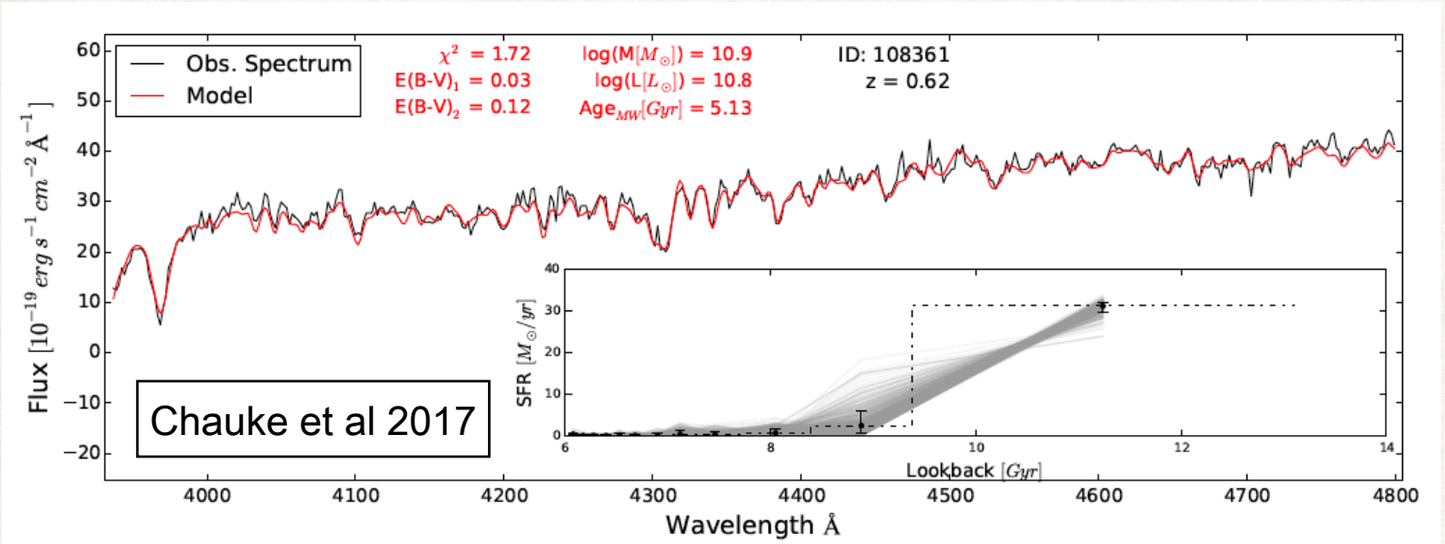
  see Chris Haines's talk
- stronger Hδ at fixed D4 than z~0 galaxies

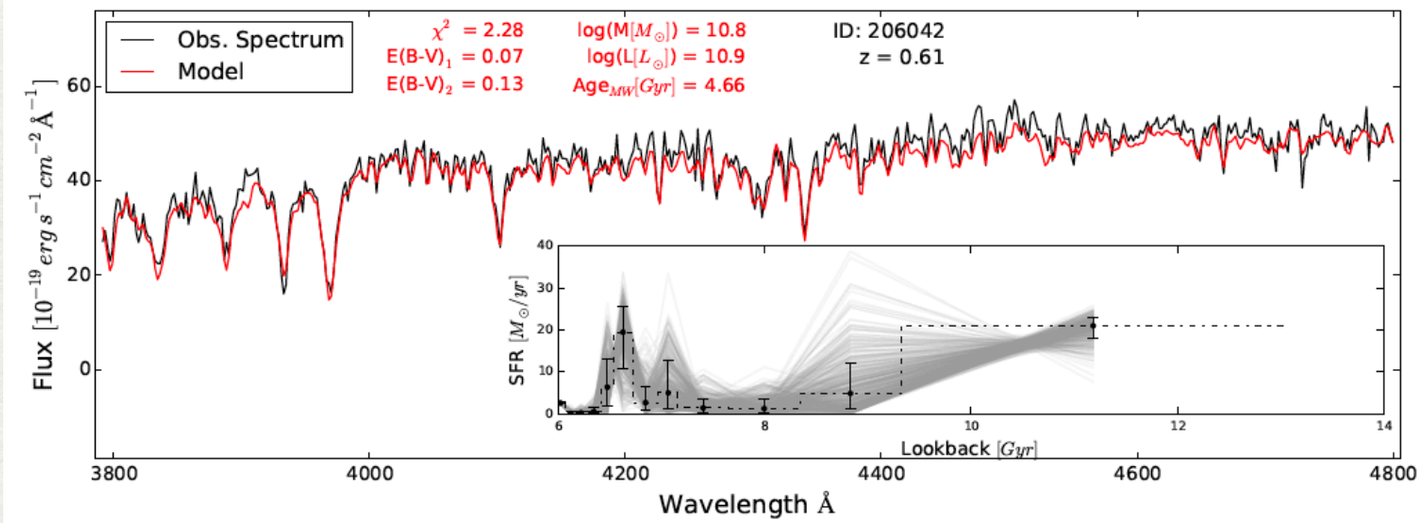


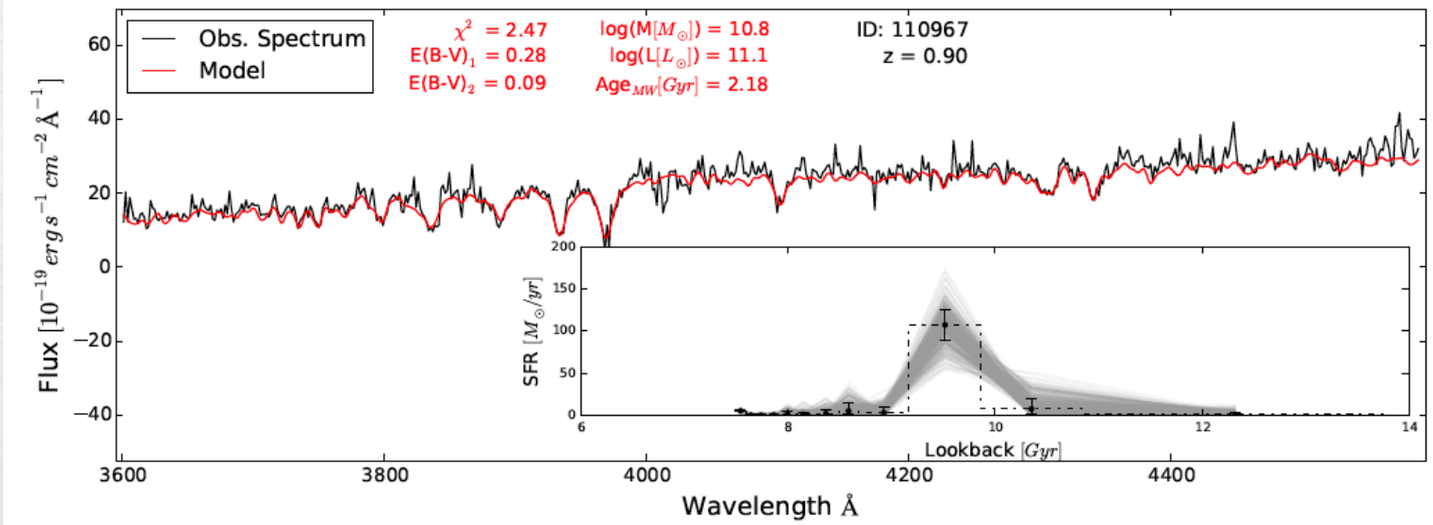
- more **bursty** SFH at z~0.8 than at z~0.1
- different amount of **dust** or dust geometry at z~0.8

RESOLVING SFHs AT Z<1 WITH LEGA-C

Chauke et al, to be submitted



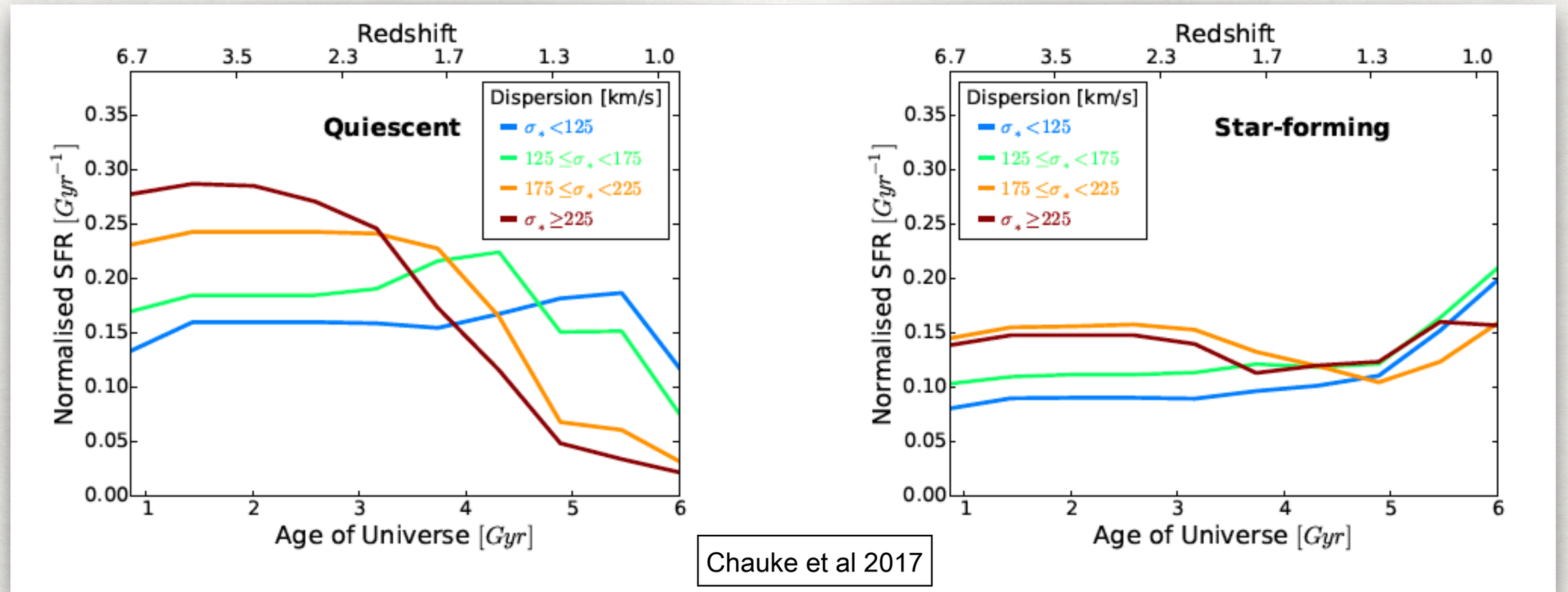




- 678 galaxies, 0.6<z<1, logM>2*10$_{10}$ $M_\odot$ FSPS stellar population code (Conroy+09) + MCMC

- sample values:
  - logM=2*10^9 - 4*10^{11} $M_\odot$, uncertainties 1-30% up to 60%;
  - log Age=60 Myr - 4.8 Gyr, 60% older than 3 Gyr, uncertainties 1-20%
- light-weighted age consistent with other studies (Gallazzi+14, Choi+14)

Chauke et al, to be subm.

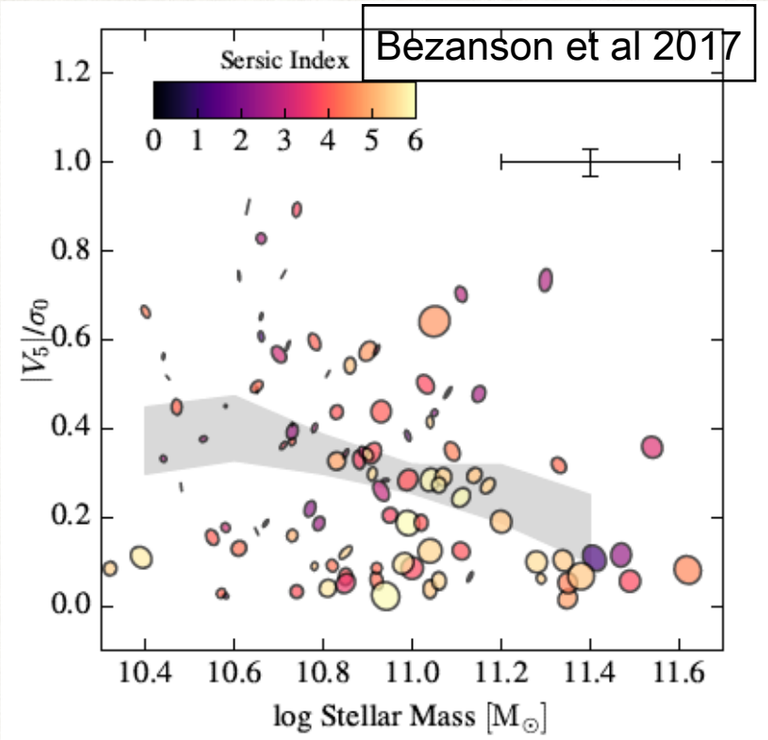


Chauke et al 2017

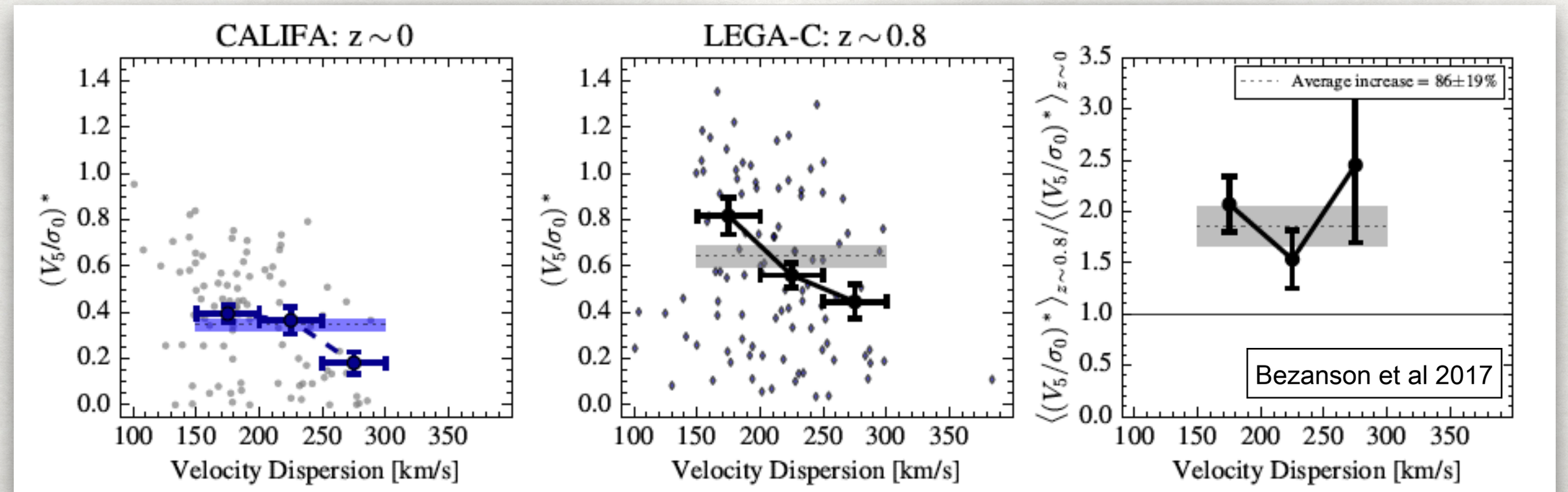
- evidence of "**downsizing**" at z~1 among the quiescent population
- lowest mass galaxies are undergoing main formation stage at z~1; massive SF galaxies peak 8.5 Gyr ago, while quiescent galaxies peak earlier (>10 Gyr)
- most galaxies are old, but **variety of SFHs** even among the oldest galaxies (some show signs of **rejuvenations** due to accretion or merger-induced SF)

INCREASED ROTATIONAL SUPPORT IN Z~0.8 QUIESCENT GALAXIES

Bezanson et al, submitted



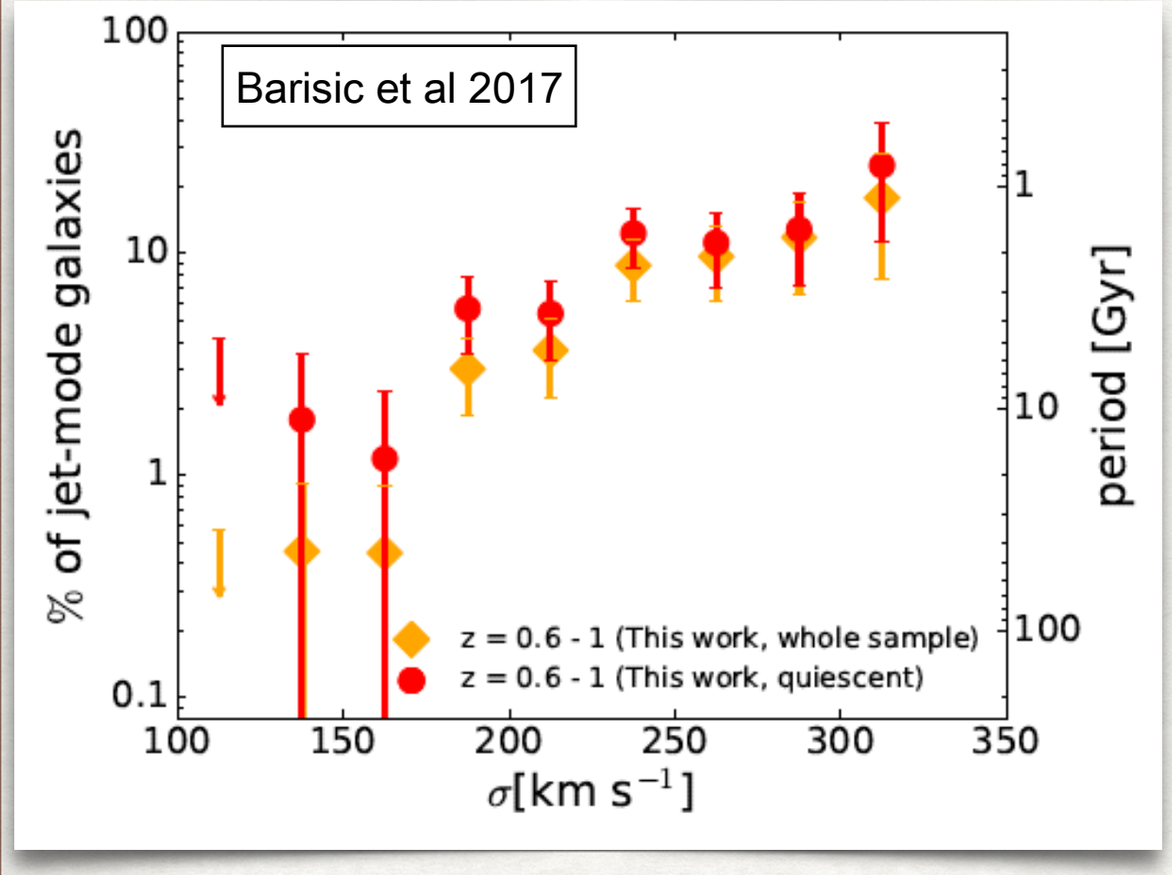
- no or little rotational support above $2*10^{11} M_\odot$; 64% of lower mass galaxies show significant rotational support
- not directly correlated with structure
- **higher average rotational support in z~0.8 quiescent galaxies compared to z~0 CALIFA quiescent galaxies**
- galaxies must lose angular momentum at or after cessation of star formation

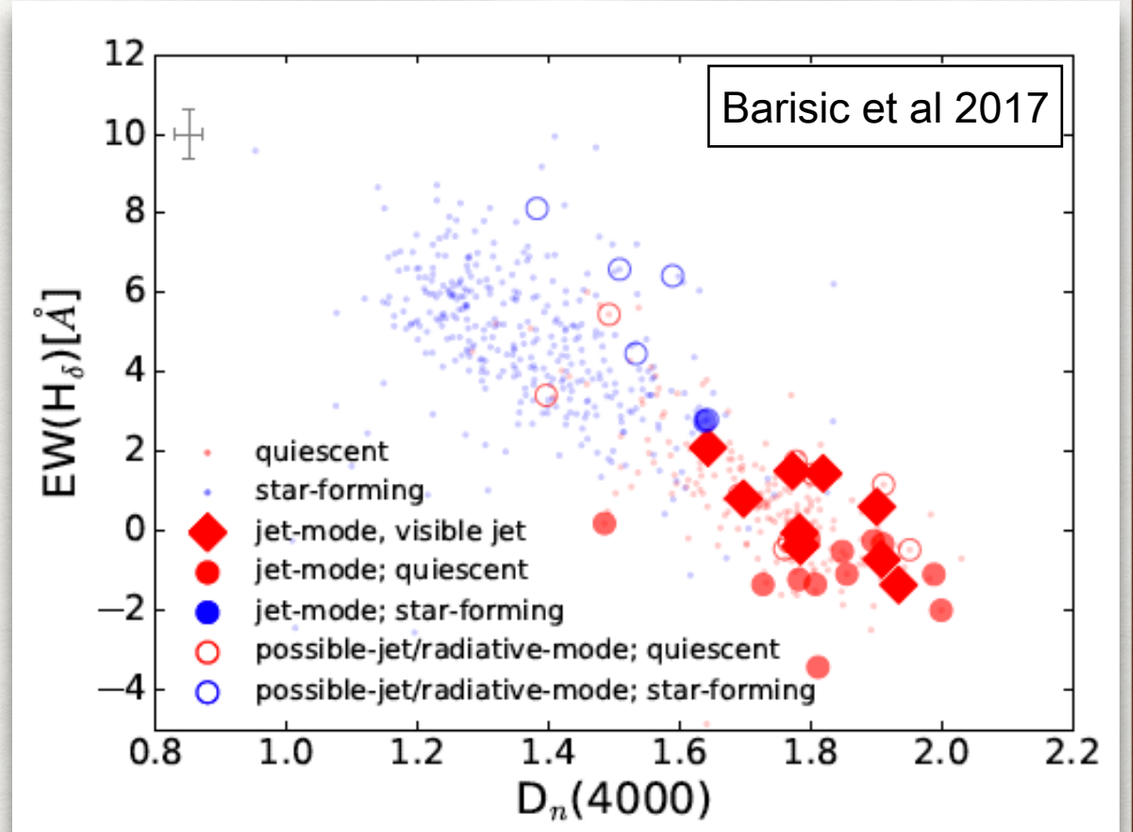


THE “SFH” OF RADIO-LOUD AGN: MAINTENANCE FEEDBACK

Barisic et al 2017

58 radio-loud galaxies from LEGA-C and VLA 3GHz cross-match (322 LEGA-C galaxies with VLA counterpart)





- fraction of radio-loud AGN at z~1 is 5-10 times higher than locally at fixed mass
- z~1 radio-loud AGN occur in old, high velocity dispersion galaxies
- D4-Hd imply that they have been quiescent for more than 1 Gyr -> radio-loud AGN with lifetime of ~100 Myr can play a role in **maintaining quiescence**
- Age and velocity dispersion measures allow to test the hypothesis that **radio-loud AGN occur in old galaxies with large velocity dispersion**, i.e. whether jet-mode galaxies have been quiescent for a long time

OUTLOOK

- **Time is ripe for statistically-significant studies at intermediate redshift with current (LEGA-C) and planned large spectroscopic surveys (WEAVE-STePs)**

- **WEAVE-StePS** survey with WEAVE @ WHT (PI: B. Poggianti, A. Iovino; start in 2019)
  - 30k I<20.5 selected galaxies at z>0.3 over 25 sq.deg.
  - R~5000, target S/N~15/A, 3700-9600A
  - trace kinematics and stellar populations of massive galaxies out to z~0.7 and their **environmental trends**

- **Extend to higher redshift** where most of the evolution in size, structure, dynamics and stellar populations is expected to happen: **NIR multi-object facilities (MOONS @ VLT, MOSAIC @ E-ELT)**