Robust constraints on the physical properties of individual passive galaxies from Lick indices in the LEGA-C survey

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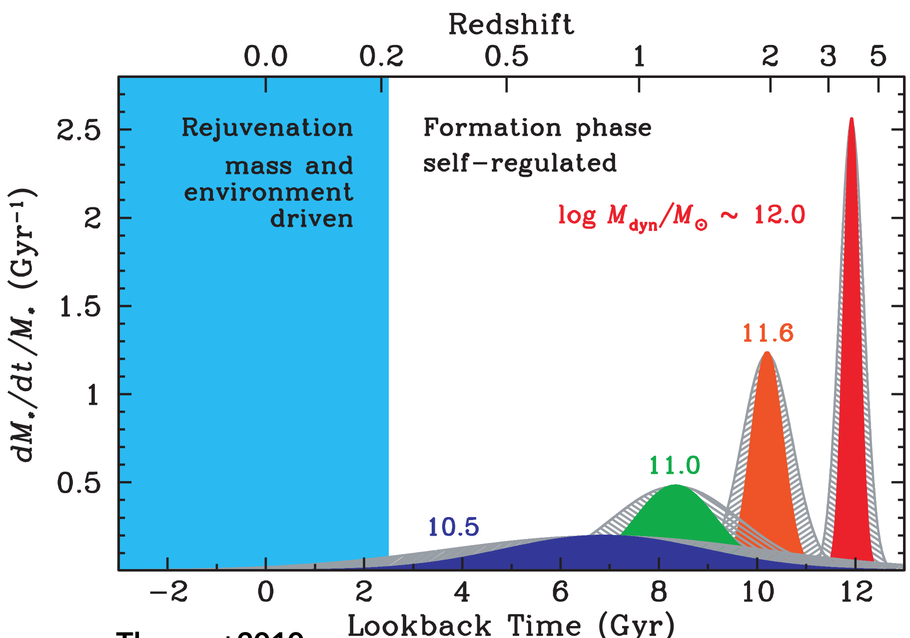
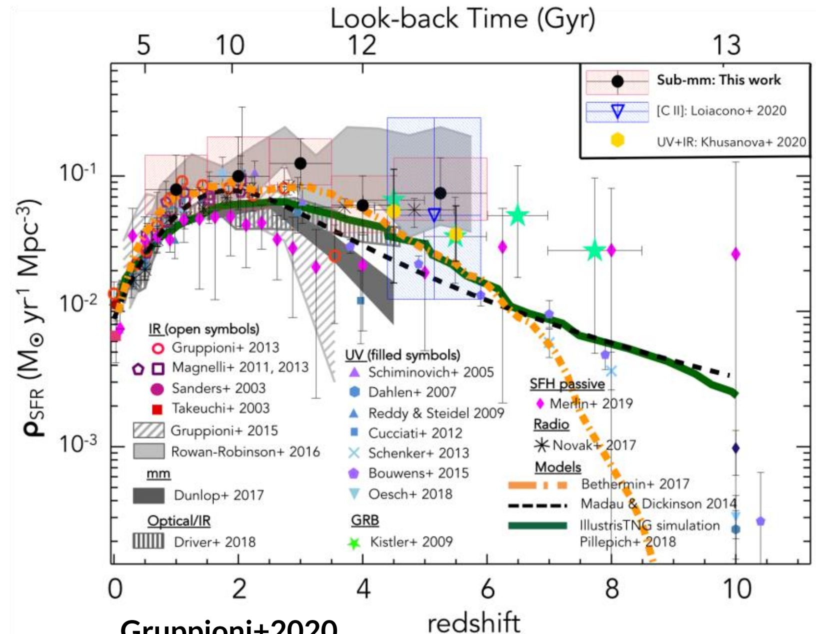
Galactic archeology & Lookback studies



Thomas+2010



Gruppioni+2020

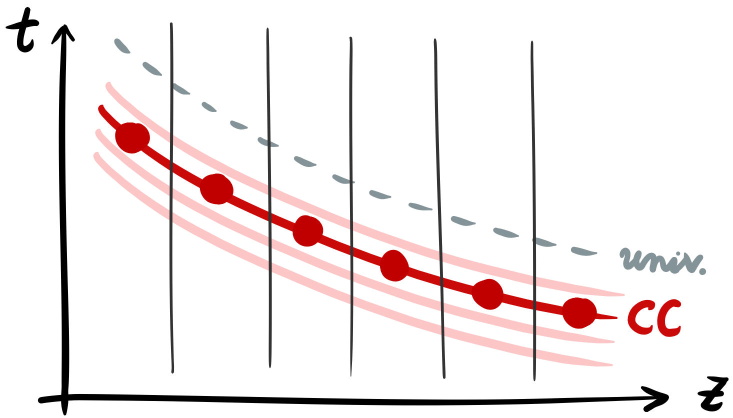
Upcoming deep spectroscopic surveys

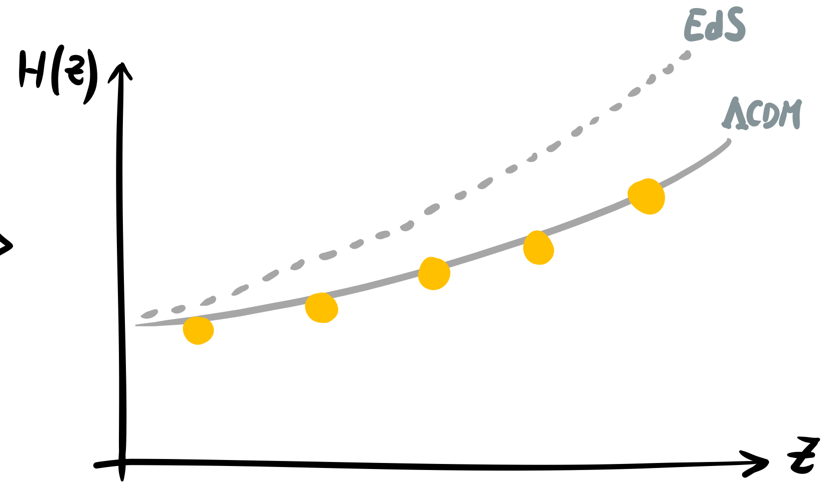
Cosmology with massive and passive galaxies

(M. Moresco talk, 22nd June)

Assuming a FRWL metric: $$H(z) = \frac{\dot{a}}{a} = -\frac{1}{1+z}\frac{\mathrm{d}z}{\mathrm{d}t}$$

(Jimenez & Loeb, 2002)





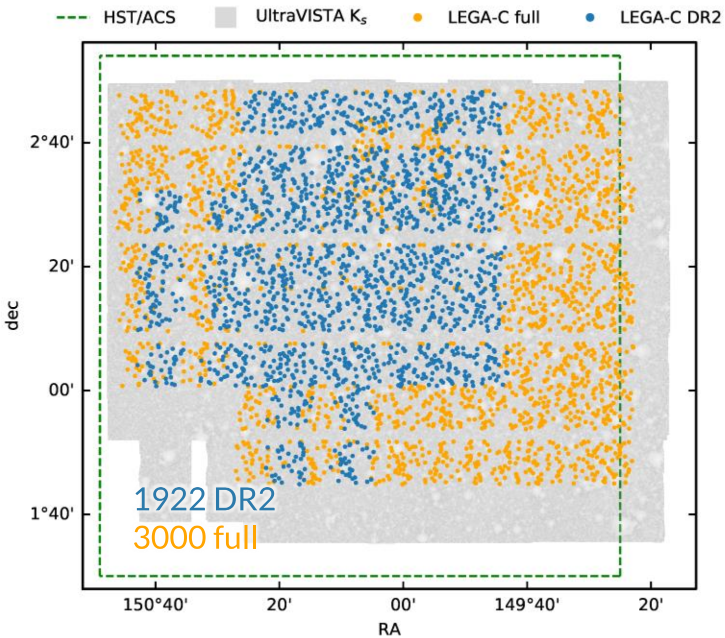
- ✓ Direct measure of H(z)
- ✓ Differential approach
- ✓ Cosmological model-independent
  ideal to test cosmological models

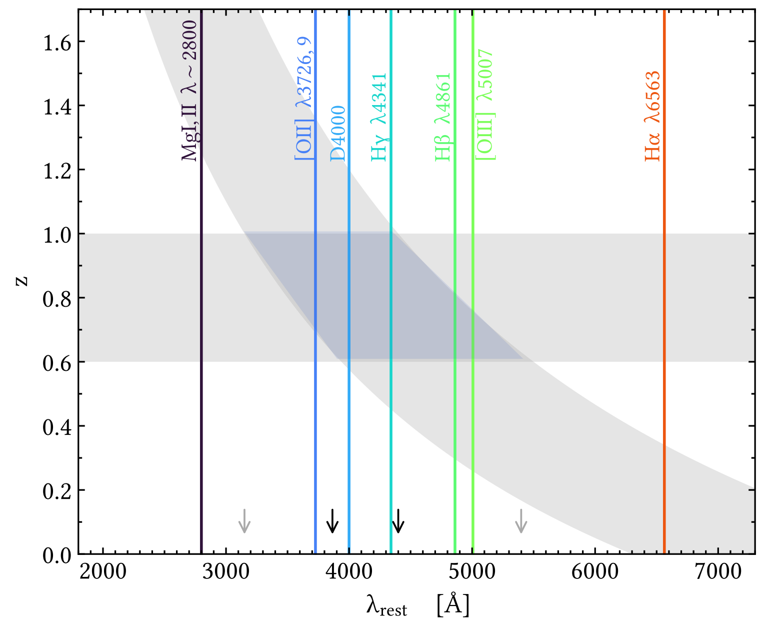
Key requirements:

1. Pure passive systems → different selection criteria
   (Renzini+06; Franzetti+07; Moresco+13)
2. Robust *dt* estimates **without cosmological priors**

The LEGA-C survey (0.6 < z < 1)

(see Van der Wel et al. 2016 and Straatman et al. 2018)

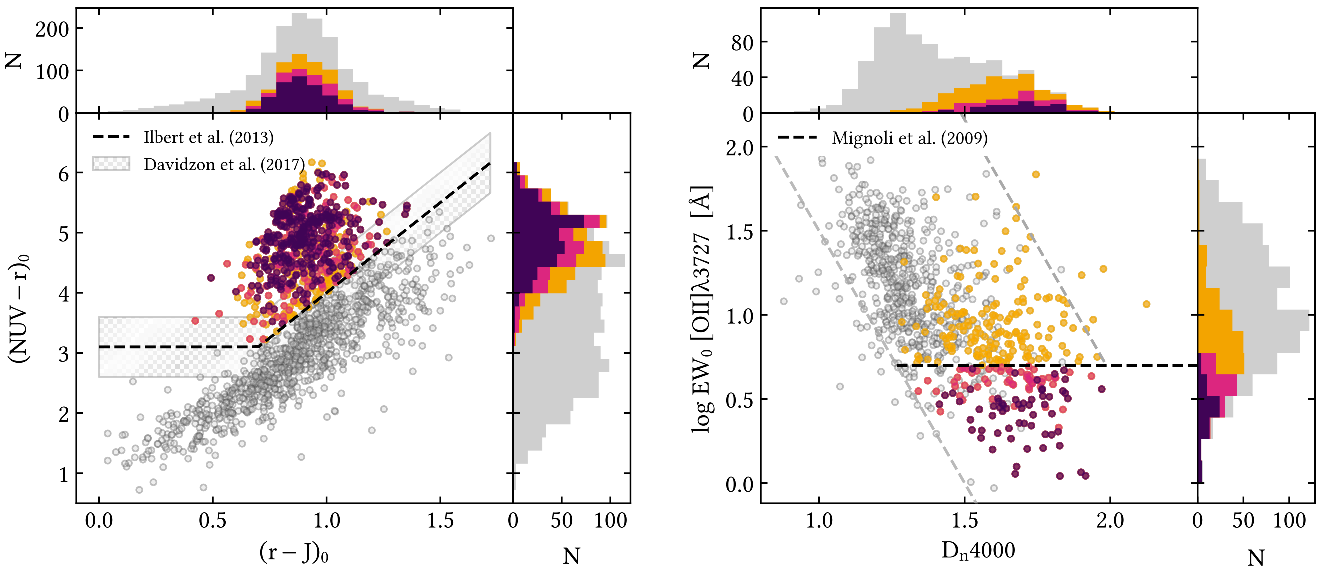


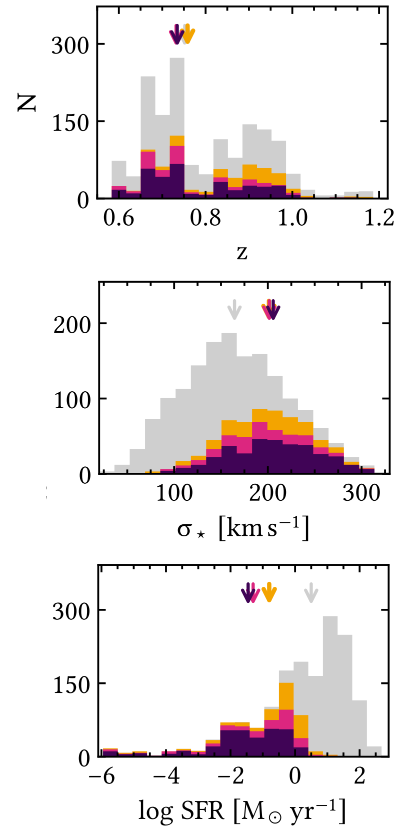


- 2 deg^2 in the COSMOS field; $K_{s,lim} = 20.7 - 7.5 \log((1+z)/1.8)$
- VLT / VIMOS HR-Red; R ~ 3500, with S/N ≳ 20
- Narrow λ_{rest} interval uniformly sampled, Δλ ~ 500 Å

Selection of passive galaxies

- NUVrJ (Ilbert et al. 2013)
- EW[OII]λ3727 < 5 Å cut (e.g. Mignoli et al. 2009)
- Visual inspection of [OII]λ3727 and [OIII]λ5007 lines

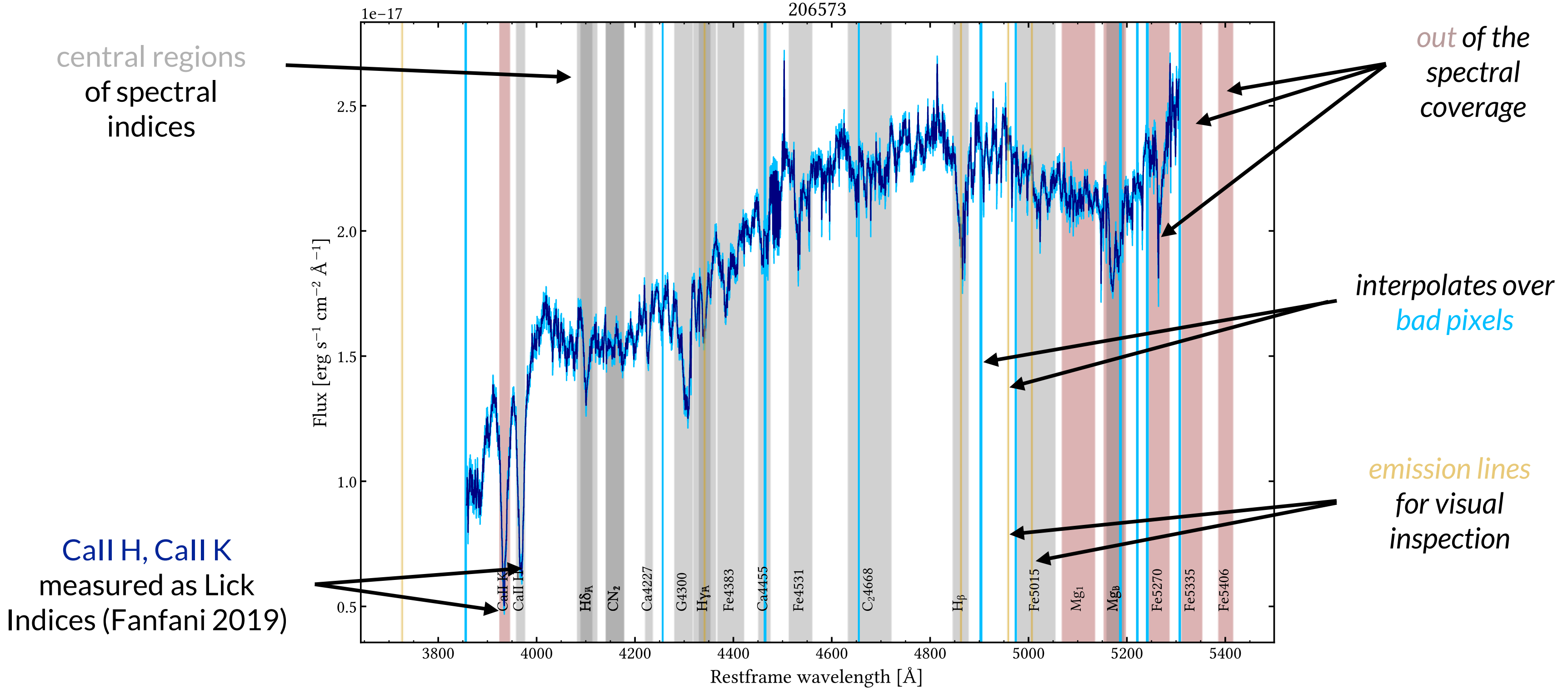




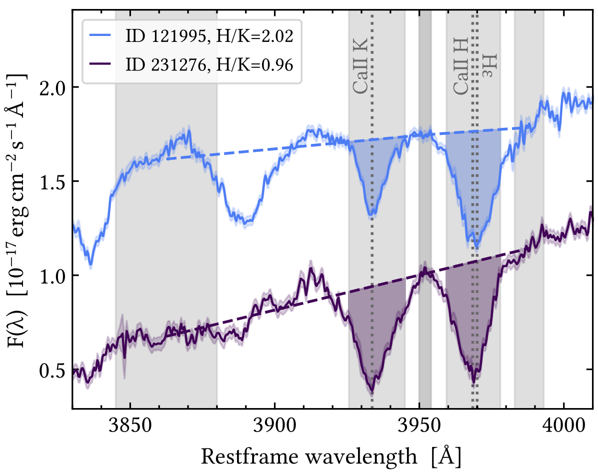
➢ 350 massive and passive galaxies with $\langle \mathrm{sSFR/yr} \rangle = -12.1$

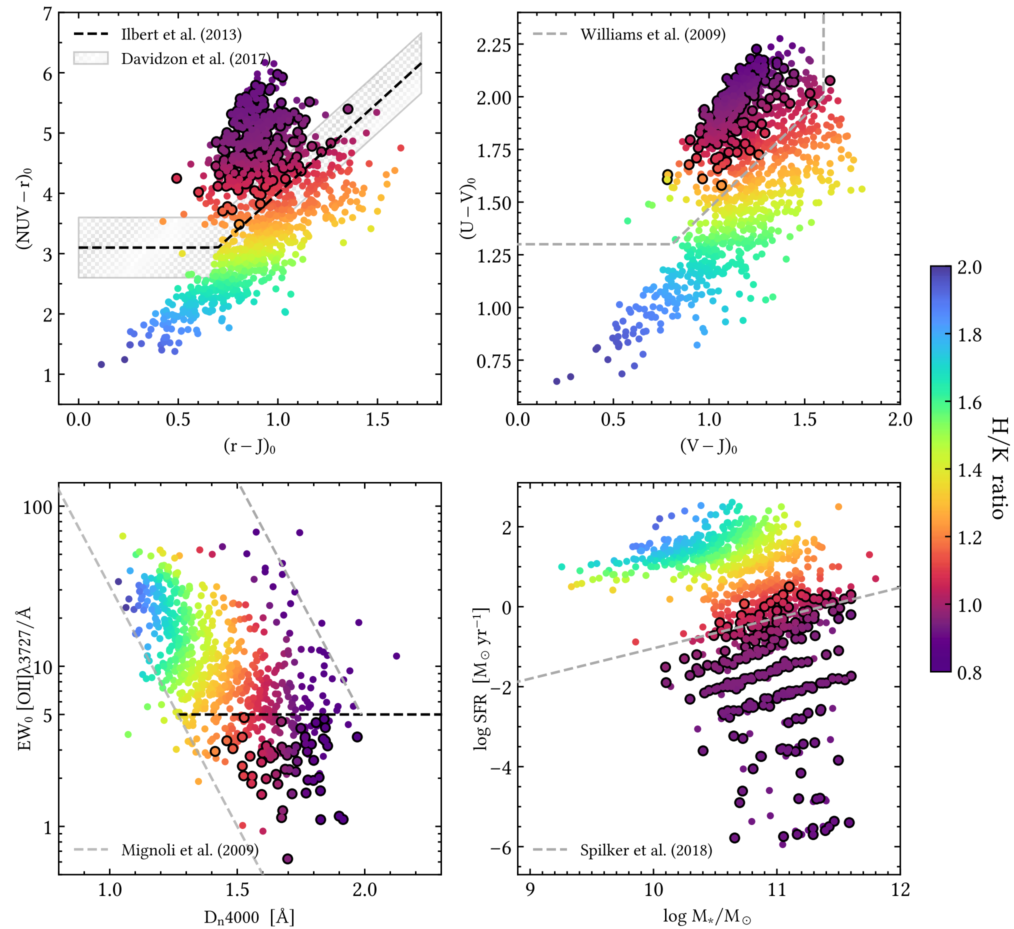
PyLick

- Flexible Python tool to measure spectral absorption features implementing several (currently **54**) index definitions. New indices can be easily defined by the user (e.g. CaII H and CaII K).



Spin-off: the H/K ratio





- CaII K bimodality, passive threshold **~5.5 Å**
- H/K = (CaII H + Hε) / CaII K
  strong Hε absorption from A & B-type stars, <1 Gyr episodes of star formation
- H/K<1.1 ↔ sSFR/yr < -11

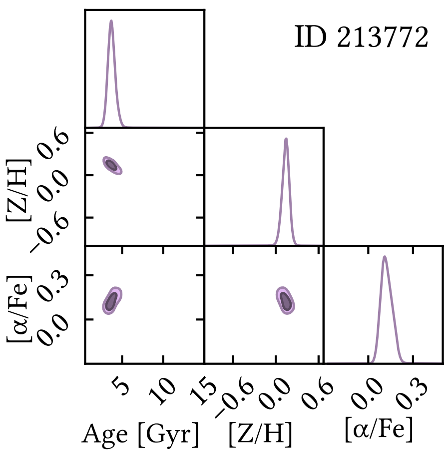
(see also e.g. Rose 1984, Longhetti+99, Moresco+18)

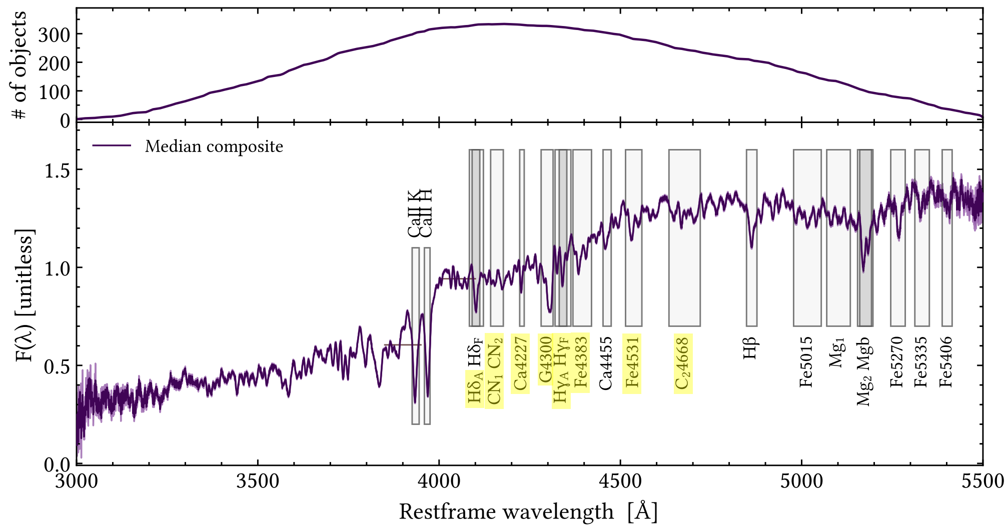
Selection of passive galaxies

1. Thomas, Maraston & Johannson 2011 (TMJ) SSP models $\rightarrow$ (*age*, [Z/H], [α/Fe])

2. Optimized set of spectral indices:

3. Bayesian approach **with uninformative priors** (e.g. no cosmological priors!)



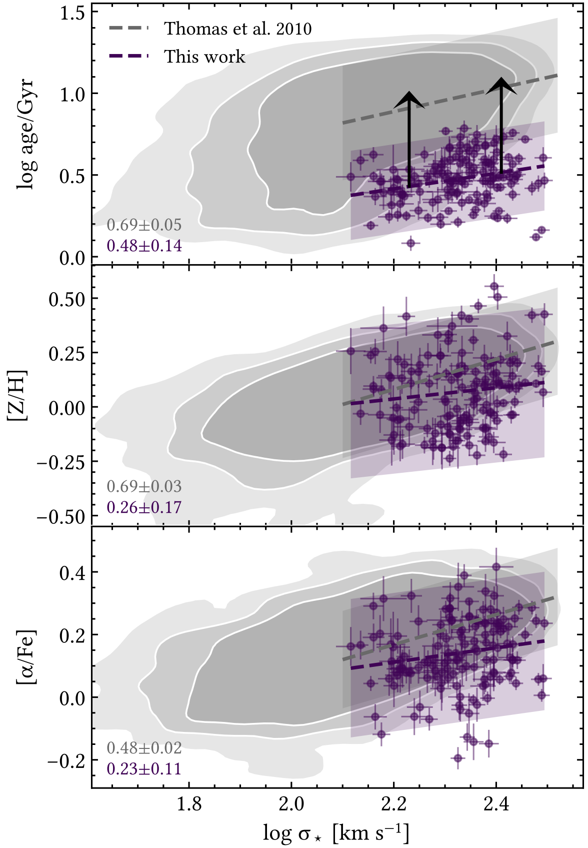


➢ Constraints for **140 individual** passive galaxies

$\langle \mathrm{S/N} \rangle \simeq 26\,\mathrm{per\ resol.\ element}$

$\sigma_{age} \simeq 0.4$ Gyr, $\quad \sigma_{[\mathrm{Z/H}],[\alpha/\mathrm{Fe}]} \simeq 0.05$ dex

Results – scaling relations



- Vertical offset of ~5.5 Gyr → very good agreement with the ageing of the Universe!

- Chemical scaling relations similar to the local ones and consistent with *mass-downsizing*

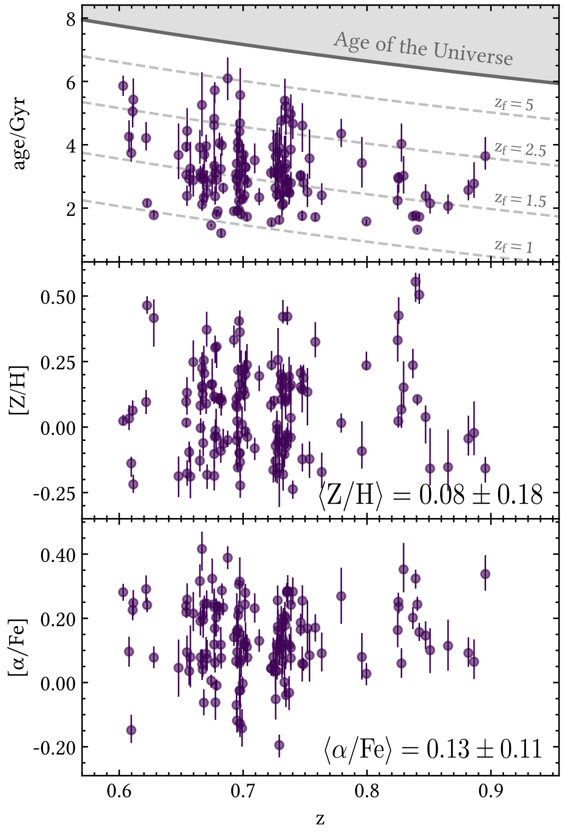
  (more massive galaxies are older, have higher [Z/H] and build up their mass over shorter Δt, e.g. Cowie et al. 1996, Cimatti et al. 2006)

y	$a \pm \mathrm{err}(a)$	$b \pm \mathrm{err}(b)$	rms
log *age*/Gyr	0.48 ± 0.14	-0.63 ± 0.33	0.14
[Z/H]	0.26 ± 0.17	-0.53 ± 0.40	0.17
$[\alpha/\mathrm{Fe}]$	0.23 ± 0.11	-0.39 ± 0.26	0.11

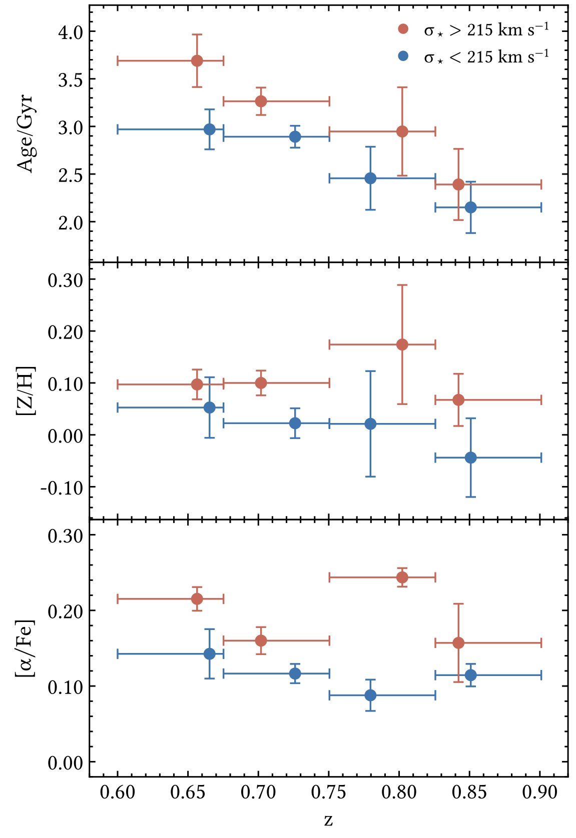
NOTE—Fits are of the form: $y = a \cdot \log \sigma_\star + b$.

(see also, e.g. Thomas+05, 10; Gallazzi+05, 14; Onodera+12, 15; Jørgensen+13; Choi+14; McDermid+15; Lonoce+15, 20; Scott+17, Siudek+17; Wu+18; Belli+19; Carnall+19; Estrada-Carpenter+19; Morishita+19; Tacchella+21; Beverage+21)

Results – age-redshift relations

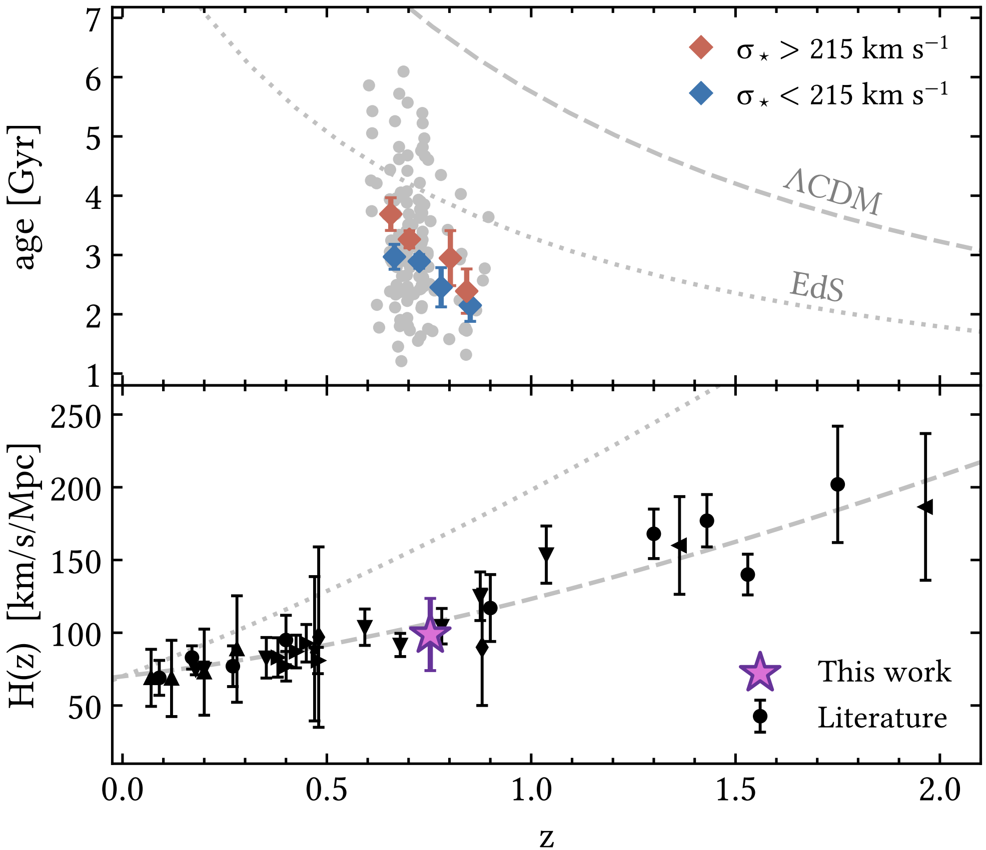


2 mass regimes (M_t~$10^{11} M_\odot$) & 4 z bins



- ➢ Confirms the downsizing scenario and the passive nature of this population
- ➢ Two **nearly parallel age-z relations** for both the higher σ ~ 230 km/s and the lower σ ~ 200 km/s mass regimes.

A new measurement of H(z)



- Four independent H(z) measurements, wmean in z and in σ_* to maximize S/N
- First H(z) estimate derived analysing single galaxies with Lick indices
  - poorly mapped redshift range
  - near to the transition phase
  - robust against SPS model choice (test with Vazdekis et al. 2015)

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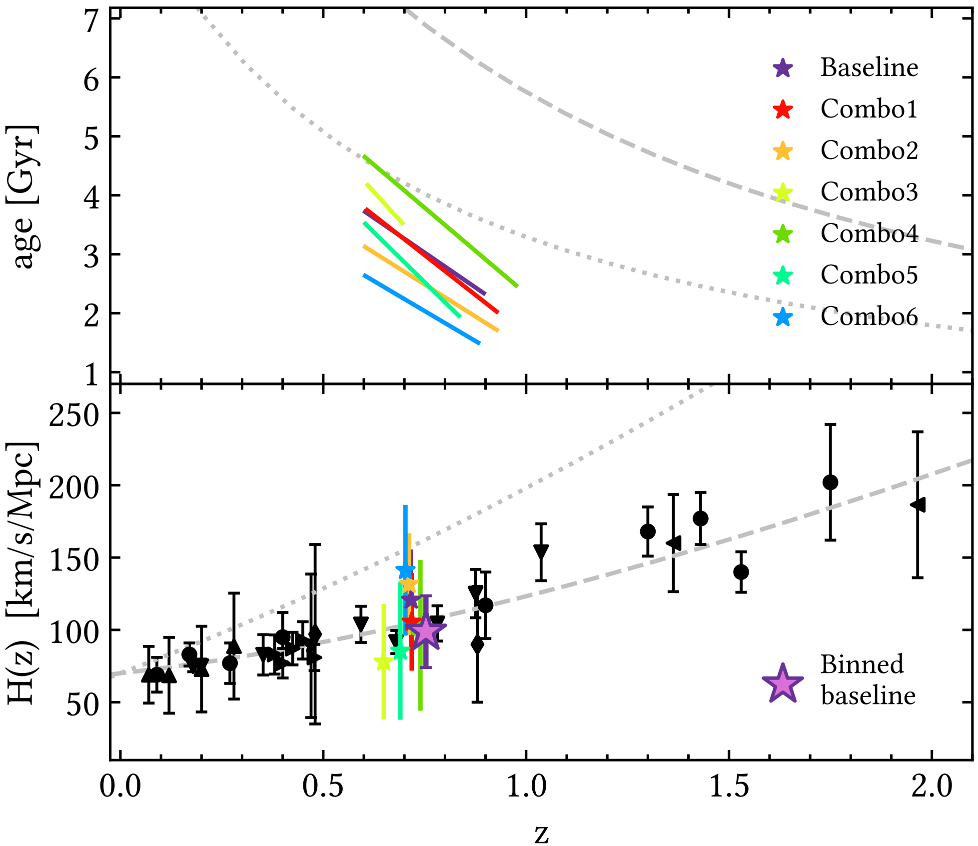

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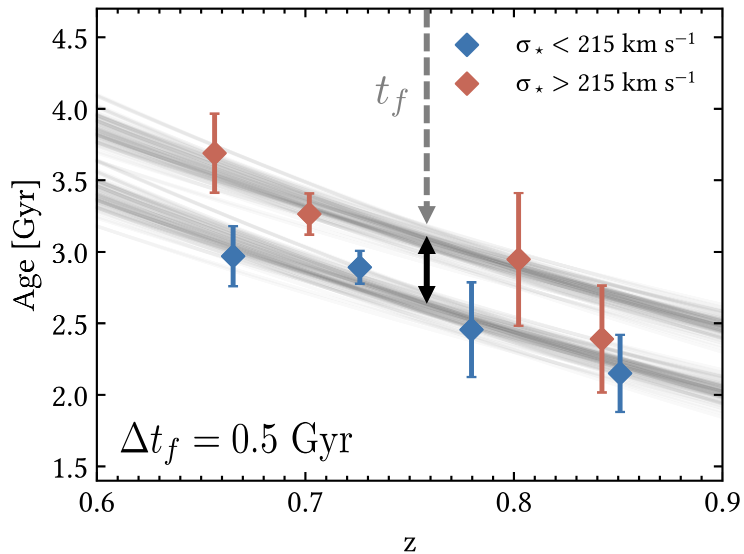
  - poorly mapped redshift range
  - near to the transition phase
  - robust against SPS model choice (test with Vazdekis et al. 2015)
- Systematic under/over-estimates of galaxy ages (±1Gyr) using different index sets
- Final H(z) measurement robust against (even very) different index sets (<0.2σ)!

Cosmological parameters constraints



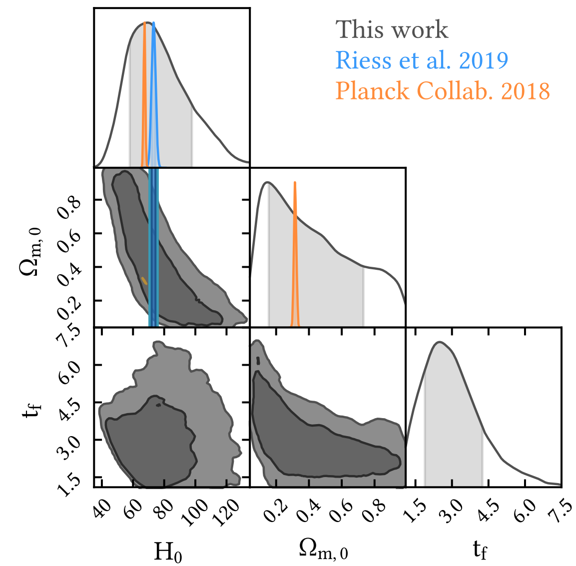


Table 1. Contraints for a fΛCDM model

Priors	H_0 [km s^{-1} Mpc^{-1}]	Ω_m	t_f [Gyr]
Flat	74^{+23}_{-16}	$0.38^{+0.36}_{-0.23}$	$2.9^{+1.4}_{-1.0}$
$\Omega_m \sim \mathcal{N}(Planck18)$	79^{+14}_{-11}	$0.31^{+0.01}_{-0.01}$	$2.8^{+0.9}_{-0.9}$

- Promising, but high degeneracies due to small redshift leverage.
- Not straightforward to combine different datasets (e.g. different methods to compute ages, index sets, …).

Summary

1. **Selected 350 massive and passive galaxies from LEGA-C DR2 at $0.6 < z < 1$**
   - High R~3500, and ⟨S/N⟩ ≃ 18 and minimal contamination (confirmed from SED-derived properties, composite spectrum, observed indices e.g. H/K).
2. **The H/K ratio is as promising diagnostic to detect star-forming contaminants.**
3. **Derived SSP (*age*, [Z/H], [α/Fe]) for 140 passive galaxies without assuming cosmological priors.**
   - Extensive study of several index combinations to select the optimal one. Results consistent with a passively evolving population.
4. **Measured positive (*age*, [Z/H], [α/Fe]) scaling relations as a function of stellar velocity dispersion.**
   - Slopes in agreement with local results and intermediate redshift results based on composite spectra analysis.

➢ **Cosmological studies** (Borghi et al, 2021b):

- **A new direct H(z=0.7) measurement**
- Hubble constant constraint assuming a fΛCDM model

Additional refs. for the CC method:

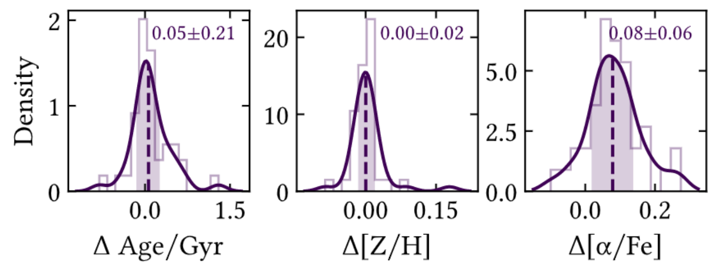
- Jimenez, R. & Loeb, A.(2002) – CCs method definition
- Moresco, M., et al. (2012a&b, 2016a&b, 2018, 2020) – H(z) measurements and cosmology constraints
- Haridasu, B. S., et al. (2018); Gómez-Valent, A. & Amendola, L. H (2018) – H0 from CCs
- Vagnozzi, S., et al. (2020) – cosmo geometry

Some of the analyzed index combinations

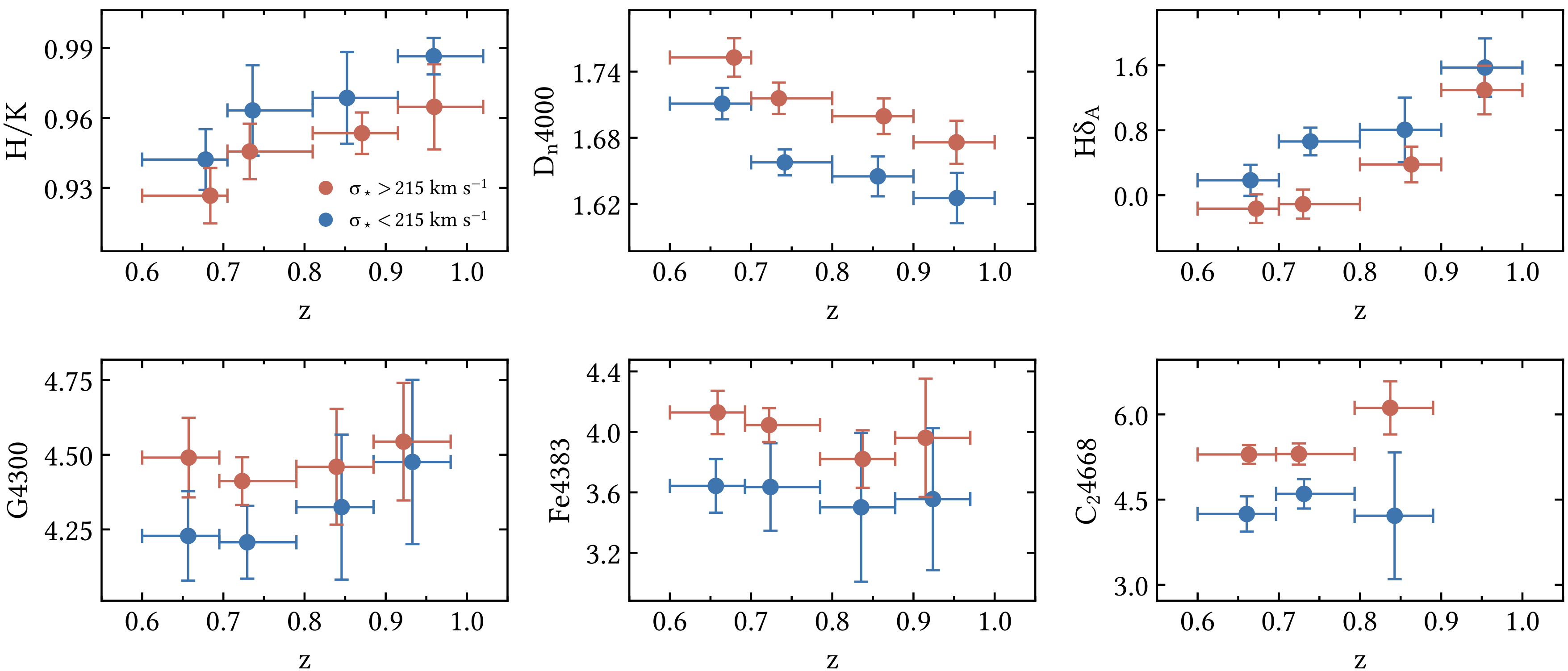
Combo ID	$H\delta_A$	$H\delta_F$	CN_1	CN_2	Ca4227	G4300	$H\gamma_A$	$H\gamma_F$	Fe4383	Ca4455	Fe4531	$C_2$4668	$H\beta$	Fe5015	Mg_1	Mg_2	Mg b	Fe5270	Fe5335	Fe5406
baseline	■		■	■	■	■	■	■	■		■	■								
1	■				■	■	■	■	■		■	■								
2	■			■	■	■	■		■		■	■								
3	■		■	■	■	■	■	■	■		■	■					■			
4	■				■	■	■	■	■		■	■			■	■	■	■	■	■
5				■	■	■		■	■											
6				■	■	■			■	■		■								

Combo ID	N (in common)	Δage (σ)	Δ[Z/H] (σ)	$\Delta[\alpha/\text{Fe}]$ (σ)
baseline	140 (140)	–	–	–
1	105 (95)	0.04 (0.06)	-0.04 (0.42)	-0.05 (0.64)
2	131 (115)	-0.42 (0.63)	0.03 (0.33)	-0.06 (0.76)
3	39 (39)	0.05 (0.08)	0.00 (0.02)	0.08 (0.92)
4	11 (8)	0.25 (0.36)	-0.01 (0.09)	0.09 (1.15)
5	133 (98)	-0.17 (0.25)	0.01 (0.08)	-0.13 (1.61)
6	119 (102)	-1.11 (1.54)	0.11 (0.95)	-0.06 (0.69)

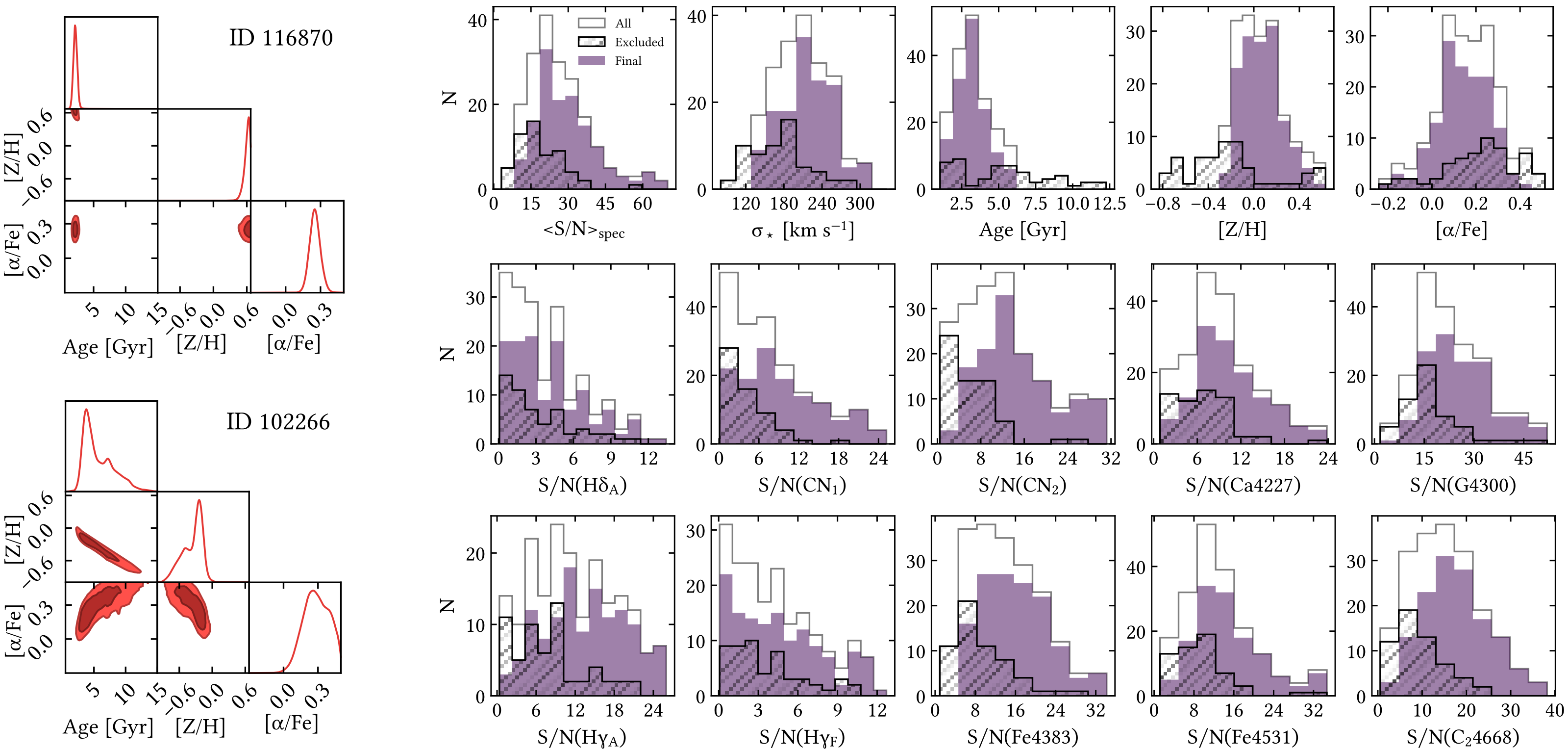
e.g.
Baseline + the alpha-sensitive Mg index



Observed index-sigma-z trends



Study of the convergence



age-z for different cosmologies