Carlos Alonso Álvarez, PhD student (SISSA, Italy)

Cosmography through the ages of low-redshift ETGs

- **Supervisors:**
- Prof. Andrea Lapi
- Prof. Alessandro Bressan
- Dr. Marcos Muñiz Cueli
- Dr. Lumen Boco

Collaborators:

Dr. Alexandre Vazdekis (TRF)

Dr. Nicola Borghi (BLQ)

Dr. Michele Moresco (BLQ)

Dr. Daniel Thomas (PWA)

Dr. Claudia Maraston (PWA)

Dr. Christy Tremonti (MSN)

SISSA

OVERVIEW

- Cosmic Chronometers
- Methodological aspects
- Cosmographic results
- Upcoming work

OVERVIEW

- Cosmic Chronometers
- Methodological aspects
- Cosmographic results
- Upcoming work

ETGs

Cosmic Chronometers

INDEPENDENT MEASUREMENT OF $H(z)$

Cosmic Chronometers

INDEPENDENT MEASUREMENT OF $H(z)$

→ **Astrophysical objects whose age -and redshift- can be measured at different moments in cosmic history**

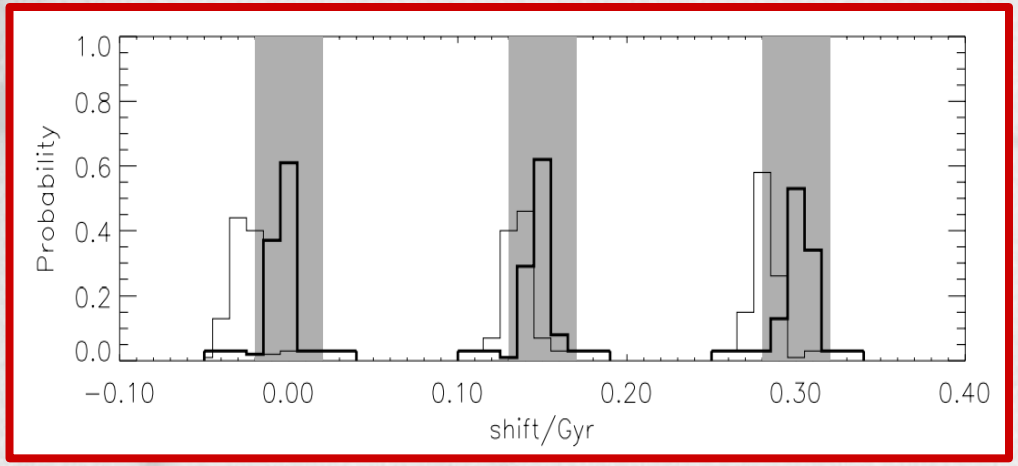
Cosmic Chronometers

EARLY TYPE GALAXIES

Cosmic Chronometers

EARLY TYPE GALAXIES

→ Jiménez and Loeb 2002: "*age difference between two ensembles of passively-evolving galaxies at somewhat different redshifts*"

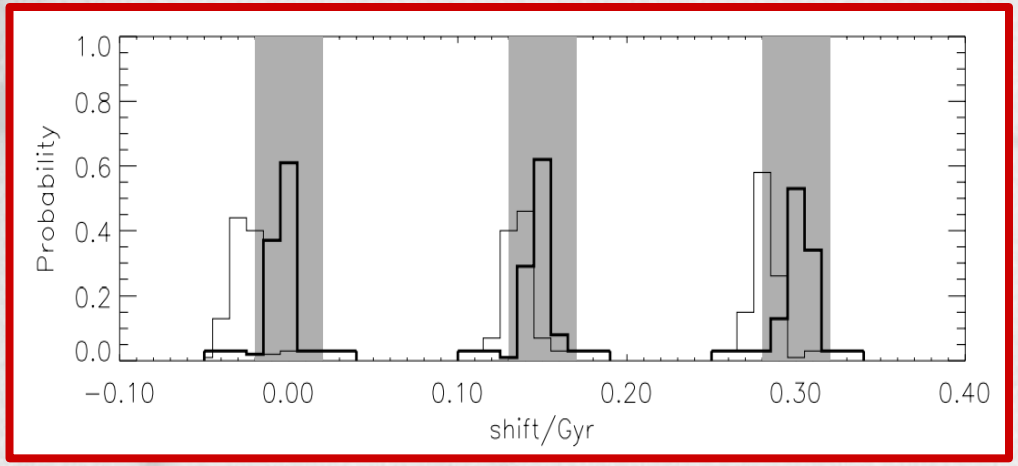


Jiménez and Loeb 2002, Fig. 4

Cosmic Chronometers

$$H(z) = -\frac{\dot{z}}{1+z} \sim -\frac{1}{1+z}\frac{\Delta z}{\Delta t}$$

→ Jiménez and Loeb 2002: "*age difference between two ensembles of passively-evolving galaxies at somewhat different redshifts*"

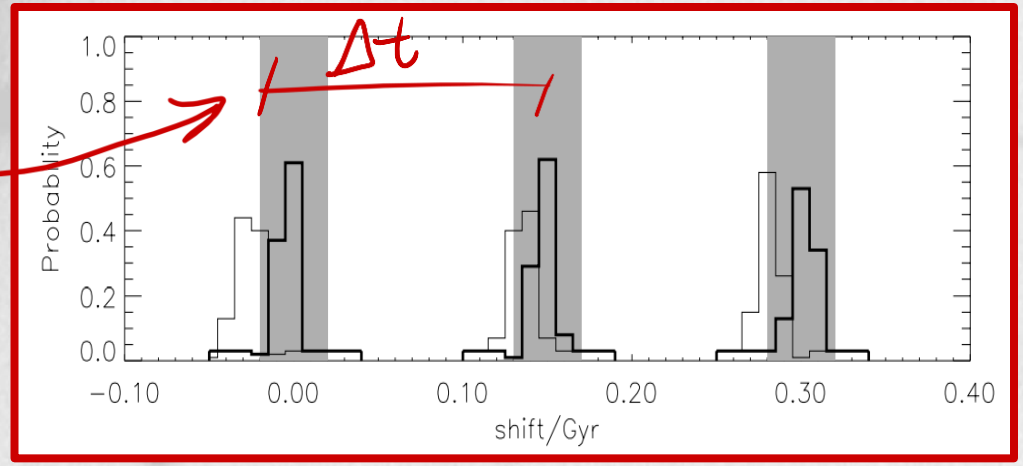


Jiménez and Loeb 2002, Fig. 4

Cosmic Chronometers

$$H(z) = -\frac{\dot{z}}{1+z} \sim -\frac{1}{1+z}\frac{\Delta z}{\Delta t}$$

→ **Jiménez and Loeb 2002: "*age difference between two ensembles of passively-evolving galaxies at somewhat different redshifts*"**

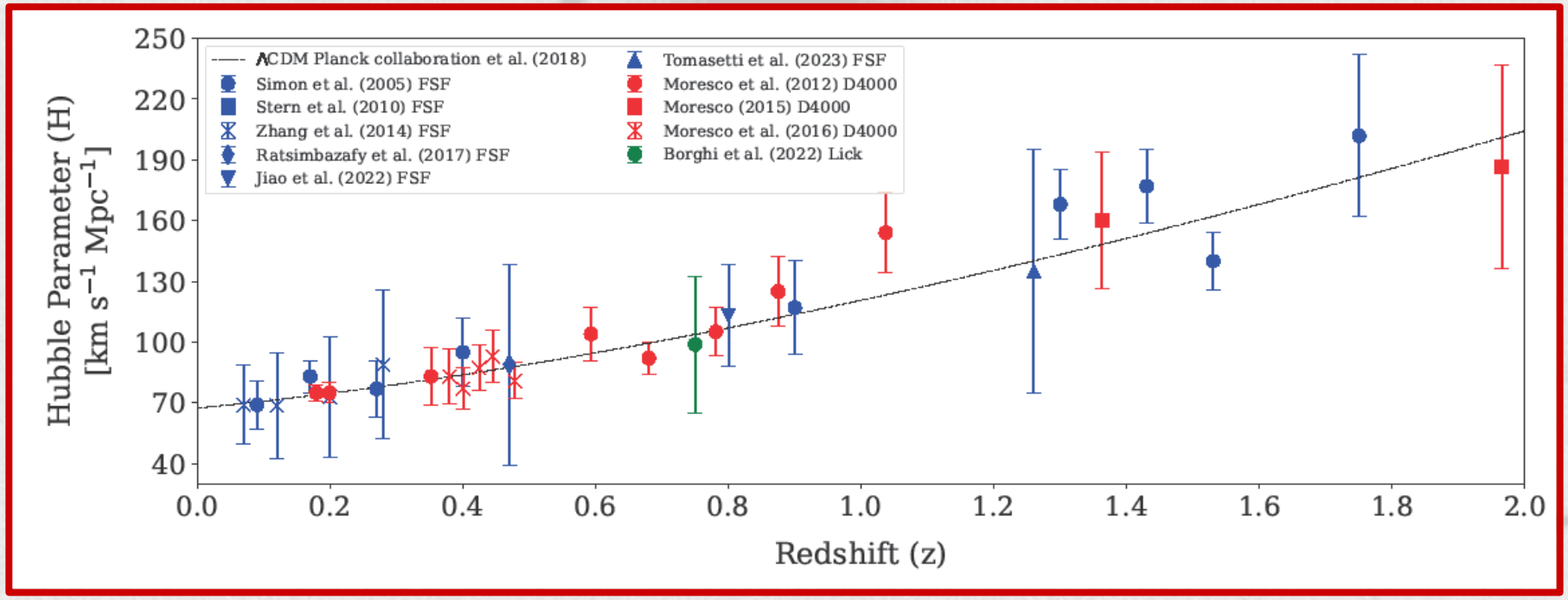


Jiménez and Loeb 2002, Fig. 4

Cosmic Chronometers

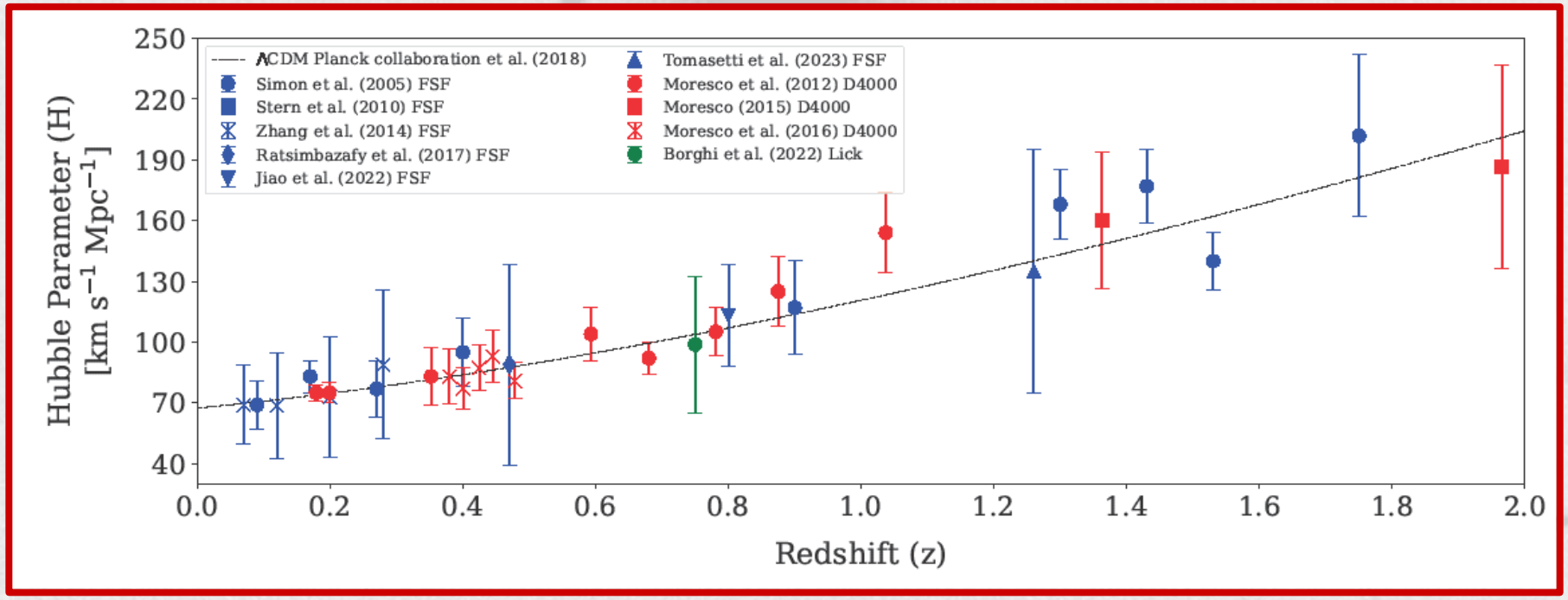
$$H(z) = -\frac{\dot{z}}{1+z} \sim -\frac{1}{1+z}\frac{\Delta z}{\Delta t}$$

→ **Jiménez and Loeb 2002: "*age difference between two ensembles of passively-evolving galaxies at somewhat different redshifts*"**



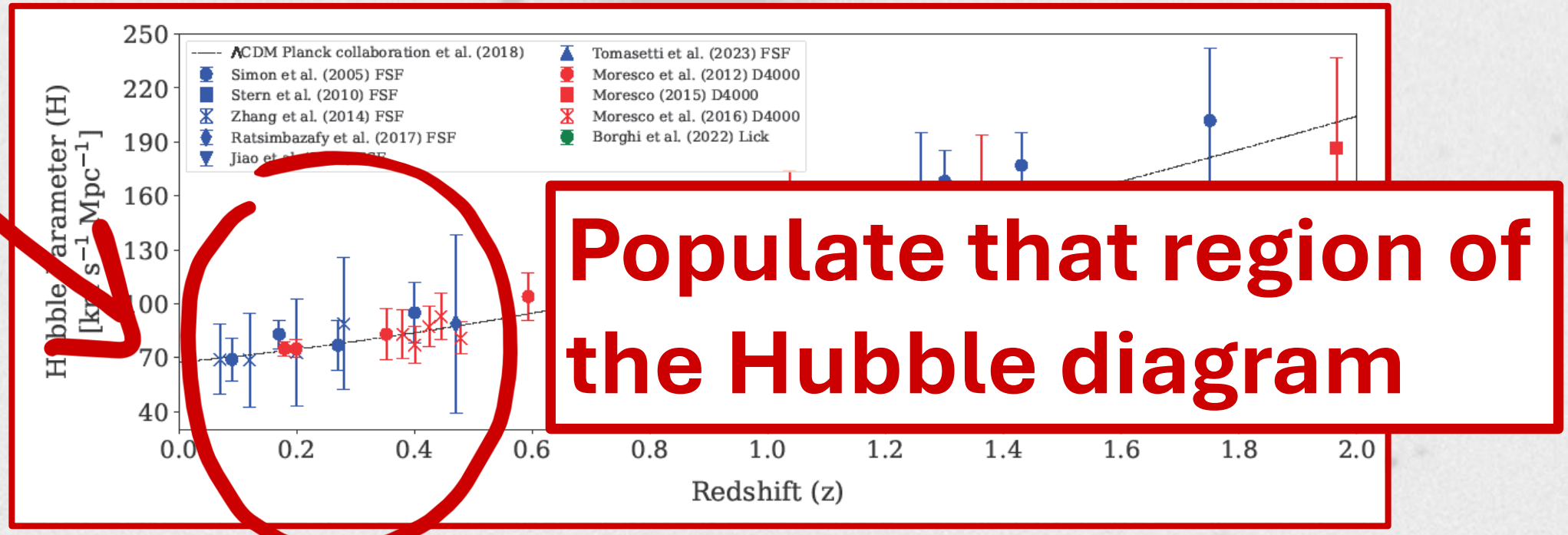
Cosmic Chronometers

→ **Our aim was...**



Cosmic Chronometers

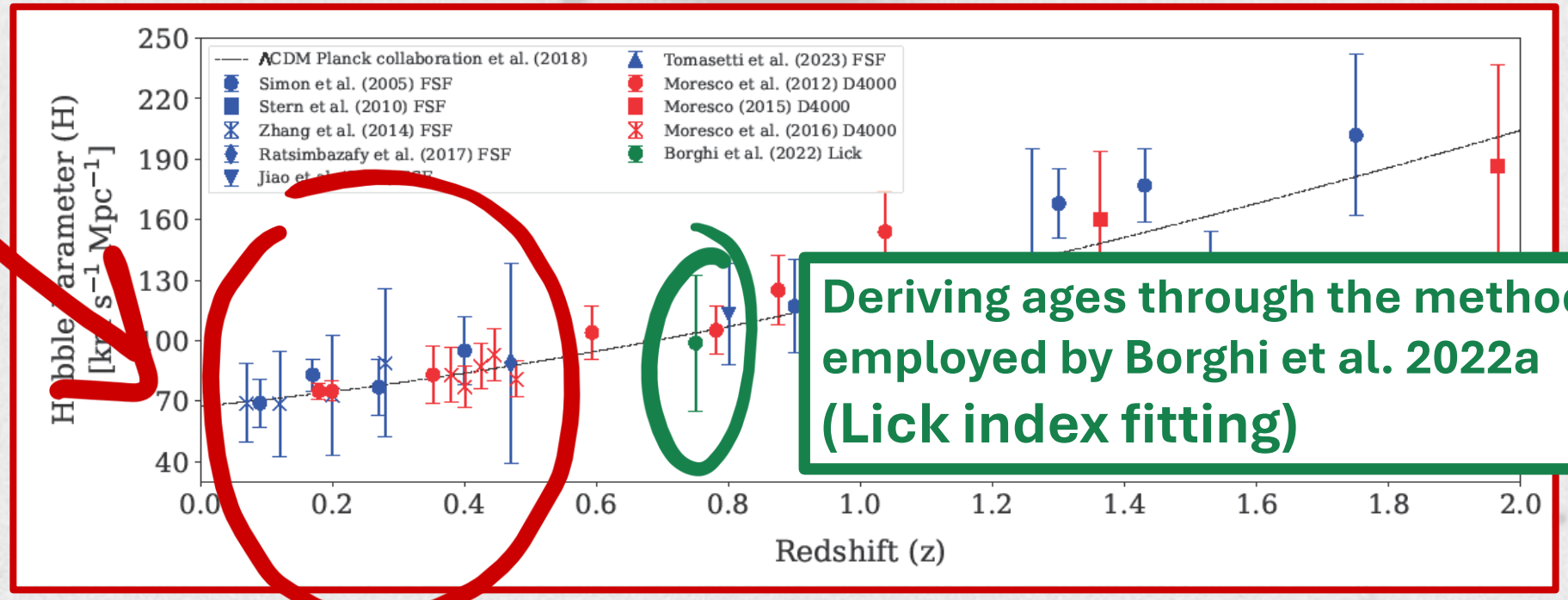
→ Our aim was...



Populate that region of the Hubble diagram

Cosmic Chronometers

→ Our aim was...



Cosmic Chronometers

Our approach

$$H(z) = H_0 \sum_{i=0}^{k} \left(\mathcal{H}_0^i \cdot y^i\right) + \mathcal{O}\left(y^{k+1}\right)$$

$$y = \frac{z}{1+z} \qquad \mathcal{H}_0^0 = 1 \qquad \mathcal{H}_0^1 = 1 + q_0 \qquad \mathcal{H}_0^2 = 1 + \frac{j_0}{2} + q_0 - \frac{q_0^2}{2}$$

$$t(z) = t_0 - \int_0^z \frac{1}{1+z'} \frac{\mathrm{d}z'}{H(z')}$$

Cosmic Chronometers

$$H(z) = H_0 \sum_{i=0}^{k} \left(\mathcal{H}_0^i \cdot y^i\right) \; (k+1)$$

$z \lesssim 0.6$ (!!!)

$$y = \frac{z}{1+z} \qquad \mathcal{H}_0^0 = 1 \qquad \mathcal{H}_0^1 = 1 + q_0 \qquad \mathcal{H}_0^2 = 1 + \frac{}{2}$$

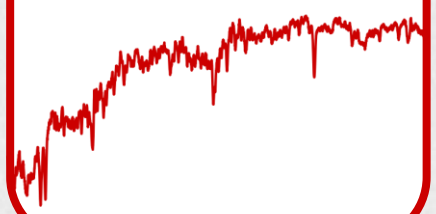
$$t(z) = t_0 - \int_0^z \frac{1}{1+z'} \frac{\mathrm{d}z'}{H(z')}$$

OVERVIEW

- Cosmic Chronometers
- Methodological aspects
- Cosmographic results
- Upcoming work

Methodology

SPECTRA



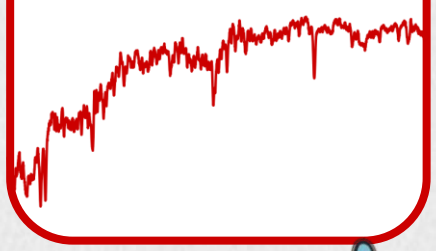
Age / t

[Z/H]

[α/Fe]

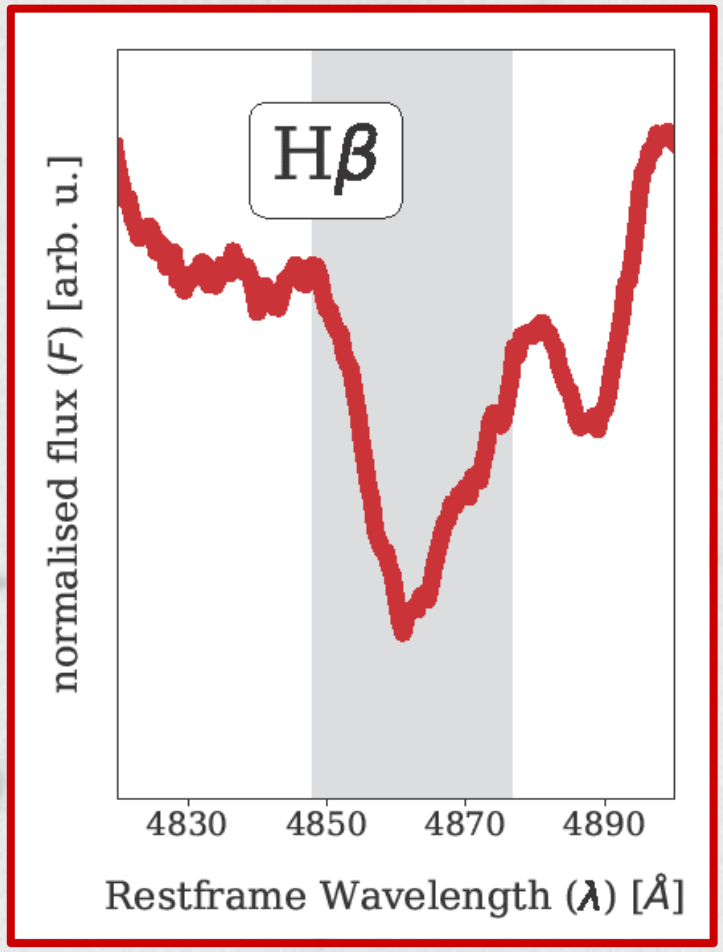
Methodology

SPECTRA



pyLick

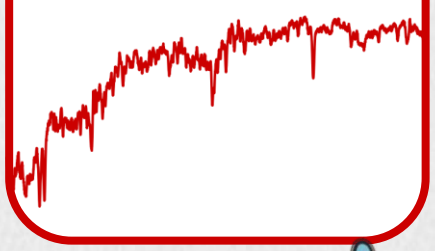
Borghi et al. (2022a)



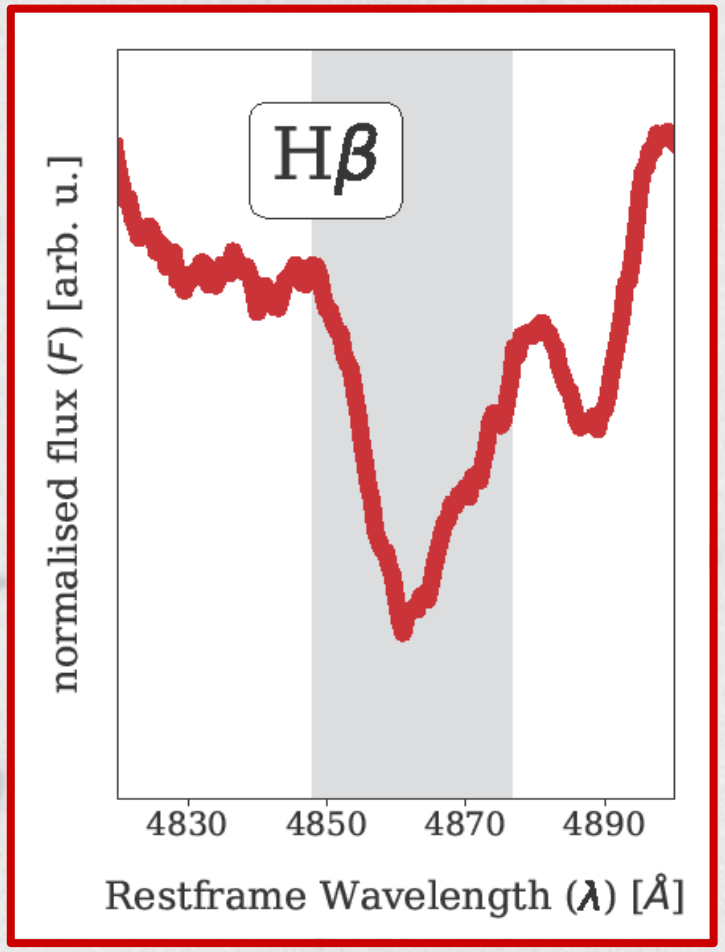
Age / t
[Z/H]
[α/Fe]

Methodology

SPECTRA



pylick



SPS models

Age / t
[Z/H]
[α/Fe]

$I_i(t, [\mathrm{Z/H}], [\alpha/\mathrm{Fe}])$

Thomas et al. 2011

TMJ

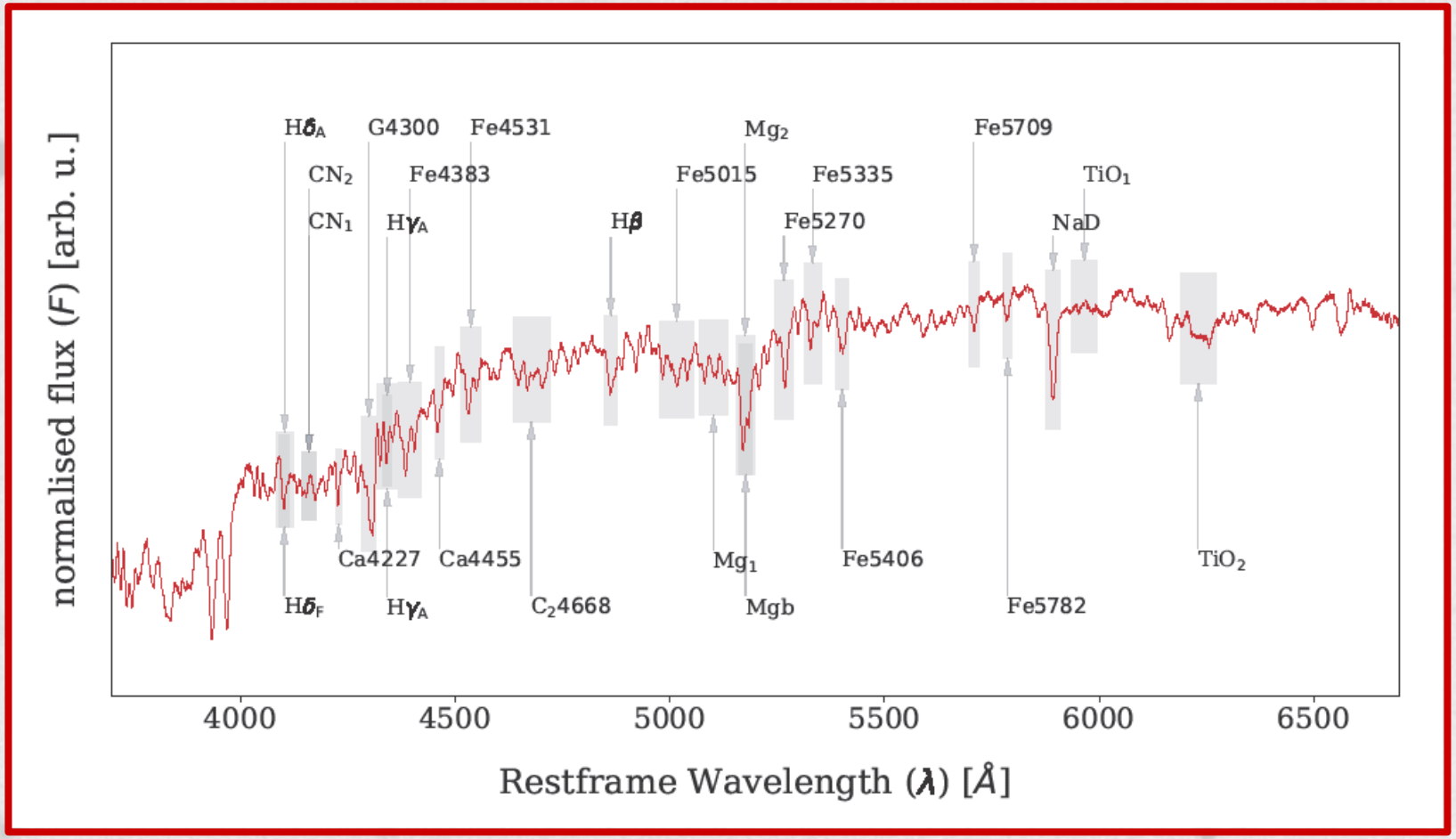
Methodology

LICK INDICES

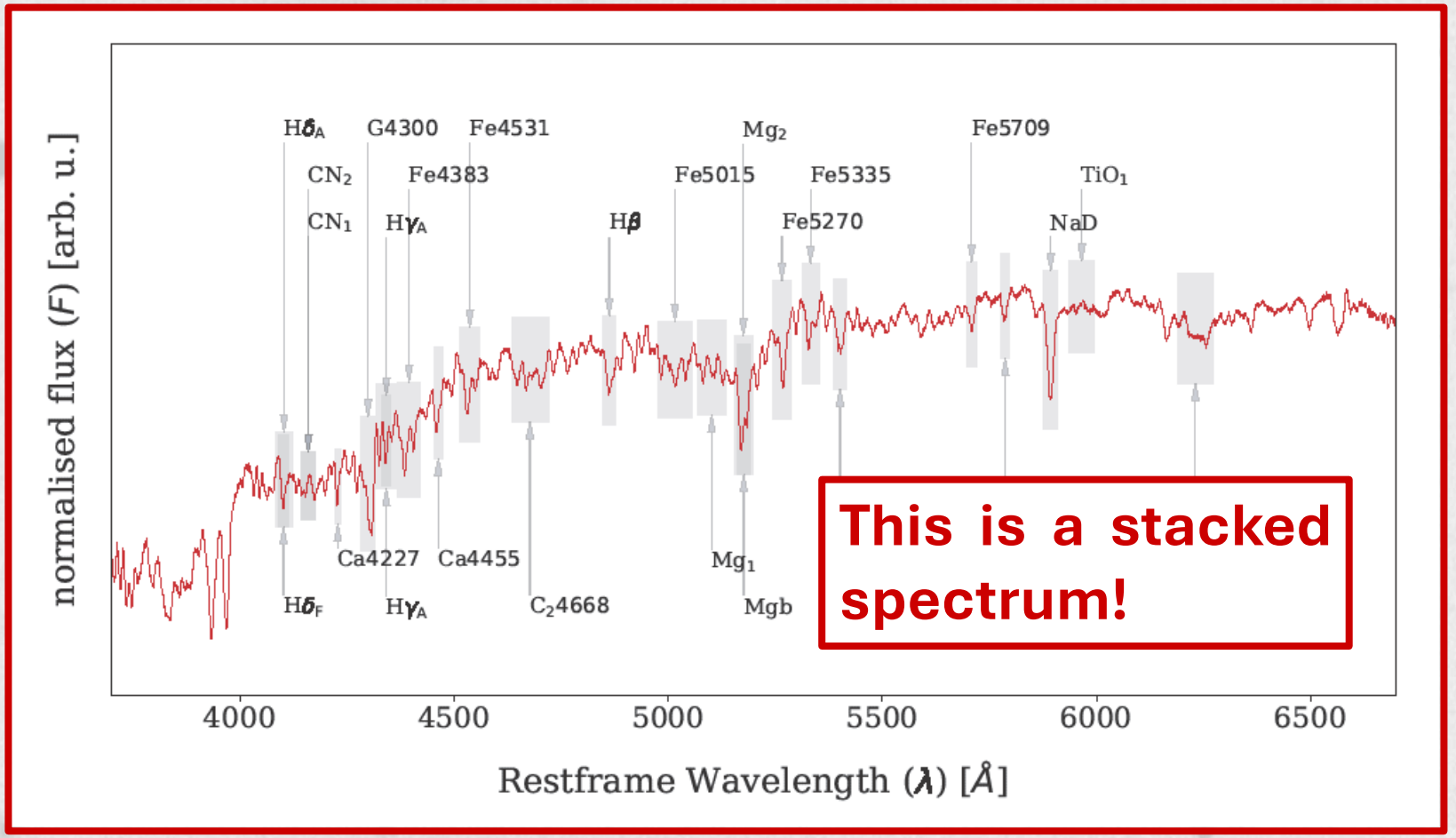
Absoprtion features

+ 20 “Metalic”

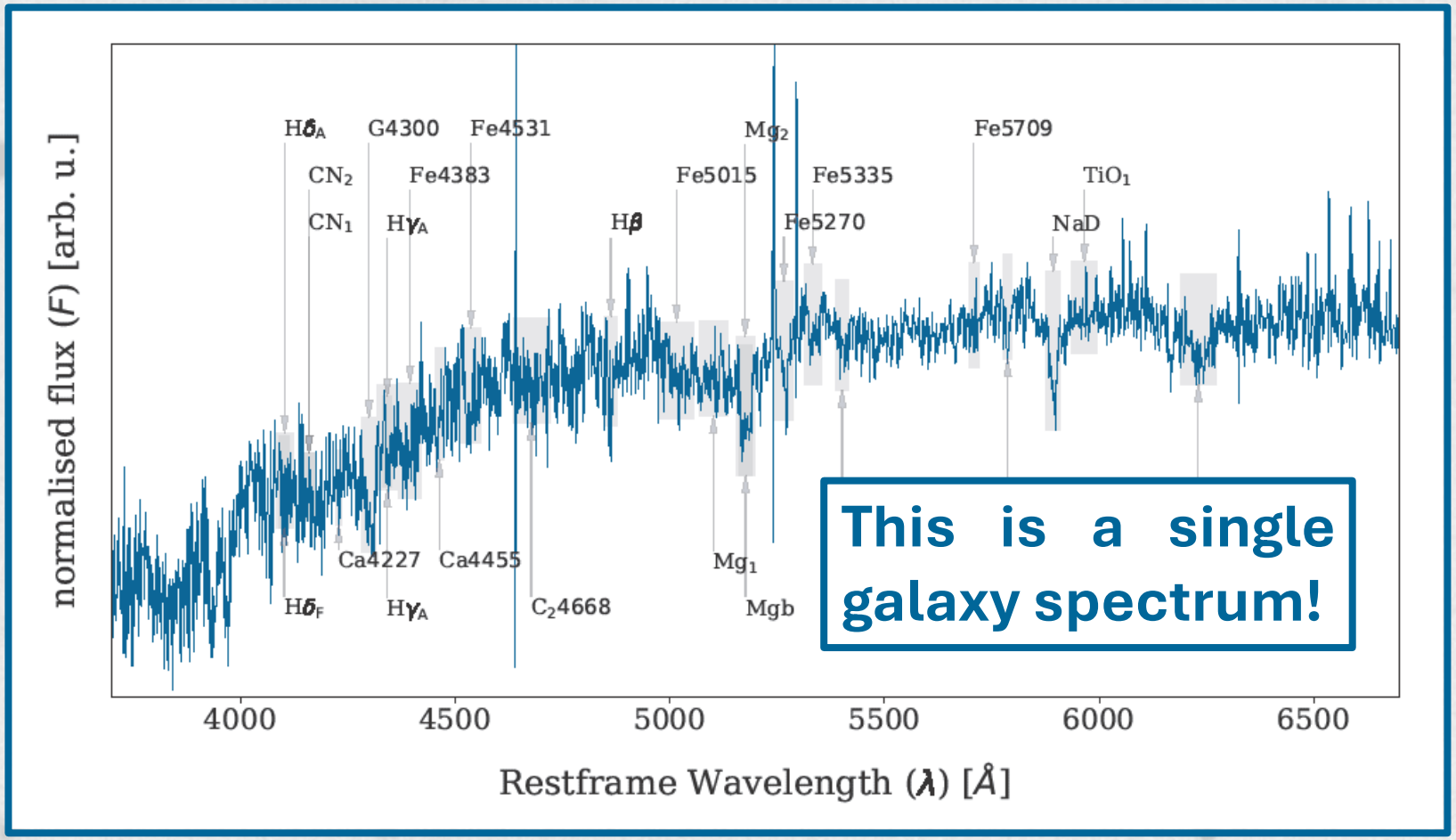
+ 5 Balmer



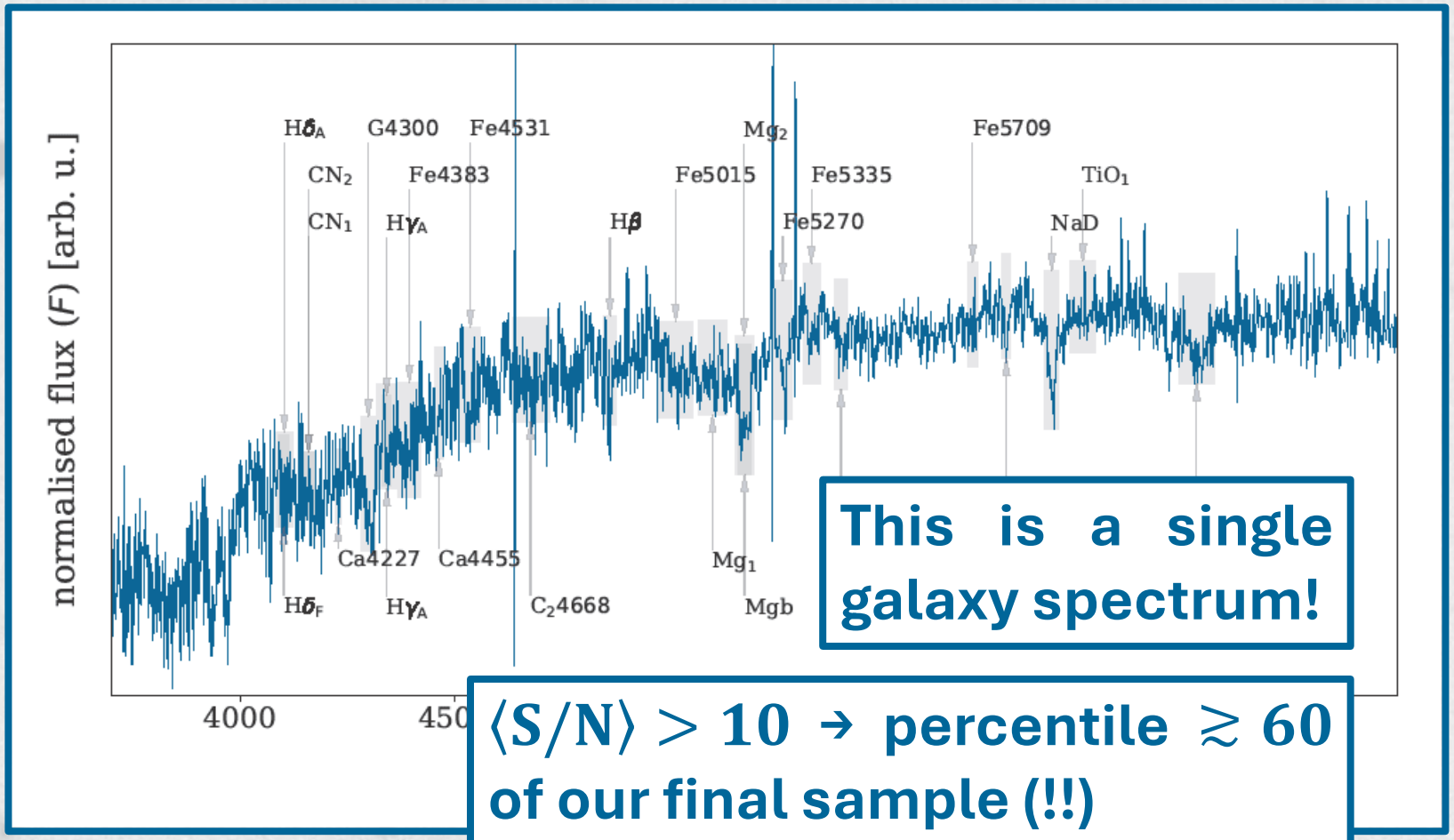
Methodology



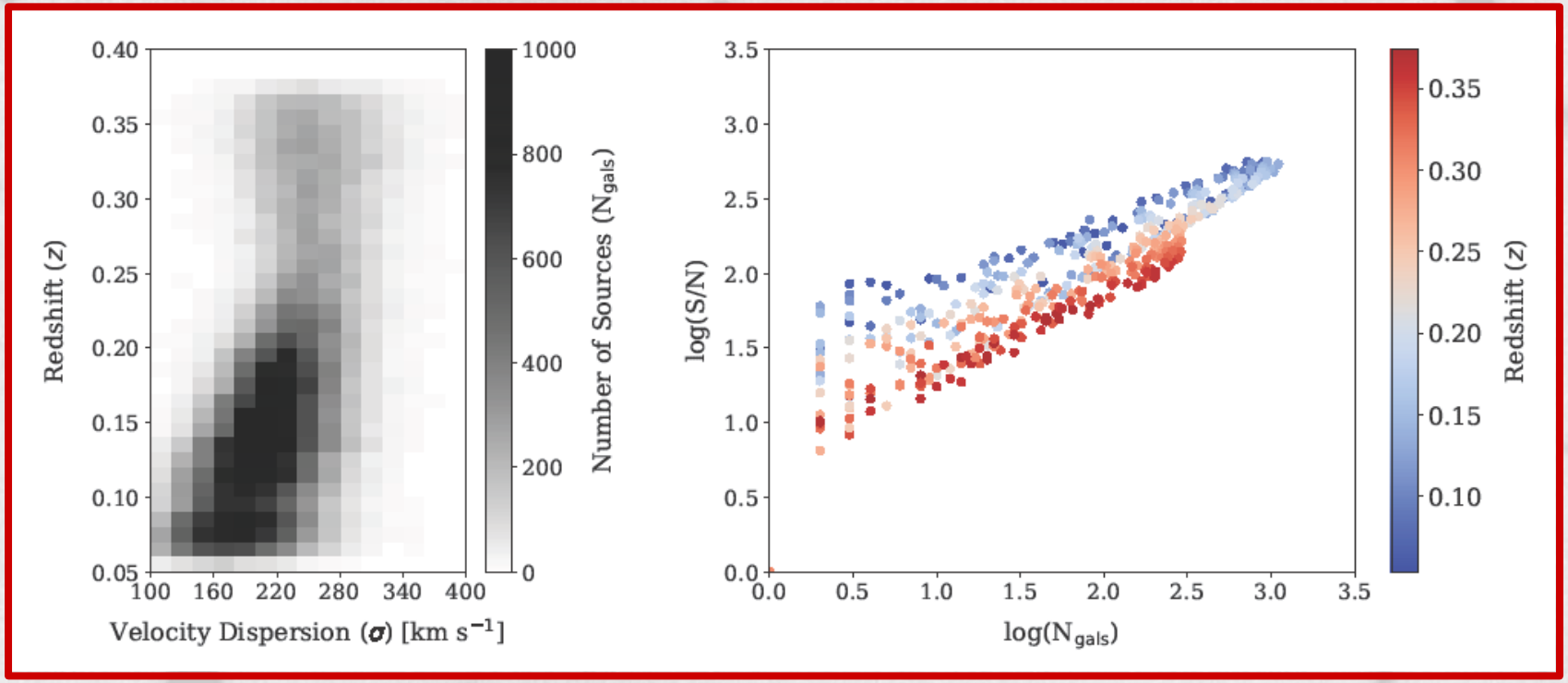
Methodology



Methodology



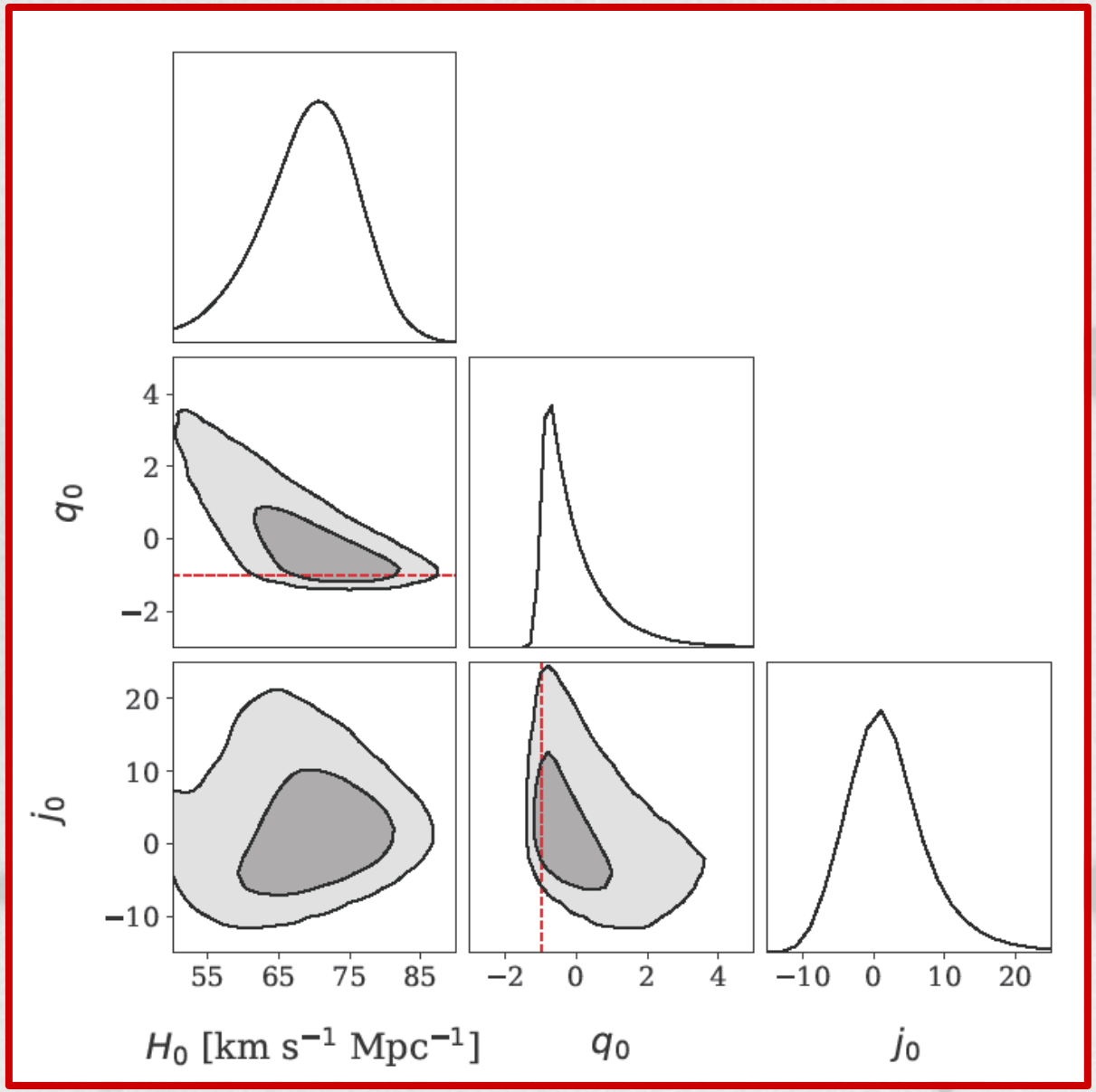
Methodology



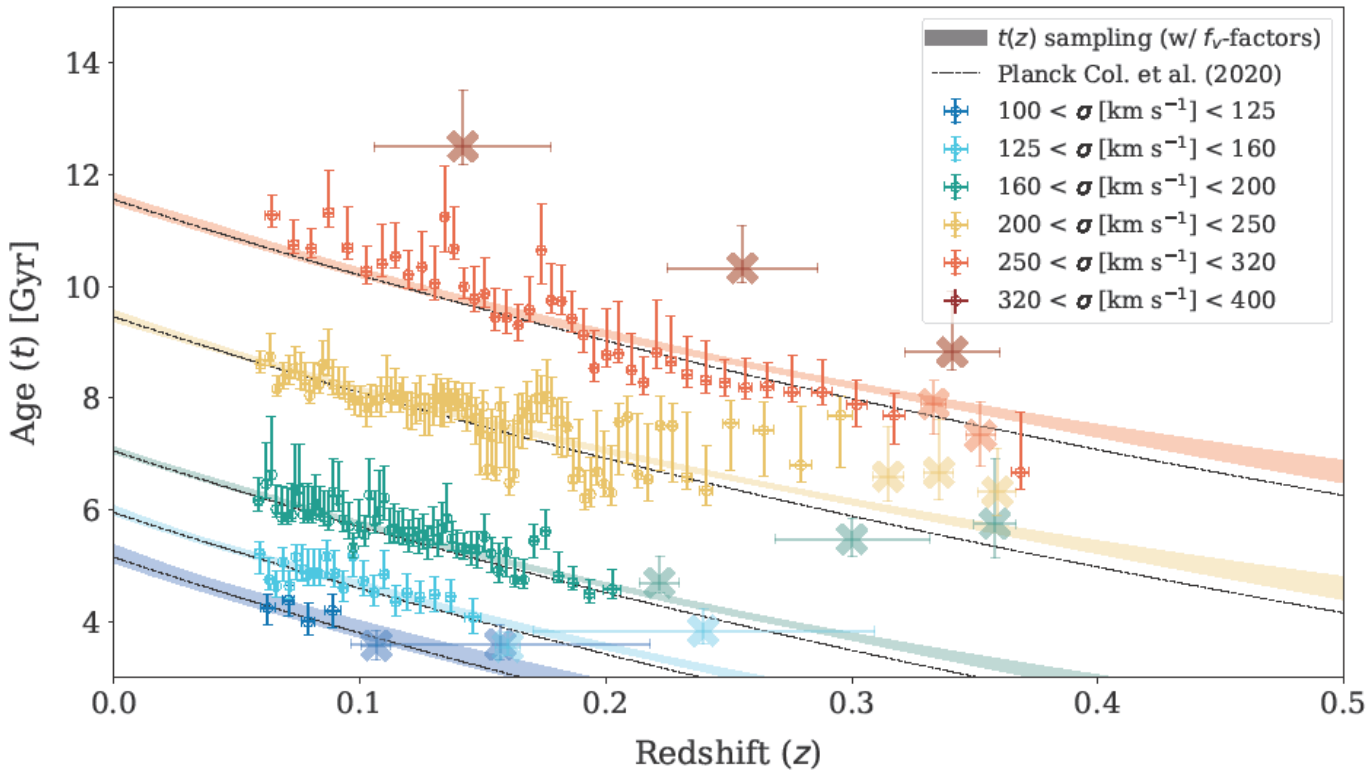
→A S/N–dependent stacking enables avoiding the arbitrary selection of a binning rule later

OVERVIEW

- Cosmic Chronometers
- Methodological aspects
- Cosmographic results
- Upcoming work

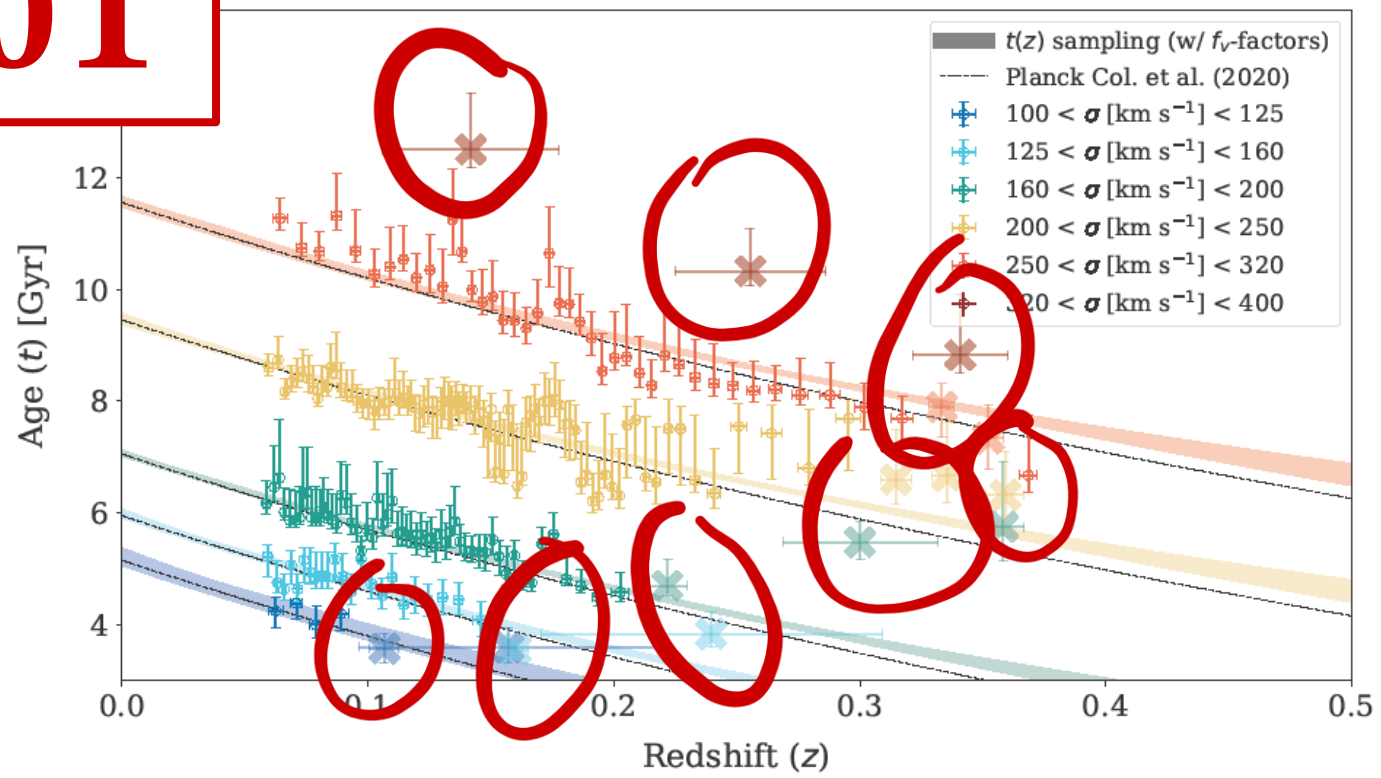


Cosmography



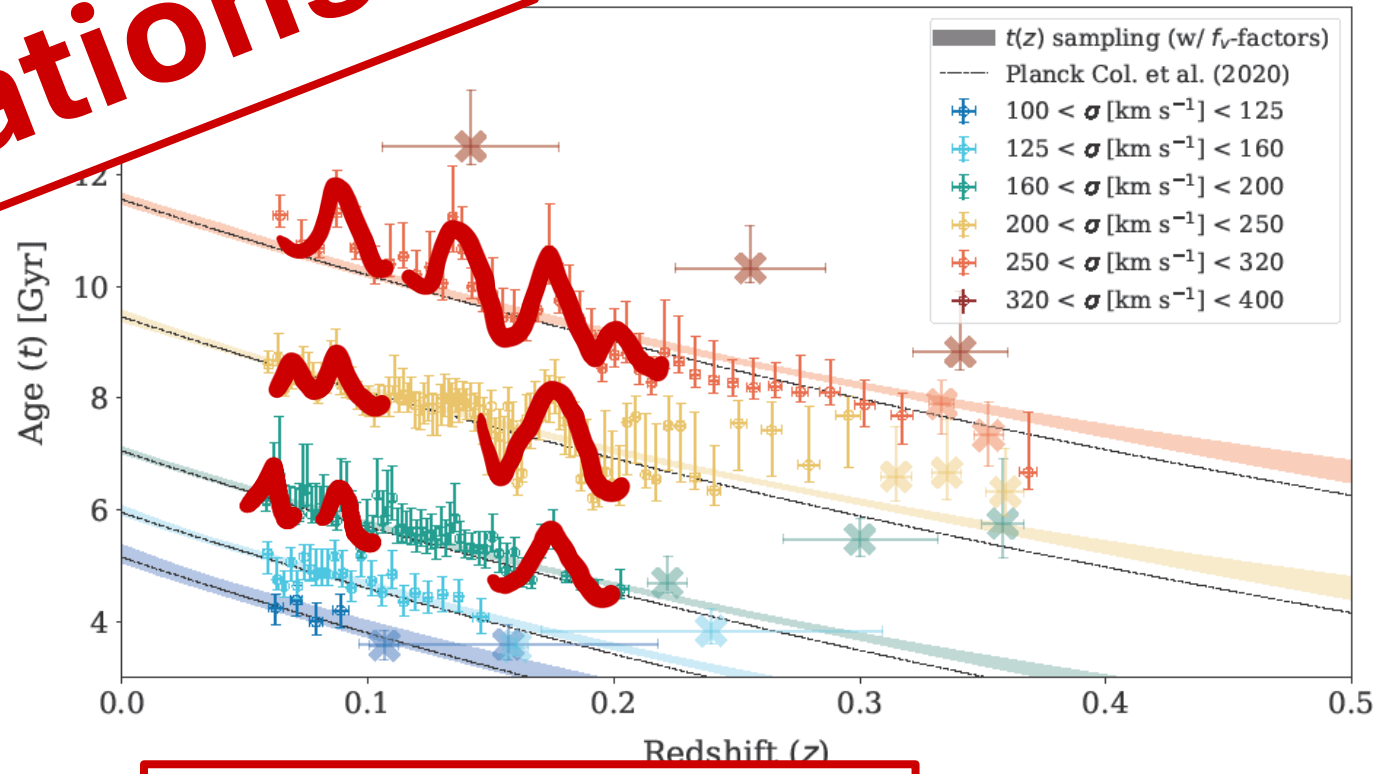
Cosmography

$$\sigma_z < 0.01$$



Cosmography

$t(z)$ oscillations?

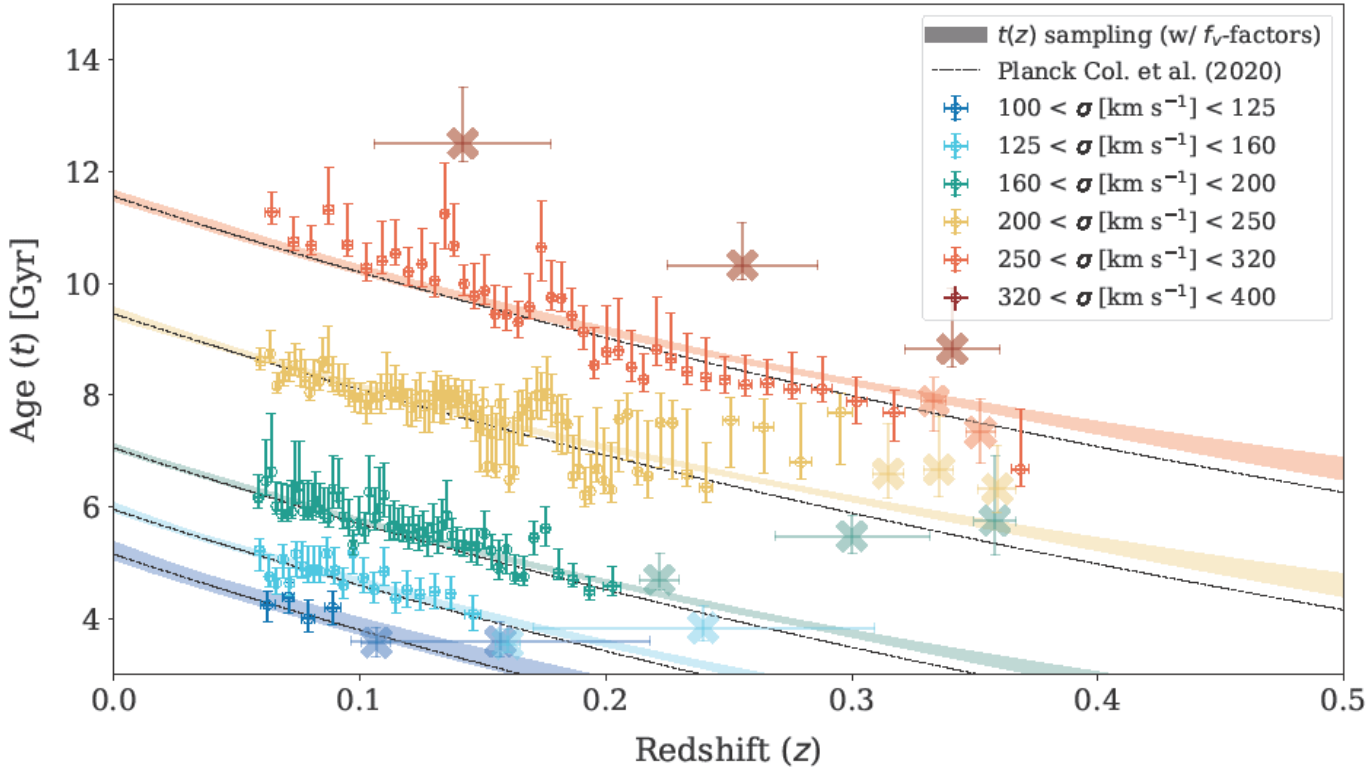


To be addressed later...

Cosmography

$$H(z) = H_0 \sum_{i=0}^{2} \left(\mathcal{H}_0^i \cdot y^i\right) + \mathcal{O}(y^3)$$

$$t_\sigma(z) = t_{0,\sigma} - \int_0^z \frac{1}{1+z'} \frac{\mathrm{d}z'}{H(z')}$$

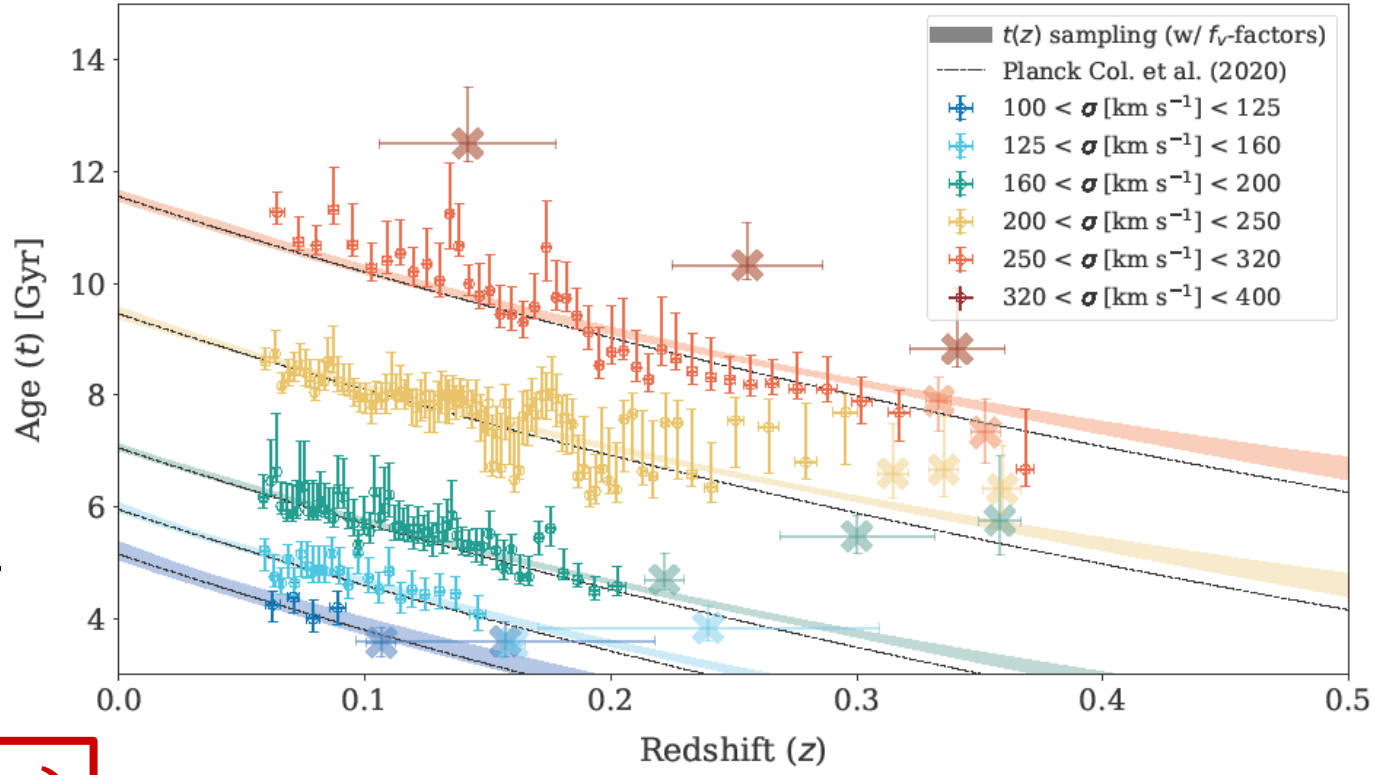


Cosmography

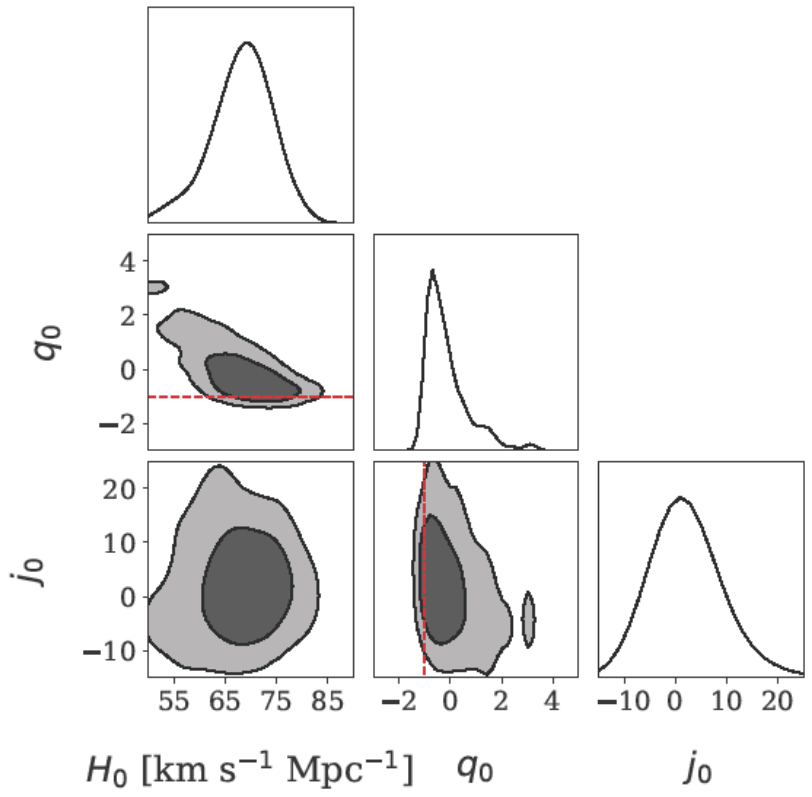
$$H(z) = H_0 \sum_{i=0}^{2} \left(\mathcal{H}_0^i \cdot y^i\right) + \mathcal{O}(y^3)$$

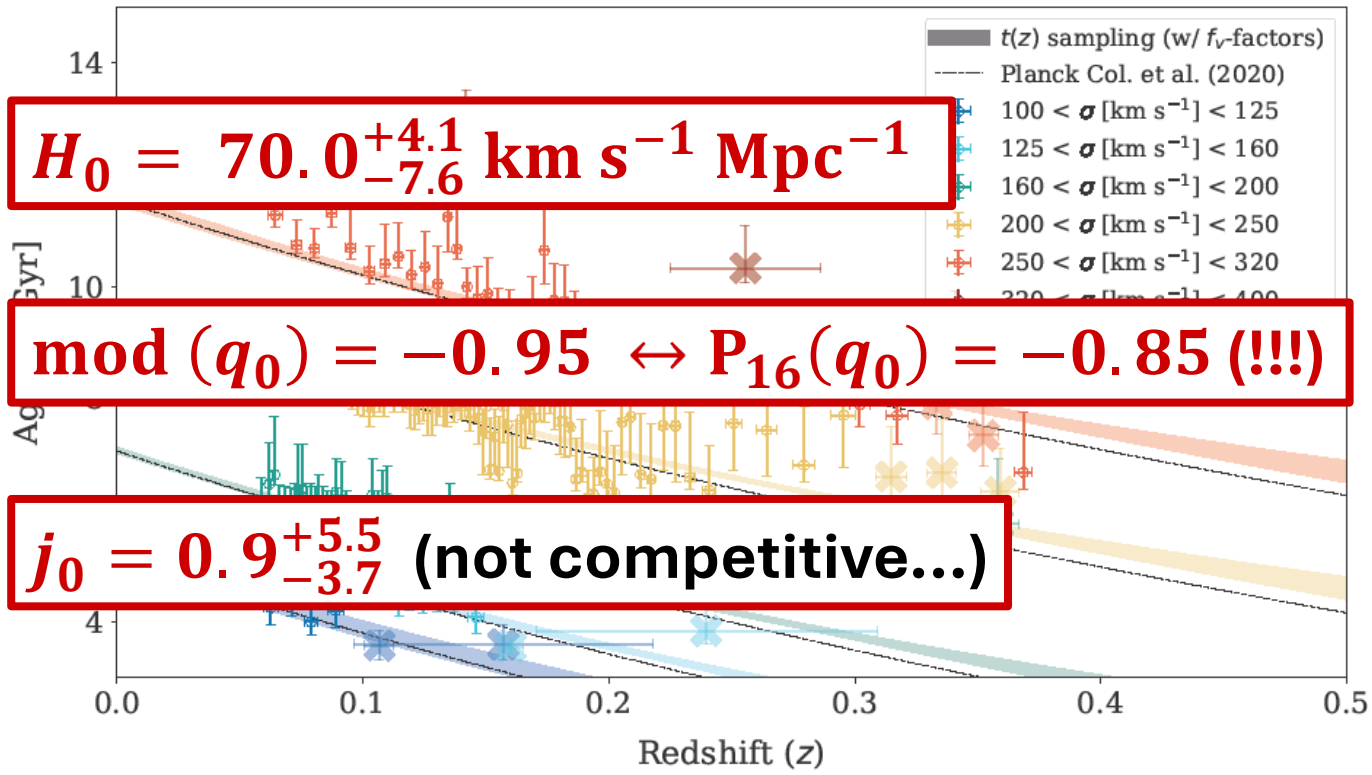
$$t_\sigma(z) = t_{0,\sigma} - \int_0^z \frac{1}{1+z'} \frac{\mathrm{d}z'}{H(z')}$$

$$t\left(z; t_{0,\sigma}, H_0, q_0, j_0\right)$$



Cosmography





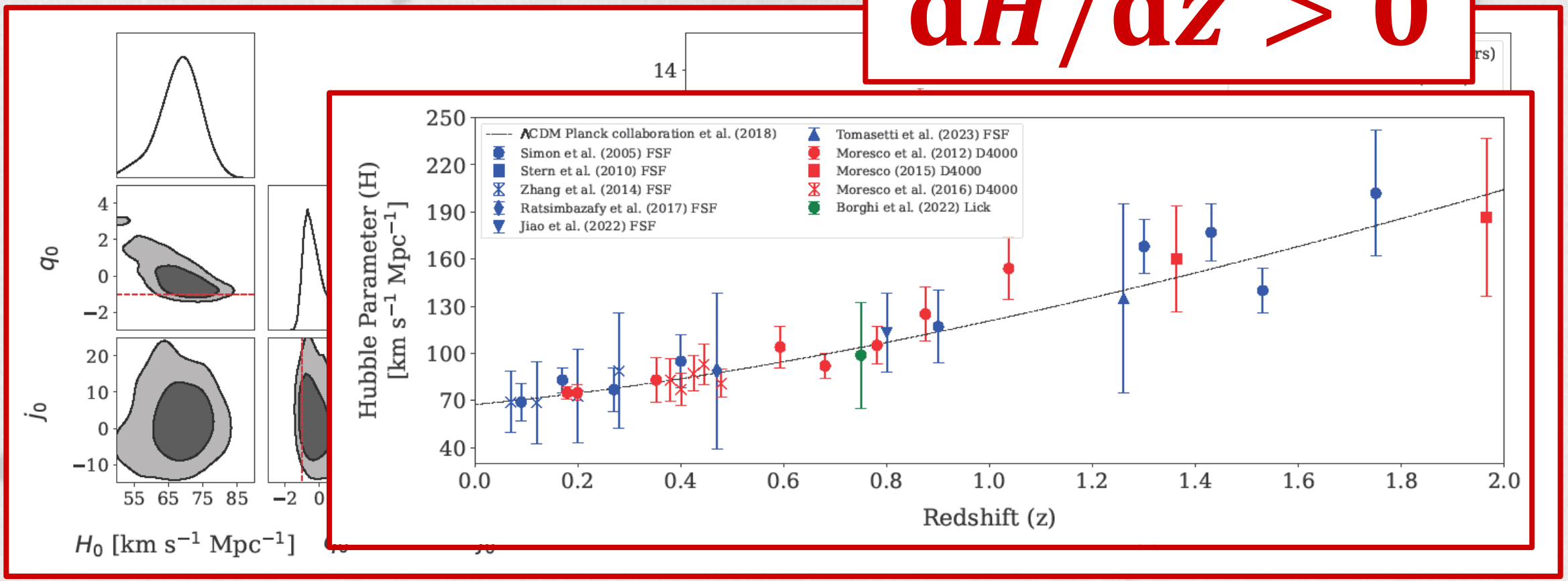
$$H_0 = 70.0^{+4.1}_{-7.6}\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$$

$$\mathrm{mod}\,(q_0) = -0.95 \leftrightarrow \mathrm{P}_{16}(q_0) = -0.85\ (!!!)$$

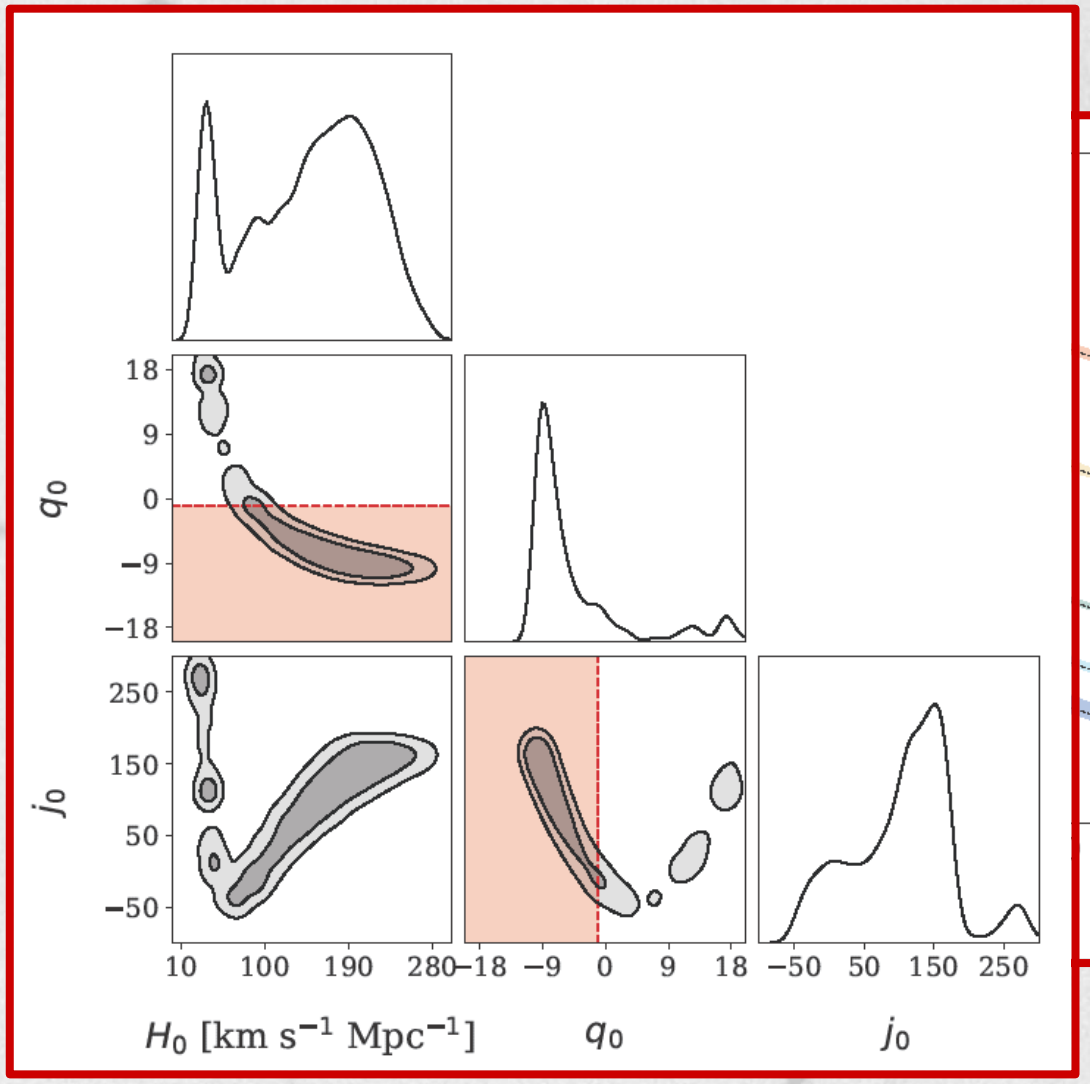
$$j_0 = 0.9^{+5.5}_{-3.7}\ \text{(not competitive...)}$$

Cosmography

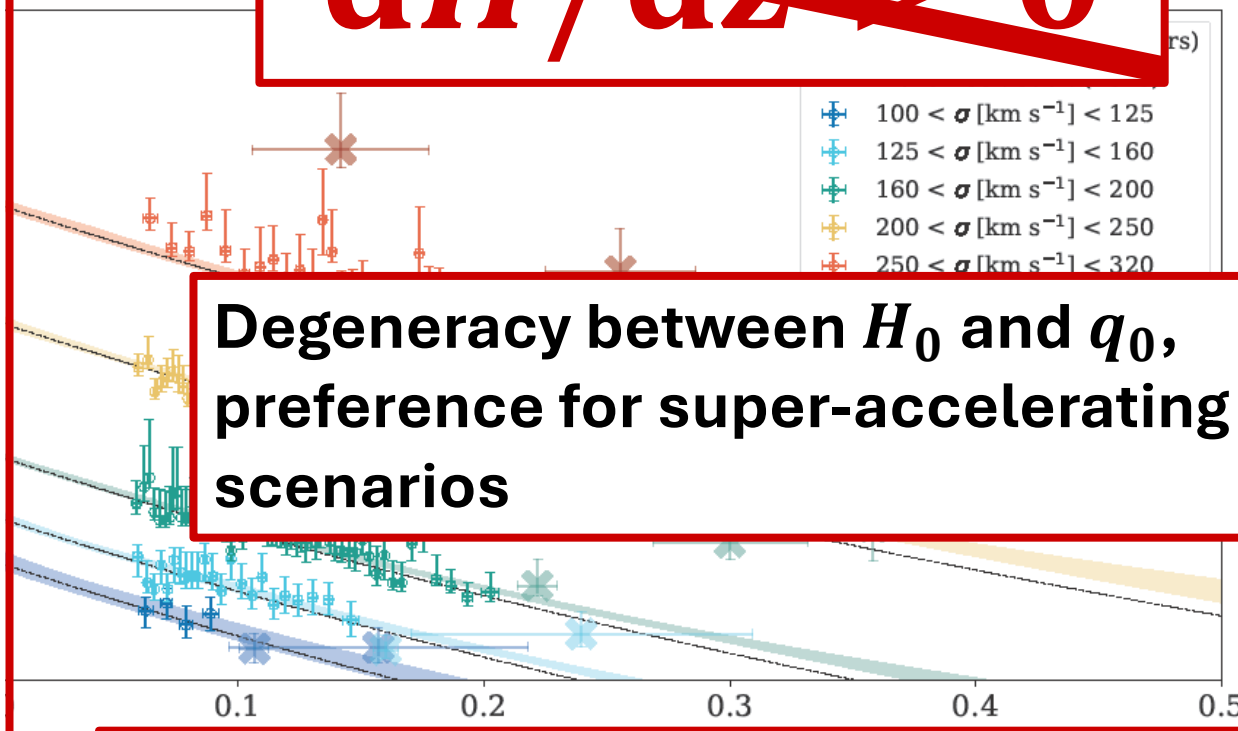
$$dH/dz > 0$$



Cosmography



$$dH/dz > 0$$

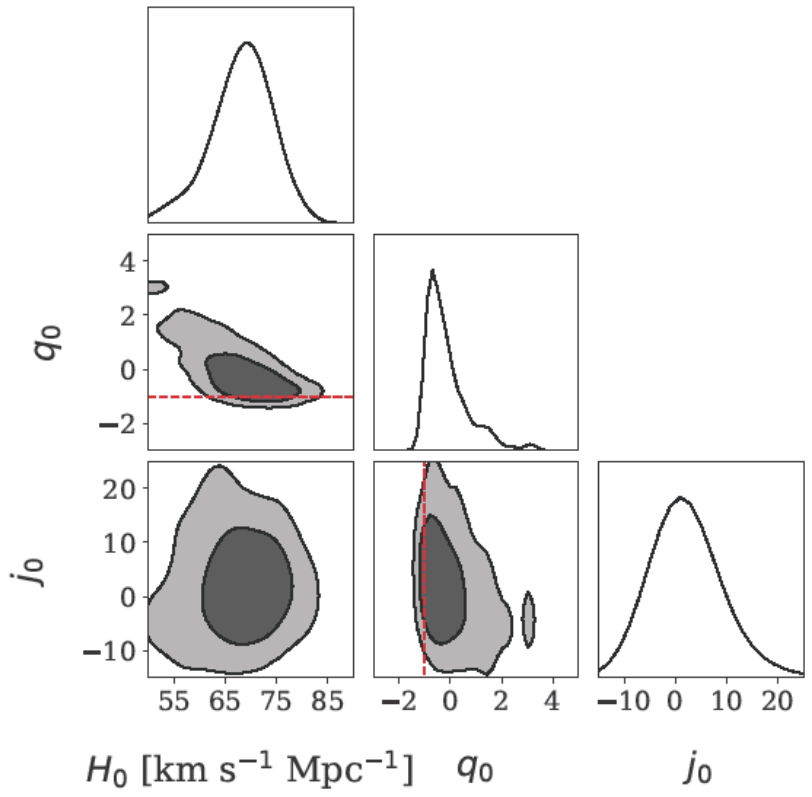


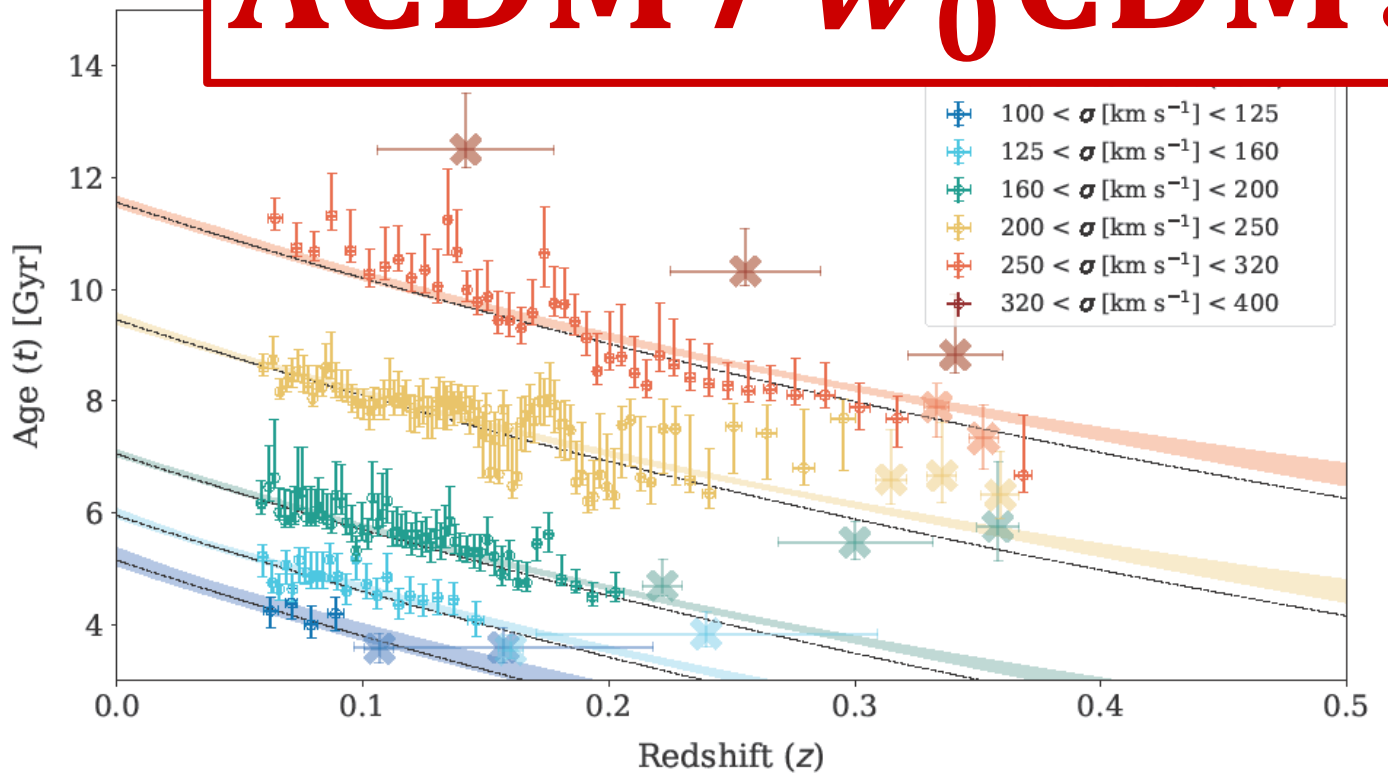
Degeneracy between H_0 and q_0, preference for super-accelerating scenarios

$$dH/dz > 0 \Leftrightarrow q(z) > -1$$

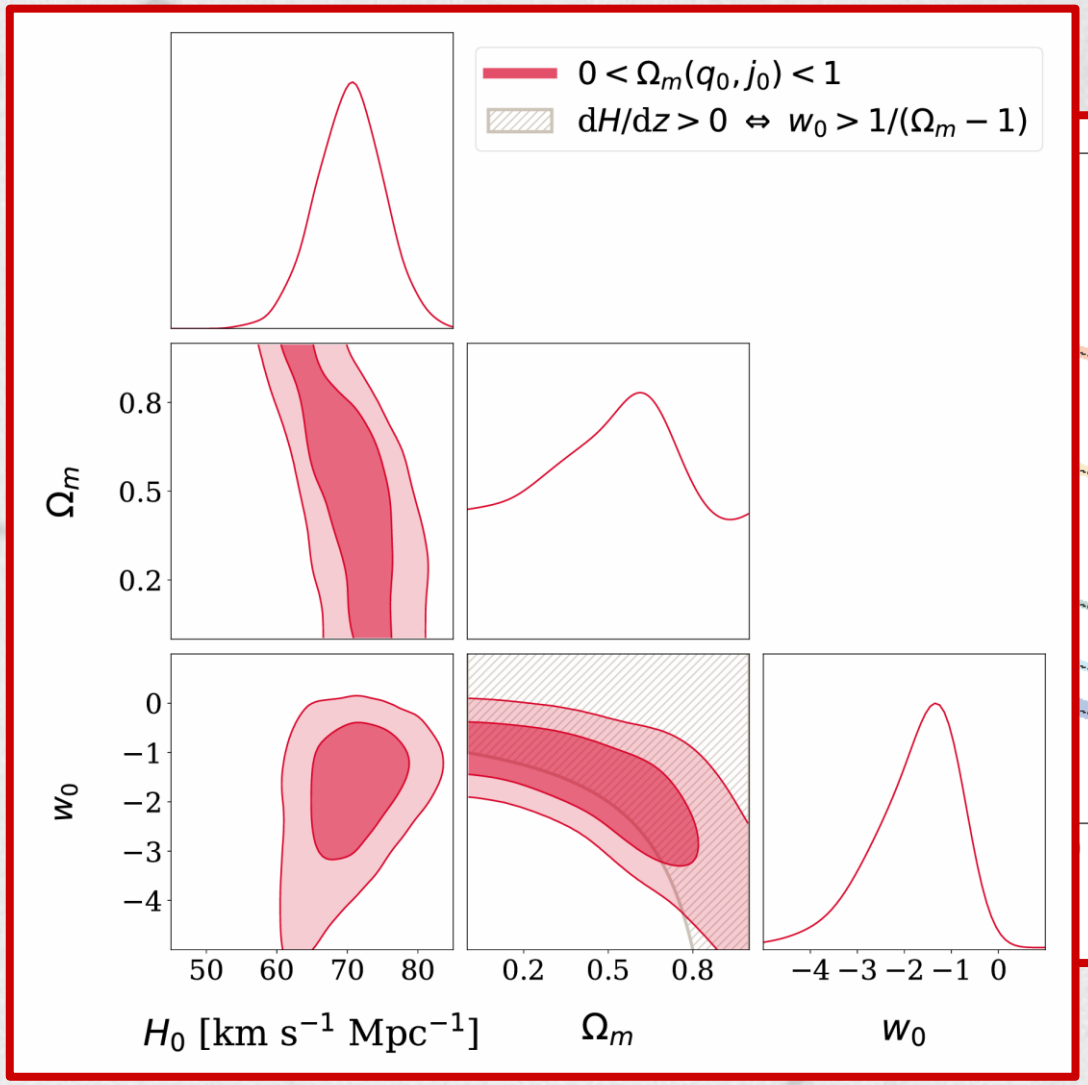
Cosmography

ΛCDM / w_0CDM?

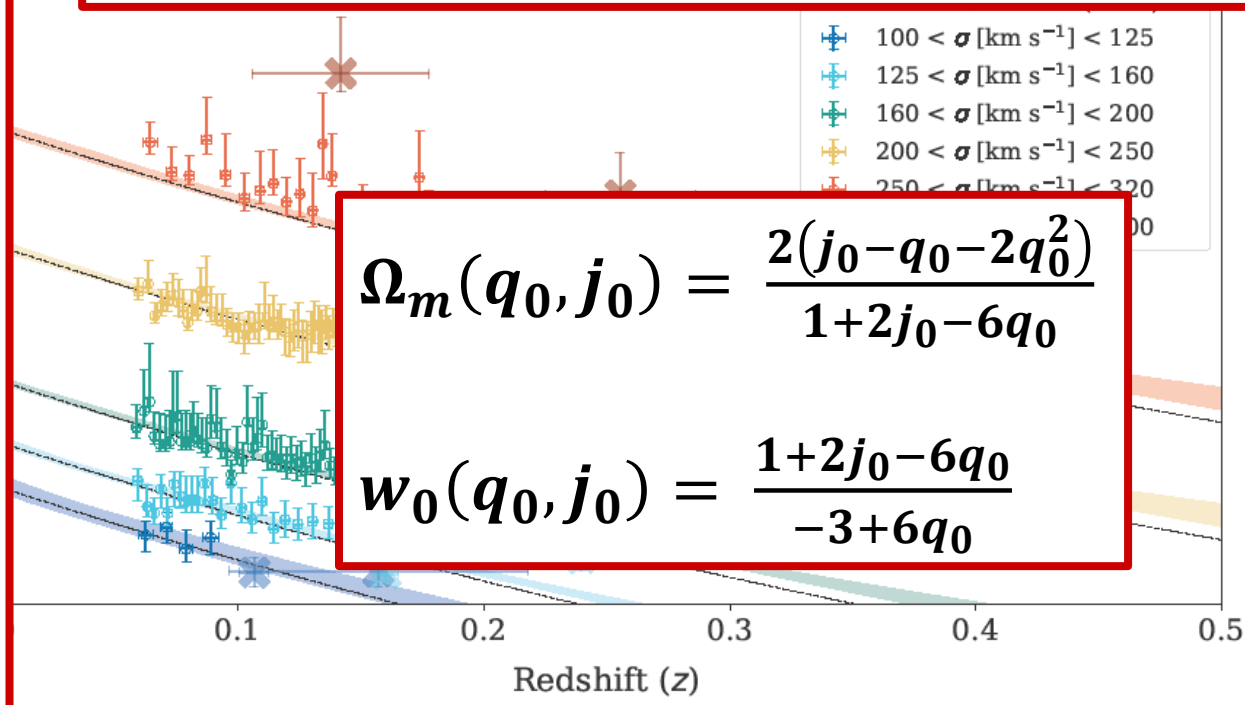




Cosmography



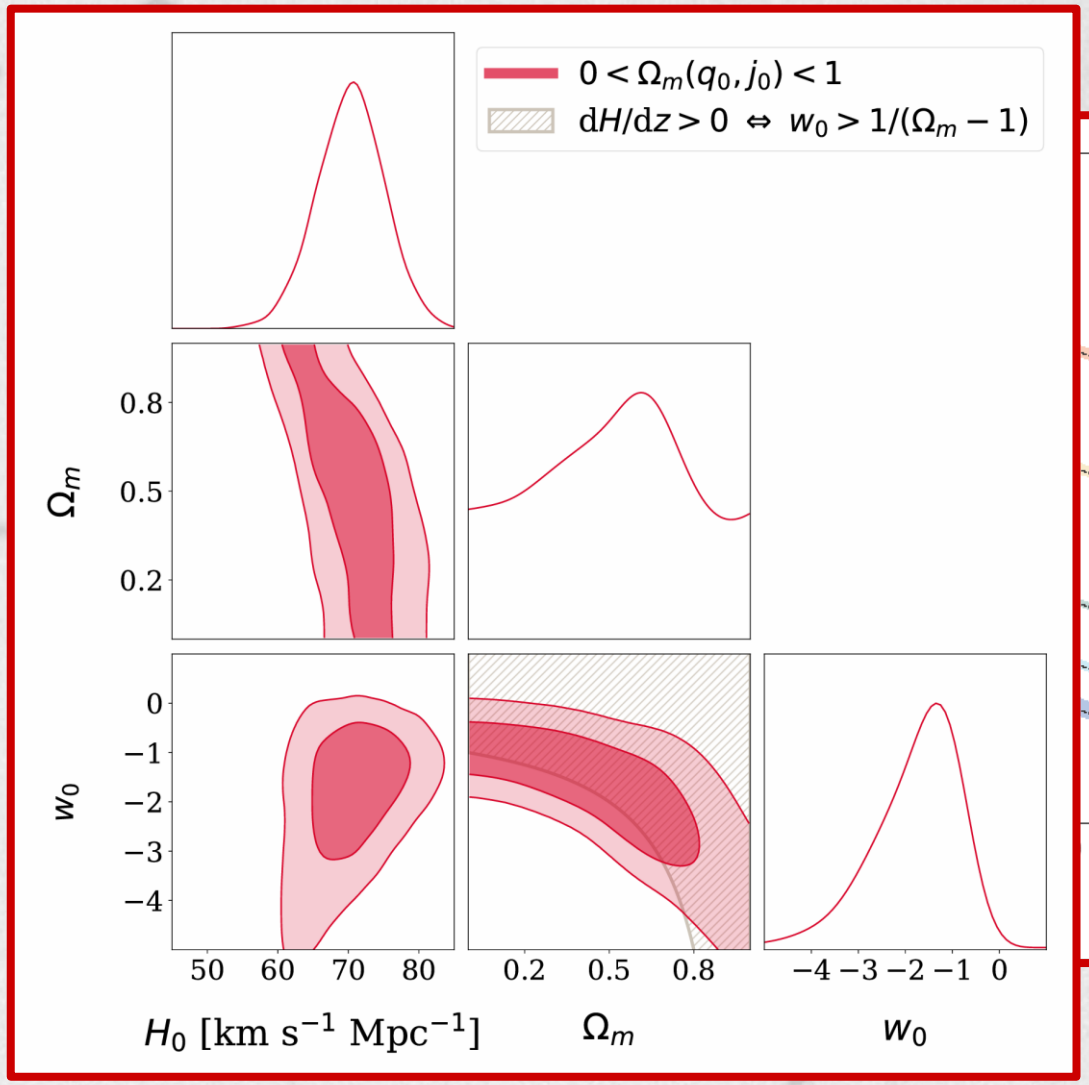
ΛCDM / w_0CDM?



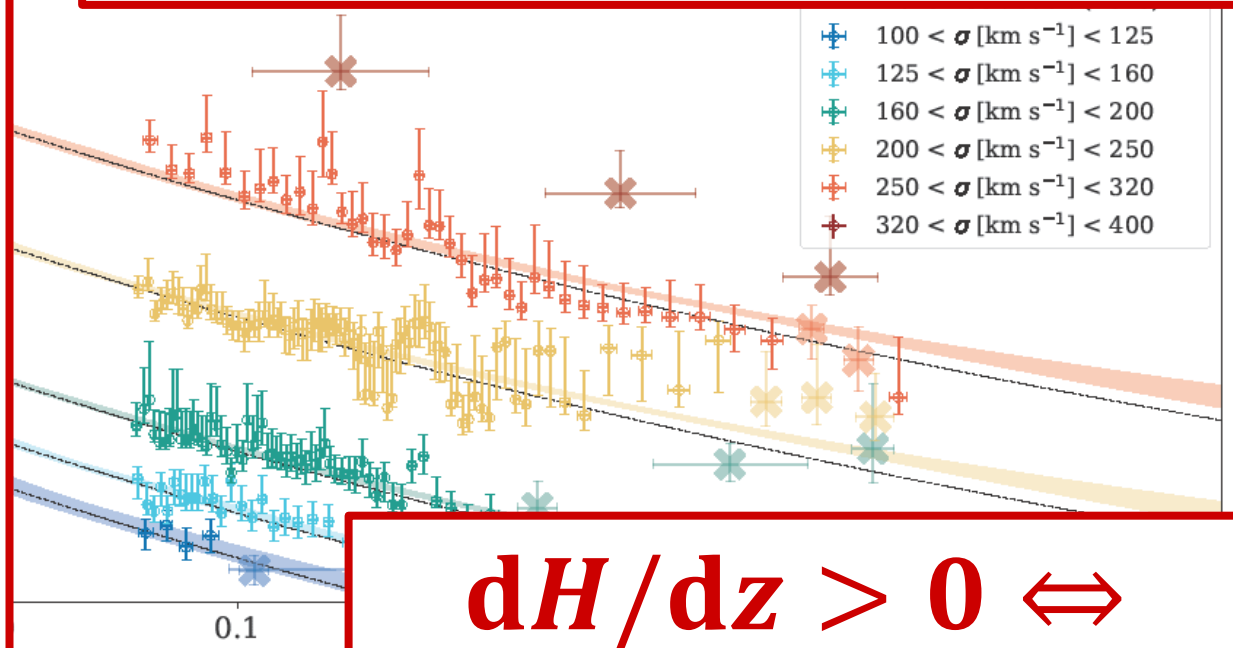
$$\Omega_m(q_0, j_0) = \frac{2(j_0 - q_0 - 2q_0^2)}{1 + 2j_0 - 6q_0}$$

$$w_0(q_0, j_0) = \frac{1 + 2j_0 - 6q_0}{-3 + 6q_0}$$

Cosmography

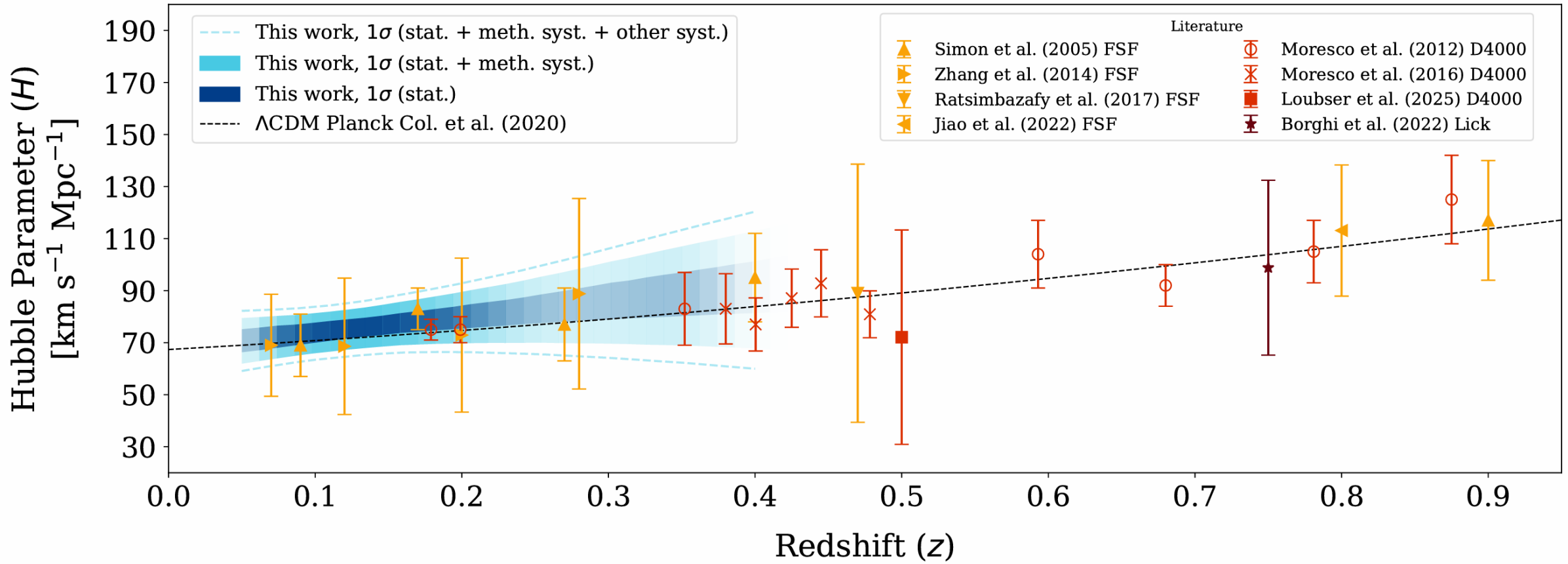


ΛCDM / w_0CDM?

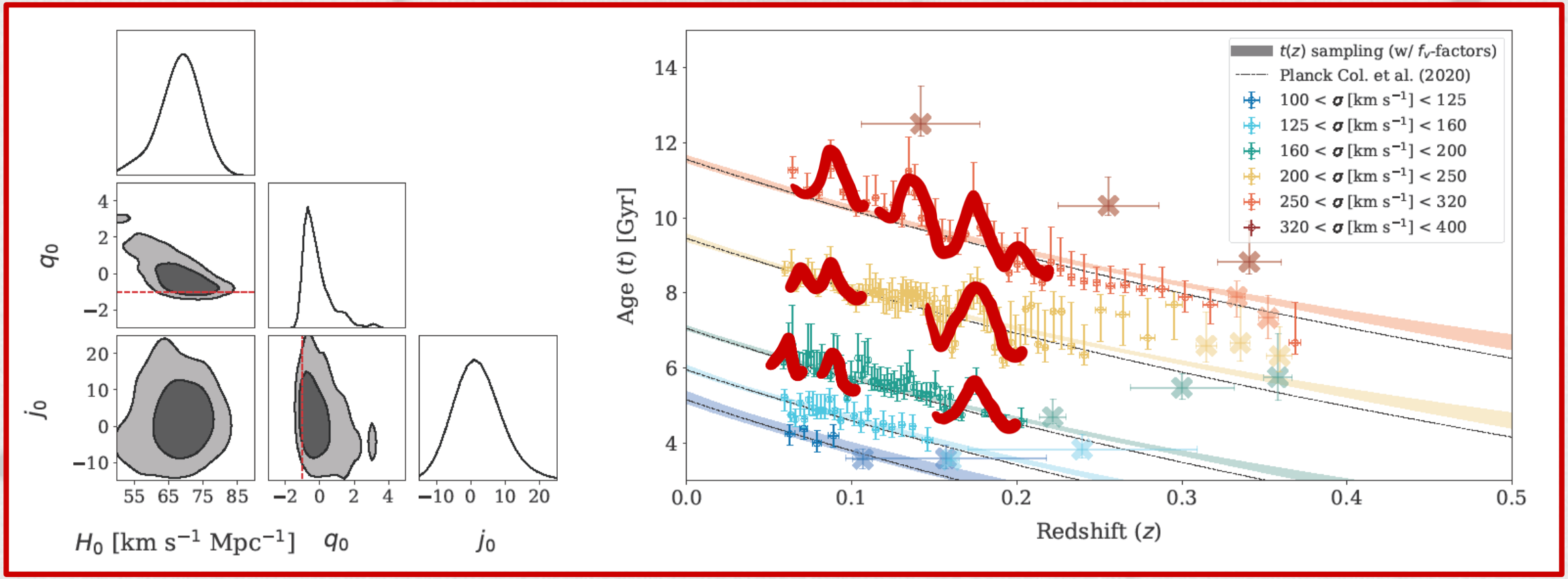


$$dH/dz > 0 \Leftrightarrow w_0 > 1/(\Omega_m - 1)$$

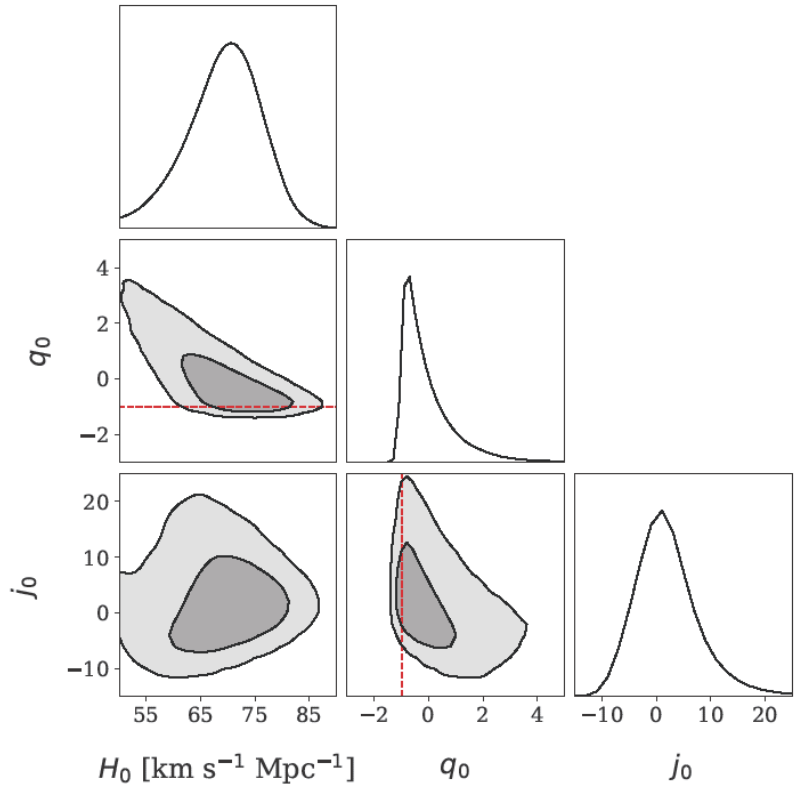
Cosmography

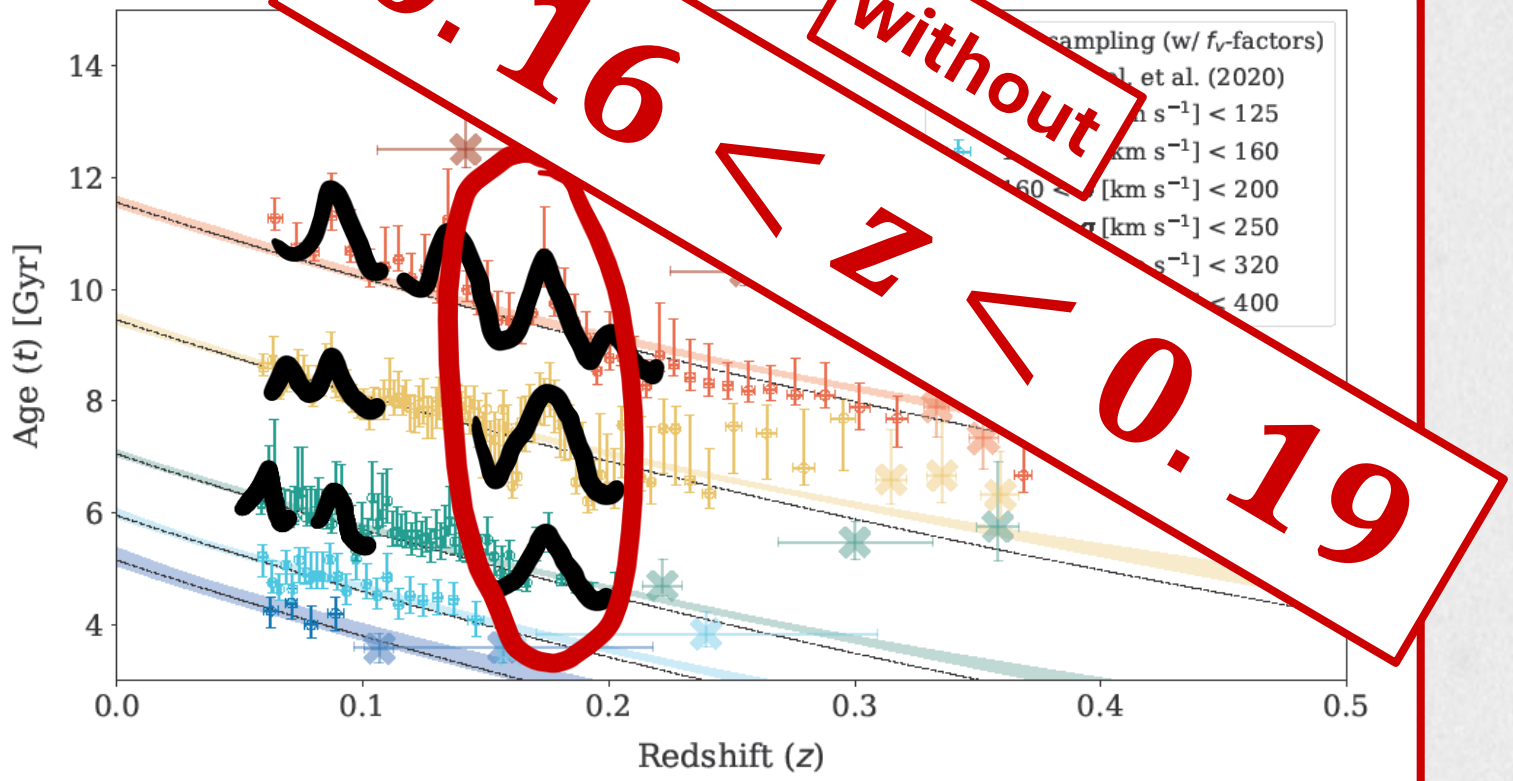


Index Oscillations



Index Oscillations

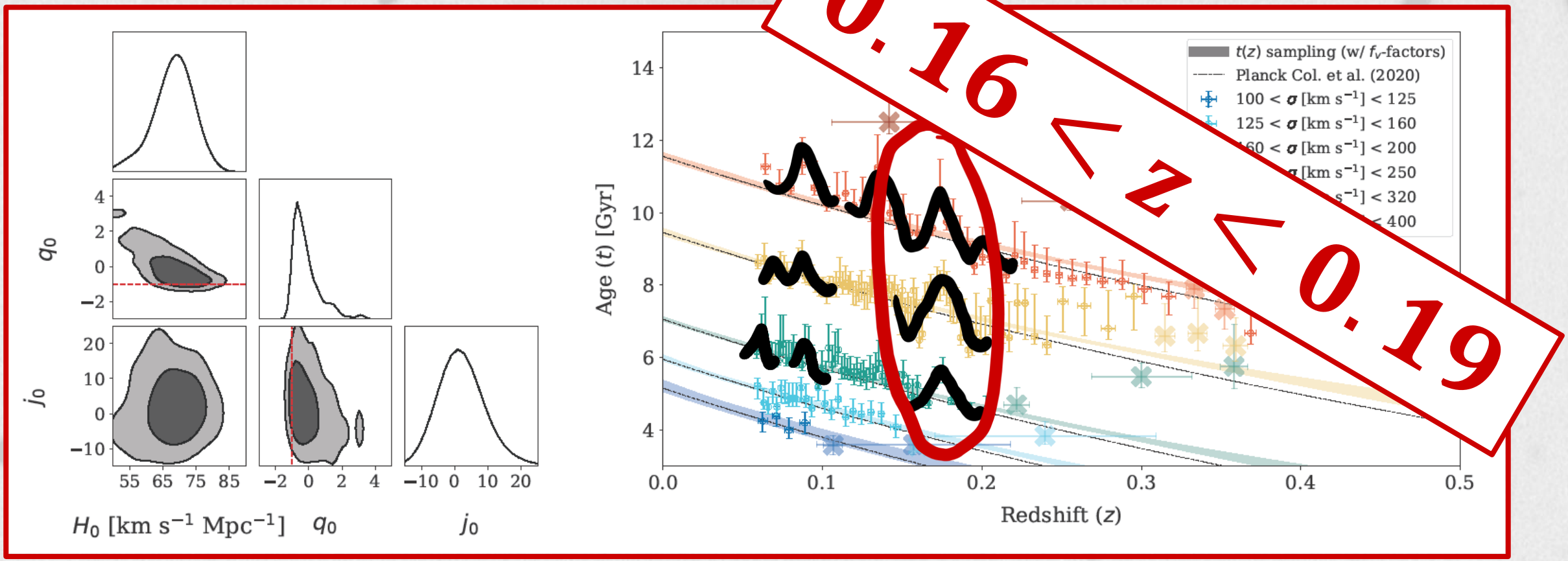




0.16 < z < 0.19

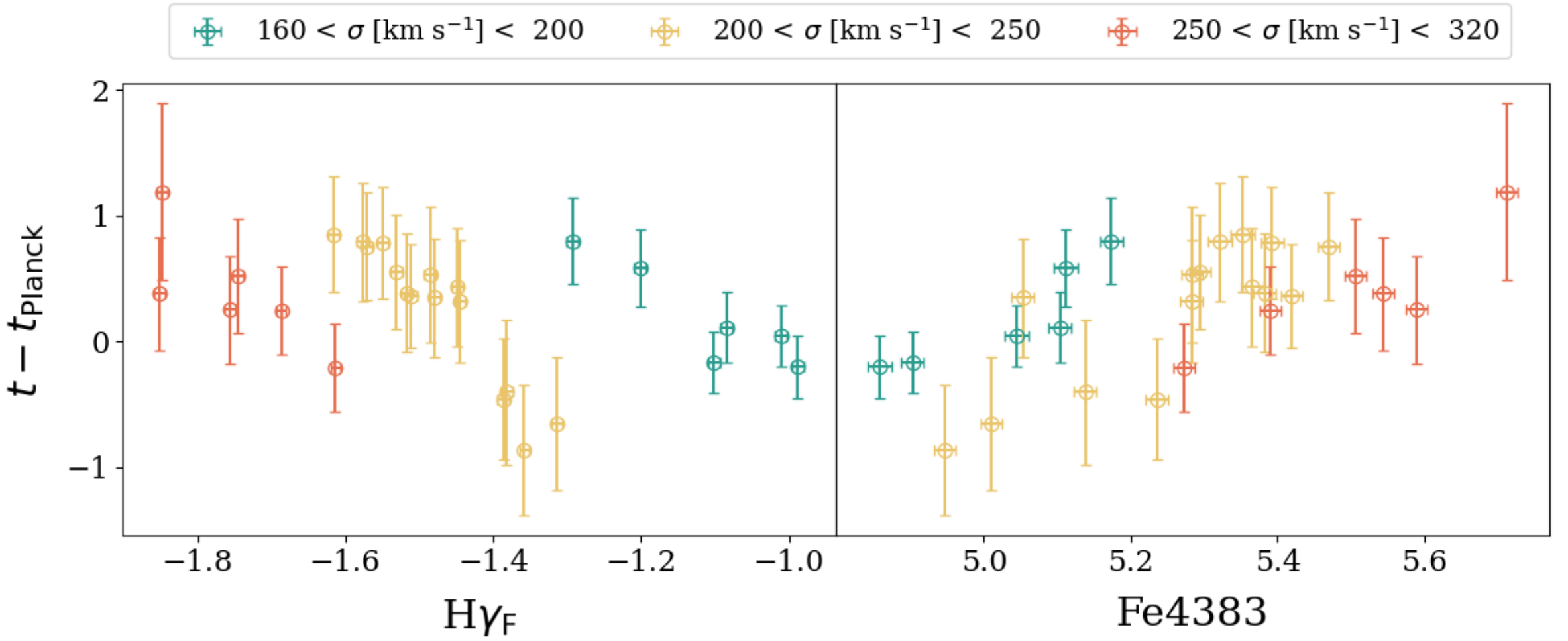
without

Index Oscillations

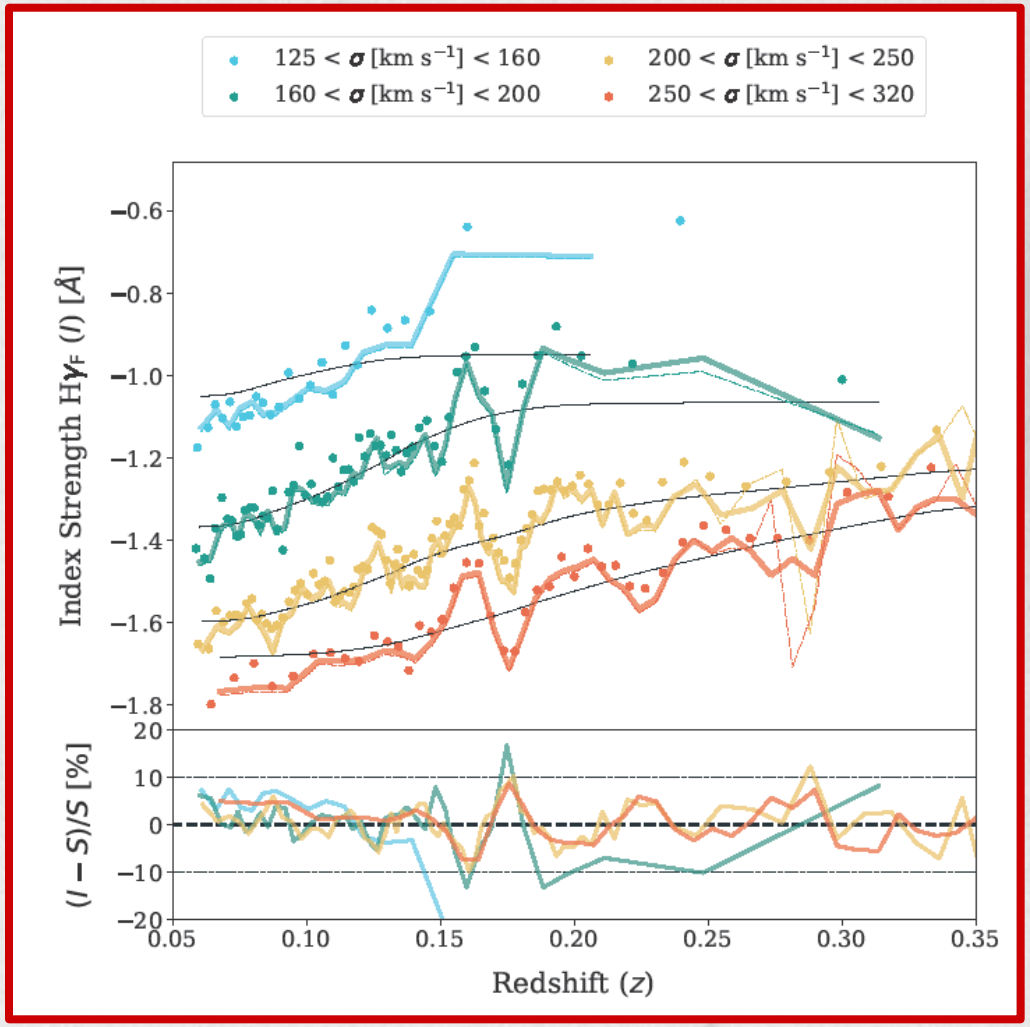


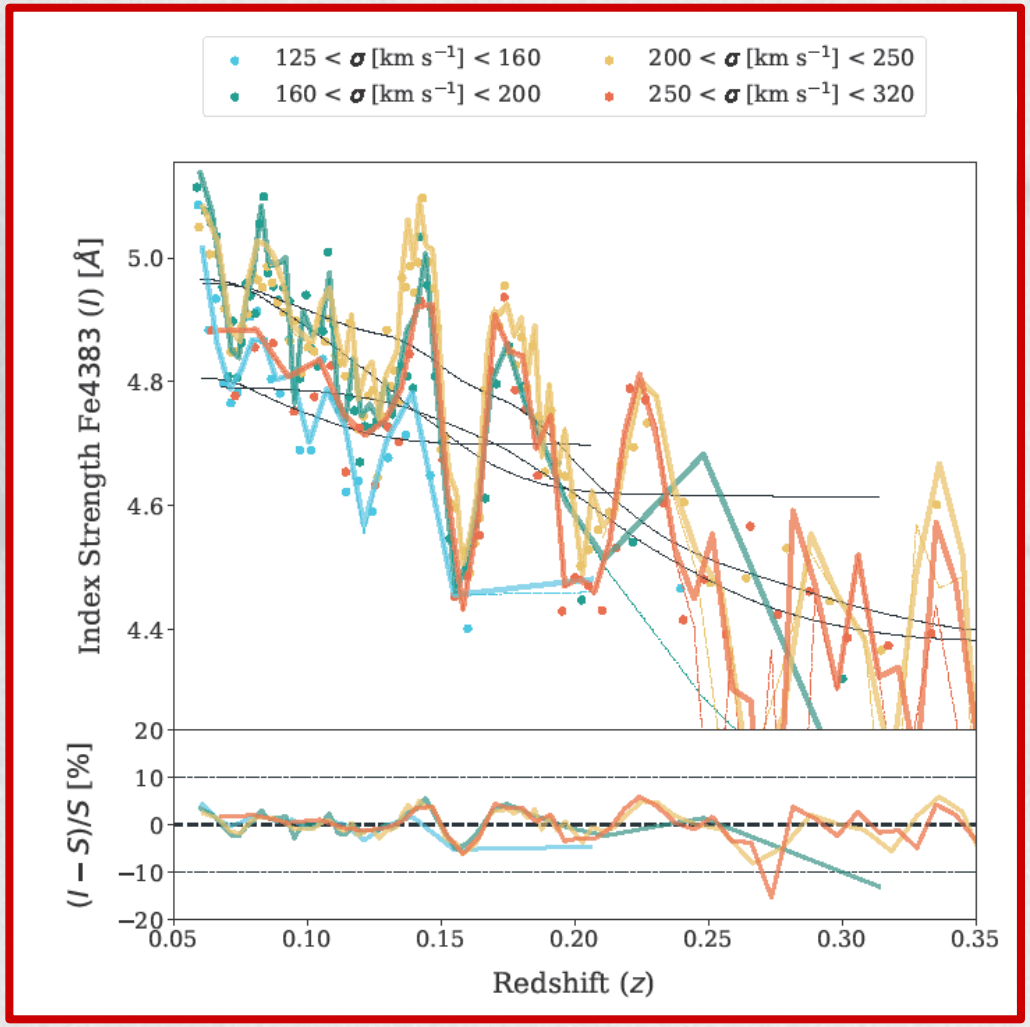
$0.16 < z < 0.19$

Index Oscillations

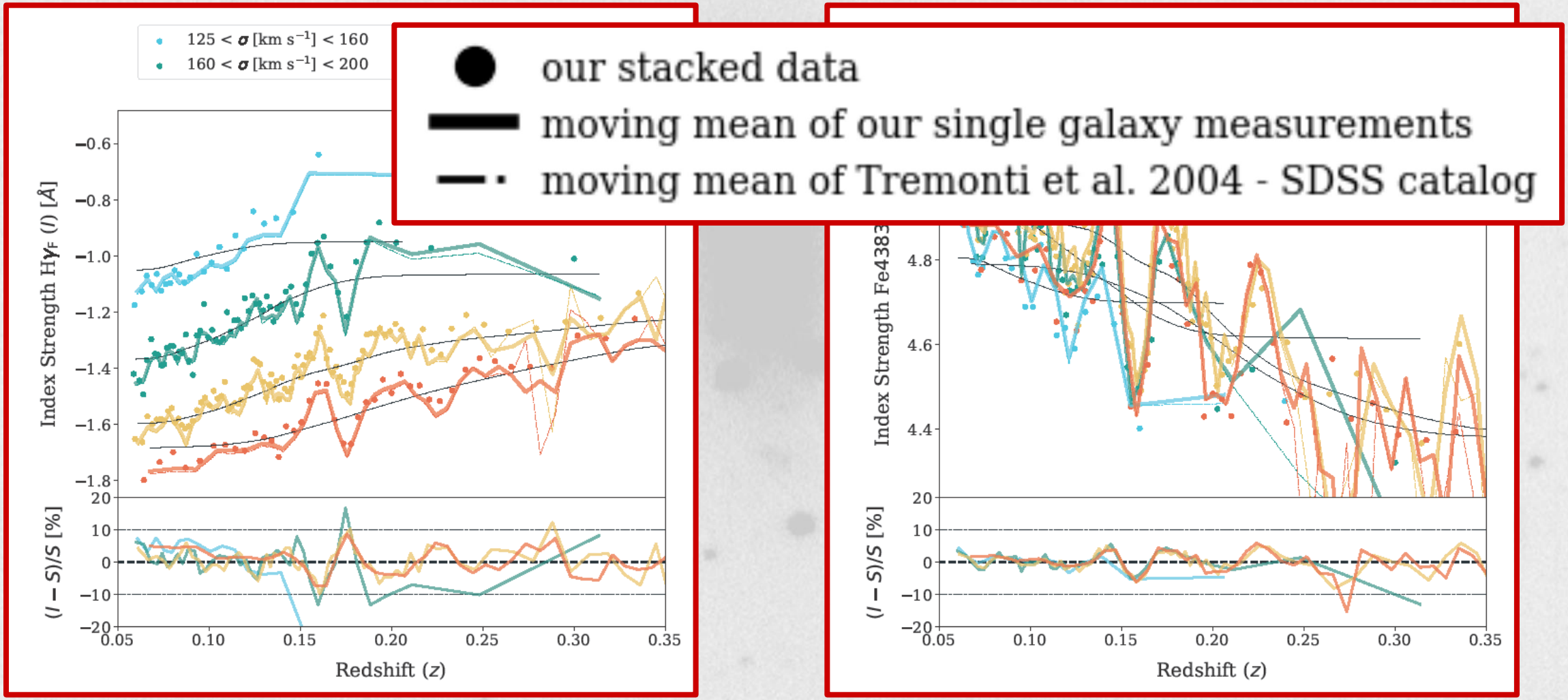


Index Oscillations





Index Oscillations



Astronomy & Astrophysics manuscript no. main
September 5, 2025

Cosmography via stellar archaeology of low-redshift early-type galaxies from SDSS

Carlos A. Álvarez[1], Marcos M. Cueli[1,2], Alessandro Bressan[1], Lumen Boco[3], Balakrishna S. Haridasu[1,2], Michele Bosi[1,4], Luigi Danese[1], and Andrea Lapi[1,2,5,6]

[1] Scuola Internazionale Superiore di Studi Avanzati (SISSA), Via Bonomea 265, 34136 Trieste (TS), Italy
e-mail: calonsoa@sissa.it
[2] Institute for Fundamental Physics of the Universe (IFPU), Via Beirut 2, 34014 Trieste, Italy
[3] Universitat Heidelberg, Zentrum fur Astronomie, Institut fur theoretische Astrophysik, Albert-Ueberle-Str. 3, 69120 Heidelberg, Germany
[4] Department of Physics, University of Trento, Via Sommarive 14, 38123 Povo (TN), Italy
[5] IRA-INAF, Via Gobetti 101, 40129 Bologna, Italy
[6] INFN-Sezione di Trieste, via Valerio 2, 34127 Trieste, Italy

September 5, 2025

ABSTRACT

Context. Cosmic chronometers offer a model-independent way to trace the expansion history of the Universe via the dating of passively evolving objects. This enables testing the validity of cosmological models without concrete assumptions of their energy content.
Aims. The main goal of this work is to derive model-independent constraints on the Hubble parameter up to $z \sim 0.4$ using stellar ages from the fitting of Lick index absorption lines in passively evolving galaxies. Contrary to recent related works that rely on finite differences to obtain a discrete measurement of the expansion of the Universe at an average redshift, our goal is to perform a cosmographic fit of $H(z)$ in terms of the Hubble constant (H_0) and the deceleration (q_0) and jerk (j_0) parameters.
Methods. We carefully select spectra of massive and passively evolving galaxies from the SDSS Legacy Survey. After applying a stacking procedure to ensure a high signal-to-noise ratio, the strength of Lick indices is fit using two stellar population models (TMJ and Knowles) to derive stellar population parameters. A cosmographic fit to the stellar ages is performed, which in turn enables the sampling of the Hubble parameter within the considered redshift range.
Results. The baseline result comes from using the TMJ-modelled ages, and it yields a value of $H_0 = 70.0^{+4.1}_{-7.6}$ km s^{-1} Mpc^{-1} for the Hubble constant, where uncertainties refer only to the statistical treatment of the data. The sampling of the Hubble parameter at $0.05 < z < 0.35$ is competitive with discreet model-independent measurements from the literature. As a by-product of the Lick index fitting procedure, we provide scaling and dispersion relations of stellar population parameters with respect to velocity dispersion using the low-redshift end of our sample. We finally draw attention to an unexpected oscillating pattern in a number of critical indices with respect to redshift, which translates into a similar behaviour in the $t - z$ relations. These features have never been discussed before, although they are present in previous measurements. We show that they do not originate from our methodology, suggesting a possible origin in the data reduction process.

Key words. Cosmography – Cosmology with Early-Type Galaxies – Stellar Ages – Galaxy Formation and Evolution

All this & more...

Álvarez et al. 2025

(accepted for publication on 01/09/2025 in A&A)

TAKE-HOME IDEAS (OUT OF WORK DONE)

→ Independent estimation of $H(z)$ (no dynamics)

→ Cosmographic (kinematic) approach: $H \equiv H(z; q_0, j_0, s_0, l_0)$

→ Continuous fit of $t(z)$: full redshift-range exploitation + stability (avoiding $H < 0$ local estimations)

→ Stacking (instead of binning after individual age estimation) + stable S/N

TAKE-HOME IDEAS (OUT OF WORK DONE)

→ Independent estimation of $H(z)$ (no dynamics)

→ Cosmographic (kinematic) approach: $H \equiv H(z; q_0, j_0, s_0, l_0)$

→ Continuous fit of $t(z)$: full redshift-range exploitation + stability (avoiding $H < 0$ local estimations)

→ Stacking (instead of binning after individual age estimation) + stable S/N

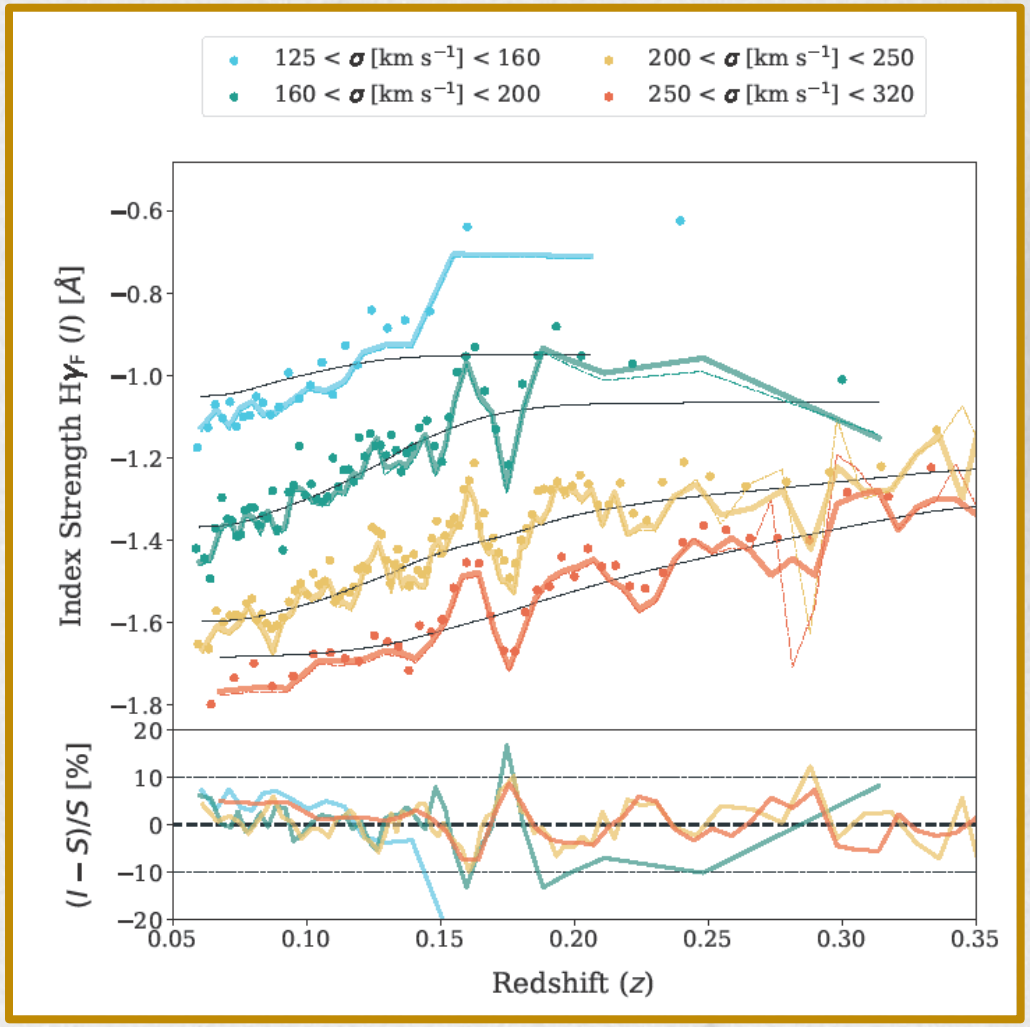
! SPS models critically affect the intermediate readout of stellar parameters (age, metallicity, α-enhancement)

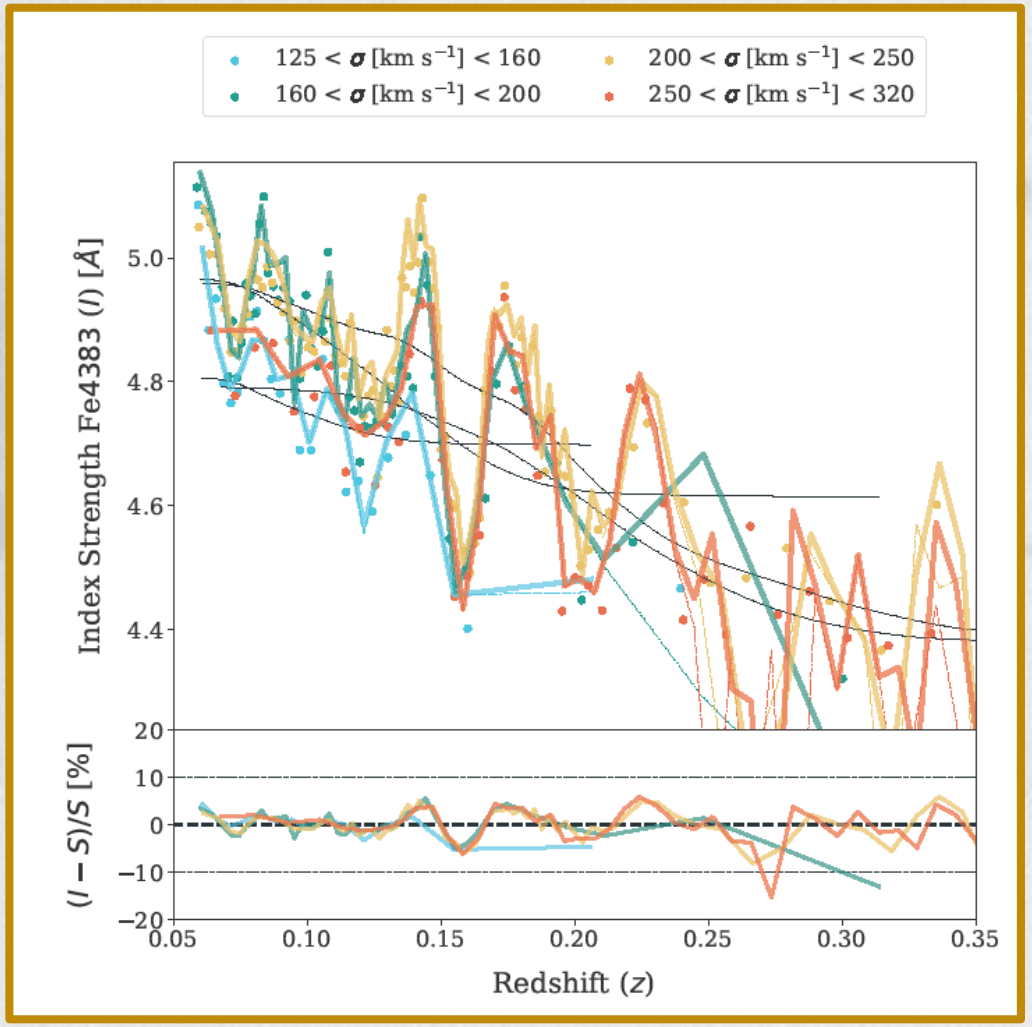
! Are index oscillations an SDSS issue?

OVERVIEW

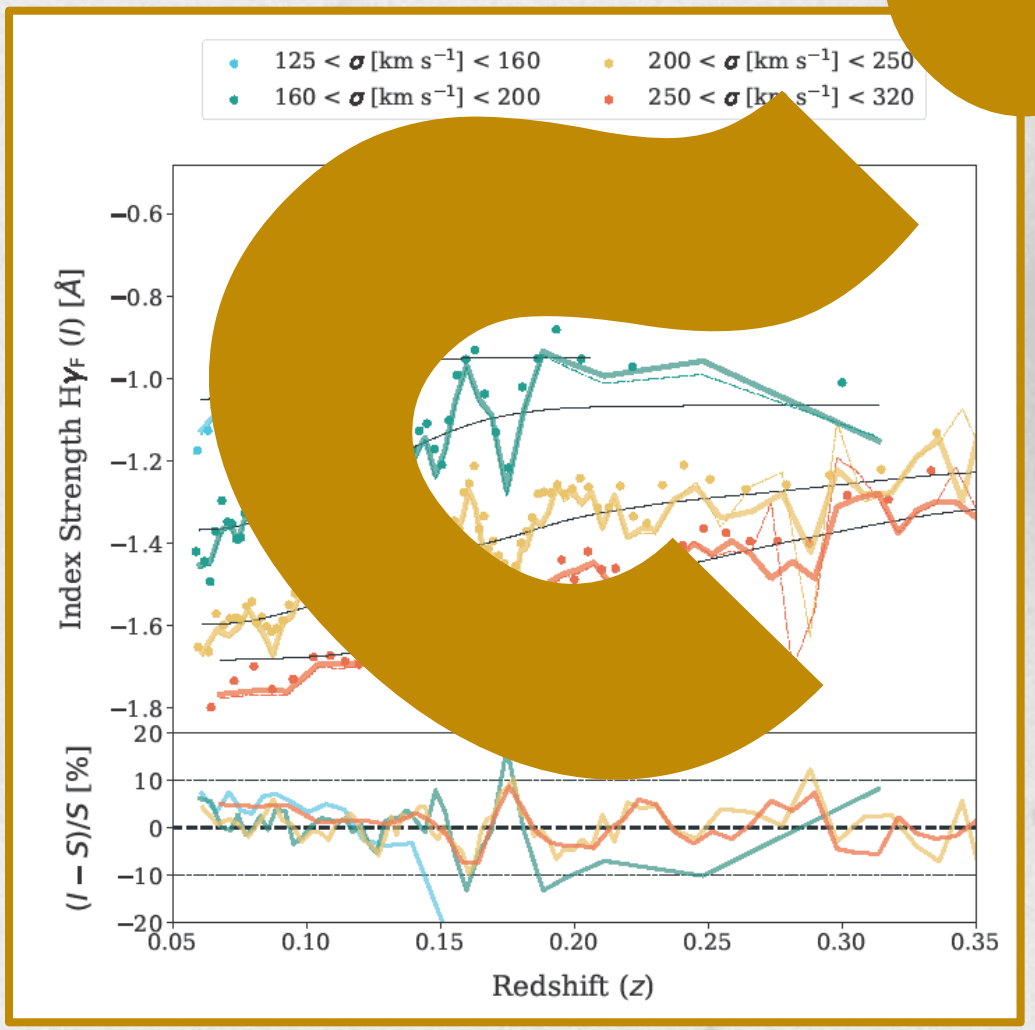
- Cosmic Chronometers
- Methodological aspects
- Cosmographic results
- Upcoming work

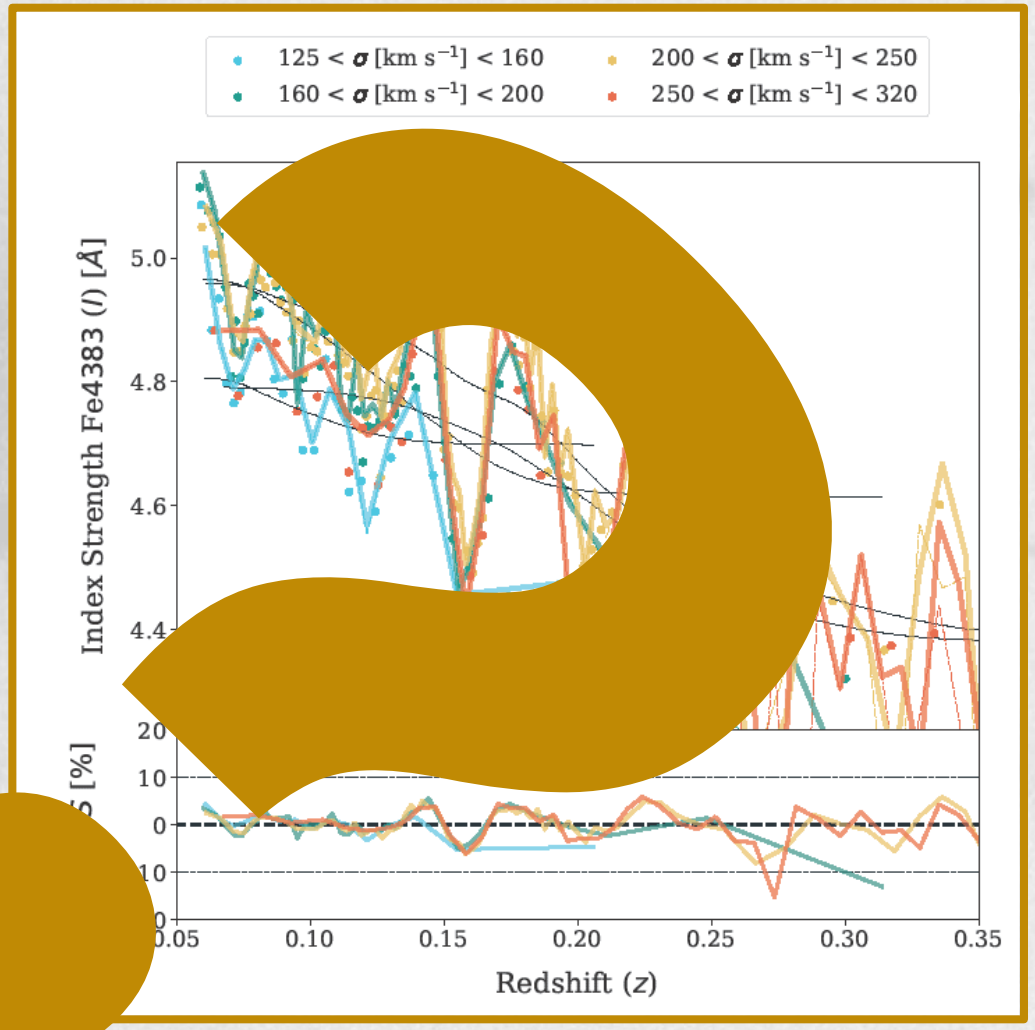
Upcoming work



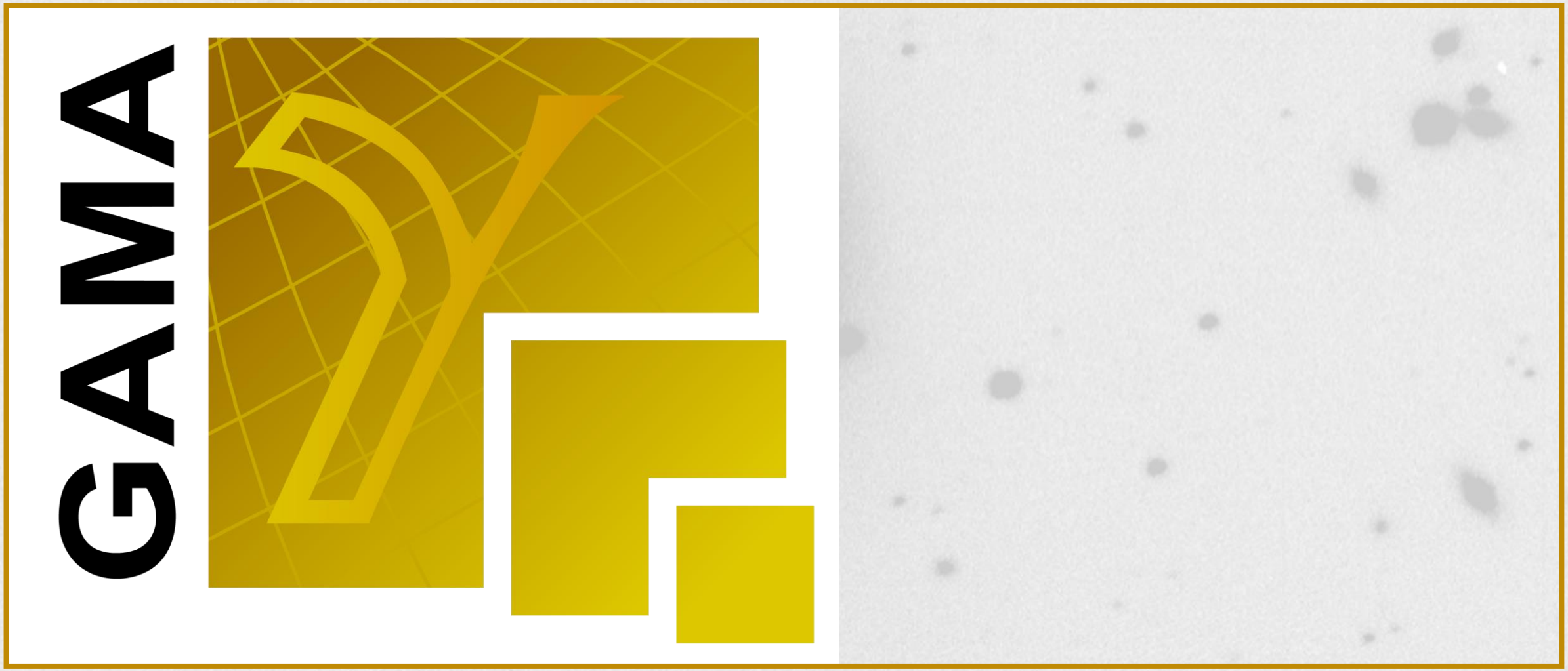


Upcoming work





Upcoming work

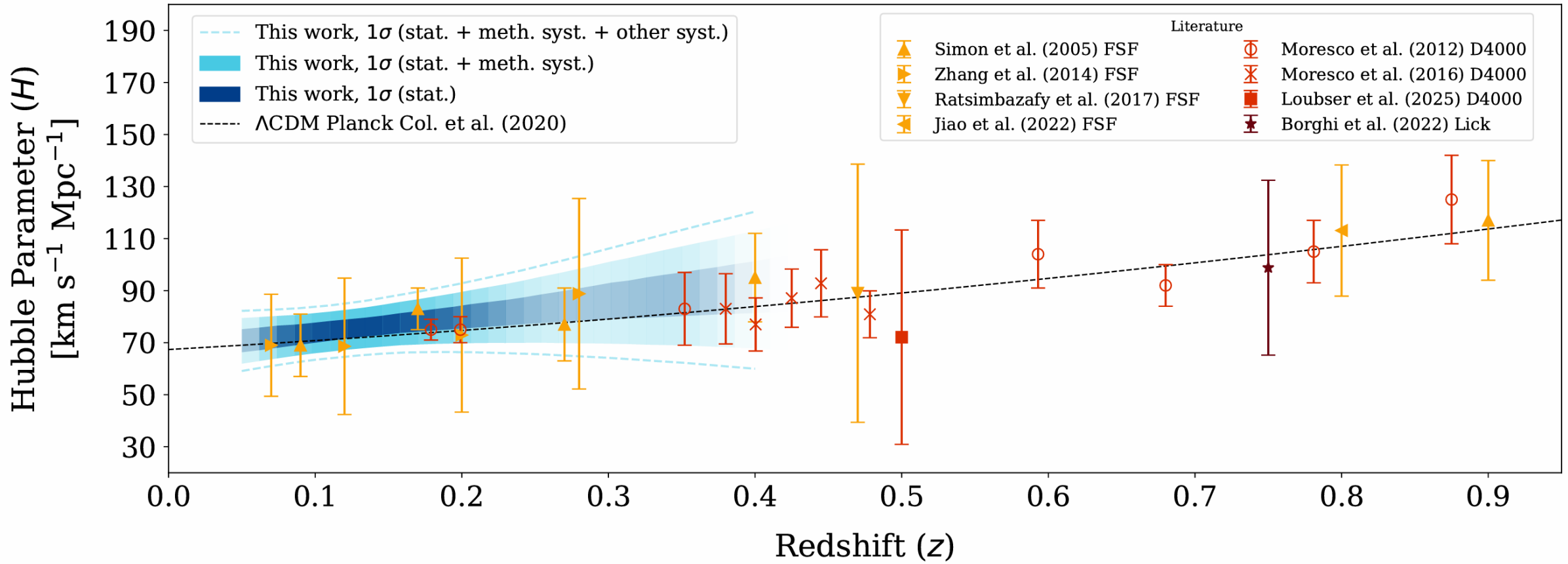


Upcoming work

→ Galaxy spectra in the upper redshift range of SDSS (Legacy); objects with r-band magnitude $r < 19.8$

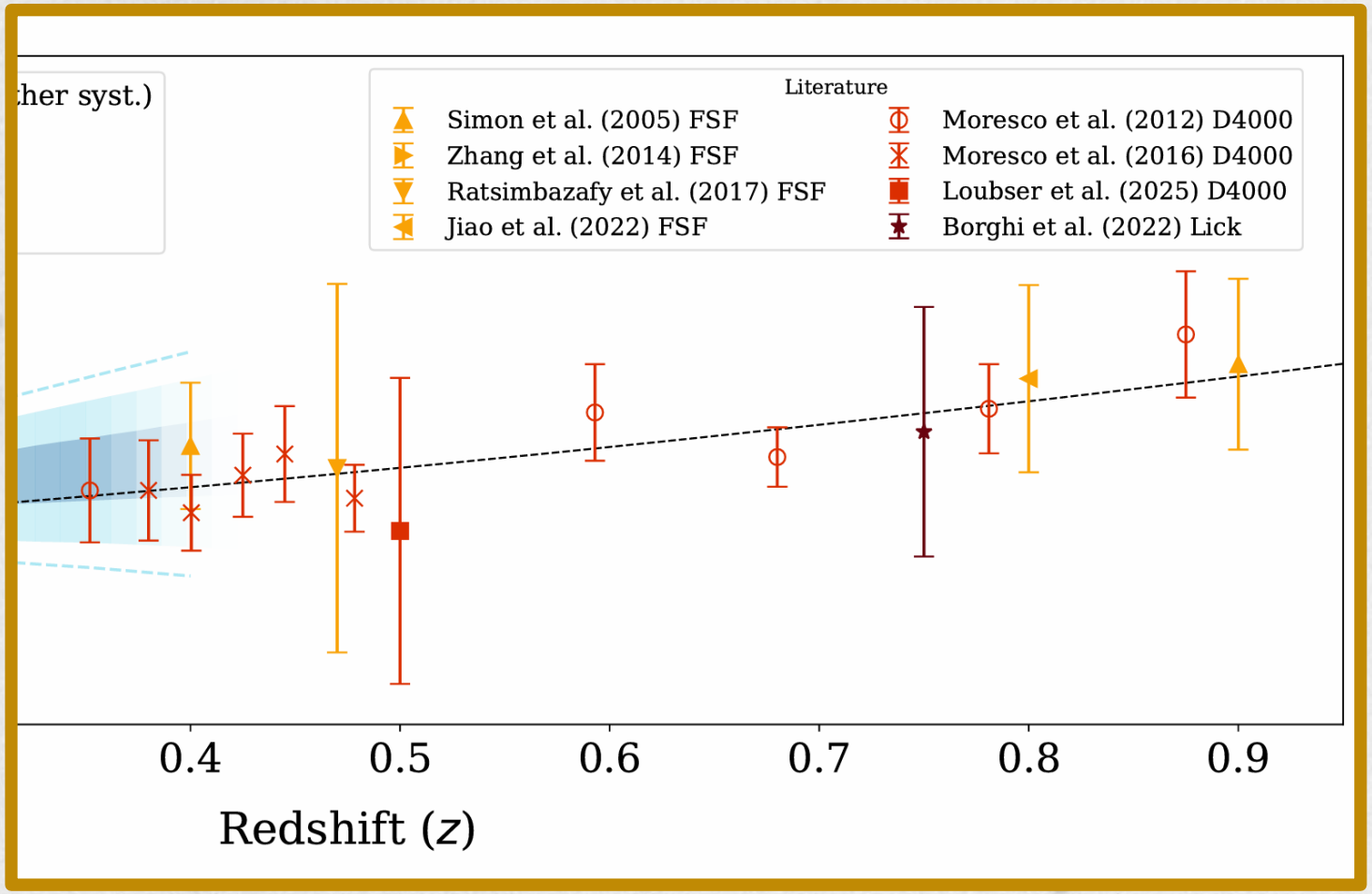
→ $> 30k$ GAMA (AAOmega spectrograph) objects with spectra compatible with passively evolving ETGs

Upcoming work

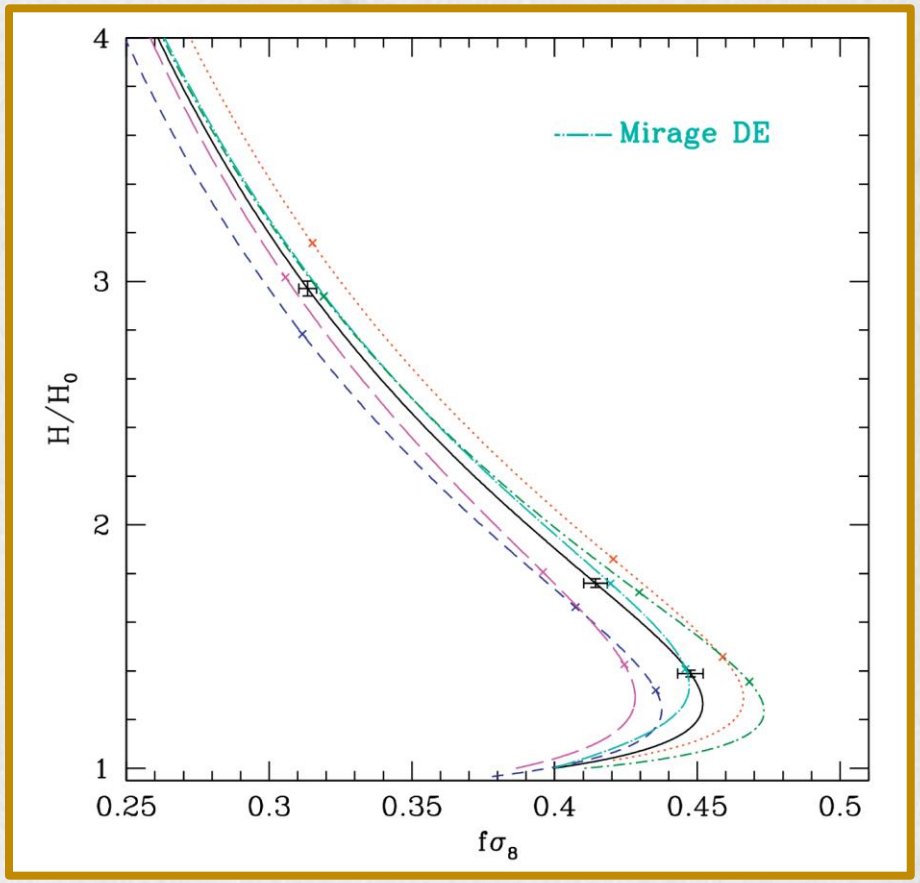


Upcoming work

- → **Extend the analysis to BOSS/eBOSS data at higher redshift**
- → **Check DESI data**
- → **Reliability of the SPS model, new/updated models?**



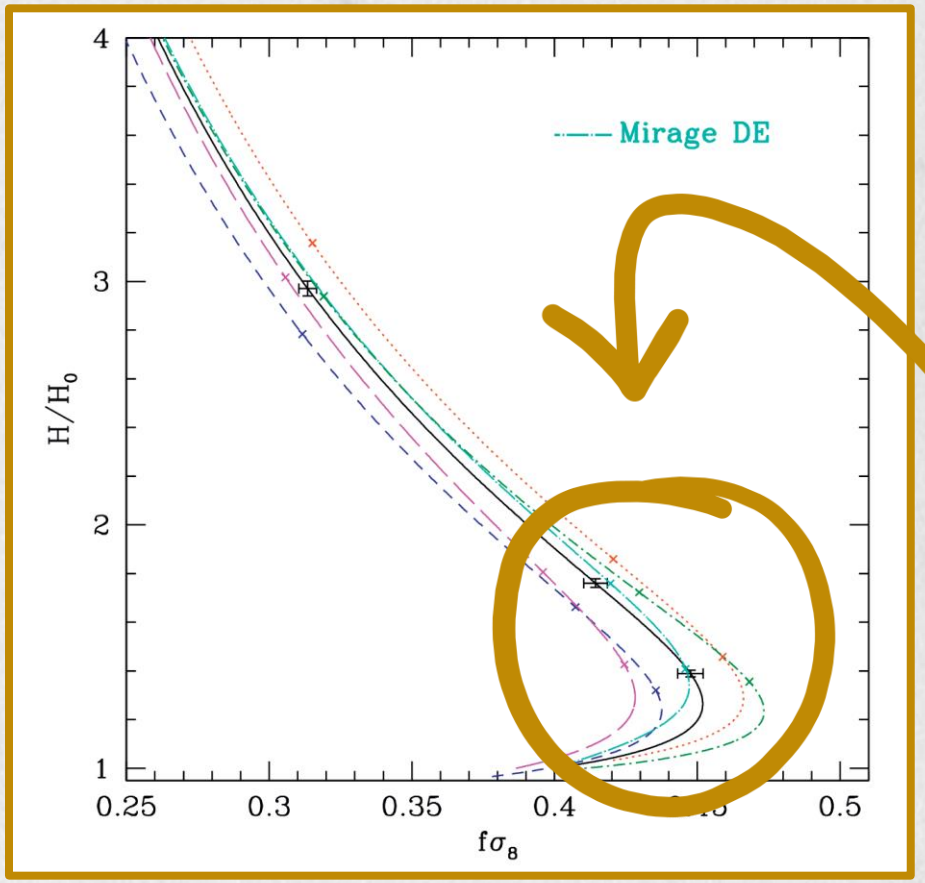
A powerful tool in cosmology



Linder 2016, Fig. 4

→ Using LRGs data from BOSS/eBOSS/DESI we can get a measurement of H/H_0. Combined with spatial statistics, we can get positions in the $\mathrm{H}/\mathrm{H}_0 - f\sigma_8$ plane.

A powerful tool in cosmology

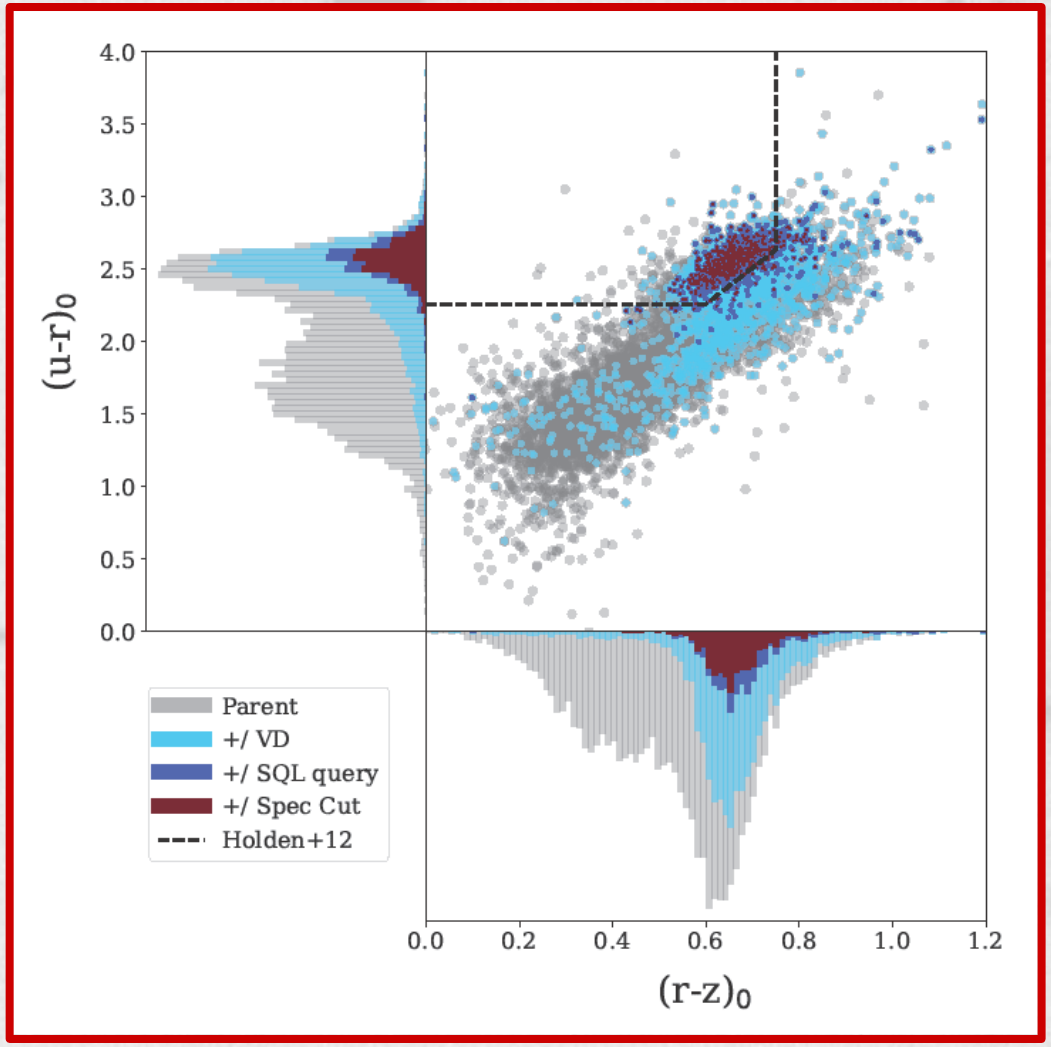


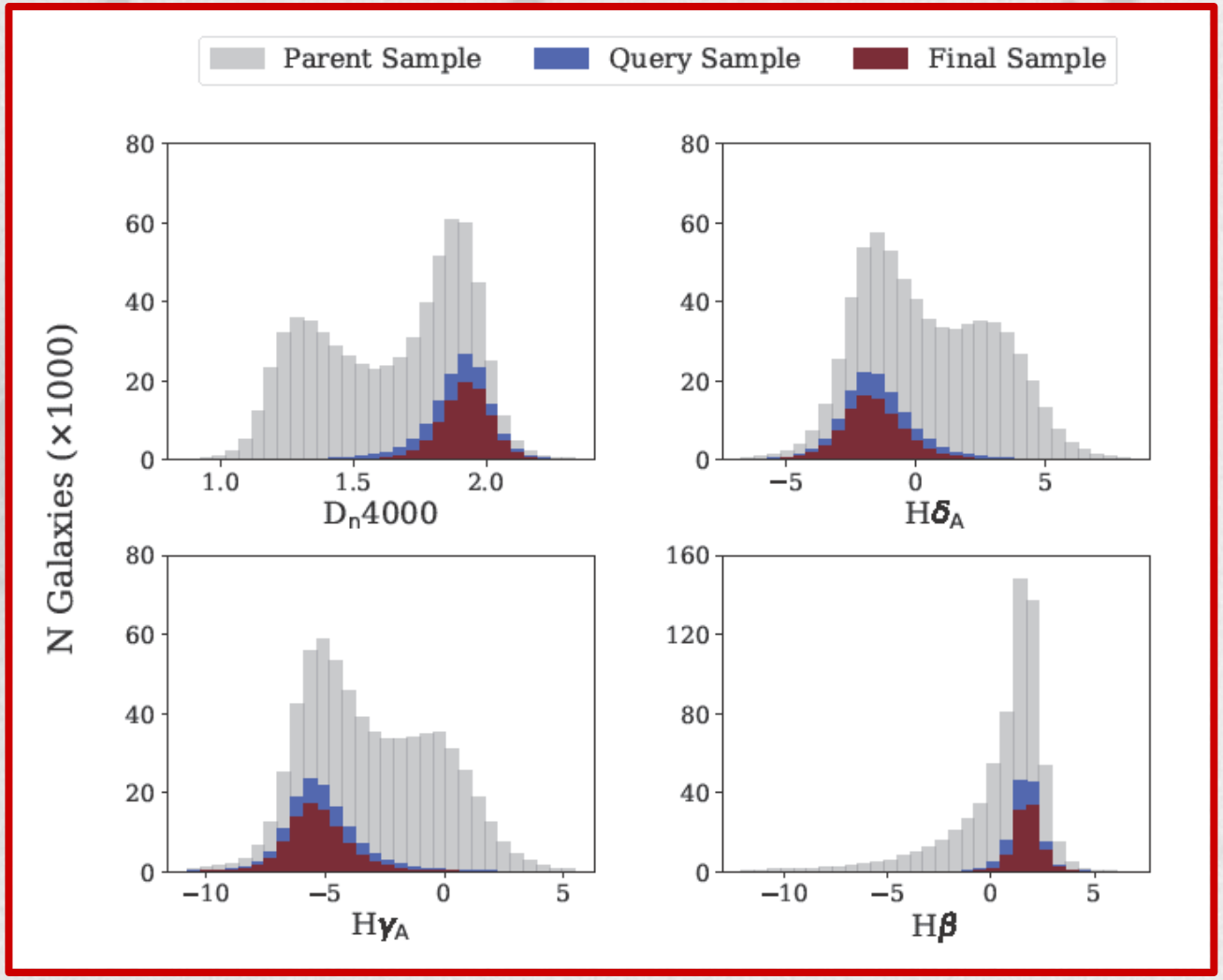
Linder 2016, Fig. 4

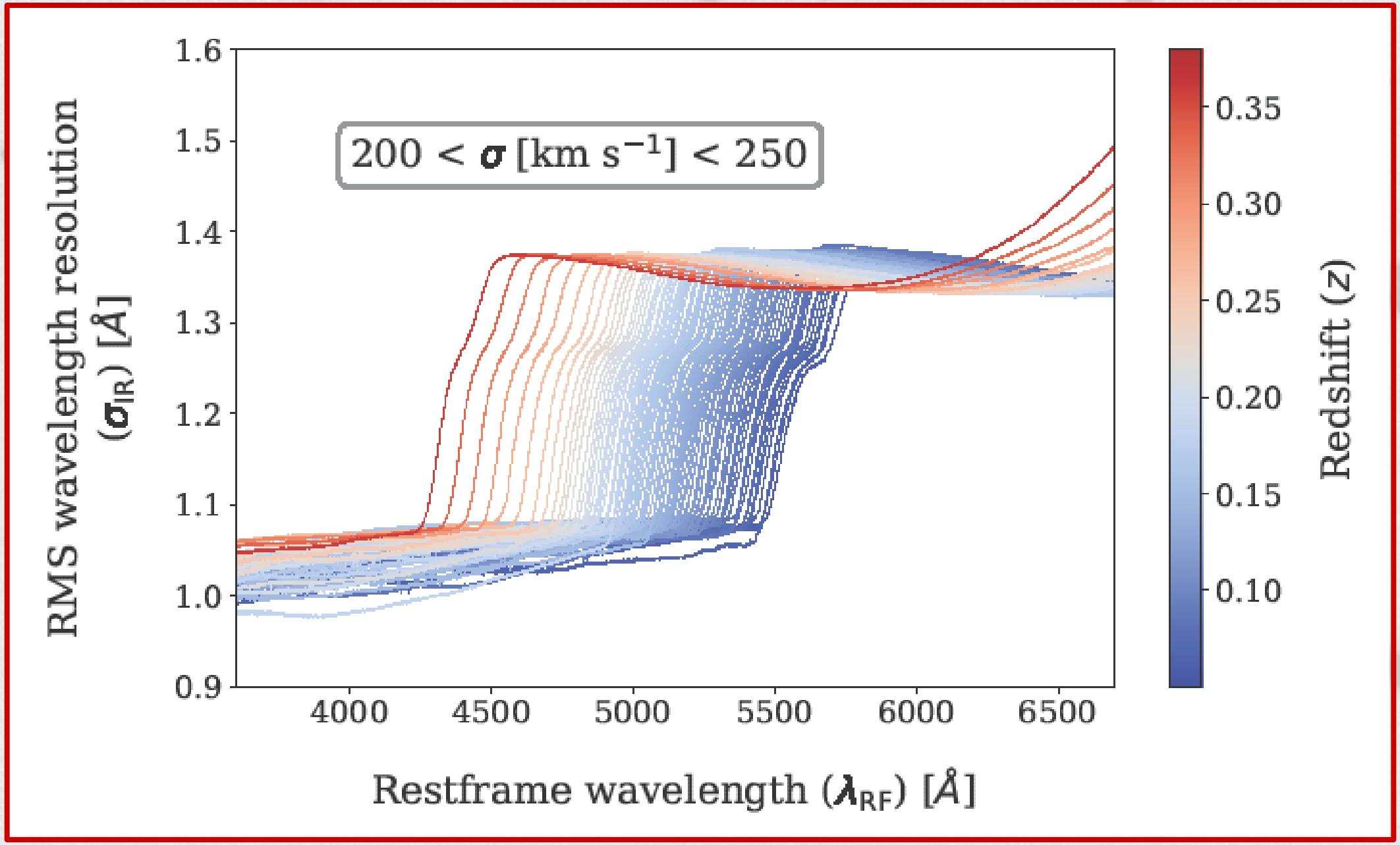
→ Using LRGs data from BOSS/eBOSS/DESI we can get a measurement of H/H_0. Combined with spatial statistics, we can get positions in the $\mathrm{H}/\mathrm{H}_0 - f\sigma_8$ plane.

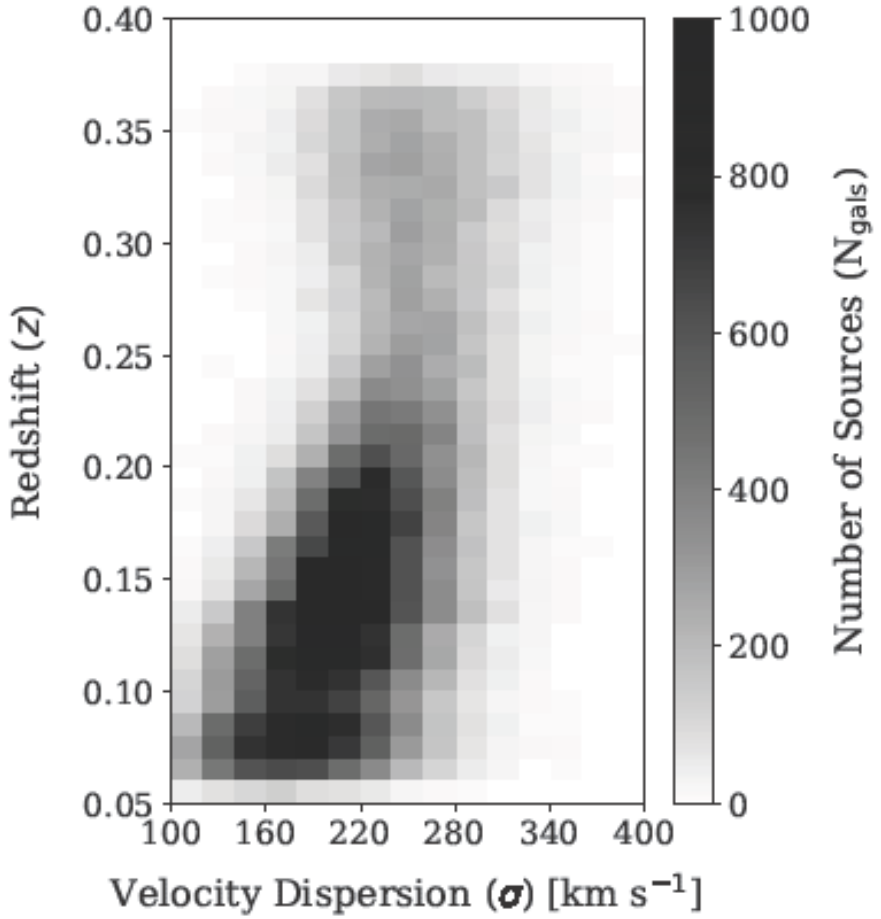
$$0.4 < z < 1.0 \rightarrow 1 < H/H_0 \lesssim 2$$

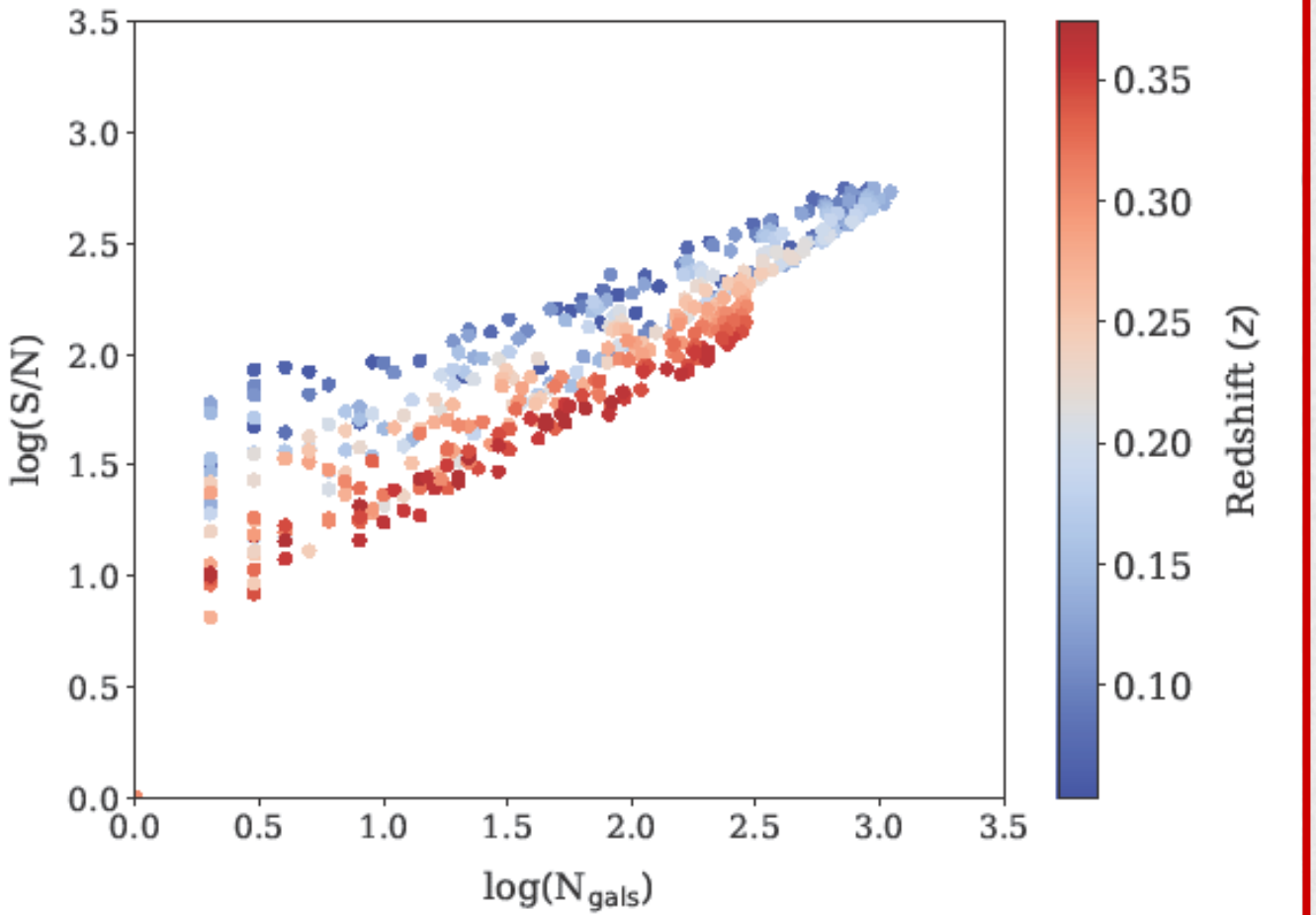
THANK YOU FOR YOUR ATTENTION!

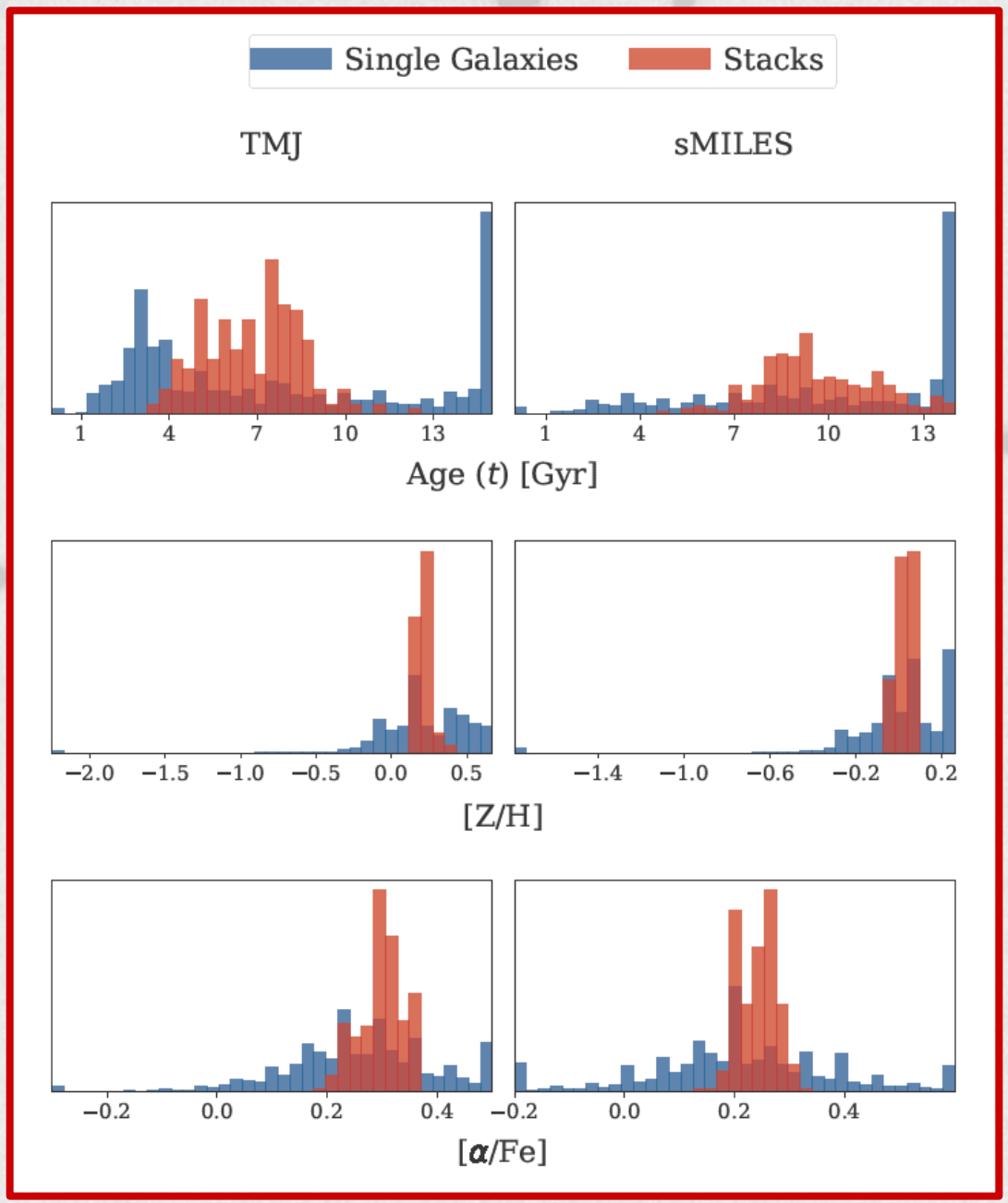

4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$(u-r)_0$
0.0
0.2
0.4
0.6
0.8
1.0
1.2
$(r-z)_0$
Parent
+/ VD
+/ SQL query
+/ Spec Cut
Holden+12

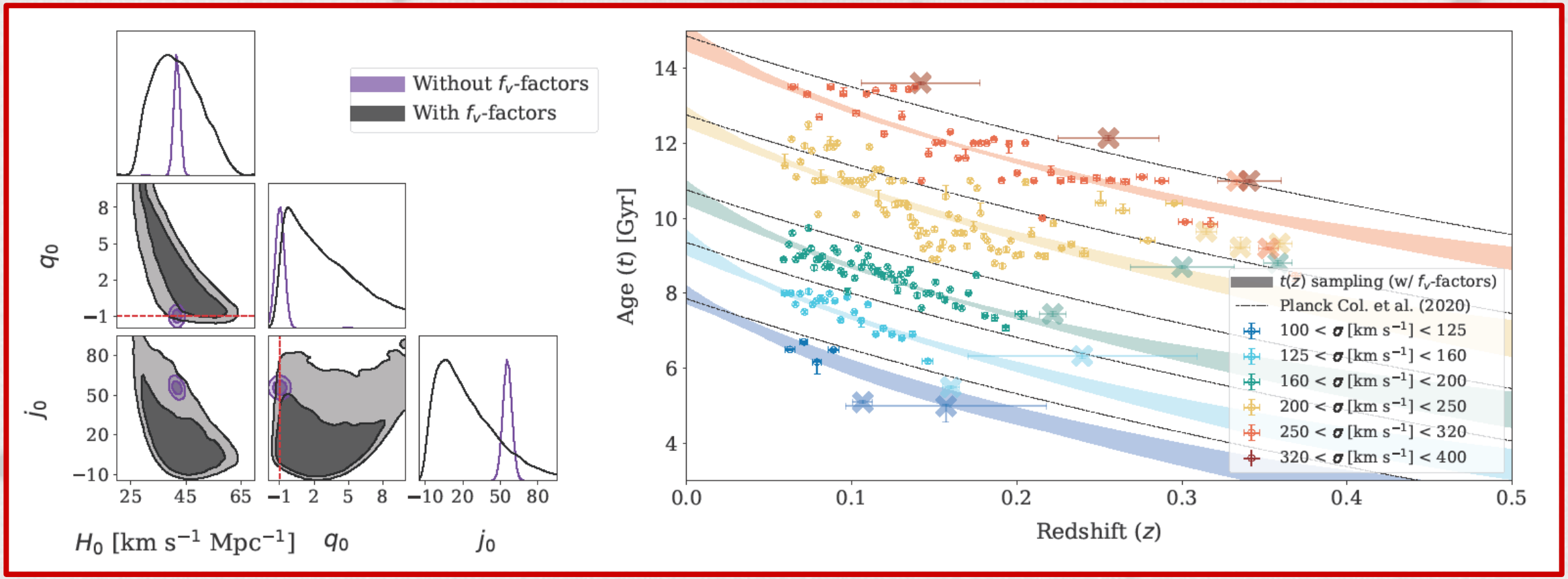

Parent Sample
Query Sample
Final Sample
N Galaxies (×1000)
D_n4000
$H\delta_A$
$H\gamma_A$
$H\beta$

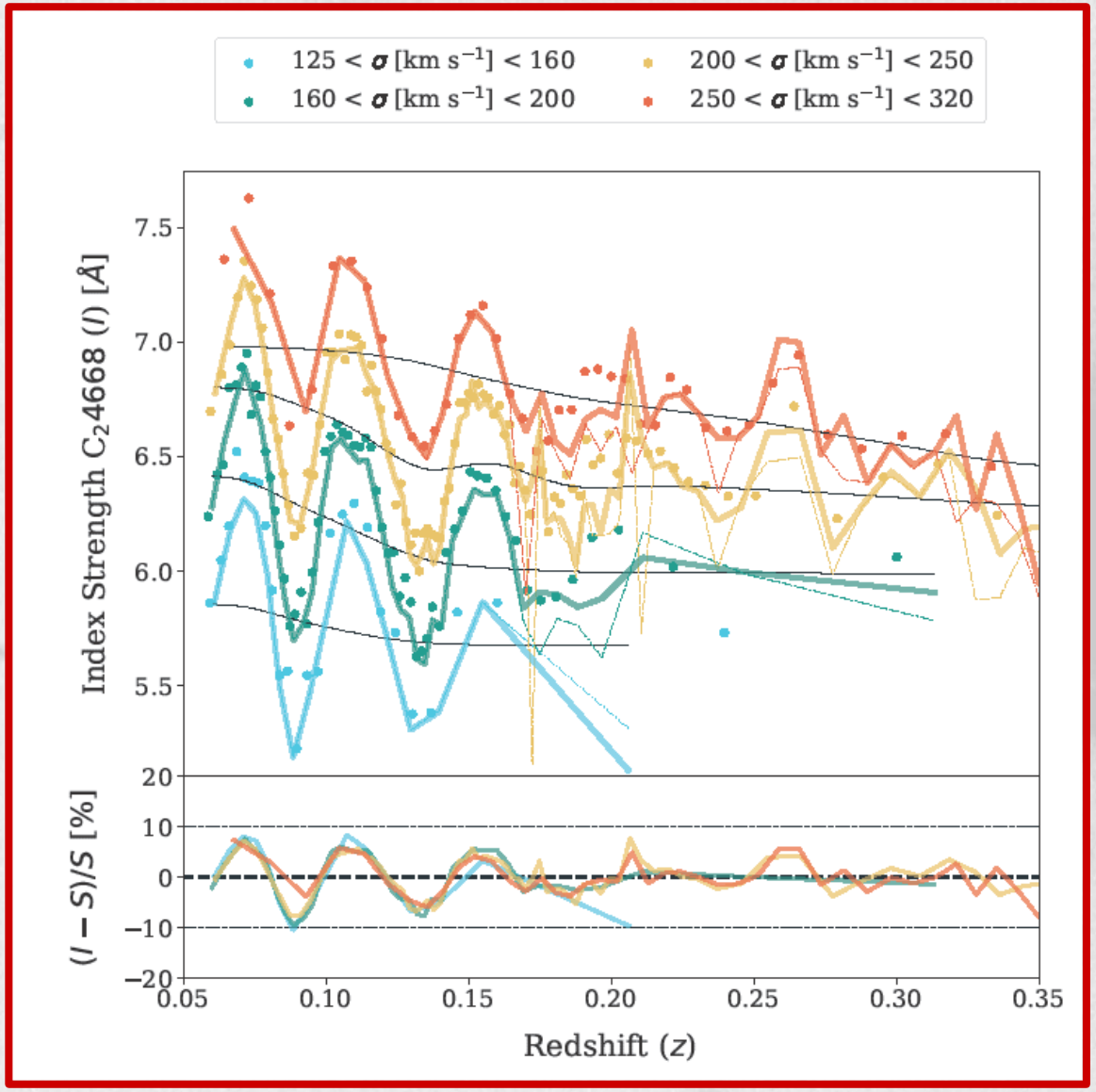

$200 < \sigma\,[\mathrm{km\ s^{-1}}] < 250$
RMS wavelength resolution (σ_{IR}) [Å]
Restframe wavelength (λ_{RF}) [Å]
Redshift (z)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
4000
4500
5000
5500
6000
6500
0.35
0.30
0.25
0.20
0.15
0.10

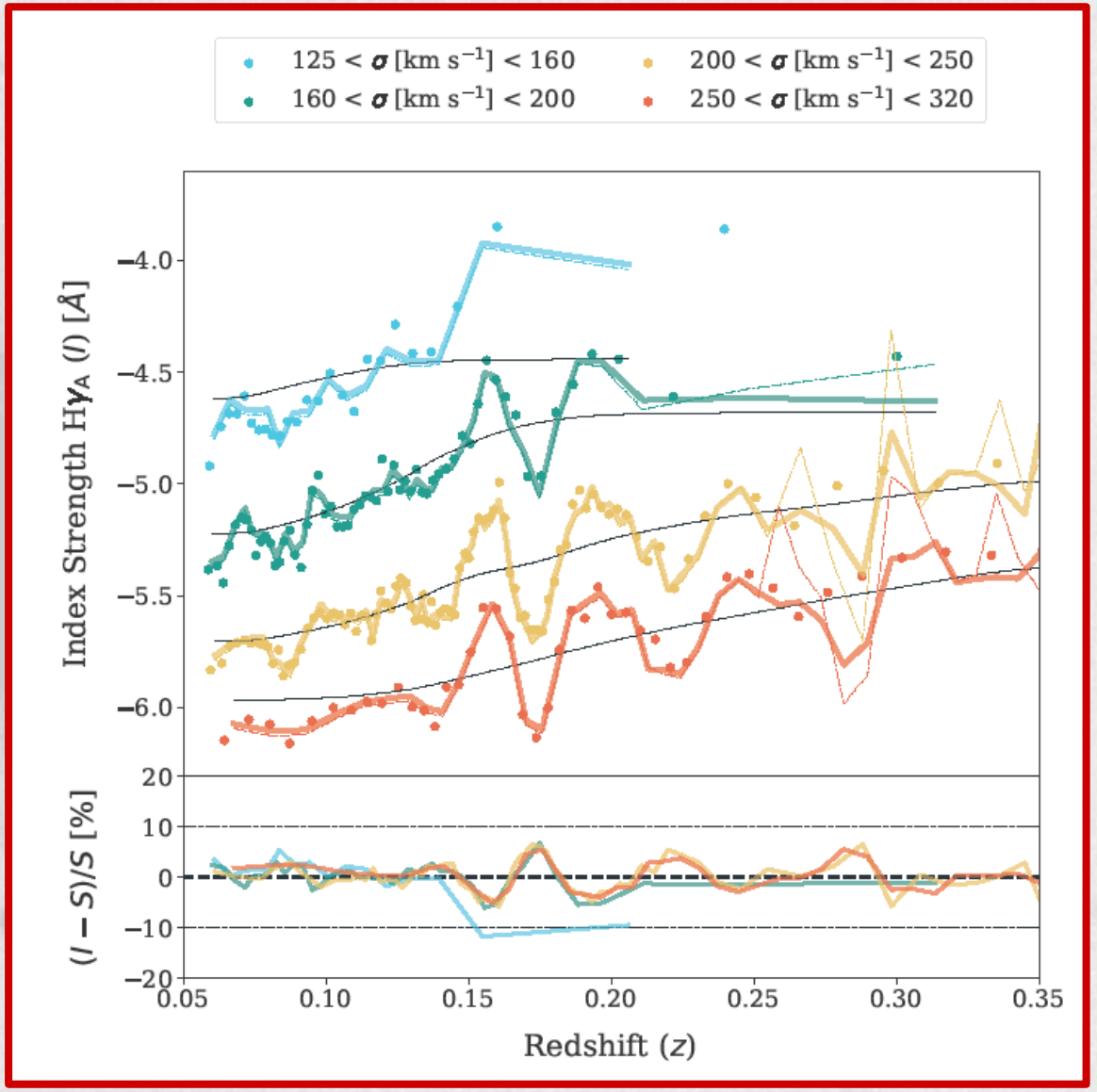

Redshift (z)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
100
160
220
280
340
400
Velocity Dispersion (σ) [km s^{-1}]
1000
800
600
400
200
0
Number of Sources (N$_{gals}$)

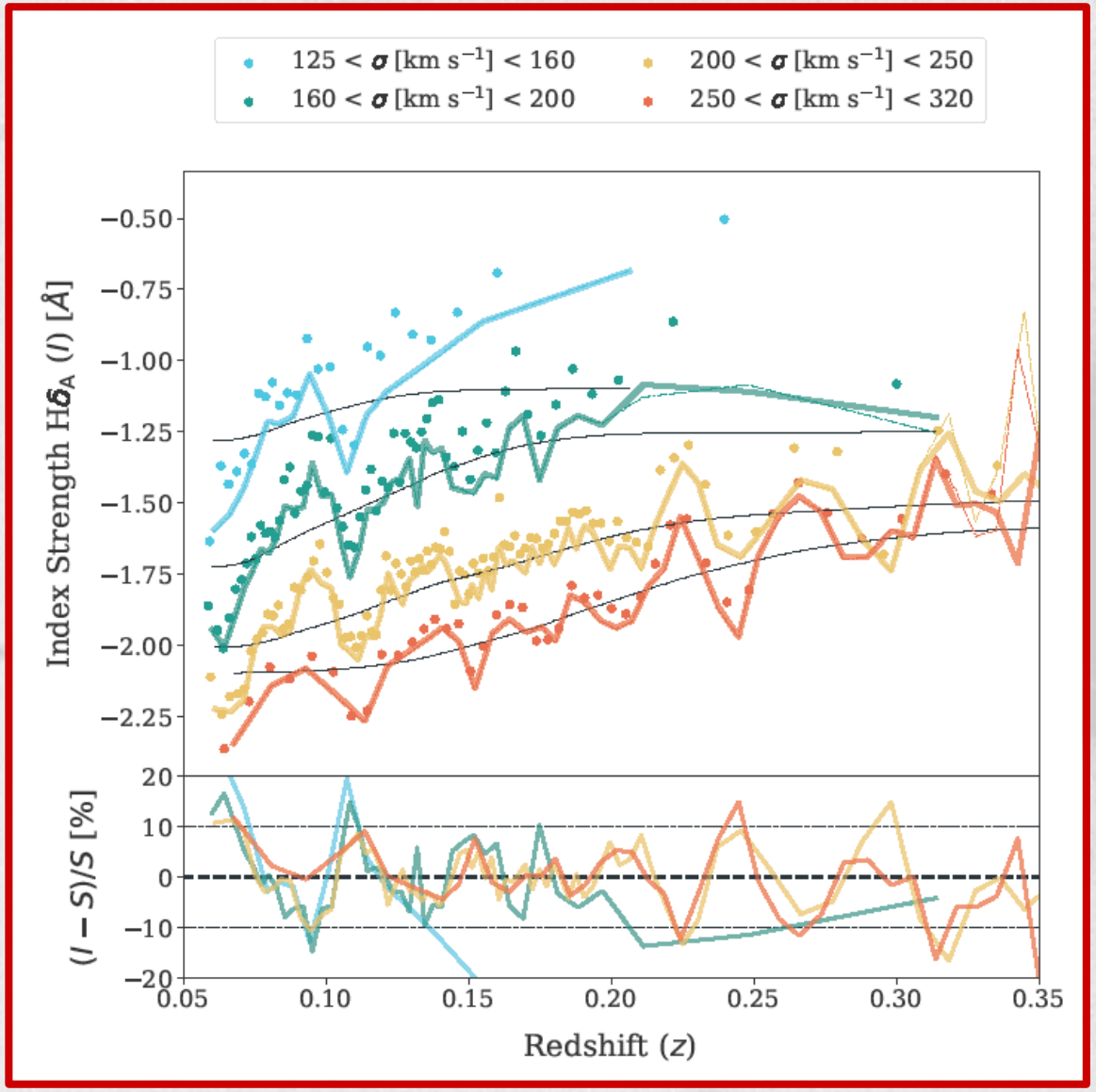

log(S/N)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
log(N$_{gals}$)
0.35
0.30
0.25
0.20
0.15
0.10
Redshift (z)

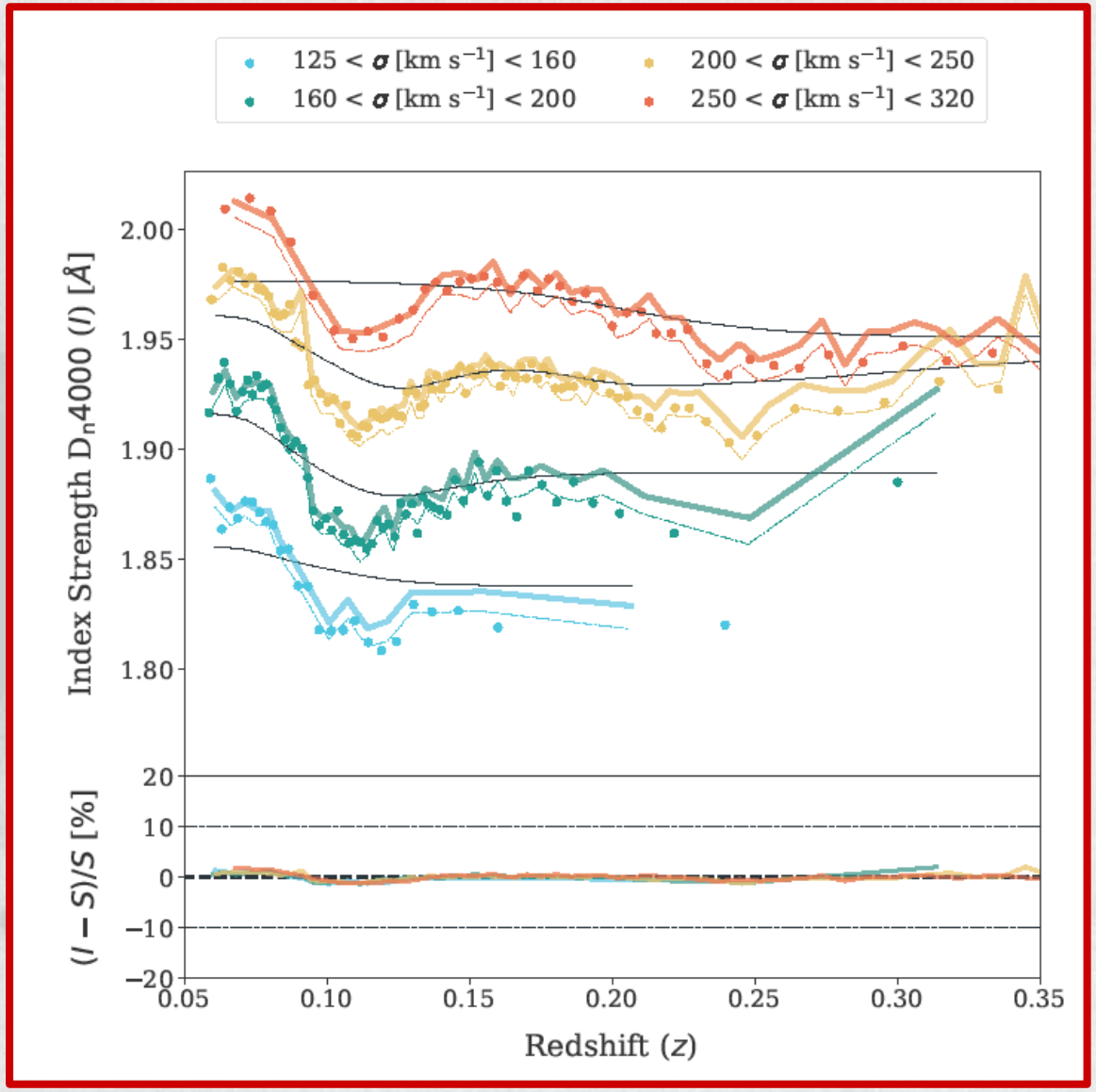

Single Galaxies
Stacks
TMJ
sMILES
1
4
7
10
13
Age (t) [Gyr]
−2.0
−1.5
−1.0
−0.5
0.0
0.5
−1.4
−1.0
−0.6
−0.2
0.2
[Z/H]
−0.2
0.0
0.2
0.4
[α/Fe]


Without f_v-factors
With f_v-factors
q_0
j_0
H_0 [km s^{-1} Mpc^{-1}]
q_0
j_0
Age (t) [Gyr]
Redshift (z)
$t(z)$ sampling (w/ f_v-factors)
Planck Col. et al. (2020)
100 < σ [km s^{-1}] < 125
125 < σ [km s^{-1}] < 160
160 < σ [km s^{-1}] < 200
200 < σ [km s^{-1}] < 250
250 < σ [km s^{-1}] < 320
320 < σ [km s^{-1}] < 400


125 < σ [km s⁻¹] < 160
160 < σ [km s⁻¹] < 200
200 < σ [km s⁻¹] < 250
250 < σ [km s⁻¹] < 320
Index Strength C2 4668 (I) [Å]
(I − S)/S [%]
Redshift (z)


125 < σ [km s⁻¹] < 160
160 < σ [km s⁻¹] < 200
200 < σ [km s⁻¹] < 250
250 < σ [km s⁻¹] < 320
Index Strength HγA (I) [Å]
(I − S)/S [%]
Redshift (z)


125 < σ [km s⁻¹] < 160
160 < σ [km s⁻¹] < 200
200 < σ [km s⁻¹] < 250
250 < σ [km s⁻¹] < 320
Index Strength HδA (I) [Å]
−0.50
−0.75
−1.00
−1.25
−1.50
−1.75
−2.00
−2.25
(I − S)/S [%]
20
10
0
−10
−20
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Redshift (z)


125 < σ [km s⁻¹] < 160
160 < σ [km s⁻¹] < 200
200 < σ [km s⁻¹] < 250
250 < σ [km s⁻¹] < 320
Index Strength Dn4000 (I) [Å]
2.00
1.95
1.90
1.85
1.80
(I − S)/S [%]
20
10
0
−10
−20
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Redshift (z)