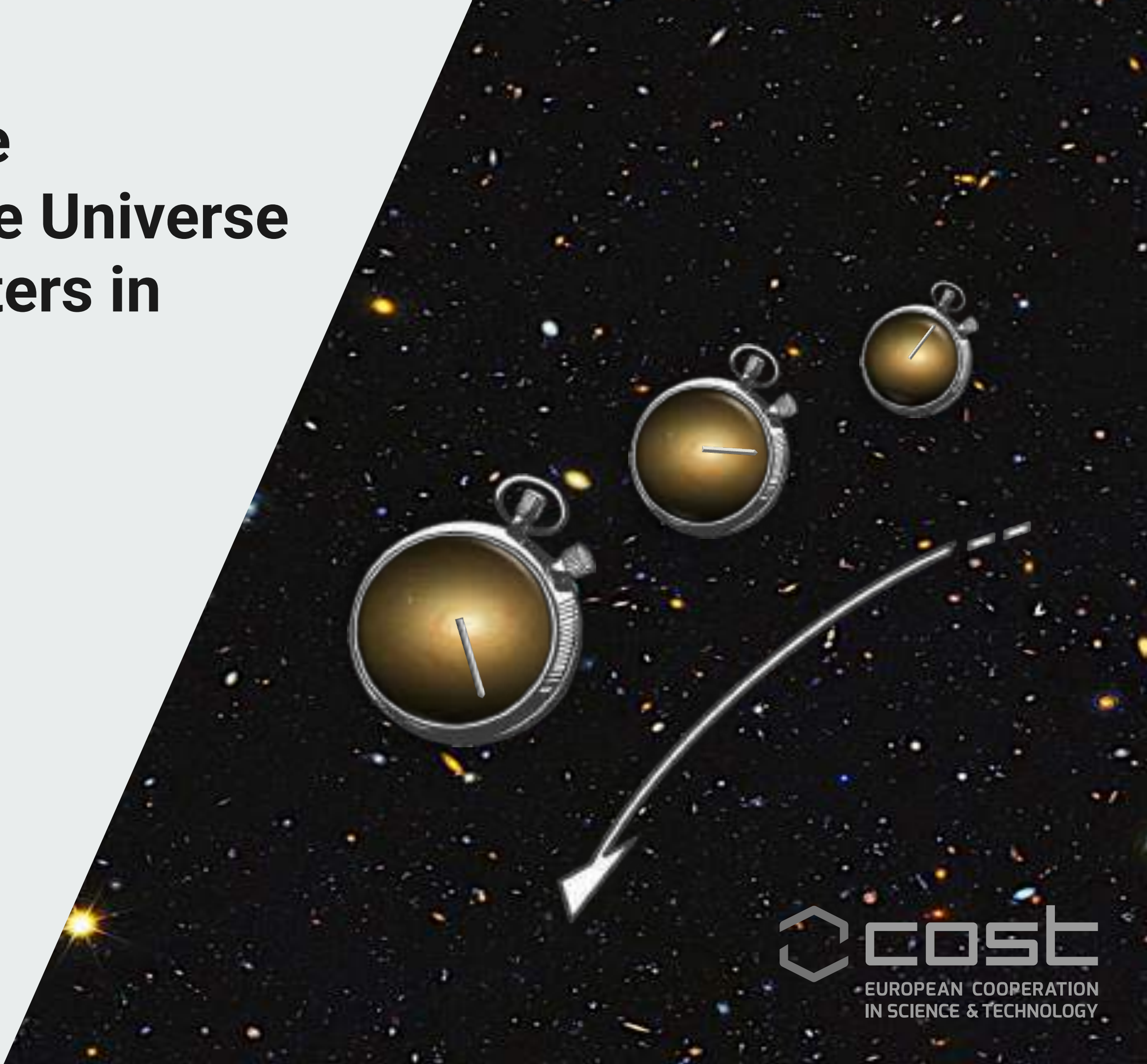
A new constraint on the expansion history of the Universe with cosmic chronometers in VANDELS

arXiv:2305.16387

ELENA TOMASETTI

PhD student
Department of Physics and Astronomy
University of Bologna

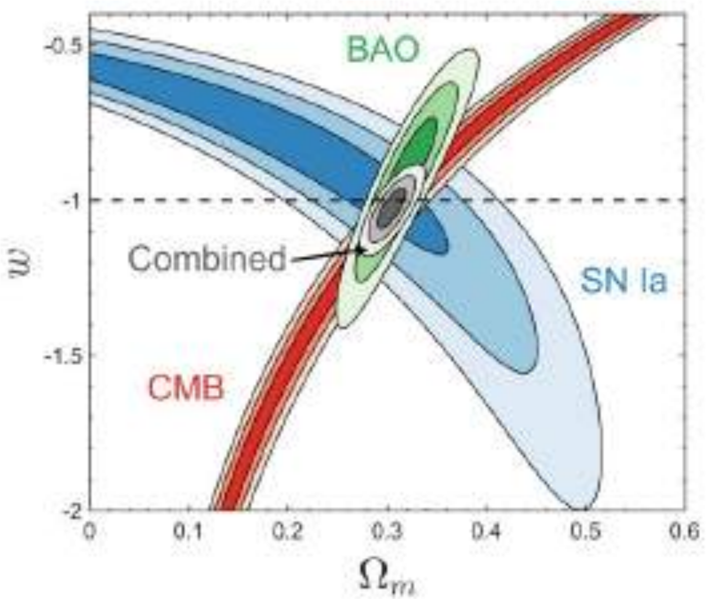
Supervisors:
Michele Moresco
Carmela Lardo
Andrea Cimatti



EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY

Scientific framework and aim of the project

Huterer et al. (2018)



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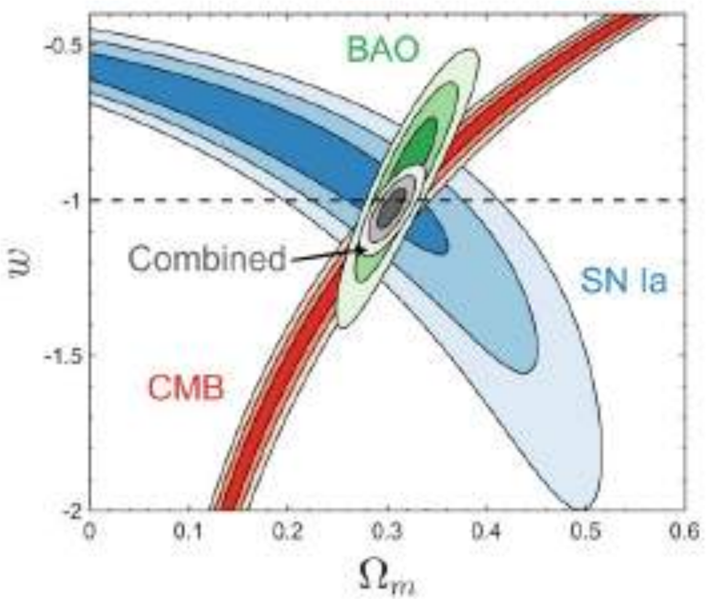

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However, the increasing precision of these measurements has highlighted **tensions** between early- and late-Universe probes (Verde et al. 2019)

⟶ it's important to find and explore new and non-standard methods! (Moresco et al. 2022)

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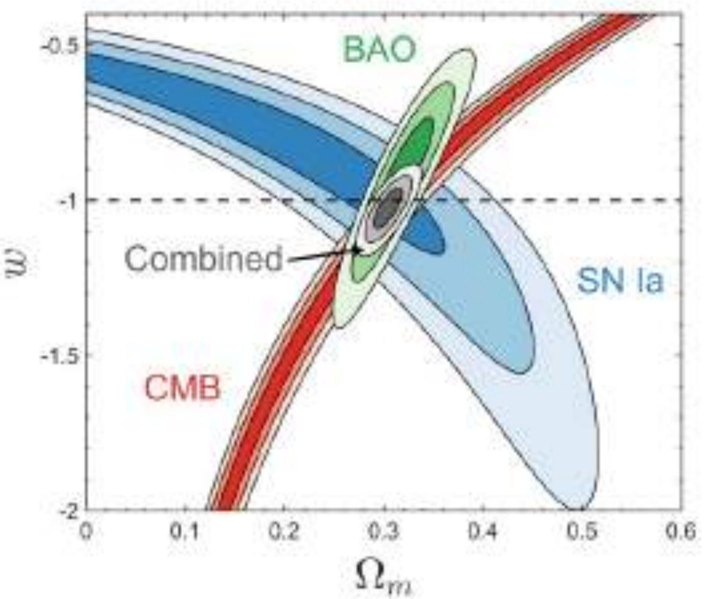

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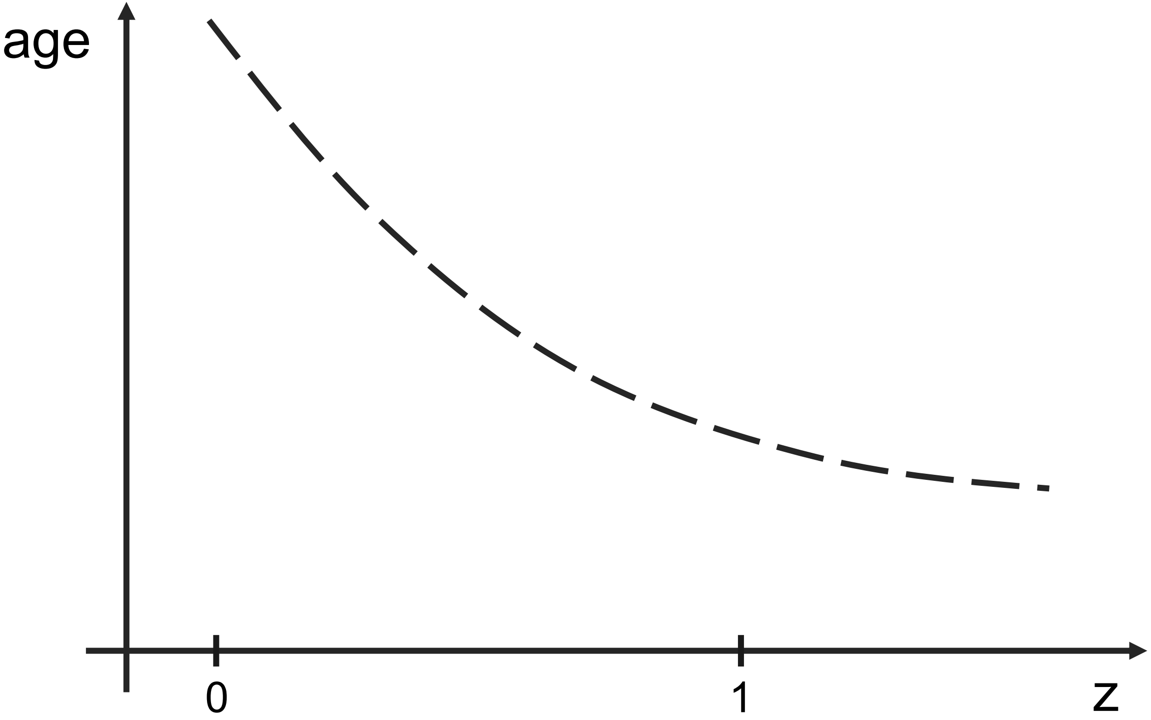
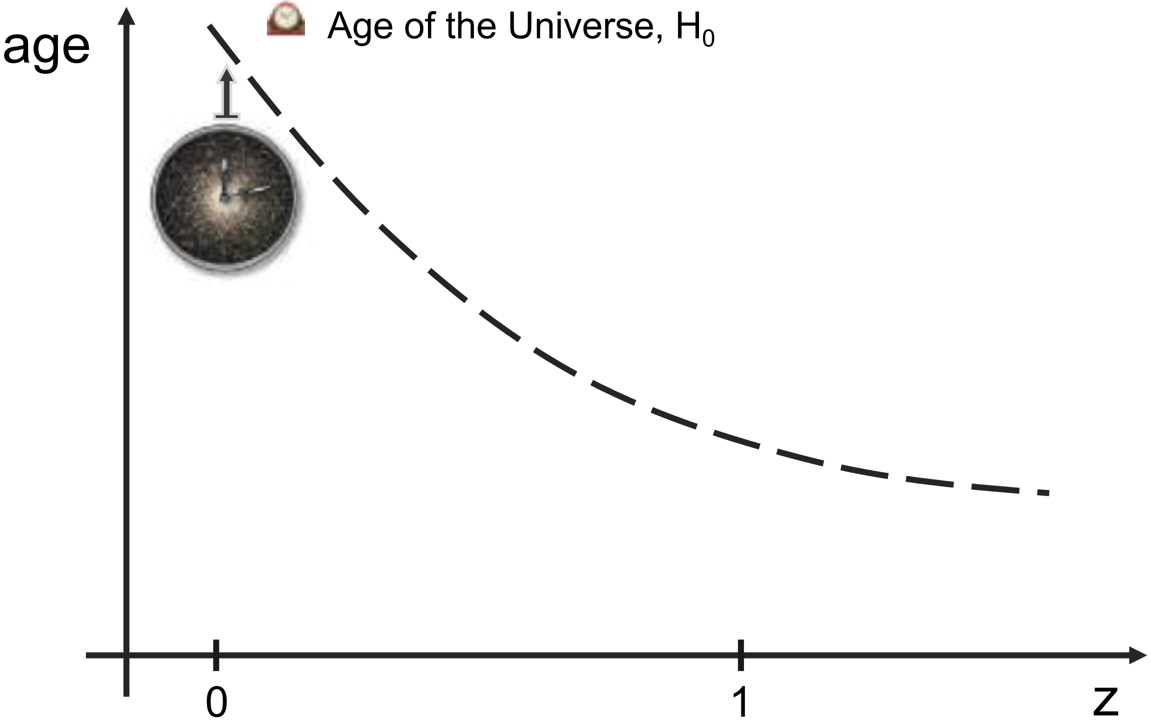
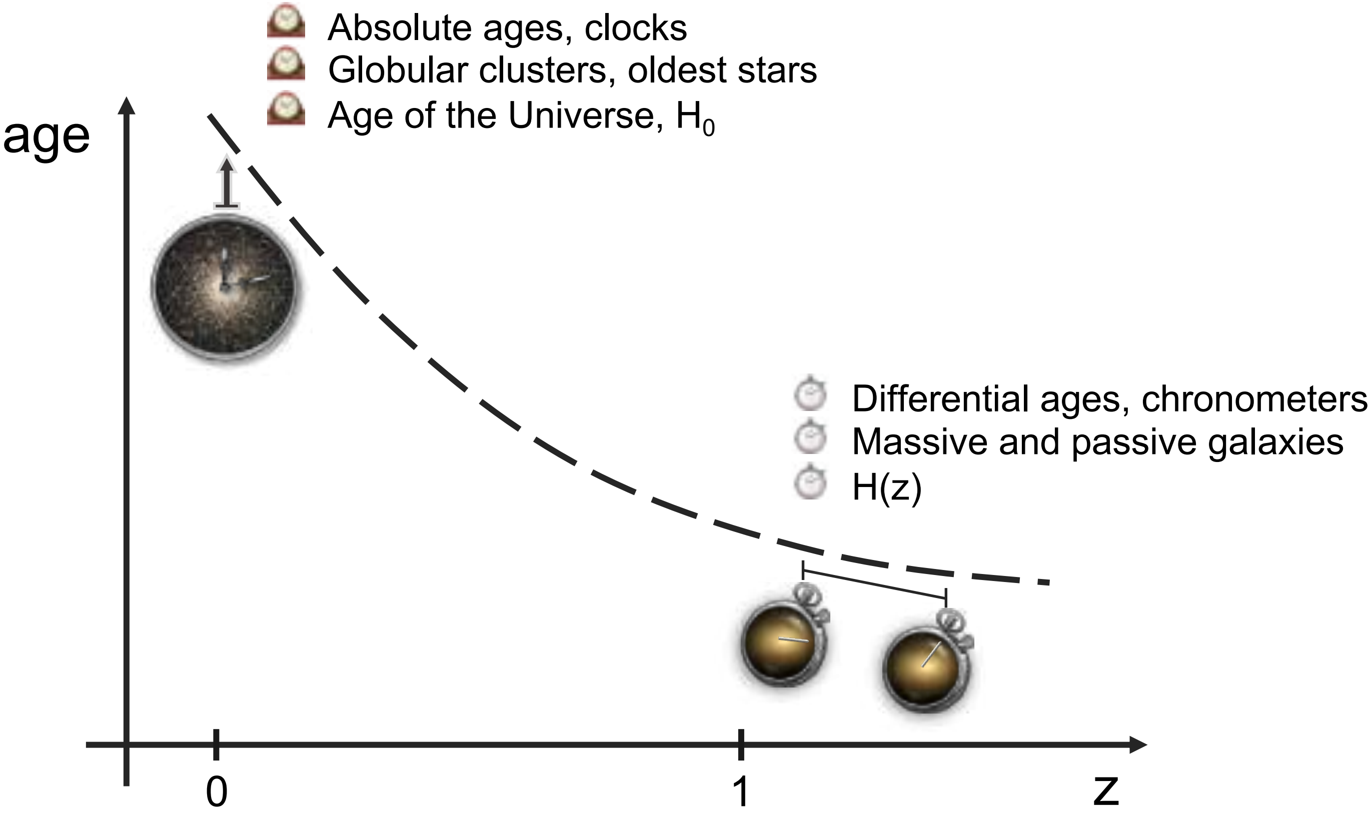
Aim: obtain new constraints on the expansion history of the Universe using **time** as tracer instead of luminosity (SNIa) or length (BAO).


age
0
1
z

- Absolute ages, clocks
- Globular clusters, oldest stars
- Age of the Universe, H_0





- Absolute ages, clocks
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- Differential ages, chronometers
- Massive and passive galaxies
- $H(z)$

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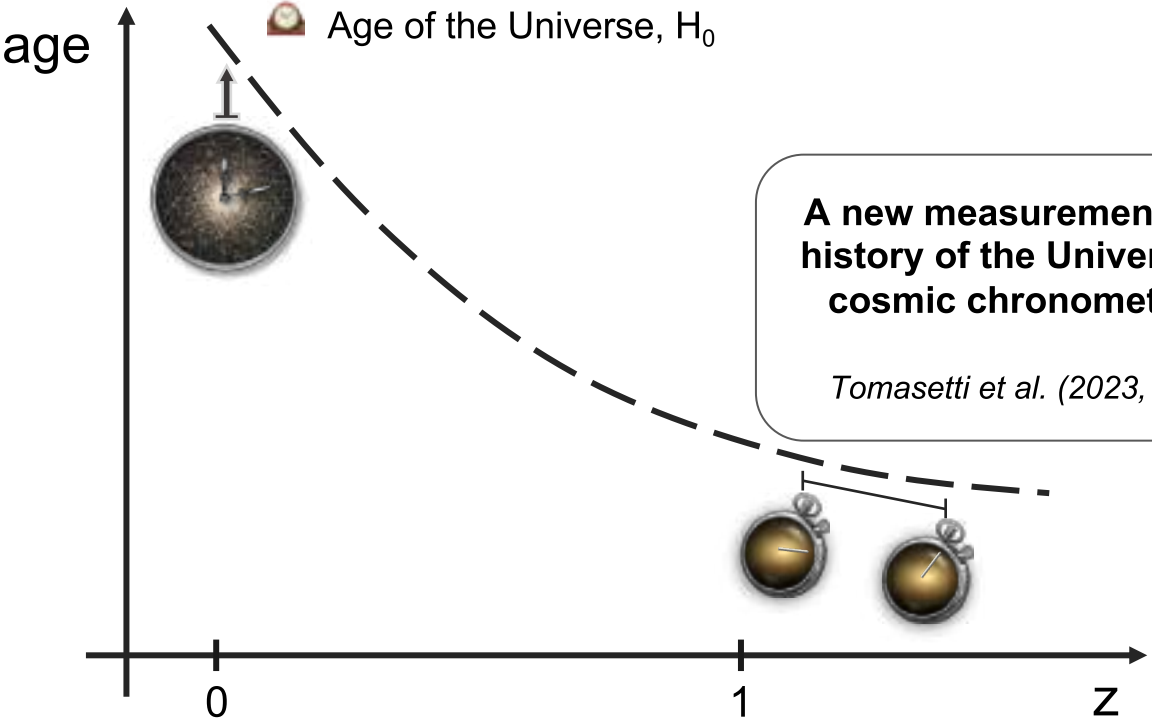
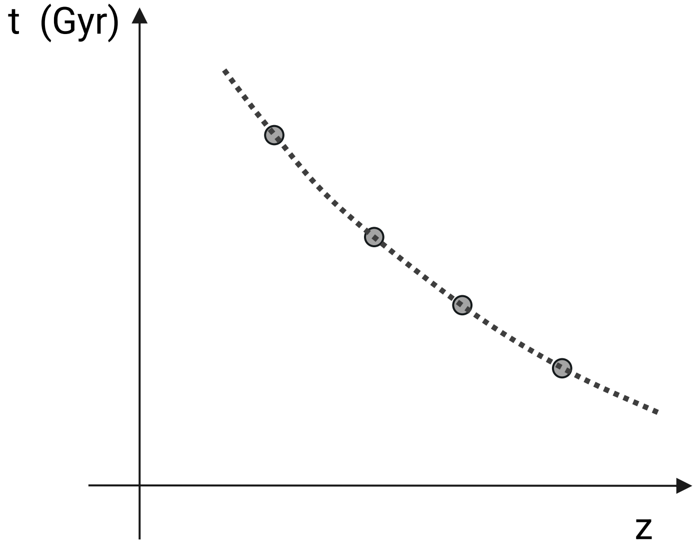


A new measurement of the expansion history of the Universe at $z = 1.26$ with cosmic chronometers in VANDELS

Tomasetti et al. (2023, arXiv:2305.16387)

The cosmic chronometers method



$$H(z) = \frac{\dot{a}}{a} = -\frac{1}{1+z}\frac{dz}{dt}$$

Jimenez & Loeb (2002)

By using cosmic chronometers it’s possible to measure *H(z)* with **no cosmological assumptions**, other than the cosmological principle and the FLRW metric.

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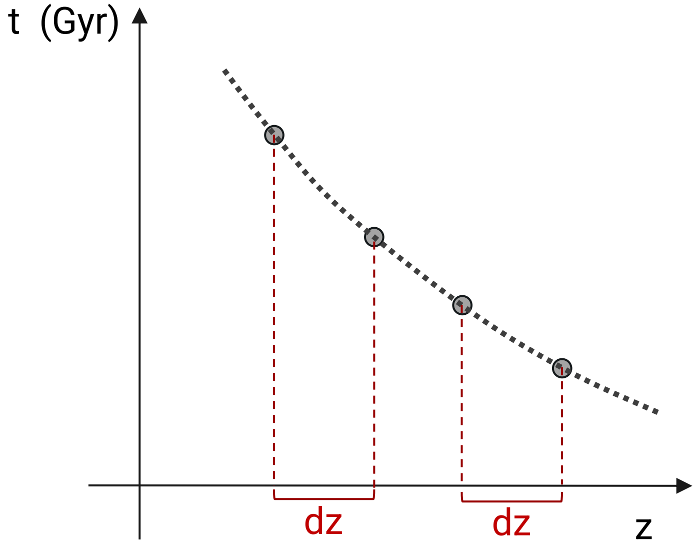

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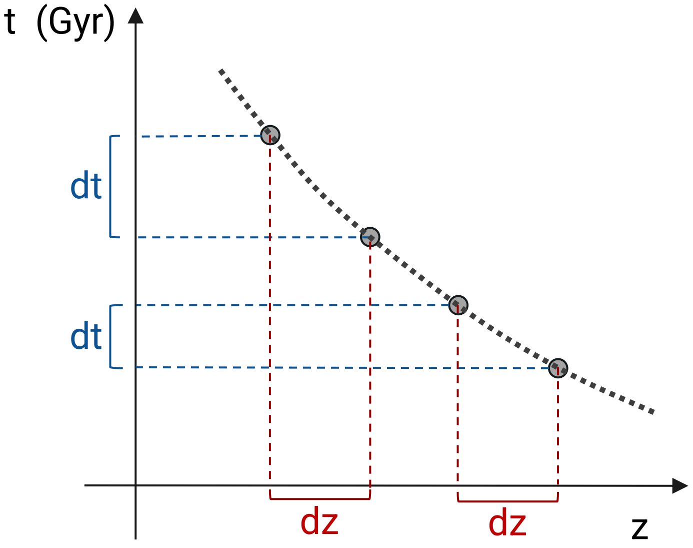

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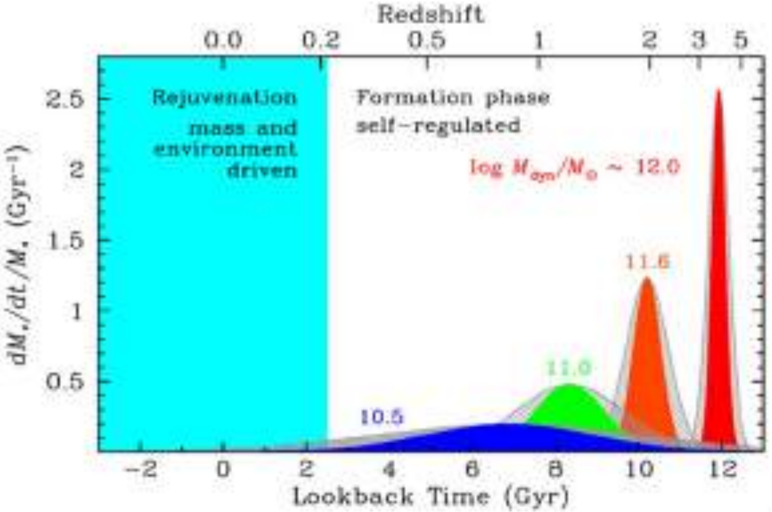
- best tracers are massive and passively evolving galaxies, which started “ticking” very soon and in-sync



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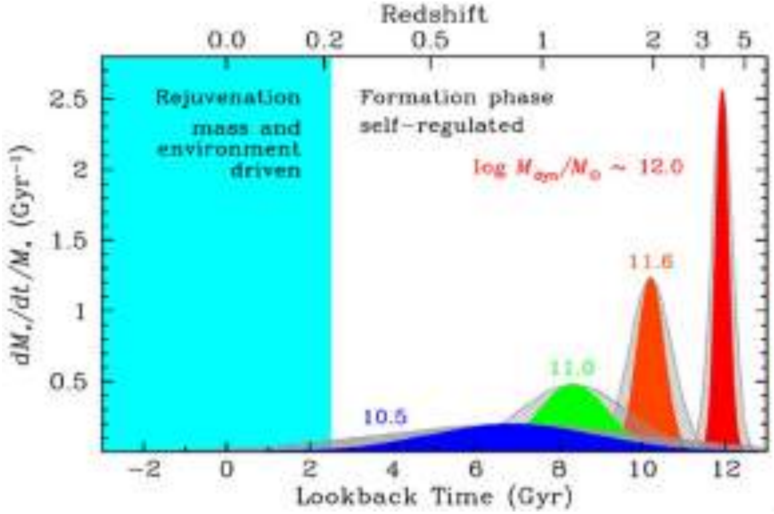

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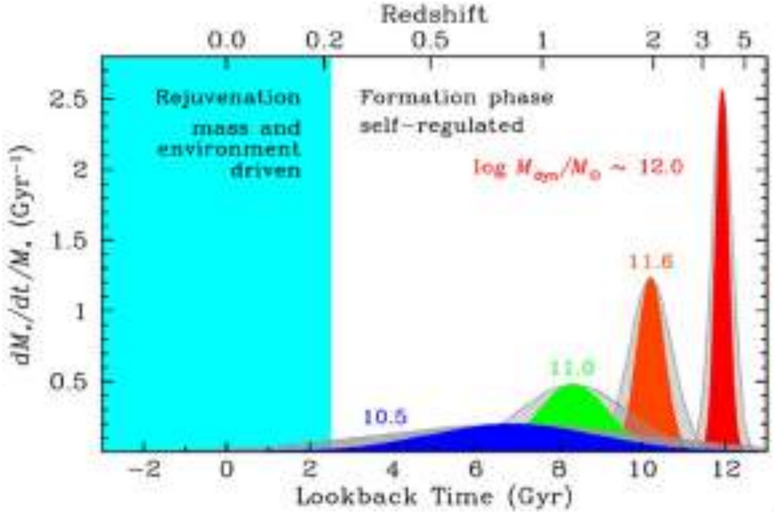

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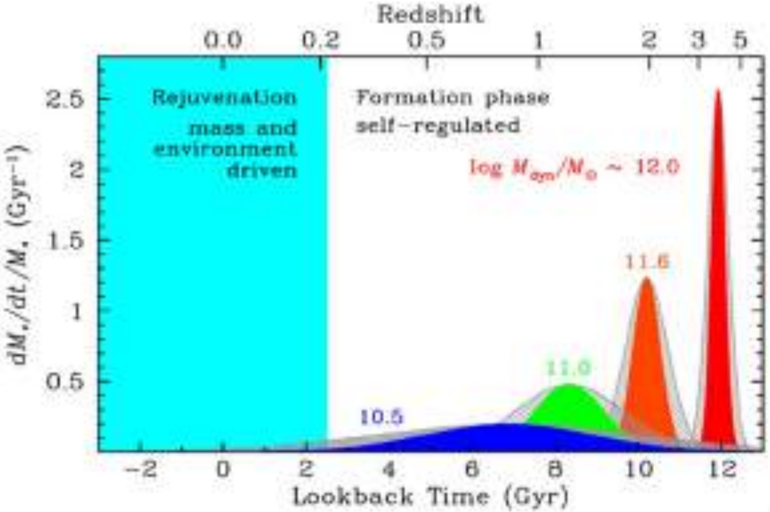

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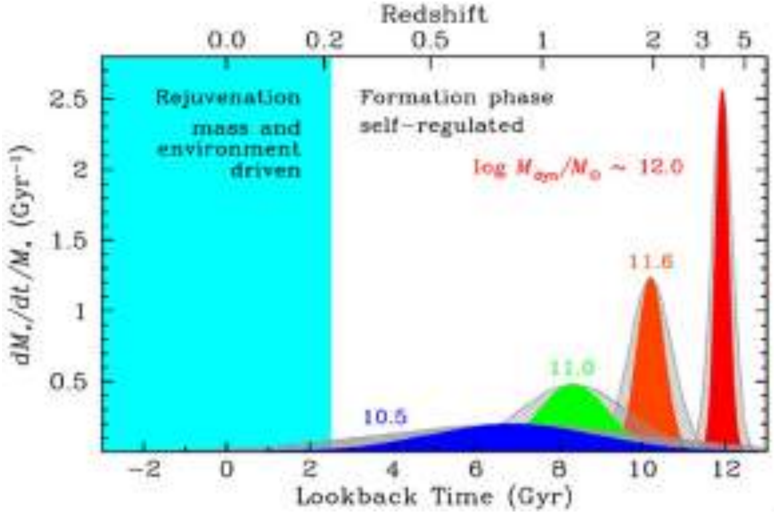

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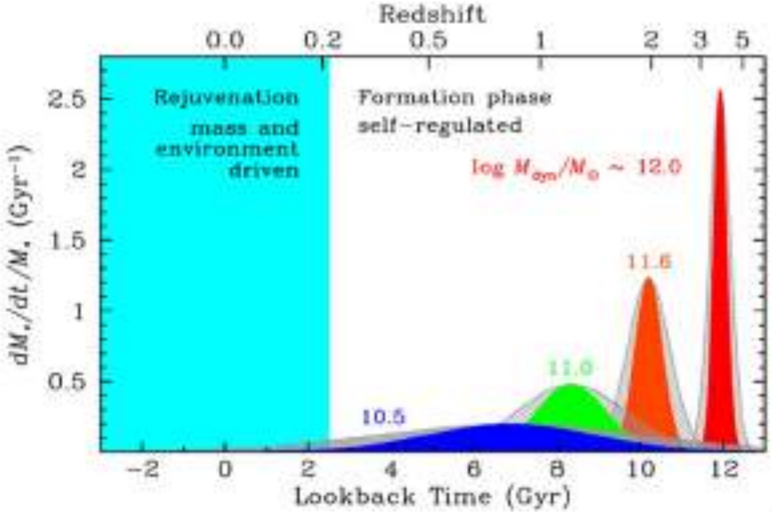

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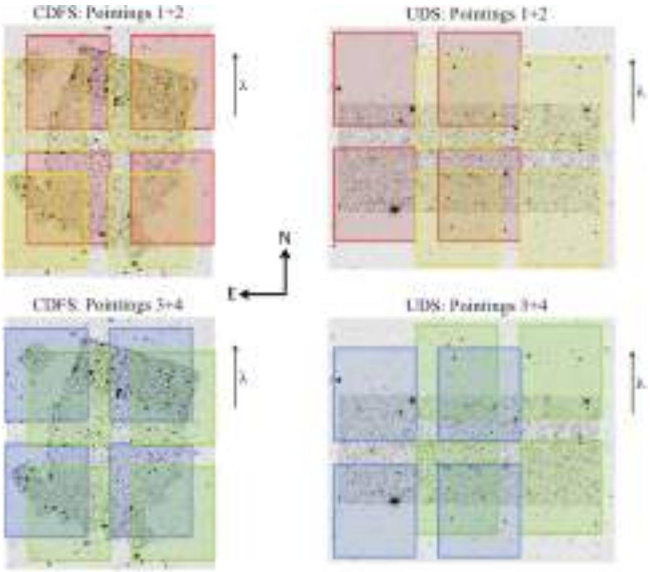
Main steps:

1. selection of a reliable sample of CC
2. robust measurements of differential ages accounting for systematics
3. computation of H(z) and its error

The VANDELS survey – data release 4

VANDELS is a deep optical spectroscopic survey in the CANDELS UDS and CDFS fields covering an area of 0.2 deg^2

INSTRUMENT	VIMOS spectrograph on VLT (480 – 1000 nm)
TARGET	different pop. of high-z galaxies
SPECTRAL RESOLUTION	R ~ 580
SIGNAL-TO-NOISE	S/N ~ 10
ANCILLARY DATA	photometry from near-UV to mid-IR



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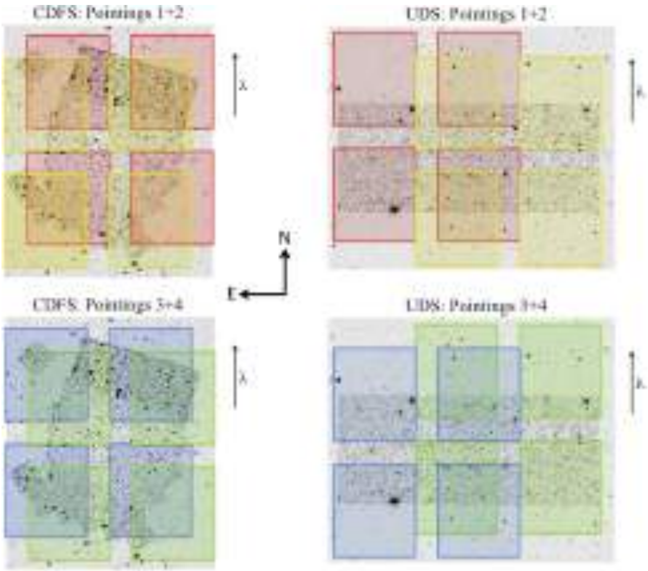

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CDFS	201	123	604	47	44	1019
UDS	216	155	655	10	32	1068
TOT	**417**	**278**	**1259**	**57**	**76**	**2087**

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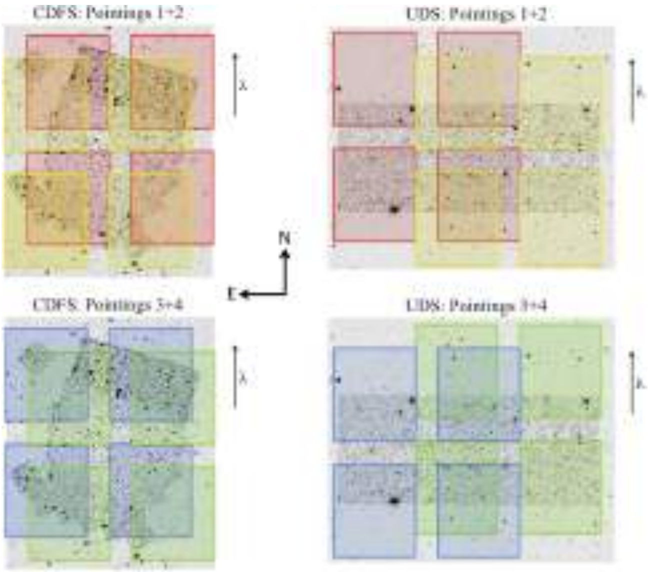

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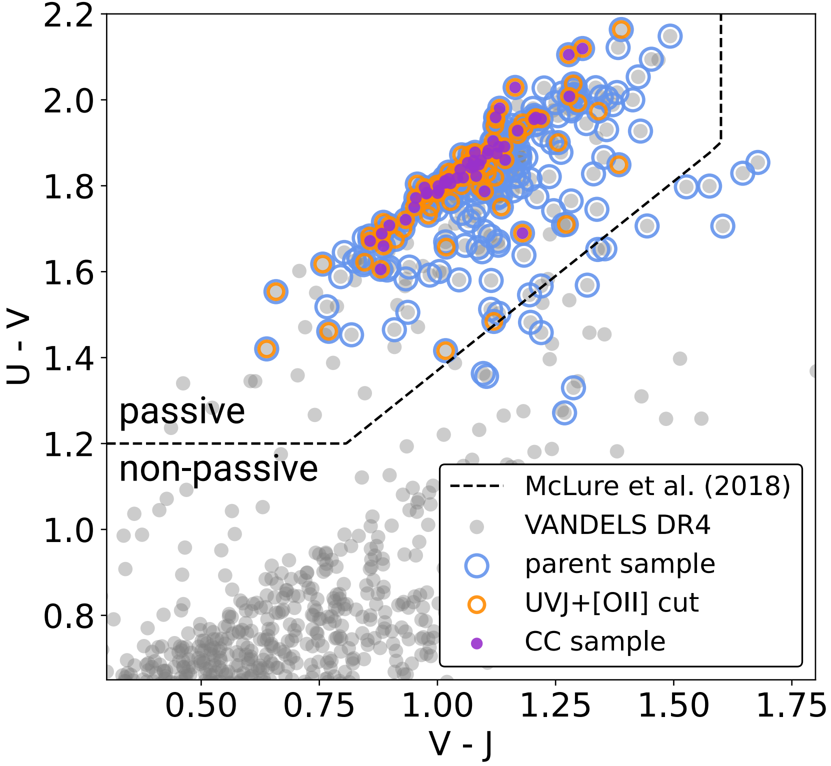
Selecting an optimal sample of cosmic chronometers in VANDELS



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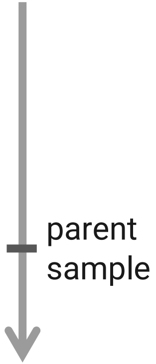

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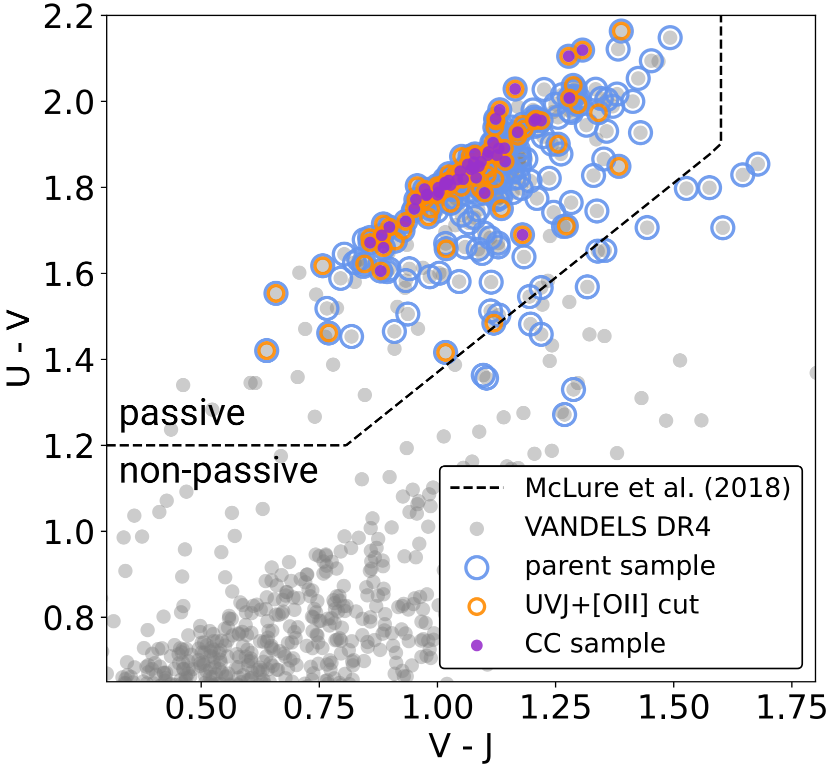

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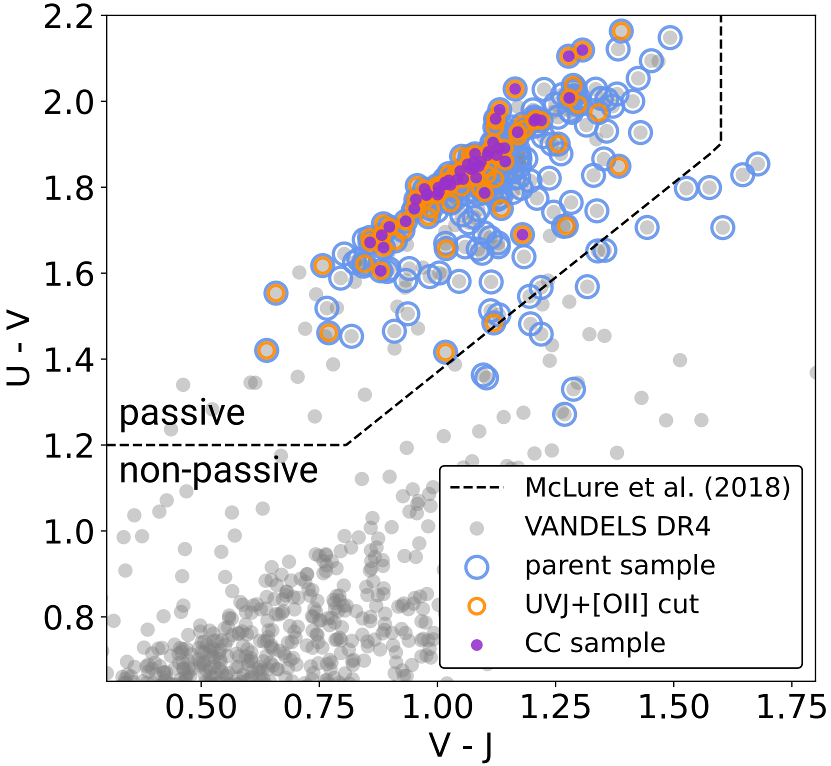

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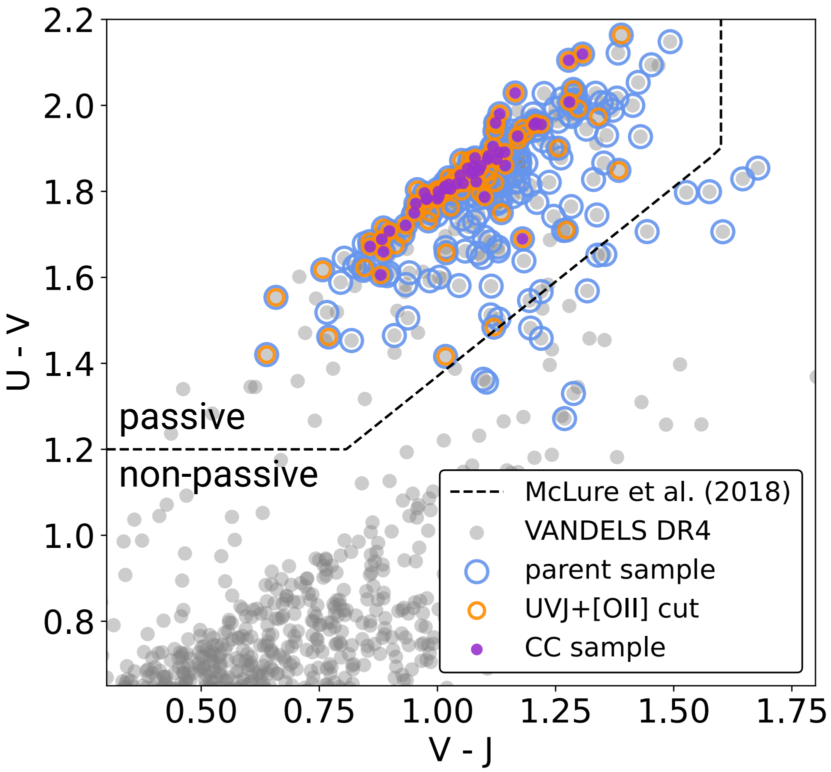

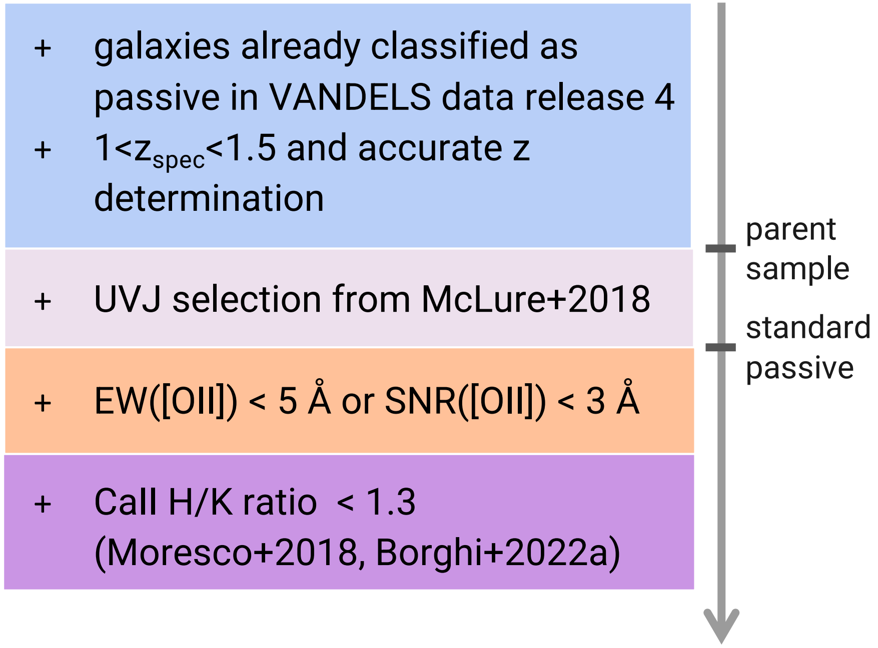

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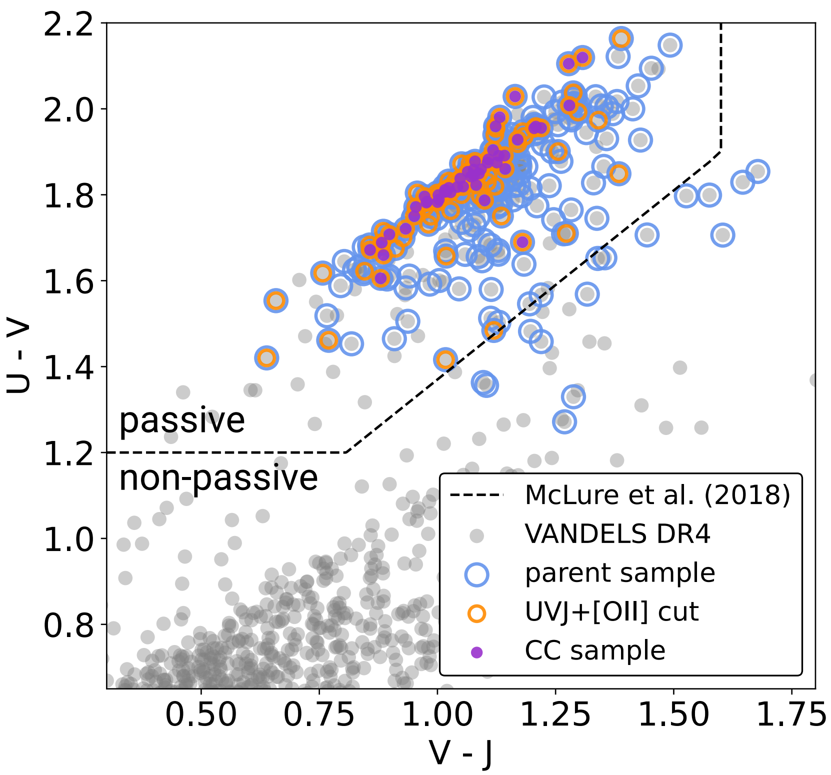

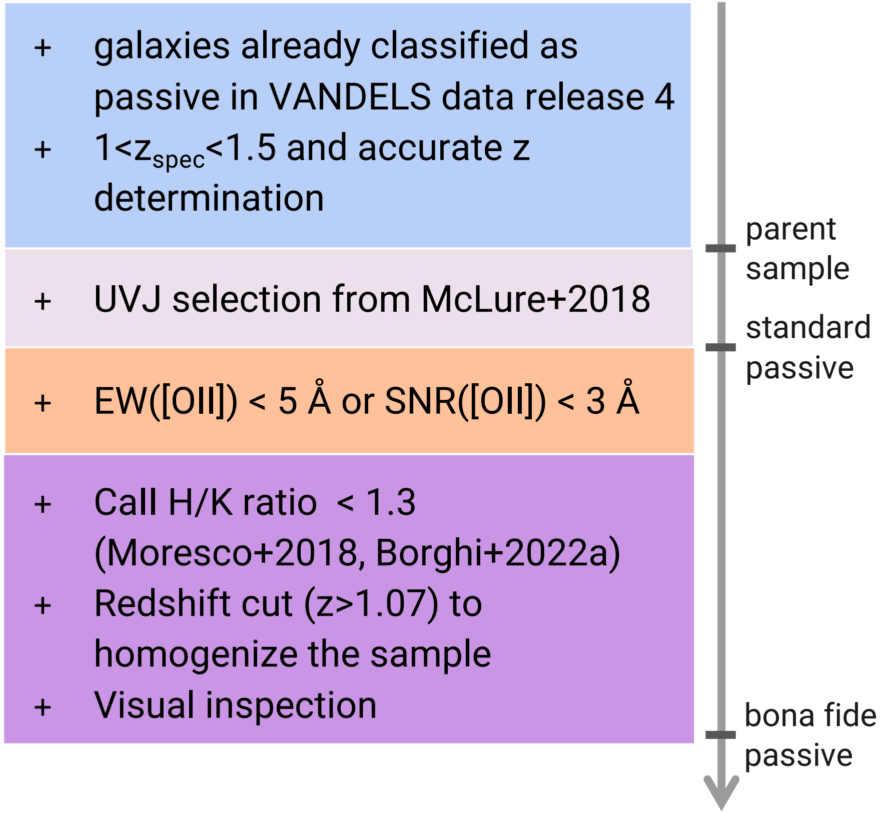

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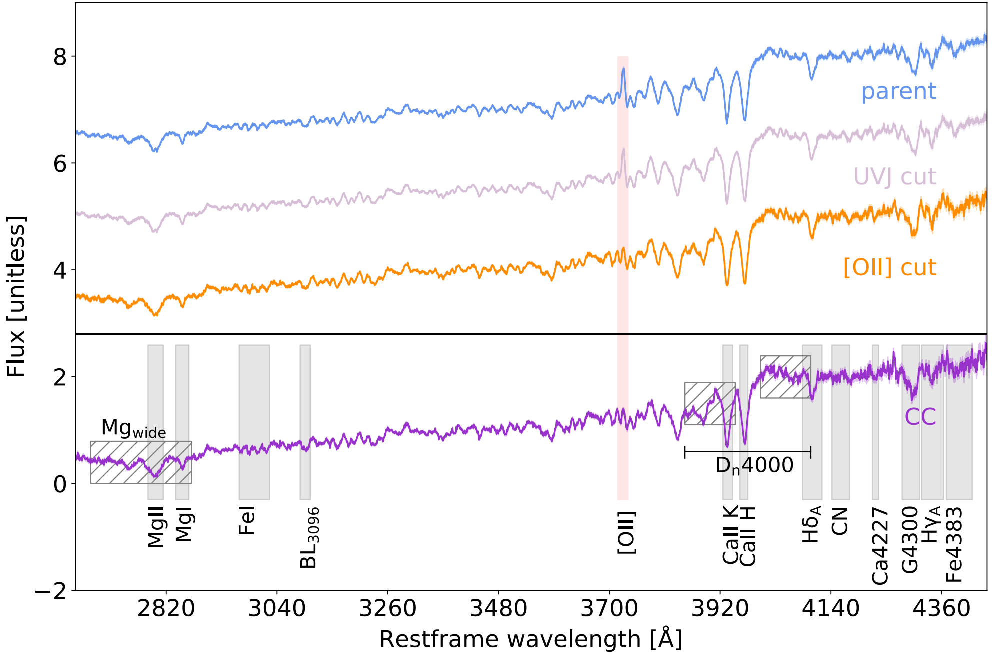

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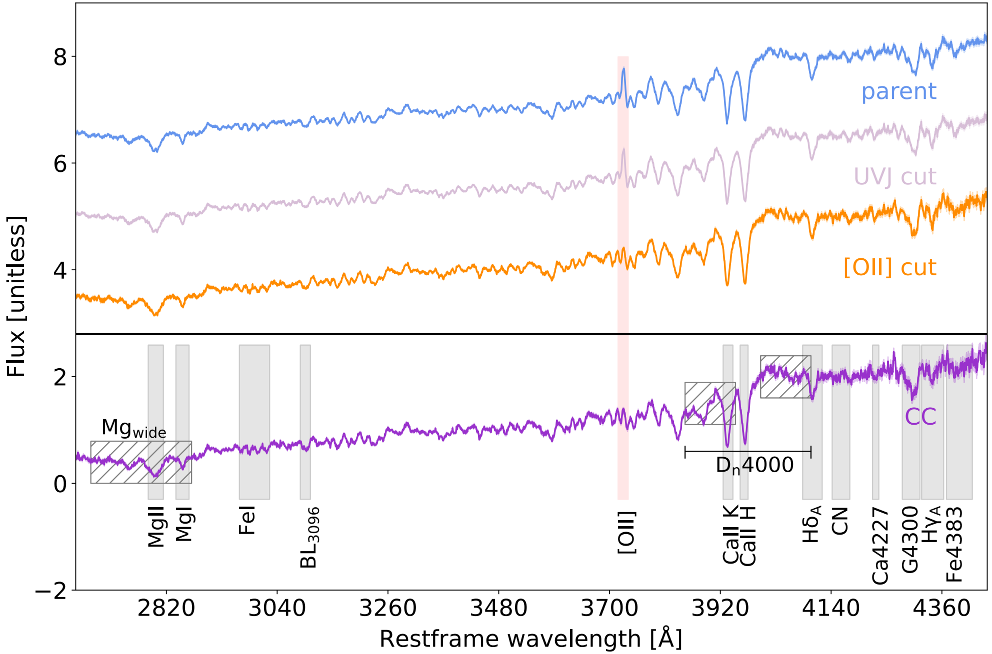

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49 cosmic chronometers

Reconstructing physical properties with full-spectral-fitting

Adopting a Bayesian full-spectral-fitting method (BAGPIPES, Carnall et al. 2018) we are able to fit **spectra and/or photometry** with a multi-component model and different SFHs. The main are:

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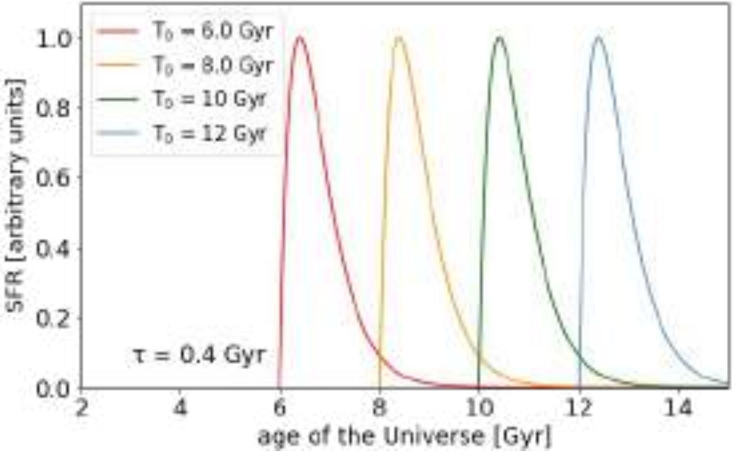
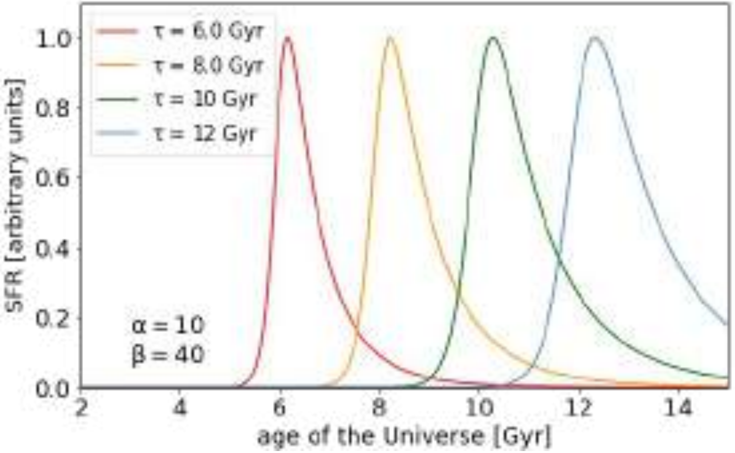


DOUBLE-POWER-LAW (DPL)

$$\mathrm{SFR(t)} \propto \left[\left(\frac{t}{\tau}\right)^{\alpha} + \left(\frac{t}{\tau}\right)^{-\beta}\right]^{-1}$$



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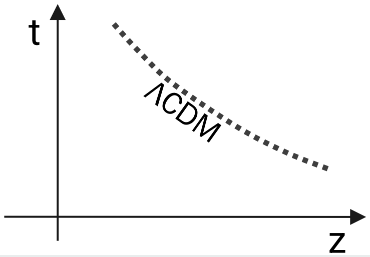
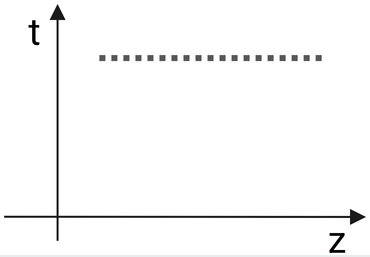


⟹

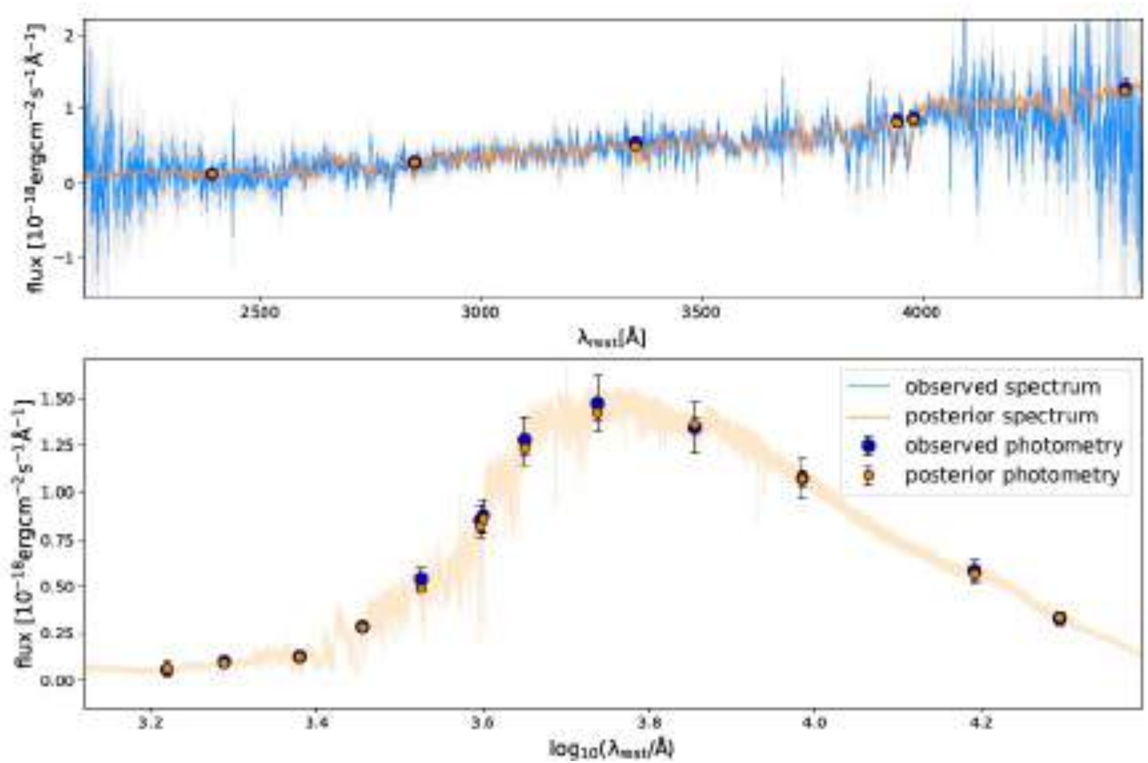
Flat prior on galaxy ages, so that they can vary in the range **0 - 20 Gyr**



Modification on the code tested and validated on the LEGA-C survey (Jiao et al., 2022)

Fit configuration

	Baseline configuration
data	spectra+photometry
SFH	delayed
age	0 – 20 [Gyr]
τ	0 – 1 [Gyr]
$Z/Z_\odot$	0.14 – 1.75
$A_{V,dust}$	0 – 4 [mag]

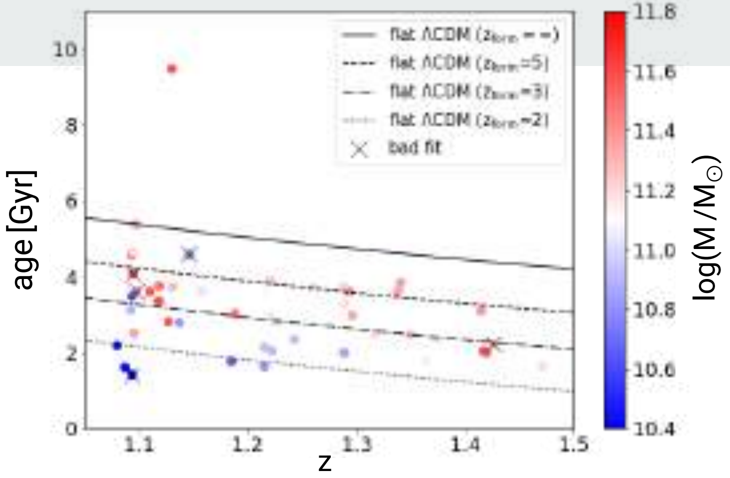


Results are visually checked to flag whether the fit is not properly converging (double peaked posterior, high χ^2 etc.)

Physical parameters of CC in VANDELS

For 44 galaxies the fit is successful and indicates:

- 95% of ages lower than age of the Universe in fΛCDM
- evidence of mass-downsizing



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- massive galaxies $\langle\log(M/M_\odot)\rangle = 11.21 \pm 0.05$
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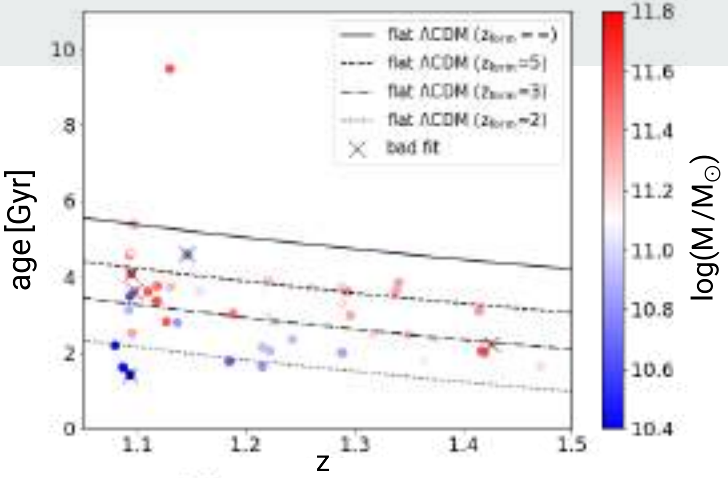

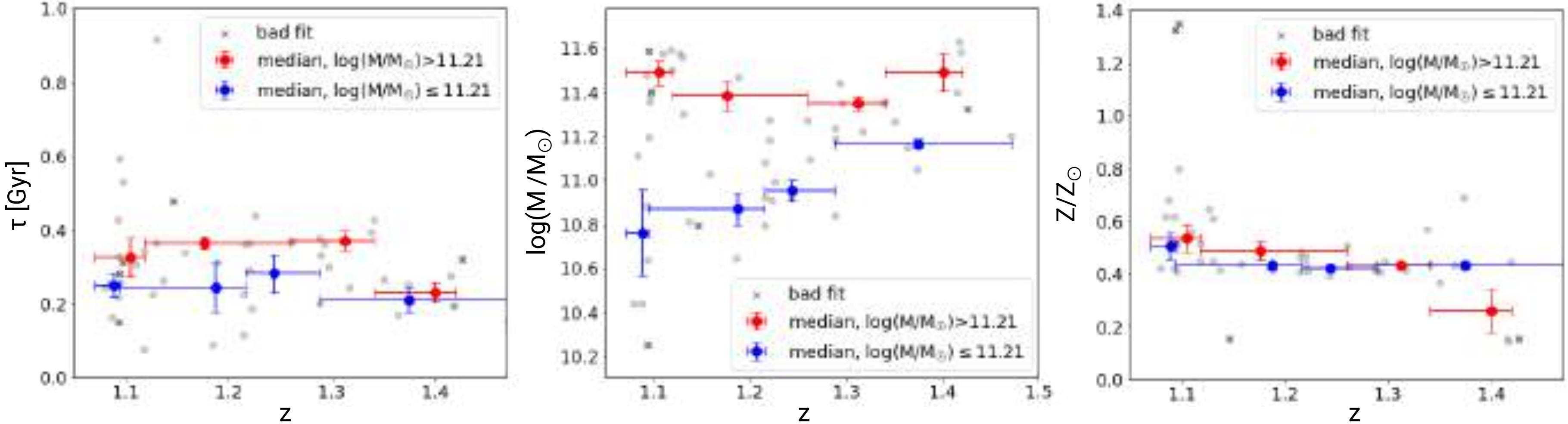

Physical parameters of CC in VANDELS

For 44 galaxies the fit is successful and indicates:

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- evidence of mass-downsizing
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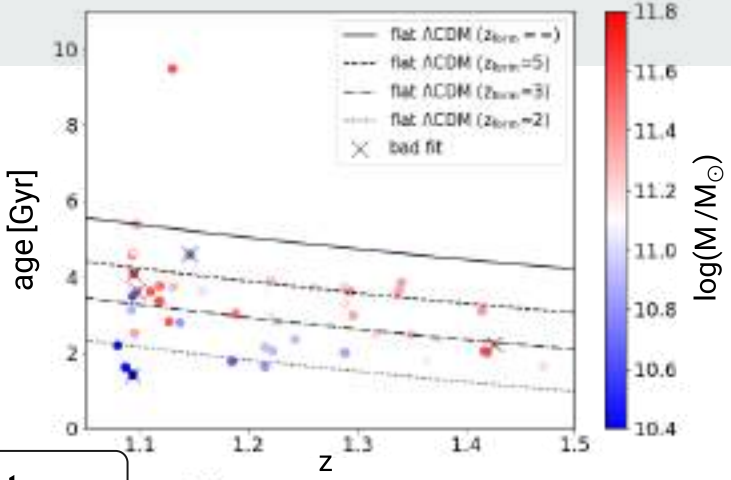
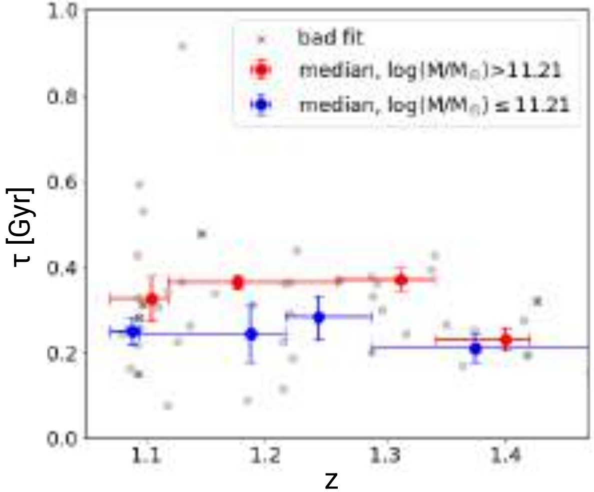
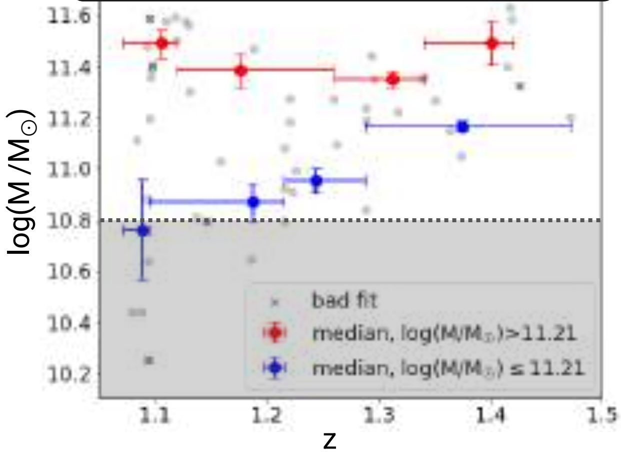
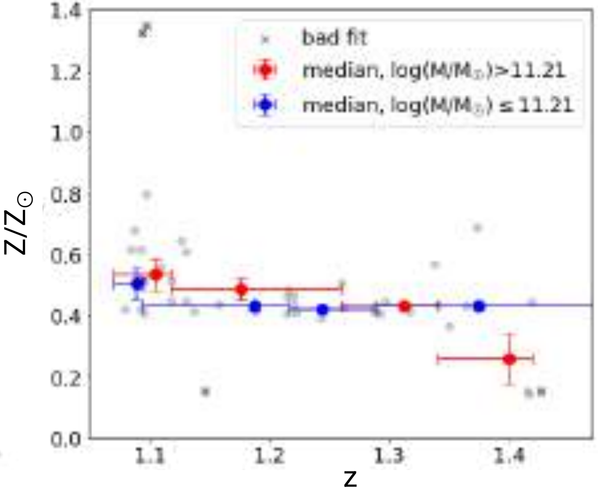


39 cosmic chronometers







Are our results robust?

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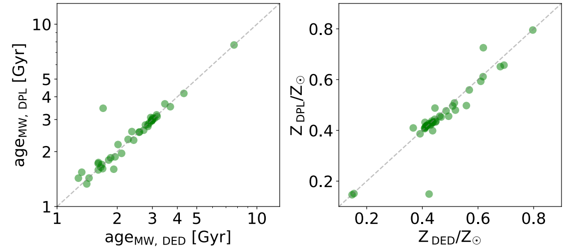
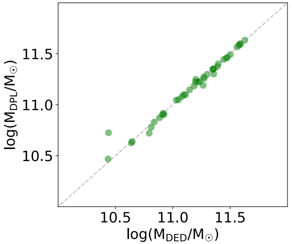
Changing the SFH





Only 2% fluctuation in median values of age, mass and metallicity

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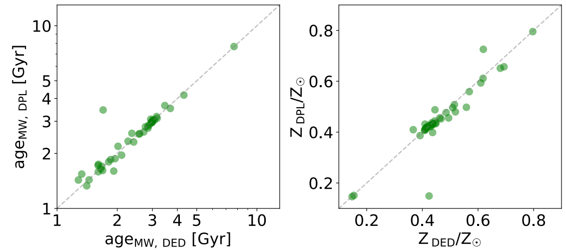

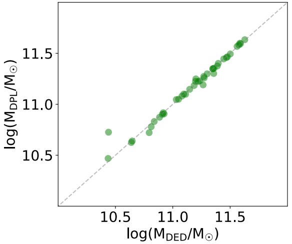

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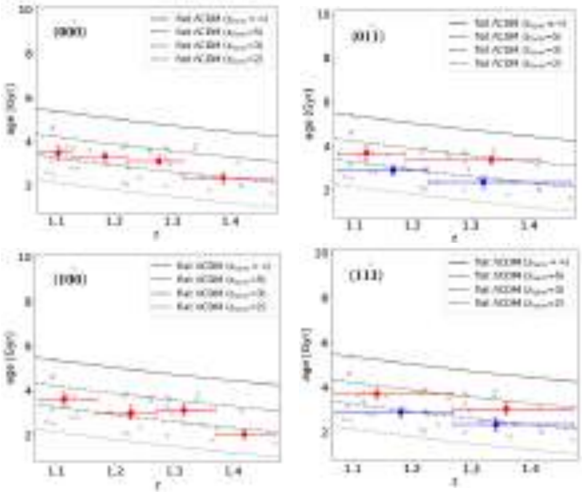

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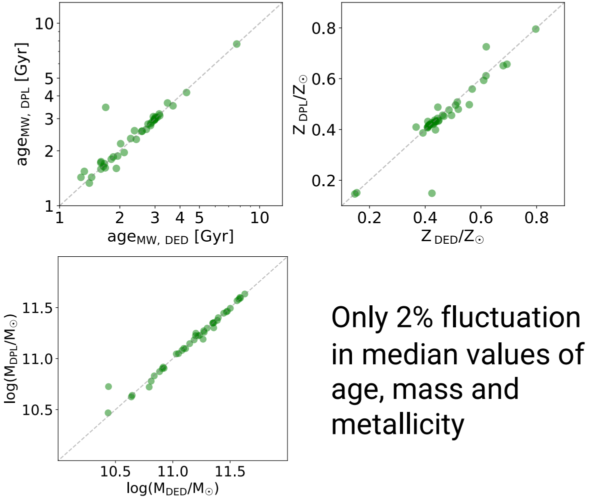

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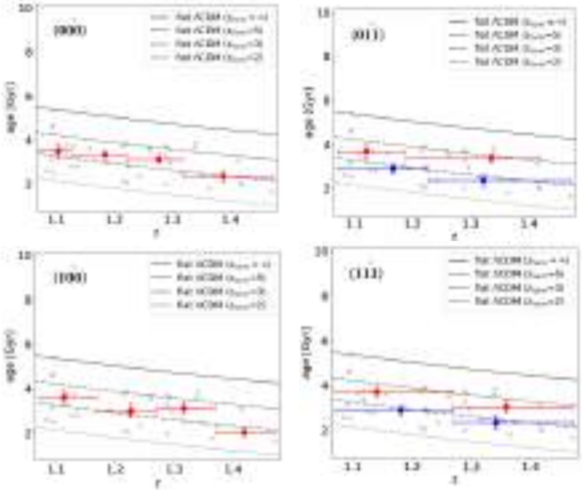
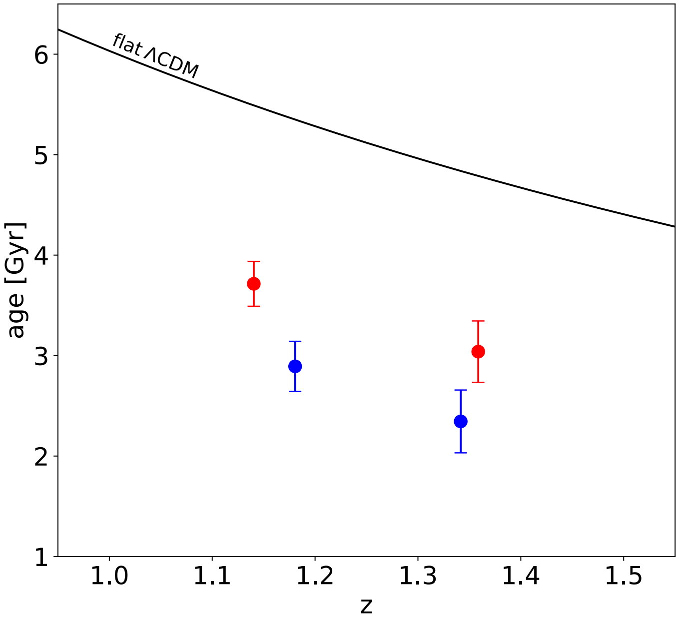


Systematic error budget on H(z)

Cosmological analysis



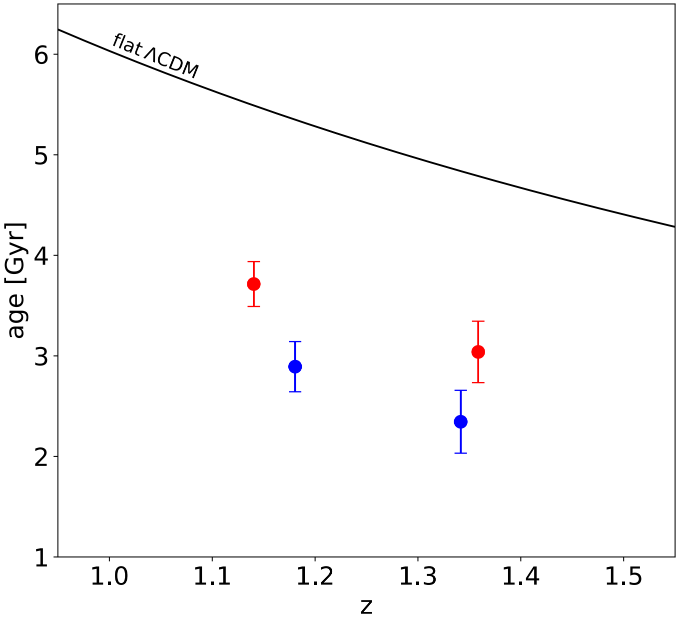
Cosmological analysis: fitting the age-redshift relation

We fit the median age-z with a **fΛCDM:**

$$t(z) = \int_0^z \frac{dz'}{H_0\sqrt{1-\Omega_{m,0}(1+z')^3}(1+z')} - t_0$$

which has 3 free parameters: $H_0, \Omega_{m,0}, t_0$.

Assumed gaussian prior on $\Omega_{m,0} = 0.3 \pm 0.02$ independent of CMB (Jimenez et al. 2019)



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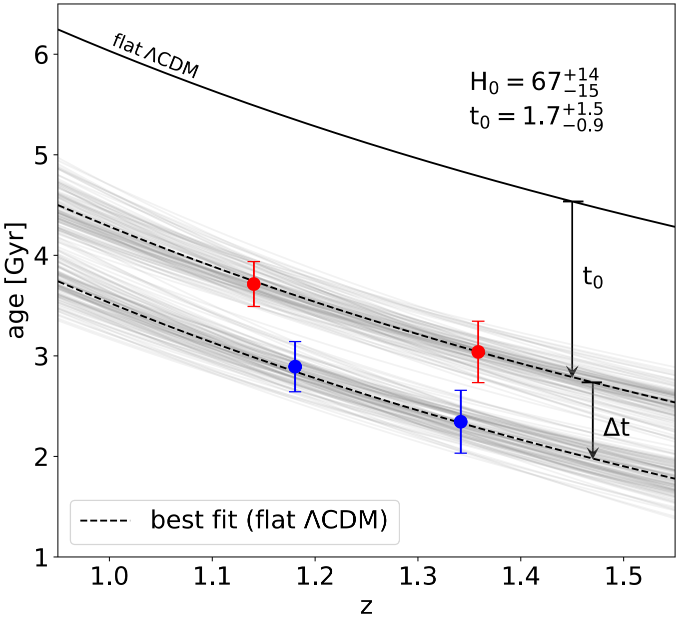
$$\boxed{H_0 = 67^{+14}_{-15} \quad \mathrm{km\ s^{-1} Mpc^{-1}}}$$



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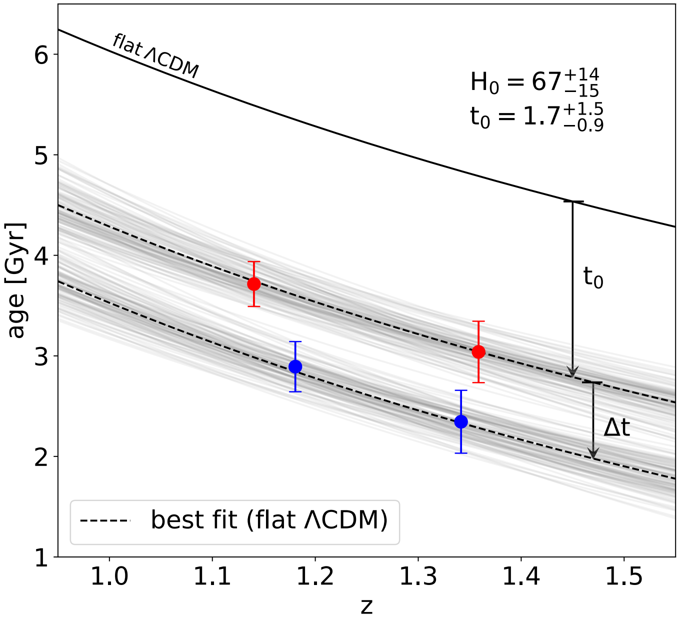
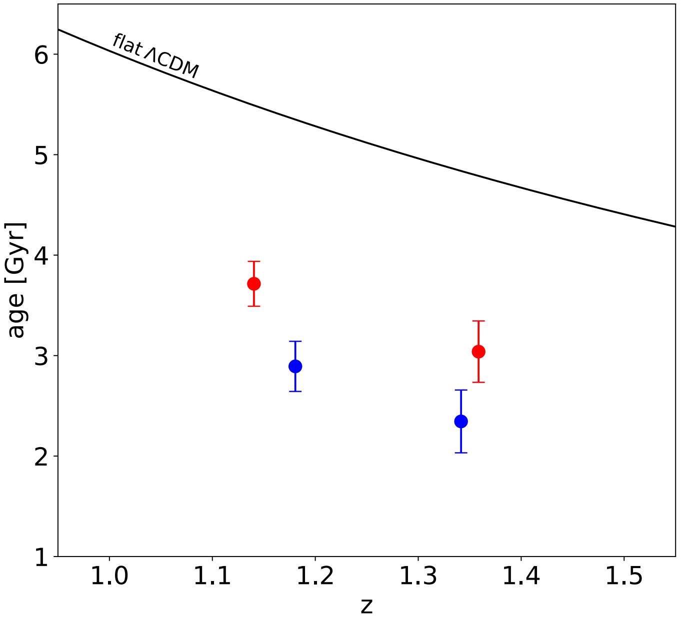


Current errors are dominated by the low number of galaxies ⟹ higher precision requires more statistics!

Cosmological analysis: the cosmic chronometers approach

With the cosmic chronometers method no cosmological model is assumed and H(z) is computed as:

$$H(z) = -\frac{1}{1+z}\frac{dz}{dt}$$



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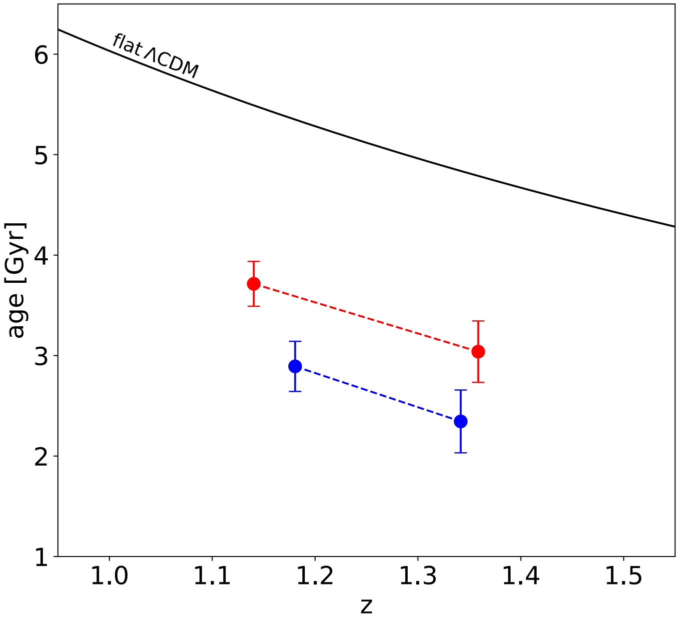

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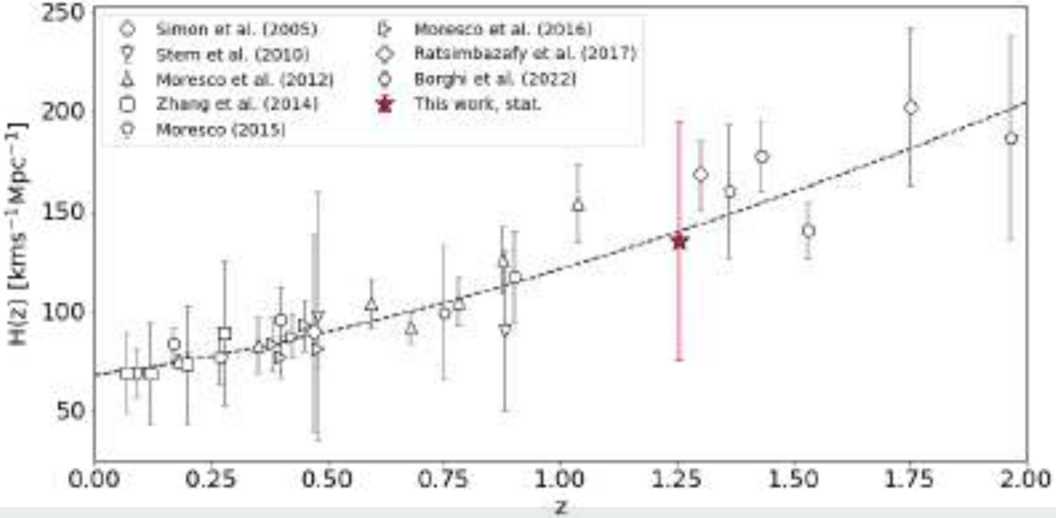

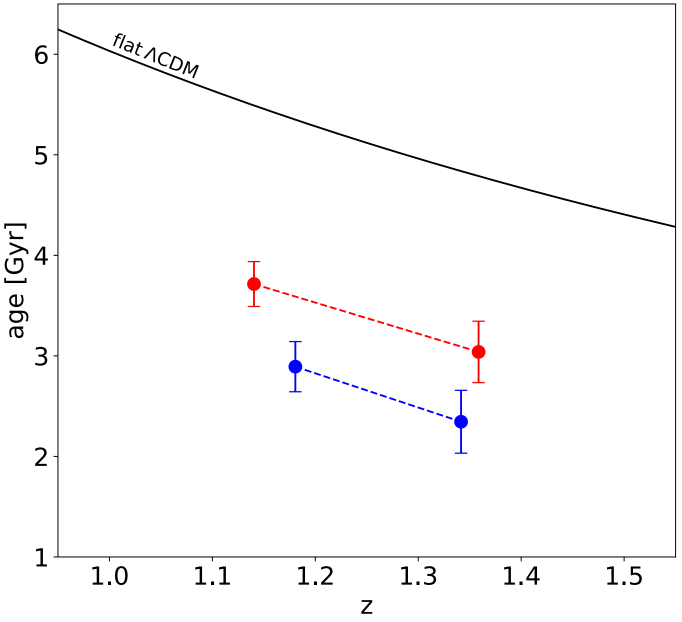

At redshift $z \simeq 1.26$ we obtain:

$$H = 135 \pm 60\ (\text{stat}) \qquad \text{km s}^{-1}\text{Mpc}^{-1}$$

Assessing the systematics

Two main sources of systematic effects are considered:

- binning – variation of H(z) **between (111) and (011)**
- SFH choice – variation of H(z) among **DED** and **DPL** results in equivalent binnings

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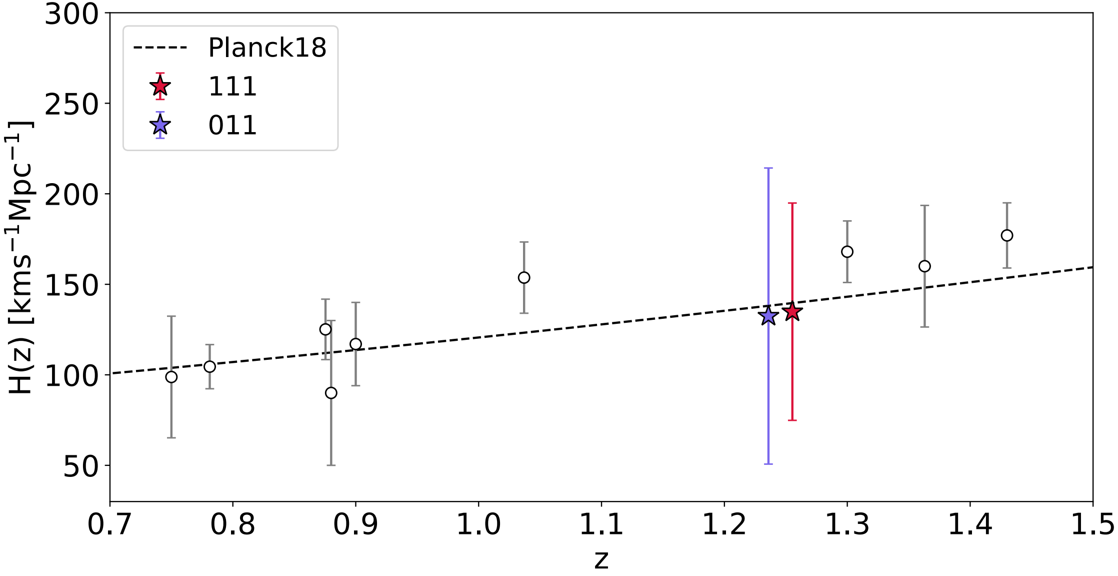

Contribution to the error budget:

$$\Delta H_{\text{bin}} = 2.4 \quad \text{km s}^{-1}\text{Mpc}^{-1}$$

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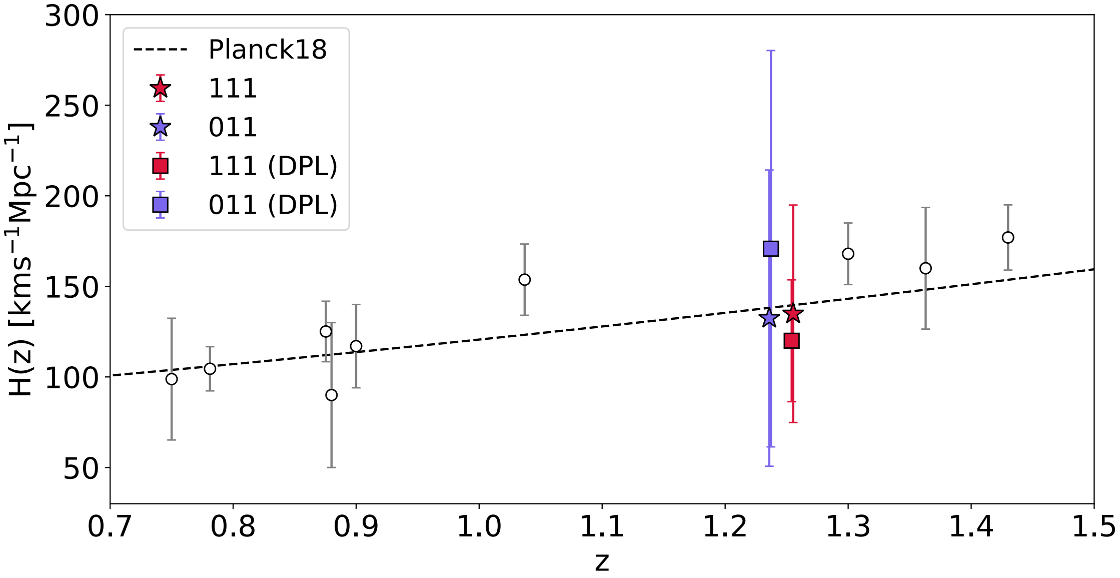

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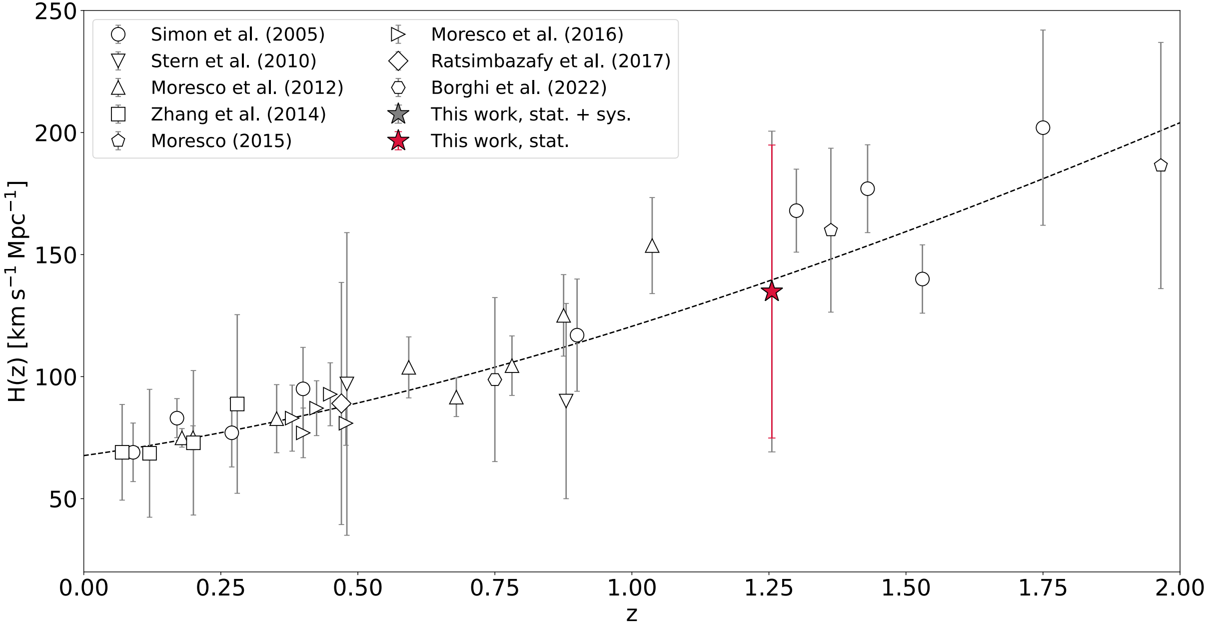
$$\Delta H_{\mathrm{bin}} = 2.4 \quad \mathrm{km\,s^{-1}Mpc^{-1}}$$

$$\Delta H_{\mathrm{SFH}} = 27 \quad \mathrm{km\,s^{-1}Mpc^{-1}}$$

Final result

Finally, with a sample of **39 cosmic chronometers** we obtain:

$$\boxed{H(z \simeq 1.26) = 135 \pm 65\ (\text{stat} + \text{sys}) \quad \text{km s}^{-1}\text{Mpc}^{-1}}$$



Conclusions

- ✓ Without assuming any cosmological model we obtain:
  - 95% of ages lower than age of the Universe in fΛCDM, **consistent with theoretical ageing**
  - evidence of **mass-downsizing**
  - **homogeneous** population in redshift

- ✓ Fitting the median age-redshift relation we obtain:

$$\mathrm{H_0} = 67^{+14}_{-15} \quad \mathrm{km\,s^{-1}Mpc^{-1}}$$

- ✓ With cosmic chronometers we are able to obtain a **new measurement** of the Hubble parameter:

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exploiting for the first time the full-spectral-fitting CC method at z>1

What's next?

Constraining the age of the Universe and the **Hubble constant** with the oldest objects in the local Universe

Constraining the Hubble constant with the oldest objects

Cimatti & Moresco (2023) arXiv:2302.07899
Tomasetti et al. (in prep)

$$H_0 = \frac{A}{t}\int_0^{z_f} \frac{1}{1+z}\left[\Omega_M(1+z)^3 + (1-\Omega_M)\right]^{1/2} dz$$

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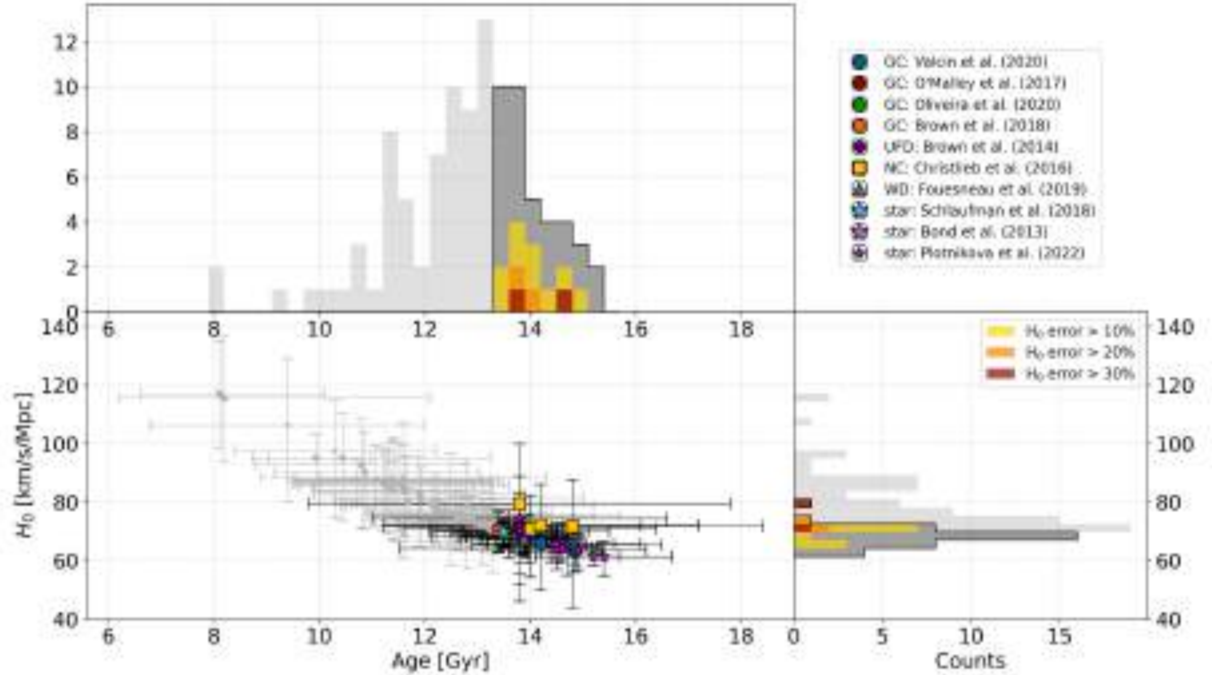

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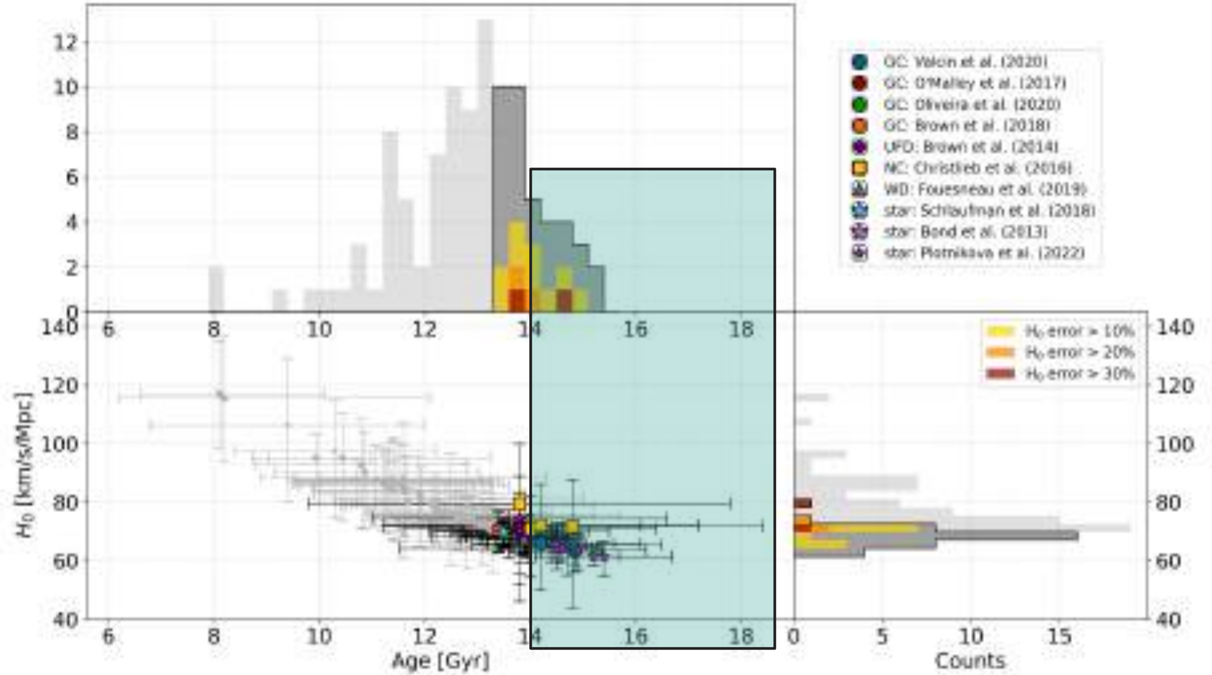

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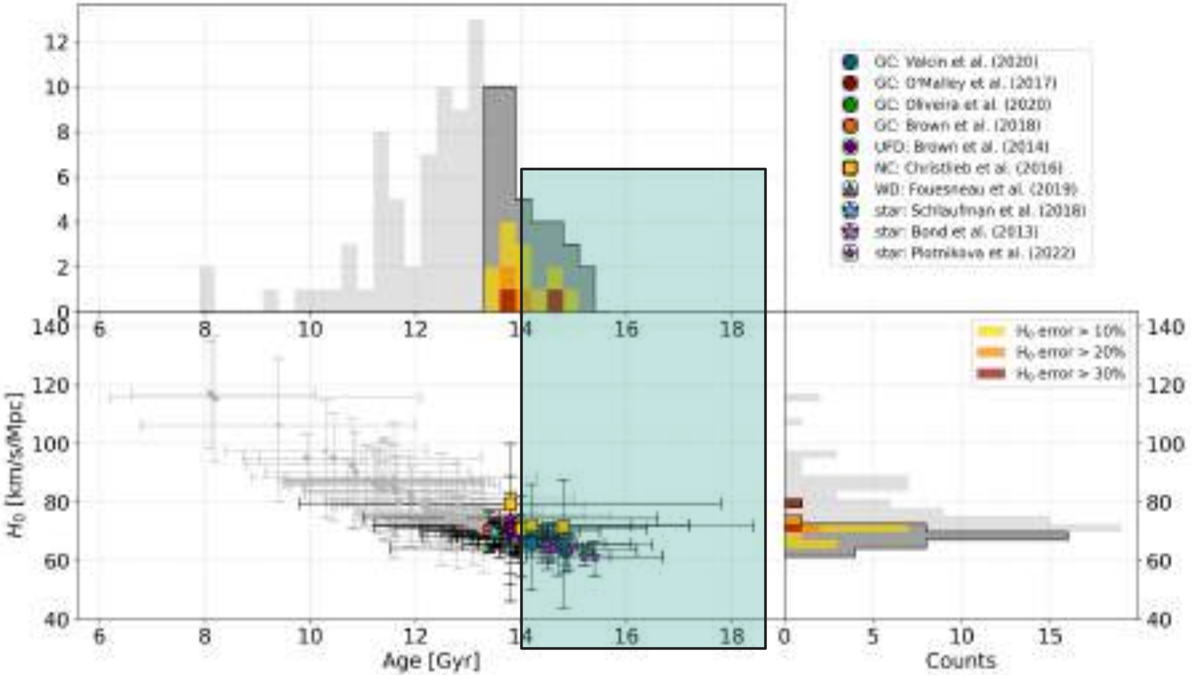

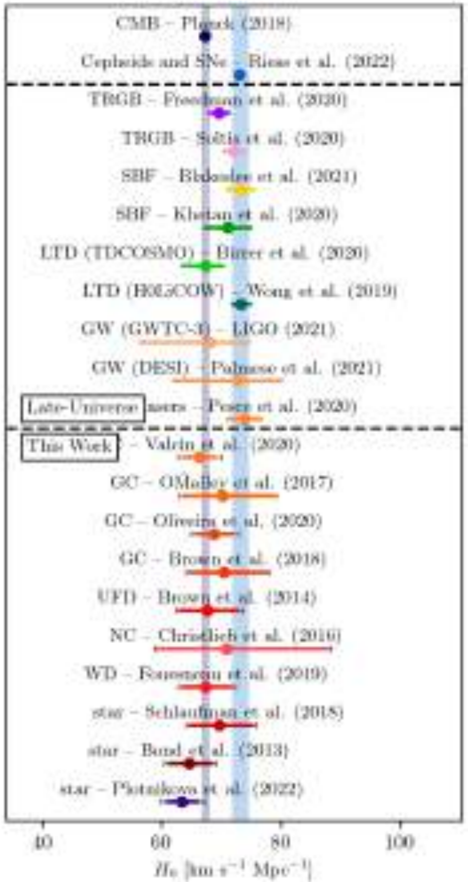

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Thank you!