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

arXiv:2305.16387

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*University of Bologna*

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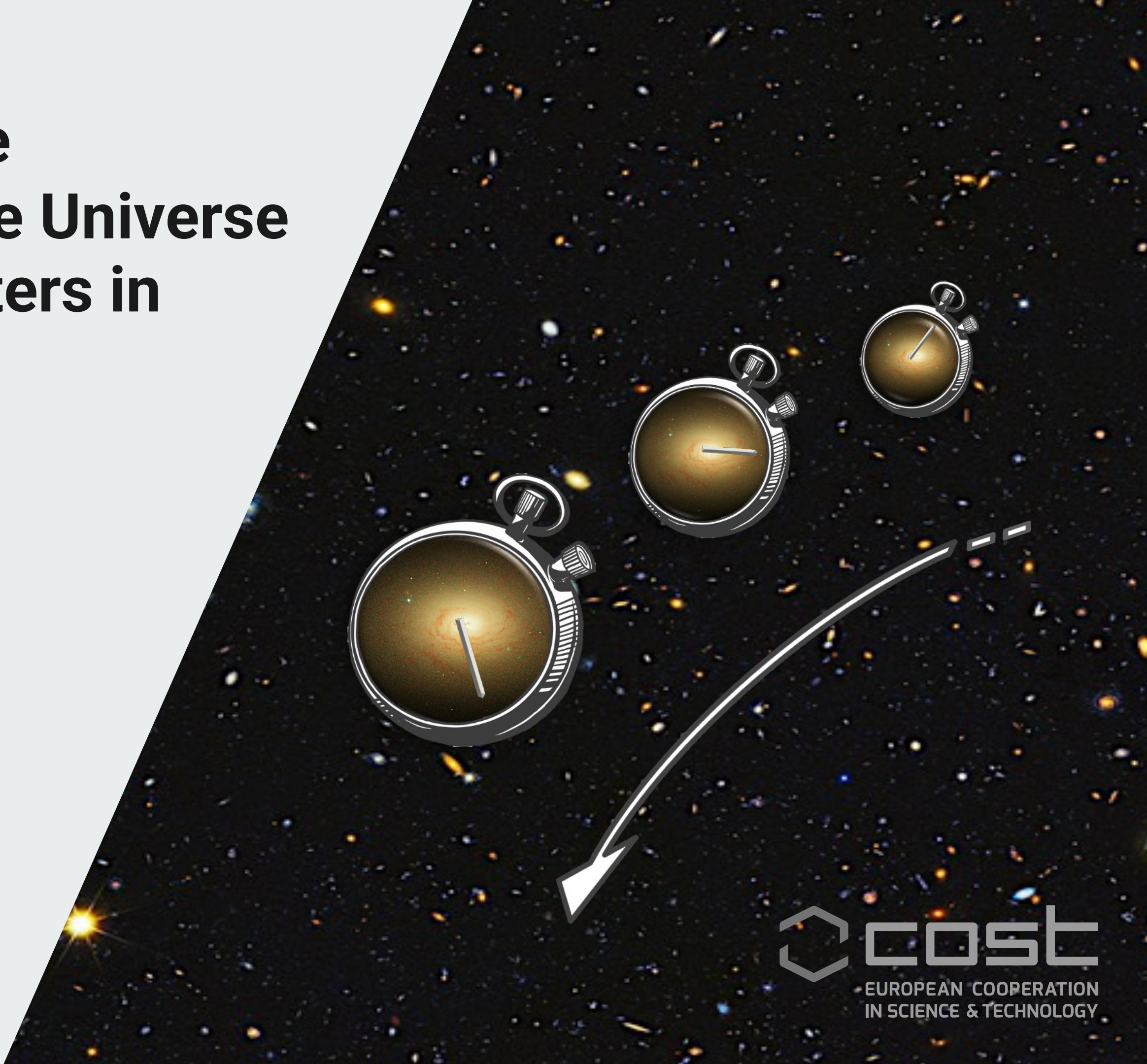
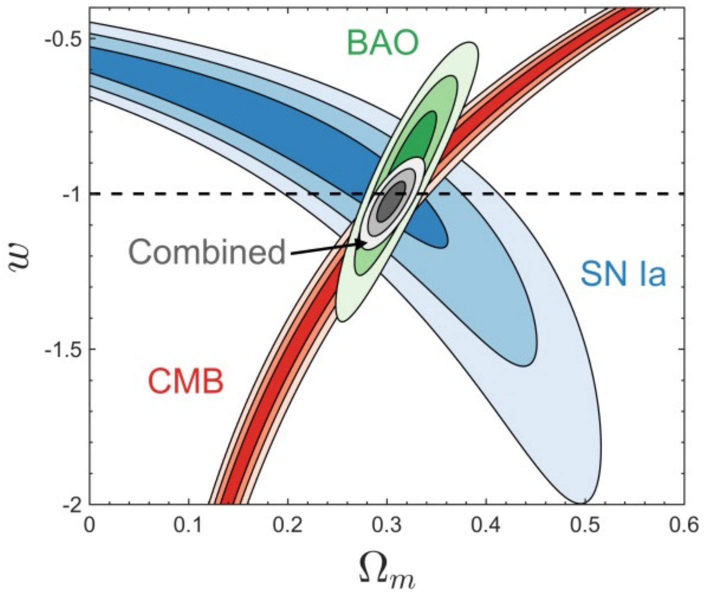
Carmela Lardo
Andrea Cimatti



# Scientific framework and aim of the project

Huterer et al. (2018)

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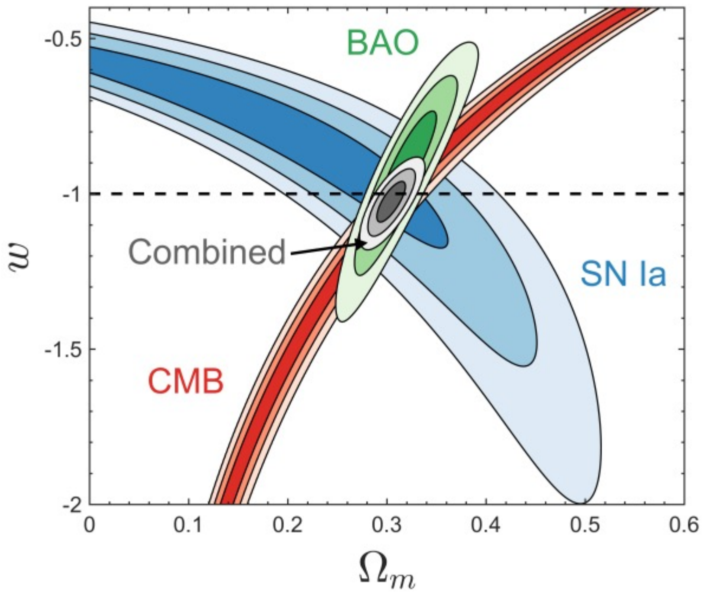


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However, the increasing precision of these measurements has highlighted **tensions** between early- and late-Universe probes (Verde et al. 2019)

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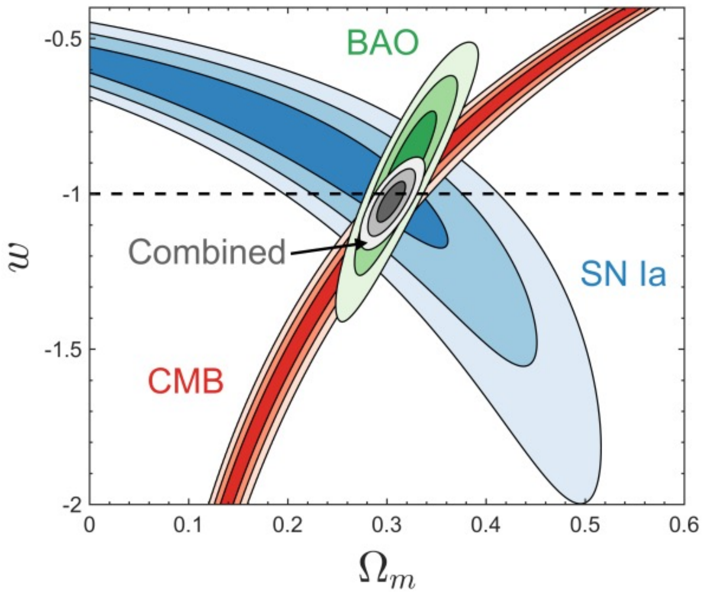


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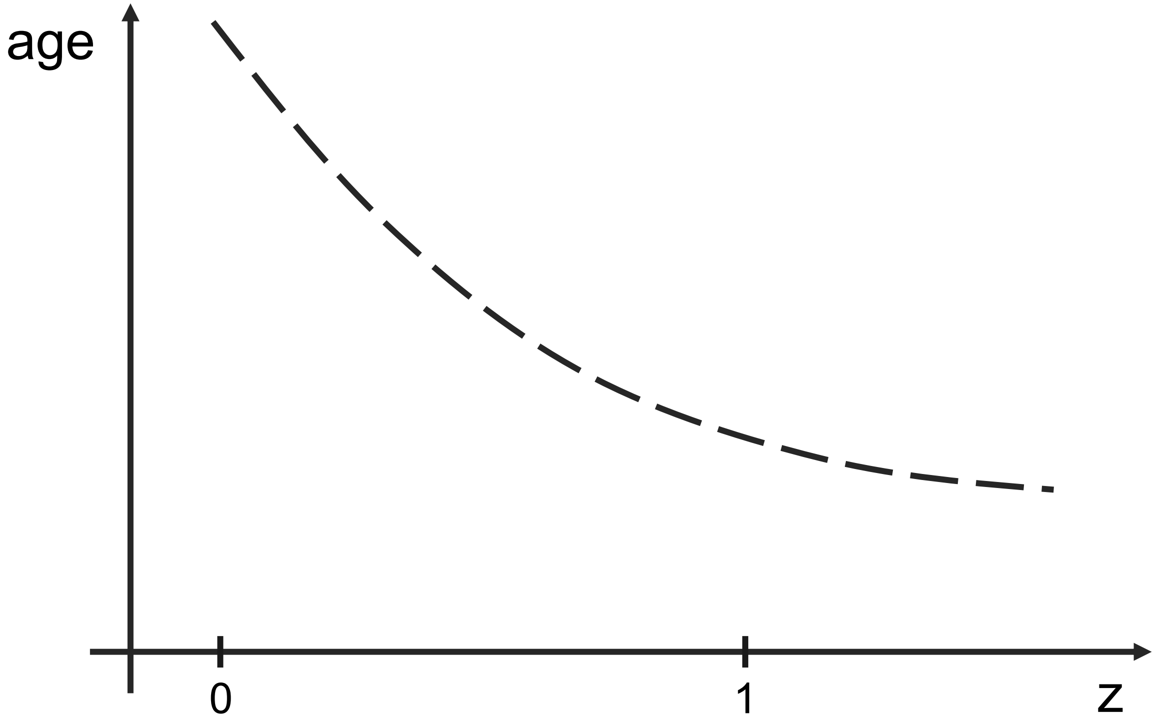
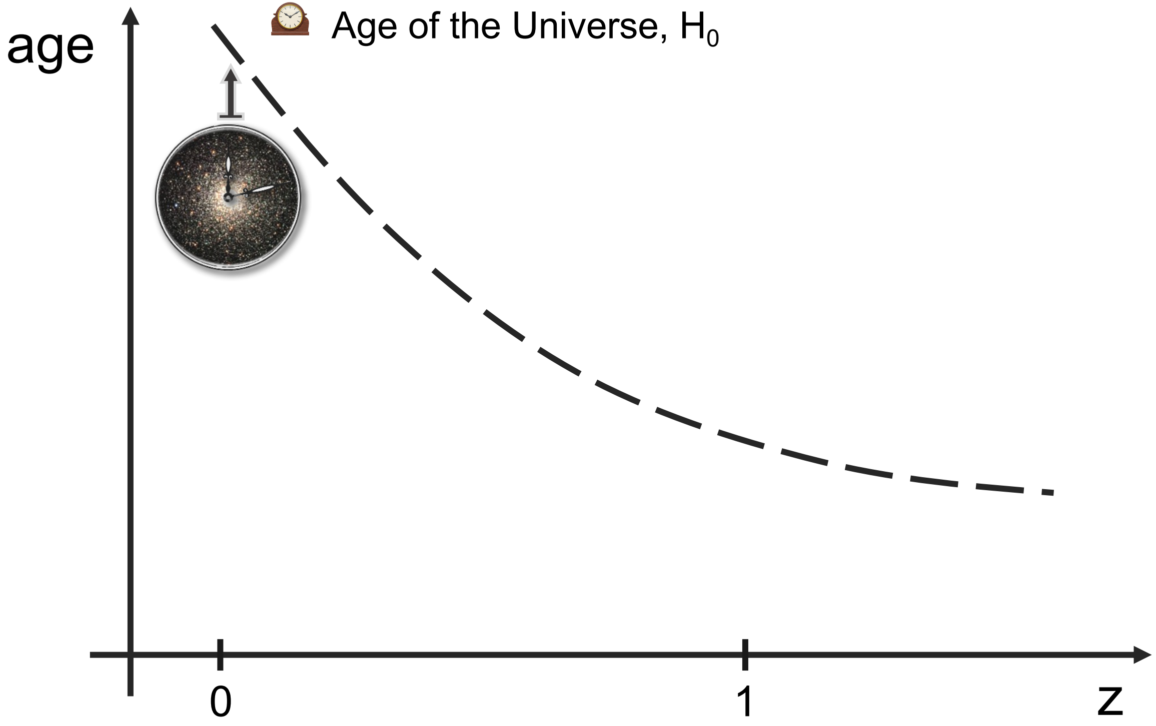
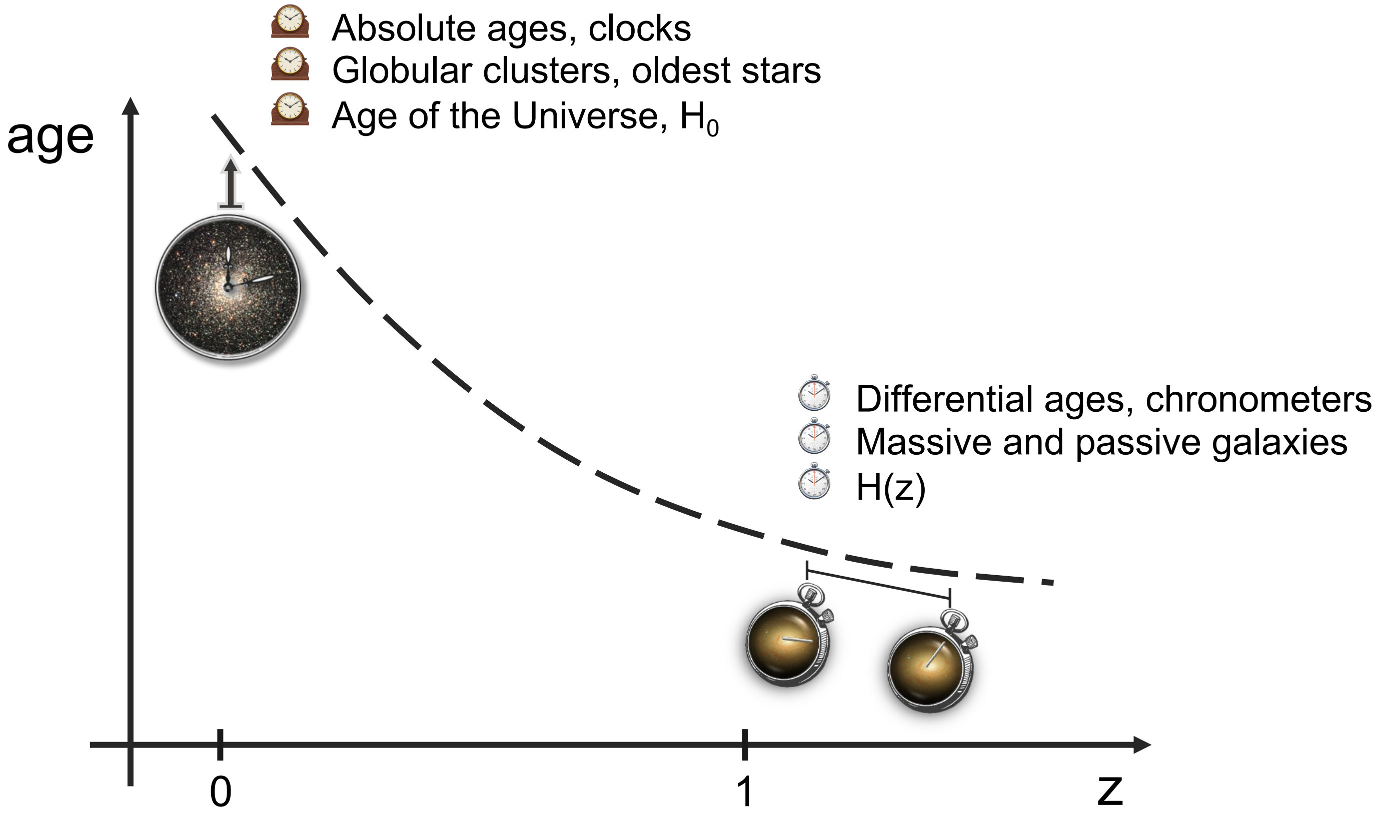
**Aim**: obtain new constraints on the expansion history of the Universe using **time** as tracer instead of luminosity (SNIa) or length (BAO).


age
0
1
z

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




Absolute ages, clocks
Globular clusters, oldest stars
Age of the Universe, $H_0$
age
Differential ages, chronometers
Massive and passive galaxies
H(z)
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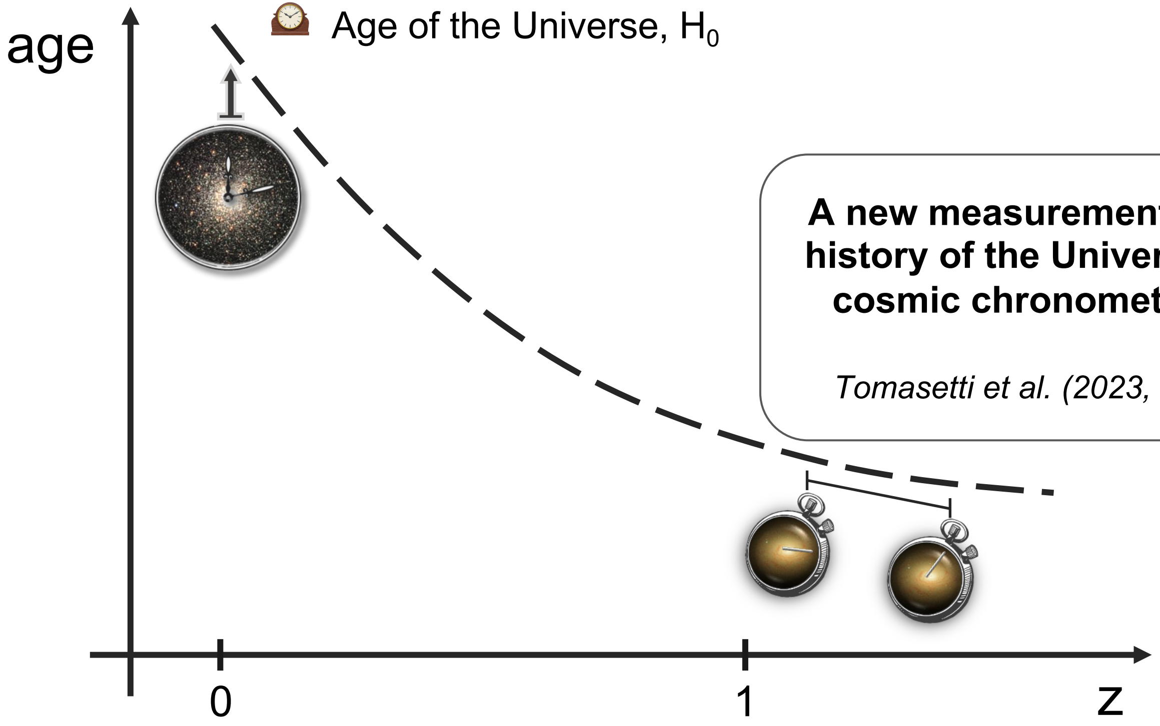
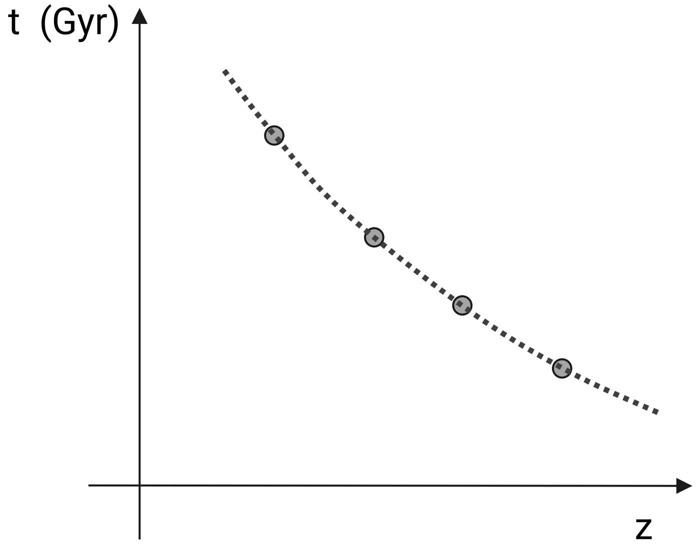



**A new measurement of the expansion history of the Universe at z = 1.26 with cosmic chronometers in VANDELS**

*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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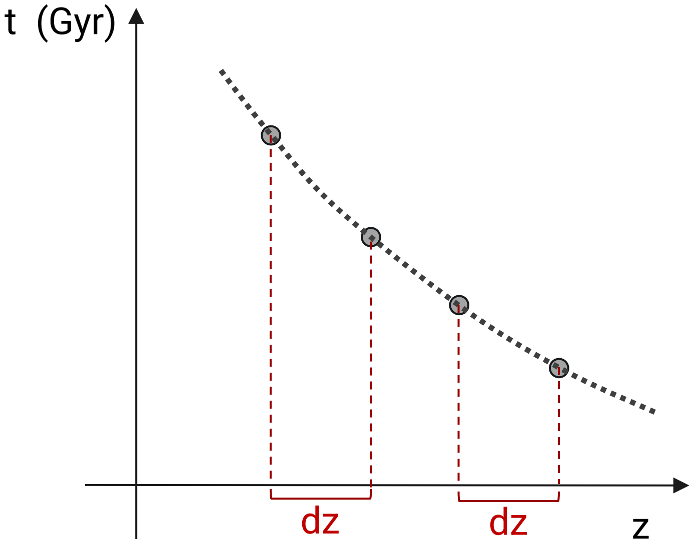


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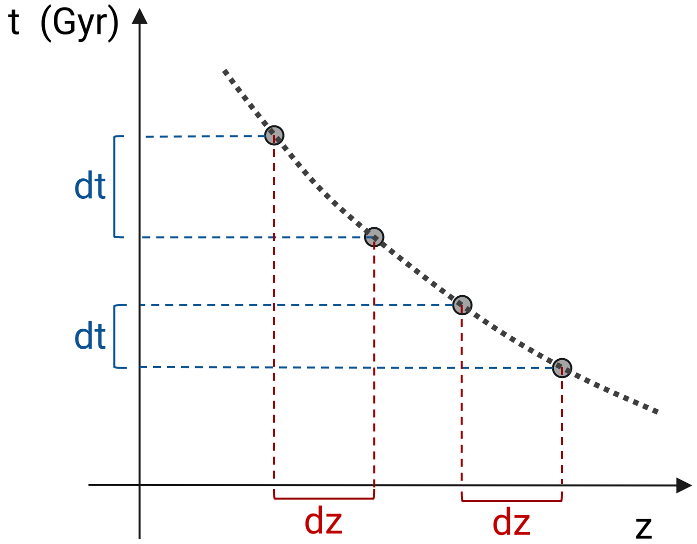


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can be traced with "chronometers"

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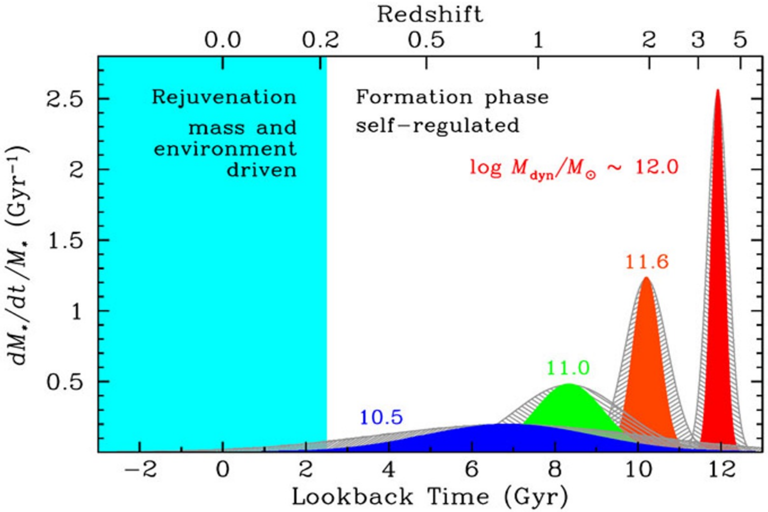


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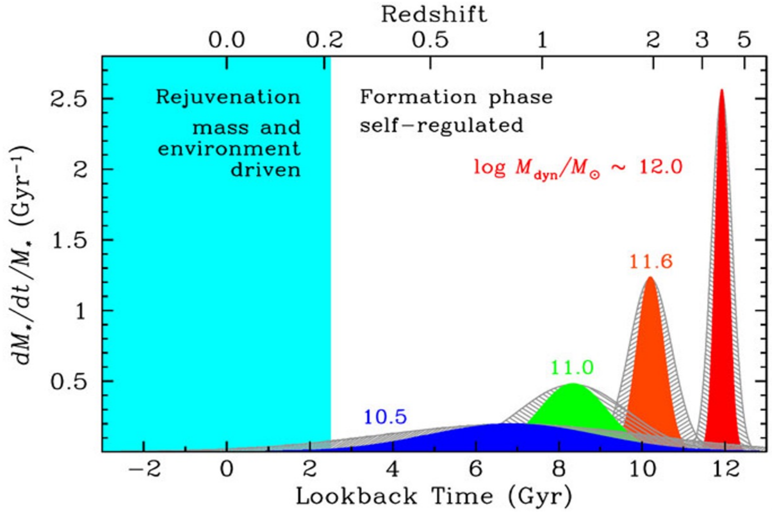

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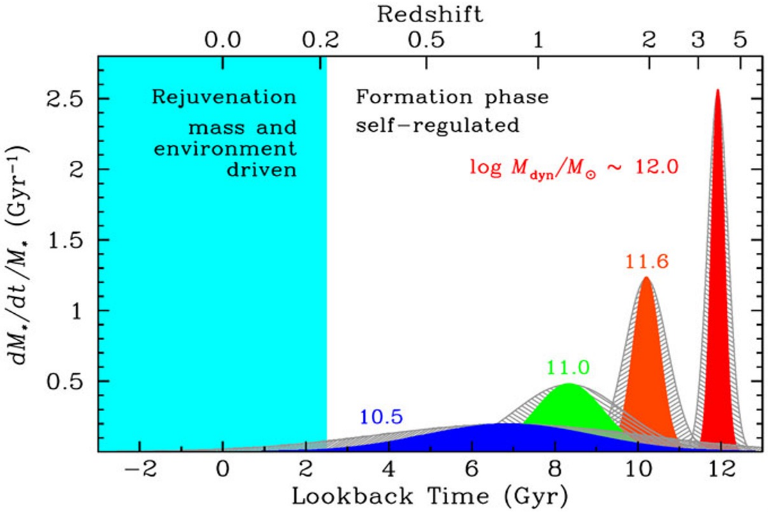


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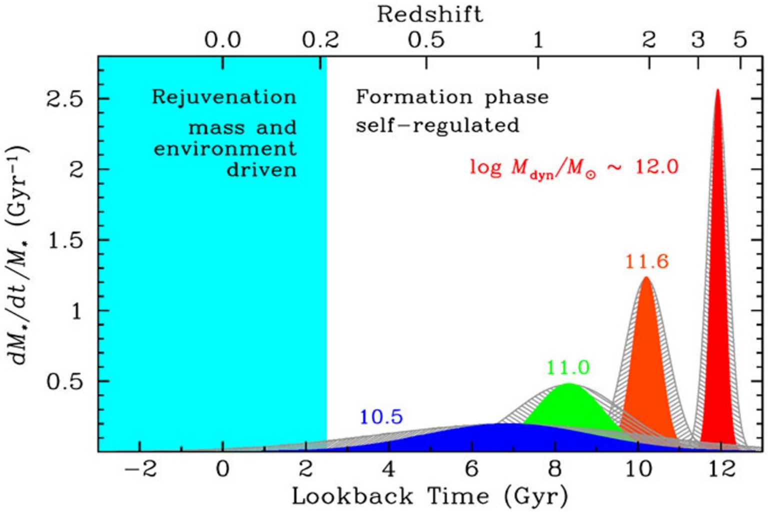


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  - ☐ SED-fitting
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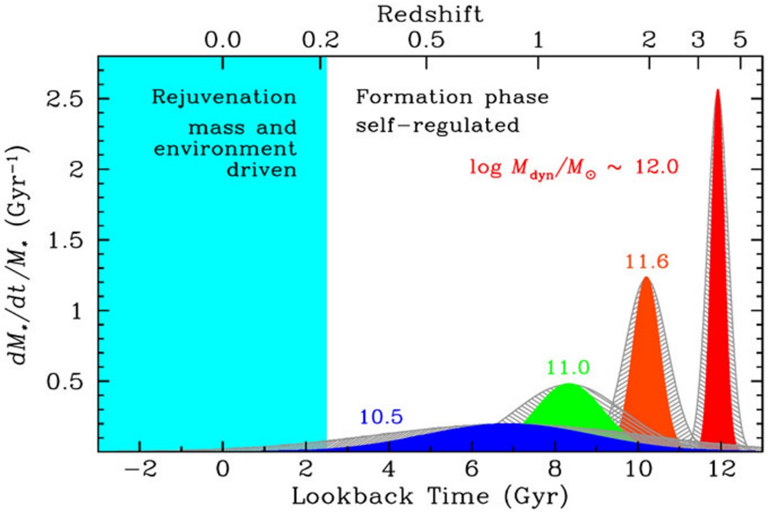


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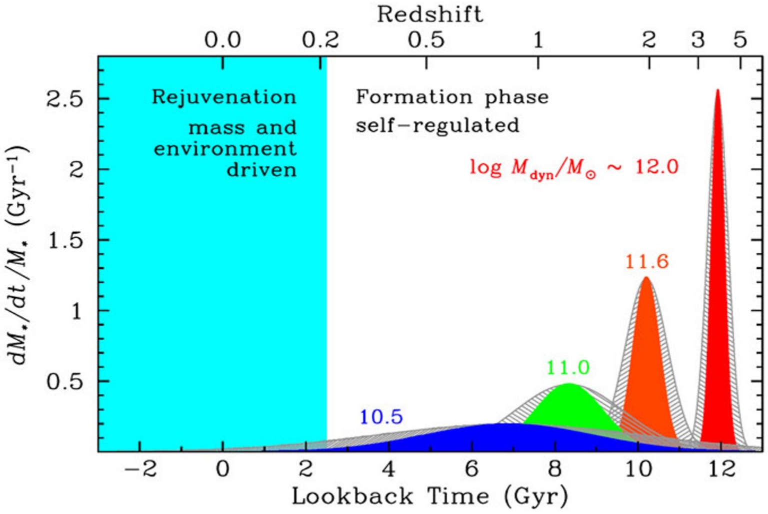


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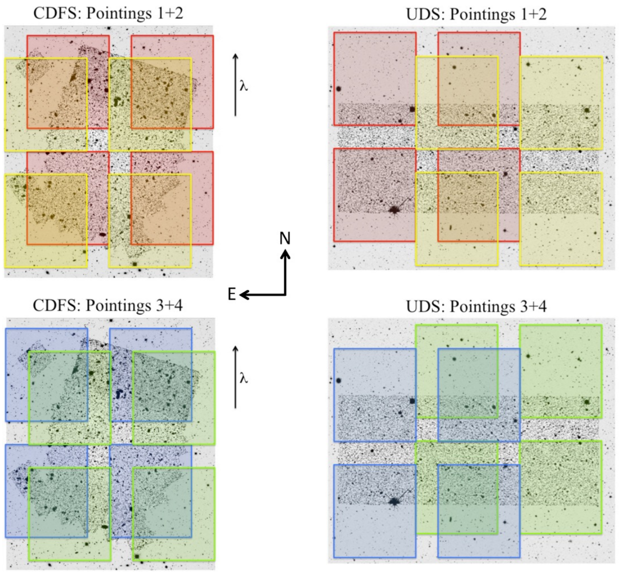
*Main steps*:

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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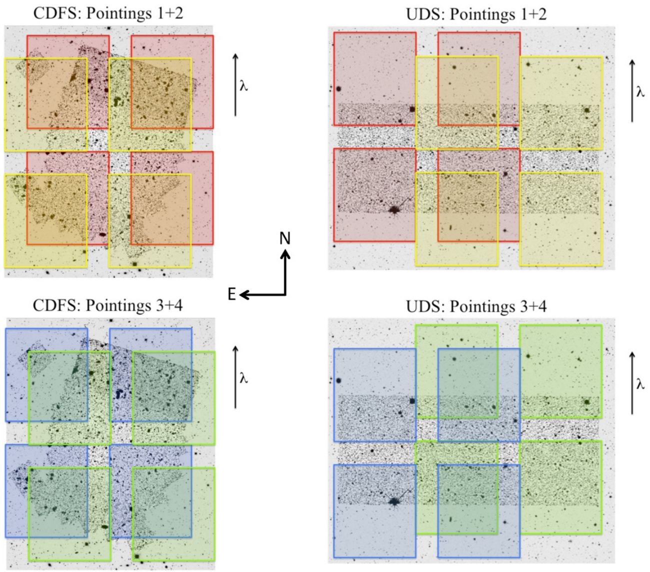


| FIELD | SFG | PASSIVE | LBG | AGN | SECONDARY | TOT |
|---|---|---|---|---|---|---|
| CDFS | 201 | 123 | 604 | 47 | 44 | 1019 |
| UDS | 216 | 155 | 655 | 10 | 32 | 1068 |
| **TOT** | **417** | **278** | **1259** | **57** | **76** | **2087** |

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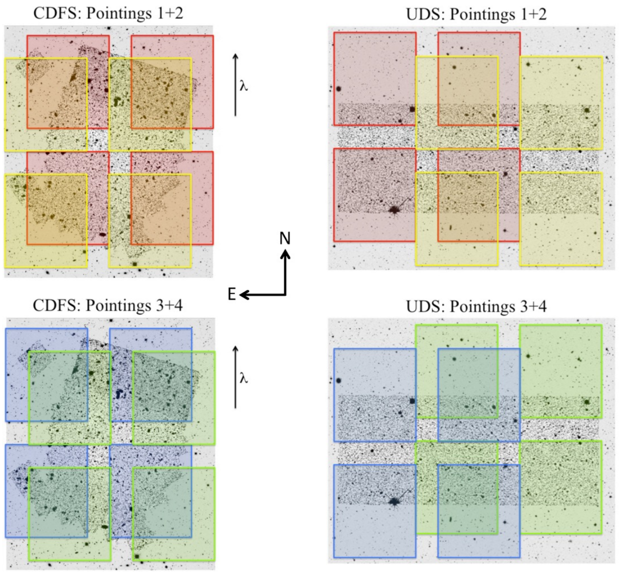


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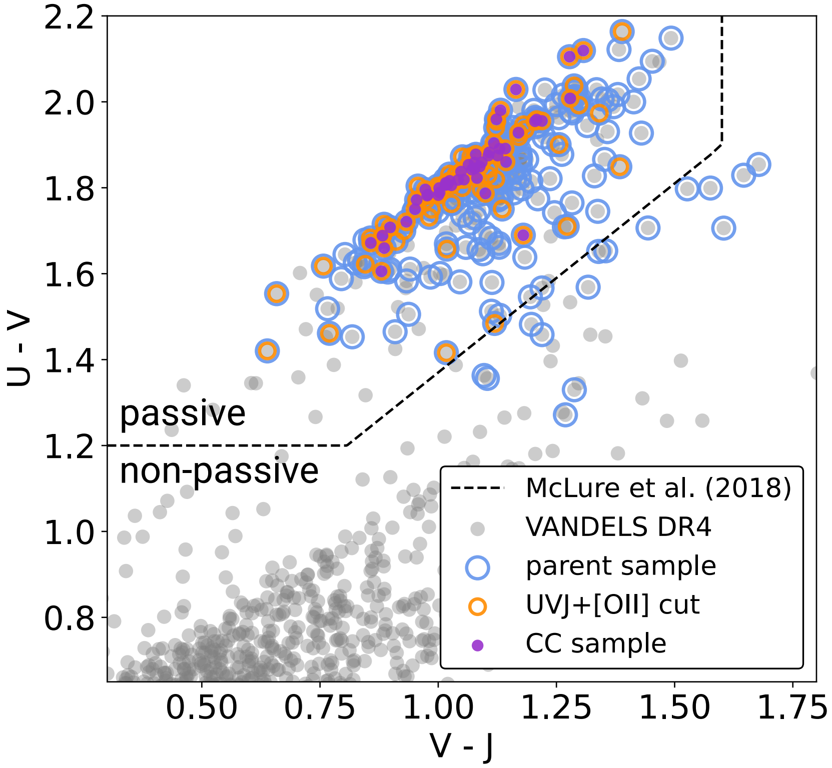


+ galaxies already classified as passive in VANDELS data release 4
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parent sample

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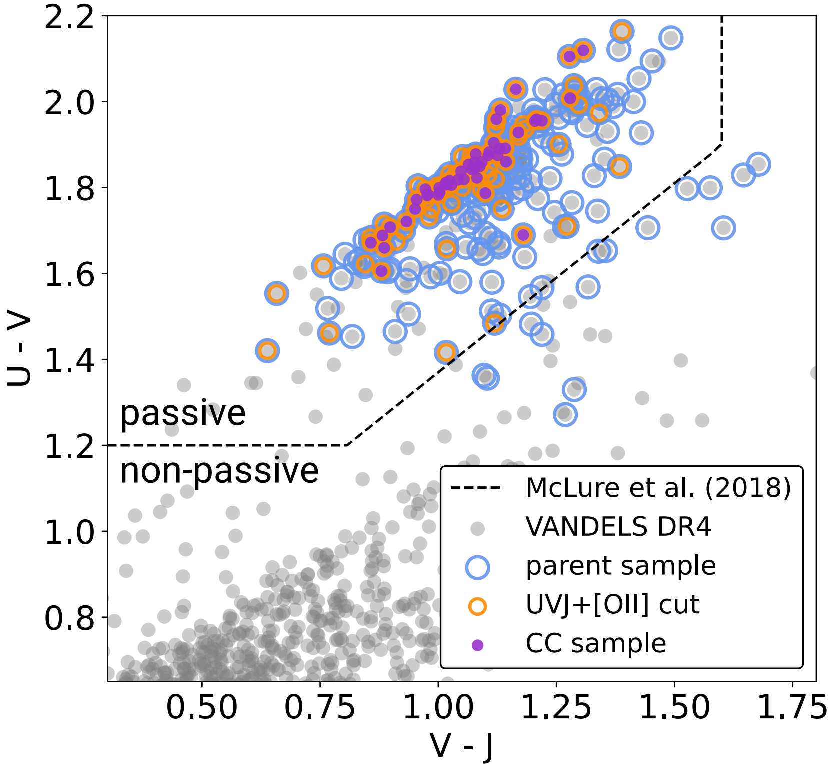


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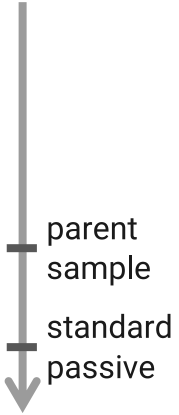

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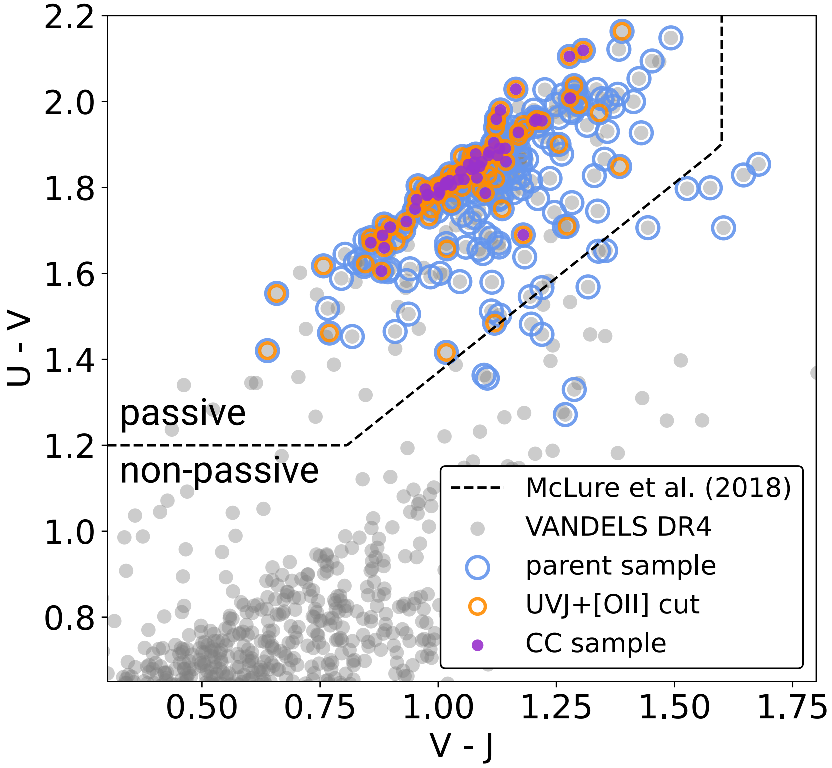


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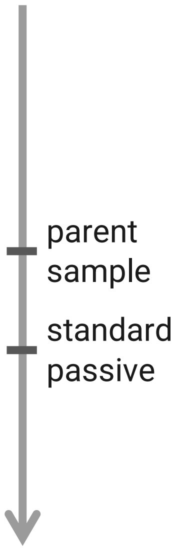

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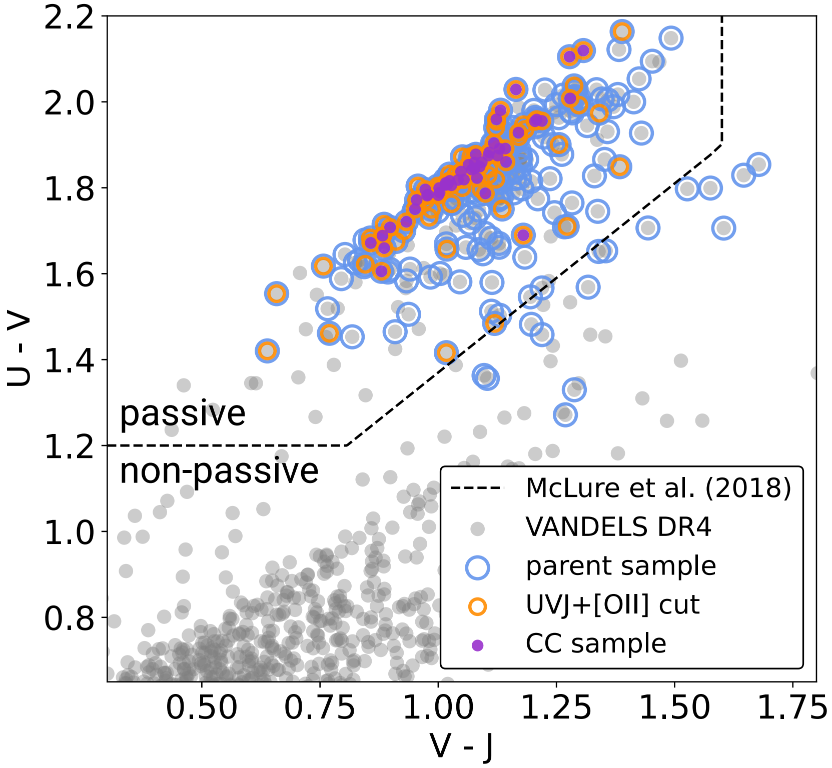


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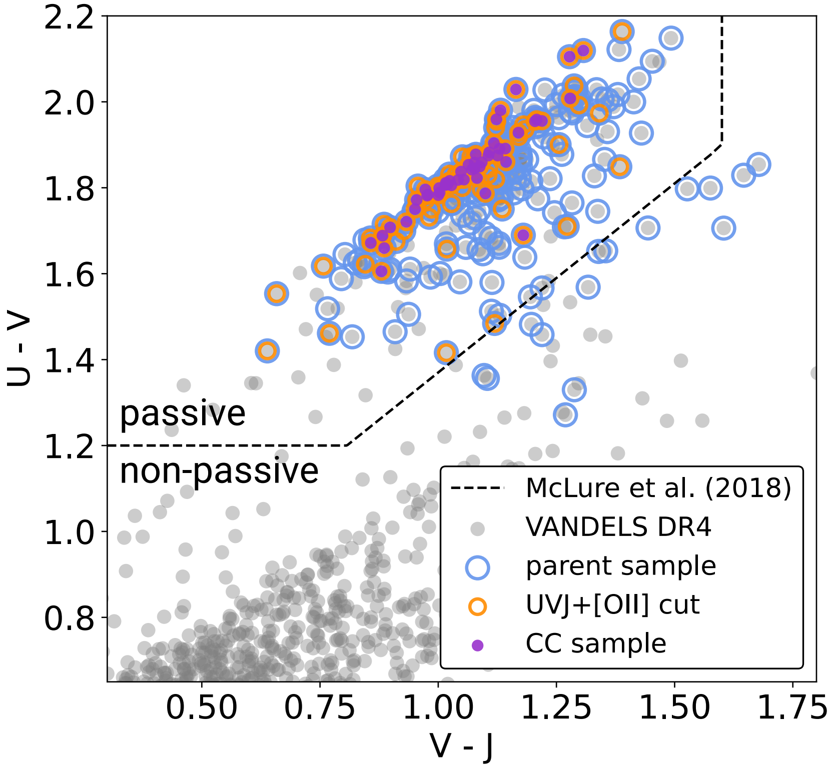


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- Visual inspection

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bona fide passive

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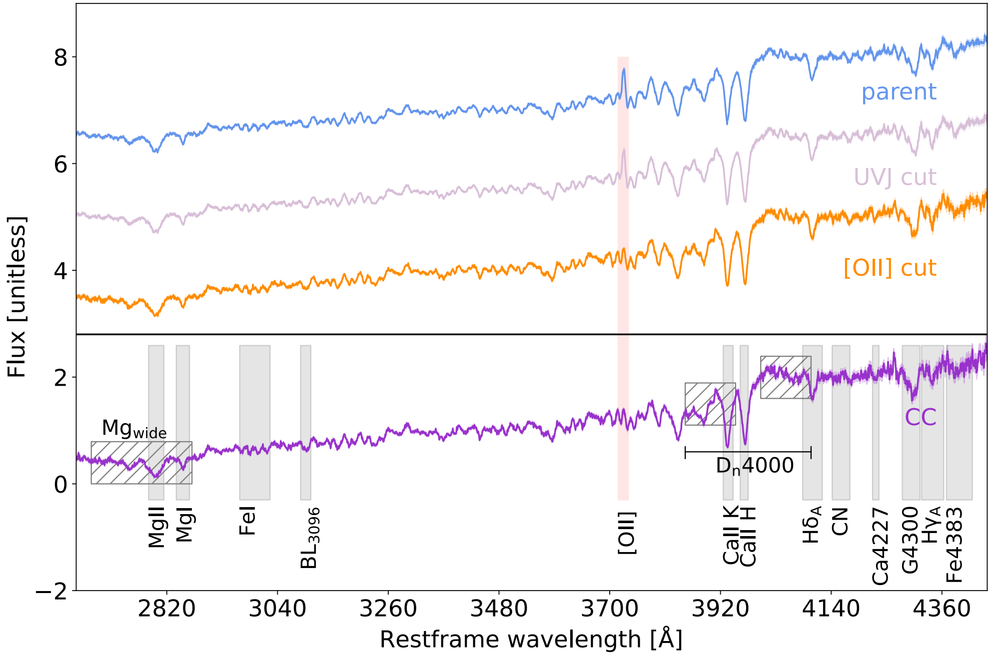


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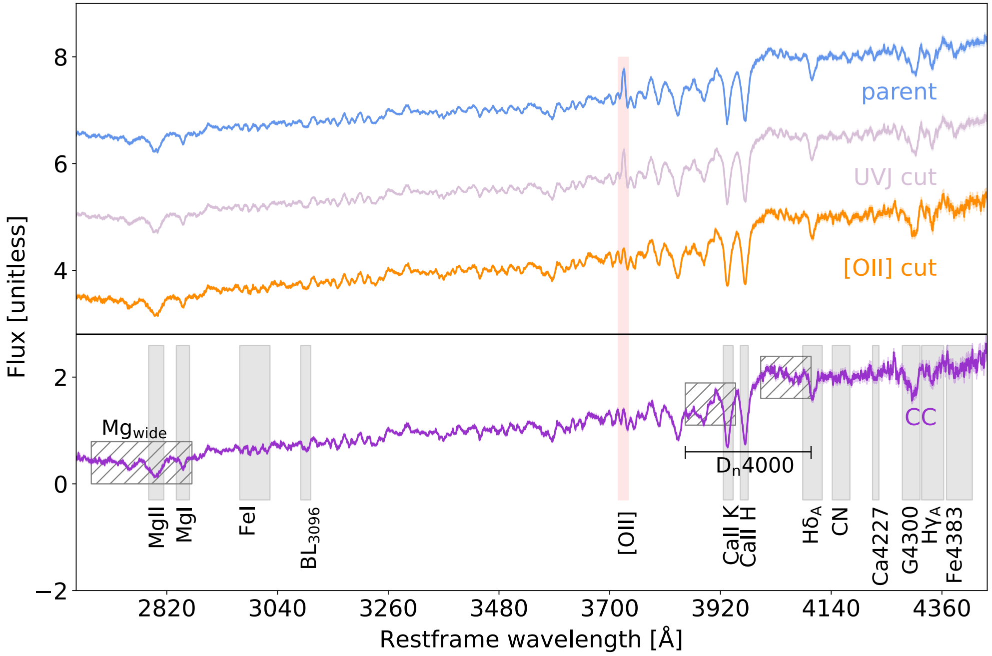


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**49 cosmic chronometers**

# 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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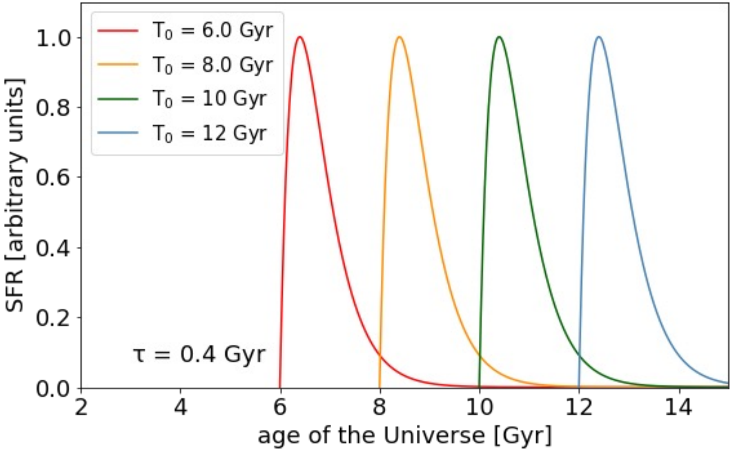


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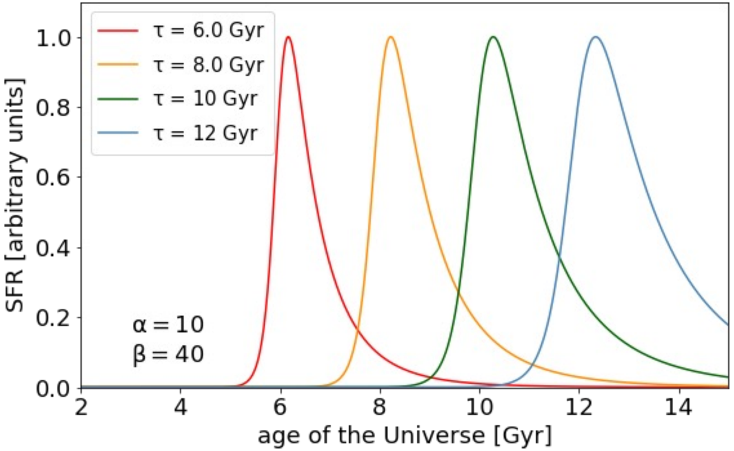
$$\mathrm{SFR}(t) \propto \left[\left(\frac{t}{\tau}\right)^{\alpha} + \left(\frac{t}{\tau}\right)^{-\beta}\right]^{-1}$$



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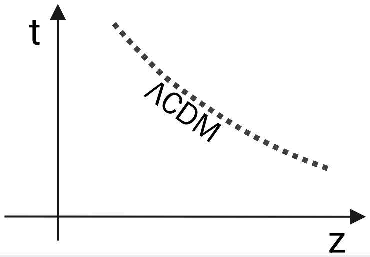
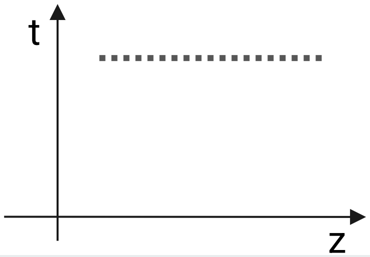


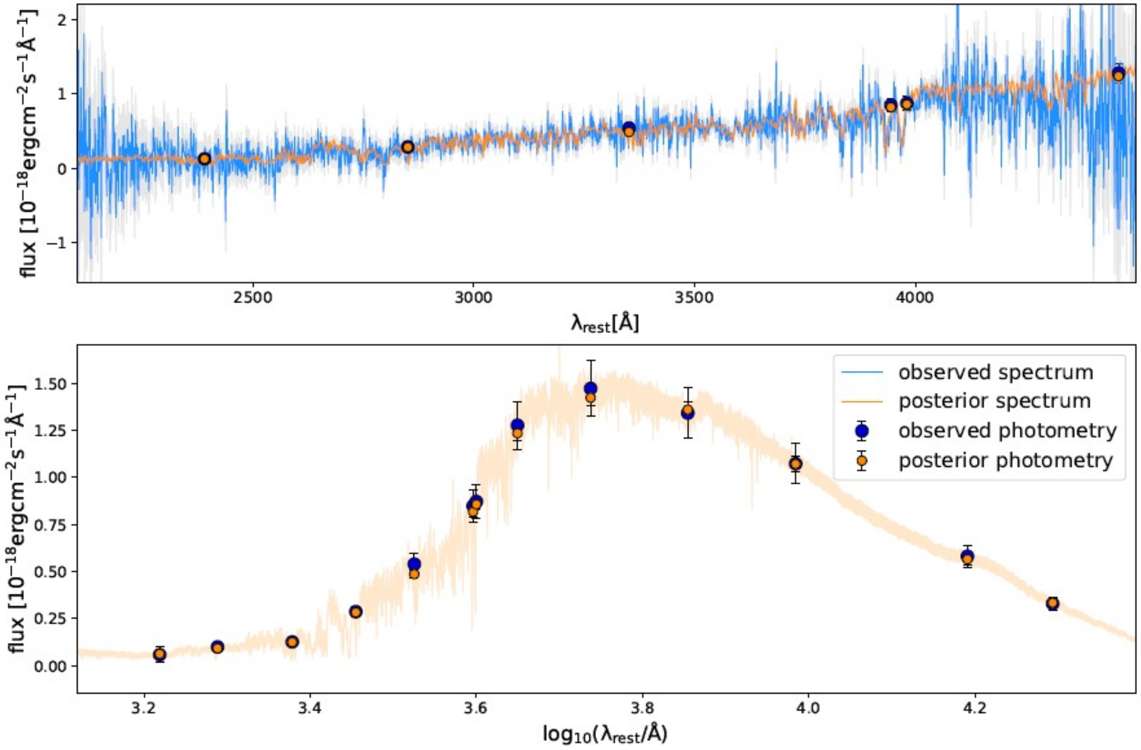

⟹ **Flat prior on galaxy ages**, so that they can vary in the range **0 - 20 Gyr**




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] |
| $\tau$ | 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 $\chi^2$ etc.)

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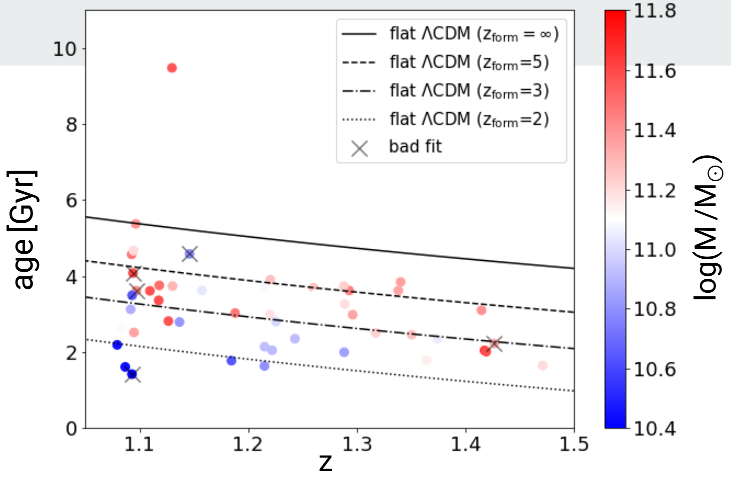
For 44 galaxies the fit is successful and indicates:

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



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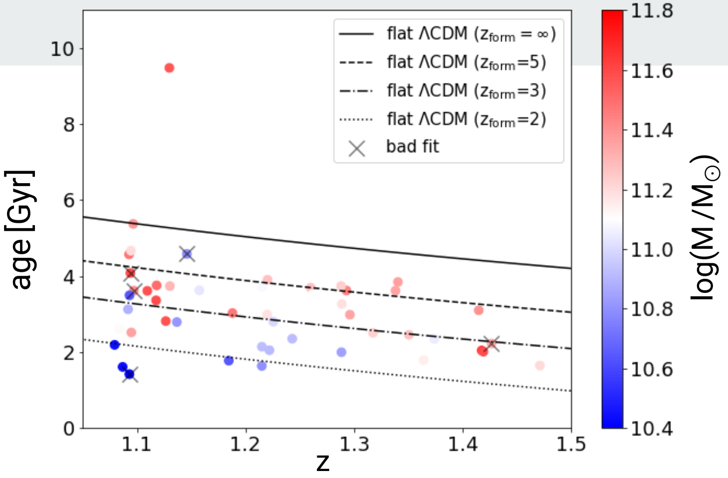
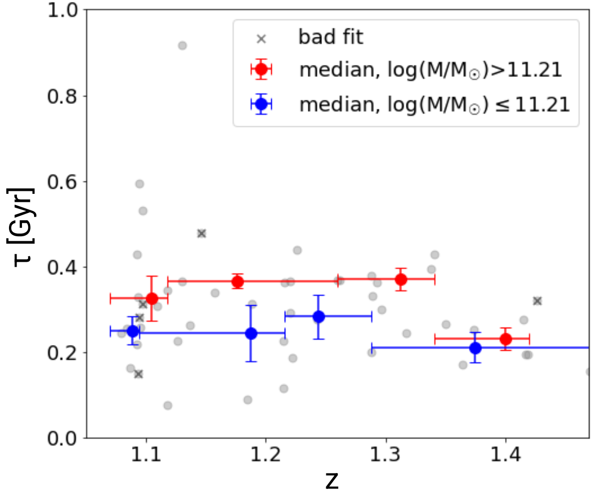
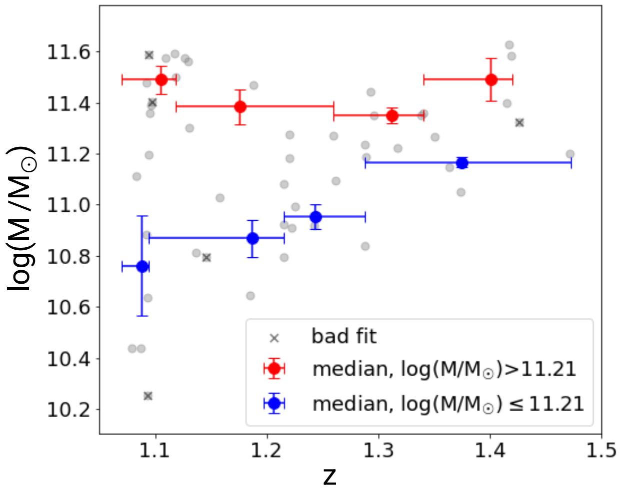
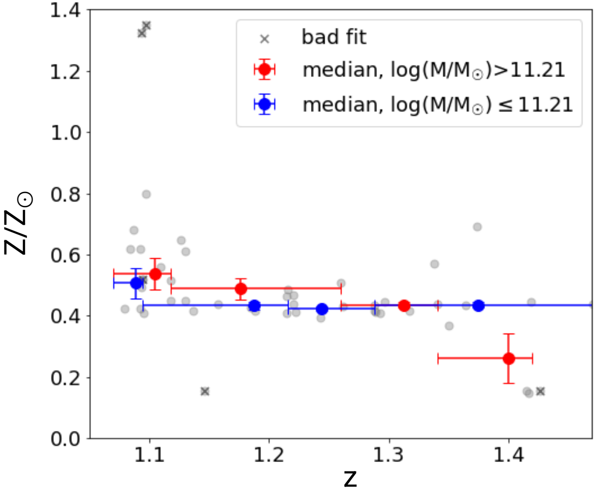
- short SFH $\langle\tau\rangle = 0.28\pm0.02$ Gyr
- massive galaxies $\langle\log(M/M_\odot)\rangle = 11.21\pm0.05$
- homogeneous population $\langle Z/Z_\odot\rangle = 0.44\pm0.01$



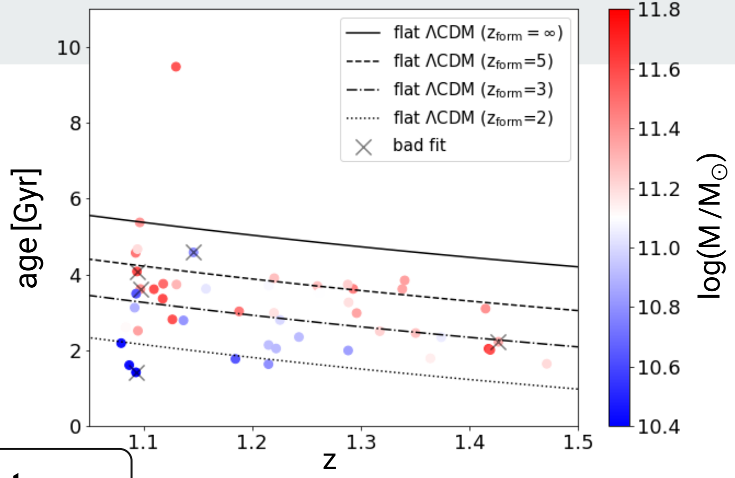



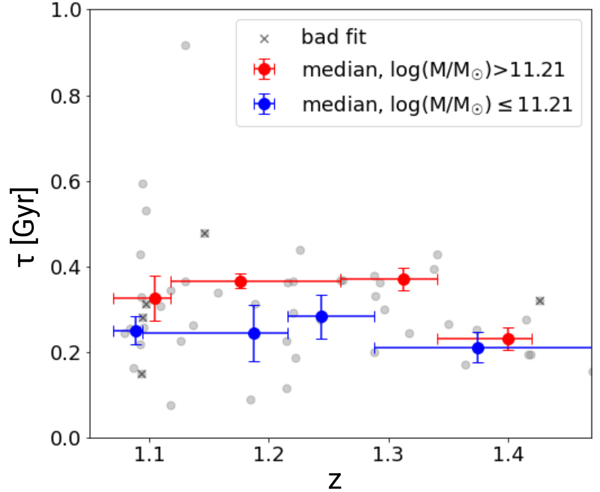



# Physical parameters of CC in VANDELS

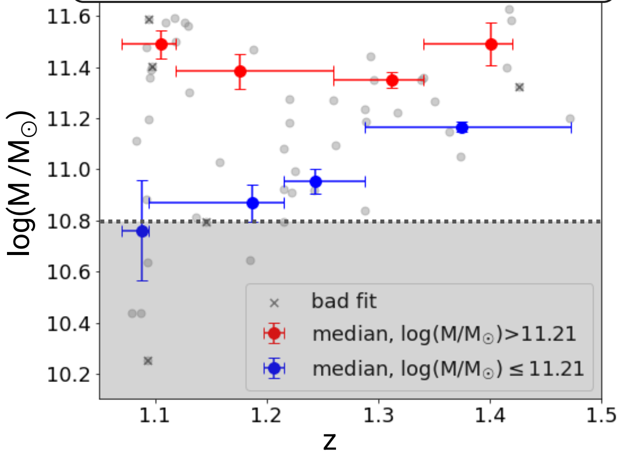
For 44 galaxies the fit is successful and indicates:

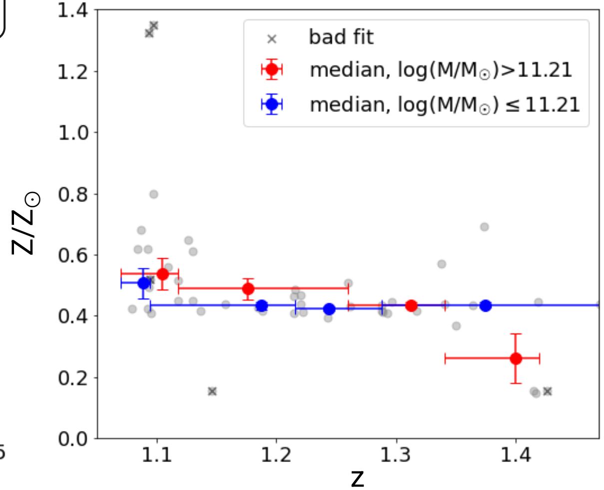
- 95% of ages lower than age of the Universe in fΛCDM
- evidence of mass-downsizing
- short SFH $\langle\tau\rangle$ = 0.28±0.02 Gyr
- massive galaxies $\langle\log(M/M_{\odot})\rangle$ = 11.21±0.05
- homogeneous population $\langle Z/Z_{\odot}\rangle$ = 0.44±0.01




**39 cosmic chronometers**



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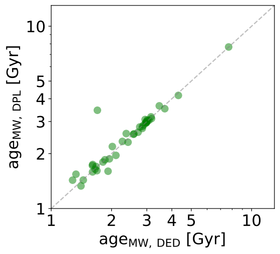
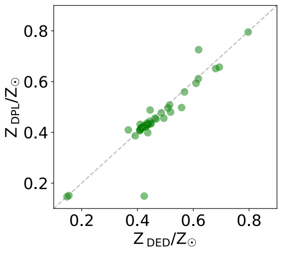
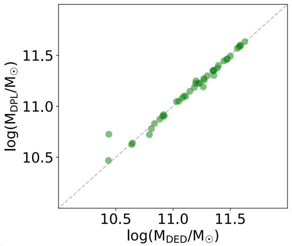
## Changing the SFH




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

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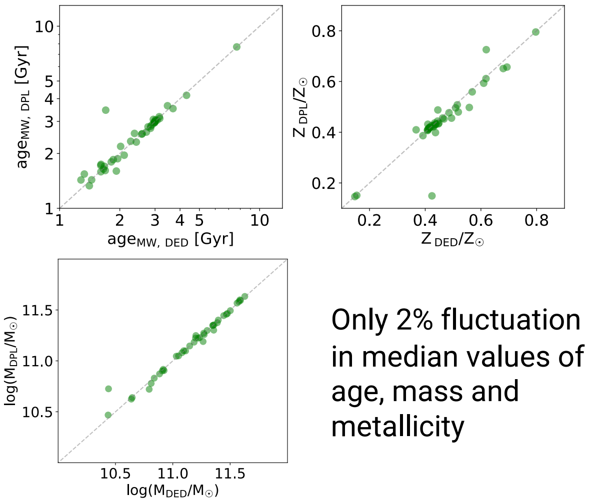


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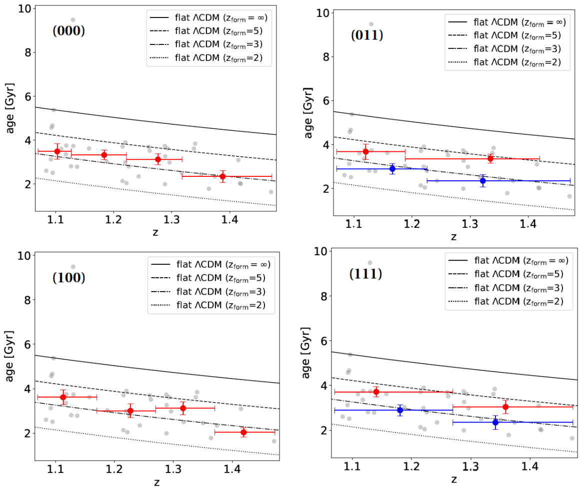
## Changing the binning



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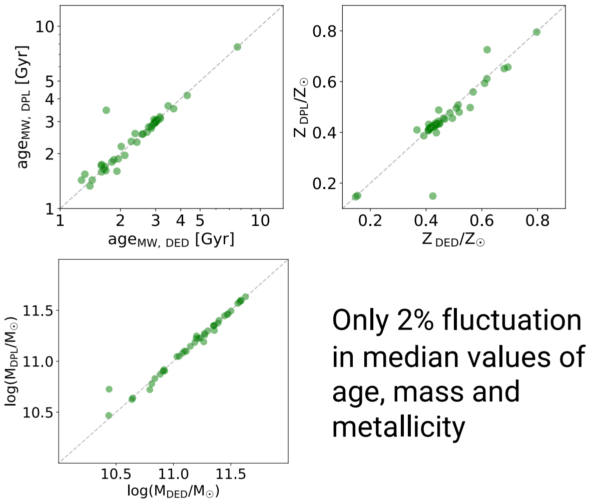


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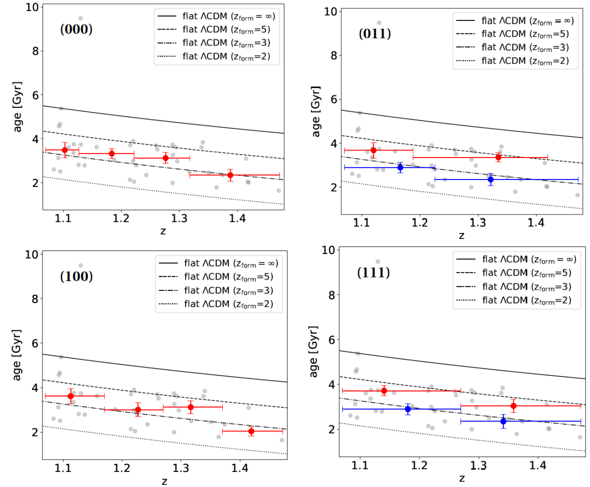
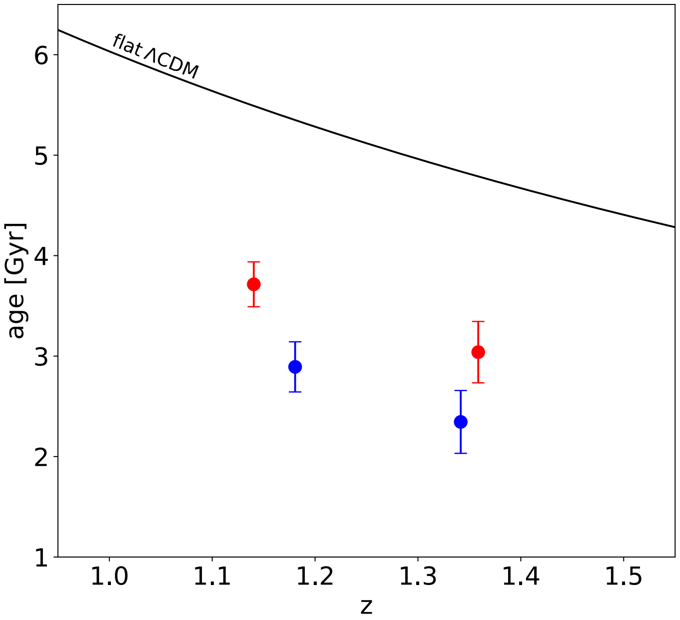



Systematic error budget on H(z)

# Cosmological analysis



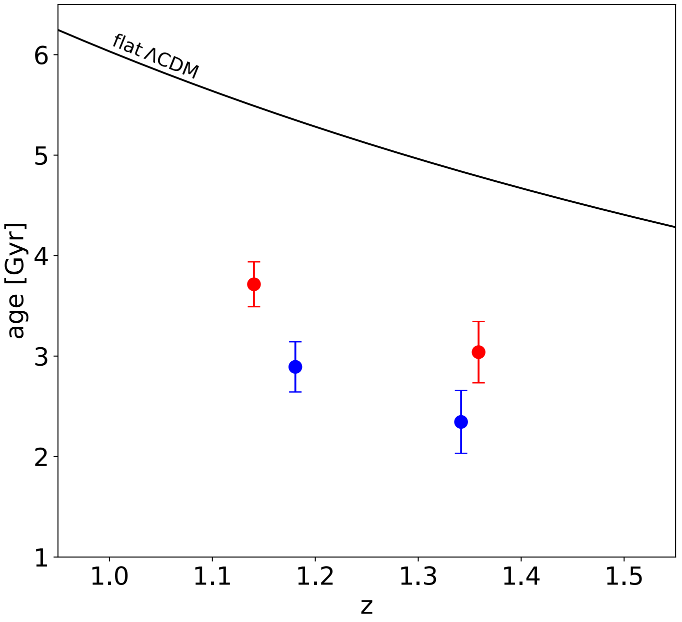
# Cosmological analysis: fitting the age-redshift relation

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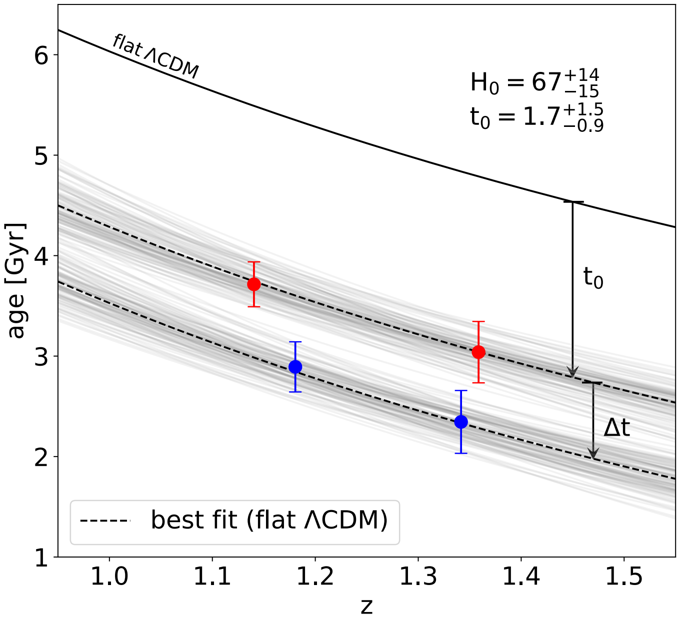
$$H_0 = 67^{+14}_{-15} \quad \mathrm{km\ s^{-1} Mpc^{-1}}$$



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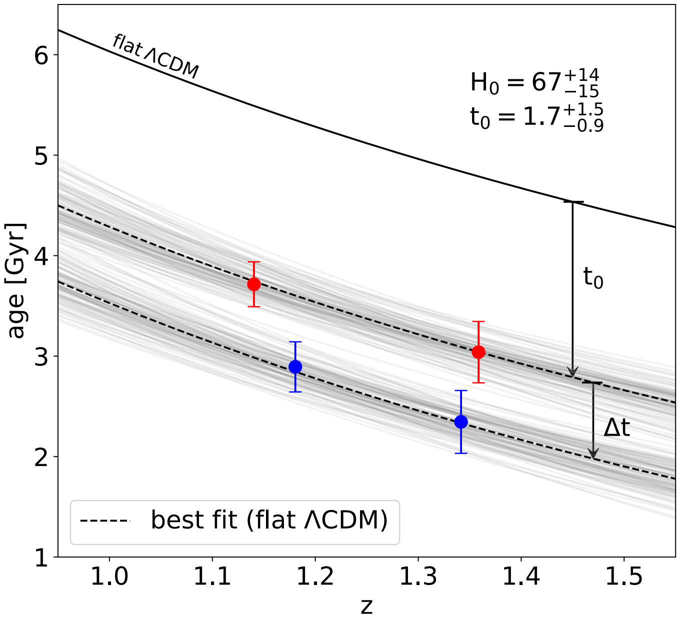
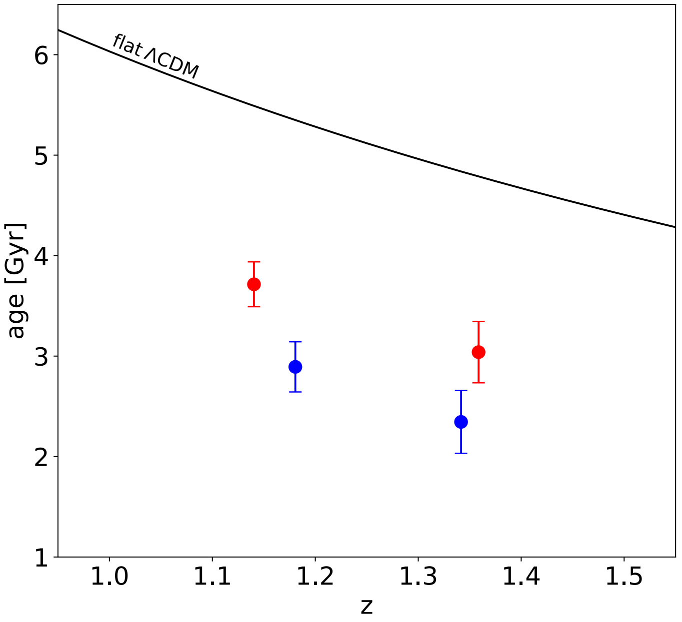



Current errors are dominated by the low number of galaxies ⟹ higher precision requires more statistics!

# 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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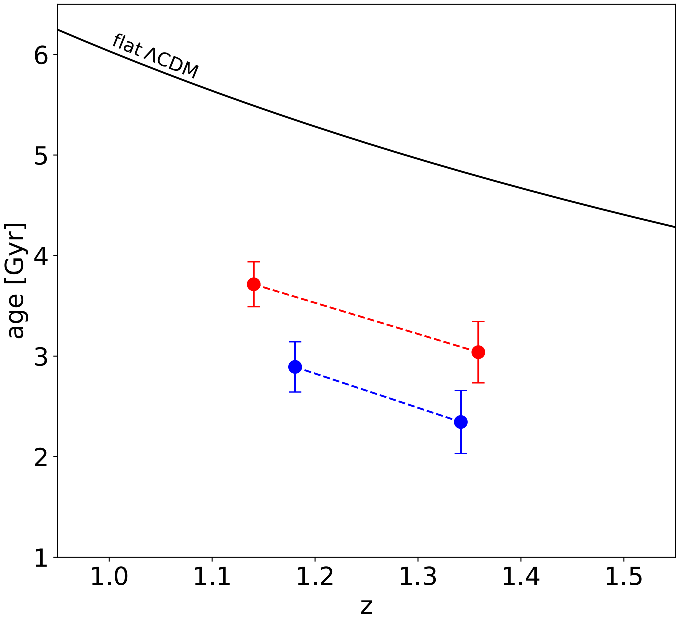

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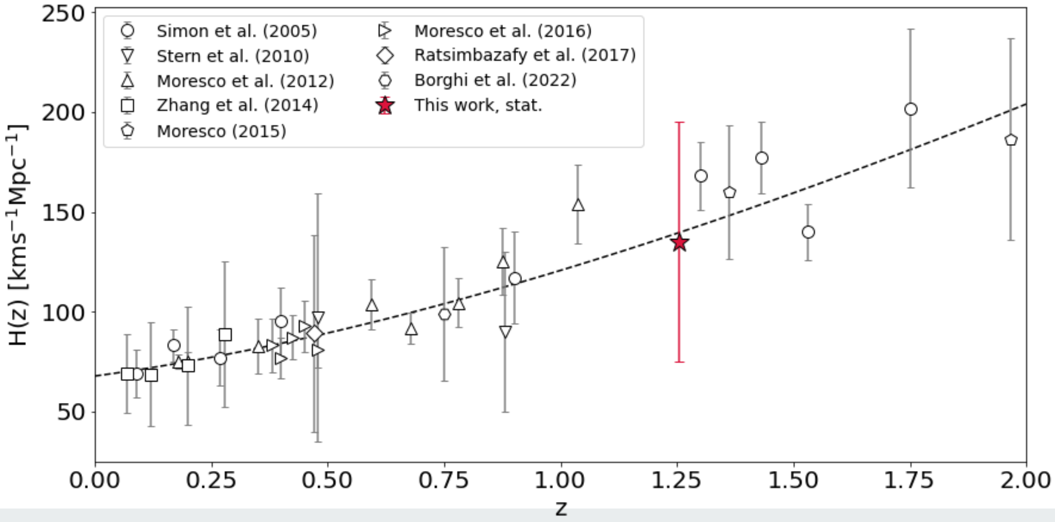


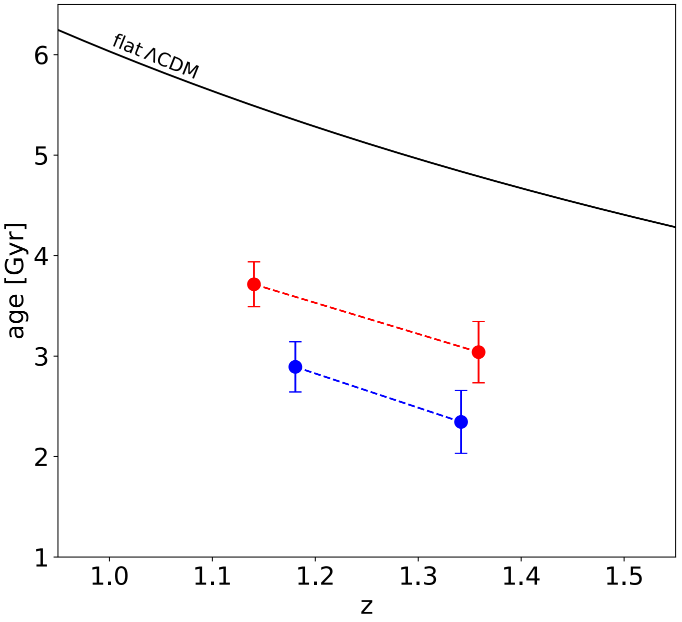


At redshift $z \simeq 1.26$ we obtain:

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

# 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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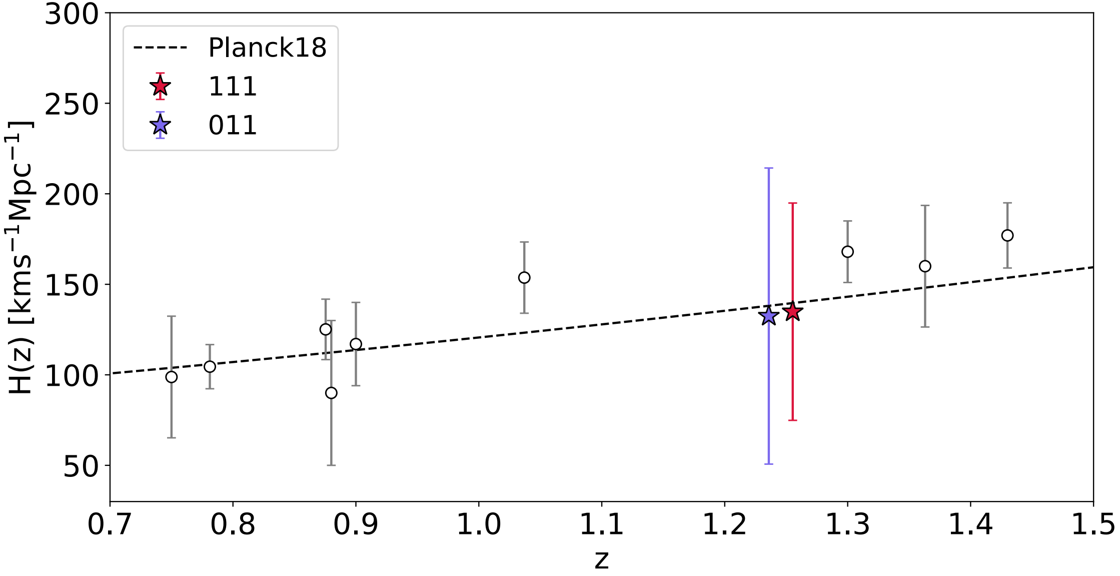


Contribution to the error budget:

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

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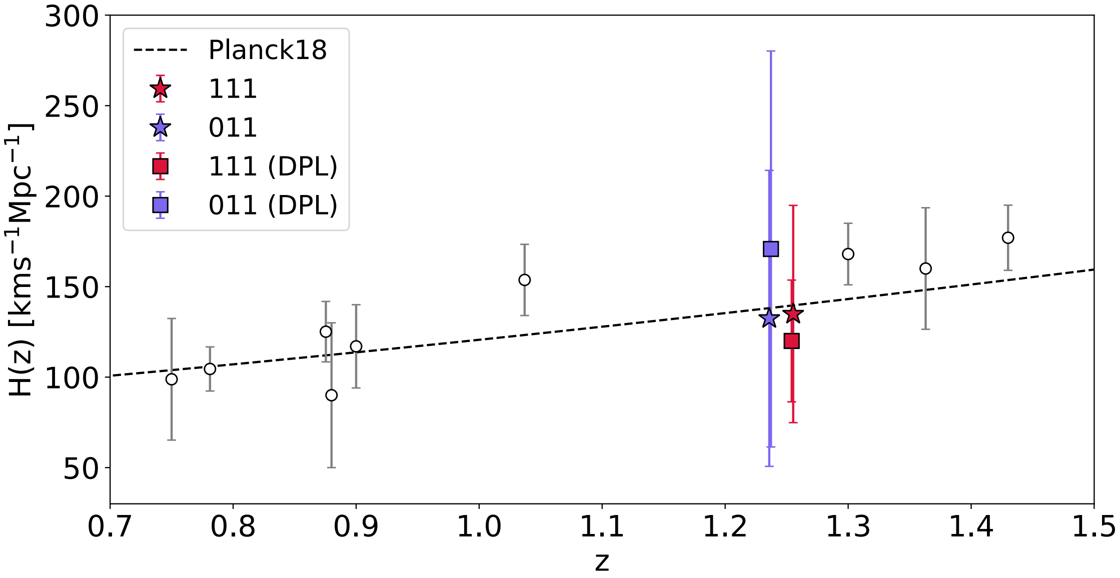



Contribution to the error budget:

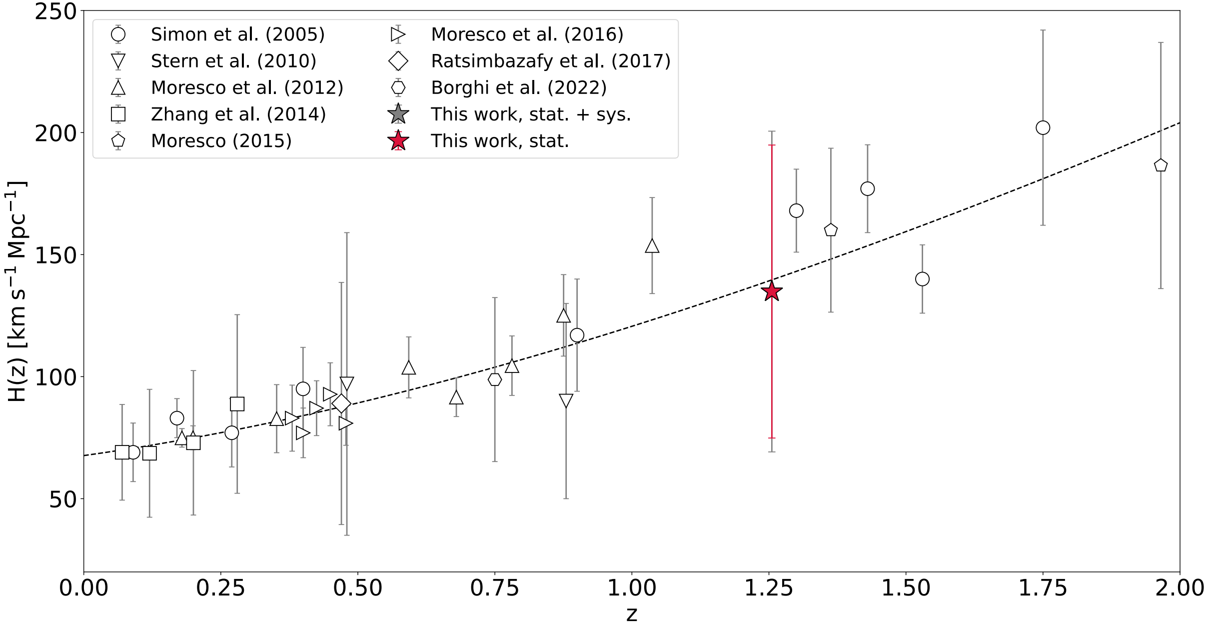
$$\Delta H_{bin} = 2.4 \quad \mathrm{km\,s^{-1}Mpc^{-1}}$$

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

# Final result

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

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



# 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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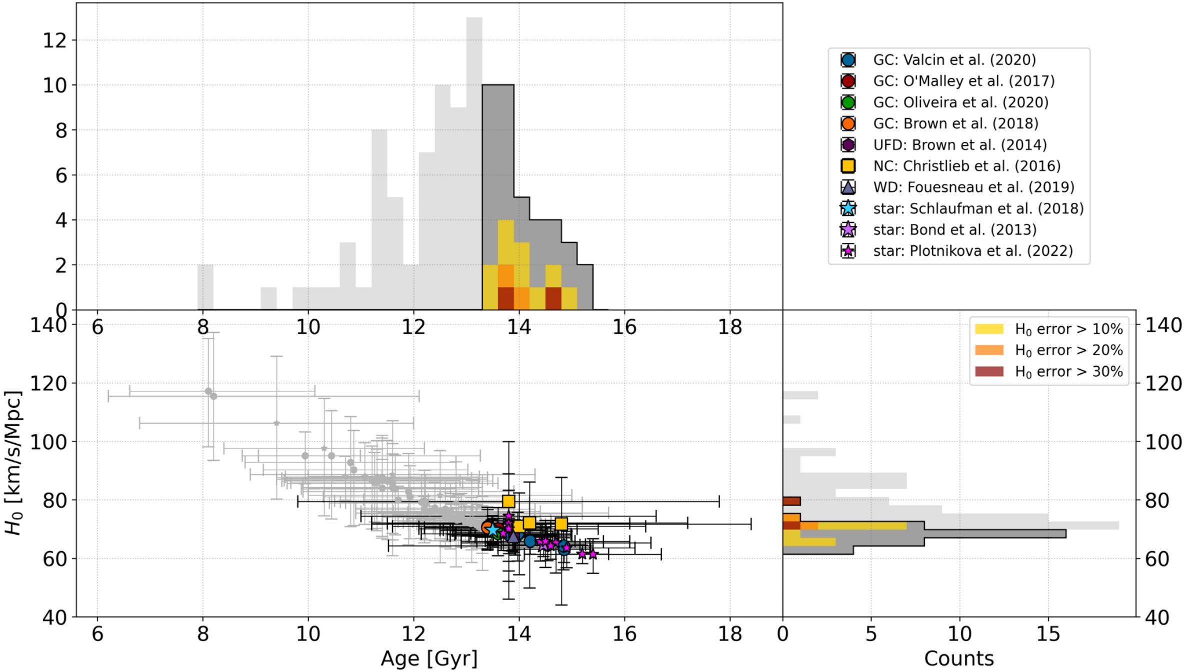

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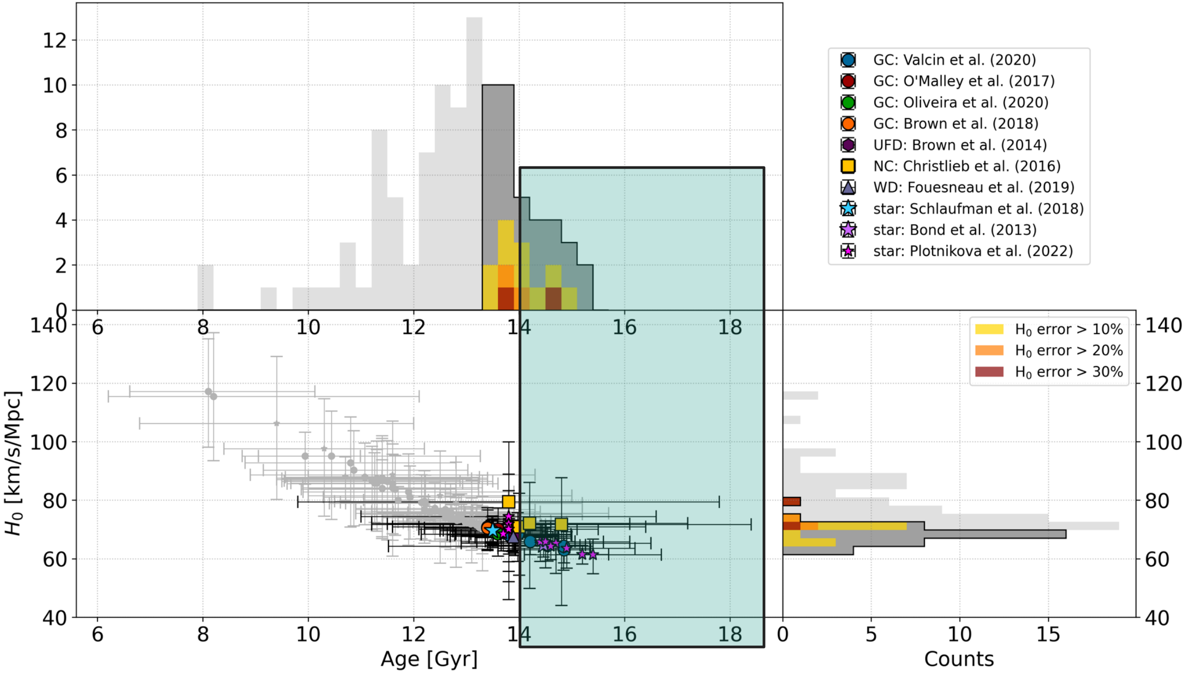

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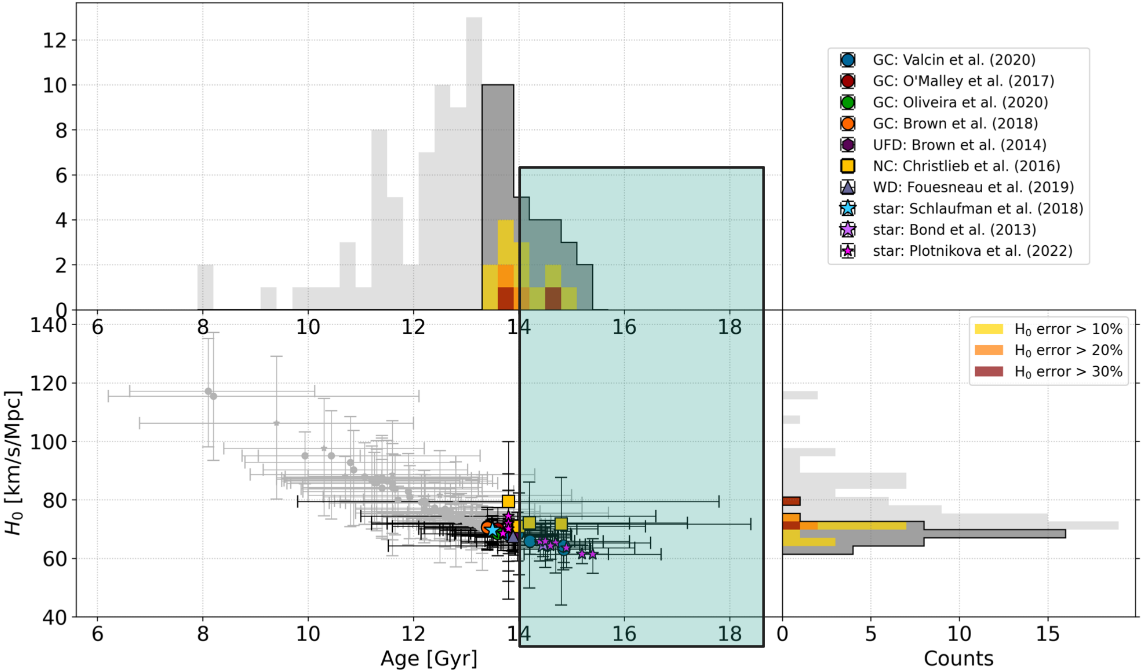


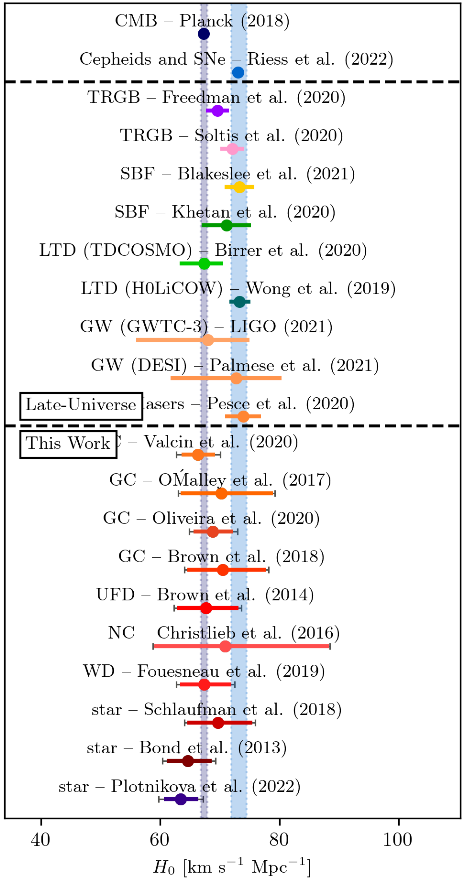

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Thank you!