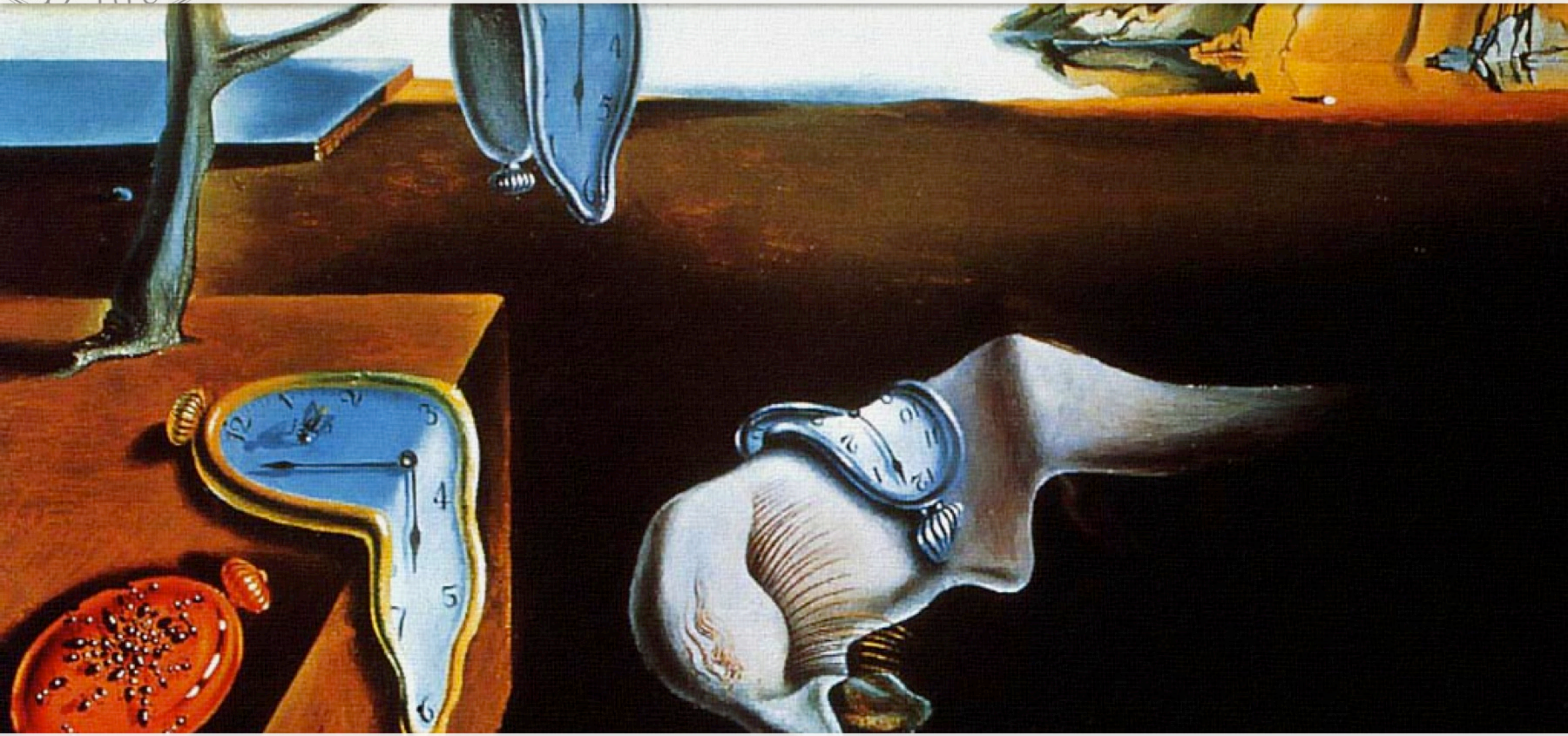
Cosmic chronometers

A new approach to constrain the expansion history of the Universe



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Complementarity is the key

1. Each method has to deal with different systematic effect
2. Each method probes different cosmic times, hence is more sensible to different parameters
3. Results obtained with different methods are useful to do cross-checks, and to keep under control the systematic effects
4. The combination of different methods is an extremely powerful tool to constrain the different components of the Universe

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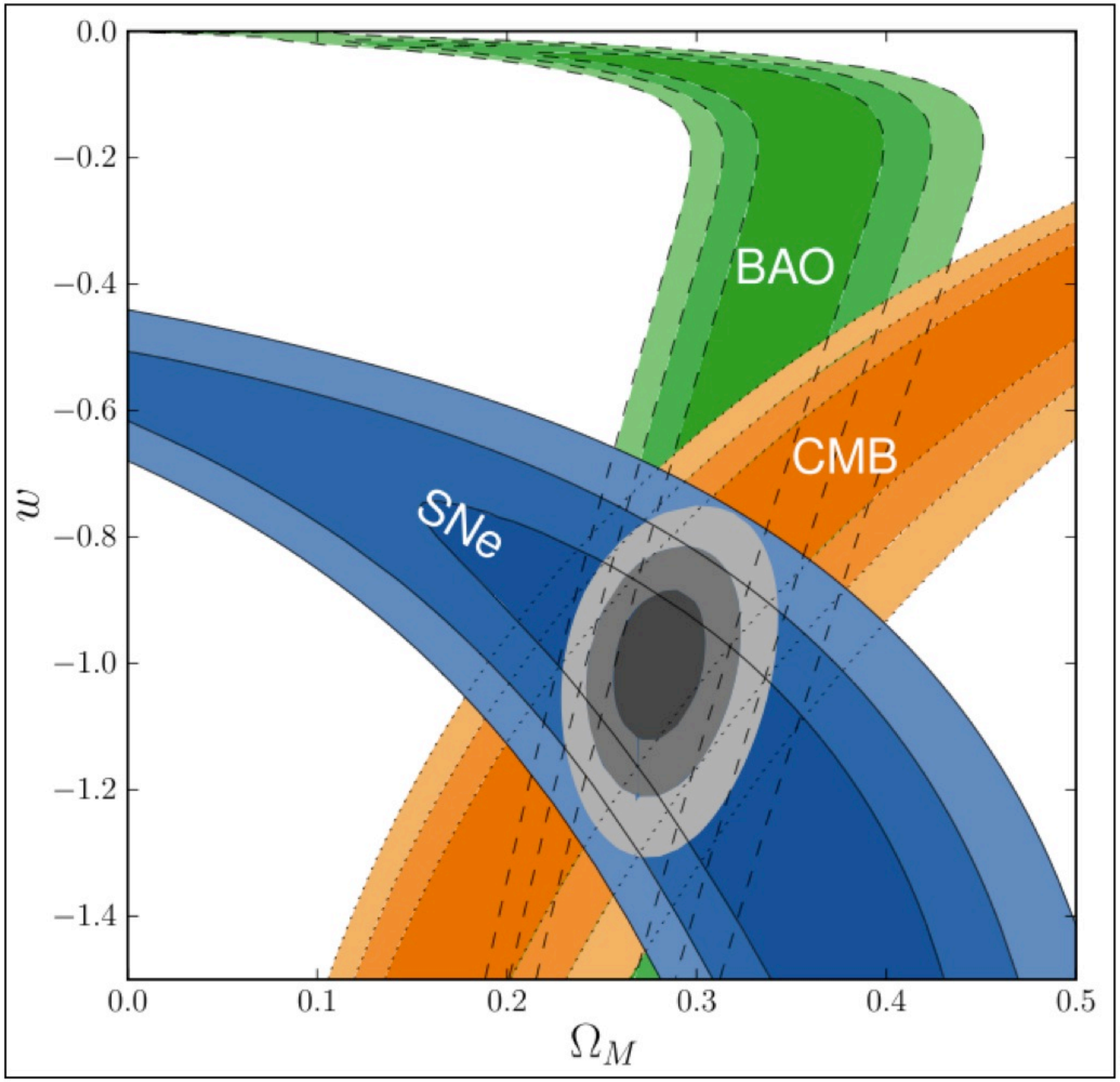
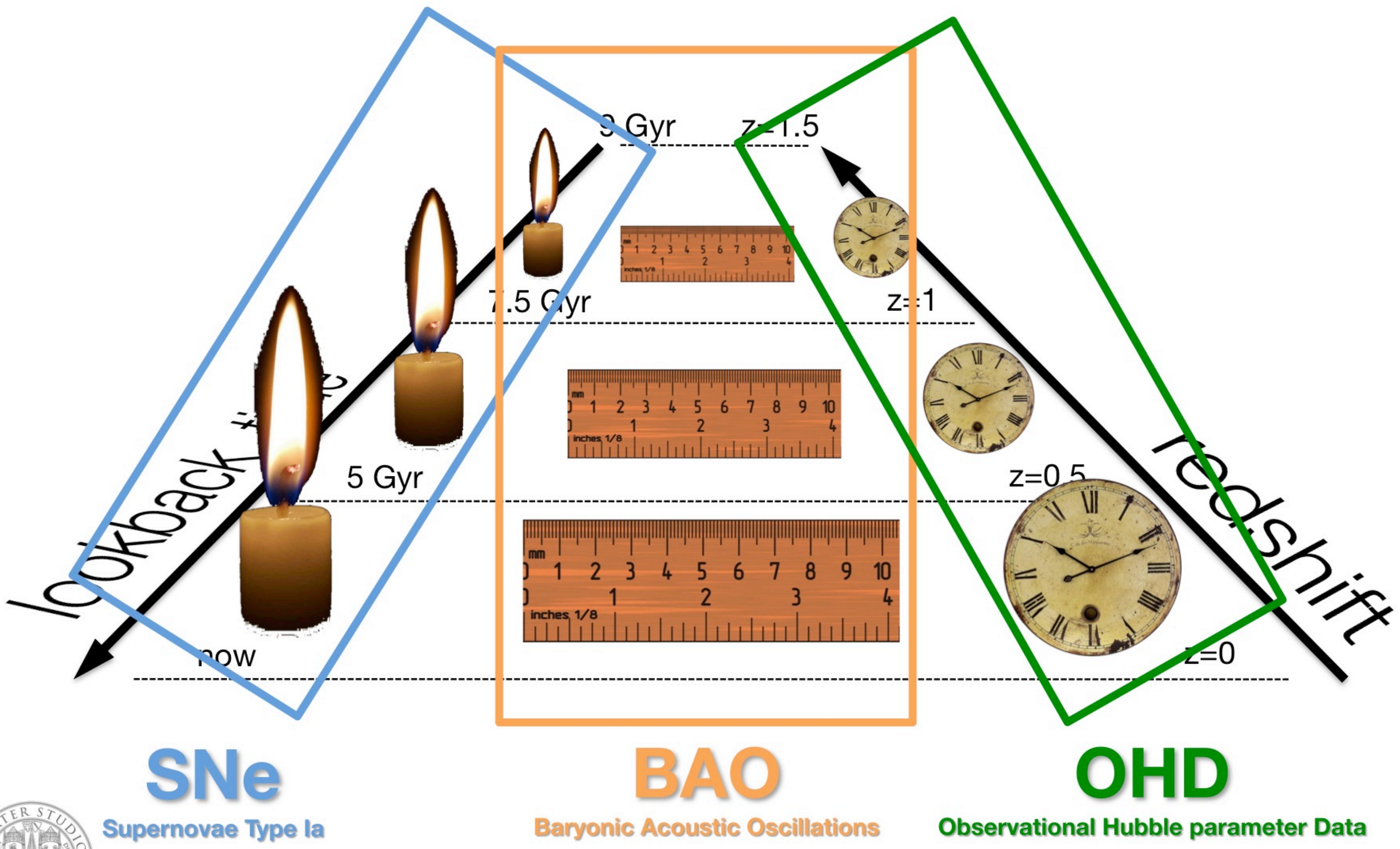


Amanullah et al. (2010)

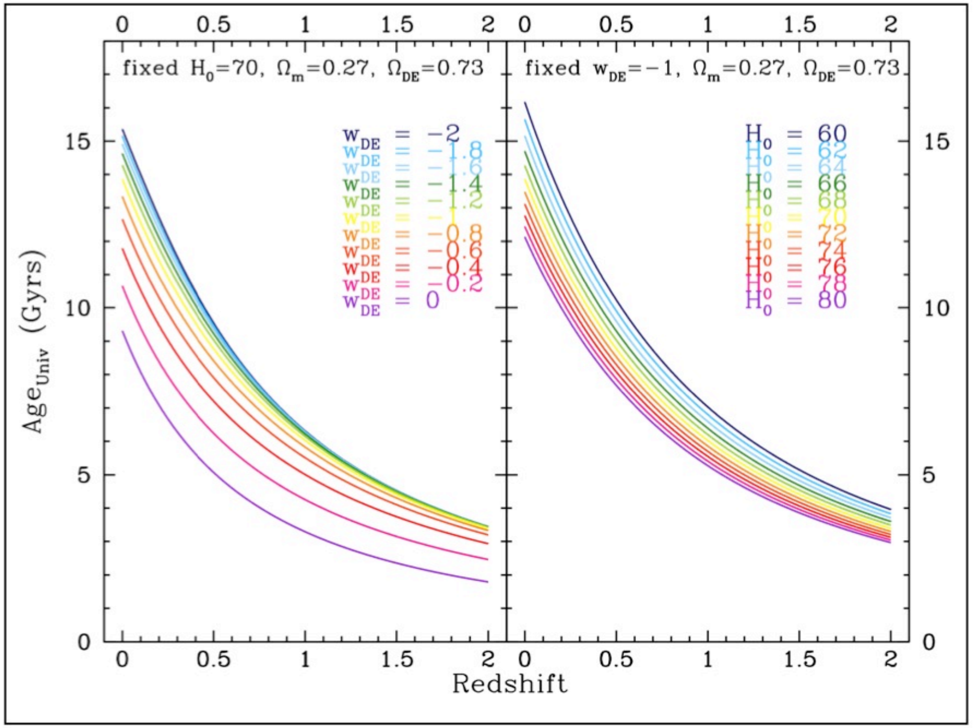
Disentangling effects



Introducing the method

Basic idea

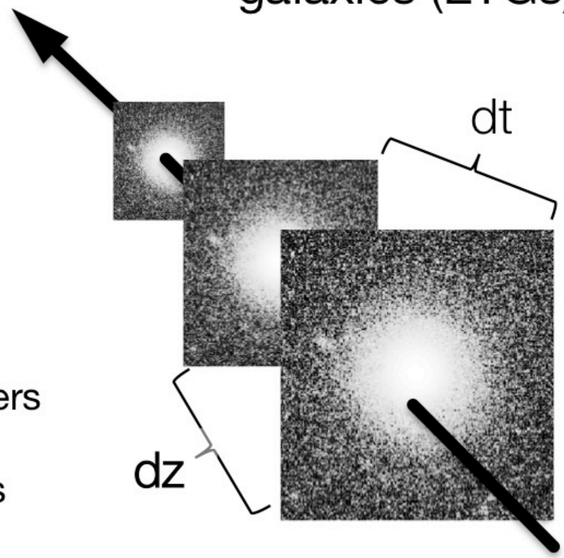
Constrain the cosmological expansion history studying the **differential age evolution** of the Universe



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

Jimenez & Loeb (2002)

massive and passive early-type galaxies (ETGs)



PROs:
- differential approach
- independent technique
- **direct measure of H(z)**
- high statistic

CONs:
- homogeneity of the tracers
- degeneracies
- treatment of systematics

Frequently **A**sked **Q**uestions

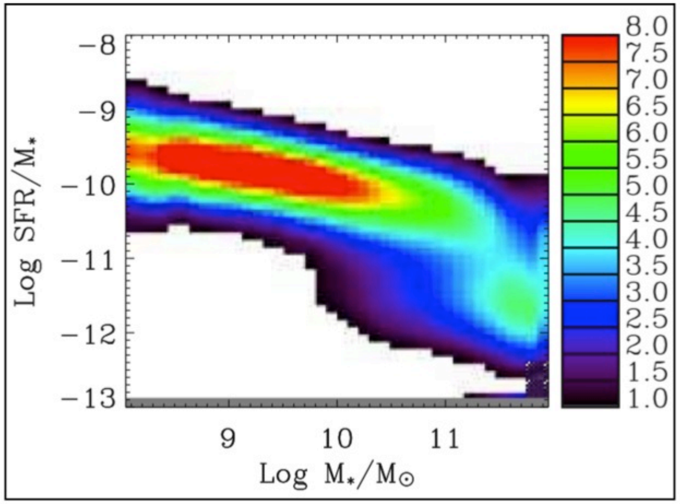
1. How well ETGs can be approximated as passively evolving sistems?
   - on-going star formation
   - are ETGs still forming at z<1 (mergers, progenitor bias)?

2. How well can we measure ETGs ages?
   - ability to accurately measure stellar ages
   - efficiency at obtaining spectra

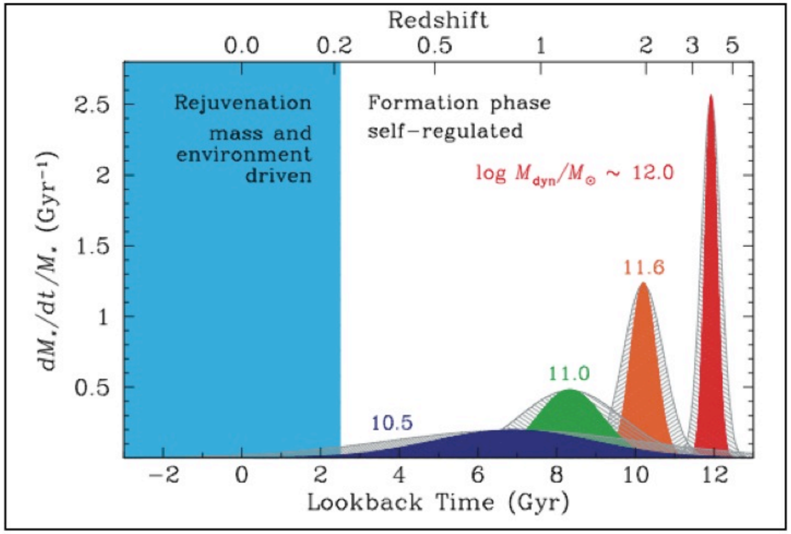
3. How well can we model ETGs ages?
   - systematics between different SPS models

Observational evidences

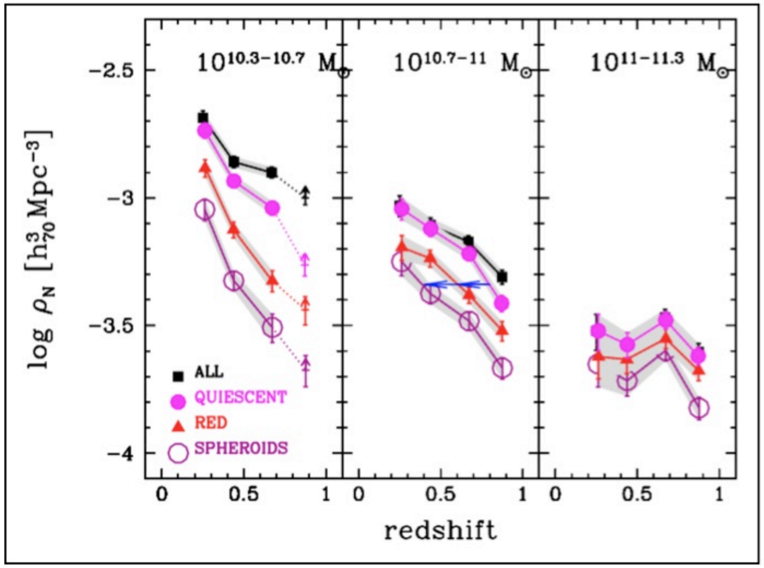
1. They dominate the luminous/massive end of the LF/MF, and are **passively evolving** systems
2. Most massive --> oldest
   --> more **synchronized SF**
3. Homogeneous population (metallicity and number density) **also in redshift**



Brinchmann et al. (2004)

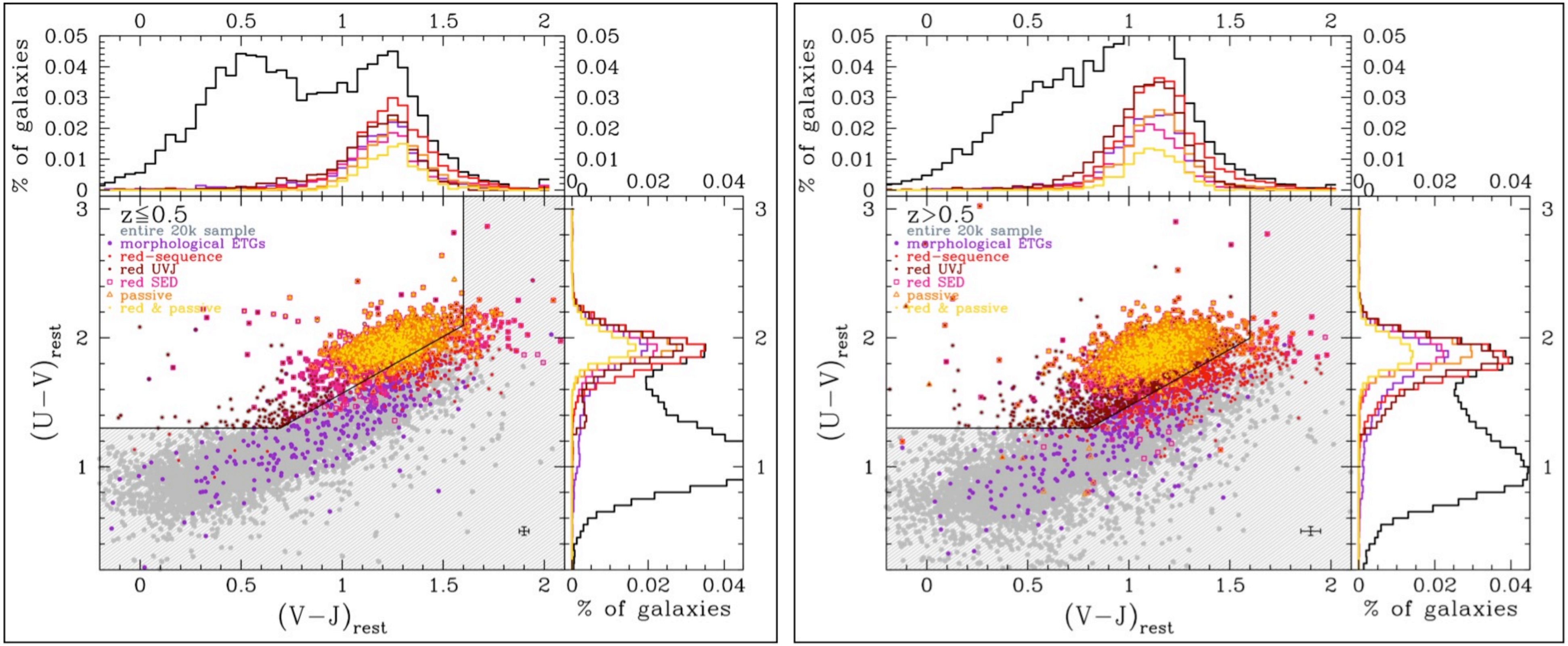


Thomas et al. (2010)



Pozzetti et al. (2010)

Selection criterion



Moresco et al. (2013)

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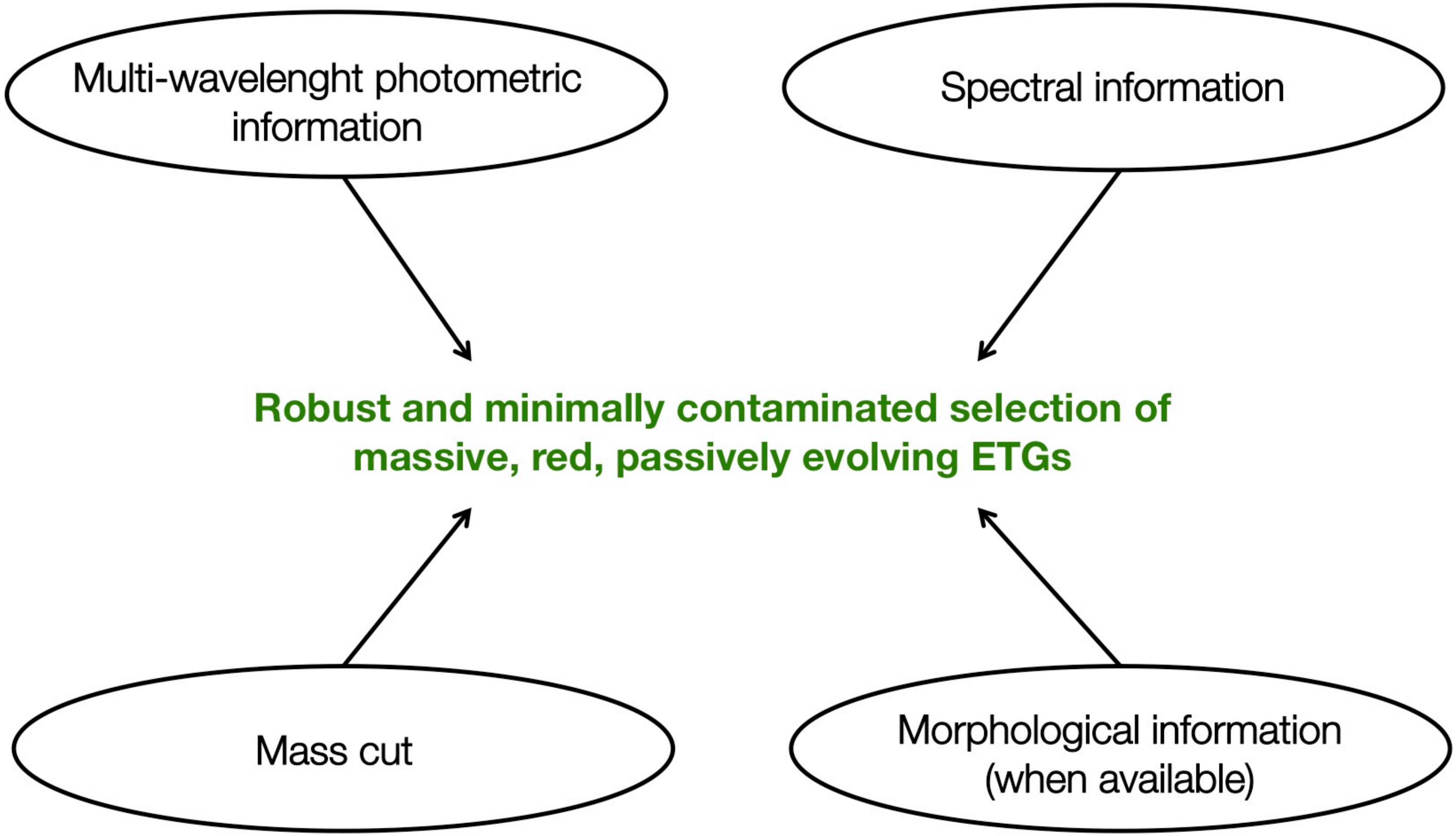

Frequently **A**nswered **Q**uestions

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    Selection criterion + differential approach

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    Better accuracy in measuring differential ages + increasing number of redshift surveys

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    Minimized dependence on SPS models with the new spectroscopic approach

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$$H(z) = -\frac{1}{1+z} A(Z,SFH) \frac{dz}{dD4000_n}$$

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The analysis

Extended data sample

Different spectroscopic surveys (SDSS MGS+LRGs, zCOSMOS-20k, UDS, GDDS, GOODS-S, K20, …)

1. **SEDs** compatible with **early-type** template;
2. **high-quality optical spectra** with reliable redshifts and suitable to provide D4000n amplitudes up to z~1.5;
3. **absence of emission lines** (Hα and/or [OII] λ 3727 depending on the redshift);
4. **stellar masses** from photometric SED-fitting to be **above $10^{11}M_\odot$**;
5. **spheroidal** morphology (when available).

More than 11000 ETGs in the range 0.15<z<1.4

metallicity measurements for SDSS MGS sample Gallazzi et al. (2005)

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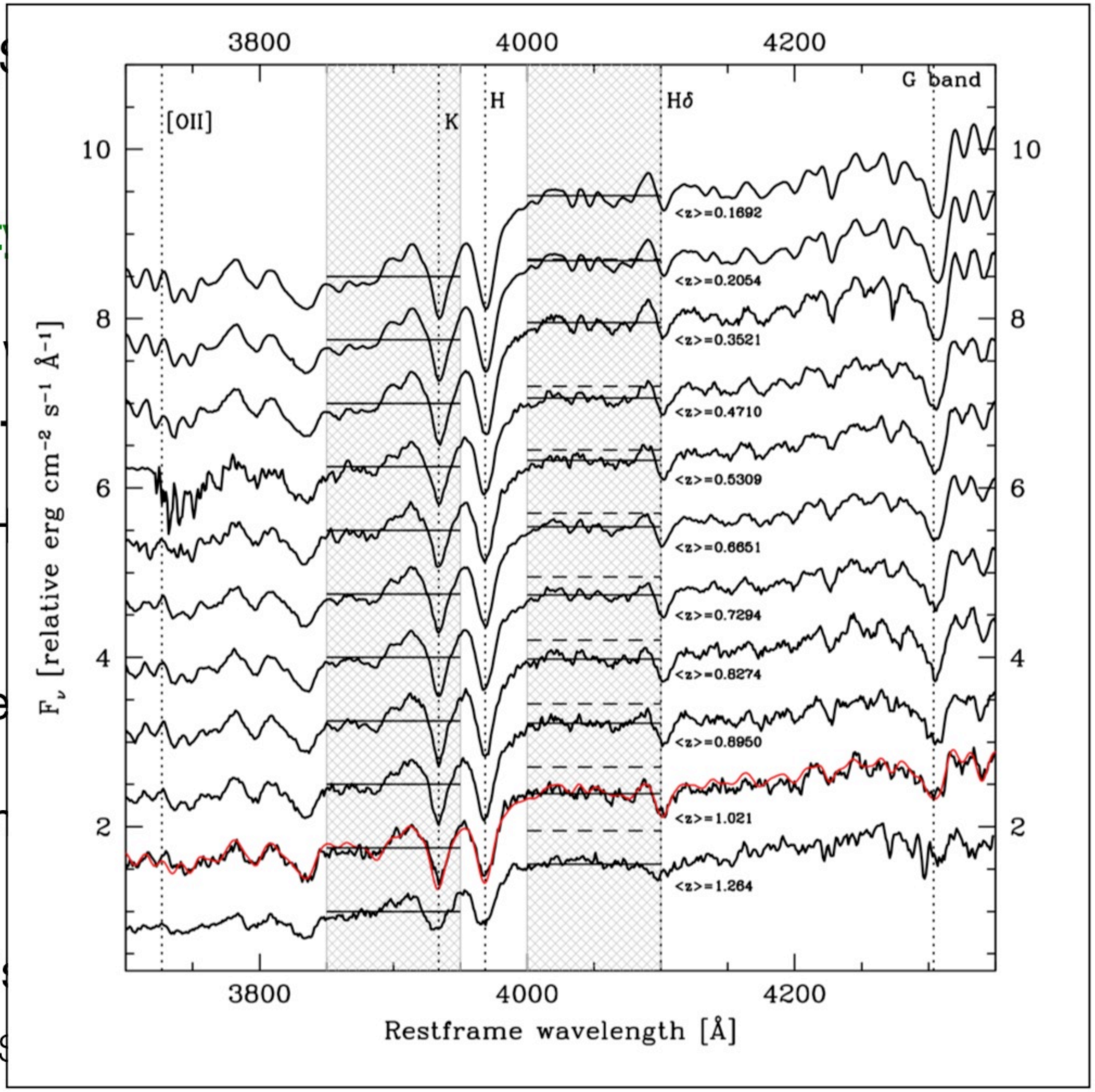
metallicity measurements for S



Moresco et al. (2012a)

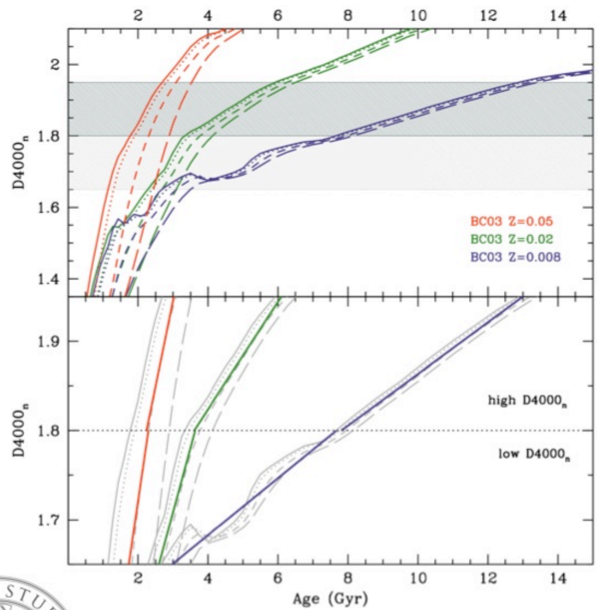
Relevant quantities

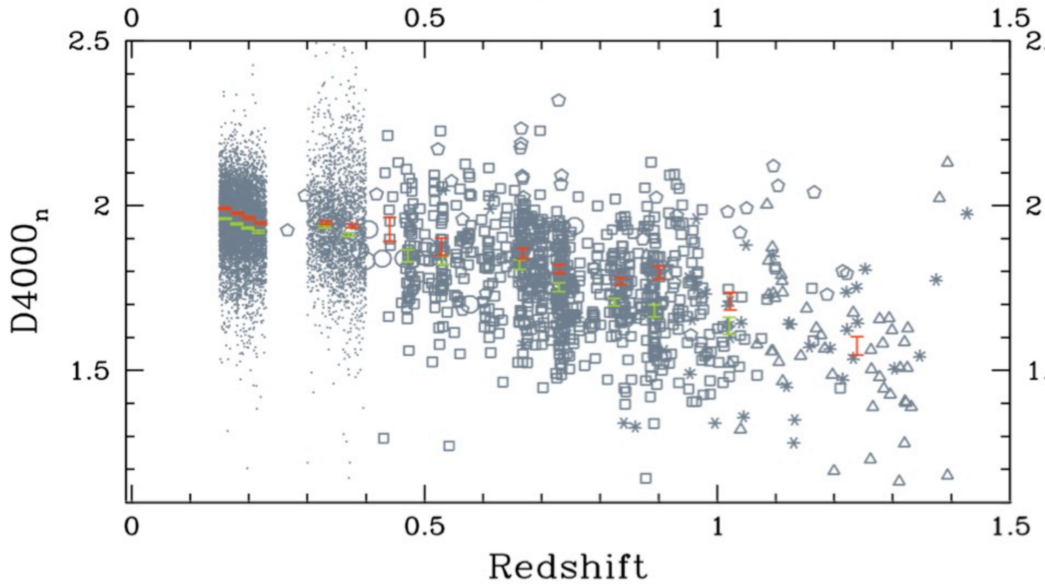
$$H(z) = -\frac{1}{1+z} A(Z,SFH) \frac{dz}{dD4000_n}$$

calibrated on different SPS models

estimated from data

$$A(Z,SFH) = \langle A(Z) \rangle \pm \sigma_A(SFH)$$



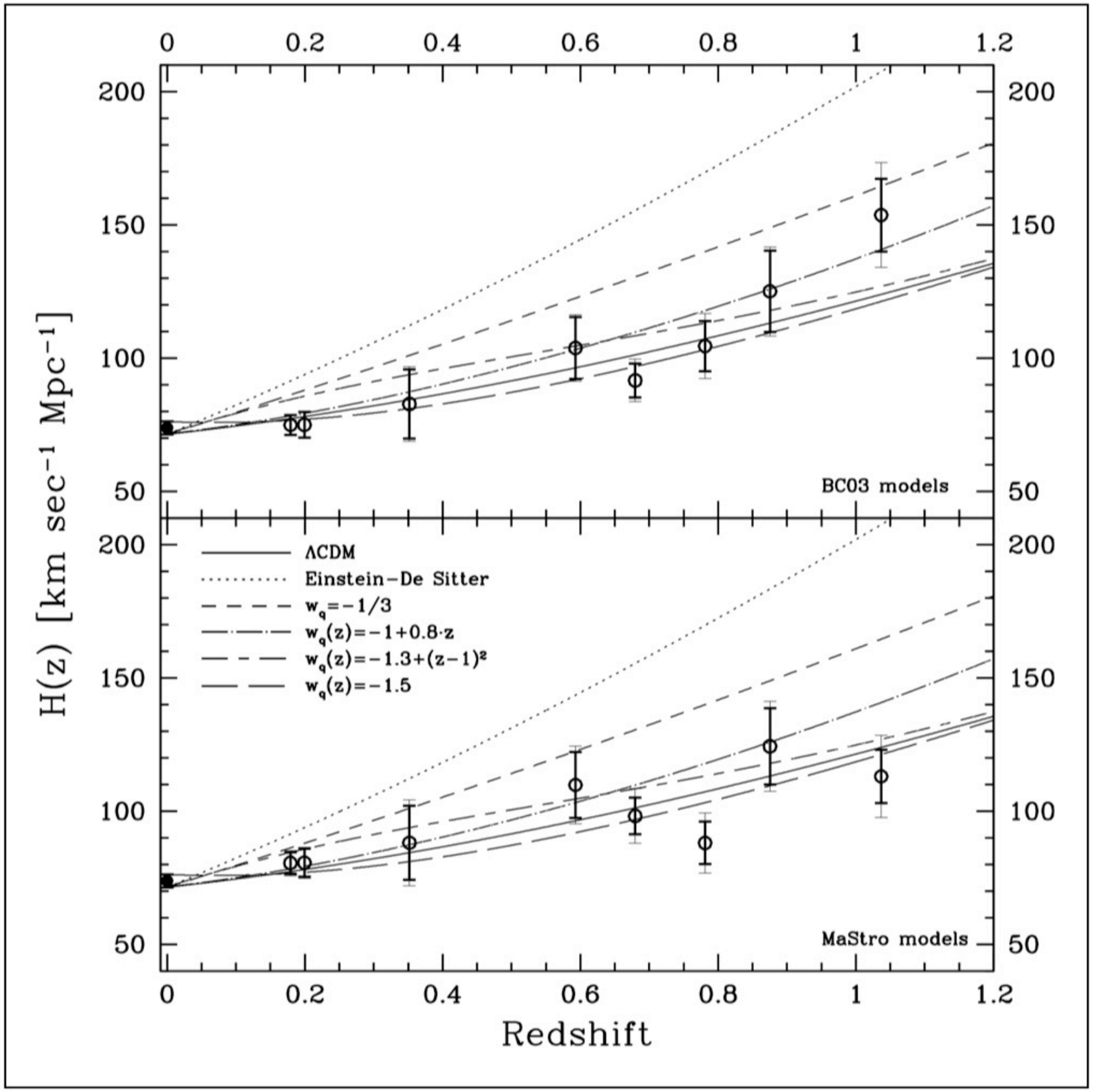


Moresco et al. (2012a)

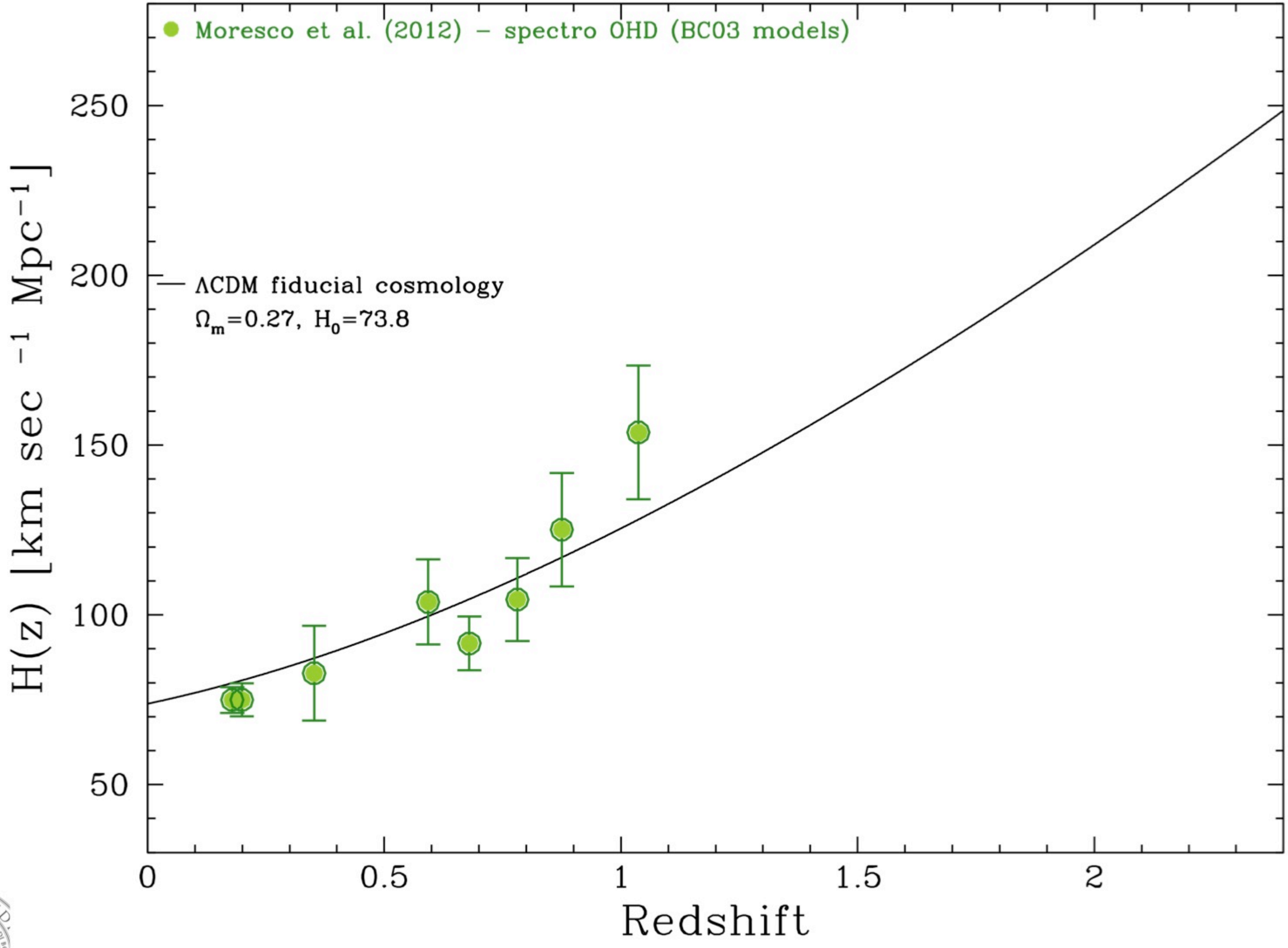
The results

Hubble parameter measurements

- precision ~5% at z~0.2
  including systematic errors
- precision ~12% across the entire redshift range
- consistent results with different SPS models
- EdS model discarded at 7σ
- direct and robust (6σ) evidence of the accelerated expansion
- new path to discriminate alternative cosmologies



Observational Hubble parameter Data



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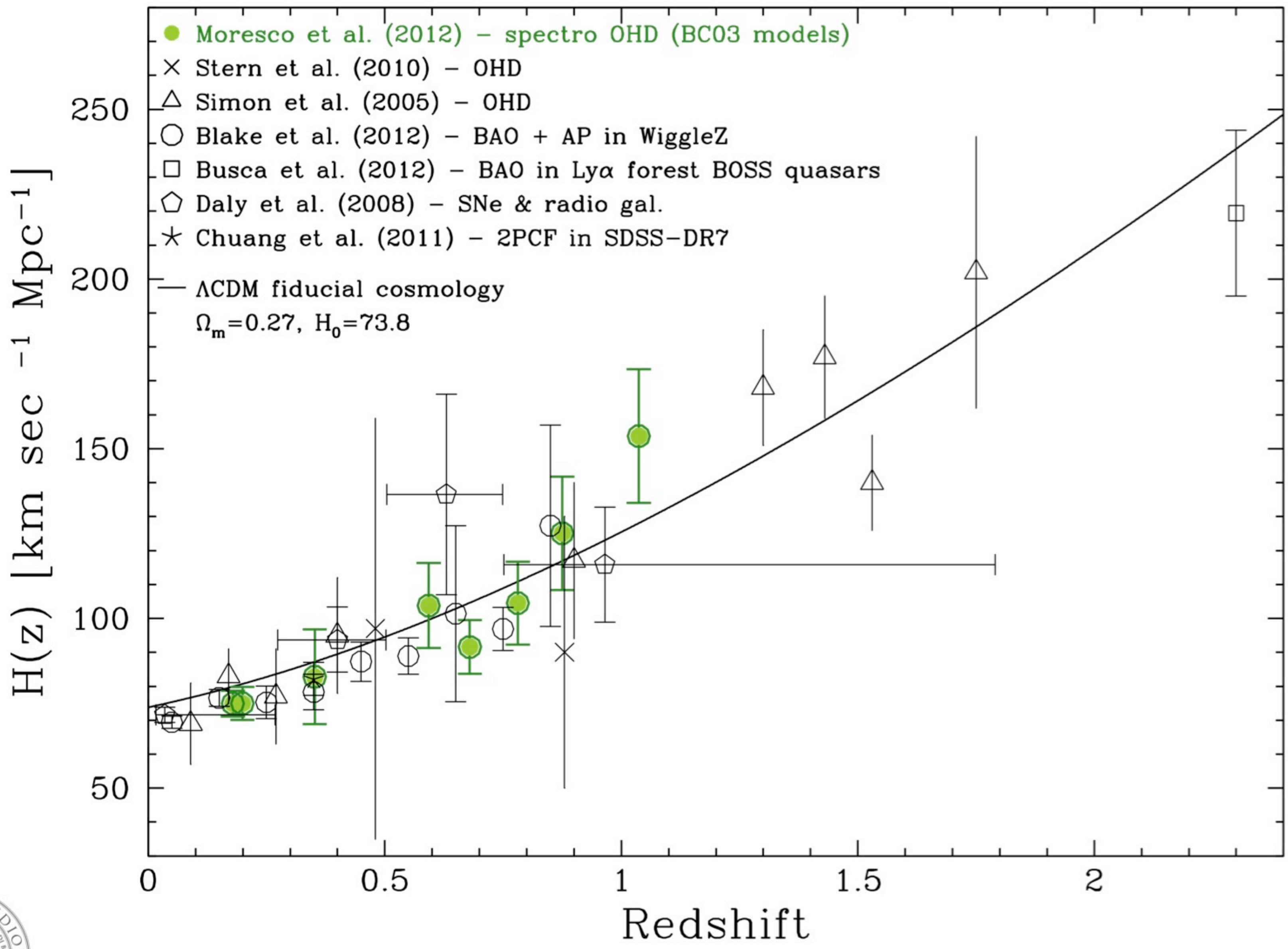
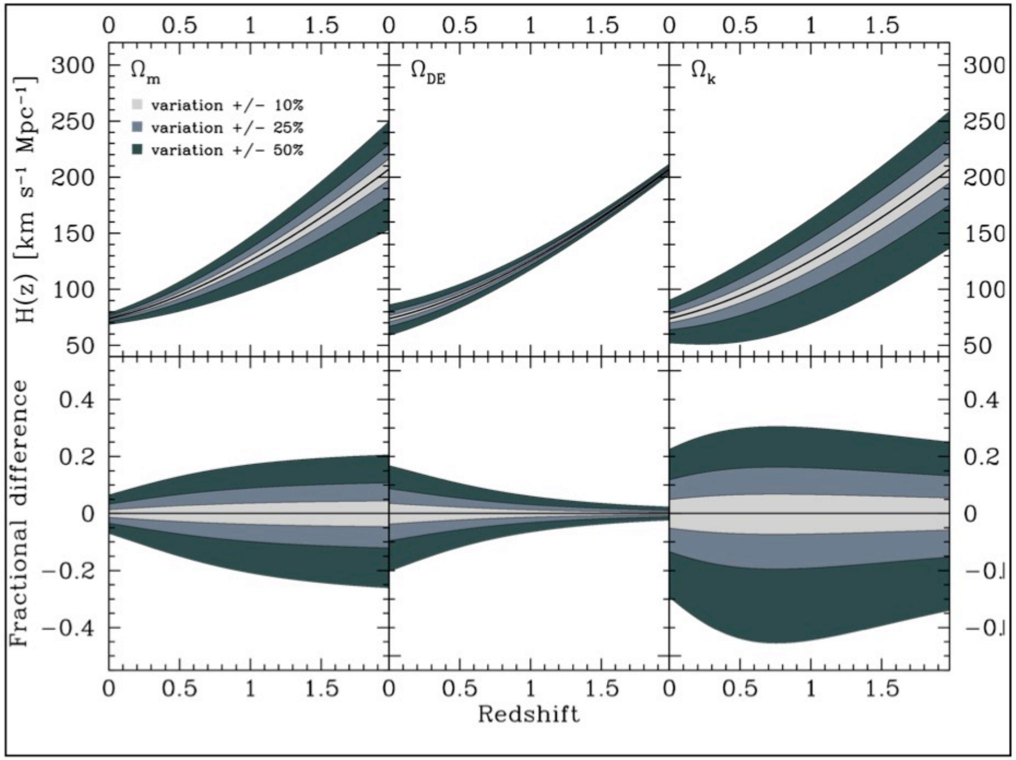
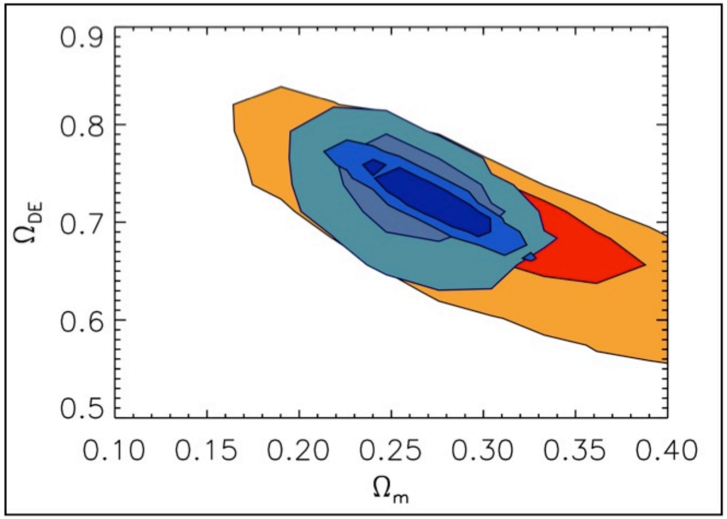


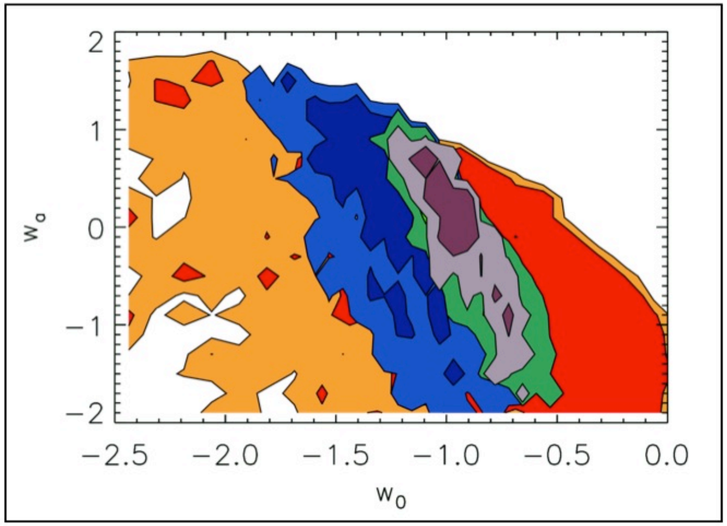
Cosmological constraints

$$H(z) = H_0\left[\Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_{DE}(1+z)^{3(1+w_0+w_a)} e^{-3w_a\frac{a}{1+z}}\right]^{1/2}$$

Moresco et al. (2012b)



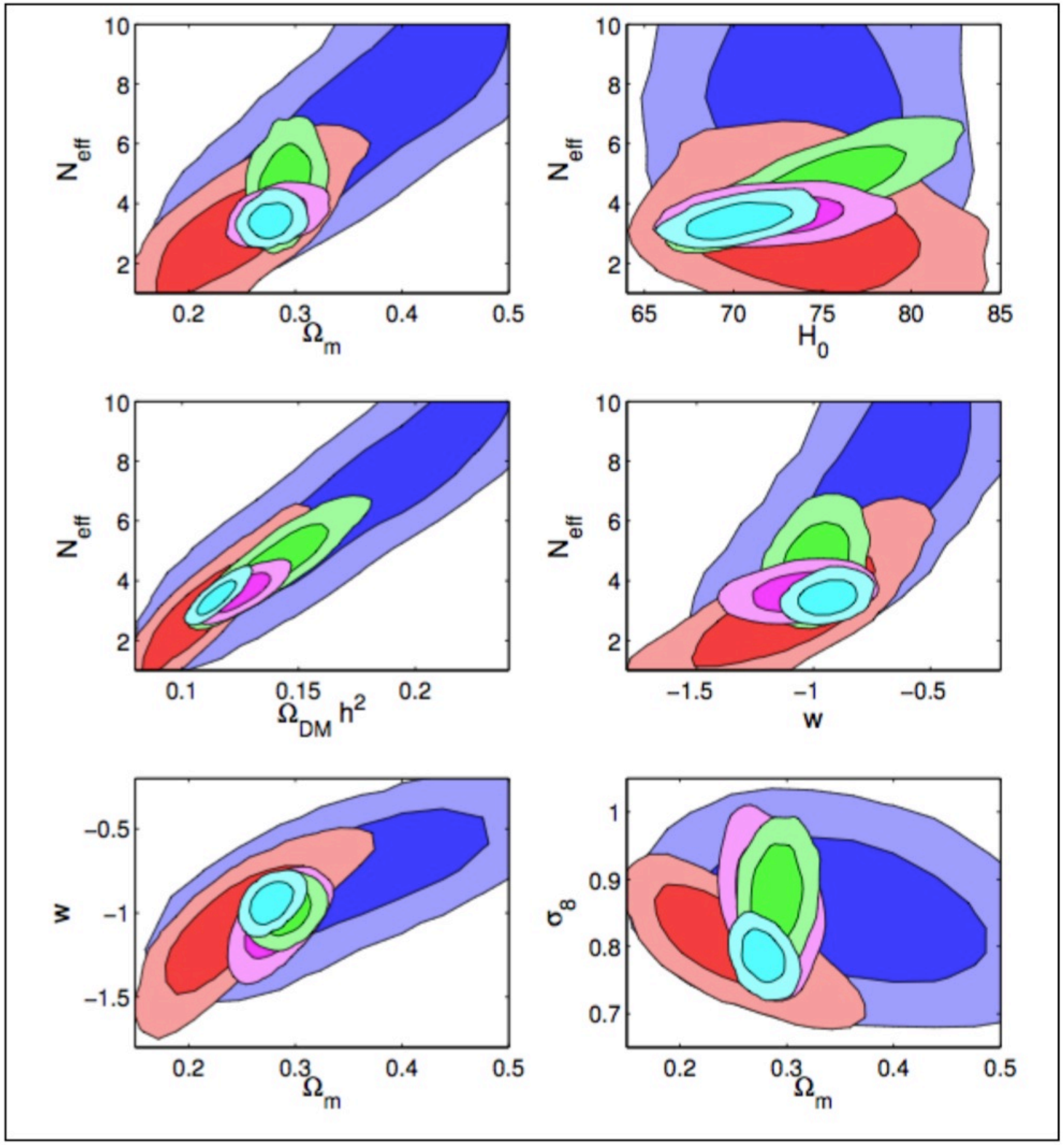




WMAP5+H_0(Freedman2001)
WMAP5+H_0(Riess2011)
WMAP5+H_0(Riess2011)+OHD
WMAP5+H_0(Riess2011)+OHD simulated 5% error
WMAP5+H_0(Riess2011)+OHD simulated 2.5% error

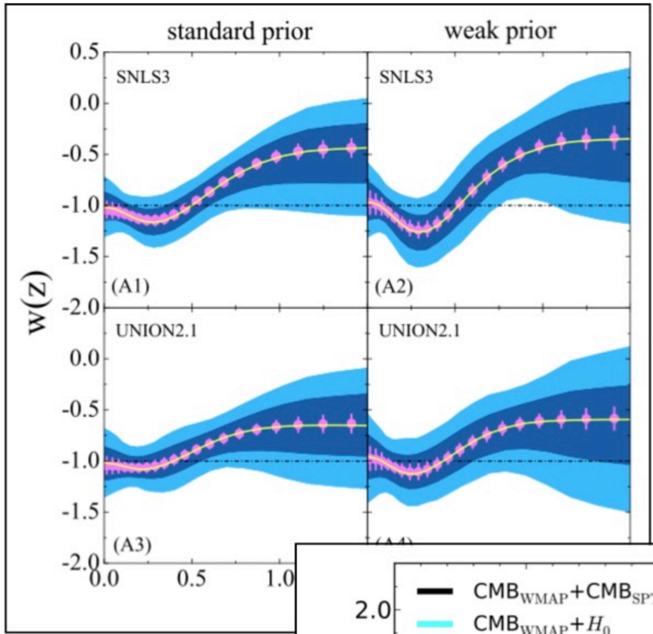
Breaking degeneracies with OHD

CMB
CMB+WL
CMB+BAO+OHD
CMB+BAO+SNe
CMB+WL+BAO+OHD+SNe



Wang et al. (2012b)

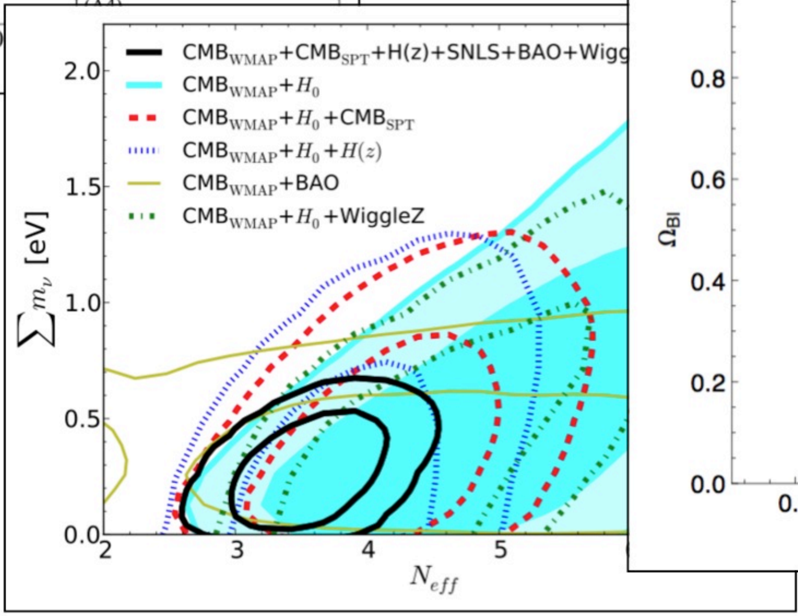
Wide cosmological applications



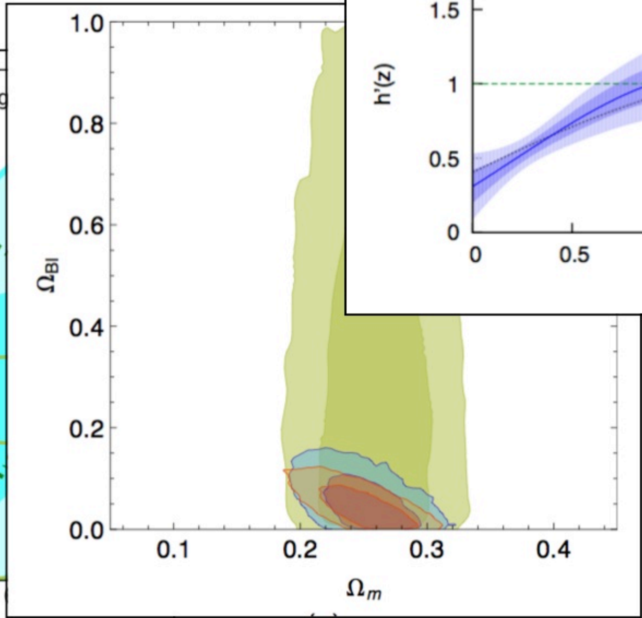
Zhao et al. (2012)

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho$$

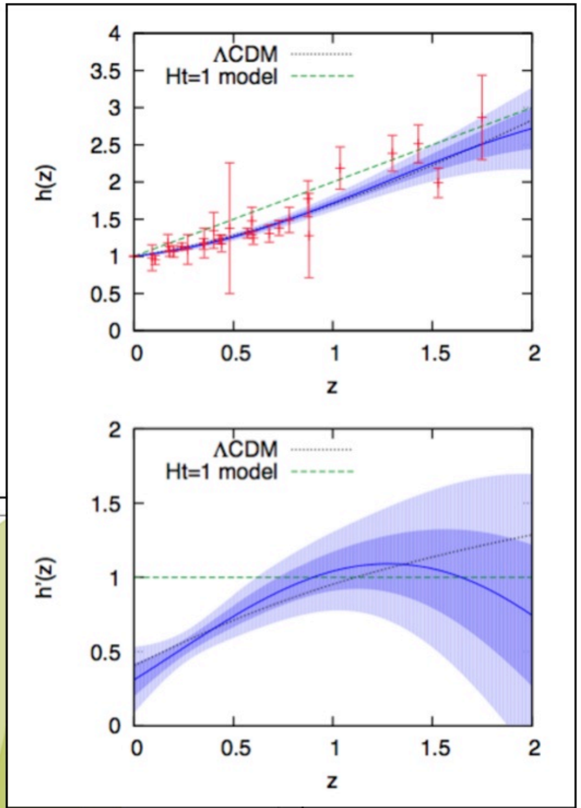
$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$



Riemer-Sorensen et al. (2012)



Breton et al. (2012)



Bilicki et al. (2012)

Conclusions

- Basics of “cosmic chronometer” approach, as complementary technique to constrain cosmological parameters
- Reliability of using ETGs as tracers of the cosmic expansion history
- **Importance of the selection criterion** adopted
- Analysis: 11000 ETGs at $0.15<z<1.4$ to obtain **8 new H(z) measurements at a precision of 5-12% in the entire range**
- Importance of OHD (in combination with CMB and H_0) to obtain **competitive constraints on cosmological parameters w.r.t CMB+BAO+Sne**
- OHD to break degeneracies between cosmological parameters

REFERENCES

Moresco et al., 2012a, JCAP08(2012)006, Improved constraints on the expansion rate of the Universe up to z~1.1 from the spectroscopic evolution of cosmic chronometers

Moresco et al., 2012b, JCAP07(2012)053, New constraints on cosmological parameters and neutrino properties using the expansion rate of the Universe to z~1.75

Data available at

http://www.physics-astronomy.unibo.it/en/research/areas/astrophysics/cosmology-with-cosmic-chronometers

for your own analysis