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UV space telescope for astrophysical tests of redshift drift and the stability of fine-structure constant

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ODYSSEUS
EUROPEAN YOUTH SPACE CONTEST

Introduction

- Astrophysical tests of the stability of fundamental constants

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  - high-resolution optical/UV spectroscopic measurements

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    1. One can only measure dimensionless combinations of dimensional constants
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Current data

- Useful constraints

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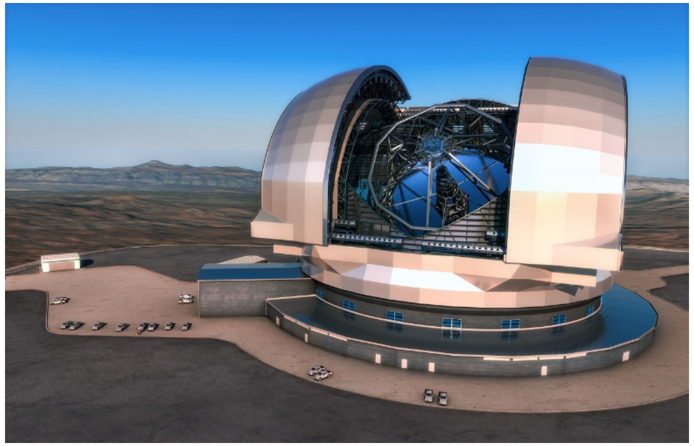
Current data → ELT (HIRES)



Credit: ESO

Artist’s impression of the European Extremely Large Telescope

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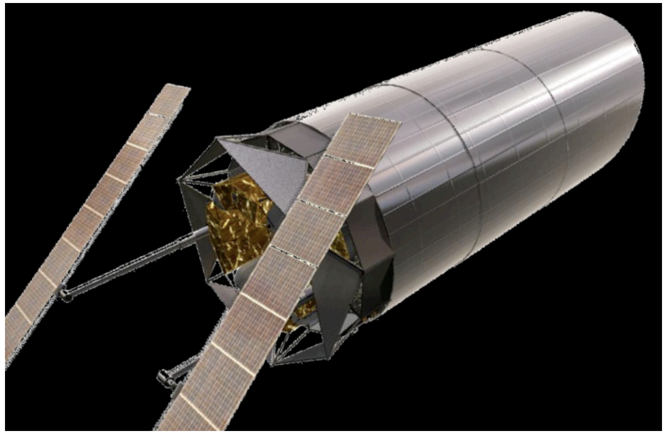
Current data → ELT (HIRES) → Space

Credit: MSFC Advanced Concepts Office



8m ATLAST artist's conception (STSCI)

Redshift

Credit: Dr. Dan Russell, Grad. Prog. Acoustics, Penn State.

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$$z = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}}$$

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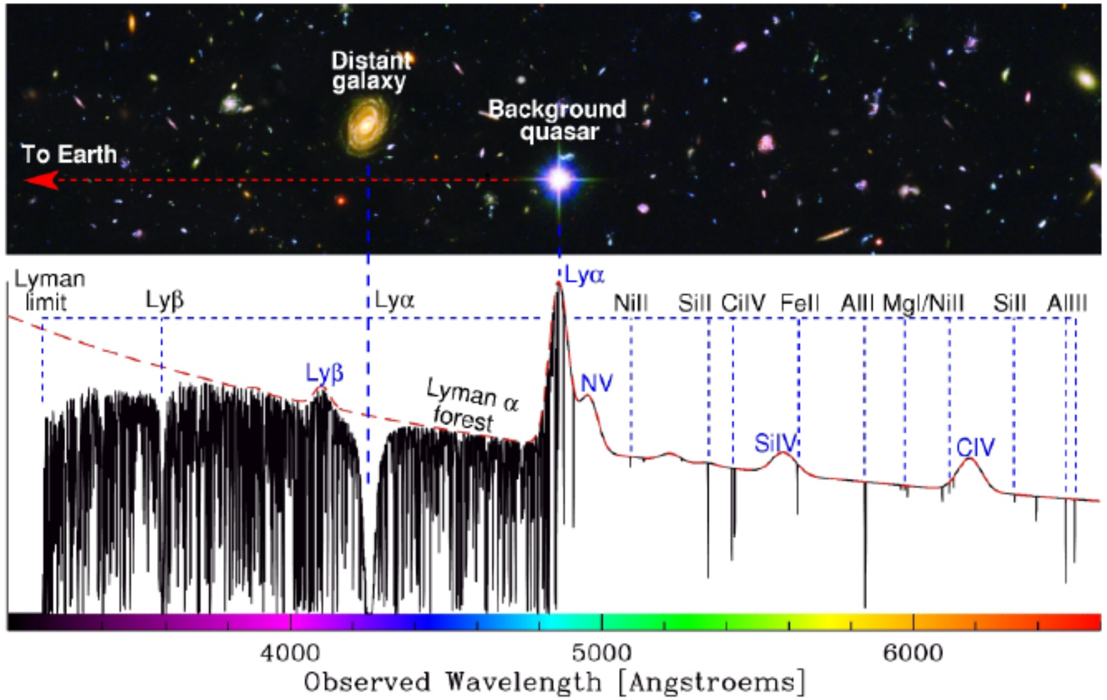
Redshift

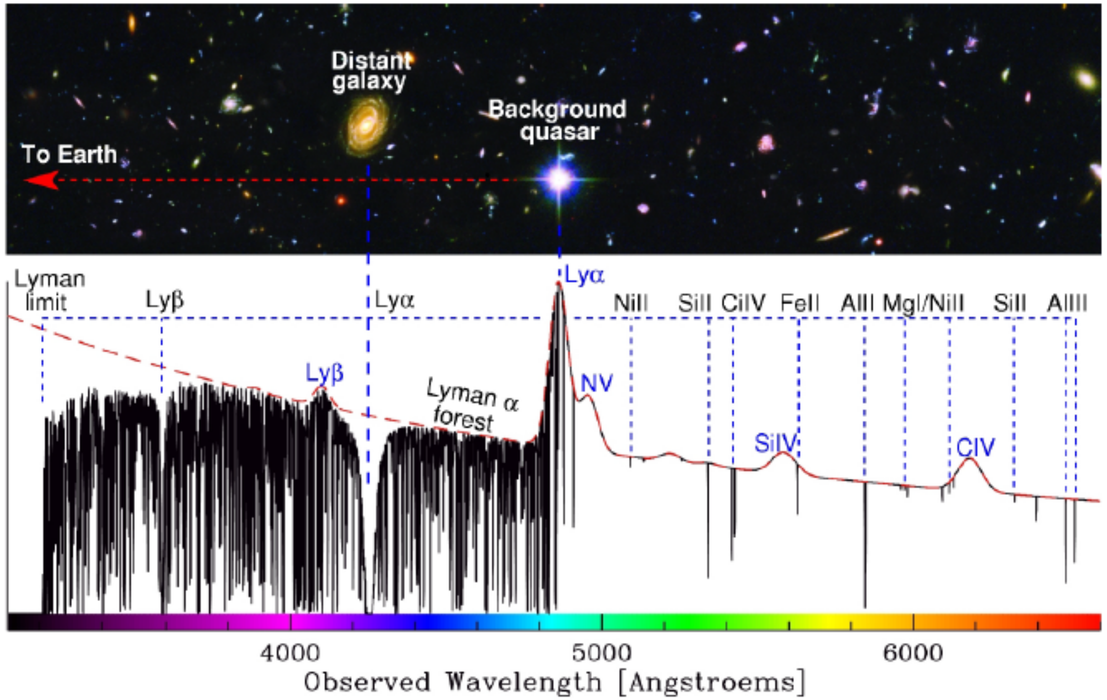


Credit: Michael Murphy, Swinburne University of Technology, Melbourne, Australia.

$$z = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}}$$

$$\frac{dz}{dt_0} = \frac{d}{dt_0}\left[\frac{a(t_0)}{a(t_e)} - 1\right] = \frac{\dot{a}(t_0) - \dot{a}(t_e)}{a(t_e)} \approx (1+z)H_0 - H(z)$$

Redshift



Credit: Michael Murphy, Swinburne University of Technology, Melbourne, Australia.

$$z = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}}$$

$$\frac{\Delta\alpha}{\alpha} = \frac{\alpha(z) - \alpha_0}{\alpha_0}$$

Varying α

- Assumptions made to relate the evolution of α to that of dark energy.

$$\frac{\Delta\alpha}{\alpha} = \zeta\kappa(\phi - \phi_0) \qquad \Omega_\phi(z) \equiv \frac{\rho_\phi(z)}{\rho_{\rm tot}(z)} \simeq \frac{\rho_\phi(z)}{\rho_\phi(z) + \rho_m(z)} \qquad 1 + w_\phi = \frac{(\kappa\phi')^2}{3\Omega_\phi}$$

$$\frac{\Delta\alpha}{\alpha}(z) = \zeta \int_0^z \sqrt{3\Omega_\phi(z')\left[1 + w_\phi(z')\right]}\frac{dz'}{1+z'}$$

Fiducial models

- Constant equation of state

$$w_0 = \text{const}$$

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- Dilaton-type model

$$w(z) = [1 - \Omega_\phi (1 + w_0)] w_0 / \Omega_m (1 + w_0)(1+z)^3 [1 - \Omega_\phi (1 + w_0)] - w_0$$

$$\phi(z) \propto (1 + z) \qquad \Omega_\phi(z)[1 + w(z)] = const.$$

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$$\phi(z) \propto (1+z) \qquad \frac{\Delta\alpha}{\alpha}(z) = \zeta\sqrt{3\Omega_\phi(1+w_0)}\,\ln(1+z)$$

Fiducial models

- Constant equation of state

$$w_0 = \mathrm{const}$$

- Dilaton-type model

$$w(z)=[1-\Omega_\phi(1+w_0)]w_0/\Omega_m(1+w_0)(1+z)^3[1-\Omega_\phi(1+w_0)]-w_0$$

- Chevallier-Polarski-Linder (CPL) parametrization

$$w(z)=w_0+w_a\,z/1+z$$

Parameters

- $\Omega_{m,fid}=0{,}3$ $\quad$ $\sigma_{\Omega_m}=0{,}03$
- $w_{0,fid}=-0{,}9$ $\quad$ $\sigma_{w_0}=0{,}1$
- $w_{a,fid}=0{,}3$ $\quad$ $\sigma_{w_a}=0{,}3$
- $\zeta_{fid}=0\,;\,5\cdot10^{-6}$ $\quad$ $\sigma_{\zeta}=10^{-4}$

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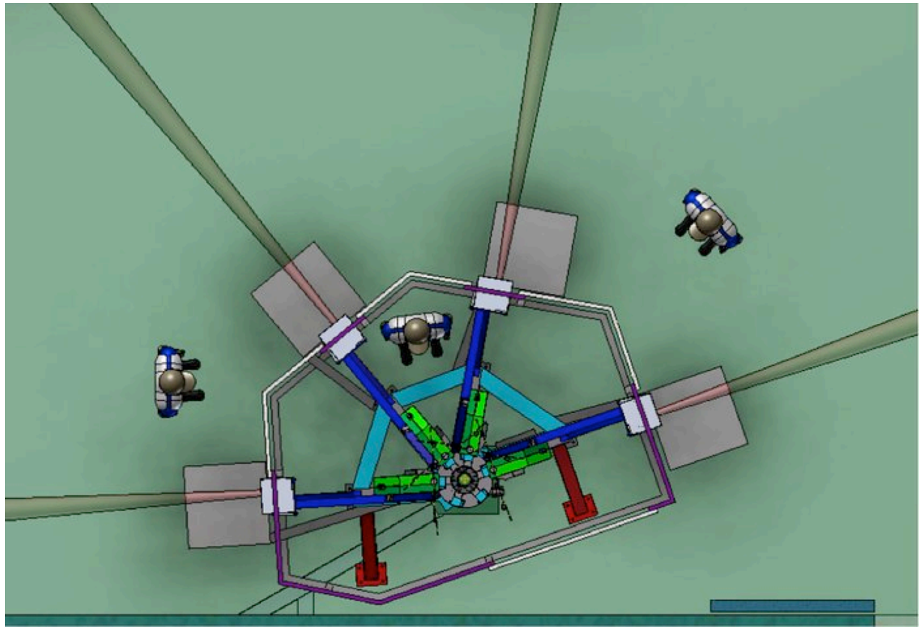
Cosmological datasets

Important remarks



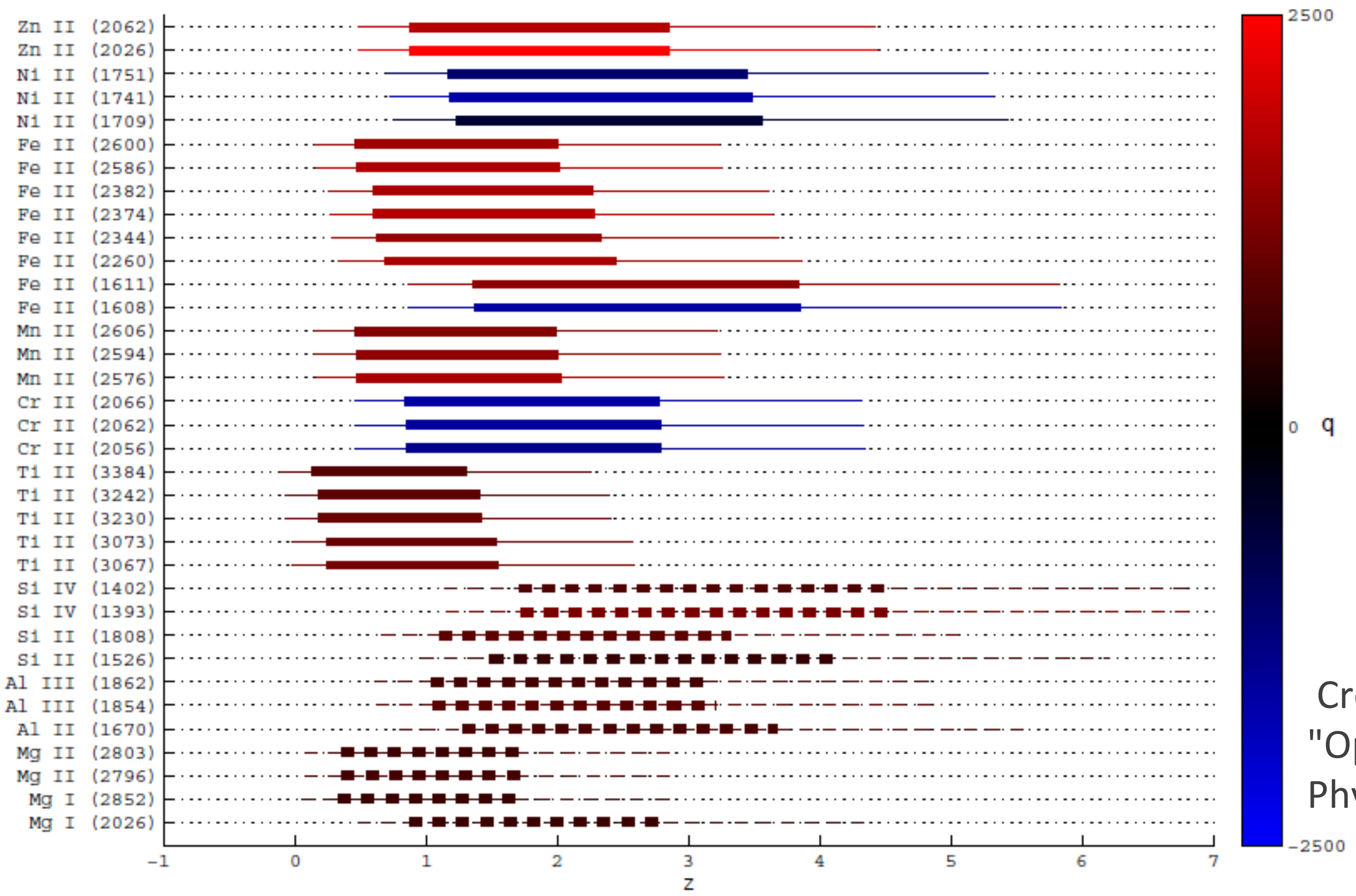
Combining the light of four VLTs for the ESPRESSO instrument
Credit: ESO/ESPRESSO Consortium

- Improvement of current bounds on the Eötvös parameter

ESPRESSO vs MICROSCOPE

HIRES vs STEP

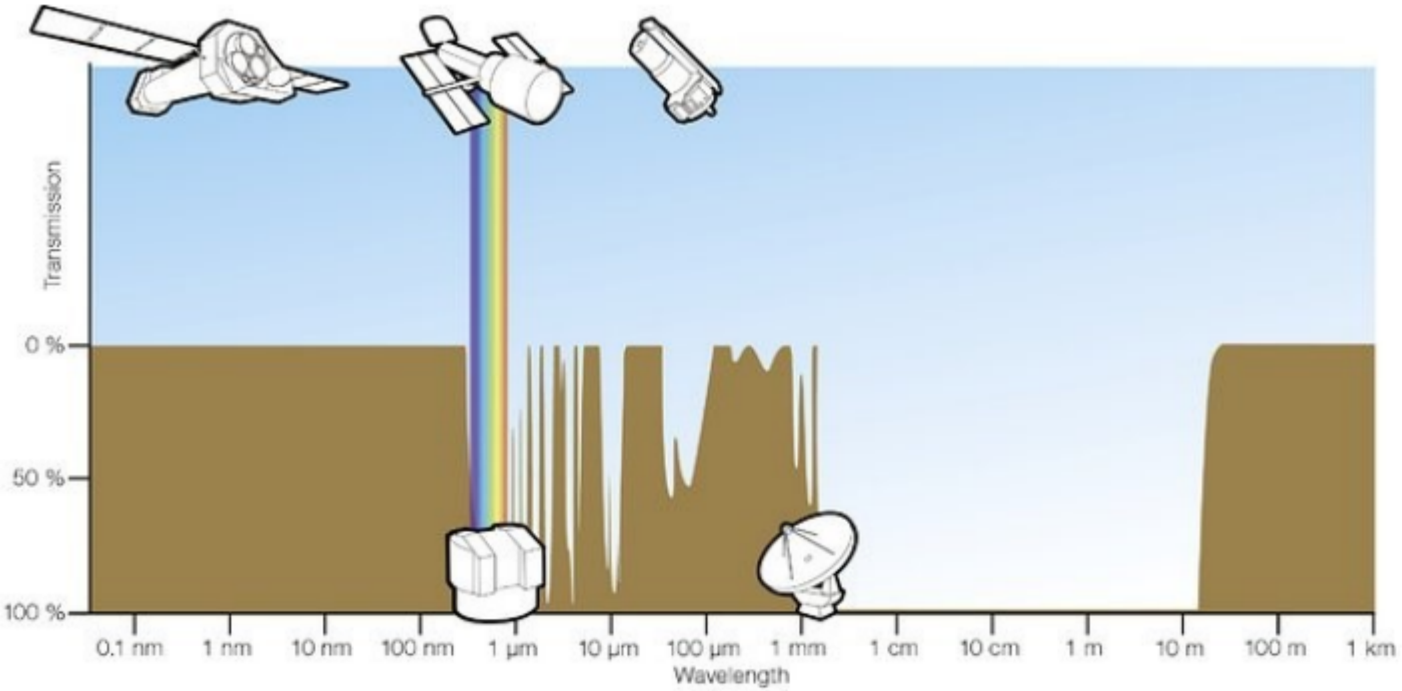
Measurements of the fine-structure constant



$$\Delta v \approx -\frac{2cq_i}{\omega_0}\left(\frac{\Delta\alpha}{\alpha}\right)$$

Credit: de Oliveira Leite, Ana Catarina. "Optimization of ESPRESSO Fundamental Physics Tests." (2015)

UV advantages



Credit: ESA / Hubble / F Granato

Analysis

- Targets (quasars)
- Recuperation of fiducial models
- Uncertainty Earth vs space

```
def Fisher(zS,sigmas,Hf,h,Om,w0,wa,N=1): # matrizes de Fisher de tama
    '''sigmas e zS têm o mm tamanho; Hf-funcao a usar; h=0, Om=1, w0=
    n=4 # está adaptada para isto
    F = np.zeros([n,n])
    for b in range(len(zS)):
        elem = np.ones([n,n]) # inicializar a matriz a somar
        for i in range(n):
            if i==0:
                deriv = dfdh(Hf,zS[b],h,Om,w0,wa,N)
            elif i==1:
                deriv = dfdOm(Hf,zS[b],h,Om,w0,wa,N)
            elif i==2:
                deriv = dfdw0(Hf,zS[b],h,Om,w0,wa,N)
            else:
                deriv = dfdwa(Hf,zS[b],h,Om,w0,wa,N)
            elem[:,i]*=deriv # preencher a linha i
            elem[i,:]*=deriv # preencher a coluna i
        elem*=sigmas[b]**-2
        F=F+elem
    if all(F[:,3]==0)==True and all(F[3]==0)==True: # não tem wa
        F=np.delete(F, 3, 1) # tira 4º coluna
        F=np.delete(F, 3, 0) # tira 4º linha
    if all(F[:,2]==0)==True and all(F[2]==0)==True: # não tem w0
        F=np.delete(F, 2, 1)
        F=np.delete(F, 2, 0)
    return F
#Fim Construir F#
```

Targets

- Data set – 333 quasares
- 35 transition
- Select the right targets:
  - wavelenght
  - α variations: anchor, redshifter, blueshifter

Recuperate the models

- 3 study cases:
  - ATLAST: $\lambda = [1100 - 25000]\,A$
  - EUVO: $\lambda = [2400 - 3500]\,A$
  - Imaginary case: $\lambda = [3500 - 4000]\,A$
- Uncertainties → Earth telescope ELT - HIRES
- Fisher matrix techniques

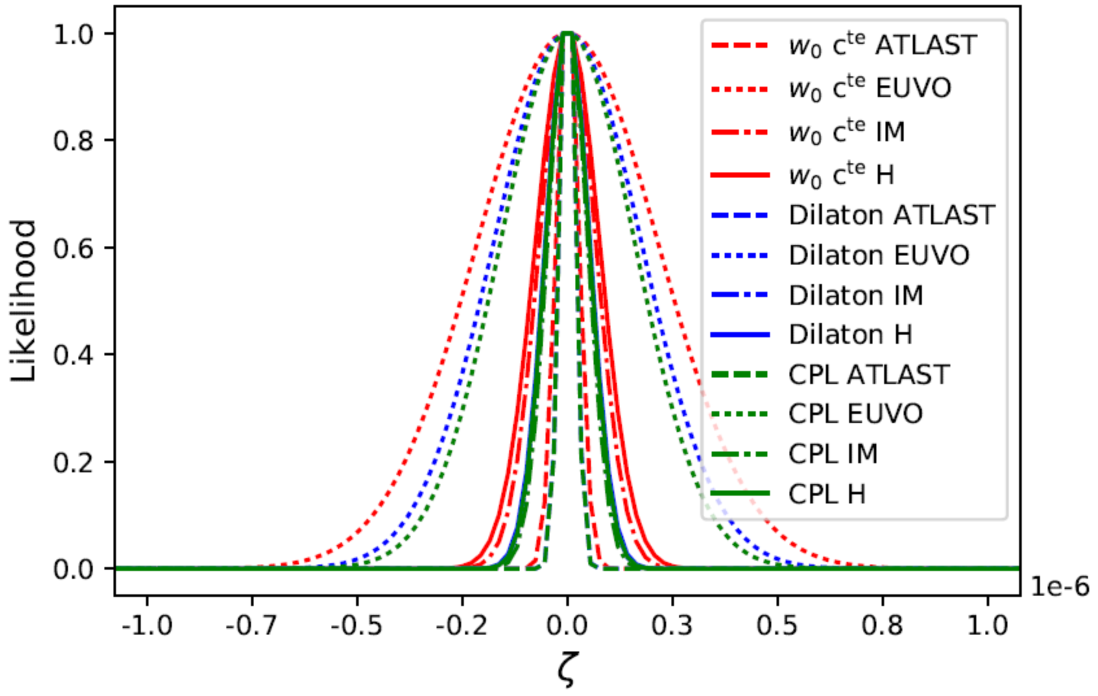
Fisher Matrix

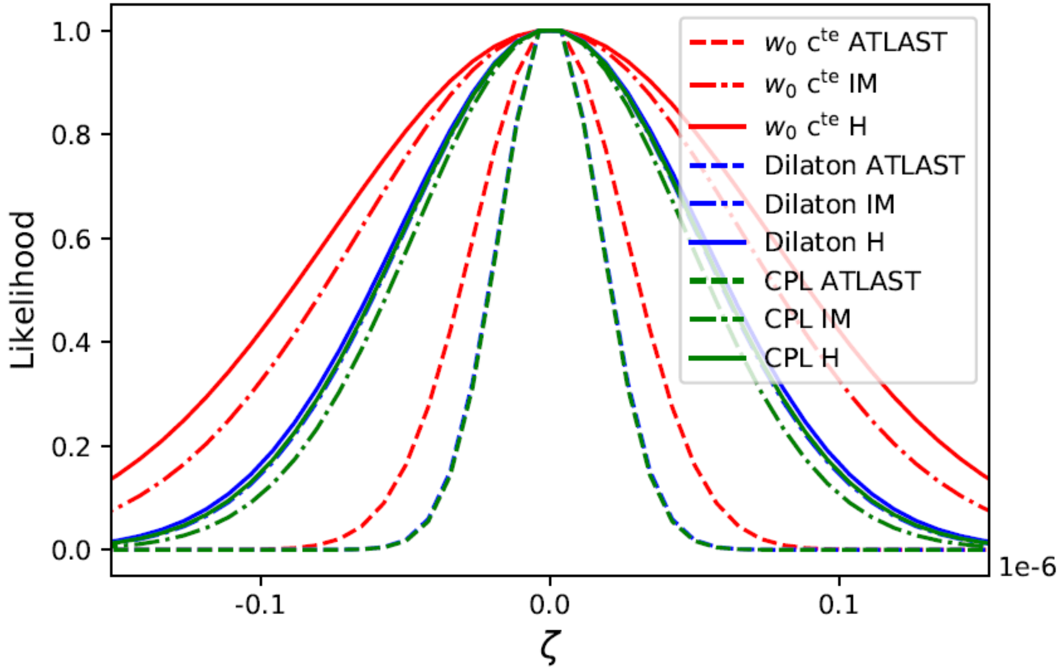
- Forecast the precision and impact of future experiments
- Analyze the combination of cosmological constraints from various data sets
- Experimental design

- Fisher matrix is the inverse of the covariance matrix

$$Cov(X,Y) = \langle (X-x)(Y-y) \rangle$$

Results – Fine-structure





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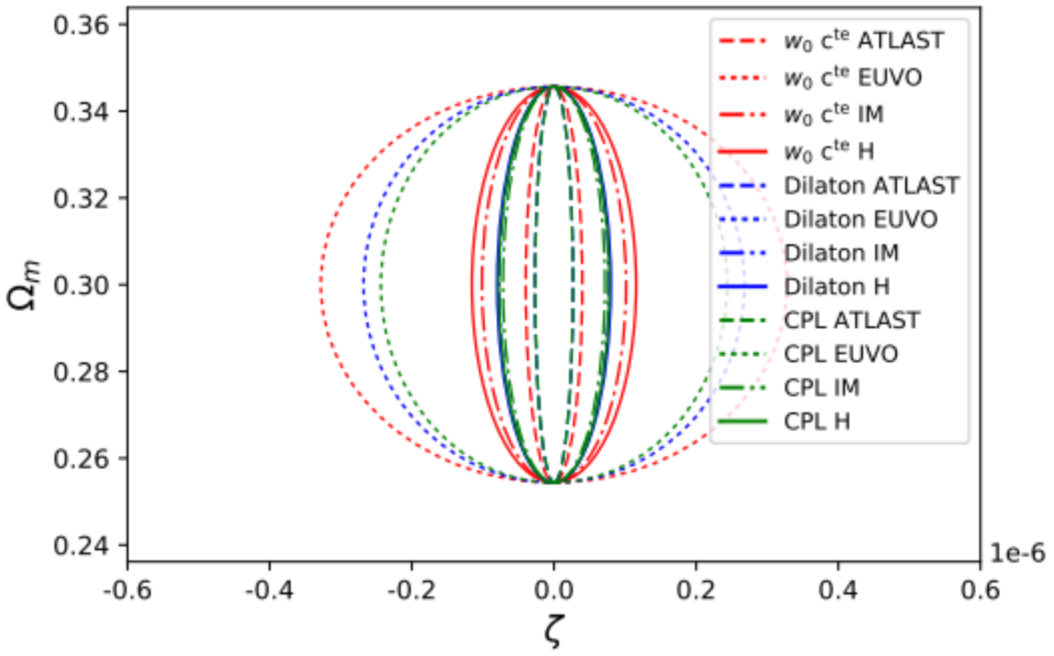

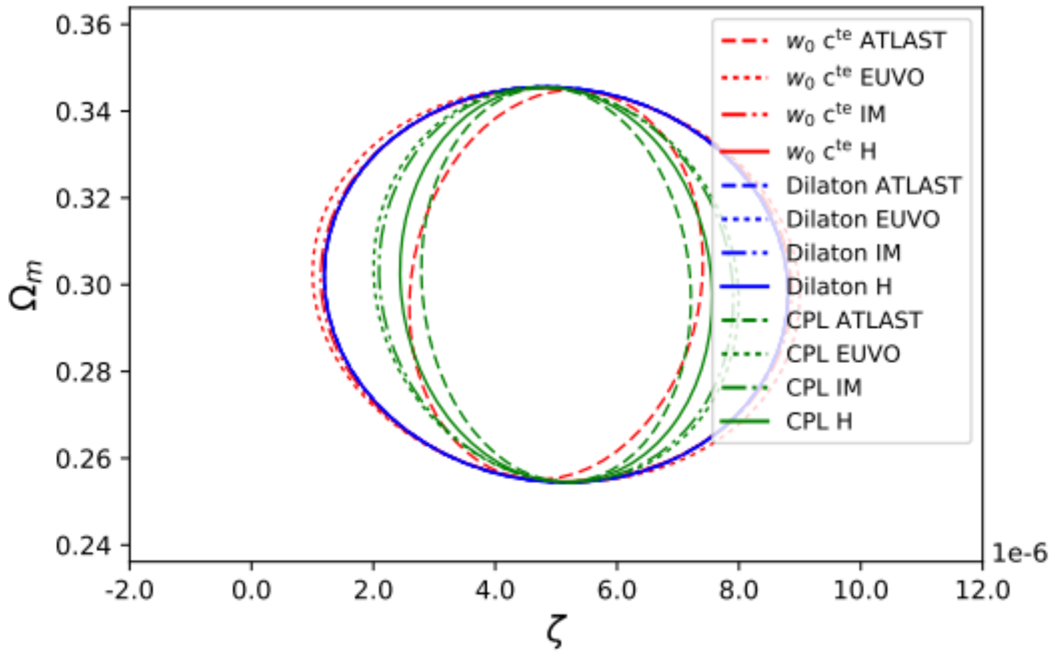

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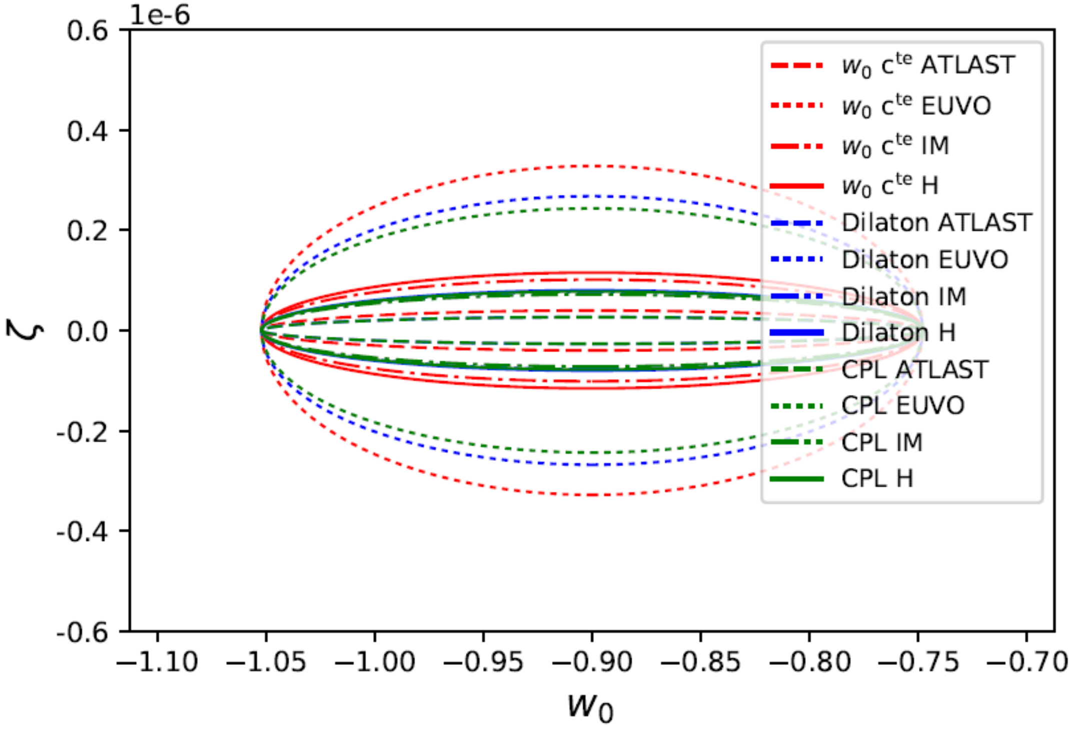

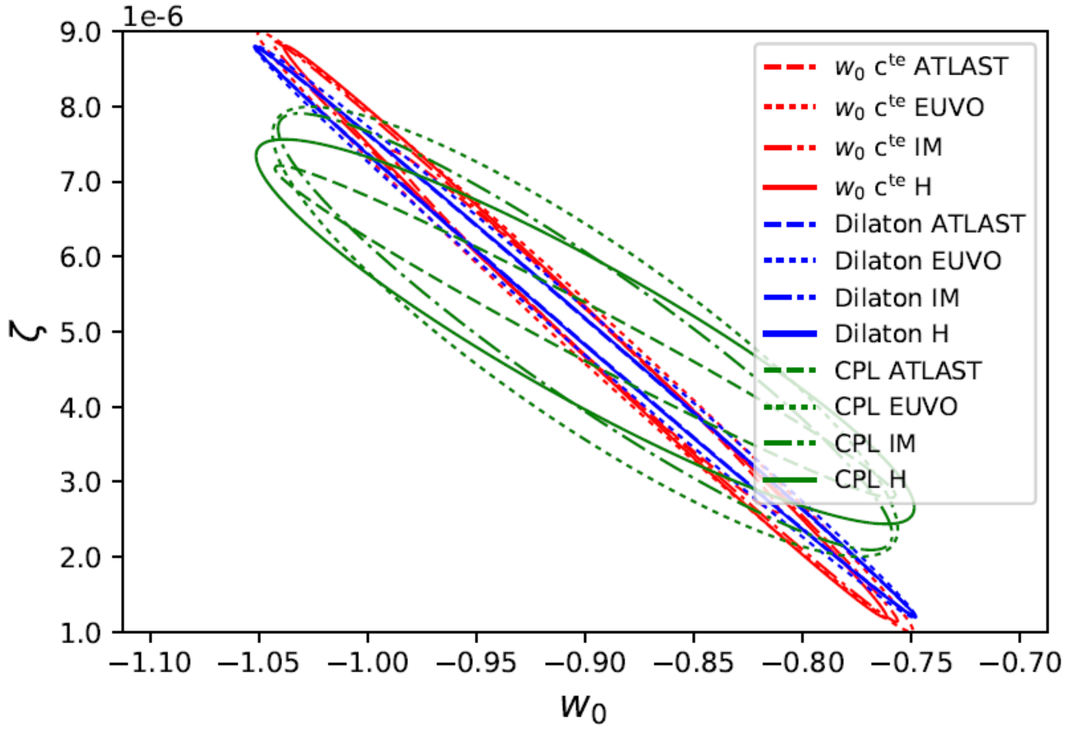

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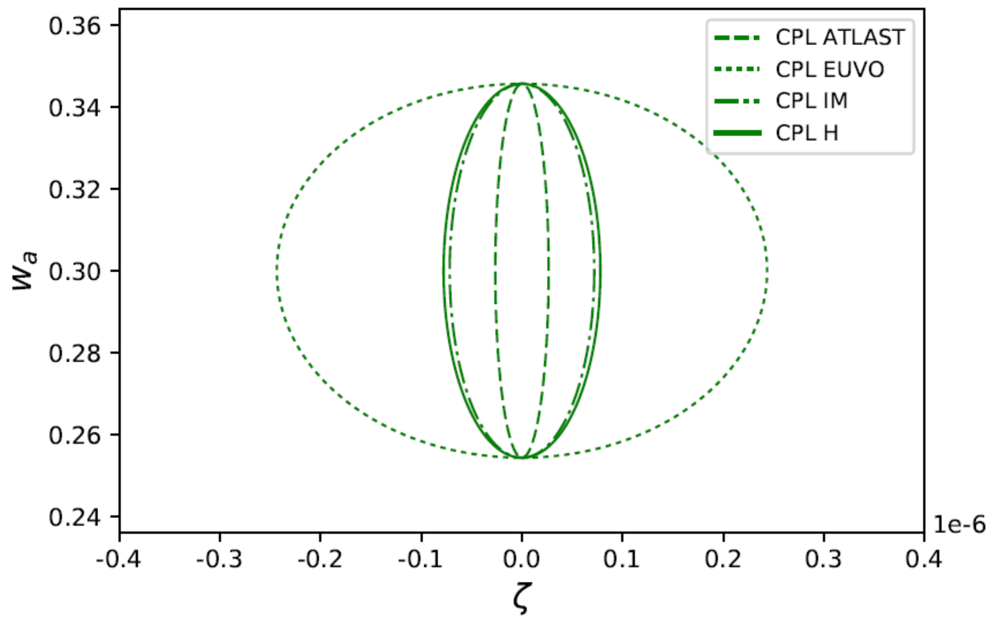
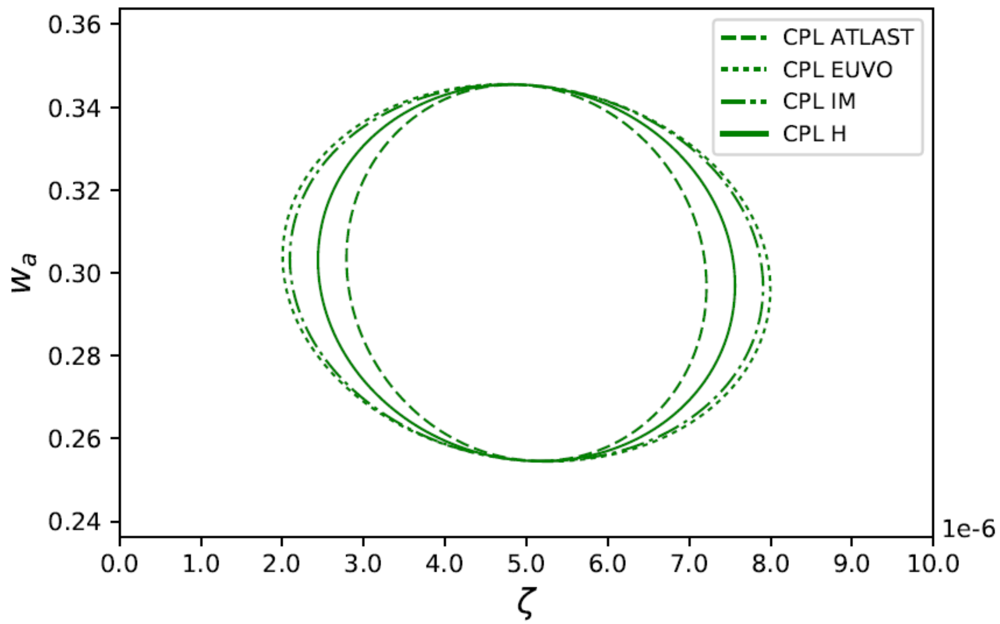
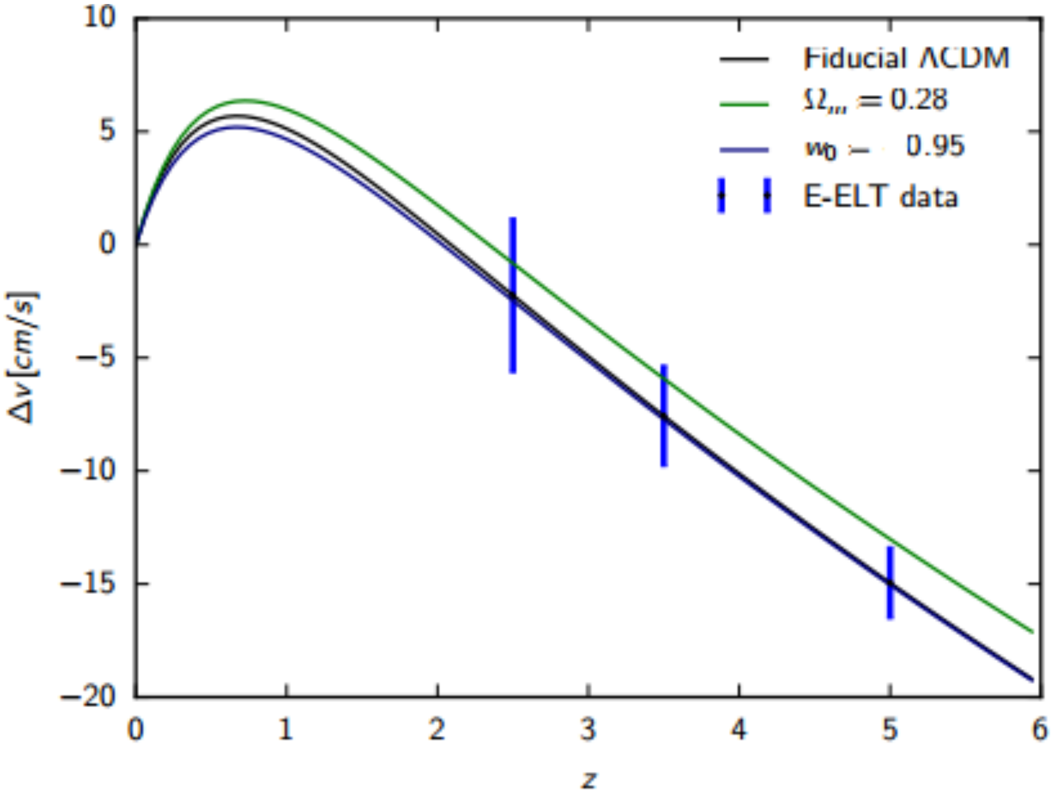


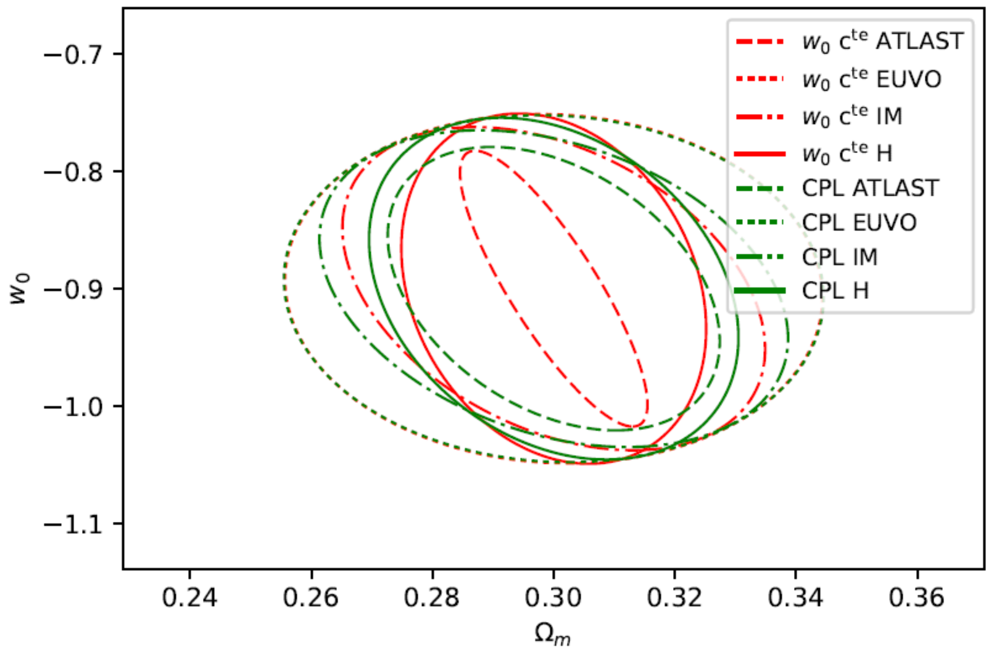


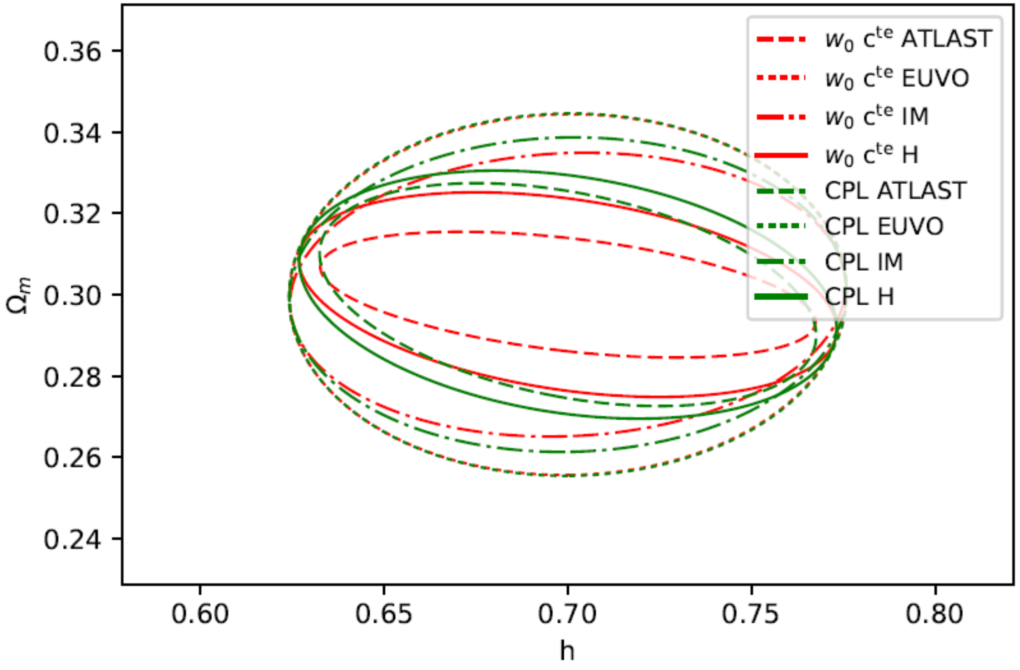
Redshift drift

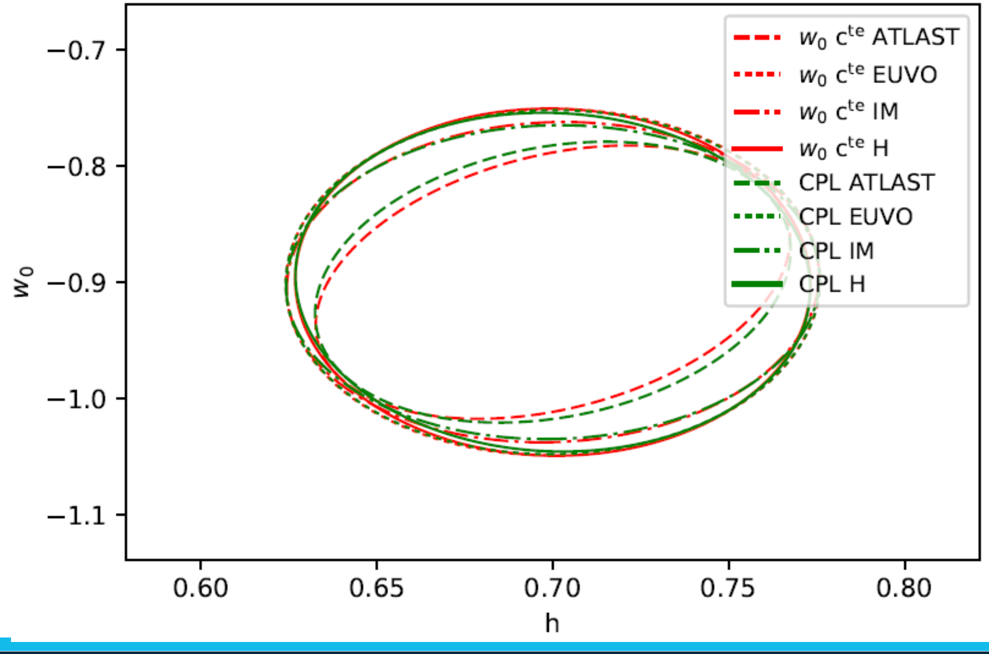


Credit: Martins et al. 2016

Results – Redshift drift



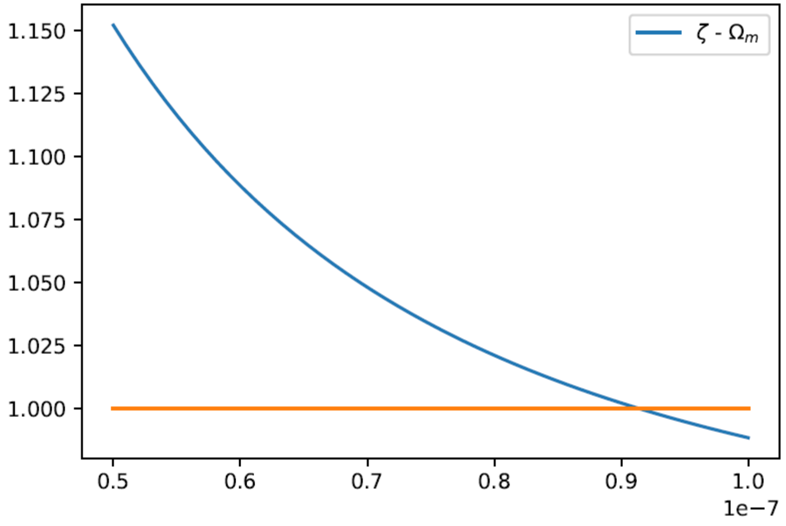


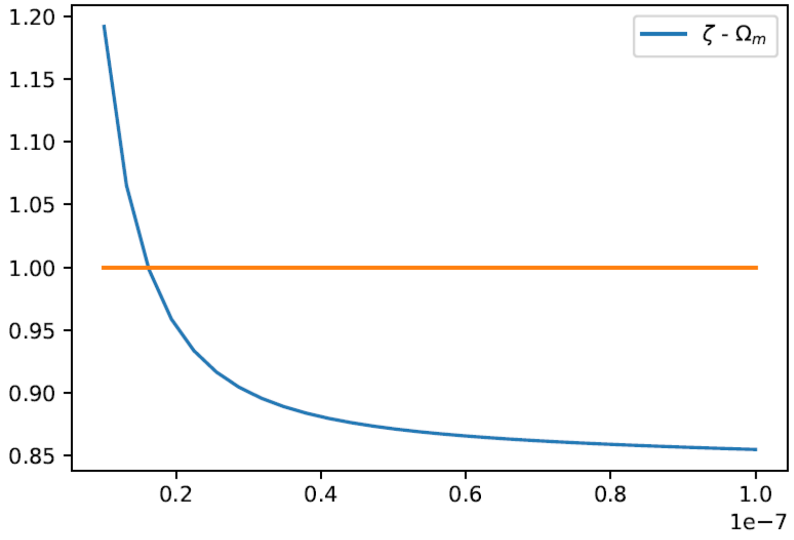


Uncertainty Earth vs space

- Figure of merit

$$FOM = 1/area$$





Conclusions

- UV is a very important frequency and it is useful to observe
- ATLAST is the best proposal now
- ATLAST provide better constrains to cosmological parameters
- Suggestion: modifications to EUVO proposal
- Suggestion: space spectroscope with $\lambda = [3500 - 4000]\, A$
- Better constrains: join measurements for $\Delta\alpha/\alpha$ and redshift drift

Future

- Different experiments to get different correlations → break degeneracies
- Our results would have been better if there were more available transitions → this is an area that should be worked on → has potential for lots of scientific knowledge on it