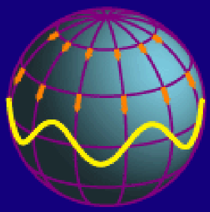
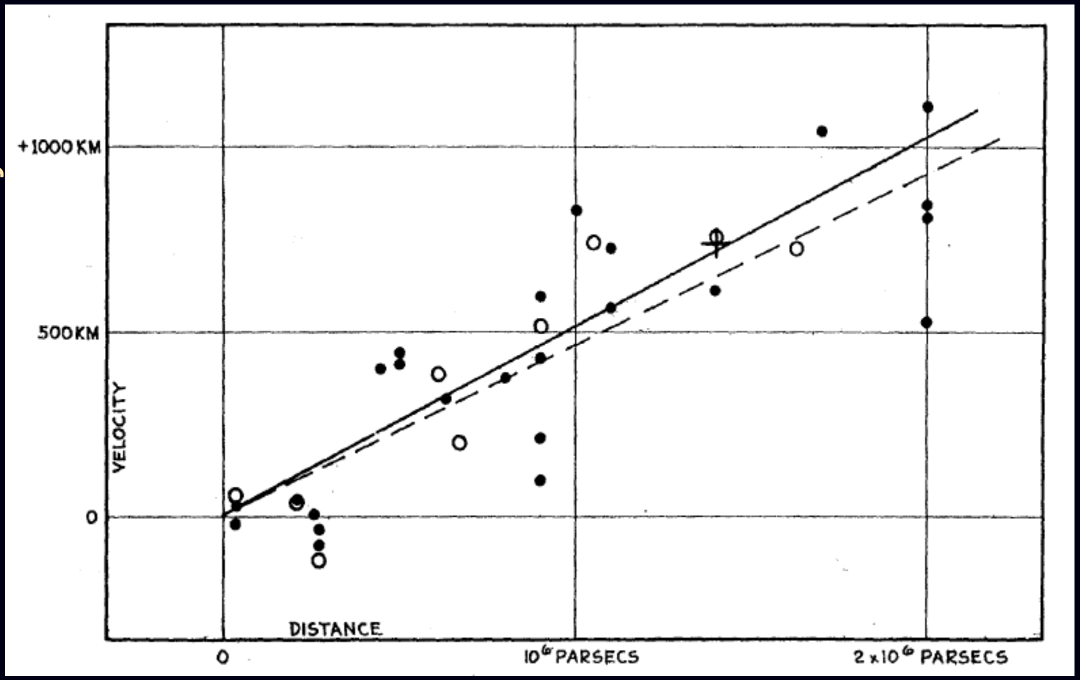
ESPRESSO - no limits

Prequel & Science

Universal Expansion

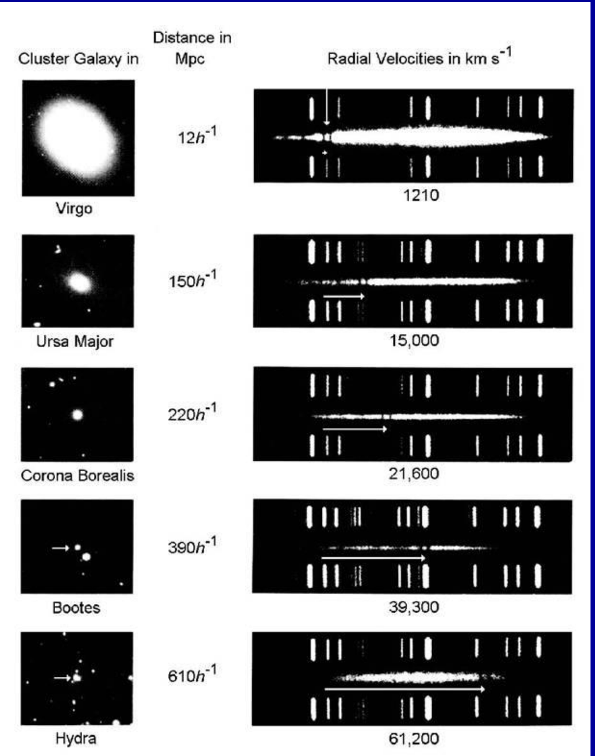


The original Hubble diagram (Hubble 1929):

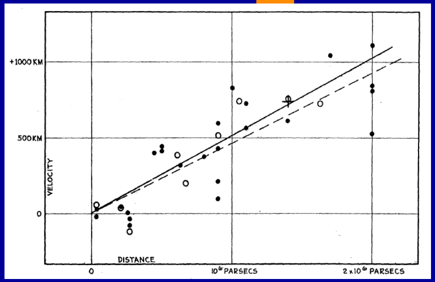


All distant galaxies are found to recede from us.

Hubble's Law: $v = H_0\, d$ → **The universe expands!**

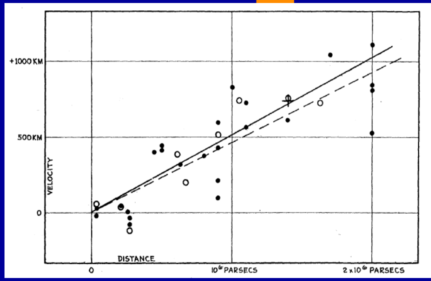


Relativistic Big Bang Cosmology

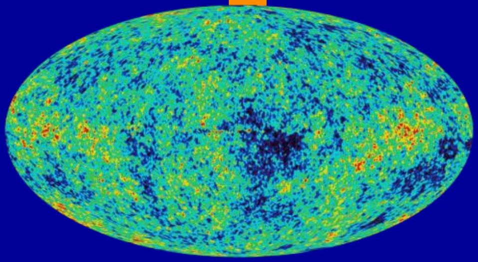


Expansion

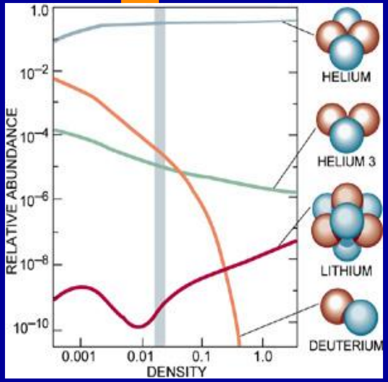
Relativistic Big Bang Cosmology



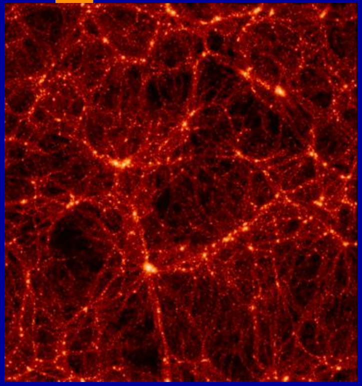
Expansion



Cosmic Microwave Background



Abundance of light elements



Structure formation

Which of the solutions of the Friedmann equation corresponds to reality?

Or in other words:
What is the stress-energy tensor of the universe?
For each mass/energy component i, what is Ω_i, w_i?

Density parameter — Equation of state parameter

How can these be measured?

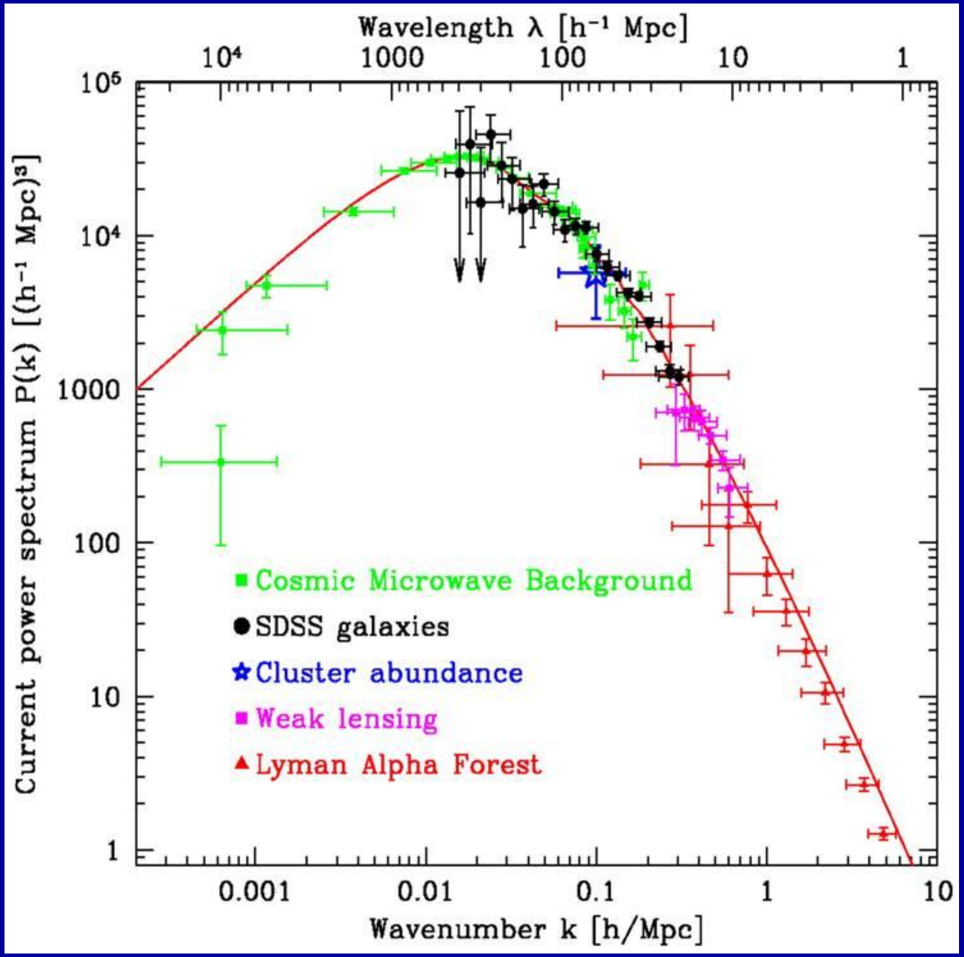
- Dynamics
- Geometry
- Clustering (the universe is not homogeneous on small scales!)

Both determined by gravity in GR

Which of the solutions of the Friedmann equation corresponds to reality?

Answers have already been provided by:

- Cosmic Microwave Background
- Supernovae type Ia
- Large scale structure of galaxies and intergalactic medium
- BAOs
- Galaxy clusters
- Weak lensing



Tegmark et al. (2004)

Standard Model

With the assumptions of homogeneity and isotropy, the concordance model finds a FRW metric with a non zero cosmological constant

$$H^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2}$$

$$H(z)^2 = \frac{8\pi G}{3}[\rho_\gamma(0)(1+z)^4 + \rho_m(0)(1+z)^3 + \rho_k(0)(1+z)^2 + \rho_\lambda]$$

$\rho_k \sim 0$ (flat space) $\quad \Omega_m \sim 0.30 \quad \Omega_\lambda \sim 0.70$

We do not know what ρ_λ is and how it evolves.

Dynamics has never been measured.

All other experiments, extremely successful such as **High Z SNae search and WMAP** measure geometry: dimming of magnitudes and scattering at the recombination surface and clustering (growth of structure).

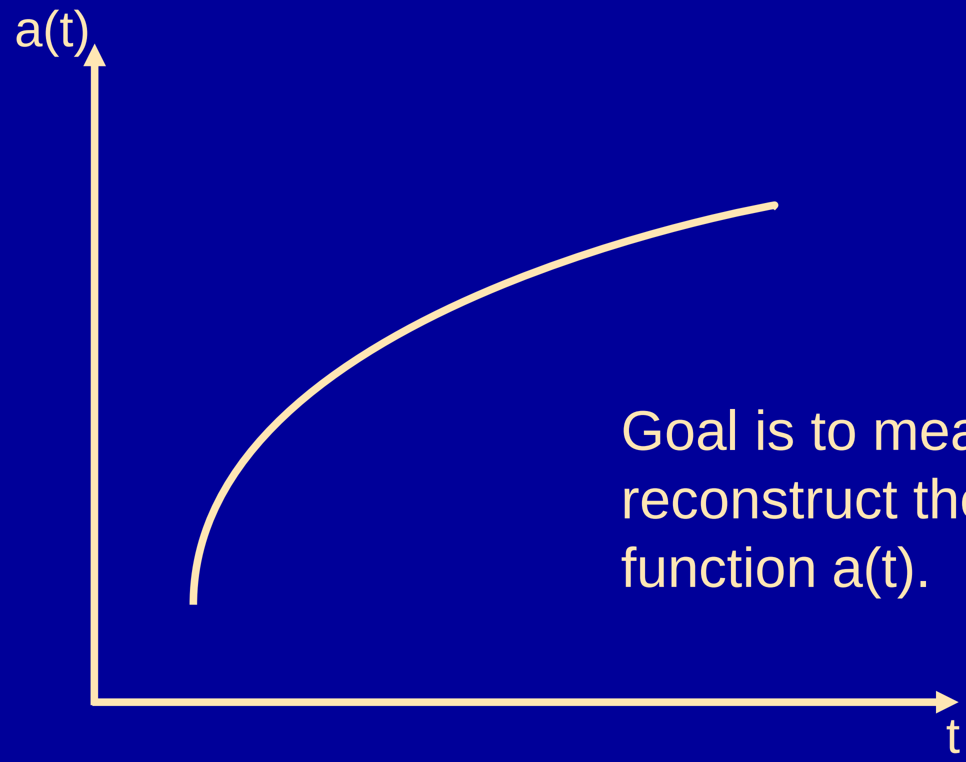
If we do not measure we do not know

But.. Geometry tells us that the Universe is Expanding, so why bother to measure dynamics?

Measurement of the dynamics of the Universe can be compared to basic experiments such as the test of the principle of equivalence between Inertial and Gravitational mass…

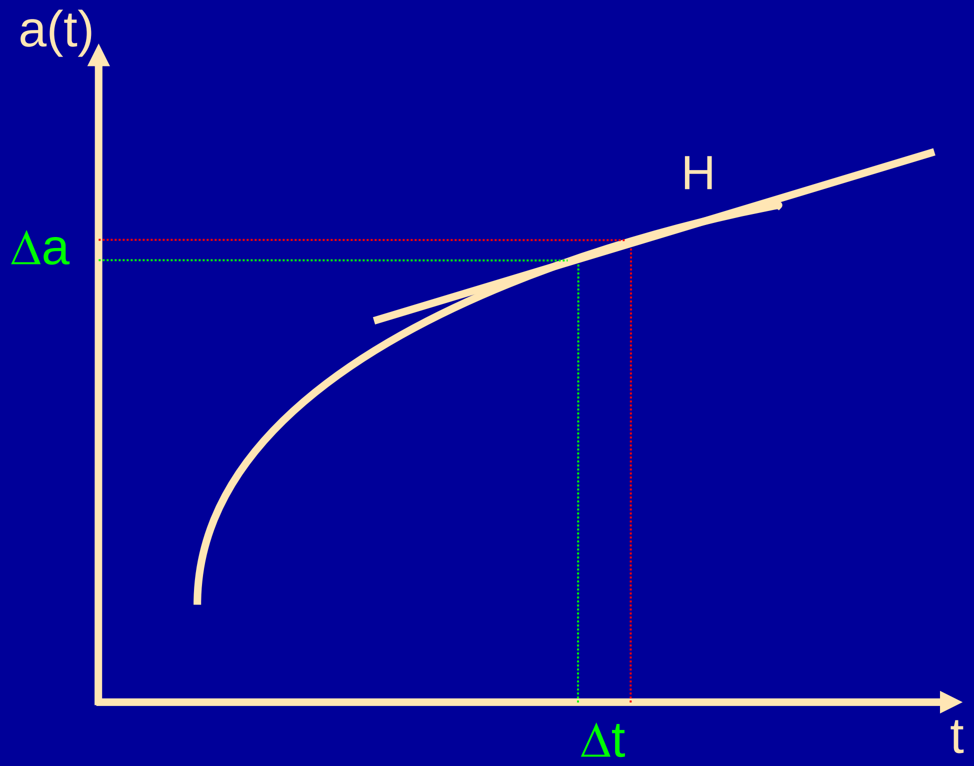
Without it, it is like measuring the geometrical orbits of planets w/o measuring their accelerations… (Copernicus without Kepler)

Can we measure the history of the expansion directly?



Goal is to measure or reconstruct the unknown function a(t).

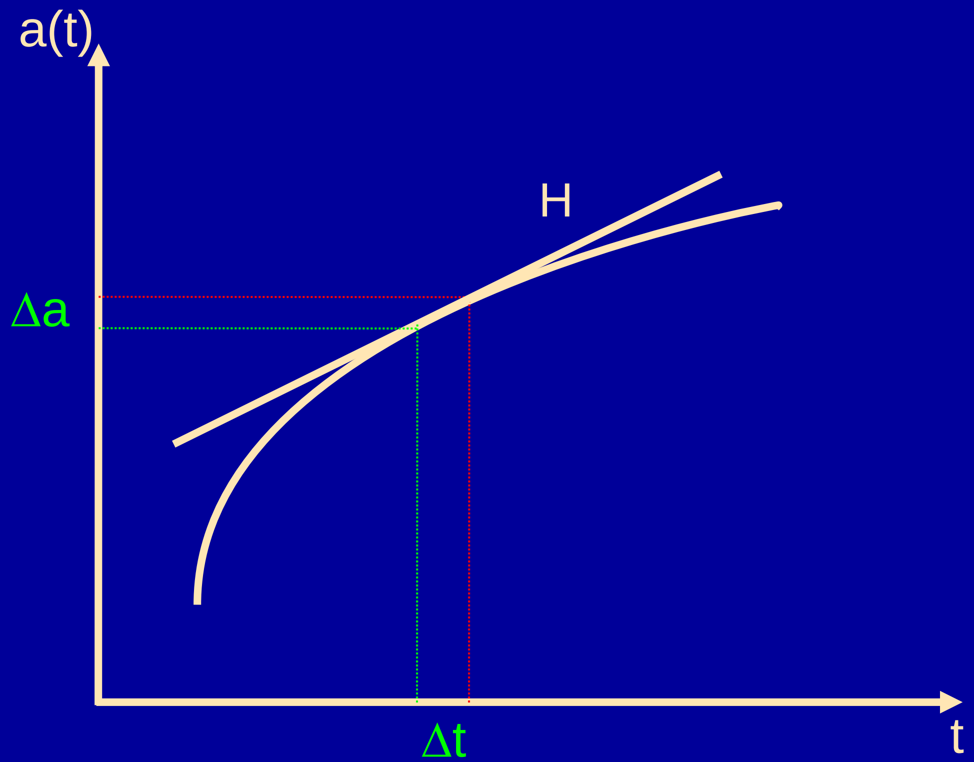
Can we measure the history of the expansion directly?



Yes: Measure a(z), da/dt(z) $\rightarrow$ a(t)

Need to measure H(z) using the dynamics!

Can we measure the history of the expansion directly?



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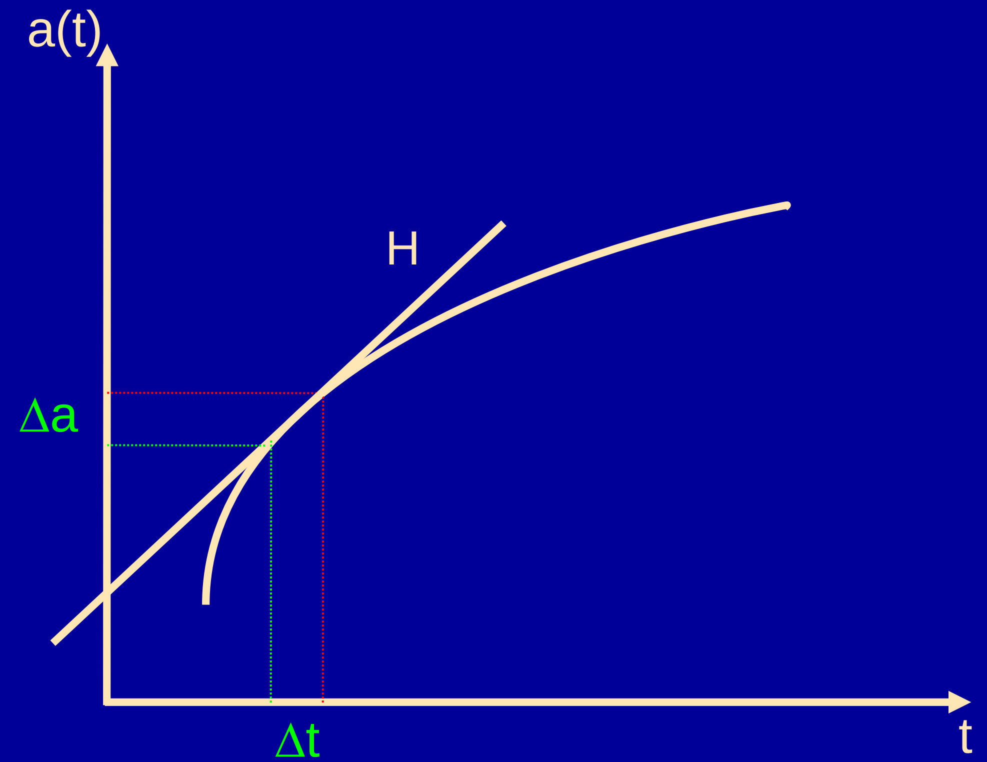


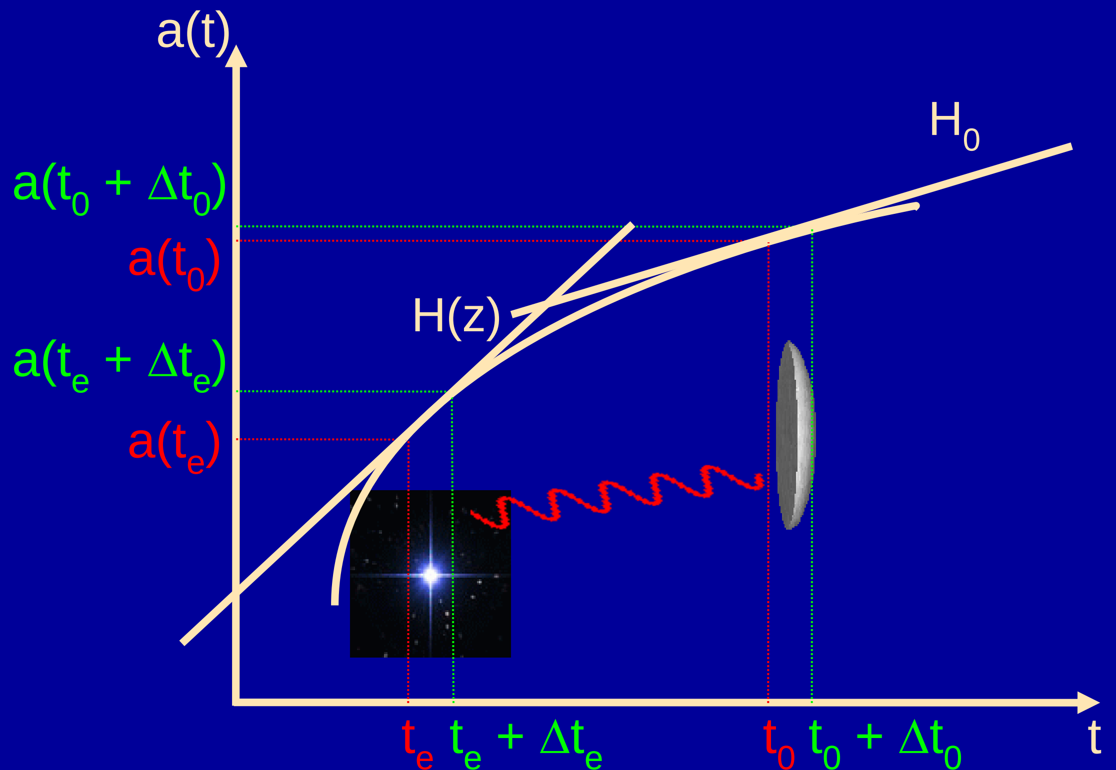
Yes: Measure a(z), da/dt(z) $\rightarrow$ a(t)

Need to measure H(z) using the dynamics!

Direct Dynamical Measurement of the Expansion

One way to implement this experiment is to monitor the redshifts of cosmological sources. The change of these redshifts as a function of time is a direct signal of the de/acceleration of the universe's expansion and hence of its dynamics.

Measuring H(z)



$$\frac{z(t_0 + \Delta t_0) - z(t_0)}{\Delta t_0} = \frac{\Delta z}{\Delta t_0} \approx \frac{dz}{dt_0} = (1+z)H_0 - H(z)$$

May 2000 Trieste - Visogliano

~1985 – Garching

Radio lines? (P.Shaver)

Cosmic Signal

$$1+z(t_0,t_e)=\frac{a(t_0)}{a(t_e)}$$

t_e=emission epoch

t_0=actual epoch

$$dz=\frac{\partial z}{\partial t_0}dt_0+\frac{\partial z}{\partial t_e}dt_e;$$

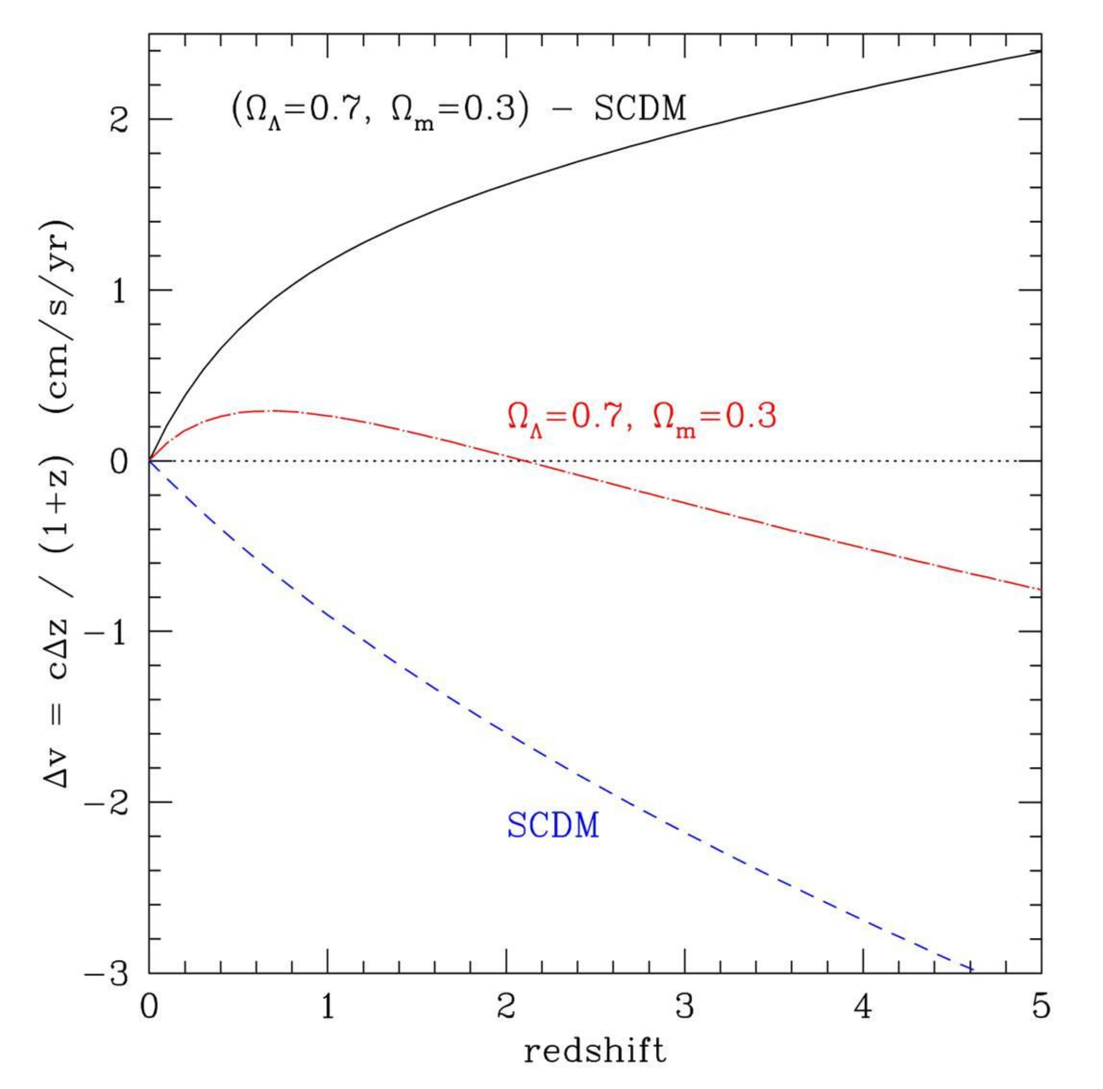
$$\dot{z}=\frac{dz}{dt_0}=\frac{\partial z}{\partial t_0}+\frac{\partial z}{\partial t_e}\frac{dt_e}{dt_0}=\frac{\dot{a}(t_0)}{a(t_e)}-\frac{\dot{a}(t_e)}{a(t_e)}\frac{a(t_0)}{a(t_e)}\frac{1}{1+z}$$

$$\dot{z}=(1+z)H_0-H(t_e)$$

$$H=H_0\left[\Omega_M(1+z)^3+\Omega_R(1+z)^4+\Omega_\Lambda+(1-\Omega_{tot})(1+z)^2\right]^{\frac{1}{2}}$$

$$\text{where}\;\Omega_{tot}=\Omega_M+\Omega_R+\Omega_\Lambda\approx 1$$

Grazian, Vanzella Cristiani et al. 2007



The Signal is SMALL!

The change in sign is the signature of the non zero cosmological constant

Direct Dynamical Measurement of the Expansion

Sandage 1962 ApJ 136,319

"It should be possible to choose between various models of the expanding universe if the deceleration of a given galaxy could be measured. Precise predictions of the expected change in $z=dl/l_0$ for reasonable observing times (say 100 years) is exceedingly small. Nevertheless, the predictions are interesting, since they form part of the available theory for the evolution of the universe"

Since then:

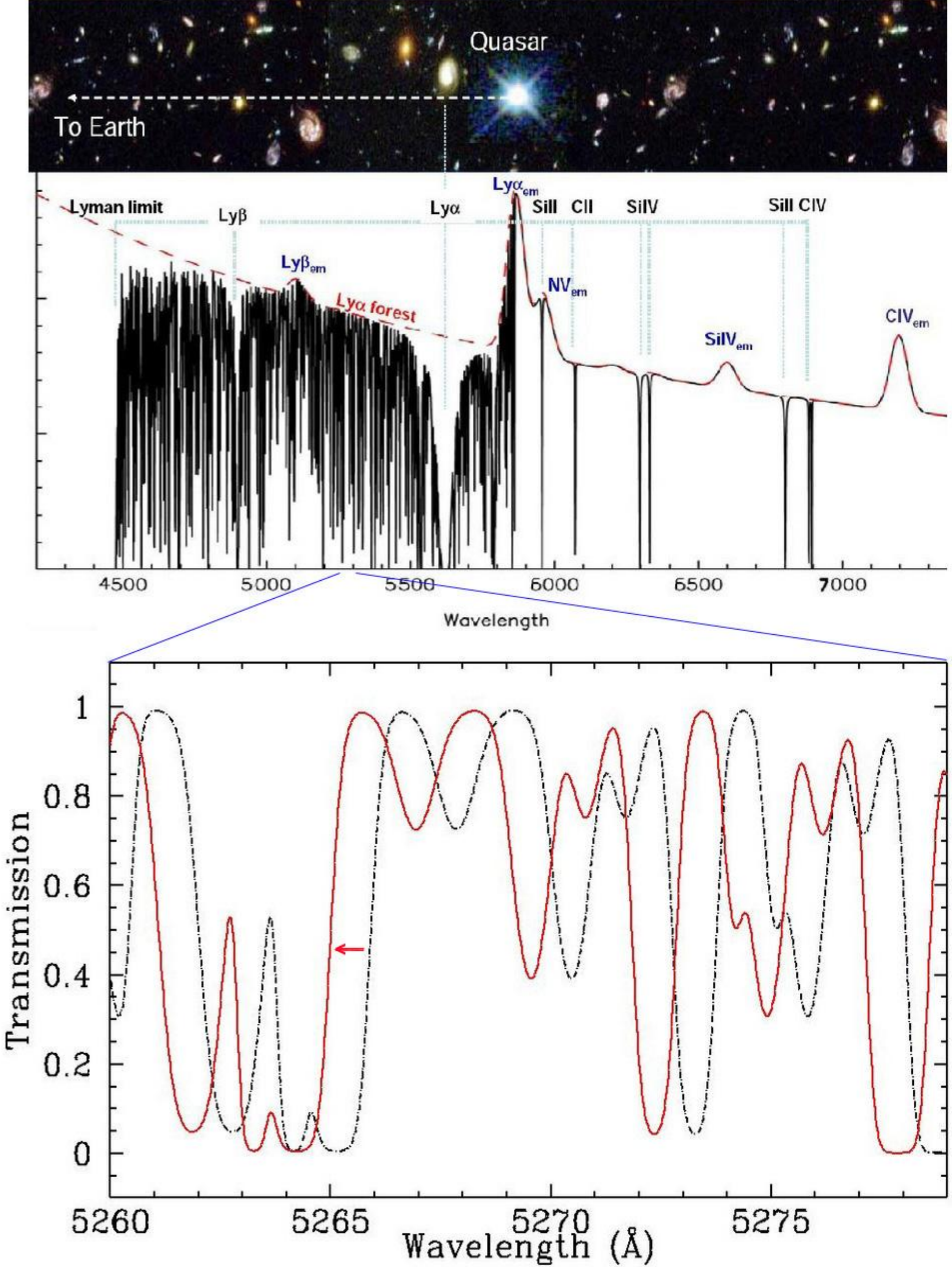
McVittie (1965), Weinberg (1972), Ebert & Trümper (1975), Davis & May (1978), Rüdiger (1980), Lake (1981), Rüdiger (1982), Phillipps (1982), Lake (1982), Partovi & Mashhoon (1984), Teuber (1986), Loeb (1998), Nakamura & Chiba (1999), Gudmundsson & Björnsson (2002), Freedman (2002), Zhu & Fujimoto (2004), Davis & Lineweaver (2004), Seto & Cooray (2006).

How to Measure this signal?

Masers : in principle very good candidates: lines are very narrow and measurements accurate: however they sit at the center of huge potential wells: large peculiar motions , larger than the Cosmic Signal are expected

Molecular Lines with ALMA: as for Masers, local motions of the emitters are real killers. Few radio galaxies so far observed show variability at a level much higher than the signal we should like to detect

Lyα forest: Absorption from the many intervening lines in front of high-z QSOs are the most promising candidates. Simulations, observations and analysis all concur in indicating that Lyα forest and associated metal lines are produced by systems sitting in a warm IGM following beautifully the Hubble flow !

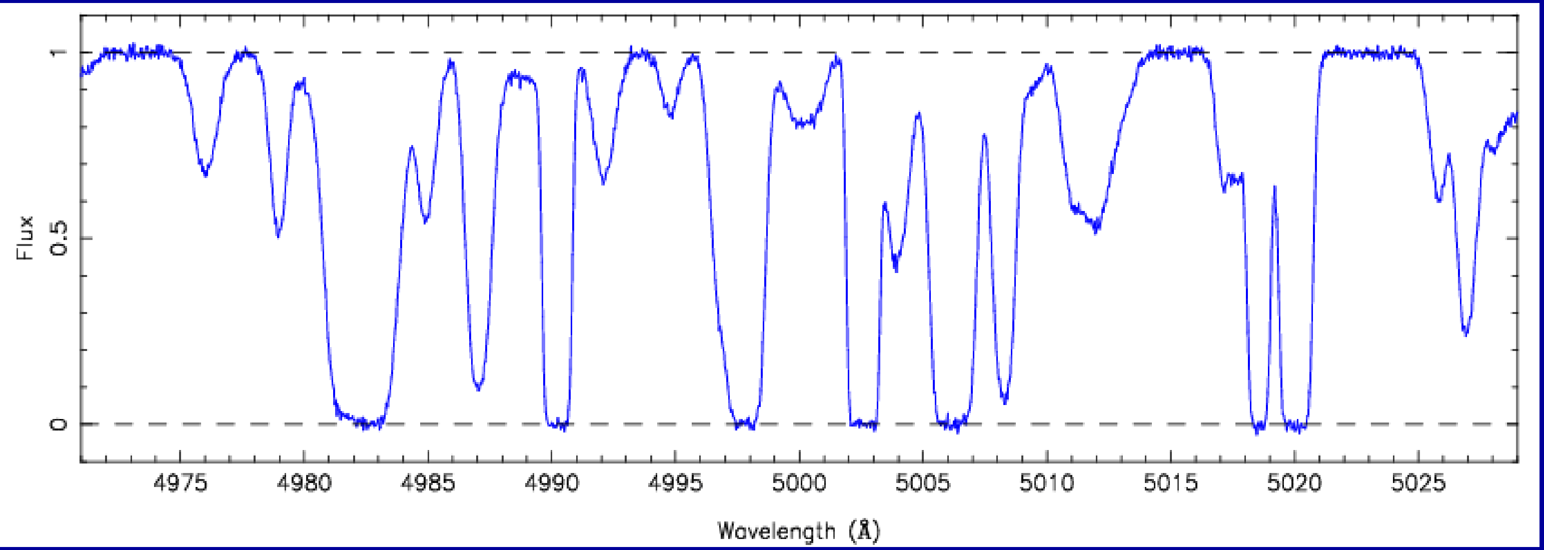


The Lyman Forest

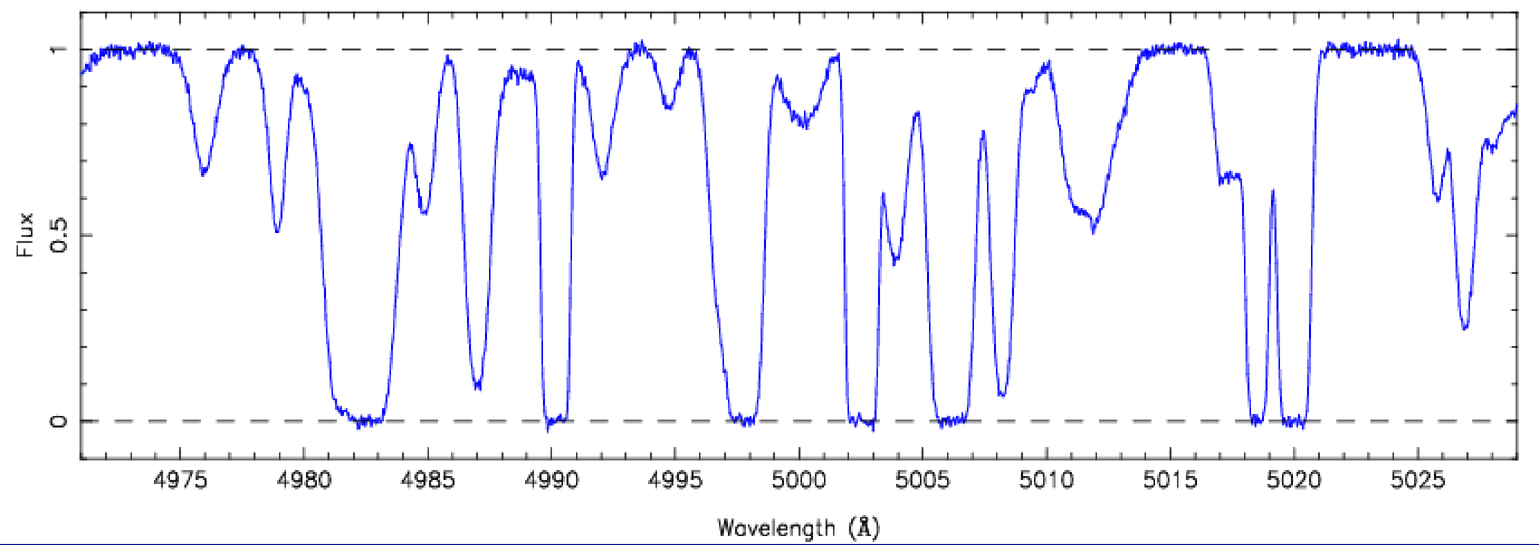
Today and …

… years after

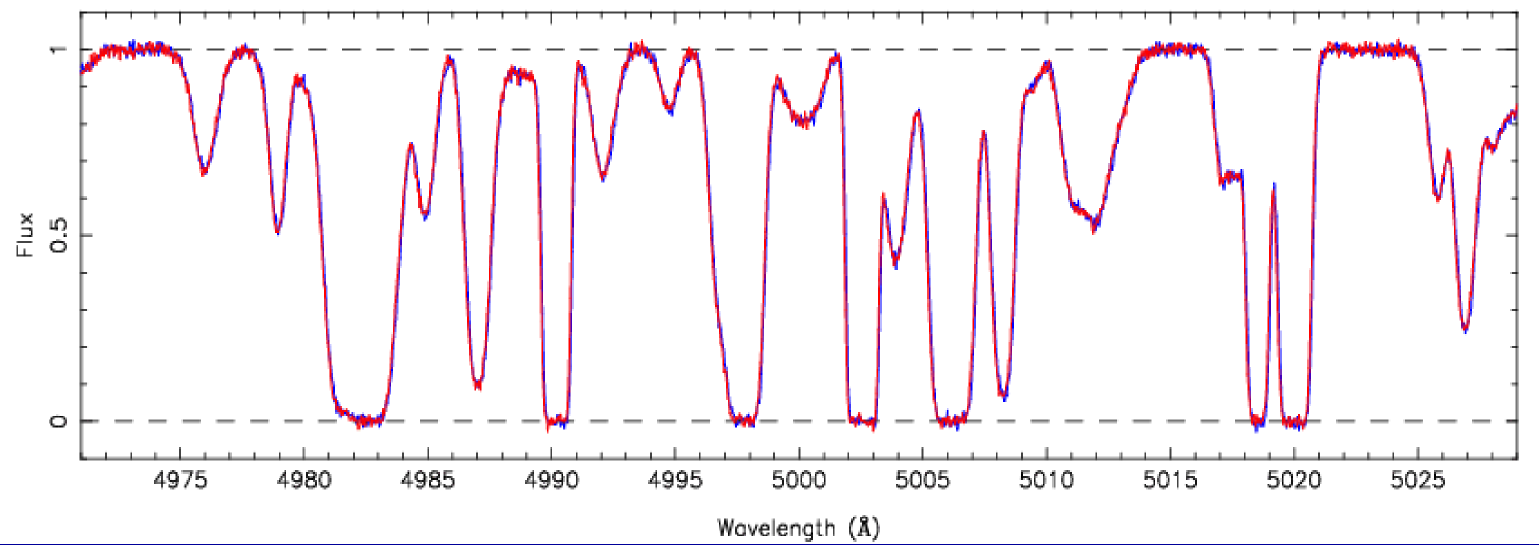
Observing dz/dt in the Ly-α Forest



Observing dz/dt in the Ly-α Forest



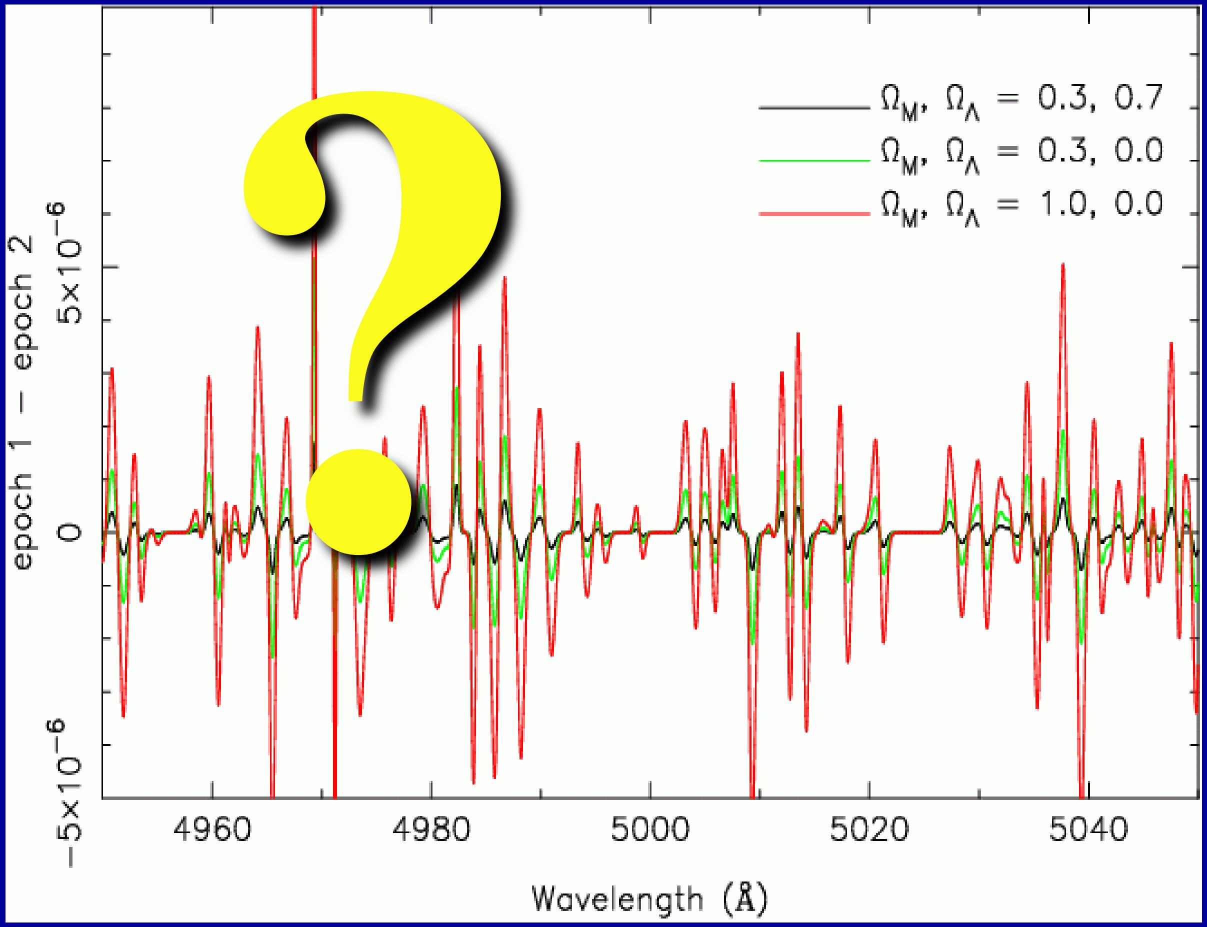
Observing dz/dt in the Ly-α Forest

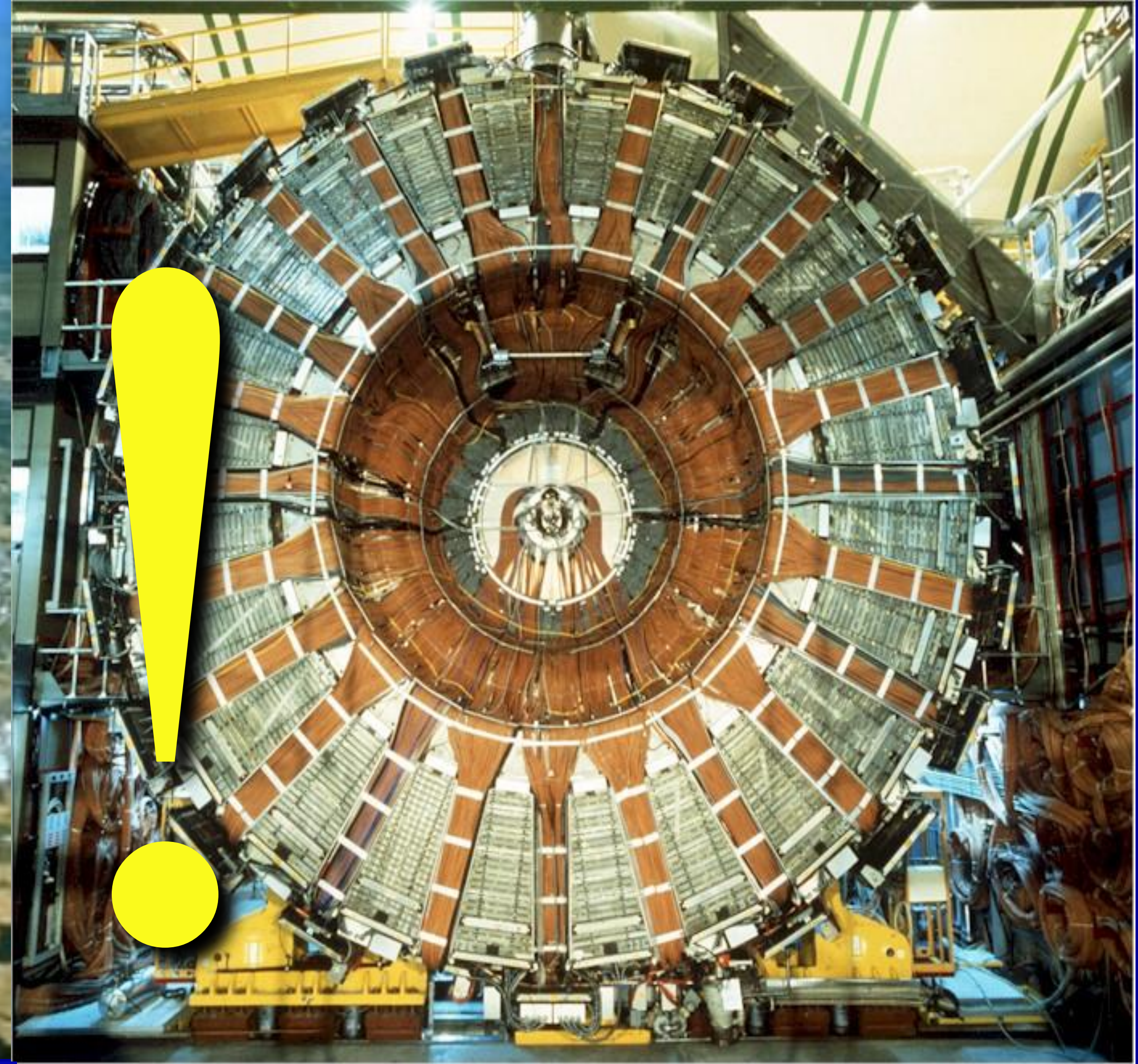


$\Delta t = 10^6$ years!

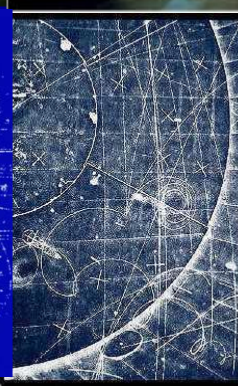
Observing dz/dt in the Ly-α Forest

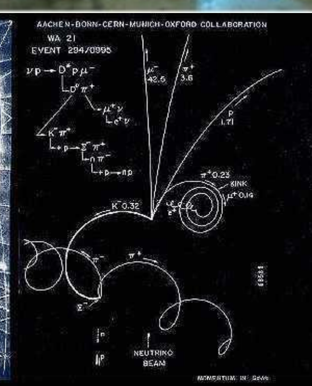
Δt = 10 years:
Δflux ~ 10^{-6}





CERN



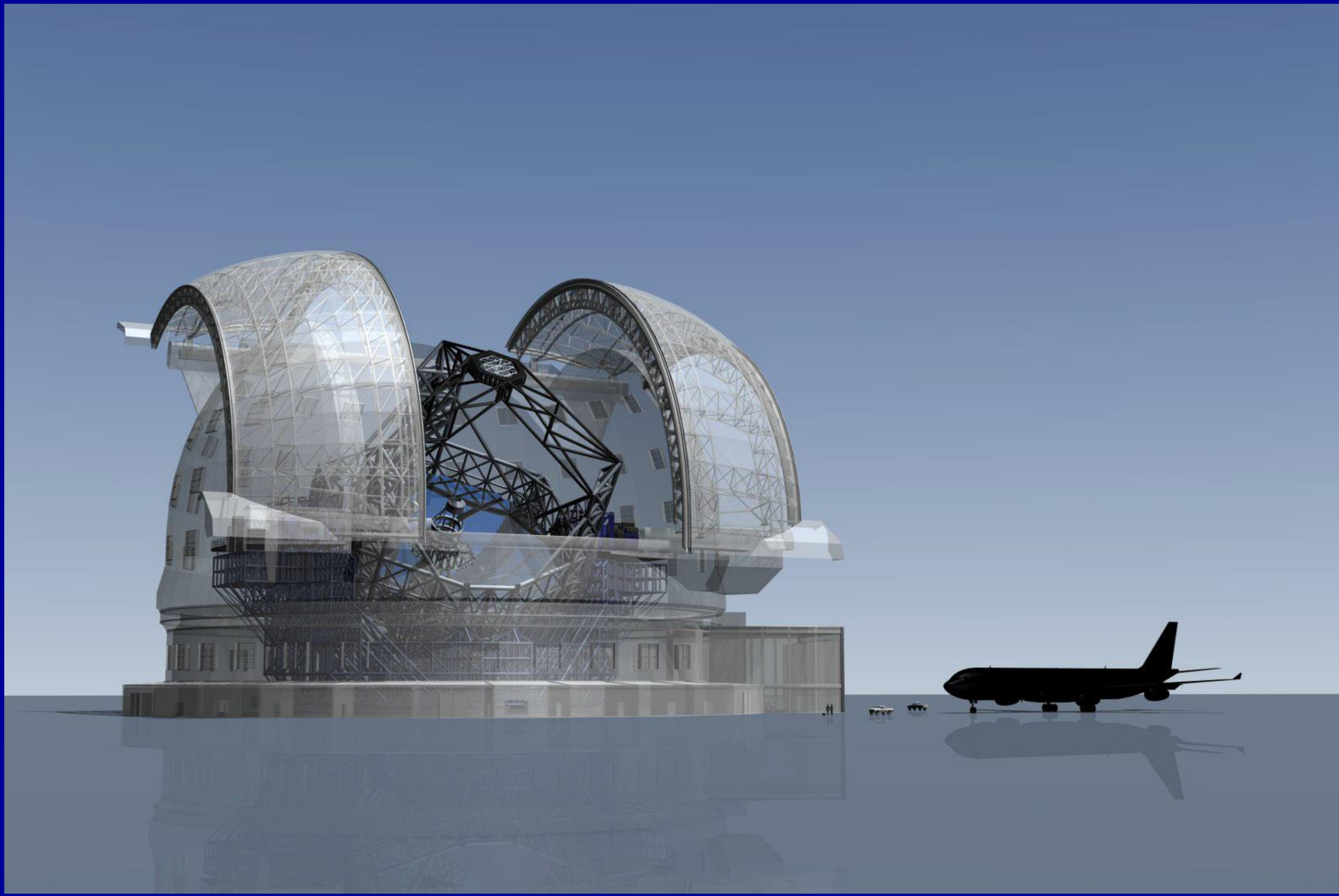


DELPHI

F C B

The E-ELT

E- ELT concept:
 42m aperture
(↓ 39? – 20%)
- ~1000 1.4m mirror exagonal segments
(↓ -2 circles)
- NIR/optical
- First light 2018? (↑)

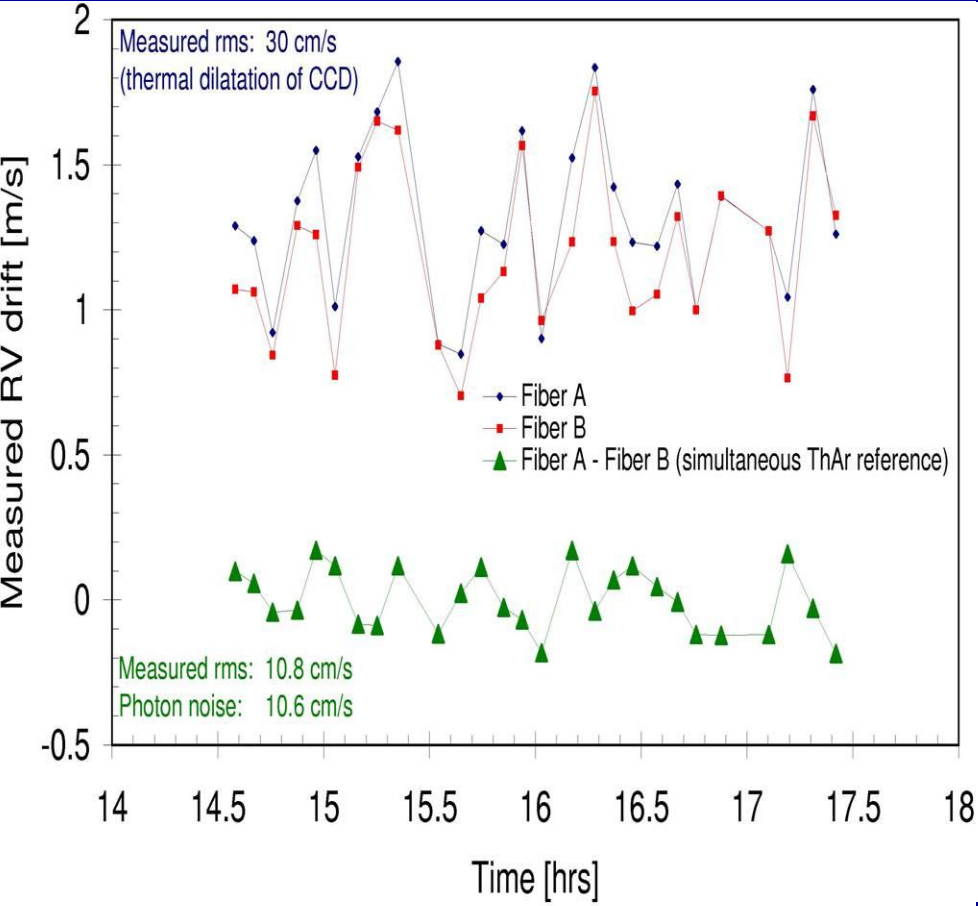


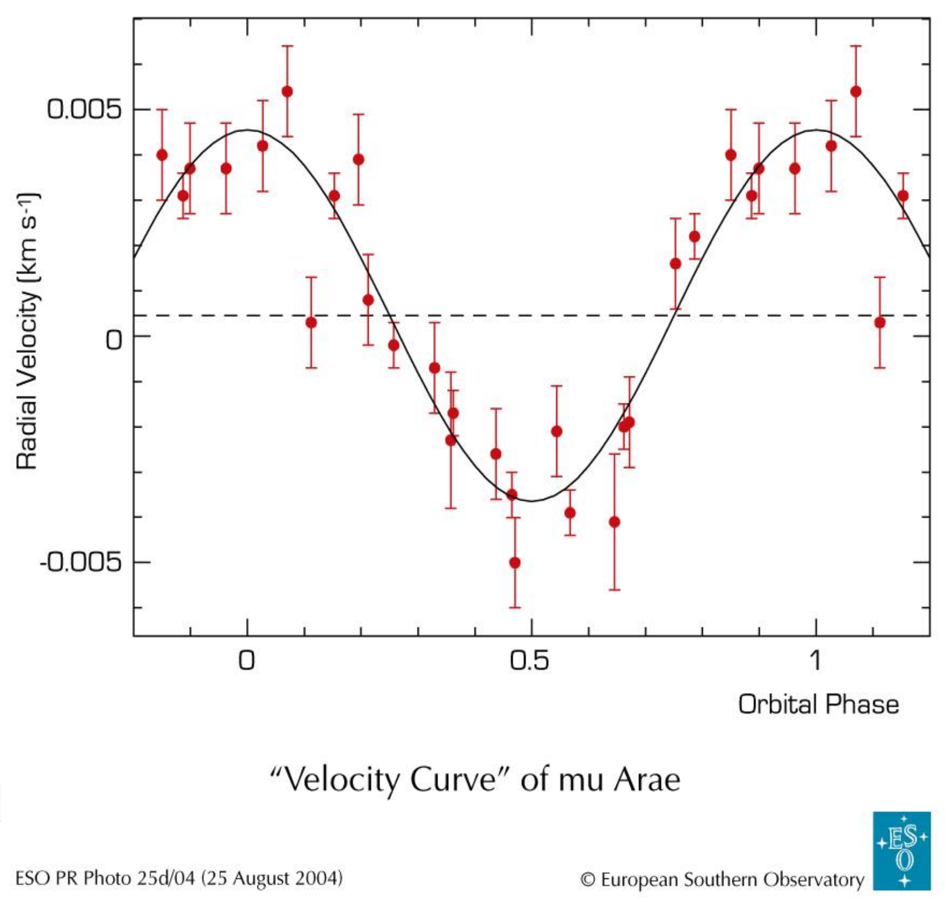
- See ESO's web pages for details

The HARPS Experience

Th-Th < 10 cm/sec

O-C < 80 cm/sec





HARPS: it is possible!

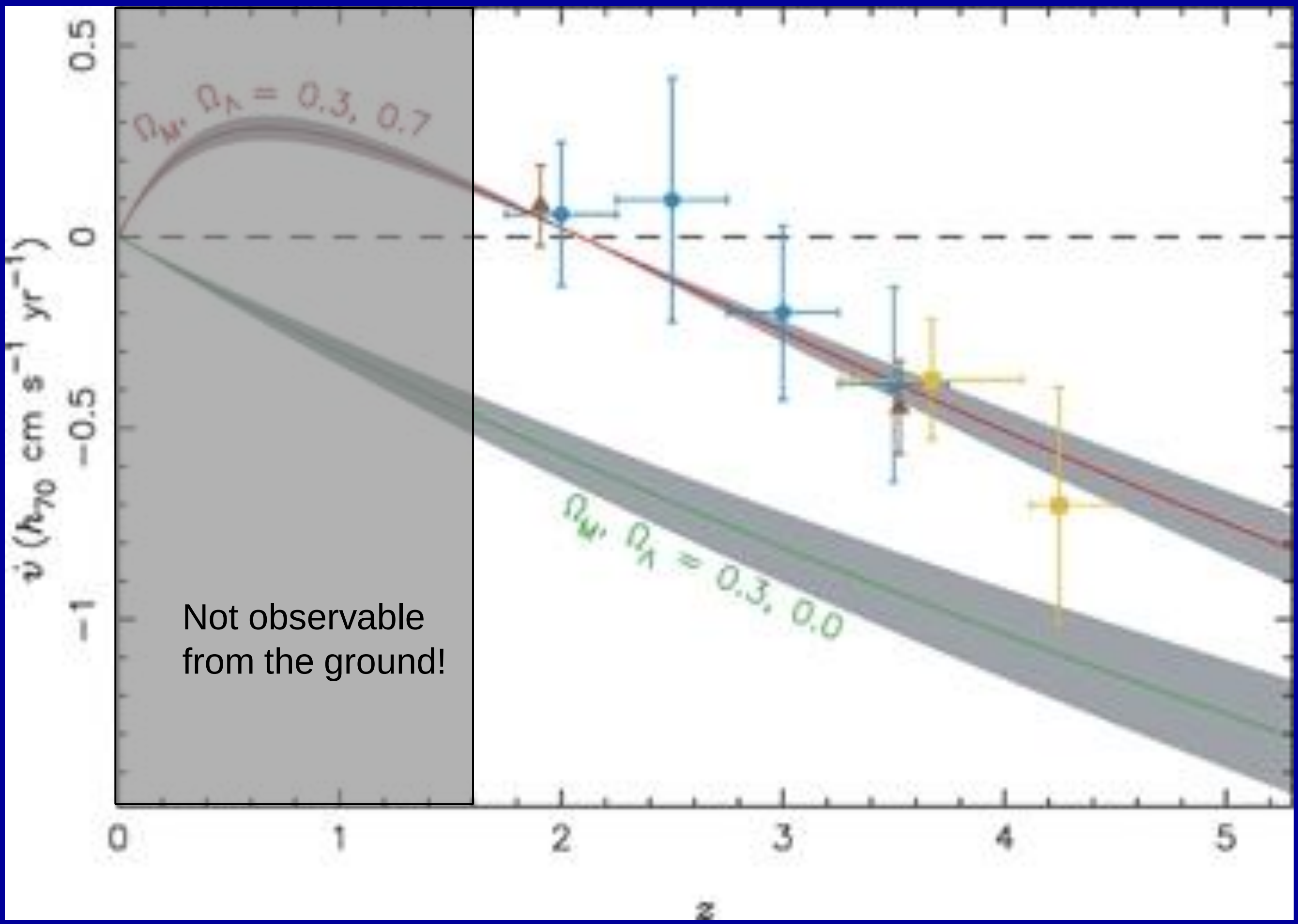
- **Exoplanets (HARPS) long term accuracy 1m/s, short term (hours) 0.1m/s (and largely understood)**

- **ELT !! LOT OF PHOTONS (we need them!!)**

COsmic Dynamics & EXoplanets

A simulated measurement

Liske et al. 2008



30 pairs of Lyα forest spectra randomly distributed in range
$2 < z_{QSO} < 4.5$

S/N = 2000

$\Delta t = 30$ yr

2000+2000 hours

One giant leap from HARPS (3.6m)?

Need for a prototype

Better… a **precursor**

ESPRESSO

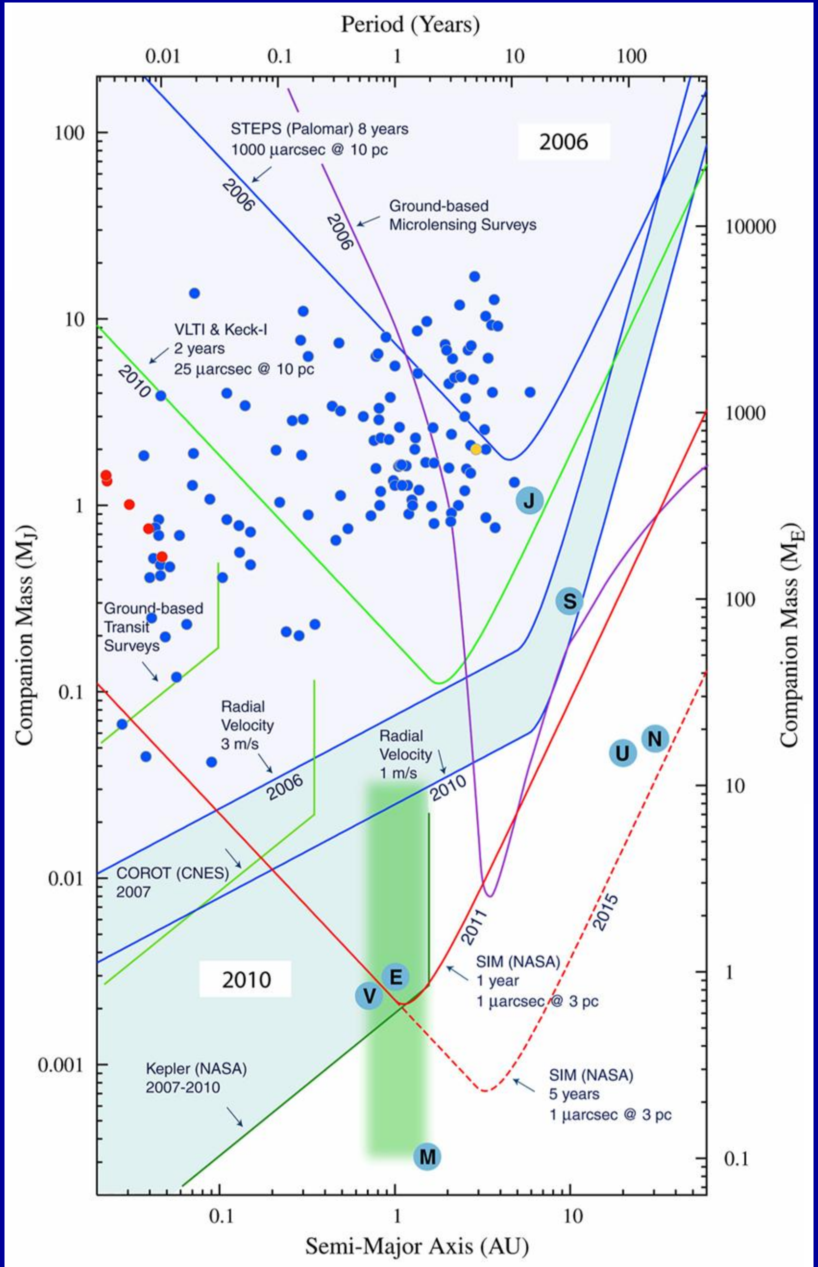
Echelle **SP**ectrograph for **R**ocky **E**xoplanets and per **S**table **S**pectroscopic **O**bservations

@ the ESO VLT – possibly @ the incoherently combined focus of the 4 UTs

ESPRESSO Science

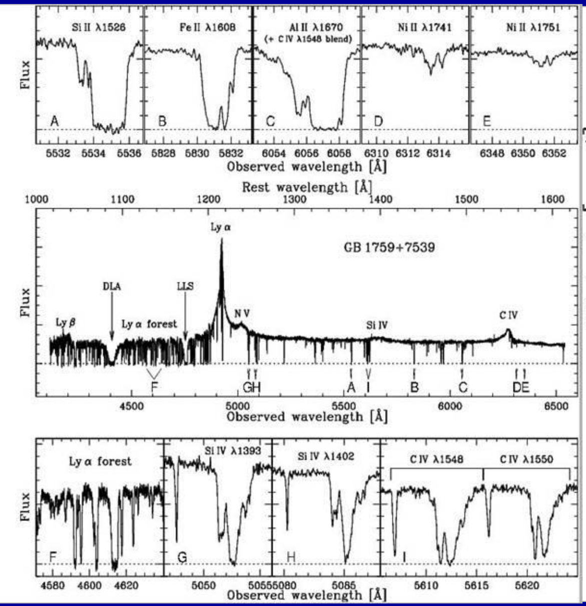
Terrestrial extra-solar planets

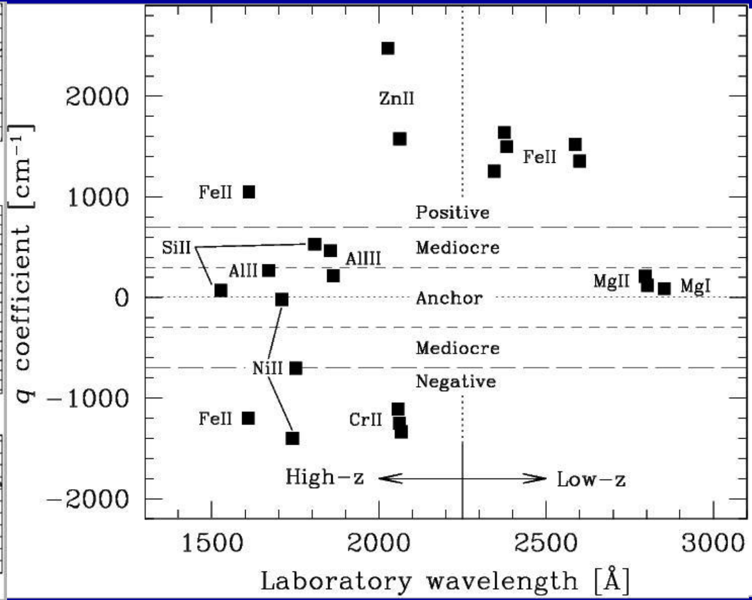
- search and characterization of rocky exoplanets in the habitable zone of quiet, nearby G to M-dwarfs.
- Radial velocity follow-up of earth-mass planet candidates discovered through other techniques (astrometry, transits).
- Different environments and formation histories (GCs, DGs)
- Difficulty: “seeing” the planet through the noise of stellar activity

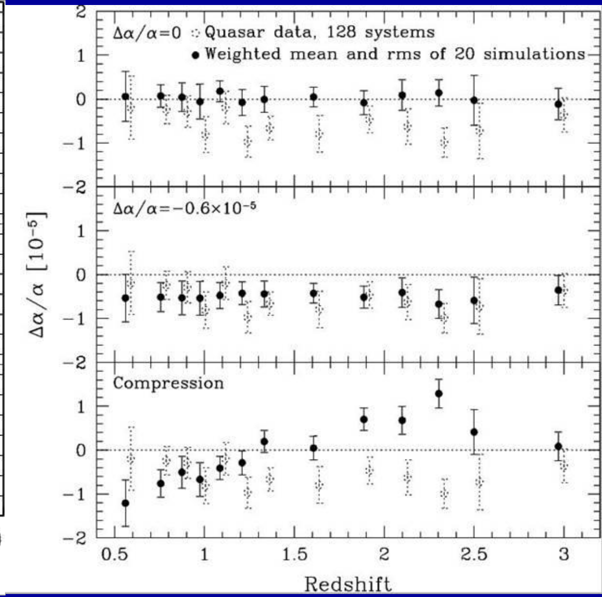


Espresso Science

- Cosmological variation of the fine structure constant, m_e/m_p ratio
  - Accuracy in $\Delta\alpha/\alpha \sim 10^{-7}$

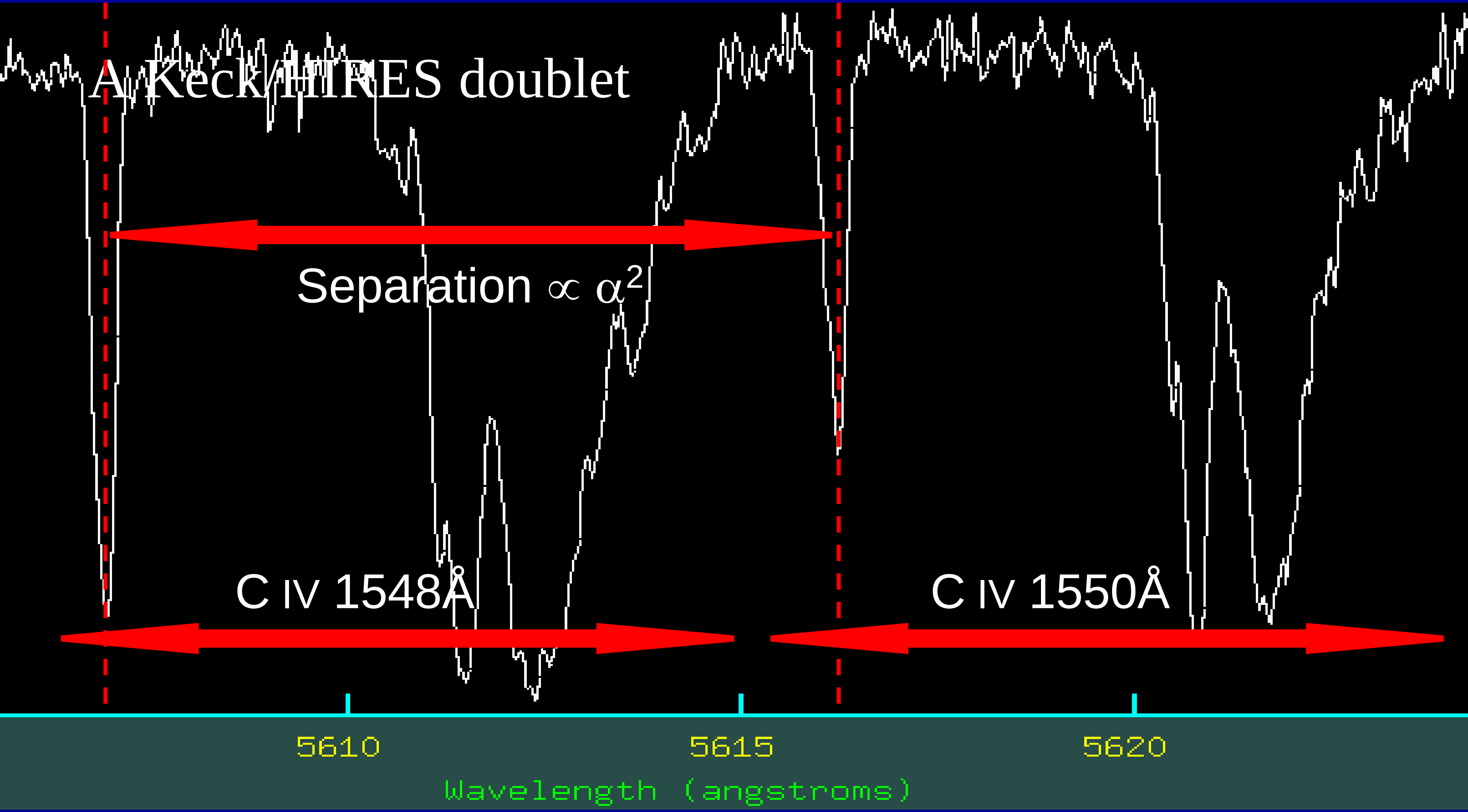




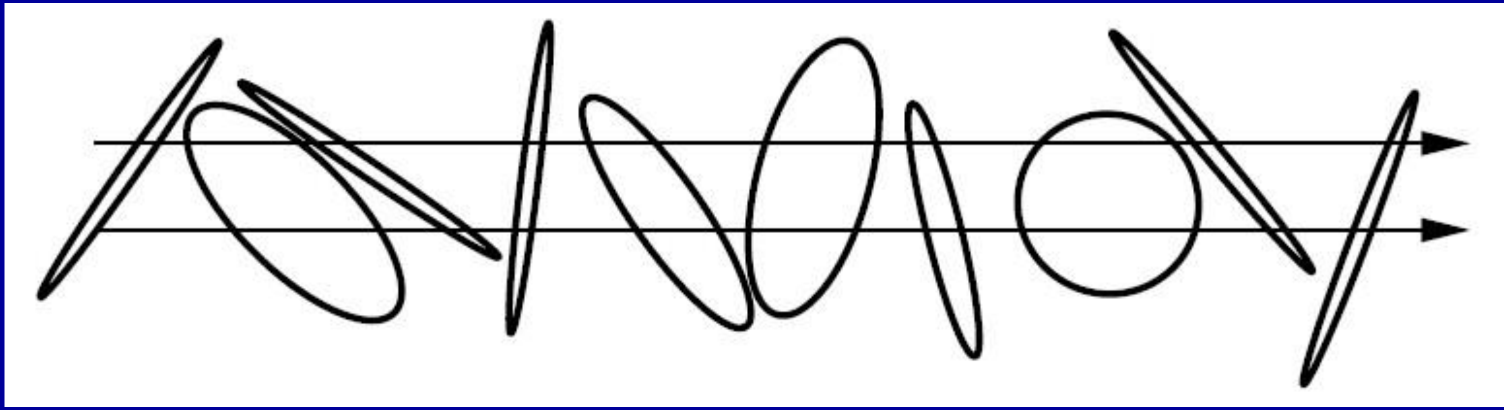


See Molaro+ 09

QSO absorption lines:



ESPRESSO - Science

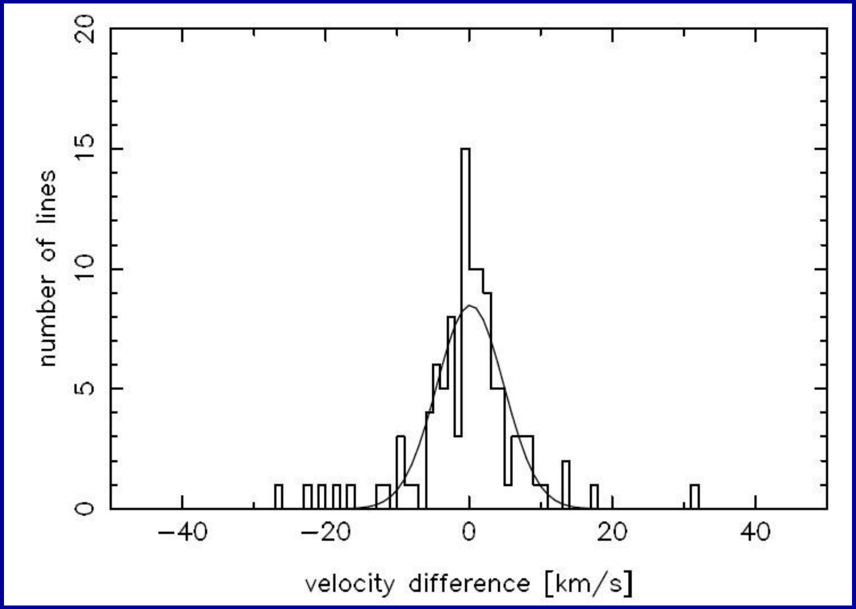


Multiple LOS

expansion-collapse in the cosmic web

winds

Rauch, Becker, Viel et al. 2006



ESPRESSO - Science

+

stellar oscillations

Precision Doppler measurements of asteroids

Abundances in Local Galaxies, MW, GCs, isotopic abundances

Molecular hydrogen and chemical elements at high-z, primordial D

SNe, GRBs and DLAs

ESPRESSO – The Instrument

Radial velocity accuracy: 10 cm/s at any time scale from 20 s up to 10yr
Spectral coverage: **(350)** 380-686 **(760)** nm corresponding to
z (1.9) 2.1 - 4.6 (5.2) in the Lya forest
Spectral Resolution: 1-UT mode R > 120,000 (goal >150,000)
1-UT mode hi-res R>220,000
4-UT mode R > 30,000
Spectral sampling: >3 pixels/FWHM (>2 pixels/FWHM in hi-res)
>2 pixels/FWHM spatial
Feed: 1 object fiber, 1 reference and/or sky fiber (Δ>7”)

Total aperture on the sky: 1.2 > FOV > 0.9 arcsec

Total detection efficiency: at least 10%, goal >14% (at peak) and not less than 7% (0.65 arsec DIMM) all modes
Performance at faint mags: 1-UT mode: SNR=10 per pix @ 550nm in 1h for a G2V star of V=17.2
4-UT mode: SNR=10 @ 550nm in 1h for V=20.1

The ESPRESSO Team

ESO:

H. Dekker, G. Avila, B. Delabre, O.Iwert, F.Kerber, G.LoCurto, J.L.Lizon, A.Manescau, L. Pasquini

IAC/Spain

R. Rebolo, M.Amate, R. García López, J.M.Herreros, J.L.Rasilla, S.Santana, F.Tenegi, M.R.Zapatero Osorio,

INAF-Trieste/Brera:

S.Cristiani, V.Baldini, R. Cirami, M.Comari, I.Coretti, G.Cupani,V. D'Odorico, V. De Caprio, P. DiMarcantonio, P. Molaro, E.Poretti, M. Riva, P.Santin, P. Spano`, E.Vanzella, M. Viel, F.M. Zerbi

Observatoire Geneve/Phinst Bern:

F.Pepe, W.Benz, M. Fleury, I.Hughes, Ch. Lovis, M. Mayor, D.Megevand, M.Pichard, D. Queloz, D.Sosnowska, S. Udry

Portugal (CAUP/FCUL Porto-Lisboa) :

N.Santos, M.Abreu, A.Armorim, A.Cabral, P.Figueira, J.Lima, A.Moitinho, M.Monteiro, J.Pinto Coelho

The ESPRESSO Resources

Estimated

~125 FTE

~12.5 MEu
(capital investment)