Concept study for measuring the

COsmic Differential EXpansion

The Sandage test

"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 $z=d\lambda/\lambda_0$ 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" **Sandage 1962 ApJ 136,31**

Sandage predictions:

z=0.4,	k=+1	dz/dt =	-0.73	cm /sec/year
	k= -1		-0.3	
	k= 0		-0.59	
	Steady state		+0.92	

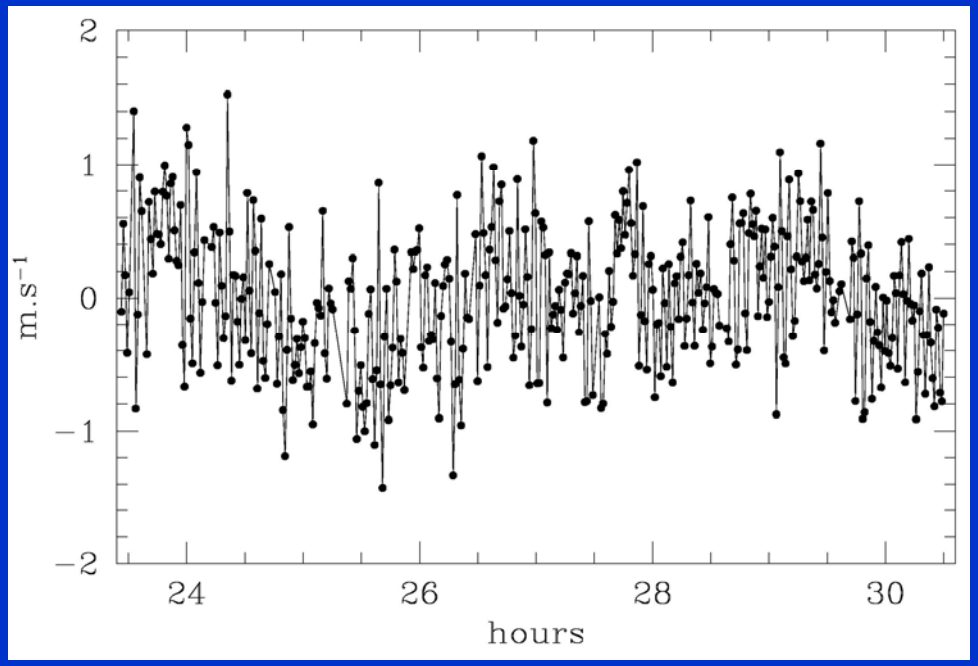
BACKGROUND

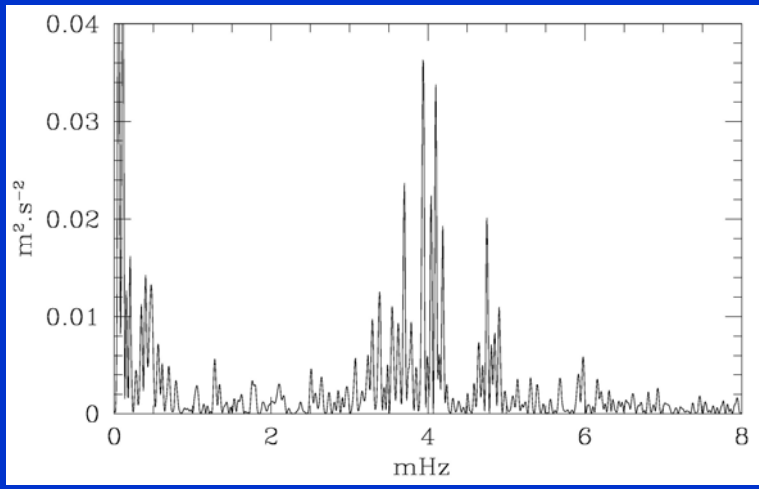
Sandage 1962
Harrison 1976,
Davis & May 1978,
Rudiger 1980,
Lake 1981,
Phillipps 1982,
Loeb 1998,
Barbachoux & Le Denmat 2002

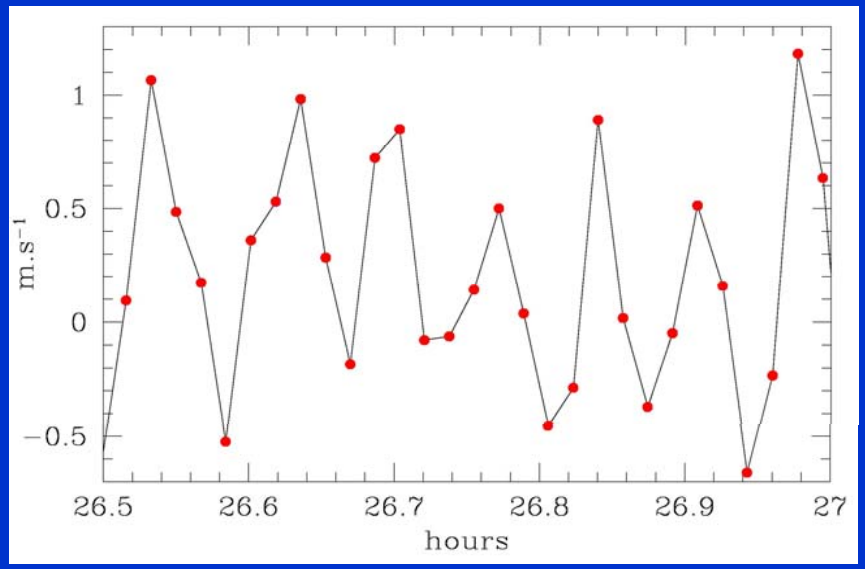
What's new

- VLT-UVES & Keck HIRES observed hundreds of bright QSOs at High Res. (R ~ 40000), z between 2 and 5, Ly α forest
- Exoplanets (HARPS) long term accuracy 1m/s, short term (hours) 0.2 m/s
- ELT (50-100m)

α CenB







0.56 m/s rms

4 minute oscillation

0.26 m/s (0.17 photon noise)

Harps collaboration

With CODEX we want

- **to revisit the possibility of a direct measurement of the cosmic acceleration $2< z< 5$, by using Ly α forest (or other absorptions) over a long time baseline (10 years or more)**

- **to identify an experiment to carry out at OWL (instrument, strategy, analysis, costs ….)**

Participants:

ESO:

G. Avila, B. Delabre, H. Dekker, S. D'Odorico, J. Liske, J.L. Lizon L. Pasquini, P. Shaver,

GENEVE:

M. Dessauges-Zavadsky, M. Fleury, C. Lovis, M. Mayor, F. Pepe, D. Queloz, S. Udry,

OAT-INAF:

P. Bonifacio, S. Cristiani, V. D'Odorico, P. Molaro, M. Nonino, E. Vanzella,

CAMBRIDGE:

M. Haehnelt, M. Murphy, M. Viel

OTHERS:

F. Bouchy (Marseille), S. Borgani (Daut-Ts)

Cosmic Signal

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

t_e=emission epoch

t_0=actual epoch

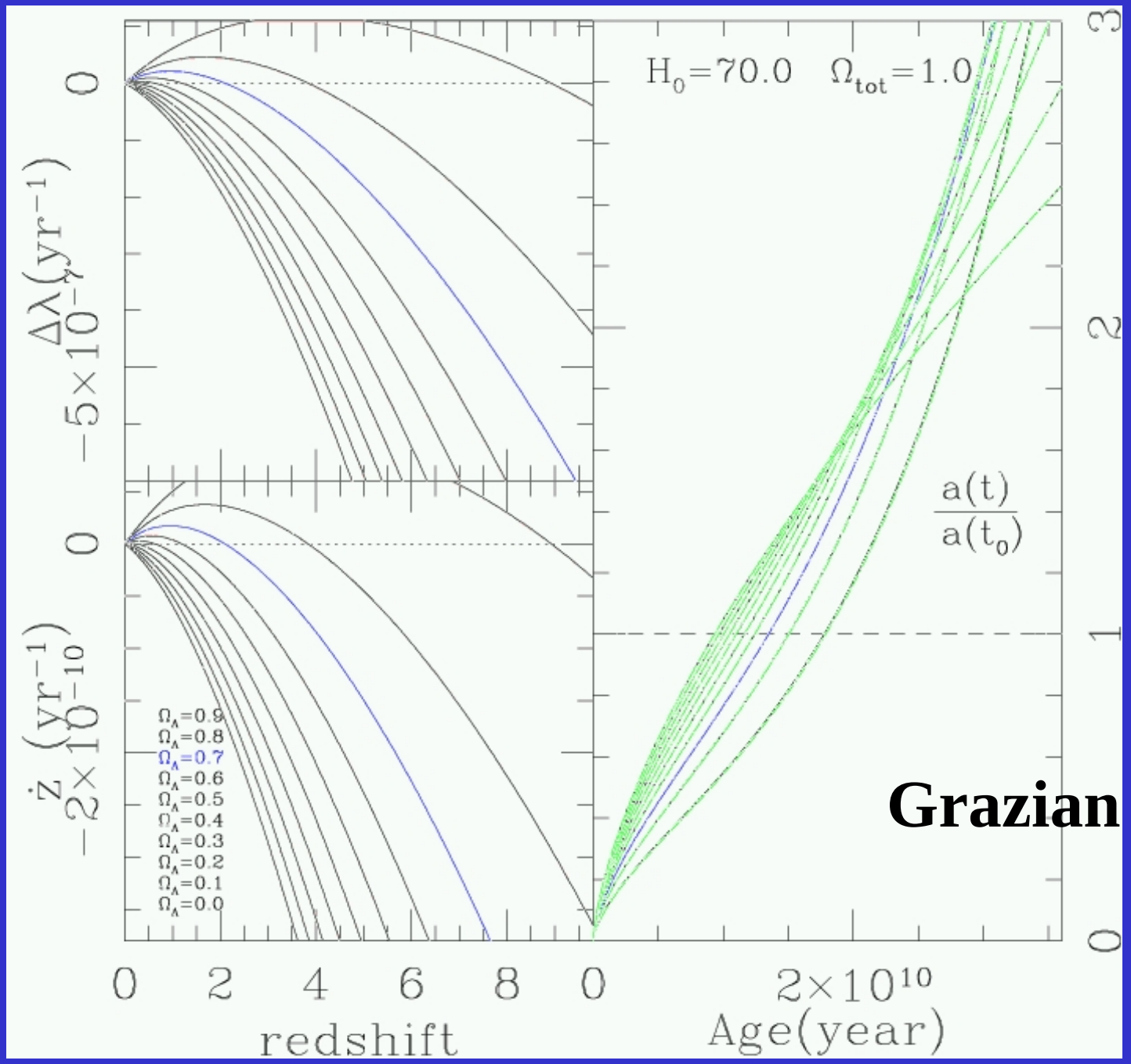
$$dz=\frac{\partial z}{\partial t_0}dt_0+\frac{\partial z}{\partial t_e}dt_e$$

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

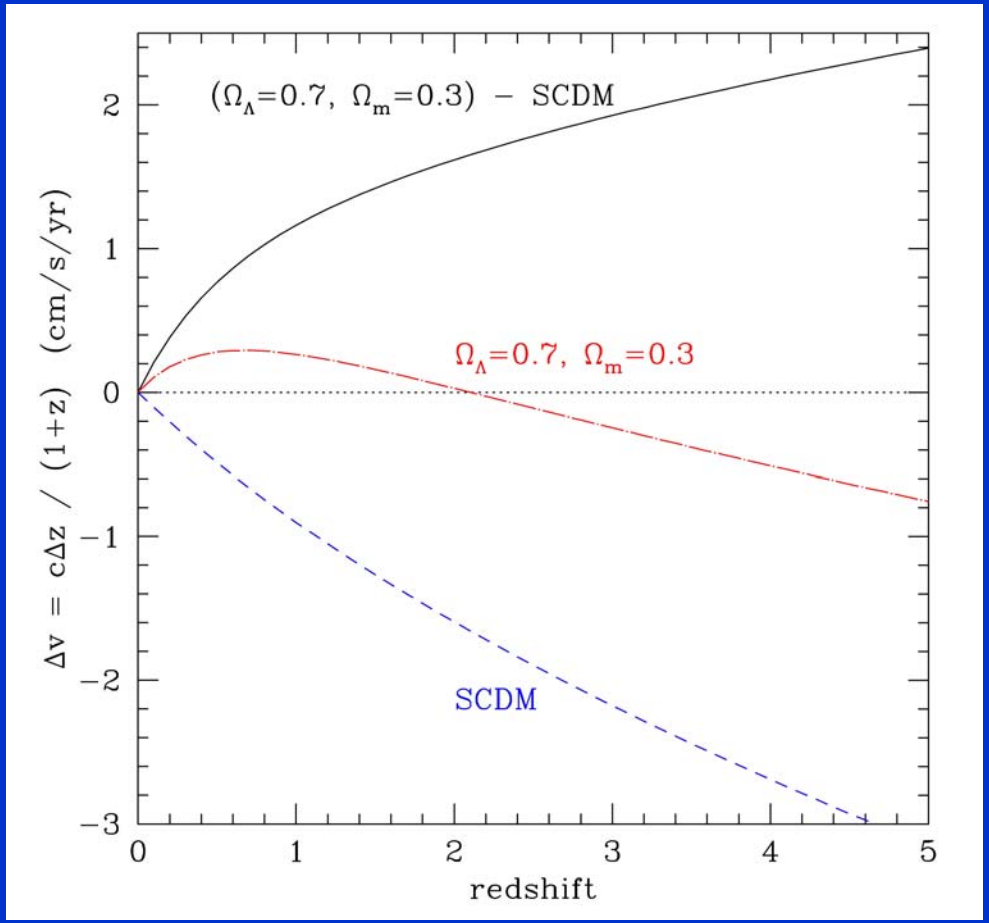
$$\dot{z}=(1+z)H_0-H(t_e).$$

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

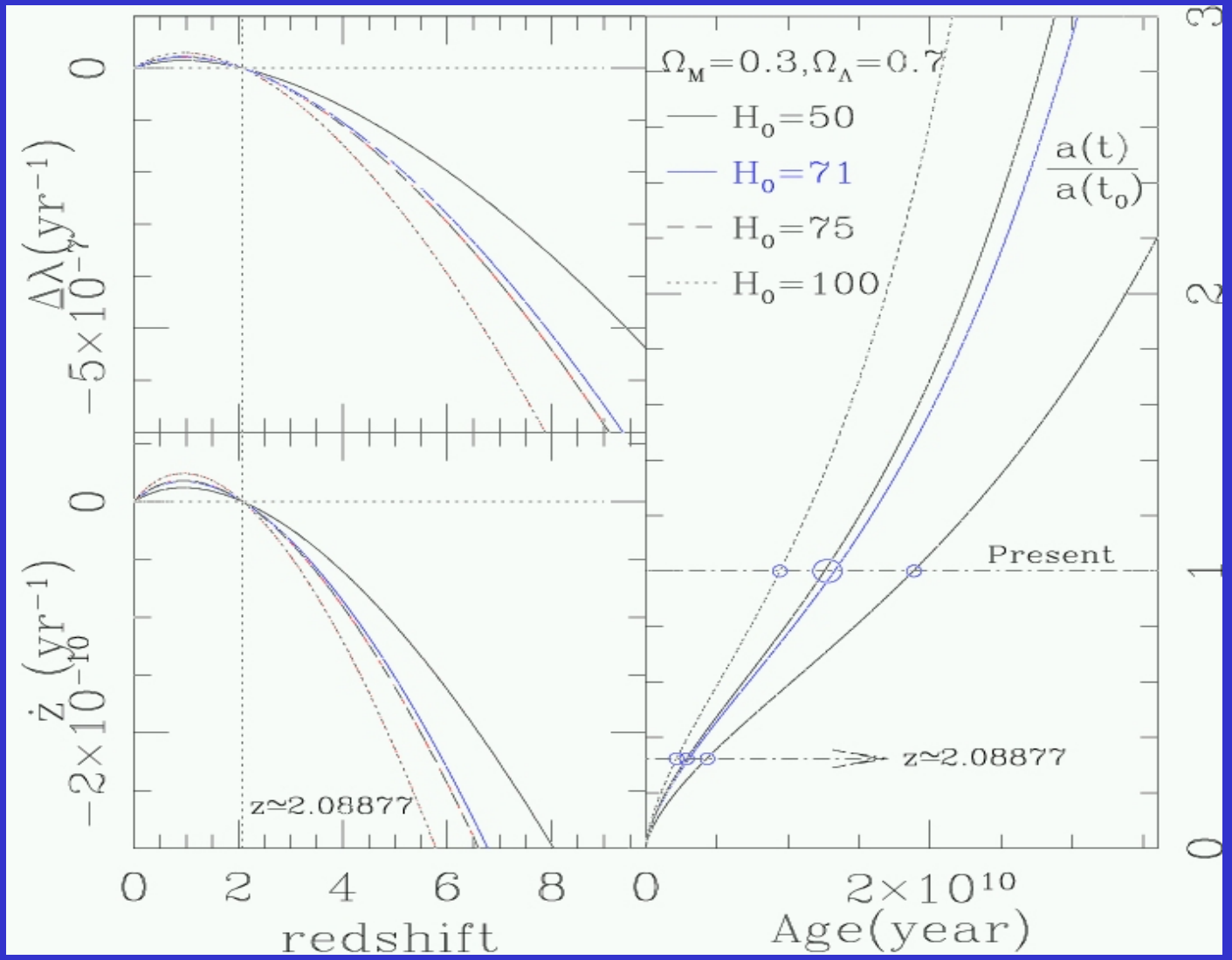
$$\text{where } \Omega_{tot}=\Omega_M+\Omega_R+\Omega_\Lambda\approx 1$$



Grazian et al 2004

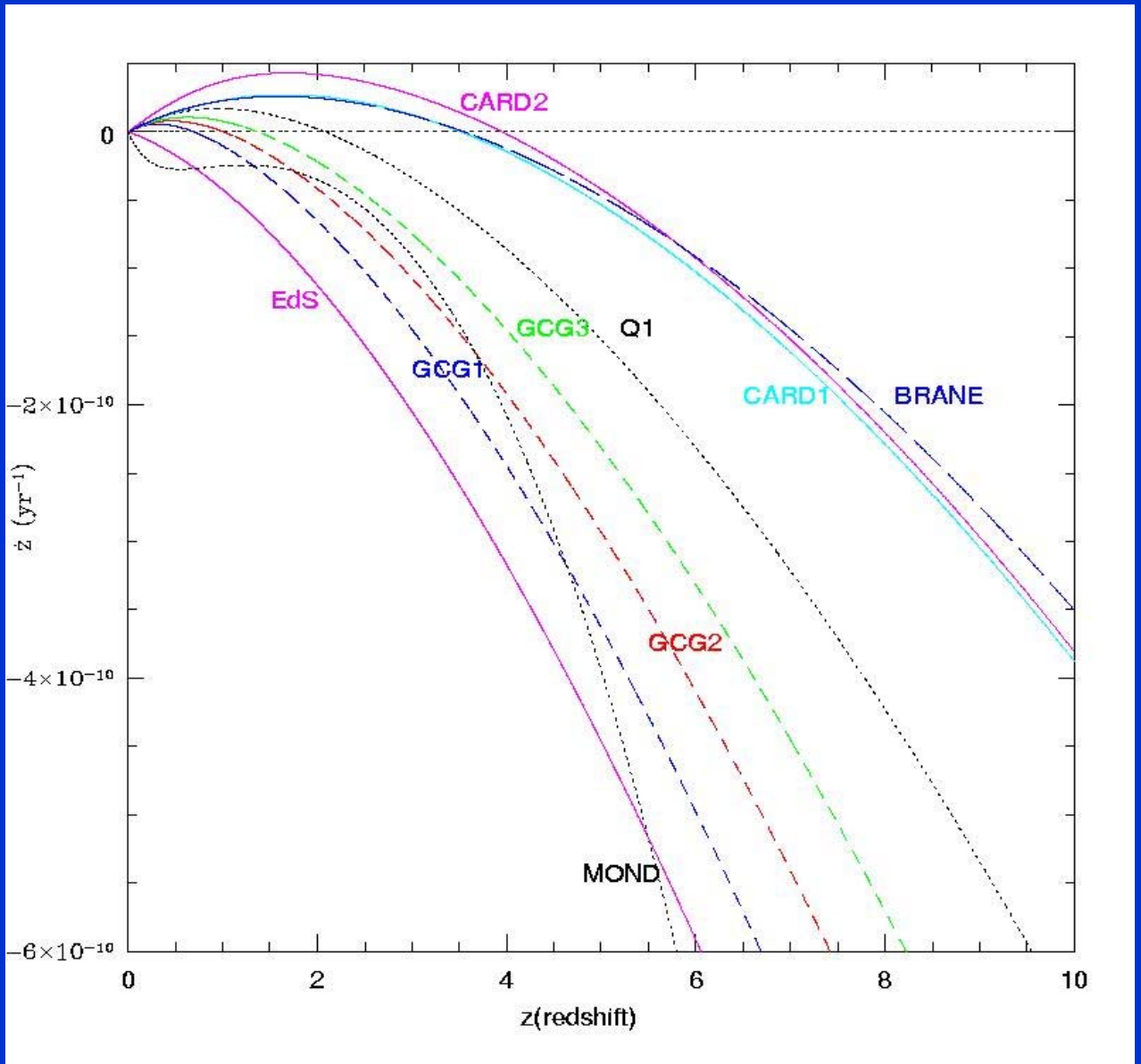

(Ω_Λ=0.7, Ω_m=0.3) − SCDM
Ω_Λ=0.7, Ω_m=0.3
SCDM
Δv = cΔz / (1+z) (cm/s/yr)
redshift
2
1
0
−1
−2
−3
0
1
2
3
4
5

Dependence from H



Grazian et al 2004

ALTERNATIVE COSMOLOGICAL MODELS



Direct measurement

- **Bias-free determination of cosmological parameters**
- **Different redshift (CMB)**
- **Not dependent from evolutionary effects of sources (SNIa)**

Key Problems

Can we built such an instrument ?

- stability on timescale of 1-10 years

Can we control the systematics?

- earth rotation , revolution around the Sun (limit the exposures, need for an ELT)
- sun motion around our Galaxy
- peculiar motions of sources

Do we have enough photons to recover the signal?

- Loeb (1998): 0.1 m/s with 2 times 100 QSOs with Keck/HIRES
- however, a significant fraction of OWL nights (50 n/year?)

More precise answer……

…….in about 1 year

parallel science

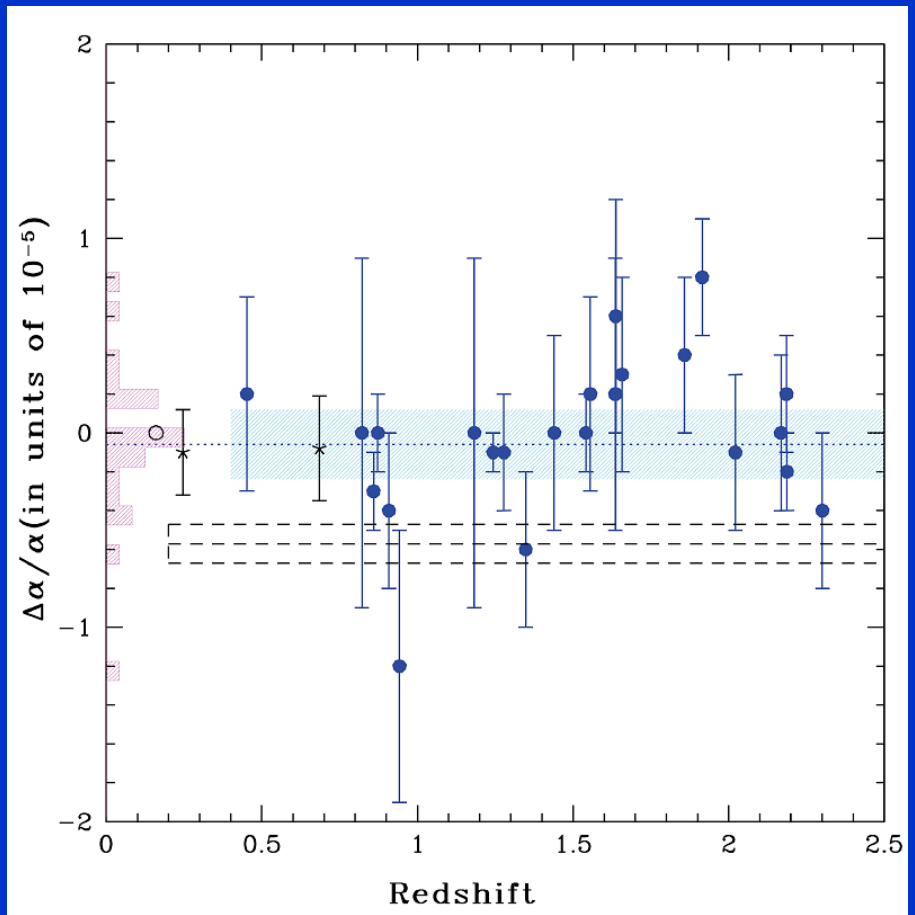
outstanding projects with an HR spectrograph @OWL:

-cosmological variation of the Fine-Structure Constant

-terrestrial planets in extra-solar systems

-others ….(SBBN, TCMB …)

Δα/α



Relative Changes with Redshift of the Fine Structure Constant
(VLT KUEYEN + UVES)

ESO PR Photo 07/04 (31 March 2004) © European Southern Observatory

143 Keck/HIRES systems

$\Delta\alpha/\alpha=(-5.7\pm1.1)\times10^{-6}$

Murphy et al 2004

23 VLT/UVES systems

$\Delta\alpha/\alpha=(+0.6\pm0.6)\times10^{-6}$

Chand et al 2004

UVES line positions accuracy :

$\sigma_\lambda \sim 3$ mÅ $\sigma_{\Delta\alpha/\alpha} \sim 10^{-5}$ (rms)

We need $\sigma_\lambda \sim 0.03$ mÅ $\sigma_{\Delta\alpha/\alpha} \sim 10^{-7}$ (rms)

to reach:

- the Oklo accuracy: $\Delta\alpha/\alpha \geq 4.5\times10^{-8}$

- or the ACES space experiment (2008) for local variation

QUANTUM UNIVERSE:
The Revolution in 21st-Century Physics

Persis Drell, chair

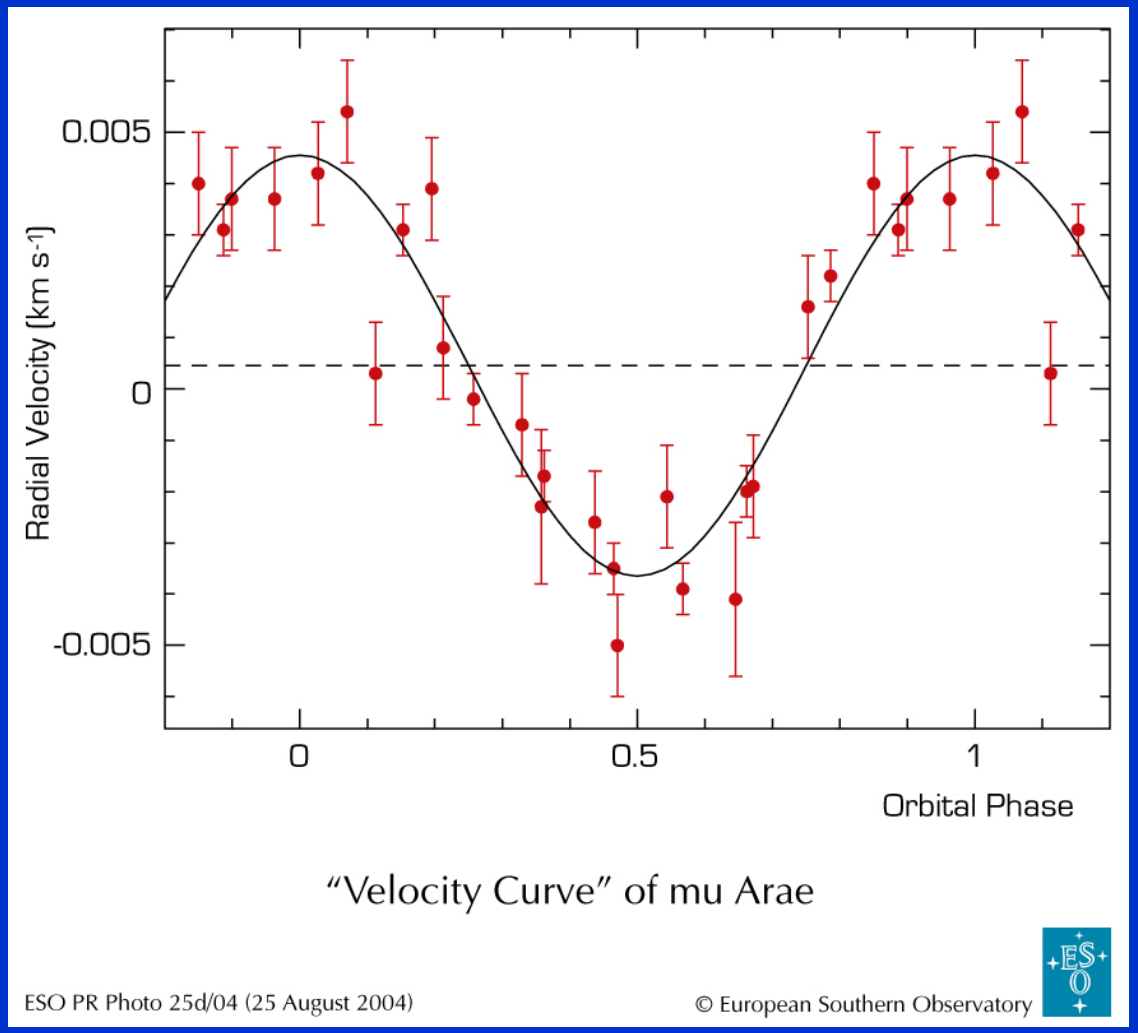
U.S Department of Energy and the National Science Foundation

June, 2004

Nine main questions

1. Are there undiscovered principles of nature ?
2. How can we solve the mystery of dark energy ?
3. Are there extra dimensions of space ?
4. Do all forces become one ?
5. Why are there so many kinds of particles ?
6. What is dark matter ?
7. What are neutrinos telling us ?
8. How did the universe come to be ?
9. What happened to the antimatter ?

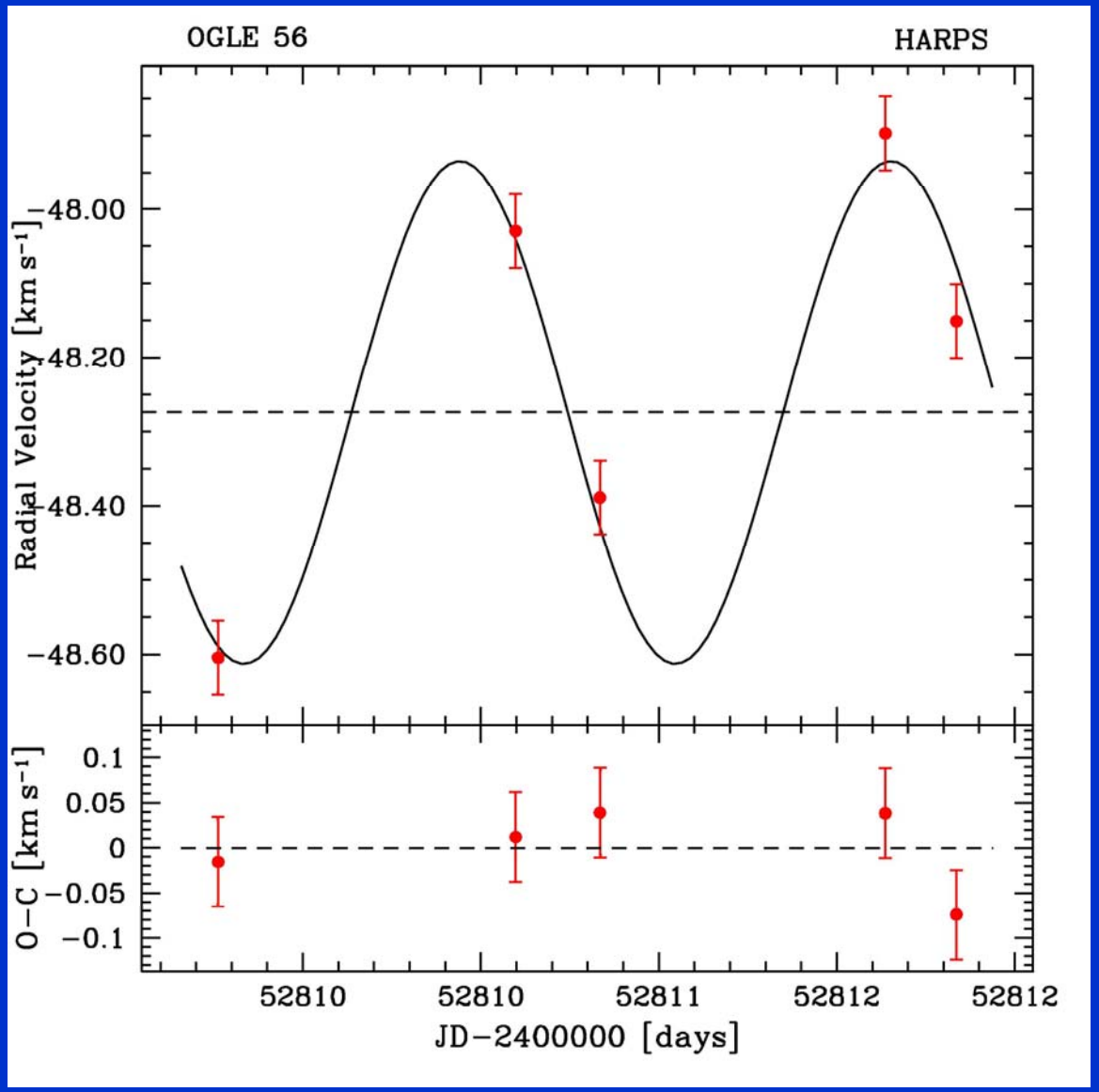
Terrestrial planets



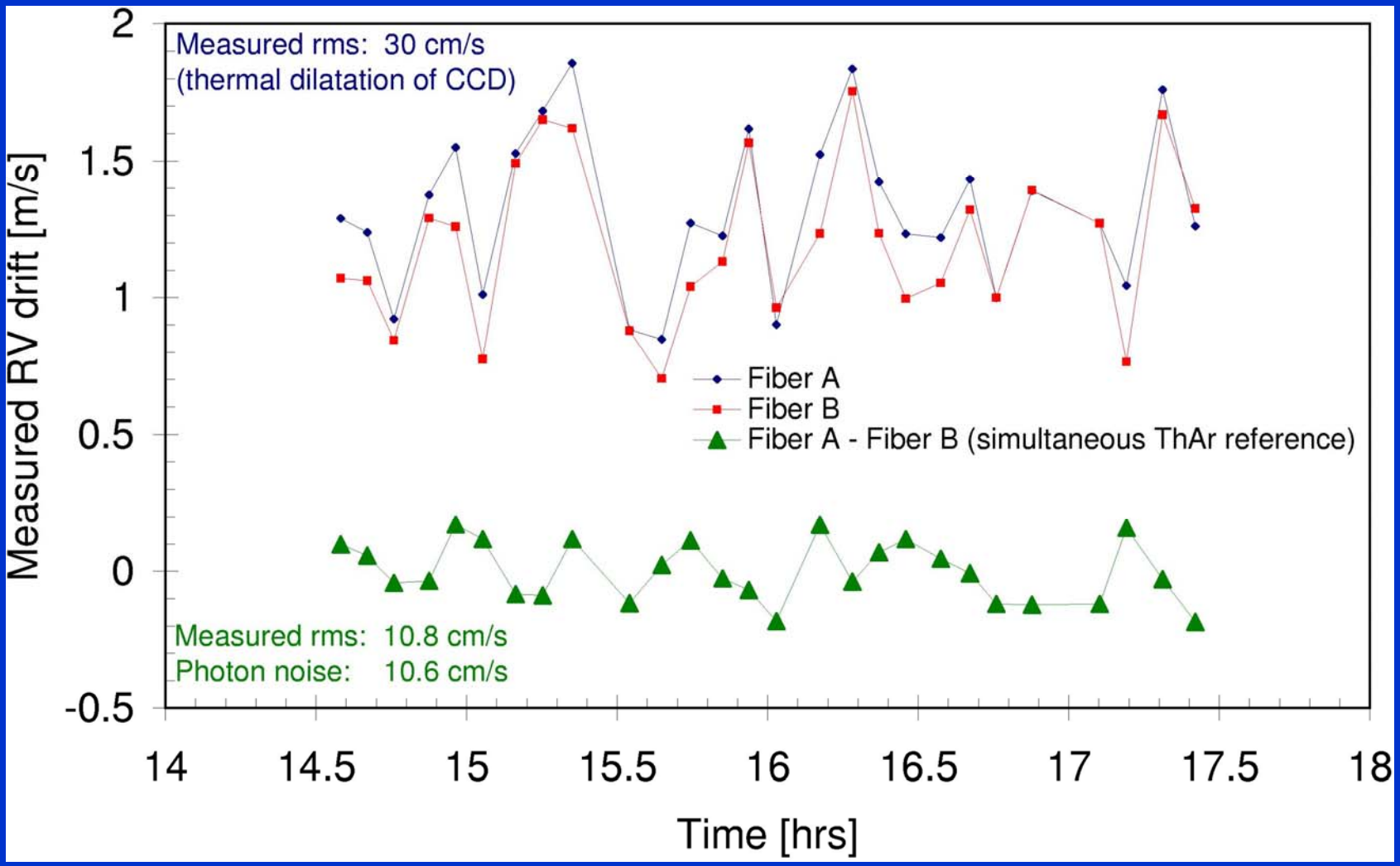
14 terr. masses

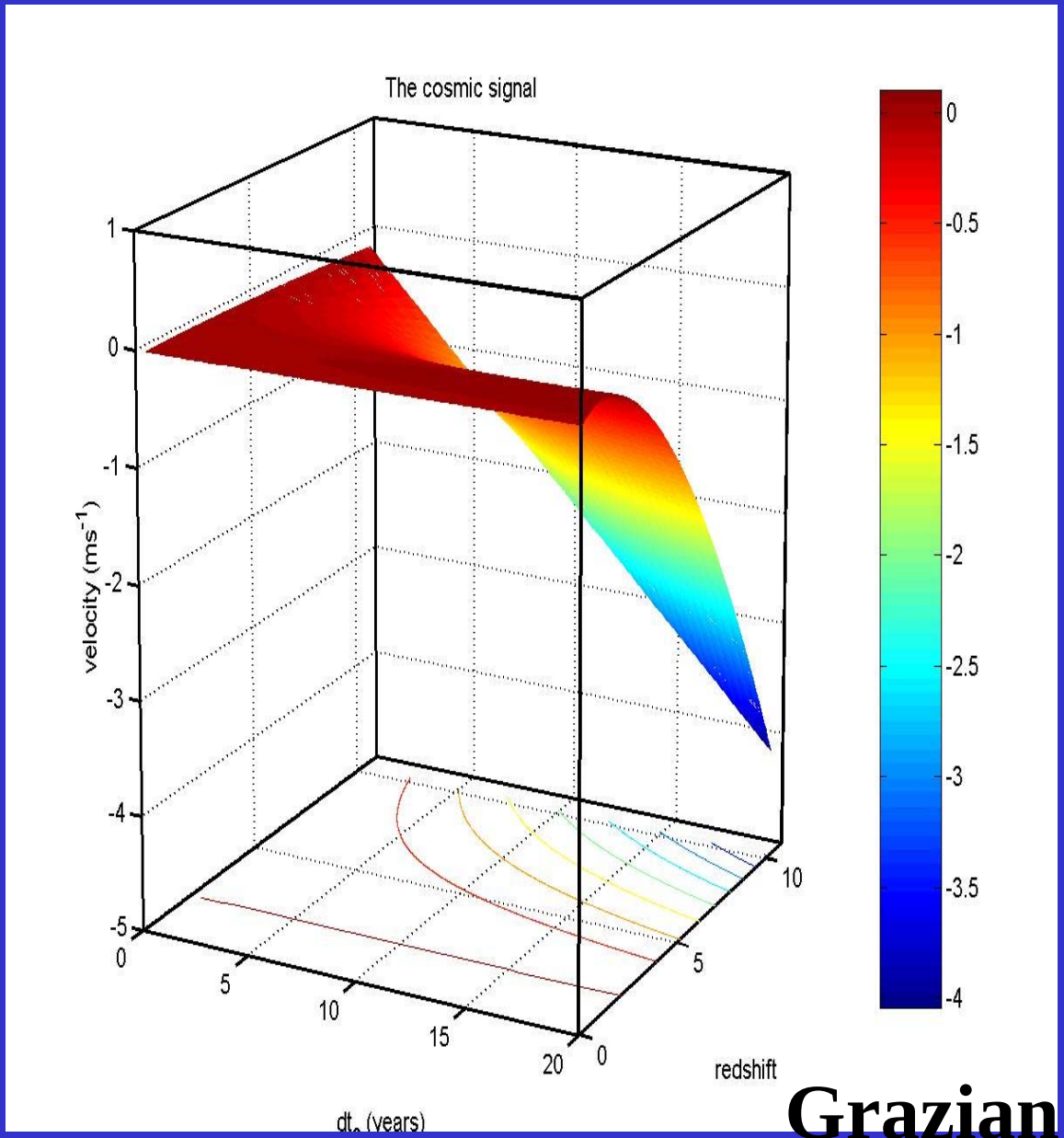
9.5h period

OGLE-TR-56

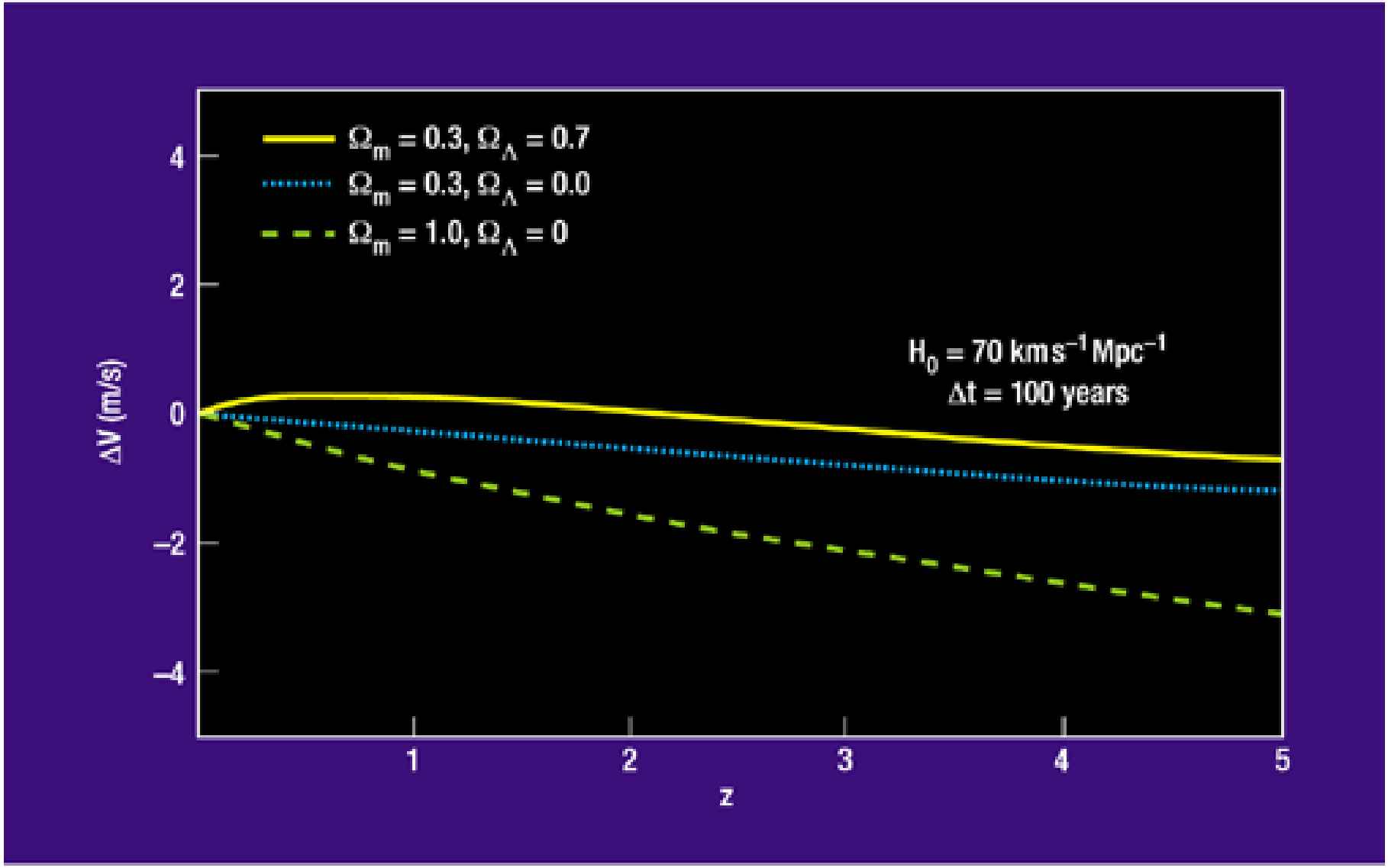


V=16.6


Measured rms: 30 cm/s
(thermal dilatation of CCD)
Fiber A
Fiber B
Fiber A - Fiber B (simultaneous ThAr reference)
Measured rms: 10.8 cm/s
Photon noise: 10.6 cm/s
Measured RV drift [m/s]
Time [hrs]
2
1.5
1
0.5
0
-0.5
14
14.5
15
15.5
16
16.5
17
17.5
18



Grazian et al 2004



Fredman 2002 from Loeb 1998