Astronomical measurements on the space-time variability of α and m_p/m_e

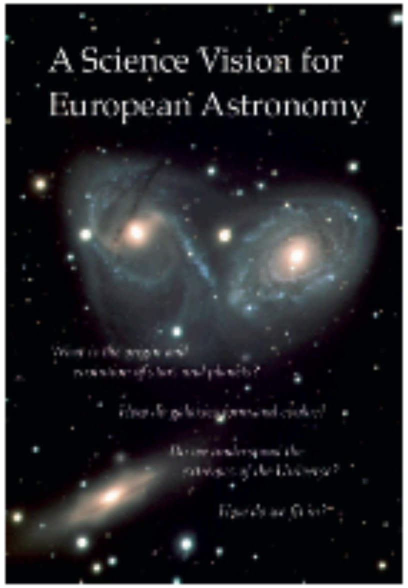
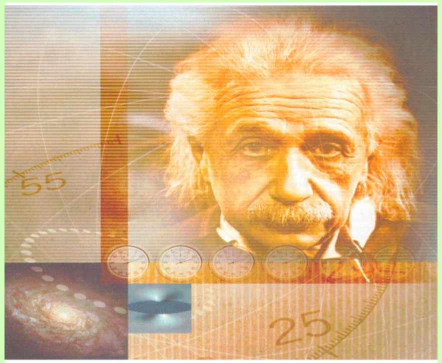
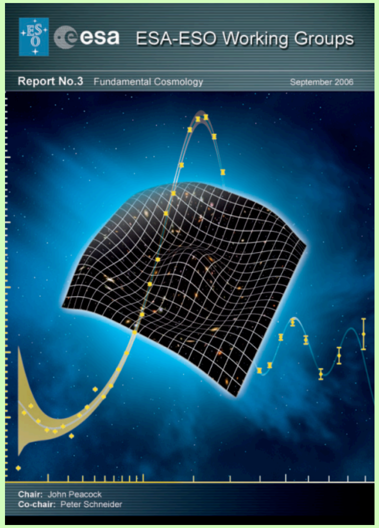


Figure 1: Cover of the ASTRONET Science Vision book.

Paolo Molaro

INAF-OAT





“*Data is not a dirty word*”

Carlos Martins 2002 astroph-0205504

Fund. const. & astronomy

- Of the 26(?) constants in the SM $\alpha = q^2/\hbar c$ and $\mu = m_p/_{me}$ are two dimensionless constants related to the fundamental forces which can be probed in the spacetime by means of astronomical observations QSO

- The fine-structure $\alpha = q^2/\hbar c$ electromagnetic force
- The $\mu = m_p/m_e$ ratio of strong to weak to forces
  - $m_p \propto 3\Lambda_{QCD}$ strong forces
  - $m_e \propto$ the vacuum expectation value (VEV) of the Higgs field; the weak scale

Overview

- The α controversy
- The μ controversy
- Future Instruments

Why constants should vary?

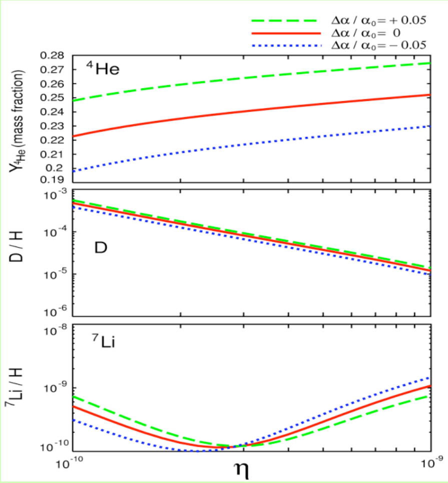
- through coupling with a scalar field
  - Quintessence (link to the dark energy)
- M-brane and multidimensional theories. Strings and Superstrings:
  - true constants are defined in the full higher dimensional theory
- In GUTs there's a relation between the variation of α and μ

$$\frac{\dot{\mu}}{\mu} \sim \frac{\dot{\Lambda}_{QCD}}{\Lambda_{QCD}} - \frac{\dot{v}}{v} \sim R\frac{\dot{\alpha}}{\alpha};$$

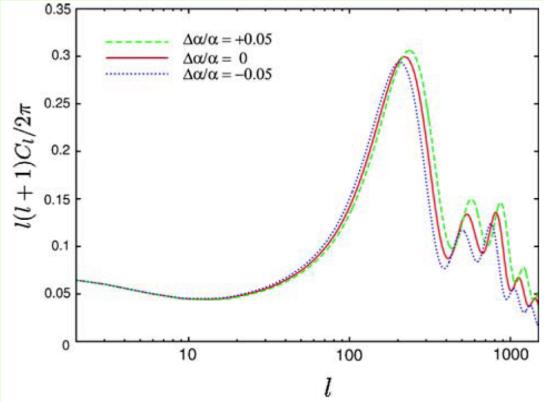
- R is model dependent ($|R| \leq 50$; μ is running faster than α. Simultaneous measurements of $\Delta\alpha$ & $\Delta\mu$ are a possible discriminant tool of GUTs models!

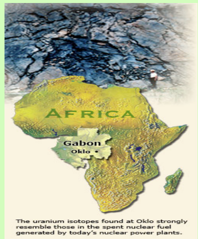
Observational Constraints on α

$$\Delta\alpha = (\alpha_z - \alpha_0)/\ \alpha_0$$



	$\Delta\alpha/\alpha$	z	method
BBN	<0.01	10^{+9}	various
CMB	<0.04	10^{+3}	various
Meteorites	$<3x10^{-7}$	0.45	Beta-decay
Oklo	$<10^{-7}$	0.18	nuclear
Laboratory	10^{-15}/year	0.0	At. clocks



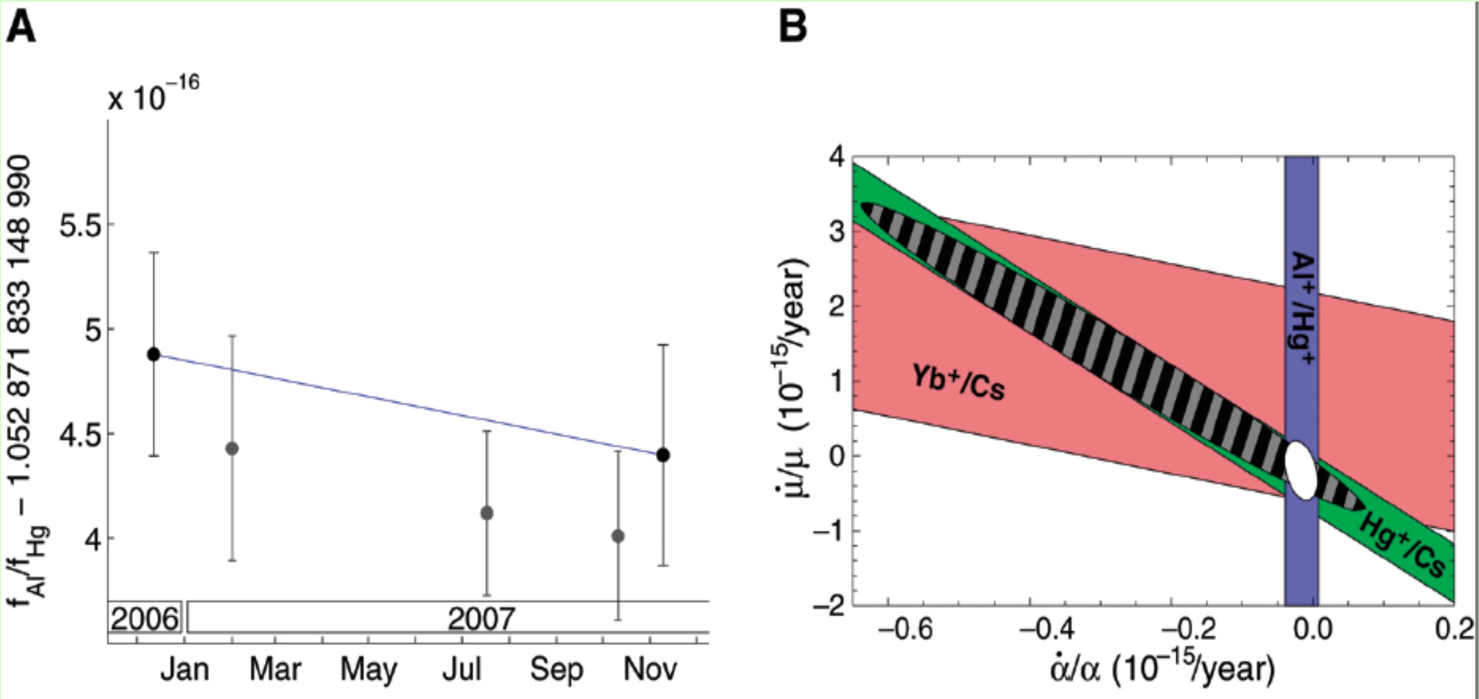


Laboratory clocks

Source	$Clock_1/Clock_2$	$d\alpha/dt/\alpha$ (10^{-15} yr^{-1})
Rosenband et al 2008	Hg+(opt)/Al+(hfs)	-1.6(0.023)
Marion *et al*, 2003	Rb(hfs)/Cs(hfs)	0.05(1.3)[a]
Bize *et al*, 2003	Hg+(opt)/Cs(hfs)	-0.03(1.2)[a]
Fisher *et al*, 2004	H(opt)/Cs(hfs)	-1.1(2.3)[a]
Peik *et al*, 2004	Yb+(opt)/Cs(hfs)	-0.2(2.0)
Bize *et al*, 2004	Rb(hfs)/Cs(hfs)	0.1(1)[a]

Metrology at the 17th decimal place

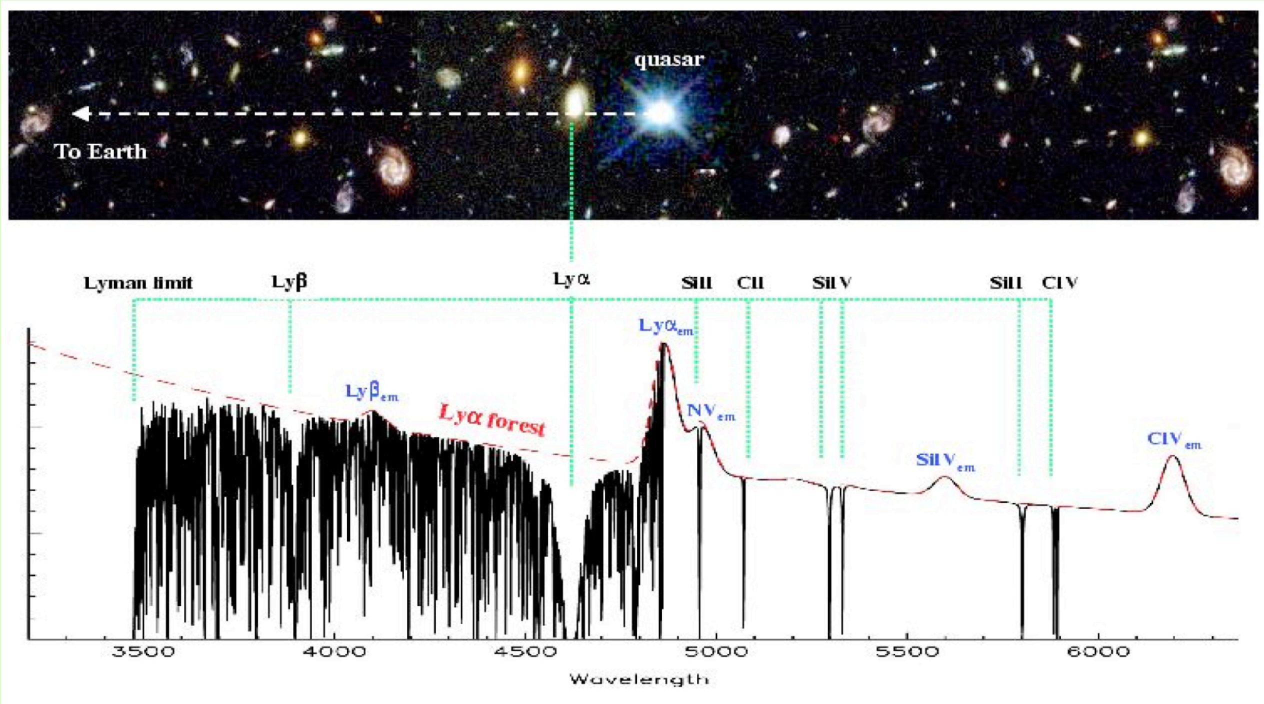
Rosenband et al March 2008



$d\alpha/dt/\alpha = (-1.6 +/- 2.3)\ 10^{-17}\ yr^{-1}$

@ 10 Gyr (z=1.85) ➔ $\Delta\alpha/\alpha = (-1.6 +/- 2.3) \times 10^{-7}$ linear variation!

QSO absorption lines



$$\omega = \omega_0 + q_1 Z^2 \left[\left(\frac{\alpha}{\alpha_0} \right)^2 - 1 \right] + q_2 Z^4 \left[\left(\frac{\alpha}{\alpha_0} \right)^4 - 1 \right]$$

q calculations

- Atomic calculations are required to compute ω (α)
- The sensitivity coefficient q are found by varying α in computer codes
- Dzuba, Flambaum several papers Porsev et al 2007

Relativistic Hartree-Fock +	Accuracy
All-orders sum of dominating diagrams	0.1-1%
Configuration Interaction + Many-Body Perturbation Theory	1-10%
Configuration Interaction	10-20%

q calculations (in cm^{-1})

Anchor lines

Atom	ω_0	*q*
Mg I	35051.217	86
Mg II	35760.848	211
Mg II	35669.298	120
Si II	55309.3365	520
Si II	65500.4492	50
Al II	59851.924	270
Al III	53916.540	464
Al III	53682.880	216
Ni II	58493.071	-20

Negative shifters

Atom	ω_0	*q*
Ni II	57420.013	-1400
Ni II	57080.373	-700
Cr II	48632.055	-1110
Cr II	48491.053	-1280
Cr II	48398.862	-1360
Fe II	62171.625	-1300

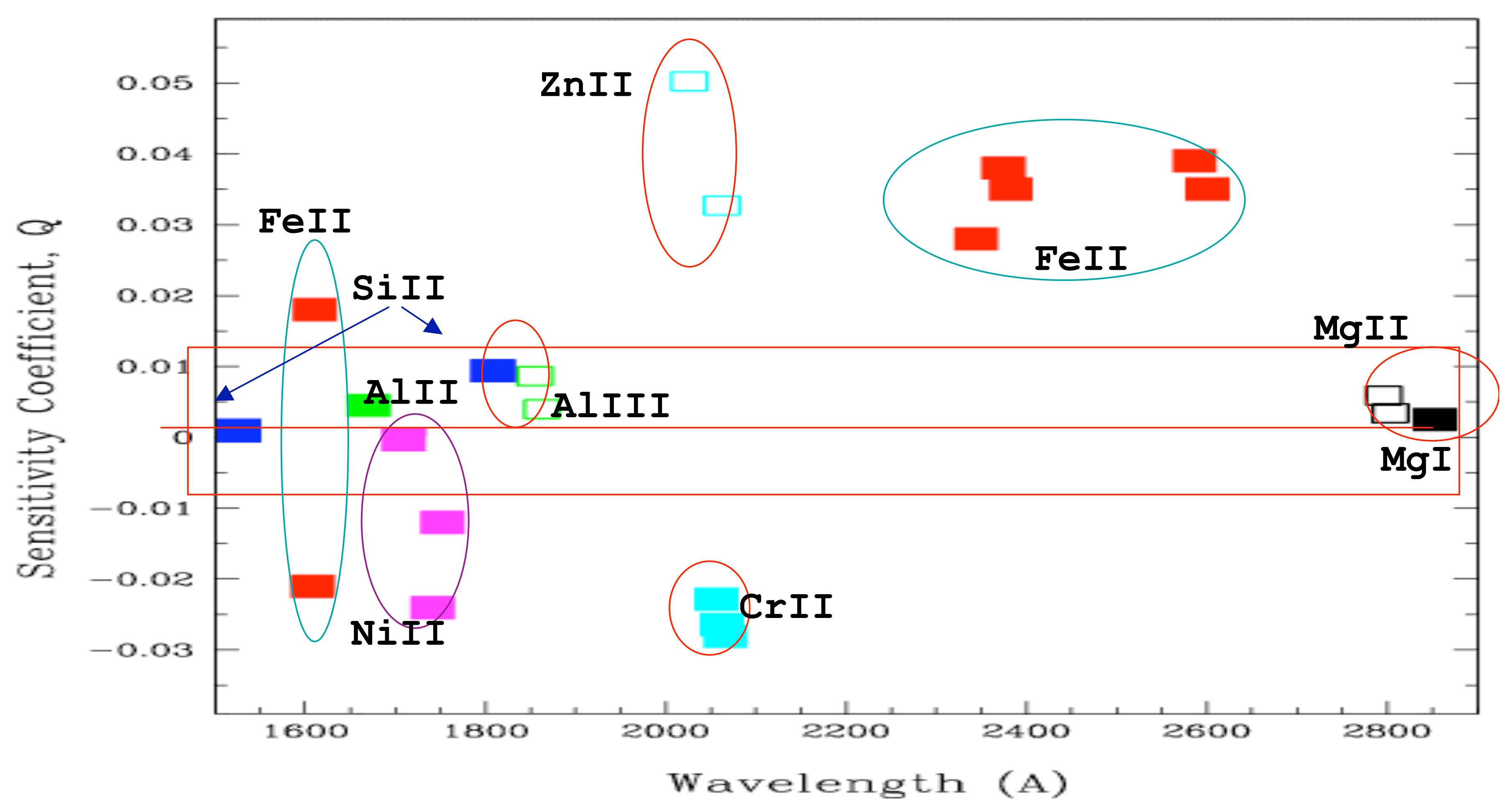
Positive shifters

Atom	ω_0	*q*
Fe II	62065.528	1100
Fe II	42658.2404	1210
Fe II	42114.8329	1590
Fe II	41968.0642	1460
Fe II	38660.0494	1490
Fe II	38458.9871	1330
Zn II	49355.002	2490
Zn II	48841.077	1584

Different signs and magnitudes of q provides opportunity to study systematic errors!

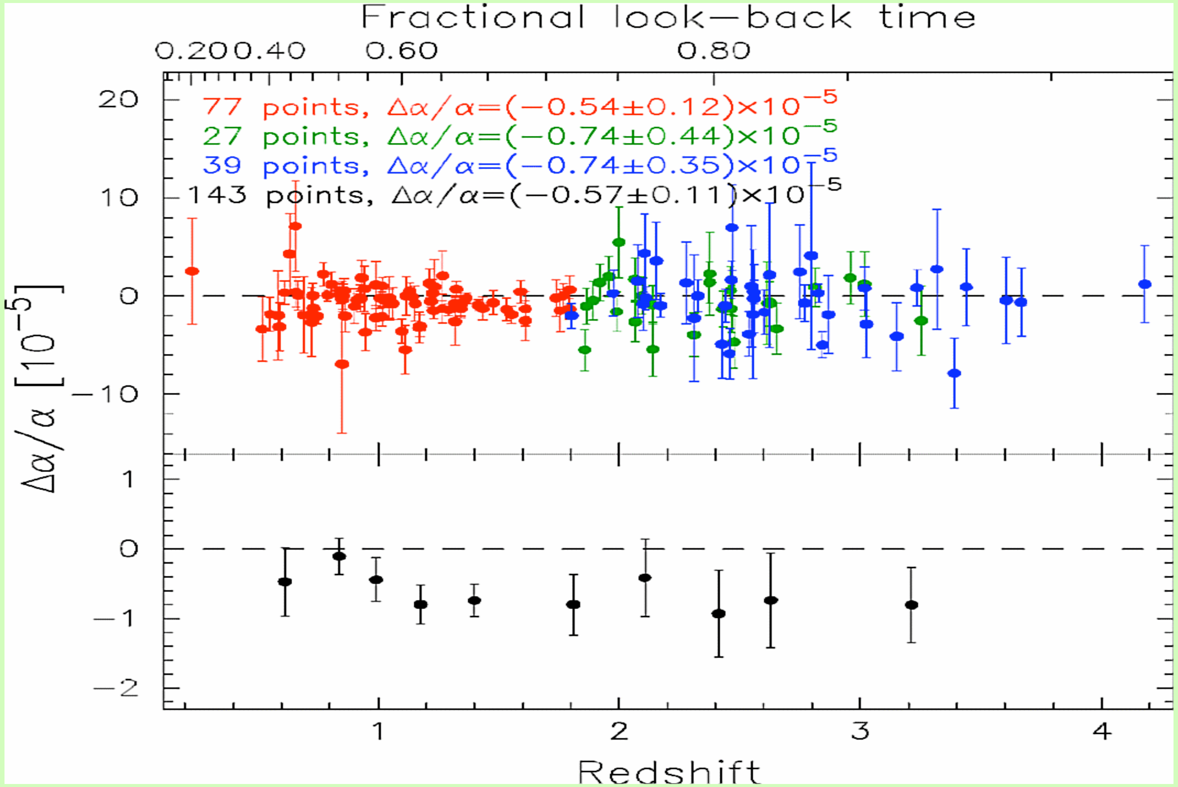
High-*z* (>1.8)

Low-*z* (0.5 – 1.8)



- Murphy, Flambaum, Webb , Dzuba, Prochaska, Wolfe (2004) ; Webb et al 1999, Murphy 2001, 2003, 2004

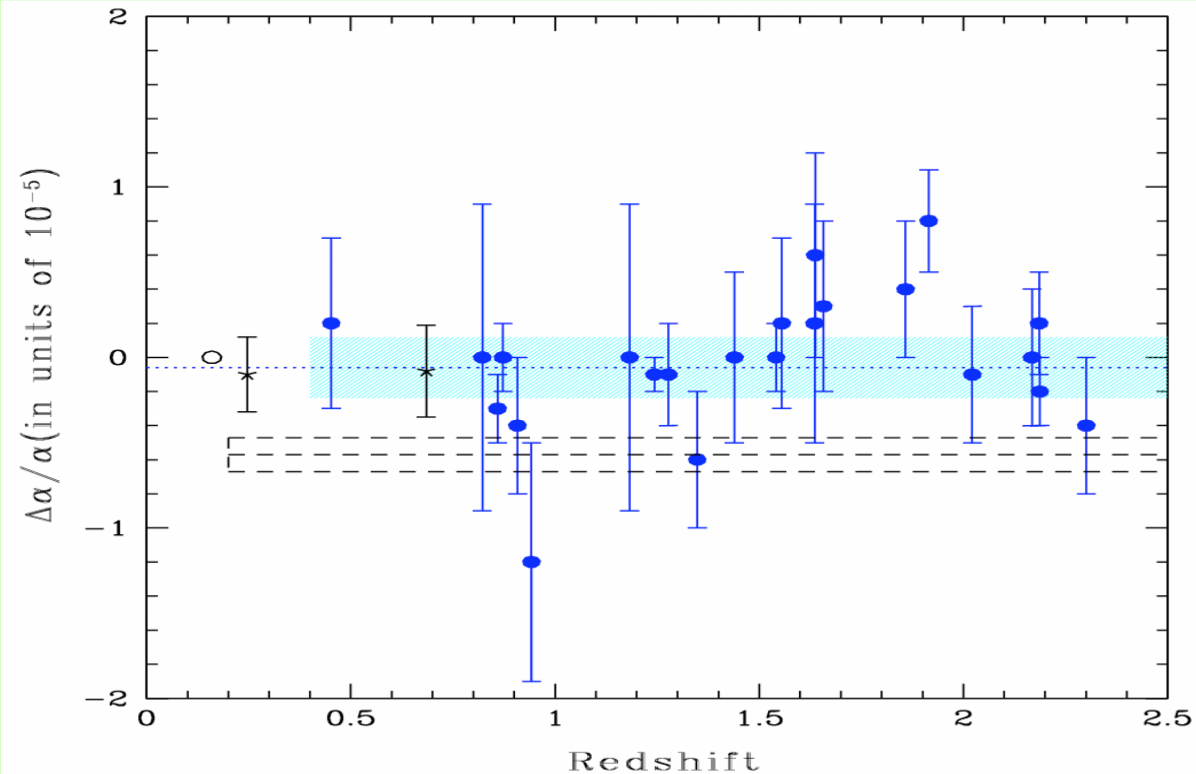
Keck/HIRES



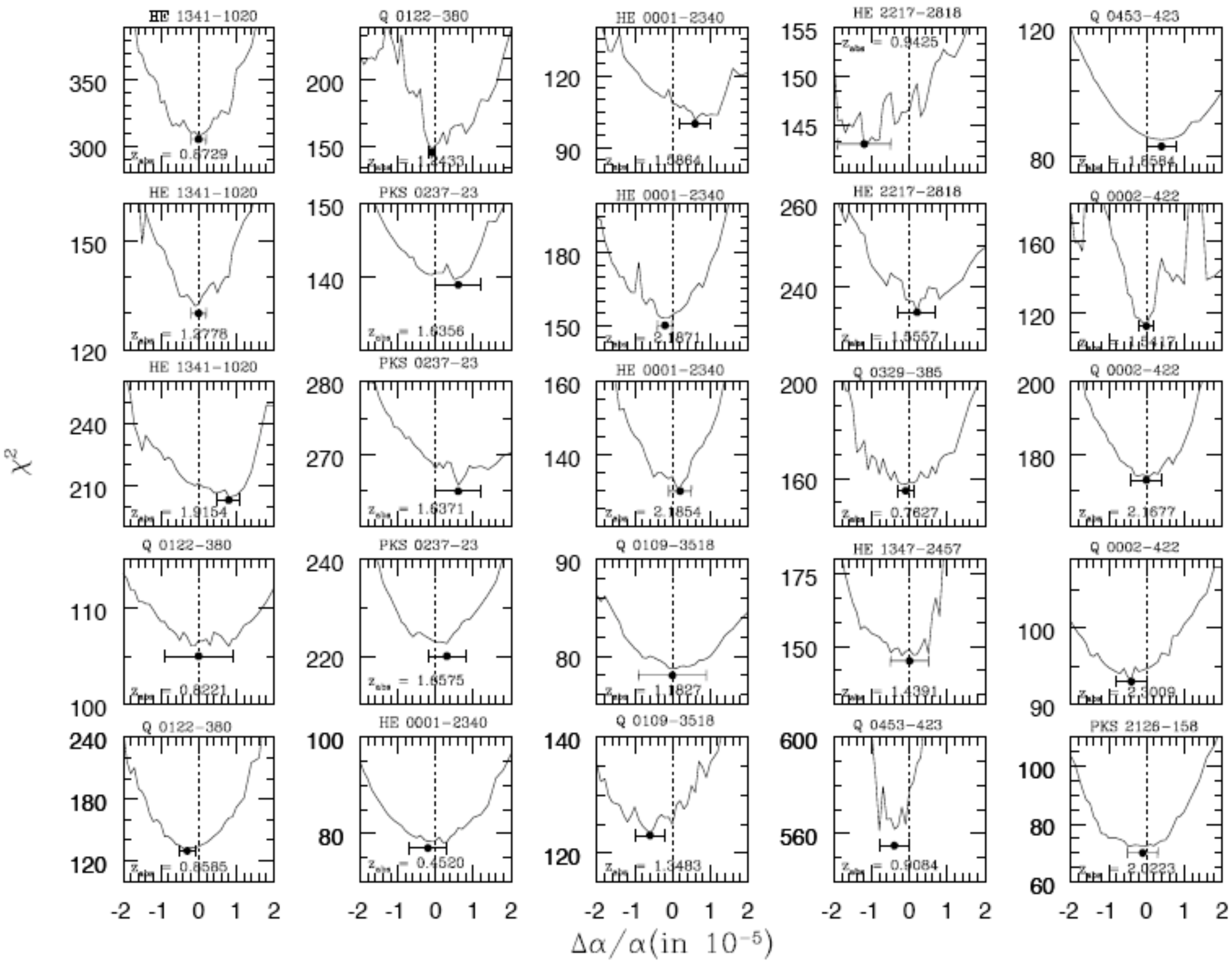
$$\Delta\alpha/\alpha = (-5.7 \pm 1.1) \text{ ppm}$$

$$d\alpha/dt/\alpha = (6.40 \pm 1.35)\ 10^{-16}\ \text{yr}^{-1}$$

Chand, Srianand, Petitjean, & Aracil (2004)



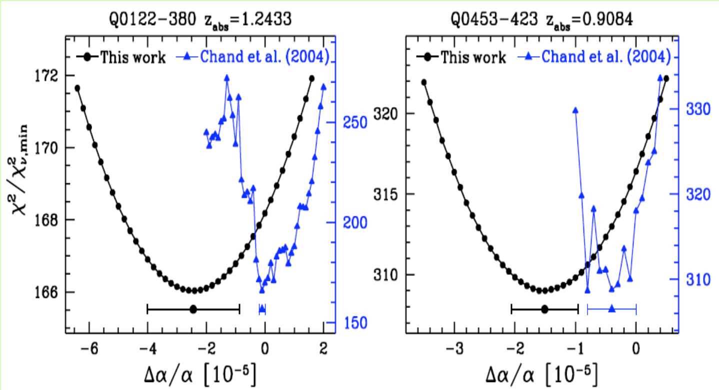
- VLT-UVES 23 systems
- No objects in common with Murphy et al
- Simpler systems (LP: J. Bergeron; not taken for the purpose)
- $\Delta\alpha/\alpha$ = (-0.6 ± 0.6) ppm

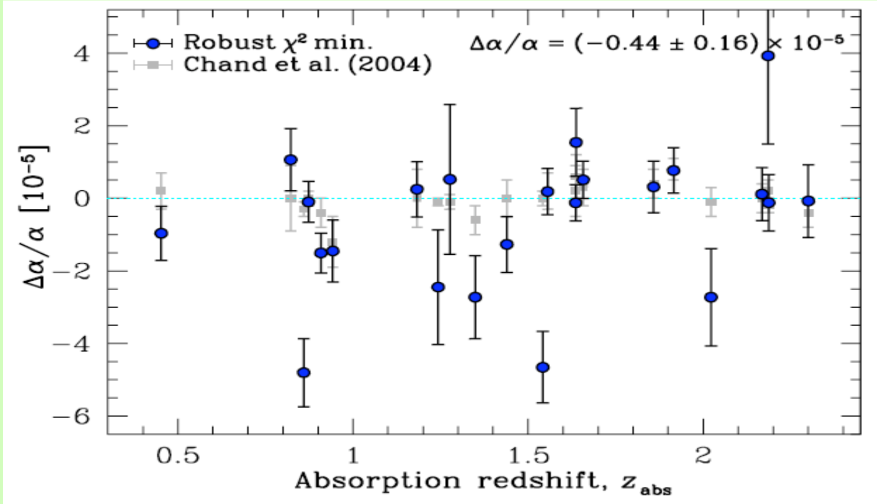

HE 1341−1020
Q 0122−380
HE 0001−2340
HE 2217−2818
Q 0453−423
PKS 0237−23
Q 0002−422
Q 0329−385
Q 0109−3518
HE 1347−2457
PKS 2126−158
χ^2
$\Delta\alpha/\alpha$(in 10^{-5})

The controversy

Revision of VLT/UVES constraints on a varying fine-structure constant

Michael T. Murphy,[1,*] John K. Webb,[2] and Victor V. Flambaum[2]
[1]Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
[2]School of Physics, University of New South Wales, Sydney, NSW 2052, Australia
(Dated: April 27, 2007)

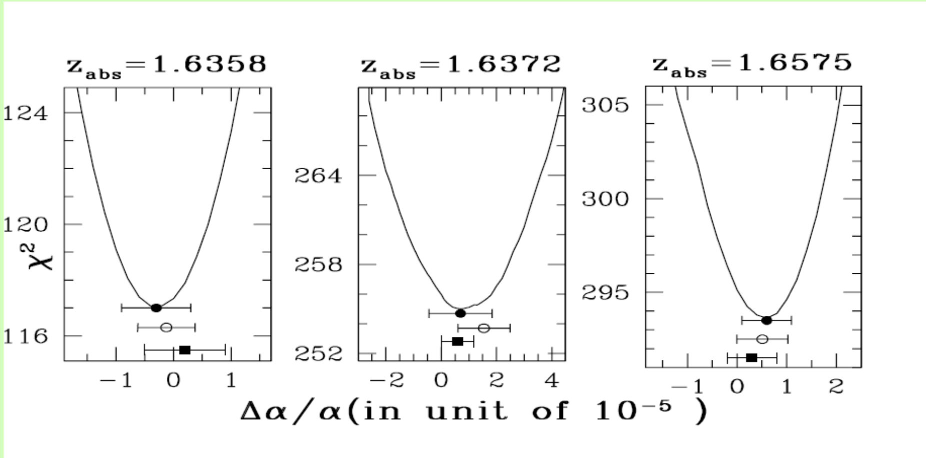




- errors in Chand et al are much larger than claimed
- no clear evidence for variability $\Delta\alpha/\alpha$ = (-4.4 ± 1.6) ppm
- real scatter, or still even larger errors (15 ppm required)?

In response to "the comments by Murphy et al."

–*R. Srianand*[1], *H. Chand*[2], *P. Petitjean*[2] *& B. Aracil*[2]



- Two only systems really deviating (>4σ)
  - Q 0002-422 (-47 ± 9.9) ppm
  - Q 0122-380 (-48 ± 9.4) ppm

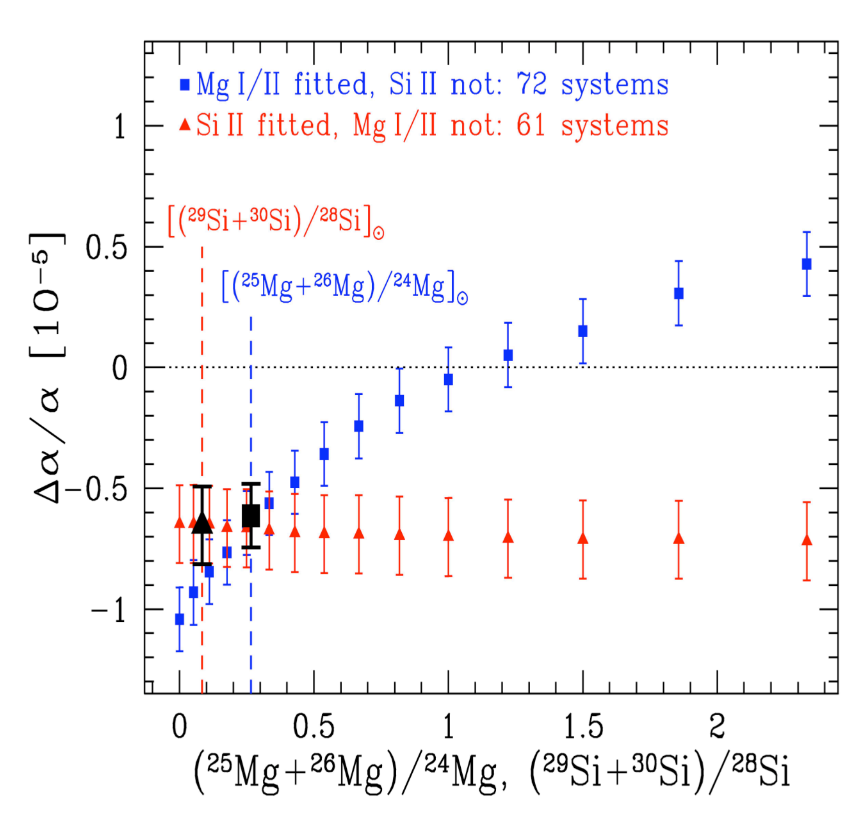
- On 21 objects $\Delta\alpha/\alpha$= (-0.1±1.5) ppm

Open issues: I. Isotopes

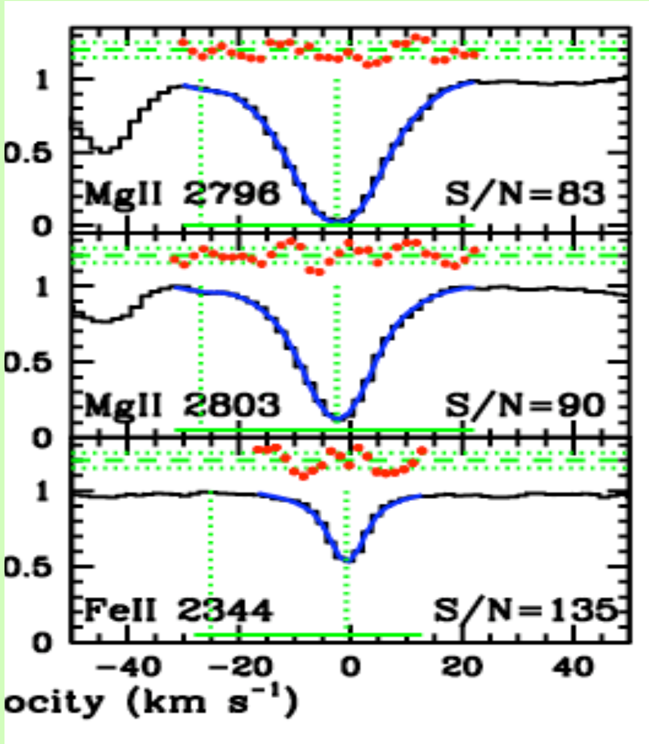
- Isotopes produce small shifts on line positions
- Murphy et al and Chand et al assume solar ratios but very little information on isotopic behaviour.

- Supersolar $^{25,26}Mg/^{24}Mg$: positive variation
- Undersolar $^{25,26}Mg/^{24}Mg$: negative variation
  - Chand et al is consistent with a variation only ^{24}Mg $\Delta\alpha/\alpha=(-3.6 \pm 0.6)$ ppm

- $^{25,26}Mg$ are contributed by Intermediate Mass Stars (4-8 M_{sun})
  - In HE 0515-4414 low ^{13}C ➡ low $^{25,26}Mg/^{24}Mg$ since both ^{13}C and $^{25,26}Mg$ are produced in the HBB AGB (Levshakov et al 05)



II. doppler shifts



CSPA04 $\Delta\alpha/\alpha$=(-2 ±2) ppm
MWF07 $\Delta\alpha/\alpha$=(-12.2 ±5.3) ppm

- Different ions form in different regions which may have slightly different average velocities
- HE 0001-2340 system at z_{abs}=2.187
  - 2 component model
- $FeII_{2344}$-$Mg_{II2796,2803}$
  - Δv=1600±50 m/s
  - $\Delta\alpha/\alpha$= 90±2.8 ppm
- ➔ evidence for doppler shifts between MgII and FeII lines (Mg is an anchor!)
  - This could explain some deviant cases
  - No reason why should produce a negative instead of positive .

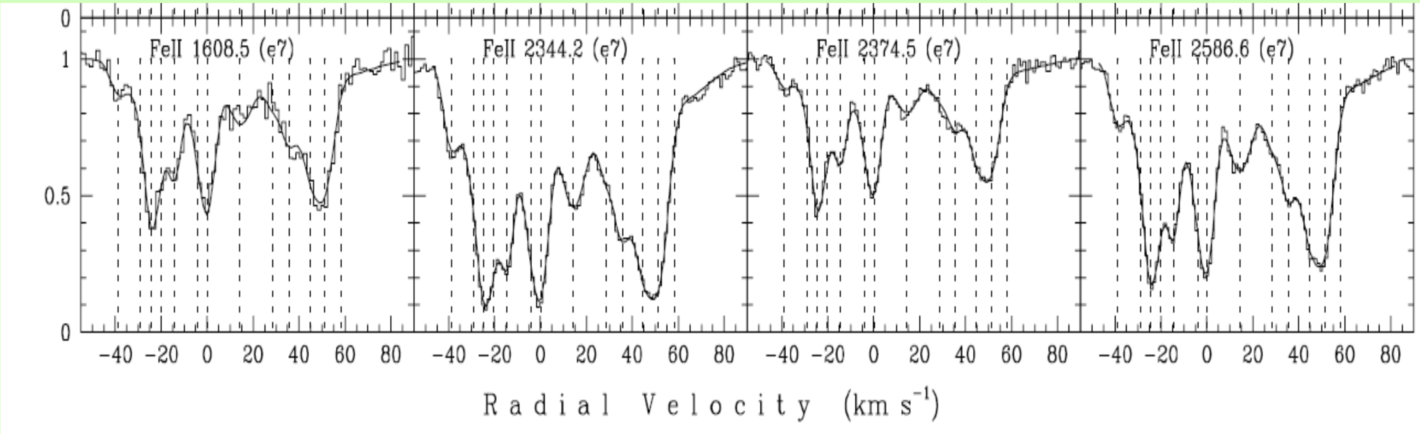
Only FeII

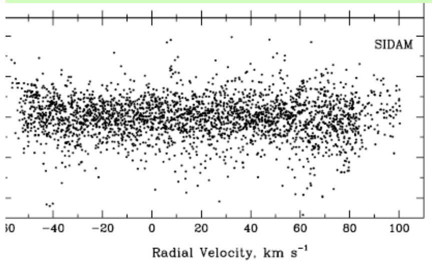
- Why only FeII?
  - Same ion so no photo-ionization structure
  - Fe has small Isotopic shifts
    - 20 m/s in $^{54,56,57,58}Fe$ while 850 m/s for $^{24,25,26}Mg$
      - Mg (79:10:11) isotopic ratio has a complex chemical evolution
      - Fe (5.8:91.8:2.1:0.3)
  - FeII has positive and negative q factors
    - $\Delta Q(Q_{FeII1608}-Q_{FeII})=0.06$ (≈factor 2 higher Mg-Fe pair), partially compensate the loss of other lines,
    - but FeII 1608 line not always available

- Special observational technique
  - Bright QSO high S/N, High Resolution, single observations
  - Attached Th-Ar Temperature and pressure monitoring
    - Δp= 1mb or ΔT=0.3°C ➔ 50 m/s (important in the coaddition)
  - Simple systems: strong but not saturated lines

HE 0515-4414

QSO V = 14.9 , DLA at z_{abs}=1.1 (8 Gyr)

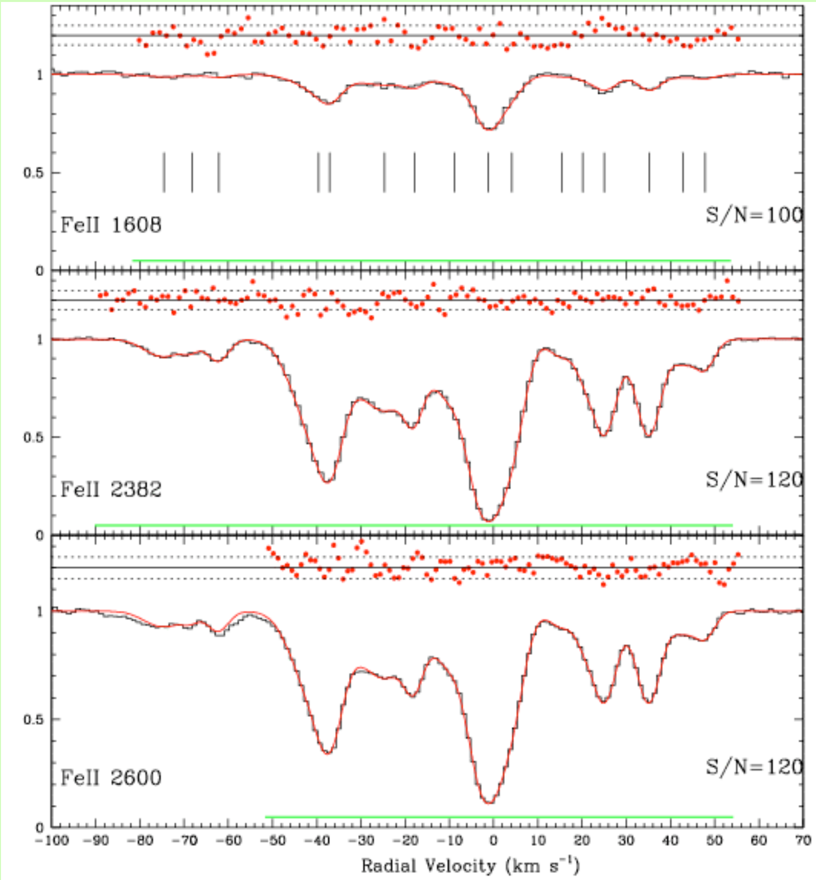




Δα/α (ppm)	source	comments
-0.12±1.8	Levshakov et al 06 Molaro et al 07	UVES data, 6 single exposures,13 comp
-0.4±1.9	Quast et al 04	Same data-coadded diff analysis (8 comp)
0.5±2.4	Chand et al 06	Diff data (HARPS) Diff analy.

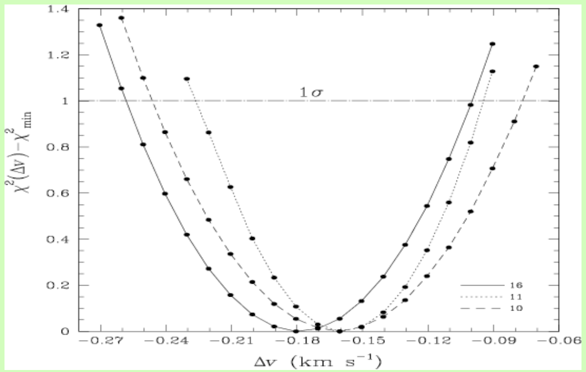
Q1101-264

Levshakov et al 07



- V=16, DLA z_{abs}=1.84
- UVES 15.4 h, R=80000
- 16 component model
  - M = 305 data points, ν=257 degrees of freedom, 47 free fitting parameters χ^2_ν = 0.901

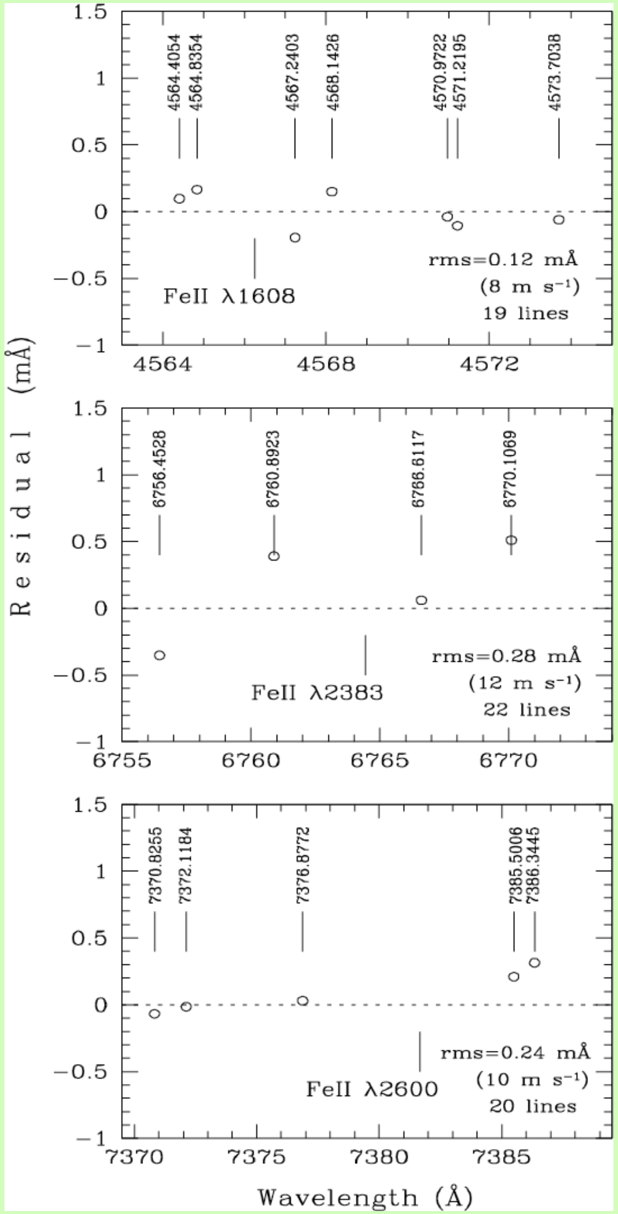
- $\Delta v_{FeII-1608}$=-180 ±85 m s^{-1}
- $\Delta\alpha/\alpha$=(5.4±2.5)ppm



- First project dedicated to α
- ThAr after each exposures. Temperature and pressure monitor
  - ΔT <0.1 K ➔ <15 m/s
  - Δp <0.3 mb ➔ < 10 m/s

- wavelength calibration optimized for the FeII lines.
  - Residuals $\sigma_\lambda \approx 0.2$ mA ➔10-20 m/s

- Test with lines with same q factor
  - $\Delta v(FeII_{2382}-FeII_{2600}) = 20$ m/s

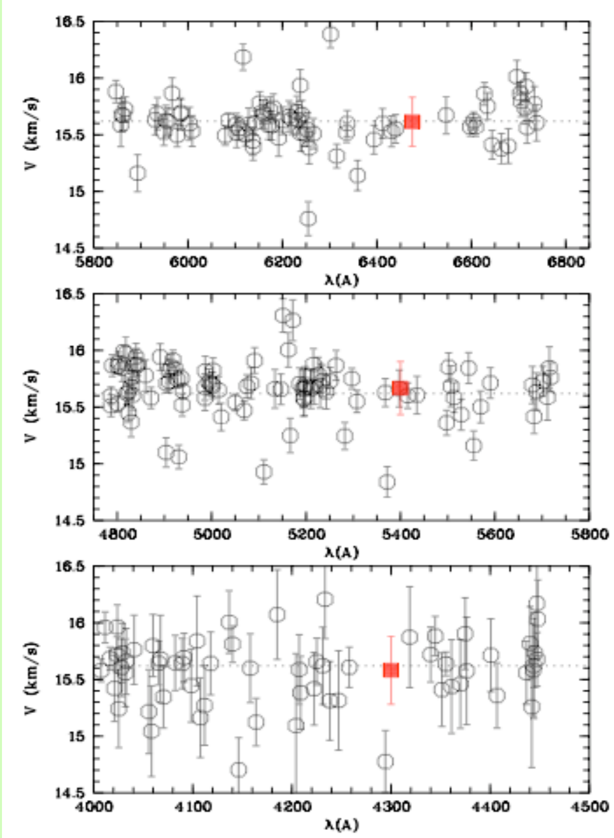


Asteroids to probe systematics

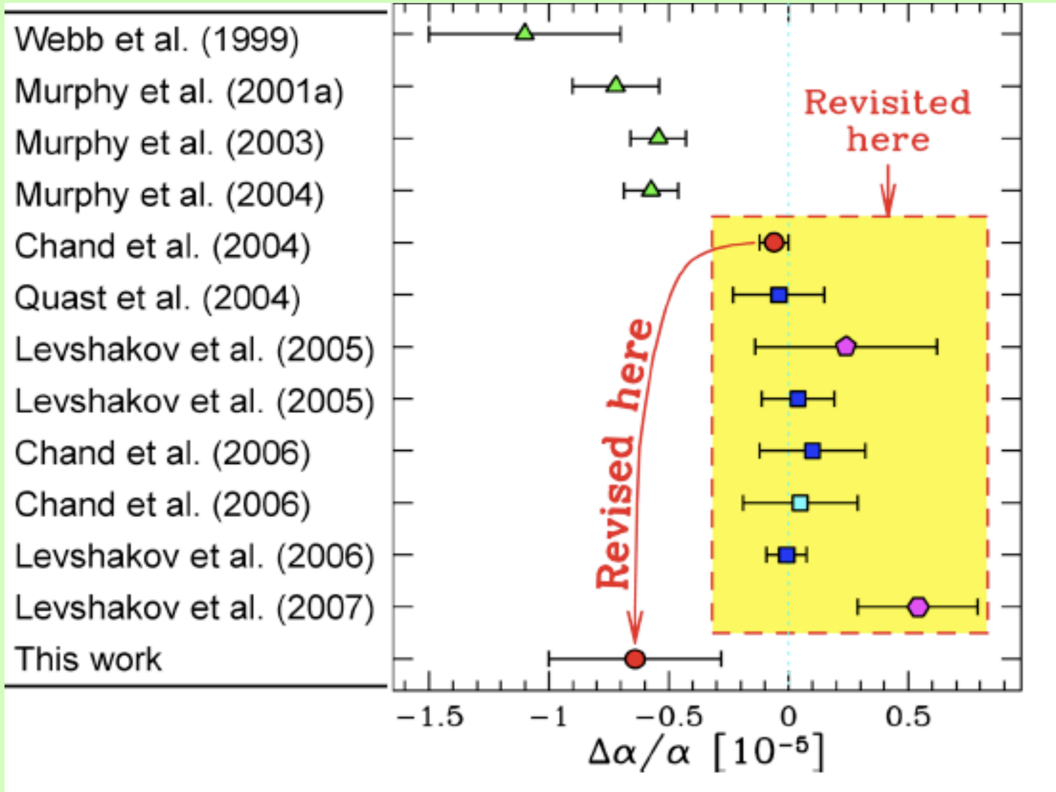
- UVES has 2 arms (and two slits)

- Asteroids best RV standards
  - RV can be predicted better than 1 m/s
  - Probe uneven slit illumination ➔ radial velocity shifts.
  - The light paths of ThAr and source are different
- Iris and Juno observed with VLT in 5 different epoch Dec 2006-Jan 2007

- Optical slits aligned within 50 m/s,
  - this cannot explain the positive positive result (Molaro et al 07)



Summary of α



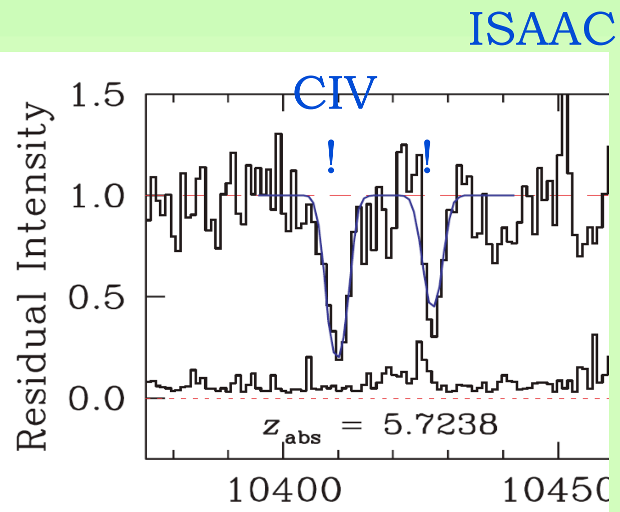
From Murphy et al 08

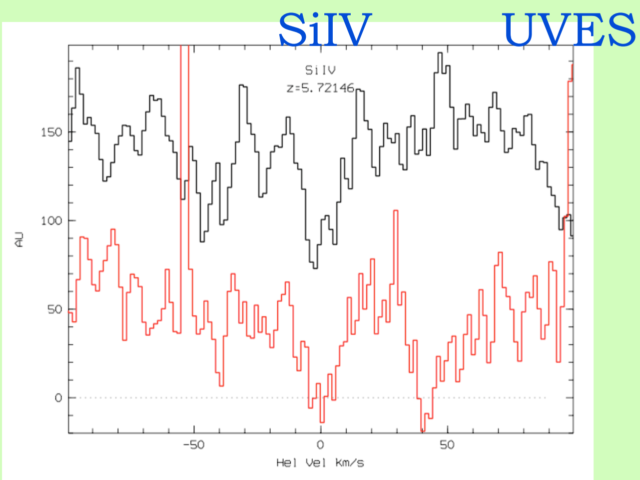
at z=5.7

- SDSS 1030+0524 z=6.28
- z-mag 20.05
- Ryan-Weber et al 07
  - CIV at z=5.7238
  - look-back time of 12.5 Gyr
- UVES 7 exp. 10.5 hours

$$\frac{\Delta\alpha}{\alpha} = \frac{c_r}{2}\left[\frac{(\Delta\lambda/\lambda)_z}{(\Delta\lambda/\lambda)_0} - 1\right]$$

  - AD(SiIV): $\Delta\alpha/\alpha$ = 5± 3x10^{-3}
  - poor but about better than CMB, (Molaro et al 2008 in prep)





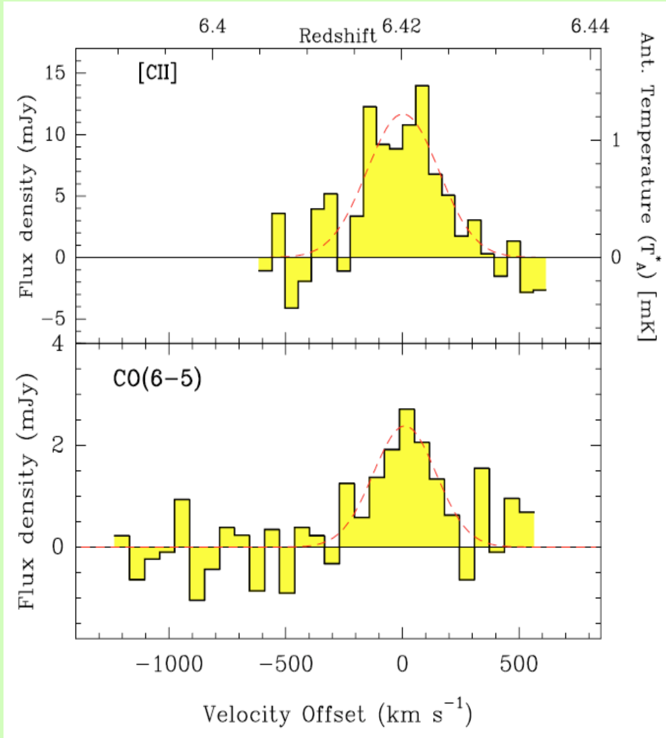
at z=6.46

A new approach for testing variations of fundamental constants over cosmic epochs using FIR fine-structure lines

S. A. Levshakov[1*], D. Reimers[1], M. G. Kozlov[2,1], S. G. Porsev[2,1], and P. Molaro[3]

- Emission lines important for z>6
- IR fine structure lines very sensitive to α:
  - the FS E is a considerable fraction of the total transition E
- QSO J1148+5251
  - [CII] -CO detected at z=6.46 look-back time=12.9
  - $F=\alpha^2/\mu$
  - $\Delta F/F=(0.1\pm1)\times10^{-4}$
- similar limit BR 1202-0725 at z=4.7

Maiolino et al 04



Far IR doublets

- Kozlov, Porsev, Levshakov, Reimers, Molaro ‘08

Computed in a semianalytical way

Atom/Ion	Transition a				Transition b				ω_b/ω_a	$\Delta Q =$
	(J_a, J'_a)	λ_a (μm)	ω_a (cm^{-1})	T_{ex} (K)	(J_b, J'_b)	λ_b (μm)	ω_b (cm^{-1})	T_{ex} (K)		$Q_b -$
C I	(1,0)	609.1	16.40	24	(2,1)	370.4	27.00	63	1.646	−0.0
Si I	(1,0)	129.7	77.11	111	(2,1)	68.5	146.05	321	1.894	−0.0
S I	(0,1)	56.3	177.59	825	(1,2)	25.3	396.06	570	2.230	0.1
Ti I	(2,3)	58.8	170.13	245	(3,4)	46.1	216.74	557	1.274	−0.0
Fe I	(2,3)	34.7	288.07	1013	(3,4)	24.0	415.93	599	1.444	0.0
	(1,2)	54.3	184.13	1278	(2,3)	34.7	288.07	1013	1.565	0.0
	(0,1)	111.2	89.94	1407	(1,2)	54.3	184.13	1278	2.048	0.0
N II	(1,0)	205.3	48.70	70	(2,1)	121.8	82.10	188	1.686	−0.0
Fe II	(5/2,7/2)	35.3	282.89	961	(7/2,9/2)	26.0	384.79	554	1.360	0.0
	(3/2,5/2)	51.3	194.93	1241	(5/2,7/2)	35.3	282.89	961	1.451	0.0
	(1/2,3/2)	87.4	114.44	1406	(3/2,5/2)	51.3	194.93	1241	1.703	0.0
O III	(1,0)	88.4	113.18	163	(2,1)	51.8	193.00	441	1.705	−0.0
S III	(1,0)	33.5	298.69	430	(2,1)	18.7	534.39	1199	1.789	−0.1
Ar III	(0,1)	21.9	458.05	2259	(1,2)	9.0	1112.18	1600	2.428	0.2
Fe III	(2,3)	33.0	302.7	1063	(3,4)	22.9	436.2	628	1.441	0.0
	(1,2)	51.7	193.5	1342	(2,3)	33.0	302.7	1063	1.564	0.0
	(0,1)	105.4	94.9	1478	(1,2)	51.7	193.5	1342	2.039	0.0
Mg V	(0,1)	13.5	738.7	3628	(1,2)	5.6	1783.1	2566	2.414	0.2
Ca V	(0,1)	11.5	870.9	4713	(1,2)	4.2	2404.7	3460	2.761	0.3
Na VI	(1,0)	14.3	698	1004	(2,1)	8.6	1161	2675	1.663	−0.1
Fe VI	(5/2,3/2)	19.6	511.3	736	(7/2,5/2)	14.8	677.0	1710	1.324	−0.0
	(7/2,5/2)	14.8	677.0	1710	(9/2,7/2)	12.3	812.3	2879	1.200	−0.0
Mg VII	(1,0)	9.0	1107	1593	(2,1)	5.5	1817	4207	1.641	−0.1
Si VII	(0,1)	6.5	1535	8007	(1,2)	2.5	4030	5817	2.625	0.3
Ca VII	(1,0)	6.2	1624.9	2338	(2,1)	4.1	2446.5	5858	1.506	−0.2
Fe VII	(3,2)	9.5	1051.5	1513	(4,3)	7.8	1280.0	3354	1.217	−0.0
Si IX	(1,0)	3.9	2545.0	3662	(2,1)	2.6	3869	9229	1.520	−0.2

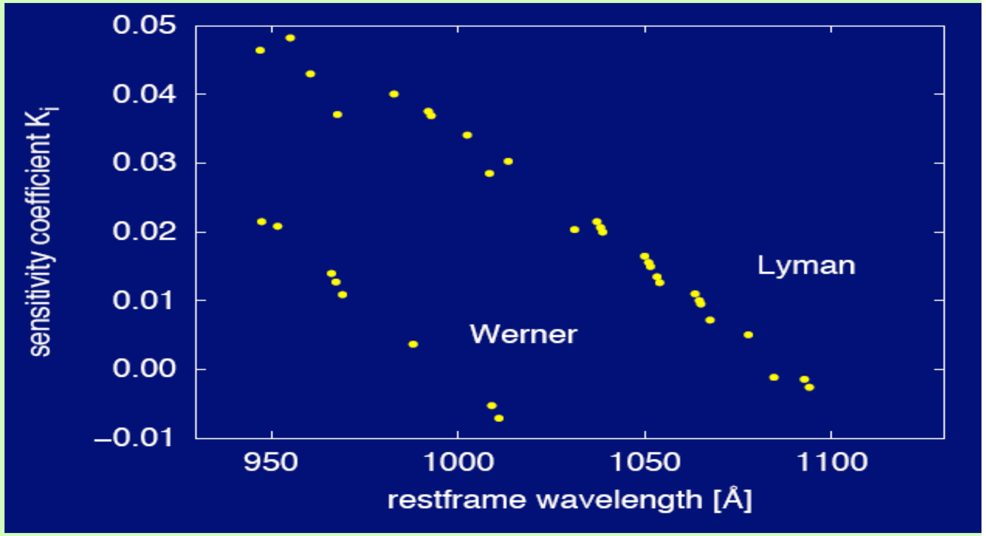
–targets for HERCHEL & ALMA

$$\mu = m_p / m_e$$

The H_2 method

- μ_0=1836.15267261(85) (Mohr & Taylor 2005)
- From molecular hydrogen H_2 (Thompson 1975)
  - electron-vibro-rotational transitions depend on reduced mass of molecule

$$\nu \simeq E_I \left(c_{\text{elec}} + c_{\text{vib}}/\sqrt{\mu} + c_{\text{rot}}/\mu\right)$$

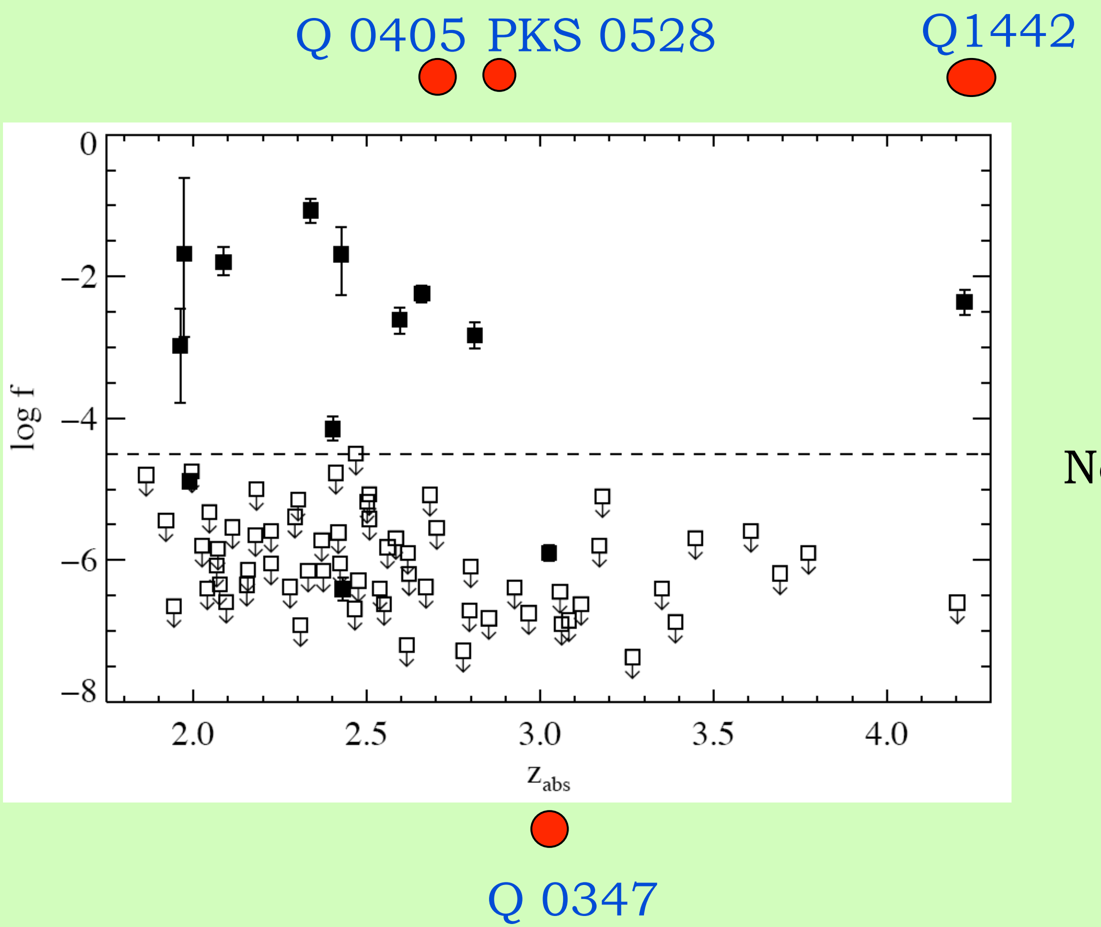


$$\lambda_{obs} = \lambda_{rest}(1+z_{abs})(1+K_i\,\Delta\mu/\mu)$$

$$K_i = -\frac{\mu_n}{\lambda_i}\frac{\mathrm{d}\lambda_i}{\mathrm{d}\mu_n} = \frac{1}{E_e - E_g}\left(-\frac{\mu_n \mathrm{d}E_e}{\mathrm{d}\mu_n} + \frac{\mu_n \mathrm{d}E_g}{\mathrm{d}\mu_n}\right)$$

$$z_i = z_{abs} + bK_i$$

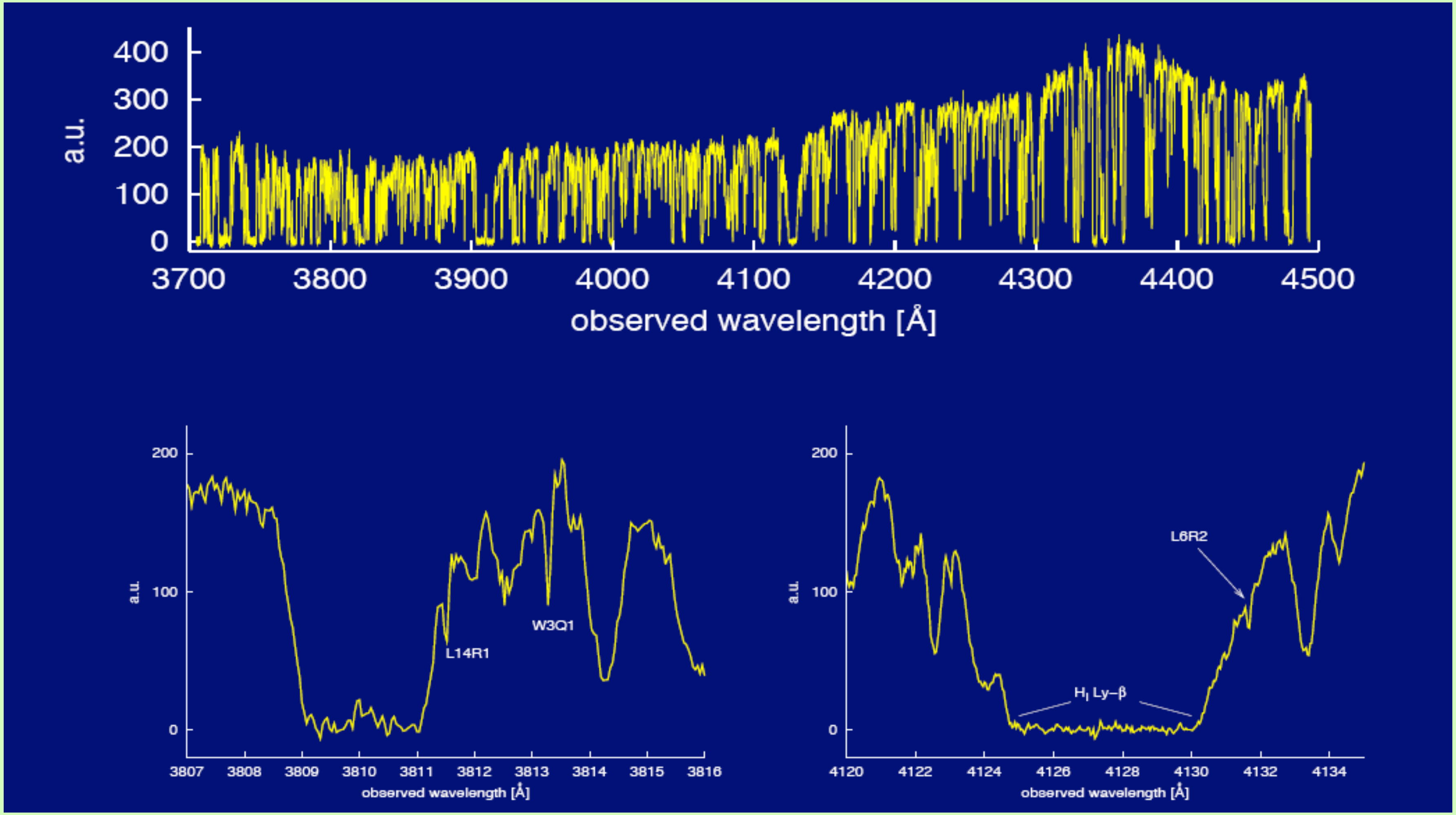
$$b = (1+z_{abs})\,\Delta\mu/\mu$$



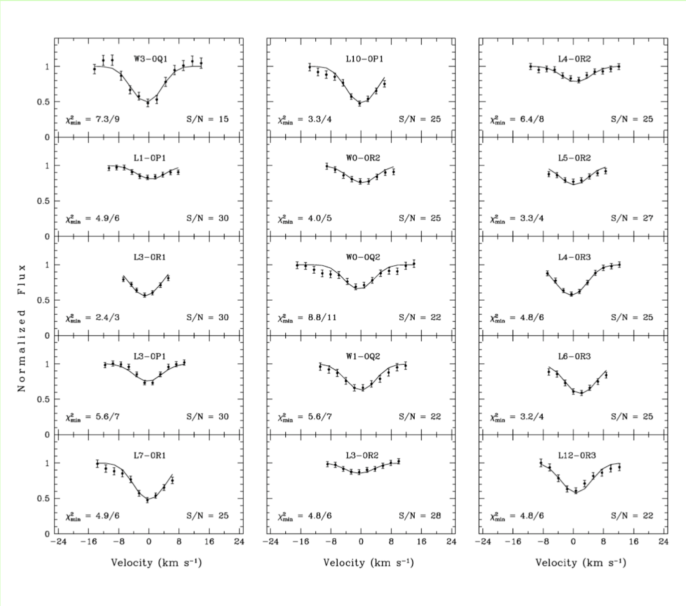
Noterdaeme et al 08

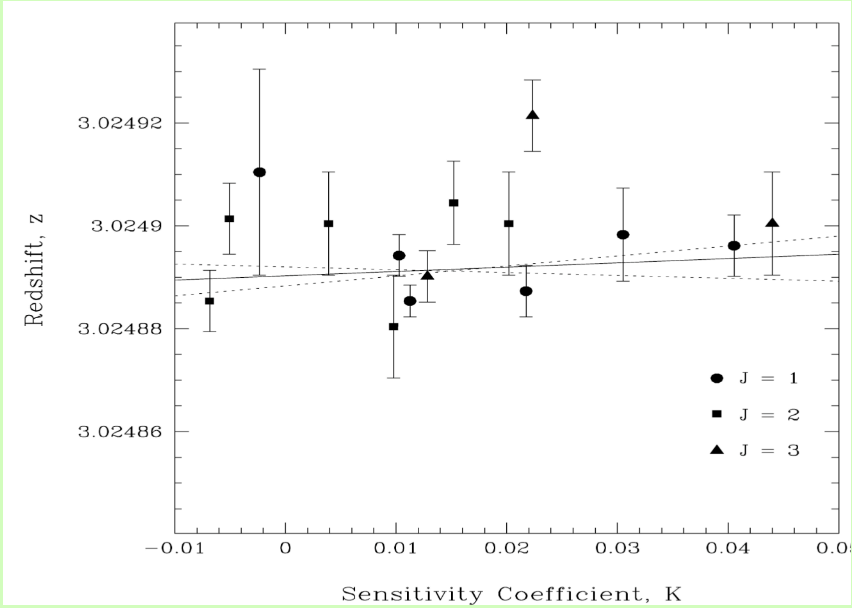
- H_2 in (few) DLA
  - lines in the UV ~ 950-1050 A, in Lyα forest, z_{abs}>2.5.
- Only 3
  - PKS 0528 z=2.8 Varshalovich Levshakov (1993)
  - Q 0347-383 Levshakov et al 2002,
  - Q 0347-383 and Q 0405-443 Ivanchick et al 2005, Reinhold et al 2006

Q 0347-383


a.u.
400
300
200
100
0
3700
3800
3900
4000
4100
4200
4300
4400
4500
observed wavelength [Å]
a.u.
200
100
0
3807
3808
3809
3810
3811
3812
3813
3814
3815
3816
observed wavelength [Å]
L14R1
W3Q1
a.u.
200
100
0
4120
4122
4124
4126
4128
4130
4132
4134
observed wavelength [Å]
L6R2
H I Ly-β

Q0347-383



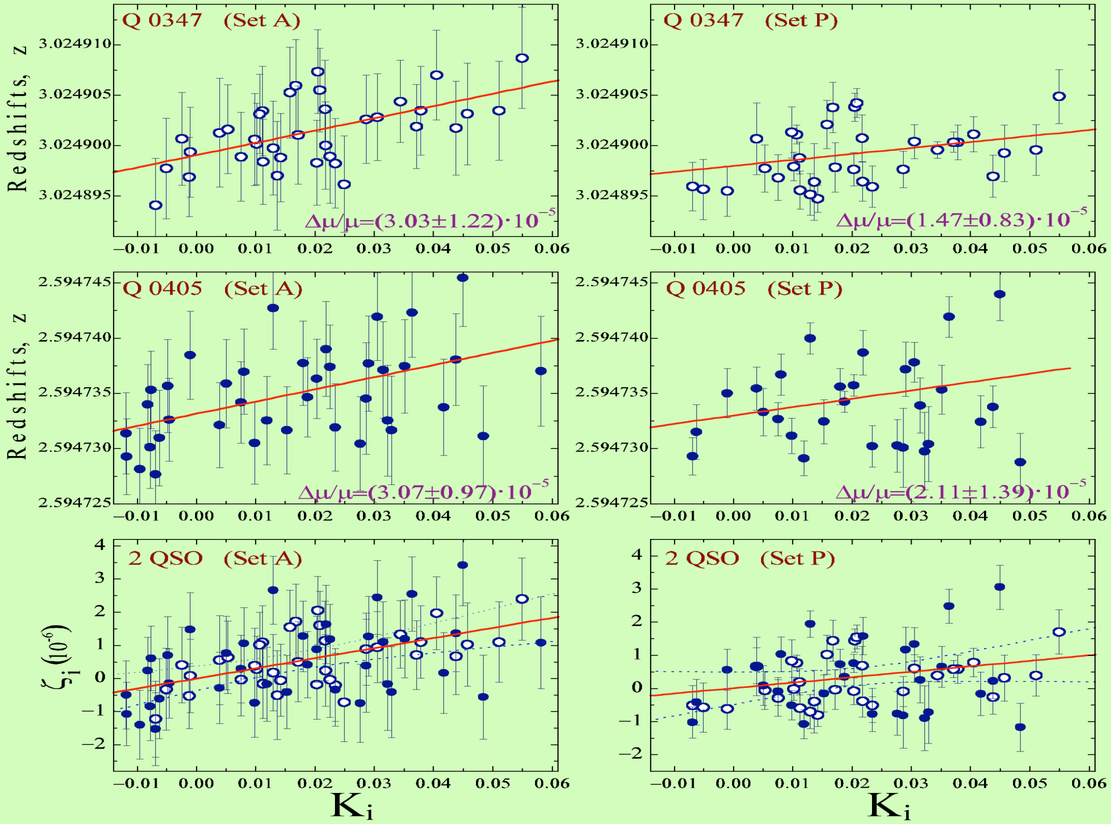


- Levshakov, Dessauges-Zavadsky, D'Odorico, Molaro (2002)
  - first UVES analysis of μ
  - $\Delta\mu/\mu=(2.1\pm 3.6)\times 10^{-5}$

Q 0347-383 & Q 0405-443

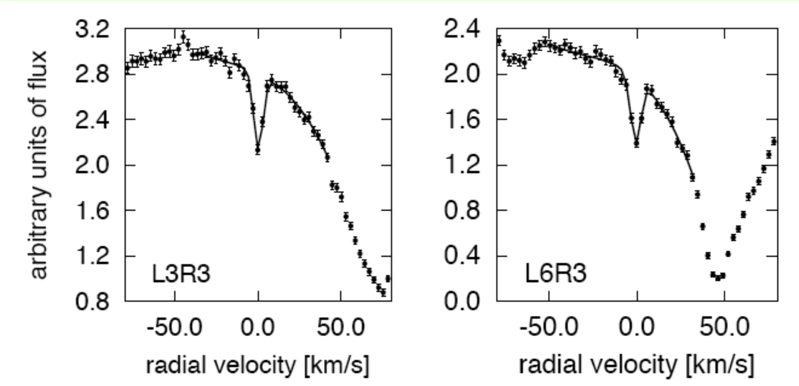
Reinhold et al 06

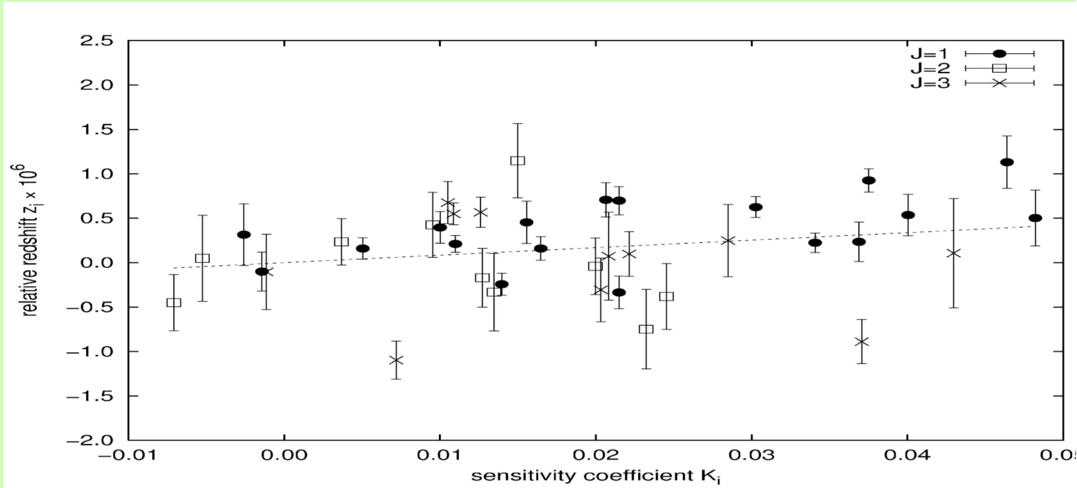
- Several improvements:
  - New observations
  - New accurate H_2 laboratory wavelengths
  - New K coefficients



$\Delta\mu/\mu = (+24 \pm 6)$ ppm weighted fit

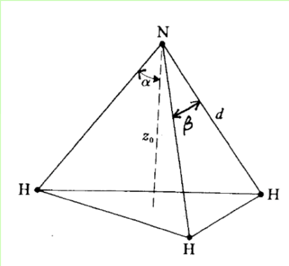
New analysis of Q0347-383

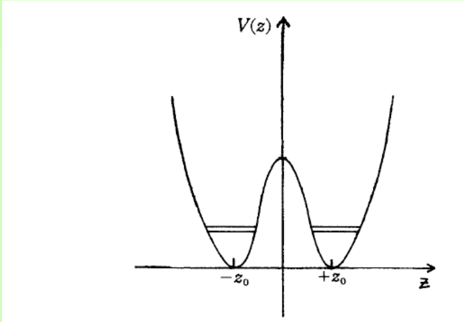




- M. Wendt D. Reimers (08)
  - Same data but different method of measuring the line position
  - Similar trend but correlation only for first rotational level J=1
  - Correlation induced by 7 lines of high vibrational levels
  - Goodnes of fit indicates errors underestimated
  - Lower significance of the correlation:
    - $\Delta\mu/\mu$= 21 ± 14 ppm (20 ± 6 ppm Reinhold et al 2008)

Ammonia NH_3





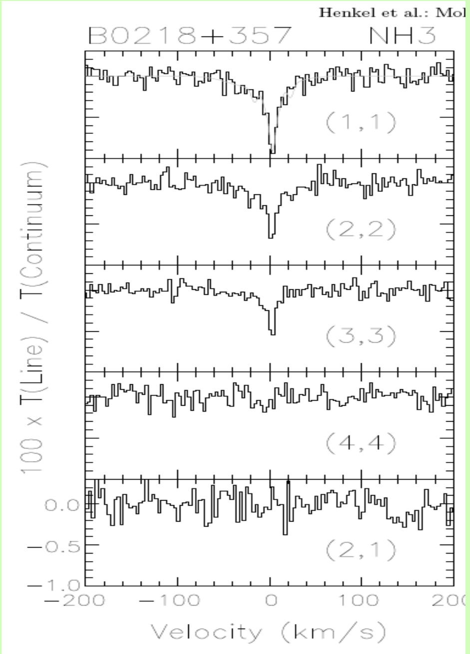
Double-well potential experienced by nitrogen atom; equilibri

- Due to the tunnelling effect the inversion spectrum is one order of magnitude more sensitive to μ (Flambaum Kozlov 2007)
- NH_3 pyramidal shape

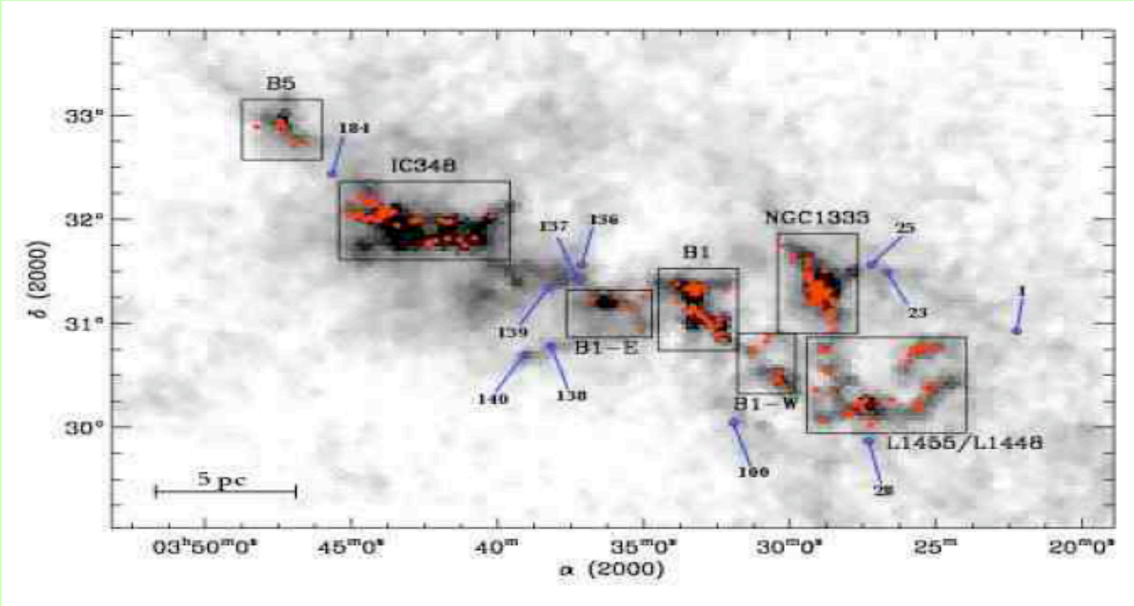
$$\Delta\omega/\omega=-4.46\ \Delta\mu/\mu$$

- B 0218+357 z=0.68
  - NH_3 (Henkel et al 2005)
  - CO, HCN,HCO^+ provide the reshift
  - $\Delta\mu/\mu$=(0.6 ±1.9) ppm

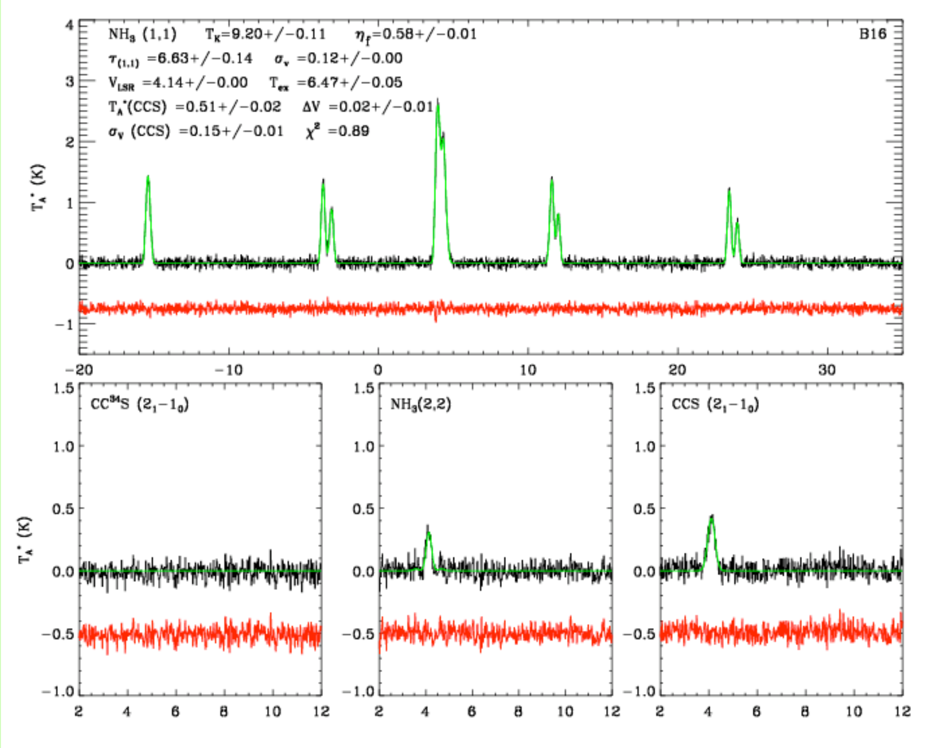
    one magnitude smaller than H_2!

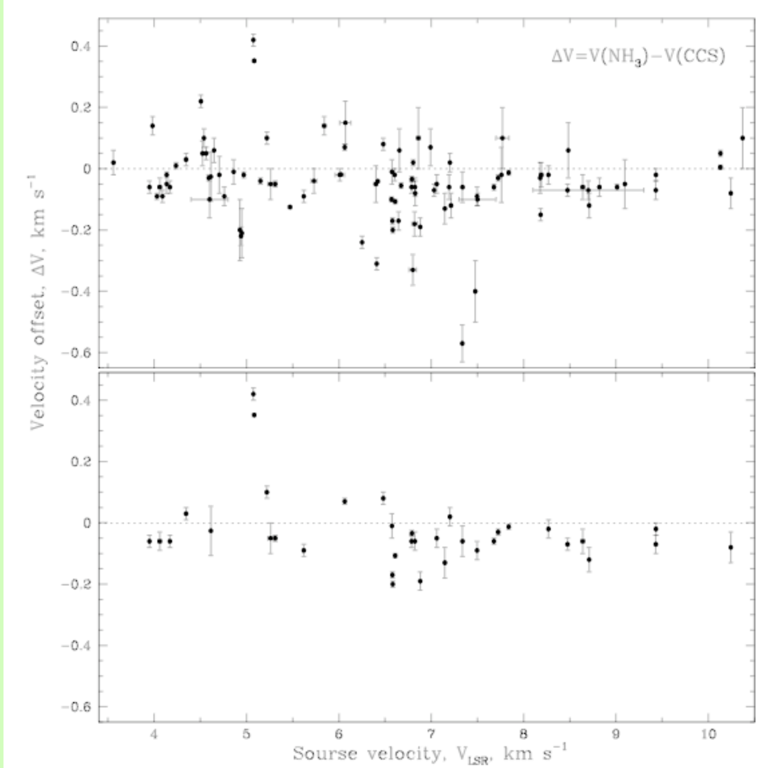


Perseus Molecular Cloud



- Star forming cores
- NH_3 & CCS detected on 96 dense cores 100m Green Bank Telescope (Rosolowsky et al 2008)
  - T=11 K
  - Narrow cores σ_v=70 m/s
  - D=1000 ly





- For 34 cores for which $0.55b_{NH3} <= b_{CCS} <= b_{(NH3)}$
- $\Delta Vr_{(NH3\text{-}CCS)}$=-16±13 m/s
  - ≈ wave accuracy of C_2S is 10 m/s
  - $\Delta\mu/\mu$ = -0.015± 0.012 ppm !!!

(Levshakov, Kozlov Molaro 2008 in prep)

Infrared Dark Clouds

Sakai et al 2008 Nobeyama R. O. 45m

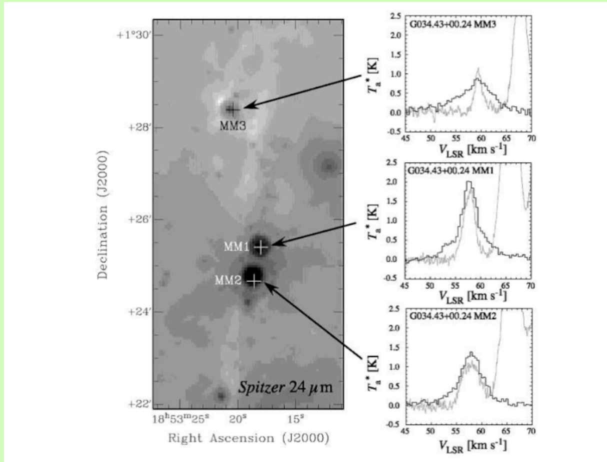


Fig. 9.— Spitzer 24 μm image toward G034.43+00.24 (left), and spectra of the CH_3OH $J_K=7_0$–6_0 A^+ (black) and N_2H^+ J=1–0 F_1=0–1 F=1–2 lines (gray) toward G034.43+00.24 MM1, MM2 and MM3 (right).

- Infrared Dark Clouds starless in the early stage of high mass star formation;
- M about 10^3 solar masses
  - 7 pairs $NH_3(1,1)$ & N_2H^+ $\Delta\mu/\mu$ = 0.03 ± 0.13 ppm
  - 8 pairs $NH_3(1,1)$ & HC_3N $\Delta\mu/\mu$ = -0.07 ± 0.04 ppm
- Distance up to 2 10^4 ly ⇒ 4×10^{-12} yr^{-1}

μ controversy

$\Delta\mu/\mu$ (ppm)	source	N.	redshift	Method
24 ± 6	Reinhold et al 06	2	z=2.5 z=3.0	H_2
21 ± 14	Wendt Reimers al 08	1	z=3.0	H_2
0.6 ±1.9	Flambaum Kozlov 07	1	z=0.8	NH_3-CO
0.015±0.030	Levshakov et al 08	96	z=0	NH_3-C_2S
0.03±0.13	Levshakov et al 08	15	z=0	NH_3-N_2H^+ NH_3-HC_3N

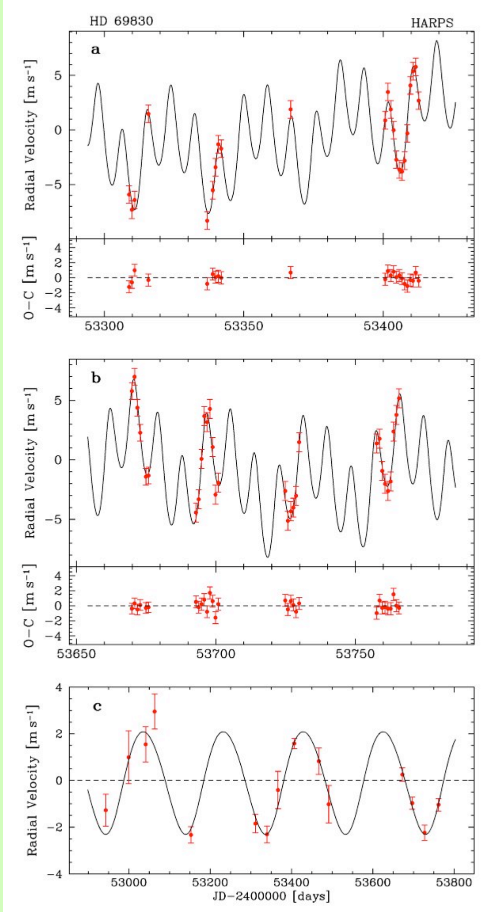
Would you like an ESPRESSO?

Echelle Spectrograph for PREcision
Super Stable Observations

The HARPS heritage

Vacuum Tank , No moving parts, Mechanical stable
Controlled environment, Simultaneous Calibration
Fibre Fed , Fibre Scrambling

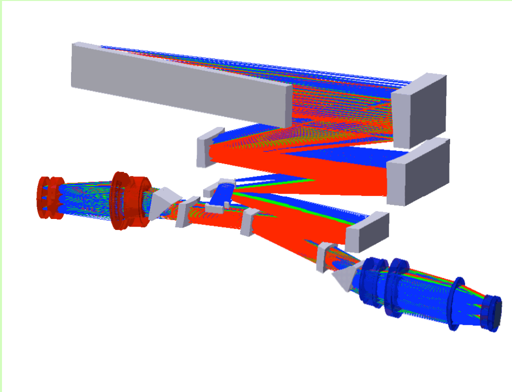
Lovis et al. 2006, 60 cm/sec



- $\Delta\alpha/\alpha$ or $\Delta\mu/\mu$ are differences of measured wavelengths (like planets but with few lines)

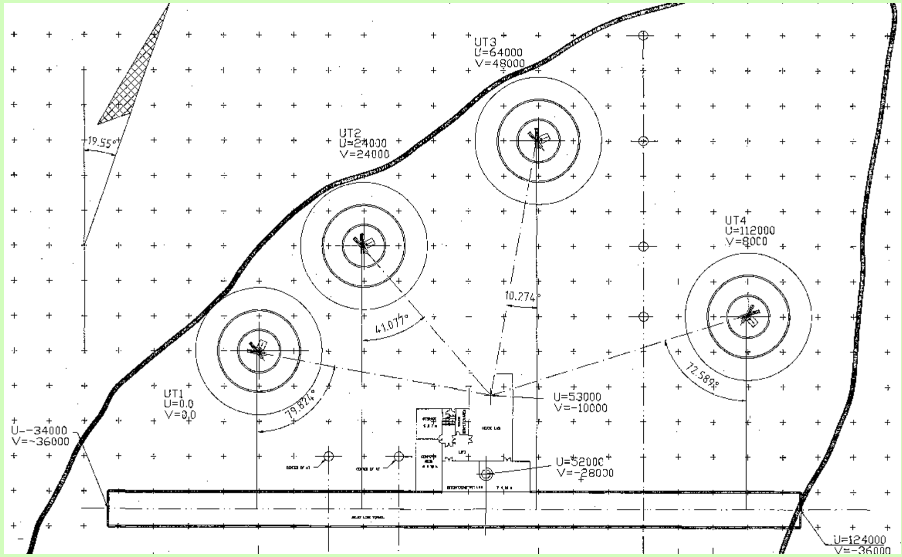
- Precision: σ_λ scales with $(S/N)^{-1}$ and with $(\Delta\lambda)^{3/2}$ ($\Delta\lambda$ pixel size) till metal lines (b=1-2 km/s) are resolved.

  – photons and resolution

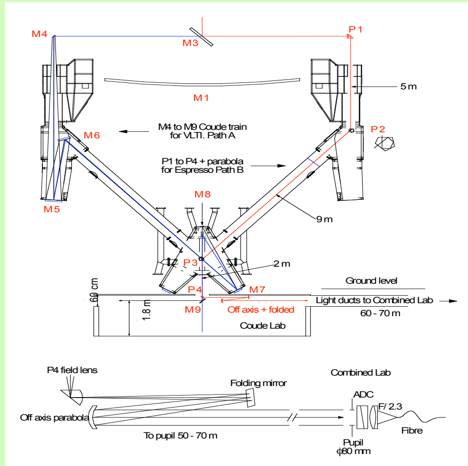


- ESPRESSO Concept
  - Super-HARPS at 1UT
  - Super UVES at 4UT
  - R=160000, 80000, 45000 at 1,2, 4 UTs
  - stability, vacuum and thermal control,
  - fiber-slit: telescope delivers pointing accuracy of ~0.05 arcsec. At R = 150,000 this corresponds to 100 m/s

The 4 VLT Telescopes
and the
Incoherent Combined Laboratory



Distances to Combined Lab
UT 1 – 69 m
UT 2 – 48
UT 3 – 63
UT 4 – 63



Who is ESPRESSO

ESO

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

Observatoire Geneve :

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

INAF-Trieste:

P. Bonifacio, S. Cristiani, P. diMarcantonio, V. D'Odorico, P. Molaro,
P. Santin, E. Vanzella, M. Viel

Institute of Astronomy Cambridge:

B. Carswell, M. Haehnelt, M. Murphy,

Instituto de Astrofisica Canarias:

R. Garcia-Lopez, R. Rebolo, M.R. Zapatero

Others:

F. Bouchy (Marseille), S. Borgani (Daut-Ts), A. Grazian (Roma), S. Levshakov (St-Petersburg), N. Santos (Porto), S. Zucker (Tel Aviv), P. Spano', F. Zerbi (INAF-Merate)

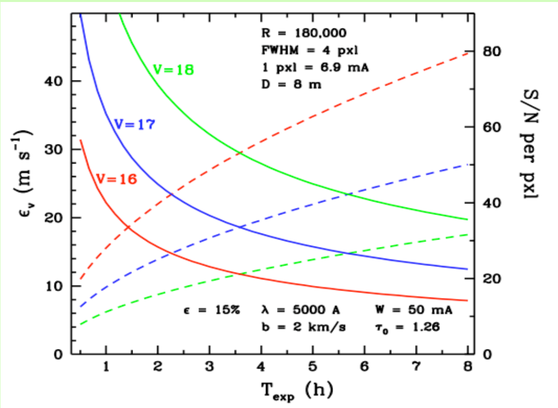
ESO: said yes!

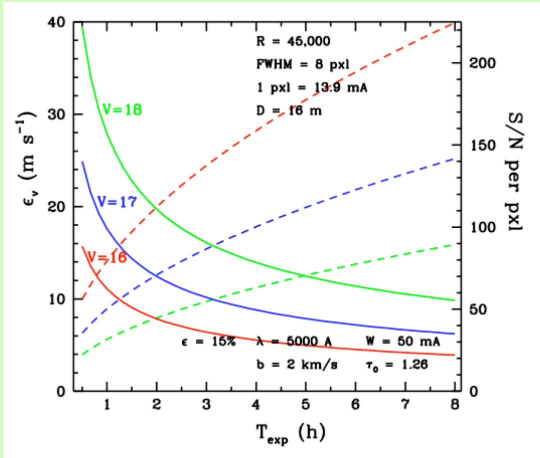
- ESO Council Dec 2007 decided to go
- 19 March 2008: call for the construction of a High Resolution, Ultra Stable Spectrograph at the incoherent combined focus of the ESO VLT

- Scientific goals:
  - Measure high precision radial velocity for search for rocky planets
  - Measure of variation of physical constants
  - Analysis of chemical composition of stars in nearby galaxies

- Instrument specifications
  - 3. Long Term radial Velocity Accuracy: 10 cm/sec (1UT) lower for 4UT
  - Resolving Power: > 120000 for 1UT mode, lower resolution in 4 UT
- Time schedule: 2014 start operations!

ESPRESSO promise

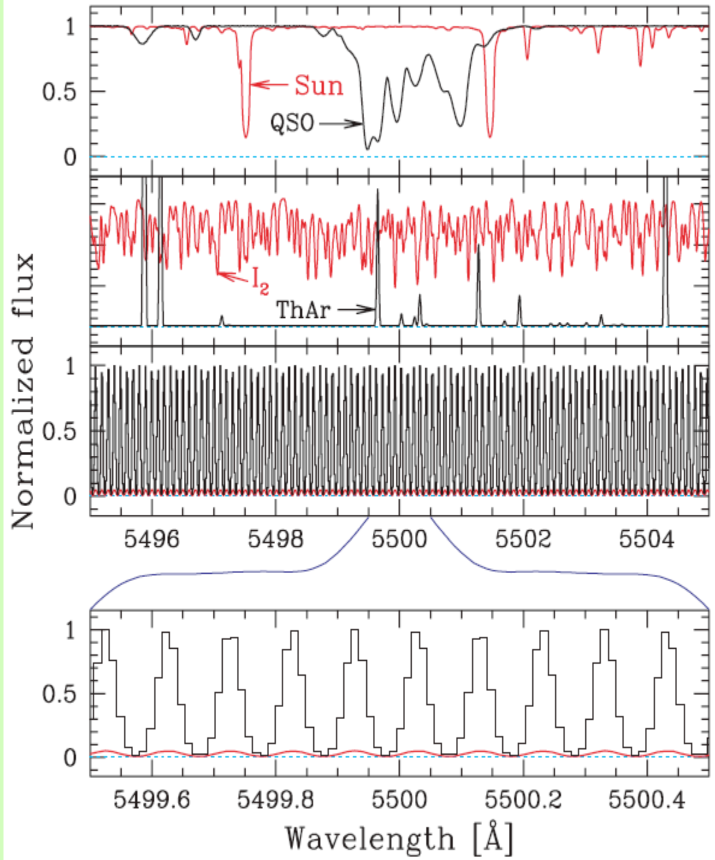




- ESPRESSO is an ideal instrument: (Resolution-photons-stability)
- $\sigma_v \sim 15$ m s^{-1} possible!! → $\sigma_{\Delta\alpha/\alpha} \sim$ 0.5 ppm for $\Delta\alpha/\alpha$
  - a factor 10 better on average! Controversy resolved!
  - but a new wavelength calibration technique required $\sigma_v < 1$ ms^{-1} (Laser Comb)

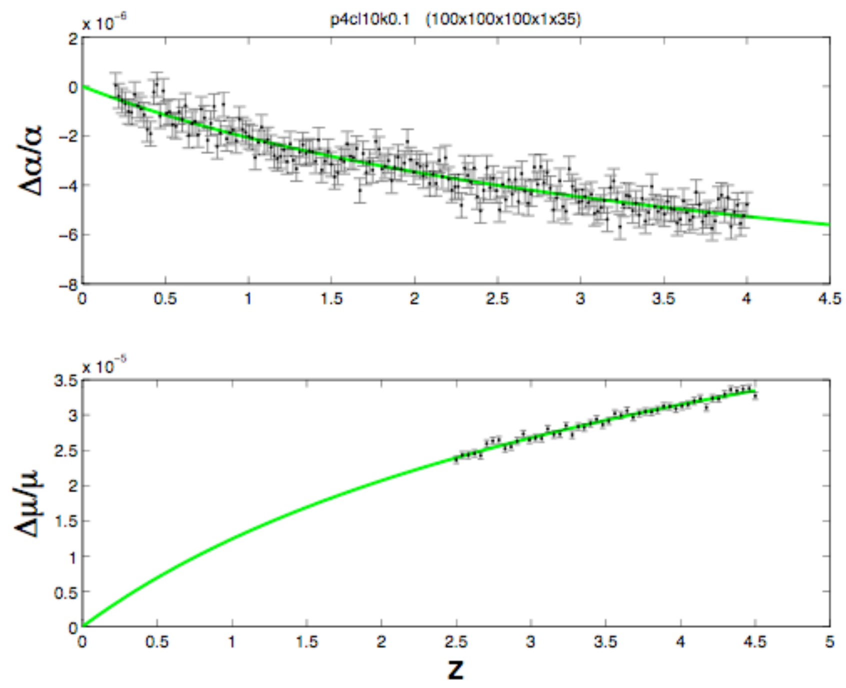
Laser Comb

- ThAr present precision 15 m/s
  - Limitation of 1 ppm (MgII-FeII) in $\Delta\alpha/\alpha$
- System pursued for ESPRESSO is a frequency comb
  - Optical or NIR laser producing a train of femptoseconds pulses (controlled by an atomic clock)
  - Produces a spectrum of evenly spaces delta-functions whose positions are known very precisely
- Prototype under construction at ESO



Simulation with espresso

- Varying constants can be used to infer the evolution of the scalar field and of $w = p/\rho$ (Avelino Martins Nunes Olive 2006 astroph/0605690)



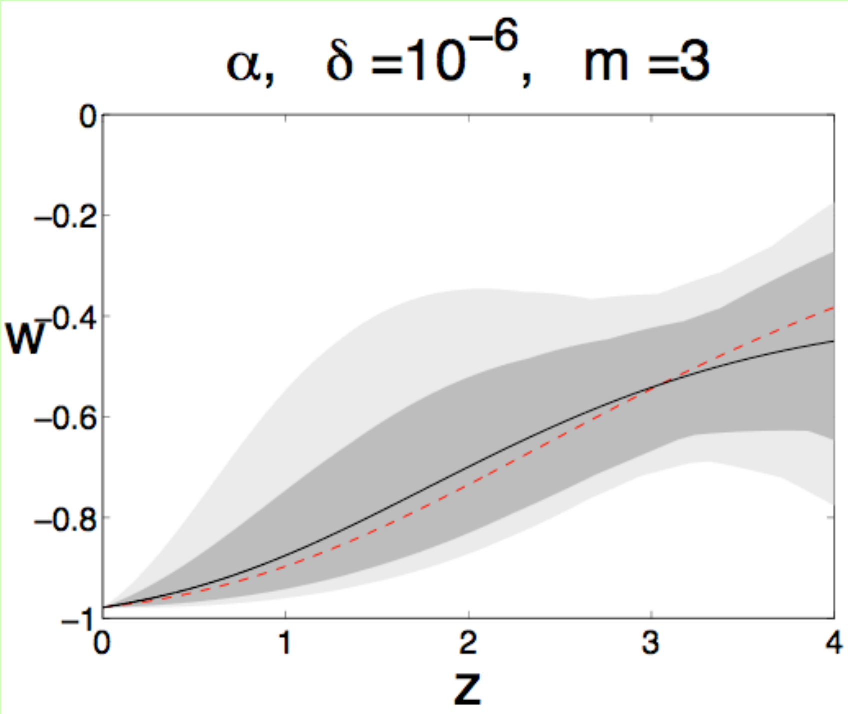
- Monte Carlo data based on redshift dependence of the scalar potential.

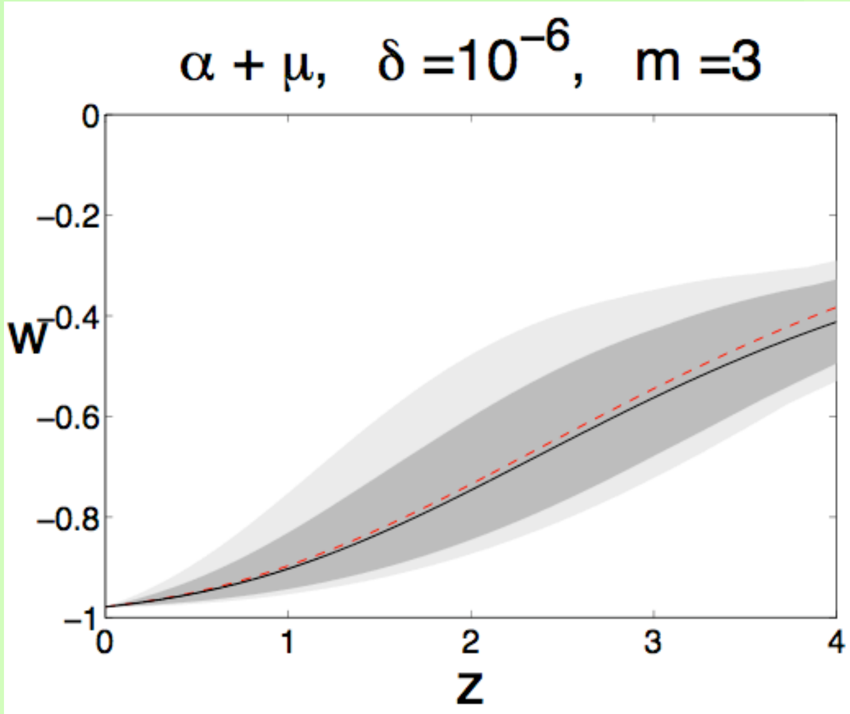
- Sample size: 200 for α and 50 for μ
  - ESPRESSO data errors of 0.5 ppm for α and μ.
  - Assumed Variation:
  - $\Delta\alpha/\alpha$ =-5 ppm at z=3 (Murphy et al)
  - assuming R= $\Delta\alpha/\Delta\mu$ = -6

- Scalar potential which account for the observed accelerated expansion:

  $V(\phi) = V_0(\exp(10k\phi) + \exp(0.1k\phi))$

reconstruction





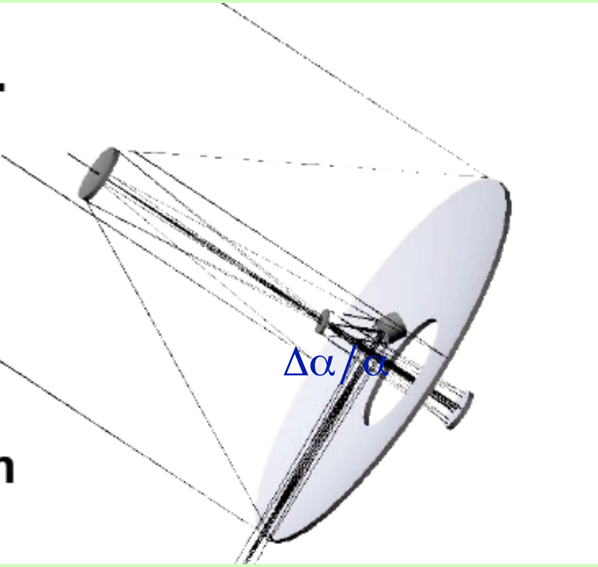
- Red line assumed w(z), black line recovered. Shaded regions show 1 and 2 CL reconstruction

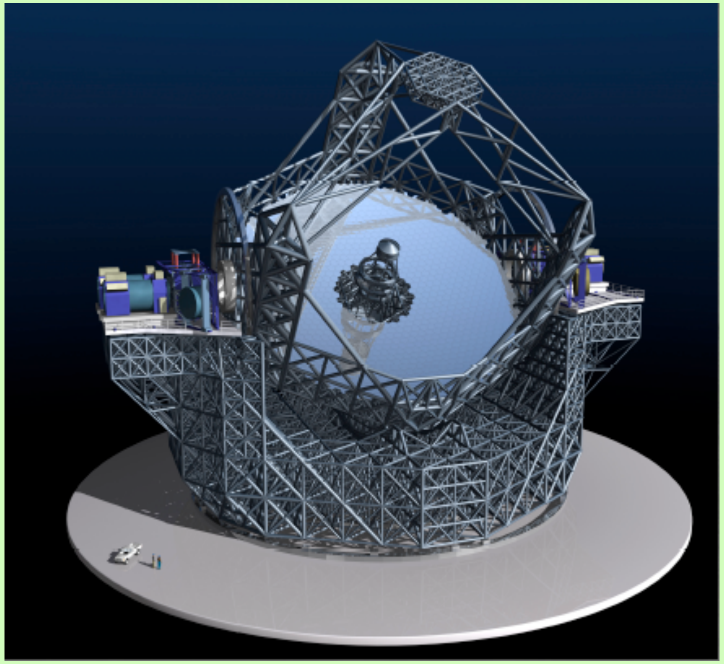
- Only few points are sufficient to revel a dynamical w(z)

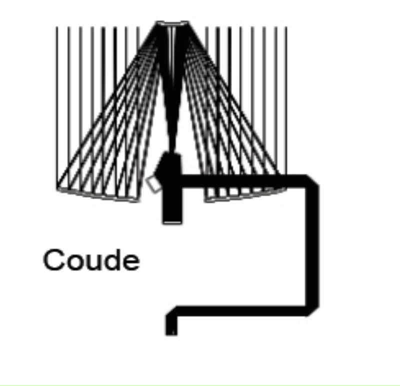
CODEX

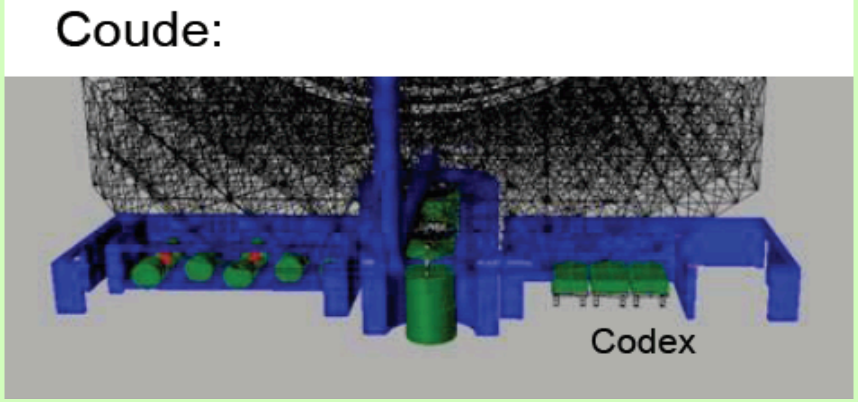
The E-ELT

- **42m baseline diameter**
- **Innovative 5-mirror design**





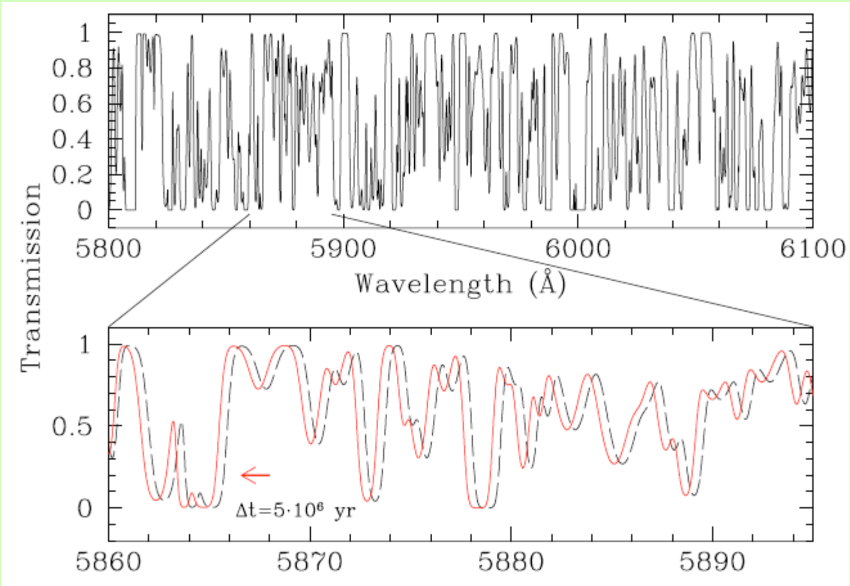


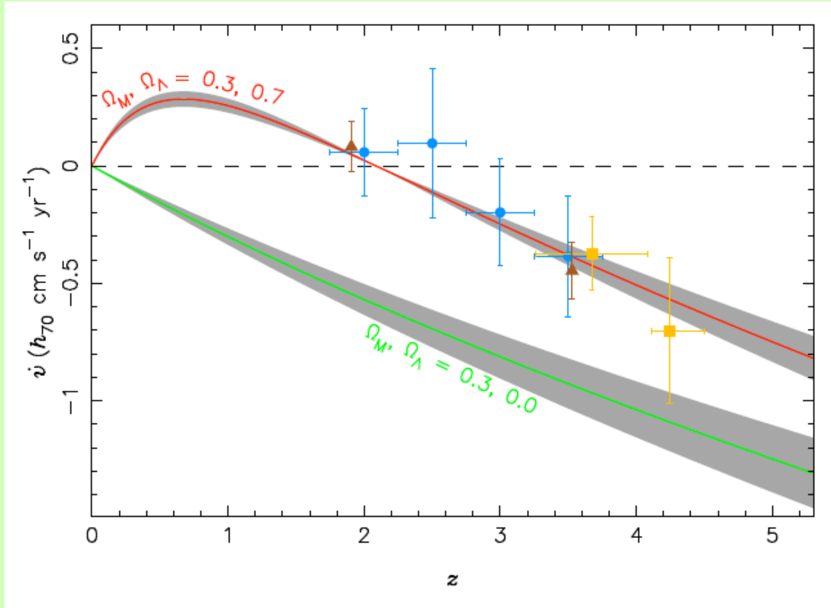


universal expansion & other

Liske et al 08

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





- 400 nights of the E-ELT over 10 years
- For α and μ CODEX will provide another order of magnitude gain in sensitivity: 0.01 ppm, (theoretically 0.001 ppm is also possible)
- Project needs the help of physical community at large

Conclusions

- Variability of physical constants is important for physics & cosmology.
- α
  - Variability at the level of -6 ppm in conflict with new lab limits for linear extrapolation
  - variability not supported by 2 individual measurements (pending a full reanalysis of the Chand et al data sample)
  - New results at high redshift possible with an E-ELT
- μ
  - Variability at 24 ppm from H_2 has low significance
  - Ammonia method < 2ppm at z=0.68
  - the Milky Way show no evidence for variation 0.1 ppm
- ESPRESSO will improve accuracy by a factor 10 both for α and μ and clarify present claims or detect variability at lower level
- CODEX at the E-ELT even lower (support needed!)