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SMR.1580 - 1

CONFERENCE ON FUNDAMENTAL SYMMETRIES AND FUNDAMENTAL CONSTANTS

15 - 18 September 2004

CONSTRAINTS ON THE TIME VARIATIONS OF FUNDAMENTAL CONSTANTS USING QSO ABSORPTION LINES

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Constraining the variation of constants using QSO absorption lines

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Plan of this talk:

Introduction: QSO absorption lines as cosmic probe.

Variation of fundamental constants:

- Fine-structure constant: α

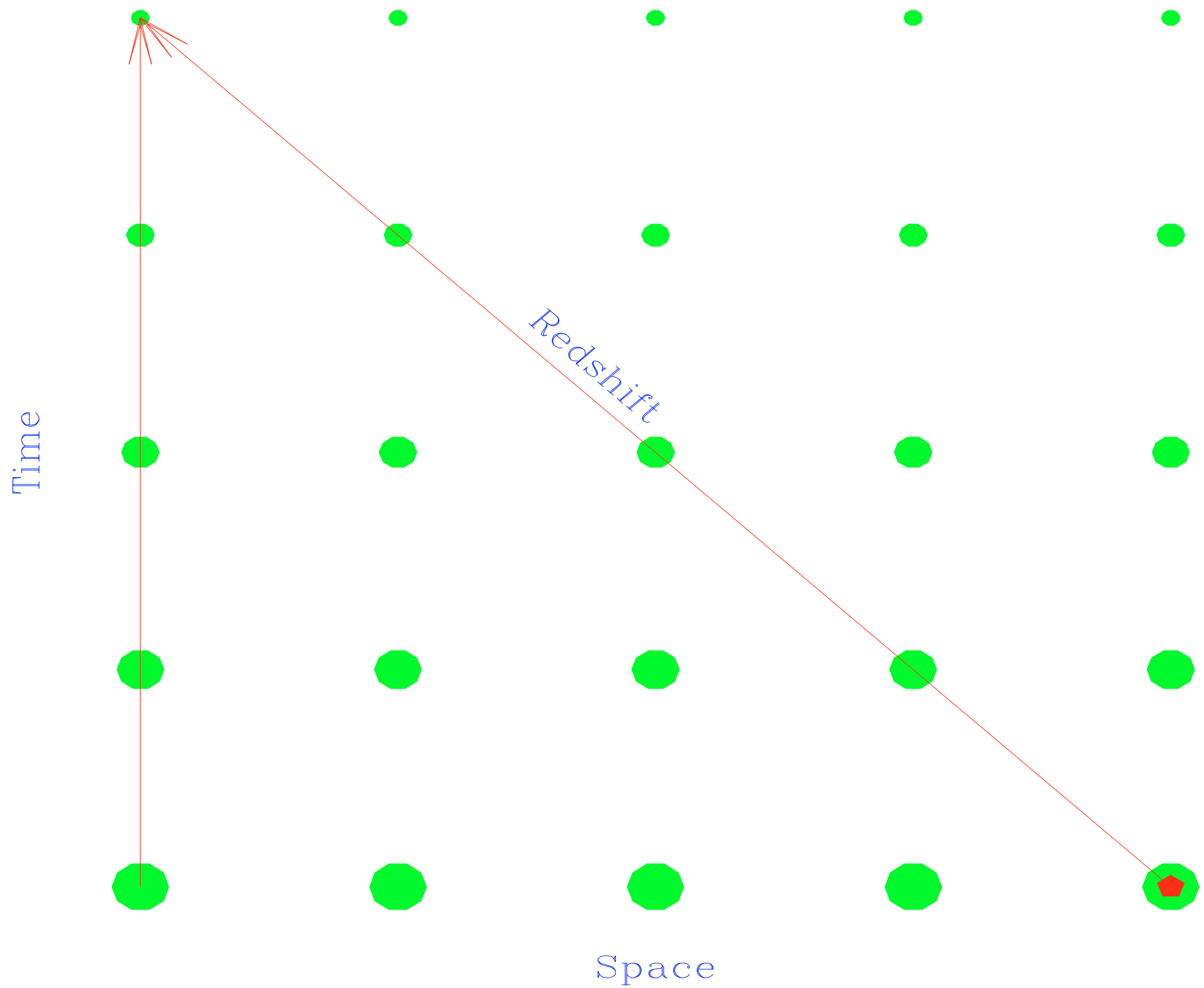
Many-multiplet method & Alkali-Doublet method

- Proton-to-electron mass ratio: μ

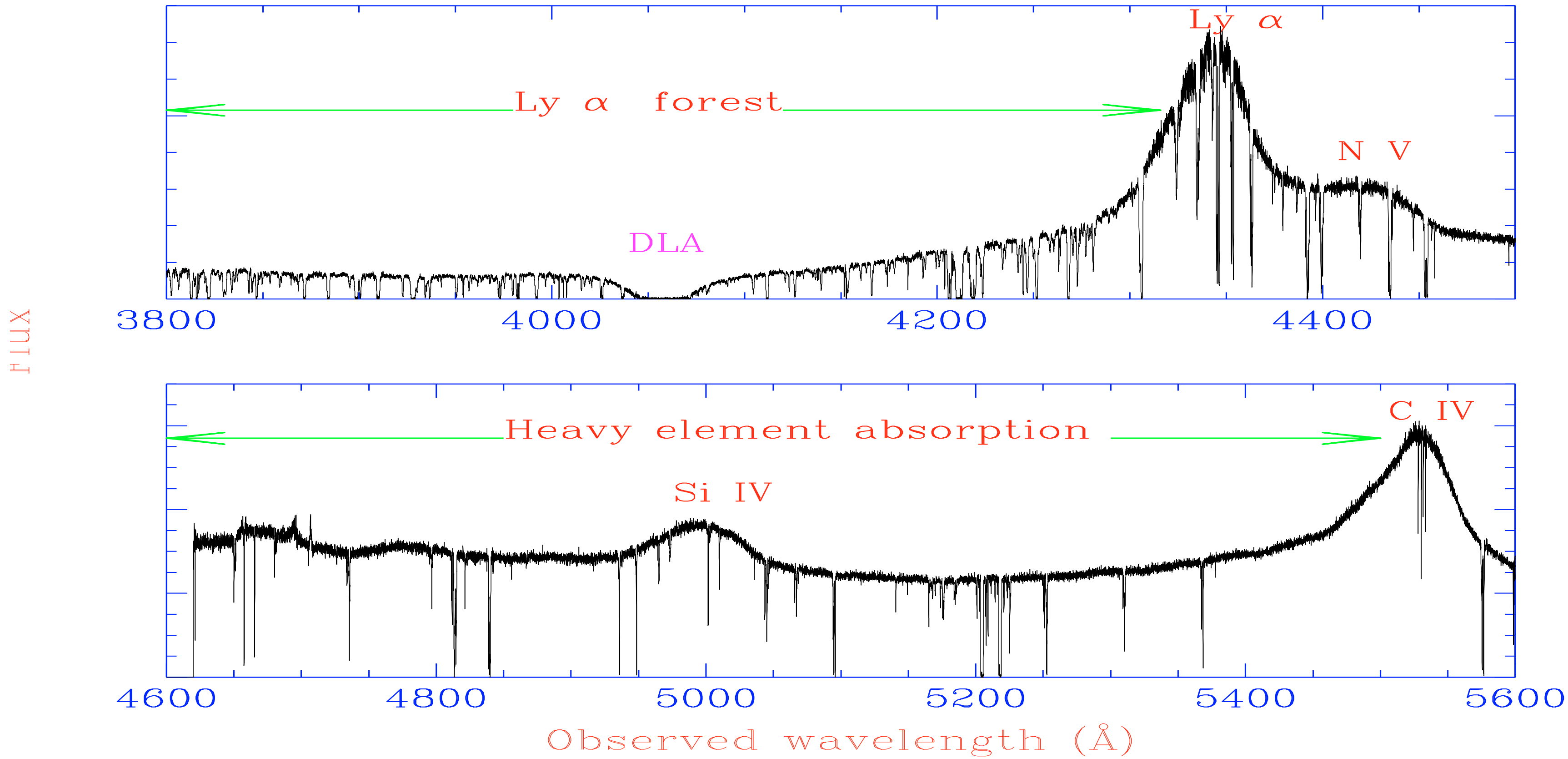
What next?:

- Very high resolution spectroscopy.
- New choices of species

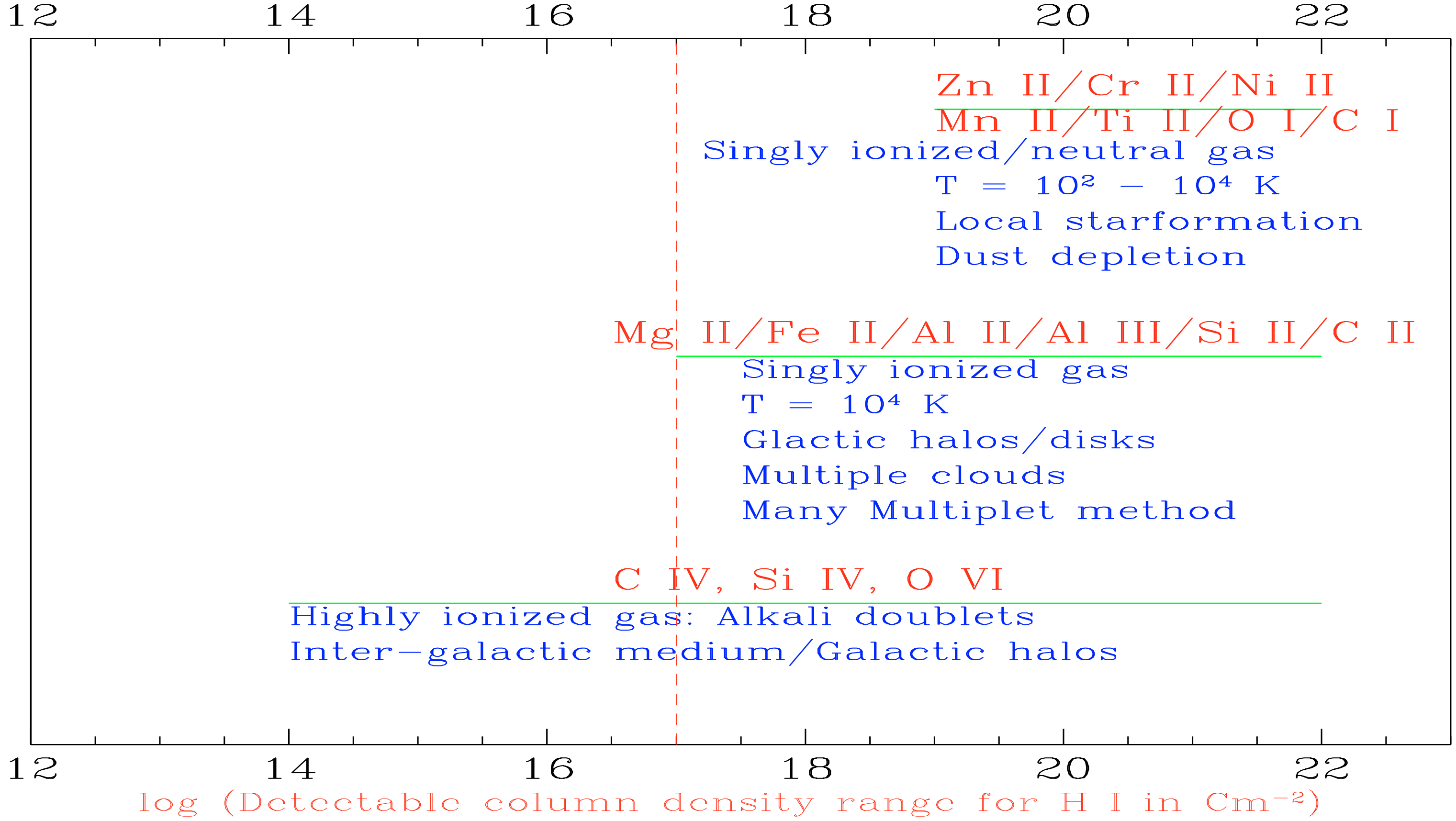
Probing Cosmological evolution:



QSO as a Probe of Cosmological evolution:



QSO absorption lines: Where they come from?



α VARIATION: MANY MULTIPLET METHOD

- **For small shifts in α**

$$\omega_z = \omega_0 + q_1 x_z + q_2 y_x$$

with

$$x_z = (\frac{\alpha_z}{\alpha_0})^2 - 1 \text{ and } y_z = (\frac{\alpha_z}{\alpha_0})^4 - 1$$

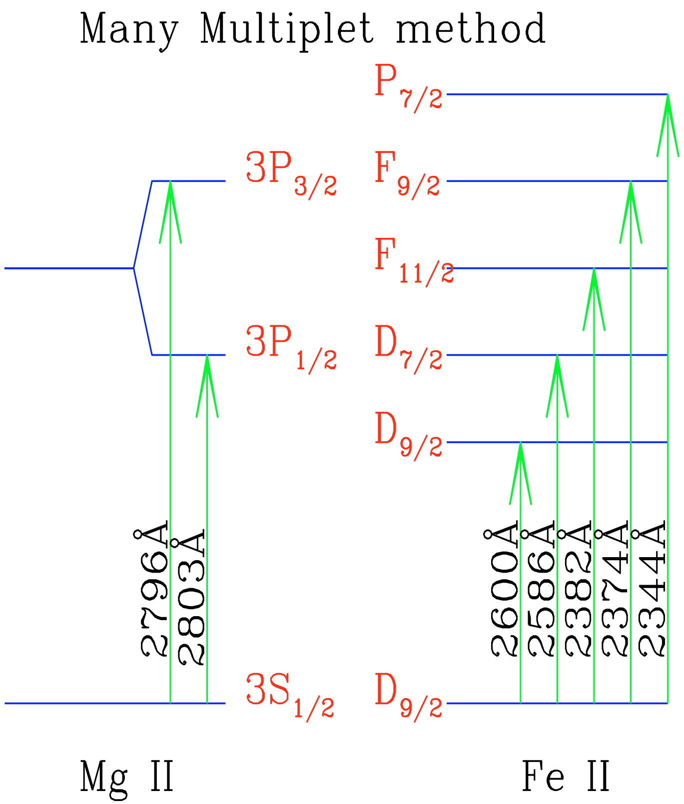
when $\Delta\alpha/\alpha <<$1

$$\omega_z = \omega_0 + q x_z$$

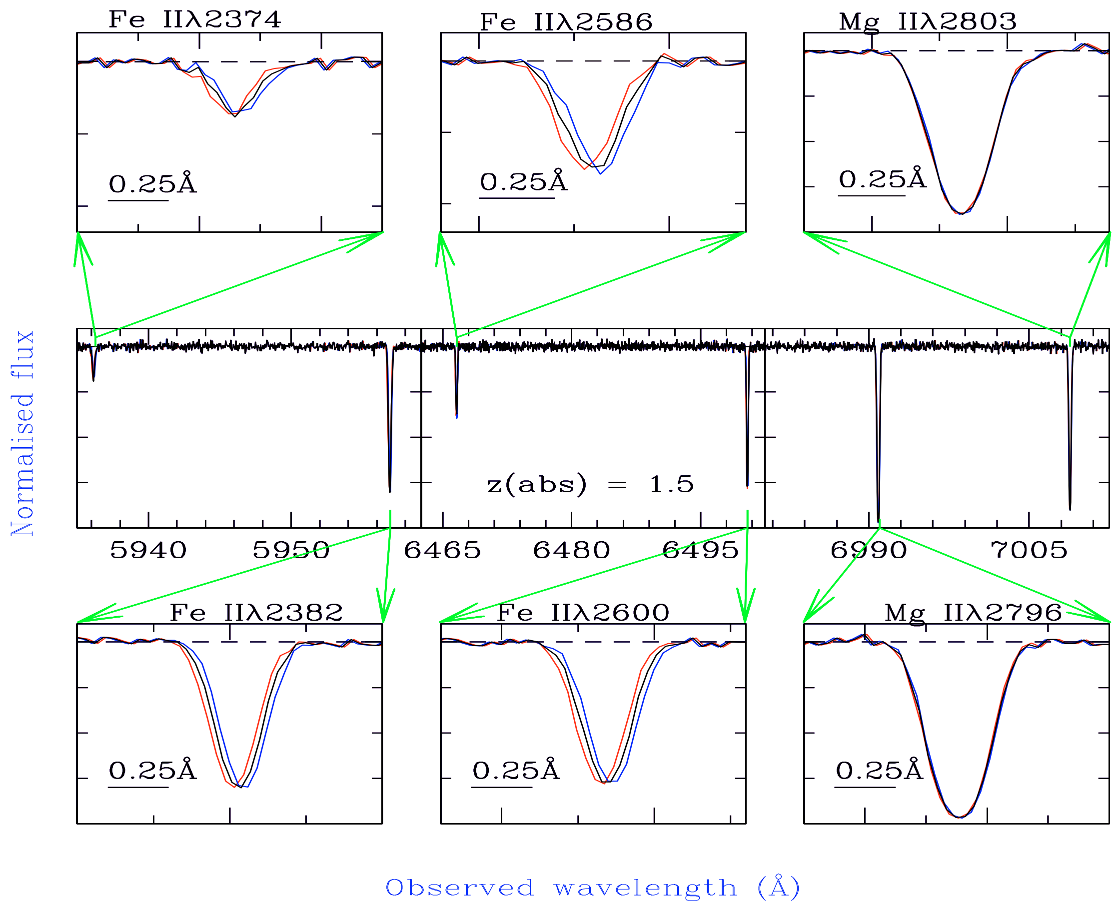
with

$$q = q_1 + 2q_2$$

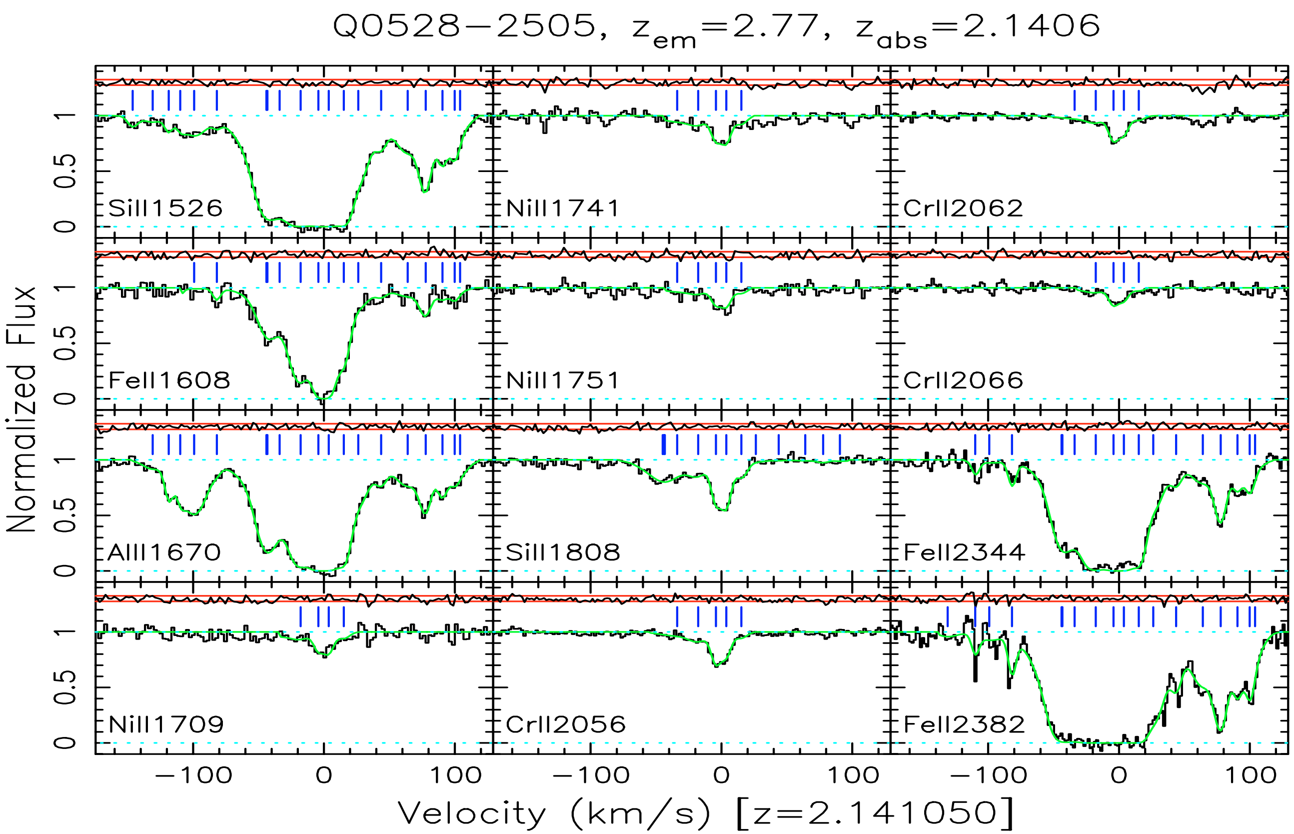
Dzuba et al (1999)



Many Multiplet Method: Simulations

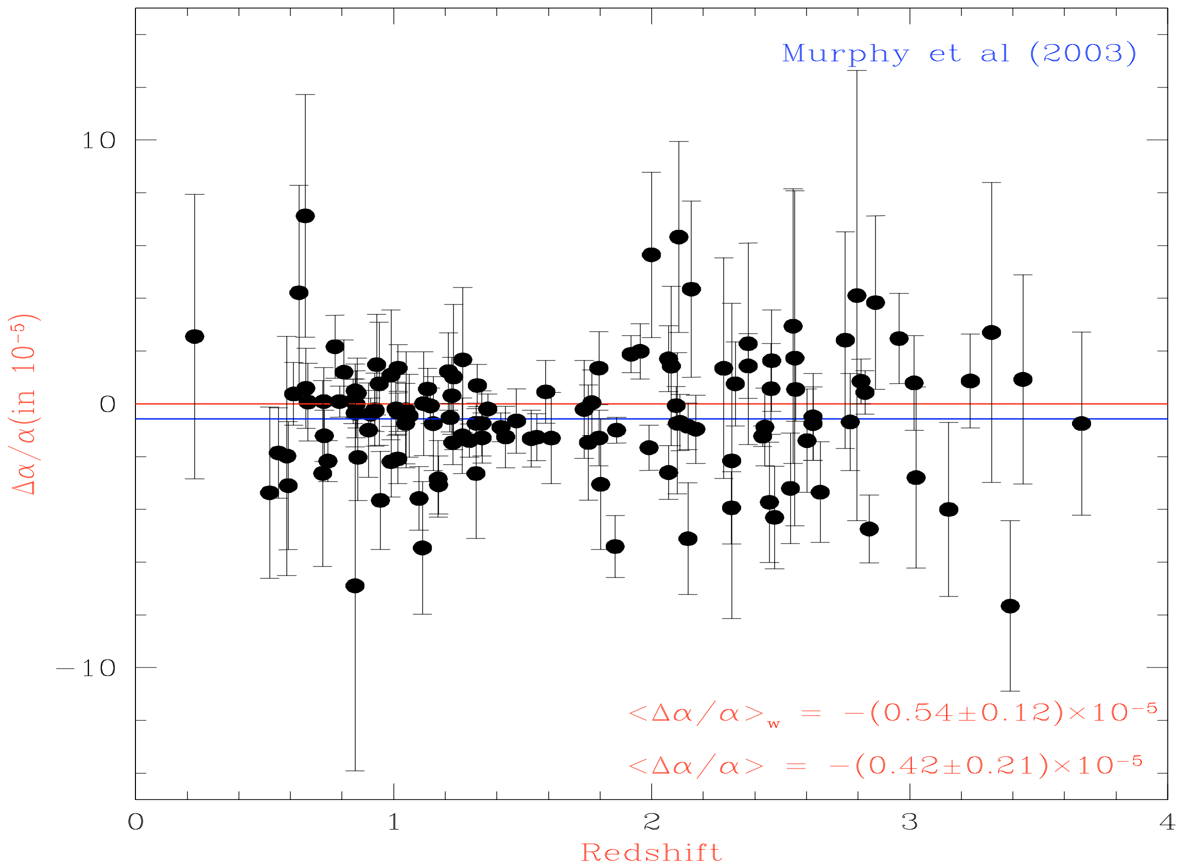


Many Multiplet Method: HIRES

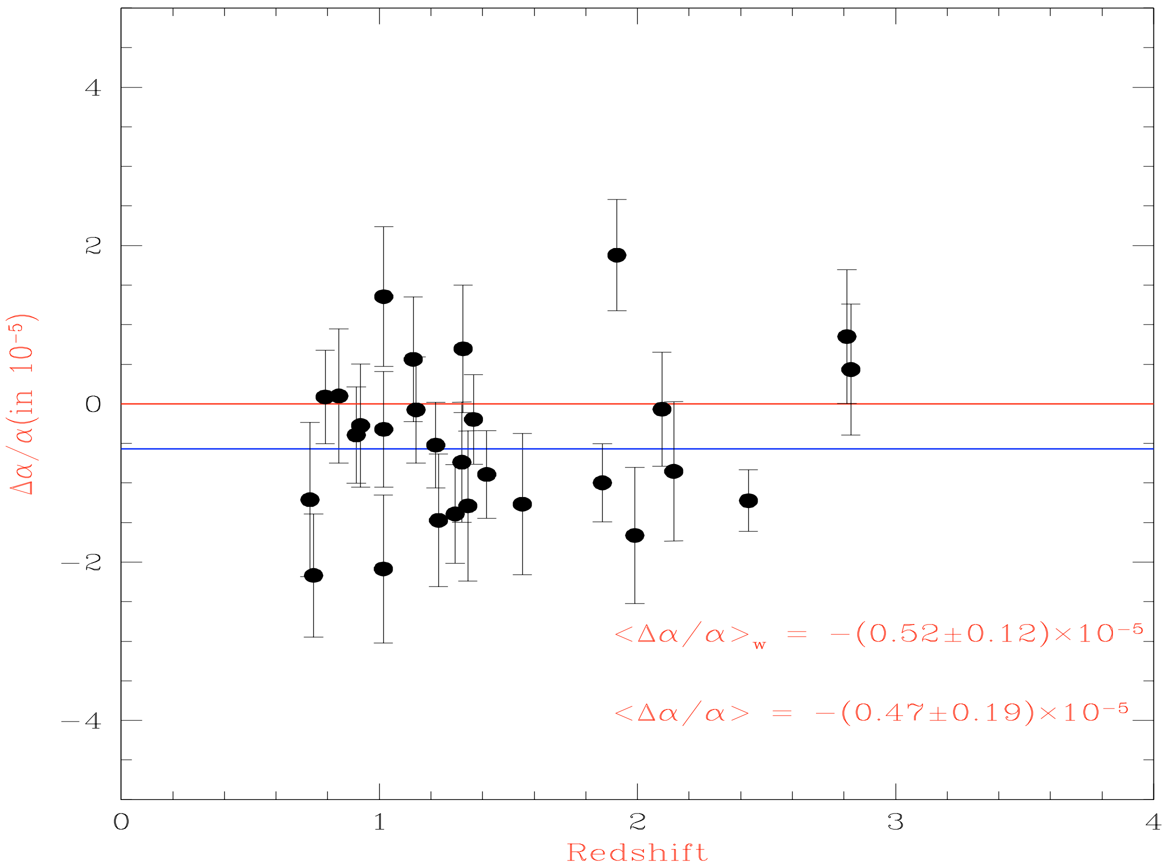


Murphy et al., 2003

Many Multiplet Method: HIRES



Many Multiplet Method: HIRES

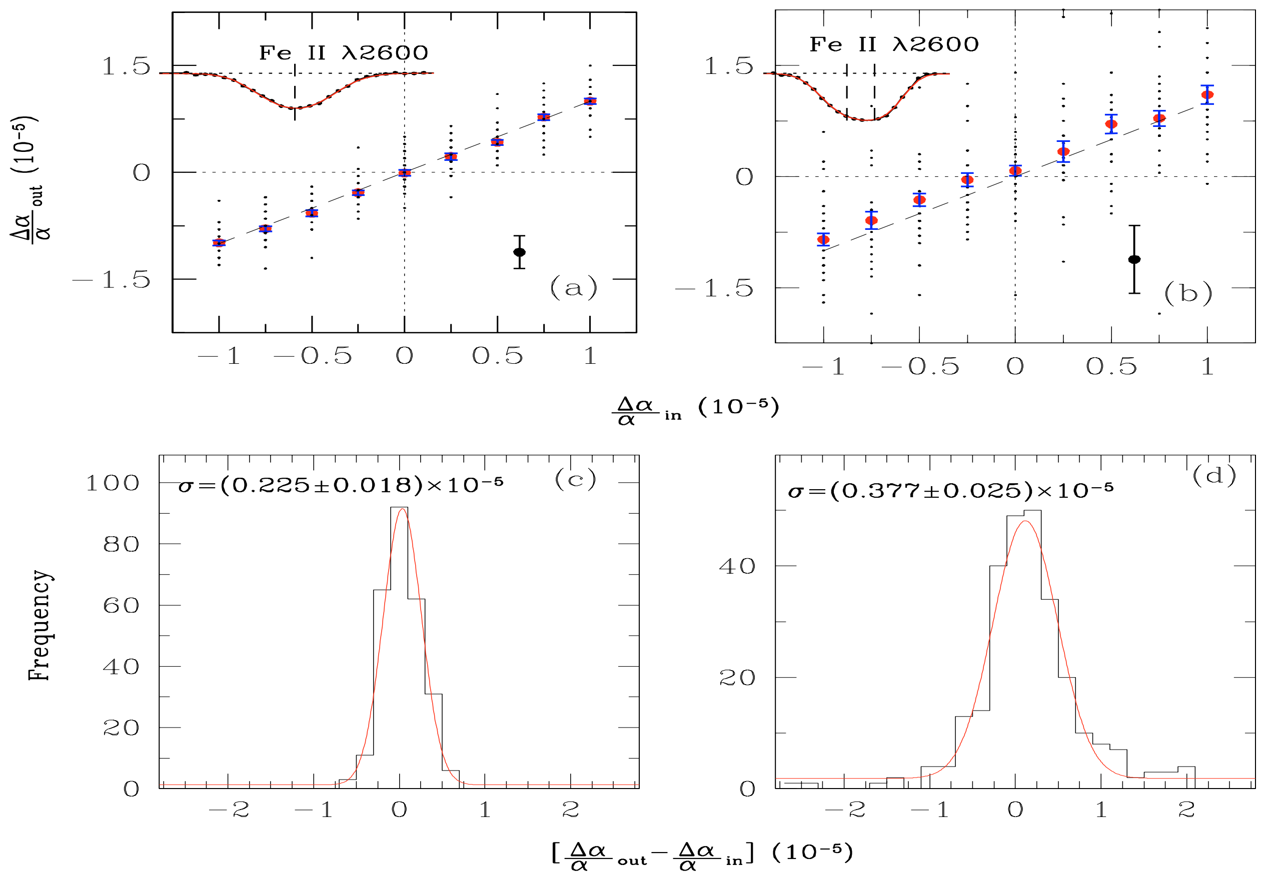


Many Multiplet Method: UVES analysis

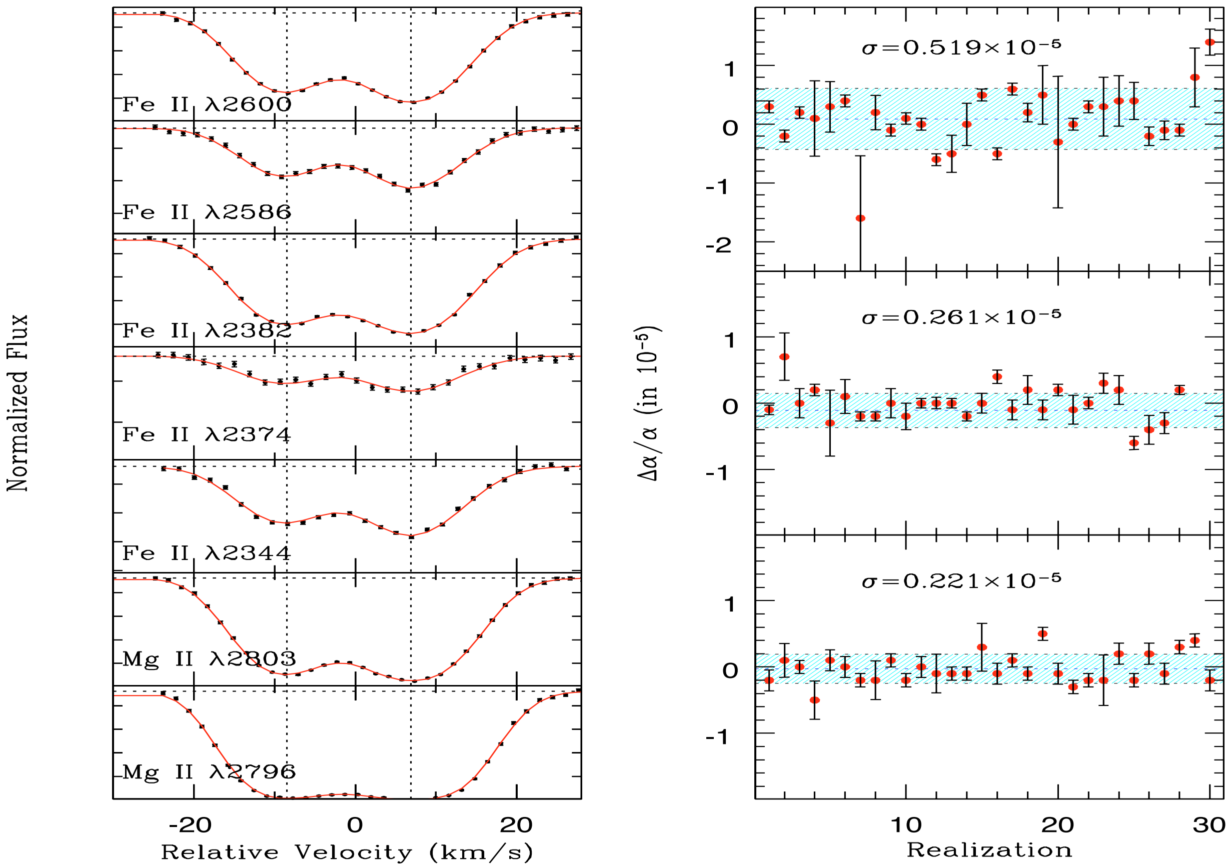
Srianand et al. (2004) and Chand et al. (2004)

- Confirming the results of Murphy et al. (2003) using independent data and analysis.
- Devising a sample selection criteria that will ensure accurate measurement of $\Delta\alpha/\alpha$. (Prevention is better than cure)
- Validating the statistical/line-fitting methods to ensure foolproof analysis.(Simulation is the first step.)
- Presenting full analysis in detail. As the DATA is public, checking the results by various groups becomes easier.

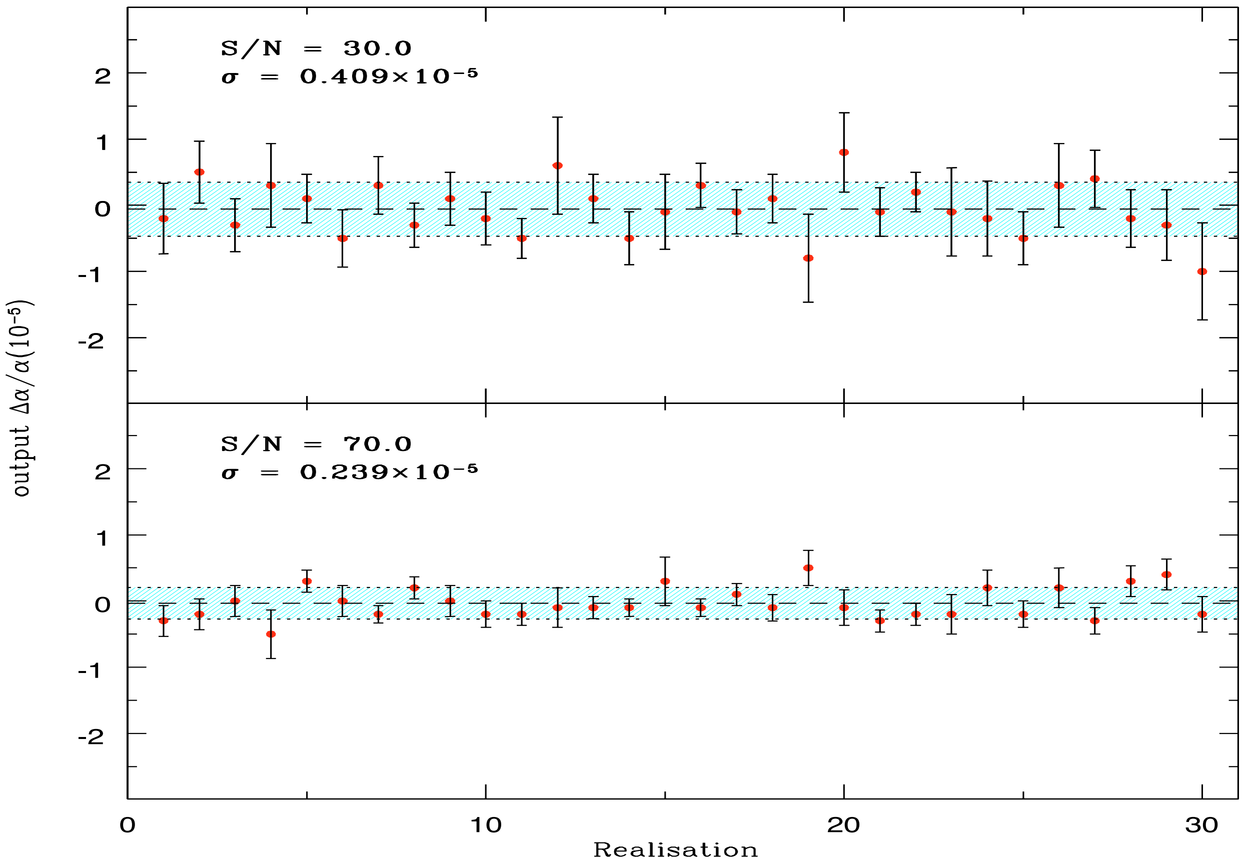
Many Multiplet Method: Validation of the procedure



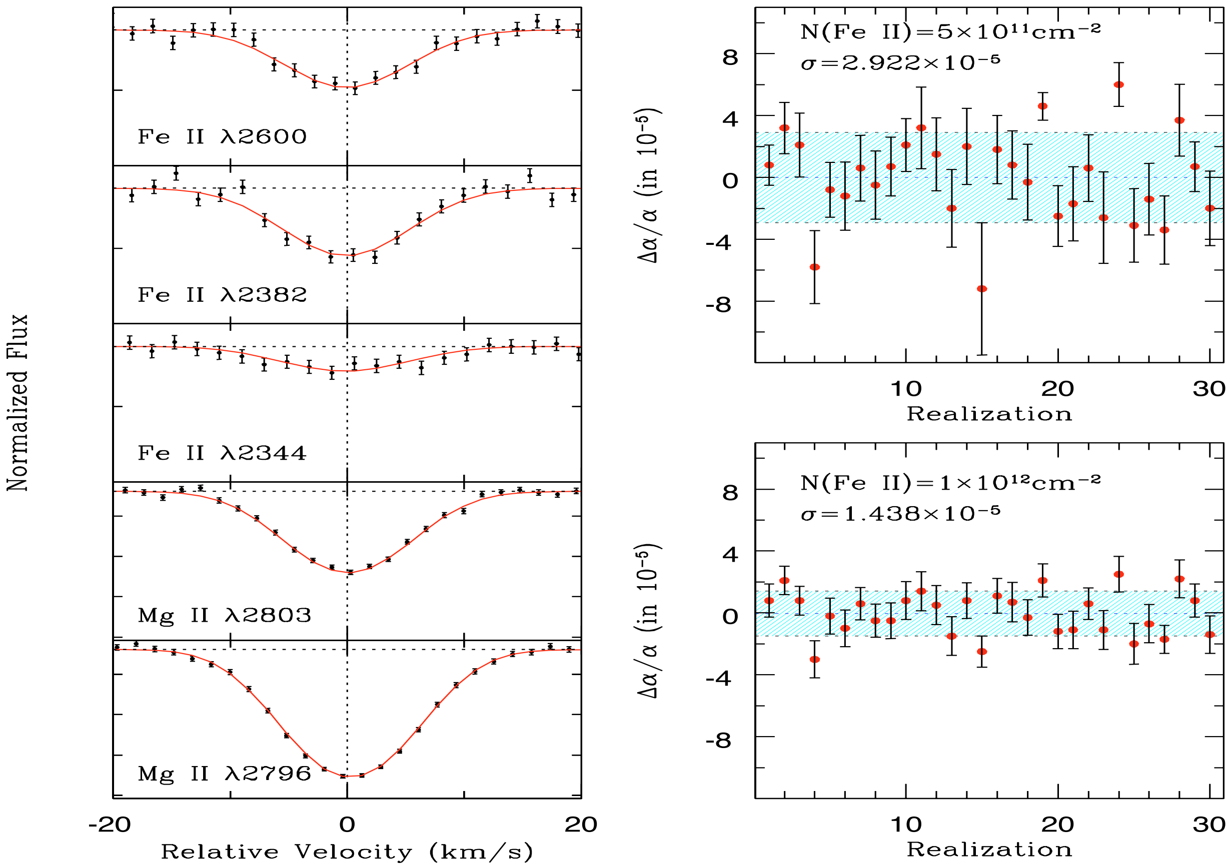
Many Multiplet Method: Effect of blending



Many Multiplet Method: Effect of signal-to-noise



Many Multiplet Method: Effect of line strength



Many Multiplet Method: Summary from simulations

- Best constraints on $\Delta\alpha/\alpha$ are obtained either from single component systems or well resolved multiple component systems.

- Increasing the signal-to-noise ratio from S/N = 30 to 70 increases the accuracy of $\Delta\alpha/\alpha$ measurements by about a factor of two.

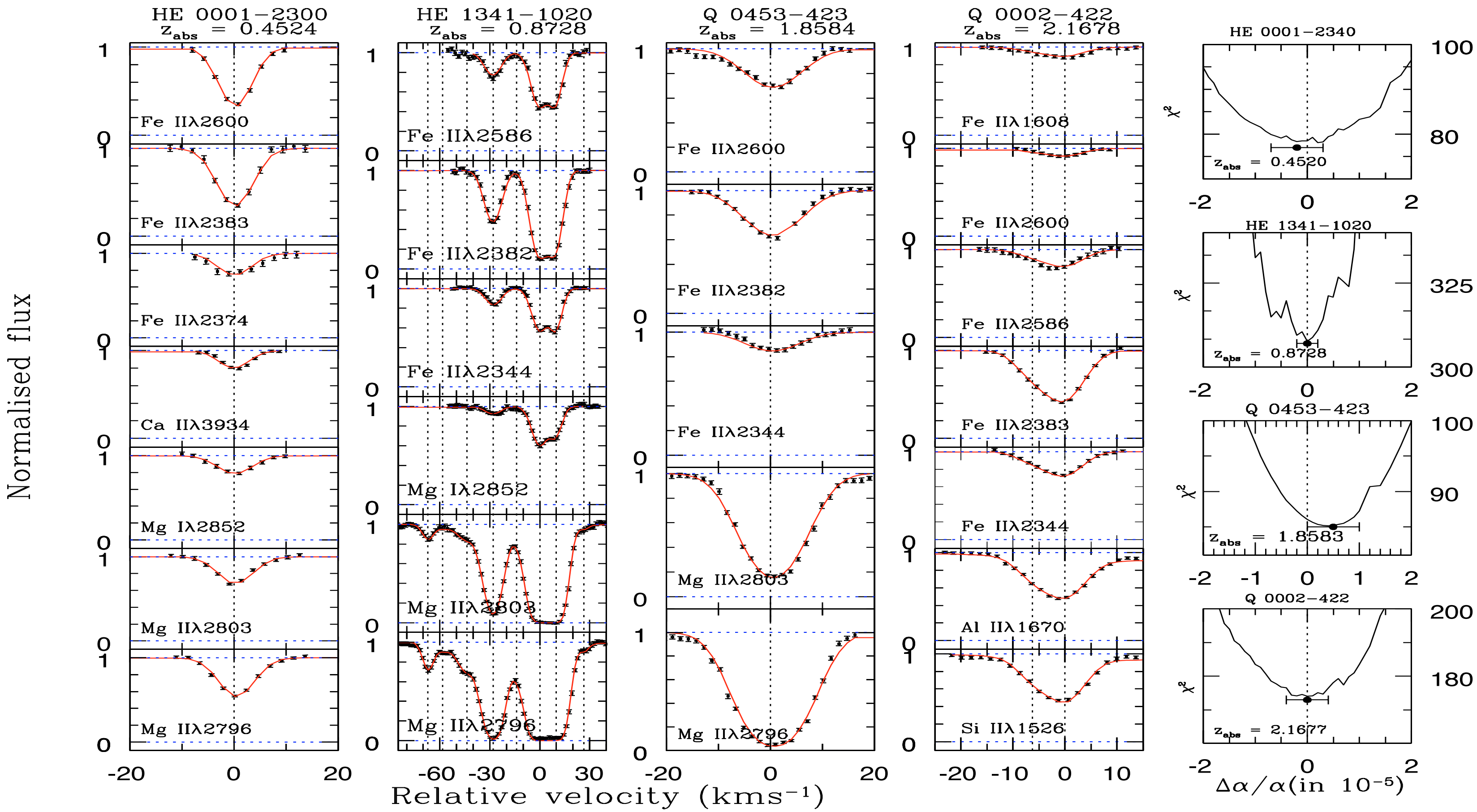
- It is better to avoid weak lines while extracting $\Delta\alpha/\alpha$ as their profiles can be distorted by Poisson noise. Thus, weak lines in the low signal-to-noise data can result in false alarm detections of non-zero $\Delta\alpha/\alpha$ values.

- There is a non-negligible probability to derive a statistically significant deviation from the actual value when one considers highly blended systems (i.e., systems where the component separations are smaller than the individual b values). Thus it is better to avoid complex blends in the analysis.

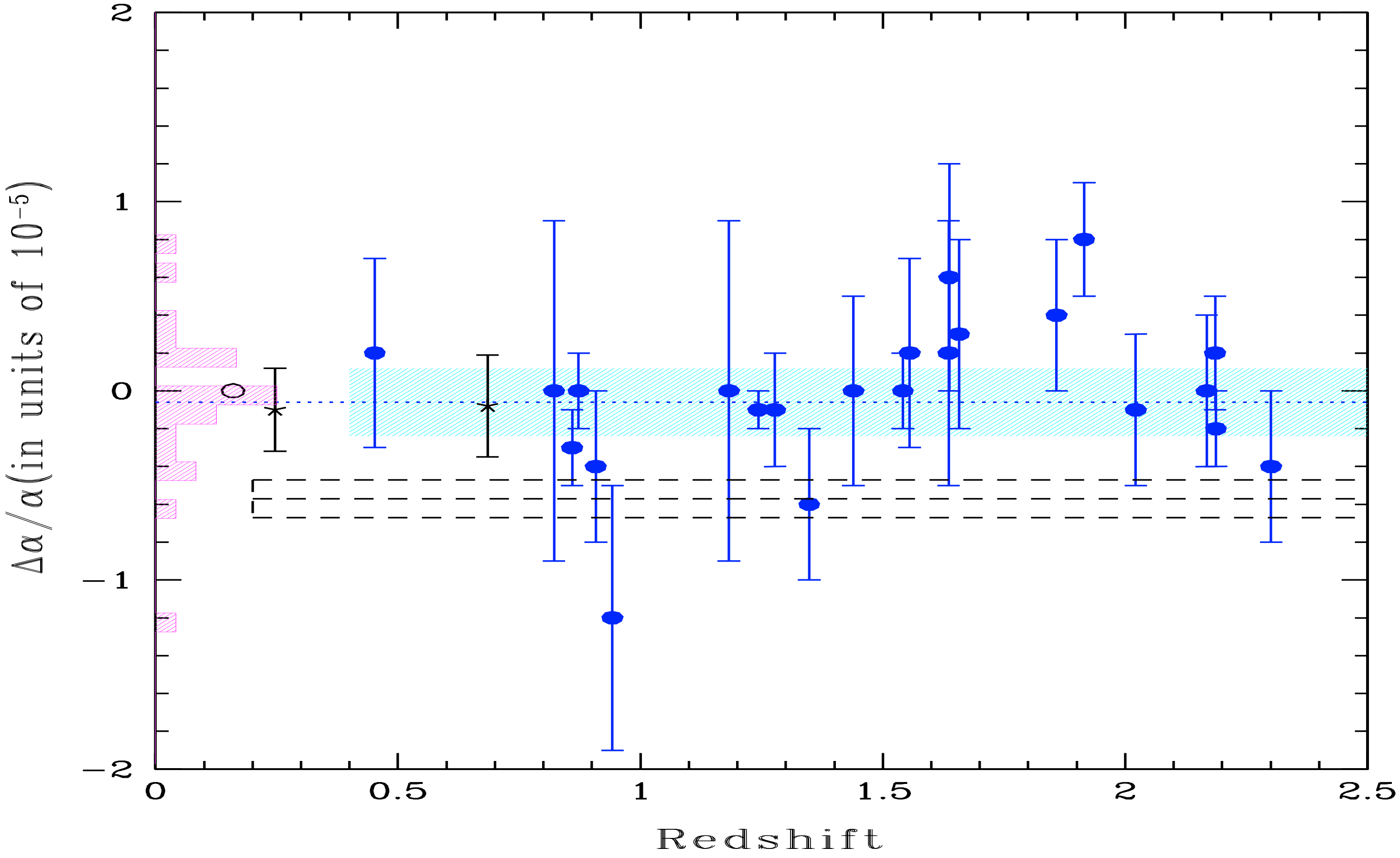
Many Multiplet Method: Data sample

- 18 Brightest high z QSOs in the south [ESO-VLT large programme "QSO absorption lines" 166.A-0106 (PI: Jacqueline Bergeron)].
- S/N = 60$-$80, R $\geq$ 44,000 and $\delta\lambda \leq$ 3 m$\mathring{A}$.
- 50 Mg II systems are detected.
- 23 used in the analysis.
- 15 are classified as weak systems (i.e N(Fe II)$\leq 2 \times 10^{12}$ cm^{-2}).
- There are 2 DLAs and 10 systems saturated/no-anchor/heavy blends.

Many Multiplet Method: Voigt profile fits



Many Multiplet Method: Results from UVES sample



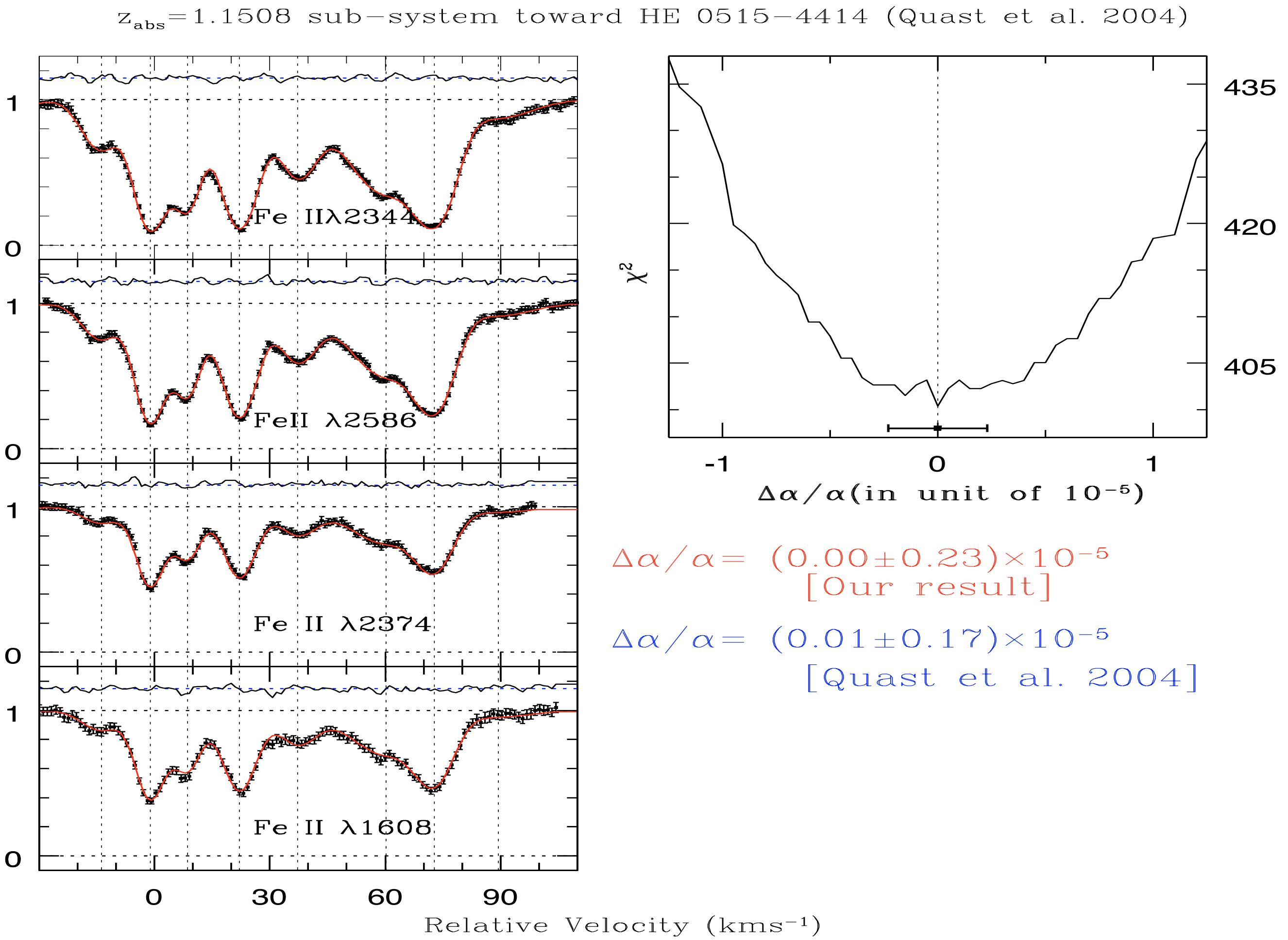
Many Multiplet Method: Summary of results:

Sample	Number	z	$\Delta\alpha/\alpha$ (10^{-5})	RMS (10^{-5})
Murphy et al. 2003	128	0.2–3.7	$-(0.54 \pm 0.12)$	2.38
			$-(0.86 \pm 0.10)$	2.43
Srianand et al. 2004/ Chand et al. 2004	23	0.4–2.3	$-(0.06 \pm 0.06)$	0.41
			$-(0.36 \pm 0.06)$	0.44
Quast et al. 2004	1	1.1	$-(0.04 \pm 0.19)$	
Levshakov et al. 2004	2	1.1,1.7	$+(0.04 \pm 0.15)$	

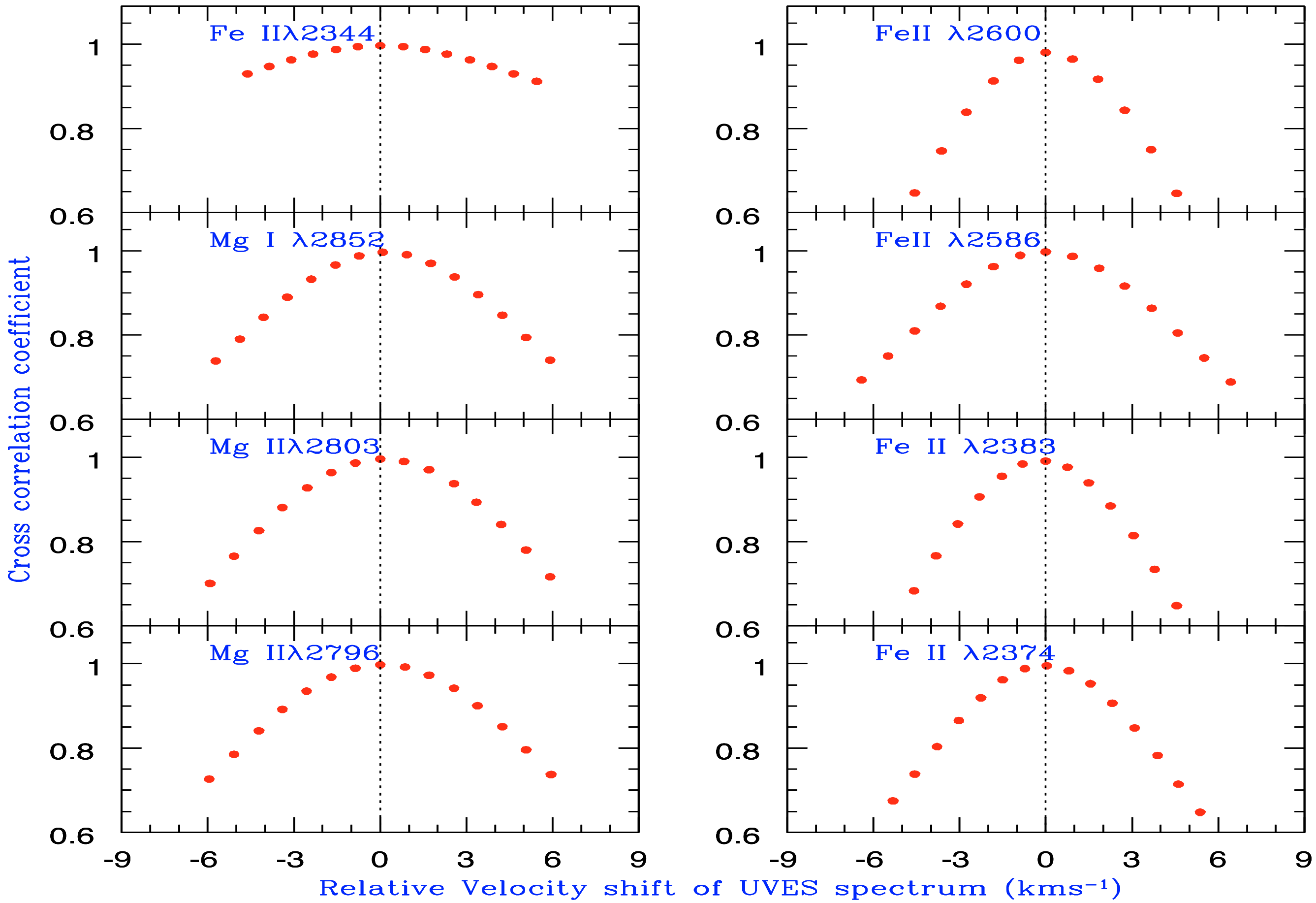
Why MM-method results are different?

- Number or quality? Reasonable number with high quality.
- Effect of isotopic abundances? Most probably not.
  (see Ashenfelter et al. (astro-ph/0404257) for details on effect of isotopes)
- How good is the fitting procedure? Not bad-independent check is useful
- Is there any problem with the wavelength Calibration? Most probably not.
- Effect of not using any selection criteria in the HIRES data Needs checking

How good is our fitting procedure?



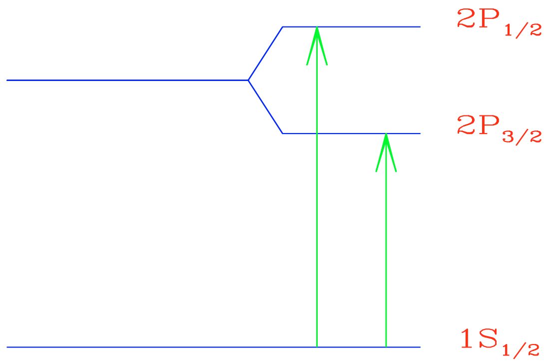
How good the UVES wavelength Calibration?



ALKALI DOUBLETS

- **Doublets at high z:**

  C IV(2.6 eV), N V(4.0 eV),
  O IV(5.7 eV), Mg II(7.2 eV),
  Al III(8.1 eV), Si IV (9.0 eV)



- **Spin orbit interaction:**

$$\frac{\Delta E_{n,j}}{E_n} \propto \alpha^2$$

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

ALKALI DOUBLETS: Previous results

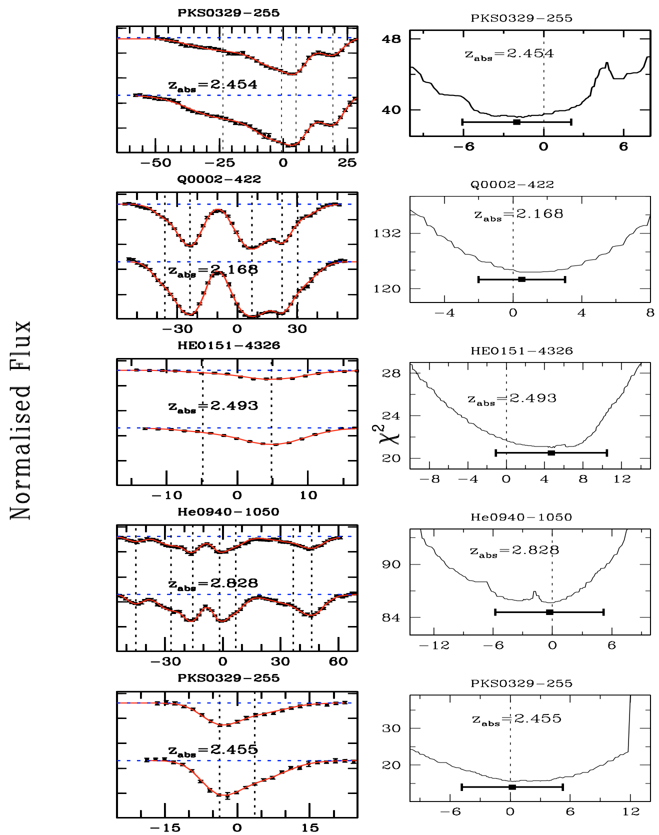
Number	Spectral resolution	S/N	$\Delta\alpha/\alpha$	References
10	≥ 36000	...	$\leq 1.1 10^{-4}$	Cowie & Songaila (1995)
16	~ 15000	15	$-(4.6 \pm 4.3)10^{-5}$	Varshalovich et al. (2000)
21	≥ 36000	15-40	$-(0.5 \pm 1.3)10^{-5}$	Murphy et al., (2001)

ALKALI DOUBLETS: New UVES sample

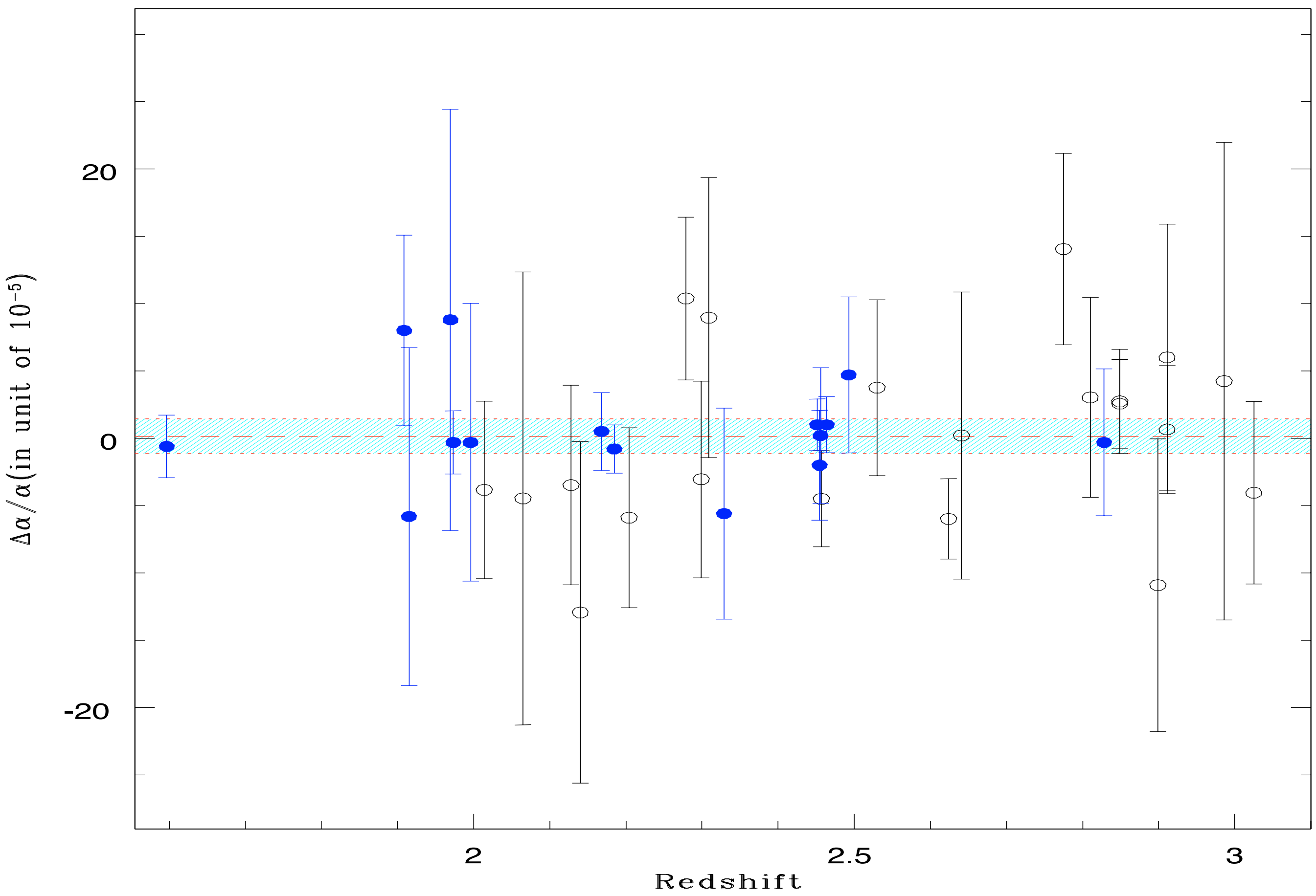
Chand et al., 2004, A&A in press; /astro-ph/0408200

Sample:

- 33 systems ($1.5 \leq z \leq 2.9$)
- 15 unblended and strong systems
- R $\geq$45000
- S/N = 60$-$80



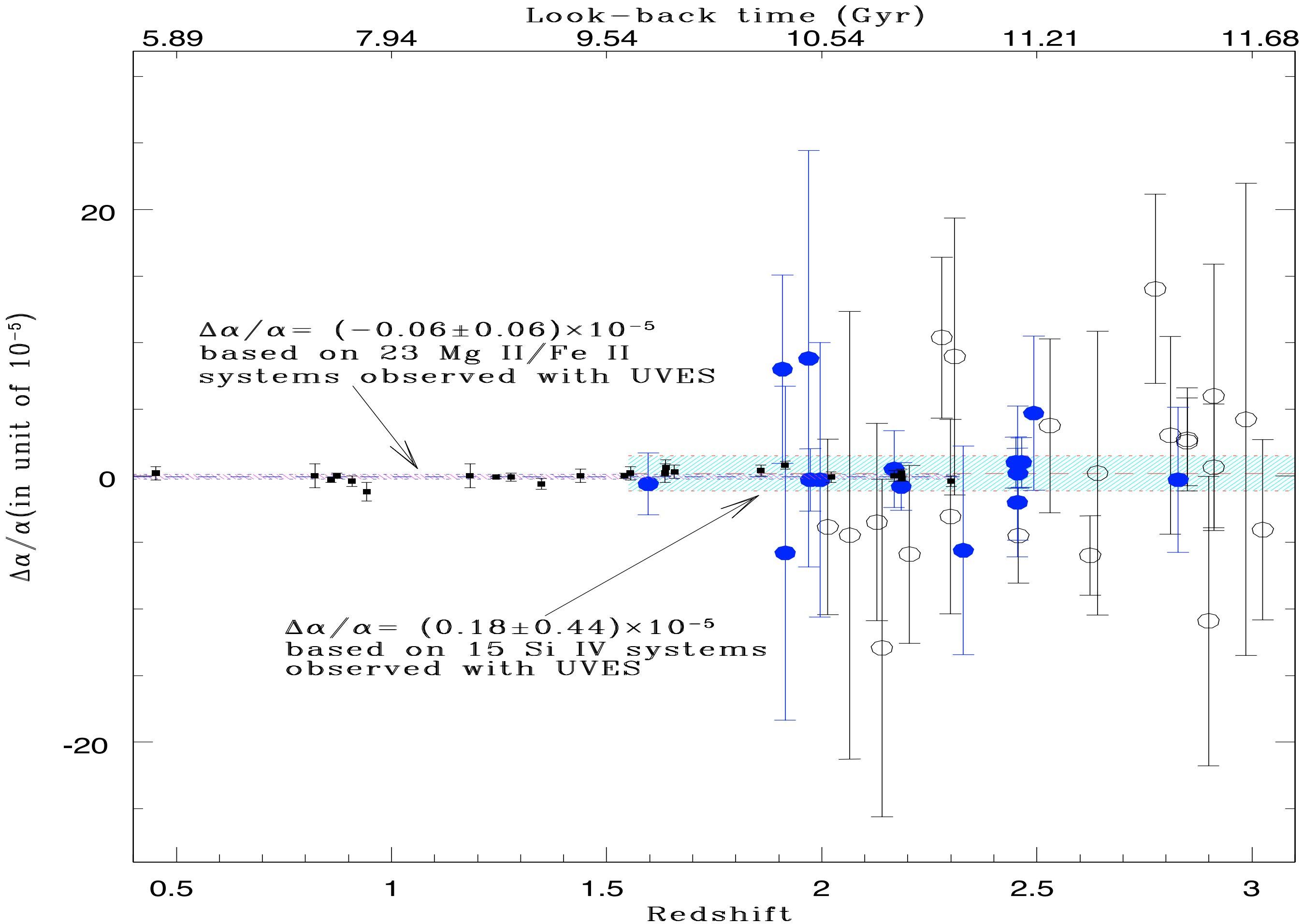
ALKALI DOUBLETS: New UVES results



ALKALI DOUBLETS: Results till date

Number	Spectral resolution	S/N	$\Delta\alpha/\alpha$	References
10	≥ 36000	...	$\leq 1.110^{-4}$	Cowie & Songaila (1995)
16	~ 15000	15	$-(4.6 \pm 4.3)10^{-5}$	Varshalovich et al. (2000)
21	≥ 36000	15-40	$-(0.5 \pm 1.3)10^{-5}$	Murphy et al., (2001)
15	≥ 45000	60-80	$+(0.15 \pm 0.43)10^{-5}$	Chand et al., (2004)

Results based on UVES samples till date:



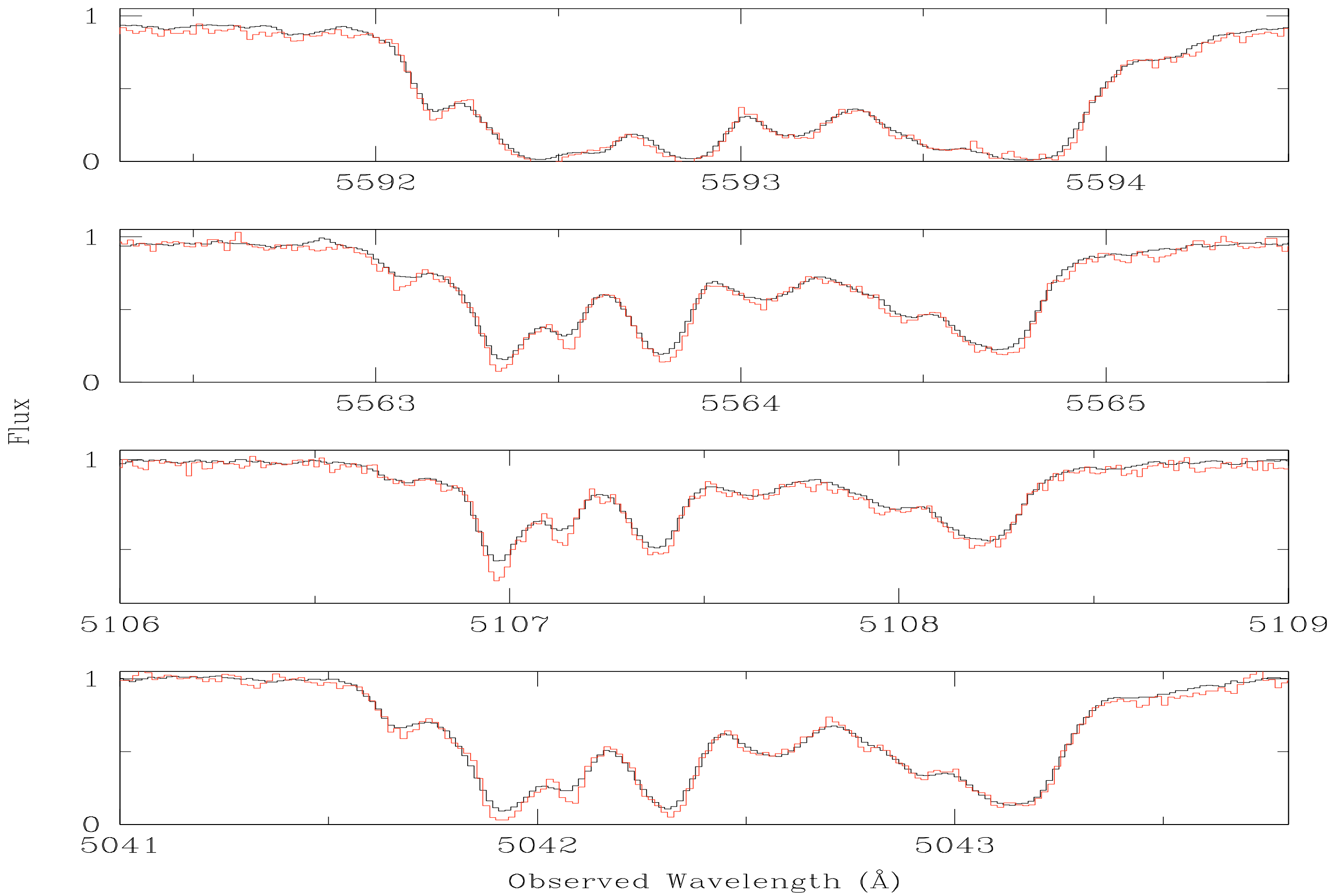
Other results from the literature:

species	z	$\Delta\alpha/\alpha$	References
Molecule	0.247	$(-0.10 \pm 0.22) \times 10^{-5}$	
	0.687	$(-0.08 \pm 0.20) \times 10^{-5}$	Murphy et al(2001)
H I+ molecule	0.247,0.687	$\leq 1.5 \times 10^{-5}$	Carilli et al (2000)
OH	0.247	$(+0.60 \pm 1.00) \times 10^{-5}$	Kanekar et al(2004)
	0.247	$(+0.51 \pm 1.26) \times 10^{-5}$	Darling(2004)
O III	0.16−0.80	$(+0.70 \pm 1.40) \times 10^{-4}$	Bahcall et al. (2003)

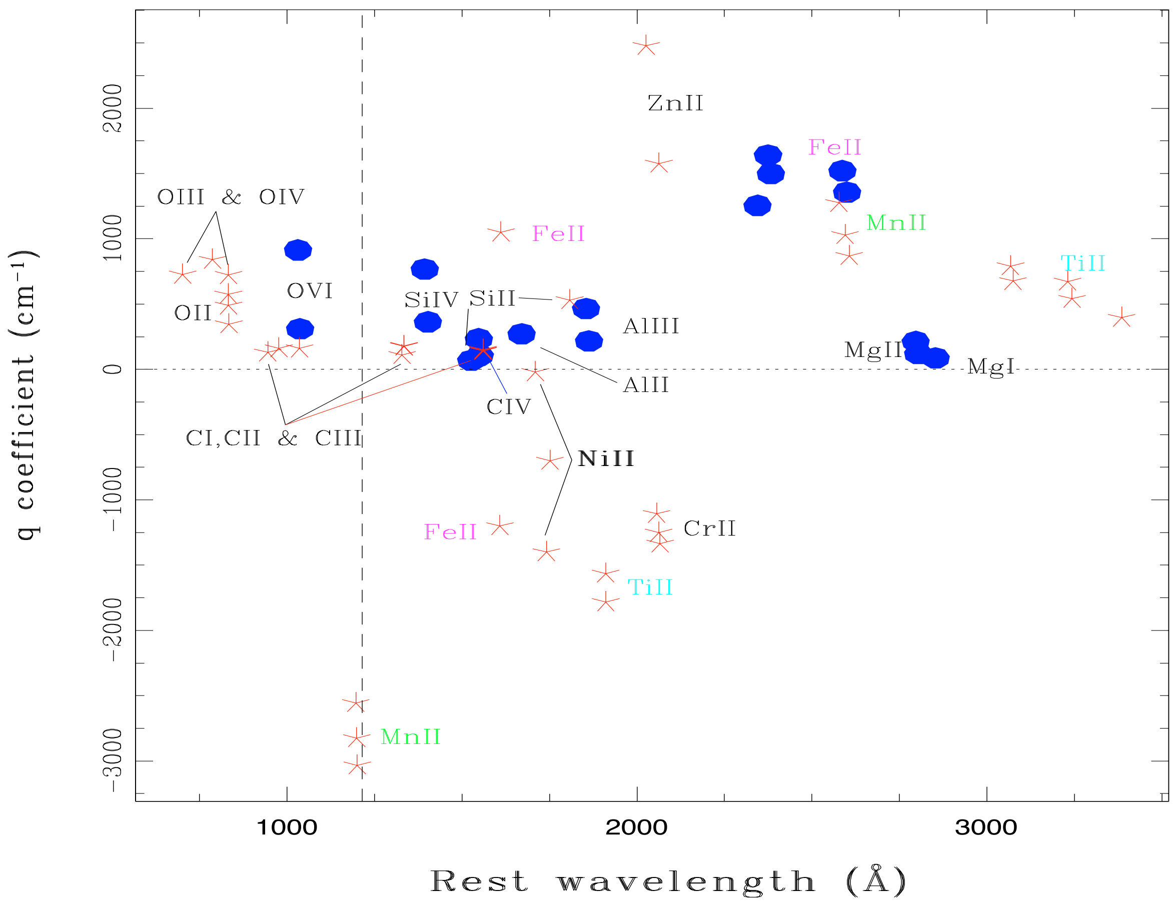
What Next?:

- Observe at very high resolution so that components are well resolved.
- Do the analysis using different sets of lines that are not affected by isotopic abunances (Fe II, Ni II, Mn II).
- Try to detect/constrain the variations of other constants.

What Next?: Very high resolution!

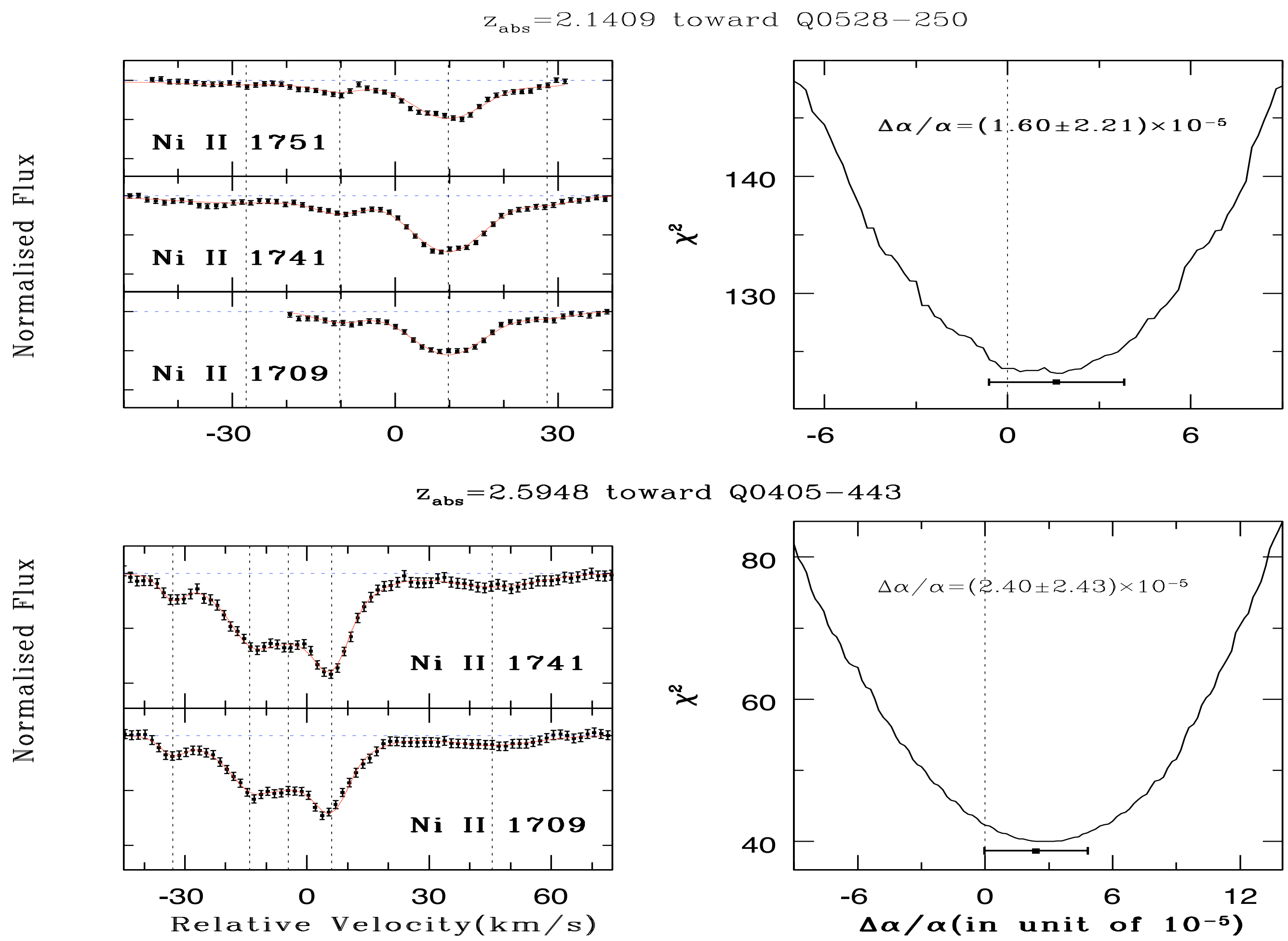


Many Multiplet Method: q parameters



Berengut et al. atro-ph/0408542

What Next?: New sets of lines!



Variations of μ: H_2 molecules at high z

Varshalovich & Levshakov (1993), Varshalovich & Potekhin (1995)

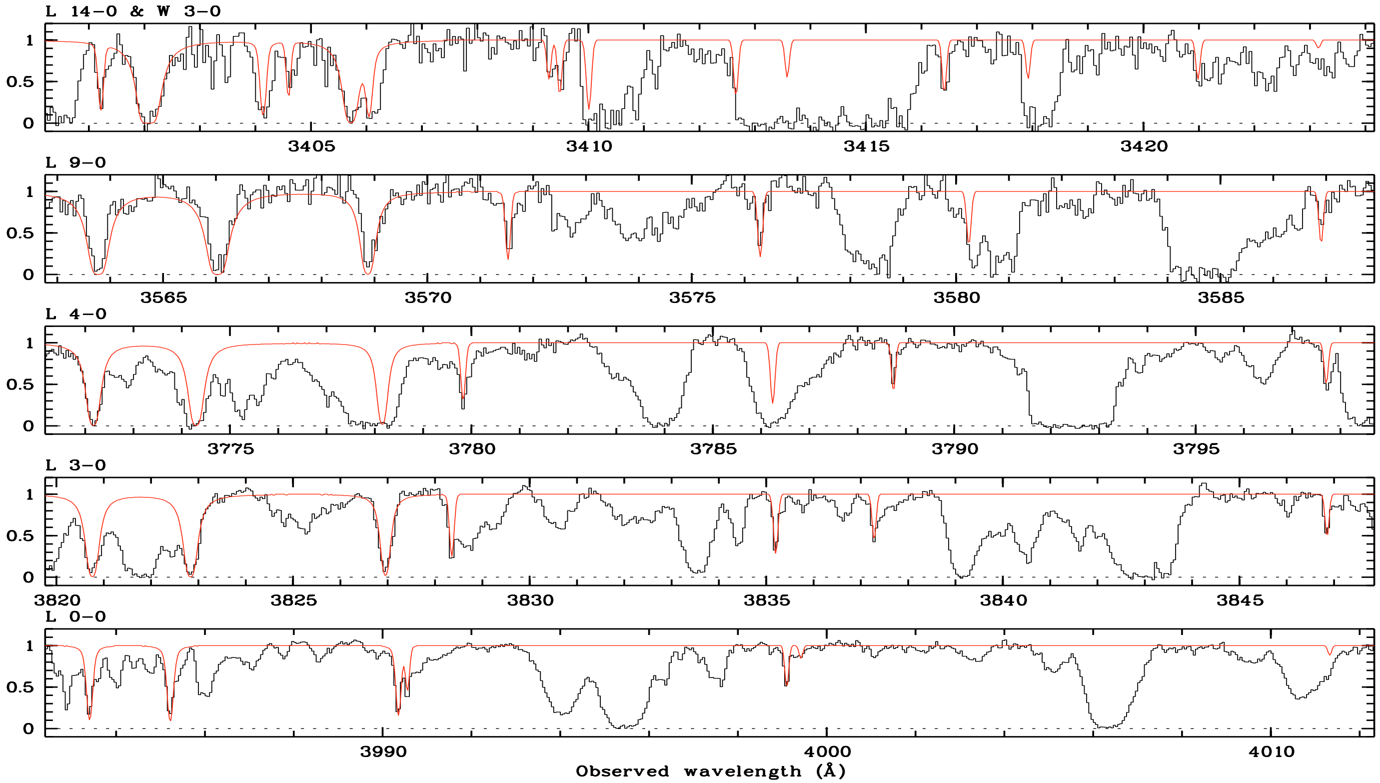
Change in λ due to change in μ can be written as,

$$\frac{\Delta\lambda}{\lambda} = K_i \Delta\mu/\mu.$$

Observed wavelength λ_i is then related to the lab wavelength λ_i^0 by

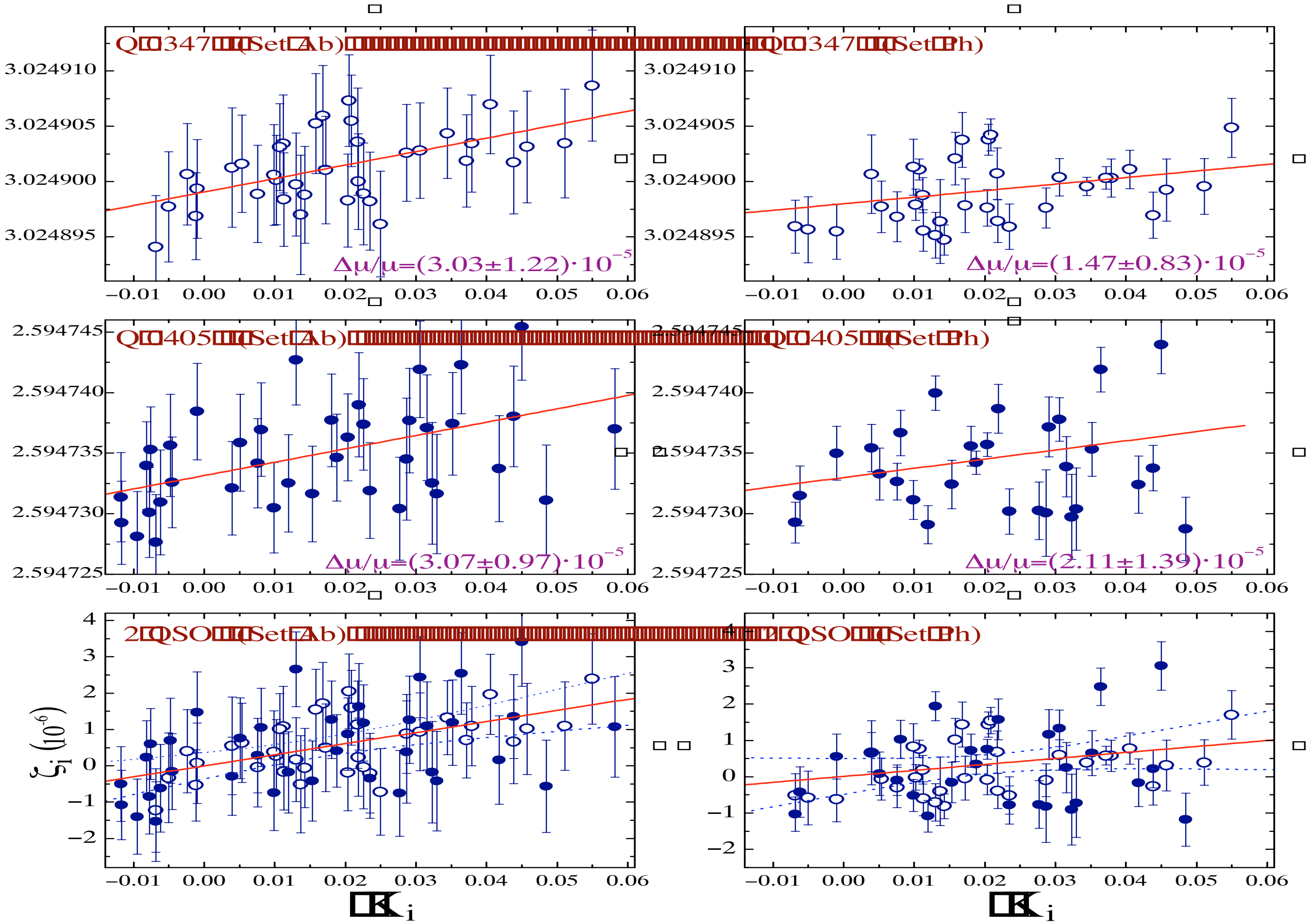
$$\begin{aligned} \lambda_i &= \lambda_i^0 (1 + z_{abs})(1 + K_i \Delta\mu/\mu) \\ z_i &= z_{abs} + (1 + z_{abs})(\Delta\mu/\mu) K_i \end{aligned}$$

Variations of μ: H_2 molecules at high z



Ledoux et al (2003)

Variations of μ: New UVES results



Variations of μ: Summary of measurements

QSO	z	$\Delta\mu/\mu$	Reference
Q 0347-382	3.02	$\|\Delta\mu/\mu\| \leq 5.7 \times 10^{-5}$	Levshakov et al. (2002)
Q 1232+082, Q 0347-382	2.33, 3.02	$5.7 \pm 3.8 \times 10^{-5}$	Ivanchik et al (2002)
Q 0347-382	3.02	$3.0 \pm 2.4 \times 10^{-5}$	Ivanchik et al (2003)
Q 0347-382, Q 0405-443	3.02,2.59	$1.6 \pm 0.7 \times 10^{-5}$	Petitjean et al (2004)

Summary of UVES results:

- Within the measurement uncertainties no variation of fundamental constants is detected using VLT.
- Eventhough the limits are improving with time they are much higher than the locally available results. New observation strategy may be needed.
- Difference between the VLT/UVES and KECK/HIRES results needs to be sortedout. A common programme with various telescopes on a well selected systems with an agreed procedure for data analysis
- Measurements based 21 cm absorption and atomic lines using SKA. DLAs are complex!
- Molecular lines in radio bands. Very good if we manage to detect strong lines. If the lines are weak it may be difficult to get the correct information.