Title: Probing the variation of fundamental constants using QSO absorption lines

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Abstract:

Probing the time variation of fundamental constants using QSO absorption lines

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Plan of this talk:

Variation of fundamental constants:

- Fine-structure constant: α

  Many-multiplet method–> Based on LP data
  Alkali-Doublet method

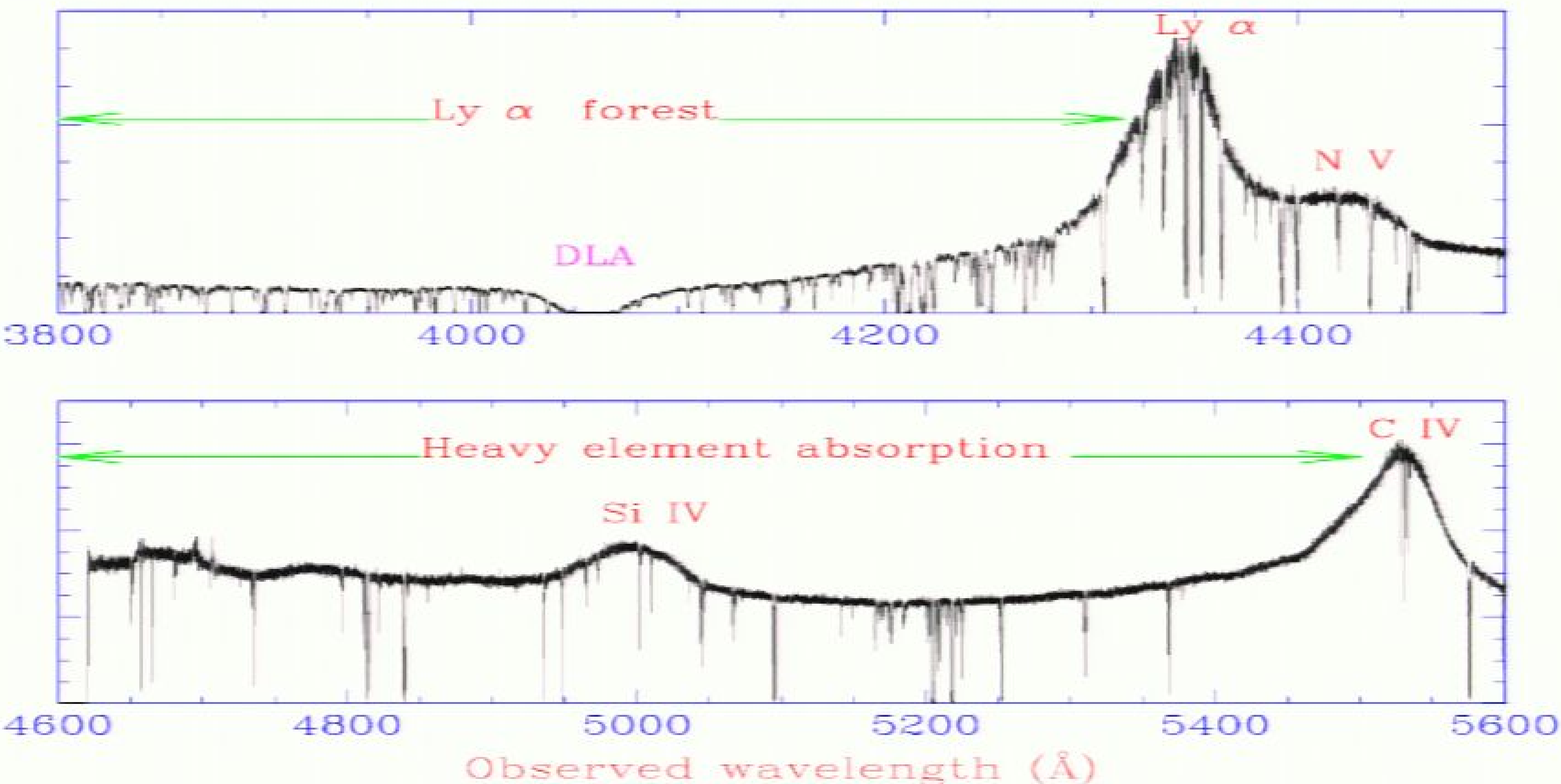
- Proton-to-electron mass ratio: μ

  Using H_2 and HD(?) –> H_2 survey using UVES

- Joint constraints on constants: $x = \alpha^2 G_p/\mu$

  21cm absorption systems–> 21cm survey using GMRT

QSO as a Probe of Cosmological evolution:



Variation of α : MM 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

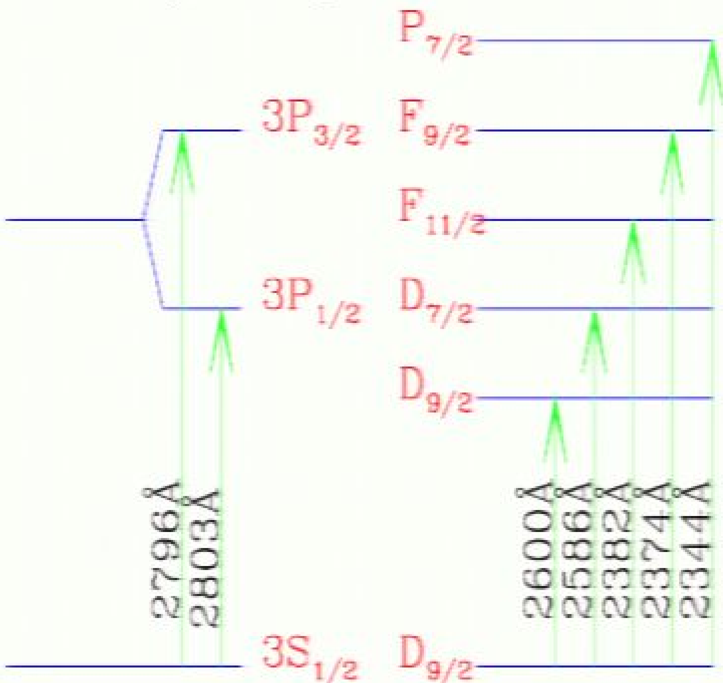
$$\omega_z = \omega_0 + q x_z$$

with

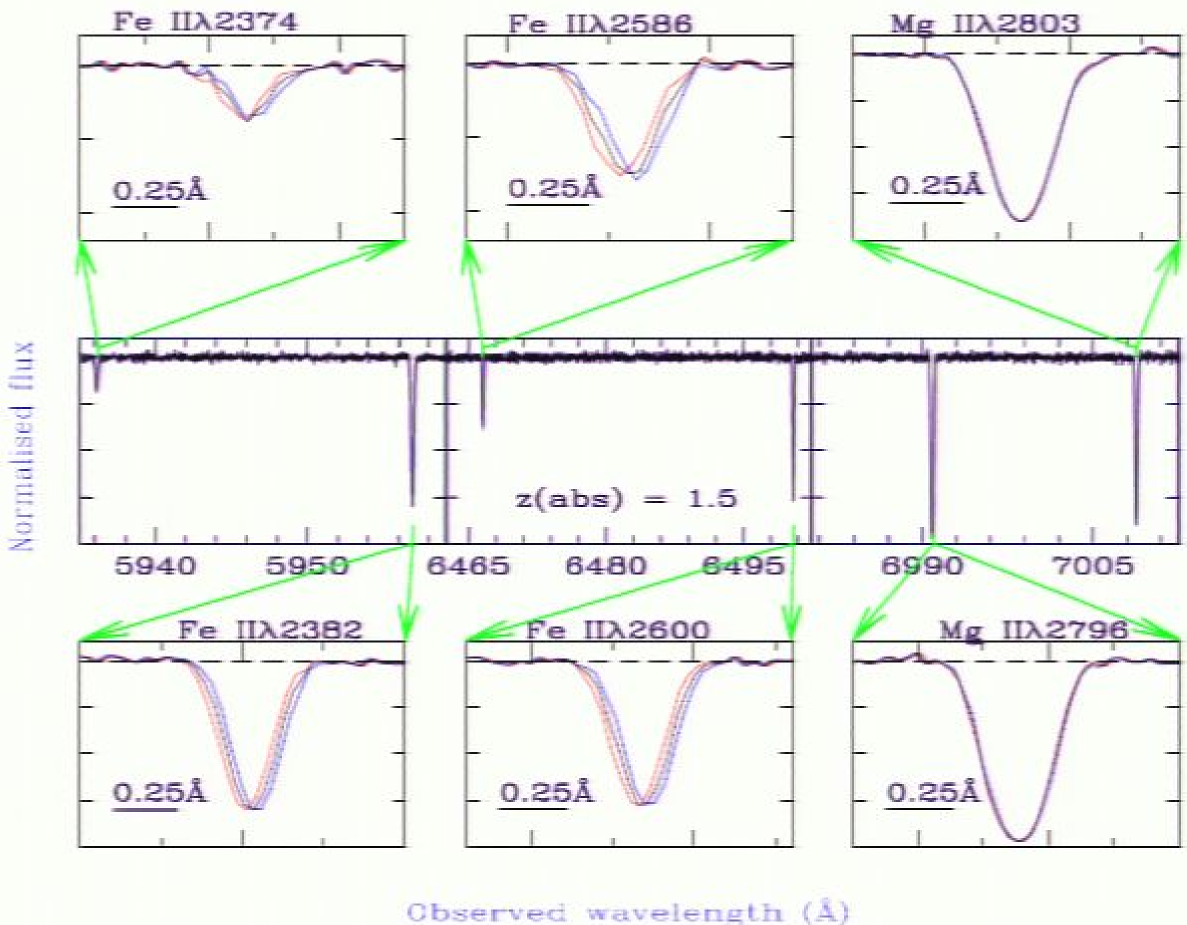
$$q = q_1 + 2q_2$$

Dzuba et al (1999)

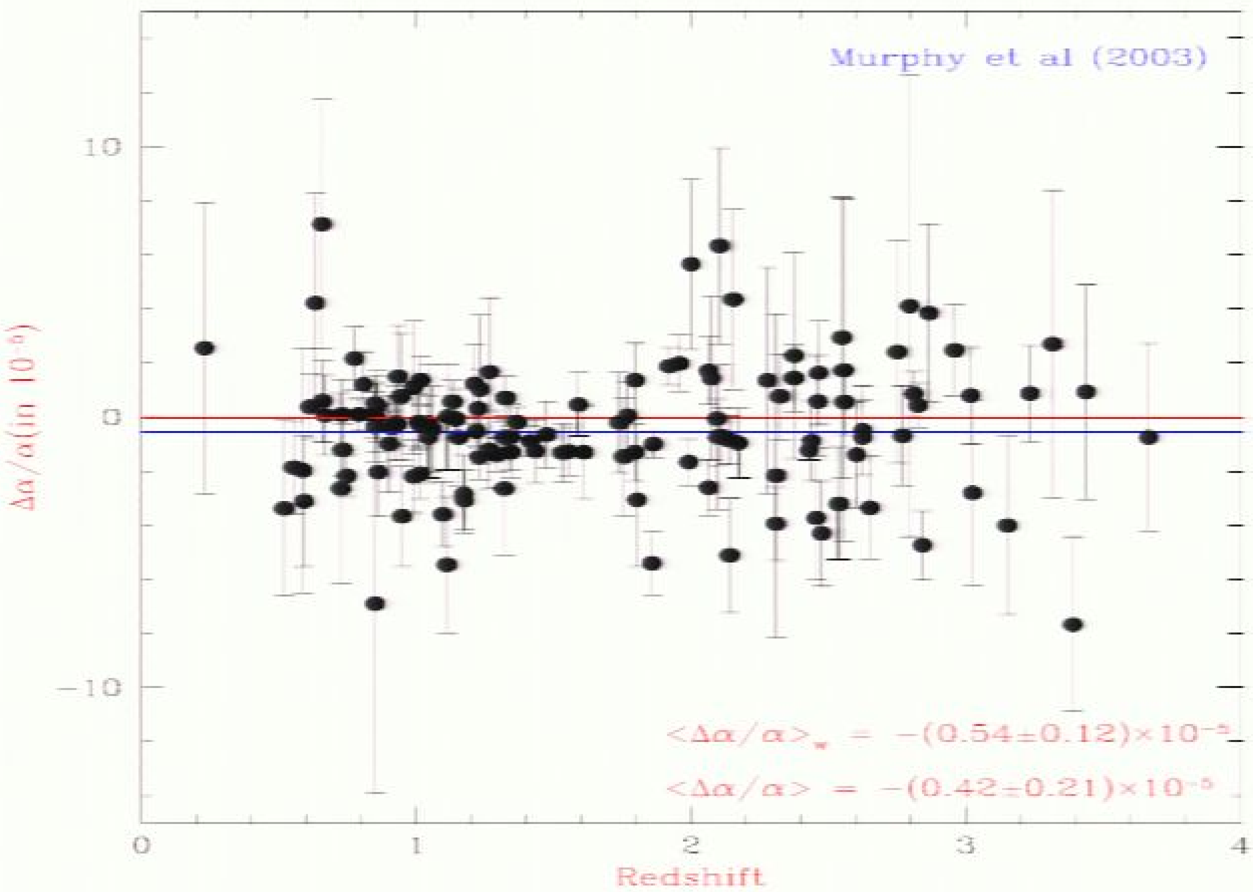
Many Multiplet method



Many Multiplet Method: Simulations



Many Multiplet Method: HIRES



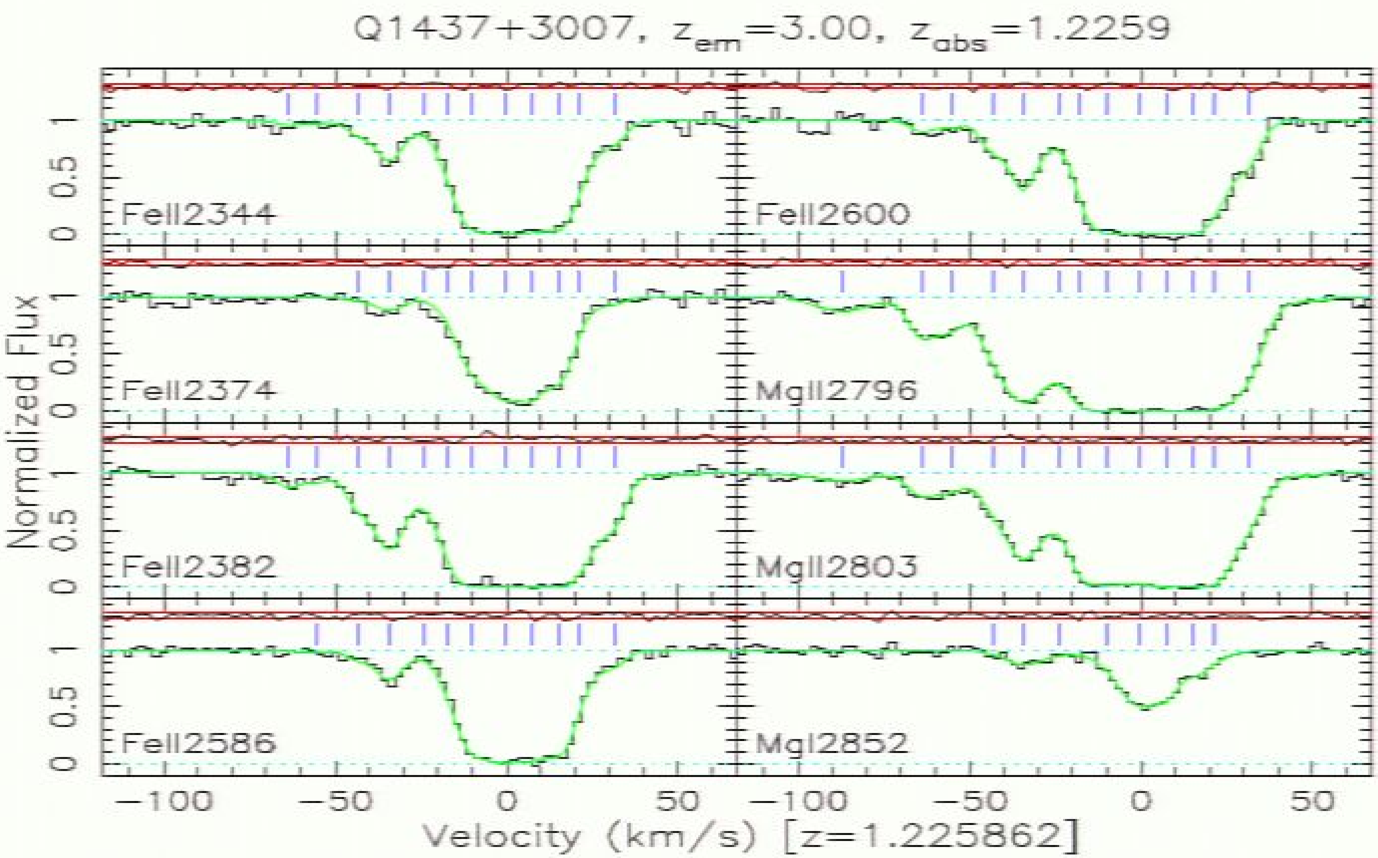
Many Multiplet Method: Reality

- The expected variation in α is very small ($\leq 10^{-5}$) and direct detection of consistent shifts is beyond available instruments.

- In general absorption profiles are complex. Usually a given absorption line is fitted with multiple Voigt profiles (each one having N, b and z). Degeneracies become prominent when the absorption profile gets more and more complex.

- Systematics can be minimised (not completely removed!) by careful selection of systems.

Many Multiplet Method (HIRES): complex profile



Murphy et al., 2003

Many Multiplet Method: Systematics?!!

Table 1: Different estimations for the same systems:

QSO	z	case 1	case2
0002+0507	0.85118	-0.346 ± 1.279	$+0.494 \pm 1.021$
1225+3145	1.7954	-1.296 ± 1.049	$+1.353 \pm 1.388$
1634+7037	0.99010	$+1.094 \pm 2.459$	-2.194 ± 1.343
2206−1958	1.0172	-0.322 ± 0.732	$+1.354 \pm 0.883$
2231−0015	2.0653	-2.604 ± 1.015	$+1.707 \pm 1.249$

Case 1: Previous low-z/high-z sample (Murphy et al. 2003)
Case 2: New sample (Murphy et al. 2003)

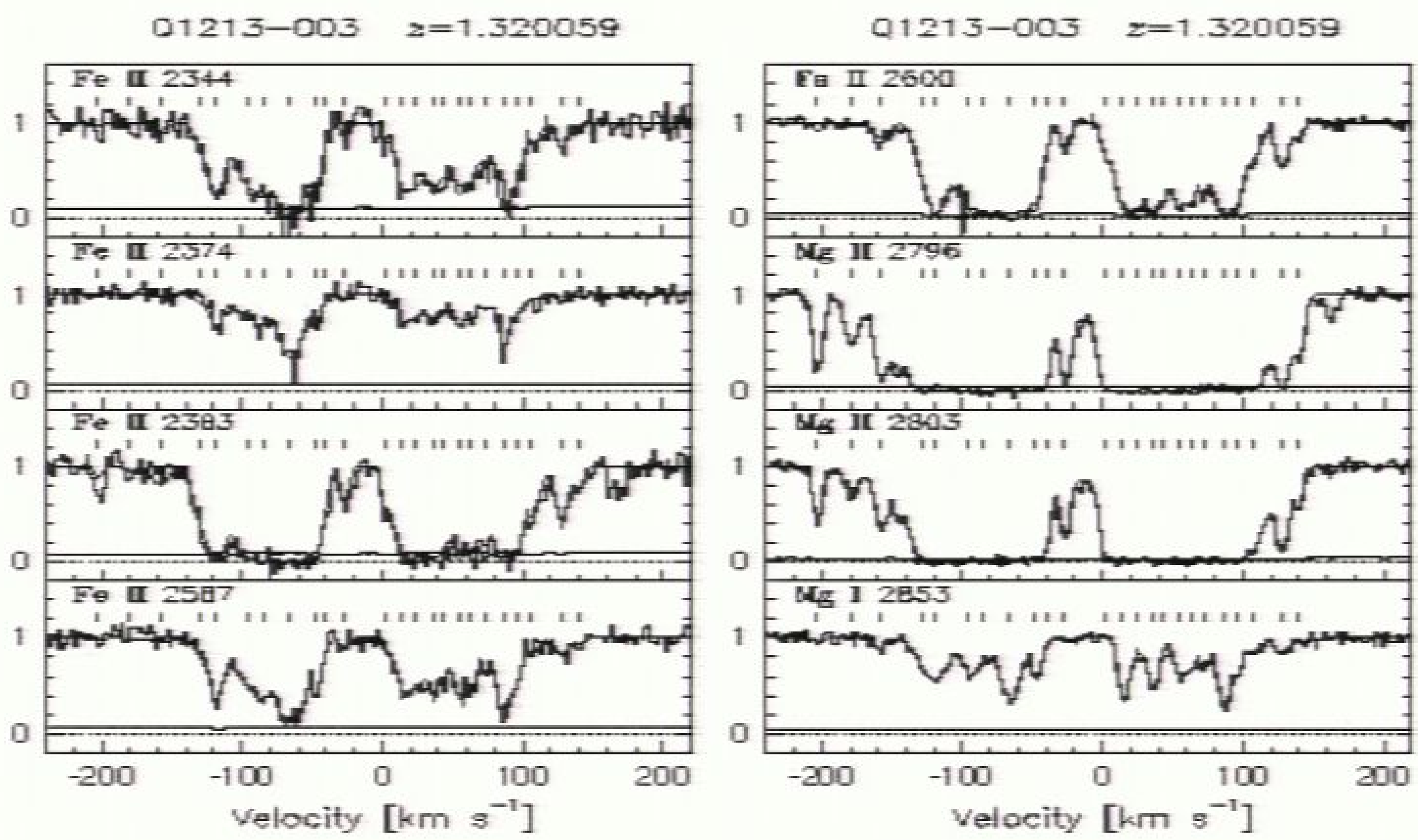
Ref: Table 3 of Murphy et al. 2003

Many Multiplet Method: Effect of line saturation

- Defining the number of components and their redshifts become difficult.
- Even if weak transition from the same species is unsaturated we will never be sure of a weak additional component in the saturated transition.

Effect of line saturation: “previous low-z sample”

Data from Dr. Churchill's home page http://astronomy.nmsu.edu/cwc/



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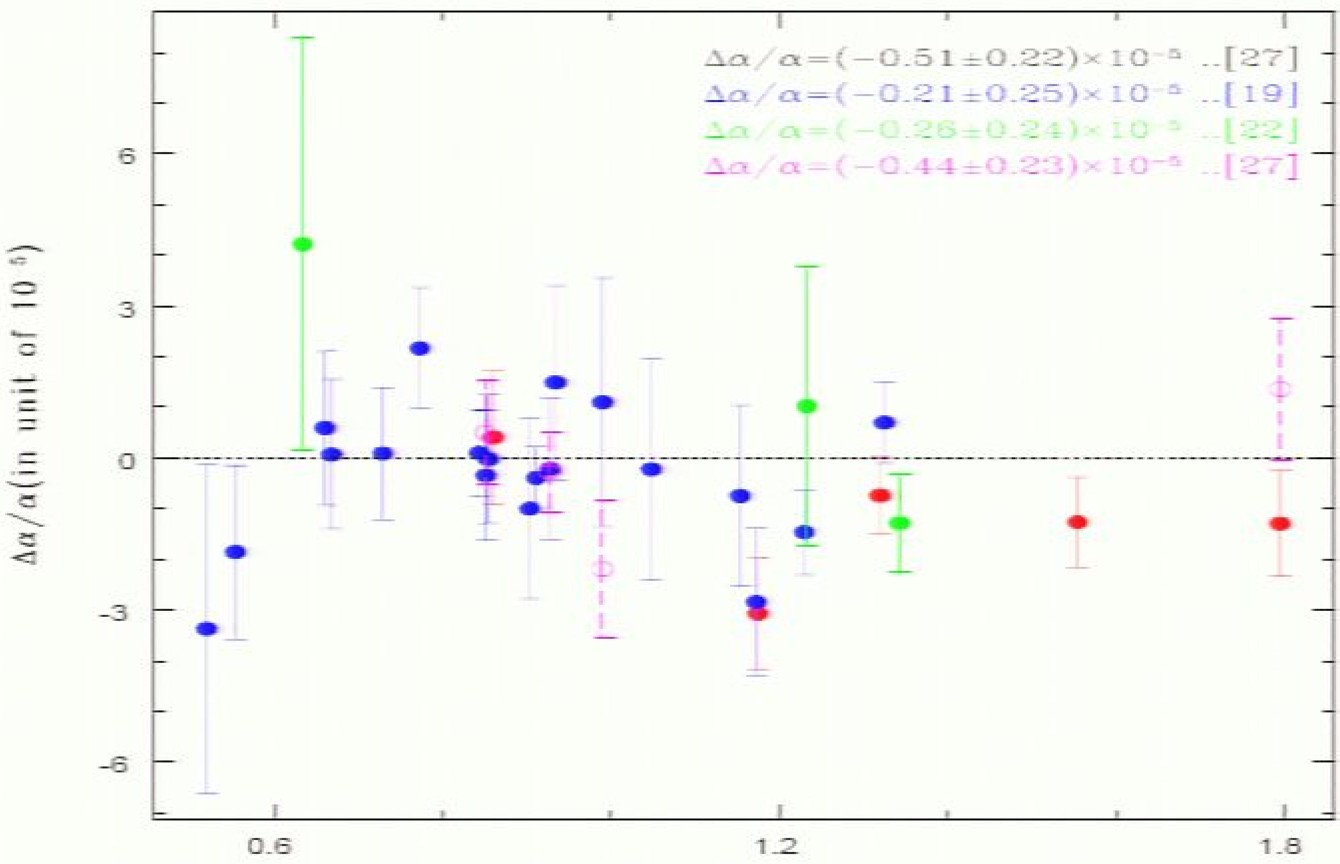

Many Multiplet Method: UVES analysis

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 $\Delta\alpha/\alpha$. (Try your best to minimize systematics)
- Avoid saturated systems –DLAs & Sub-DLAs
- Validating the statistical/line-fitting methods. (Simulation is the first step.)
- Presenting full analysis in detail. As the DATA is public, checking the results by various groups becomes easier.

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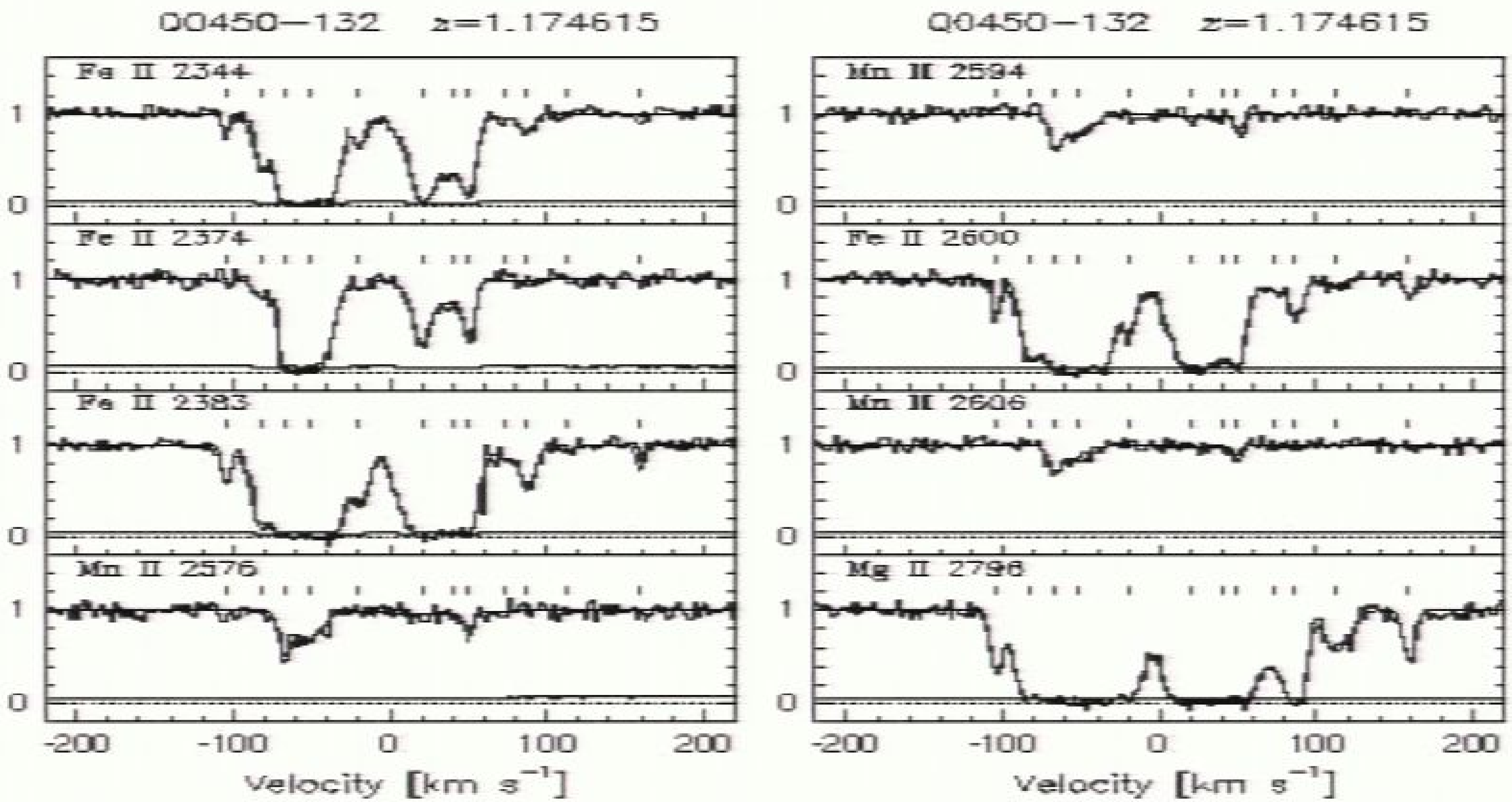

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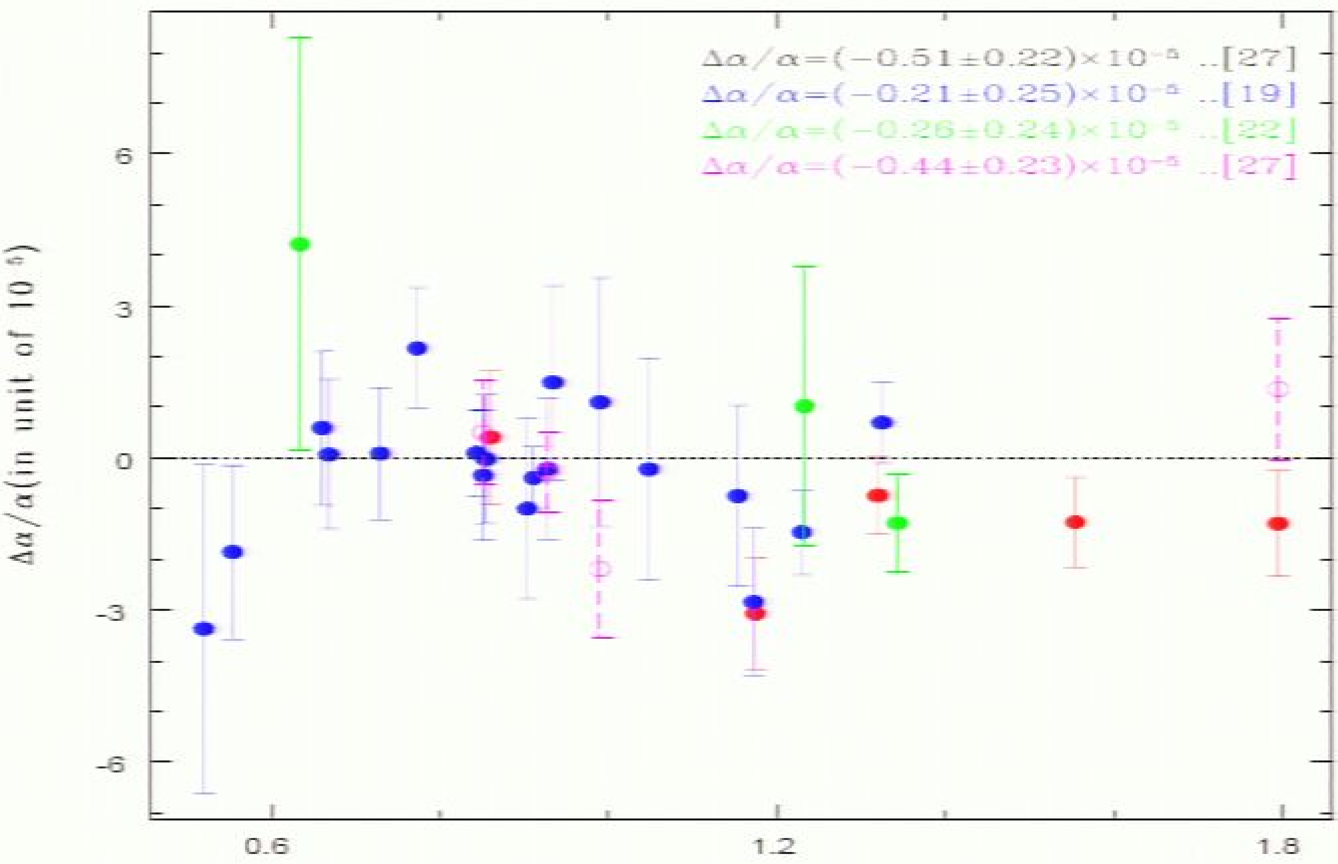

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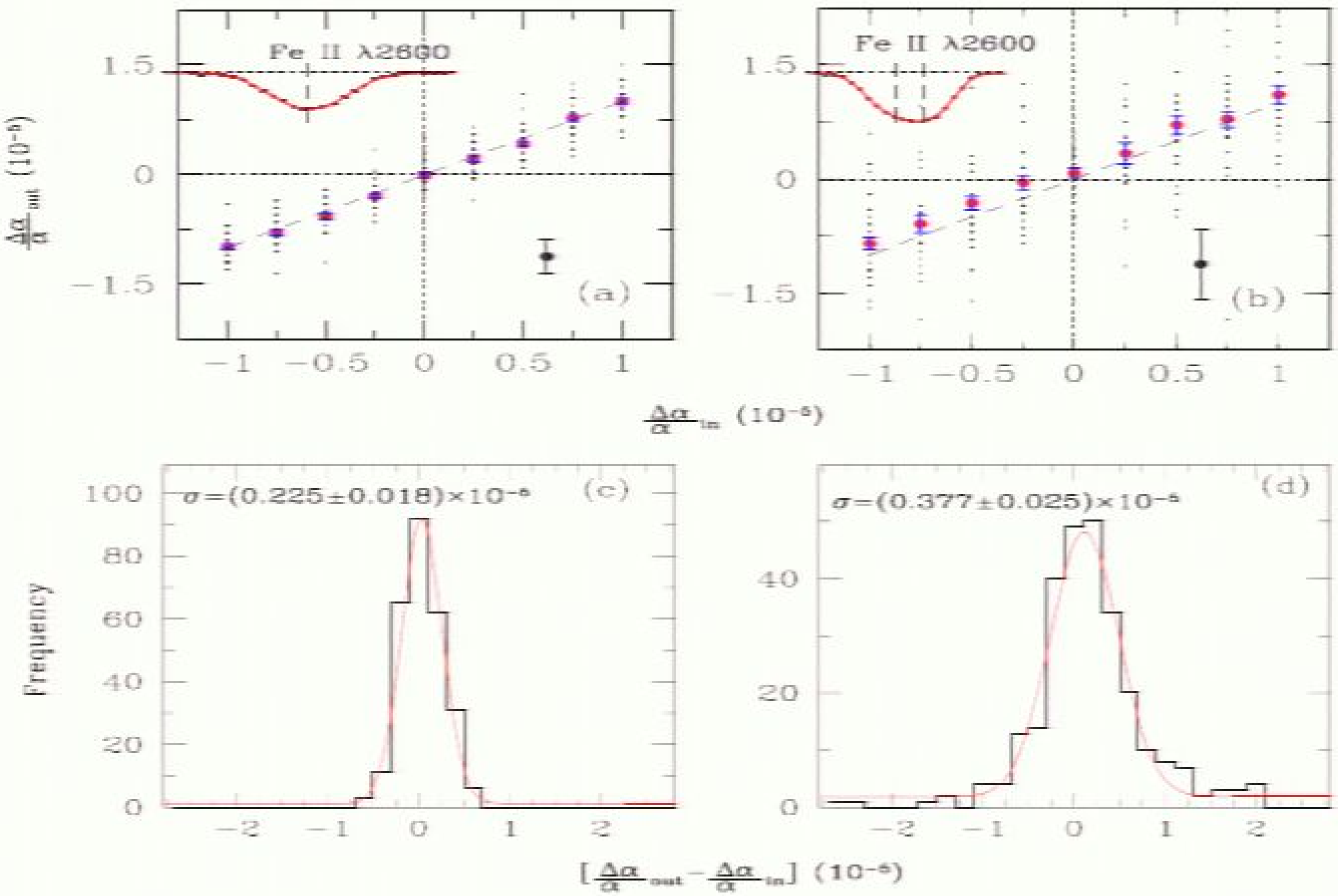
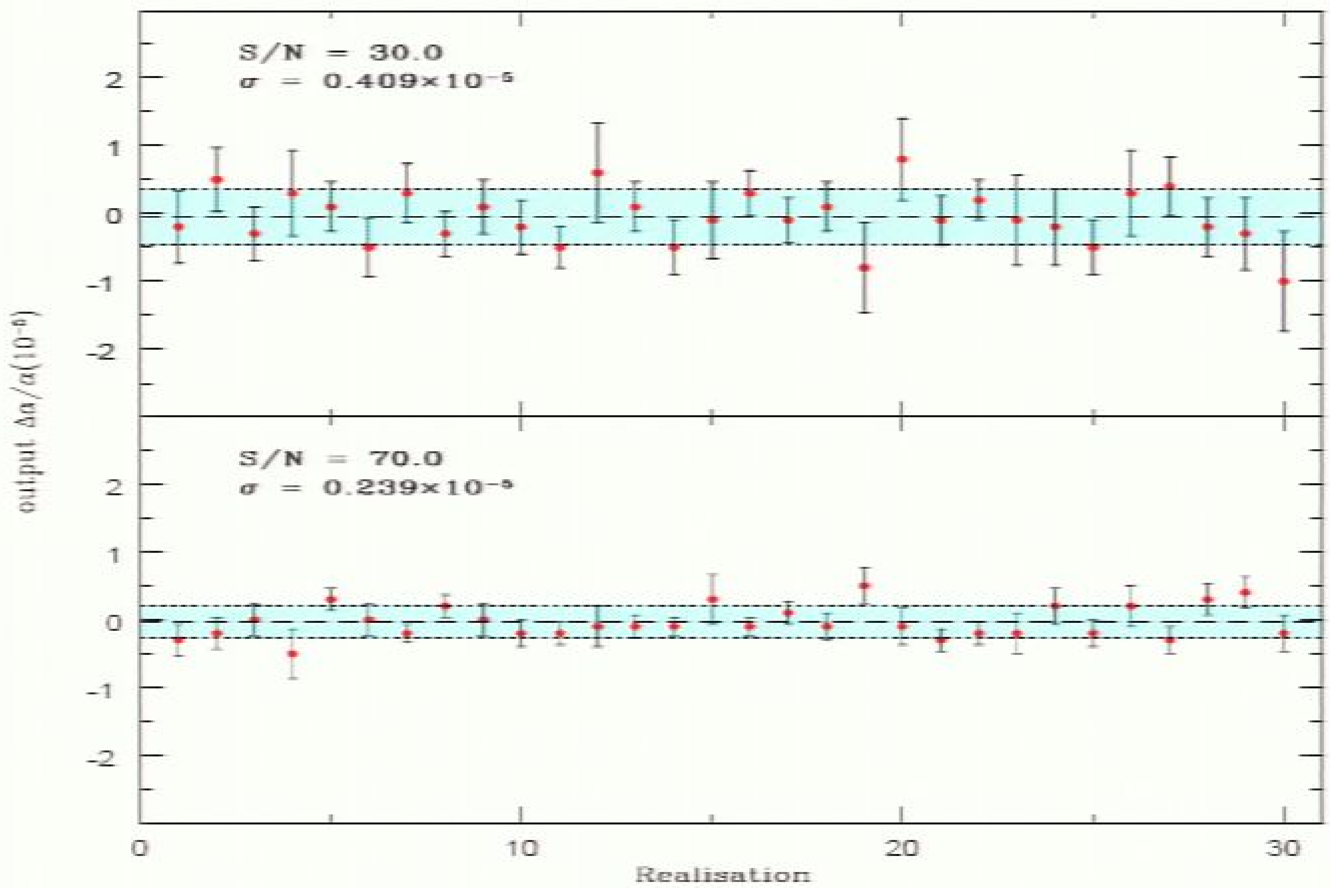
Many Multiplet Method: Validation of the procedure



Many Multiplet Method: Effect of signal-to-noise



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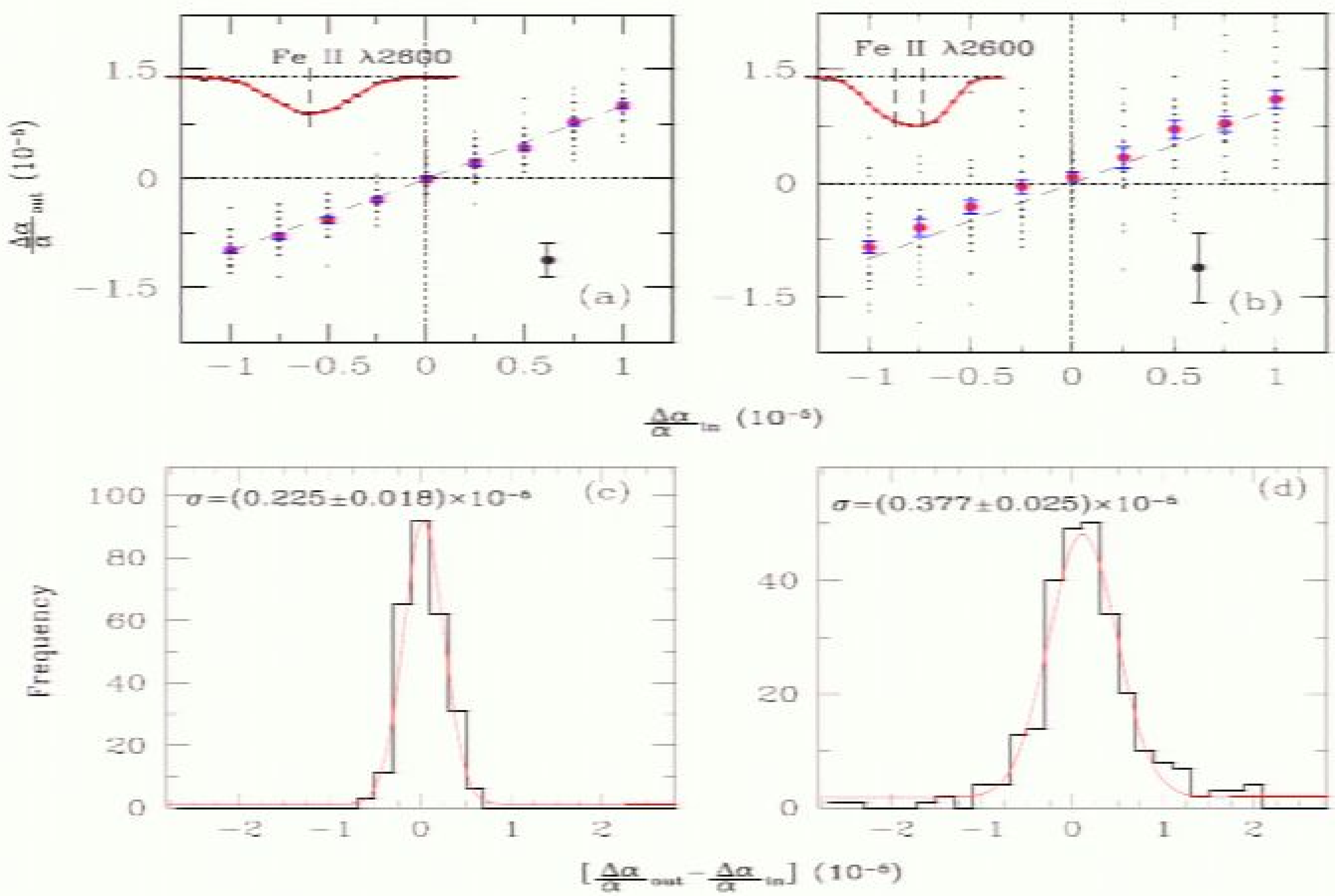

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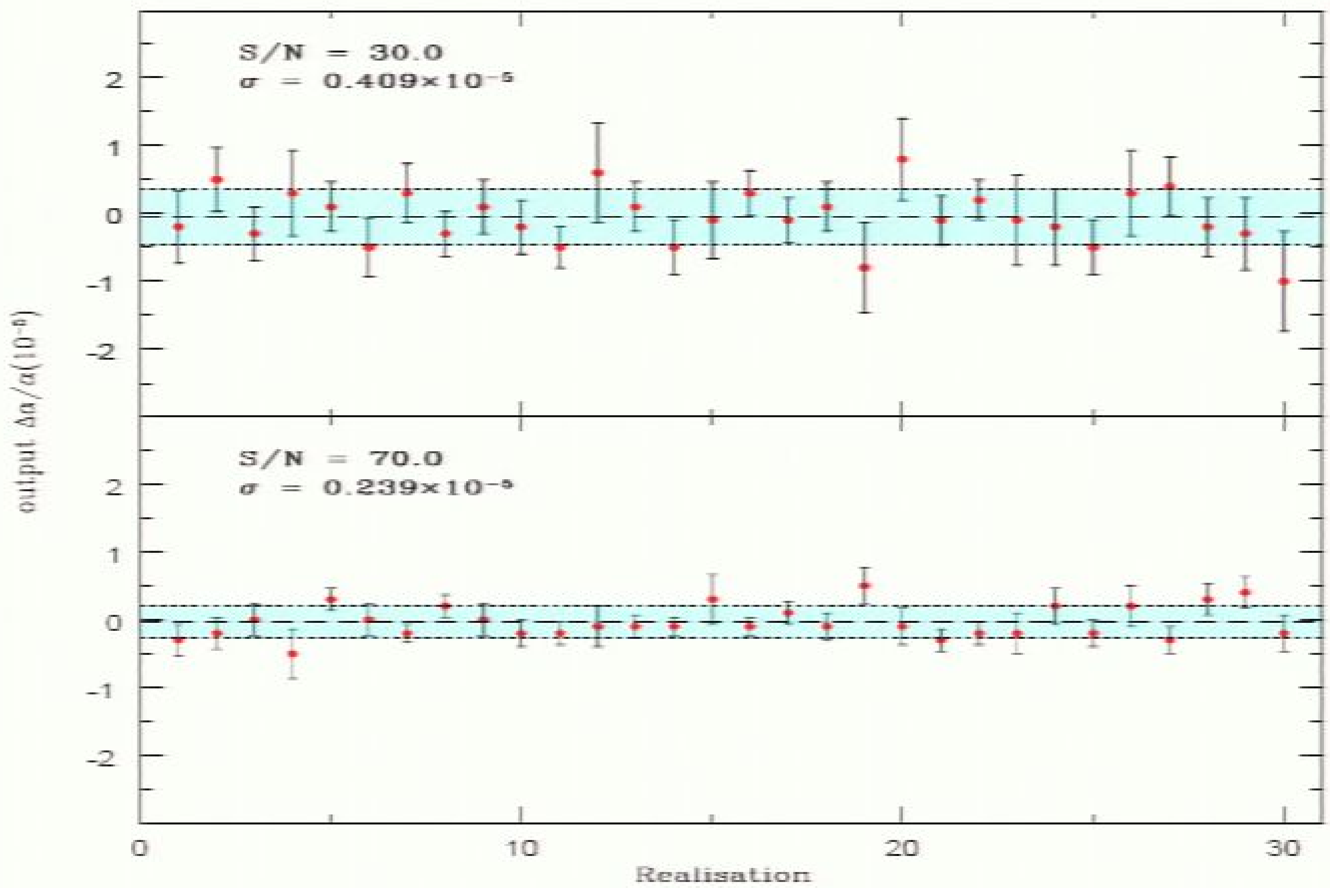
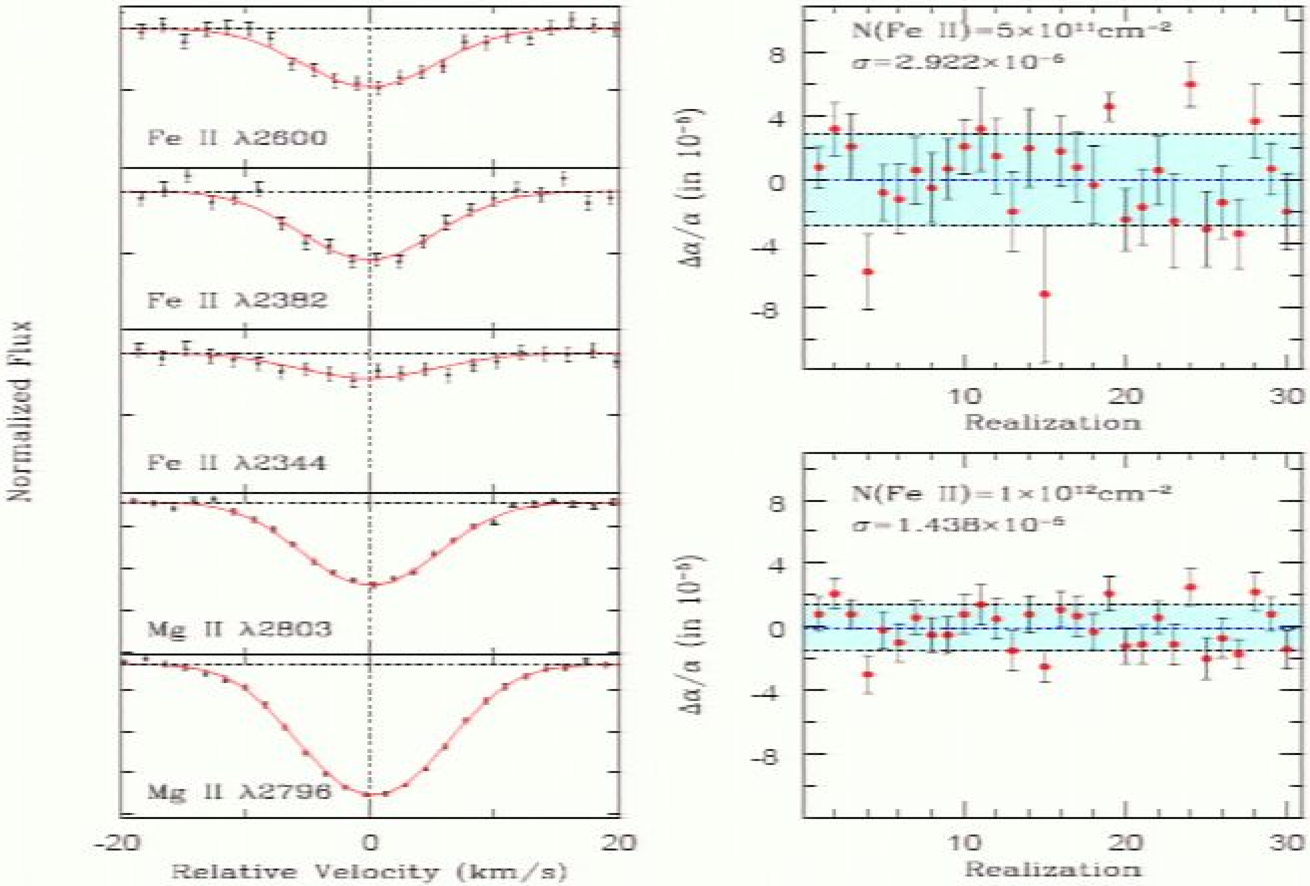


Many Multiplet Method: Effect of line strength



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.

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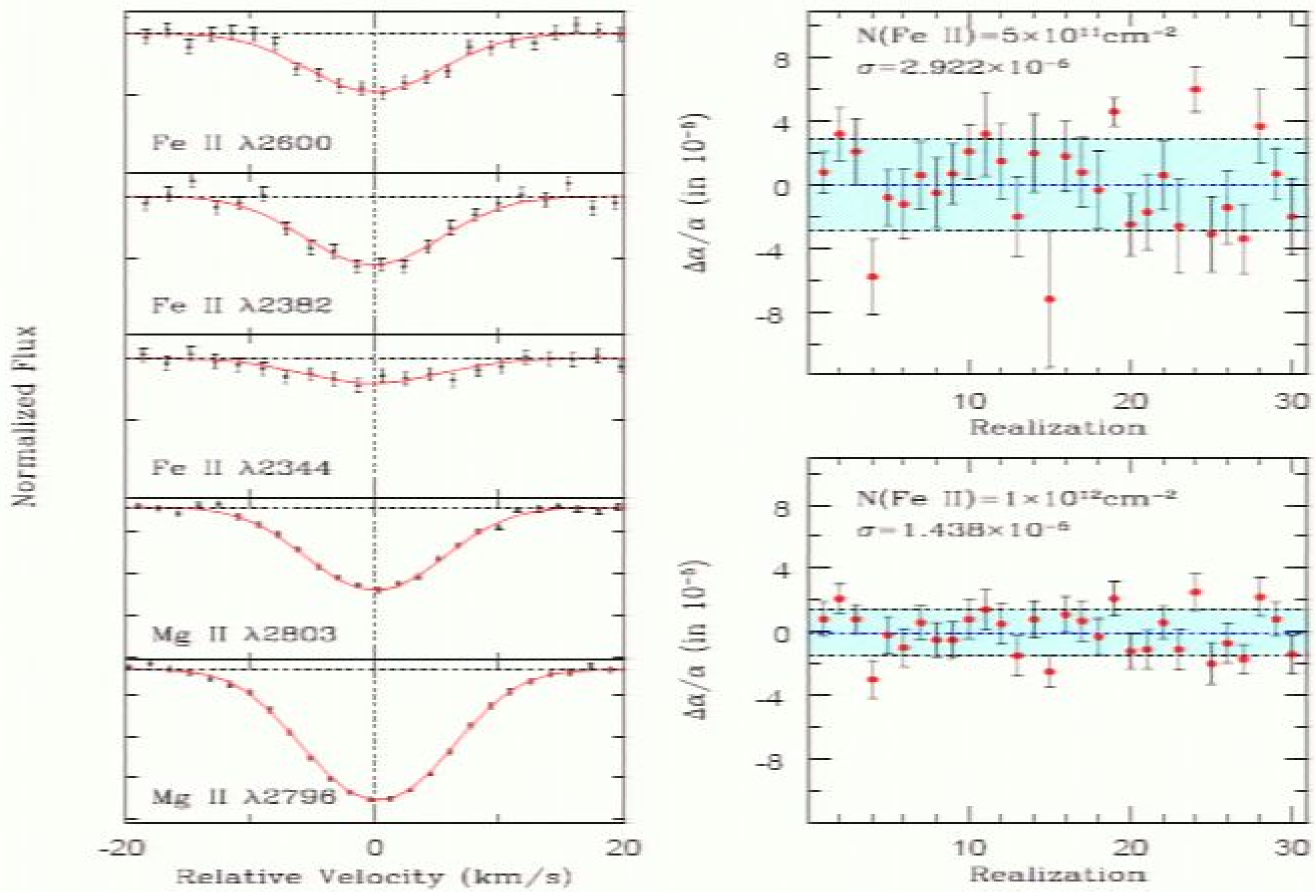

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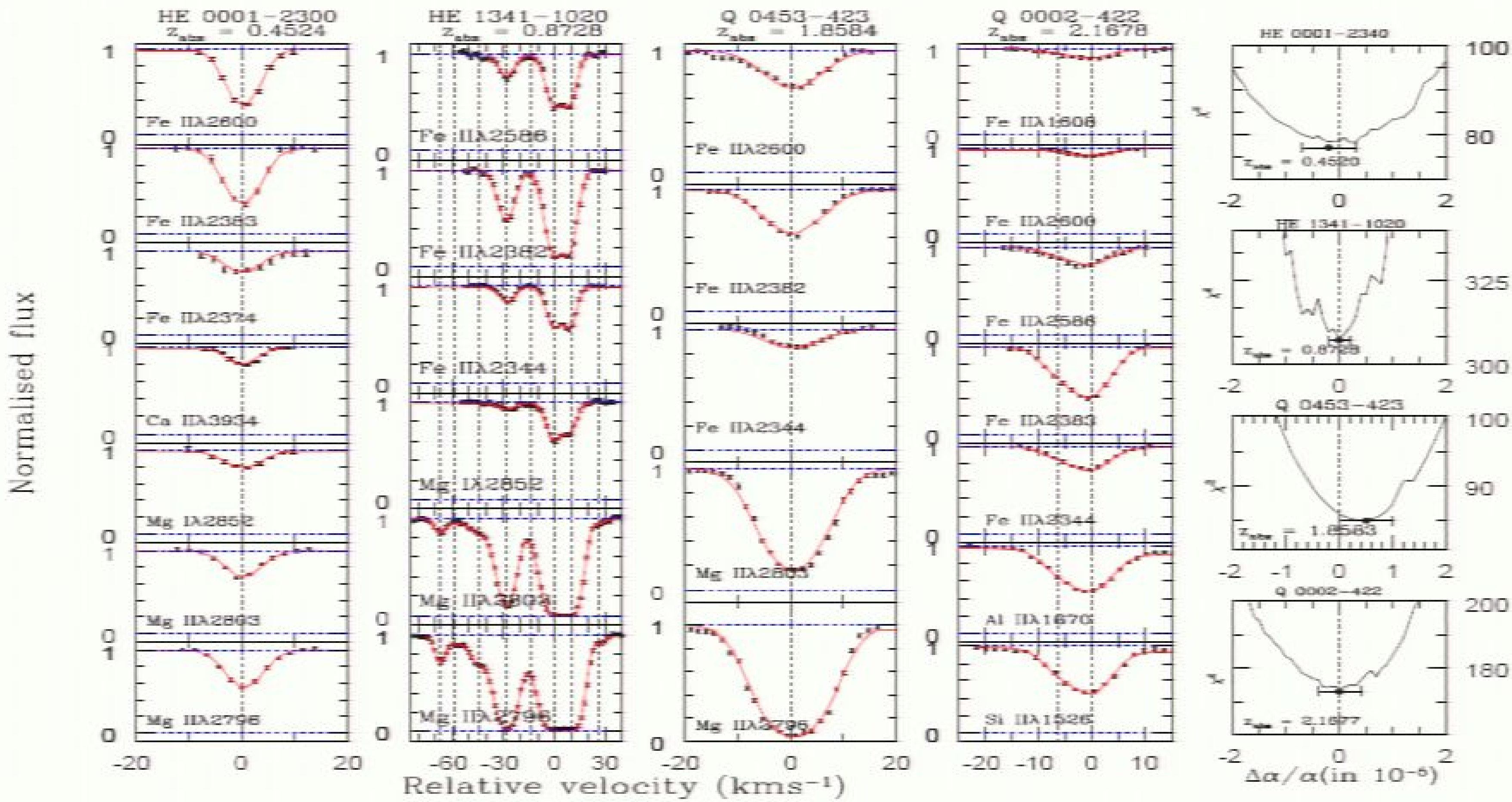
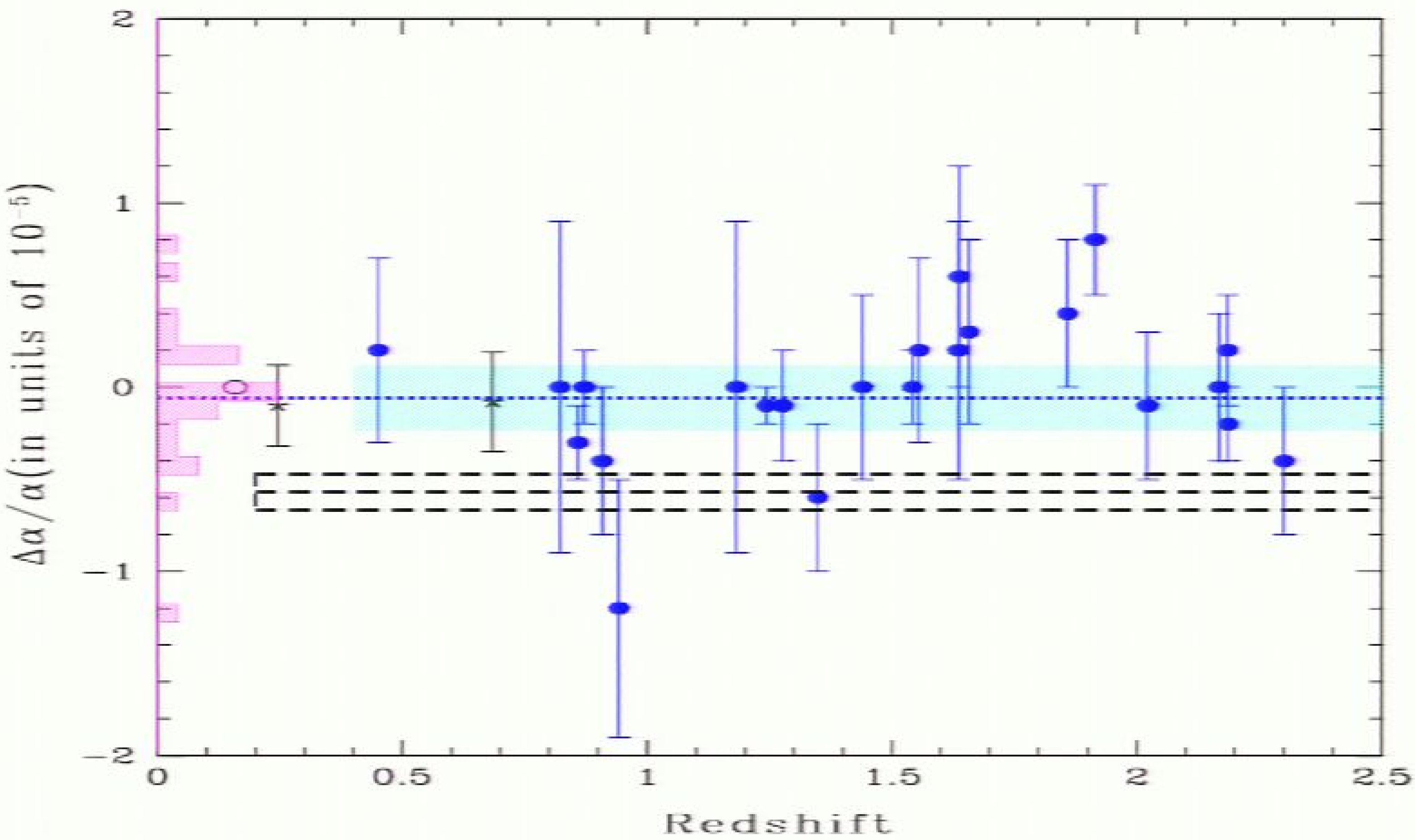
Many Multiplet Method: Data sample

- 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$\AA$.
- 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	$-(0.54 \pm 0.12)$ $-(0.86 \pm 0.10)$	2.38 2.43
Srianand et al. 2004/ Chand et al. 2004	23	0.4–2.3	$-(0.06 \pm 0.06)$ $-(0.36 \pm 0.06)$	0.41 0.44
Quast et al. 2004	1	1.15	$-(0.04 \pm 0.19)$	
Levshakov et al. 2004	2	1.15,1.85	$+(0.04 \pm 0.15)$	
Levshakove et al. 2007	1	1.84	$+(0.54 \pm 0.25)$	

ALKALI DOUBLETS

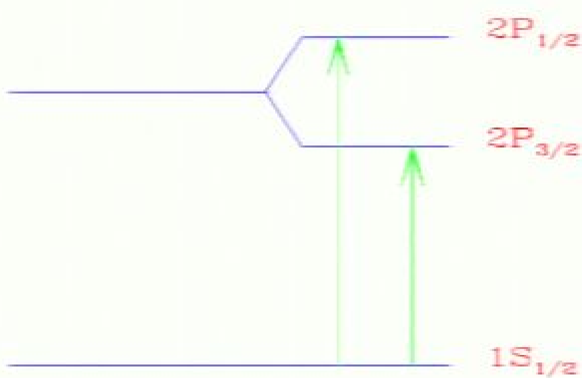
- **Doublets at high z:**

  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)

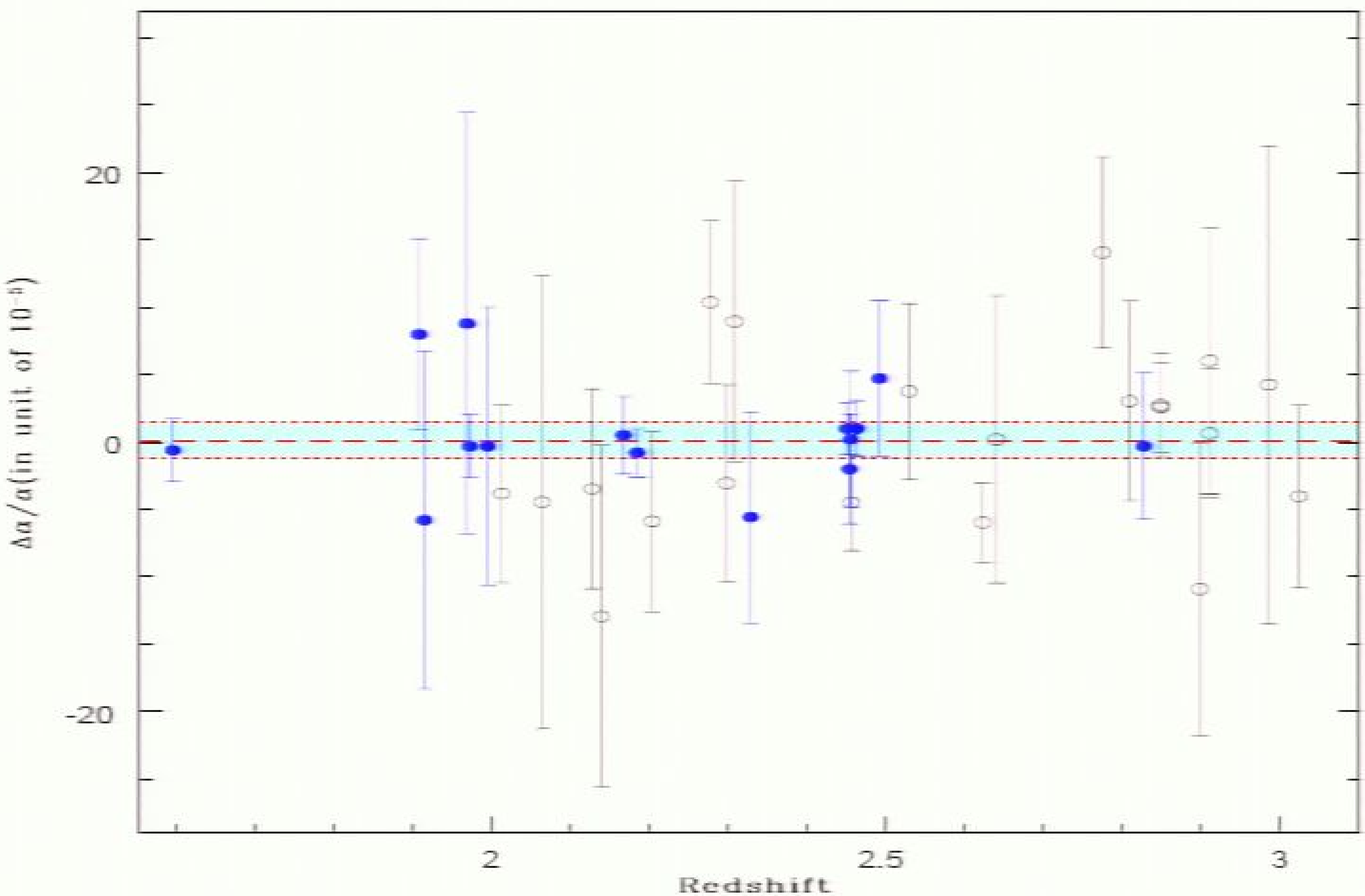
- **Spin orbit interaction:**

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

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



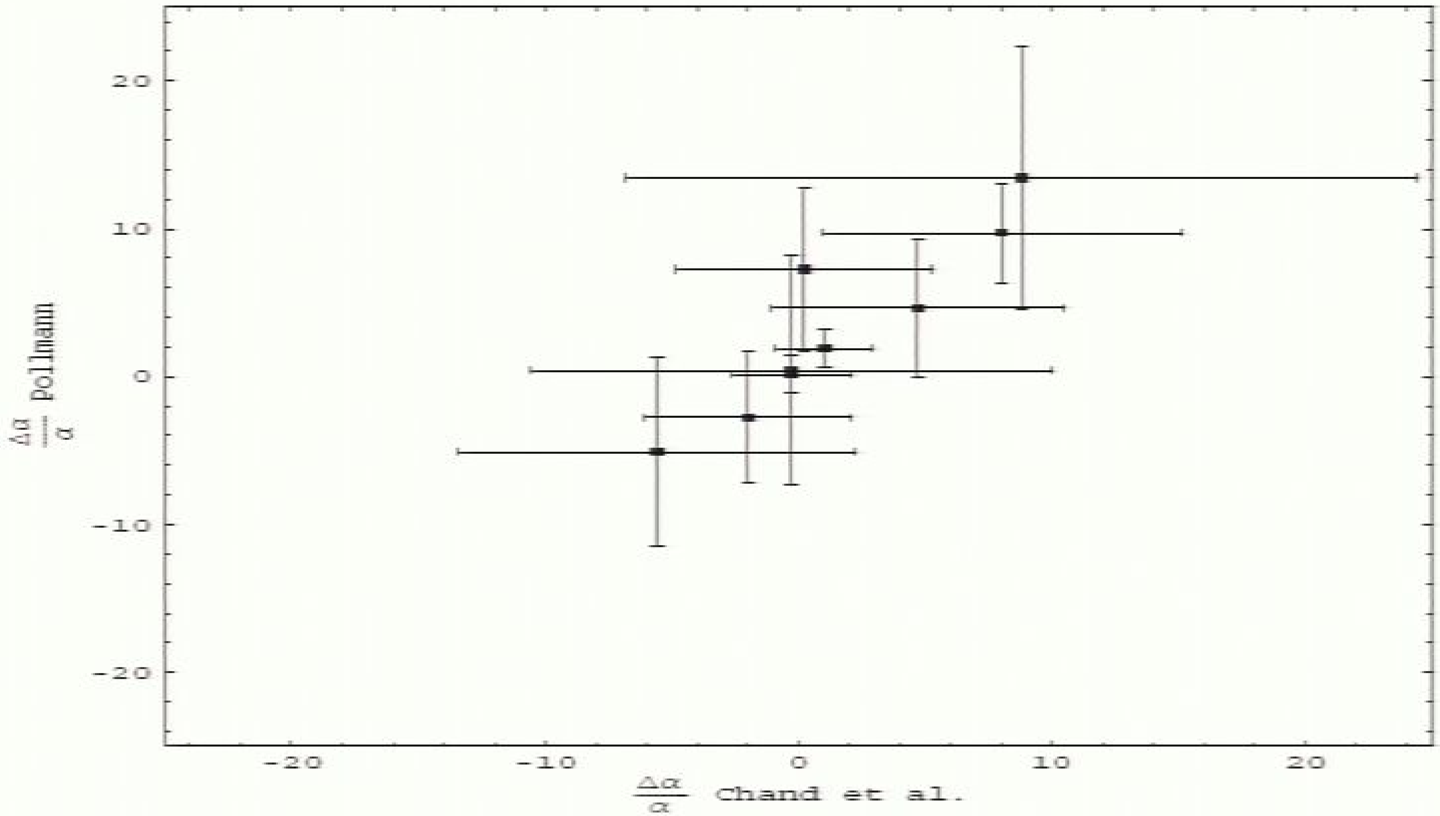
ALKALI DOUBLETS: New UVES results



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., (2005)
36			$-(0.02 \pm 0.55)10^{-5}$	Chand et al., (2005)

ALKALI DOUBLETS: Reanalysis



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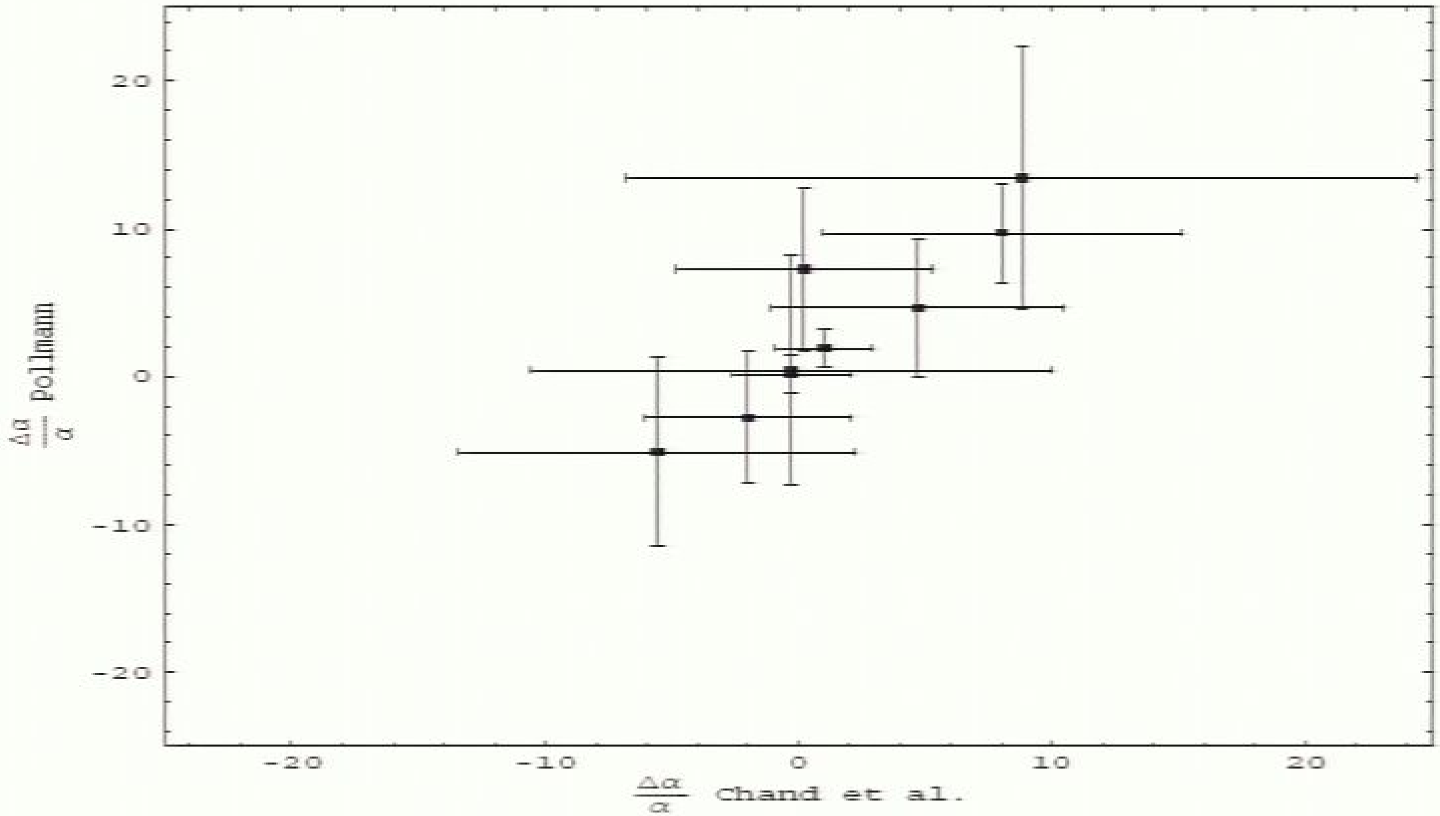
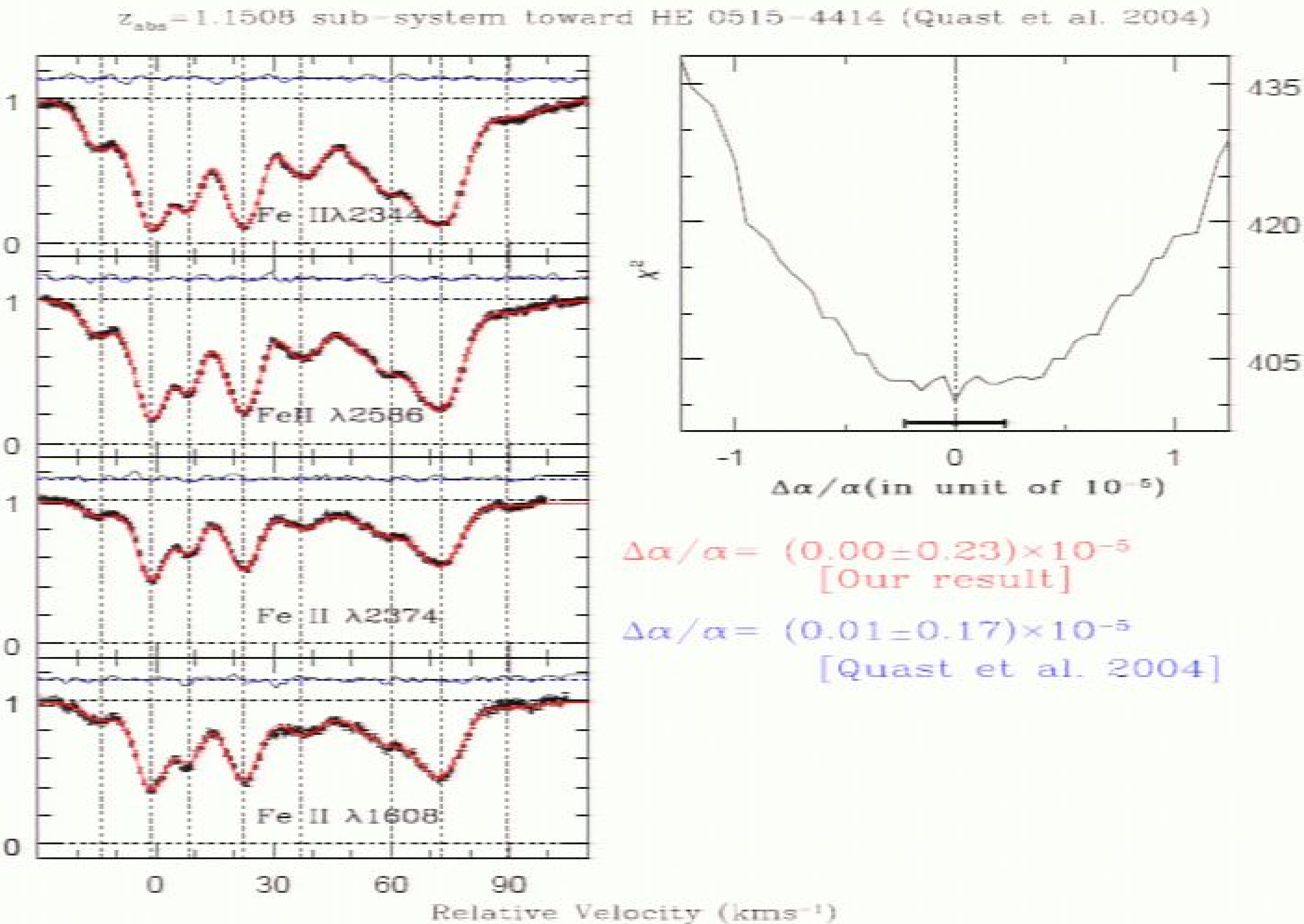


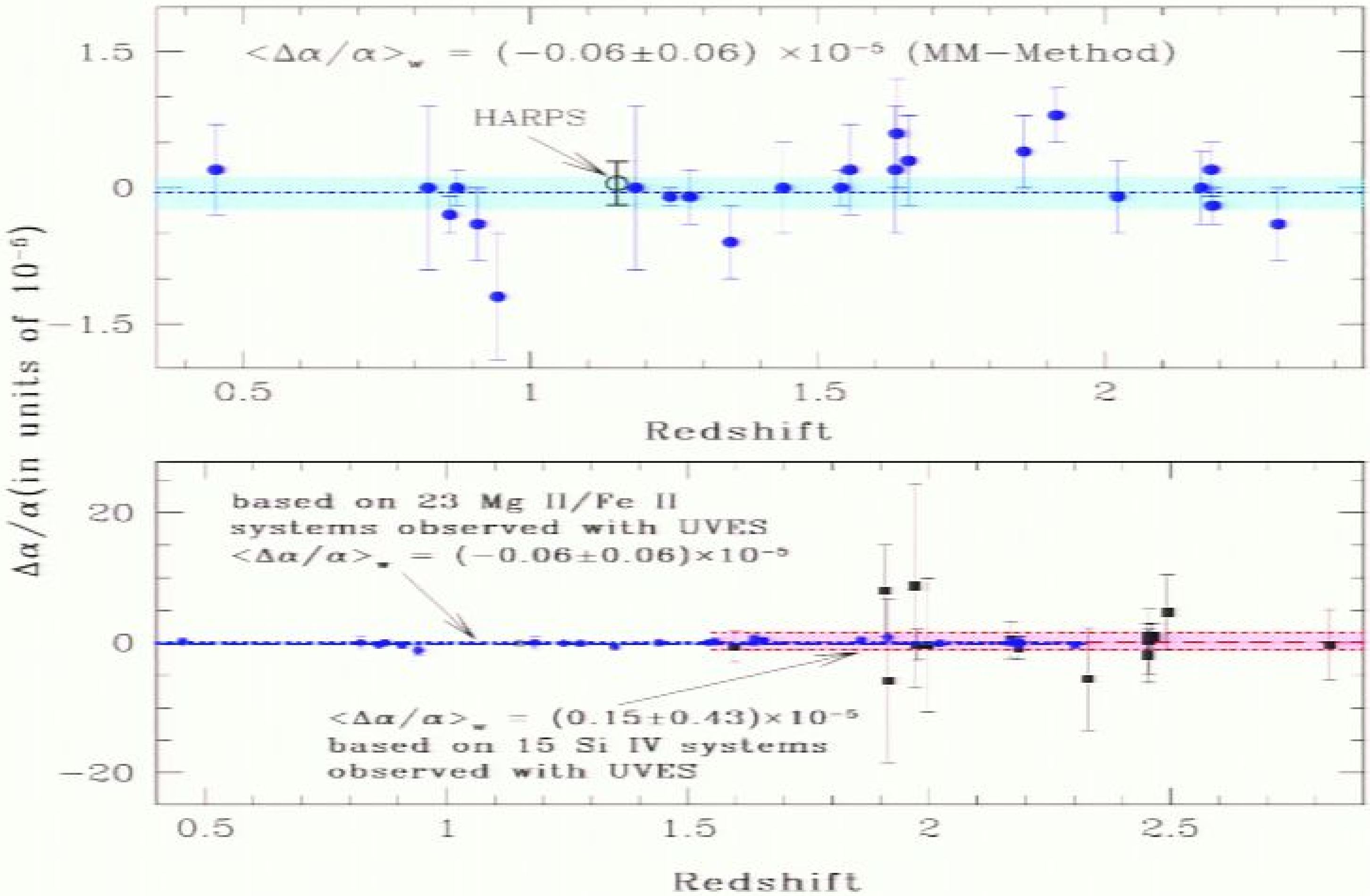
Reanalysis of Quast et al's data:



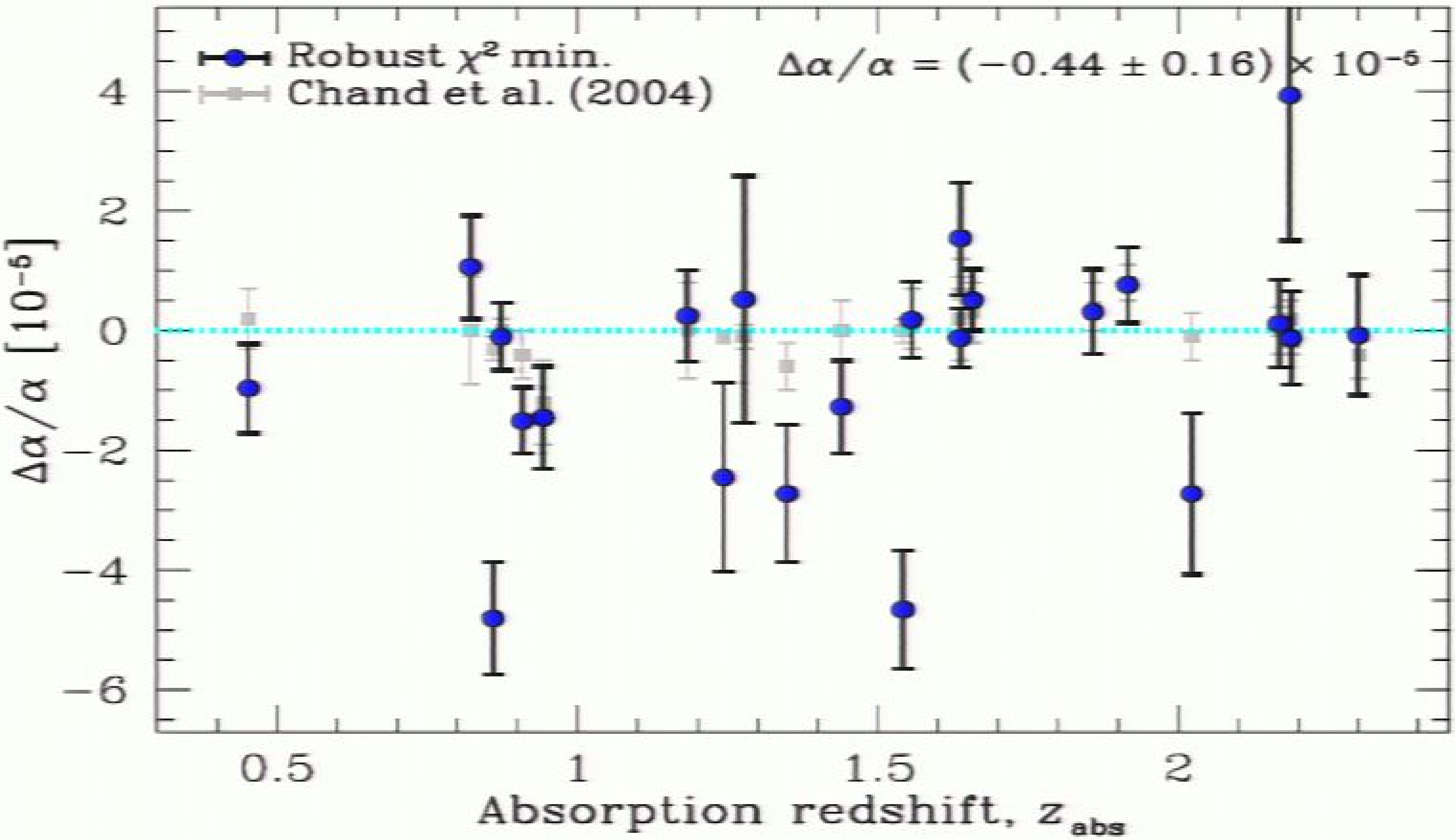
$\Delta\alpha/\alpha = (0.00 \pm 0.23) \times 10^{-5}$
[Our result]

$\Delta\alpha/\alpha = (0.01 \pm 0.17) \times 10^{-5}$
[Quast et al. 2004]

Results based on UVES samples till date:



Reanalysis of LP data by Murphy et al.



Reanalysis of LP data by Murphy et al.

Immediate response:

- In the case of z= 1.5419 system towards Q0002-422 and z = 0.8593 system towards Q0122−380 the results, $\Delta\alpha/\alpha = -4.655 \pm 0.988 \times 10^{-5}$ and $\Delta\alpha/\alpha = -4.803 \pm 0.941 \times 10^{-5}$, are an order of magnitude larger than the final quoted result.

- The weighted mean of other 21 systems is $\Delta\alpha/\alpha = -0.19 \pm 0.16 \times 10^{-5}$.

- For 16 systems the 1σ allowed ranges overlap we get $\Delta\alpha/\alpha = +(0.03 \pm 0.09) \times 10^{-5}$ for Chand et al. (2004) and $\Delta\alpha/\alpha = +(0.06 \pm 0.18) \times 10^{-5}$ for Murphy et al. 2007.

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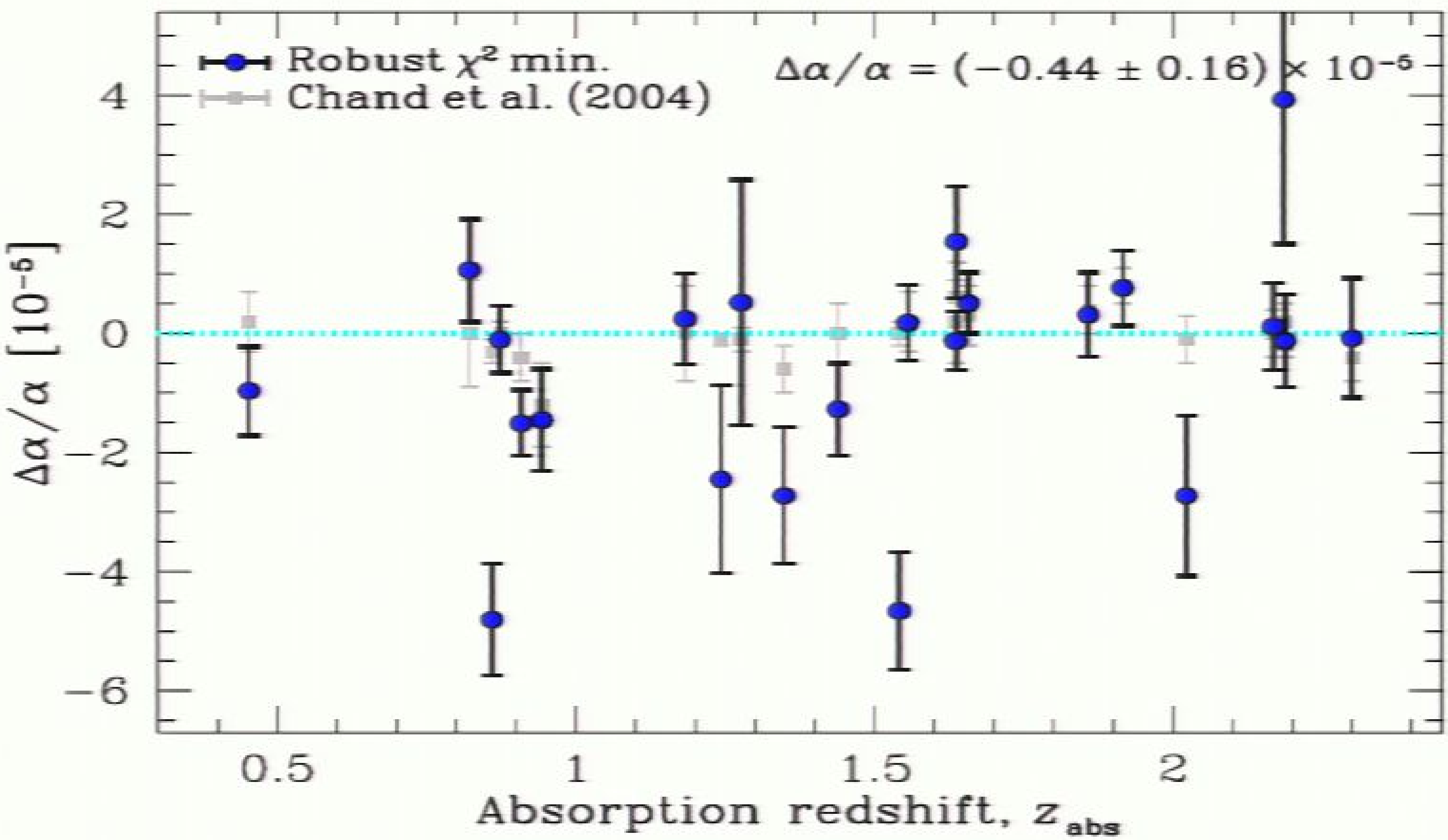

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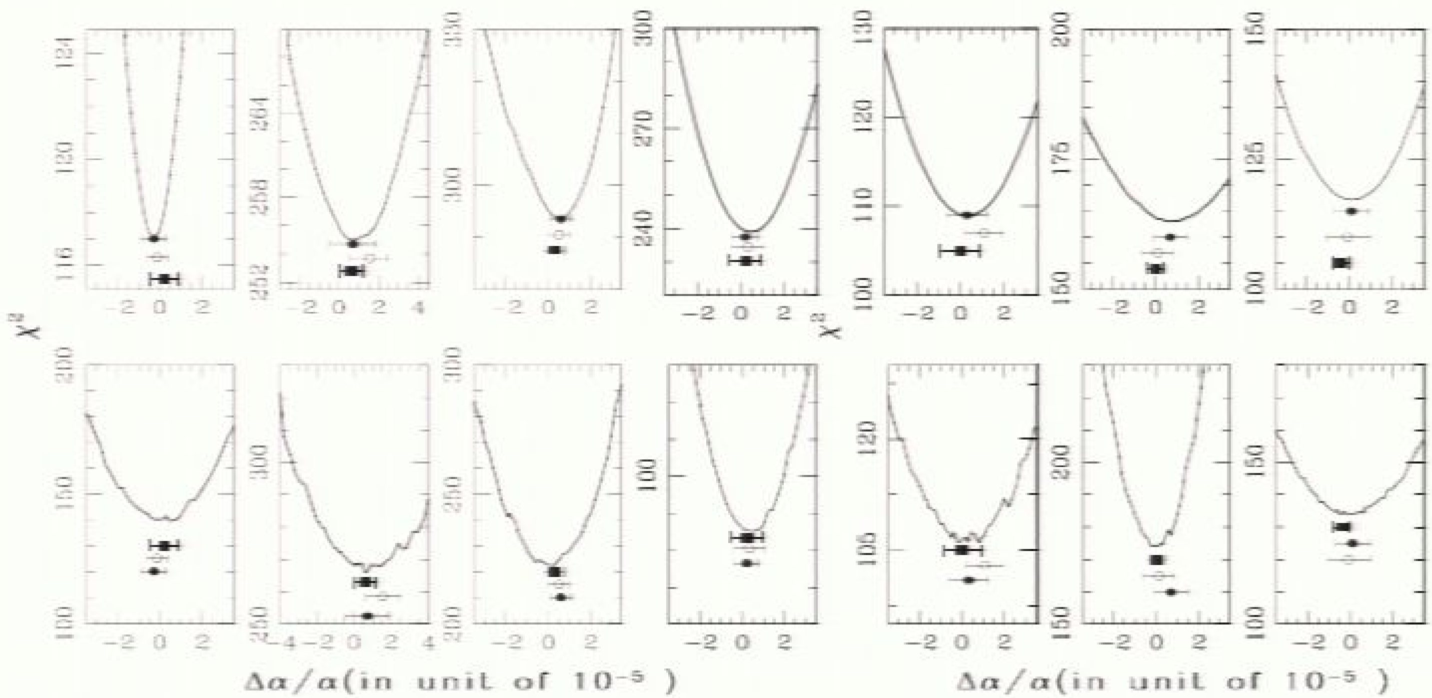
Reanalysis of LP data by Murphy et al.

Detailed response:

- Is our code systematically pushing the χ^2 curves towards zero on an average by 0.5×10^{-5} in $\Delta\alpha/\alpha$? - not seen in the simulations
- Do we underestimate the errors?
- Reanalysis using standard VPFIT code but keeping α as an external parameter. The data points and errors are identical the component structure and initial guess parameters are kept identical.
- Reanalysis using our code keeping $\Delta\alpha/\alpha$ as an internal parameter. -in progress

Srianand et al. 2008, PRL,100b9902S

Reanalysis of LP data with VPFIT:



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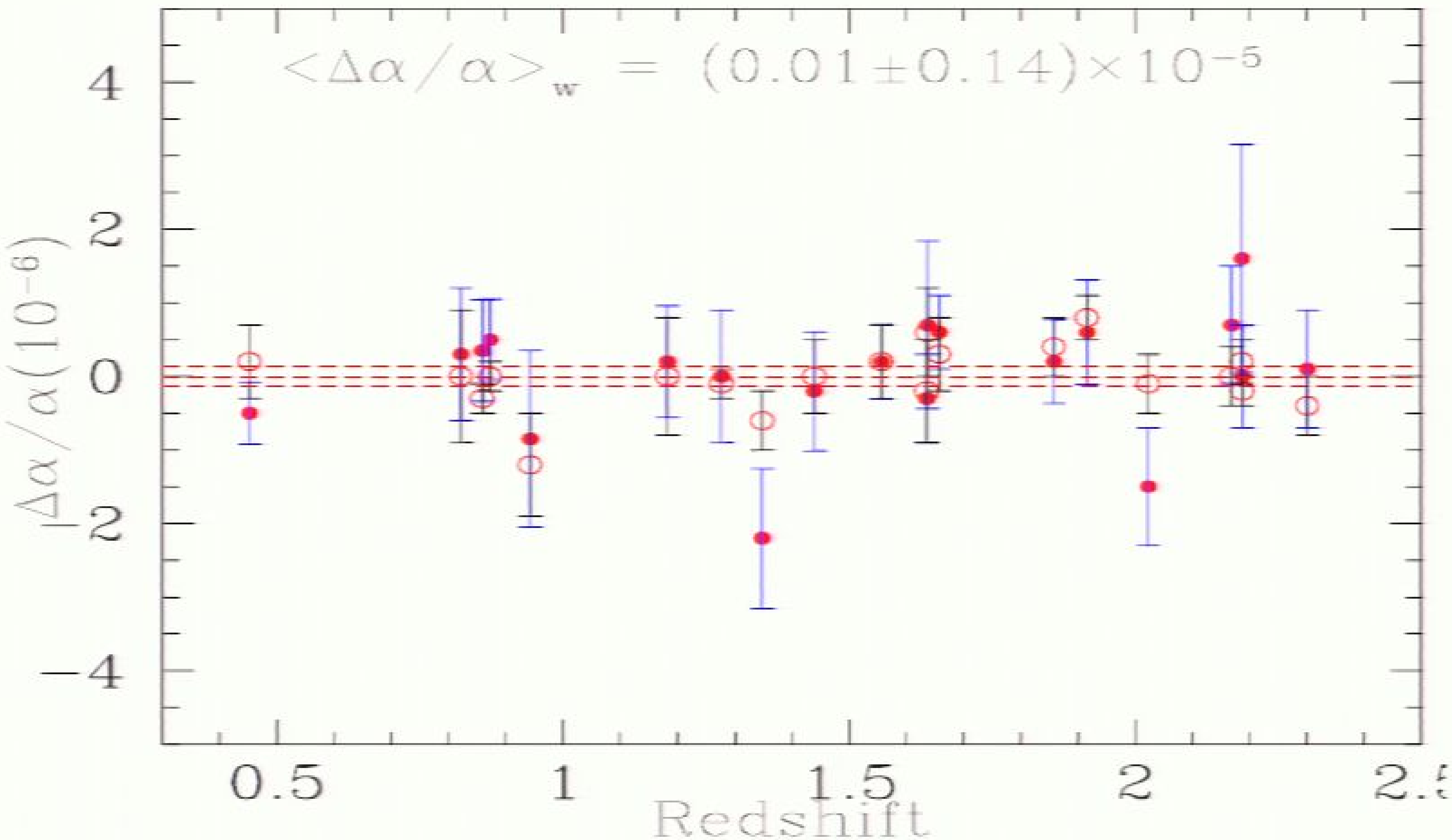
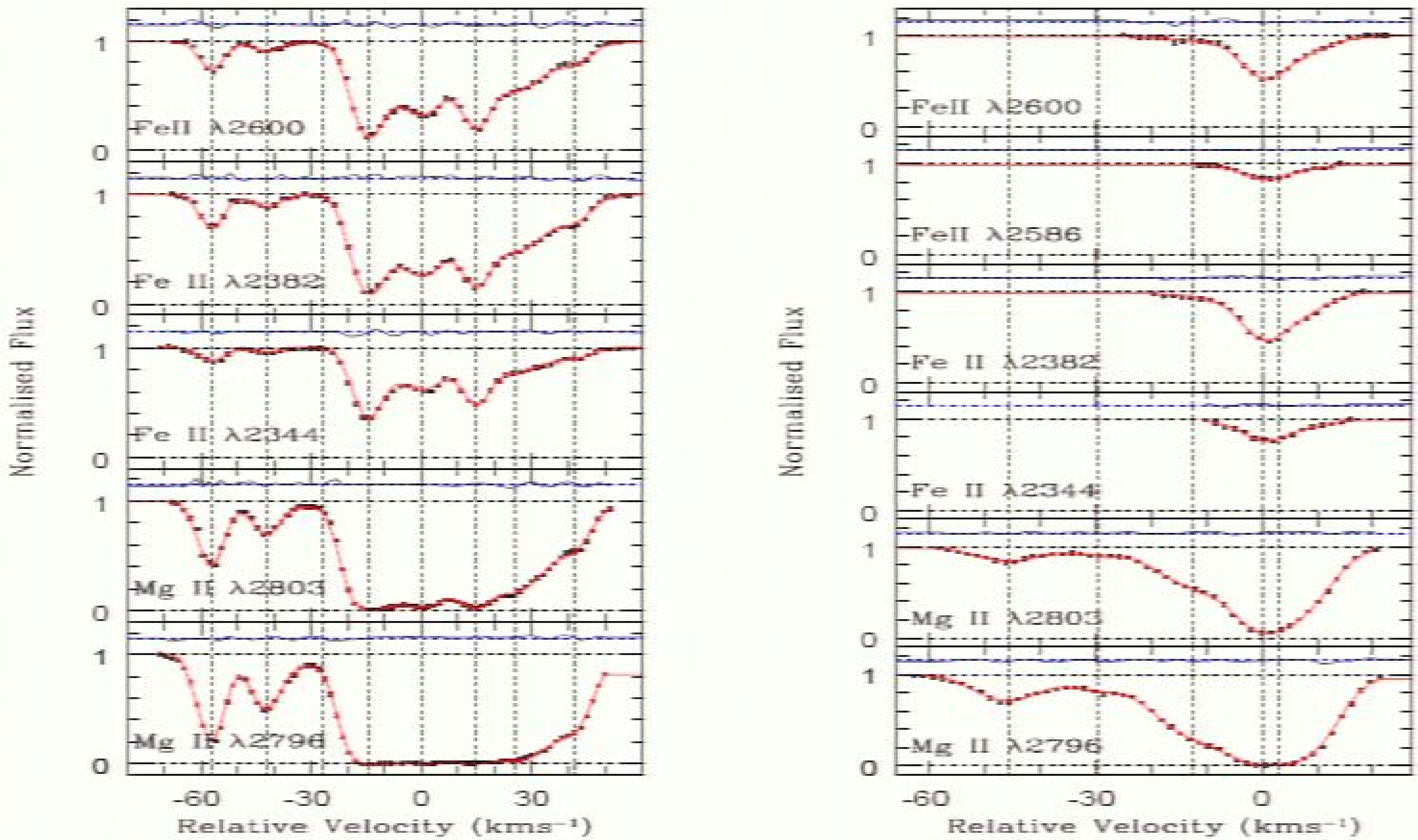


Reanalysis of LP data with VPFIT: 2 systems



z = 0.9084 (Q0453-423) and z = 1.5419 (Q0002-422)

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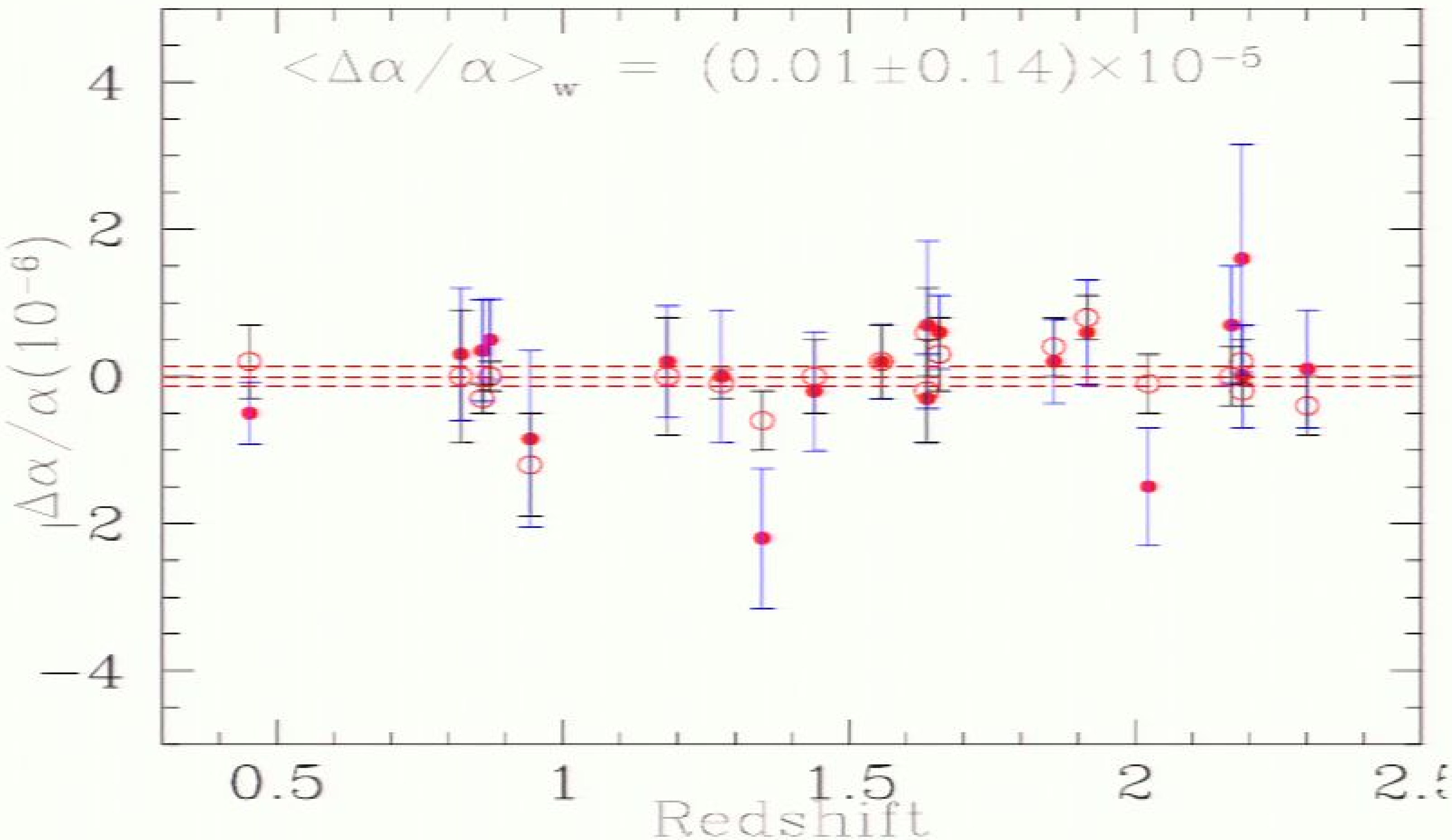

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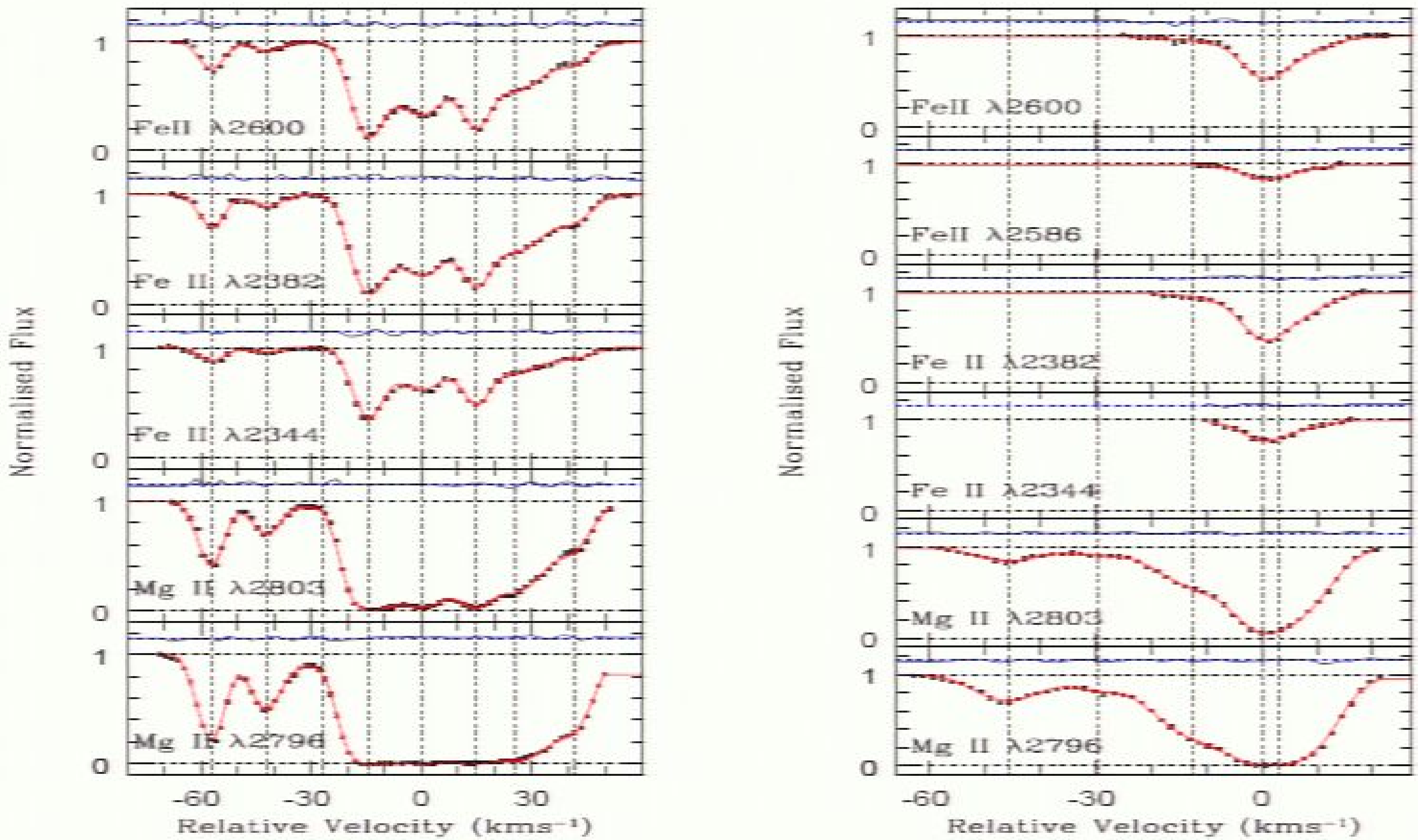

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LP data results.

- Apart from two system result of reanalysis of 21 systems using VPFIT provides consistent results with Chand et al. (2004) and Srianand et al. (2004).

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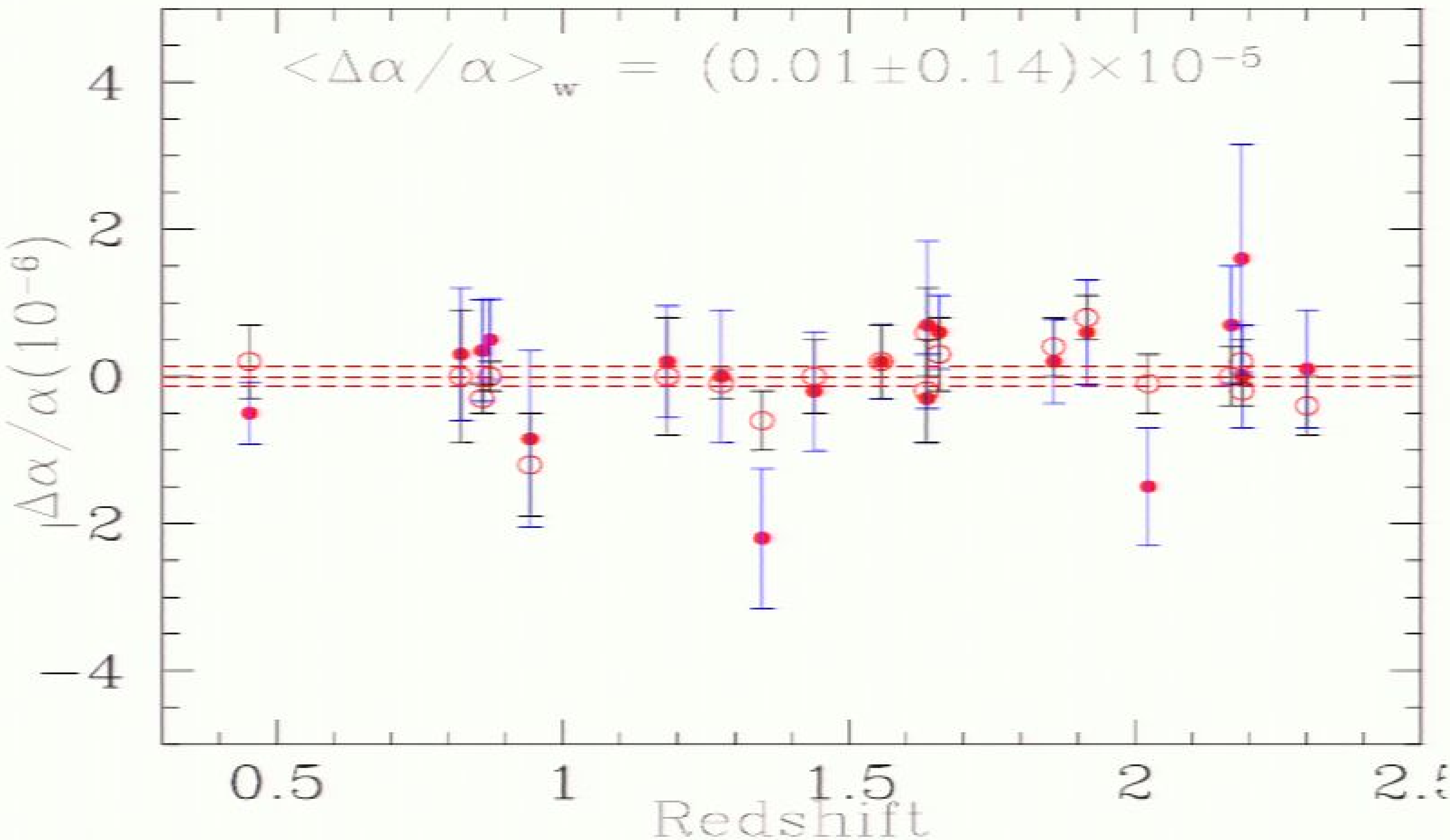
	21		$+(0.01 \pm 0.14)$
VLT Re-analysis?	23	0.4–2.3	$-(0.06 \pm 0.12)$
ICTP 05	74	0.4–2.8	$+(0.00 \pm 0.09)$
	52		$-(0.02 \pm 0.10)$

Voigt profile fitting & disagreements

- N vs b correlation in IGM -early 90's
  - Equation of state of the IGM.
- Ω_b from D/H using D I/H I
  - WMAP data.
- Variation of α
  - More systems with simple absorption profiles.
  - Analysis by a new group of people.
  - Constraints from independent observations

Reanalysis of LP data with VPFIT:



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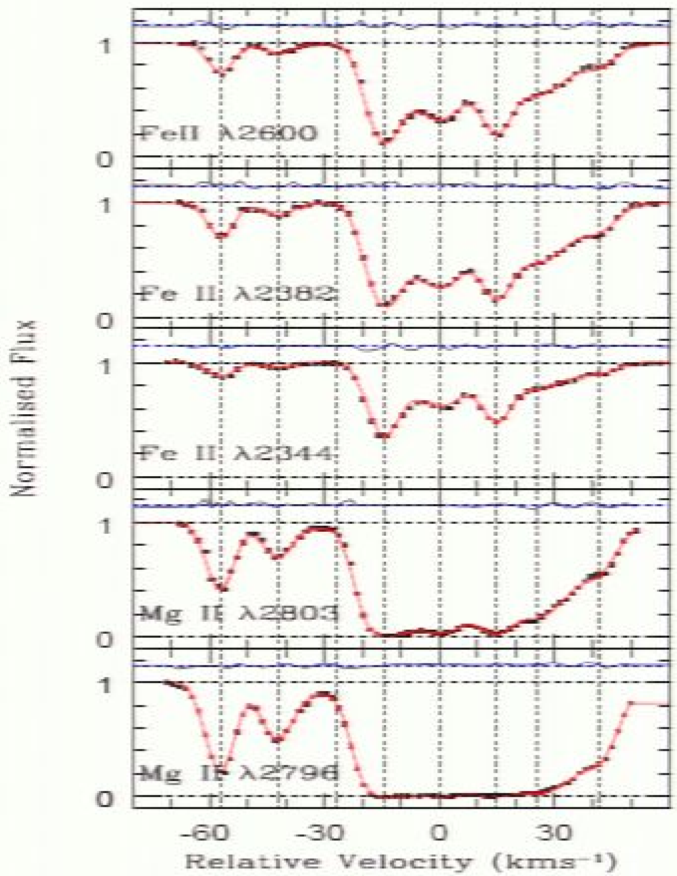

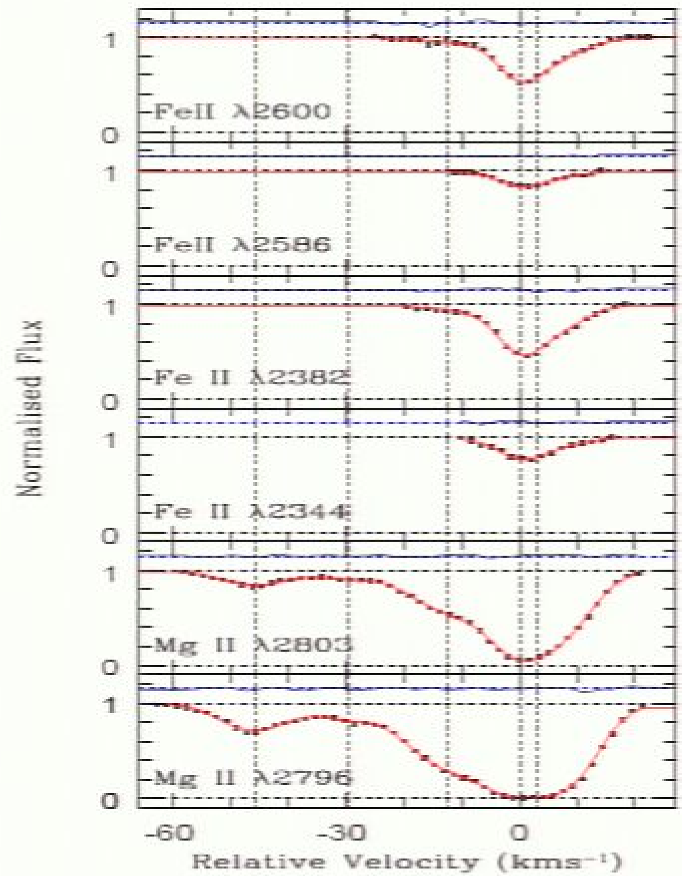

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Variations of other constants

- μ using H_2 and HD transitions -Inside the Lyman$-\alpha$ forest- different origin of different J transitions

- x using 21cm absorption systems - identifying the corresponding UV component - radio sources are extended

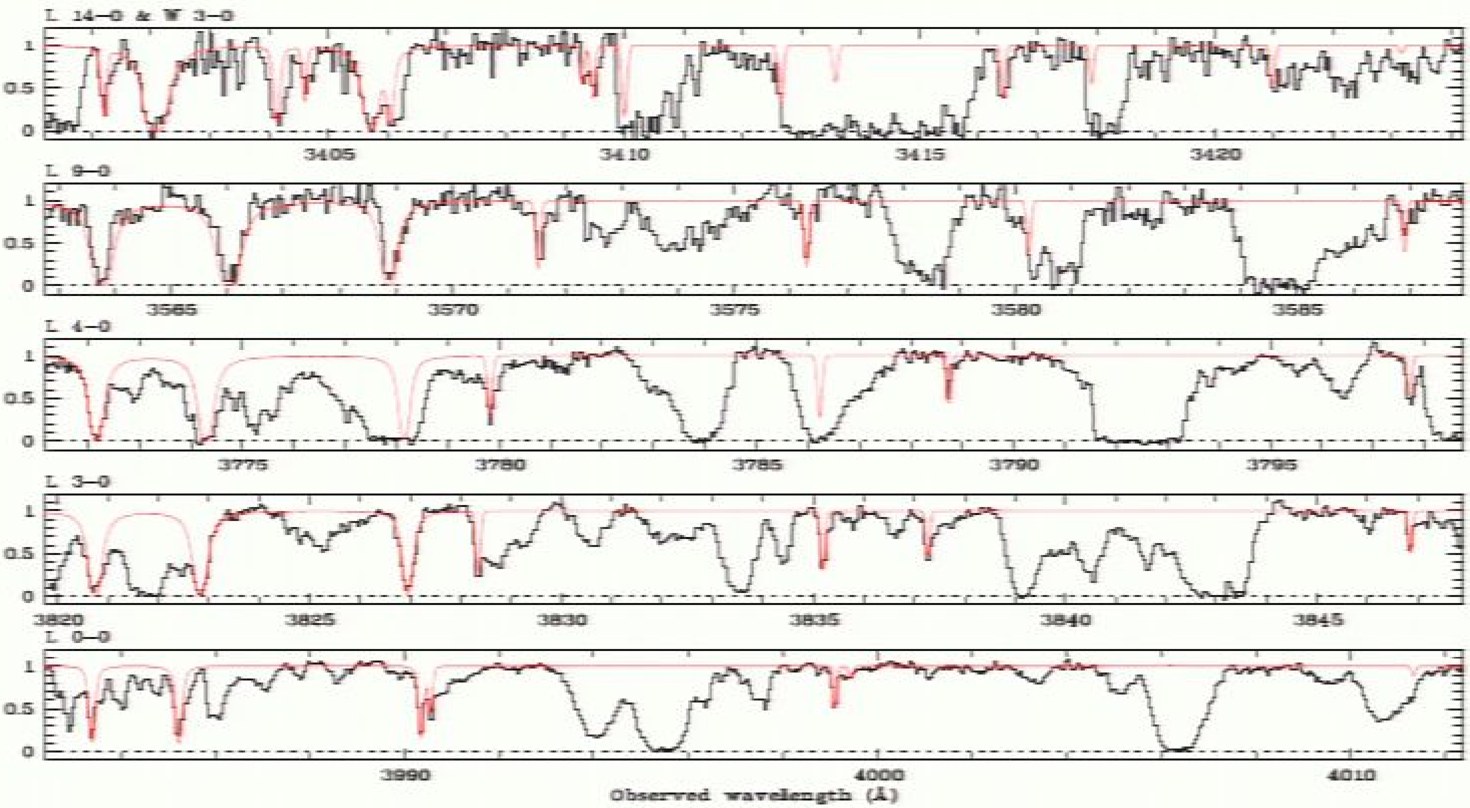
- Both H_2 and 21cm absorbers are rare -need systematic surveys to identify good systems for experiments on the variation of constants

H_2 SURVEY WITH VERY LARGE TELESCOPE:

- The sample includes 90 DLAs along the line of sight.
- Spectral resolution R = 43,000; S/N $\geq$20 per pixel and wavelength range 3000$-$10000 Å .
- H_2 is detected in 17 systems.
- In the case of non detection upper limits of 1.2$\times 10^{-7} - 1.6 \times 10^{-5}$ is achieved for molecular fraction, f.
- One CO and 2 HD detections.

in collaboration with Petitjean, Ledoux& Noterdaeme

Variations of μ: H_2 molecules at high z



Ledoux et al (2003)

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Using 21-cm absorption lines:

- $x = \alpha^2 G_p/\mu$
- $\frac{\Delta x}{x} = \frac{(x_z - x_0)}{x_0} = \frac{z_{UV} - z_{21}}{1+z_{21}}$
- The most recent measurements are from Tzanavaris et al. (2007, MNRAS, 374, 634). $\Delta x/x = (0.63 \pm 0.99) \times 10^{-5}$ over $0.23 \leq z \leq 2.35$ using a heterogeneous sample of 21-cm absorption systems.

ISSUES

- Associating of 21cm and UV absorption.
- Radio morphology.

SDSS-GMRT sample of Mg II systems:

- Looked for Mg II systems with W(Mg II)$\geq$1Å using an automatic procedure. (60,000 QSO spectra from SDSS-DR5)
- Select the systems with 1.15$\leq z \leq 1.45$ (2893 systems)
- Cross-correlate the SDSS QSO with NVSS and FIRST.
- Pick the systems with flux density at the redshifted 21 cm wavelength greater than 50 mJy (37 systems).
- 400hrs of observations are completed-and we now have 9 new detections. Five systems are in front of radio sources that are compact at milli-arcsec scales.
- One of them is showing large proper motion.

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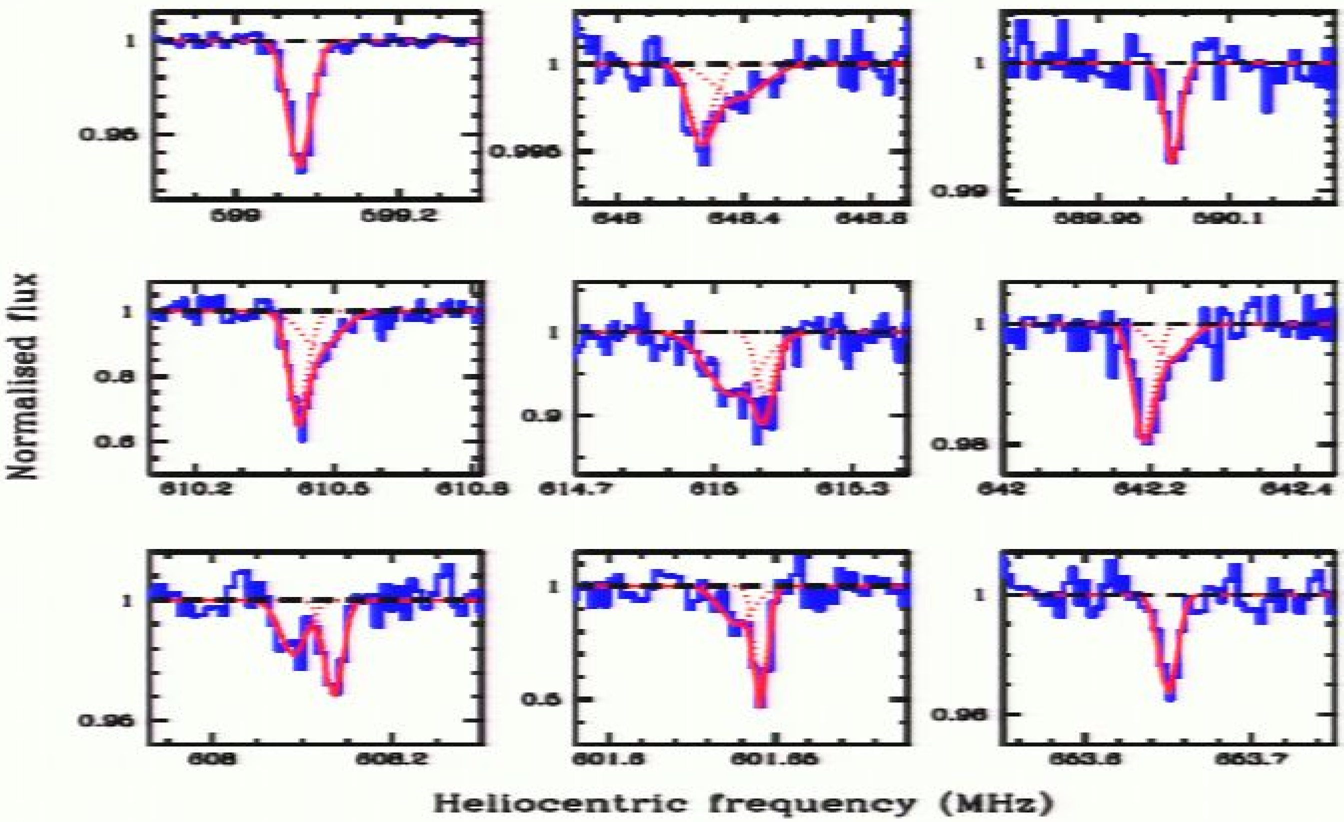
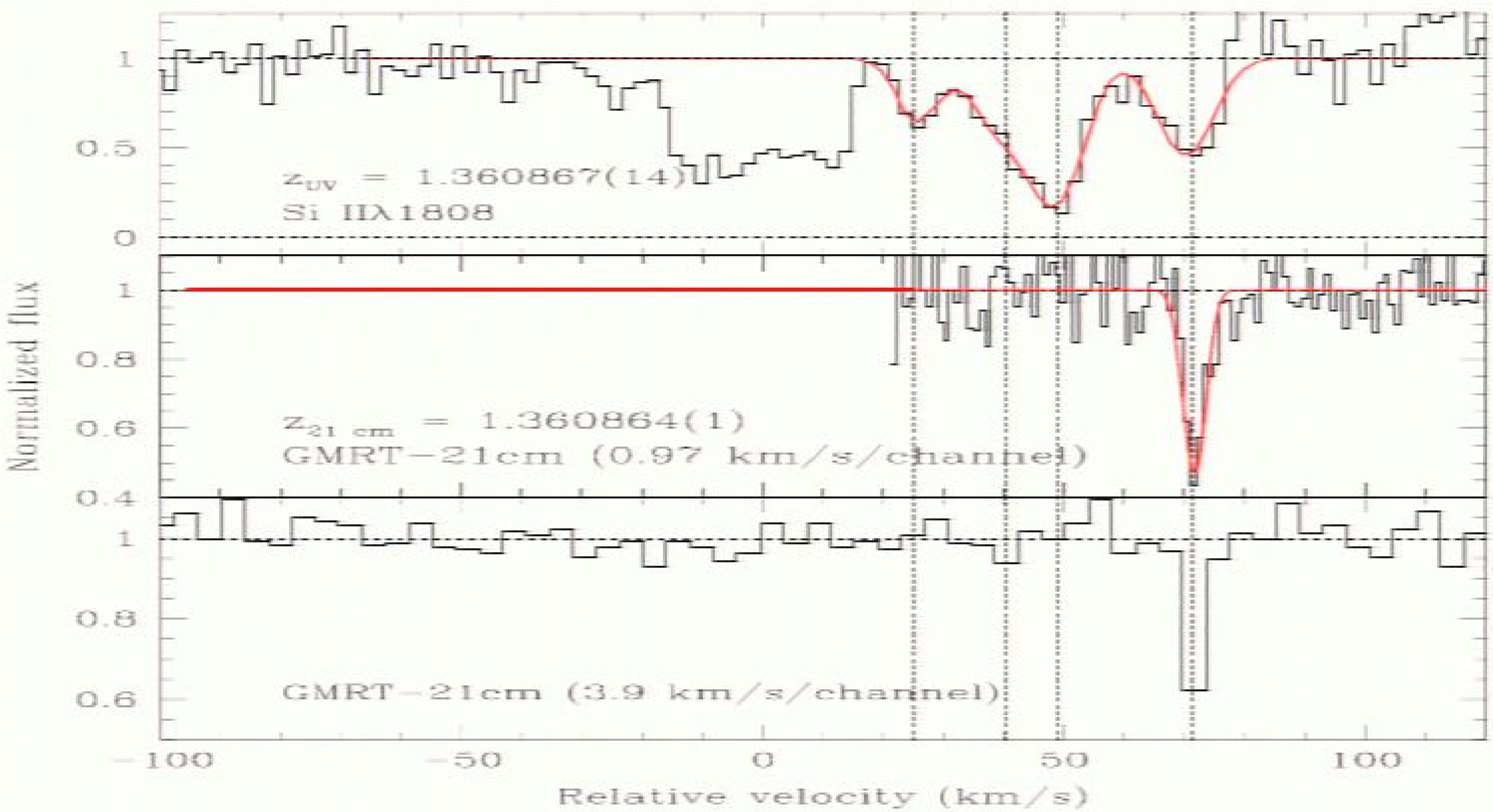
GMRT sample of 21-cm absorption:



GMRT sample of 21-cm absorption:

$$\Delta x/x = (1.27 \pm 2.96) \times 10^{-6}$$



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)
	0.685, 0.765	$\leq 6.7 \times 10^{-6}$	Kanekar et al (2006)
O III	0.16–0.80	$(+0.70 \pm 1.40) \times 10^{-4}$	Bahcall et al. (2003)

Discussion!

- Within the measurement uncertainties no variation of fundamental constants is detected using VLT.
- Effect of isotopes on MM method needs to be addressed -Very high resolution observations of some well selected systems is needed.
- Non-Voigt profile nature of the absorption lines -we never bother about it!.
- Measurements based 21 cm absorption and atomic lines. Need good 21cm absorption systems-more surveys
- Molecular lines in radio bands. Very good if we manage to detect strong lines– Not known at z≥ 0.7 – Avoid lenses and complex radio sources.