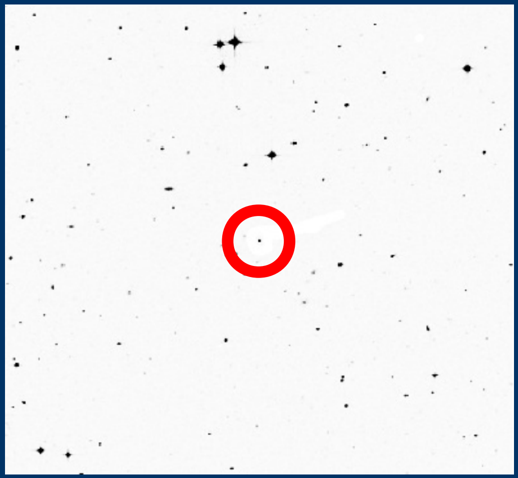
Robust Limit on a varying proton-to-electron mass ratio from a single H_2 system

Martin Wendt



14' × 14' (STScI)

JENAM 2010, September 7th

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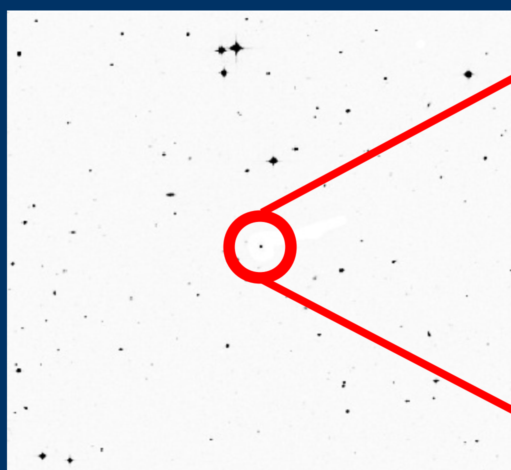

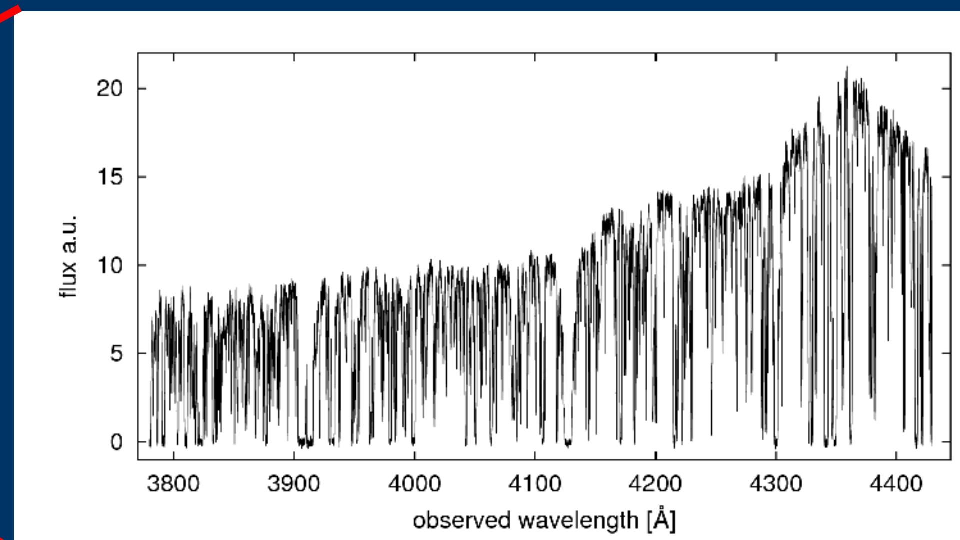

QSO 0347-383

JENAM 2010, September 7th

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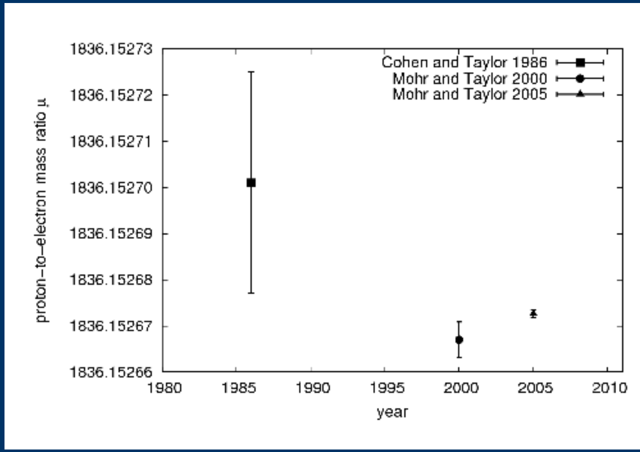
Overview

- Theoretical background
- Quasar absorption lines
- Status quo
- Data
- Analysis
- Summary & Outlook

Theoretical background

The proton-to-electron mass-ratio **μ** reflects the ratio of the strong couplings (proton mass via Λ_{QCD}) to the electroweak forces (electron mass is related to the Higgs field) .



μ = 1836.15267261(85) (NIST)

Theoretical background

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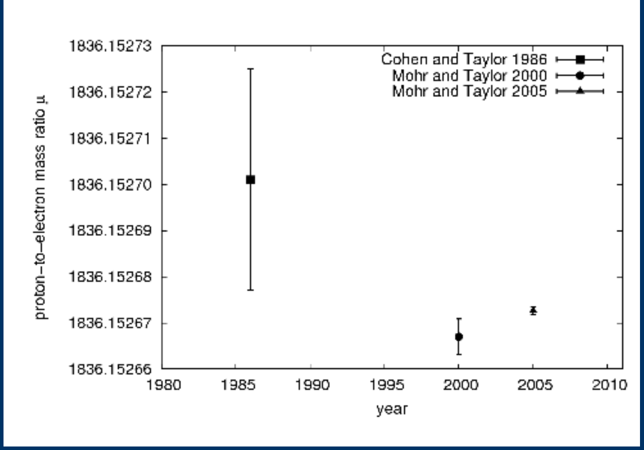
- To determine spatial variation:
  measure **μ** at great distances and the local values of **μ**.

- For temporal variation:
  measurements at great distances and today's **μ**.



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Theoretical background

- Electron-vibro-rotational transitions depend on reduced mass of the H_2 molecule.

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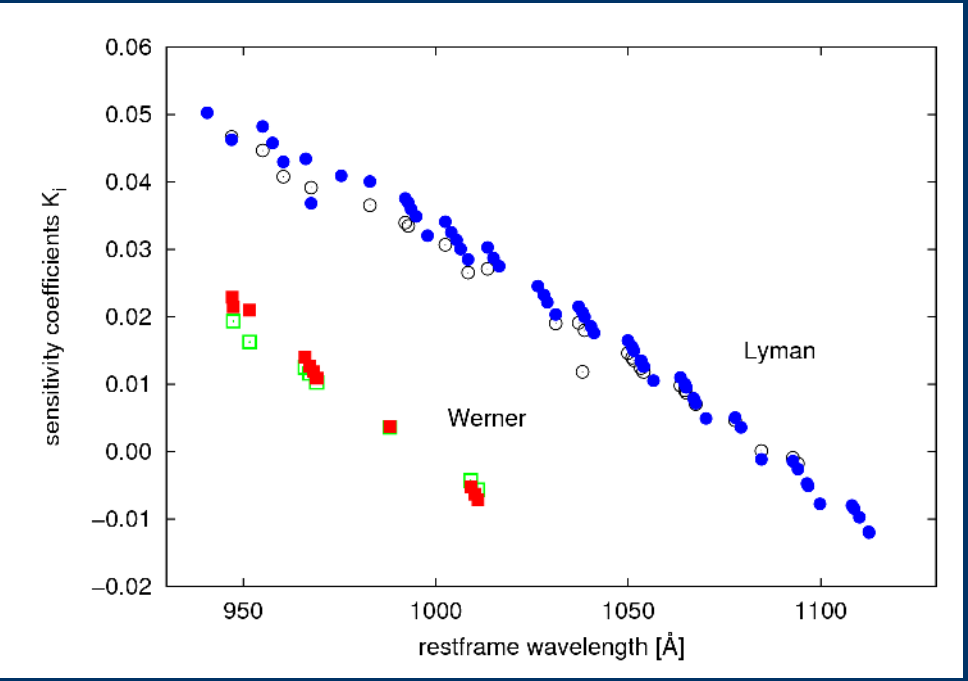

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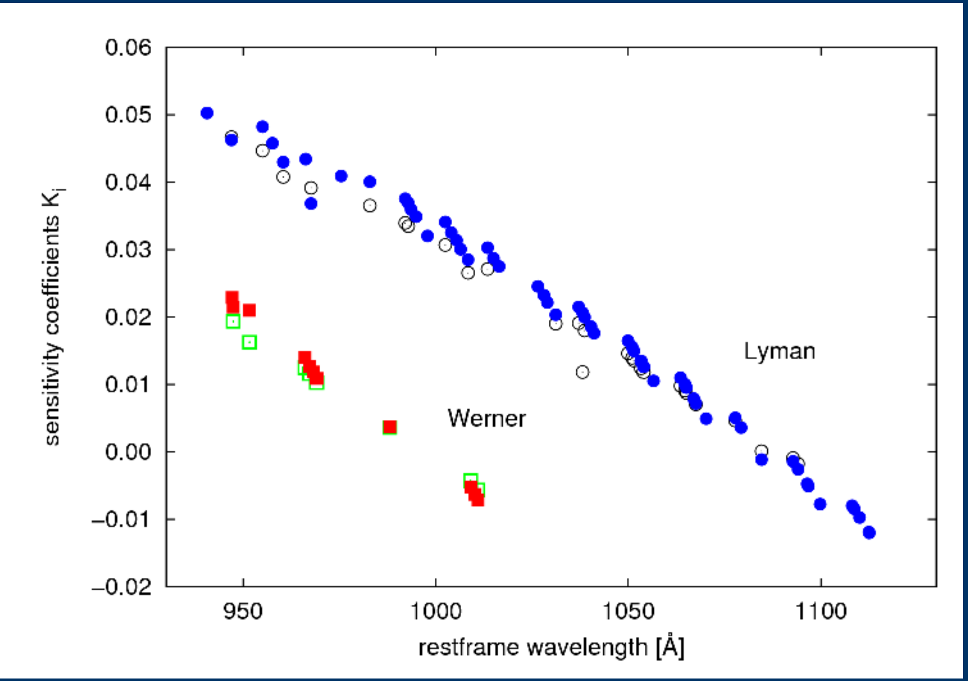
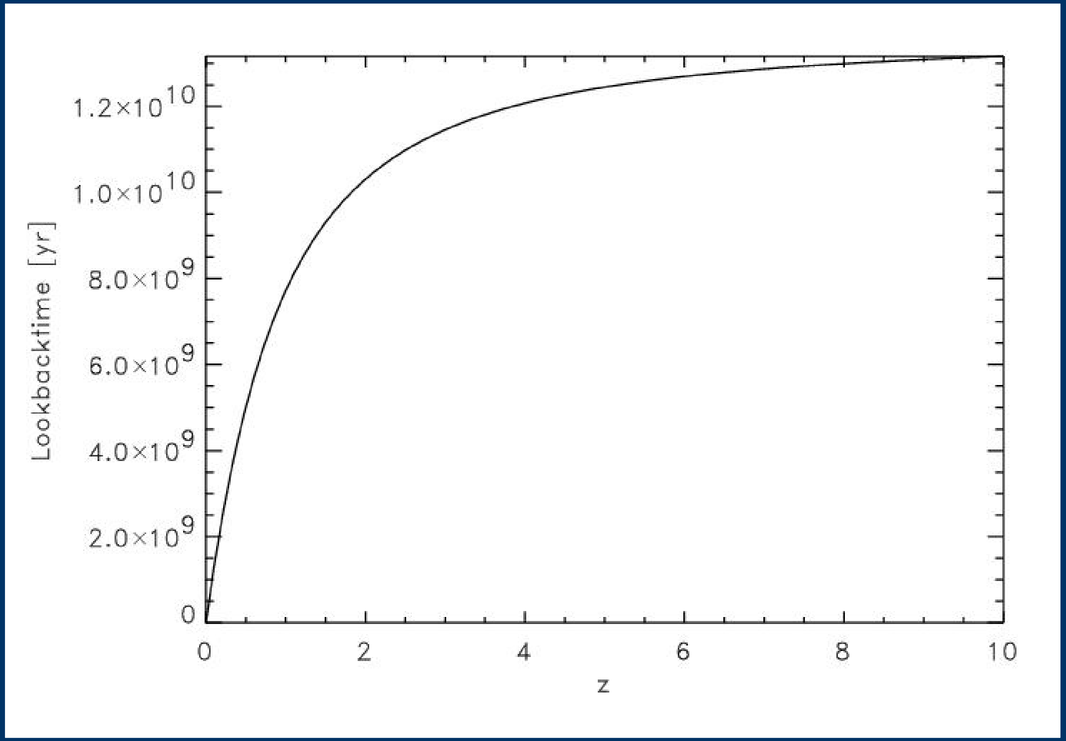


Distinguish cosmological redshift of a line from the shift caused by possible variation of μ.

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

Quasar absorption lines

- **z** ~ 3 corresponds to about 12 Gyr look-back time.



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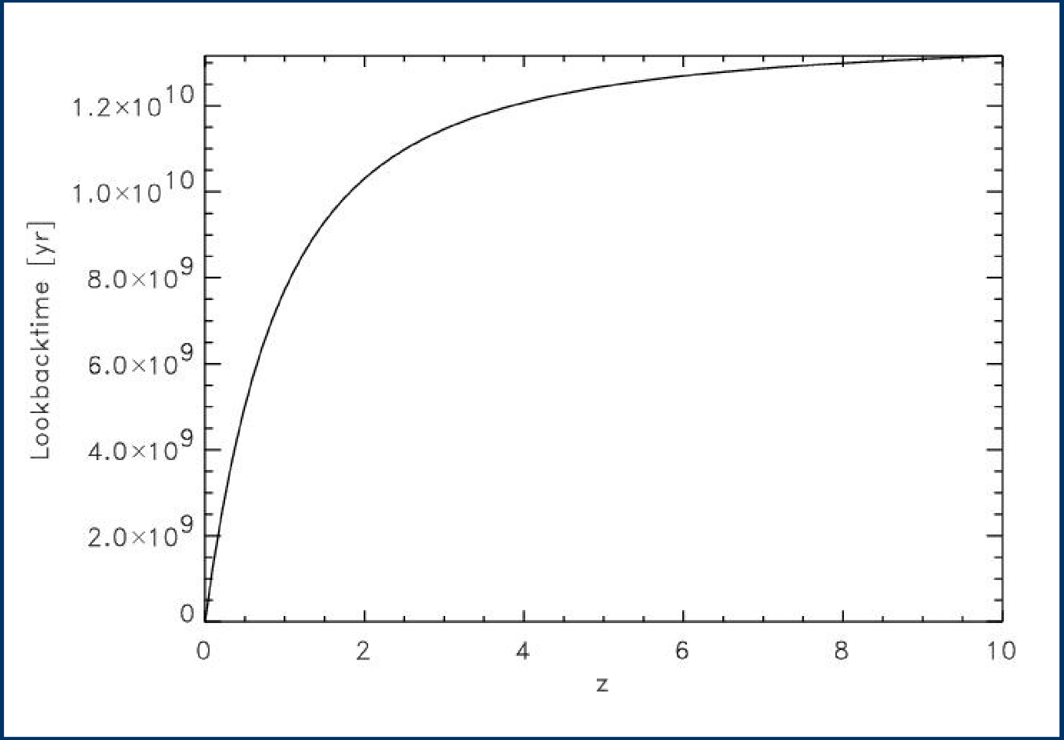
- H_2 transitions originate at ~ 950 – 1050 Å.



Quasar absorption lines

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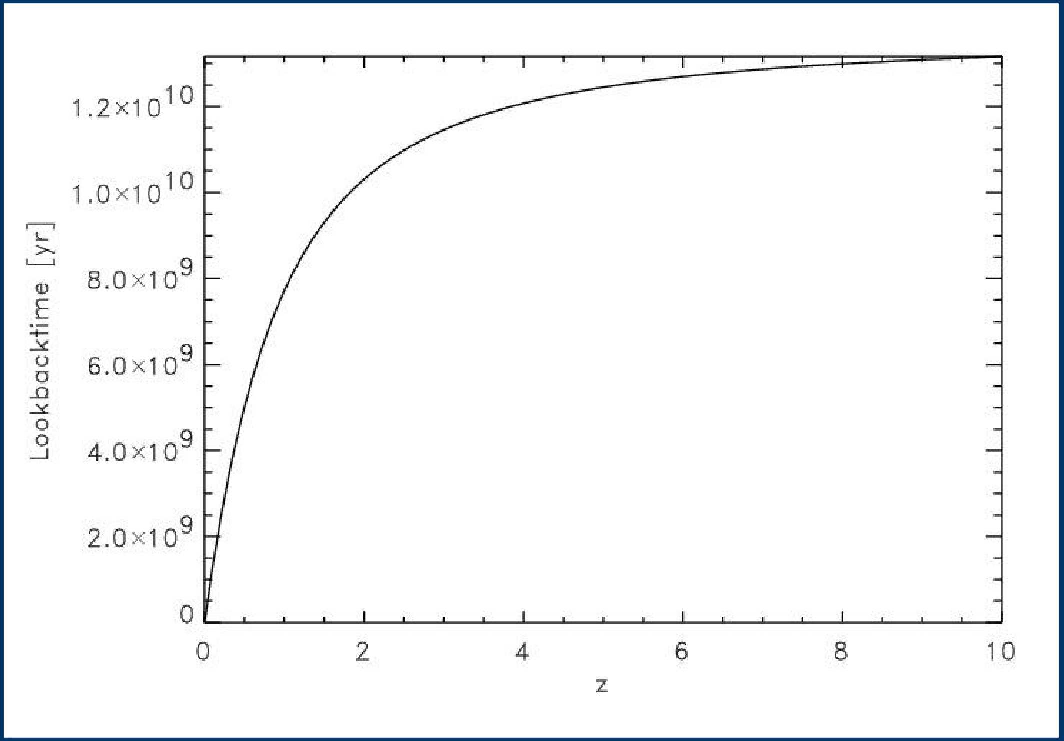
- H_2 transitions originate at ~ 950 – 1050 Å.
- For z > 2.5 the transitions are shifted into the optical range and the Ly-**α** forest.



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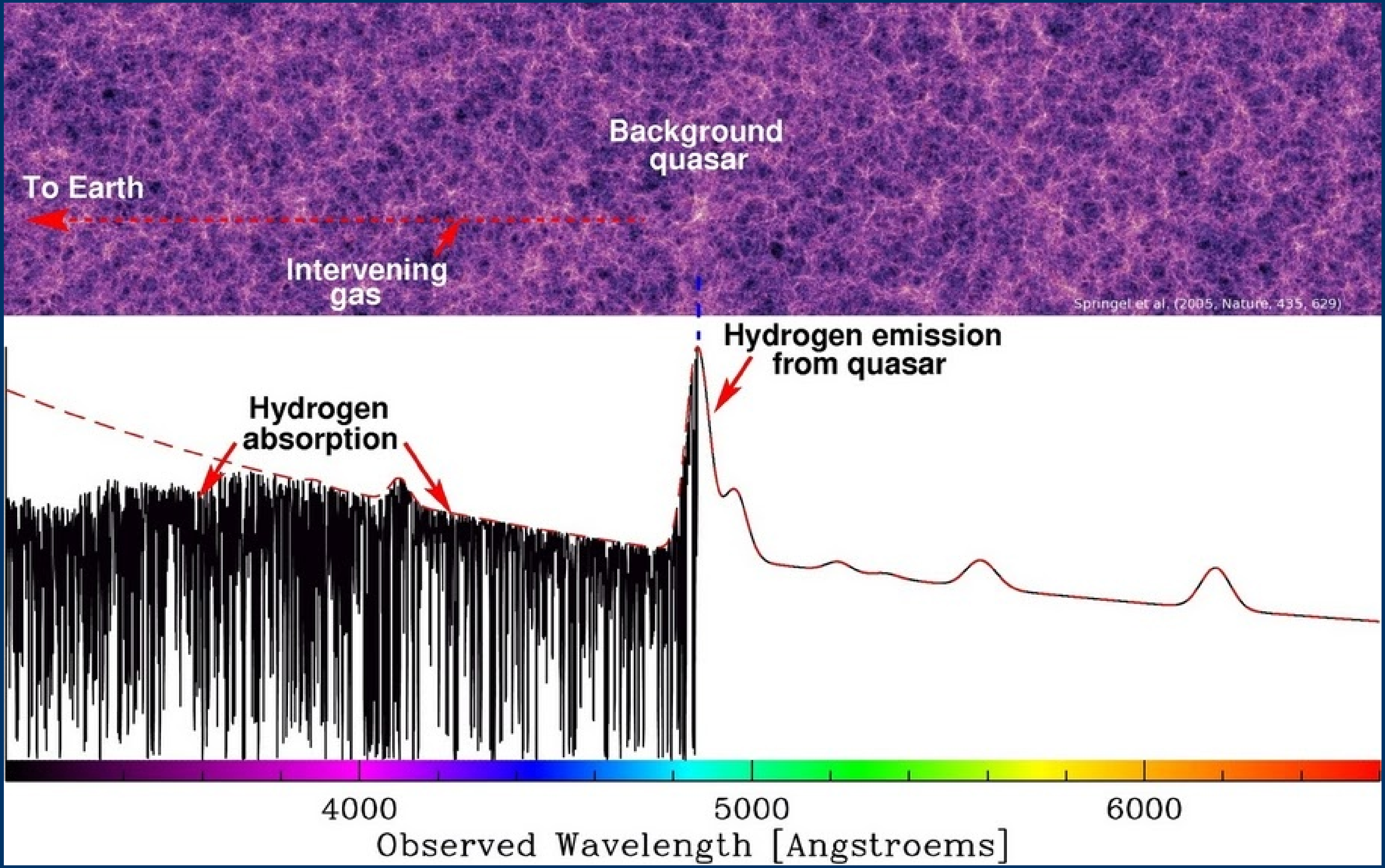

(M. Murphy)

Status quo

Numerous **$\Delta\mu/\mu$** measurements via H_2 mainly based on UVES observations in 2002.

For QSO 0347-383 and Q0405-443 at $z \sim 3$, results range from:

$\Delta\mu/\mu$ $= (20 \pm 6) \times 10^{-6}$ *(Reinhold 2006)* to
$\Delta\mu/\mu$ $=$ **(**$-28 \pm 16) \times 10^{-6}$ *(Thompson 2009)*.

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$\Delta\mu/\mu = (15 \pm 15) \times 10^{-6}$ *(Wendt & Molaro 2010).*

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$\Delta\mu/\mu$ = (15 ± 15) × 10^{-6} *(Wendt & Molaro 2010).*

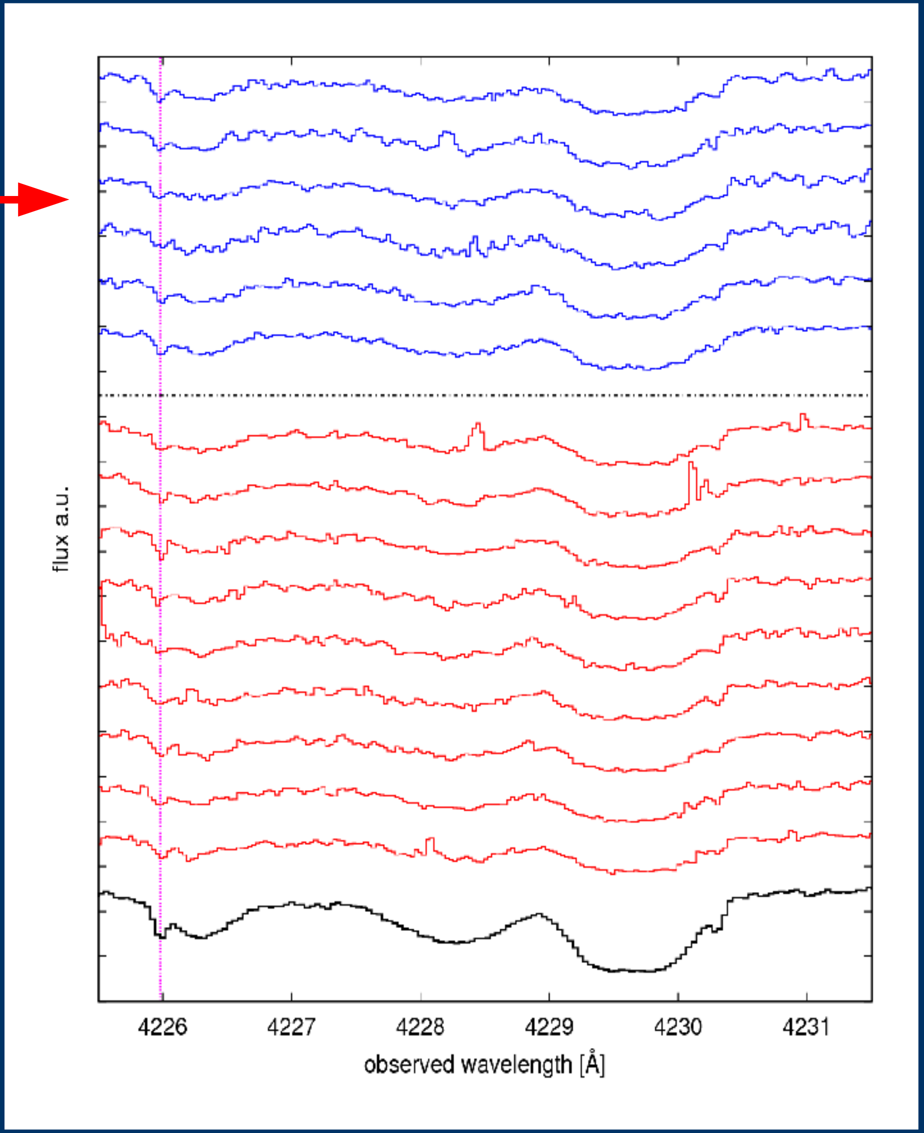
New data in 2009 for QSO 0347-383:
$\Delta\mu/\mu$ = (2.9 ± 8) × 10^{-6} .

Data preparation

Utilizing overlooked data of QSO 0347-383.

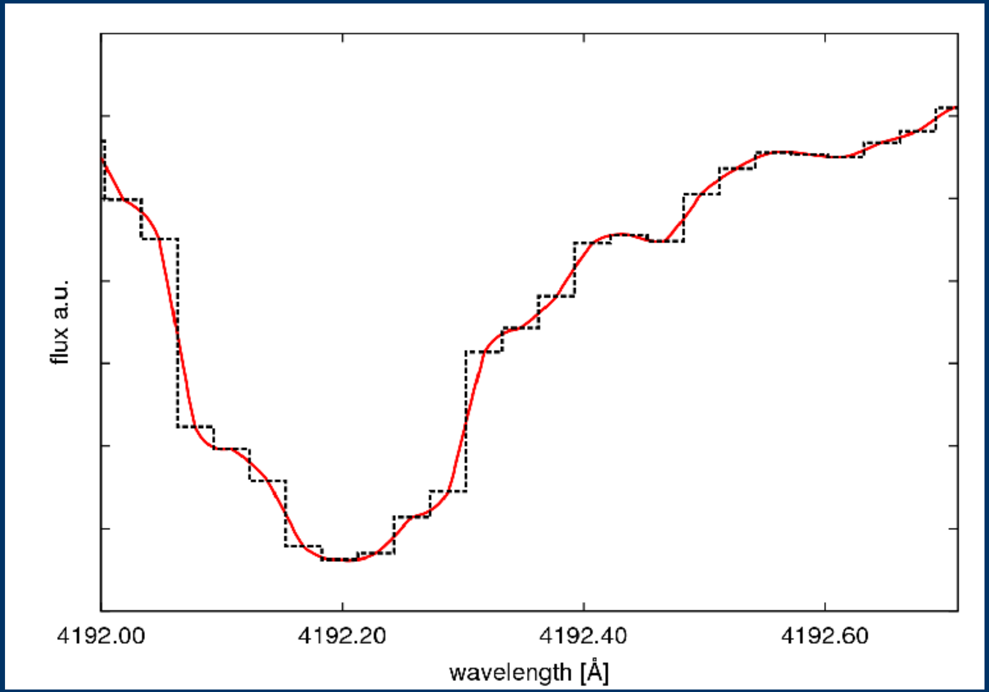
Correction for constant velocity shifts inbetween them.

Pixel size ~ 35 mÅ.



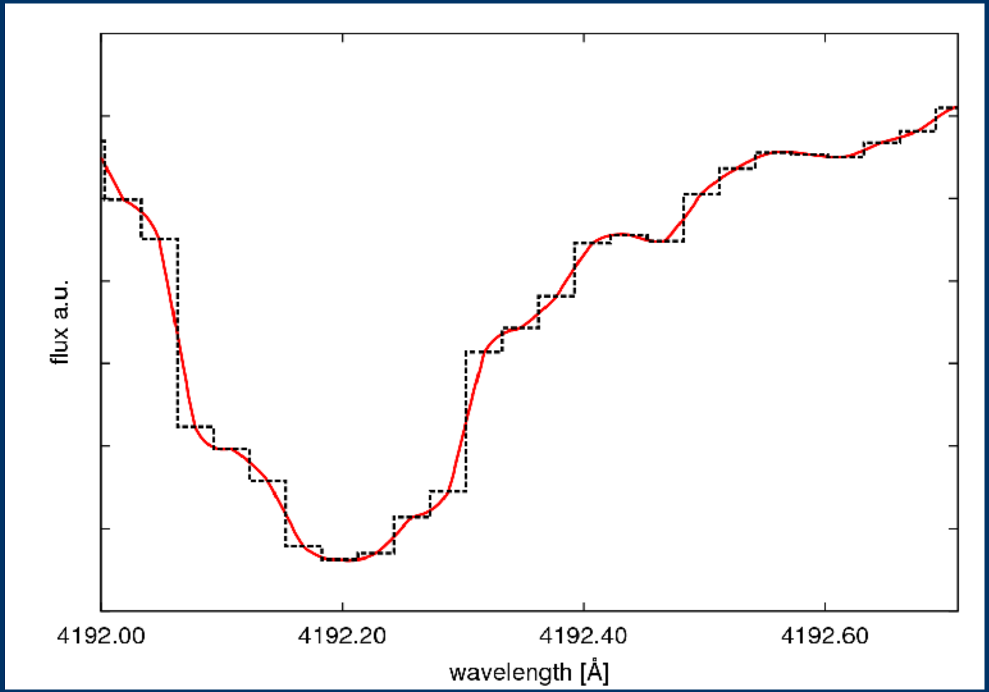
6 + 9 observed spectra of QSO 347-383.

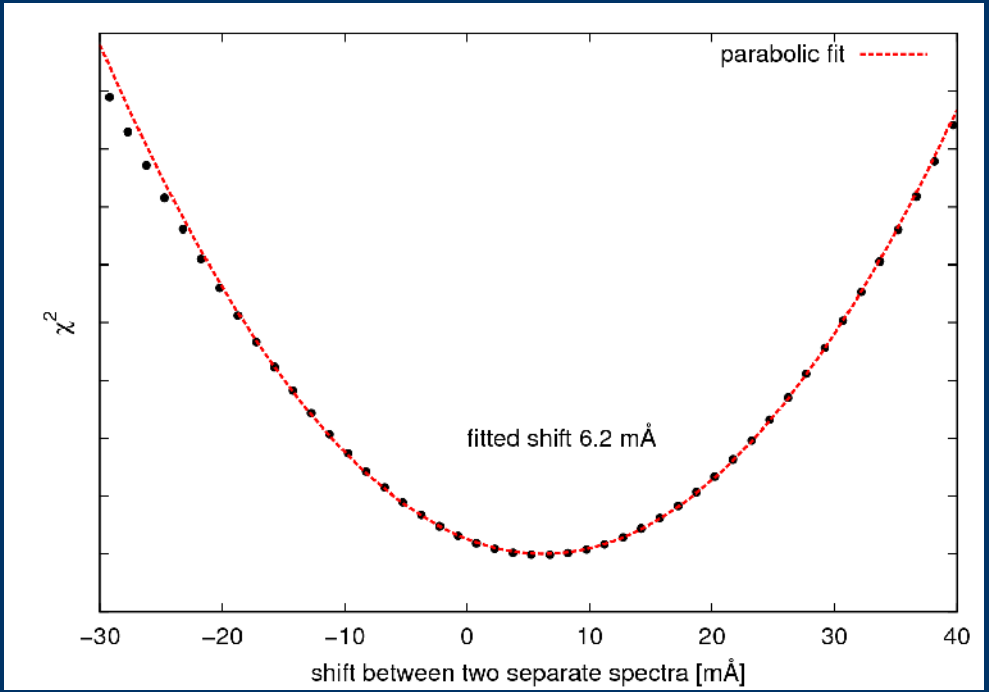
Data preparation



Polynomial interpolation of flux.
Cross correlation without rebinning of data.

Data preparation

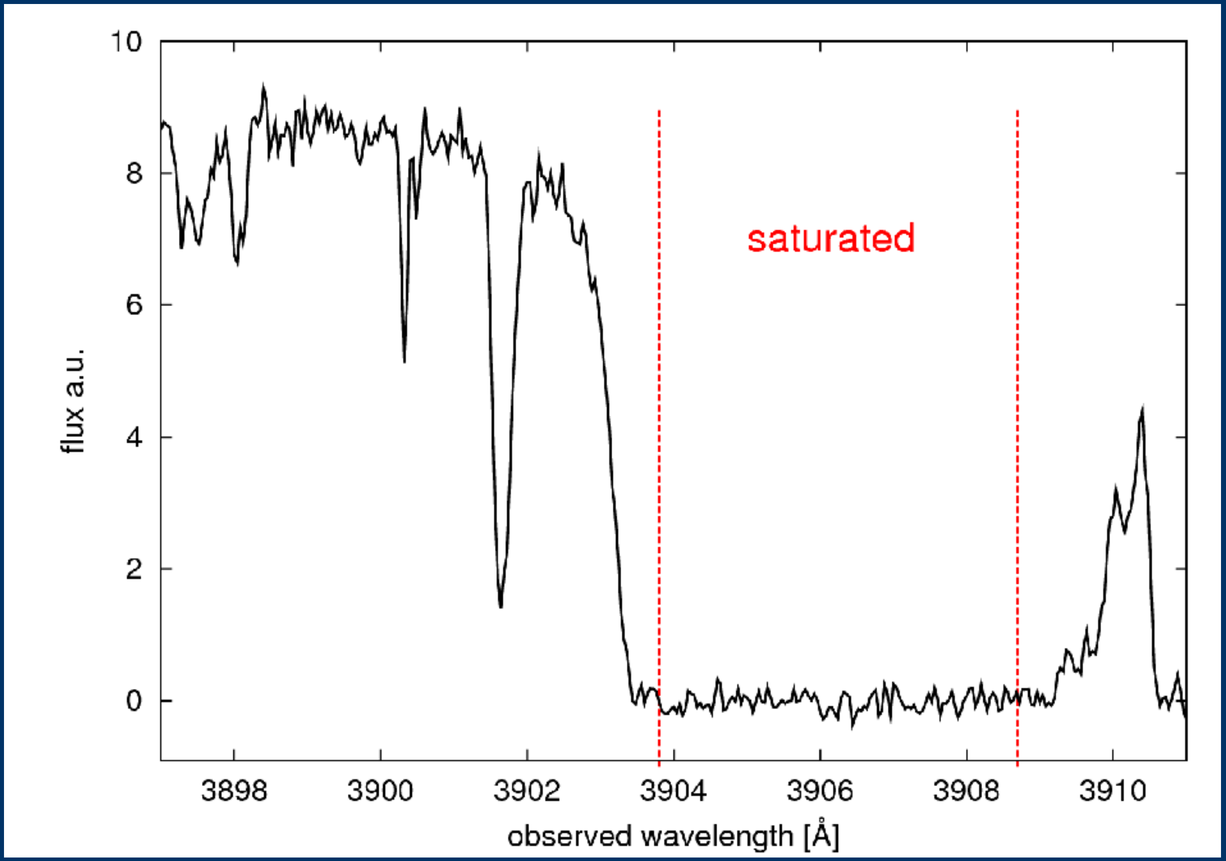




Polynomial interpolation of flux.
Cross correlation without rebinning of data.

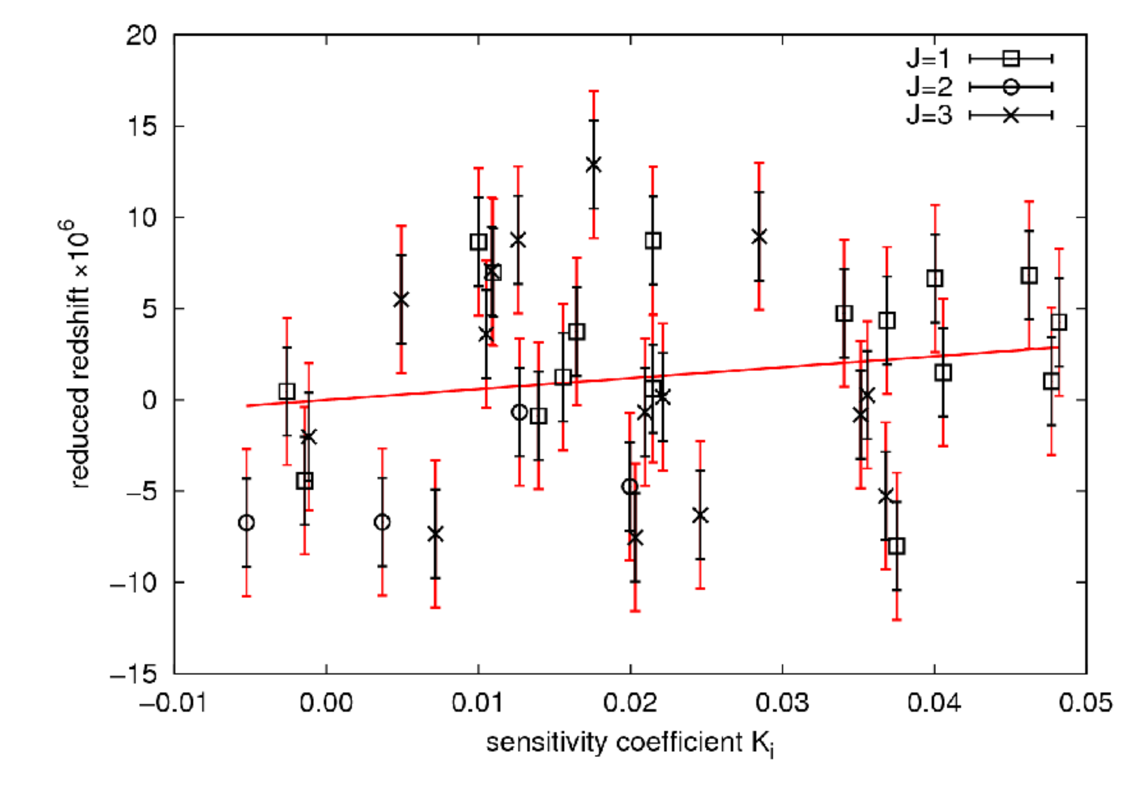
Shifts up to several mÅ.
Average deviation ~2.3 mÅ.

Data preparation



Test of the error level of the UVES reduction pipeline in saturated areas.

Results



Combined fit of 38 lines fit simultaneously.

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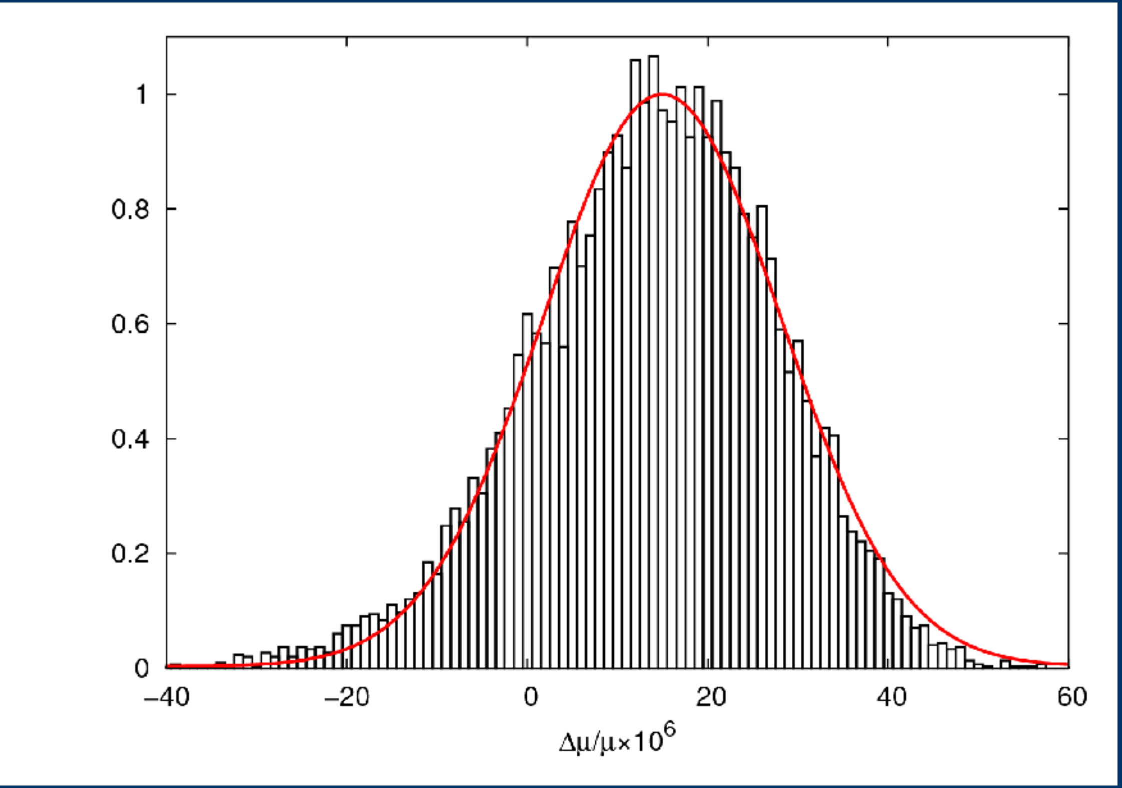
Results



$$\Delta\mu/\mu = [15 \pm (9_{stat}+6_{sys})] \times 10^{-6}.$$

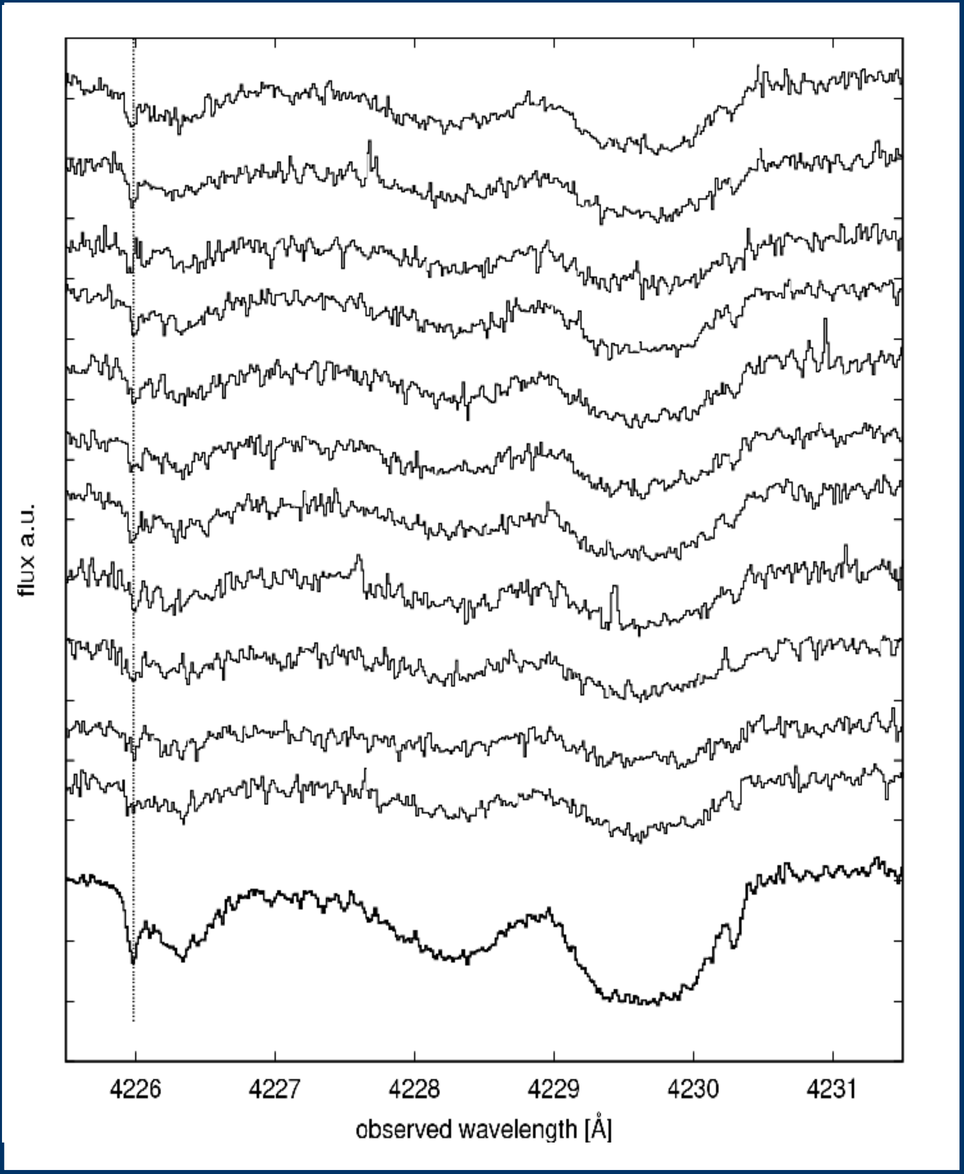
New state-of-the-art data

Verfication of aimed at precision with early test observations in September 2009.

No 2×2 binning of CCD pixels → enhanced resolution.

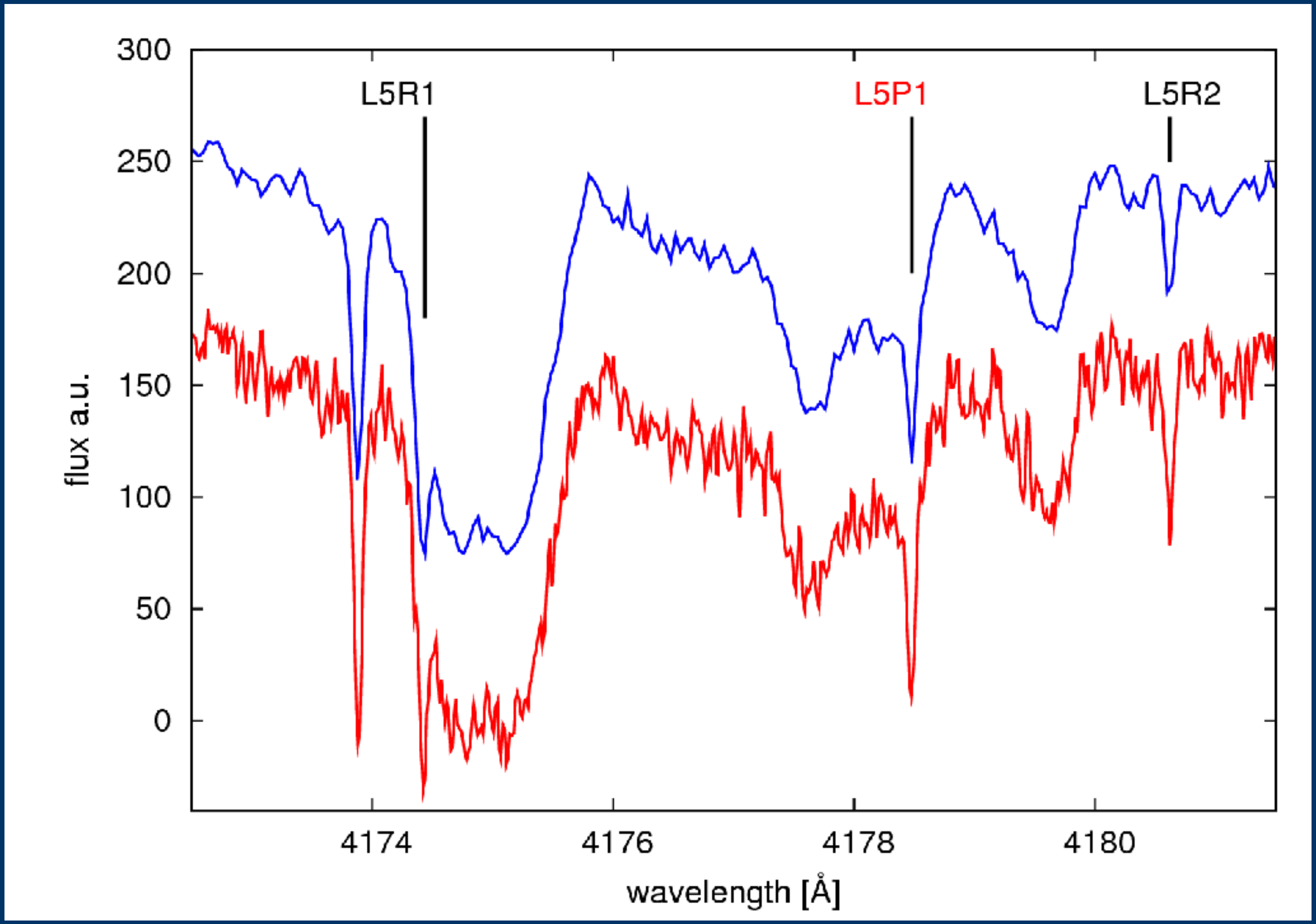
Thorium Argon lamp spectra taken right after and before each scientific exposure.

No reset of grating between successive exposures.



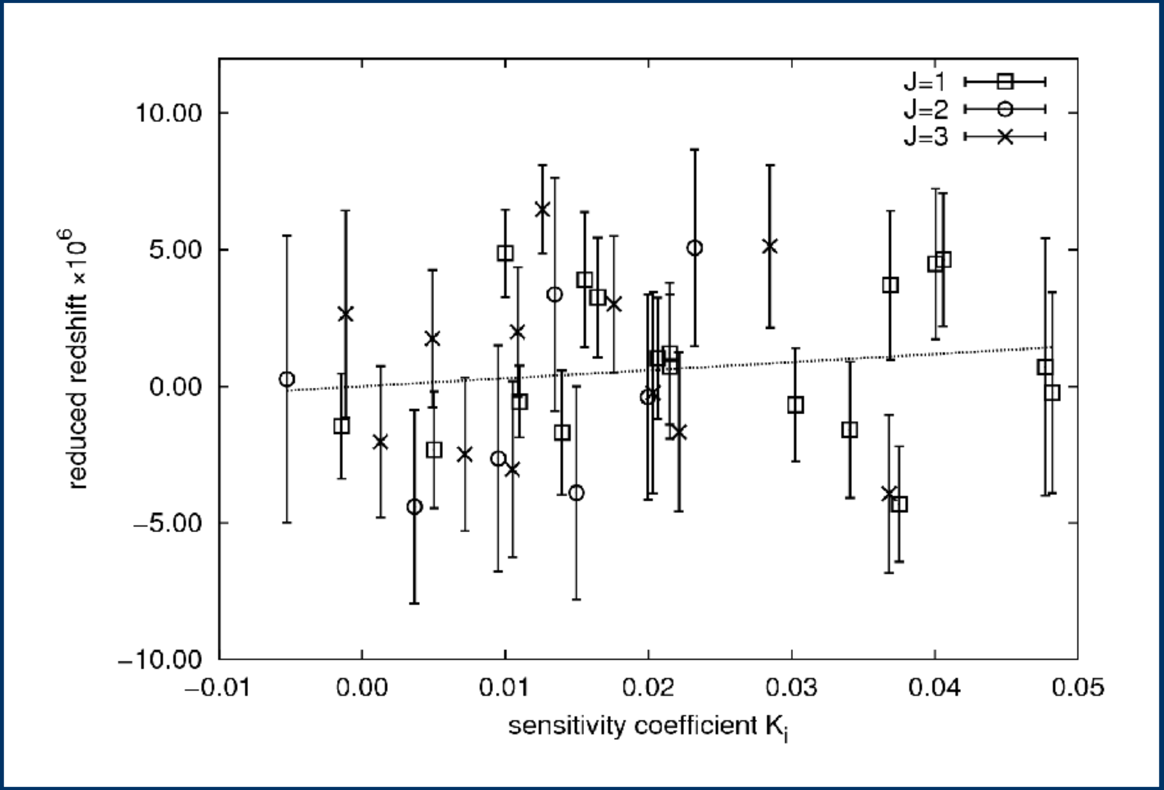
11 observed spectra of QSO 347-383.

New state-of-the-art data



2002 and 2009 data of QSO 0347-383.

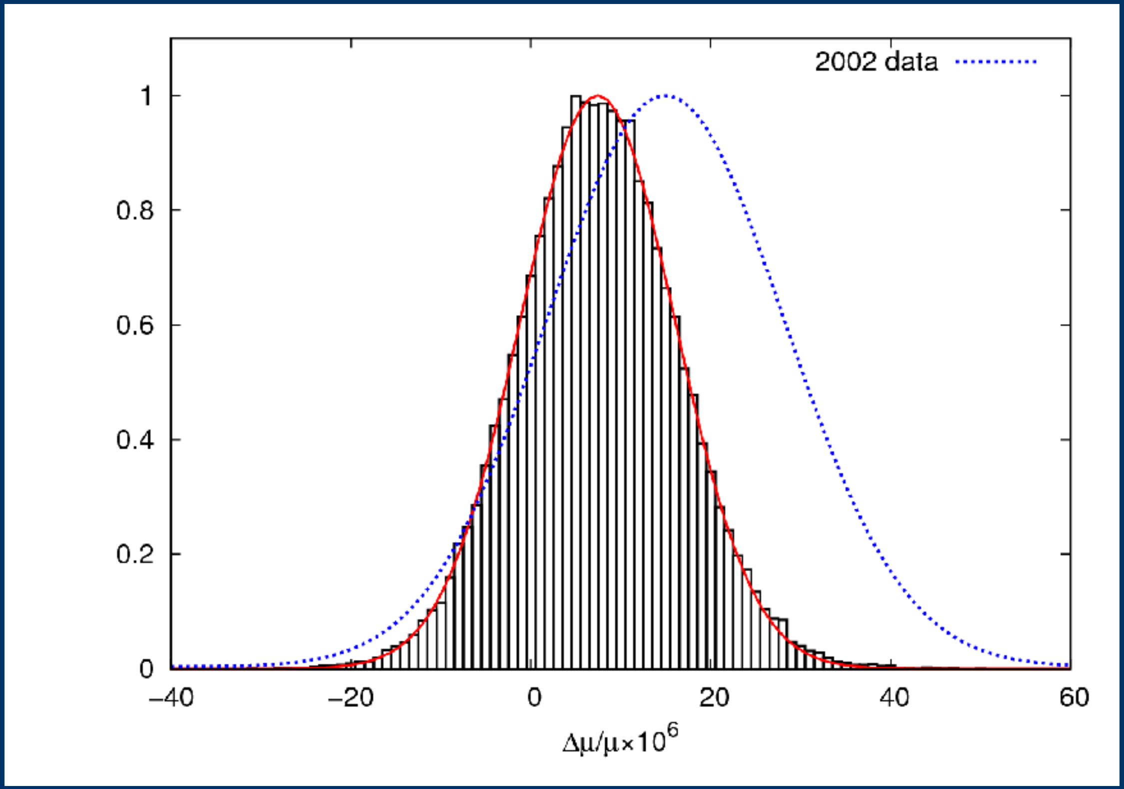
Results



Preliminary result based on recent data:

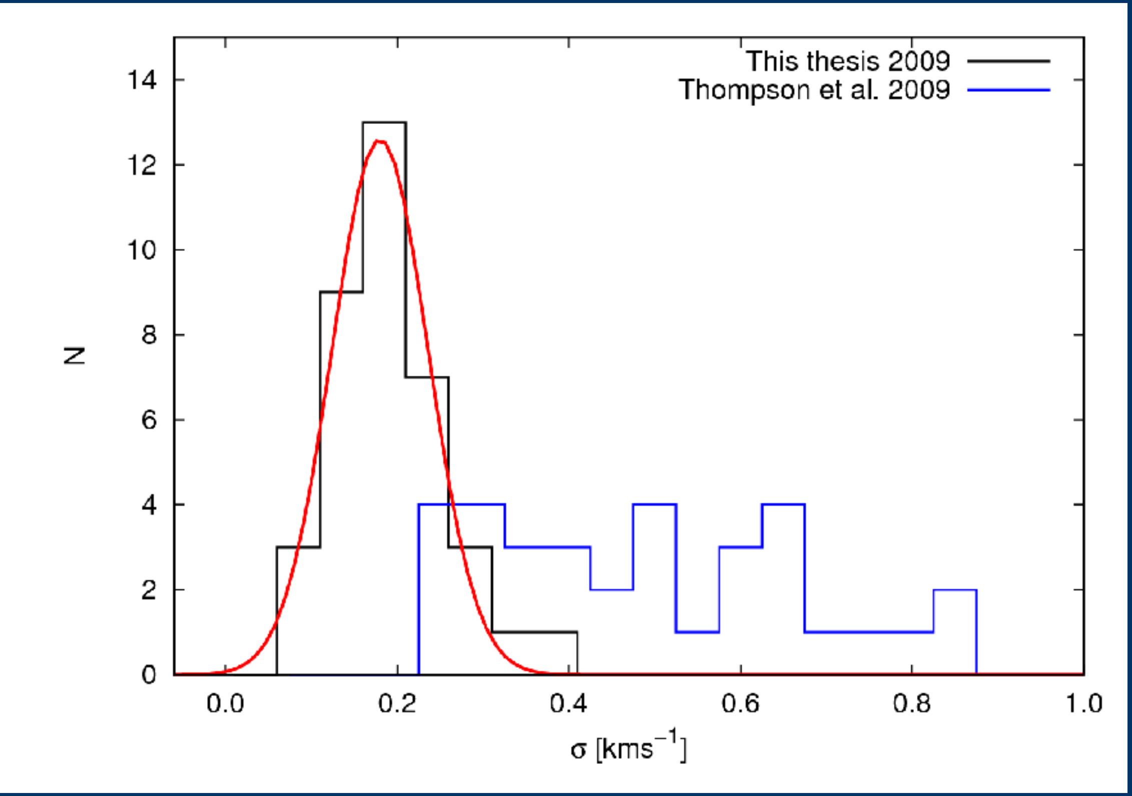
$\Delta\mu/\mu = [2.9 \pm (6_{stat}+2_{sys})] \times 10^{-6}$.

Results



Bootstrap sampling and gaussian fit of 2009 data and 2002 data.

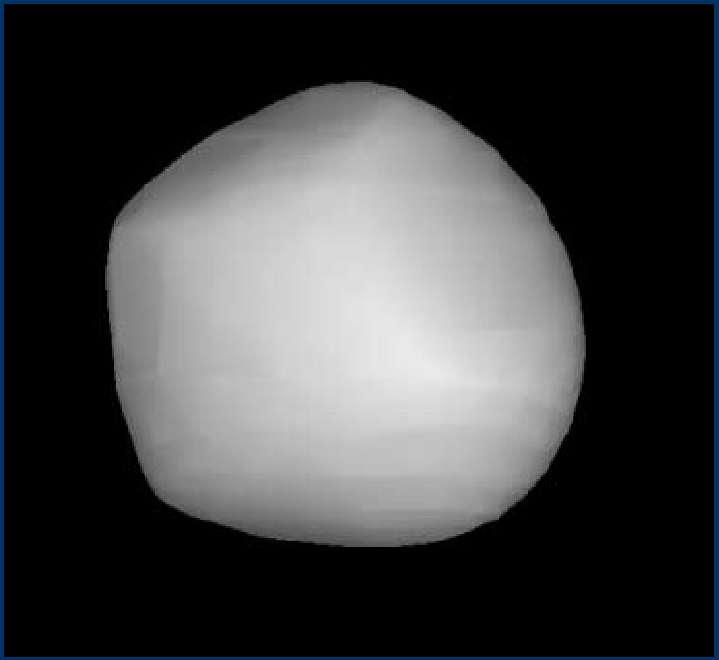
Results



Positioning errors of statistical nature.

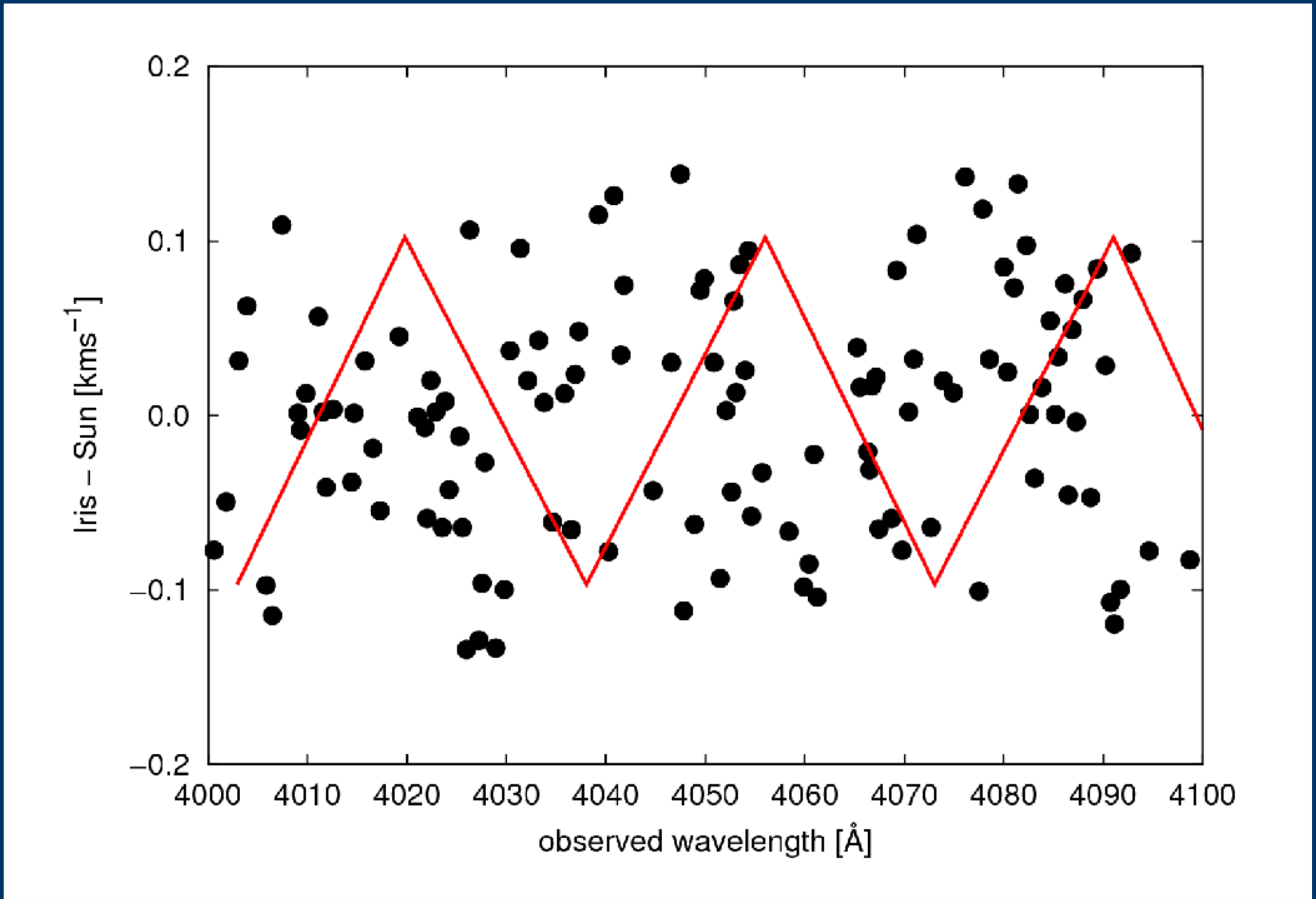
Facing calibration issues

Quantitative analysis of UVES Echelle spectrograph calibration.
Solar spectra taken via observations of the asteroid Iris-7 at 10^m.
With a diameter of > 200 km its spherical and evenly illuminated.
Pointlike source of < 0.2".



Model by Kaasalainen et al. 2002

Facing calibration issues



Prediction by Whitmore *et al.* (2010) and comparison with data from the HARPS spectrograph.

Summary

- No variation in μ detected to the level of 1 ppm over a time span of ~ 12 Gyr.
- Spectral resolution and signal-to-noise ratio are the dominant limiting factors.
- Wavelength calibration is critical and of increasing importance for future observations.
- Robust upper limit of $\boldsymbol{\mu}$ variation rules out further theoretical models and sets even tighter constraints on the fine structure constant.

$$\frac{\delta(m/\Lambda_{QCD})}{(m/\Lambda_{QCD})} \sim 35 \frac{\delta\alpha}{\alpha}$$

(Flammbaum 2006)

Outlook

- ESO Large Program granted and running...
- New data to apply refined analysis.
- Work out new methods for analysis and simulation to meet future requirements (E-ELT).
- Modeling of macroscopic velocity fields in the absorber.

ESO Observing Programmes

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Define new query

185.A-0745(A) on 12 Jun 2010, VLT-Kueyen

Period	85	Mode	Visitor
Telescope	VLT-Kueyen		
Nights	5		
Programme Type	Large		
Instrument	UVES		
PI/CoI	Molaro/ Petitjean/ Murphy/ Levshakov/ Reimers/ Srianand/ Lopez/ Martins/ Bonifacio/ Centuri'on/ Wendt/ D'Odorico/ Malec/ Vladilo/ Monai		
Observer			
Remarks	*Type: Large*		
Title	*THE UVES LARGE PROGRAM FOR TESTING FUNDAMENTAL PHYSICS*		
Abstract	Abstract not available		
Raw Products	FileList		
Publications	N/A		

Thank you.

Martin Wendt, JENAM 2010, September 7th