Large Programme Results on α
And some interesting systematic error analysis

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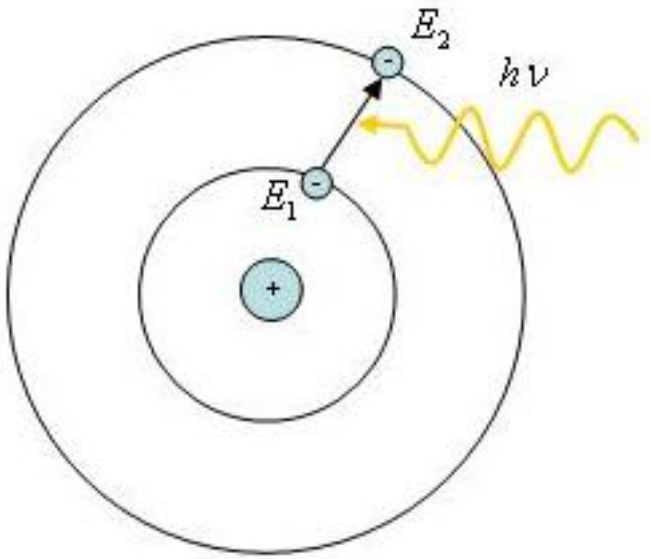
Fine-Structure Constant

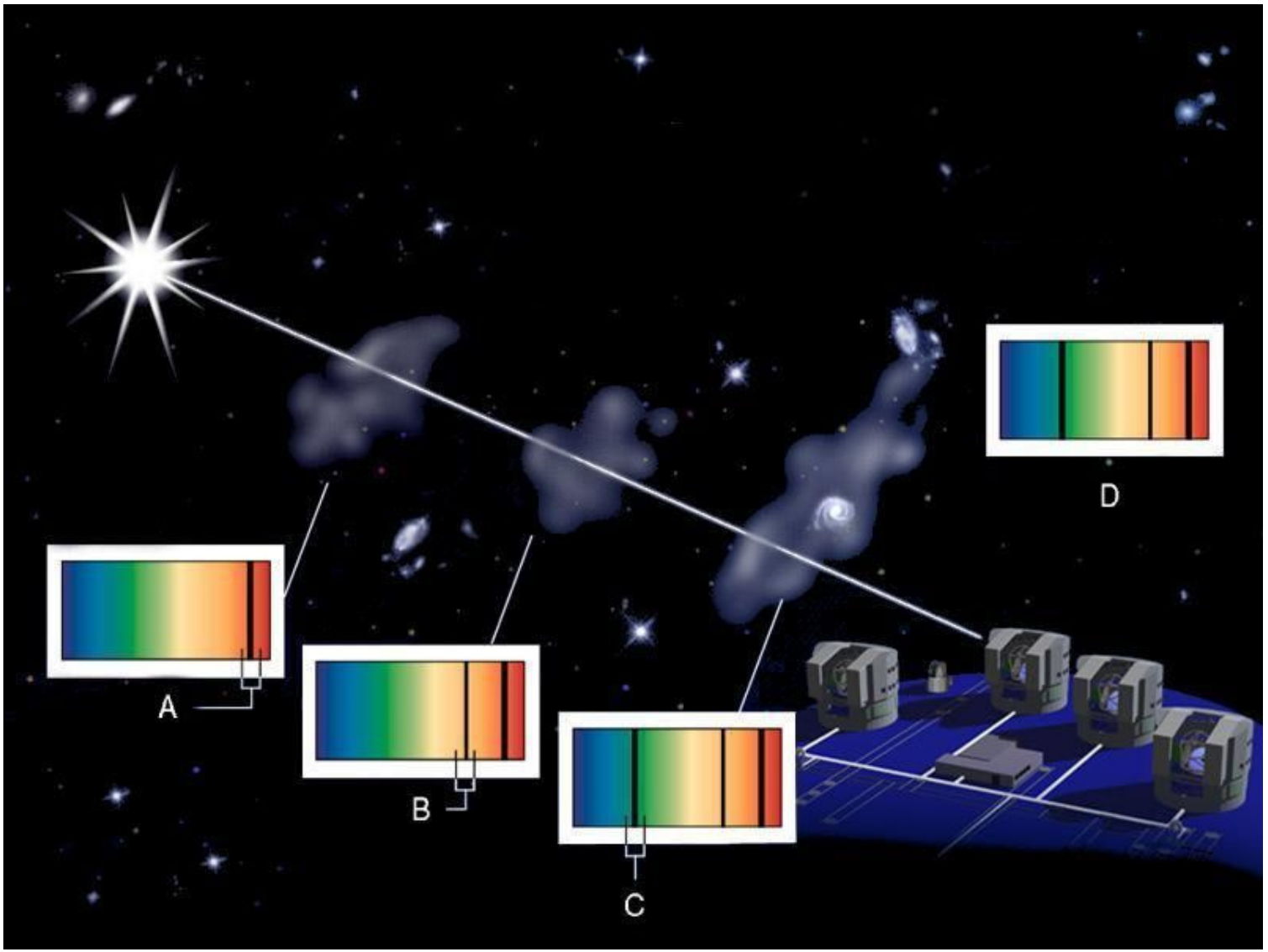
$$\alpha \equiv \frac{e^2}{\hbar c}$$

$$\alpha \approx \frac{1}{137}$$

$$\frac{\Delta\alpha}{\alpha} = \frac{\alpha_z - \alpha_0}{\alpha_0}$$



Precise Atomic Physics across the Universe



Credit: Ed Janssen, ESO

DEMO

- Signal for $\frac{\Delta\alpha}{\alpha}$ is *relative* wavelength shifts
- Relative wavelength shifts are *small*.

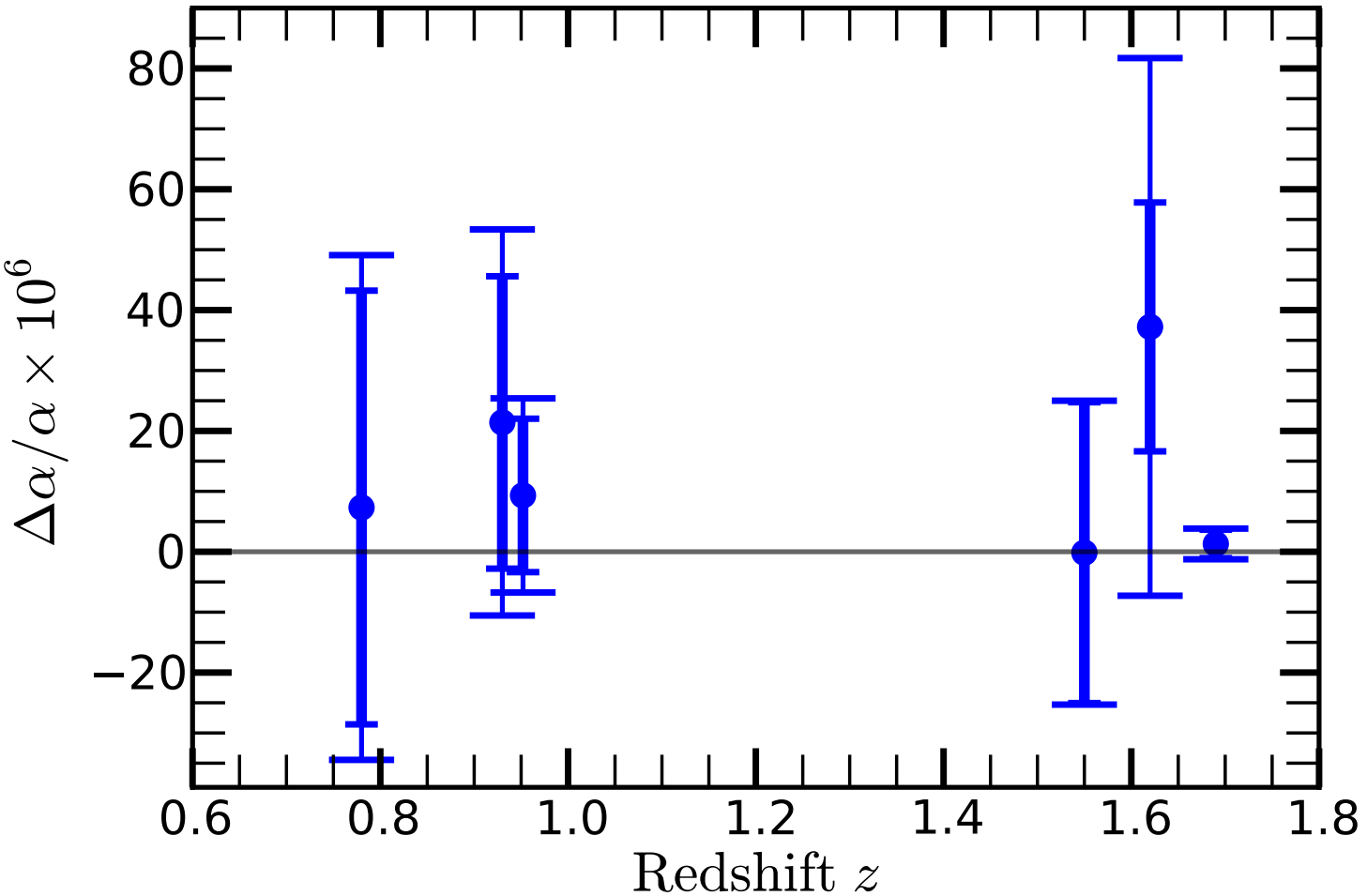
ESO Large Programme

The UVES Large Program for Testing Fundamental Physics

PI: Molaro

- Large observational program dedicated to the measurement of varying constants
- 25 nights of observation and 108 hours service mode on VLT-UVES
- Several major observational (and theoretical) groups
- 15 QSOs (≈ 45 absorption systems)

1st $\frac{\Delta\alpha}{\alpha}$ Results: J222006-280323



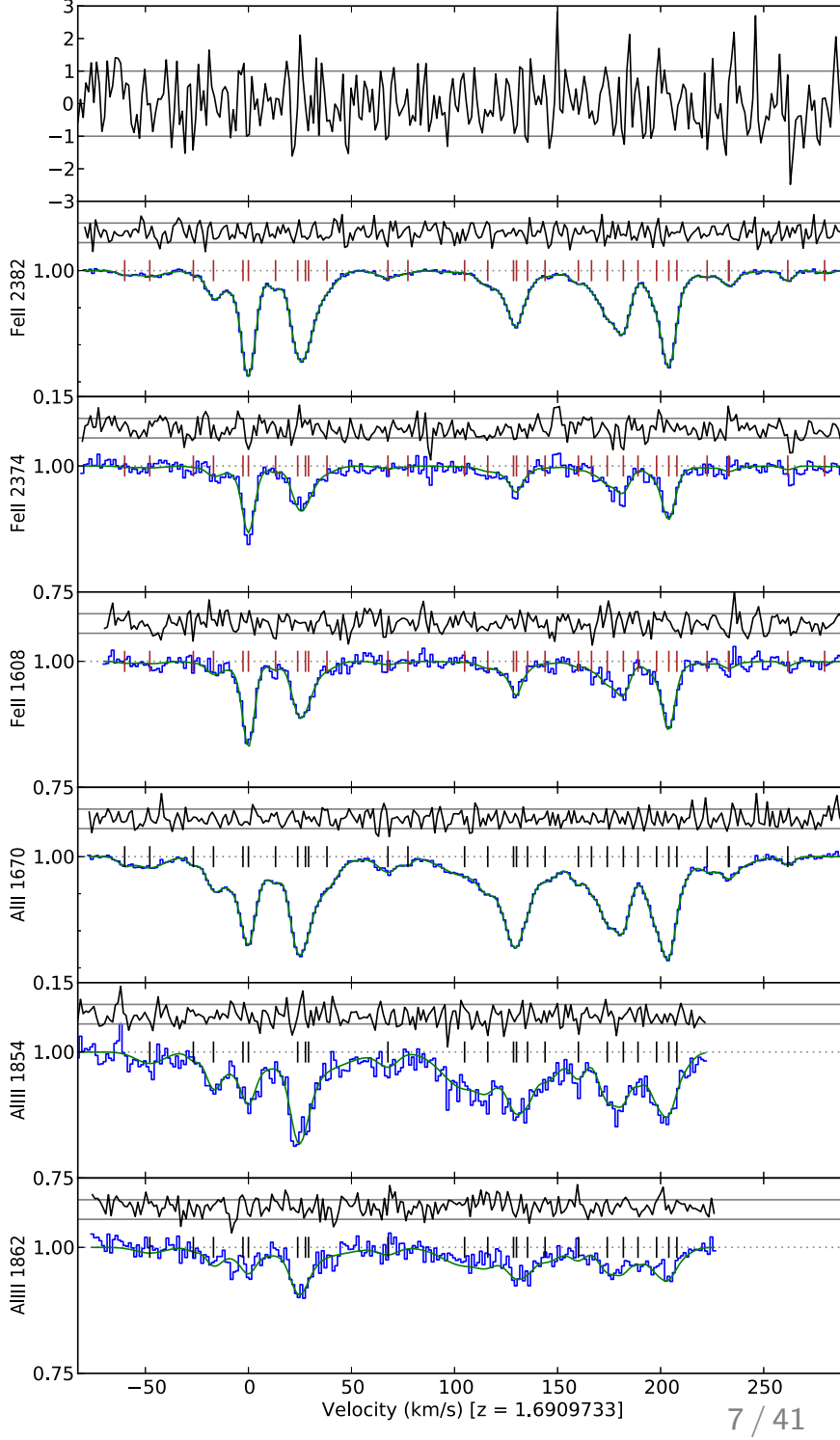
$$\mathbf{z_{1.69}}: \frac{\Delta\alpha}{\alpha} = +\mathbf{1.29 \pm 2.35_{stat} \pm 1.0_{sys}} \text{ppm}$$

Source: (Molaro, et al. 2013)

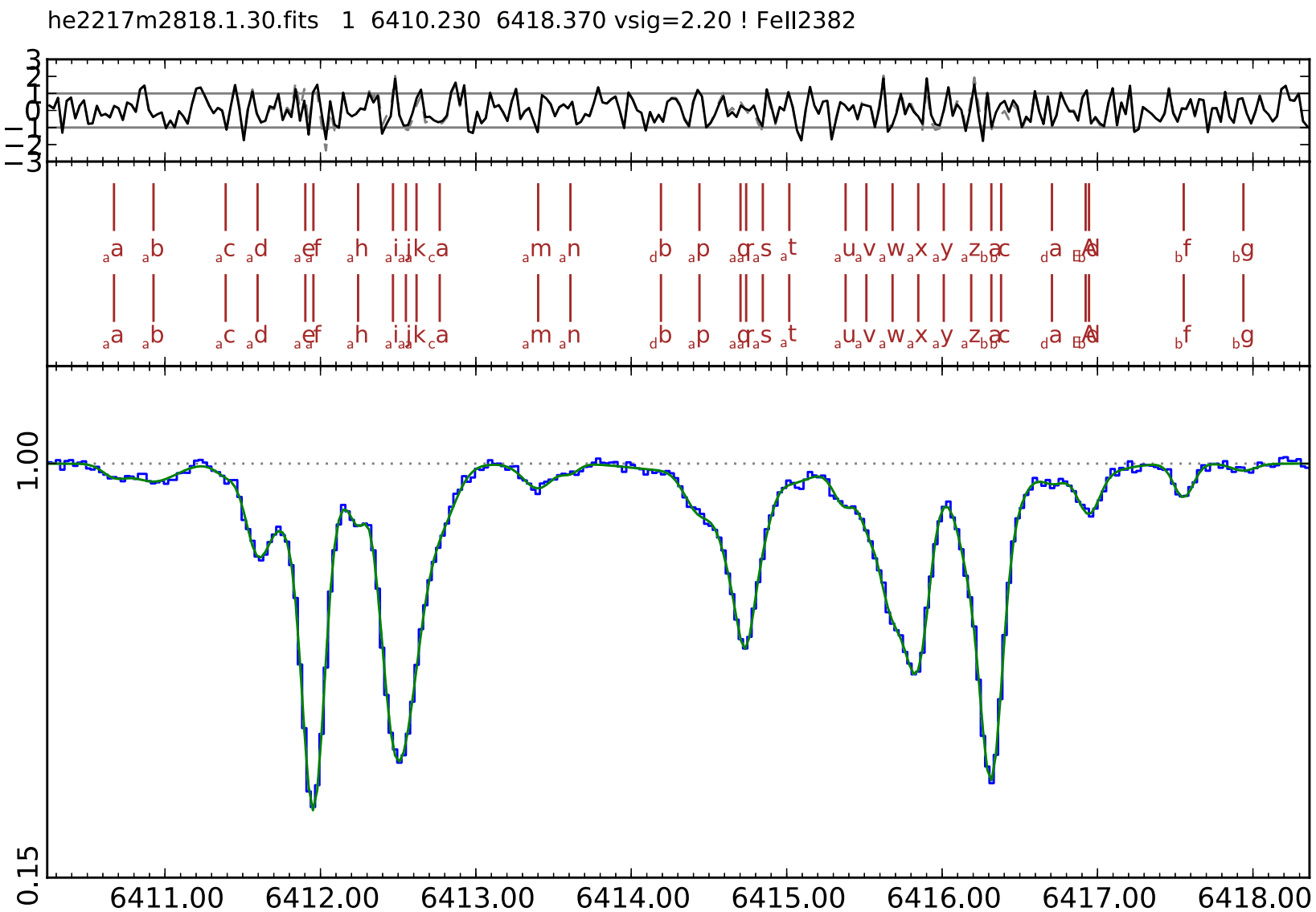
1st α J222006-280323 $z_{em} = 2.4$

$z = 1.6919$

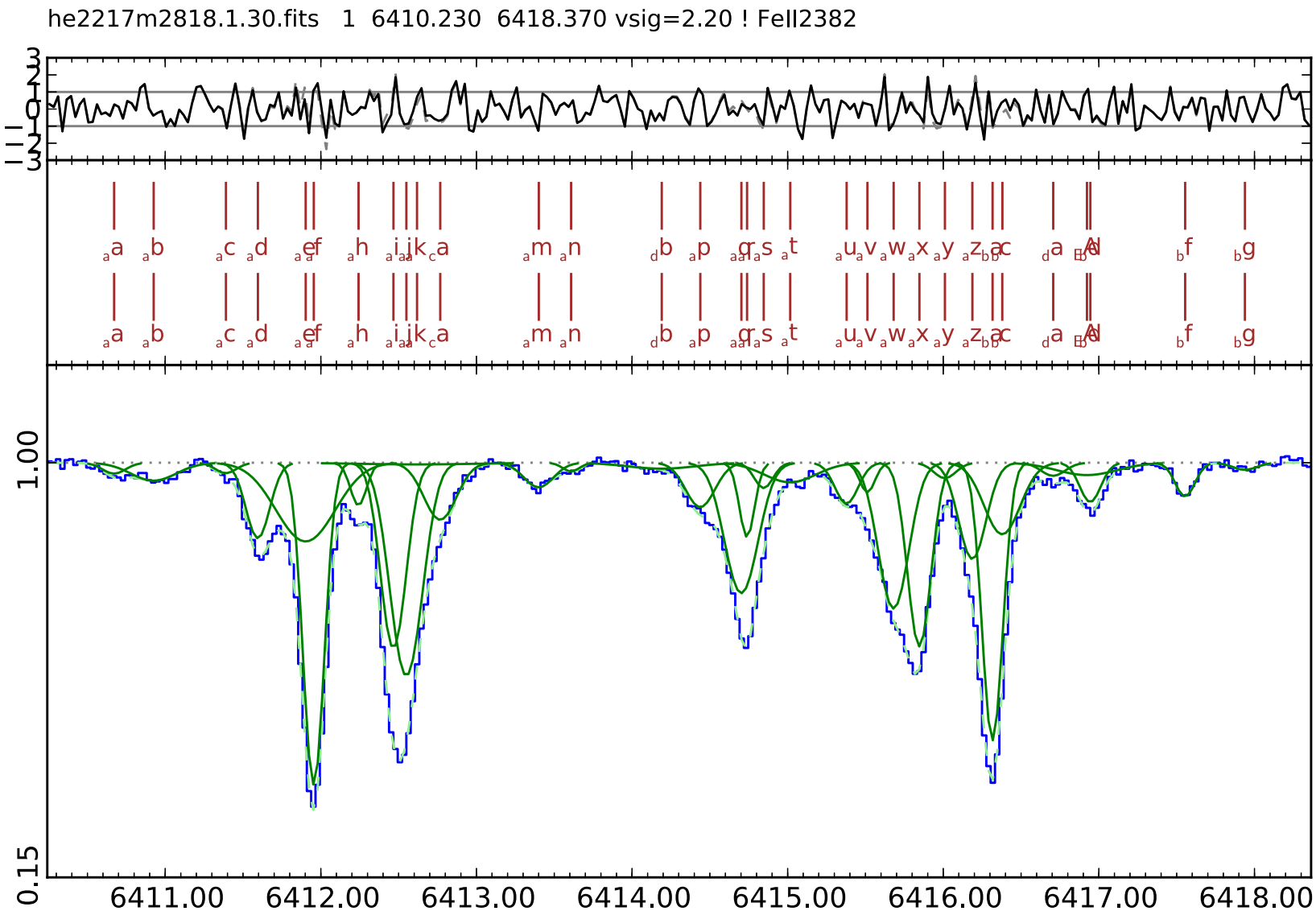
- 16 exposures (4000 s)
- SNR $\approx$ 100
- VPFIT
- 32 velocity components
- Systematic error estimate



FeII 2382


he2217m2818.1.30.fits 1 6410.230 6418.370 vsig=2.20 ! FeII2382
3
2
1
0
-1
-2
-3
1.00
0.15
6411.00
6412.00
6413.00
6414.00
6415.00
6416.00
6417.00
6418.00

FeII 2382 - Decomposed Fit



ESO Large Programme

Summary and future work.

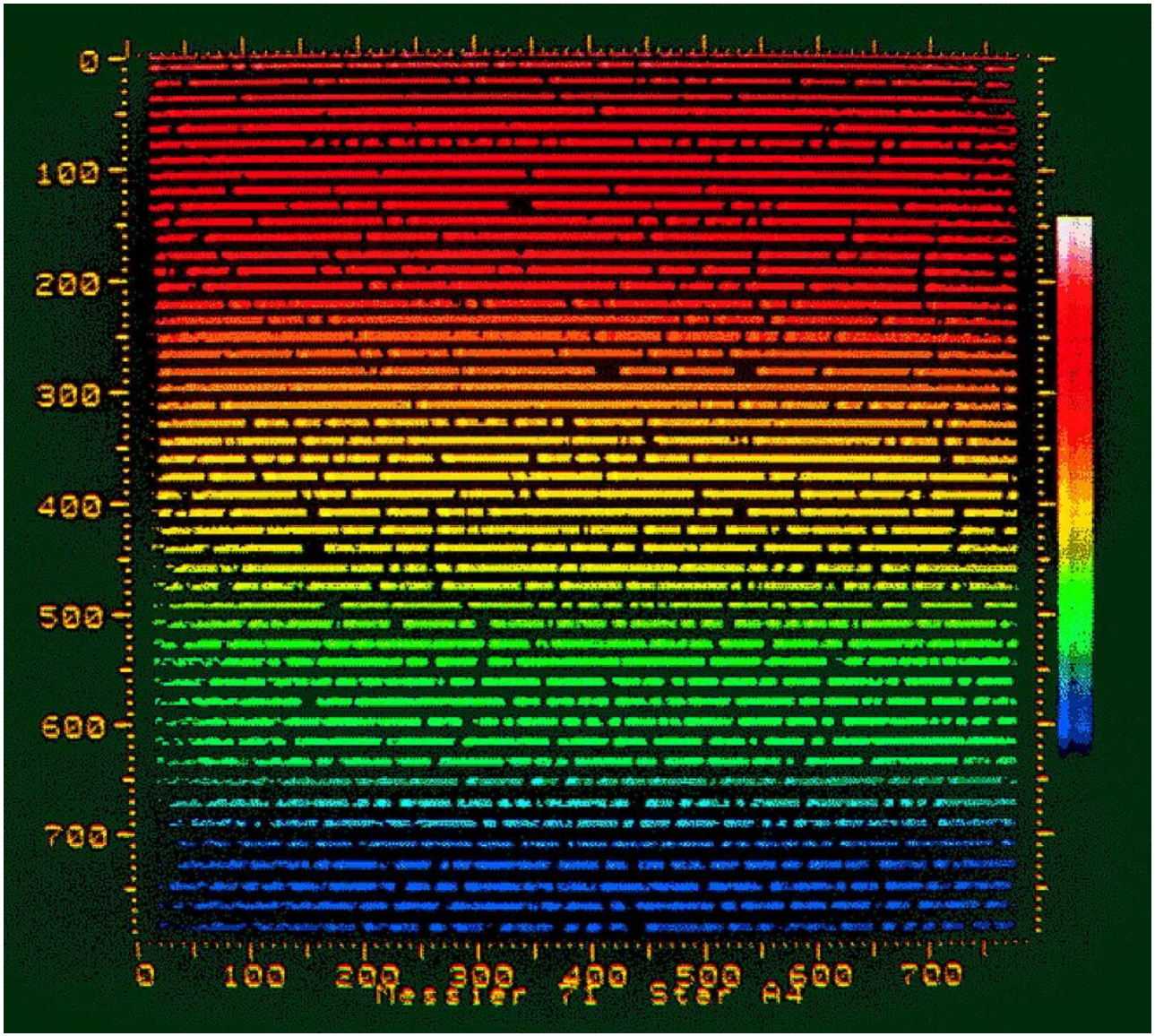
- Dedicated observations to specifically test varying constants.
- Blinding data to $\frac{\Delta\alpha}{\alpha}$ analysis.
- Extra calibrations (new methods).
- More results soon.

Preliminary.

The Story of a Wavelength Calibrated Science Exposure

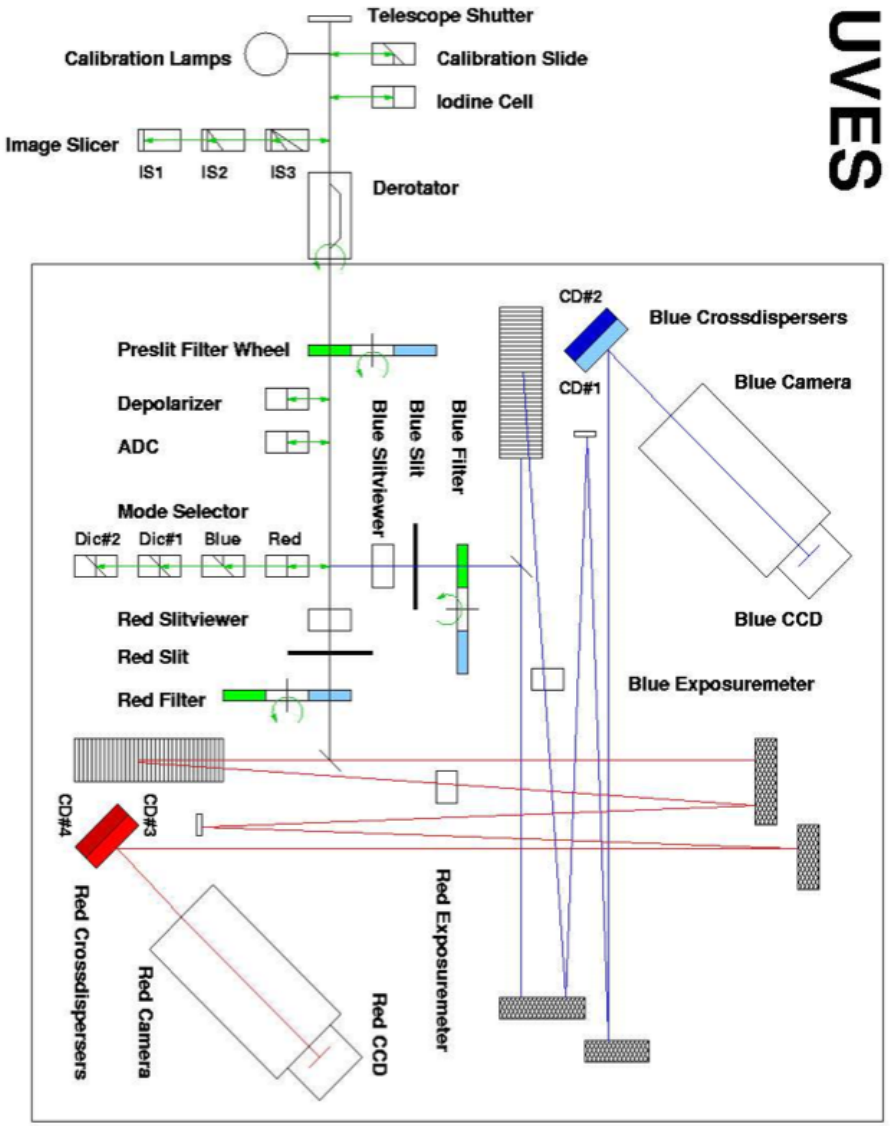
(Standard Way)

Echelle Spectrograph



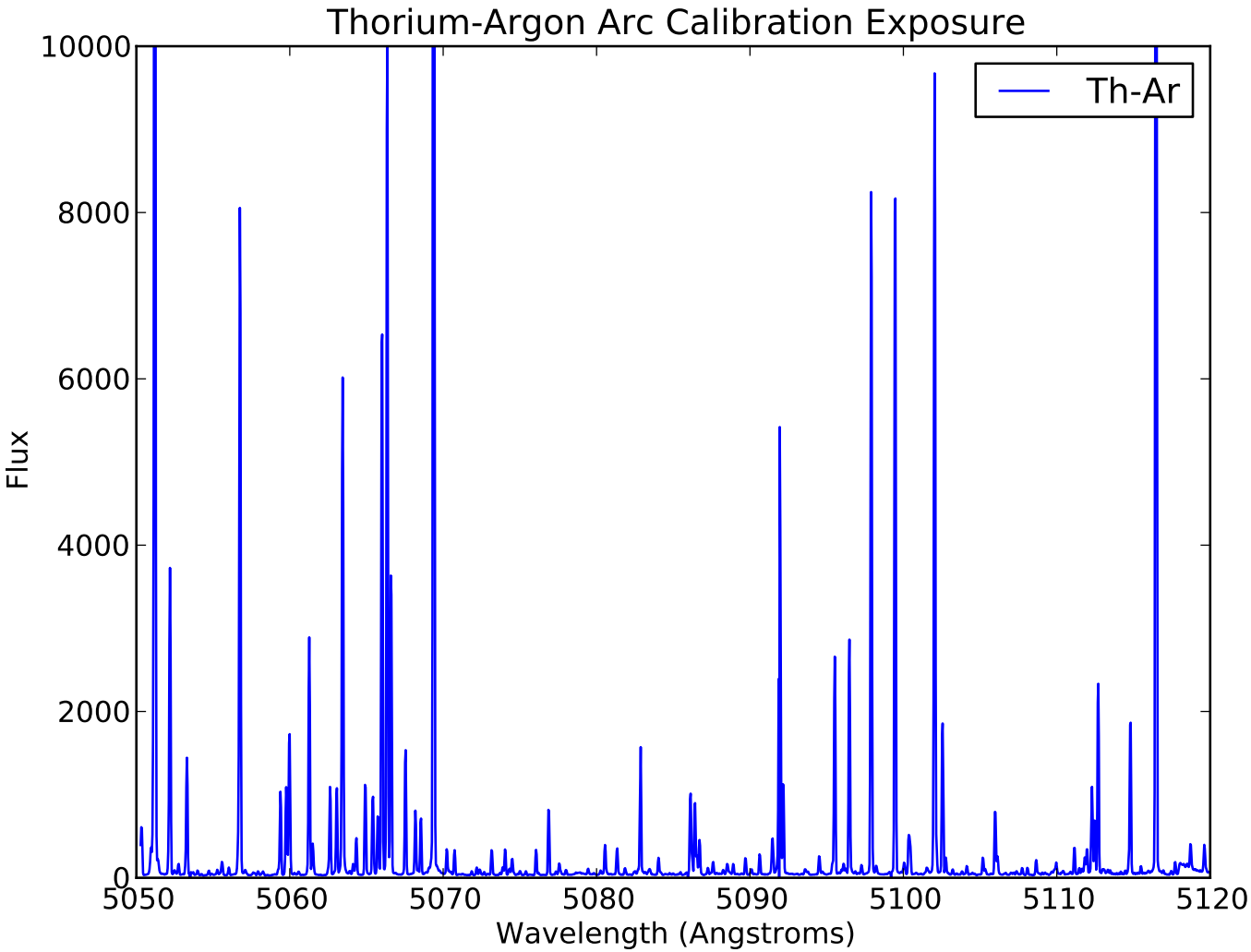
Credit: W.M. Keck Observatory

ThAr Calibration Echelle Spectrograph

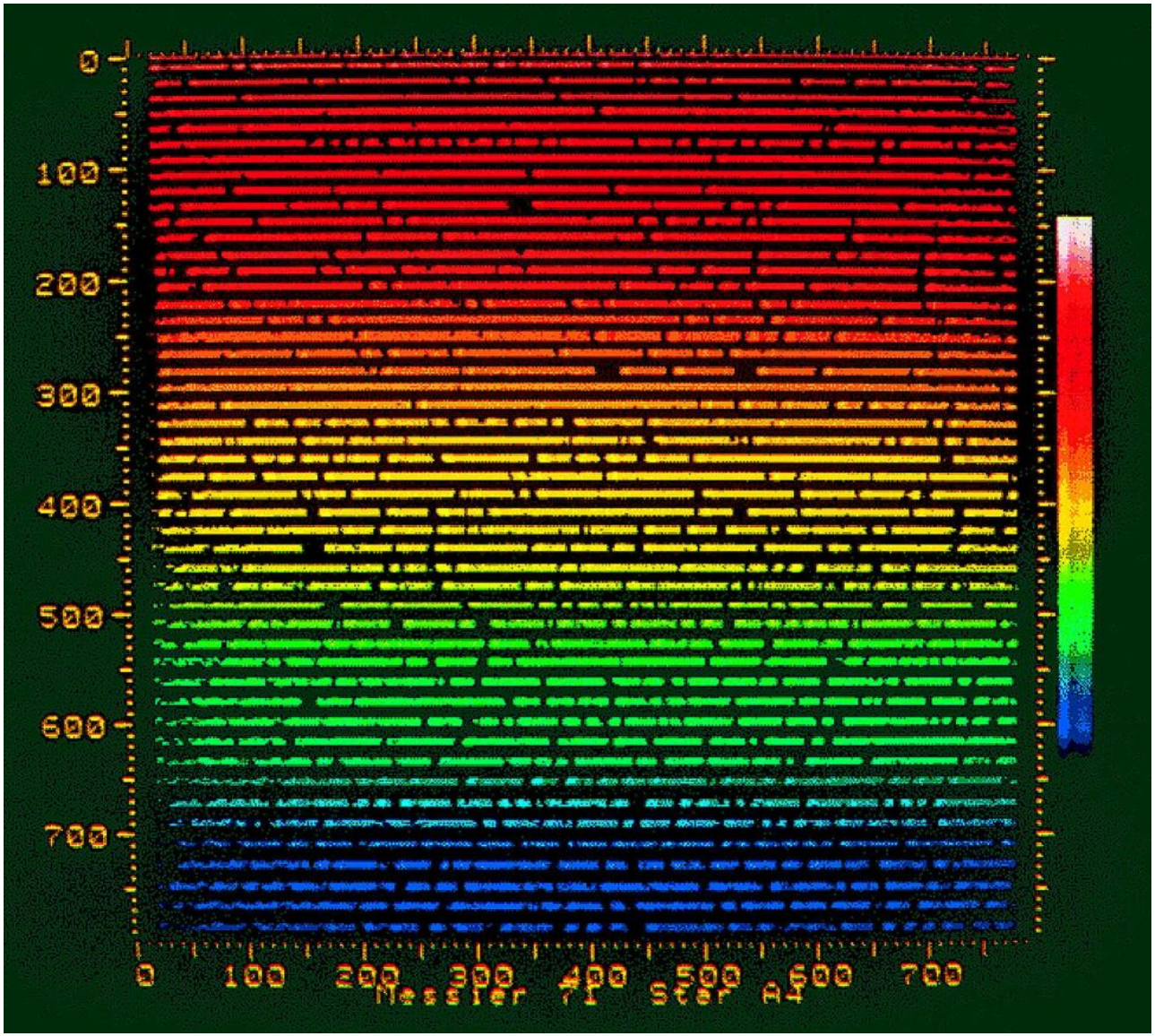


Credit: ESO

Calibrate Spectrograph



Echelle Spectrograph



Credit: W.M. Keck Observatory

Standard Procedure Recap

1. Take science exposure
2. Take ThAr (calibration exposure)
3. Map wavelength solution from ThAr to the science exposure

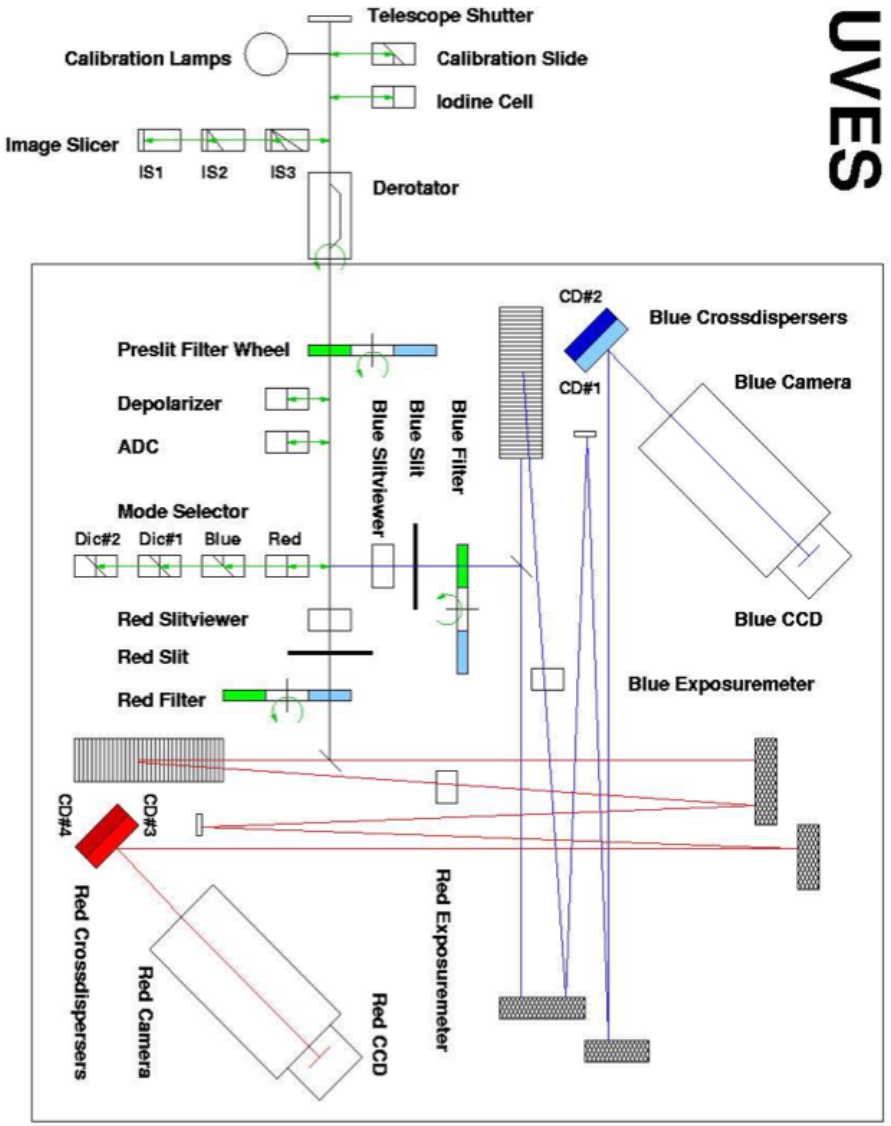
What could go wrong, and why does it matter?

λ miscalibration $\rightarrow$ wrong $\frac{\Delta\alpha}{\alpha}$

Iodine Cell Wavelength Calibration Check

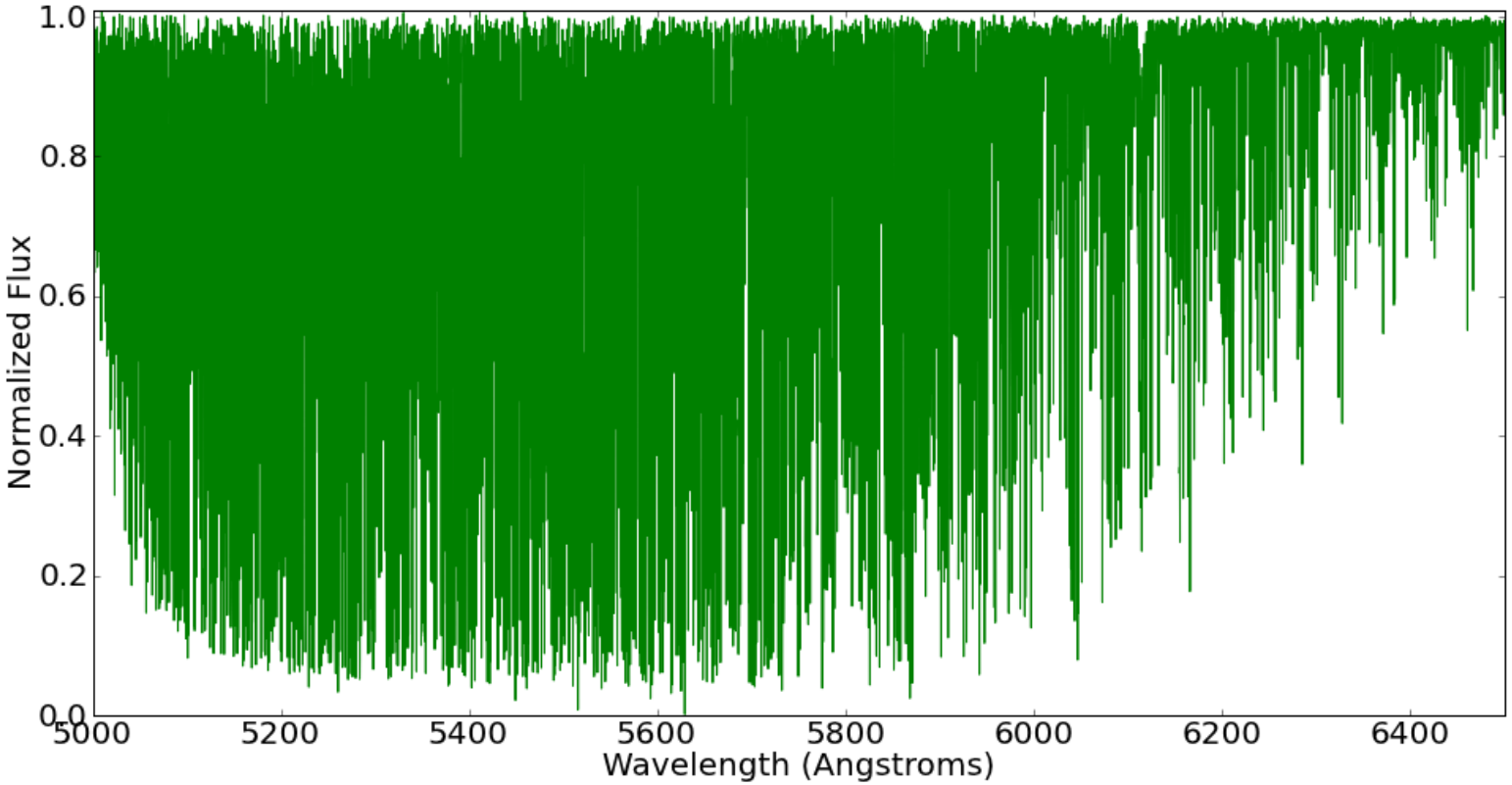
1. Take science exposure *with a known reference spectrum imprinted*.
2. Take ThAr (calibration exposure).
3. Map wavelength solution from ThAr to the science exposure.
4. Check the standard wavelength calibration: compare science exposure with the reference spectrum.

Iodine Cell in the Light Path

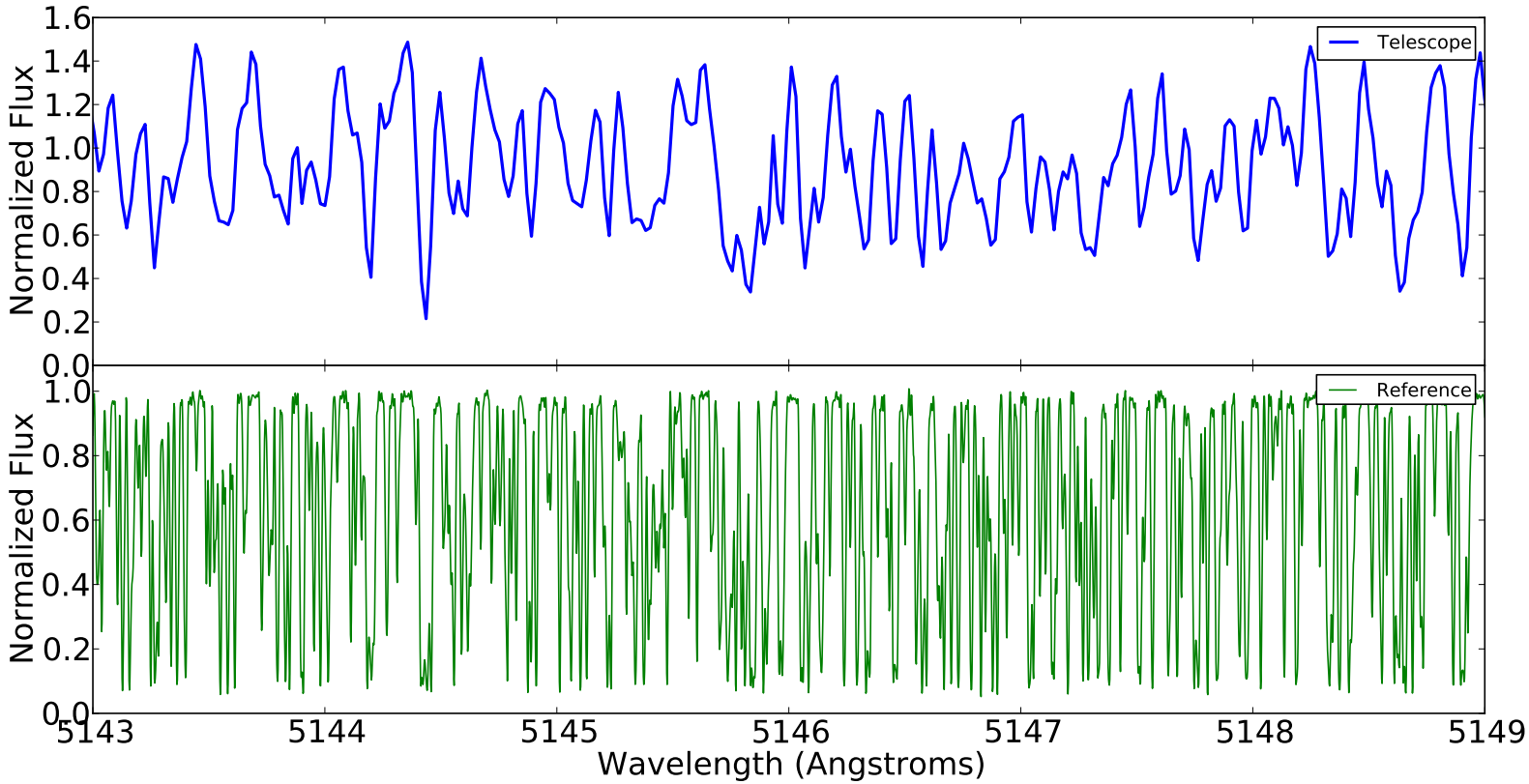


Credit: ESO

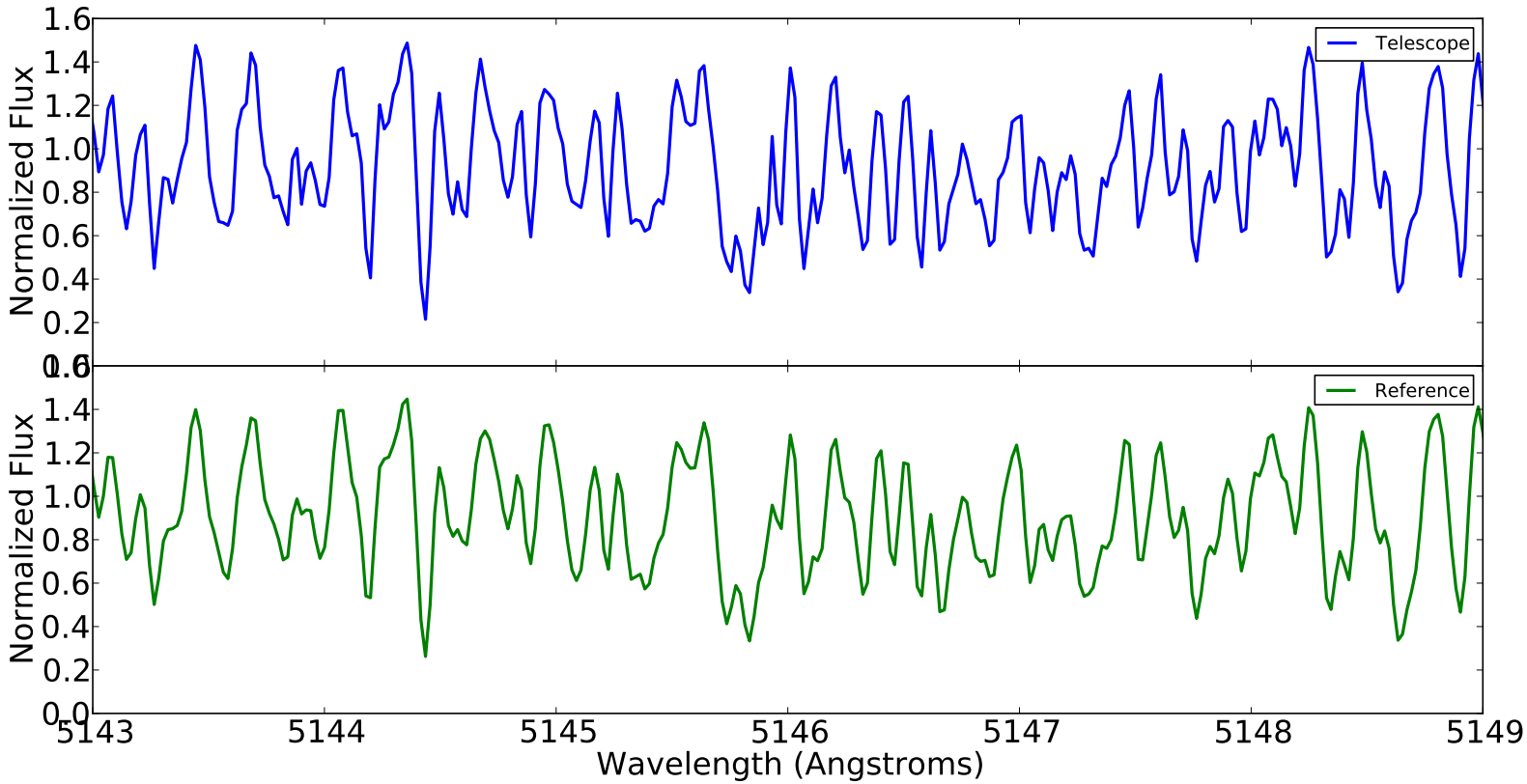
Molecular Iodine Absorption Forest – FTS



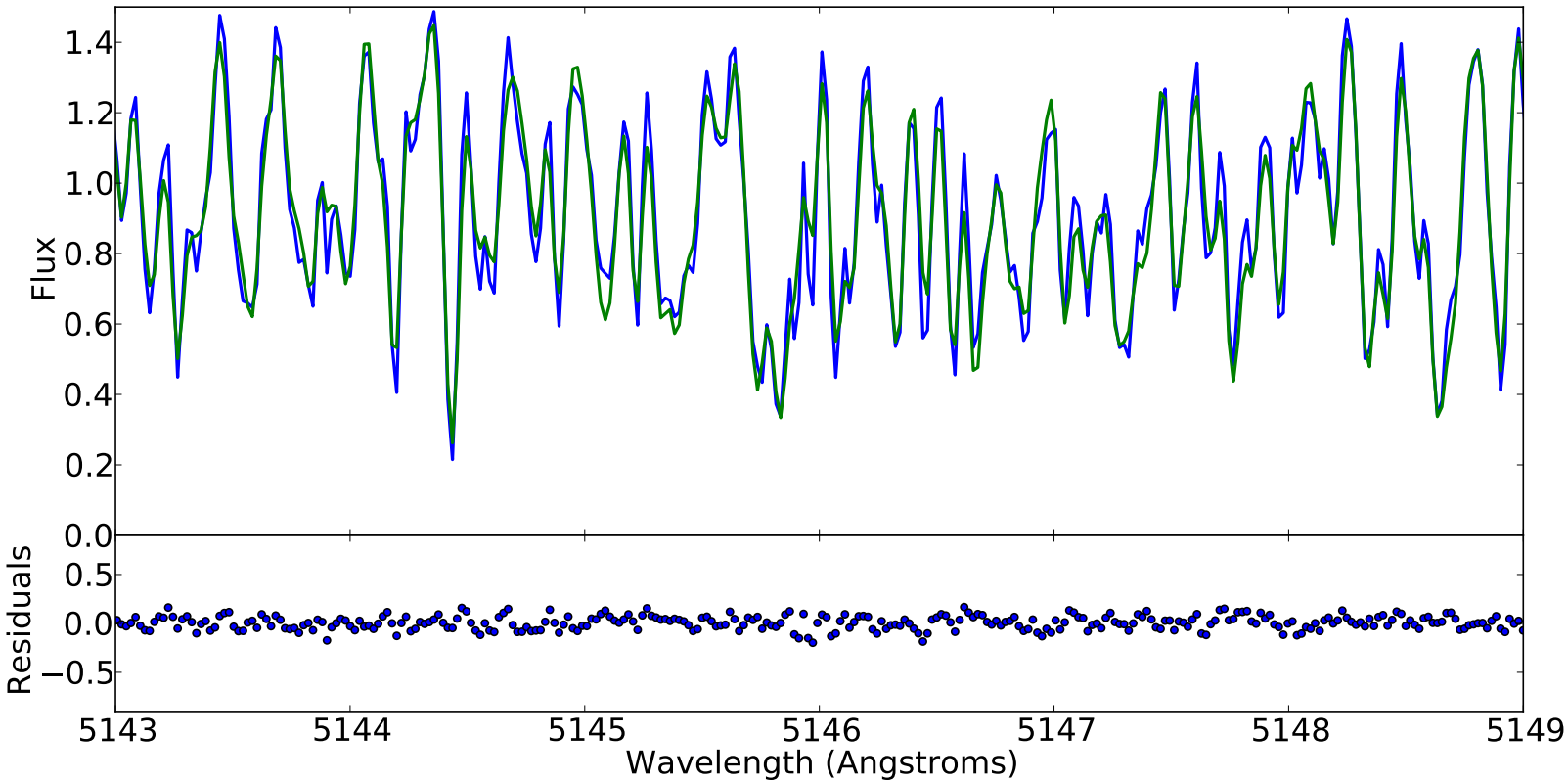
VLT-UVES vs. FTS spectrograph



Convolve with Instrument Profile



Single Bin – One velocity shift value

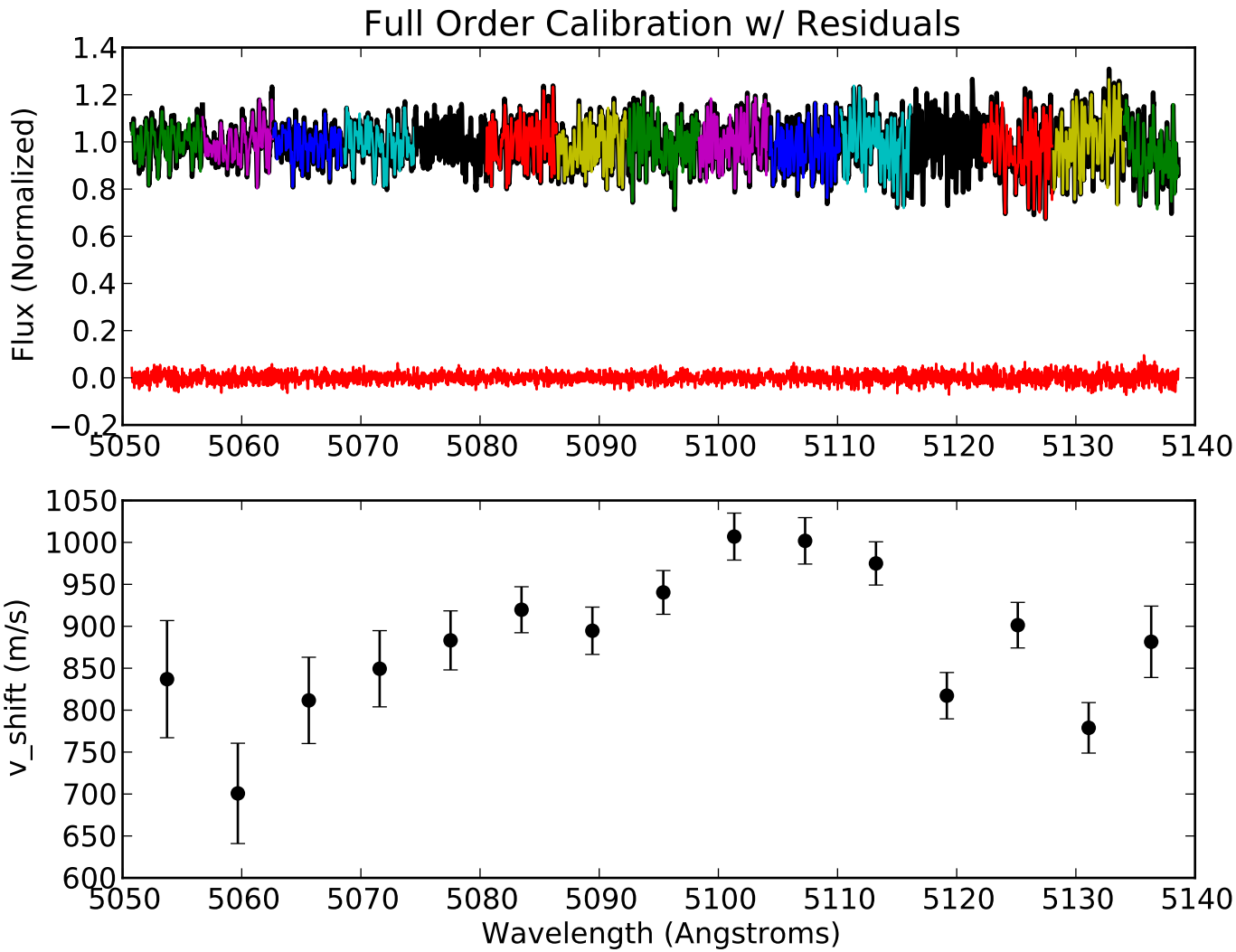


Plotting Miscalibrations

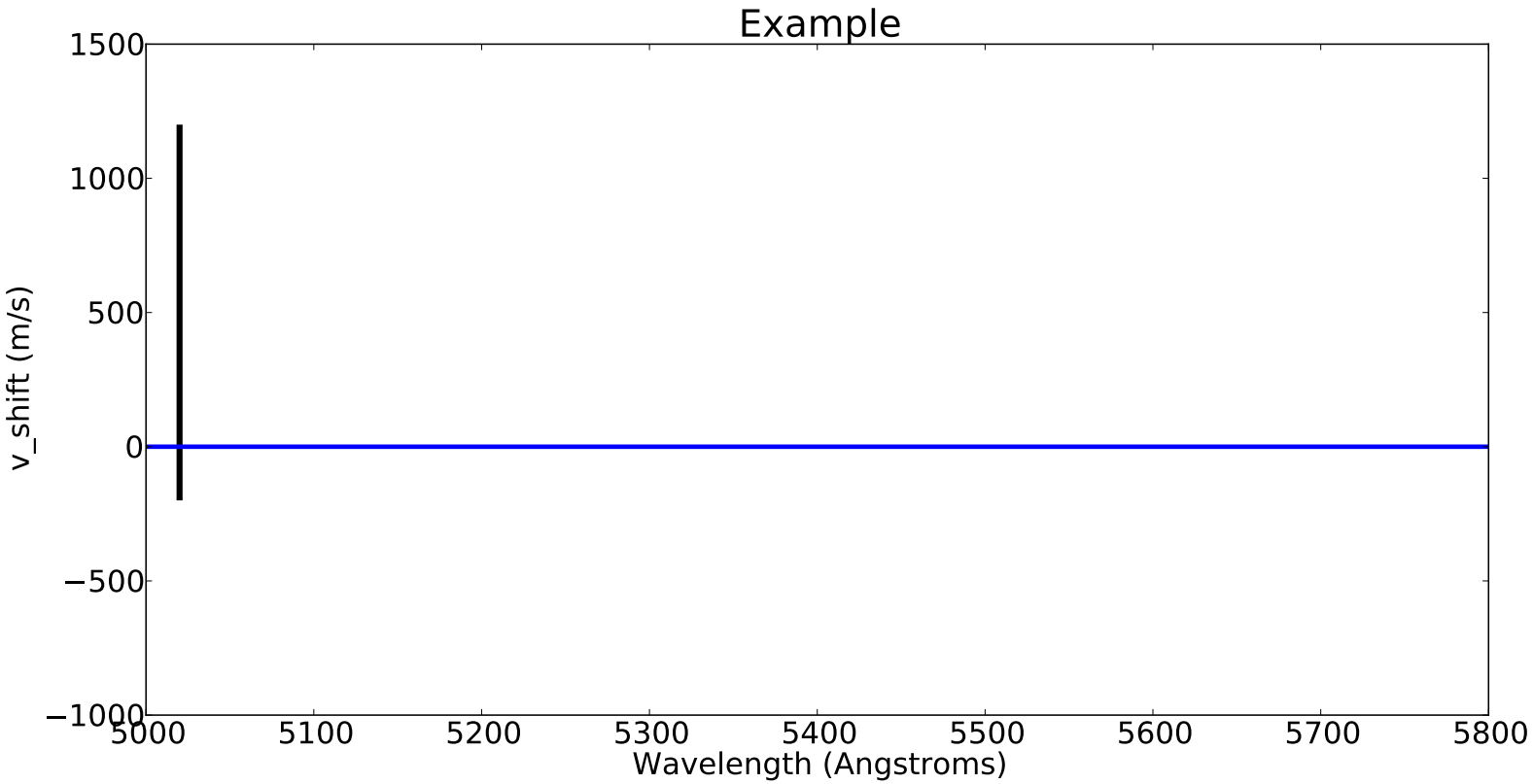
$$\lambda_{\text{reference}} = \lambda_{\text{ThAr}} + \lambda_{\text{shift}}$$

$$v_{\text{shift}} = c \times \frac{\lambda_{\text{shift}}}{\lambda}$$

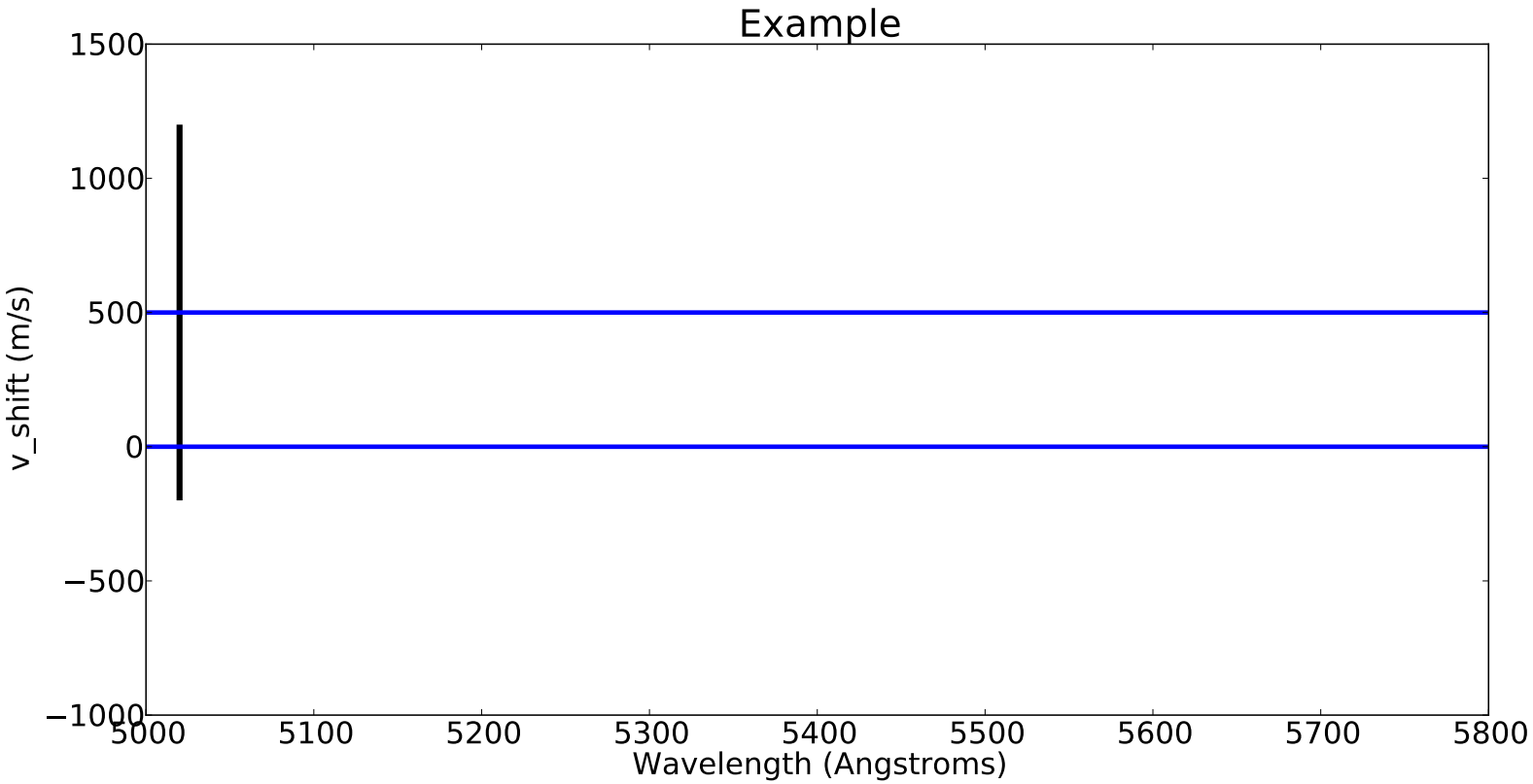
One Order


Full Order Calibration w/ Residuals
Flux (Normalized)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
5050
5060
5070
5080
5090
5100
5110
5120
5130
5140
v_shift (m/s)
1050
1000
950
900
850
800
750
700
650
600
Wavelength (Angstroms)

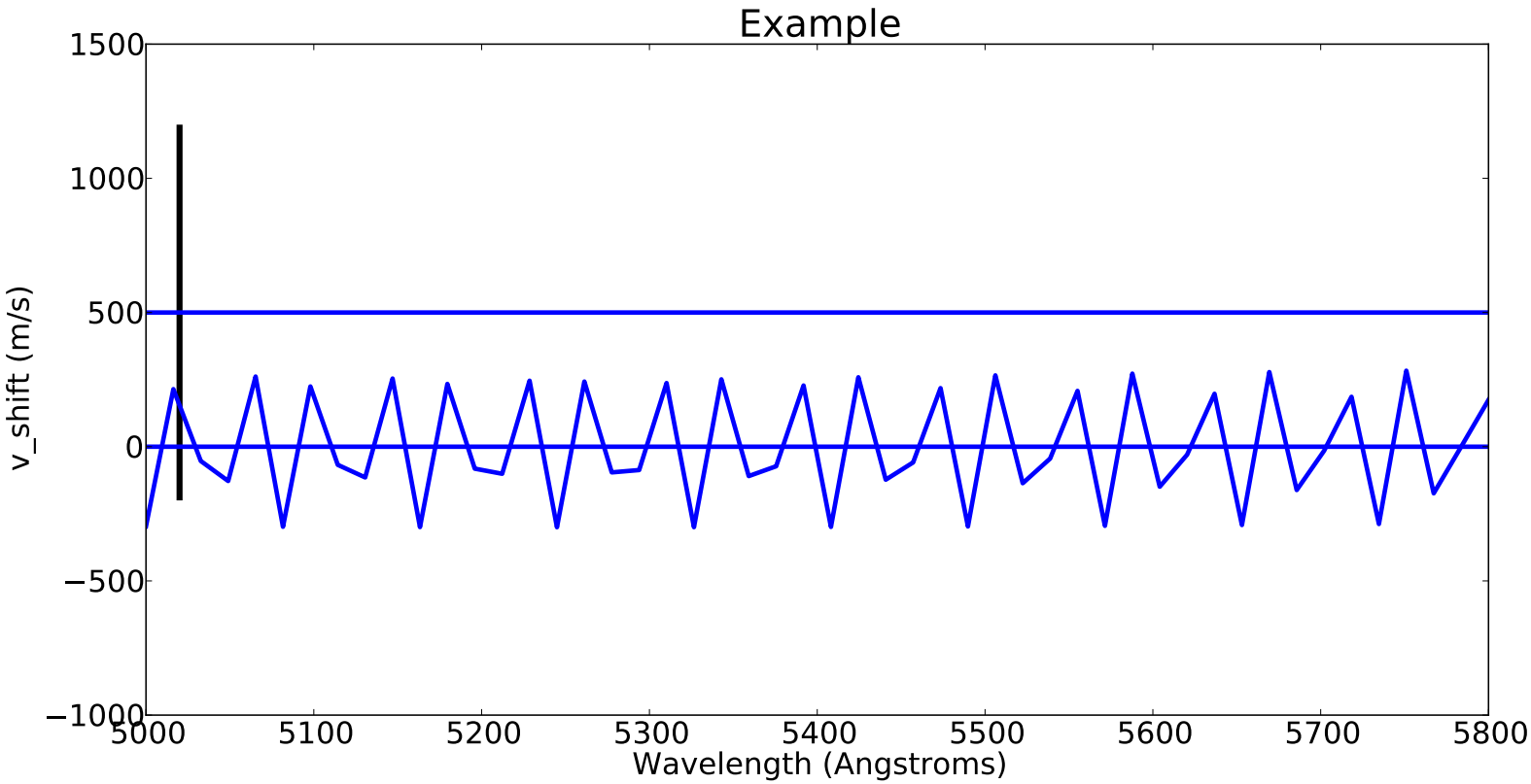
Example Distortion Plot



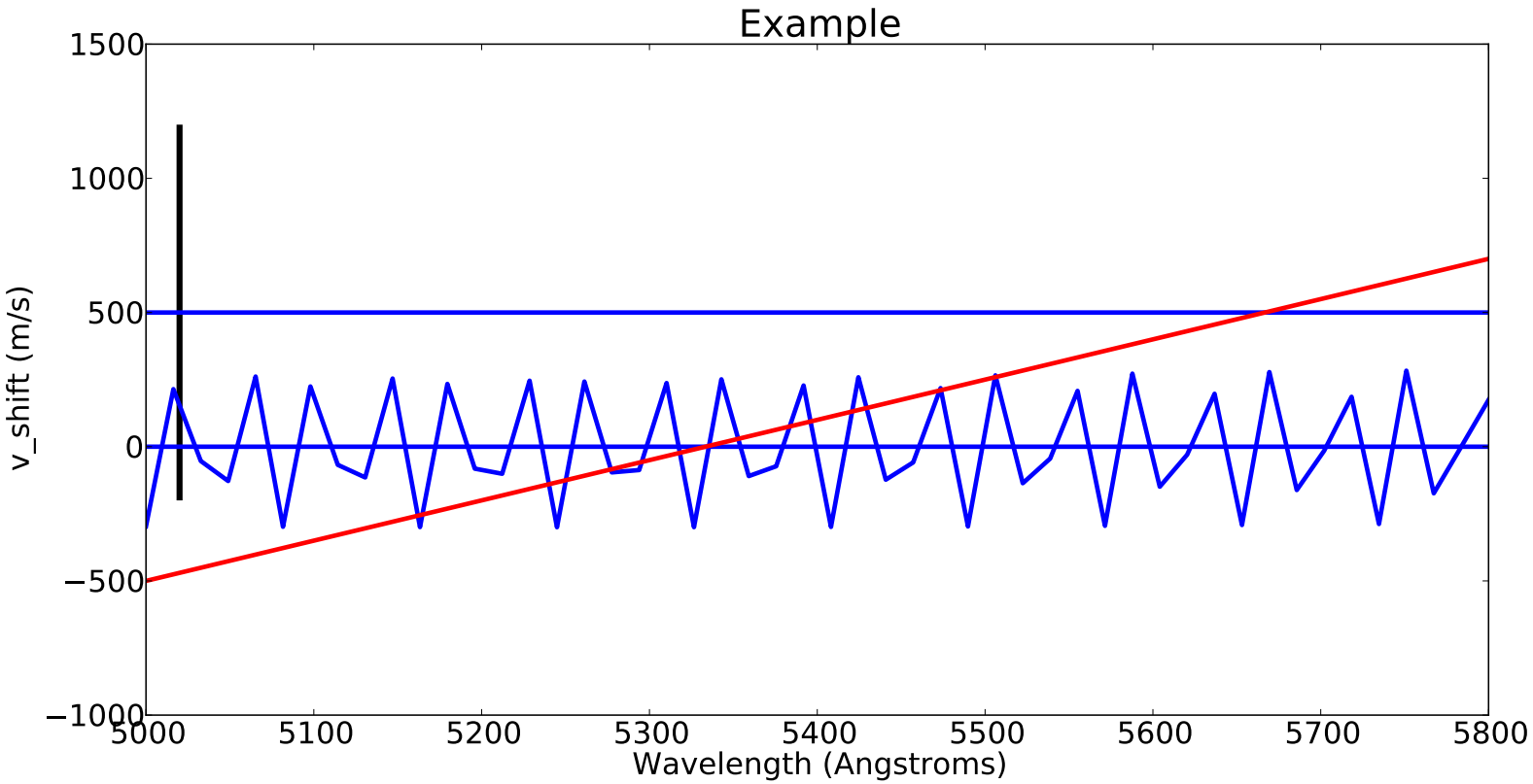
Example Distortion Plot



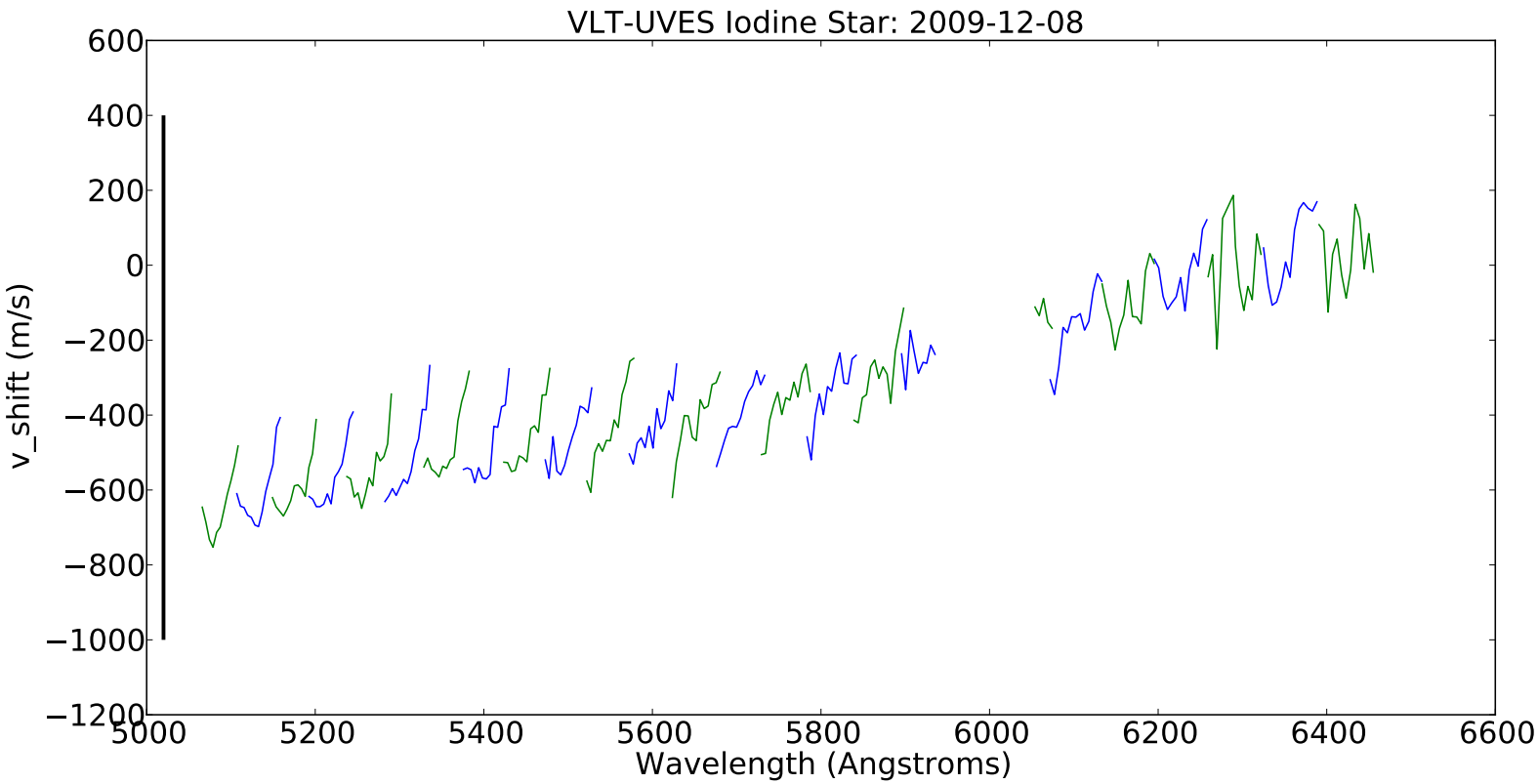
Example Distortion Plot



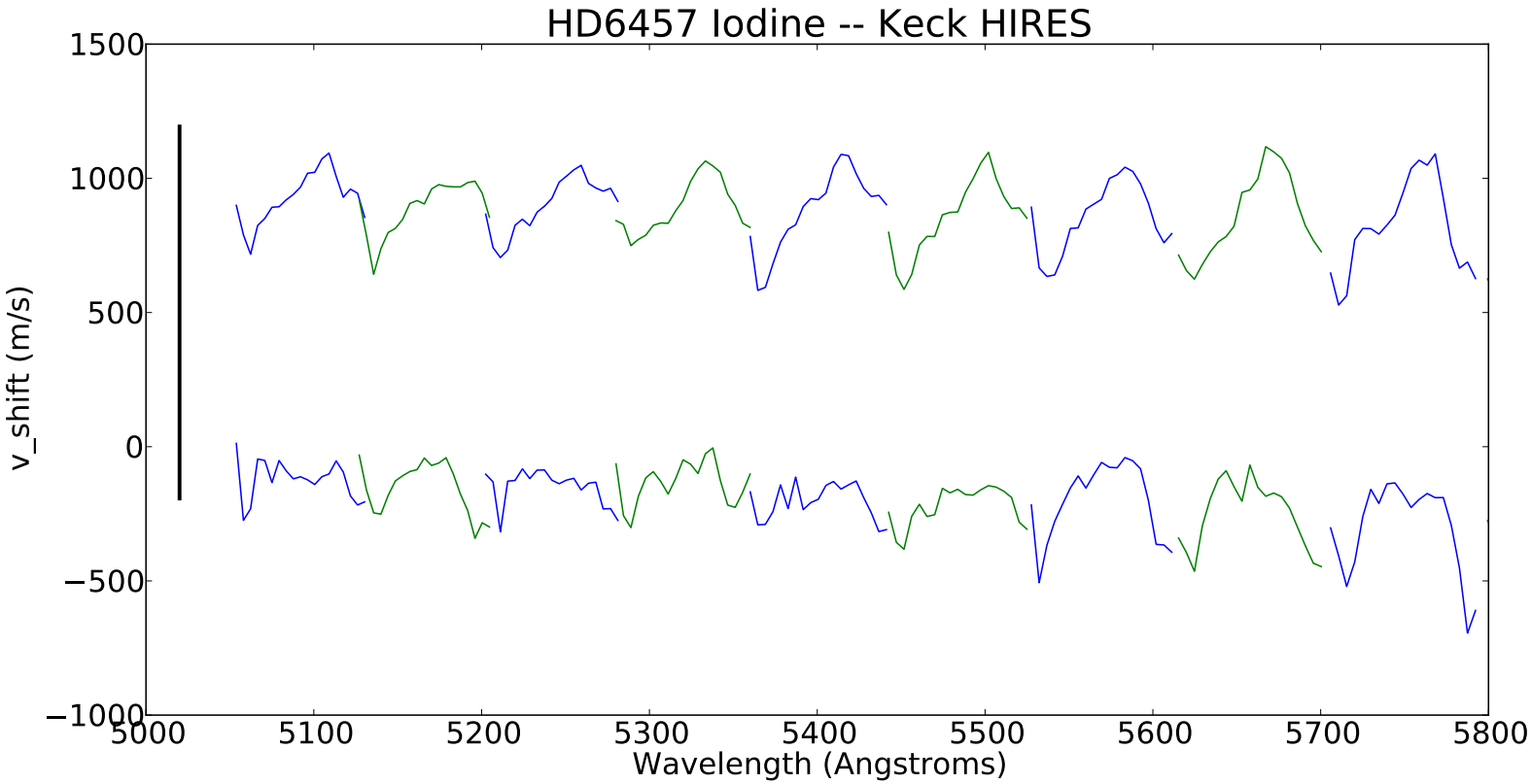
Example Distortion Plot



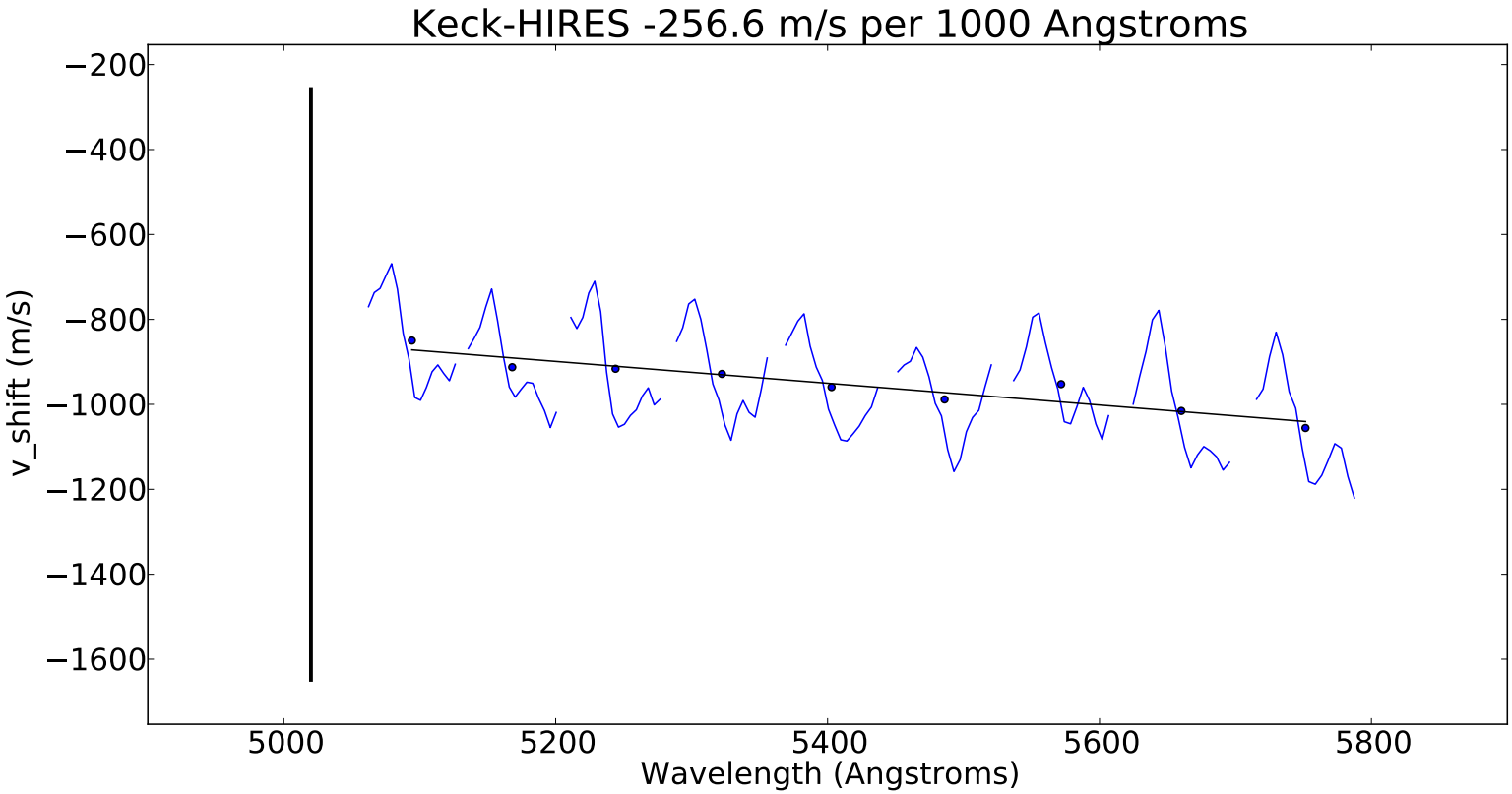
Full Iodine Wavelength Coverage



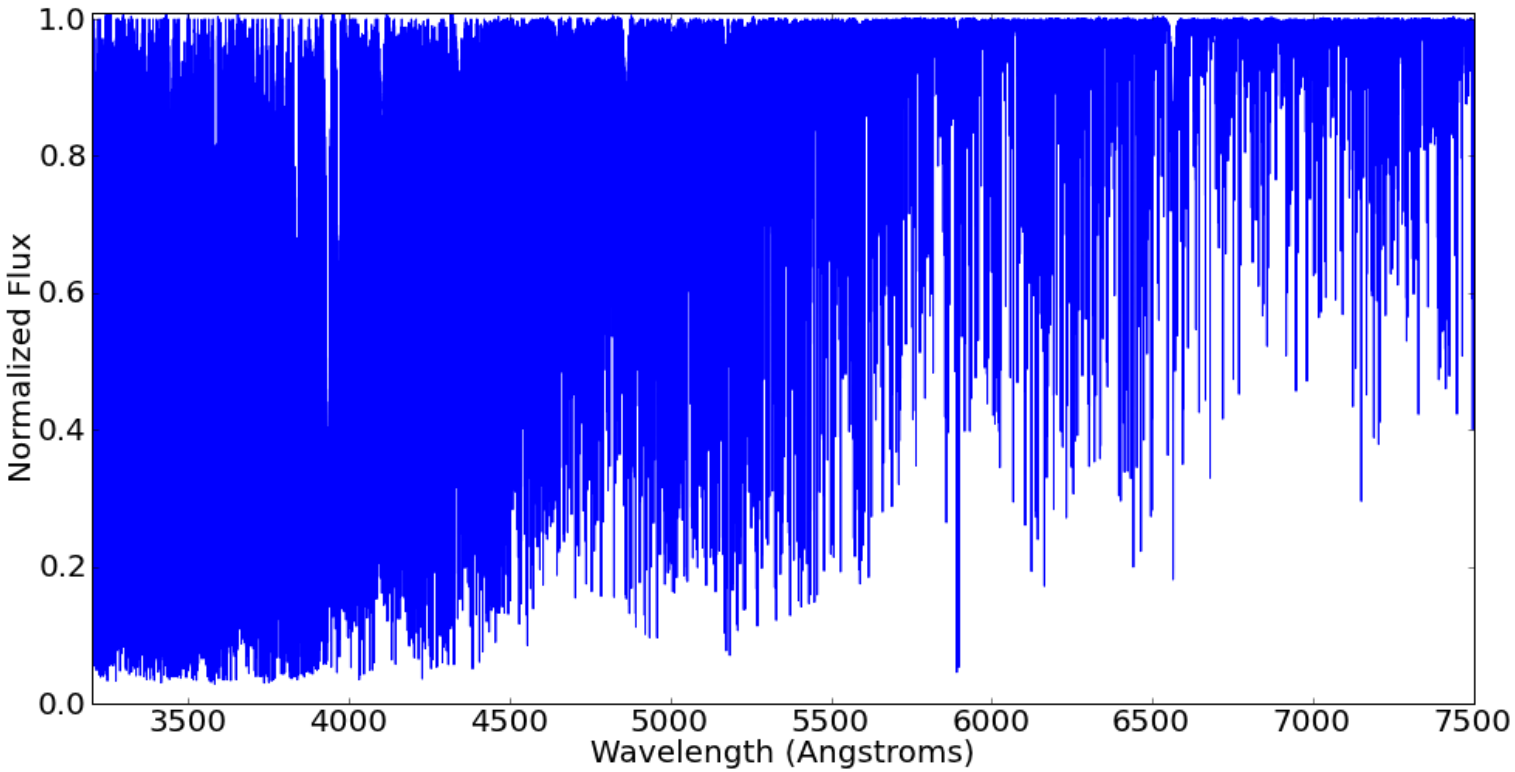
Keck HIRES – Iodine Star



Keck HIRES – Possible Long-Range Distortion??

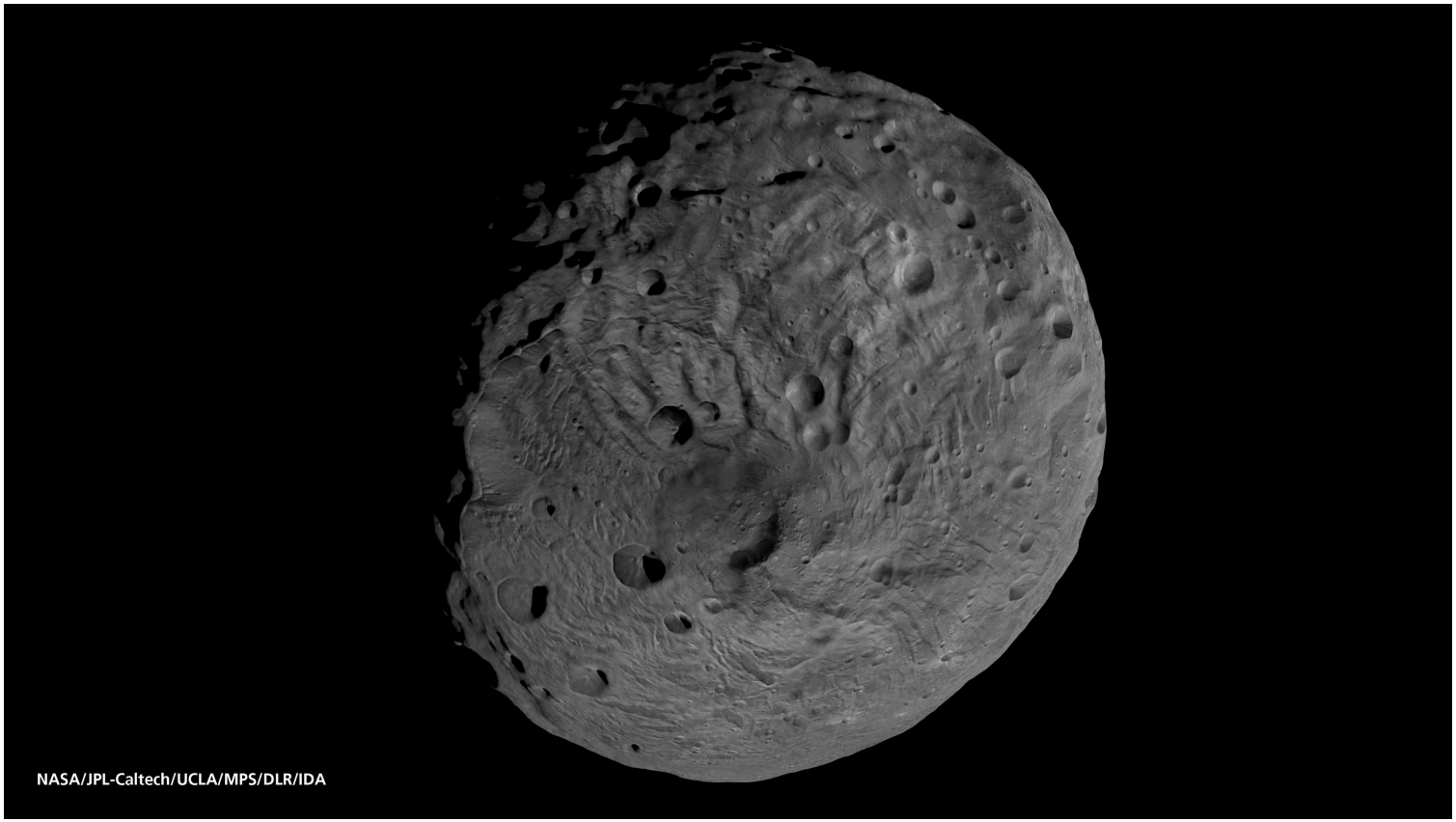


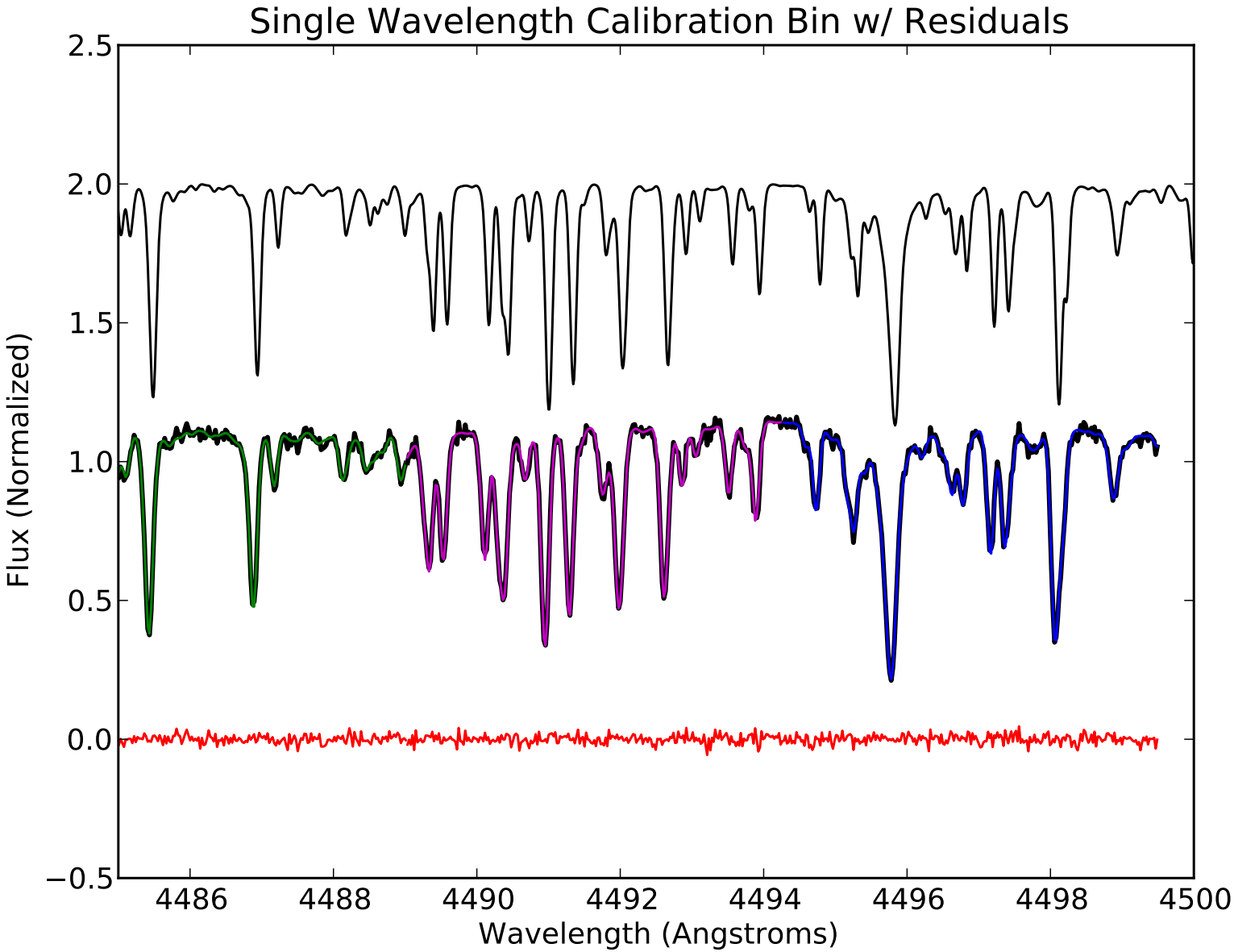
Solar Spectrum – FTS



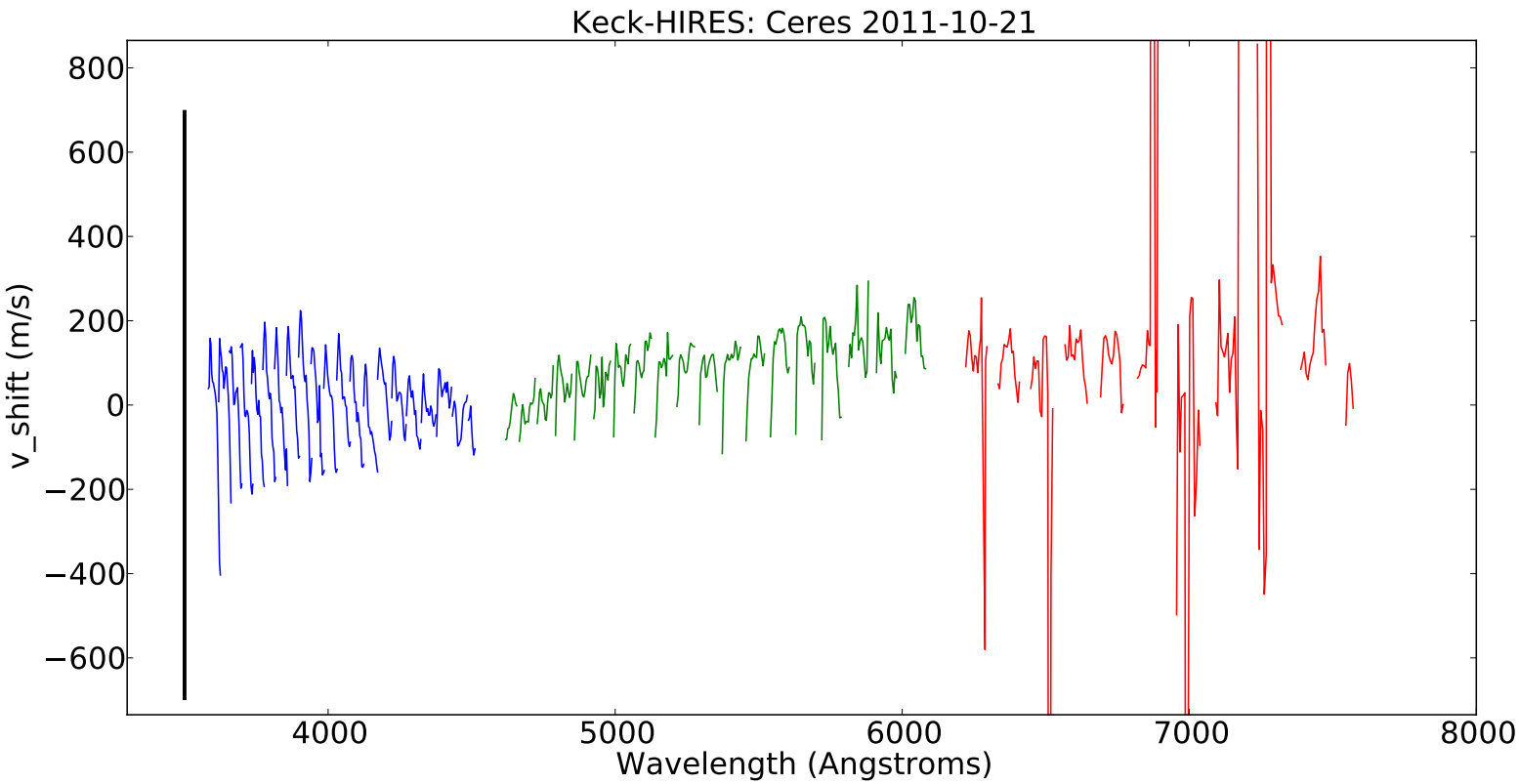
Source: (Chance, Kurucz 2010)

Asteroids: Giant Space Mirrors

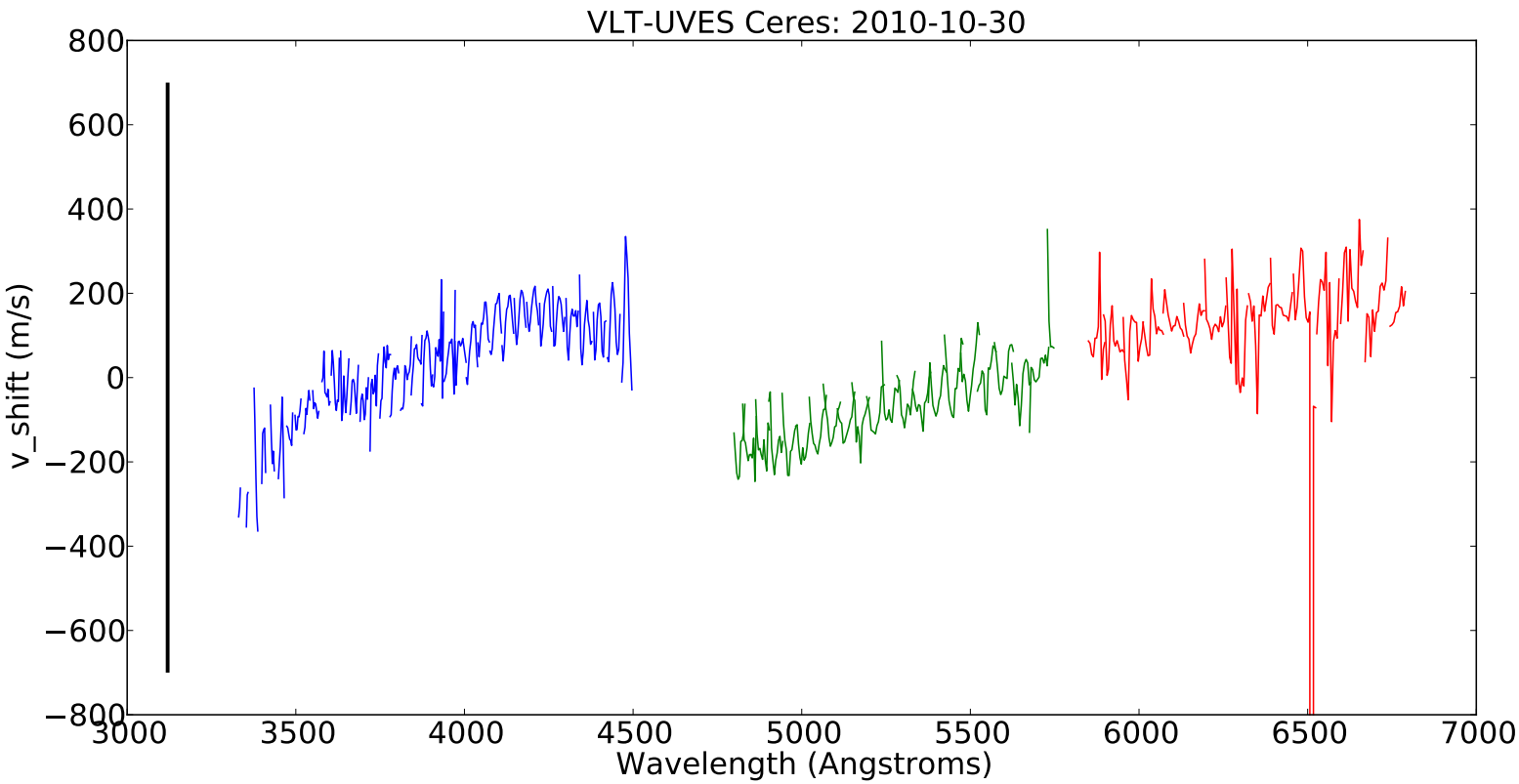



Single Wavelength Calibration Bin w/ Residuals
Flux (Normalized)
Wavelength (Angstroms)
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
4486
4488
4490
4492
4494
4496
4498
4500

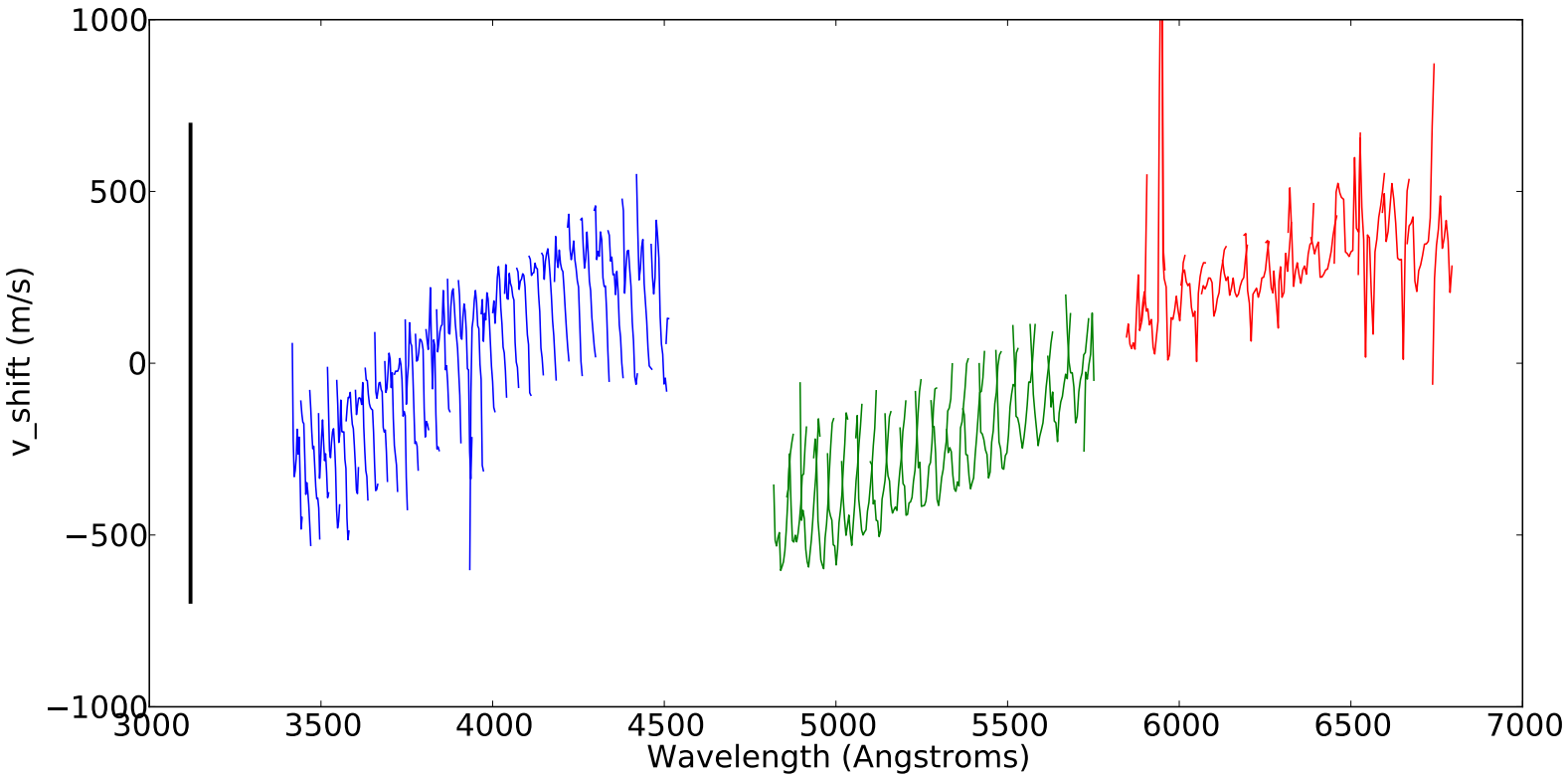
Keck-HIRES Asteroid: minor long-range distortions



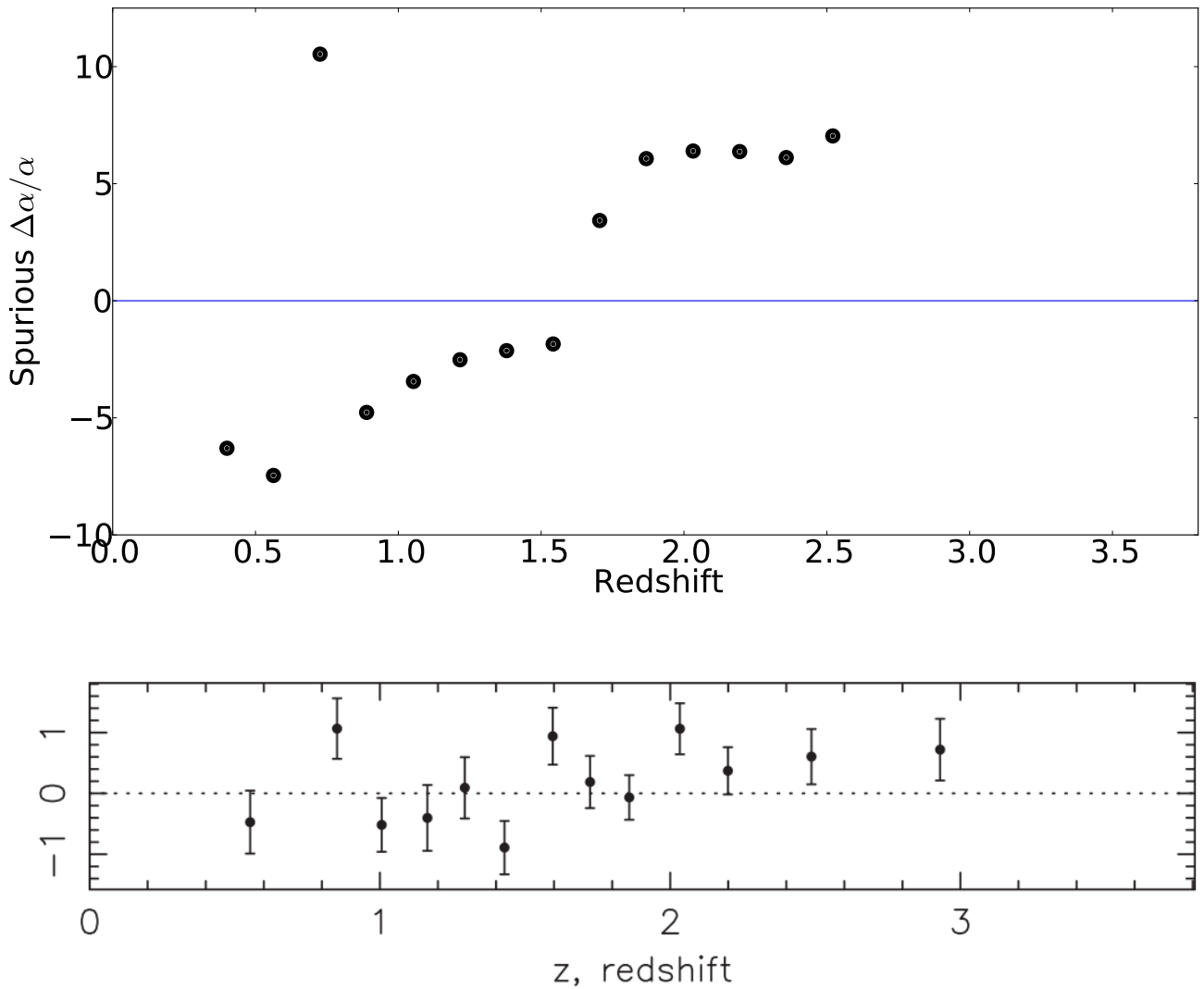
VLT-UVES Asteroid: Long-range wavelength distortions



VLT-UVES 2013 – Solar Twin: Long-range wavelength distortions



Simulated Distortion: AlII, FeII, MgII



Source: Figure 9 (King, et al. 2012)

Concluding Questions

- Source of distortions?
- Stability of wavelength distortions? (correctable?)
- What is the impact on the dipole result?

Thanks!