Nowy spektrograf Echelle w Piwnicach

Pierwsze wrażenia

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In the beginning

The prototype

In the beginning

The final product

Mounting on the TSC and location of the parts

Fibre injection and guiding unit

Mounting on the TSC and location of the parts

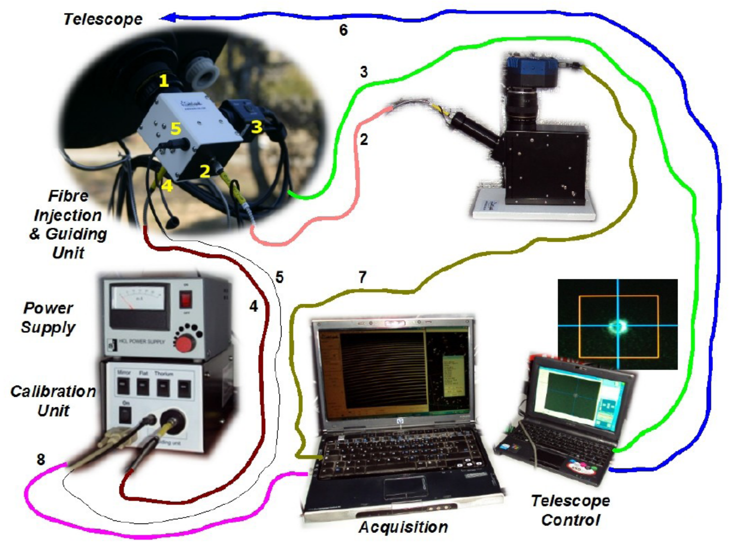
Spectrograph, power supply and calibration unit

Mounting on the TSC and location of the parts

Control room

Mounting on the TSC and location of the parts

How it works ?

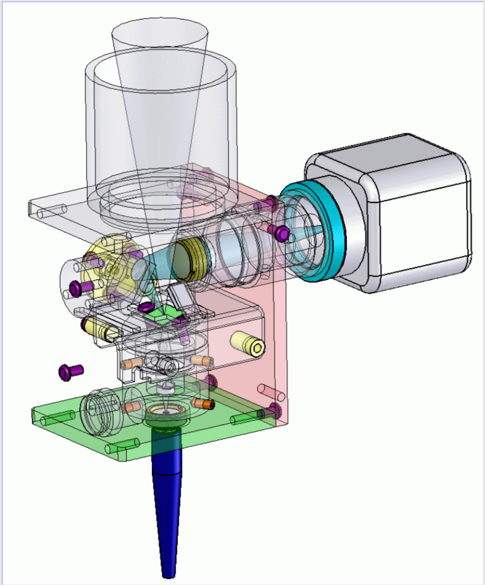


Fibre injection and calibration unit

- 2″ or Schmidt-Cassegrain Telescope interface
- miror based with light going through a hole (75 μm) in the middle
- calibration input (remote controlled)
- FC fibre connectors
- scientific fibre 50 μm
- calibration fibre 200 μm
- guiding camera

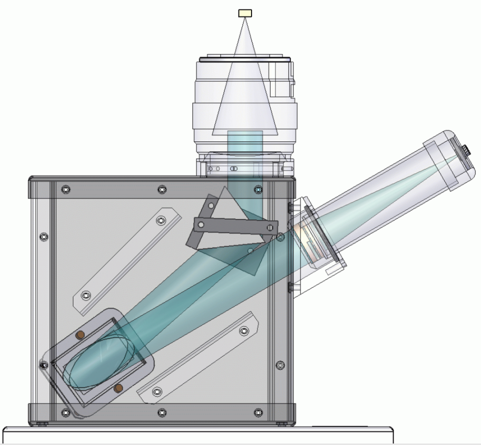
In our case additionally

- 0.63$\times$ focal reducer ($f/9.45$)



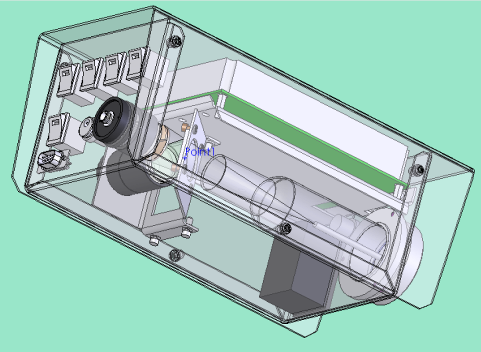
Spectrograph

- fibre-fed
- cross-dispersed echelle
- $f = 125\,\mathrm{mm}$ collimator ($f/5$)
- $R2$ high efficiency echelle grating
- coated prism cross-disperser
- resolving power $R \sim 10\,000$
- visible domain (around $4500 - 7000\,\text{Å}$)
- choice of imaging camera



Calibration unit

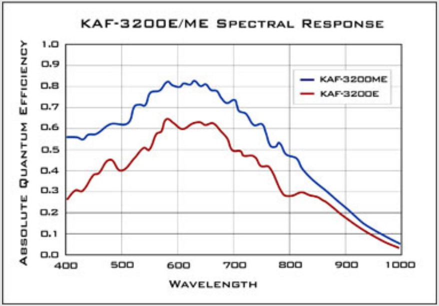
- ThAr lamp with high voltage power supply for precise calibration
- flat lamp for echelle order geometry and blaze processing



Imaging camera – QSI 532s+

QSI (Quantum Scientific Imaging) 532s+

- Canon $f = 85$ mm lens adapter
- Kodak KAF-3200ME



Imaging camera – QSI 532s+

Feature	Model 532s	Model 532ws
Standard CCD Image Sensor	KAF-3200ME	KAF-3200ME
Shutter	Mechanical, exposure range: 0.03 seconds to 240 minutes	
Internal Color Filter Wheel	No	Yes - 5 Position, 1.25" std filters
Camera Body Configuration	Medium Enclosure 	Full Enclosure 
Dimensions	W4.45" x H4.45" x D2.00" (add 0.23" for T-Mount)	W4.45" x H4.45" x D2.50" (add 0.23" for T-Mount)
Weight, without Nosepiece	34 oz. / 950g	40 oz. / 1120g
Optical Back Focus (without Filters in path)	0.90" with T mounting adapter 0.68" with C mounting adapter 0.68" w/o mounting adapter	1.40" with T mounting adapter 1.18" with C mounting adapter 1.18" w/o mounting adapter
Thermoelectric CCD Cooling	Temperature regulation +/- 0.1°C, @ 0°C to -40°C CCD temperature	
In free air, Fans @ Full Speed	Typically 38°C below ambient air with 85% cooling power	
With Opt Liquid Cooling - Fans Off	Typically 45°C below circulating liquid with 85% cooling power (adds 0.75" to camera depth)	
Cooling Fan Control	Intelligent, user configurable	

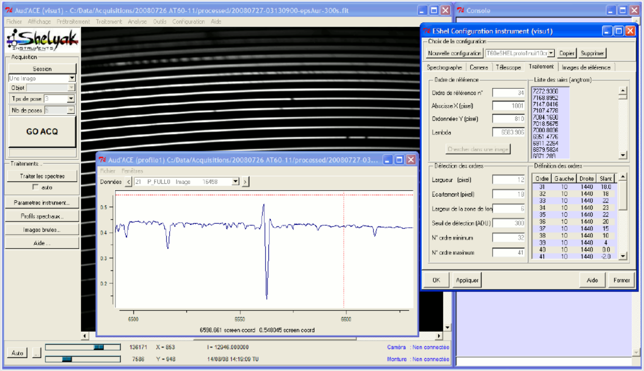
Imaging camera – QSI 532s+

Camera Gain	1.3 electrons per ADU	
Digital Resolution	16 bits	
Total System Read Noise	Typically <8 electrons RMS (CCD specification limited)	
Pixel Dark Current	<0.5 electron per second at 0°C <0.05 electron per second at -25°C	
Full Image Read and Download Time	Typically <8 seconds (host computer dependent)	
Binning Modes	Symmetrical on-chip 2x2 and 3x3, user selectable	
Status and Notification	User configurable multi-color LED status indicator and multifunction audible beeper. Over-temperature and high/low voltage alarms.	
Power Consumption	12v, 1.5A (18 watts) at max cooling, max fans and filter moving (25 AC watts max with included 90-240V AC power supply)	
Operating Environment	Temperature: -20°C to 30°C, Humidity: 10% to 90% non-condensing	
Computer Connectivity	USB 2.0 (USB 1.1 compatible)	
Other Ports	Optically isolated 4 channel control port for telescope guiding or other application specific control	
T Mounting Adapter	Standard adapter - T-Thread, 42mm x .75mm	
C Mounting Adapter (1" x 32TPI)	Optional, C-Mount lens focus compatible (17.5mm backfocus)	Optional, for non-lens adapters and accessories (standard C-Mount lens does not reach focus)
Nosepiece	Standard, T-Adapter to 2" nosepiece Optional, T-Adapter to 1.25" nosepiece	

Software

- based on open source AudeLA platform
- automated acquisition procedure with full remote control of the spectrograph and the calibration unit

- process spectra on the fly
- generate standard FITS spectra files, export in text format
- view spectra
- reprocessing by batch of the spectra



Gain and readout noise

- operating temperature 0° C
- six pairs of master bias and master flat field images were used
- all CCD and regions without hot pixels were measured

The estimated gain was 1.34 electrons per ADU and the readout noise was 10.52 electrons r.m.s.

For the same type cameras R. Berry and C. Buil estimated the gain 1.33 and 1.34 respectively and the readout noise 10.5 and 11.9 respectively

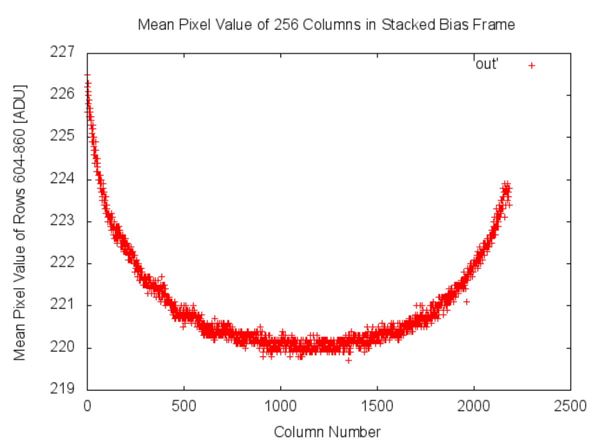
For the KAF-3200ME chip Kodak specifies a readout noise between 7 and 12

Residual pattern noise

- operating temperature -20° C
- an average of 256 bias frames was used
- then 256 rows $(604 - 860)$ were averaged

There is a difference $\sim 2\%$ in ADU between the edges and the center of the chip

The semi-random patterns amplitude is less than 1% of the readout noise



Dark current

- averaged bias and 1000-seconds dark frames were used
- region free of hot pixels was measured

Temperatura **[°C]**	**Średni *dark current*** **[elektron/piksel/sekundę]**
0	0.036
-5	0.014
-10	0.0056
-15	0.0012
-20	0.0005

The result is much better in comparison to the camera specification ($<$ 0.05 electron per second at -25° C)

Pixels statistics

- operating temperature -20° C
- 256 bias frames and 256 dark frames with 60 sec exposure were used

✓ 99.8% of the pixels follow a Gaussian distribution

✓ 0.2% of the pixels show a long-tailed distribution toward higher values

✓ total number of pixels 3 214 848

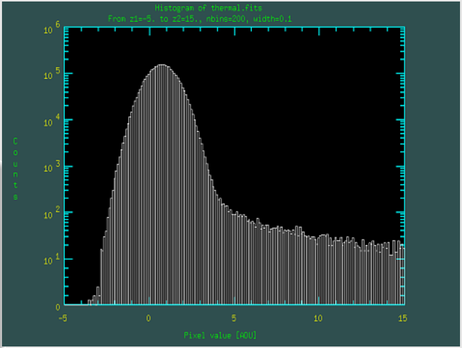
✓ 1 pixel – 9157 ADU

✓ 22 pixels – $>$ 1000 ADU

✓ 209 pixels – $>$ 100 ADU

✓ 4209 pixels – $>$ 10 ADU

✓ 8076 pixels – $>$ 4 ADU



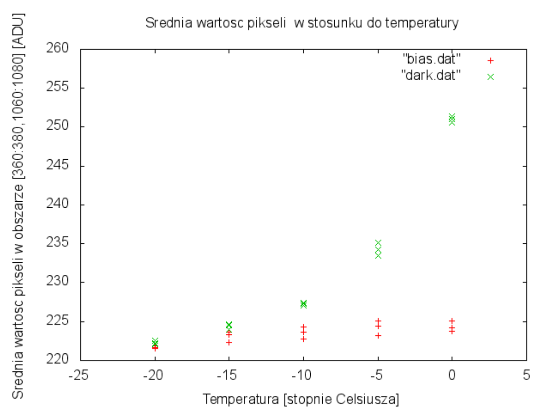
The hottest hot pixel had a dark current of 204 electrons/pixel/second (average 0.0005 at -20° C)

The dark current at -20° C for 99.8% of the pixels on the CCD is practically negligible

"Good" pixels

- bias frames and 1000-seconds dark frames were used
- region entirely free of hot pixels was used

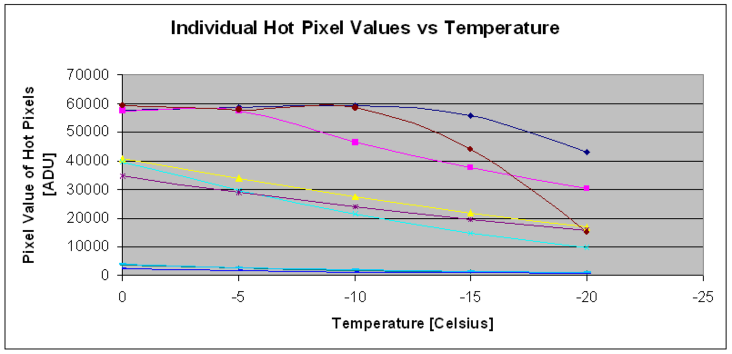
At temperatures of -15° C and lower, dark frames nearly match the values found in bias frames



Temperature behaviour of hot pixels

- 1000-seconds dark frames were used
- six pixels close to saturation or more than halfway to saturation at 0° C, and three pixels with values below 5000 ADU were measured

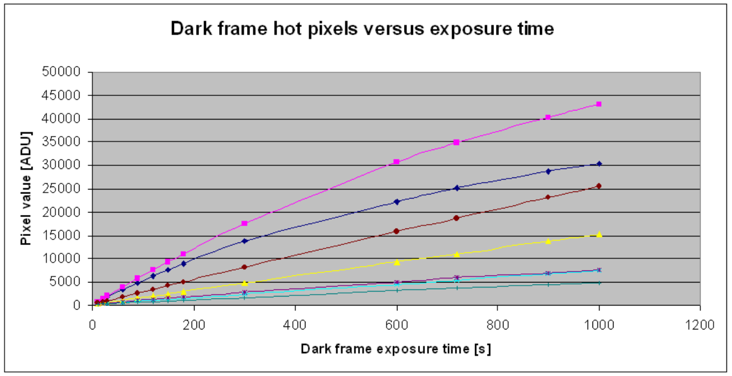
All hot pixels become cool with lower temperature, but the rate of decrease differ



Exposure behaviour of hot pixels

- averaged dark frames with exposures ranging from 10 sec to 1000 sec were used

The dark current of high-value hot pixels is non-linear with respect to exposure time

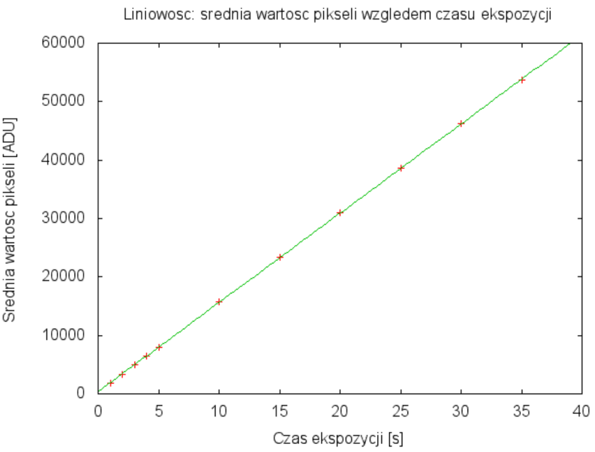


Linearity

- averaged, dark corrected flat field frames with different exposures were used
- region free of hot pixels was used

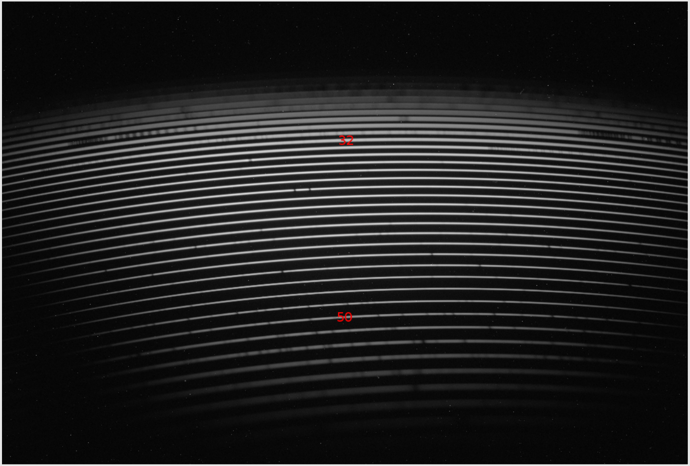
The points are fitted with a straight line and the plot looks linear

Kodak specifies that the deviation from a straight line fit between 2% and 90% of saturation can reach 1%



Object, ThAr and flat field frames

- the spectral region can be slightly changed playing with the camera focus
- with the present set-up the best usable orders are from 32 to 50
- i.e. from ∼ 4300 Å to ∼ 7200 Å



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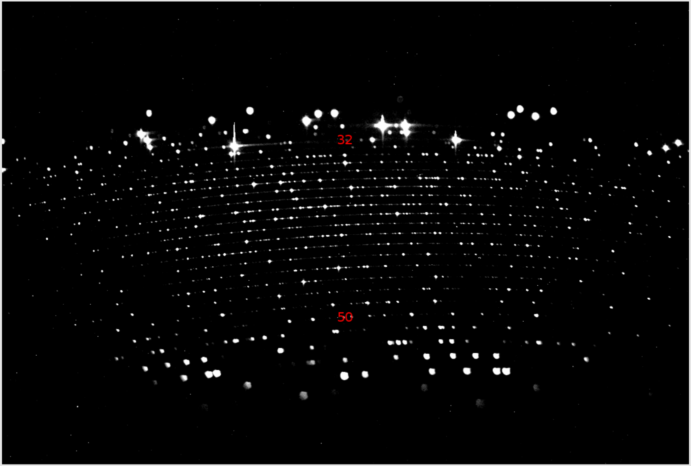

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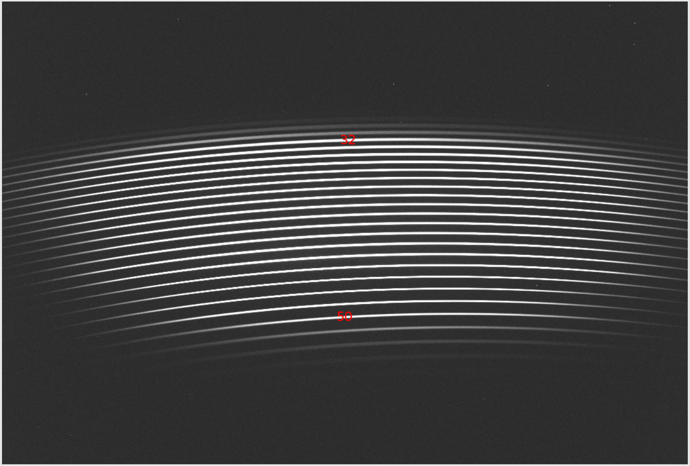
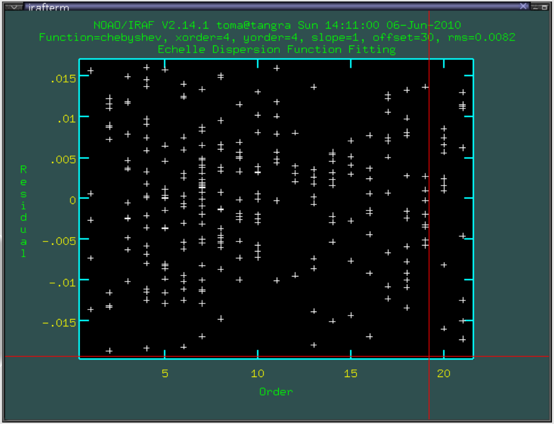


Data processing

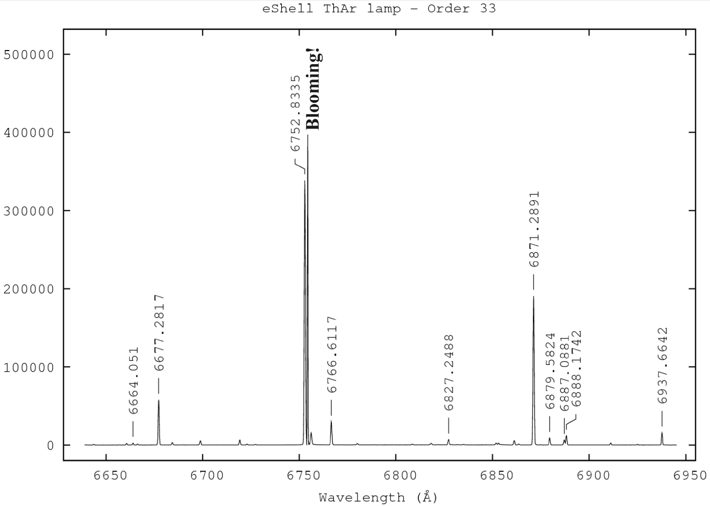
- we used two ways to process the data
  - ✓ the standard IRAF way
  - ✓ the pipeline script written by P. Konorski

We did not find any differences in the order extraction and the wavelength calibration between these two methods



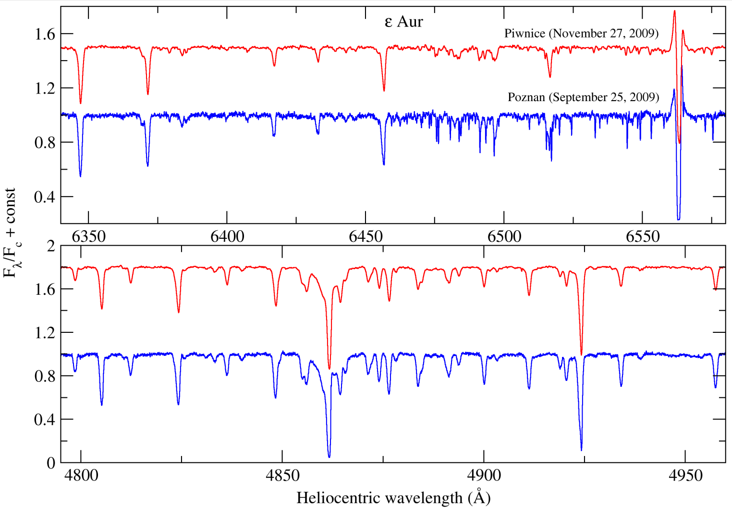
Data processing

- thanks to P. Konorski an atlas of the ThAr lamp in the region $\sim 4200 - 7700$ Å was prepared



Comparison with the Poznan echelle spectrograph

- the Poznan echelle spectrograph is a replica of MUSICOS with a resolving power $R \sim 35\,000$



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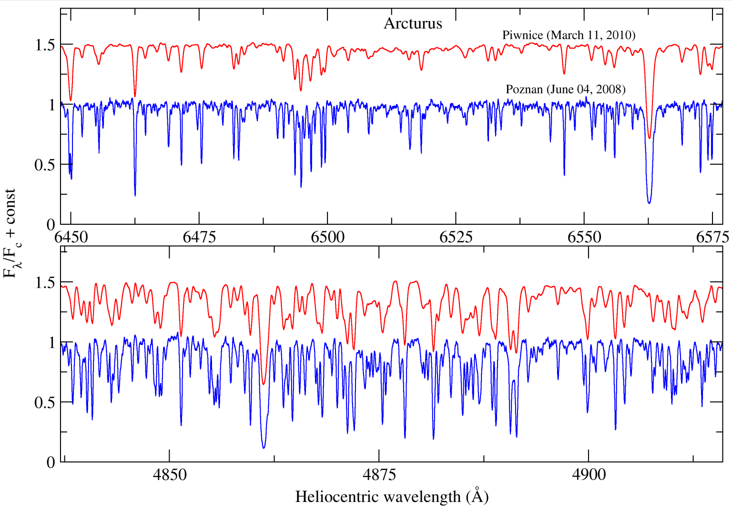
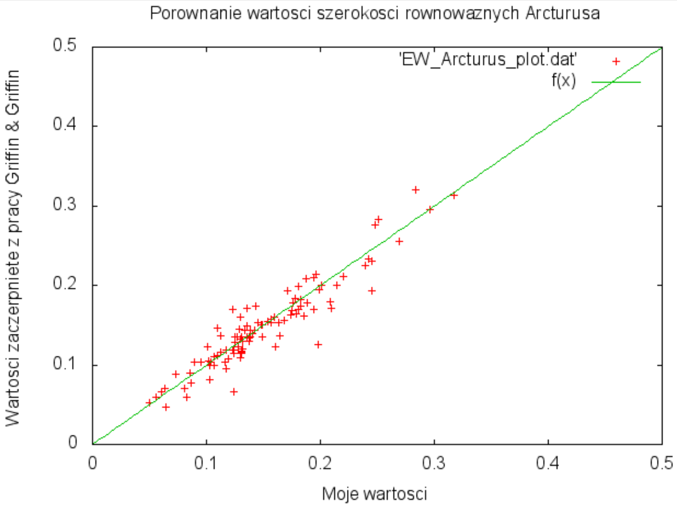


Equivalent widths

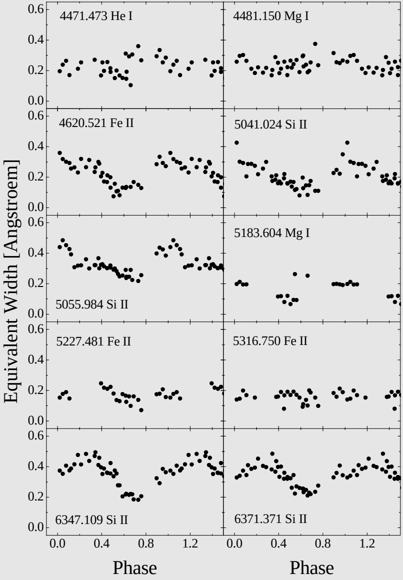
- the equivalent widths of 104 lines measured in the spectrum of Arcturus were compared with the data of Mäckle et al. 1975



Equivalent widths

CU Vir observations

- fast rotating Ap star
- $P \sim 0\overset{d}{.}5$



Radial velocities

The standard RV of Arcturus is $-5.3 \pm 0.3\,\mathrm{km\,s^{-1}}$

RV of Arcturus measured by the use of the IRAF task *rvidlines*

Date	RV	Mean err	N of lines
	$\mathrm{km\,s^{-1}}$	$\mathrm{km\,s^{-1}}$	
11.03.2010	−5.62	0.10	105
24.03.2010	−6.17	0.13	82
17.04.2010	−6.38	0.12	114
Mean	−6.06	0.12	

RV of Arcturus measured with cross-correlation techniques

Date	Resolving power	RV	Mean err
		$\mathrm{km\,s^{-1}}$	$\mathrm{km\,s^{-1}}$
11.03.2010	20 000	−6.10	0.82
11.03.2010	12 000	−6.14	0.70
24.03.2010	20 000	−5.69	0.76
24.03.2010	12 000	−5.69	0.75
17.04.2010	20 000	−6.24	0.82
17.04.2010	12 000	−6.25	0.82
Mean		−6.02	0.78

Exposure times

A very, very, very rough estimation of the exposure times