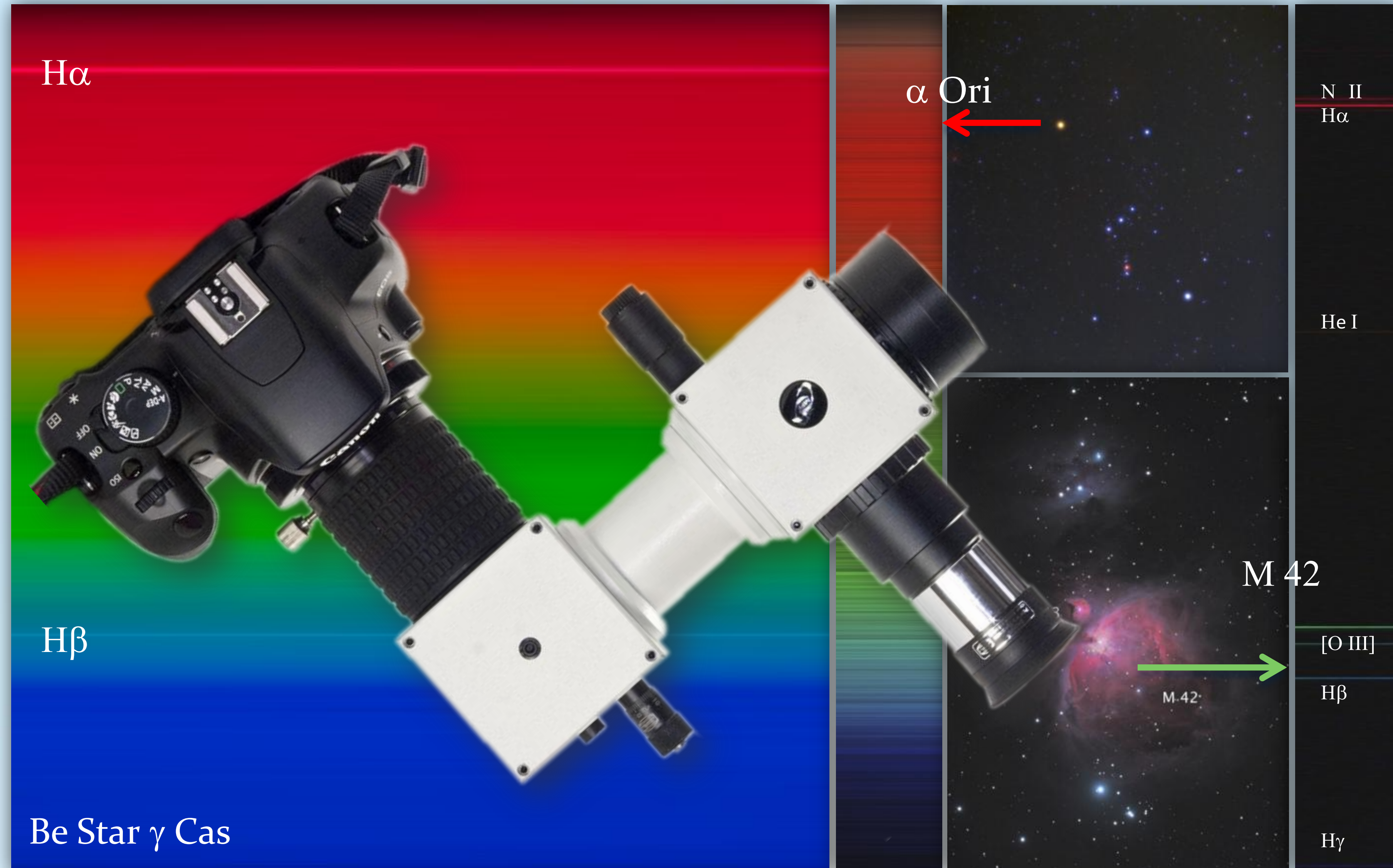
BAADER DADOS SLIT-SPECTROGRAPH TUTORIAL by Bernd Koch



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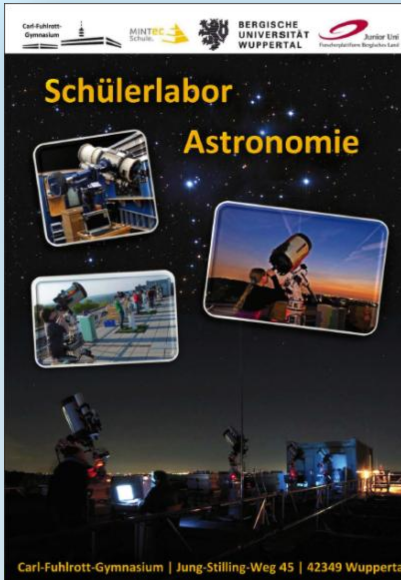
Workshop on stellar spectroscopy at the college CFG Wuppertal

The student astronomical observatory, on the roof of the college Carl-Fuhlrott-Gymnasium, in Wuppertal, Germany, is well equipped with six identical telescope units. We provide astronomy and astrophysics education for larger groups of students from other colleges and the nearby Bergische Universitaet Wuppertal.



Equipment: Astro-Physics 900GTO mount, Celestron 11“ EdgeHD telescope, Pentax 75 SDHF refractor, Celestron ED 80/600mm refractor, Canon EOS 450D DSLR camera, SBIG STF-8300M CCD camera and lot of accessories.

Special workshops on the topic of stellar spectroscopy are held with six units of the DADOS spectrograph. Gratings with 200/900/1200 lines/mm are available, as well as spectral calibration lamps. Tutors: Michael Winkhaus, Bernd Koch and Ernst Pollmann.

Please look at the report of Dr. Thomas Schroefl of Vienna, Austria, who attended our October 21-25, 2013 workshop (all pages in German).
http://www.waa.at/bericht/2013/10/20131021sfl00.html
http://www.waa.at/bericht/2013/10/20131022sfl17.html


Michael Winkhaus

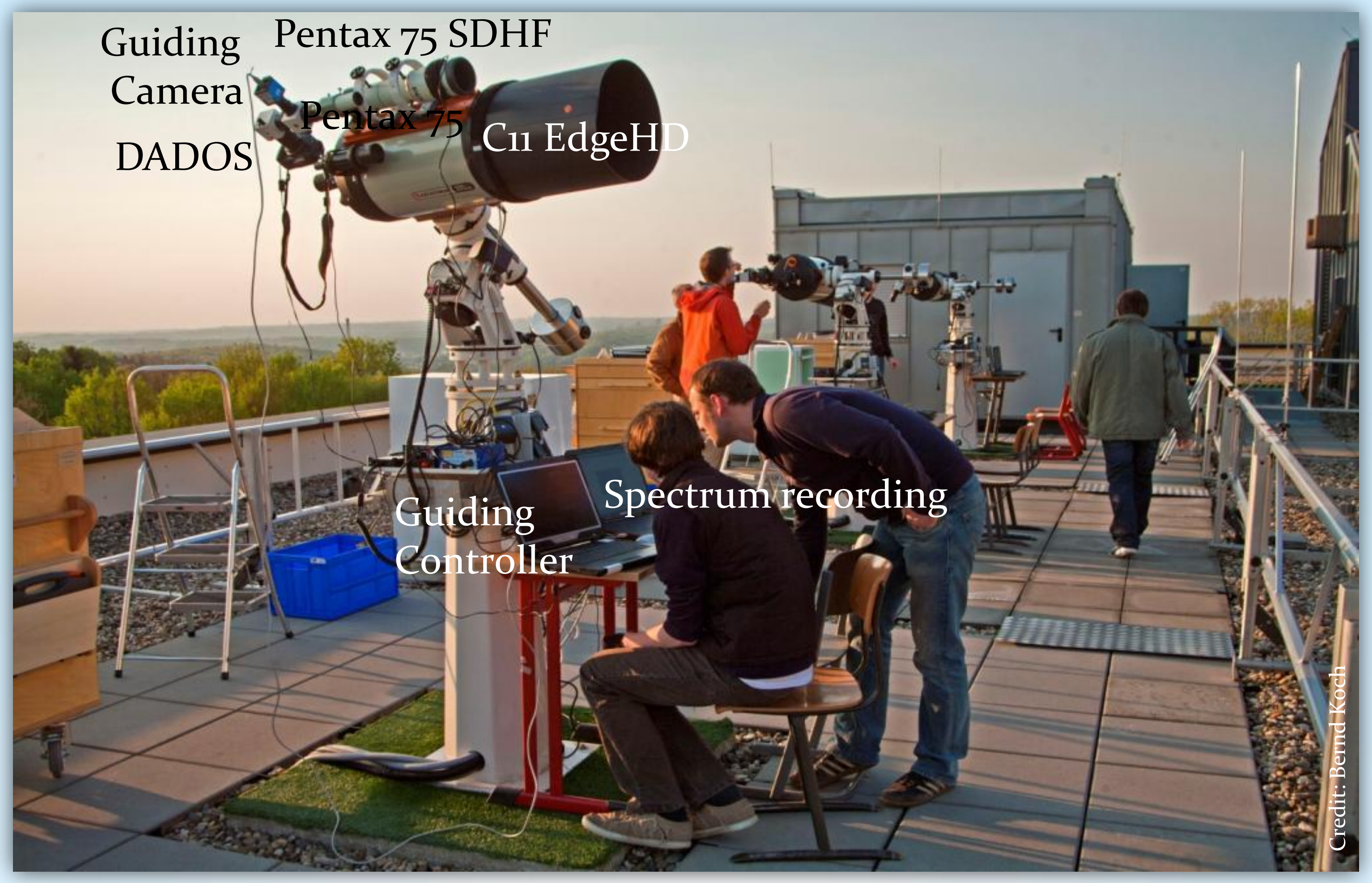

Ernst Pollmann

If you are interested in a workshop, please have a look at our website www.schuelerlabor-astronomie.de or contact Mr. Michael Winkhaus, head of the observatory: Michael.Winkhaus@t-online.de

Please address inquiries about the DADOS spectrograph directly Mr. Bernd Koch, b.koch@baader-planetarium.de


Bernd Koch

Workshop on stellar spectroscopy at the college CFG Wuppertal

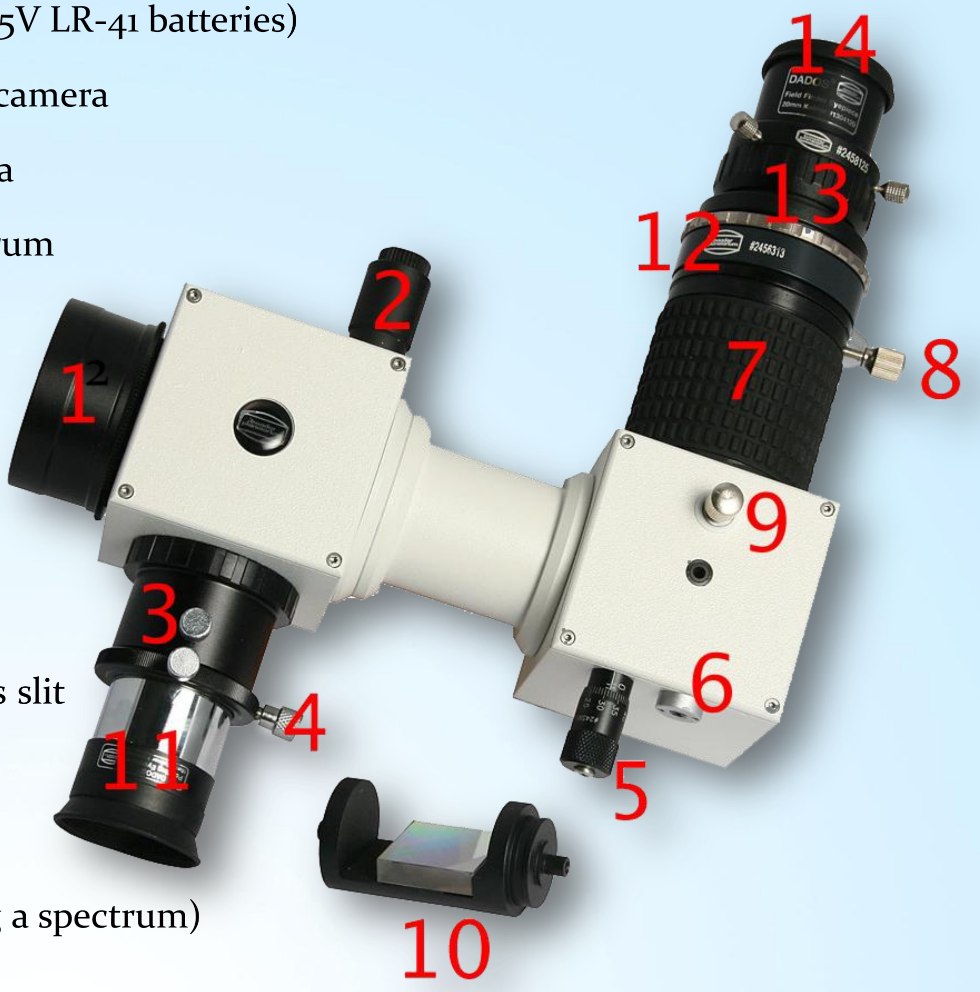


Interested in a workshop? Please contact: Michael Winkhaus, Michael.Winkhaus@t-online.de | Workshop April, 2011

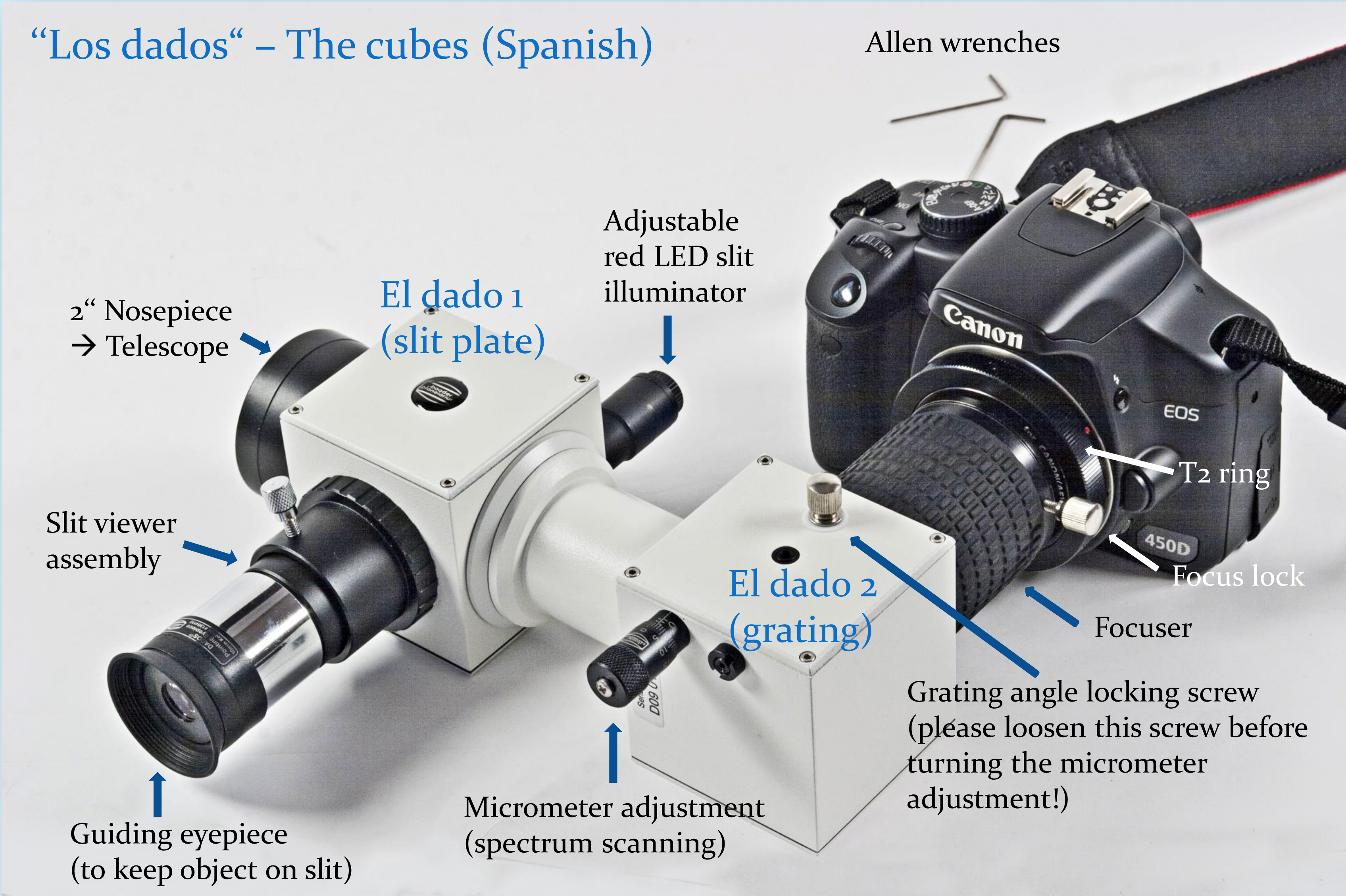
DADOS & accessories

DADOS layout

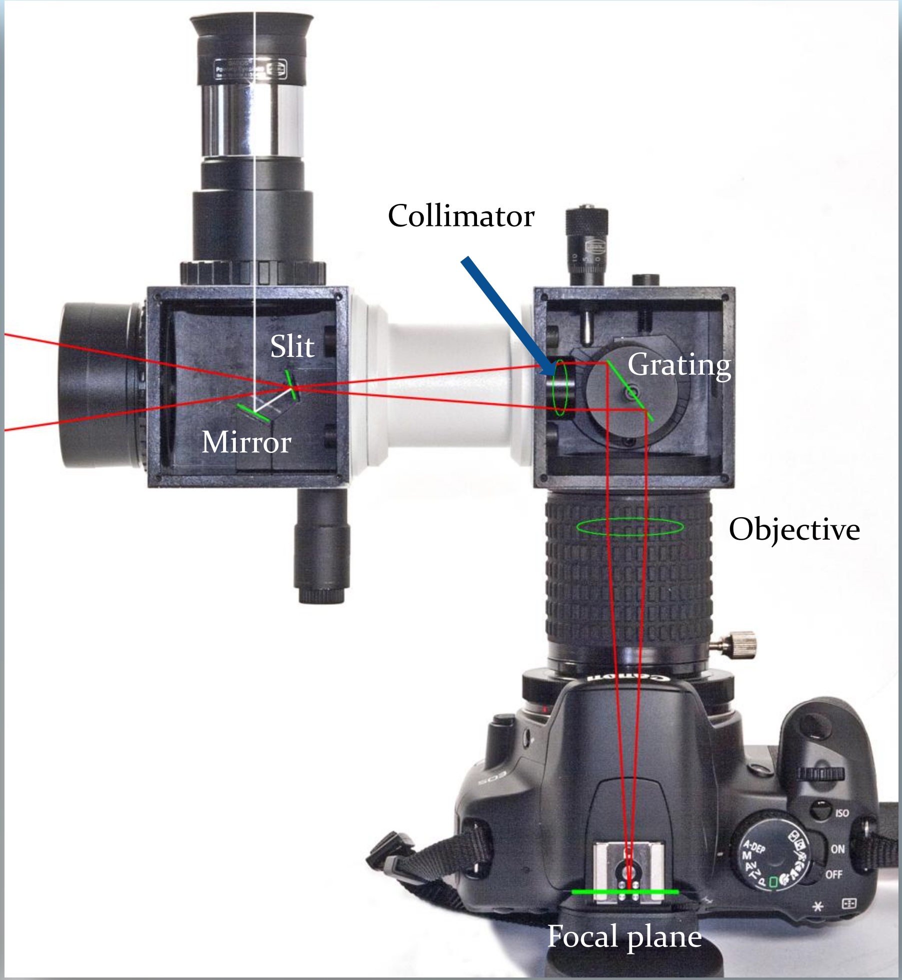
1) 2" Nosepiece (-> Telescope)
2) Adjustable red LED slit illuminator (incl. two 1.5V LR-41 batteries)
3) 1¼" Slit viewer port for guiding eyepiece (11) or camera
4) 1¼" Stop ring for guiding eyepiece (11) or camera
5) Micrometer adjustment for scanning the spectrum
6) Rotation stage counter spring (do not touch)
7) Focuser
8) Focuser locking screws
9) Grating angle locking screw
10) Optional 900 lines/mm grating
11) Guiding eyepiece for viewing the spectrograph's slit
12) Quick changer (optional, but not for DSLR)
13) Focusing eyepiece holder, T2 -> 1¼"
14) 10 mm or 20 mm Kellner eyepieces for viewing a spectrum)



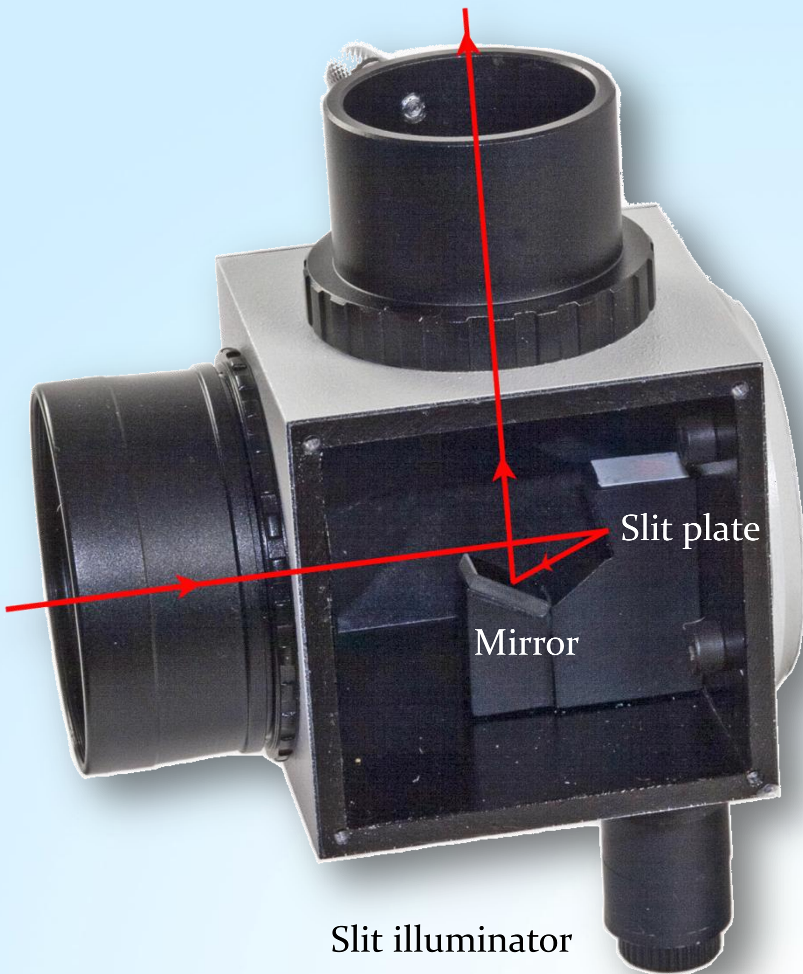
Spectrum photography & visual guiding



Optical path



Dado #1, the “guiding port“: Slit plate, mirror and slit illuminator



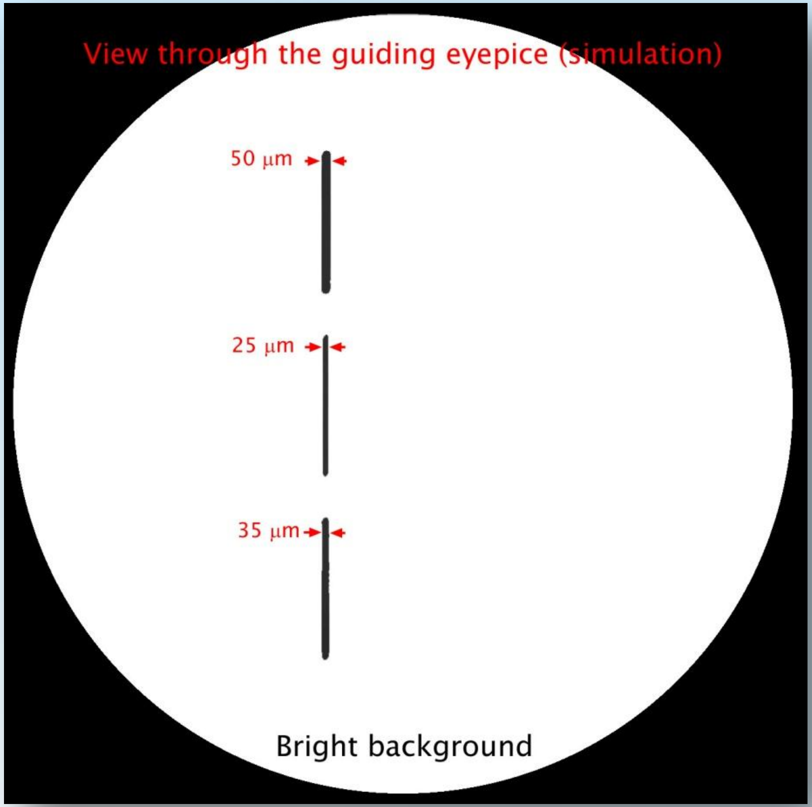
Slit plate:
The slit plate contains three slits of different widths: 25 µm, 35 µm, and 50 µm.

Mirror:
The small mirror allows the observer at the slit viewing port to keep an object‘s image exactly on one the slits.

Slit illuminator:
To be visible against a dark sky background, the slits can be illuminated by an adjustable red LED.

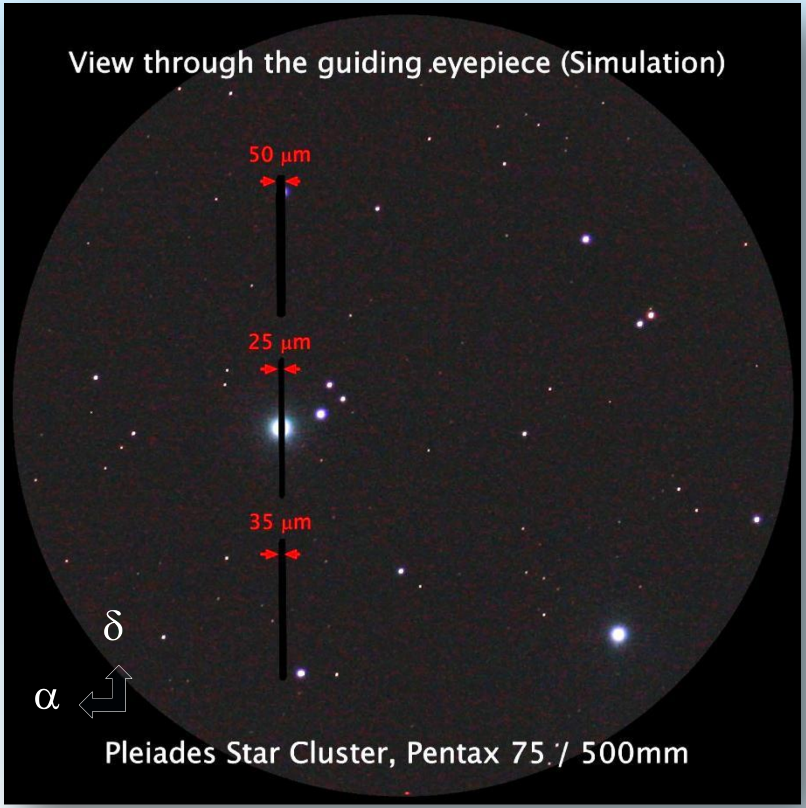
Please note:
Don‘t forget to switch off the slit illuminator before starting the exposure of the spectrum. Otherwise the red LED stray light will be superimposed on the image of the spectrum. To save battery energy always be sure to switch off the illuminator while not in use. The illuminator holds two 1.5V batteries LR41.

Dado #1: Field of view at the slit viewing port



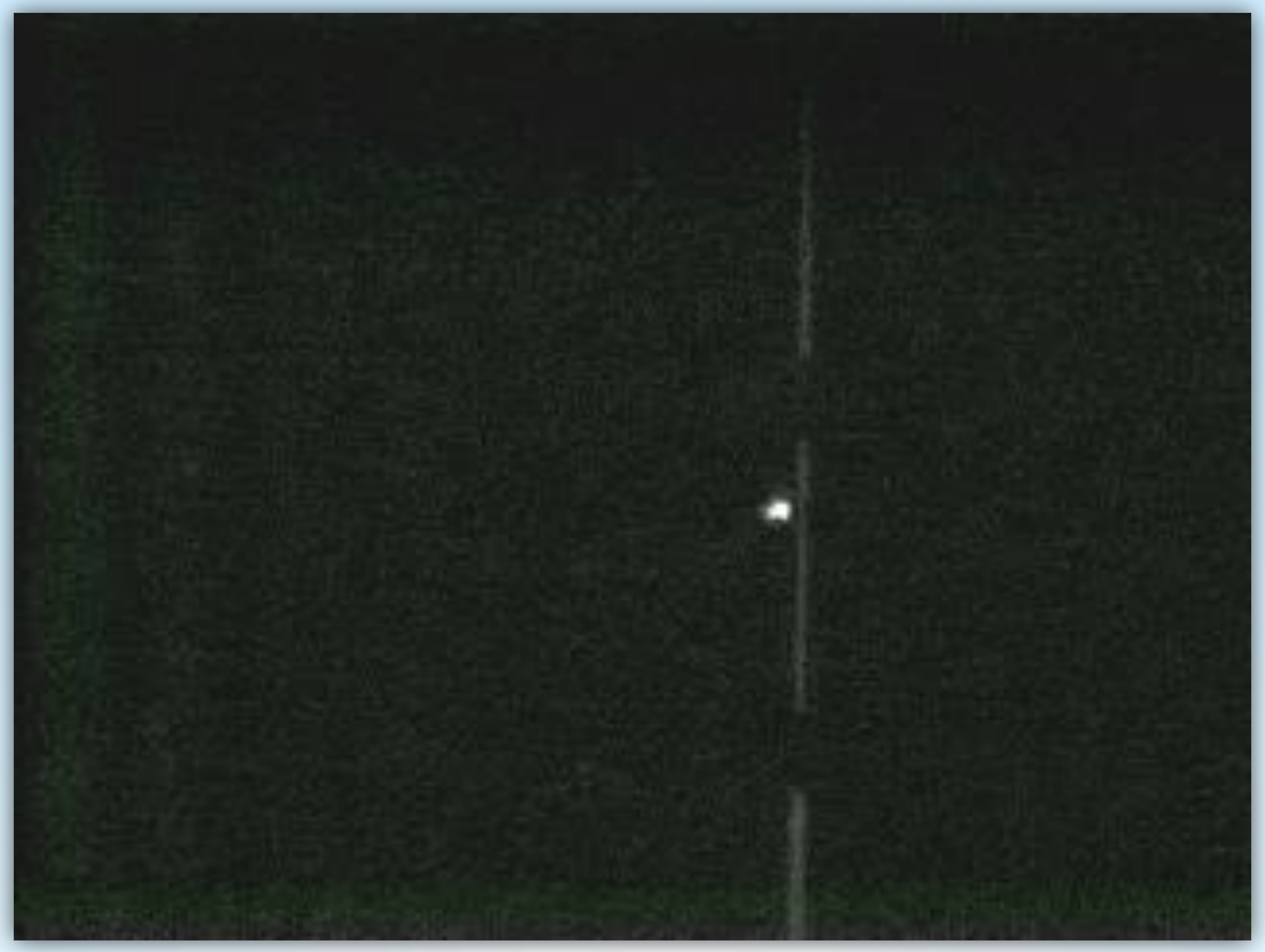
- Point the 2“ nosepiece at a bright light source
- Look through the guiding eyepiece
- Each of the three slits has a different width
- The width of a slit is crucial for spectral resolution
- The length of a slit is irrelevant

Dado #1: Field of view at slit viewing port



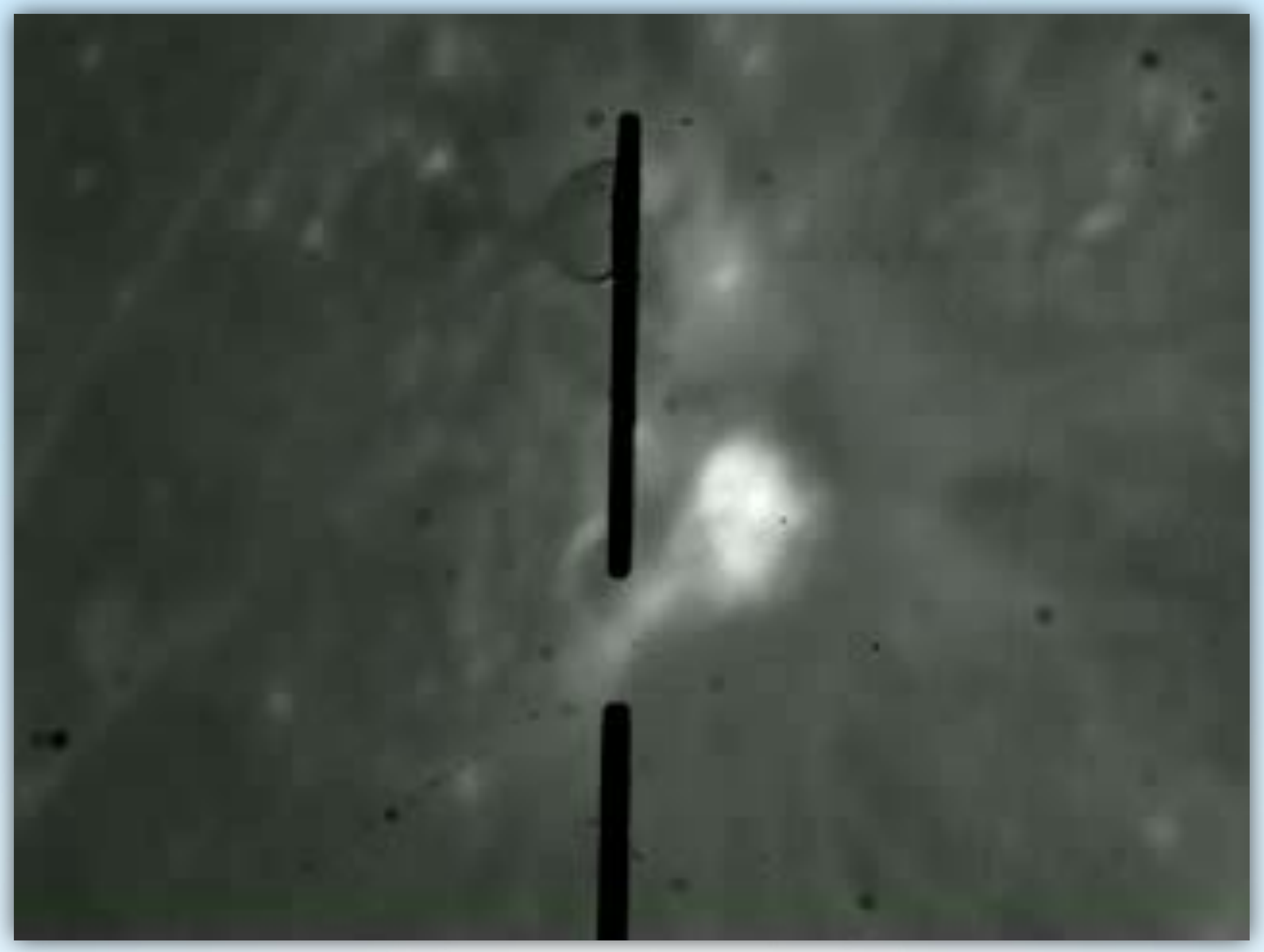
- Central slit (25 µm) gives best spectral resolution
- The 50 µm slit provides the brightest visual stellar spectra
- Spectral resolution is independent of the telescope‘s focus
- Perfect telescope focus maximizes contrast of spectral lines
- Guiding is possible at the slit viewing port
- The slit‘s length should be parallel to Declination δ direction

Dado #1: α CMa (Sirius) close to 25 µm Slit (DMK41 - video camera)



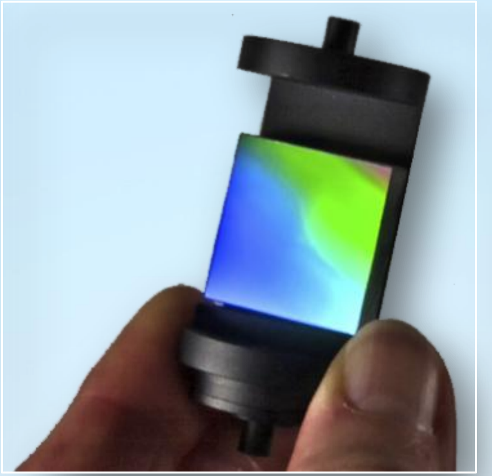
Video: Bernd Koch

Dado #1: Lunar Spectroscopy – The Aristarchus Plateau (DMK 41)



Video: Jonas Niepmann /
Laurenz Sentis / Bernd Koch

Dado #2: The blazed reflection grating



Resolving power λ / Δ λ on camera objective axis and 25 µm slit

Grating of 200 lines/mm

Theoretical	Measured	λ (nm)
396	542	@ 416
606	647	@ 616
668	723	@ 697

Grating of 900 lines/mm

Theoretical	Measured	λ (nm)
2038	2000	@ 371
3910	3000	@ 561
5376	5000	@ 800

Limiting magnitude for a 30 cm Ø telescope with S/N 50 and 20 minutes of exposure time.

For the 200 lines/mm grating :	$m_V = 8$
For the 900 lines/mm grating :	$m_V = 6$

Credit: DADOS Spectrograph User Manual

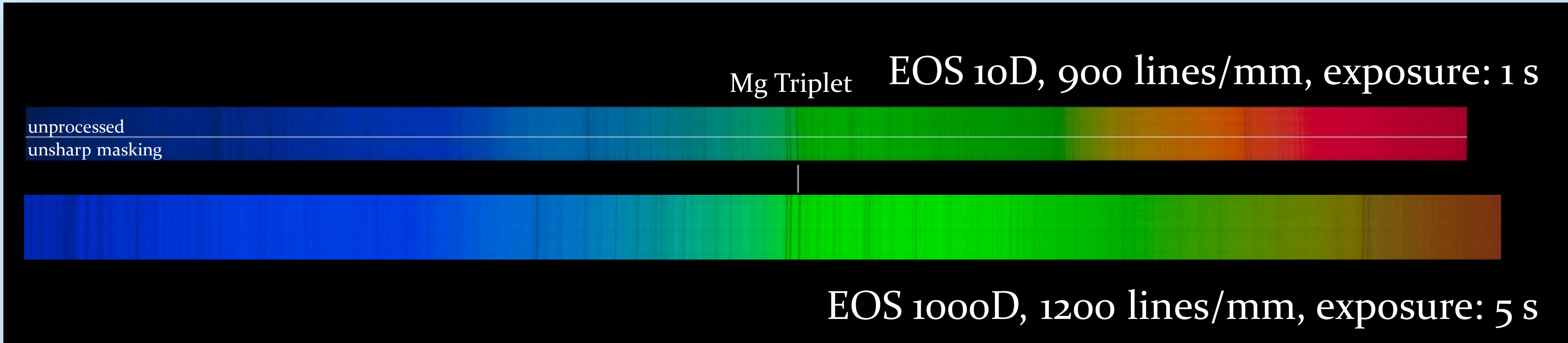
To avoid damage, please change the grating strictly according to DADOS user manual. Also be careful with the tiny set screws and don‘t touch the optical surface of the grating !!!!

Two blazed reflection gratings are recommended by the designers of the DADOS spectrograph:

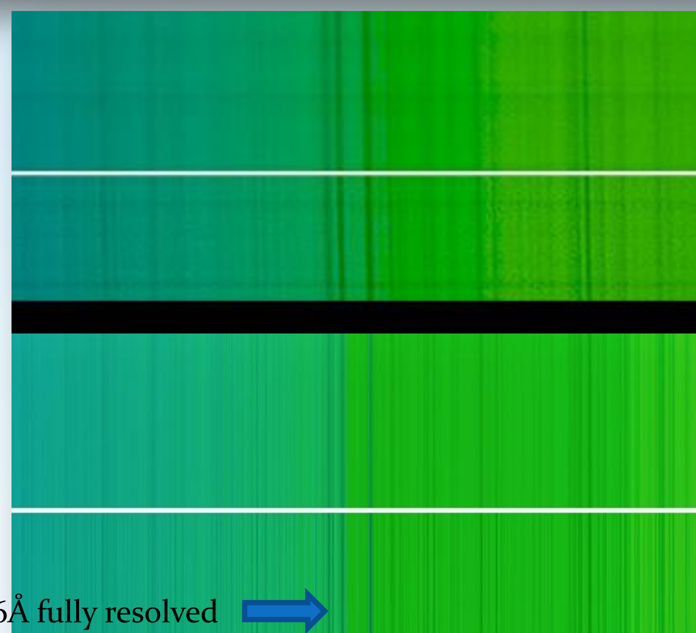
- ❖ Low resolution 200 lines/mm, linear dispersion 2.16 Å/px (0.2 nm/px) @ 6563 Å / 5.4 micron pixel
- ❖ Medium resolution 900 lines/mm, linear dispersion 0,59 Å/px (0.059 nm/px)
- ❖ Optional: High resolution 1200 lines/mm, linear dispersion 0.46 Å/px (0.046 nm/px)

A modified DSLR Camera with an 18 mm x 22 mm APS-size sensor covers the whole spectrum (about 400 nm – 700 nm) only if used with the 200 lines/mm grating. The camera field should be aligned parallel to the spectrum to minimize aliasing errors due to rotation of the spectrum. This can be achieved by loosening three set screws at the T2-adapter, rotating the inner T2-ring, and tightening the set screws.

Daylight spectrum of 900 l/mm grating and 1200 l/mm grating



900 lines/mm
Exposure: 1 s



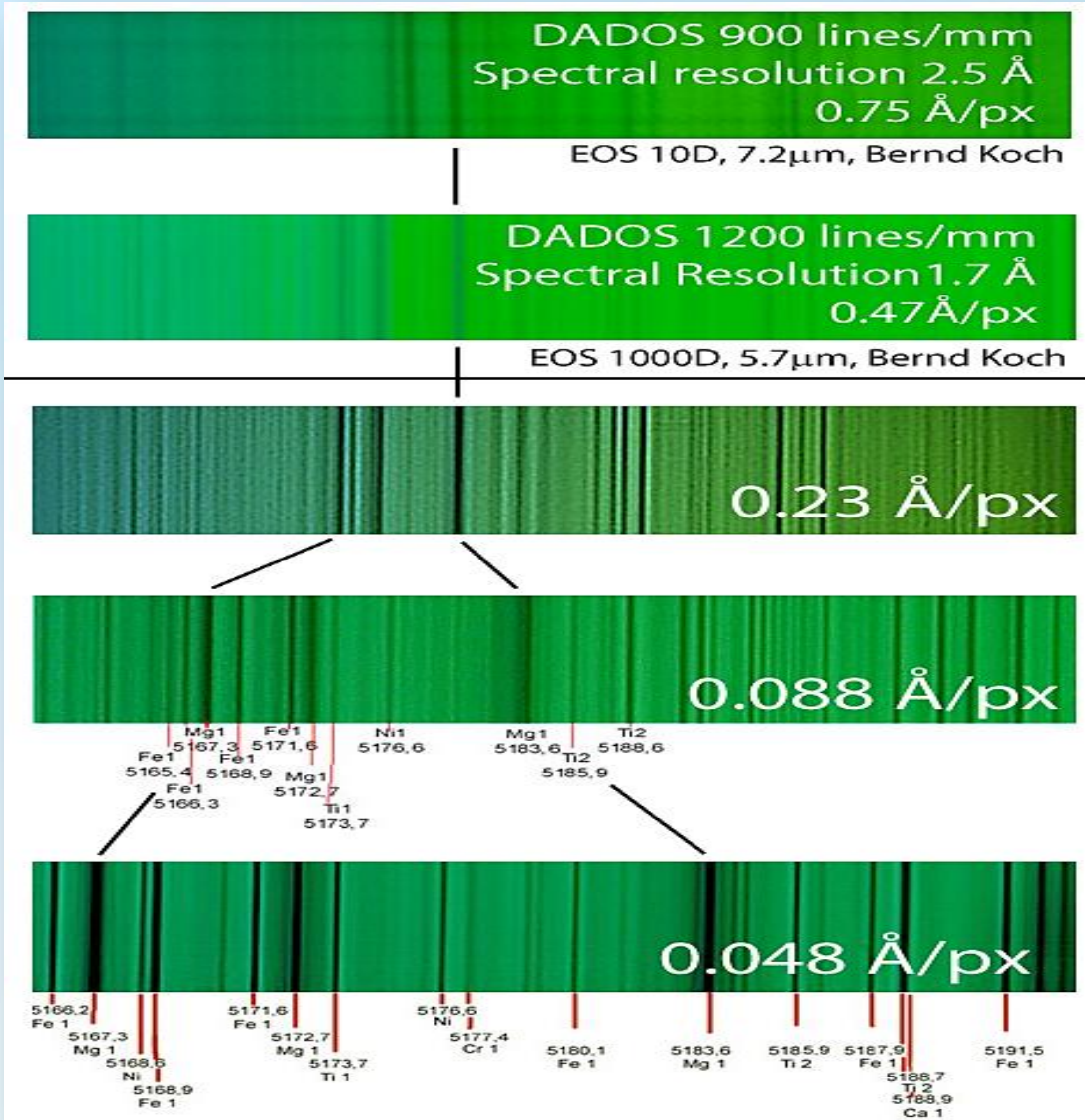
Unsharp masking

1200 lines/mm
Exposure: 5 s

Unsharp masking

$\Delta\lambda$ = 1,6Å fully resolved

Daylight spectrum of 900 lines/mm grating and 1200 lines/mm grating



www.lightfrominfinity.org /HIRSS/HIRRS.htm

Dado #2: Grating replacement – Part 1

A.2 Grating replacement

Attention

Touching the grating will destroy it beyond repair!

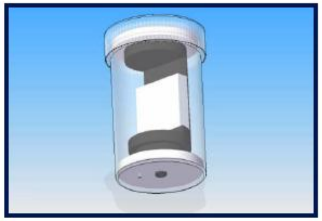
Do not attempt to remove dust by breathing or blowing air onto the grating! Small droplets of moisture and saliva can permanently damage the grating as well.

Do not use compressed or canned air! This will likewise transport moisture, grease or propellant onto the grating.

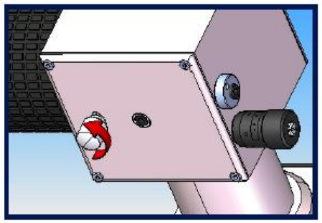
Any exchange of grating holders should always be performed in clean surroundings, free of dust and static build up.

Arrange your workplace for ensure a quick and clean grating exchange.

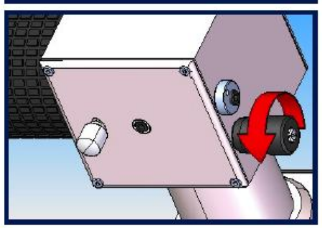
Dado #2: Grating replacement – Part 2



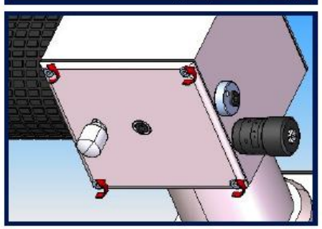
Have the 900 lines/mm grating with holder readily available.



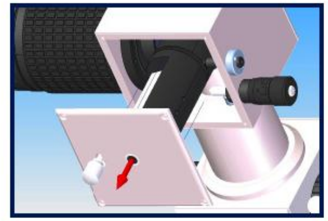
Loosen the grating angle locking screw (#9) by one turn only.



Rotate the micrometer backwards to show an 8mm setting on the Vernier scale.

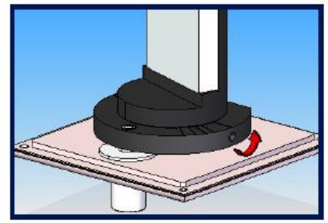


Use the 1.5mm Allen wrench to remove the four hex-head screws.

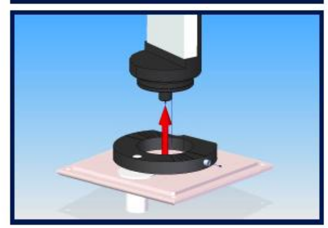


Take off the side plate/grating holder assembly.

Be careful not to touch the grating.



Release the headless set screw inside of the pressure plate by 2 full turns counterclockwise using the 1.5mm Allen wrench.

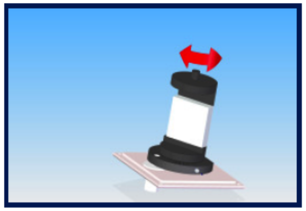


Remove the grating holder from the pressure plate.

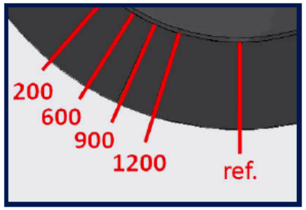
Take the 900 lines/mm grating holder out of the storage container and store the 200 lines/mm grating in it.

Dado #2: Grating replacement – Part 3

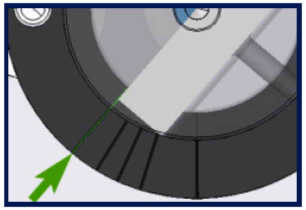
Place the 900 lines/mm grating holder into the pressure plate.



Rotate the grating holder to adjust the proper position in regard to the markings in the pressure plate.

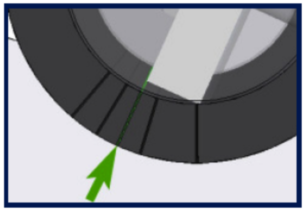


Each mark indicates the position of a specific grating. Be sure to use the proper one to achieve the optimal throughput.



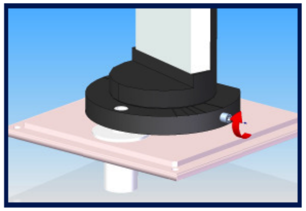
Example of position:

200 lines/mm grating.

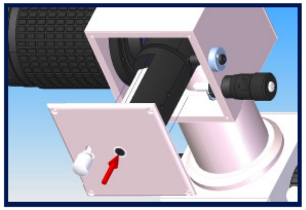


Example of position:

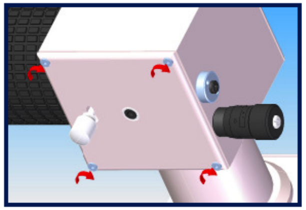
900 lines/mm grating.



Lock the pressure plate by tightening the headless set screw clockwise.

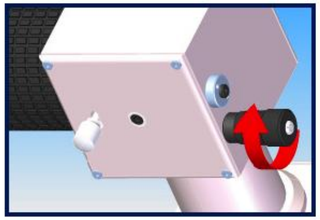


Carefully replace the side plate/grating holder assembly.

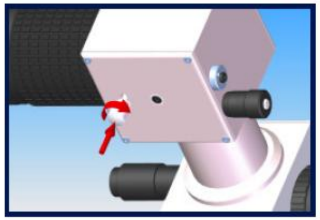


Replace and tighten the 4 screws that secure the side plate.

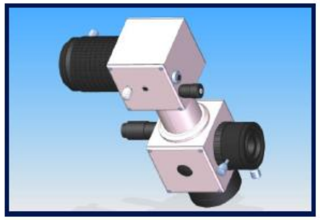
Dado #2: Grating replacement – Part 4



Adjust the micrometer to a Vernier position of approximately 2.5.



Lock the grating tilt mechanism by rotating the grating angle locking screw clockwise.



DADOS with grating exchanged.

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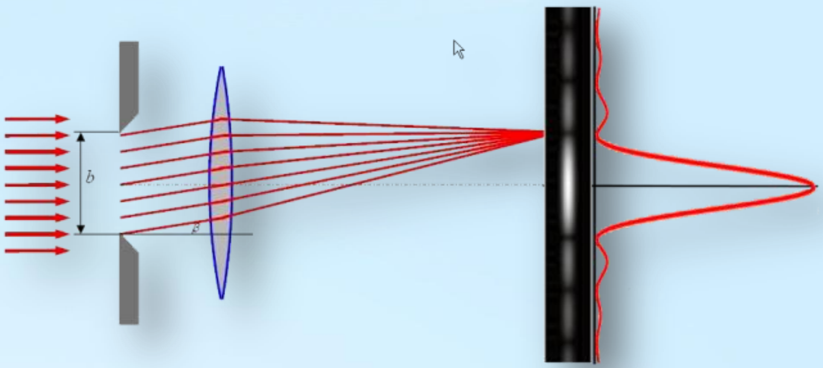
Diffraction of light (transmission)

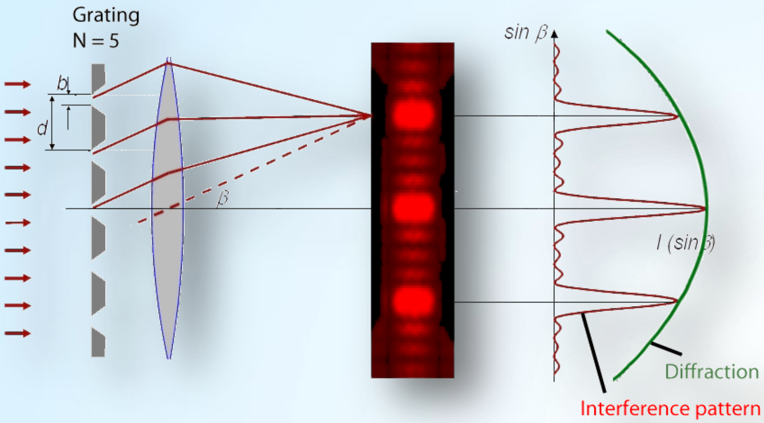
Single-Slit Diffraction

Diffraction is described by the Huygens–Fresnel principle and the principle of superposition of waves. The propagation of a wave can be visualized by considering every point on a wavefront as a point source for a secondary spherical wave. The wave displacement at any subsequent point is the sum of these secondary waves. When waves are added together, their sum is determined by the relative phases as well as the amplitudes of the individual waves so that the summed amplitude of the waves can have any value between zero and the sum of the individual amplitudes. Hence, diffraction patterns usually have a series of maxima and minima.
Reference: http://en.wikipedia.org/wiki/Diffraction#Single-slit_diffraction



Diffraction grating

An idealized grating is made up of a set of slits of spacing d, that must be wider than the wavelength to cause diffraction. When a plane wave of wavelength λ with normal incidence perpendicular to the grating, each slit in the grating acts as a quasi point-source from which light propagates in all directions. After light interacts with the grating, the diffracted light is composed of the sum of interfering wave components emanating from each slit in the grating. At any given point in space through which diffracted light may pass, the path length to each slit in the grating will vary. So will the phases of the waves at that point from each of the slits, and thus will add or subtract from one another to create peaks and valleys, through the phenomenon of additive and destructive interference. When the path difference between the light from adjacent slits is equal to half the wavelength λ/2, the waves will all be out of phase, and thus will cancel each other to create points of minimum intensity. Similarly, when the path difference is λ, the phases will add together and maxima will occur.
Reference: http://en.wikipedia.org/wiki/Diffraction_grating



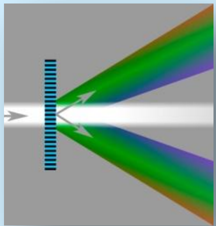
$$I(\sin\beta) = I_0\left(\frac{\sin(\frac{\pi b}{\lambda}\sin\beta)}{\frac{\pi b}{\lambda}\sin\beta}\right)^2 \cdot \left(\frac{\sin(\frac{N\pi d}{\lambda}\sin\beta)}{\frac{\pi d}{\lambda}\sin\beta}\right)^2$$

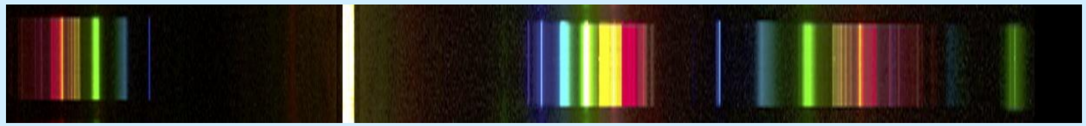
Diffraction term of a slingle slit width b

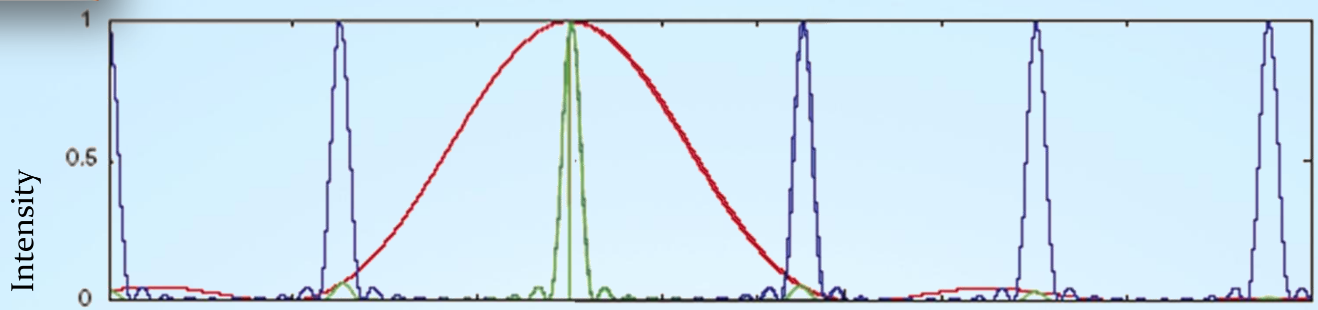
Interference term of N slits at distance d

Reference: No5_Monochromatoren_d_BAneu.doc - 2/21

Transmission grating







Maximum intensity in zero order

Disadvantages of a transmission grating

- Light is dispersed among the various diffraction orders, leading to low intensity in the higher ones.
- Transmission losses are due to selective absorption in the glass.
- Maximum intensity is the undiffracted zeroth order.
- A blazed transmission grating will improve things.

Blazed transmission grating vs. blazed reflection grating

Although in some cases transmission gratings are applicable or even desirable, they are not often used. Reflection gratings are much more prevalent in spectroscopic and laser systems, due primarily to the following advantages:

- Reflection gratings can be used in spectral regions where glass substrates and resins absorb light (*e.g.*, the ultraviolet).
- Reflection gratings provide much higher resolving power than equivalent transmission gratings, since the path difference between neighboring beams (*i.e.*, separated by a single groove) is higher in the case of the reflection grating. Therefore transmission gratings must be wider (so that more grooves are illuminated) to obtain comparable resolving power.
- Reflection grating systems are generally smaller than transmission grating systems, because the reflection grating acts as a folding mirror.

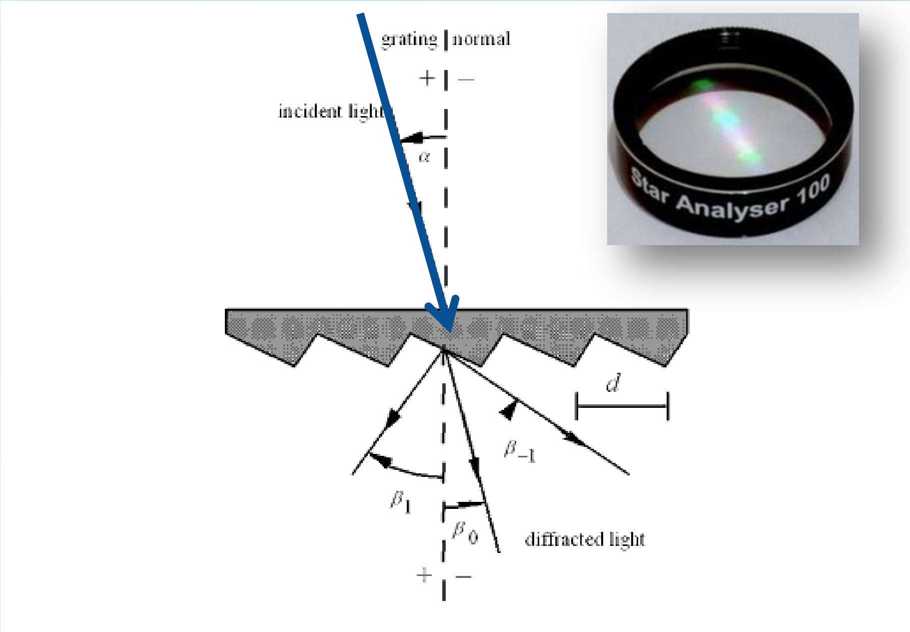
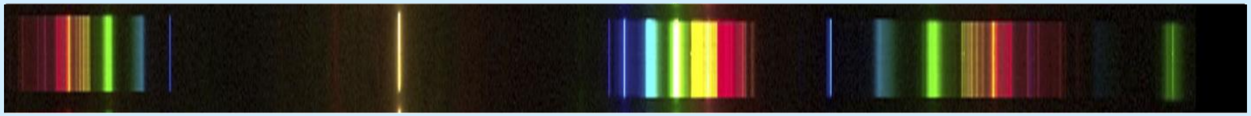
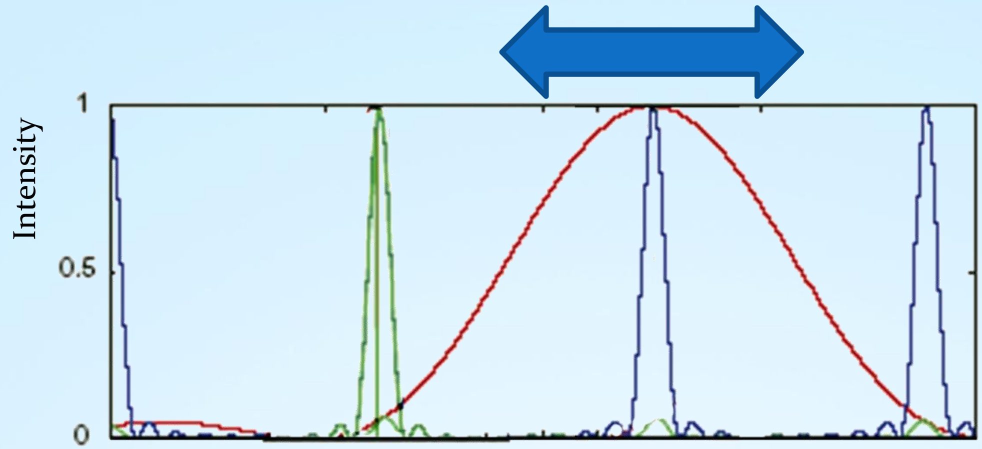


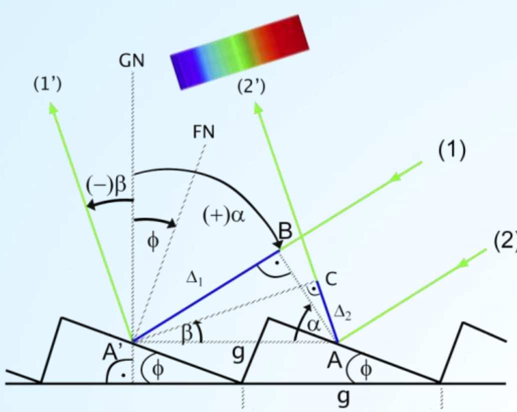
Figure 12-1. Diffraction by a plane transmission grating. A beam of monochromatic light of wavelength *l* is incident on a grating at angle *a* to the grating normal, and diffracted along several discrete paths {*bm*}, for diffraction orders {*m*}. The incident and diffracted rays lies on opposite sides of the grating. The configuration shown, in which the transmission grating is illuminated from the back, is most common.

http://gratings.newport.com/information/handbook/chapter12.asp#12.2

Blazed reflection grating



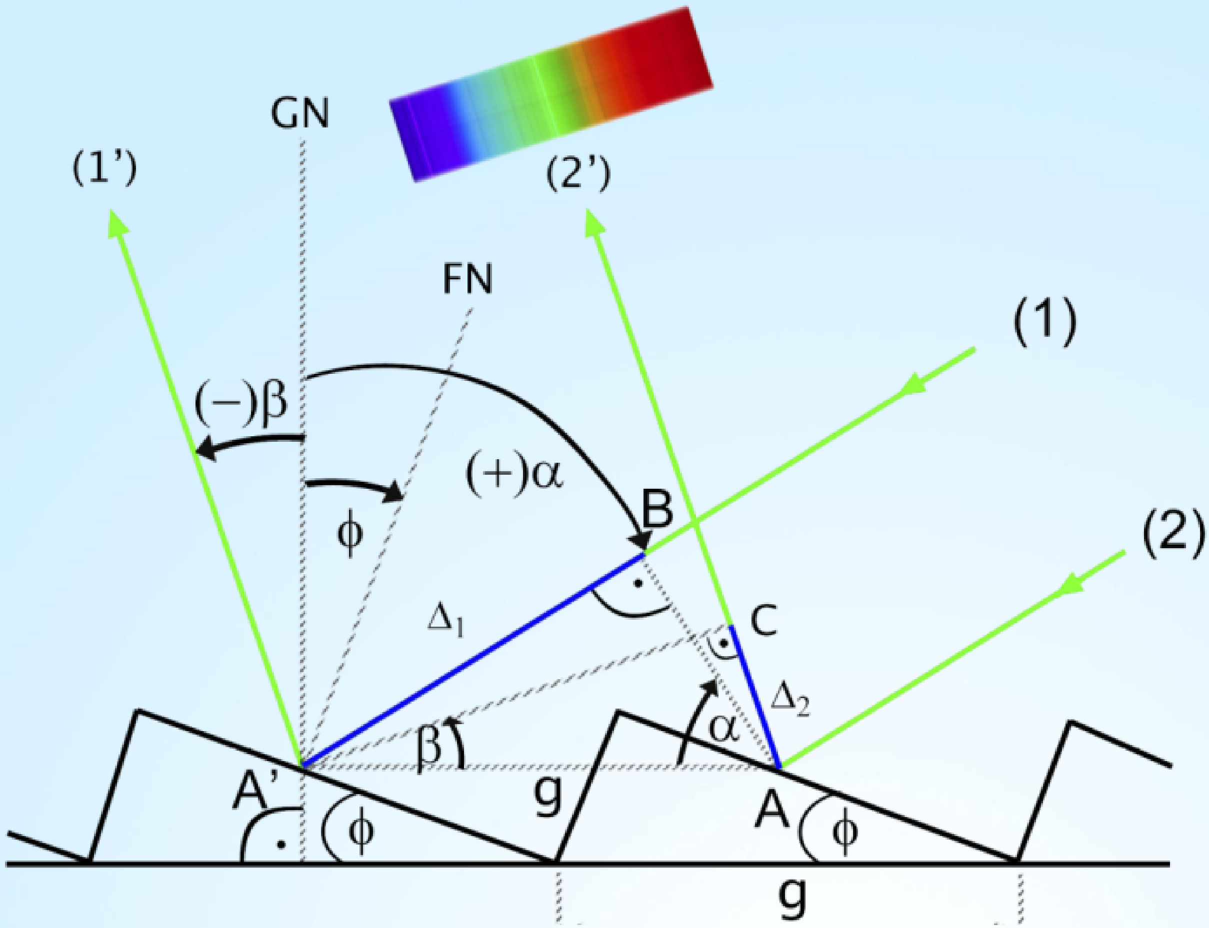




Advantages

- The highest efficiency is in first order with the correct blaze angle.
- The reflectivity is higher than the throughput of a blazed transmission grating .

Blazed grating theory: Definition of parameters



GN: Grating normal

FN: Face normal

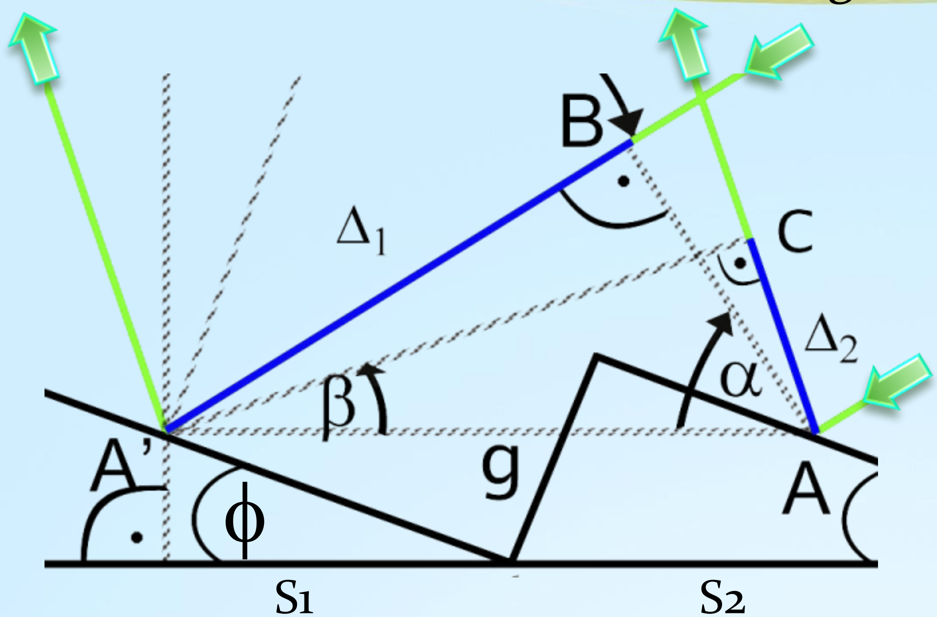
g: Groove spacing

ϕ: Blaze angle

α: Angle of the incident light

β: Angle of reflected light

Blazed grating theory



GN: Grating normal

FN: Face normal

g: Groove spacing

ϕ: Blaze angle

α: Angle of the incident light

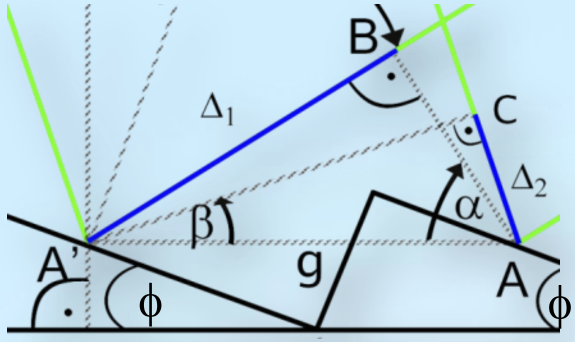
β: Angle of reflected light

Additive interference occurs when the total path difference Δ of light from adjacent slits (S1) and (S2) is an integer multiple of the wavelength λ: The phase is then the same, so the beams' intensity add.

Path difference of incident beam: $\Delta_1 = BA' = g \sin \alpha$,
Path difference of reflected beam: $\Delta_2 = AC = g \sin \beta$

$$\Delta = m \lambda = \Delta_1 - \Delta_2 = g (\sin \alpha - \sin \beta) \text{ with } m = 0, \pm 1, \pm 2 \ldots \text{ (Grating equation)}$$

Blazed grating theory



GN: Grating normal
FN: Face normal
g: Groove spacing
ϕ: Blaze angle
α: Angle of the incident light
β: Angle of reflected light

Grating equation: $m\lambda = g(\sin\alpha - \sin\beta)$ → $\lambda = \frac{g}{m}(\sin\alpha - \sin\beta)$

Derivative with respect to β: $\frac{d\lambda}{d\beta} = -\frac{g\cos\beta}{m}$

Angular dispersion: $\left|\frac{d\beta}{d\lambda}\right| = \frac{m}{g\cos\beta}$

Linear dispersion: $\left|\frac{dx}{d\lambda}\right| = f\left|\frac{d\beta}{d\lambda}\right| = f\,\frac{m}{g\cos\beta}$ “f“ is the focal length of the objective lens

Blaze angle: $\phi = \frac{\alpha-\beta}{2} = \frac{\alpha}{2} - \frac{1}{2}\arcsin\left(\frac{m\lambda}{g} - \sin\alpha\right)$

Calculation example: DADOS with blazed 200 lines/mm grating

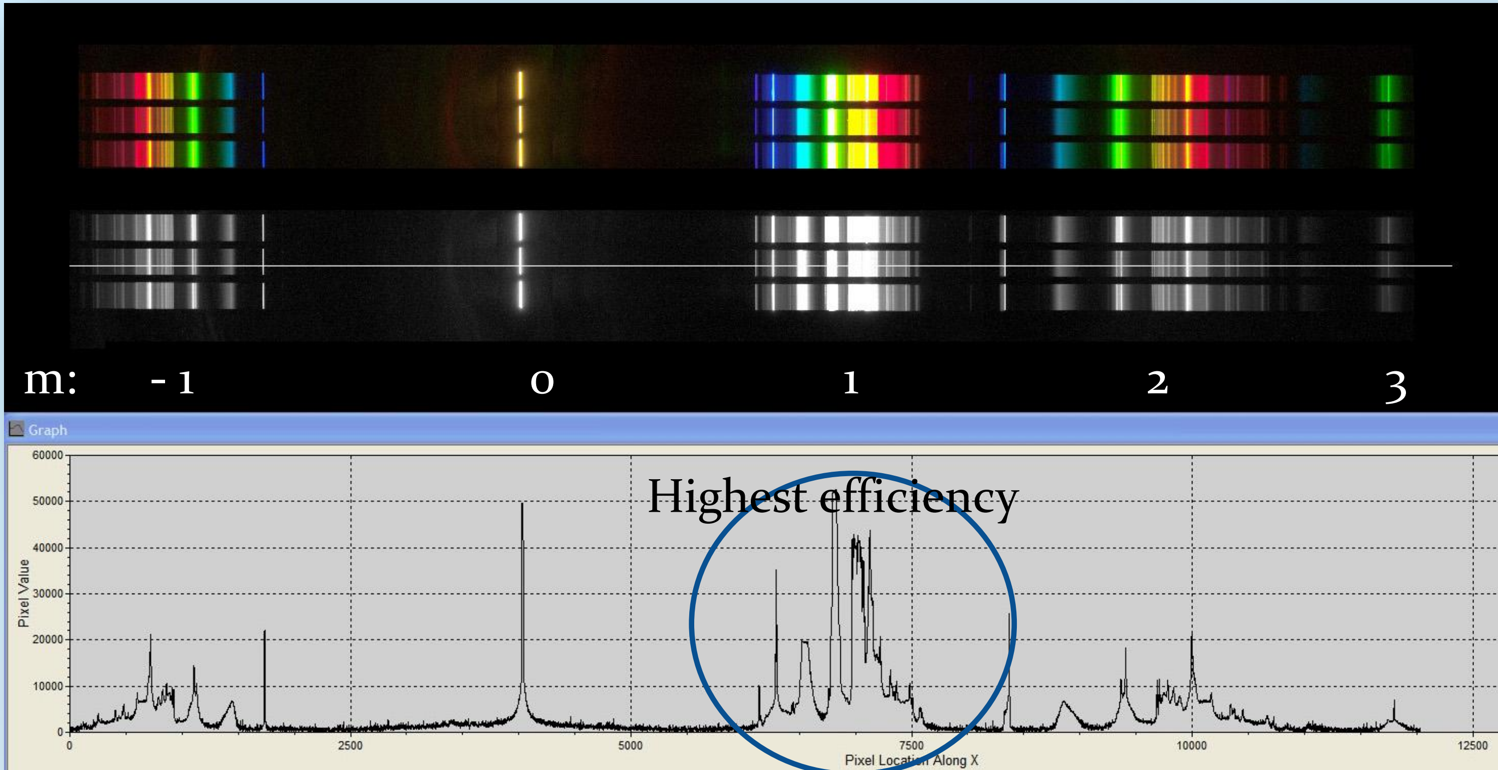
Data Entry:
Celestron C11
Telescope aperture: 280 mm
Telescope focal length: 2800 mm
Grating groove density: 200 $lines/mm$
Groove spacing $g = \frac{1}{200} mm$
Total deflection angle: $\alpha + \beta = 90°$
Central wavelength: $\lambda = 520\ nm = 5200$ Å
Diffraction order : $m = 1$
Slit width: 25 µm
Camera: Canon EOS 450D

SimSpec Results:
Angle of incident light: $\alpha = 49.22°$
Angle of reflected light: $|\beta| = 40.78°$
Dispersion: 2.05 Å/px
Spectral resolution: 13.62 Å at 5200 Å
Resolving power: 382
Blaze angle: $\varphi = 4.22° = 4° 13'$
Linear dispersion: 394.37 Å/mm
Length of the spectrum: ca. 8 mm

Row	A–E	Value	Unit	F	G	H	J	K	L
1	SIMSPEC V4.0 english version, by Ken Harrison , original version by Christian Buil						Latest Revision:	Apr 12	
2									
3	Enter data in highlighted cells								
4									
5	Telescope			Spectrograph			Camera		
6	Diameter (D) :	280	mm	Collimator			pixel sizel (p) :	5,20	microns
7	Focal length (f) :	2800	mm	Collimator-Focal length (f1) :	80	mm	number of X pixels(Nx) :	4272	
8	F/D (F#) :	10,0		Collimator-Required Focal ratio (Fc):	10,0		quantum efficiency (η) :	54	%
9	Central obstruction (ε) :	0,3		Collimator-Minimum diameter (d1) :	8,0	mm	Read noise (RON) :	18	e-/pixel
10	Telescope throughput (To) :	0,9		Resolution of Collimation lens-FWHMo :	15	microns	Dark noise (Nd) :	0,1	e-/s/pixel
11				Camera			Binning, X axis (fλ) :	1	
12	Seeing/ Atmosphere			Camera-Focal length (f2) :	96	mm	Binning, Y axis (fy) :	1	
13	Seeing (ϕ) :	2	"	Camera-Distance to grating (T) :	140	mm	Sampling Factor :	6,64	
14	Atmospheric transmission (Ta) :	0,75		Camera-Minimum lens diameter (d'2) :	41,7	mm	Exposure		
15	Sky magnitude (mag/arc sec^2) :	16		Camera-Maximum focal ratio (Fo) :	2,3		Subs, exposure time (ts) :	300	secs
16	Star size at focus (FWHM):	27,1	microns	Resolution of Camera lens-FWHMc :	15	microns	number of subframes (n) :	12	
17							Total exposure time (t):	3600	secs
18				Collimator/Camera -Total angle (γ) :	90	°	Spectrum size/ spread		
19	NOTES:			Slit width (w) :	25	microns	Height of Spectrum (n) :	12	pixel
20	See www.astrosurf.org/buil/us/spe2/hresol1.htm			Grating					
21	www.astrosurf.org/buil/us/stage/calcul/design_us.htm			Grating-Lines/ mm (n) :	200		Target Star		
22	(explanatory notes and worked example)			Grating-Diffraction order (k) :	1		Magnitude (m) :	12	
23				Grating- Minimum height (H) :	8,0	mm	Effective temperature (Te) :	10800	K
24	SUMMARY			Grating- Minimum width (W) :	12,2	mm	Bolometric Correction (BC) :	-0,4	
25	Resolving power R	382		Dispersion (ρ) :	2,05	Å/ pixel	SNR		
26	Spectral resolution	13,62	Å	Resolving power (R) :	382		Signal/Noise (SNR) :	37	
27	Wavelength range	8761	Å	Spectral resolution (Δλ) :	13,62	Å	Limiting Mag		
28	Grating-Lines/ mm	200		Dispersion (r) :	39,4	nm/mm	Limiting Mag.(Bowen-mod):	15,36	
29	Grating-Diffraction order	1		Wavelength Range					
30	Slit width	25	microns	Reference wavelength (λ0) :	5200	Å	EOS 450D: 185,19 px/mm		
31	Target Mag.	12,0		Lambda min. (λ1) :	820	Å			
32	Signal/Noise (SNR)	37		Lambda max. (λ2) :	9580	Å			
33				Wavelength range/ image frame:	8761	Å	SNR Calculations		
34							Number of photons (E) :	1,63E-02	photons/cm2/s/Å
35	Other Results		°	Throughput efficiency			Sky background(Ed) :	4,09E-04	photons/cm2/s/Å/ arc sec
36	Angle of incidence (α) :	49,22	°	Transmission efficiency- guide system:	1		Final Efficiency (R) :	0,12	%
37	Angle of diffraction (β) :	-40,78		Transmission efficiency -Littrow mirror:	1		Useful signal (Nm) :	8856	e-/pixel
38	Anamorphic factor (r) :	0,86	microns	Transmission efficiency-Collimator lens (To) :	0,92		Background noise (Ns) :	131	e-/pixel
39	diffraction limit grating, FWHMd :	5,38	microns	Transmission efficiency-Camera lens (Tc) :	0,92		Noise(σ) :	237	e-
40	Slit/ image width on CCD, FWHMt :	34,52		Transmission efficiency-Grating (Tg) :	0,6		Signal/Noise by interval Δλ :	96	e-/pixel
41				Entrance slit transmission(Tf):	0,71		*Noise from Signal :*	*95*	
42				Total Transmission of Spectrograph (Ts) :	0,36		*Noise from Electronics :*	*216*	*e-/pixel*
43									
44									
45									
46	REVISION:								
47	**V4.0 - April 2012**	**New layout. Added Data Page. Updated comments**							
48	V3.3a -Jan 2012	Collimator focal ratio set to match telescope. Camera focal ratio no longer an input.							
49	V3.3 -May 2011	Corrections to the equation for FWHMt (incorrectly calculated for slit<star)							
50	V3.2c-Oct 2010	-Slit width now in micron							
51	V3.2b -July 2010	Transmission efficiencies added for guider and Littrow mirror							
52	V3.2a -April 2010	- Fixed slit width v's star size for resolution calculation. Based on CAOS data.							
53		-SNRcalculations amended to follow CAOS formulae							
54		-Bowen magnitude now based on spectrum width and units corrected.							

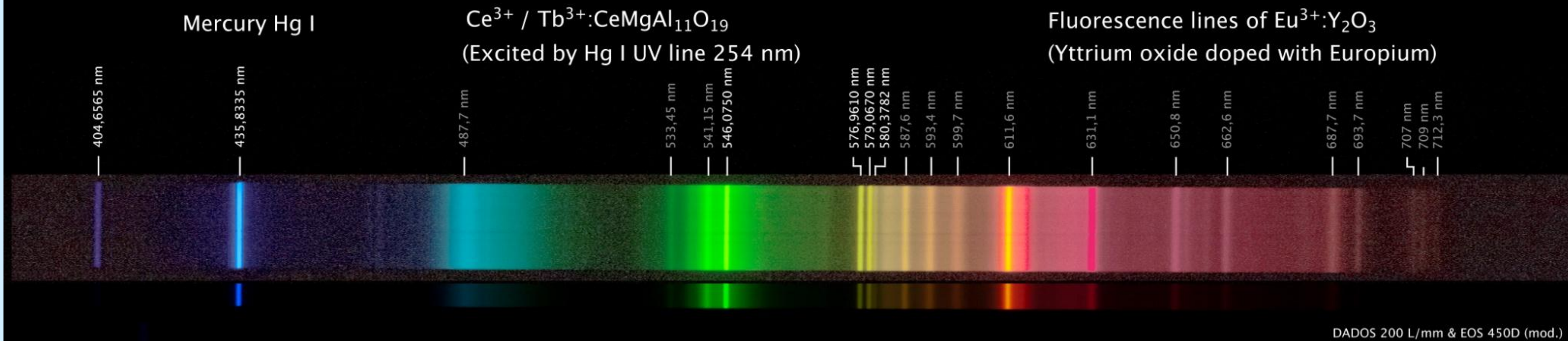
http://www.astrosurf.com/buil/us/compute/SimSpec_V4_0.xls

Energy saving lamp ORMALIGHT 9W - DADOS with 200 lines/mm grating



- **1st Order m = 1** is most efficient. Can be used for stellar spectroscopy from 3500 Å to about 10,000 Å with an ultraviolet and infrared sensitive CCD camera.
- In that case be careful: 1st order in the infrared beyond 8500 Å overlaps the 2nd order! You may check this by taking the sun's spectrum (daylight spectrum) with your camera. A DSLR camera modified with a Baader UV/IR cut filter is only sensitive between roughly 4000 Å and 7000 Å.
- **Higher Orders than the first** can be used for spectroscopy only in a smaller wavelength range. But the higher spectral resolution is bought dearly due to low efficiency. A grating with 900 lines/mm or 1200 lines/mm is recommended to achieve higher spectral resolution.

Spectrum of Energy Saving Lamp (ESL) ORMALIGHT 9W



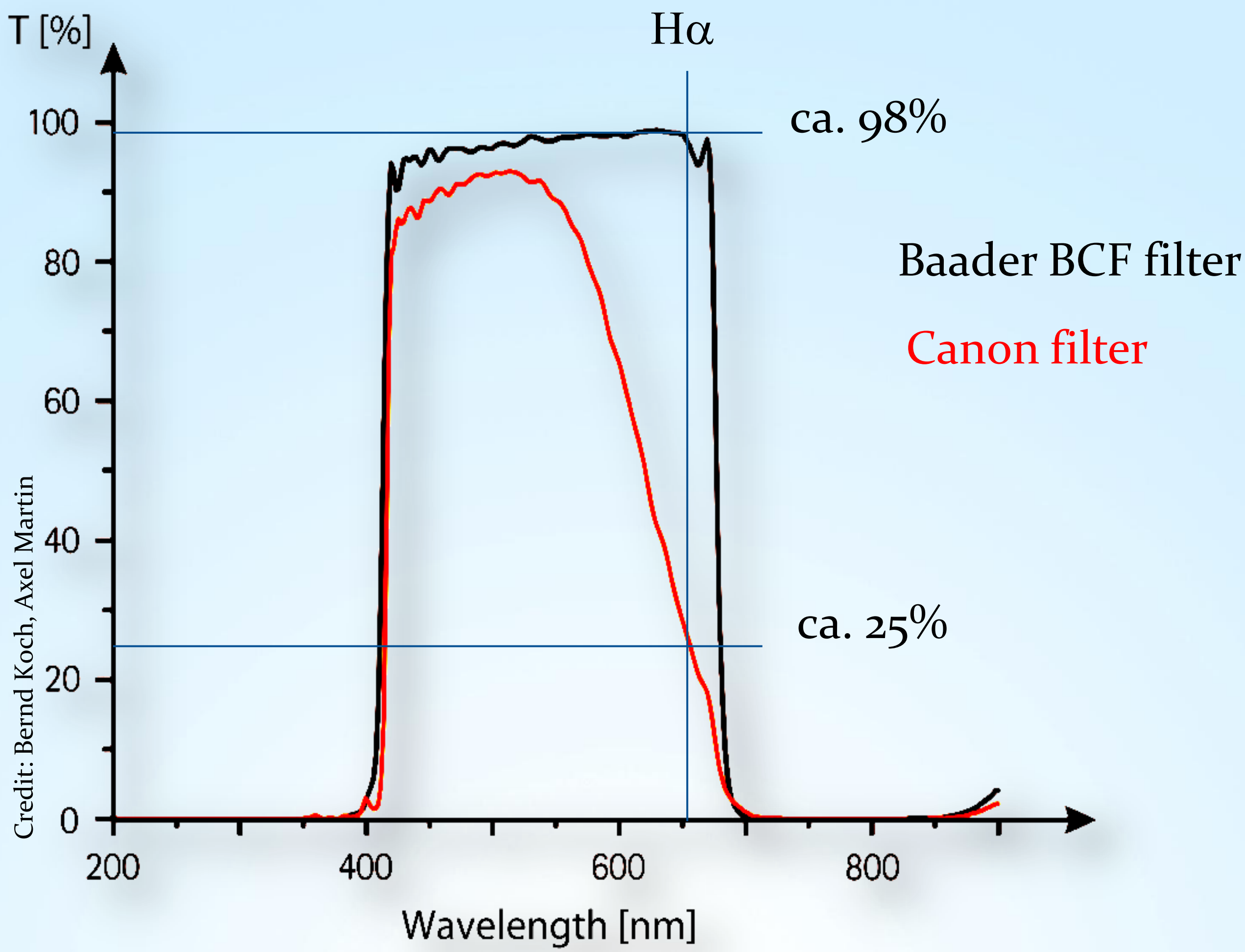
Weblink to article on fluorescent substances (2003): http://www.electrochem.org/dl/interface/sum/sum03/IF6-03-Pages48-51.pdf

Stacking/calibration of stellar spectra

- **Stacking & calibration of spectra obtained with a DSLR camera**
  + If you already have a DSLR camera, please practice with it by recording a daylight spectrum (= solar spectrum, G2V)
  + Cheaper than any CCD camera with a similar "big" sensor (APS-C)
  + Easier handling than a CCD camera
  + LiveView mode for easy focusing at a bright light source, e.g. ESL
  + You can easily find your way through the spectrum (red/blue)
  + Easy identification of spectral features due to color
  + Autodark improves SNR at the cost of exposure time
  - Low signal-to-noise ratio images
  - Low sensitivity at less than 4000Å means the Ca II lines are barely visible
  - Non-modified DSLRs have low sensitivity above 6000Å

- **Stacking & calibration of spectra obtained with a cooled b&w CCD camera**
  + Sensitive from about 3500Å ("Balmer Jump" at 3646Å) to about 10000Å (IR)
  + High signal-to-noise ratio images
  + Separate dark frames useful (dark frame library)
  + No need for a color camera: Synthetic color spectra can be created with Vspec
  - Difficult to handle for beginners in astrophotography and astrospectroscopy

Stacking/calibration of stellar spectra from a Canon DSLR camera



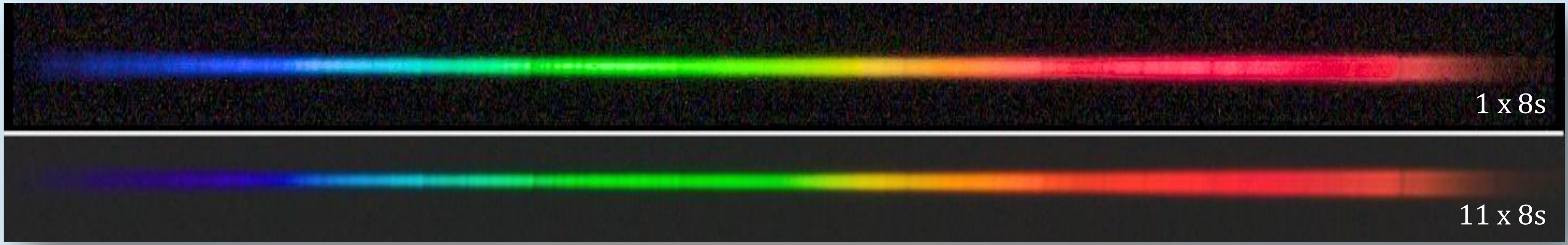
http://www.baader-planetarium.de/sektion/s45/canon_astroupgrade-english.htm

Stacking/calibration of stellar spectra from a Canon DSLR camera

Exercise 1: α Orionis (Betelgeuse)

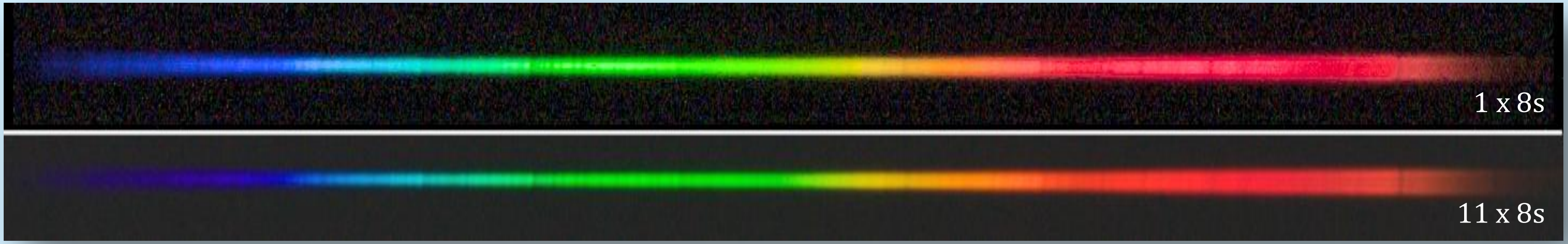
Date 2010-12-15
Pentax 75 SDHF / 500mm
Canon EOS 450D (Baader BCF-Filter)
ISO 800
Spectrograph: DADOS
Grating: 200 l/mm
Spectral resolution: 12 Å @5500 Å
Scale: 2.1 Å/Pixel
Betelgeuse: Spectral Class M2Iab
Apparent magnitude: 0.7 mag
Set of 11 spectra, each 8 s exposed
Darkframes: not used
Flatflields: not used

Images: .../Betelgeuse_200L_2010-12-15/

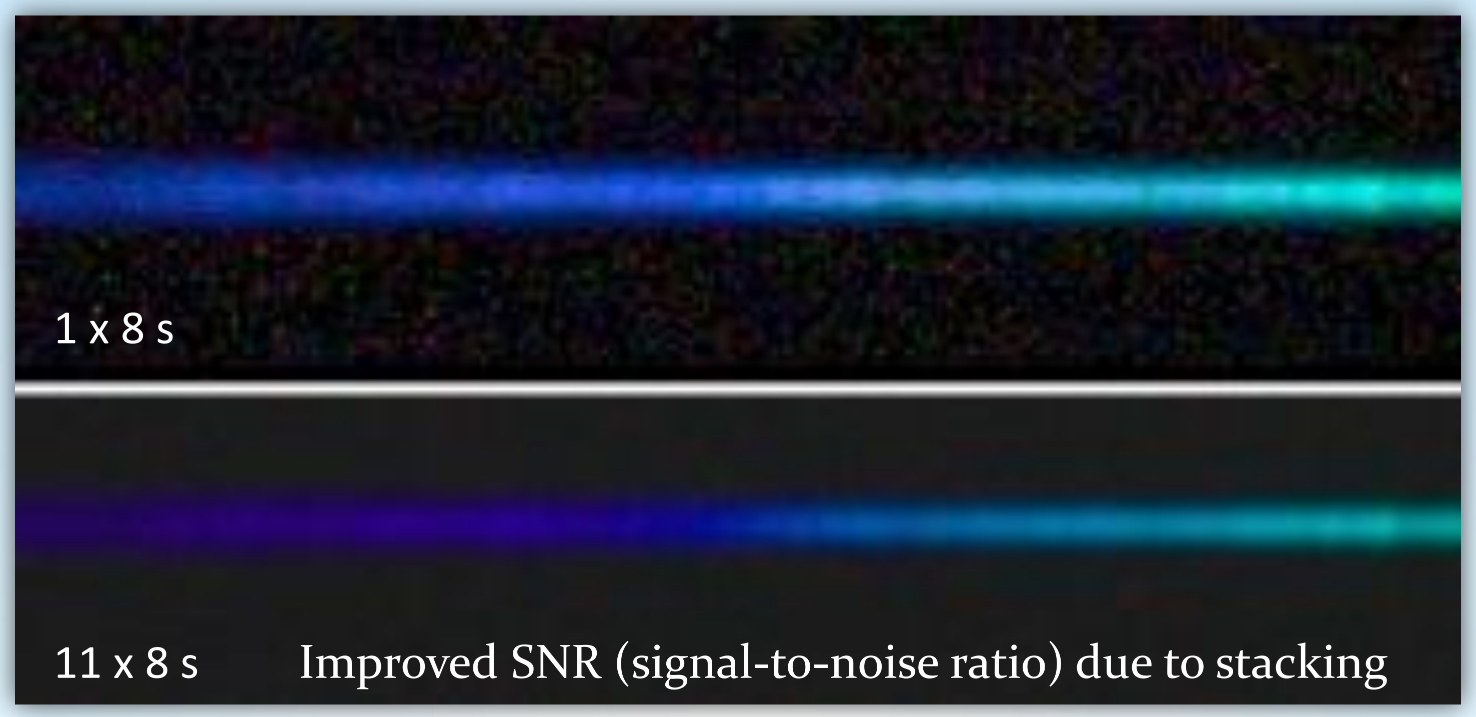


Stacking/calibration of stellar spectra from a Canon DSLR camera

α Orionis (Betelgeuse), M2Iab



DADOS 200 lines/mm, Canon EOS 450D (BCF filter)



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 1: Image Browser - Check the quality of spectral images

Step 2: Fitswork - Download and check settings

Step 3: Fitswork – The stacking process: Create an averaged color spectrum

Step 4: Fitswork – Rotate, crop, convert to monochrome spectrum & save

Step 5: Visual Spec (VSpec) – Spectrum calibration (w/o instrumental response)

Step 6: Visual Spec (VSpec) - Visualize Profile as synthetic (color) profile

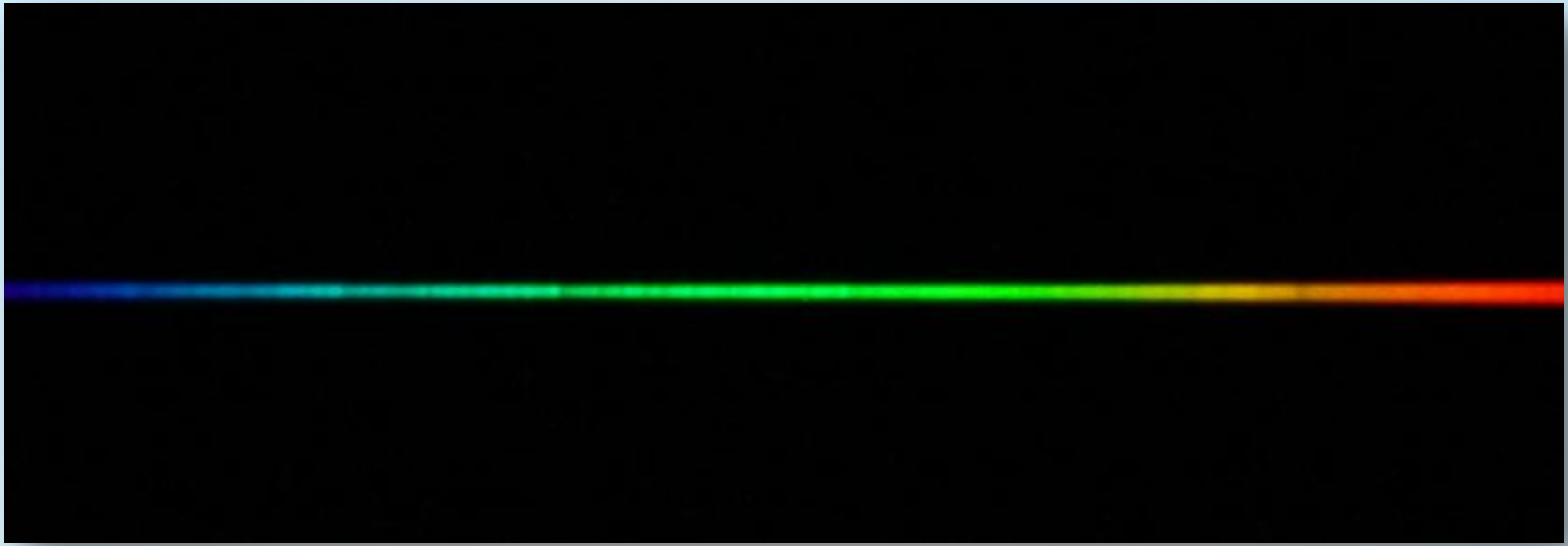
Step 7: VisualSpec (VSpec) – Spectrum calibration by instrumental response and calculation of the effective temperature of Betelgeuse from its spectrum

Step 8: Visual Spec (VSpec) - Visualize profile as a synthetic (color) profile

Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 1: Check the quality of spectral images in an image browser
Dataset: .../Betelgeuse_200L_2010-12-15/**1_Spectra_JPG**/

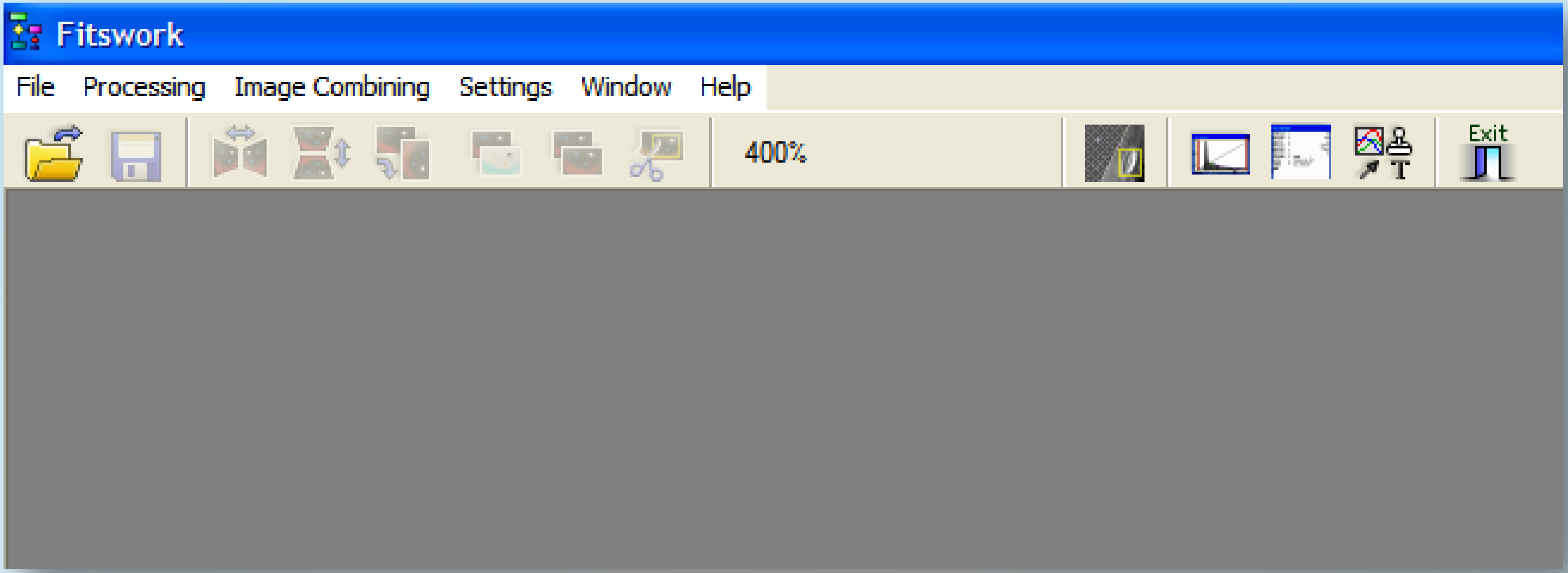
→ Note the image numbers of the perfectly imaged spectra with regard to exposure time and sharpness of spectral features. Ignore imperfect spectra!



Stacking/calibration of stellar spectra from a Canon DSLR camera

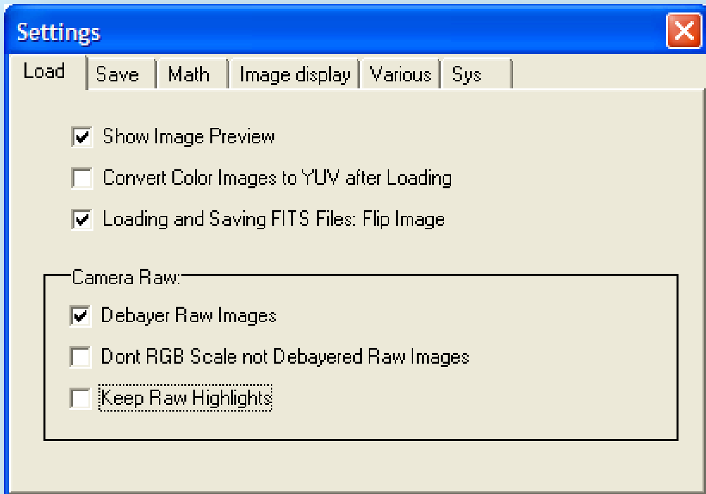
Step 2: Spectrum stacking with Fitswork

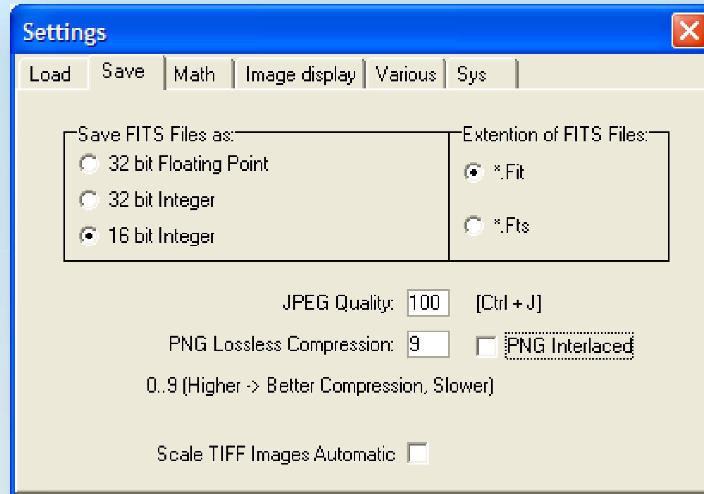
- Download Fitswork at http://www.fitswork.de/software/softw_en.php
- Start Fitswork

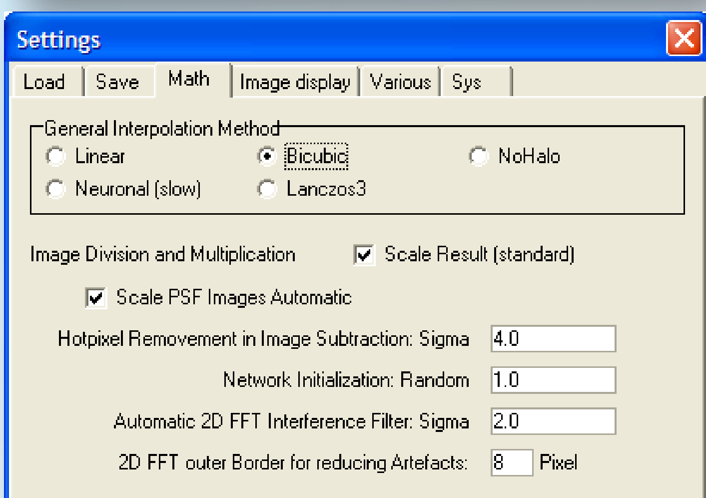


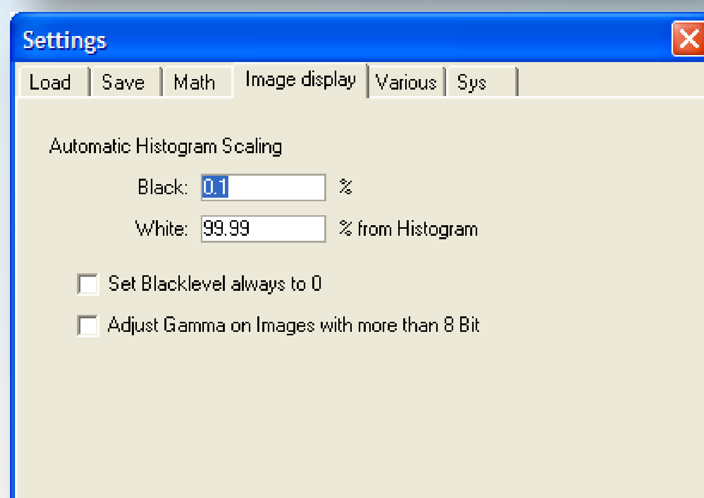
Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 2: Spectrum stacking with Fitswork → Settings







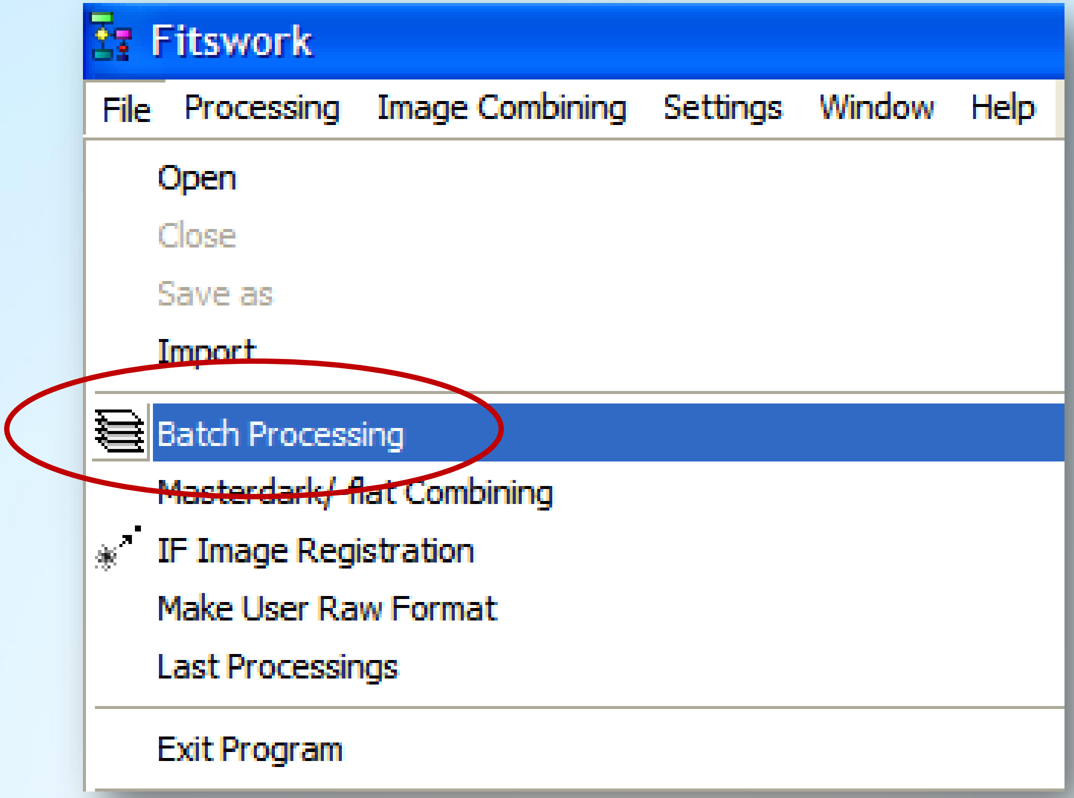


Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 3: Fitswork – The stacking process: Create an averaged color spectrum

Dataset: .../Betelgeuse_200L_2010-12-15/**2_Spectra_raw_images_CR2**

File → Batch Processing

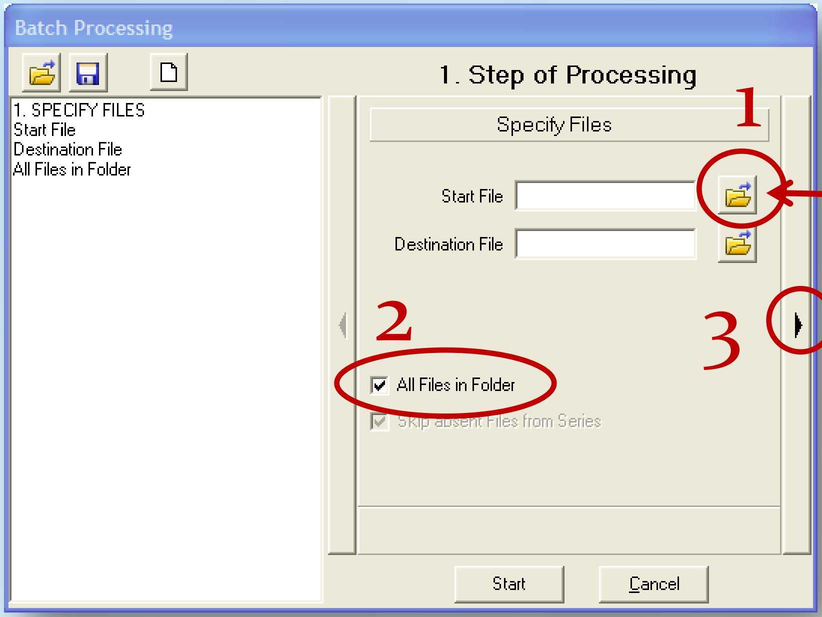


Stacking/calibration of stellar spectra from a Canon DSLR camera

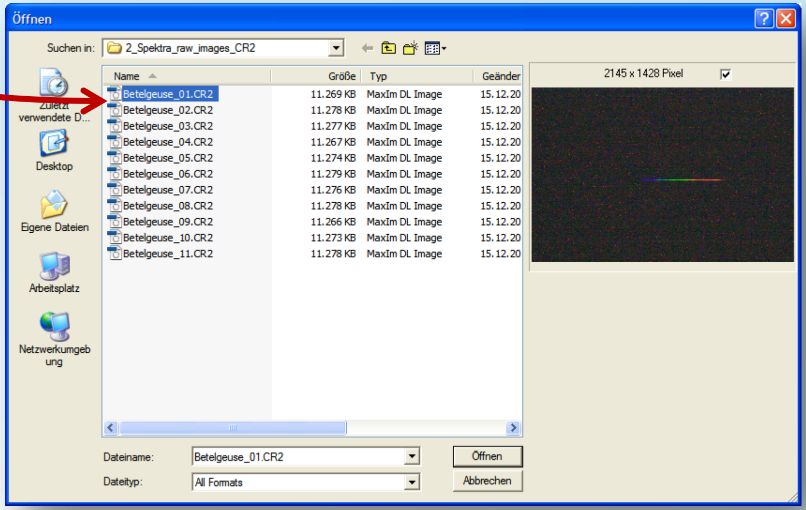
Step 3: Fitswork – The stacking process: Create an averaged color spectrum

Dataset: .../Betelgeuse_200L_2010-12-15/2_Spectra_raw_images_CR2

1. Step of Processing [sic]



1. File → Select first raw image file
2. All files in folder
3. Press right arrow button to proceed

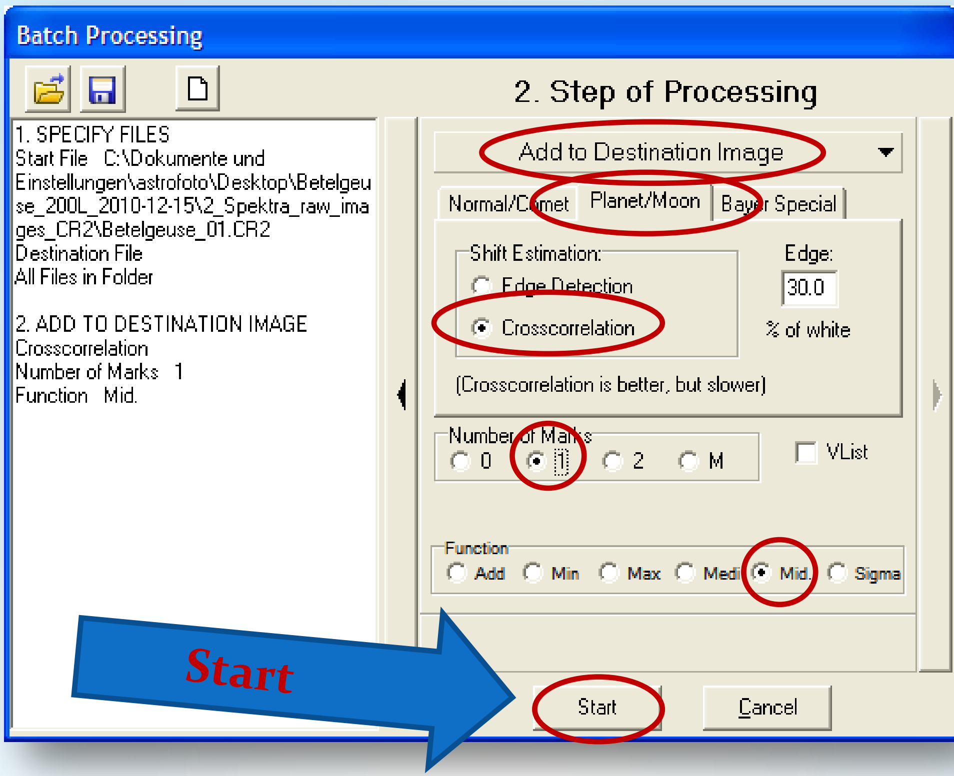


Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 3: Fitswork – The stacking process: Create an averaged color spectrum

Dataset: .../Betelgeuse_200L_2010-12-15/2_Spectra_raw_images_CR2

2. Step of Processing [sic]→ Add to destination image → Planet/Moon
→ Crosscorrelation → Number of Marks → Function: Mid. (means average)
→ Press start button

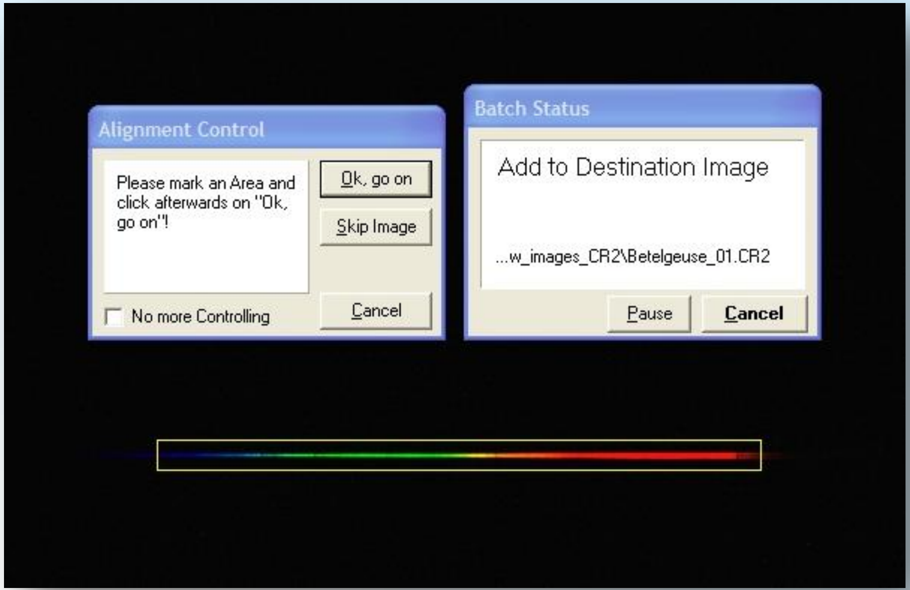


Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 3: Fitswork – The stacking process: Create an averaged color spectrum

Dataset: .../Betelgeuse_200L_2010-12-15/**2_Spectra_raw_images_CR2**

1. Draw a tight yellow frame around the first spectrum
2. Skip bad images which are not properly focused or exposed
3. Load the next frame ("Ok, go on")
4. Check if the area is marked (yellow frame is still in place)
5. Go through all images with or without controlling image quality
6. The final image, the stacked spectrum, will be saved after a while as "Result_image.fit"
7. Create a new folder "3_Results" and save copy of "Result_image.fit"
8. "3_Results" is your new working directory

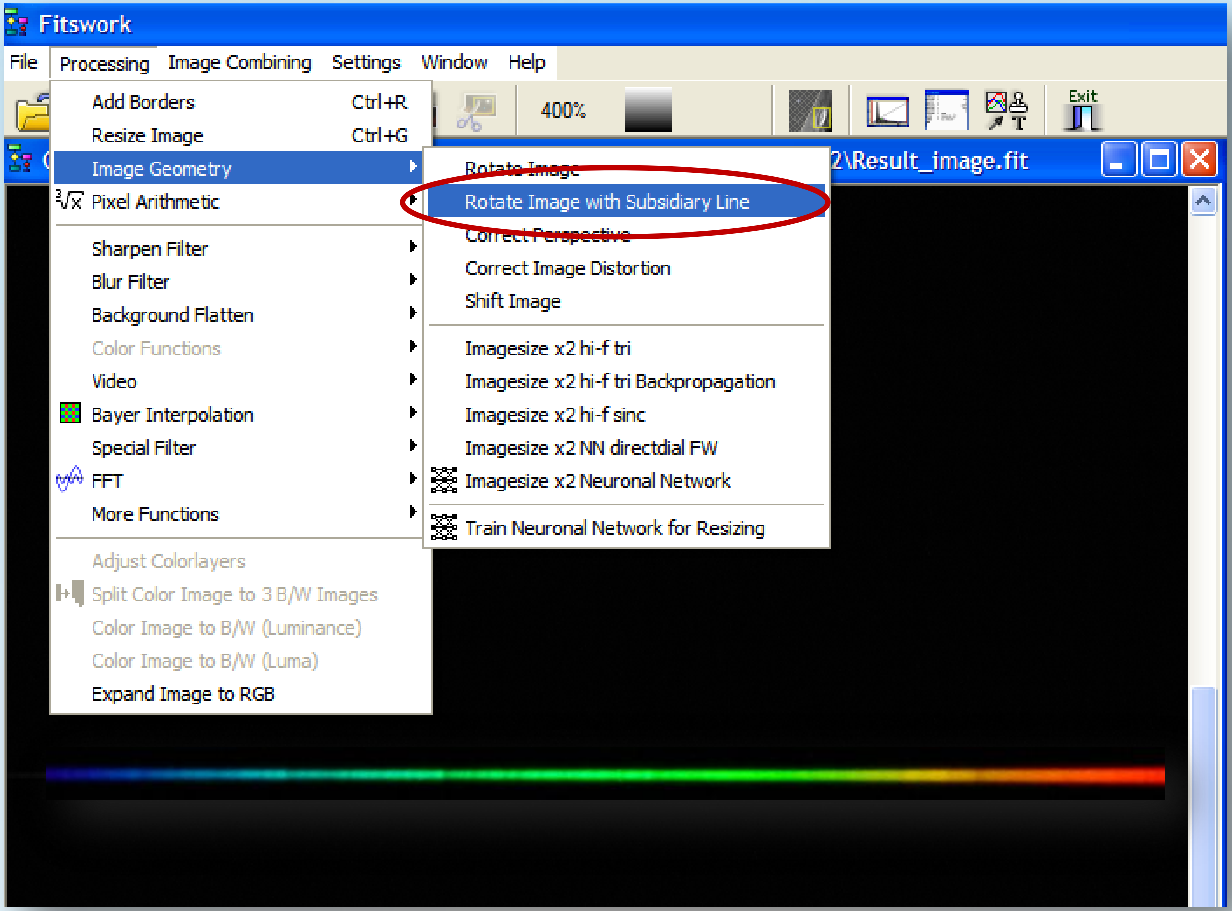


Please note!
The quality of the final spectrum depends on recognizing spectral lines in each single image. Spectra with short exposure times, and consequently low contrast, may not stack properly.

Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 4: Fitswork - Rotate and save again as “Result_image.fit“

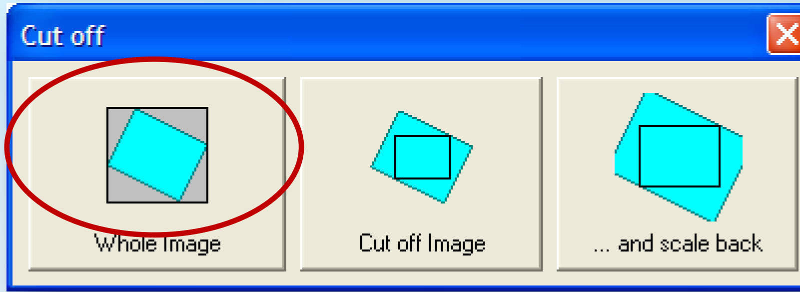
Rotate “Result_image.fit“ to achieve a perfectly leveled spectrum
Processing → Image Geometry → Rotate image with Subsidiary Line



Stacking/calibration of stellar spectra from a Canon DSLR camera

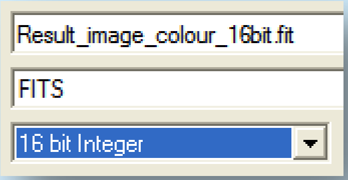
Step 4: Fitswork - Rotate “Result_image.fit“ → perfectly leveled spectrum

- Please mark a line exactly along the spectrum with the left mouse button
- then → Ok → Whole Image

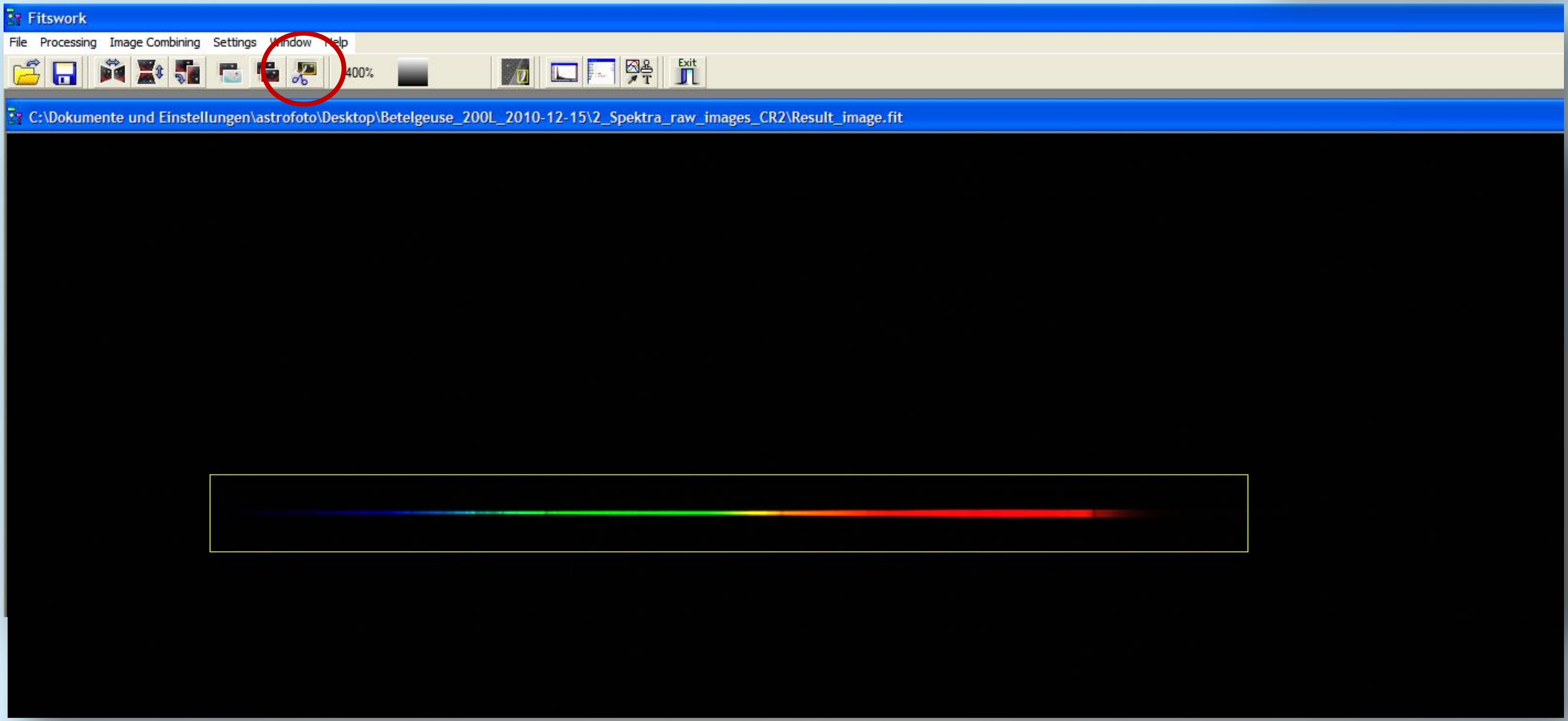


Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 4: Fitswork – Crop & save



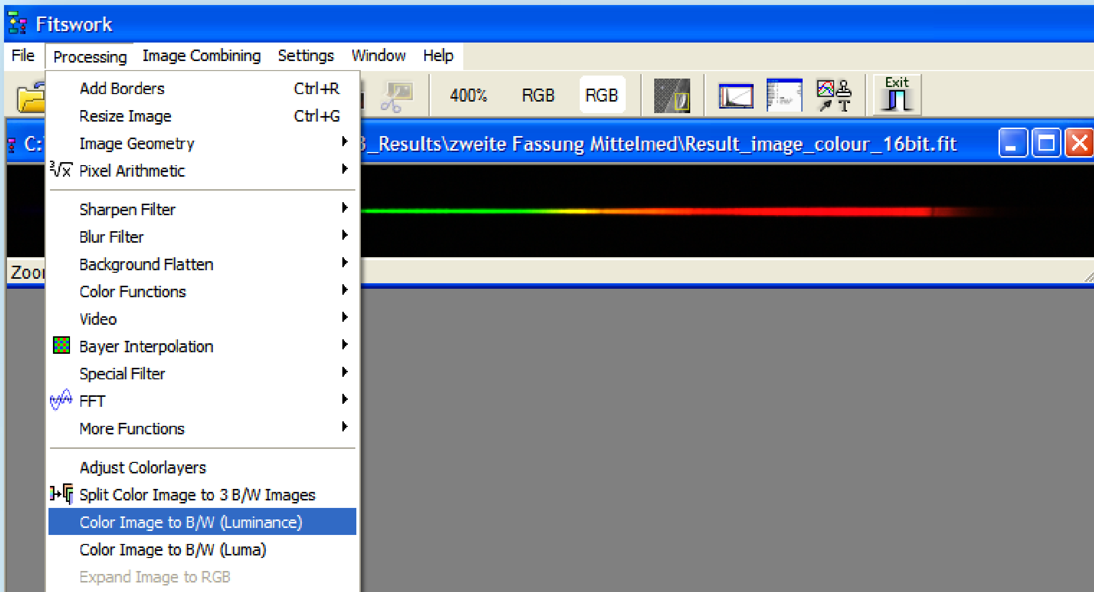
→ Draw a yellow frame around the spectrum
→ Cut off → Save as "**Result_image_color_16bit.fit**"

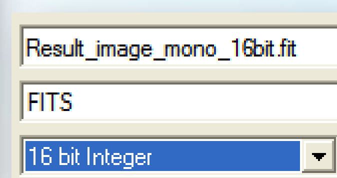


Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 4: Fitswork – Convert to black & white image and save

Processing → Color image to b/w (luminance)



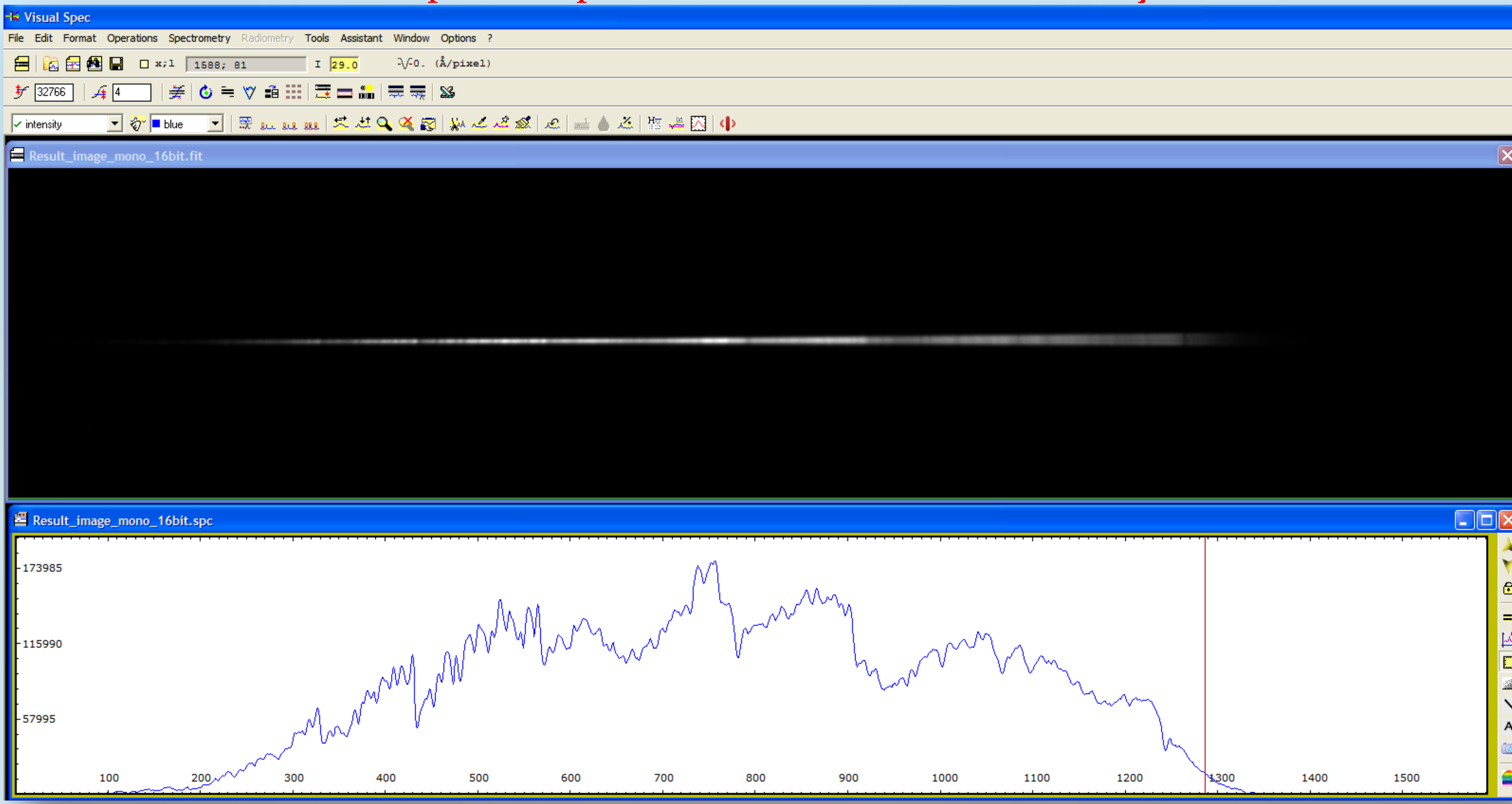


Save as → "Result_image_mono_16bit"

Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: VisualSpec (VSpec) – Spectrum calibration

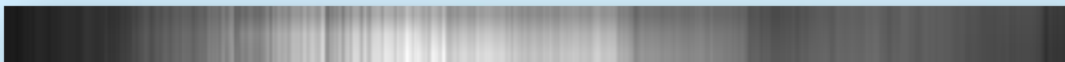
- VSpec Software Download: http://valerie.desnoux.free.fr/
- Please note: VisualSpec accepts monochrome 16 bit files only



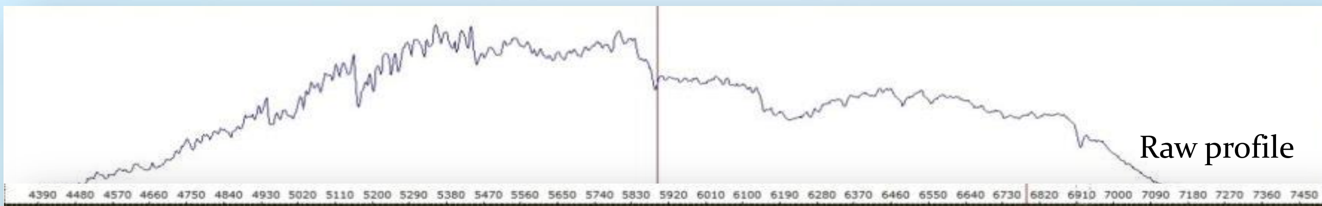
Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: VisualSpec (VSpec) – Spectrum calibration without correction for the instrumental profile

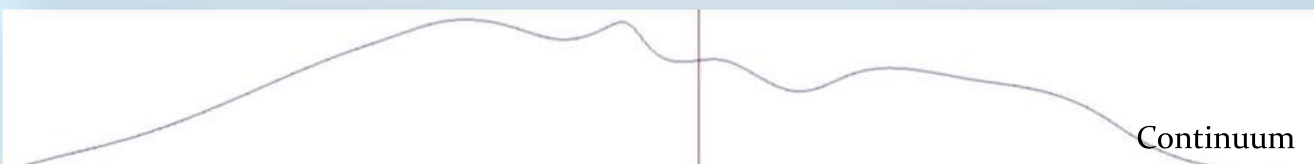
Betelgeuse: Result_image_mono_16bit



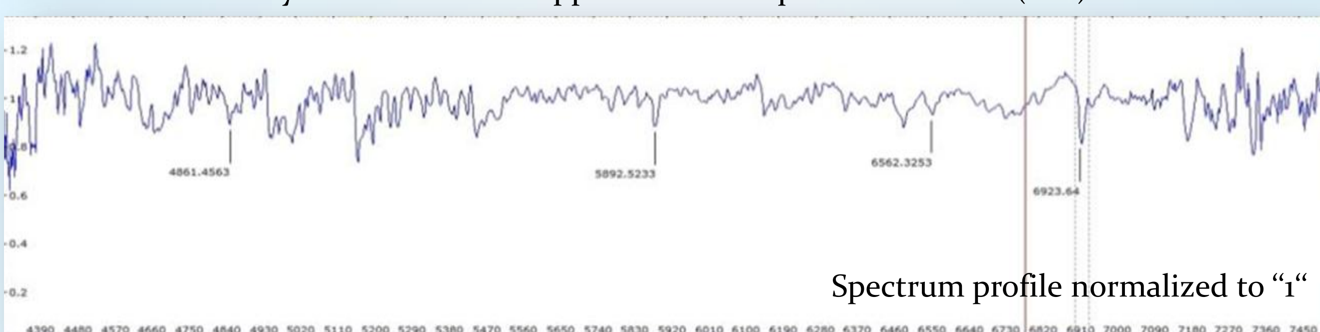
Create a spectrum profile → Identify spectral lines → Calibrate wavelength



Divide a continuum profile, which was extracted from the raw profile



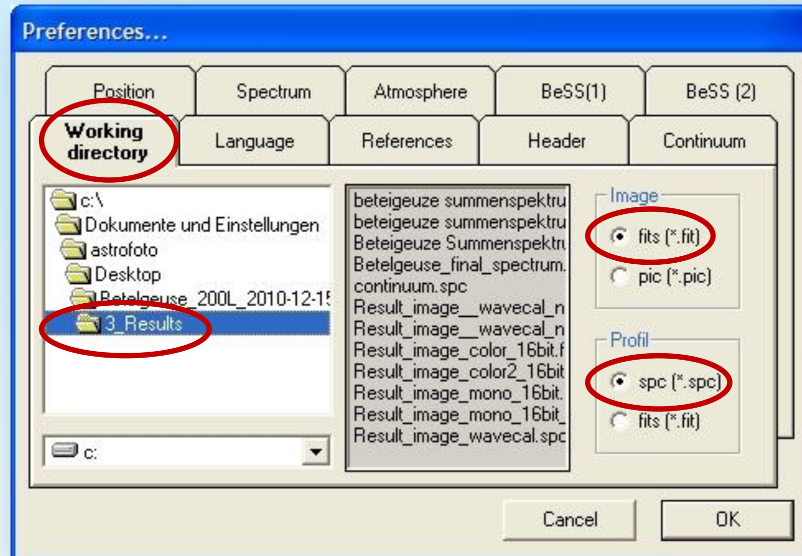
Normalize intensity to “1“. Measure Doppler shifts or Equivalent Widths (EW) of lines



Stacking/calibration of stellar spectra from a Canon DSLR camera

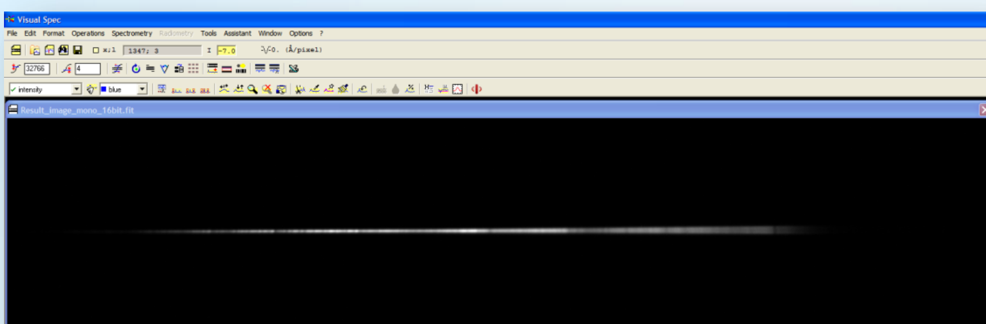
Step 5: VisualSpec (VSpec) - Preferences

5.1 Open VSpec



5.2 Options → Preferences → Working directory "3_Results"
Image → .fits and Profile → .spc

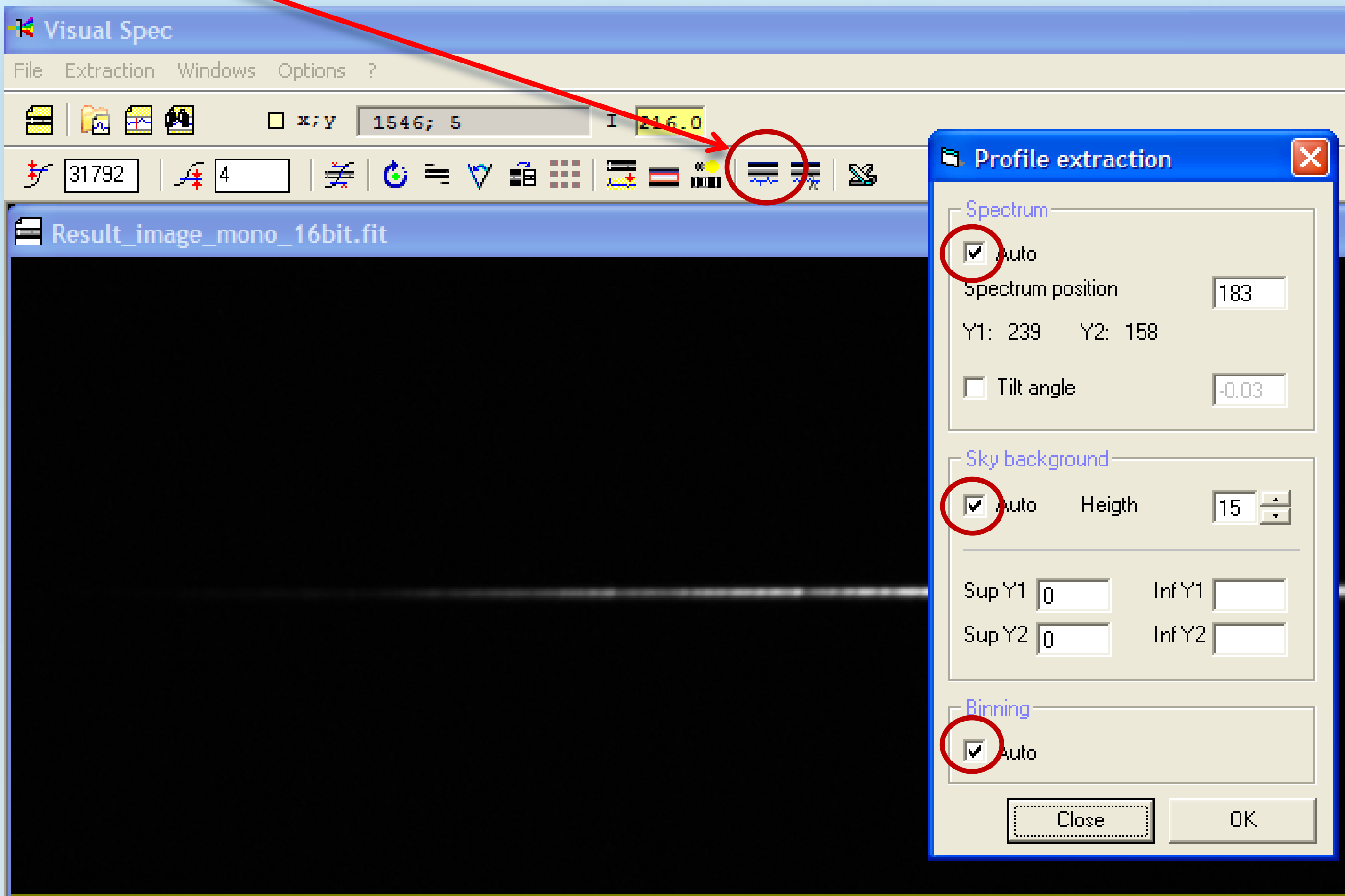
5.3 File → Open image: "**Result_image_mono_16bit.fit**"



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: VisualSpec (VSpec) – Create a spectrum profile

5.4 Profile extraction → All set to “Auto“ → OK → Close

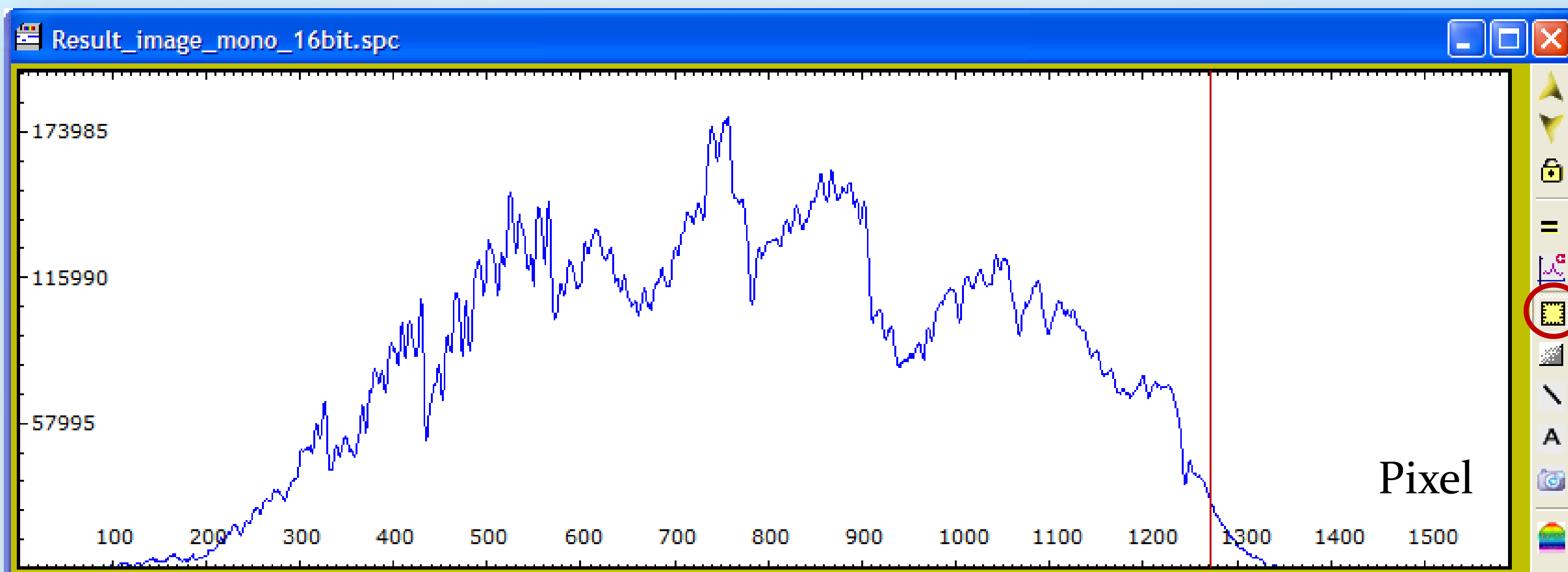


Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: VisualSpec (VSpec) – Save the spectrum profile

5.5 Press [button] to display pixel positions and intensity
The result is a spectrum profile with (x,y) = (pixel positions, intensity).
“Tilt“: Spectrum is not perfectly leveled (angle -0.01°), so the spectral lines are not perfectly perpendicular. This has no measurable effect on the calibration.

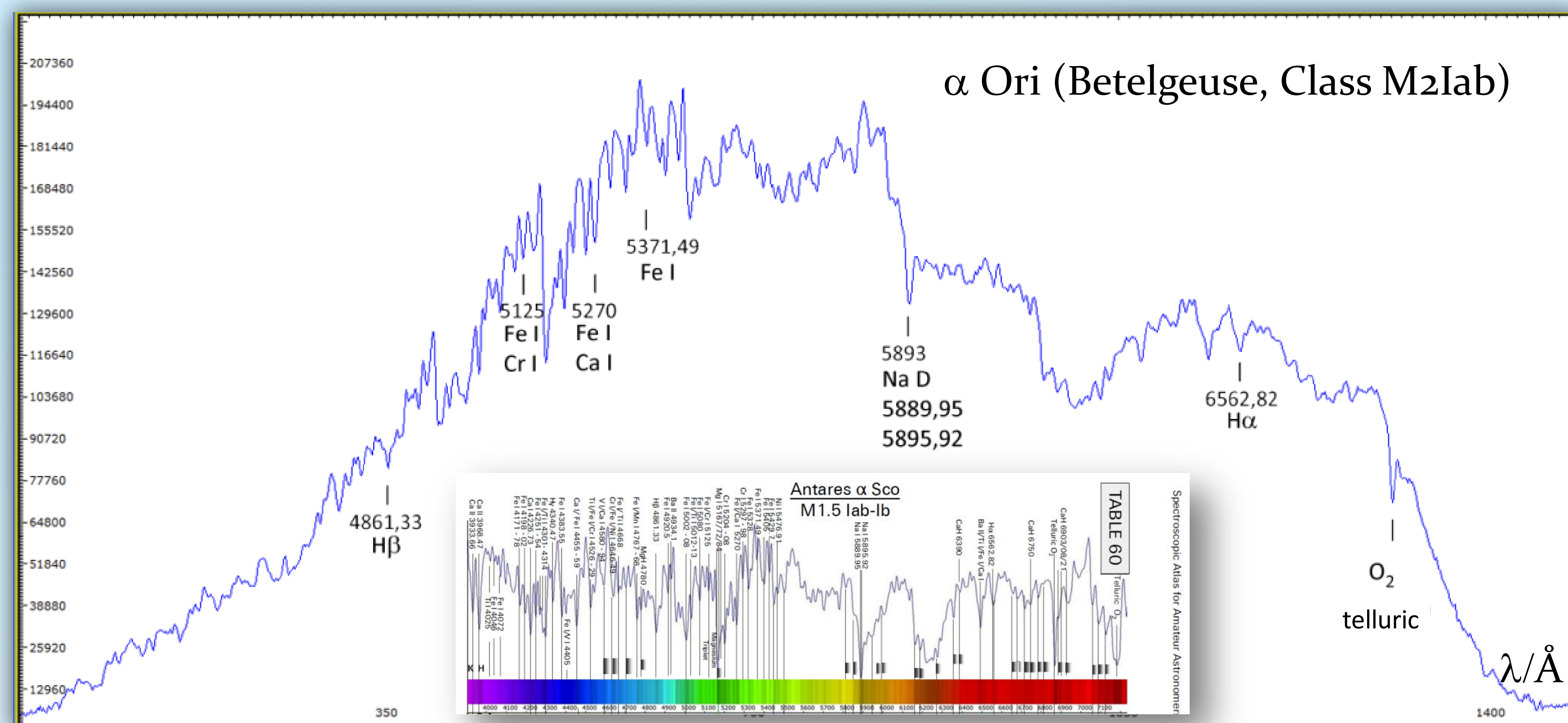
5.6 Save “Result_image_16bit.spc“
Due to a different stacking procedure and color conversion, the spectrum intensities on the following pages differ somehow. This has no effect on the final profile as it is being calibrated (continuum removed or instrumental profile used).



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – Identification of spectral features

5.7 Print the raw profile and note the wavelengths of precisely known spectral lines of a star of similar class



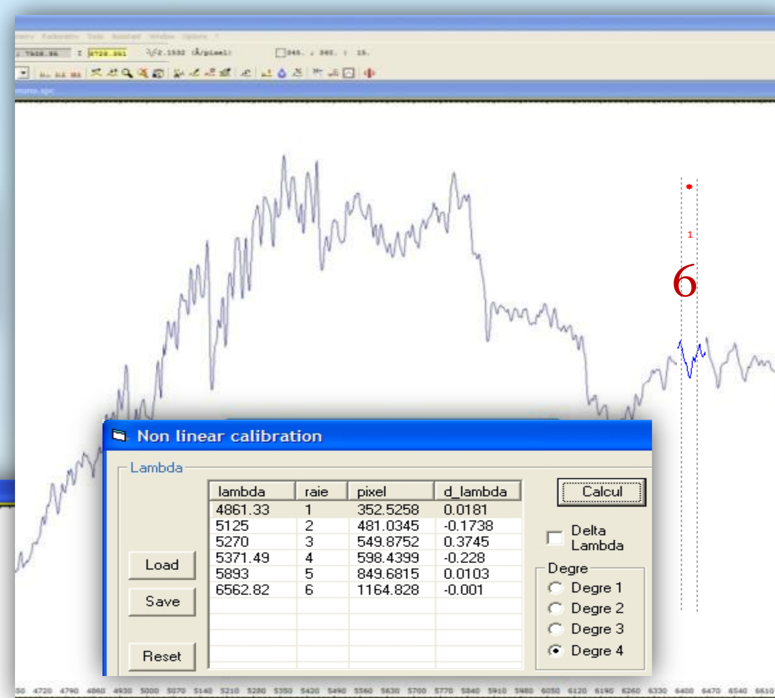
Suggested reference: Spectroscopic Atlas for Amateur Astronomers, by Swiss amateur astronomer Richard Walker
http://www.ursusmajor.ch/downloads/spectroscopic-atlas-4.0.pdf

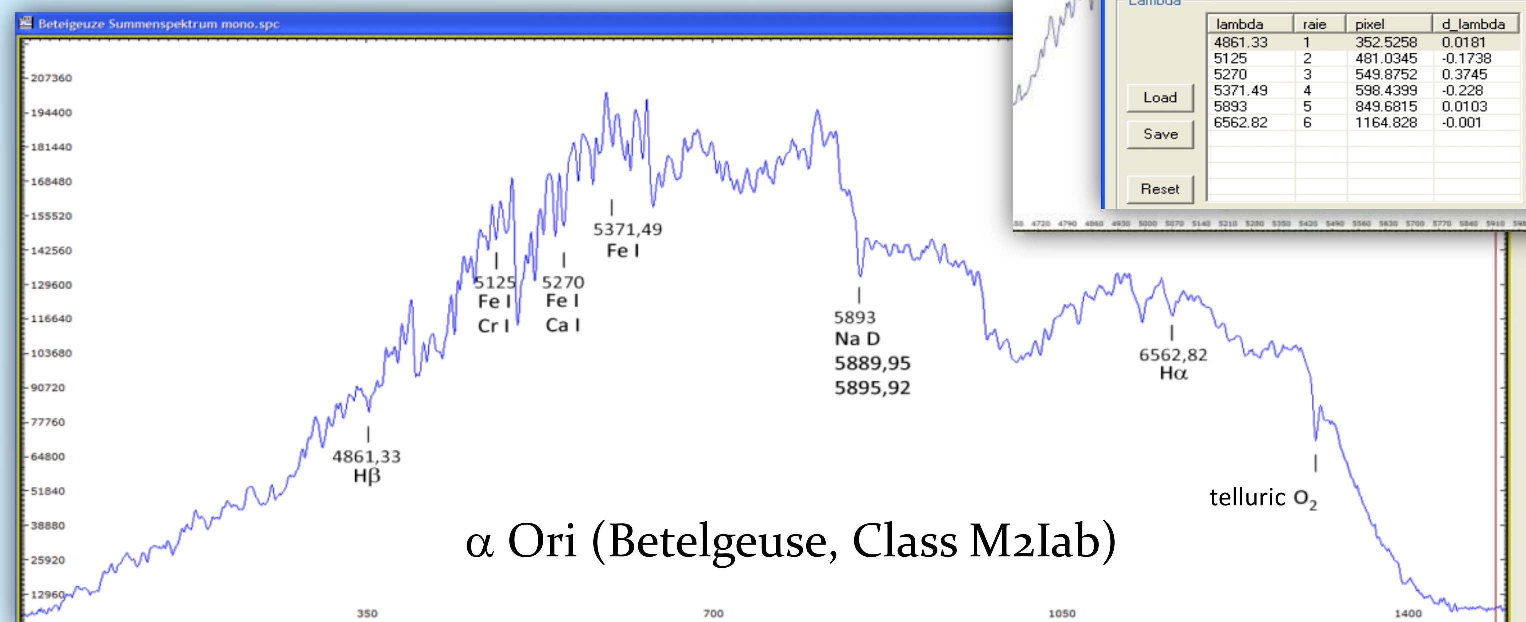
Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – From pixel to Ångstrom: Wavelength calibration of the x-axis

5.8 Calibration multiple line

5.9 Save as → “**Result_image_wavecal.spc**“





α Ori (Betelgeuse, Class M2Iab)

Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – Continuum extraction from the raw profile

5.10 Compute continuum

Stacking/calibration of stellar spectra from a Canon DSLR camera

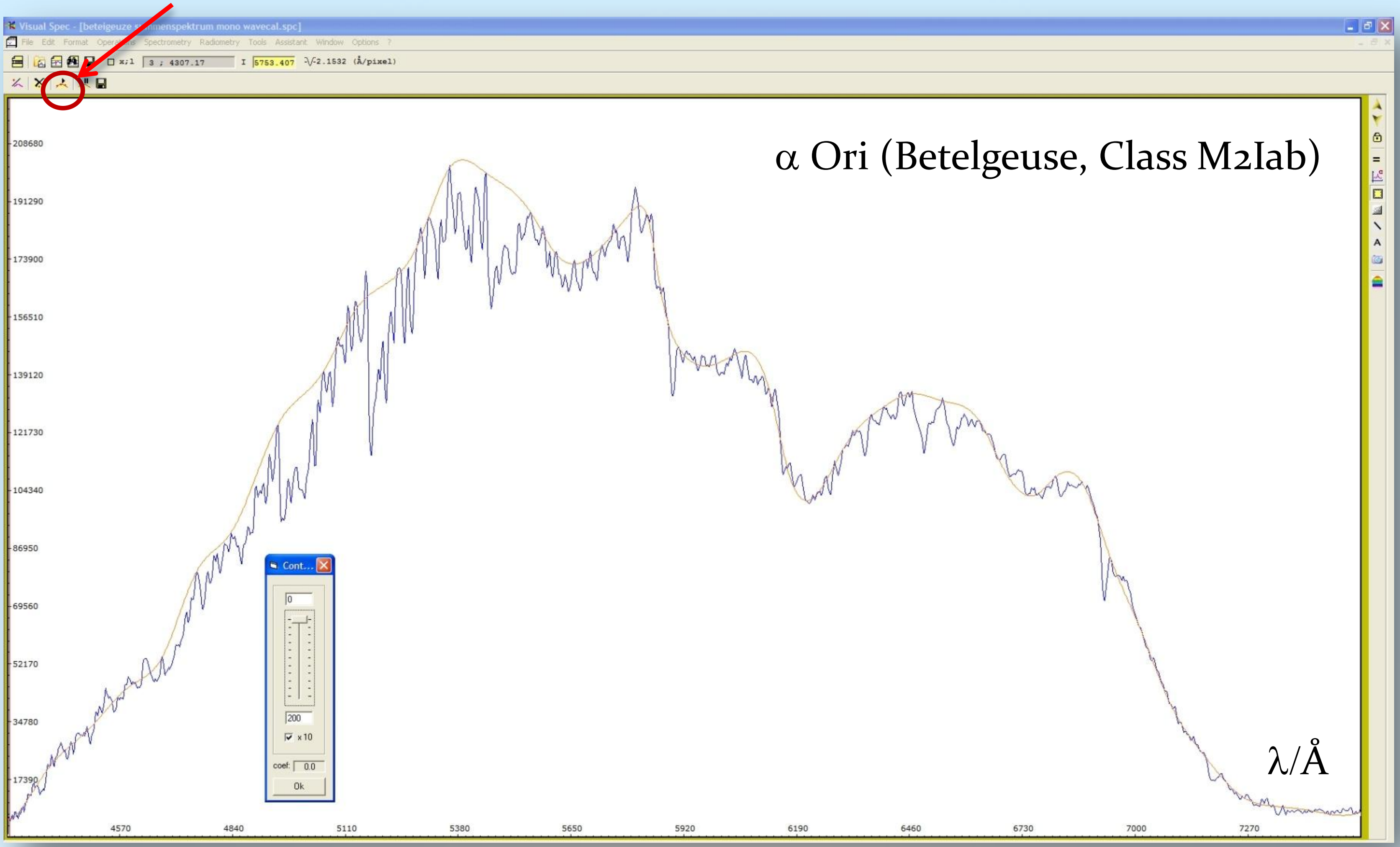
Step 5: Visual Spec (VSpec) – Continuum extraction from the raw profile

5.11 Press "point/courbe[sic]": set 20 to 50 points (actually green crosses) along the continuum (upper limit)

Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – Continuum extraction from the raw profile

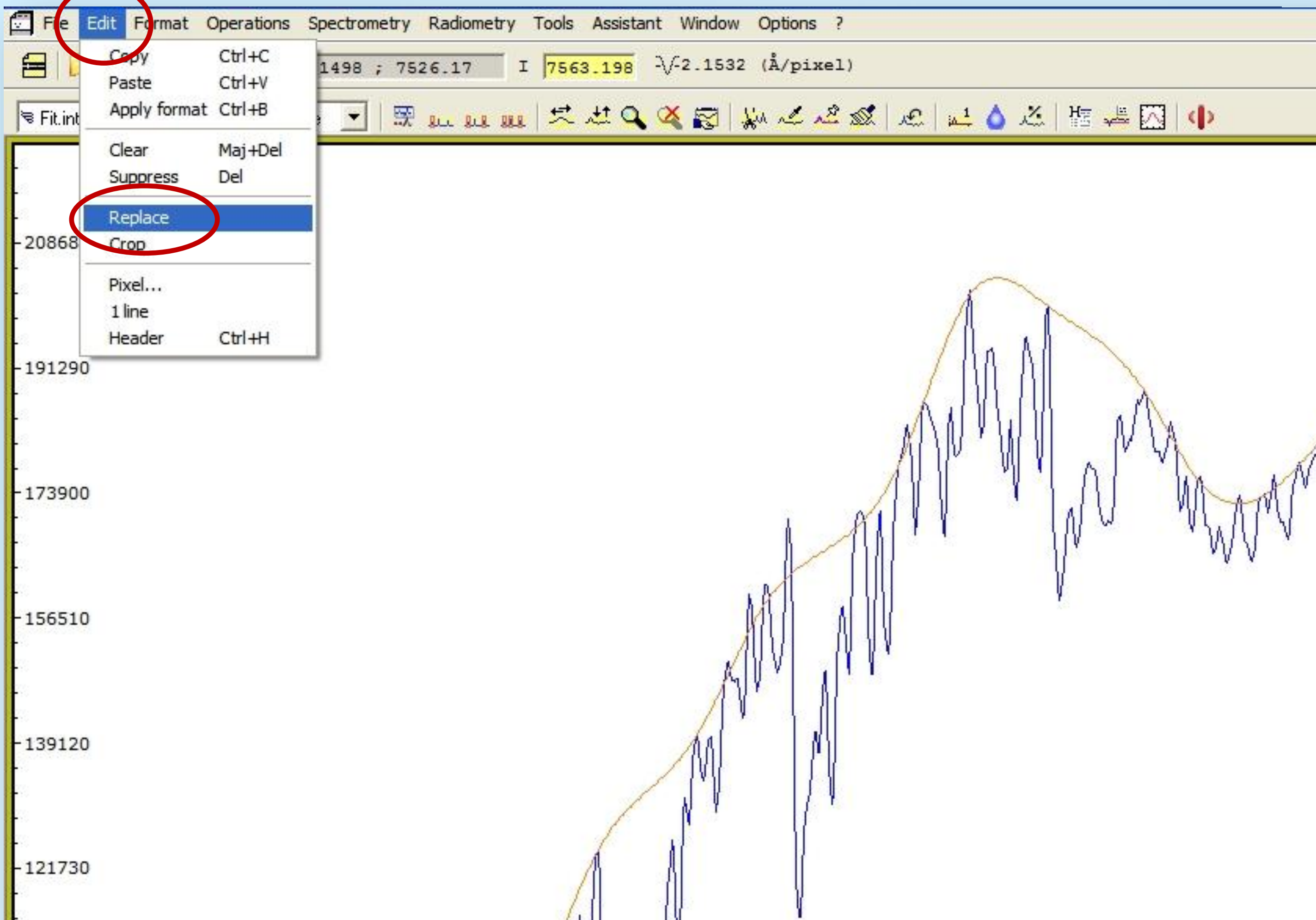
5.12 Press “Execute“. The resulting continuum is the orange-red line



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – Continuum extraction from the raw profile

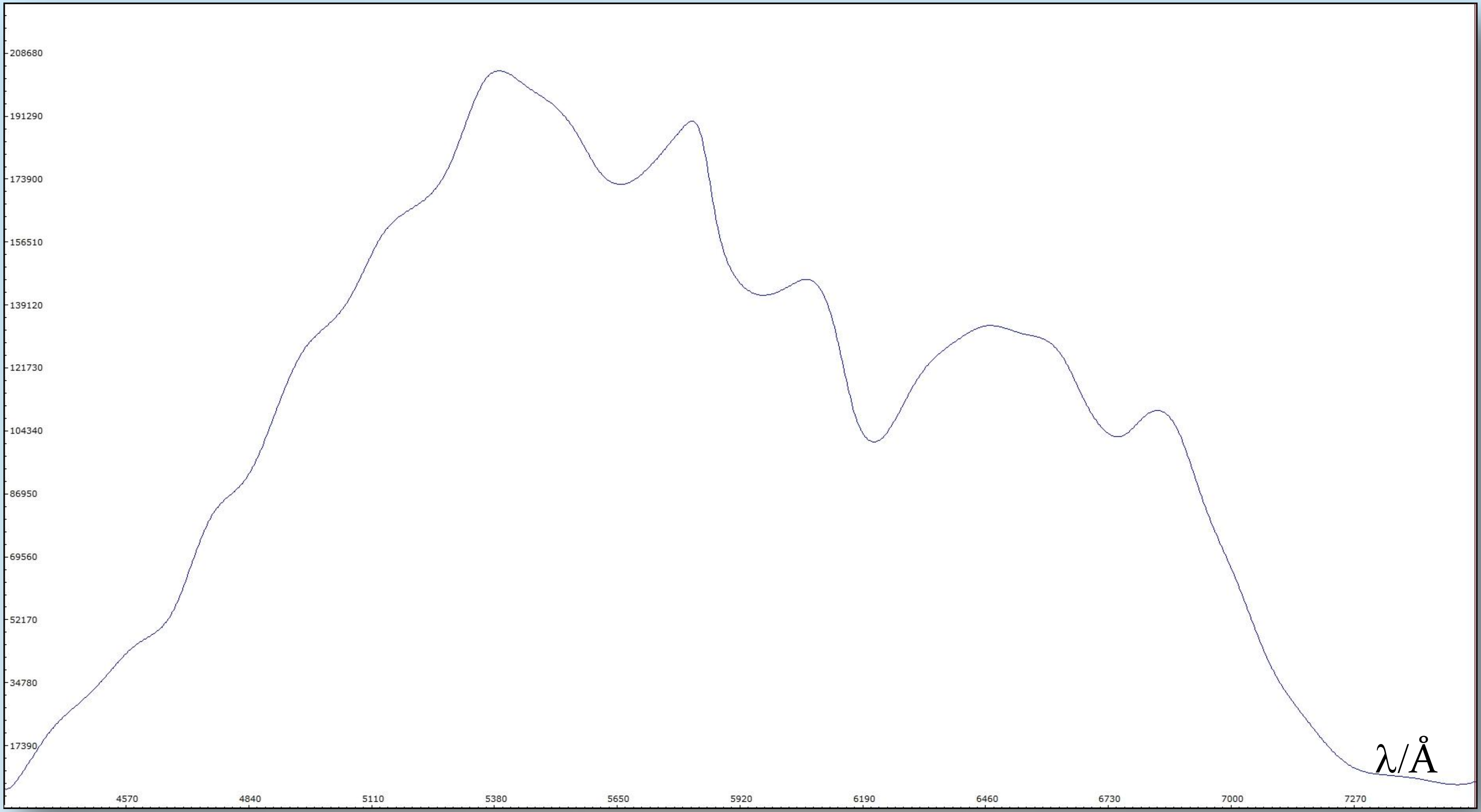
5.13 Edit → Replace → Intensity



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – Continuum extraction from the raw profile

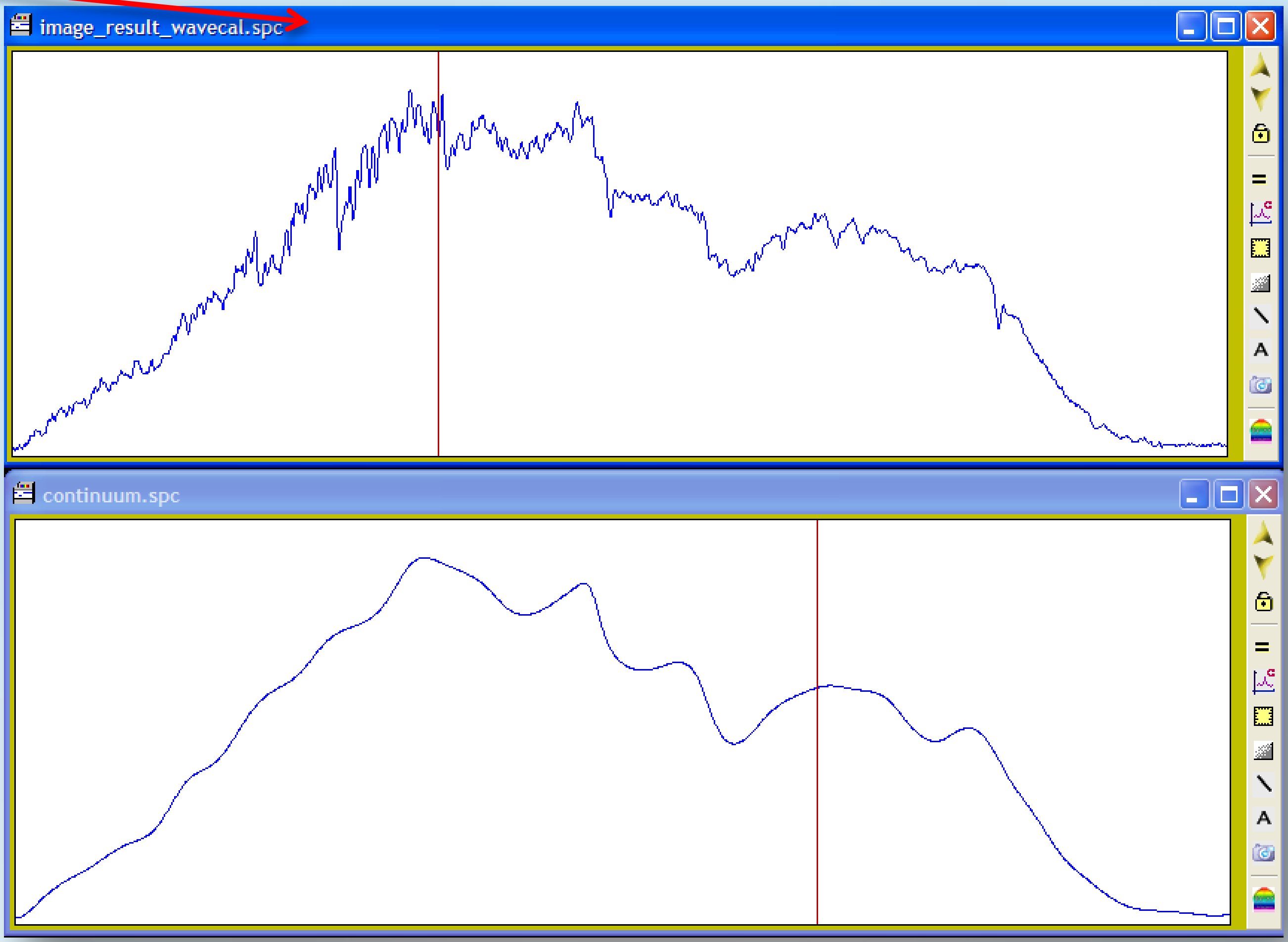
5.14 Save as → Continuum.spc



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – Continuum division

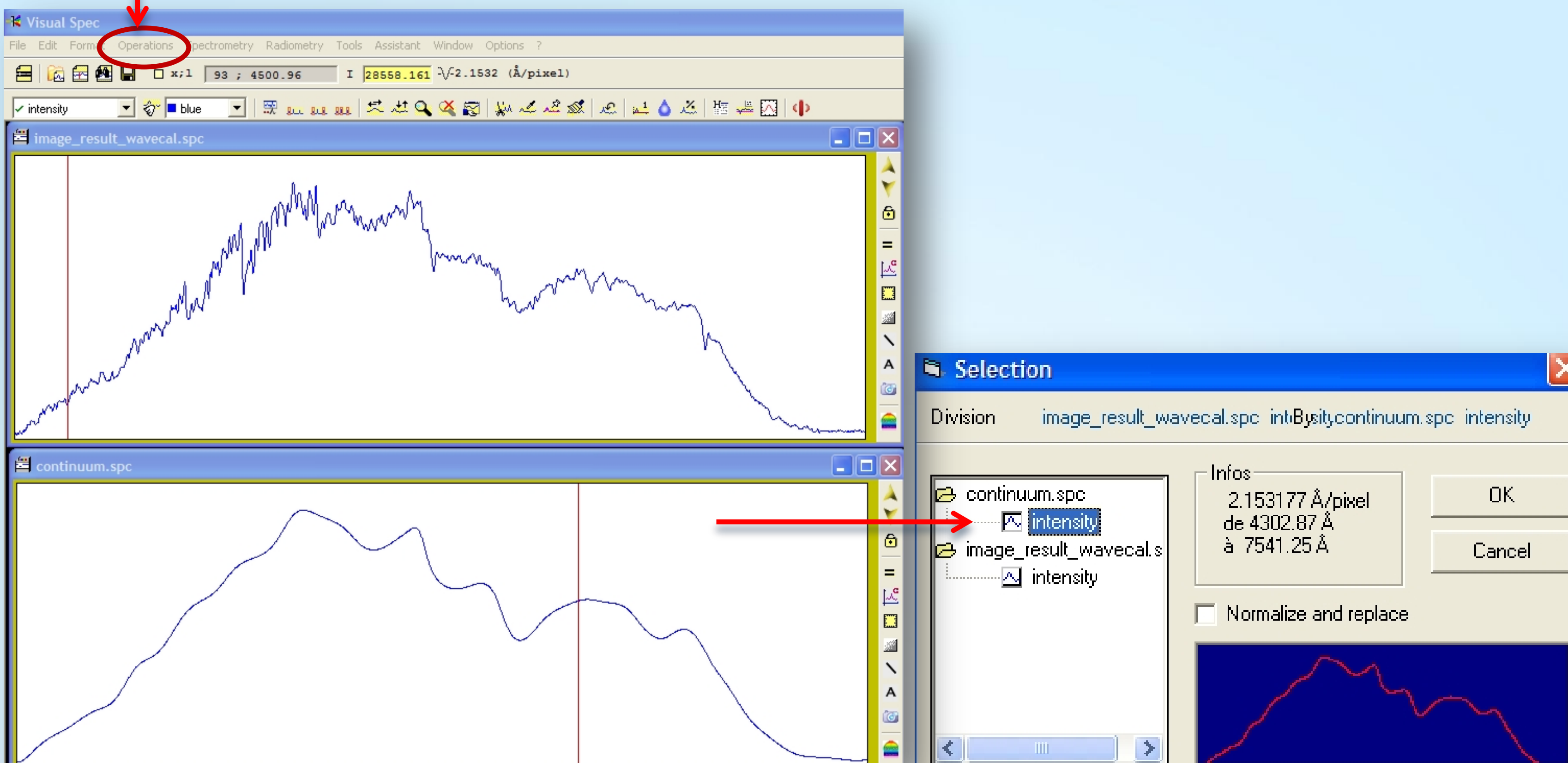
5.15 File → Open profile → Continuum.spc and "Result_image_wavecal.spc"
5.16 Highlight the window "Result_image_wavecal.spc"



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – Continuum division

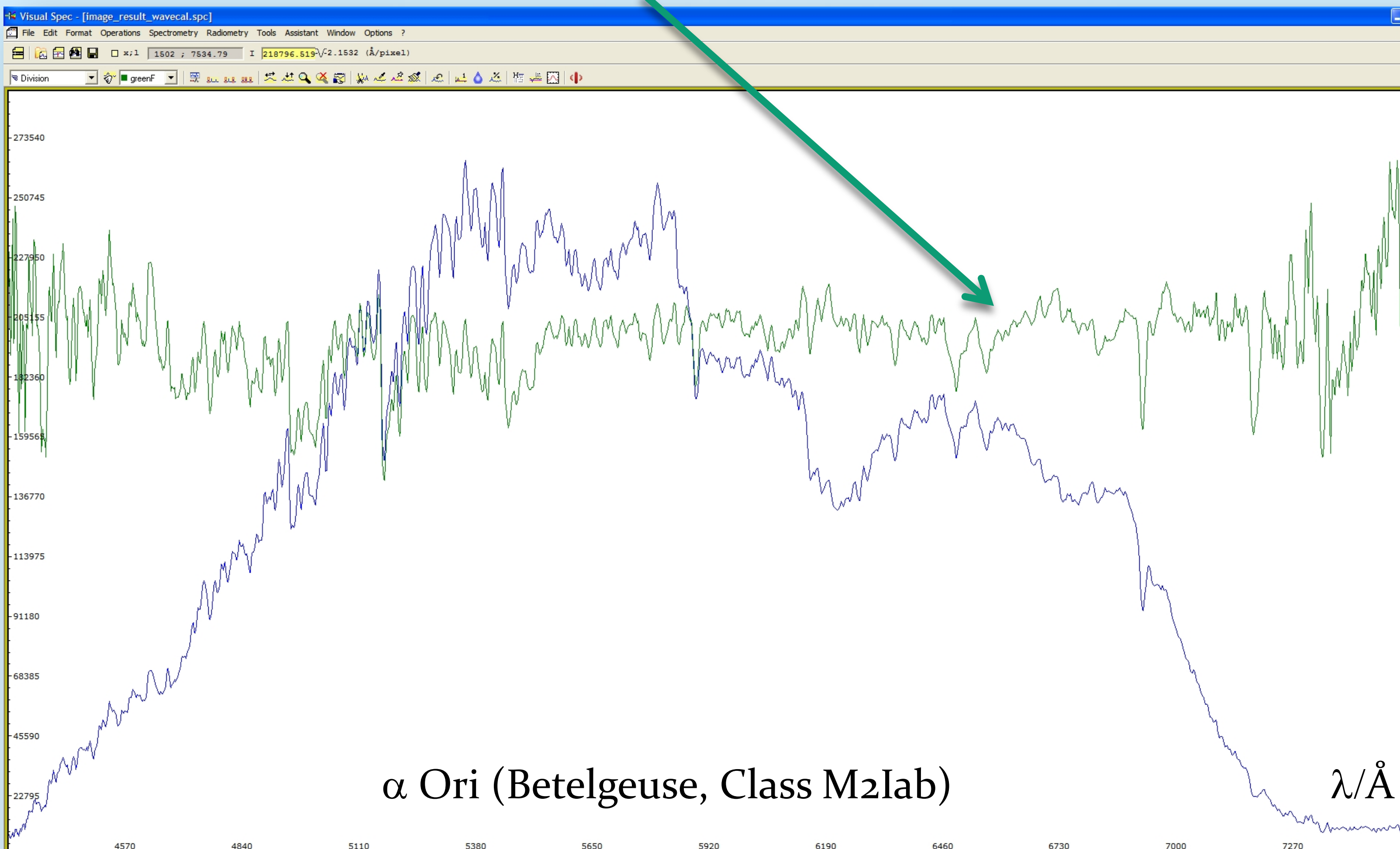
5.17 Operations → Divide profile by profile → Click on: continuum.spc → intensity



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – Continuum division

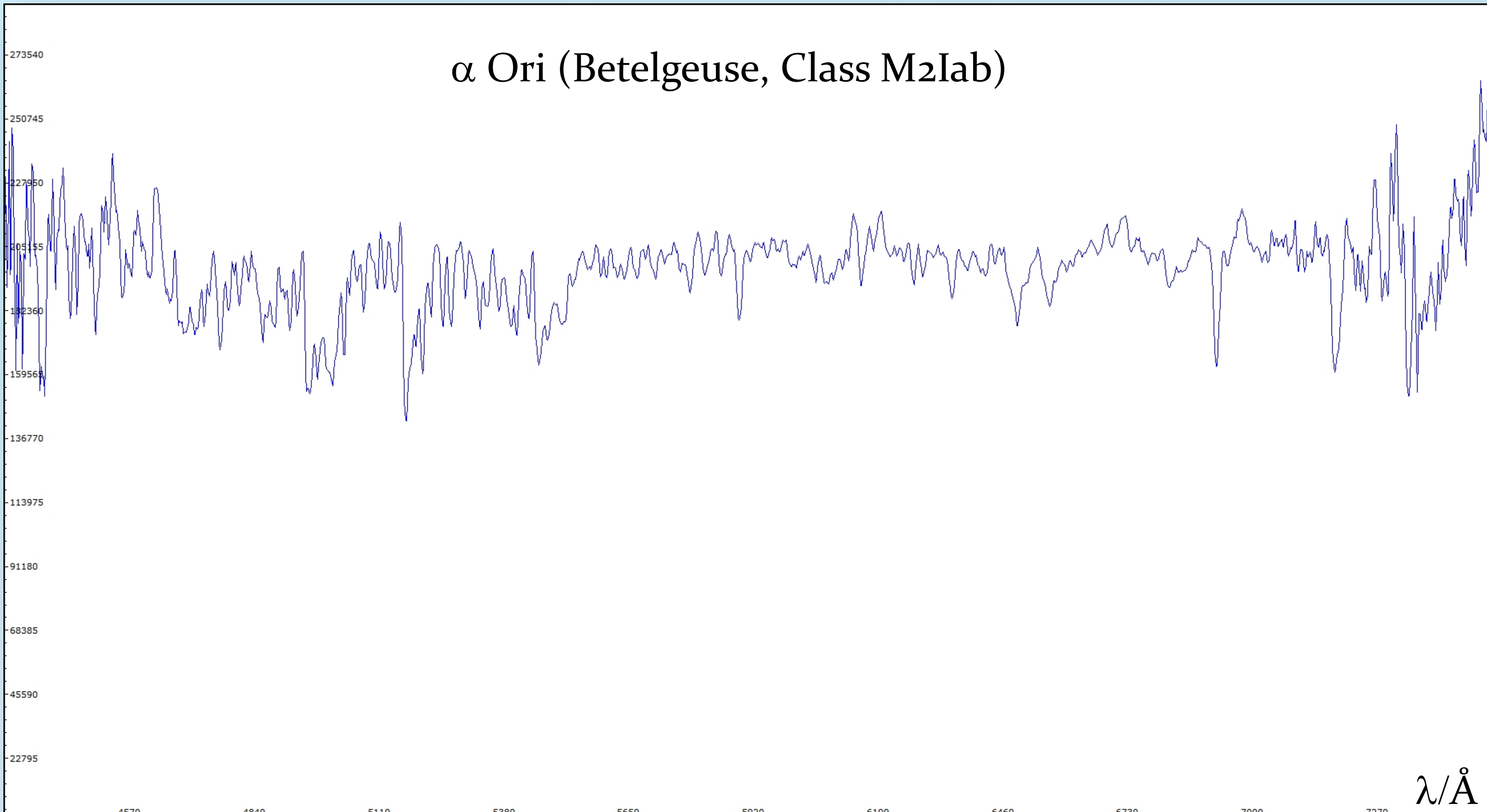
5.18 The “green profile“ is the result of division. Now, prepare to save the result:



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – The normalized profile of Betelgeuse

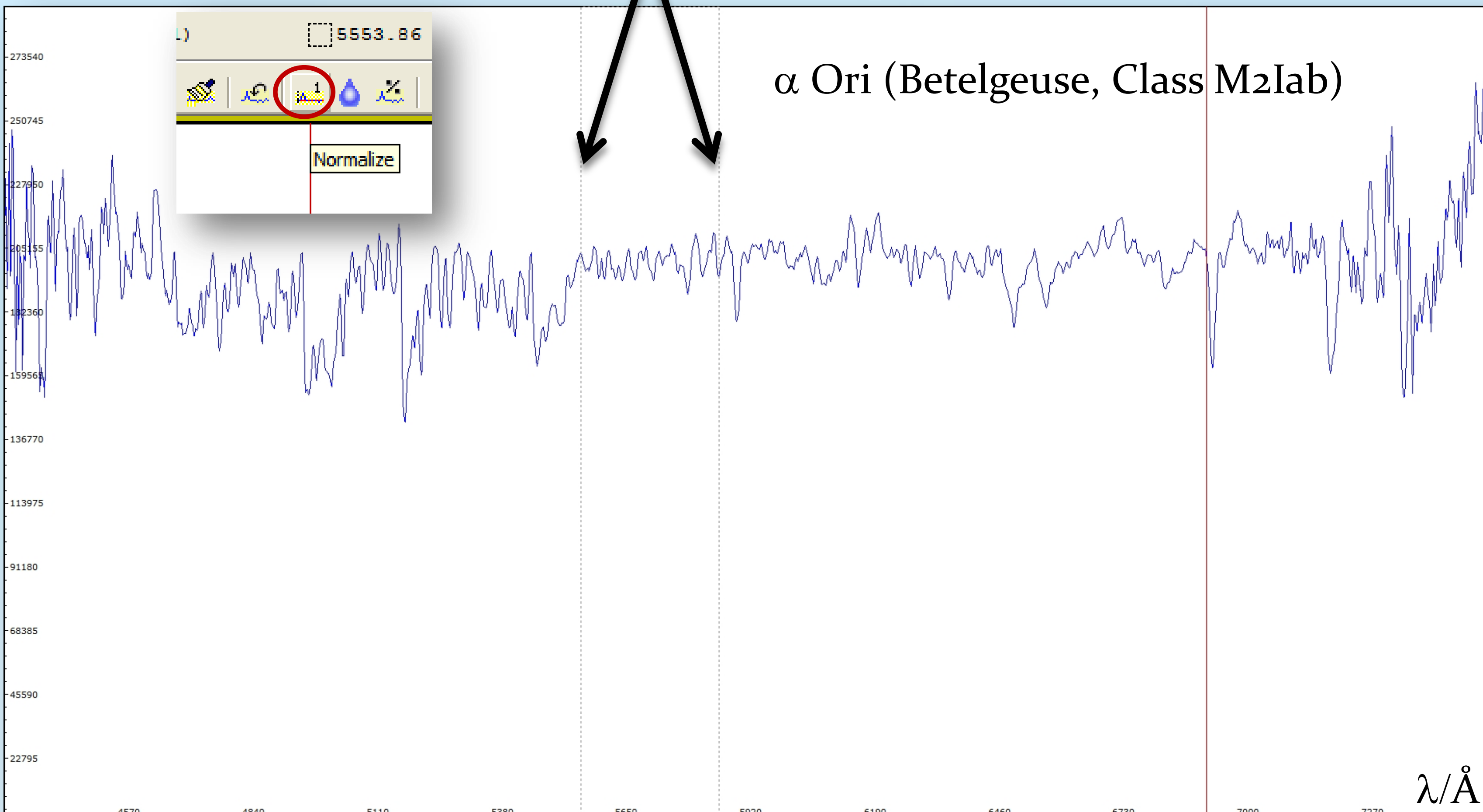
5.19 Edit → Replace → Intensity
5.20 Save as → "Result_image_wavecal_normalized.spc"



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – The normalized profile of Betelgeuse

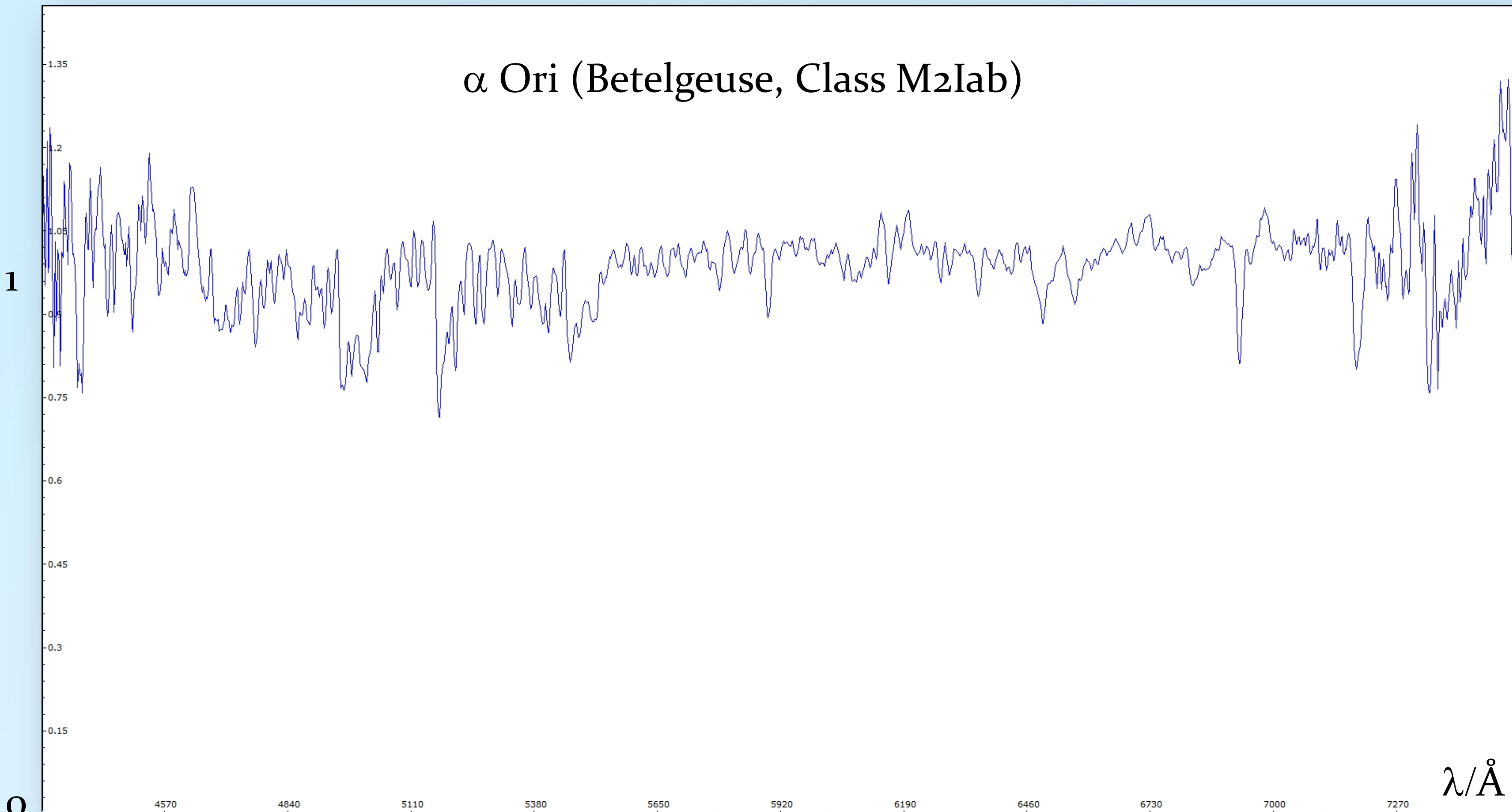
5.21 Indicate middle area with left mouse button to become “1“ in intensity
5.22 Press button “Normalize“



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec) – The normalized profile of Betelgeuse

5.23 Result: Wavelength calibrated and intensity normalized profile of Betelgeuse
5.24 Save as “Result_image_wavecal_normalized to 1.spc“



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 5: Visual Spec (VSpec): Calibration summary

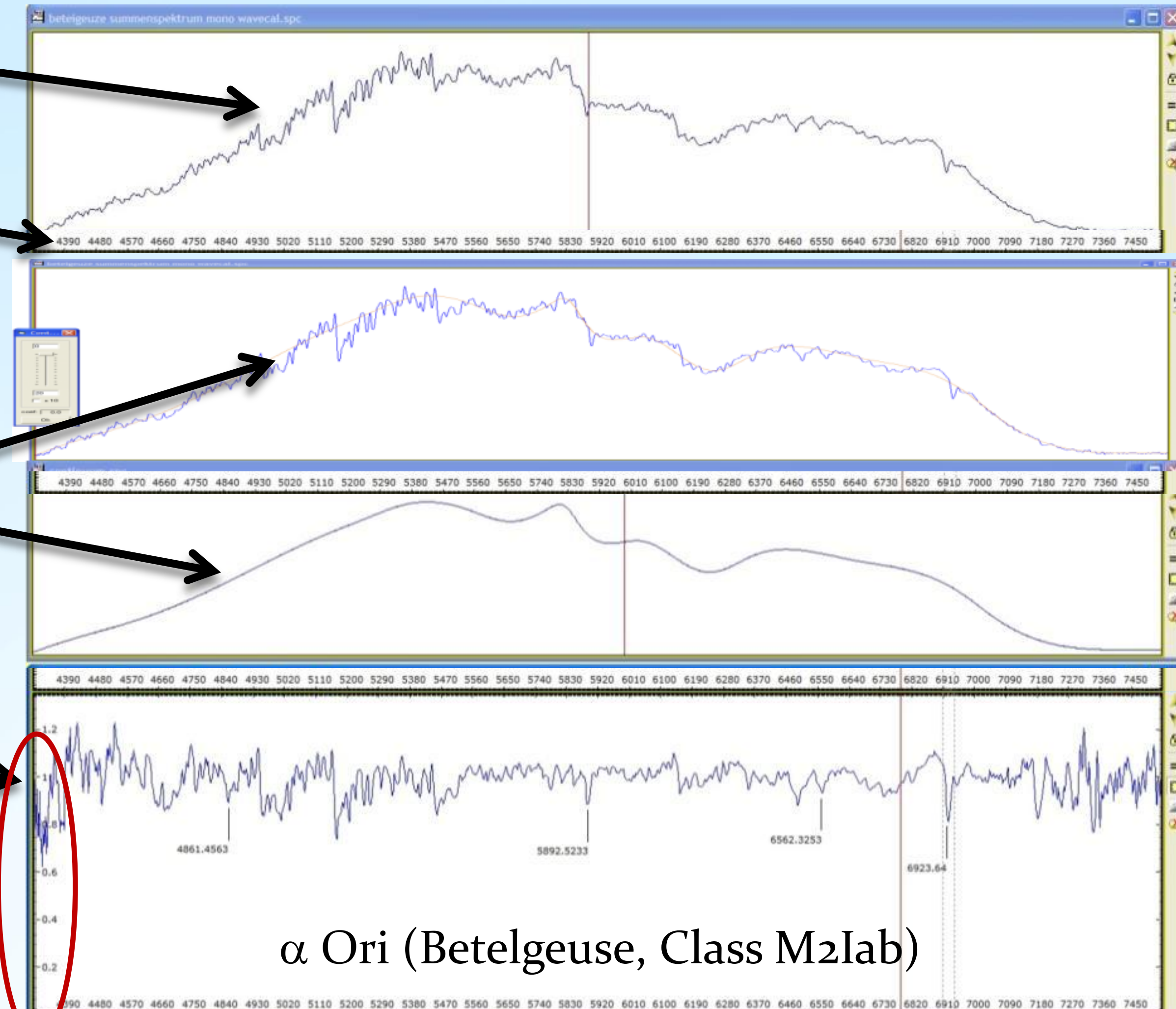
Raw profile

Wavelength calibrated

Pseudo continuum (to be divided)

Normalization to "1"

→ Final result, but not corrected for the instrumental profile

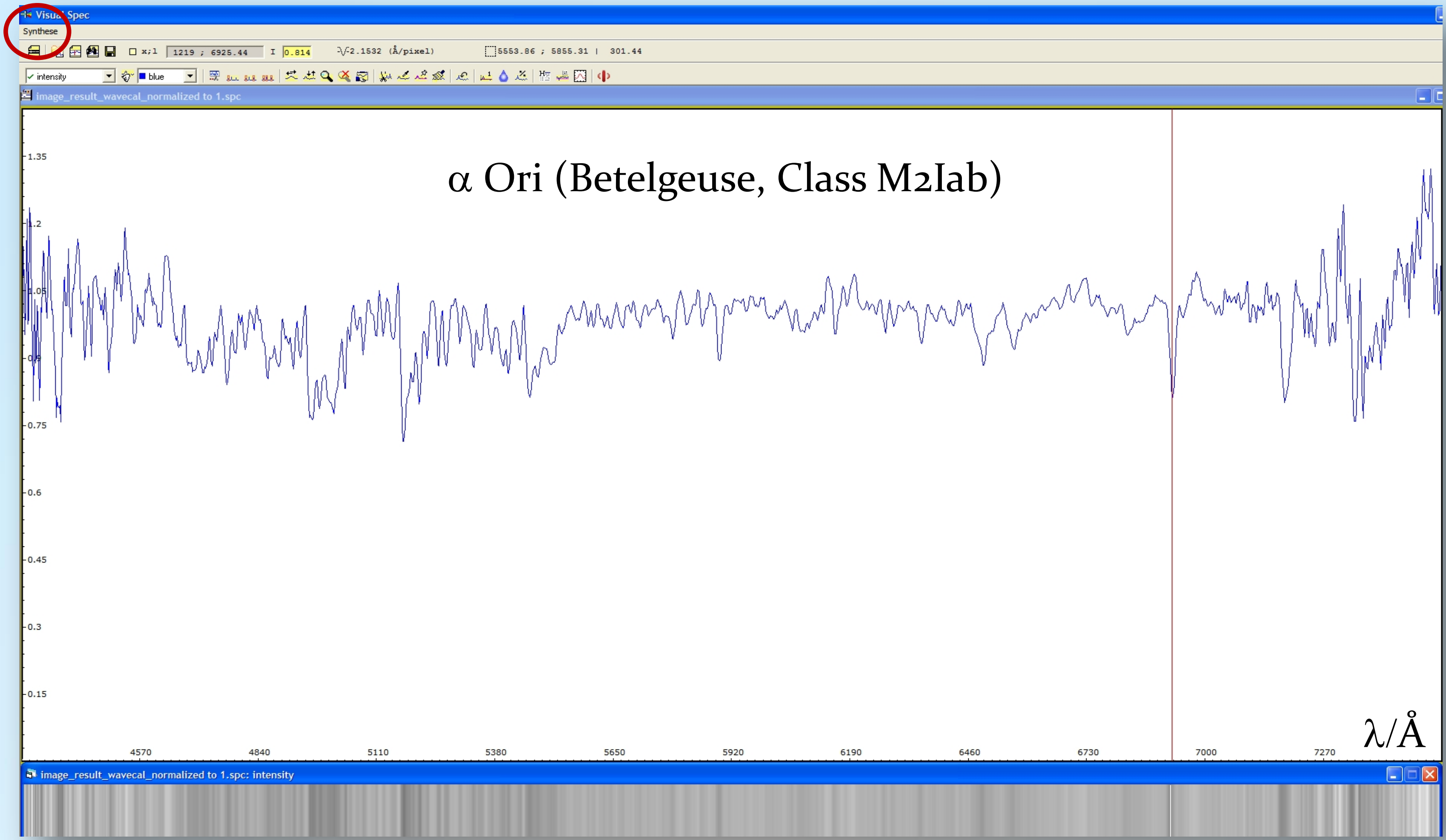


α Ori (Betelgeuse, Class M2Iab)

Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 6: Visual Spec (VSpec) - Visualize profile as synthetic profile

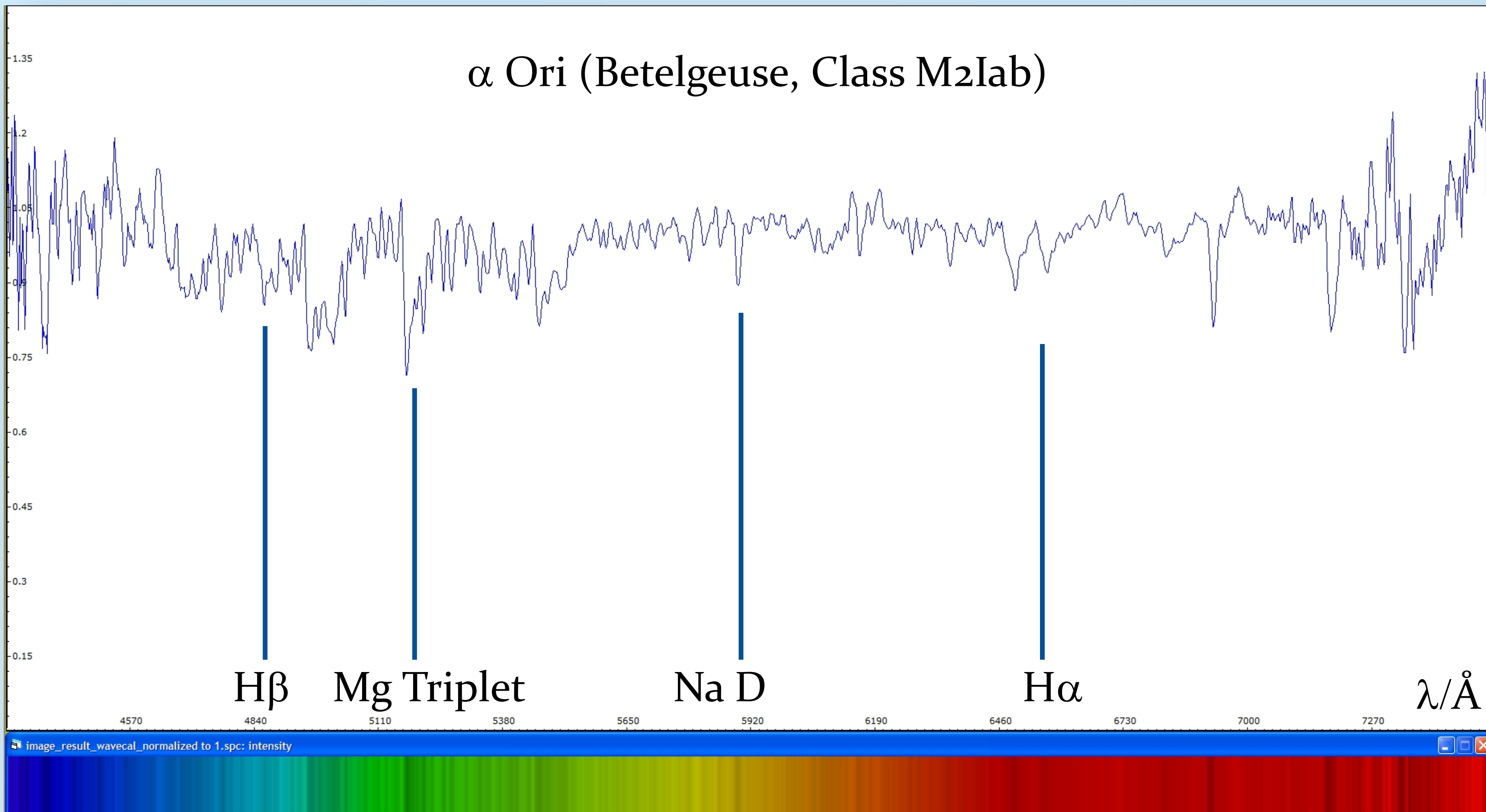
6.1 Tools → Synthese[sic]: Creates a synthetic black & white spectrum



Stacking/calibration of stellar spectra from a Canon DSLR camera

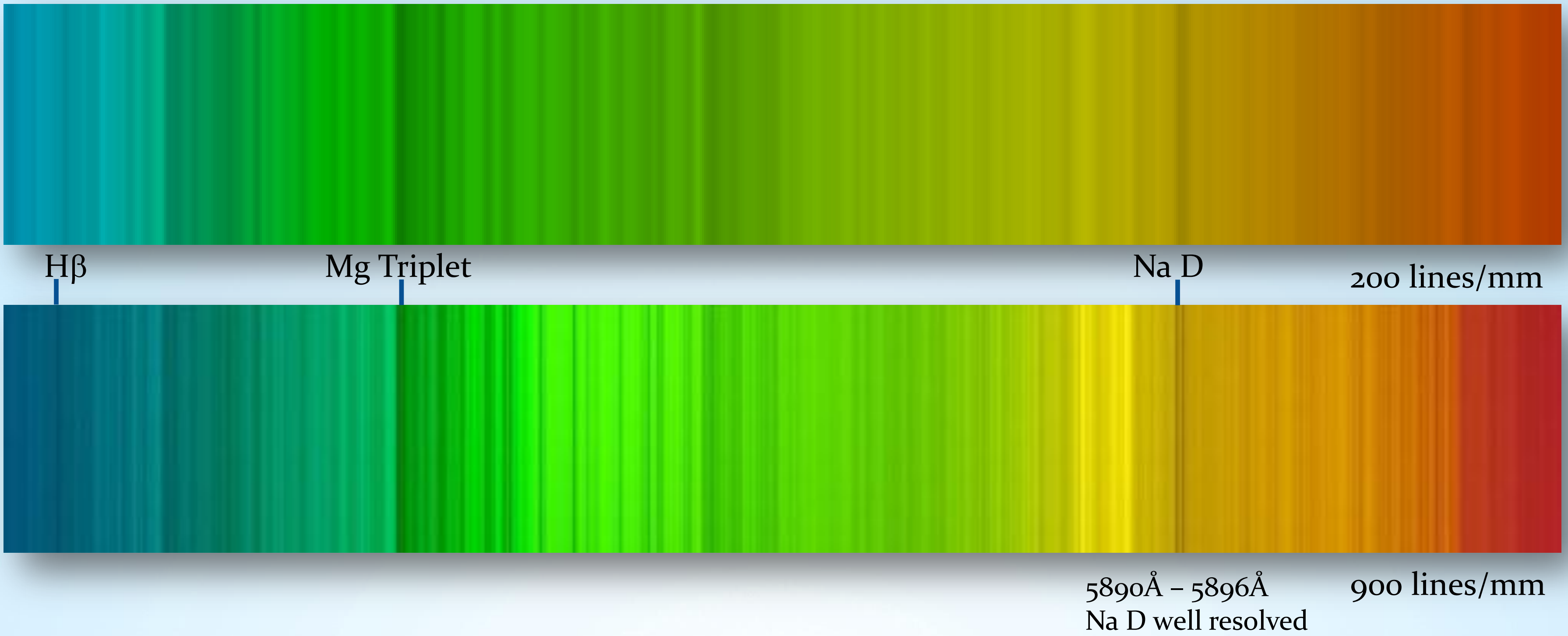
Step 6: Visual Spec (VSpec) - Visualize profile as synthetic profile

6.2 Synthese[sic] → Colorer[sic]: creates a colored synthetic spectrum



Stacking/calibration of stellar spectra from a Canon DSLR camera

Comparison of spectral resolution of Betelgeuse spectra: DADOS 200 lines/mm and 900 lines/mm

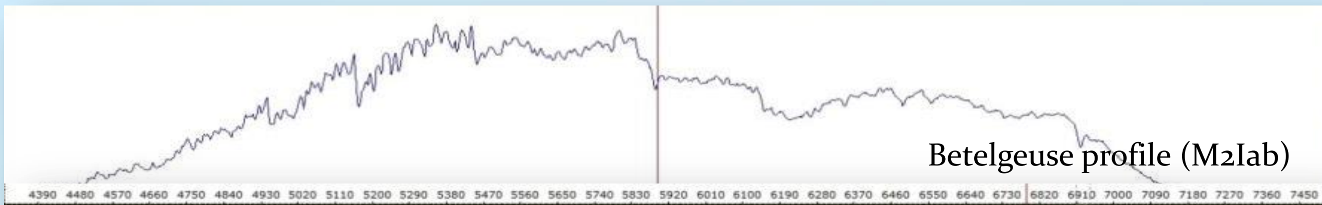


Stacking/calibration of stellar spectra from a Canon DSLR camera

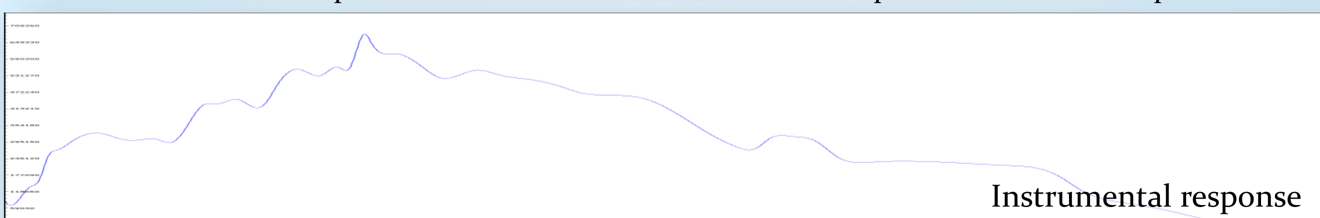
Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

Betelgeuse: Result_Image_mono_16bit

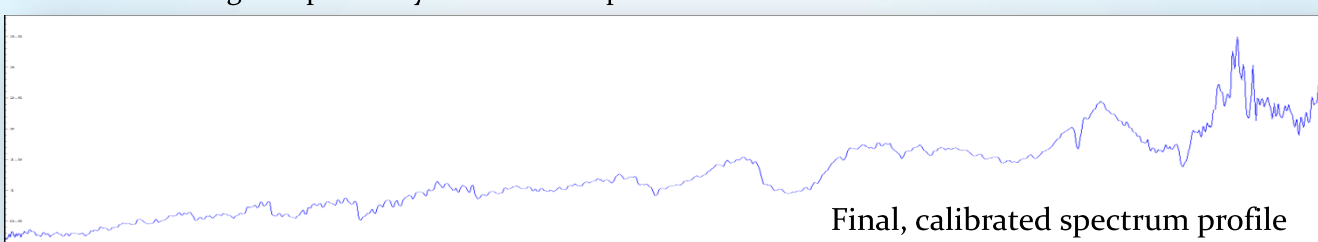
Create a spectrum profile → Identify spectral lines → Calibrate wavelength



Create the instrumental profile function via the use of a reference spectrum of the same spectral class



Divide the Betelgeuse profile by instrumental profile function



Stacking/calibration of stellar spectra from a Canon DSLR camera

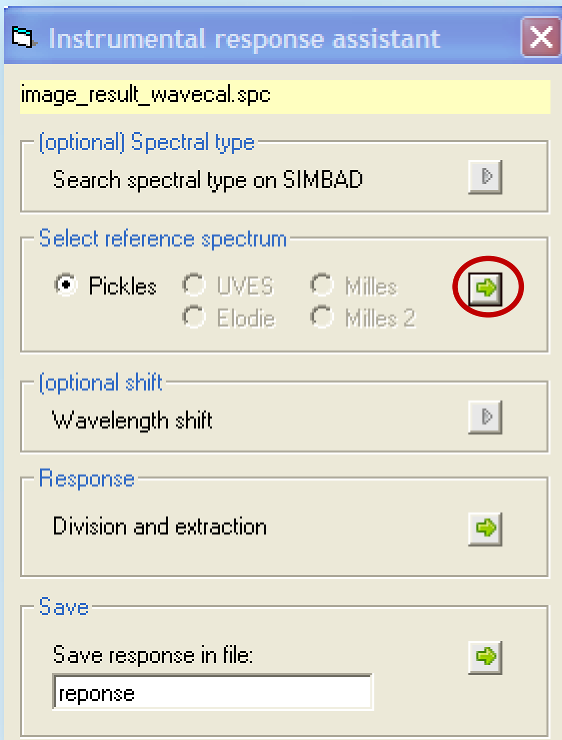
Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

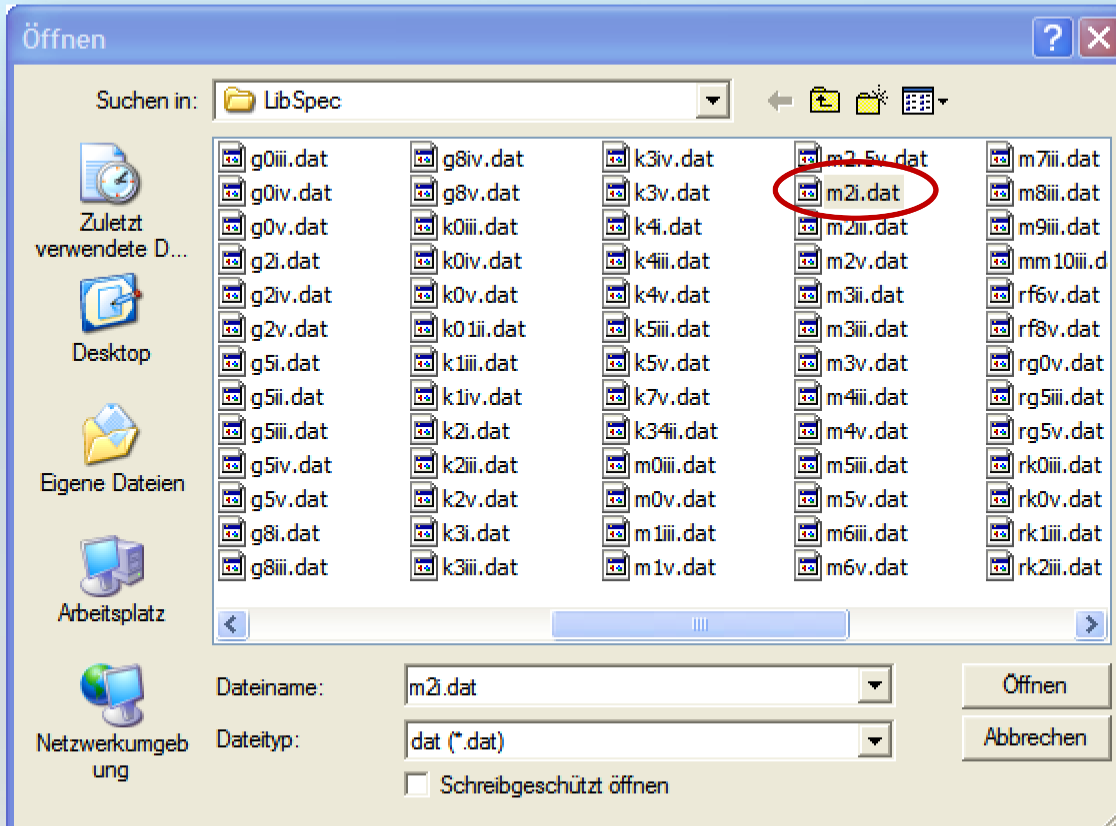
7.1 File → Open profile → “Result_image_wavecal.spc“

Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

7.2 Assistant → Instrumental response [sic] assistant
7.3 Pickles → Press on green arrow button → Open "m2i.dat" (= Class M2I)





Stacking/calibration of stellar spectra from a Canon DSLR camera

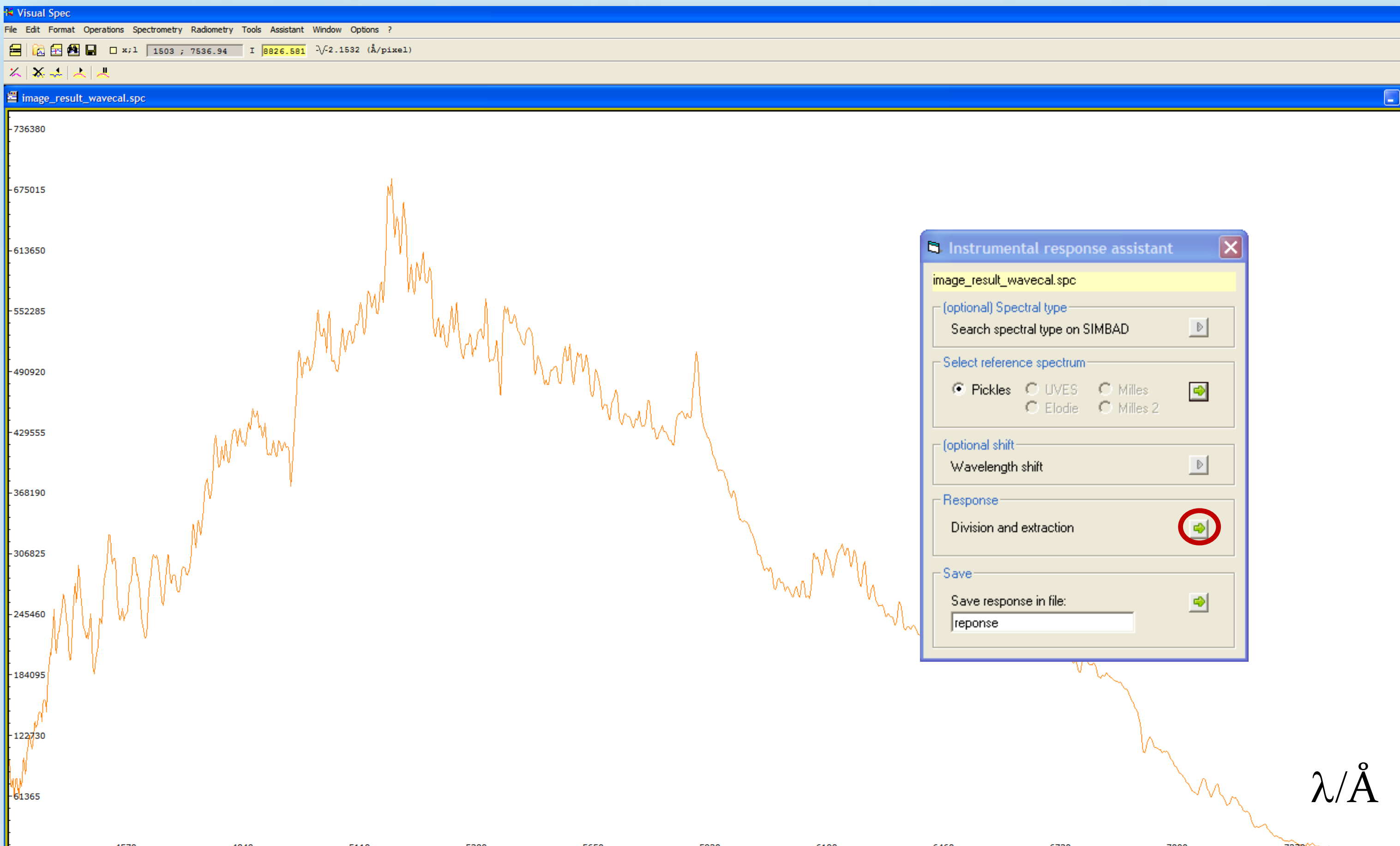
Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

The red profile is the reference spectrum of a star of similar spectral class

Stacking/calibration of stellar spectra from a Canon DSLR camera

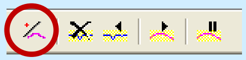
Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

7.4 Press green arrow button “Division and extraction“
Result: The orange profile is the (unsmoothed) instrumental profile



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

7.5 Smooth the instrumental profile. Press button “point/curve“  and set about 60 “green crosses“ along the continuum

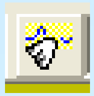
Stacking/calibration of stellar spectra from a Canon DSLR camera

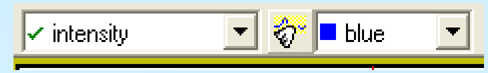
Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

7.6 Press button “OK“ and press “execute“

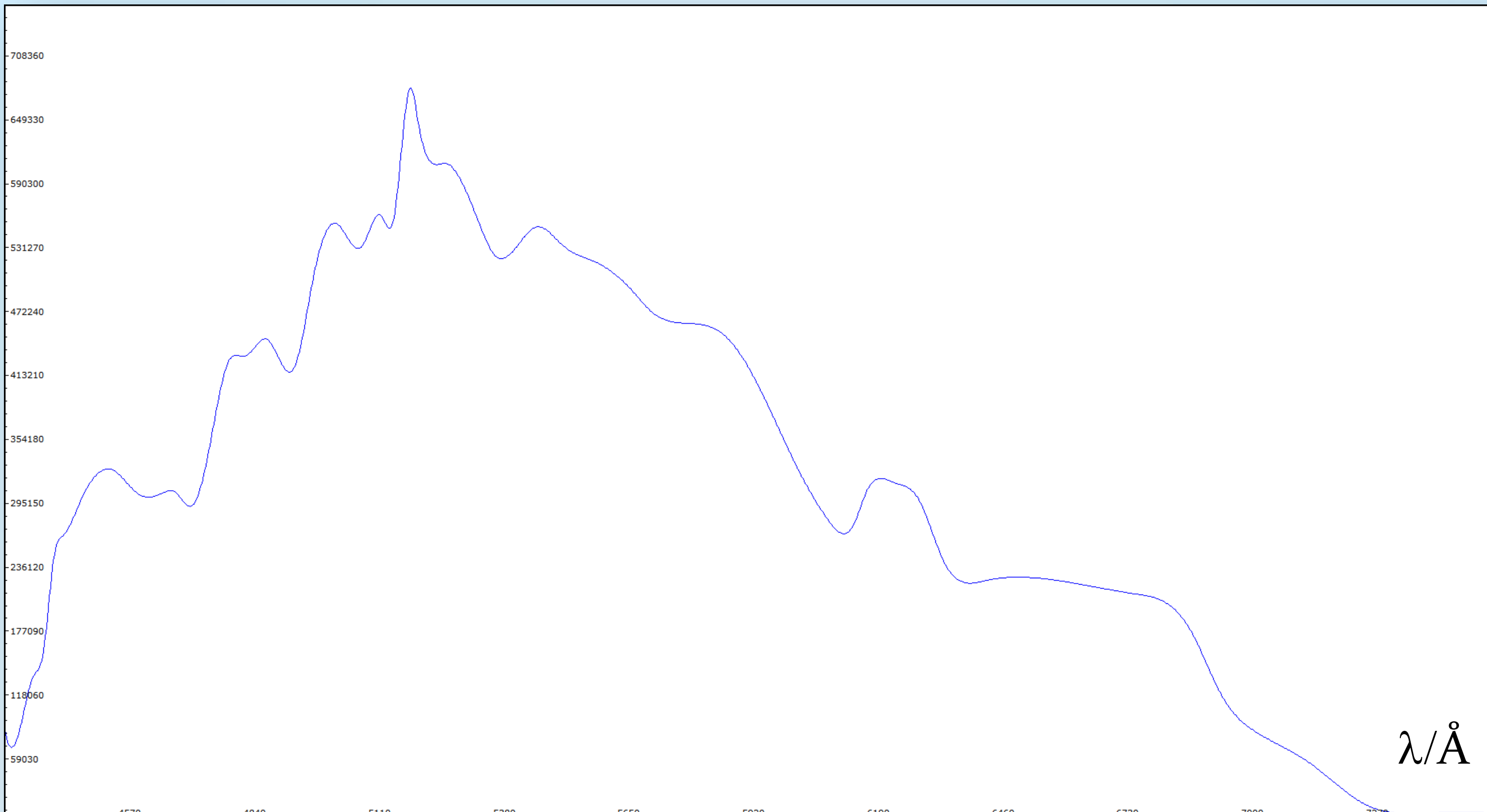
Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

7.7 Erase graphic  → Edit → Replace: Intensity



7.8 File → Save as → "response.spc"



Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

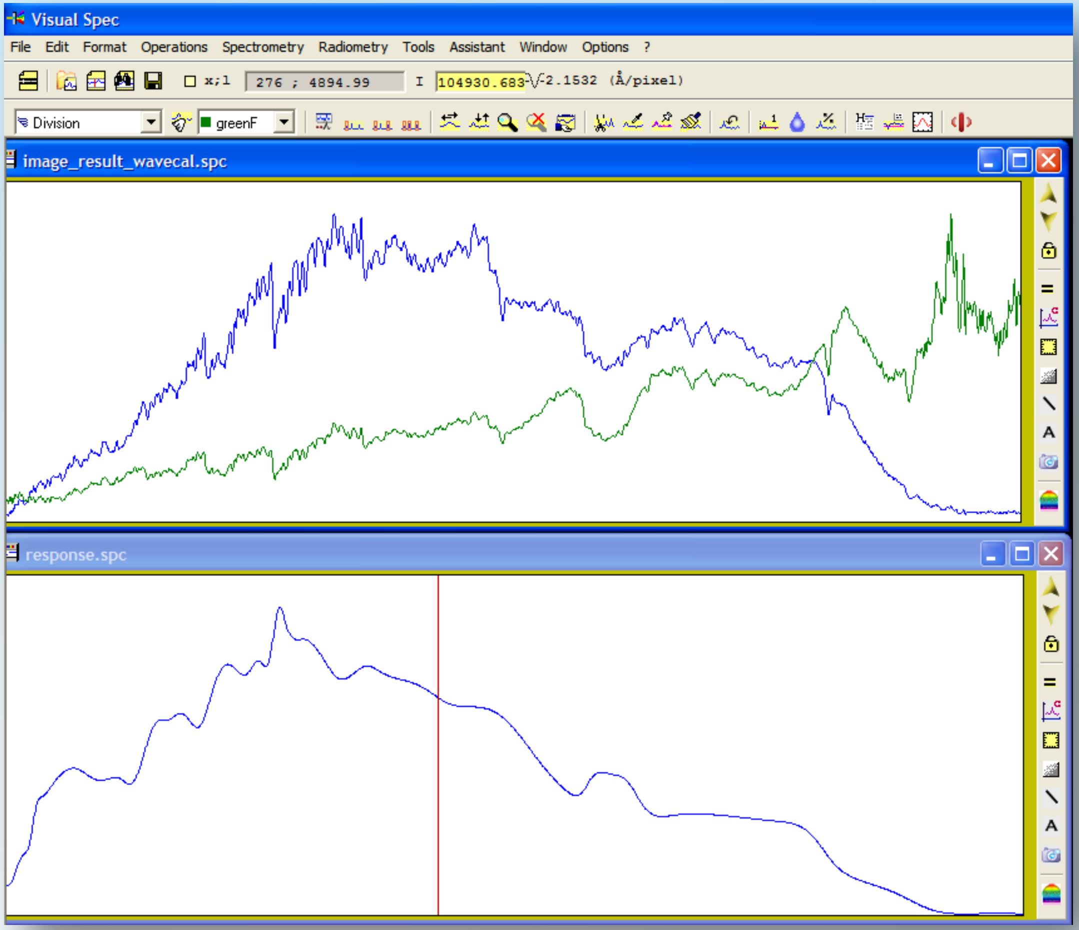
7.9 While "response.spc" is still open:
File → open profile → "Result_image_wavecal.spc" (please highlight)
7.10 Operations → Divide profile by profile: Select "intensity" (below response.spc)

Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

Result: The green profile is the calibrated, true spectrum profile of Betelgeuse, corrected for instrumental profile

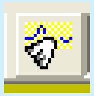
7.11 Close "response.spc"



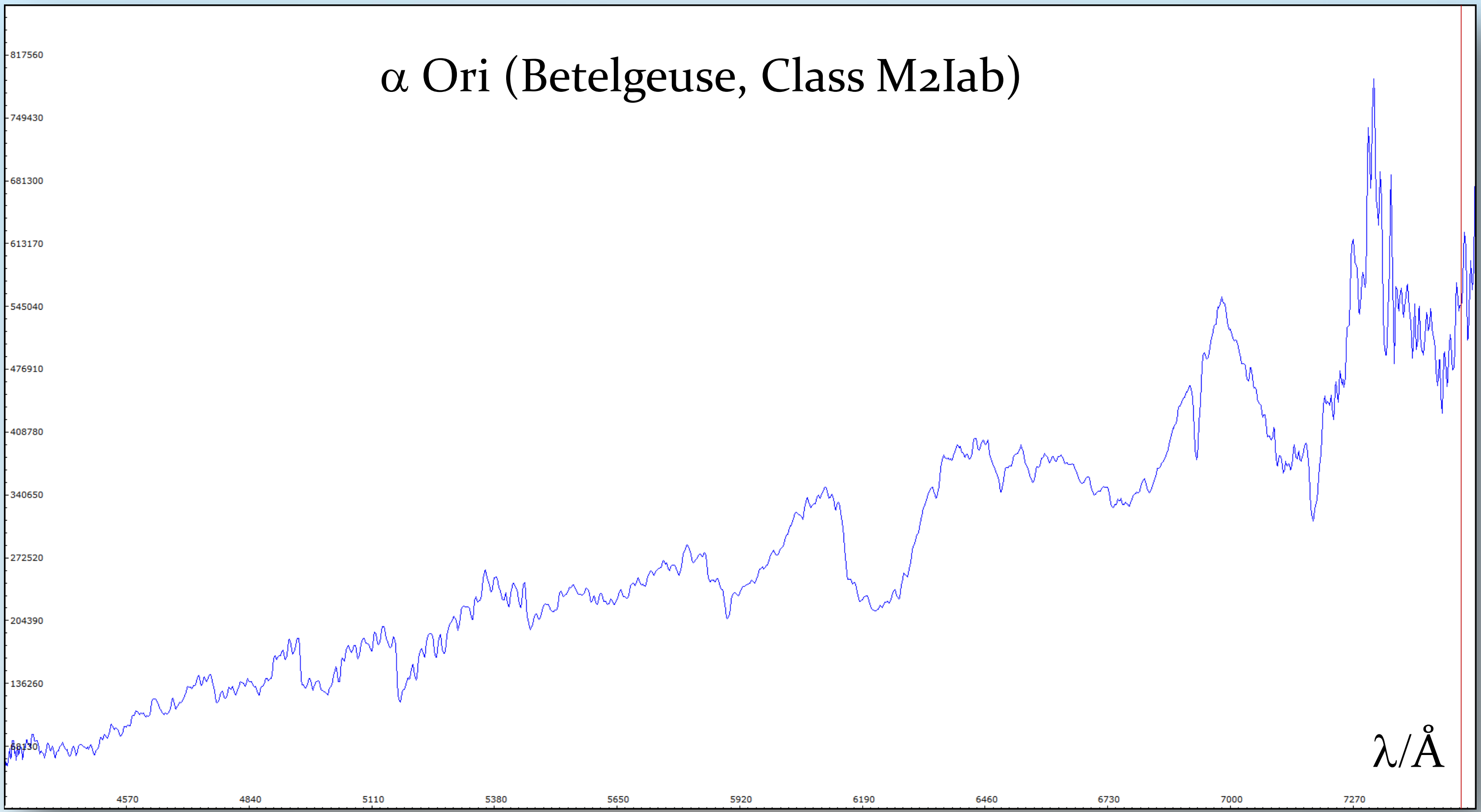
Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

The green profile must be converted to a blue profile, before it can be saved

7.12 Erase graphic  → Edit → Replace: Intensity

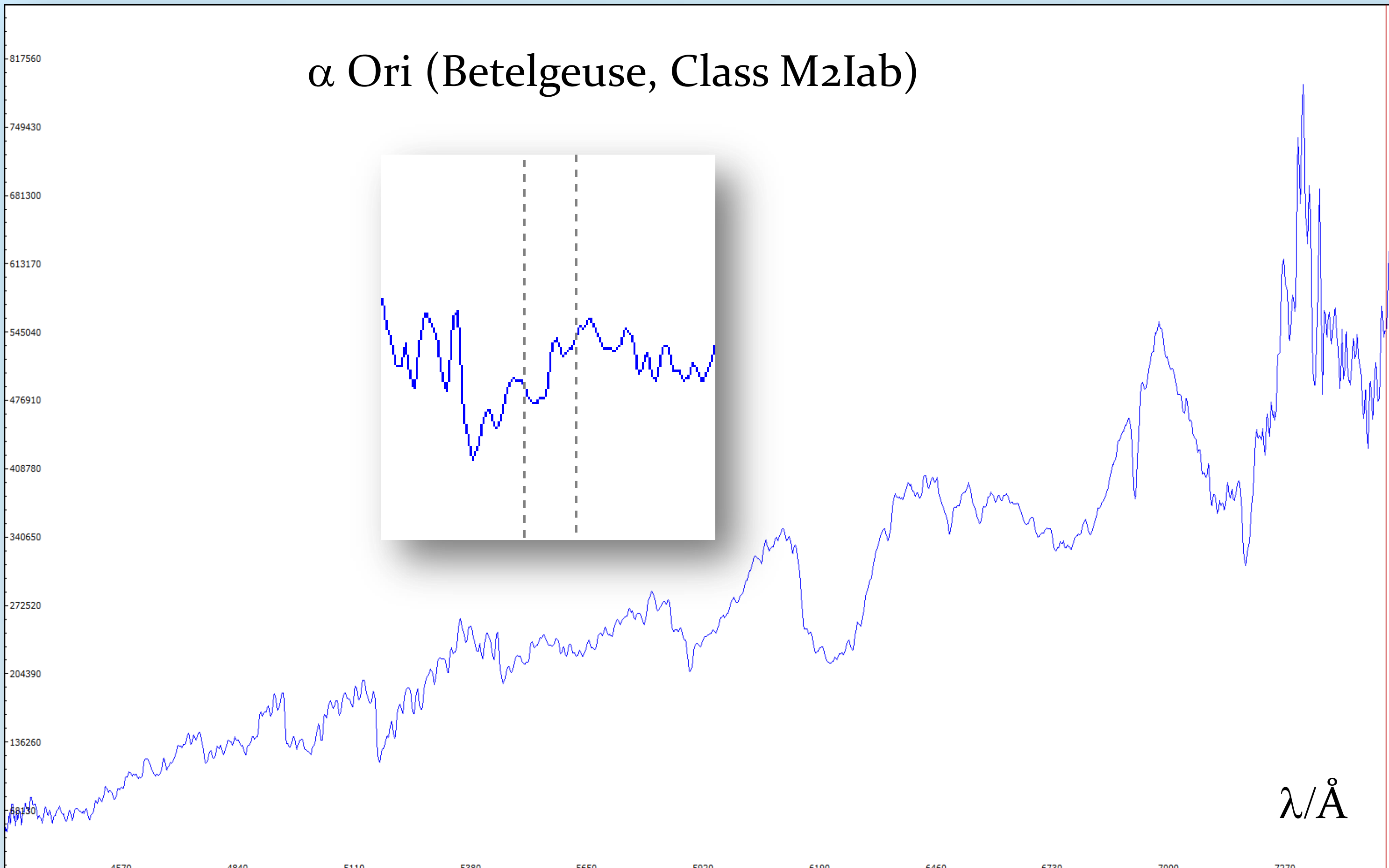
7.13 File → Save as → "Betelgeuse_final_spectrum.spc"



Stacking/calibration of stellar spectra from a Canon DSLR camera

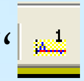
Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

7.14 Use left mouse button and select area around 5500Å

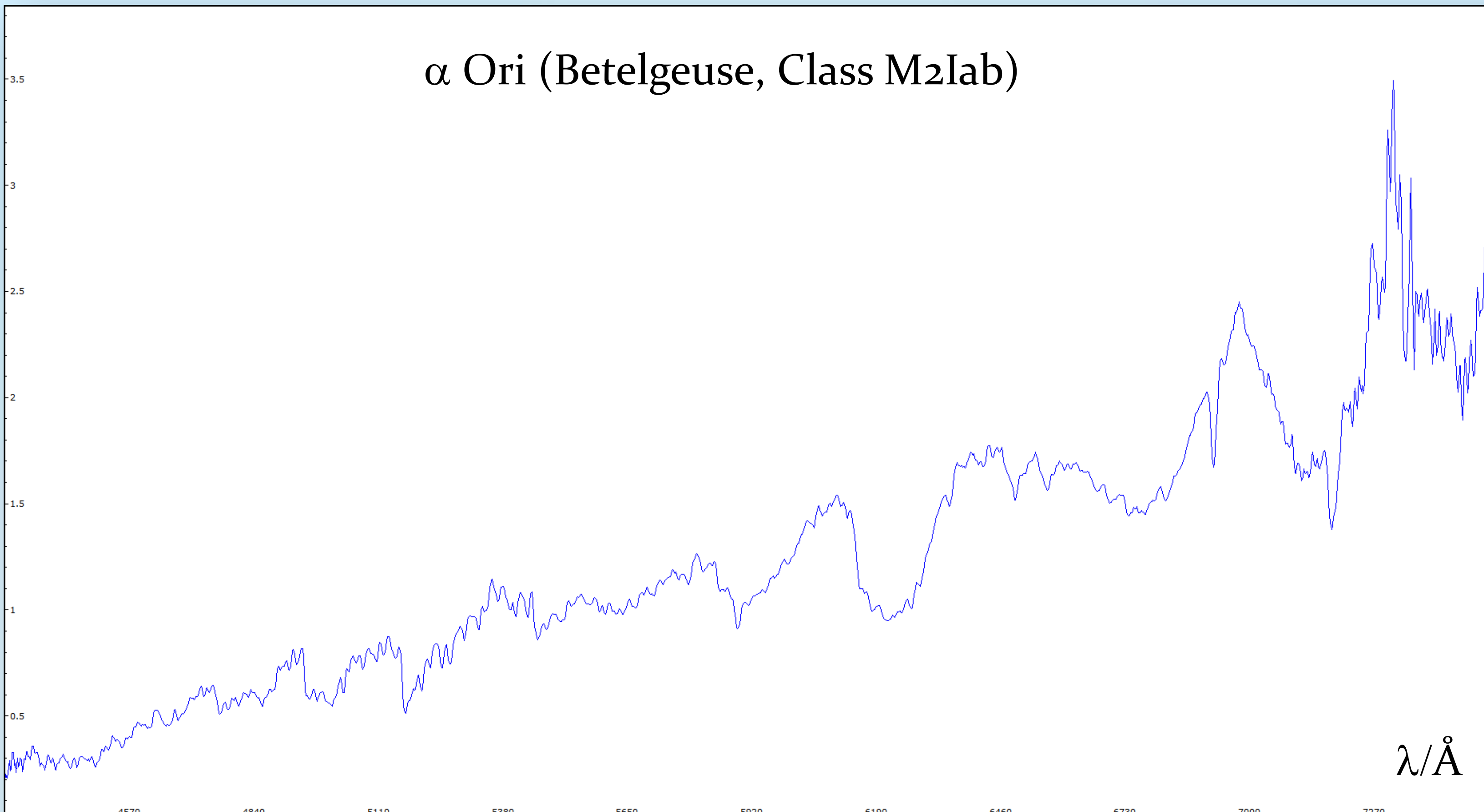


Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 7: Visual Spec (VSpec) – Spectrum calibration by removing the instrumental profile

7.15 Normalize to 1: Press button "1" 

7.16 File → Save as → "Betelgeuse_final_spectrum.spc"



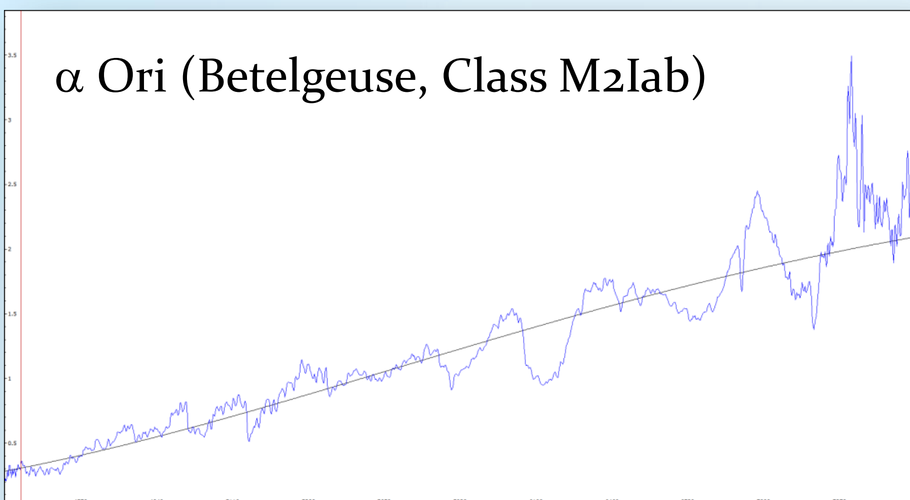
Stacking/calibration of stellar spectra from a Canon DSLR camera

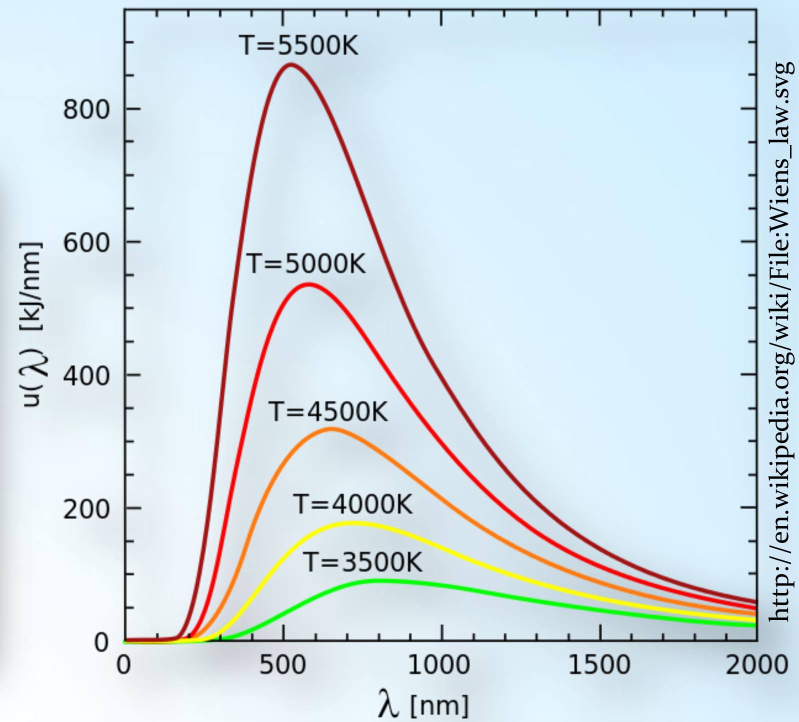
Step 7: Visual Spec (VSpec) – Using the spectrum to estimate temperature

7.17 Calculation of the effective temperature of Betelgeuse from its spectrum
We assume thermal radiation of a black body according to Planck‘s Law.

Radiometry → Auto Planck (black line)

A Planck spectrum with T_{eff}=3000K (best fit) is fitted by VSpec: →





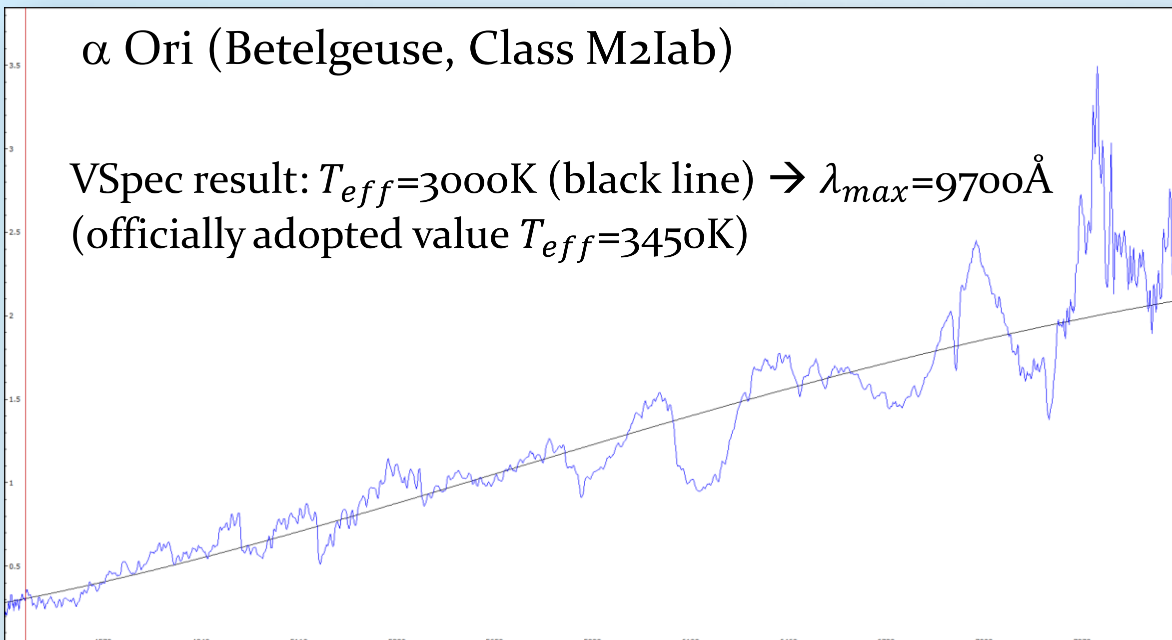
Stacking/calibration of stellar spectra from a Canon DSLR camera

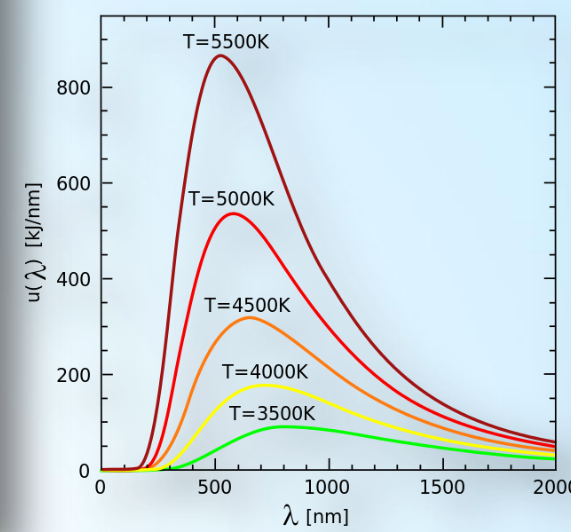
Step 7: Visual Spec (VSpec) – Using the spectrum to estimate temperature

7.18 Wien's law

$$\lambda_{max} \approx \frac{29000 \cdot 10^3 \text{Å} \cdot K}{T_{eff}}$$

λ_{max} : Wavelength of the maximum of the assumed black body emission
T_{eff} : Effective Temperature [K]

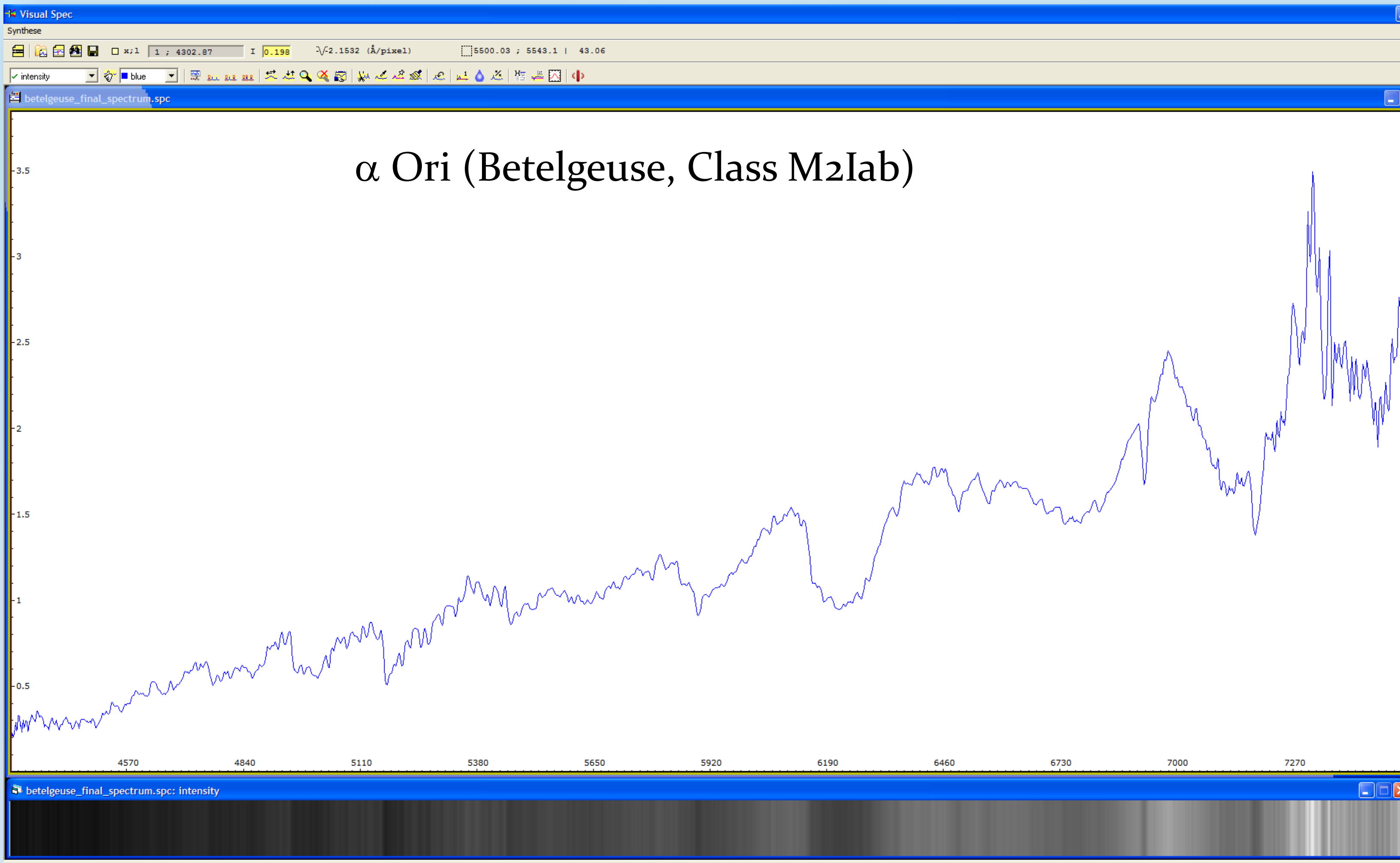




Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 8: Visual Spec (VSpec) - Visualize profile as synthetic profile

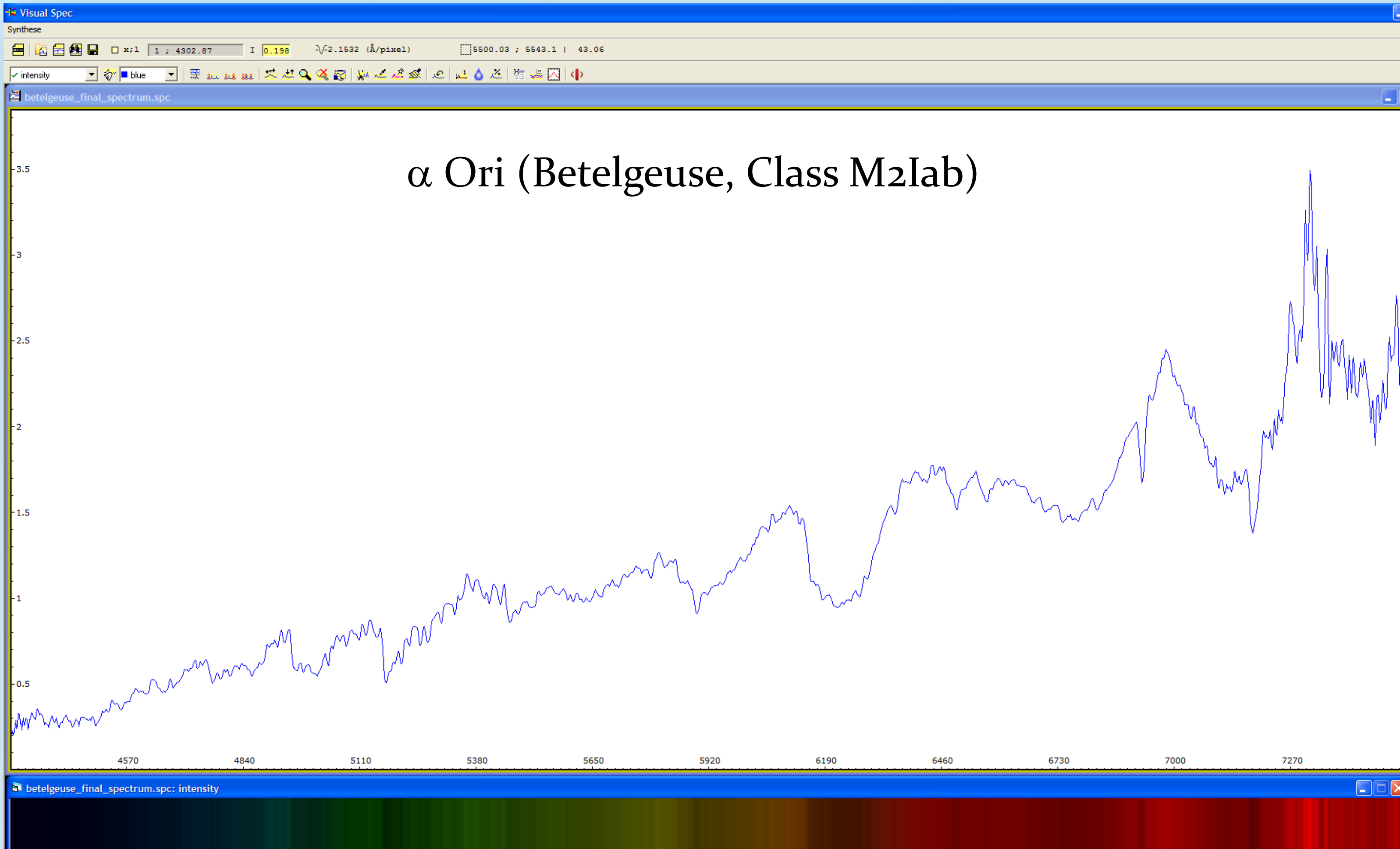
8.1 Synthese [sic] → Creates a synthetic black & white spectrum



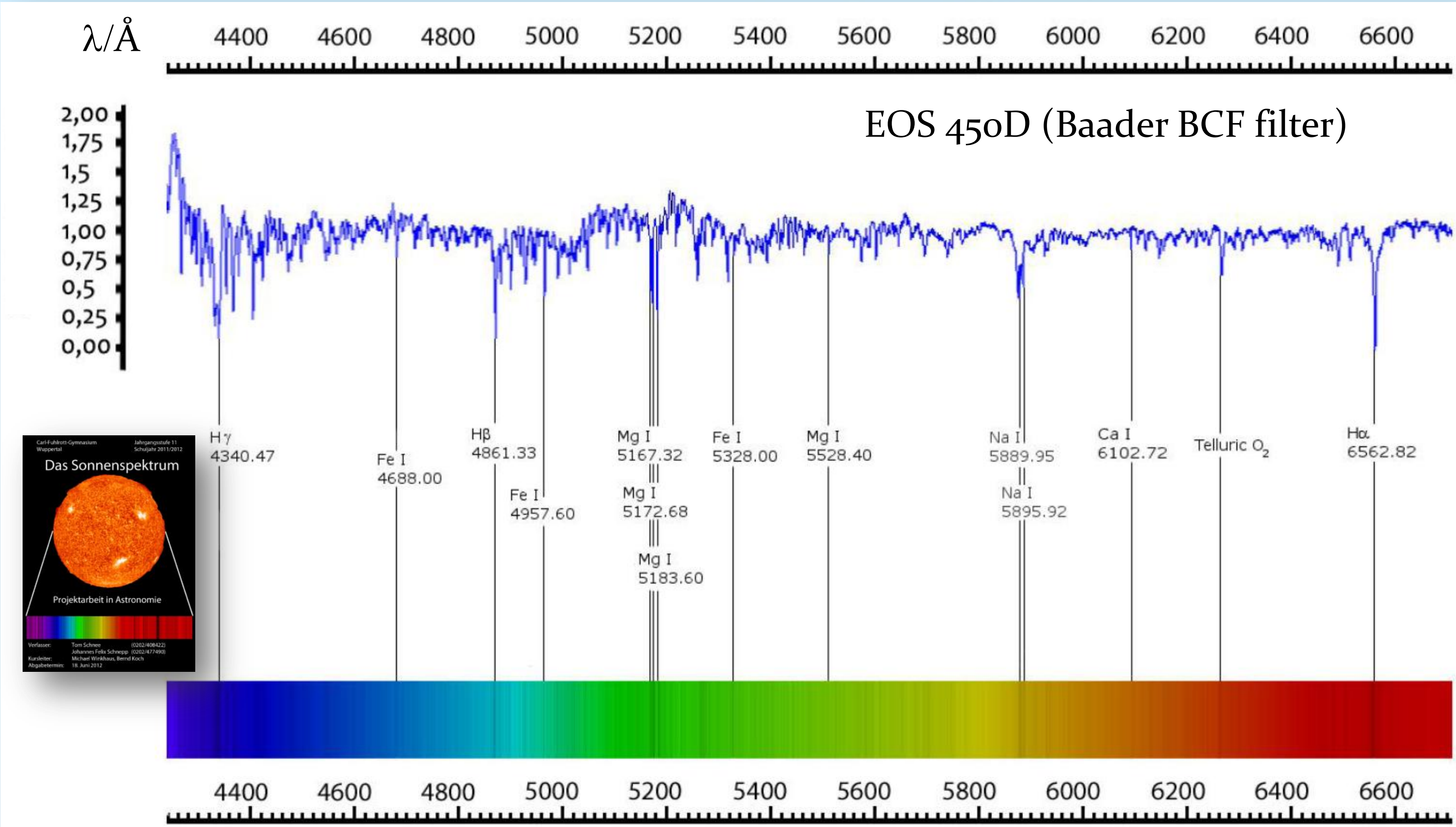
Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 8: Visual Spec (VSpec) - Visualize profile as synthetic profile

8.2 Synthese [sic] → Colorer [sic] → Creates a synthetic color spectrum for presentation

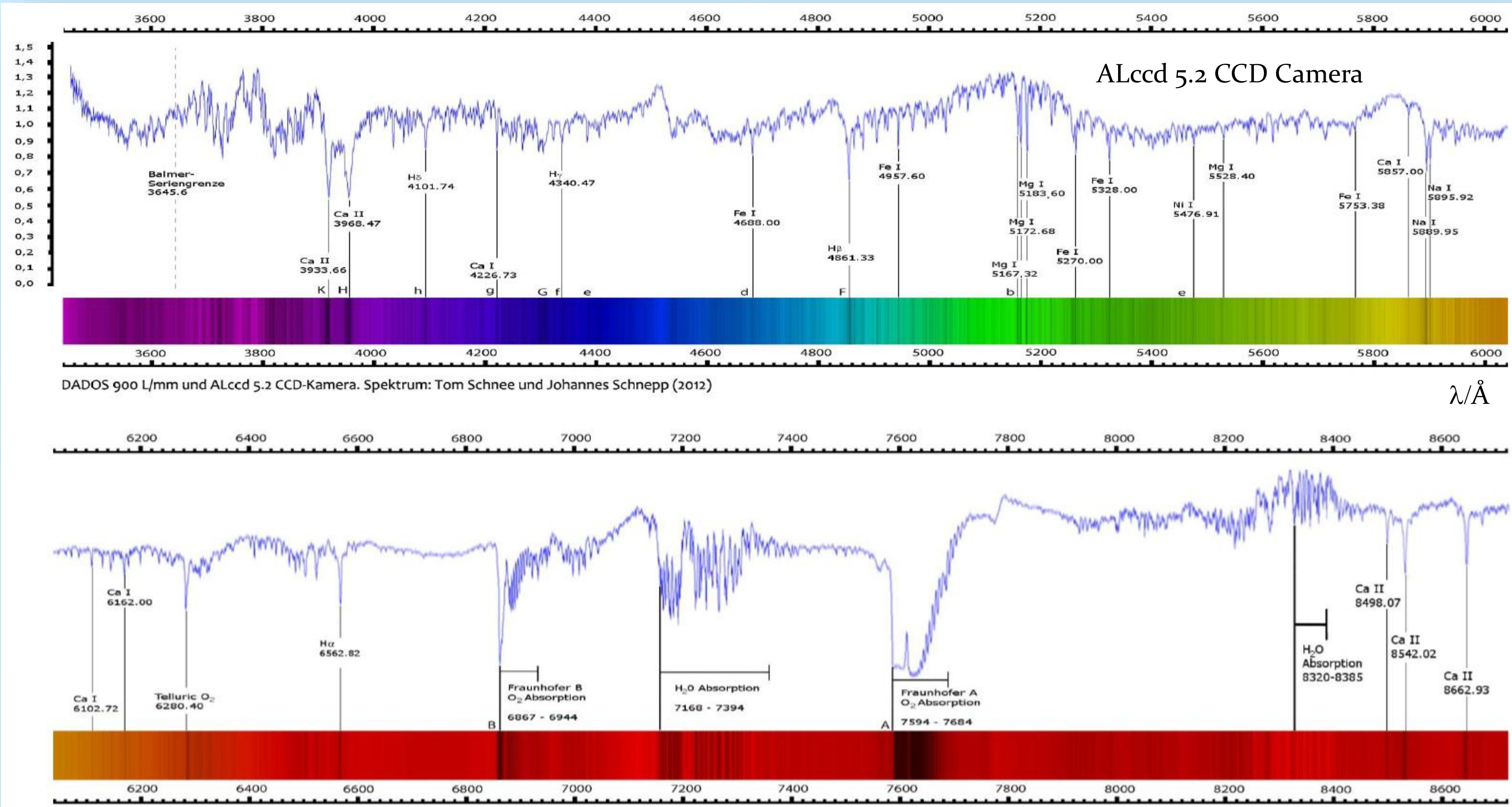


The solar spectrum



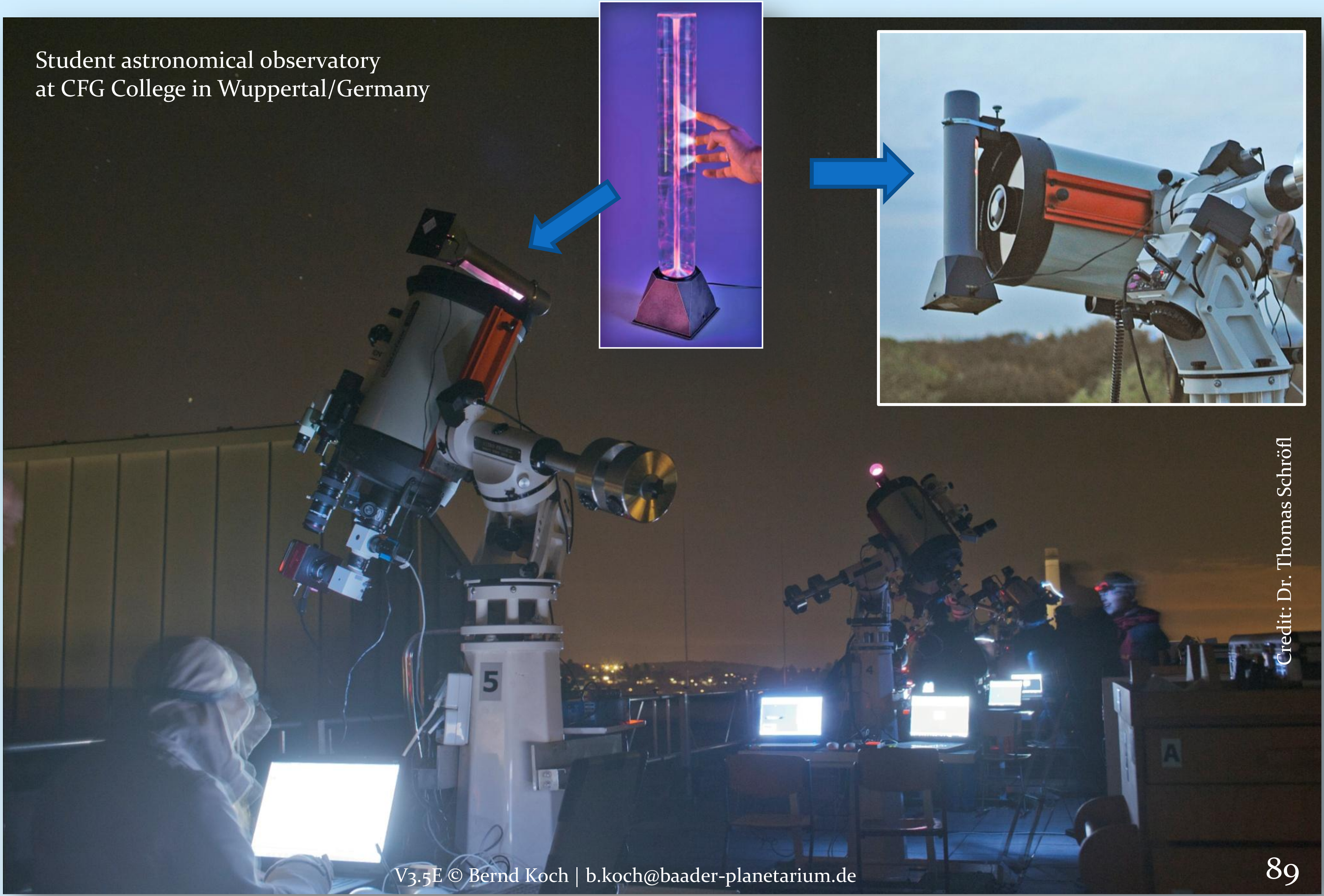
DADOS 900 lines/mm and DSLR camera Canon EOS 450Da (BCF). Paper by Tom Schnee and Johannes Schnepp (CFG Wuppertal, 2012)

The solar spectrum



DADOS 900 lines/mm and ALccd 5.2 CCD camera. Paper by students Tom Schnee and Johannes Schnepp (CFG Wuppertal, 2012)

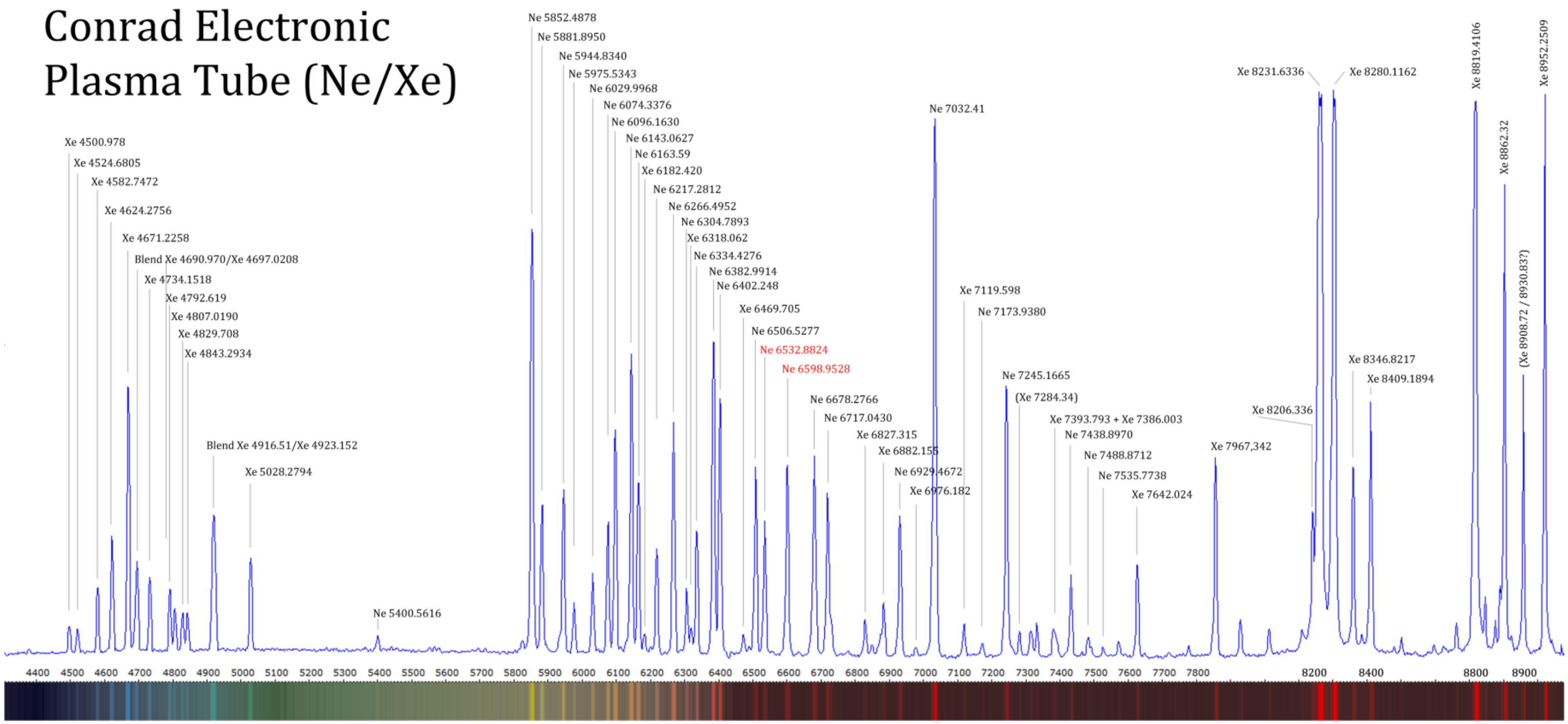
Calibration of spectra with a Ne/Xe plasma tube from Conrad Electronic



Student astronomical observatory
at CFG College in Wuppertal/Germany

Credit: Dr. Thomas Schröfl

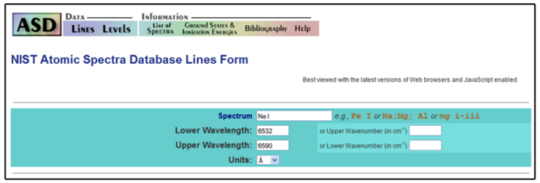
Calibration of spectra with a Ne/Xe plasma tube from Conrad Electronic

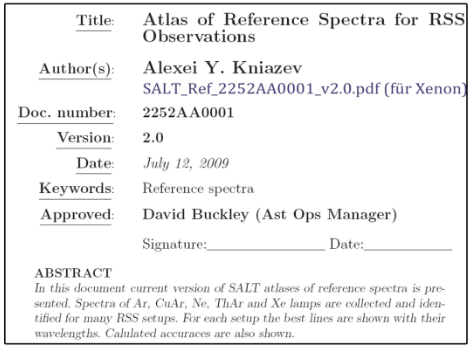


Spectrograph: Baader Planetarium DADOS 200 L/mm and CCD Camera SBIG ST-8300M. Dispersion: appr. 2Å/px. Identification of spectral lines & Calibration of Xenon Spectrum 4500Å - 5028Å: [Kniazev, 2009]

Ne/Xe-Plasma Tube: www.conrad.de/ce/de/product/591136/Magic-Plasma-Roehre-Lichteffekt? queryFromSuggest=true.

Note: Blended spectral lines can be resolved with a high-res grating and then also be used for calibration. The wavelengths of observed lines of groud state Xenon (Xe I) and Neon (Ne I) have been obtained from NIST Database http://physics.nist.gov/PhysRefData/ASD/lines_form.html).

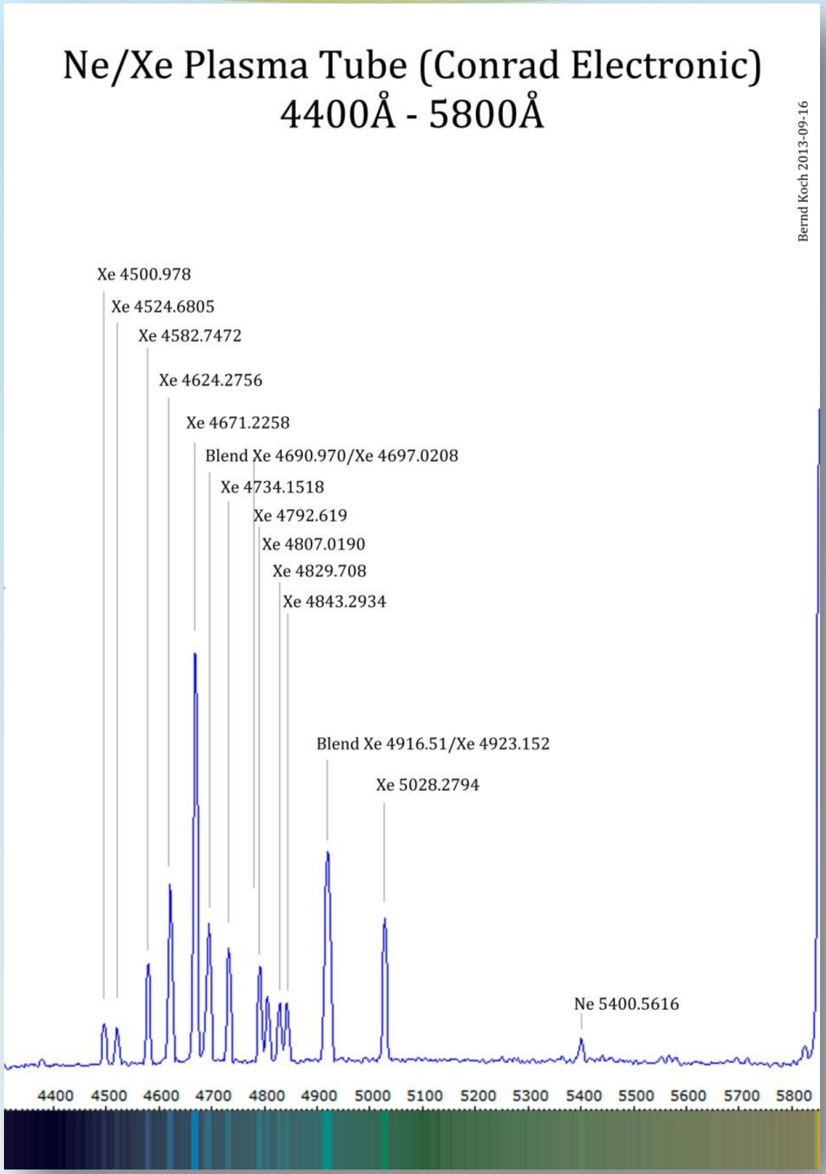




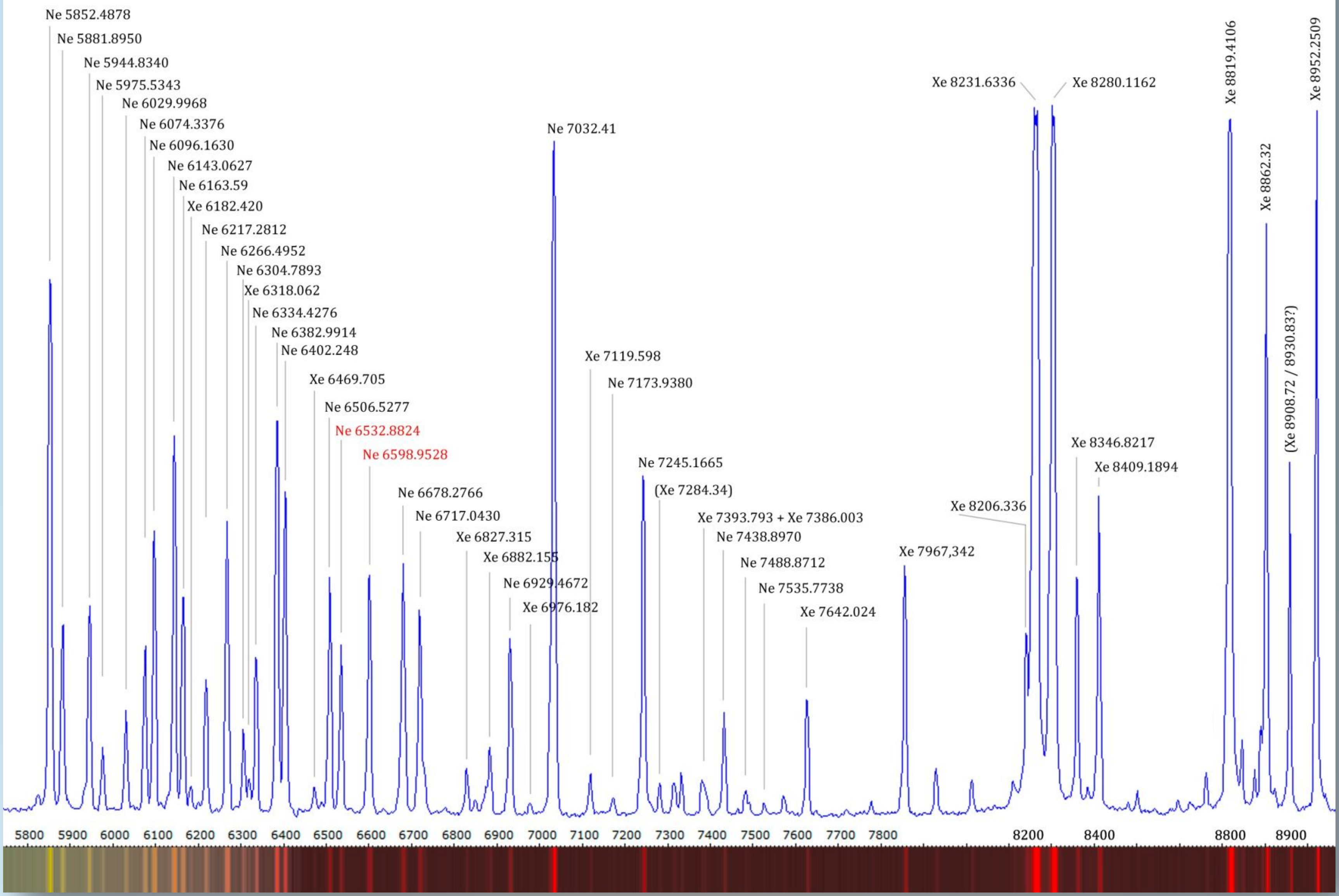
Title:	Atlas of Reference Spectra for RSS Observations
Author(s):	Alexei Y. Kniazev SALT_Ref_2252AA0001_v2.0.pdf (für Xenon)
Doc. number:	2252AA0001
Version:	2.0
Date:	*July 12, 2009*
Keywords:	Reference spectra
Approved:	David Buckley (Ast Ops Manager)
	Signature:__________ Date:__________

ABSTRACT
In this document current version of SALT atlases of reference spectra is presented. Spectra of Ar, CuAr, Ne, ThAr and Xe lamps are collected and identified for many RSS setups. For each setup the best lines are shown with their wavelengths. Calulated accuracies are also shown.

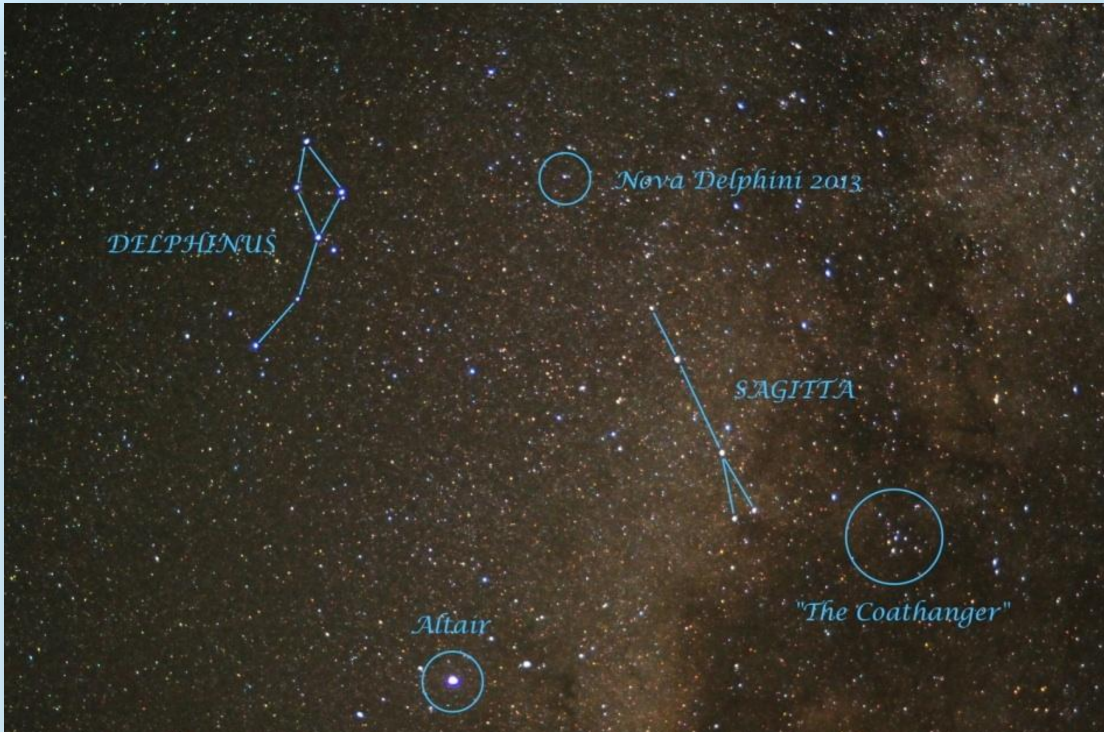
Calibration of spectra with a Ne/Xe plasma tube from Conrad Electronic

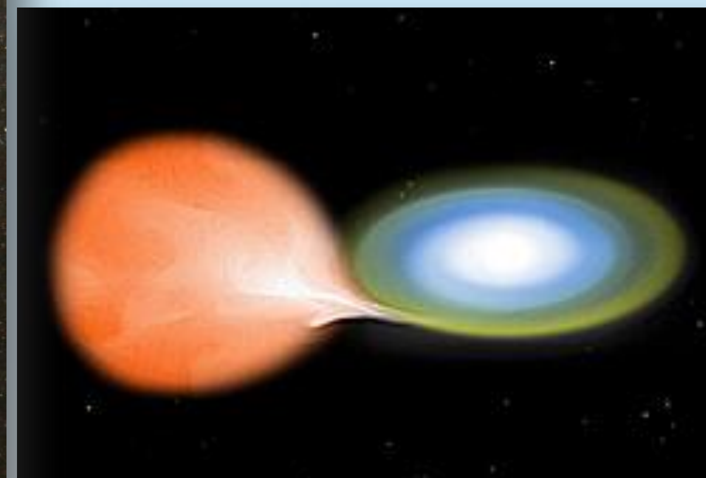


Calibration of spectra with a Ne/Xe plasma tube from Conrad Electronic



Nova Delphini 2013: Discovery August 14.8174 UT





http://en.wikipedia.org/wiki/Nova_Delphini_2013

PNV J20233073+2046041 (or **Nova Delphini 2013**) is a bright nova star in the constellation Delphinus. It was discovered on 14 August 2013 by amateur astronomer Koichi Itagaki in Japan, and confirmed by the Liverpool Telescope on La Palma. The nova appeared with a magnitude 6.8 when it was discovered and peaked at magnitude 4.3 on 16 August.[1]

Nova

From Wikipedia, the free encyclopedia

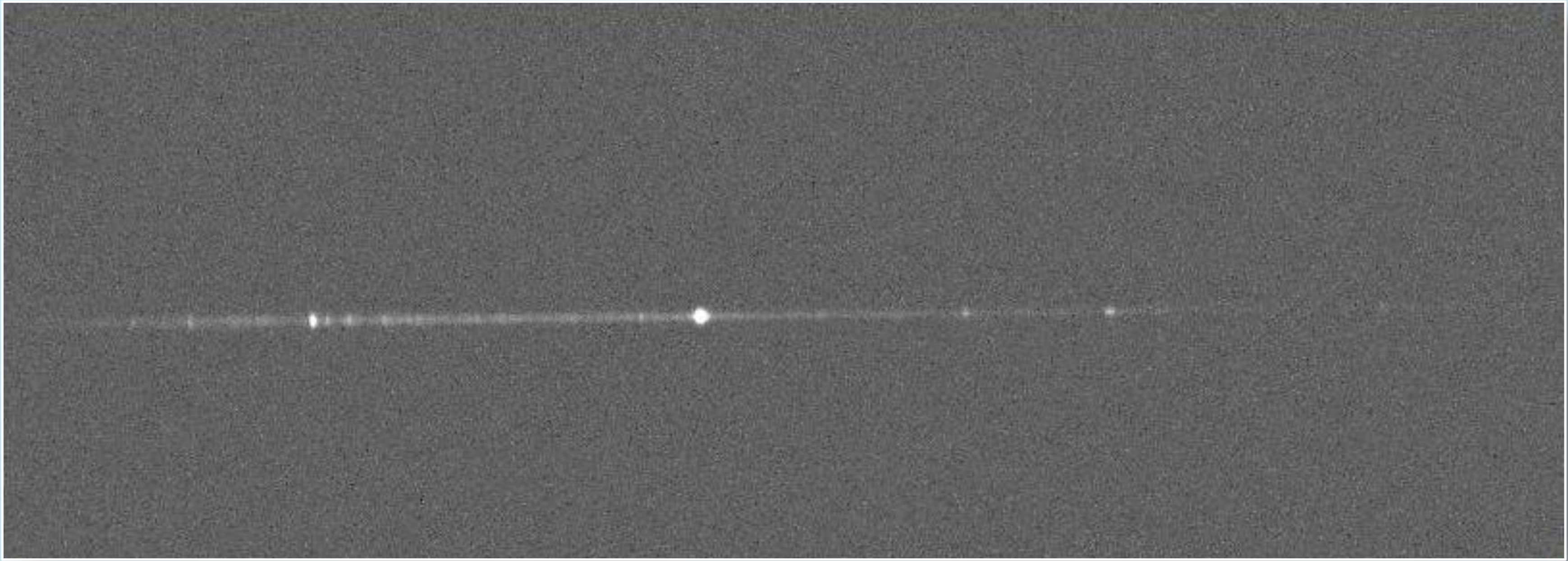
For other uses, see Nova (disambiguation) and Novas (disambiguation).

A **nova** (plural *novae* or *novas*) is a cataclysmic nuclear explosion in a white dwarf, which causes a sudden brightening of the star. Novae are not to be confused with other brightening phenomena such as supernovae or luminous red novae. A nova is caused by the accretion of hydrogen on to the surface of the star, which ignites and starts nuclear fusion in a runaway manner. Novae are thought to occur on the surface of a white dwarf in a binary system. If the two stars are close enough, material can be pulled from the companion star's surface onto the white dwarf.

Nova Delphini 2013: August 16, 2013

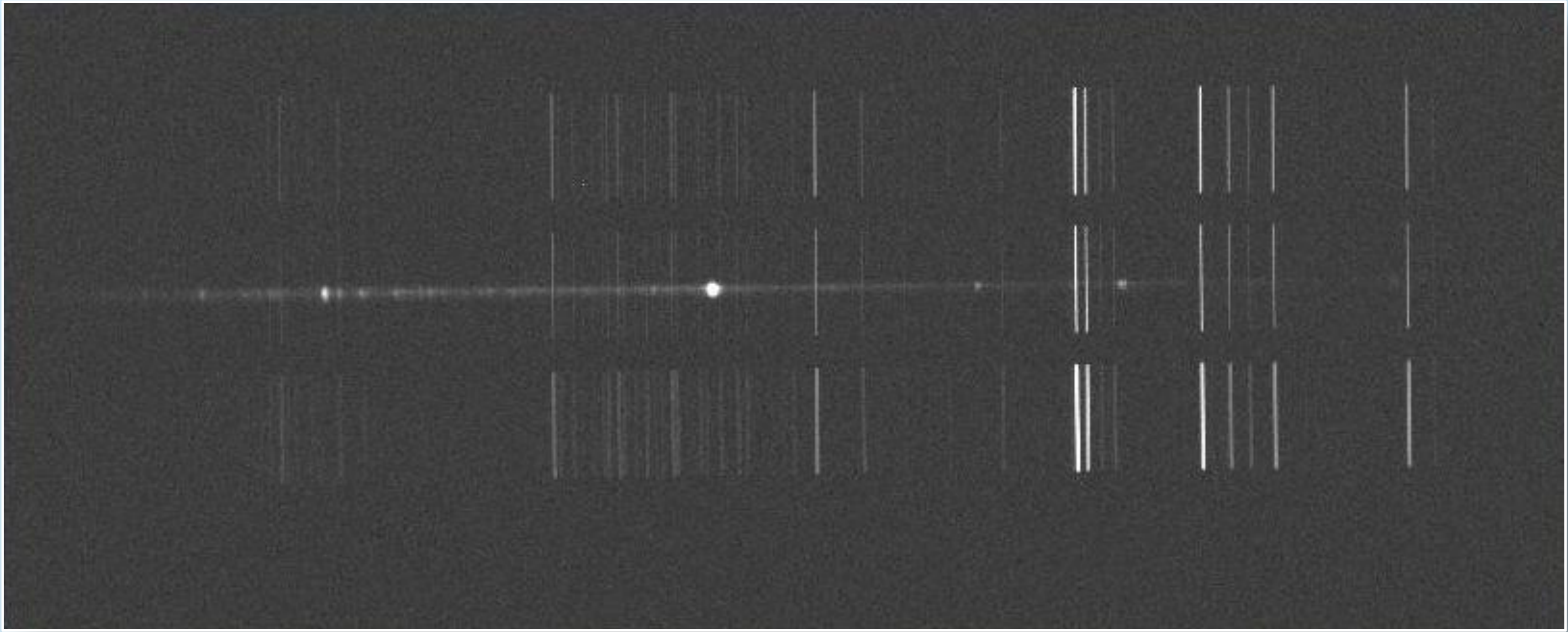
2013-08-16 | 23.22 UT – 23.55 UT | mid Exposure August 16.985 UT | 0.3m aperture, f/7.8
f=2340mm | SBIG ST-8300M | Baader RGB Filter | Nova maximum: Aug. 16.45 @ V=4.3 mag
Image & Processing: Bernd Koch, Sorth/Germany

Nova Delphini 2013: 2013-09-05.9 UT



Spectrum: DADOS 200 lines/mm & SBIG ST-8300M CCD camera | 0.3m Telescope

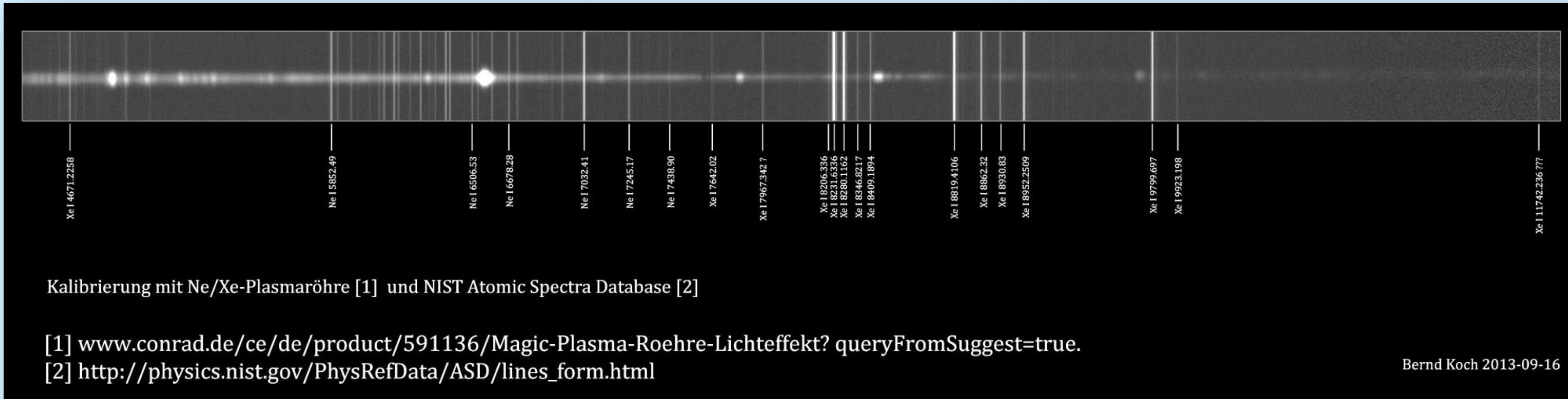
Nova Delphini 2013: 2013-09-05.9 UT
Calibration with a Ne/Xe plasma tube from Conrad Electronic

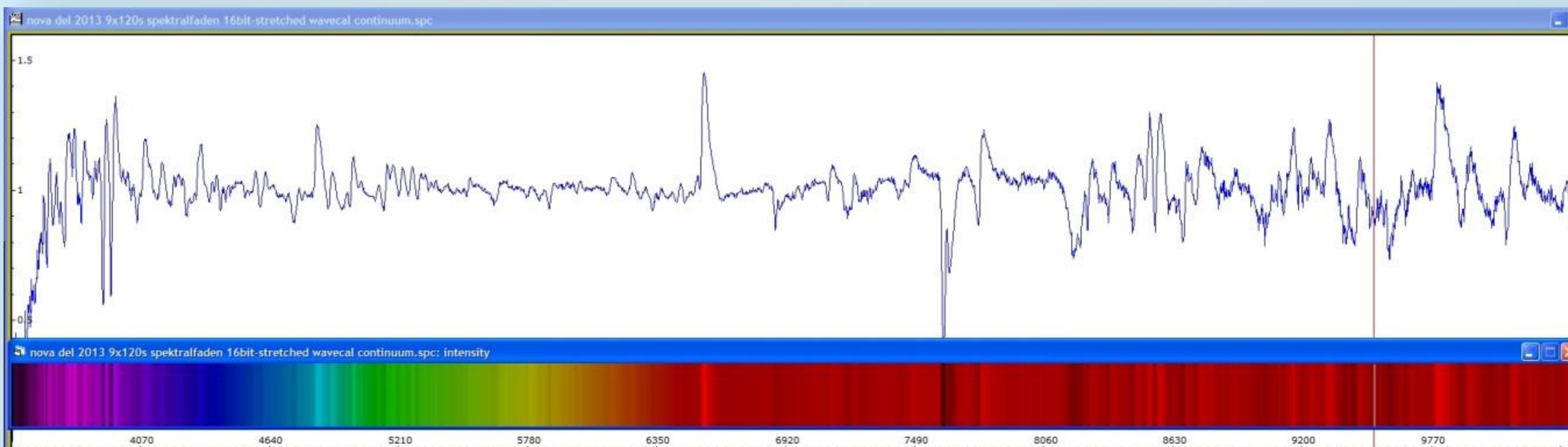


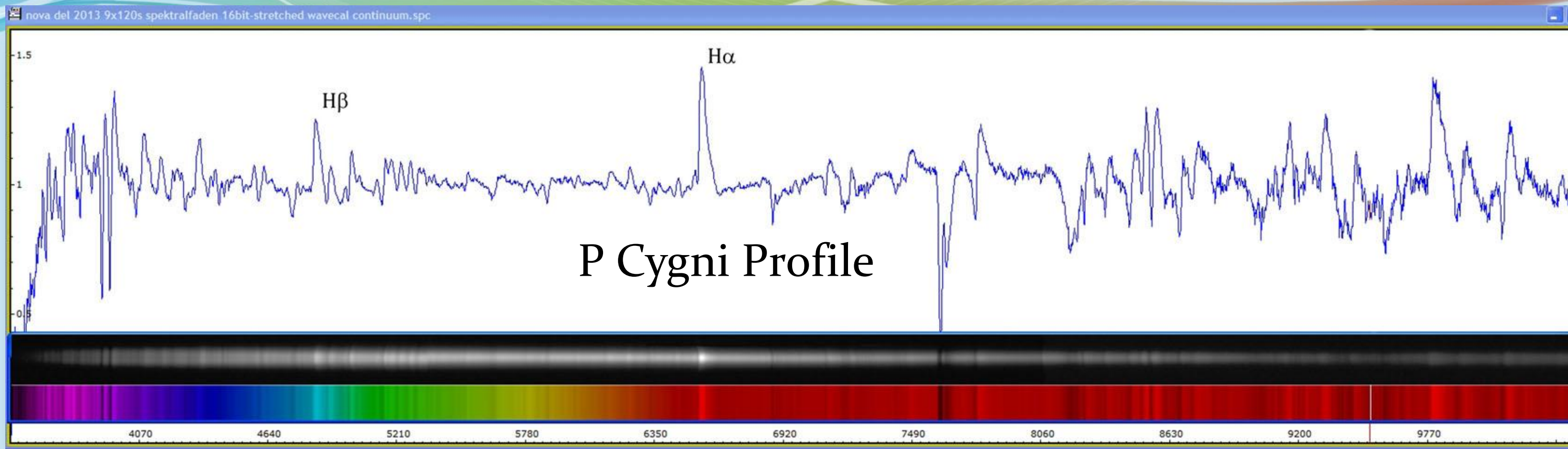
Spectrum: DADOS 200 lines/mm & SBIG ST-8300M CCD camera | 0.3m Telescope
Ne/Xe plasma tube in front of the telescope, and spectrum superimposed during exposure.
Note the changes in spectral resolution due to the different slit widths.

Nova Delphini 2013-09-05.88785 UT

Calibration with a Ne/Xe plasma tube from Conrad Electronic





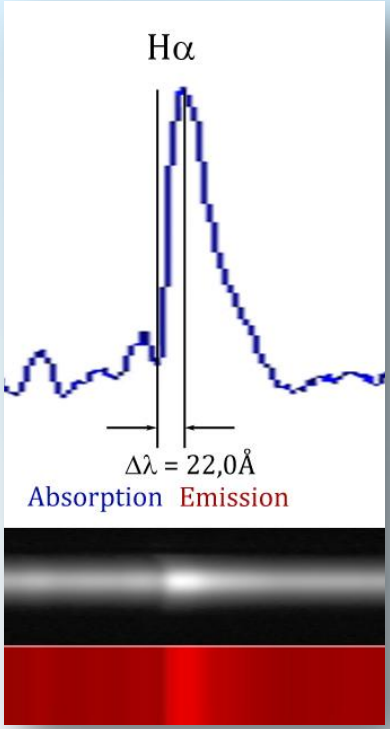


2013-08-19 | 20.01 UT – 20.33 UT | Mid-exposure: August 19.84722 UT | DADOS 200 lines/mm
Stacking: FITSWORK with 9 x 120s | Calibration: VisualSpec

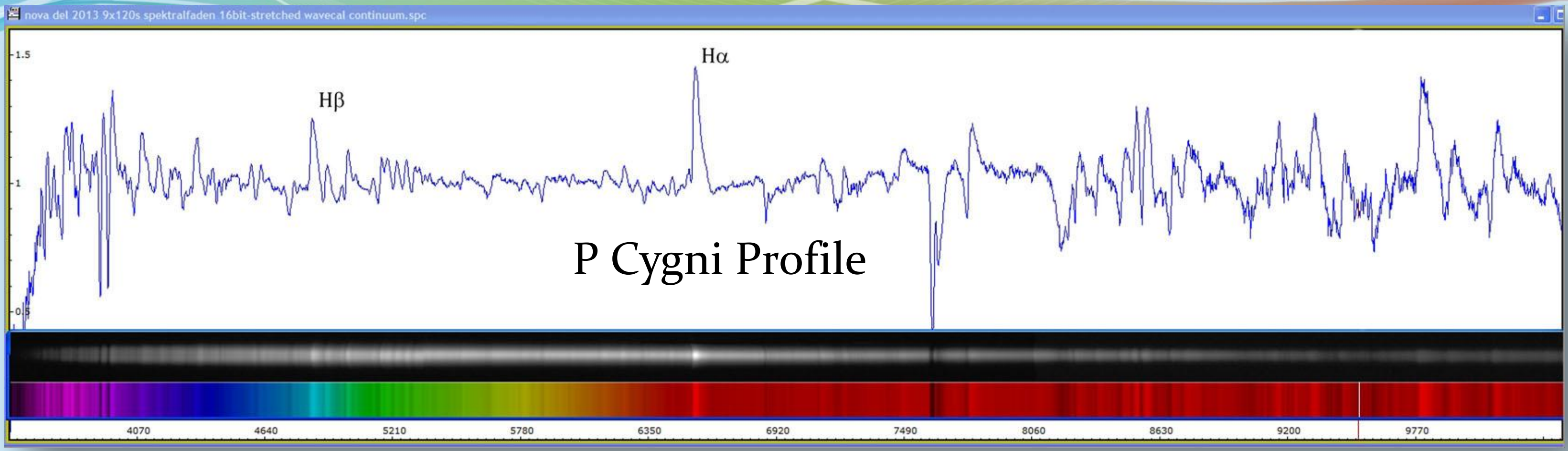
The expansion velocity v_r of the nova‘s envelope is calculated by the P Cygni profile method, measured at Hα:

$$v_r = \frac{\Delta\lambda}{\lambda_0} c_0 = 1005 \frac{km}{s}$$

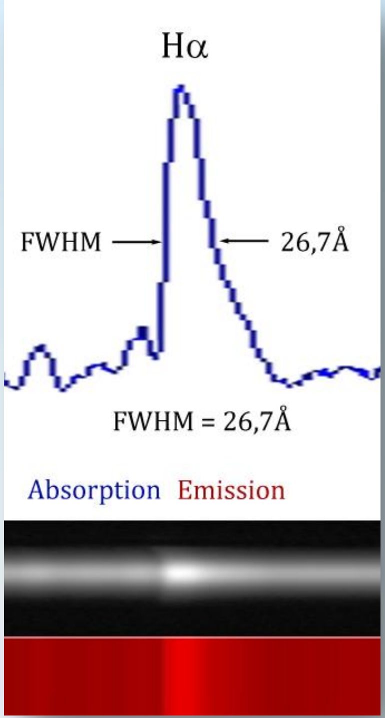
$$\Delta\lambda = 22.0Å, \lambda_0 = 6562.82Å, c_0 = 299792 \frac{km}{s}$$



Ref.: www.ursusmajor.ch/downloads/analysis-and-interpretation-of-astronomical-sp.pdf



2013-08-19 | 20.01 UT – 20.33 UT | Mid-exposure: August 19.84722 UT| DADOS 200 lines/mm
Stacking: FITSWORK with 9 x 120s | Calibration: VisualSpec



The expansion velocity v_r of the nova's envelope can also be calculated by the broadening of the emission lines, measured at Hα:

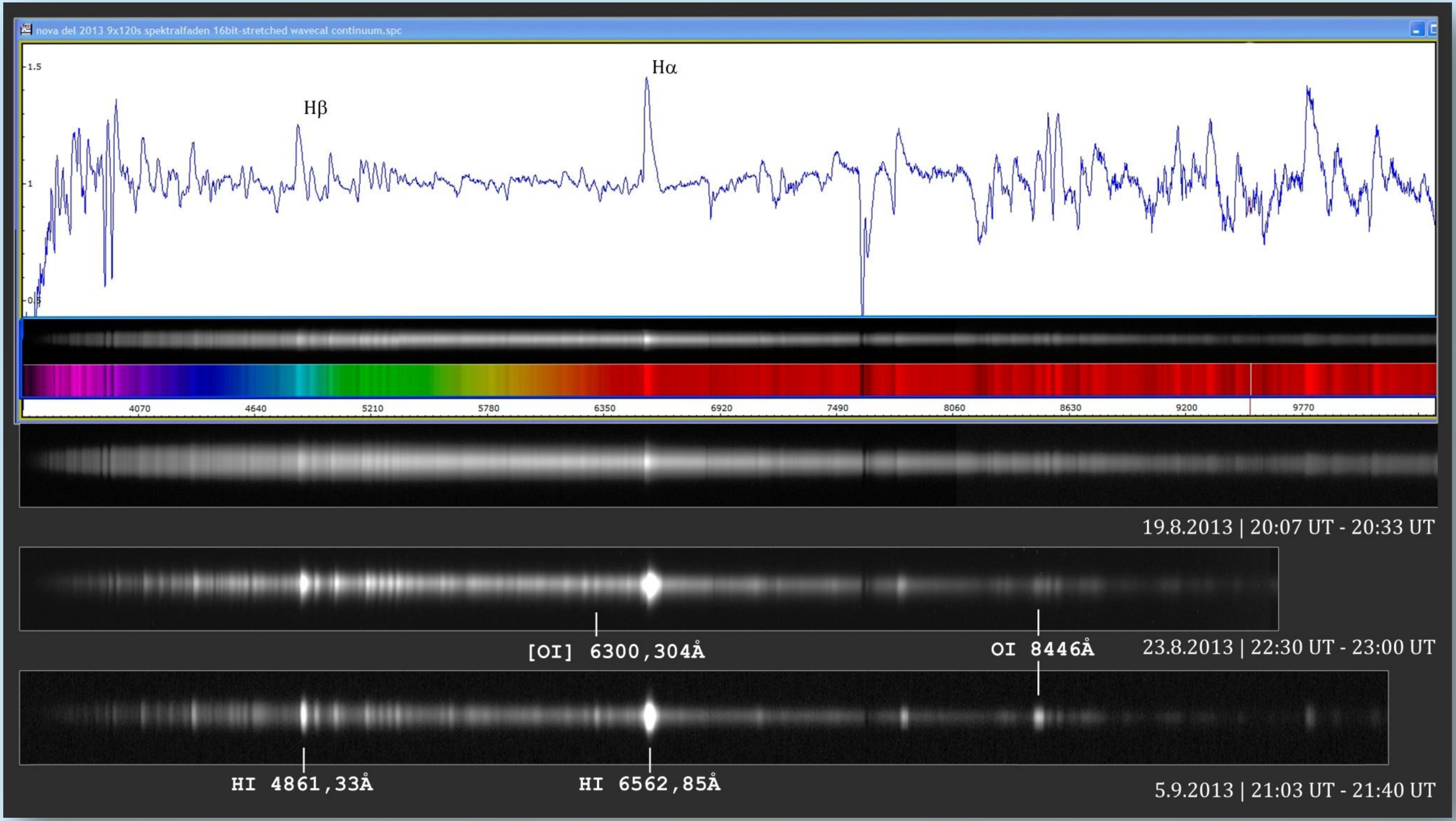
$$v_r \approx \frac{FWHM}{\lambda_0} c_0 = 1220 \frac{km}{s}$$

$$FWHM = 26.7Å, \lambda_0 = 6562.82Å, c_0 = 299792 \frac{km}{s}$$

Ref.: www.ursusmajor.ch/downloads/analysis-and-interpretation-of-astronomical-sp.pdf

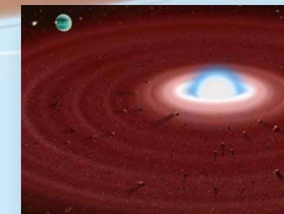
Nova Delphini 2013-08-19/23 & 2013-09-05 summary

All spectra taken with DADOS 200 lines/mm with 0.3m Telescope by Bernd Koch



Nova Delphini database: www.astrosurf.com/aras/novae/Nova2013Del.html

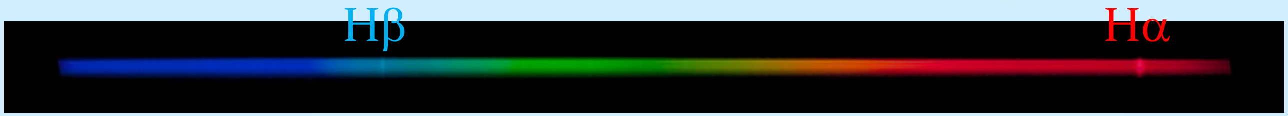
Spectroscopy of Be star γ Cas

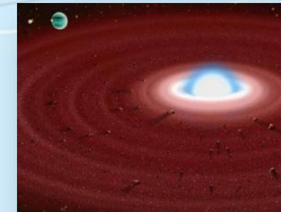


Credit: Gemini Observatory Illustration by Jon Lomberg

- Celestron 11 + DADOS 900 lines/mm + STF-8300M CCD camera
- Pentax 75 + 2x-Converter + DADOS 900 l/mm + STF-8300M CCD camera
- Spectrum recording & video camera guiding: MaxIm DL, Win XP/7 32-bit tested
- ➢ Set γ Cas on the middle of the three slits (25 µm) for highest resolution
- ➢ The slit's length should be parallel to Deklination (δ) direction
- ➢ Center spectrum on Hα by turning the micrometer adjustment
- ➢ Keep exposure time well below the saturation level of the sensor (1s … 60s)
- ➢ Guiding: Video camera Skyris 274M / TIS DMK 41 or else
- ➢ Number of images per spectrum: Minimum 20. Save in folder: "gamma Cas"
- ➢ Expose 20 darks of same exposure time and sensor temperature: Folder: "darks"
- ➢ Optional: Flat fields with auto darksubtraction. Folder: „flats"
- ➢ Dark/Flat calibration with MaxIm DL, stacking with FITSWORK
- ➢ Spectrum calibration with Visual Spec (VSpec).

Spectroscopy of Be star γ Cas





Credit: Gemini Observatory Illustration by Jon Lomberg

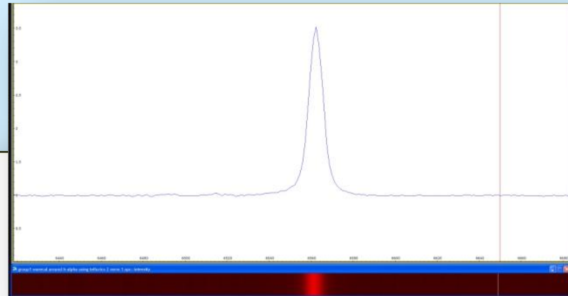
- Celestron 11 + DADOS 900/200 lines/mm + EOS 450D (ISO 800, Autodark)
- Pentax 75 + 2x-Converter + DADOS 900/200 lines/mm + EOS 450D (ISO 800)
- Spectrum recording & video camera guiding: MaxIm DL, Win XP/7 32-bit tested
- The slit‘s length should be parallel to Deklination (δ) direction
- Center spectrum on Hα or Hβ by turning the micrometer adjustment
- Keep exposure time well below saturation of sensor (1s to about 60s)
- Guiding: Video camera Skyris 274M / TIS DMK 41 or else
- Number of images per spectrum: Minimum 20. Save in folder: “gamma Cas“
- Stacking with FITSWORK
- Spectrum calibration with Visual Spec (VSpec)

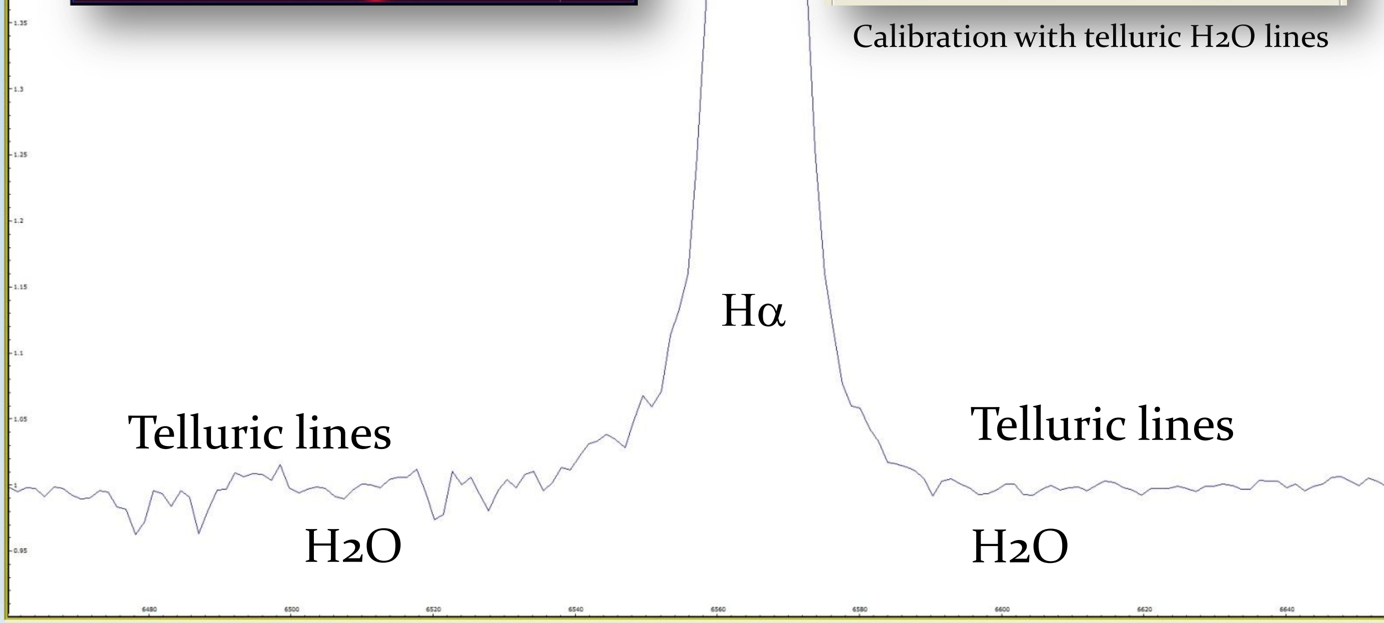
Spectrum of Be star γ Cas

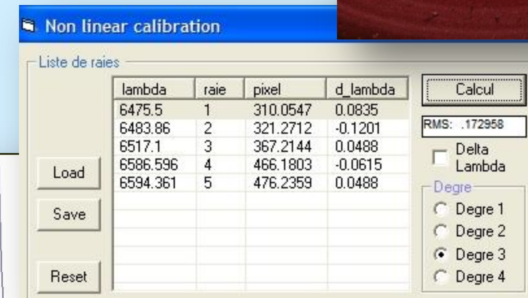
γ Cassiopeiae (circled) is found in the middle of the "W"

Observation data	
Epoch J2000	Equinox J2000
Constellation	Cassiopeia
Right ascension	00h 56m 42.50108s [1]
Declination	+60° 43′ 00.2984″ [1]
Apparent magnitude (V)	2.47 [2]
Characteristics	
Spectral type	B0.5 IVe [3]
U−B color index	−1.08 [2]
B−V color index	−0.15 [2]
Variable type	Gamma Cas
Astrometry	
Radial velocity (Rv)	−6.8 [4] km/s
Proper motion (μ)	RA: +25.17 [1] mas/yr Dec.: −3.92 [1] mas/yr
Parallax (π)	5.94 ± 0.12 [1] mas
Distance	550 ± 10 ly (168 ± 3 pc)
Details	
Mass	19.3 ± 0.1 [5] $M_\odot$
Radius	10 [6] $R_\odot$
Luminosity	55,000 [7] $L_\odot$
Surface gravity (log g)	3.50 [6] cgs
Temperature	30,900 [7] K
Rotational velocity (v sin i)	300 [7] km/s

http://en.wikipedia.org/wiki/Gamma_Cas







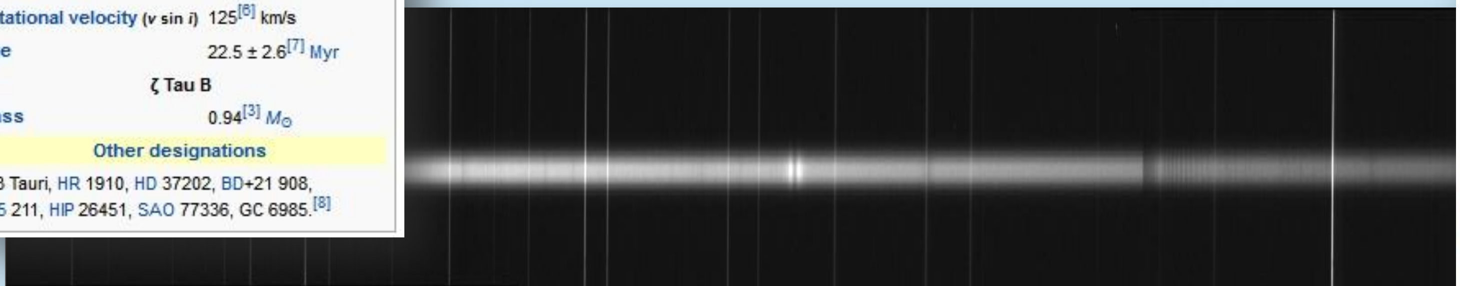
Calibration with telluric H2O lines

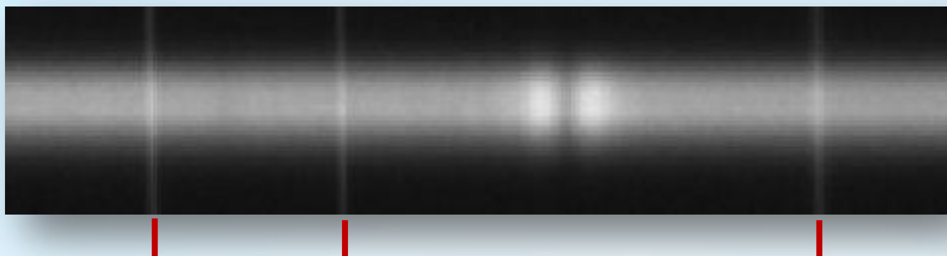
Credit: Gemini Observatory Illustration by Jon Lomberg

Date: 2011-04-19.882 UT | C11 EdgeHD (0.28m aperture, f/10). DADOS 900 lines/mm grating. CCD camera Alccd 5.2 (QHY6). Single exposure: 120s. Average of 20 exposures. Darkframe subtraction, no flatfielding. Spectral resolution 2.3 Å at 6563Å. Calibration with VisualSpec (telluric H2O). FWHM=7.9Å, EW=-23.4Å (6520Å-6605Å), RV=-5.2 km/s. Spectrum obtained at a spectroscopy workshop at the College CFG Wuppertal/Germany. Calibration & results: Bernd Koch

Spectrum of Be star ζ Tau

Details	
ζ Tau A	
Mass	11.2[3] $M_\odot$
Radius	5.5[3] $R_\odot$
Luminosity	4,169[5] $L_\odot$
Temperature	15,500[5] K
Rotational velocity ($v \sin i$)	125[6] km/s
Age	22.5 ± 2.6[7] Myr
ζ Tau B	
Mass	0.94[3] $M_\odot$
Other designations	
123 Tauri, HR 1910, HD 37202, BD+21 908, FK5 211, HIP 26451, SAO 77336, GC 6985.[8]	





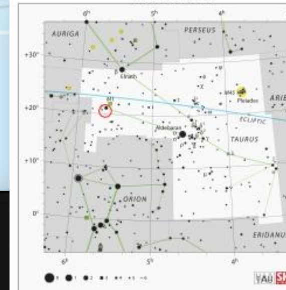
Ne I 6506.5277Å

Ne I 6532.8824Å

Hα

Ne I 6598.9528Å

Zeta Tauri

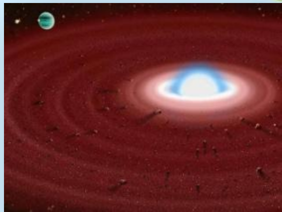


Location of ζ Tauri (circled)

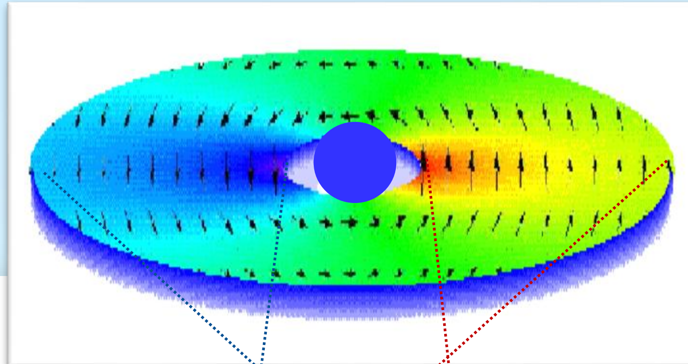
Observation data	
Epoch J2000.0	Equinox J2000.0 (ICRS)
Constellation	Taurus
Right ascension	$05^h\ 37^m$ 38.68542s[1]
Declination	+21° 08′ 33.1588″[1]
Apparent magnitude (V)	3.010[2]
Characteristics	
Spectral type	B2 IIIpe[3]
U−B color index	−0.749[2]
B−V color index	−0.164[2]
Astrometry	
Radial velocity (R_v)	+20[4] km/s
Proper motion (μ)	RA: +1.78[1] mas/yr Dec.: −20.07[1] mas/yr
Parallax (π)	7.33 ± 0.82[1] mas
Distance	approx. 440 ly (approx. 140 pc)
Orbit[3]	
Period (P)	132.987 days
Semi-major axis (a)	1.17 AU
Eccentricity (e)	0.0 (assumed)
Inclination (i)	92.8°
Longitude of the node (Ω)	−58.0°
Periastron epoch (T)	2,447,025.6 HJD
Argument of periastron (ω) (secondary)	0.0 (assumed)°
Semi-amplitude (K_1) (primary)	7.43 km/s

Date: 2014-03-10, mid-exposure 23.30 UT| 0.3m aperture, f/10. DADOS 1200 lines/mm grating. CCD camera SBIG ST-8300M, total exposure 3x300s with darkframe subtraction, without flatfielding. Spectral resolution about 1.49 Å. Calibration with Xenon/Neon plasma tube and VisualSpec software. Image processing & spectrum calibration: Bernd Koch

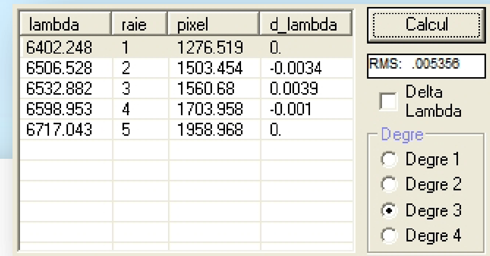
Spectrum of Be star ζ Tau



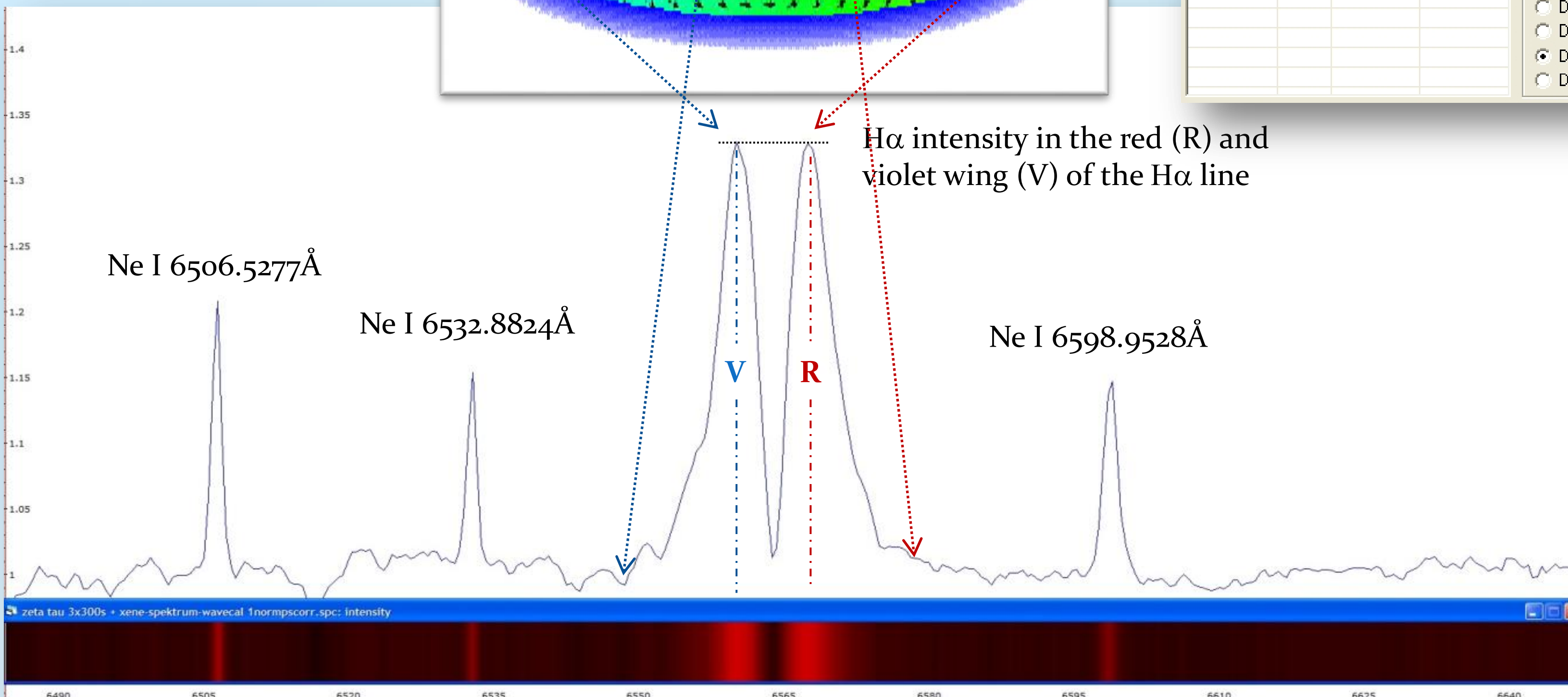
DADOS 1200 lines/mm
SBIG ST-8300M, 1 x 1 Binning



Spectrum calibration VisualSpec



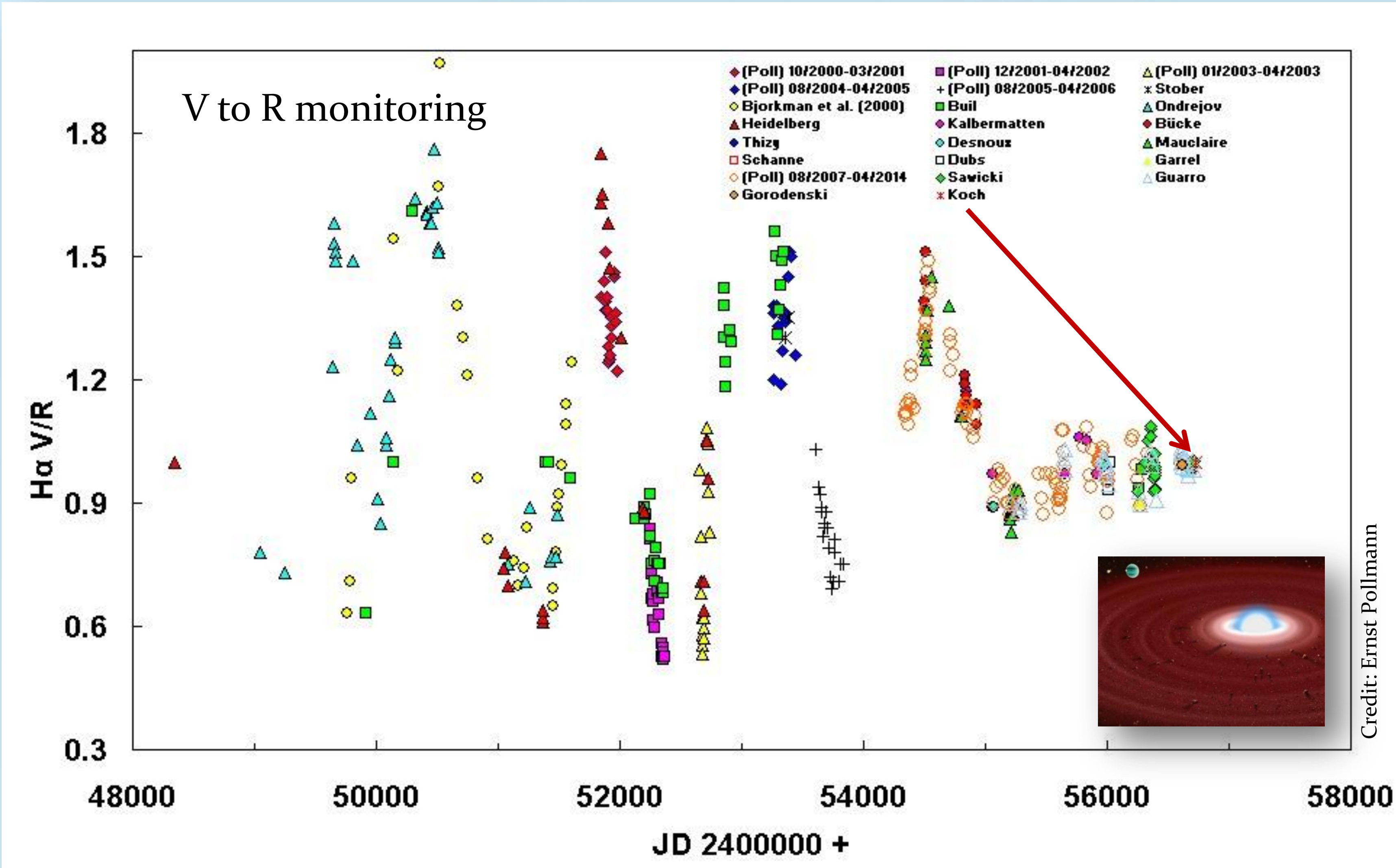
lambda	raie	pixel	d_lambda
6402.248	1	1276.519	0.
6506.528	2	1503.454	-0.0034
6532.882	3	1560.68	0.0039
6598.953	4	1703.958	-0.001
6717.043	5	1958.968	0.



Credit: Gemini Observatory Illustration by Jon Lomberg

Date: 2014-03-10, JD 2456727.386 | Spectral resolution: 1.5Å | Radial velocity v=30.9 km/s
EW=-3.9Å (6540Å-6590Å) | V/R=1.00 | by Bernd Koch and Ernst Pollmann

Spectrum of Be star ζ Tau



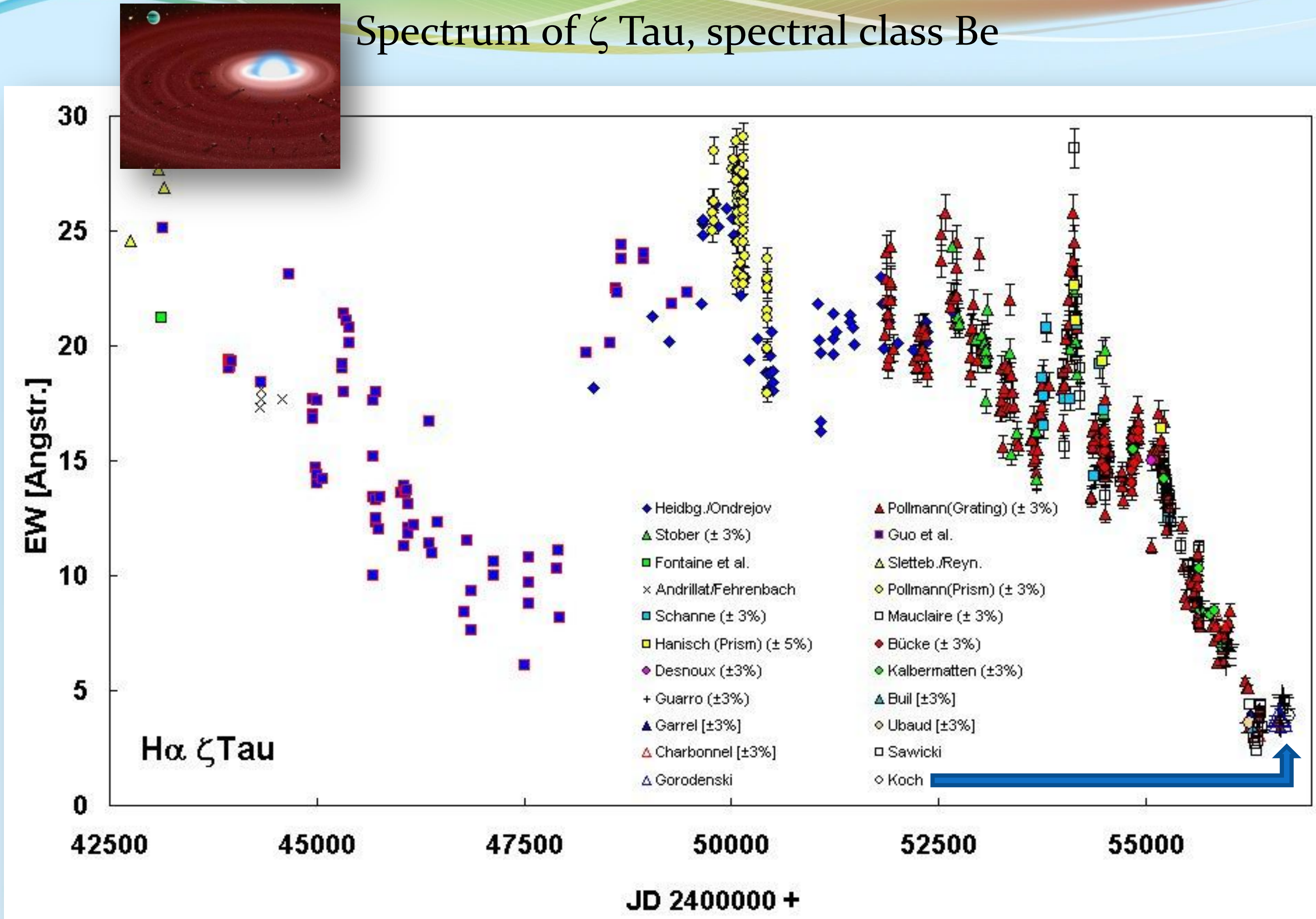
Credit: Ernst Pollmann

Credit: Gemini Observatory Illustration by Jon Lomberg

Multi-epoch Near-Infrared Interferometry of the Spatially Resolved Disk Around the Be Star ζ Tau (Schaefer et al., http://arxiv.org/abs/1009.5425)

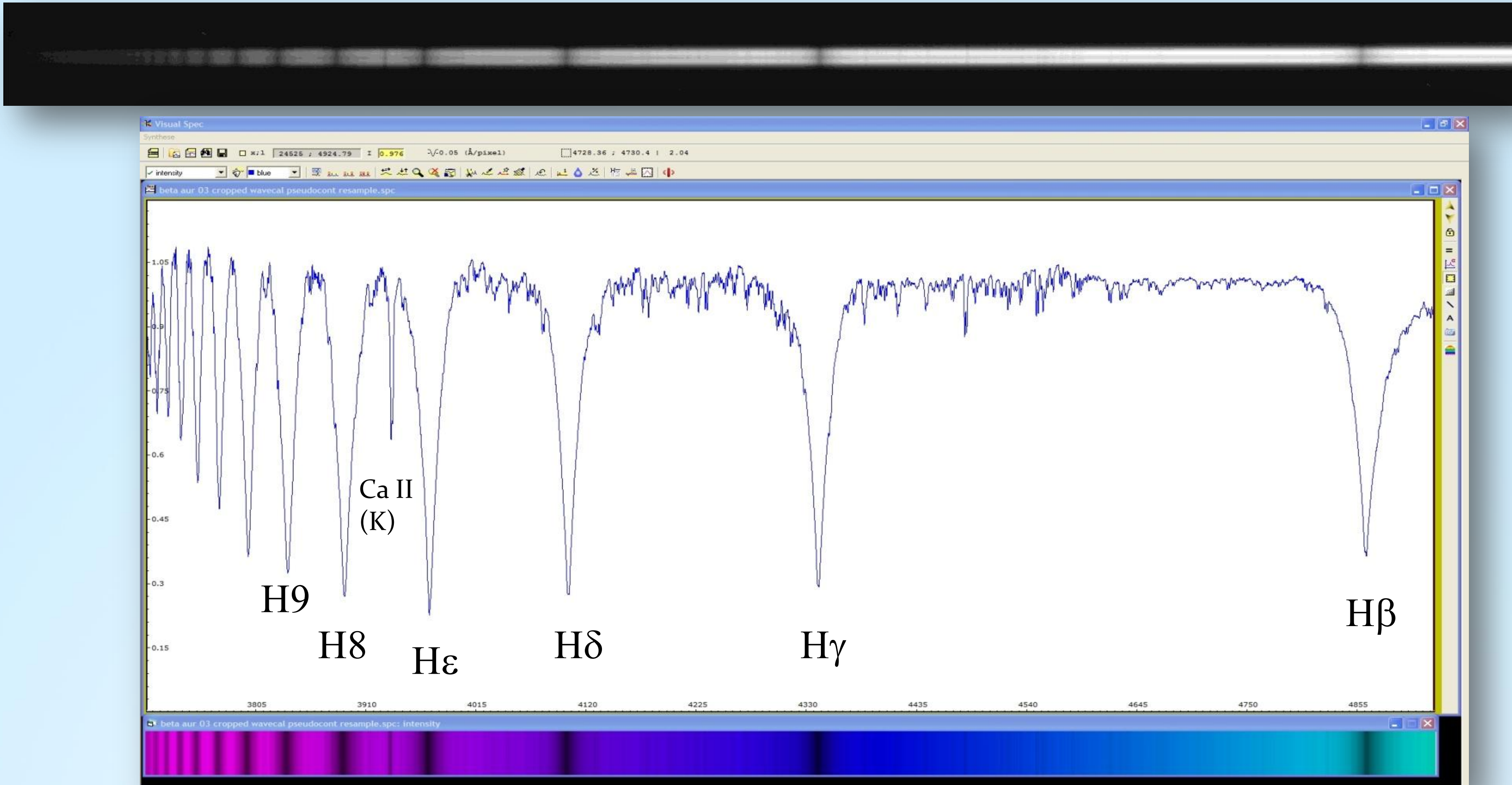
Spectrum of ζ Tau, spectral class Be

Credit: Gemini Observatory Illustration by Jon Lomberg



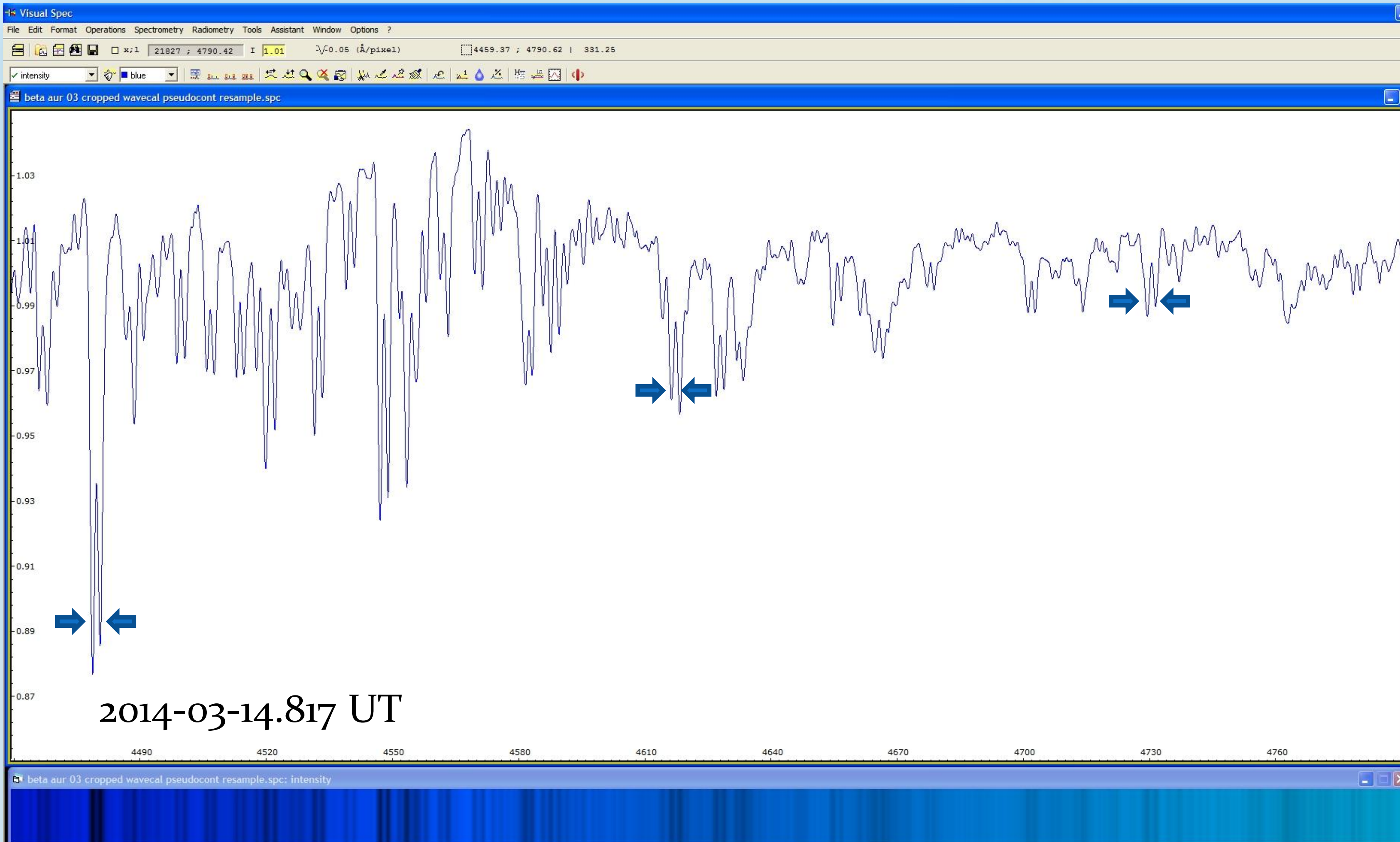
Credit: Ernst Pollmann

Spectroscopic binary star β Aur



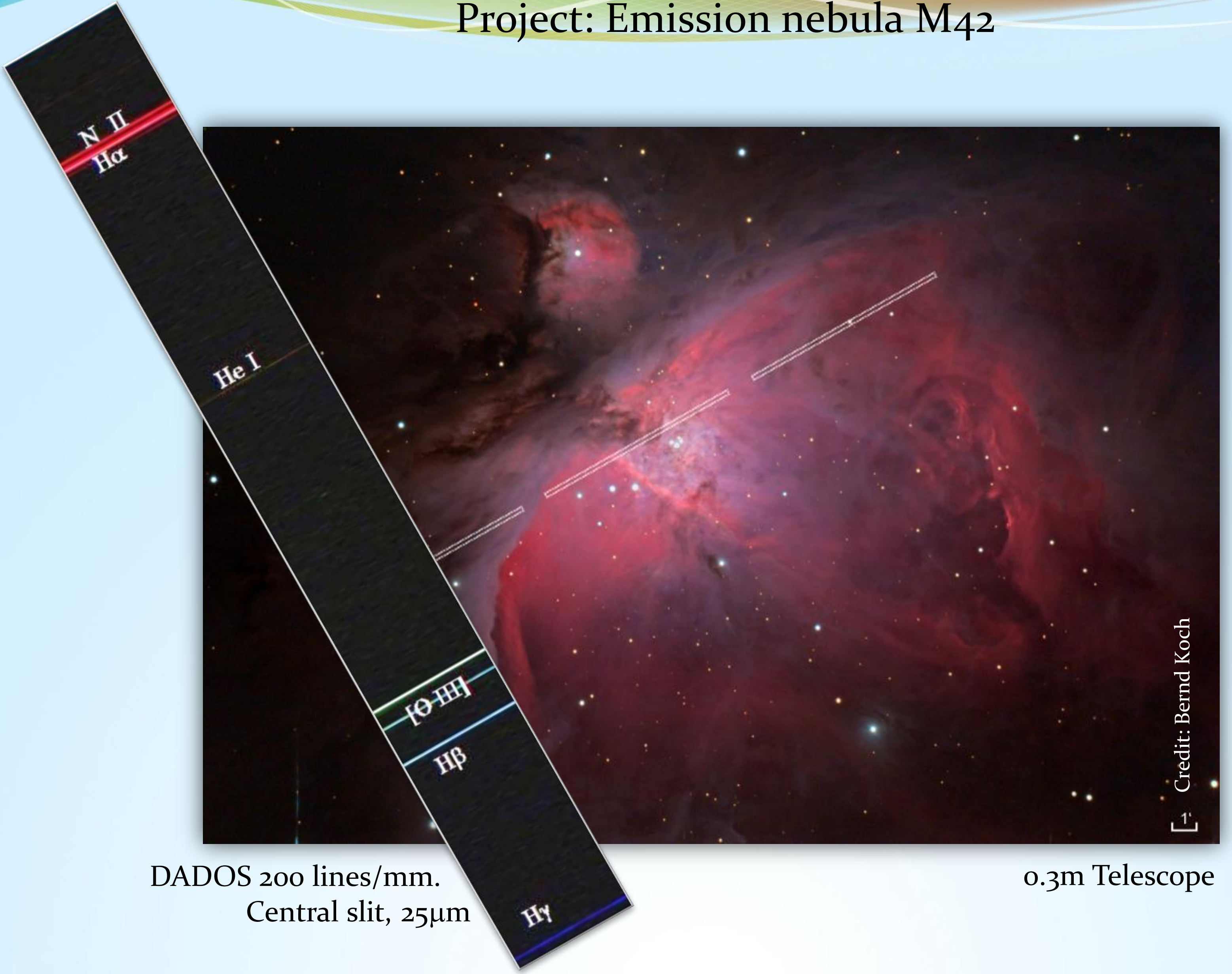
Date: 2014-03-14.817 UT | 0.3m aperture f/10 | DADOS 1200 lines/mm grating | 120s exposure
CCD camera SBIG ST-8300, 5.4 Micron Pixel | Spectral resolution 1.5Å | Calibration and creation of a synthetic colour spectrum with VisualSpec software| Image and calibration by Bernd Koch

Spectroscopic binary star β Aur



Line splitting $\Delta\lambda$ approximately 1.9Å in the covered spectral range due to Doppler shift caused by the stars' combined rotational velocity v. $\Delta\lambda/\lambda = v/c$. $c = 299792.5\ km/s$, average: $v = 126.3\ km/s \pm 6.2\ km/s$

Project: Emission nebula M42



DADOS 200 lines/mm.
Central slit, 25µm

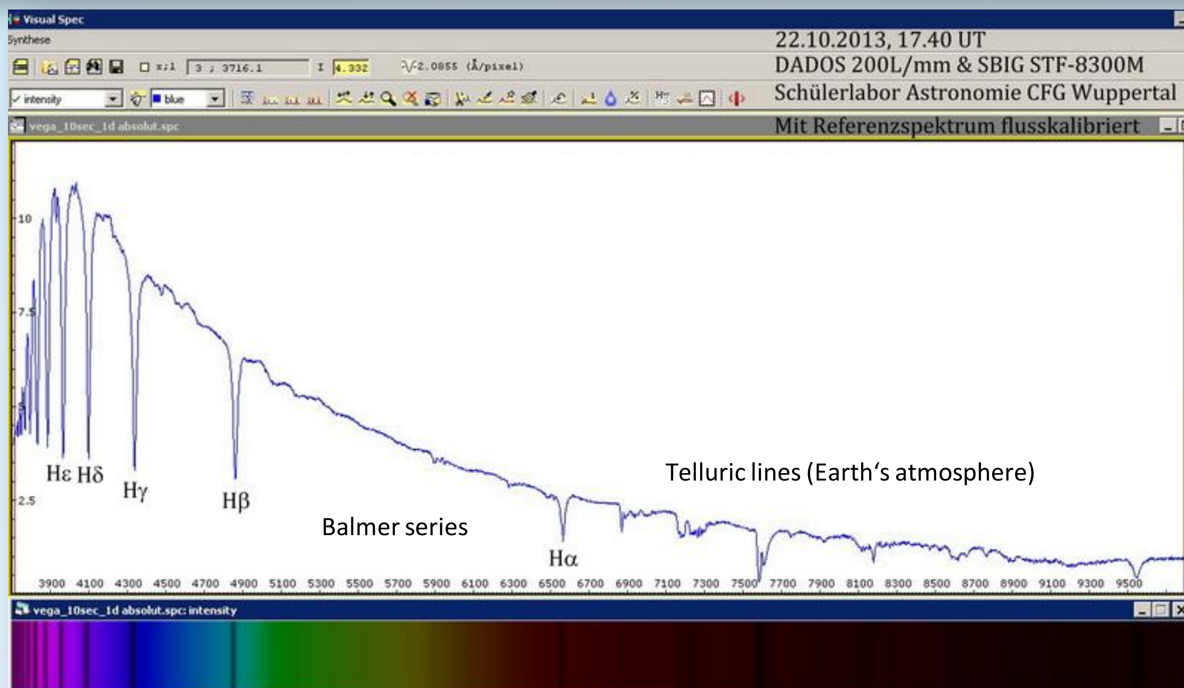
0.3m Telescope

Stacking & full calibration of spectra taken by a STF-8300M CCD camera

In an upcoming release, the subject of stacking and full calibration of spectra obtained with a monochrome CCD camera will be described. Stay tuned ….

α Lyr (Vega) – Spectral Class A0V

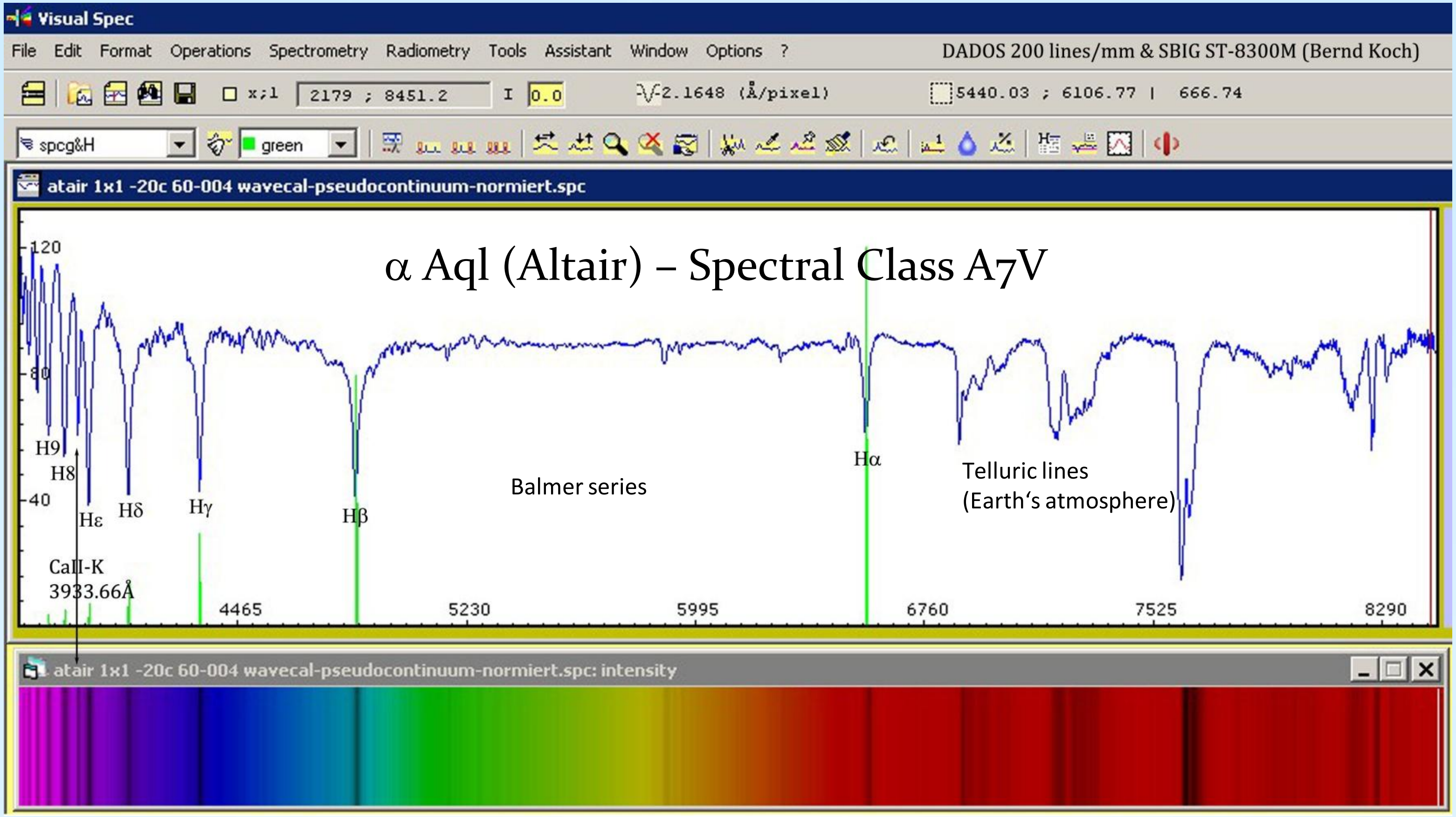
2013-10-22 | 17.40 UT | Exposure time 10s (with Autodark)| DADOS 200 lines/mm | SBIG STF-8300M |
Student astronomical observatory at Carl-Fuhlrott College in Wuppertal/Germany | Credit: Thomas Schröfl



Calibration by Bernd Koch

Stacking & full calibration of spectra taken by a STF-8300M CCD camera

In an upcoming release, the subject of stacking and full calibration of spectra obtained with a monochrome CCD camera will be described. Stay tuned ….



2013-09-13 | 19.20 UT | Stack of 10 x 1s exposure time 10s (Autodark)| DADOS 200 lines/mm | SBIG ST-8300M
Image and calibration: Bernd Koch

References & recommended reading

by Bernd Koch

DADOS Spectrograph‘s user manual
www.baader-planetarium.de/dados/download/dados_manual_english.pdf

Richard Walker’s astronomical spectroscopy
www.ursusmajor.ch/astrospektroskopie/richard-walkers-page/

- Spectroscopic Atlas 4.0 [11'487 KB]
- Practical Aspects of Astronomical Spectroscopy 2.0 [4'209 KB]
- Analysis and Interpretation of Astronomical Spectra 9.1 [5'330 KB]
- The Spectrum of Quasar 3c273 1.2 [745 KB]
- Atomic Emission Spectroscopy 2.0 [4'983 KB]
- SQUES RELCO SC480 Calibration Lines 2.0 [2'210 KB]

References & recommended reading

by Matthew Buynoski

“Introduction to Astronomical Spectroscopy” by Immo Appenzeller
ISBN 978-1-107-60179-6
Wonderful little book by a master of the art of spectroscopy, and contains interesting topics (atmospheric dispersion compensators, volume phase gratings, etc).

“Observation and Analysis of Stellar Photospheres” by David Gray
ISBN 978-0-521-06681-5
Parts of this book are highly technical and suitable only for those with physical science degrees, but other portions of it, describing equipment and how it works (e.g. detectors, spectroscopes, telescopes) are suitable by everyone. Dr. Gray is also a master of the art of spectroscopy.

“Stars and Their Spectra” by James Kaler
ISBN 0-521-30494-6
This book is a good introduction to stars and what their spectra reveal about them. It is not too technical, and suitable for any amateur astronomer. Dr. Kaler is another master of the art.

http://stars.astro.illinois.edu/sow/spectra.html
Dr. Kaler also has a website on the same subjects as his book (above). This specific web address is one entry port into a trio of websites about stars and their spectra.

Safety and other rules

SAFETY RULES

1. NEVER look directly at the Sun with your eyes. You can burn a hole in your retina resulting in partial blindness.
2. NEVER change how solar observing equipment is set up for you. Doing so may result in permanent blindness for yourself or others.
3. If we are using the spectral calibration lamp, take care not to touch the bulb as it gets hot enough to burn fingers.
4. If you see a yellowish-green indistinct “fog” while using the solar spectroscope in the deep blue end of the spectrum, you have gone too far and ultraviolet in the sunlight is causing the vitreous humor in your eye to fluoresce. This is not the best thing for your eye; adjust the spectroscope to head away from the deep blue until the fog disappears.
5. Avoid mashing your eye into the eyepiece. Doing so is unnecessary and raises the risk of spreading conjunctivitis (pink eye). It also makes the telescope jiggle and observation harder.
6. Don’t play around with the batteries. They can give you a serious electrical jolt.
7. If you are unsure about anything, ask!

OTHER RULES

1. Apply only light pressure to make allowed adjustments (focusing, for example). Less force means less jiggling and thus easier observation.
2. This equipment is expensive, in the thousands of dollars. Treat it carefully and don’t horse around near it.
3. Minor accidents do happen; should you bump something, let the docent know so he can get the observed object back in view.
4. Don’t touch any of the glass optics with your hands. This can damage the optical coatings.
5. Please ENJOY YOUR OBSERVATIONS, and ASK LOTS OF QUESTIONS about anything you don’t understand or about which you wish to know more.

Disclaimer

While the methods shown in this tutorial work well, they assume an underlying knowledge of astrophotography not covered here. The user must be able to specify, purchase, operate and maintain appropriate equipment for the task at hand: optical tube assemblies, eyepieces, equatorial mounts, autoguiding equipment, cameras, spectroscopes, computers, image processing software, and astronomical accessories. The user must know skills such as cleaning and collimation of optics, physical balancing of the system, polar alignment, setting periodic error correction and gear backlash for the mount in use, dew control, navigating across the sky, operation of a computer and its programs to collect and reduce data, etc.

The equipment used in this tutorial is expensive, well over ten thousand US$ per student set-up. Expect that equipment of similar value must be used in order to achieve good results. All that said, please accept our best wishes for your success in astrospectroscopy!

The author thanks Michael Winkhaus, head of the Student Astronomical Observatory of the college Carl-Fuhlrott-Gymnasium, in Wuppertal, Germany, for the opportunity to give workshops in astronomy, astrophotography, and astrospectroscopy.

These workshops are held in collaboration with Ernst Pollmann of Leverkusen. Ernst is the head of Active Spectroscopy in Astronomy (ASPA, http://www.astrospectroscopy.de) and well-known for his expertise in high-resolution stellar spectroscopy.

The author thanks Matthew Buynoski (buynoski@batnet.com), who does visual spectroscopy for presentation to schoolchildren, for his helpful review and proofreading of this tutorial.