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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/2013/10/20131021sfloo.html http://www.waa.at/bericht/2013/10/20131022sfl17.html

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

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Michael Winkhaus



Ernst Pollmann



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 layout

DADDS SLIT-SPECTROGRAPH TUTORIAL

- 1) 2" Nosepiece ( -> Telescope)
- 2) Adjustable red LED slit illuminator (incl. two 1.5V LR-41 batteries)
- 3)  $1\frac{1}{4}$ " Slit viewer port for guiding eyepiece (11) or camera
- 4)  $1\frac{1}{4}$ " 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,  $T_2 \rightarrow 1\frac{1}{4}$ "
- 14) 10 mm or 20 mm Kellner eyepieces for viewing a spectrum)



### **Optical** path





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

Slit viewing port (guiding port)



#### Slit plate:

The slit plate contains three slits of different widths:  $25 \mu m$ ,  $35 \mu m$ , and  $50 \mu m$ .

#### **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



View through the guiding eyepice (simulation)
50 μm 🖌 🗸
25 μm ► ←
35 μm <b>→</b> →
Bright background

- 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



View through the guiding eyepiece (Simulation)



Pleiades Star Cluster, Pentax 75.1/ 500mm

- Central slit ( $_{25} \mu m$ ) 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  $\delta$  direction

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



Video: Bernd Koch





Video: Jonas Niepmann / Laurenz Sentis / Bernd Koch

### Dado #2: The blazed reflection grating



Resolving power  $\lambda / \Delta \lambda$  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 <sub>v</sub> = 8
For the	900 lines/mm grating :	m <sub>v</sub> = 6

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



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



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www.lightfrominfinity.org

/HIRSS/HIRRS.htm



### Dado #2: Grating replacement – Part 1

#### A.2 Grating replacement



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.

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### 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.



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



Take off the side plate/grating holder assembly.

Release the headless set

plate by 2 full turns

screw inside of the pressure

counterclockwise using the 1.5mm Allen wrench.



Be careful not to touch the grating.







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











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.

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### 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.

Copyright: DADOS Spectrograph's User's Manual by Baader Planetarium GmbH

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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  $\lambda$ 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  $\lambda/2$ , 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  $\lambda$ , the phases will add together and maxima will occur. Reference: http://en.wikipedia.org/wiki/Diffraction\_grating



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#### 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  $\{b_m\}$ , 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.



### **Blazed** reflection grating



#### Blazed grating theory: Definition of parameters









GN: Grating normal

FN: Face normal

g: Groove spacing

φ: Blaze angle

 $\alpha$ : Angle of the incident light

 $\beta$ : Angle of reflected light

Additive interference occurs when the total path difference  $\Delta$  of light from adjacent slits (S1) and (S2) is an integer multiple of the wavelength  $\lambda$ : 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:  $\Delta_2 = AC = g \sin \beta$

 $\Delta = m \lambda = \Delta_1 - \Delta_2 = g (\sin \alpha - \sin \beta)$  with m =0, ± 1, ± 2 ... (Grating equation)





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: 
$$m \lambda = g (\sin \alpha - \sin \beta) \rightarrow \lambda = \frac{g}{m} (\sin \alpha - \sin \beta)$$
  
Derivative with respect to  $\beta$ :  $\frac{d \lambda}{d \beta} = -\frac{g \cos \beta}{m}$   
Angular dispersion:  $\left| \frac{d \beta}{d \lambda} \right| = \frac{m}{g \cos \beta}$   
Linear dispersion:  $\left| \frac{d x}{d \lambda} \right| = f \left| \frac{d \beta}{d \lambda} \right| = f \frac{m}{g \cos \beta}$  "f" is the focal length of the objective lens  
Blaze angle:  $\phi = \frac{\alpha - \beta}{2} = \frac{\alpha}{2} - \frac{1}{2} \arcsin\left(\frac{m \lambda}{g} - \sin \alpha\right)$ 

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### 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:  $\alpha + \beta = 90^{\circ}$ Central wavelength:  $\lambda = 520$  nm = 5200 Å Diffraction order : m = 1Slit width: 25 µm Camera: Canon EOS 450D

#### SimSpec Results: 🗲

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

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14       Amospheric transmission (18):       0.75         15       Stym agnospheric transmission (18):       0.75         16       Star size at focus (FWHM):       27,1         16       Star size at focus (FWHM):       27,1         17       Camera-Havinum focial ratio (FO):       2,3         18       More and the second of the s	13	Seeing (	T-1.	0.70	-		Camera-Distance to grating (1):	140	mm	sampling ractor :	0,04			
15       Sky magnitude (magnitic Set 2):       10       Collimator (Camera Anazymith Total (Critica):       300       300       set size at focus (FWHM):	14	Atmospheric transmission (1	(a):	0,75			Camera-Minimum lens diameter (d2):	41,7	mm	Exposure	200			
Star size at rocus (rvmin):       27.1 microns       (resolution of camera ensister vmmic):       15 microns       number of subortances (n):       12 microns         18       Collimator/Camera -Total angle (r/):       90 *       Spectrum size/ spread       5pectrum size/ spread       5pectrum (n):       12 microns       12 microns       Spectrum size/ spread       12 microns       Feedowing how many size/ spread       12 microns       Spectrum size/ spread       12 microns       Spectrum (n):       12 microns       12 microns       Spectrum (n):       12 microns       12 microns       Spectrum (n):       12 microns       12 microns       Magnitude (m):       12 microns       12 microns       12 microns       Magnitude (m):       12 microns       12 microns       Magnitude (m):       12 microns       12 micros       12 microns       12 micros <td>15</td> <td>Sky magnitude (mag/arc sec</td> <td>c**2) :</td> <td>16</td> <td></td> <td></td> <td>Camera-Maximum tocal ratio (Fo) :</td> <td>2,3</td> <td></td> <td>Subs, exposure time (ts) :</td> <td>300</td> <td>secs</td> <td></td> <td></td>	15	Sky magnitude (mag/arc sec	c**2) :	16			Camera-Maximum tocal ratio (Fo) :	2,3		Subs, exposure time (ts) :	300	secs		
1/1       Iotal exposure time (t):       300 (paces)         1/1       Iotal exposure time (t):       300 (paces)         1/1       Iotal exposure time (t):       300 (paces)         1/1       Interview (t):       25 microns         1/1       Interview (t):       25 microns         1/2       Interview (t):       1/2         1/2       Interview (t):	16	Star size at focus (F	whim):	21,1	microns		Resolution of Camera lens-FWHMC :	15	microns	number of subframes (n):	12			
18       Columator/Lampera - total angle (?):       90       Spectrum size/ spread         20       See www.astrosurf.org/buil/us/spe2/hresolt.htm       Silt width (w):       22         21       See www.astrosurf.org/buil/us/spe2/hresolt.htm       Grating-Unifraction order (k):       1         22       Explanatory notes and worked example)       Grating-Unifraction order (k):       1         23       Grating-Minimum height (H):       8,0         24       SumMARY       Grating-Minimum height (H):       8,0         25       Resolving power R       32       Signal/Noise (SNR):       37         26       Spectrum minimum height (H):       13,62       A       Resolving power R):       332         26       Spectral resolution (DA):       13,62       A       Limiting Mag       2         27       Wavelength range       8761       A       Spectral resolution (A):       13,62       A         27       Wavelength ange       Sitt width       25       Sitt minimum height (H):       8,0       Imminum height (H):       8,0         28       Signal/Noise (SNR)       37       Limiting Mag       Limiting Mag       1       Signal/Noise (SNR)       37         29       Signal/Noise (SNR)       37       Lambda min. (1): <td>1/</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>I otal exposure time (t):</td> <td>3600</td> <td>secs</td> <td></td> <td></td>	1/									I otal exposure time (t):	3600	secs		
Ind INCLES:       Stit width (v):       Zb microns       Height of Spectrum (n):       12 pxel         20       See www.astrosurf.org/buil/us/stage/alc/ul/design_us.htm       Grating_Lines/mm (n):       200       Magnitude (m):       12         21       www.astrosurf.org/buil/us/stage/alc/ul/design_us.htm       Grating_Lines/mm (n):       200       Magnitude (m):       12         22       (explanatory notes and worked example)       Grating_Hininum height (H):       8,0       Magnitude (m):       12         24       SumMARY       Grating_Hininum height (H):       8,0       Magnitude (m):       12         25       Besolving power R       382       Besolving power (R):       382       Silt windth (W):       12,6         26       Spectral resolution       13,62       A       Resolving power (R):       382       Silt windth (W):       12,6         27       Wavelength range       8761       A       Spectral resolution (A):       13,62       A       Limiting Mag. (Bowen-mod):       15,36         26       GratingDiffraction order       1       Wavelength range       Magnitude (m):       12       Magnitude (m):       12         27       Wavelength range       816       Magnitude (M):       14       Limiting Mag. (Bowen-mod):       15,36	18						Collimator/Camera - I otal angle (7):	90	· .	Spectrum size/ spread				
20       See www.astrosurt.org/buil/usspe2/inresolf.htm       Grating-Lines/mm (n):       20         21       www.astrosurt.org/buil/usspe2/inresolf.htm       Grating-Lines/mm (n):       20         22       (explanatory.notes and worked example)       Grating-Lines/mm (n):       1         23       Grating-Minimum height (H):       8.0 mm       Effective temperature (Te):       1000 K         24       SumMARY       Grating-Minimum width (W):       12.0 Å       Magnitude (m):       12         25       Resolving power R       382       Balometric Correction (BC):       -0.4         26       Spectral resolution (1):       13,62 Å       Resolving power (R):       382       Singal/Noise (SNR):       37         27       Wavelength range       8761 Å       Spectral resolution (A):       13,62 Å       Limiting Mag.(Bowen-mod):       15.36         26       Grating-Mineum height (H):       8.0 m       Limiting Mag.(Bowen-mod):       15.36         27       Wavelength range       Rating-Lines/mm       Limiting Mag.(Bowen-mod):       15.36         28       Grating-Mineum height (H):       8.0 Å       EoS 450D:       Limiting Mag.(Bowen-mod):       15.36         29       Grating-Mineum height (H):       8.0 Å       EoS 4       EoS 450D:       EoS 450D: <td>19</td> <td>NOTES:</td> <td></td> <td></td> <td></td> <td></td> <td>Slit width (w) :</td> <td>25</td> <td>microns</td> <td>Height of Spectrum (n) :</td> <td>12</td> <td>pixel</td> <td></td> <td></td>	19	NOTES:					Slit width (w) :	25	microns	Height of Spectrum (n) :	12	pixel		
21       www.astrosurf.org/builus/stage/calcu/design_us.htm       Grating-Lines/ mm (h):       200       Larget sur         23       (explanatory notes and worked example)       Grating-Lines/ mm (h):       1       Magnitude (m):       12         23       SulMMARY       Grating-Unies/ mm (h):       200       Magnitude (m):       12         24       SulMMARY       Grating-Unies/ mm width (W):       12.2 mm       Bolometric Correction (BC):       -0.4         26       Spectral resolution       15.62 Å       Resolving power (R):       324       Signal/Noise (SIRR):       37         27       Wavelength range       8761 Å       Spectral resolution (A):       13.62 Å       Limiting Mag.       15.35         27       Grating-Diffraction order       1       Wavelength Range       Imition Mag.       15.35         28       Signal/Noise (SNR)       37       Lambda min. (11):       820 Å       EOS 4500: 185,19 px/mm         29       Grating-Diffraction order       1       Wavelength range / image frame:       8761 Å       SNR Calculations         31       Target Mag.       12,0       Lambda min. (11):       820 Å       EOS 4500: 185,19 px/mm       1         32       Signal/Noise (SNR)       37       Lambda max. (22):       SS60 Å <td< td=""><td>20</td><td>See www.astrosurf.org/bu</td><td>il/us/spe</td><td>e2/hresol</td><td>1.htm</td><td></td><td>Grating</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>	20	See www.astrosurf.org/bu	il/us/spe	e2/hresol	1.htm		Grating							
22       (explanatory notes and worked example)       Grating-Ultracton order (k):       12         23       SilMitARY       Grating-Ultracton order (k):       12         24       SilMitARY       Grating-Ultracton order (k):       12         25       Resolving power R       332       Dispersion (p):       2,6         26       Spectral resolution       13,62       A       Signal/Noise (SNR):       37         27       Wavelength range       8761       A       Spectral resolution (A):       13,62       A         26       Grating-Ultracton order       1       Spectral resolution (A):       13,62       A       Limiting Mag.(Bowen-mod):       15,36         27       Wavelength Range       Spectral resolution (A):       13,62       A       Limiting Mag.(Bowen-mod):       15,36         28       Grating-Ultracton order       1       Lambda min. (1):       620       A       EOS 450D: 185,19 px/mm       1         31       Target Mag.       2,0       Lambda min. (2):       9500       A       EOS 450D: 185,19 px/mm       1         32       Signal/Noise (SNR)       37       Vavelength range/ image frame:       8761       A       SNR Calculations       1         34       Transmission efficiency<	_21	www.astrosurf.org/buil/us/	stage/c	alcul/des	ign us.htm		Grating-Lines/ mm (n) :	200		larget Star				
23       Grating-Minimum height (h):       8,0 mm       Effective temperature (i (i):       10800 jk         26       Resolving power R       382       Grating-Minimum width (W):       12,26 År pixel       SNR       0         26       Spectral resolution 13,62 Å       Resolving power (R):       327       Signal/Noise (SNR):       37         27       Wavelength range       8761 Å       Spectral resolution (A);       13,62 Å       Limiting Mag.       37         27       Grating-Lines/ mm       200       Signal/Noise (SNR):       37       Limiting Mag.       15,36         27       Grating-Lines/ mm       200       Signal/Noise (SNR):       37       Limiting Mag.       15,36         28       Grating-Minimum width (1):       8200 Å       EOS 450D: 185,19 px/mm       15,36         29       Signal/Noise (SNR)       37       Lambda max. (2):       9580 Å       EOS 450D: 185,19 px/mm         29       Signal/Noise (SNR)       37       Lambda max. (2):       9580 Å       EOS 450D: 185,19 px/mm       16         20       A       EOS 450D: 185,19 px/mm       Enclosed max. (2):       9580 Å       Enclosed max. (2):       9580 Å         20       A       EOS 450D: 185,19 px/mm       Enclosed max. (2):       Sin Calculations	22	(explanatory notes and wo	rked ex	ample)			Grating-Diffraction order (k) :	1		Magnitude (m) :	12			
24       Grating-Mininum width (W):       12,2 mm       Beloometric Correction (BC):       -0,4         28       Resolving power (R):       32       SNR	23						Grating- Minimum height (H) :	8,0	mm	Effective temperature (Te) :	10800	к		
25         Resolving power R         382         Dispersion (p):         2,05 År pixel         SNR         sint           26         Spectral resolution         13,62 Å         Resolving power (R):         332         Signal/Noise (SNR):         37           27         Wavelength range         8761 Å         Spectral resolution (Δ2):         13,62 Å         Limiting Mag            26         Grating-Lines/mm         200         Dispersion (r):         39,4         Immun         Limiting Mag. (Bowen-med):         15,36           30         Sitt width         25         microns         Reference wavelength (A):         5200 Å         EOS 450D: 185,19 px/mm            31         Target Mag.         12,06         Lambda max. (2):         9550 Å             32         Signal/Noise (SNR)         37         Wavelength range/ image frame:         8761 Å         SNR Calculations            34         Throughput efficiency         Wavelength range / image frame:         8761 Å         SNR Calculations            35         Other Results         *         Throughput efficiency         SN background(E):         4,085-02           36         Angle of incidence (x):         49.22         *         Transmission eff	24	SUMMARY					Grating- Minimum width (W) :	12,2	mm	Bolometric Correction (BC) :	-0,4			
26       Spectral resolution (3): 362 A       Resolving power (R): 382       Signal/Noise (SNR): 37         27       Wavelength range (Bread)       Signal/Noise (SNR): 37       Signal/Noise (SNR): 37         28       Grating-Diffraction order 1       Wavelength Range       Limiting Mag (Bowen-mod): 15,36         29       Grating-Diffraction order 1       Wavelength Range       EDS 4500: 185,19 px/mm         31       Target Mag. 12,0       Lambda min. (1): 820 Å       EDS 4500: 185,19 px/mm         31       Target Mag. 12,0       Lambda mix. (2): 9560 Å       EDS 4500: 185,19 px/mm         32       Signal/Noise (SNR) 37       Wavelength range / image frame: 8761 Å       SIR Calculations         34       Throughput efficiency       Stok scarpound(G): 4,095-04 photons/cm2/s         35       Other Results       *       Throughput efficiency       Ski background(G): 4,095-04 photons/cm2/s         36       Angle of diffraction (B): -40,78       Transmission efficiency -Litrow mirror: 1       Useful signal (Mm): 8856 e-/pkel         37       Angle of diffraction (B): -40,78       Transmission efficiency-Colimator lens (To): 0,92       Background noise (N): 131 e-/pkel         38       Angle of diffraction (B): -40,78       Transmission efficiency-Colimator lens (To): 0,92       Background noise (N): 237 e-/pkel         39       diffraction imt grating, FW	25	Resolving power R	382				Dispersion (p) :	2,05	A/ pixel	SNR				
Vavelength range     8761 Å     Spectral resolution (A):     13,62 Å     Limiting Mag       29     Grating-Diffraction order     1     Dispersion (r):     39,4     Imm/mm       30     Sitt width     25     microns     Reference wavelength (J0):     5200 Å     EOS 450D: 185,19 px/mm       31     Target Mag.     2.0     Lambda min. (J1):     820 Å     EOS 450D: 185,19 px/mm       32     Signal/Noise (SNR)     37     Wavelength range/ image frame:     8761 Å       36     Other Results     *     Throughput efficiency     SNR Calculations       36     Angle of incidence (x):     49,22     *     Transmission efficiency guide system:     1       37     Angle of incidence (x):     49,22     *     Transmission efficiency Guimator Instructions (R):     0,12       38     Anage of incidence (x):     49,22     *     Transmission efficiencyColimator Instructions (R):     1,322       39     diffraction (M):     :0.66     microns     Transmission efficiency-Colimator Instructions (R):     0,12       39     diffraction inst grating, FWHMd : 5,38     microns     Transmission efficiency-Colimator Instructions (R):     0,22       39     diffraction (M):     :34,52     Transmission efficiency-Colimator Instructions (R):     0,36       39     diffr	26	Spectral resolution	13,62	A			Resolving power (R) :	382		Signal/Noise (SNR):	37			
28         Grating-Lines/ mm         200         Dispersion (r):         39.4         Limiting Mag.(Bowen-mod):         15.36           30         Grating-Lines/ infraction order         1         Wavelength Range         1	27	Wavelength range	8761	Å			Spectral resolution (Δλ):	13,62	Å	Limiting Mag				
Understand         Wavelength Range         Example           31         Sitt with         25         microns         Reference wavelength (J0):         5200 Å         EOS 4500: 185, 19 px/mm           31         Target Mag.         12,0         Lambda min. (A1):         820 Å         EOS 4500: 185, 19 px/mm           32         Signal/Noise (SIIR)         37         Wavelength range/ image frame:         3761 Å         SIR Calculations           34         Wavelength range/ image frame:         3761 Å         SIR Calculations         1, 638-02           36         Other Results         *         Throughput efficiency         Six background(Ci):         1, 638-02           37         Angle of Incidence (a):         49.22         *         Transmission efficiency- guide system:         1           38         Angle of Incidence (a):         49.22         *         Transmission efficiency- Guimator lens (To):         0,92           39         diffraction limit grating, FWHMd : 5,38         microns         Transmission efficiency-Colimator lens (To):         0,92           39         diffraction limit grating, FWHMd : 5,38         microns         Transmission efficiency-Guide system:         1           41         Entrance sit transmission of ficiency-Guide system:         0,82         Background noise (Nis):	28	Grating-Lines/ mm	200				Dispersion (r) :	39,4	nm/mm	Limiting Mag.(Bowen-mod):	15,36			
30       Sitt width       25       microns       Reference wavelength (/0):       5200 Å       EOS 450D: 185, 19 px/mm         31       Target Mag.       12, 00       Lambda mix. (1):       82:00 Å       EOS 450D: 185, 19 px/mm         32       Signal/Noise (SNR)       37       Lambda max. (2):       9580 Å       Market Mag.       1       Final Efficiency         33       Other Results       *       Throughput efficiency       Sint Calculations       Mumber of photons (E):       1,63E-02         36       Other Results       *       Throughput efficiency       Sity background(Ed):       4,09E-04       photons/cm2/s.         37       Angle of incidence (x):       49.22       *       Transmission efficiency-due writer:       1       Final Efficiency (8):       0.12 %         38       Anamorphic factor (1):       0.86       microns       Transmission efficiency-Camera lens (Tc):       0,92       Background noise (Ns):       131 efficiency (1):         39       diffraction limit grating, FWHM:       5.38       microns       Transmission of ficiency-Camera lens (Tc):       0,92       Noise from Electronics :       237 e-         40       Silvi mage width on CCD, FWHMI:       34.52       Teatsmission of Spectrograph (Ts):       0,71       Noise from Electronics :       216 e-/pixe	29	Grating-Diffraction order	• 1				Wavelength Range							
31       Target Mag.       12,0         25       Signal/Noise (SNR)       37         32       Signal/Noise (SNR)       37         34       Wavelength range/ image frame:       8761 Å         34       Number of photons (E):       1,638-02         36       Other Results       *         37       Angle of incidence (x):       49.22 *         38       Angle of diffraction (B):       -40,78         39       Transmission efficiency-ultrow mirror:       1         38       Anamorphic factor (r):       0,68         39       diffraction imit grating, FWHMd :       5,38         41       Fransmission efficiency-Colimator lens (To) :       0,92         42       Transmission efficiency-Colimator lens (To) :       0,92         43       Transmission efficiency-Colimator lens (To) :       0,92         44       Transmission efficiency-Colimator lens (To) :       0,92         44       Transmission efficiency-Colimator lens (To) :       0,92         45       Total Transmission of Spectrogra	30	Slit width	25	microns			Reference wavelength (\lambda 0) :	5200	Å	EOS 450D: 185,19 px/mm				
22       Signal/Noise (SNR)       37         33       Characterization       9500 Å         34       Wavelength range/ image frame:       8761 Å         35       Other Results       *         36       Angle of incidence (x):       49.22 *         37       Angle of incidence (x):       49.22 *         38       Angle of incidence (x):       49.22 *         39       Transmission efficiency- guide system:       1         38       Anamorphic factor (r):       0.66         39       diffraction [kh]:       -40.78         37       Angle of incidence (x):       49.22 *         38       Anamorphic factor (r):       0.66         39       diffraction [kh]:       -40.78         39       diffraction [kh]:       -40.78         30       Transmission efficiency-Colimator lens (To):       0.52         30       Background noise (kh3):       131         31       Transmission efficiency-Grating (Tg):       0.62         32       Transmission of ficency-Grating (Tg):       0.62         31       Transmission of Spectrograph (Ts):       0.61         32       Total Transmission of Spectrograph (Ts):       0.36         33       Total T	31	Target Mag.	12,0				Lambda min. (λ1):	820	Å					
33     Wavelength range/ image frame:     8761     A     SNR Calculations       34	32	Signal/Noise (SNR)	37				Lambda max. (\.2) :	9580	Å					
34     Number of photons (E):     1,83:-02 photons/cm2/s       35     Other Results     *     Throughput efficiency       36     Angle of incidence (a):     49,22     *       37     Angle of diffraction (B):     -40,78     Transmission efficiency- guide system:     1       38     Anamorphic factor (r):     0.86     microns     Transmission efficiency-follmator lens (To):     0.92       39     diffraction (Imt grating, FWHMd :     5,38     microns     Transmission efficiency-Collmator lens (To):     0.92       39     diffraction (Imt grating, FWHMd :     5,38     microns     Transmission efficiency-Collmator lens (To):     0.92       41     SignalWoles by Interval A):     96     e-/pixel       42     Total Transmission of Spectrograph (Ts):     0.36       43     Cotal Transmission of Spectrograph (Ts):     0.36       44     44     45     46	33						Wavelength range/ image frame:	8761	Å	SNR Calculations				
35       Other Results       *       Throughput efficiency       Sky background(Ed):       4,09E-04 [photons/cm2/s         36       Angle of Incidence (a):       49.22       *       Transmission efficiency- guide system:       1       Final Efficiency (R):       0,12       %         37       Angle of Incidence (a):       49.22       *       Transmission efficiency-cutrow mirror:       1       Useful signal (Nm):       8856 e-/pixel         38       Anage of Indication (B):       40.76       Transmission efficiency-Cutrow mirror:       1       Useful signal (Nm):       8856 e-/pixel         39       diffraction limit grating, FWHMI:       5,38       microns       Transmission efficiency-Camera lens (Tc):       0,92       Background noise (Ns):       131 e-/pixel         40       Sit/ image width on CCD, FWHMI:       34.52       Transmission efficiency-Camera lens (Tc):       0,92       Noise(c):       237 e-         42       Total Transmission of Spectrograph (Ts):       0,71       Noise from Signal :       95       -         43       Total Transmission of Spectrograph (Ts):       0,36       Noise from Electronics:       216 e-/pixel         44       FWISION:       Hold advance dat       Hold advance dat       Hold advance dat       -         48       Hold advance dat	34									Number of photons (E) :	1,63E-02	photons/cm	12/s/Å	
36       Angle of incidence (a): 49.22 *       Transmission efficiency-guide system:       1       Final Efficiency (R):       0.12 %         37       Angle of diffraction (b):       -40,78       Transmission efficiency-Litrow mirror:       1       Useful signal (Nm):       8856 e-/pkel         38       Anamorphic factor (r):       0.86       microns       Transmission efficiency-Colimator lens (To):       0,92       Background noise (Ns):       131 e-/pkel         39       diffraction imit grating, FWHMd :       5,38       microns       Transmission efficiency-Colimator lens (To):       0,92       Background noise (Ns):       131 e-/pkel         41       SB/ image width on CCD, FWHM :       34,52       Transmission efficiency-Garate lens (To):       0,62       Noise(o):       227 e-         42       Total Transmission of Spectrograph (Ts):       0,71       Noise from Signal :       95         43       Total Transmission of Spectrograph (Ts):       0,36       Noise from Electronics:       216         45       Entrance       Hold space metric       Hold space metric       Hold space metric       Hold space metric         46       EVISION:       Hold space metric       Hold space metric       Hold space metric       Hold space metric	35	Other Results			•		Throughput efficiency			Sky background(Ed) :	4,09E-04	photons/cm	2/s/Å/ ar	c sec
37     Angle of diffraction (β):     -40,78     Transmission efficiency -Littrow mirror:     1     Useful signal (Nm):     8856     e-/pkel       38     Anamorphic factor (r):     0,88     microns     Transmission efficiency-Clittrow mirror:     1     Useful signal (Nm):     8856     e-/pkel       39     diffraction imit grains, FWHMB:     3,38     microns     Transmission efficiency-Camera lens (Tc):     0,92     Background noise (Ns):     131     e-/pkel       40     Sil/ image width on CCD, FWHMI:     34,52     Transmission efficiency-Grating (Tg):     0,6     Signal/Noise by interval Δλ:     96     e-/pixel       41     Entrance silt transmission of Spectrograph (Ts):     0,36     Noise from Signal :     95     e-/pixel       42     Total Transmission of Spectrograph (Ts):     0,36     Noise from Electronics:     216     e-/pixel       43     Etransmission of Spectrograph (Ts):     0,36     Noise from Electronics:     216     e-/pixel       44     Etransmission of Spectrograph (Ts):     0,36     Noise from Electronics:     216     e-/pixel       46     EVISION:     Evision     Entrance sit     Entransmission     Entransmission     Entransmission	36	Angle of inciden	ice (a) :	49,22	•		Transmission efficiency- guide system:	1		Final Efficiency (R) :	0,12	%		
38     Anamorphic factor (r):     0.86     microns     Transmission efficiency-Colmera lens (To):     0.92     Background noise (Ns):     131 le-/pkel       39     diffraction limit grating, FWHMd :     5.38     microns     Transmission efficiency-Camera lens (Tc):     0.92     Noise(o):     237 le-       41     Signal/Noise by interval Δλ :     96 e-/pixel     Transmission efficiency-Camera lens (Tc):     0.71     Noise from Signal :     96 e-/pixel       42     Total Transmission of Spectrograph (Ts):     0.36     Noise from Electronics:     216 e-/pixel       43     Table     Total Transmission of Spectrograph (Ts):     0.36     Noise from Electronics:     216 e-/pixel       45     Table     Table     Table     Table     Table     100 feb/pixel	37	Angle of diffracti	ion (β) :	-40,78			Transmission efficiency -Littrow mirror:	1		Useful signal (Nm) :	8856	e-/pixel		
39     diffraction limit grating, FWHMd : 5,38     5,38     microns     Transmission efficiency-Camera laws (Tc) : 0.52     Noise(o) : 227 [e-       40     Sil/ image width on CCD, FWHMt : 34,52     Transmission efficiency-Grating (Tg) : 0.5     Signal/Noise by interval Δλ : 96 [e-/pixel]       41     Entransmission of Spectrograph (Ts) : 0.56     Noise from Signal : 95 [e-/pixel]       43     Total Transmission of Spectrograph (Ts) : 0.36     Noise from Electronics : 216 [e-/pixel]       44     Entransmission of Spectrograph (Ts) : 0.36     Noise from Electronics : 216 [e-/pixel]       45     Entransmission of Spectrograph (Ts) : 0.36     Noise from Electronics : 0.36	38	Anamorphic fac	ctor (r) :	0,86	microns		Transmission efficiency-Collimator lens (To) :	0,92		Background noise (Ns) :	131	e-/pixel		
40       Sit/ image width on CCD, FWHMt : 34,52       Transmission efficiency-Grating (Tg) : 0.6       Signal/Noise by interval Δλ.: 96 (e-/pixel)         41       Entrance sit transmission(Tf): 0,71       Noise from Signal : 95         42       Total Transmission of Spectrograph (Ts) : 0,36       Noise from Electronics : 216         43       Filter State	39	diffraction limit grating, FI	WHMd :	5,38	microns		Transmission efficiency-Camera lens (Tc) :	0,92		Noise(o) :	237	e-		
41     Entrance sit transmission(Tf):     0,71     Noise from Signal :     95       42     Total Transmission of Spectrograph (Ts):     0,36     Noise from Electronics :     216       43     44     44     44     44     44     44       45     46     46     46     46	40	Slit/ image width on CCD, F	WHMt :	34,52			Transmission efficiency-Grating (Tg) :	0,6		Signal/Noise by interval Δλ:	96	e-/pixel		
42     Total Transmission of Spectrograph (Ts):     0,36     Noise from Electronics:     216     e-/pixel       43     44     45     46     46     46     46     46	41						Entrance slit transmission(Tf):	0,71		Noise from Signal :	95	-		
43 44 45 46 REVISION:	42						Total Transmission of Spectrograph (Ts):	0,36		Noise from Electronics :	216	e-/pixel		
44 45 46 REVISION:	43													
45 <b>6 REVISION:</b>	44													
46 REVISION:	45													
17 VAR And 10040 How book Added Bate Book Hended and the	46	REVISION:												
47 V4.0 - April 2012 New layout. Added Data Page. Updated comments	47	V4.0 - April 2012	New la	ayout. Ad	dded Data I	Page.	Updated comments							
48 V3.3a -Jan 2012 Collimator focal ratio set to match telescope. Camera focal ratio no longer an input.	48	V3.3a -Jan 2012	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 sitestar)	49	V3.3 -May 2011	May 2011 Corrections to the equation for FWHMt (incorrectly calculated for slit <star)< td=""><td></td><td></td><td></td><td></td><td></td><td></td></star)<>											
50 V3.2c-Oct 2010 -Sitt width now in micron	50	V3.2c-Oct 2010	Oct 2010 -Sit width now in micron											
51 V3.2b -July 2010 Transmission efficiencies added for guider and Littrow mirror	51	V3.2b -July 2010	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.	52	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	53	-SNRcalculations amended to follow CAOS formulae												
54 -Bowen magnitude now based on spectrum width and units corrected.	54													

http://www.astrosurf.com/buil/us/compute/SimSpec\_V4\_o.xls

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



- ist 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

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### 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

 $\alpha$  Orionis (Betelgeuse), M2Iab



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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 <a href="http://www.fitswork.de/software/softw\_en.php">http://www.fitswork.de/software/softw\_en.php</a>
- Start Fitswork





# Stacking/calibration of stellar spectra from a Canon DSLR camera

### Step 2: Spectrum stacking with Fitswork → Settings

Settings 🛛 🔀	Settings 🔀
Load       Save       Math       Image display       Various       Sys         ✓       Show Image Preview         □       Convert Color Images to YUV after Loading         ✓       Loading and Saving FITS Files: Flip Image         Camera Raw:         ✓       Debayer Raw Images         □       Dont RGB Scale not Debayered Raw Images         □       Keep Raw Highlights	Load       Save       Math       Image display       Various       Sys         Save FITS Files as:       Extention of FITS Files:         32 bit Floating Point       • *.Fit         32 bit Integer       • *.Fit         • 16 bit Integer       • *.Fts         JPEG Quality: 100 (Ctrl + J)         PNG Lossless Compression:       9         09 (Higher -> Better Compression, Slower)         Scale TIFF Images Automatic
Settings       Image display       Various       Sys         General Interpolation Method       Image Division Method       NoHalo         Neuronal (slow)       Lanczos3         Image Division and Multiplication       Scale Result (standard)         Scale PSF Images Automatic         Hotpixel Removement in Image Subtraction: Sigma       4.0         Network Initialization: Random       1.0         Automatic 2D FFT Interference Filter: Sigma       2.0         2D FFT outer Border for reducing Artefacts:       8	Settings       Image display       Various       Sys         Load       Save       Math       Image display       Various       Sys         Automatic Histogram Scaling       Black:       1       %         White:       99.99       % from Histogram         Set Blacklevel always to 0       Image display       Adjust Gamma on Images with more than 8 Bit

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\_CR**2

File  $\rightarrow$  Batch Processing

₹ <b>s</b> F	itswork				
File	Processing	Image Combining	Settings	Window	Help
0	Open				
0	Close				
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ŧ	Batch Process	ing			
	<del>4asterdark/ f</del>	at Combining			
ا %	F Image Regi	stration			
N 1	Make User Ra	w Format			
1	ast Processin.	gs			
E	Exit Program				

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. Step of Processing

D

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

1. SPECIFY FILES Start File Destination File	Specify Files	Öffnen 🛛 🔀 Suchen in: 🔁 2_Spektra_raw_images_CR2 🔍 🔶 🖆 📸 📰 •
All Files in Folder	Start File Destination File 2 3 0 V All Files in Folder Skip absent Files from Series	Suchen in:       2.Spektra_raw_images_CR2 <ul> <li></li></ul>
	Start <u>C</u> ancel	Dateityp: All Formats  Abbrechen



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]  $\rightarrow$  Add to destination image  $\rightarrow$  Planet/Moon
- $\rightarrow$  Crosscorrelation  $\rightarrow$  Number of Marks  $\rightarrow$  Function: Mid. (means average)
- $\rightarrow$  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.

Please mark an Area and	<u>O</u> k, go on	Add to Des	tination	Image
click afterwards on "Uk, go on"!	<u>Skip Image</u>	w_images_CR2	'\Betelgeus	e_01.CR2
No more Controlling	<u>C</u> ancel		Pause	<u>C</u> ancel



## 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  $\rightarrow$  Image Geometry  $\rightarrow$  Rotate image with Subsidiary Line





Stacking/calibration of stellar spectra from a Canon DSLR camera

### 

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







Stacking/calibration of stellar spectra from a Canon DSLR camera

Step 4: Fit	swork –	Crop &	save
-------------	---------	--------	------

- $\rightarrow$  Draw a yellow frame around the spectrum
- → Cut off → Save as "**Result\_image\_color\_16bit.fit**"

Result_image_colour_16bit.fit
FITS
16 bit Integer

Fitswork	
File Processing Image Combining Settings Unndow help	
C:\Dokumente und Einstellungen\astrofoto\Desktop\Betelgeuse_200L_2010-12-15\2_Spektra_raw_images_CR2\Result_image.fit	

Stacking/calibration of stellar spectra from a Canon DSLR camera

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

Processing  $\rightarrow$  Color image to b/w (luminance)



#### Save as → "Result\_image\_mono\_16bit"

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**•** |



Stacking/calibration of stellar spectra from a Canon DSLR camera

# Step 5: VisualSpec (VSpec) – Spectrum calibration

- VSpec Software Download: <u>http://valerie.desnoux.free.fr/</u>
- 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





#### Step 5: VisualSpec (VSpec) - Preferences

5.1 Open VSpec



5.2 Options  $\rightarrow$  Preferences  $\rightarrow$ Working directory "<u>3\_Results</u>" Image  $\rightarrow$  .fits and Profile  $\rightarrow$  .spc

BeSS (2)	
Continuum	
B s (*.fit) ic (*.pic) c (*.spc) ts (*.fit)	

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  $\rightarrow$  All set to "Auto"  $\rightarrow$  OK  $\rightarrow$  Close





Infos...

Reset

b1: 265.11 b2: 264.83

angle: -0.01 \*

# Stacking/calibration of stellar spectra from a Canon DSLR camera

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

#### 5.5 Press 🔲 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.o.pdf

Stacking/calibration of stellar spectra from a Canon DSLR camera



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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)



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# 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  $\rightarrow$  Replace  $\rightarrow$  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  $\rightarrow$  Continuum.spc





# Stacking/calibration of stellar spectra from a Canon DSLR camera

## Step 5: Visual Spec (VSpec) – Continuum division

5.15 File  $\rightarrow$  Open profile  $\rightarrow$  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  $\rightarrow$  Divide profile by profile  $\rightarrow$  Click on: continuum.spc  $\rightarrow$  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:



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## Stacking/calibration of stellar spectra from a Canon DSLR camera

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

5.19 Edit  $\rightarrow$  Replace  $\rightarrow$  Intensity 5.20 Save as  $\rightarrow$  "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





# 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





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

6.2 Synthese[sic]  $\rightarrow$  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



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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  $\rightarrow$  Instrumental response [sic] assistant 7.3 Pickles  $\rightarrow$  Press on green arrow button  $\rightarrow$  Open "m2i.dat" (= Class M2I)

	Öffnen					? 🗙
Instrumental response assistant	Suchen in:	🗀 LibSpec		•	+ 🗈 💣 🎟 -	
age_result_wavecal.spc (optional) Spectral type Search spectral type on SIMBAD  Select reference spectrum  Pickles C UVES C Milles	Zuletzt verwendete D Desktop	g0iii.dat g0iv.dat g0v.dat g2i.dat g2iv.dat g2v.dat g2v.dat g2i.dat	g8iv.dat g8v.dat k0ii.dat k0iv.dat k0v.dat k0v.dat k01ii.dat k1ii.dat	國 k3iv.dat 國 k3v.dat 國 k4i.dat 國 k4ii.dat 國 k4v.dat 國 k5iii.dat 國 k5v.dat	m2i.dat m2i.dat m2i.dat m2i.dat m2v.dat m3ii.dat m3ii.dat m3ii.dat m3v.dat	m7ii.dat m8ii.dat m9ii.dat mm10ii.d rf6v.dat rf8v.dat rf8v.dat
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Division and extraction	Arbeitsplatz	<				>
Save Save response in file:	Netzwerkumgeb ung	Dateiname: Dateityp:	m2i.dat dat (*.dat) Schreibgesc	chützt öffnen	•	Öffnen Abbrechen
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

• Visual Spec	E
ile Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?	
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×   ★ 柔   <u>本</u>   <u>本</u>	
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-736380	
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613650	📮 Instrumental response assistant 🛛 🗙
	image result unused and
	inage_resuit_wavecal.spc
-552285	(optional) Spectral type
	Search spectral type on SIMBAD
ALTING VIENDER AND A	
490920 WV V V V V V V V V V V V V V V V V V V	Select reference spectrum
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w l Ward al	C Elodie C Milles 2
429555	
	(optional shift
	Wavelength shift
368190	Deserves
	Response
	Division and extraction
306825	
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245460 I A A I A A A A A A A A A A A A A A A	Save response in file:
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4570 4840 5110 5380 5650 5920 6190	6460 6730 7000 7270

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



Stacking/calibration of stellar spectra from a Canon DSLR camera

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

🗸 intensity

💌 🤣 🗖 blue

7.7 Erase graphic  $\rightarrow$  Edit  $\rightarrow$  Replace: Intensity 7.8 File  $\rightarrow$  Save as  $\rightarrow$  "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)



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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"



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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  $\rightarrow$  Edit  $\rightarrow$  Replace: Intensity

7.13 File  $\rightarrow$  Save as  $\rightarrow$  "Betelgeuse\_final\_spectrum.spc"



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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



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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" <u>▲</u>
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  $\rightarrow$  Auto Planck (black line)



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

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

 $\lambda_{max}$ : 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]  $\rightarrow$  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]  $\rightarrow$  Colorer [sic]  $\rightarrow$  Creates a synthetic color spectrum for presentation





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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





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



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### 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.<sup>[1]</sup>

#### 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

V3.5E © Bernd Koch | b.koch@baader-planetarium.de



### 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 <u>during</u> exposure. Note the changes in spectral resolution due to the different slit widths.



# Calibration with a Ne/Xe plasma tube from Conrad Electronic



Kalibrierung mit Ne/Xe-Plasmaröhre [1] und NIST Atomic Spectra Database [2]

- [1] www.conrad.de/ce/de/product/591136/Magic-Plasma-Roehre-Lichteffekt? query From Suggest=true.
- [2] http://physics.nist.gov/PhysRefData/ASD/lines\_form.html



#### V3.5E © Bernd Koch | b.koch@baader-planetarium.de

Bernd Koch 2013-09-16





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 H $\alpha$ :

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

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

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





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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 H $\alpha$ :

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

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

Ref.: www.ursusmajor.ch/downloads/analysis-andinterpretation-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

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## Spectroscopy of Be star γ Cas

- 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  $\gamma$  Cas on the middle of the three slits (25  $\mu$ m) for highest resolution
- > The slit's length should be parallel to Deklination ( $\delta$ ) direction
- > Center spectrum on H $\alpha$  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  $\gamma$  Cas

Ha





- 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 ( $\delta$ ) direction
- > Center spectrum on H $\alpha$  or H $\beta$  by turning the micrometer adjustment
- Keep exposure time well below saturation of sensor (1s to about 6os)
- 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)

Hβ





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: 1205. 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

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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



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

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#### Spectrum of Be star ζ Tau



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) V3.5E © Bernd Koch | b.koch@baader-planetarium.de 106



Credit: Gemini Observatory Illustration by Jon Lomberg

### Spectrum of ζ Tau, spectral class Be





### 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





### 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 ....

 $\alpha$  Lyr (Vega) – Spectral Class AoV

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





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 ....

네셜 Visual Spec		
File Edit Format Operations Spectrometry Radiometry	y Tools Assistant Window Options ?	DADOS 200 lines/mm & SBIG ST-8300M (Bernd Koch)
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$\alpha$ Ac	<b>μl (Altair) – Spectral C</b>	Class A7V
4465 52	5995	6760 7525 8290
🛋 atair 1×1 -20c 60-004 wavecal-pseudocontinuum-normiert.spc: intensity		

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 (<u>buynoski@batnet.com</u>), who does visual spectroscopy for presentation to schoolchildren, for his helpful review and proofreading of this tutorial.

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