BACHES

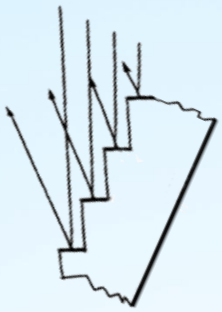
Echelle Spektrograph

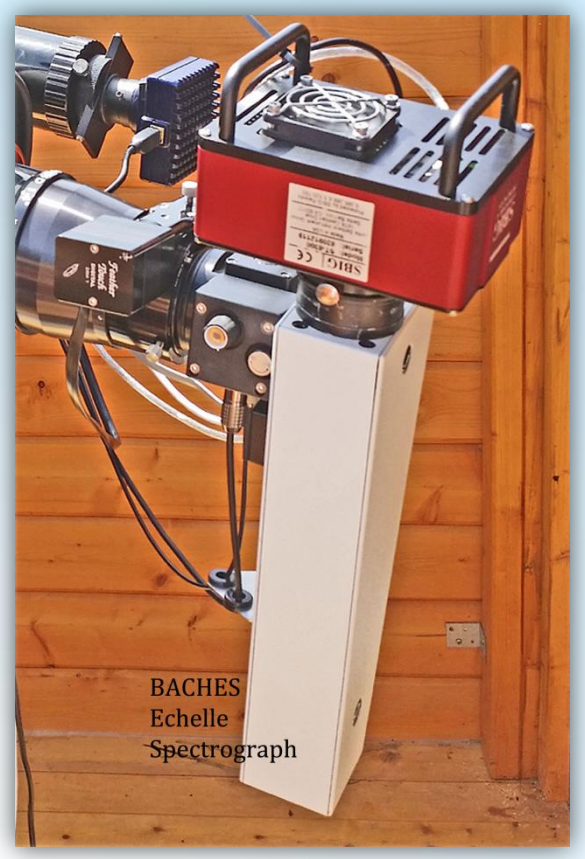
and Remote Calibration Unit

ATT Essen May 21, 2016 | Bernd Koch | Baader Planetarium GmbH

The BACHES Echelle Spectrograph

- ✓ BACHES is the acronym for BAsic ECHElle Spectrograph
- ✓ „Echelle“ is a french word, which means „ladder“
- ✓ Developed by ESO Scientists and Baader Planetarium GmbH

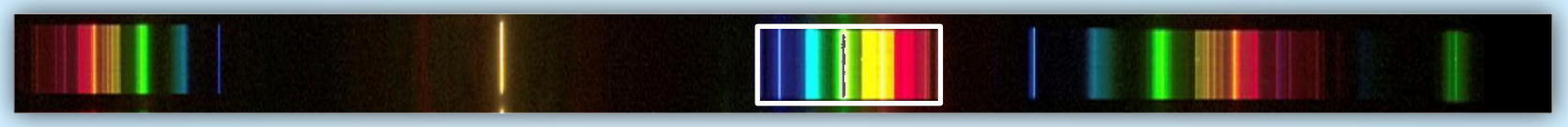




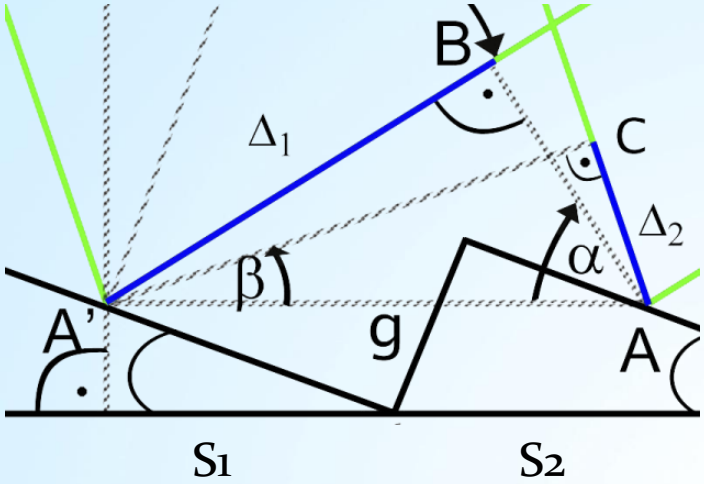
A conventional Blazed Grating Spectrograph

Designed for maximum efficiency in the first order

Higher orders order not useable due to overlap



Fluorescent lamp



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.

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

g: Groove spacing, m: Order number

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A conventional Blazed Grating Spectrograph

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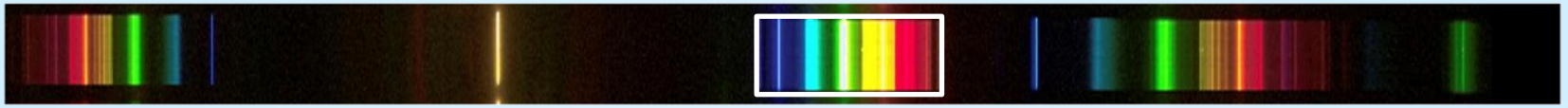
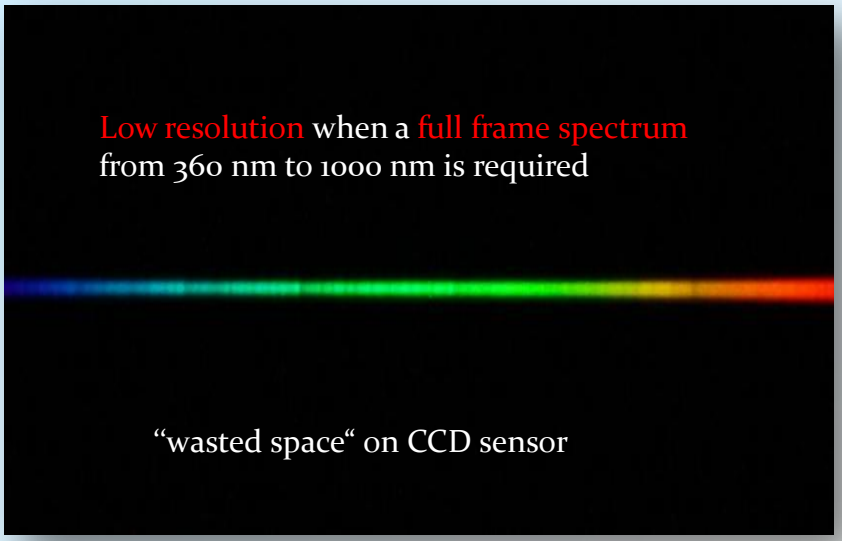
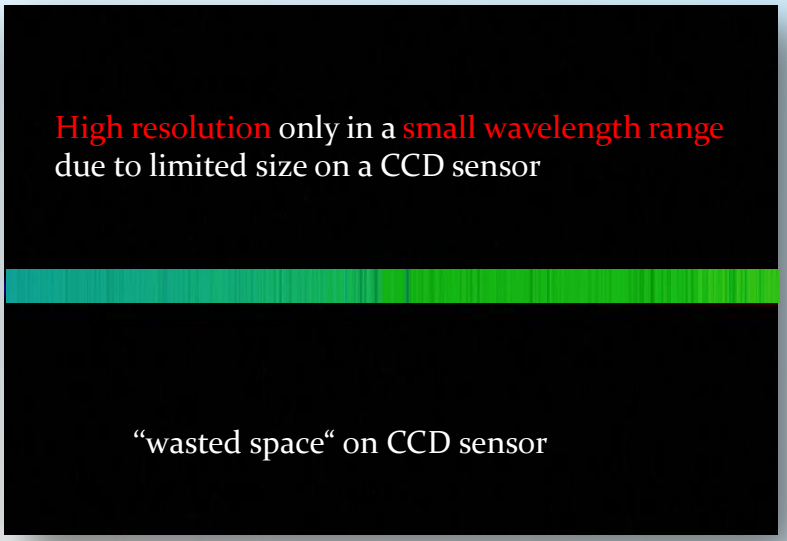


First order | Zero order | First order | Second order | Third order

Fluorescent lamp





The Echelle Optical Path

Incoming light

High resolution spectrum separated from about 390 nm(top) to 760 nm (bottom)

BACHES echelle grating in high order

Mixed color:
Cross Disperser separating the orders ca. #33 to ca. #58

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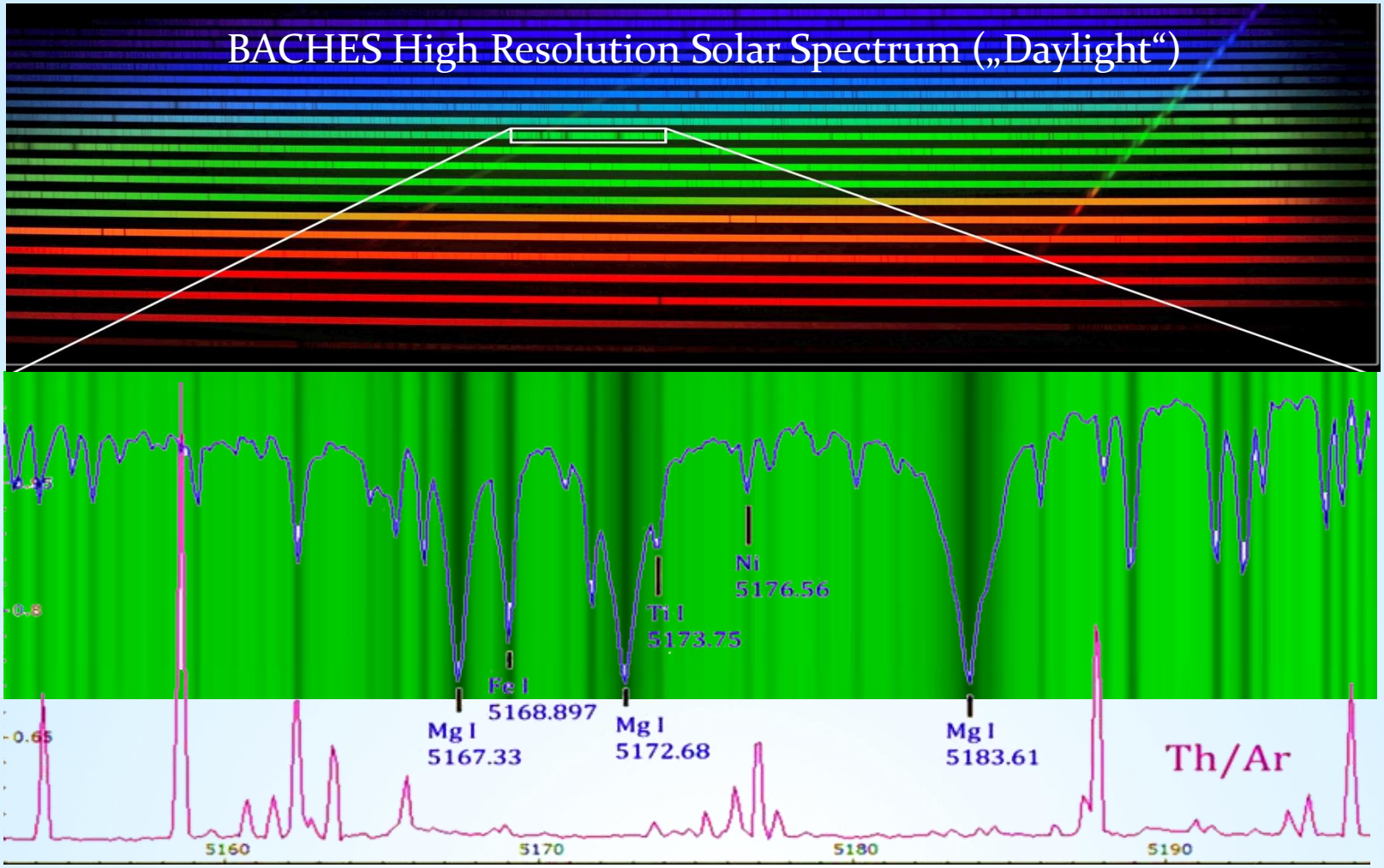
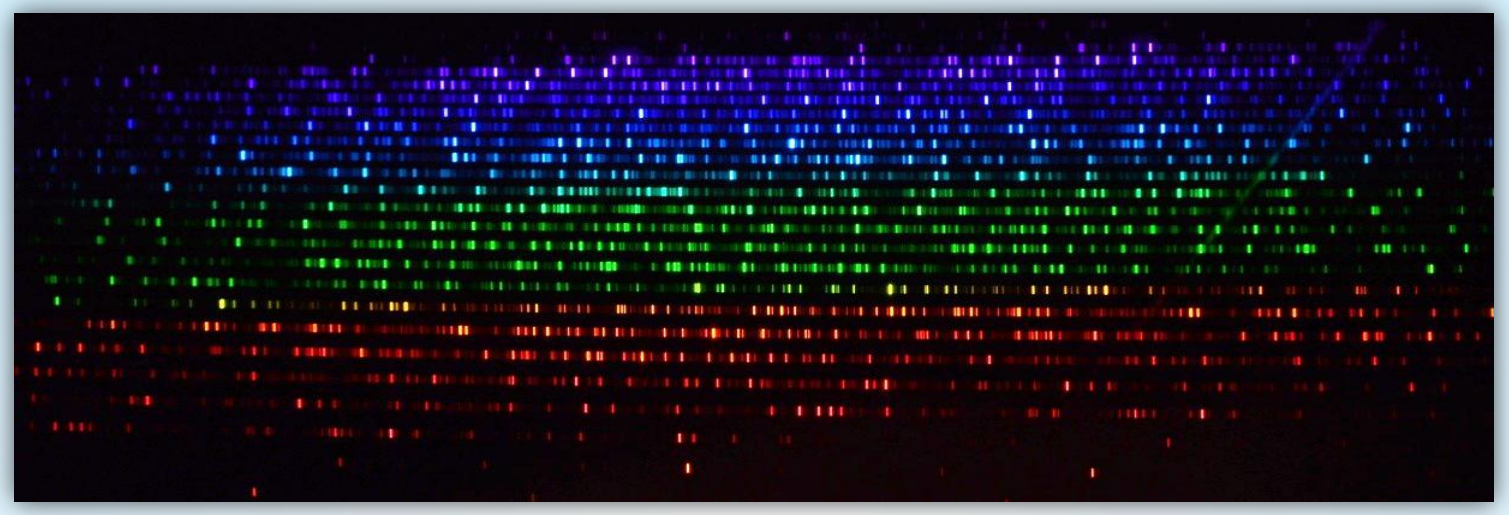


BACHES Considerable Advantages

- High average spectral resolution R = 18 000
- Complete spectrum from about 392nm to 800nm can be captured with a single exposure (depends on size of the sensor)
- Constant focus over a wide temperature range
- Spectra lines perpendicular to spectral orders. No slanted lines
- Spectral orders almost parallel to each other



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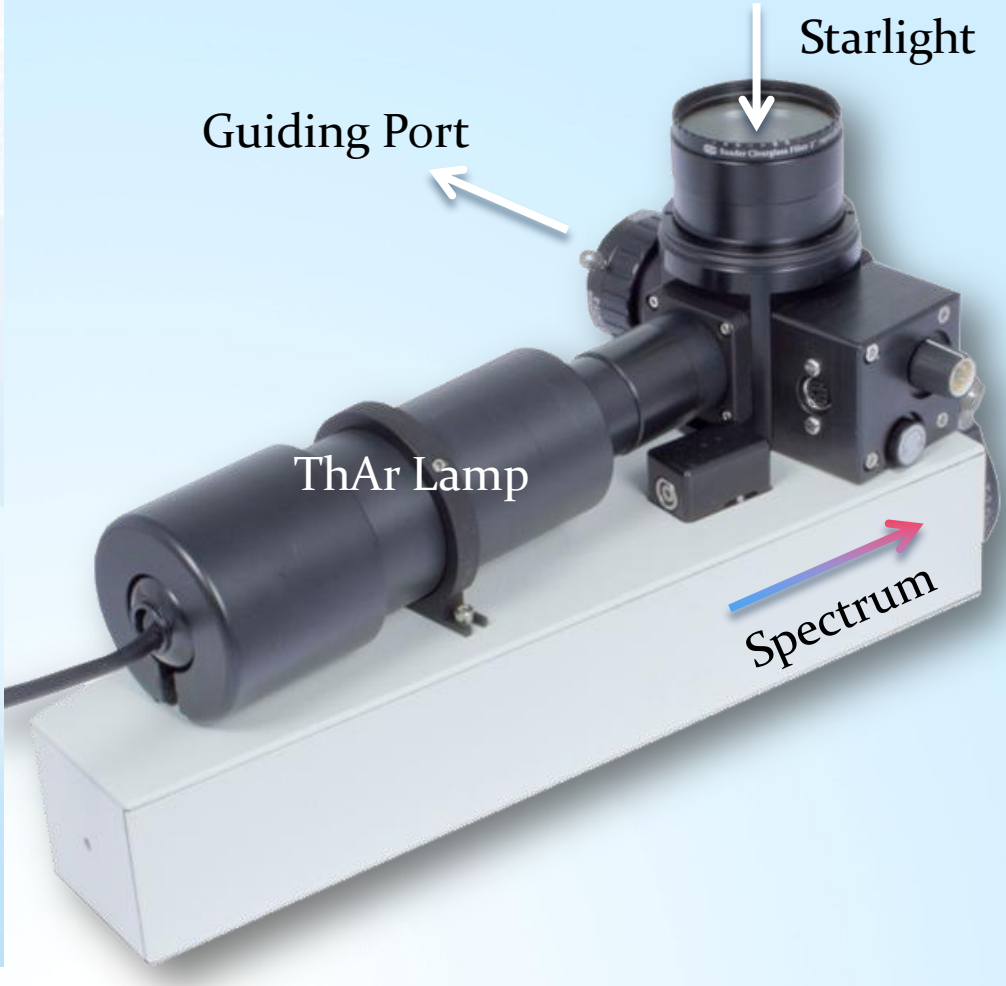
BAADER BACHES ECHELLE-SPECTROGRAPH

High Resolution Echelle Spectrograph with Autoguiding Port and Remote Calibration Port

- average spectral resolution **R = 18,000**
- optimized wavelength range **392-800nm***
- changeable **25 and 50µm** slits. Slit length 125µm
- light and compact, **only 1350g** (without CCD camera)
- high mechanical stability, FE designed, **torsion deformation below 9µm** at 180° rotation
- optimized for sensor sizes **ca. 15x10mm, 9µm Pixel** (i.e. KAF-1603), usable with 7x4mm sensor sizes (i.e. ST-402) and **DSLR's**
- collimator focal ratio **f/10**
- optimized for 8" to 24" **f/10 telescopes** (full resolution from f/8 to f/12)
- delivered in **calibrated condition**
- solenoid switches between the **light from the telescope** and the **ThAr calibration and flatfield lamp** of the RCU
- manual red LED for **Slit-Focusing**
- **two optional BACHES calibration versions available:** ***Standard*** with ThAr lamp mounted on BACHES body (with separate power supply). ***Professional*** with Remote Calibraion Unit (RCU) with built-in ThAr lamp and halogen flatfield lamp remotely controlled via web interface

* depending on the size of the sensor

BACHES Calibration Version *Standard*



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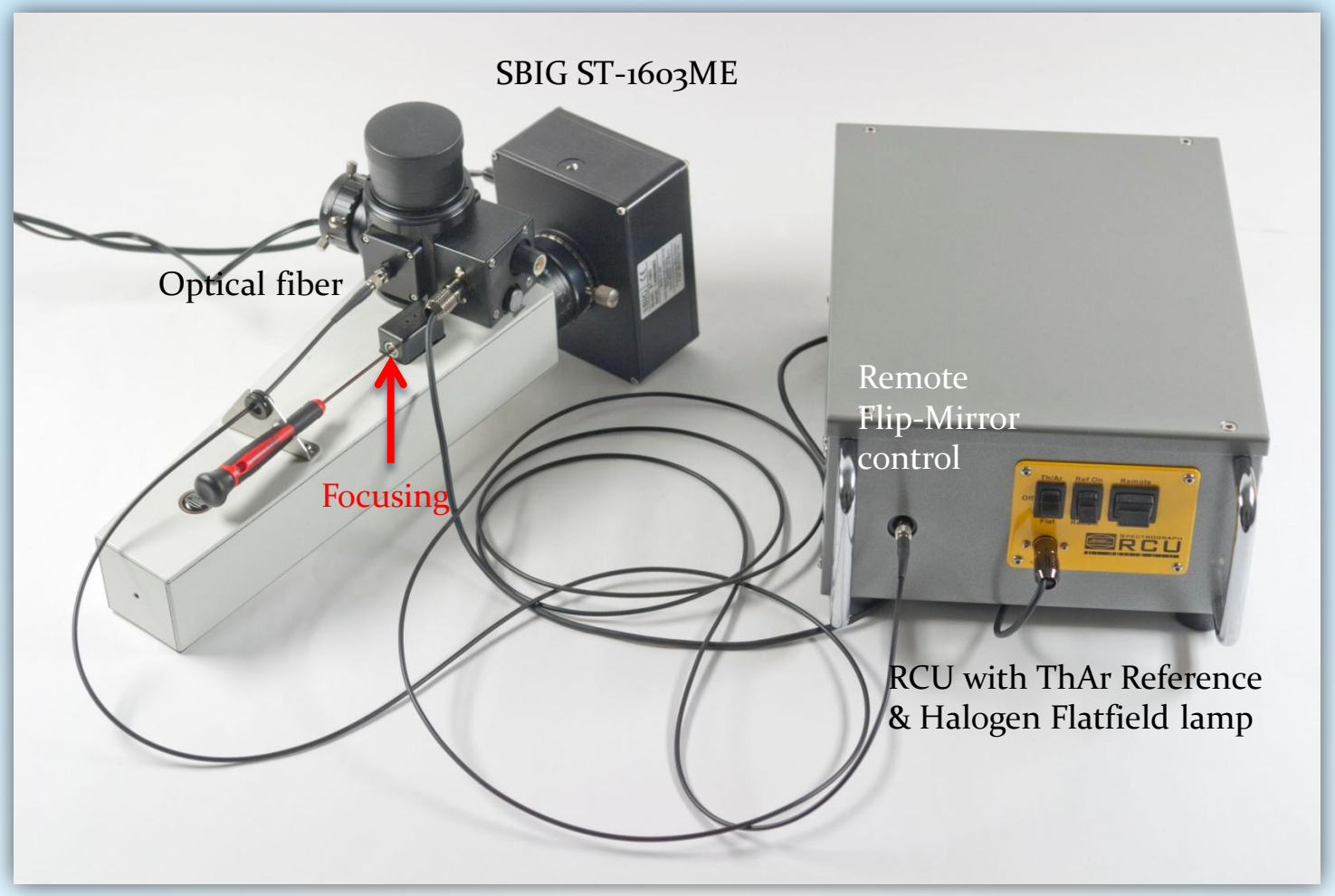
BACHES Calibration Version *Professional* with Remote Calibration Unit RCU



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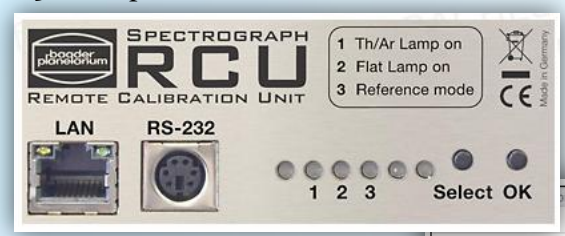
Echelle Spektrograph
and Remote Calibration Unit

1. Glass fiber coupler
2. Power connector for motor
3. Three position switch for OFF, Th/Ar ON, or flat-field ON
4. Two position switch for coupling calibration mirror in BACHES
5. Two position switch to select remote and manual operation



Rear panel

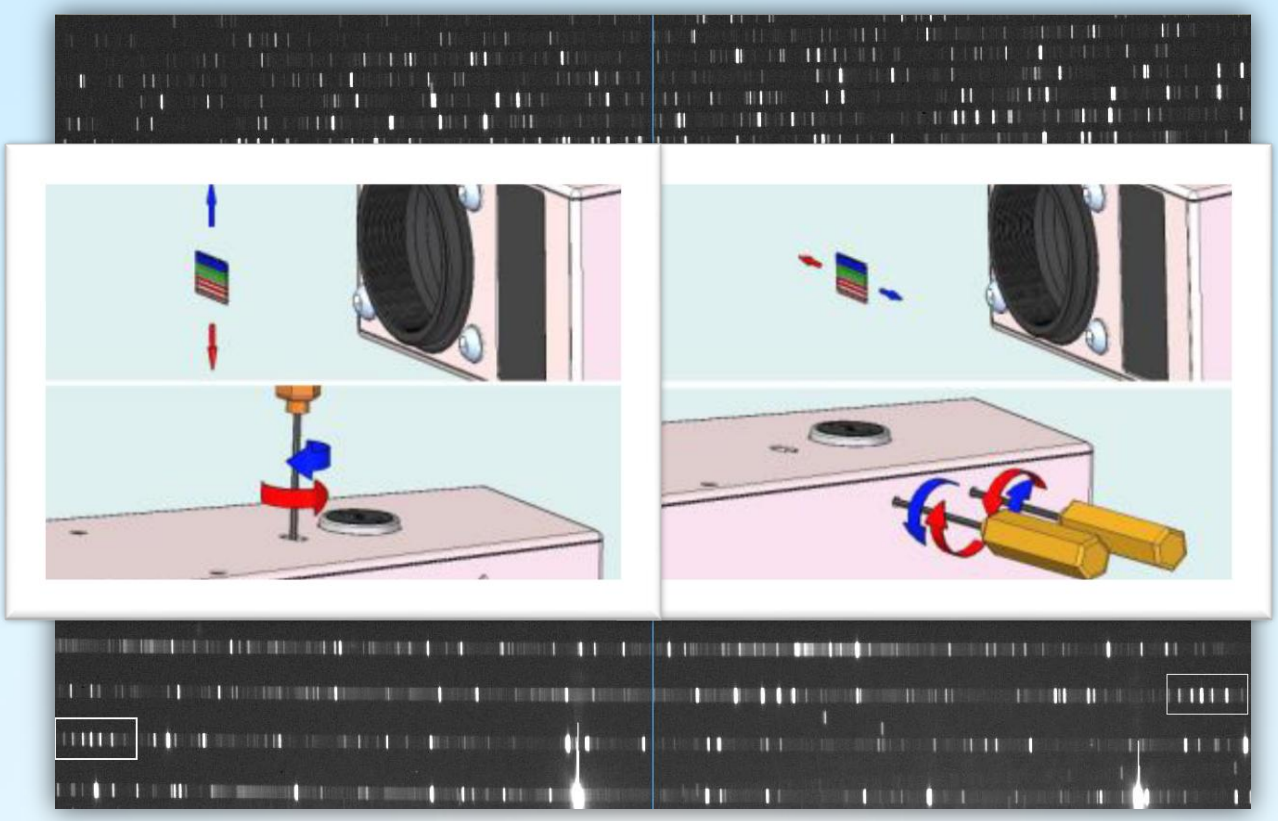
Remote control by Internet Browser

SPECTROGRAPH RCU
REMOTE CALIBRATION UNIT

Accurate and Professional Calibration of BACHES Echelle-Spectra

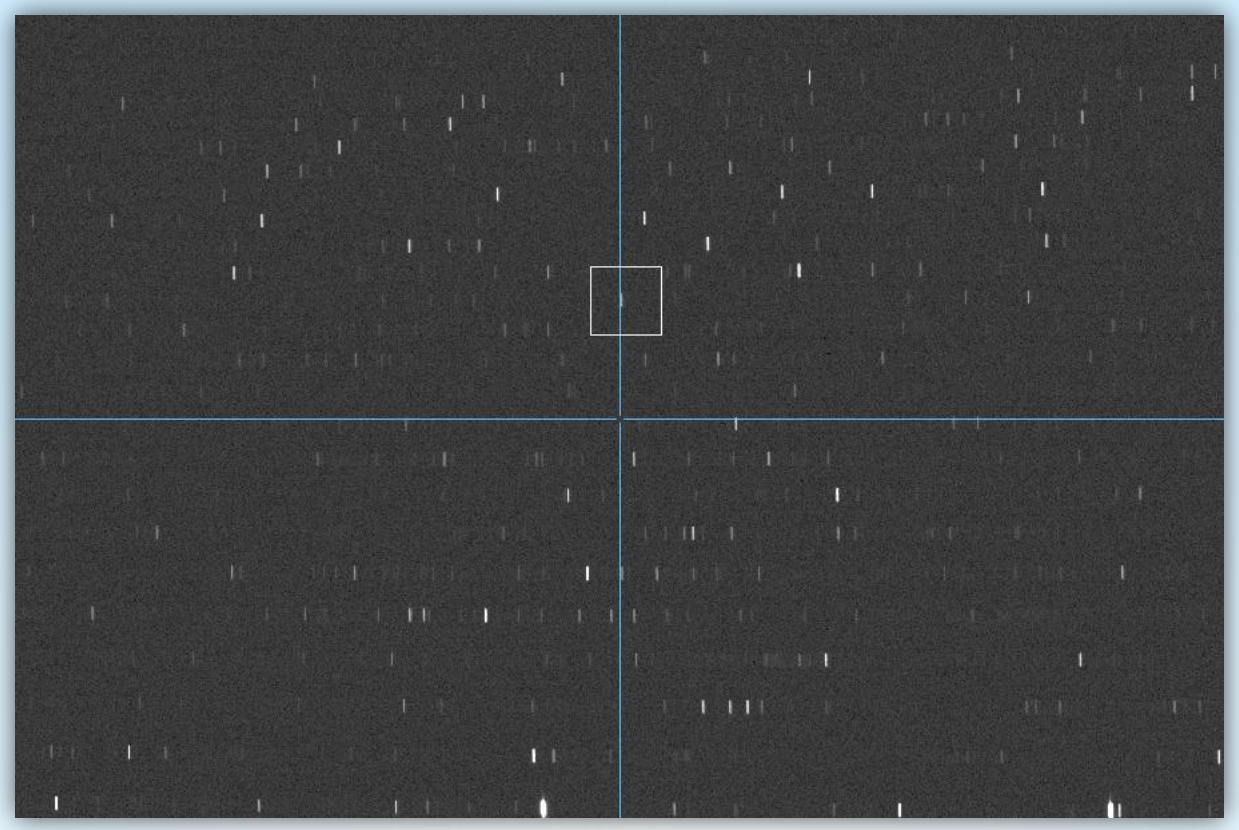
- **switchable** between fully manually controlled and fully remote controlled
- integrated **ThAr lamp and white light lamp** for spectral calibration and flatfielding
- **integrated power supply** for all components
- **high voltage 15mA current control** for maximum ThAr lamp efficiency
- **pre-aligned fiber coupling** to BACHES for the ThAr lamp and flatfield lamps, with a removable 50µm fiber, 2.5m in length
- **6 pin, 2.5m power cable** for the BACHES solenoid to switch between the **telescope light** and **the flatfield lamp**
- Remote control via **10/100 Mbit/s 10base Ethernet** (RJ-45), TCP/IP protocol
- integrated web server **for fast and easy internet access** with any web browser
- additional local PC remote control via **RS232 serial line**
- size **320mm (L) x 215mm (W) x 125mm (H)**. L=345mm with handles
- weight net **5.6kg.** Power supply **230V AC, 25W**
- shielded case with four rubber pads for **vibration damping**
- **optional mounting accessories**, for either a 19“ rack or direct telescope attachment, respectively

Alignment of BACHES Echelle Spectra

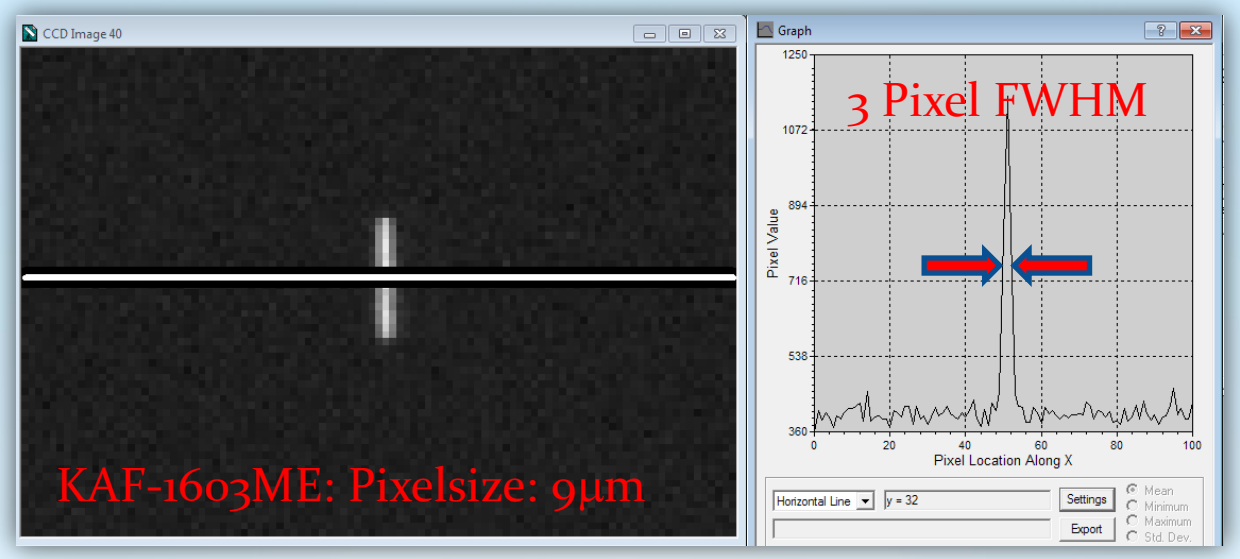


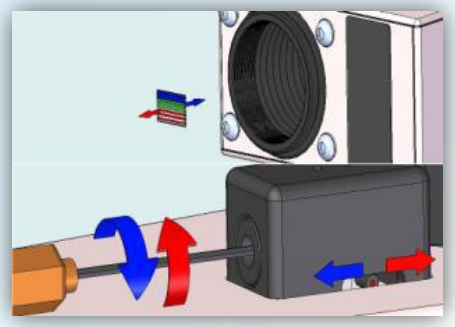
Recommended minimum Sensor Size: 9 x 13 mm

Spectrum Focusing



Spectrum Focusing





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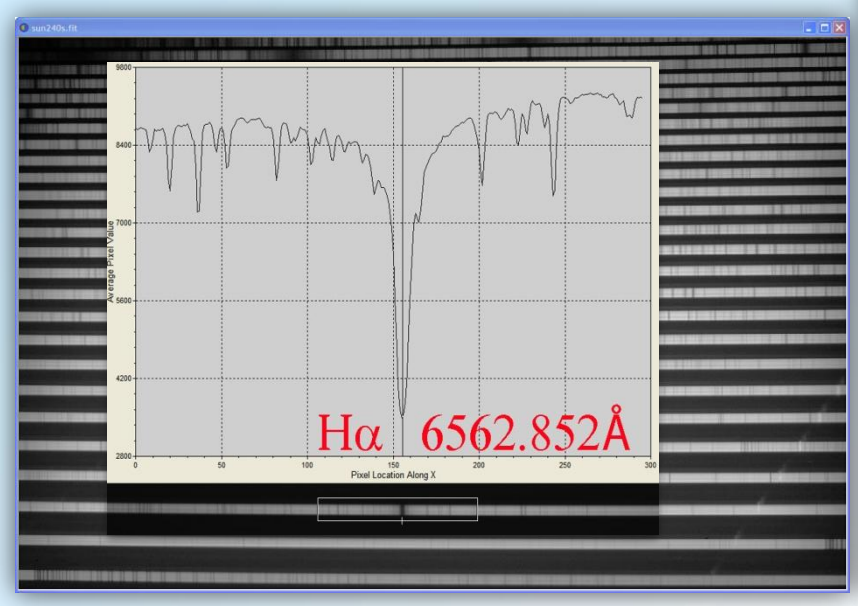
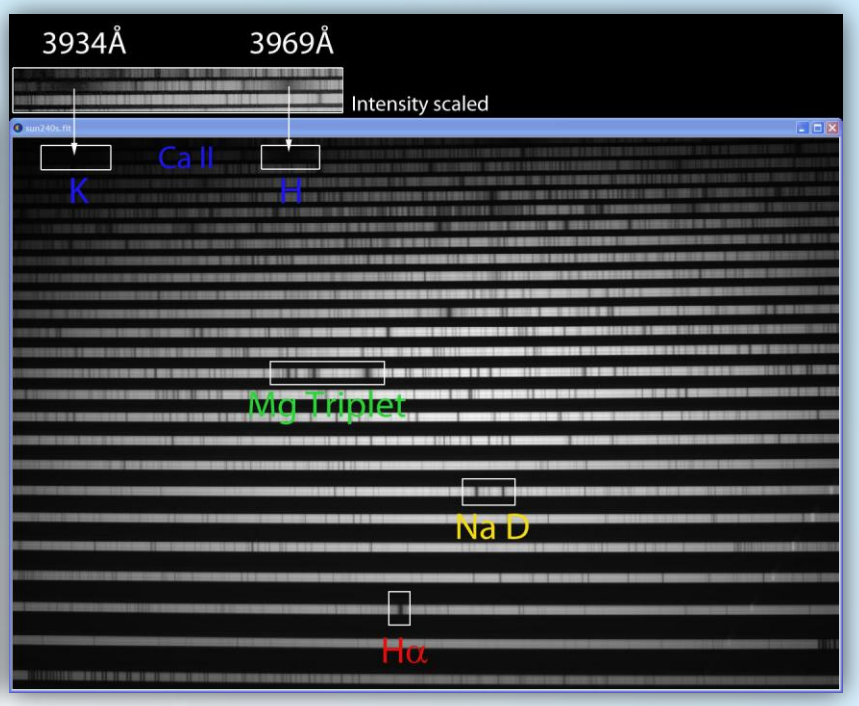
Calibration of BACHES Echelle Spectra

1. Manual calibration by identification of spectral lines -> selected orders only

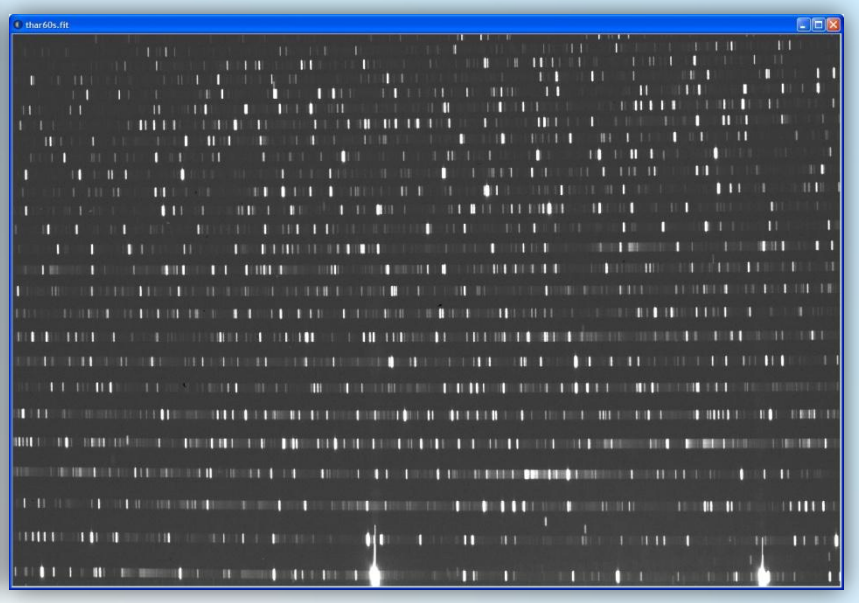




- Daylight spectrum -> Class G2 V
- Prominent spectral lines from Ca II (K) to Hα

Calibration of BACHES Echelle Spectra

2. Manual wavelength calibration with the Thorium-Argon reference lamp



- Daylight spectrum -> Class G2 V
- The Thorium-Argon spectrum provides about 2,000 precisely known wavelengths for calibration

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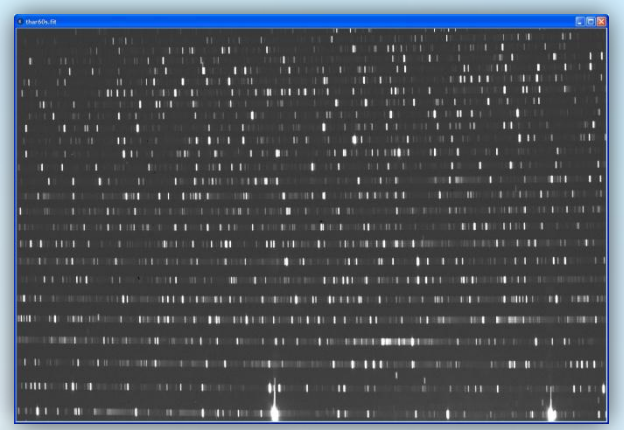
Calibration of BACHES Echelle Spectra

3. Semi-automatic calibration with the RCU's Thorium-Argon reference lamp and flatfield lamp with ESO-MIDAS



✓ ThAr reference spectrum

Daylight spectrum -> Class G2 V

✓ Halogen flatfield spectrum

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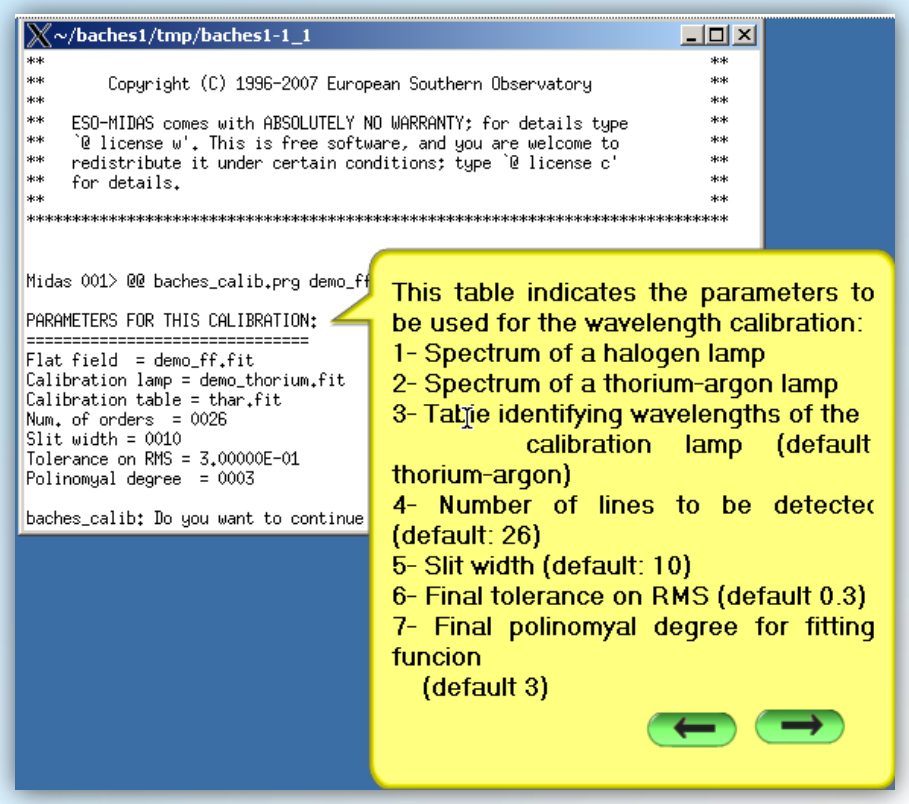
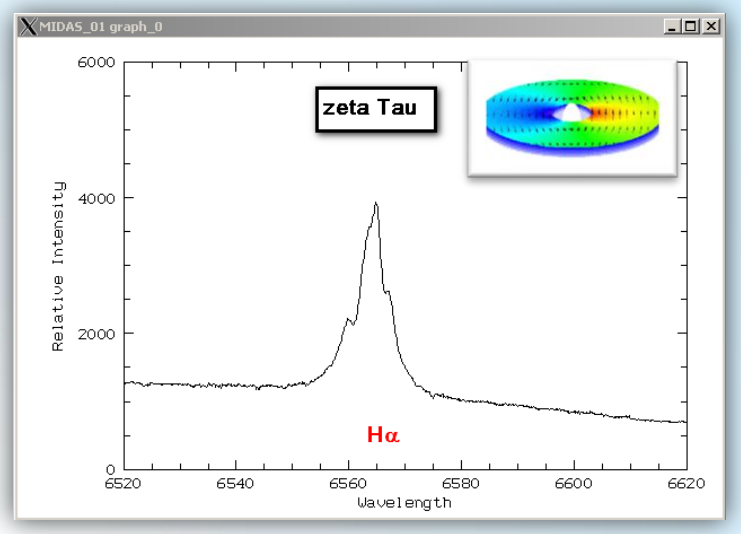
Calibration of BACHES Echelle Spectra

5. How to semi-automatically calibrate with ESO-MIDAS -> Video Tutorial



Wavelength calibration of
the emission line star zeta Tau:
www.baader-planetarium.de/baches/



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Calibration of BACHES Echelle Spectra

6. How to semi-automatically calibrate with ESO-MIDAS -> Manual & Exercise Files

www.baader-planetarium.de/baches/download/midas_manual_e.pdf

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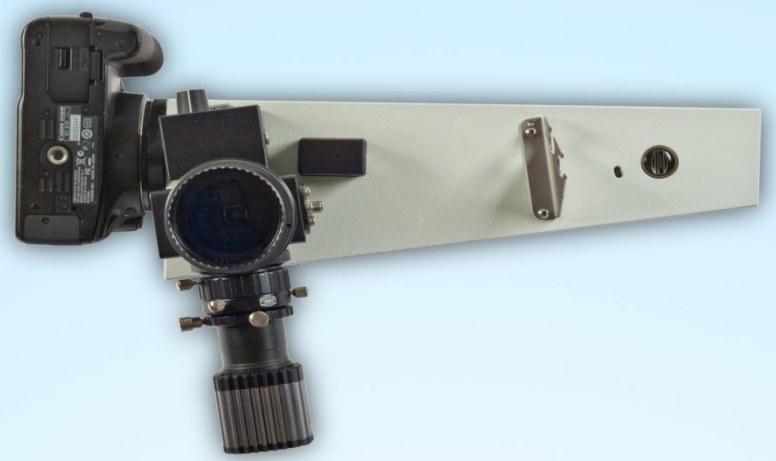
BACHES & DSLR Camera Layout



Guiding Camera (Skyris 274M)

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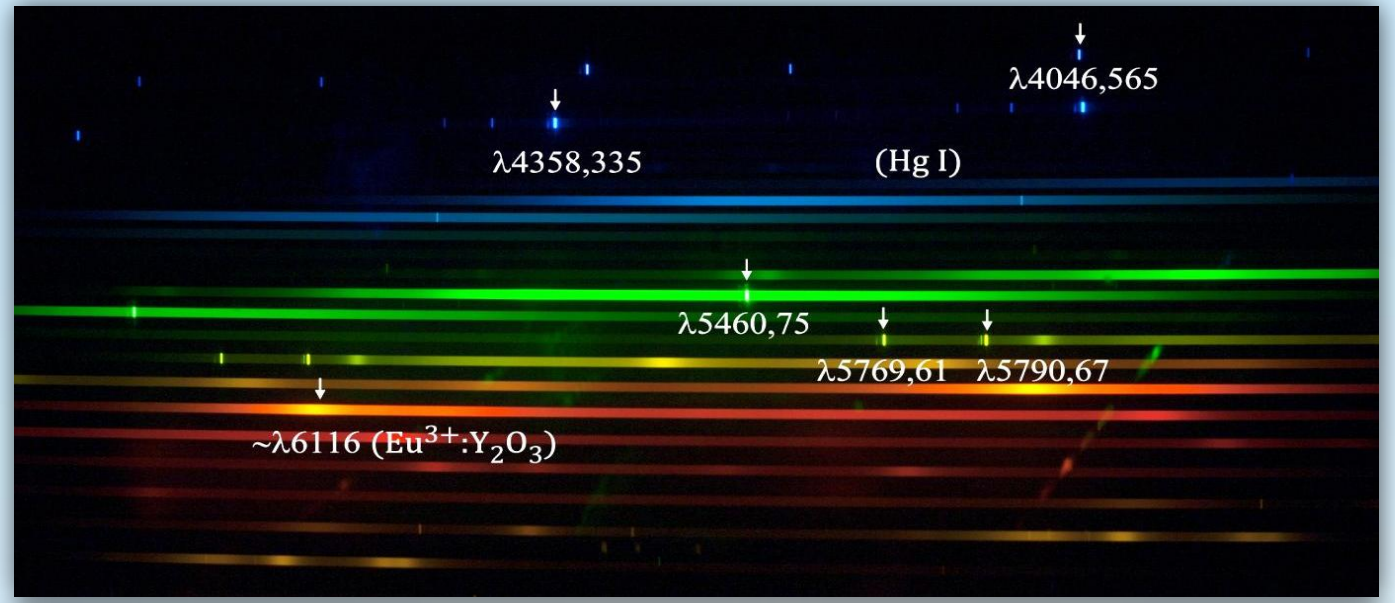
BACHES & DSLR Camera: Energy Saving Lamp



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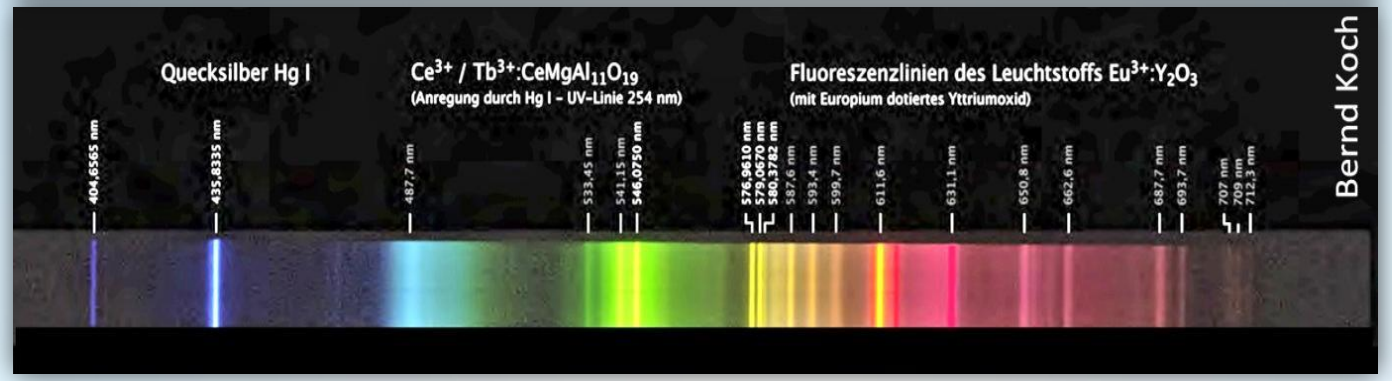
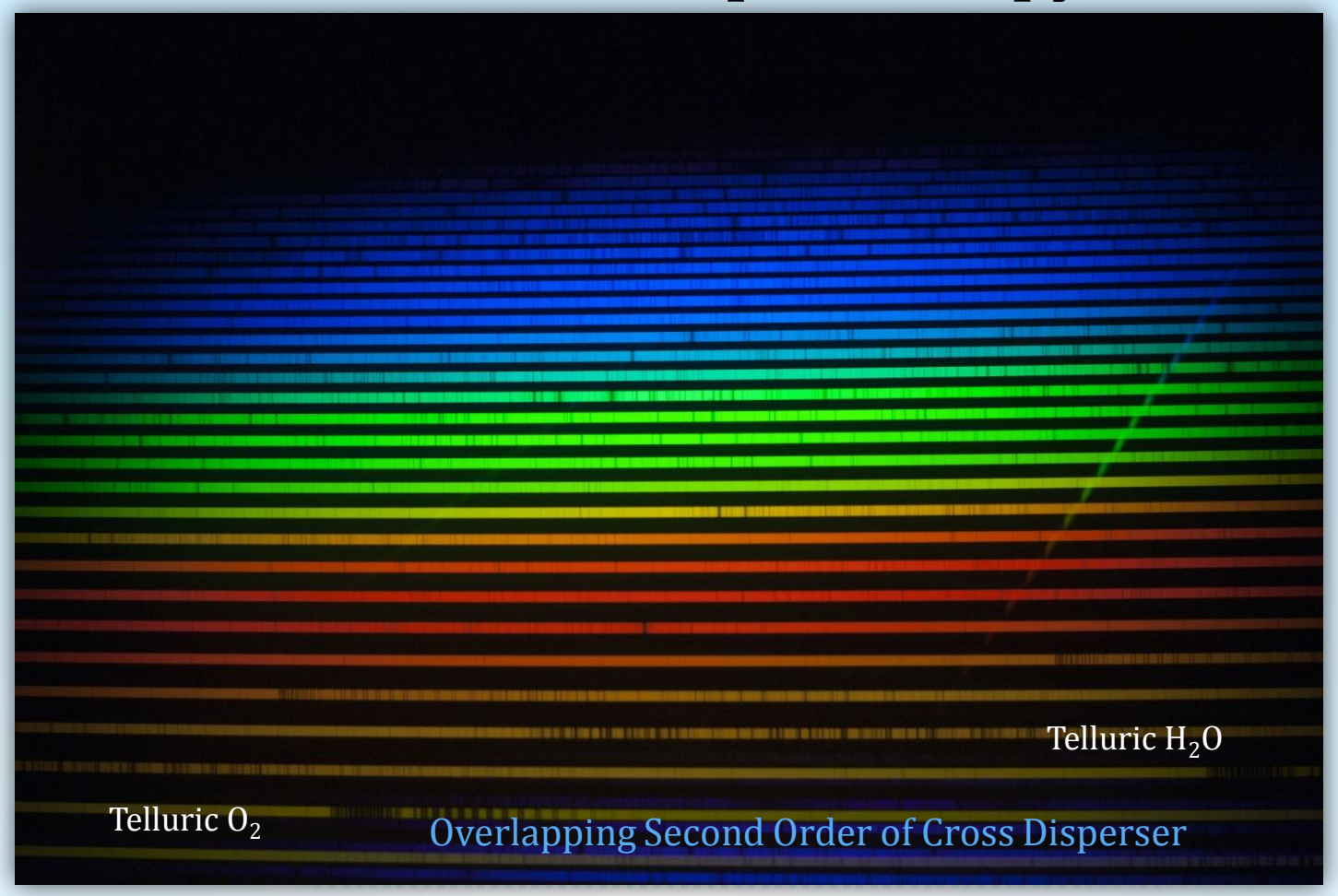


DADOS 200L/mm

BACHES Solar Spectroscopy



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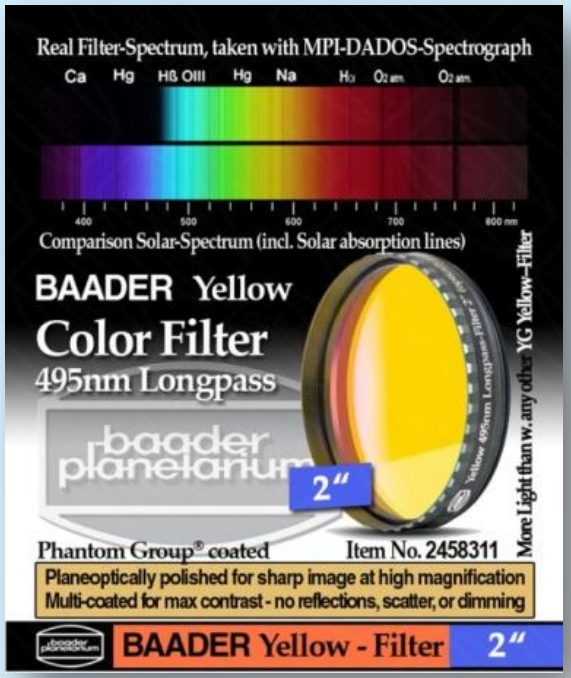
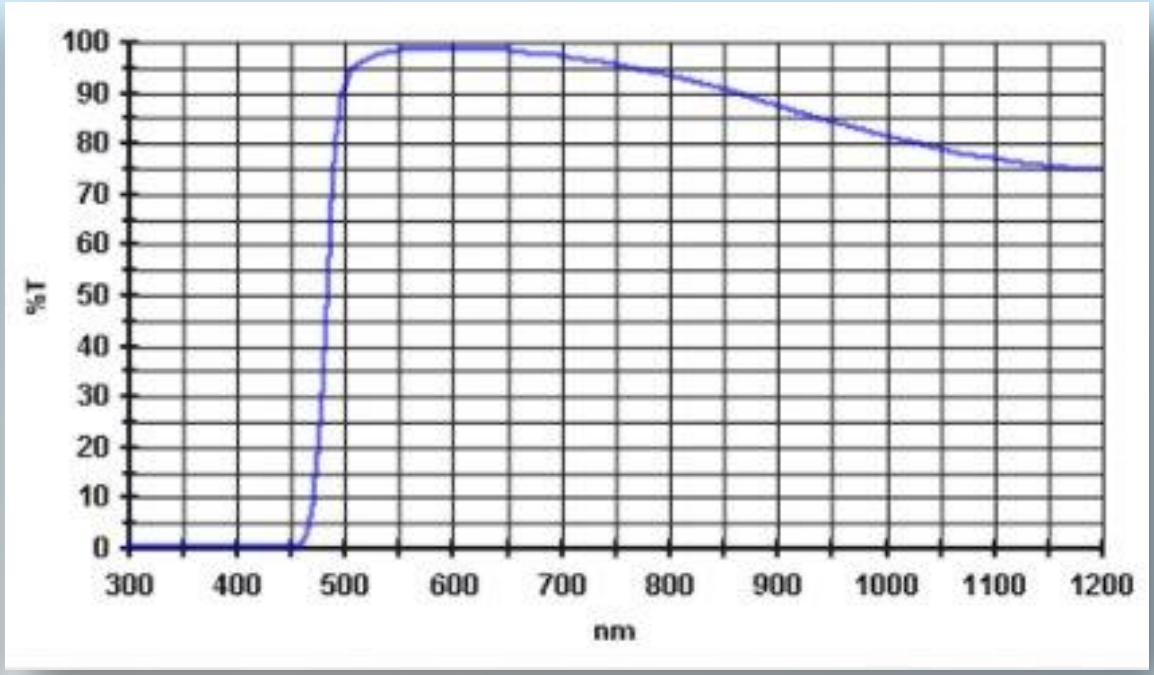
Investigating Telluric Infrared Lines in the Solar Spectrum with a Baader 495nm Longpass Filter





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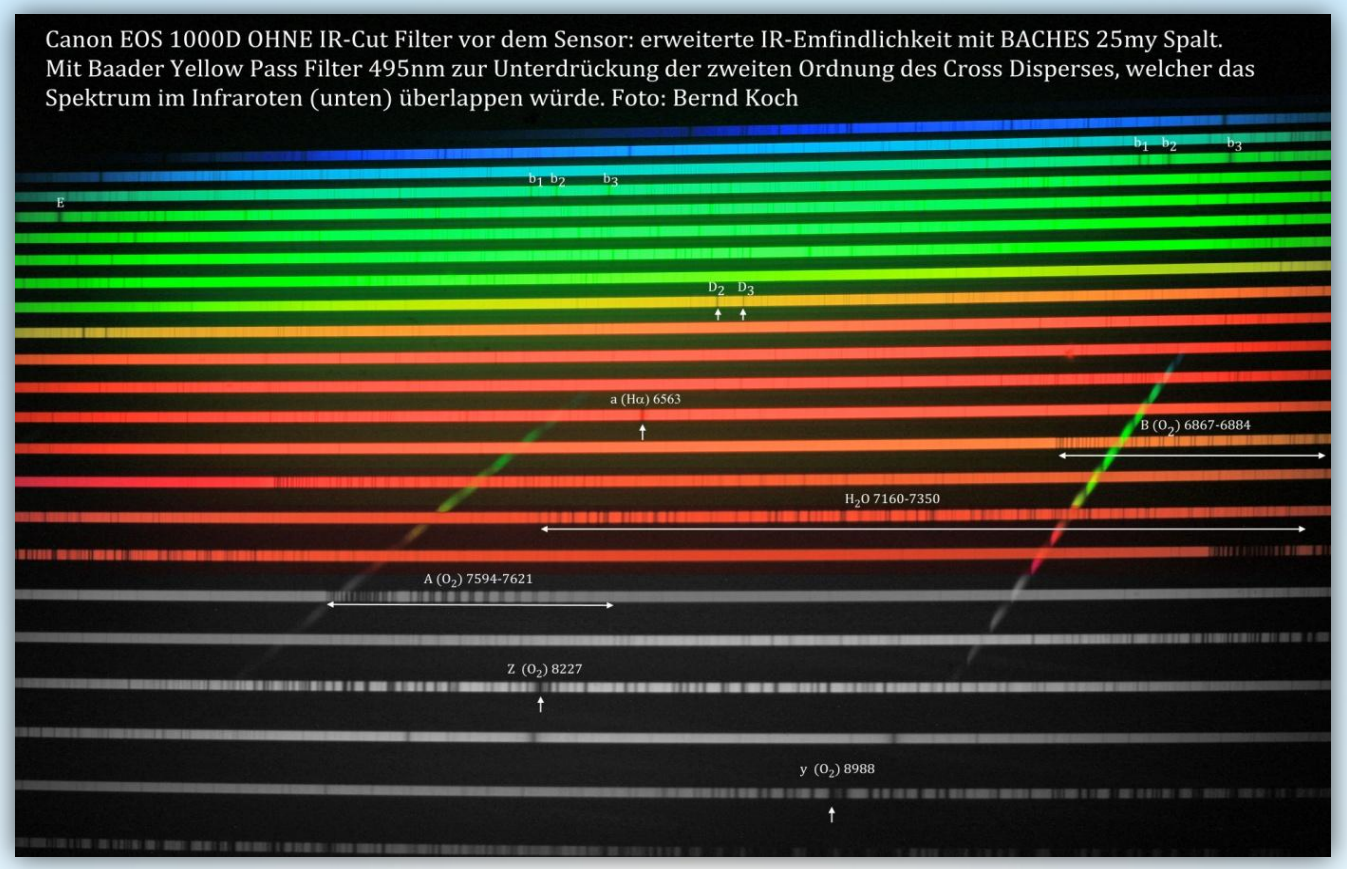

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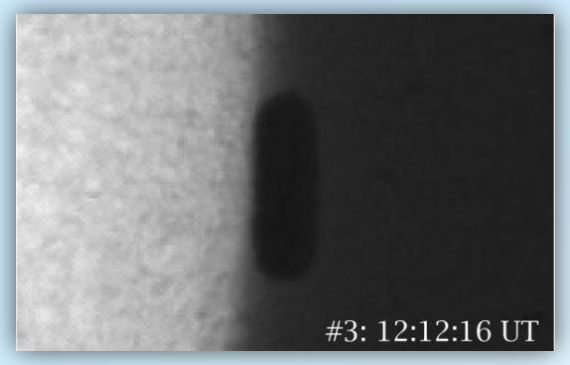
Solar Chromosphere Spectrum from Ca II 3934Å to Hα 6563Å



Refractor 130mm f/6 +
1.5x Barlow Lens
Baader AstroSolar D=3.8
BACHES 25µm Slit

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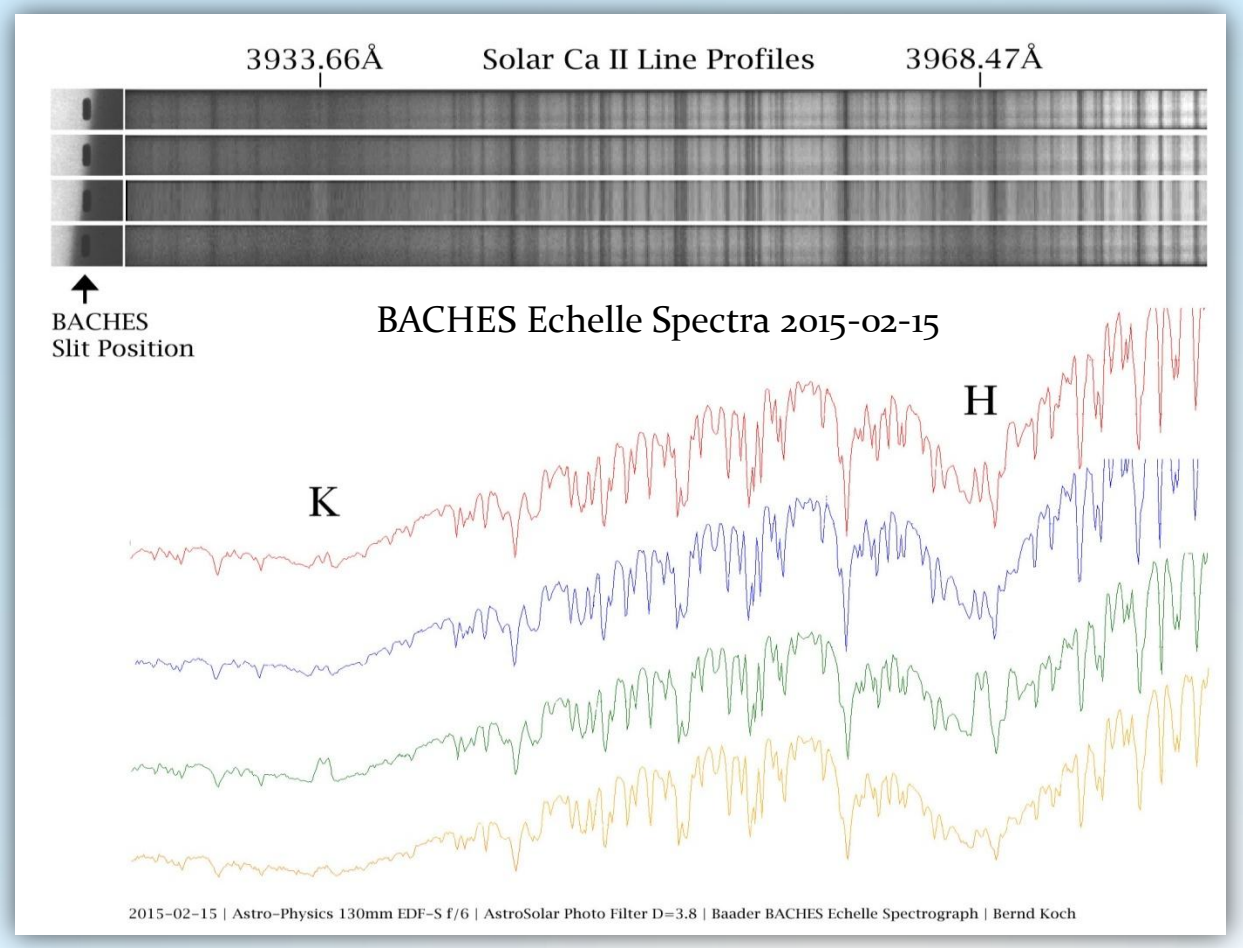
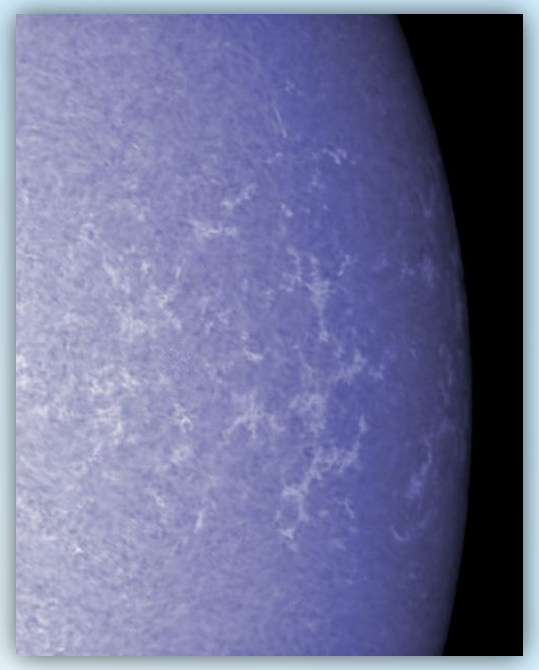
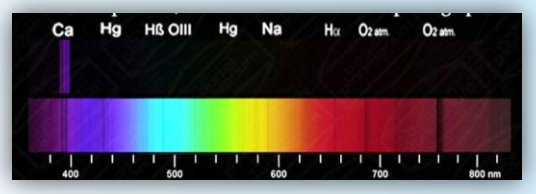
Solar Calcium Ca II Lines 3933.66Å and 3968.47Å





Baader Calcium K-Line Filter



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Solar Photosphere/Chromosphere Ca II K-Line 3933.66Å

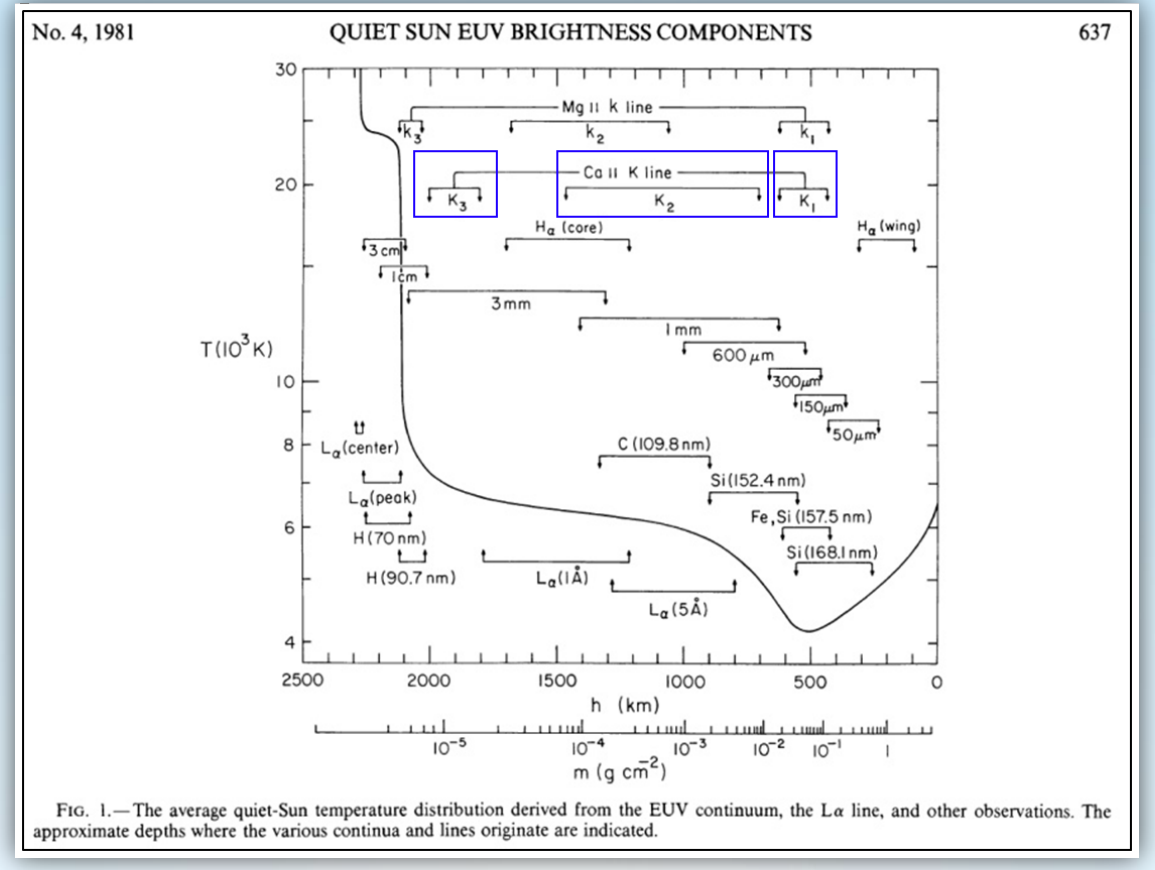

FIG. 1.—The average quiet-Sun temperature distribution derived from the EUV continuum, the Lα line, and other observations. The approximate depths where the various continua and lines originate are indicated.

Vernazza, J.E. et al., Structure of the solar chromosphere. III - Models of the EUV brightness components of the quiet sun The Astropysical Journal Supplement Series, 45:635-725, 1981 April, http://adsabs.harvard.edu/abs/1981ApJS...45..635V

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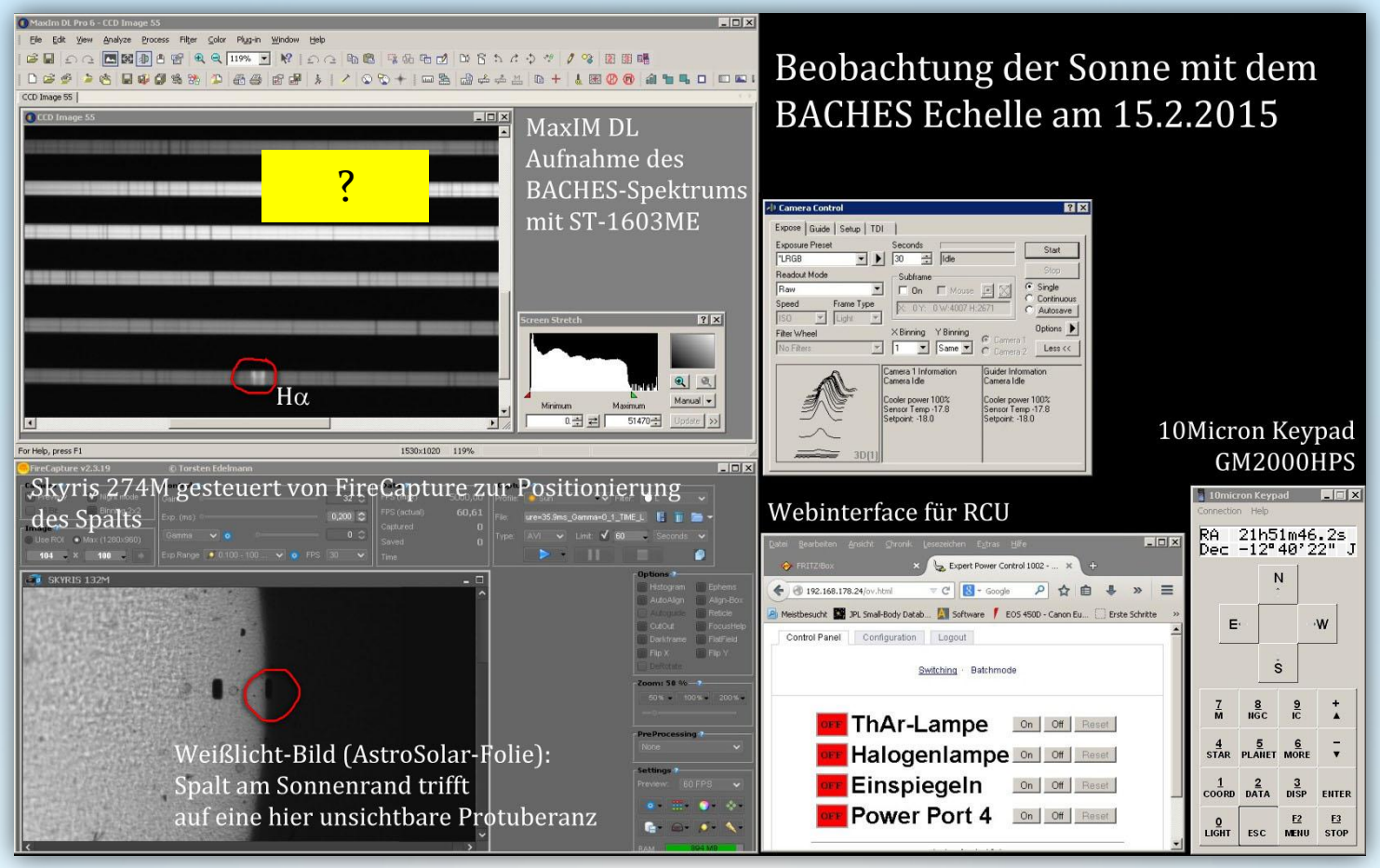
Solar Chromosphere Spectrum Hα 6563Å



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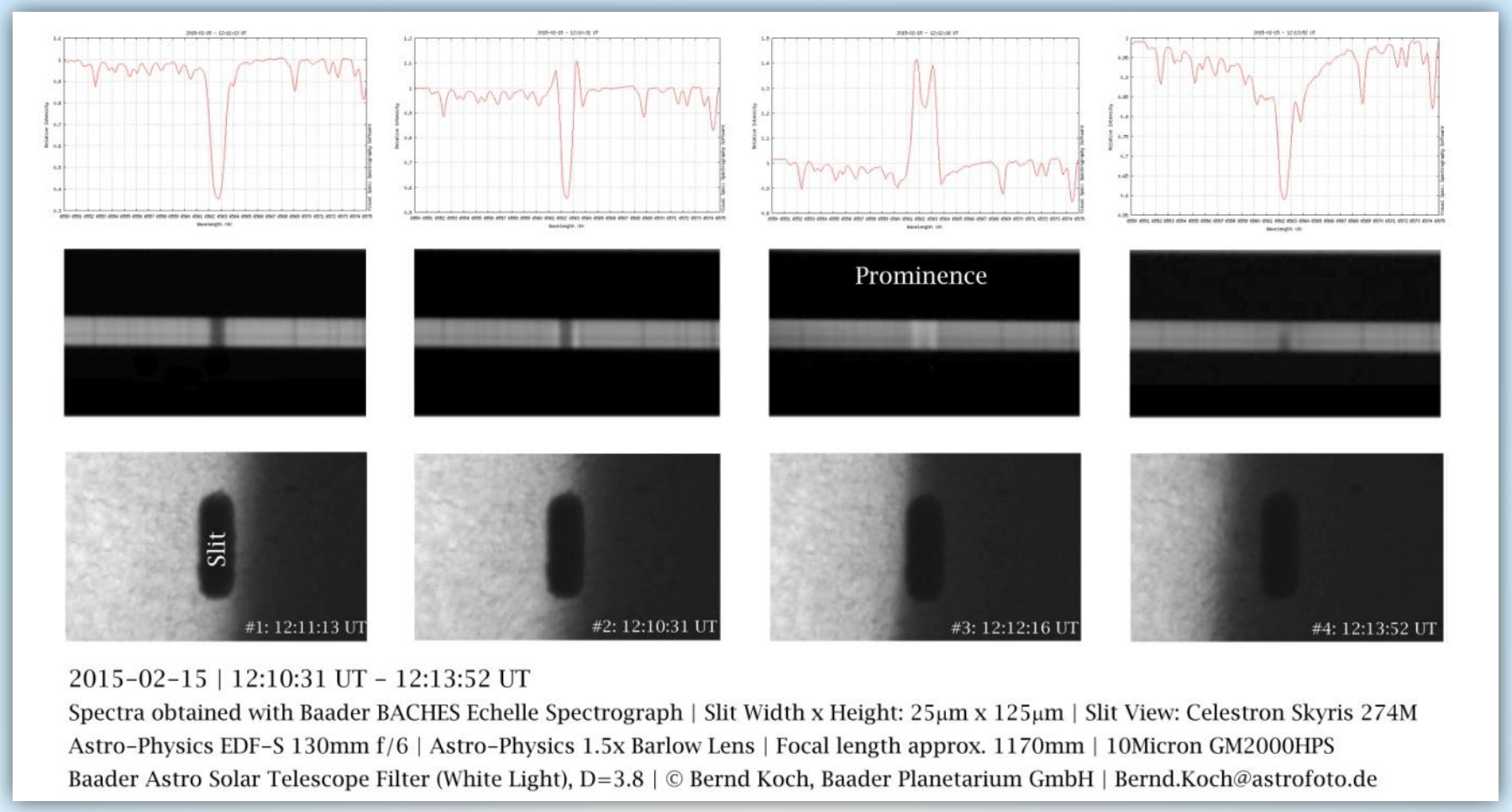
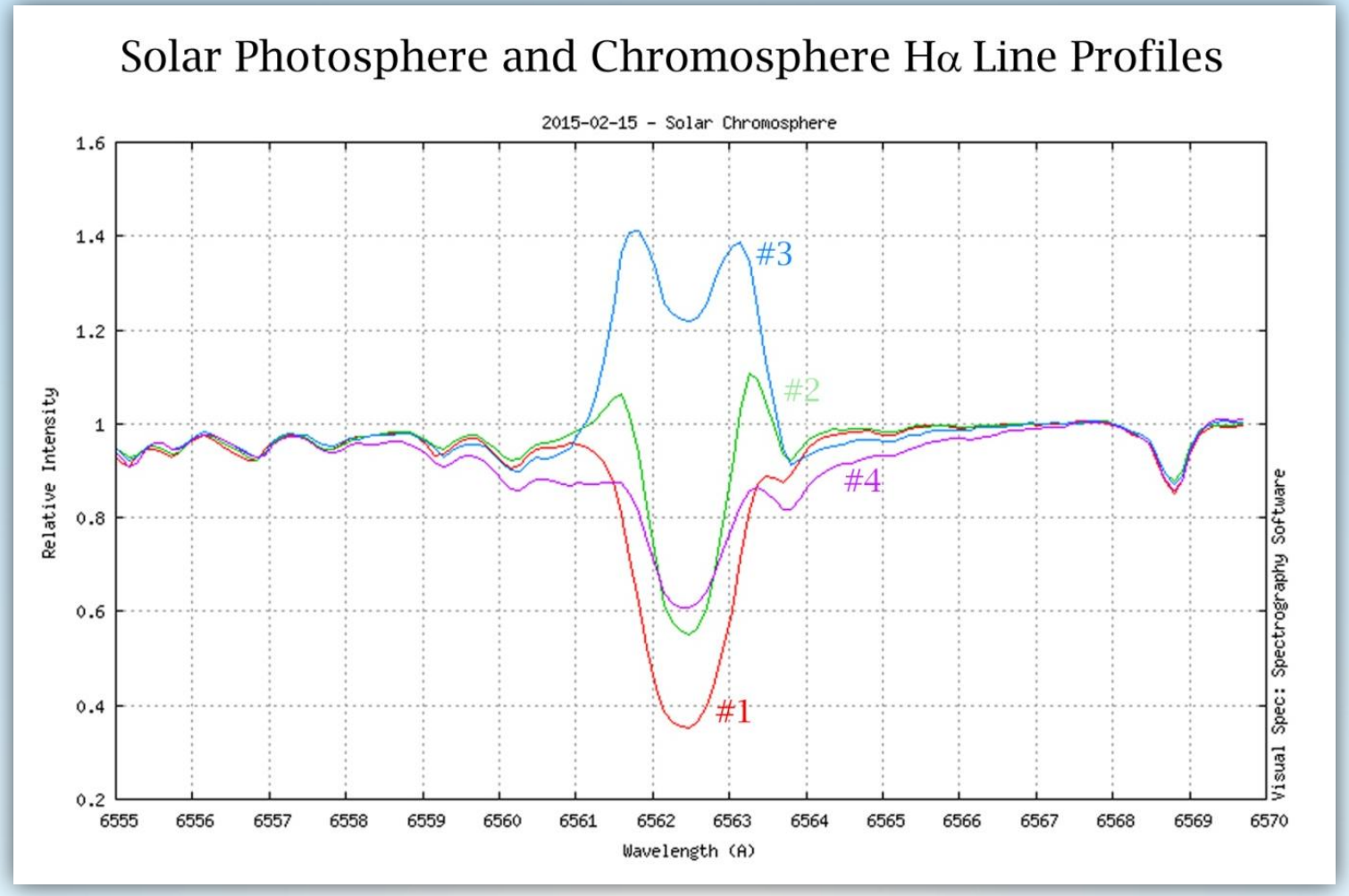
Solar Photosphere/Chromosphere Spectrum Hα 6563Å



2015-02-15 | 12:10:31 UT – 12:13:52 UT

Spectra obtained with Baader BACHES Echelle Spectrograph | Slit Width x Height: 25µm x 125µm | Slit View: Celestron Skyris 274M
Astro-Physics EDF-S 130mm f/6 | Astro-Physics 1.5x Barlow Lens | Focal length approx. 1170mm | 10Micron GM2000HPS
Baader Astro Solar Telescope Filter (White Light), D=3.8 | © Bernd Koch, Baader Planetarium GmbH | Bernd.Koch@astrofoto.de

Solar Photosphere/Chromosphere Spectrum Hα 6563Å



Solar Photosphere/Chromosphere Spectrum Hα 6563Å

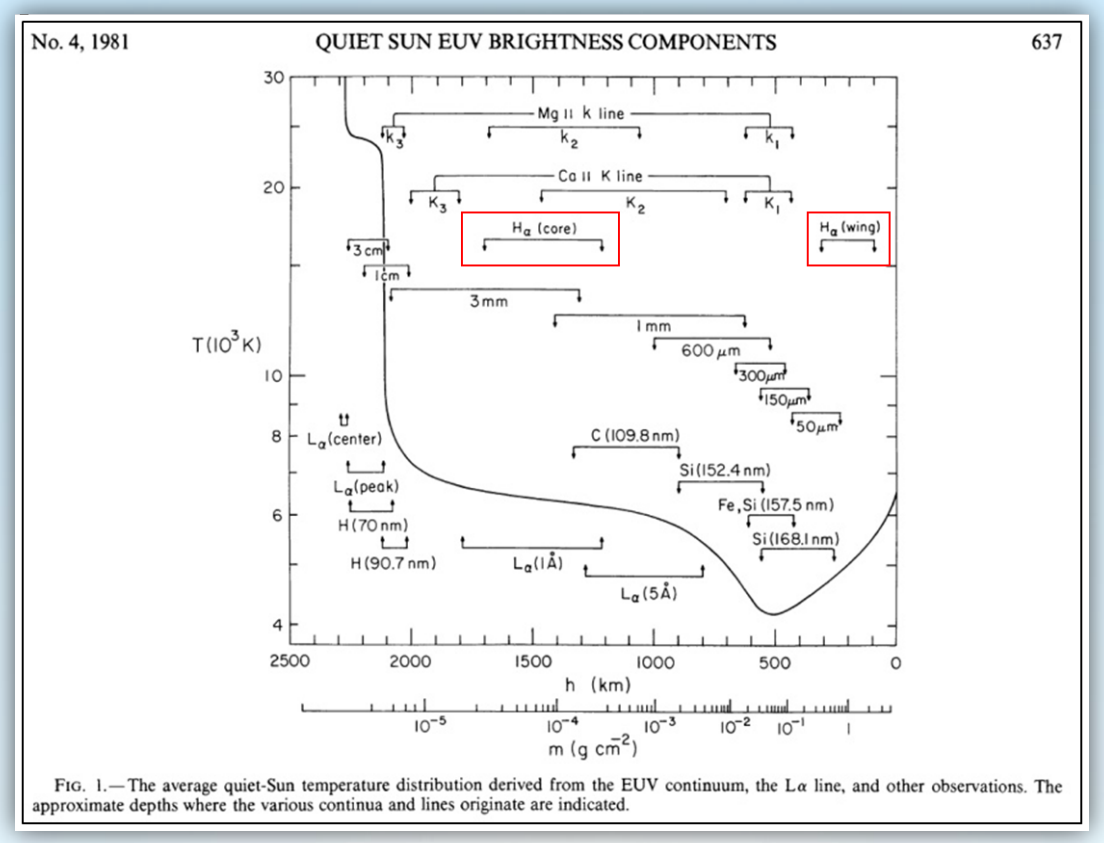


FIG. 1.—The average quiet-Sun temperature distribution derived from the EUV continuum, the Lα line, and other observations. The approximate depths where the various continua and lines originate are indicated.

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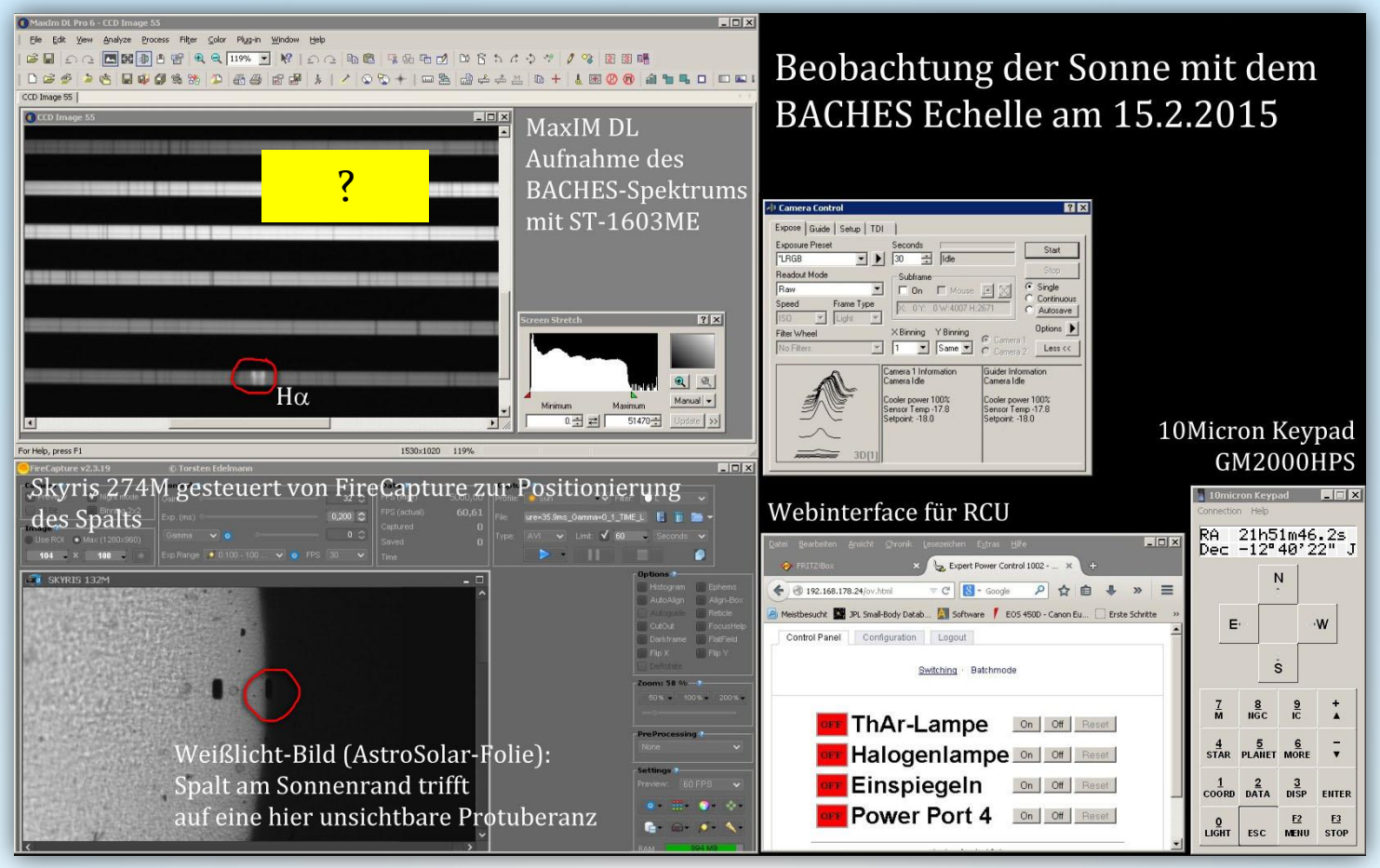
Solar Chromosphere Spectrum: ?



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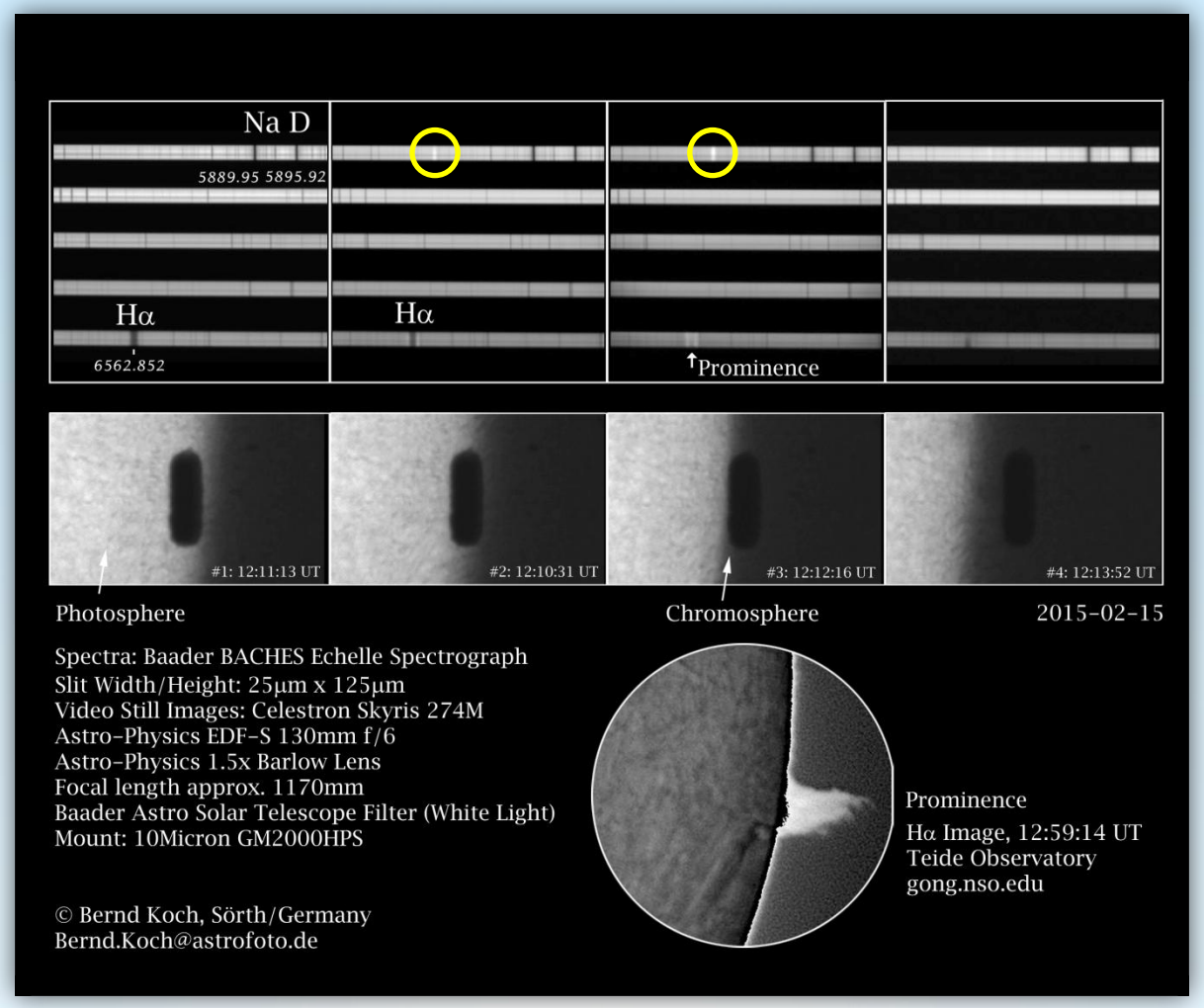
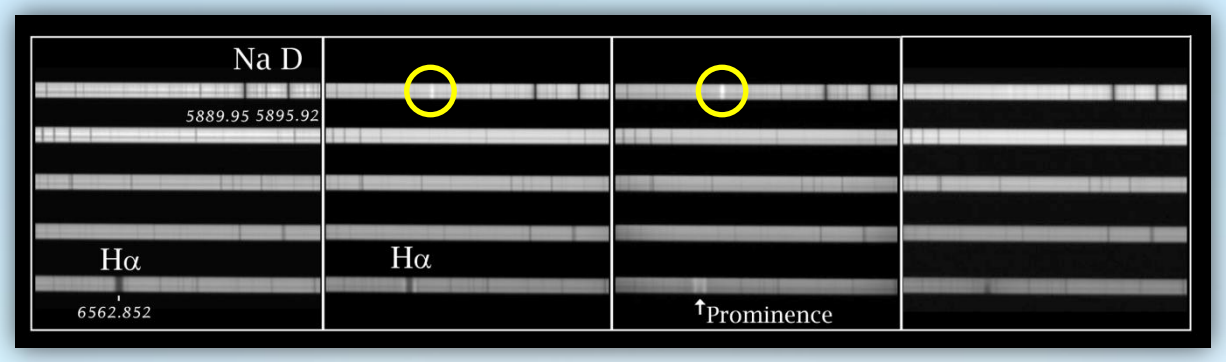


Year 1868: Signature of unknown chemical element



- Unidentified spectral line close to Sodium D1,D2
- Discovered by french astronomer Jules Janssen in solar spectrum August 19, 1868
- 1870: Norman Lockyer, english astronomer postulates a new element
- He calls it „Helium“ according to the greek god Helios
- 1895: English Chemist William Ramsay extracts Helium
- https://en.wikipedia.org/wiki/Solar_eclipse_of_August_18,_1868

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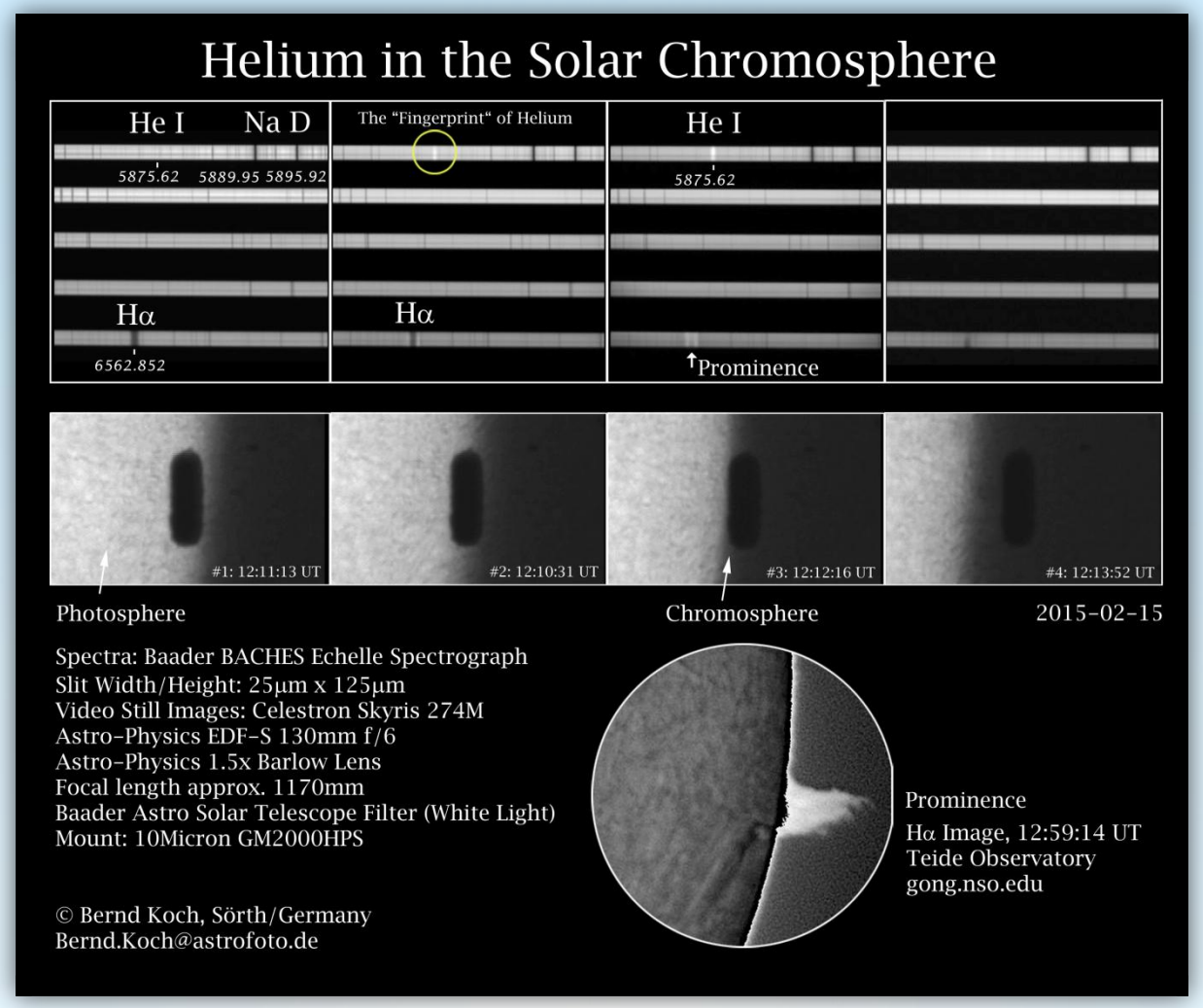
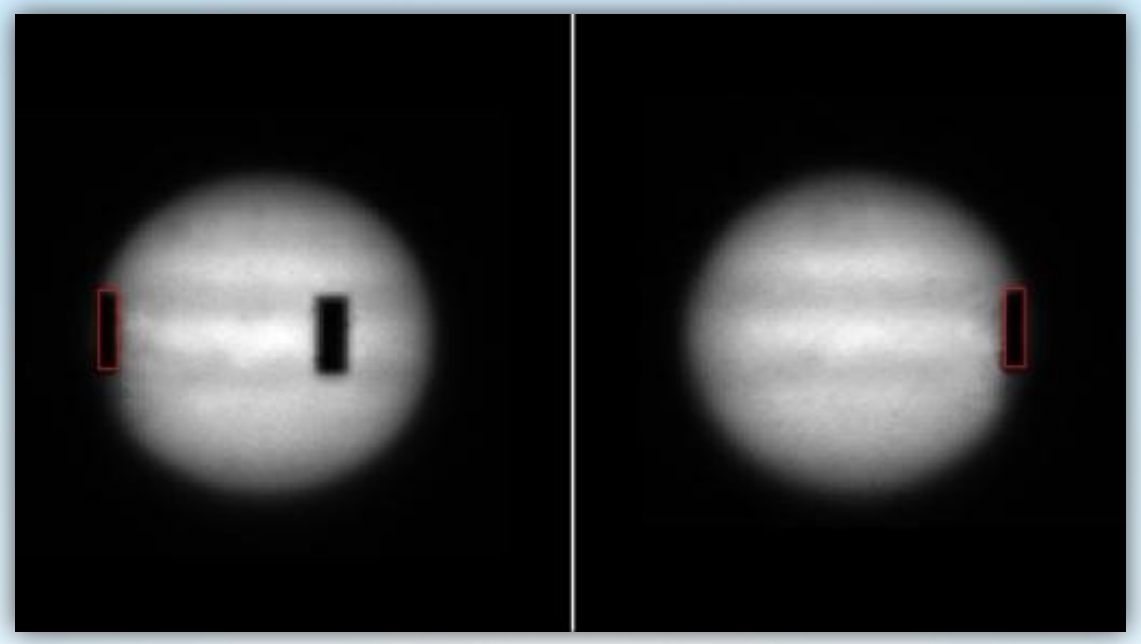
Echelle Spektrograph
and Remote Calibration Unit



The Rotation of Planet Jupiter

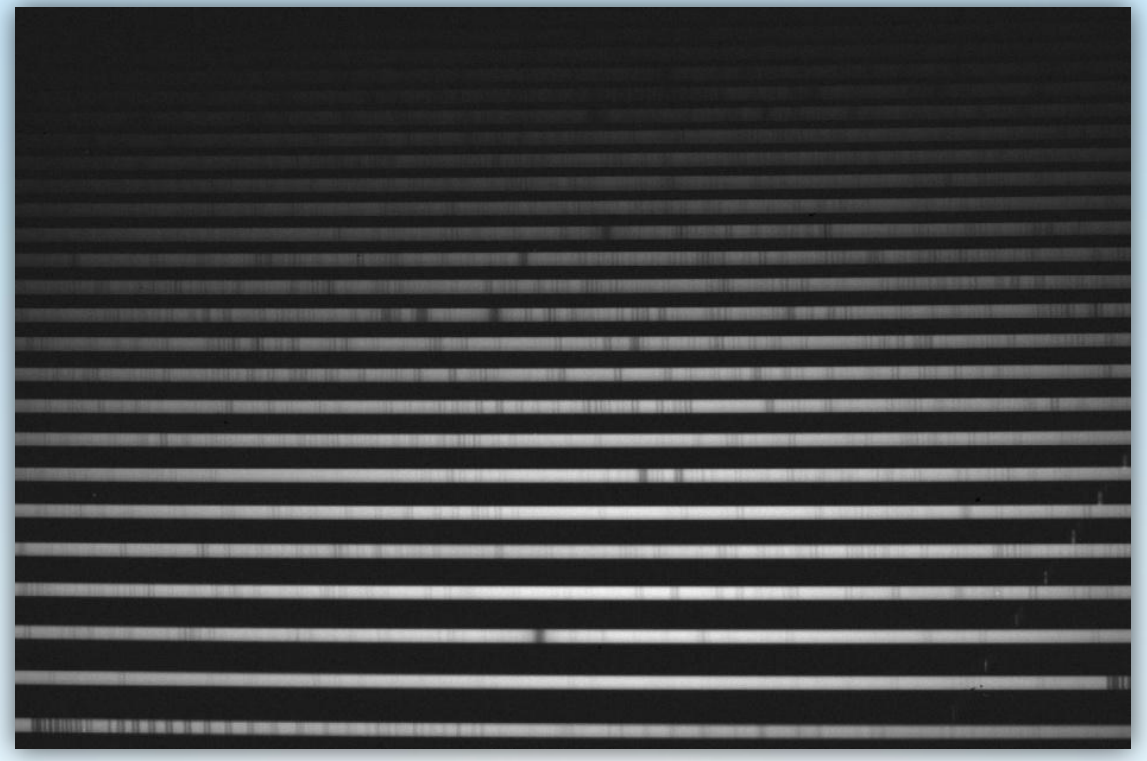
$$v_{rot} \cdot \sin i = \frac{|v_r|}{4} = c \cdot \frac{\Delta\lambda}{4\,\lambda}$$



2016-03-10. BACHES 25µm slit set at left and right edge of Jupiter. Image of the Skyris 274M video guiding camera. Telescope: Celestron 14 EdgeHD with 0,7x reducer setted on GM2000HPS mount

BACHES
ECHELLE SPEKTROGRAPH
and Remote Calibration Unit

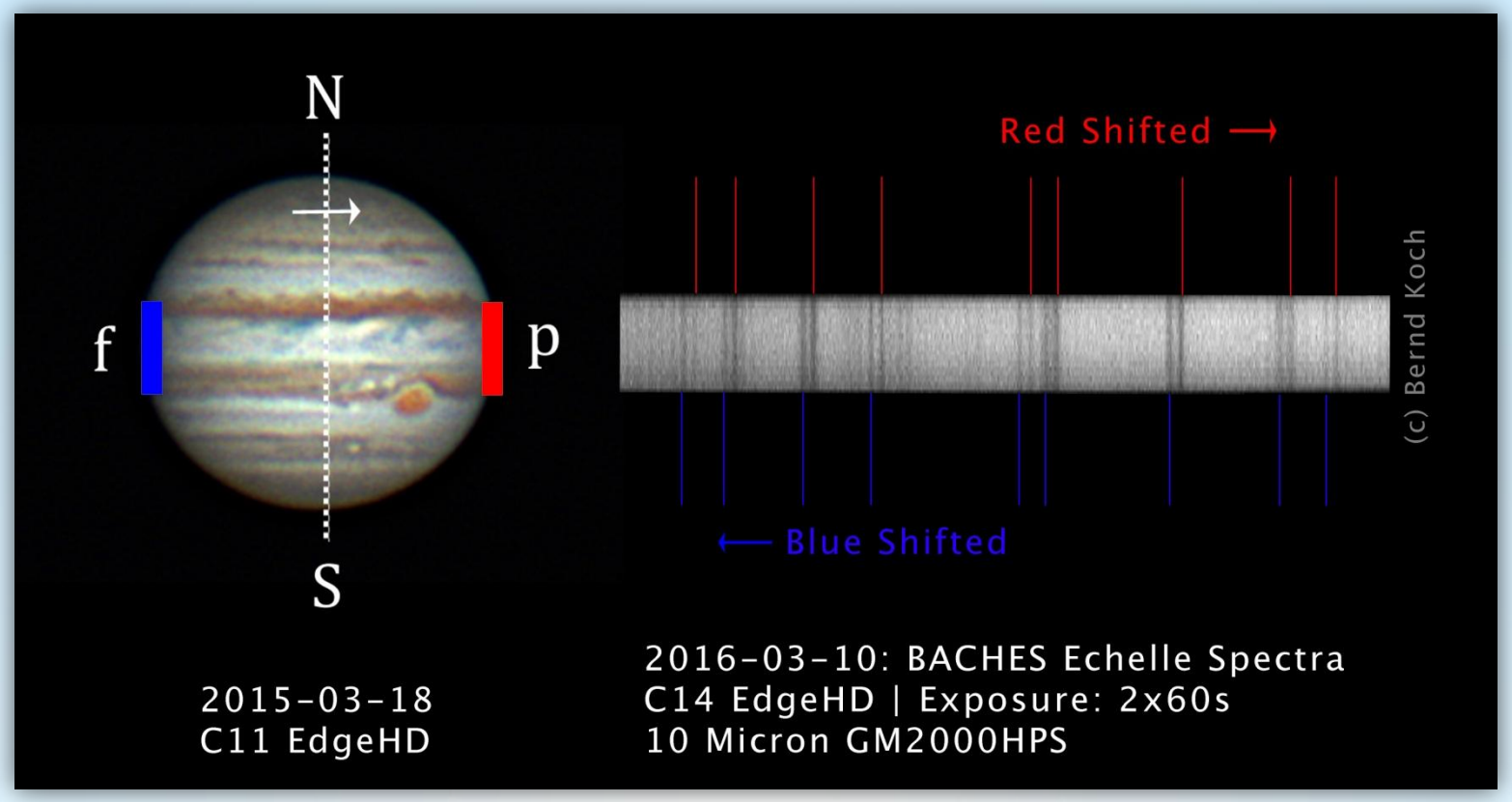
The Rotation of Planet Jupiter



Spectrum of planet Jupiter 2016-03-10. C14 EdgeHD | BACHES Echelle Spektrograph | SBIG ST-1603ME. Two 60s spectra, taken at left and right edge of Jupiter, were co- added to reveal line doubling . The distance between both lines is about 1Å. Please note the double lines in the bottom row: These are telluric lines of Oxygen, by chance also separated about 1Å. Not subject to Jupiter!

The Rotation of Planet Jupiter

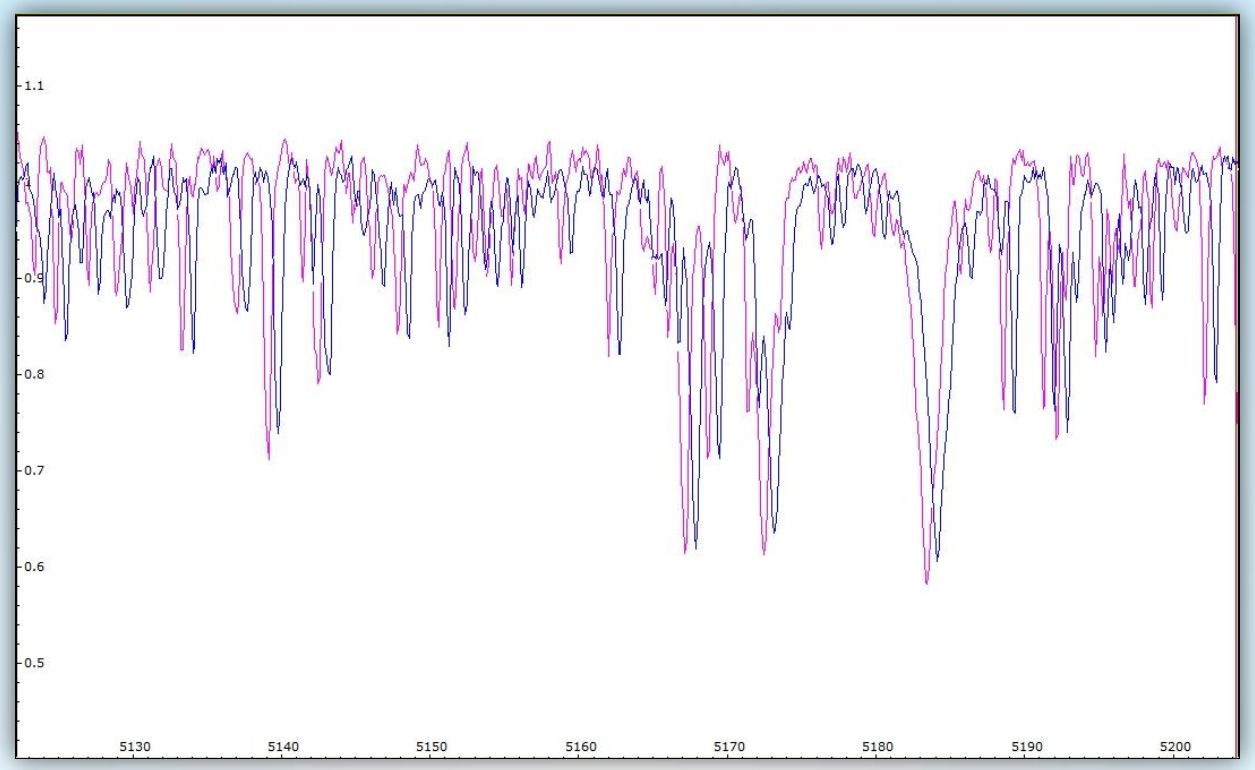
$$v_{rot} \cdot \sin i = \frac{|v_r|}{4} = c \cdot \frac{\Delta\lambda}{4\,\lambda}$$



The Rotation of Planet Jupiter

Around the Mg – Triplet: $\Delta\lambda = 0.72$Å. *Center Wavelength*: $\lambda = 5160$Å

$$v_{rot} = c \cdot \frac{\Delta\lambda}{4\lambda} = 299792.5\frac{km}{s} \cdot \frac{0.72\text{Å}}{4 \cdot 5160\text{Å}} = 10.5\frac{km}{s}\ (-16{,}6\%), correct\text{: } 12.6\frac{km}{s})$$



The Rotation of Planet Jupiter

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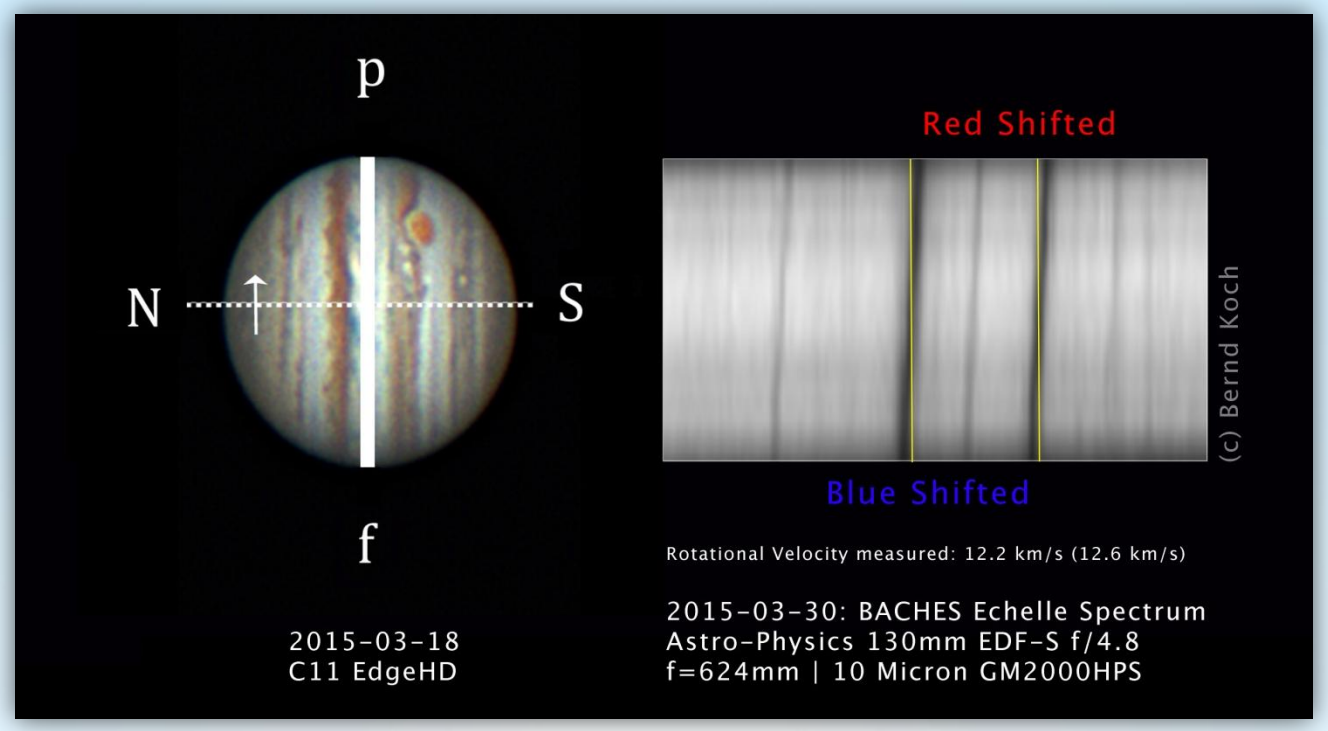

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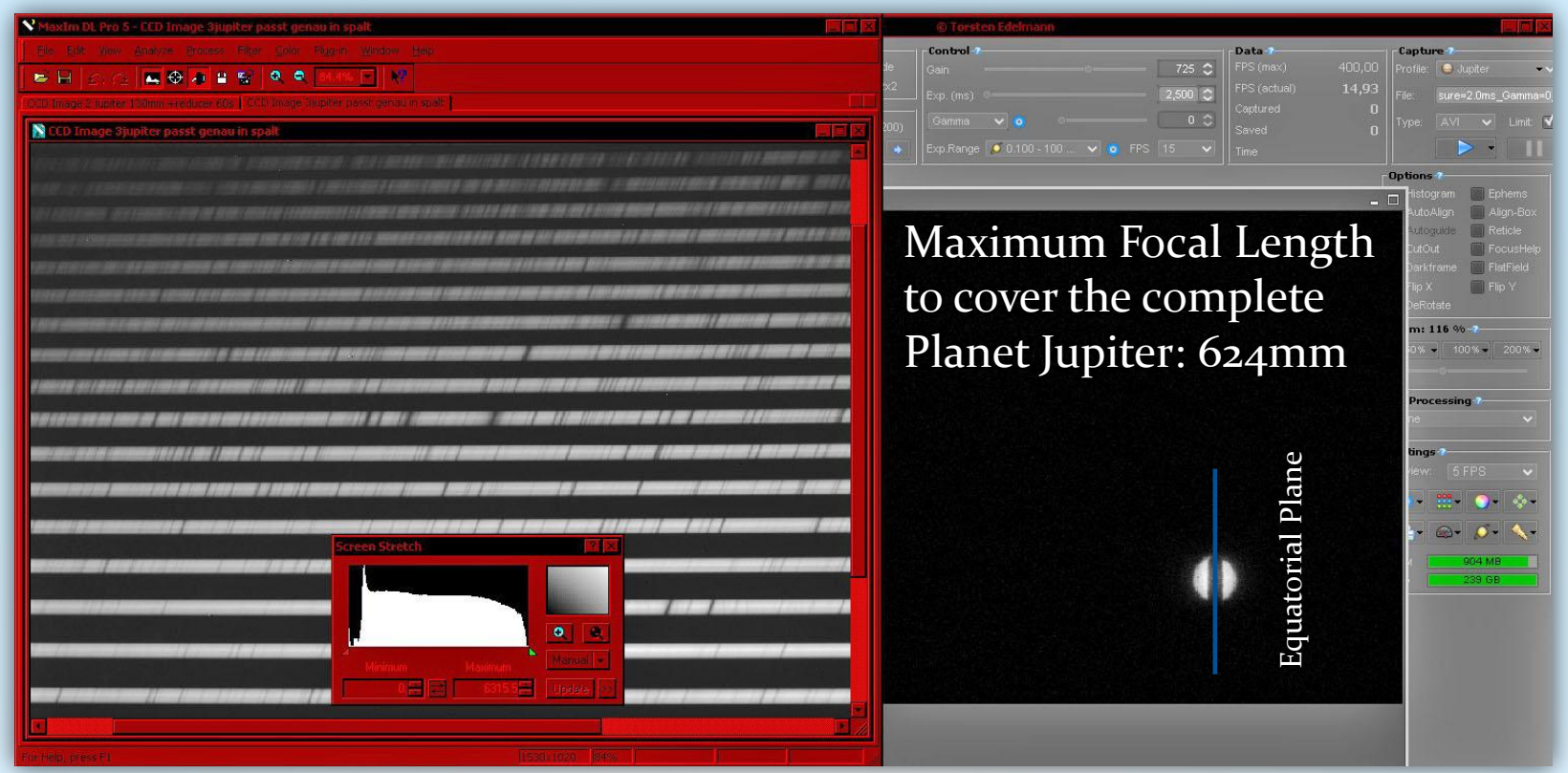
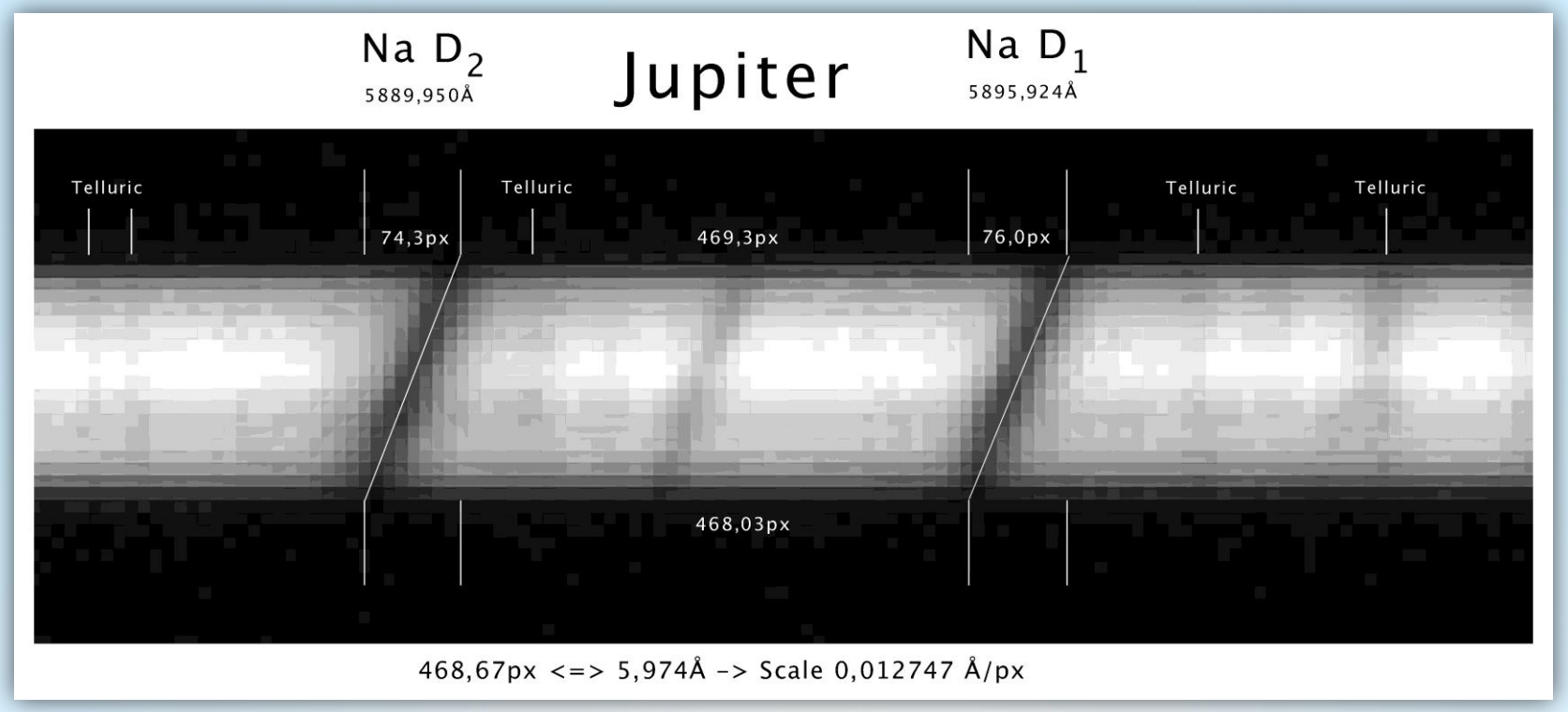
The Rotation of Planet Jupiter



Left: Complete Jupiter spectrum obtained with BACHES Echelle, Slit width 25µm. 130mm refractor, 624mm focal length, exposure 60s with SBIG ST-1603ME. Right: Video window (FireCapture software) with 90° rotated Jupiter image. During exposure manual guiding by means of the 10Micron keypad.

The Rotation of Planet Jupiter



The Rotation of Planet Jupiter

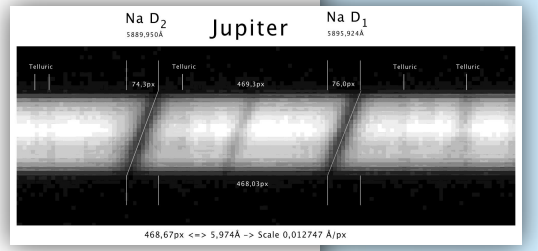
30.3.2015: $i = 89.9° \approx 90°; \sin i = 1$; Einzelvermessung des Versatzes der Linien D1 und D2

D1 – Linie: $\Delta\lambda = 76.0px \cdot 0.012747 \frac{Å}{px} = 0.9687Å;\ \lambda = 5895.924Å$

$$v_{rot} = c \cdot \frac{\Delta\lambda}{4\lambda} = 299792{,}5 \frac{km}{s} \cdot \frac{0.9687Å}{4 \cdot 5895.924Å} = 12.31 \frac{km}{s}$$

D2 – Linie: $\Delta\lambda = 74.3px \cdot 0.012747 \frac{Å}{px} = 0.9471Å;\ \lambda = 5889.950Å$

$$v_{rot} = c \cdot \frac{\Delta\lambda}{4\lambda} = 299792.5 \frac{km}{s} \cdot \frac{0.9471Å}{4 \cdot 5889.950Å} = 12.05 \frac{km}{s}$$



Mittelwert aus zwei Einzelmessungen: $v_{rot} = 12.18 \frac{km}{s} \pm 0.13 \frac{km}{s}$

Mit dem Äquatorradius des Planeten Jupiter $r = 71492\ km$ beträgt die Rotationsdauer am Jupiteräquator: $T = \frac{2\pi r}{v_{rot}} = \frac{2\pi \cdot 71492km}{12.18\ km/s} = 36879.9s = 10h\ 14.6m$

Jupiter	Correct Value	Measured	Difference
v_{rot}	12.6 km/s	12.2 km/s	-3.2%
T (Equator)	9h 55.5m	10h 14.6m	+3.2%

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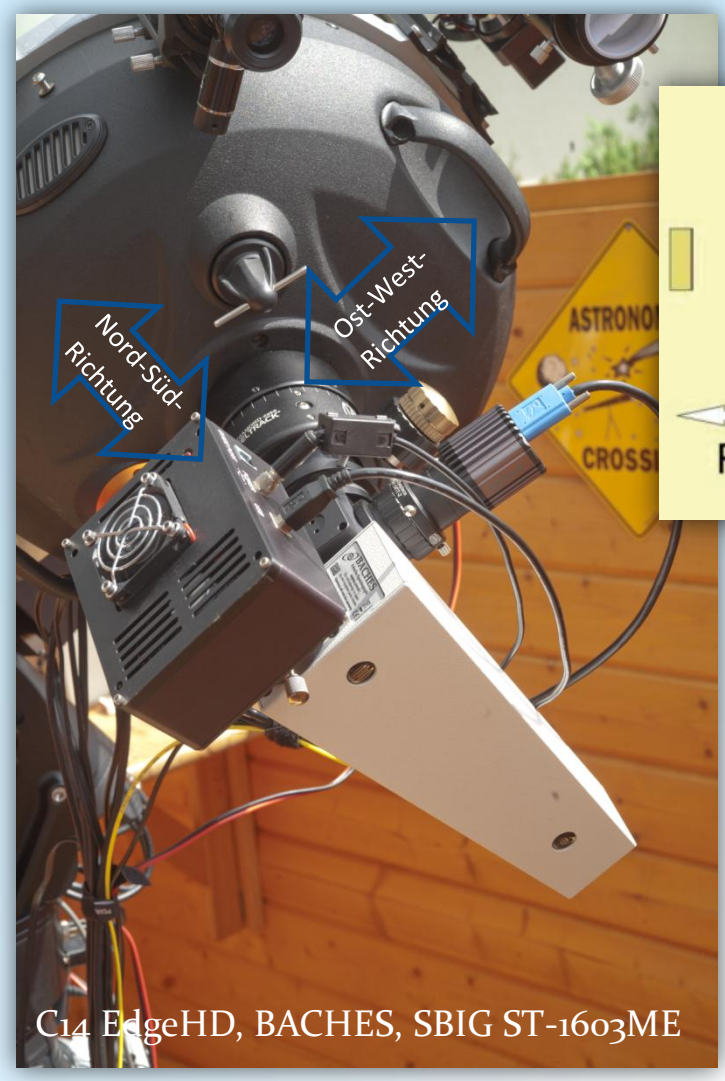
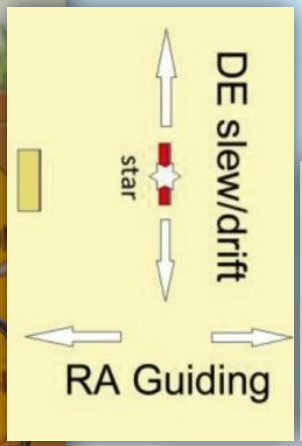
Echelle Spektrograph
and Remote Calibration Unit

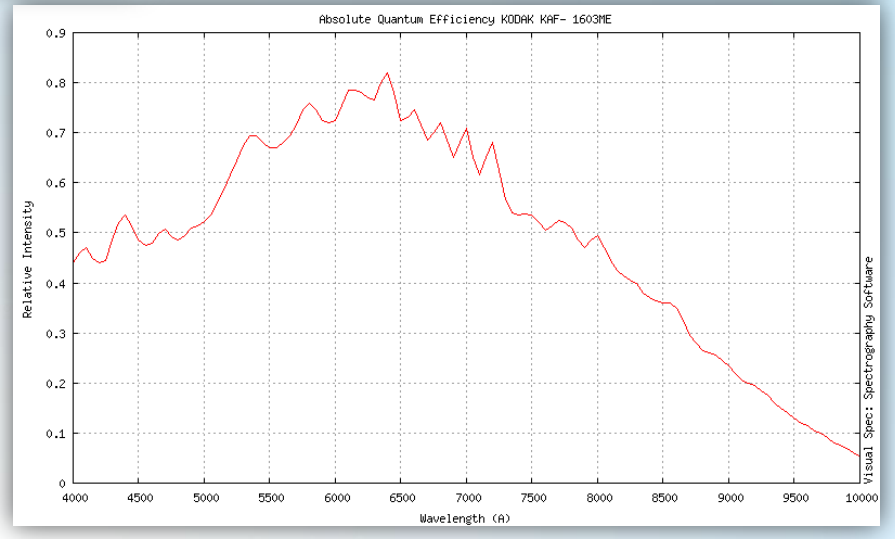
BACHES & CCD Camera attached to the Telescope



C14 EdgeHD, BACHES, SBIG ST-1603ME



Imaging CCD	Kodak KAF-1603ME
Imaging/Pixel Array	1530 x 1020 pixels
CCD Size	13.8 x 9.2 mm
Total Pixels	1.56 million
Pixel Size	9 x 9 microns
Full Well Capacity	~100,000 e-
Dark Current e/p/s at 0 C	1e-/pixel/sec at 0 deg.
Antiblooming	NABG Only
Peak QE	>80%



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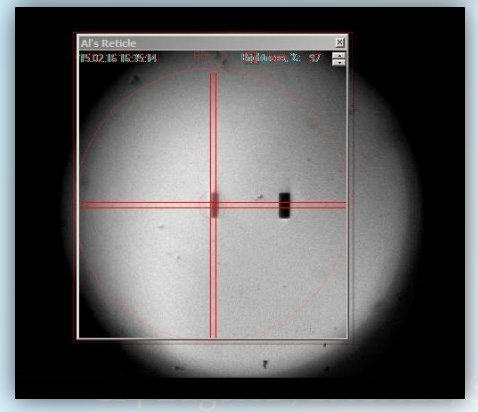
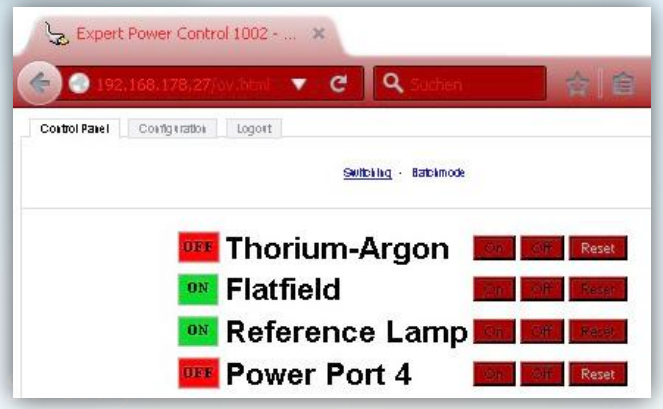
Spectrum guiding on a star:
Manual Guiding with any TIS or Celestron Skyris Video Camera

	Skyris 274M (825155)
A/D Wandler	12-bit
Maximale Bildrate	20 fps
Sensor	Sony ICX274AL Monochrome CCD
Teleskopanschluss	1¼" Stutzen und C-Gewinde
Temperaturbereich	40°C bis -40°C
Optisches Fenster	Nein
Verschluss	Global
Software-Kompatibilität	iCap, IC Capture, DirectShow
Sub-Framing	Wählbar
Stromversorgung	Über USB
Kameraauflösung	1600x1200
Sensorgröße	8,5 mm x 6,8 mm
Pixelgröße	4,4 µm²
System-voraussetzungen	PC / Laptop mit Windows XP/Vista/7/8 & freiem USB 2.0/3.0 Port
Gewicht	0,1 kg



RCU Web Interface



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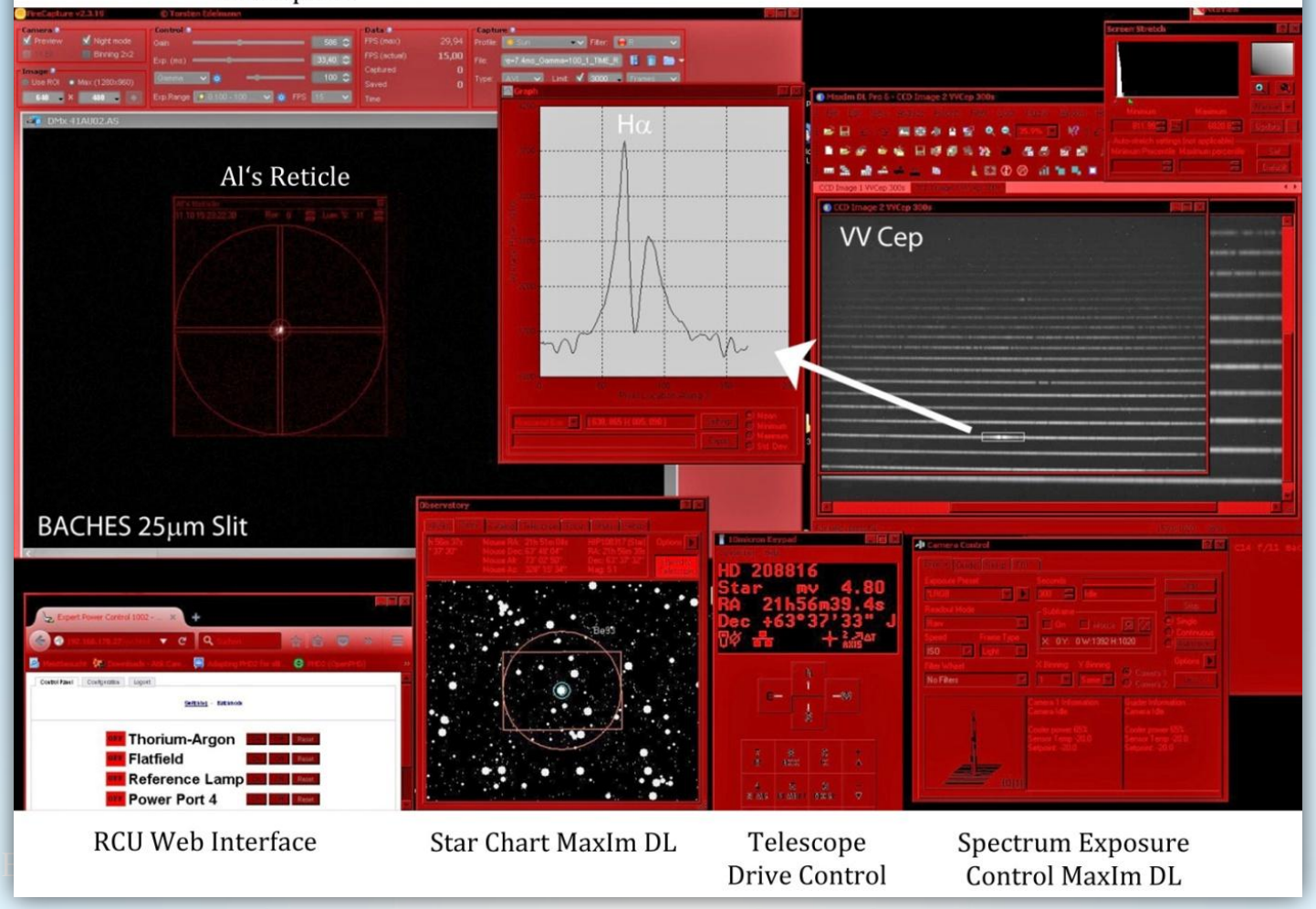
and Remote Calibration Unit

Spectrum guiding on a star: Manual Guiding

Guider Camera Control
FireCapture

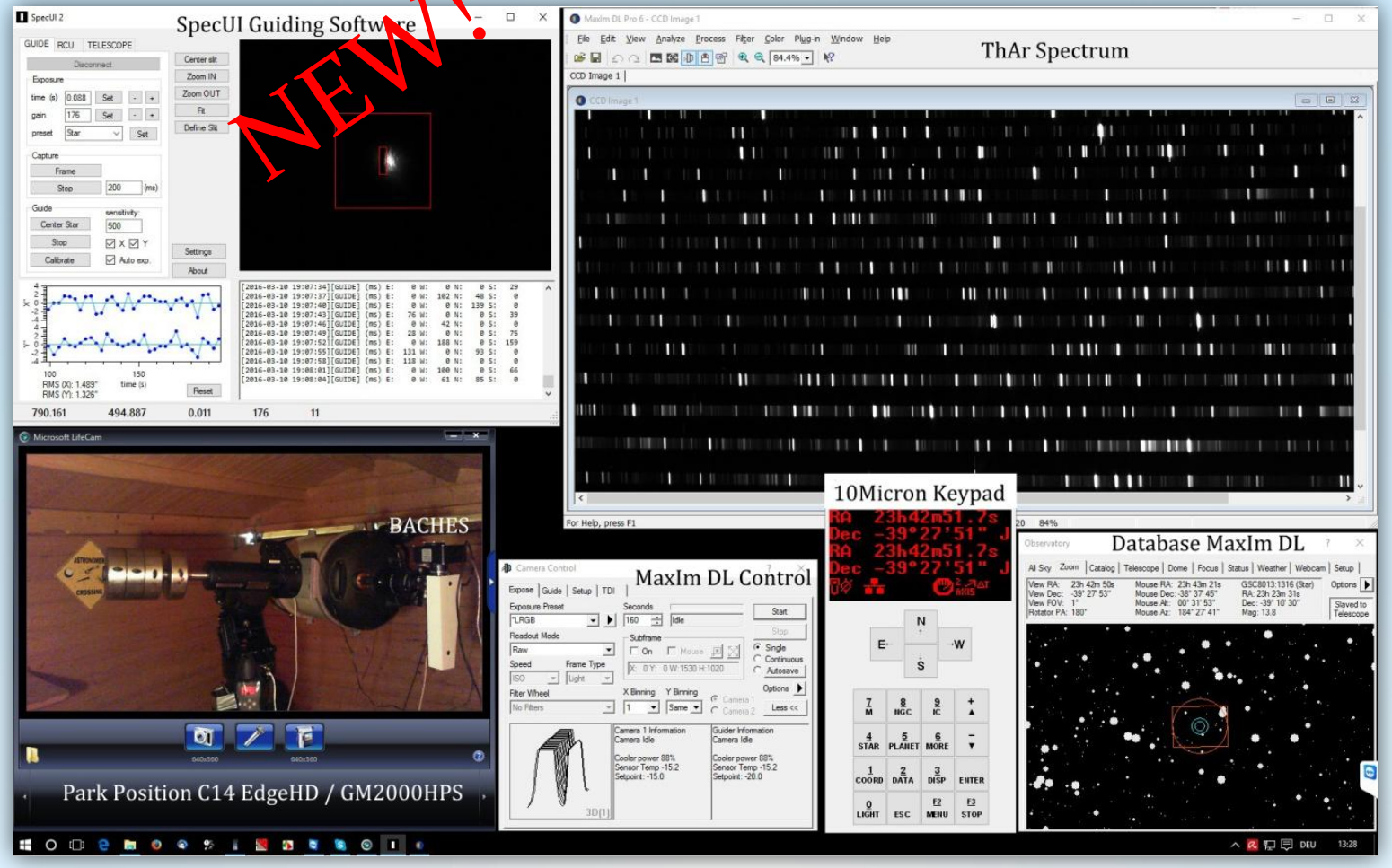


RCU Web Interface | Star Chart MaxIm DL | Telescope Drive Control | Spectrum Exposure Control MaxIm DL

BACHES
ECHELLE SPEKTROGRAPH
and Remote Calibration Unit

baader planetarium

Spectrum self-guiding on a star: *SpecTrack* Guiding Software



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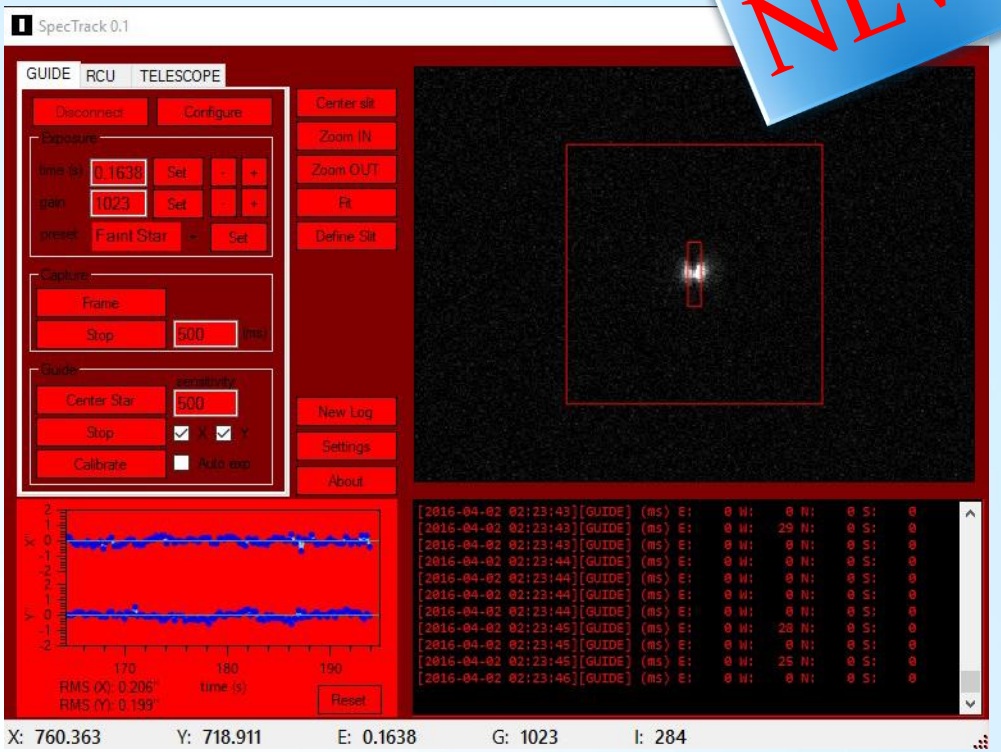
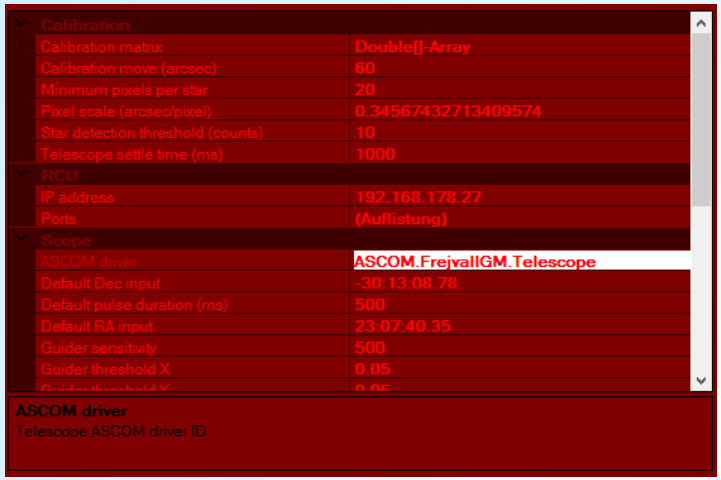
and Remote Calibration Unit

Spectrum self-guiding: *SpecTrack* Guiding Software

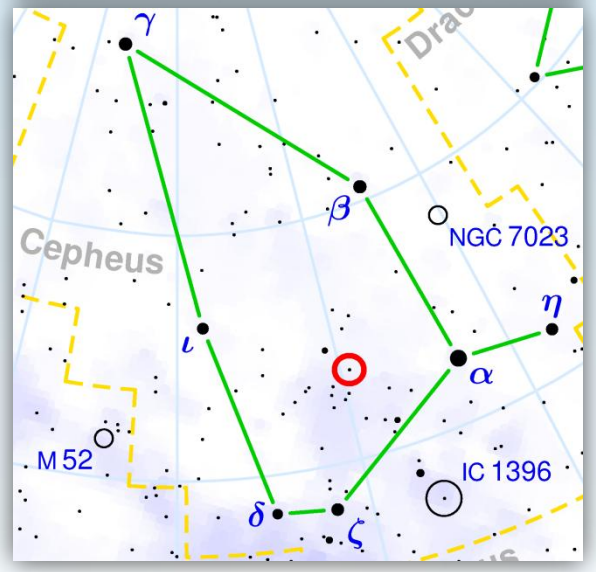
- ✓ GUIDE: *The Imaging Source (TIS)* or *Celestron Skyris* video cameras supported
- ✓ RCU: Full Thorium-Argon and halogen-flatfield hamp control (Ethernet)
- ✓ TELESCOPE: Chose your favourite ASCOM driver
- ✓ Position of slit defined by mouse
- ✓ Keeps an object on the slit
- ✓ Can be used also for guiding of astrophotos

NEW!





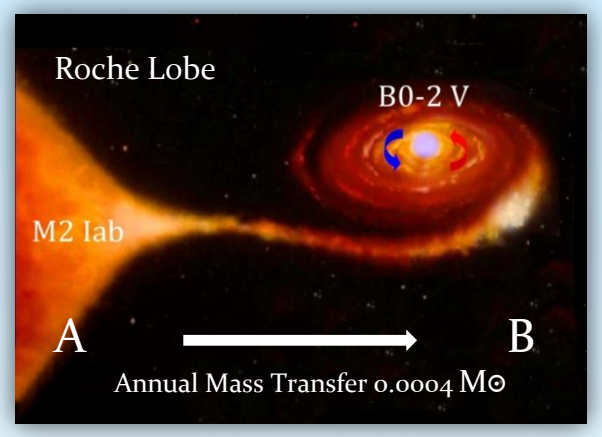
Eclipsing Binary VV Cephei



Observation data	Epoch J2000	Equinox J2000
Constellation	Cepheus	
Right ascension	$21^h\ 56^m\ 39.14385^s$[1]	
Declination	+63° 37′ 32.0174″[1]	
Apparent magnitude (V)	4.91[2] (4.80 - 5.36[3])	
Characteristics		
U–B color index	+0.43[4]	
B–V color index	+1.73[4]	
Variable type	EA + SRc[3]	
A		
Spectral type	M2 Iab[2]	
U–B color index	+2.07[4]	
B–V color index	+1.82[4]	
B		
Spectral type	B0-2 V[2]	
U–B color index	−0.52[4]	
B–V color index	+0.36[4]	

Astrometry	
Parallax (π)	1.33 ± 0.20[1] mas
Distance	4.9k ly (1.5k[5] pc)
Absolute magnitude (M_V)	−6.93[6]
Orbit[7]	
Period (P)	7,430.5 days
Semi-major axis (a)	16.2 ± 3.7[2]" (12.7 AU)
Eccentricity (e)	0.346 ± 0.01
Inclination (i)	84[8]°
Semi-amplitude (K_1) (primary)	19.43 ± 0.33 km/s
Semi-amplitude (K_2) (secondary)	19.14 ± 0.68 km/s
Details	
A	
Mass	2.5[9] or 20[10] $M_\odot$
Radius	1,050[8] (-1,800[10]) $R_\odot$
Temperature	3,826[2] K
B	
Mass	8[9] or 20[7] $M_\odot$
Radius	13[7] $R_\odot$
Metallicity	−0.14[11]
Age	25[12] Myr

Eclipsing Binary VV Cephei



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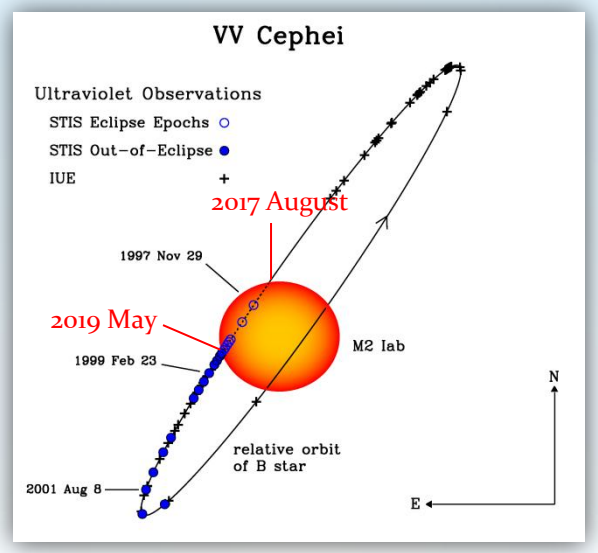

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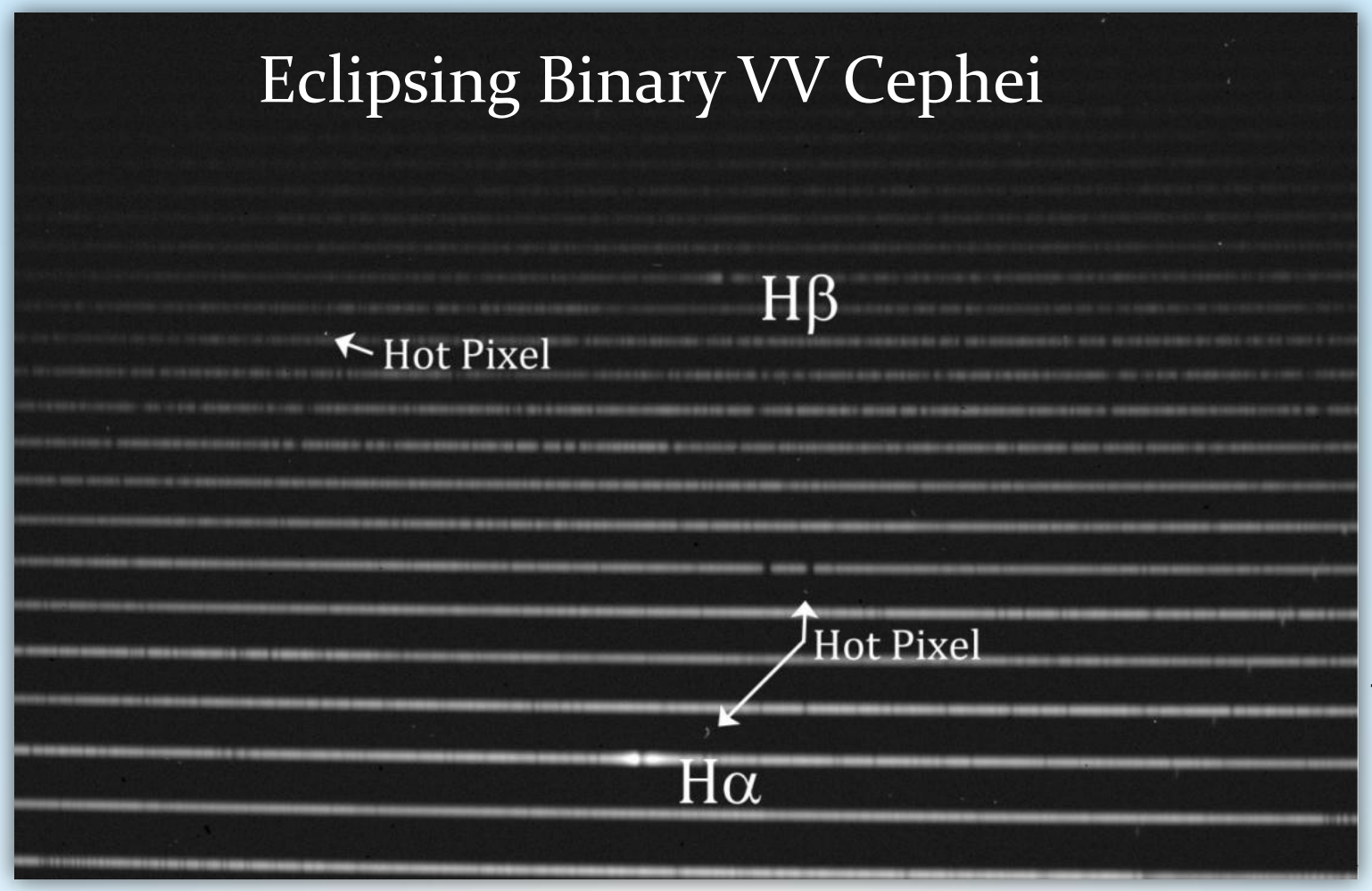
Eclipsing Binary VV Cephei



2015-10-11 | 21.23 UT

Eclipsing Binary VV Cephei

Midas > calib/baches ff16os.fit thar8os.fit 22 20 20 0 0.1

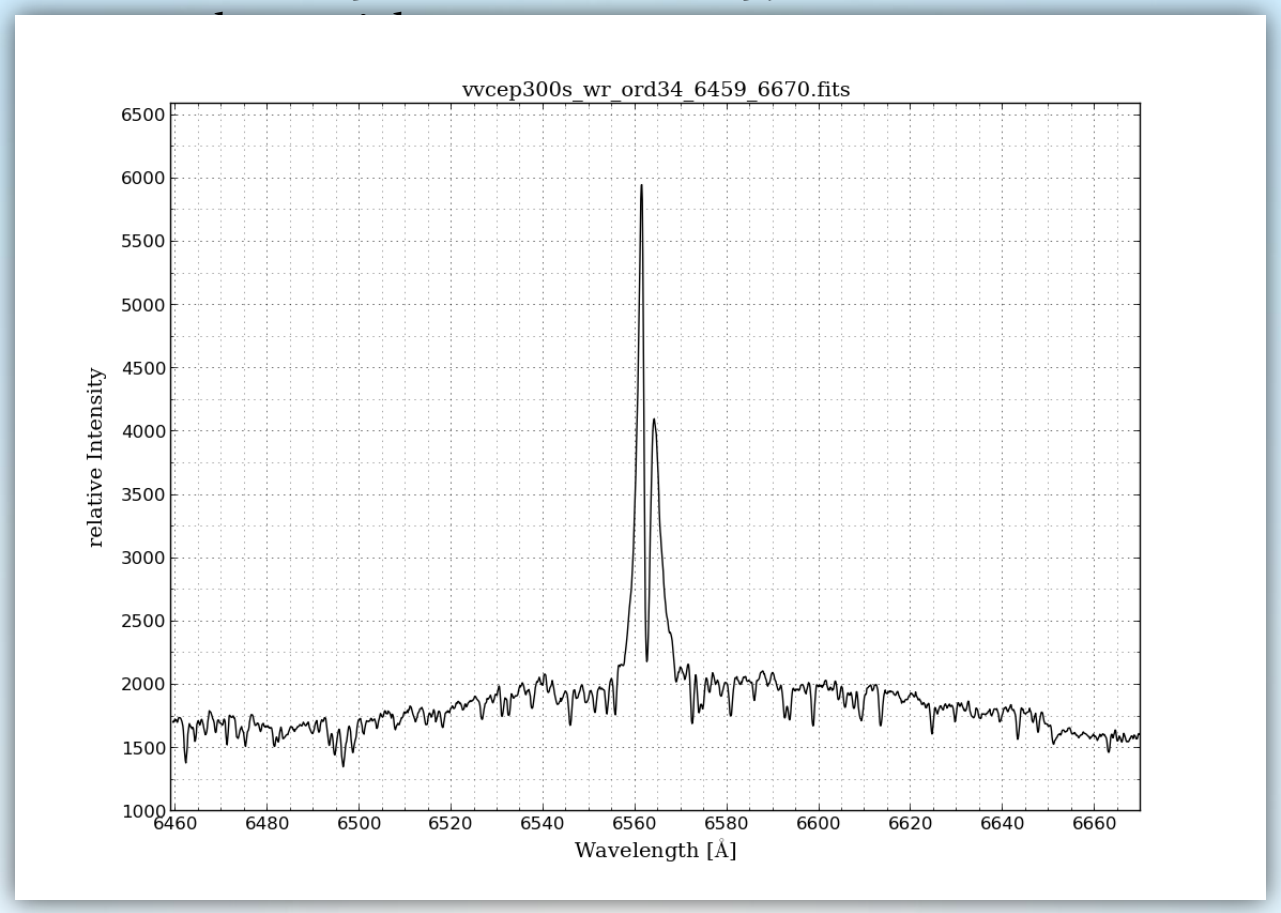
Orders: 22 | Width: 20 px | Extract: 20px | 0 | RMS: 0.1Å

SPECTRAL ORDER	NO.LINES	WL START	WL END	STD. DEV. ANGSTROEM
54	15	4068.25	4201.01	0.00411
53	21	4144.87	4280.23	0.00559
52	23	4224.45	4362.49	0.00489
51	25	4307.17	4447.98	0.00554
50	23	4393.21	4536.89	0.00451
49	22	4482.78	4629.43	0.00483
48	28	4576.10	4725.82	0.00468
47	28	4673.39	4826.32	0.00466
46	31	4774.92	4931.18	0.00564
45	25	4880.97	5040.69	0.00559
44	22	4991.85	5155.19	0.00451
43	30	5107.88	5275.00	0.00503
42	27	5229.45	5400.52	0.00466
41	26	5356.94	5532.16	0.00537
40	29	5490.81	5670.38	0.00444
39	31	5631.54	5815.68	0.00549
38	36	5779.68	5968.63	0.00520
37	40	5935.82	6129.84	0.00569
36	38	6100.63	6300.00	0.00487
35	21	6274.85	6479.89	0.00565
34	20	6459.30	6670.35	0.00609
33	19	6654.93	6872.36	0.00429
			MEAN RMS:	0.00506

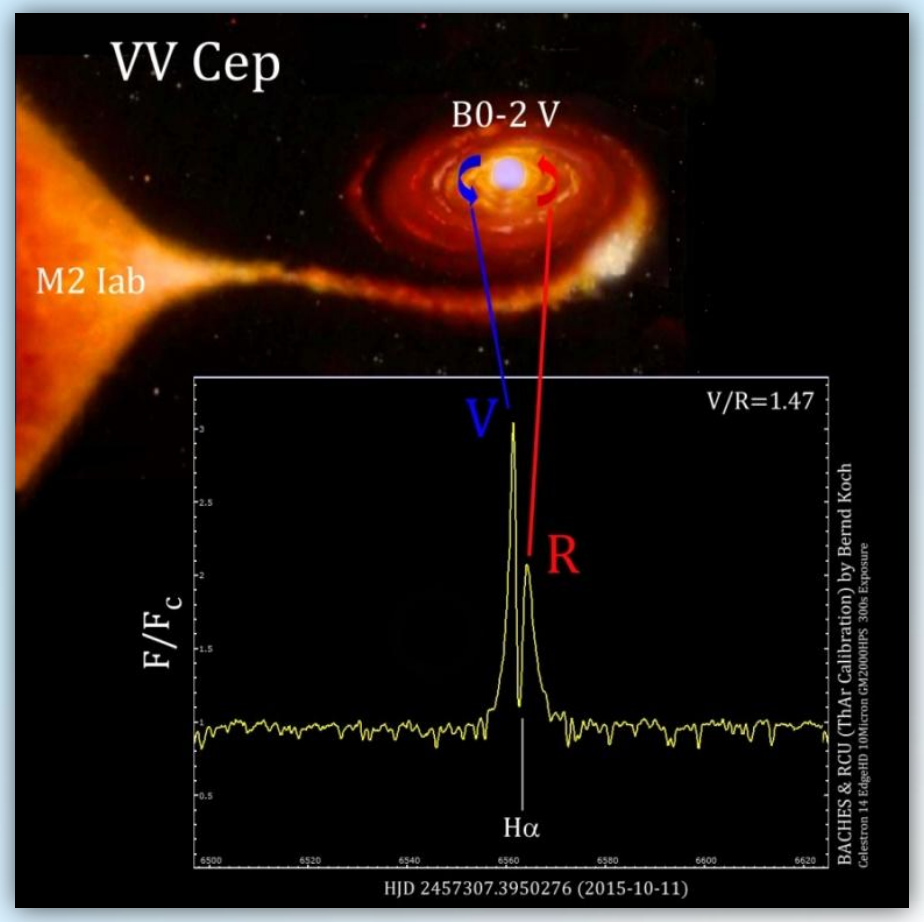
Each of the 22 orders from #33 to #54
Will be saved calibrated in wavelength
(RMS 0.00506Å) and saved in separate files
for further processing:
FITS, PNG, PDF

Eclipsing Binary VV Cephei

Order #34 contains Hα: 6459Å bis 6670Å



Eclipsing Binary VV Cephei



Normalized peak intensities:
V = 2.99, R = 2.04: V/R ≈ 1.47

Equivalent Width between 6550Å bis 6570Å
EWα ≈ - 14.2Å

Heliocentric Radial Velocity of central Absorption: HRV ≈ - 14.0 km/s

2015-10-11 | 21.24.30 UT
HJD=2457307.39437

BACHES
Echelle Spektrograph
and Remote Calibration Unit

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number **6156**

Konkoly Observatory
Budapest
11 January 2016
HU ISSN 1587 - 2440 (on-line)

The Long-term Binary System VV Cep

Pollmann, E.[1]; Bennett, P. D.[2]; Hopkins, J. L.[3]

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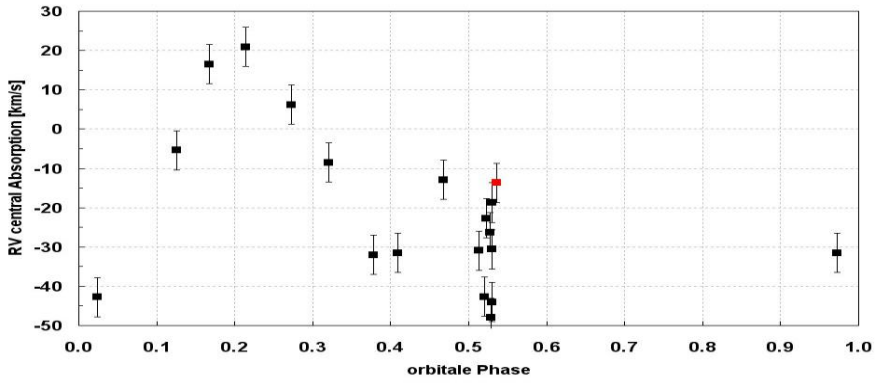
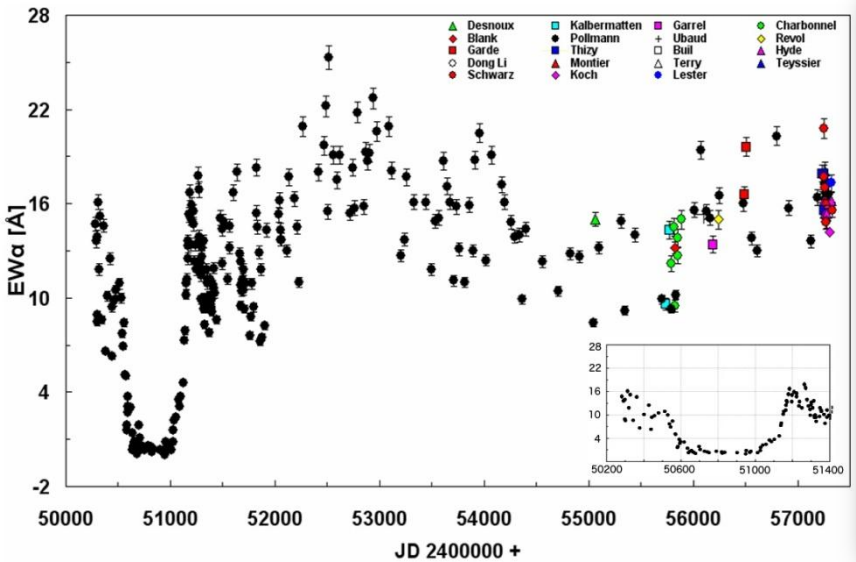
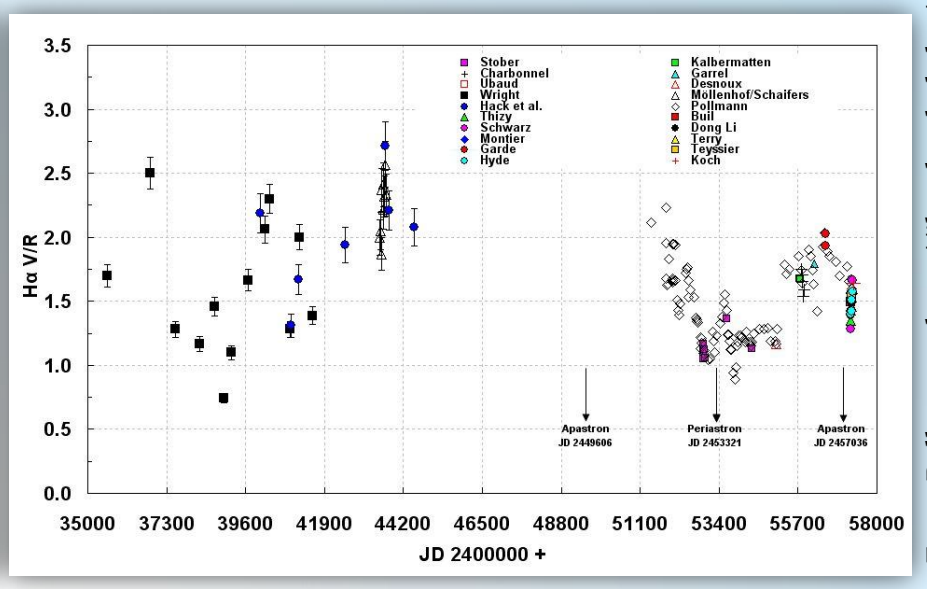
e-mail: ernestospec @ hotmail . de
(2) Department of Astronomy & Physics, Saint Mary's University, Halifax, NS B3H 3C3,
e-mail: pbennett @ ap . smu . ca
(3) 7812 West Clayton Drive, Phoenix, Arizona USA, e-mail: phjeff @ hposoft . com







Ernst Pollmann, http://ibvs.konkoly.hu/cgi-bin/IBVS?6156

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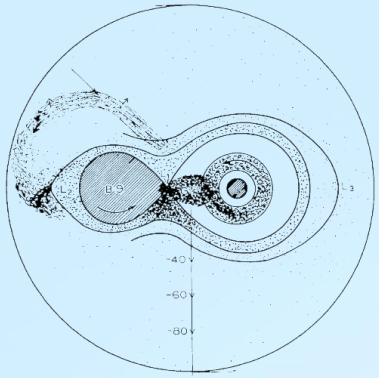
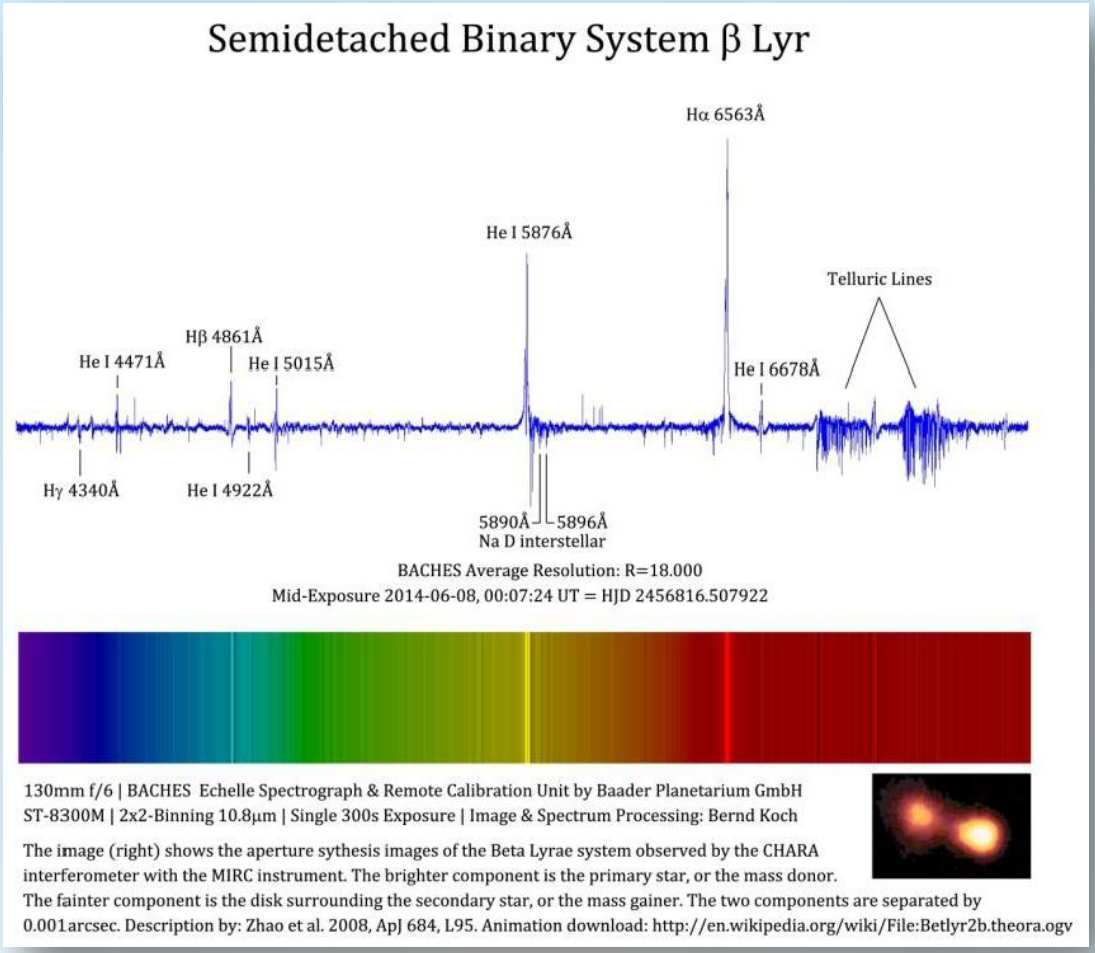


Semi-Detached Binary Star β Lyrae

Emission line stars:
Simultaneous monitoring of variations in stellar flux at different wavelengths
Example: Semi-detached binary star beta Lyrae.
Purpose: Tracking variations during a binary orbit
silmultaneously
at different wavelengths in the BACHES echelle spectrum

Fig. 2: Spectrum of semi-detached binary system β Lyrae, taken on June 8, 2014 at 00:07:24 UT. The spectrum was recorded with BACHES echelle spectrograph and a SBIG ST-8300M CCD camera, Pixel size 10.8 µm. This is a single 300s exposure from which a darkframe has been substracted.

Semi-Detached Binary Star β Lyrae



www.baader-planetarium.de/baches/

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Semi-Detached Binary Star β Lyrae

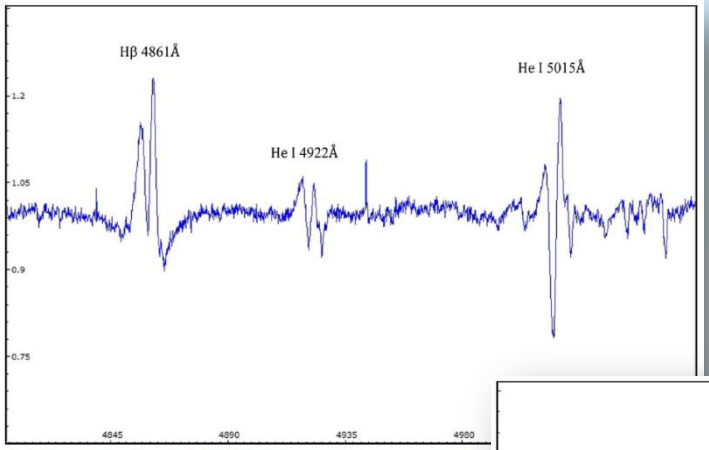

Fig. 7: This is a section of the recorded BACHES echelle spectrum showing varying strength o
P-Cygni-Profiles at Hβ 4861Å, He I 4922Å, and He I 5015Å with different flux.

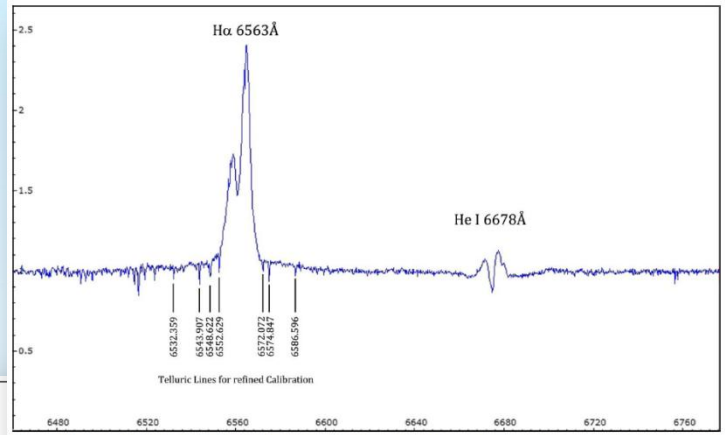

Fig. 9: Detail near Hα 6563Å and He I 6678Å. The precisely known wavelengths of the telluric lines around Hα can be used for fine calibration of that section of the spectrum.

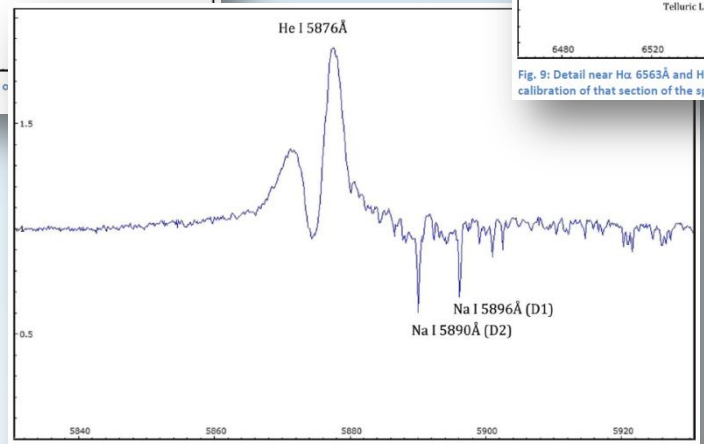

Fig. 8: P-Cygni-profile of β Lyr at He I 5876Å is close to the narrow interstellar Sodium lines (Na I Doublet D1, D2). "The He I 5876Å and the He I 6678 lines are well suited for the study of the stellar wind from the [B8...] B9 component of β Lyr" (Etzel, Meyer; 1983). The Na I Doublet may also be used to map interstellar absorption along the line of sight (Welsh et al.; 2010).

http://www.baader-planetarium.de/baches/download/beta_lyr_baches_poster_e2_bernd_koch.pdf

ATT Essen May 21, 2016 | Bernd Koch | Baader Planetarium GmbH

Thank you very much for your attention

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