

SPECTROGRAPHS & OPTICS

Marc Trypsteen

HOW IT WORKS

and

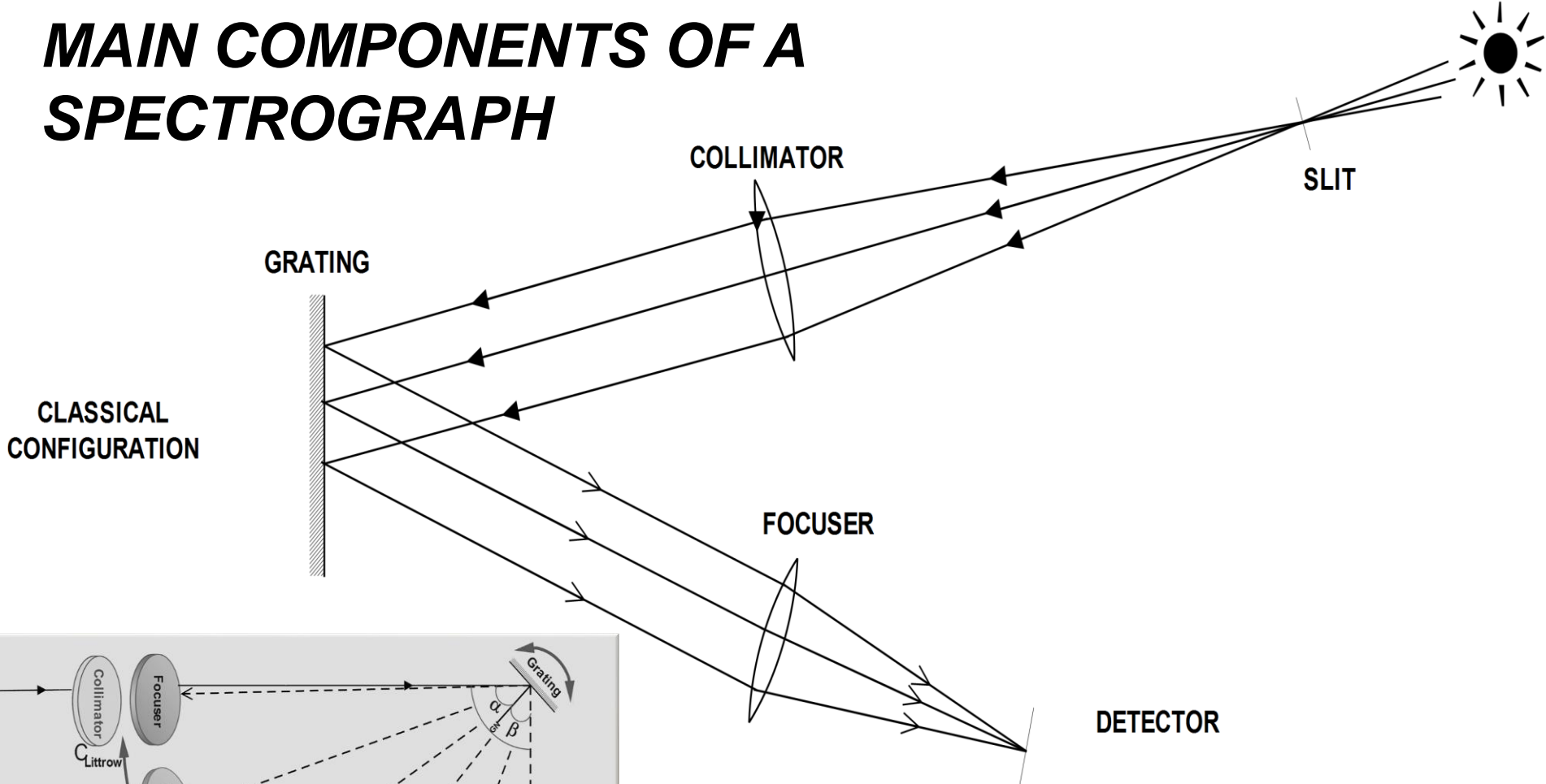
HOW TO TEST IT

Optica studiedag

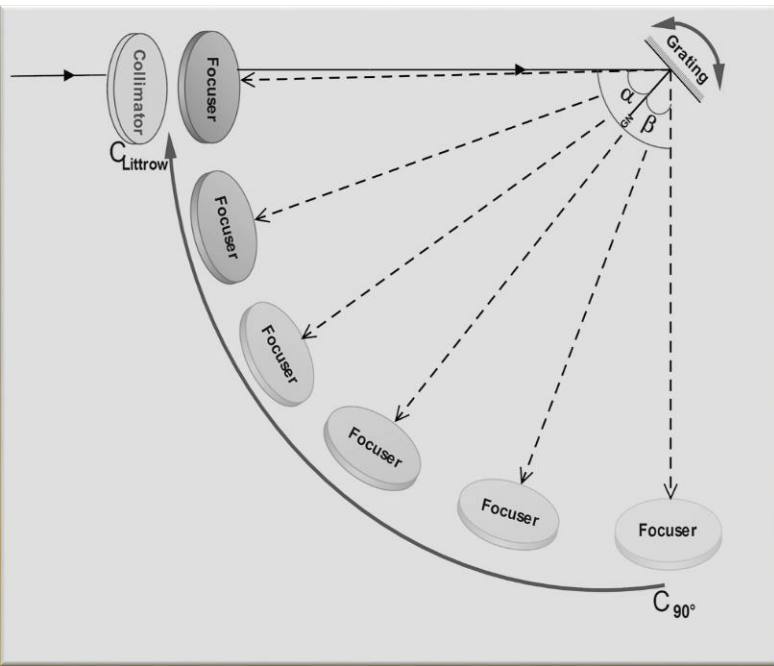
UGent 18 maart 2017

Volkssterrenwacht Armand Pien

MAIN COMPONENTS OF A SPECTROGRAPH

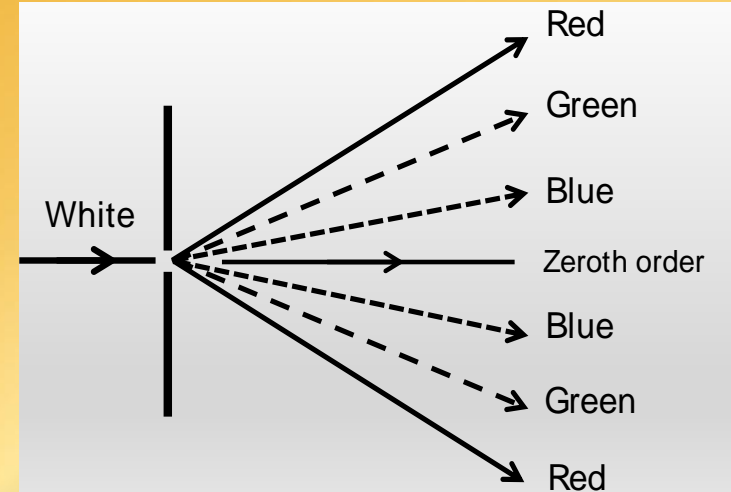
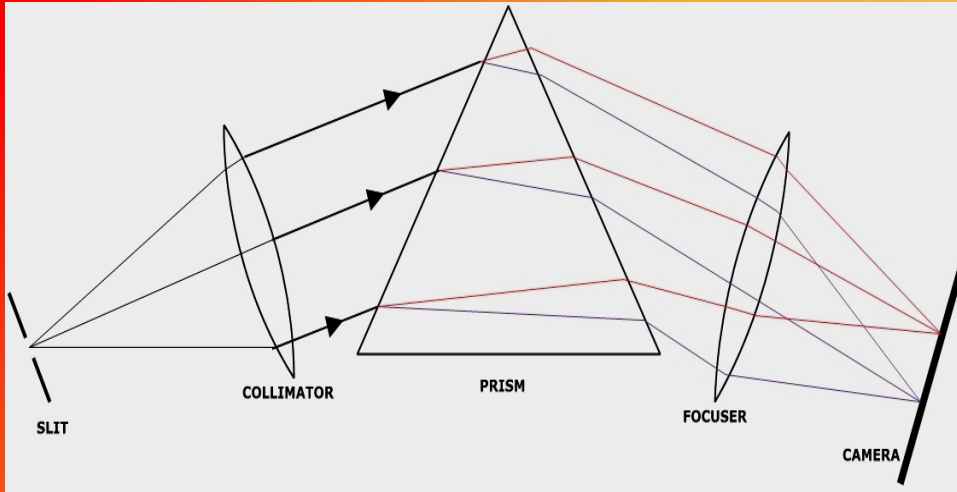


CLASSICAL CONFIGURATION



- Classical
- Littrow
- Czerny-Turner
- Rowland
- Echelle: cross-dispenser extra

DISPERSION by REFRACTION versus DIFFRACTION



Dispersion	By Refraction	By Diffraction
Bending	Blue side > Red side	Red side > Blue side
Causing Mechanism	Push/Pull on electrons Absorption/Re-emission	λ versus slit opening Dimension difference
Examples	Rainbow, Prism spectrographs	Transmission-/Reflective grating spectrographs

ETENDUE :

OPTICAL INVARIANT of THROUGHPUT

$$L = A \cdot \Omega$$

A = maximum aperture area

Ω = maximum solid angle divergence

RESOLVING POWER

$$R = \frac{\lambda}{\Delta\lambda}$$

SPECTROGRAPH EFFICIENCY

$$E = L \cdot R$$

= constant !

INFLUENCES OF THE SLIT

□ **WIDTH:** ↑ Amount of light entering ↑
Intensity ↑ Amplitude ↑
BUT Resolving Power ↓
S/N ratio ↓

□ **HEIGHT:** ↑ Etendue L ↑
BUT Amount of Straylight ↑
Increase of Aberrations ↑

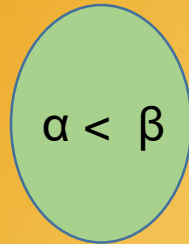
□ **SPATIAL RESPONSE:**
Point Spread Function (PSF)
Spectrograph efficiency E ↑
if angular slit widths ↓

COLLIMATOR → FOCUSER OPTICAL TRAIN

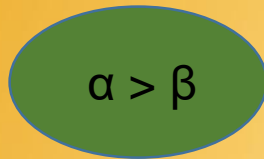
□ COLLIMATOR :

Focal ratio matching with Telescope !

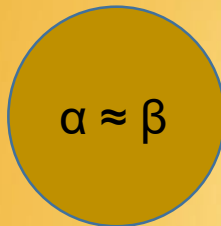
□ ANAMORPHIC FACTOR r :



❖ Input angle < Output angle → $r > 1$



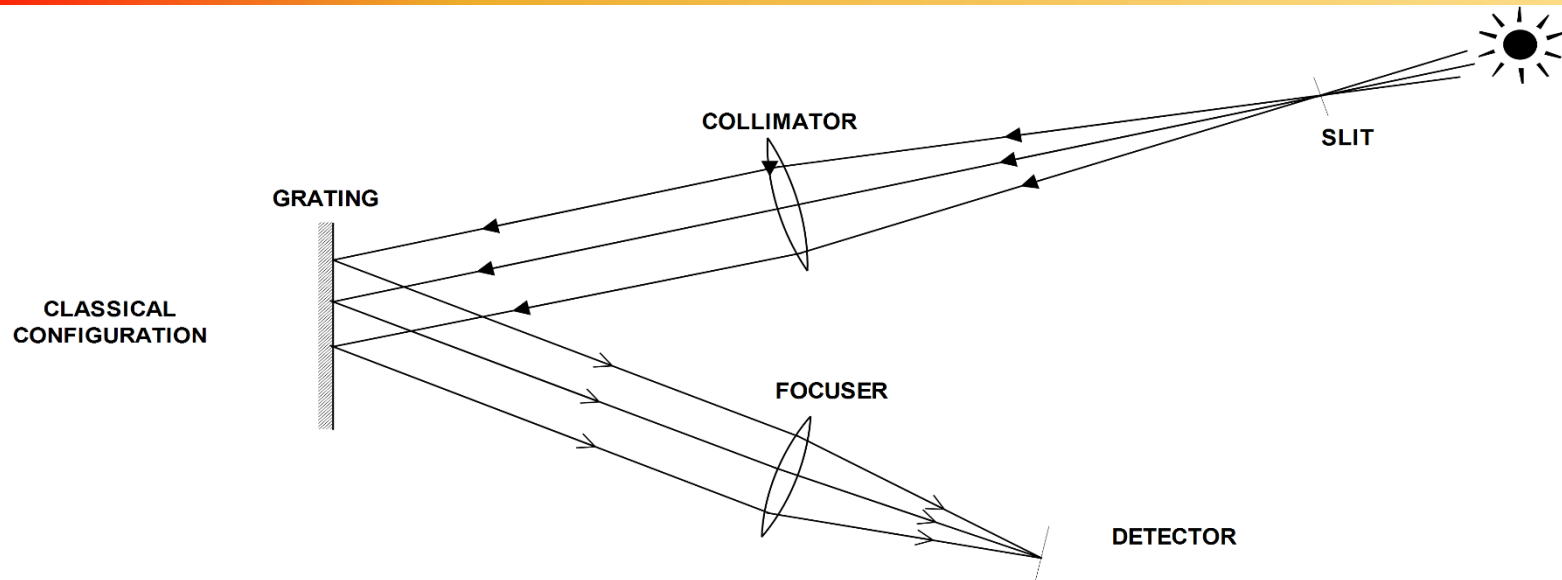
❖ Input angle > Output angle → $r < 1$



❖ Input angle \approx Output angle → $r \approx 1$



INFLUENCES OF THE OPTICAL DESIGN and RECORDING DEVICES



OPTICAL PART / DEVICE	% LIGHT LOSS	% RECOVERED LIGHT
COLLIMATOR	3	97 % TRANSMISSION
GRATING	12	88 % REFLECTION
FOCUSER	2	98% TRANSMISSION
DETECTOR	9	91% ABSORPTION

TOTAL THROUGHPUT = (0,97)² * 0,88 * (0,98)² * 0,91 = 0,72

INFLUENCES OF ORDER OVERLAPS

Order m	λ [Å]								m→m+1
1	4000	6000	8000	10000	12000				
2	2000	3000	4000	5000	6000	8000	10000	12000	1/2
3	1333	2000	2667	3333	4000	5333	6667	8000	2/3
4	1000	1500	2000	2500	3000	4000	5000	6000	3/4

Overlapping ratio in wavelength ranges of ultraviolet ($\lambda < 4000$), visible (apricot shaded) and infrared ($\lambda > 8000$) for diffraction orders 1 to 4 of a grating.

TESTING and EVALUATING OPTICAL PERFORMANCE OF SPECTROGRAPHS

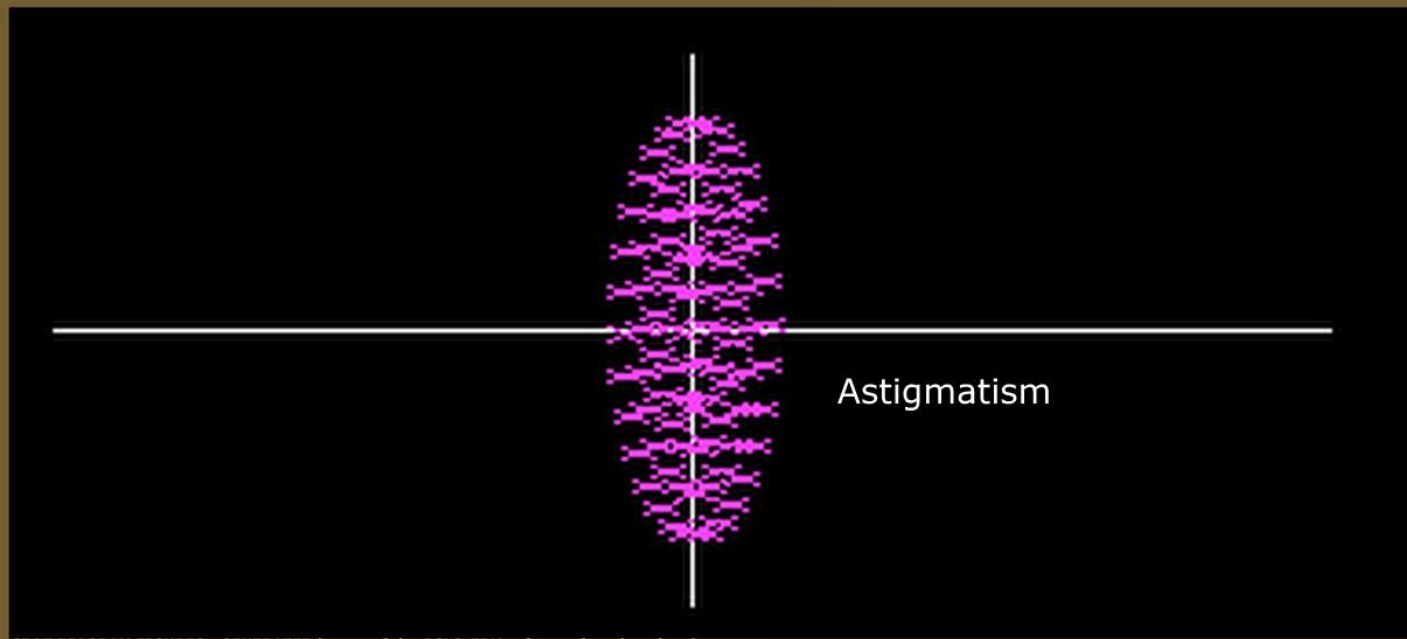
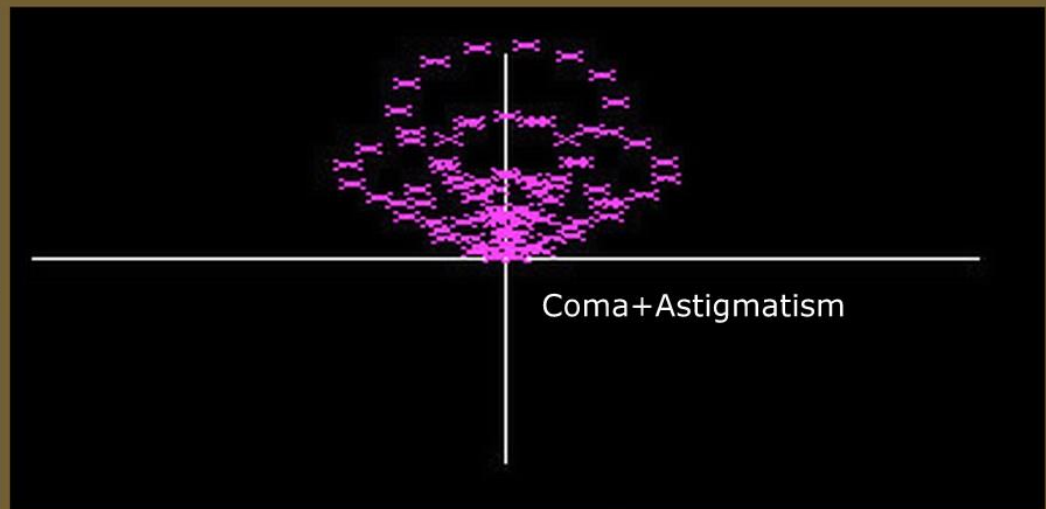
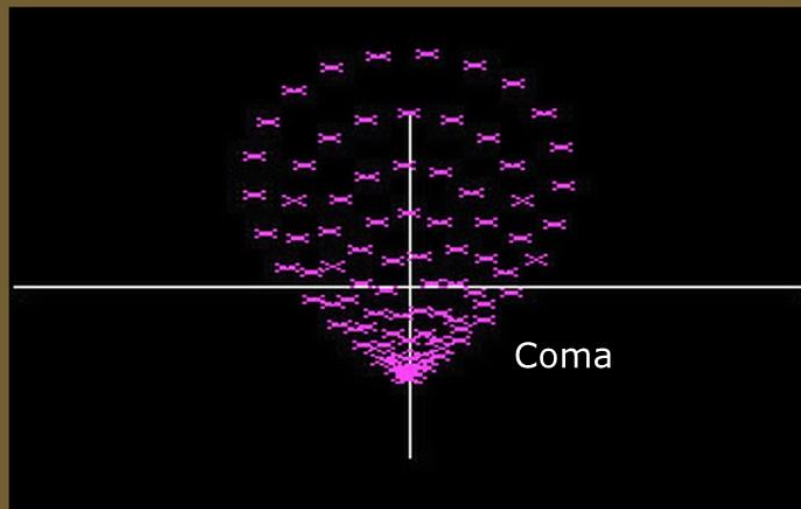
- ❑ ***Quality related*** : *mirrors, lenses, gratings,...*
- ❑ ***Setup related*** : *divergence/convergence, collimator, focuser*
- ❑ ***Design related*** : *amount of optical surfaces, choice of grating,...*

Quality related :

EVALUATION BY SPOT DIAGRAM/PSF SOFTWARE

- **MODAS** : **M**odern **O**ptical **D**esign and **A**nalysis **S**oftware
Freeware version: MODAS NG
www.myoptics.at/modas
- **OSLO** : **O**ptics **S**oftware for **L**ayout and **O**ptimization
Commercial versions: Premium/Standard/Light
Free educational version : OSLO-EDU
download: www.lamdares.com/oslo-university-program
www.lamdares.com/oslo
- **WinLens**: www.winlens.de
Free Basic version available
- **ZEMAX** : OpticsStudio
www.zemax.com
trial version available

EVALUATION BY SPOT DIAGRAM/PSF SOFTWARE

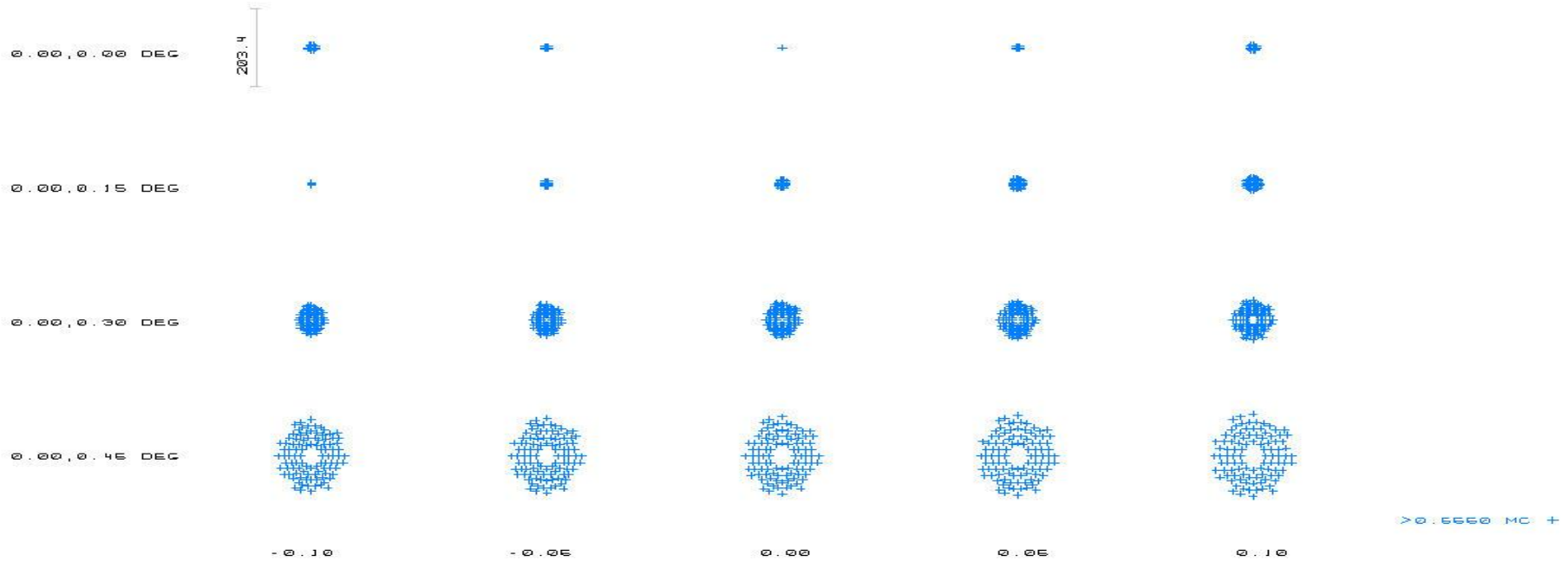


SPOT DIAGRAM FIGURES - GENERATED by use of the OSLO-EDU software for educational purposes

Multi Spot Diagram 1

Options Tools Update Window Zoom

THROUGH FOCUS SPOT DIAGRAMS



RITCHY-CHRETIEN TELESCOPE

FIELD	:1	2	3	4
RMS RAD	:0.059	6.802	27.357	61.623
GEOM RAD	:0.131	11.251	45.136	101.719
ENPD	:304.00	DELTA FOCUS: 100.00 MC		
FOCL	:2432.00	SCALE DRAW : VERT. BAR		
BFL	:608.00	SCALE UNIT : MICRONS		
FN	:8.00	SCALE BAR : 203.4		

C:\USERS\MARC\MODASTEST\MODAS
SAT 4/03/2017 12:52:57

MODAS NG, MYOPTICS

Preliminary GRISM DESIGN and EVALUATION with WINLENS 3D

WinLens3D Basic: C:\Users\marc\Documents\GRISMMARC.SPD

File Edit View Tables Graphs Transmission Engineering Database Optimise Options Window Help

Auto Update User Update TRA OPD File Edit Tables Graphs Transmission Engineering Databases Optimisation

System Parameter Editor

Main | Conjugates | Aperture | Field | Waveband | Obj/Img

Object Distance: -1000.0

Stop Rad: 1.0 Show

|Object Angle| [deg]: 1.0 Zoom..

Title

Defocus to X-Z Image Plane Real Ray Traces in X-Z Plane

System Data Editor

Edit system Groups & Modules Tilts & Decenters

#	Stop	Dirn	Component	Z	Sepr
4					20.000
5					
6		Nom	prism	--	1.000
7		Nom	392149000	0	
8					12.000
9		Nom	322239322	--	
10					

Grating Database

54 Qioptiq gratings out of 54

392149000: Transmission grating
300lines/mm [17.5deg blaze angle]
Dimensions: 12.0 x 12.0mm

Grating	Lines / mm	Info	Descri
51 392148000	300	17.5	Transmission Grating
52 392149000	300	17.5	Transmission Grating
53 392150000	300	31.7	Transmission Grating
54 392151000	300	31.7	Transmission Grating

All gratings
Reflection Gratings - ruled

Lens Drawing

Spot Diagrams Y-Z Section

Scale: 0.5mm Spacing: 1.0mm Def: 0.0mm

Scale: 0.5mm Spacing: 1.0mm Def: 0.0mm

Spacing: -2.0mm -1.0mm 0mm 1.0mm 2.0mm

Lat. Colour removal [%]: 0% summary

Summary: -587.6nm

Spot Diagrams: Full Field

Scale: 0.5mm Def: 0.0mm

Define Grid: 12.3mm [0.71] Object Top on-axis [0.0] -12.3mm [-0.71]

Defocus: 12.3mm [0.71] on-axis [0.0] -12.3mm [-0.71]

Summary: -587.6nm

Prism Database

59 Qioptiq prisms out of 59

334481000 Wedge Prism [dispersive] N-BK7 Dia: 22.4mm Rd: 4.5mm

Prism	Type	Description
1 334481000	Wedge	dia:22.4 Rd:4.5
2 334482000	Wedge	dia:22.4 Rd:6.0
3 334483000	Wedge	dia:40.0 Rd:8.0

All types: 45° Bauernfeind [reflective];
60° [dispersive]; Dove [reflective];
30° [dispersive]; Penta [reflective];
Wedge [dispersive];
Double Amici [dispersive];
90° [reflective];

Lens Database

Achromat f = 140/31.5 mm
Efl ~ 140.05mm [at 587.6nm]
ø31.5 190 items

NoMount	MicroB	NanoB	Mounted	Title
63	322239322			Achromat f = 140/31.5 mm
64	322241000		032585000	Achromat f = 1000/80 mm
65	322242000		032586000	Achromat f = 1185/80 mm

Full Database Query Database ...

Free Version Defocus Undefined Slider Undefined Slider Undefined Slider Undefined Slider Undefined Slider Undefined Slider Undefined Slider Undefined Slider

SETUP RELATED:

□ **Telescope coupling**

- ***f/ collimator versus f/ telescope***
- ***Most amateur telescopes optics f/10***
- ***If f/? ↓ : collimator opening ↑***

□ **Distance Slit / Collimator**

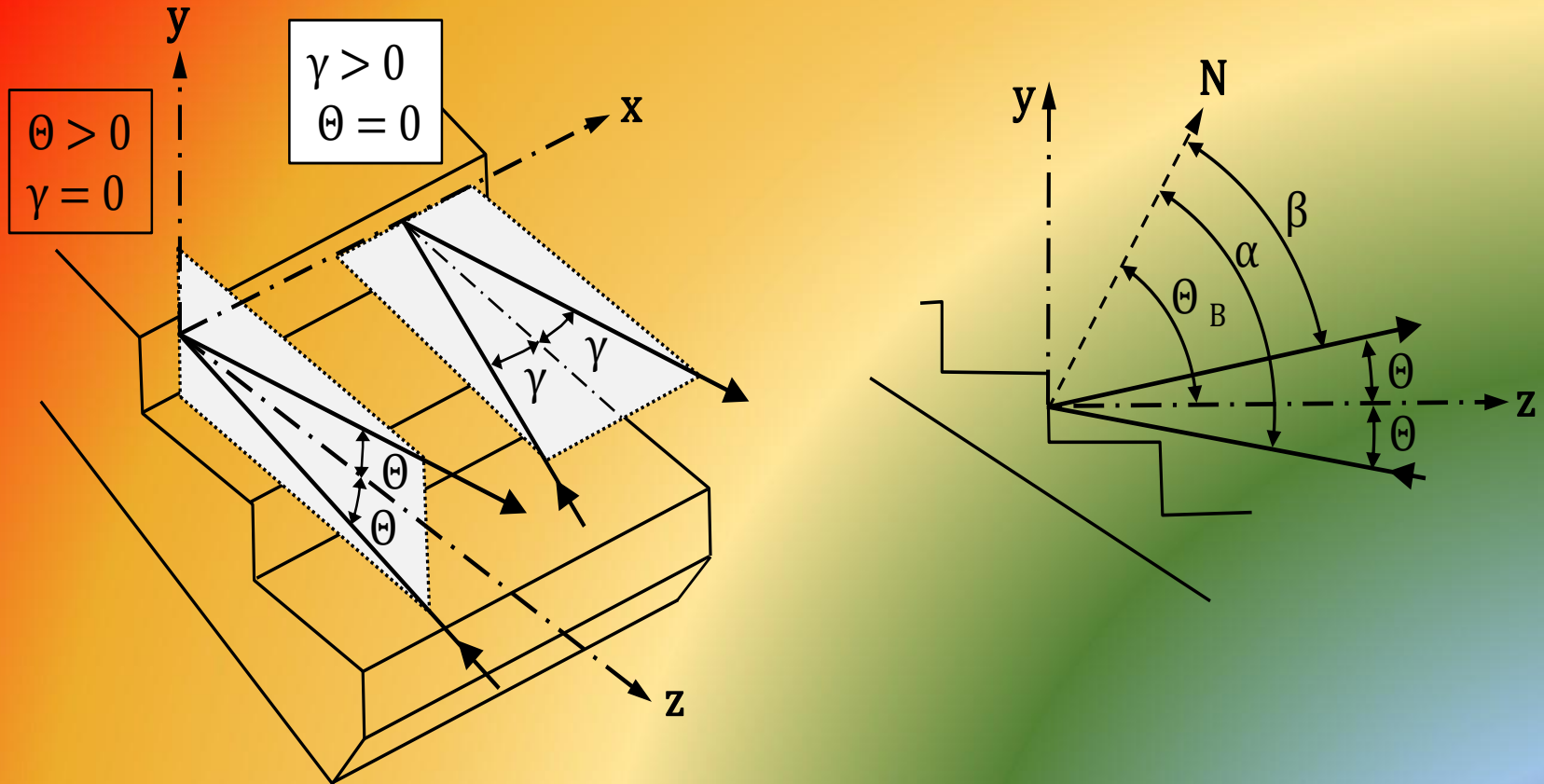
- ***influences the dimensions of the beam***
- ***improper illumination of the grating***
- ***horizontal and vertical focal points differ***
→ ***astigmatism***
- ***multiple peaks with double maxima or minima***

□ **Camera**

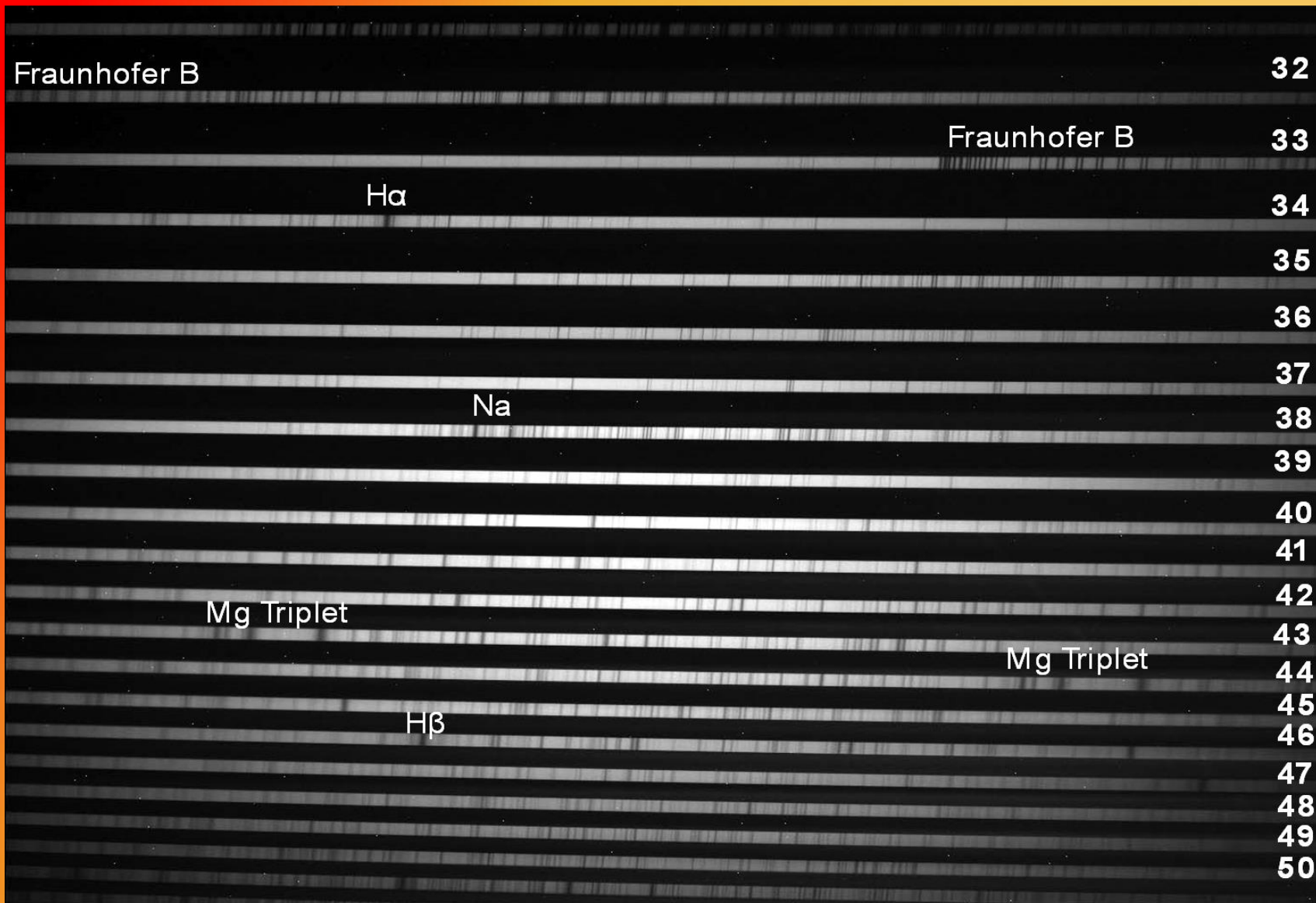
- ***Cave interference fringes (wavelength dependent!)***

DESIGN RELATED:

Example: Echelle gratings

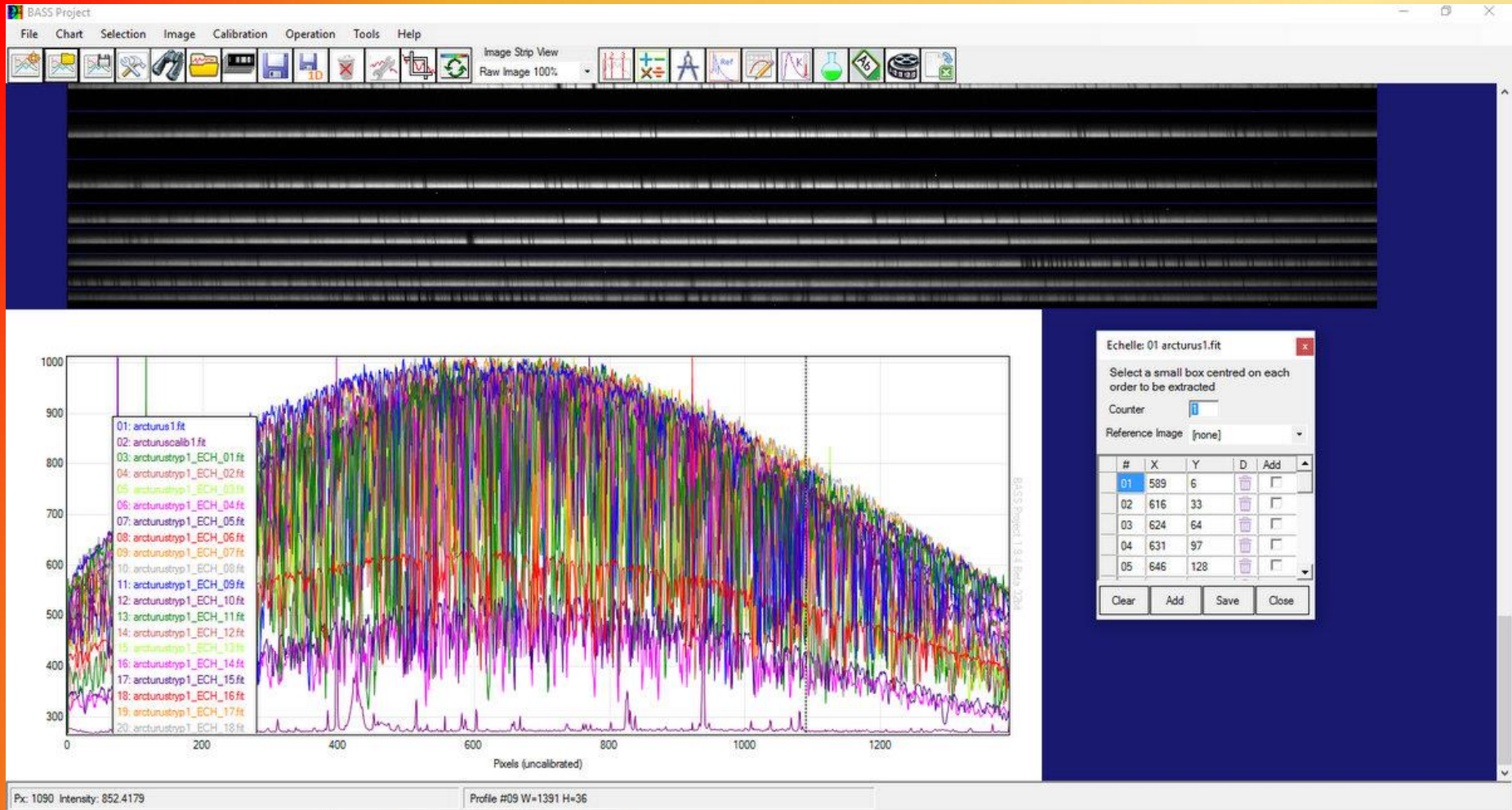


Off-axis angle positions of the light pathway on Echelle gratings.
3D-view and longitudinal section by M. Huwiler, schematically after [158].

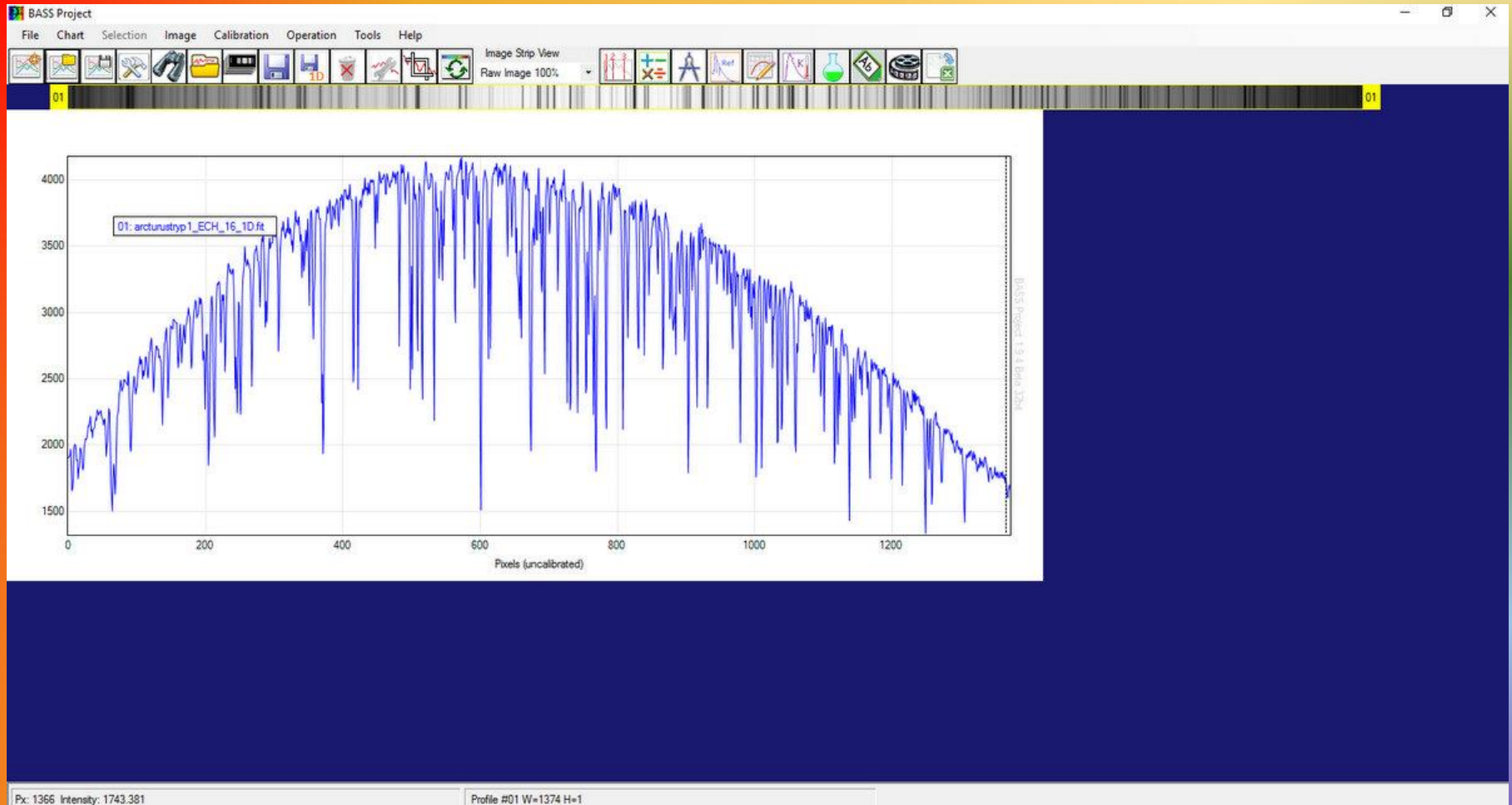


Orders 32 – 50 of the solar spectrum, recorded by SQUES Echelle spectrograph.

Spectrum of Arcturus (32-50) SQUES Echelle spectrograph, Reduction: BASS project



Spectrum of Arcturus (one order) ***SQUES Echelle spectrograph,*** ***Reduction: BASS project***



DESIGN RELATED : ECHELLE GRATINGS TYPES

Echelle R number \neq R of Resolving Power

Blaze Angle	R
63.4°	2
71.5°	3
76°	4
79°	5

Echelle R \uparrow caveats:

- **Ghosts \uparrow**
- **\angle incident/diffracted rays \downarrow**
- **Shadows \uparrow**
- **Performance 31.6 \rightarrow 79 L/mm: Red \rightarrow Blue \uparrow**
- **Cross dispenser: prism \rightarrow grating \uparrow**
- **Thermal stability \uparrow**
- **Complexity of Reduction process \uparrow**
- **Focal length of Collimator \downarrow**

How to test your spectrograph

SPECTRAL LINE ANALYSIS

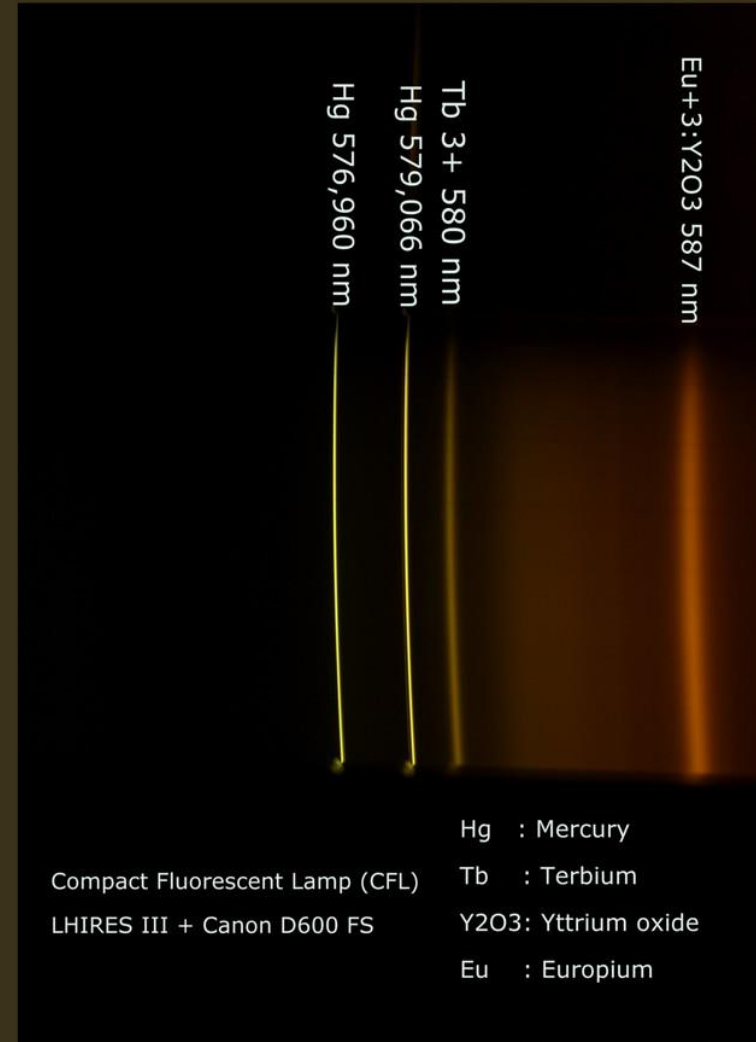
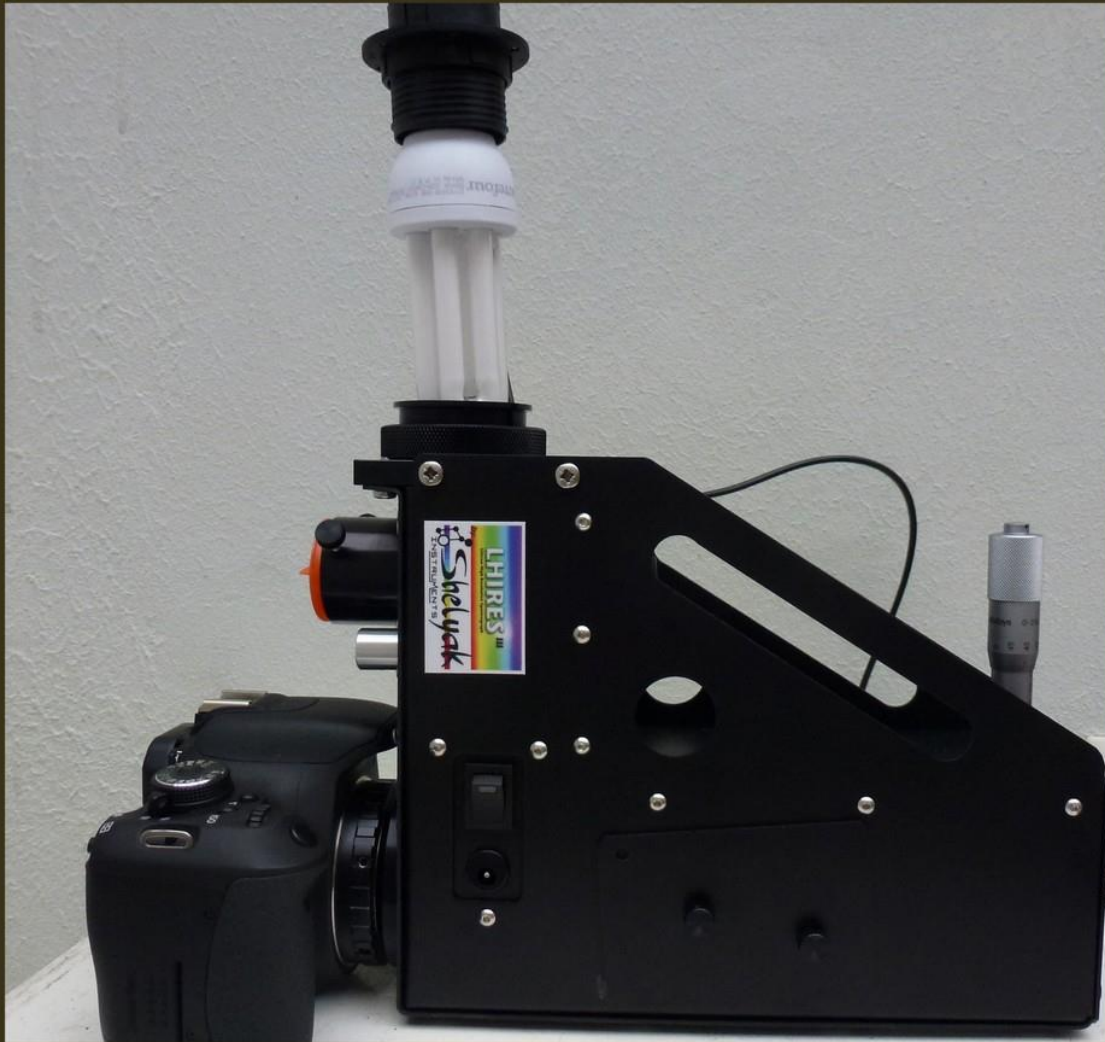
- ***Monochromatic lightsources :***
 - gas discharge tubes***
 - laser light***

- ***Calibration lightsource :***
 - Ne/Ar/Th- calibration lamps***
 - Relco -starterlamps***
 - CFL – Hg I lines***
 - Laser Frequency Comb***

CHECK LIST

- **Optical alignment : in- and output of the lightbeam**
- **Determination of the brightest order as working order**
- **Reduction software packages for calibration and analysis of spectral lineshapes**
- **Resolving power test by doublet (or triplet) spectral line analysis**

SPECTROGRAPH TESTING by imaging CFL SPECTRAL LINES



©2014 Marc Trypsteen

Hg 435,833 nm

(LFC)

LHIRES III + Canon D600 FS



Hg 546,074 nm

(LFC)

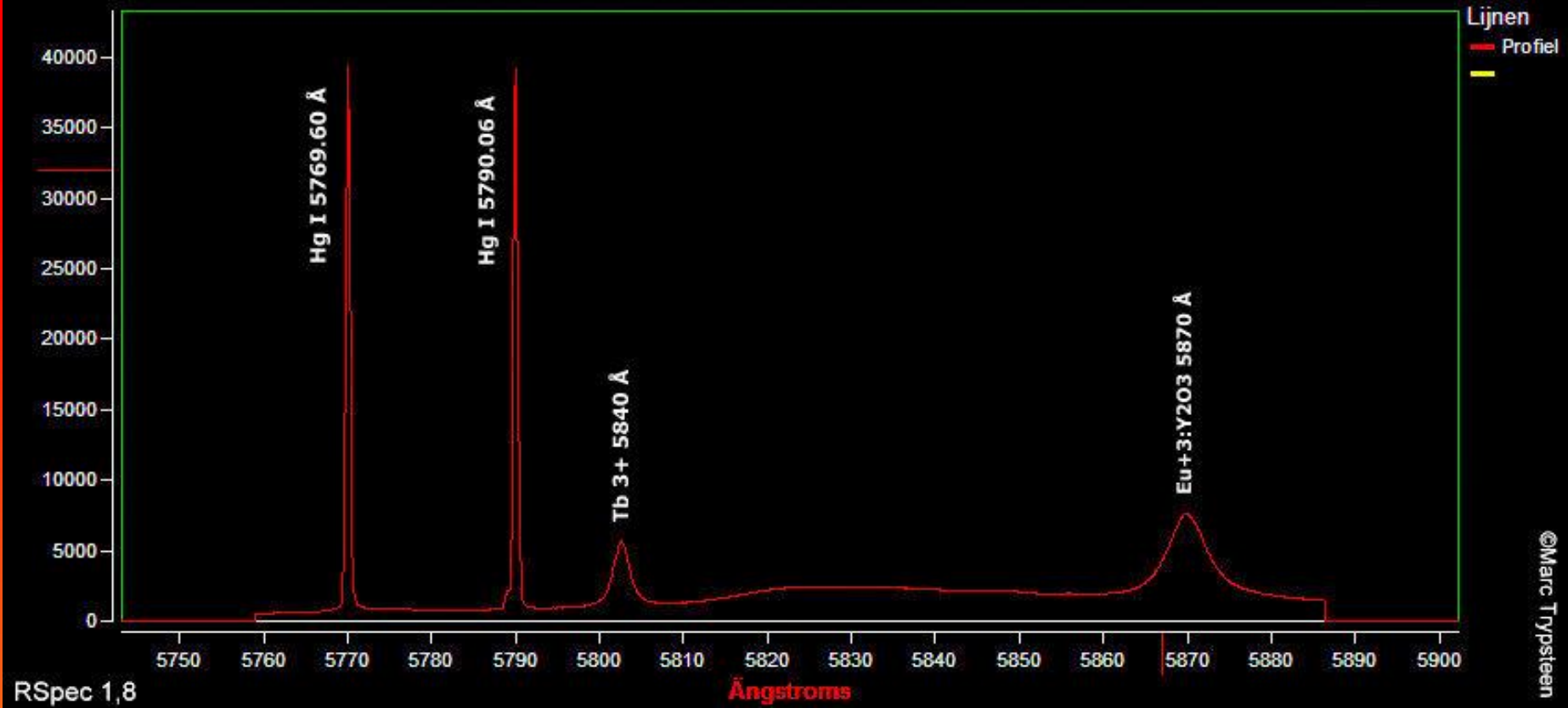
LHIRES III + Canon D600 FS



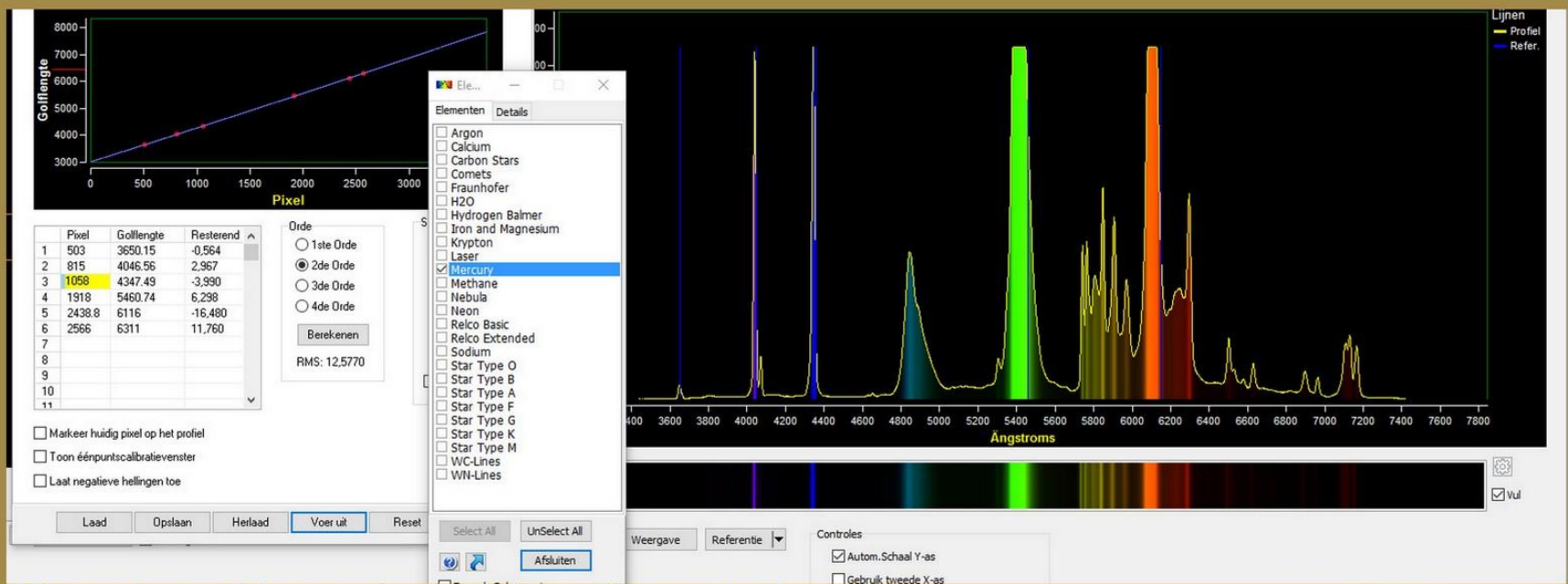
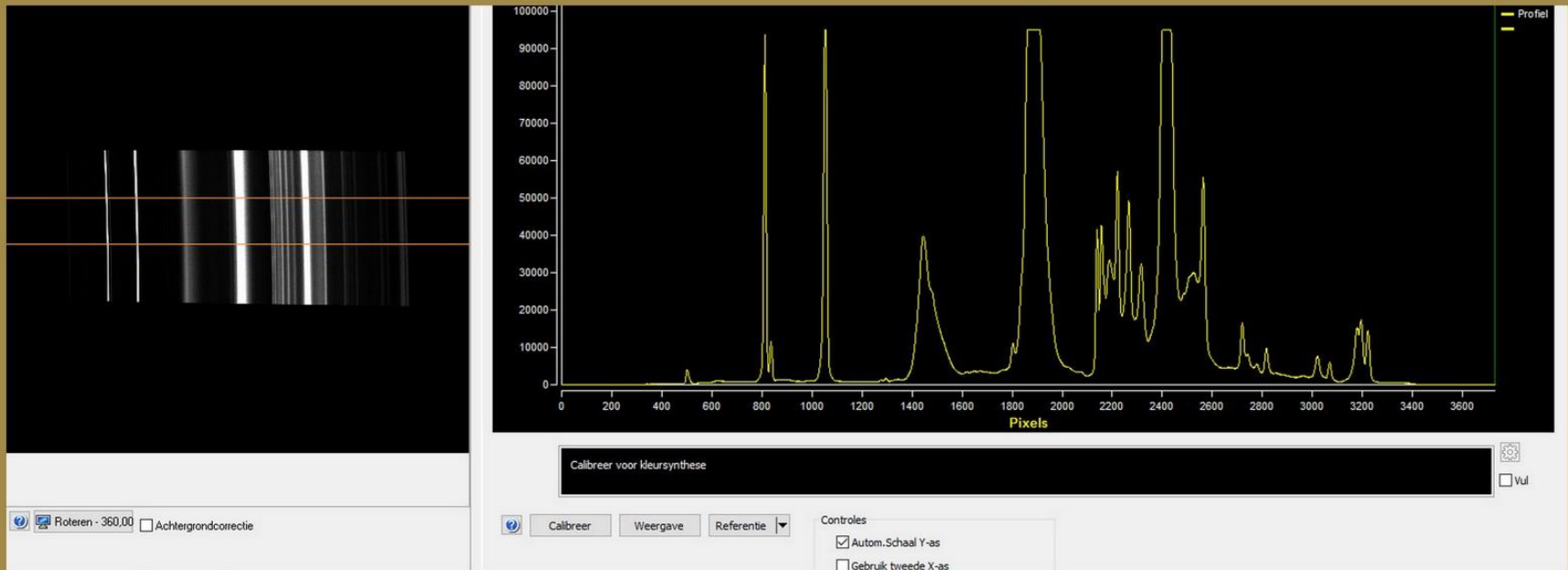
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*Spectrograph Optics: A practical guide
for Amateur Astronomers, Trypsteen M*

CFL Spectrum LHIRES 2400l/mm + ATIK 414EX



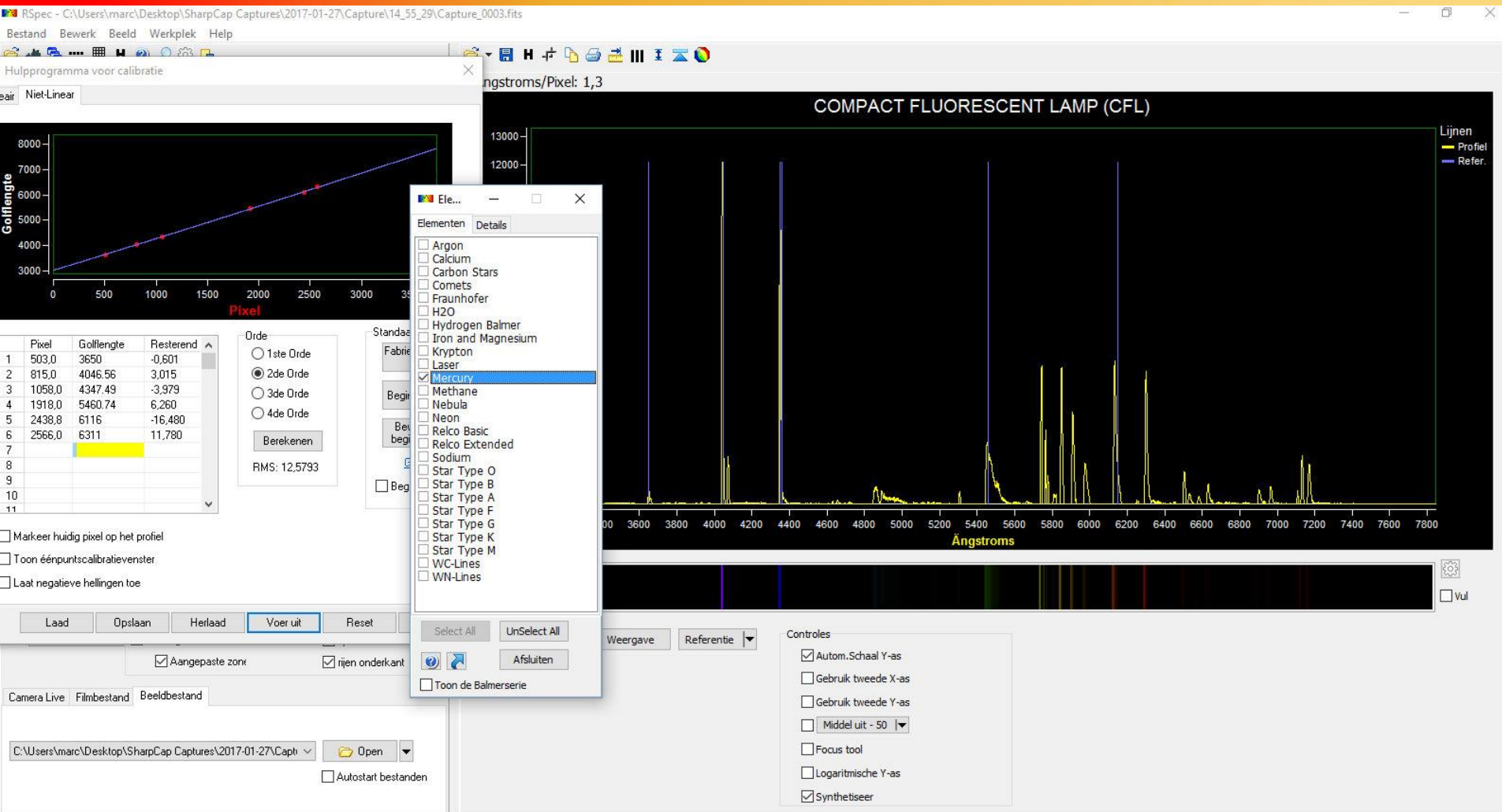
Compact Fluorescent Lamp spectrum – Grism spectrograph Alpy



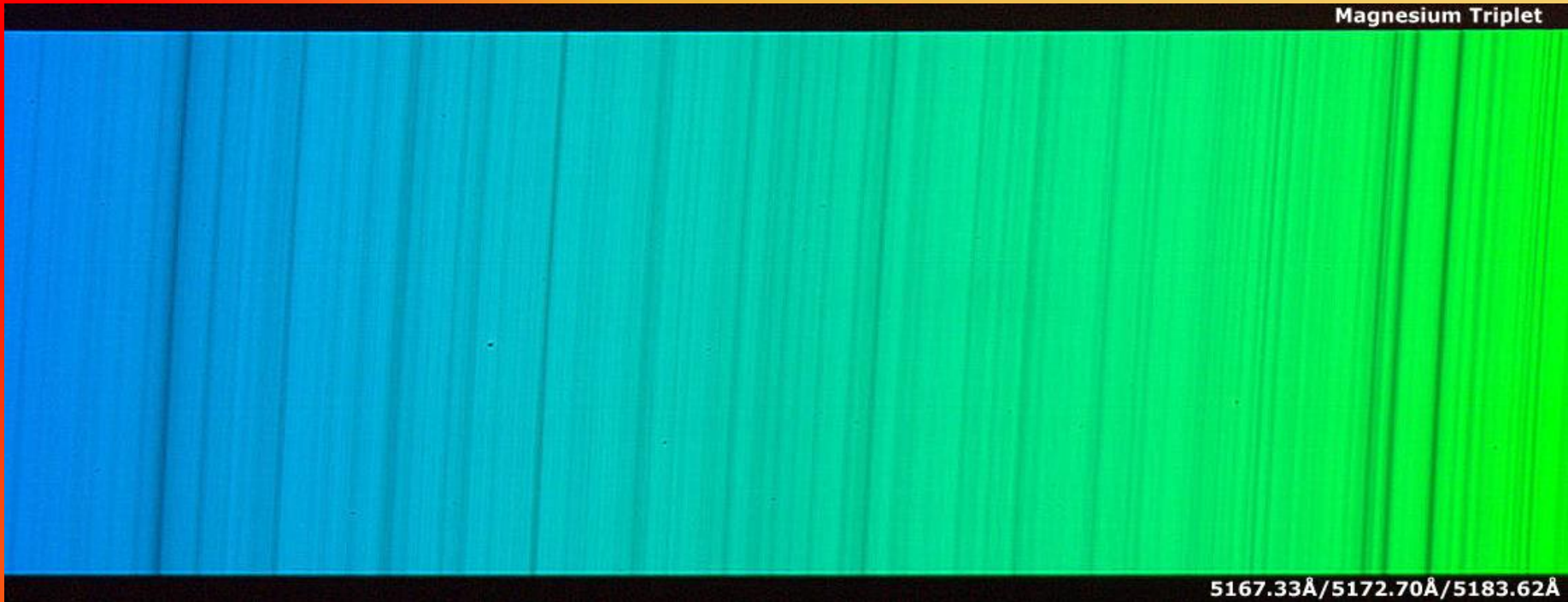
CFL-spectrum - Grism spectrograph Alpy - RSpec reduction software

©2017 Marc Trypsteen

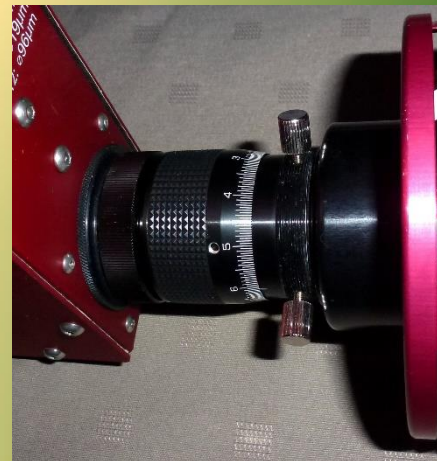
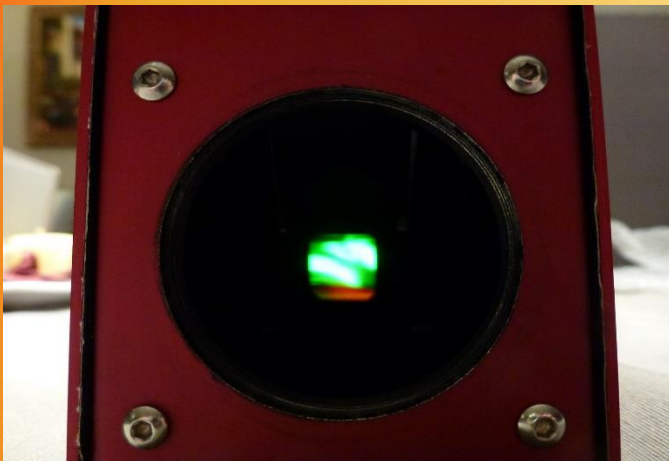
Compact Fluorescent Lamp spectrum – Grism spectrograph Alpy



Magnesium Triplet

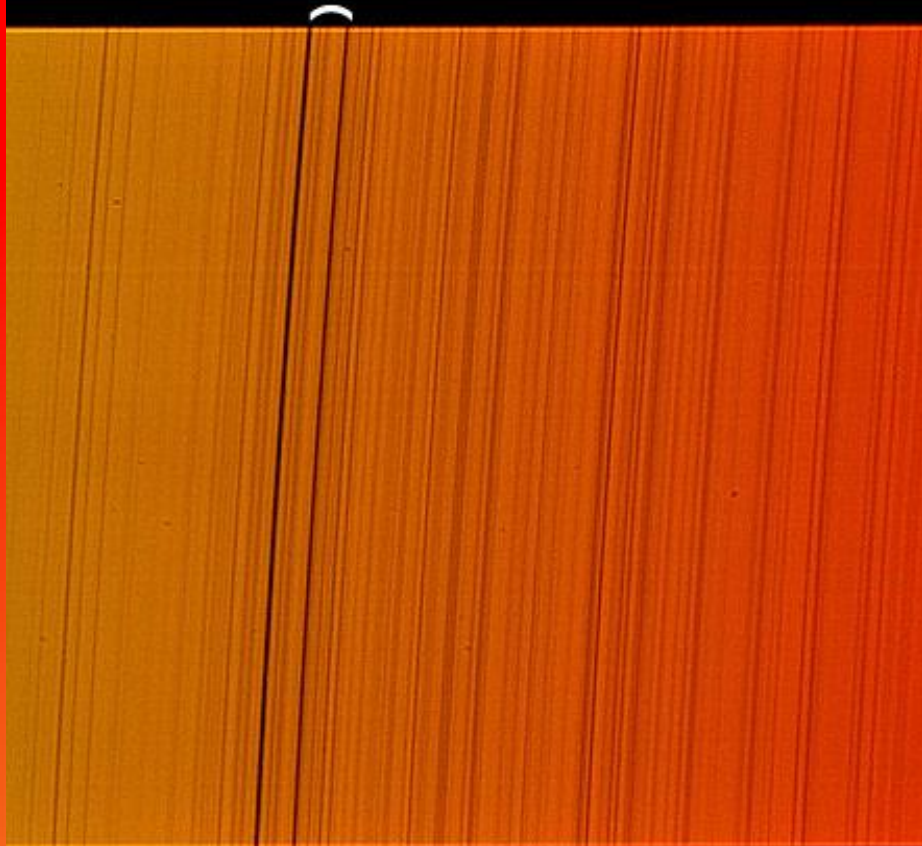


5167.33Å/5172.70Å/5183.62Å



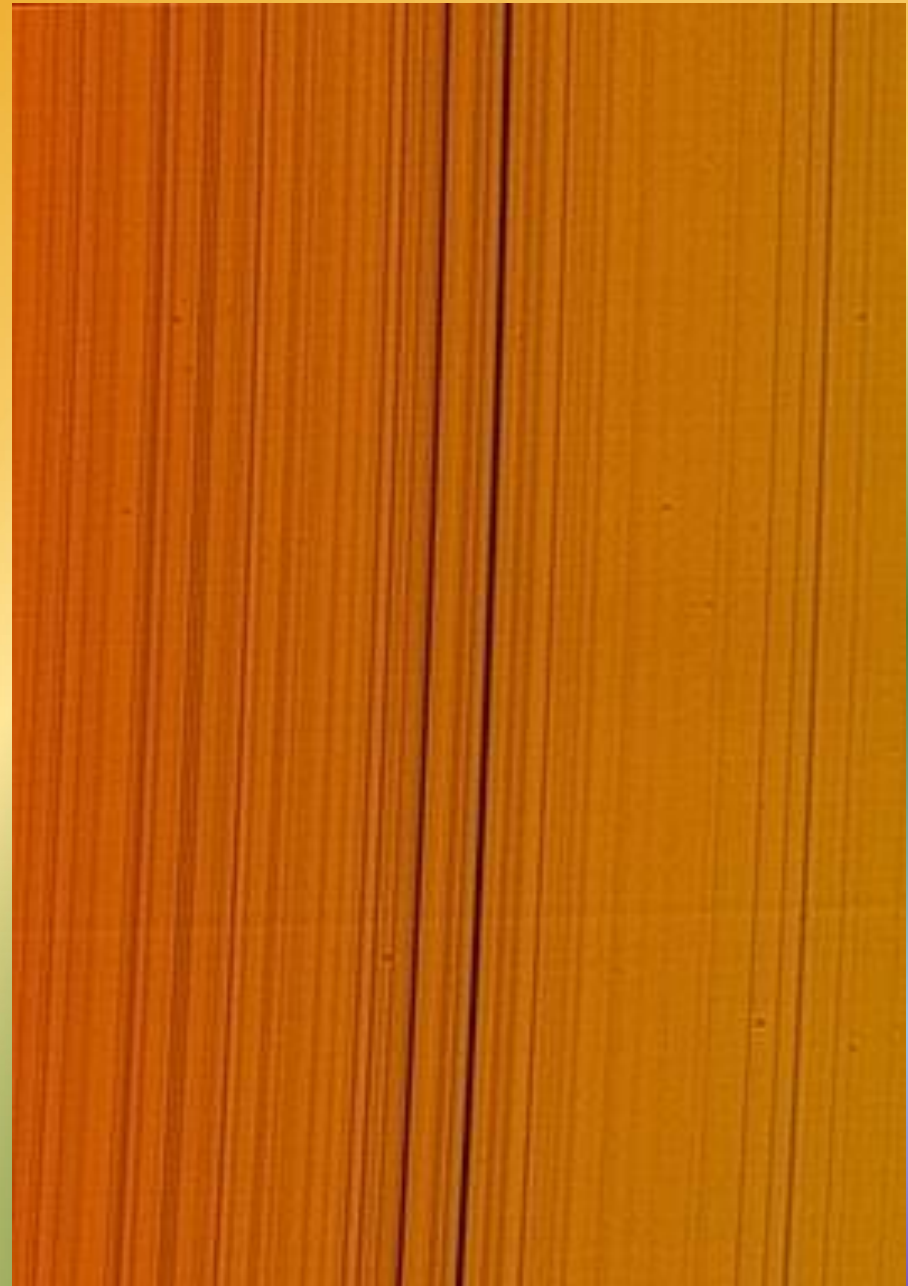
Spectra L200
1800 L/mm
0,4 Å/pixel
Mg-triplet in
Solar Spectrum

Sodium Doublet



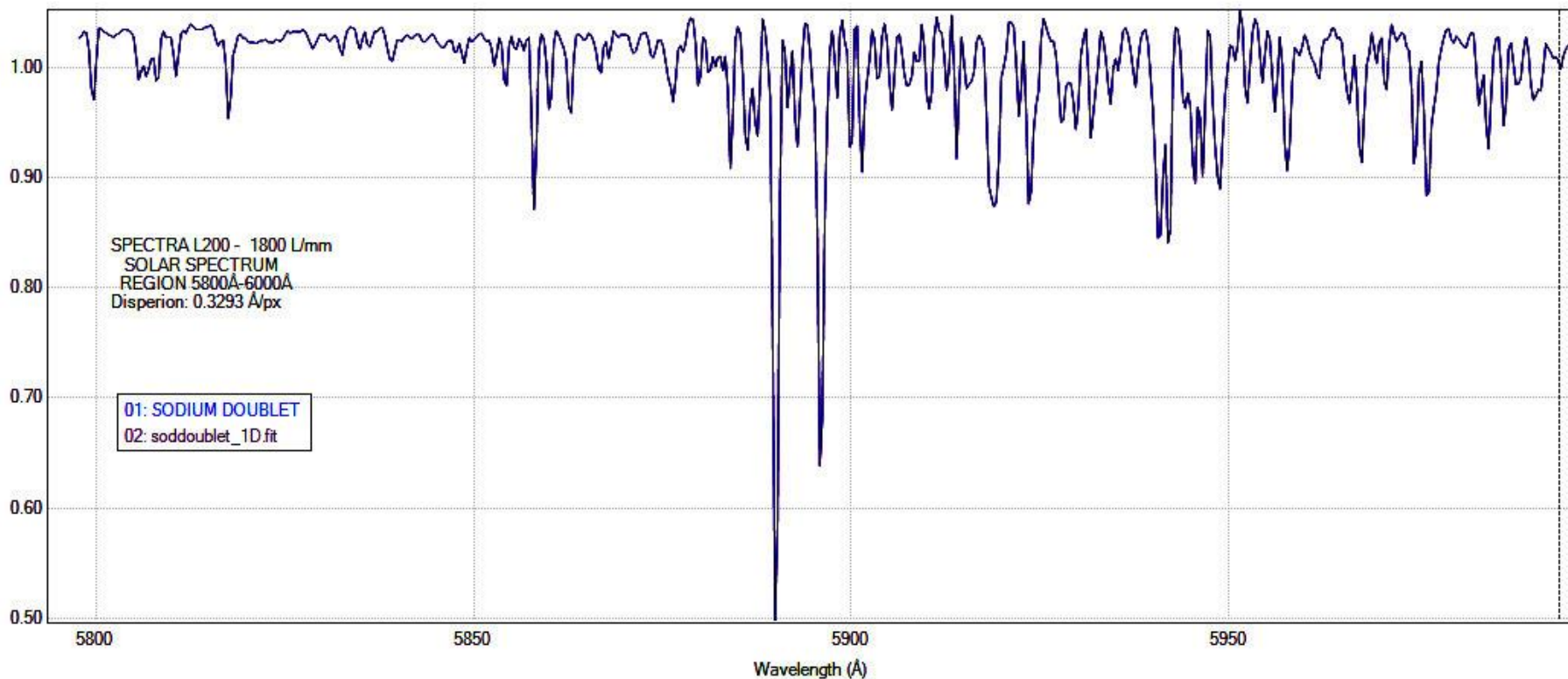
5889.95Å \uparrow \uparrow 5895.92Å

Spectra L200
Sodium doublet
in Solar spectrum



REDUCTION OF RECORDED SPECTRUM:

BASS Project: soddoublet.bass



Reduction process procedures:
Flat+Dark – Inst.Resp.- Smile & Slant
corrections – Calibration –
Continuum removal – Normalisation -
1D .FIT file conversion.

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SPECTRA L200 – DOUBLET TEST – ESTIMATION OF RESOLVING POWER R



Element Lines	Measurement Options	Measurement Results	Python
Selected End	: 5891Å (295.43 px)		
Selected Width	: 1.8164Å (5.3877 px)		
Max Flux	: 1.0612 at 5891Å (295.39 px)		
Min Flux	: 0.48061 at 5890Å (292.24 px)		
Flux Range	: 0.58067		
Average Flux	: 0.7895 (RMS 0.81308)		
Std Deviation	: 0.19441		
SNR	: 4.0611		
Continuum Slope	: 2.9916 ADU/Å 0.010086 ADU/px		
Profile Area	: 0.13728		
Line Area	: 0.04059 (22.819 %)		
Continuum Area	: 0.17787		
Equiv Width	: 0.41449 Å		
FWHM	: 0.77332 Å (R = 7617 @5890Å)		
Barycentre	: 5890Å (292.36 px)		

Element Lines	Measurement Options	Measurement Results	Python
Selected End	: 5896.9Å (313.23 px)		
Selected Width	: 2.019Å (6.136 px)		
Max Flux	: 0.98432 at 5894.9Å (307.1 px)		
Min Flux	: 0.62116 at 5895.9Å (310.3 px)		
Flux Range	: 0.36316		
Average Flux	: 0.84727 (RMS 0.85687)		
Std Deviation	: 0.12793		
SNR	: 6.6227		
Continuum Slope	: -0.64803 ADU/Å -0.0021323 ADU/px		
Profile Area	: 0.16571		
Line Area	: 0.029987 (15.324 %)		
Continuum Area	: 0.19569		
Equiv Width	: 0.30939 Å		
FWHM	: 0.79041 Å (R = 7459 @5895.9Å)		
Barycentre	: 5896Å (310.46 px)		

SPECTROGRAPHS & OPTICS

HOW IT WORKS and HOW TO TEST IT

TAKE-HOME MESSAGE

A → Alignment !

B → Brightest order !

***C → Calibration and Control
of spectral lineshapes !***

D → Doublet test for R !

*Ancient cultures
looked up to the stars,
telling each other
myths and legends:
beautiful starlores.
The moral of those tales,
over the years
survived for mankind.*

*Modern cultures
look to the stars too:
the era of the
high tech eyes
explores the universe
in another way
and will help
mankind to survive*

*Enjoy the fascinating
world of astronomical
Spectroscopy !*

Marc Trypsteen

THANKS !