SPECTROGRAPHS & OPTICS

Marc Trypsteen

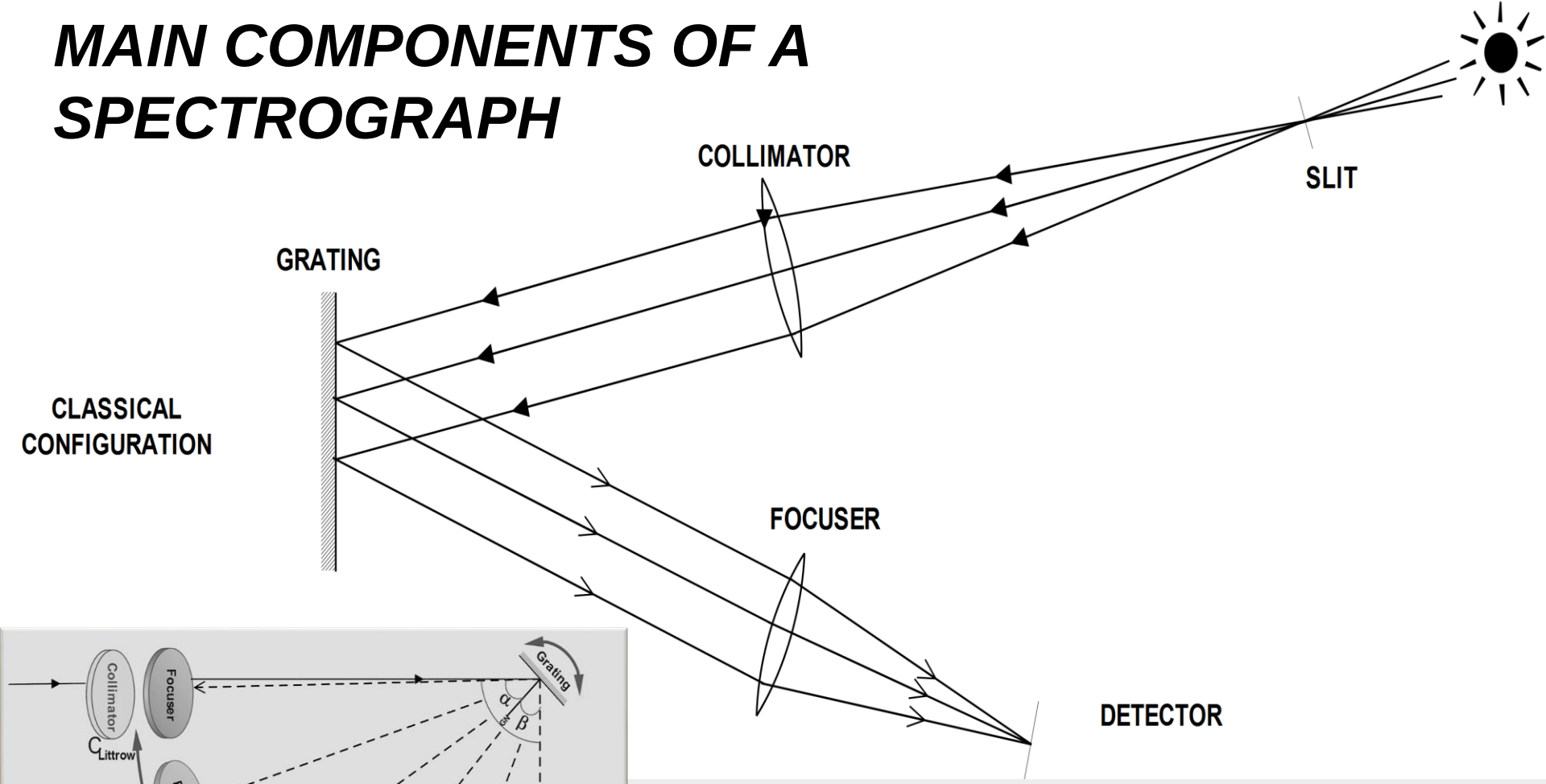
HOW IT WORKS

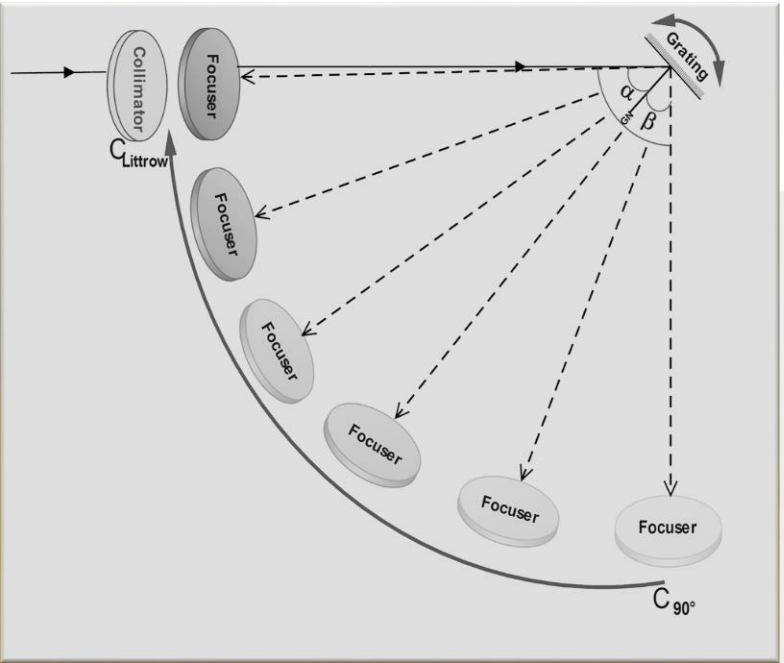
and

HOW TO TEST IT

Optica studiedag
UGent 18 maart 2017
Volkssterrenwacht Armand Pien

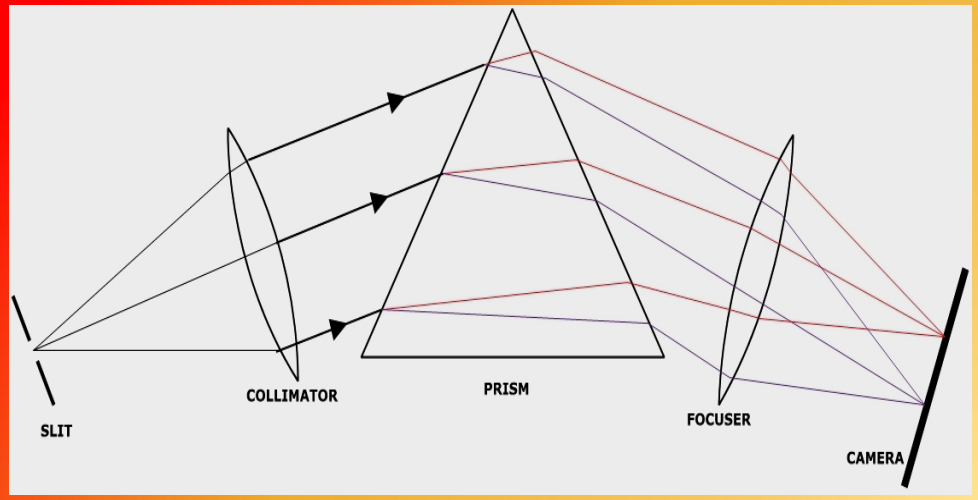
MAIN COMPONENTS OF A SPECTROGRAPH

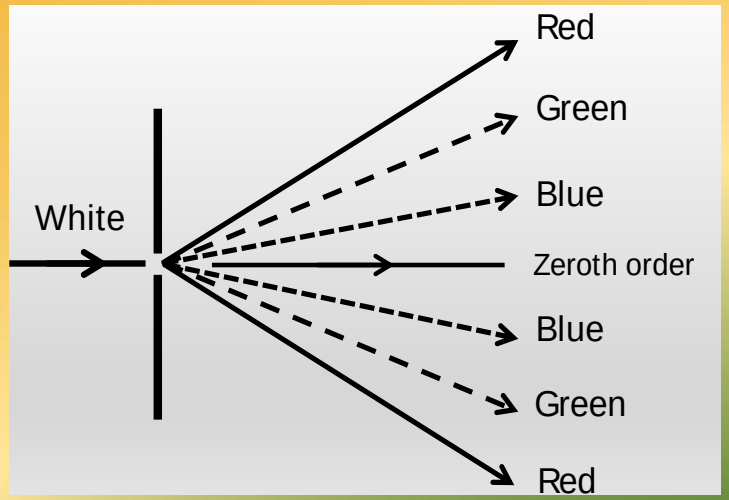




- Classical
- Littrow
- Cerzny-Turner
- Rowland
- Echelle: cross-dispenser extra

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 ↓

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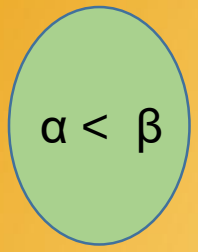
COLLIMATOR → FOCUSER OPTICAL TRAIN

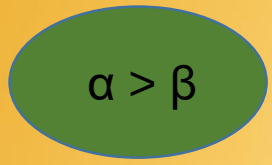
- **COLLIMATOR :**

  Focal ratio matching with Telescope !

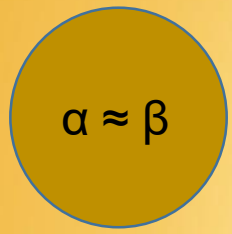
- **ANAMORPHIC FACTOR r**:



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



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



❖ **Input angle ≈ Output angle → r≈1**

←==Δλ==→

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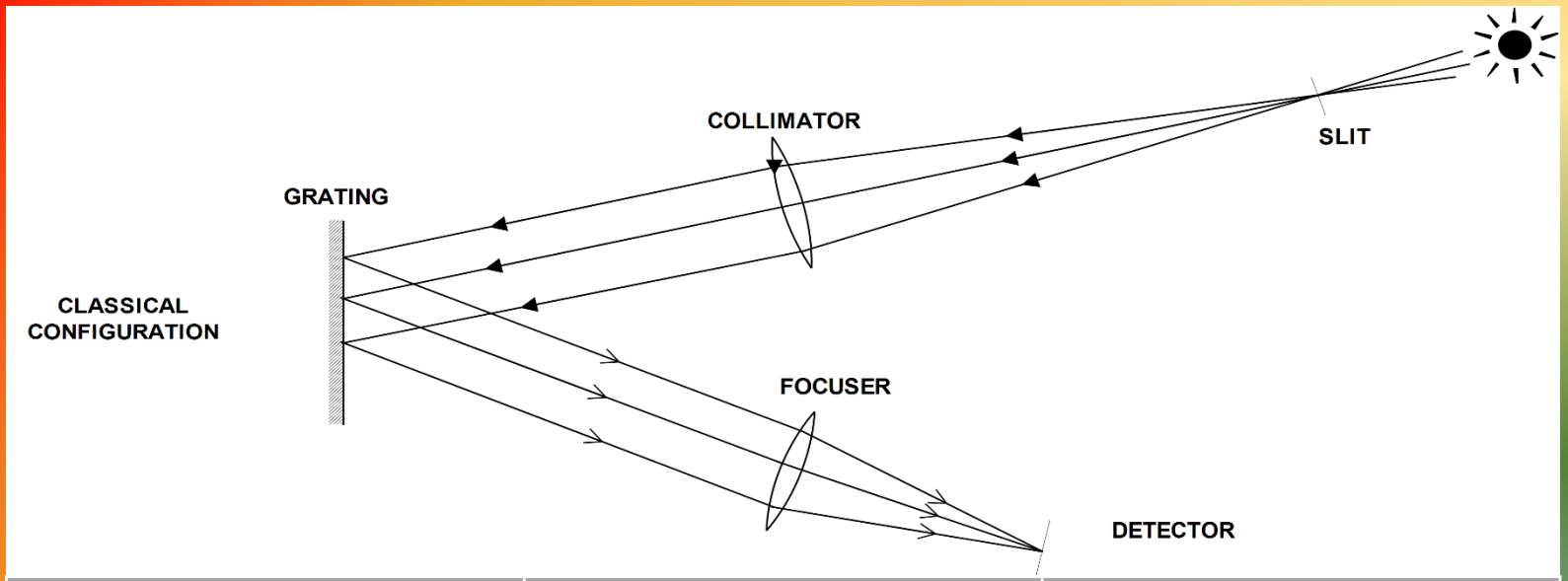
INFLUENCES OF THE OPTICAL DESIGN and RECORDING DEVICES



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

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

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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 (λ<4000), visible (apricot shaded) and infrared (λ>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,…***

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Quality related :

EVALUATION BY SPOT DIAGRAM/PSF SOFTWARE

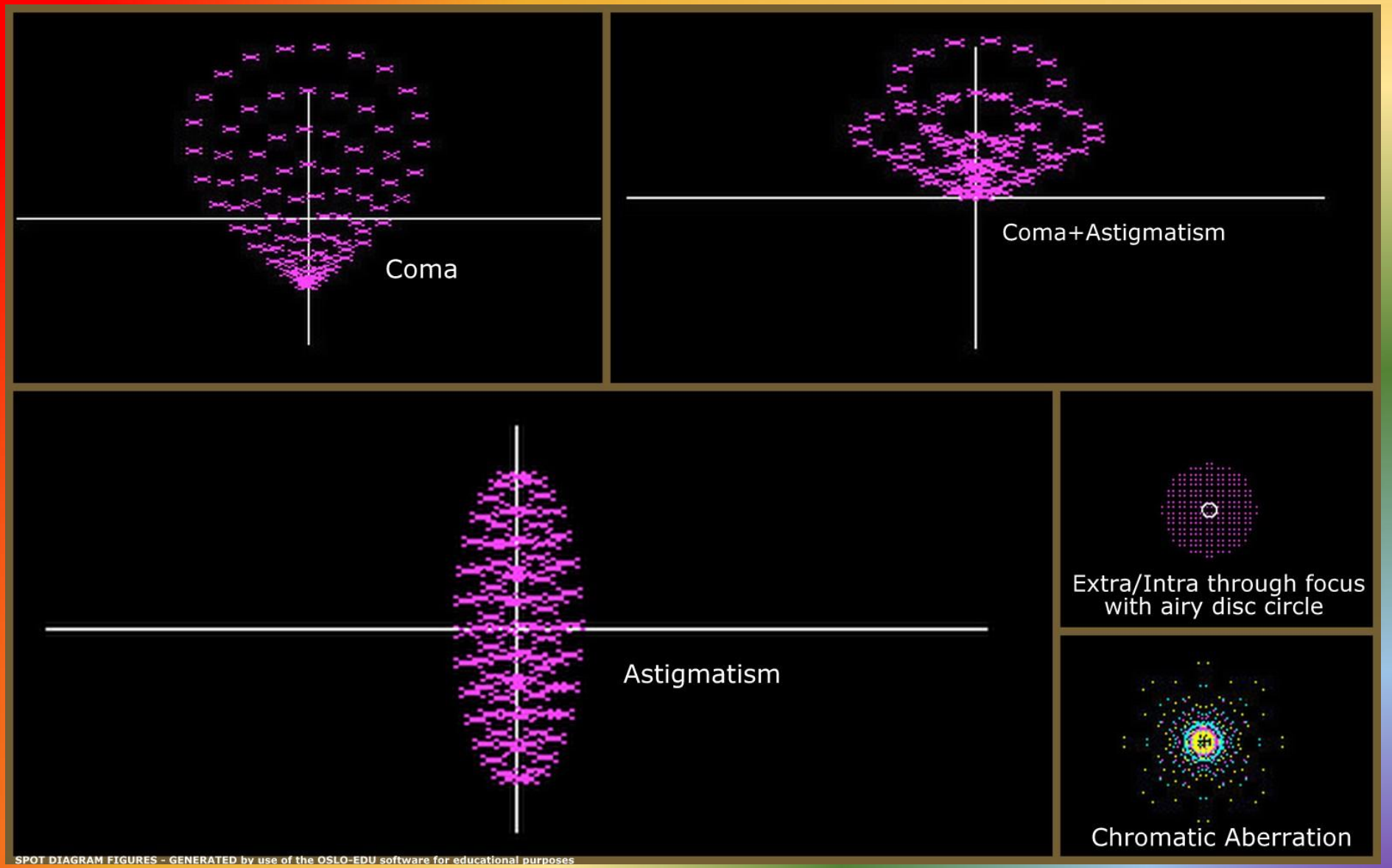
- **MODAS** : **M**odern **O**ptical **D**esign and **A**nalysis **S**oftware
  Freeware version: MODAS NG
  www.myoptics.at/modas

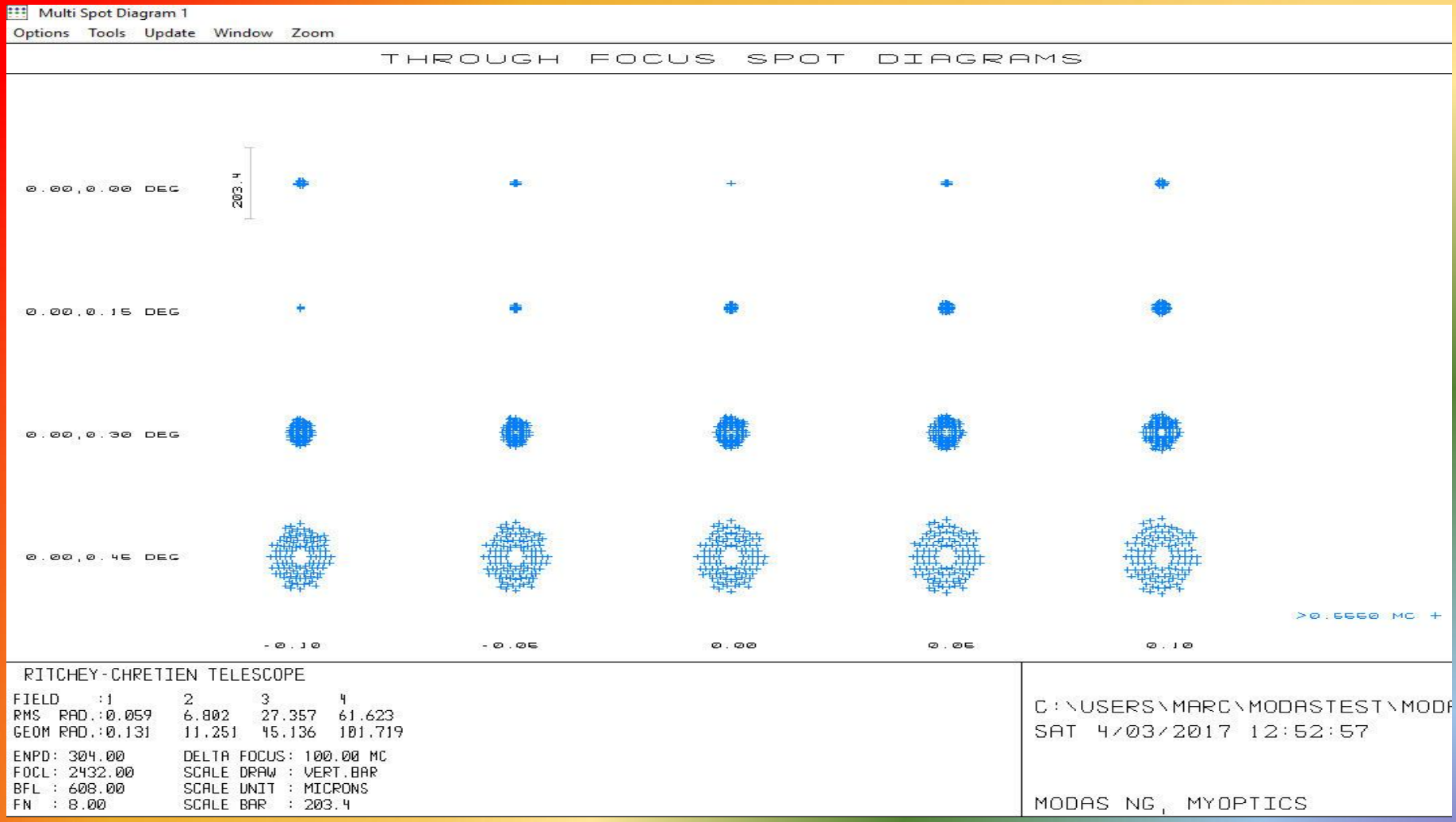
- **OSLO** : **O**ptics **S**oftware for **L**ayout and **O**ptimization
  Commercial versions: Premium/Standard/Light
  Free educational version : OSLO-EDU
  download: www.lambdares.com/oslo-university-program
  www.lambdares.com/oslo

- **WinLens**: www.winlens.de
  Free Basic version available

- **ZEMAX** : OpticsStudio
  www.zemax.com
  trial version available

EVALUATION BY SPOT DIAGRAM/PSF SOFTWARE




Multi Spot Diagram 1
Options Tools Update Window Zoom
THROUGH FOCUS SPOT DIAGRAMS
0.00,0.00 DEG
0.00,0.15 DEG
0.00,0.30 DEG
0.00,0.45 DEG
203.4
-0.10
-0.05
0.00
0.05
0.10
RITCHEY-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
FOCL: 2432.00
BFL : 608.00
FN : 8.00
DELTA FOCUS: 100.00 MC
SCALE DRAW : VERT.BAR
SCALE UNIT : MICRONS
SCALE BAR : 203.4
C:\USERS\MARC\MODASTEST\MODA
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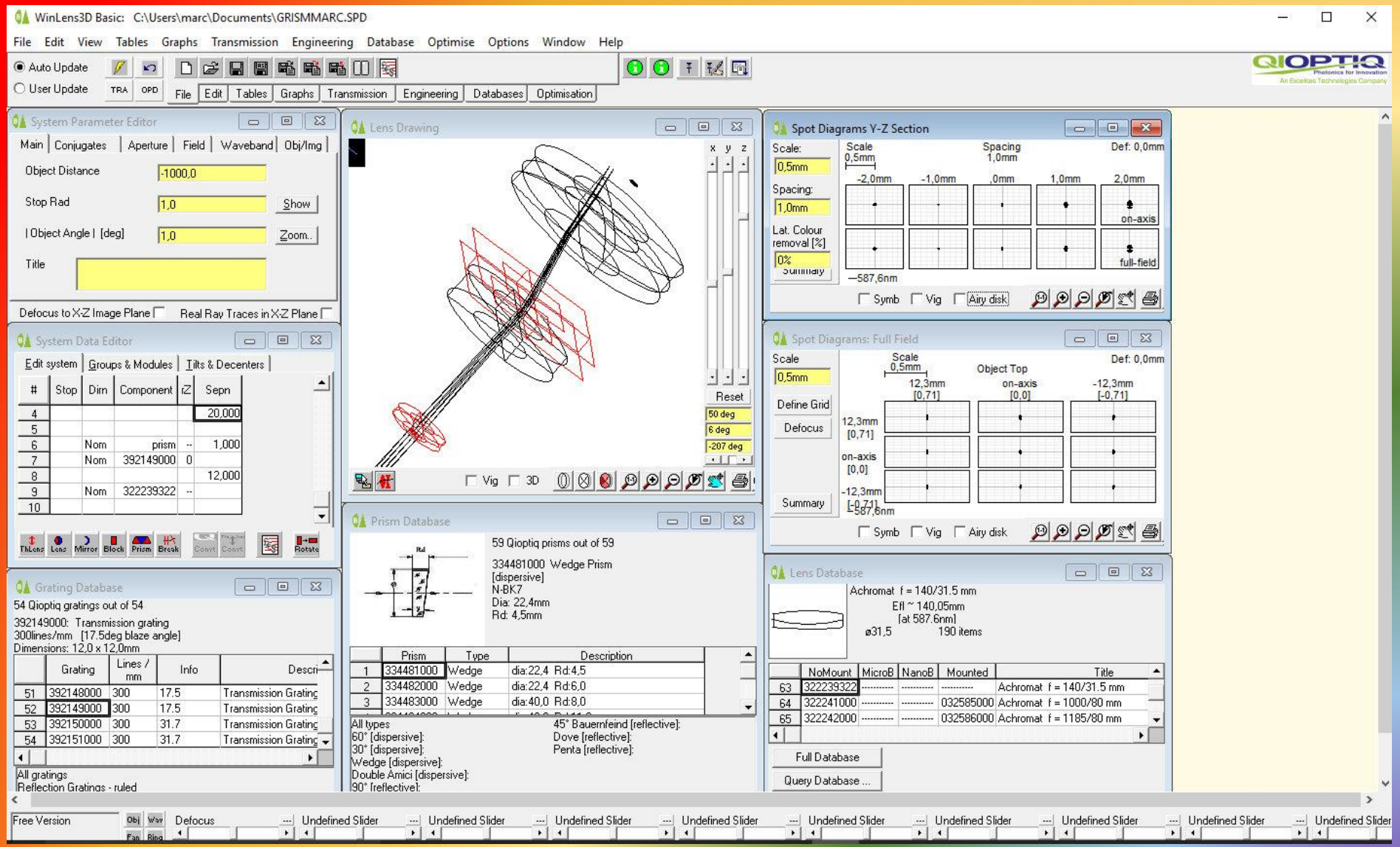
MODAS NG, MYOPTICS

Preliminary GRISM DESIGN and EVALUATION with WINLENS 3D



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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!)

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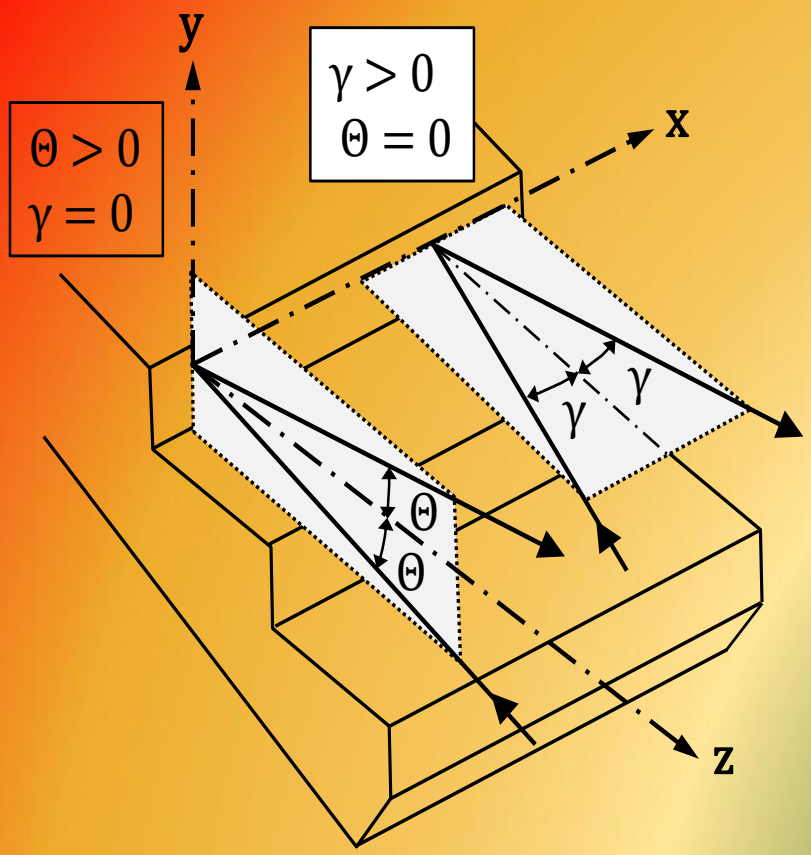
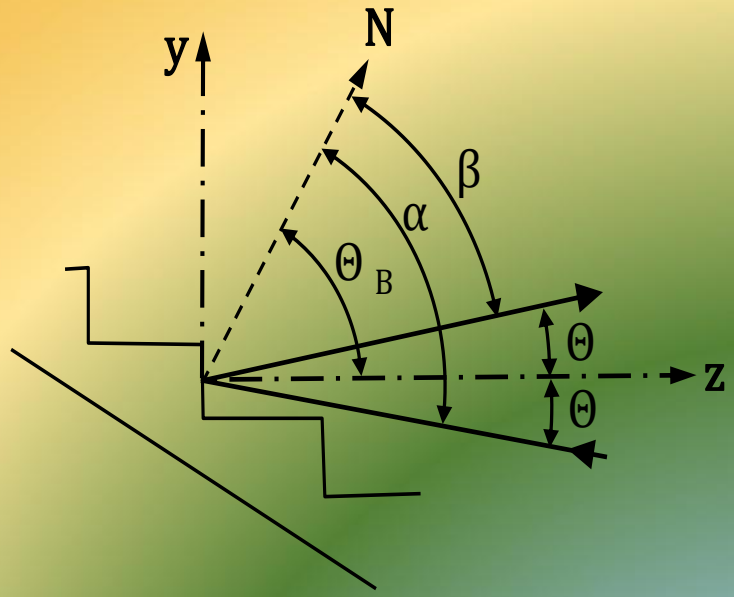
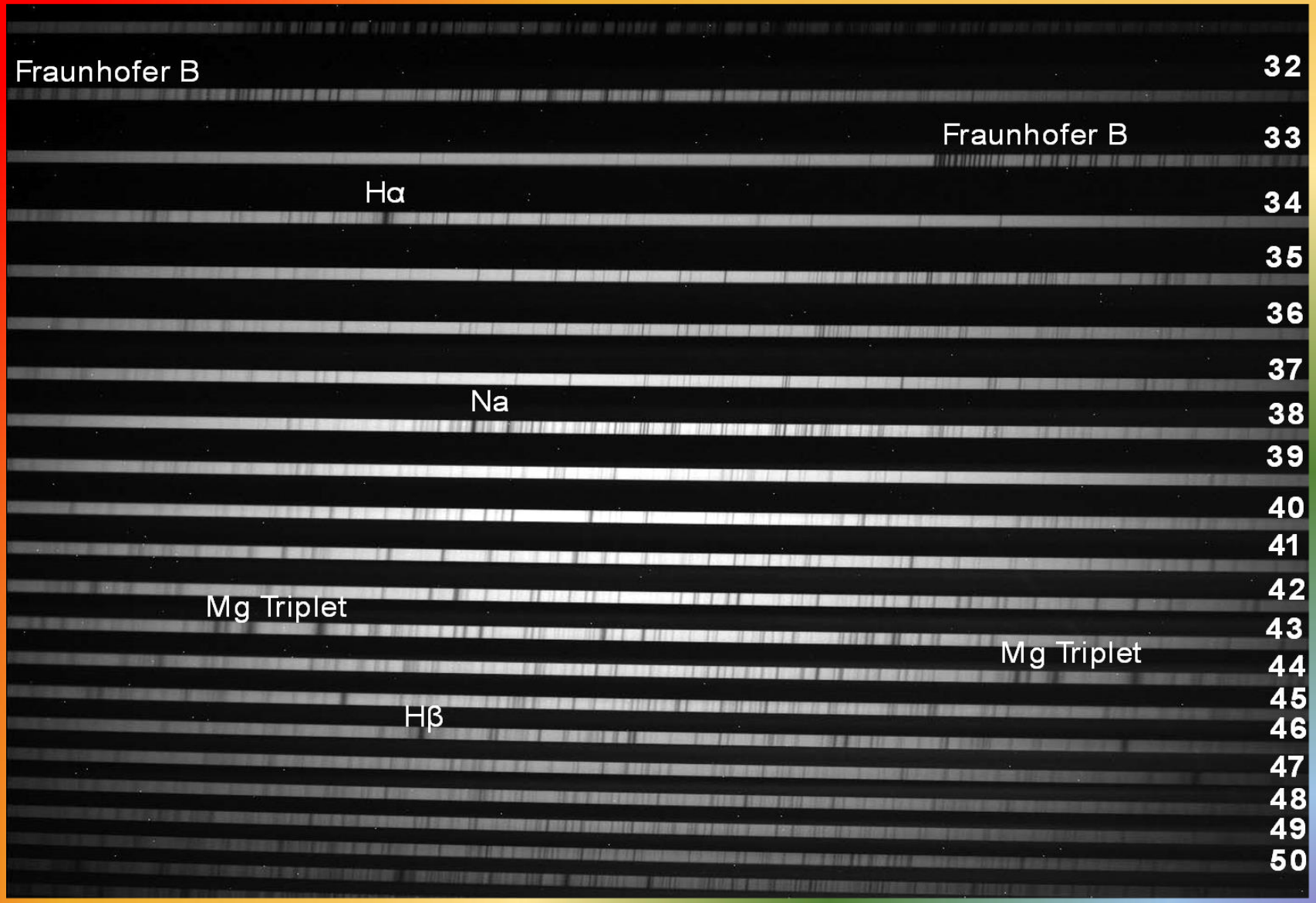
DESIGN RELATED:

Example: Echelle gratings



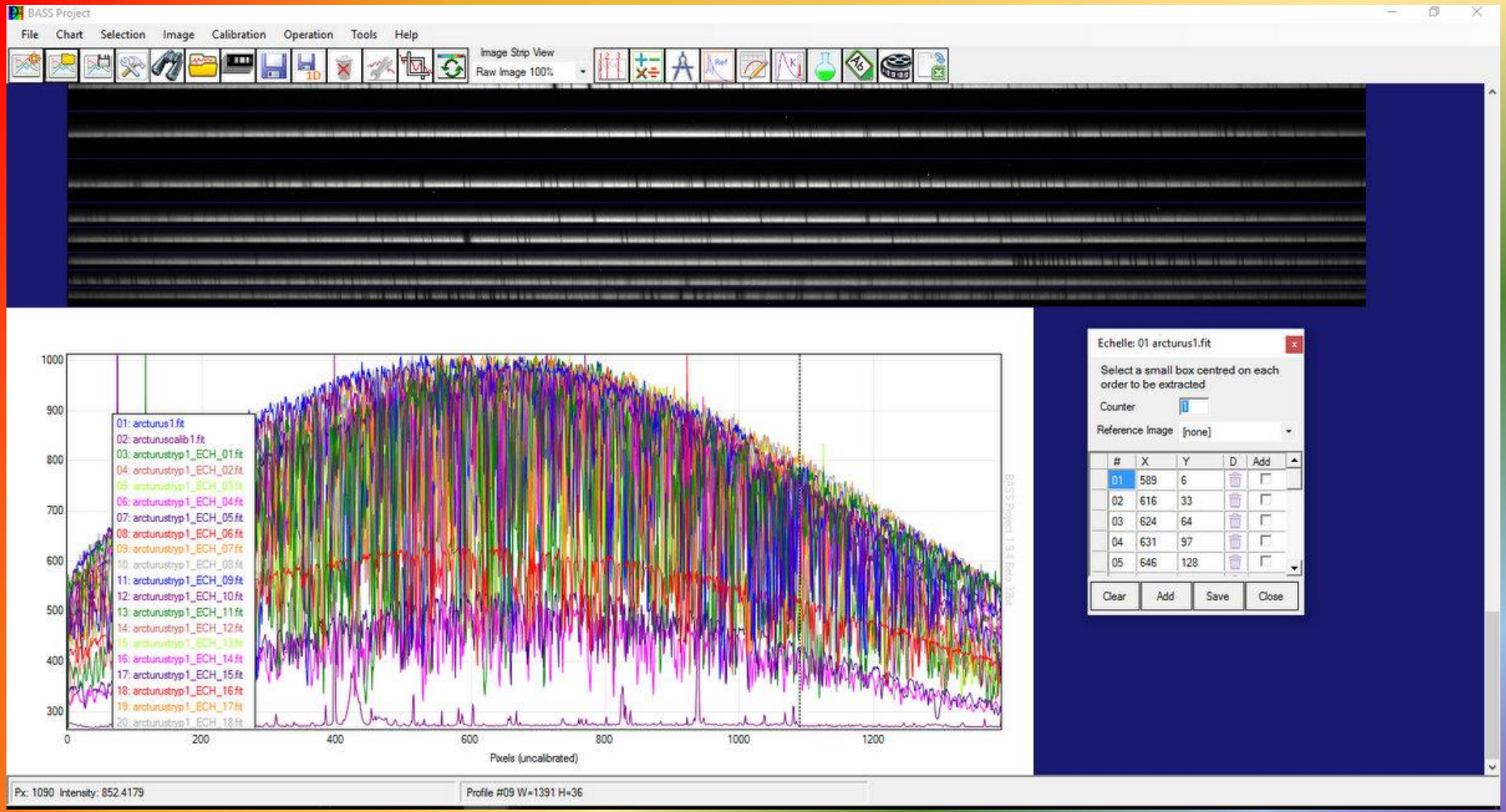


Off-axis angle positions of the light pathway on Echelle gratings.
3D-view and longitudinal section by M. Huwiler, schematically after [158].



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

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



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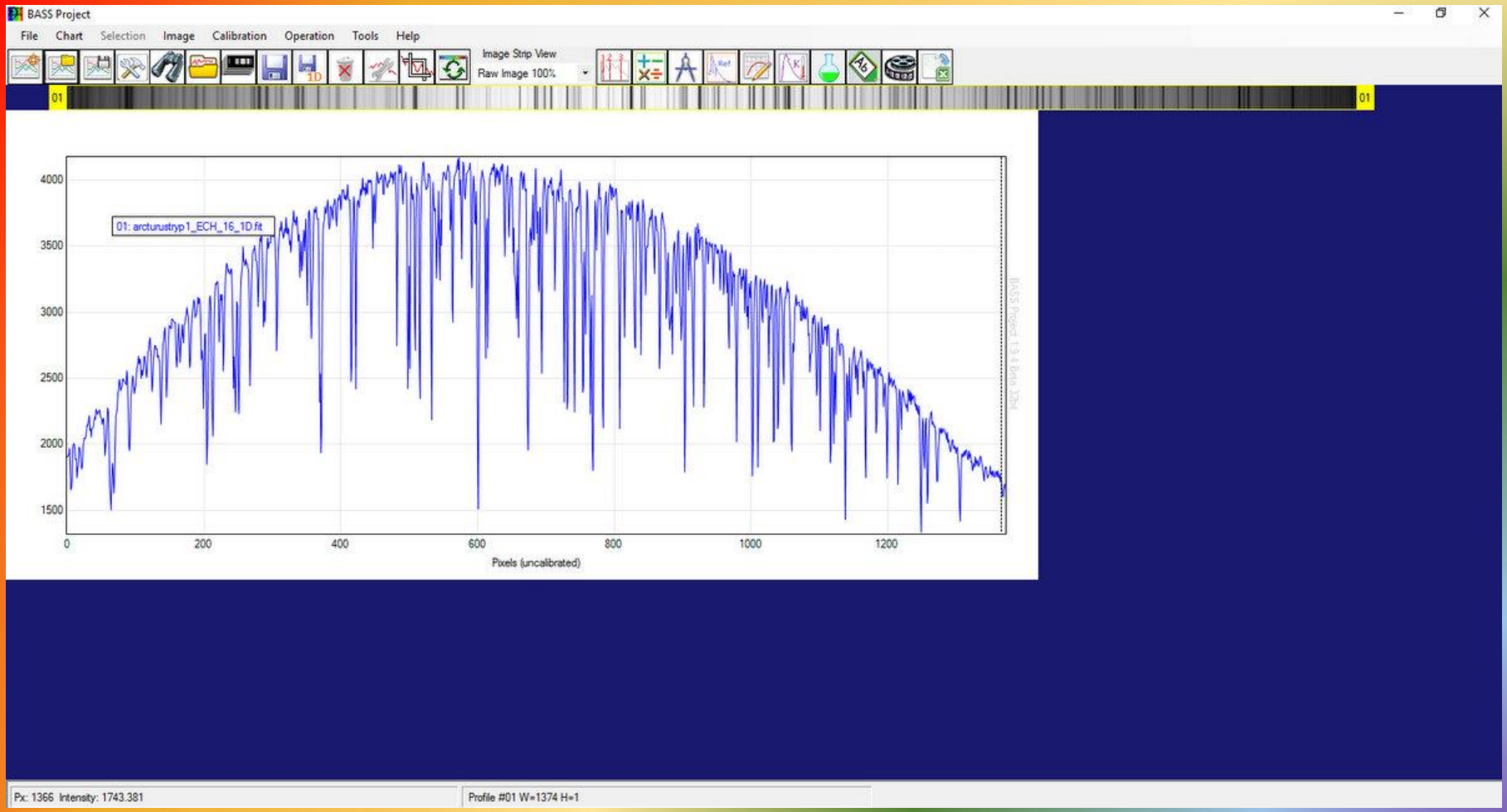
Spectrum of Arcturus (one order)
SQUES Echelle spectrograph,
Reduction: BASS project



DESIGN RELATED : ECHELLE GRATING TYPES

Echelle R number ≠ R of Resolving Power

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

Echelle R ↑ caveats:

- *Ghosts ↑*
- *∠ incident/diffracted rays ↓*
- *Shadows ↑*
- *Performance 31.6 → 79 L/mm: Red → Blue ↑*
- *Cross dispenser: prism → grating ↑*
- *Thermal stability ↑*
- *Complexity of Reduction process ↑*
- *Focal length of Collimator ↓*

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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

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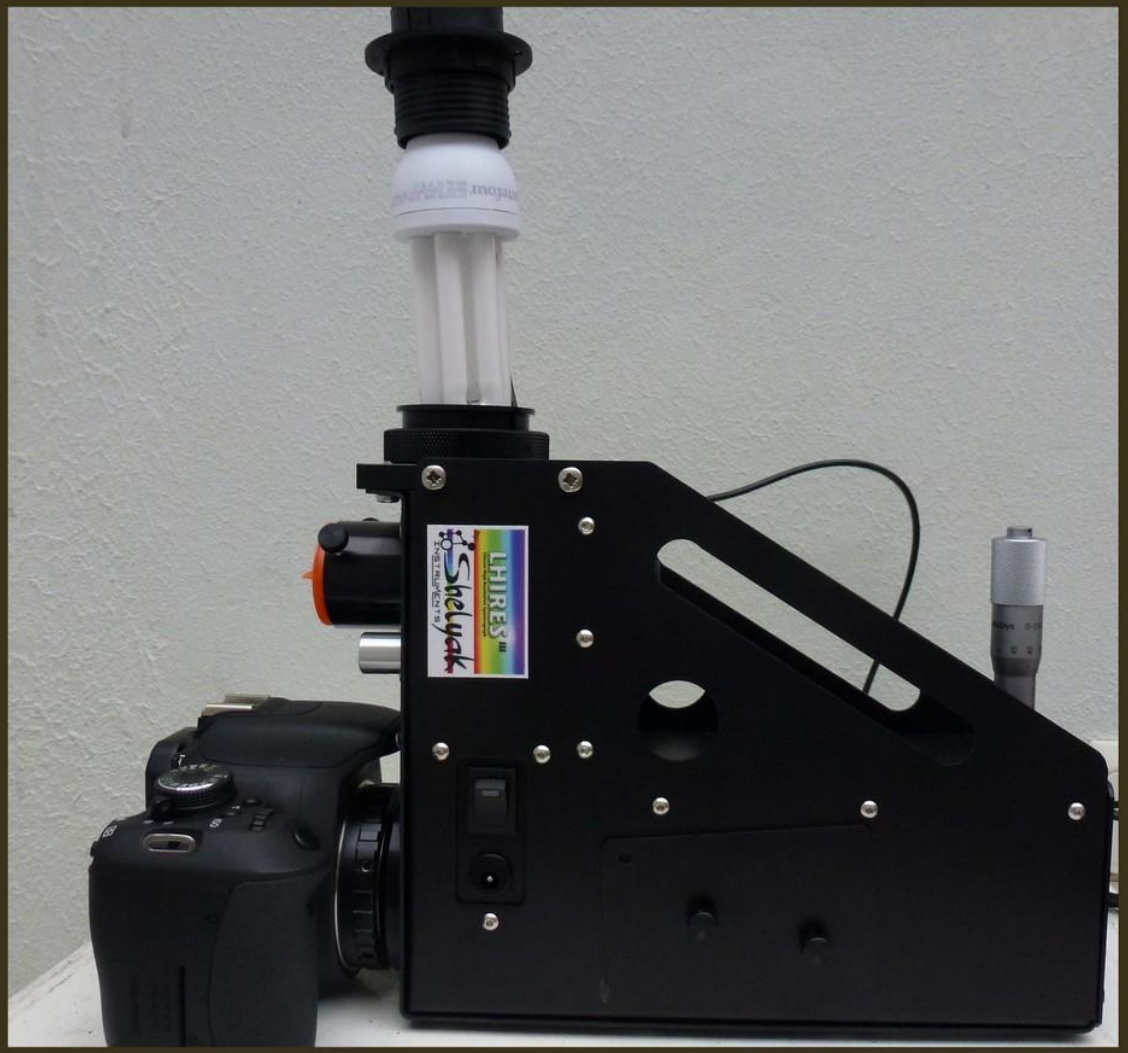
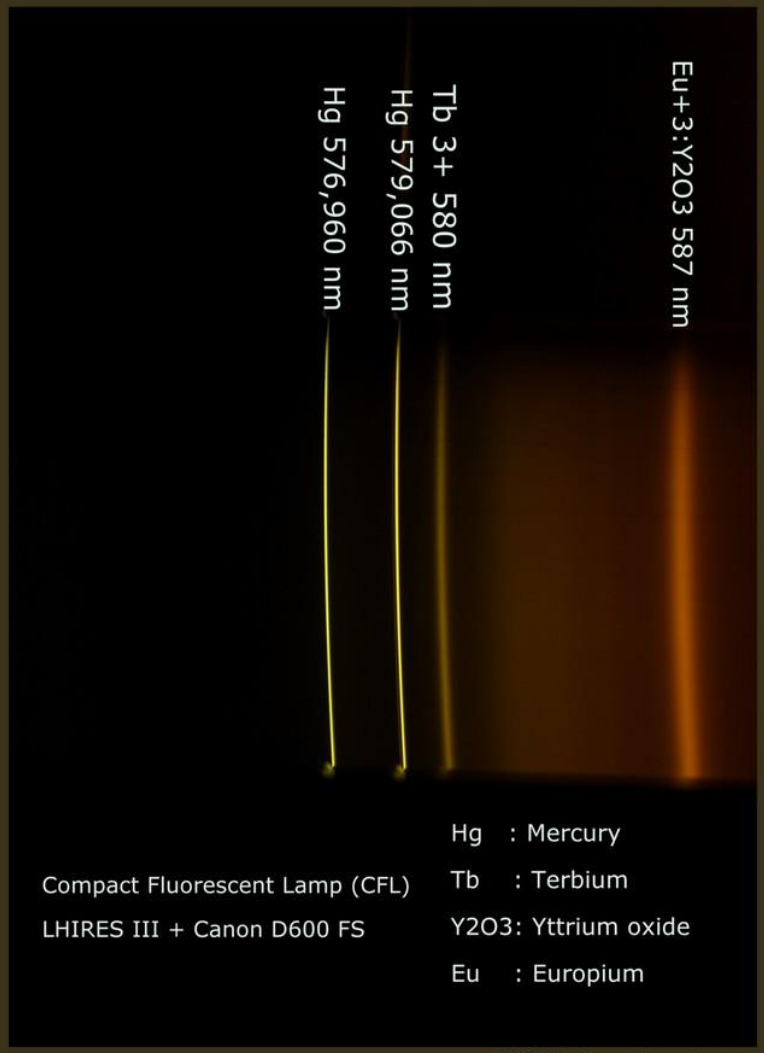
CHECK LIST

- ***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





Hg 435,833 nm

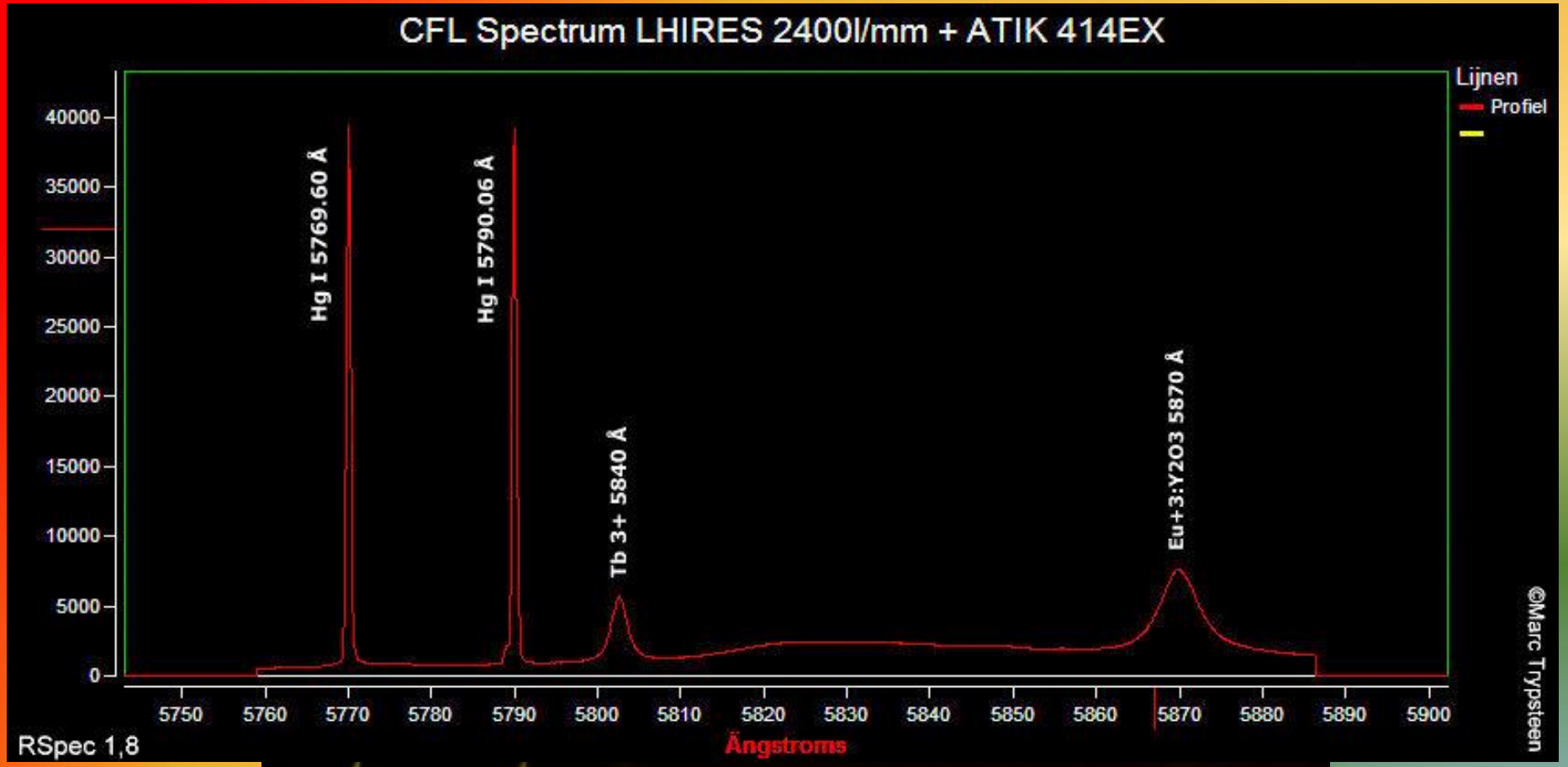
(LFC)

LHIRES III + Canon D600 FS

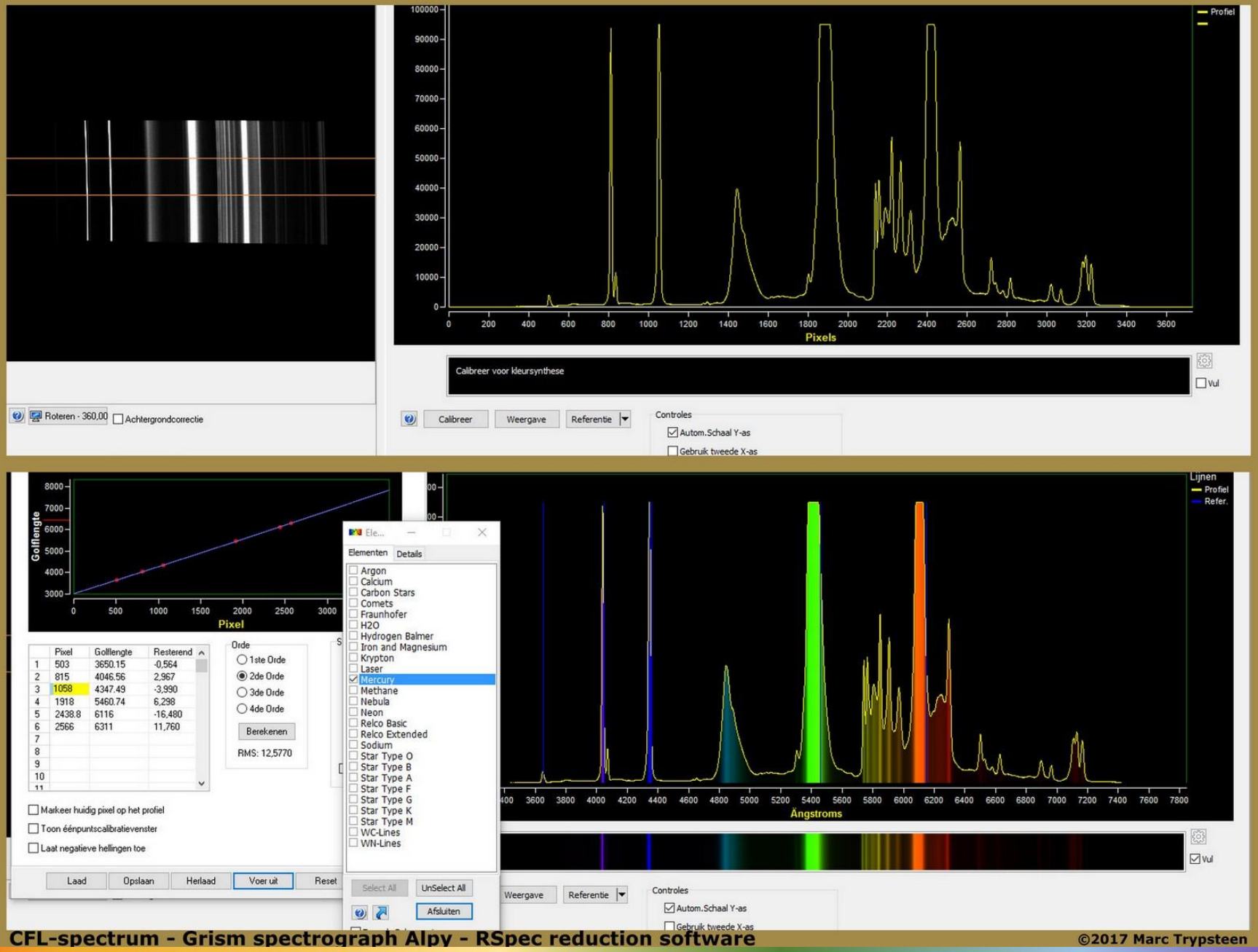
Hg 546,074 nm

(LFC)

LHIRES III + Canon D600 FS

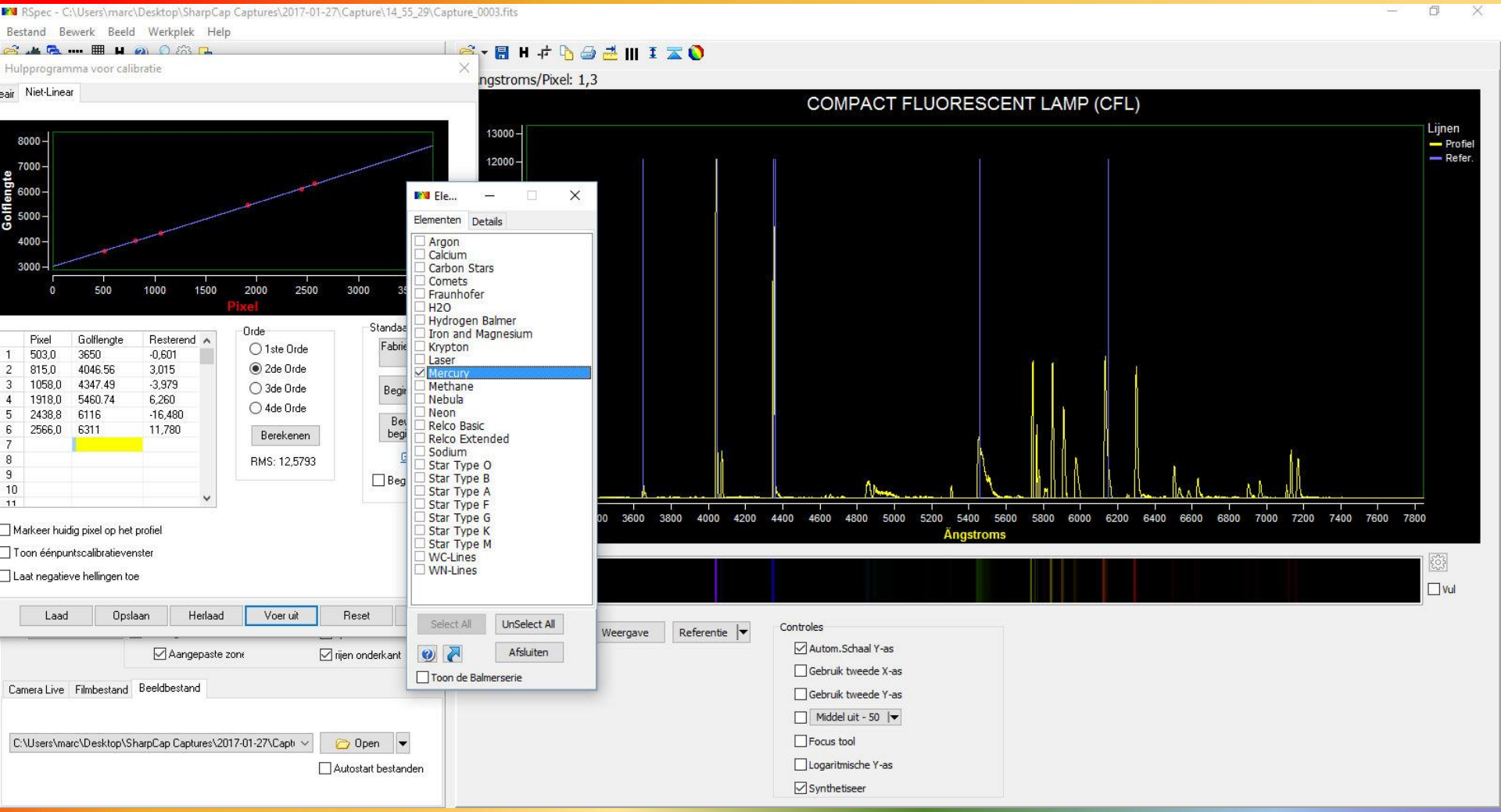

CFL Spectrum LHIRES 2400l/mm + ATIK 414EX
Lijnen
Profiel
Hg I 5769.60 Å
Hg I 5790.06 Å
Tb 3+ 5840 Å
Eu+3:Y2O3 5870 Å
40000
35000
30000
25000
20000
15000
10000
5000
0
5750
5760
5770
5780
5790
5800
5810
5820
5830
5840
5850
5860
5870
5880
5890
5900
Ångstroms
RSpec 1,8
©Marc Trypsteen

Compact Fluorescent Lamp spectrum – Grism spectrograph Alpy



CFL-spectrum - Grism spectrograph Alpy - RSpec reduction software

Compact Fluorescent Lamp spectrum – Grism spectrograph Alpy



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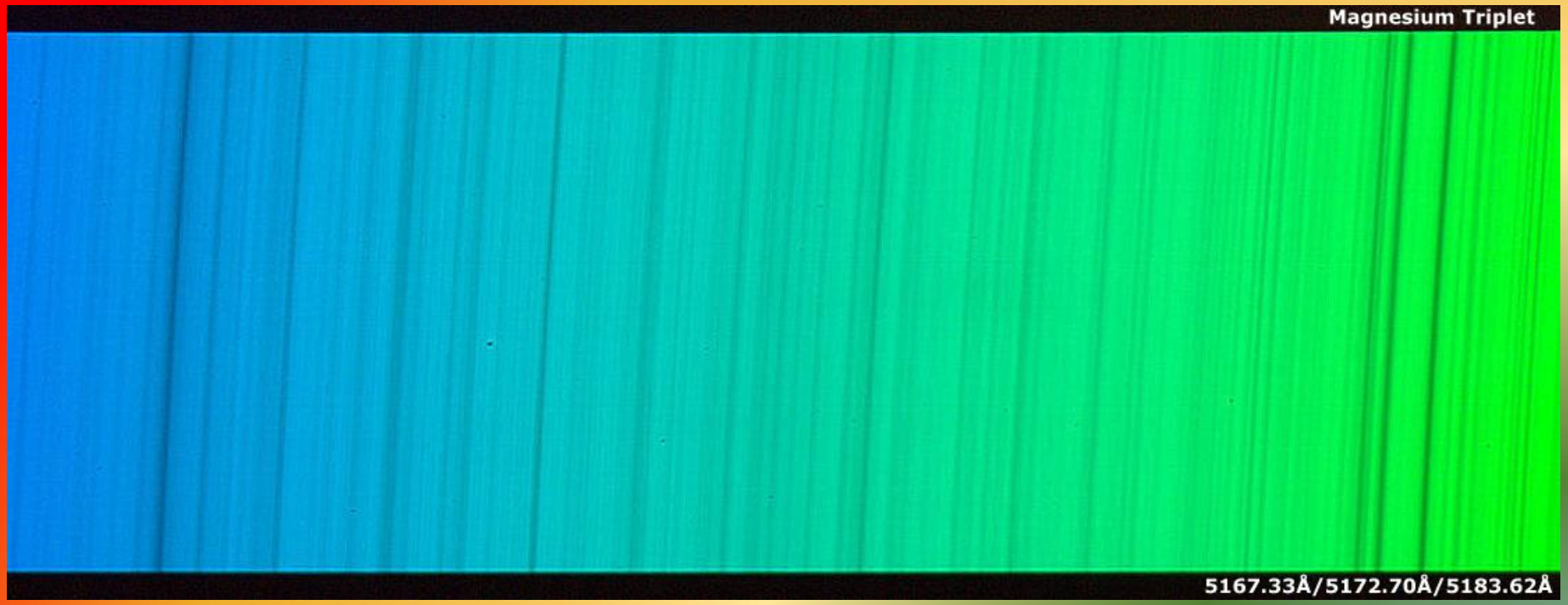

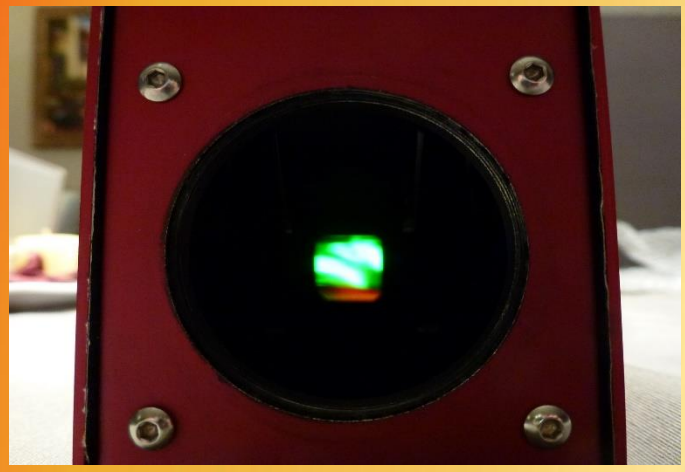

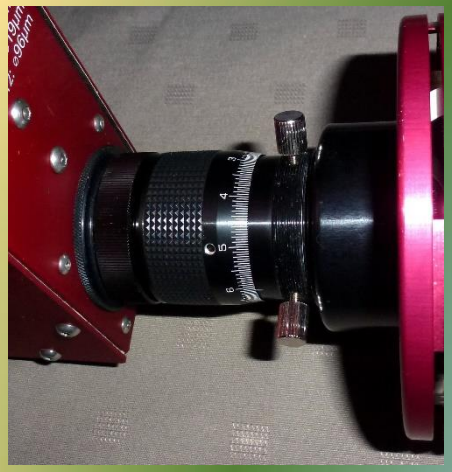

Spectra L200
1800 L/mm
0,4 Å/pixel
Mg-triplet in
Solar Spectrum

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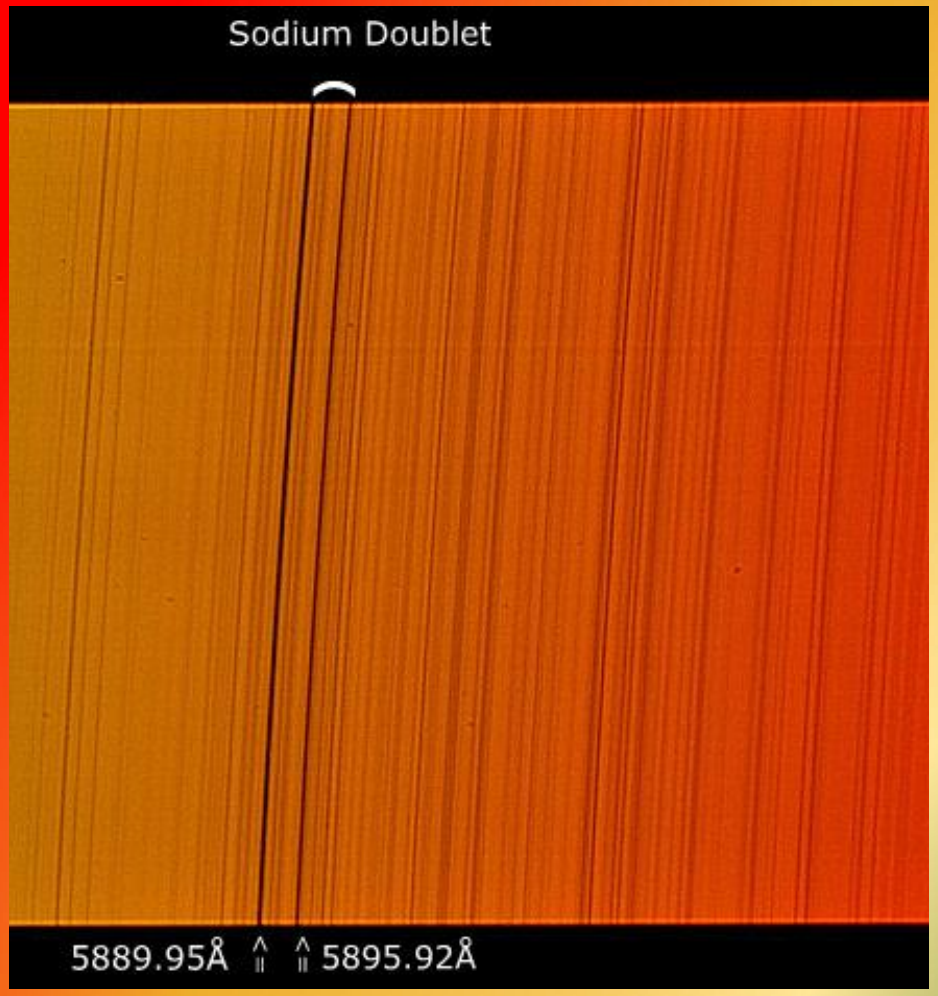

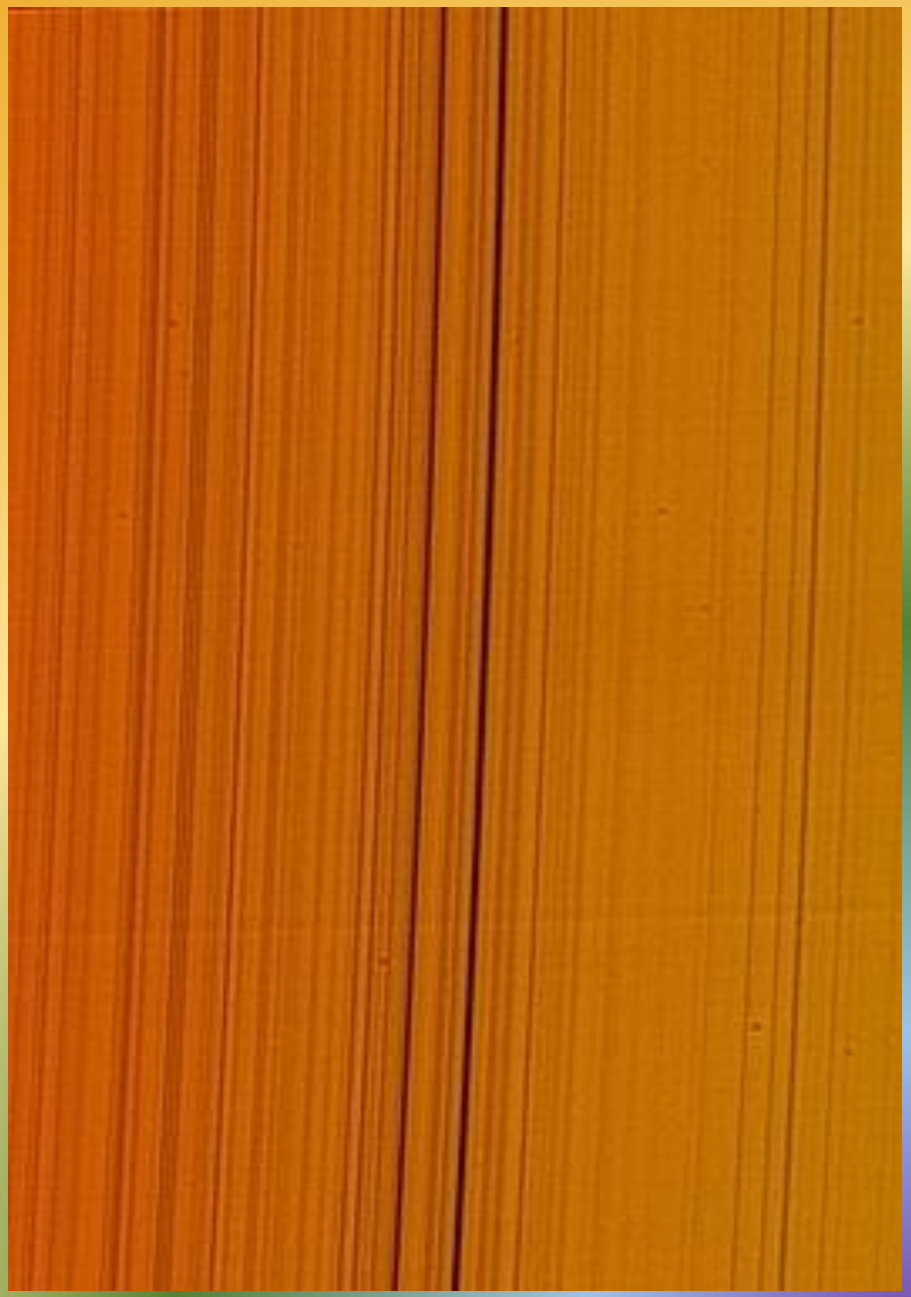

Spectra L200
Sodium doublet
in Solar spectrum

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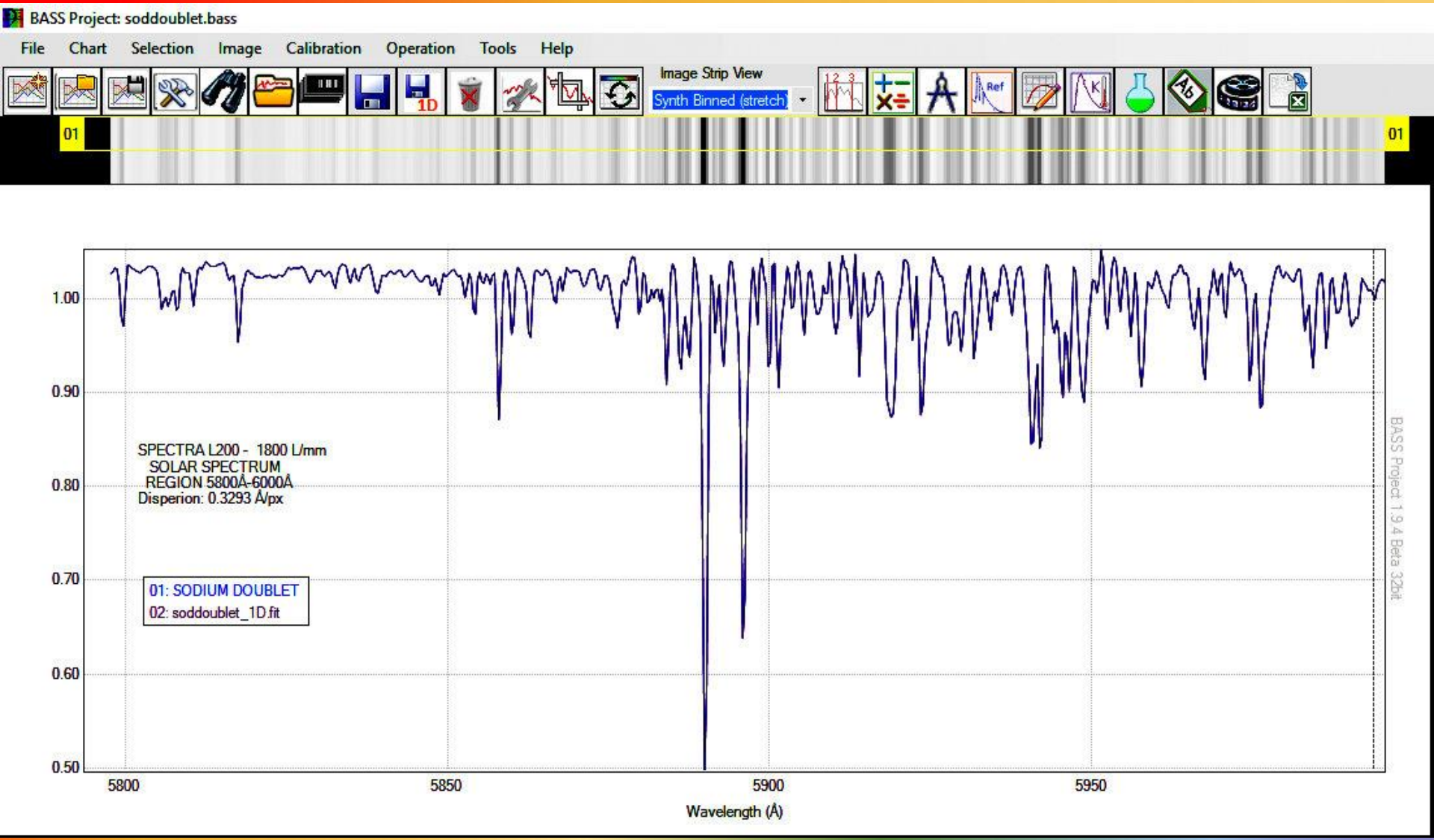
REDUCTION OF RECORDED SPECTRUM:



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

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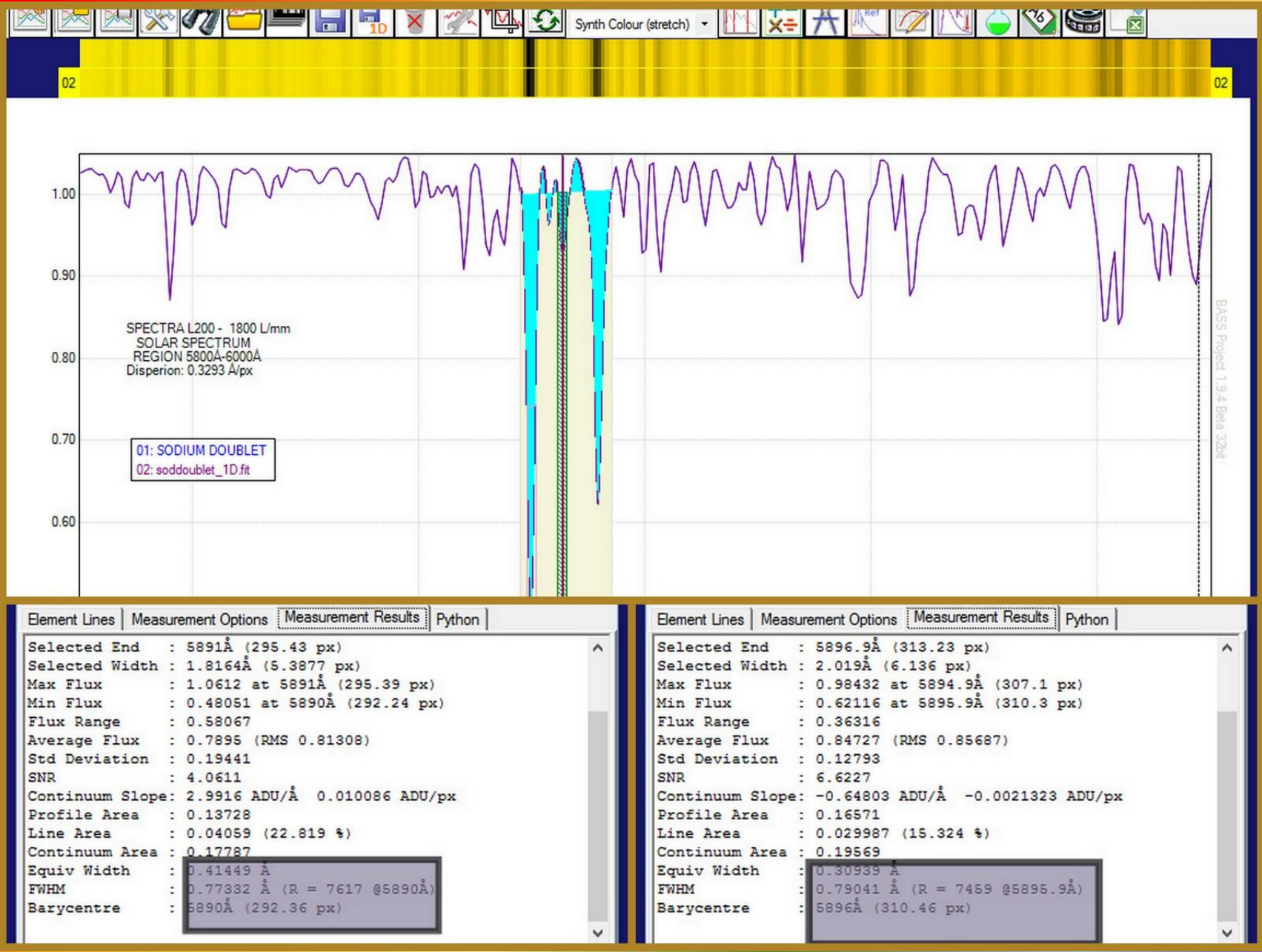
SPECTRA L200 – DOUBLET TEST – ESTIMATION OF RESOLVING POWER R



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 !