UltraVioletEXplorer

Version 3

By
Christian Buil, Pierre Dubreuil, Stéphane Ubaud,
Alain Lopez, Jean-Luc Martin, Pierre Thierry

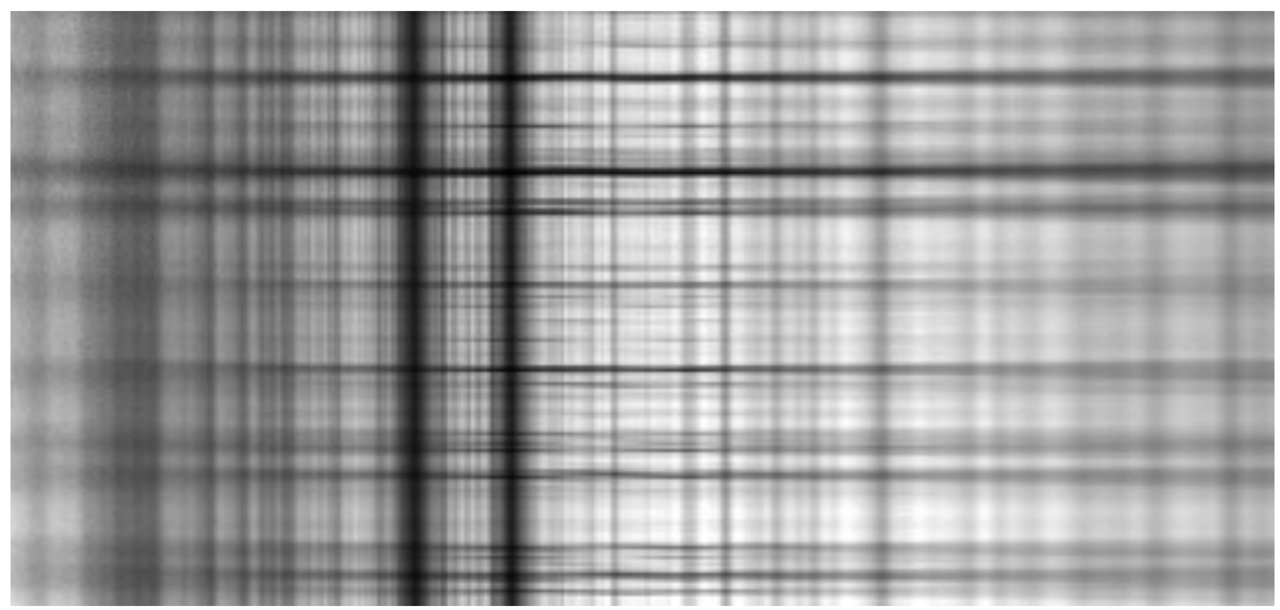
Why UVEX ?

A classical problem in spectroscopy : chromatic aberration of the optic

Optical rays are not focused at the same location in function of wavelength

Sharp image

Image given by a classical amateur spectrograph in the near UV :



« Transversalium » (defects on the slit)

Ca II lines at 3934 and 3968 A

Blur image

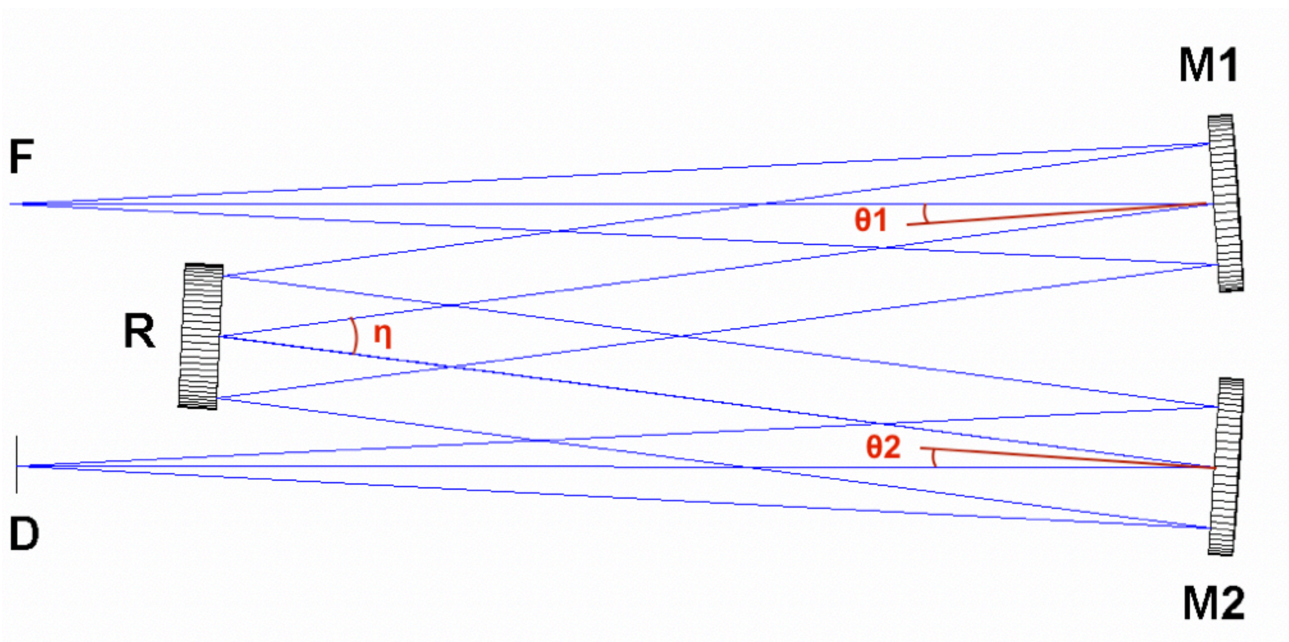
Blur image

The goal of UVEX : obtain sharp spectra from ultraviolet to infrared

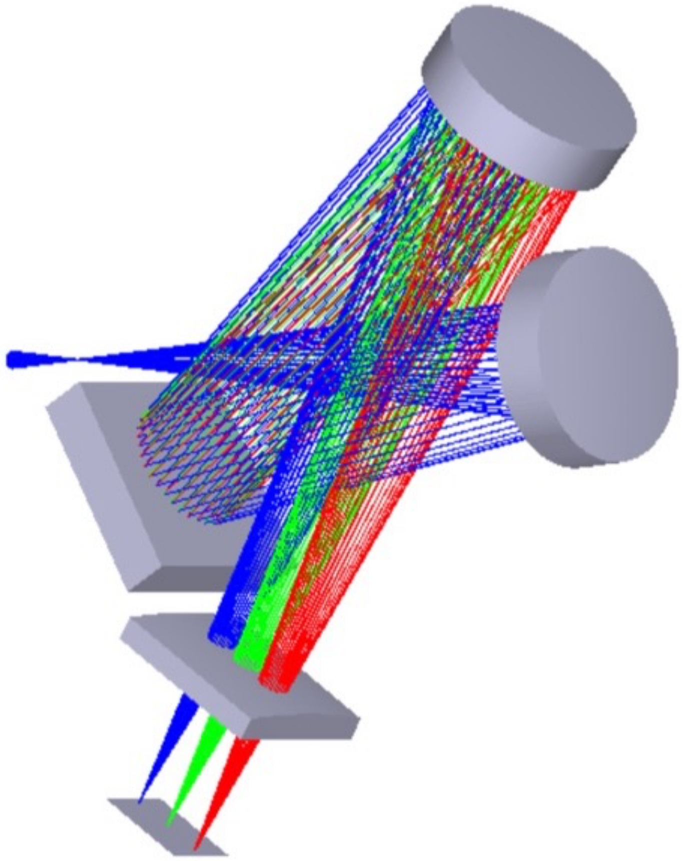
UVEX is the acronym of **UltraViolet EXplorer**

UVEX project

UVEX is a spectrograph based on a simple optical concept: a slit, two spherical mirrors (Czerny-Turner disposition), a grating, and of course, a detector :



Basic optical drawing

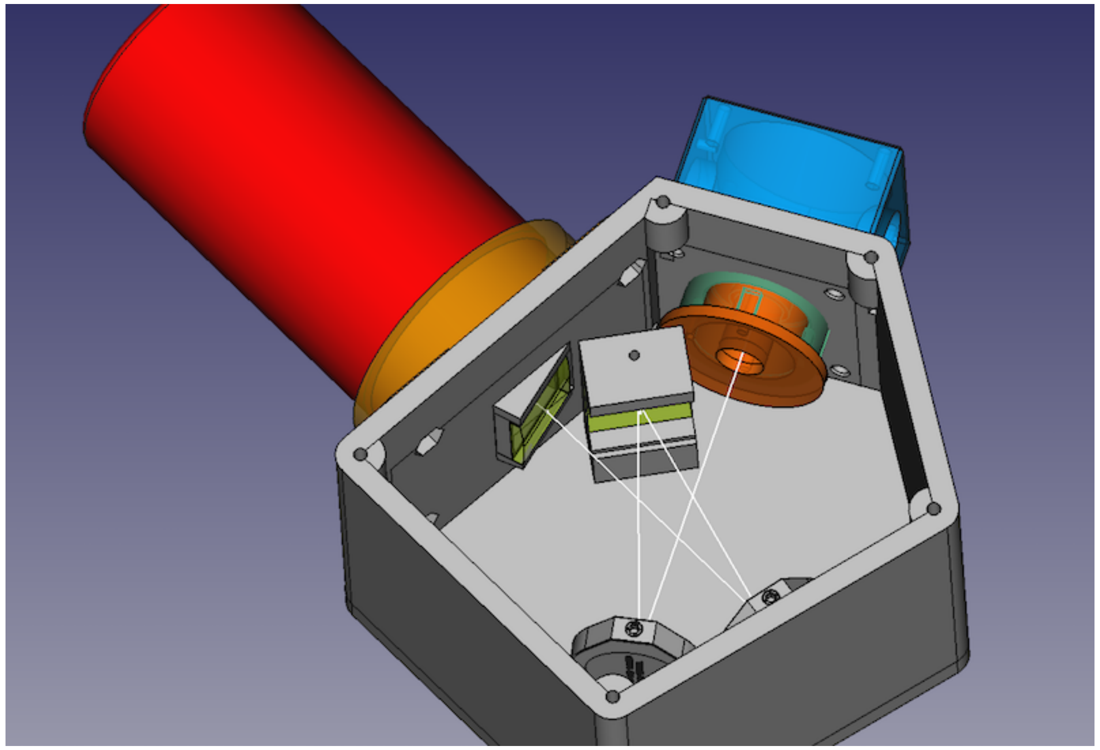


UVEX crossed version of Czerny-Turner

The adopted version of the Czerny-Turner for UVEX is crossed and add a cylindrical lens for correct astigmatism aberration.

The great interest of this setup : nearly fully achromatic (no chromatic aberration). For this reason, it is possible to observe parts of the spectrum rarely (never) explored by amateurs - towards the ultraviolet (and towards the infrared).

Made yourself the spectrograph

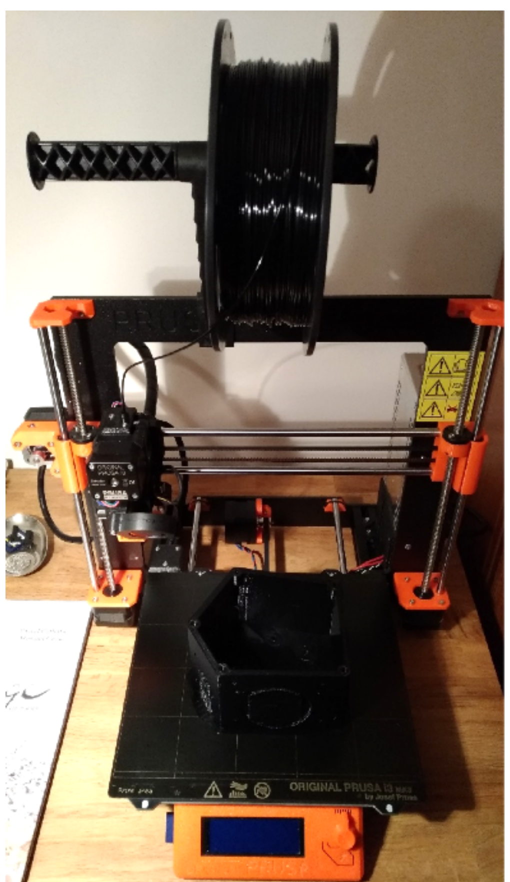


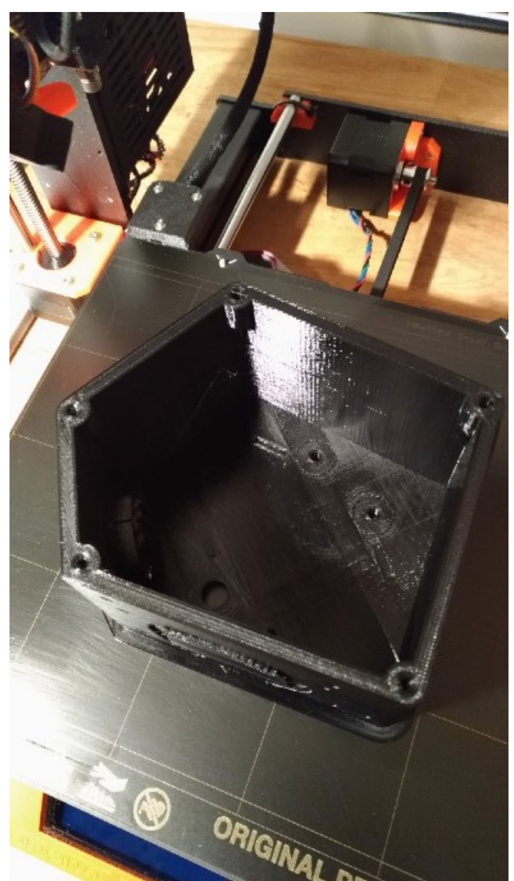
The key idea of the current version (V3): offer the possibility to realize the spectrograph by yourself at low cost using 3D printing technology.

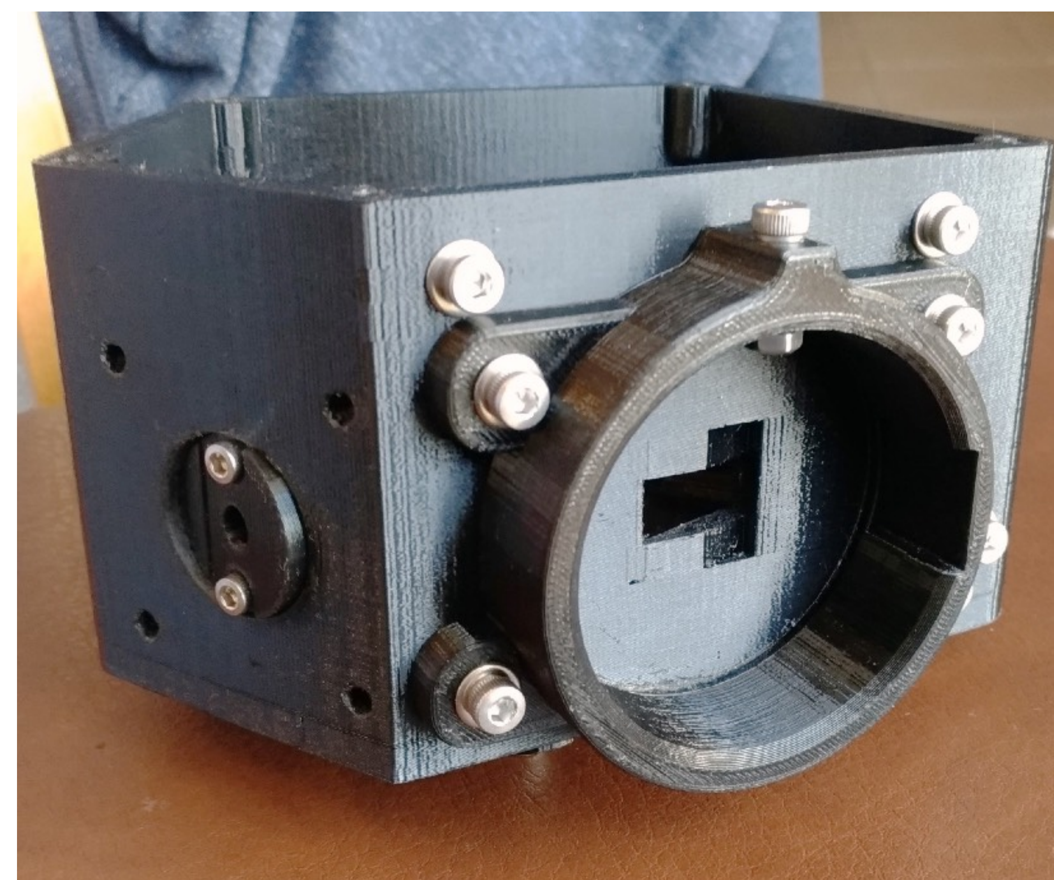
See also the example of LOWSPEC project.

But, each spectrograph is a prototype, a unique adventure!

This philosophy is very different from buying a spectrograph off the shelf!







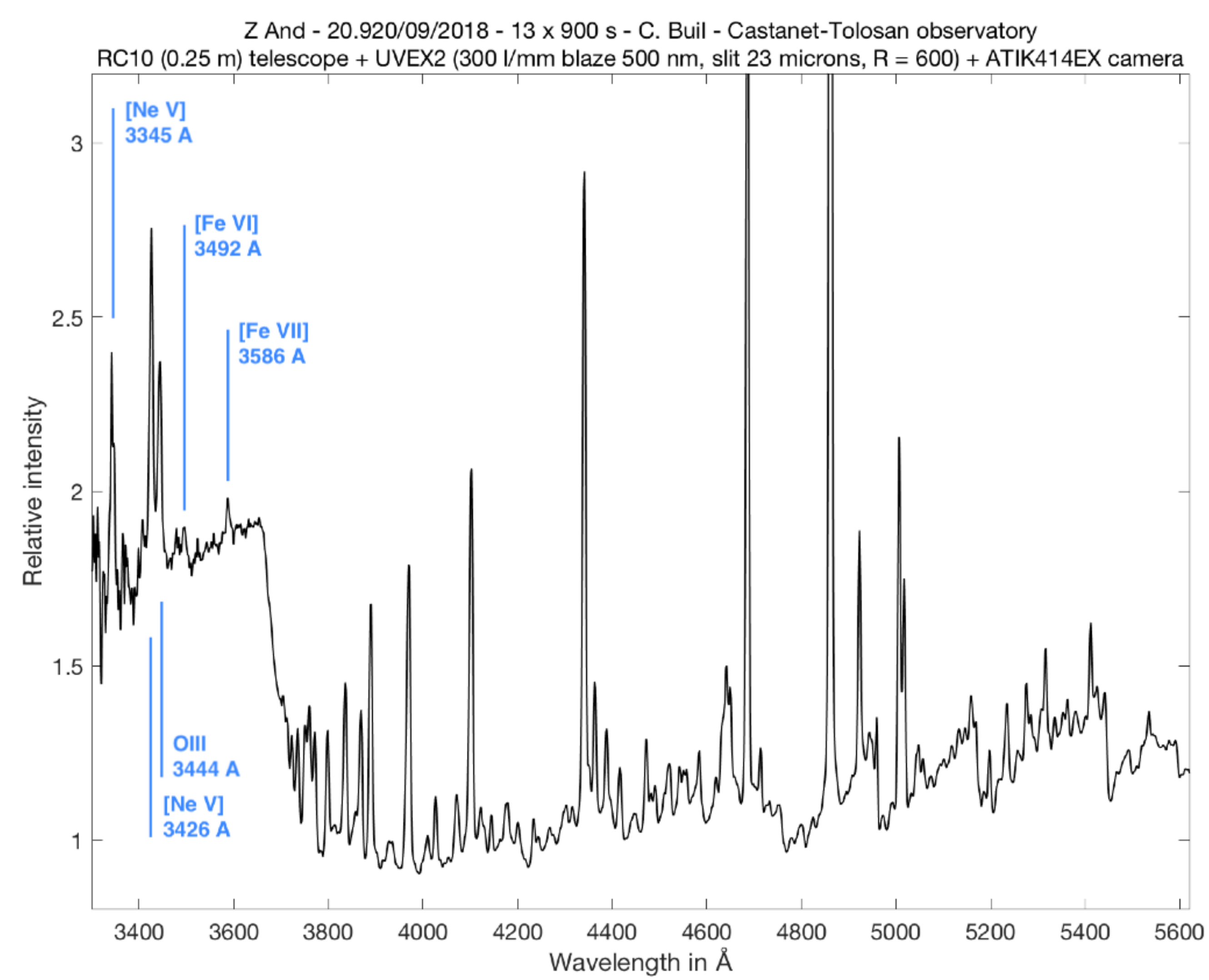
UVEX(3), a low cost projet, but with some limitations…

- **Optimized only for small telescopes (10 cm < D < 40 cm).**
- **Ideal f-ratio between f/8 and f/10 (The target telescopes are f/10 Schmidt-Cassegrain (SC) and f/8 Ritchey-Chretien (RC)). Newton telescope are not recommended, but possible (less spectral resolution).**
- **Because you build the spectrograph, you also have the responsibility to adjust the optics (a not so simple task on a Czerny-Turner…).**
- **The mechanical rigidity is far from a metallic industrial model.**

UVEX(3) is primarily an **experimental project**. Ideal for understanding how a spectrograph works (excellent end-to-end project for clubs, schools and universities).

UVEX is a spectrograph for **education**, OK, but also for **sciences and astrophysics…**

At right, the spectrum of symbiotic star Z And taken by using UVEX(2) on a RC10 spectrograph. Note the detection of [Ne IV] line at 3345 angströms. A first for amateurs!



UVEX versus other spectrograph

UVEX

UVEX: Better spectral resolution (R=1000 to 3000)

Alpy 600: More compact and more easy to use

Alpy 600

UVEX: More polyvalent

LISA : Compatible with large telescope, more luminous on extended object.

LISA

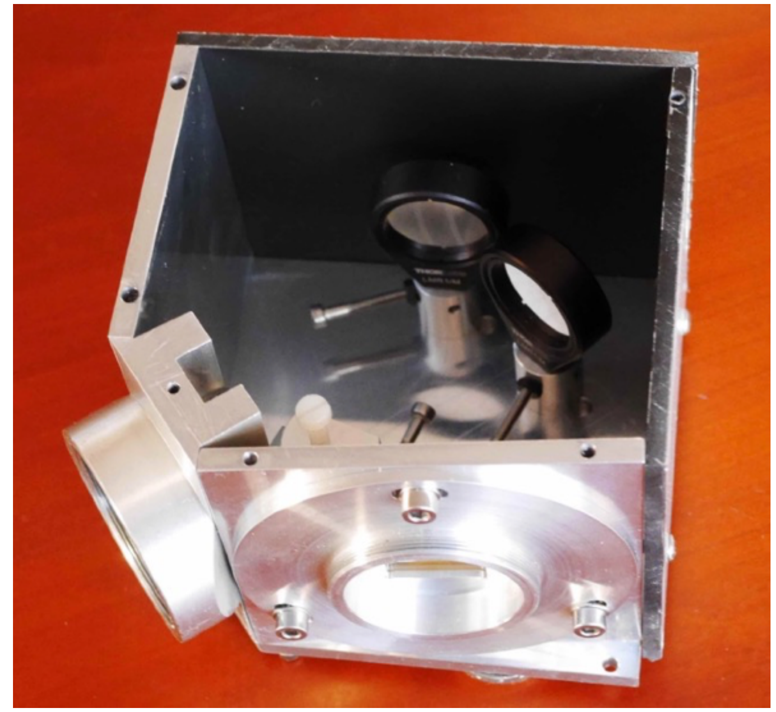
UVEX & LHIRES: Capacity to change the grating, but better chromatic correction for UVEX

LHIRES: Higher spectral resolution (R=15000 with a 2400 l/mm grating)

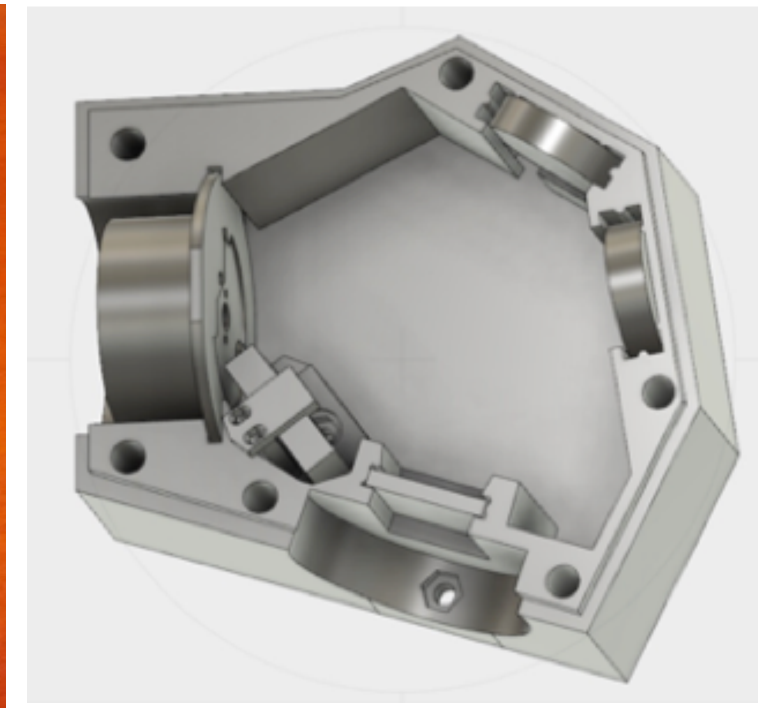
LHIRES III

A short story (1/3)

The idea of a Czerny-Turner for amateur spectrography is from 2014. After some adventures (...) the first light of metallic UVEX(0) is doing the September 20, 2016 (Christian Buil). Tests validate the concept.



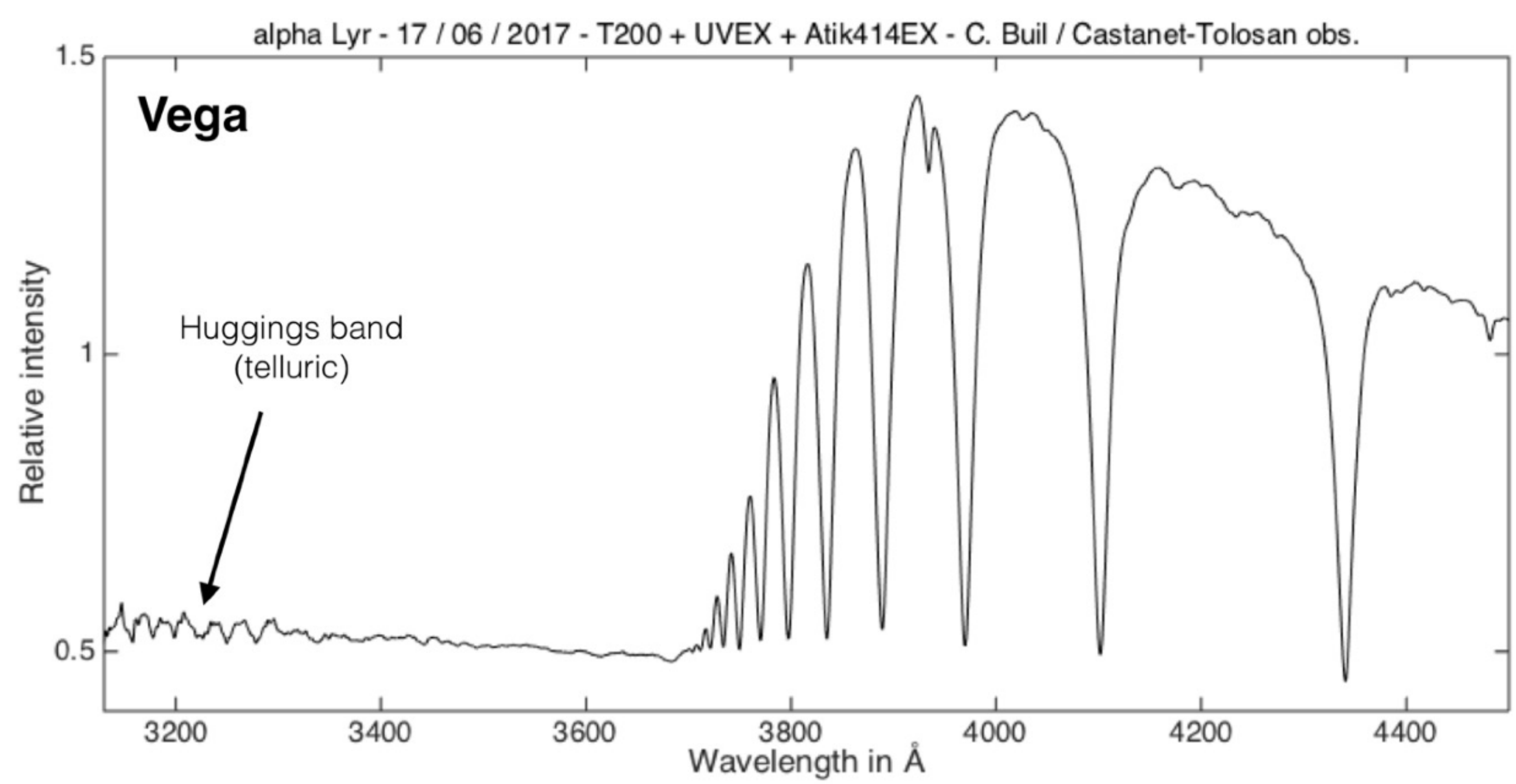
UVEX(0)



UVEX(1)

At the start of 2017, a new prototype is designed (Christian Buil and Pierre Thierry), by using a 3D printing technique. UVEX(1) take it's first spectra at spring 2017. Spectral features near wavelength 320 nm are observed. UVEX is a real ultraviolet explorer !

Left, detection of UV earth atmospheric ozone band (O3) in a Vega spectrum.

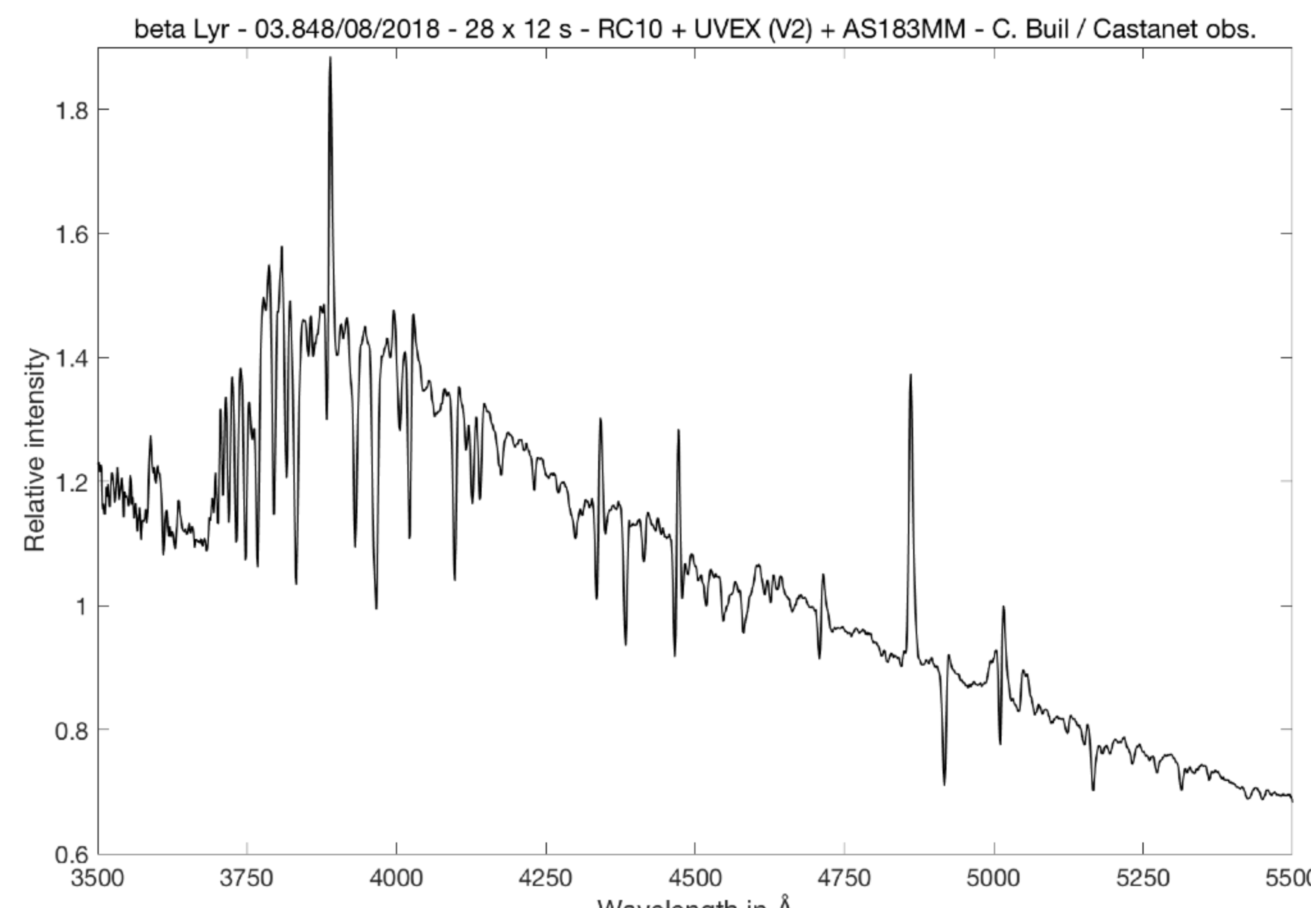


A short story (2/3)

During the spring and summer of 2018, Christian Buil, Pierre Dubreuil, Stéphane Ubaud, Alain Lopez and Jean-Luc Martin (« Brice de Nice » group) develop UVEX (2)prototype on new basis, which benefits from the experience of the first two versions

Working session at Antibes (french Riviera) - summer 2018

UVEX(2) first light - August 3, 2018.

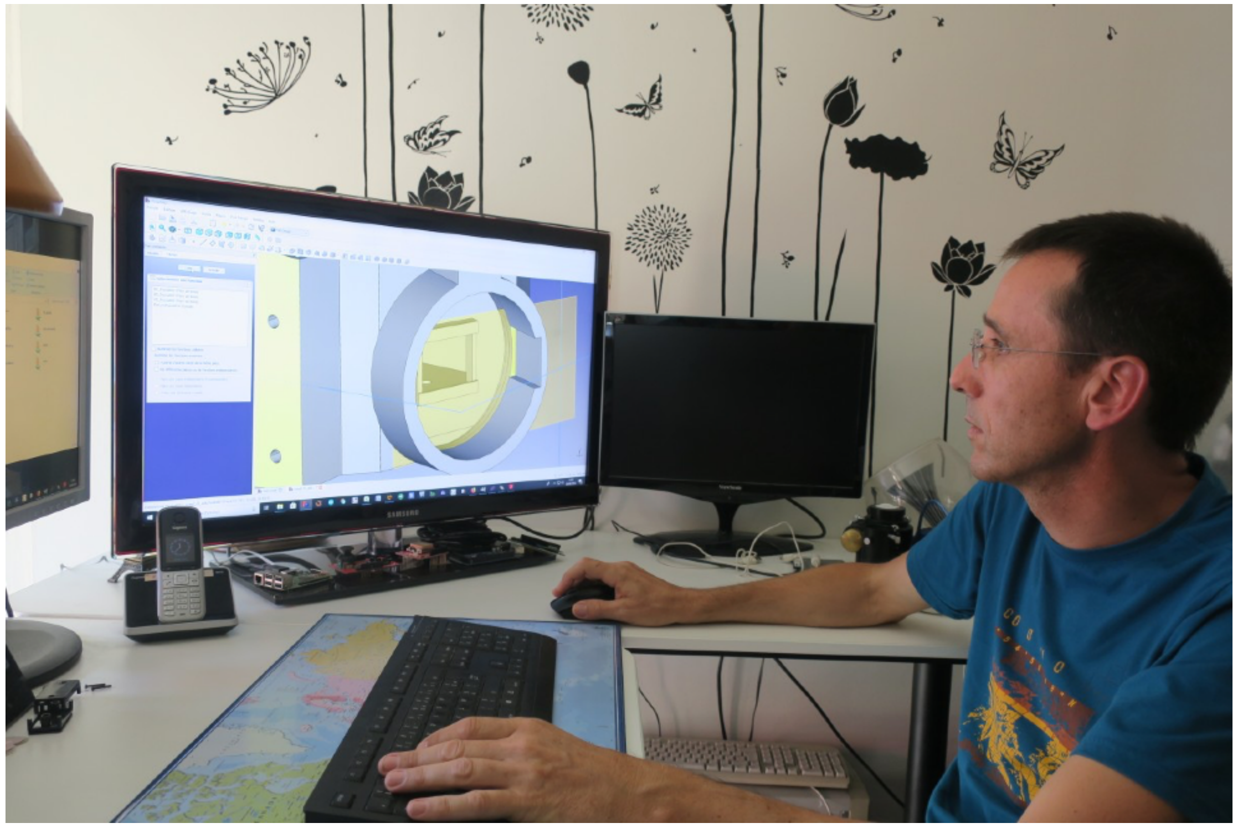


A short story (3/3)

Test of UVEX(2) at the 60 centimeters telescope of Pic du Midi Observatory (french Pyrénées).

Valérie Desnoux during the september 2018 UVEX(2) mission at Pic du Midi observatory.

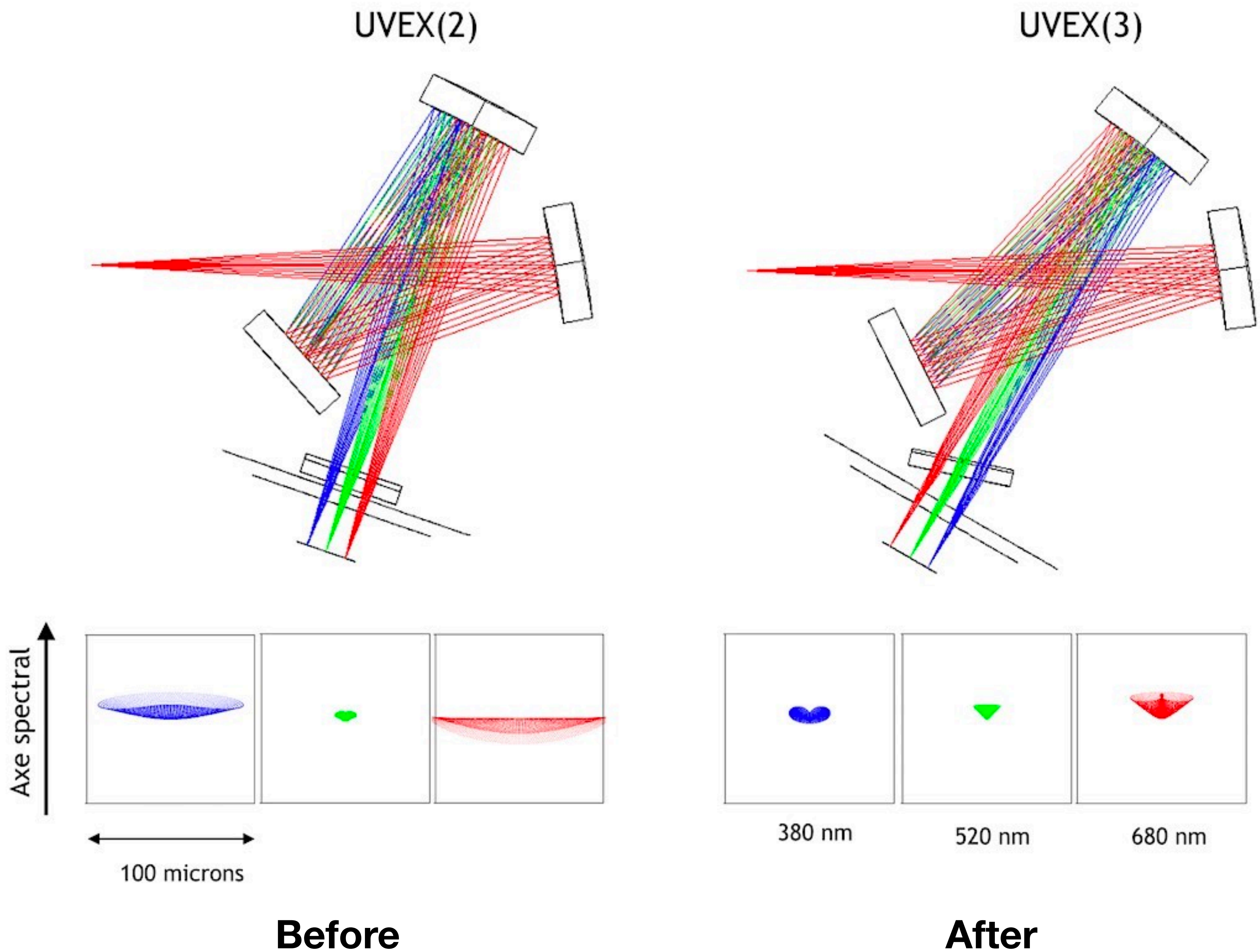
The latest version is **UVEX(3) :** improved optic and capacity to choose the camera model.



Stéphane Ubaud during an UVEX(3) conception session.

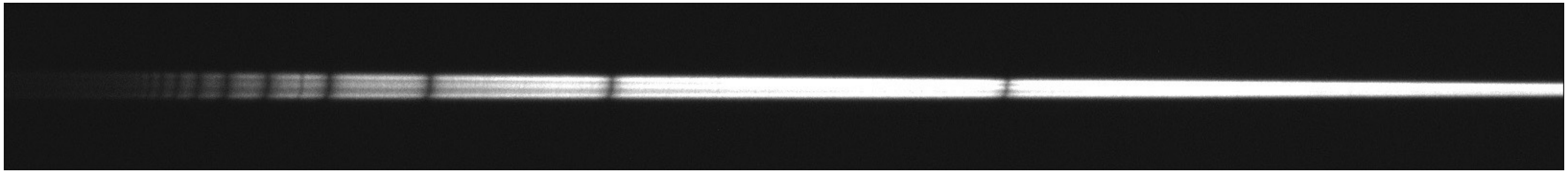
From UVEX(2) to UVEX(3)

Rotation of the cylindric lens by an angle of 18° for a better correction of astigmatism :

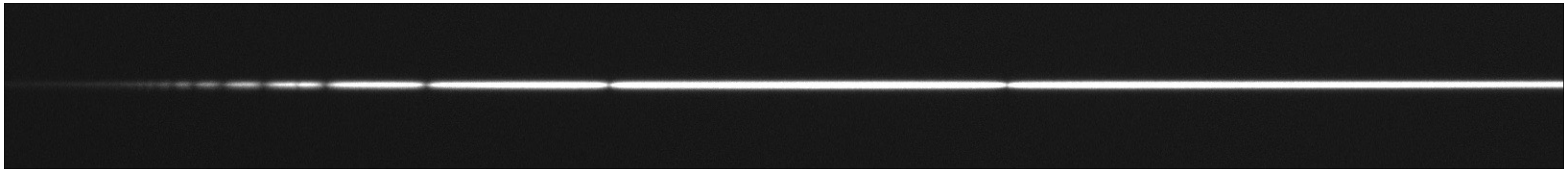


About astigmatism on Czerny-Turner spectrographs

An exemple of astigmatism
aberration (CR-ROM spectroscopy)



UVEX 2D spectrum of a star before astigmatism correction



UVEX 2D spectrum of a star after astigmatism correction

Performances : Spectral resolution

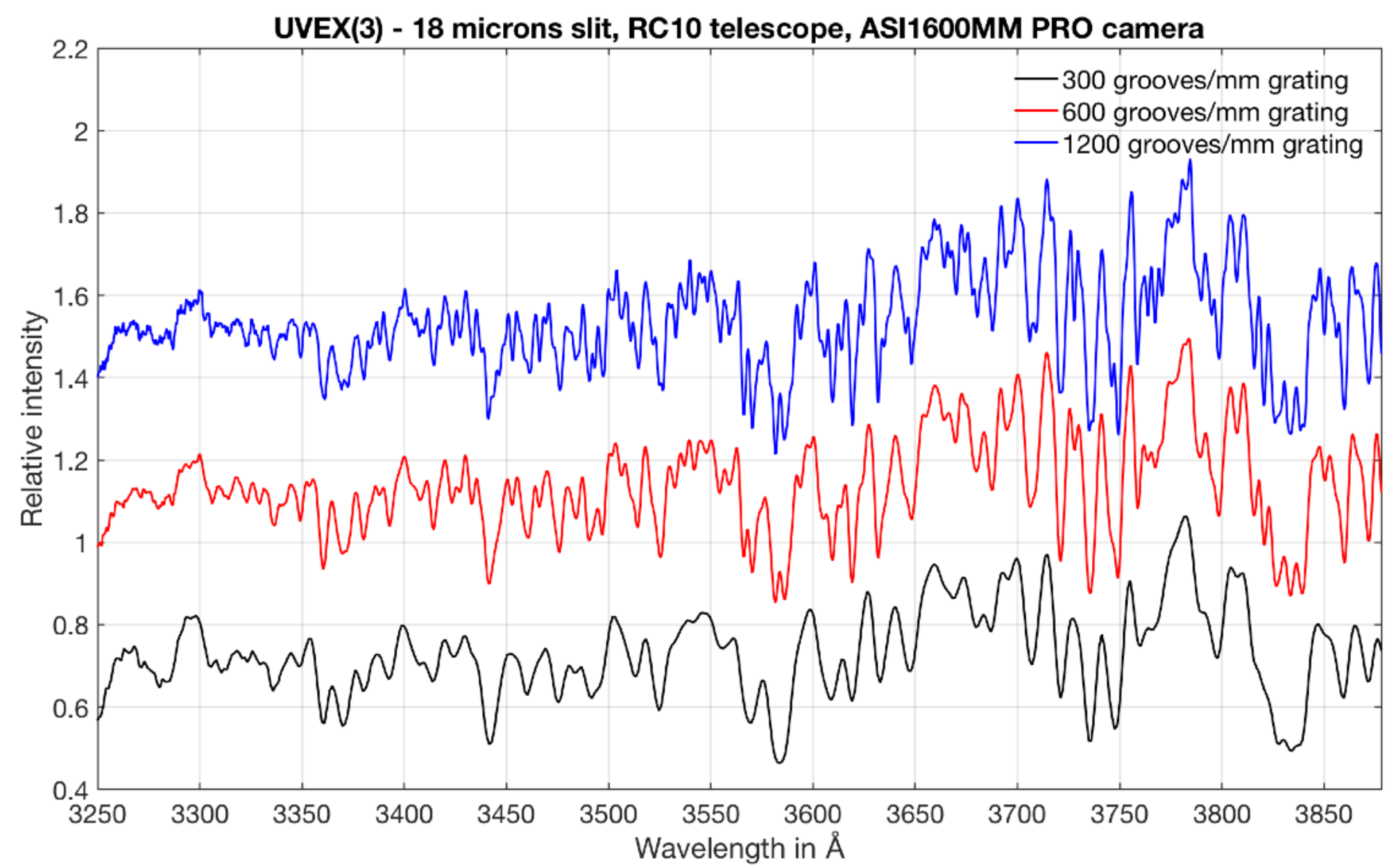
UVEX is optimized for the use of a 300 lines/mm grating. But you can select the grating groove density for modulate the spectral resolution.

The spectral resolution is also function of the slit wide.

Here, the spectral resolution power ($R = \lambda/\Delta\lambda$) for some configurations at 650 nm:

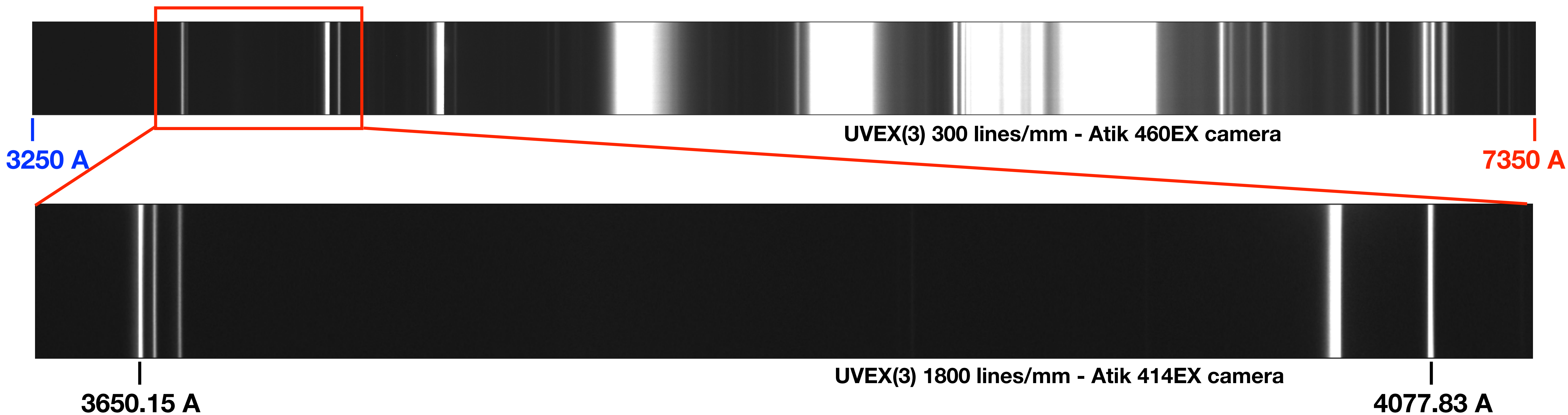
Grating	Slit 18 microns	Slit 23 microns
300 l/mm	1200	950
600 l/mm	2000	1500
1200 l/mm	3100	2300

Left, aspect of daylight UV spectrum in function of grating groove density for a f/8 entrance beam.

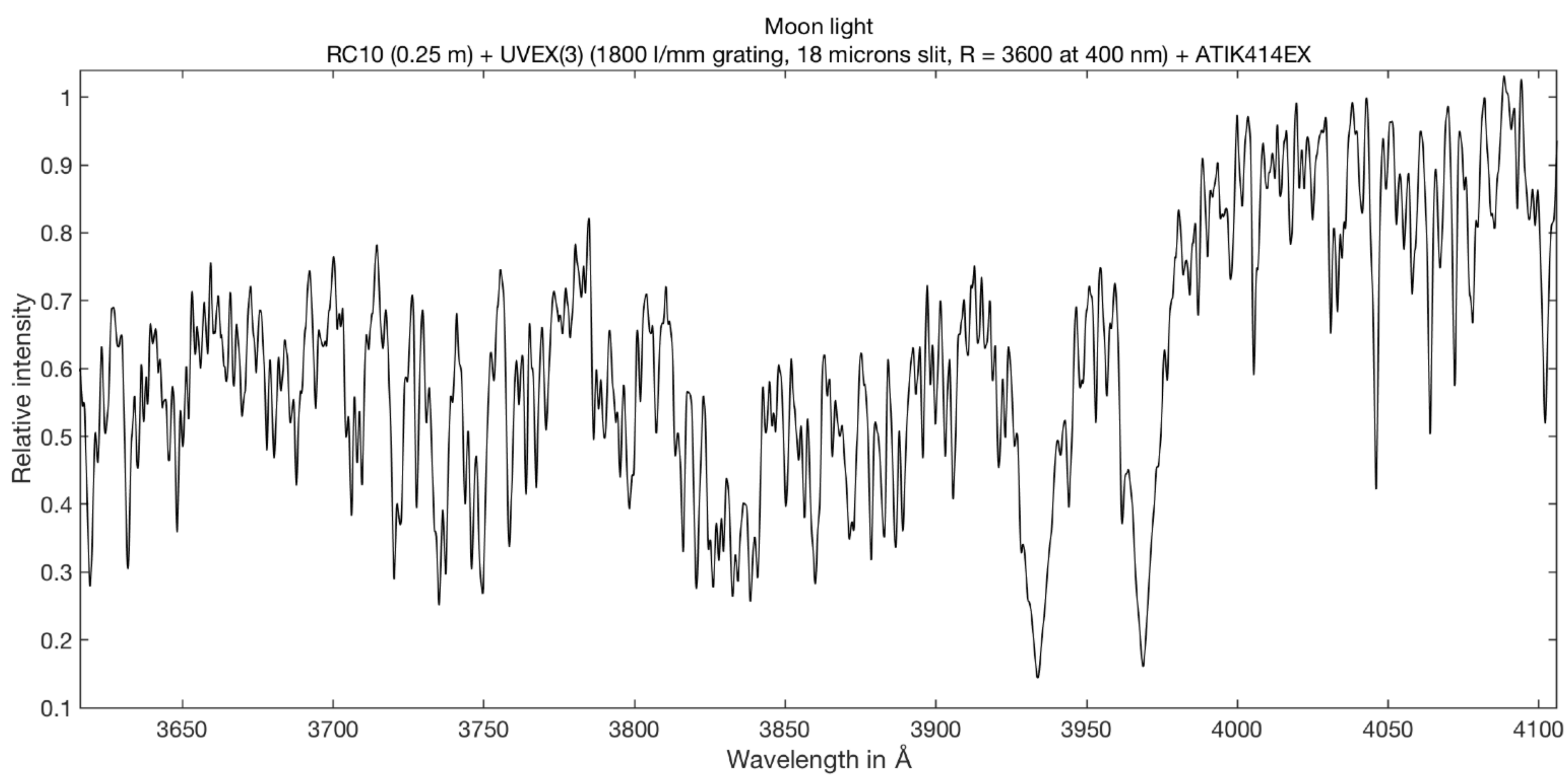


« Extreme » resolution: 1800 lines/mm grating (only for the UV region)

Aspect of a « fluo-compact » lamp spectrum for two UVEX(3) extrema spectral resolution:



Ideal for spectral classification (student project)



Left, UV moonlight spectrum
R = 3600 at 400 nm

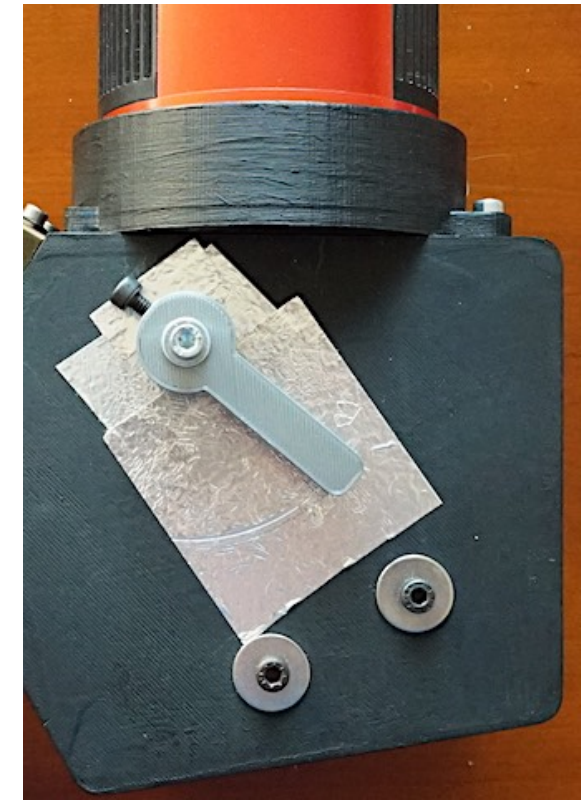
(but only an experimental mode)

Spectral coverage

Theoretical observed spectral domain wide in function of the camera model:

	300 lines/mm	600 lines/mm	1200 lines/mm
ATIK414EX	3000 A	1500 A	750 A
ATIK460EX	4170 A	2080 A	1040 A
ASI183MM	4400 A	2200 A	1100 A
ASI1600MM	(5900 A)	(2980 A)	(1490 A)

In practice, consider these values as the maximum values for UVEX



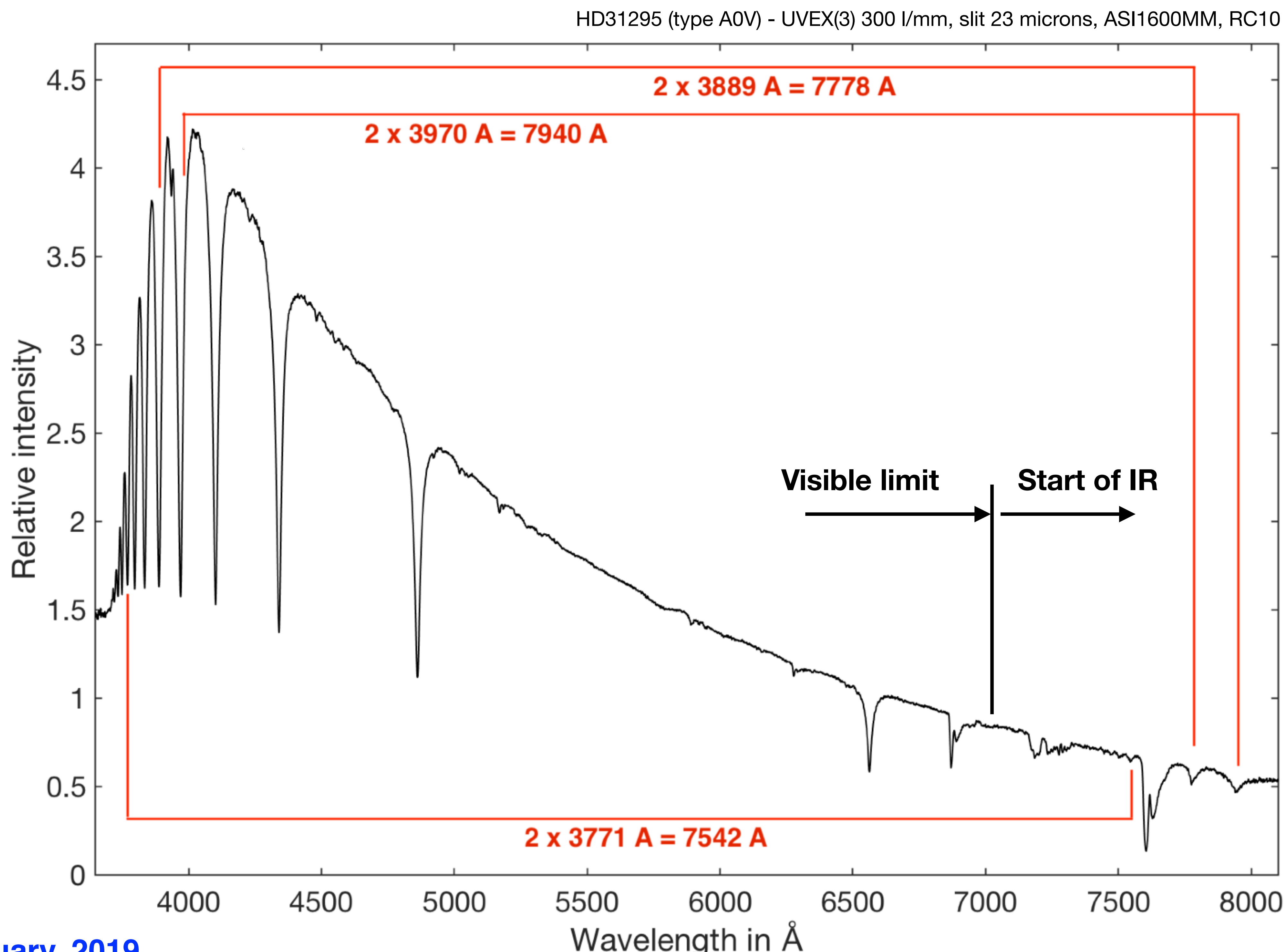
Spectral domain can be changed from the exterior

Example of covered spectral domain on some spectral source - Configuration : UVEX(3) 300l/mm associated at an Atik460EX camera

Spectral coverage

UVEX excels in the UV part of the spectrum, but of course, the visible part of the spectrum is also accessible.

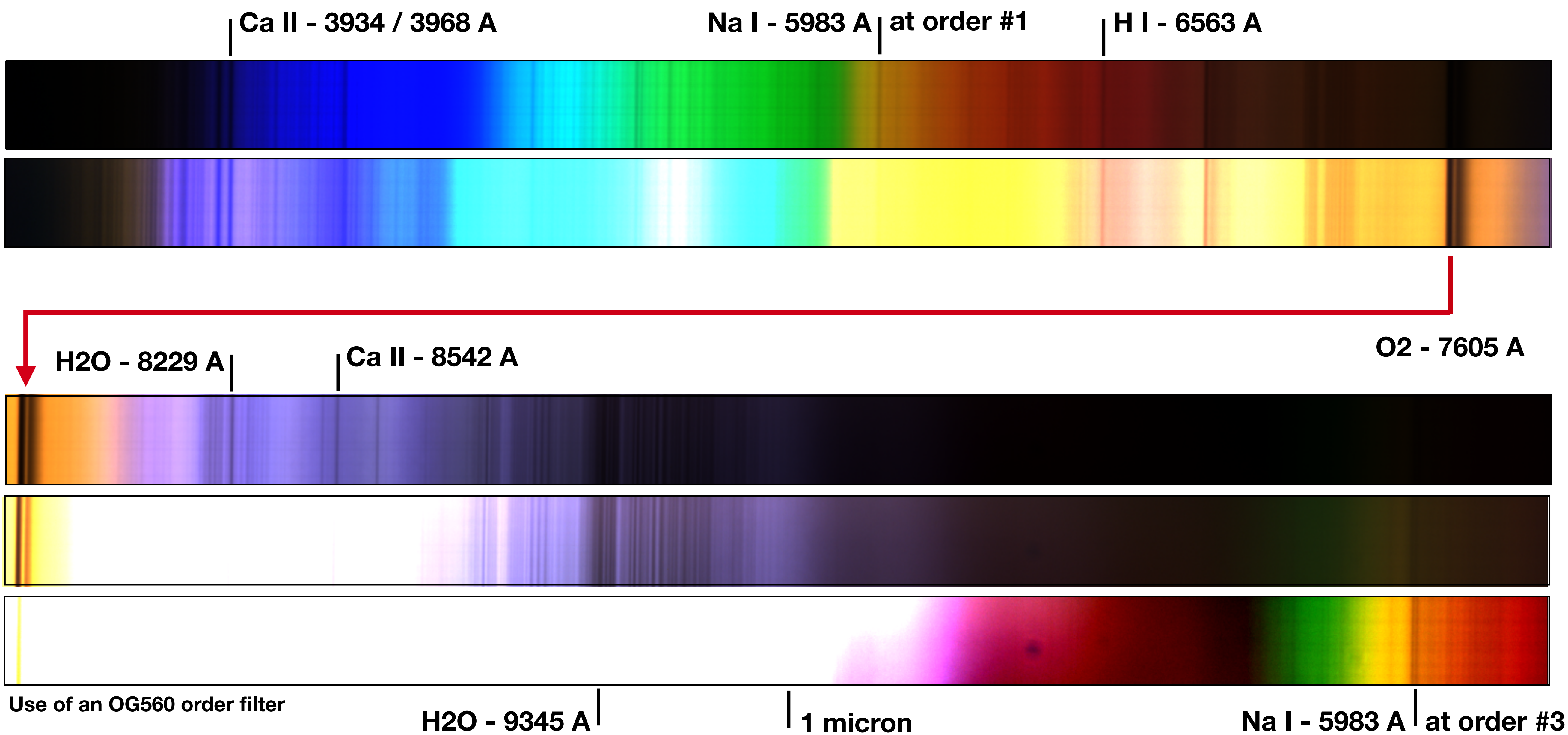
Warning, pay attention to order recovery!



Increase spectral coverage

« True colors » spectroscopy UVEX(3) 300 lines/mm + color camera ASI294MC (ZWO)

Use of a CFA detector (Color Filter Array) for capture color (Sony IMX294)

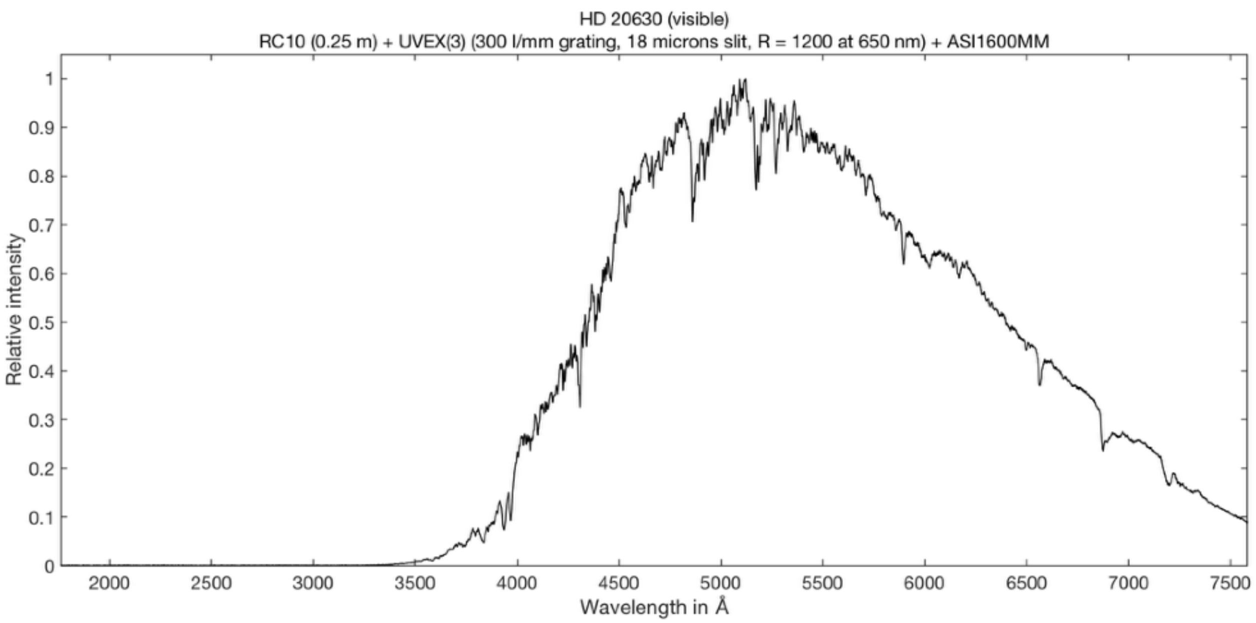


Sun light - ***A typical educational project (no telescope is needed)***

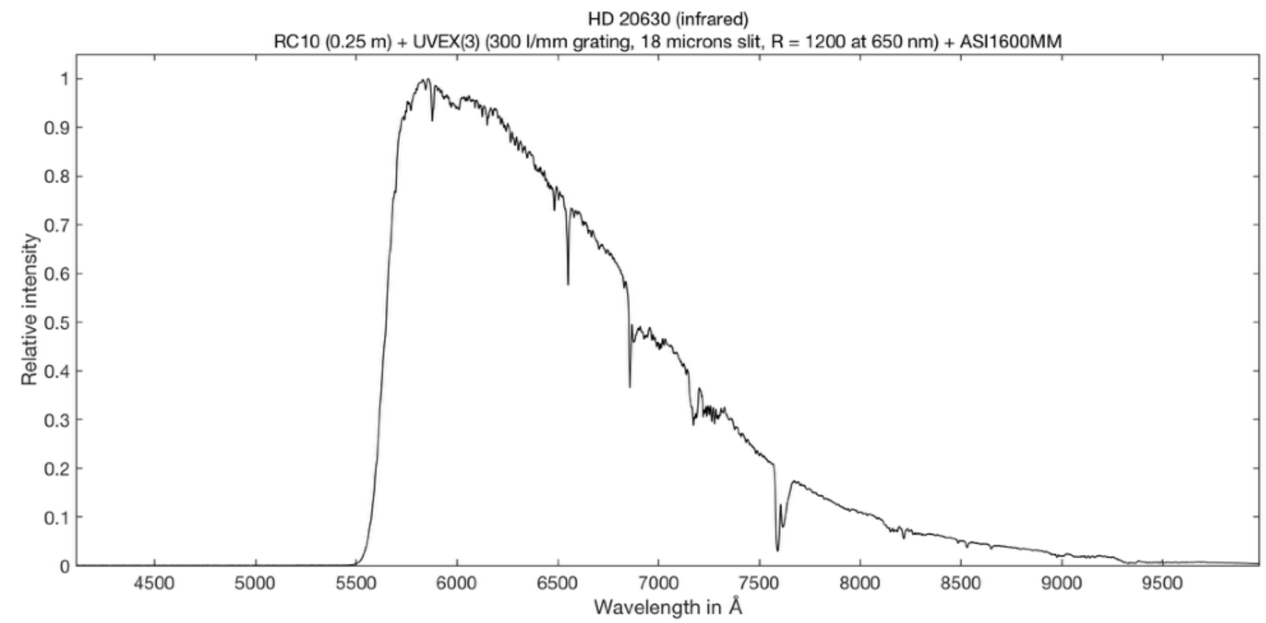
Increase spectral coverage

Thanks to the achromatism of the optical formula, UVEX makes it possible to observe a wide spectral range without refocusing the camera. The operation is simple, change the angle of the grating holder.

But remember that you must also use a red filter to capture the (near) infrared…

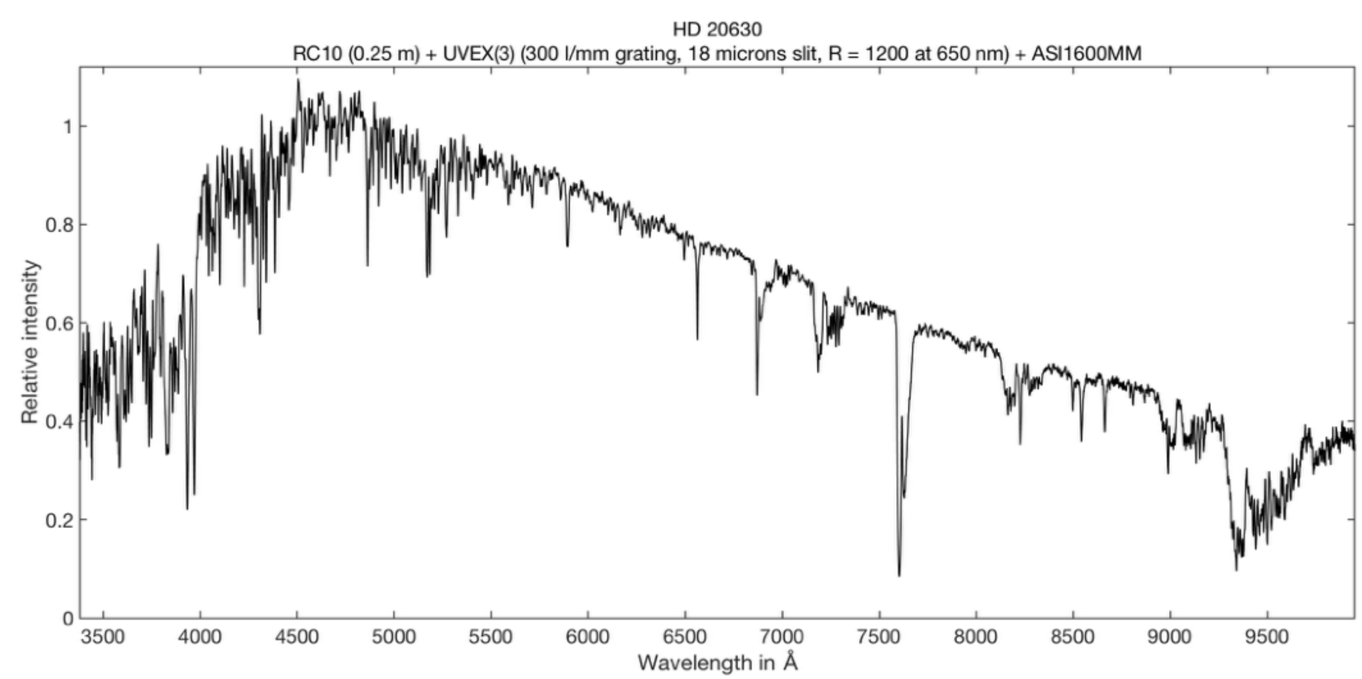


Step #1: Acquisition of the « visible » part of the spectrum.



Step #2: Acquisition of the « infrared » part of the spectrum (add of OG560 order filter.

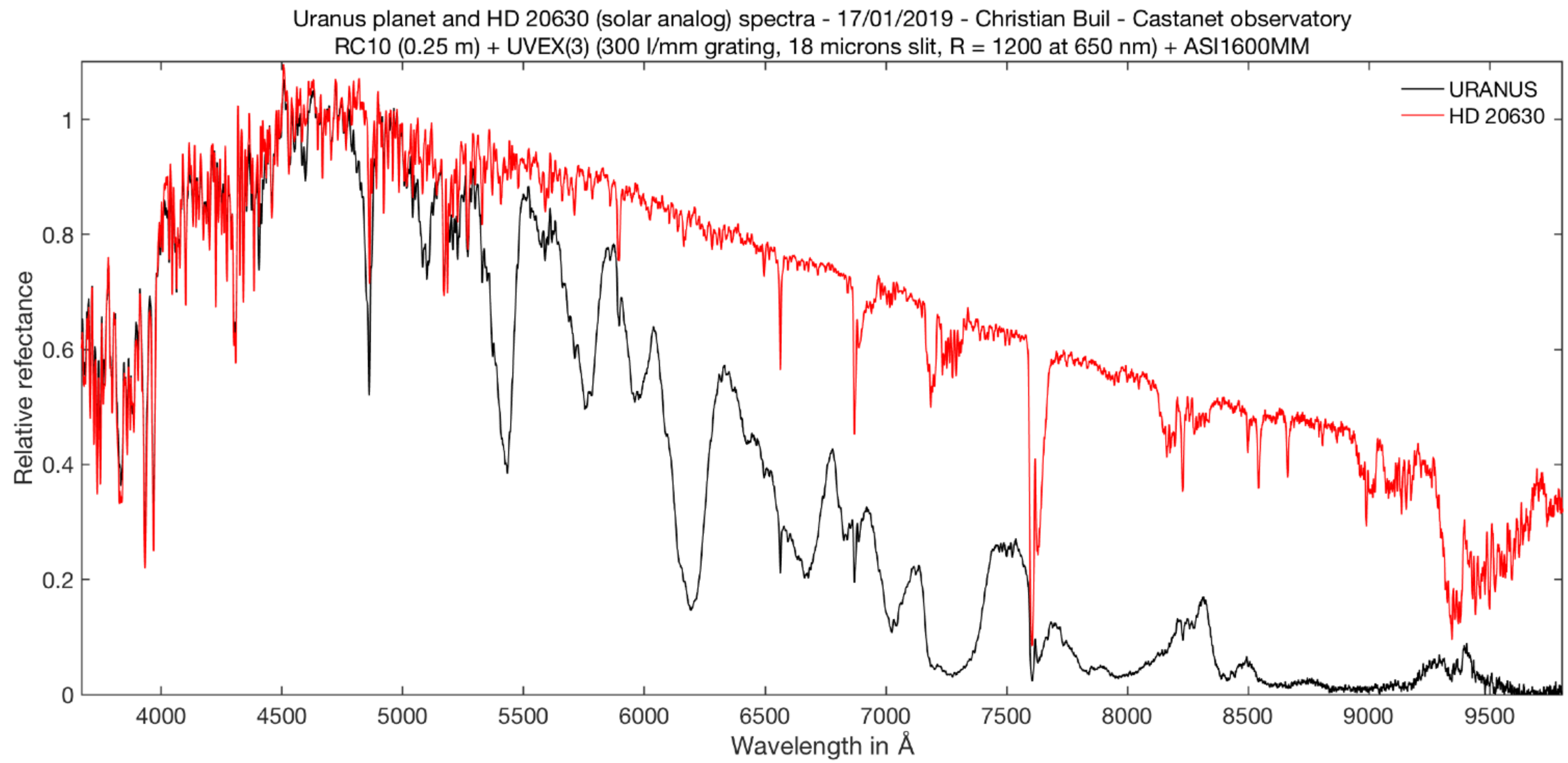
The red order filter is fixed into a filter wheel (ZWO).



Fusion of visible and infrared part (HD20630 is a solar like star). Instrumental response is now corrected.

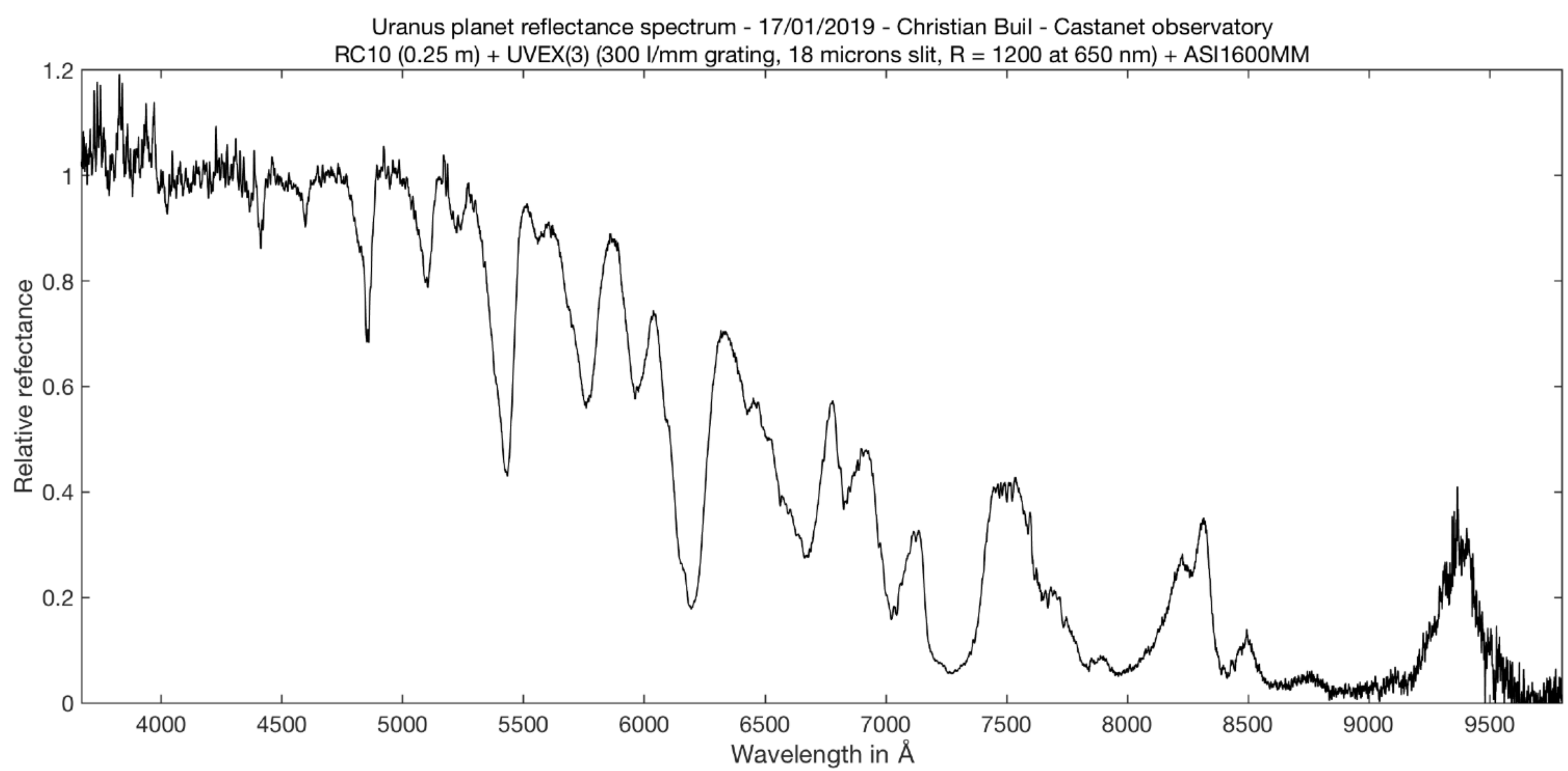
Increase spectral coverage

An exemple of wide spectral band spectroscopy: observation of near infrared planetary atmosphere.



In red: the spectrum of a star similar to the sun

In dark: the apparent spectrum of Uranus planet

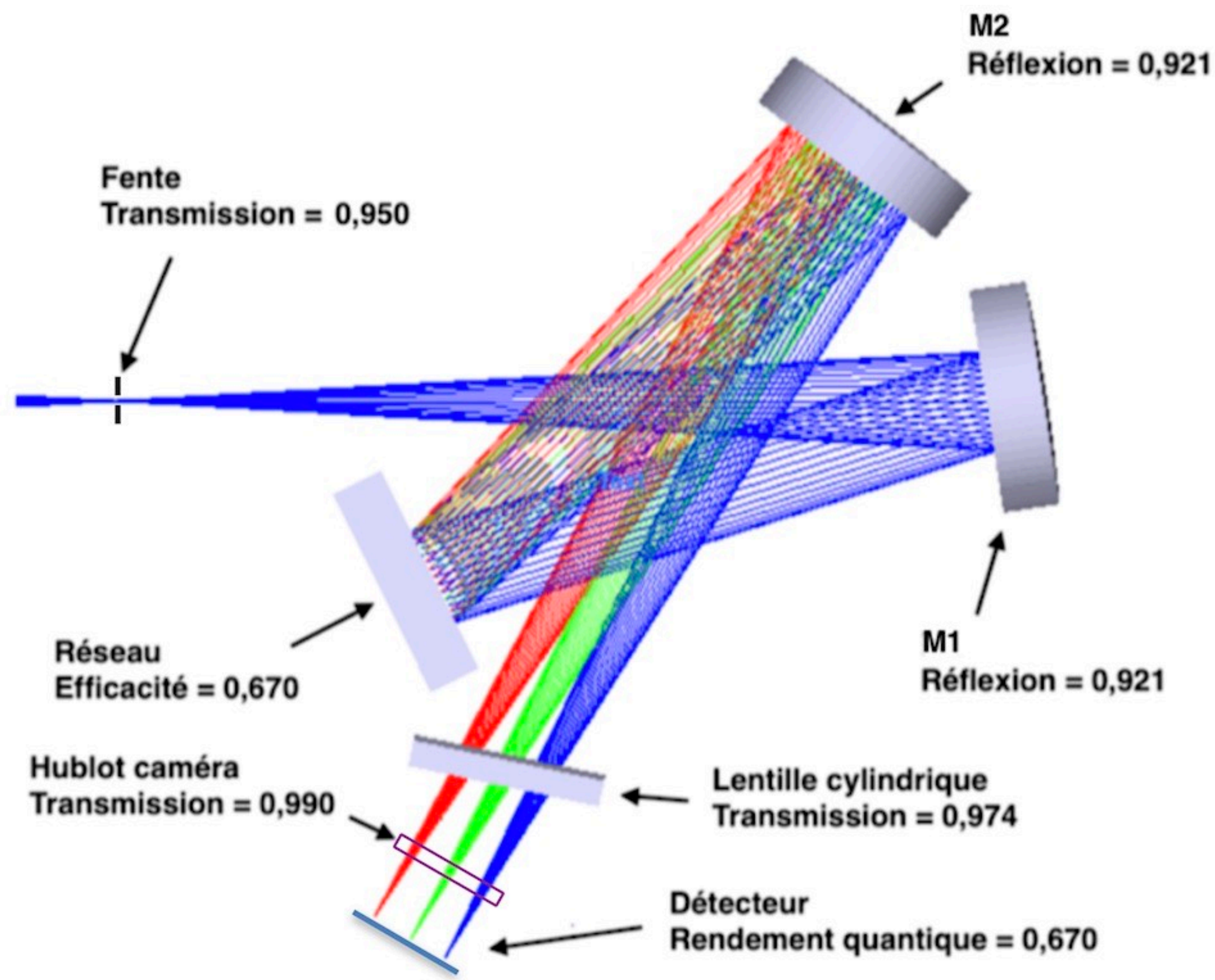


The ratio of Uranus apparent spectrum and solar like spectrum = reflectance of Uranus atmosphere (note presence of many deep CH_4 bands)

Fusion of two UVEX(3) spectra (VIS + IR). CMOS ASI1600MM camera

Radiometric efficiency (throughput)

Throughput at 550 nm

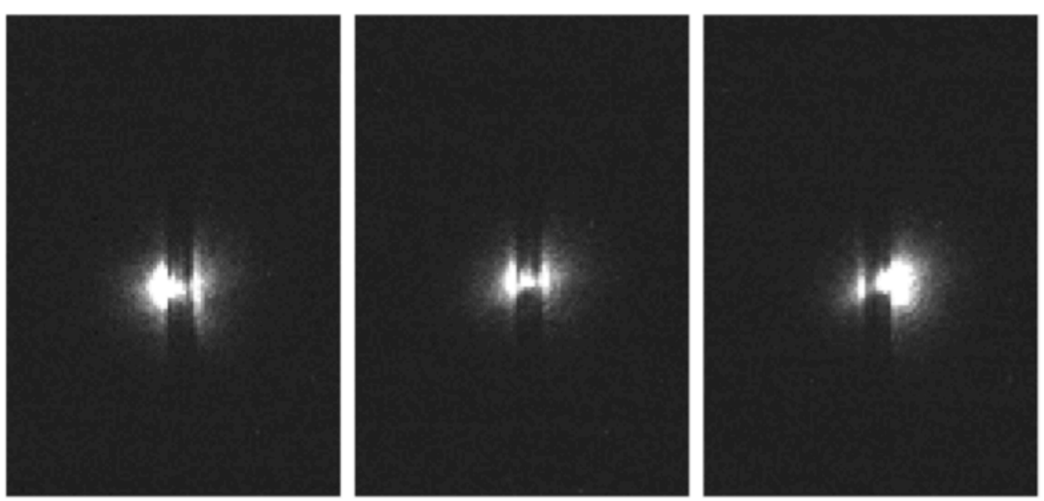


Th = 0,950 x 0,921 x 0,670 x 0,921 x 0,974 x 0,990 x 0,670 = 0,349

A throughput of 35% is an excellent performance for a spectrograph

It is also necessary to take into account the slit transmission…

Stellar image on the slit



Slit geometrical transmission - Seeing 2.5 arcsec - f/10

	Slit 18 microns	Slit 23 microns
D = 20 cm	0,618	0,726
D = 25 cm	0,516	0,618
D = 30 cm	0,440	0,534
D = 40 cm	0,338	0,415
D = 50 cm	0,273	0,338

Typical total spectrograph efficiency (2.5 arcsec seeing) : 0.35 x 0.62 = 0.22

Impact of grating selection

Measured relative diffraction efficiency values of THORLABS grating (500 nm blaze, pixel 6.45 microns) :

At wavelength 400 nm

Grating	Dispersion	Relative diffraction efficiency
300 l/mm	2,140 A/pixel	1,000
600 l/mm	1,078 A/pixel	0,588
1200 l/mm	0,542 A/pixel	0,510
1800 l/mm	0,358 A/pixel	0,434

At wavelength 650 nm

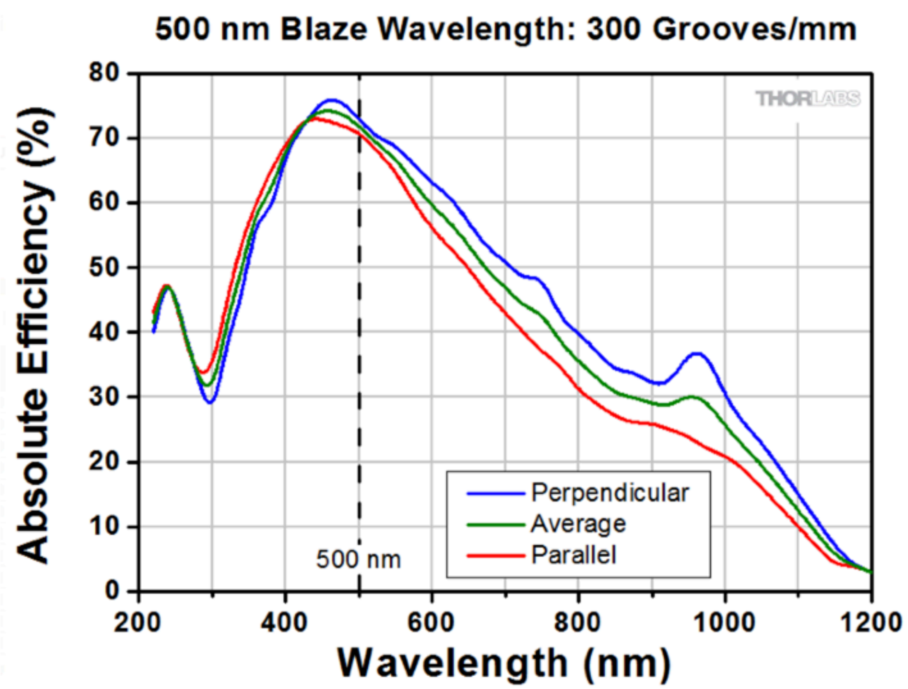
Grating	Dispersion	Relative diffraction efficiency
300 l/mm	2,151 A/pixel	1,000
600 l/mm	1,084 A/pixel	0,940
1200 l/mm	0,533 A/pixel	1,019
1800 l/mm	0,330 A/pixel	0,888

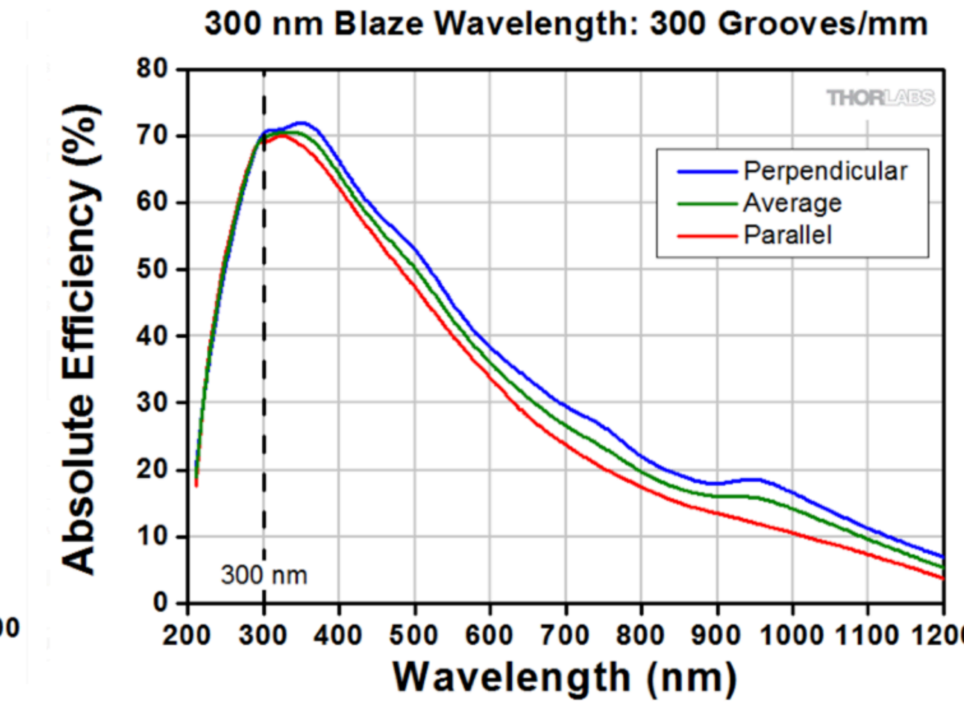
The maximum efficiency is achieved by using the 300 lines/mm grating

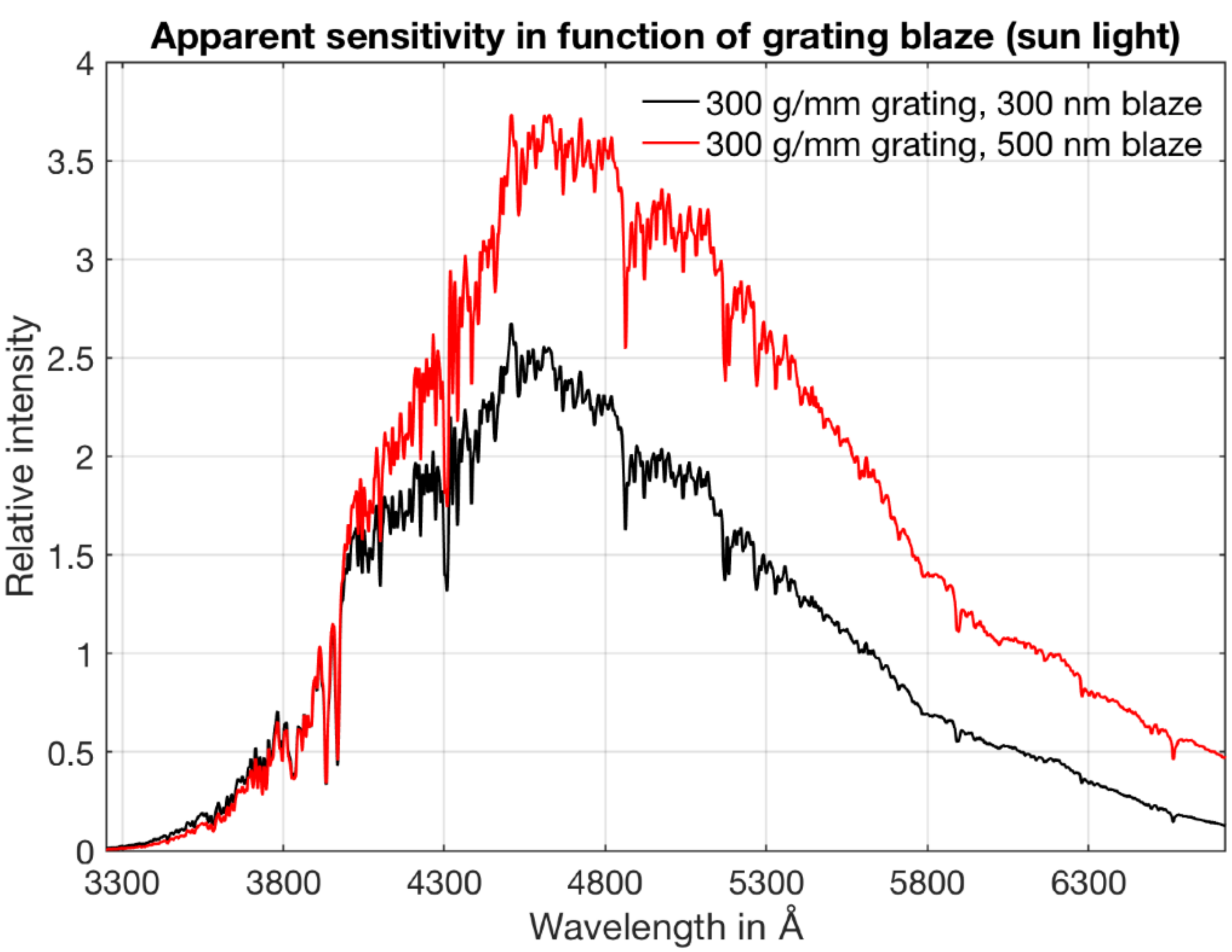
Radiometric efficiency (throughput)

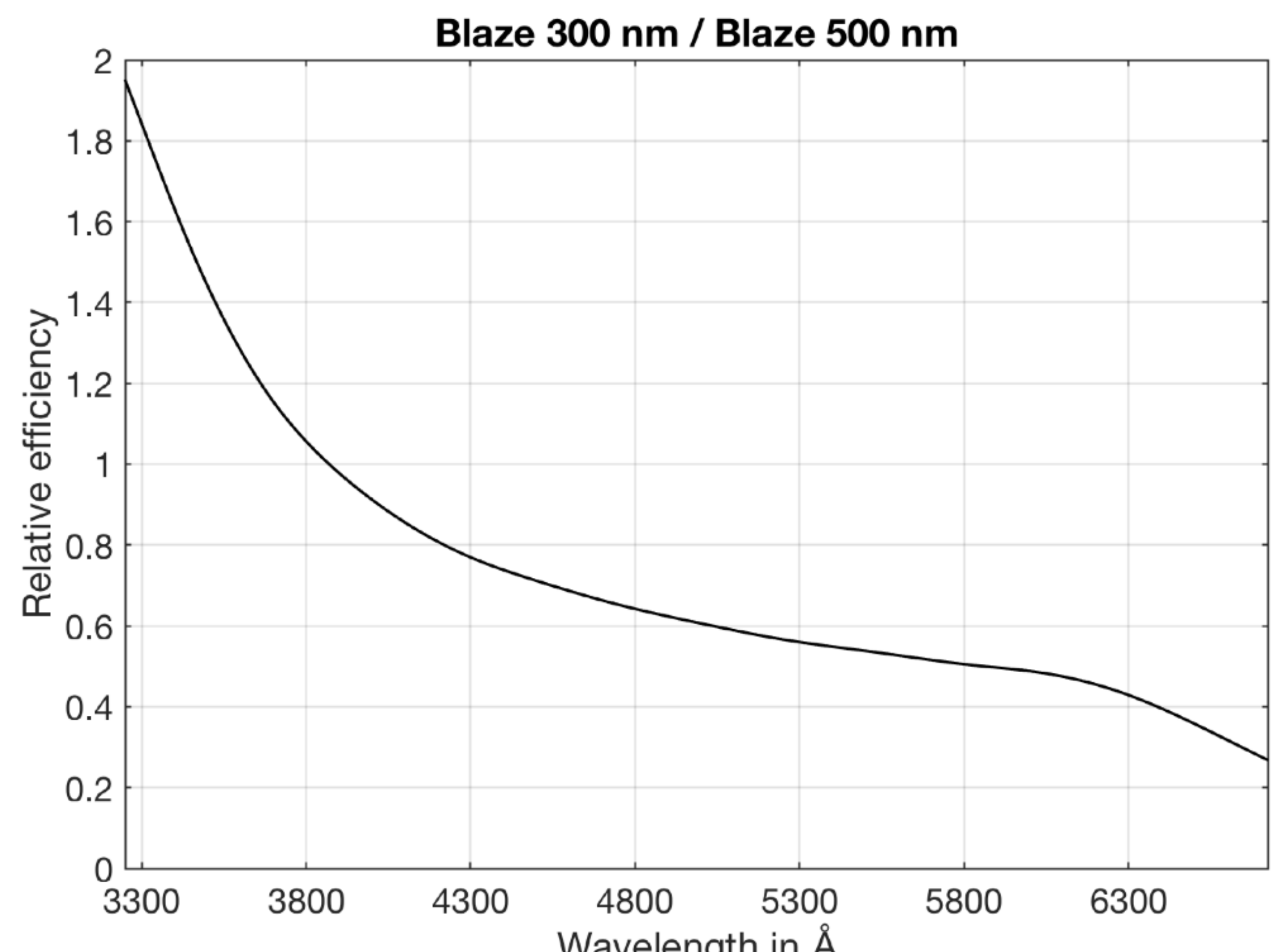
Optimize wavelength blaze of the grating for tracking the UV photons

Documents THORLAB



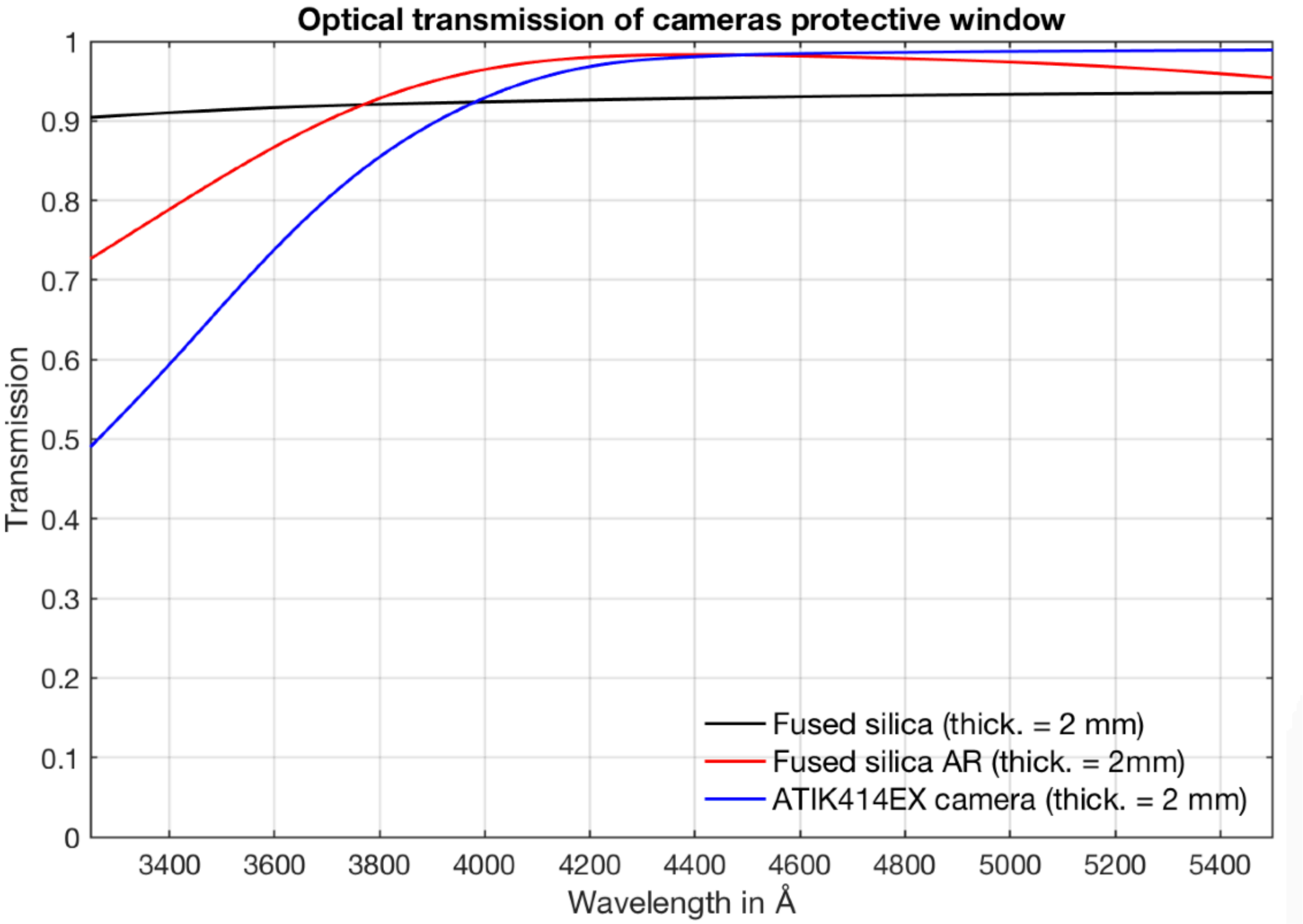






Radiometric efficiency (throughput)

Change the protective glass of CMOS/CCD camera for improve UV responsivity



Optional of course !

Radiometric efficiency (throughput) : detector impact (1/3)

The essential parameters for a detector in spectroscopy :

- **The readout noise (RON)**
- **The quantum efficiency (QE)**

Values for popular cameras :

Atik 414EX

ReadOut Noise (RON) = 4.1 e-
Electronic gain = 0.265 e-/ADU
Pixel size = 6.45 microns

Wavelength	Quantum efficiency
7500 A	38 %
6500 A	52 %
5500 A	65 %
4500 A	66 %
4000 A	51 %
3800 A	40 %
3500 A	17 %

Atik 460EX

ReadOut Noise (RON) = 5.5 e-
Electronic gain = 0.274 e-/ADU
Pixel size = 4.54 microns

Wavelength	Quantum efficiency
7500 A	35 %
6500 A	47 %
5500 A	67 %
4500 A	68 %
4000 A	54 %
3800 A	35 %
3500 A	7 %

ASI1600MM

ReadOut Noise (RON) = 1.3 e-
Electronic gain (20 dB) = 0.475 e-/ADU
Pixel size = 3.80 microns

Wavelength	Quantum efficiency
7500 A	18 %
6500 A	35 %
5500 A	52 %
4500 A	59 %
4000 A	45 %
3800 A	33 %
3500 A	11 %

Comparison between ATIK 414EX and ASI1600MM

A performance criteria : the Signal to Noise Ratio (SNR)

The fundamental formulae :

$$\mathrm{SNR} = \frac{QE \times N_p}{\sqrt{QE \times N_p + \mathrm{BinFactor} \times \mathrm{RON}^2}}$$

QE = Quantum Efficiency, RON = ReadOut Noise, Np = number of incident photons per unit area,
BinFactor = conversion factor to the same surface detection (or same spectral resolution element).
If BinFactor = 1 for ATIK camera (arbitrary), BinFactor = 2.88 for ASI camera (square of pixel size ratio)

Not an unique answer…

Photon limited regime (high signal)

Suppose Np = 10 000

Wavelength	ATIK SNR	ASI SNR
7500 A	62	42
6500 A	72	59
5500 A	81	72
4500 A	81	77
4000 A	71	67
3800 A	63	57
3500 A	41	33

Detector limited regime (faint signal)

Suppose Np = 10

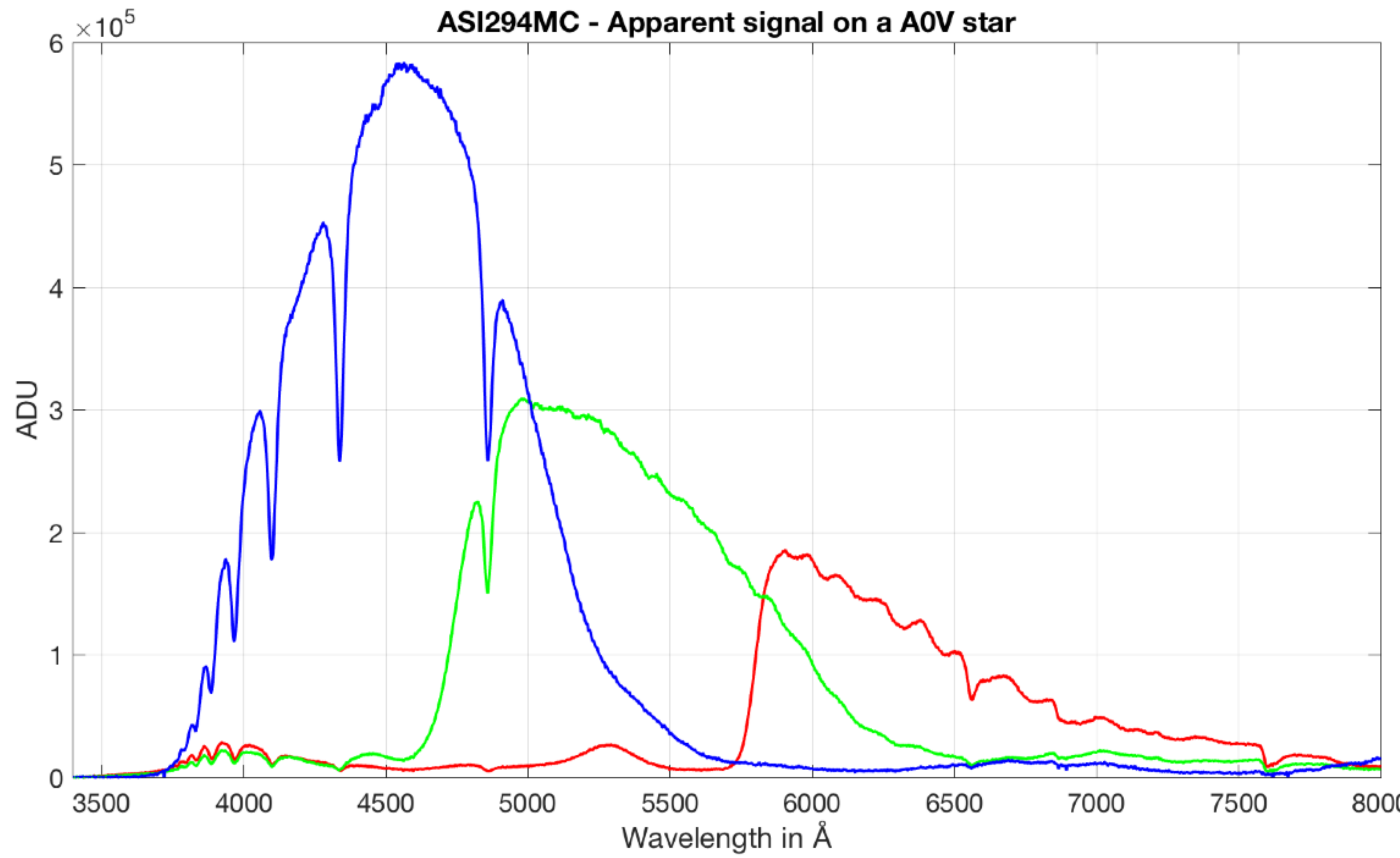
Wavelength	ATIK SNR	ASI SNR
7500 A	0.84	0.70
6500 A	1.11	1.21
5500 A	1.35	1.64
4500 A	1.38	1.80
4000 A	1.09	1.47
3800 A	0.88	1.15
3500 A	0.39	0.45

Radiometric efficiency (throughput) : detector impact (3/3)

ASI 294 MC
(color camera)

ReadOut Noise (RON) = 1.4 e-

Electronic gain (20 dB)
R = 0.326 e-/ADU
V = 0.379 e-/ADU
B = 0.197 e-/ADU
Pixel size = 4.63 microns



Channel R

Wavelength	Quantum efficiency
7500 A	6 %
6500 A	10 %
5500 A	0 %
4500 A	0 %
4000 A	2 %
3800 A	2 %
3500 A	0 %

Channel G

Wavelength	Quantum efficiency
7500 A	3 %
6500 A	2 %
5500 A	16 %
4500 A	1 %
4000 A	2 %
3800 A	2 %
3500 A	1 %

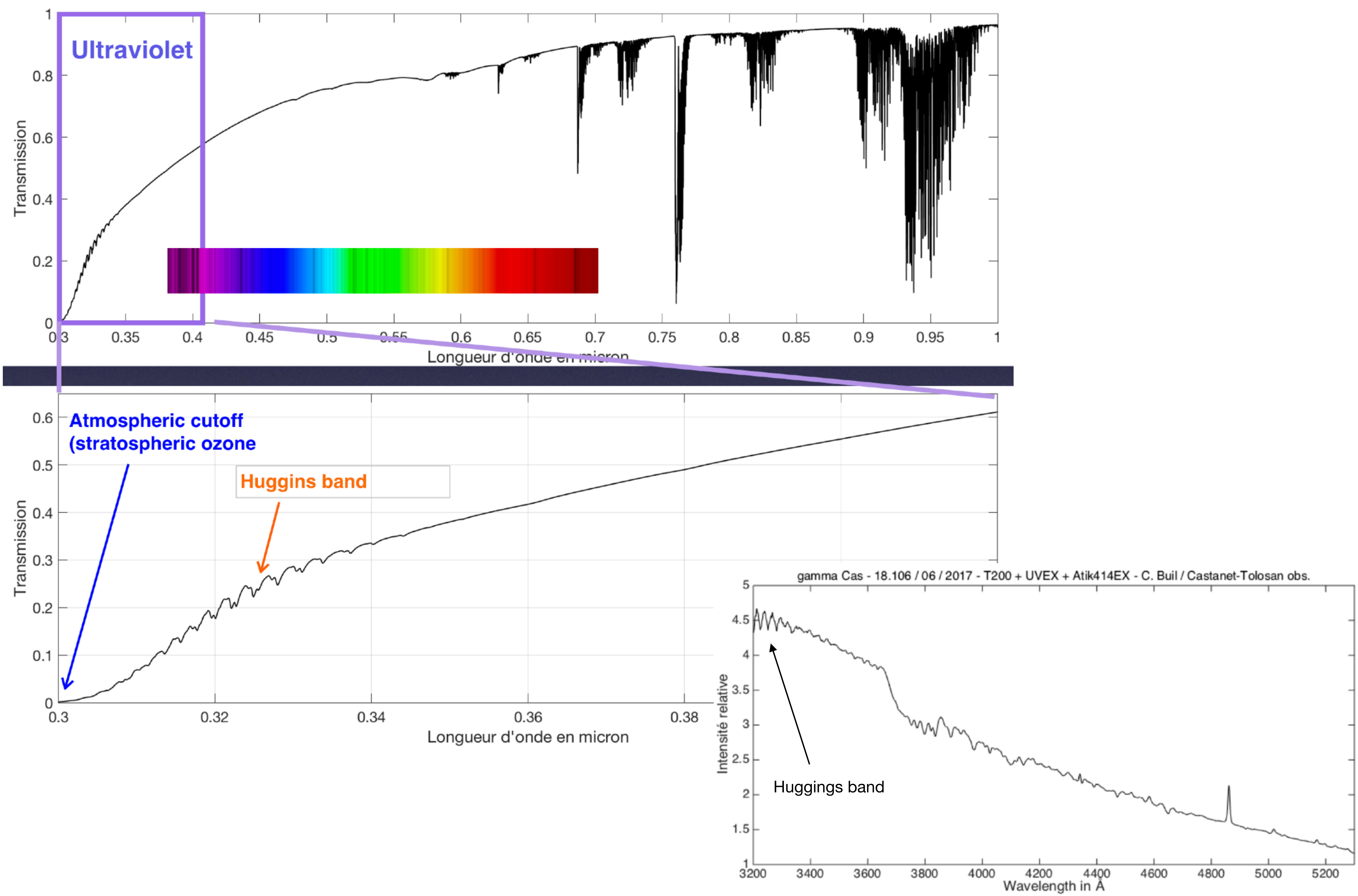
Channel B

Wavelength	Quantum efficiency
7500 A	0 %
6500 A	1 %
5500 A	1 %
4500 A	17 %
4000 A	10 %
3800 A	3 %
3500 A	0 %

B&W 9.26 microns

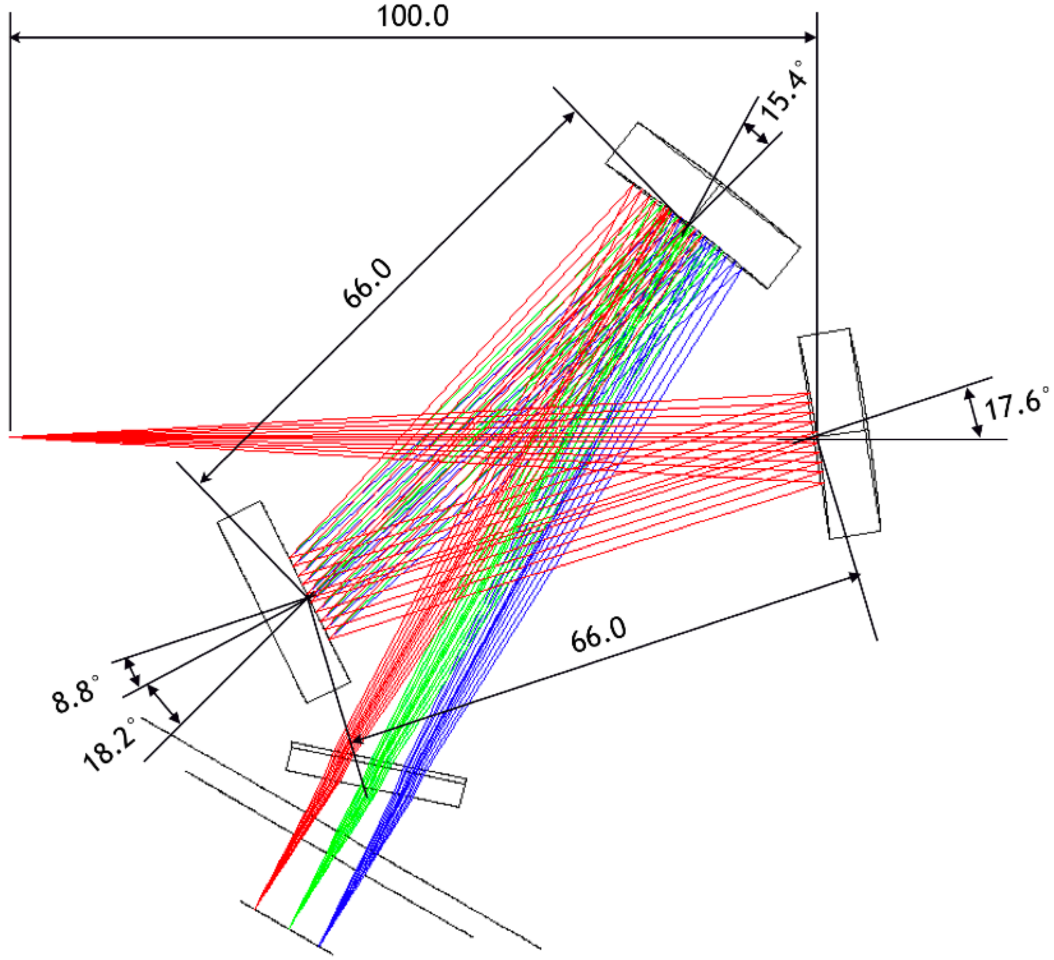
Wavelength	Quantum efficiency
7500 A	18 %
6500 A	15 %
5500 A	33 %
4500 A	19 %
4000 A	14 %
3800 A	9 %
3500 A	2 %

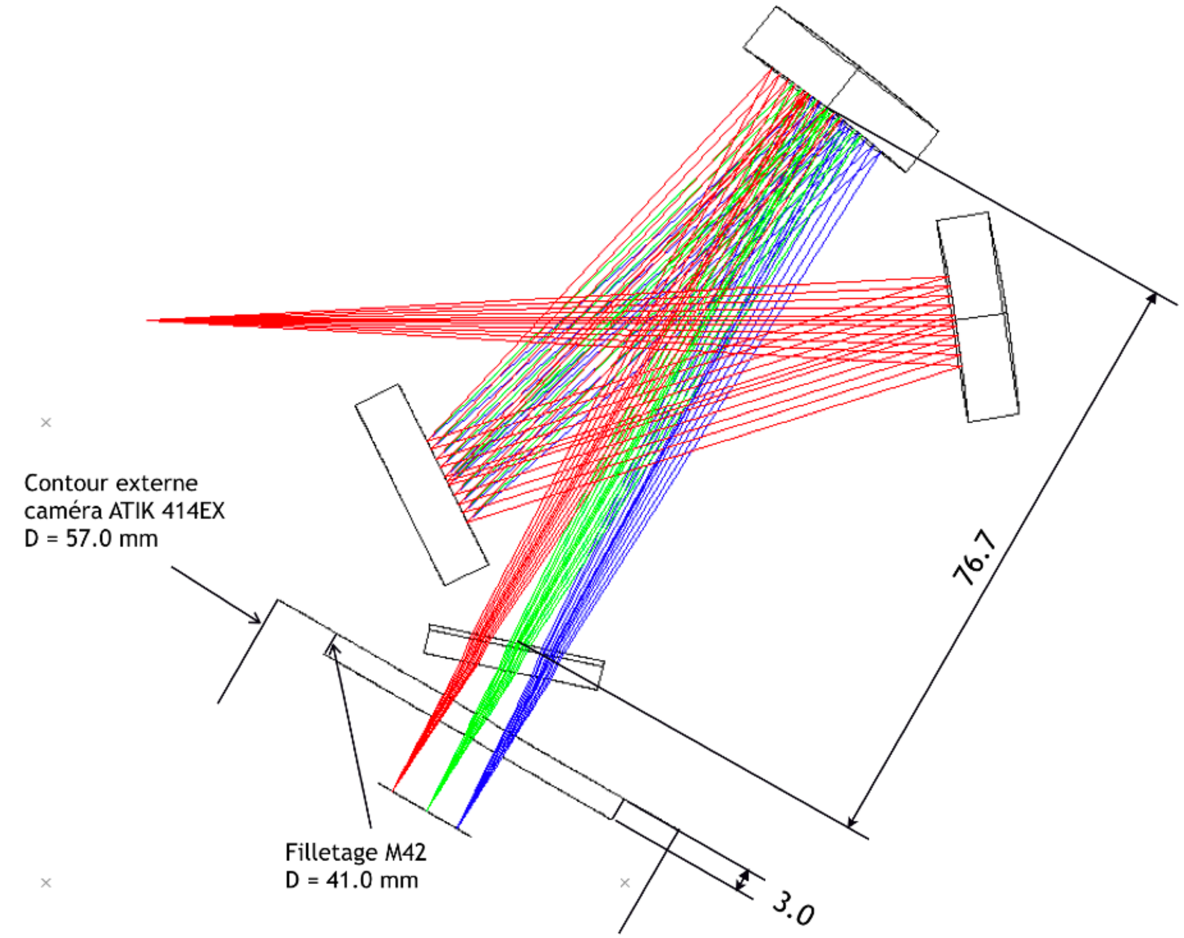
The Ultraviolet fundamental limit : the terrestrial atmosphere

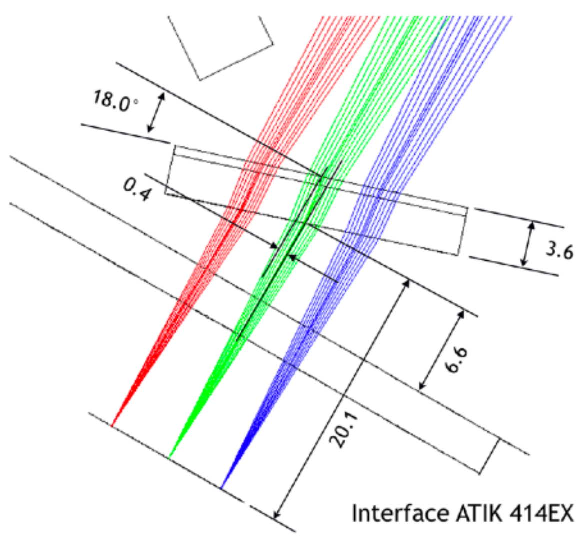


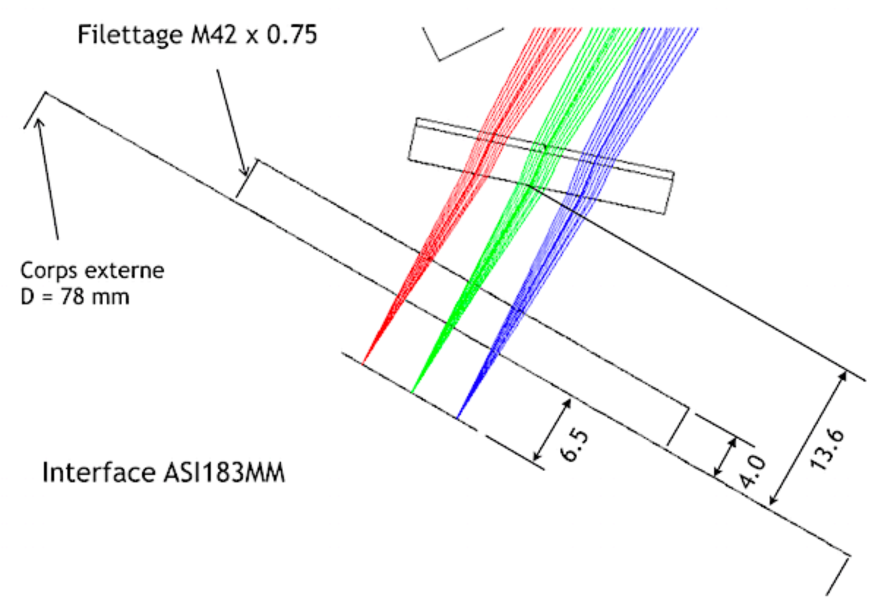
UVEX(3) details

Important: all UVEX(3) project plans will be public (also STL files for 3D manufacturing)

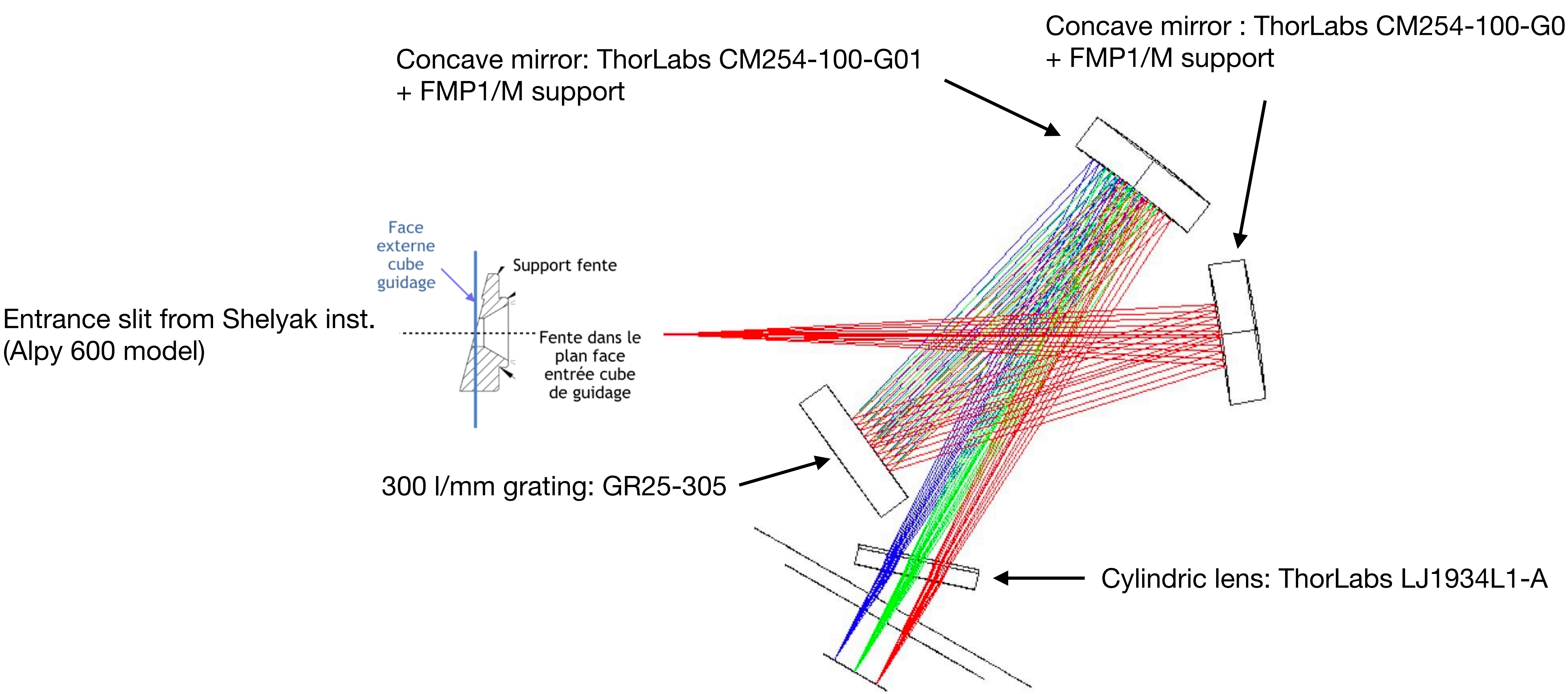






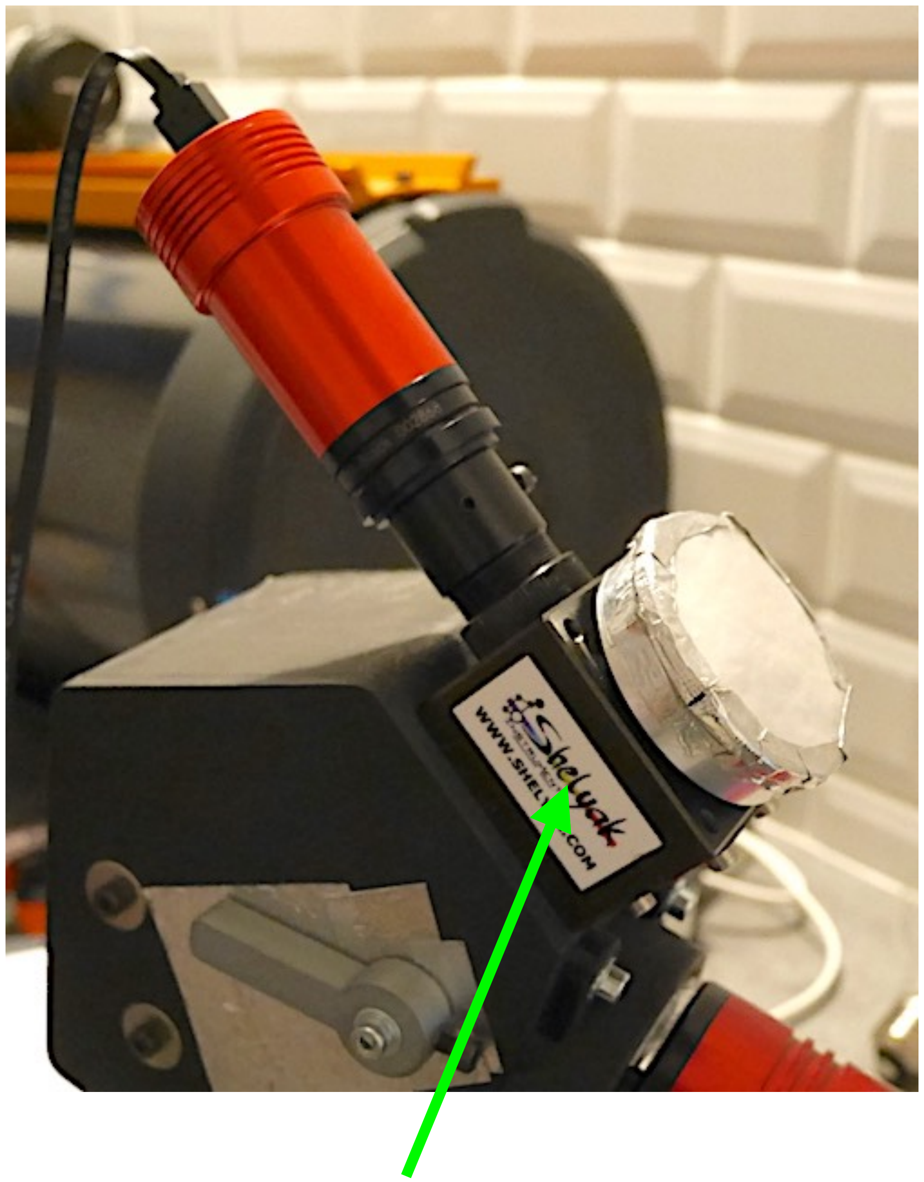


All optical components are available from THORLABS catalog



Design compatible with Shelyak guidance module (Alpy 600 spectrograph)

A companion for faint object spectrography…



Shelyak Inst. guidance « cube » (Alpy 600).

Shelyak guidance module (PF0036)

Amovible slit (SE0145)

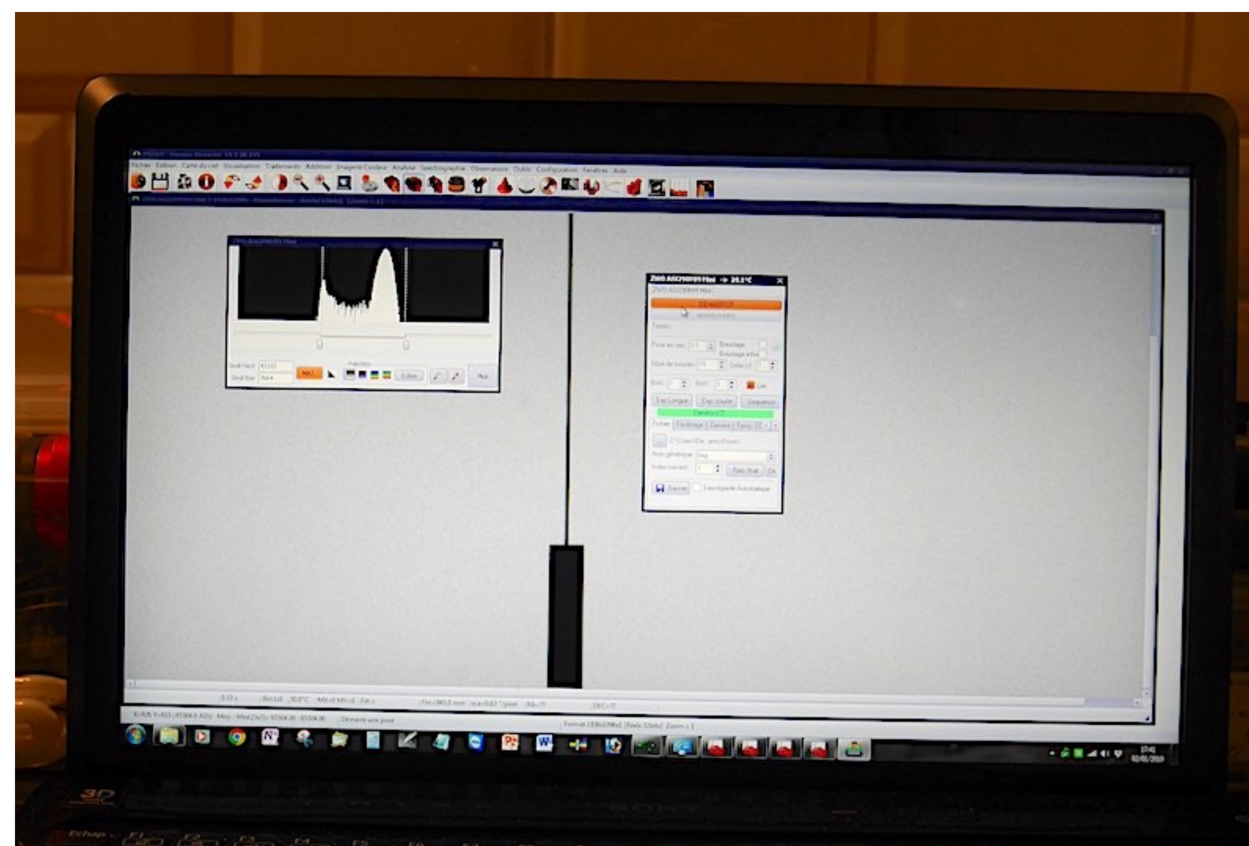
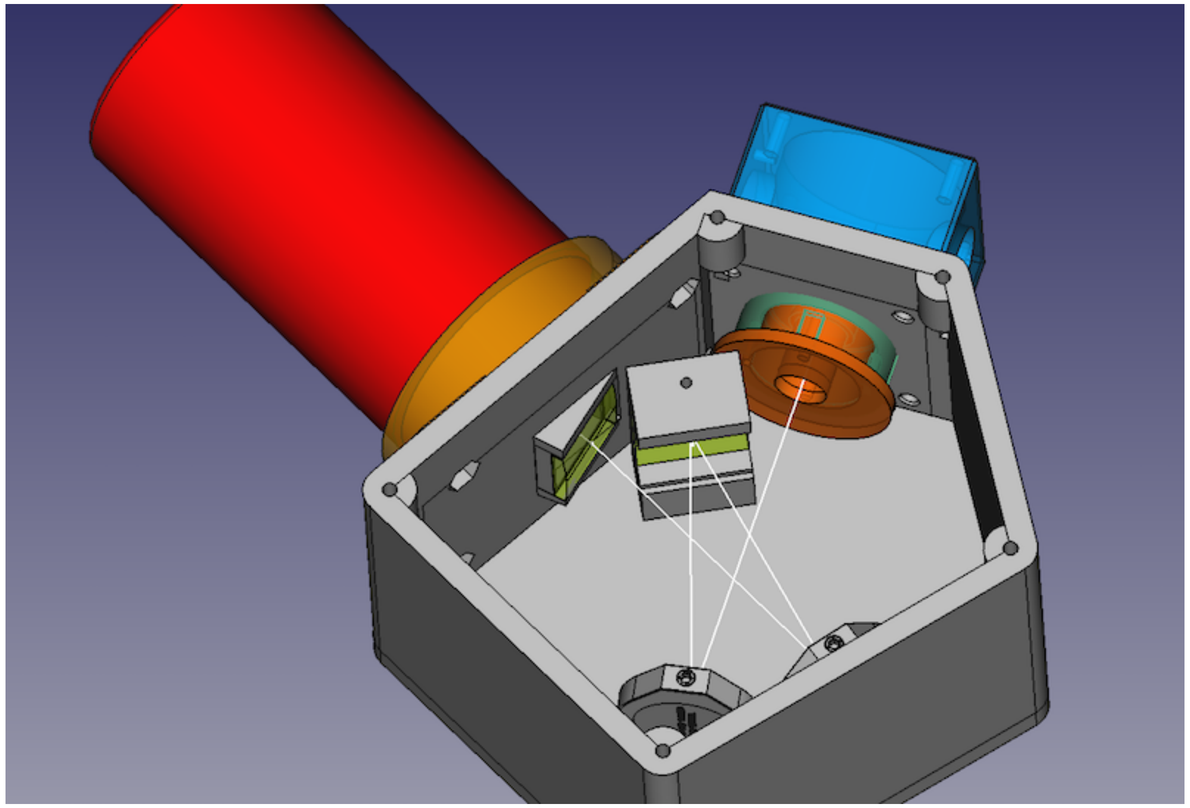
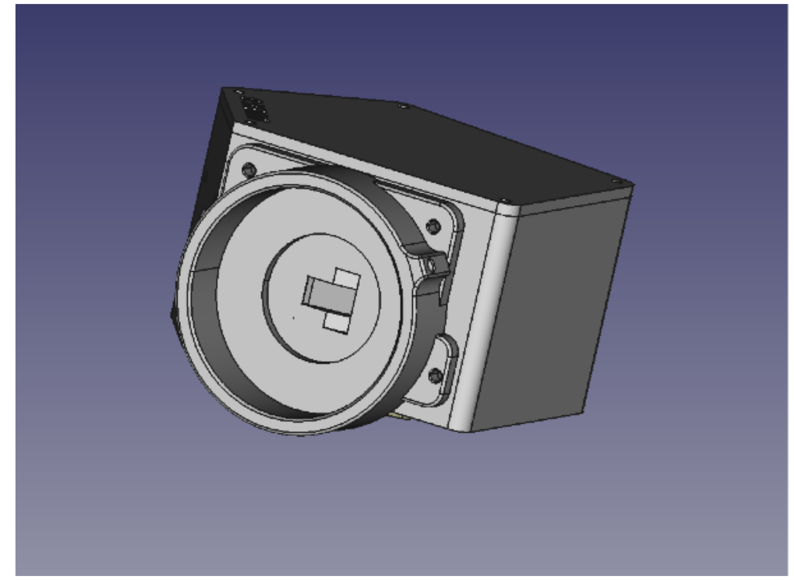


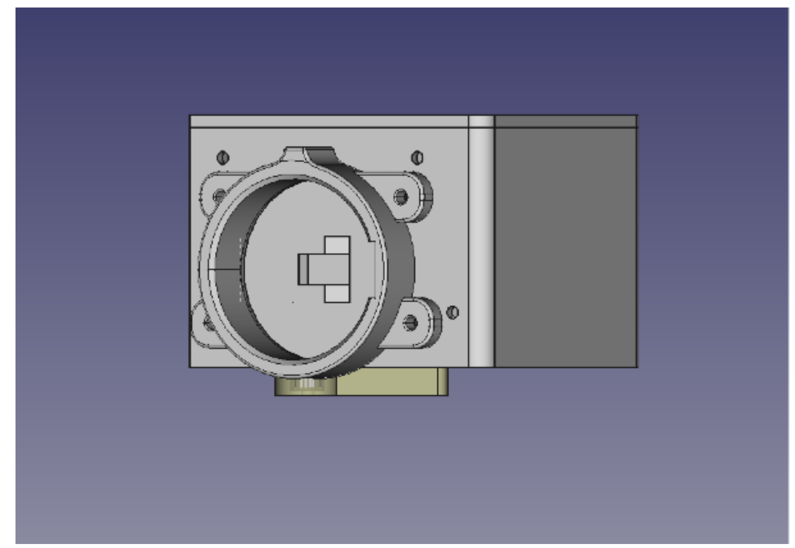
Image of a Shelyak photometric slit given by a mini camera ASI290MM (ZWO).

Some CAO views

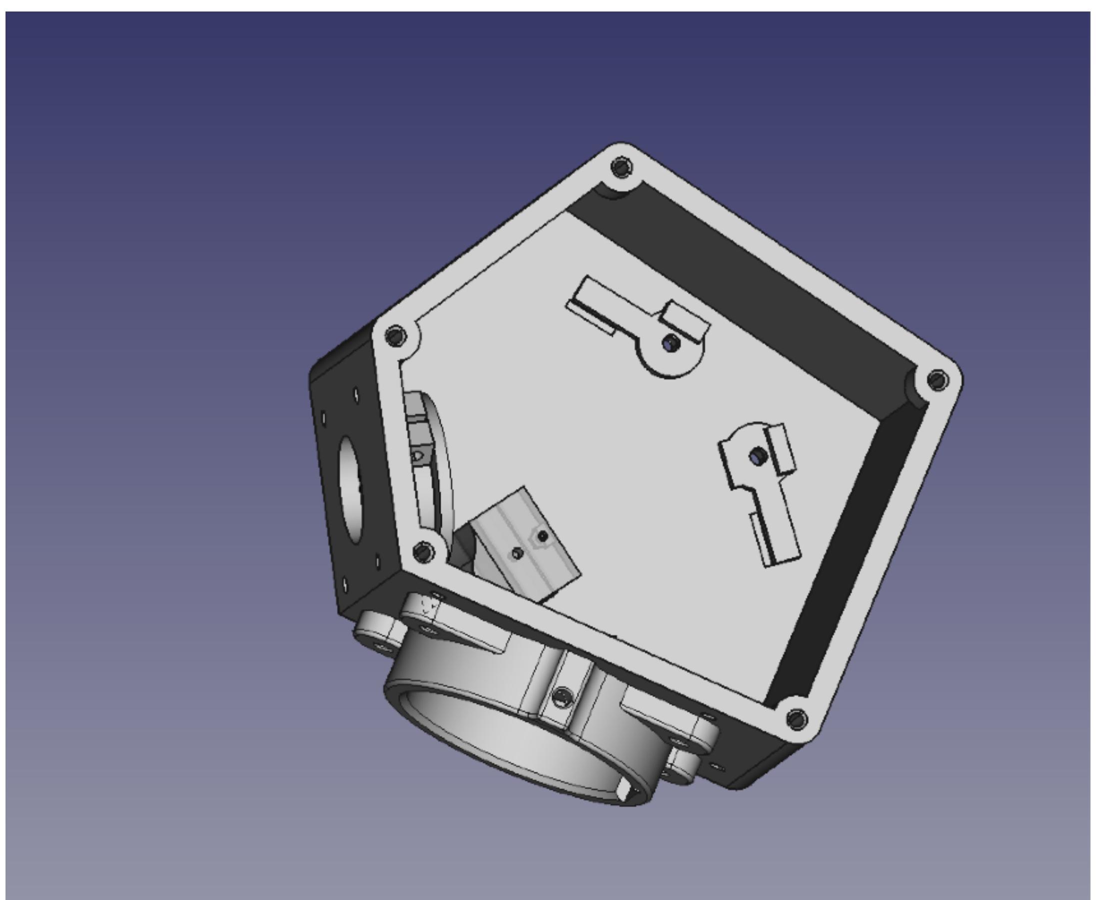


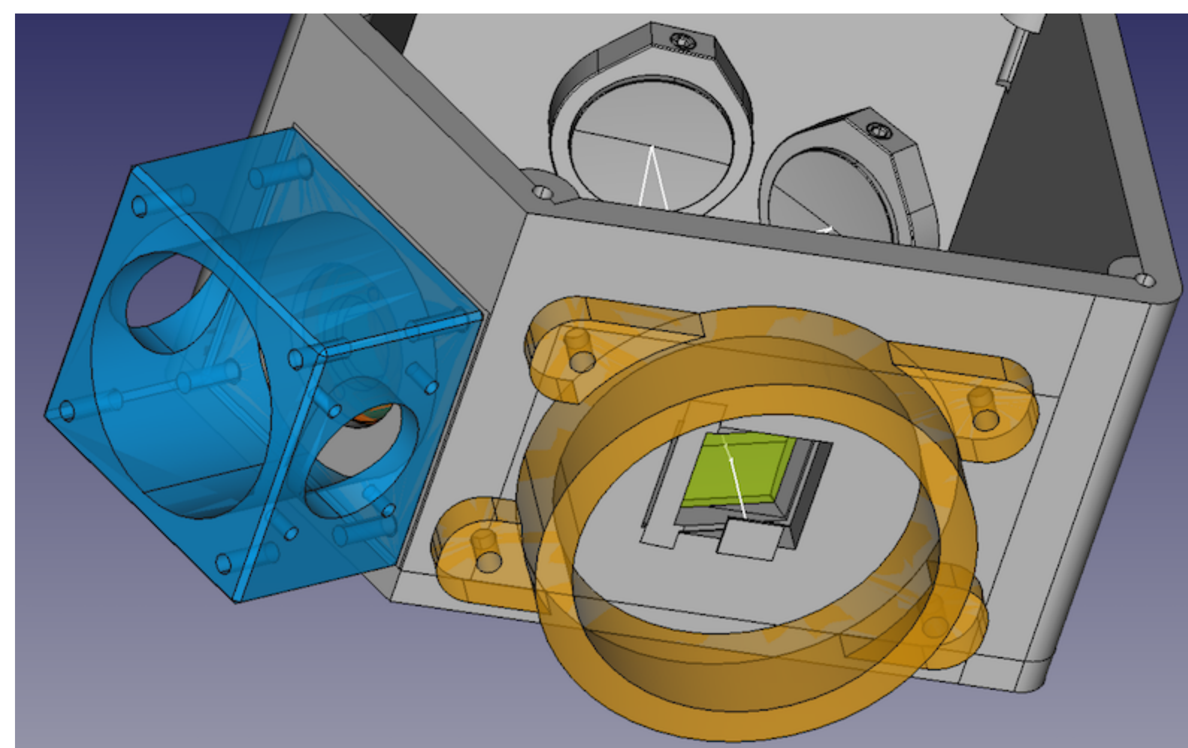


Amovible ZWO cameras interface.

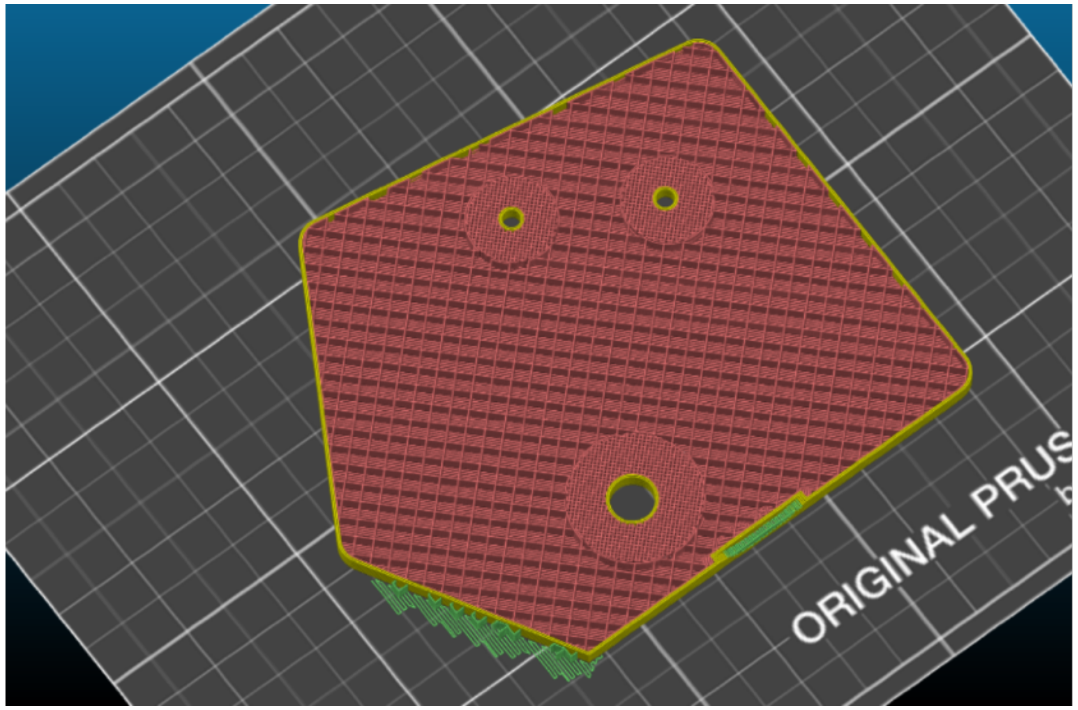


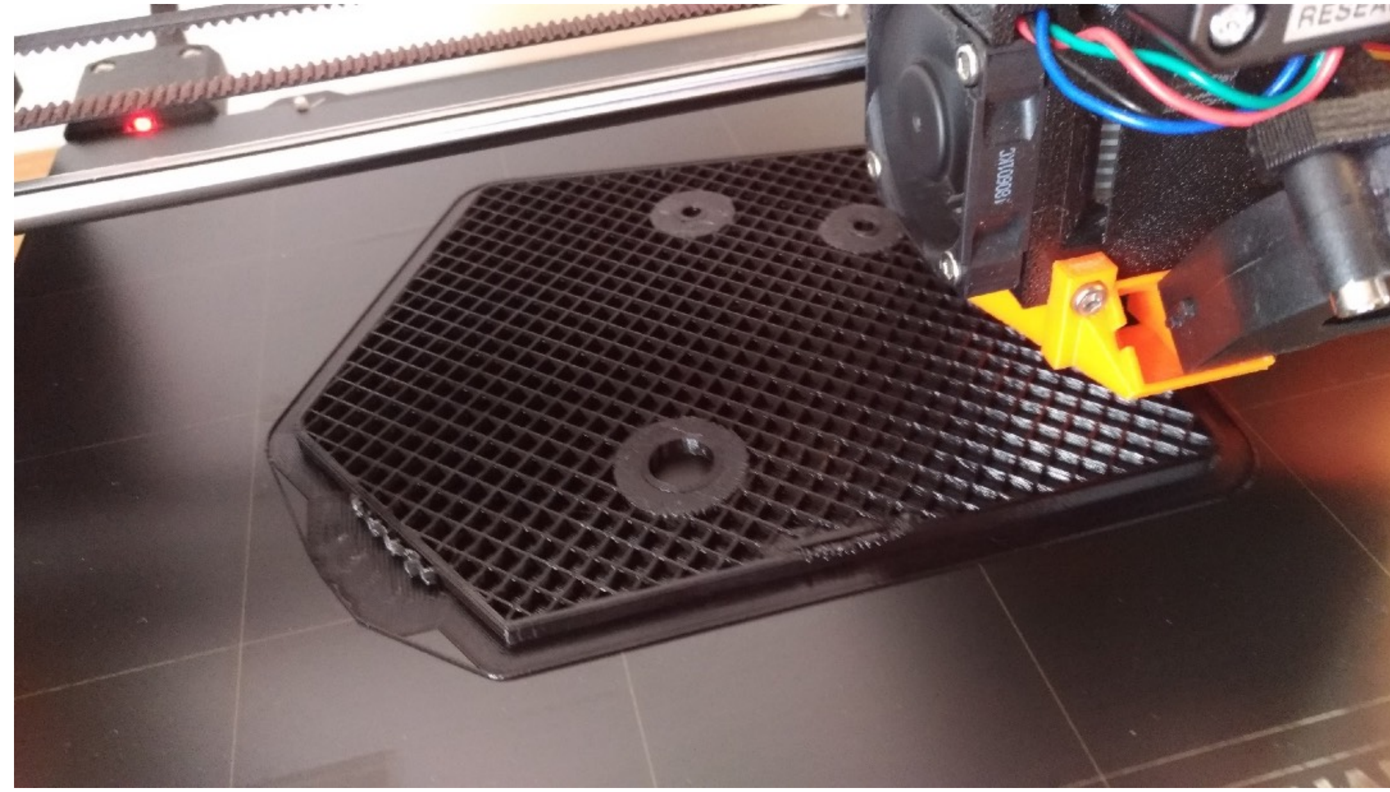
Amovible ATIK cameras interface.





Fabrication



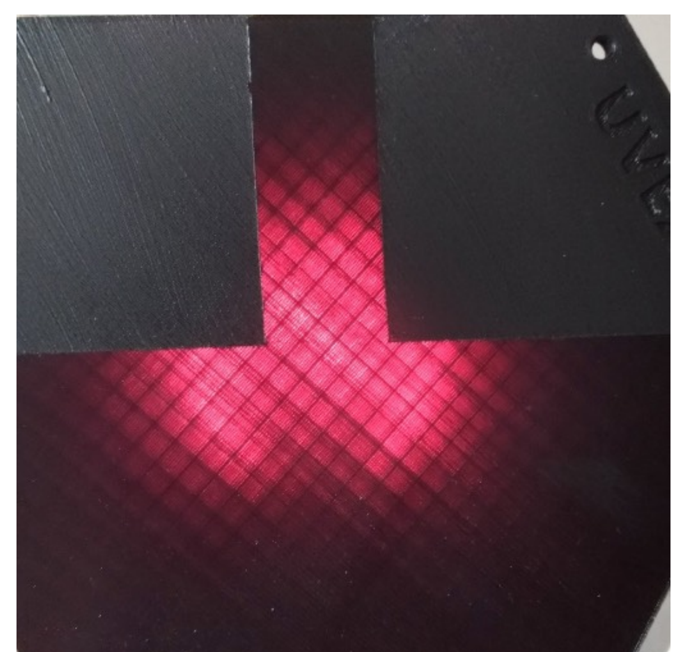


For the UVEX(3) we use a PRUSA MK3 I3 printer

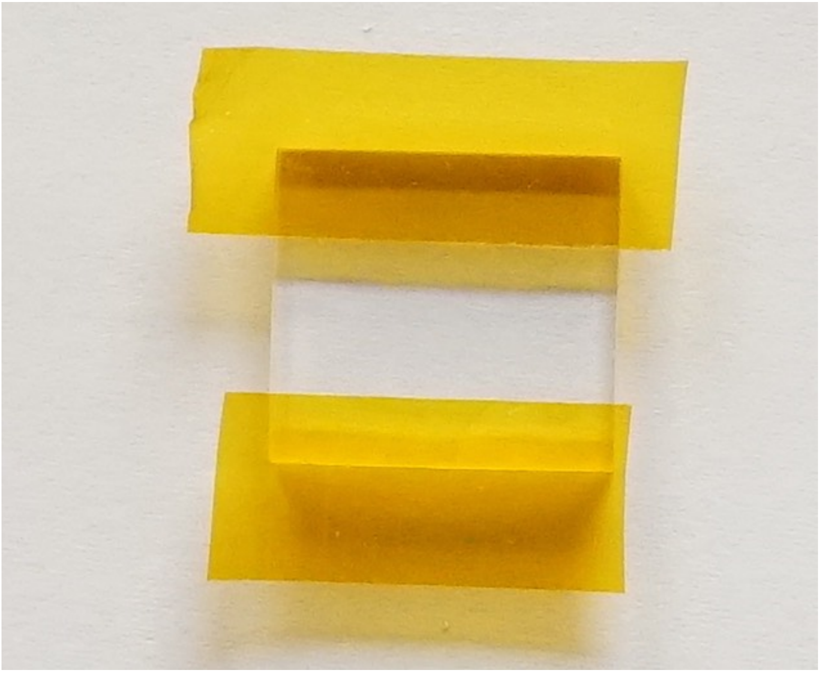
Material selection

The PLA is good option (but sensitive to temperature)

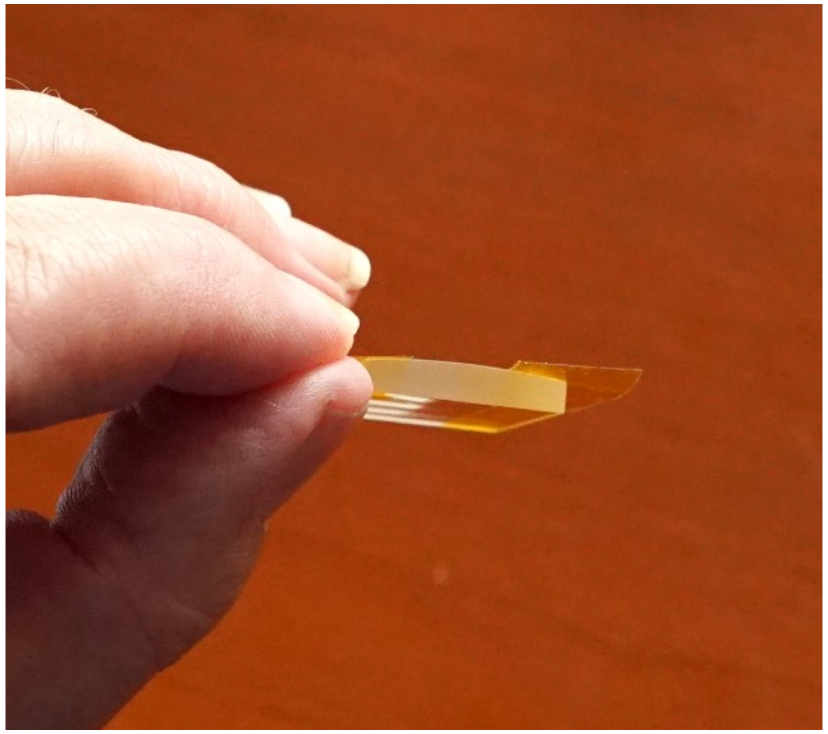
The PETG is more robust, but transparent to deep-red and infrared radiations is you do not select an opaque version!

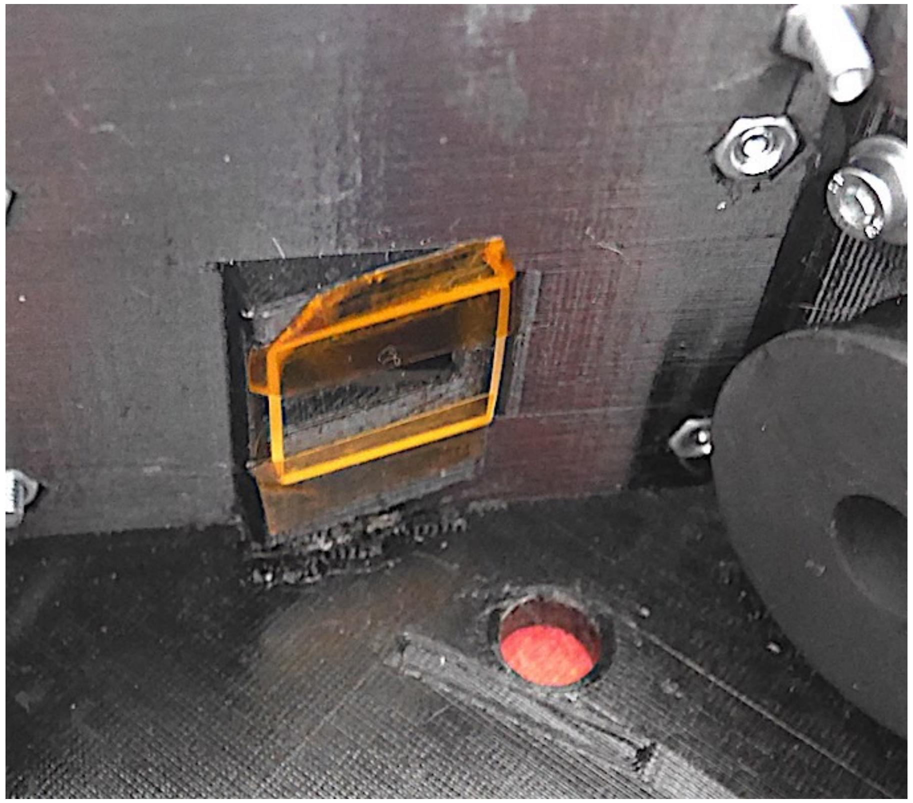


Integration : Cylindric lens



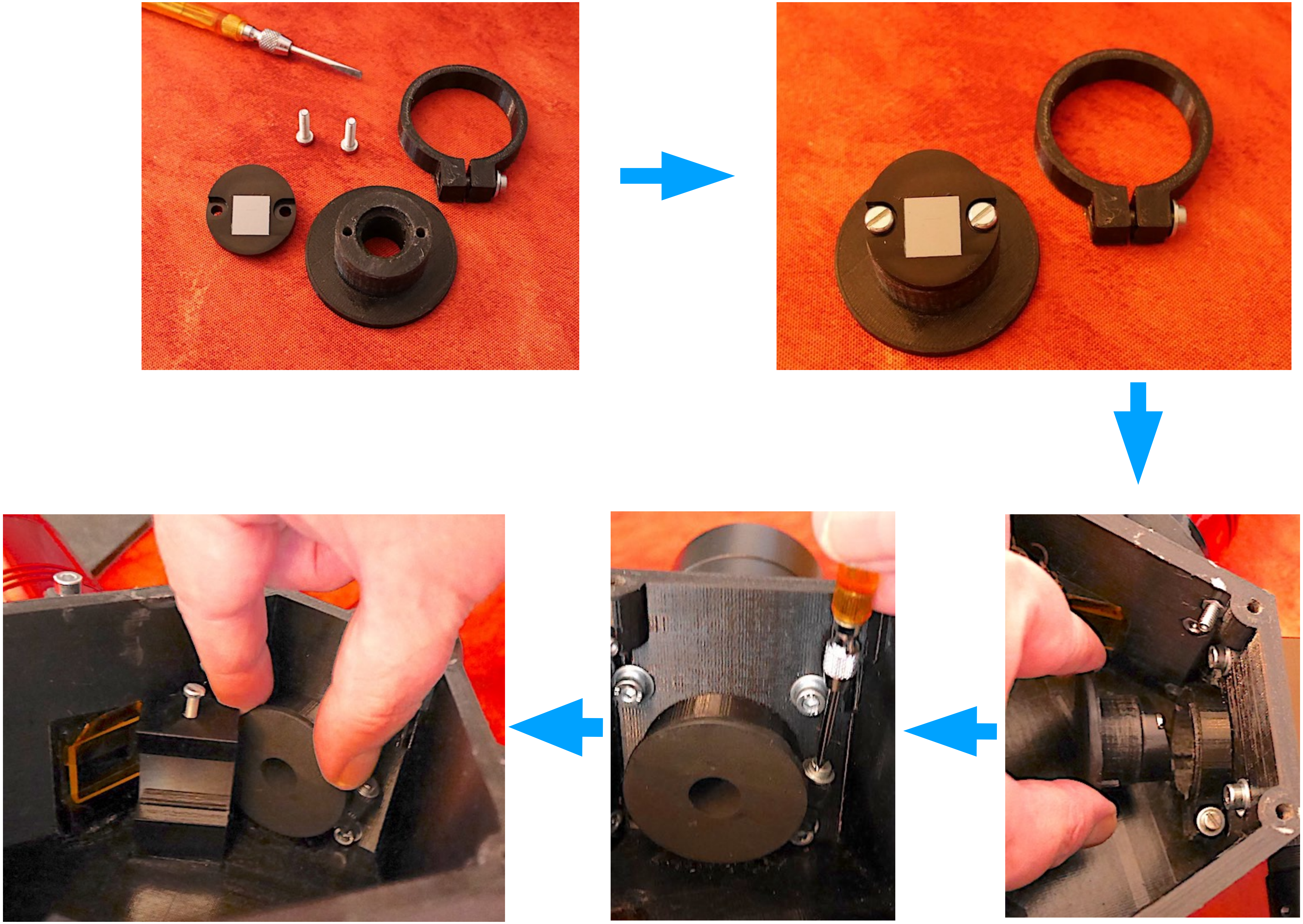
Kapton adhesive film



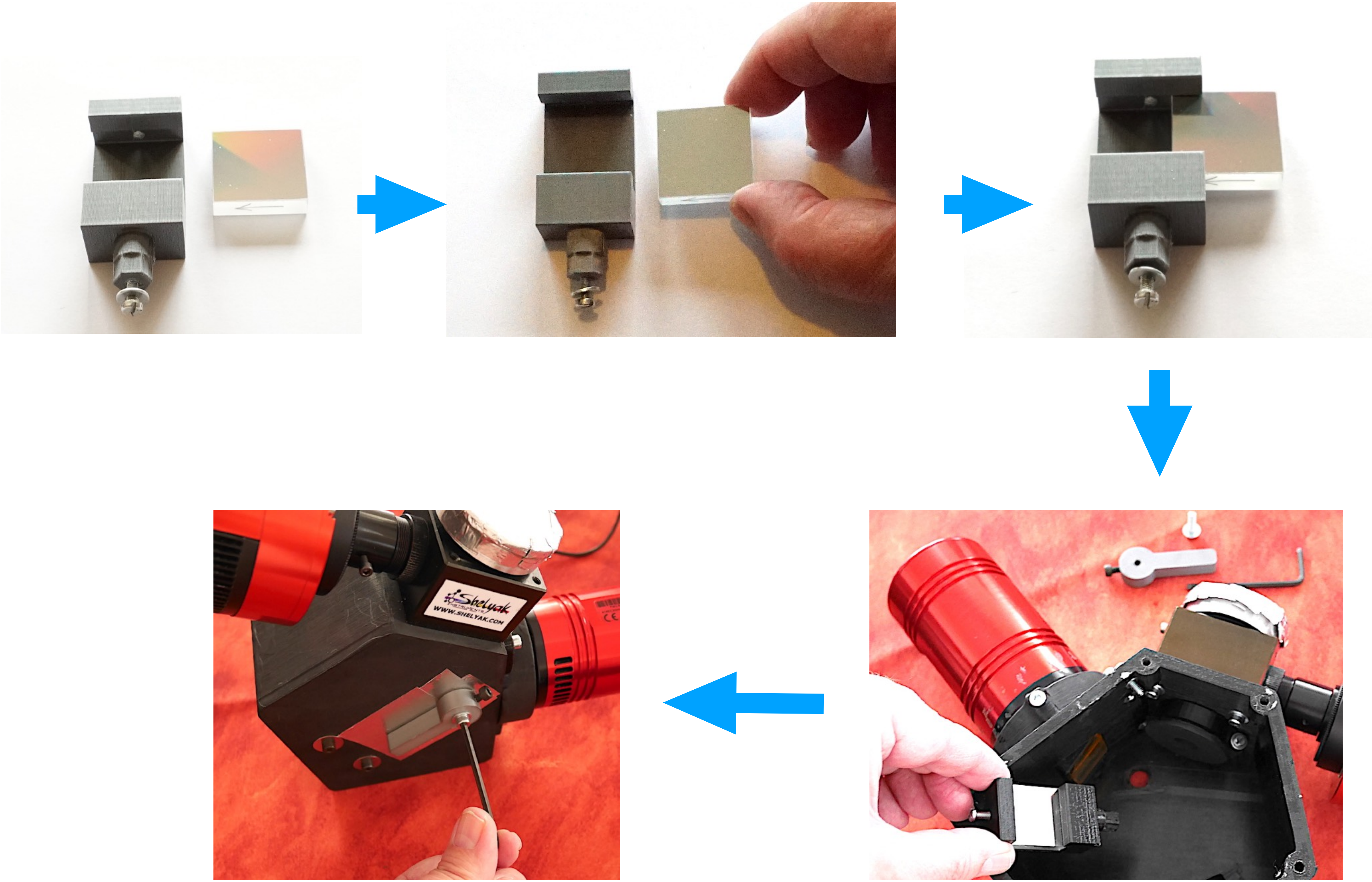


Integration : Mirrors

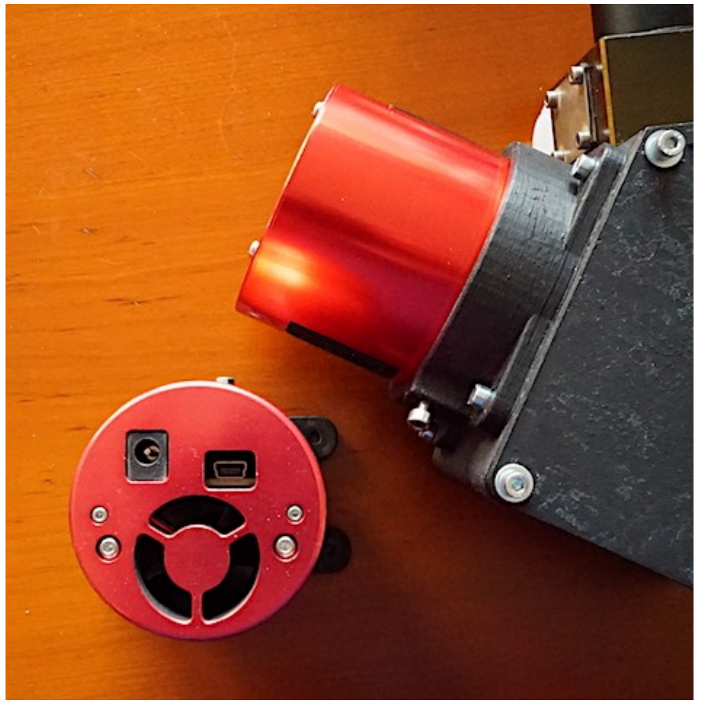
Integration : Slit



Grating fixation



The final touch



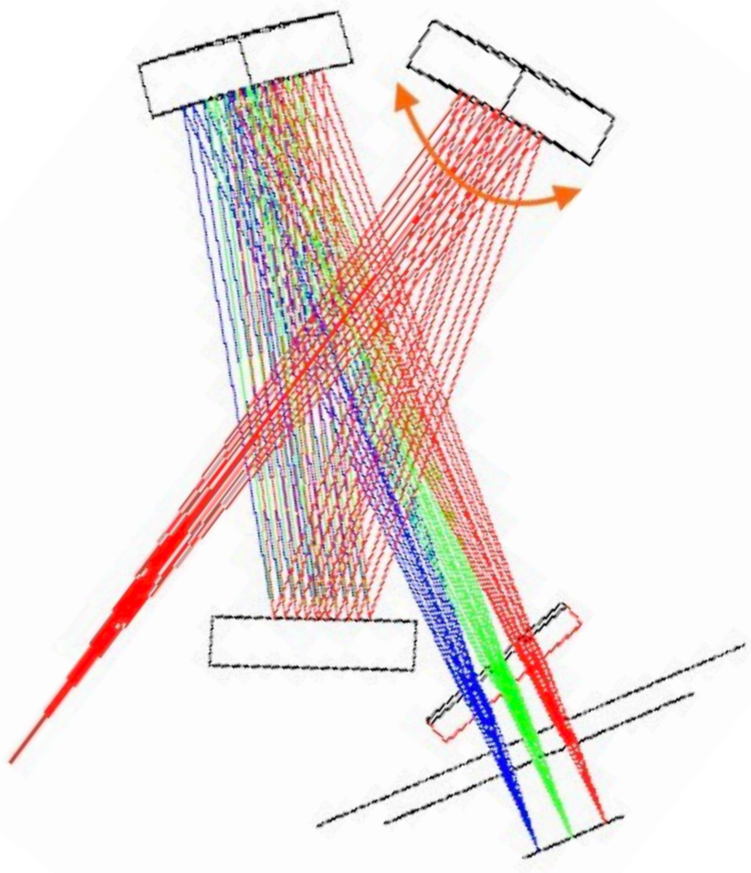
Attach the camera

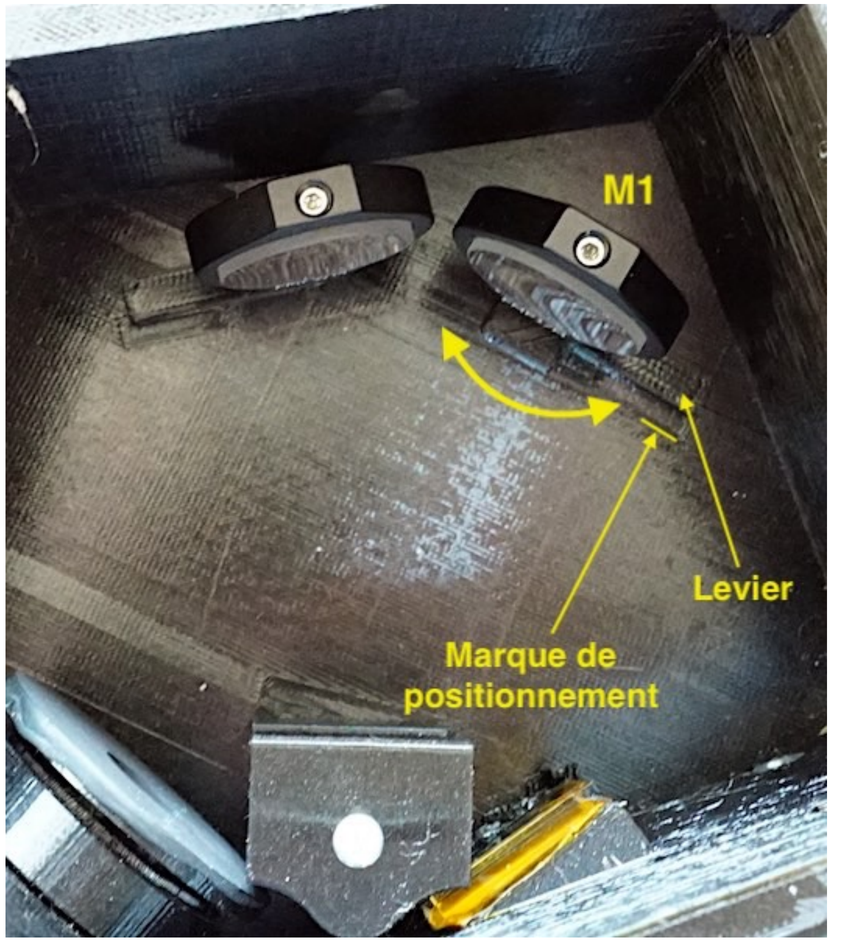
Choose the spectral domain

and observe…

Hum… it's no so easy !

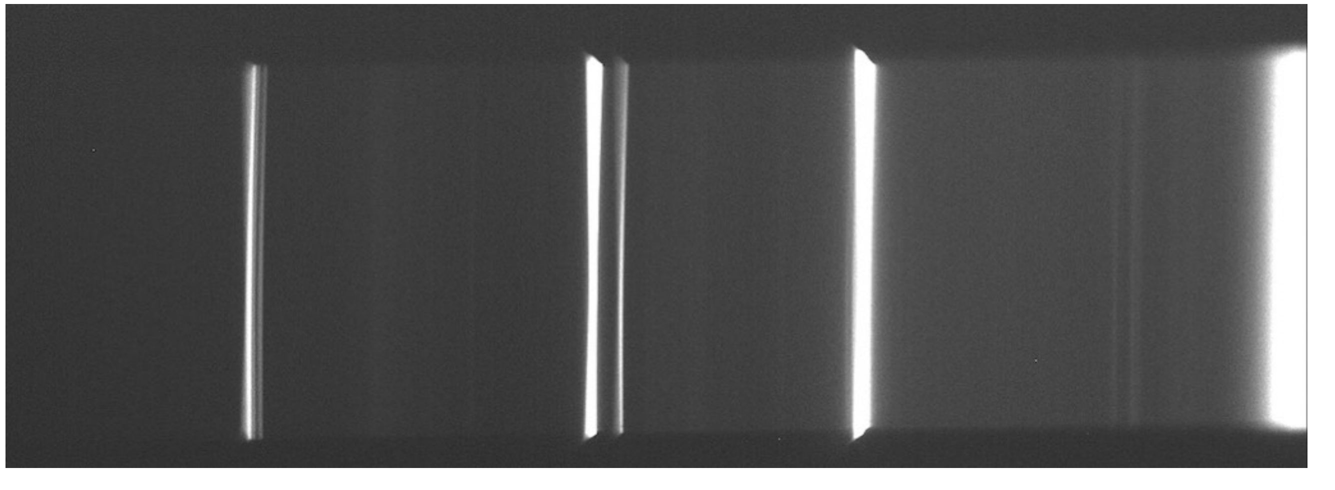
Some adjustments are needed to get a fine spectrum…





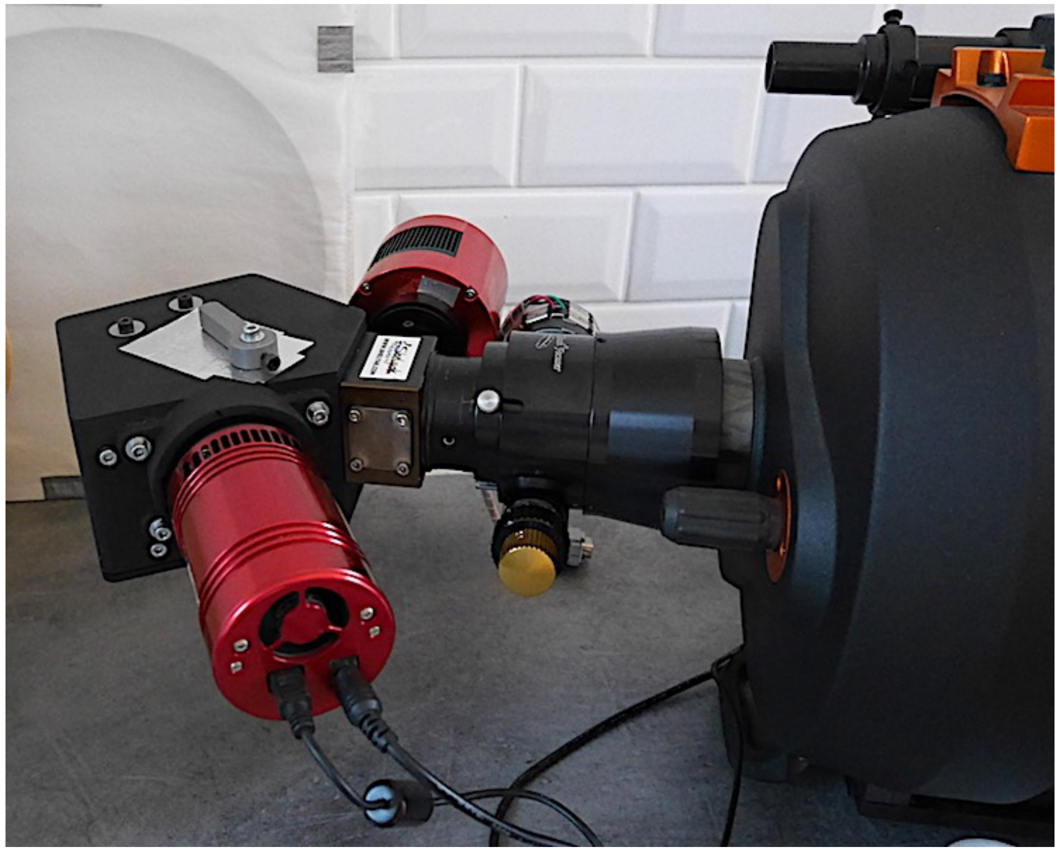
The main difficulty is to find the correct M1 and M2 orientation. The tolerance is near +/-0,1°

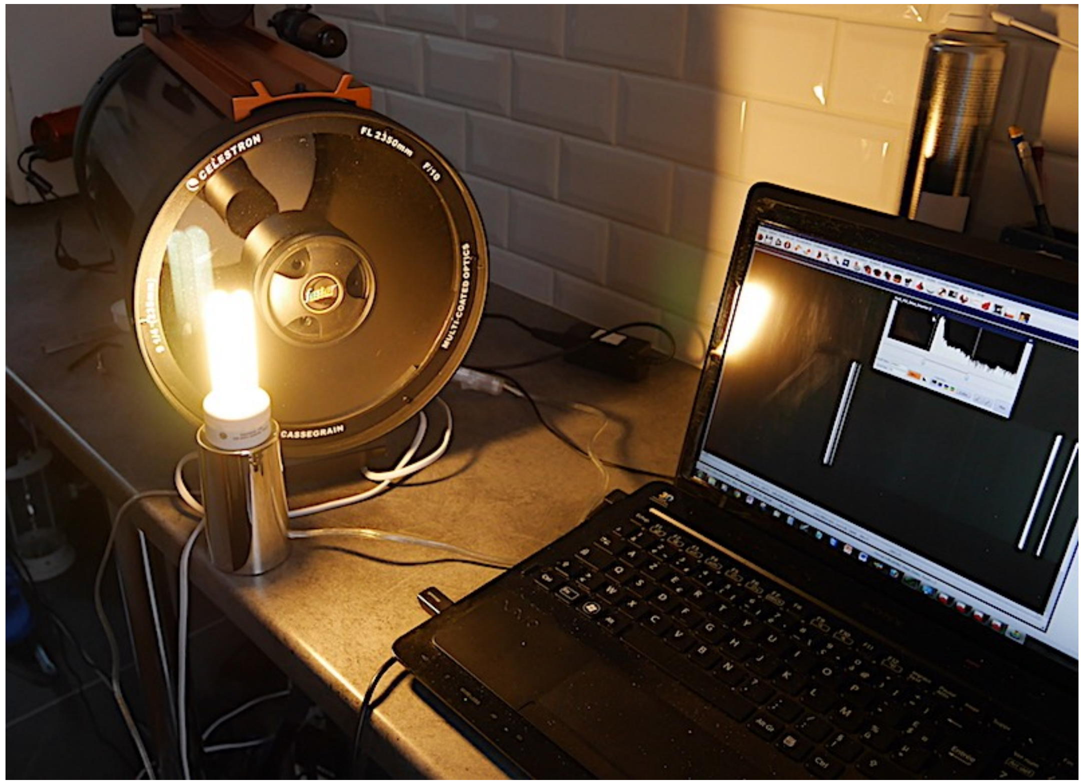
The criterion success is based on the observation of the appearance of the emission lines. An iterative process…



Highly recommended: « laboratory » bench test of the spectrograph

UVEX during setting at the focus of a C9.25 telescope (on a table)

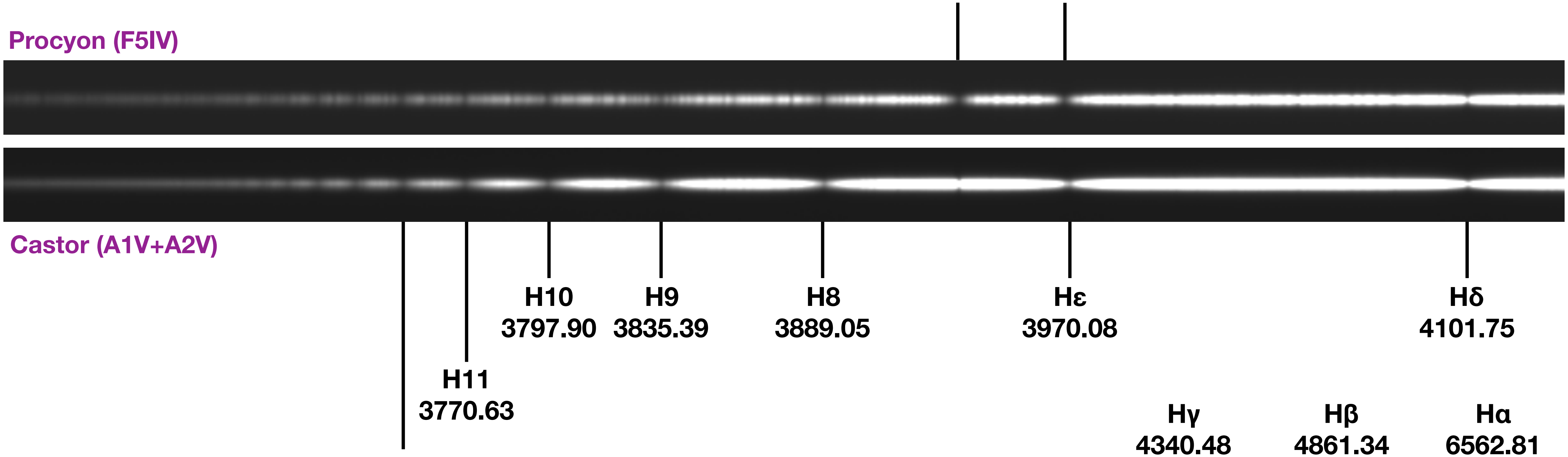




Ultraviolet spectral calibration : Use of stellar lines

…for evaluate spectral dispersion equation (2nd order polynomial function)

UVEX(3) 1200 lines/mm, 23 microns slit, Atik414EX camera



H13
3734.34

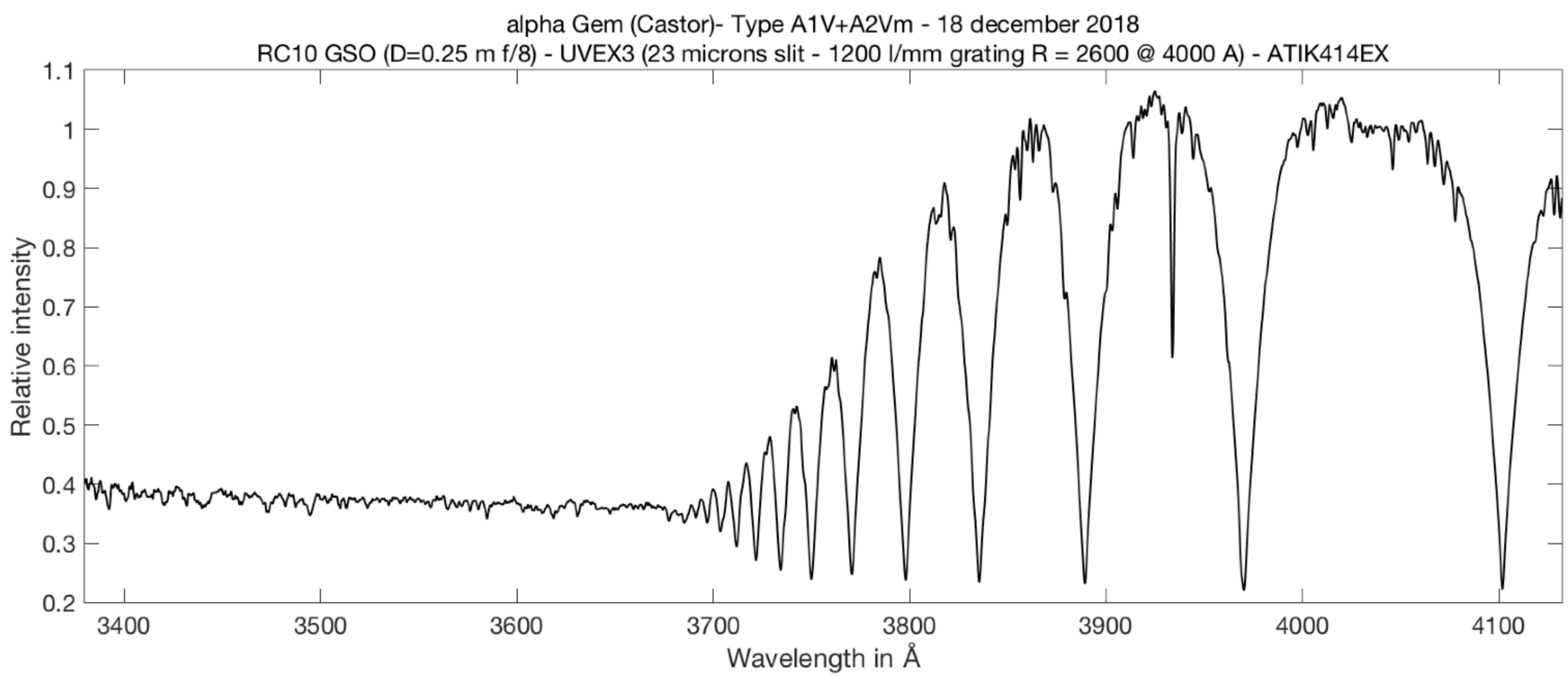
H14
3721.94

H15
3711.97

H16
3703.86

H17
3697.15

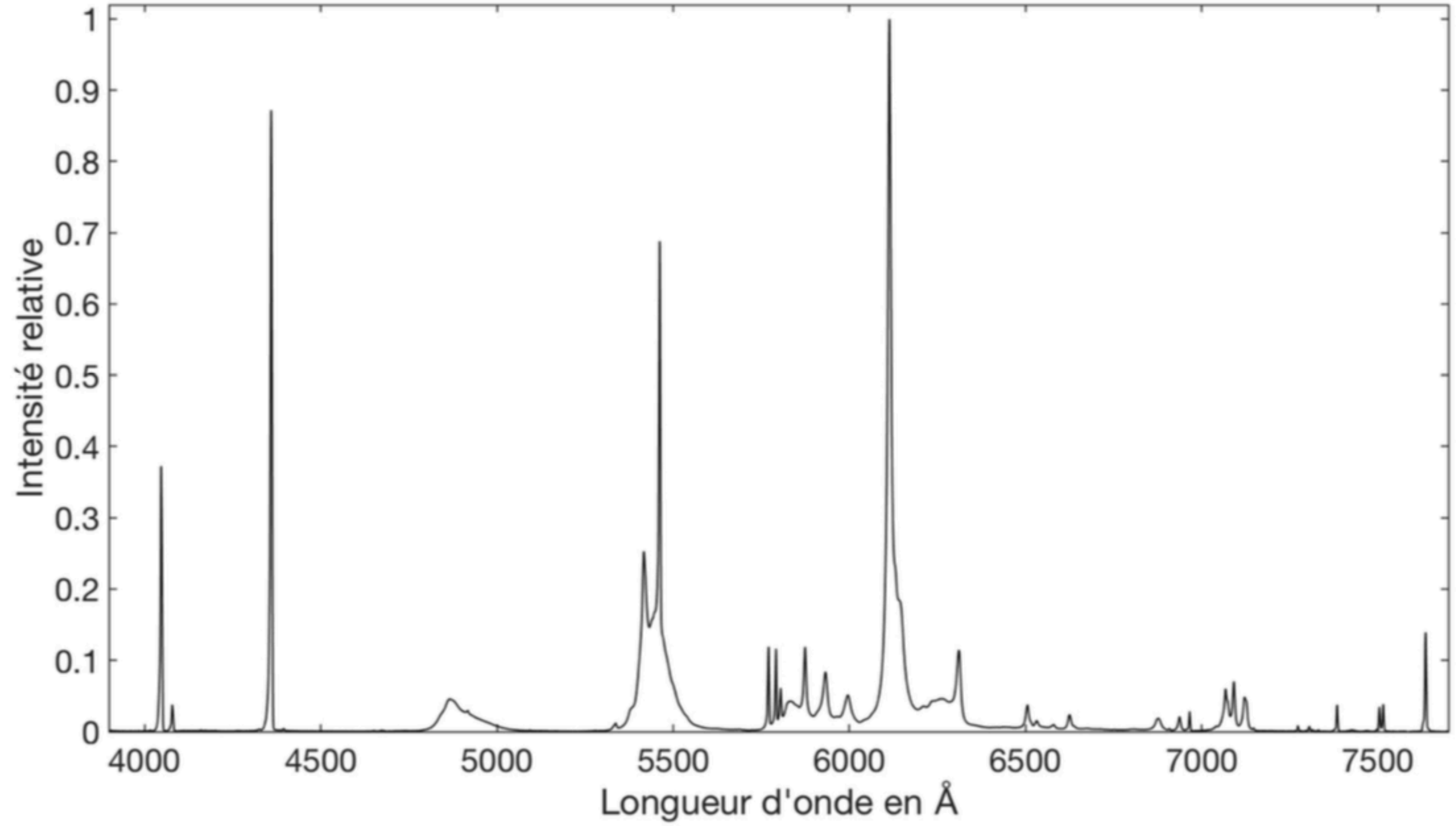
H18
3691.56



Emission lines lamp (easy to find)

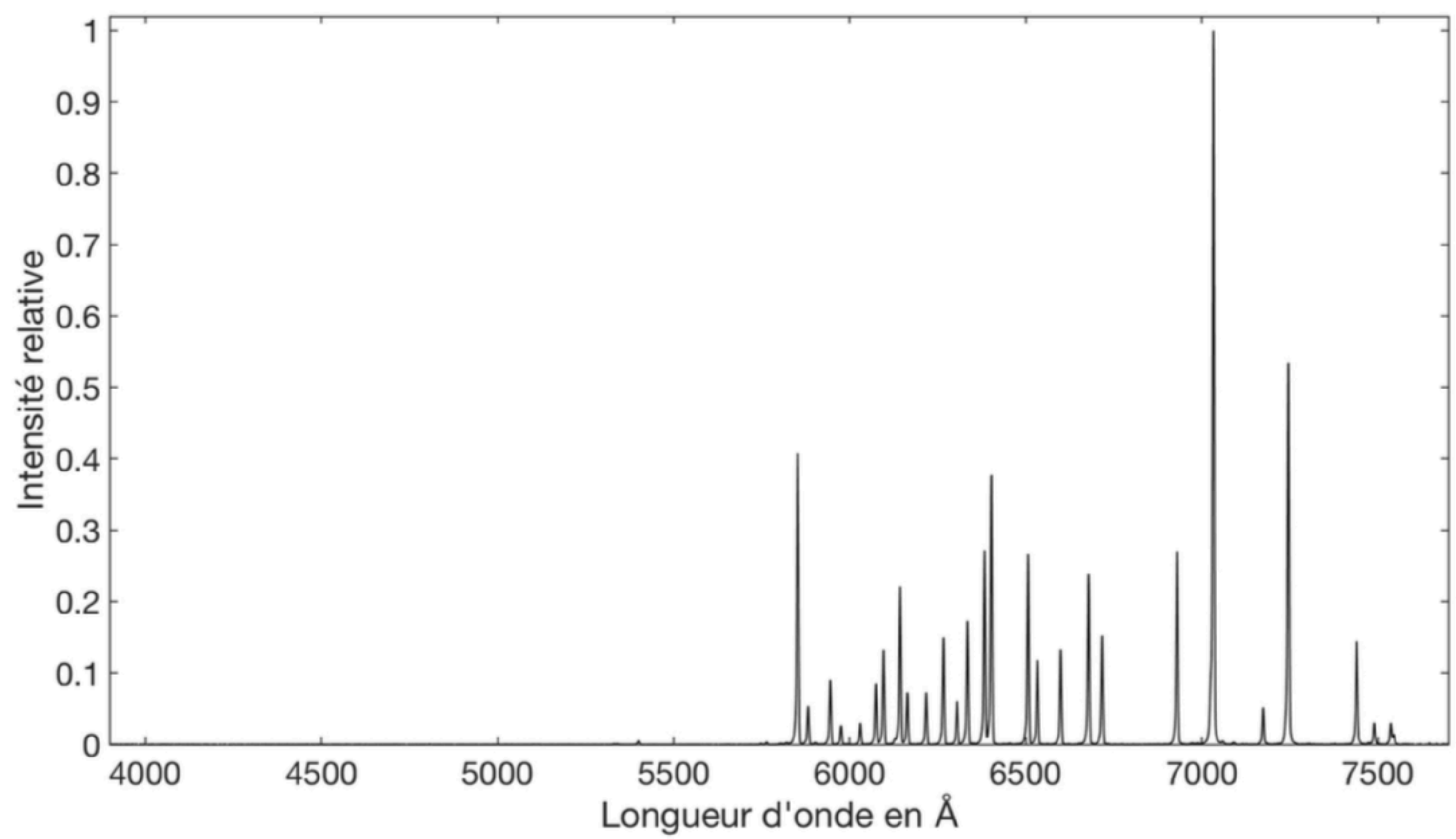
Fine for calibrate UVEX 300 lines/mm spectra (Hg and Ar lines)

Fluo-compact



Fine for calibrate red spectra at all resolution power (neon lines)

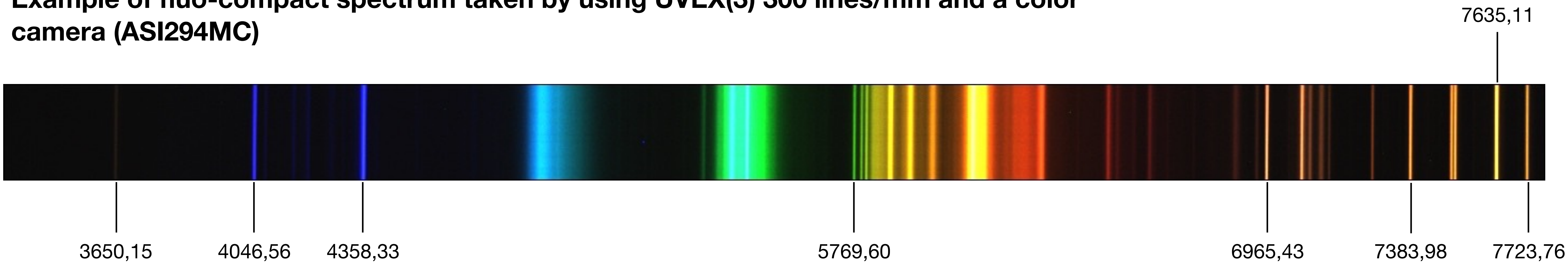
Neon



Use of an emission lines lamp (domestic fluo-compact, i.e. Hg + Ar lines)

A manual method, but effective… the calibration lamp at the front telescope aperture

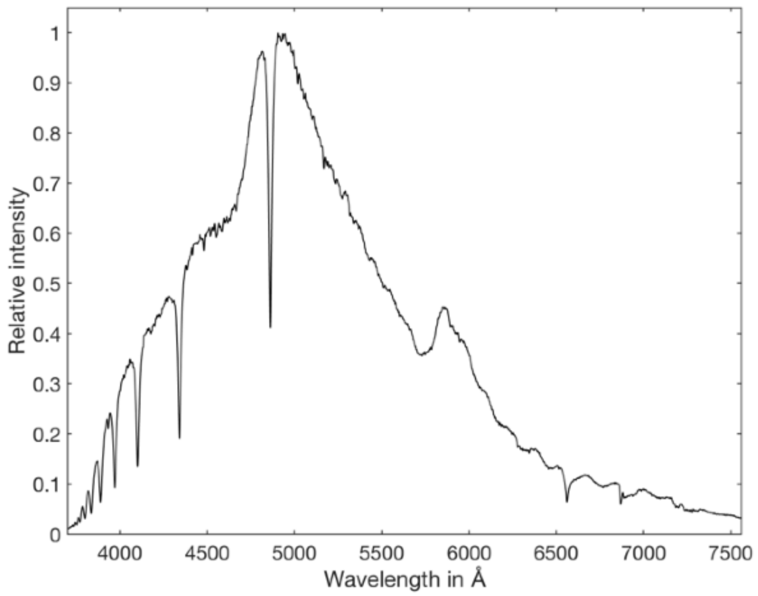
Example of fluo-compact spectrum taken by using UVEX(3) 300 lines/mm and a color camera (ASI294MC)



Use a continuum lamp for responsivity evaluation

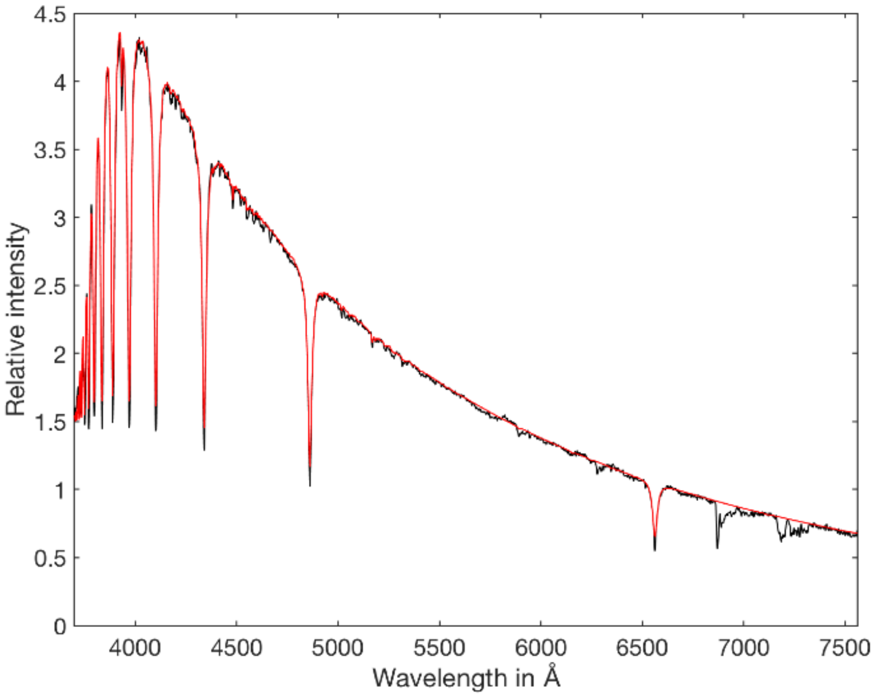
A manual method… halogen lamp at the front telescope aperture

Here a standard use of halogen 3000 K (120 W)



Before instrumental response rectification

(data from a ASI294MC color camera)



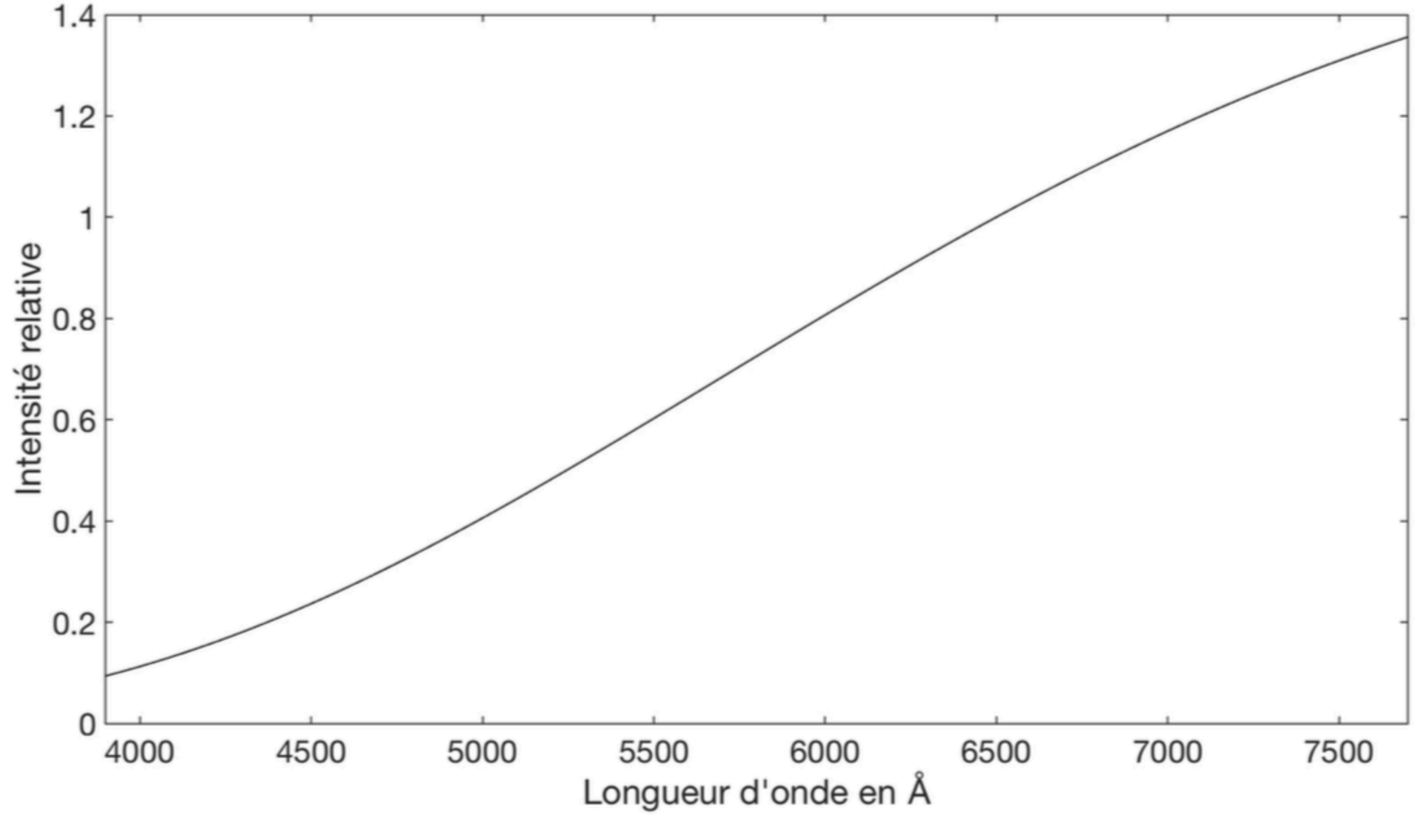
After instrumental response rectification

(A0V type star)

Find the instrumental responsivity - Selection of continnum sources (1/2)

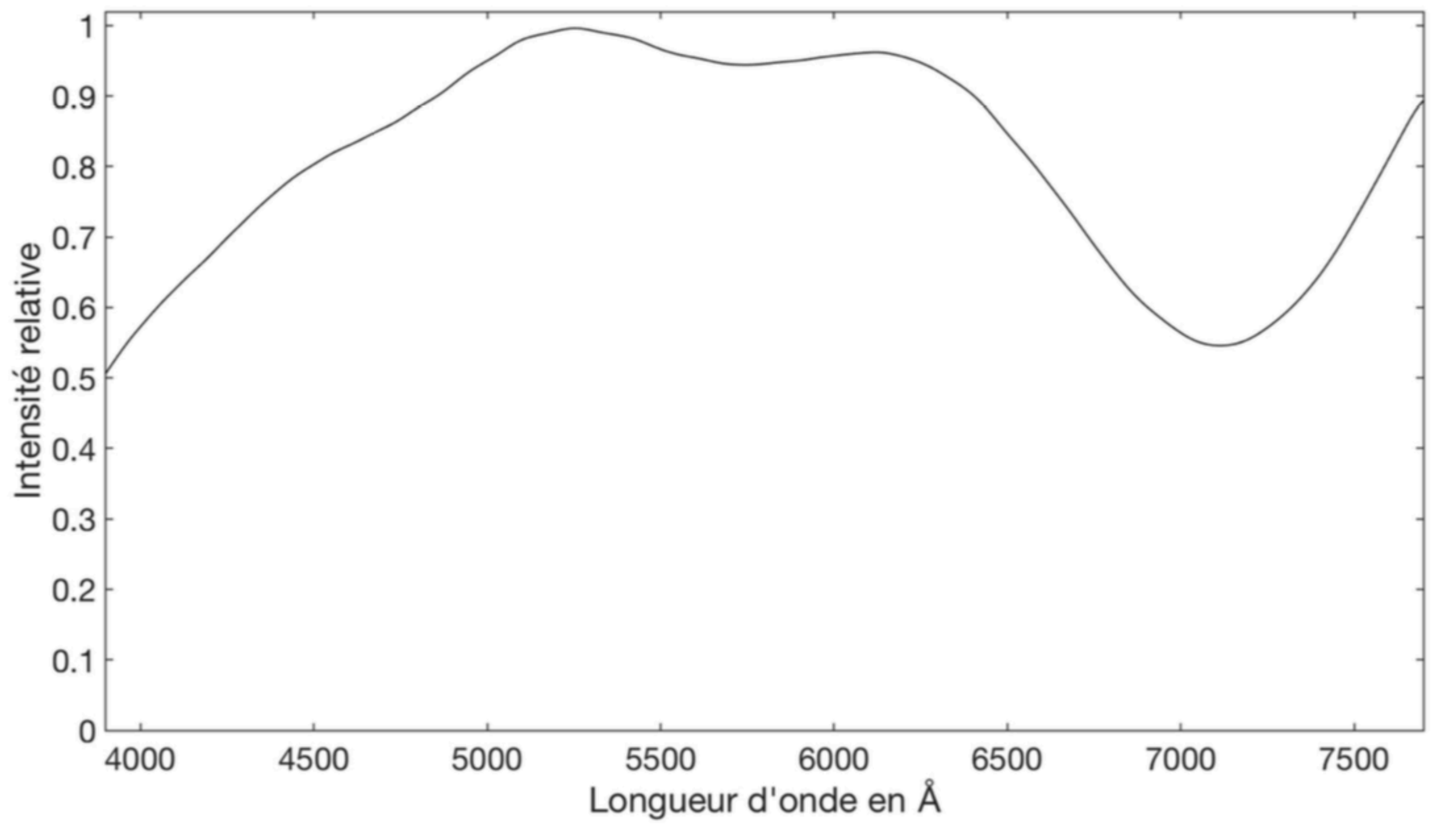
Good solution
Regular and well know (Planck)

3000 K halogen lamp



Good solution
White and intense UV flux
(StarLux model)

4700 K halogen lamp

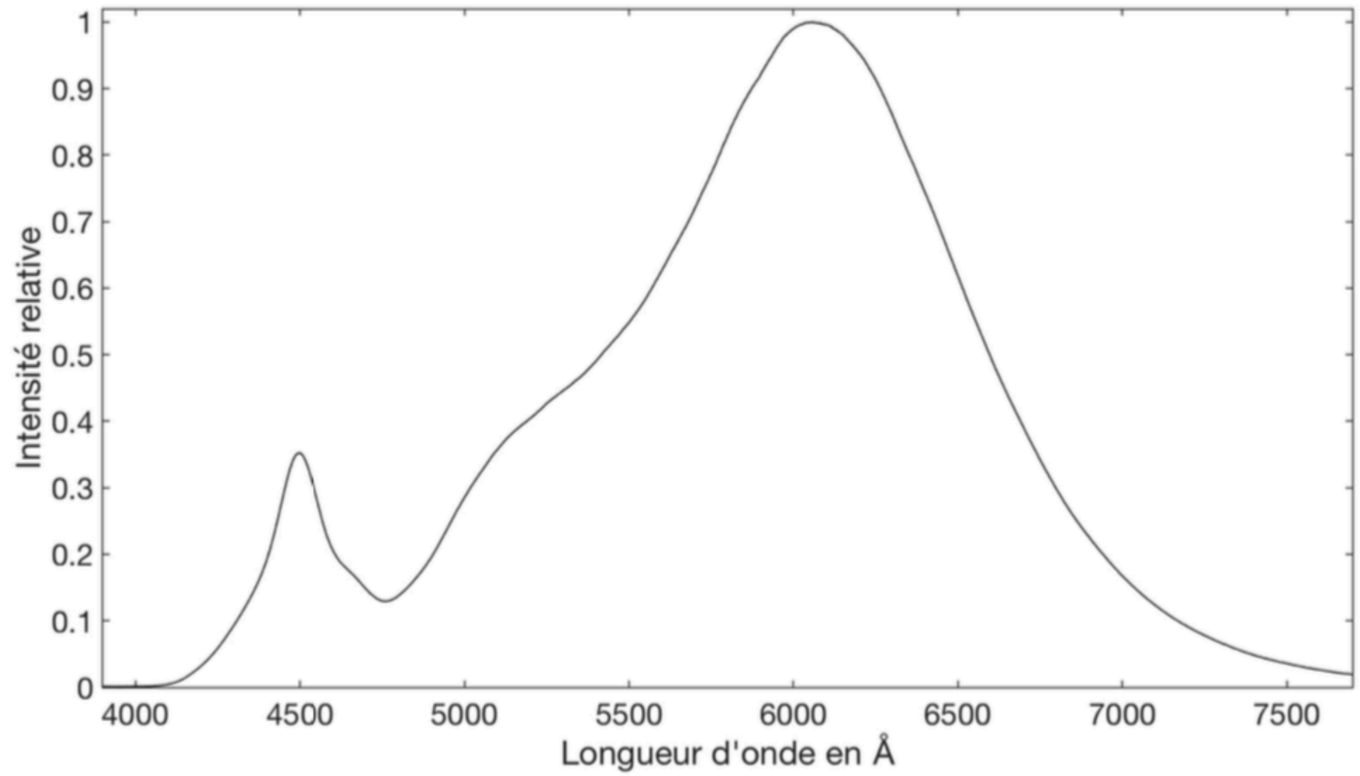


Find the instrumental responsivity - Selection of continnum sources (2/2)

Bad solution

Poor UV and instable

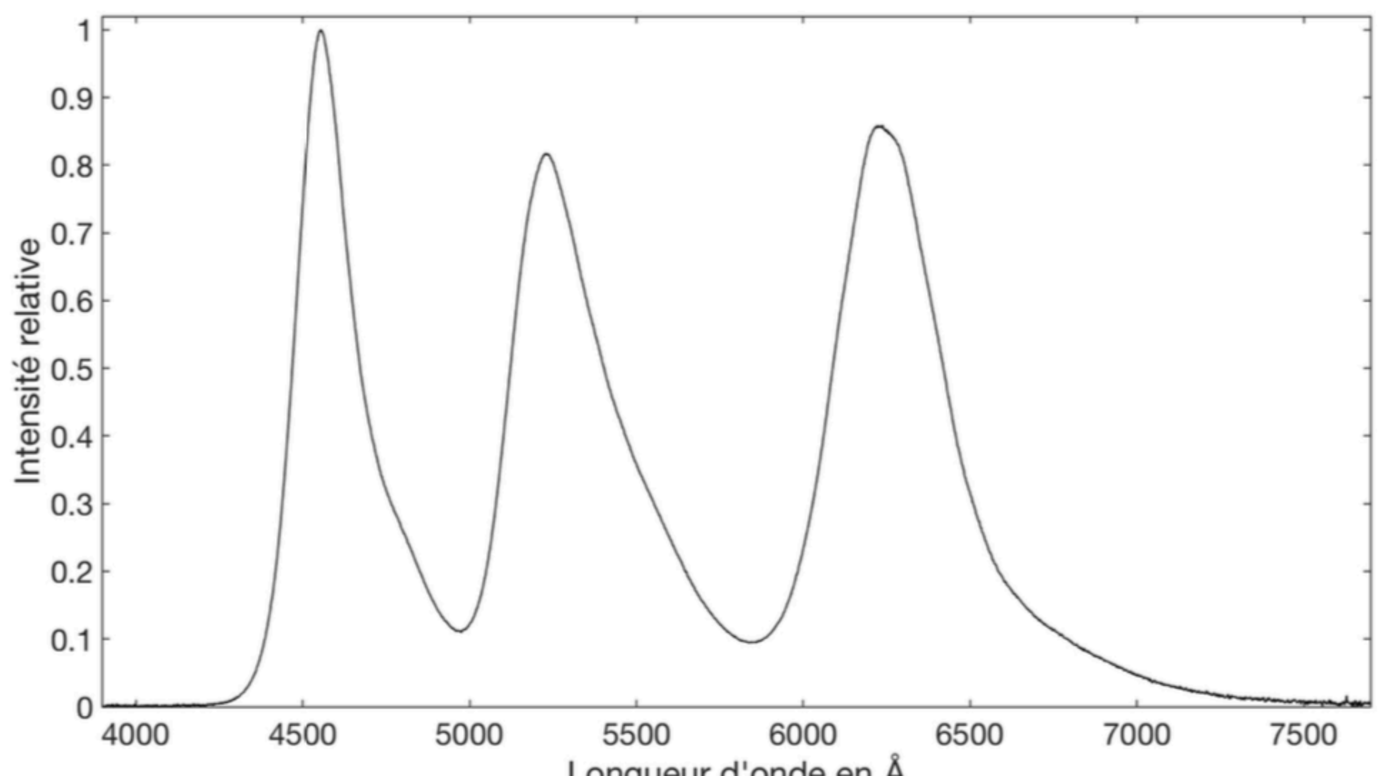
LED



Bad solution !

…

iPhone screen



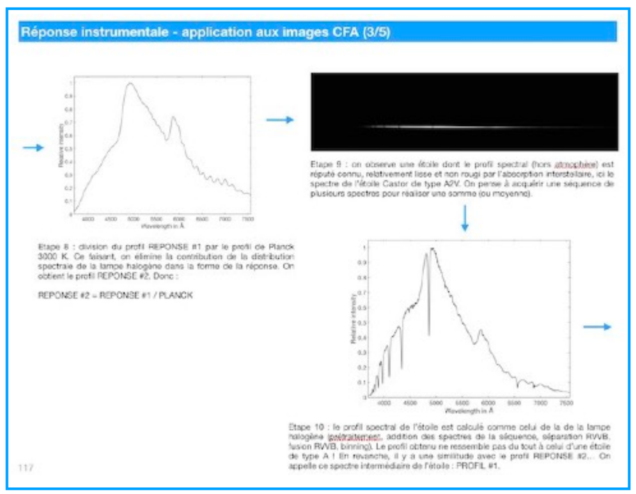
UVEX project and ISIS software (1/2)

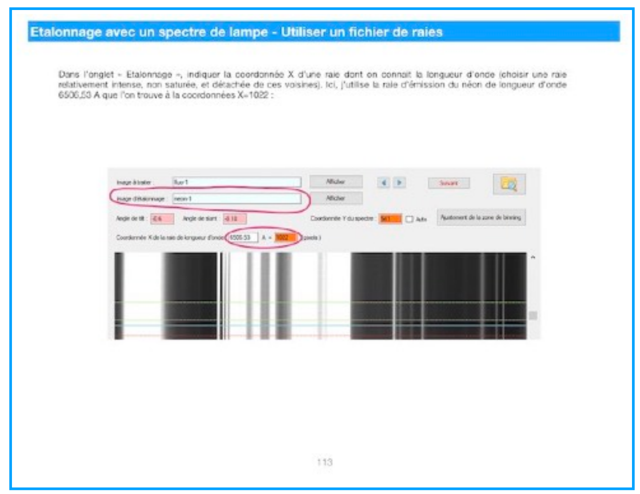
UVEX is the opportunity for ISIS improvements AND updated documentation !

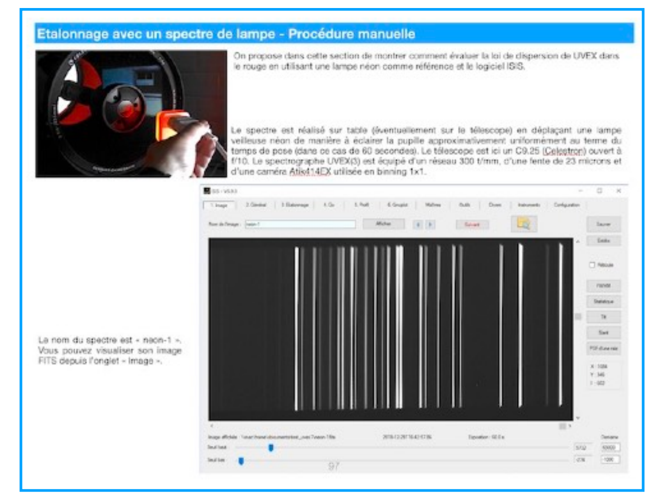
Many PDF format slide available on-line + graphical approach adopted for a quick and practical access to the information

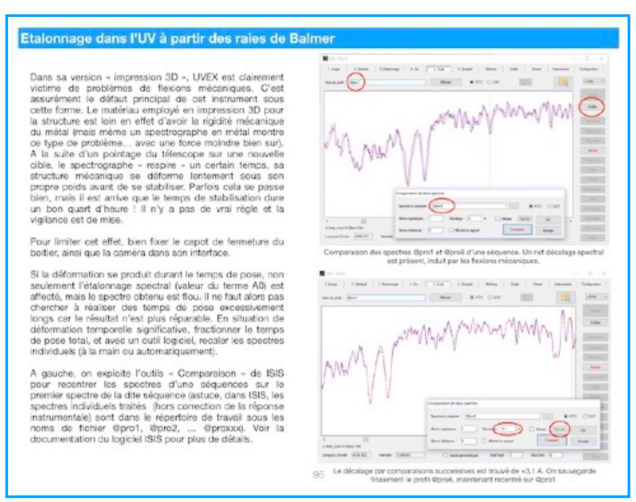
Support demo spectra can be dowloaded from the UVEX link

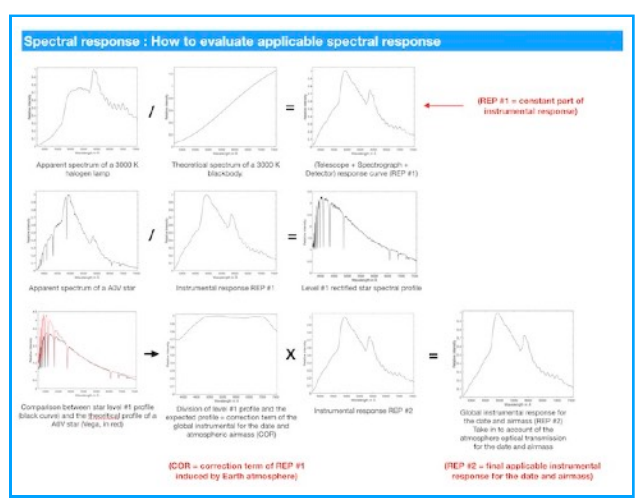
These new documentation is also useful for Alpy 600, LISA, … user's, of course !


Réponse instrumentale - application aux images CFA (3/5)


Etalonnage avec un spectre de lampe - Utiliser un fichier de raies


Etalonnage avec un spectre de lampe - Procédure manuelle


Etalonnage dans l'UV à partir des raies de Balmer


Spectral response : How to evaluate applicable spectral response

…

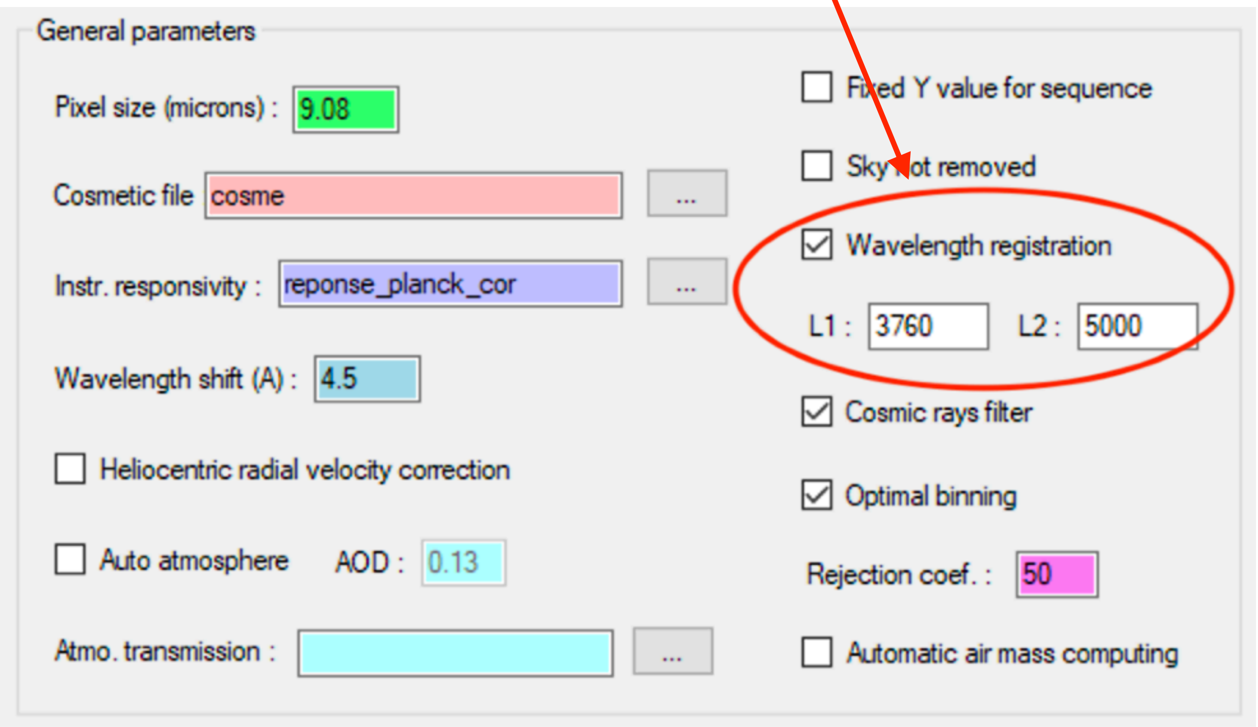
Consult WEB site: http://www.astrosurf.com/buil/

UVEX project and ISIS software (2/2)

Example…

ISIS version 4.9.4 and upper

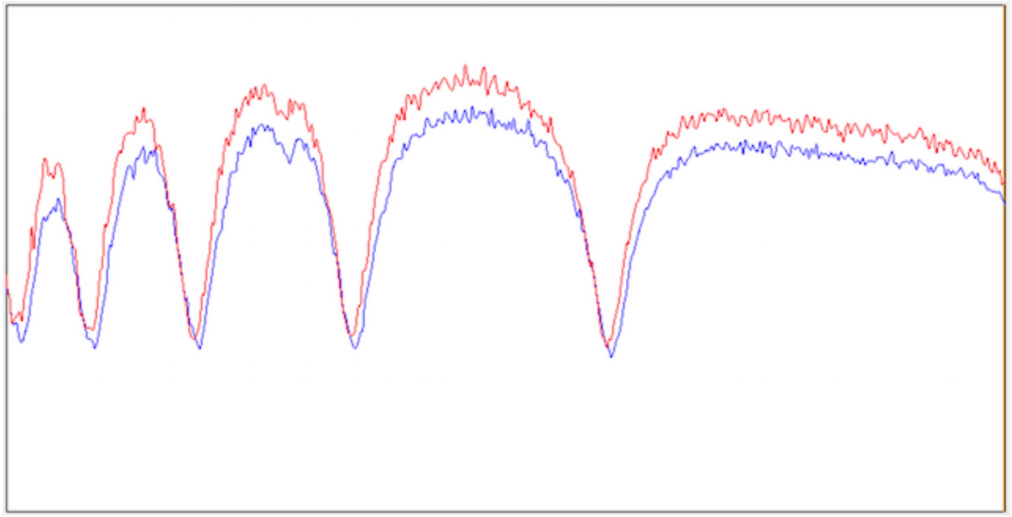
Improved function for compensate spectral shift during an acquisition sequence (spectrograph mechanical flexure along the time)



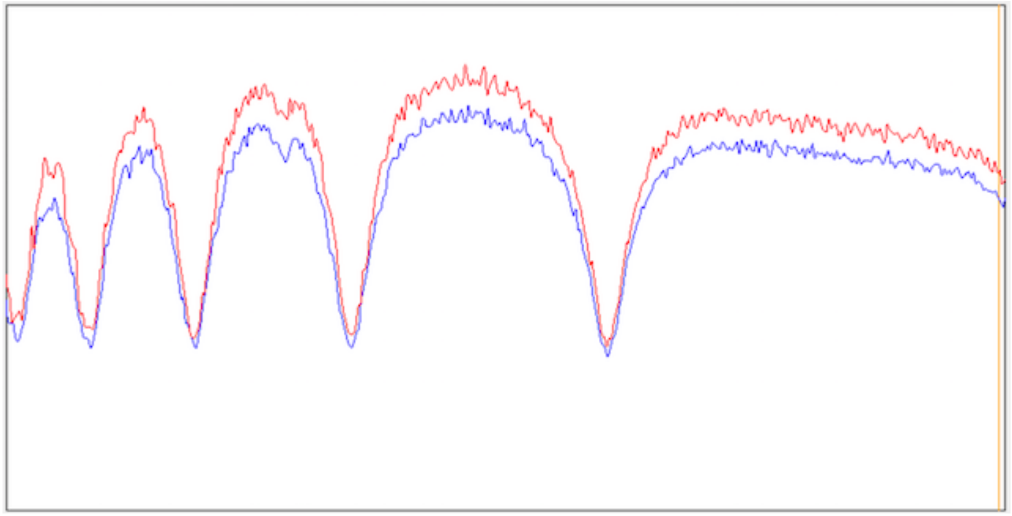
Registration of individual spectra...
(3760, 5000)
File #1 -> 0.000 A
File #2 -> -0.408 A
File #3 -> -0.155 A
File #4 -> -0.291 A
File #5 -> 0.274 A
File #6 -> 0.145 A
File #7 -> 0.076 A
File #8 -> 0.183 A
File #9 -> 0.469 A
File #10 -> 0.996 A
File #11 -> 0.360 A
File #12 -> 1.318 A

Write final profile : w:\test_uvex31_tmp_20190215_763.fits
Write final profile : w:\test_uvex31_tmp_20190215_763.dat

You can check the spectral shift values

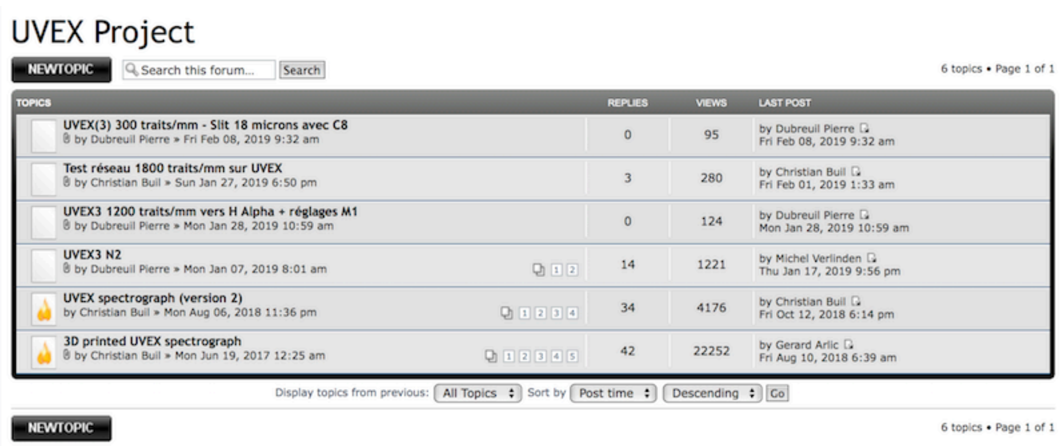


No correction

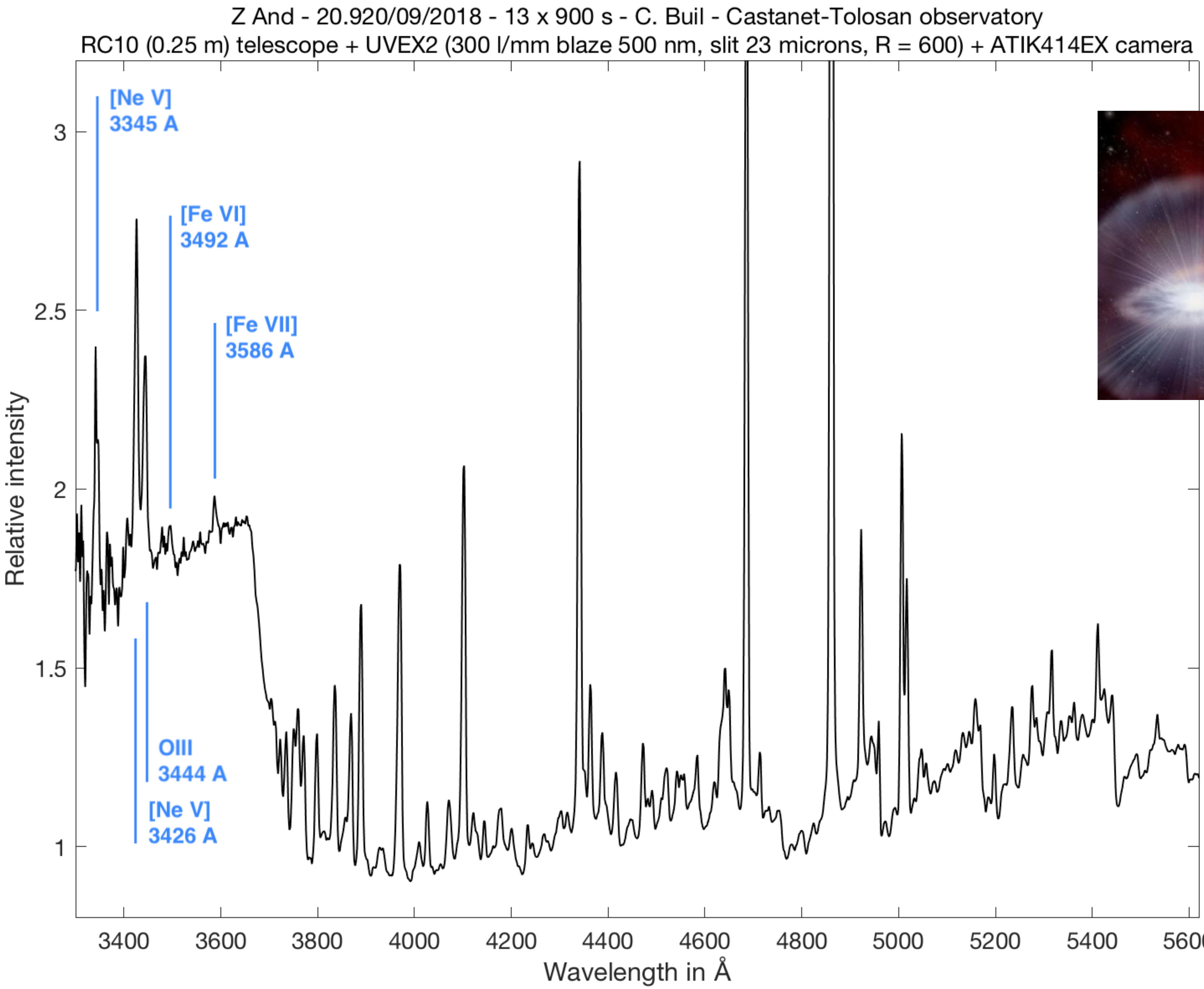


Automatic correction applied

A recommandation: consult ARAS forum
http://www.spectro-aras.com/forum/

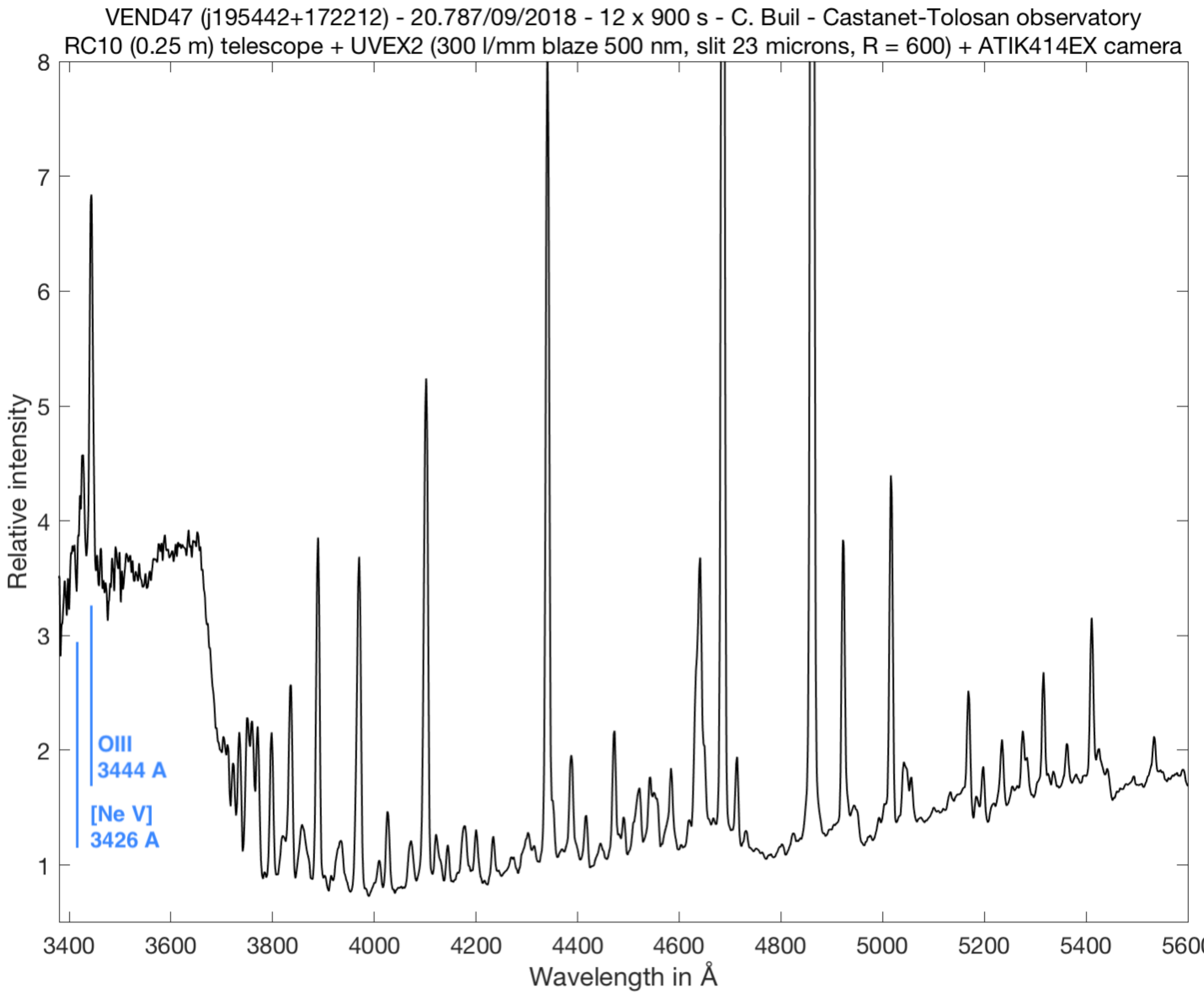


Sample of spectra - near UV observations (1/4)



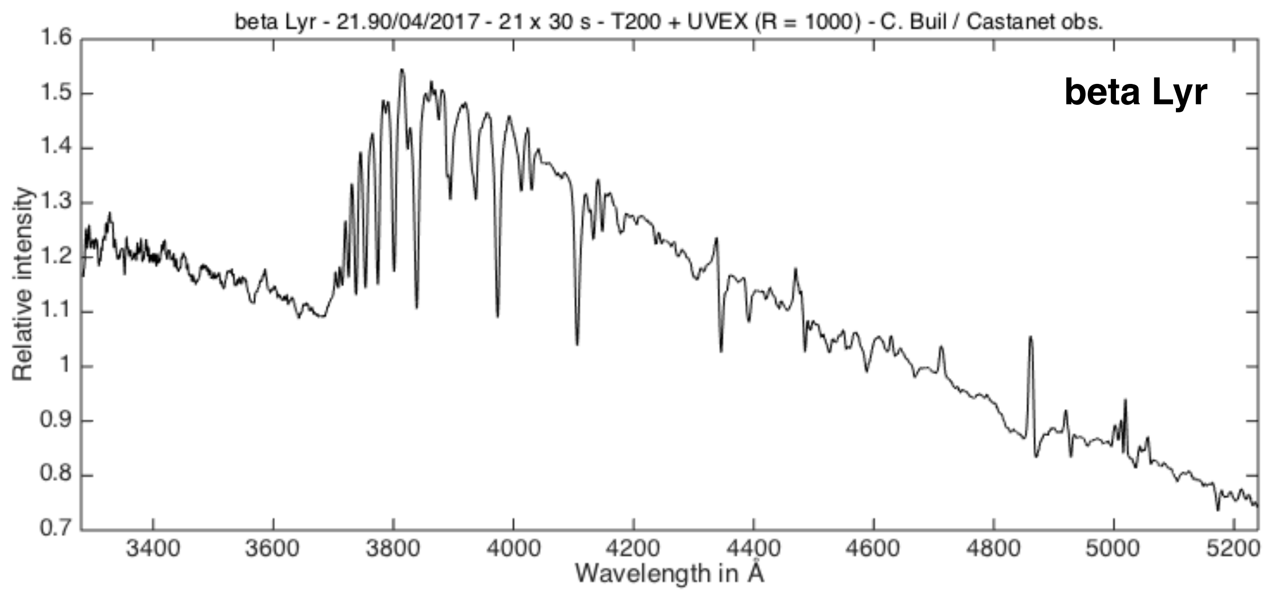
Symbiotic star Z And

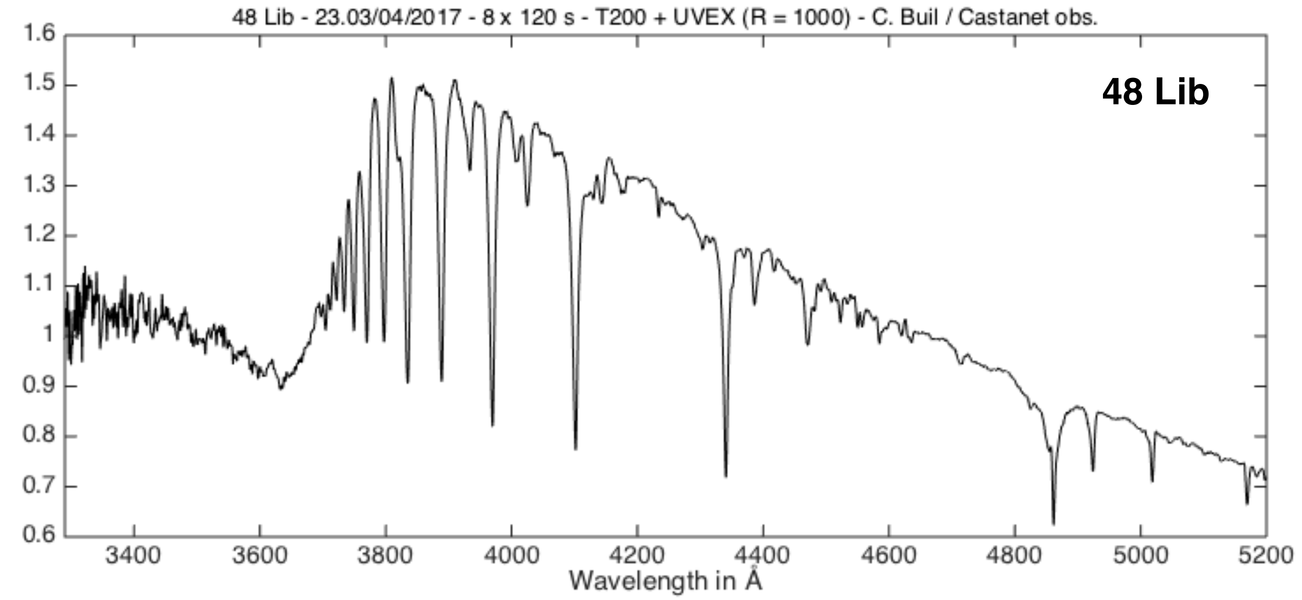
Sample of spectra - near UV observations (2/4)

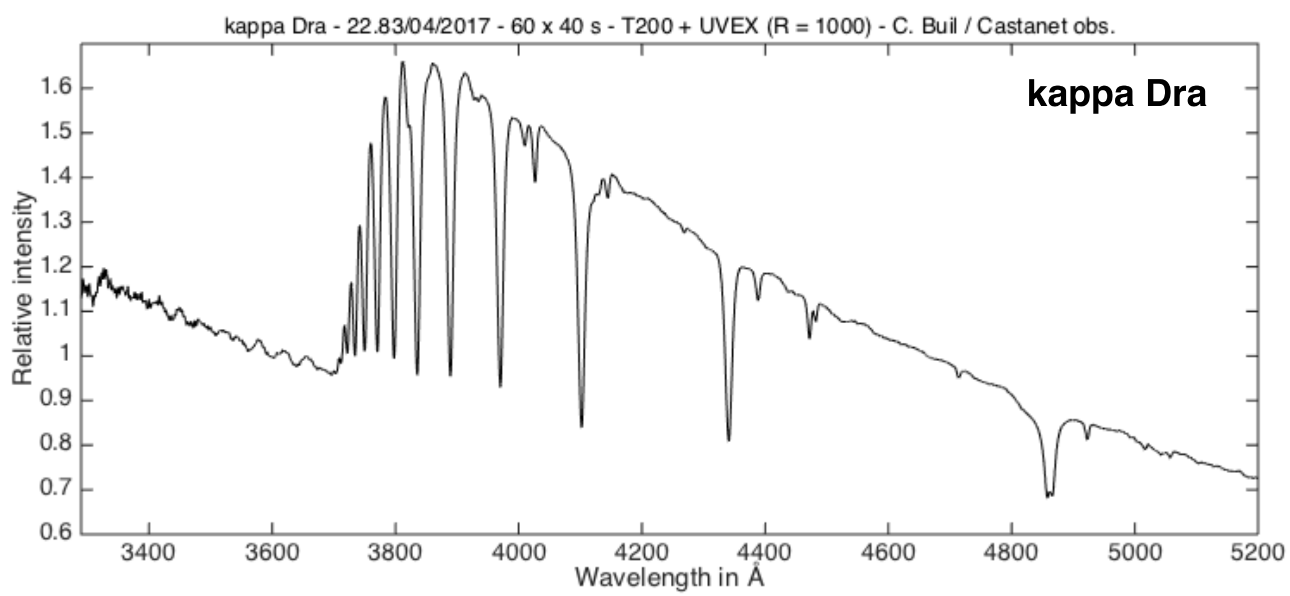


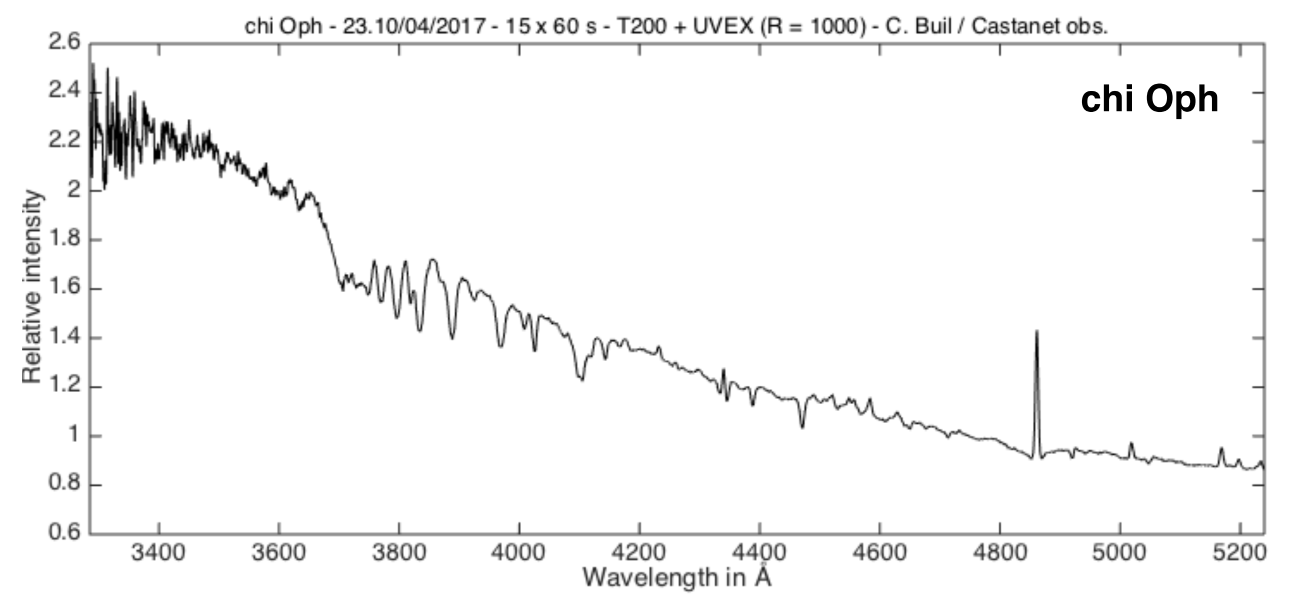
Symbiotic star VEND47

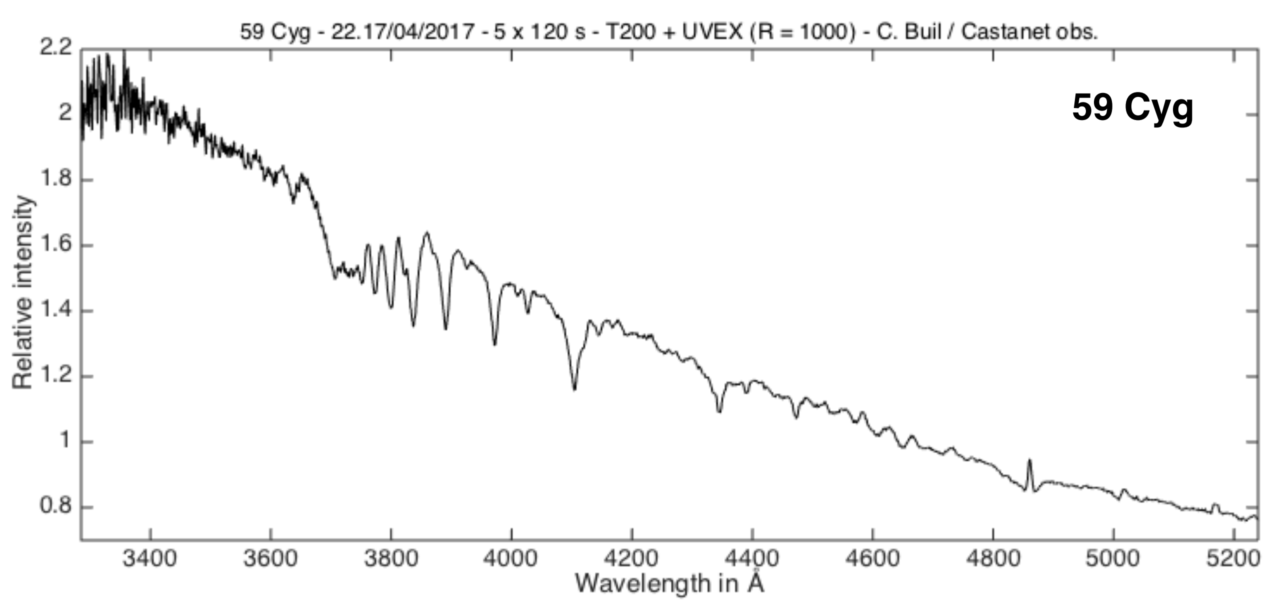
Sample of spectra - near UV observations (3/4) - Be stars

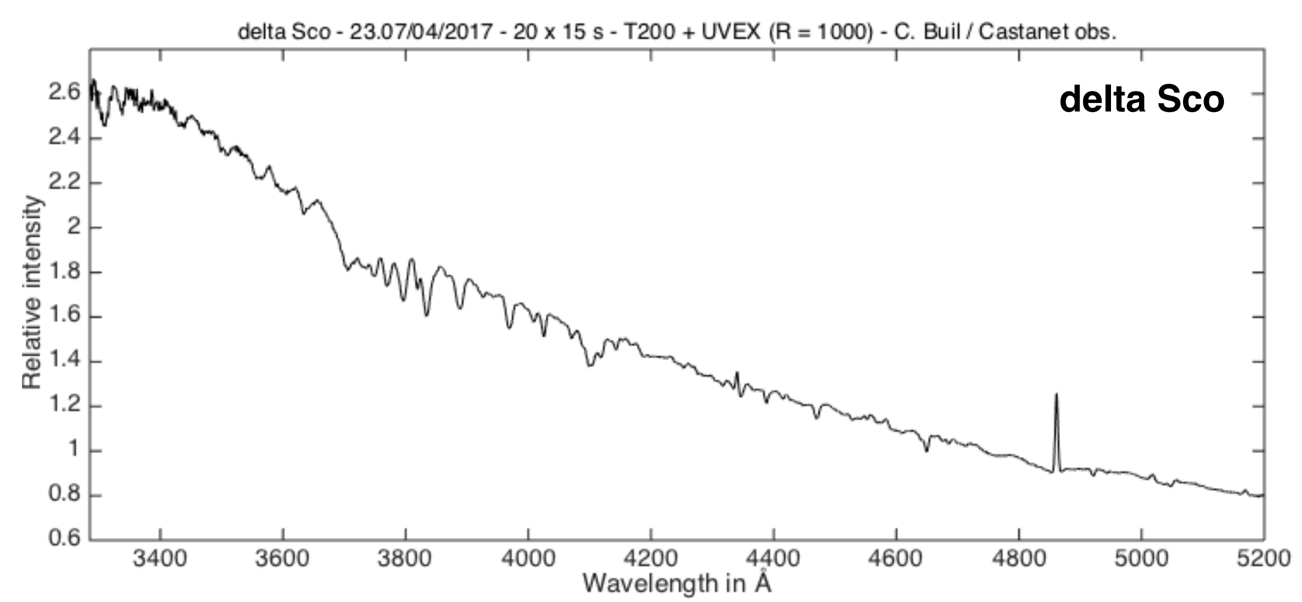






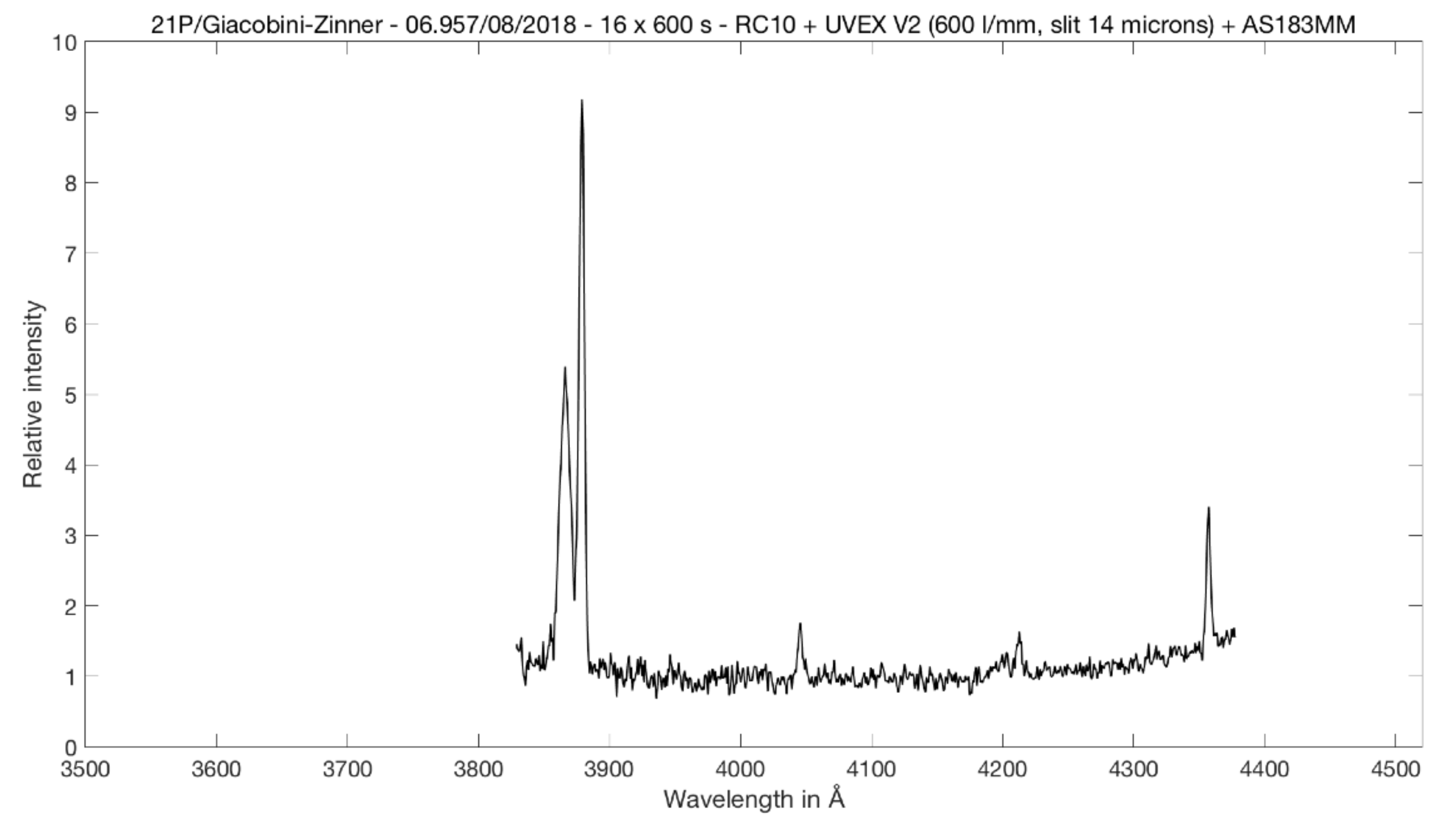


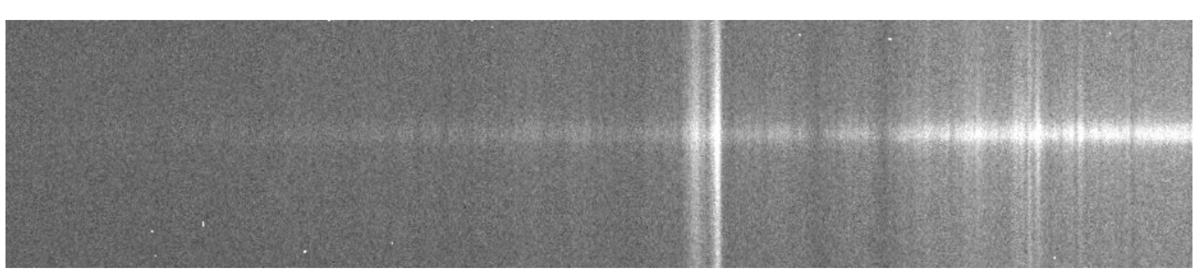




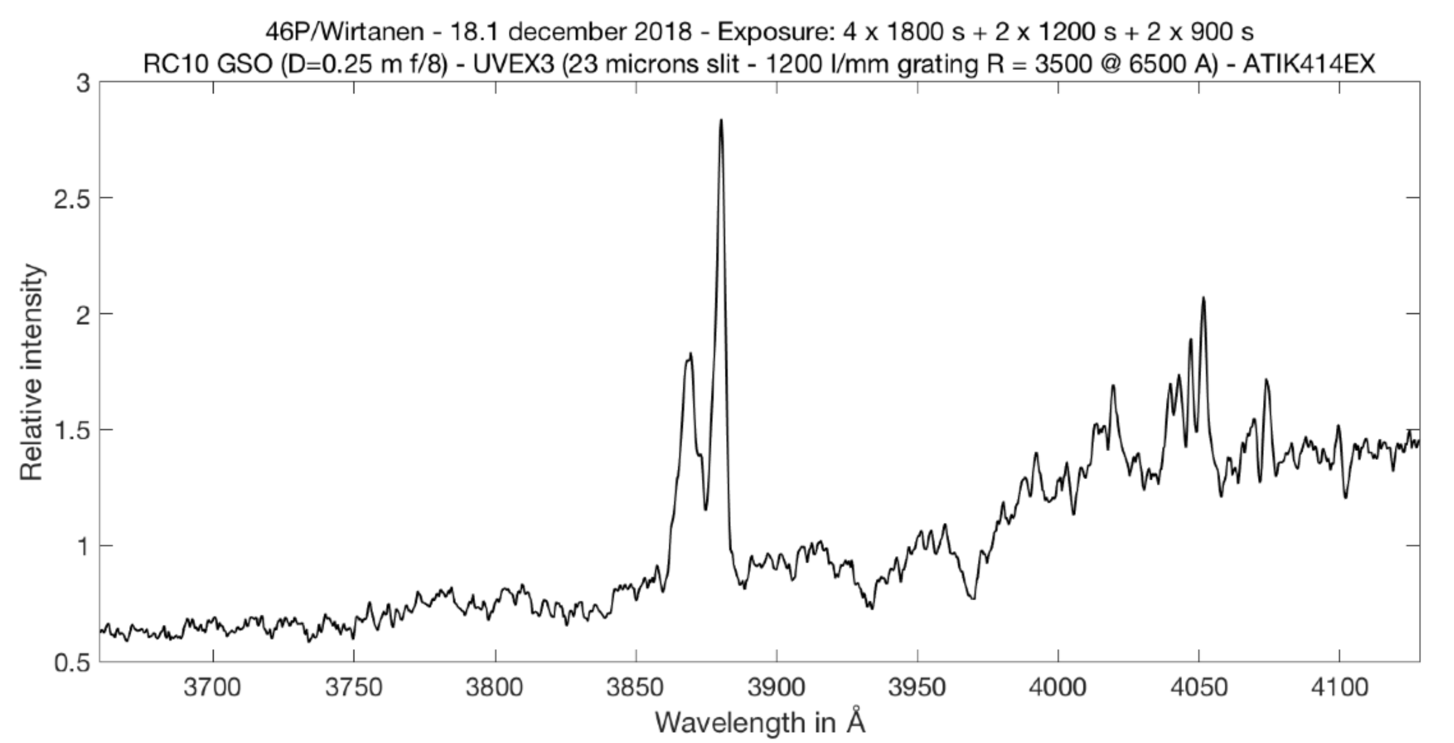
Sample of spectra - near UV observations (4/4)

Comet 21P/Giacobini-Zinner

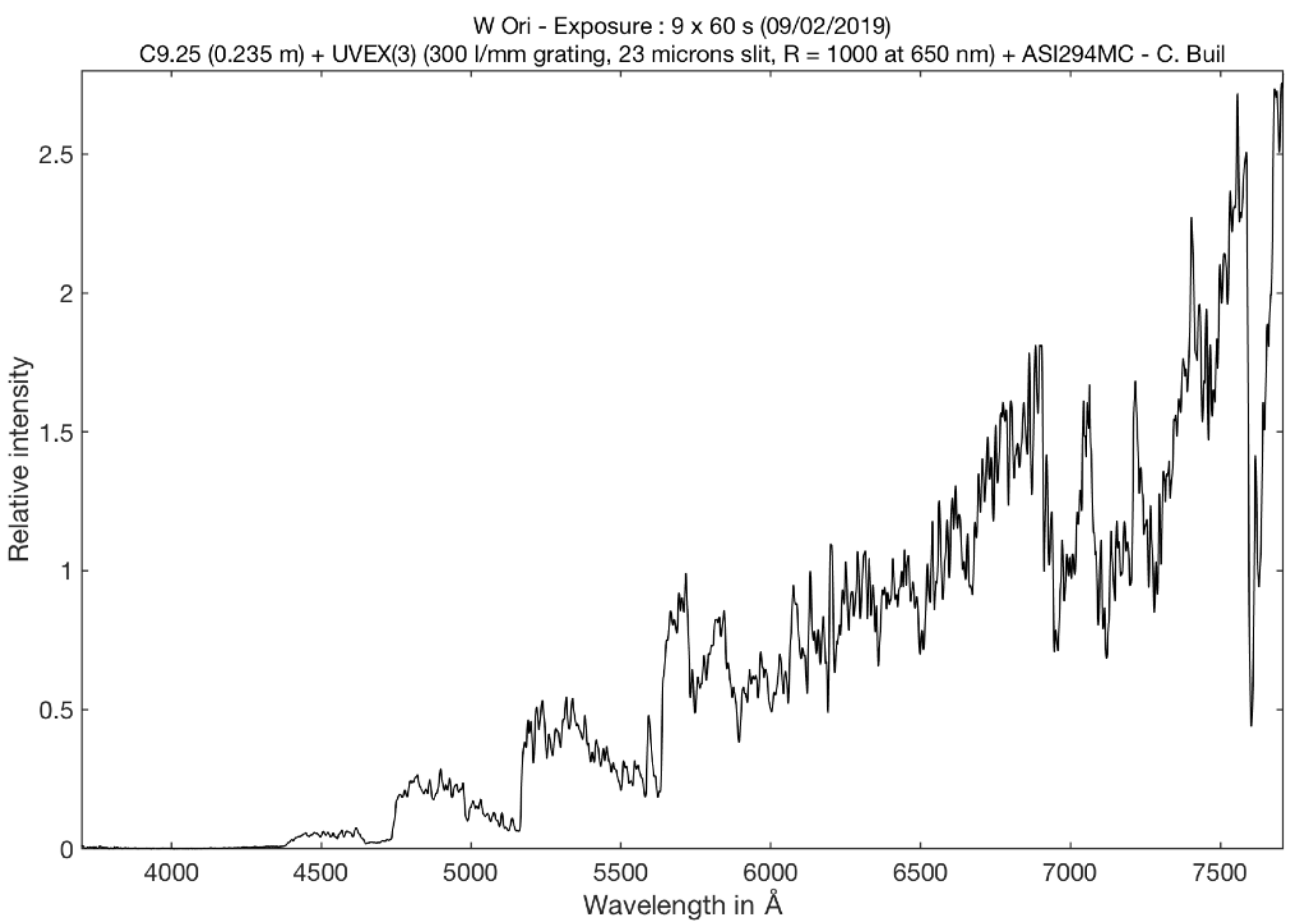


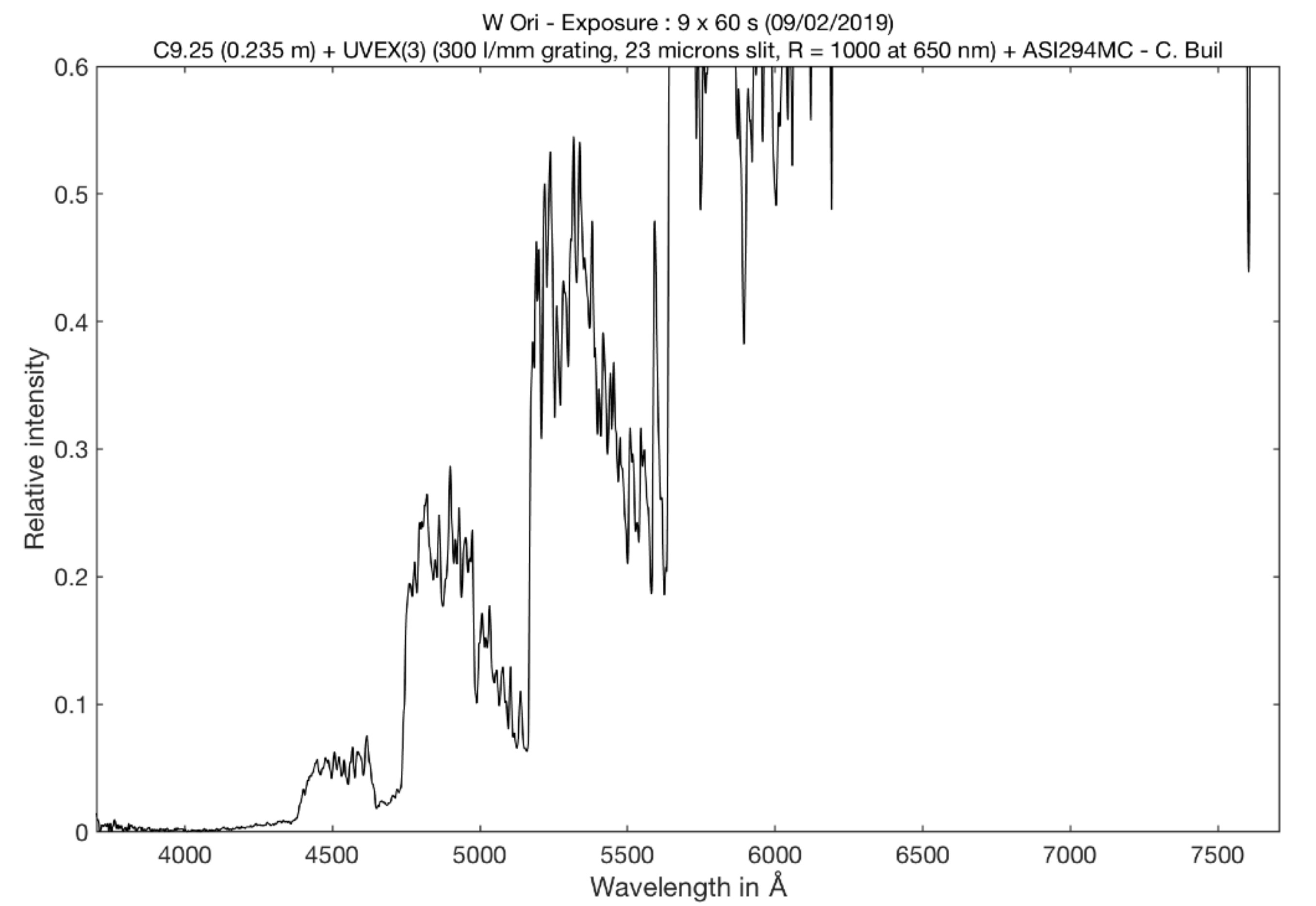


Comet 46P/Wirtanen



Sample of spectra - visible observations

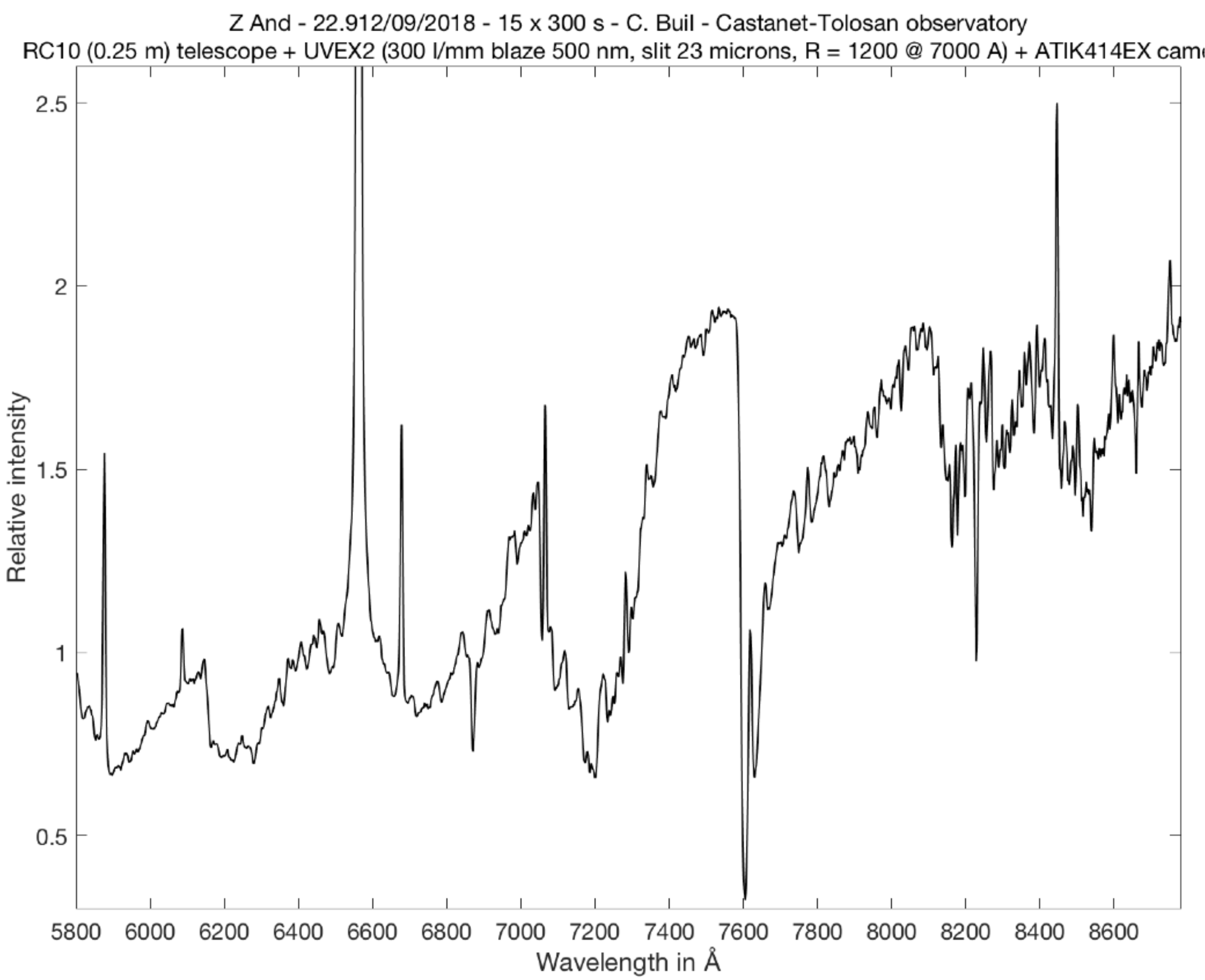




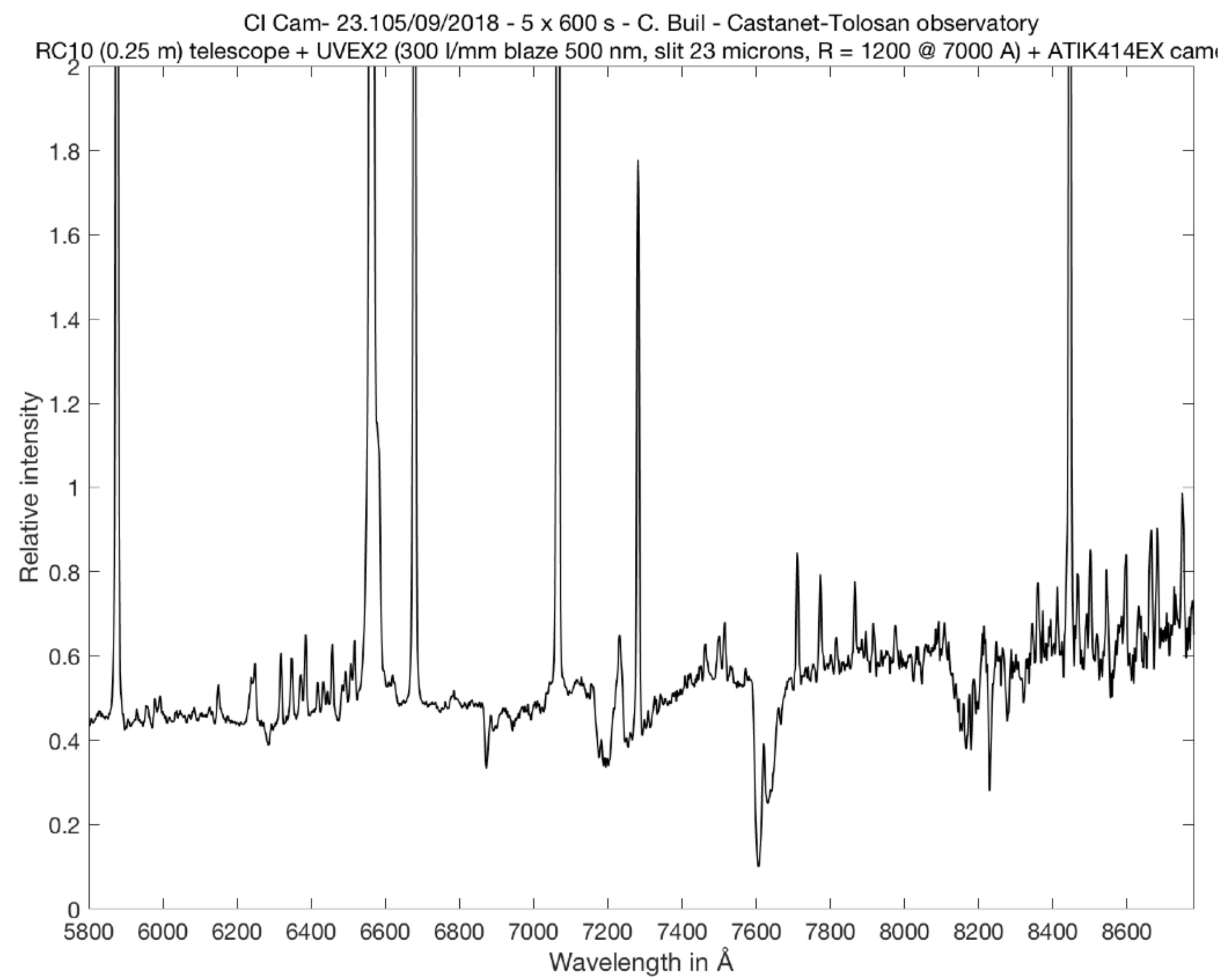
Carbon star W Ori

Sample of spectra - near infrared observations (1/2)

The other name of UVEX can be IREX (InfraRed Explorer)

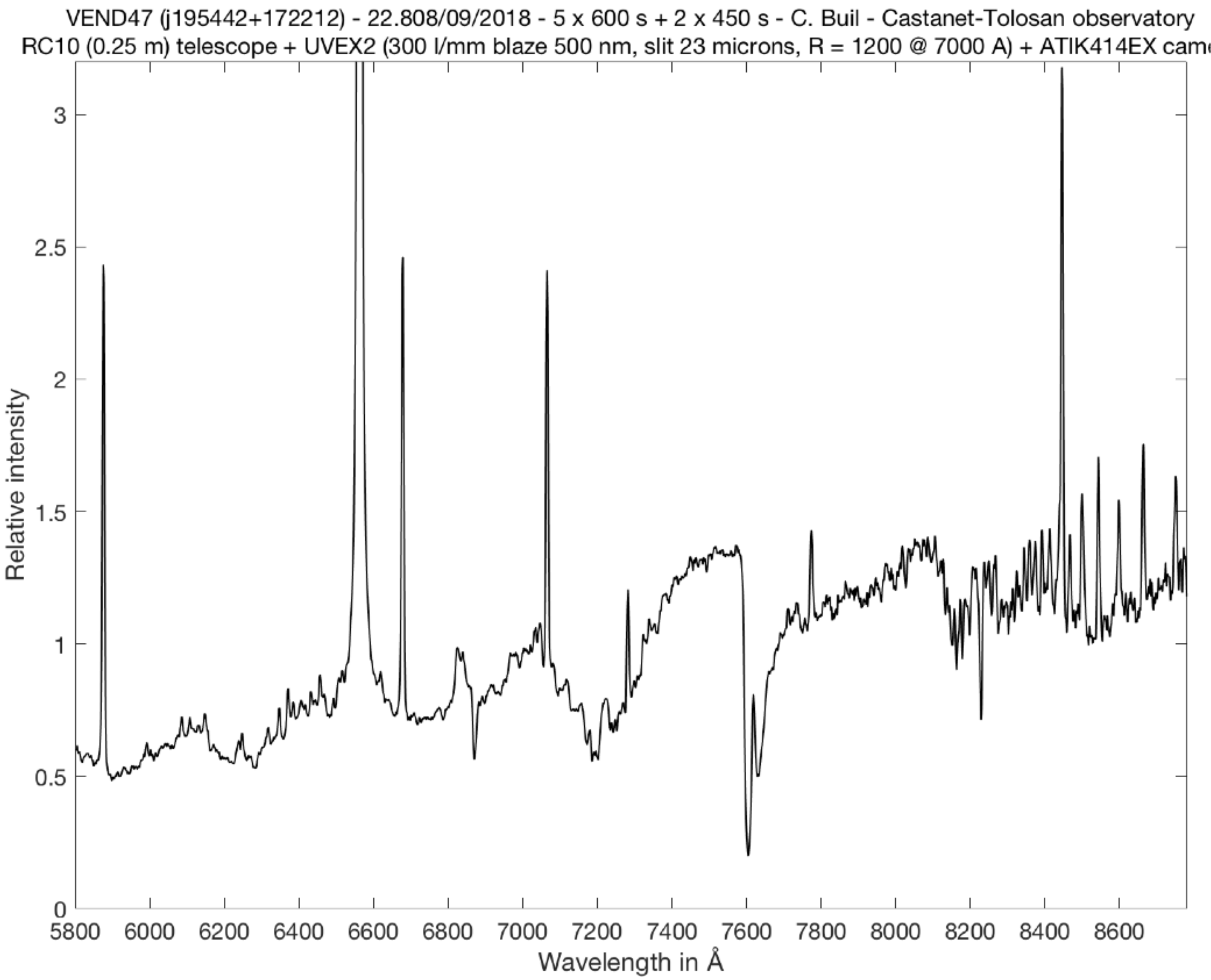


Symbiotic star Z And

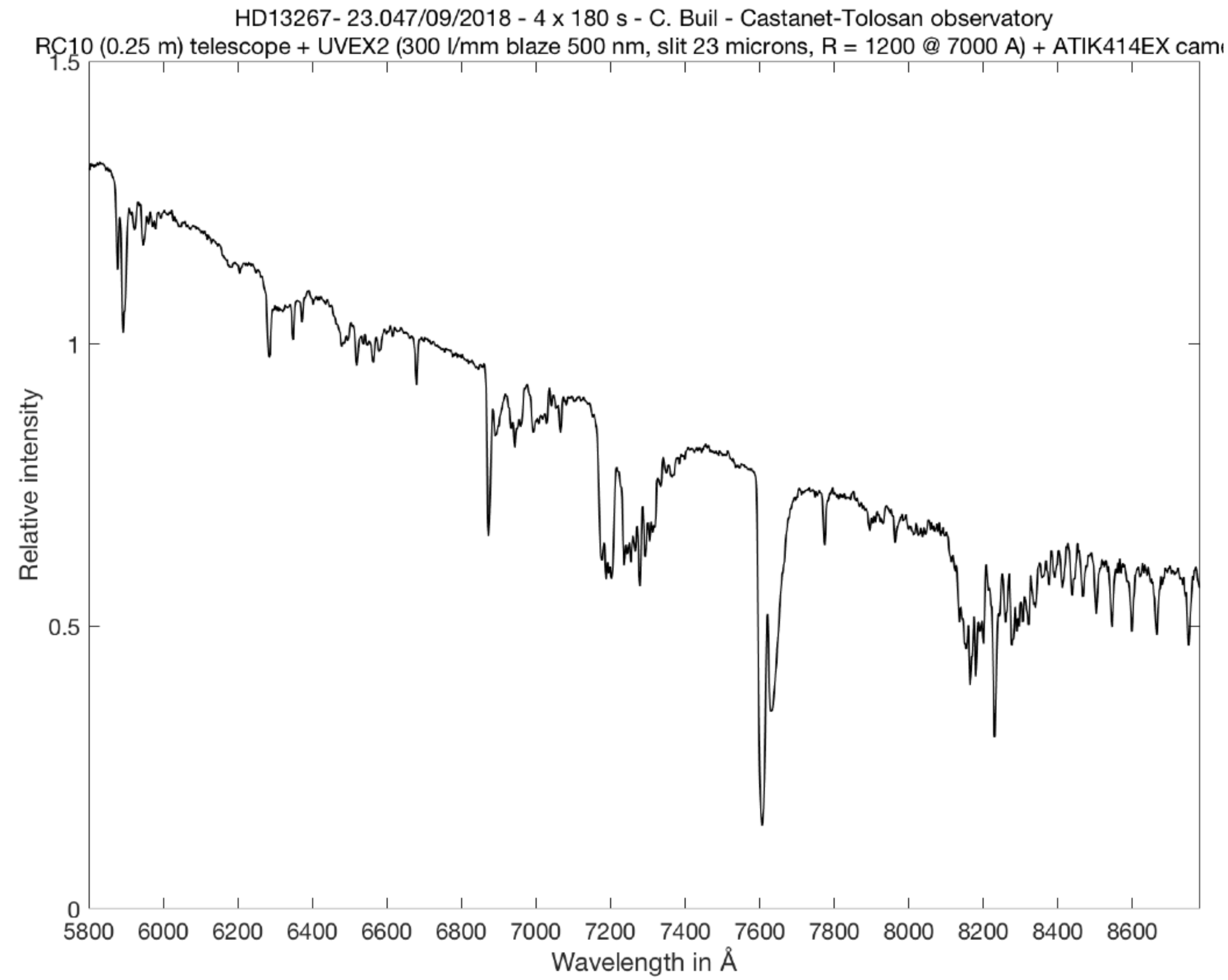


B[e] star CI Cam

Sample of spectra - near infrared observations (2/2)



Symbiotic star VEND47

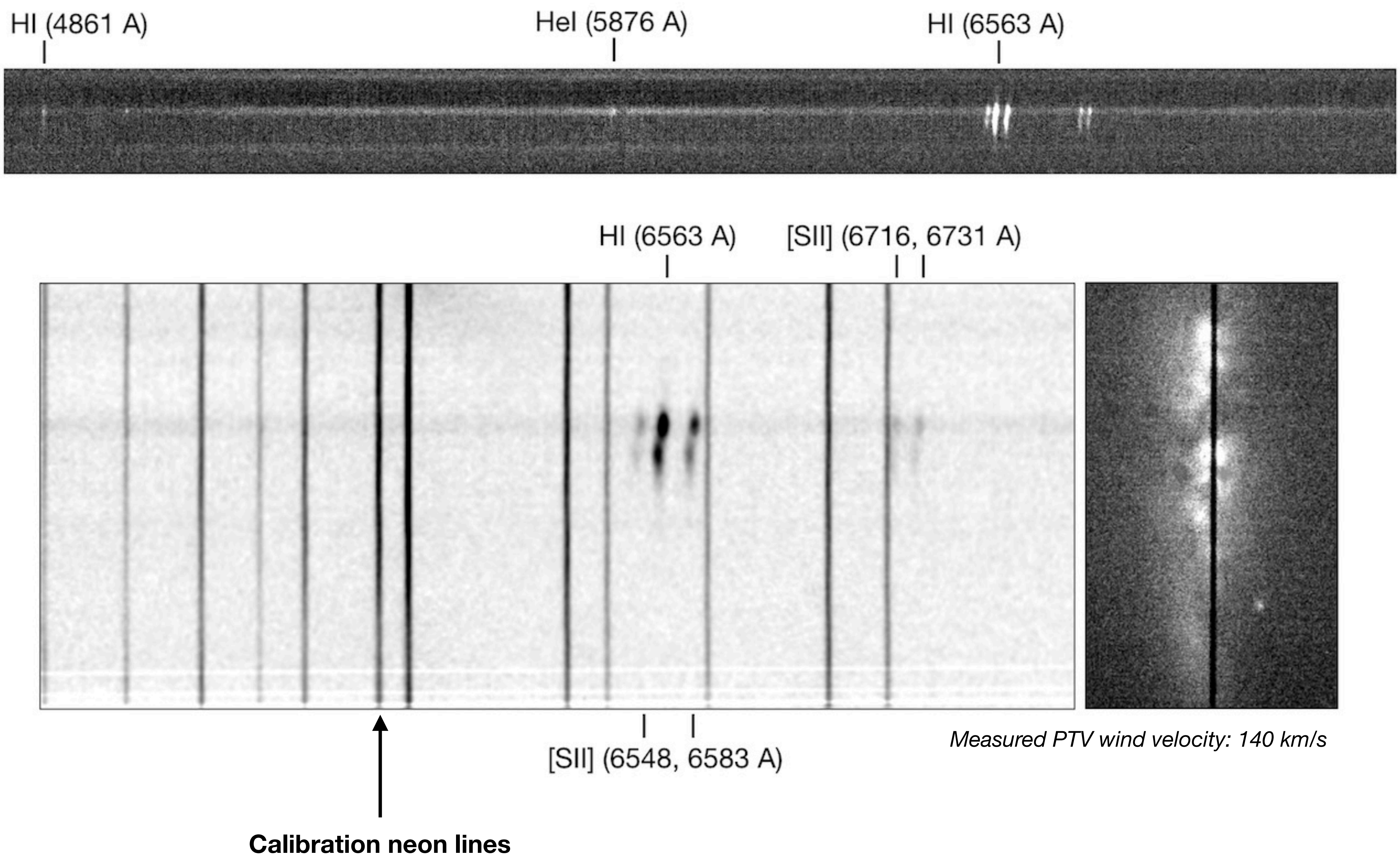


B5Ia star HD 13267

Distant object spectroscopy

Messier 82 core spectrum

UVEX(3) - 600 grooves/mm grating - 23 microns slit - Color CMOS camera ASI294MC - 10-inch RC telescope - City background



Thank you for your attention !