Hydrogen alpha solteleskop av en Vesper Optics 60 mm f/15 refraktor

Roar Skartlien 2019, 2020

Sammendrag/Abstract

- Blokkering av UV or IR, helst bruke ERF (energy rejection filter UV/IR/passbånd) filter før objektiv

- Høyt F-forhold eller bruke kollimator for parallelle stråler gjennom filtere. Gir smalere effektiv båndbredde
  - Kollimering: Konkav linse før hovedfokus, eller konveks linse etter hovedfokus
  - Trenger refokusering etter filtere, hvis kollimator brukes

- Bølgelengdekalibrering
  - Effekt av større tiltvinkel: passbånd flyttes til kortere bølgelengder (blåforskyvning)
  - Bruke H-alpha emitter (lysrørstarter) og eventuelt spektroskop for kalibrering (emitter + kontinuerlig klide samtidig)
  - Kalibrere primærfilter først, ta ut sekundærfilter
  - Sett inn sekundærfilter og kalibrer dette til at en oppnår maks lysstyrke
  - Sjekk temperaturdrift. Måle temperatur ved kalibrering, ca 20 Celsius

- Hindre sagging av filter-modul
  - Sagging av filtermodul gir blåforskyvning av passbånd relativt til kalibrert verdi

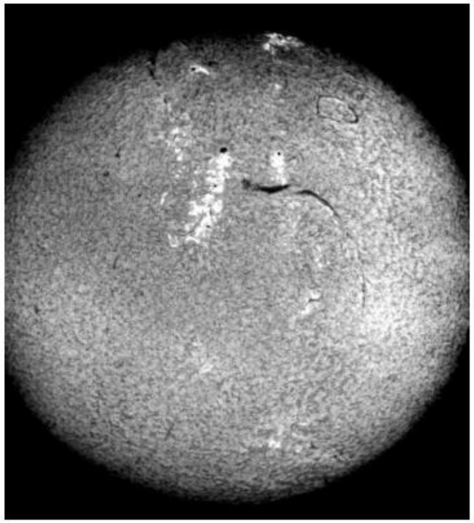
- Temperatur-stabilisering og/eller temperatur-kompensasjon
  - 3-5 grader Celsius +/-, gir typisk +/- 1Å drift (kortere, jo lavere temperatur) hvis en tar oppgitt rate 0.3 Å / grad som god fisk
  - Kompensere med tilt/blåforskyvning, forutsatt høy nok temp
  - ERF reduserer oppvarming. Kan bruke aktiv termostatregulering i filtermodul

- Trimmefilter hvis nødvendig
  - Trenger bare dette for rent FP filter som produserer "stakitt-transmisjon". Må bare slippe gjennom H-alpha passbåndet for god kontrast
  - Brukes i LUNT, trenger ikke dette for Omega filter-enheter

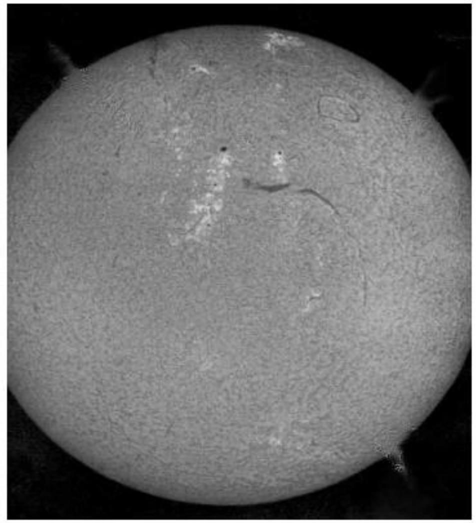
- Prosedyre:
  1. Kalibrere spektrograf med emitter + kontinuerlig kilde samtidig (15-20 grader celsius). Merke av posisjon på primærfilter
     - Bruk halvverdier av oppgitte tiltverdier, resten rotasjon. Dette gir bedre rotasjons-fleksibilitet
  2. Sette inn filtermodul uten sagging. Heise opp filtermodul med de fire bakplateskruer
  3. Sett på varme hvis under 15 grader ute

Teori/Theory

Chromospere vs prominences

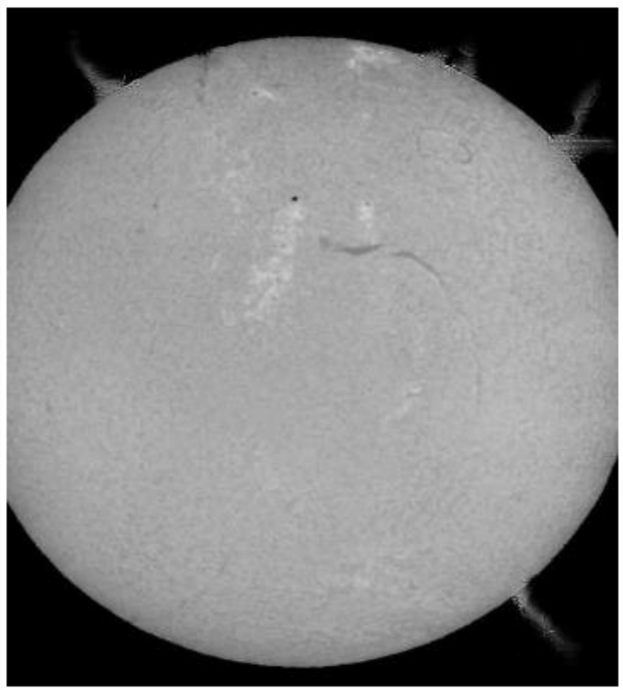


0.5Å Bandpass (38,961 bytes)

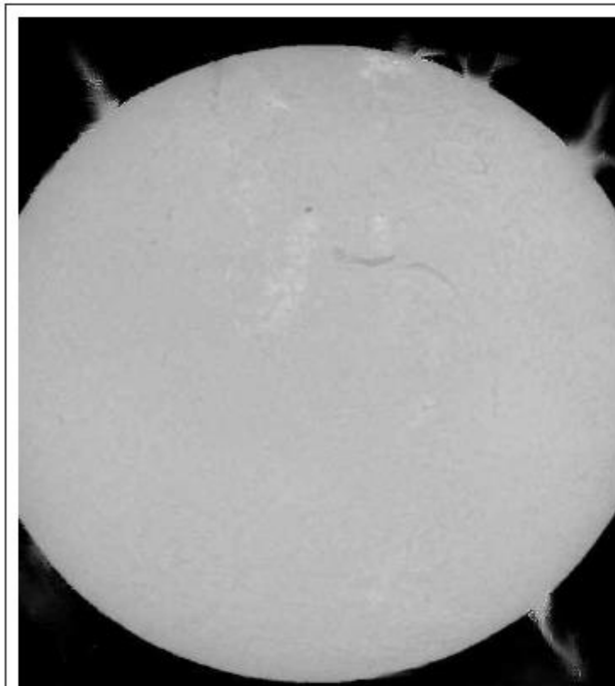


0.6Å Bandpass (30,655 bytes)

We will be somewhere here:



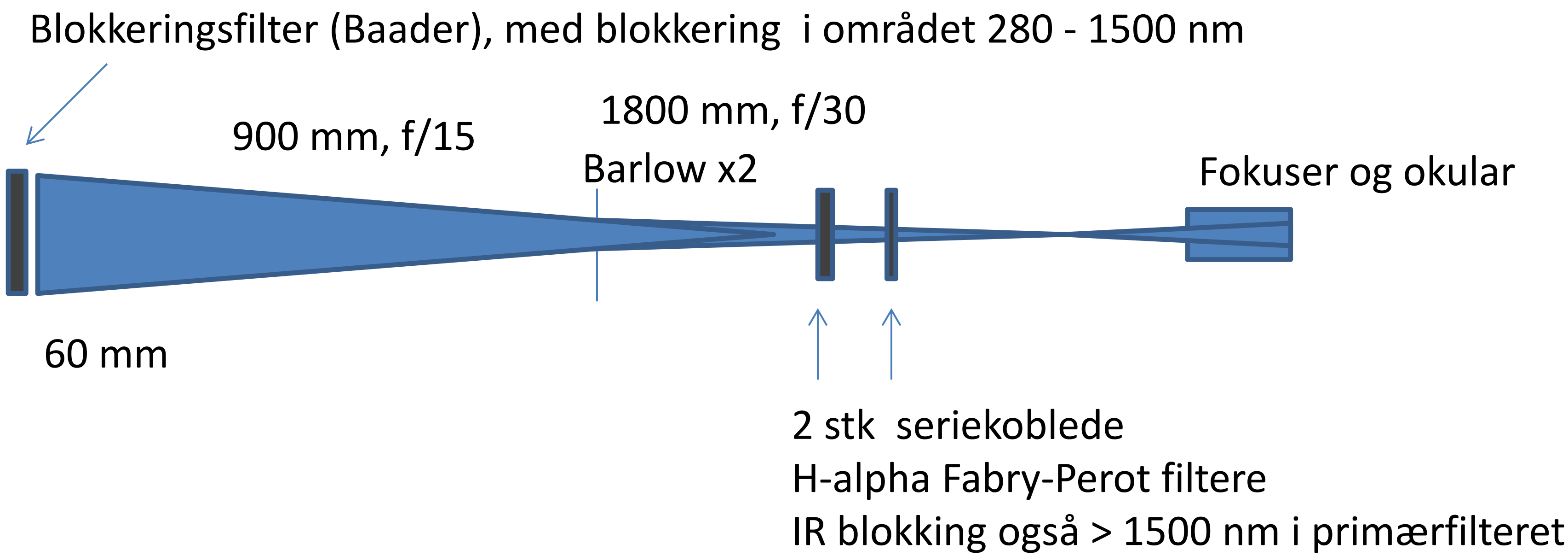
0.7Å Bandpass (20,435bytes)



0.95Å Bandpass (15,872 bytes)

Narrower bandpass, more striking surface features, but less bandwidth to observe prominences. Wider bandpass, finer surface structures less apparent, but larger prominences and Coronal Mass Ejections more apparent.

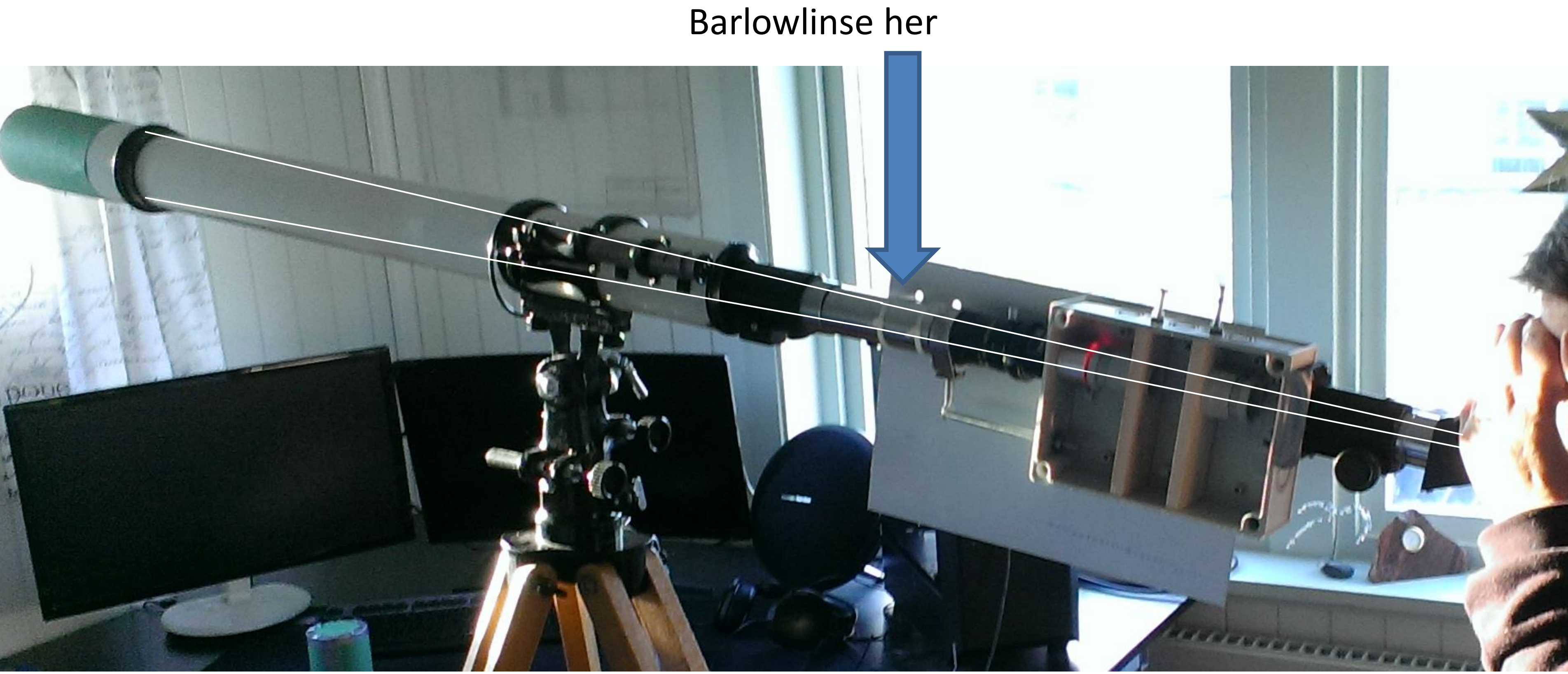
Strålegang uten kollimator



- Vesper optics 2” 900mm f/15 akromat fra 1960 tallet (gave fra Hans Brubak, Fetsund)
- Bruker 2x Barlow linse for mer parallell strålegang for f/30
- Ved flytting av Barlow nærmere objektiv kan kollimering realiseres hvis en ønsker dette

- FP filter:
  to semi-transperente parallelle speil gir resonans og transmisjon på bestemte bølgelengder

Strålegang uten kollimator

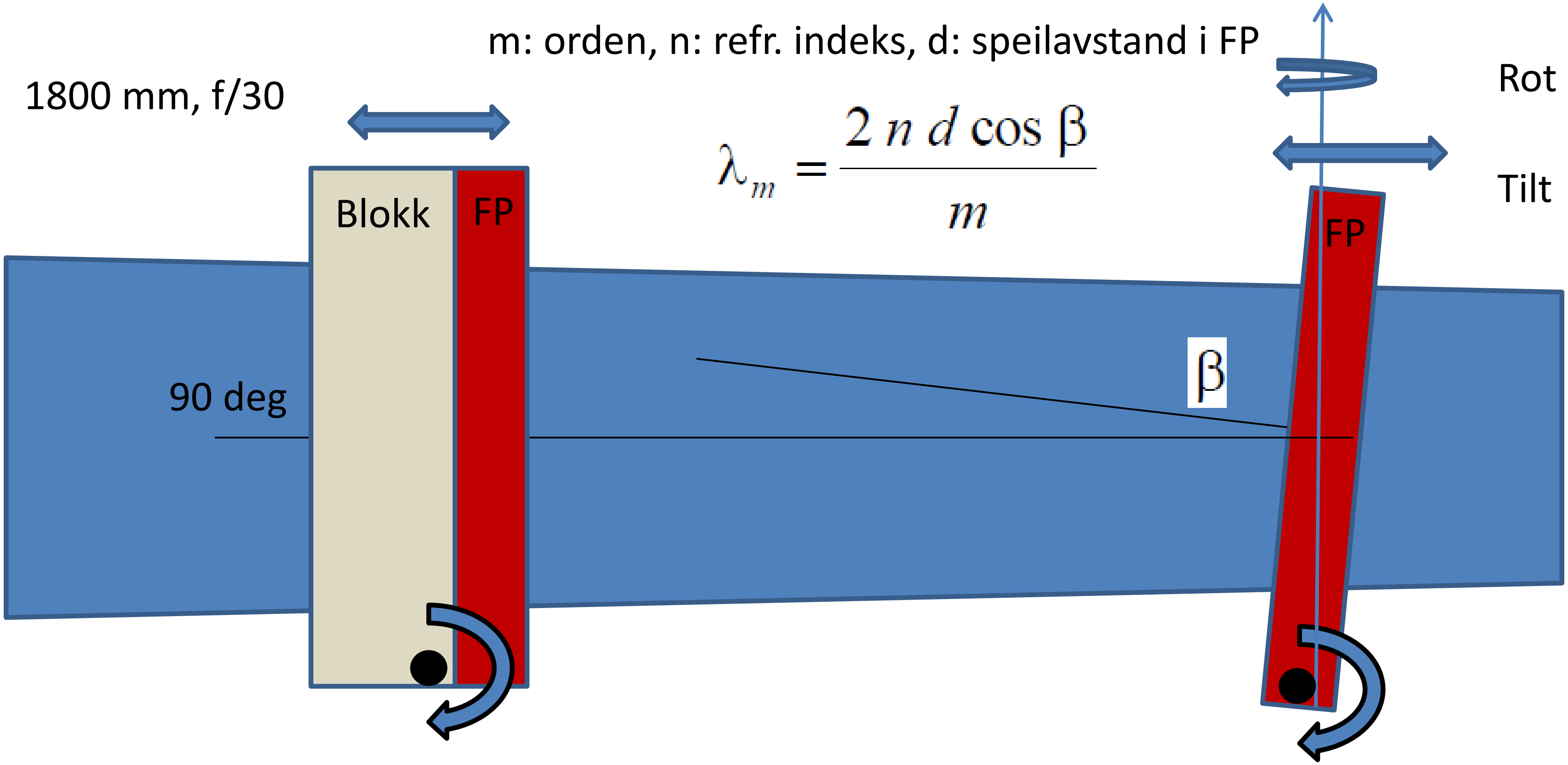


- Halv til kvart soldiameter i felt, med okular med lang brennvidde/vidvinkel
- OK for protuberanser

Filter-tilt for bølgelengde-tuning

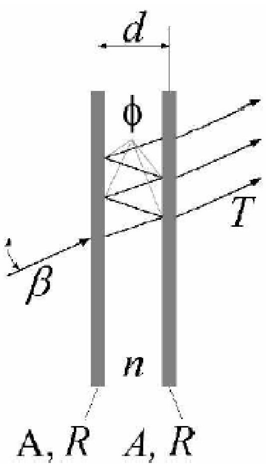
m: orden, n: refr. indeks, d: speilavstand i FP

$$\lambda_m = \frac{2\, n\, d \cos \beta}{m}$$



- Tilting i en akse vinkelrett på optisk akse, for CWL (central wavelength) tuning
- To filtere med forskjellig litt bølgelengde gir smalere kombinert transmisjonsbånd

1. Tilting av primærfilter justerer lysstyrken i H-alpha og kan endre CWL område
2. Trenger deretter å tilte sekundærfilteret for god kontrast
3. Finjuster med å rotere sekundærfilteret om akse i tegningsplanet



T	transmittance
n	gap refractive index
d	gap width
β	angle of incidence
R	mirror reflectance
A	mirror absorptance
ϕ	phase at reflection

Fig. 1: Schematic of the FPI arrangement

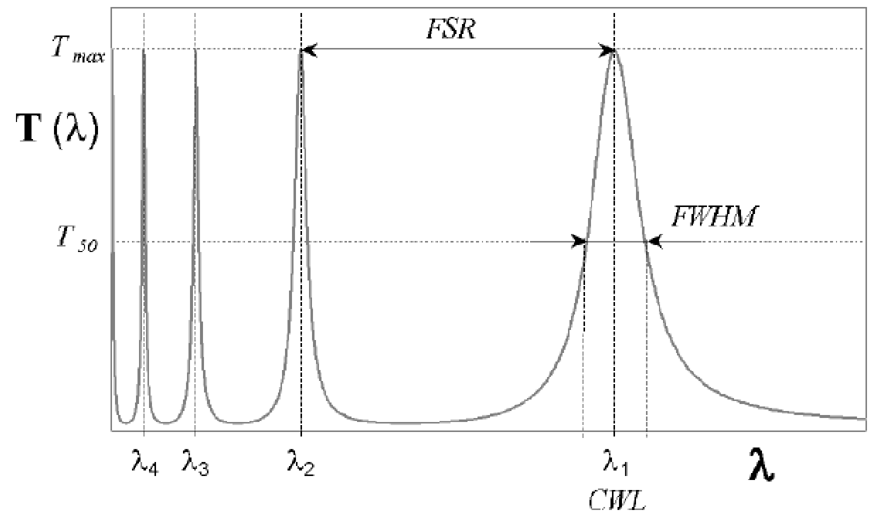


Fig. 2: Airy-function over wavelength

The transmittance spectrum $T(\lambda)$ of a FPI is described by the Airy-Function (eq. 2).
The center wavelength (CWL) of the filter corresponds to the resonant wavelength. In our case the first interference order is used ($m=1$) while the higher orders are blocked by means of an additional bandpass filter. The spectral bandwidth ($FWHM$) is the decisive factor regarding the spectral resolution of a FPF-based spectrometer (eq. 3).

$$T = \left(1 - \frac{A}{(1-R)}\right)^2 \frac{1}{1 + \frac{4R}{(1-R)^2}\sin^2\left(2\pi n d \frac{1}{\lambda}\cos\beta - \phi\right)} \qquad (2)$$

$$FWHM \approx 2d\left(\frac{1-R}{\pi\sqrt{R}}\right) \qquad (3)$$

Design, Operation and Performance of a Fabry-Perot-Based MWIR Microspectrometer

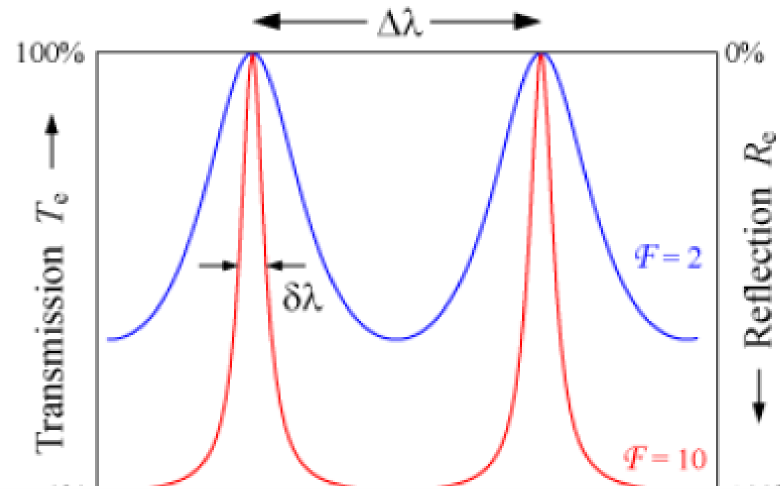
Martin Ebermann[1], Karla Hiller[2], Steffen Kurth[3], Norbert Neumann[1]

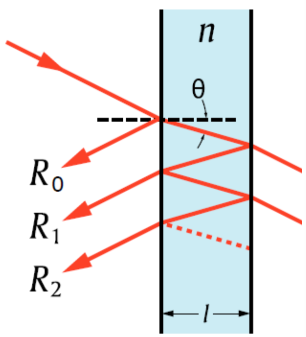
Free Spectral Range for rent FP-filter

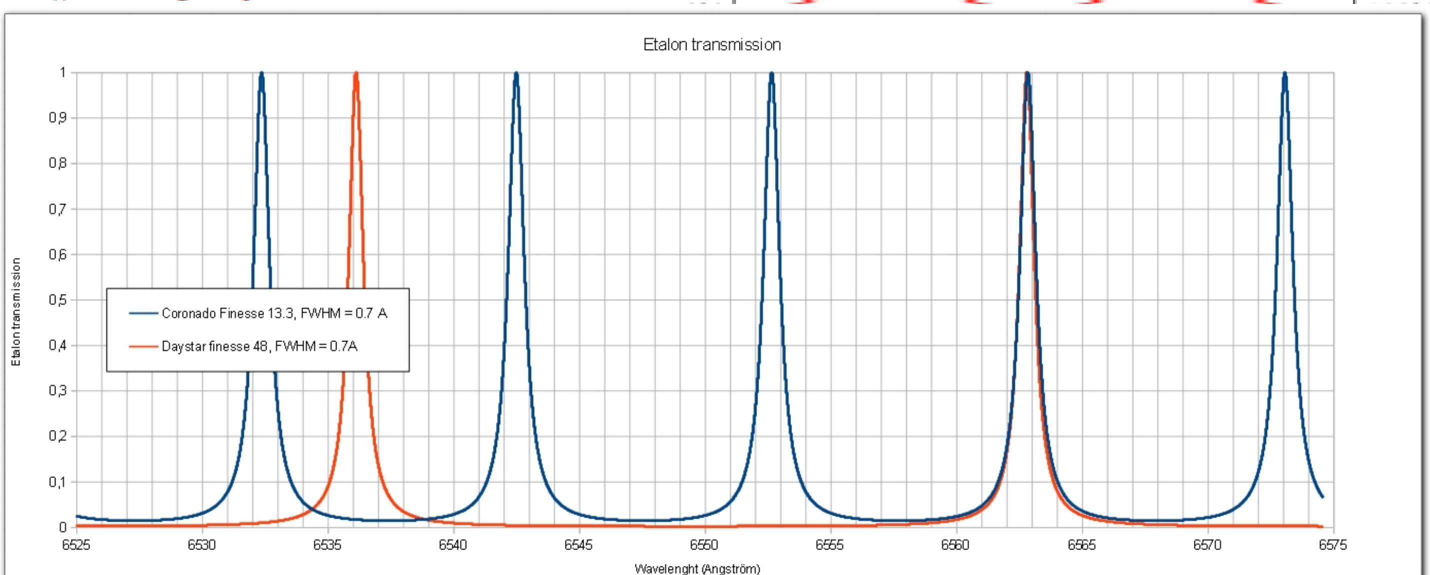
The wavelength separation between adjacent transmission peaks is called the free spectral range (FSR) of the etalon, $\Delta\lambda$, and is given by:

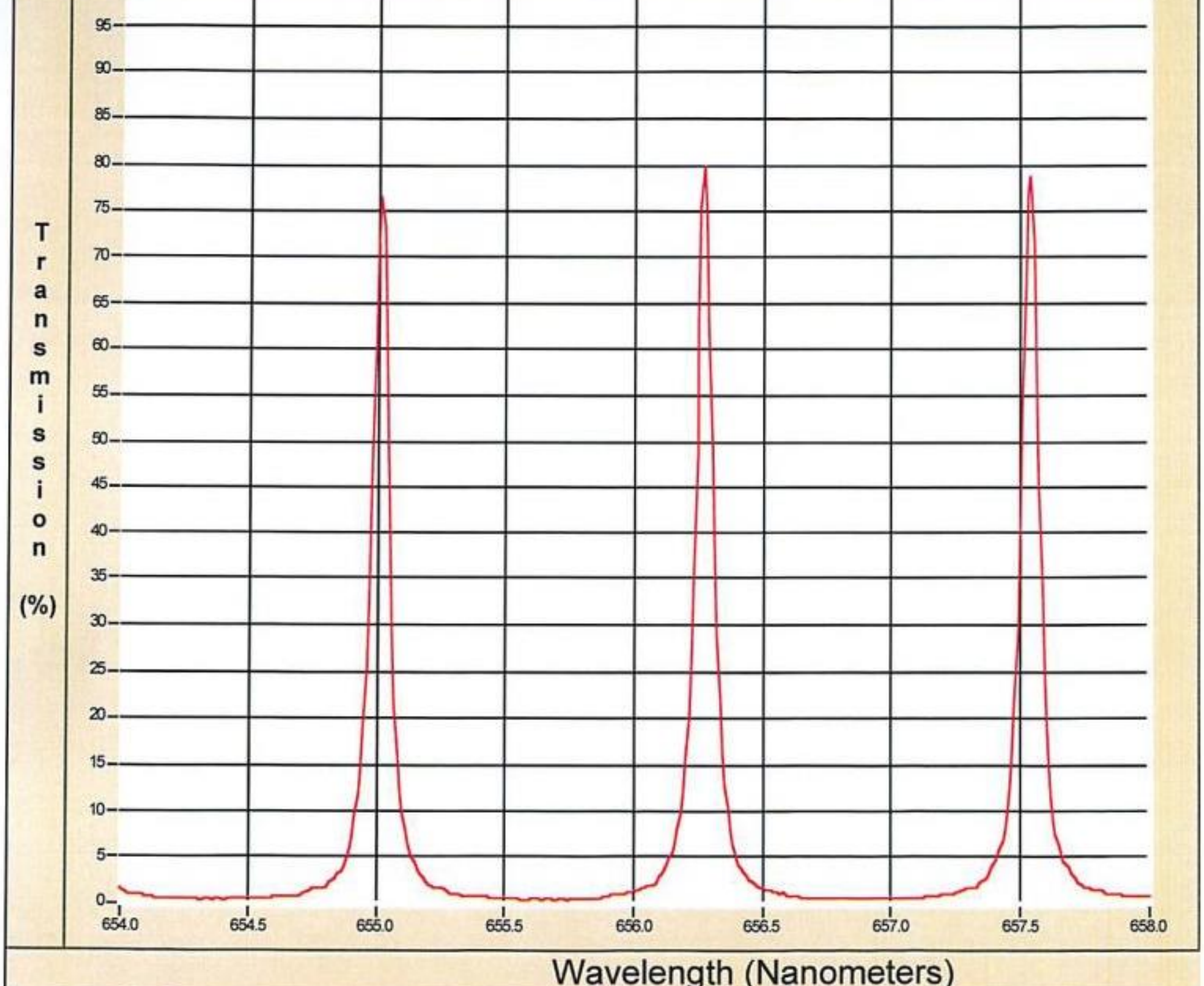
$$\Delta\lambda = \frac{\lambda_0^2}{2n_g\ell\cos\theta + \lambda_0} \approx \frac{\lambda_0^2}{2n_g\ell\cos\theta}$$

where λ_0 is the central wavelength of the nearest transmission peak and n_g is the group refractive index. The









- Lunt FSR = 12.5 Ǻ

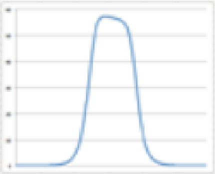
Ex: Andover 10Å pass filter for trimming

656.3nm Bandpass Filter, FWHM 1nm, 25mm dia.	656FS02-25	$267	$227	27

Center Wavelength	656.3 +0.2/-0 nm
Bandwidth	1.0+0.2/-0.2 nm
Transmission	45%
Blocking	1x10-4 avg. X-Ray to FIR
Size	25.0 +0/-0.25mm
Thickness	6.4 +0/-nom mm
Effective refractive index (n*)	2.05
Filter Type	2 (Click for profile)
CSV File (typical)	656FS02.csv

Qty	Price
1-5	$267
6+	$227

Estimated delivery: 1-2 days.
Note: Always **free ground shipping** on all domestic orders.



Click icon to display graph.

- LUNT: 6Å trimmefilter

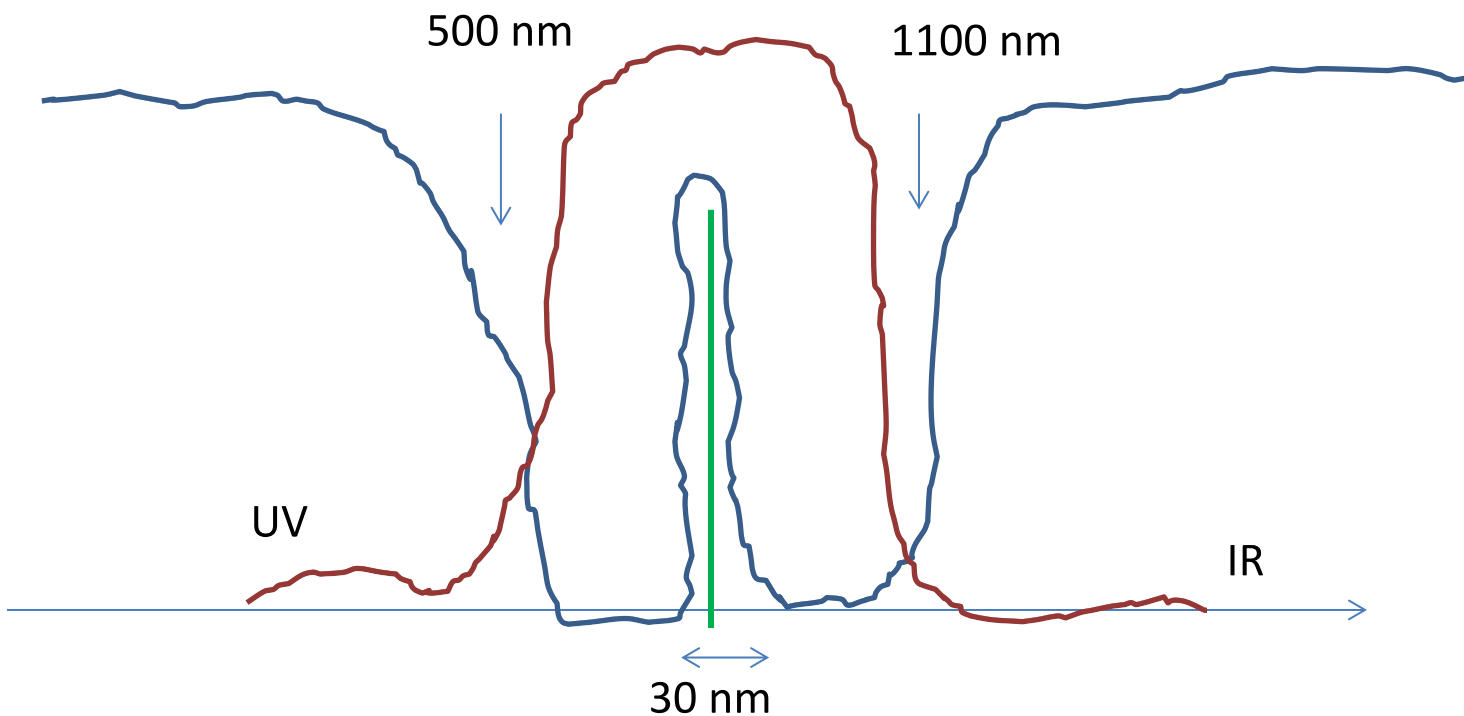
Omega filters dont have this “comb”, so don’t need trimming filter

- Tested with QCSPEC spectrograph over a few hundred Å range
- Both the primary “filter bank” with blocking + H-alpha, and the secondary “cyan” H-alpha tested
- The primary, one peak
- The secondary, one peak + some wide lobes in cyan
- These interference filters are still mainly a “black box” to me. Assuming basic FP behavior for tilt and effects of collimation

Bob's (Robert Johnson Omega Optics) info on e-Bay

- The pair is made of a Primary filter that is an assembly of an ultra-narrow FP filter with a measured bandwidth of .2 to .3 nm, attached to a discriminating band pass filter of about 30nm, and an IR attenuating filter. This assembly will only pass hydrogen alpha light, with other wavelengths attenuated to average of OD 4.0. This filter is mounted in the solar-scope in a region of highly collimated light, along with a second filter of 0.2 to .3nm, and the angles tuned to pass the Balmer Alpha line at 656.28nm.

From Roberts letter + e-Bay info we <u>guess</u> the following response curves from the three filter pairs (six interference filter assemblies) in the <u>primary</u> filter:



- This "stack" removes the basic picket fence behavior, as confirmed in the spectrograph
- The cyan filter is less well described, but no pickcet fence (in spectrograph as well) , but some lobes near H alpha (hence cyan color visually)
- Green is the ultra narrowband pair (as for the secondary)

Effekt av tilt og ukollimert strålebunt på filterprofilen

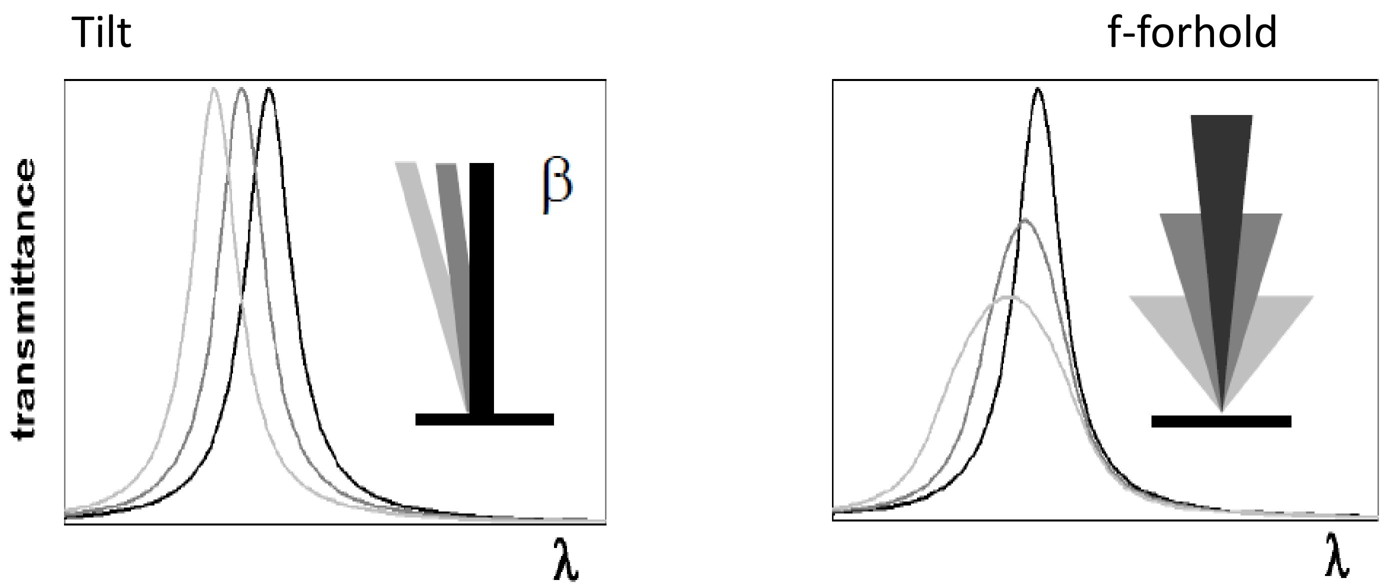


Fig. 9: Influence of angle shift and divergence angle on bandwidth and peak transmittance of a FPF

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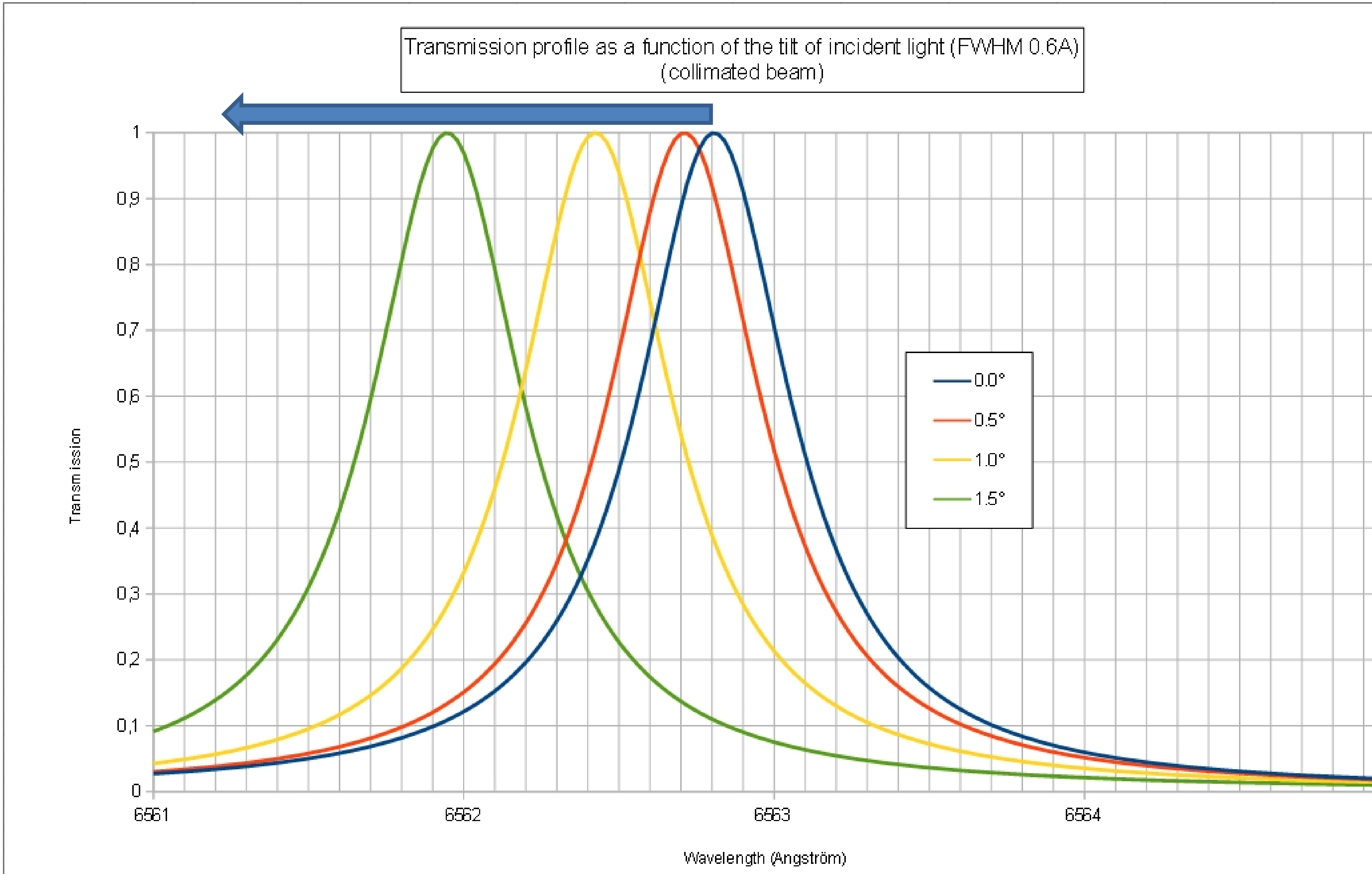
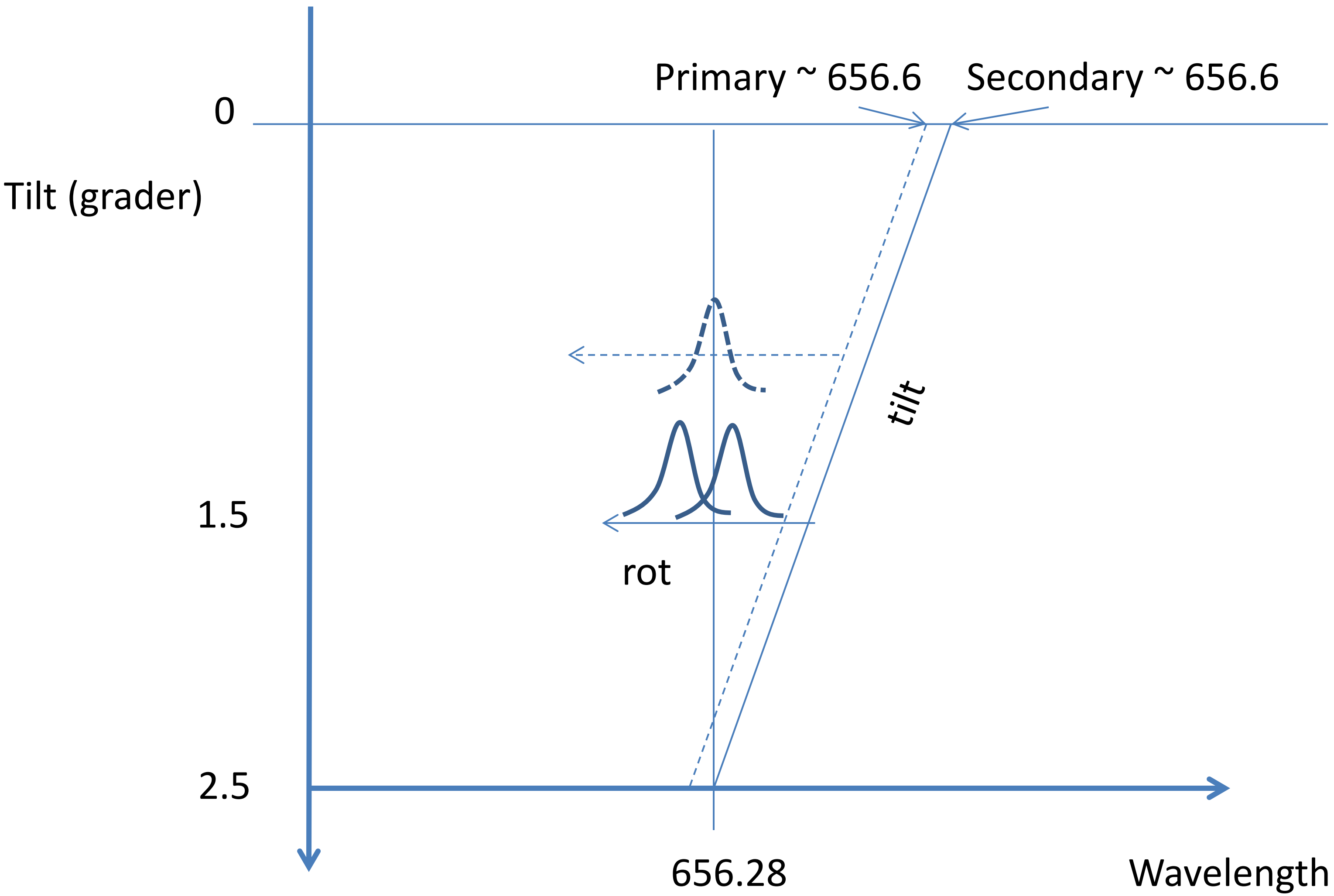
Filter tilt example

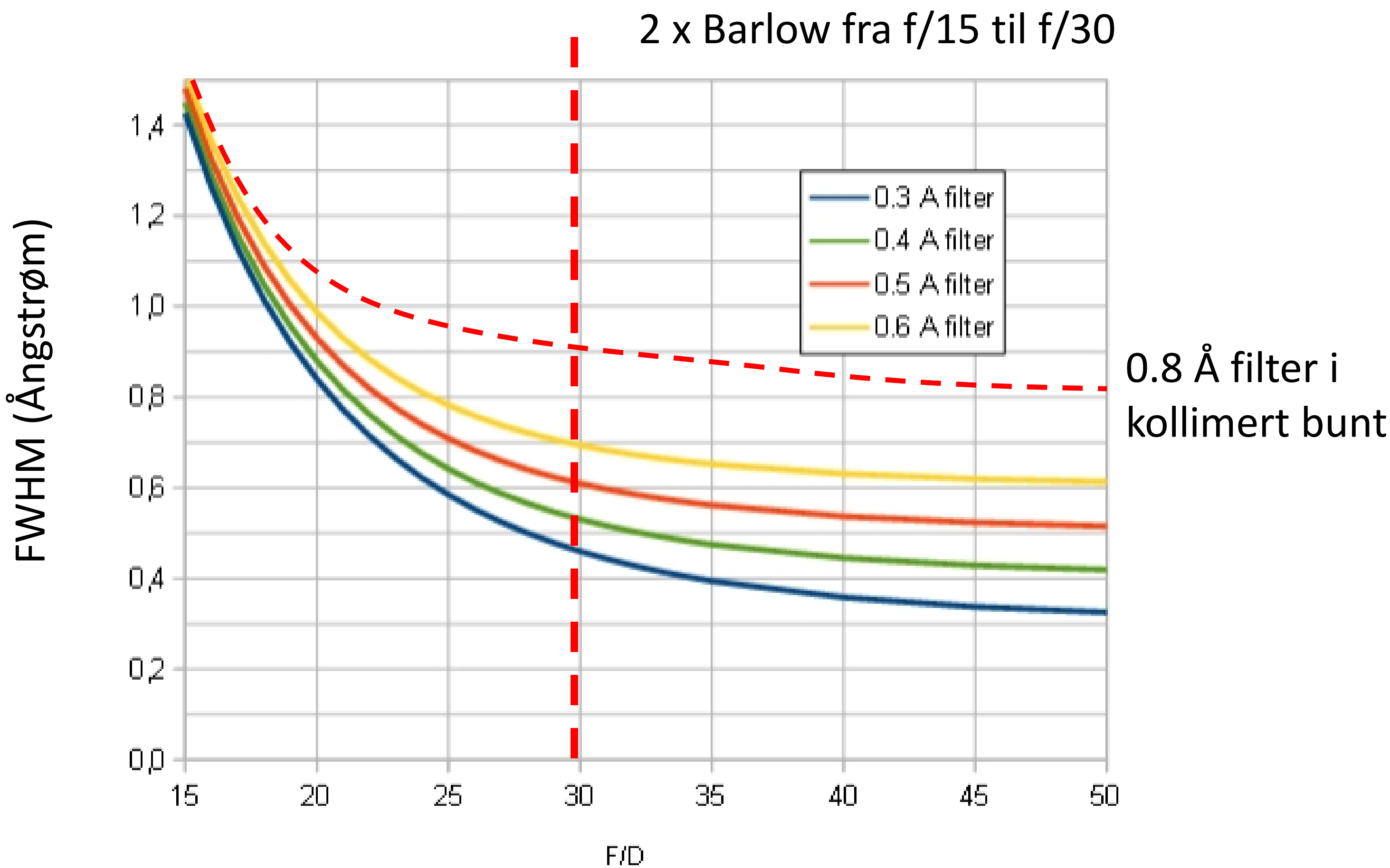
http://www.astrosurf.com/



Effekt av tilt & rotasjon på transmisjonsprofiler

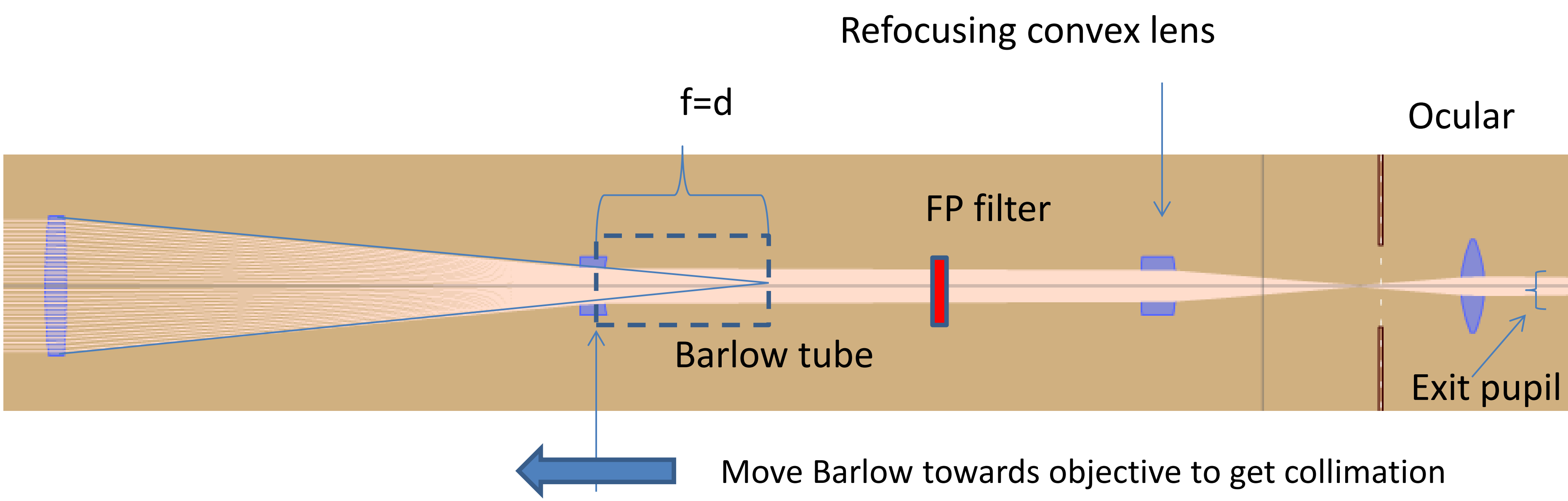


Ukollimert strålebunt:
Økt FWHM (filterbredde) for lavere f-forhold, F/D



Mindre forbedringer i FWHM for f >30

Optimal configuration with collimator

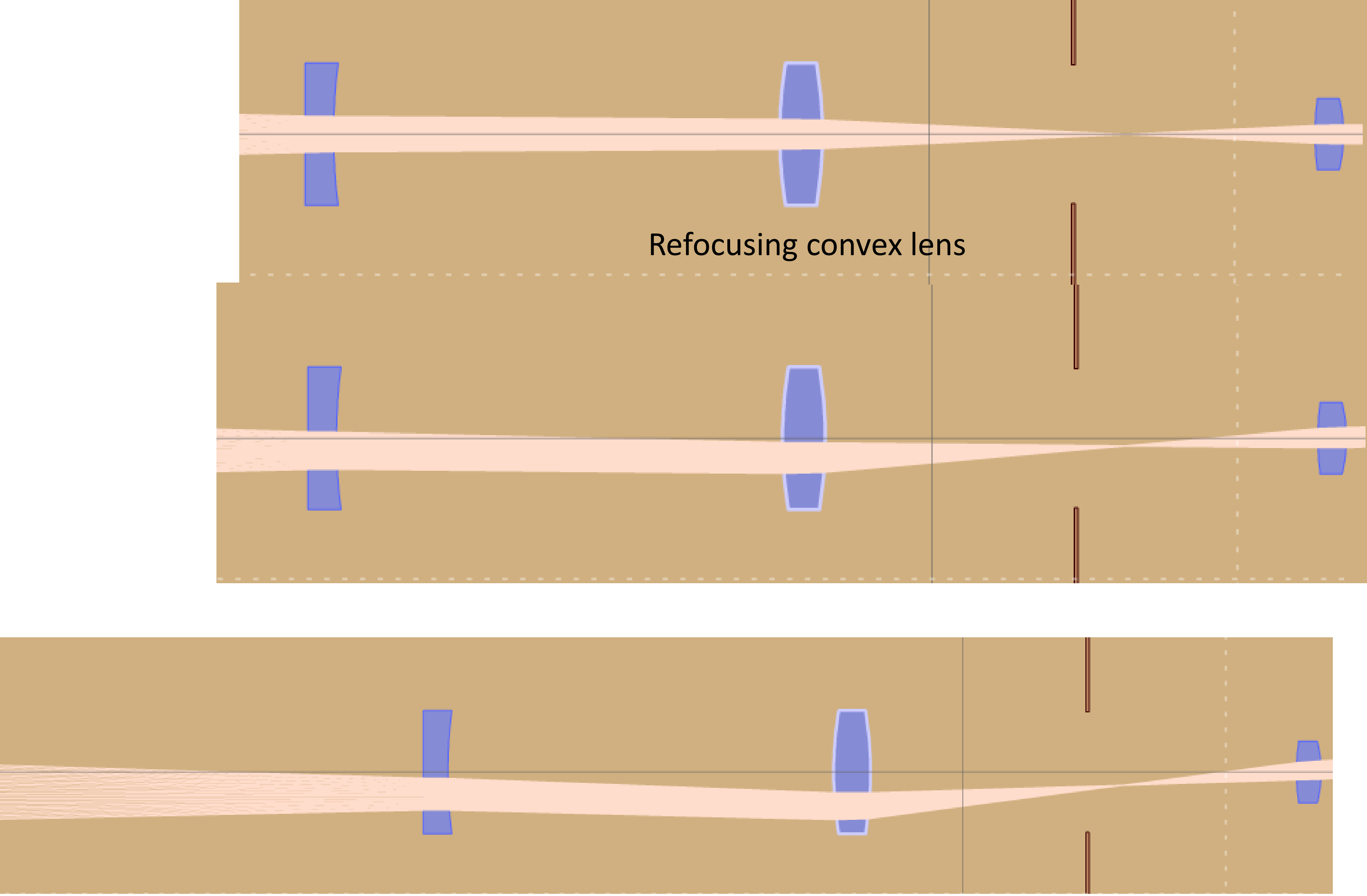


Collimation/parallel rays occurs when Barlow placed within prime focus at a distance **d equal to the focal length f** of the Barlow lens

Will now need a refocusing lens, to enable viewing
Use small telescope with focus @infinity (includes ocular)
Adjust Barlow to focus, will then have collimated beam!

Parallel rays into the eye (or almost, enabling focus on retina)

- **On-line ray tracing program:** http://nagykrisztian.com/synthrays/
- http://nagykrisztian.com/synthrays/synthrays.html

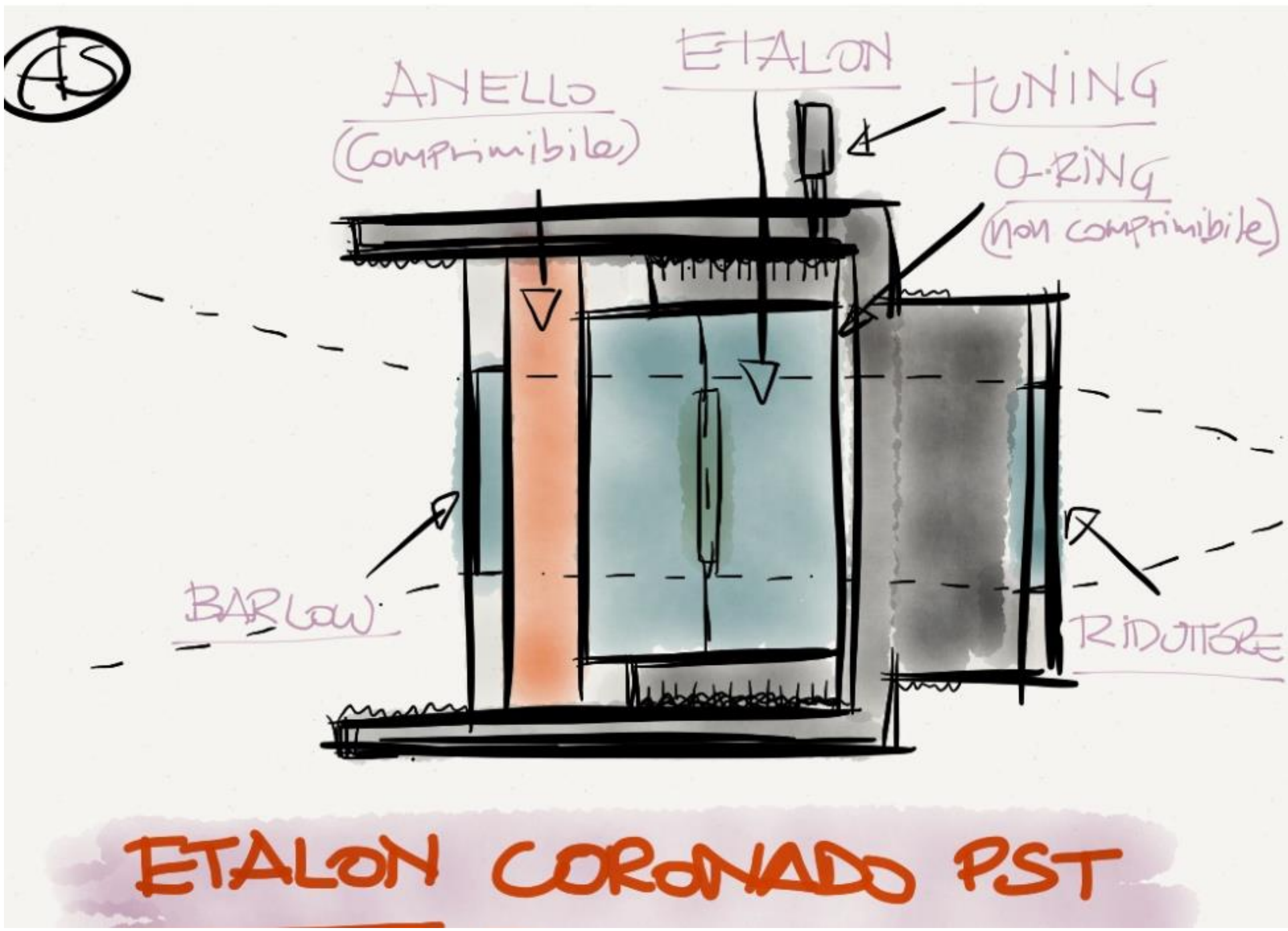


- 0,0.1,0.2 degrees off axis. Near parallel but slanted beam, so will not get same filter response over solar disk

Issues with moving Barlow far inside the telescope focal point

- May have to make extension on Barlow tube to move lens sufficiently far towards the objective from the back opening of the scope
- Danger of introducing aberration as more lens area is used (beyond spec.)
  - Less sensitive for monochromatic?
- Truncation of light cone from objective
  - Less sensitive for higher f-ratio of objective

Coronado Personal Solar Telescope has similar Barlow collimation setup



- https://observingthesun.wordpress.com/double-stack-con-etalon-del-pst/

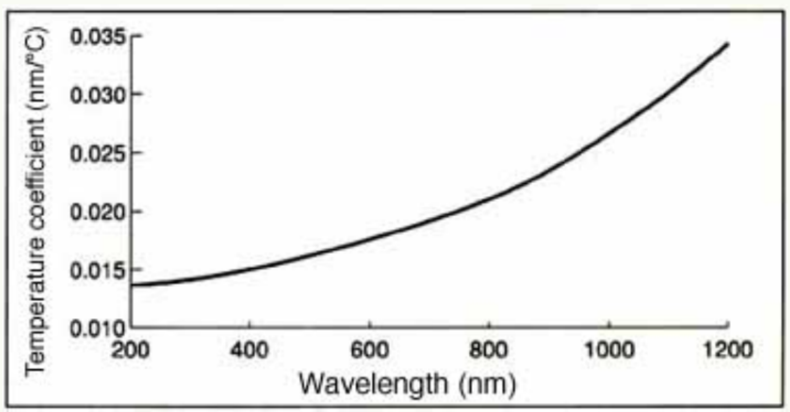
Temperature sensitivity of Omega filter

- 0.03 nm/centigrade = 0.3 Å/centigrade
- So that's quite sensitive!

From the Andover site
https://www.andovercorp.com/technical/bandpass-filter-fundamentals/
This is only about 0.02 nm / centigrade around H-alpha:

Wavelength Shift With Temperature

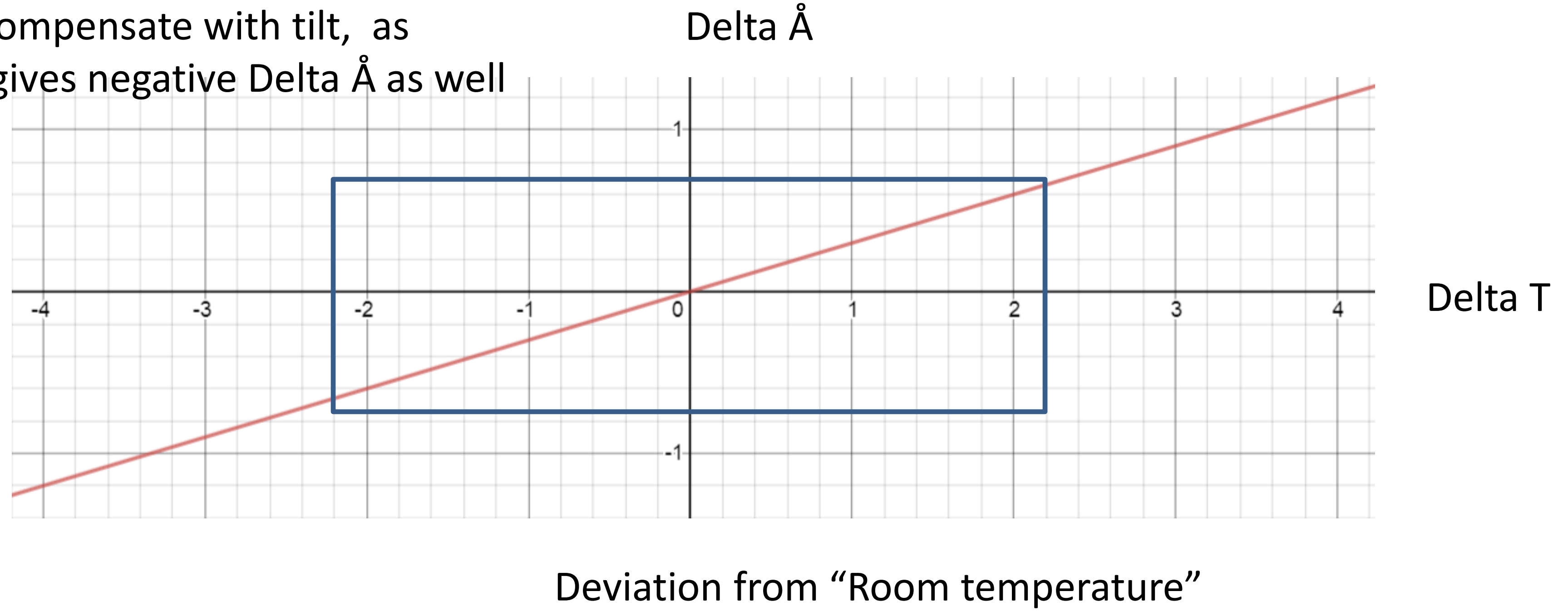
The center wavelength of an interference filter will shift linearly with changes in ambient temperature, therefore it is very important to specify the operating temperature when ordering. The wavelength shifts in the direction of the temperature change, up with a positive change and down with a negative change. This shift factor will vary depending upon the filter's initial center wavelength. Please refer to the following chart for the proper temperature coefficient.



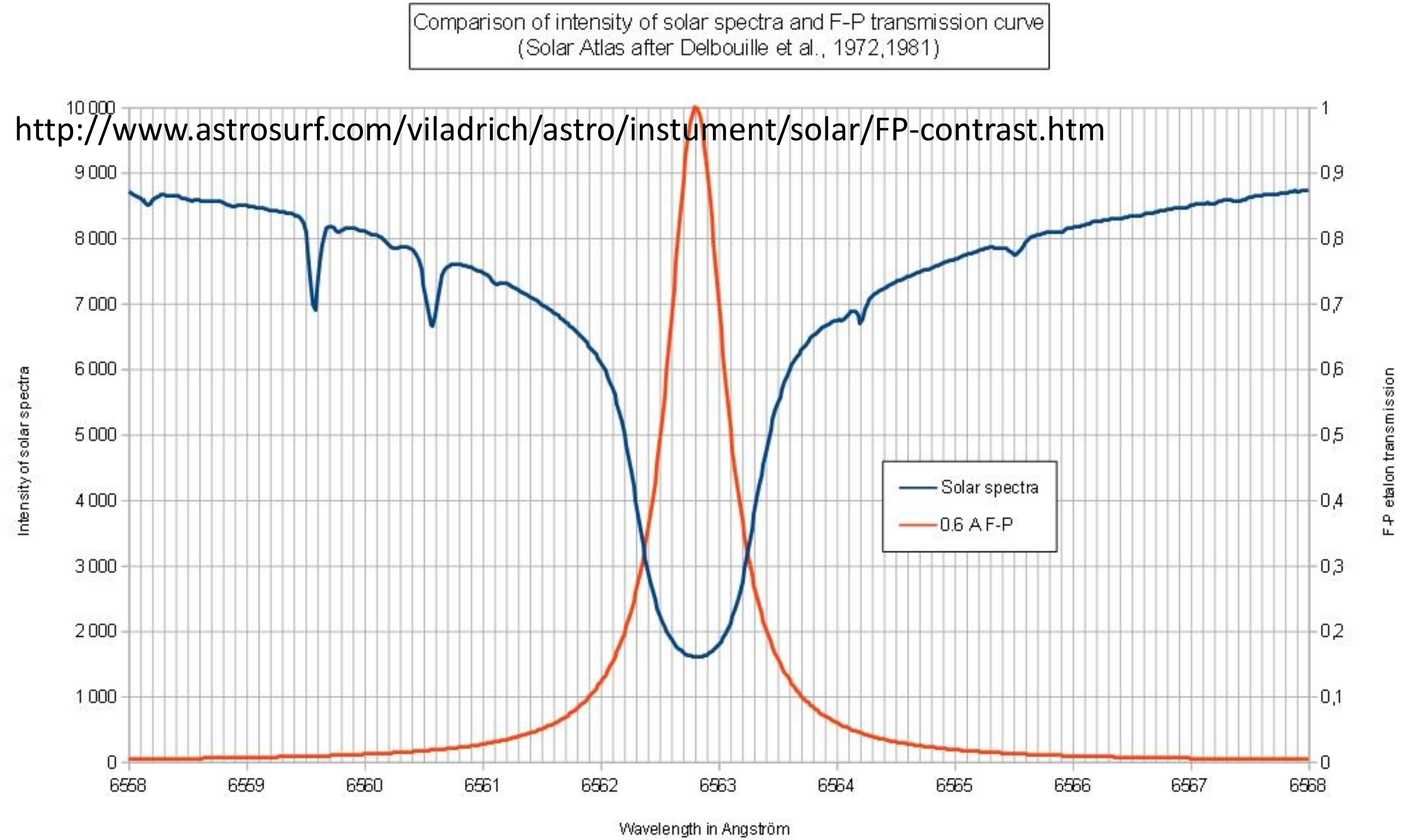
To reduce the chance of damage due to thermal shock, we recommend a maximum operating temperature of 70°C, and a maximum temperature change of 5°C per minute.

0.3 Å/centigrade for the Omega filters

Lower T can be impossible
to compensate with tilt, as
tilt gives negative Delta Å as well



- Quark: the Etalon is heated to approximately 100-150°F to control the pasband wavelength, rater than tilt-tuning
- Should operate in the range +/- 2 degrees for +/- 0.5 Å
- Temp for Omega measurements not specified, assume 20 Celsius (Room temp)!



- About 1 Å uncertainty or error may shift the filter peak from the core to the wings, rendering H-alpha structures invisible
- This implies about MAX +/- 3 degrees deviations from calibration temperature for the Omega filters
- Temperature control may be necessary, as in the Quark unit

Heating reduction

Filter Orientation

As a general rule, the highly reflective side of the filter should always face the source of radiation. This minimizes the thermal load on the absorbing glass blocking components and epoxies, thereby extending the lifetime of the filter. Apart from reduction of thermal effects, filter orientation is without influence on the spectral characteristics.

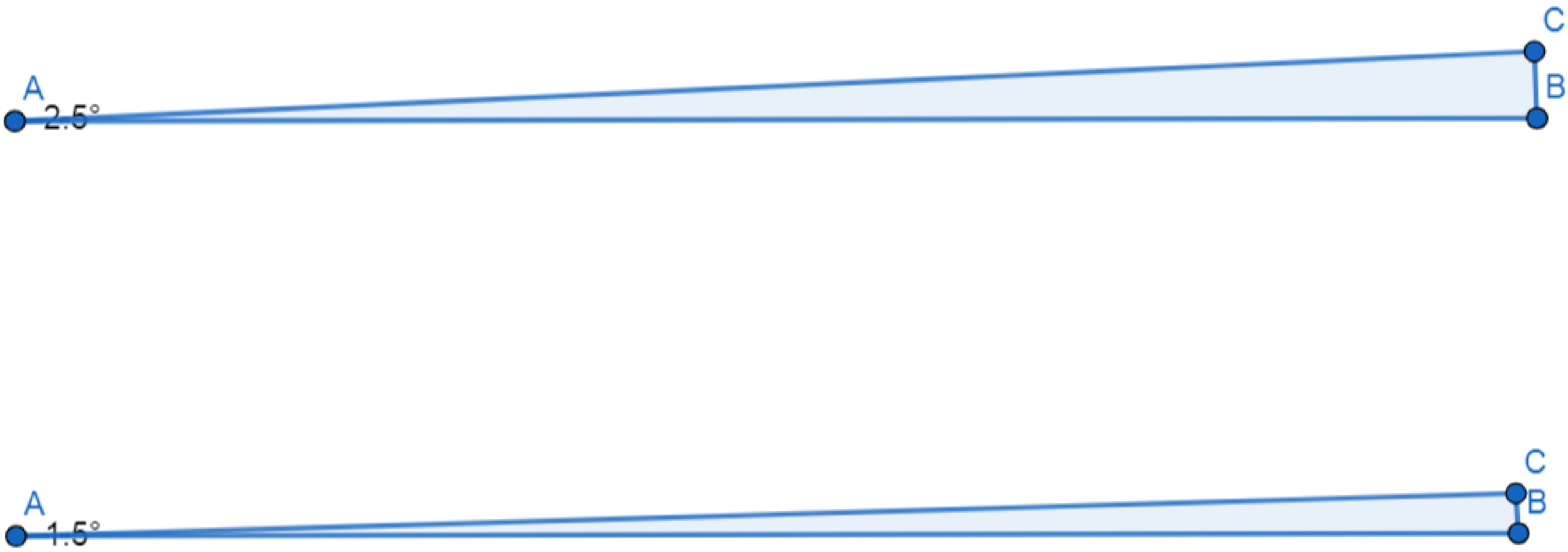
- From andover site https://www.andovercorp.com/technical/bandpass-filter-fundamentals/

- May use a narrowband filter before the etalon, say the 10nm = 100Å Edmund optics filter
- With ERF filter, this may not be necessary, unless the extra filter blocks the IR range further

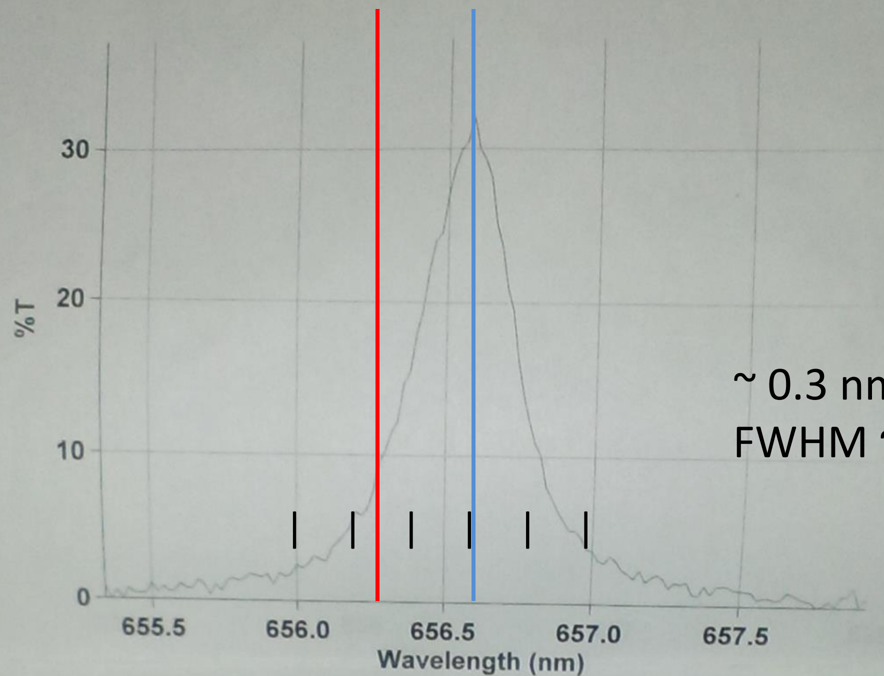
Omega filter data

- D=25mm CWL ~656.6 nm, H-alpha på 656.28 nm
- Primærfilter:
  - Total tilt 1.5 grader til 656.28 nm
  - FWHM ~ 0.4 nm
  - Blokkfilter i sort innfatning, mot sol
- Sekundærfilter
  - Tilt 2.5 grader til 656.28 nm
  - FWHM ~ 0.3 nm

2.5 & 1.5 degree tilt



- GeoGebra software



~ 0.3 nm shift
FWHM ~ 4 Å

Scan Analysis Report

Report Time : Mon 17 Apr 07:59:33 AM 2017
Batch:
Software version: 02.00(25)
Operator:

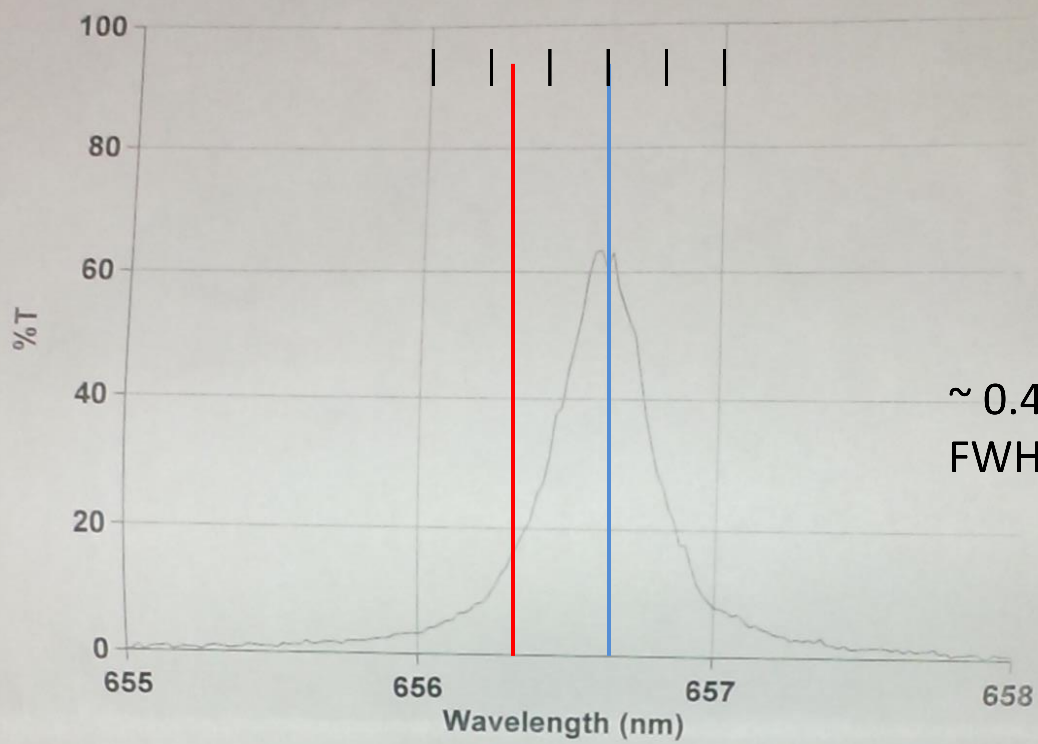
Sample Name: 656.28SC0.15 25mm primary
Collection Time 4/17/2017 7:59:50 AM

Scan Analysis Report

Report Time : Mon 17 Apr 08:00:58 AM 2017
Batch:
Software version: 02.00(25)
Operator:

Sample Name: 656.28SC0.15 25mm primary1
Collection Time 4/17/2017 8:01:01 AM

Tilt ~ 1.5°
to peak @ 656.28nm



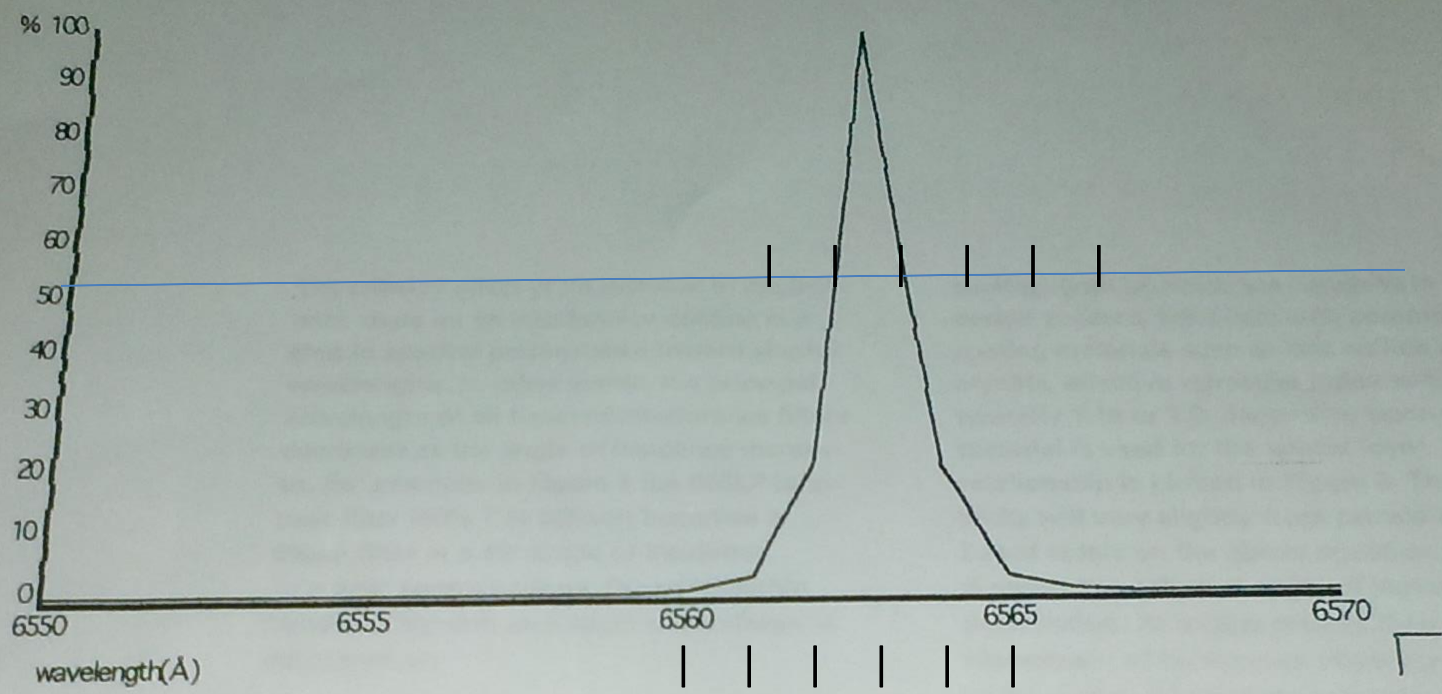
~ 0.4 nm shift
FWHM ~ 3 Å

Scan Analysis Report

Report Time : Mon 17 Apr 08:10:26 AM 2017
Batch:
Software version: 02.00(25)
Operator:

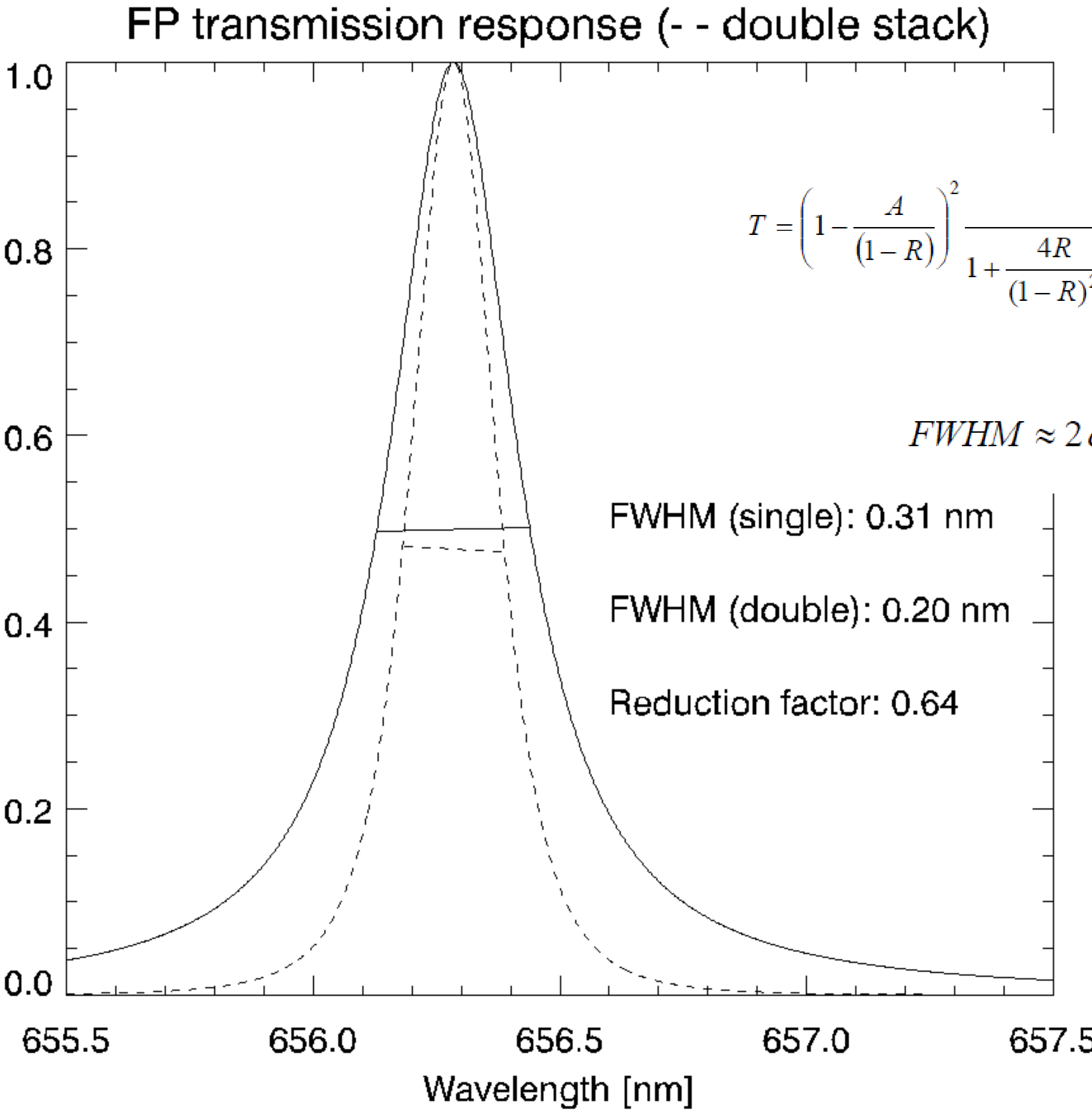
Sample Name: 656.28SC0.15 25mm Secondary3
Collection Time 4/17/2017 8:10:29 AM

Tilt ~ 2.5° to
peak @ 656.28 nm



Double stack: FWHM ~1 Å

Theoretical performance of both primary & secondary passband.

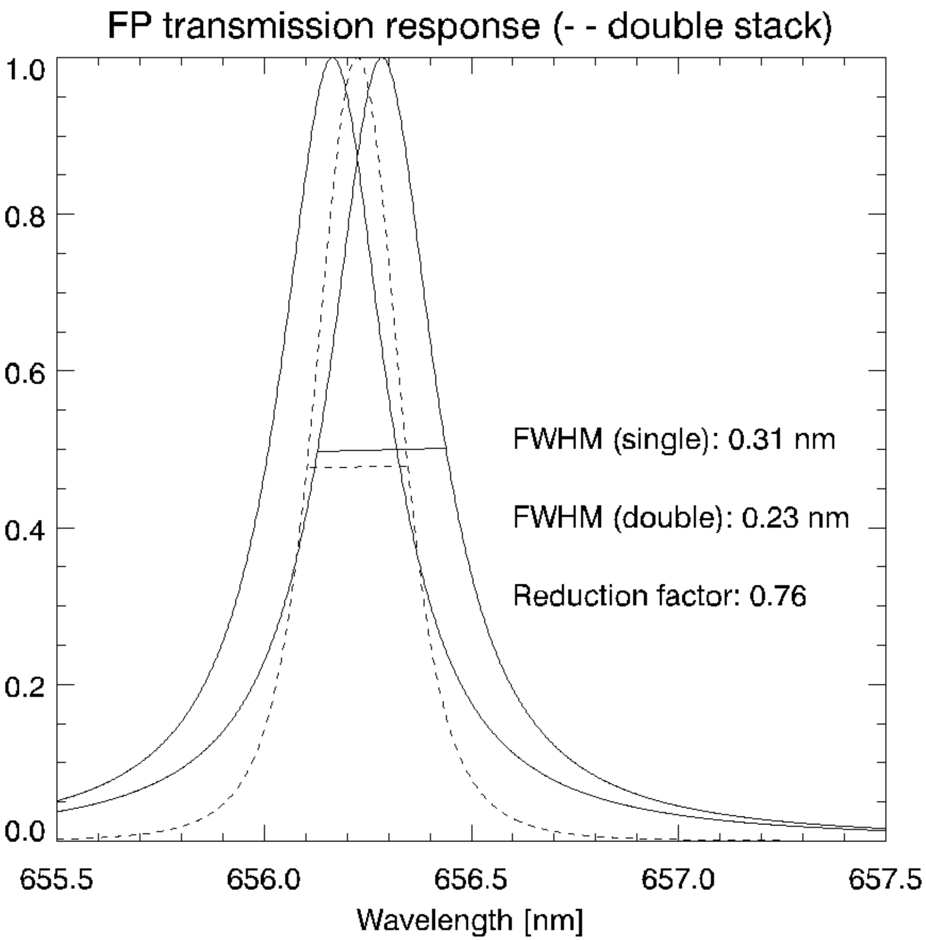


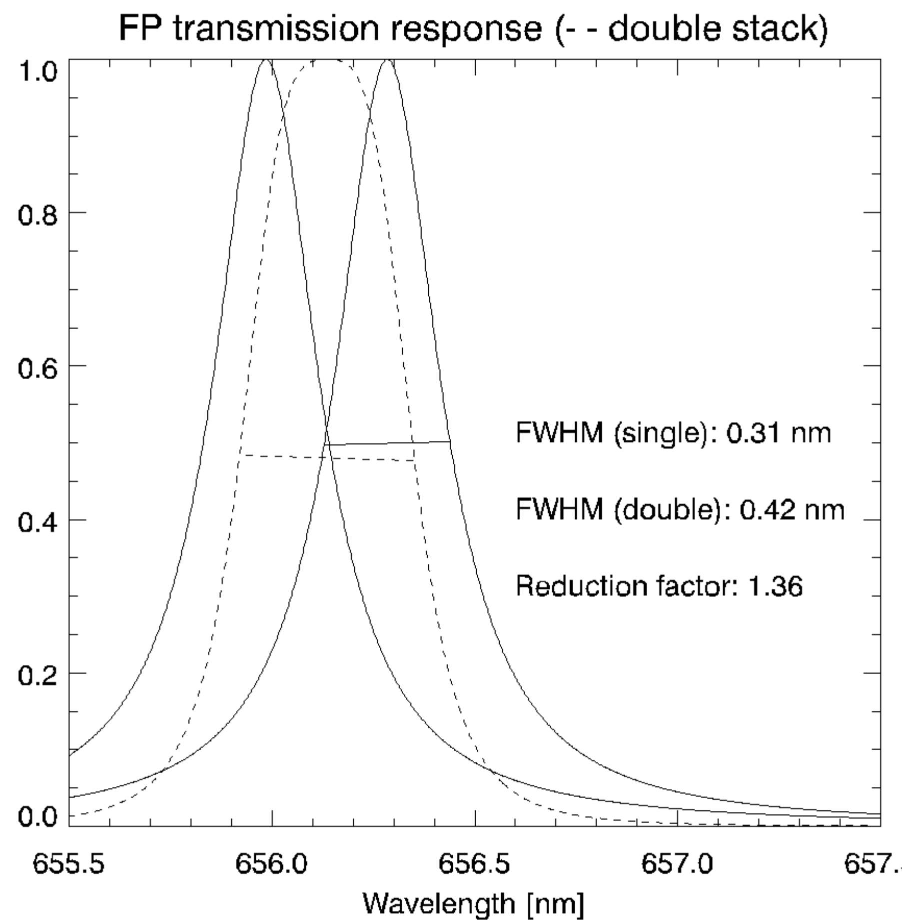
$$T = \left(1 - \frac{A}{(1-R)}\right)^2 \frac{1}{1 + \frac{4R}{(1-R)^2}\sin^2\left(2\pi nd\frac{1}{\lambda}\cos\beta - \phi\right)} \qquad (2)$$

$$FWHM \approx 2d\left(\frac{1-R}{\pi\sqrt{R}}\right) \qquad (3)$$

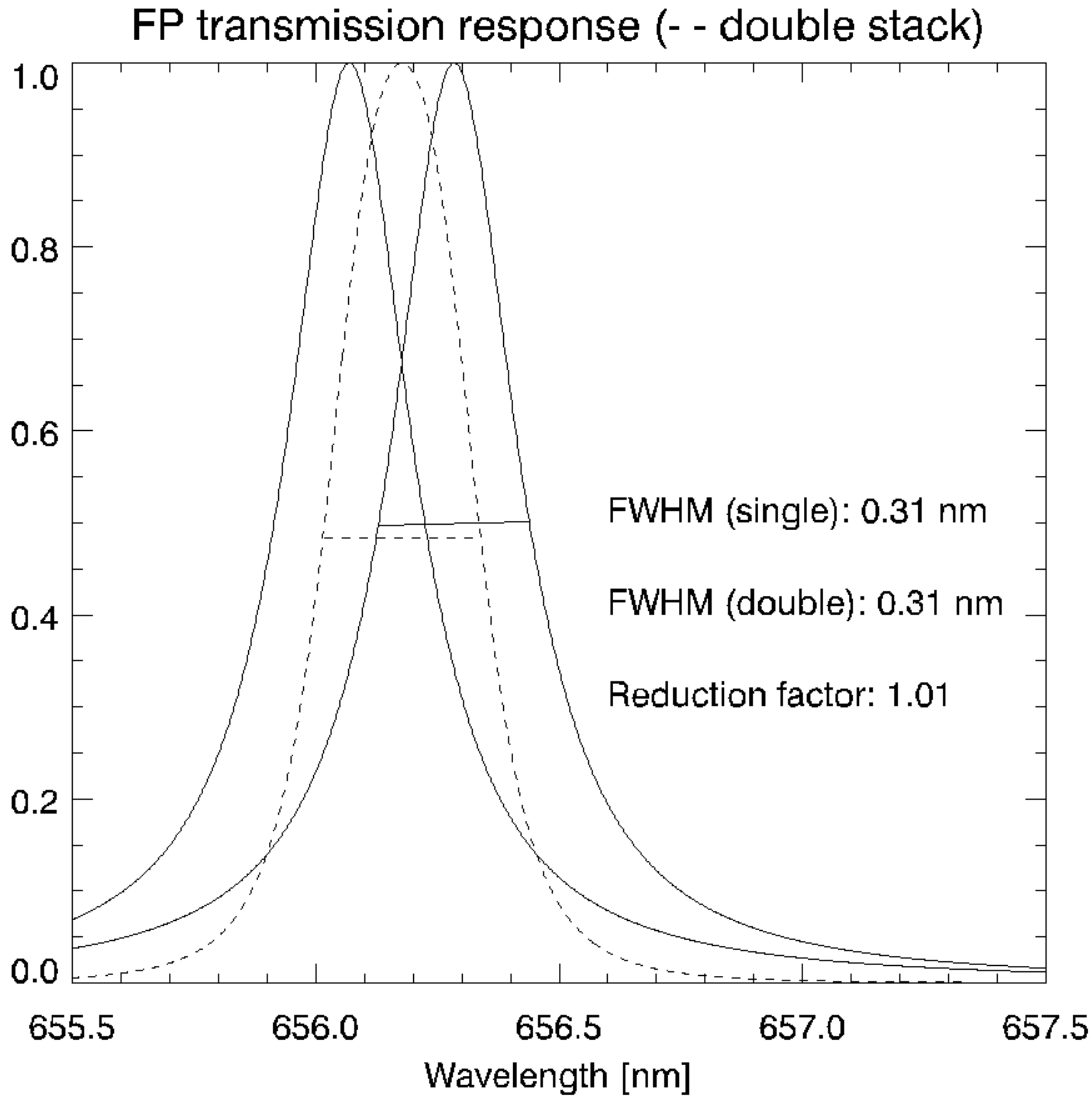
- Tuning the coefficients to match the measured responses approximately
- Narrowest passband by centering the filters relative to each other
- Approximately 2 Å FWHM (full width half max) can be achieved with double stacking two 3 Å filters
- 1 Å as stated is too optimistic/unrealistic

Non-centered gives larger FWHM



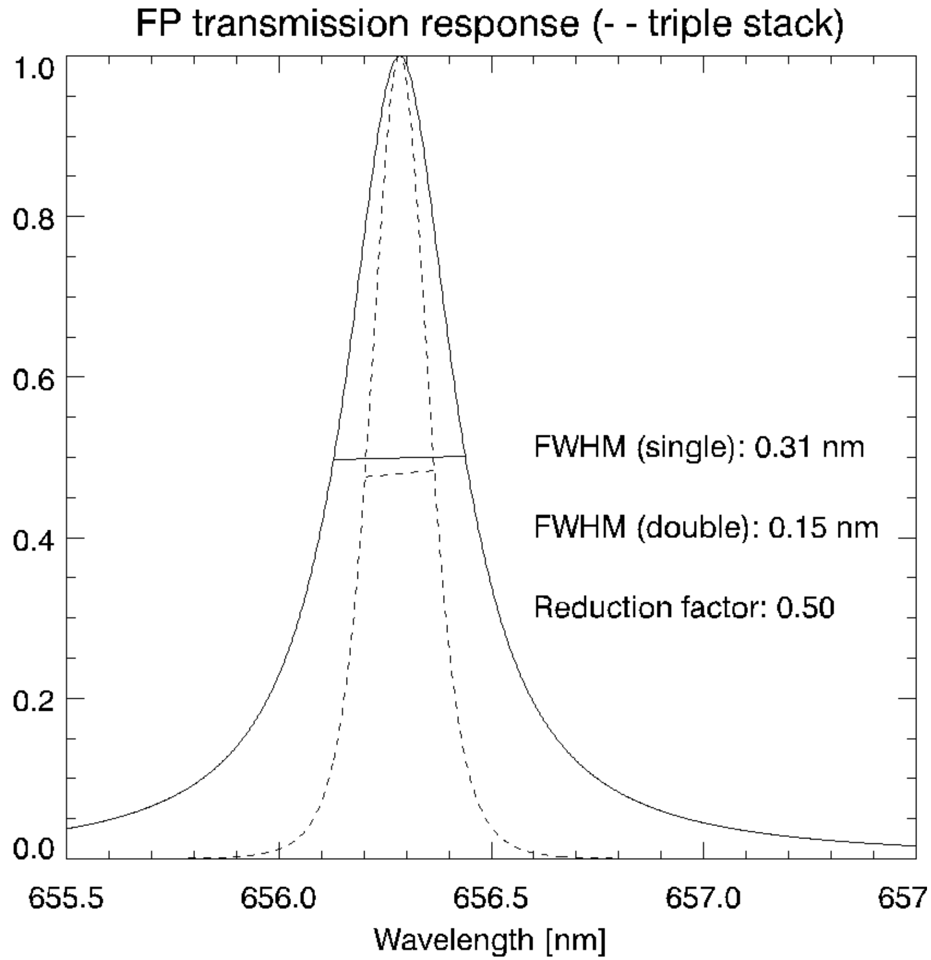


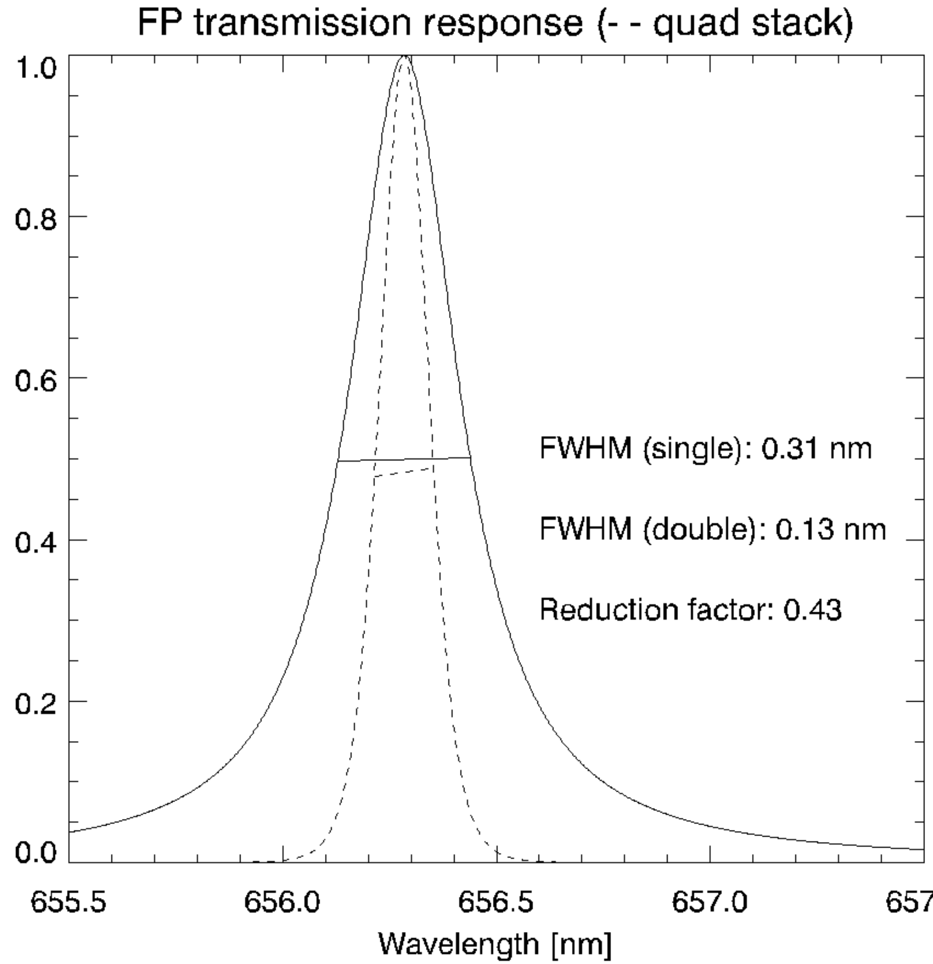
- Worse performance with larger relative shifts
- Double stacking gives even worse performance than a single filter, above a certain shift!

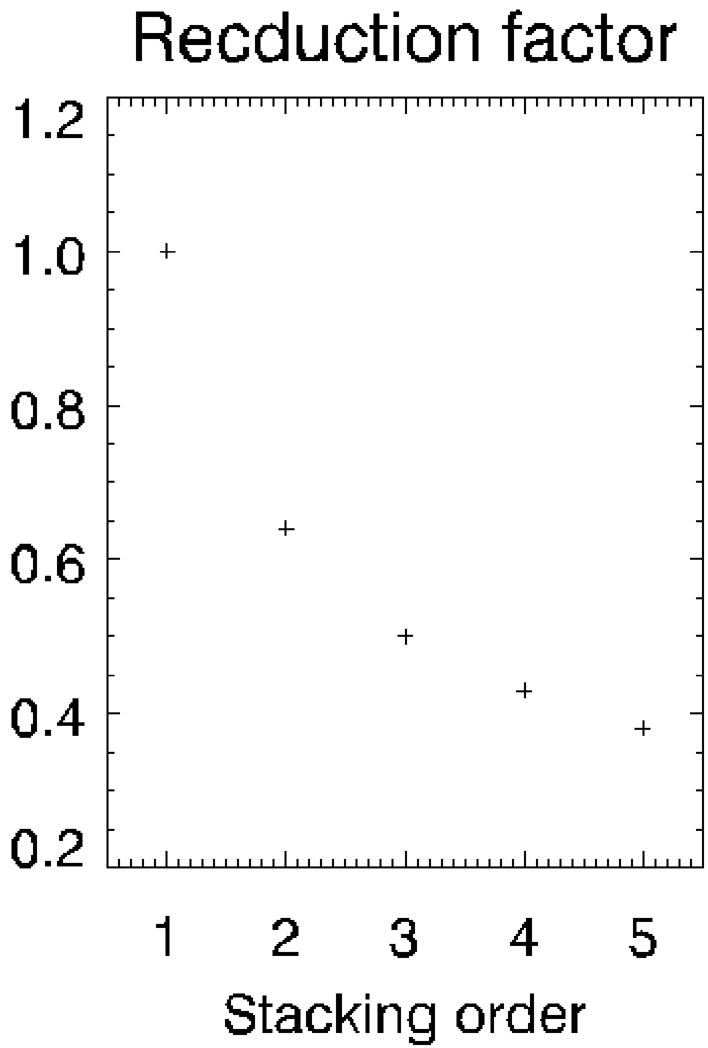


- Shift tuned to give same FWHM
- Double stacking gives steeper flanks (more box-shaped response)
- That is an improvement in filter steepness, but not the bandwidth

Multi-stacking

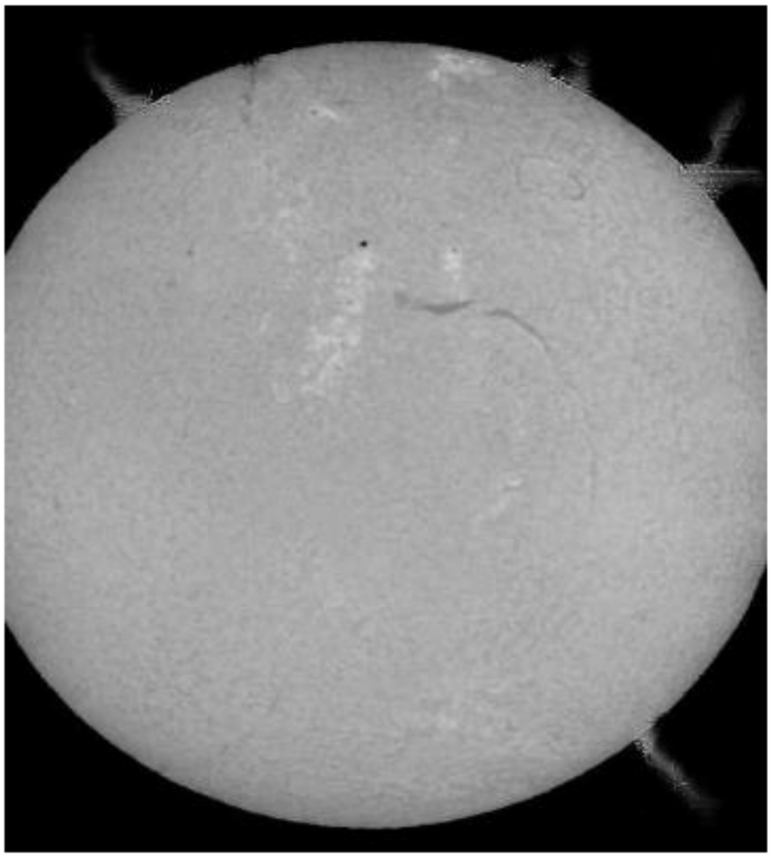




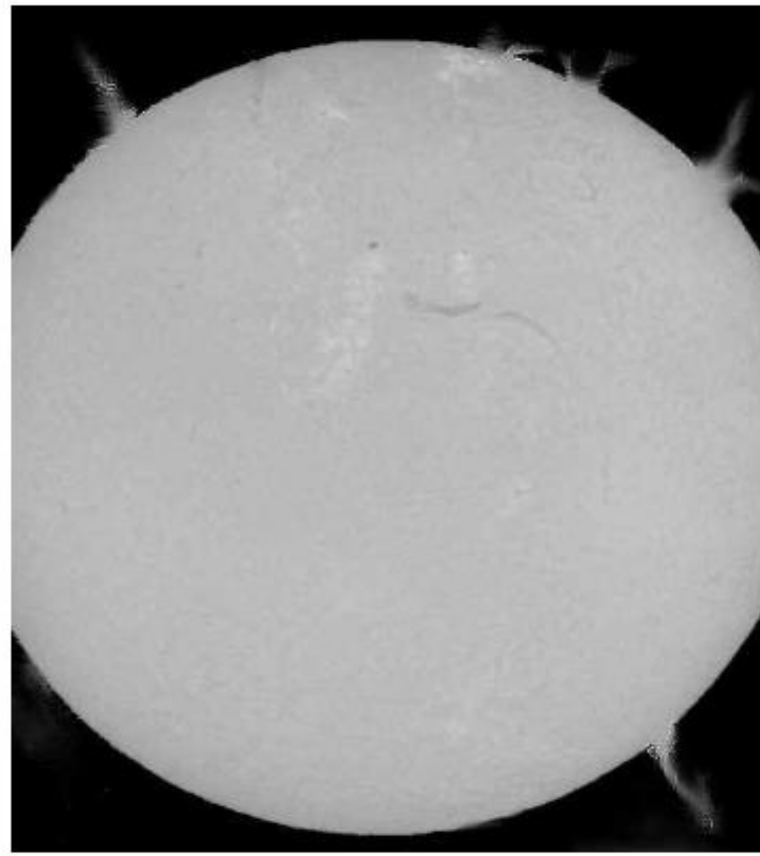


- The five-fold stack gives a reduction factor of 0.38
- Significant improvement with increasing stacking order from 2 to 3
- Not much to gain above order 4 (unless we use a very costly large order)
- Can achieve FWHM = 2Å, 1.5Å, 1.3 Å with double, triple, quad stack, respectively

FWHM at ~0.8-1.0 Å bandwidth is still primarily a prominence detector

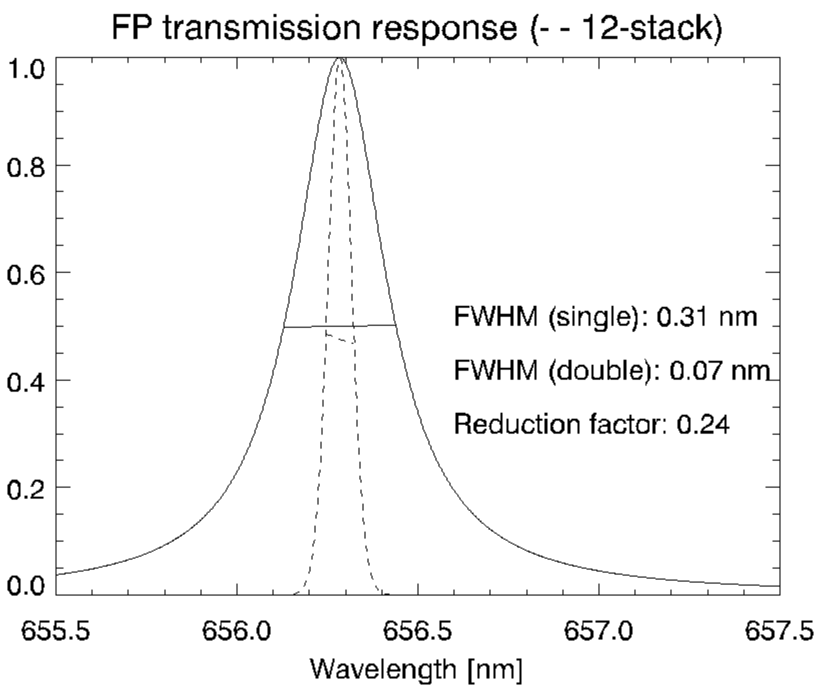


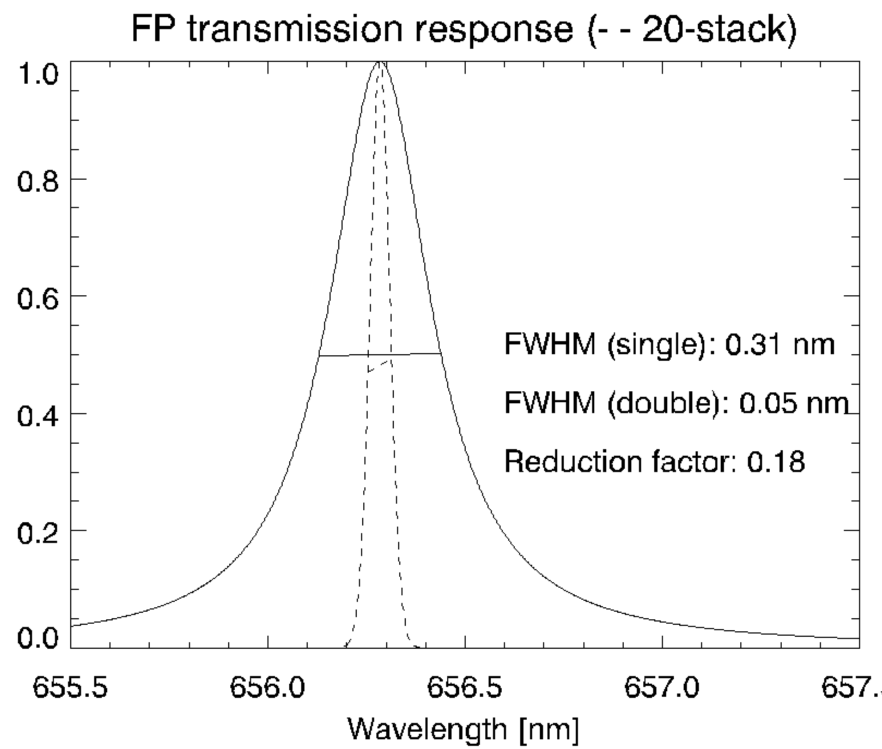
0.7Å Bandpass (20,435bytes)



0.95Å Bandpass (15,872 bytes)

Narrowband versions possible?



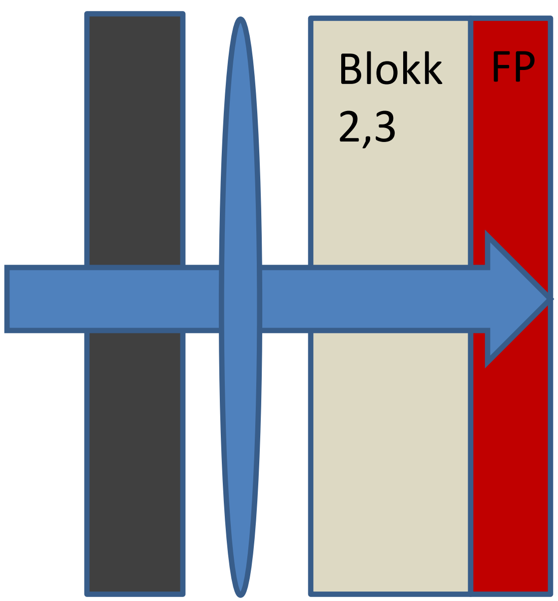


- 12/20 Omega filters would be needed for FWHM=0.7/0.5Å

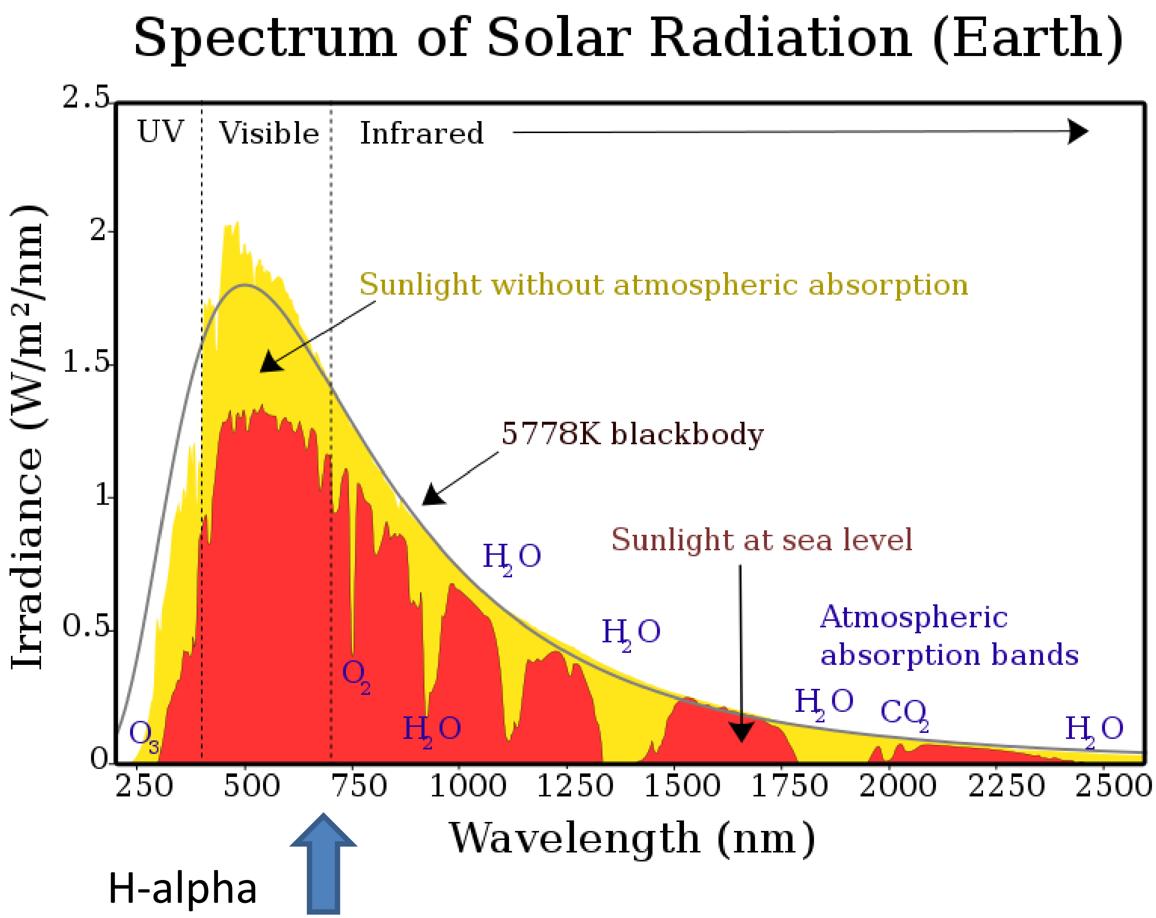
Konstruksjon

Sikkerhetstiltak: alt sollys må vekk før FP filtre bortsett fra H-alpha

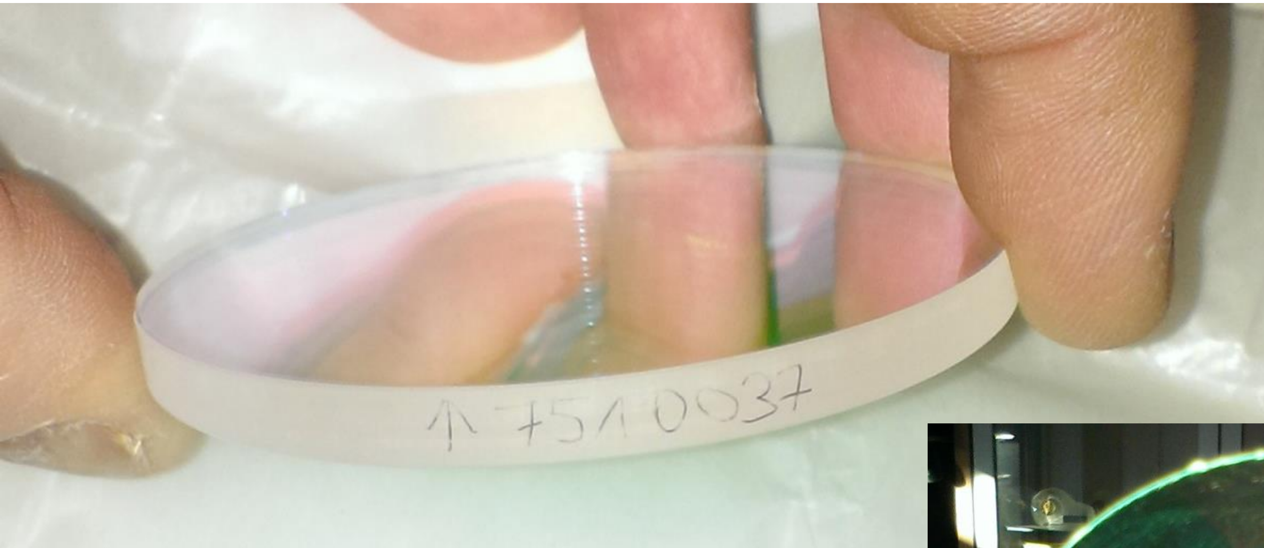
1. Energy rejection filter (ERF) in front of main lens
2. IR blocking
3. Bandpass



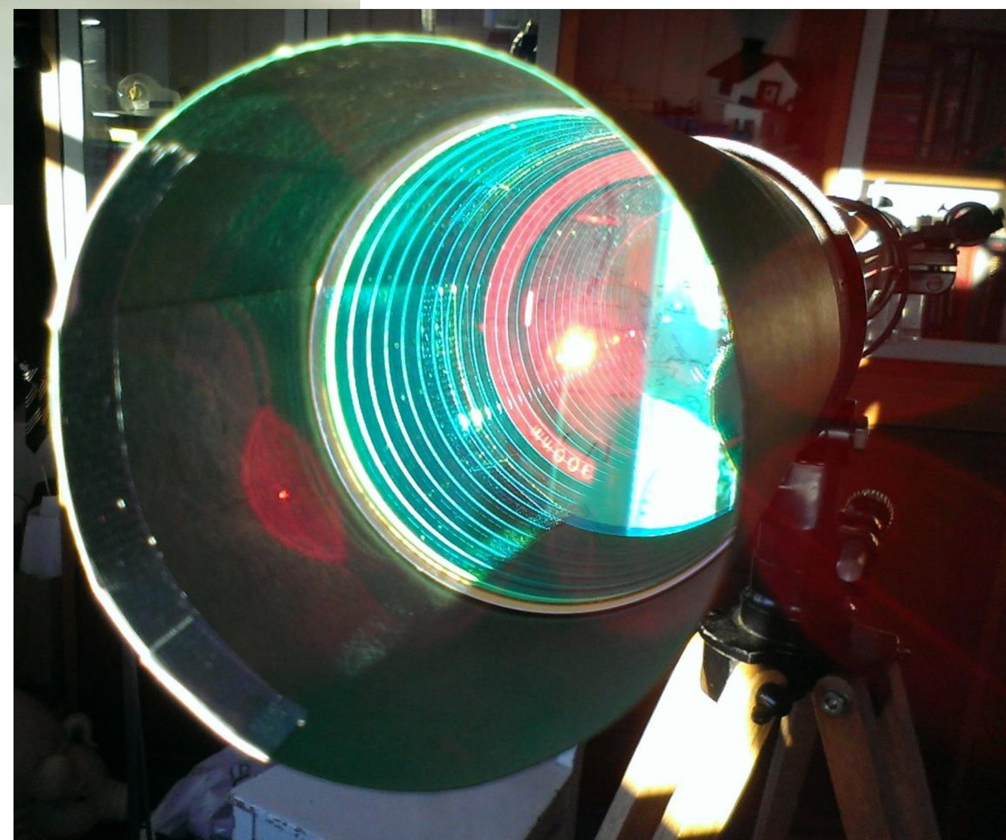
ERF, 1



Baader ERF montering



Pil mot sol, serienummer 7510037

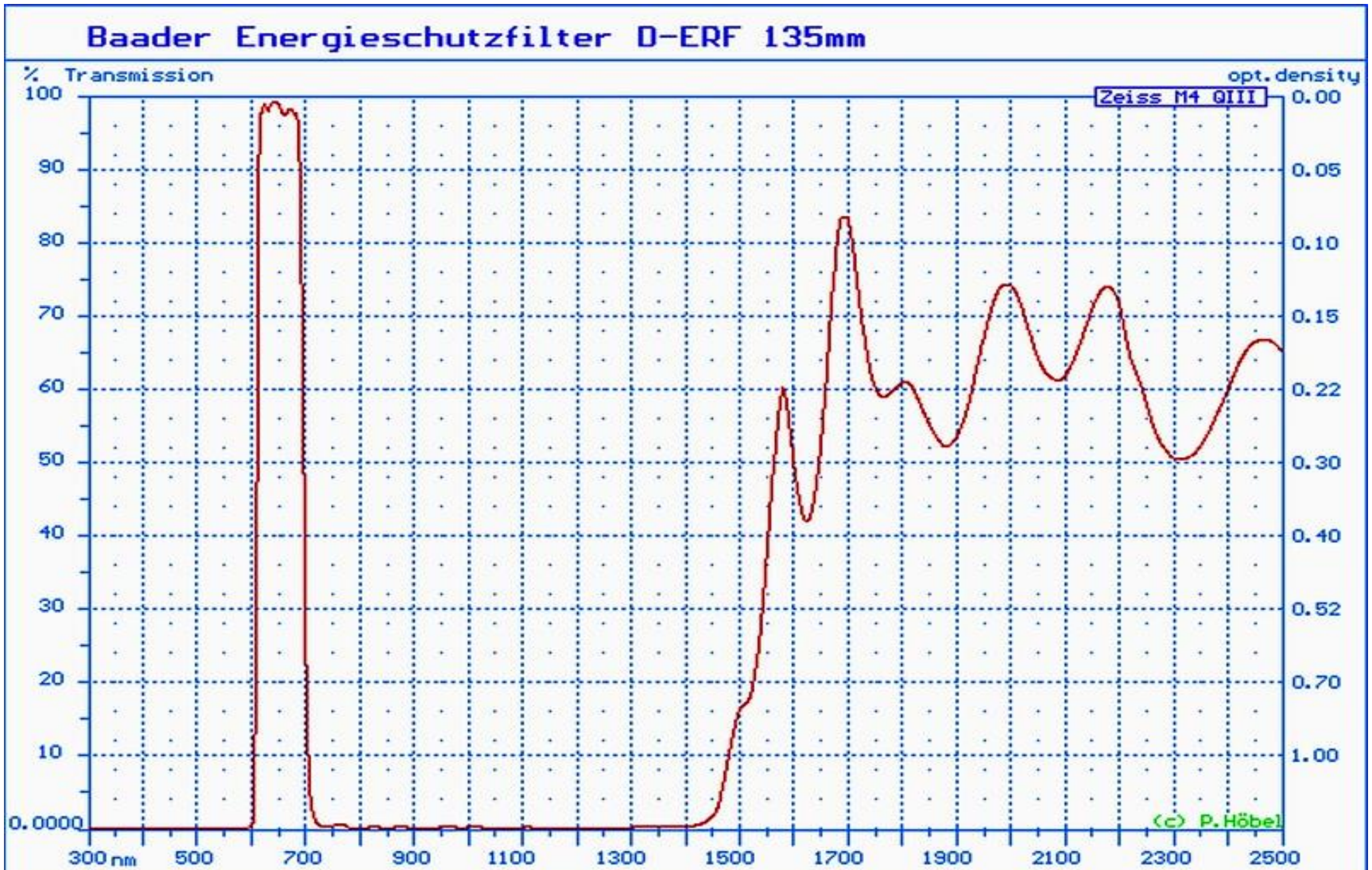


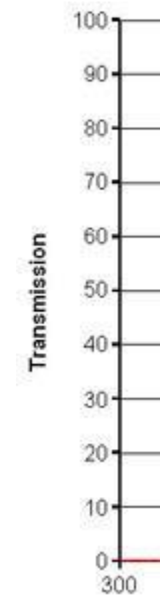
- Tape + papp

Baader D-ERF (not safe in IR > 1500 nm!)

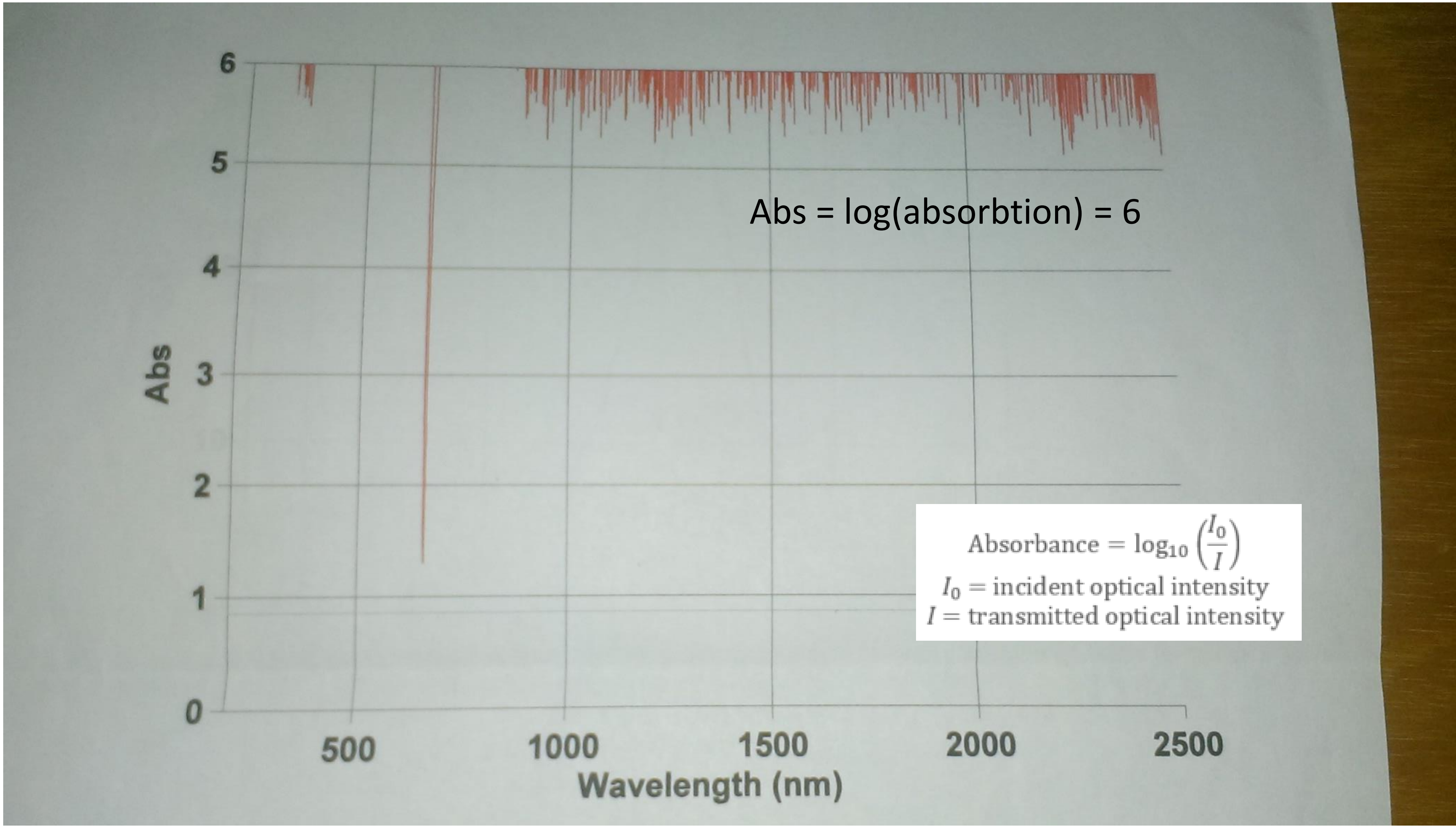
- **231 EUR**. BULK ENERGY REJECTION filter
- Dielectric Energy Reflection Filter 75 mm (5,0 mm thick / Ø 75 mm ± 0,05 mm)
- This reflects from 280 nm up to 1500 nm, while leaving a 45nm-wide spectral window around H-alpha
- GOLDEN SIDE TO THE SUN; BLUE SIDE TOWARDS THE SCOPE

Transmission





H-alpha primær-filteret: IR blokkering også over 1500 nm + ~30 nm = 300 Å båndpass

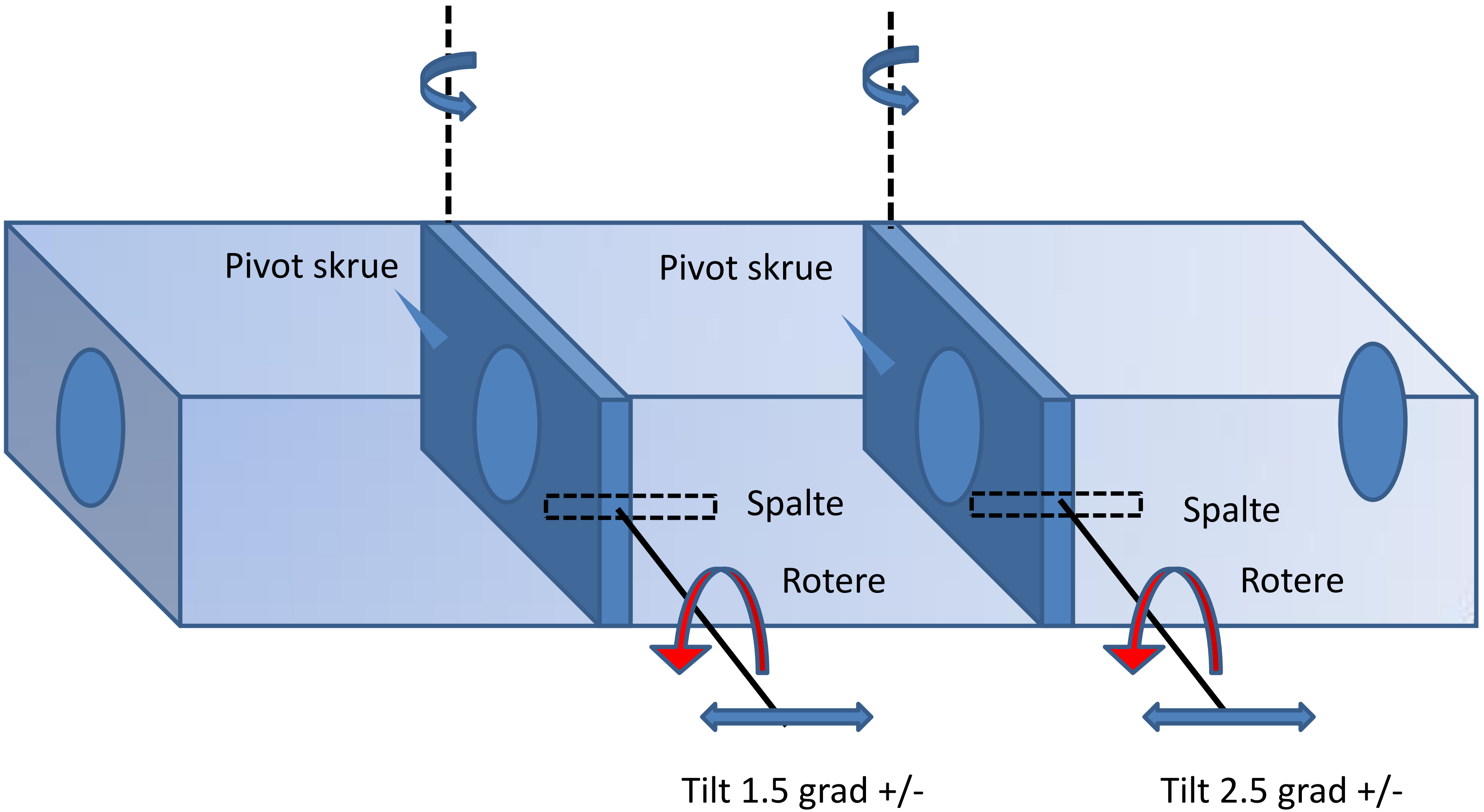


$$\text{Absorbance} = \log_{10}\left(\frac{I_0}{I}\right)$$

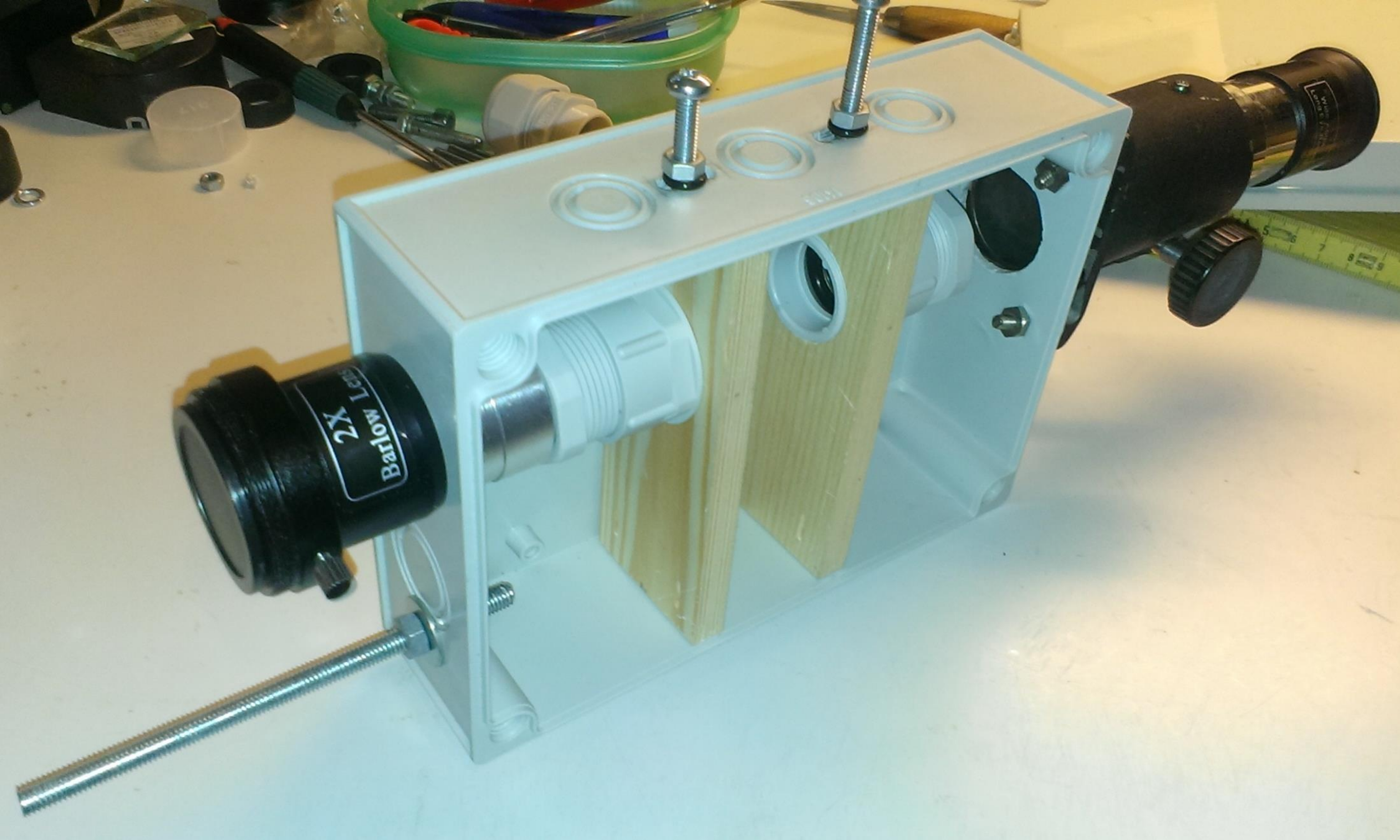
I_0 = incident optical intensity

I = transmitted optical intensity

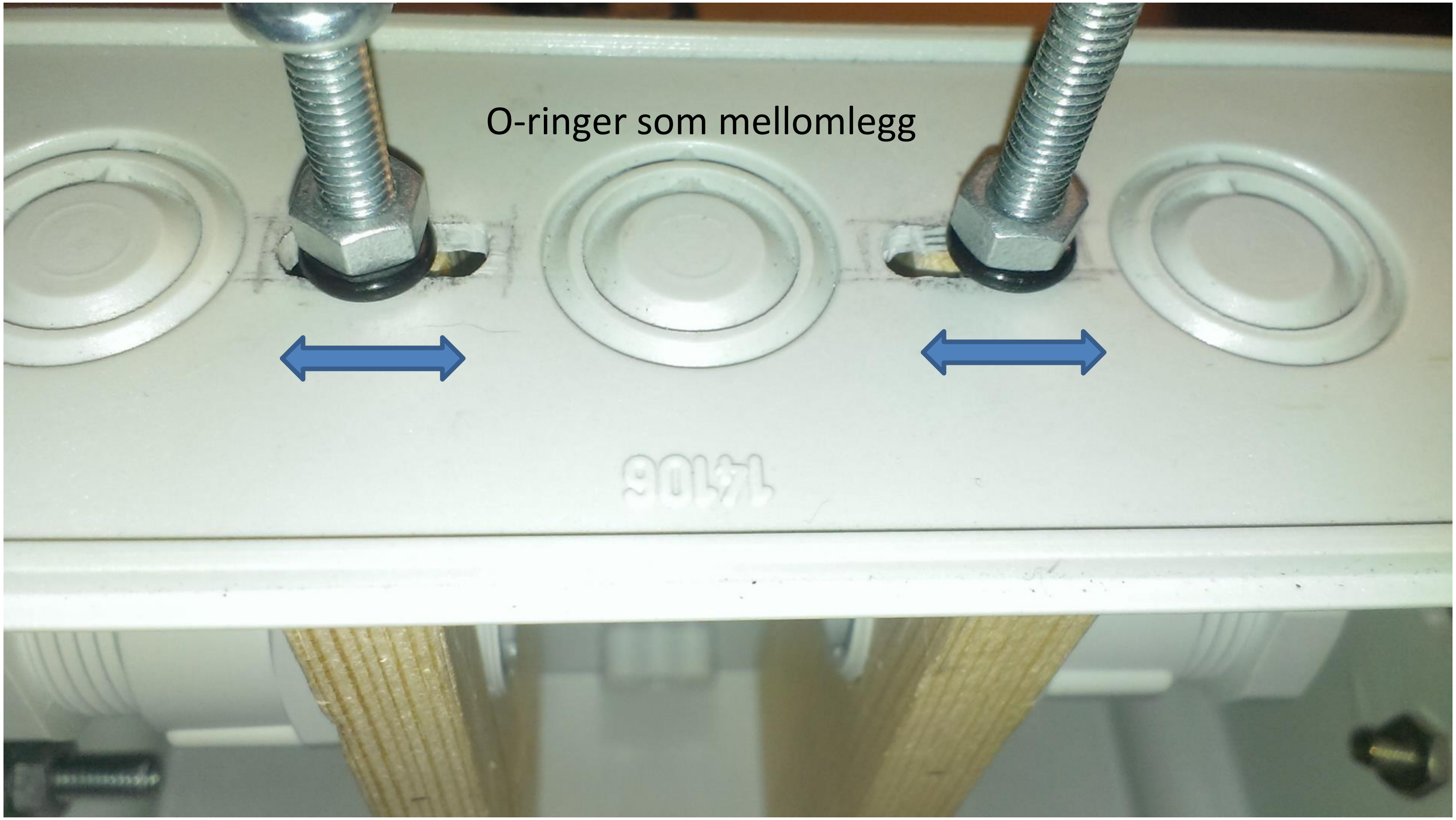
Filterboks

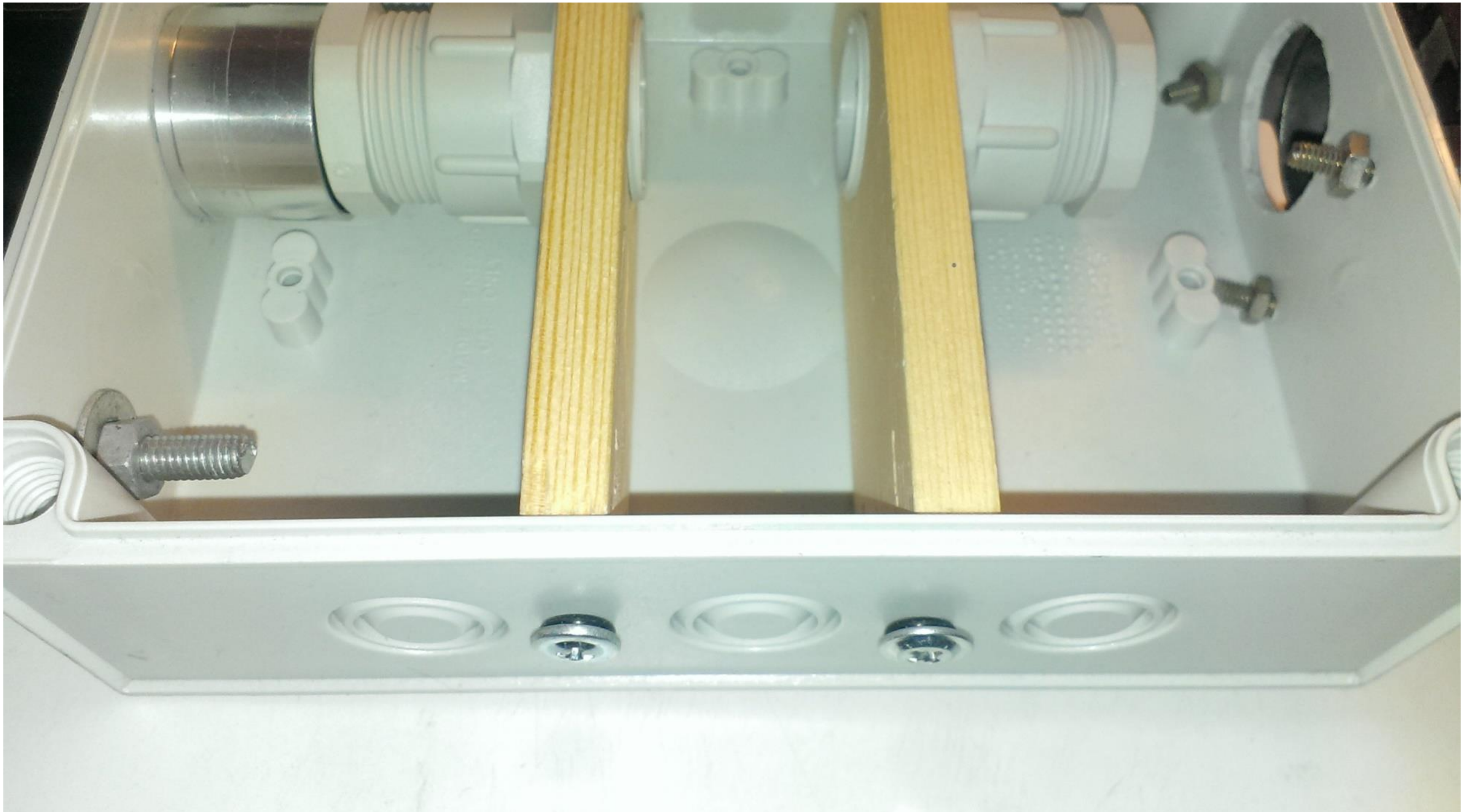


- Treplater justeres i to akser
- Elektrisk koblingboks med passe hull for Barlow og okularholder
- Plater festes i posisjon med vingemutter, gjengejern
- Gradeskala ved spaltene

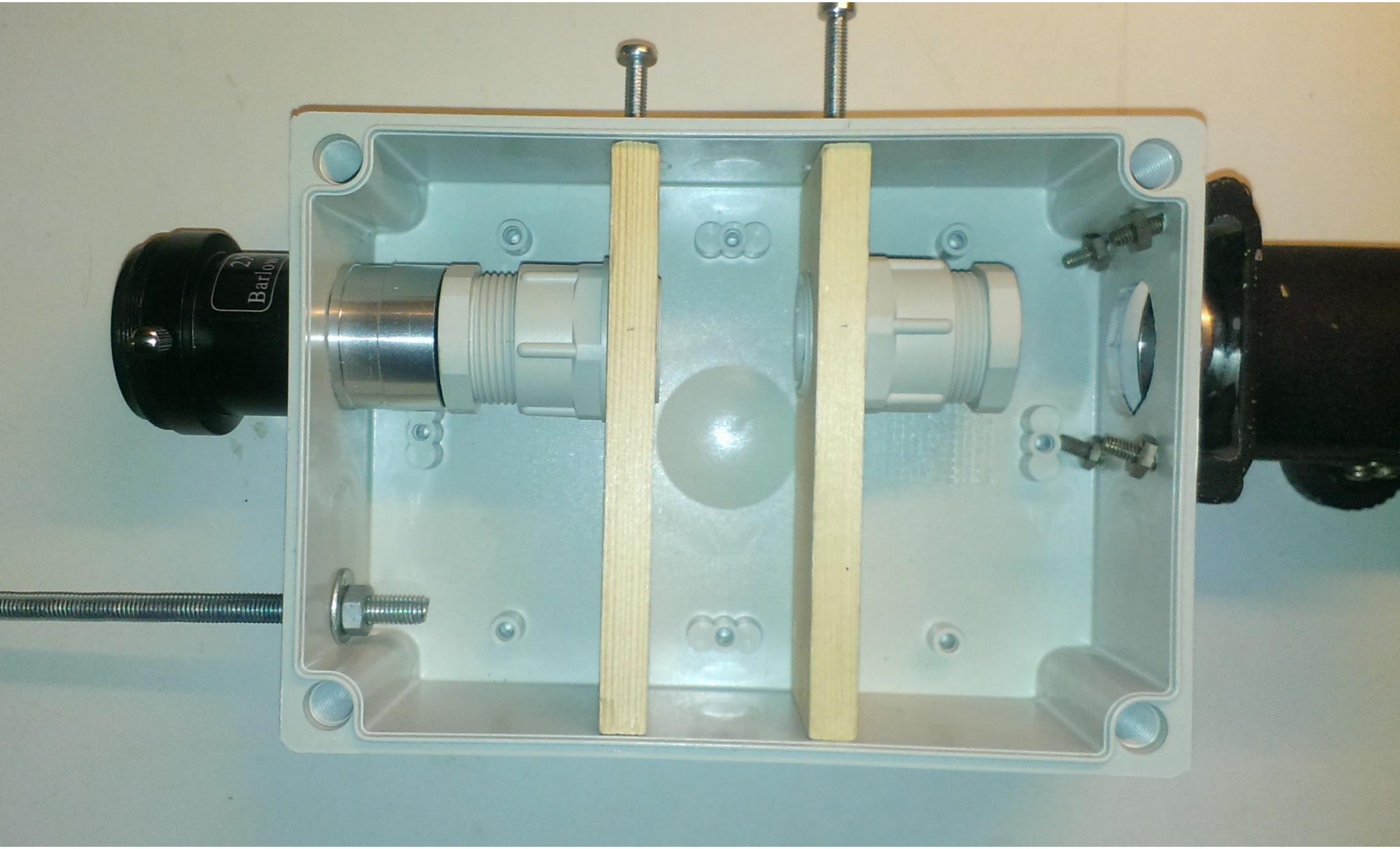


- “Elektrikerboks” med nipler (fra Heia gjenvinningsstasjon), O-ringer, trefjøler, skruer, gjengestang
- Okularholder (fra Jacob Lingås) , Barlowholder uten linse, reversert

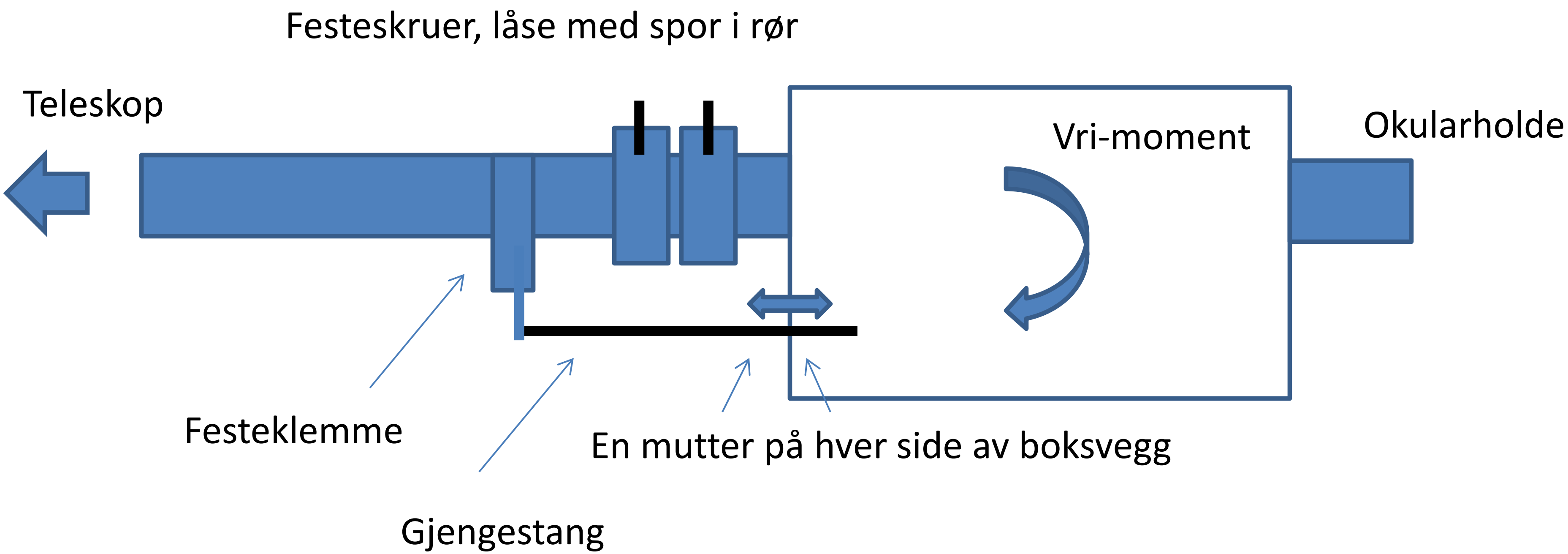

O-ringer som mellomlegg
14106



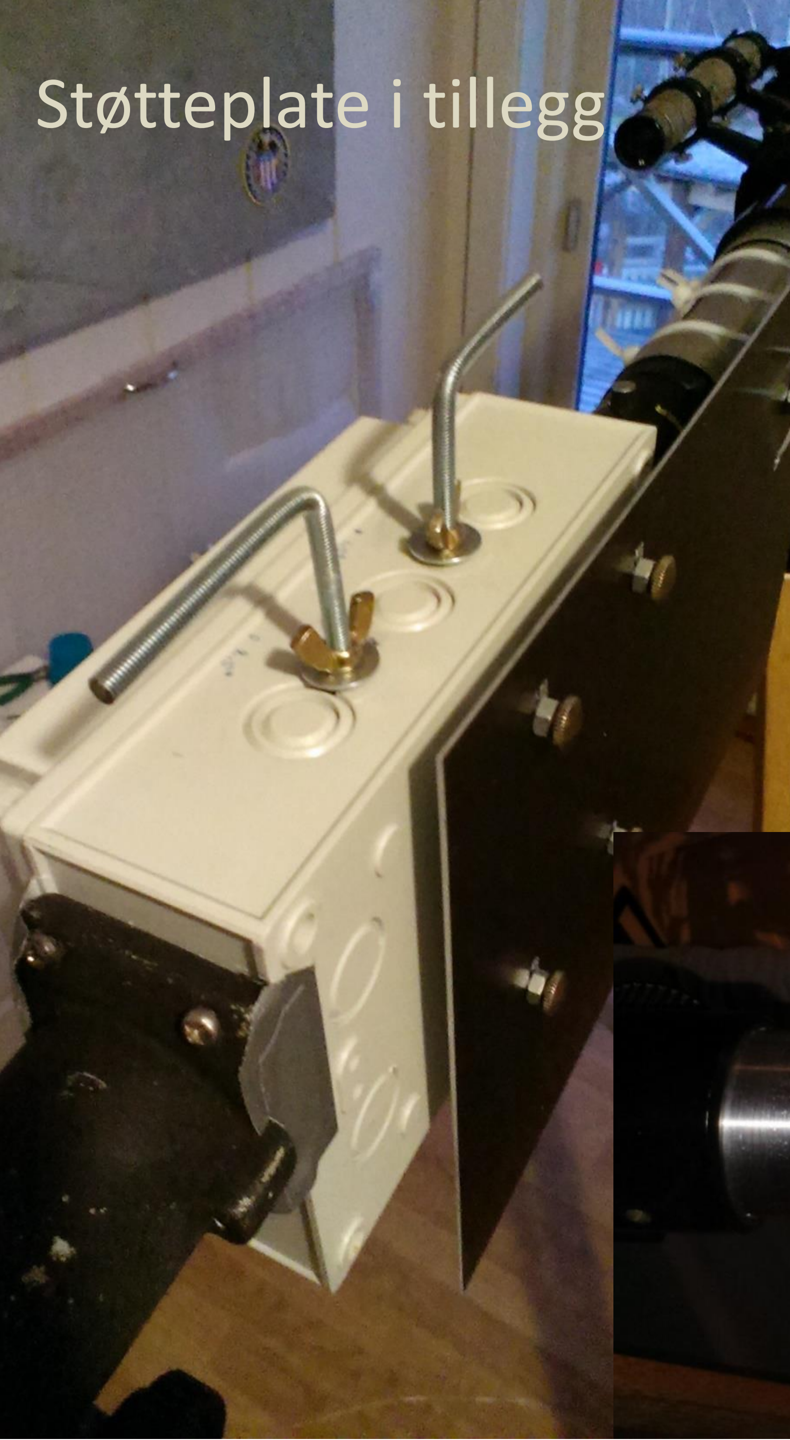
- Pivot-skruer: treskruer med O ring under.

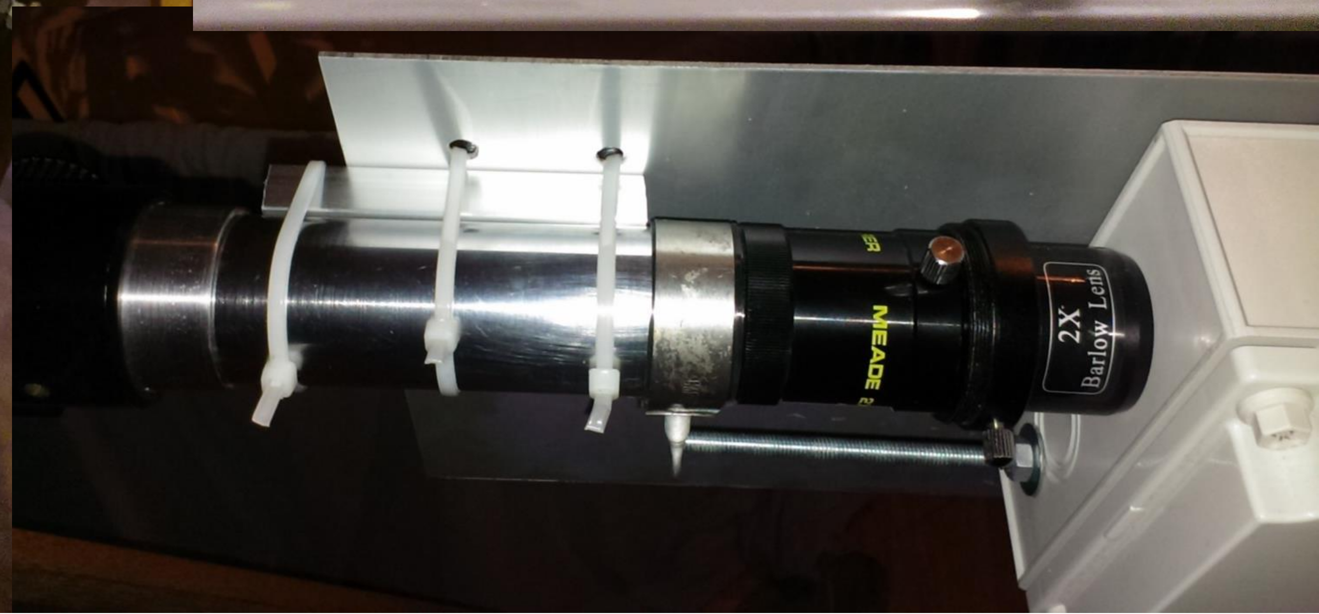

Barlow

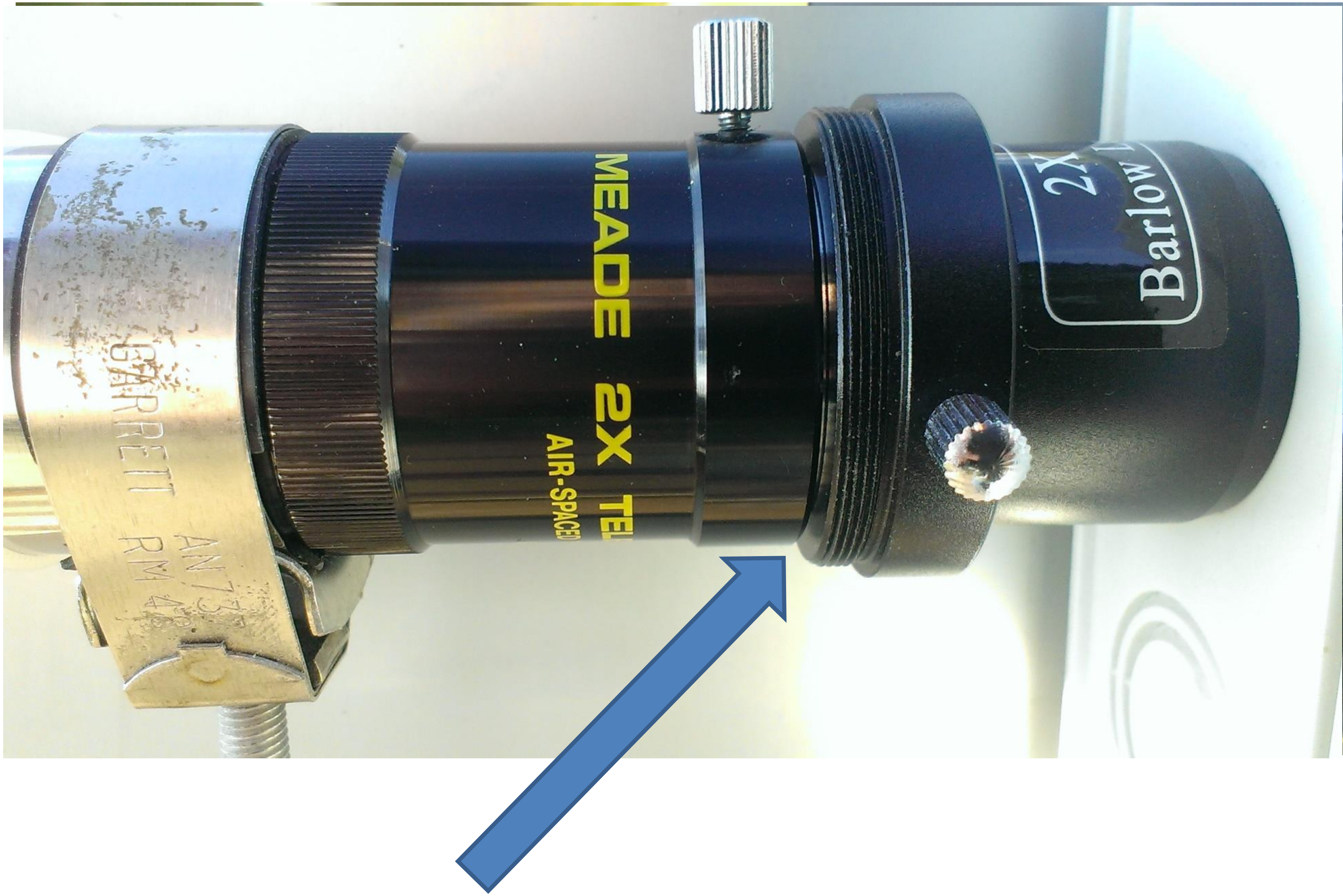
Avstivning av filterboks, hindre sagging



Støtteplate i tillegg



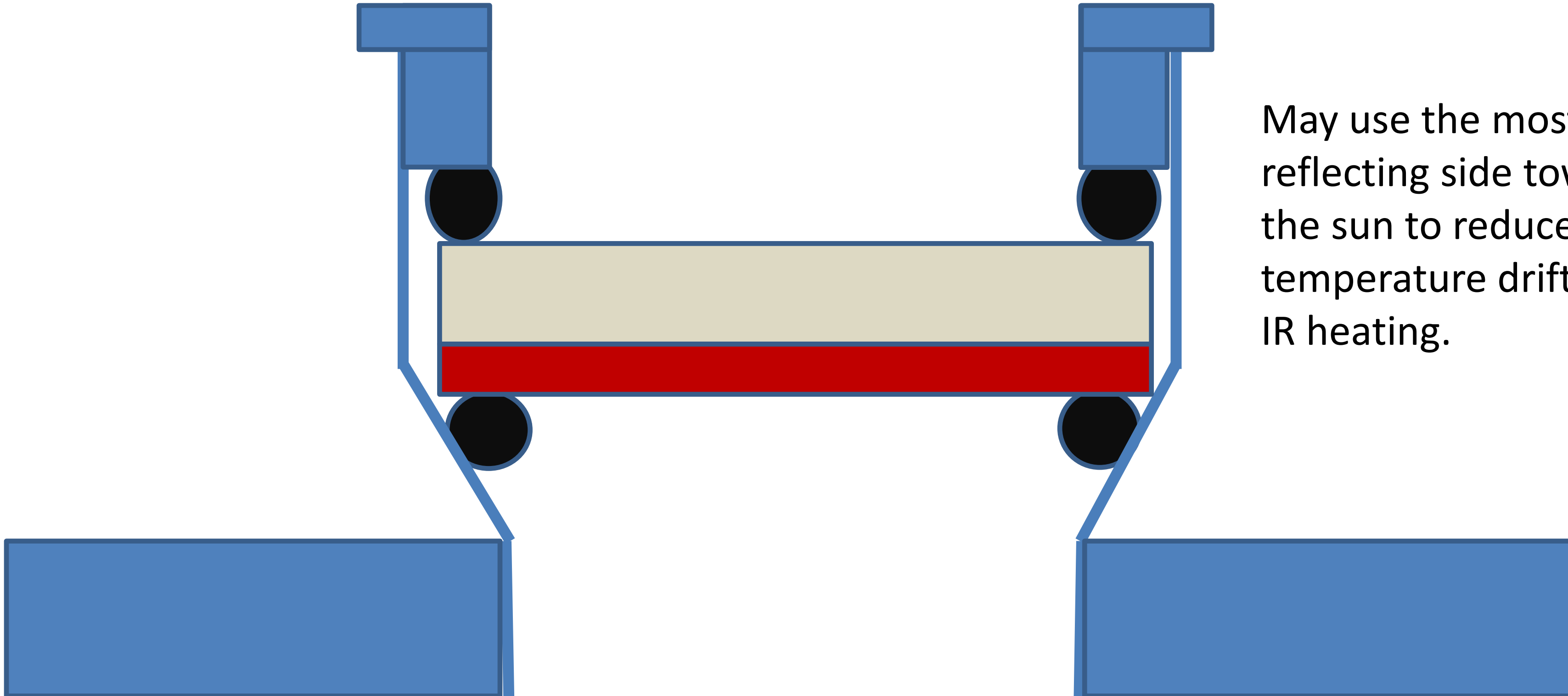




- **No-sag test: parallell parts, even spacing**
- Use backplate screws to lift up the filter module to a linear confinuration

Filterholder for primærfilter

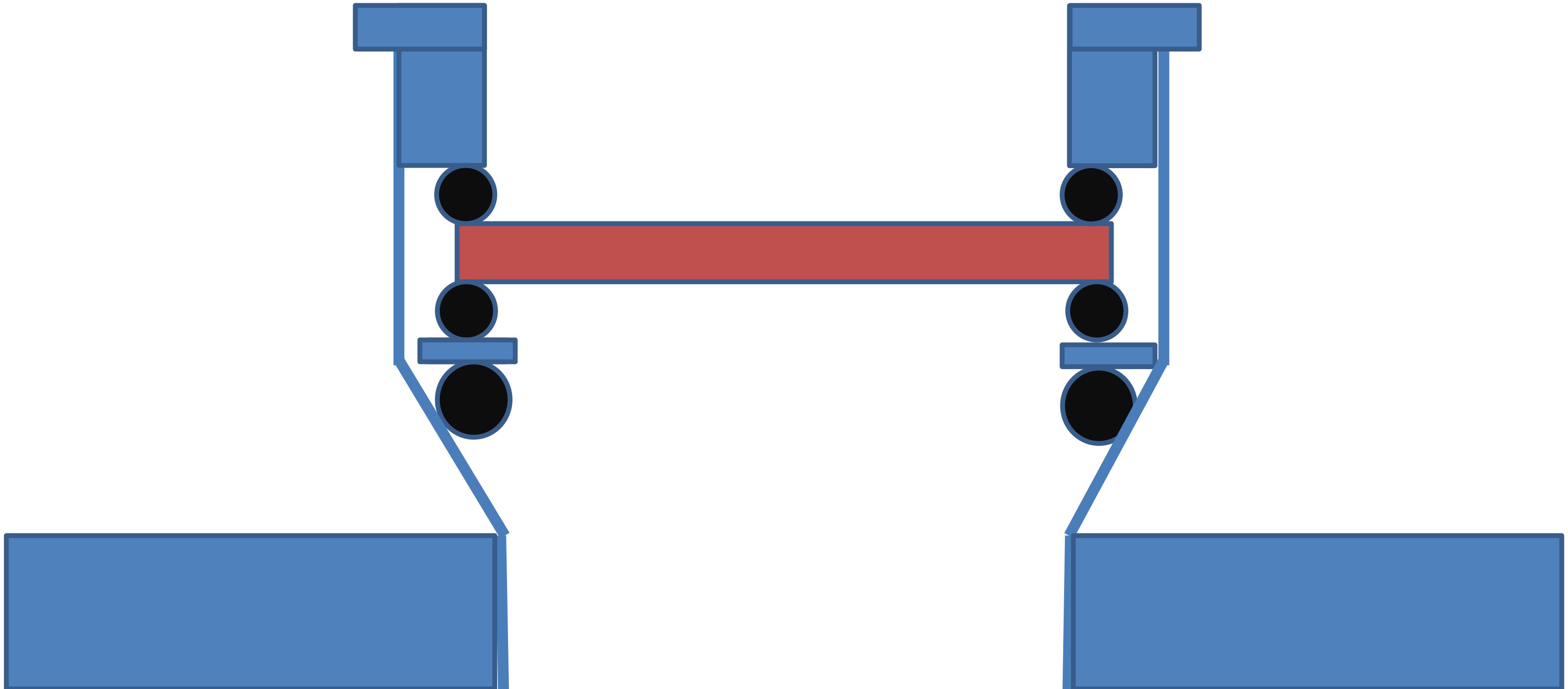
- Nippel for kabelgjennomføring, 27 mm indre Diam
- Festes i treplate med hull
- Doble sett O-ringer, en på hver side av filter

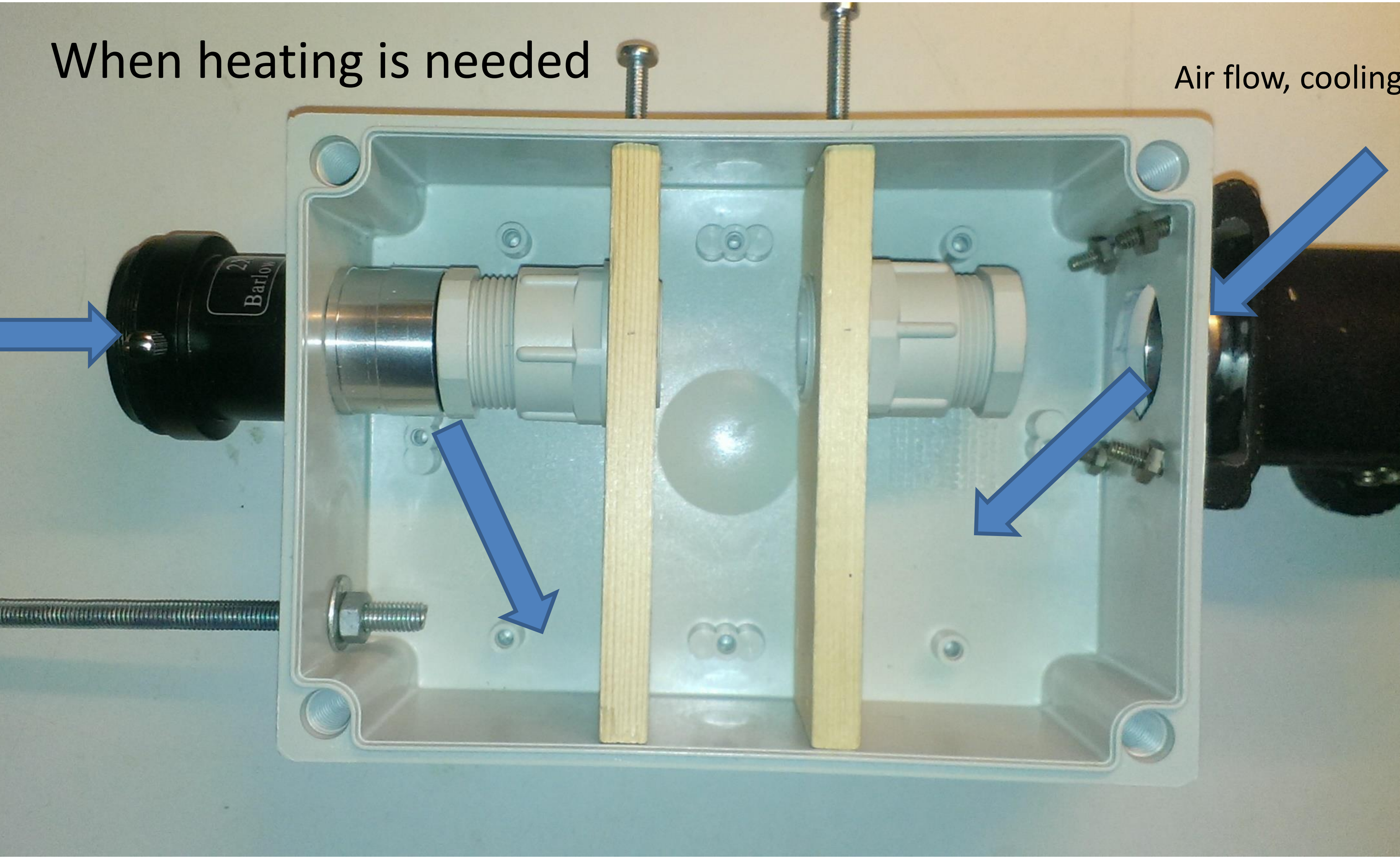


May use the most reflecting side towards the sun to reduce temperature drift from IR heating.

Filterholder sekundærfilter

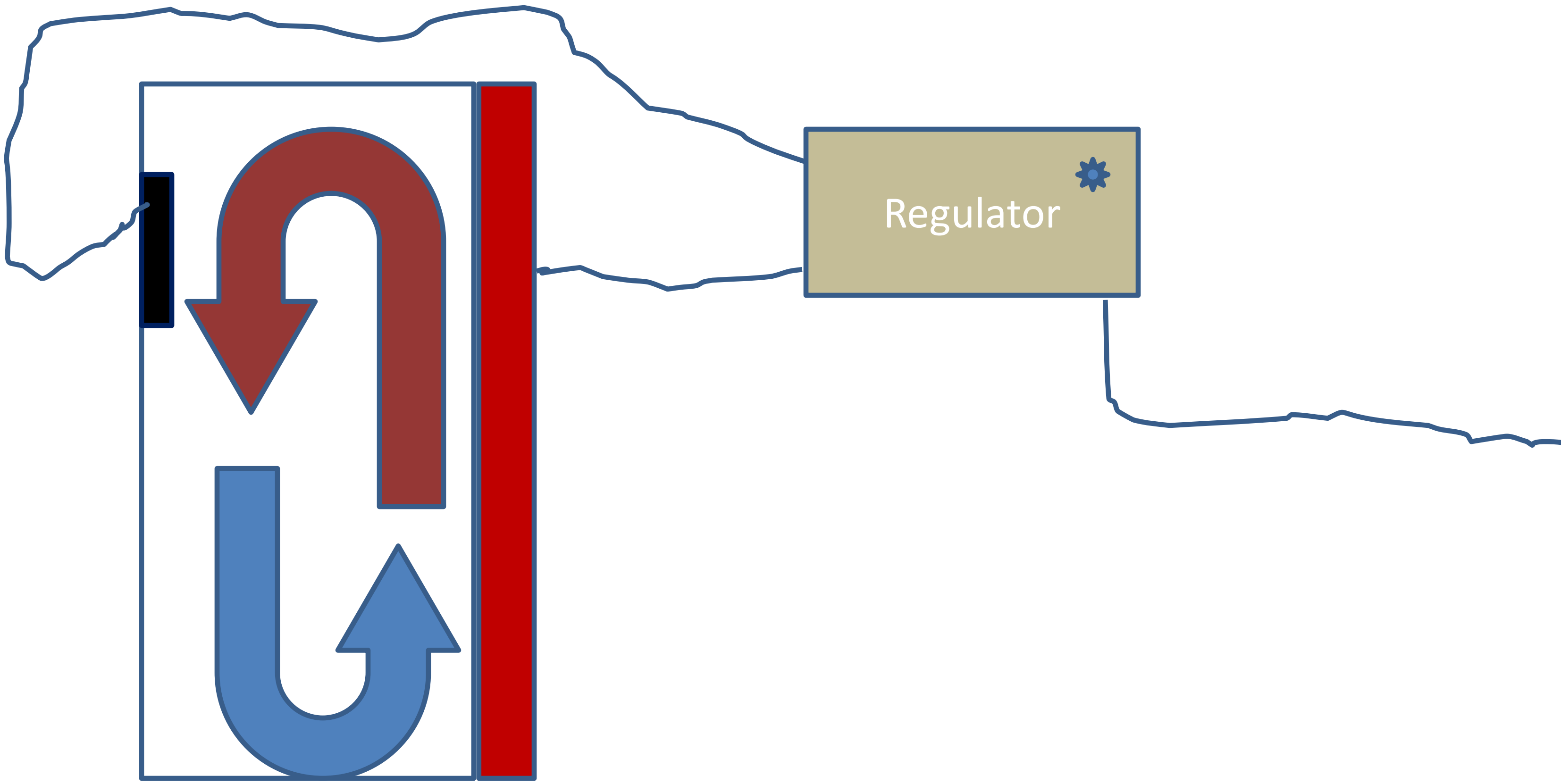
- Nippel for kabelgjennomføring, 27 mm indre Diam
- Skive og doble sett O-ringer, en på hver side av filter





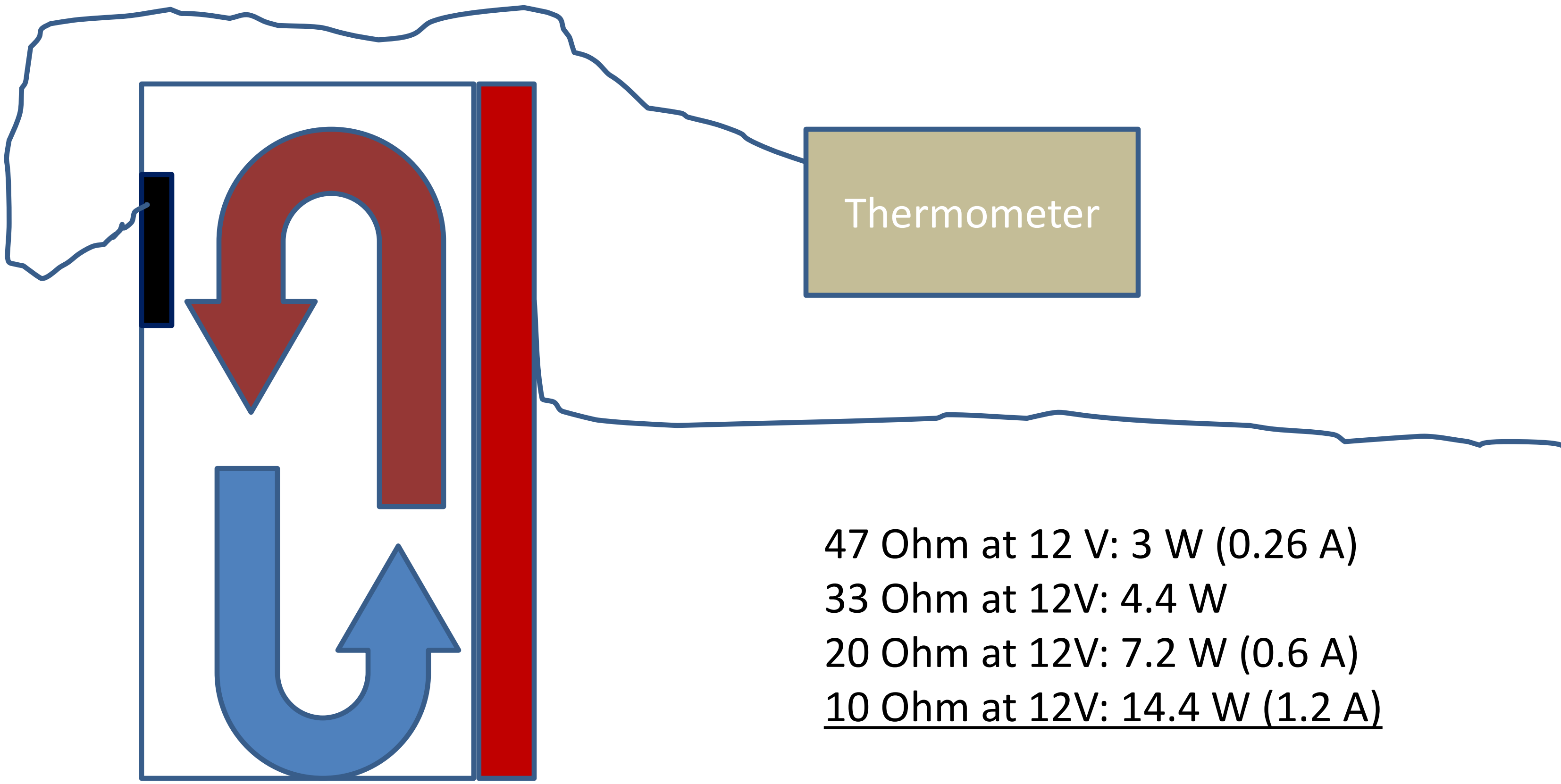
- Plug in glass or yellow/red color or narrowband filters in both holes!

Heating with thermostat regulation



- Heating in lid (resistor, 12V), sensor in box

Manual on/off regulation

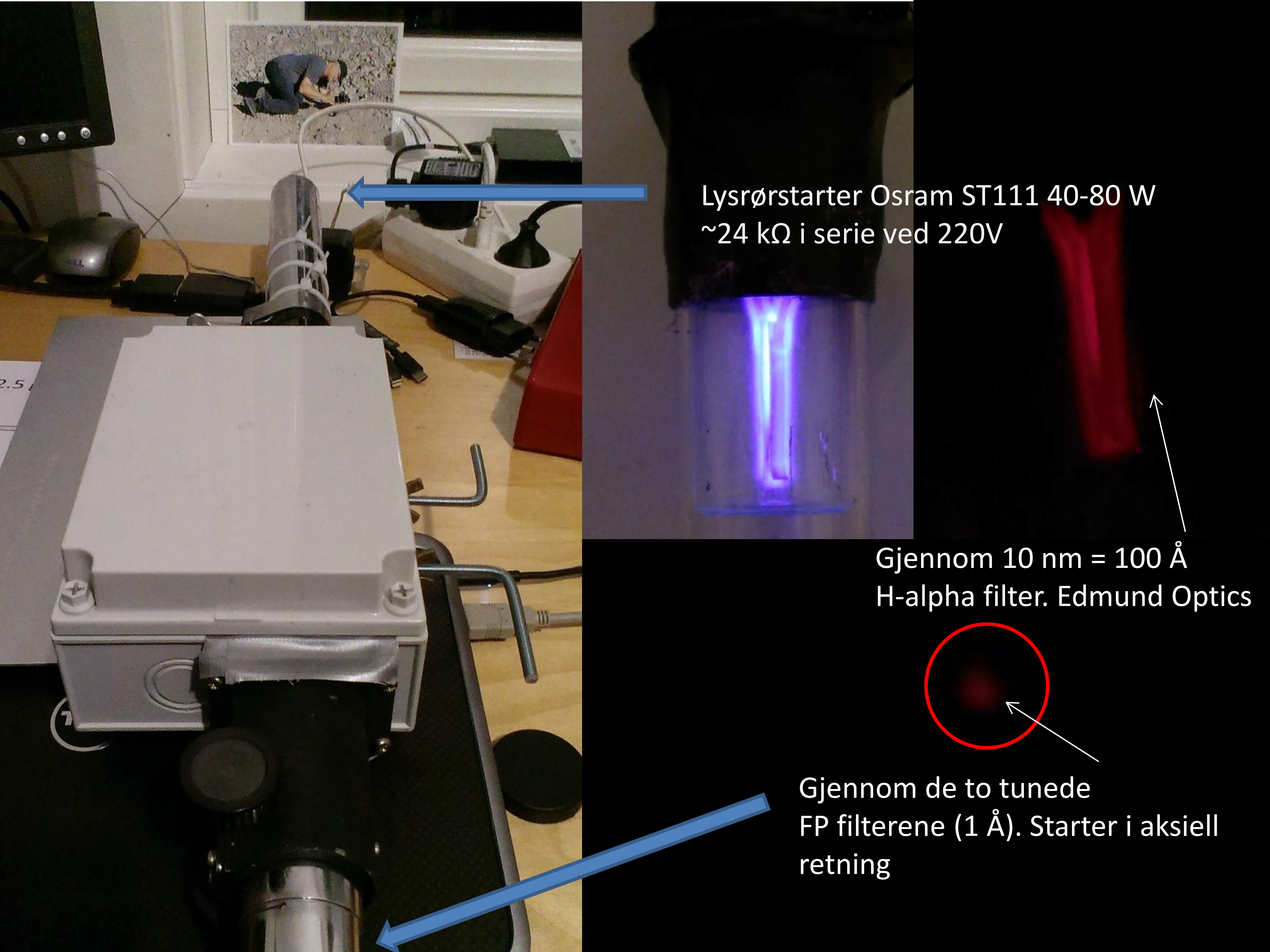


47 Ohm at 12 V: 3 W (0.26 A)
33 Ohm at 12V: 4.4 W
20 Ohm at 12V: 7.2 W (0.6 A)
10 Ohm at 12V: 14.4 W (1.2 A)

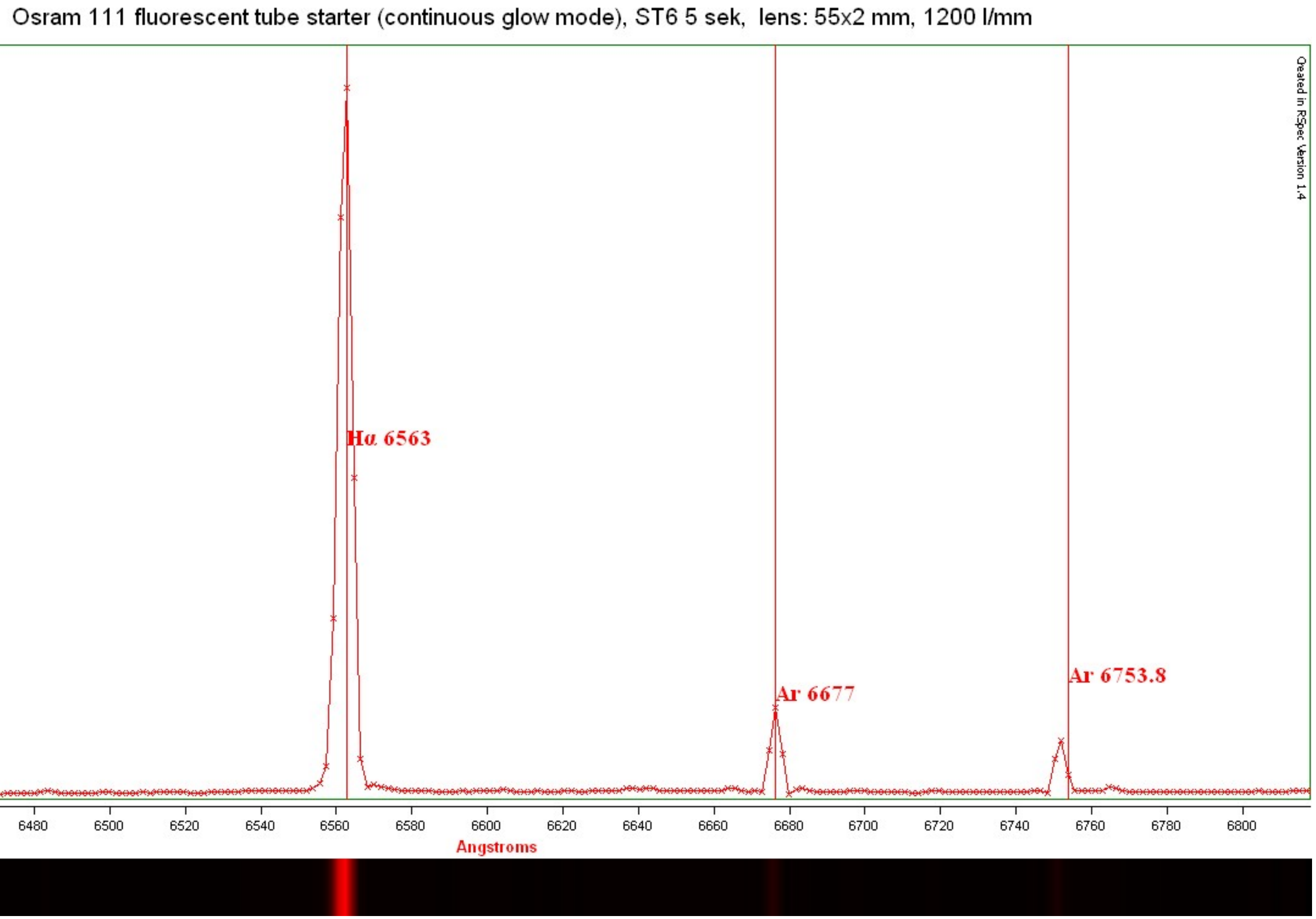
¼ W for 6V, ½ A for 6V

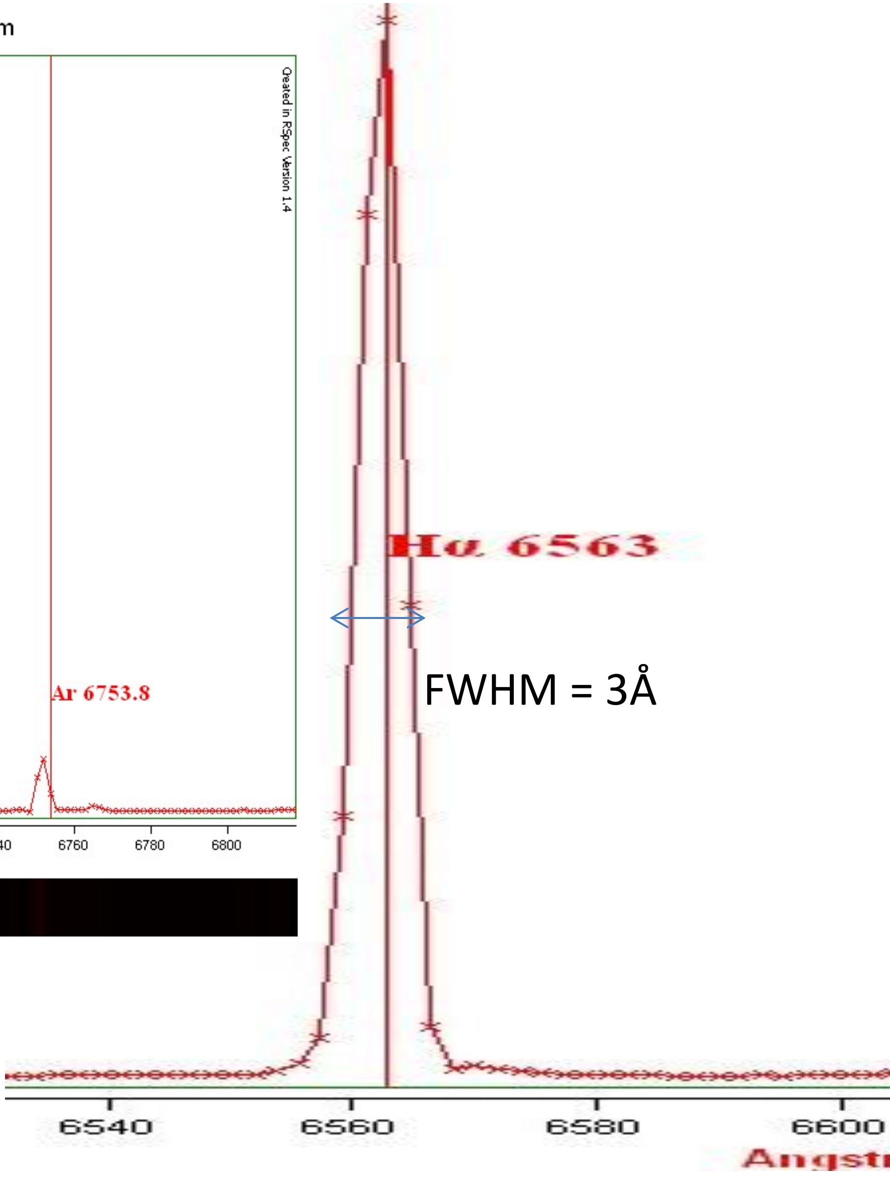
- Heating in lid (resistor, 12V, 6V), sensor in box

Kalibrering/Calibration


Lysrørstarter Osram ST111 40-80 W
~24 kΩ i serie ved 220V
Gjennom 10 nm = 100 Å
H-alpha filter. Edmund Optics
Gjennom de to tunede
FP filterene (1 Å). Starter i aksiell
retning

Lysrørstarter: H-alpha emitter





-Hydrogen- og argon-linjer
-Tidligere data fra QCSPEC spektrograf

Spectrum Glow Starter OSRAM ST 111 4-80W Grating: 900L/mm

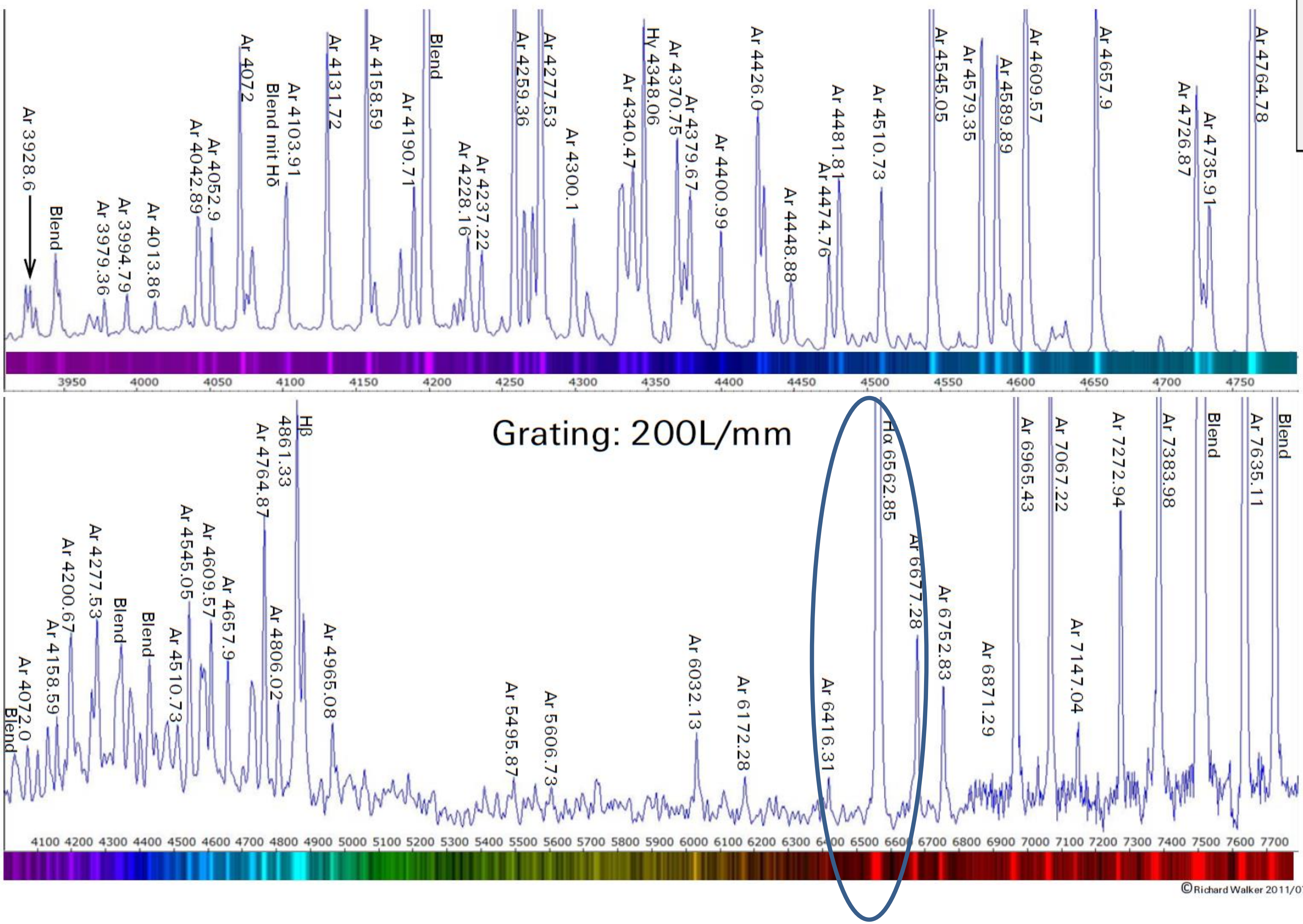
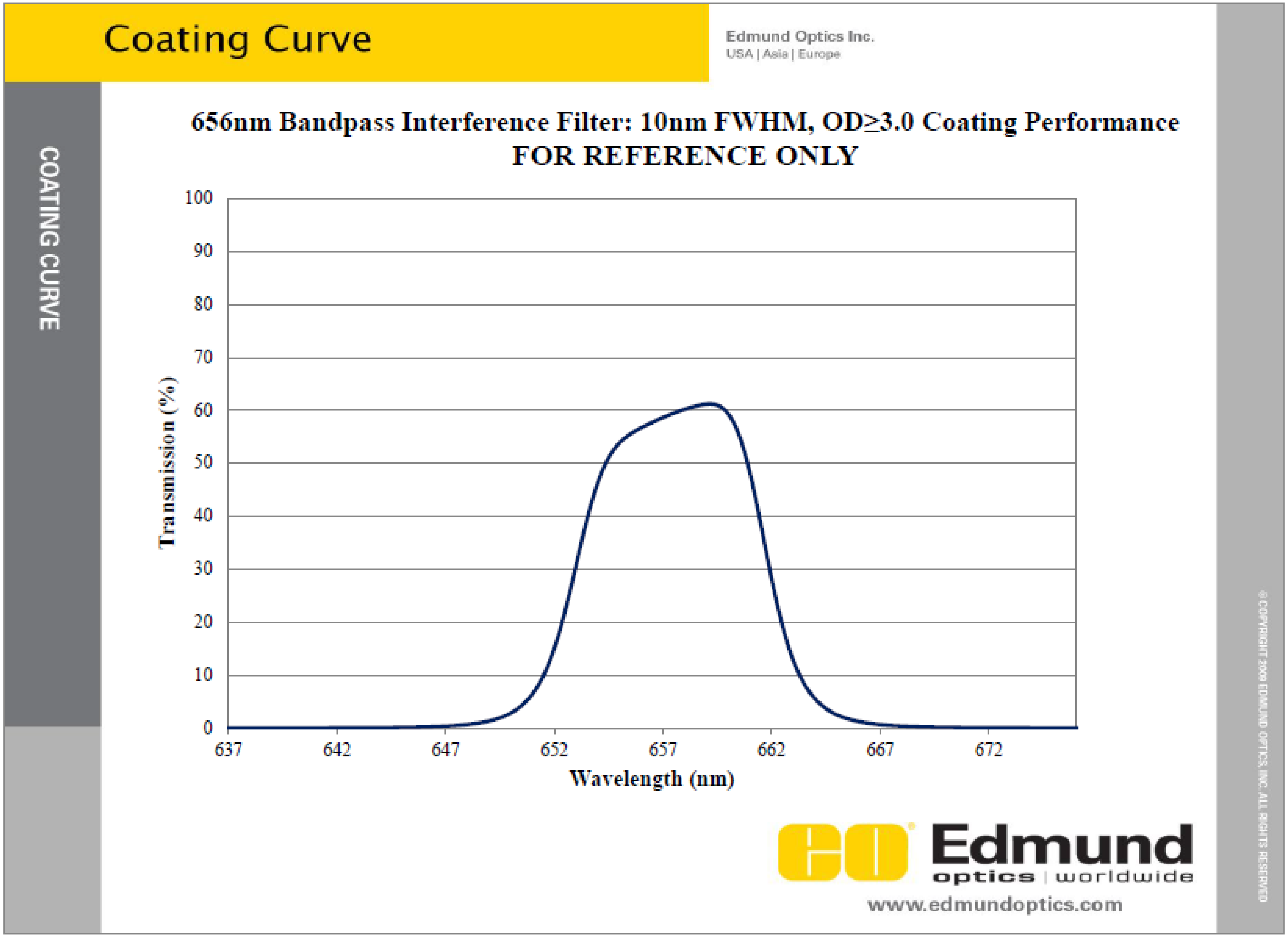


TABLE 106

Spectroscopic Atlas for Amateur Astronomers

132

Richard Walker: Spectroscopic Atlas for Amateur Astronomers

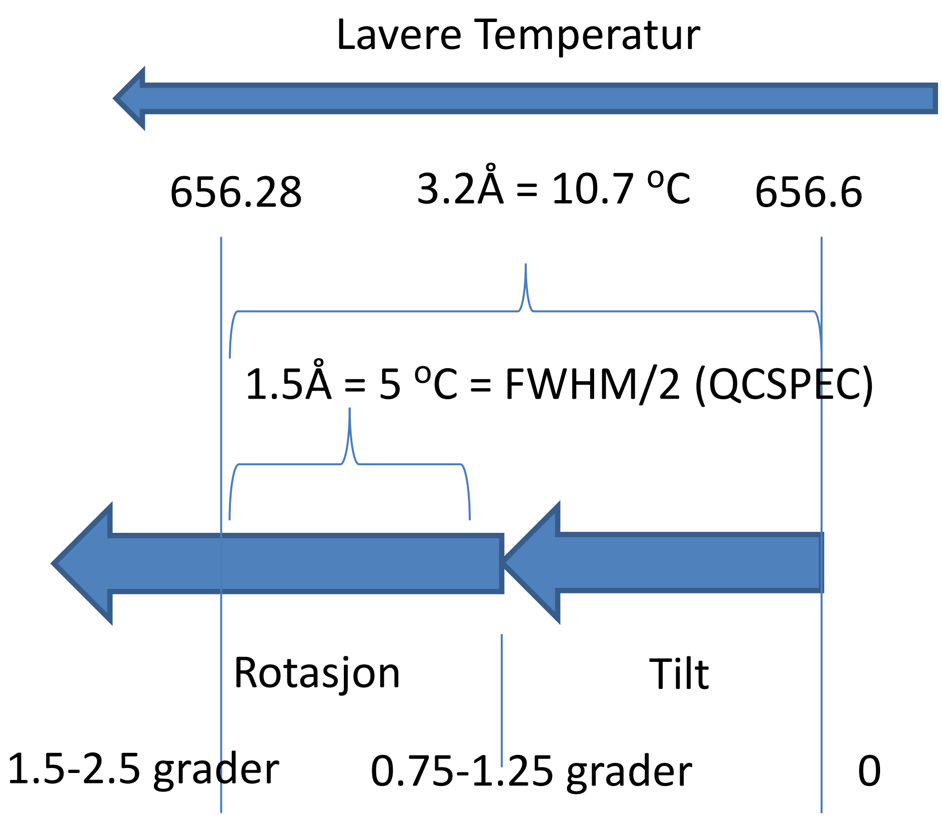


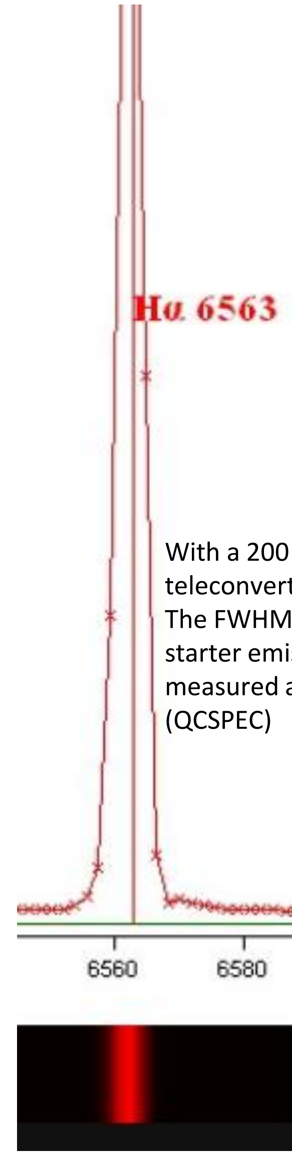
- 100Å filter

Check also https://www.lambda.cc/product/band-pass-filters/

Tiltkalibrering med spektrograf

- Primær og sekundærfilter, samme prosedyre
- Kalibrere ett filter av gangen, merk av i boks
- Registrer temperatur ved kalibrering
- Begge filtere må temperaturkompenseres
  ute, med rotasjon eller oppvarming. Mål temperatur i boks



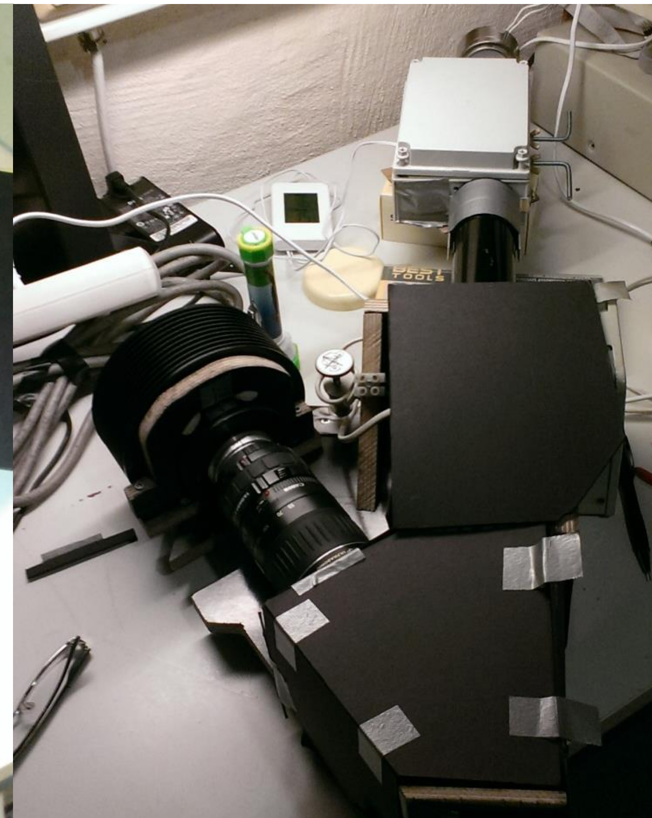


With a 200 mm lens with a 2x teleconverter: 0.5 Angstrom/pix The FWHM from the Glow starter emission line was here measured at 3 Ångstrøm. (QCSPEC)

- Tilte til litt lengere bølgelengde, deretter rotere for fintuning
- **Bruk halvparten av oppgitte totale tilt verdier, resten rotasjon for 5 °C margin. Maks 10°C margin (null tilt)**

- Total tilt ~ tilt angle + rotation angle
- If temperture drops, then use less rotation angle, down to zero rotation angle for 5 ^{o}C temperature drop relative to calibration temp (if setup is as shown in the drawing, with the given “half value” of the tilt angle)

QCSPEC calibration setup

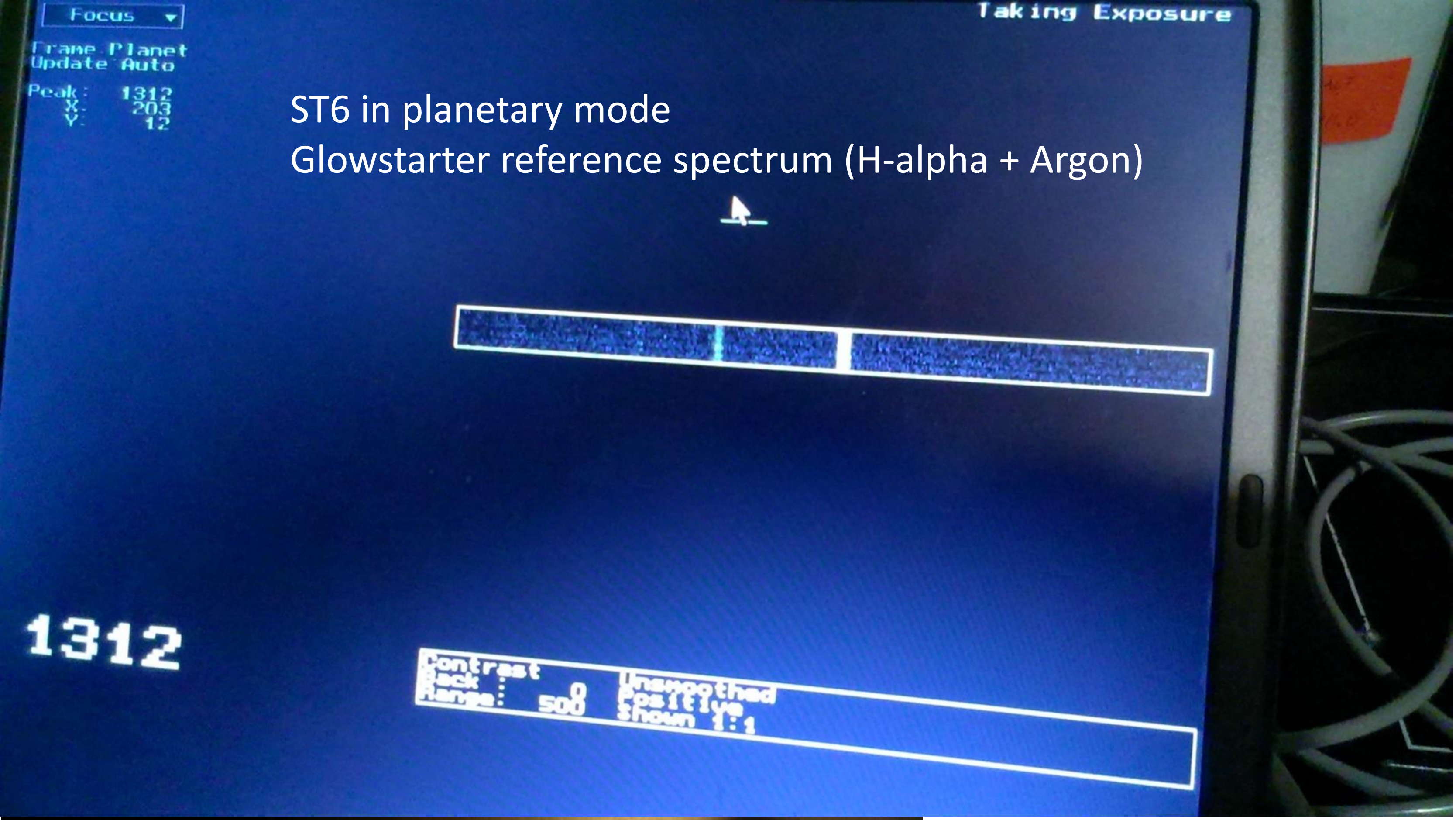


- 1200 lines/mm reflection grating (Edmund Optics). Thor Labs slit.
- White light diffuse illumination in front of etalons superposed on glow starter light close to slit

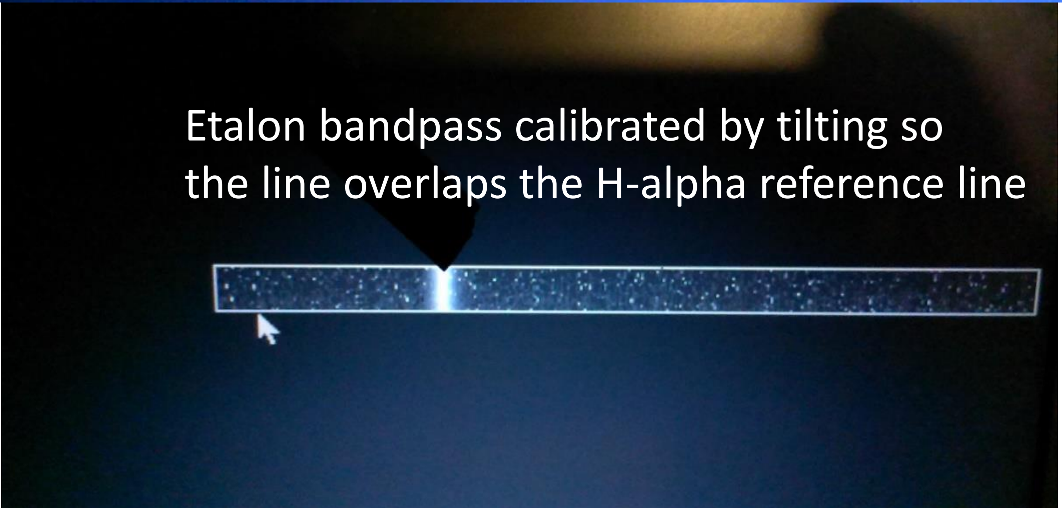
Calibration light sources

- Use the spectrograph with white light input to adjust the filters to overlap the superposed H-alpha line from the glow starter
- This will not confuse with the nearby Argon lines from the glow starter
- Use 20-30 kΩ resistor in series with the glow starter:

  ST111 40-80W: ~24 kΩ, at 220V



ST6 in planetary mode
Glowstarter reference spectrum (H-alpha + Argon)



Etalon bandpass calibrated by tilting so
the line overlaps the H-alpha reference line

Testing

- Will it work, then (hahaha)?

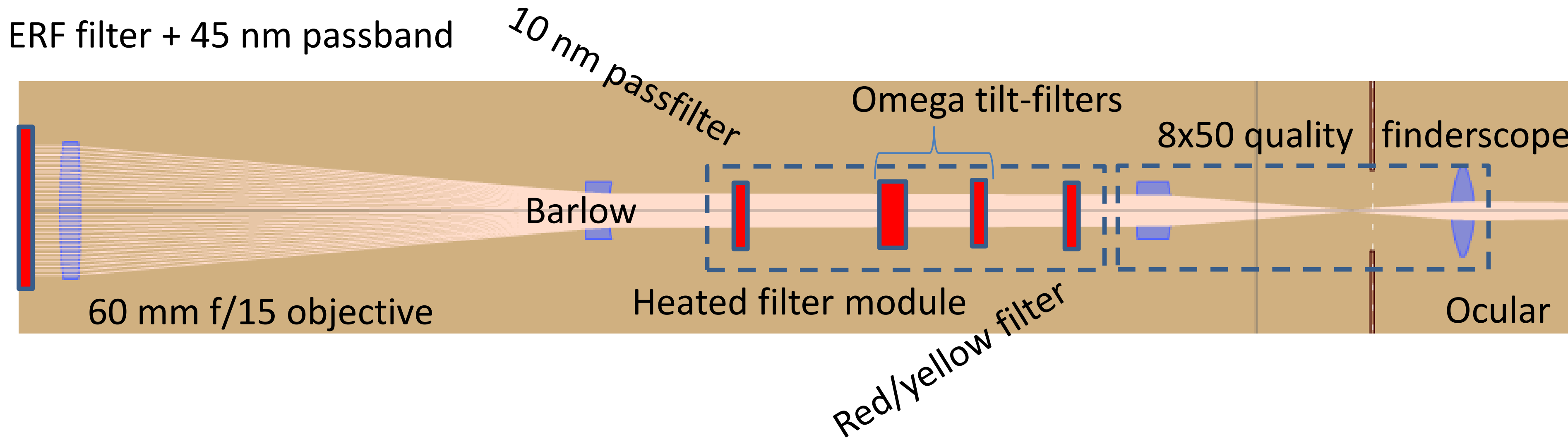
Testing januar-mars 2020

- Solar minimum
- Bad seeing
- Test 1,2,3 fiasco due to
  - Uncollimated beam?
  - Uncalibrated filters?
  - Bad seeing?
  - No temp regulation?
    - Test 2: cold outside (around 0 degrees)
- Test 4: successful (Friday 13/3 2020), low contrast in chromosphere, mediocre seeing, no prominences

Test nr	Beam collimation	Filter calibration
1	No, Barlow but light cone	Yes, glowstarter visual
2	Yes, beam test. Barlow closer to objective	no
3	Yes, focuser scope test. Limb in focus when Barlow slightly away from objective again	Yes, glowstarter and white light, QCSPEC
4	yes	Yes, now Temp-control


SCOPE
2 focus marks
14 W heater, 12 V battery
8x50 finderscope
as refocuser and ocular

Final configuration with collimator and for visual observation

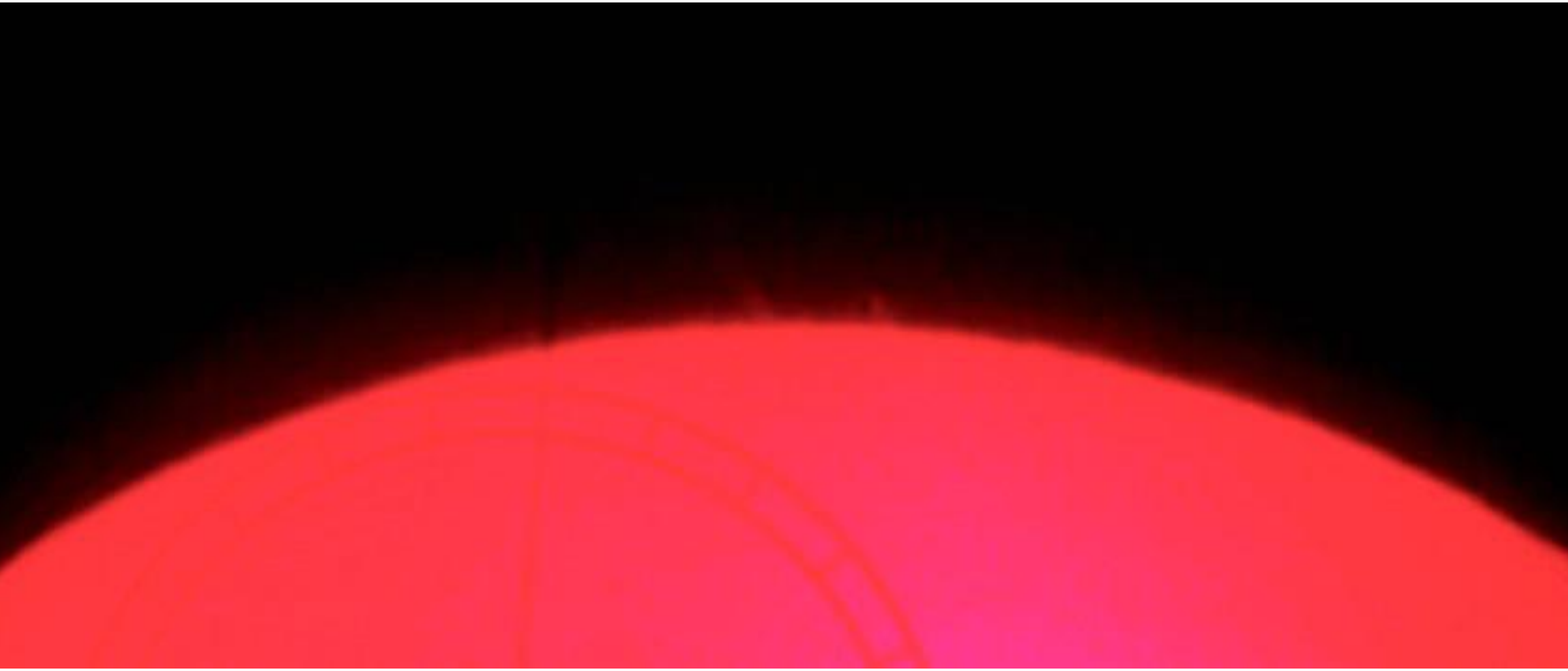


- The 10 nm filter to reduce heating of the primary Omega filter, and to block cold air from seeping in from the outside

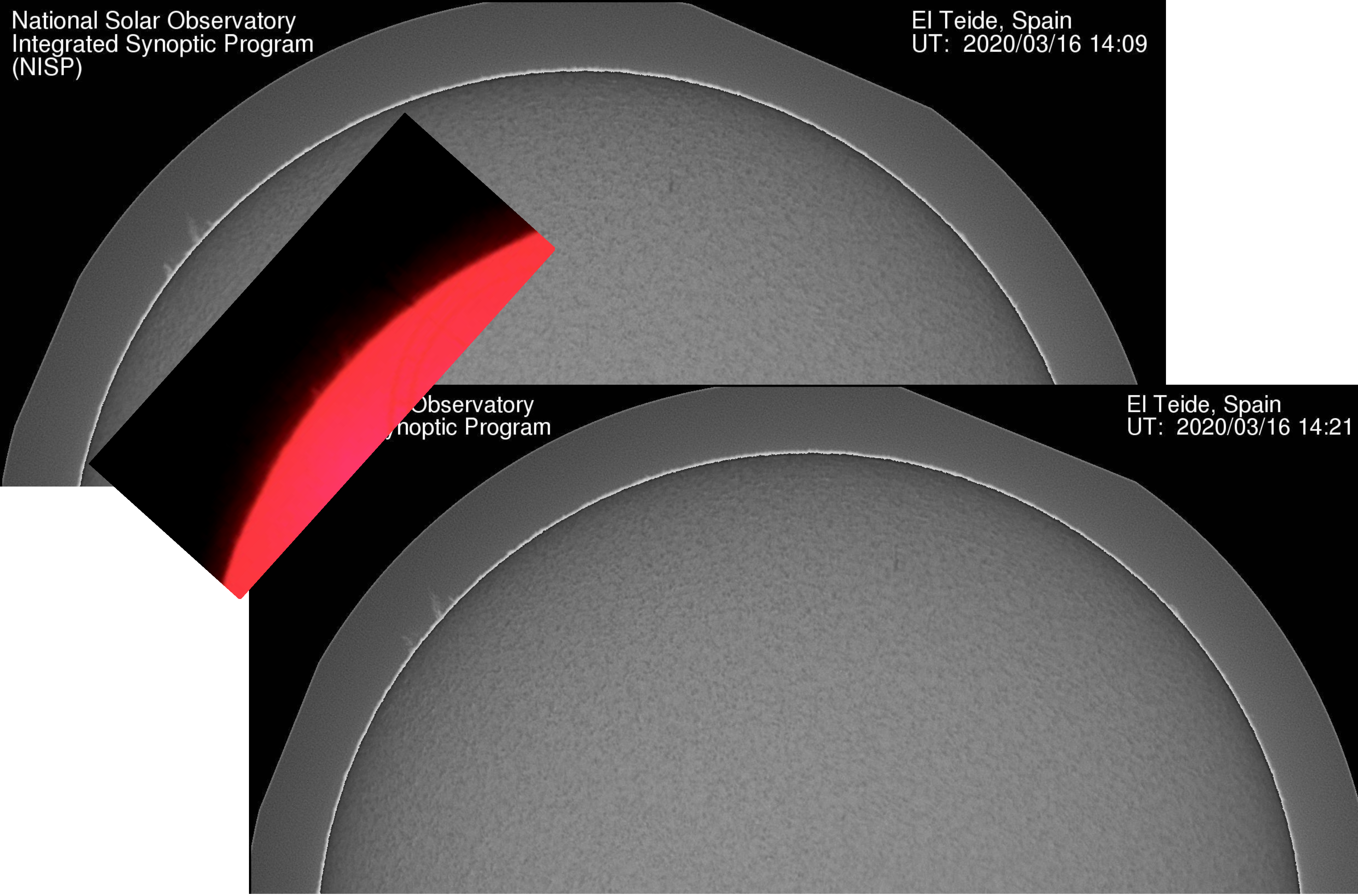
- Red/yellow filter to block cold air

- And the name is "H-alpha-omega budget solar telescope"
  - ✓ 1x 60 mm ERF Baader filter: **231 EUR**
  - ✓ 2x Omega filters: **225 EUR**

March 16. 2020 (test 5). First prominences through poor cell phone camera!

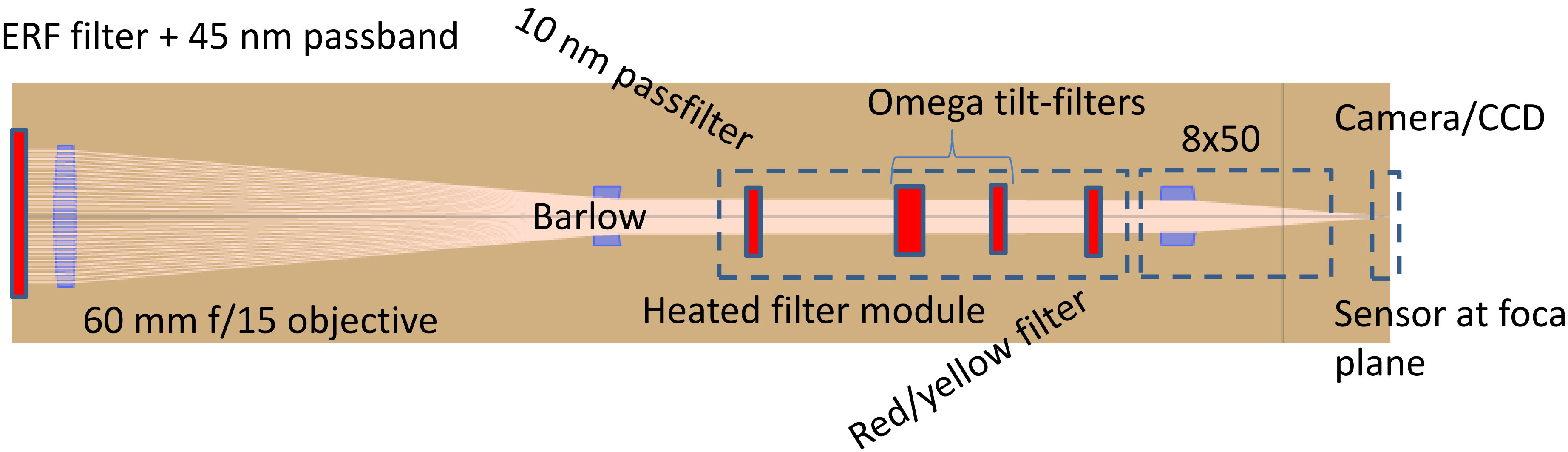


- Heating to around 20 celsius. Minimum sag. Seeing variable, some haze. No chromospheric detail visible. Used earlier calibration tilt values, approximately
- Sharp image in the center region of the ocular (no tilted rays there)
- Mobile phone image through ocular



- Compared to GONG at the same time 14:13 UT

Ocular projection mode with camera. Same setup, but no ocular

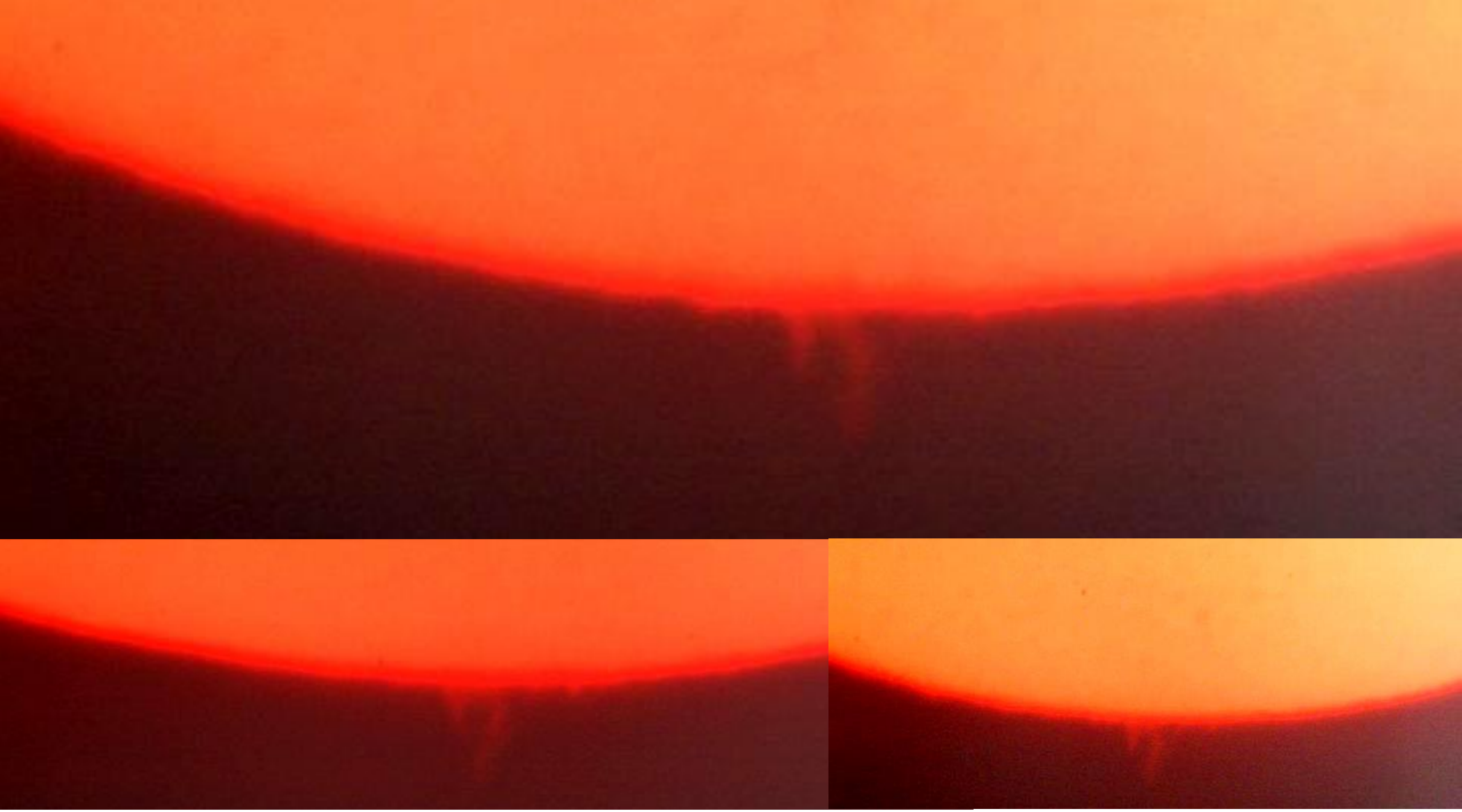


The objective of the finderscope provides converging rays onto the imaging plane.

Enabling focus on CCD/film plane.

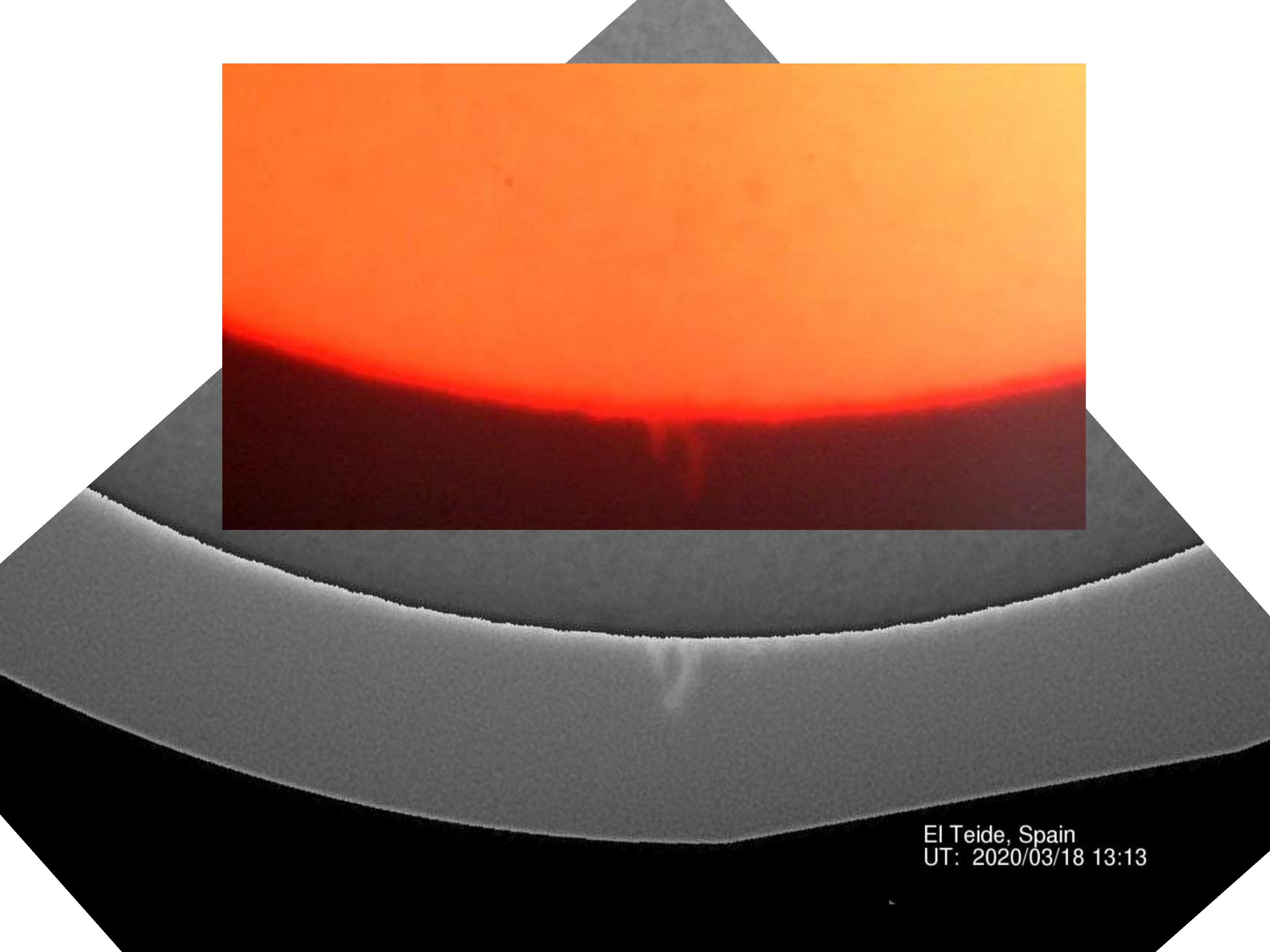
- One lens less! (a consideration if you have to buy lenses)

First primary focus single image with ”webcamera” MEADE LPI, 18/3/2020
Poor seeing, prominences still “prominent”. Exposure 23 ms, 16:53 PM



- LPI software provides
  - Automatic stacking of best images (option)
  - Manual contrast adjustment for live images

Field is good for prominences, requires good seeing conditions. Sensor centered in field so filters tuned on-band


El Teide, Spain
UT: 2020/03/18 13:13


Adapter + CCD
replaces diagonal
and ocular

Full field in camera about ¼ solar diameter

- About ½ diameter in the ocular

And the saga continues…

Tillegg/Appendix

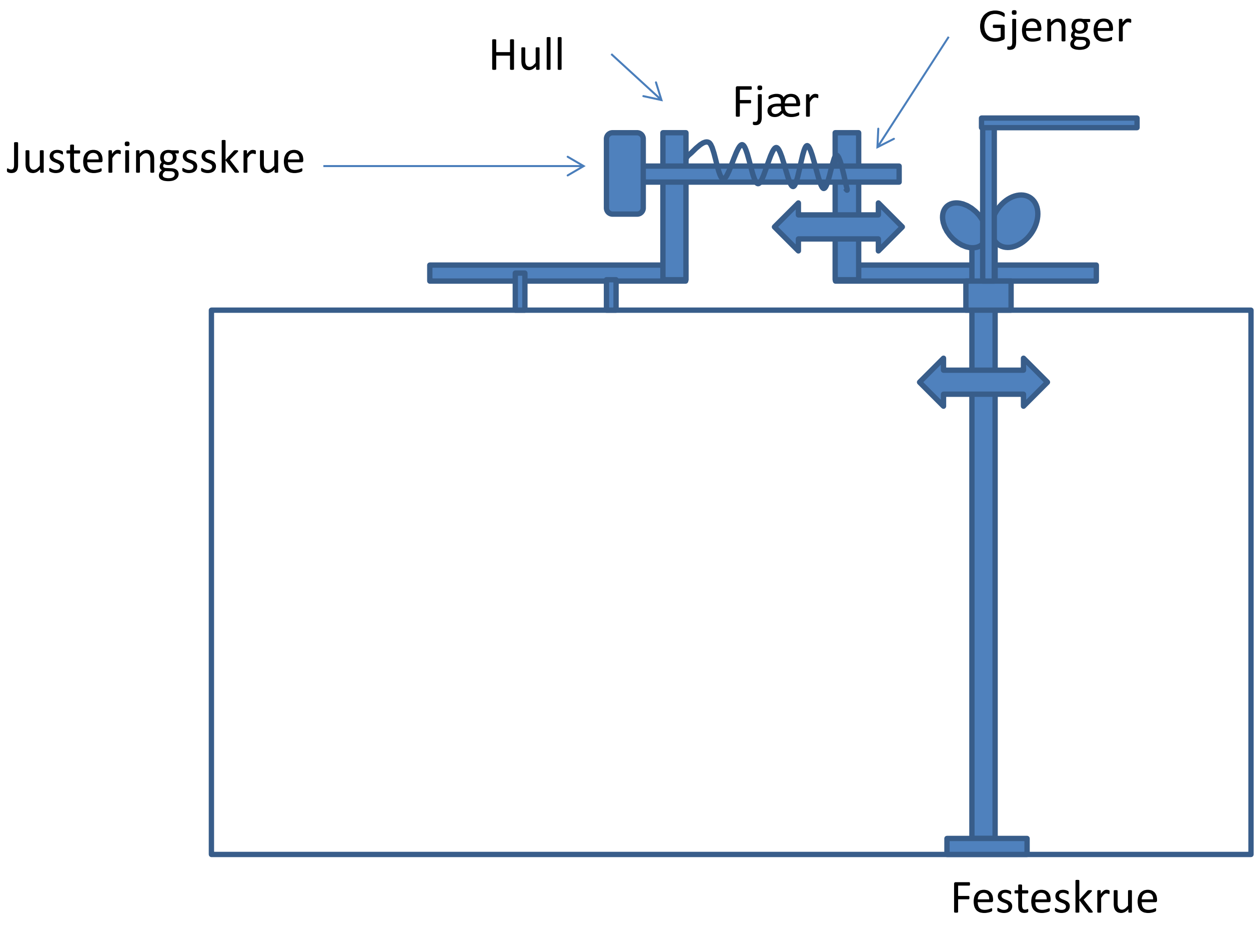
Omega filters with telecentric collimation

Peter Zetner, https://pbase.com/p_zetner/omega_halpha&page=all

Peter Zetner writes:

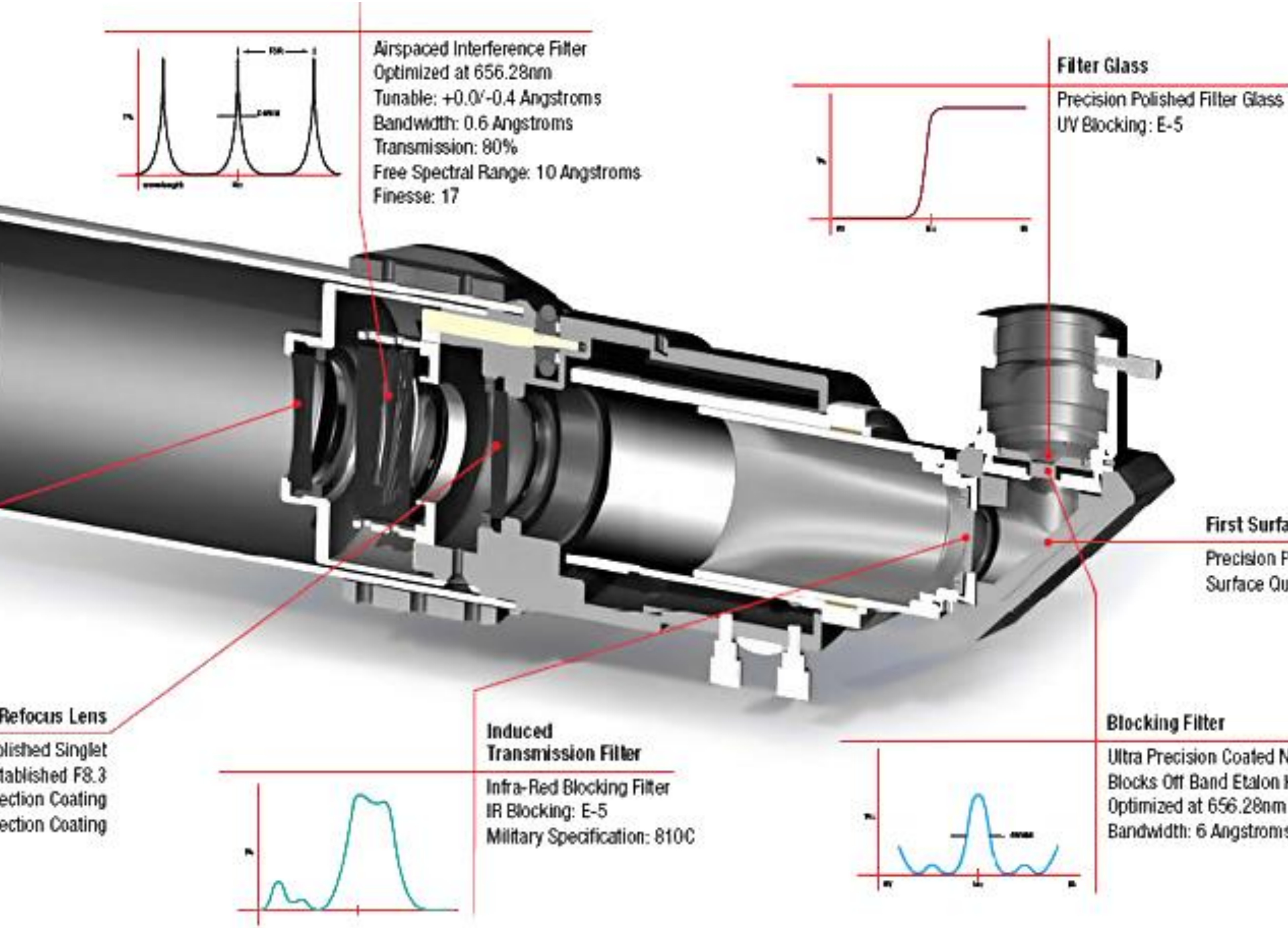
- The original intent was to use the eBay filter pair offered by eBay seller bjomejag (Omega Optical). This pair consists of a thick filter (narrowband + blocking) and a thin "cyan" filter (narrowband Halpha but passes some blue). I had some difficulties with the thick filter. It is a wedge design and different wavelength transmission modes are separated by a relatively small angle (restricting the field of view in the scope to the same small angle - beyond which you get overlapping solar images). **The filters I used here are 2 of the thin "cyan" filters** - no major problems with restricted angle in the fov.

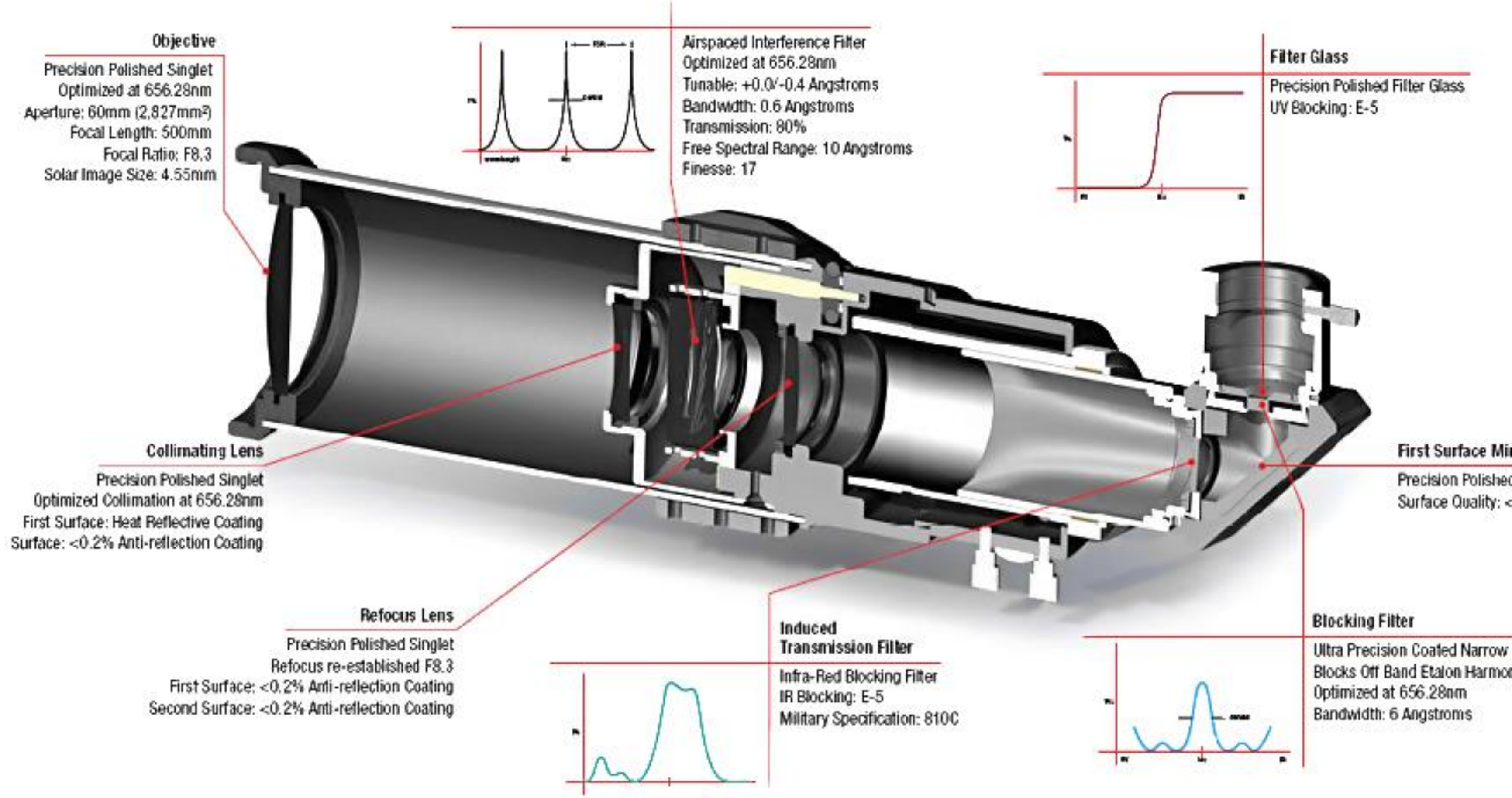
Eventuell fjærjustering på tilt

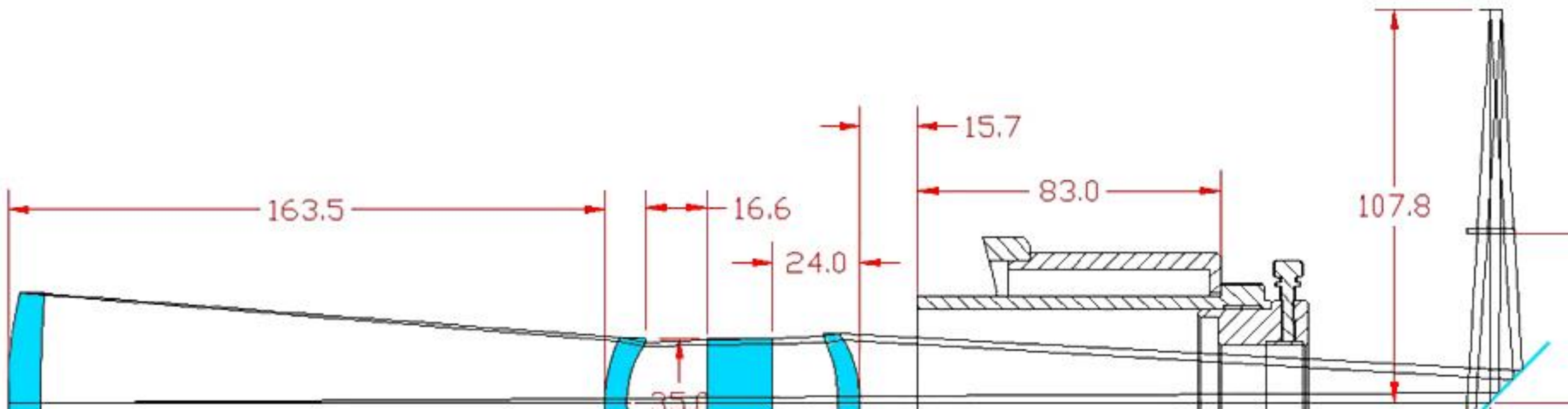


LUNT

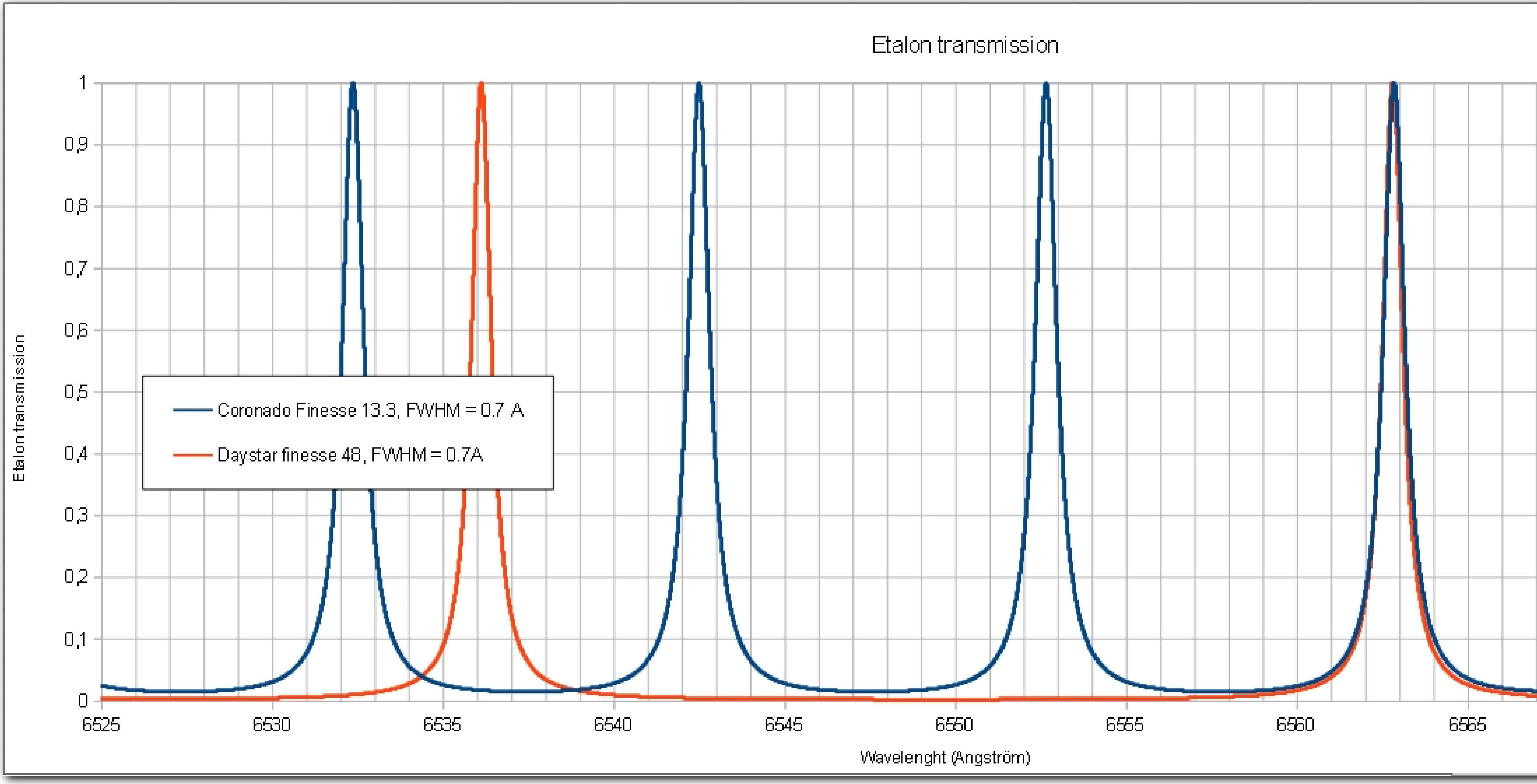
- LUNT variant: en annen rekkefølge på filtre
- Samme prinsipp
- Med kollimator


Airspaced Interference Filter
Optimized at 656.28nm
Tunable: +0.0/-0.4 Angstroms
Bandwidth: 0.6 Angstroms
Transmission: 80%
Free Spectral Range: 10 Angstroms
Finesse: 17
Filter Glass
Precision Polished Filter Glass
UV Blocking: E-5
First Surfa
Precision P
Surface Qu
Refocus Lens
olished Singlet
tablished F8.3
ection Coating
ection Coating
Induced
Transmission Filter
Infra-Red Blocking Filter
IR Blocking: E-5
Military Specification: 810C
Blocking Filter
Ultra Precision Coated N
Blocks Off Band Etalon
Optimized at 656.28nm
Bandwidth: 6 Angstroms


Objective
Precision Polished Singlet
Optimized at 656.28nm
Aperture: 60mm (2,827mm²)
Focal Length: 500mm
Focal Ratio: F8.3
Solar Image Size: 4.55mm
Airspaced Interference Filter
Optimized at 656.28nm
Tunable: +0.0/-0.4 Angstroms
Bandwidth: 0.6 Angstroms
Transmission: 80%
Free Spectral Range: 10 Angstroms
Finesse: 17
Filter Glass
Precision Polished Filter Glass
UV Blocking: E-5
Collimating Lens
Precision Polished Singlet
Optimized Collimation at 656.28nm
First Surface: Heat Reflective Coating
Surface: <0.2% Anti-reflection Coating
First Surface
Precision
Surface Quality:
Refocus Lens
Precision Polished Singlet
Refocus re-established F8.3
First Surface: <0.2% Anti-reflection Coating
Second Surface: <0.2% Anti-reflection Coating
Induced
Transmission Filter
Infra-Red Blocking Filter
IR Blocking: E-5
Military Specification: 810C
Blocking Filter
Ultra Precision Coated Narrow
Blocks Off Band Etalon
Optimized at 656.28nm
Bandwidth: 6 Angstroms

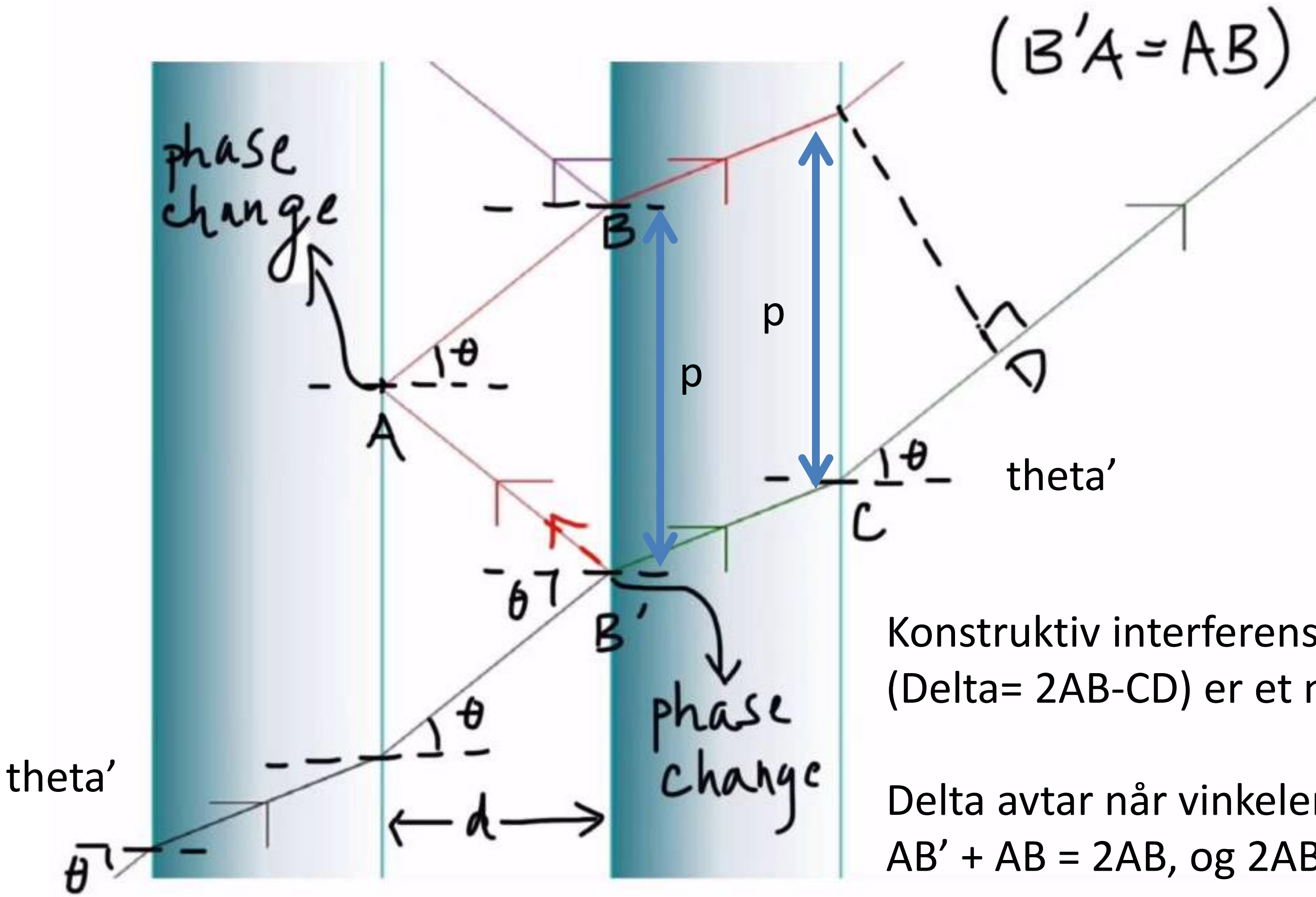

15.7
163.5
16.6
83.0
107.8
24.0

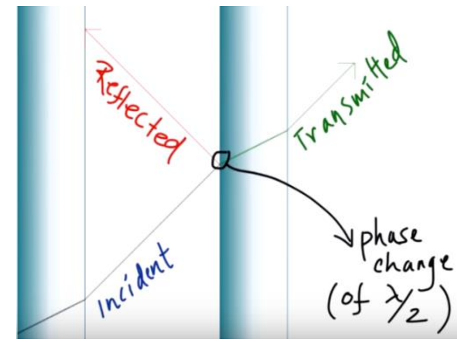
http://www.astrosurf.com



- Coronado: FSR = 10 Å = 1 nm!

FP filter og geometrisk optikk





Konstruktiv interferens når forskjellen i veilengde (Delta= 2AB-CD) er et multippel av bølgelengden.

Delta avtar når vinkelen øker fordi CD "tar innpå" AB' + AB = 2AB, og 2AB-CD minker.

Delta = 2AB-CD

CD=p sin(theta'); p/2 = AB sin(theta) -> CD=2AB sin^2 (theta); antar theta=theta'

Delta=2AB(1-sin^2 (theta)) = 2AB cos^2(theta)

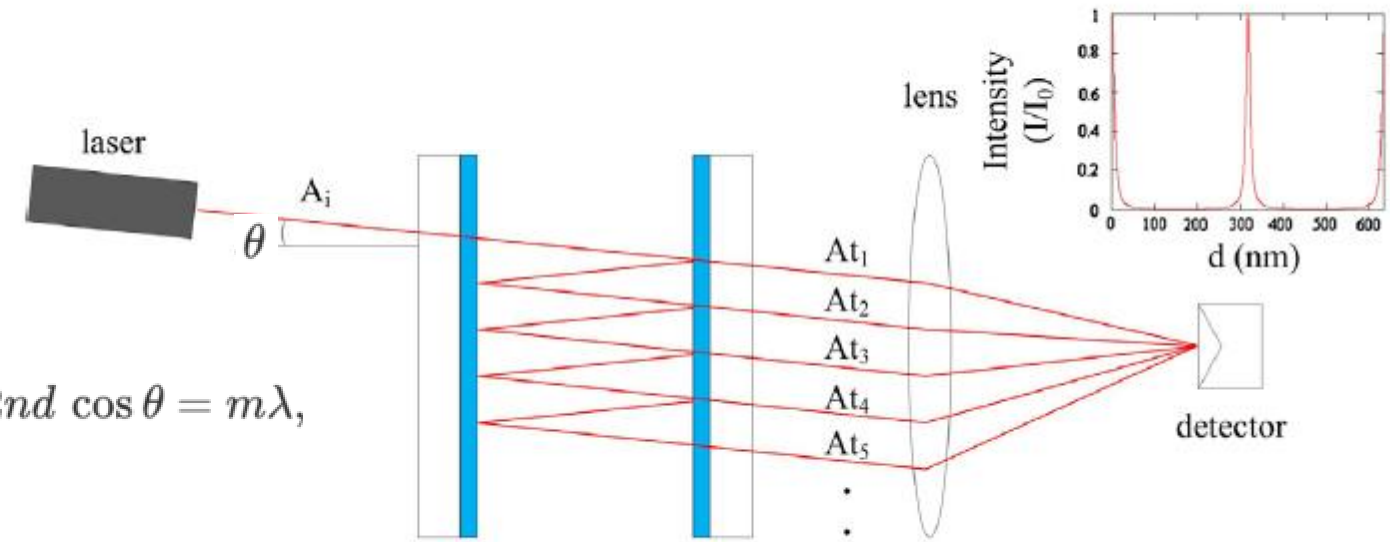
AB=d/cos(theta) -> Delta= 2d cos(theta) . QED.

Resonans for :

Delta = m lambda -> 2d cos(theta) = m lambda

Mer generelt: **2 n d cos(theta) = m lambda;** der n er refraktiv indeks mellom platene, og anta refraktiv indeks = 1 utenfor platene.

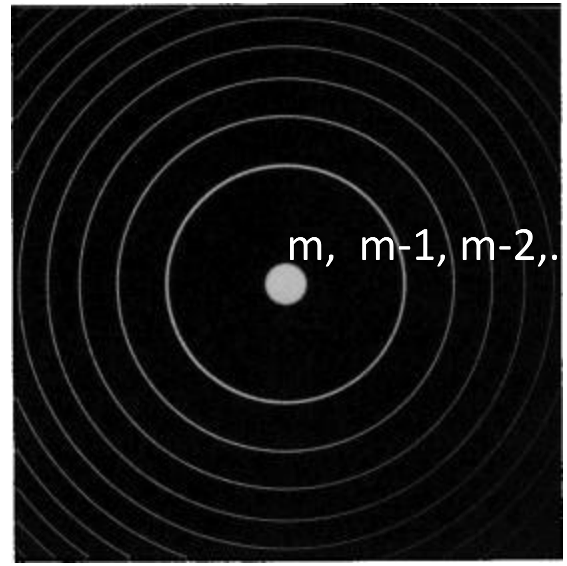
Plane wavefront in one direction (point source at infinite distance, or collimated beam from same point source, through telescope)



$$2nd\ \cos\theta = m\lambda,$$

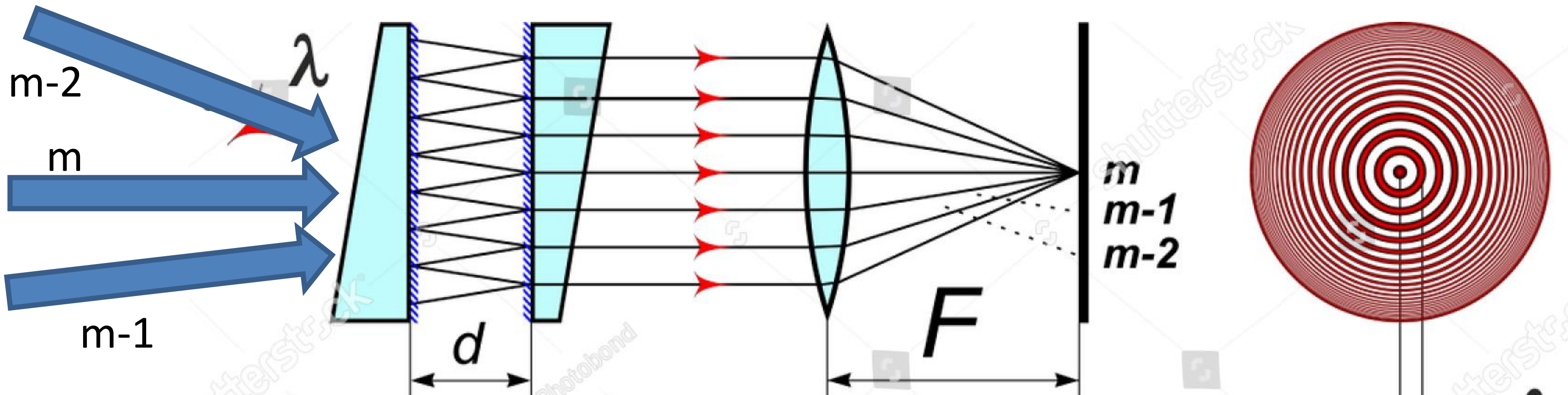
- A ray parallel to the ray shown, would focus on the same point in the detector.
  - The wavelength must be close to the CWL λ at the given angle for transmission.
- This gives a point with a certain point spread function in the image plane.
- Interferece fringes would be formed when integrating over all angles (corresponding to an extended source), due to the various filter orders m, corresponding to a set of discrete angles with respect to the optical axis.

With an *extended source of monochromatic* light of wavelength λ, the interference pattern observed in transmitted light consists of narrow concentric rings (fringes of equal inclination) corresponding to the condition



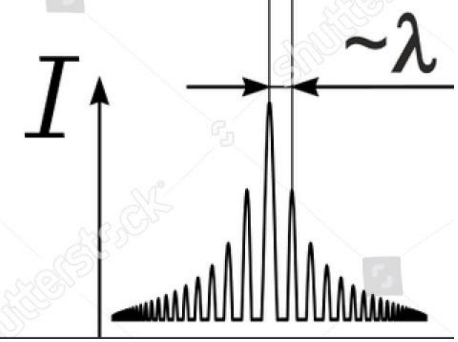
$$2nd\cos\theta = m\lambda,$$

where *d* is the separation of the FP mirror surfaces, *n* is the refractive index of the medium between them, and θ is the angle of incidence.



Longest path difference for normal incidence: Max($m\lambda$,)

$$I = \frac{I_0}{1+4R/(1-R)^2 Sin^2(k\Delta/2)}$$



Links

- https://solarspectrumopticalfilters.com/
- http://www.company7.com/daystar/products_old.html

Kostnad vs hyllevare

- 1x ERF filter: **231 EUR**
- 2xFP filtere: **225 EUR**
- Total ca 500 EUR = ca 5000 Nok
  - Halv pris ifht tilsvarende hyllevare:

- Pris sammenliknbar med billigste 1 Å, D=40 mm Coronado-variant (single Etalon = single FP)
- D=40 mm, Dual Etalon ("double stack") 0.5 Å variant "ligger på" ca 1200 $ = ca 10000 Nok

Ocular projection mode with camera, simplified drawing