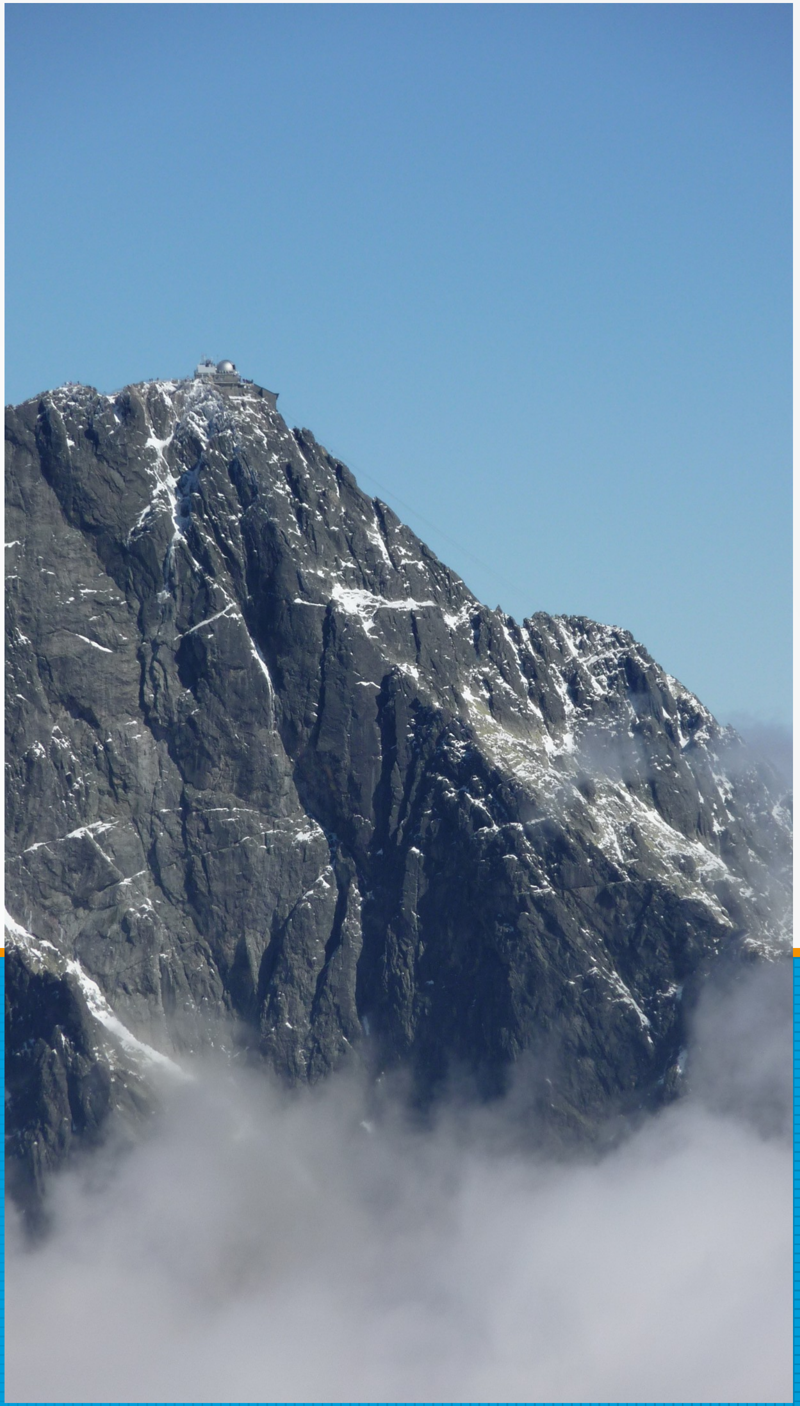
LSO summer internship program: Lyot - Ohman filter

Ján Rybák
Lomnický Štít Observatory (LSO)
AI SAS, Tatranská Lomnica, Slovakia

2024



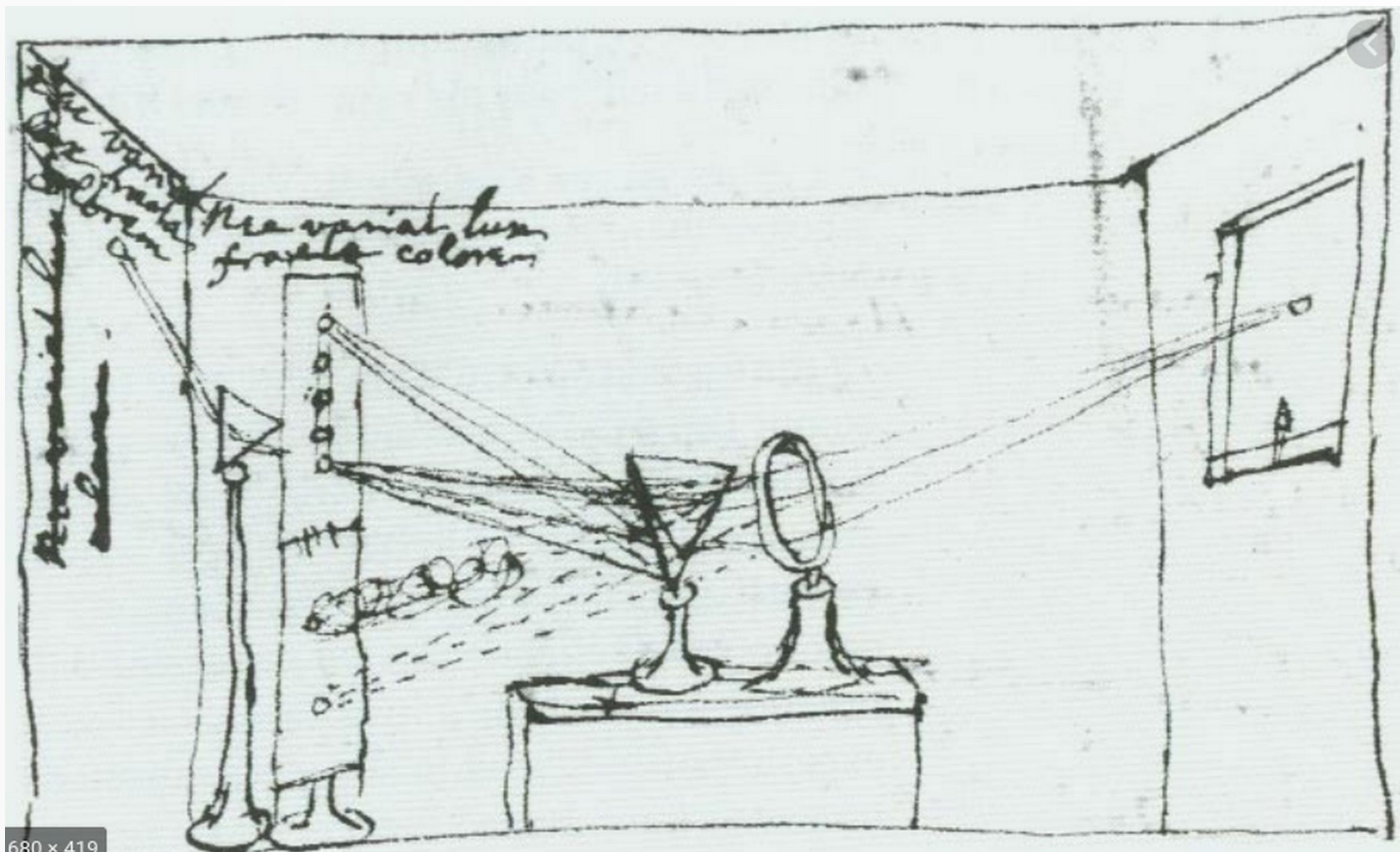
Content:

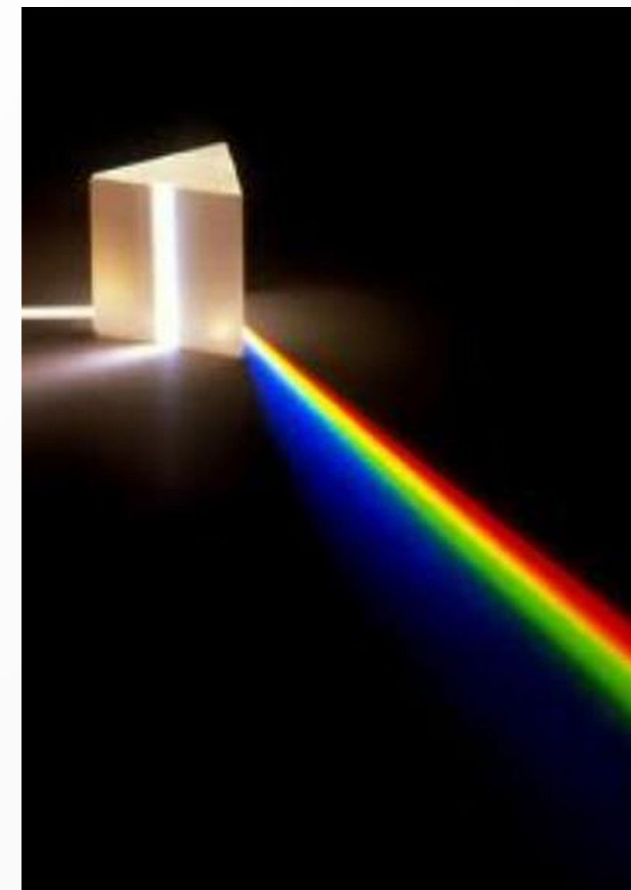
- A tribute to the Bernard Lyot genius – part 2

- Two main topics + a little of history:
  - Lyot- Ohman filter
  - CoMP-S instrument @ LSO coronagraph

Spectrometers: a little of history

- Beginning of the story

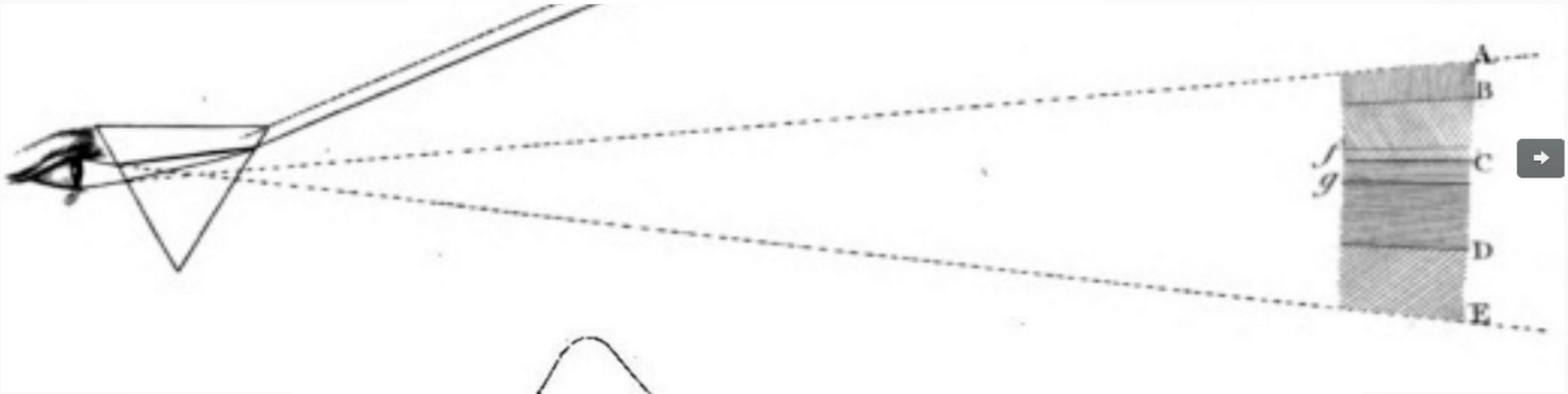


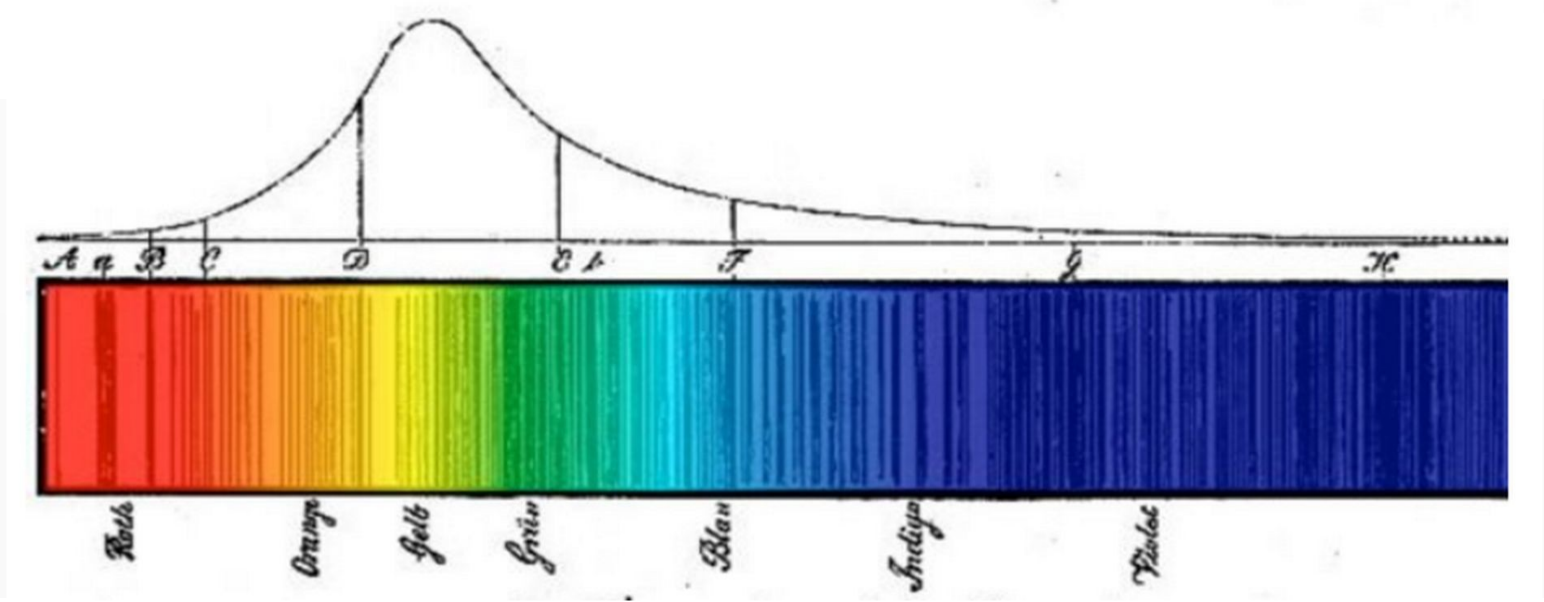


Isaac Newton

Spectrometers: a little of history

- The next step



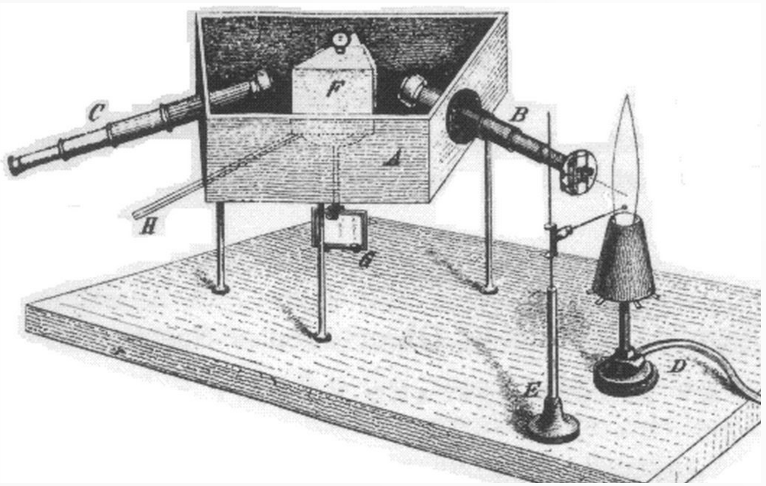


W.H. Wollaston

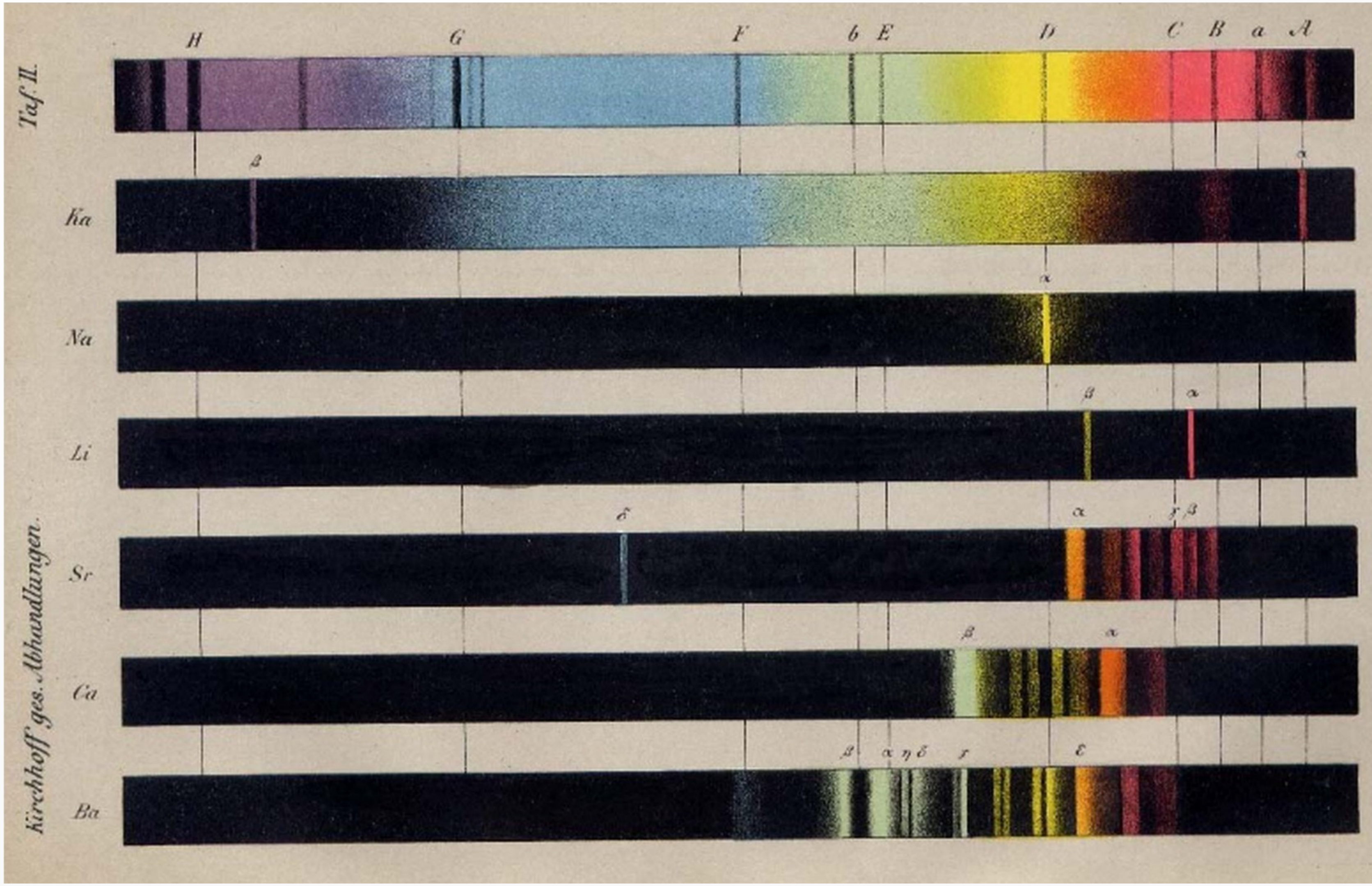
J. Fraunhofer

Spectrometers: a little of history

- What is the universe made of ? No Nobel price…



G. Kirchhoff & R. Bunsen



Spectrometers: a little of history

- Prism → diffraction grating (echelle,...)
- No 2D spectrometers (narrow slit → 2D area) used in astronomy until 40ties
- Sun as a 2D object ~ 1D slit of the prism or diffraction grating spectrometers
- (Solar observations in general: 4D problem ~ time: X,Y,λ, polarization ~ time)
- Lyot: at least X,Y for λ_i at the same time

Lyot-Ohman filter

B. Lyot @ Pic du Midi

- Lyot's spectral instruments:
    - Prism
    - diffraction grating
- Lyot: at least X,Y for λ_i at the same time
- No narrow slit!
- 2D area as entrance
- Task: select the desired λ_i and block the rest λ for a 2D FoV

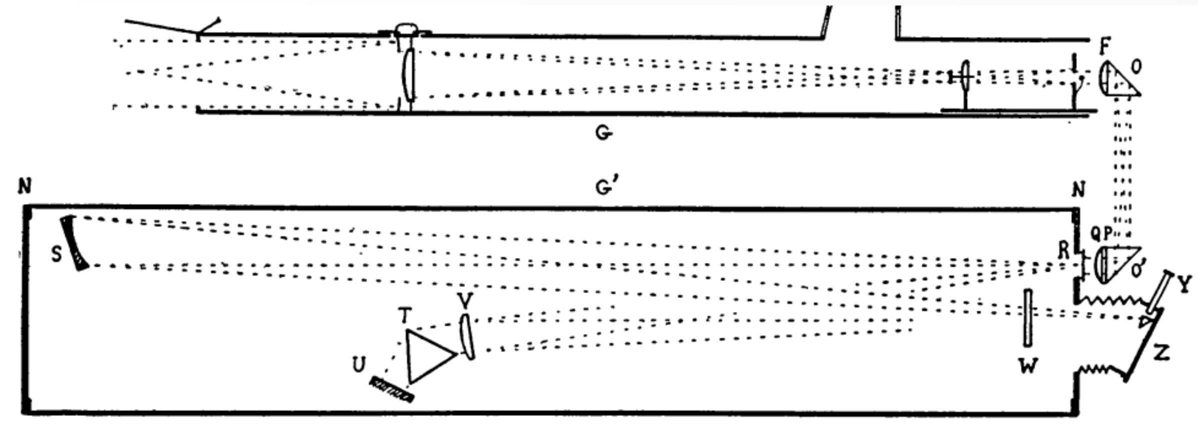


FIG. 6.—*Plan of the coronagraph and the spectrographs used in 1931.*

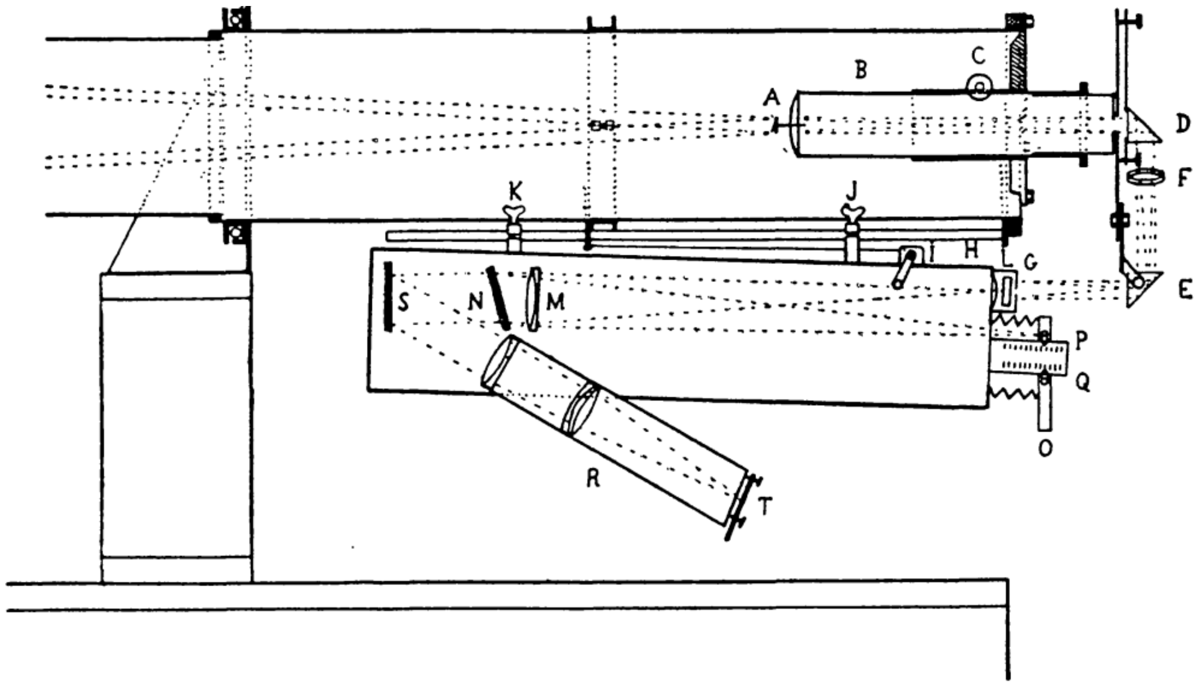


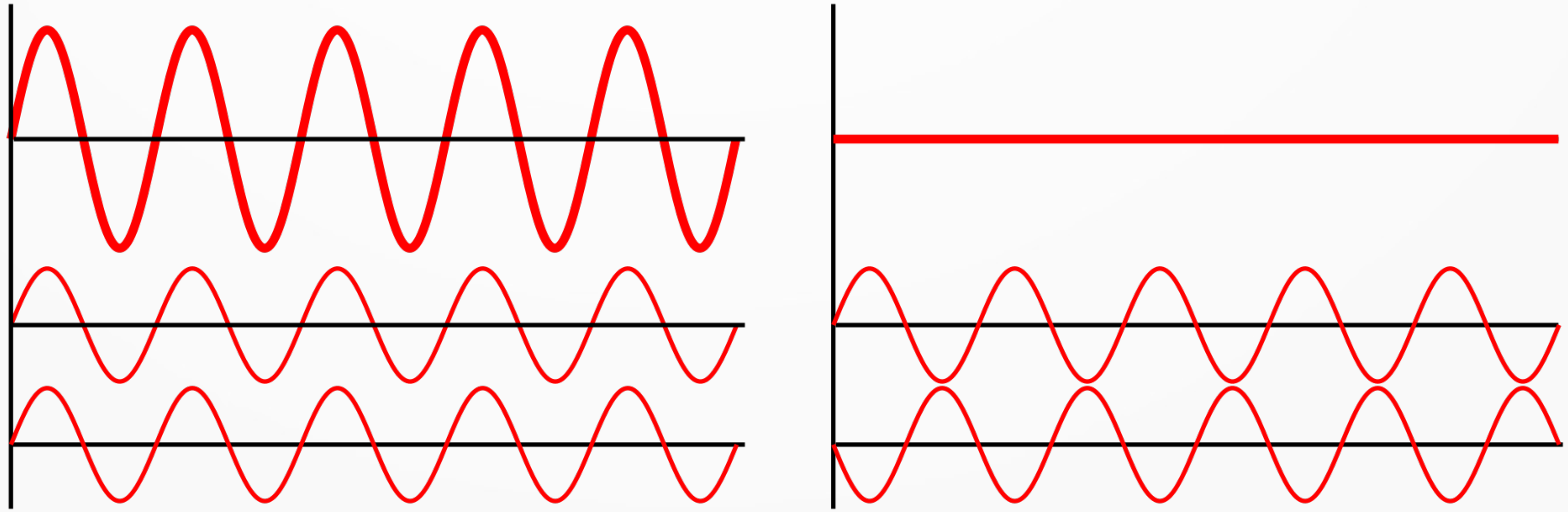
FIG. 7.—*Plan of the final coronagraph and the spectrograph used since 1935.*

B. Lyot @ PdM or in Paris

- Task: select the desired λ_i and block the rest λ for a 2D FoV
- Possibilities: light and its properties – electromagnetic transverse waves and interference & diffraction & polarization & scattering

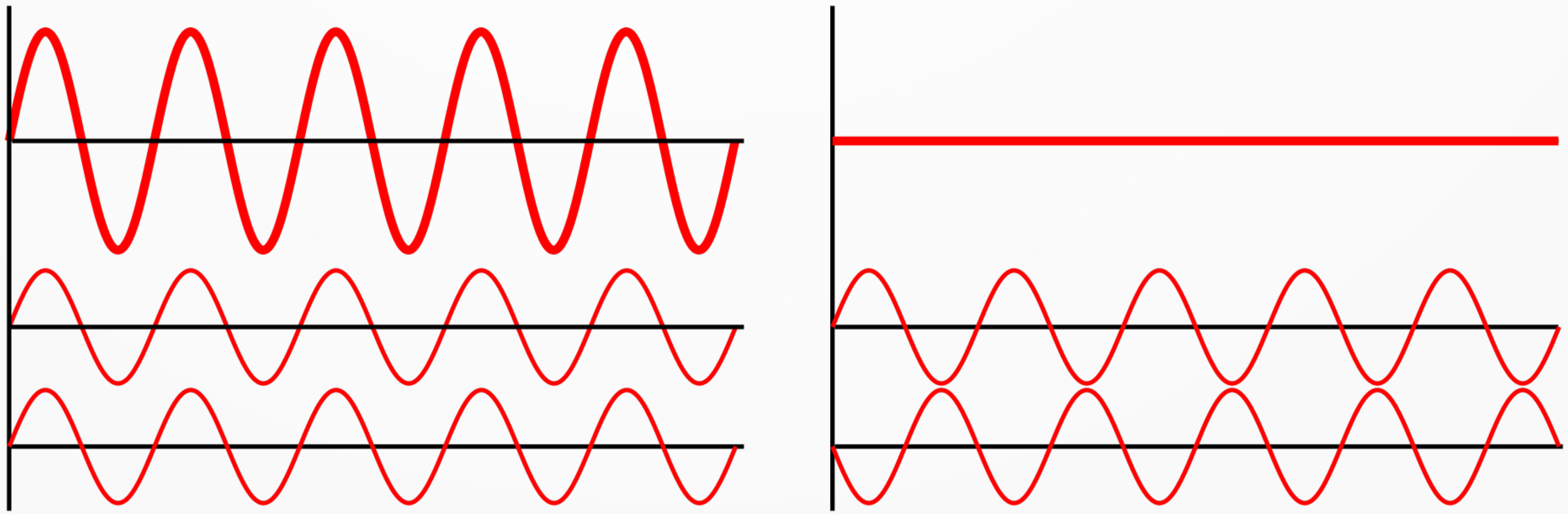
B. Lyot @ PdM or in Paris

- electromagnetic transverse waves and interference:
  - Wiki: interference is a phenomenon in which two coherent waves are combined by adding their intensities or displacements with due consideration for their phase difference → constructive or destructive interference if the two waves are in phase or out of phase, respectively.



B. Lyot @ PdM or in Paris

- Wiki: Two monochromatic beams from a single source always interfere. Beams from different sources are mutually incoherent.
- JR: also the same linear polarization plane (or opposite circular polarization) are required to get interference



B. Lyot @ PdM or in Paris

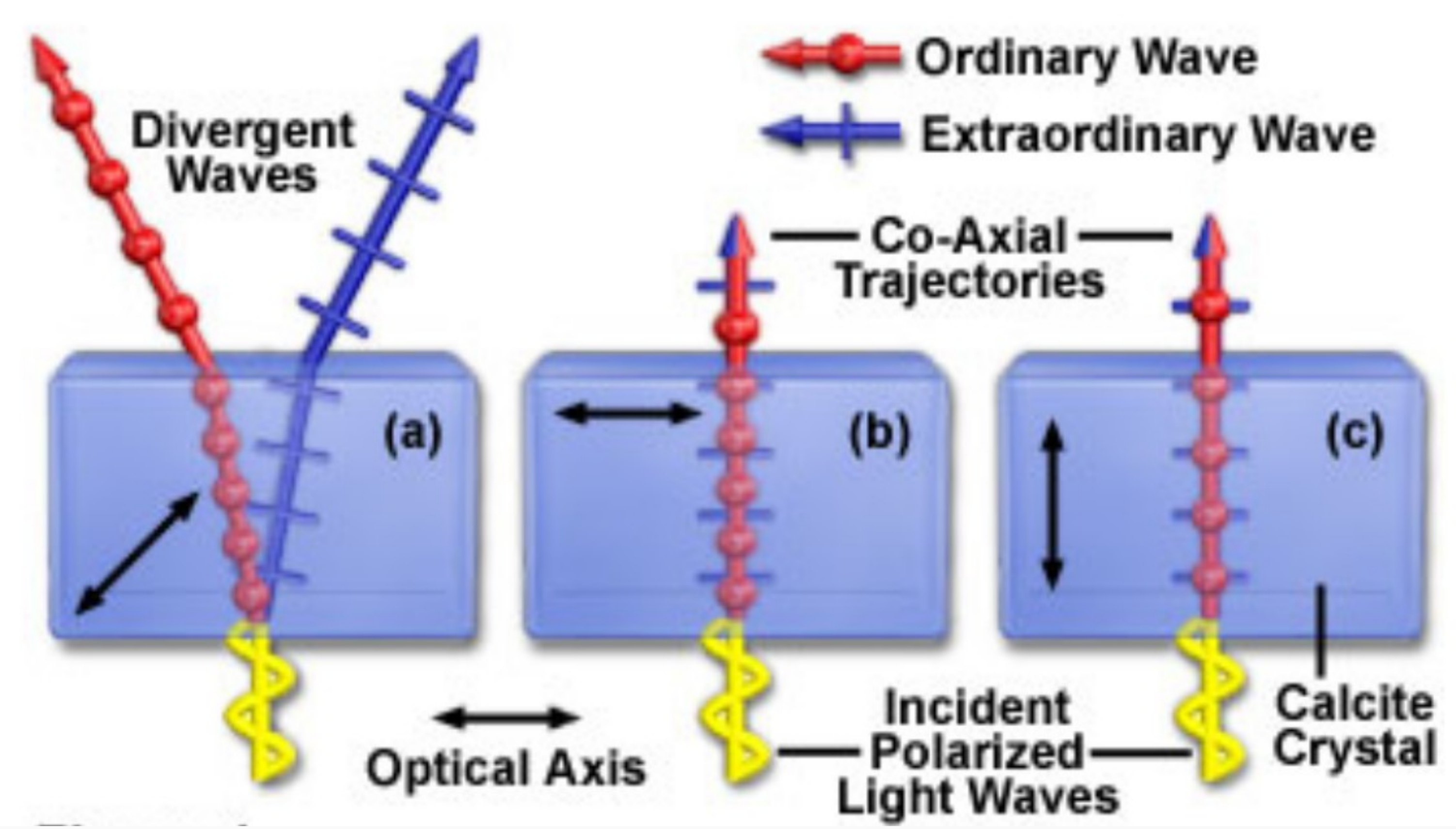
- How to make phase difference for light from 2D FoV? Probably a 3D object of the homogeneous properties over at least one 2D side generating the phase difference in the 3rd dimension
- Basic course of optics: also prisms, cubes, polarizers – boring... Not for Lyot!
- Promising solution: birefringence crystals! Really? It is a toy!

B. Lyot @ PdM or in Paris

- *Following: Wenda Cao, (BBSO/NJIT, USA): Lecture07: Filters*
- Birefringence (double refraction) is the decomposition of a ray of light into two rays when it passes through certain anisotropic material (birefringent crystal), such as crystals of calcite.
- When a beam of light is incident on a birefringent crystal, the waves are split upon entry into orthogonal polarized components: ordinary and extraordinary.
- o and e components travel through the molecular lattice along different pathways, depending on their orientation with respect to the crystalline optical axis – $\mathbf{n_e \# n_o}$

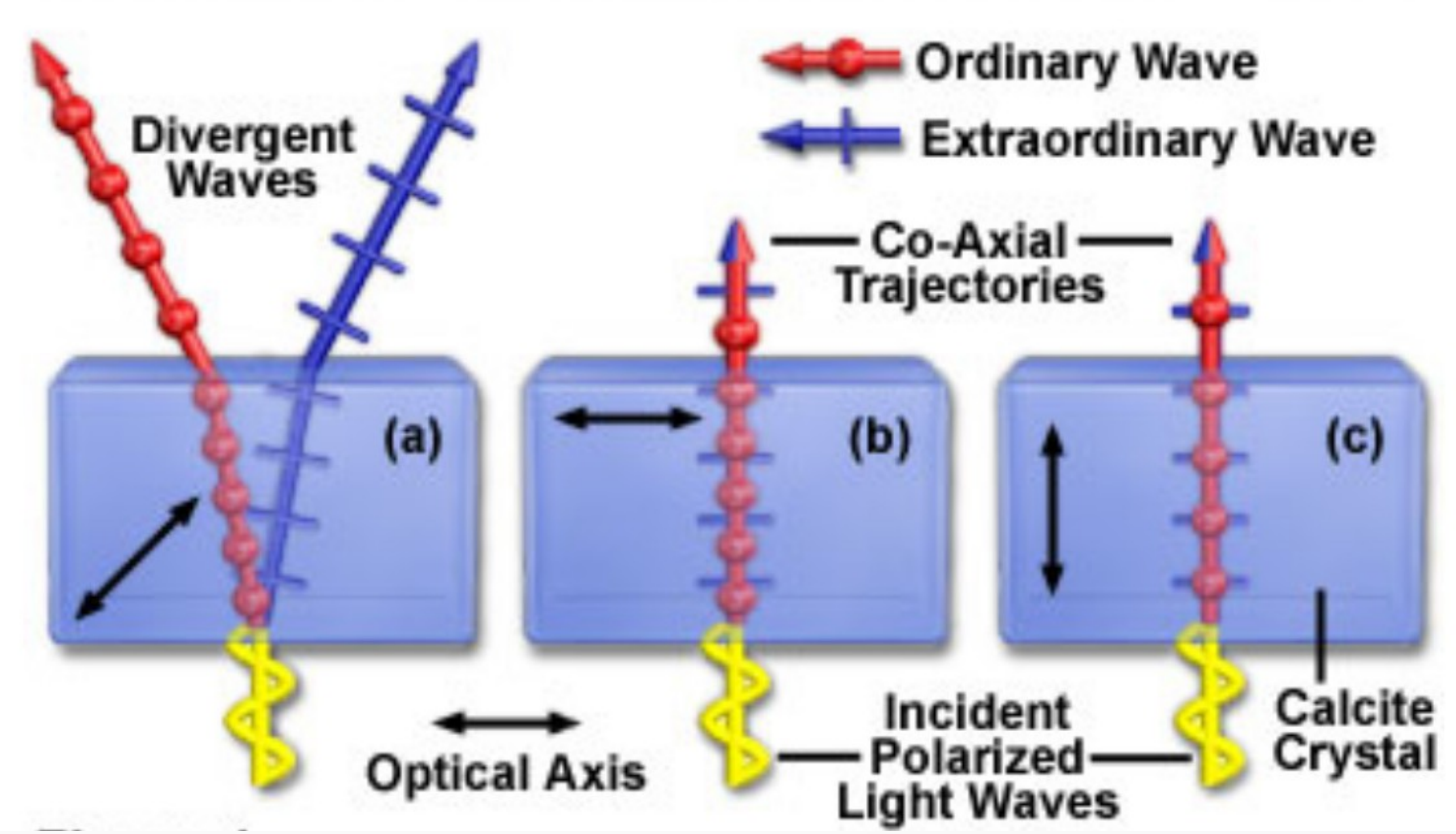
B. Lyot @ PdM or in Paris

- Light passing through a birefringent crystal:
  - Oblique: o and e diverge and follow different paths, and o travels faster
  - Parallel: o and e wavefront coincide in amplitude, phase, and trajectory
  - Perpendicular: no divergence between o and e, o wave still travels at a higher speed than does e wave. **Bingo!**



B. Lyot @ PdM or in Paris

- Light passing through a birefringent crystal:
  - Perpendicular: no divergence between o and e, o wave still travels at a higher speed than does e wave. **Bingo!**
  - Not exactly: the output o and e beams are of linear polarization with mutually orthogonal planes!

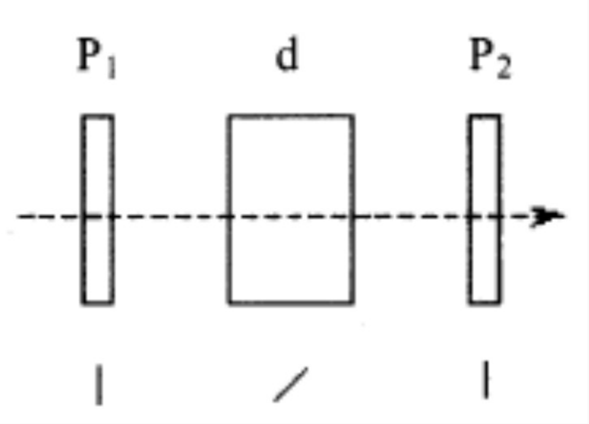


B. Lyot @ PdM or in Paris

- Perpendicular entry: o and e beam speed differ
- Birefringent index **$\mu = n_e - n_o$**
- Crystal of thickness **d** with a phase delay **delta**

$$\delta = \frac{2\pi(\Delta OPL)}{\lambda} = \frac{2\pi d(n_e - n_o)}{\lambda} = \frac{2\pi \mu d}{\lambda}$$

- Consider a birefringent crystal of a thickness of **d**, which is placed between two linear polarizers with the same polarization direction. Assume the optical axis of the crystal is 45° with respect to the polarization directions of linear polarizer → the transmitted light is



$$T = \cos^2(\frac{\delta}{2}) = \cos^2(\frac{\mu d}{\lambda}\pi) = \cos^2(\sigma\pi)$$

B. Lyot @ PdM or in Paris

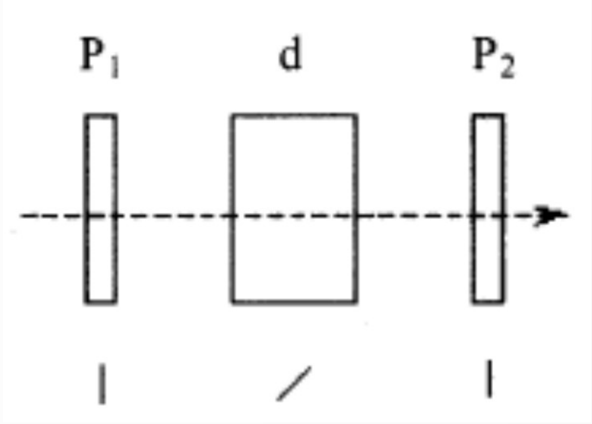
- d_1

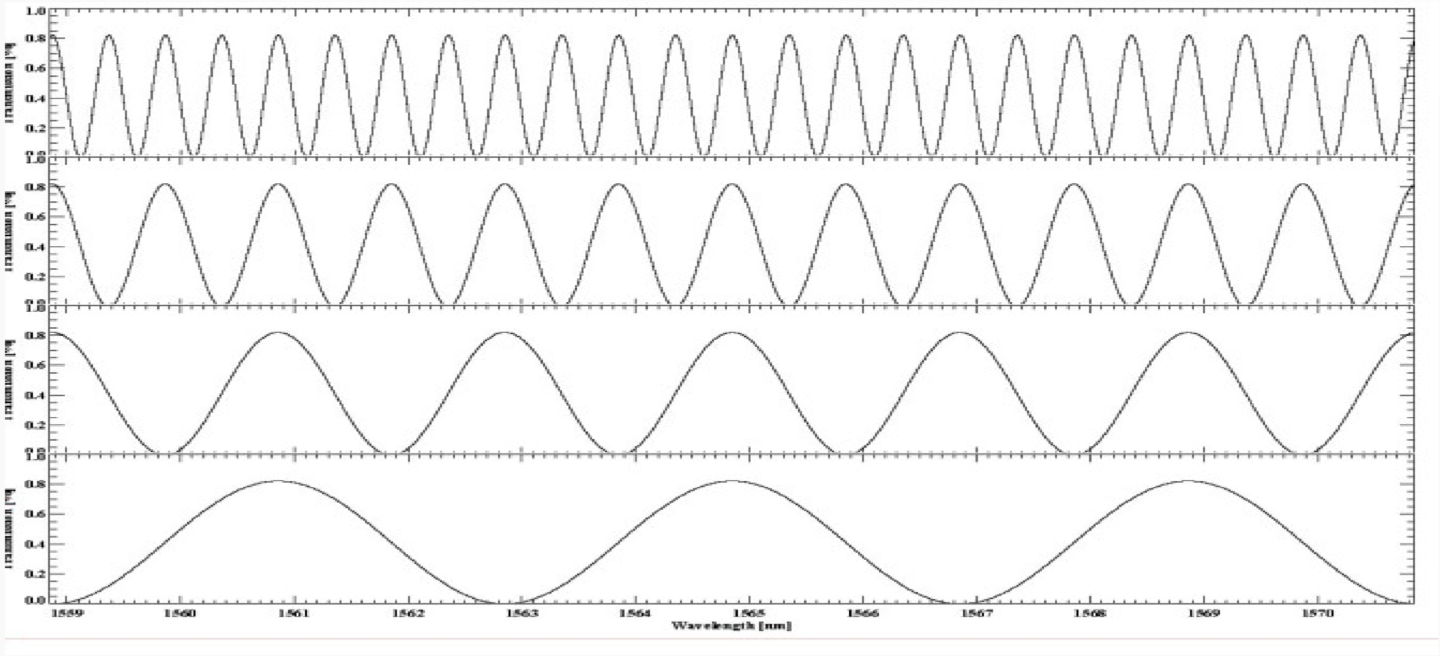
$$T_1 = \cos^2(\frac{\delta_1}{2}) = \cos^2(\frac{\mu d_1}{\lambda}\pi) = \cos^2(\sigma_1 \pi)$$

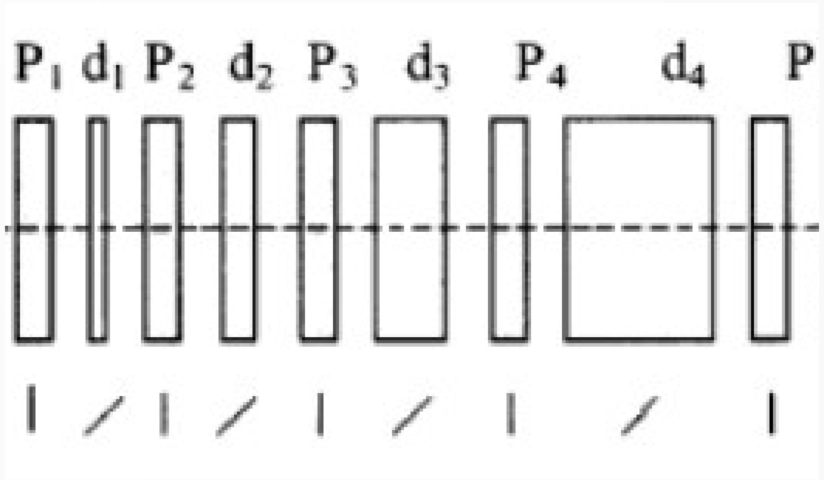
- $d_2 = 2*d_1$

$$T_2 = \cos^2(\frac{\delta_2}{2}) = \cos^2(\frac{\mu d_2}{\lambda}\pi) = \cos^2(\sigma_2 \pi) = \cos^2(2\sigma_1 \pi)$$

- $d_3 = 2*d_2 = 4*d_1$, $d_4 = 8*d_1$



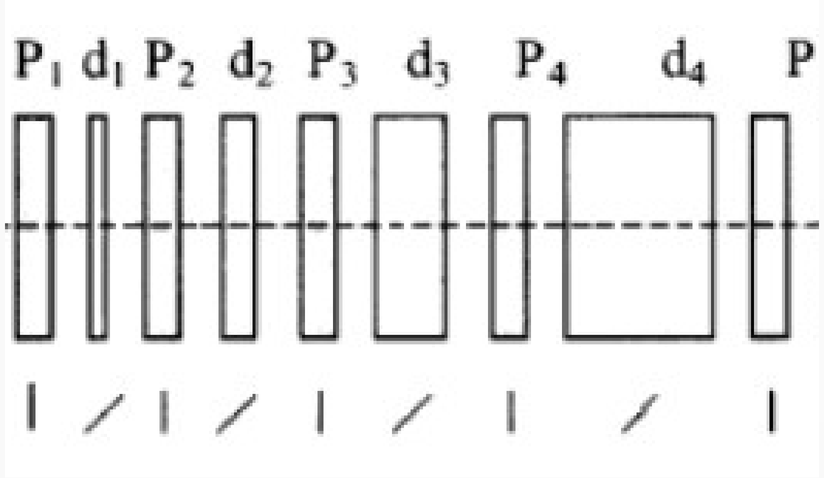


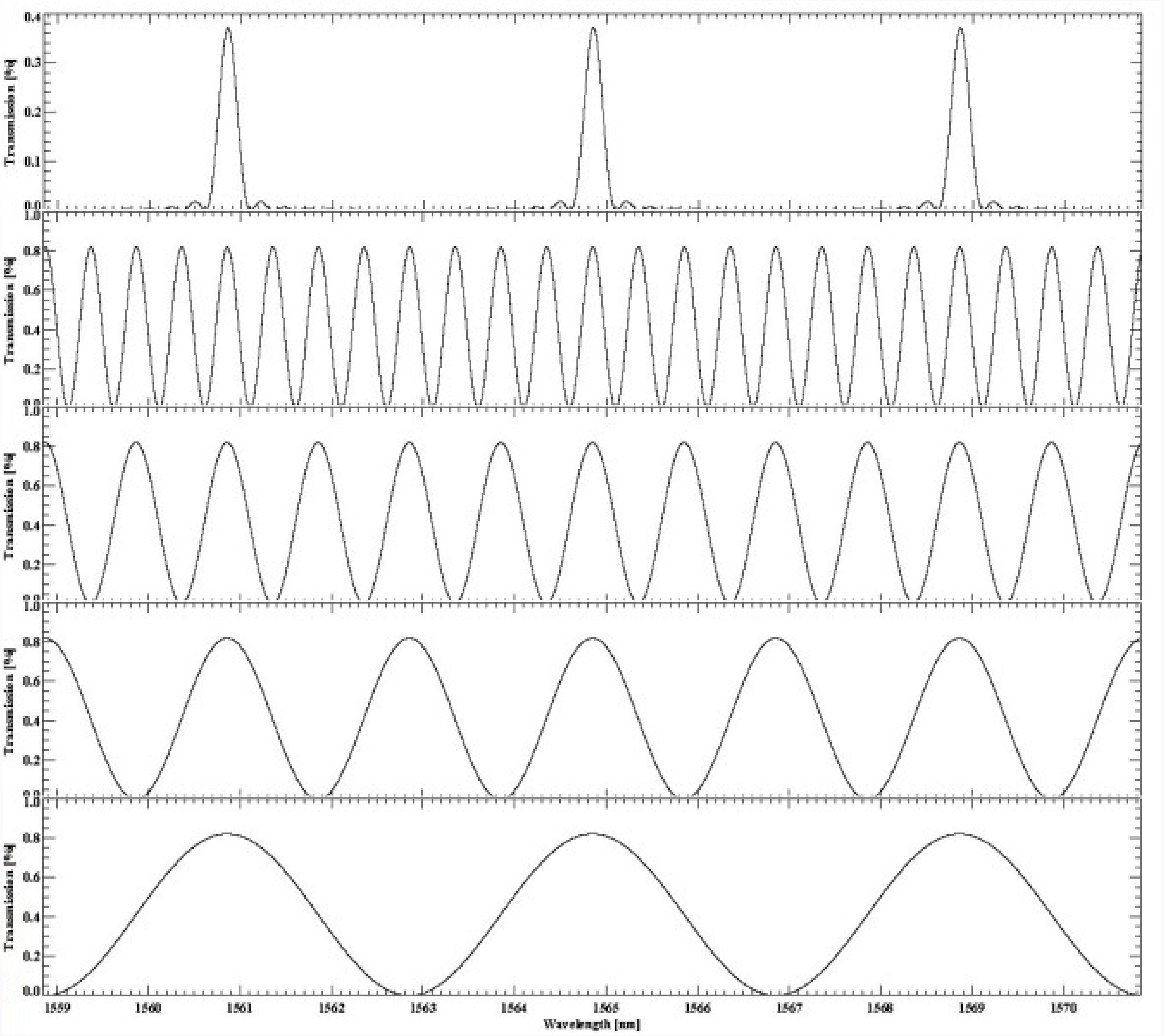


B. Lyot @ PdM or in Paris

- $D_1, D_2, D_3, D_4 \rightarrow T=T_1{*}T_3{*}T_3{*}T_{14}$

$$
\begin{aligned}
T &= T_1 T_2 T_3 T_4 \\
&= \cos^2\left(\frac{\mu d_1}{\lambda}\pi\right)\cos^2\left(\frac{\mu d_2}{\lambda}\pi\right)\cos^2\left(\frac{\mu d_3}{\lambda}\pi\right)\cos^2\left(\frac{\mu d_4}{\lambda}\pi\right) \\
&= \cos^2(\sigma_1\pi)\cos^2(2\sigma_1\pi)\cos^2(4\sigma_1\pi)\cos^2(8\sigma_1\pi)
\end{aligned}
$$





B. Lyot @ PdM or in Paris

- Full Width at Half Maximum (FWHM): determined by the thickness of the thickest stage d_{thick}

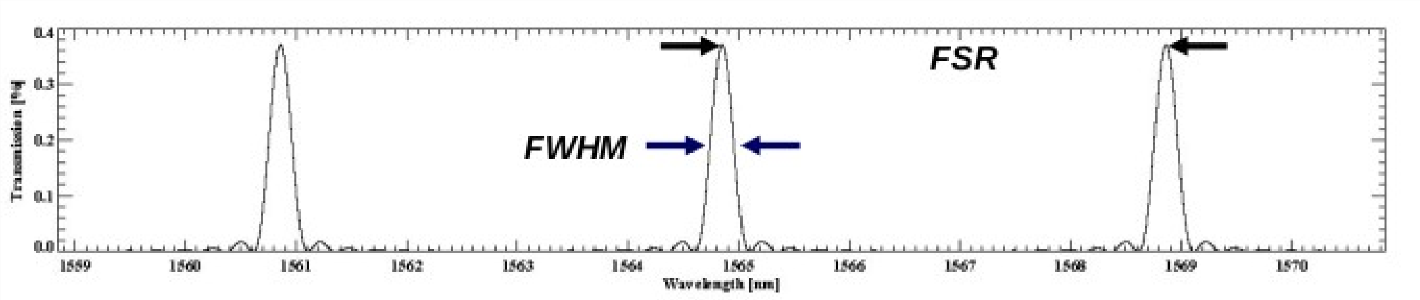
$$\Delta\lambda_{FWHM} = \frac{\lambda^2}{2\mu d_{thick}}$$

- Free Spectral Range (FSR): determined by the thickness of the thinnest stage d_{thin}

$$FSR = \frac{\lambda^2}{\mu d_{thin}}$$

- for a Lyot filter with n stages, $d_{thick} = (2n)d_{thin}$, so

$$FSR = \frac{\lambda^2}{\mu d_{thin}} = (4n)\Delta\lambda_{FWHM}$$



B. Lyot + Y. Ohman

- Lyot, B., 1944, “Le filtre monochromatique polarisant et ses applications en physique solaire”, Annales d'Astrophysique, Vol. 7, p.31, http://adsabs.harvard.edu/abs/1944AnAp....7...31L
- Ohman, Y, 1938, “A New Monochromator”, Nature, vol.141, no.3560, p. 157, https://ui.adsabs.harvard.edu/abs/1938Natur.141..157O

FIG. 2

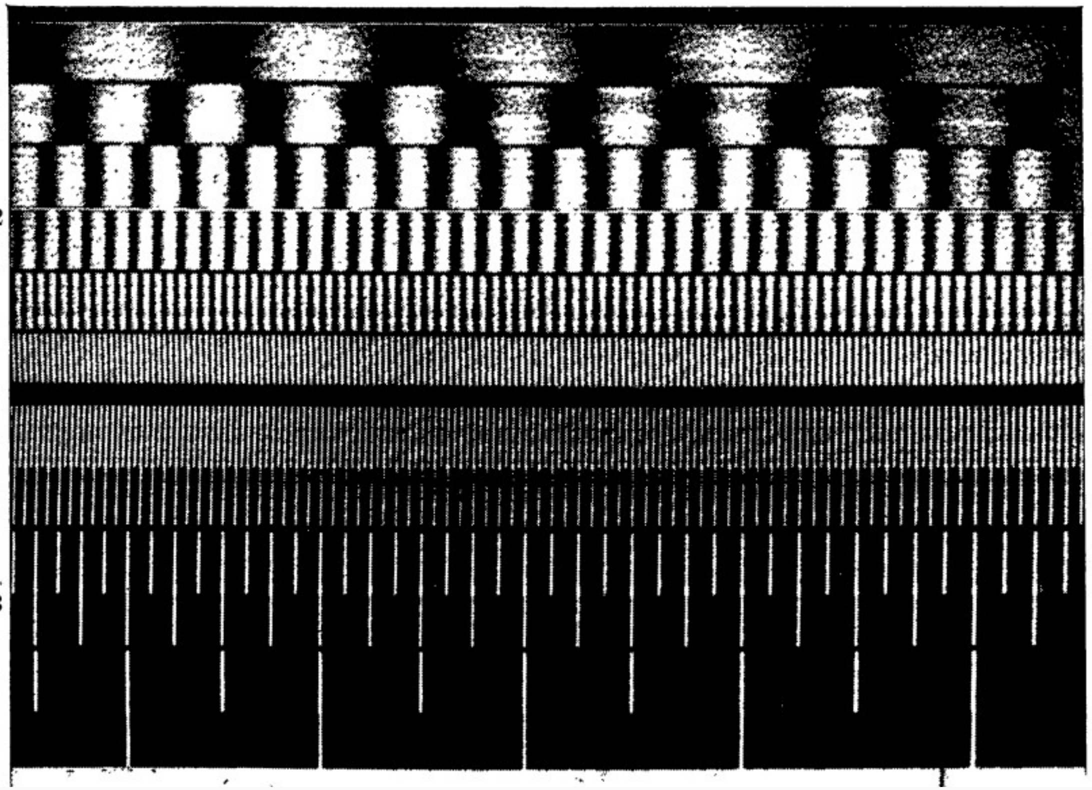
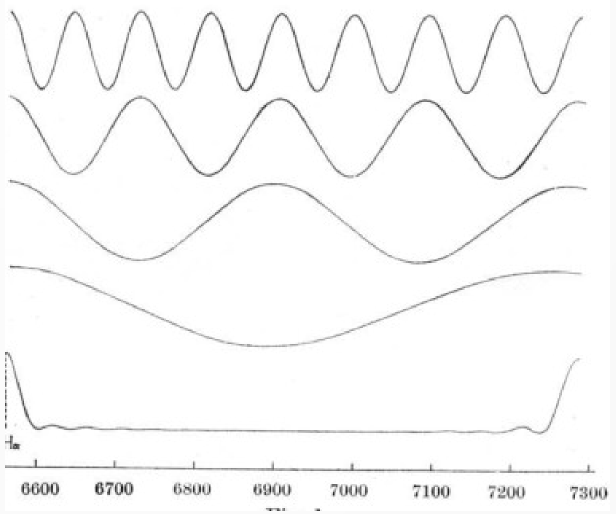
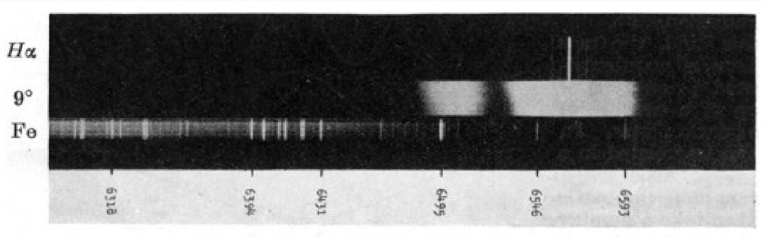


FIG. 3





CoMP-S 2D spectropolarimeter

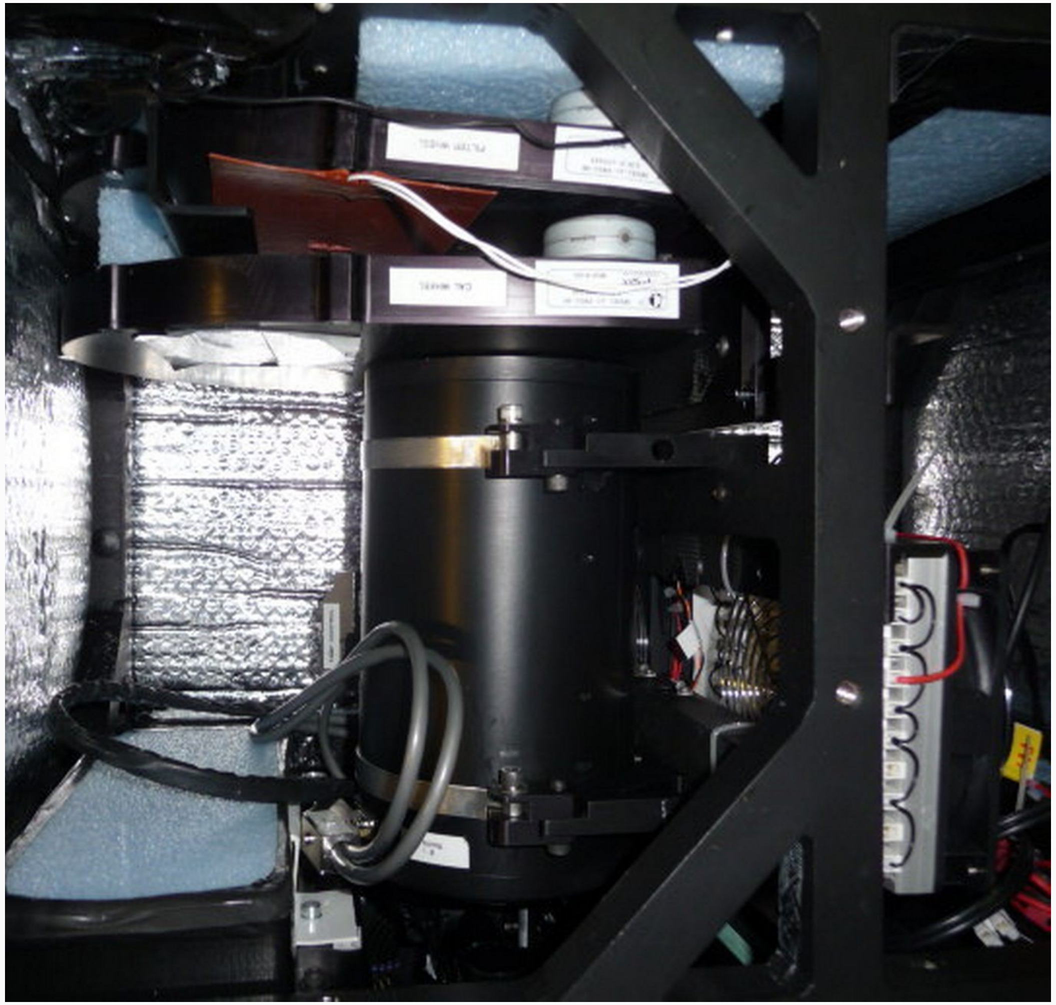
- Coronal Multiline polarimeter for Slovakia
- HAO/NCAR (Boulder, CO, USA): S. Tomzcyk + S. Sewell

CoMP-S 2D spectropolarimeter

- two boxes of 2 modules

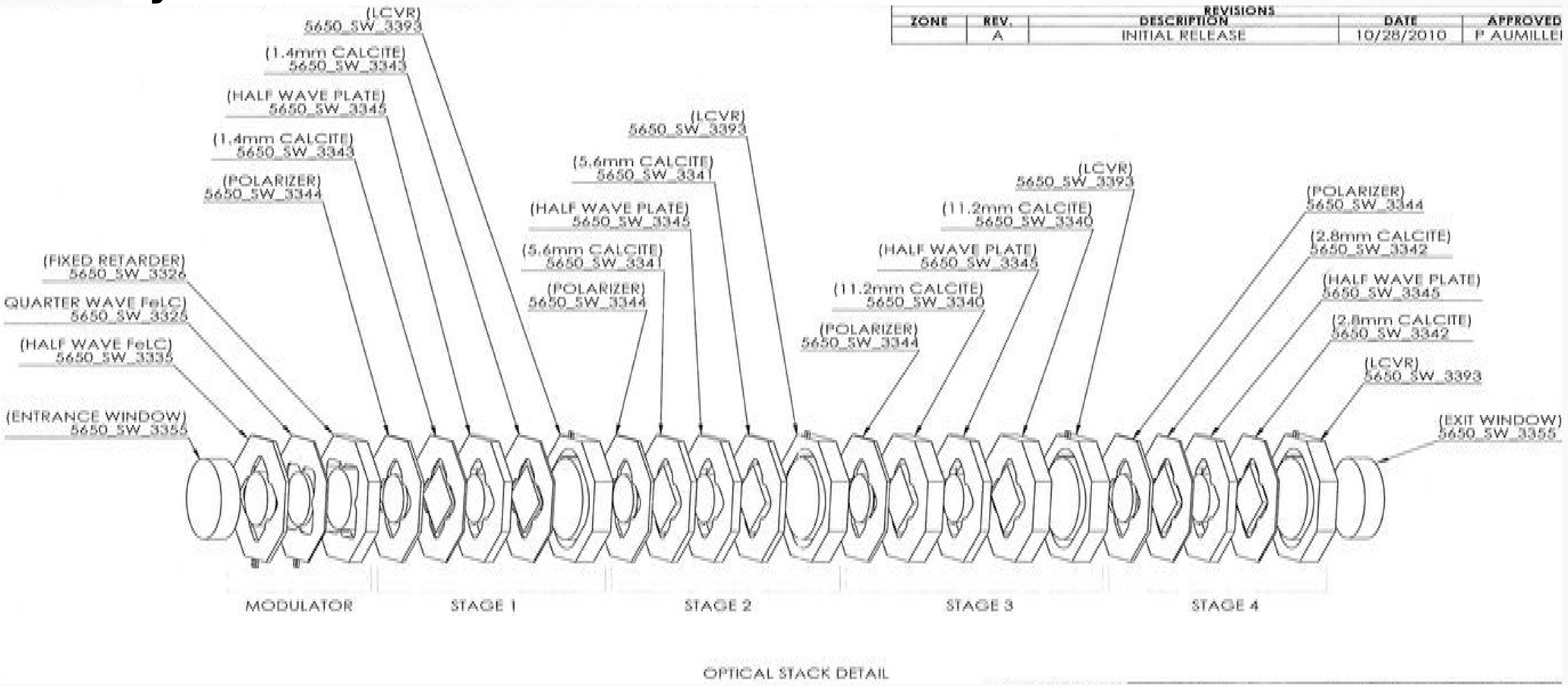
CoMP-S 2D spectropolarimeter

- filter module: Lyot filter, 2 filter wheels



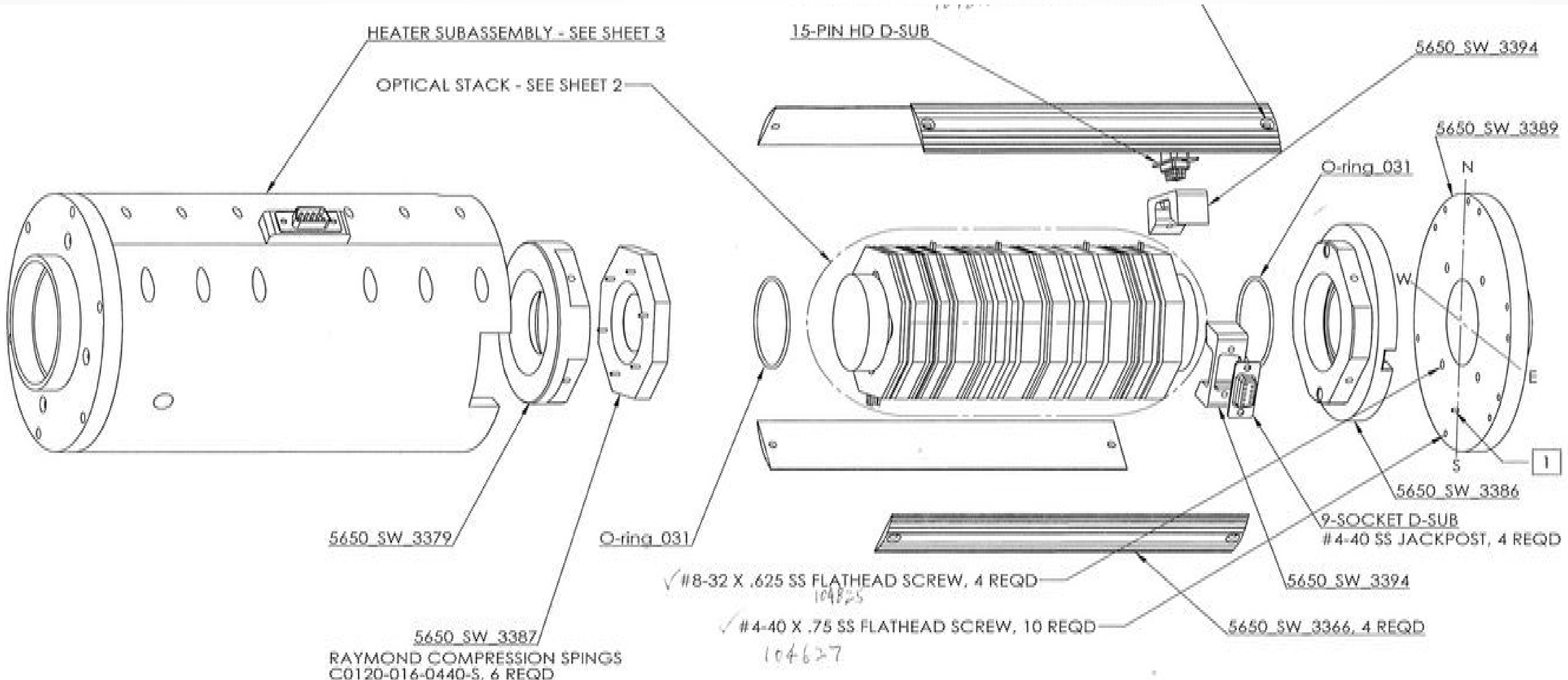
CoMP-S 2D spectropolarimeter

- Lyot filter



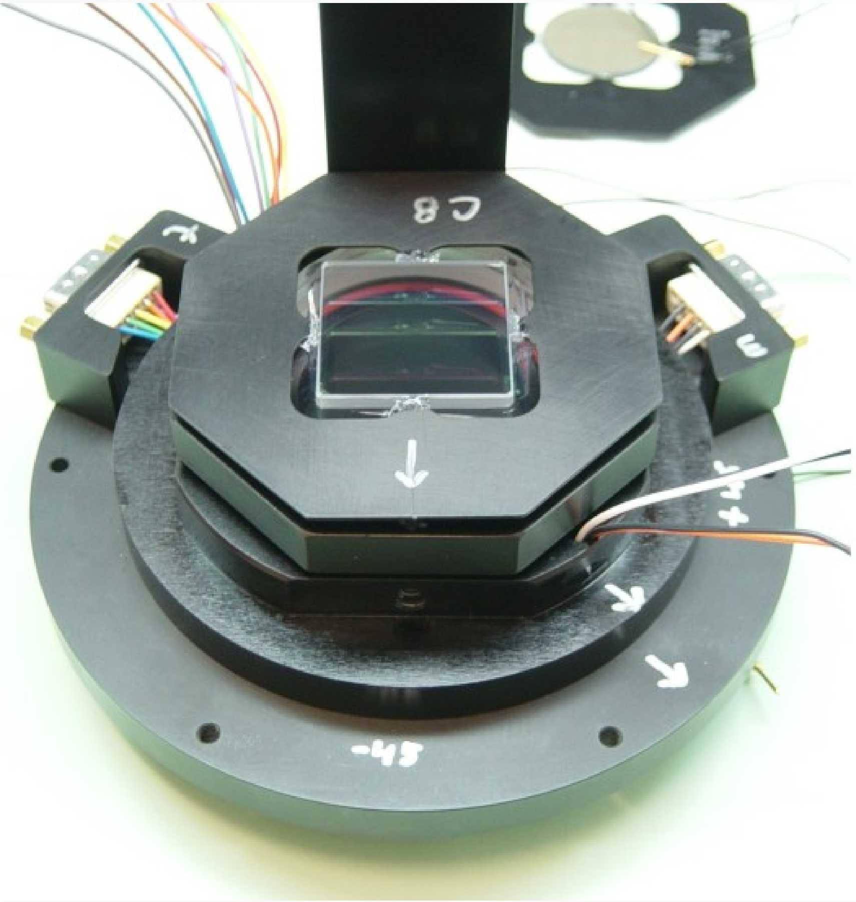
CoMP-S 2D spectropolarimeter

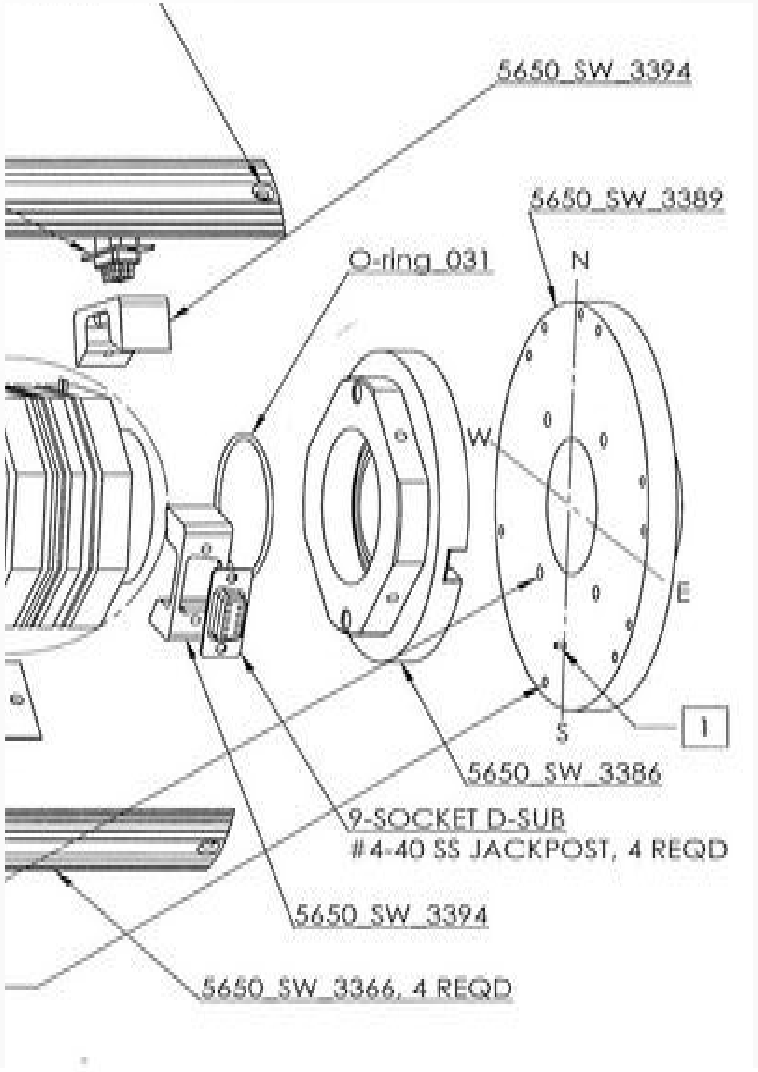
- Lyot filter



CoMP-S 2D spectropolarimeter

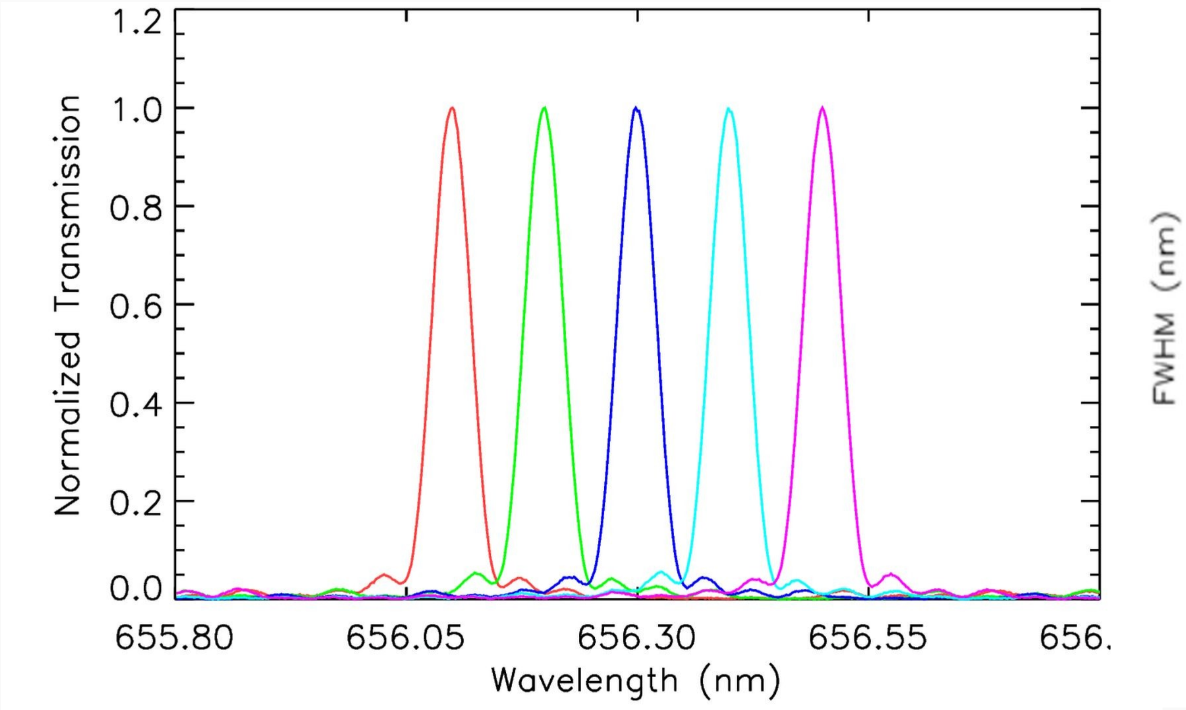
- Lyot filter

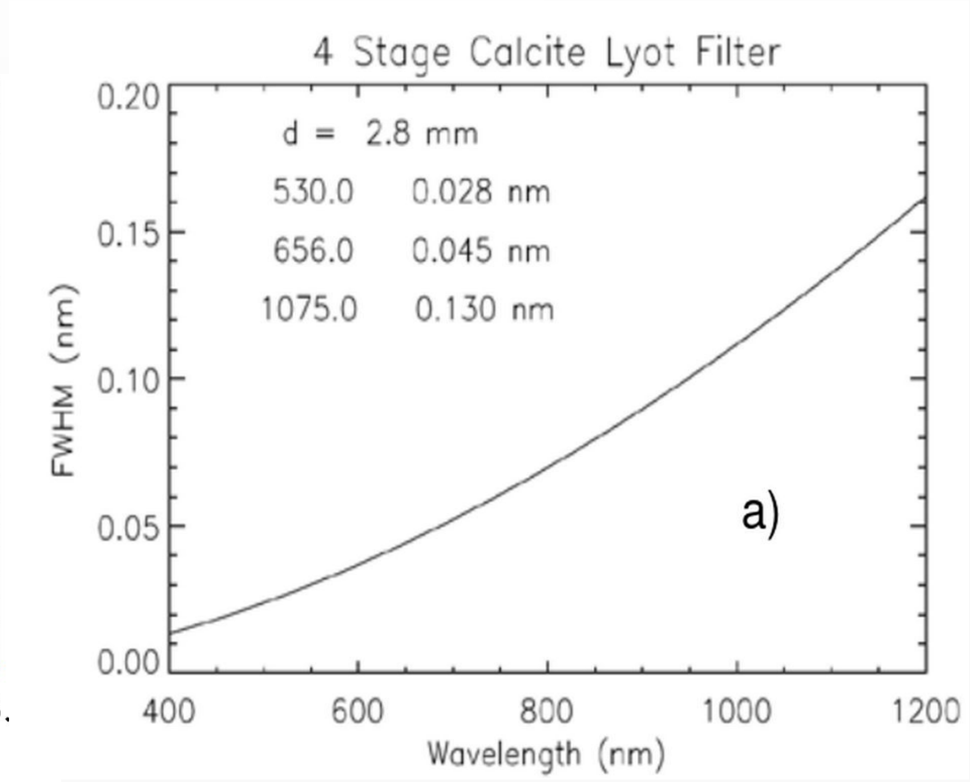




CoMP-S 2D spectropolarimeter

- "Coronal" spectral lines: **Fe X 637 nm** (Fe XIV 530, FE XIII 1074+1079 nm)
- "Prominence" spectral lines: **He D3 587 nm, H I 656 nm, Ca II 854 nm** (He I 1083 nm)
- LF passband:





CoMP-S 2D spectropolarimeter

- LT tuning:
  - Temperature (Lyot),
  - Angle (Ohman)

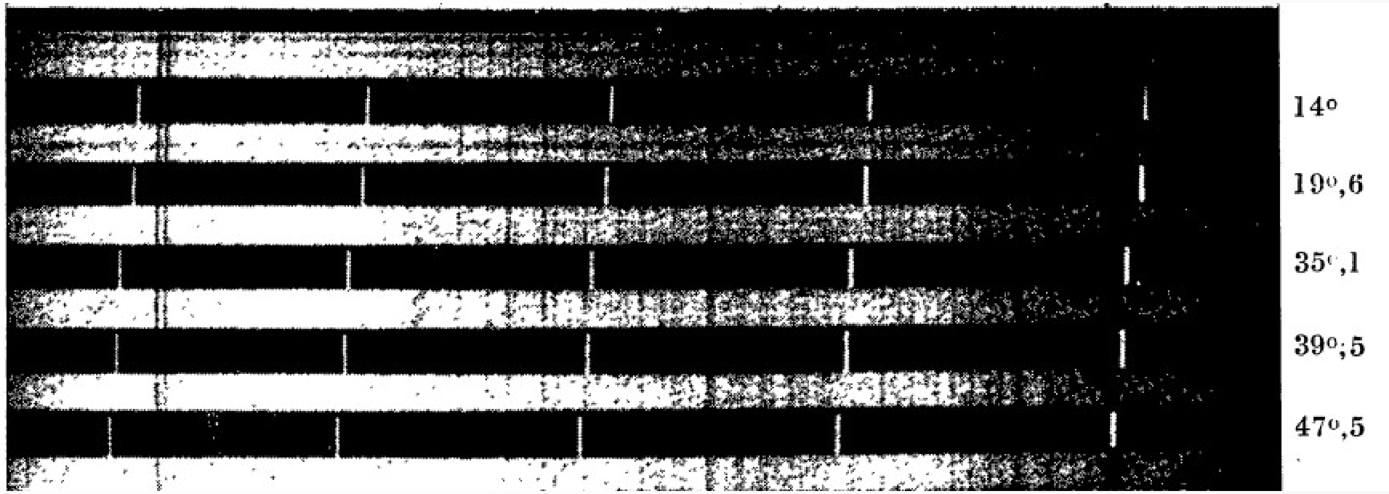
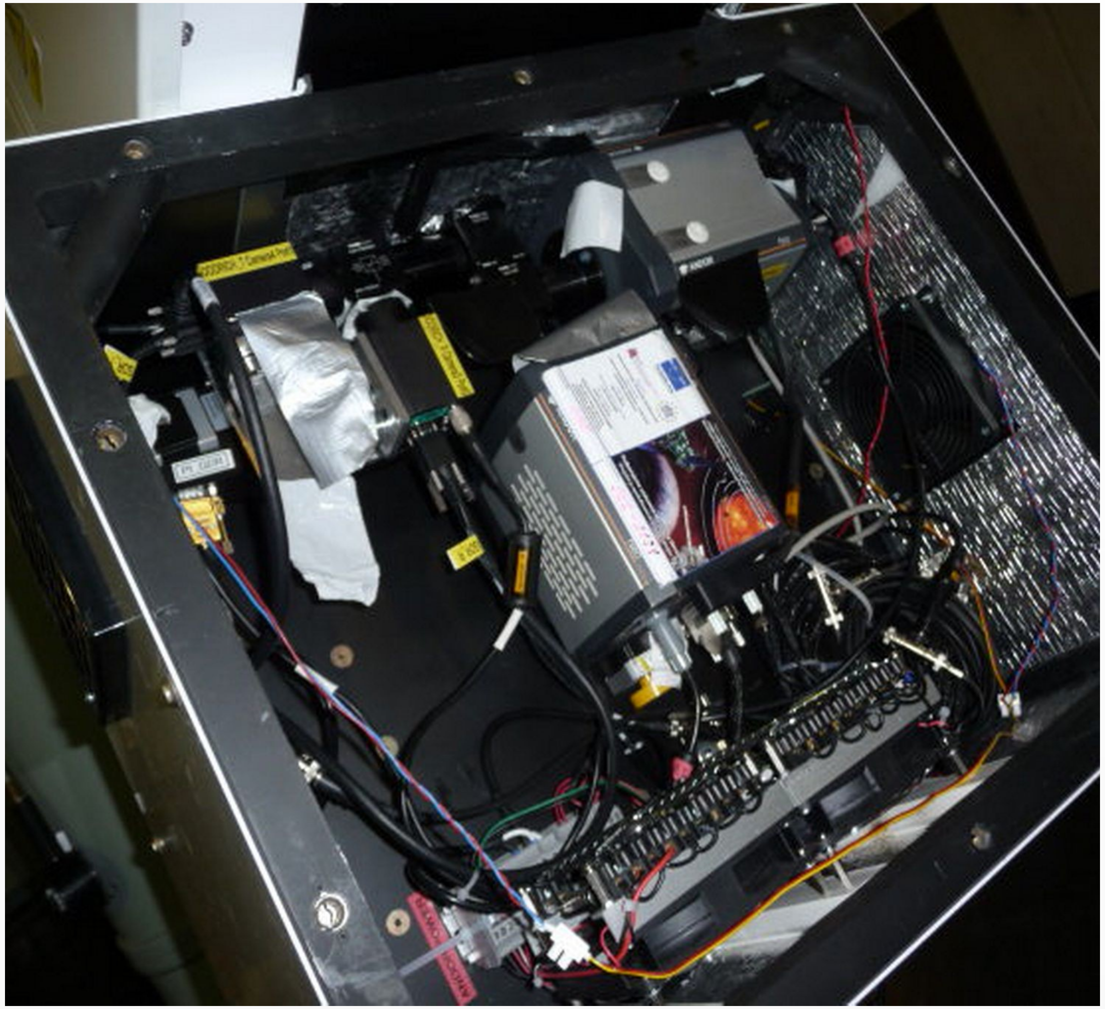


FIG. 11

  - LCVR: dielectric molecules orientation ~ direct voltage

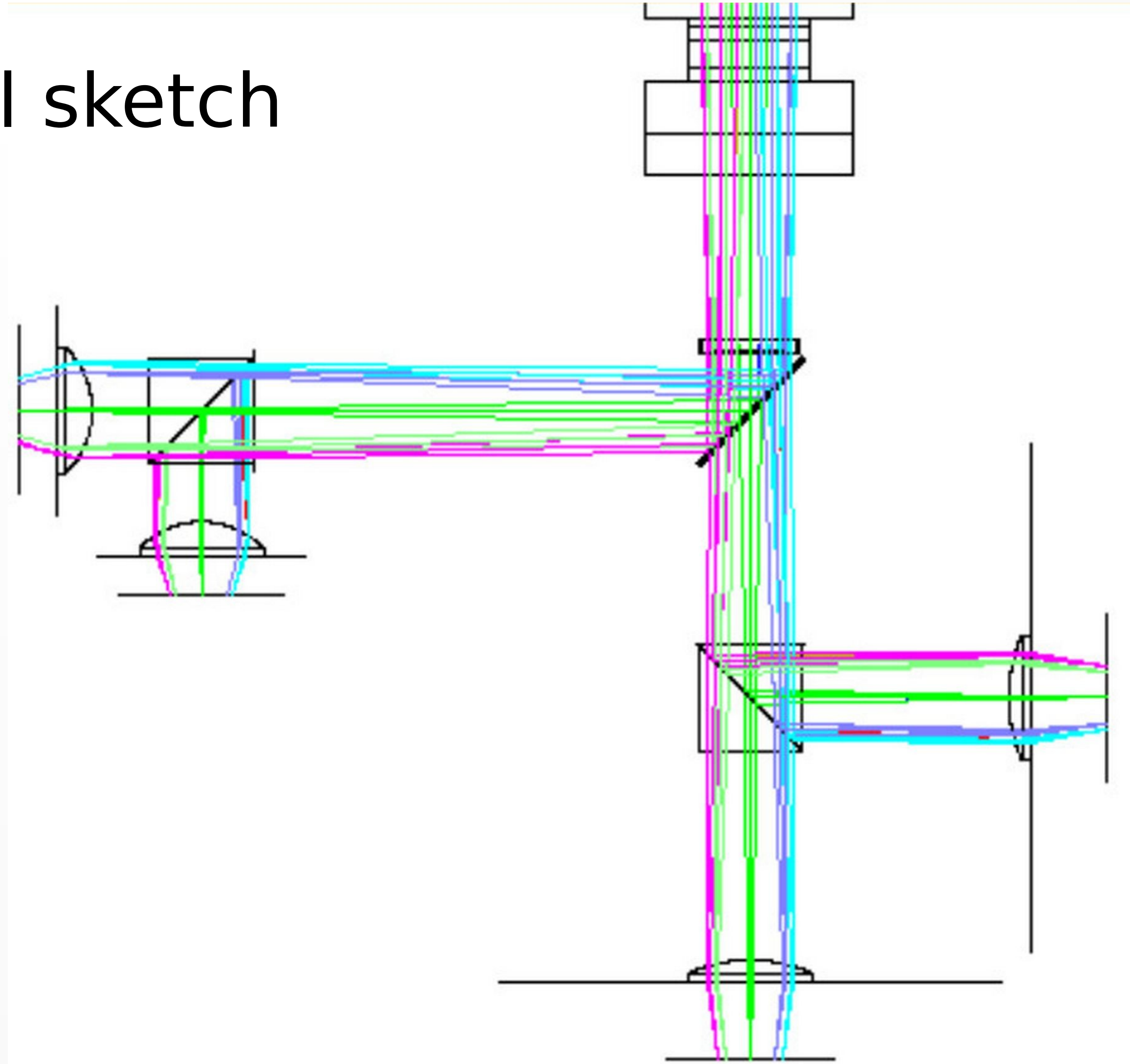
CoMP-S 2D spectropolarimeter

- Camera module: optical + electronic compartments



CoMP-S 2D spectropolarimeter

- Camera module: optical sketch
  - Negative lens
  - Dichroic mirror
  - VIS + IR channels:
    polarizing beam splitter
    cameras

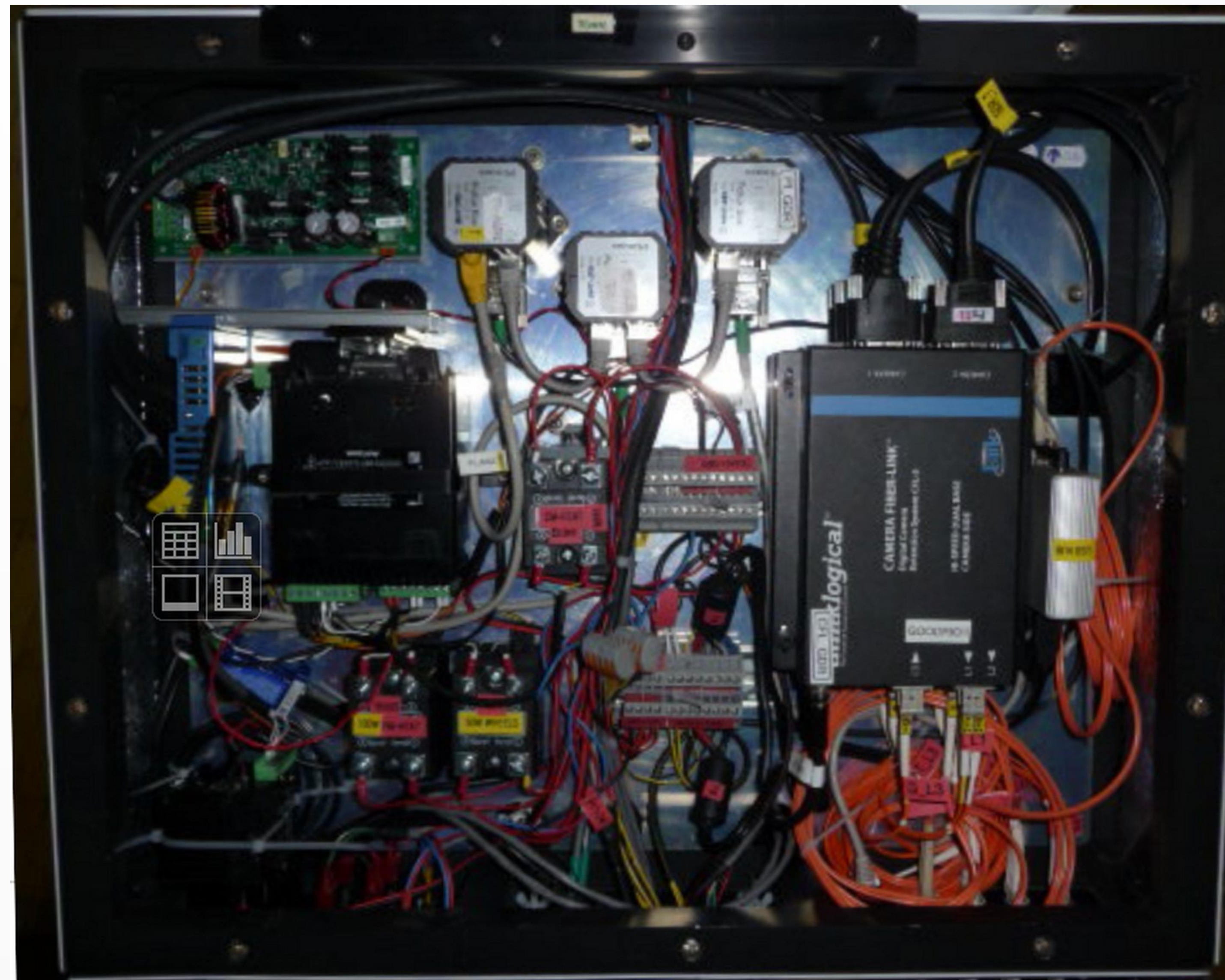


CoMP-S 2D spectropolarimeter

- Camera module: opt. compartment

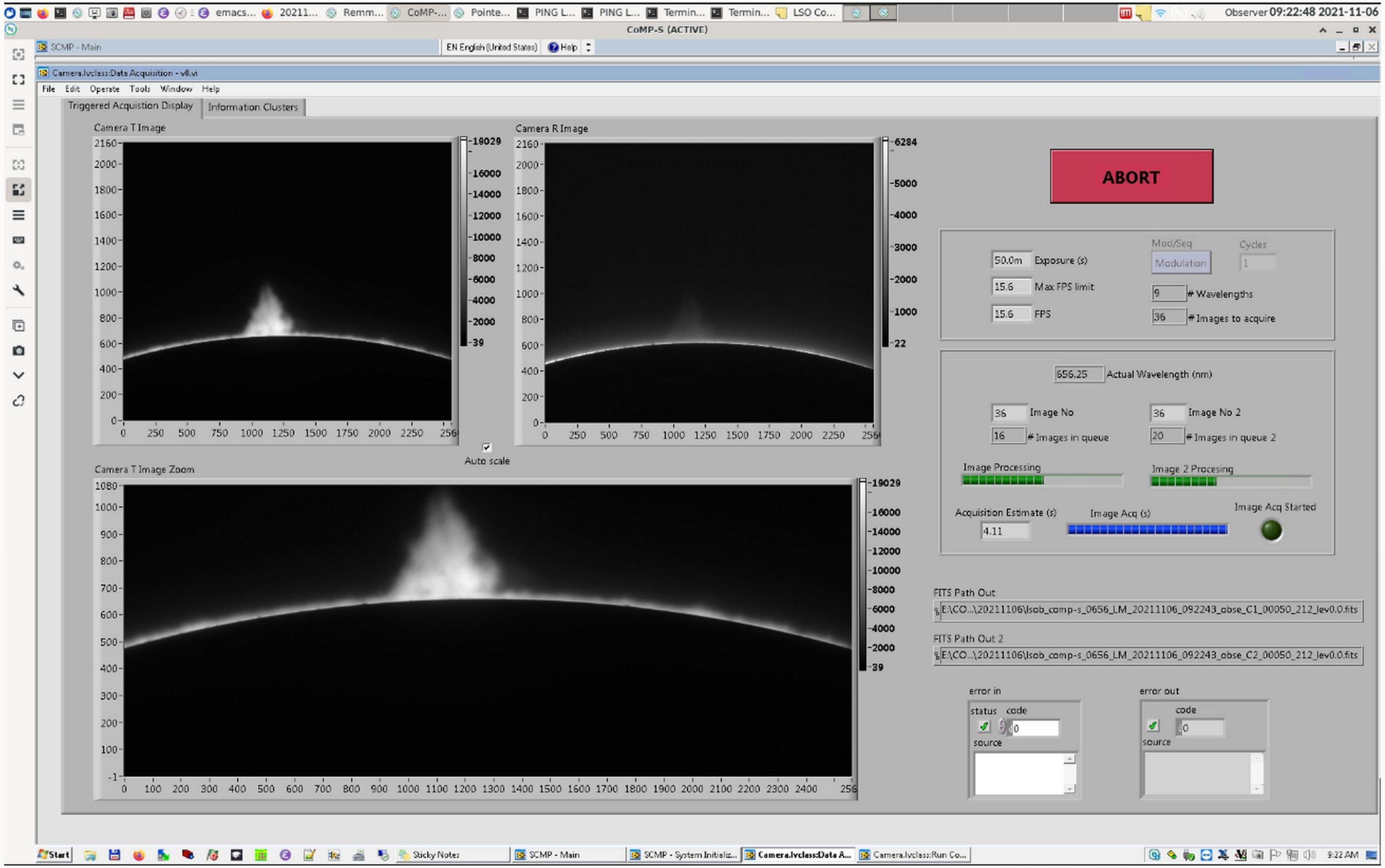
CoMP-S 2D spectropolarimeter

- Camera module:
- el. compartment



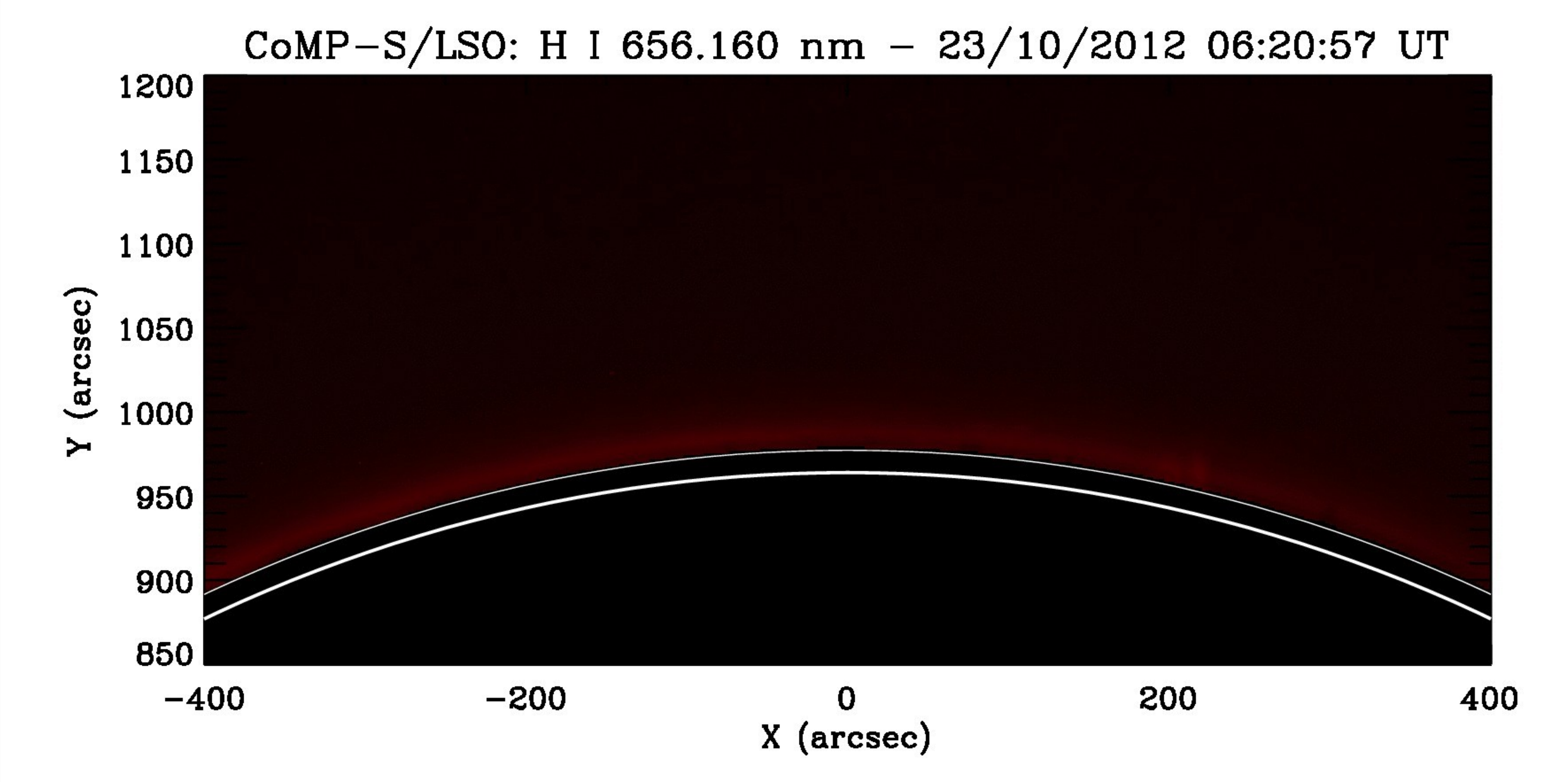
CoMP-S 2D spectropolarimeter

- Computer operation code(LabVIEW)

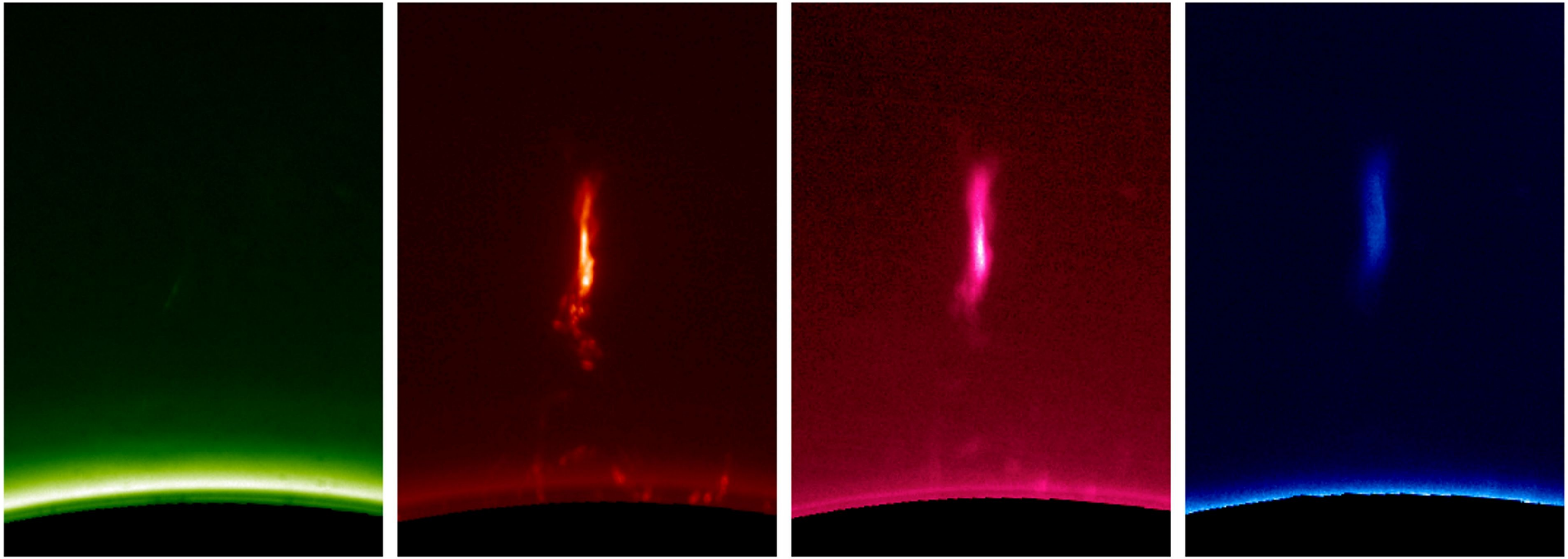


CoMP-S 2D spectropolarimeter

- Tuning through an emission profile of the spectral line



CoMP-S 2D spectropolarimeter

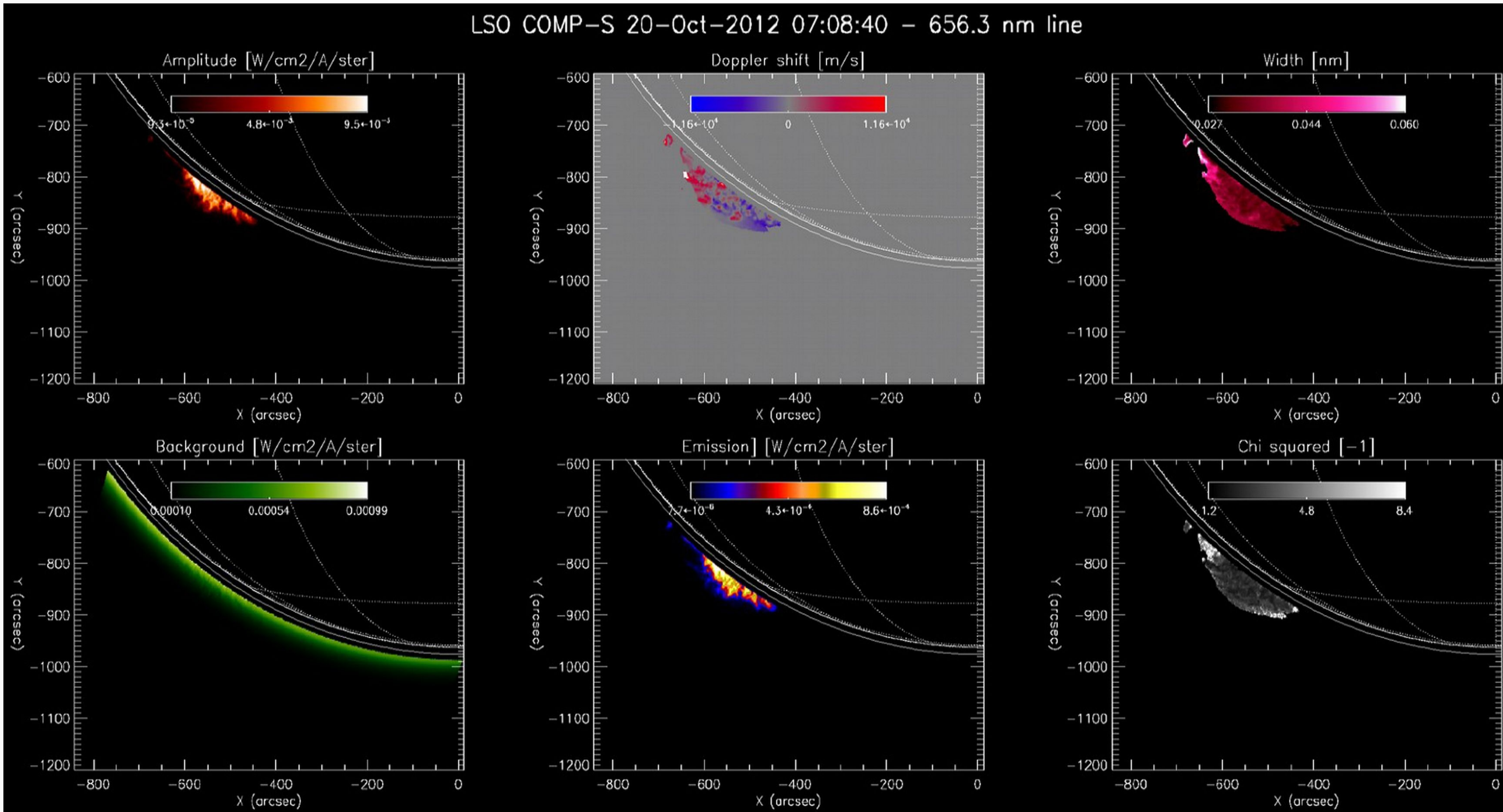


Eruptive promimence: 10/03/2014, AR 11991) v 4 spectral lines:
He I D3 587 nm (08:25:17), H I 656 nm (08:21:53), Ca II 854 nm (08:19:35), and He I 1083 nm (08:15:59 UT)

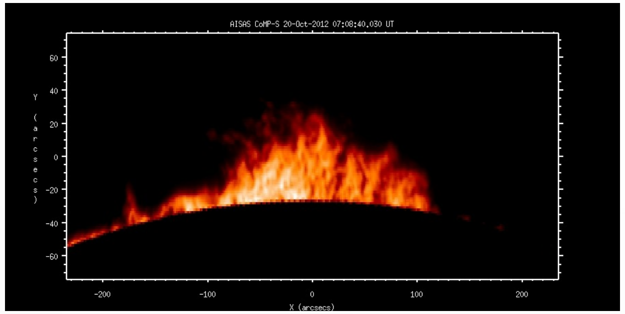
CoMP-S 2D spectropolarimeter

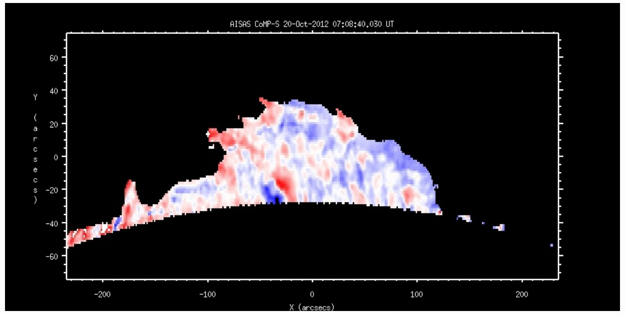
- Eruptive promimence – 11/05/2023: 04:59-06:54 UT

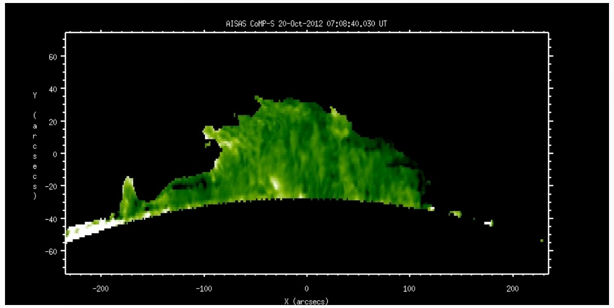
CoMP-S 2D spectropolarimeter

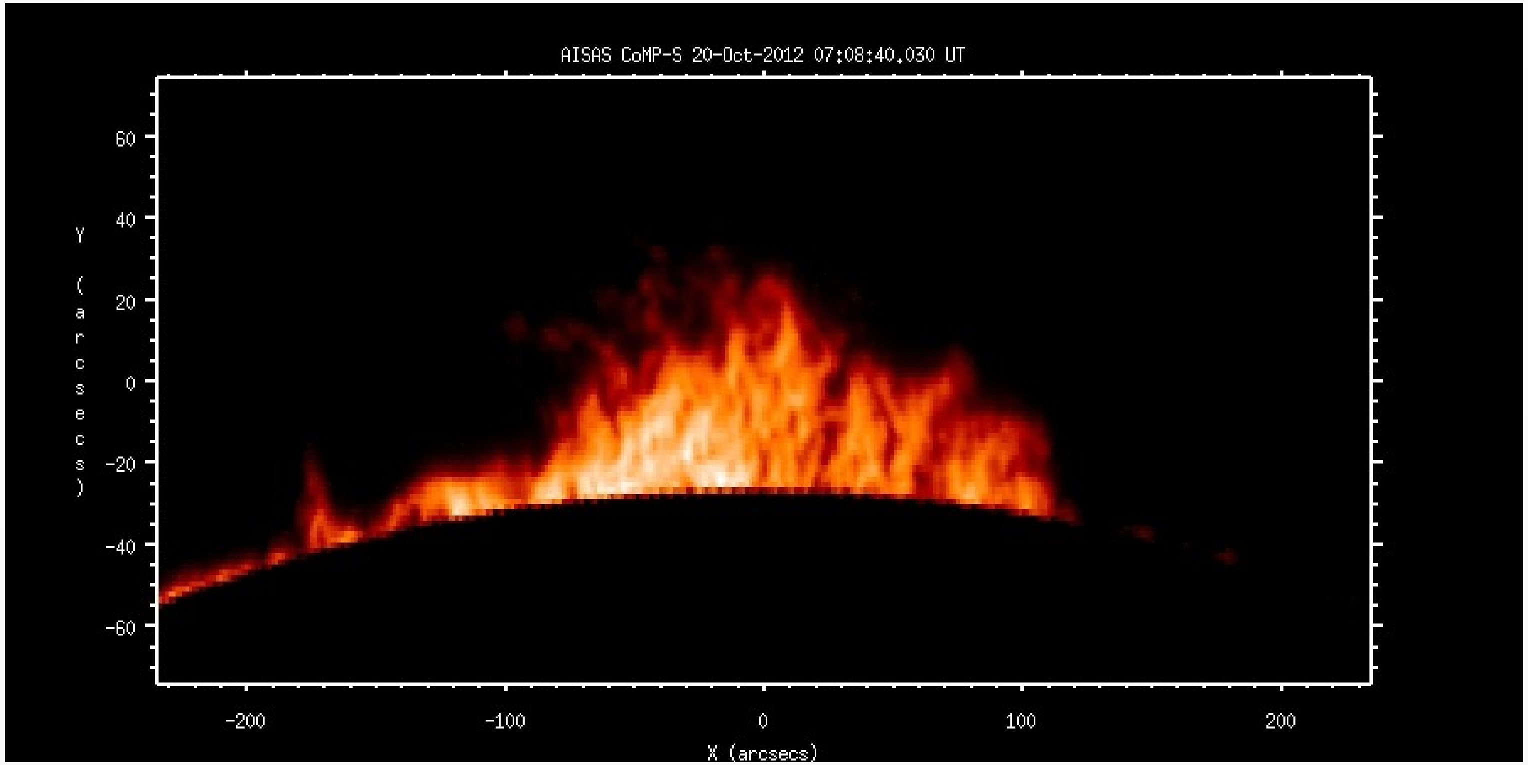


CoMP-S 2D spectropolarimeter



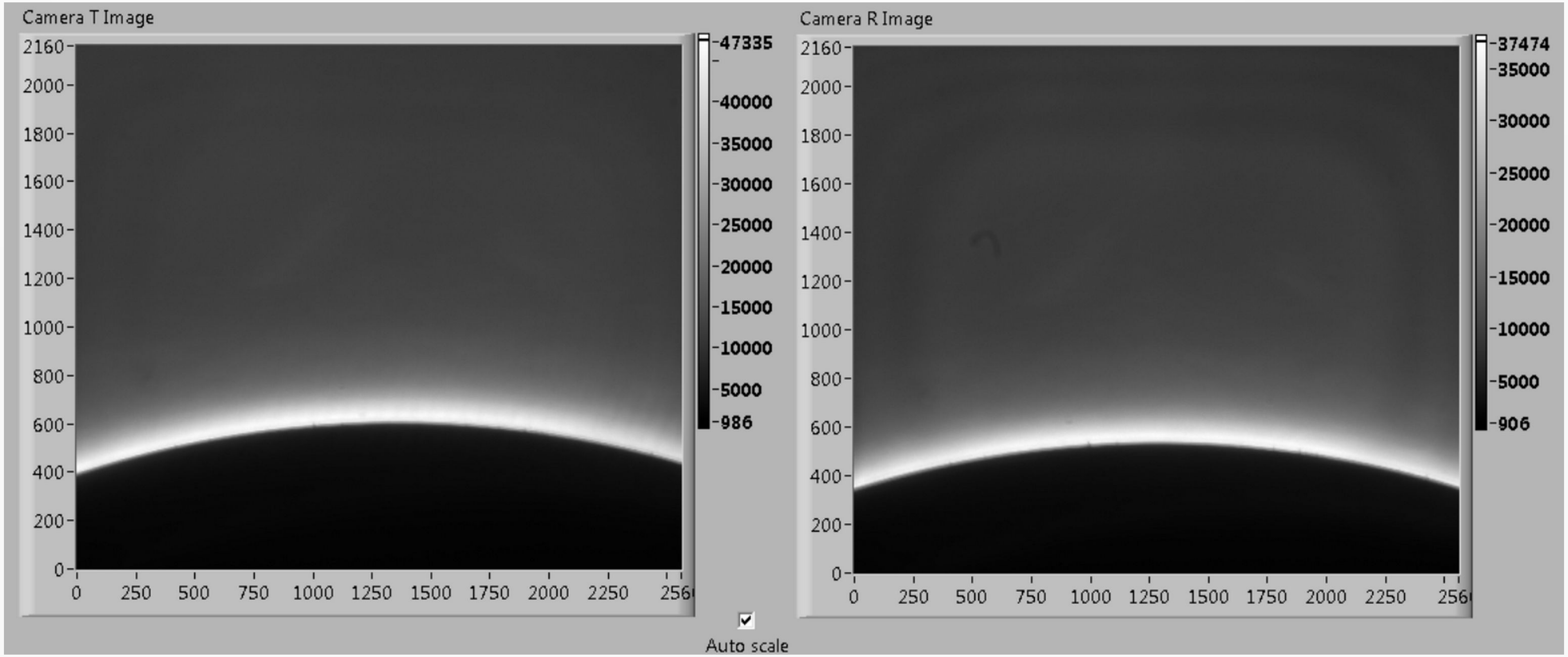






CoMP-S 2D spectropolarimeter

- On-line: no coronal emission seen using the automatic dynamic range due to large scattered light intensity range
- Pipeline in development: subtraction of the BKG scattered light (coalignment, intensity intercalibration, subtraction)



CoMP-S 2D spectropolarimeter

- Let’s see the CoMP-S in the dome…