LSO summer internship program: coronagraph

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

2024

Content:

- A tribute to the Bernard Lyot genius – part 1

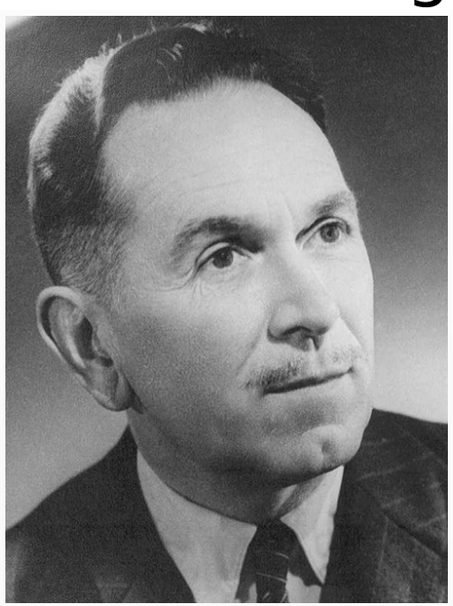
- Two main topics:
  - Bernard Lyot and invention of coronagraph: interesting instrumental development
  - The LSO coronagraph: ZEISS 200/3000/4000 instrument

Problem:

- “how to observe something very faint just near something very bright through the terrestrial atmosphere?”
- It is so simple! (Once it is solved...)

Solving person:

- Bernard Lyot, ~1930, Meudon + Pic du Midi (France)
- the lunar surface behaves like volcanic dust and that Mars has sandstorms,...
- Inventor and almost a “genius”

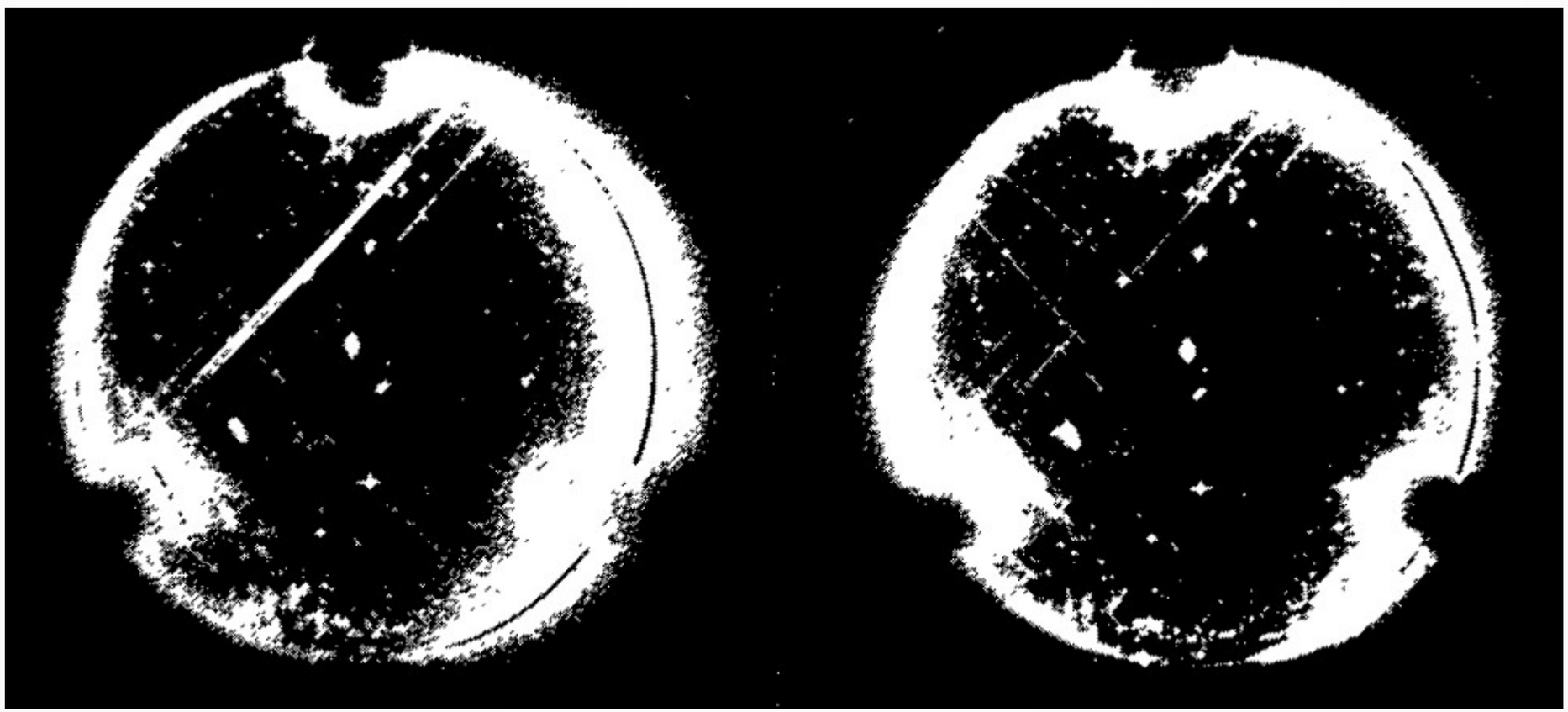


Instrumental parasitic light?

- What is the reason we do not see coronal emission from high latitudes?
- They have to be in the telescope! Where?
- Telescope parts
  - The objective lens?
  - The occulter (artificial moon)?
  - Something else?

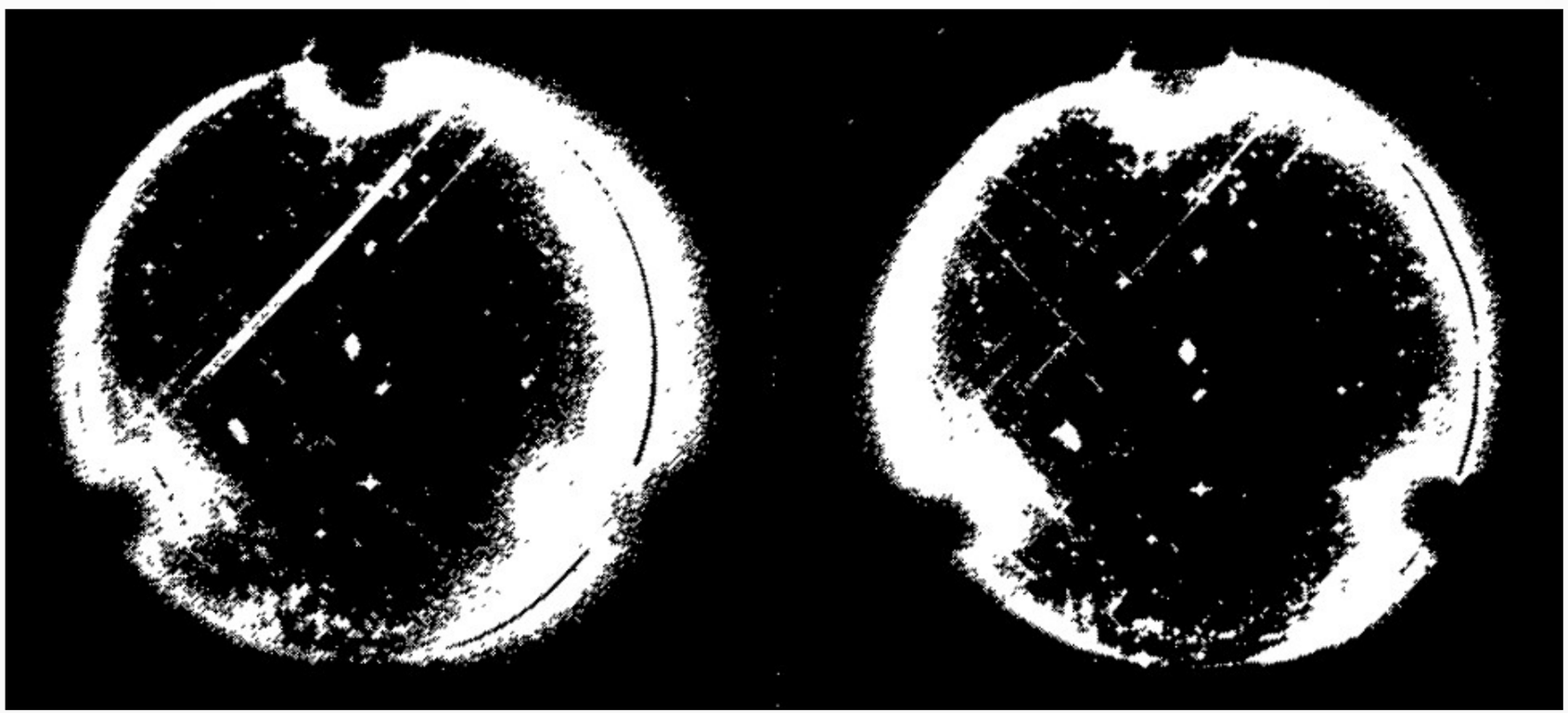
Step by step - 1

- An objective lens: history, status of perfection, have a look from another side...



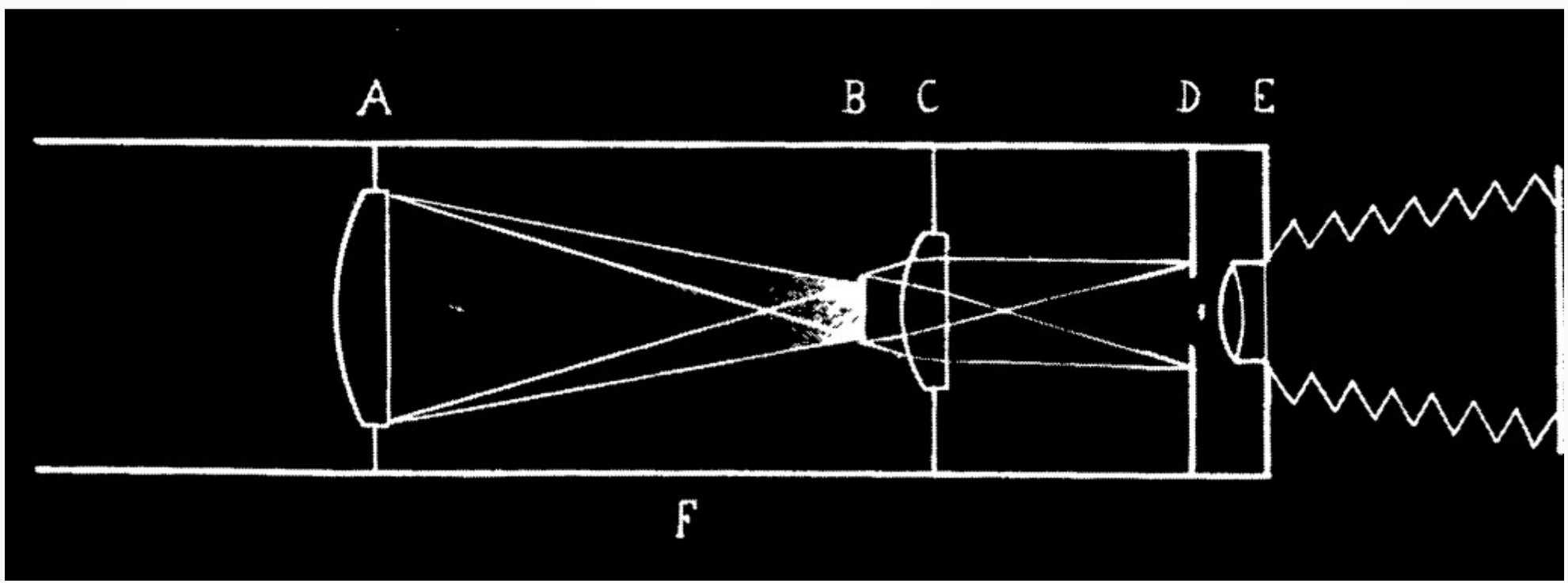
Step by step - 2

- An objective lens:
  - dust, scratches → clean + perfect
  - balsam + multiple lenses → single lens (crazy person!)



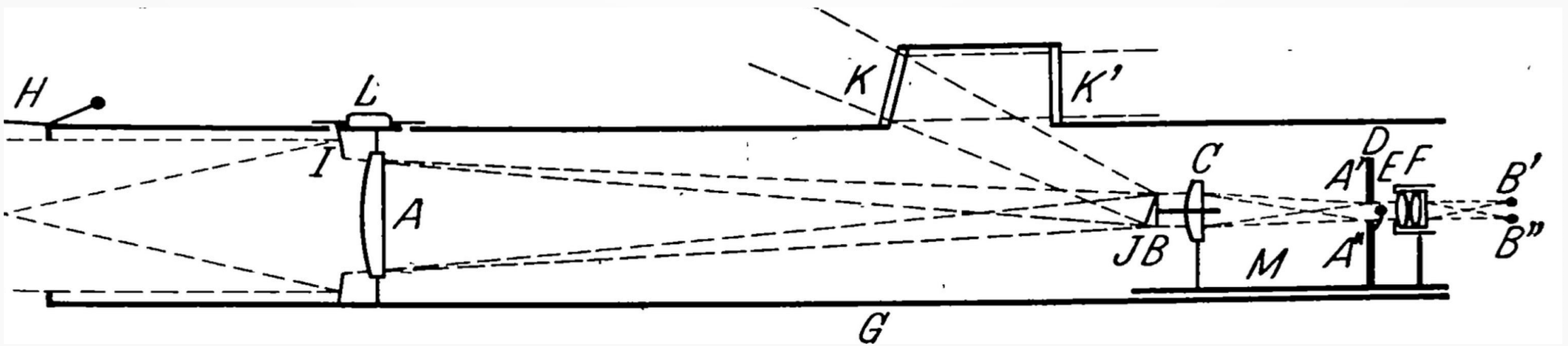
Step by step - 3

- An objective lens:
  - clean and perfect single lens
  - a second optical system to image the solar image but to stop the parasitic light originating at the aperture



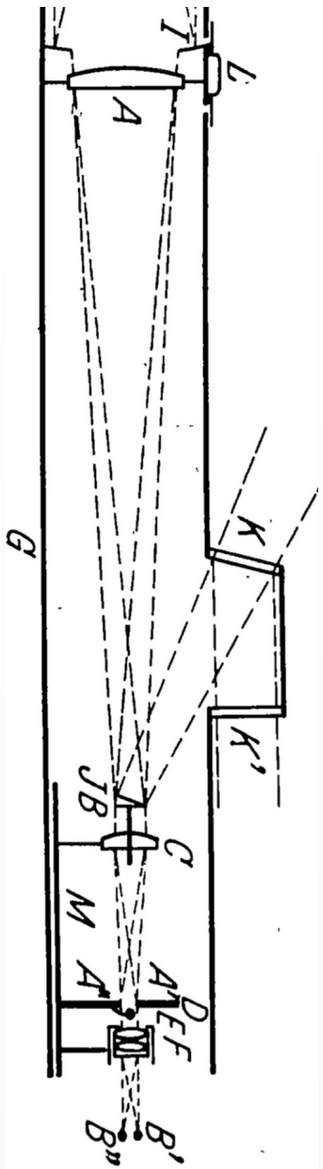
Step by step – 3

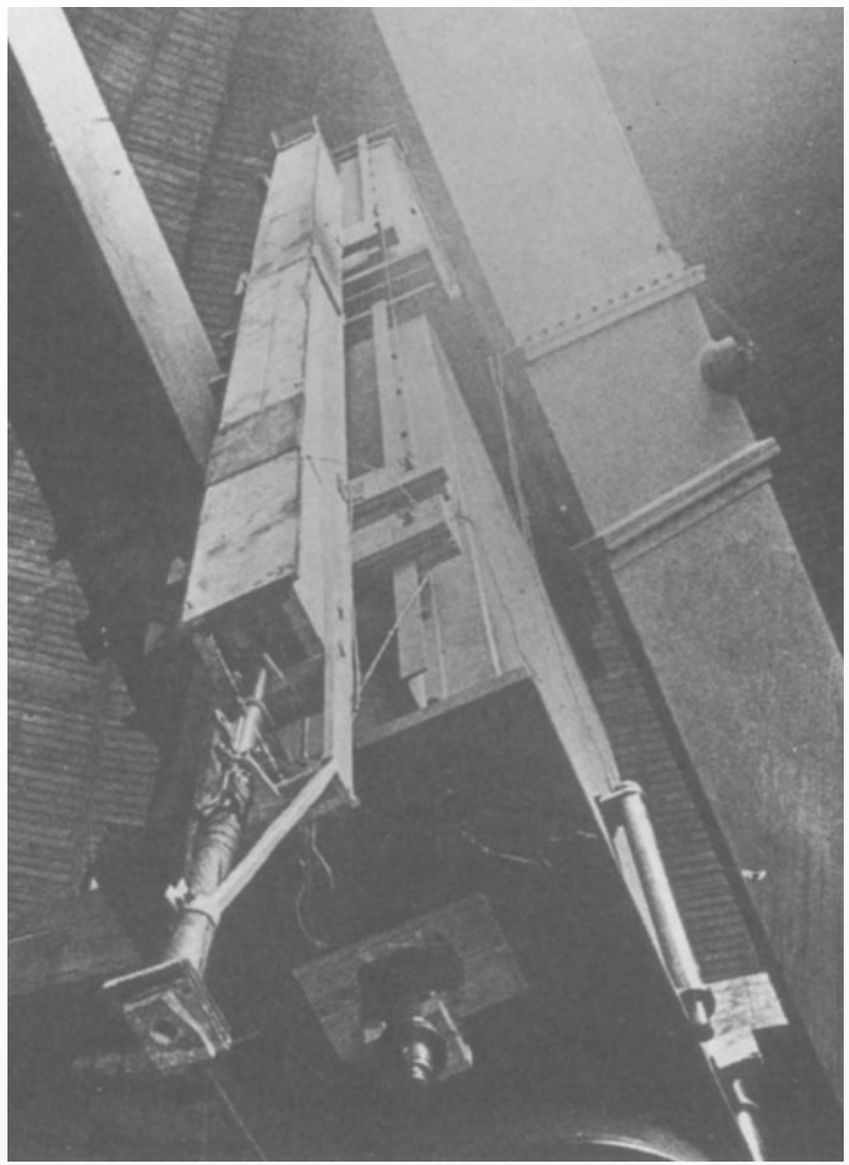
- An objective lens:
  - clean and perfect single lens
  - a second optical system to re-image the solar image but to stop the parasitic light from the aperture
  - Coronagraph: 2 mutual optical systems: telescope + re-imaging secondary optical system



Step by step – 4

- Realization:
  - Pic du Midi, July 1930
  - improvements till 1939





References (in English):

- Hufbauer, K., 1994, Artificial eclipses: Bernard Lyot and the coronagraph, 1929-1939, Historical Studies in the Physical and Biological Sciences, Vol. 24, No. 2, pp. 337-394 , https://doi.org/10.2307/27757726
- Loyt, B, 1932, 1932, Zeitschrift für Astrophysik, Vol. 5, p.73, https://ui.adsabs.harvard.edu/abs/1932ZA.....5...73L
- Lyot, B., 1933, Journal of the Royal Astronomical Society of Canada, Vol. 27, p.225, https://ui.adsabs.harvard.edu/abs/1933JRASC..27..225L
- Lyot, B., 1933, Journal of the Royal Astronomical Society of Canada, Vol. 27, p.265, https://ui.adsabs.harvard.edu/abs/1933JRASC..27..265L
- Lyot, B., 1939, Monthly Notices of the Royal Astronomical Society, Vol. 99, p.580, https://ui.adsabs.harvard.edu/abs/1939MNRAS..99..580L

Imperfections

- Nothing is perfect in the real world...
- Single lens:
  - chromatic aberration → focal length ~ wavelength
  - physical aberrations → inner (paraxial) and outer beams with different focus and image quality → very low D/f ratio
  - low light intensity

Pic du Midi (1929)

- Pyrénées (2877 m asl, 1929)

Scientific results – a diary

- 13/07/1930 - he got unmistakable views of three solar prominences - the first sightings of prominences in full daylight ever made without spectroscopic equipment
- 25/07/1930: rapid motions in prominences → discovery by...
- 29/07/1930: polarization of the coronal emission
- 20/07+03/08/1930: visually 530 + 637 nm coronal lines
- 08/1930: photographs of the white-light corona and spectra of the 530 + 637 nm coronal lines
- Esclangon presented Lyot's paper to the Académie on November 10, 1930 and in print a month later + other articles later (French → English)

Scientific results – a summary

- He documented that thank to Pic du Midi conditions and his innovative coronagraph concept it is possible:
  - solar prominences and emission corona in their prominent emission lines
  - spectral profiles of the prominent emission lines of solar prominences and emission corona
- Cordial response of the french astro community
- A hot topic: PdM superior conditions + bright corona or really the coronagraph principle?
- An independent check: W. Grotrian and H. Kienle, 12/07/1931

Scientific results – awards

- Lalande Prize from the French Academy of Sciences
- Janssen Medal from the French Academy of Sciences
- Prix Jules Janssen, the highest award of the Sociéte astronomique de France
- Gold Medal of the Royal Astronomical Society (1939)
- Howard N. Potts Medal (1942)
- Bruce Medal (1947)
- Henry Draper Medal of the National Academy of Sciences (USA)

Solar “coronal” stations

- Pic du Midi: 1931-1939 – developments + occasional observations
- Highlight in 40ties (as the exoplanets nowadays)
- Regular observations: Pic du Midi (1943→?) → Arosa (Switzerland, 1947-1975), Wendelstein (Germany, 1947-1979), Kanzelhoehe (Austria. 1948-1964), Climax (USA, 1947-1957), Sacramento Peak (USA, 1953-1966-?), Kislovodsk (USSR, 1957→), Alma Ata (USSR, 1957-1962 + 1973→?), Ulan Bator (Mongolia, 1971-1973) and Lomnicky Stit (Slovakia, 1966→2009)

  => Maona Loa (USA), Kislovodsk (Russia), LSO (Slovakia) + orbit
- What for?

Coronography nowadays

- Solar:
  - ground-based (Maona Loa, Kislovodsk, LSO + DKIST)
  - space-borne: SOHO, STEREO (Spartan, SMM, Skylab)
- Stellar: with adaptive optics as a inevitable condition for the g-b
  - ground-based - Hale 5.1m Mt. Palomar, VLT/NACO, Keck/NIRC2, Gemini South/NICI, Gemini North/NIRI, VLT/SPHERE, Gemini South/GPI, MagAO/Clio2, Subaru/SCExAO
  - space-born - HST - Near Infrared Camera and Multi-Object Spectrometer (NICMOS), JWST - NIRCam and Mid-Infrared Instrument MIRI, Extrasolar Imaging Planetary Coronagraph (in plan).
- What for? Extrasolar planets, circumstellar disks, AGN, host galaxies in quasars

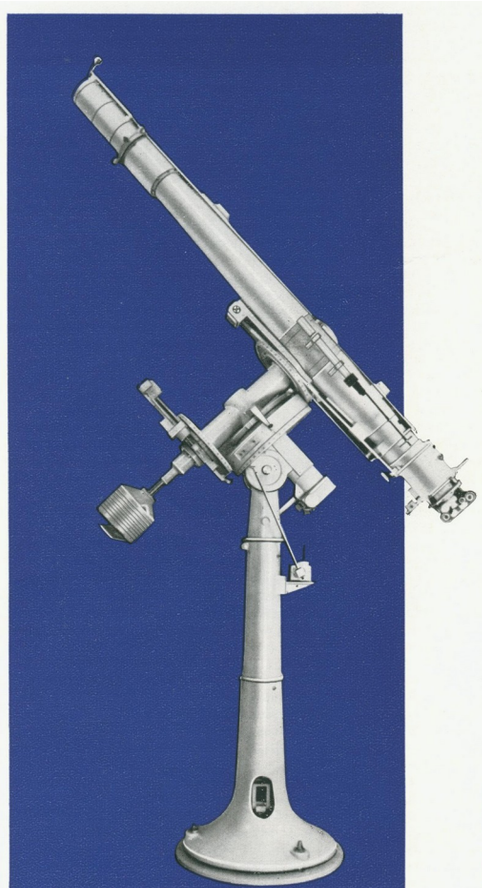
LSO

- LSO coronagraphs: ZEISS 200/3000/4000

Koronograph 200

Coronagraph 200

CARL ZEISS JENA



Koronograph 200
Links: Aufbewahrungsbehälter mit Zubehörteilen

Coronograph 200
Left: Storage case containing accessories

Daten

Koronographenobjektiv	
freie Öffnung	200 mm
Brennweite	3000 mm
Fokussierung im Bereich	393 bis 1080 nm
Vergrößerung des Zwischenabbildungs-systems	1,33fach
Fokussierungsbereich	110 mm
Okulare ergeben mit dem Zwischenabbildungssystem folgende Vergrößerung:	

Okular/f	Vergrößerung
6 mm	675 ×
10 mm	400 ×
16 mm	250 ×
25 mm	160 ×
40 mm	100 ×

Spiegelblenden im Durch-messerbereich von	26,8 bis 29,4 mm
in Stufen von	0,1 mm
Sucherfernohr-Vergrößerung	17,5fach
Parallaktische Montierung der Größe VII S	
Stundenteilkreis	Teilungswert 5 min
Deklinationsteilkreis	Teilungswert 1°
Stundenfeinbewegung	≈ ± 12,5% der Stunden-bewegung
Deklinations-feinstbewegung	± 1,3′ pro Minute
Kuppelmindest-durchmesser	5 m
Masse des Gerätes	2800 kg
Elektrischer Anschluß	220 V 50 Hz Notstromversorgung aus Akkumulatoren möglich

Lieferumfang

1 Koronograph 200/3000
1 Säulenmontierung VII S
1 Schalttafel
1 Zubehörbehälter mit
  1 Praktina-Kamera II A mit Magnetauslöser, Motoraufzug und 17-cm-Kassette
  1 Zeitmarkierungseinrichtung mit Datumsplatte und Stufenkeil
  1 Wechselring mit 5fach-Revolver
  1 Wechselring mit Okularsteckhülse
  1 Wechselring mit Schraubeinsatz für Okulare
5 Okulare
1 Behälter mit Metallinterferenzfilter
1 Behälter mit 27 Spiegelblenden
2 Schiebegewichte
1 Aufbewahrungsbehälter mit Protuberanzenspektroskop lose Teile, Ersatzteile, Werkzeuge

Data

Coronograph objective:	
free aperture	200 mm
focal length	3000 mm
Focussing range	393 to 1080 millimicrons
Magnification of the inter-mediate lens system	1.33 ×
Focussing range of the focal plane	110 mm
With the intermediate lens system, the eyepieces have the following magnifica-tions	

Focal length	Magnification
6 mm	675 ×
10 mm	400 ×
16 mm	250 ×
25 mm	160 ×
40 mm	100 ×

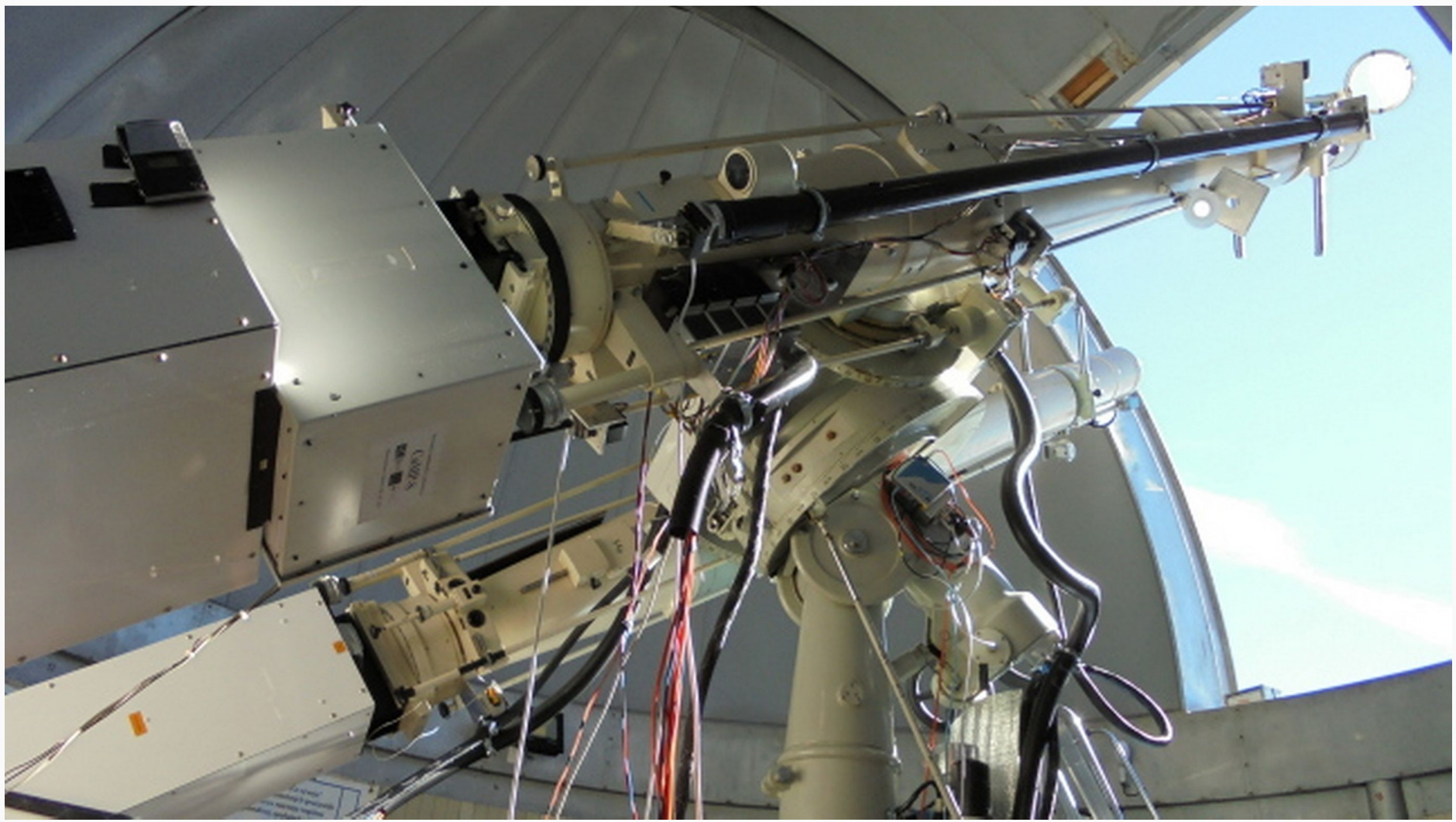
Occulting discs, diameters	26.8 to 29.4 mm
In steps of	0.1 mm
Finder telescope, magnification	17.5 ×
Equatorial mounting	type VII S
Hour circle, in divisions of	5 minutes
Declination circle, in divisions of	1°
Slow-motion in hour	about ± 12.5% of "Uhrgan"
Slow-motion in declination	± 1.3′ per minute
Minimum diameter of dome	5 m
Weight of instrument	2800 kg (6160 lb.)
Power supply	220 V, 50 cycles; Emergency supply by batteries is possible

The standard equipment comprises:

1 Coronograph 200/3000
1 Pillar mounting, type VII S
1 Switchboard
1 Case with accessories:
  1 Praktina-camera II A with magnetic release, motor wind, and magazine for 17 cm film
  1 Time-marking device with datum plate and step-wedge
  1 Quintuple eyepiece turret with interchange ring
  1 Eyepiece sleeve with interchange ring
  1 Interchange ring with thread for single eyepieces
5 Eyepieces
1 Container with metal interference filters
1 Container with 27 occulting discs
2 Sliding weights
1 Case with a prominence spectroscope, loose parts,
1 Case with a prominence spectroscope lose parts, spares, and tools

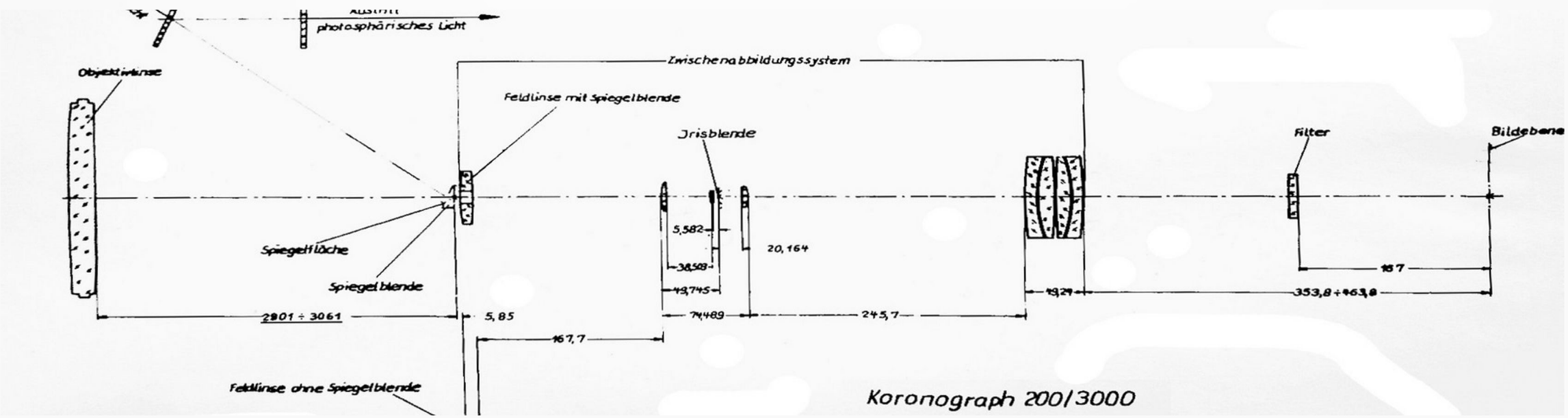
LSO: ZEISS 200/3000/4000

- ZEISS 200/3000/4000 coronagraph(s)



LSO: ZEISS 200/3000/4000

- ZEISS 200/3000/4000 coronagraph
  - developed for the AISAS at 50ties/60ties
  - primary objective lens: D=~20 cm, f_{cor}=~3m, f_{eff}=~4m
  - solar disk image diameters: d_{cor}=~30mm, d_{eff}=~40 mm



LSO: ZEISS 200/3000/4000

- Optics calculations: analytical, secondary optical system is diffraction limited!

Über das optische System des Koronographen 200/3000/4000

Von

Walter Kühn

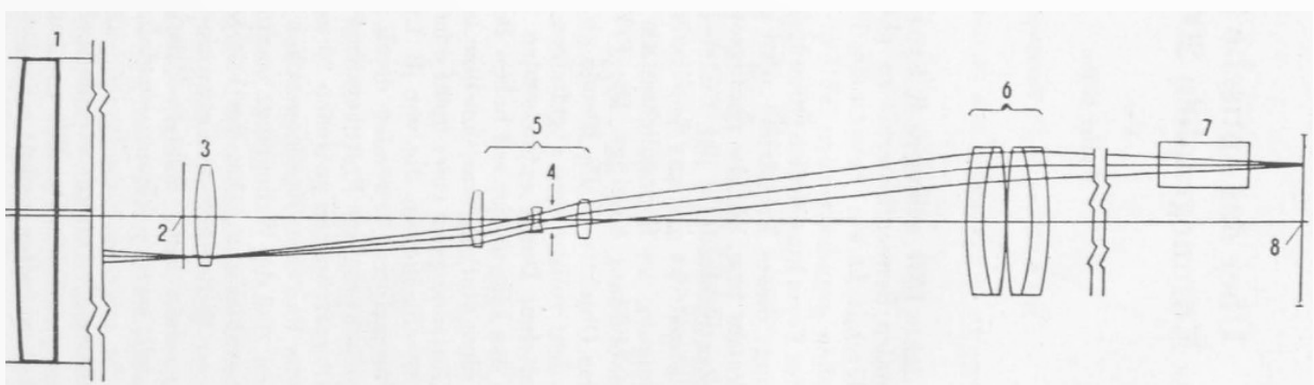


Bild 2. Aufbau des Koronographen 200/3000/4000

1 Objektiv
2 Primärbildebene
3 Feldlinse
4 Aperturblende
5 Vordere Gruppe des Umkehrsystems
6 Hintere Gruppe des Umkehrsystems
7 Filter
8 Bildebene

Tabelle 2. Seidelsche Summen der Bildfehler für die Wellenlänge 546,1 nm

	I	II	III_a	P	V
$\sum_{\nu=1}^{2}$ (Objektiv)	+4,946	+0,657	+1,423	+ 0,885	+ 0,7
$\sum_{\nu=3}^{4}$ (Feldlinse)	—0,002	—0,105	—0,681	+10,411	— 47,2
$\sum_{\nu=5}^{10}$ (vord. Gruppe)	—2,985	—0,010	—3,128	—19,632	+ 93,0
$\sum_{\nu=11}^{16}$ (hint. Gruppe)	+0,102	—0,104	—0,686	+ 9,808	+234,3
$\sum_{\nu=1}^{16}$ (Gesamtsystem)	+2,061	+0,438	—3,072	+ 1,472	+280,8

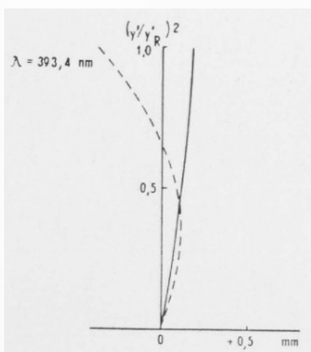


Bild 3

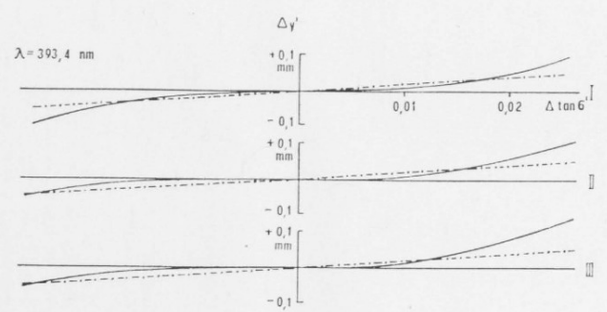


Bild 4

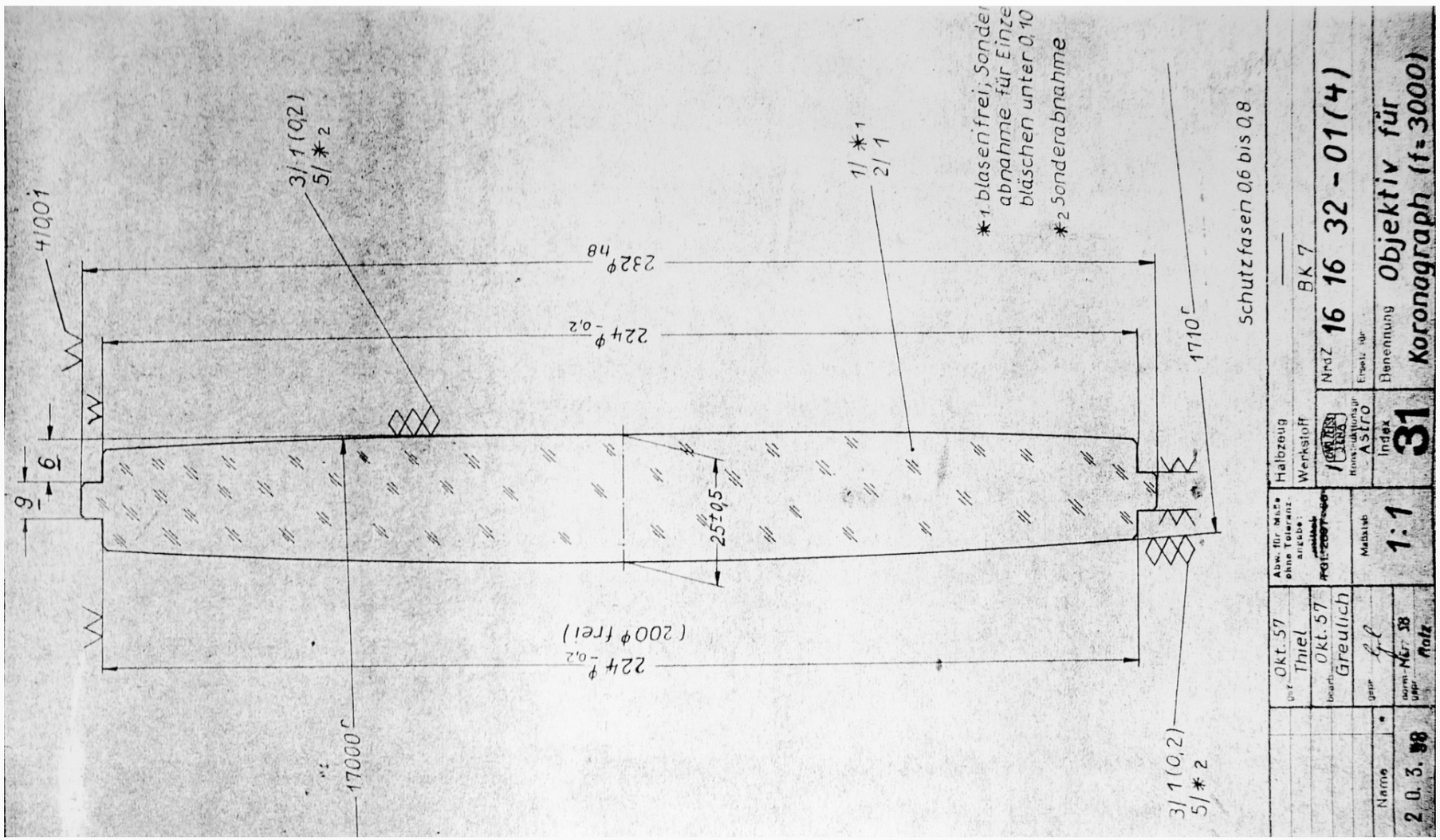
Bild 3. Meridionale und sagittale Bildfeldwölbung b_m' bzw. b_s' in Abhängigkeit vom Quadrat des Verhältnisses der jeweiligen Bildhöhe y' zur Bildhöhe y_R' des Feldrandes

b_m' ——— b_s' — — —

Bild 4. Querabweichung $\Delta y'$ in Abhängigkeit von $\Delta \tan \sigma'$ für den Achsenpunkt (I $\sigma = 0'$), die Feldzone (II $\sigma = -23', 0$) und den Feldrand (III $\sigma' = -32', 3$). Die eingezeichneten Geraden bedeuten die günstigste Einstellebene

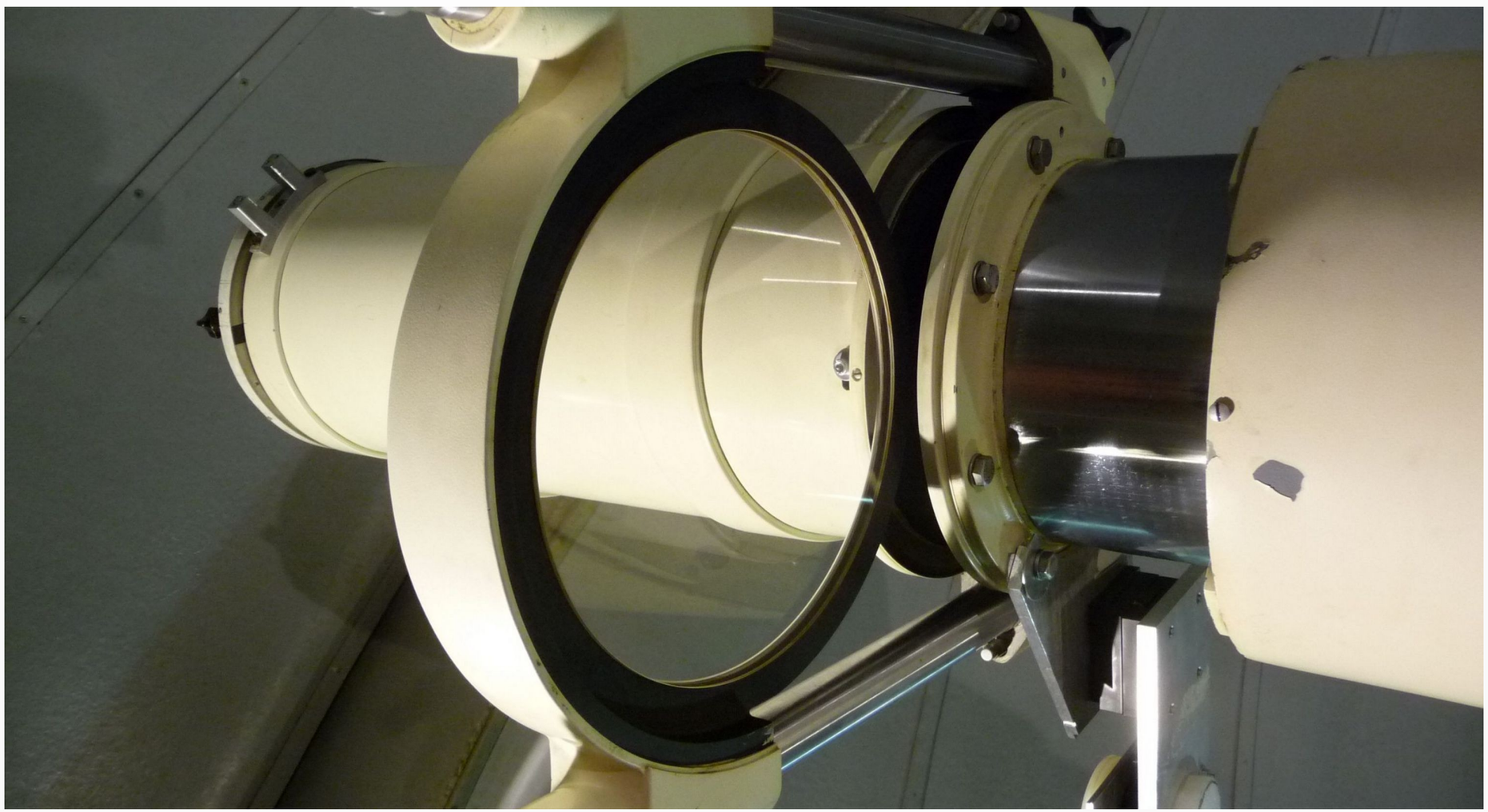
LSO: ZEISS 200/3000/4000

- Primary objective lens: BK7 glass



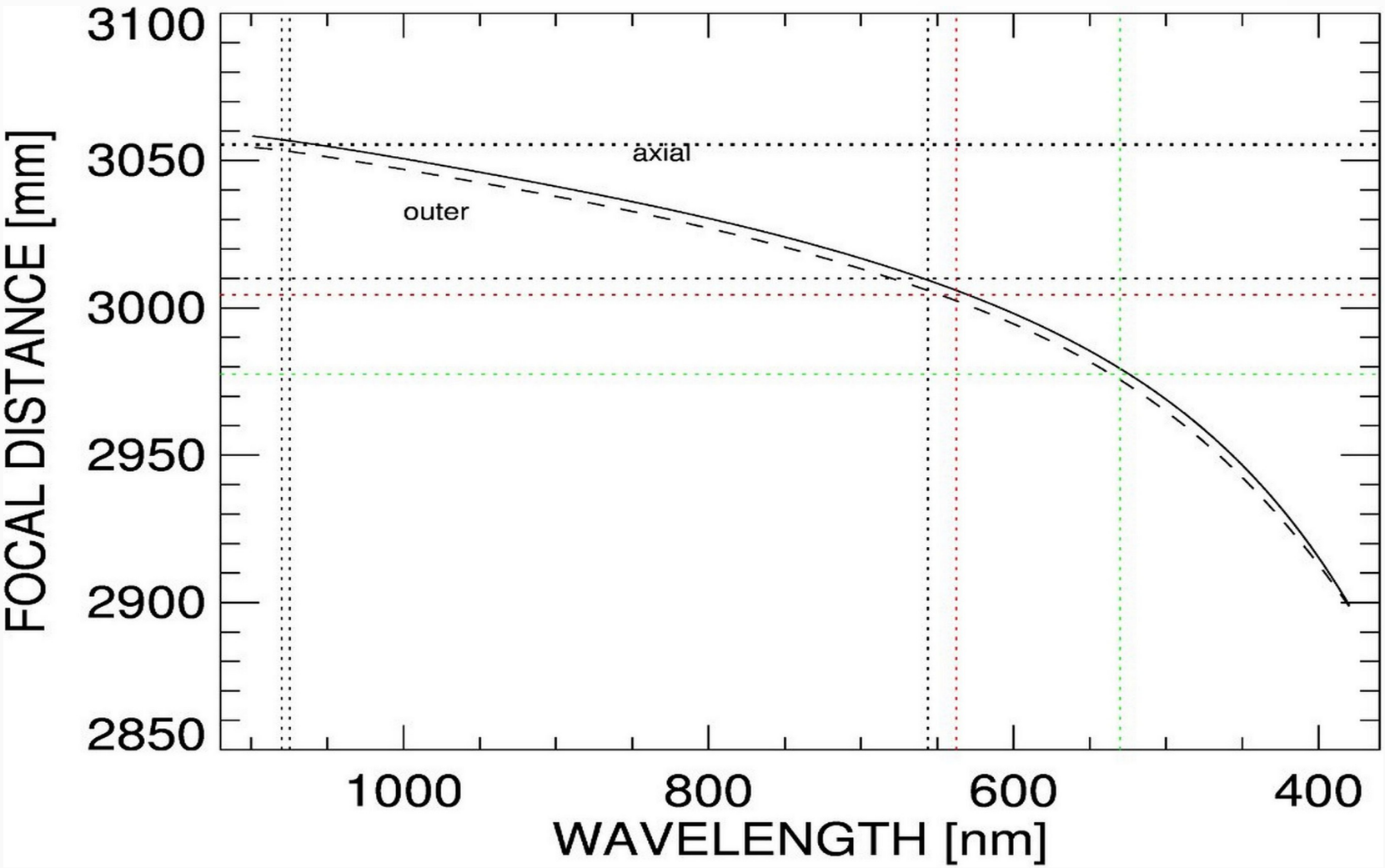
LSO: ZEISS 200/3000/4000

- Primary objective lens: BK7 glass



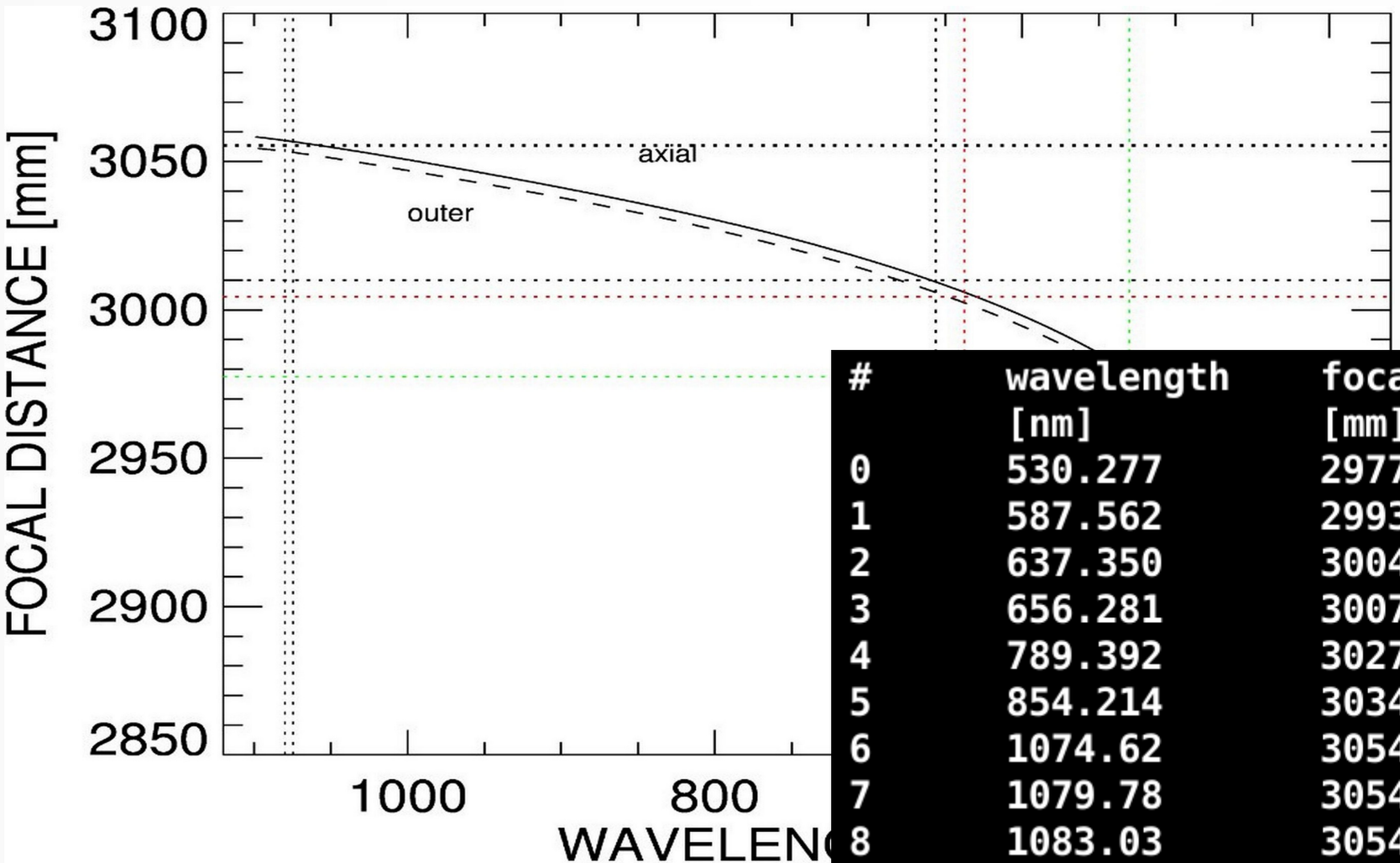
LSO: ZEISS 200/3000/4000

- Primary objective lens: BK7 glass



LSO: ZEISS 200/3000/4000

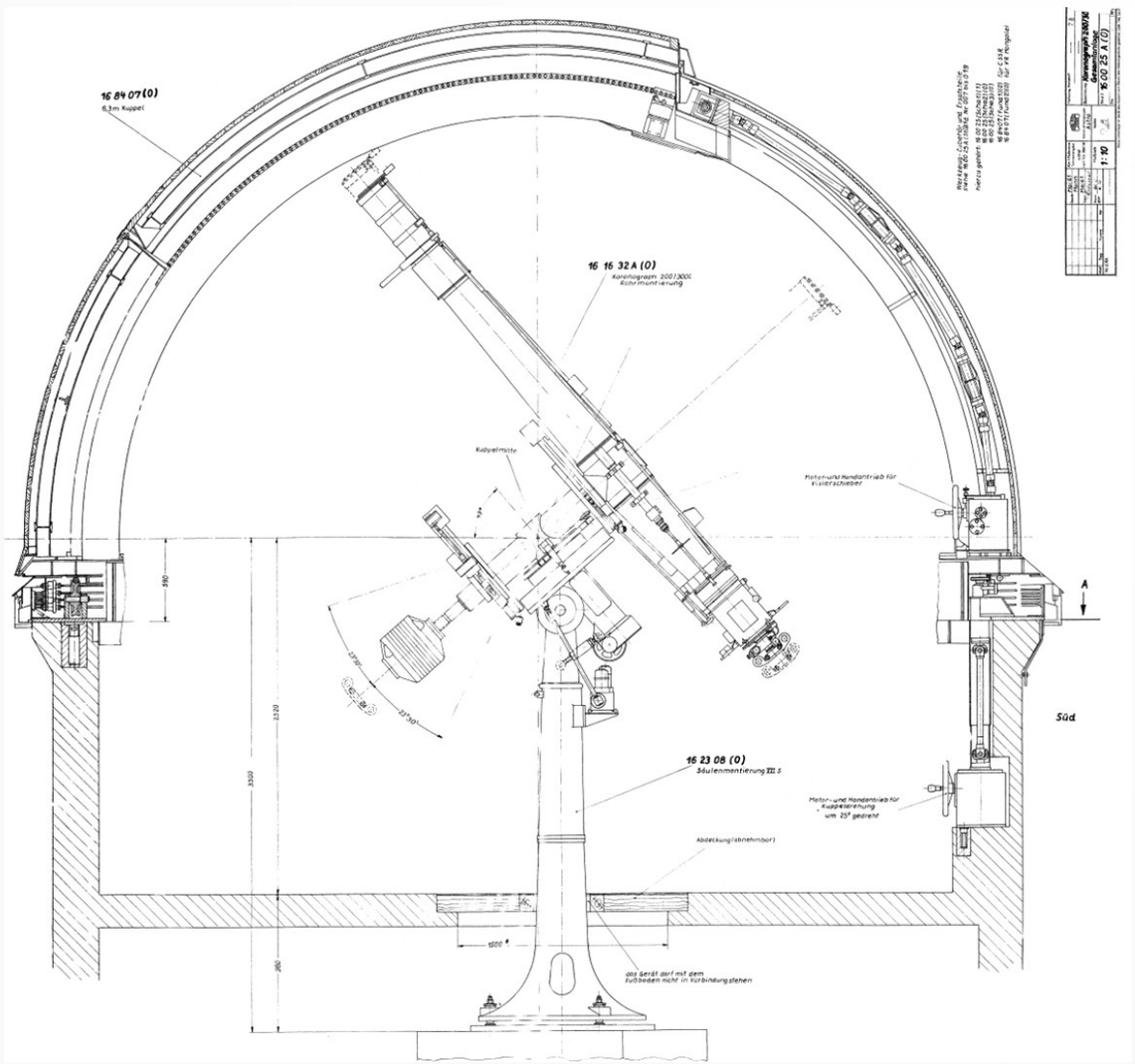
- Primary objective lens: BK7 glass

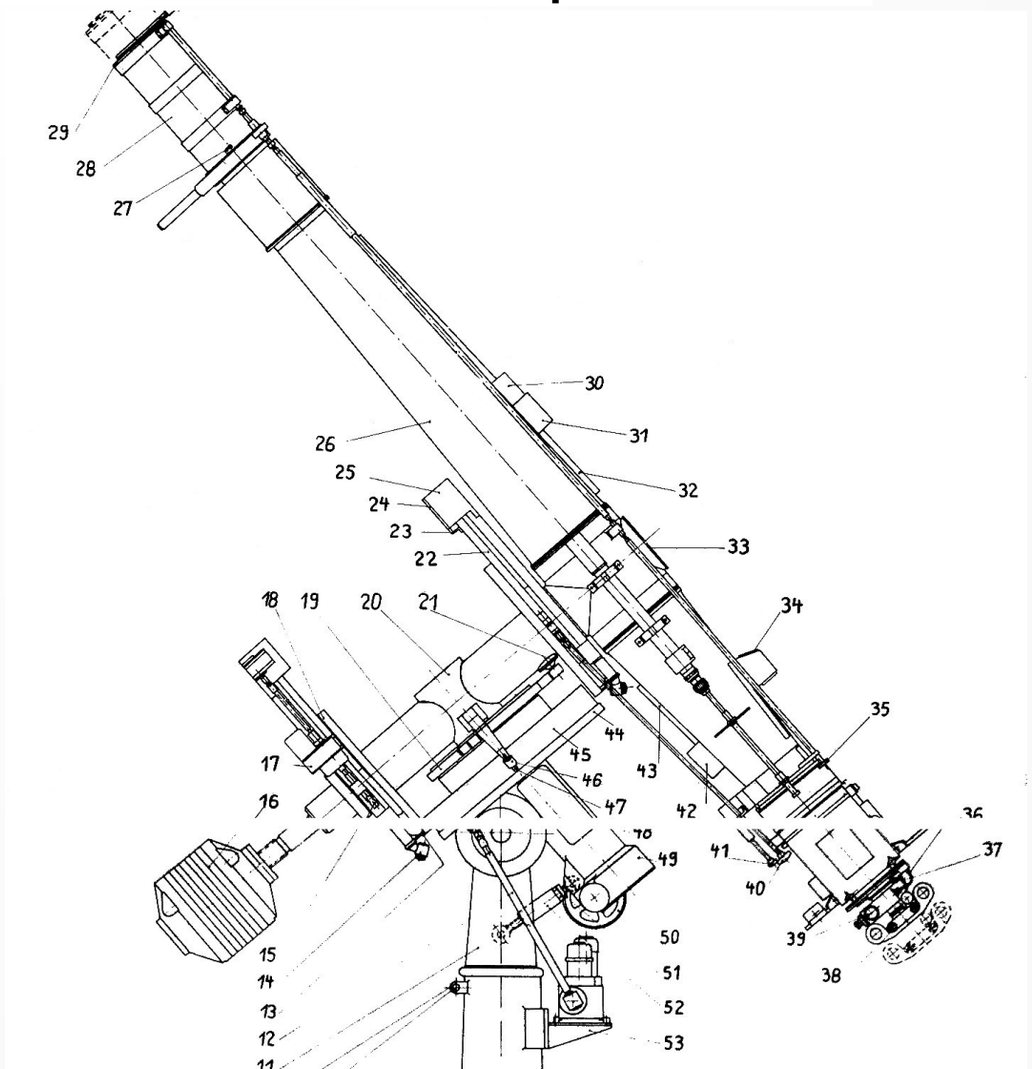


#	wavelength [nm]	focal_length [mm]	image_scale [arcsecs/mm]
0	530.277	2977.4781	69.275069
1	587.562	2993.3621	68.907468
2	637.350	3004.0563	68.662161
3	656.281	3007.5908	68.581471
4	789.392	3027.2427	68.136262
5	854.214	3034.5744	67.971639
6	1074.62	3054.0153	67.538953
7	1079.78	3054.3445	67.531675
8	1083.03	3054.5433	67.527279

LSO: ZEISS 200/3000/4000

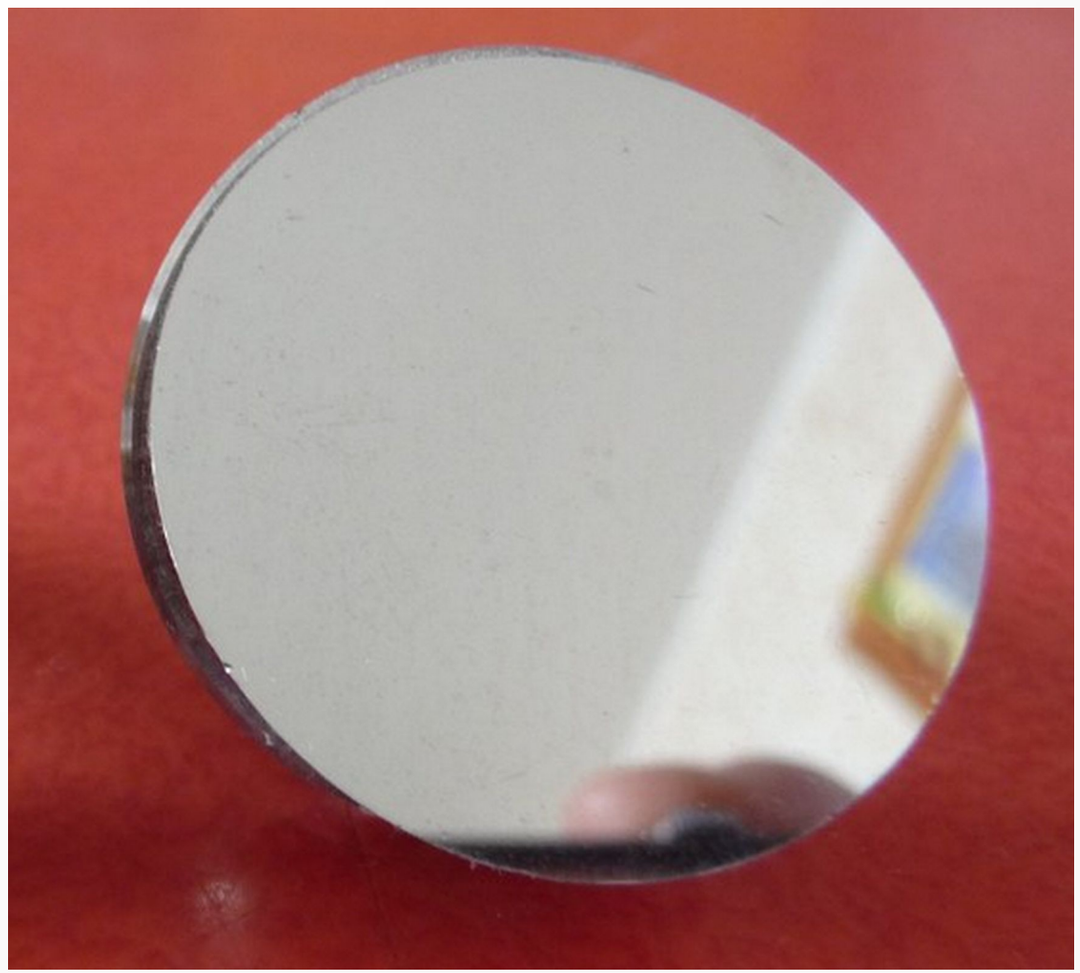
- Mechanics: coronagraph + mount + dome + (operation)





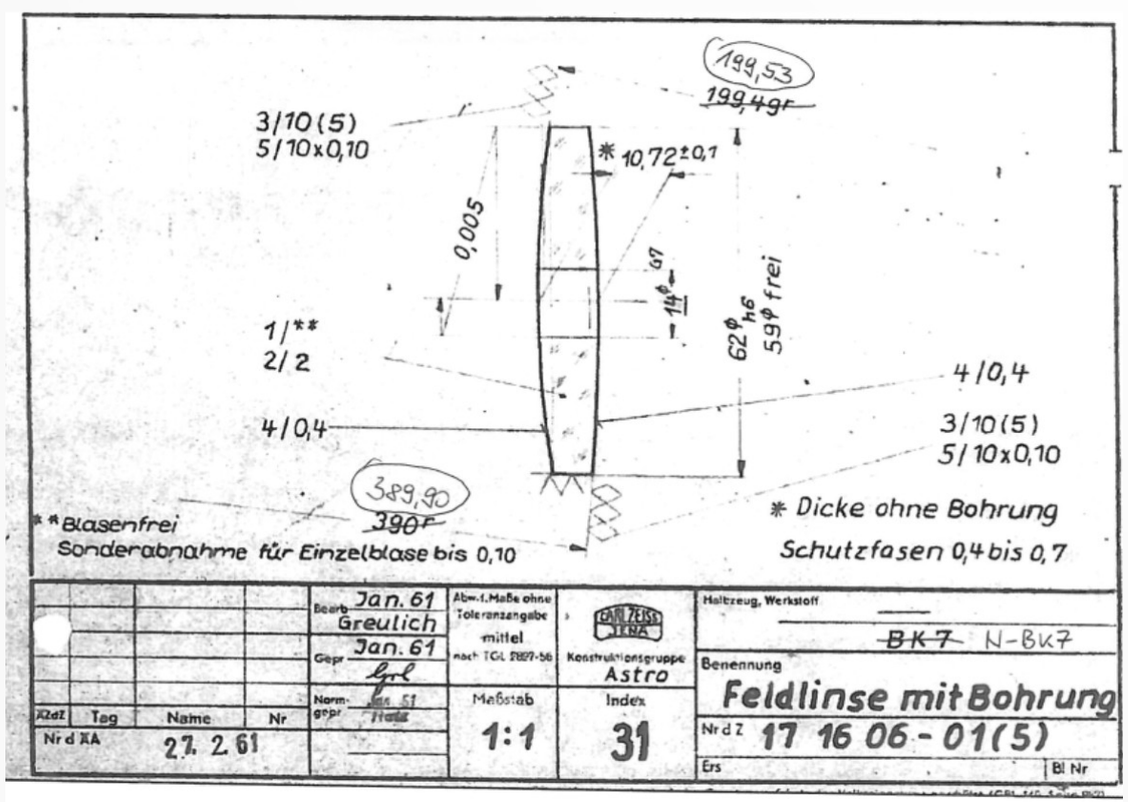
LSO: ZEISS 200/3000/4000

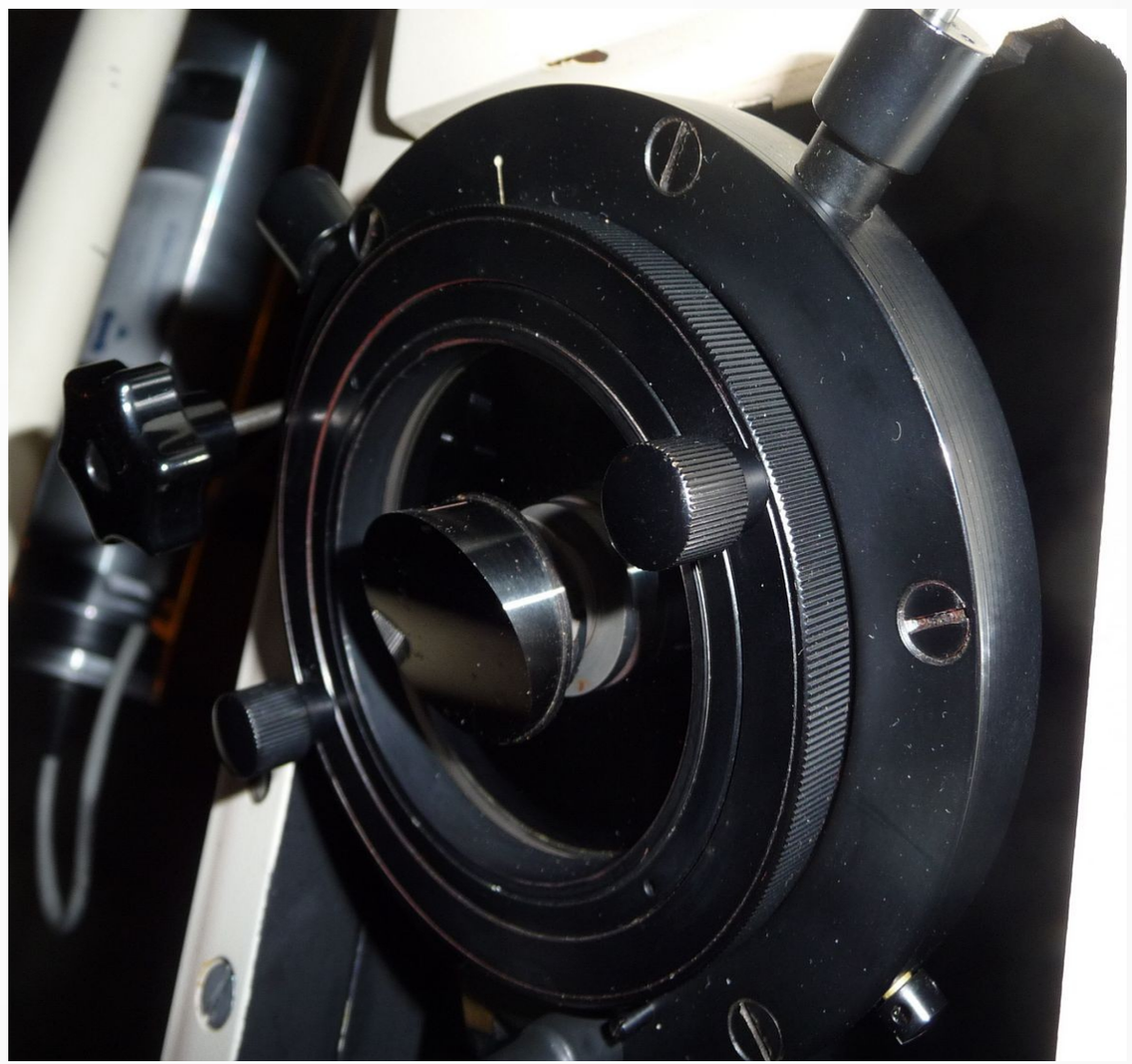
- The occulting mask (artificial moon):
  - different diameters
  - a reflecting plane to reject the solar disk image light
  - a “skirt” in the focal plane of coronagraph
  - pros and cons...



LSO: ZEISS 200/3000/4000

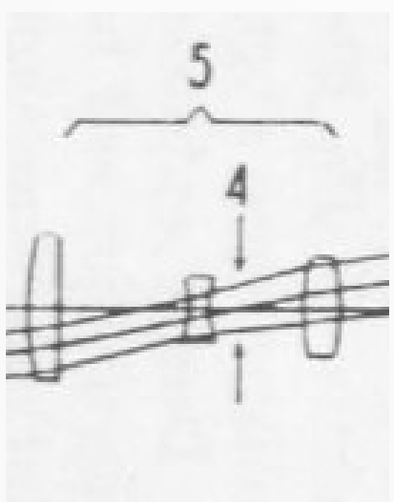
- The field lens: BK7, hole in the center with a special screw, tilting holder for the occulter exchange

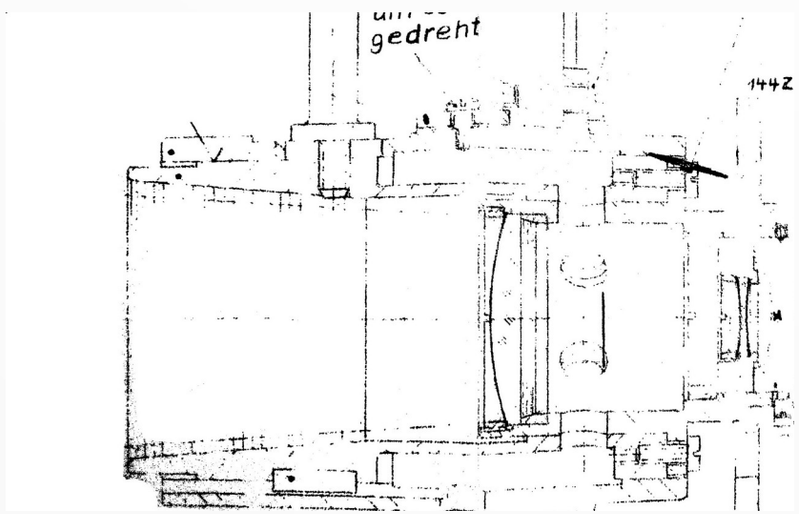




LSO: ZEISS 200/3000/4000

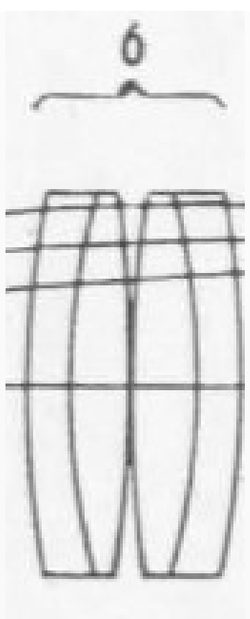
- Secondary optics around the Lyot stop
  - 1/ D 34 mm; curvature radius +52.88 mm / ∞
  - 2/ D 13 mm; curvature radius -33.48 mm / -45.99 mm
  - Lyot stop (iris diaphragm)
  - 3/ D 24 mm; curvature radius -1392.90 mm / +42.70 mm

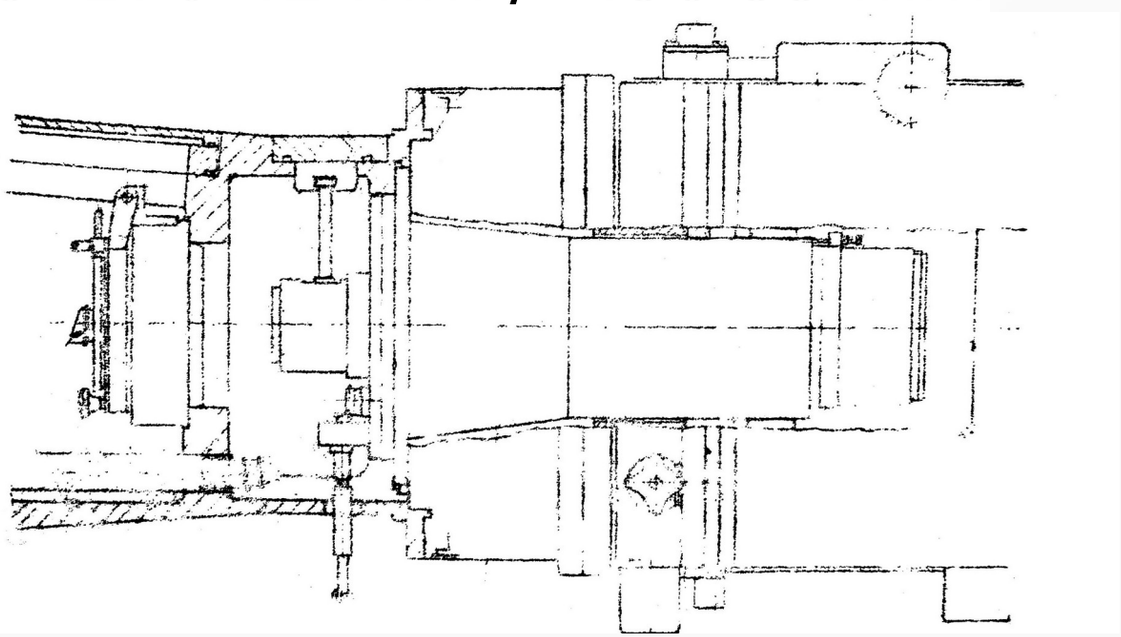




LSO: ZEISS 200/3000/4000

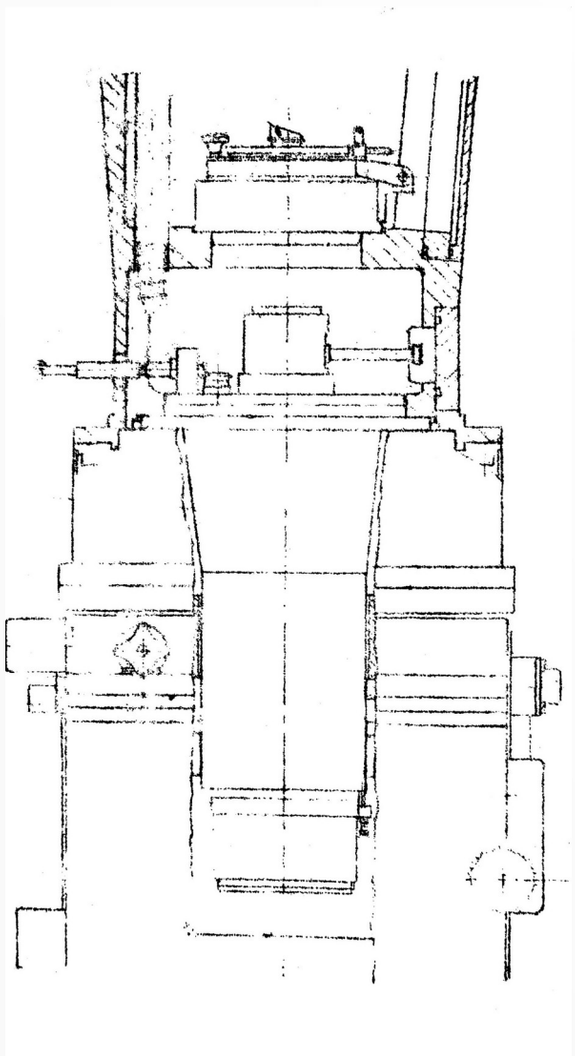
- Re-imaging objective lens: BK7 glass, diameter 94 mm
  - 1/ curvature radius 440.60 mm / -177.060 mm
  - 2/ curvature radius 176.14 mm / 588.50 mm
  - 3/ curvature radius 588.50 mm / 176.14 mm
  - 4/ curvature radius -176.42 mm / 438.35 mm

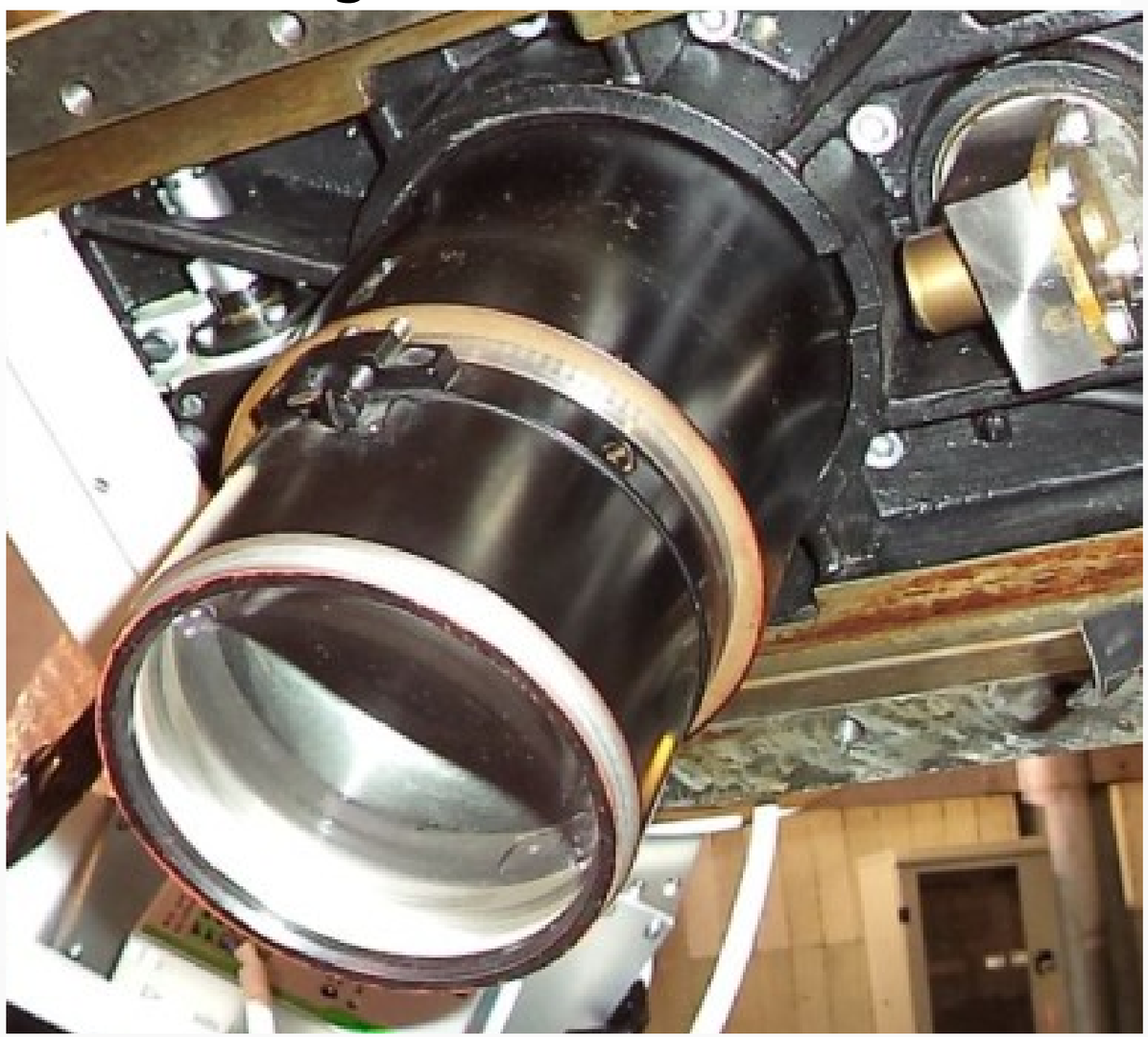




LSO: ZEISS 200/3000/4000

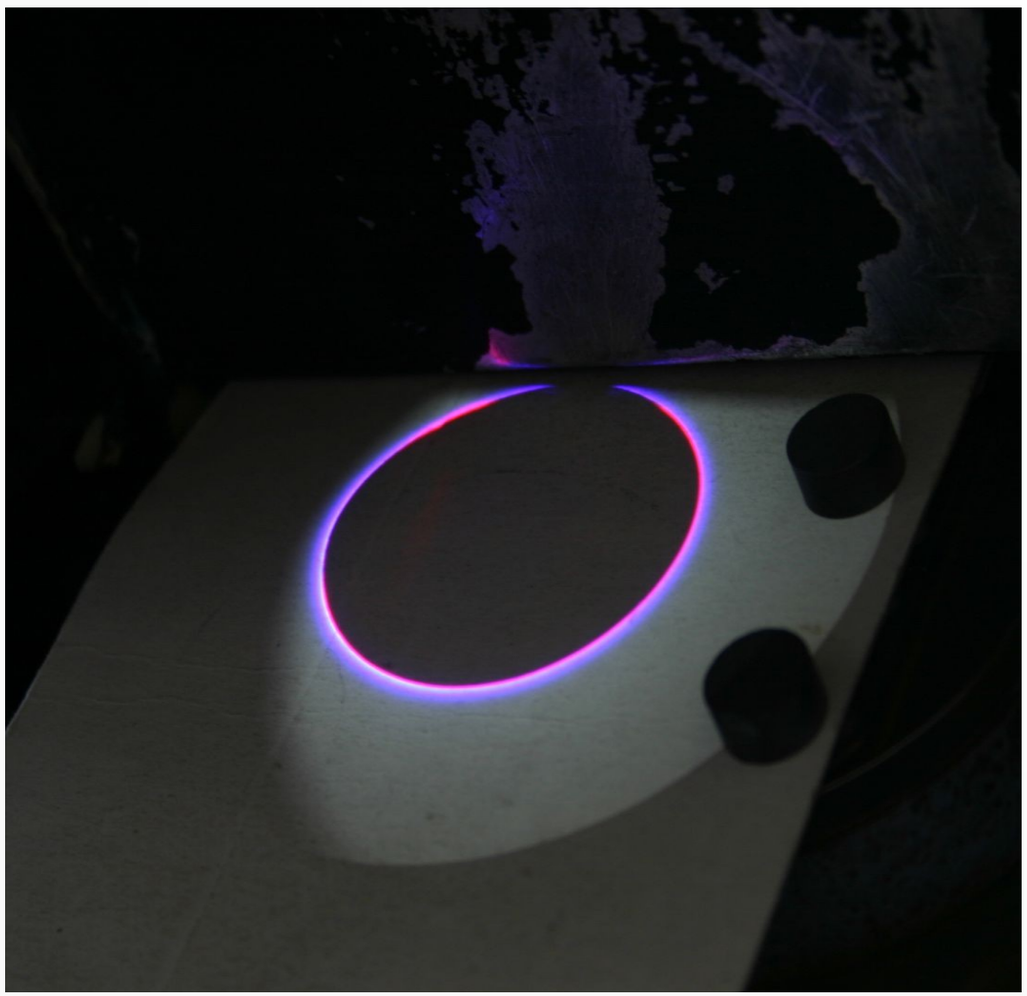
- Re-imaging objective lens: BK7 glass, diameter 94 mm





LSO: ZEISS 200/3000/4000

- The final image (primary obj. lens focus set for λ 530 nm)!

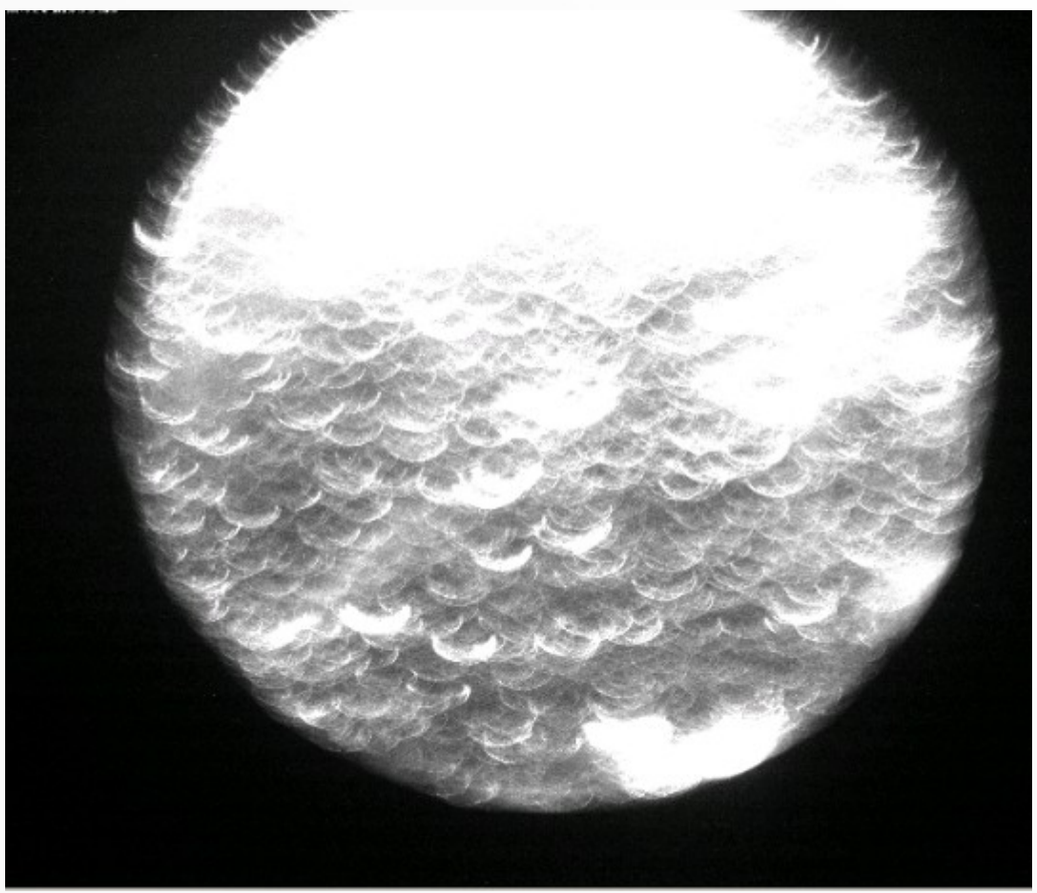


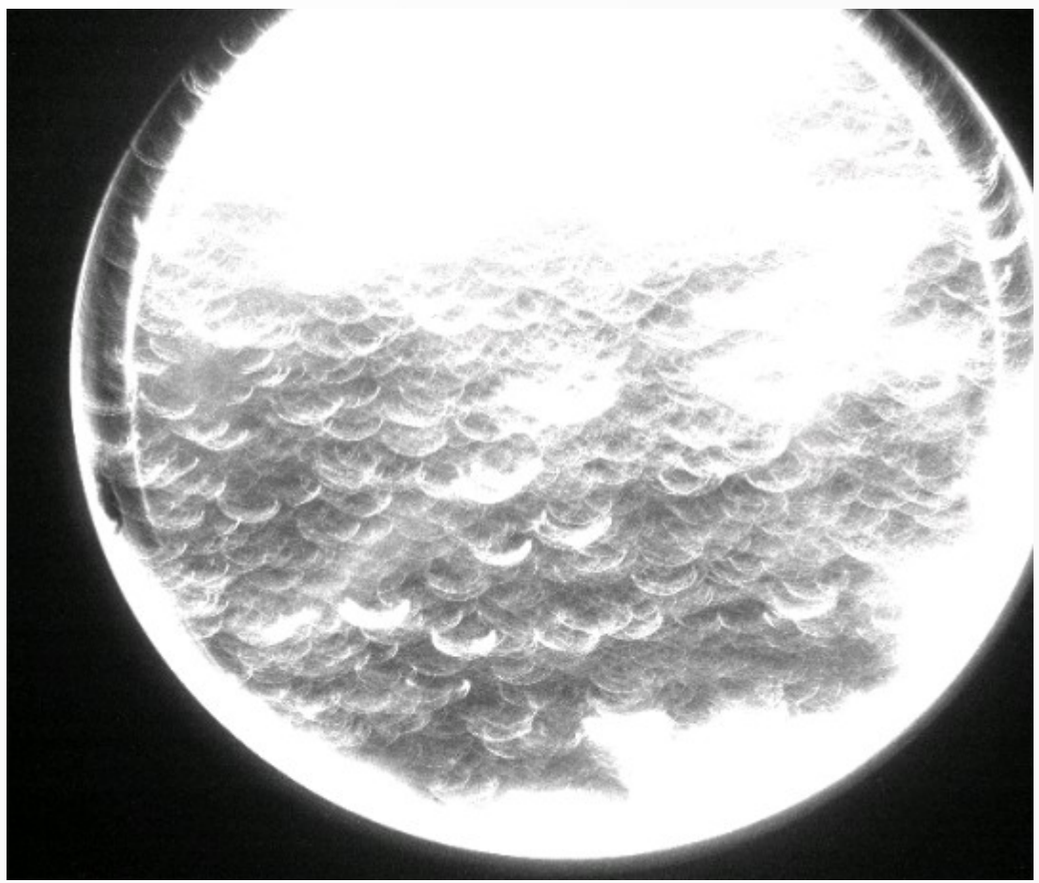
LSO: ZEISS 200/3000/4000

- The final image (primary objective lens focus: 530 nm)
  - focused/defocused light
  - Coronal/solar disk light
  - Eye sensitivity ~ λ

LSO: ZEISS 200/3000/4000

- The Lyot stop effect





LSO: ZEISS 200/3000/4000

- How to see the coronal/prominence light? Block somehow the unfocused light!
- Options:
  - detector sensitivity ~ λ
  - optical narrow-band filter
  - spectral instruments:
    - prism
    - diffraction grating
    - Lyot-Ohman filter
    - Fabry-Perot
    - ...

B. LYOT @ Pic du Midi

- BL's spectral instruments:
  - Prism spectrometer
  - diffraction grating sp.
  - Lyot-Ohman filter

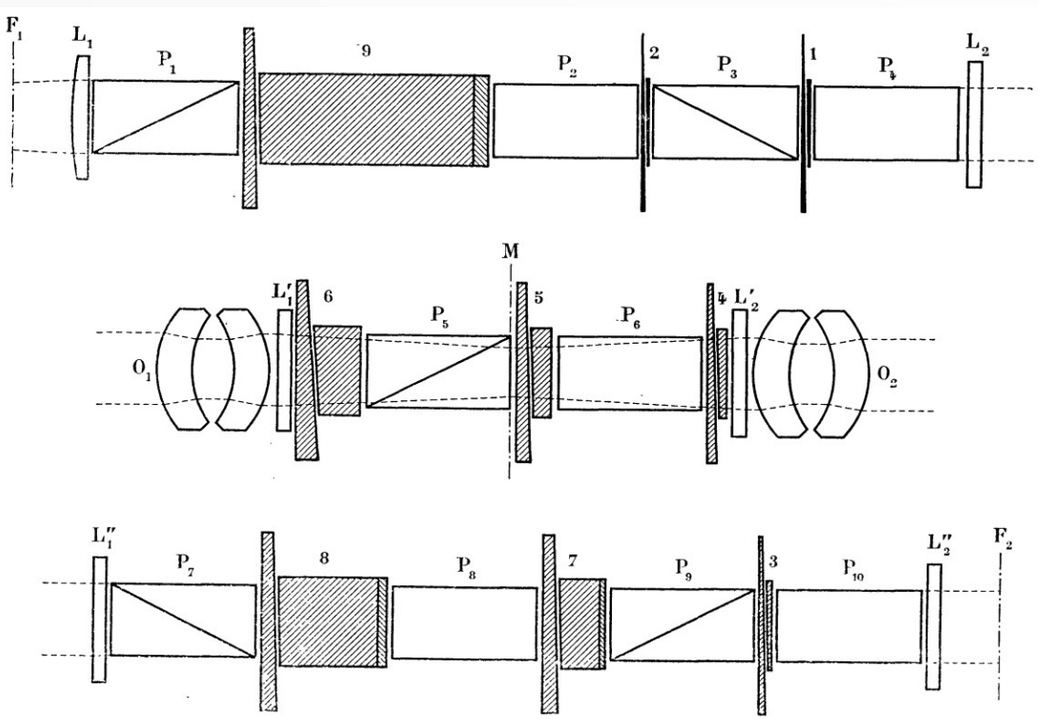


FIG. 10. — Schéma du premier filtre.

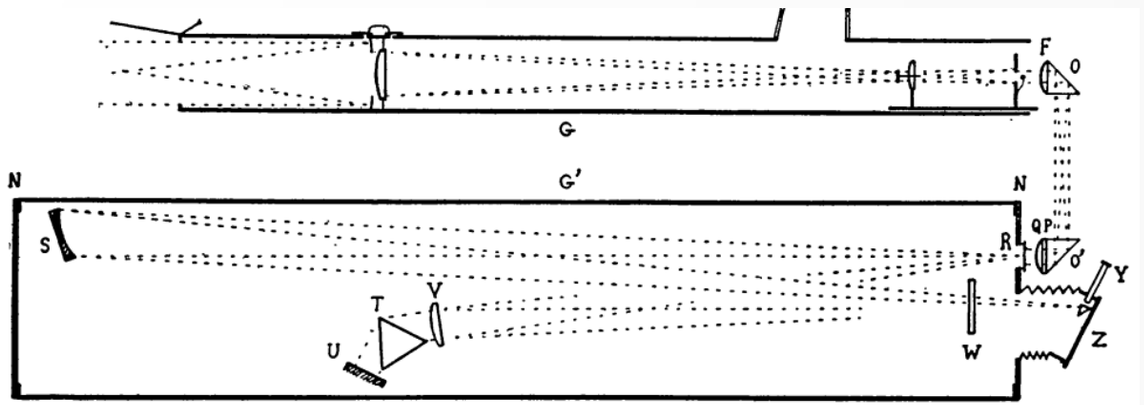


FIG. 6.—*Plan of the coronagraph and the spectrographs used in 1931.*

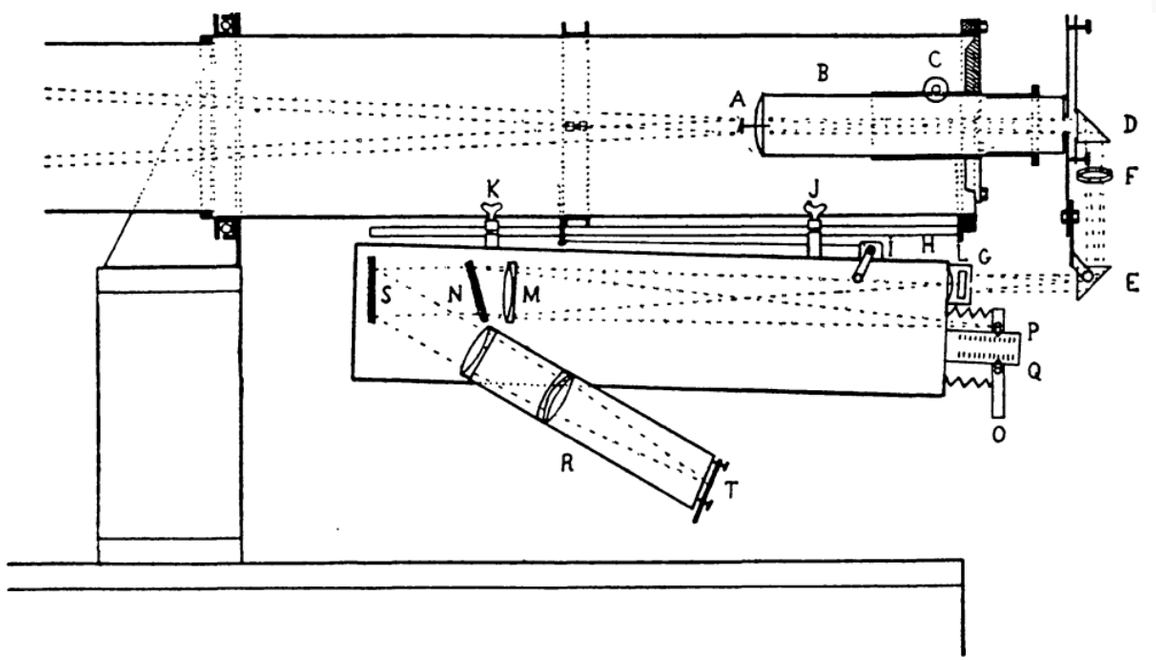
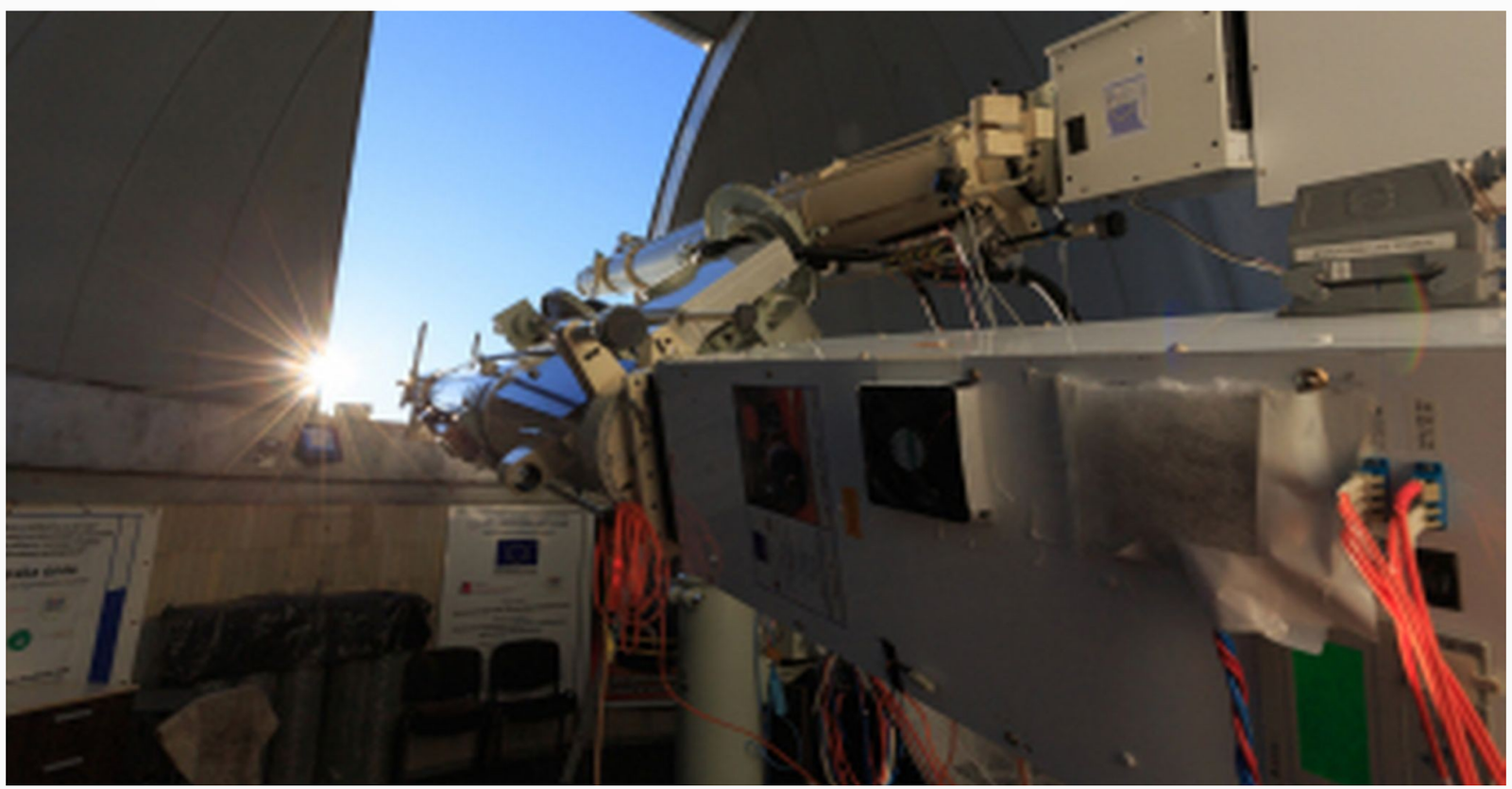


FIG. 7.—*Plan of the final coronagraph and the spectrograph used since 1935.*

LSO: ZEISS 200/3000/4000

- Seeing is more convincing…
- Let’s go to the dome to see the ZEISS 200/3000/400 coronagraph!



LSO: ZEISS 200/3000/4000

- Optics: obj. lens, art. moon, field lens, Lyot stop, 3 add. lenses, re-imaging objective
- Mechanics: front tube, diffuser, intensity calibration mask, obj. lens focusing and cleaning, atr. moon exchange, post-focus instrument: radial shift + rotation