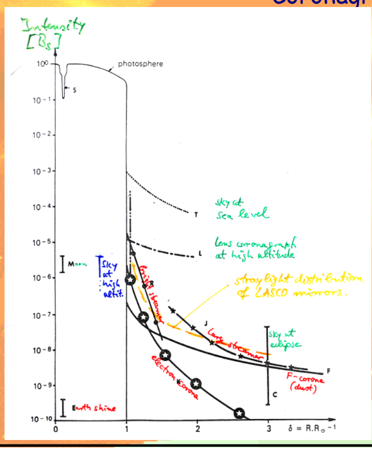
Space Instrumentation (8)

Lectures for the IMPRS June 23 to June 27 at MPAe Lindau
Compiled/organized by Rainer Schwenn, MPAe,
supported by Drs. Curdt, Gandorfer, Hilchenbach, Hoekzema, Richter, Schühle

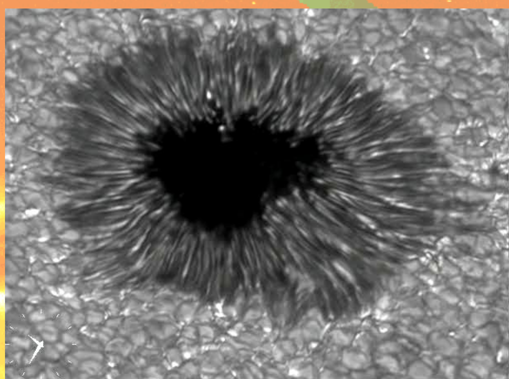
Wed, 25.6., 16:00 Optical Instruments, an overview.
Coronagraphs (RS)

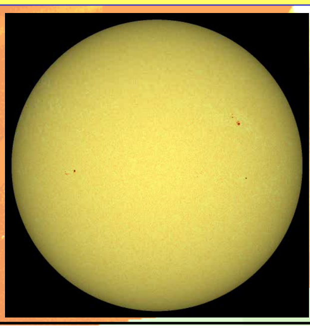


Observing the Sun from ground

Sunspots

Sunpots are dark areas (umbra, penumbra) on the solar disk. They are due to strong magnetic fields which inhibit energy transport from solar interior. Their frequency varies with the 11-year solar activity cycle





Telescopes make use of radiation from the Sun, but the Earth's atmosphere is disturbing!

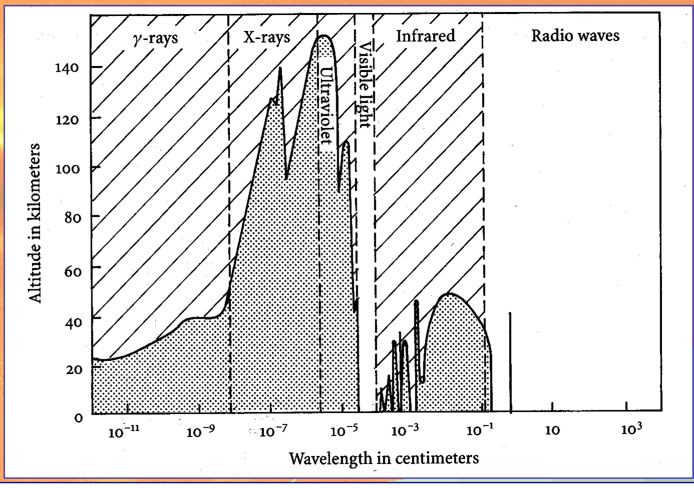
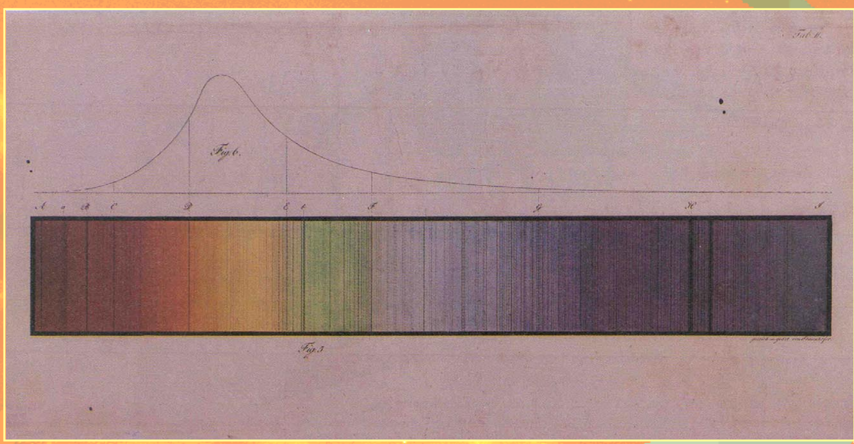
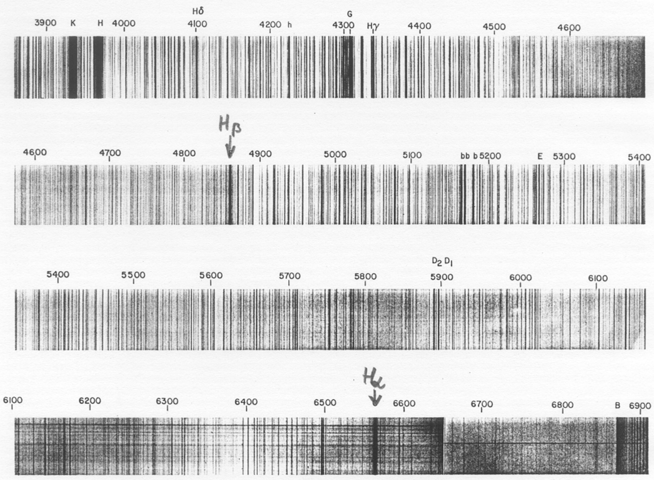


Figure 1. Depth of penetration of energetic short wavelength solar radiation as a function of wavelength. Altitudes correspond to an attenuation of 1/e for an overhead Sun. The main absorbers and ionization limits are indicated.

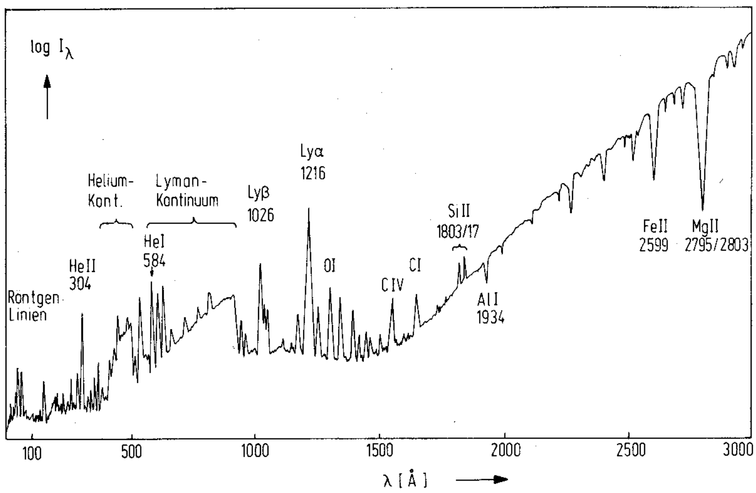


Fraunhofer's original spectrum showing solar absorption lines in his nomenclature

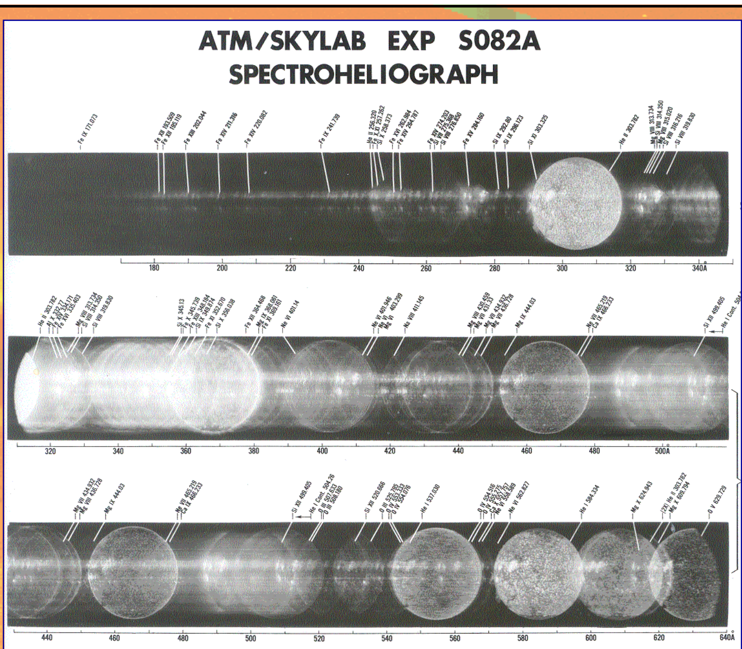


2.8 *Photographic image of the visible solar spectrum obtained with a large grating spectrograph. Wavelengths are given in Angstrom units at the top of the spectrum. The lines labeled B, C, D (shown here as D_1 and D_2), E, F, G, H, K are Fraunhofer's original description (see text). Also labeled are the hydrogen Balmer lines Hα (Fraunhofer's C line), Hβ, Hγ, and Hδ. (Courtesy Mt. Wilson Observatory, Carnegie Institution of Washington.)*

Almost all Fraunhofer lines are optically thin.
That allows to determine element abundances in the solar atmosphere

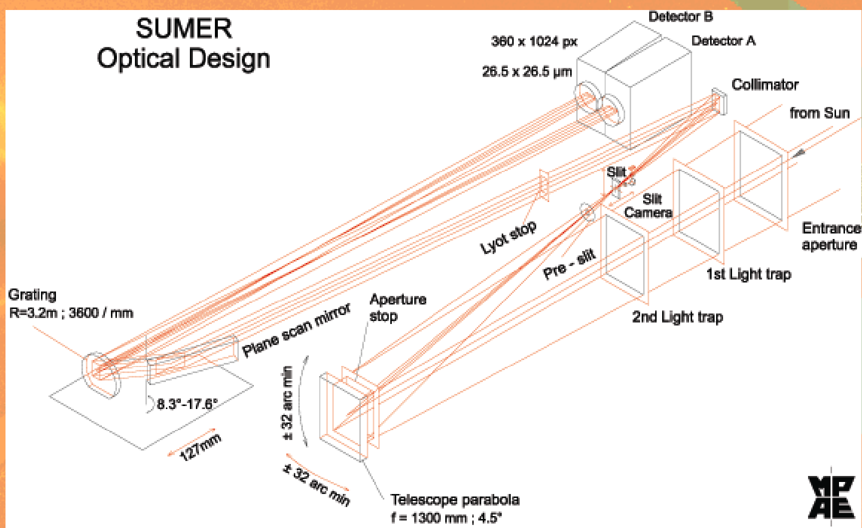


Spectrum of the solar radiation in the visible and UV range. Note the transition from continuum radiation from photosphere (with Fraunhofer absorption lines) into the non-thermal emission line spectrum from the corona



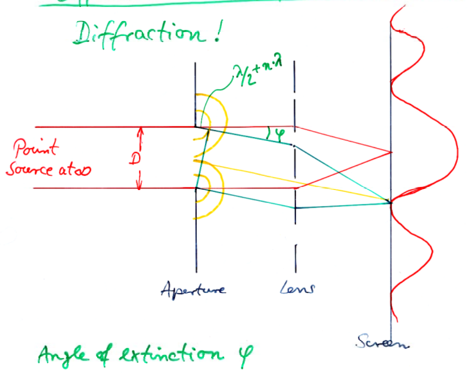
A „stigmatic" UV spectrum of the whole sun, taken with a slitless spectgrograph

How to measure a UV spectrum from space: SUMER on SOHO



Diffraction limit of spatial resolution

Diffraction!



Angle of extinction φ

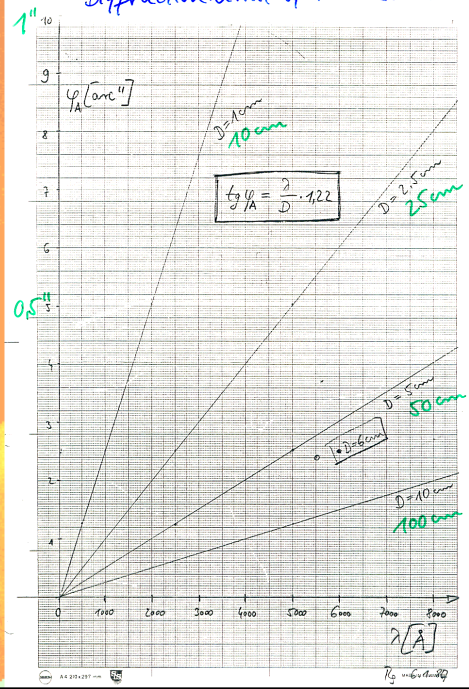
$\sin\varphi = \frac{\lambda}{2}\cdot\frac{1}{D}$

Exact: $\boxed{\sin\varphi_{min} = 1.22\cdot\frac{\lambda}{D}}$ diffraction limit of resolution

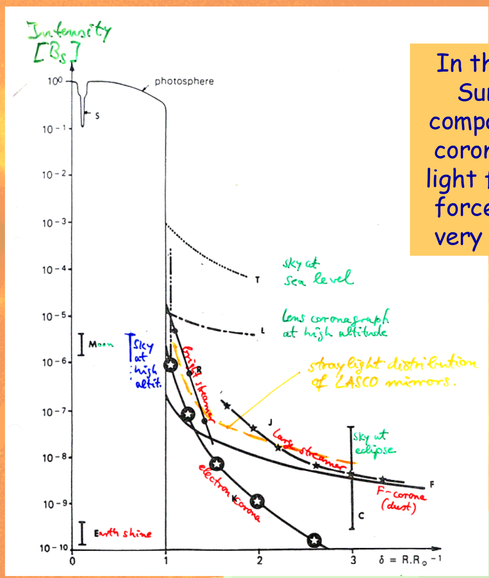
	λ	D	φ	
	1000 nm	1 m	0.25"	IR
Note:	500 nm	10 cm	1.25"	Vis. ≙ 1000 km on sun!
	100 nm	10 cm	0.25"	UV
	10 nm	10 cm	0.025"	X-rays
	1 mm	1 m	4,2'	300 GHz Radio

Example: Object of 1 m from 500 km distance: $\varphi \approx 0.4''$

Diffraction limit of resolution



Remote sensing of the corona: coronagraphs in space open a new era



In the visible spectral range the Sun's disk is much too bright compared to the faint signal from coronal emission lines. Scattered light from the Earth's atmosphere forces us to put coronagraphs to very high altitudes or into space.

Brightness distributions around the Sun's disk

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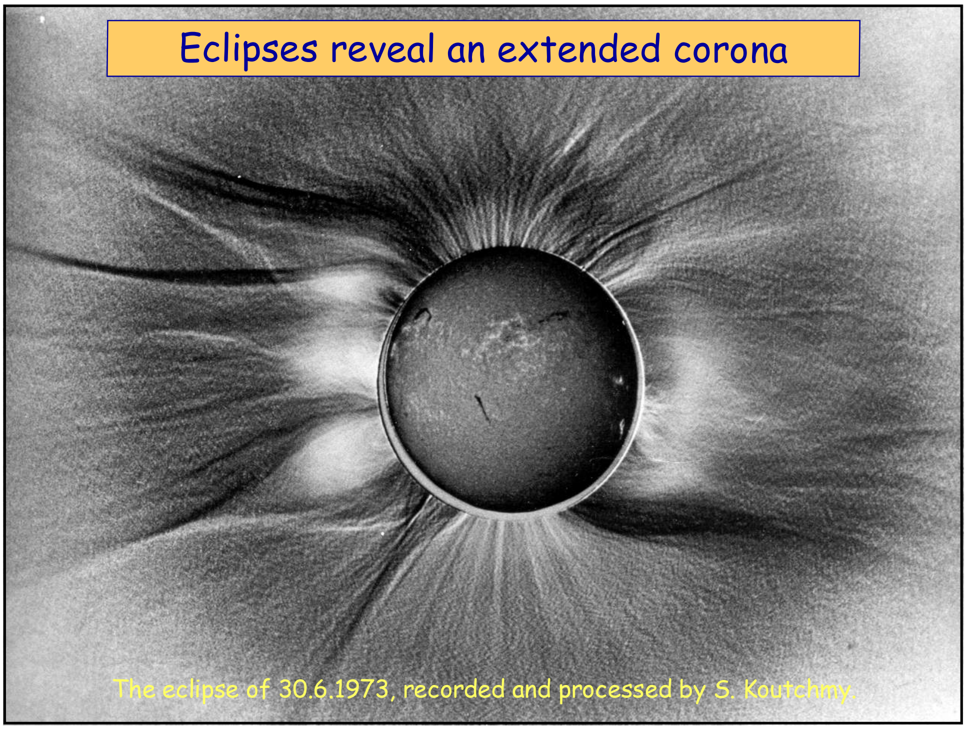
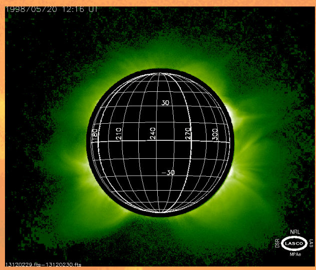
Eclipses reveal an extended corona

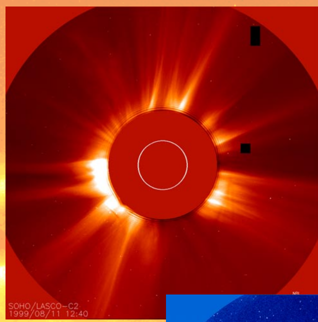


The eclipse of 30.6.1973, recorded and processed by S. Koutchmy.

Remote sensing of the corona: coronagraphs in space open a new era

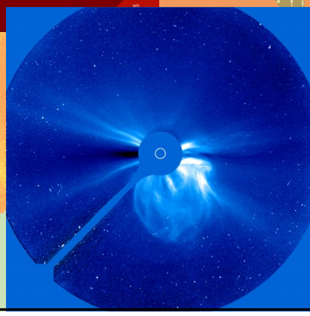


LASCO-C1

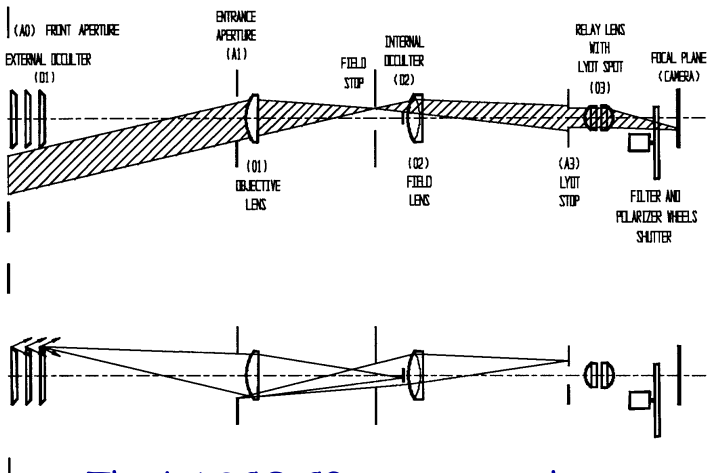


LASCO-C2

MICA



LASCO-C3

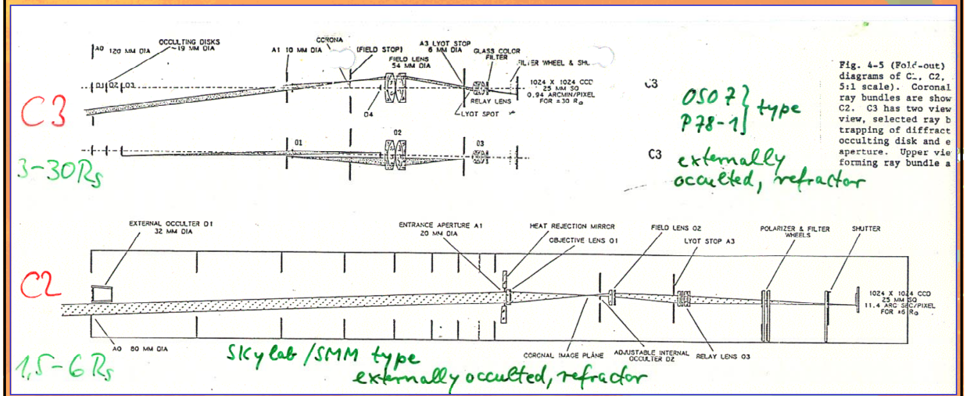


The LASCO C3 coronagraph

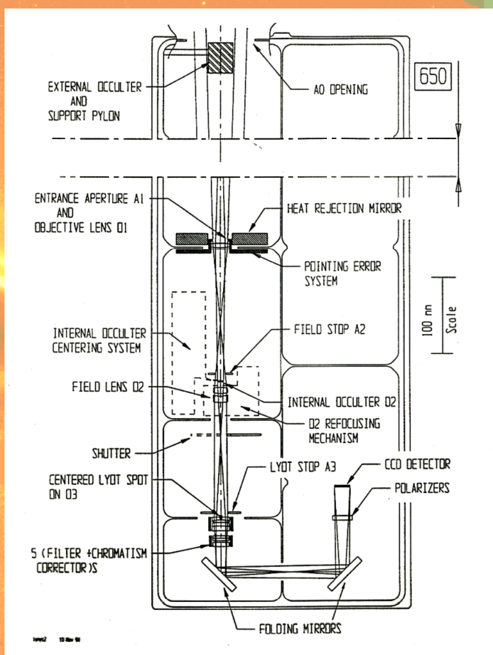
Figure 6-1: Conceptual diagram of the C3 coronagraph. The top diagram illustrates the image paths, and the bottom diagram the supression of stray light.

Remote sensing of the corona: coronagraphs in space open a new era

LASCO-C2/C3 coronagraph scheme



External occultor system is perfect to view the very outer corona, but near the inner edge it suffers from vignetting and allows no more resonable spatial resolution



LASCO C2

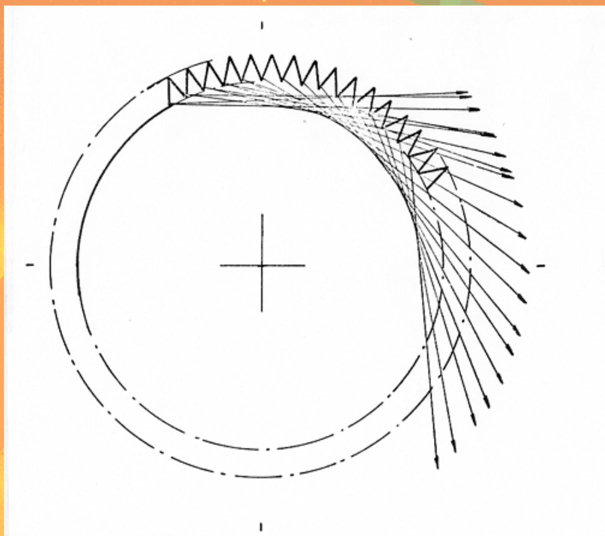
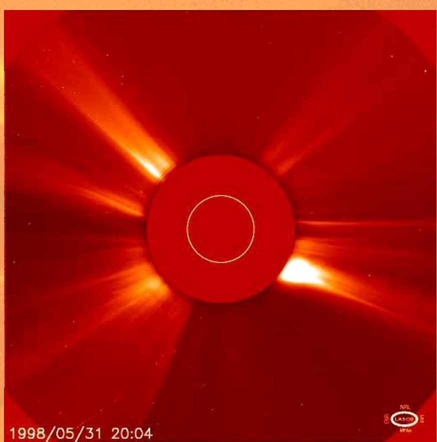
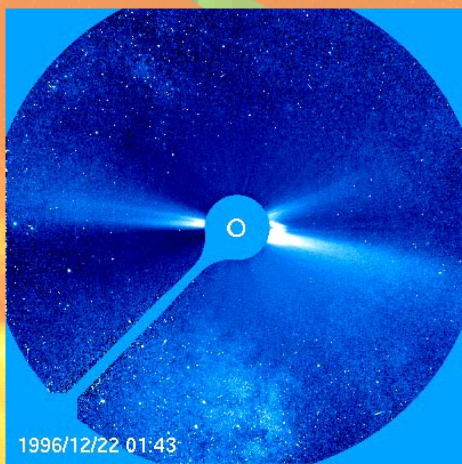


Fig. 7. Direction of diffracted parallel light from the periphery of a sawtooth disk or serrated edge (from Purcell and Koomen, 1962). The incident beam is perpendicular to the plane of the figure and the directions of the diffracted rays are shown in projection on the plane of the figure, so they do not reach the optical system of a coronagraph.

A cerrated external occulter, for straylight reduction

LASCO C2

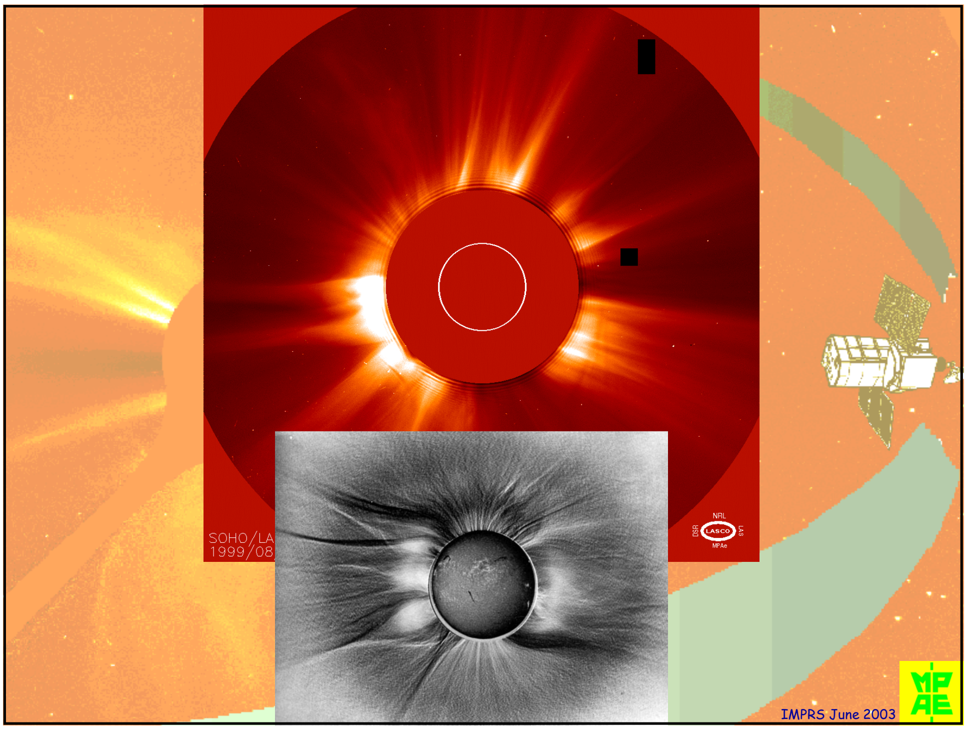


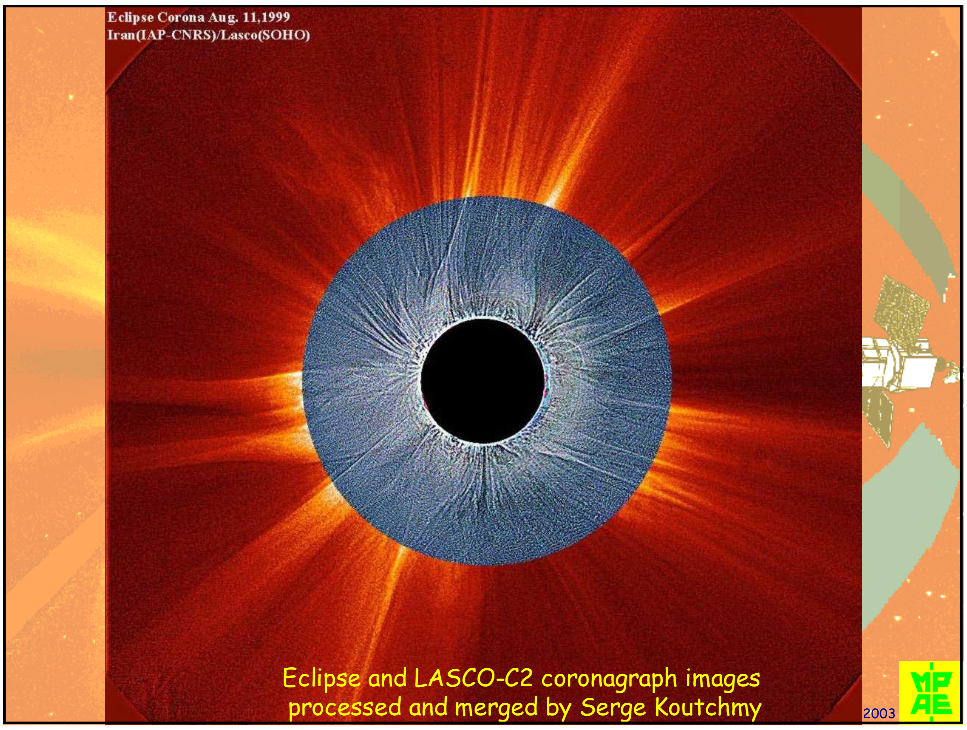


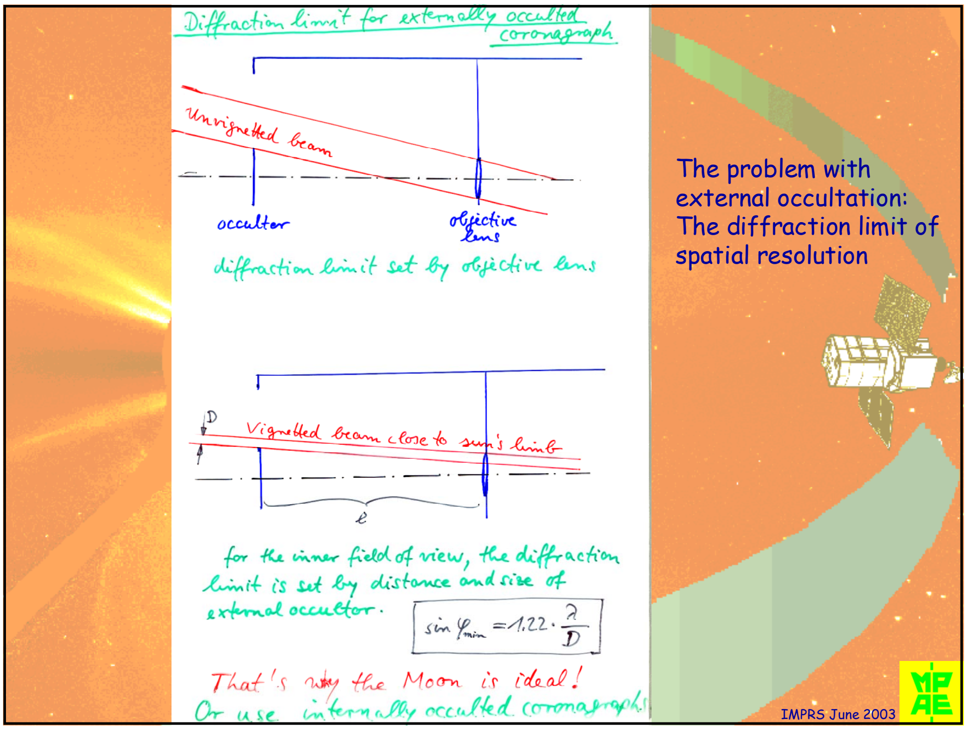
LASCO C3

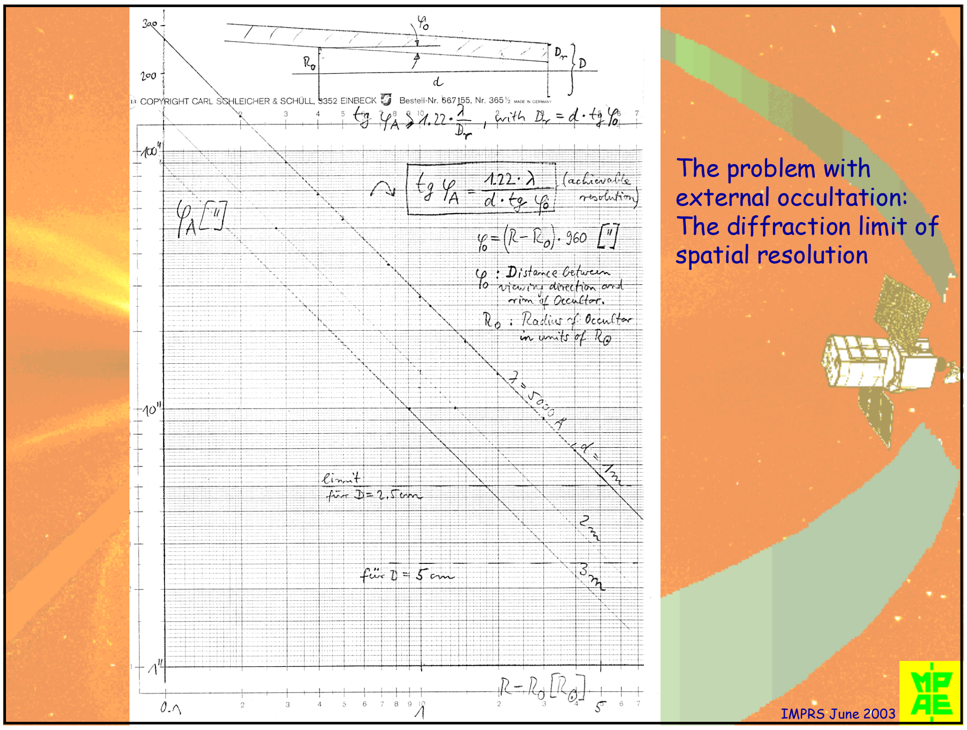
http://star.mpae.gwdg.de/

http://lasco-www.nrl.navy.mil/lasco.html


SOHO/LA
1999/08
IMPRS June 2003


Eclipse Corona Aug. 11,1999
Iran(IAP-CNRS)/Lasco(SOHO)
Eclipse and LASCO-C2 coronagraph images
processed and merged by Serge Koutchmy
2003


Diffraction limit for externally occulted coronagraph
Unvignetted beam
occulter
objective lens
diffraction limit set by objective lens
D
Vignetted beam close to sun's limb
l
for the inner field of view, the diffraction limit is set by distance and size of external occultor.
$\sin \varphi_{min} = 1.22 \cdot \frac{\lambda}{D}$
That's why the Moon is ideal!
Or use internally occulted coronagraphs!
The problem with external occultation: The diffraction limit of spatial resolution
IMPRS June 2003


φ_0
R_0
D_r
D
d
COPYRIGHT CARL SCHLEICHER & SCHÜLL, 3352 EINBECK Bestell-Nr. 667155, Nr. 365½ MADE IN GERMANY
$tg\, \varphi_A \geq 1.22 \cdot \frac{\lambda}{D_r}$, with $D_r = d \cdot tg\, \varphi_0$
$tg\, \varphi_A = \frac{1.22 \cdot \lambda}{d \cdot tg\, \varphi_0}$ (achievable resolution)
φ_A ["]
$\varphi_0 = (R - R_0) \cdot 960$ ["]
φ_0 : Distance between viewing direction and rim of Occultor.
R_0 : Radius of Occultor in units of $R_\odot$
λ = 5000 Å, d = 1m
2m
3m
limit für D = 2.5cm
für D = 5cm
100"
10"
1"
$R - R_0$ [$R_\odot$]
The problem with external occultation: The diffraction limit of spatial resolution
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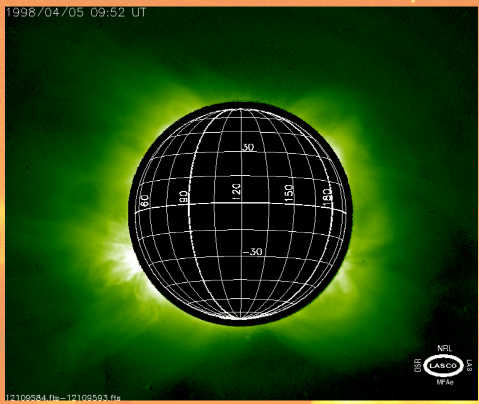

Newkirk and Bohlin, 1963:

„The reflecting coronagraph and the simple externally occulted coronagraph can be made freer of scattered light by at least one ore two orders of magnitude, respectively, than the Lyot coronagraph“

Advantages of mirror coronagraph versus lens coronagraph

1. no multiple internal reflections as in lenses,
2. no lens bulk scatter,
3. no problems due to potential browning and fluorescence of lens glass,
4. no chromatic aberration, allowing sharp focussing of the solar image on to the occultor simultaneously over the whole spectral regime,
5. no wavelength dependence of image dimensions both on the occultor and in the detector focal plane,
6. independence of atmospheric or vacuum refractive indices,
7. compact folded design possible,
8. capability of internal pointing correction by tilting objective mirror,
9. capability of "dynamic imaging" by tilting objective mirror, in order to improve spatial resolution,

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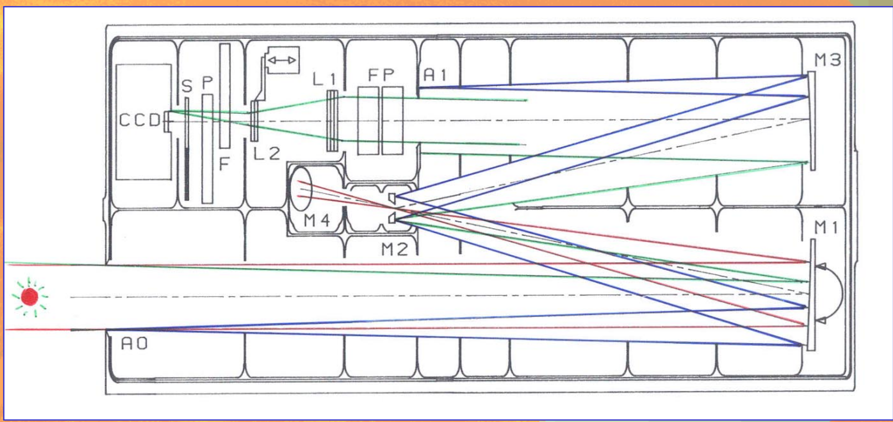
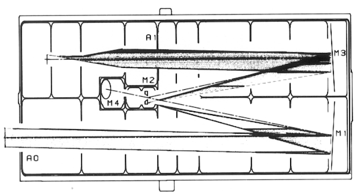
LASCO-C1/MICA coronagraph scheme

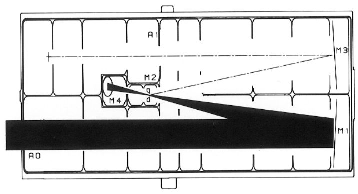


Internal occultor system avoids vignetting of inner corona and allows very high spatial resolution, but it has high instrumental straylight levels.



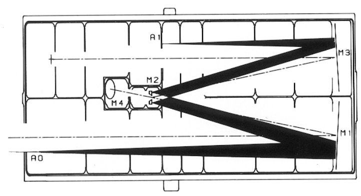
Licht von der Korona

Die Korona wird über M1 auf M2 abgebildet ("Zwischenbild"). Über M3 und das Teleobjektiv und durch die spektralen Filter hindurch gelangt das Koronalicht auf die CCD-Kamera.



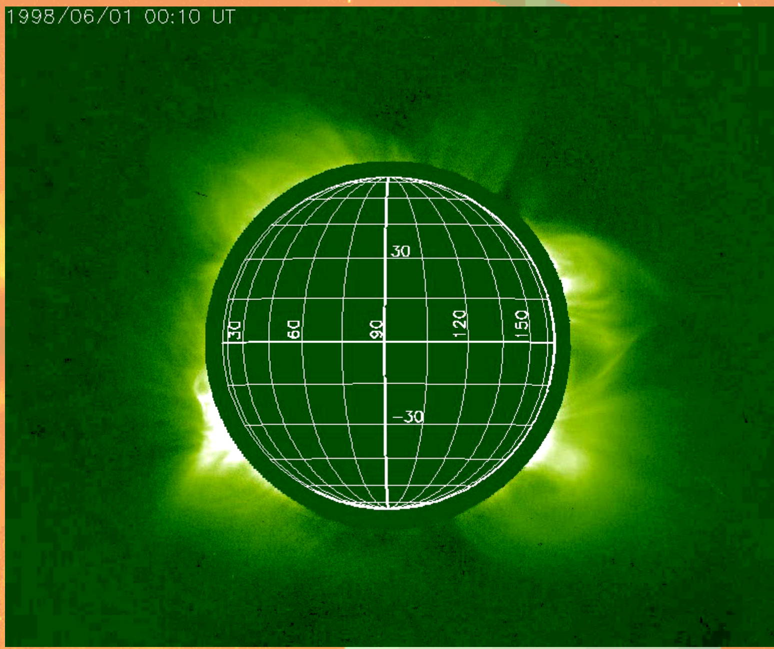
Licht von der Sonnenscheibe

Auch die Sonnenscheibe wird in der Ebene von M2 abgebildet. Das helle Sonnenlicht fällt durch ein Loch in M2 auf den schräg gestellten Spiegel M4 und wird nach außen geleitet.



Streulicht aus dem Instrument

Streulicht von der sonnen-beschienenen Eintrittsblende A0 wird durch die Blende A1 ("Lyotblende") abgefangen.



LASCO C1 images, unprocessed

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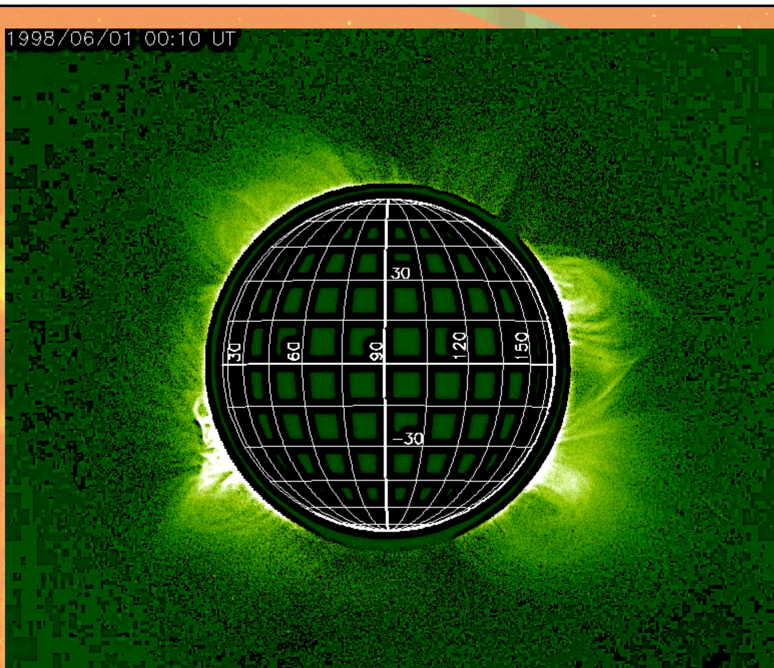

LASCO C1 images, processed using wavelets

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