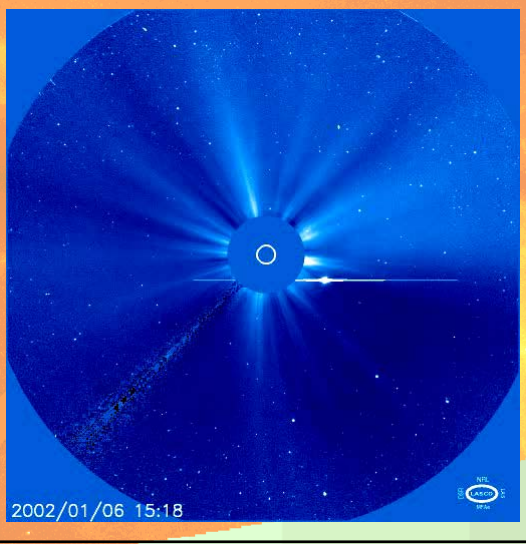
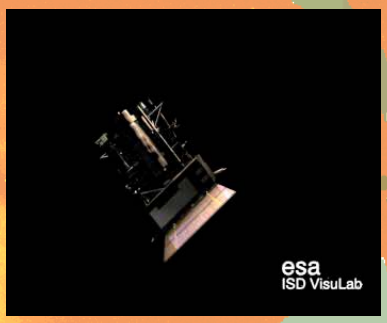
Space Instrumentation: Coronagraphs

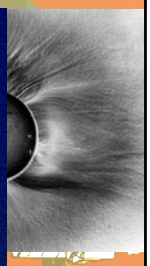
Lecture for the IMPRS, December 5, 2006, at MPS Lindau
given by Rainer Schwenn
schwenn@mps.mpg.de





Eclipses reveal an extended corona

Mankind has always been stunned at the rare occasions of eclipses

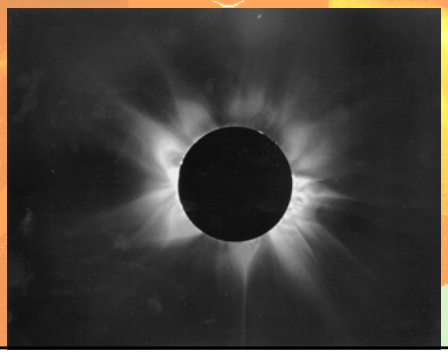


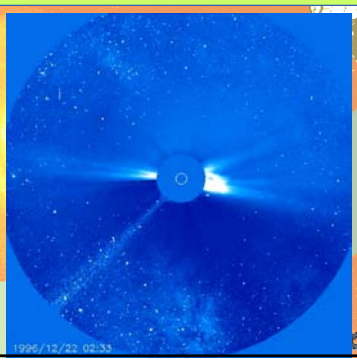
The solar corona: four different types

Note: all coronal radiation is optically thin!

1. The K-corona (*kontinuierliches* Spektrum):

- **White light** from the photosphere, scattered on free electrons in the ionized corona (*Thompson-scattering*), i.e. a continuous spectrum like the photospheric spectrum, but
- **no Fraunhofer absorption lines**, because of high electron temperature in the corona causing *Doppler* smear-out,
- the intensity is proportional to the electron density, summed up along the line of sight,
- the light is strongly polarized, parallel to solar limb,
- visible from ground only during eclipses or using *coronagraphs* from very high mountains at extremely clear skies.





The solar corona: four different types

2. The F-corona (*Fraunhofer* corona)

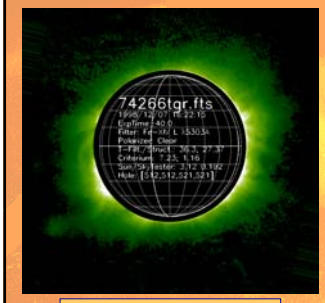
- **White light** from the photosphere, scattered on dust particles (*Rayleigh-scattering*), i.e. , a continuous spectrum like the photospheric spectrum, **including Fraunhofer lines**,
- very low degree of polarization,
- other name: *Zodiacal light*, visible by eye in dawn or dusk at favorable conditions.
- Note: The Fraunhofer line characteristics can be used for differentiating the two corona types!

Zodiacal light

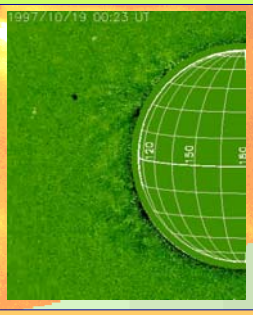
The solar corona: four different types

3. The E-corona (*emission line* corona)

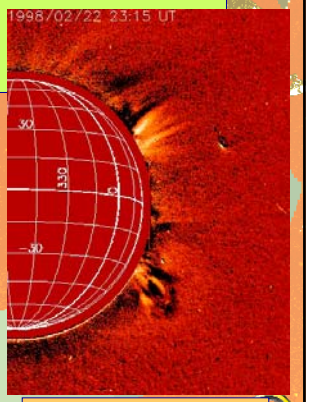
- **Line emission** from various atoms and ions in the corona,
- strongest line in visible spectral range: 530.3 nm of FeXIV ions (the *green* line), apart from H-alpha line at 656.3 nm of cold neutral hydrogen atoms (chromosphere),
- strongest line in UV: Lyman-alpha at 121.6 nm from neutral hydrogen atoms,
- very many lines in UV and EUV spectral ranges,
- strong radial gradients,
- many *forbidden* lines, therefore various polarization states,
- visible using spectrographs during eclipses, or coronagraphs.



MICA (green line)



LASCO-C1 (green line)



LASCO-C1 (red line)

The solar corona: four different types

4. The T-corona (*thermal* corona), barely visible

- Thermal radiation of heated dust particles,
- continuous infrared spectrum, according to temperature and color of dust particles,

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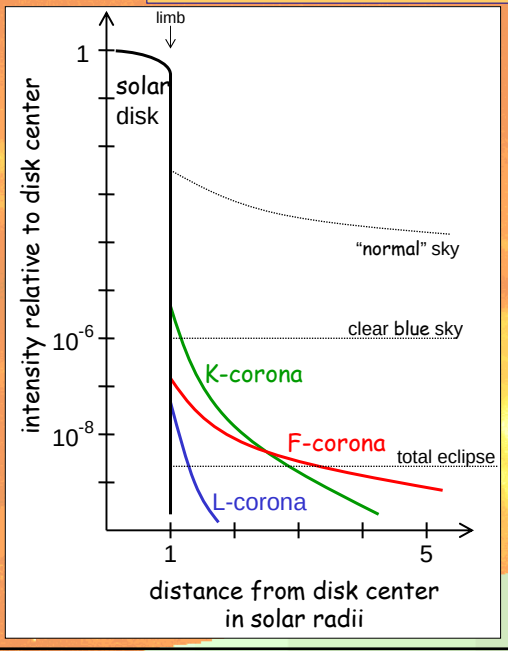
The solar corona: the 3 main types



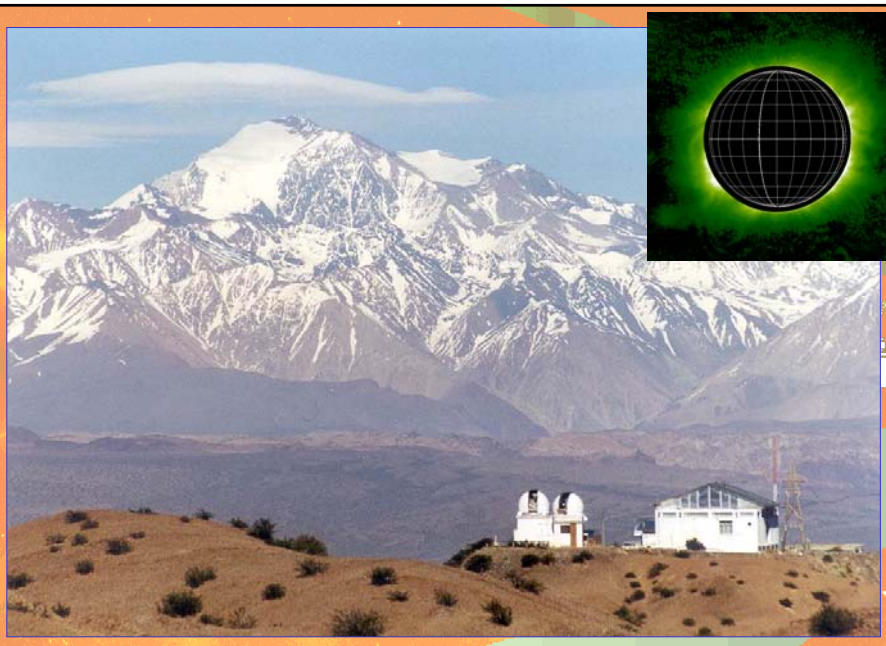
(K) continuum corona
- no absorption lines
- polarised: free electron scattering

(F) Fraunhofer corona
- absorption lines visible
- not polarized: dusk scattering
- Zodiac light…

(L) Line corona
- emission lines: e.g.: "green coronal line"
- *emission of atoms / ions:* new elements? helium, "coronium"

Ground-based coronagraphs

Bernhard Lyot put up his new coronagraph in the 1930s right here and saw, for the first time, the solar corona outside an eclipse.



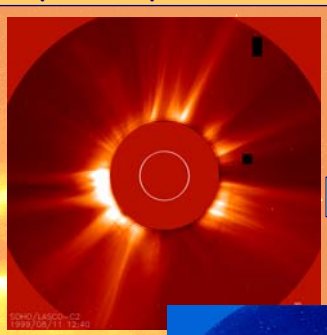
The German Argentinean Solar Observatory near San Juan, Argentina, with the MICA coronagraph (MPAe) and the HASTA telescope (MPE)

Mandatory for ground-based coronagraphy:
A well-calibrated thumb...

Mandatory for ground-based coronagraphy:
A well-calibrated thumb...

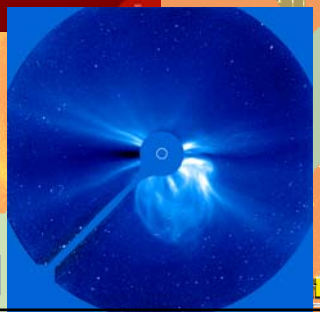
Remote sensing of the corona: coronagraphs in space open a new era

LASCO-C1



LASCO-C2

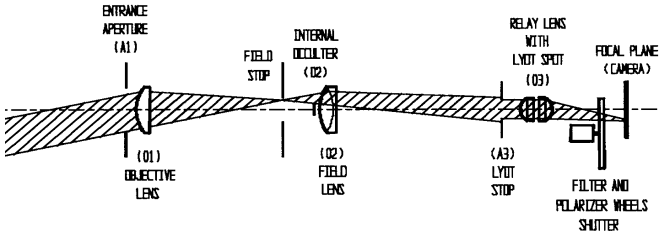
MICA



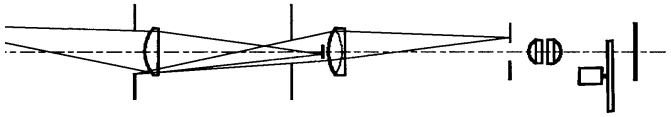
LASCO-C3

How to suppress the Sun and solar straylight?

„Internal occultation" cuts out the solar image inside the instrument, at the location of the first focal plane. Problem: Straylight from fully illuminated front lens and aperture.

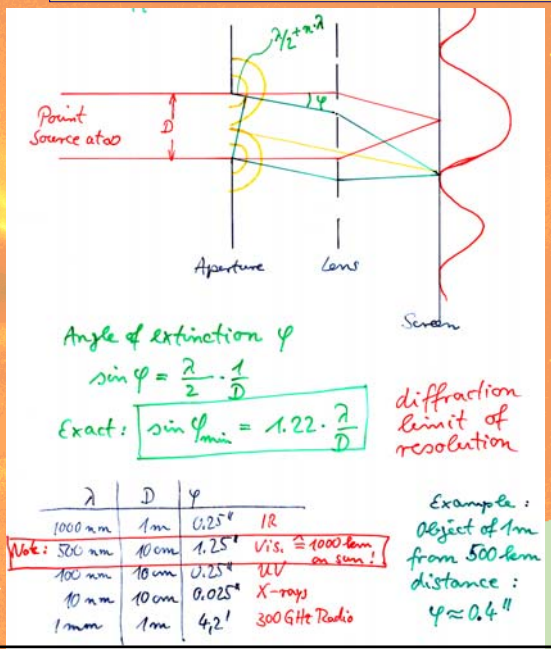


„External occultation" (like moon!) avoids direct sunlight on the objective lens. Problem: Diffraction limit of spatial resolution.



The Lyot trick applied in the LASCO C3 coronagraph

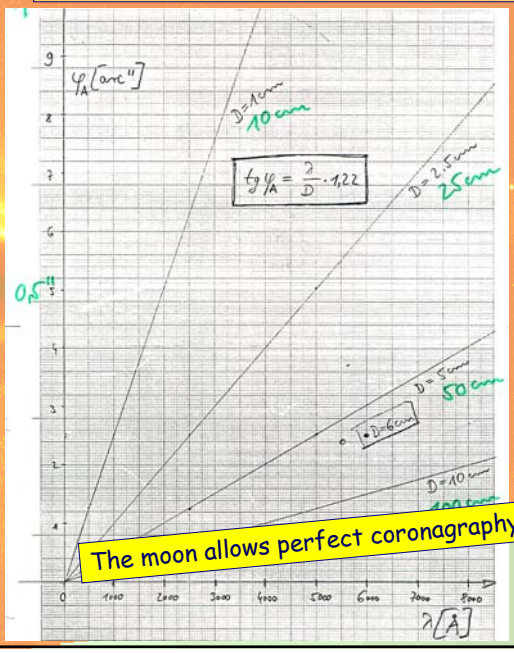
Diffraction limit of spatial resolution



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

Spatial resolution is limited by pupille size!

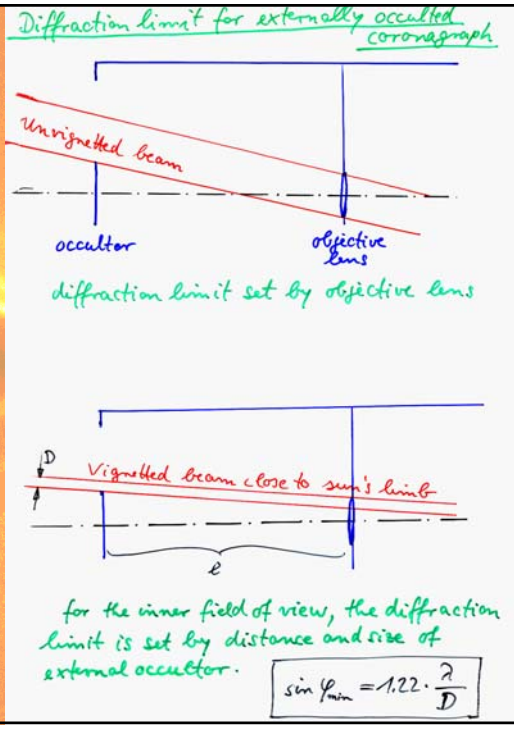
Diffraction limit of spatial resolution



The moon allows perfect coronagraphy!

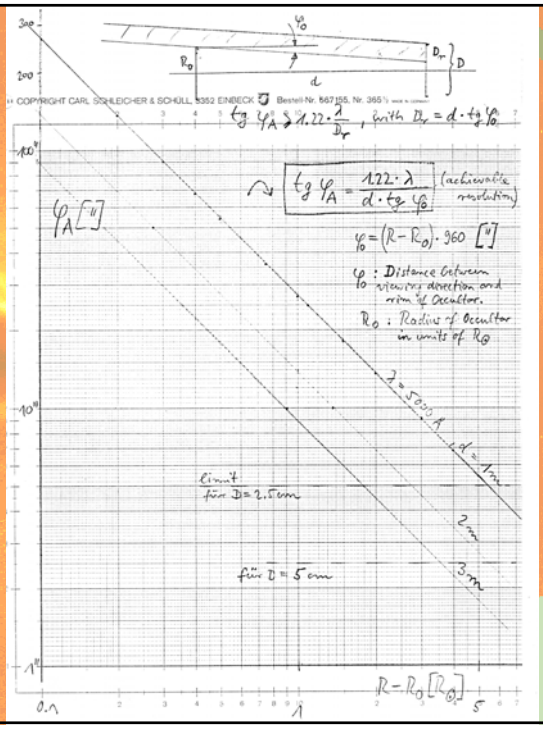
Spatial resolution is limited by pupille size!

Diffraction limit of spatial resolution



The problem with external occultation in coronagraphs of limited size: For regions close to the limb there is substantial vignetting.

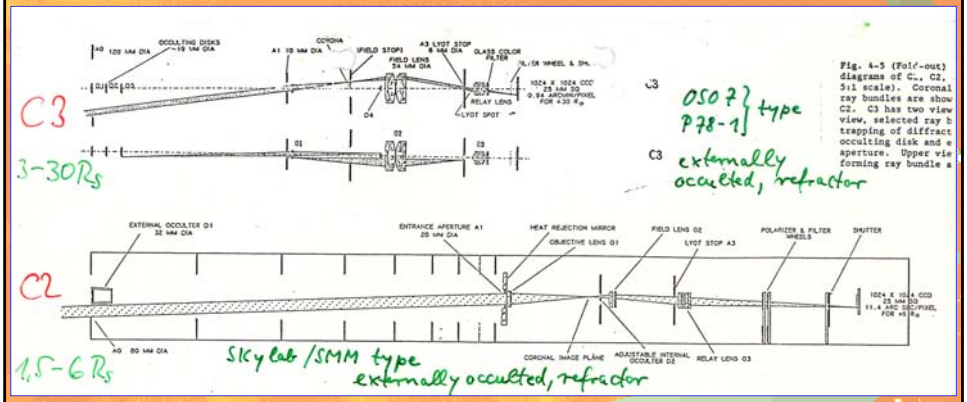
Diffraction limit of spatial resolution



The problem with external occultation in coronagraphs of limited size: For regions close to the limb there is substantial vignetting.

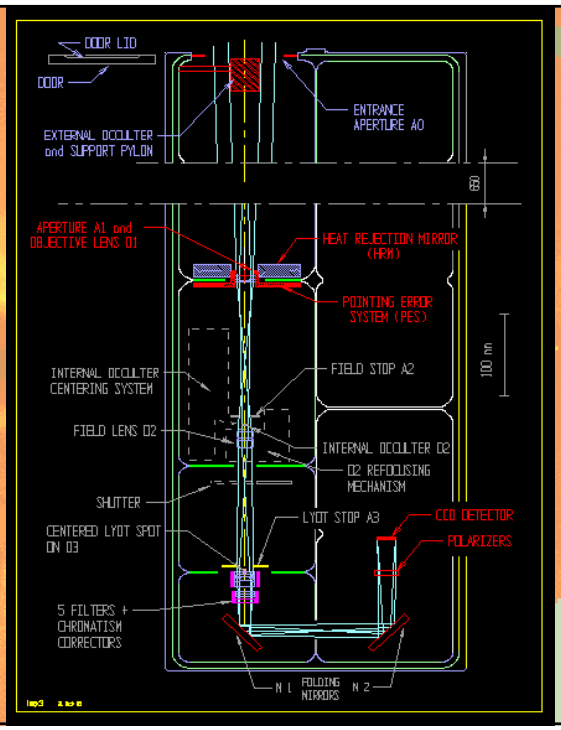
Remote sensing of the corona: coronagraphs in space open a new era

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



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The art of external occulting

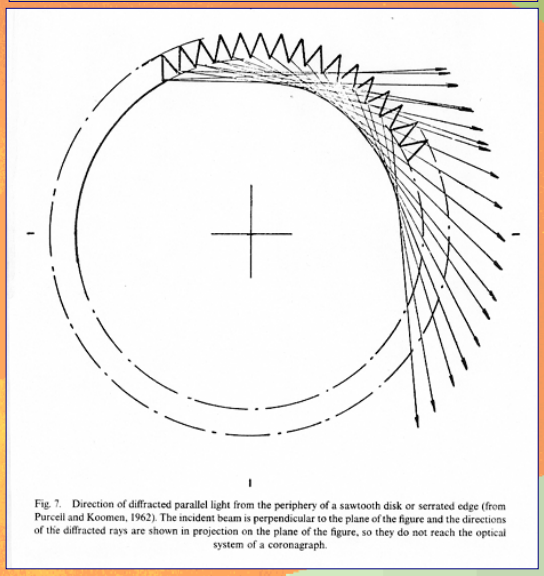

Fig. 7. Direction of diffracted parallel light from the periphery of a sawtooth disk or serrated edge (from Purcell and Koomen, 1962). The incident beam is perpendicular to the plane of the figure and the directions of the diffracted rays are shown in projection on the plane of the figure, so they do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

A cerrated external occulter, for straylight reduction

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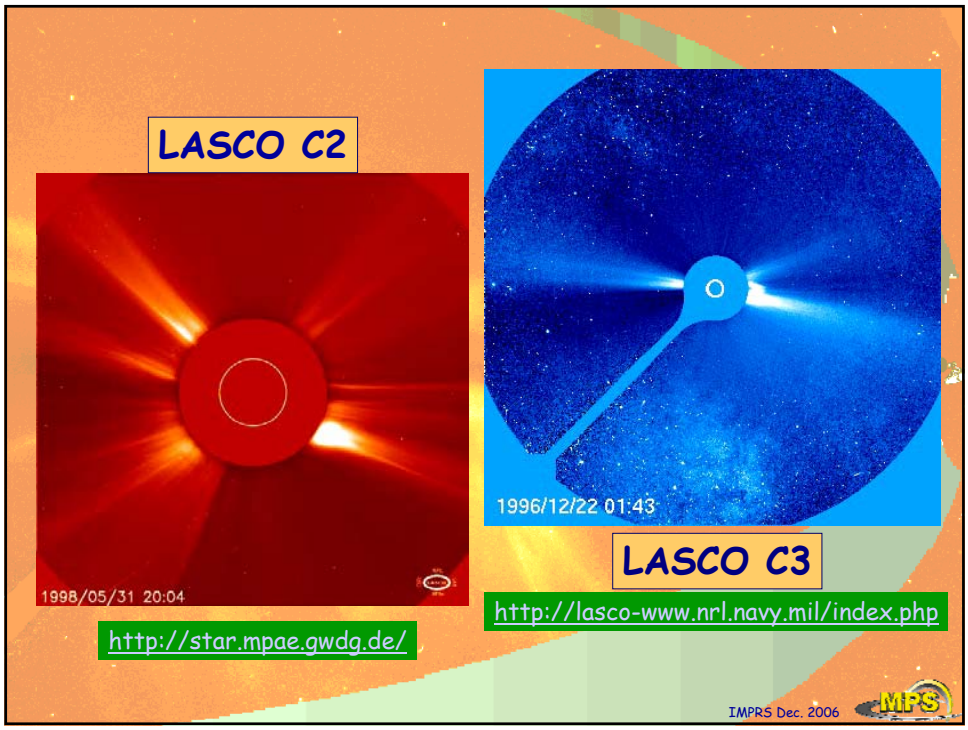
LASCO C2
1998/05/31 20:04
http://star.mpae.gwdg.de/
1996/12/22 01:43
LASCO C3
http://lasco-www.nrl.navy.mil/index.php
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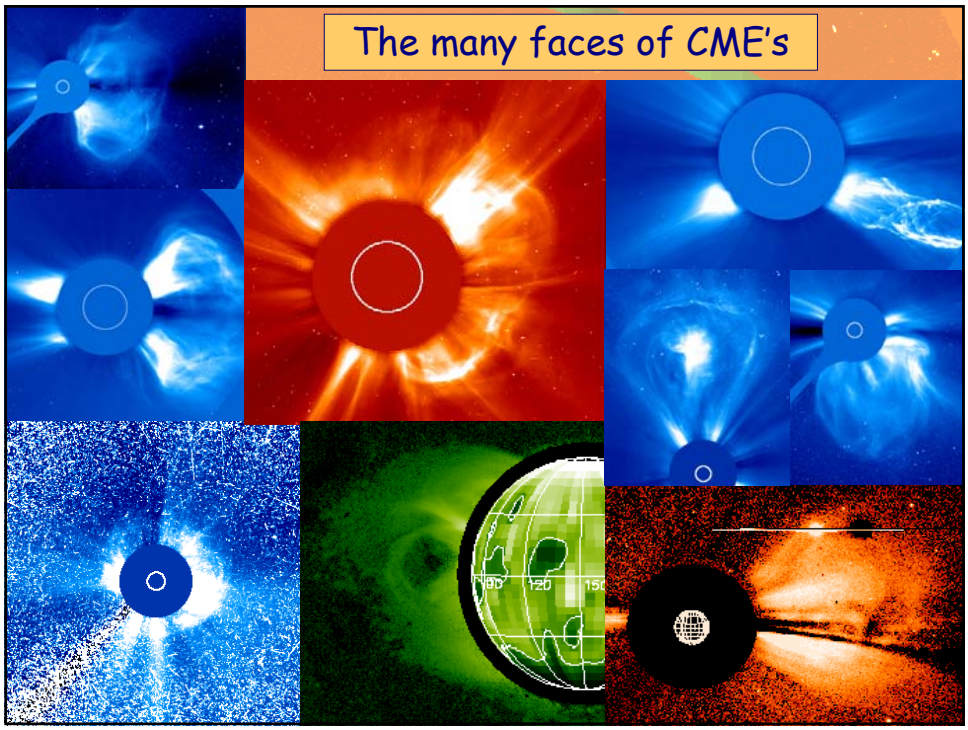
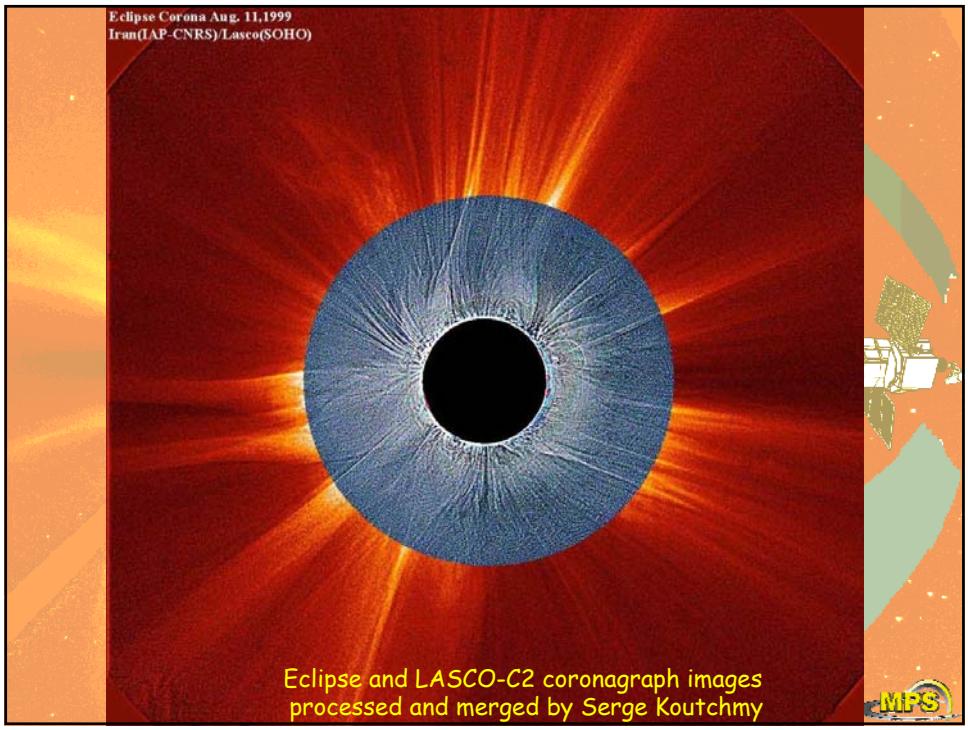
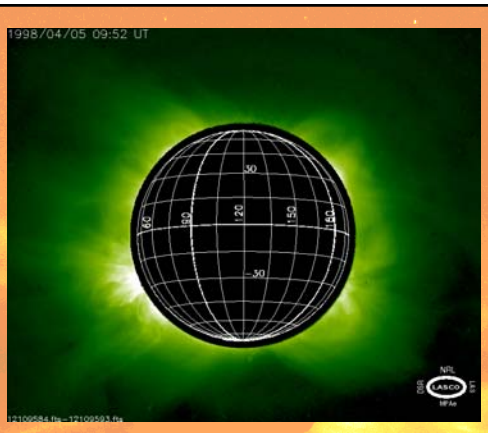

The many faces of CME's



Eclipse and LASCO-C2 coronagraph images processed and merged by Serge Koutchmy



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"

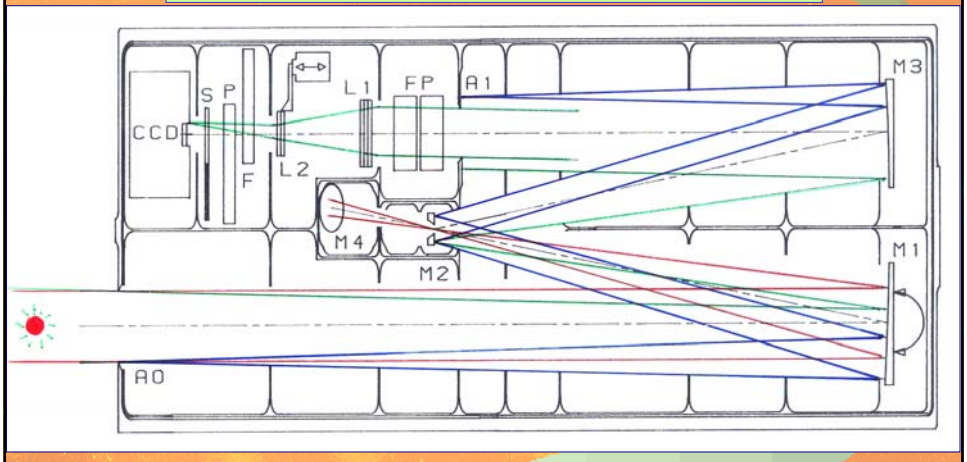
Advantages of mirror coronagraph versus lens coronagraph

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,

Concept of first spectroscopic coronagraph: LASCO-C1

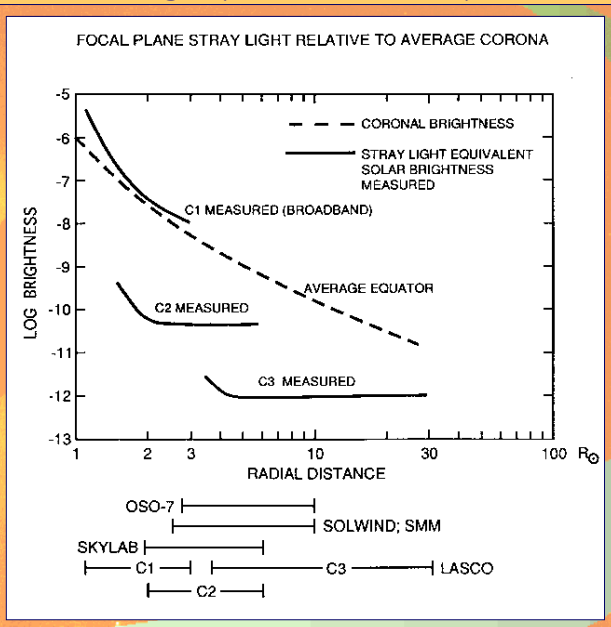
Remote sensing of the corona: coronagraphs in space open a new era

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.

Multiple coronagraphs needed: dynamical range!



The "Bergmodell" (prototype of LASCO-C1), here on Mauna Loa, in July 1991, was further used as an experimental set-up on Sac Peak and on Pic du Midi

LASCO on SOHO, 1995

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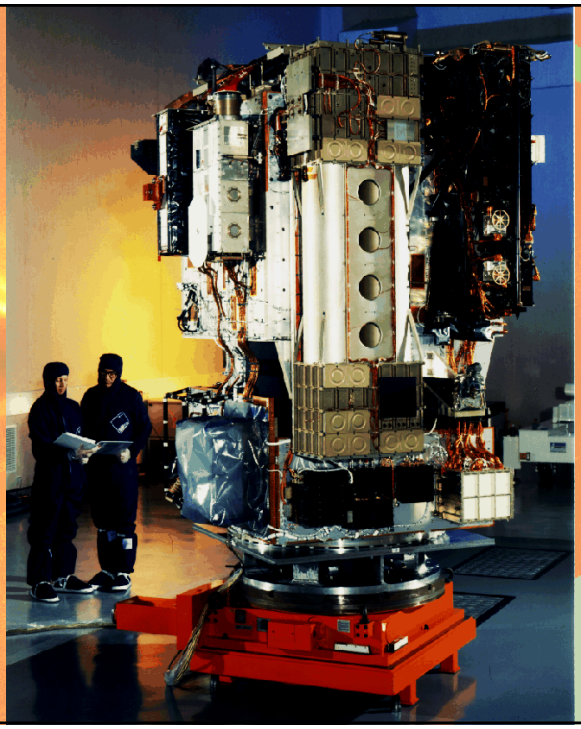
SOHO, 1995



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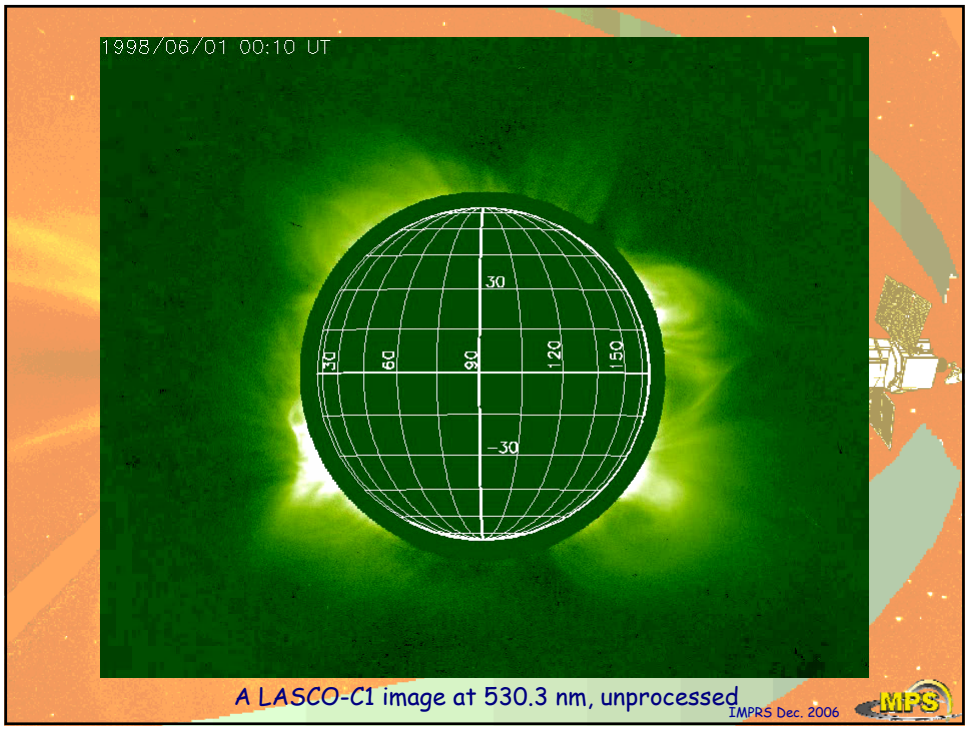
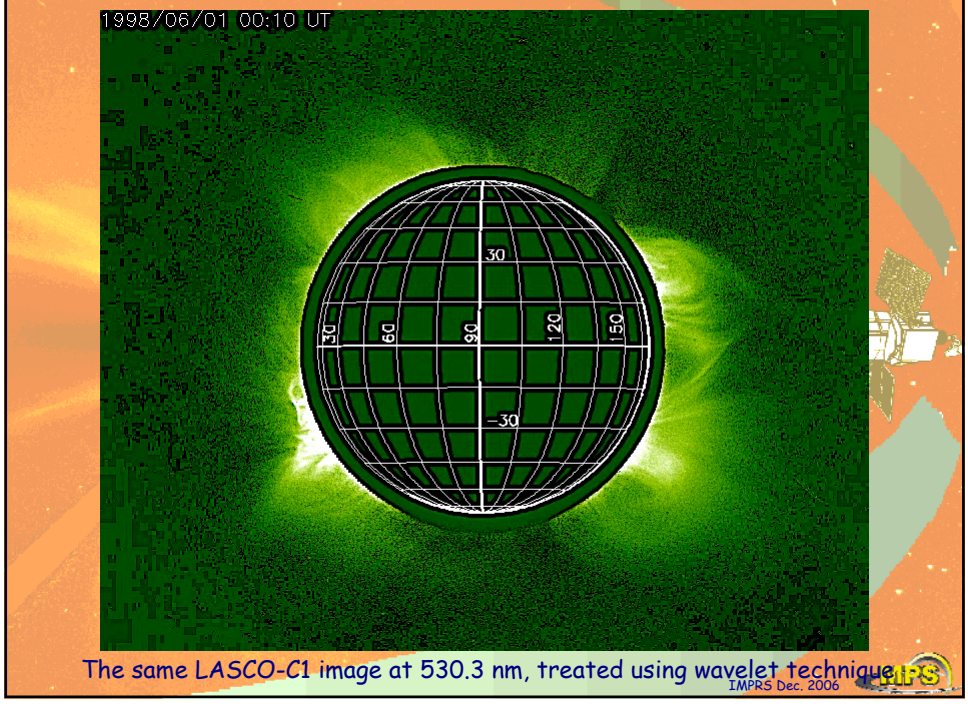
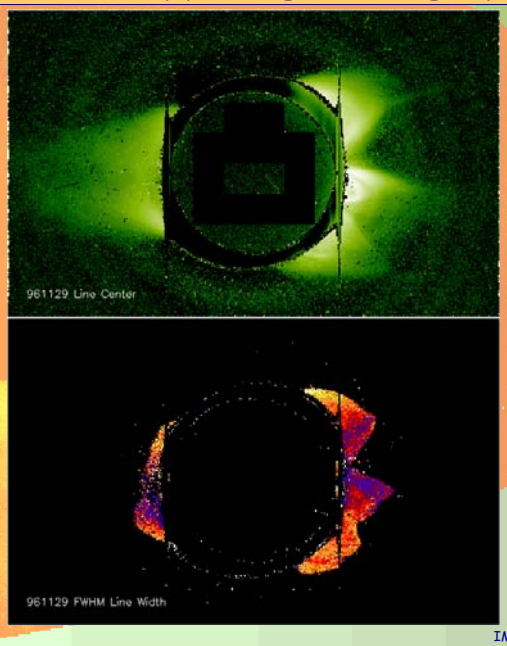


A LASCO-C1 image at 530.3 nm, unprocessed



The same LASCO-C1 image at 530.3 nm, treated using wavelet technique

Spectroscopy using coronagraphs

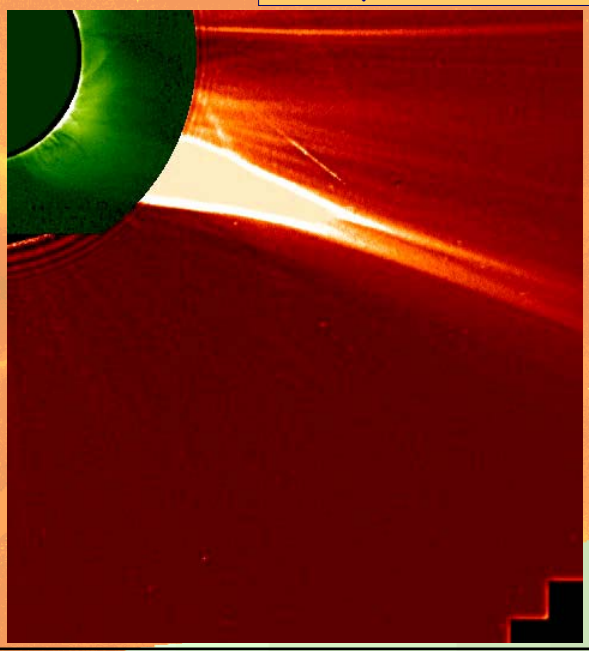


Intensity of green line

Linewidth of green line

LASCO-C1

Multiple instruments



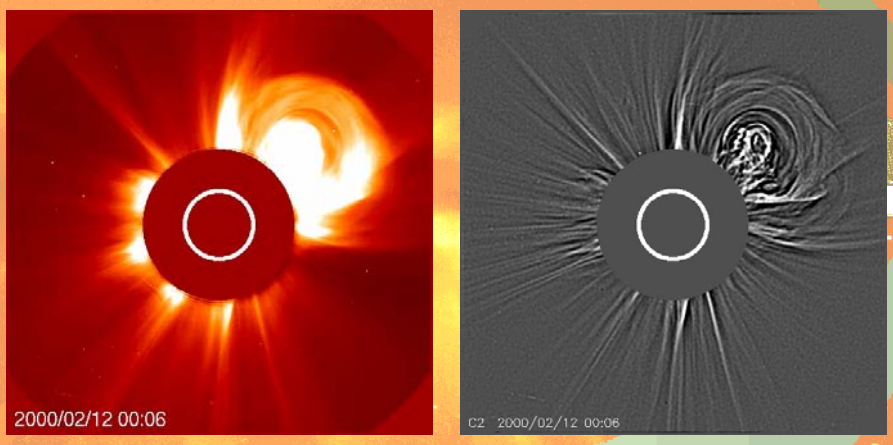
Covering the huge dynamical range in the corona

The big CME of June 2nd, 1998

Green: LASCO-C1
Red: LASCO-C2

Modern image processing!

LASCO-C2



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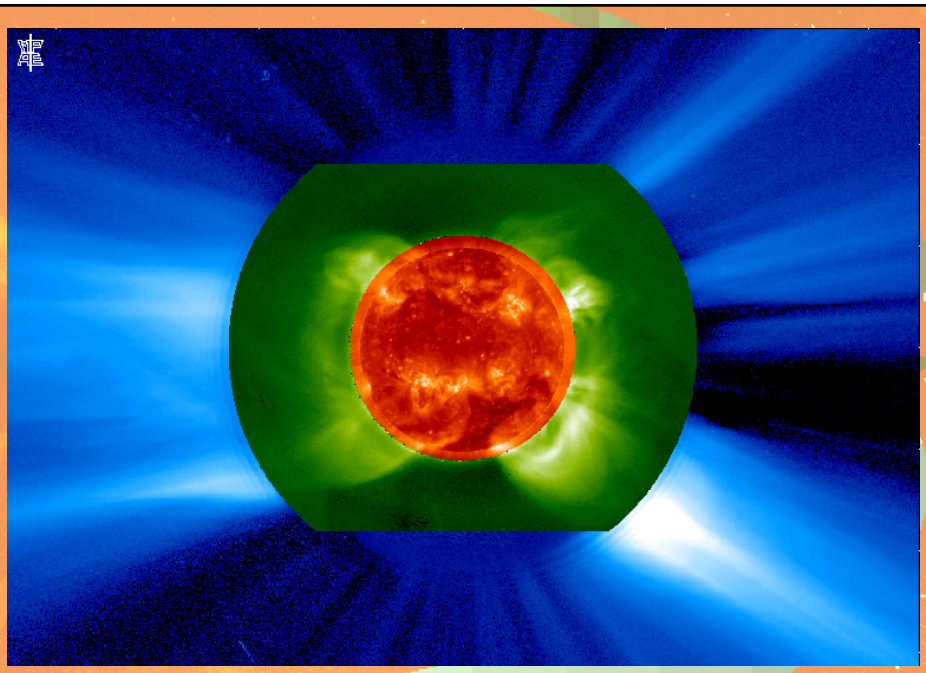

Red: EIT 19.5nm, green: LASCO-C1, 530.3 nm, blue: LASCO-C2, white light

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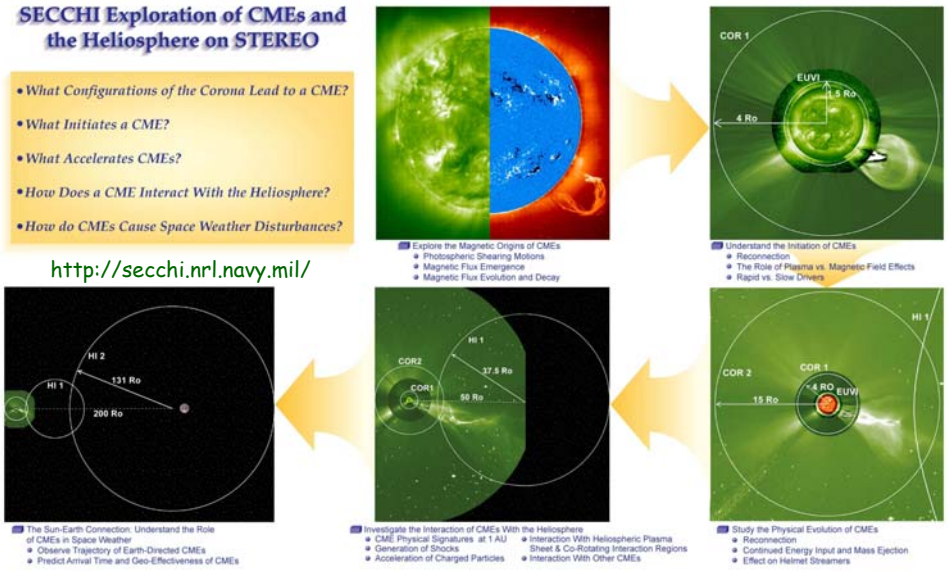
The future is beginning now: STEREO

SECCHI Exploration of CMEs and the Heliosphere on STEREO

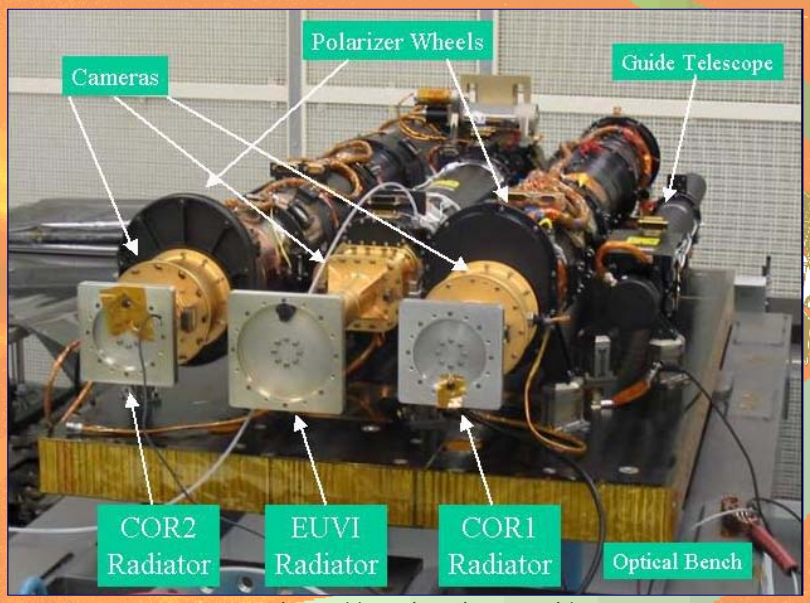
- *What Configurations of the Corona Lead to a CME?*
- *What Initiates a CME?*
- *What Accelerates CMEs?*
- *How Does a CME Interact With the Heliosphere?*
- *How do CMEs Cause Space Weather Disturbances?*

http://secchi.nrl.navy.mil/



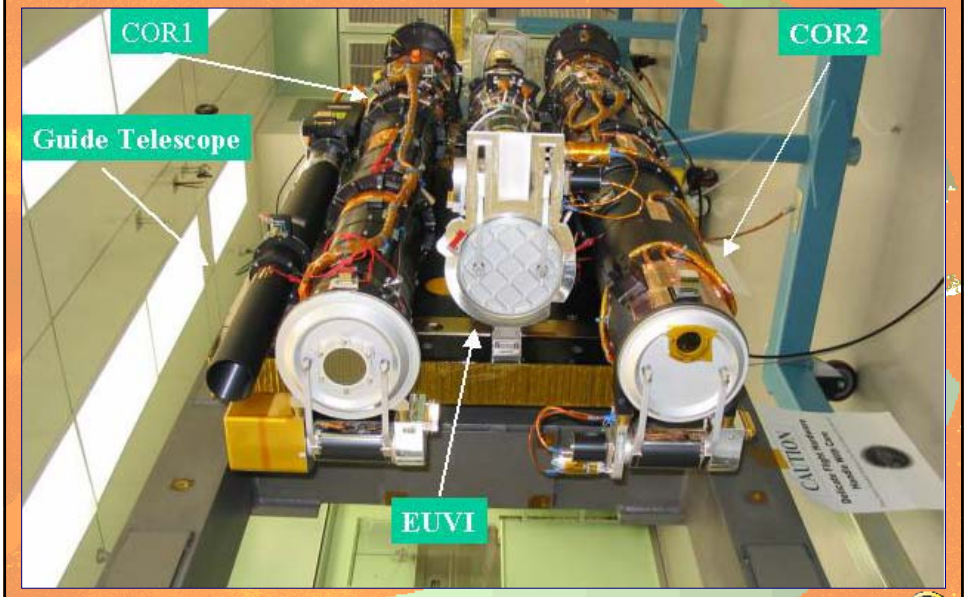
http://www.nasa.gov/mission_pages/stereo/main/index.html

SECCHI on STEREO



http://secchi.nrl.navy.mil/

SECCHI on STEREO



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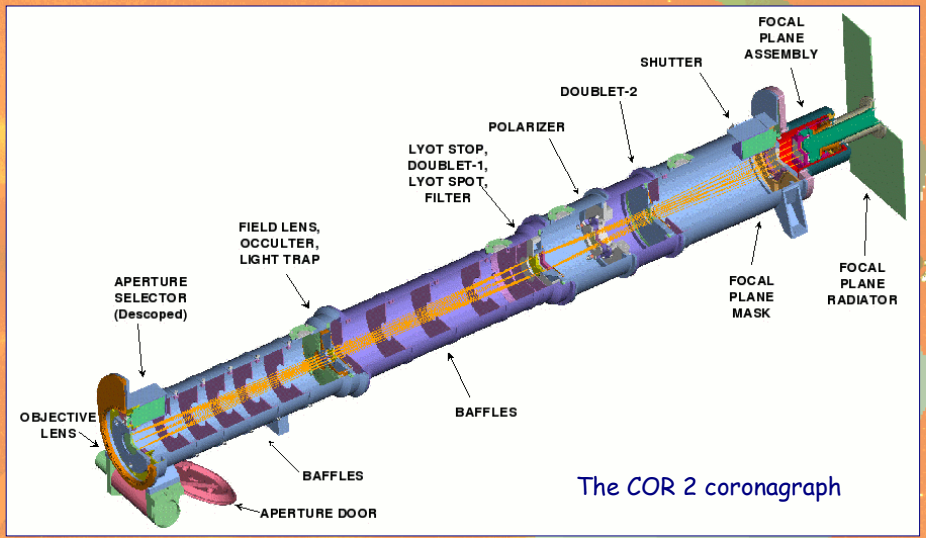
SECCHI on STEREO



The COR 2 coronagraph

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SECCHI on STEREO

The heliospheric imager HI

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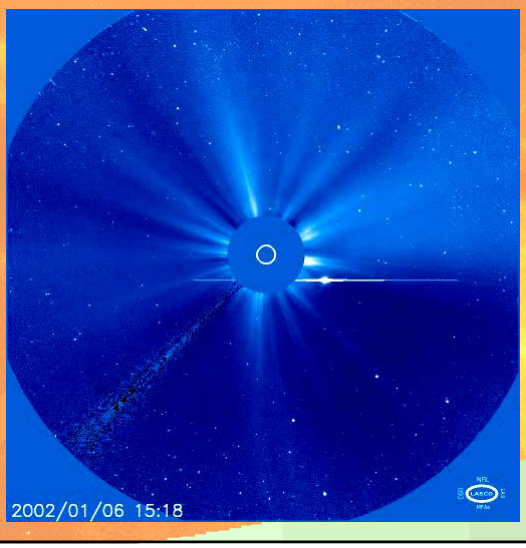
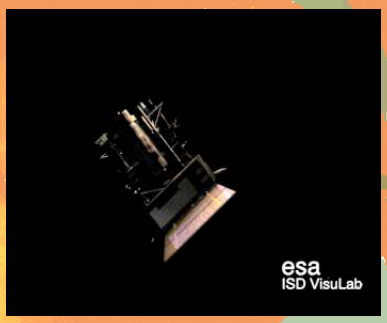
Space Instrumentation: Coronagraphs

Lecture for the IMPRS, December 5, 2006, at MPS Lindau

given by Rainer Schwenn
schwenn@mps.mpg.de





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