MICA

Objectives

- ***Morphology of the Emission Line Corona***
- ***Triggering and Initial Evolution of Dynamical Events***

What do we need?

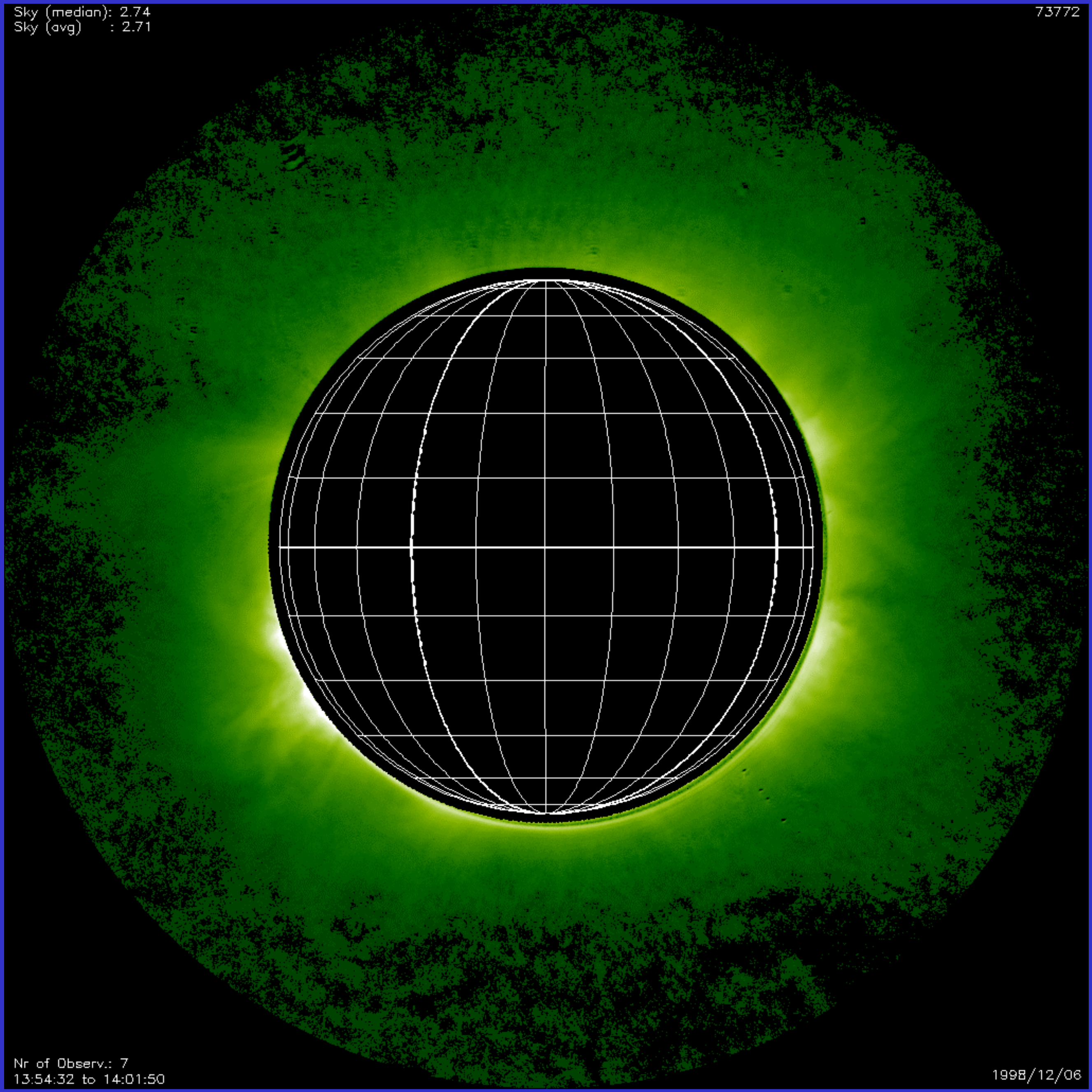
- ***Coronagraphy*** - lens vs mirror coronagraphs
  - internally vs externally occulted

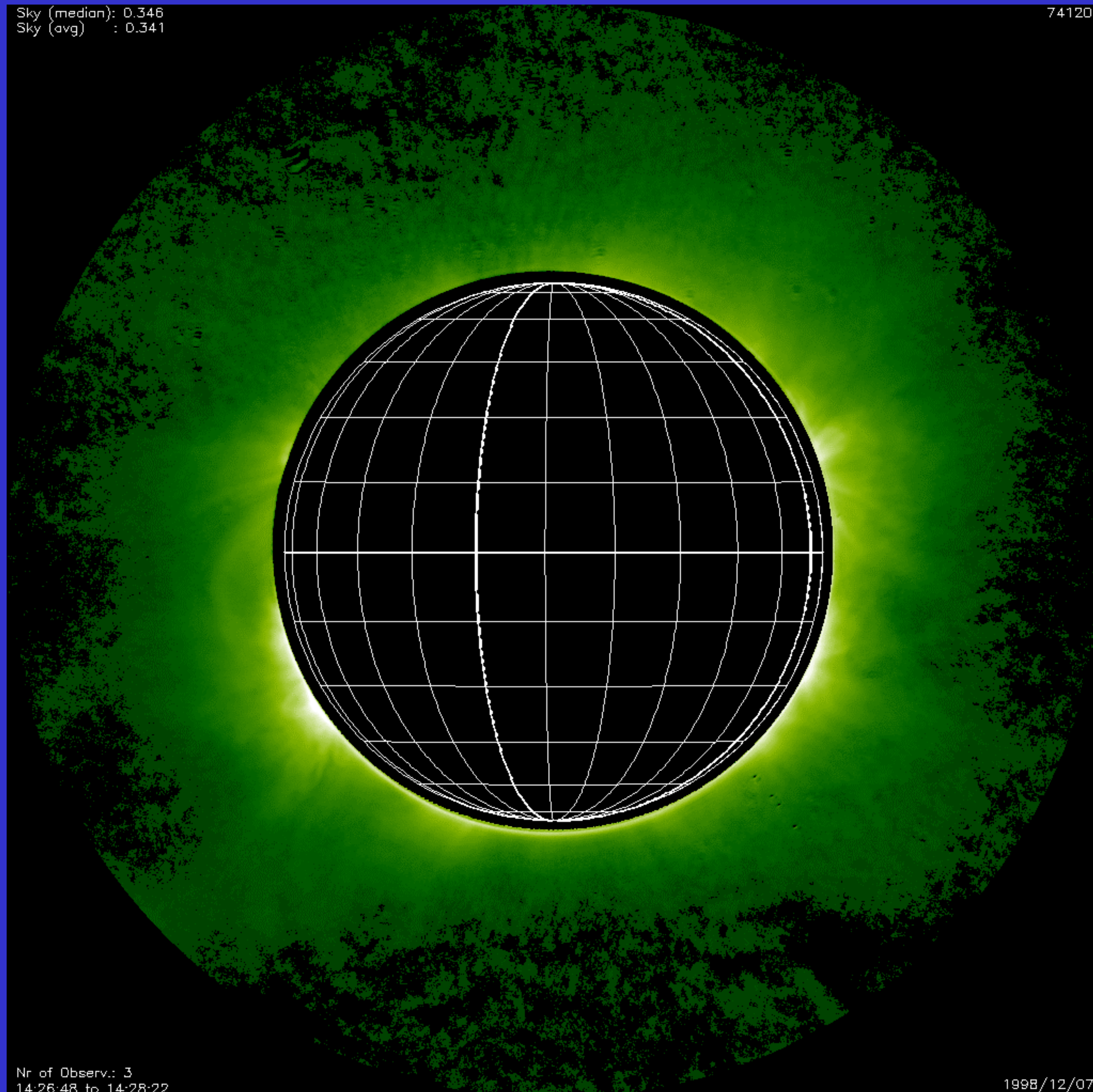
What is MICA?

- ***MICA as an internally occulted mirror coronagraph***
  - Instrument Layout
  - Technical specifications → Filters background
    → Camera background

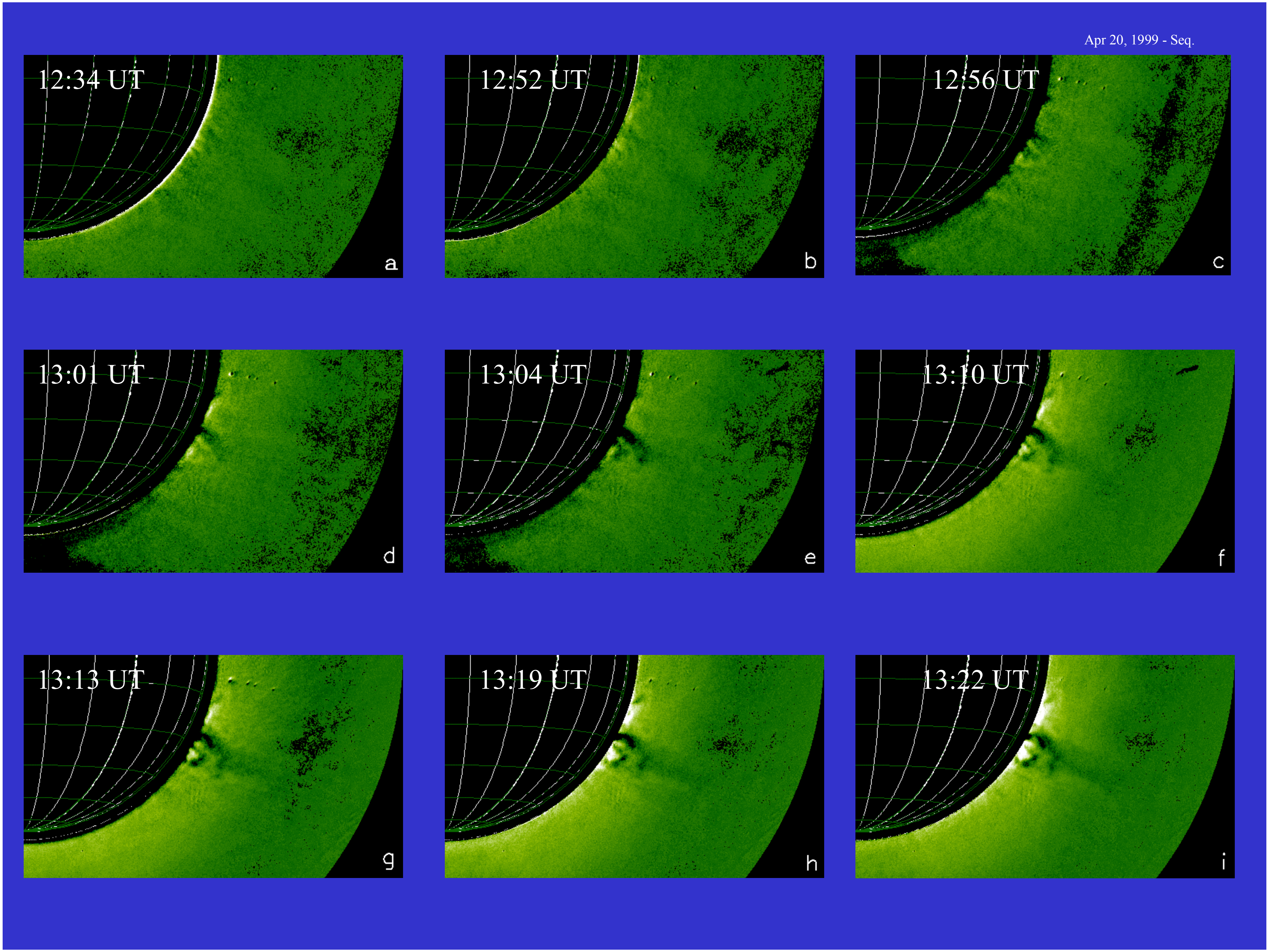
How does MICA work?

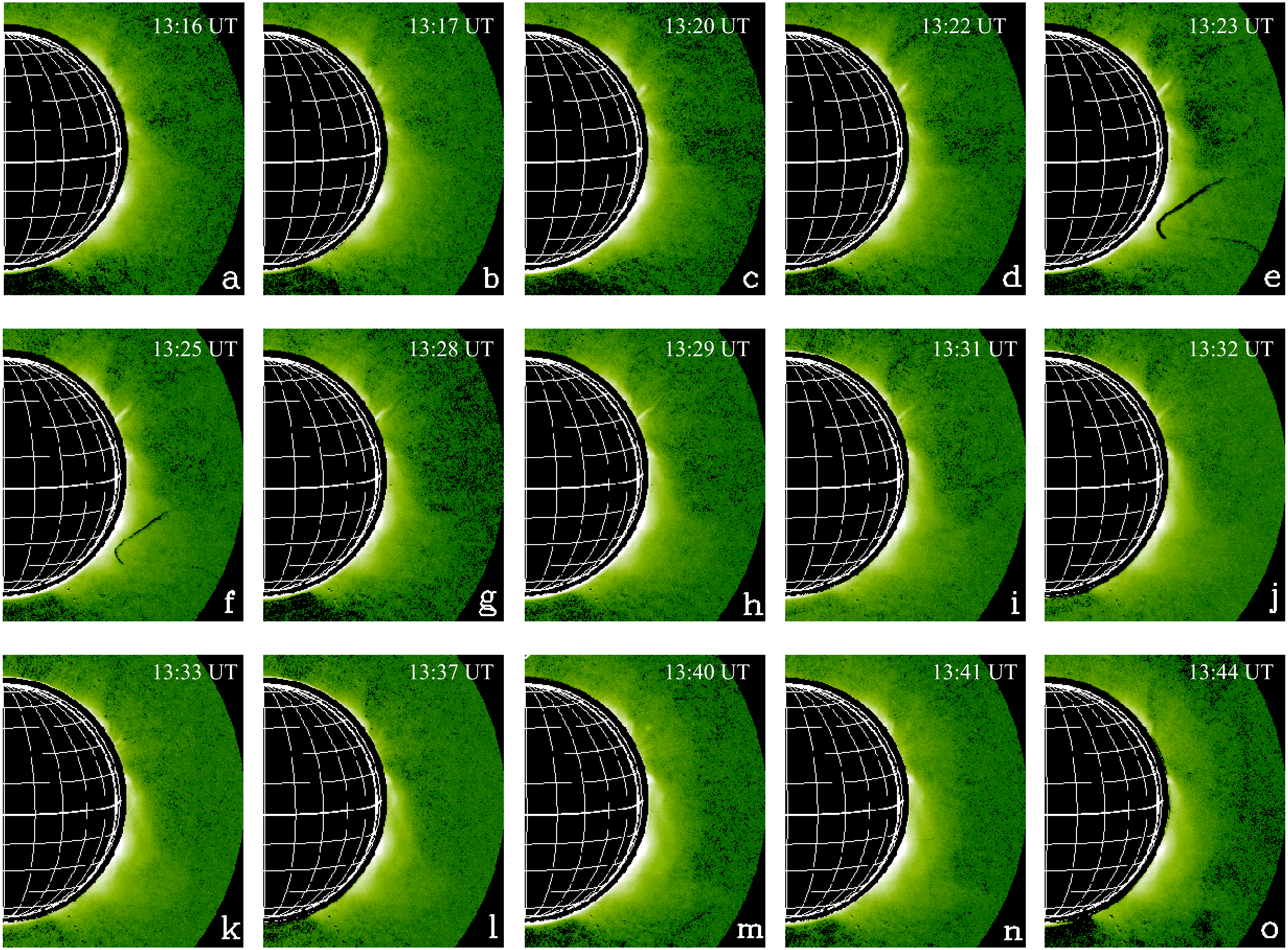
- ***Observation technique*** → Narrow band imagery
- ***Auxiliary Devices***


Sky (median): 2.74
Sky (avg) : 2.71
73772
Nr of Observ.: 7
13:54:32 to 14:01:50
1998/12/06



Sky (median): 0.346
Sky (avg) : 0.341
74120
Nr of Observ.: 3
14:26:48 to 14:28:22
1998/12/07


Apr 20, 1999 - Seq.
12:34 UT
a
12:52 UT
b
12:56 UT
c
13:01 UT
d
13:04 UT
e
13:10 UT
f
13:13 UT
g
13:19 UT
h
13:22 UT
i


13:16 UT
a
13:17 UT
b
13:20 UT
c
13:22 UT
d
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j
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k
13:37 UT
l
13:40 UT
m
13:41 UT
n
13:44 UT
o

The solar corona: Four different components

The K-corona (kontinuerliches Spektrum)

- *White light from the photosphere scattered on free electrons in the partly ionized corona*
- *Absence of Fraunhofer absorption lines (high electron temperature: Doppler-smear-out)*
- *Intensity proportional to electron density (summed up along line of sight)*
- *Strongly polarized, parallel to solar limb*

The F-corona

- *White light from the photosphere, scattered on dust particles*
- *Continuum spectrum like in the photospeheric one, including Fraunhofer lines*
- *Very low degree of polarization*
- *Also known as Zodiacal light*

The T-corona (thermal corona)

- *Thermal radiation of heated dust particles*
- *Continuous infrared spectrum, according to temperature of dust particles*
- *Barely visible*

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 (green line)*
- *Many lines in UV and EUV spectral ranges, e.g., FeXII (19.5 nm), FeXV (28.4 nm)*
- *Strong radial gradients*
- *Many forbidden lines, therefore various polarization states*

The high ionization state of emitting species reveals the high temperature of the emission corona.

Knowledge of the observational characteristics of the different corona components

↓

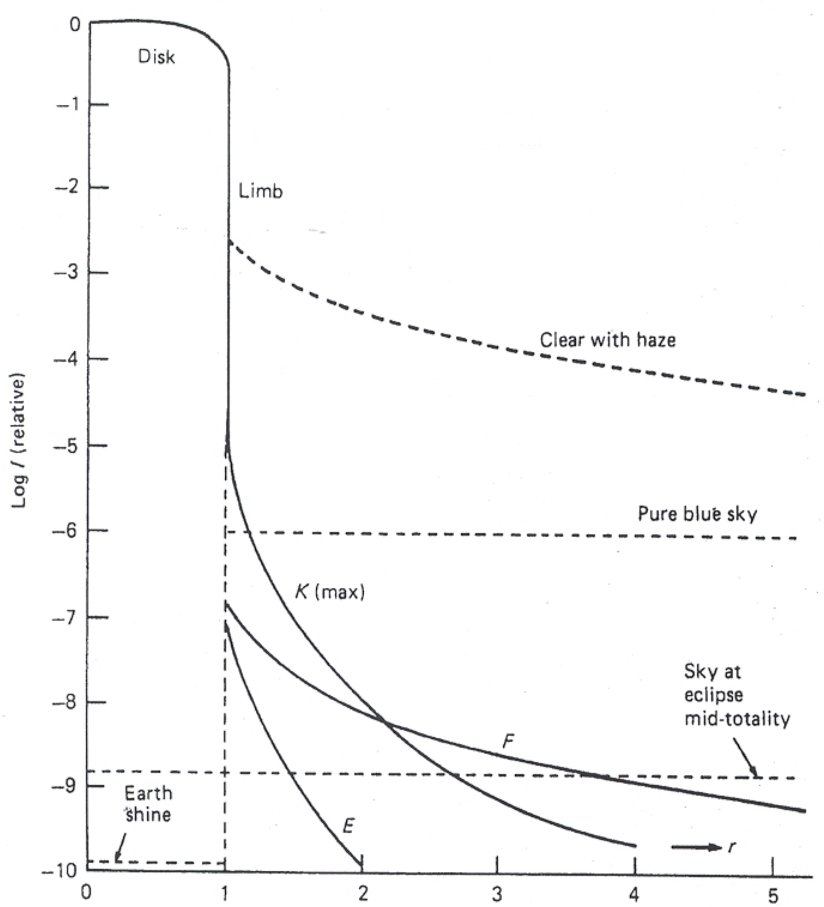
Understanding of the physical mechanisms responsible of the emission

↓

Separation of the components

Polarizers → *Isolation of the K-corona.*

Narrow band filters
\+
Background subtraction techniques → *Isolation emission lines*



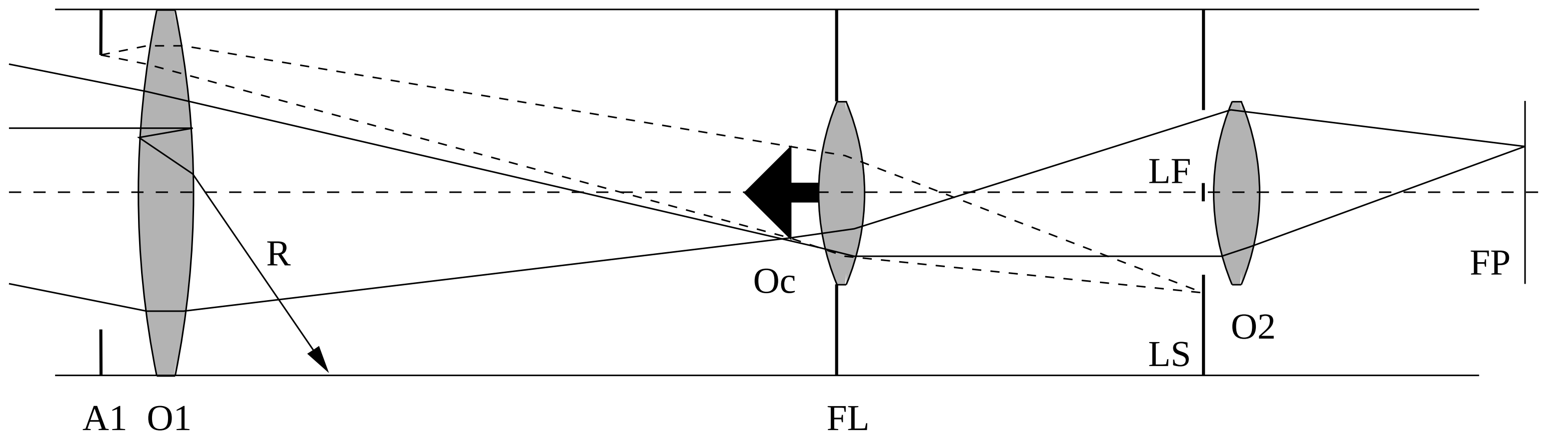
E: *Emission Line Corona*

F: *Fraunhofer Corona*

K: *Continuum ("white light") Corona*

Relative intensity of the coronal light components and the sky as function of solar distance (in solar radii). The relative intensity is normalized to the intensity at the center of the solar disk.
After van der Hulst, 1953.

Lyot refractive internally occulted coronagraph



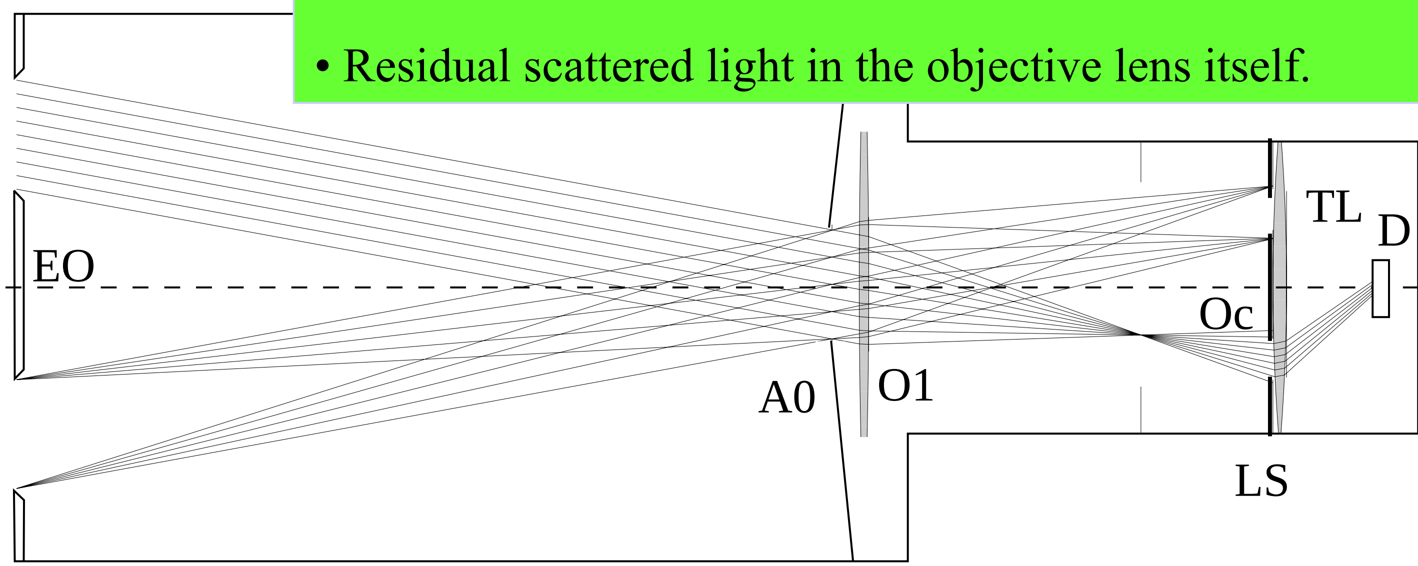
A1: *entrance aperture*
O1: *objective lens*
Oc: *internal occulter,*
FL: *field lens*
LS: *Lyot stop*
LF: *Lyot spot*
O2: *transfer lens*
FP: *focal plane.*

The solid lines show the rays coming from a point in the inner corona. The dashed line indicates the path of the diffracted light at the edges of the entrance aperture. Internal reflections in the objective lens are denoted with the letter R.

Lyot observed that each optical element or edge illuminated by solar radiation gave a contribution to the stray-light level of the coronagraph.

Refractive externally occulted coronagraph
(Sky tester)

- Diffracted sunlight from the edge of the external occulting disk
- Residual scattered light in the objective lens itself.



E0: *external occulter*
A0: *entrance aperture*
O1: *objective lens*
Oc: *internal occulter*
LS: *Lyot stop*
TL: *telelens*
D: *detector (focal plane)*

Constraints

Refractive optics

- ***Residual scattered light*** in the objective lens itself.

- Monochromatic and ***chromatic*** aberration at the position of the internal occulter.

  ↓

  Optimum size and position along the optical axis of the image of the external occulting disk is wavelength dependent.

- ***Aperture limitation*** due to the problem of producing large diameter slabs of glass of requisite quality for the primary objective.

Examples externally occulted refractive coronagraphs

- **LASCO-C2 and C3** onboard SOHO
  Brueckner et al., 1995

External occulter

- ***Vignetting:*** Spatial resolution strongly degraded at the inner edge of the field of view.
  → Degradation roughly proportional to the vignetting effect in the radial direction.

- ***Spatial resolution:***

Example 1
Example 2

Diffraction limit

→ *Inner fov*: set by the distance and size of the external occulter.

→ *Outer fov*: set by the effective aperture of the objective lens: $sin\theta = 1.22\lambda / D$ or size of detecting elements.

> Dimensional constraints impede to build sufficiently long externally occulted coronagraphs to observe the innermost corona with high spatial resolution.

Solutions

Refractive optics → *Reflective optics*

- Instrumental stray-light can be considerably reduced by the use of reflective optics (Newkirk & Bohlin, 1963).

  Unlike lenses, mirrors have no problems with bulk scatter or multiple internal reflections.

- No chromatic aberration at the occulter.
- Large apertures are feasible.

External occulter → *Internal occulter*

- No vignetting
  - → Full resolution over the entire field.
  - → Field of view: closer to the limb
- Diffraction limit
  - → Effective aperture of the objective.
  - → Size of detecting element (pixel size).

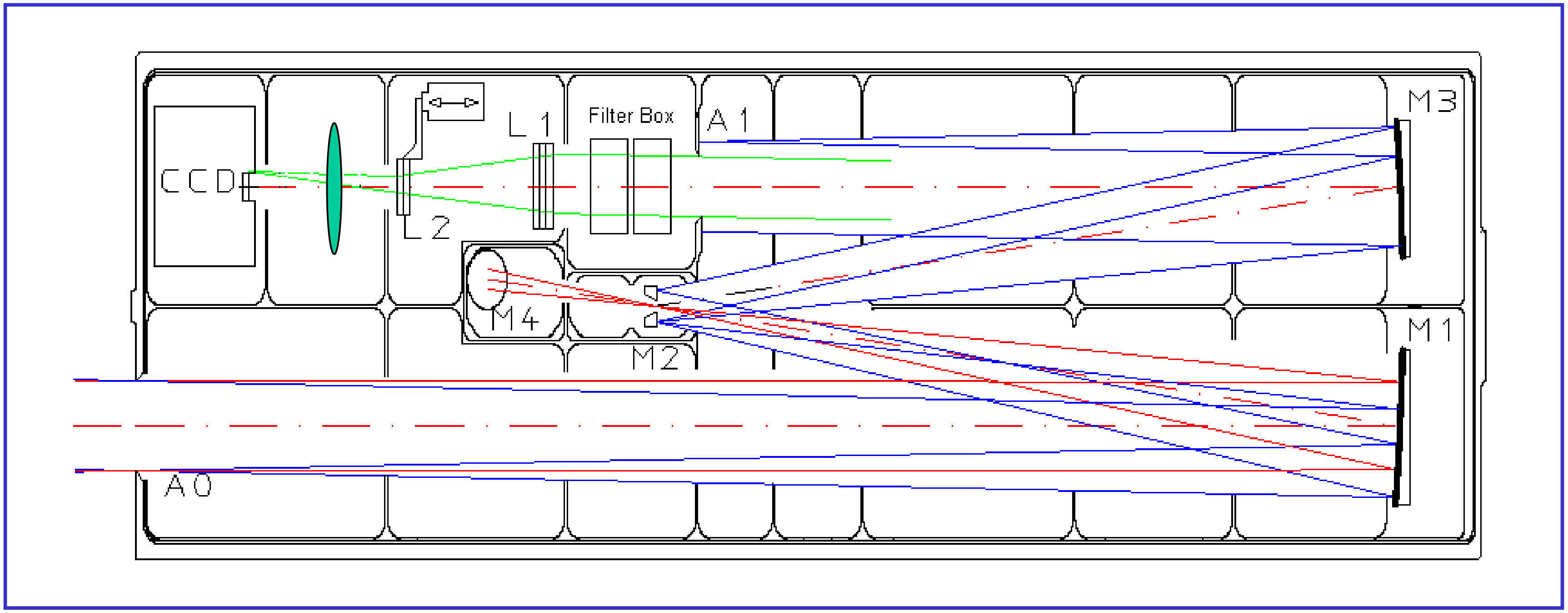
Examples externally occulted mirror coronagraphs

- Bonnet, 1966
- Kohl et al., 1978
- Smartt, 1979

Internally occulted mirror coronagraphs

- **PICO** (Pic Du Midi Coronagraph), Epple & Schwenn, 1994
- **LASCO-C1** Brueckner et al., 1995
- **MICA** (Mirror Coronagraph for Argentina) Stenborg et al., 1999

MICA as an internally occulted mirror coronagraph



Red: *photospheric sun light (solar disk)*

Blue: *diffracted sun light at the edges of A0*

Green: *scattered sun light + coronal light*

instrumental ← ← *K-corona*

in the sky ← ← *E-corona*

MICA Technical Data

Elem.	Type	Aperture (in mm)	Curvature (in mm)	Remarks
A0	Circ. Aperture	59	-	Entrance
M1	Off-axis Parabola	90	FL = 750	Primary Mirror
M2	Convex Sphere	ID=7 OD=20	R = 2422	Occultor
M3	Off-axis Parabola	90	FL = 750	
S	Shutter	40	-	Mechanical
A1	Annular Aperture	ID=38.4	-	Lyot Stop
TL	Telelens		-	
CCD	Camera	16 µ/pxl	-	1280x1024 pxl (~3.8 arcsec/pxl)

Comparison with Lasco-C1

The MICA system is almost identical to the LASCO-C1. However, there are a few differences (LASCO features in parentheses):

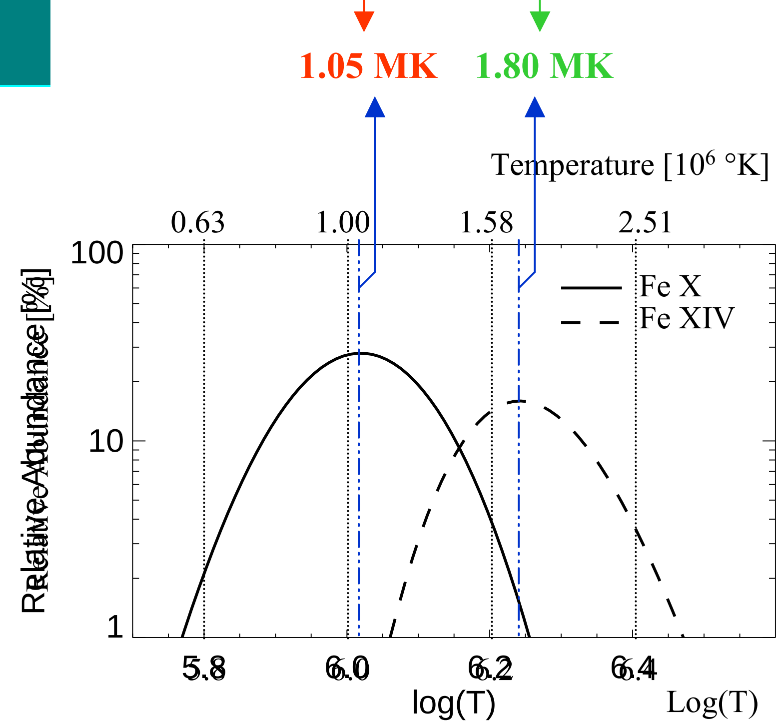
- MICA uses a set of narrow-band interference inserted alternately using a specifically designed mechanism (Fabry-Perot interferometer).
- MICA's field-of-view reachs out to 2.0 solar radii (3.0).
- The inner edge of the field of view is 1.05 solar radii (1.1).
- A pixel in the MICA system subtends 3.7 arc-sec (5.6 arc-sec). Thus, the maximum possible spatial resolution is around 8 arc-sec (~12 arcsec).
- The whole telescope is enclosed in a lightweight thermal canister which maintains thermal stabilization of MICA during operations at all seasons in El Leoncito.
- Two of the newly developed sky and sun “testers” are mounted close to MICA in order to register the sky and solar disk brightness continuously. Their signals are used for the automatic operation of the telescope.

MICA and the driver electronics are protected by a small cupola of 3 m diameter with a removable roof. The control electronics, computers and screens are located at a common control center used also by HASTA. During operations, the presence of an observer right at the MICA site is usually not required.

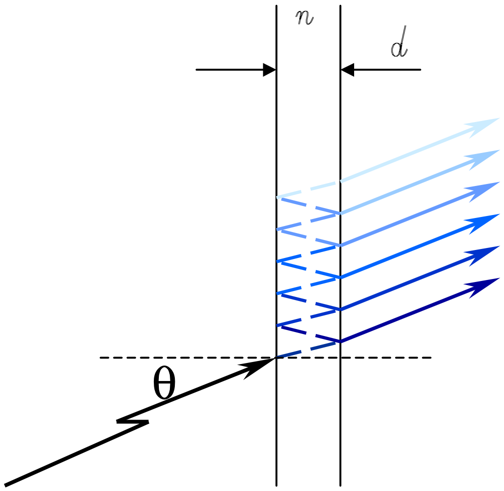
The filters in MICA

	λ (nm)	FWHM (nm)	Max.Trans.	Flatness
Fe XIV (line)	530.3	0.15	52 %	λ/4/45 mm
Fe XIV (cont)	526.0	1	56 %	λ/4/25 mm
Fe X (line)	637.4	0.15	57 %	λ/4/45 mm
Fe X (cont)	634.0	1	36 %	λ/4/25 mm

- ***Model of the continuum at the wavelength of the on-line filter.***
  - - Far from line center, to avoid contamination by emission in the line itself.
  - - Relatively broad passband to be sure that no major emission lines contribute to the measured continuum flux.



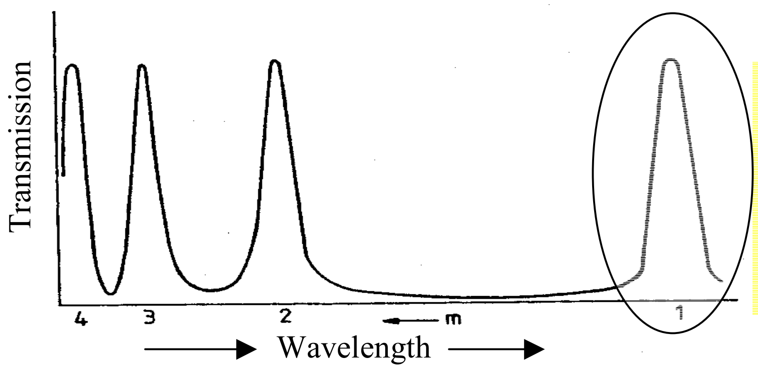
Principle of an interference filter



Multiple reflections between two paralell surfaces

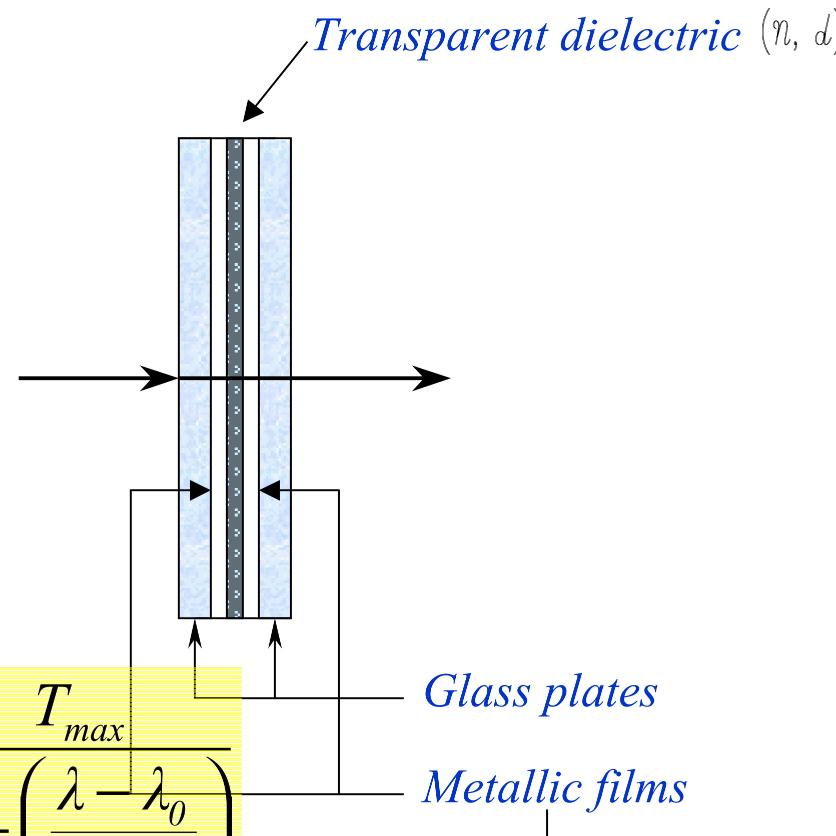
- Maxima at (normal incidence θ = 0)

$$2nd = m\lambda \quad (m = 1, 2, \ldots)$$



- Tilting by θ ==> $\lambda_{m\theta} = \lambda_m \sqrt{1 - \frac{\sin^2(\theta)}{n^2}} \xrightarrow{\theta \to 0} \lambda_{m\theta} - \lambda_0 \approx \frac{\theta^2}{2n^2}$

Practical interference filter used at normal incidence

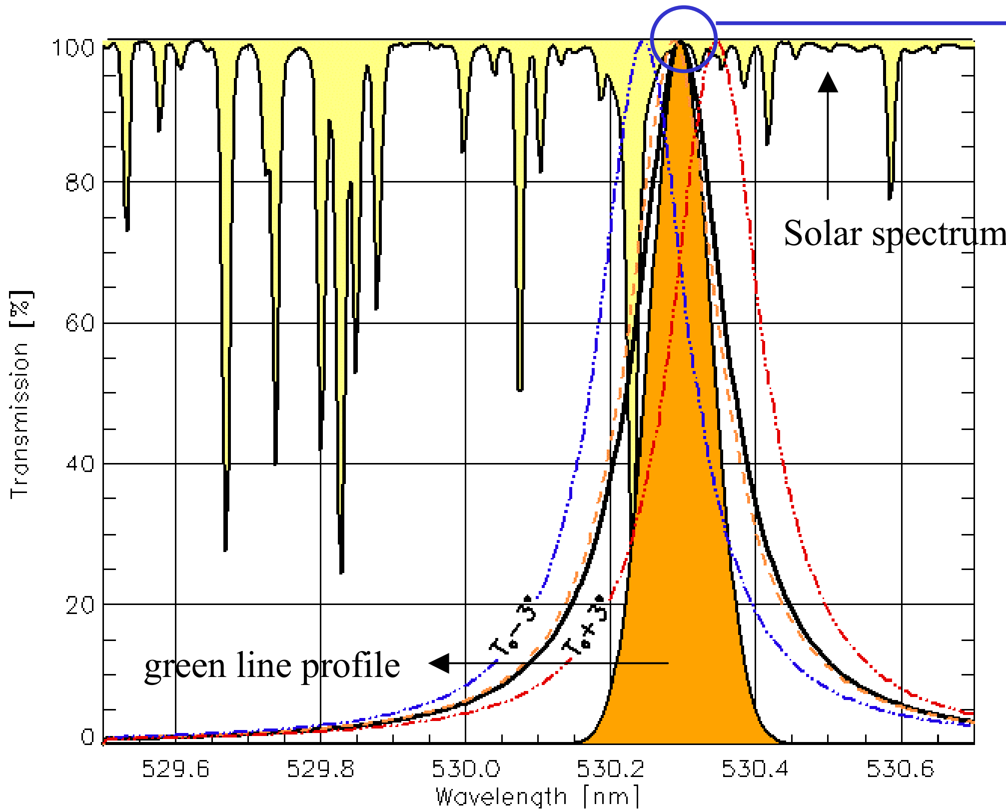


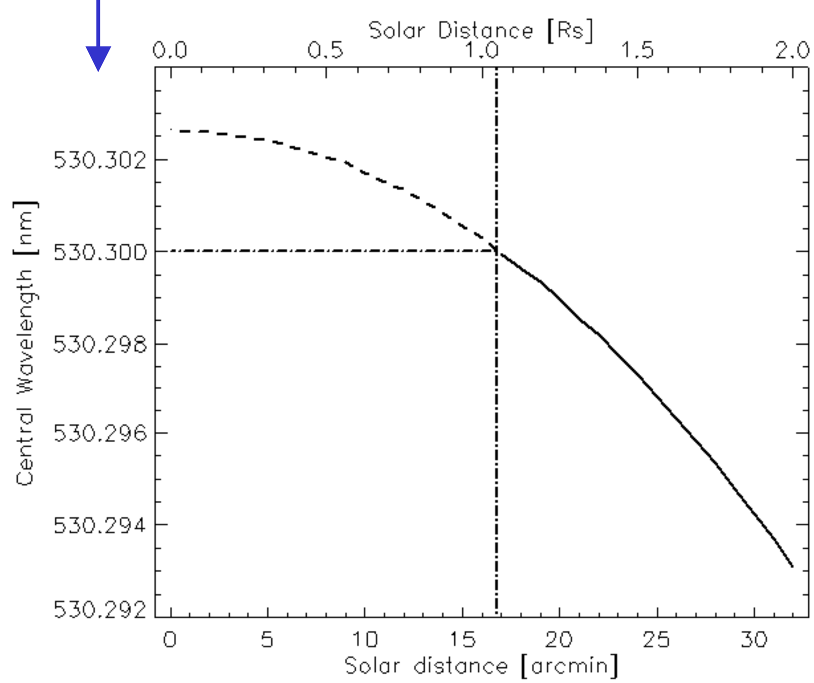
$$T_0 = \frac{T_{max}}{1 + \left(\frac{\lambda - \lambda_0}{\Delta/2}\right)}$$

Reflectivity of the metal films determine width of the maxima

Shifting of the green line filter passband with temperature and solar distance

Filter in the parallel beam
FWHM = 0.15 nm

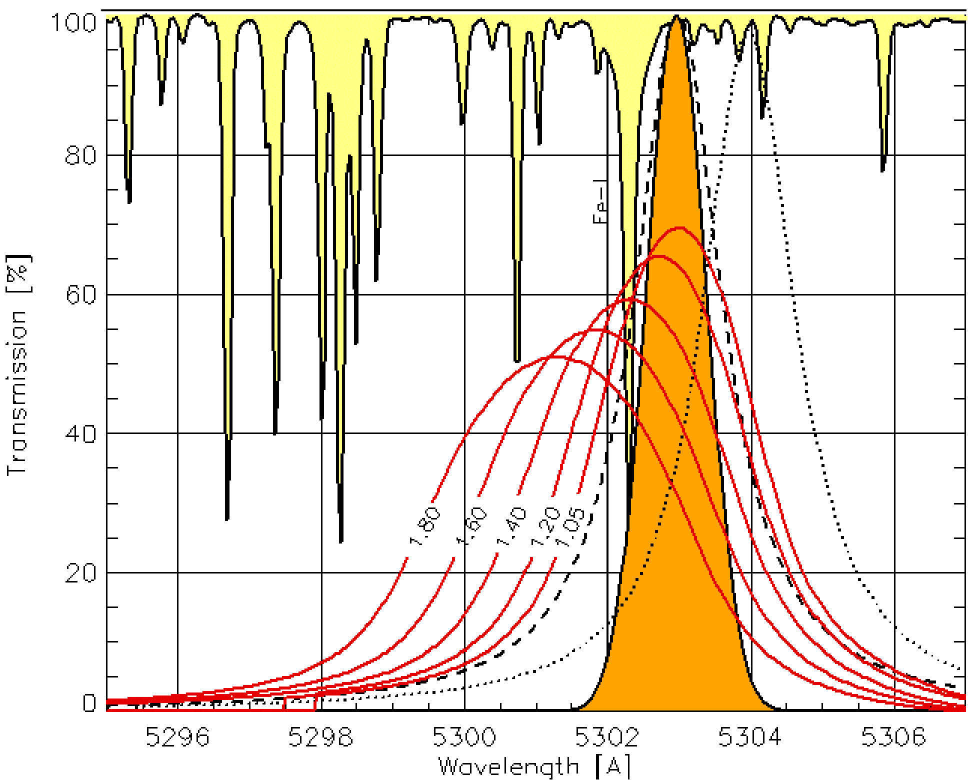




***Solid line (black)**: filter transmission at the temp. where the green line emission close to the limb is observed to be maximum, i.e,* T_0.

***Dashed line (brown)**: filter passband at the edge of the field of view, at the same temperature* T_0.

***Dashed-dotted-dotted line**: filter passband close to the limb at* T_0+3° ***(red)** and* T_0-3° ***(blue)**.*
Temperature coefficient: K_T = 0.0168 nm/°C.



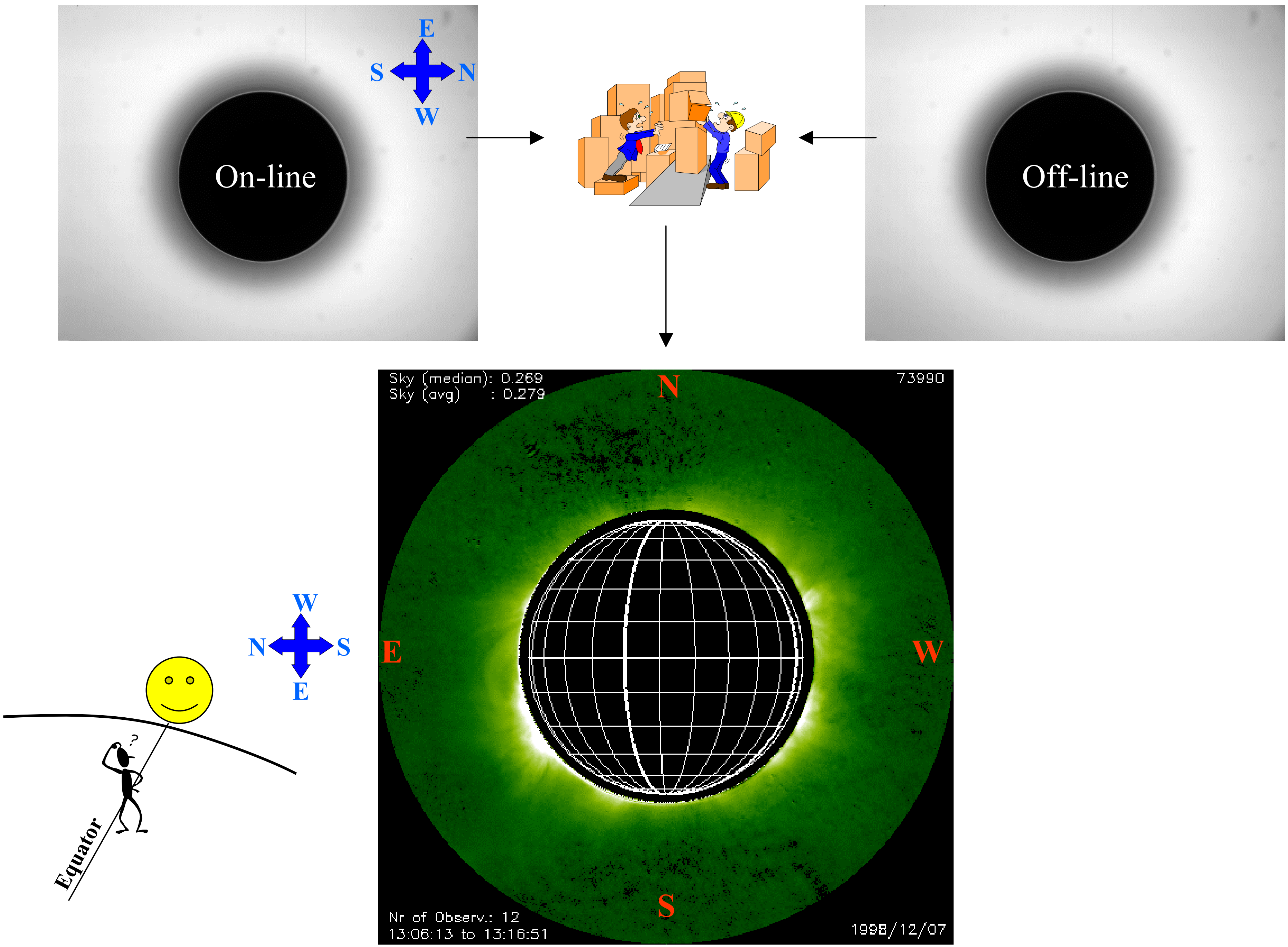
Shifting of the green line filter passband with solar distance

Filter in homocentric beam FWHM = 0.15 nm

*For comparison, the **dashed line (black)** shows the passband of a filter located in the parallel beam.*

***Dotted line (black)**: filter transmission at normal incidence.*

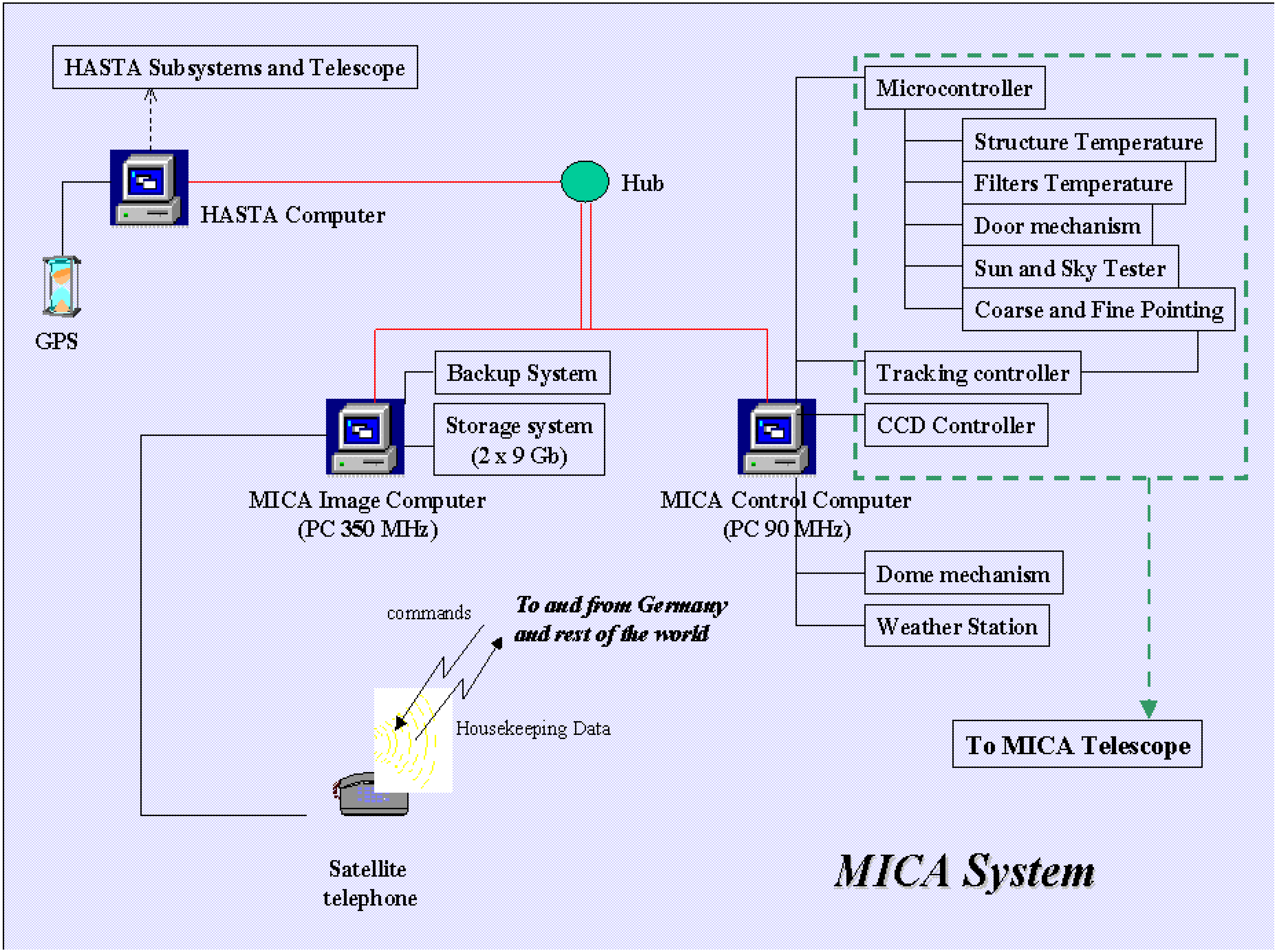
***Solid line (red)**: filter transmission across the field of view.*


E
S
N
W
On-line
Off-line
Sky (median): 0.269
Sky (avg)   : 0.279
73990
N
E
W
S
Nr of Observ.: 12
13:06:13 to 13:16:51
1998/12/07
W
N
S
E
Equator

Some Comments on Image Processing

The unprocessed direct images from MICA show practically no coronal signal. They are affected by the strong radial gradient of the instrumental straylight and the scattered light in the terrestrial atmosphere. Furthermore, the images taken at line center (on-line images) have also an additional contribution from the continuum (or 'white') corona which is due to Thomson scattering of the photospheric light by electrons in the corona. In order to remove the aforementioned contributions from the on-line images and reveal the coronal structures it is then necessary to subtract a nearby continuum image (off-line images) from the on-line ones, taken at a wavelength sufficiently far from line center, i.e., at 5260 Å for the green line, to avoid contamination by emission in the line itself. Both on- and off-line images are bias-corrected and flat-fielded before subtraction. Since the flat-fields are also used for calibration purposes, after 14 images flat-fields for both images are taken. In order to reduce the effects of the sky variability (and also the effects of solar rotation on the structures along the line of sight) it is necessary to obtain the reference continuum images very close in time to the respective on-line images. For the routine observations, the time difference between the on- and off-line images used is not longer than 3 minutes. A detailed description of the calibration procedure will be presented in a dedicated paper.

The processed images are obtained in almost real time, as processed by the so called 'Image Computer'. At the end of the observing day both raw (fits format) and processed images (10 minutes average, gif format) are stored in a DAT system in order to be shipped to MPAe and IAFE monthly.


HASTA Subsystems and Telescope
HASTA Computer
Hub
GPS
Microcontroller
Structure Temperature
Filters Temperature
Door mechanism
Sun and Sky Tester
Coarse and Fine Pointing
Tracking controller
CCD Controller
Backup System
Storage system
(2 x 9 Gb)
MICA Image Computer
(PC 350 MHz)
MICA Control Computer
(PC 90 MHz)
Dome mechanism
Weather Station
commands
To and from Germany
and rest of the world
Housekeeping Data
To MICA Telescope
Satellite
telephone
MICA System

Auxiliary Instruments

- **Sky Tester**

  It measures the brightness of the sky around the sun disk (aureola). Very sensitive to the clouds. The lower the value recorded by this instrument, the better the quality of the sky (provided no thick clouds cover the Sun. In that case the Sun Tester allows distinguishing between both cases).

- **Sun Tester**

  It measures the intensity of the sun disc. The higher this value, the more intense the brightness of the disc.

Measurements of the aforementioned intensities are made every 5 seconds in average. These values are then used by the control software of the telescope (in conjunction with the wind speed as obtained by a weather station) to automatically decide whether the conditions are good for coronal observations. The program which controls the instrument decides in this way, whether it is allowed to start the observation routine or if it should be stopped (in case of being observing).

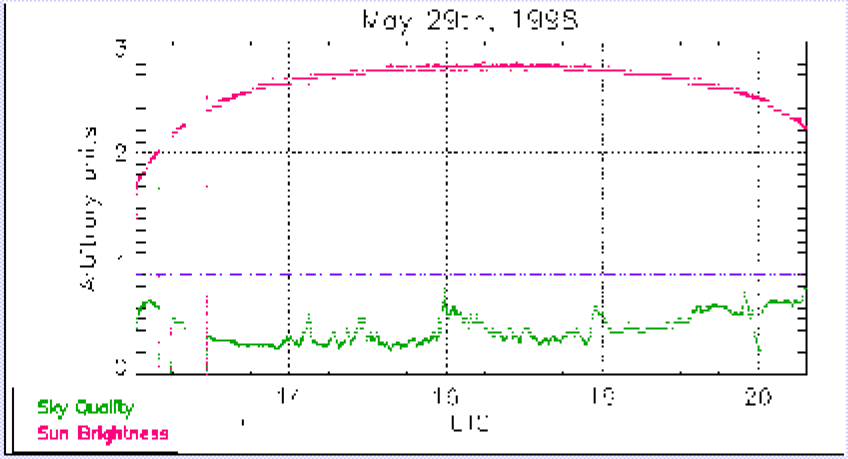
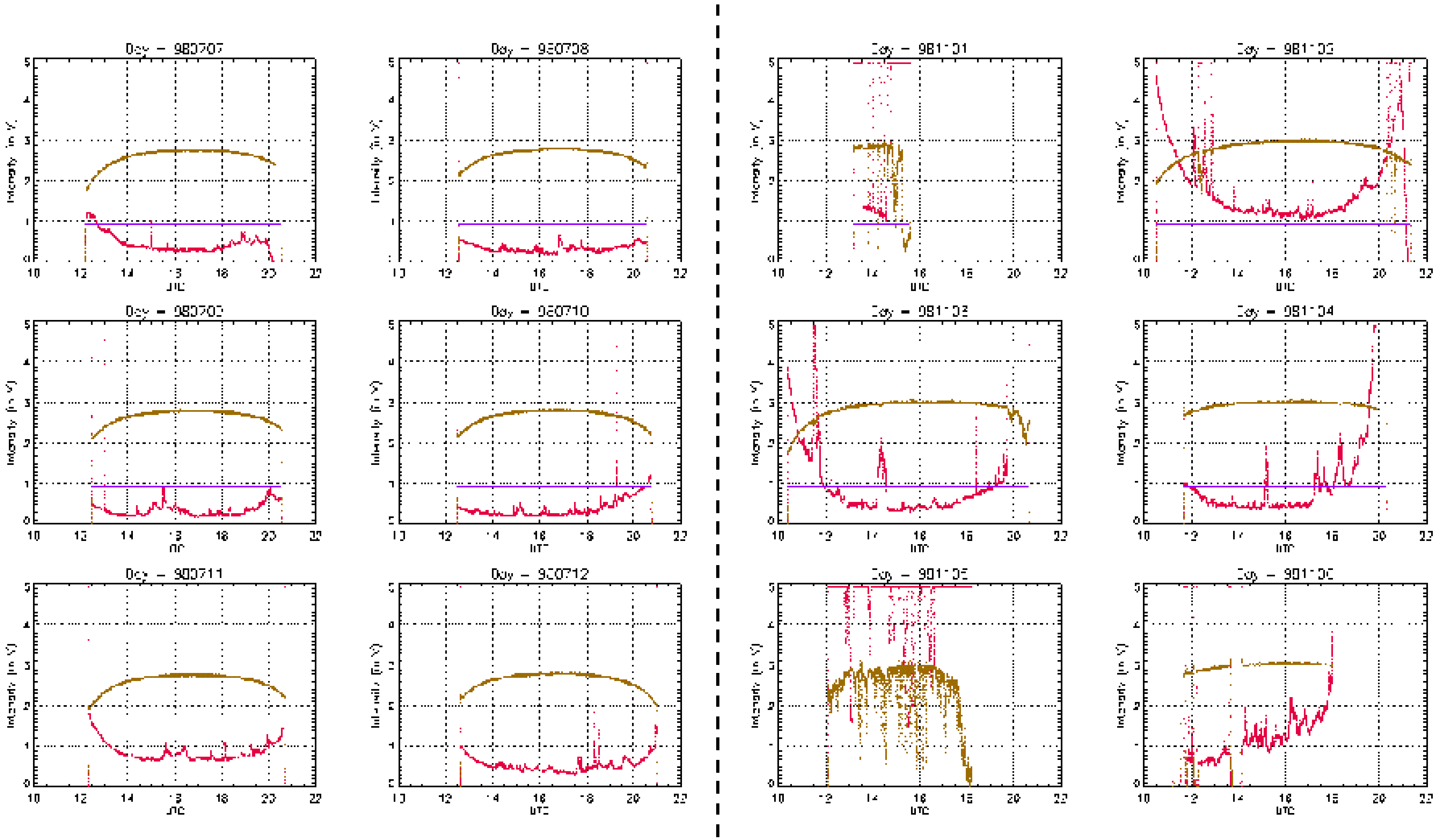


Figure 2: *Example of intensities recorded by the sky and sun tester. The dashed line correspond to the threshol for the sky intensity.*



Examples of Sky quality (red) and Sun brightness (brown) as measured by sky and sun tester respectively
When the sky intensity is below the lila line and the sun brightness is above 2, the instrument observes.
When the these both conditions are not fulfilled, it automatically stops and waits until the conditions are good again to resume operations.

That's it !!

The ***diffraction limit*** *is the minimum angular separation that two different sources must have in order to be resolved by the telescope.*

Chromatic aberration occurs due to the variation of refractive index with wavelength for a lens material. This wavelength dependence results in slightly different focal lengths for different wavelengths of light. Therefore, the lens produces a coloured blurring rather than a true color, sharply focussed image.

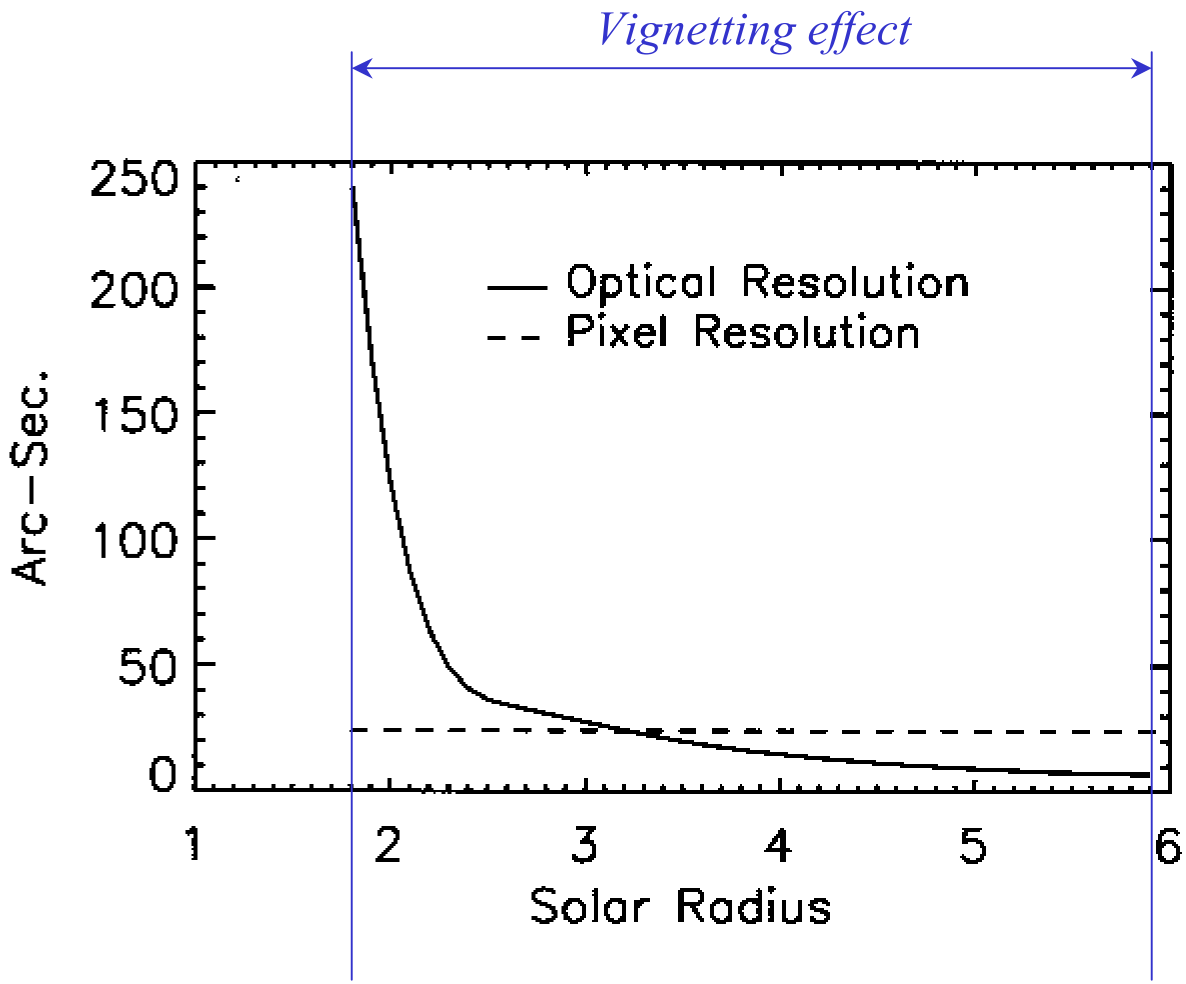


Fig. 5. Optical and pixel resolution of C2. (Pixel resolution is equivalent to the size of two pixels.)

*Brueckner et al., 1995. (Sol. Phys., **162**, 357)*

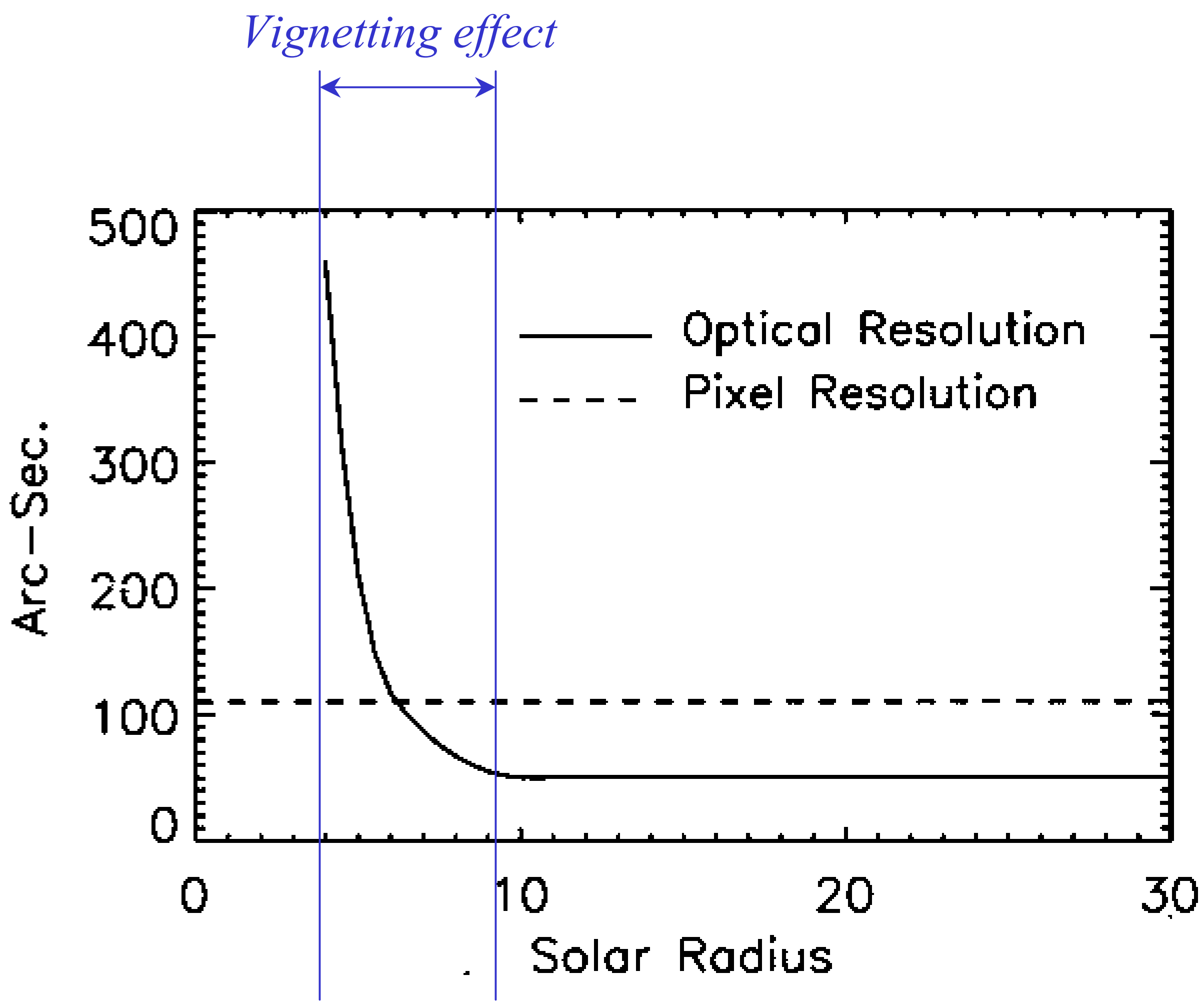


Fig. 6. Optical and pixel resolution of C3. (Pixel resolution is equivalent to the size of two pixels.)

*Brueckner et al., 1995. (Sol. Phys., **162**, 357)*

Construction of a typical filter

- *Glass plates: no role. Mechanical support for the filter.*

- *Surface of one plate coated with:*
  - *a thin evaporated film of high reflectivity,*
  - *a thin layer of a transparent dielectric, and*
  - *another metal film.*

- *The other plate is added for protection.*