THE PICARD MISSION

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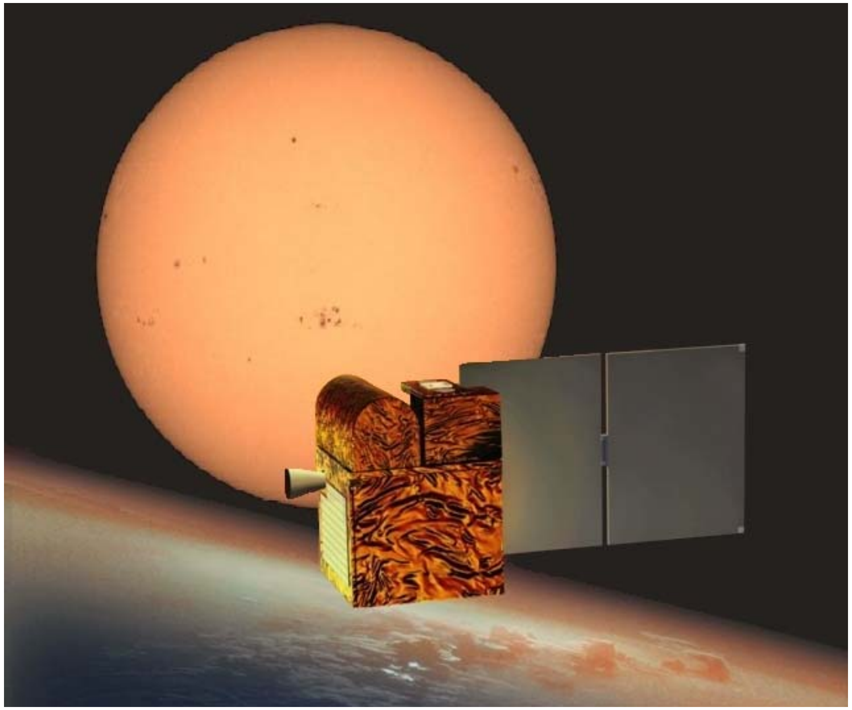
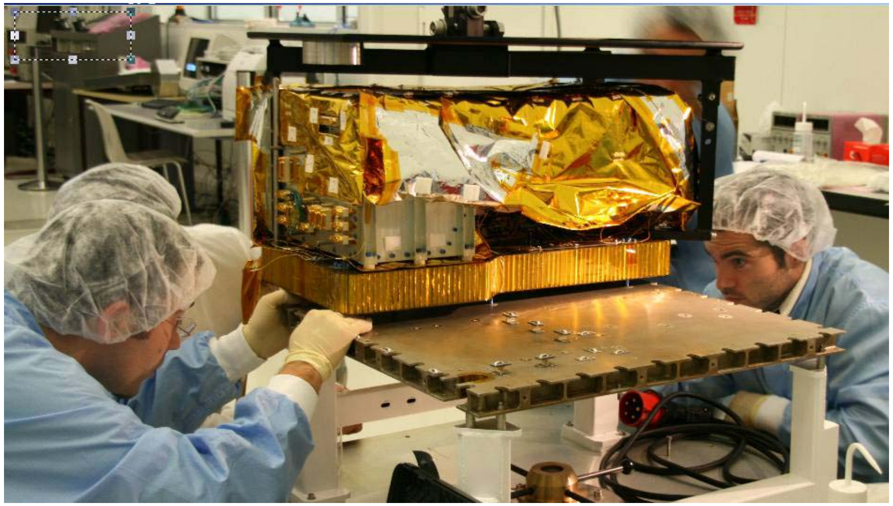
Service d'Aéronomie du CNRS

and The PICARD Team

Nice, 3 December 2008

PICARD is a CNES led satellite mission to simultaneously measure key parameters necessary to understand the origin of the solar activity and its links with the Earth's climate.





OUTLINE

- BACKGROUND

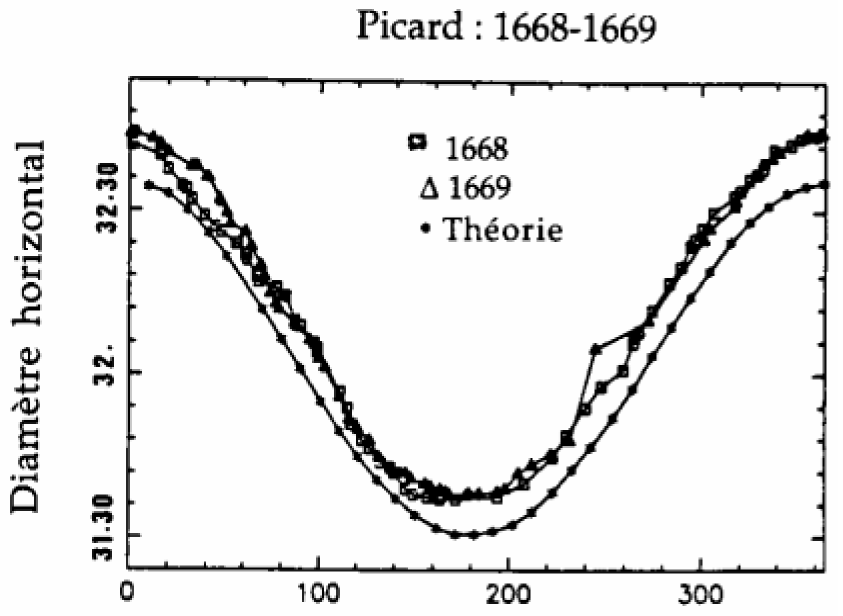
- MISSION SCIENTIFIC OBJECTIVES

- INSTRUMENTS

- MEASUREMENTS

- PRESENT STATUS OF DEVELOMENT

THE PICARD MISSION GENESIS



day

Jean PICARD (1620-1682), a French astronomer measured the solar diameter as a function of the day of the year to determine the Earth'orbit eccentricity.

Ribes (1987) processed the data at one A.U. It appeared that the Sun was slightly bigger than today!

Furthermore, these measurements were made during the Maunder minimum, for which the TSI was lower than today. These two results opened an active debate about the anti correlation between diameter and luminosity.

After 20 years, this question remains open!!!

THE PICARD mission

SA (F)
IRMB (B)
PMOD (Ch)

OCA
Obs. Meudon
Nice University
IAS
LMD
DAPNIA-CEA

Jean PICARD (1620 - 1682)

Yale University
HAO
GSFC
JPL
NRL
CSA
Valencia U

ILWS

FUNDAMENTAL SOLAR INPUTS

Parameters that are key constraints for validating the physics of solar interior models:

- Solar diameter, limb shape, asphericity in the photosphere
- Total solar irradiance (TSI)
- Oscillation modes
- Temperature
- Solar spectrum

and their variability

CURRENT SITUATION OF THE SOLAR MEASUREMENTS

Among the previous quantities, the solar diameter is the least reliable.

Several reasons may explain the discrepancies:

- Measurements on the ground, which contain the effect of the Earth's atmosphere.

- Instrumental effects (sampling, psf, wavelength domain…)

- Data processing (filtering effect)

SOLAR DIAMETERS

Photospheric diameter:

defined by the inflection point position of the limb shape determined by optical instruments.

Seismic diameter:

Determined from frequency oscillation modes by adjusting the solar radius to minimize the model/measurements difference (Antia et al. 1998). It is model dependent and corresponds to a region below the photosphere depending of l.

RESULTS FROM GROUND OBSERVATIONS

There are several optical methods (Mercury transits in front the Sun, solar eclipses, astrolabes, imaging telescopes) showing :

- in phase, or anti phase with the 11-year solar cycle, or none variation.

To explain the discrepancies, the role of the atmosphere is considered, however to which extend?

Given that the ground based observations constitute the longest series, within the variations, what part is of solar origin?

RESULTS FROM SPACE

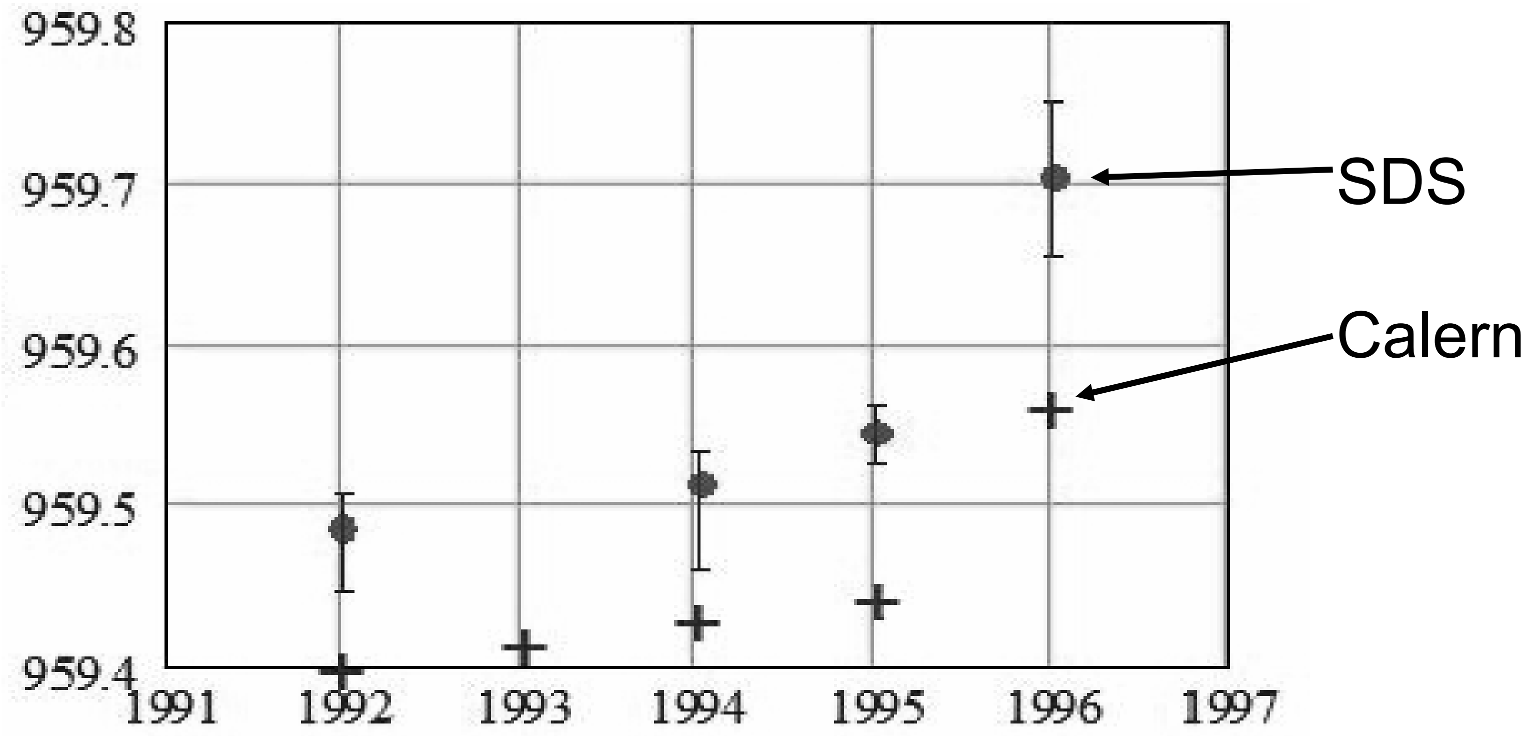
MDI/SoHO images have been used to determine the radius variation as a function of time. The recent results show a maximum change of 15 mas from 1995 to 2004 (Kuhn et al., 2004).

MDI has no internal means to check the instrument angular scale. Thermoelastic effects and ageing were carefully corrected by models. However, they can be questioned.

The **Solar Disk Sextant (SDS)** has measured the diameter variability with an instrument carried by a stratospheric balloon. An anti correlation is found with the solar activity, however only based on four flights.
SDS has an internal angular scale to check the instrument *psf* in flight.

DIAMETER VARIATION FROM STRATOSPHERIC BALLOON OBSERVATIONS

Sofia et al. (1994) have built the Solar Disk Sextant (SDS) including an angular reference. Operated on board a stratospheric balloon, four flights were achieved.



Results of four stratospheric balloons flights carrying SDS (Egidi et al., 2006) showing a diameter increase of 0.2“ while the solar activity decreases.

PICARD MISSION MAIN SCIENTIFIC OBJECTIVES

(1) Modelling of the solar machine

using simultaneous measurements of several fundamental solar properties and their variability.

Role of the magnetic field, on surface or deeper in the convective zone. Origin of the solar activity?

This is an essential objective.

(2) Contribution to solar luminosity reconstruction

(3) Long term trend using the solar diameter referred to stars angular distances

(4) Understanding of the ground based measurements

(5) Contribution to Space Weather

A strong synergy with several other solar missions is anticipated.

PICARD MEASUREMENTS IN ORBIT

Images:

- Diameter, limb shape and asphericity in the continuum (535, 607, 782 nm).

  Diameter (215 nm)

  Precision: 3 mas per single image

  Diameters are refered to stars angular distances
- Activity (215 nm, Ca II)

Spectral irradiance:

- Several solar spectral channels with redundancy observing the same wavelengths as above.

  Two channels dedicated to ozone measurements

Total Solar Irradiance:

- 2 independent radiometers as on SoHO, and one bolometric channel

  SORCE-TIM: 5 W/m^2?

Solar oscillations (535 nm):

- on limb, macropixels and spectral channels

Variability: of the above quantities as a function of time

HELIOSEISMOLOGY MEASUREMENTS WITH PICARD

- Limb is measured every two minutes.

- Macropixels:

Macropixels were initially sampled each two minutes using a 32 X 32 binning.

There are now sampled each minute using a 8 X 8 binning allowing to reach l = 256

The telemetry increase has been accepted by CNES.

Additional information is provided by sunphotometers at 10 s sampling, for different spectral domains.

PICARD CONTRIBUTION TO LONG TERMS VARIATIONS:

- *A critical information for solar physics (Maunder minimum?),*
- *Climate simulations also require predictions over some decades time frame.*

- Theoretical approach: In depth understanding of the mechanism of solar variability ⇒ prediction

- New experimental method: PICARD will measure the solar diameter with an instrument geometrically calibrated on angular distances of several stars doublets (9) with the accuracy of 1 mas.

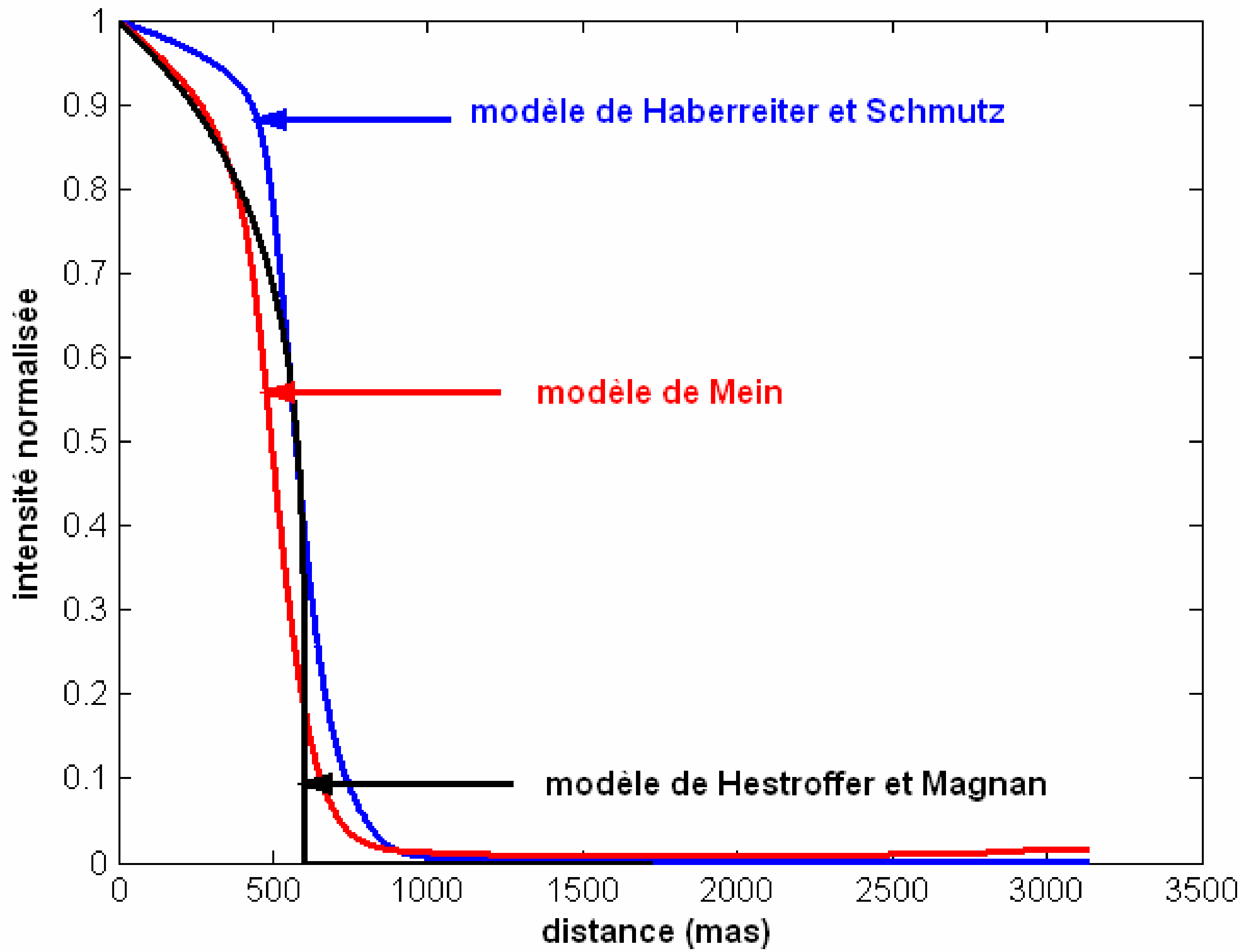
Advantage: these measurements can be resumed with the same stars doublets for calibration (ideally at the next solar minimum) ⇒ trend.

Condition: The diameter variation needs to be corrected for the stars proper motions. This can be done by using positions measured by Hipparcos (1991) and GAIA (2012). GAIA will allow to calibrate diameter measurement in the absolute scale.

SOLAR MODELING WITH PICARD (1/3)

Limb shape and diameter measurements, and model predictions:

- Solar diameter as a function of wavelength
- Solar diameter with chromospheric lines contribution
- Limb shape as a function of wavelength



Comparison between the empirical model of Hestroffer and Magnan (1998), and two theoretical models from Mein (2006) and Habereiter and Schmutz (2003) at 606.9 nm. The empirical limb shape has no inflection point and no reference of origin.

SOLAR MODELING WITH PICARD (2/3)

- Effect of solar variability on the diameter, on p-mode frequency, limb shape and TSI.

- Photospheric/seismic diameters: how do they compare?

- TSI, p-mode frequency and solar diameter variations: how these results are comparable to the theoretical modeling predictions (e. g. Sofia et al. 2005)

SOLAR MODELING WITH PICARD (3/3)

Convective zone modelling

The modelling of the solar interior using simultaneous measurements of the TSI, helioseismologic observations, limb shape, solar asphericity, and solar diameter is in development at Yale University and Montréal University.

At CEA (France), two models are also in development:
- a 1D model (code CESAM) with implementation of all dynamical processes (rotation effect, angular momentum effect, and mixing of chemical species.
- a 2 D model having the capability to reproduce the 11-year solar cycle.

Solar limb shape

A model is in development at Yale/SA, LASP

2D MODELS OF THE SOLAR INTERIOR

(Sabatino Sofia's Group)

Precision: 10^{-8}

Includes:

Rotation
Turbulence
Toroidal Magnetic Fields
Simple Magnetic Field/Turbulence Interaction
Computes 2D diagnostics of Oscillations

To be developed:

Poloidal Magnetic Fields
Realistic Magnetic Field/Turbulence Interaction
Advanced Model Atmosphere

ATMOSPHERE AND CLIMATE MODELING WITH PICARD

- Development of three different chemistry-Climate models to study the coupling of the stratosphere-troposphere by including the solar forcing:

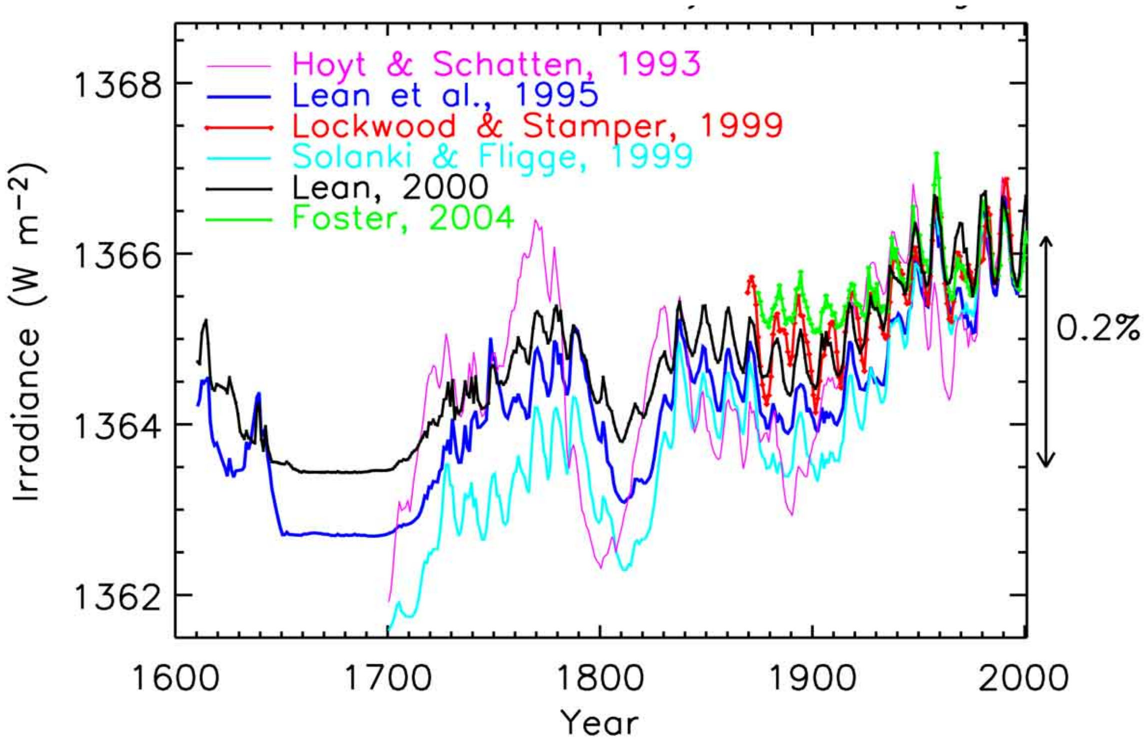
  - *France: LMDz-REPROBUS (Service d'Aéronomie),*
  - *Canada: CMAM (CSA, UofT, YorkU), IGCM-FASTOC (McGill)*
  - *Switzerland: PMOD model.*

A collaborative approach to optimise efforts and increase the robustness of the results.

- Validation of the CNRS model to correct the effect of the atmospheric turbulence on images recorded by the ground compared with images from space obtained using the same instrument.

LUMINOSITY RECONSTRUCTION

Reconstructions are based on different hypothesis (stellar evolution, ….) and different data sets (sunspots, length of the cycle, cosmogenic concentration variations, ….). Reconstructions disagree at certain periods and disagreements increase towards the past.



If PICARD determines the diameter/luminosity relationship, the best historical diameter determination as provided by eclipses, will be used. Eclipse of 1715 presents an important opportunity.

INSTRUMENTS FOR THE PICARD MISSION

In orbit:

Two radiometers of different type allow to discriminate between variations of instrumental and of solar origin. PICARD uses the same configuration as SoHO with the instruments DIARAD (IRMB) and PMO6 (PMOD-Ch).

- SOVAP: radiometer and bolometer, PI: Dr S. Dewitte (IRMB)
- PREMOS: radiometer and 3 sunphotometers, PI: Dr. W. Schmutz (PMOD, CH)
- **SODISM** : metrological imaging telescope, SA(F)

Instruments design takes into account the heritage of instruments previously designed for these measurements.

On the ground:

At Plateau de Calern, **SODISM II** measures the solar diameter, and limb shape. **MISOLFA** measures the local turbulence.

A collaboration with the PSPT network and Observatoire de Meudon is foreseen.

SODISM MODES

SCIENTIFIC MODES:

Helioseismology at 535.7 nm

Diameter at all wavelengths

Activity: 215 and 393 nm

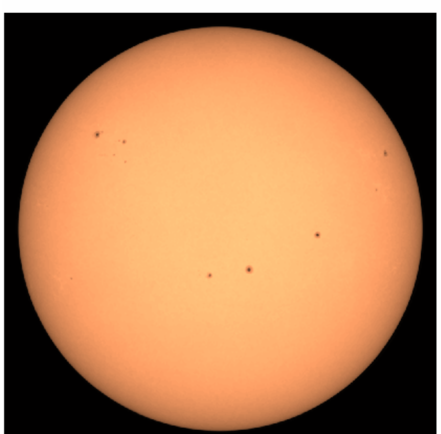
Absorption

CALIBRATION MODES MEASUREMENTS:

- Dark current
- Stellar observations
- Flat field (internal divergent lens and using the primary mirror)
- Distorsion around the optical axis by spacecraft rotation
- Validation of the instrument thermal model at eclipse exit

TYPE OF SODISM IMAGES

- Full Images (1/orbit/λ @ λ = 215, 393, 535, 607, 782 nm)
- Limbs: - 22 pixels width for heliosismology (1/2 mn @ λ = 535 nm)
  - 40 pixels width for diameter mesurement (2 per orbit/λ) outside the particles precipitation zones
- Images “macropixel” (1/mn @ λ = 535 NM)
- Images dark current within the limb and full image
- Flat Field (1/d/λ)
- Stellar images



Full Image

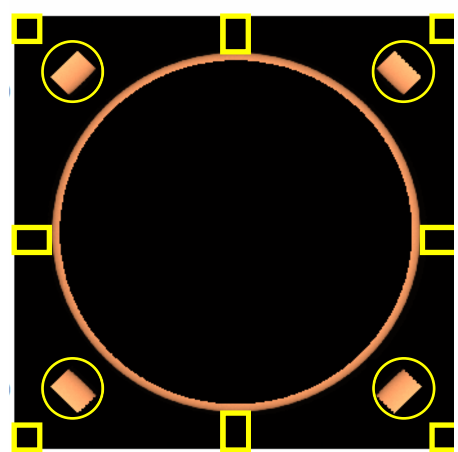
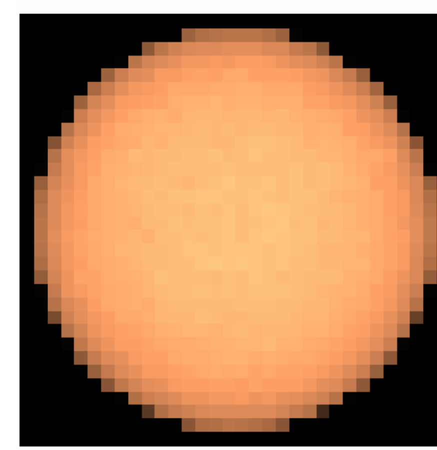


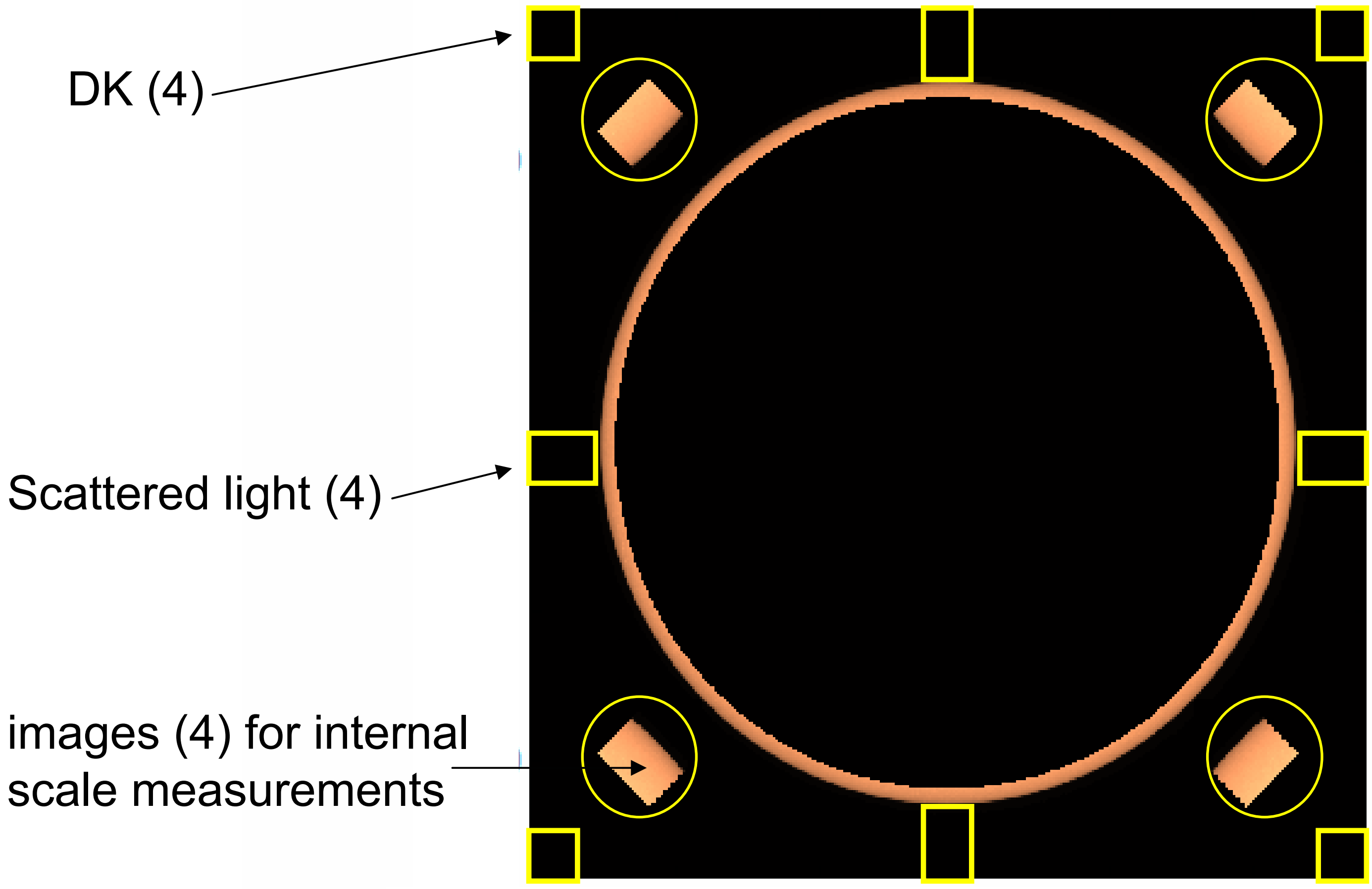
Image @ 535 nm

Not scaled



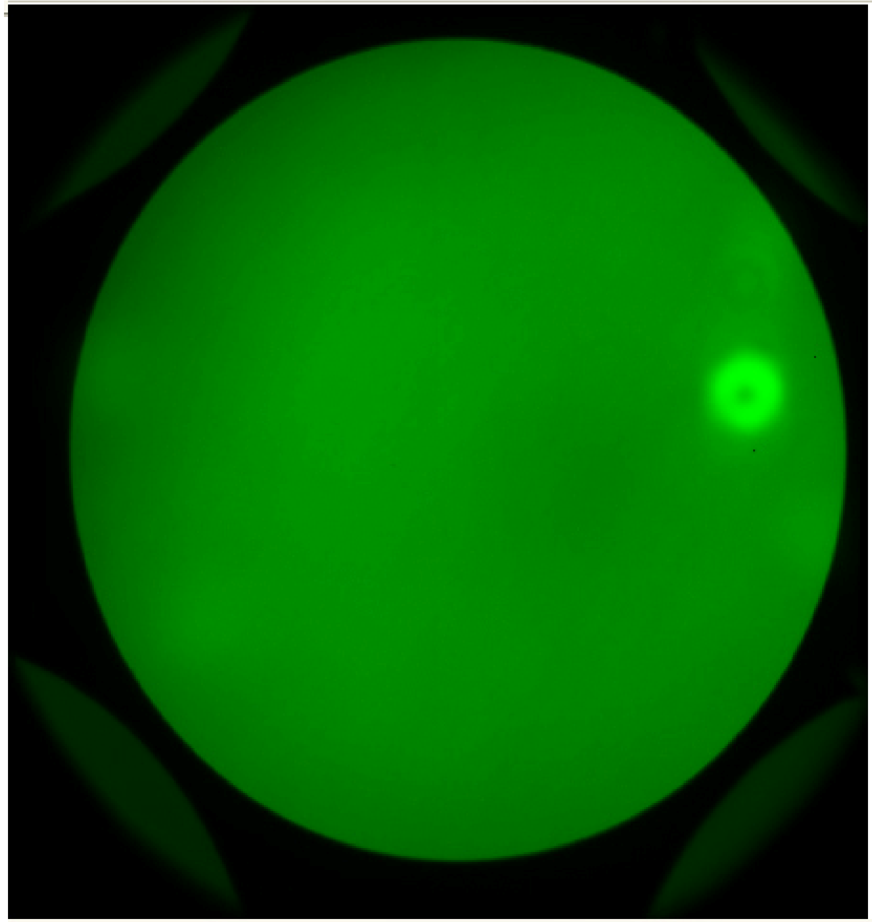
Macropixel image

IMAGE at 535 nm

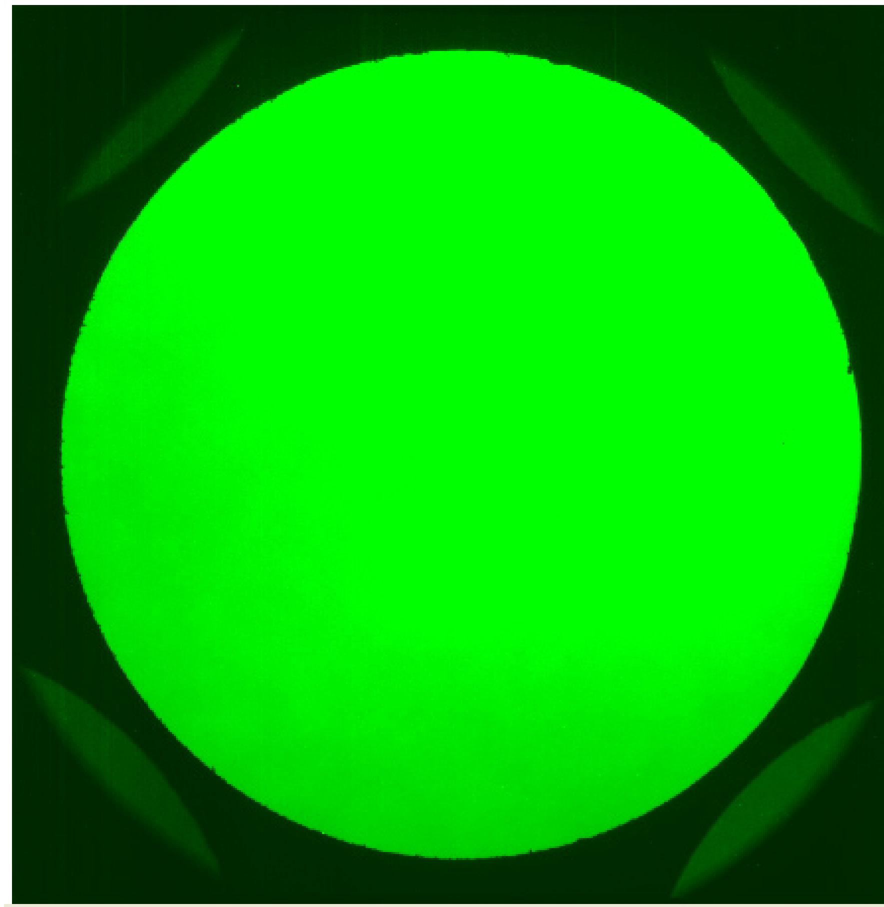


Data: limb, 4 areas for DK monitoring, 4 areas for scattered light monitoring, 4 auxiliairy images for internal scale measurements

FILTRE à 535 nm POUR LA MESURE DU DIAMETRE SOLAIRE

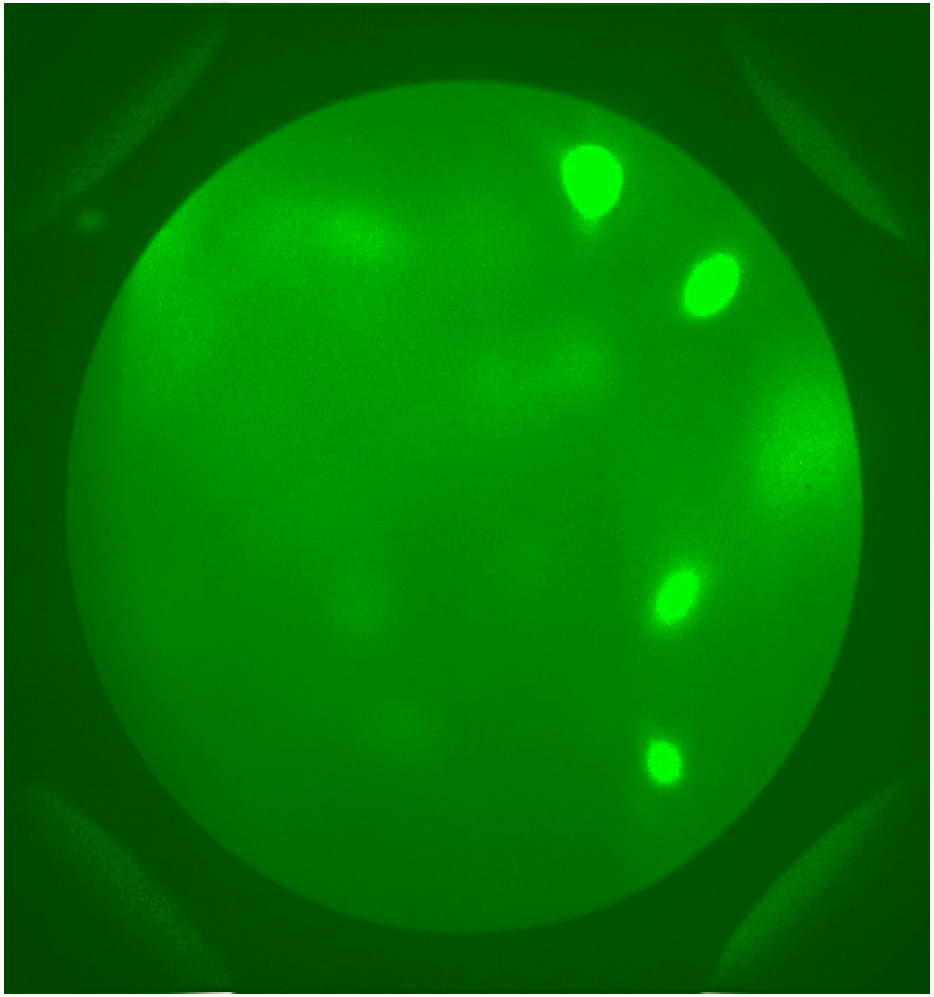


Avant

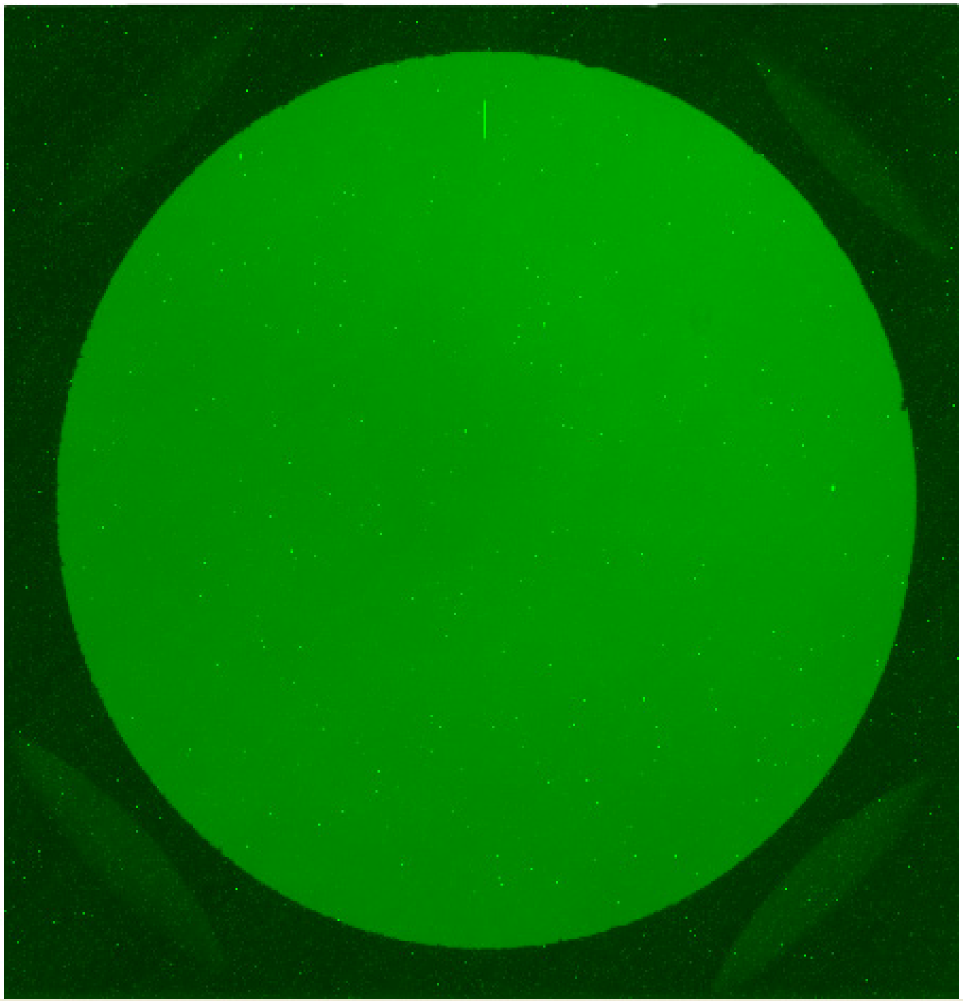


Après

FILTRE à 535 nm POUR LES MESURES HELIOSISMOLOGIQUES



Avant



Après

State of Development

- Two complete models were built (QM and one FU).

- The FU has been qualified in mechanical vibrations and thermal vacuum.

- The guiding telescope and the image telescope are adjusted wthin 2 arc minutes.

- A problem occurred: FU interference filters were worse than the QM

a demounting and manufacturing of a set of new filters, and remounting and re-adjusting all the elements were made.
Then, the instrument has been mechanically vibrated (with success as no image displacement occurred).

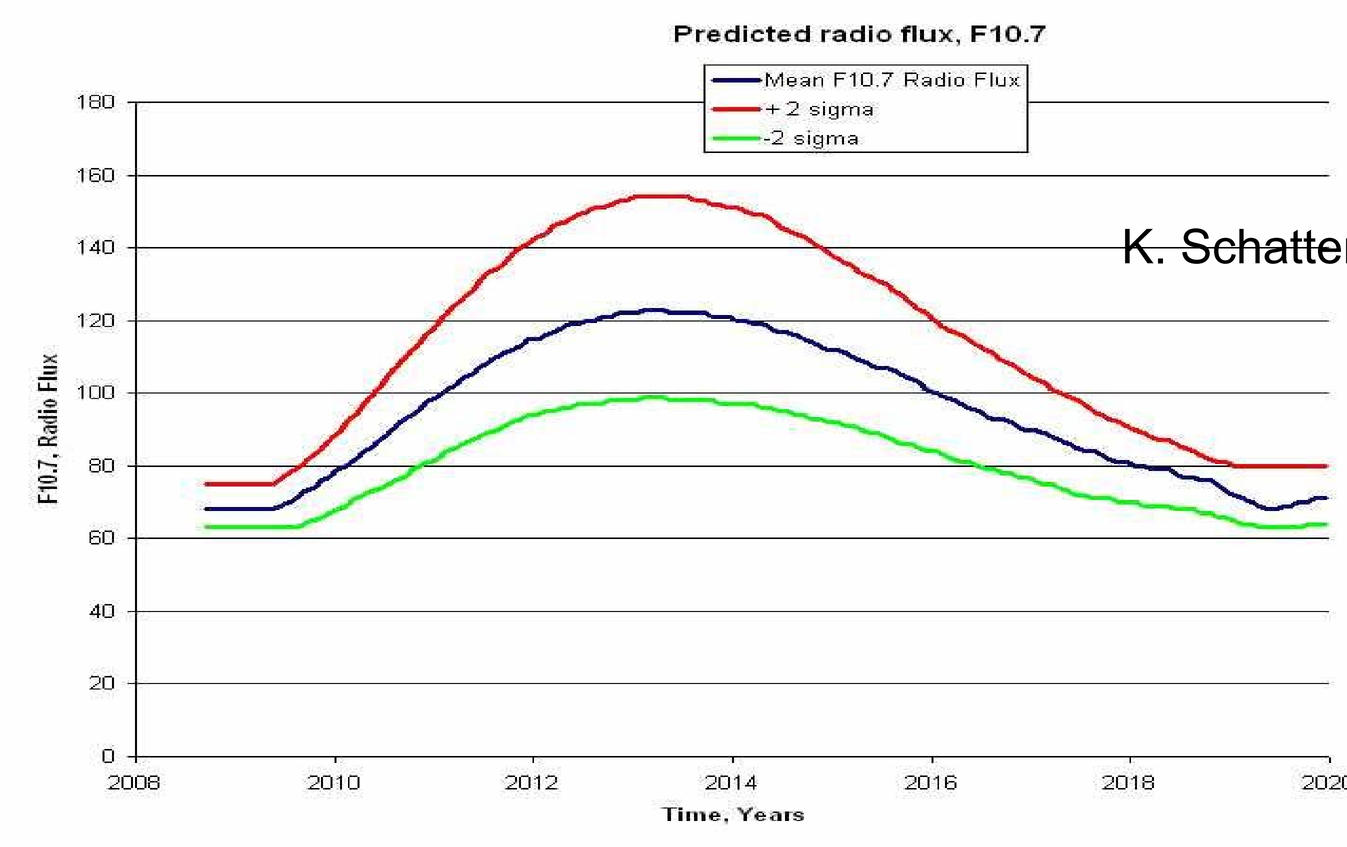
- Characterisation images were taken.

- The instrument has been delivered to CNES for integration on the PICARD space craft on 14 October. PREMOS was already delivered. SOVAP has been delivered on 25 October. However, last week, a problem appeared with SODISM:
- No image. The CCD, its associated electronics and capacitors are suspected.
Investigations of the origin of the failure have been made. The capacitors are the cause of the problem. Launch will be delayed from June/July to September.
- The QM will be prepared as a ground based instrument.

LAUNCH DATE and PREDICTIONS

Greater solar variability is expected during the ascending phase of the solar cycle than during the descending phase.

PICARD took advantage of a late start of cycle 24. A launch by July/August 2009 woul provide appropriate variability for the measurements.



K. Schatten, Sept. 2008

SOLAR DISK SEXTANT
CORRELATED MEASUREMENTS WITH PICARD

This instrument flew four times during the descending phase of cycle 22.

The instrument has an internal angular reference, and its psf is 0.12 arcsecond width.

It is foreseen to fly SDS once a year.

Advantages for PICARD

- Useful comparison and validation of the solar diameter determination.

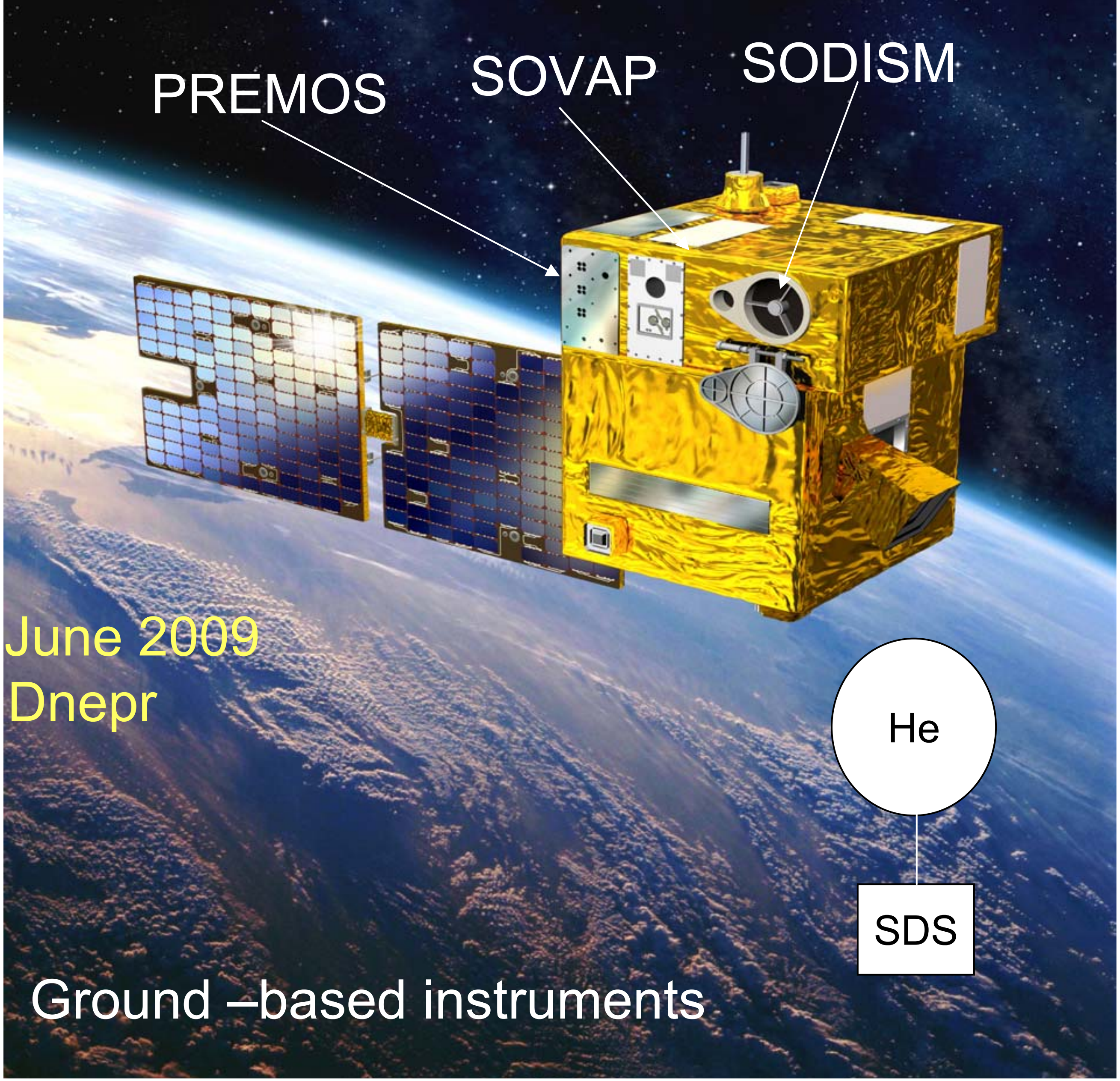
- Validation of the limb shape, and asphericity.

- Validation of the SODISM optical distorsion measurement by spacecraft rotation

Main work: implementation of a filter wheel to measure within the same spectral domains as SODISM.

Yale is the responsible institute of this operation.

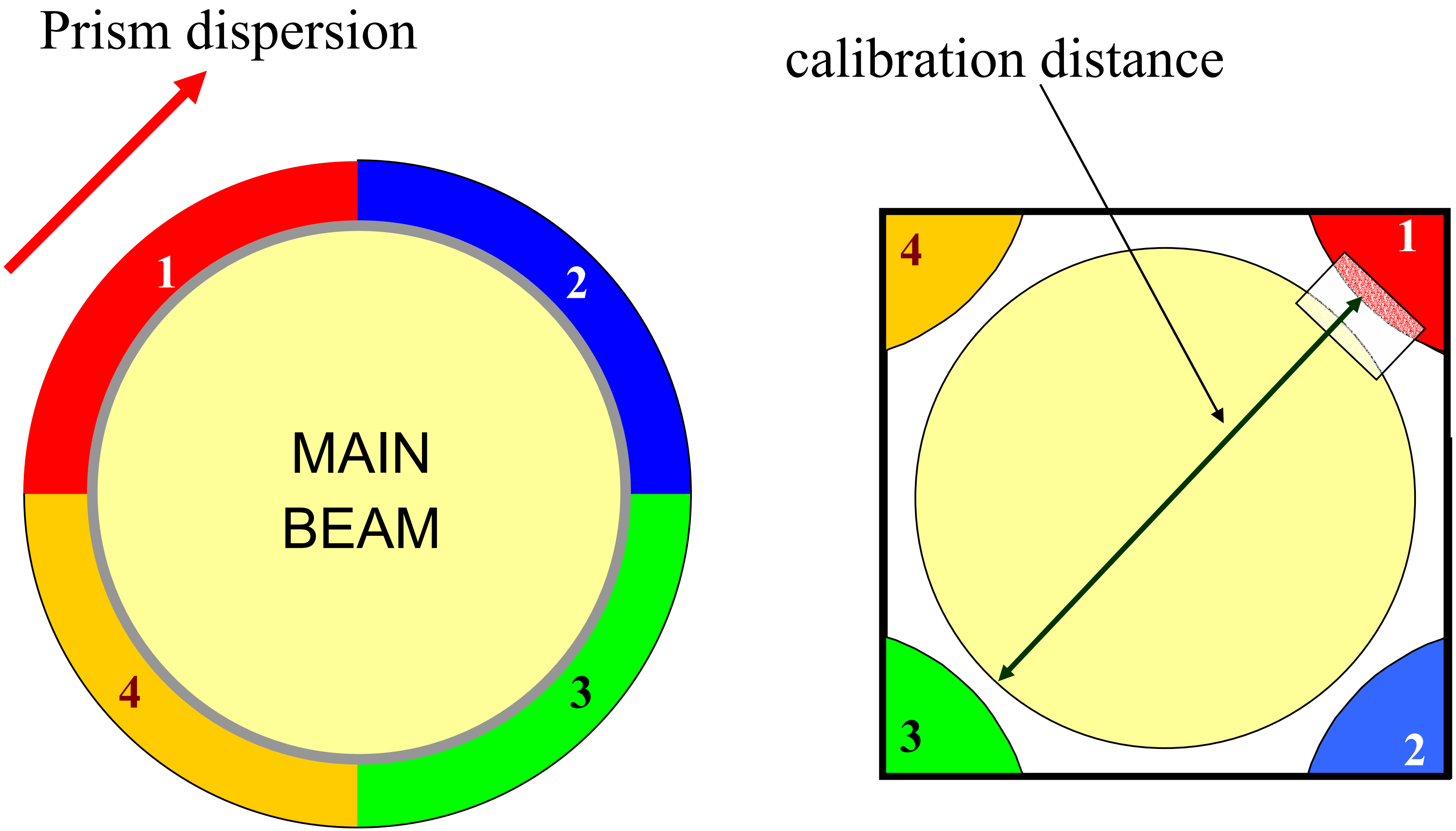
Launch: June 2009
Launcher: Dnepr



Institutes providing instruments: CNRS, RMIB, PMOD-WRC, OCA

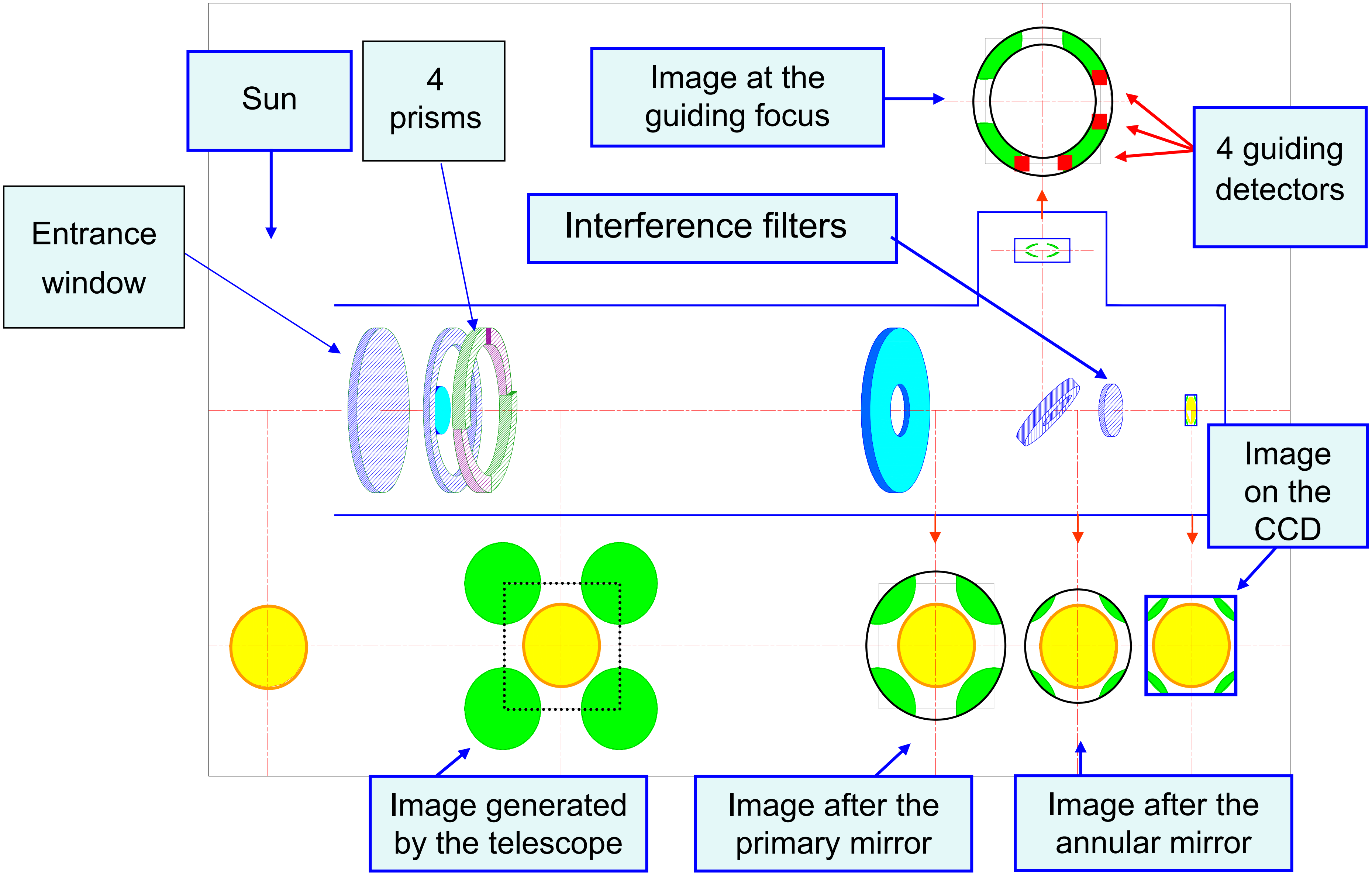
http://smsc.cnes.fr/PICARD/Fr/

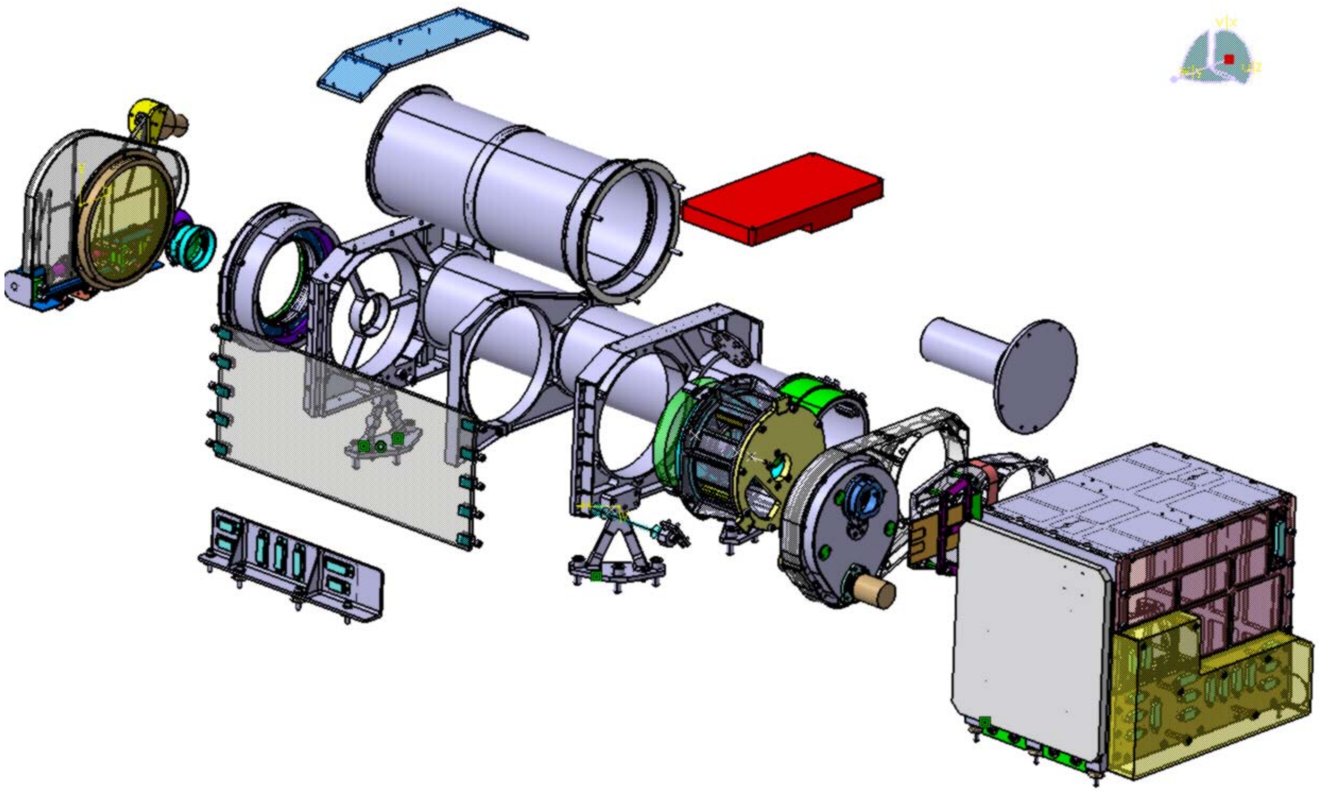
MAIN IMAGE - AUXILIAIRY IMAGES



PUPIL PLANE

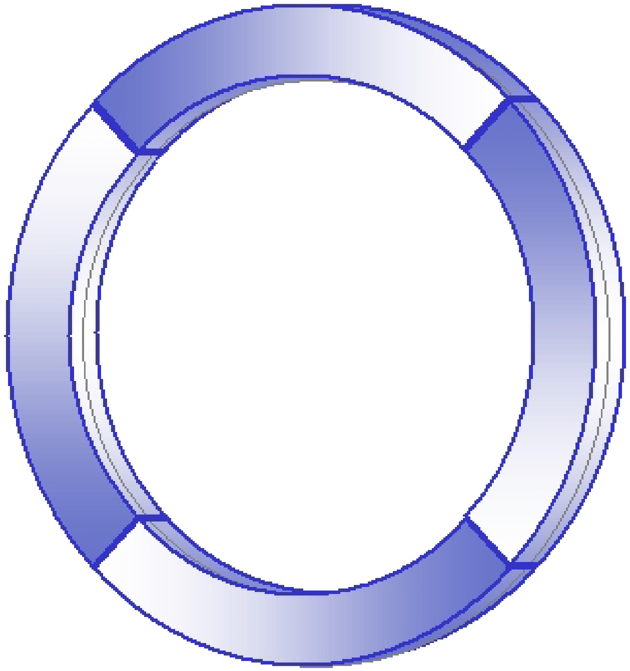
CCD PLANE

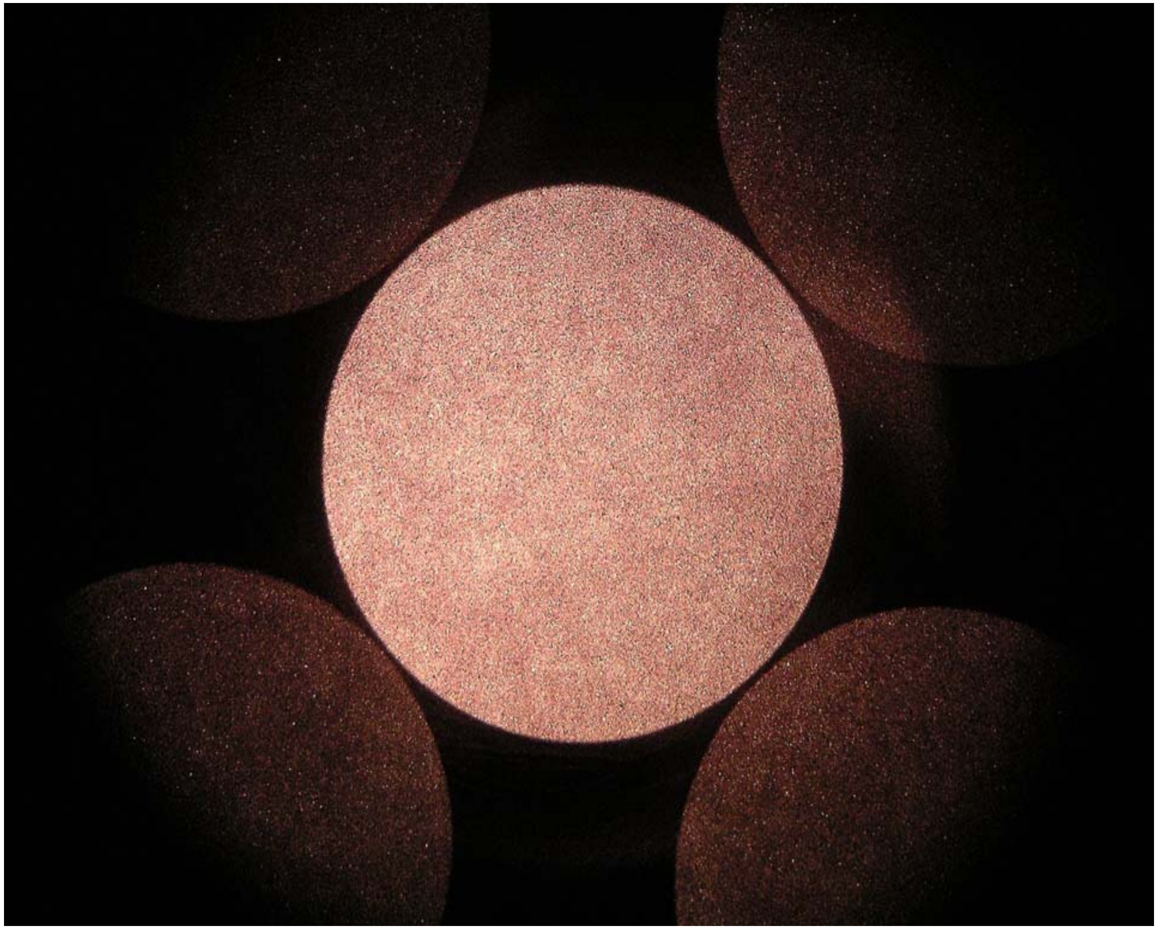

Sun
4
prisms
Image at the
guiding focus
4 guiding
detectors
Interference filters
Entrance
window
Image
on the
CCD
Image generated
by the telescope
Image after the
primary mirror
Image after the
annular mirror



SODISM imaging telescope

Solar diameter : 3 mas per image
Oblatness: 1 mas

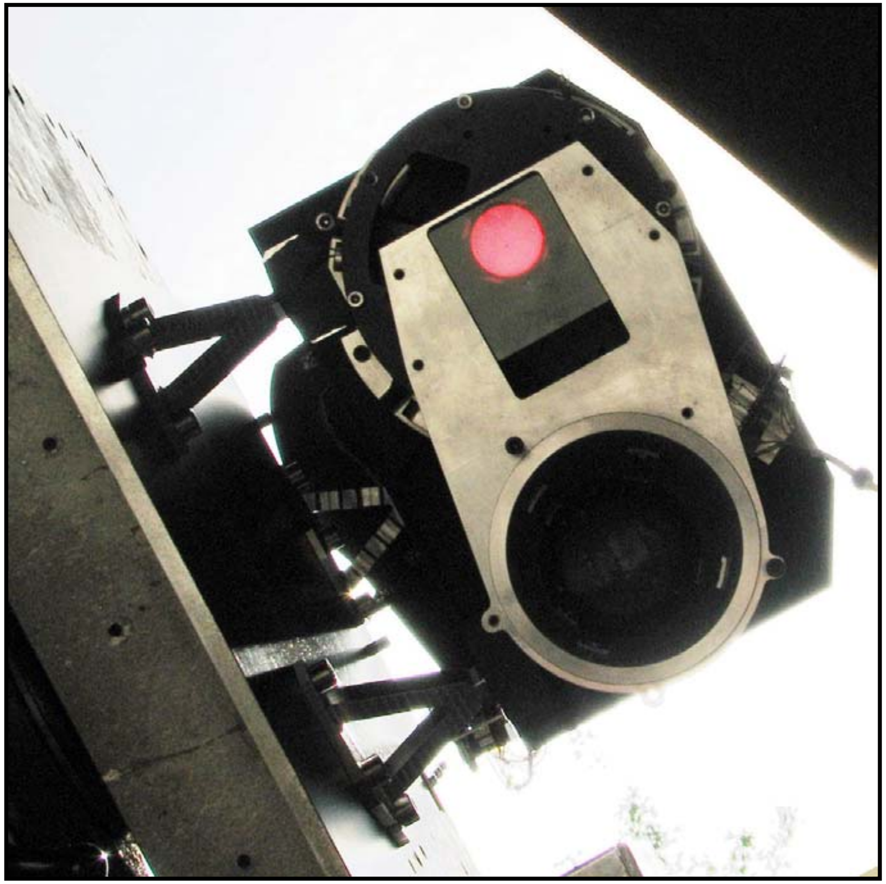


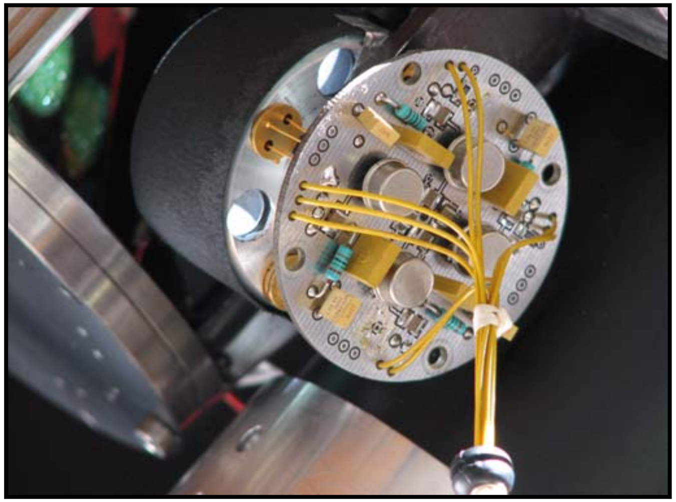


The 4-prim system

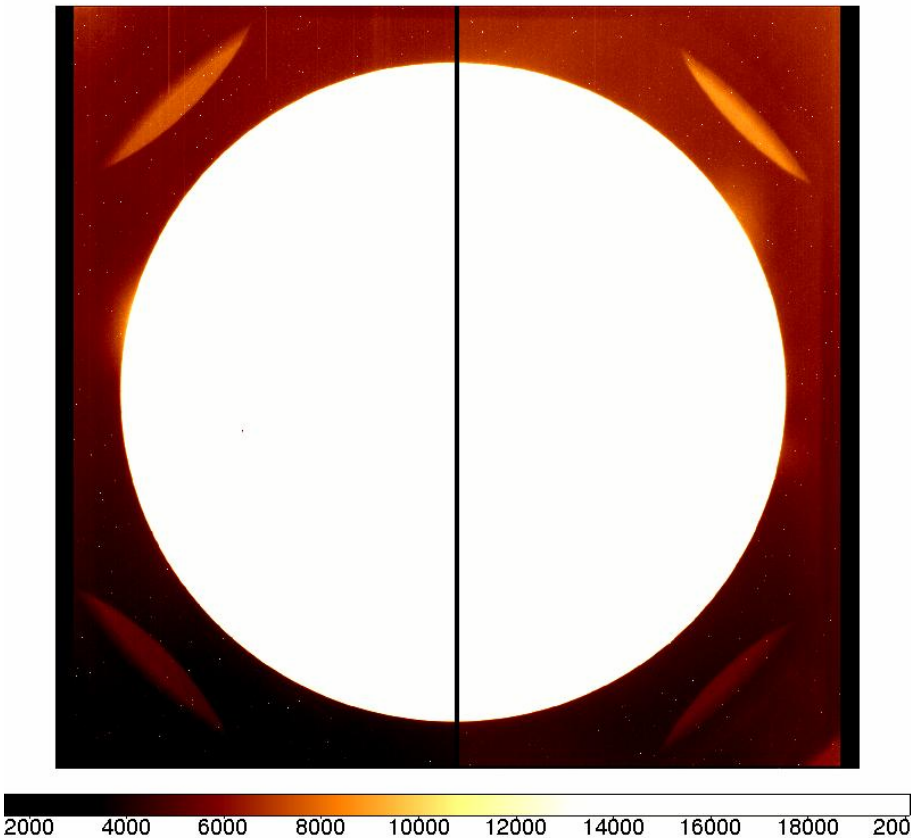
Images in the focal plane

TELESCOPE LOOKING TO THE SUN

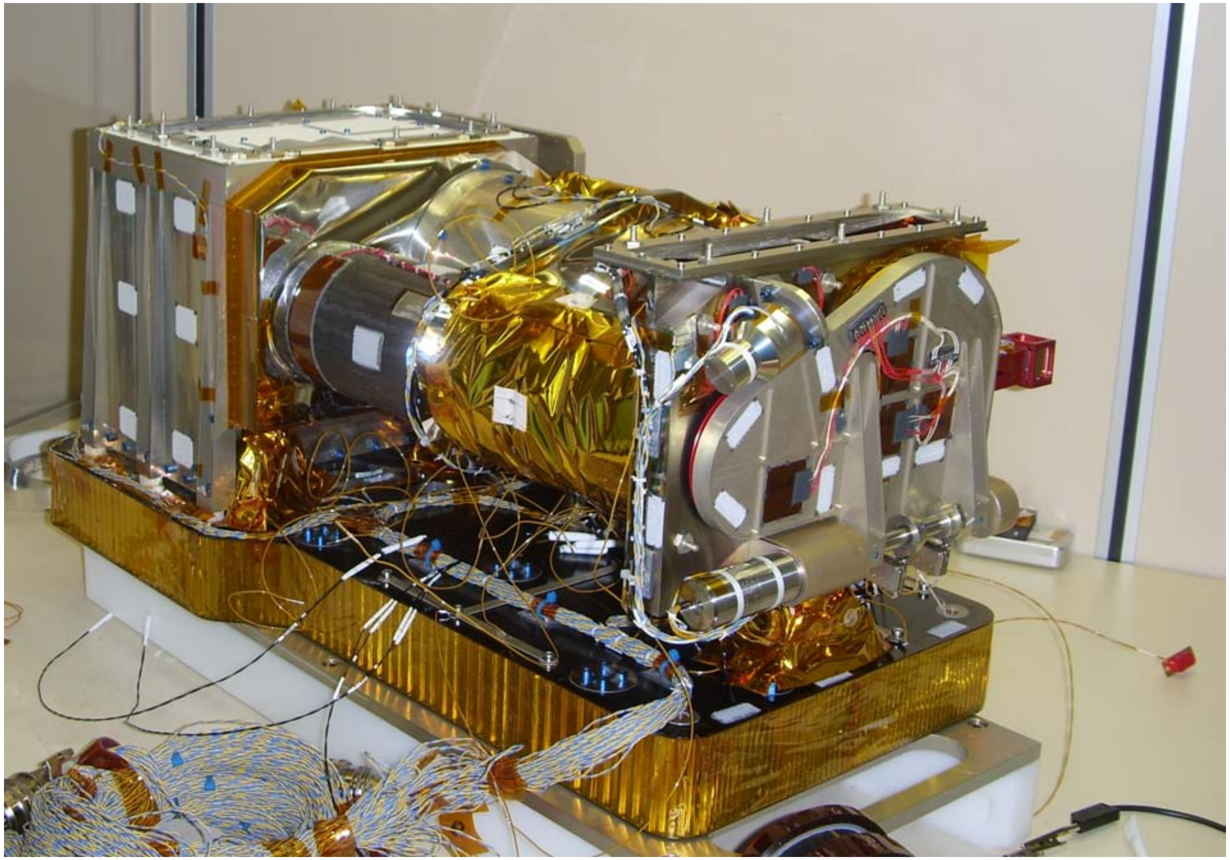




QM model



mv



FLIGHT UNIT: Front view

The three instruments during mechanical tests