The PICARD MISSION

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The solar diameter during the Maunder Minimum

Modern solar diameter measurements

Scientific objectives of the PICARD mission

Instruments and design

Present PICARD situation

SUN ACTIVITY DURING THE 17th CENTURY

- ^{14}C,

- Sunspots number,

- Aurora frequency occurrence,

- solar corona during the Sun eclipses

- Observations by Jean Picard, Philippe de la Hire, J.-D. Cassini, Flamsteed (differential rotation, rotation rate at the equator), provided results differing at the Maunder Minimum period and after, in particular:

Solar diameter

Comparing the solar diameter during the deep Maunder minimum and in 1715, shows an anticorrelation

METHODS TO DETERMINE THE SOLAR DIAMETER

- Astrolabe

- Mercury transits in front the Sun

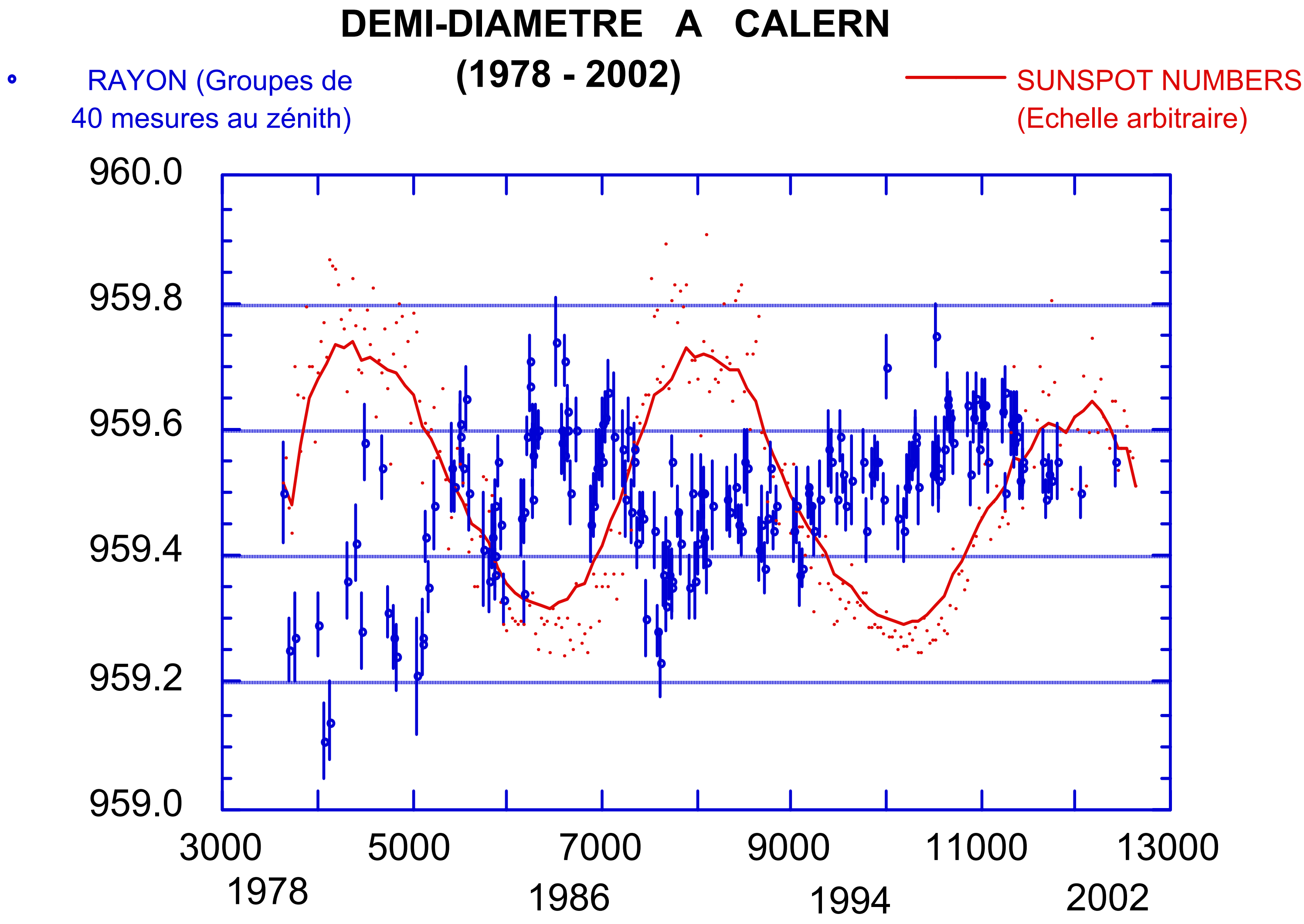
- Solar eclipses

- Helioseismology

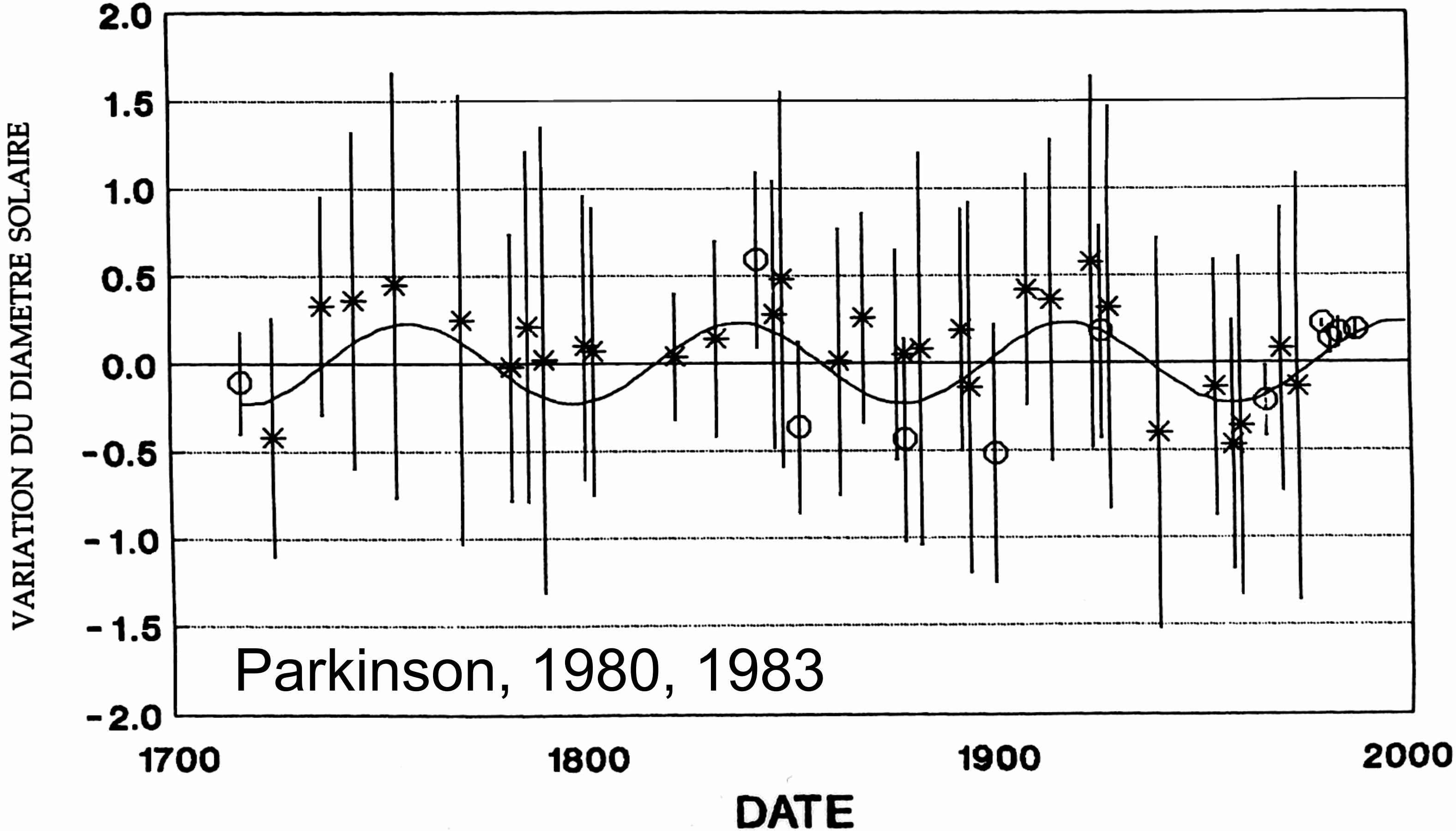
- Imaging telescope

Observations made by different astrolabe reveal inconsistent variations (no relation, a positive or a negative correlation with solar activity).

Furthermore, the longest series exhibited a negative correlation till 2000. The recent measurements now suggest a possible reversal of the correlation. This is shown below.


DEMI-DIAMETRE A CALERN
(1978 - 2002)
RAYON (Groupes de
40 mesures au zénith)
SUNSPOT NUMBERS
(Echelle arbitraire)
960.0
959.8
959.6
959.4
959.2
959.0
3000
5000
7000
9000
11000
13000
1978
1986
1994
2002

Mercury transits in front the sun provide enough observations to determine a trend, but individual measurements have a low accuracy.



Solar eclipses timing (Sofia et al., 1983)

Solar eclipse timing allows to derive the solar diameter.

Accuracy depends critically of :

1) Accurate geographic location of the observers near the edges (North and South) of the path totality (better than 50 m)

2) Location and depth of the Moon valleys (second contact)

For the eclipses of 1925 and 1979, the moon had the same configuration with respect to the Earth:

It results a reliable diameter decrease of 470 mas while the solar activity increased from 5.5 to 137.5 sunspots number.

Solar radius derived from helioseismologic observations

Observation of the oscillation modes allows to determine the solar helioseismologic radius (Schou al., 1997). Waves reflection occurs at about 5000 km below the photosphere. The table below shows inconsistencies in radius variations.

	Measurements	Radius variation	Correlation with activity
1	MDI/SoHO	R min @ minimum activity	>0
2	MDI, larger data base	none	0
3	GONG	R ↓de 5 km from 95 to 98	<0
4	MDI + GONG	R ↓de 1 km from 95 to 98	<0
5	MDI	R ↓de 1.5 km from 95 to 98	<0
6	MDI	none	0

References for the above works:

1 Dziembowski et al., 1998, ApJ., 509, 546
2 Dziembowski et al., 2000, ApJ., 537, 1026
3 Antia et al., 2000, Sol. Phys., 192, 459
4 Antia et al., 2001, Proc SOHO 10/GONG 2000 Worshop ESA SP 464, 27
5 Dziembowski et al., 2001, ApJ., 553, 897
6 Antia et al., 2003, ApJ., 590, 567

MDI data to infer a solar radius variation as a function of time:

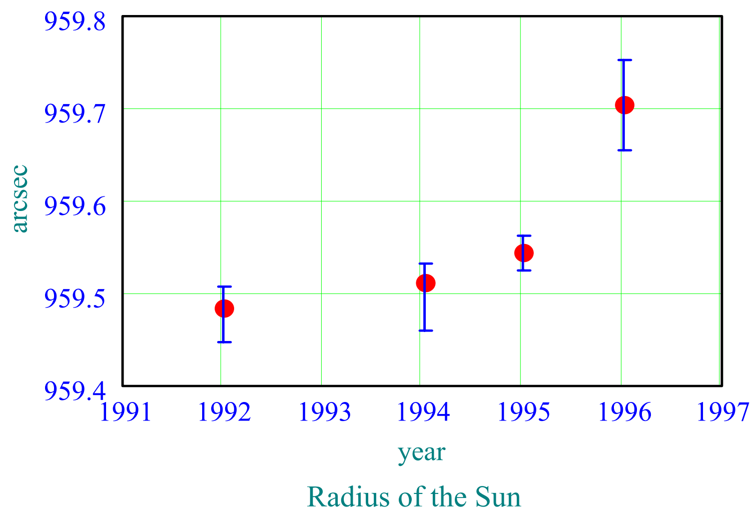
A thermal model is required to monitor the optical properties of the instrument (focal length, etc, …)

Results are function of the thermal corrections precision.

To ensure the stability of the instrument scale, an angular reference included in the instrument can be used:

DIAMETER VARIATION FROM STRATOSPHERIC BALLOON OBSERVATION

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



Results of four stratospheric balloons flights carrying SDS (Egidi et al., 2004) showing the diameter increase while the solar activity decreases.

DETERMINATION of $W = \delta r/r \,/\, \delta L/L$

r and L being the radius and luminosity, respectively.
Solar models provide W.
Former models predicted W to be about 10^{-4} to 10^{-3} (>0 or <0).

Recent models are based on assumed properties of the dynamo magnetic field which must be calibrated by observations.
Consequently, W must first be derived from reliable observations.

W	Authors
- 0.2	Laclare et al., 1996
<0	Sofia et al., 1994; Egidi et al, 2004
1.2	Noël, 2002
<0	Egidi et al., 2003
0.	Brown & Christensen-Dalsgaard (1998)

The reported inconsistencies are likely originating from:

- atmosphere effects which cannot be excluded,
- techniques of measurements,
- accuracy of the measurements

PICARD plans to measure the solar diameter as follows

- from space
- with a thermally stable instrument
- incorporating an angular reference
- refering the measurements to stars positions

This is why the PICARD mission was named after the astronomer who made the first diameter measurements. To study the solar diameter and luminosity relationship, TSI will be simultaneously measured.

The PICARD mission is based on data provided by three instruments:

SOVAP, a DIARAD radiometer under the responsibility of IRMB (B). TSI measured each 2 mn.

PREMOS, three redundant sunphotometers under the PMOD responsibility (CH) at 215, 268, 535, 782 nm sampled each 10s.

SODISM, an imaging telescope with an angular reference under the responsibility of Service d’Aéronomie (F). Images taken each 2 mn at 535 nm and each 40 mn at 535, 607, 782 nm for diameter, and 215 nm and 393 nm Ca II for active regions determination.
Instrument precision : 1 mas.
Final geometrical reference is provided by stars angular distances.
The three instruments are placed on a microsatellite under the CNES responsibility.

PICARD MISSION OBJECTIVE 1 :

CONTRIBUTION TO SOLAR MODELLING

Improvements of solar modelling is important for:

Solar physics
Climate prediction

Climate prediction needs solar activity anticipation.

Helioseismology and asphericity information provide strong constraints to the solar interior models.

For photosphere, TSI and solar spectral irradiance are key inputs.

PICARD can bring two others: limb shape, asphericity and diameter variability (Li et al., 2003).

PICARD MISSION OBJECTIVE 2 : LONG TERM VARIABILITY

Using the diameter as a proxy of solar variability

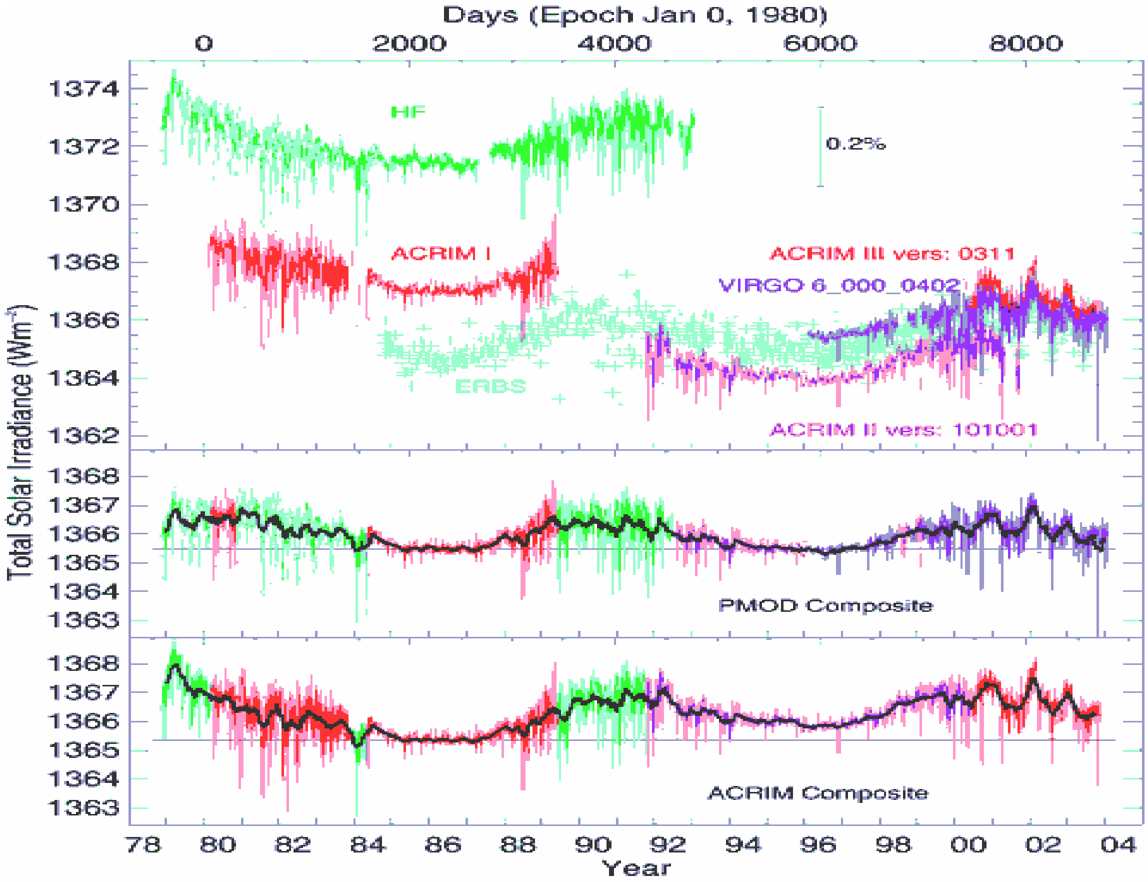
- Observations are first referred to the internal instrument scale provided by a set of four prisms.

- By observing several sets of bright doublet or triplet of stars, the internal reference is scaled on these stars angular distances at a given time, allowing during the mission to further verify the stability of the diameter measurements instrument scale.

Stars constitute an angular relative scale reference available to all future investigations. After PICARD, it is expected that a similar instrument will fly. The use of stars allows mission interruptions and allows to compare the data obtained by other instruments.

The stars position and their proper movement are known with the appropriate accuracy (Hipparcos and next catalogue).

The stellar angular scale allows to derive a long term trend, if any. The next slides illustrates the difficulty in obtaining this trend from TSI data.



Upper panel: Compared are daily averaged values of the Sun's total irradiance TSI from radiometers on different spaceplatforms since November 1978: HF on Nimbus7, ACRIM I onSMM, ERBE on ERBS, ACRIM II on UARS, VIRGO on SOHO, and ACRIM III on ACRIM-Sat. The data are plotted as published by the corresponding instrument teams. Note that only the results from the three ACRIMs and VIRGO radiometers have inflight corrections for degradation. Lower Panels:The PMOD and ACRIM composite TSI as daily values plotted in different colors for the different originating experiments

PICARD MISSION OBJECTIVE 3:

CONTRIBUTION TO TSI RECONSTRUCTION

Discrepancies in TSI reconstruction exist (see Lean et al., 1995 versus Hoyt and Schatten, 1993).
Assuming W is not time dependent, luminosity variation can be inferred from diameter variation using the most reliable data provided by eclipses duration (Sofia et al, 2004) at some specific times.

Existing TSI reconstructions will be compared with the results provided by this method.

OTHER OBJECTIVES:

- Understanding of the ground based diameter observations
has implications for Atmospheric Physics (turbulence, ..) and will allow to study which solar signature is present in these measurements.

- Ozone budget

- Ca II index for atmosphere modeling

A SECOND RADIOMETER ON BOARD PICARD (1/2)

SOHO and EURECA missions carried two radiometers of DIARAD (IRMB, B) and PMO6 (PMOD, CH) design. This strategy and the overlapping missions have been demonstrated as appropriate to provide the most accurate radiometric measurements.

Initially foreseen on PICARD, the second radiometer was renounced by lack of weight resources. In Feb. 2004, CNES announced an extra 10 kg to the European Members States. Switzerland anwsered and proposed a PMO6 radiometer provided by PMOD. This is already scientifically supported, but has to be approuved by CNES. If so, PICARD will fly with the same configuration as on SOHO.

A SECOND RADIOMETER ON BOARD PICARD (2/2)

In 2008, SORCE radiometer should be still in operation or/ and a successor could be in orbit. Today, no radiometer is foreseen on SDO.

On the International Space Station, the SOLAR payload consists of two radiometers (as on SoHO) and a set of spectrometers covering the 17-3000 nm spectral range. However, uncertainties exist concerning the launch date and mission duration (expected date October 2007).

PICARD will ensure the measurements overlapping with a two-radiometer system as on SOHO, will extent the data base, will bridge with NPOESS and will contribute to the synergy with SDO.

OBSERVATION MEANS FOR THE PICARD MISSION

Several instruments will observe at the same time from ground and orbit

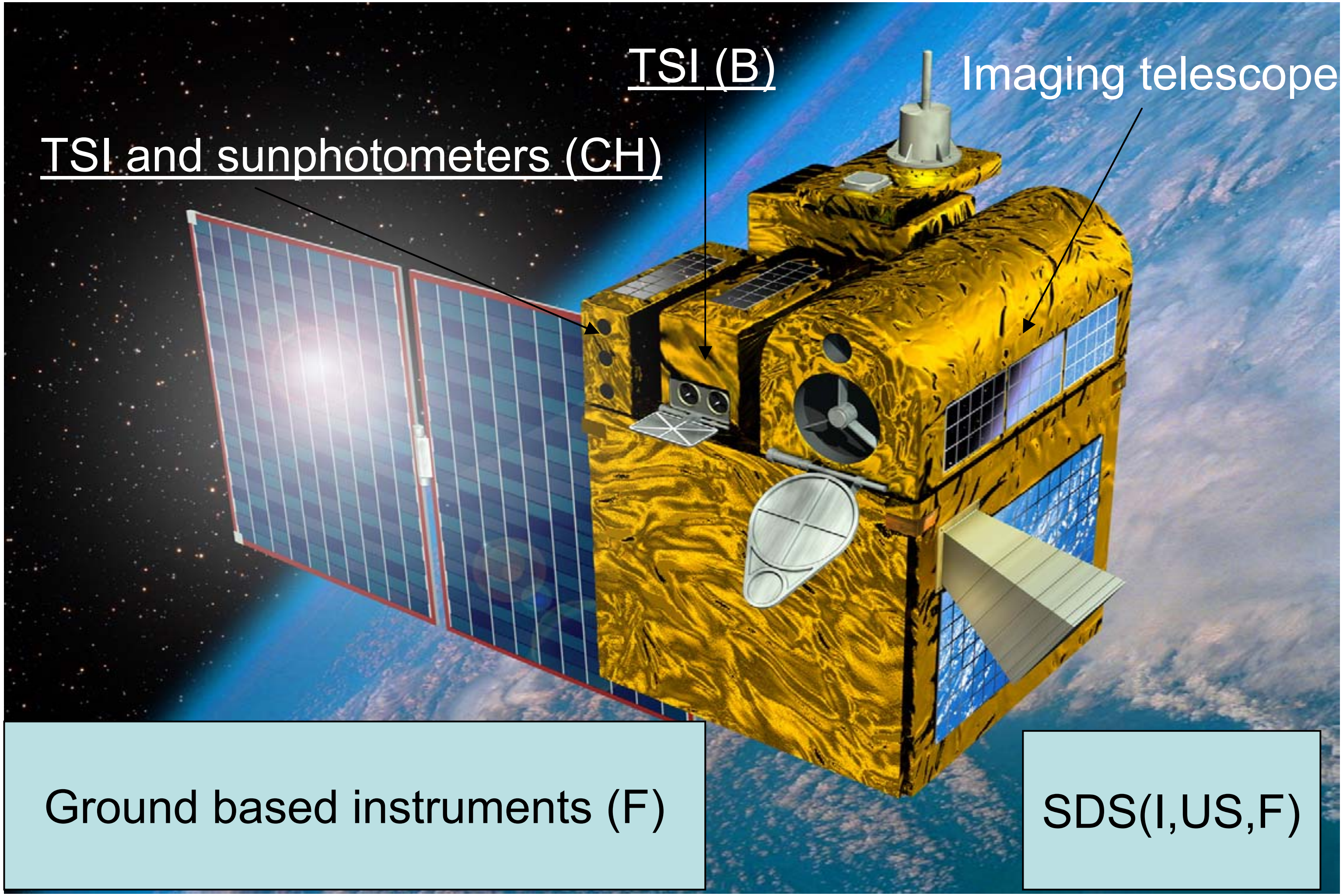
In space :
PICARD: diameter, asphericity, limb shape, solar oscillations, TSI, some spectral measurements for helioseismology and ozone photochemistry

On the ground :
Diameter measurements : DORAYSOL (new Laclare'astrolabe) and SODISM II (duplicate of the space instrument)
Atmosphere characterization (MISOLFA)

On a stratospheric balloon : SDS (Sofia et al., 1995) is foreseen to fly prior, during and after the mission. Scientifically, the project is accepted in cooperation with the Rome observatory. Fundings are in progress.

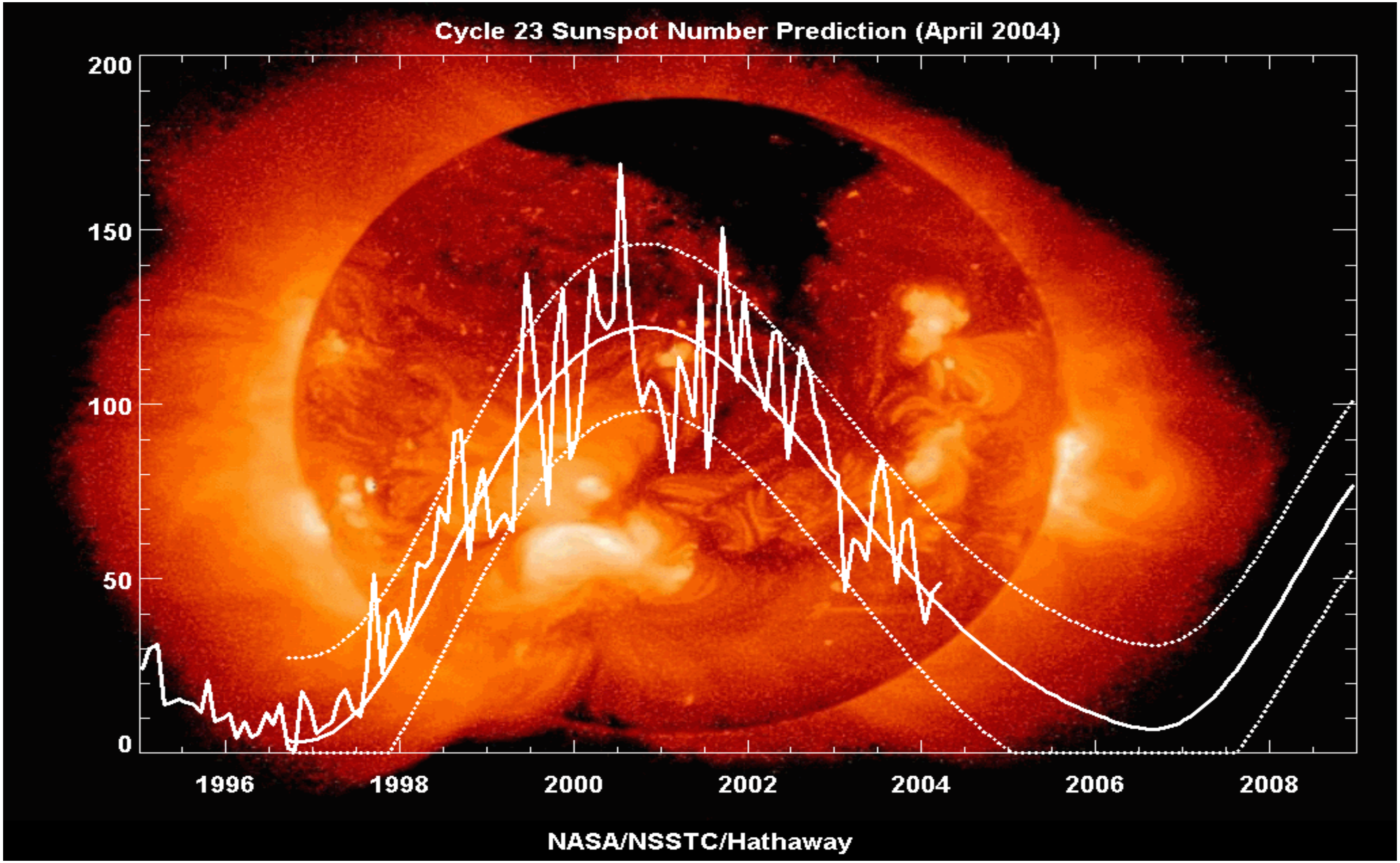
PICARD ground based station at Calern Observatory

PICARD Mission launch : beginning of cycle 24



Climate	PICARD Measurements	Instruments
	Diameter variability (W)	SODISM
	TSI	SOVAP and PREMOS
	Ozone	PREMOS
Solar physics	Limb shape, diameter, asphericity, differential rotation	SODISM
	TSI	SOVAP and PREMOS
	Helioseismology sounding and Helioseismologic radius	SODISM and PREMOS
Atmospheric Physics	Limb shape and diameter Orbit/ground	SODISM + ground Instr.
Sp. Weather	UV and Ca II line images	SODISM

The PICARD launch date is chosen to benefit of the solar cycle 24 rising part



PICARD synergy with the other solar missions

Missions	2006	2007	2008	2009	2010	2011
SORCE	--------------------------→					
SOLAR B	--------------------→					
STEREO	-------------------→					
ISS		----------------------------→				
SDO			-----------------------------→			
PICARD			----------------------------→			
NPOESS				--------------------------		

ISS : TSI and solar spectrum from 17 to 3000 nm

SORCE : TSI and solar spectrum from 12 to 2500 nm

SOLAR B : launch in September 2006

STEREO : launch in November 2005

The LIVING With a Star program

- To quantify the physics, dynamics, and behaviour of the Sun-Earth system over the solar cycle.

- To improve understanding of the effects of solar variability and disturbances on terrestrial climate.

SDO SCIENTIFIC MAIN OBJECTIVES

1 Understand the solar cycle

2 Identify the role of the magnetic field in delivering energy to the solar atmosphere

3 Study how the outer regions of the Sun’s atmophere evolve with time

4 Monitor the radiation levels of the solar output

5 Space Weather

PICARD contributions and its synergy with SDO (1/2)

TSI and its variability : PICARD will ensure TSI continuity with SORCE and ISS with the same instrumentation as on SoHO.

Solar asphericity and its relation with the Sun interior Dynamics

Diameter and solar activity

Helioseismologic diameter and optical diameter

Space Weather (Ca II, UV)

Finally, coupling high resolution multi-wavelength images, magnetic field measurements, helioseismologic investigations, asphericity and precise radius measurements will bring a unique data set for MHD modeling allowing to connect interior dynamo and photospheric output.

PICARD contributions and its synergy with SDO (2/2)

HMI/SDO and PICARD have complementary observations and may also measure similar solar quantities.

However, the instruments are different. It is important to point out that delicate measurements have to be performed by using different techniques. The consistency of the results ensures that the observations are made without systematic uncertainties.

This strategy is still used for example, concerning the radiometric measurements as it was successfully applied to the UV measurements when in certain circumstances several instruments were in operation at the same time on bord UARS and ATLAS.

SODISM PRINCIPLES OF DESIGN

1) Use of stable materials

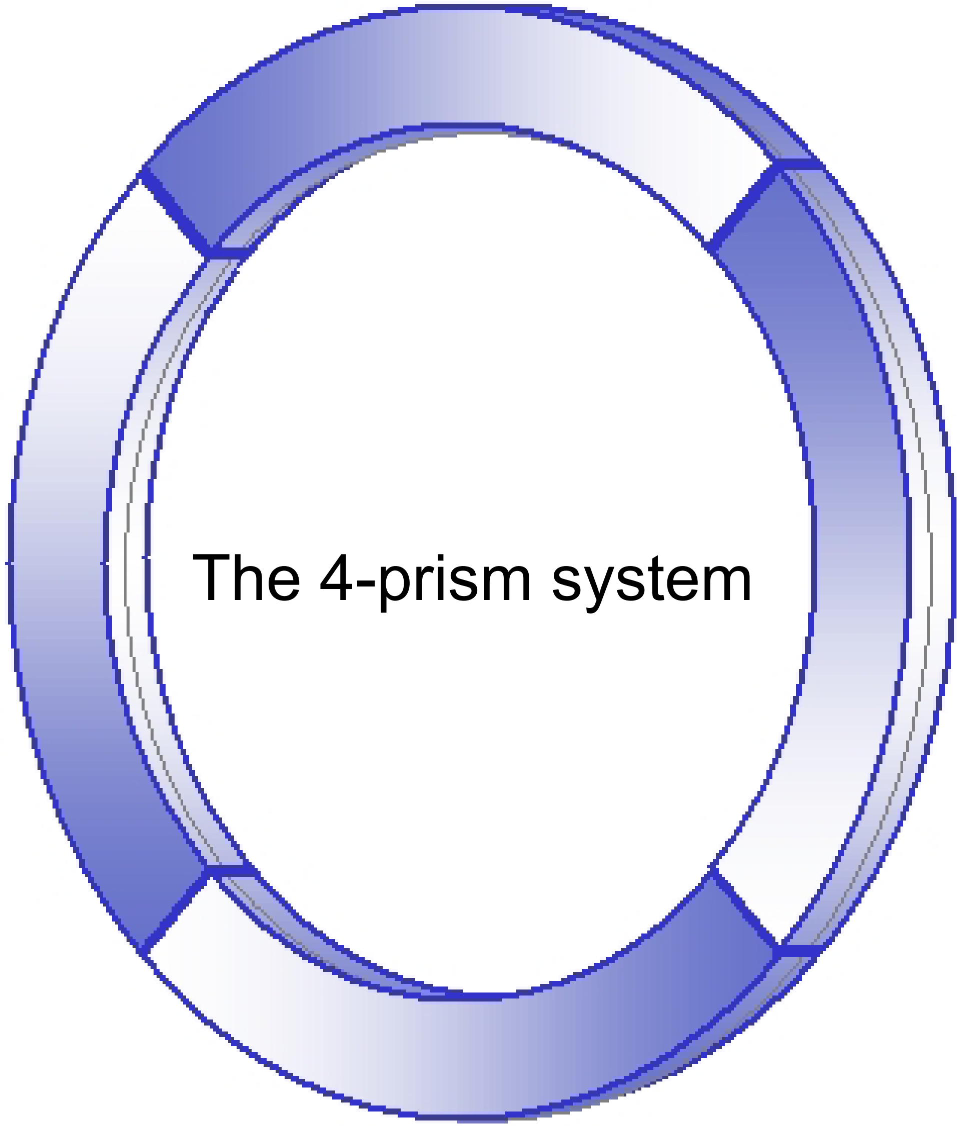
ZERO DUR for mirrors

INVAR and C-C for structure

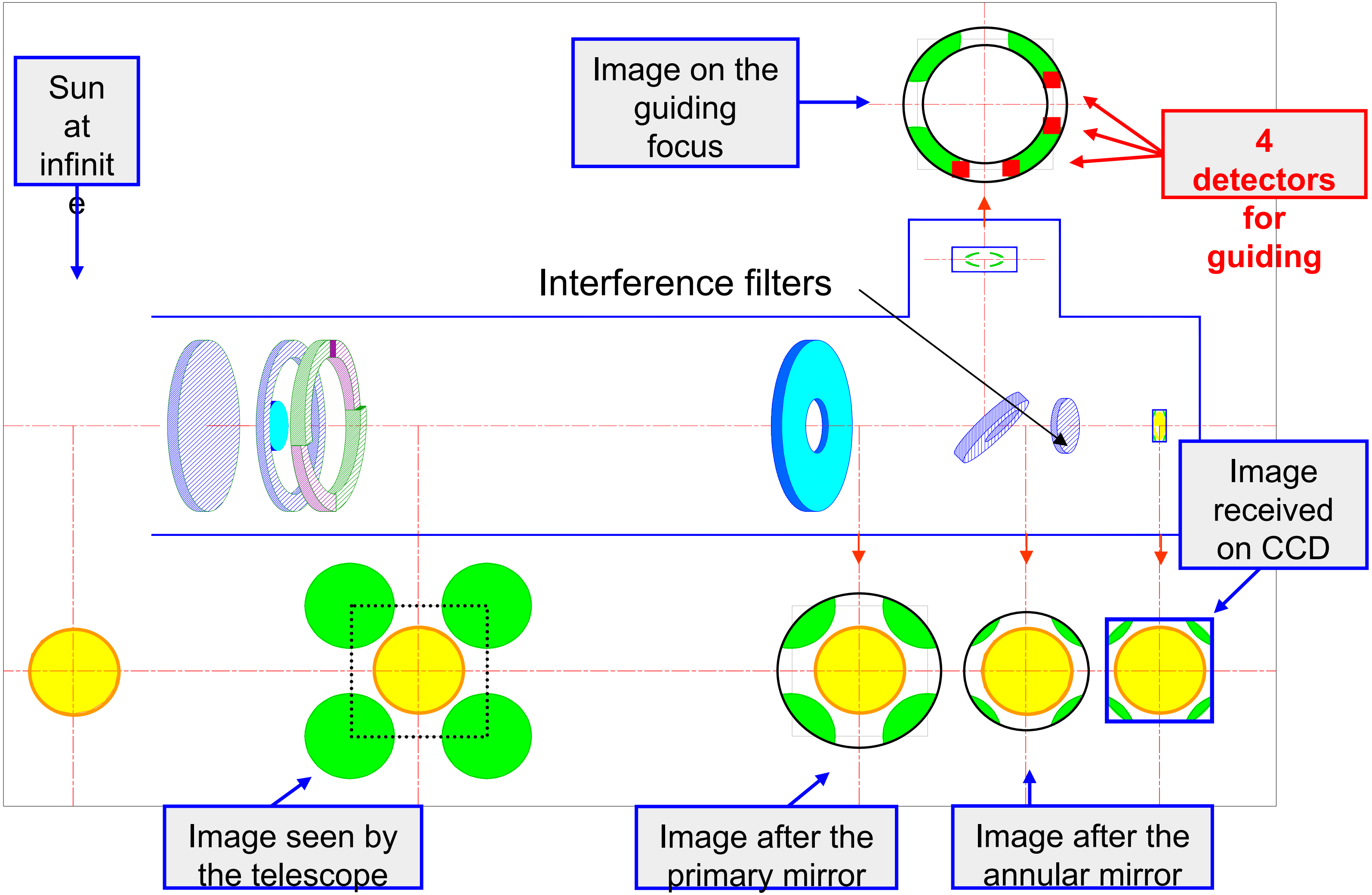
2) The whole instrument is kept at 20°C within 0.3 °C

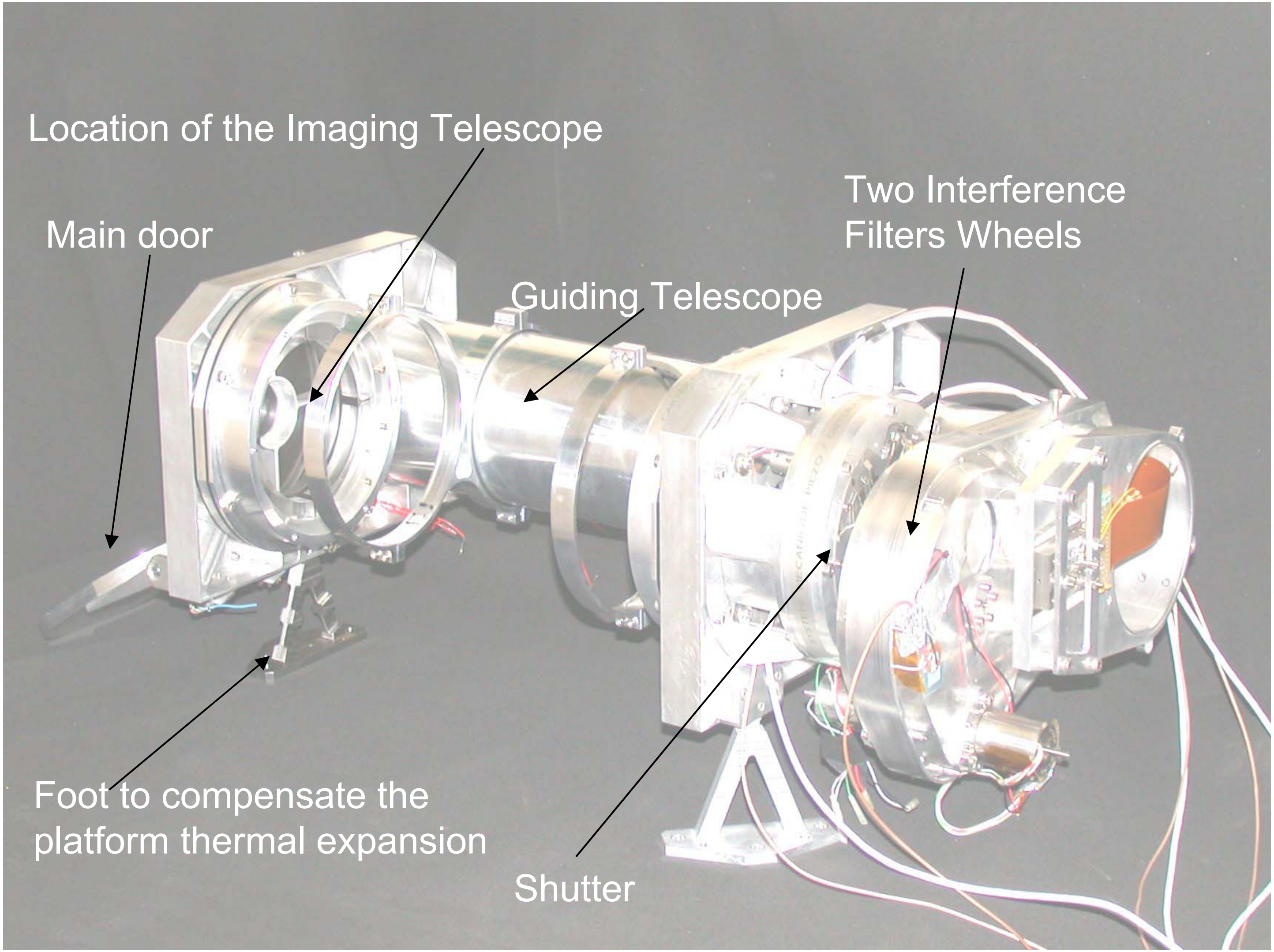
3) a four-prism system measures the internal geometrical instrument scale

4) the 2k x 2K CCD is kept at 40°C within 0.1°C


The 4-prism system

PICARD SODISM – Optical schematics




Location of the Imaging Telescope
Two Interference
Filters Wheels
Main door
Guiding Telescope
Foot to compensate the
platform thermal expansion
Shutter

STATE OF THE MISSION (1/2)

Optics design completed (including the scattered light study). Mechanical and thermal design are achieved.

External door, filter wheel, shutter, piezoelectric system are space qualified and satisfied their expected life duration.

Mechanics in fabrication. Engineering model available.

CCD available and characterized (FU).

Electronics design is completed and partly in fabrication. The four prisms system has been fabricated.

Entrance window is qualified under UV radiations.

Primary mirror pointing in progress.

Data on board compression software, qualified with simulated, PSPT and MDI data. Mission Control Center (Brussels) partly designed. Main scientific data processing algorithms completed. PDR was made on 2 March 2004. QM foreseen for end 2005.

STATE OF THE MISSION (2/2)

Given its budget situation in May 2003, CNES has « frozen » several missions including PICARD. However, a minimum budget was available and the instrument team activity was kept. This allowed to continue the instrument design and qualification of the sub-systems.

On Feb. 2004, ESA has confirmed the PICARD science objectives.

A scientific support to PICARD from LWS would certainly contribute significantly to « defreeze » the project.

The PICARD mission final decision for « defreezing » will be taken by CNES after the recomendation of the CNES Scientific Program Committee meeting (6-7 July 2004).