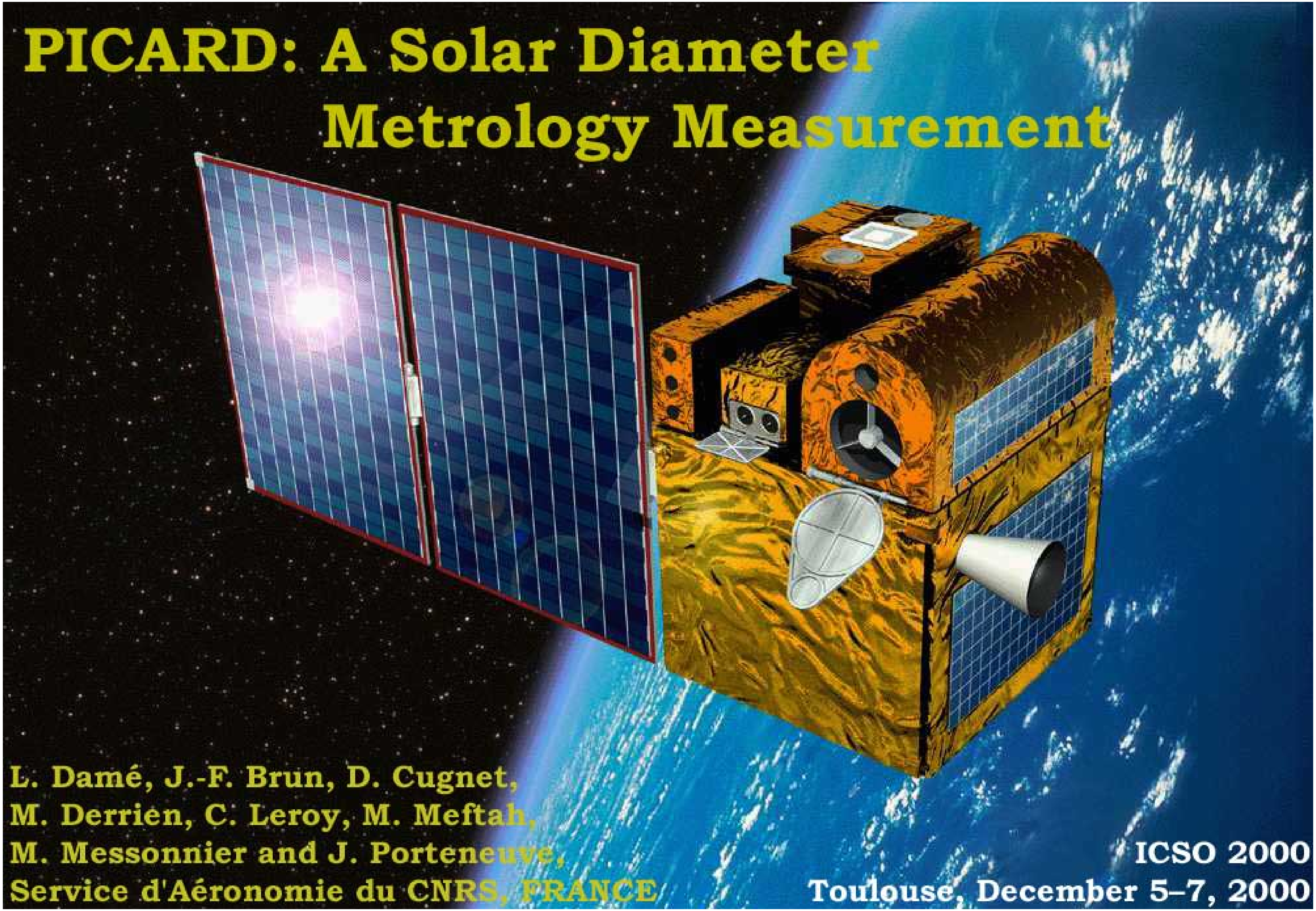
PICARD: A Solar Diameter
Metrology Measurement
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Service d'Aéronomie du CNRS, FRANCE
ICSO 2000
Toulouse, December 5–7, 2000

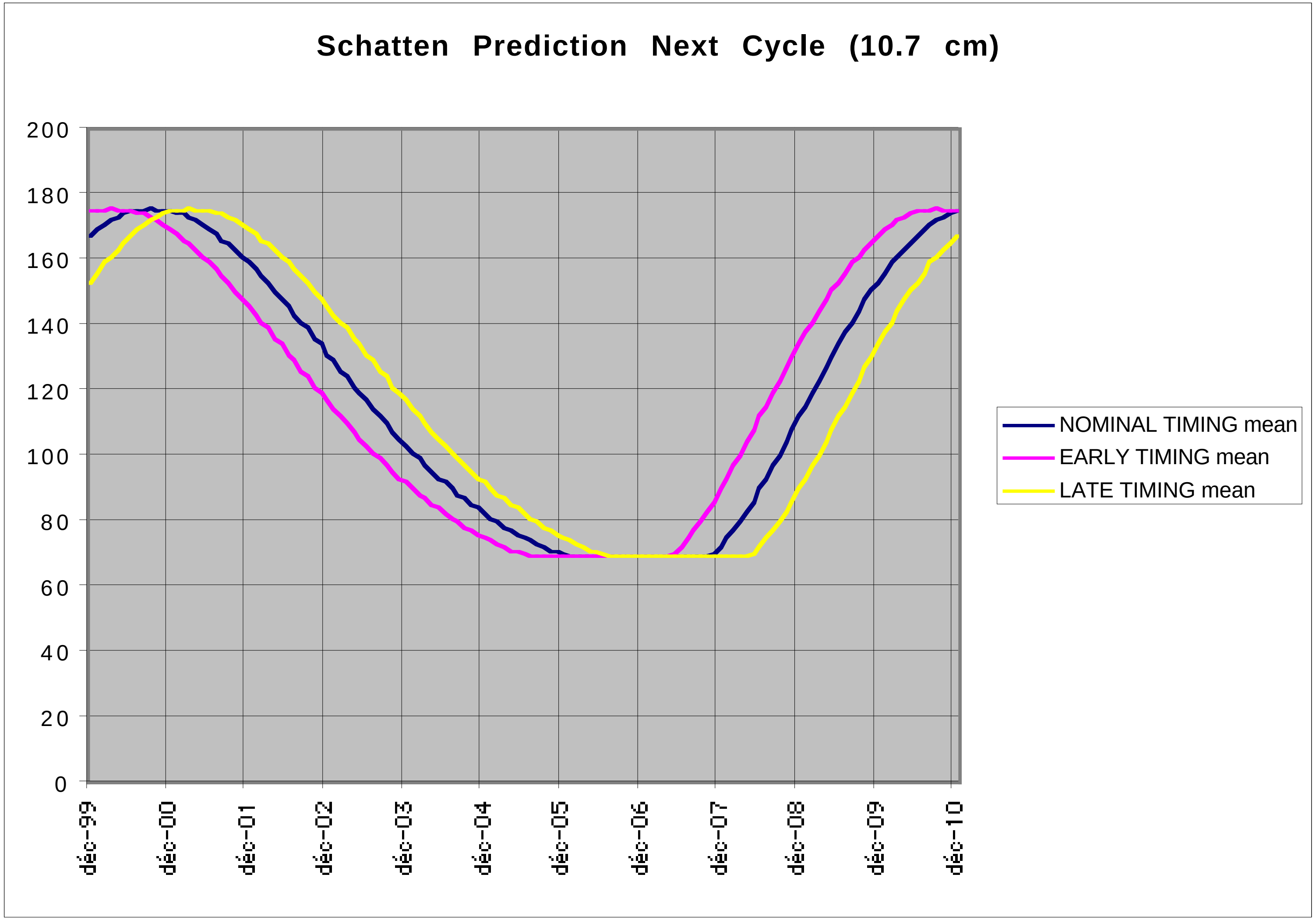
Presentation Content

- Key Mission aspects
- Scientific objectives
- Performance requirements
- SODISM/PICARD telescope concept
- Outline major issues (optical view point): scaling factor
- Development status
- Conclusion

PICARD Mission Facts

- Proposed January 98; selected October 98; Phase B 7/03/2000
- The CNES provides the microsatellite as a Line of Product bus (satellite 110 kg ; power 72 W; dimensions 60x60x80 cm^3):
  - ➥ Payload mass: up to 42 kg (no propulsion); power up to 42 W
  - ➥ Payload dimensions: 60x60x30 cm^3; Data rate: ≥ 1.5 Gbits/day
  - ➥ Pointing | normal (platform): ± 0.1°
scientific (active guiding using payload information): ± 0.01°
stellar calibration mode: ± 0.1°
stellar stability: 0.01°/s
bus pointing: > 90° in 10 mn (0.5°/s)
  - ➥ Datation: ± 0.5 s
  - ➥ Orbit restitution: ± 1 km
- Orbit and launch:
  - ➥ Launch now expected between mid-2005 & 2007 (before next solar maximum)
  - ➥ Nominal orbit: SSO 6h/18h 750 km 98° (➠ near continuity: oscillations) dedicated DNEPR launcher (PICARD master payload)

Launch Window for Ø/Cste Relation



Depending upon microsatellite lifetime, **3 or 4 y**:

launch **mid-2005 to mid-2007**

PICARD Scientific Objectives

- Confirm diameter variations (and validate ground measurements and their accuracy)
- Establish relation diameter/global irradiance/differential rotation
- Study the variability (long and short terms) of the parameters
- In particular (limb advantage) observe low degree p-modes and, if their amplitude allows, detect g-modes
- Oblateness measure and solar shape to higher orders (dynamo and convection)
- Provide Space Weather – solar activity full Sun images with 1'' resolution in magnetically sensitive lines (Lyman α) & continua (160 nm)

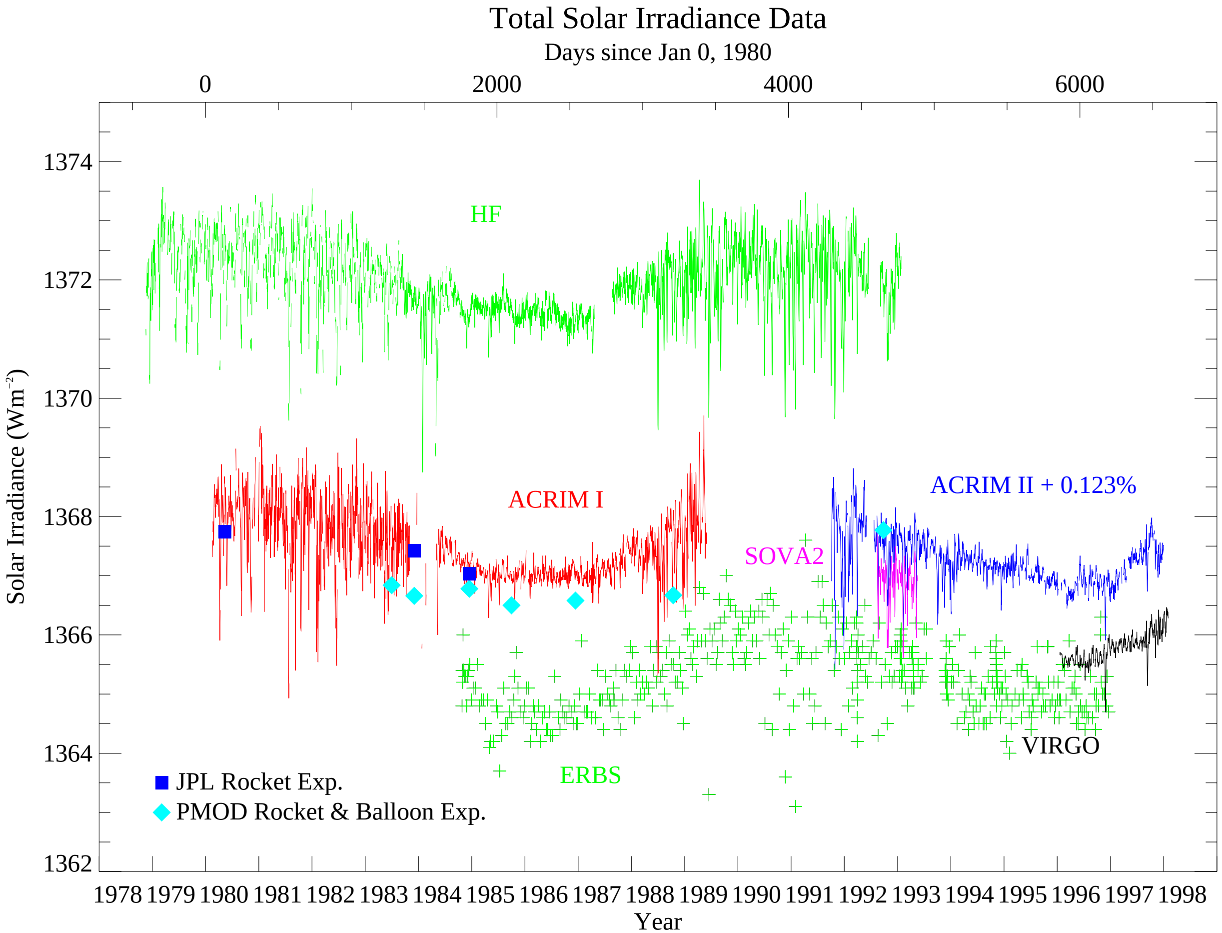
PICARD Measurements

- **Diameter at 230 nm (SODISM)**
- **Diameter at 548 nm**
  - ➥ link with & validation of ground measurements
- **Lyman Alpha images of the solar disk ⇨ Ionosphere**
- **160 nm images of the solar disk ⇨ magnetic activity**
- **Differential rotation**

- **The solar constant - global irradiance (SOVAP)**

- **The integrated solar UV flux at 230 nm (PREMOS)**
  - ➥ **ozone & photometric calibration of the CCD and in selected UV and visible bands (311, 402 and 548 nm)**

Solar Variability



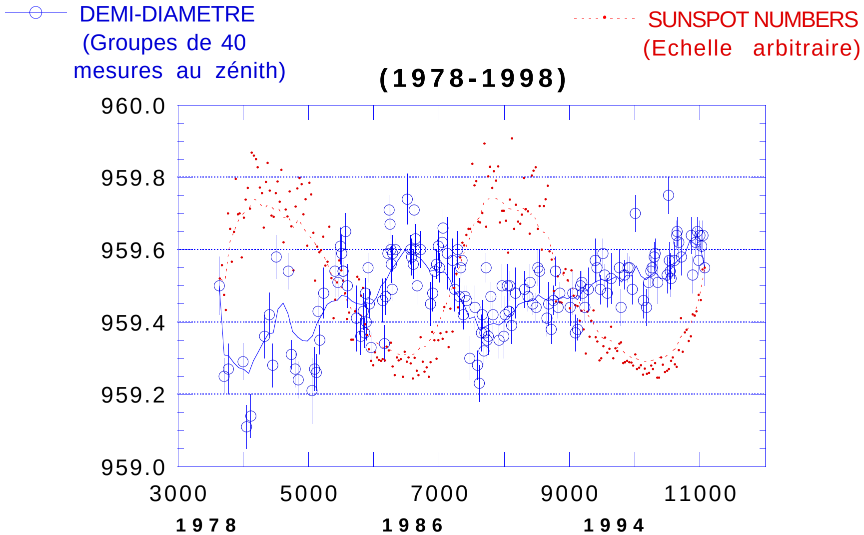
Cumulated Solar irradiance measures since 1980 (Fröhlich and Lean, 1998)

- **Variations of the solar irradiance ~ 0.1% with a period of 11 years (activity)**
  (with ~ 0.05% due to rotational modulation)
- **BUT: variations are principally due to the ~ 1% ultraviolet spectrum**
- **at 200 nm the variations of the spectral irradiance on the 11 years cycle is about 8%**
  (with ~ 4% due to rotational modulation)

Required Precision on the Diameter Measure (Climat)

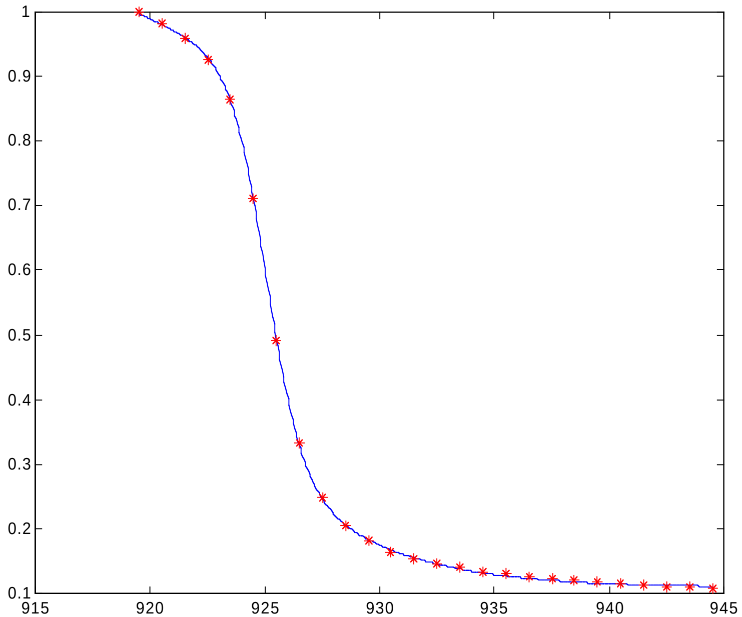
- **22 years F. Laclare serie (CERGA Astrolab)**

  ⇨ variation of ~ 0.2" on the semi-diameter, ~ 0.4" on the diameter over a solar cycle (less recently)



- **Desirable precision for SODISM would then be 0.004" (± 2 mas at 3σ) to evidence 11 years cycle variations and the tendency on longer periods (siecle). Further, PICARD measurement is nominally on 3 to 4 years only (amplitude variation < 0.1").**
- **The diameter measure is geometrical, absolute and reproducible :**
  - ➥ Absolute precision of **± 2 mas on the diameter** ⇨ dynamic of 25 on the measure (assuming ± 0.05" amplitude. If, like Kuhn, 2000, SOHO/MDI, only 20 mas variation observed on 3 years ⇨ dynamic of 5 on the measure only...)

Precision on the Diameter Measure



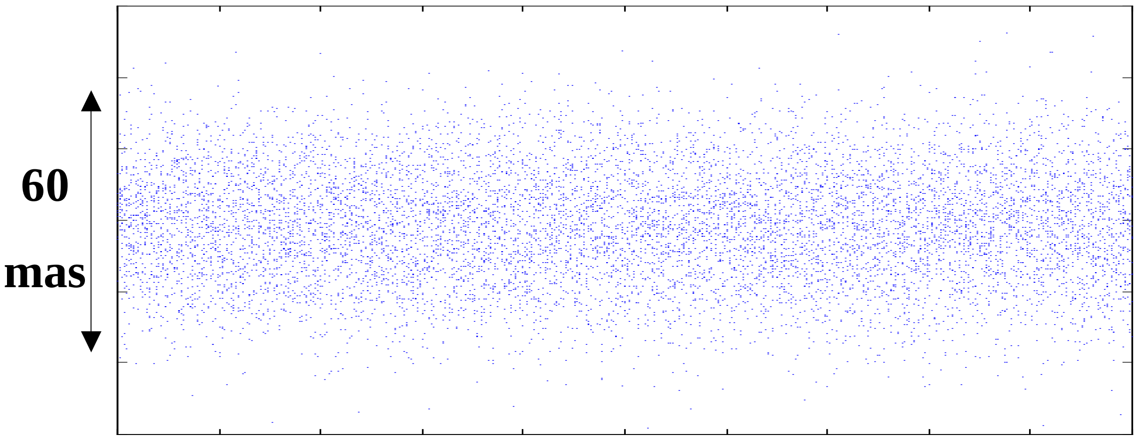
* Inflexion point measurement:

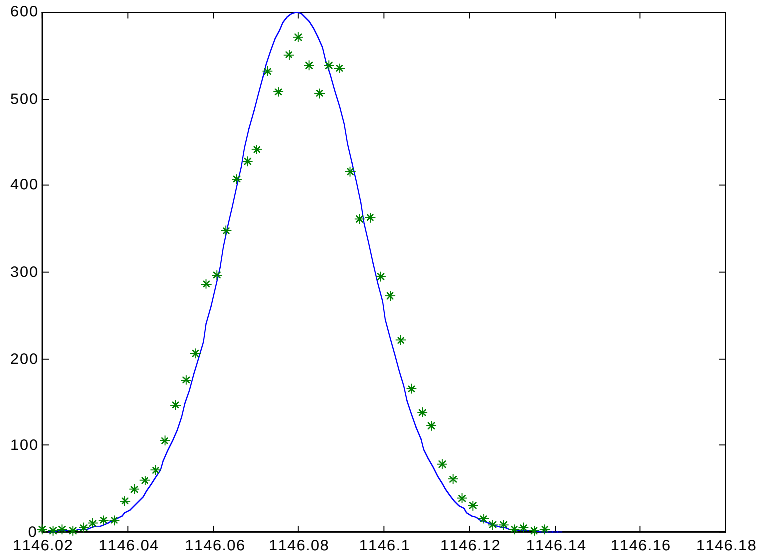
$$I(x) = a_1 + a_3 . \left(1 + \left(1 + e^{a_4 .(x - a_2)}\right)^{a_5}\right) . \left(1 + \left(1 + e^{a_6 .(x - a_2)}\right)^{a_7}\right)$$

* Precision on one realisation: σ ~ **10 mas**

* Precision on 100 measures: σ ~ **1 mas**

on 1000 limb measures: σ ~ **0.3 mas**





g-modes Limit with PICARD

- g-modes < 3 mm/s (GOLF)
- Objective: 0.1 mm/s (Kumar et al., 1996)
- Mode of one hour period: amplitude 0,2 m
- Application of the limb enhancement factor: 0,2 x 5 = 1 m
- In term of arcsec: $1.4\ 10^{-6}$

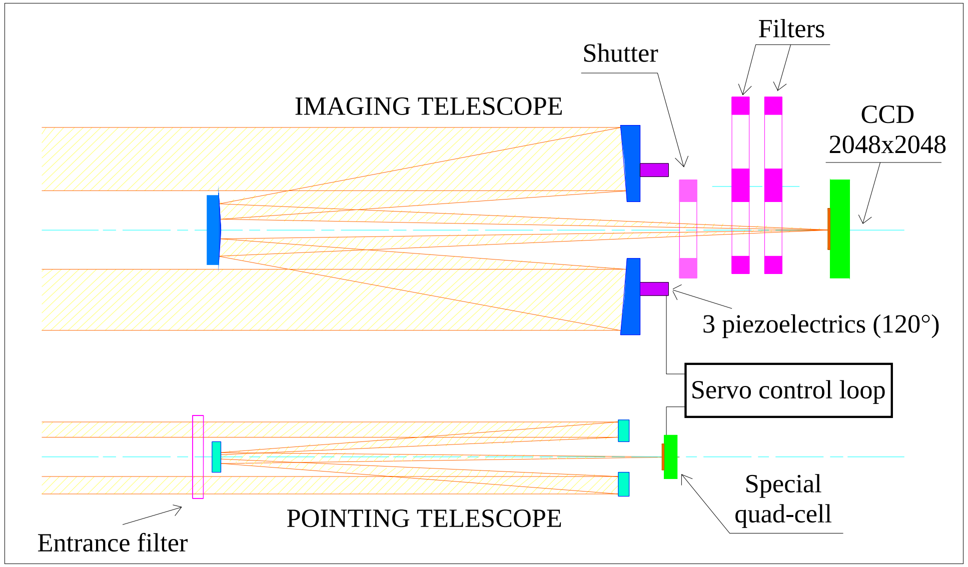
- If we suppose an instantaneous measure of 0.3 mas every 3 minutes we have:

$\sqrt{20 \times 24 \times 365 \times 2} \sim 590$ of noise reduction after two years

$0.3/590 \Rightarrow 0.5\ 10^{-6}$ i.e. a theoretical limit of ~ 0.1 mm/s

and PICARD mission is extensible to 6 years...

SODISM/PICARD Concept



4 observing modes and
2 calibration ones

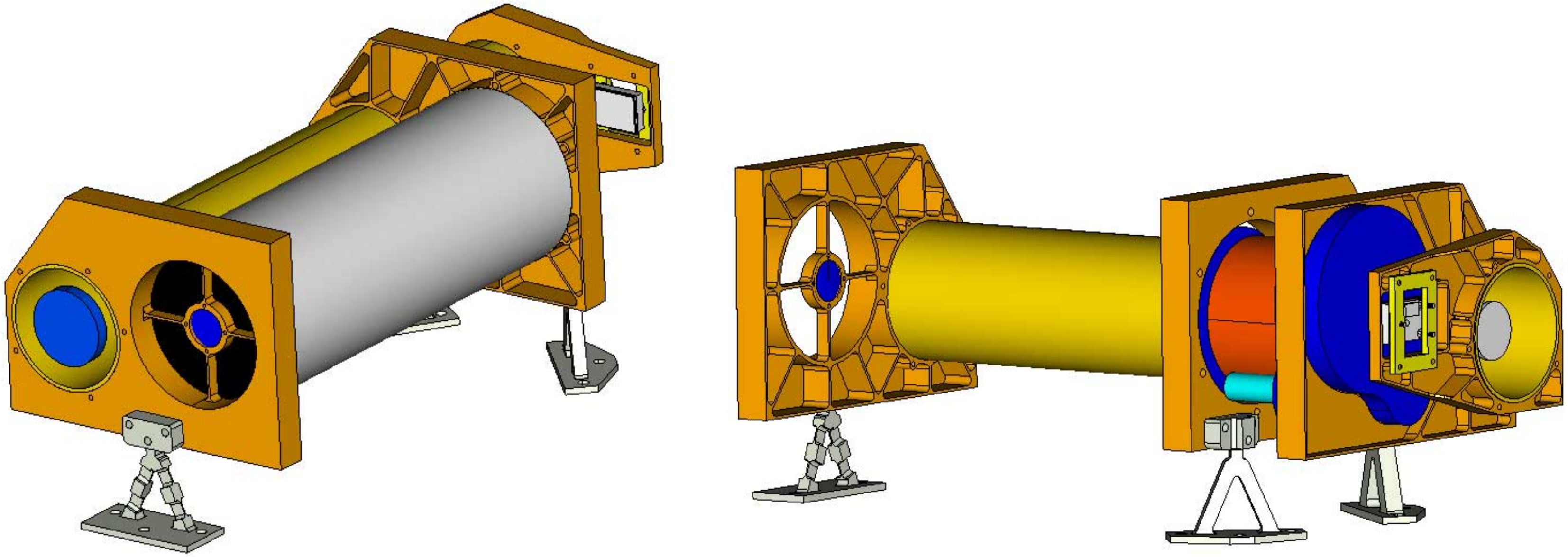
UV Nominal Mode	230 nm Δ8nm
Visible	548 nm Δ8nm
Magnetic Activity	160 nm Δ8nm
Prominences and Activity	Lyman α Δ8nm
Flat Field CCD	"Diffusion"
Stellar Field Imaging Δf	"Empty"

- Sound optical concept
  - active telescope Ø120 mm (3 piezos controlled by a guiding telescope)
  - large 2048x2048 CCD (thinned & back illuminated)
  - two filter-wheels behind a shutter
- "Best" choice of wavelengths
  - 230 nm "neat" UV continuum (limited limb-darkening; flat continuum)
  - Visible, 548 nm for ground validation
  - Activity monitoring at 160 nm & Lyα
- Mechanical stability
  - Carbon-carbon low dilatation structure allowing ± 0.5° control
  - SiC mirrors: no aging of coatings and high conductivity
- Absolute dimensional calibration
  - HIPPARCOS star field calibration absolute ≤ 2 mas; relative << 1 mas

Material Characteristics

	SIC	CC	Zerodur	INVAR superior	CFRP 954-3/K135 2U
ρ in Kg/m^3	3200	1500	2500	7800	1700
E in MPa	420 000	60 000	91 000	145 000	320 000
Re in MPa	70	40	5	150	150
α 10^{-6} m/m°C (CTE)	2	-0,1	0,02 à 0,05	0,75 à 2	-1
λ in W/m°C	180	7	1,6	10	45
λ/α	90	70	80	10	45
E/ρ	131	40	36	19	188
Long term instability µm/m	0	0	2	2	6

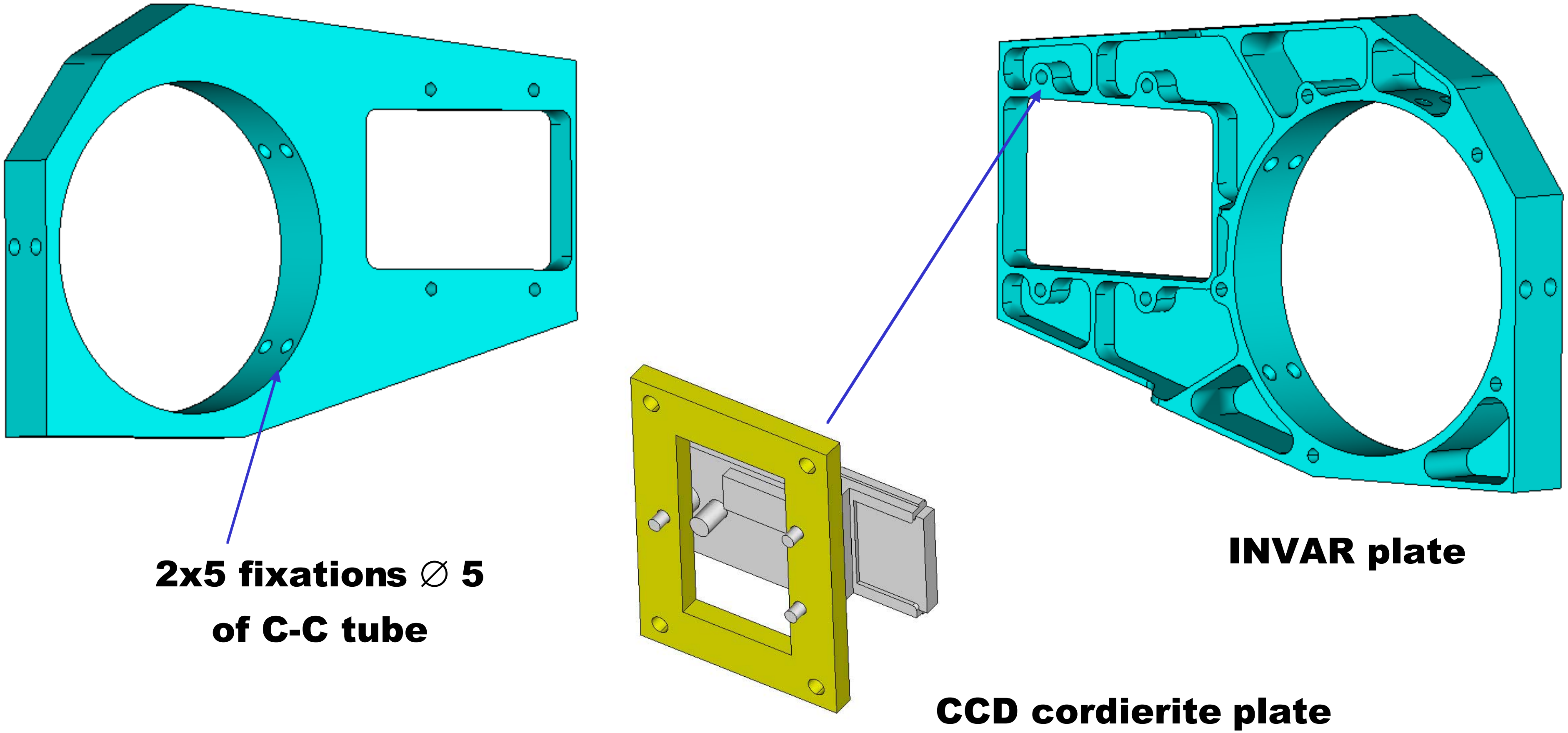
Mechanical Design of SODISM/PICARD



- Mechanical structure of the SODISM/PICARD telescope (350 mm between the primary and secondary mirror and 150 mm between the primary and the CCD surface.
- Note the **4 INVAR plates** linked together with the 550 mm long **Carbon-Carbon tube** (shown in light brown) of Ø100 mm.
- The primary mirror is mounted on 3 piezoelectrics driven by a guiding telescope directly placed inside the C-C tube.
- The **CCD (cooled to –40°C)**, is uncoupled of the INVAR plate by a **Cordierite support**.

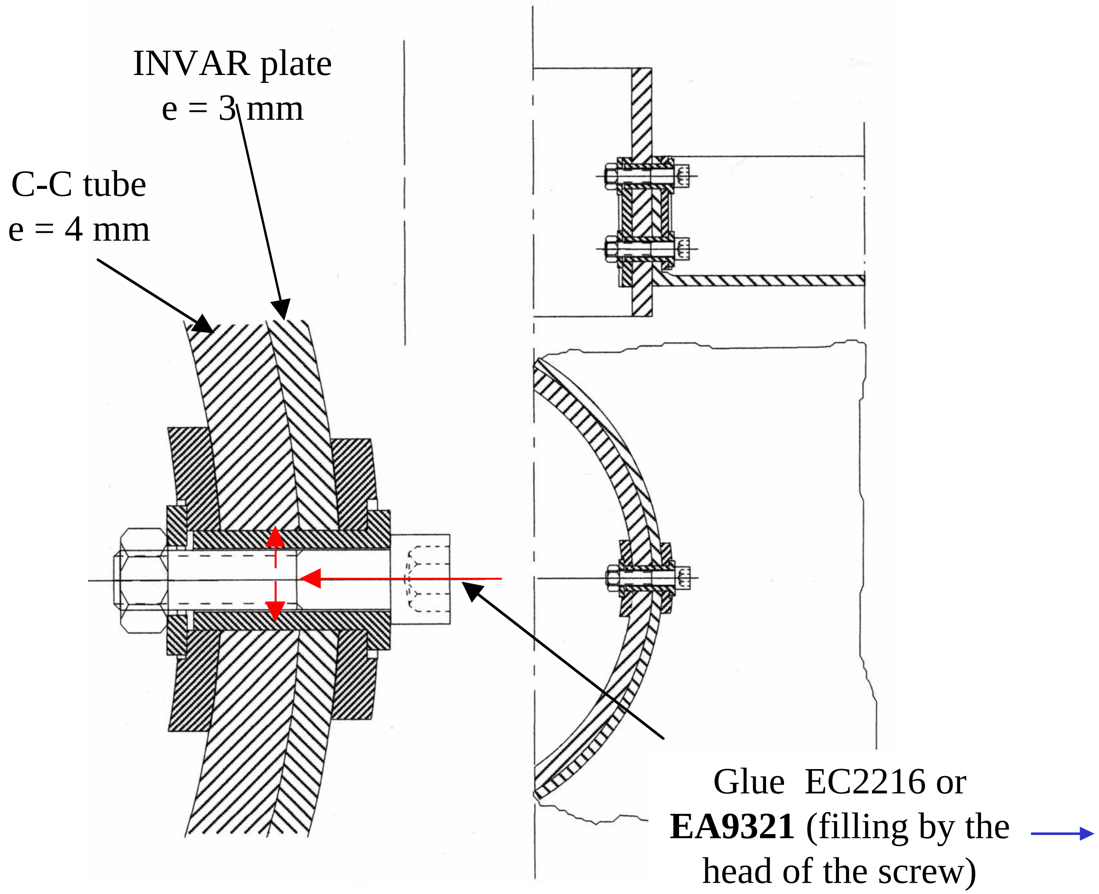
Interfaces (1)

CCD plate **Height 130 mm; Length 202 mm; thickness 20 mm; mass 0.6 kg**



Interfaces (2)

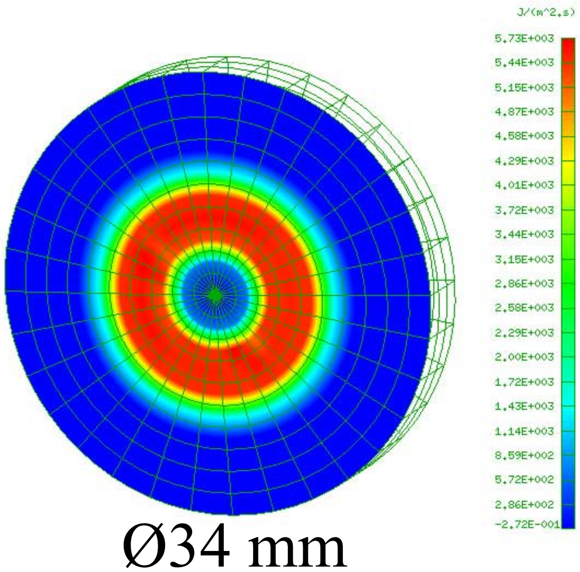
Fixation C-C tube with the INVAR plates

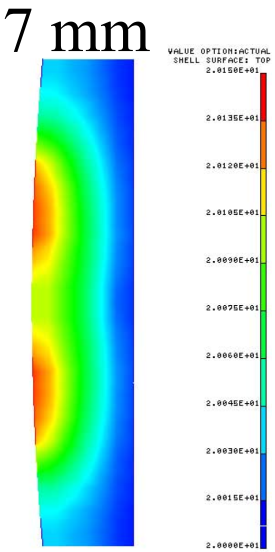


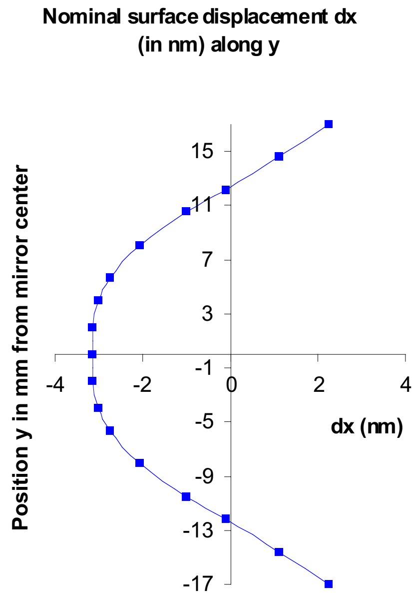
This limits µslipering

(glue elasticity)

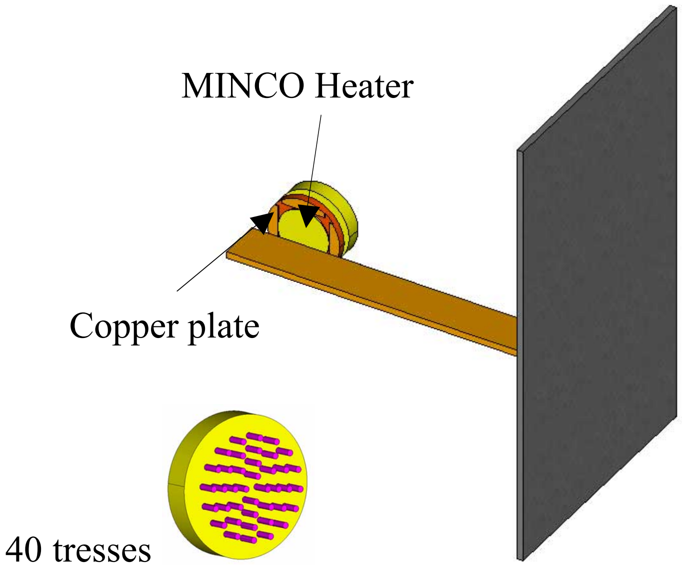
M2 Mirror Shape and Cooling







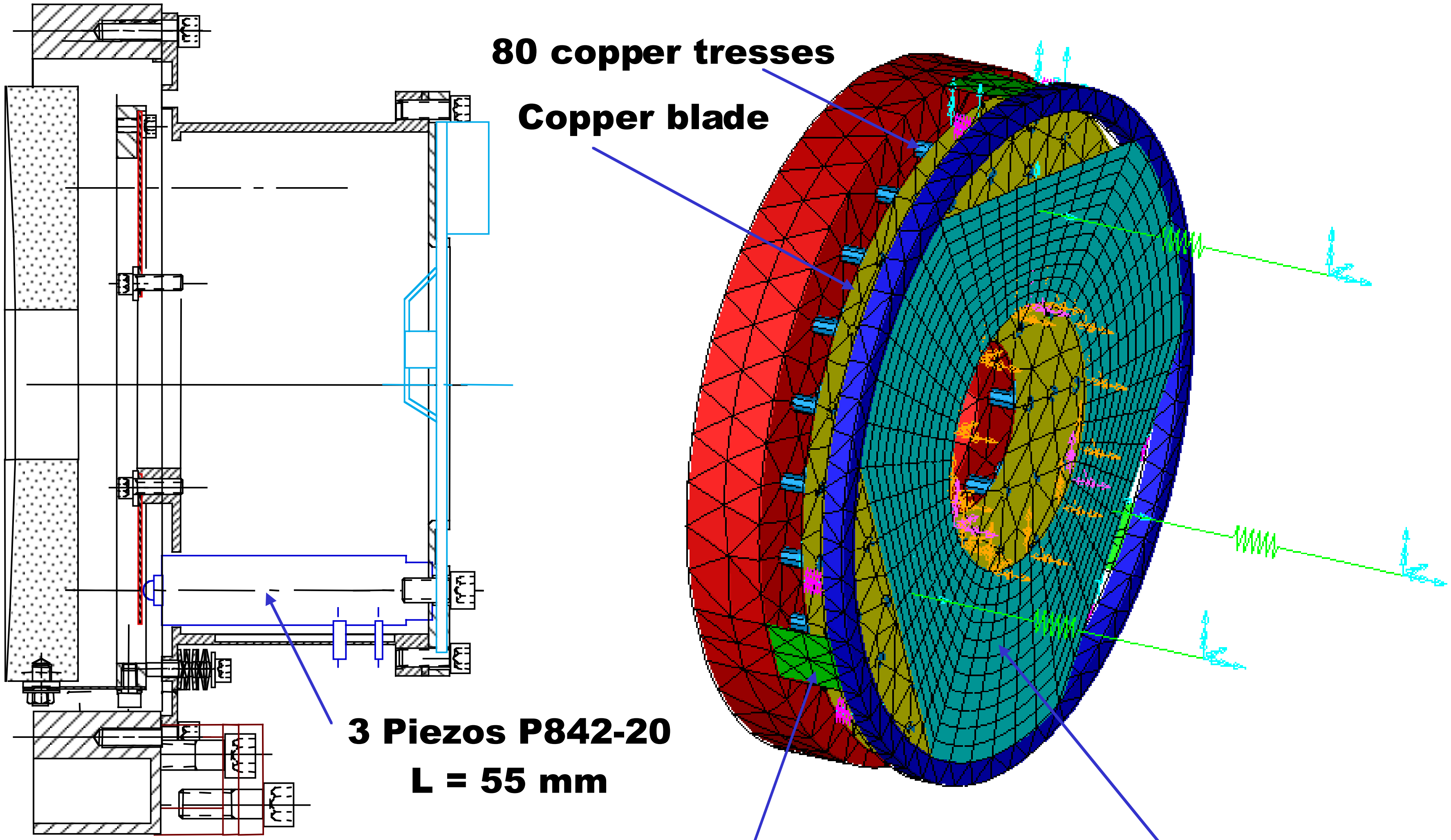
3 nm
⇓
12 mas



Half FOV (°)	COOLING 4°C ΔR = 1.563µm	COOLING 4.14°C ΔR = 1.618µm	COOLING 4.3°C ΔR = 1.680µm
0.05	-0.109	-0.042	0
0.1	-0.226	-0.092	0.033
0.15	-0.301	-0.100	0.059
0.20	-0.365	-0.097	0.125
0.25	-0.366	-0.031	0.204
0.2667	**-0.354**	**0.003**	**0.346**

Angular error on the diameter when cooling from Sun to Stars (in mas)

M1 Mirror Support (Piezos & Cooling)



Pointing Issues

- Requirement of 0.1'' (1/10th of a pixel) classical criteria of image quality) on an openloop system ± 30'' (± 15'' mirror) @ 50 Hz response
- The pointing telescope provides an error signal to the satellite to control its pointing to the ± 30'' pre-fine pointing range
- PI piezos foreseen, type 842.20 PI, double jauge (athermal at first order)
- Maximum hysteresis of 0.2%. If 15'' represents 6 μm (on piezo accounting coupling by thin blade) then 0.2% gives 0.06''

Focal Plane

- 2k x 4 k CCD by Marconi (EEV 4280), thinned and back illuminated, square pixels 13.5 μm. Frame transfer device identical to COROT CNES Proteus Mission. 2k x 2k used (exposure time controlled by shutter) @ -40°C
- Excellent characteristics:
  - ➥ Dark current: 0.1 e-/s/pixel
  - ➥ Flatness: smooth and < 1 μm (on solar limb position)
  - ➥ Flatfield: some irregularities at short wavelengths
    ➠ ~ 15% @ 230 nm (laser stabilization)
- 2 EM (eng. models) delivered and currently under test
- Impact on imaging/scaling is due to CCD dimensions. Silicon CTE is $2\ 10^{-6}$ ➠ stringent temperature control to 0.2° for 0.4 mas error on radius (3 heaters on INVAR housing)

Error Budget Summary

Error source	Nature of the error	Dilatation	Effect on radius
Structure	tube carbon-carbon: 2 10^{-7} on 350 mm @ 0.5°C)	± 40 nm	0.25 mas
	primary mirror to focal plane: C-C tube on 150 mm @ 0.5°C	± 17 nm	0.11 mas
	links (Invar plates to tube, mirrors supports, piezos)	± 20 nm	0.12 mas
Optics	curvature of the primary mirror in SiC and thermal stability @ 0.2°C	12 nm	< 0.1 mas
	curvature of the secondary mirror in SiC and thermal stability @ 0.1°C	3 nm	< *0.4 mas*
CCD	silicon thermal expansion 2 10^{-6} on 12.5 mm @ 0.2°C	0.005 µm	*0.4 mas*
Mean quadratic error budget (3σ)			***0.65 mas***

Error budget of SODISM telescope on the solar radius measurement

At <u>6σ</u> on the DIAMETER ➠ 1.8 mas

Absolute Geometrical Calibration

- We use HIPPARCOS 100 000 stars: positions known to 1 mas in 1991 but: proper movement error of 0.6 to 1 mas per year

  ➥8 to 10 mas error in 2005 (DIVA?)

- 3, 4 or more stars ⇨ better precision on the absolute scaling factor
  With 6 stars ⇨ 15 relations and precision x 4
- Method : barycenter of stars (spreading by pointing stability of 0.01°/ second (± 18'' on 1 second)
- Influence of photon noise and exposure time (dark current)
- In practice: if σ = 6 pixels (6''), 10^7 photons (m_v = 5; type B5) in 1 s

  ⇨ absolute error on 1 star (beside absolute position) = 3 mas.
  Several stars and several exposures, shorter exposure time or better pointing:

  2 mas or less

Development Status

- Delays in the program and an alternative design proposed for the telescope resulted in a CNES AUDIT which ended recently
- The original concept (SiC mirrors, C-C tube, large CCD) is confirmed as the <u>nominal solution</u>
- Cooling of mirrors has to be confirmed by breadboarding before PDR (➠ launch in 2005-2007 window)
- Breadboard of active pointing carried in parallel
- The 2 EM of the Marconi/EEV CCD have been receipted and present excellent characteristics (dark current, flatness and flatfield). A test bench is setup (based on COROT bench)
- Electronics (CCD acquisition, compression and control) is under definition and could benefit of MPI/Lindau expertise

Conclusion

- The rightness of the proposed concept (C-C structure, SiC mirrors, large CCD) is confirmed and performances in the range of ± 2 mas on the absolute solar Diameter measure is foreseen. Relative measures to a significant fraction of a mas are probably possible.
- Despite the excellent properties of SiC, the heavy thermal load generated by Solar observing requires a careful cooling of the SiC mirrors because of the residual gradients
- Straylight effects have been sized (see the excellent P. Echeto poster)
- We thank the CNES who made these small missions a reality well suited for scientific needs by its coherent possibilities for pointing, mass, power, volume, telemetry and launch capabilities
- One concern though: the "spirit" of microsatellite based on short stimulating developments much along the UMEX line is in risk of "sedimentation" as classical 5-6 years programs. CNES and laboratories have responsabilities to reorient the current tendancy if several μsat per year are really expected (CNES and laboratories management structures)