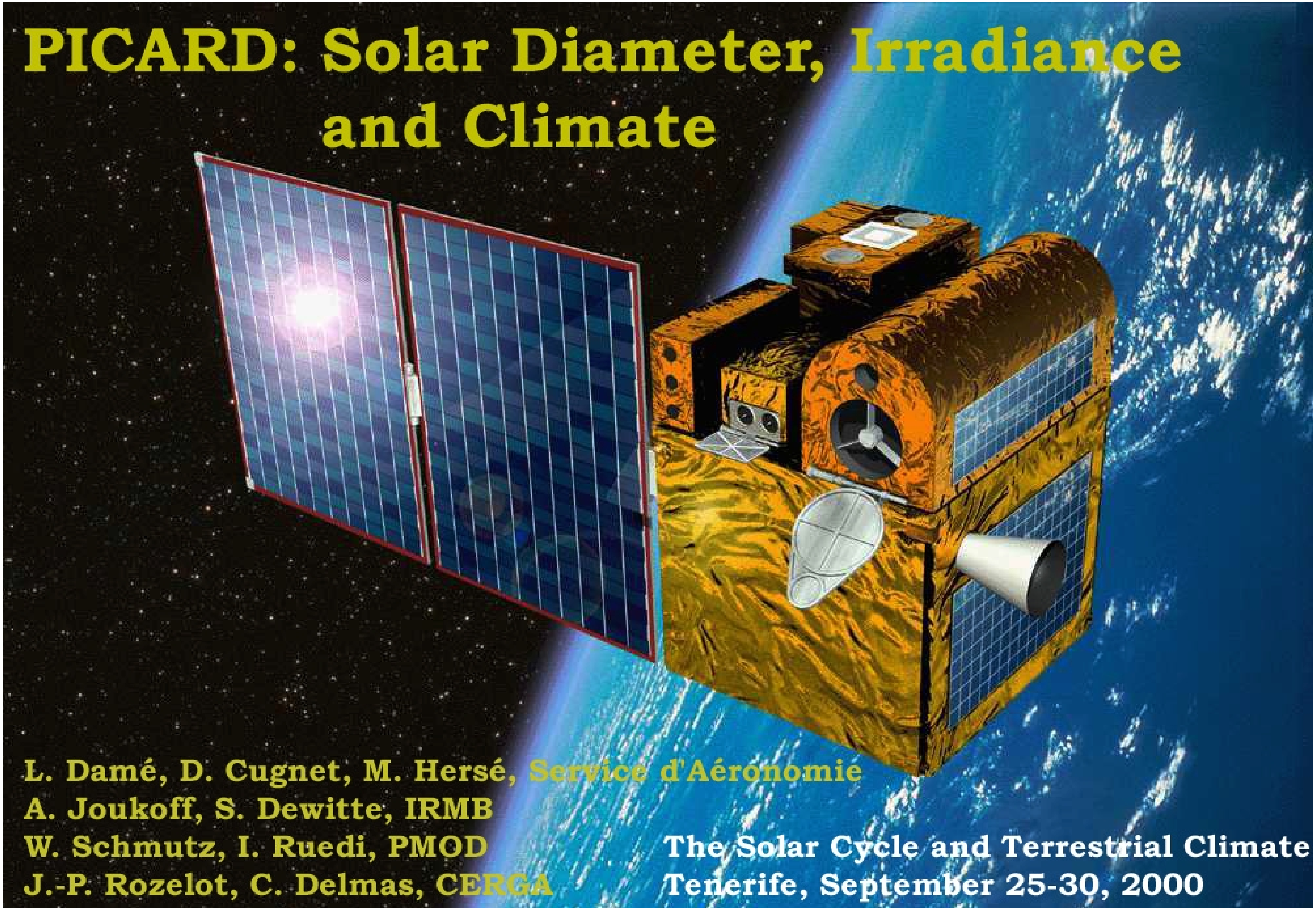

PICARD: Solar Diameter, Irradiance
and Climate
L. Damé, D. Cugnet, M. Hersé, Service d'Aéronomie
A. Joukoff, S. Dewitte, IRMB
W. Schmutz, I. Ruedi, PMOD
J.-P. Rozelot, C. Delmas, CERGA
The Solar Cycle and Terrestrial Climate
Tenerife, September 25-30, 2000

PICARD

Simultaneous measurements of the solar diameter, differential rotation, solar constant and of their variabilities.
Consequences for Earth climate and the internal structure of the Sun.

- **Scientific objectives:**
  - Confirm diameter variations (and validate ground measurements and their accuracy)
  - Establish relation diameter/global irradiance/differential rotation
  - Study their variabilities 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)
- **Three instruments:**
  - SODISM for the diameter measure (1 mas) and differential rotation (UV, 230 nm, and visible)
  - SOVAP for the solar constant (TSI)
  - PREMOS for flux monitoring in selected UV and visible spectral bands (ozone: 230 nm)

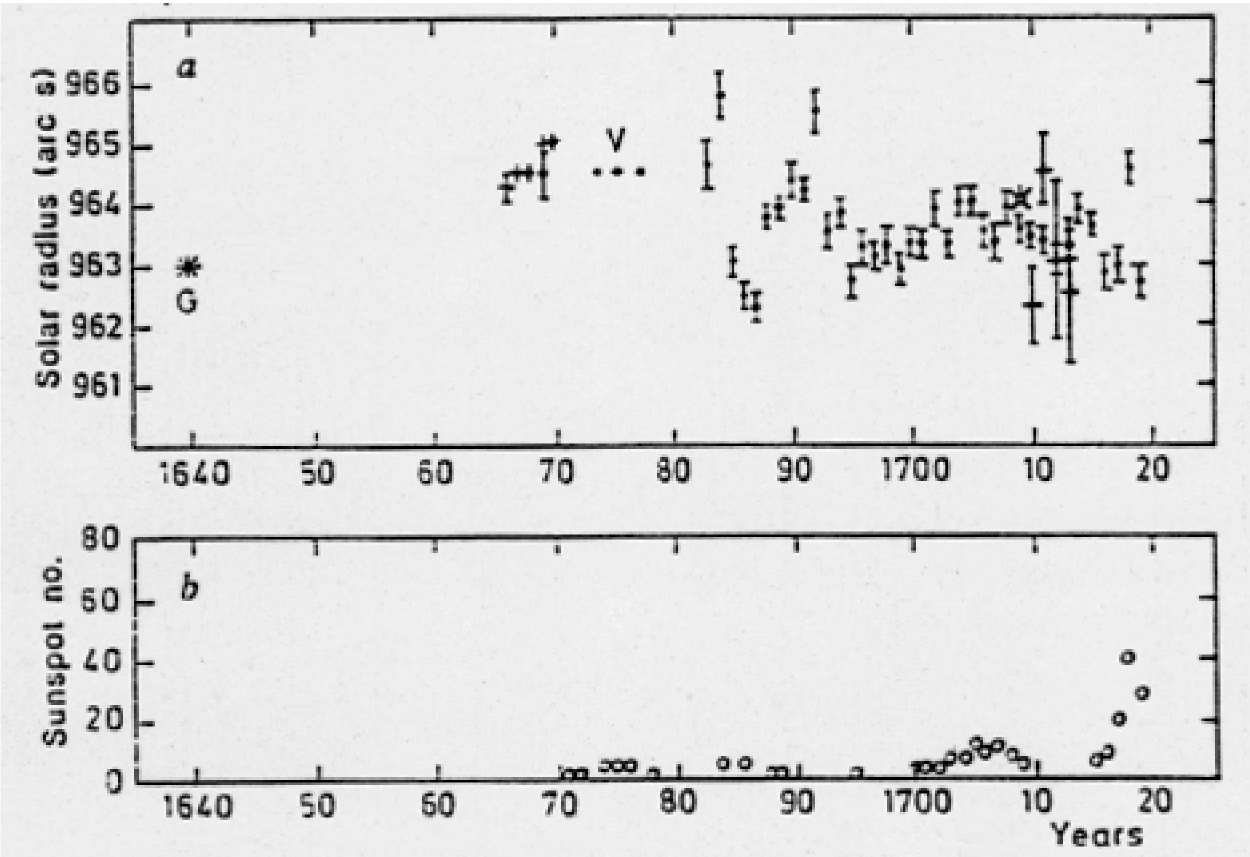
PICARD Mission Facts

- 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 80 W; dimensions 60x60x80 cm^3):
  - ➥ Payload mass: up to 45 kg (no propulsion); power up to 48 W
  - ➥ Payload dimensions: 60x60x30 cm^3; Data rate: 1.6 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 expected before the end of 2003 (before solar minimum)
  - ➥ Nominal orbit: SSO 6h/18h 800 km 98° (➠ near continuity: oscillations) dedicated DNEPR launcher (PICARD master payload)

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's Historical Diameter Measures

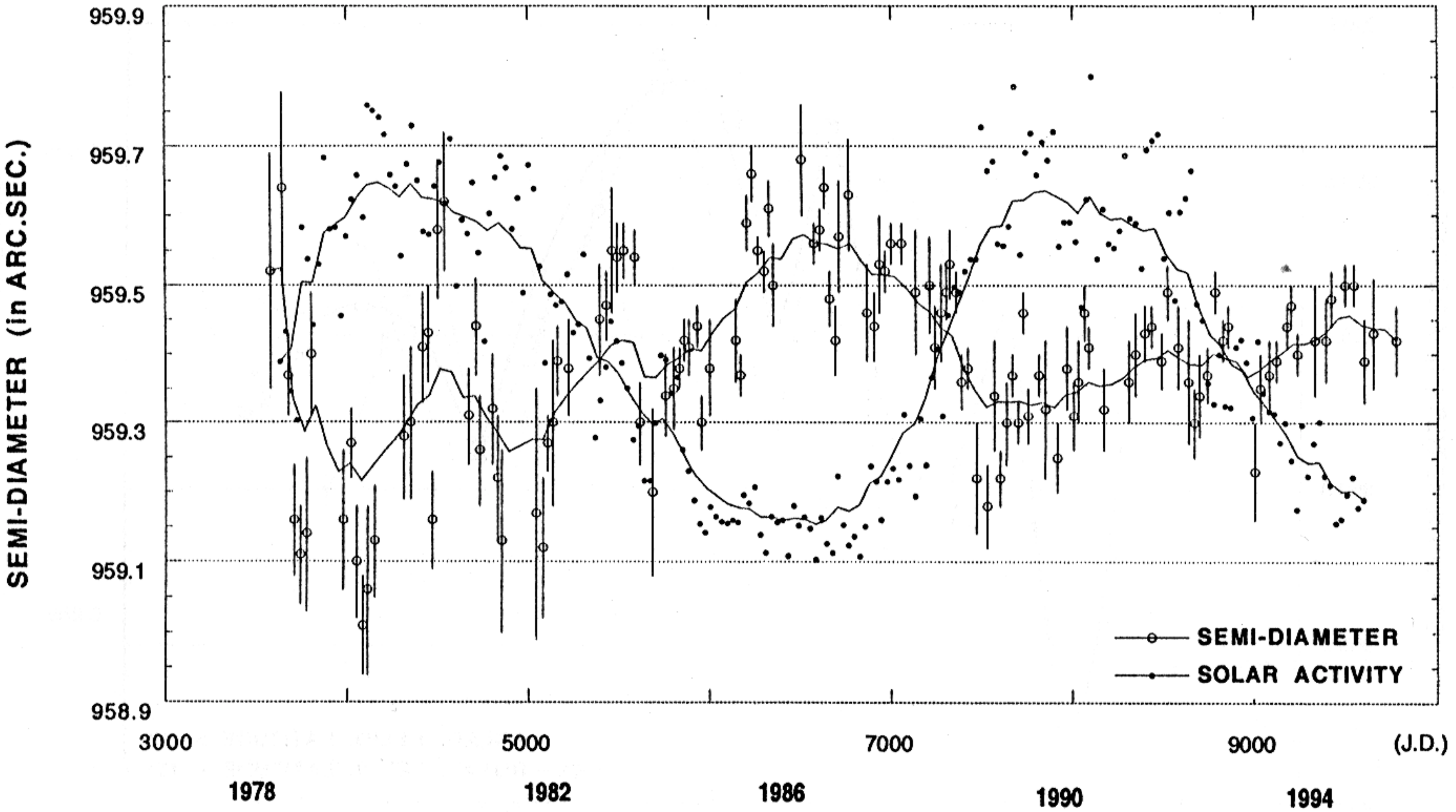


Solar diameter variation between 1640 and 1720.

Sunspot Number variation during the same period.

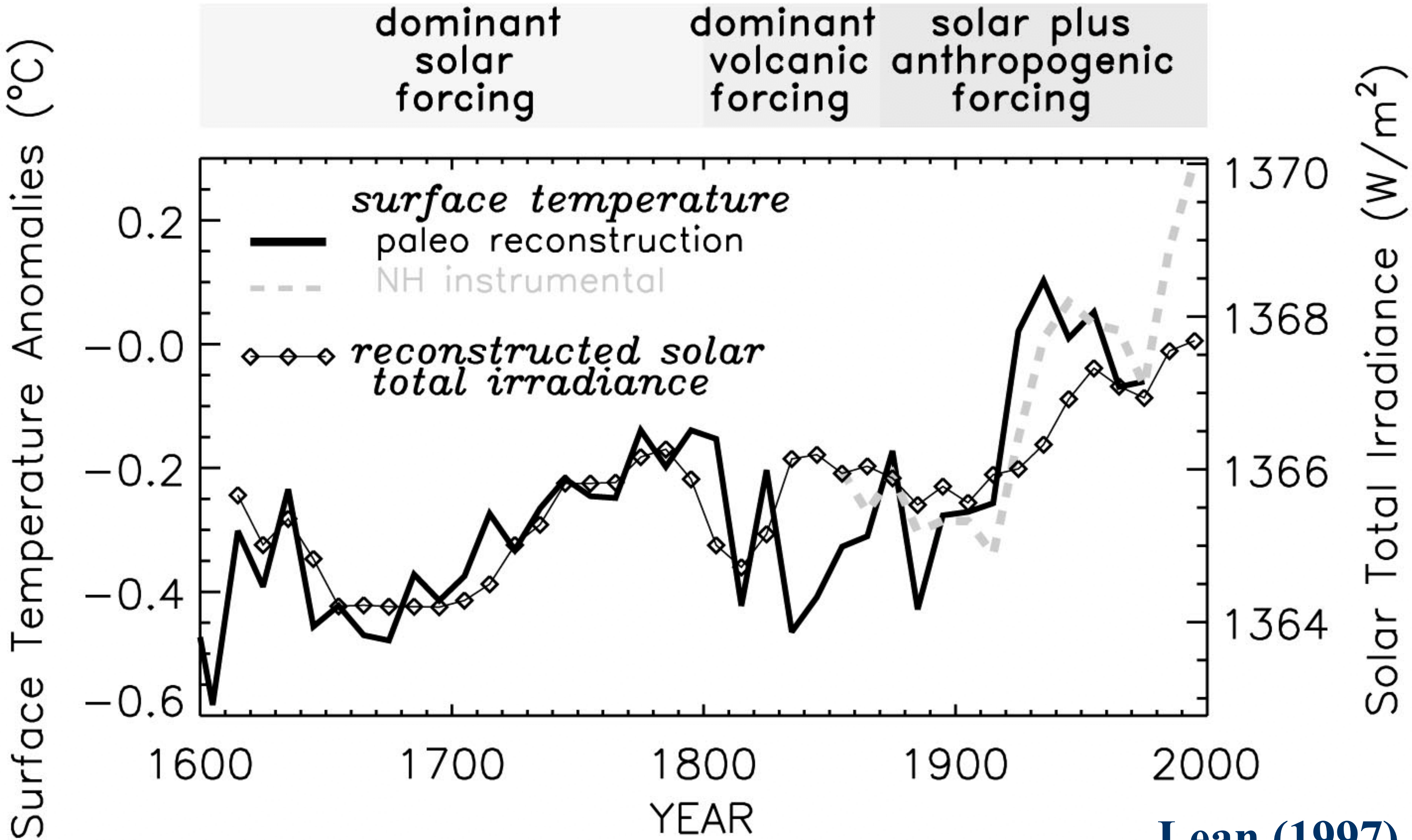
Outside the <u>Maunder Minimum</u>, the values of the diameter measured by Picard are significantly **smaller than the ones measured during the Maunder Minimum** (Ribes <u>et al</u>., 1987). Point "G" was measured by Gascoigne. The crosses are measurements obtained by the micrometer, and the points by the time laps.

Opposing Phase between Sunspot Number and Semi-Diameter Variations (Laclare et al., 1996)



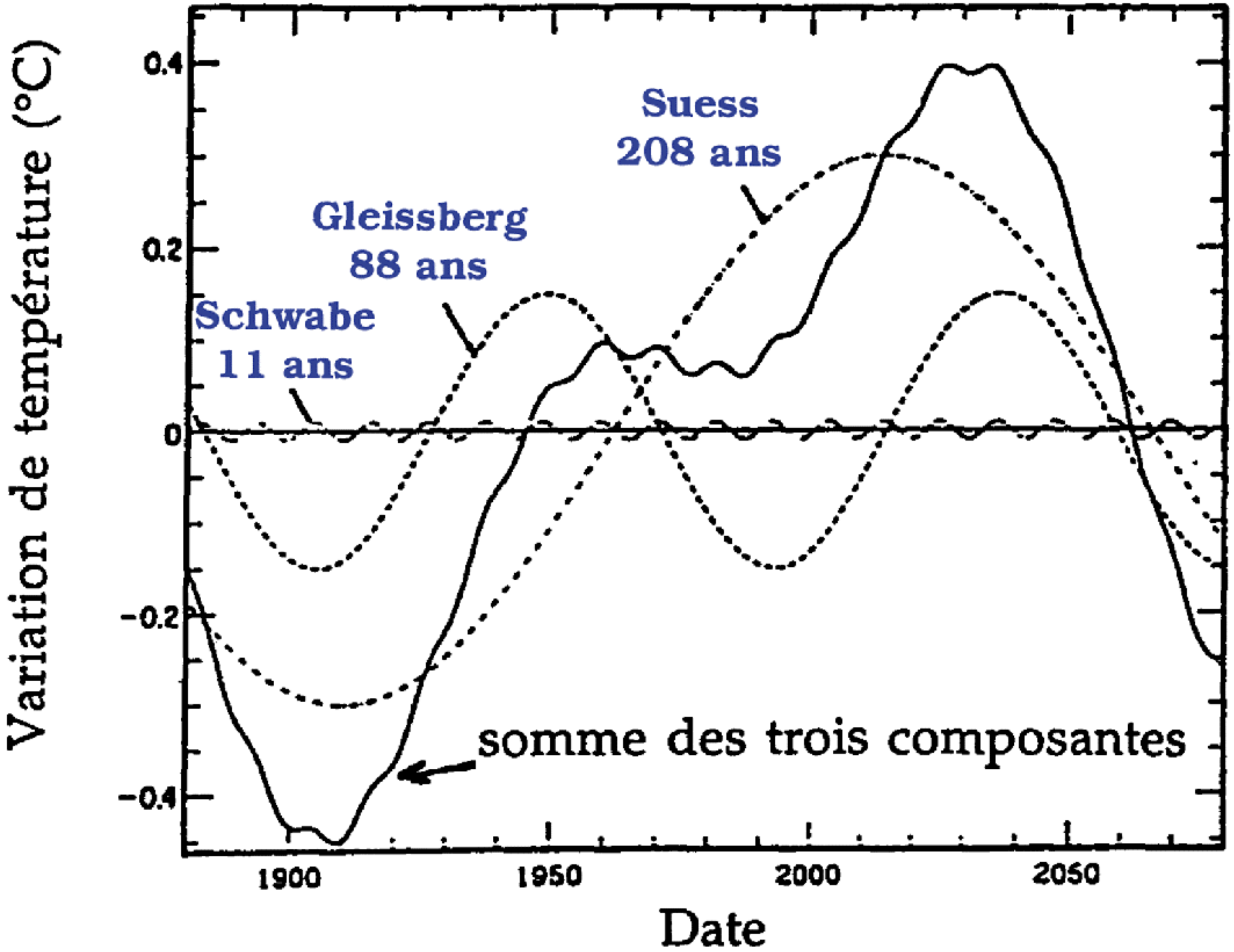
Observations carried with the Astrolabe of CERGA

Solar Irradiance and Surface Temperature



Lean (1997)

Climate and Solar Cycles Possible Effect

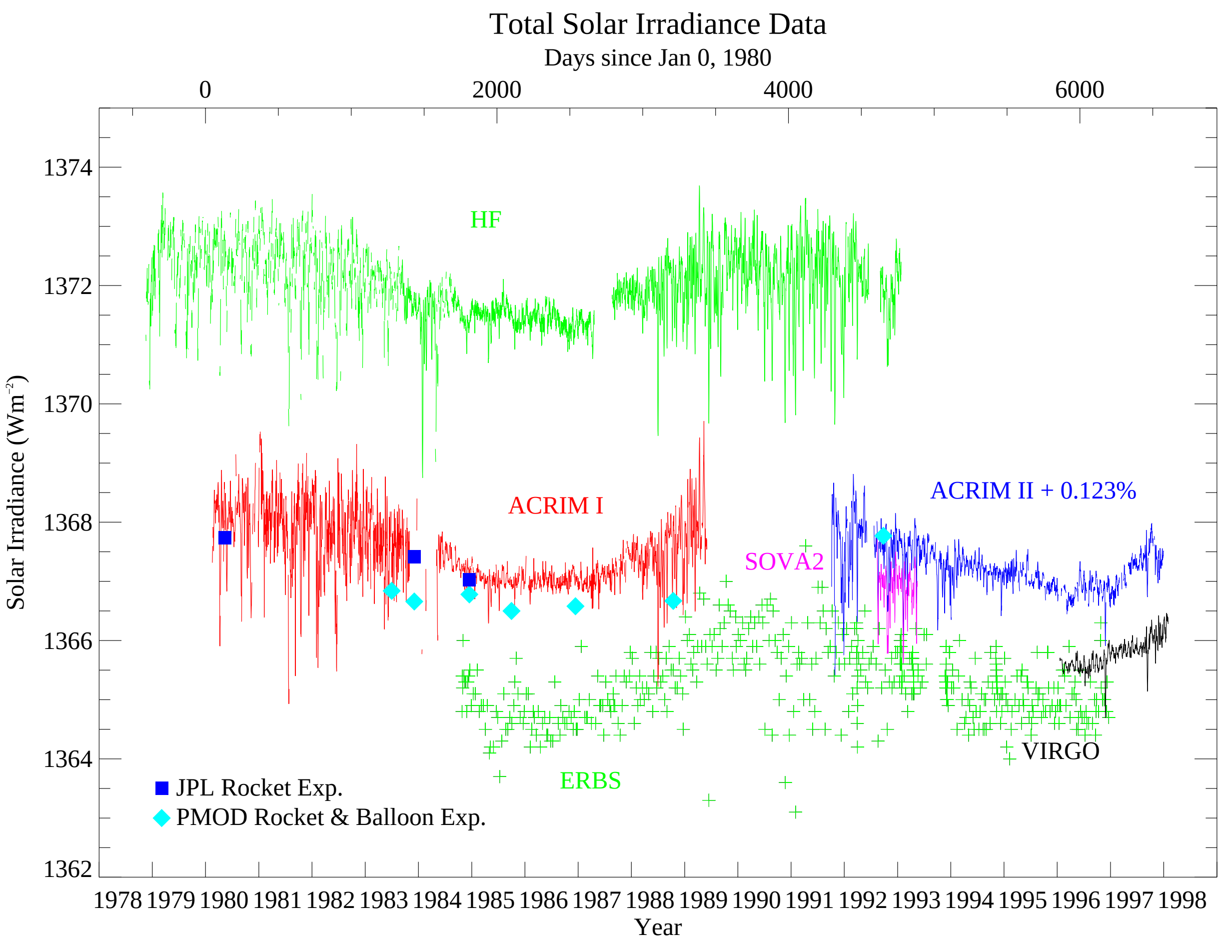


Damon & Jirikowic (1992)

Diameter vs. Solar Constant

- Radiometers: absolute precision limited to $\pm$ 0.15%
- Use of the same instrument? (ACRIM I & II...)
- Diameter: absolute <u>geometrical</u> measure - reproducible
  - ➥ precision 2 mas ➠ dynamics $\geq$ 200 (assuming 0.4'' over 11 years)

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)**

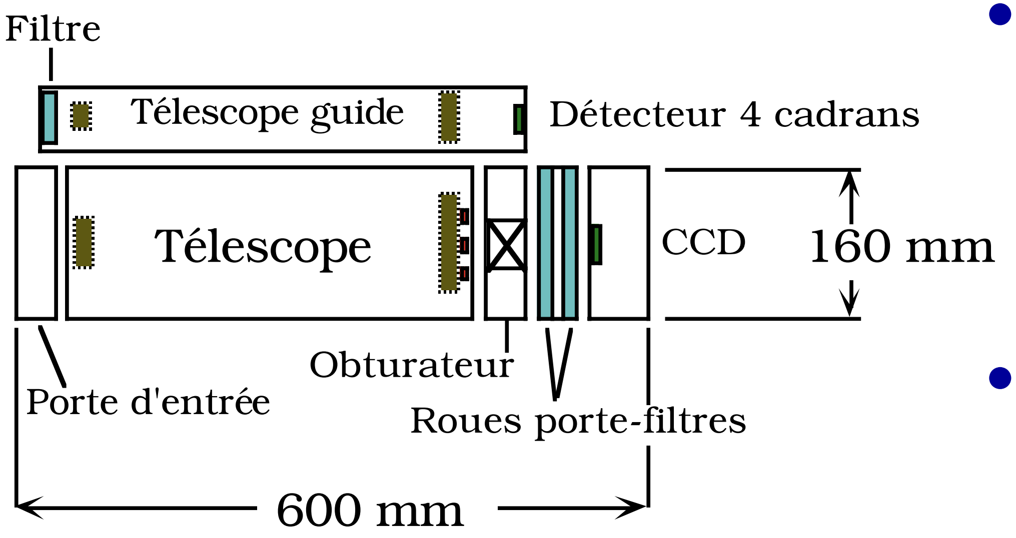
PICARD Measurements

- 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)

SODISM/PICARD Concept

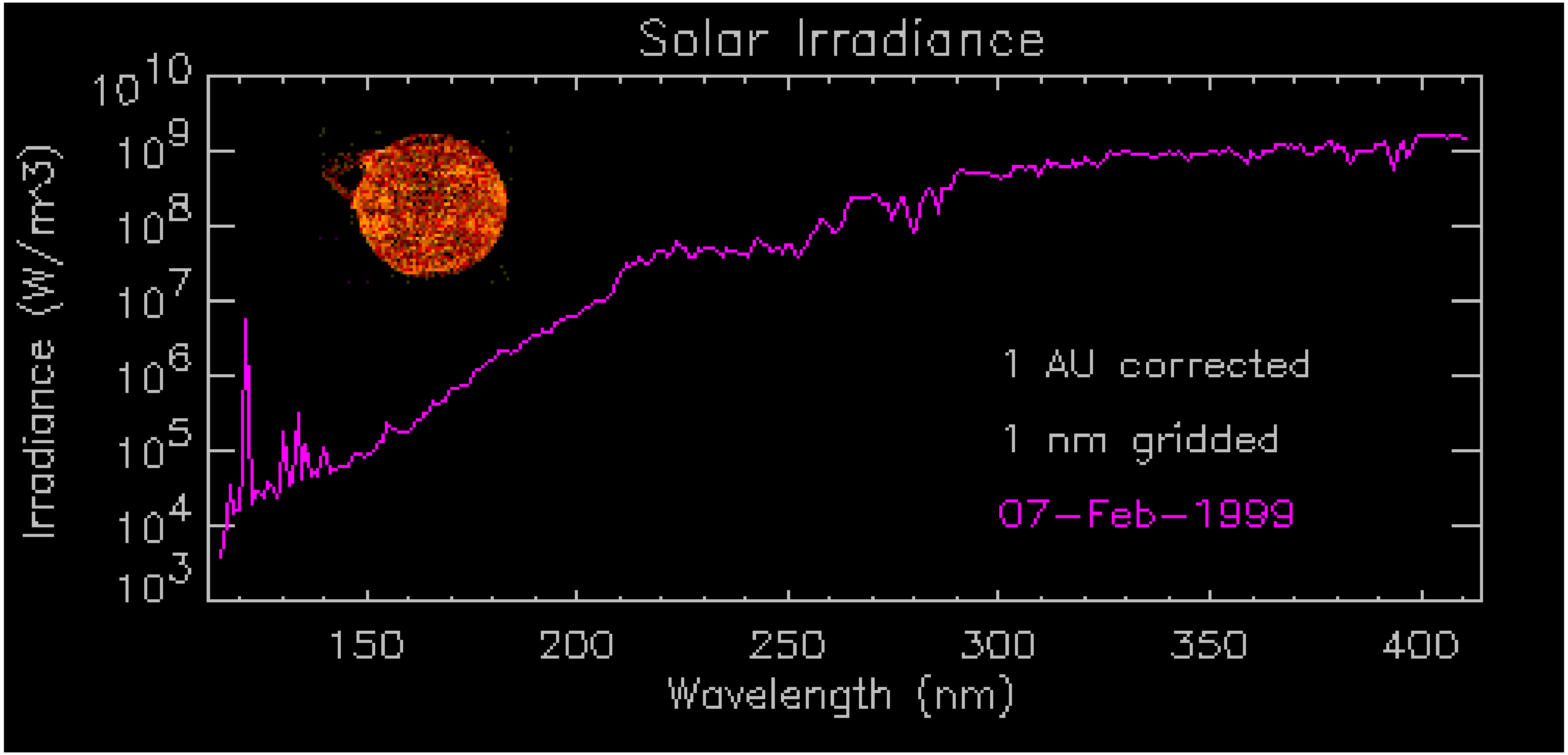


4 observing modes and
2 calibration ones

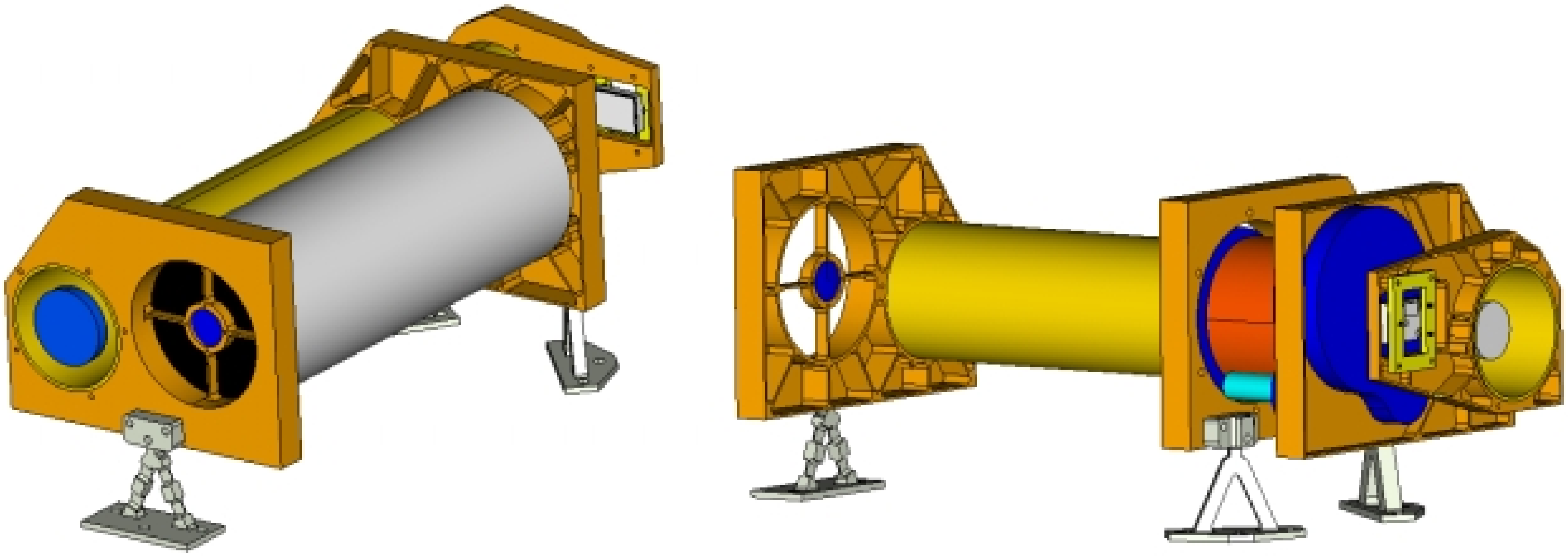
UV Nominal Mode	230 nm Δ8nm
Visible	548 nm Δ8nm
Magnetic Activity	160 nm Δ8nm
Prominences and Activity	Lyman α Δ8nm
Flat Field CCD	"Diffusion"
Stellar Field Imaging Δf	"Empty"

- **Sound optical concept**
  - active telescope Ø120 mm (3piezos 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 ≤ 1 mas; relative << 1 mas

Solar Irradiance:
Recent Solar spectrum from SUSIM UARS



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: total length without cover of 550 mm). Note the 3 Invar plates linked together with the 550 mm long carbon-carbon (shown in light brown) tube 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 decoupled of the Invar plate by a Cordiérite support.

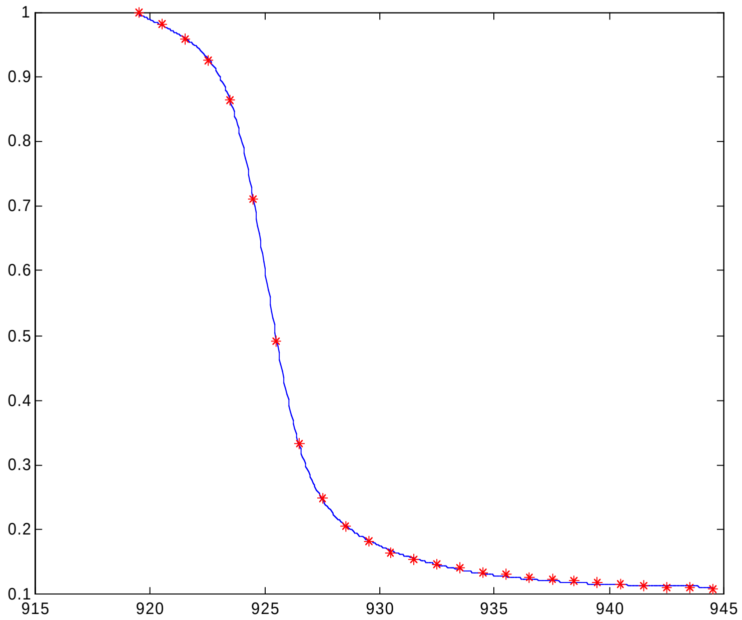
Absolute Geometrical Calibration

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

  ➥8 to 10 mas error in 2003
- 2, 3 or more stars ⇨ better precision on the absolute scaling factor
- Method : barycenter of stars (spreading by pointing stability of 0.01°/ second (36'' 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 and type B5) in 1 seconde ⇨ absolute error on 1 star = 3 mas. <u>Several stars or shorter exposure time or several exposures or better pointing</u>:

  1 mas or less

Precision on the Diameter Measure



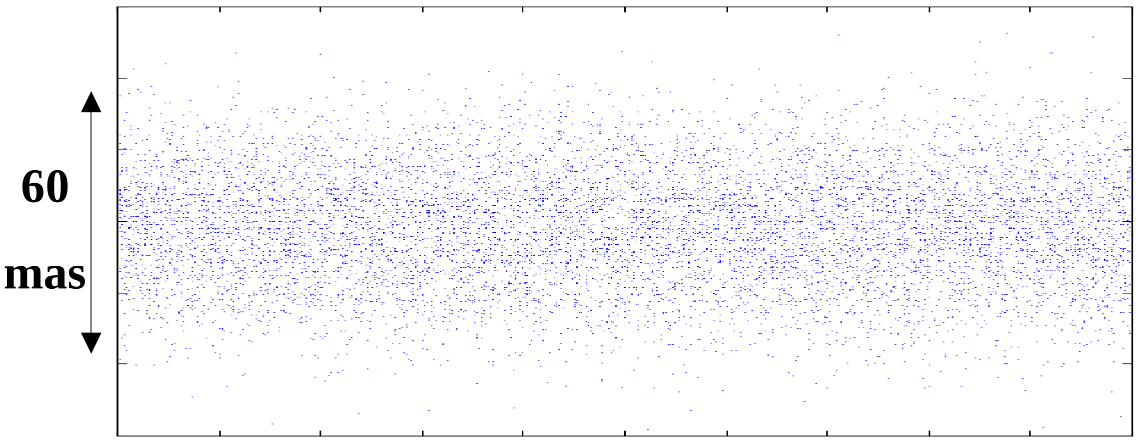
* Inflexion point measurement:

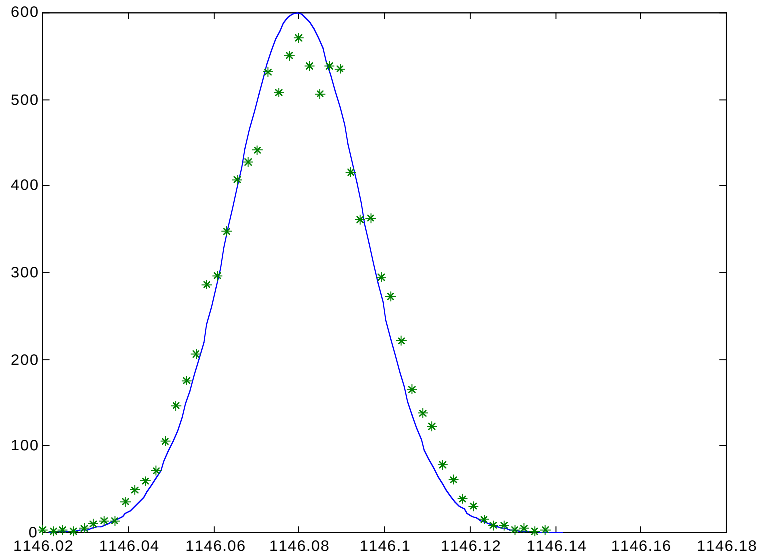
$$I(x) = a_1 + a_3.\left(1 + \left(1 + e^{a_4.(x-a_2)}\right)^{a_5}\right).\left(1 + \left(1 + e^{a_6.(x-a_2)}\right)^{a_7}\right)$$

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

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

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





Scientific Data Flow

DNEPR launcher, 6:00–18:00, 800 km, 98°

No (or short) eclipses – full Sun orbit

DATA	Repetition rate	Production (in 90 mn)	Compression	Total
Continuum 230 nm - Limb Mode (*)	3 min	128560 x 16 x 30 = 60 Mbits	2 (ND)	30 Mbits
Continuum 230 nm - Full Image	45 min	2048x2048 x 16 x 2 = 128 Mbits	20	6.4 Mbits
Visible 538 nm - Limb Mode (*)	3 min	128560 x 16 x 30 = 60 Mbits	2 (ND)	30 Mbits
Visible 538 nm - Full Image	45 min	2048x2048 x 16 x 2 = 128 Mbits	20	6.4 Mbits
Continuum 160 nm (T. min.)	45 min	2048x2048 x 16 x 2 = 128 Mbits	20	6.4 Mbits
Lyman alpha, 121.6 nm	45 min	2048x2048 x 16 x 2 = 128 Mbits	20	6.4 Mbits
TOTAL per 24 hours (including 20% overhead)				1.6 Gbits

(*): 40 pixels wide area around the solar limb (1/10) — 22 pixels only (9/10)
(ND): Non-Destructive compression for precise diameter measurement