Solar Astrometry, Radiometry and Seismology with PICARD

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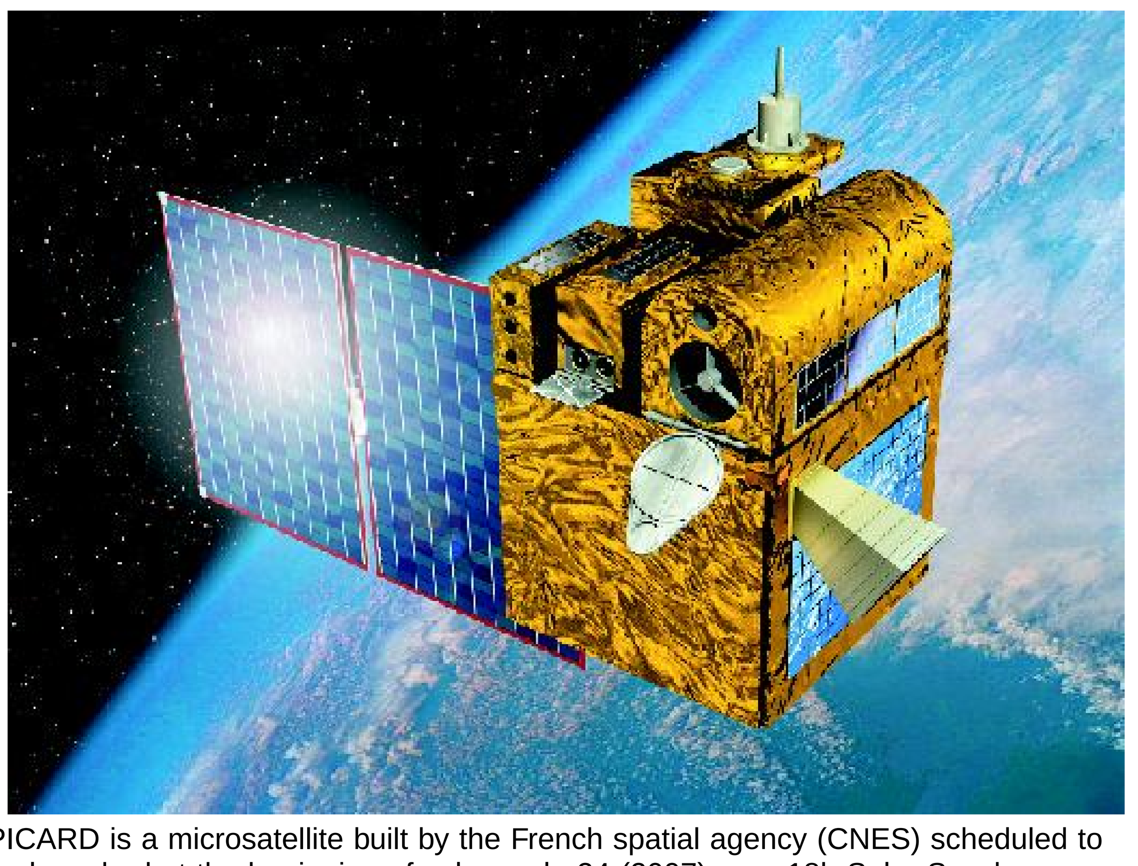
Abstract

The CNES microsatellite PICARD is primary designed to achieve unprecedented precision and stability for solar diameter measurements in order to answer one of the most controversial and long standing open question about the Sun: is there any Solar diameter variations and, if so, how are they correlated with solar activity? The main instrument is a 11 cm telescope (SODISM) equipped with a 2048^2 CCD camera and a guided primary mirror. Observations will be made at different wavelengths in the photospheric continuum (535, 607, 782 nm) and as a function of the heliographic latitude thereby providing limb shape and asphericity measurements. The high precision and continuous measurements of solar limb intensity fluctuations by SODISM also open a new window for detecting low frequency p-modes and searching for the still undetected g-modes. PICARD payload also includes 2 radiometers and 3 photometers for total and UV spectral solar irradiance measurements in continuation of what is achieved on board SOHO. The satellite will be launched on a Sun synchronous orbit allowing the thermal stability and the nearly continuous observations needed. It will be complemented by a ground based version of the SODISM telescope assisted by a generalized solar seeing monitor (MISOLFA) in order to quantify the effects of atmospheric turbulence on solar diameter measurements and establish the link with historical astrolabe ground based measurements. PICARD is anticipated to operate during the ascending phase of the next solar cycle in conjunction with NASA's SDO (Solar Dynamics Observatory) mission to be launched in 2008.

THE MISSION



PICARD is a microsatellite built by the French spatial agency (CNES) scheduled to be launched at the beginning of solar cycle 24 (2007) on a 18h Solar Synchronous Orbit (730-750Km). The mission's PI is G. Thuillier (SA), A. Joukoff (IRMB) and W. Schmutz (PMOD) are PI of the SOVAP and PREMOS instruments respectively (see instruments description below). They have described the mission in **[1]**.

FUNDAMENTAL QUANTITIES MEASURED

- **Total Solar Irradiance (TSI)**
- **UV spectral Irradiance**
- **Photospheric diameter & asphericity**
- **Oscillations**

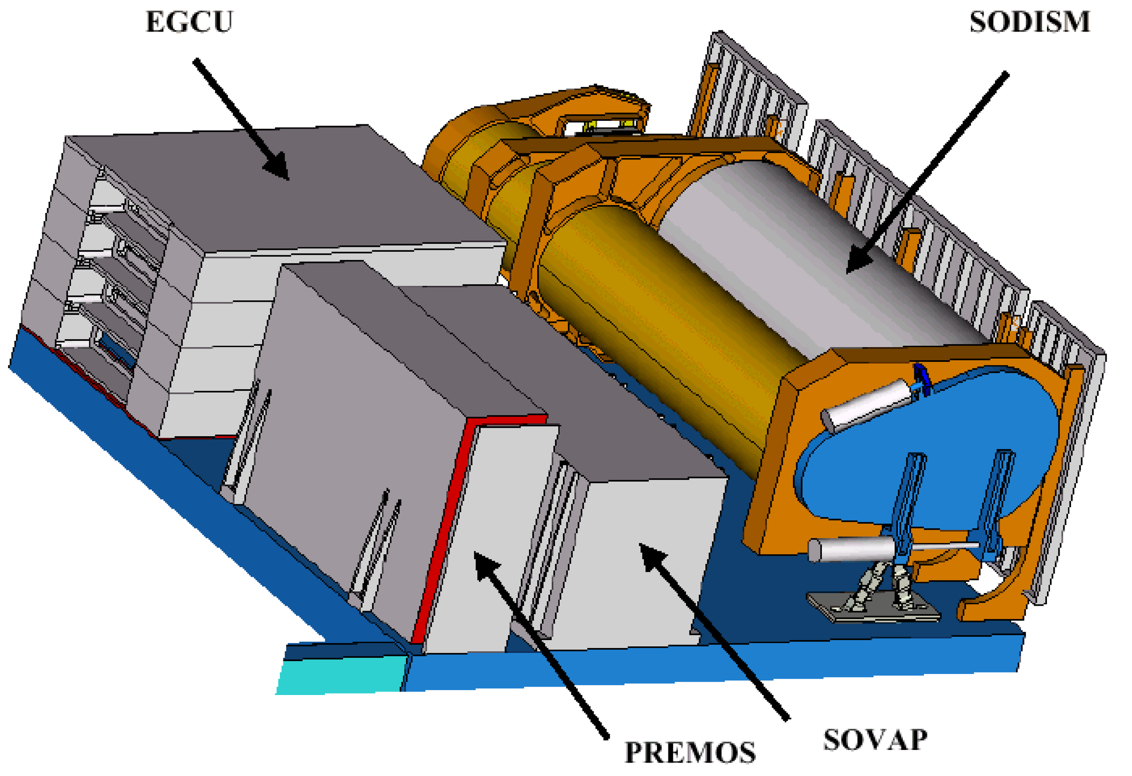
SCIENTIFIC OBJECTIVES

Better understand the solar cycle, its origin and its influence on Earth climate.

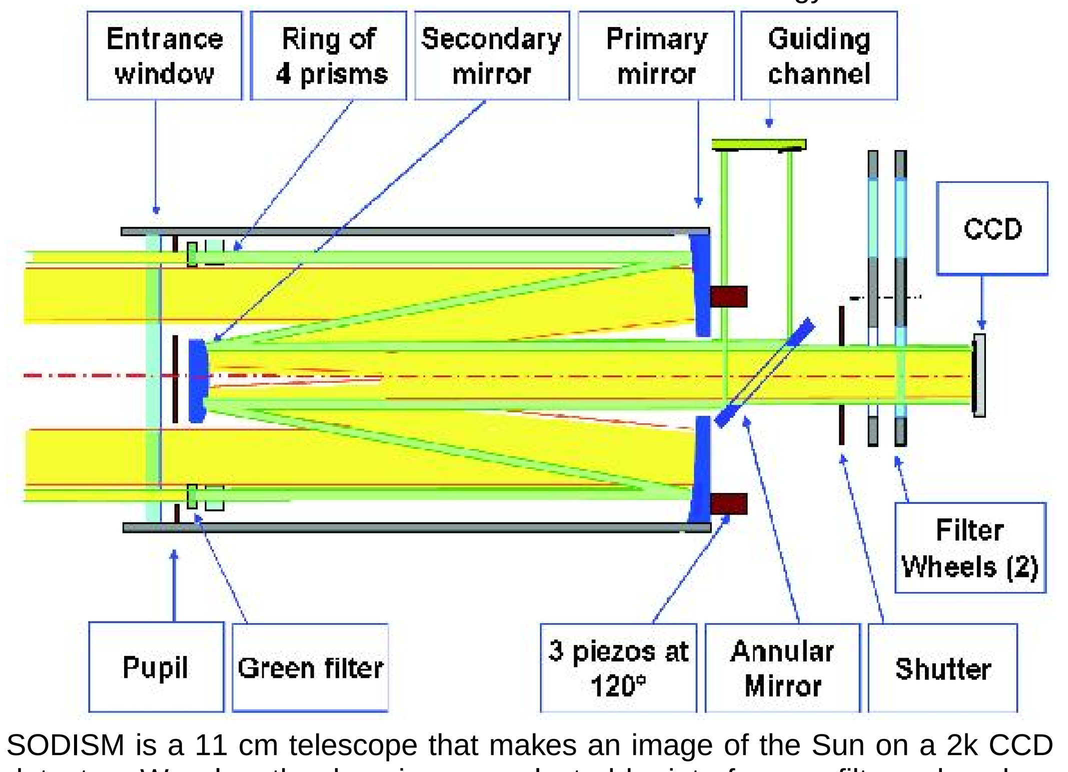
- *Confirm diameter variations and validate ground based measurements and their accuracy.*
- *Establish the relation between diameter, total irradiance and differential rotation variations.*
- *Study the long and short terms variability.*
- *Monitor the UV spectral irradiance for its influence on ozone and climate.*
- *Limb advantage: observe low frequency p-modes and search for g-modes.*

PAYLOAD

The project manager of the payload is M. Messonnier (SA).



- SODISM (Solar Diameter Imager and Surface Mapper). Developed at the Service Aéronomie for Diameter and seismology measurements.



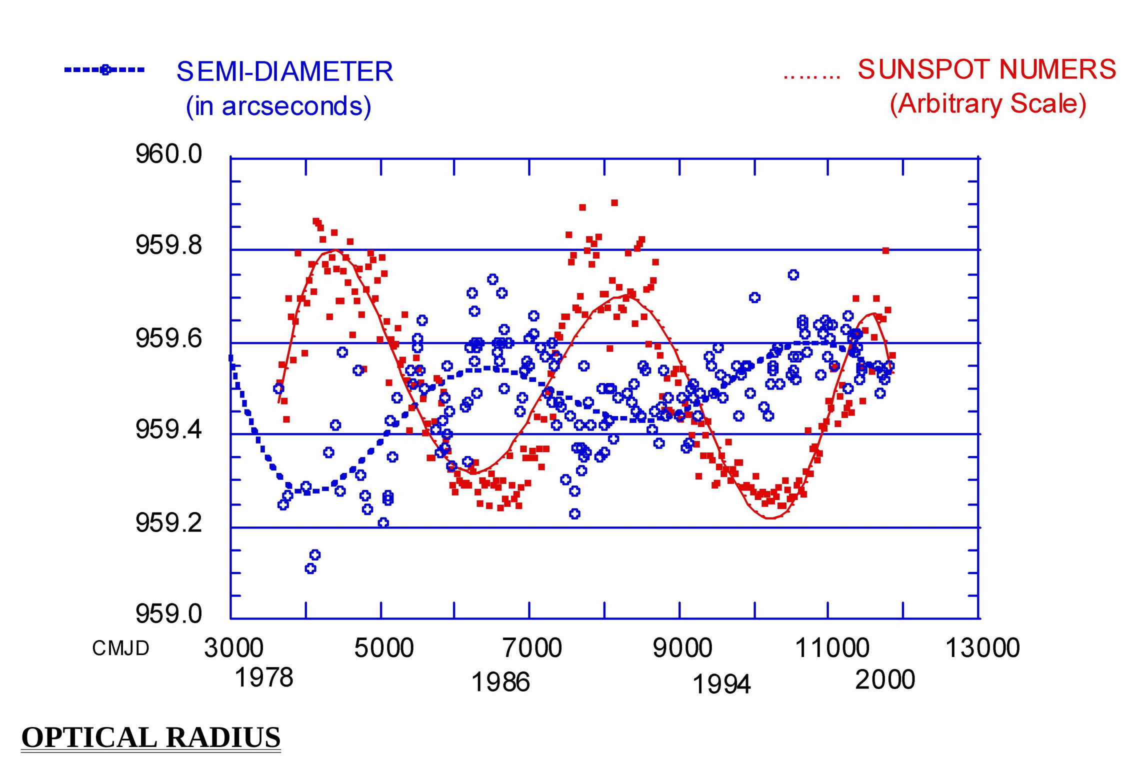
SODISM is a 11 cm telescope that makes an image of the Sun on a 2k CCD detector. Wavelengths domains are selected by interference filters placed on a wheel. They are chosen free of Fraunhofer lines (535.7, 607 and 782 nm). Active regions are detected in the 215 nm domain, and the CaII (393nm) line.

- Two types of absolute radiometers: SOVAP (Solar Variability PICARD) based on a DIfferential Absolute Radiometer (DIARAD) developed at IRMB for Total Solar Irradiance measurements and a PM06 developed at the PMOD.
- PREMOS (PREcision Monitor for OScillation Monitor) is a 4 channels filter radiometer developed at the PMOD for studying UV spectral irradiance leading to ozone formation and destruction (215, 268 nm) and seismology measurements (535.7, 782 nm). It has 3 identical radiometer heads in order to assess a possible degradation.

ASTROMETRY

One major objective of PICARD is to measure the optical solar diameter variations and to validate long term ground based experiments.

PREVIOUS MESUREMEMTS



OPTICAL RADIUS

- **Ground based measurements [2]** have shown an optical diameter variation of 200 mas anticorrelated with activity (see figure above).
  Dispersion: visual 0.28", CCD 0.22", theoretical minimunm: 0.1" **[3]**.
- **From balloon flights:** Analysis of the Solar Disk Sextant (SDS) measurements is still ongoing but early results indicate changes anticorrelated with the activity cycle **[4]**.
- **From space (MDI/SoHO)**, Photospheric radius at 676.8 nm: Variation of 8 mas/yr (1996-1998) **[5]** but MDI was not designed for astrometric measurements and yearly variations of about 100mas due to the spacecraft temperature fluctuations had to be fitted in an ad-hoc way.

To date, ground based or space measurements of the optical photospheric solar radius are inconsistent. Depending on the experiment, they can show correlation or anticorrelation with the solar cycle or no variation at all.

OTHER RADIUS

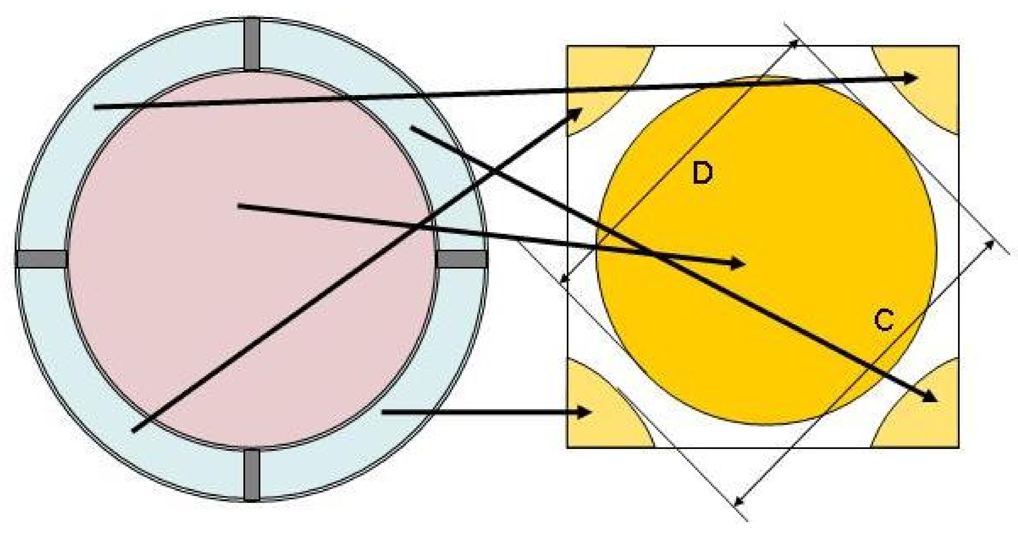
- **Seismic radius:**(layers 1-16Mm below the photosphere). From f-modes analysis **[6]** obtain $\frac{\Delta R}{R} < 3 \times 10^{-6}$ i.e. $<$3 mas.
- **Radius at radio frequencies** (17GHz) ($>$ 10 Mm above the photosphere): Using the Nobeyama Radioheliograph, **[7]** have detected a mean variation of 3 arcsec in the mean solar "radio radius", well correlated with activity .

PICARD ASTROMETRIC OBJECTIVES AND METHOD

Optical (photospheric) radius at 535.7, 607 and 782 nm. Precision: 3 mas (Instrumental design for 1 mas) + Absolute measurements at 10-15 mas.

In order to reach this objectives:

- **Instrument stability:** Use of stable materials. Zerodur for mirrors, C-C and Invar for structure. The whole instrument is temperature stabilized (0.5°C). The CCD is also temperature stabilized (0.1°C). In order to limit the solar energy, a window is set at the telescope entrance limiting the input to 5% of the TSI. No significant ageing has been measured in the laboratory for the duration of the mission.
- **Pointing stability:** The platform is stabilized at 36". The telescope primary mirror stabilizes the Sun image within 0.1" using piezo electric actuators.
  vspace0.5



- **An internal angular reference** is provided by a 4-prism system (see above). The entrance pupil is divided in five parts to produce 5 images of the sun on the CCD. The real diameter is $\frac{\alpha D}{C}$ where α is a constant. The stability of this constant depends only on prism stability. This is done in two perpendicular directions.
- **Absolute measurements:** The diameter measurements are referred to star angular distances by rotating the spacecraft towards some stars (using Hipparcos catalogue and next) likely every 6 months. This process allow mission interruption and the measurements can be resumed later using the same stars as reference.
- **Simultaneous ground based measurements** will be made at Calern (OCA) using a ground version of SODISM assisted by a Generalized Seeing Monitor (MISOLFA). These first simultaneous ground and space measurements will allow us to calibrate for the first time the atmospheric effects on solar diameter measurements thus giving a better base for interpreting long term ground based programs such as the automated astrolabe measurement (DORAYSOL) also developed at Calern observatory **[3]**.

SEISMOLOGY

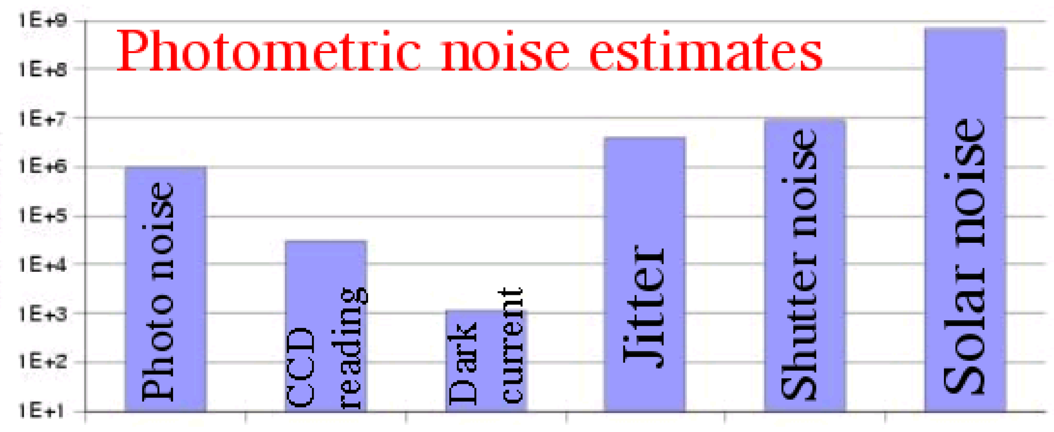
MOTIVATIONS

- Gravity modes remain undetected by SOHO instruments. An upper limit can be set at $0.5ppm$ for their amplitude **[8]**.
- These modes are the only ones penetrating the nuclear solar core. Their detection would give new constraints on stellar angular momentum evolution theories and on the properties of the newly discovered oscillating neutrinos.
- It has been shown both theoretically **[9]** and observationally **[10] [11]** that the amplitude of solar p-modes is enhanced near the solar limb. The same effect is expected for gravity modes.

Thus, PICARD seismic measurements consist in taking advantage of the unprecedented stability and precision that we will reach near the limb in order to look for gravity modes. It will also be able to detect low frequency pressure and f-modes that can be used to infer the seismic radius simultaneously to the photospheric radius measurements.

SODISM SEISMIC MEASUREMENTS

- We will analyze sequences of limb images consisting in 22 pixels rings taken every 2 mn in visible light at 535.7 nm.
- We will also keep 32^2 macro-pixels on the solar disk with the same 2 mn cadence. This will allow the detection of low frequency solar p-modes and facilitate mode identification.



- First simulations show that the dominant noise will remain the solar noise generated by super granulation motions in the g-mode range from 100 to 300μHz. The second dominant noise is the shutter noise produced by the uncertainty on the exposure time ($\pm 50\mu$s for 2s exposure) but it remains at least a factor 10 bellow the solar noise itself.
- **With a non ambiguous detection level estimated at a S/N ratio from 4 to 5 in amplitude, we can expect to detect 0.03ppm without ambiguity during a 3 year mission.**

RADIOMETRY

With SOVAP, PREMOS and PM06 total and spectral radiometers, PICARD will be able to continue and complement the irradiance measurements currently made by VIRGO on board SOHO and SORCE. It will also make the link with SOVIM measurements scheduled on the space station for the end of 2006.

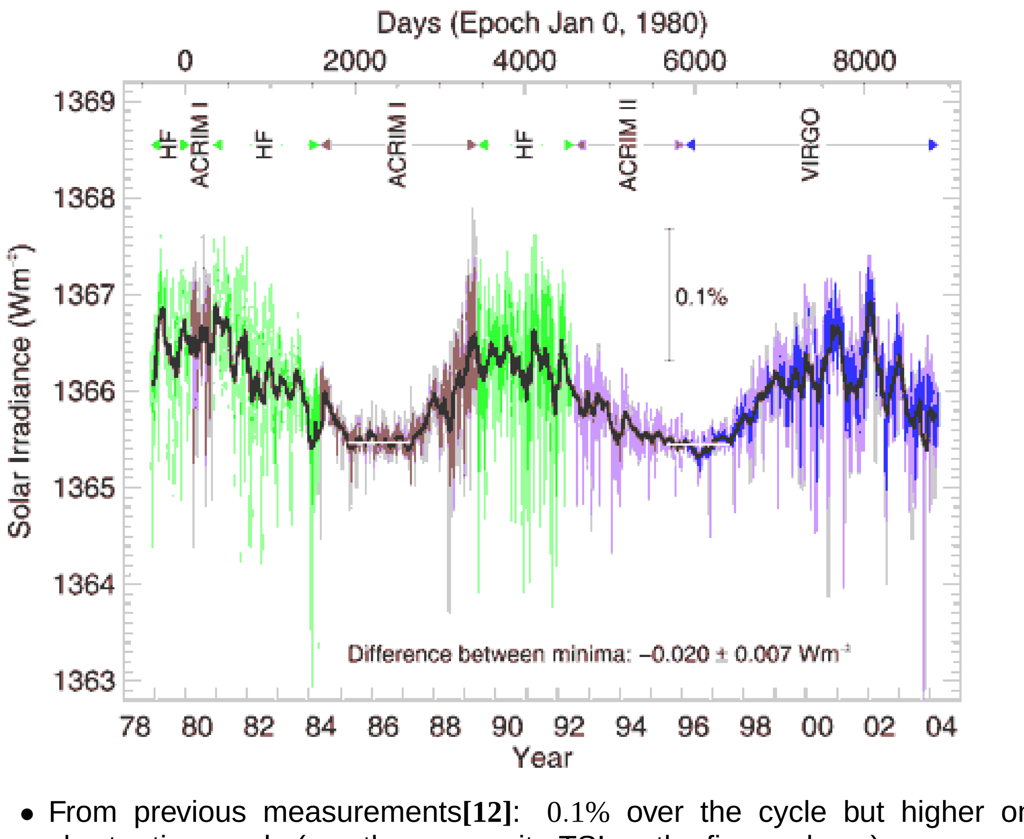
OBJECTIVES

Total and spectral irradiance measurements with 0.1% absolute precision.

MOTIVATIONS: IRRADIANCE AND CLIMATE

There are 3 principal mechanisms for Sun/Earth Climate connection

1. **Total irradiance variations**



   - From previous measurements**[12]**: 0.1% over the cycle but higher on shorter time scale (see the composite TSI on the figure above).
   - 90% of these variations are well explained by effect of sunspots + faculae **[13]**
   - 0.1% of the total irradiance on the upper atmosphere represent (after taking into account the earth albedo) $\sim 0.24W/m^2$ which is one order of magnitude less than the estimated radiative forcing by anthropogenic greenhouse gases and of the same order of magnitude as other anthropogenic sources (sulfate aerosol, tropospheric ozone) **[14]**.
   - But the high inertia of oceans could absorb the 11 year fluctuations and therefore we need to search for more long term effects and PICARD will provide absolute measurements and atmospheric effect calibrations needed for long the term studies
2. **Spectral Irradiance variations**
   - UV variations are well identified processes for changes in stratospheric ozone production and stratospheric dynamic.
   - But, how does it influence the troposphere and therefore climate?
   - Visible and IR variations are less than UV but can penetrate directly the low atmosphere.
   - PREMOS measurements will consequently be used (together with the TSI of SOVAP/PM06 and the images of SODISM) as input for simulations in order to investigate the response of the Earth's atmosphere to the solar irradiance variations.
3. **Solar wind and cosmic rays:** This part will notably be investigated by instruments on board the Solar Dynamic Observatory scheduled to be launched at the same time as PICARD (2008).

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