PICARD MICROSATELLITE PROGRAM

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ABSTRACT – The PICARD microsatellite mission will provide 2 to 6 years simultaneous measurements of the solar diameter, differential rotation and solar constant to investigate the nature of their relations and variabilities. It will provide an absolute measure of the diameter and the solar shape better than 10 milliarcsec. The 100–110 kg satellite has a 40 kg payload consisting of 3 instruments: SODISM, which will deliver an absolute measure (better than 10 milliarcsec) of the solar diameter and solar shape, SOVAP, for the total solar irradiance measure, and PREMOS, dedicated to the UV and visible flux in selected wavelength bands. Now in Phase B, PICARD is expected to be launched before mid-2003. We review the scientific goals linked to the diameter measurement, present the payload and instruments' concepts and design, and give a brief overview of the program aspects.

RESUME – *Le programme microsatellite PICARD de mesures simultanées du diamètre solaire, de la rotation différentielle, de la constante solaire et de leurs variabilités, a été sélectionné par le CNES. Les travaux de définition et de réalisation sont maintenant engagés depuis plus d'un an et le lancement aura lieu avant la mi-2003 (durée de la mission : 2 ans, extensible à 6 ans). Nous présentons la mission (un microsatellite de 100–110 kg), ses objectifs et les mesures qui seront effectuées par 3 instruments (charge utile de 40 kg) et qui intéressent directement la Physique Solaire, l'Héliosismologie, la Climatologie de la Terre et la Météorologie de l'Espace. Les excellentes performances de la plate-forme permettent de mettre en place une charge utile relativement complexe (plusieurs instruments, un télescope optique stabilisé avec pointage actif, des miroirs SiC et des structures stables, un grand CCD rétroéclairé et aminci de 2048 x 2048 pixels utiles, etc.) dont nous présentons les caractéristiques les plus importantes.*

1 – INTRODUCTION

Since the solar energy is one of the major driving inputs for terrestrial climate and since it exists some correlations between surface temperature changes and solar activity, it appears important to know on what time scale the solar irradiance and other fundamental solar parameters, like the diameter, vary in order to better understand and assess the origin and mechanisms of the terrestrial climate changes.

Global effects, such as diameter changes, large convective cells, the differential rotation of the Sun's interior and the solar dynamo at the base of the convective zone, can probably produce variations in the total irradiance or, at least, correlate with these variations associated ,during maximum, with the changing emission of bright faculae and the magnetic network. The aim of these correlations is double: on one side prediction and on the other explanation of the past history of climate, like the Maunder minimum period.

To establish long-term links and trends between solar variability and climate changes, it is necessary to achieve not only high precision but also absolute measurements, what the diameter measurements of PICARD shall bring. Further, this high precision allows "instantaneous" monitoring of the diameter changes, i.e., with a proper orbit for the microsatellite, oscillations and, in particular, the gravity modes.

2 – SCIENTIFIC OBJECTIVES

2.1 – Why the diameter?

From 1666 to 1719, Jean Picard and his student Philippe de la Hire measured the solar diameter, observed the sunspots and determined the Sun rotation velocity. Fortunately, these measurements covered the Maunder minimum and some time after. The data were re-examined by Ribes et al. (1987) who, after removing the seasonal variation of the solar diameter, obtained the annual means at 1 AU. These values, averaged for the Maunder minimum period, and after while the Sun recovered a significant activity, show a definitive difference of the order of 0.5 to 1 arcsec, corresponding to a larger Sun diameter during the Maunder minimum. As expected, few sunspots were observed. However, Picard's data also showed a slow down of the Sun rotation velocity at equator and significantly more sunspots in the south Sun hemisphere than in the north.

2.2 – Diameter and Earth's climate

The solar constant measurements performed in space by the radiometers since 1978 were modeled using the sunspots number and faculae. This allowed to reconstruct the solar constant variation till 1610 (Lean, 1997). This showed that the solar constant experienced a significant decrease during the Maunder minimum. The temperature in the northern hemisphere has been also reconstructed for the same period. The cooling of this period is known as the Little Ice Age. The similarity of the temperature and solar constant variations strongly suggests the Maunder minimum as the cause of the Little Ice Age. To assess this suggestion, climate models were run by Sadourny (1994) that showed the Maunder minimum as the possible cause of the Little Ice Age. Volcanic eruptions (major ones) also play a certain role, but their effects do not extent more than a few years.

As during the Maunder minimum where, as suggested by Picard's data, the Sun radius experienced a significant change, the modern data of Sun diameter measurements and sunspots number, set together by Laclare et al. (1996), reveal a relation between the Sun radius and solar constant variations corresponding to an increase of the Sun radius for a decrease of the solar constant (cf. Fig. 1). Therefore, in order to establish experimentally without ambiguity the Sun constant and diameter relationship, we propose to operate from space by measuring simultaneously both quantities from the same platform and in non-magnetic lines or continua. The importance of the measurements for climatology is straightforward taking into account the Little Ice Age and the Maunder minimum events.

2.3 – Prediction and precision

The total solar irradiance measure made by radiometers from space over the last 20 years, is excellent in relative terms (10^{-5}) but poor in absolute. The amplitude of the variation over the cycle (0.1 %) is small and is about the same than the uncertainty on the absolute value from one instrument to the other. Prediction tendency of climate change from such data is not straightforward and adjustment of data sets of different origins an art (cf. Fröhlich and Lean, 1998). On the contrary, and if the relation irradiance-diameter is established by PICARD, the diameter measure which is precise, reproducible and absolute to 10 mas (or even better when the HIPPARCOS data will be recalibrated by FAME or GAIA) and which, accordingly to Laclare et al. (1996), has an amplitude over the solar cycle of 0.4–0.6 arcsec or so, provides a proper — and quantified — sampling of the activity change over the cycle. Furthermore, the diameter measure will be done in the visible but also in the UV at 230 nm a wavelength band much more variable (6 to 8%) with the solar cycle and well known for its role in the chemistry of ozone, incidentally one of the possible links between solar activity and Earth climate.

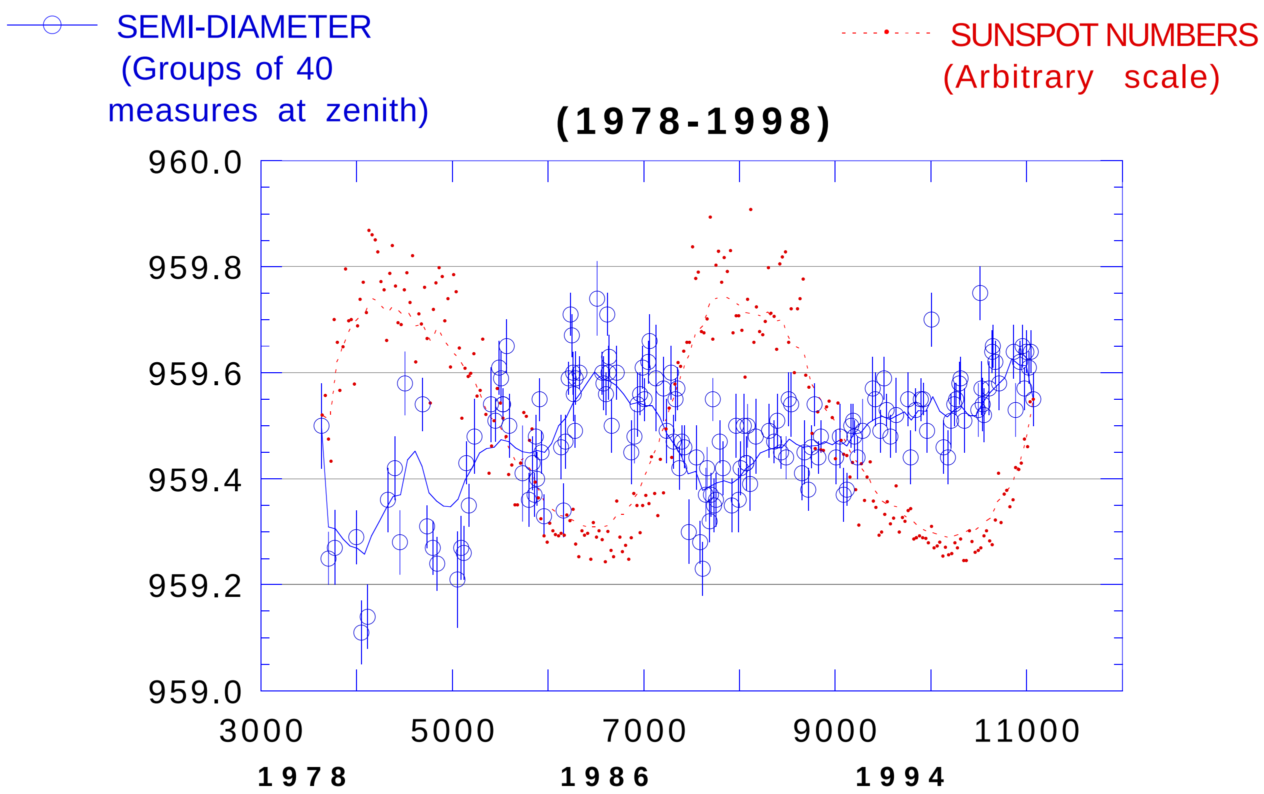

Fig. 1 — Opposing phase observed between the sunspots number and the semi-diameter measured at the CERGA's Astrolabe over the last 20 years (courtesy of Francis Laclare).

2.4 – Lyman alpha monitoring

Lyman alpha irradiance has been monitored since 1977 and more recently by UARS since 1991. The EOS/SOLSTICE experiment will be launched in late 2002 and it will also monitor Lyman alpha irradiance. Since these irradiance monitoring experiments observe the Sun as a star, there is no information about the physical causes of the observed irradiance changes. To identify the causes of changes in Lyman alpha, one needs to compare the full disk irradiance data with images. PICARD will provide high spatial resolution (1 arcsec) and continuous (every 45 minutes) Lyman alpha images which will complement the EOS/SOLSTICE measurements. These images will make possible to better account for the observed Lyman alpha changes and also for a better reconstruction of the long-term Lyman alpha data set. Lyman-alpha irradiance is important for the ozone changes and for the formation of the ionospheric D-region in the Earth's atmosphere. Its understanding should result in significant progress in atmospheric science and aeronomy.

2.5 – Oscillations

Another major objective of PICARD is to attempt the detection of the gravity modes (g-modes) of the Sun. These modes are of prime importance to understand the structure and dynamics of the solar core which cannot be studied by using solar pressure modes (p-modes) alone. So far the g-modes have not been discovered by any set of instruments onboard the SOHO spacecraft (Appourchaux et al., 2000). The 1- upper limit of g-mode amplitude at around 200 µHz is typically 1 mm/s or 0.1 ppm (Fröhlich et al., 1998). Given a velocity amplitude of 1 mm/s at 200 µHz, the displacement of the solar surface would be of about 1.6 m p-p which is equivalent to a variation of solar radius of about 2 µarcsec. This level could be marginally detected by PICARD although this is not the method we are using for detecting the g-modes with our instrument. Nevertheless, it is worth noticing that MDI/SOHO was able to — without an optimized, stable and distortion free telescope as SODISM/PICARD — to observe a 10 µarcsec high frequency p-mode (5 min.) solar limb oscillation signal (Kuhn et al., 1997).

With PICARD we want to detect intensity fluctuations at the solar limb that will perturb the equivalent solar radius signal. Appourchaux and Toutain (1997) reported to have detected p-modes using the limb data of the LOI instrument. In some case the amplification with respect to full-disk integrated data is about 4, i.e. it means that a p-mode with an amplitude of 1 ppm in full disk is observed with an amplitude of 4 ppm at the limb (cf. Damé et al., 1999). This amplification factor was roughly predicted by theory (Appourchaux and Toutain, 1997). If we hope that the same amplification factor holds for the g-modes, we may detect them faster with the limb data of PICARD than with the SOHO data. A pessimistic derivation gave 20 years for the detection of the first few g-modes with SOHO (Fröhlich et al., 1998). With PICARD we can seriously envisage detecting them in 16 months with the amplification factor above.

3 – PICARD PAYLOAD

To carry the proposed measurements PICARD has 3 instruments: SODISM, the "SOlar Diameter Imager and Surface Mapper", for the measure of the diameter and differential rotation (this is, therefore, a whole Sun imager), SOVA (SOlar VAriability), for the measure of the total absolute solar irradiance (correlation with SODISM measurements) and PREMOS (PREcision MOnitoring of Solar variability), a package of 3 set of 4 UV and visible Sun photometers. Fig. 2 presents an artist view of PICARD's microsatellite. SODISM is realized by the Service d'Aéronomie du CNRS, France, in collaboration with the Space Science Department of ESTEC, SOVAP by the Royal Meteorological Institute of Belgium, and PREMOS by the World Radiation Center of Switzerland.

3.1 – SODISM/PICARD

SODISM is a simple telescope of useful diameter 110 mm. It forms a complete image of the Sun on a large, back thinned, CCD of 2048 x 2048 useful pixels. The pixel, 13.5 µm, corresponds to 1.05 arcsec (at 1 AU) and the effective spatial resolution is also about an arcsec (at the limb). SODISM observes in 4 wavelengths bands the whole Sun (230 nm, 548 nm, 160 nm and Lyman alpha) and 2 calibration channels (cf. Table 1) accessible through the use of 2 cascading filterwheels, each with 5 positions.

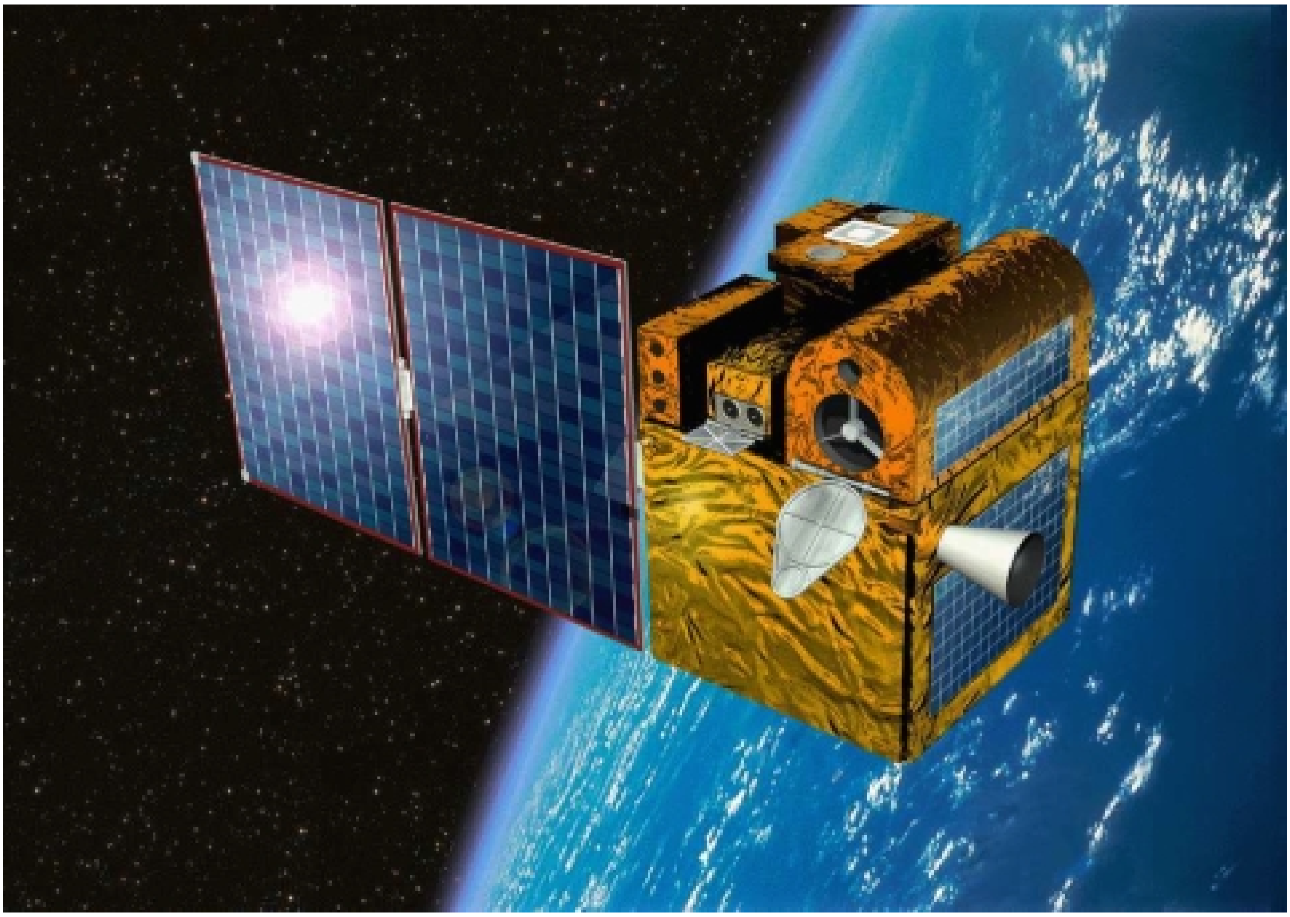

Fig. 2 – Artist view of PICARD microsatellite: 60x60x80 cm^3 only! Shown are the 3 instruments: SODISM, telescope and guiding, right, SOVAP, differential radiometer, center, and PREMOS (flux monitors) left, near the solar panels. Behind, one can see the electronics box supporting two S-band antennae and a solar pointer (acquisition maneuvers).

UV nominal mode	230 nm
Visible	548 nm
Active regions	160 nm
Prominences and ionosphere	Lyman alpha
CCD Flat Field	"Diffusion"
Scaling factor	"Star field"

Table 1 – Observing and calibration modes of SODISM/PICARD.

Operational modes

The main observing wavelength is 230 nm (8 nm bandwidth). It corresponds to a mostly flat UV continuum formed in the high photosphere. It is the best possible choice of wavelength since it is sensitive to UV variations (about half of the MgII index variability for instance), it corresponds to the ozone bands (and by chemical interaction in the stratosphere, the UV may affect the stratospheric dynamics and, consequently, the clouds coverage — which may be one of the paths of the Sun influence on the Earth's climate) and the limb darkening in this continuum is limited.

In addition, SODISM/PICARD observes 548 nm which is near the center wavelength of the 100 nm bandpass used by Francis Laclare CERGA's group for the solar diameter measurement with the Astrolabe (and, in the near future, with the new DORAYSOL instrument). The 160 nm and Lyman alpha filters are used for identification of active regions and prominences. This is essential to prevent activity manifestations to affect the "quiet" radius determination. This possibility to avoid, in the diameter computation, the pixels at the limb affected by faculae, active regions, prominences, sunspots or pores, is an essential feature of SODISM/PICARD since activity, therefore, does not add noise to the diameter measure (active solar pixels are not accounted).

The diffusion plates are simply used to monitor the CCD response and sensitivity (Flat Field). The CCD itself is a complete state-of-the-art system (EEV 4280 2048x4096 pixels back thinned and with frame transfer) hopefully developed in parallel of our program for the COROT asteroseismology CNES/PROTEUS program.

Finally, specific to PICARD — and providing an ABSOLUTE diameter reference better than 10 mas (milliarcsec)— is the "Star field" channel. It provides access to stellar fields in which (with a limit magnitude of 7 or so) stars' triplets of the HIPPARCOS reference catalog are imaged, allowing to scale our diameter measure and, if required, to identify and to follow any structural change in the focus or CCD dimensions which could affect the diameter measure.

Optical concept

SODISM has a sound optical concept allowing to achieve a distortion free and dimensionally stable image of the solar limb. It has a symmetry of revolution (no complex optics — filters at normal incidence — nothing else than the two mirrors and a filter set in the optical path) and a single telescope-detector-guiding telescope support structure for common referencing and stability. The telescopes mirrors are made of SiC without coatings (reflectivity of 35–40 % in the UV and yet 20 % in the visible). Advantage is indeed that the photometry will not change by aging and degradation of coatings since there are no coatings. Further, the primary and secondary mirrors will help to remove 96 % of the visible solar flux, preserving the filters from degradation and, due to the high conductivity of SiC, this flux will be evacuated to external radiators.

Mechanical/thermal stability

To provide a stable measurement of semi-diameters to a couple mas over the two to six years duration of the mission, SODISM/PICARD mechanical stability has to be excellent intrinsically and controlled. The design selected achieves mechanical and thermal stability because of the choice of a single monolithic structure — a tube of carbon-carbon — to link the SiC mirrors of the telescope and to the detector. As well the guiding telescope is in the same structure, its mirrors and the 4-quadrant detector being directly linked to the carbon-carbon structure. This new type of structure (developed for example by ALCATEL SPACE, cf. Bailly et al., 1997) allows to reduce the thermal regulation to a couple tenths of °C for a relative change of the diameter < 1 mas (1 thousand of a pixel). The isotropic property of carbon-carbon and a detailed knowledge of the experiment (interferometric calibration), will help to further gain, by modelisation, a factor 100 to 1000 on the short term diameter variations (useful for the solar limb oscillations). This means that 10 to 1 µarcsec could be inferred, allowing a direct monitoring of limb oscillations. Note that, beside focusing, the only other systematic error which affects the diameter directly is the size of the detector (silicium has an expansion coefficient of ~ 2 10^{-6} and requires, to keep errors below ± 0.5 mas, a ± 0.1 °C temperature regulation).

Fig. 3 shows the structure design of the SODISM/PCARD telescope and, in particular, its dynamical behavior. Note the important flexure of the small titanium feet which account for the dilatation of the platform instrumental plateau.

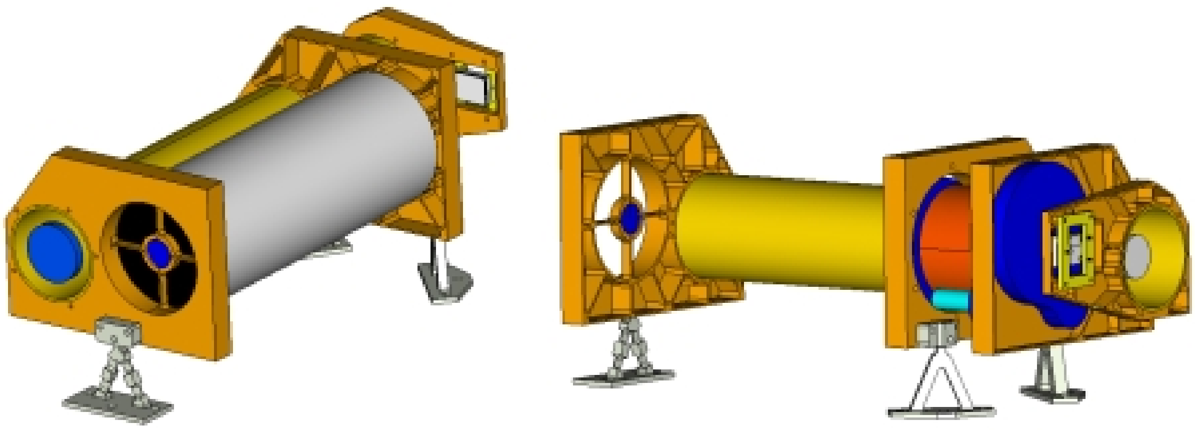

Fig. 3a – Mechanical structure of the SODISM/PICARD telescope (350 mm between the primary and secondary mirror and 150 mm between the primary and the CCD surface: total length without cover of 550 mm). Note the 3 Invar plates linked together with the 550 mm long carbon-carbon (shown in light brown) tube 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.

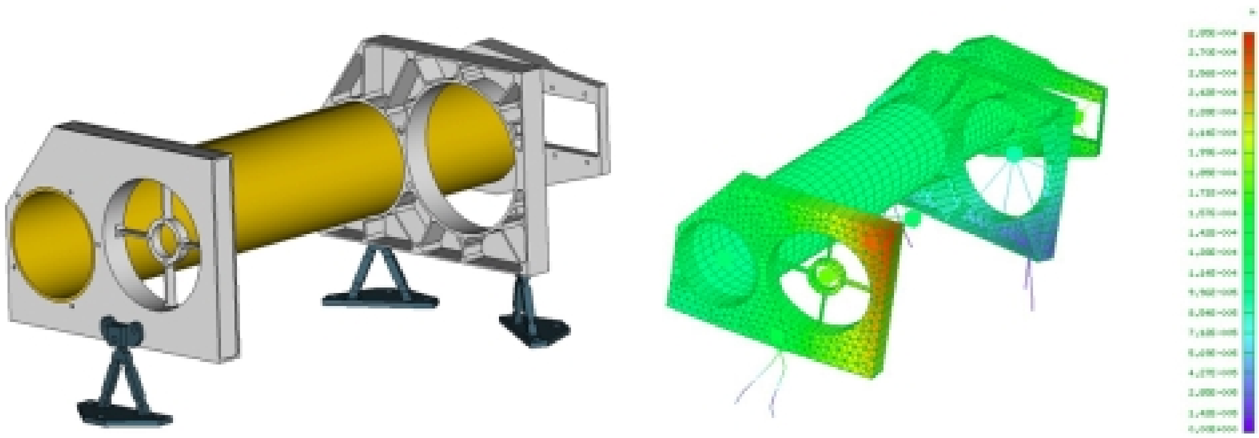

Fig. 3b – Mechanical and dynamical (under 15 g) models of SODISM. Notice that the distance between the SiC mirrors is maintained to a fraction of a micron by a very low dilatation (-$0.1\ 10^{-6}$) tube in carbon-carbon of 100 mm diameter and 4 mm thickness.

Measurements	Solar diameter(s), differential rotation and full Sun UV and visible imaging
Number of channels	6 (230, 548, 160 nm, Ly , "Flat Field" & "Star Field")
Telescope focal length— solar image	2650 mm — Ø25 mm
Telescope optics	Primary Ø120 mm (used: 110 mm) Secondary Ø34 mm (used: 25 mm)
EEV-4280 back thinned CCD detector	2048x4096 square pixels of 13.5 µm (frame transfer: 2048x2048 pixels used)
Guider acquisition range	1.2°
Guider nominal pointing range	± 30"
Guider servo bandwidths	0 to a few Hz (platform) a few Hz to 50 Hz (fine guiding on the primary mirror)
Quad-cell image displacement sensitivity	$< 10^{-2}$"
Piezo displacement range	± 6 µm (± 1 arcmin)
Absolute solar shape precision	Better than 10 mas (HIPPARCOS calibration in 2003)
Relative semi-diameter precision	Better than 1 mas

Table 2 – Characteristics of SODISM.

Pointing

Image guiding and stabilization is provided by an off-axis telescope with the same optical properties than the main telescope and directly implemented in the carbon-carbon structural tube. The 4-quadrant detector assembly is fine guiding the piezoelectrics which activate the primary mirror of the telescope. Fine guiding is used so that the image of the Sun on the CCD does not move by more than 0.1 arcsec, i.e. 1 tenth of a pixel (about 1 tenth of the Airy disk as well at 230 nm). The 4-quadrant detector will also provide (by access to the low frequency part of the control signal) accurate guiding to the microsatellite itself. In that case the coarse guiding of the stellar sensor is overruled by our sensor when the Sun acquisition is effective in the nominal ± 0.6° field of view.

The 4-quadrant detector is provided by ESTEC and similar to the one used with success on SOHO by the LOI/VIRGO instrument.

Ground program: PICARDSOL

The Engineering Model of SODISM will be used in CERGA, France, in conjunction with the newly working DORAYSOL and the longstanding (25 years of observations) Astrolabe of Francis Laclare. As such, and for the first time, the same instrument will be used in space and on ground to measure the solar diameter, deduce atmospheric bias and state on ground instruments possible accuracy. It is expected that the ground instrument will operate for more than a solar cycle. A new generation seeing monitor, measuring the coherence length and temporal coherence, will be used in conjunction with PICARDSOL and DORAYSOL to better assess atmospheric effects on the ground diameter measure (in order to validate the past historical measurements).

3.2 – SOVAP

To measure the solar constant, PICARD will use a SOVA 1 type radiometer, SOVAP, the "P" standing for PICARD. SOVA 1 is a differential absolute solar radiometer developed at the RMIB, Royal Meteorological Institute of Belgium (Crommelynck and Domingo, 1984). The RMIB radiometers have been flown in Space 8 times from 93 to 98. SOVAP radiometric core is formed by two blackened cavities constructed side by side on a common heat sink. In between each cavity and the heat sink a heat flux transducer is mounted. The difference between the two transducers' outputs gives a differential heat measurement, in which the common part of the thermal surrounding radiation seen by the two cavities is eliminated. By the symmetrical construction and good insulation thermal asymmetry is minimized. SOVAP characteristics are summarized in Table 3.

Measured quantity	Total irradiance (Wm^{-2})
Number of channels	2
Number of reference voltages	6
Cavity type	Cylindrical, diffuse black
Diameter precision aperture	1 cm
Slope angle	2.5°
Solar sampling period	3 minutes
Duty cycle	50 %
Instrument noise	< 0.1 Wm^{-2}

Table 3 – Characteristics of SOVAP (default measurement mode).

3.3 – PREMOS

This instrument is provided by the World Radiation Center, Davos, Switzerland. It consists in 4 "filter radiometers", based on the same principle than a radiometer (equilibrium of the flux inside a cavity) but with the preselection of a known and reduced spectral bandwidth. These photometers are observing in the UV and the visible, at the same wavelengths, 230 and 548 nm than SODISM and in two other UV wavelengths: 311 and 402 nm. 3 sets of these 4 photometers are used — one being a reference — in order to monitor aging effects. The 230 nm channel has a dual function: it estimates the UV flux in this ozone sensitive bandwidth, and it indicates a possible degradation of SODISM's CCD.

Measured quantity	Spectral irradiance at 230, 311, 402 and 548 nm (Wm^{-2})
Number of photometers	12 (3 sets of 4)
FWHM bandwidth	8 nm (except at 402: 5 nm)
Cavity type	Cylindrical, diffuse black
Full view angle	2.5°
Slope angle	0.7°
Diameter precision aperture	3 mm
Accuracy of aperture area	$<10^{-3}$
Cross-Talk	$< 10^{-5}$

Table 4 – Characteristics of PREMOS.

4 – THE PICARD MISSION

The PICARD's system uses most of the basic components of the CNES microsatellite product line, namely, the ground segment (MIGS) made of the "Centre de Contrôle Microsatellites" (CNES Toulouse), a band S station (and most probably a complementary station at high latitude) and the flight microsatellite segment. These components will be qualified by the first microsatellite mission of the product line, namely, the mission DEMETER. The PICARD system is operated mostly the same way than DEMETER and, in this way, confirms the generic character wanted and developed for the microsatellite product line.

4.1 – Orbit

The PICARD's mission requires, ideally, an orbit with constant viewing of the Sun or, at minimum, with limited or short duration eclipses. The mission lifetime is 2 years nominally with a possible extension to 6 years. A study of the launch opportunities on such orbits has shown than the highly elliptical Geostationary Transfer Orbit (GTO) envisaged as an option by the microsatellite program cannot be accounted for without very important modifications of the product line (both on the ground and flight segments). Accordingly, and in view of the costs involved, this type of orbits has been abandoned.

The other opportunities are essentially Sun Synchronous Orbits (SSO) with local time 6h/18h (little or no eclipses) or between 10h and 14h. Several scenarios are still under consideration for the PICARD flight which is due before mid-2003 (the launch date is important since the diameter/constant relationship will definitively be better determined during the near linear part of the cycle, rising or falling — our case — than at minimum or maximum when the "constant" is mostly "constant"…). The favored orbits are those providing only brief or non-eclipsing Sun-synchronous viewing in order to achieve both the thermal stability for the absolute long term diameter measurement and the near continuous sampling for the long periods g-modes oscillations. At present launch is planed nominally on a Sun Synchronous Orbit (SSO 12h or so), as a secondary passenger of the Indian PSLV rocket.

Opportunities for 6h/18h are fewer and may results in larger launch costs. These alternatives, optimizing the mission throughput since providing nearly continuous Sun viewing (no eclipses allowing to carry the oscillations' program) could be a launch with Radarsat 2 (Canadian satellite) which has a high (800 km) full Sun SSO orbit or, with comparable characteristics, a dedicated launch with the Dnepr russian rocket.

4.2 – Pointing needs

The pointing needs on the PICARD satellite (for the scientific measure) is a pointing in the Z axis (telescope axis), towards the Sun, and with a precision of ± 0.01°. This performance will be achieved by the attitude control system using an ecartometry information from the payload (from the SODISM guiding telescope: pointing differences between the telescope and the Sun center direction). This, by itself, illustrates nicely the optimization capacity offered by the microsatellite system.

Pointing needs also imply a specific configuration of the stellar sensors to preserve a permanent stellar pointing calibration along the orbit (stellar calibration need for the SODISM telescope scaling factor).

4.3 – Characteristics

To the exception of the attitude control system, the microsatellite platform for PICARD is very similar of the one of DEMETER. Globally, the adaptations are reasonable (in cost and complexity) and confirm the right choice of recurring technologies in the initial microsatellite product line.

Characteristics	PICARD's Microsatellite
Size (cm^3) [L x W x H]	60 x 75 x 80
Mass (kg)	Platform (with lest): 65 kg Payload: 45 kg max Total 110 kg (for 120 kg nominal: 10 kg margin)
Power (w)	Platform: 30 W (average on an orbit)

	Payload: 48 W maximum on average on an orbit Total: 78 W maximum (critical)
Pointing accuracy	3 axis stabilized, 0.1°
Pointing stability	0.01°
Mass Memory	1 Gbits
Telemetry flow	400 Kbits/s
TC (commands)	10 Kbits (immediate or delayed)
Orbit restitution	1 km
Onboard datation	< 0.5 s (TU difference)

Table 5 – Performances and characteristics of PICARD microsatellite.

Table 5 summarizes the essential characteristics of the present PICARD's microsatellite. The performances are derived, mostly, from the microsatellite product line. To the exception of the power allowance, somewhat critical, these are well along the payload needs (cf. Table 6).

Characteristics	PICARD Payload	SODISM	SOVAP	PREMOS	Electronics boxes (2)
Mass (kg)	40.4	17.5	5.8	4.1	9 & 4
Size	60x60x30 20x20x20†	60x27x28	35x15x15	30x9x14	<20x26x15 <20x20x20†
Power (W) Thermal Control (W)	28.5* 19.8*	19.9* 16.3*	4.2 2	4.4 1.5	NA NA
Average Telemetry (Mbits/day)	1210–1810‡	1200–1800‡	5	5	NA

†this electronic's box is placed under the microsatellite platform
**average between measures, stand-by and eclipses (PSLV/SSO)*
‡as a function of the orbit: with eclipses (e.g. PSLV/SSO) or without eclipses (e.g. Radarsat 2)

Table 6 – Major characteristics of PICARD model payload.

Table 6 summarizes the mass, power and nominal telemetry characteristics of the PICARD mission. Note that the PICARD Mission Center will normally be operated by the RMIB and that, most probably, antennas (S band) in Toulouse and Kiruna will be used for telemetry needs (about 1.2 Gbits per day). In the case of a non-eclipsing orbit, telemetry might be higher (1.8 Gbits per day), requiring a third antenna.

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