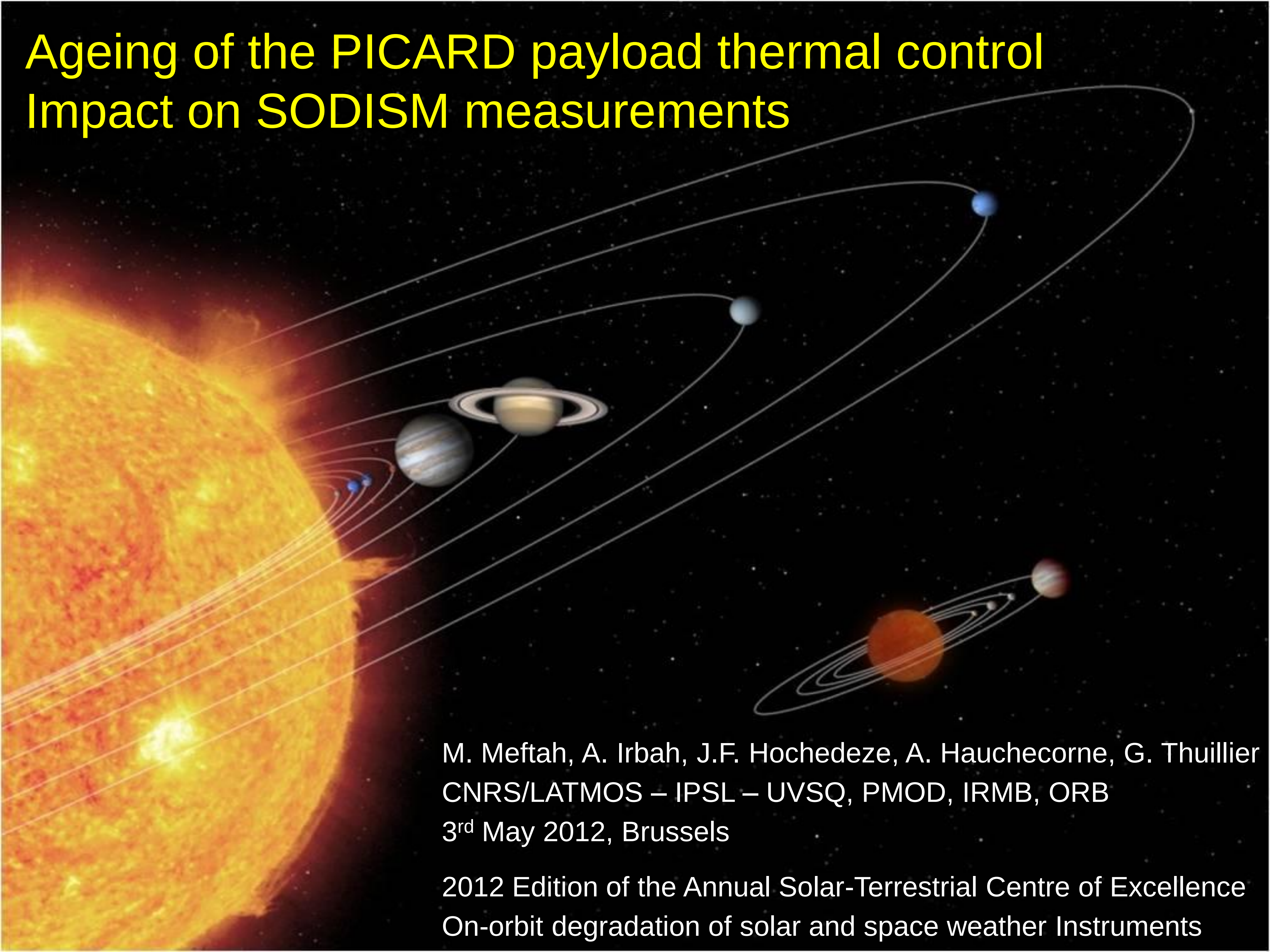

Ageing of the PICARD payload thermal control Impact on SODISM measurements

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CNRS/LATMOS – IPSL – UVSQ, PMOD, IRMB, ORB

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2012 Edition of the Annual Solar-Terrestrial Centre of Excellence
On-orbit degradation of solar and space weather Instruments

Presentation outline

1 - Scientific objectives of the PICARD mission
2 - The payload of the PICARD mission
3 - Thermal control, contamination, and environmental effect
4 - Environment, and impact on the measurements
5 - Temperature, and intensity – Degradation/Contamination

Conclusion and lesson learned

1 – Scientific objectives of the PICARD mission (1/1)

Metrology and science of the diameter and the limb (Sci. fld. 1)	• Measurement of the radial profile (shape) of the solar limb • Measurement of the angular profile (asphericity) of the solar disc • Measurement of the photospheric diameter
Helio-seismology (Sci. fld. 2)	• Inference of the helio-seismic diameter • Detection and characterization of solar intensity oscillations, and especially of g modes
Science of the solar irradiance (Sci. fld. 3)	• Accurate, precise and redundant measurements of the Total Solar Irradiance (TSI) • Contribution to the estimation of the spectral irradiance
Other solar physics studies (Sci. fld. 4)	• Measurement of the photospheric solar differential rotation • Assessment of the magnetic activity and delivery of SpW information • (serendipity)
Solar-terrestrial relationships & aeronomy (Sci.fld.5)	• Studies of the Earth atmosphere via e.g. solar occultations during the eclipse seasons, albedo studies with the BOS, etc. • Contribution of PICARD to the understanding of Sun-Earth connection processes and of terrestrial climate

G. Thuillier, S. Dewitte, W. Schmutz et al, Simultaneous Measurements of the Total Solar Irradiance and Solar Diameter by the PICARD mission, Adv. Space Res. 1792-1806, 2006.

2 – The payload of the PICARD mission (1/5)

PICARD is a mission dedicated to the study of the Sun-Earth atmosphere relationship with the main following objectives: measurements of TSI (Total Solar Irradiance), UV (UltraViolet rays) irradiance, solar radius by metrological instrumentation and the variability of all these measurements.

PICARD was launched on June 15, 2010 on a Dnepr-1 launcher.

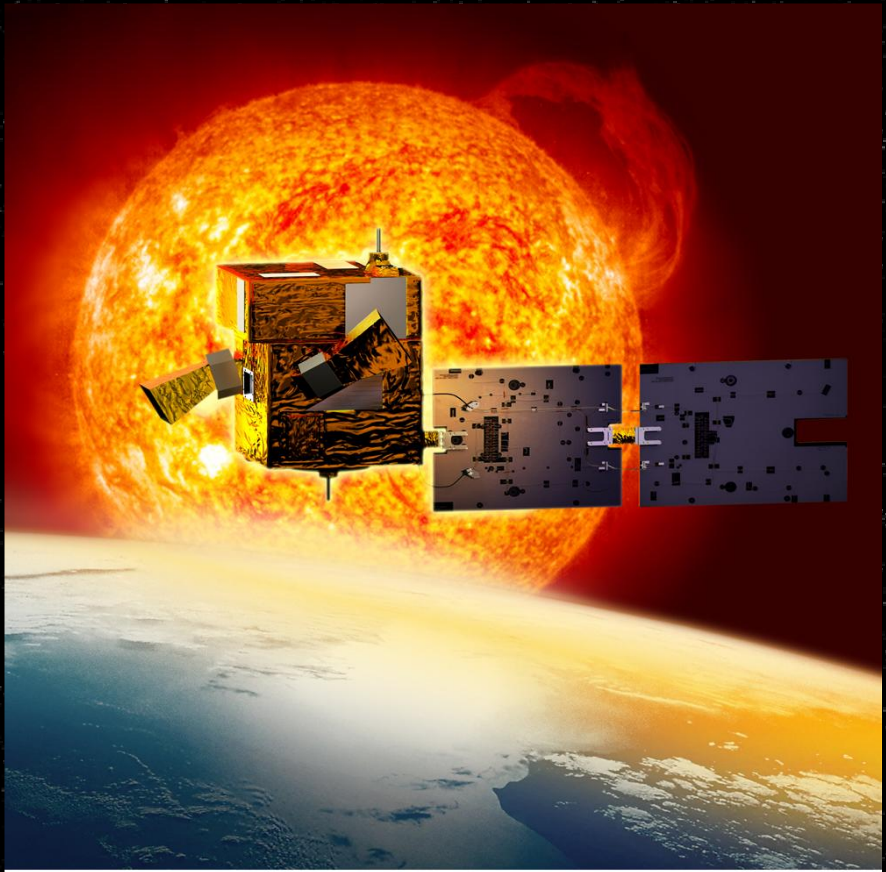
Orbit:

- Sun Synchronous Orbit
- Ascending node: 06h00
- Altitude: 735 km
- Inclination: 98.29°
- Eccentricity: 1.04x10-3
- Argument of periapsis: 90°

PICARD/SODISM 393.37 nm

2012-03-08 11H53 UTC

Credits: CNRS/LATMOS

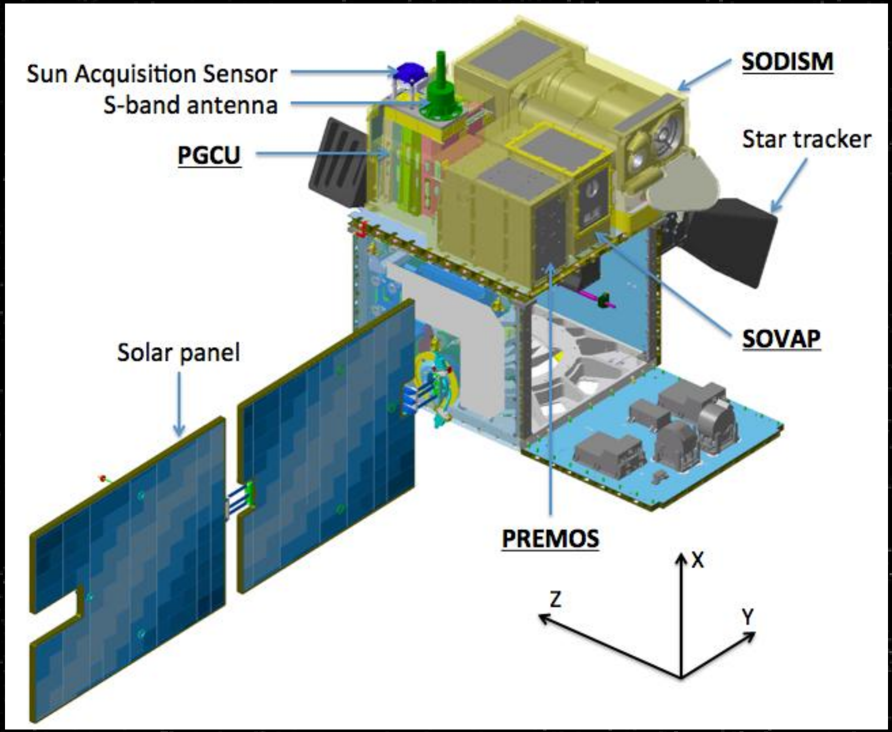


2 – The payload of the PICARD mission (2/5)

PREMOS (PREcision MOnitoring Sensor) is made of four units: a set of 3 Sun photometers and the radiometer PMO6 as used on SoHO to measure the absolute Total Solar Irradiance (PMOD).

SOVAP (SOlar VAriability PICARD) measures the absolute Total Solar Irradiance. This instrument is a radiometer of DIARAD type used in previous space missions, SOHO, and SOLCON on the Space Shuttle (IRMB).

SODISM (SOlar Diameter Imager and Surface Mapper) is an imaging telescope measuring the solar diameter and limb, and performs helioseismologic observations to probe the solar interior.

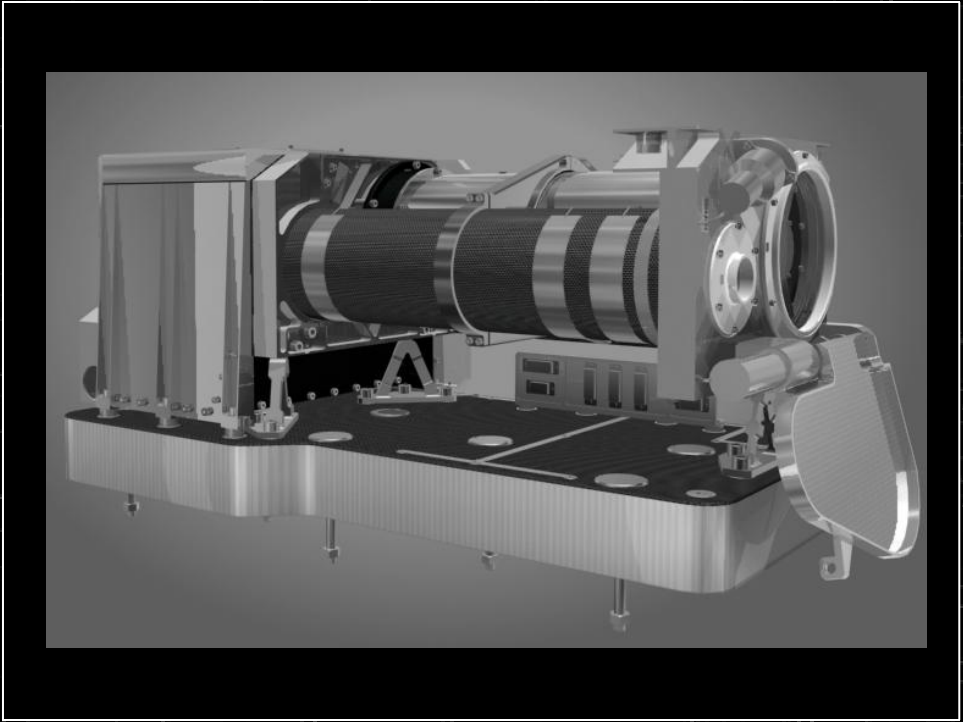


2 – The payload of the PICARD mission (3/5)

SODISM is an 11-cm Ritchey-Chretien imaging telescope developed at CNRS by LATMOS (ex. Service d'Aéronomie, France) associated with a 2Kx2K Charge-Coupled Device (CCD), taking solar images at five wavelengths.

SODISM main characteristics:

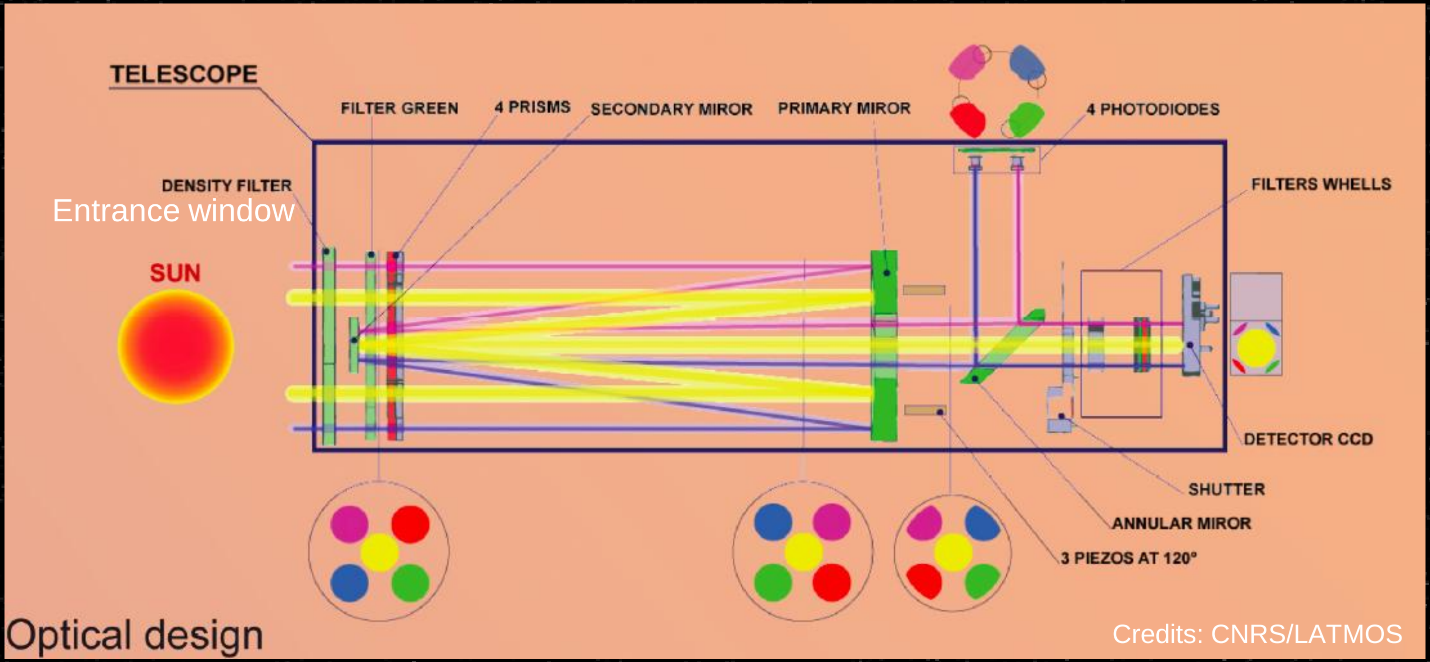
- Telescope type: Ritchey Chretien
- Focal length: 2626 mm
- Field of view: 35 arc-minutes
- Angular resolution: 1.06 arc-secondes
- Dimensions: 300x308x370 mm^3
- Mass: 27.7 kg
- Power (SODISM and PGCU): 43.5 W
- Data flow: 2.2 Gbits per day
- One image per minute



Credits: CNRS/LATMOS

2 – The payload of the PICARD mission (4/5)

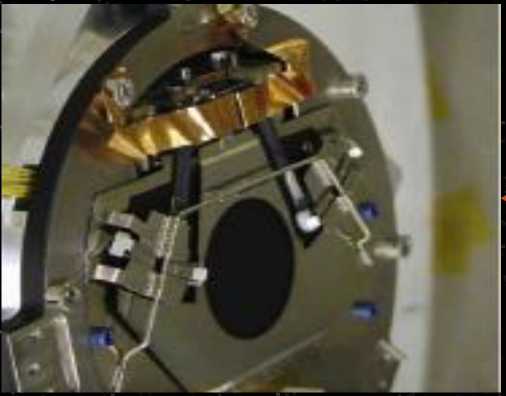
SODISM optical path and interferential filters characteristics



Wavelength λ in nm	Bandwidth Δλ in nm	Function
215	7	Sun activity, O3, measurement, diameter
393.37	0.7	Active regions observation
535.7	0.5	Oscillations (helioseismology)
535.7	0.5	Diameter, oscillations (helioseismology)
607.1	0.7	Diameter
782.2	1.6	Diameter

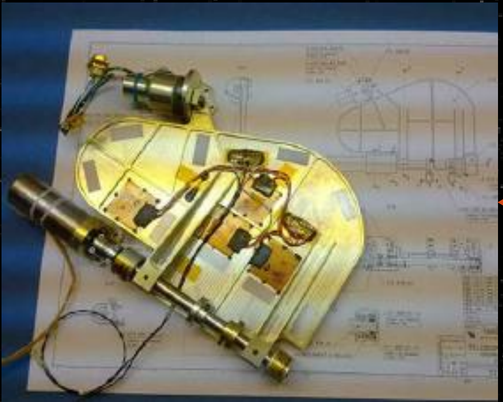
2 – The payload of the PICARD mission (5/5)

SODISM uses two filters wheels, a door at the entrance of the instrument, and a mechanical shutter.

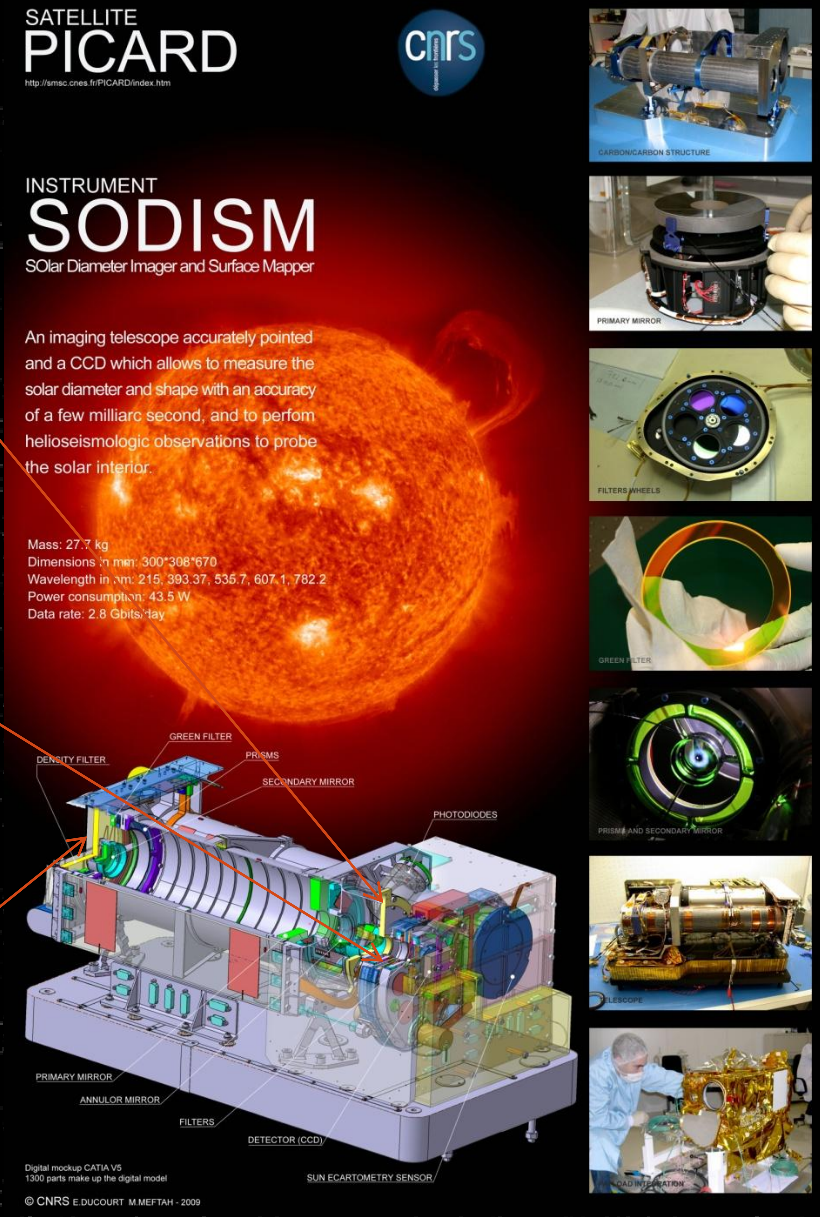


Shutter

Filters wheel



Door



3 – Thermal control, contamination, and environmental effect (1/1)

The purpose of the thermal control

Throughout the mission, thermal control ensures that each instrument or equipment unit is maintained at temperatures consistent with nominal operation.

Most of instruments only operate correctly if maintained at the right temperature and if temperature changes are within acceptable limits.

Thermal control surfaces and optics of the payload are exposed to space environmental effects including contamination, atomic oxygen, ultraviolet radiation, and vacuum temperature cycling.

Contamination, and environmental effects on the performance of the payload

Materials having low values of solar absorptance are often used for reflective surfaces designed to minimize heat absorption. Thermal balance can be maintained over the payload lifetime only if the reflective surfaces maintain its thermal properties.

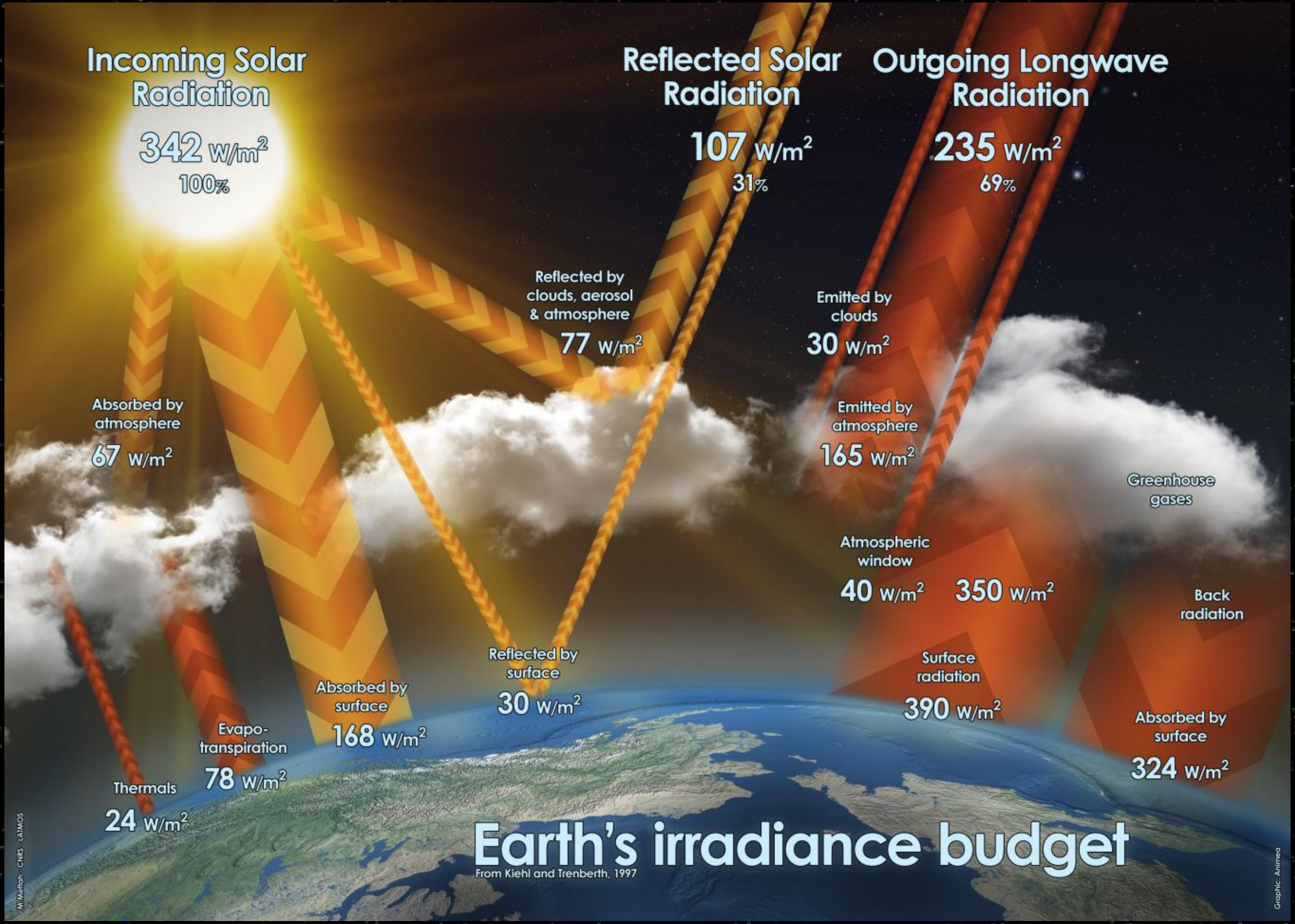
The presence of contamination on thermal control surfaces alters absorptance/emittance ratios and changes thermal balance leading to increase the temperatures of the payload.

Contamination in optical instruments decreases signal throughput, thus further decreasing performance. PICARD payload is sensitive to contamination.

4 – Environment, and impact on the measurements (1/11)

The flux variations (thermal environments) affect the temperature of the payload. When temperatures change (orbital variation, effect of eclipses, long-term variation), the instrument performances are impacted.

The annual mean global energy balance for the Earth-atmosphere system is very important to understand.



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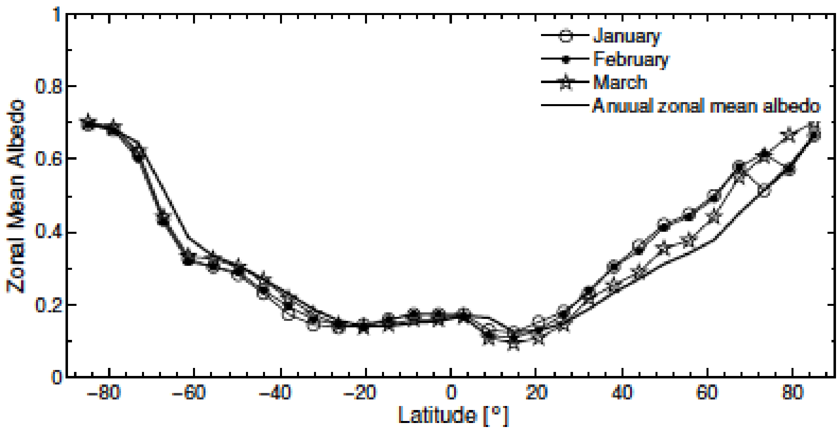
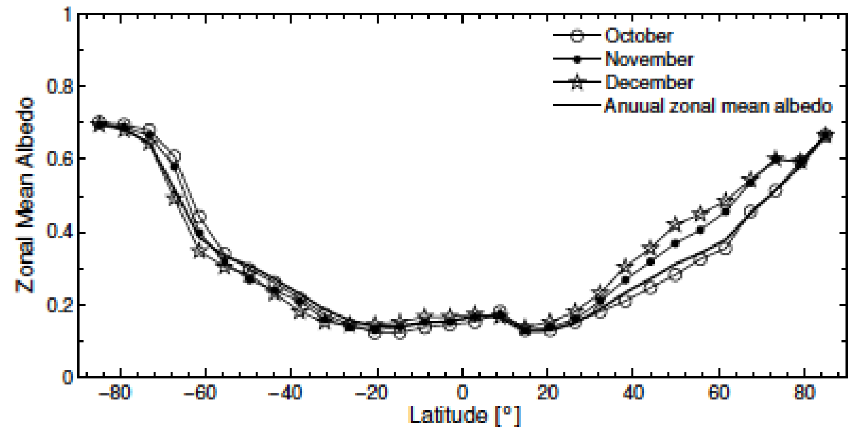
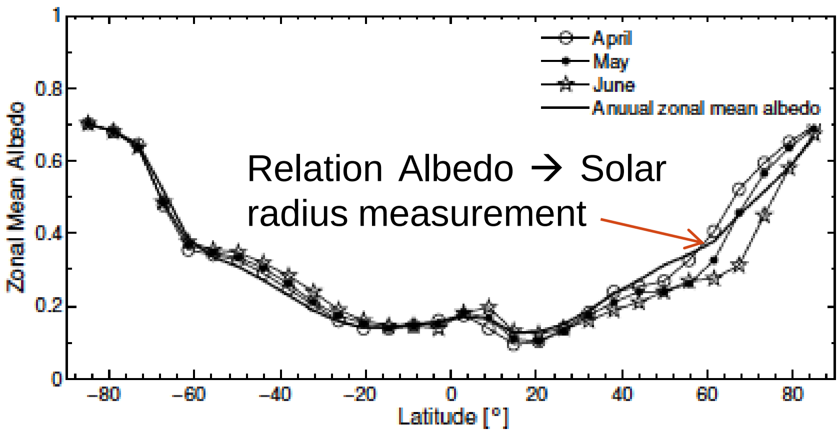
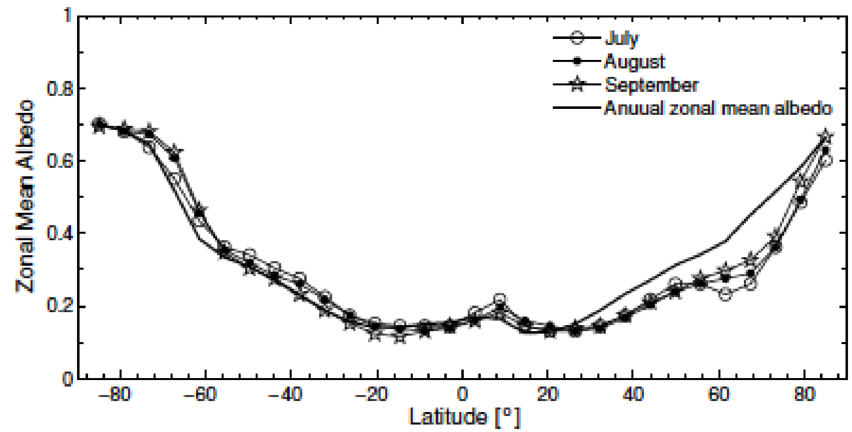
4 – Environment, and impact on the measurements (2/11)









There is a flux variation with the latitude (tropical zones about 20 degrees, poles).

The first Earth's albedo peak, corresponds to the time when the Antarctic sea ice is at its maximum.

The second Earth's albedo peak, corresponds to the time when at higher latitudes much of the land mass is covered with snow (mainly in the Northern hemisphere). Southern hemisphere is mostly covered by ocean.

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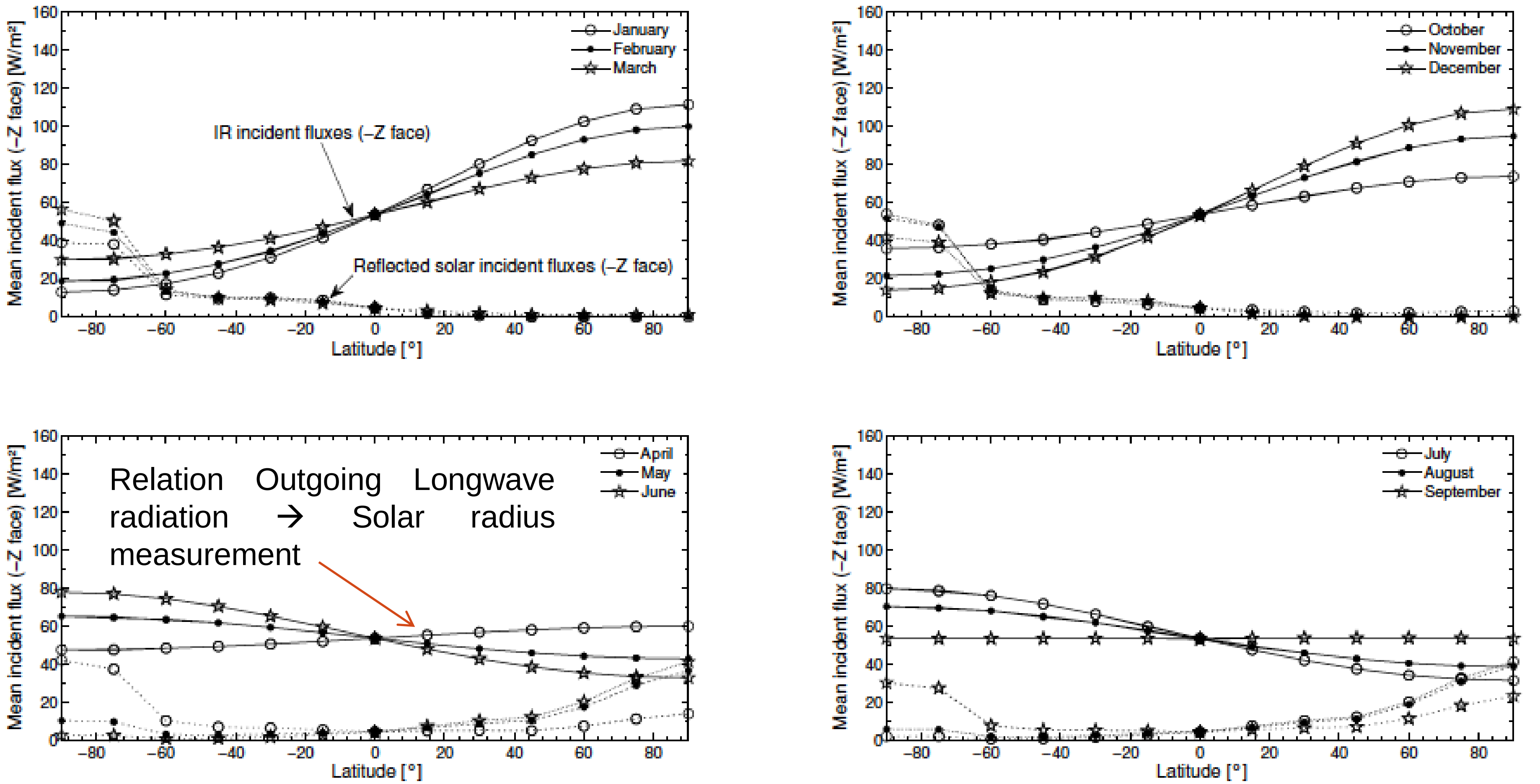
4 – Environment, and impact on the measurements (3/11)



<u>Optical elements are on the front face of the PICARD payload</u> (-Z face). These elements may be sensitive to temperature change. The incident fluxes change during the year.

There is a relationship between latitude and the measurement of the solar radius. This relationship evolves over the years → this is the predominant effect.

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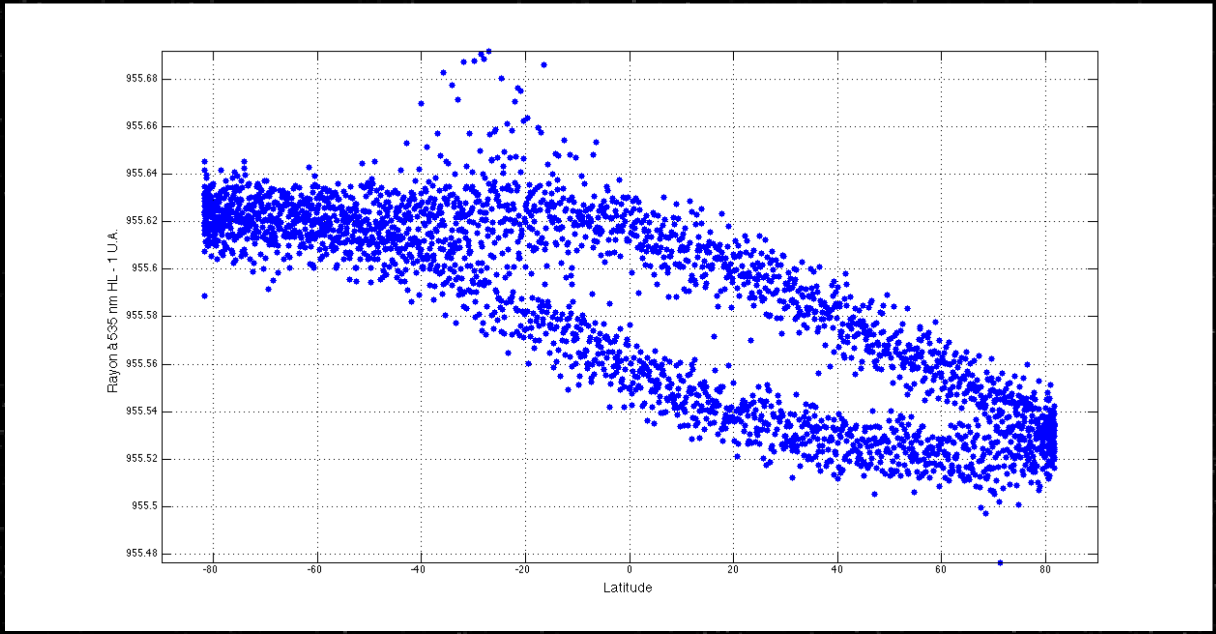
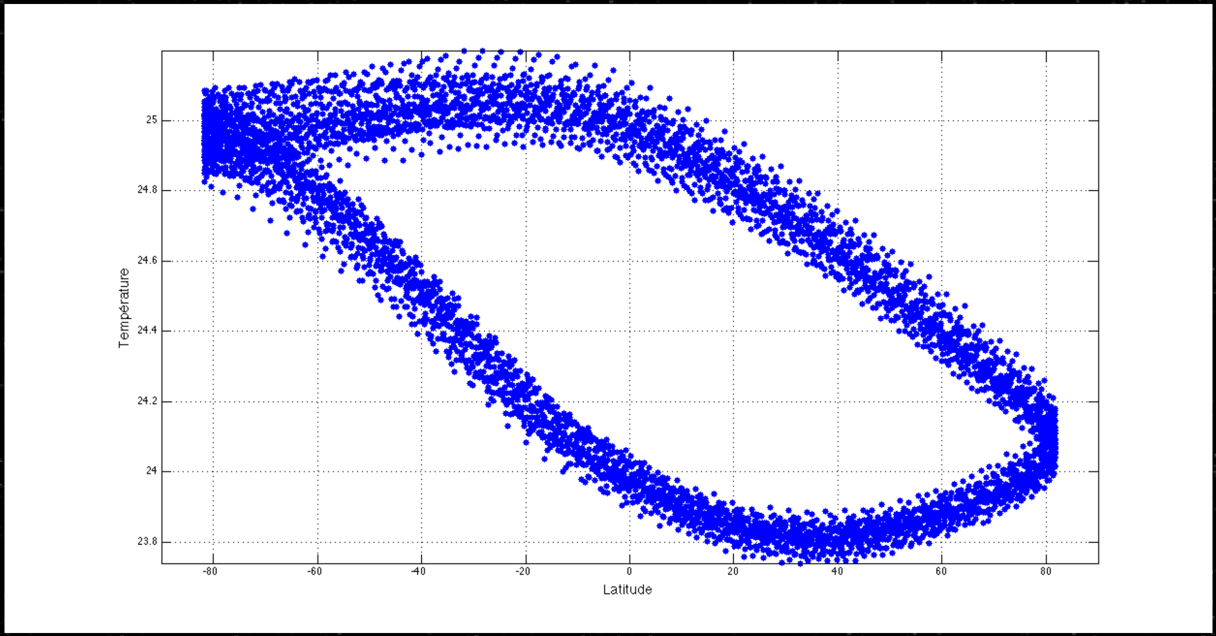
4 – Environment, and impact on the measurements (4/11)

May 2011

SODISM measurements

Temperature

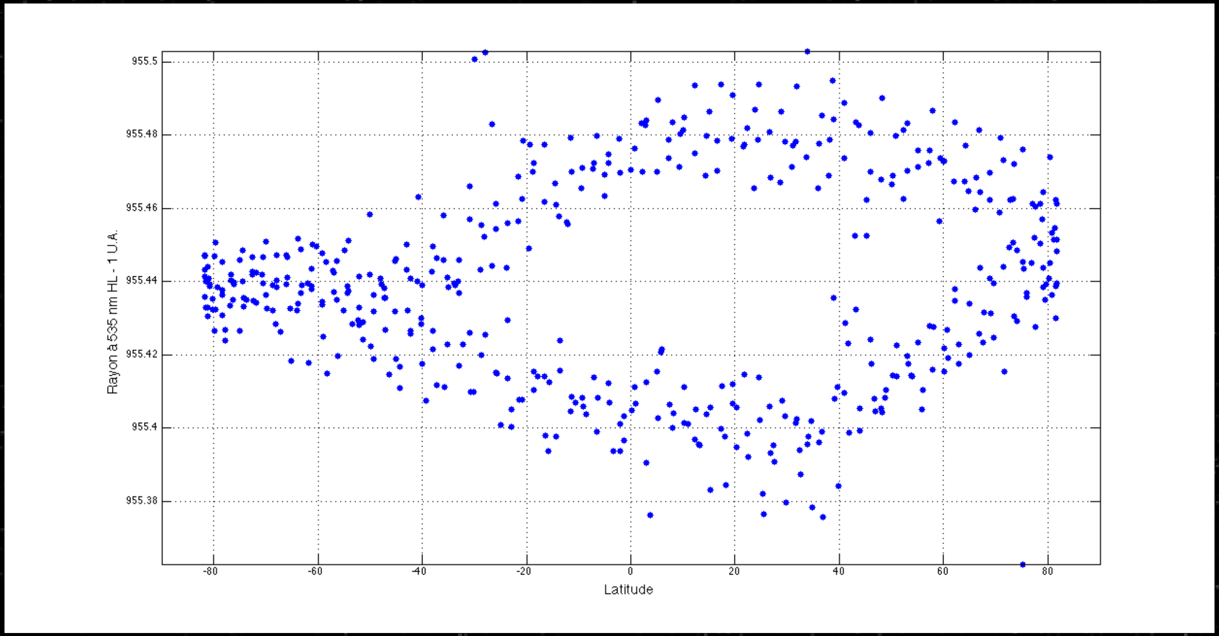




Short term
Orbital effect

4 – Environment, and impact on the measurements (5/11)

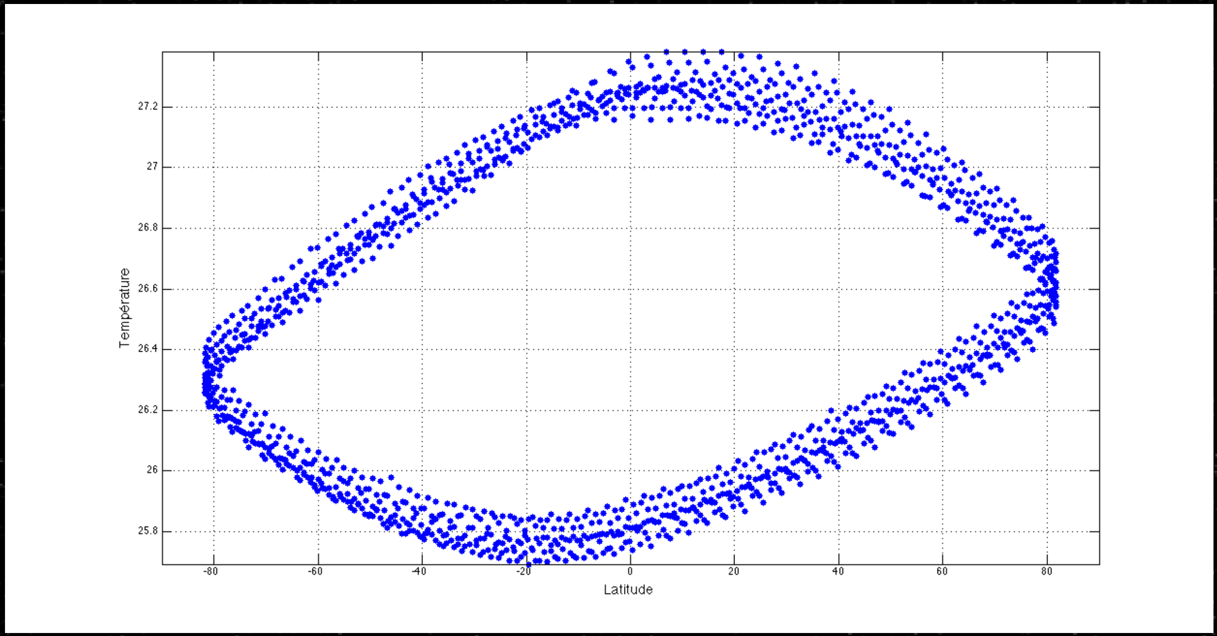
October 2011



SODISM measurements

Temperature

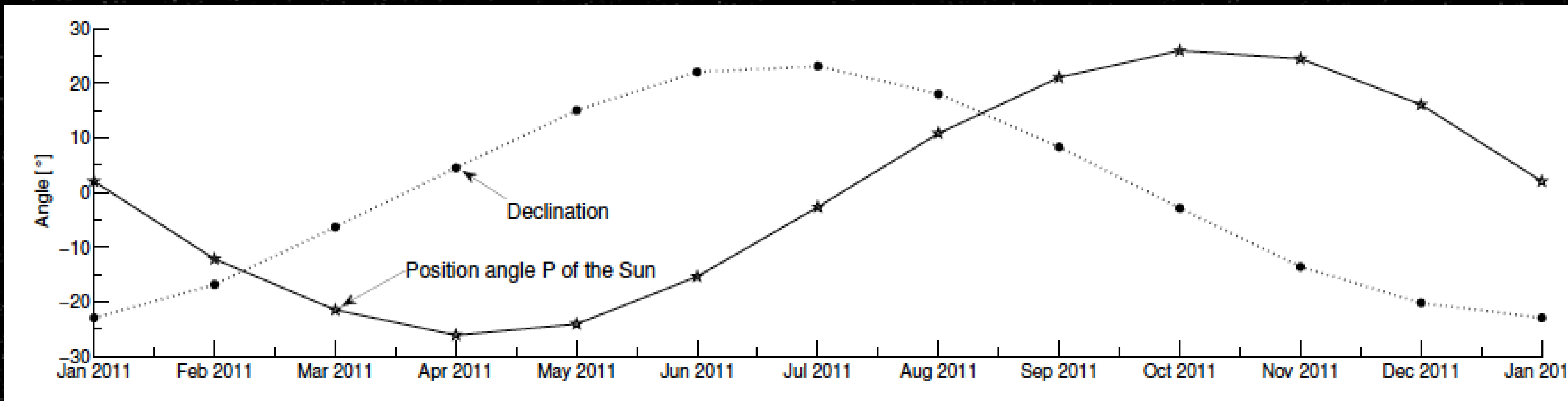
Short term Orbital effect



4 – Environment, and impact on the measurements (6/11)

Explanations concerning the relationship Measurements vs Temperature

Two parameters affect the orientation of the spacecraft (declination and the position angle P). This effect has an impact on the temperature of the spacecraft (relationship between the latitude of the Earth and temperature).



Earth’s irradiance budget, and flux absorbed by the payload

Using the temperatures (housekeeping of the payload) of thermal sensors measured in space, we can compute the unknown at each time. This yields a set of N equations.
This approach is interesting and provides a knowledge of incident fluxes (Irbah, Meftah approach).

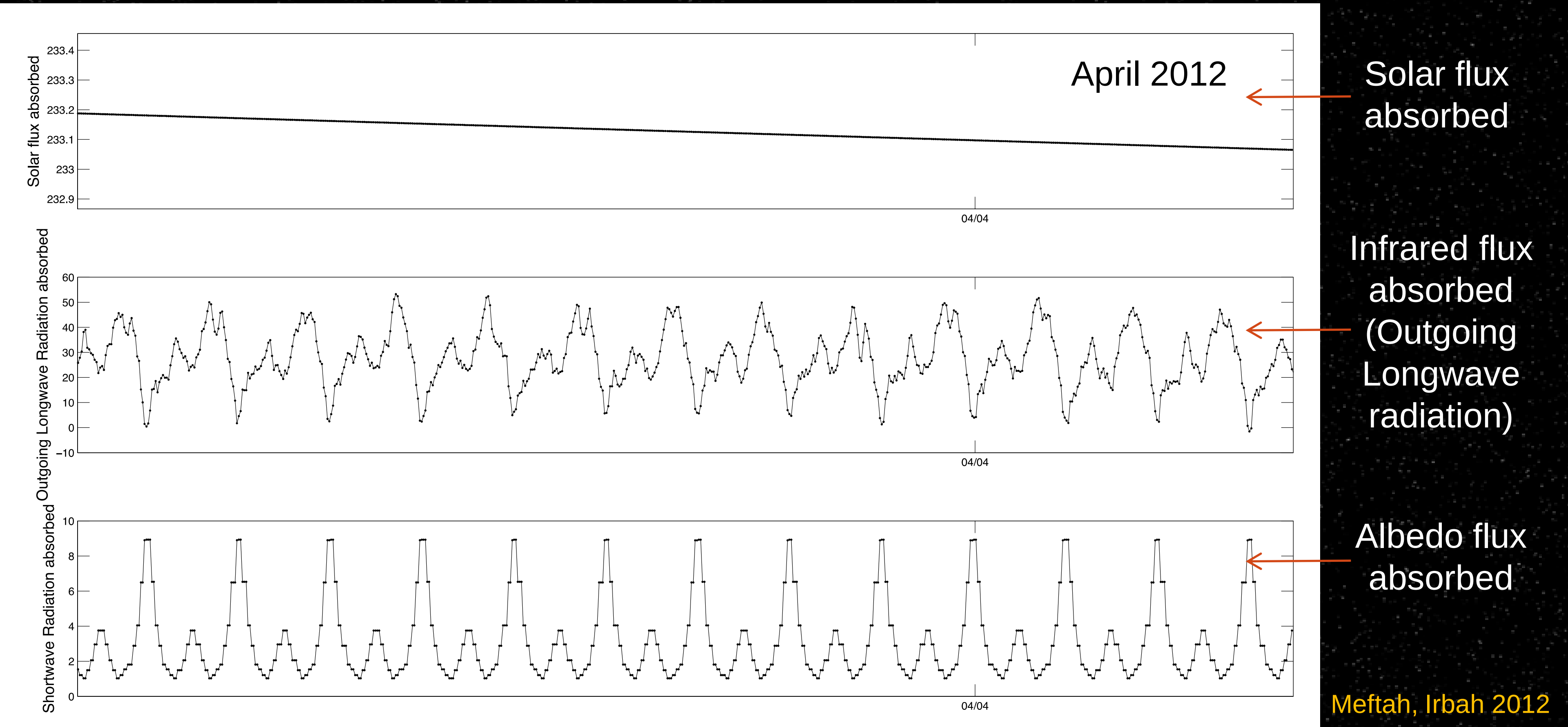
$$\begin{aligned}
&A_w \cos(\theta_w)\frac{d^2}{d^2_{w-Sun}}\int_\lambda SI(\lambda)\alpha_w(\lambda)d\lambda \;+ A_w F_{w-Earth}\int_\lambda \varepsilon_w(\lambda)EI(\lambda)d\lambda\\
&\quad + A_w\frac{d^2}{d^2_{w-Sun}}F_{w-albedo}\int_\lambda aSI(\lambda)\alpha_w(\lambda)d\lambda\\
&\quad + GL_{w-I}(T_I - T_w) + \sigma\int_\lambda \varepsilon_w(\lambda)d\lambda\;(T^4_{space} - T^4_w) + QI_w = 0
\end{aligned}$$

$$\begin{aligned}
&A_b \cos(\theta_b)\frac{d^2}{d^2_{b-Sun}}\int_\lambda SI(\lambda)\alpha_b(\lambda)d\lambda \;+ A_b F_{b-Earth}\int_\lambda \varepsilon_b(\lambda)EI(\lambda)d\lambda\\
&\quad + A_b\frac{d^2}{d^2_{b-Sun}}F_{b-albedo}\int_\lambda aSI(\lambda)\alpha_b(\lambda)d\lambda\\
&\quad + GL_{b-I}(T_I - T_b) + \sigma\int_\lambda \varepsilon_b(\lambda)d\lambda\;(T^4_{space} - T^4_b) + QI_b = 0
\end{aligned}$$

4 – Environment, and impact on the measurements (7/11)

Optical elements are on the front face of the PICARD payload (-Z face). These elements may be sensitive to temperature change. The incident fluxes change during the year.

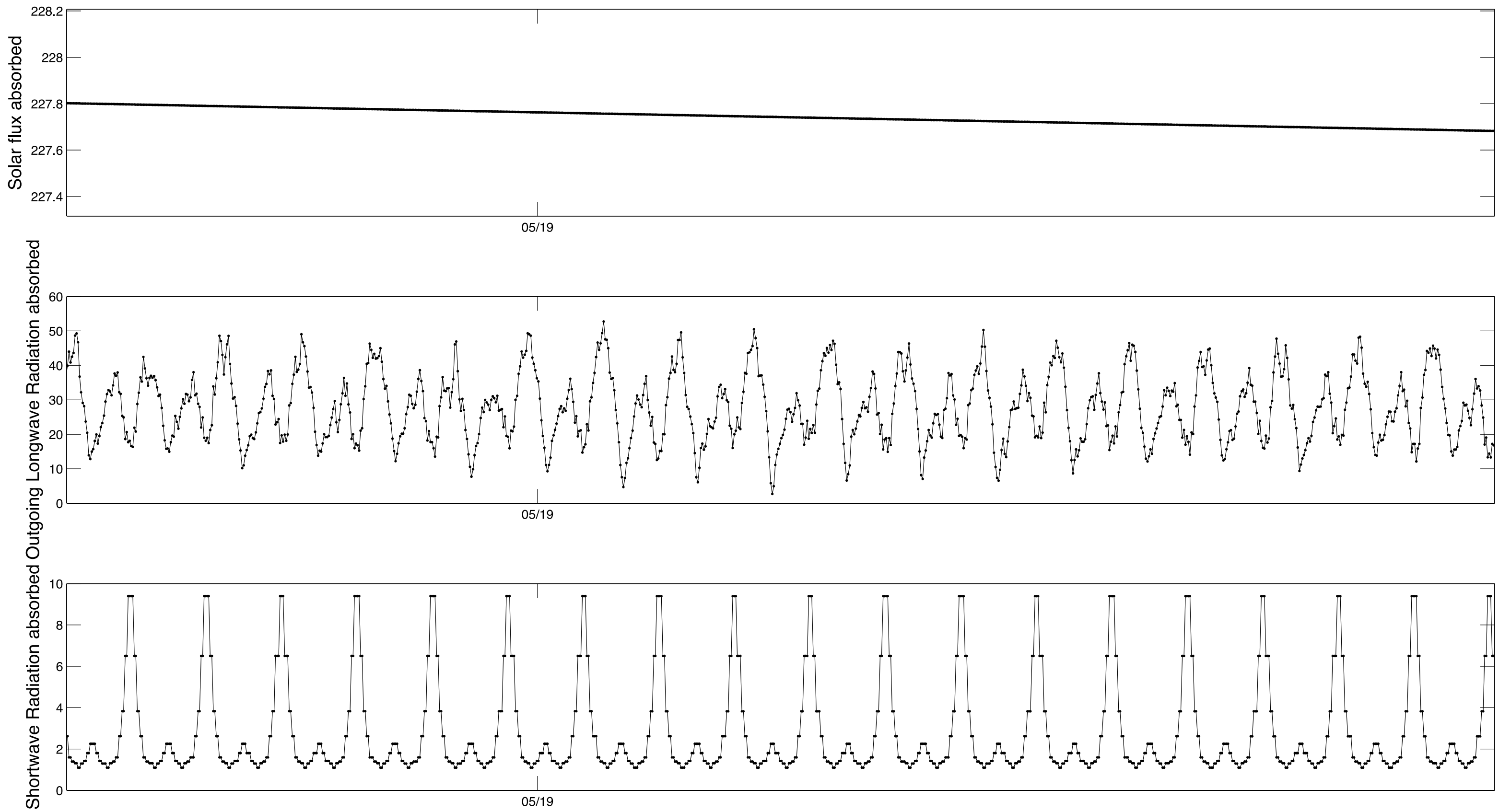
- Solar flux absorbed → Low variation during one orbit of 99.4 minutes
- Infrared flux absorbed → Variation of 60 W (major effect)
- Albedo flux absorbed → Variation of 10 W (significant effect)



Meftah, Irbah 2012

4 – Environment, and impact on the measurements (8/11)

May 2011

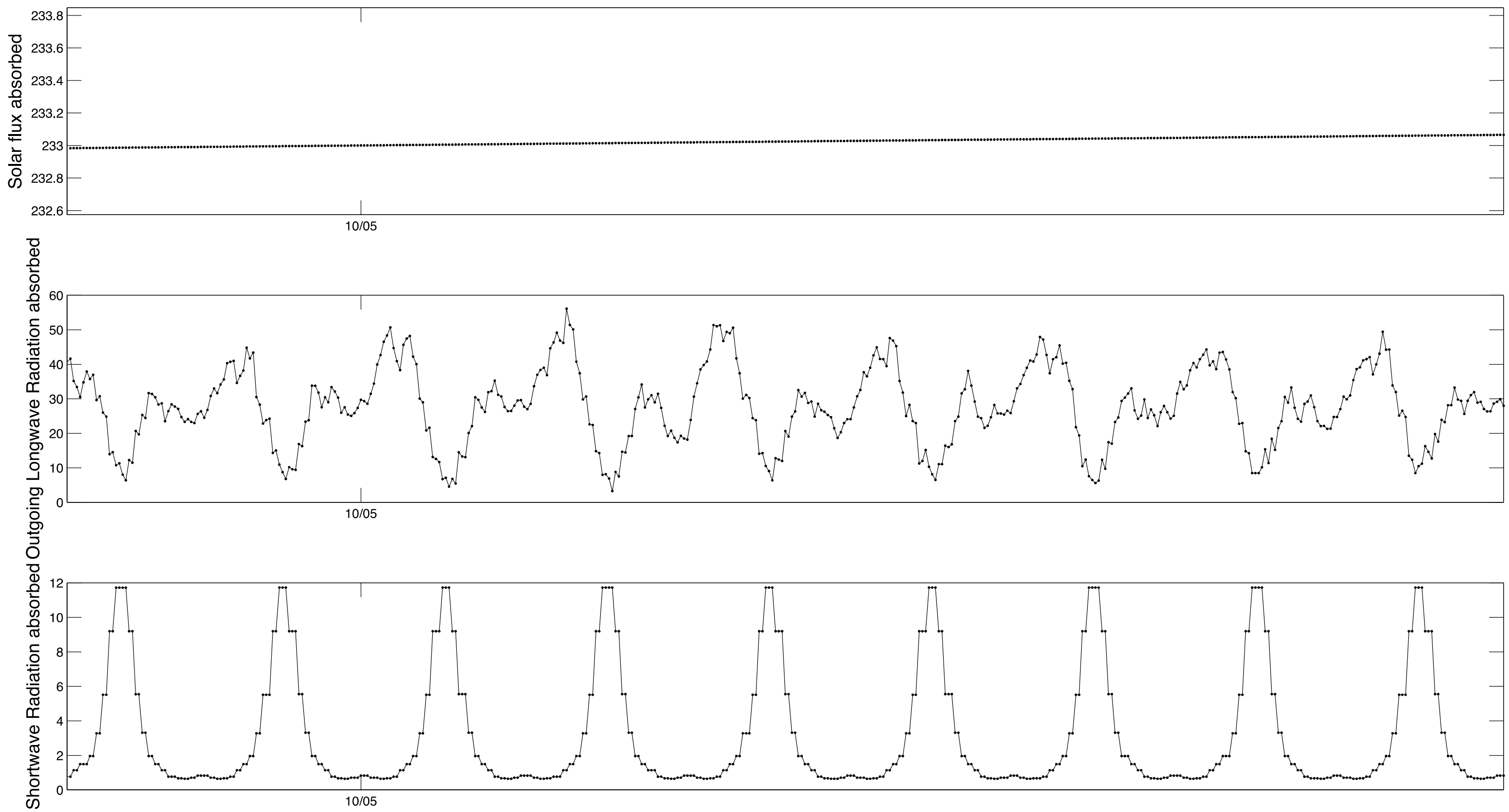


With PICARD data

Infrared flux absorbed, and Albedo flux absorbed on the front face of the PICARD payload → Evolution during the month

4 – Environment, and impact on the measurements (9/11)

<u>October 2011</u>

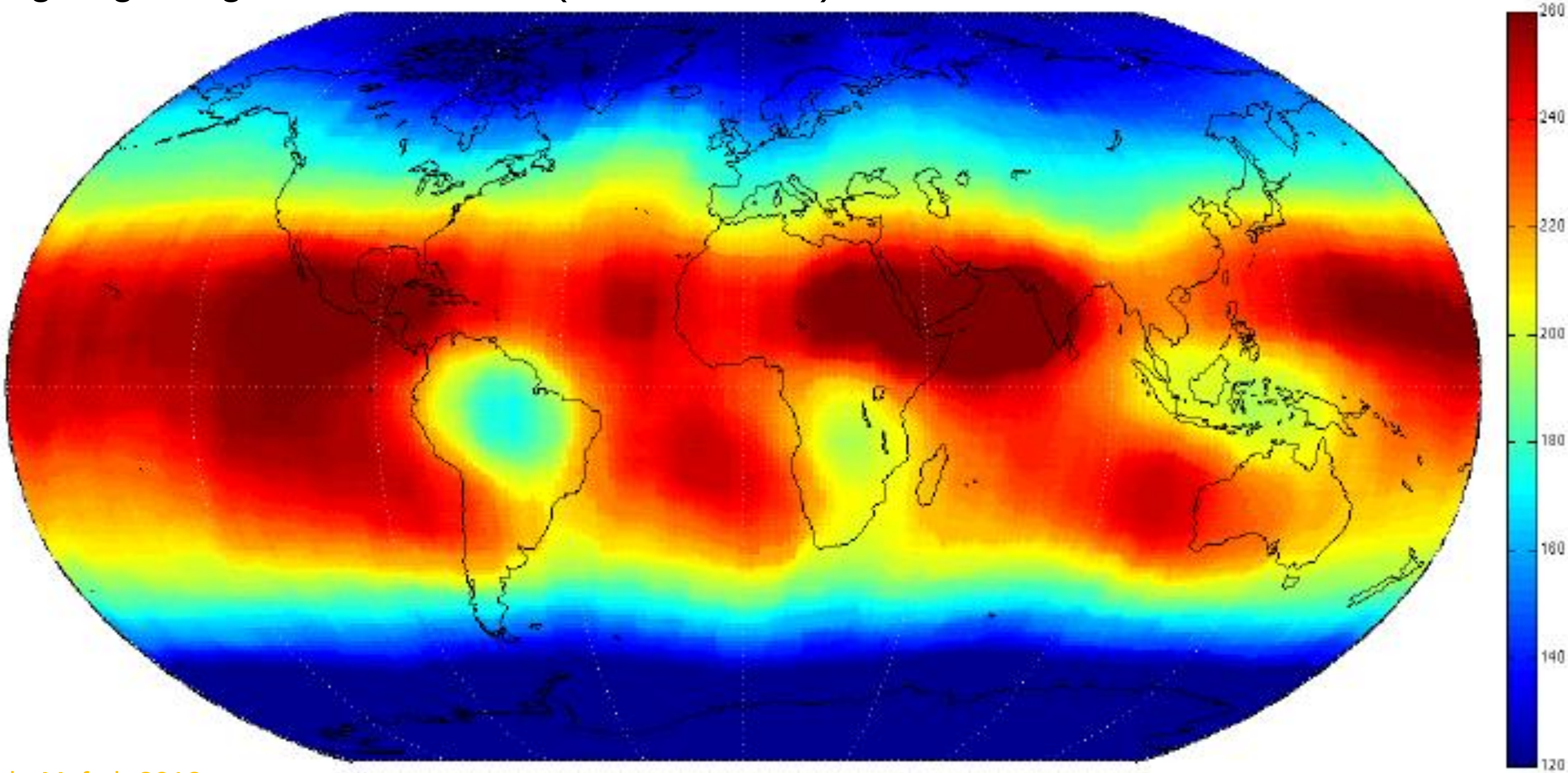


With PICARD data

Infrared flux absorbed, and Albedo flux absorbed on the front face of the PICARD payload → Evolution during the month

4 – Environment, and impact on the measurements (10/11)

Outgoing Longwave Radiation (OLR in W/m^2) – with PICARD data



Irbah, Meftah 2012

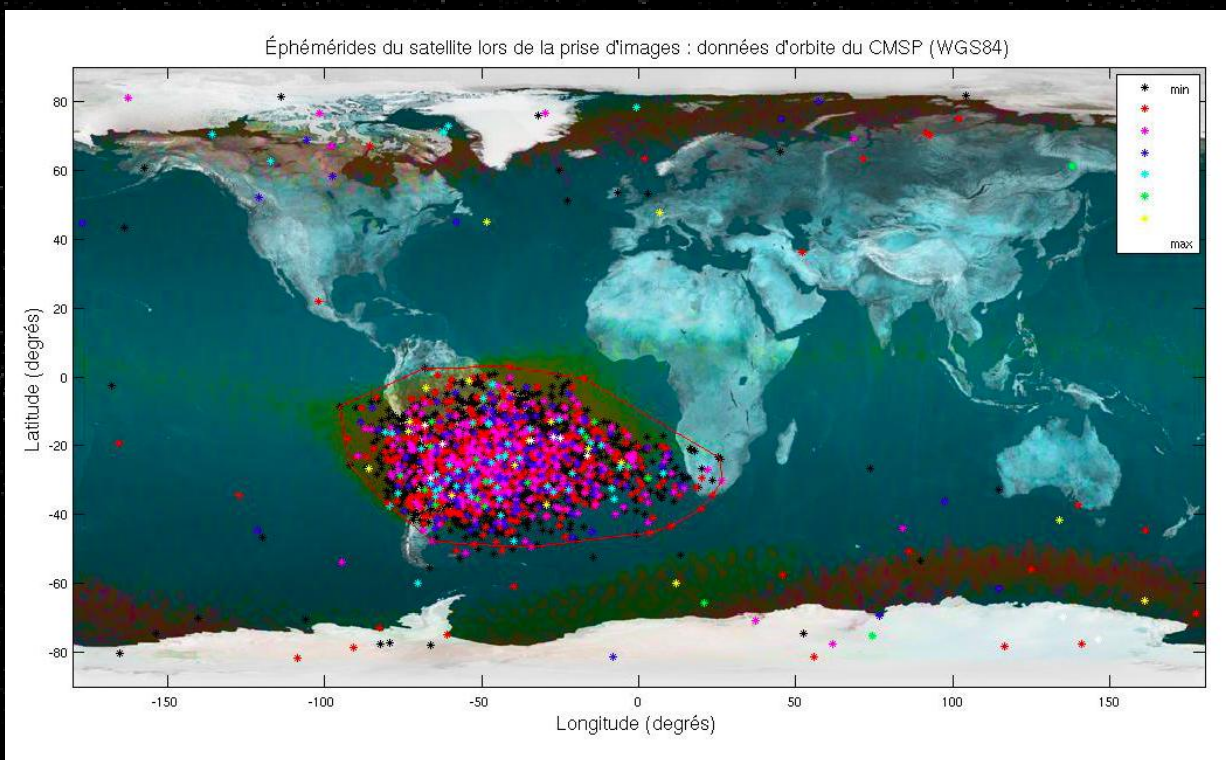
Our measurements are continuously transient (Spacecraft mass, proximity to Earth, ...).
There is a relation between TEMPERATURE and MEASUREMENTS.

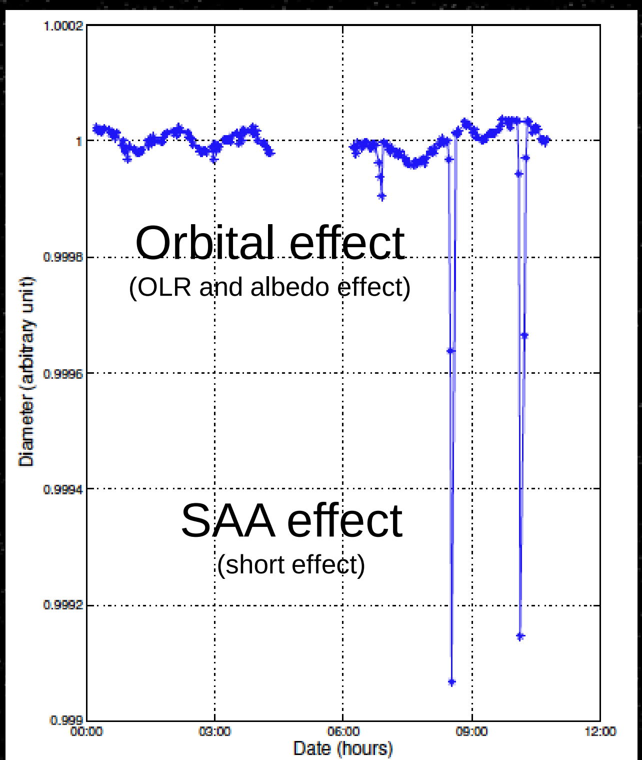
Keyword: TRANSIENT

4 – Environment, and impact on the measurements (11/11)

The SODISM CCD camera is in fact strongly impacted by the particles when the satellite crosses the SAA (South Atlantic Anomaly).

We can also observe that it has a periodic variation on the Sun Diameter which corresponds to the satellite orbital period. This effect needs to be modeled (orbital effect) to correct the solar radius measurements.

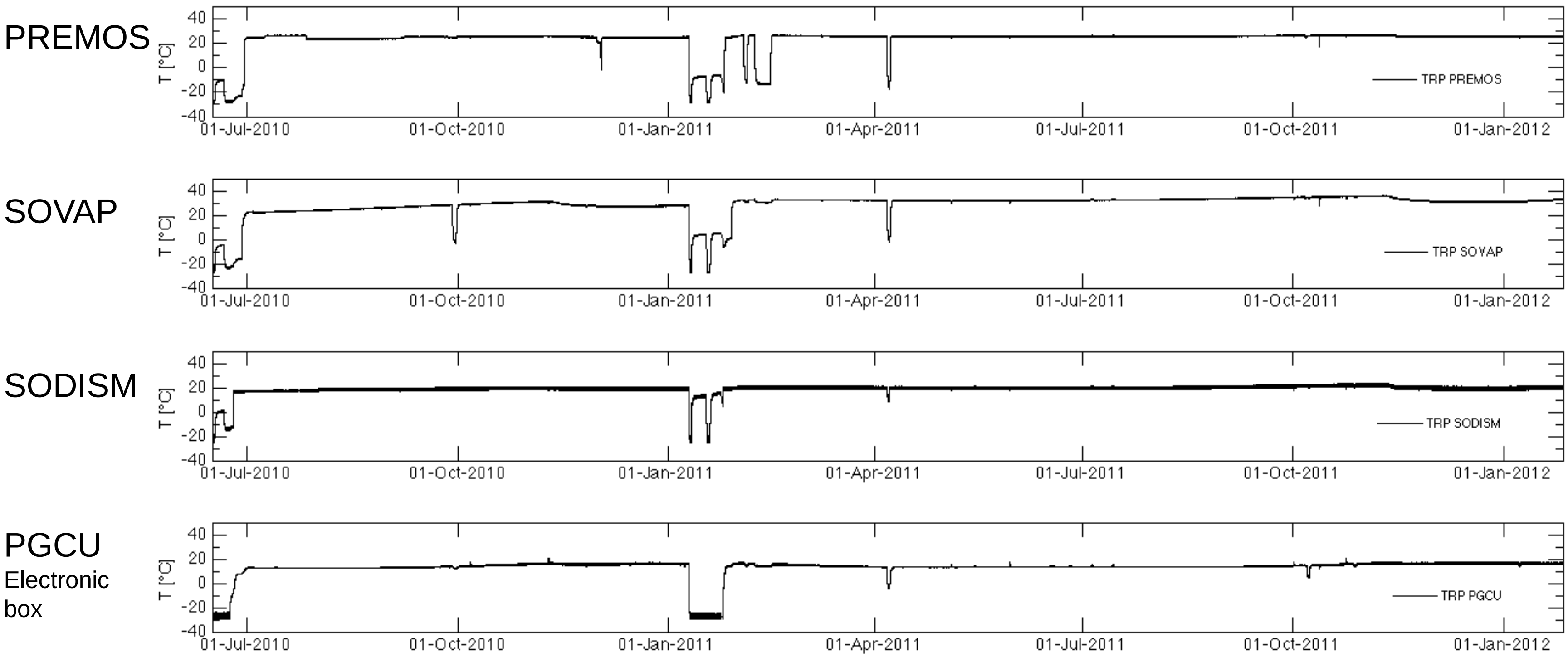




Sun diameter evolution
(arbitrary units)

Keyword: SAA

5 – Temperature, intensity, contamination (1/10)

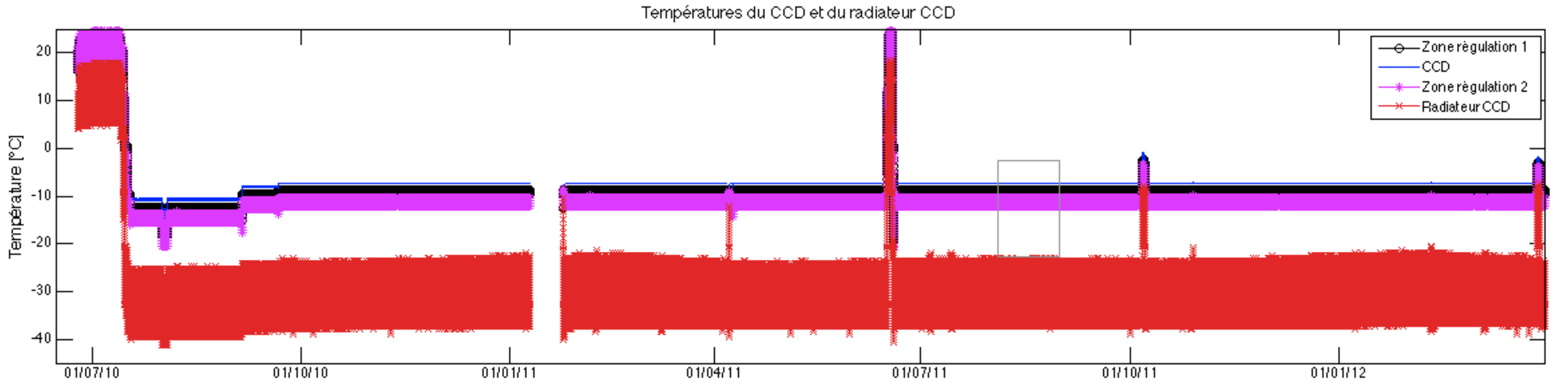


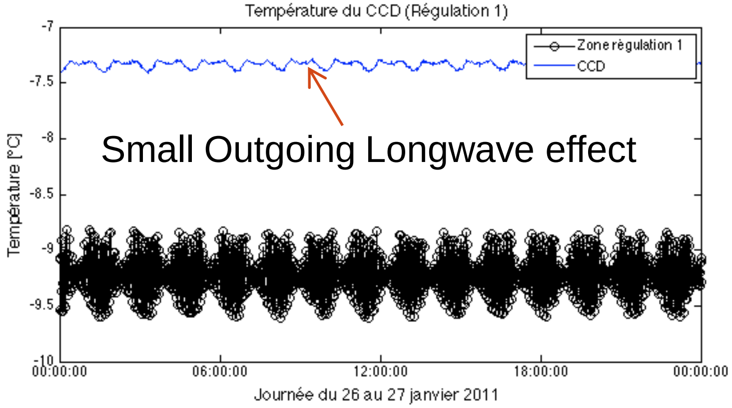
Fluctuations in the PICARD payload temperatures result from a large number of factors. There are short term factors (orbital variation, bakeout, switch OFF/ON instrument, spacecraft rotation, stellar calibration).

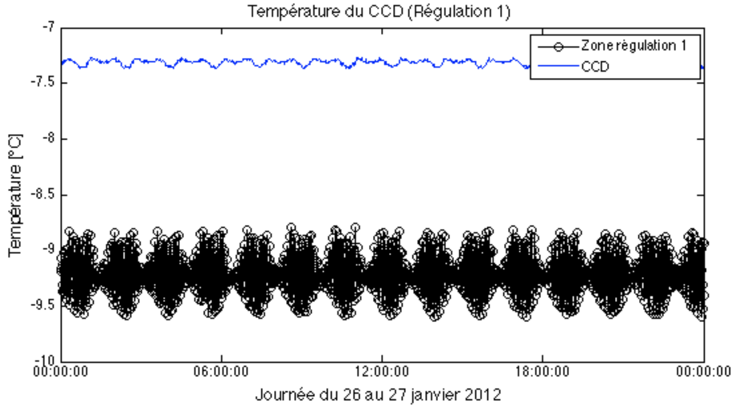
There are several heaters onboard PICARD payload that are used to maintain a specific thermal environment for the scientific instruments (PREMOS, SODISM). Despite the establishment of an active thermal control, there is an environmental short term effect on all the instruments.

5 – Temperature, intensity, contamination (2/10)

SODISM



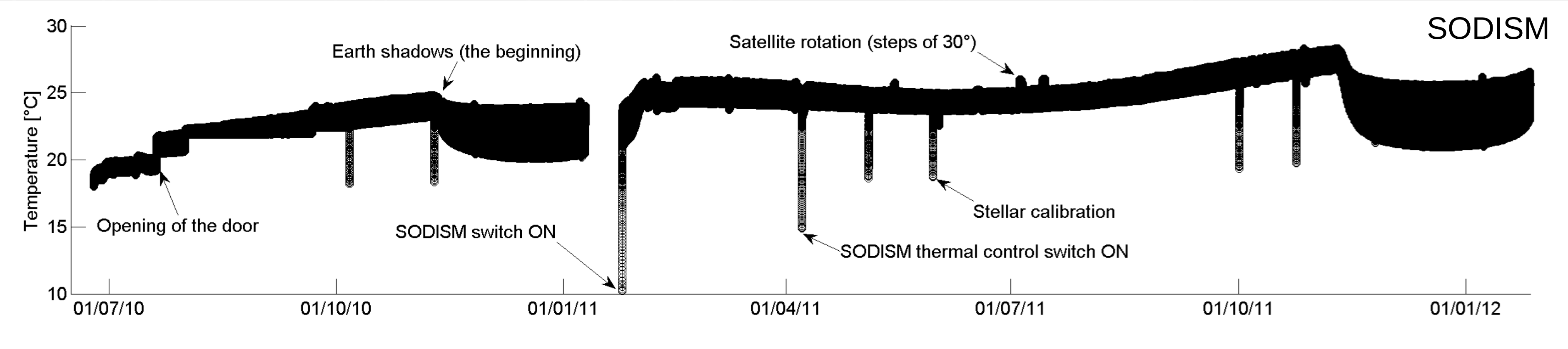




The elements of the payload that are regulated, and not exposed to Sun remain stable in temperatures (PREMOS, SODISM [CCD, interferential filters, mechanism, structure]).

We can see that the temperature of the SODISM/CCD is very stable (better than 0.1°C).
That is the same for SODISM filters wheels (0.03°C).

5 – Temperature, intensity, contamination (3/10)



PICARD payload thermal control system included several temperature control techniques: reflective covers, coatings, insulation, and heat sinks.

Deterioration of the covers, coatings, and insulation was expected to be cumulative with time.

This general deterioration of the thermal control system might be observed in the long term increase of specific temperatures (in particular in the front face of SODISM).

The temperature of SODISM front face varies greatly during the orbit and its temperature variation depends strongly on latitude, and day of the year (variation and effect of incident fluxes).

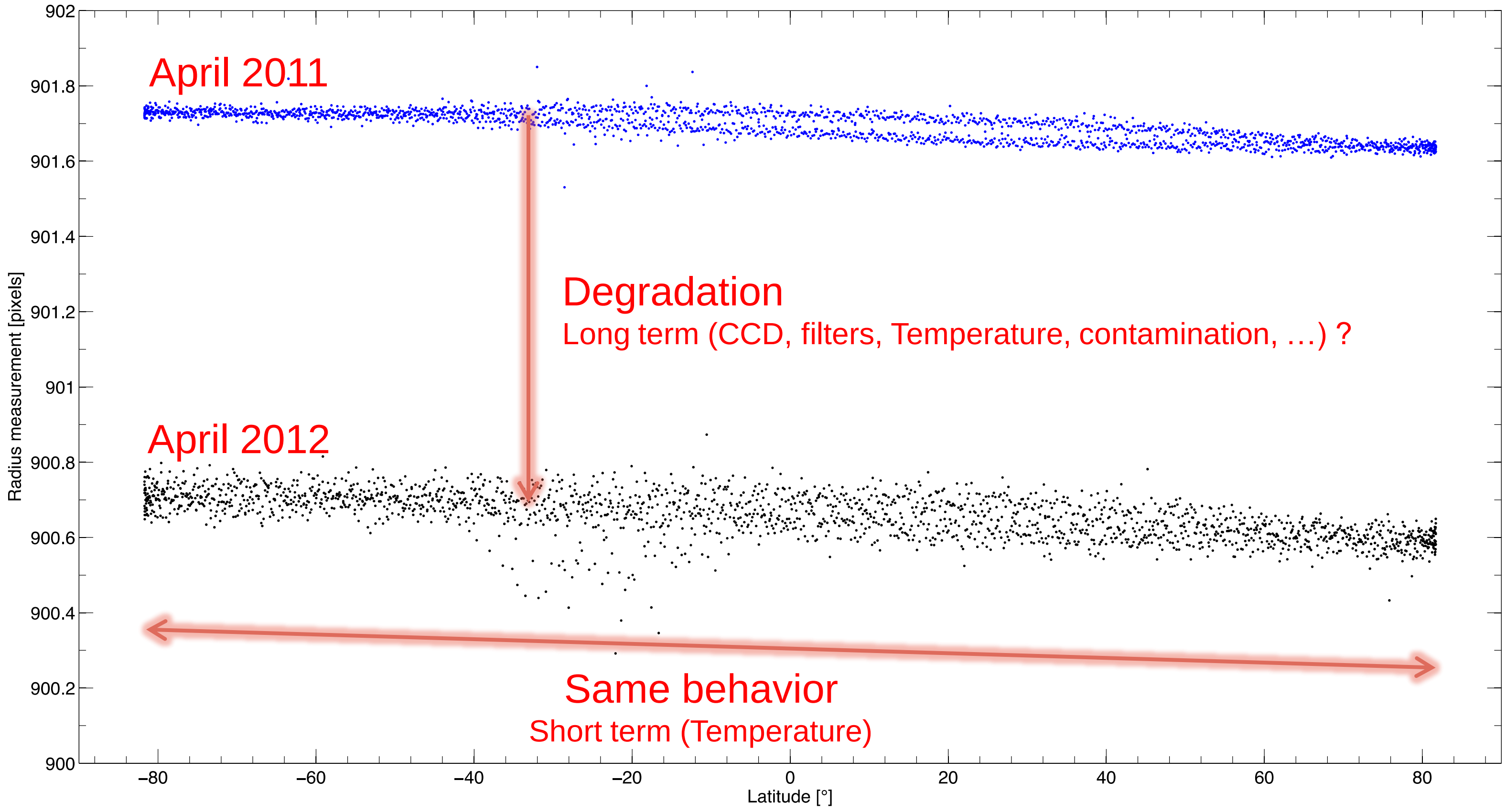
There is the same problem for SOVAP (DIARAD and the BOS).

The use of a Sun shield for PREMOS limit temperature changes over time.

5 – Temperature, intensity, contamination (4/10)

SODISM measurements ⟷ Long term

SODISM



For long term evolution on SODISM measurement, we suspect a degradation of:

CCD response (detector) and/or, **Interferential filters** and/or, **Density filter** (Entrance window of SODISM). Temperature plays a role in the short term effects (orbital effect). Work in progress.

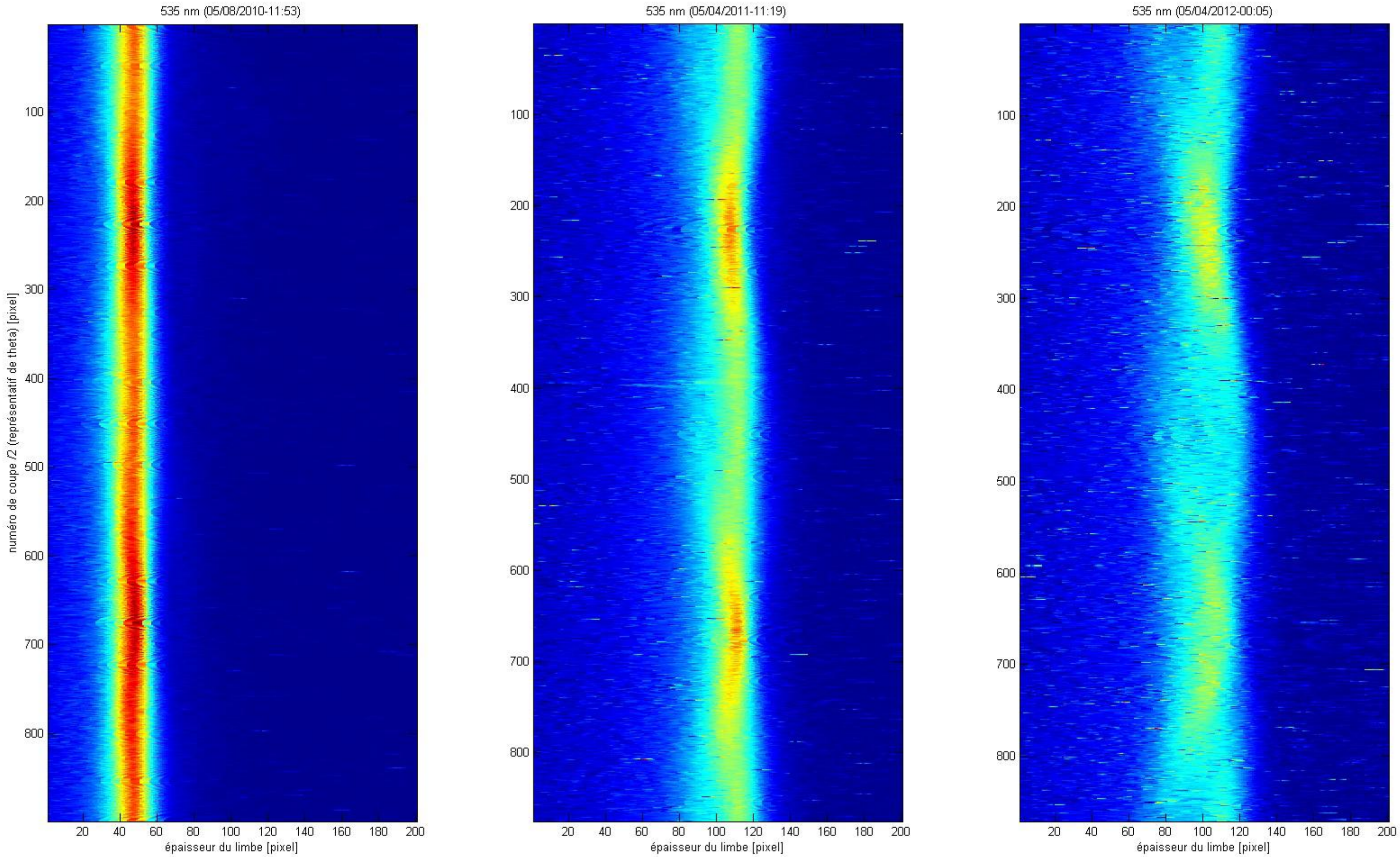
5 – Temperature, intensity, contamination (5/10)

Long term

SODISM

August 2010 | April 2011 | April 2012

Angle position on SODISM image [0 → 2 Pi]



Limb width thickness measurement [pixels]

Fryer, Meftah, Irbah, 2012

Limb width evolution (wavelet method - Haar)

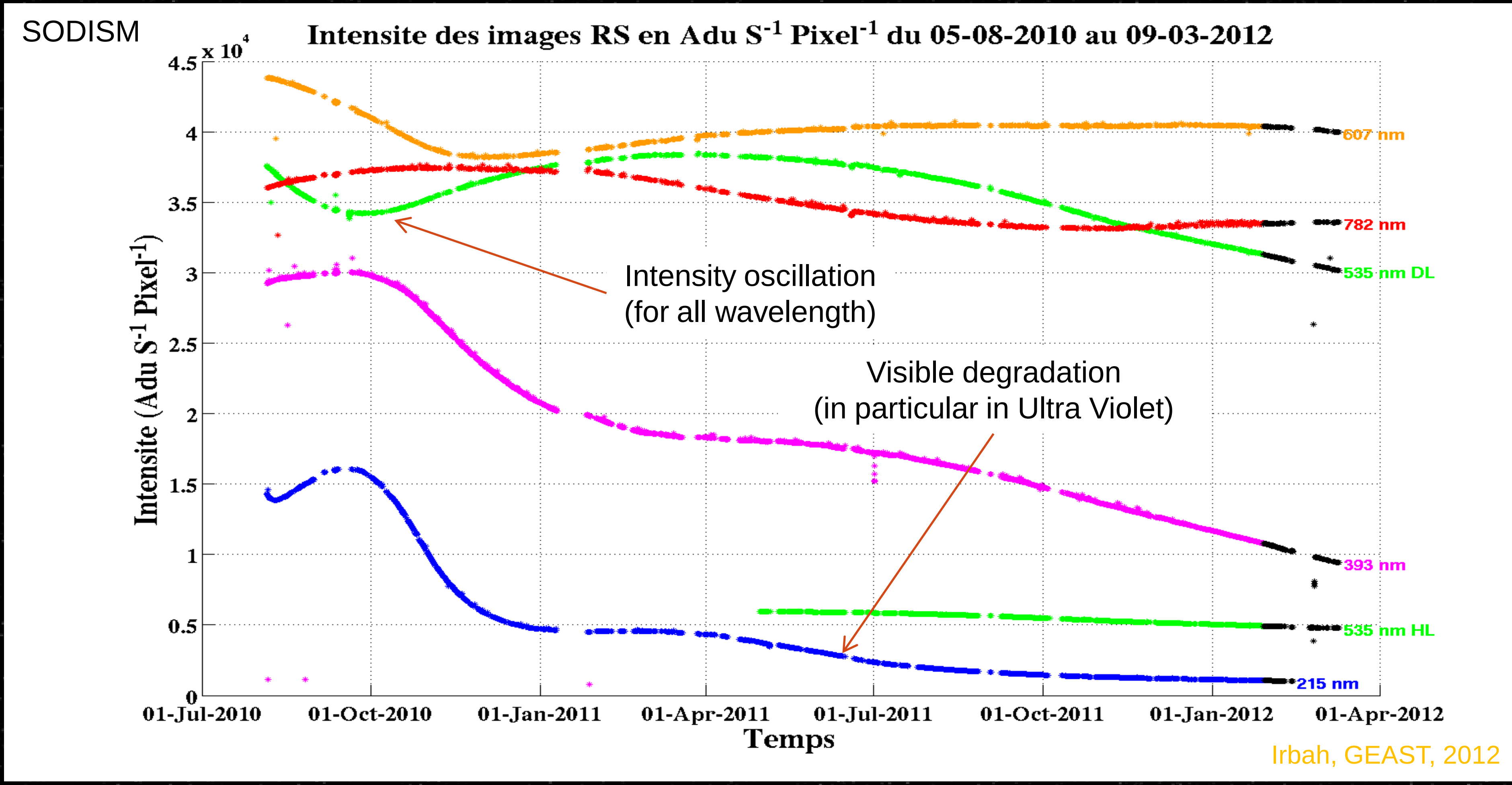
Degradation of the measurement (long term effect → 20 months)

5 – Temperature, intensity, contamination (6/10)

The SODISM images intensity (normalized to 1 AU) evolves over time:

- Intensity oscillation: 535.7 nm, 607.1 nm, 782.2 nm
- Intensity oscillation and important degradation: 215 nm, 393.37 nm

We suspect that this is a combination of contamination, and etching of the surface.
This combination creates an effectively material with high dispersion and inhomogeneity.

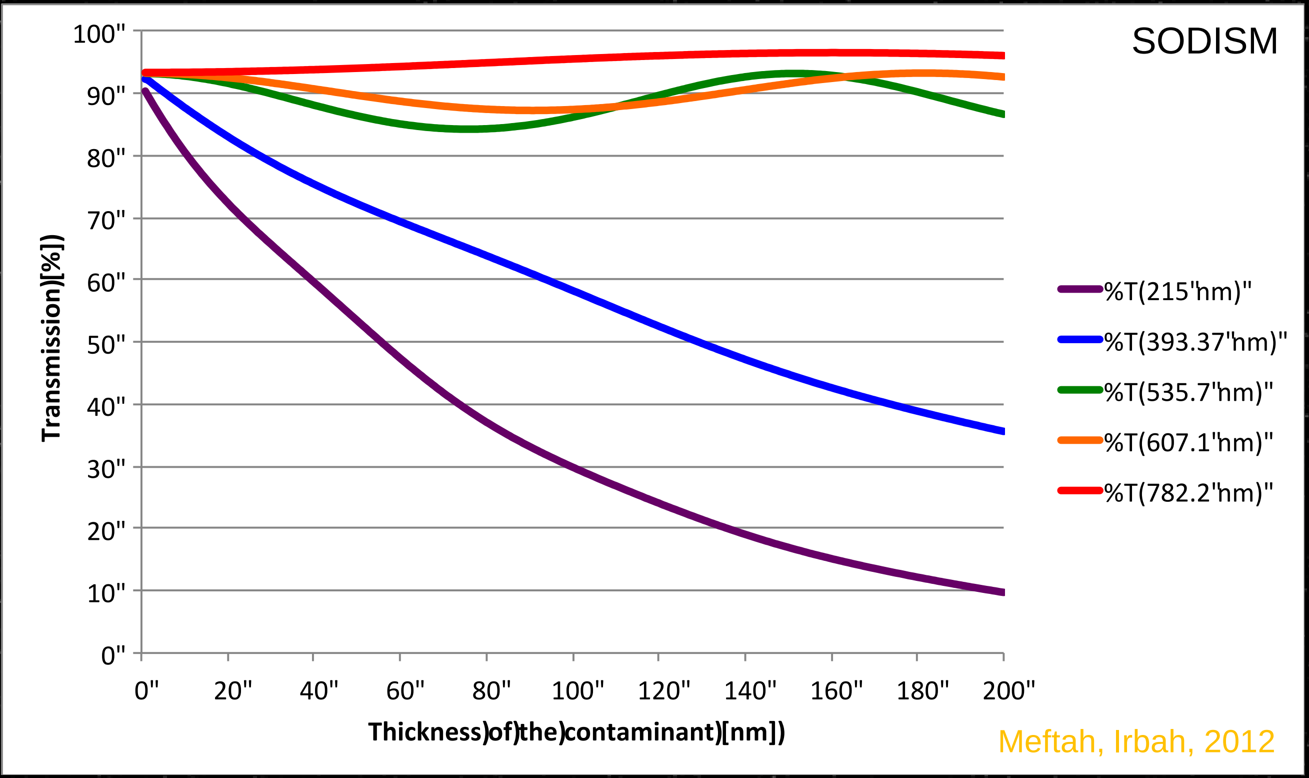


5 – Temperature, intensity, contamination (7/10)

Simulation of the temporal transmission characteristics of the 5 wavelengths observed from 2010 to March 2012, on SODISM.

Each wavelength demonstrated a different change in intensity over time.
We have attempted to model this behavior by creating a material.

We then examined how the transmission would change as a function of layer thickness.
In principle this is equivalent to deposition of a contaminant over time.



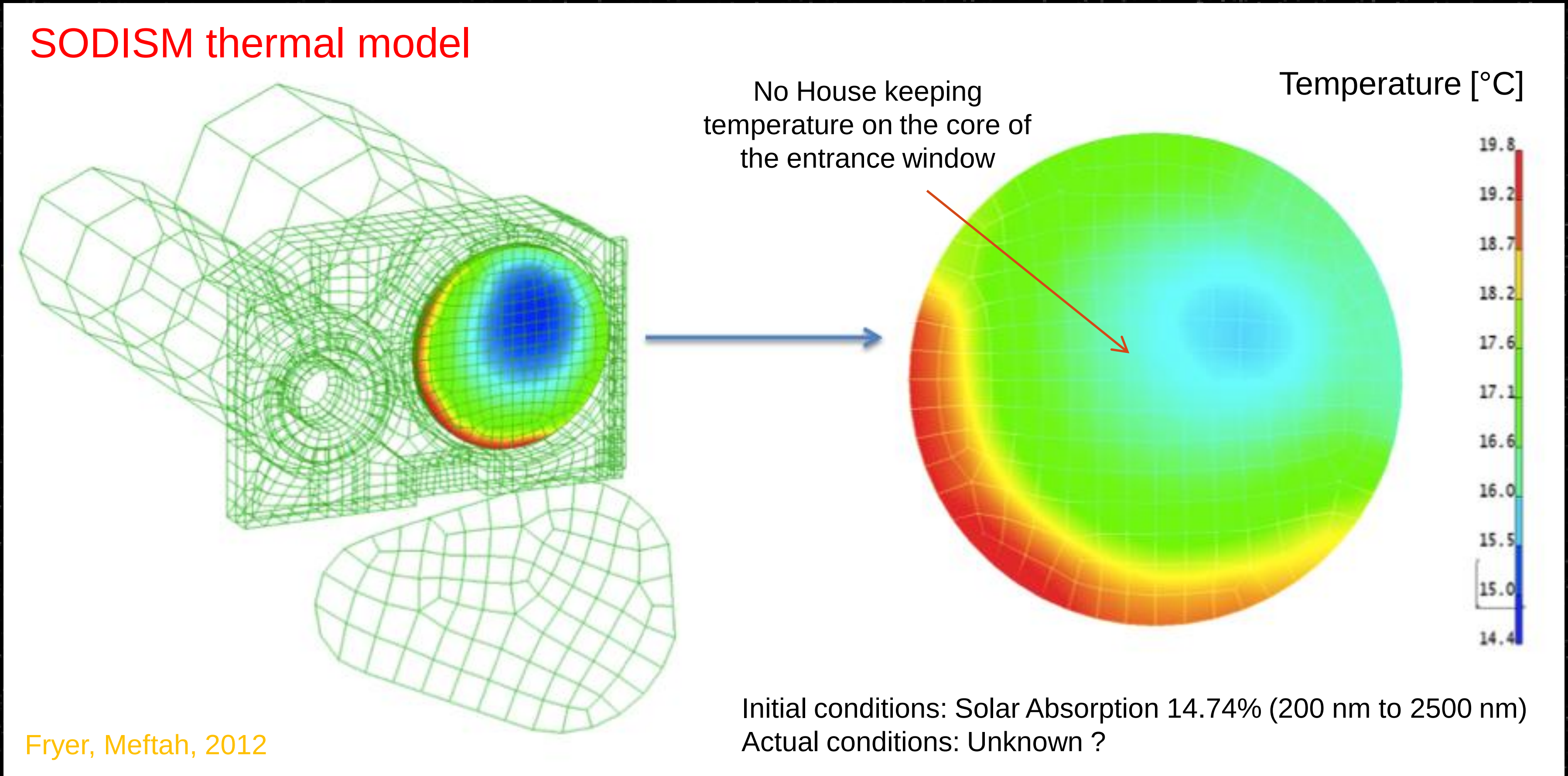
Transmission at each wavelength as a function of layer thickness.

Wavelength	index	k
200.00	2.20000	0.2
300.00	2.10000	0.15
400.00	2.00000	0.15
500.00	1.80000	0.0
600.00	1.70000	0.0
700.00	1.30000	0.0
800.00	1.20000	0.0
900.00	1.10000	0.0

Keyword: <u>CONTAMINATION (nature of the contaminants ? Hydrocarbons, Silicones, …)</u>

5 – Temperature, intensity, contamination (8/10)

Understand the orbital effect → thermal model (IDEAS)



The effects described above have an impact on instrumental performance (temperature change of the core of the entrance window of SODISM instrument).

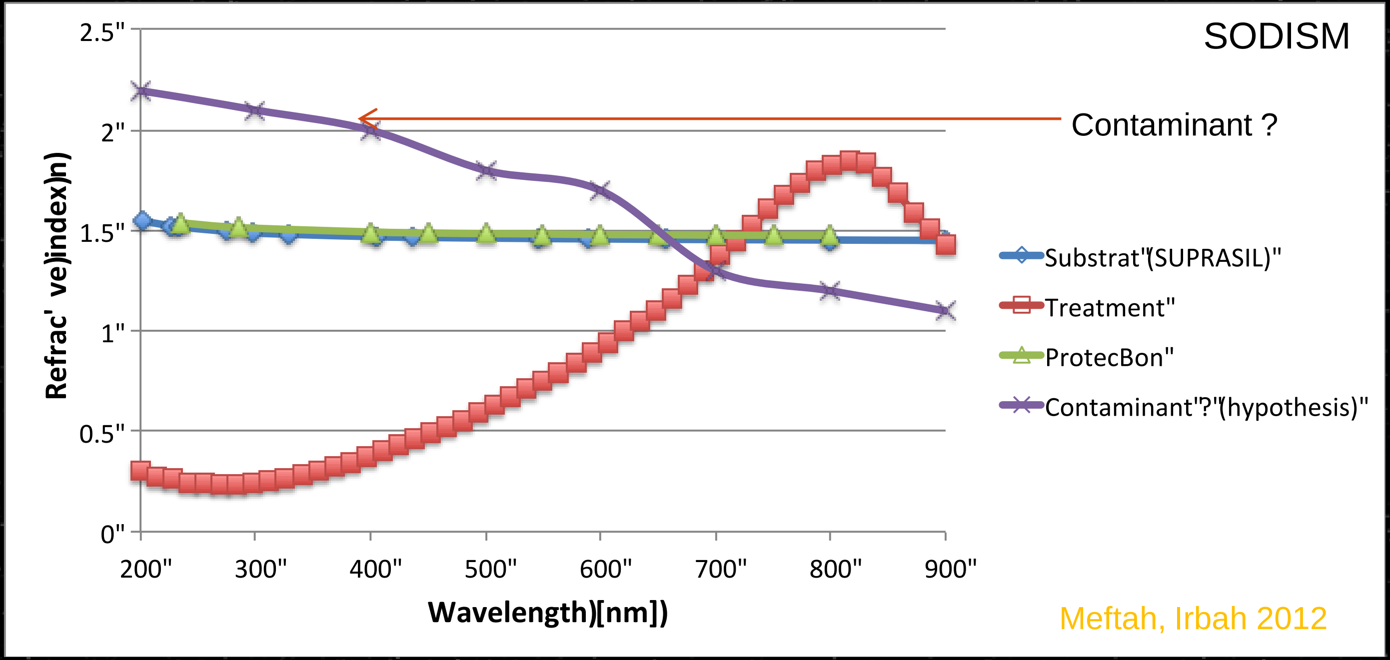
The achieved model shows a significant temperature gradient on the entrance window.
This gradient varies (orbital effect) and changes over time.

5 – Temperature, intensity, contamination (9/10)

Understand the orbital effect → optical model (ZEMAX)

$$f'_F = -\frac{1}{2}\frac{n_F}{n_F - 1}\frac{R_F^2}{e_F(\beta_F + n_F\alpha_F)\Delta T_F}$$

where f'_F is the focal length of the density filter, n_F is the refractive index (1.46008 at 546.07 nm), R_F is the radius of the density filter (63 mm), e_F is the thickness of the density filter (8 mm), β_F is the coefficient of refractive index thermal variation (10.2 ppm/^{o}C at 546.07 nm), α_F is the coefficient of thermal expansion of the density filter (5.5 10^{-7} m/m/^{o}C) and ΔT_F is the gradient through the density filter between the edge and the center of the window.



Optical coating:
Cr
Al
SiO2

Optical simulation of the entrance window with substrate, protection, and treatment.

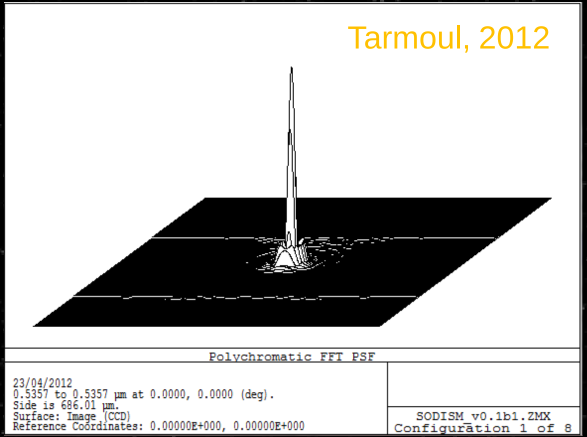
5 – Temperature, intensity, contamination (10/10)

<u>Understand the orbital effect → tools (ZEMAX, MATLAB, IDL, and NASTRAN)</u>

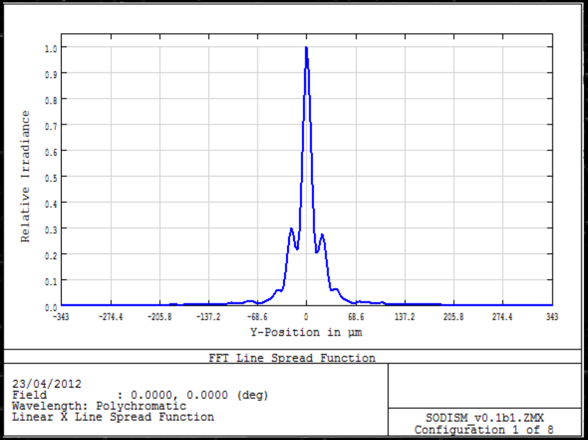
<u>Process in progress:</u>

- From the intensity measured at the SODISM instrument SODISM, determination of the contaminant element (refractive and dispersion index)
- Evaluation of the solar absorption of the entrance window (from 14.74% to ?)
- Evaluation of the solar flux absorbed, the infrared flux absorbed, and the albedo flux absorbed
- Thermal calculation (evaluation of the T gradient)
- Mechanical calculation (evaluation of the curvature)

- Optical simulation of SODISM (ZEMAX) with the characteristics of the entrance window (substrate, protection and treatment) and solar limb profile* (COSI)
    - Nominal case analysis (PSF, LSF, position of the image on the CCD)
    - Nominal case analysis with a thermal gradient between the edge and the center of the window (PSF, LSF, position of the image, mechanical analysis of the effect on the window, …) → short term (orbital effect)
    - Non nominal case analysis (with contaminant element) → long term evolution



SODISM nominal PSF
SODISM nominal LSF
(Line Spread Function)



* G. Thuillier, J. Claudel, D. Djafer, M. Haberreiter, N. Mein, S. M. L. Melo, W. Schmutz, A. Shapiro, C. I. Short and S. Sofia
The Shape of the Solar Limb: Models and Observations, 268: 125–149, Solar Physics, 2011

Conclusion

The PICARD payload is functional and operational.
The hardware is robust (No Single Event Unit, No Latch Up, …).
Any interruption caused by the instrument.

The payload does not measure noise. There is a good repeatability in measurements.

Most of calibration requires THERMAL and/or OPTICAL corrections.

Thermal coatings chosen for the PICARD payload are adequate for maintaining temperatures in the acceptable range.
We have seen an increase of the solar absorptivity of SOVAP radiator oriented to the Sun (0.09 after 4 months, and stabilized to 0.15 after 16 months). The use of radiators facing the Sun is not a good compromise. We must advocate the use of Sun shield to guard the important effects of ageing on thermal coatings.

The SODISM entrance window, and the front of the instrument facing the Sun has a significant temperature increase. Performances of instruments are affected by fluxes variability seen in orbit (Direct solar radiation, planetary infrared for the Earth, and Earth reflected solar), and by the Sun (Latitudes, albedo, declination, Position angle P of the Sun, ...).

The SODISM measurements show a complex dependency of the optical behavior with thermal (short term, seasonal, and ageing), stray light (to be confirmed), and contamination effects (intermediate, and long terms).

Lessons learned

- The use of radiators (white paint, or SSM) facing the Sun is not a good compromise. For solar mission, Sun Shield (with Back Surface Mirror) should be used.

- The objective of Cleanliness and Contamination Control is to ensure a successful mission by the definition of acceptable levels (definition of levels for the entire spacecraft, avoid organic material, and determination of contamination sensitivity).

- Low Temperature of the CCD (reduction of dark current, reduction of the effect of the lattice defects produced by the radiation once in orbit) is very important (less than -20°C). To outgas the accumulated contaminant on the CCD, a bake out heater is installed on SODISM, allowing periodic warms up to +20°C during three days → It is not effective (another approach to develop for the outgassing of the CCD).

- Rapid degradation in the UV filters for PICARD mission. For the future mission, make a drastic test campaign on UV filters (including radiation tests, UV tests, contamination simulation tests, and select an experimented manufacturer).

- On solar observation telescopes, provide systems for refocusing (to try to correct the instrumental degradations). Use of radiometric or bolometric sensor on optical faces (absorbed fluxes information's for optical correction if it is necessary).

- Avoid low orbits for solar missions, and avoid spacecraft with low mass (for metrology mission like PICARD). Pre-flight calibration is very important.