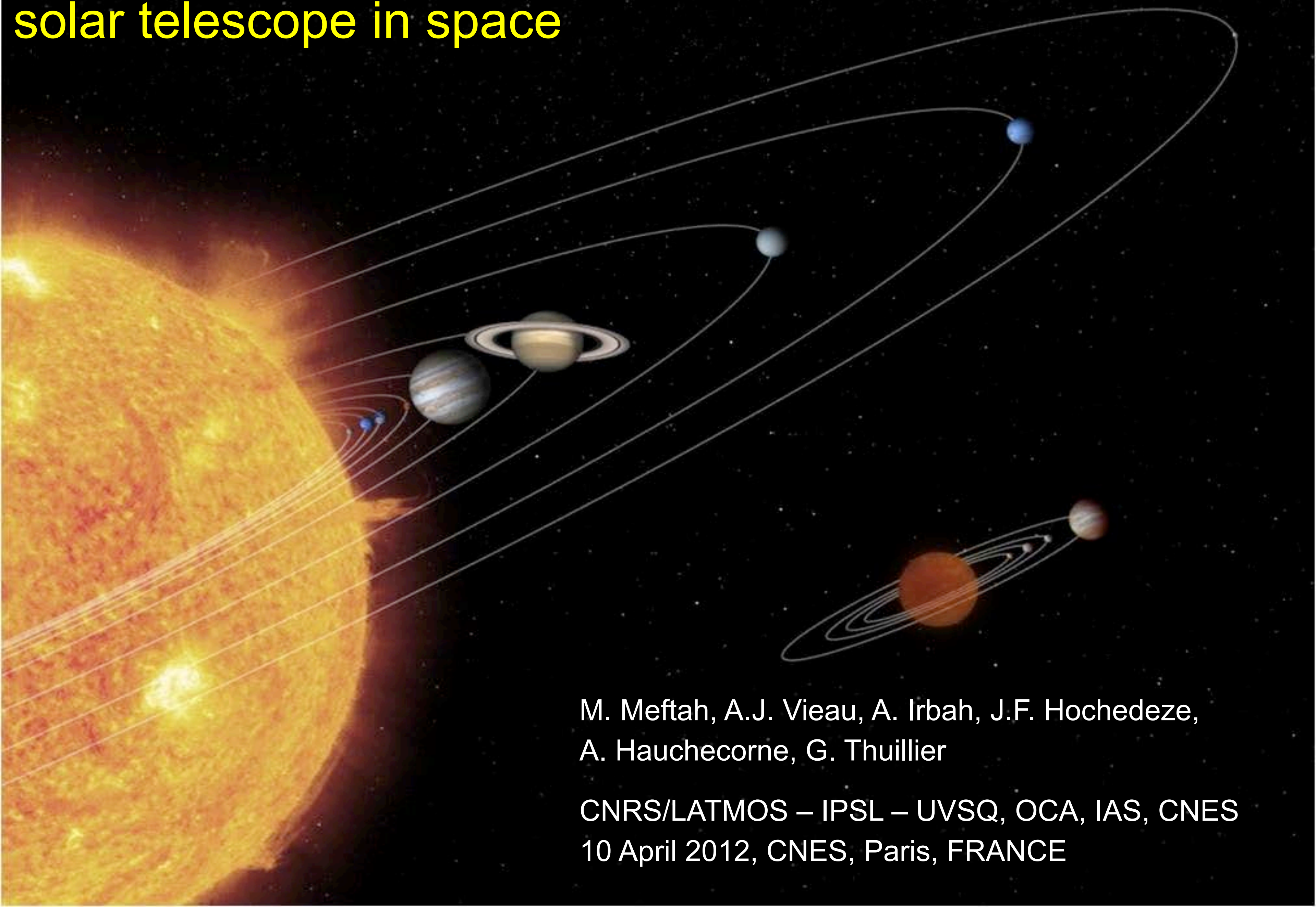
The Space instrument SODISM, a visible light solar telescope in space



M. Meftah, A.J. Vieau, A. Irbah, J.F. Hochedeze,
A. Hauchecorne, G. Thuillier

CNRS/LATMOS – IPSL – UVSQ, OCA, IAS, CNES
10 April 2012, CNES, Paris, FRANCE

Presentation outline

1 - Scientific objectives of the PICARD mission
2 - The space instrument SODISM of the PICARD mission
3 - SODISM mechanism status
4 - SODISM pointing mechanism status
5 - Calibration: Distortion mode
6 - Calibration: Orbital effect
7 - Temperature and intensity – Degradation/Contamination
8 - Calibration: Stellar mode
9 - Transit of Venus 2012

Conclusion

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 space instrument SODISM of the PICARD mission (1/3)

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

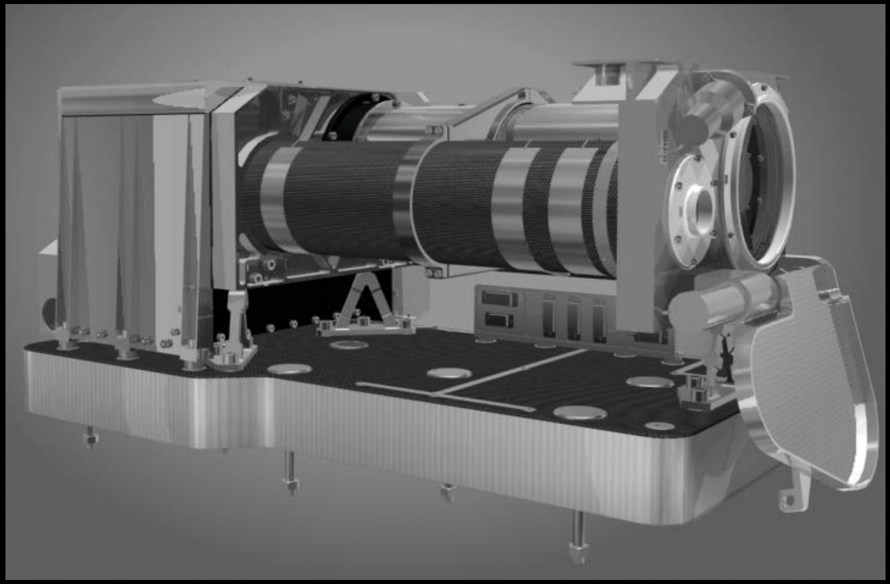
PICARD was launched on June 15, 2010 on a Dnepr-1 launcher.

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

Orbit:

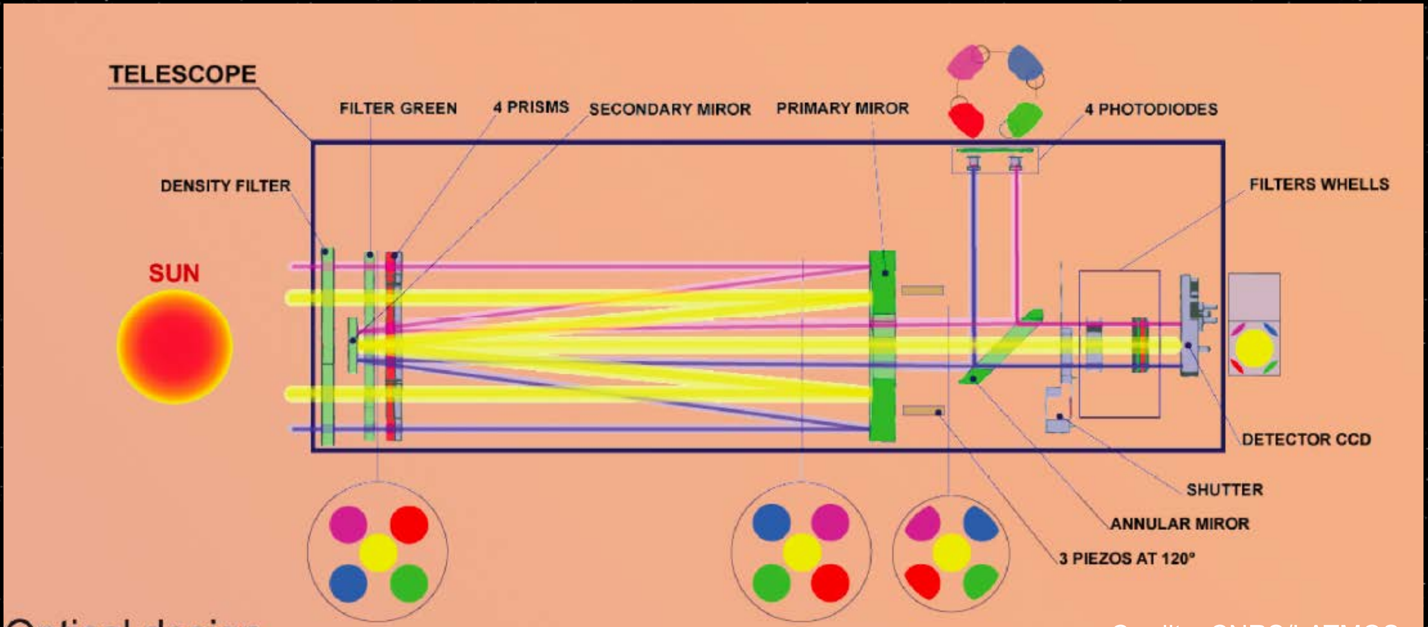
- Sun Synchronous Orbit
- Ascending node: 06h00
- Altitude: 735 km
- Inclination: 98.29°
- Eccentricity: 1.04×10^{-3}
- Argument of periapsis: 90°



Credits: CNRS/LATMOS

2 – The space instrument SODISM of the PICARD mission (2/3)

SODISM optical path and interferential filters characteristics



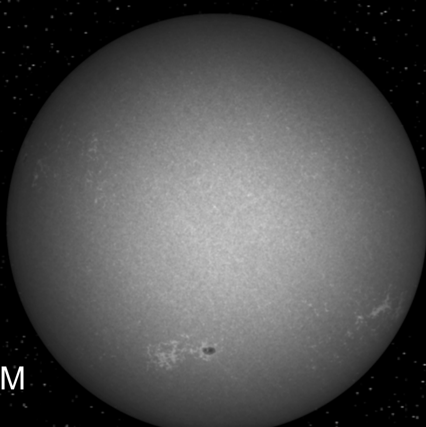
Optical design

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
607.1	0.7	Diameter
782.2	1.6	Diameter

2 – The space instrument SODISM of the PICARD mission (3/3)

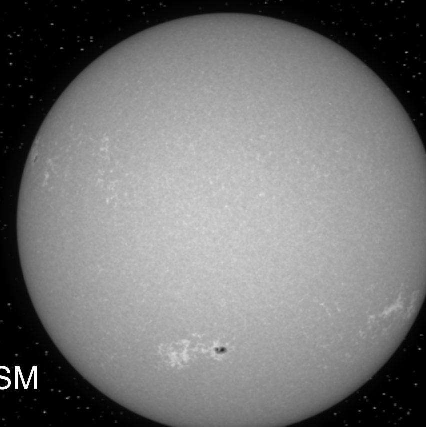
Data flow

Image type	**Telemetry size (Byte)**
Diameter Limb 215 (40 pixels)	324,896
Diameter Limb 393 (40 pixels)	296,417
Diameter Limb 535D (40 pixels)	299,168
Diameter Limb 607 (40 pixels)	301,129
Diameter Limb 782 (40 pixels)	301,496
535 Helio Limb (22 pixels)	202,907
MacroPixel 8*8	58,424
Limb Dark Current (40 pixels)	314,283
Full Dark Current	4,854,996
Full Image Compressed without lost	5,248,210
Full Image Compressed with lost (Langevin IBR 16)	531,050



PICARD / SODISM
215 nm

Credits: CNRS/LATMOS

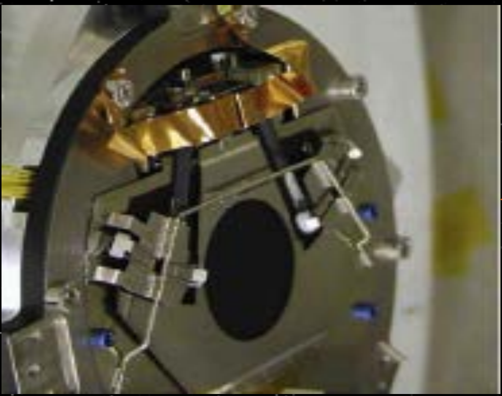


PICARD / SODISM
393.37 nm

Credits: CNRS/LATMOS

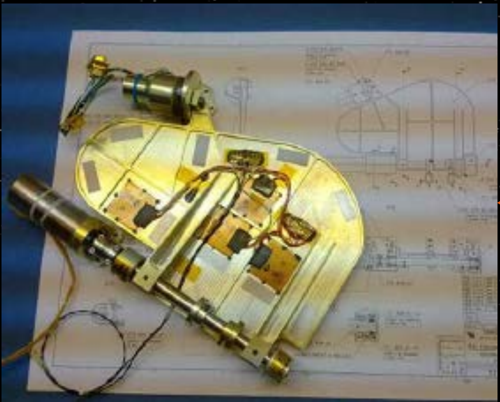
3 – SODISM Mechanism status (1/3)

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



Shutter

Filters wheel

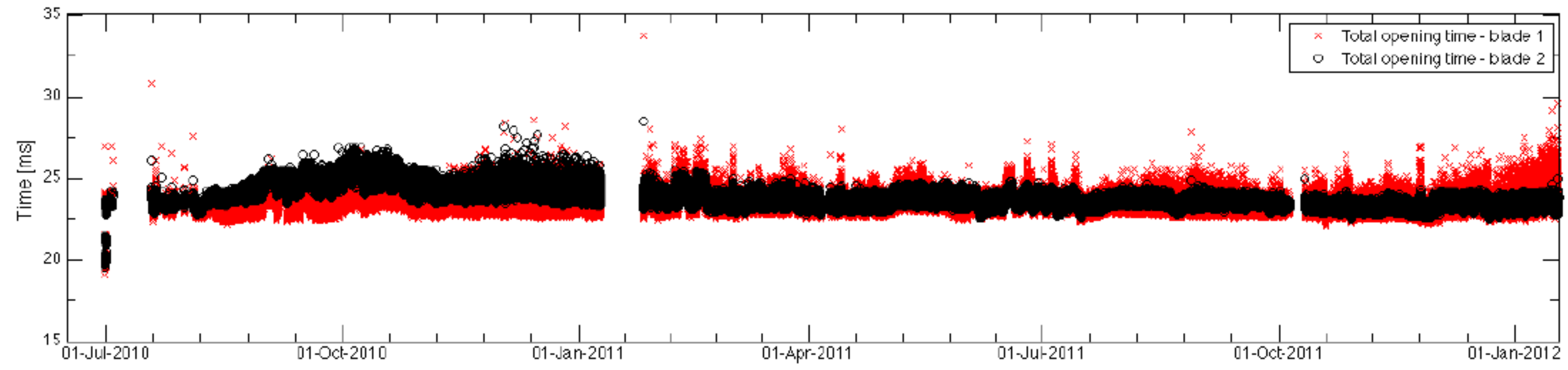


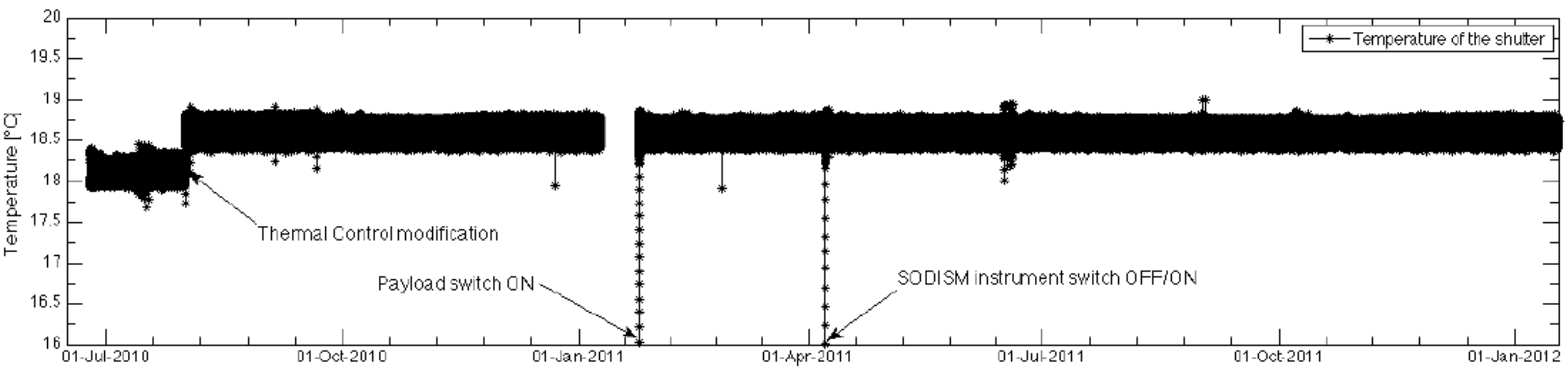
Door

3 – SODISM Mechanism status (2/3)

The electronic shutter in operation aboard PICARD/SODISM is an electro-programmable shutter.

The PICARD/SODISM shutter is in orbit since June 2010 and is operational. 382,743 openings and closings. The shutter is a critical mechanical and electrical element that have limited lifetimes. The shutter has been qualified to survive a minimum of 1,329,560 exposures.



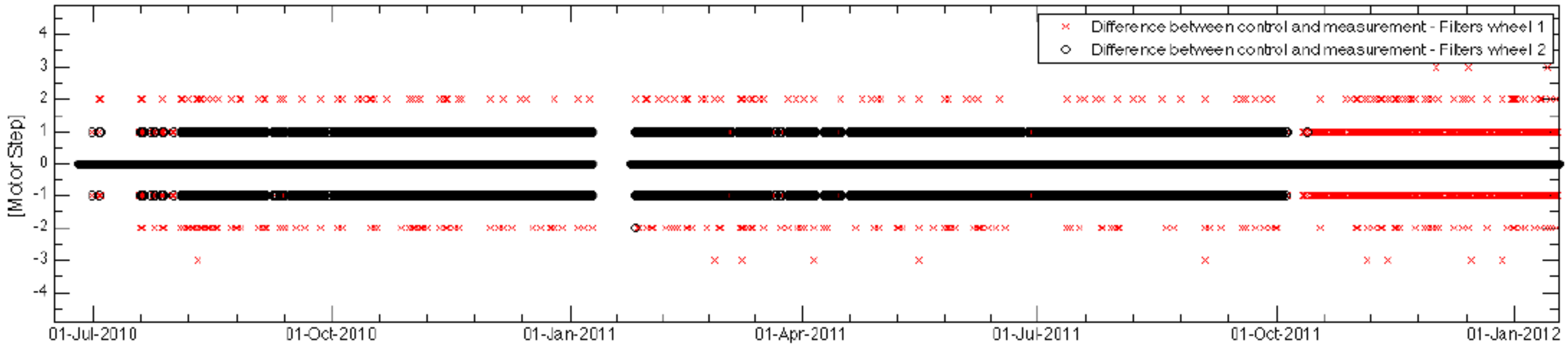


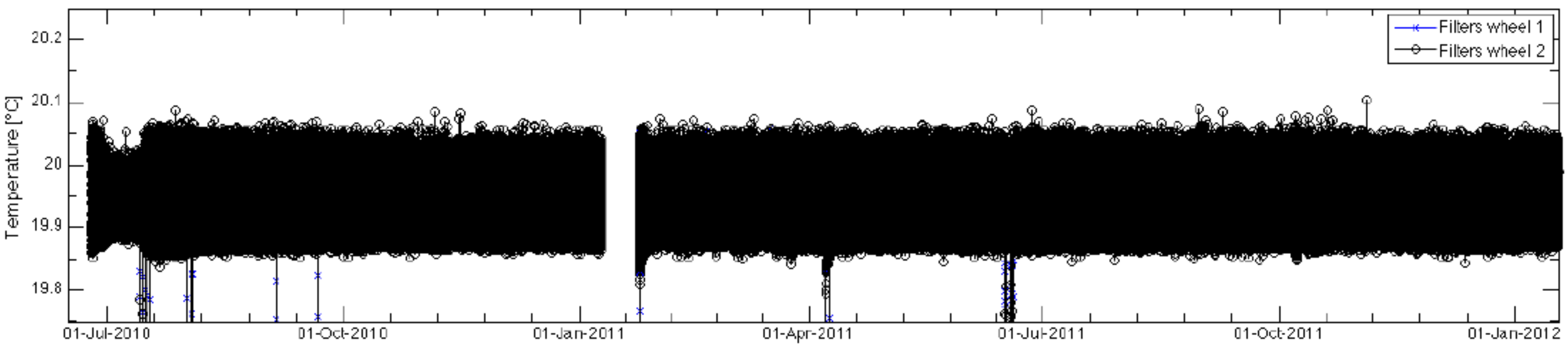
3 – SODISM Mechanism status (3/3)

The filters wheel has 5 positions: 4 imaging filters.

- Filters wheel 1: 215nm, 535.7nm (diameter), 607.1nm, 782.2 nm
- Filters wheel 2: 393.37 nm, 535.7 nm (helioseismology), diopter (stellar mode), lens (FlatField)

51,892 cycles are done per year (maximum for the filters wheel 2).
The filters wheel has been qualified to survive a minimum of 444,400 cycles.

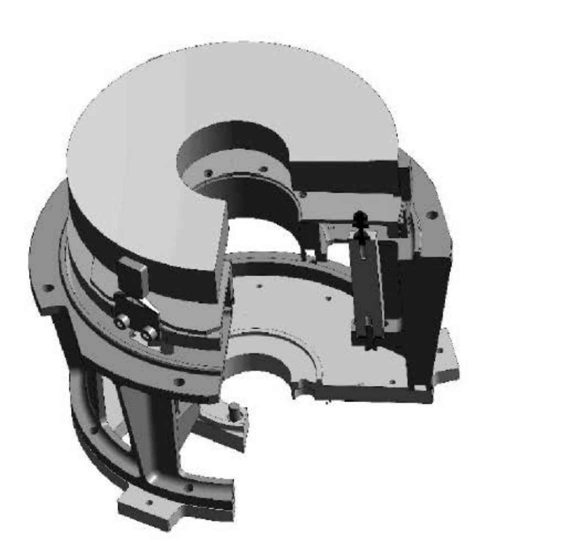


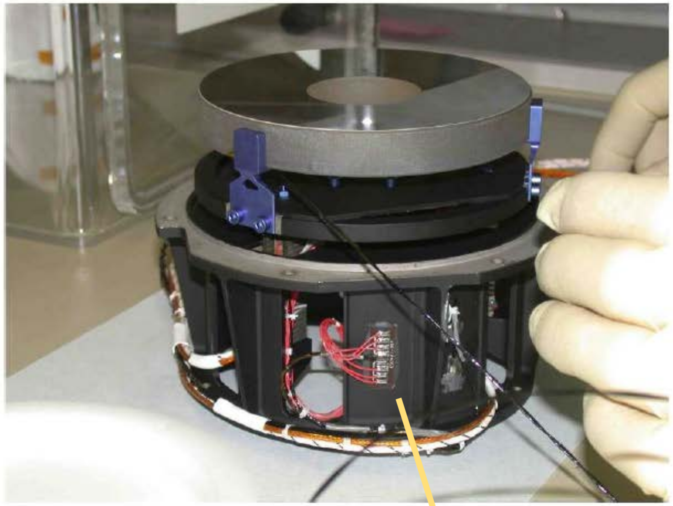


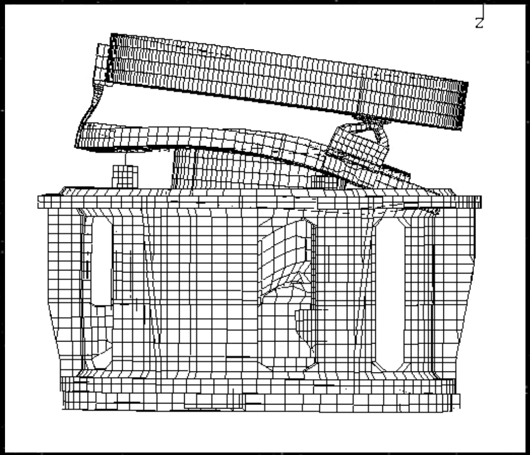
4 – SODISM pointing mechanism status (1/5)

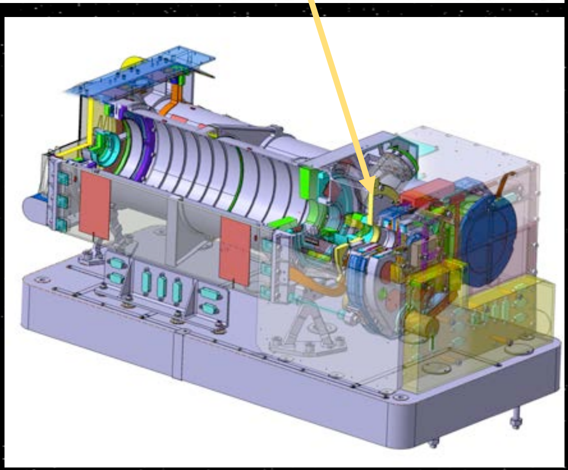
- <u>The pointing mechanism</u>

For the fine pointing, SODISM uses three piezoelectric devices acting on the primary mirror M1. Piezoelectric actuators have been modified to get a higher mechanical preload and include piezoelectric ceramics.









4 – SODISM pointing mechanism status (2/5)

The first image of the Sun was taken by the SODISM instrument on July 22, 2010.
It is a raw image, level L0, thus obtained before processing.

The PICARD/SODISM pointing mechanism is very important.

- <u>Correct the main optical and radiometric defaults of the raw image</u>

Several solar images at different wavelength have been recorded since the beginning of the mission for create the best Flatfield.

Flatfield corrections are important for achieving good quality images and for improved photometric measurements.

Kuhn, Lin and Loranz (1991) present methods of flatfielding using only image data and the first SODISM flat-fields were computed using the algorithm of Kuhn et al.

→ Use of the PICARD/SODISM mechanism

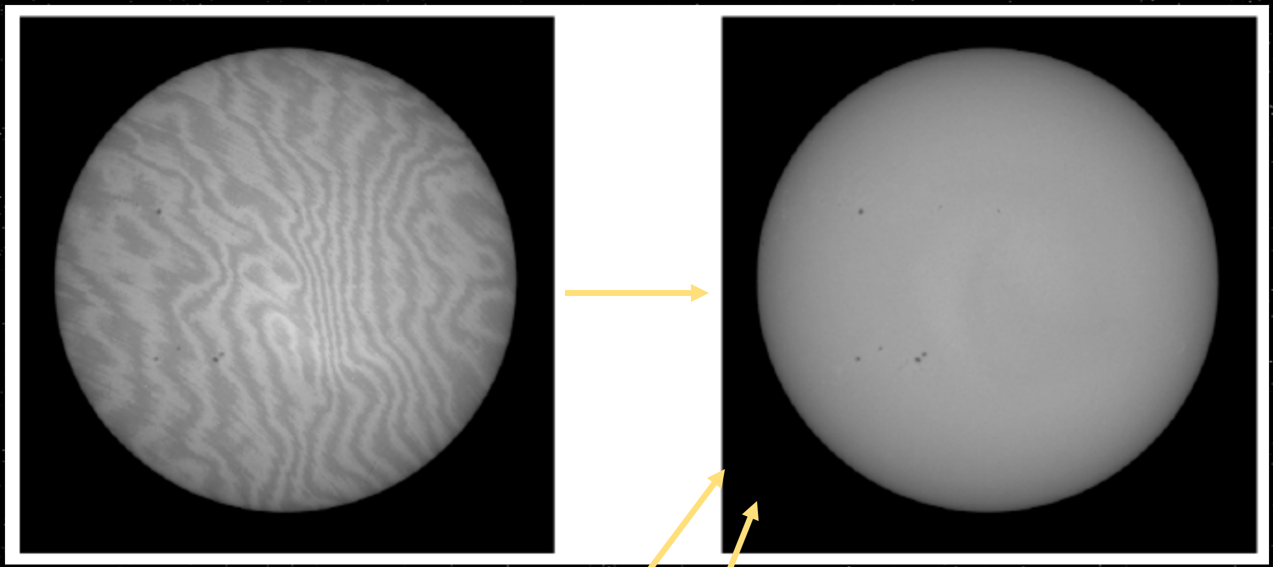
We move the image on the matrix using the mechanism.
The movement is limited by the stroke of the piezoelectrics (60 arcseconds or pixels).

- <u>Stabilize the Sun image on the CCD with an accuracy of 0.2 arcseconds</u>

→ Use of the PICARD/SODISM mechanism

4 – SODISM pointing mechanism status (3/5)

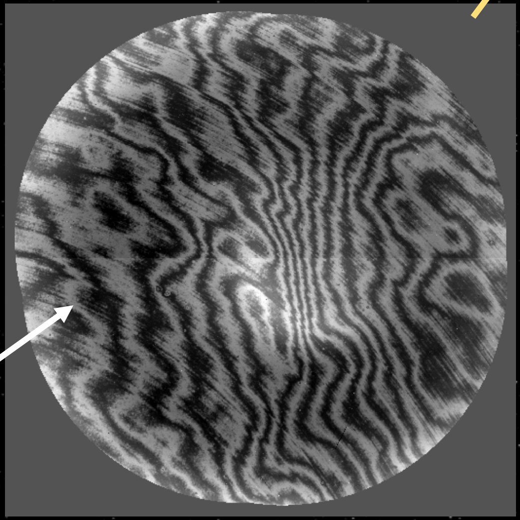
- Correct the main optical and radiometric defaults of the raw image



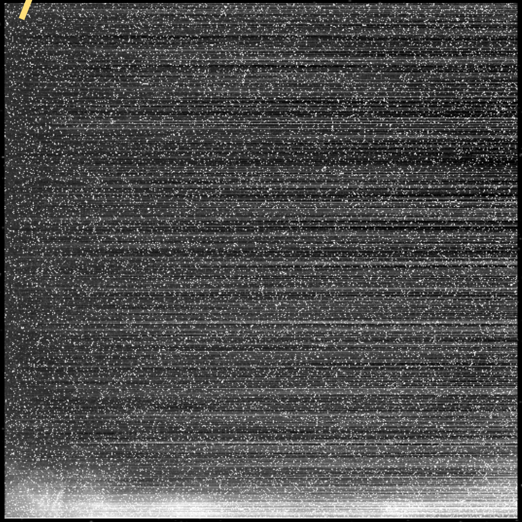
Raw image of the Sun, level L0

Image of the Sun, level L1

Coverage area of the CCD (limited by the stroke of the piezoelectrics)



Flat Field at 782 nm



Dark current, 1 second

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4 – SODISM pointing mechanism status (4/5)

- <u>Stabilize the Sun image on the CCD with an accuracy of 0.2 arcseconds</u>

An image is taken every 2 minutes, leading to 720 images per day.

The Figure 1 shows the angular deviations performed by the pointing mechanism over 3 days. The standard deviation is equal to 0.31 pixel (whose size corresponds to 1.06 arcsecond).

This means that the image stability (standard deviation) corresponds to an angular value of +/- 0.234 arcsecond. The initial specification was +/- 0.2 arcsecond.

It can be concluded that the pointing mechanism implemented and qualified in the SODISM instrument is effective.

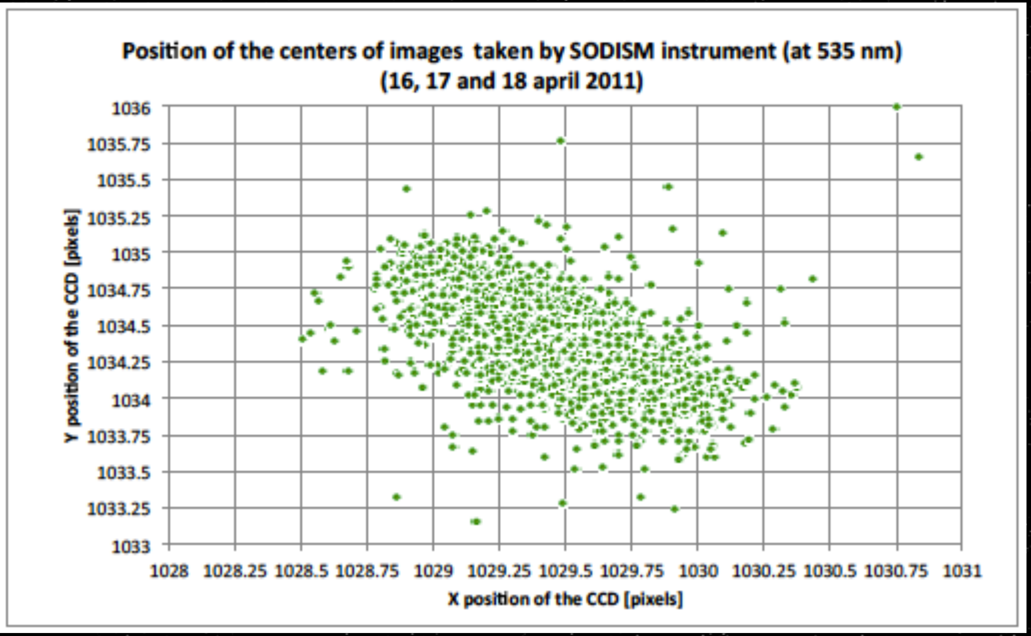
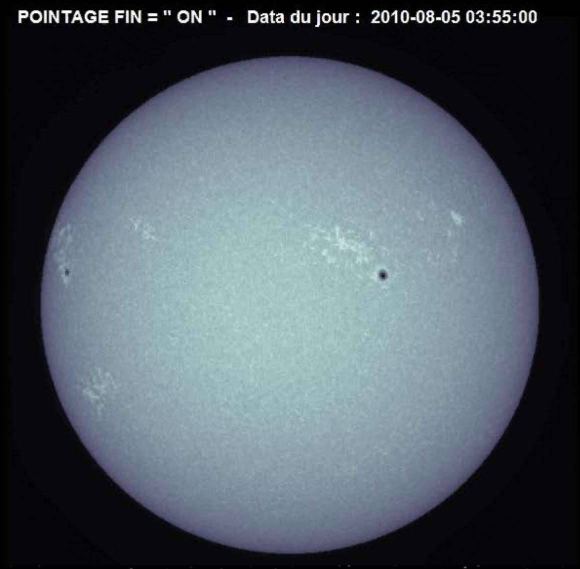


Figure 1: Angular correction performed by the mechanism

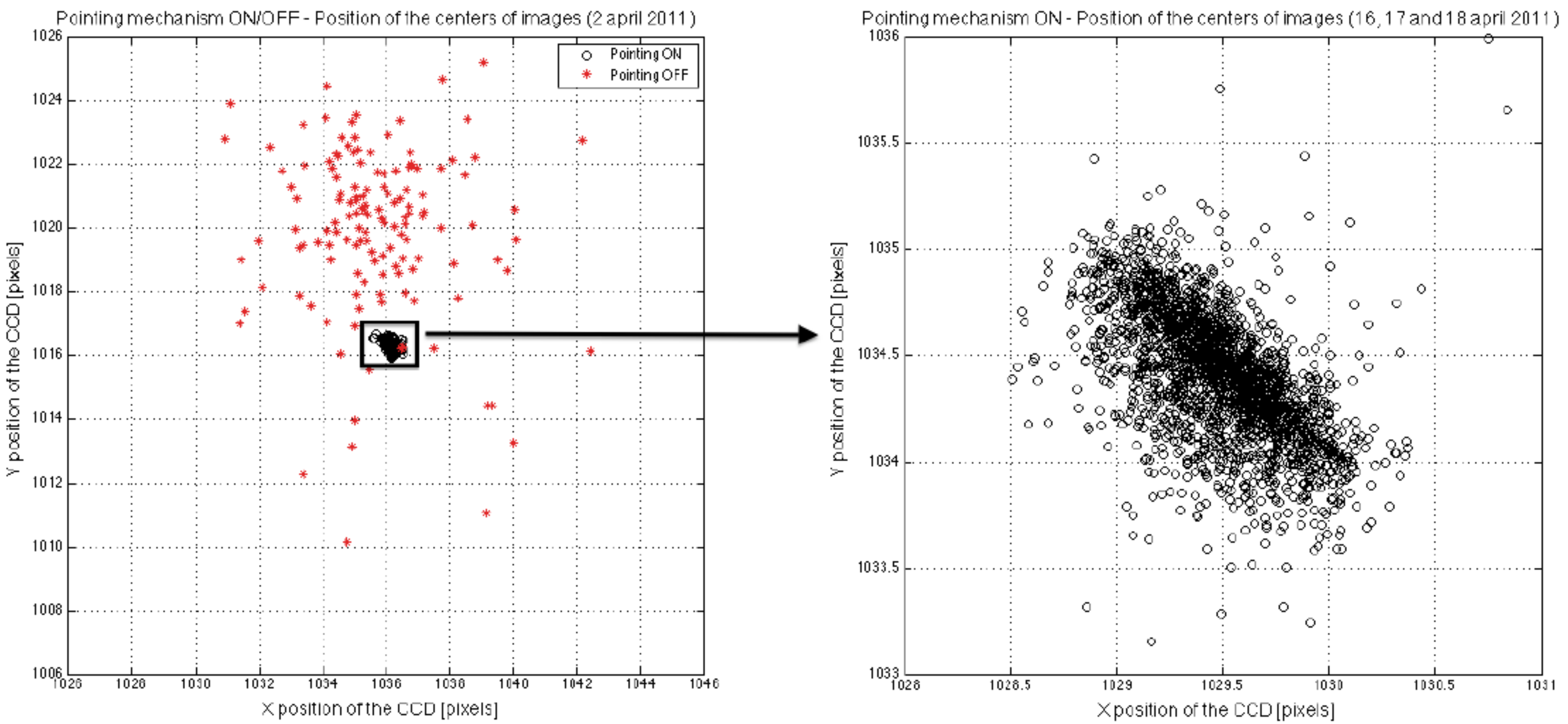


PICARD/SODISM: Sun image at 393 nm – Pointing ON

4 – SODISM pointing mechanism status (5/5)

The Figure (left side) shows the improvement brought by the pointing mechanism and its effect on the achieved image stability.

An image is taken every 2 minutes, leading to 720 images per day. The Figure (right side) shows the displacement of the image on the CCD performed by the pointing mechanism over 3 days. The standard deviation is equal to 0.31 pixel (whose size corresponds to 1.06 arcsecond). This means that the image stability (standard deviation) corresponds to an angular value of ± 0.234 arcsecond.



5 – Calibration – Distortion Mode (1/5)

Objectives:

- SODISM optical distortion by spacecraft rotation (30° rotation – thirteen sets of measurements)
- Solar oblateness during this special operation (by differential method)

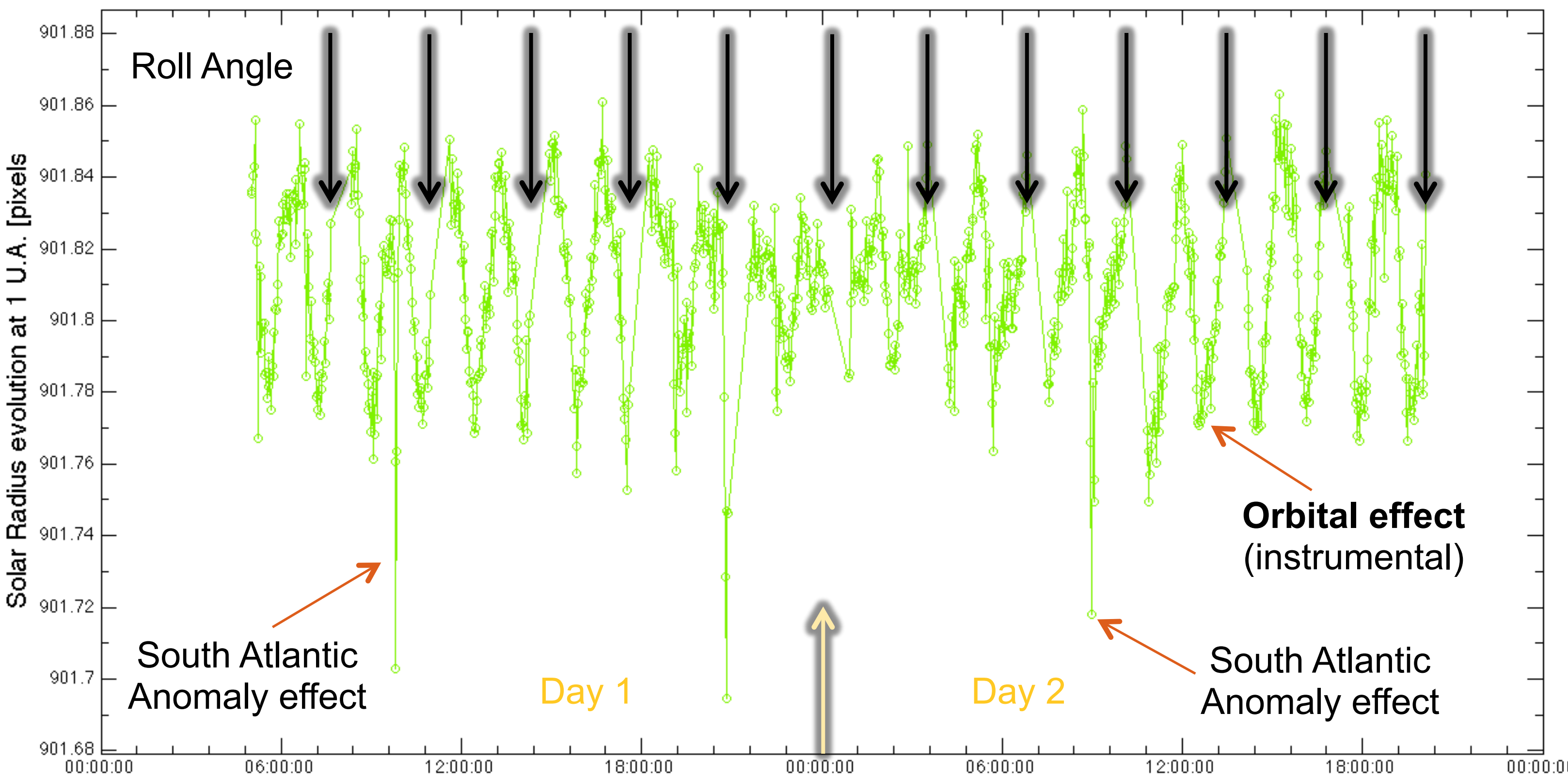
Date	215 nm	393.37 nm	535.7 nm H	535.7 nm D	607.1 nm	782.2 nm
22 to 23/09/2010	X	X		X	X	X
27/09/2010			X			
25 to 26/11/2010	X	X		X	X	X
07 to 08/01/2011	X	X		X	X	X
07 to 08/02/2011	X	X		X	X	X
09/03/2011	X	X		X	X	X
04 to 05/04/2011	X	X		X	X	X
14 to 15/05/2011						X (60 mn)
04 to 05/07/2011				X (160 mn)		
13 to 15/07/2011				X (RS)		
27 to 28/10/2011				X (160 mn)		
11 to 12/02/2012			X (two sequences)	X (two sequences)		
05 to 06/03/2012				X (two sequences)		

5 – Calibration – Distortion Mode (2/5)

Limb-disk images were obtained in 2011 and 2012, by stepping PICARD Satellite by 30° increments through 360° in roll angle. At each position 80 images were obtained.
For this special operation, we obtain 1040 images for one wavelength.

Duration of the operation: Two days.

→ Best method: Determination of the solar oblateness with ONE ORBIT wavelength MEASUREMENT DURING ONE ROLL ANGLE (July and October 2011 measurement)



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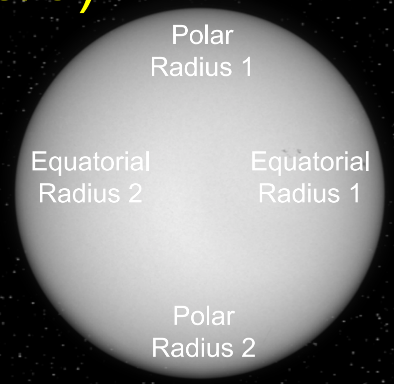
5 – Calibration – Distortion Mode (3/5)

→ Repeatability of measurements: SODISM does not measure noise

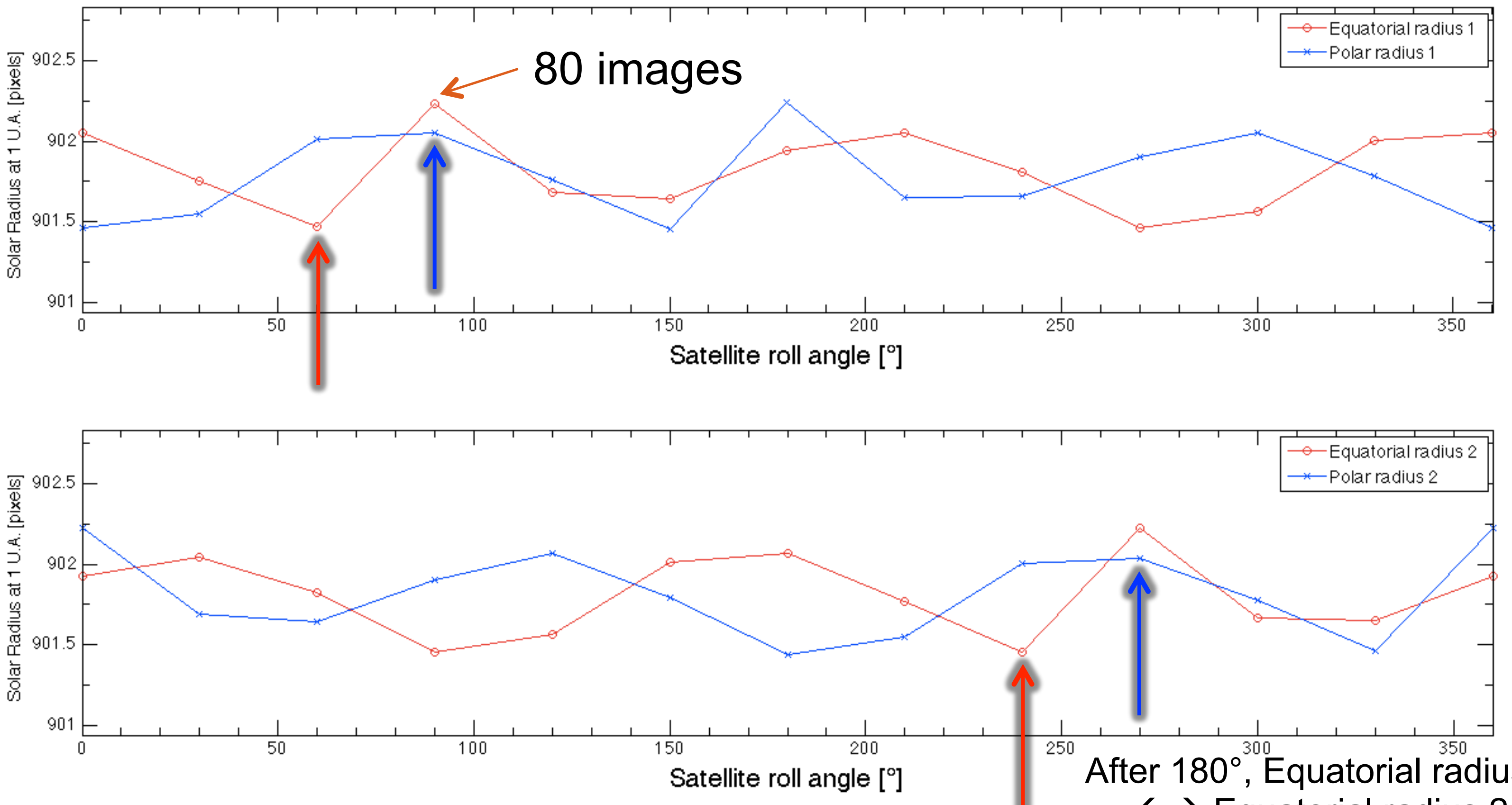
→ From this measurement method, it is possible to extract the solar component of the instrumental component

→ Importance of orbital effect



PICARD / SODISM 535 nm

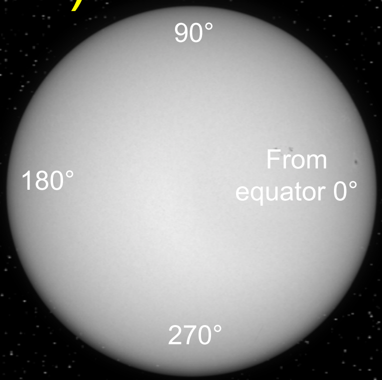
Position of the inflection point
Mean measurement during the orbit



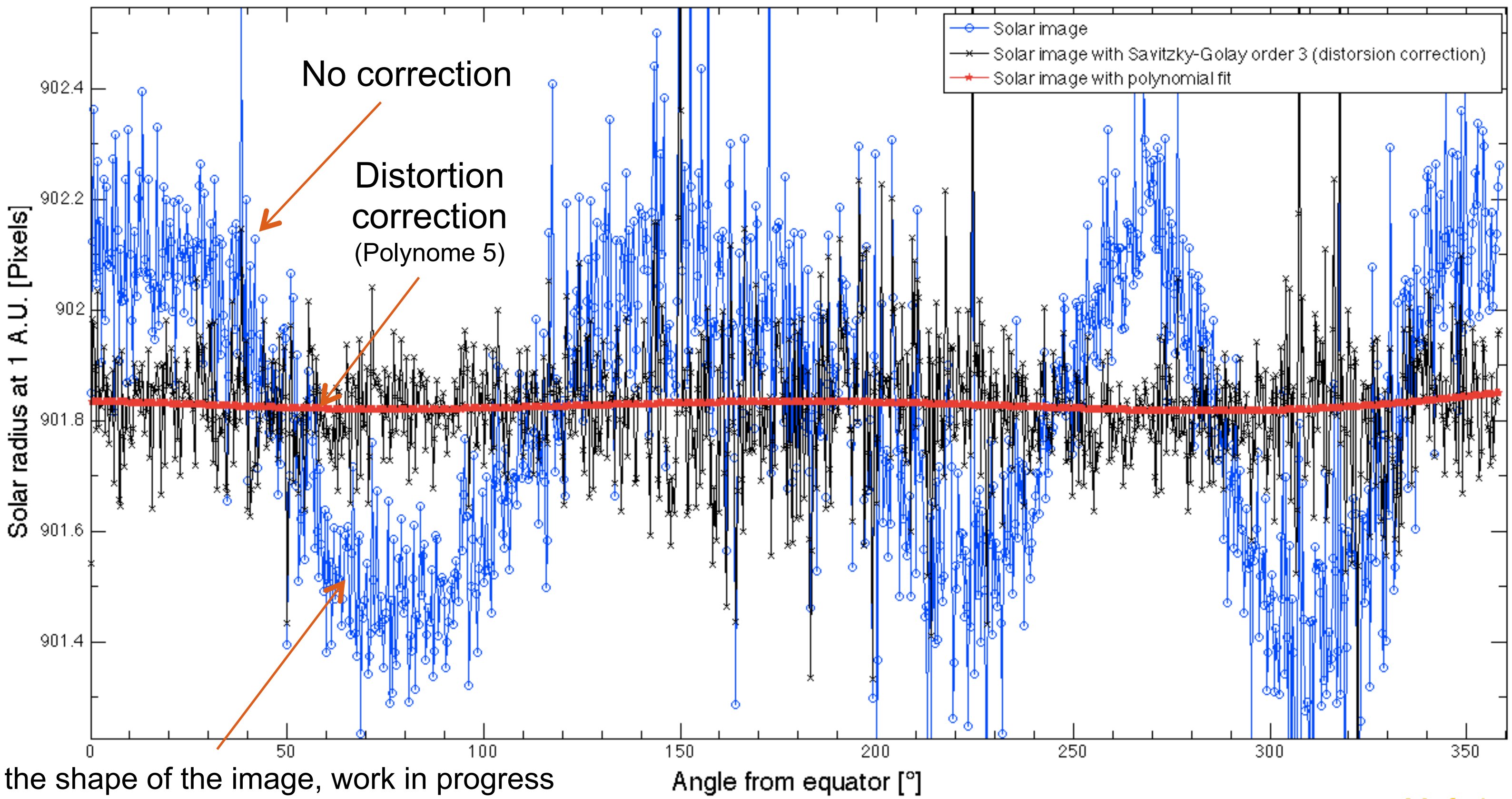
After 180°, Equatorial radius 1 ←→ Equatorial radius 2

5 – Calibration – Distortion Mode (4/5)

$$P(\theta_i) = \frac{1}{80}\sum_{k=1}^{80} P_k(\theta_i) = \frac{1}{80}\sum_{k=1}^{80} S_k(\theta_i) + \frac{1}{80}\sum_{k=1}^{80} A\cos(2\pi i / T - w_k)$$



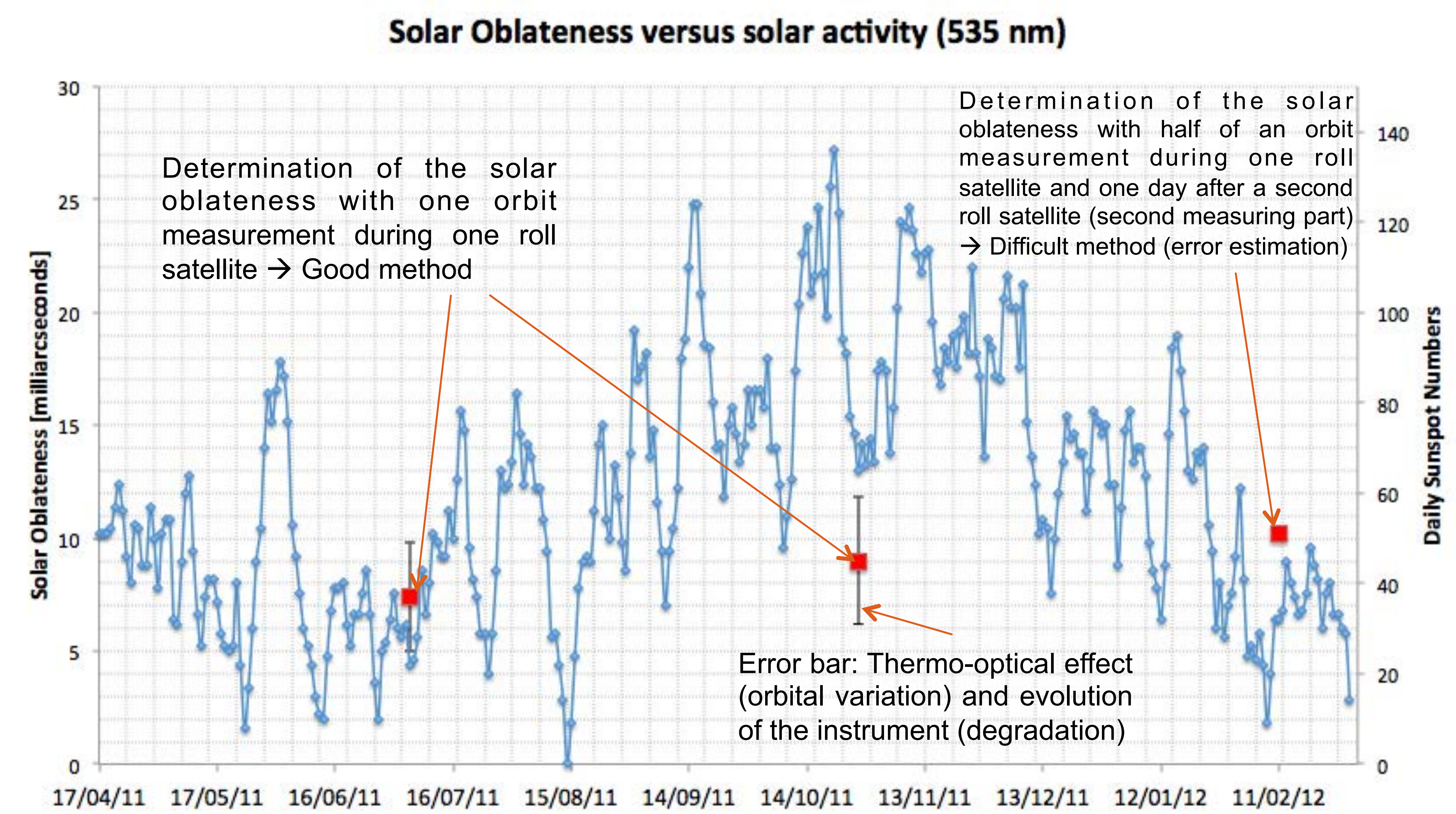
References:
- D. Djafer, G. Thuillier, S. Sofia, and A. Egidi, Processing Method Effect on Sun Diameter Measurement: Use of Data Gathered by Solar Disk Sextant, Solar Physics, 247-2, 225-248, 2008.
- Kuhn, J. R., Bush, R. I., Scheick, X., and Scherrer, Ph., The Sun's shape and brightness, Nature, 392, 6672-6679, 1998.



Origin of the shape of the image, work in progress
(N. Tarmoul, J.F. Hochedeze, A. Irbah, M. Meftah)

Meftah, Irbah 2012

5 – Calibration – Distortion Mode (5/5)

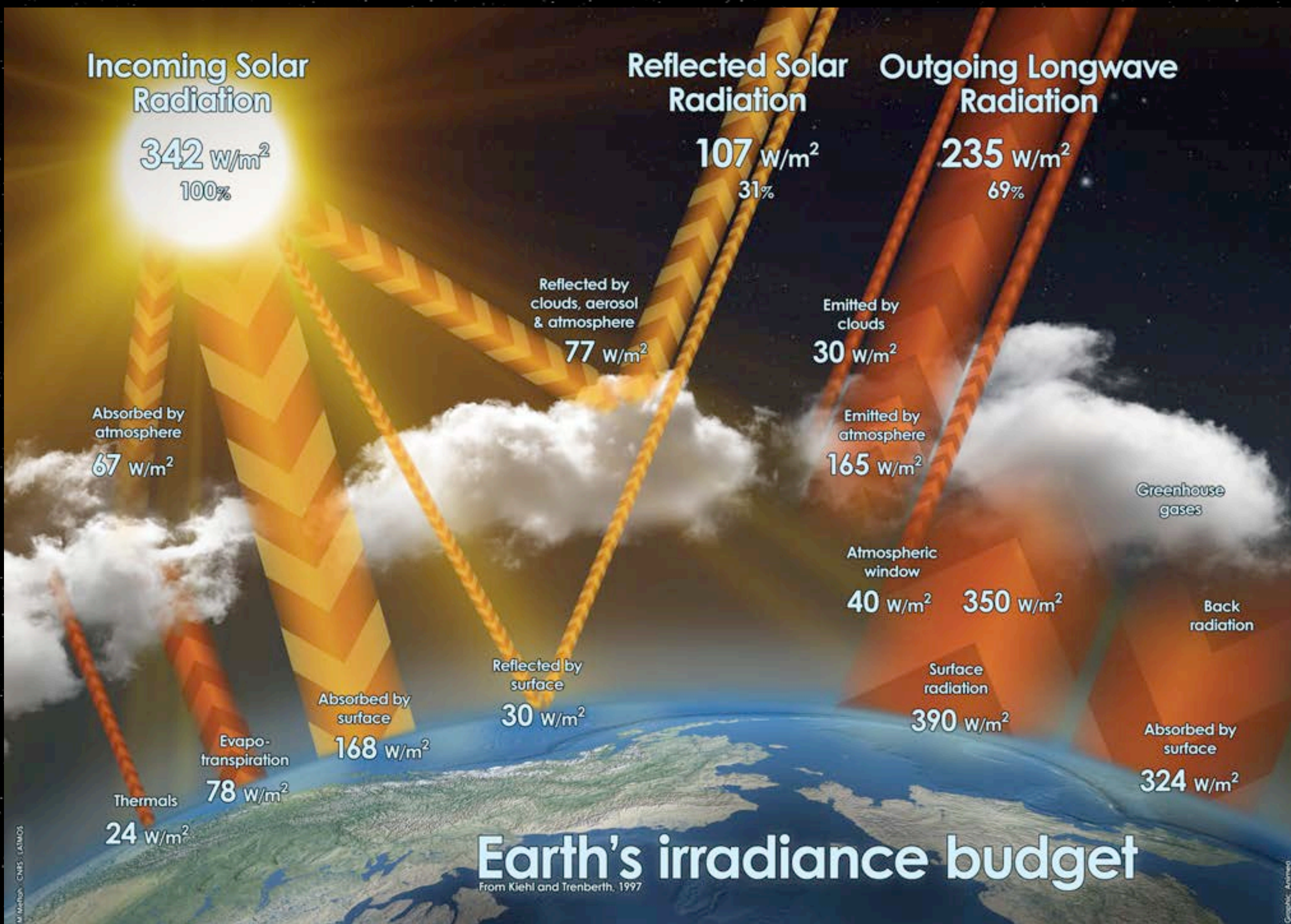


- Error Scale factor knowledge: <+/-0.02 milli-arcseconds
- Error on orbital effect: <+/-2.5 milli-arcseconds (without correction)
- Error on Algorithm: <+/-1.0 milli-arcseconds (differential method)

G. Thuillier, A. Hauchecorne, S. Sofia, A. Irbah, J.F. Hochedeze, M. Meftah, 2012 → Work in progress

6 – Calibration – Orbital effect (1/6)

PICARD is a metrology mission.
The flux variations (thermal environments) will affect the temperature of the payload. When temperatures change (orbital variation, effect of eclipses, long-term variation), the instrument performance are impacted. The annual mean global energy balance for the Earth-atmosphere system is very important to understand.



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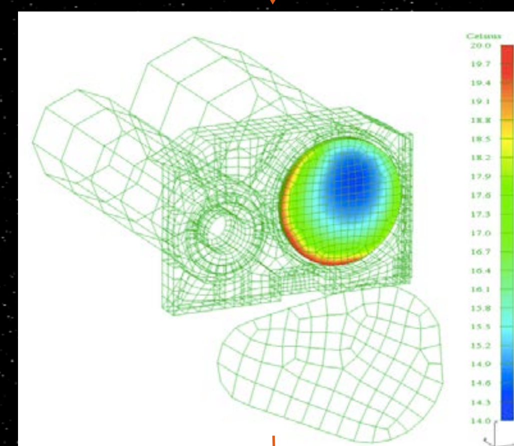
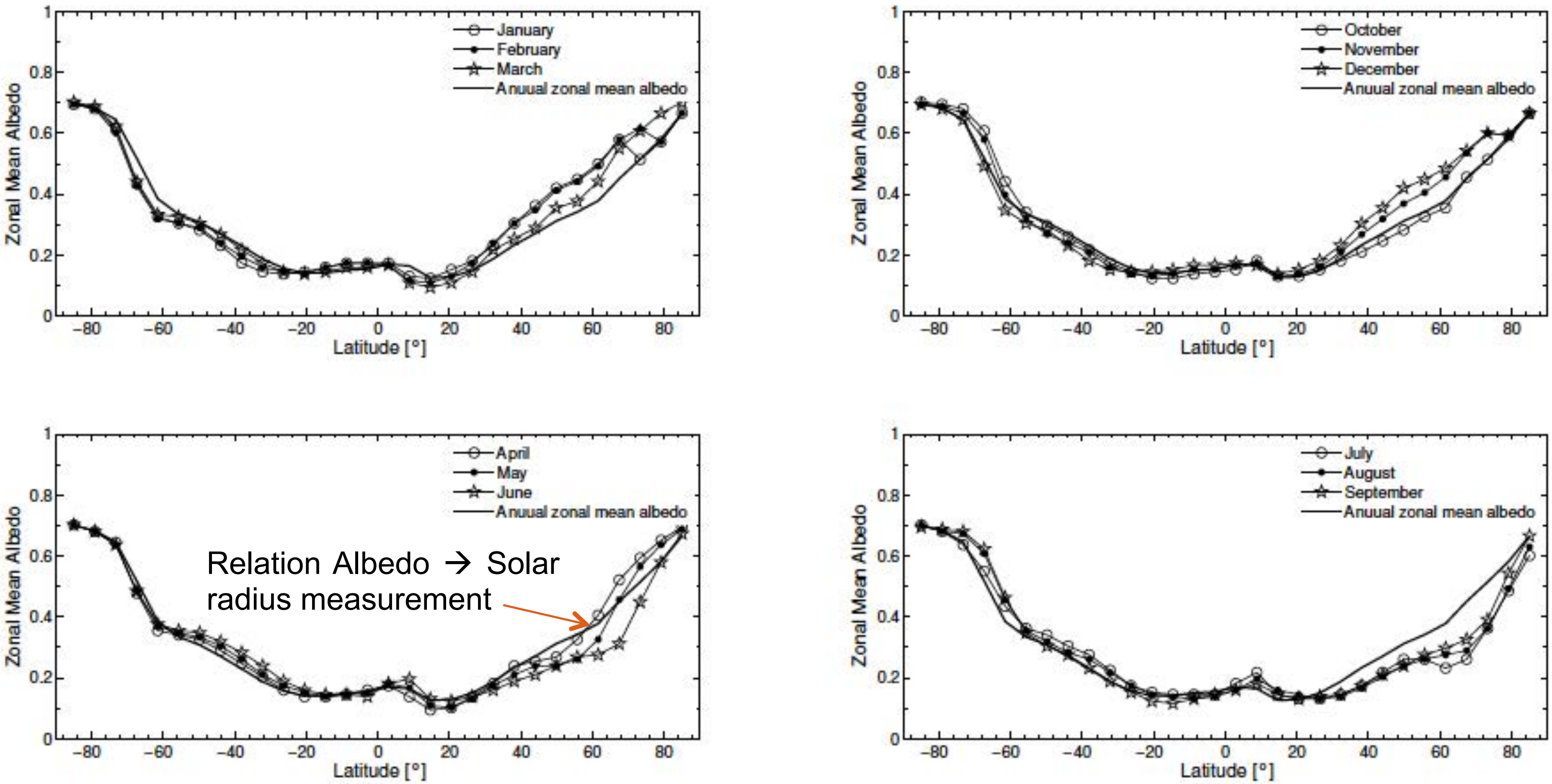
Main effect at the temperature of the front window of SODISM
(Time constant: 25 minutes)



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

6 – Calibration – Orbital effect (2/6)



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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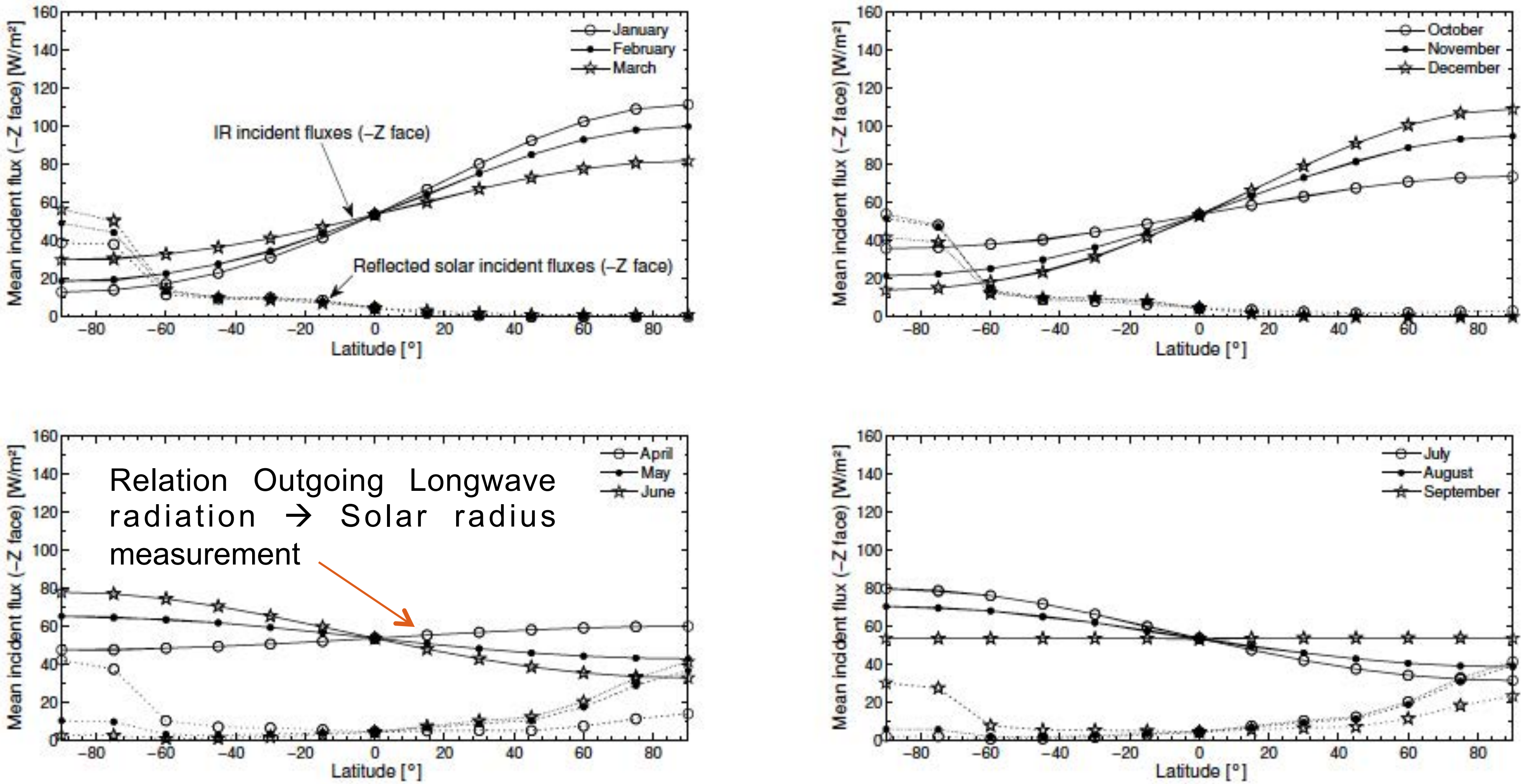
6 – Calibration – Orbital effect (3/6)



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.

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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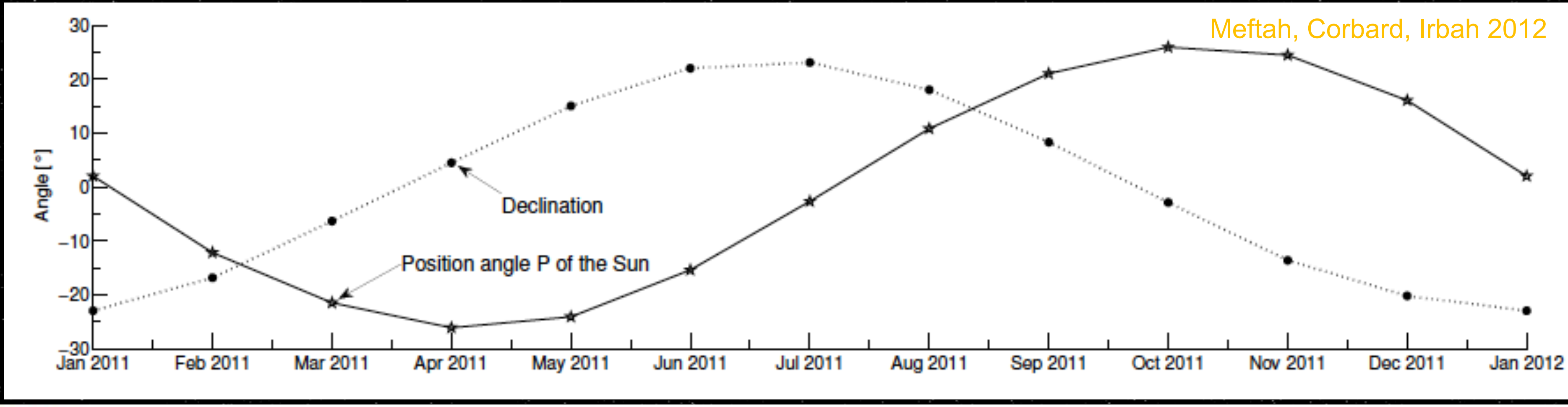
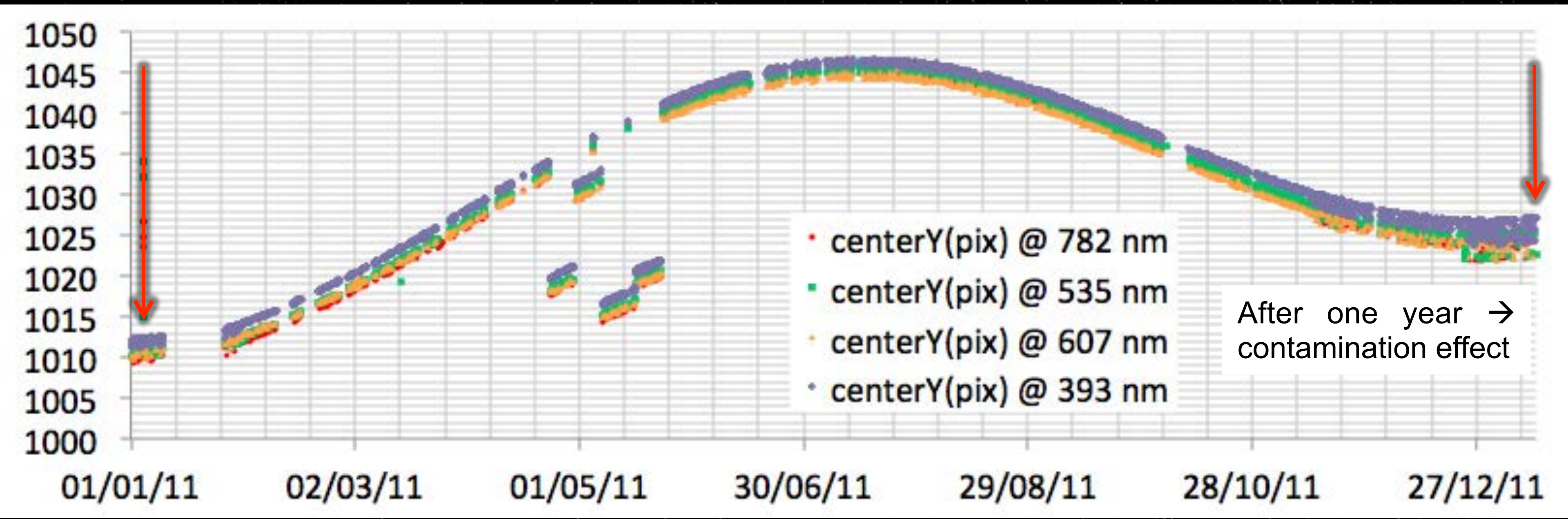
6 – Calibration – Orbital effect (4/6)

Two parameters affect the orientation of the satellite (declination and the position angle P).
This effect has an impact on the temperature of the satellite (relationship between the latitude of the Earth and temperature). There is an effect on the displacement of the image (relation with declination) → same effect in HMI/SDO (T. Corbard, M. Meftah).





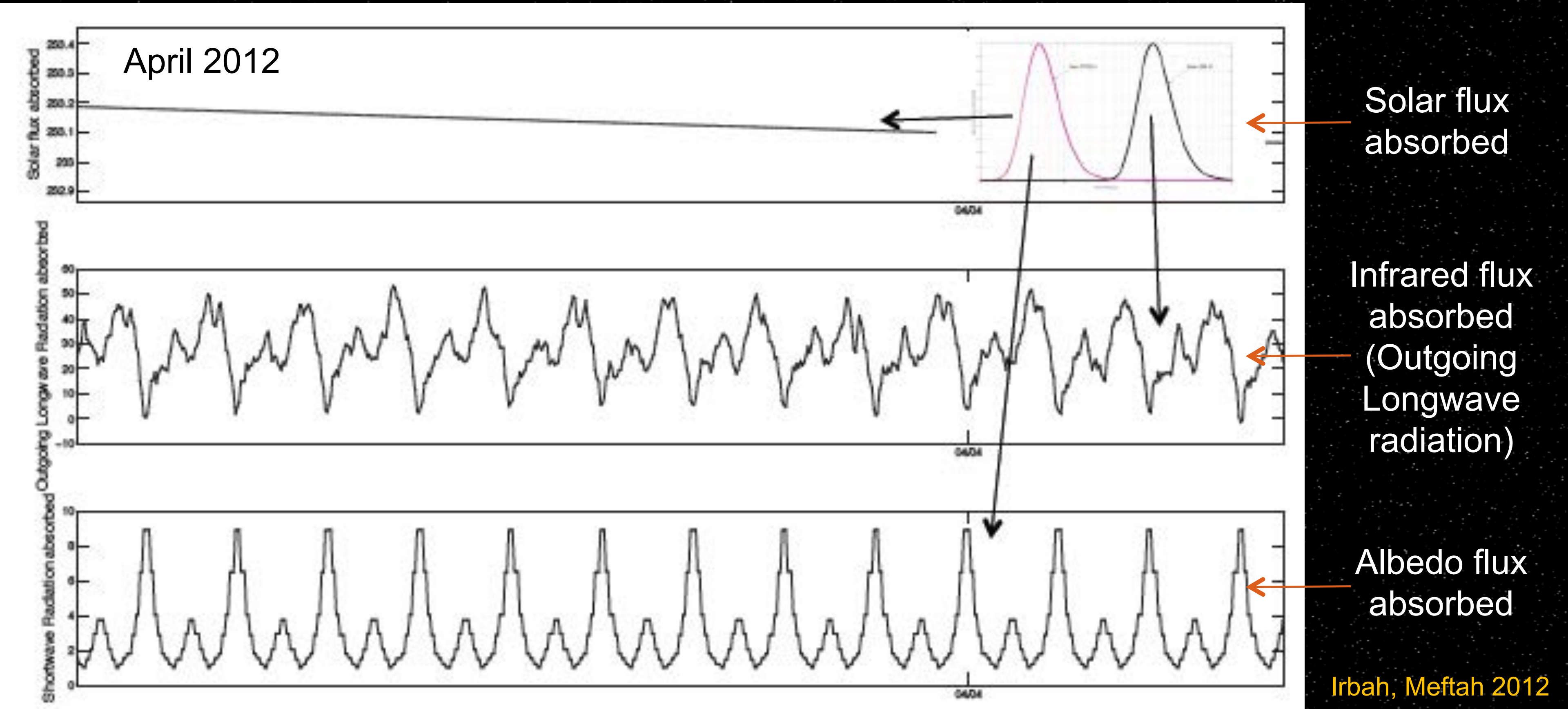
6 – Calibration – Orbital effect (5/6)

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).

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

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



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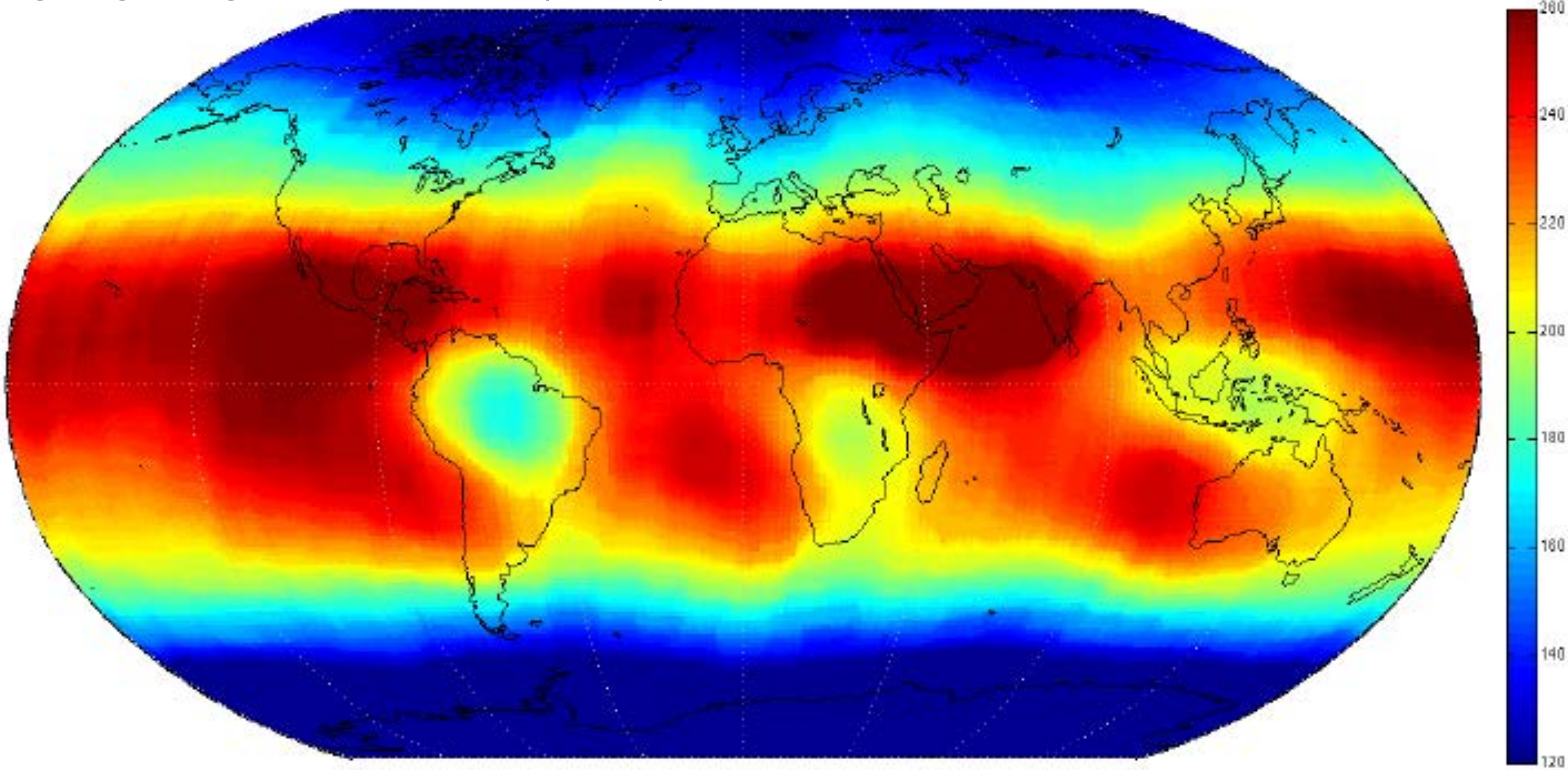
6 – Calibration – Orbital effect (6/6)

Outgoing Longwave radiation (W/m^2) – with PICARD data

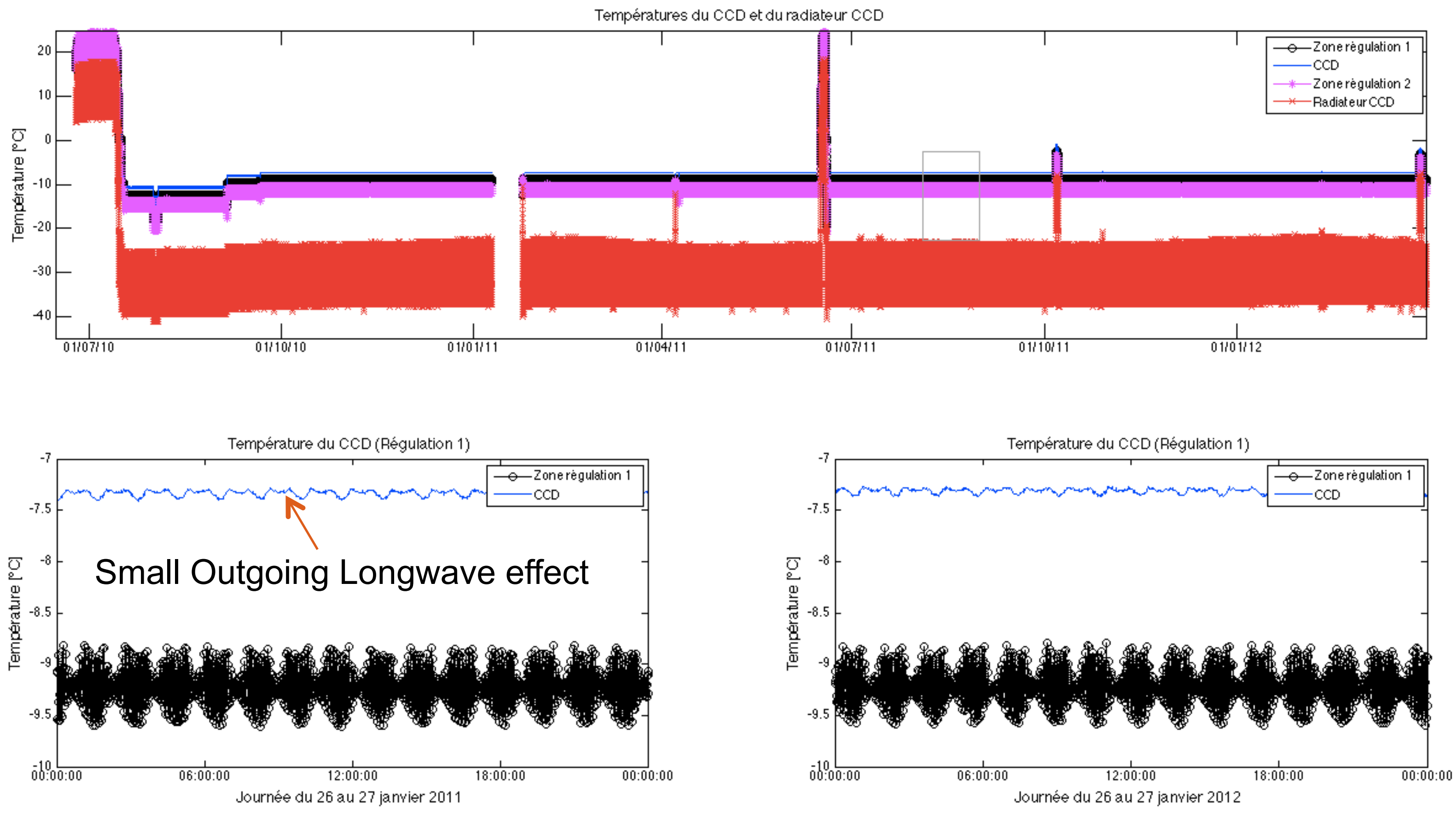


Our measurements are continuously transient (Satellite mass, proximity to the Earth, ...).

Keyword: <u>TRANSIENT</u>

Irbah, Meftah 2012

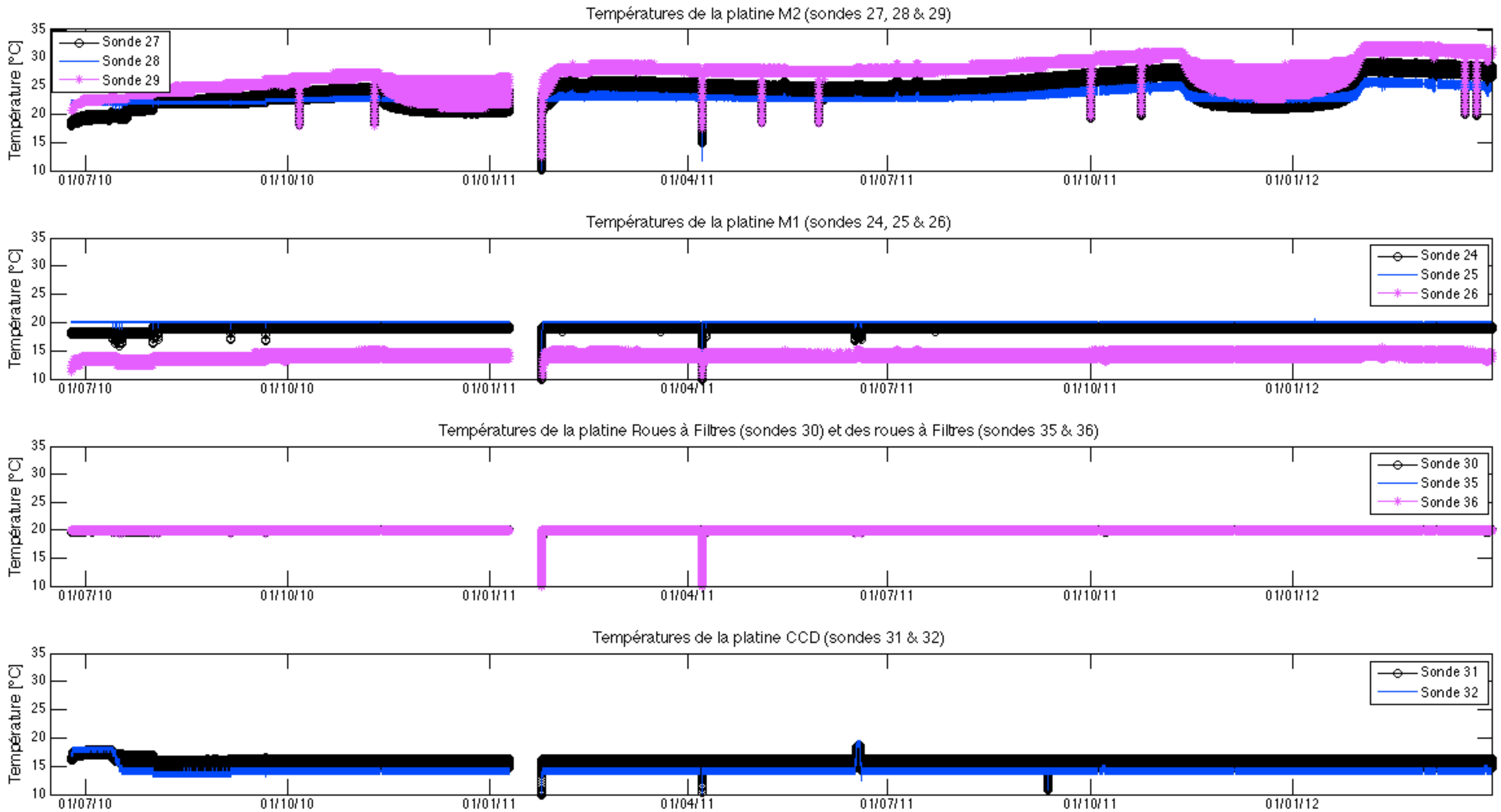
7 – Temperature and intensity – Degradation/Contamination (1/5)



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

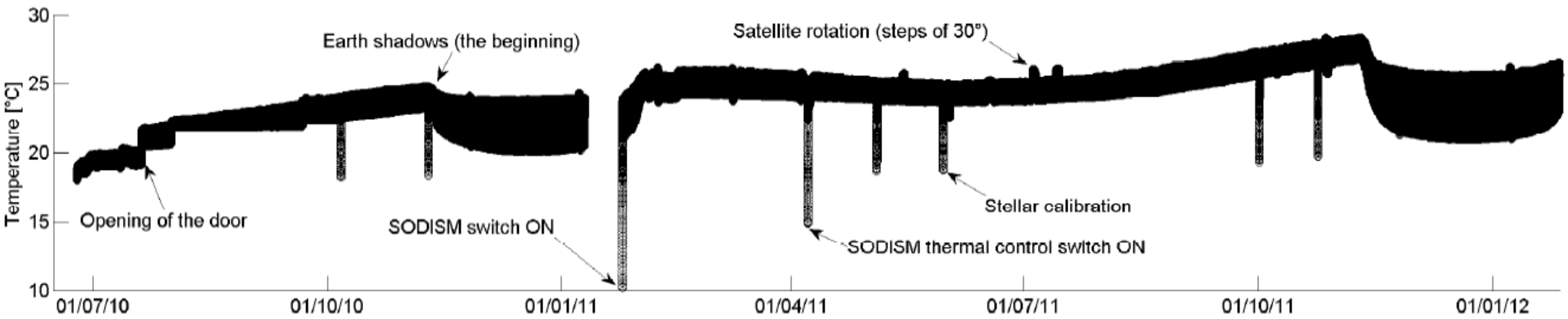
We can see that the temperature of the CCD is very stable (better than 0.1°C).
That is the same for the filters wheels (0.03°C).

7 – Temperature and intensity – Degradation/Contamination (2/5)



In contrast, 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).

7 – Temperature and intensity – Degradation/Contamination (3/5)



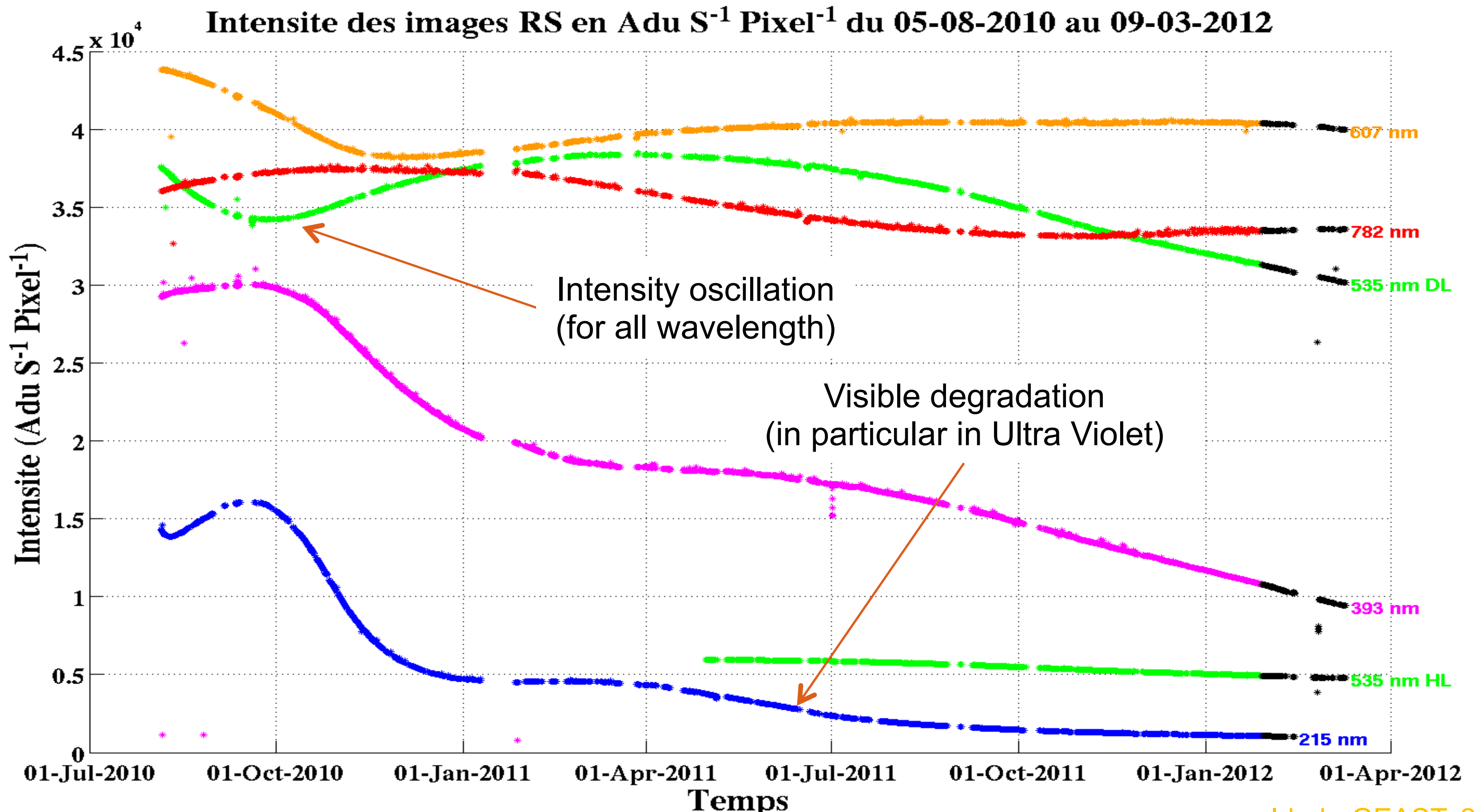
PICARD payload thermal control system included several temperature control techniques: reflective covers, coatings, insulation, and heat sinks.

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

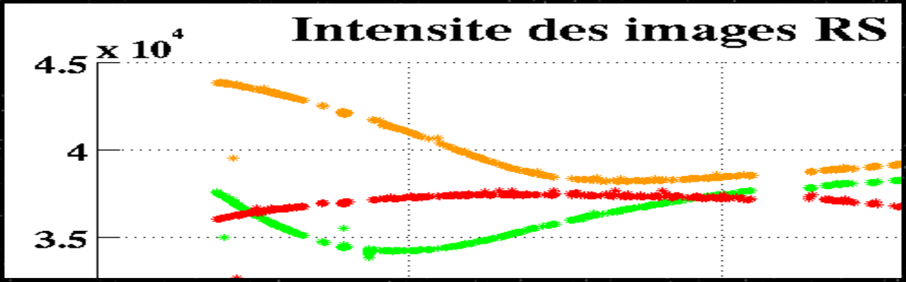
7 – Temperature and intensity – Degradation/Contamination (4/5)

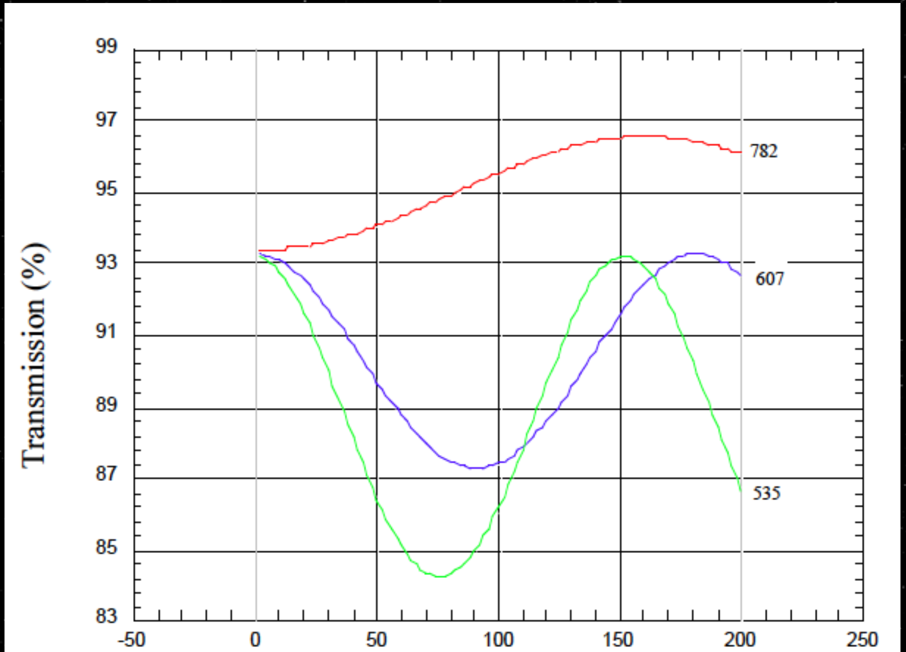
The images intensity (normalized to 1 AU) evolves over time.



Irbah, GEAST, 2012

7 – Temperature and intensity – Degradation/Contamination (5/5)





Evolution of the contaminant thickness (nm) – dependence with nature of contaminants

Meftah, Irbah 2012 → Work in progress

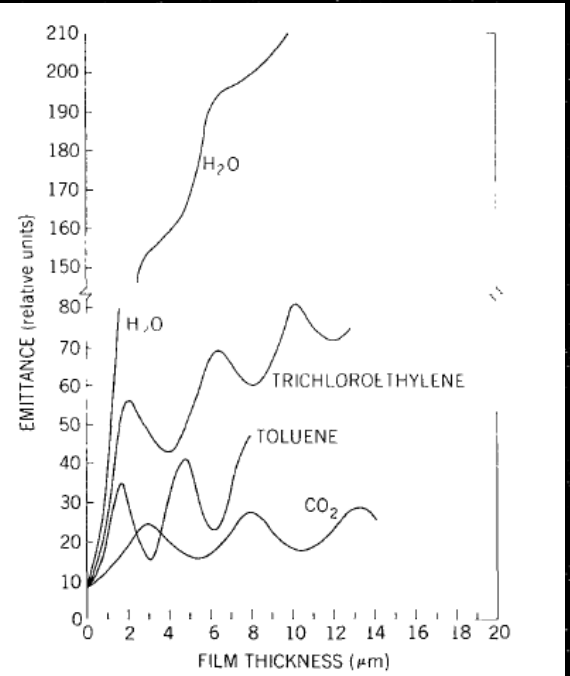


Figure 6—Emittance as a function of film thickness at 10.8 ± 0.5 μm.

Effects of surface contamination of highly reflective surfaces at cryogenic temperatures

by Walter Viehmunn and Alfred G. Eubunks, Goddard Space Flight Center Greenbelt, Md. 20771

Structures	Epoxies, polycarbonates, polyurethanes, polyamines, polyimides, flourocarbons
Potting/Encapsulation	Polyurethanes, epoxies, silicones
Conformal Coatings	Polyurethanes, epoxies, silicones
Adhesives	Epoxies, silicones, polyurethanes
Tapes	Polyesters, acrylics, polyamides, flourocarbons
Other	Acetates, epoxies, acetals, polyamides

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.

Keyword: <u>CONTAMINATION (nature of the contaminants ?)</u>

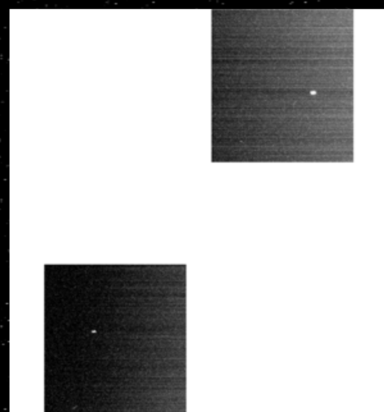
8 – Calibration – Stellar mode (1/2)

<u>Objectives</u>:

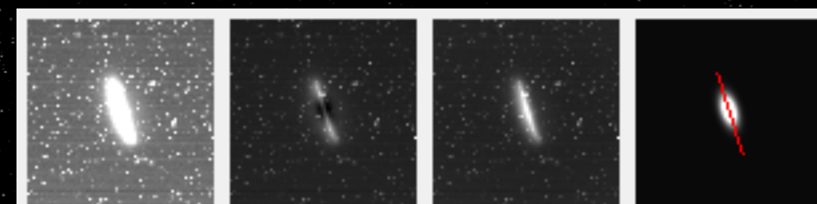
- Scale factor of the instrument
- PSF of the instrument

➡ 8 stellar calibrations since the beginning of the mission were conducted

- 6/10/2010
- 9/11/2010
- 4/5/2011
- 30/5/2011
- 1/10/2011
- 24/10/2011
- 19/03/2012
- 24/03/2012



30 May 2011 at 08H01

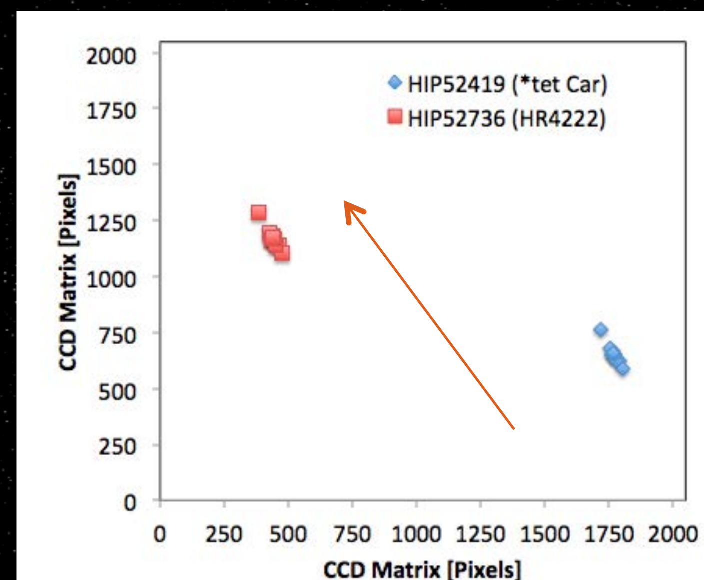


24 March 2012 at 10H24
Photo center determination

- Peak Satellite displacement of 15 pixels/second (during SODISM exposure)

- Mean Satellite displacement of 0.3 pixels/second (from the determination of photo center)

→ Optimization between exposure time and displacement of the Satellite



19 March 2012 – Satellite displacement

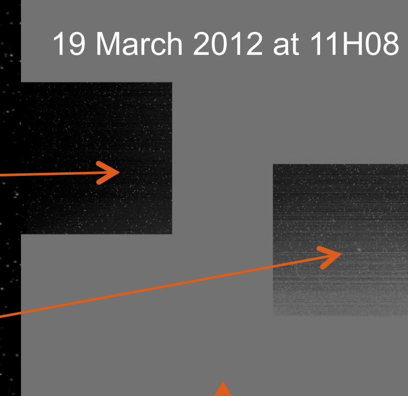
8 – Calibration – Stellar mode (2/2)

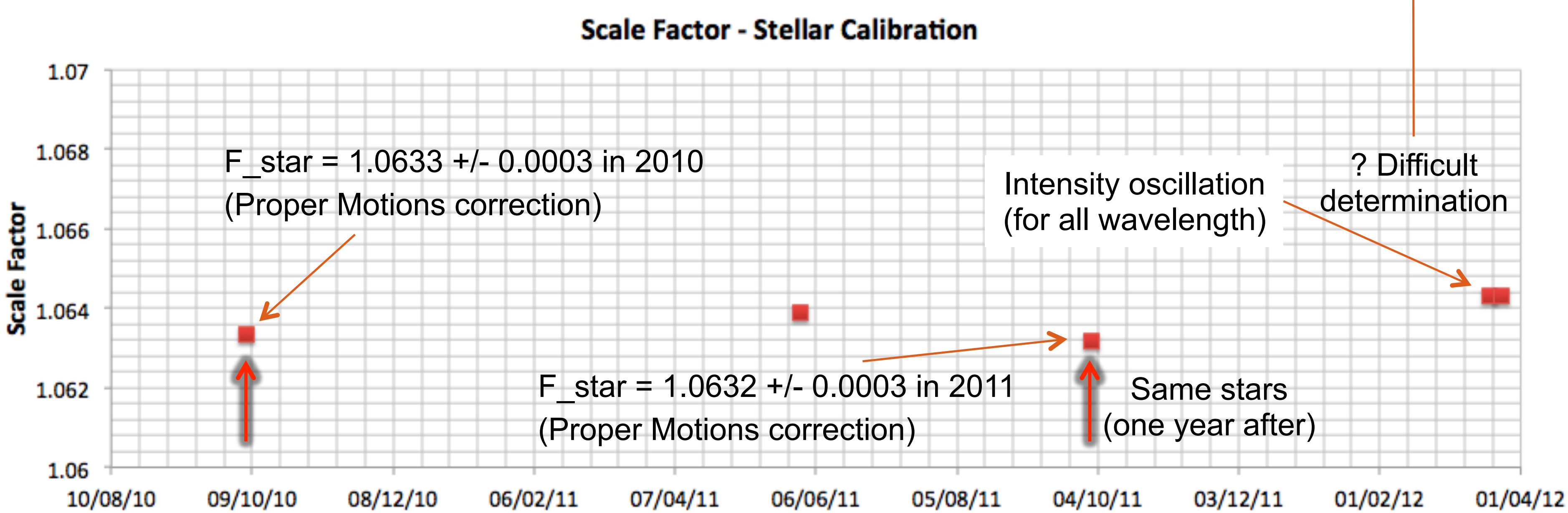
➡ Determining the scale factor of the telescope ?

We'll have to increase the exposure time (X by 3).

HR 4222 star (B3IV)
B 4.70 (Fluxes)

* tet Car star (B0V)
B 2.54 (Fluxes)





Meftah, Assus, Herse, Hochedeze 2012 → Work in progress

$$R_{Sun@607.1\,nm} = (R_{Measure@607.1\,nm} \times \zeta + \theta) \times F\_star \times \frac{f_{filter@607.1nm}}{f_{diopter}}$$

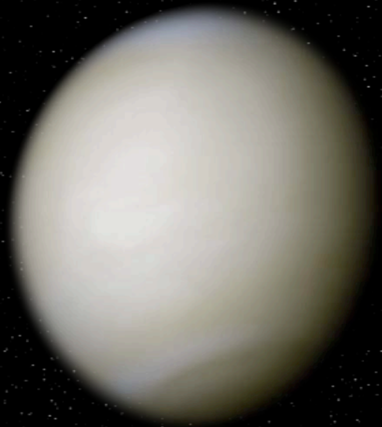
Example:
For one wavelength

- Solar radius (arc-seconds)
- Measurement after stellar mode (pixels) → 901.896 (10/11)
- PSF effect correction (TBC) → 1.00023 (10/11)
- Thermal effect (pixels) (TBC) → 0.5 (10/11)
- Optical correction (laboratory adjustment) → 1.000013 (constant)

9 – Transit of Venus 2012 (1/3)

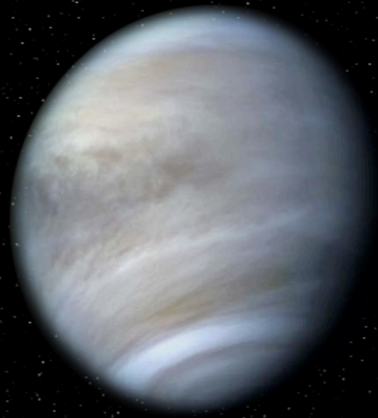
The next transit of Venus will occur on June 5-June 6 in 2012, succeeding the previous transit on June 8, 2004. The "Venus transit » is a celestial event.

Visible Venus
Real color Venus image



Credits: R. Nunes/NASA

UV Venus
False color UV Venus image



Credits: R. Nunes/NASA

Transit of Venus
Animation

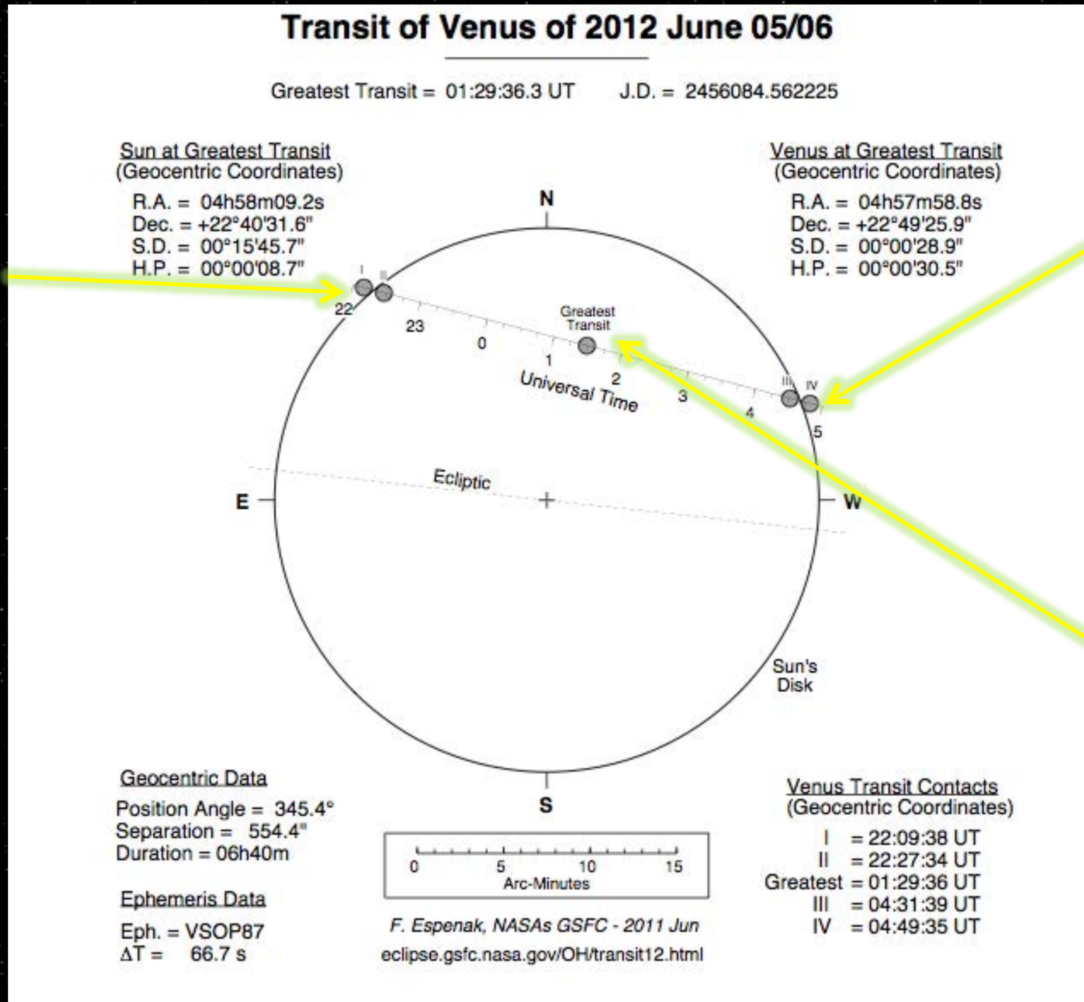
Source NASA: http://svs-f.gsfc.nasa.gov/~wfeimer/SEC/Gen_SEC/IP/Transit.mpg

Transit of Venus
NASA's Sun-observing TRACE spacecraft

Source NASA: http://anon.nasa-global.speedera.net/anon.nasa-global/venus_transit/UV1600_eastlimb.mov

9 – Transit of Venus 2012 (2/3)

The apparent crossing of Venus in front of the Sun will be observed with PICARD/ SODISM at different wavelength (215 nm, 393 nm, 535 nm, 607 nm and 782 nm).



VENUS TRANSIT CONTACT

June 5, 2012 from 10:00 p.m. to 10:40 p.m. (UTC):

- We will take an image per minute
- Wavelength: **607 nm**
- 41 images

VENUS TRANSIT CONTACT

June 6, 2012 from 04:20 a.m. to 05:00 a.m. (UTC):

- We will take an image per minute
- Wavelength: **607 nm**
- 41 images

VENUS TRANSIT

June 5, 2012 from June 6, 2012 :

- Wavelength: **215 nm** 2 images
- Wavelength: **393 nm** 20 images
- Wavelength: **535 nm** 20 images
- Wavelength: **607 nm** 21 images
- Wavelength: **782 nm** 20 images

9 – Transit of Venus 2012 (3/3)

- Interest 1: Technique in exoplanets search (Intensity variation)
Measurement of the characteristics of the decrease in brightness of the Sun obscured by Venus (techniques implemented in exoplanets search).
These test methods help to detect exoplanets and their atmospheres (refraction and absorption).

- Interest 2: Atmosphere and refraction effect
Venus is surrounded by an atmosphere. We want to make observation of horizontal refraction of the atmosphere of Venus.
SODISM observations in several wavelengths (215 nm, 393 nm, 535 nm, 607 nm, 782 nm).

- Interest 3: SODISM Point Spread Function (PSF)
Determination of SODISM PSF depending on the position of Venus on the solar disk: we look at how the flow varies in the pixels near the disk of Venus.

- INTEREST 4: SODISM SCALE FACTOR AND COMPARISON WITH STELLAR MODE
Determining the image scale of the telescope is important for measuring the absolute value of the solar radius (scale factor provided by the stellar calibration of the instrument).
The ephemeris for Venus, the Sun, and PICARD are precisely known (apparent path of Venus across the Sun during the 2012 transit).

Conclusion

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

All the PICARD/SODISM mechanisms are functioning. These good results have been obtained thanks to the respect of the development mechanism methodology (dimensioning with margins, models philosophy, and qualification tests).

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

Most of calibration require THERMAL and/or OPTICAL corrections.

For the observed apparent variation in the solar radius with the SODISM instrument, it is necessary to understand the behavior of the telescope in space.
Two points are very important: we are always in TRANSIENT case, and the instrument is affected by CONTAMINATION.

Determining the image scale of the telescope is important for measuring the absolute value of the solar radius (scale factor provided by the stellar calibration of the instrument, and during the transit of Venus).

Thank you for your attention