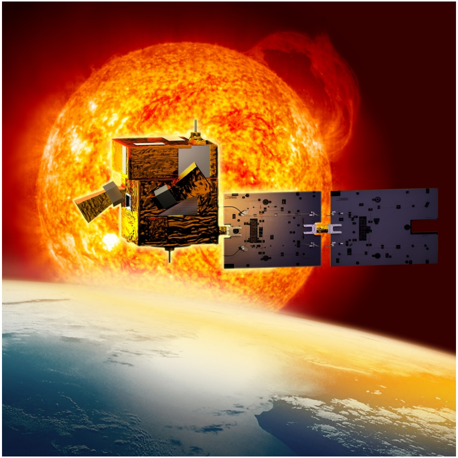
The Bolometric Oscillation Sensor

P. Zhu, M. van Ruymbeke, J.-P. Noël

April 10, 2012

PICARD Satellite



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The PICARD mission is dedicated to the study of the Sun-atmosphere connection. The total mass of the platform is about 120Kg, which was launched on June 15, 2010 [1].

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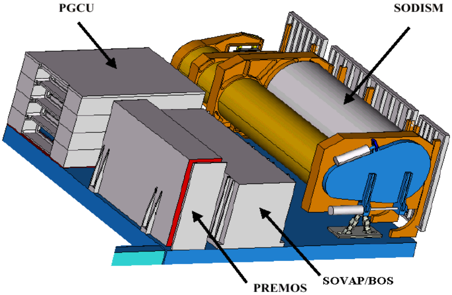

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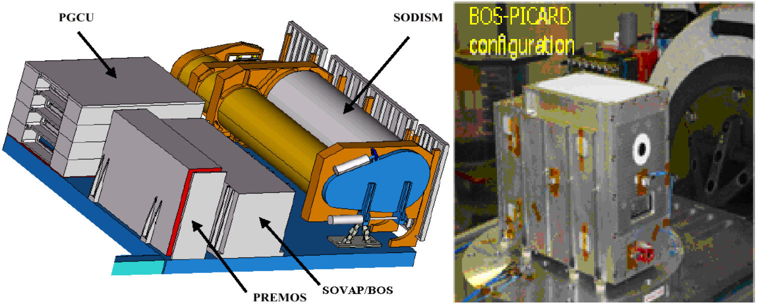

FIGURE: The payloads of the PICARD and the BOS instrument.

Scientific Objectives of PICARD

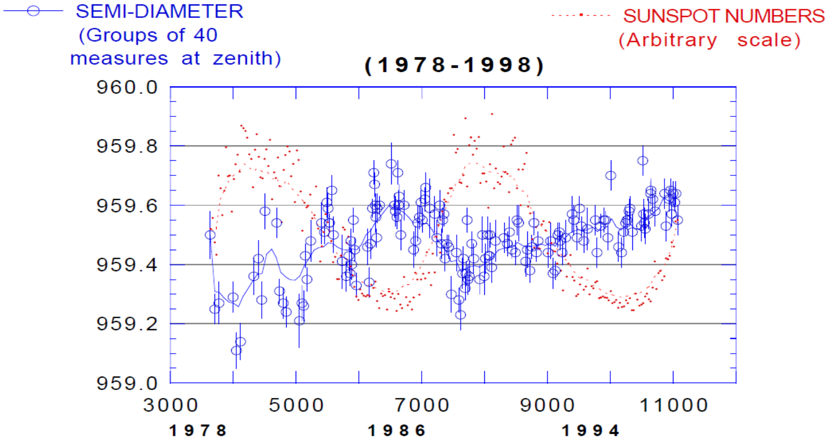

FIGURE: Opposing phase observed between the sunspots number and semi-diameter measured at CERGA's Astrolabe (1978-1998). Damé, et.al, 2000.

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4. The Bolometric Oscillation Sensor (BOS) under the responsibility of the Royal Observatory of Belgium measures the incoming flux from Sun and Earth.

Sum up the information caught from the TSI, the diameter of the Sun, the solar oscillations, it will help us diagnosing Sun-Earth's climate connections. Is TSI increasing accompanied with a smaller Sun and vise versa? Will the acoustic modes be detected from the solar diameter measurement?

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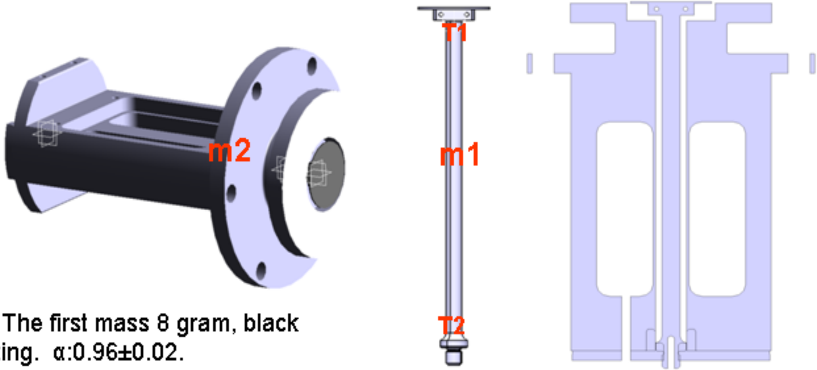
Principle: Instruments



m1: The first mass 8 gram, black coating. α:0.96±0.02.

m2: The second mass 160 gram, white coating. α:0.20±0.02.

FIGURE: The BOS instruments have two detectors: the black coating light mass absorber m_1 and the white coating heavy mass absorber m_2.The emissivity of black painting $m1$ ($\epsilon_1 = 0.88 \pm 0.04$) and The emissivity of white painting ($\epsilon_2 = 0.88 \pm 0.03$);

Principle: Measurements

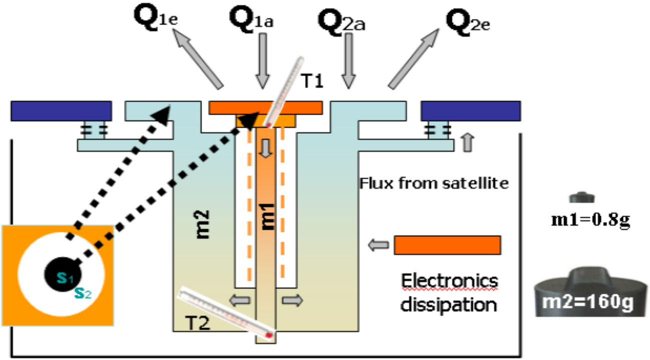


FIGURE: Suppose a TSI value $1361W/m^2$, the energy absorbed by the mass m1 is $0.336 \pm 0.007W$, by m2 is $0.168 \pm 0.02W$. The radiation energy on the black coating detector is nearly 30 times of white coating detector, thus the difference temperature $(T_1 - T_2)$ show a picture of incoming flux.

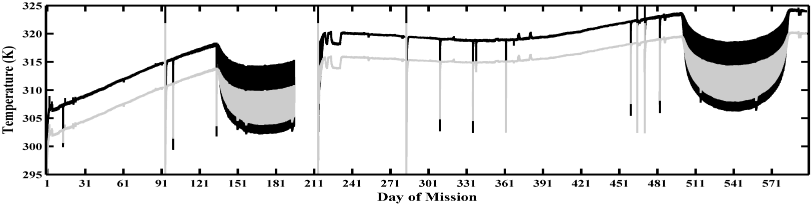
Principle: The calibration function

$$F_1 = \frac{1}{\alpha_1 S_1}(Cm_1 \frac{\partial T_1}{\partial t} + K_{sh}(T_1 - T_2) + \epsilon_1 \sigma T_1^4) \quad (1)$$

$$F_2 = \frac{1}{\alpha_2 S_2}(Cm_2 \frac{\partial T_2}{\partial t} + K_{sh}(T_2 - T_s) + \epsilon_2 \sigma T_2^4) \quad (2)$$

Where,
C: is the thermal capacity of aluminum;
T_1: the temperature of m_1;
T_2: the temperature of m_2;
T_s: the temperature between the BOS instrument and satellite;
K_{sh}: thermal conductivity of the shunt $K_{sh} = kS/l$, k, the thermal conductivity of aluminum;
S_1: The surface of m_1;
S_2: The surface of m_2;
α_1: The absorbing coefficient of black coating ($\alpha_1 = 0.96 \pm 0.02$);
ϵ_1: The emissivity of black painting ($\epsilon_1 = 0.88 \pm 0.04$);
α_2: The absorbing coefficient of white coating ($\alpha_2 = 0.20 \pm 0.02$);
ϵ_2: The emissivity of white painting ($\epsilon_2 = 0.88 \pm 0.03$);
σ: Stefan Boltzmann constant $\sigma = 5.670400 \times 10^{-8} Js^{-1}m^{-2}K^{-4}$.

The first records of BOS: Calibrated records



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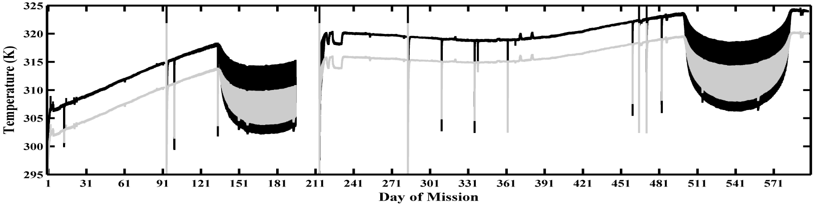

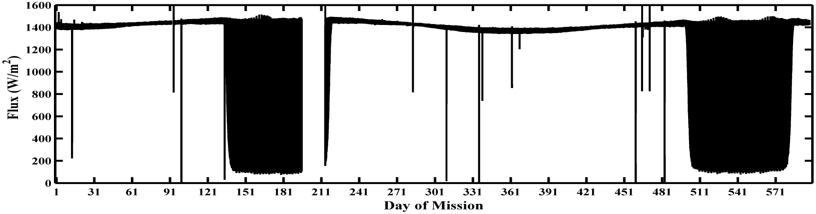

FIGURE: Even including the period of 'PICARD Vacances', the mission duty of BOS instruments is $> 96\%$.

The first records of BOS: Sun+Earth

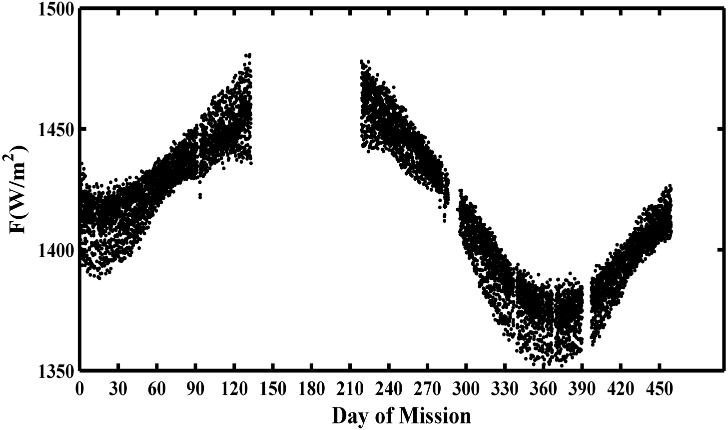

FIGURE: The instrument drift, stellar-pointing manoeuver and solar eclipses were removed.

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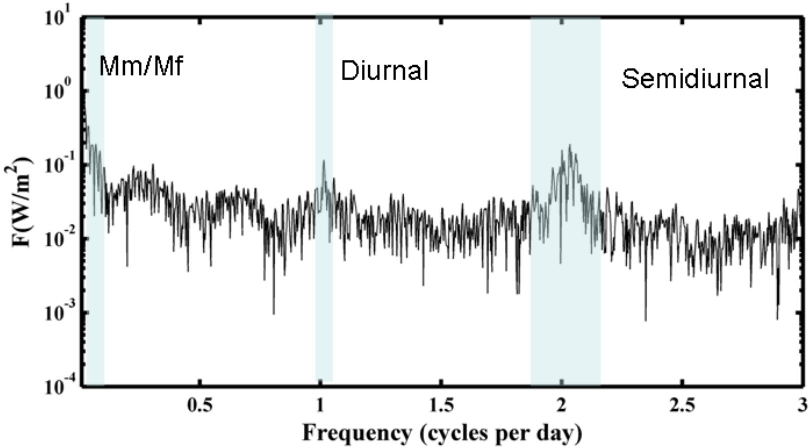


FIGURE: The amplitude Fourier Spectrum of the records.

The first records of BOS: Calibrated records

Date	$T_1(K)$	$T_{12}(K)$	$Flux(W/m^2)$
2009/12/15†	294.9 ± 0.90	-0.3 ± 0.03	368.2 ± 1.11
2009/12/16†	296.3 ± 1.38	-0.2 ± 0.10	379.7 ± 1.62
2010/10/06♮	301.0 ± 1.70	-6.1 ± 0.14	22.6 ± 2.22
2010/11/09♮	303.9 ± 1.14	-4.8 ± 0.30	32.6 ± 2.79
2011/05/04♮	306.2 ± 1.36	-5.2 ± 0.16	35.2 ± 1.14
2011/05/30♮	305.9 ± 1.31	-5.1 ± 0.15	35.9 ± 1.37

†: The measurements at the launch base.
♮: The measurements during the stellar pointing.
The uncertainties (noise level 1σ value) of the absolute temperature measurements is $1.32K$, the difference temperature measurements is $0.17K$, the flux measurement is $1.81W/m^2$.

The first records of BOS: The long-term drift

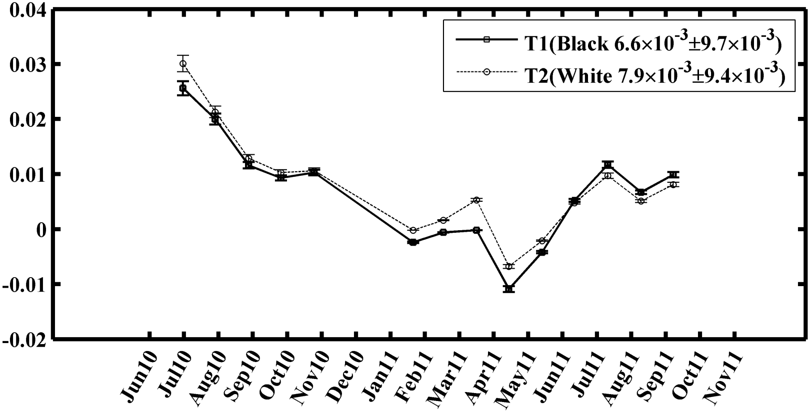
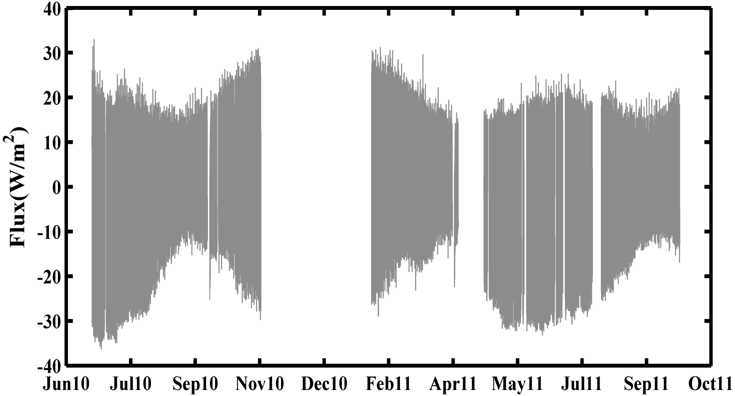


FIGURE: The degrading and drift of instruments are originated from the black and white coating and non-linearity of the thermistors.

The first records of BOS: Cleaned data



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The first records of BOS: The power spectrum density

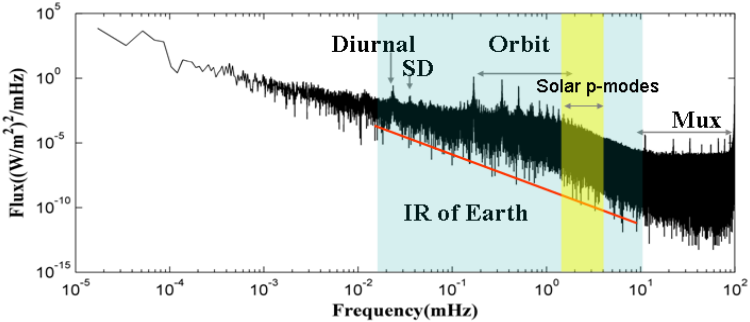

FIGURE: Power Spectrum Density (PSD) of BOS data computed with the measurements from 2010/06/29 to 2011/11/20. The infrared radiation of the Earth is dominated between 0.01mHz to 10mHz. Unfortunately, it overlaps the frequency band of solar p-modes (2m -4mHz). In addition, the orbit period is another source of perturbation since the sensor is completely exposed to the space with a large filed of view.

The first records of BOS: Infrared radiation of the Earth

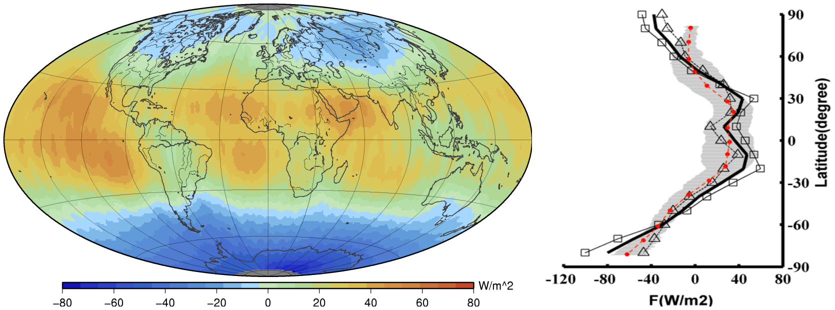

FIGURE: Left, Variations of the measured irradiance derived from one year of observation (July 2010 to July 2011). Right is a latitudinal plot of the BOS measurements. The solid line is the zonal mean of the Earth's long wave radiation (infrared), the rectangular and triangle signs mark the upper and lower limit of IR respectively, which is derived from the Earth's Radiant Energy System CERES observation.

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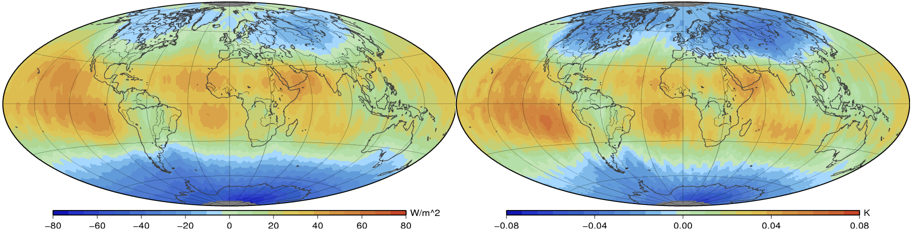

FIGURE: Infrared radiation of the Earth, left variation of Flux, right the difference temperature measurements $(T_1 - T_2)$. The flux (F1) was measured with the first mass(m1),see equation1.

The first records of BOS: The p-modes of the Sun

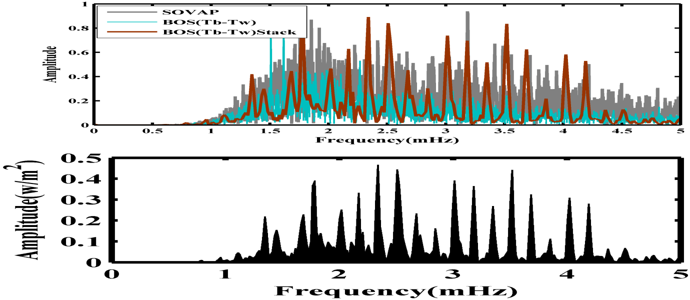

FIGURE: At the previous section, we have showed that the 'Mux' can induce some noise in the records. In order to evaluate the effects,It was suppressed during one week. We computed the residuals of the SOVAP, the $T_{12} = (T_1 - T_2)$ and flux F using wavelet denoising. Upper panel, the amplitude Fourier spectrum of the difference temperature T_{12}, SOVAP right channel; Lower channel: FFT was computed by the stacking three months's records of BOS.

The first records of BOS: The total and partial solar eclipses

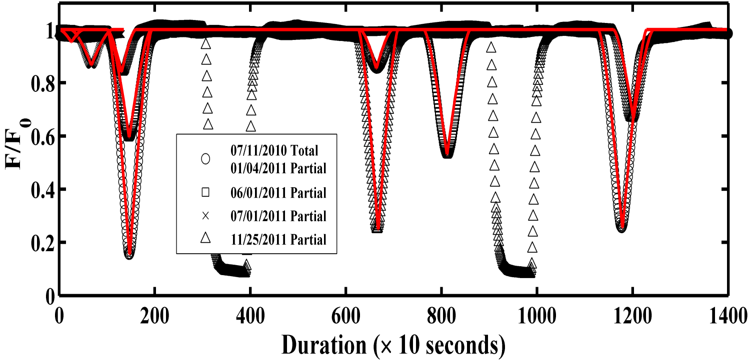

FIGURE: Five solar eclipses (black signs) are shown together with the model prediction (red solid line). Two Sun occultation by the Earth are displayed by black triangles.

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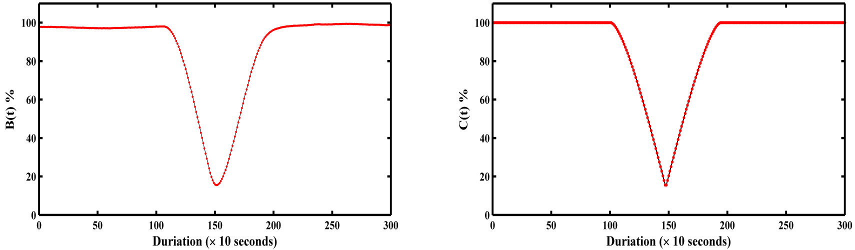

FIGURE: Modeling the process when the satellite was passing the shadow of the Moon.

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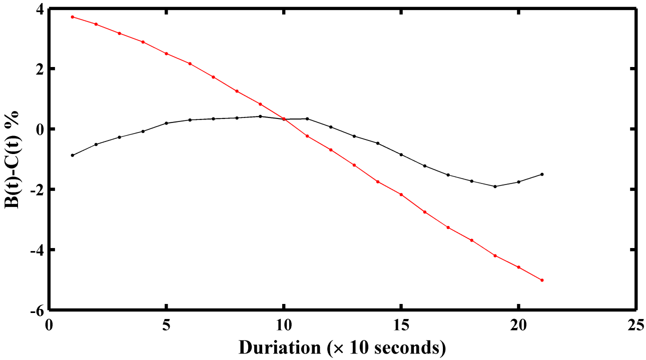

FIGURE: Modeling the process when the satellite was passing the shadow of the Moon,A radius 960.329 ± 0.095 arcsecond of the Sun can be deduced from the 20 times entering and exiting the shadow of the Moon.

Summary: Characteristics

The Bolometric Oscillation Sensor (BOS) is a simply designed instrument. The advantage is that it can work with the minimum of resources requirement in terms of power and data budget, which is also the key to guarantee the mission duty of BOS is $> 96\%$. It has a relative broad dynamic range $> 100dB$, thus the short- and long-period irradiance of Sun's and Earth's variation can be detected from the BOS measurements.

Pros	Cons
Flat absorber (Wide FoV)	Separate the origin of flux
Energy balance (Mass+Coating)	Degrading
Thin shunt (Variations)	Uncertainties (Absolute)

Summary: product & data reduction

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- For the Earth, compare the infrared observations with other missions, CERES et.al.
- Fly on other missions.

Thank You!