A high-dynamic and accurate electromagnetic radiation and thermal energy detector for planetary studies

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Highlights: SOLAR IRRADIANCE, IR RADIATION, UV, ALBEDO, TEMPERATURE, AND THERMAL INITIAL precise measurements for planetary missions.

1 The solar radiation

The Sun emits radiation through all the electro-magnetic spectrum from radio-waves to Xrays. This radiation spreads out through the whole solar system. Observed radiation decreases with the square root of the distances(Table 1). The solar radiation is the main external driving force of the planetary physics and climate. Its interaction with the planetary surface and atmosphere provide inside to the atmospheric and surface properties of solar system objects. Thus, it is important to measure the solar irradiance (SI) at the same time with the irradiance from the planets and even small asteroids. It will help us understanding better the climate and the physics of planets. Meanwhile, it will bring additional information about the activities of the Sun

Planet	Orbit (AU)	T (K)$^\flat$	SI (W/m^2)$^\natural$	BA$^\sharp$
Mercury	0.3871	440.1	9126.6	0.068
Venus	0.7233	184.2	2613.9	0.900
Earth	1.0000	254.3	1365.5	0.306
Moon	1.0000	270.7	1365.5	0.110
Mars	1.5240	210.1	589.2	0.250
Jupiter	5.2000	110.0	50.5	0.343
Saturn	9.5400	81.1	14.9	0.342
Uranus	19.1800	58.2	3.7	0.300
Neptune	30.0600	46.6	1.5	0.290
Pluto	39.4400	37.5	0.9	0.500

$\flat$: Black-body temperature, $\natural$: Solar irradiance, $\sharp$: Bond Albedo. data credits: `http://nssdc.gsfc.nasa.gov/planetary/factsheet/`

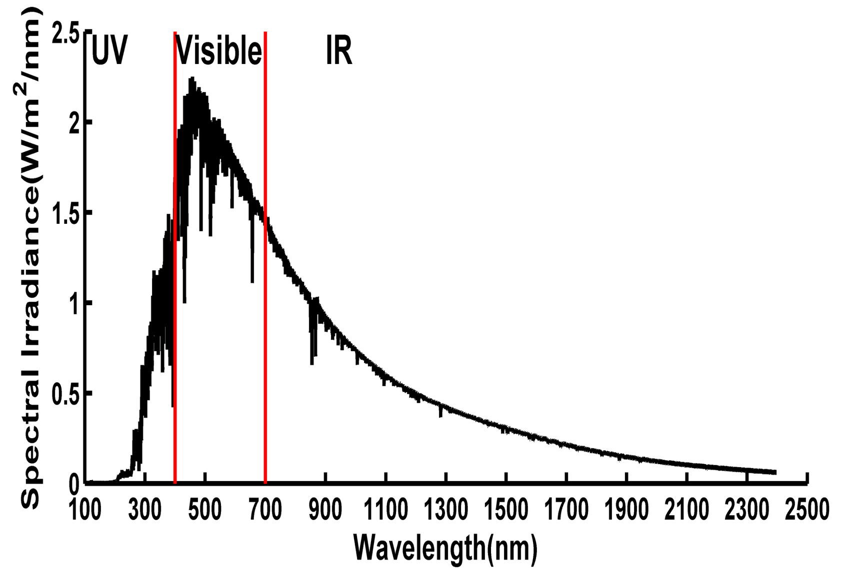
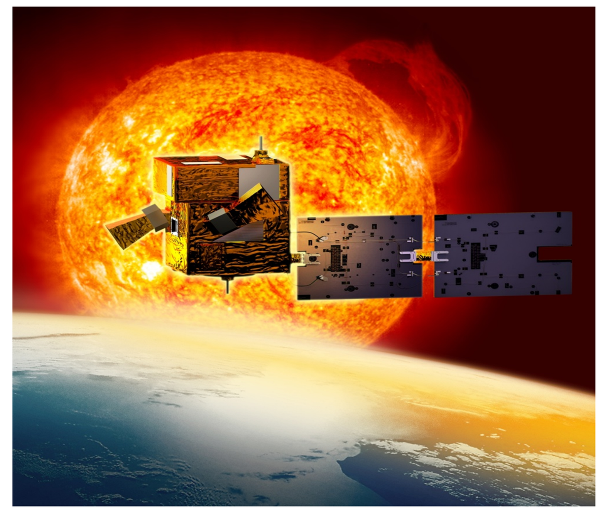
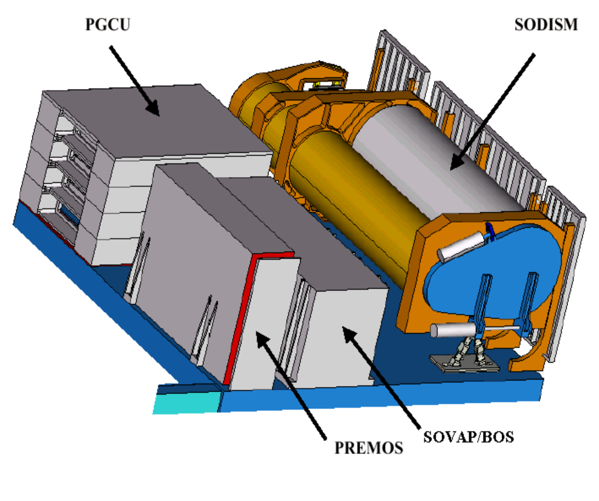


Figure 1: The radiation of the Sun observed at the top of Earth's atmosphere.

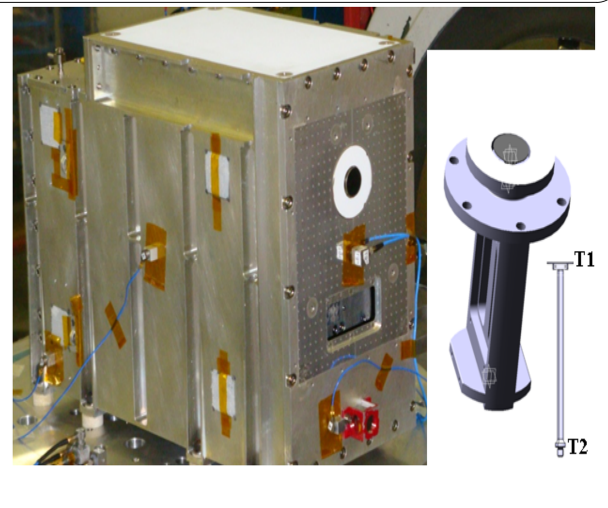
The BOS for PICARD mission is designed for monitoring the energy coming form the Sun (Figure 1) as well as from the Earth in all wavelengths with 10 seconds sampling. The principle and transfer function of the measurements will be shown as well as the performance of the instrument. Based on the BOS-PICARD experiments, we also works on the version of the sensor to determine the properties of airless bodies. The surface temperature, infrared radiation(IR) and the Albedo of planet and asteroid. The sensor can be adapted to planetary missions for different platforms varying from cubsats with limited resources to much larger spacecrafts.



PICARD Satellite (↑↑June 15, 2010)



PICARD Payload

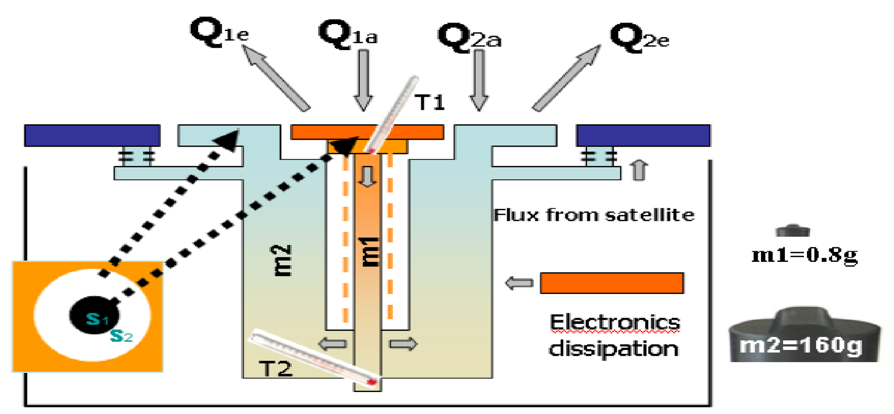


BOS-PICARD

2 Current Mission: BOS-PICARD

2.1 Measurement Principle

The instrument thermal flux regulation can be reached by carefully select the geometry and material, Suppose two thermal flux (F_1 & F_2) are measured, and the $F_1 > F_2$ showed as the following sketch, the flux can be modelized:

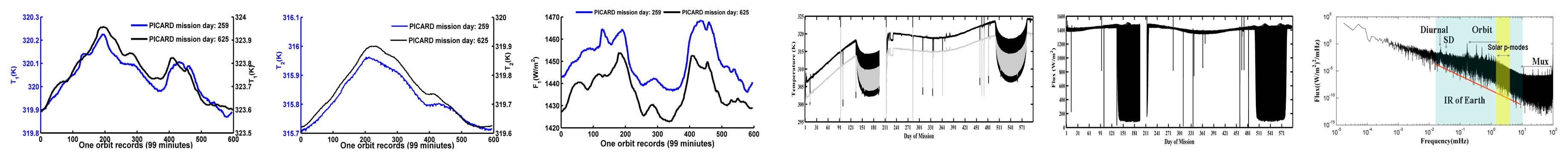


$$F_1 = \frac{1}{\alpha_1 S_1}\left(Cm_1\frac{\partial T_1}{\partial t} + K_{sh}(T_1 - T_2) + \epsilon_1\sigma T_1^4\right) \quad (1)$$

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

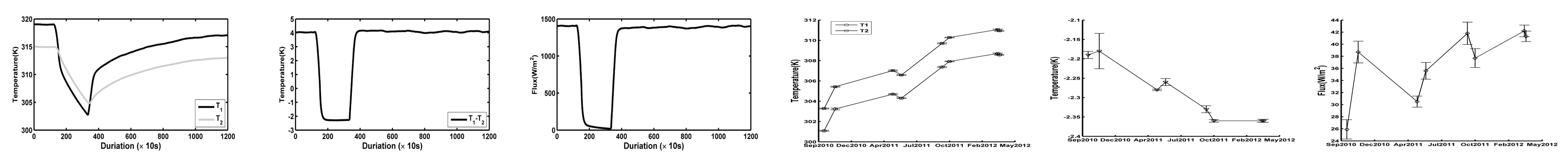
Then the goal to regulate the flux is reached. We can make a simple calculation with the design of left sketch. For a given solar irradiance $1361W/m^2$, the energy absorbed by the mass m_1 is $0.336 \pm 0.007W$, by m_2 is $0.168 \pm 0.02W$. The radiation energy on the black coating detector is nearly 2 times of white coating detector, thus the difference temperature $(T_1 - T_2)$ show a picture of incoming flux.

2.2 The first records of BOS-PICARD

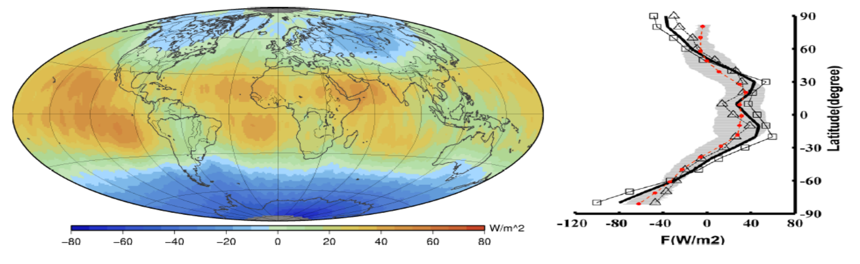


One orbit T_1 records | One orbit T_2 records | One orbit F_1 records | Data(T) since launch | Data(F) since launch | PSD of F_1.

The noise level of BOS is computed with 8 times stellar-pointing(SP) between 10/06/2010 and 03/24/2012.



T_1&T_2 during SP | $T_1 - T_2$ during SP | F_1 during SP | Uncertainties of T_1&T_2 | Uncertainties $T_1 - T_2$ | Uncertainties F_1



The long-wave radiation ($5\mu m - 25\mu m$) of Earth observed with BOS instrument. We compared the zonal mean of IR of the Earth from the BOS (red dot) with the CERES values (Solid line) right figure.

The characteristics of BOS is summarized:

- Dynamic range $> 100\ dB$;
- The mission duty $> 96\%$;
- T_1: $\pm 0.042\ K$;
- T_2: $\pm 0.038\ K$;
- $T_1 - T_2$: $\pm 0.008\ K$;
- F_1 $\pm 1.2\ W/m^2$.

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

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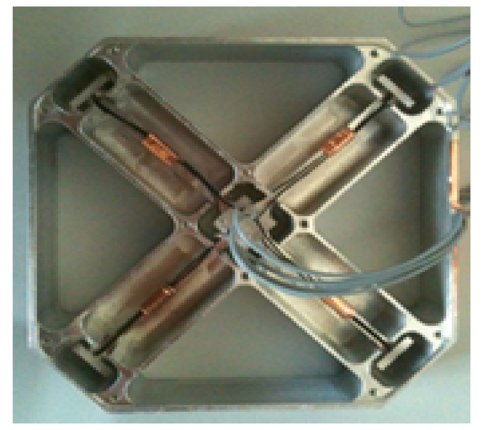
3 Planetary studies

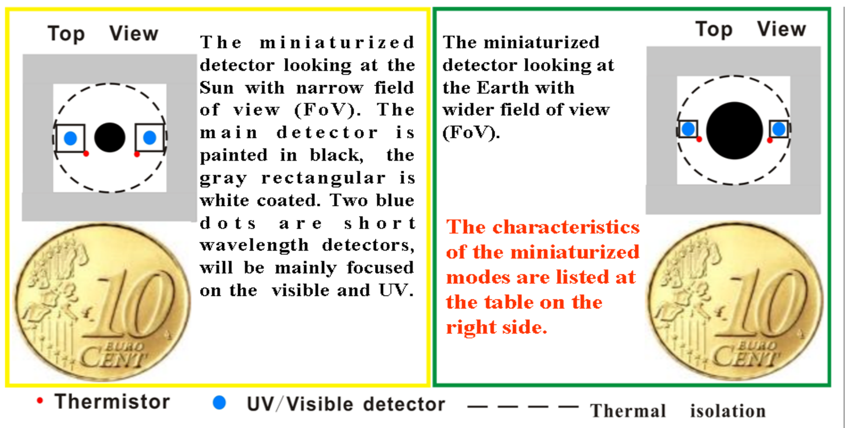
3.1 Improving the design of BOS-PICARD

The BOS instrument is now working in space on board the PICARD satellite. When observing the Sun, it also receives a contribution from the IR radiation and albedo of the Earth. These components can be spitted given some specific circumstances such as solar eclipses by the Moon and the Earth. However, in order to precisely measure the radiation from different resources, the easiest way is to add additional detectors with a selected field of view (FoV), which is depending on the requirement of observations.

3.2 A miniaturized sensor for nano-satellite missions



The engineering mode designed to accommodate the nano-satellite.



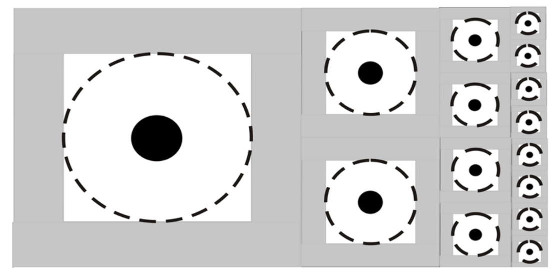
The main detectors are same than BOS, we added the cavity to focuse on different objects.

Parameters	Data
Mass (gram)	200
Volume (cm^3)	120
Peak power (mW)	500
Sampling (s)	10
Date rate (kB/day)	150
FoV ($Degree$)	7.15$^\flat$
FoV ($Degree$)	14.25$^\natural$
Temperature (K)	< 0.05
Flux (W/m^2)	< 1

$\flat$: Sun $\natural$: Earth

3.3 Radiation and thermal initial measurements

- The surface temperature ($1K$ above ($\sim$ $200K$)). The spatial resolution $< 10m$ and thermal inertia $< 10\%$.
- Mid-IR ($5\mu m - 25\mu m$).
- Landing area ellipse mid-IR radiation with a spatial resolution of decimeters.
- Near-surface investigations.



An array detectors were designed to precisely measure the radiation and thermal initial of the planet or alien bodies. The detectable range of wavelength are focused on the mid-IR and IR. The spatial resolution is depending on the orbit. For instance, with a spacecraft orbiting an object at a 5 Km altitude, the spatial resolution along the track are listed at the table on the right side. The expected precision of temperature and radiation measurements are also given.

Parameters	Data
Mass (gram)	500
Volume (cm^3)	228
Peak power (mW)	800
Sampling (s)	1
Date rate (Mb/day)	1.2
FoV ($Degree$)	0.72 – 5.72
Spatial resolution(m)	< 10
wavelength(μm)	5 to 30
Temperature (K)	< 0.05
Flux (W/m^2)	≤ 1

4 Summary

The accuracy of the BOS-PICARD is $\pm 0.05K$ for absolute temperature measurements in a range of 300K to 320K and for flux is $\pm 1.2W/m^2$. The detector can be accommodated to any kind of spacecrafts from nano-satellite with limited resources to a larger one. It will produce SI, IR radiation, UV, Albedo, Temperature, and Thermal initial measurements. The high spatial resolution of remote sensing can be achived with an array detectors. The main detector can also be installed in the lander to make in-situ temperature profile.

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