

PROBA 3

ABSOLUTE RADIOMETER AND SUN SENSOR

DEFINITION DOCUMENT

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1. INTRODUCTION

The purpose of the Absolute Radiometer and Sun Sensor Requirements and Definition Document is to provide an overall description of the equipment conveniently called "ARaSS".

2. ACRONYMS

AIV	Assembly, Integration & Verification
ARaSS	Absolute Radiometer and Sun Sensor
BNR	Branch Not Regulated
DAQ	Data Acquisition
DRB	Design Review Board
EGSE	Electrical Ground Support Equipment
EICD	Electrical Interface Control Document
FM	Flight Model
FOV	Field-of-View
H/W	Hardware
HK	Housekeeping
I/F	Interface
N/A	Not Applicable
OBC	On Board Computer
PA	Product Assurance
PCDU	Power Control & Distribution Unit
PDR	Preliminary Design Review
QA	Quality Assurance
S/C	Spacecraft
S/W	Software
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written
TSI	Total Solar Irradiance

3. APPLICABLE AND REFERENCE DOCUMENTS

[AD1] PROBA 3 Product Assurance Requirements
P3-EST-RS-1005 1.1

[AD2] PROBA 3 Environmental Specification
P3-EST-RS-6003 v 1.1

[RD1] PROBA 3 Mission Requirements Document (MRD)
P3-EST-RS-1006

[RD2] Summary of PROBA3 Mission Analysis for Coronagraph Instrument
P3-EST-TN-7002 1.0

4. PROBA 3 MISSION OBJECTIVES

The ESA PROBA 3 technology mission is aimed at the in-orbit demonstrating of new Formation Flying techniques and technologies. It is composed of two small spacecrafts (Coronagraph spacecraft and Occulter spacecraft) flying in formation in a highly elliptical Earth orbit. Both spacecrafts accommodate FF flying technologies in order to demonstrate FF configurations and performances required for future missions (metrology, propulsion, GNC). The objectives include also the validation of FF at system level by the accommodation of a guest payload to critically evaluate the effect of formation flying on scientific observations. The baseline of the project is a “giant” white-light, externally-occulted solar coronagraph as the payload. One spacecraft hosts the occulting disk and the other the coronal imager/coronagraph. The spacecraft fly in formation with a separation of 150 meters. The mission is designed for a life-time of 2 years.

The objectives of the PROBA 3 mission are:

- The development to technology readiness level (TRL) 9, in-orbit demonstration, of the formation flying techniques and associated technologies, this in turn implies
- The development and validation of the ground verification tools and facilities
- The implementation of a guest mission devoted to the observation of the sun-corona as part of the demonstration of FF

5. SCIENTIFIC GOALS

The Absolute Radiometer and Sun Sensor will be an experiment on board of the Occulter spacecraft and with the scientific goal to achieve high accuracy and long-term stability measurement of the Total Solar Irradiance.

The science goals of ARaSS are described here below.

• Radiometry

The absolute scale to measure Total Solar Irradiance is given by Space Absolute Radiometric Reference (SARR) introduced by Crommelynck et al. (1995) and which is today represented by the experiment VIRGO on SOHO. This scale was challenged by the space experiment TIM on SORCE. The LASP group who built TIM insists that their value, which is 4.54 W/m^2 lower than SARR lower, is correct. The intrinsic uncertainties of both instruments are much smaller than this difference. Although all groups involved in space radiometry cooperated in several round table discussions, the issue could not be resolved and remains a puzzle for the metrology of radiation in space. Ultimately, the unresolved problems may affect the calibration of space experiments measuring radiation in space, depending on the origin of the discrepancy (Fox, 2003). Both instruments, TIM/SORCE and VIRGO/SOHO, have been fully characterized so they are measuring in absolute terms. The common understanding is that the problem is linked to the transfer of calibration into space. There is a fundamental difference in the measurement principle of TIM and VIRGO: TIM measures the irradiance in a phase sensitive mode of operation whereas VIRGO awaits a thermal equilibrium state.

The specified equipment ARaSS for PROBA3 shall be able to be operated in both modes of measurement principles. The ARaSS measurements will lead to a fundamental improvement of the uncertainty of the solar

constant. However, the more important result than the value itself is that the discussion of its uncertainty is then fully traceable to SI.

- **Space Weather**

UV radiation has a direct influence on the atmospheric composition of terrestrial middle and upper atmosphere. Measuring UV radiation in selected wavelength bands would be the direct approach. However, UV measurements suffer from serious long-term stability issues (both filter radiometers and spectrometers). A better approach is thus having the TSI measurements. The TSI variations are highly correlated with the UV intensity variations and in fact, the TSI variations are dominated by the contribution from the UV. As direct space weather application, the observed variations will be used as input for Climate-Chemistry Models to now-cast the chemical composition of the middle atmosphere.

This science goal shall be operational as long as ARaSS is delivering data.

- **Space Climate**

There is a clear evidence for the influence of the Total Solar Irradiance (TSI) on the terrestrial climate [e.g. Haigh J. D., (2001) *Science* 294]. A major goal of the ARaSS equipment is to monitor the TSI with unprecedented accuracy and sensitivity and to extend the TSI data record to span the next solar cycle. Various space experiments have been monitoring the TSI continuously since 1978, covering two solar minima. It is still a matter of debate whether or not the minima levels of the TSI have changed. The ARaSS equipment data would provide the extension of this time series into the next solar minimum, thus helping to solve this essential question for climate models.

This science goal is evaluated after the PROBA3 mission. The full time series of ARaSS will be compared with that of all other TSI experiments that are operational during the mission time of PROBA3. The result will be an evaluation of the long term stability of the experiments. It is expected that at least two other TSI experiments will be operational: The American GLORY mission (a replacement of TIM/SORCE) and PREMOS on the French satellite PICARD (launch 2009).

- **Helioseismology**

The measurement rate of the ARaSS equipment shall be adjustable down to 10 seconds, which is the response time of the measuring cavities. Short-term solar variability on time scales ranging from seconds to minutes is thought to be a key observable when trying to understand the dynamics of solar atmosphere. ARaSS will be the highest-cadence solar radiometer in space to date, allowing to explore the variability of the TSI at frequencies up to 25 mHz. Unlike their low-frequency (below ~5.4 mHz) counterparts, high-frequency acoustic waves are not trapped in the solar interior but can travel freely in the solar atmosphere (Ulrich 1970). They thus carry acoustic energy from the solar interior to the outer layers of the atmosphere, where they eventually form shocks due to the rapidly decreasing pressure scale height. In this way, travelling waves not only contribute to the heating of the chromosphere and corona but may also be a driver for many of the dynamical processes that are being observed in those layers of the solar atmosphere. In the thin and ionized plasma of the chromosphere pressure fluctuations easily couple to the magnetic field, causing the sound waves to be partially converted into magneto-acoustic and Alfvén waves (Bogdan et al. 2003), hence to affect the structure and dynamics of the magnetic fields in the chromosphere and corona. TSI measurements are ideal for monitoring the total acoustic power escaping the solar interior and travelling into the solar atmosphere. Being absolute measurements, the amplitude of TSI fluctuations can be directly converted into pressure amplitudes in the adiabatic case. Corrections for non-adiabaticity of the photosphere are small and can readily be implemented if needed. The observed TSI amplitudes are neither affected by position on the solar disk (like line-of-sight Doppler velocity) nor do they suffer from poor absolute calibration (like filter radiometer observations).

This science goal is addressed by dedicated high-rate measurement campaigns of several hours every week.

6. TECHNOLOGY DEMONSTRATION

ARaSS will demonstrate new concept of radiometer to achieve higher accuracy and long-term stability as described in more details in the following chapter. ARaSS is expected to be more accurate than any other flown radiometer before – but its technology has to be demonstrated to be selectable for other upcoming missions like e.g. Solar Orbiter or Solar-C.

7. INSTRUMENT CONCEPT

ARASS is a new generation room temperature radiometer. It consists of three active cavities, which are all pointed towards the Sun. The cavities are operated differentially: one cavity (the reference cavity) is heated with a constant electrical power while the heater power in the remaining two cavities (active cavities) is actively controlled to equalize the heat fluxes from each cavity to the heat sink. While one of the active cavities (measuring cavity) will be periodically exposed every ten seconds to provide continuous measurements of the TSI, the second (backup cavity) will be exposed only once per month to monitor the degradation of the blackening of the measuring cavity. All three cavities are capable of measuring solar irradiance and can be assigned for reference, measuring, or backup type.

The optical design of the ARASS will have three precision apertures of 4 mm nominal diameter mounted in the front plate of the package, followed by cylindrical housings containing the shutters, the view limiting apertures and the light absorbing cavities, which are mounted 50 mm behind the entrance apertures. To cover the full solar disk the diameter of the cavities will be 6 mm, yielding a slope angle of 1.1° . All light entering the front apertures will be absorbed in the cavities.

The dissipated heat per cavity will be held constant at 35 mW throughout the mission. In the measuring cavity the solar contribution to the total heat dissipation is of order ~ 17 mW. The temperature gradient between the cavities and the heat sink will be of order 1°C .

The triple cavity design offers redundancy as well as the possibility for in-flight monitoring of the instrumental performance and degradation. Special modes of operation will be implemented to periodically determine characteristic parameters such as the reflectance of the cavities and the thermal resistance between the cavities and the heat sink.

The Sun Sensor detects the solar position accurate to 2.5 arc seconds.

- **Novel data processing scheme**

The data will be evaluated by a frequency analysis of the instrument's response by extracting the signal at the fundamental of the shutter frequency. This so-called phase sensitive mode of operation offers many advantages over the normal "active cavity" operation in e.g. SOHO/VIRGO, which relies on reaching an equilibrium state before measurements can be taken. It is insensitive to any out-of-frequency or out-of-phase noise.

The electrical power fed to the cavity will be sampled at 10 Hz and frequency analyzed. The raw data will be transmitted to ground. The amplitudes and phases of the shutter fundamental frequency plus the first few harmonics of it will be analyzed. Only the in-phase signal at the shutter fundamental is needed to calculate the irradiance, the harmonics are for the in-flight characterization of the temporal behavior of the detectors. On-board analysis might be envisaged but is not foreseen, since no significant data reduction could be achieved. Some of the correction factors, needed for the final evaluation of the irradiance, can be determined and/or checked in flight.

• Optical design

The optical design of the ARASS will have three precision apertures of 5 mm nominal diameter mounted in the front plate of the package, followed by 50 mm long tubular housings containing the shutters and the light absorbing cavities with view-limiting apertures. To cover the full solar disk during all orbital phases the diameter of the view limiting apertures will allow a slope angle of 1.1° and field-of-view of 5° . All sun-light entering the front apertures will enter the view-limiting apertures and be absorbed in the cavities.

• Structure

ARASS sensor box and SS unit are made from 6082 aluminum and will be mounted on the S/C with at least 4 M6 screws (tbc).

• Thermal Design

For best performance of the ARASS the instrument's temperature should not vary quickly. This is achieved on one hand by keeping the amount of dissipated heat in the detector cavities at a constant level.

Individual controlled method:

The ARASS sensor box is thermally insulated from its environment, conductively and radiatively by thermal washers and MLI. Its temperature is controlled in a classical way by an active system based on heaters and temperature sensors and two radiation shields (front and top) for power dissipation.

As an option, using a collectively controlled S/C platform, with a good thermal contact between the package and the S/C's thermal mass, would help to solve thermal difficulties for ARASS and would help to have a stable thermal environment.

• Detectors

The absorbing cavities are blackened cavities in which the solar radiation is absorbed.

Absolute radiometers are based on an electrically calibrated heat flux transducer and a cavity as receiver. The cavity ensures high absorption over a very large spectral range including FUV and IR. The principle of the measurement relies on the substitution of the radiant power by electric power. During operation of the instrument, an electronic circuit maintains a constant heat flux from the cavity heater by adjusting the input power. The heat flux is measured differentially between two cavities in order to compensate for the rate of change of the heat sink's temperature. The standard mode of operation of radiometers consists of alternate measurements with the shutter closed and open.

The special characteristics of the cavities in comparison to other realizations are their small size and mass. The cavities will respond to TSI variations significantly faster than the cavities which are used in current phase-sensitive radiometers such as the TIM on SORCE. The light-weight design is crucial for future interplanetary missions such as Solar Orbiter and KuaFu-A. Modified coatings are currently under consideration to reduce the effect of non-equivalence. If they prove successful in ground tests they will be used in the ARASS.

SS: The sensors of the Sun Sensor are based on the principle of a one-dimensional diffraction image of the sun on a linear CCD array. Some characteristics:

- Pixel resolution 48.5×10^{-6} rad or approx. 10 arc sec
- Accuracy 2.5 arc sec
- View angle $\pm 1^\circ$

8. ORBIT, OPERATIONS AND POINTING REQUIREMENTS

ARASS will need the entire solar disk in its observational field of view of 5° . The off-pointing tolerance is 1° allowing for unaffected operation when the S/C is pointed to the sun.

The observing sequences are straightforward since no target selection is necessary. However, the periodic operation of the backup channel and re-characterization procedures has to be controlled by time-tagged telecommands.

9. CALIBRATION

Pre-Launch

Calibration: Late access to the test connectors is needed since internal reference voltages shall be measured as late as possible before launch. The alignment of the package (alignment cube) with respect to the S/C shall be inline with the system/experiment requirements.

In Flight

The sensitivities (thermal resistance) of the ARASS sensors are continuously calibrated by electrical heating of known power.

The data acquisition system will be calibrated regularly with internal voltage reference elements.

10. ACCOMMODATION

ARASS shall be mounted along its optical axis on the Occulter spacecraft. If the thermal concept is based on individual control on experiment level, the front and top radiator of ARASS shall be exposed to space to be able to dissipate the power losses. If a collectively controlled system is applied, the front area can be covered with S/C MLI with cut-outs for the instruments optical inlets.

Alignment Requirement

At integration on the S/C, the instruments optical axis shall be aligned with the S/C mounting plane, defined by the S/C Sun Sensor mirror cube, within ± 5 arc minutes.

Alignment Method

ARASS has a removable optical cube (tbc) with the vertical sides parallel to the optical axis of the instrument; using an external test equipment, the angles in two perpendicular directions of the optical axis of ARASS and of the sun sensor shall be determined with an uncertainty of ± 1 arc minute.

Alignment Hardware

The arrangement of the ARASS alignment jig on top of the experiment is TBD.

The main characteristics of the alignment jig are:

Dimension	20 x 20 x 20 mm
Material of cube	BK7
Optical property	better than $\lambda/4$ (surface roughness)
Parallelism	better than 20 arc seconds

11. INTERFACE AND PHYSICAL RESOURCES REQUIREMENTS

- **Data rate**

ARASS Data Rate (Preliminary)			
	Samples/sec	Bits / sec	Raw data kByte / day
Science Data (ARASS)		240	2532
Instrument Housekeeping and Status		16	169
SW and MicroController Health and Status		8	85
Sun Sensor*	1	32	338
Overhead (Time synch, etc.) 10%		30	313
Total Raw data per day (kByte)			3437

*) The SS sampling mode can be chosen by telecommand, ranging from one reading per hour to ten readings per second. In the table above one reading per second is used to determine the data rate. If the SS is read with 10 samples/sec the average data rate for the whole experiment would be 643 bits/s.

- **Data Interface**

It is foreseen to use two RS-422 interfaces, one for SS data transmission (science-, housekeeping- and status data) and receiving (telecommands), the other one for the same data types, but for the rest of the instrument.

- **Mass**

Table 1: ARASS Mass Budget (Nominal)

Item	Item Mass (g) incl. 10 % contingency
AR Unit	3900 + 400 = 4300
SS Unit	1000 + 100 = 1100
MLI	130 + 10 = 140
Harness	TBD
Total	5540 + TBD harness

- **Envelope and Volume**

ARASS contains the absolute radiometer with 3 active cavities, the 3 shutter motors and pre-amplifier electronics and DC/DC converters and the sun sensor (separate housing, TBC).

Unit dimension AR: X/Y/Z 156 mm/182 mm/228 mm

Unit dimension SS: X/Y/Z 80 mm/80 mm/280 mm

- Power Consumption

Power Consumption AR						
Item	Comment	+5V	+10V	-10V	28V	Power
		[mA]	[mA]	[mA]	[mA]	[W]
Shutter	Shutter Cycle 10sec	0			5	0.14
Hall Effect Sensors	one open one close Sensor	10				0.05
Ref Cavity Heater		10				0.05
Passive Cavity		8				0.04
Active Cavity		4				0.02
ASIC		20				0.1
Control Electronics		100	50	50		1.5
Contingency	15% Contingency					0.285
DC/DC Loss	Efficiency 55%					1.788
Total Power AR						3.97
Power Consumption SS						
Item	Comment	+5V	+10V	-10V	28V	Power
		[mA]	[mA]	[mA]	[mA]	[W]
SS total		100	60	10	20	1.46
Contingency	15% Contingency					0.219
DCDC Loss	Efficiency 55%					1.374
Total Power SS						3.05
Power Consumption Operational Heaters						
					28V	Power
					[mA]	[W]
					107	3
Total Power Heaters						3
Total for ARASS						10.02

Remark: Operational Heater power is TBD and depending on the S/C thermal concept.

Remark: SS could be switched off between sampling, if running at low frequencies.

12. PRODUCT ASSURANCE, CLEANLINESS, GROUND OPERATIONS AND OTHER REQUIREMENTS

- **Product assurance**

The product assurance shall be compliant with the PROBA 3 product assurance requirements [AD1].

- **Cleanliness**

The guidelines for “Cleanliness and Contamination Control” are given in the document ECSS-Q-70-01A. The PA plan shall include criteria and tasks for contamination control. Contamination and outgassing sources have to be reduced to a minimum. All materials (listed in the DML) shall fulfill the minimum outgassing requirements, which are $< 1,0 \%$ for RML (TBC) and $< 0,1 \%$ for CVCM (TBC).

- **Cleanroom Facilities**

Before assembly of any flight hardware all individual parts shall be cleaned according to their specific cleaning process, listed in the DPL. During assembly phases all parts / subsystems / assemblies of the instrument shall be stored or handled in cleanroom environment (better than class 10'000) if no cleaning process is following.

If not possible the instrument shall be purged with dry nitrogen and covered with a Mylar foil.

During integration and launch preparation phases the contamination control cannot be guaranteed. Therefore appropriate protection devices shall be implemented.

- **Purging Facilities**

ARASS will be equipped with purging facilities. Dry nitrogen (Class 5.3 or better) will be used for continuous purging if the instrument is not in a clean condition or during transport.

- **Transport Container**

A special transport container shall be available for ARASS. The container is sealed, contains some over pressure valves and protects the instrument against contamination or mechanical damage. The instrument is mounted in a shock resisting manner. The container includes its own purging equipment and therefore allows clean transport or storage of the instrument.

13. INSTRUMENT DATA SHEET

The following table is provided to record the main characteristics of ARASS.

Mechanical data

Dimension X/Y/Z	AR: 156 mm/182 mm/228 mm SS: 80 mm/80 mm/280 mm
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Mass	5540 g & TBD harness
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I/F Bolts	4 times M6
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Electrical data

Primary Voltage	28V DC	Range TBD by system
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Power demand (primary)	10 W (incl. 10% contingency)	May be reduced depending on thermal concept
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Data rate	3437 kByte/day (Max: 643 bits/s)	Type: 2 times RS-422
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Optical data

Alignment requirement	+/- 5 arc minutes
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