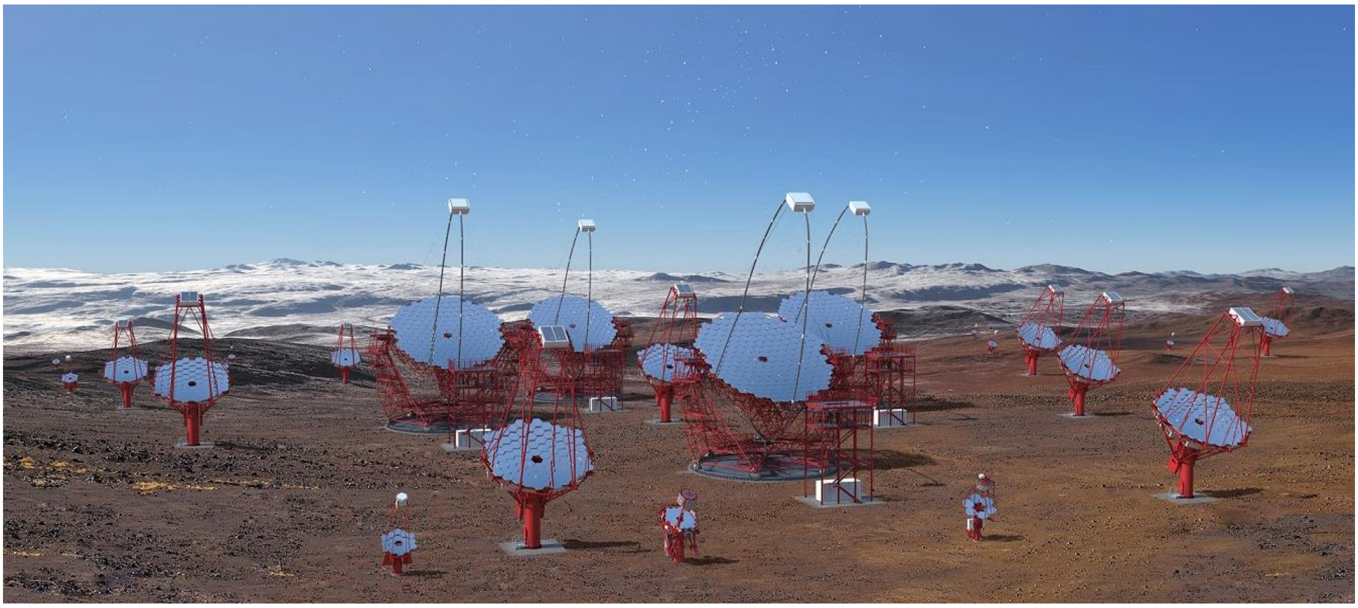
Effect of the ASTRI focal plane IR filter on the Optical Cross-Talk of the SiPM detectors



Prepared by:	Name: **Giuseppe Romeo**	Signature:	Date:	14/09/2017
Reviewed by:	Name: **Giovanni Bonanno**	Signature:	Date:	14/09/2017
Approved by:	Name: **Giovanni Bonanno**	Signature:	Date:	14/09/2017

INDEX

DISTRIBUTION LIST

ASTRI mailing list	astri@brera.inaf.it
Bruno Sacco	bruno.sacco@iasf-palermo.inaf.it
Giovanni Pareschi	giovanni.pareschi@brera.inaf.it
Stefano Vercellone	stefano@ifc.inaf.it
Rodolfo Canestrari	rodolfo.canestrari@brera.inaf.it
Osvaldo Catalano	osvaldo.catalano@iasf-palermo.inaf.it
Enrico Cascone	cascone@na.astro.it
Giovanni La Rosa	larosa@ifc.inaf.it
Giovanni Bonanno	gbo@oact.inaf.it
Giuseppe Romeo	giuseppe.romeo@oact.inaf.it
Domenico Impiombato	domenico.impiombato@ifc.inaf.it
Patrizia Caraveo	pat@lambrate.inaf.it
Davide Marano	davide.marano@oact.inaf.it
Alessandro Grillo	agrillo@oact.inaf.it
Luca Stringhetti	luca@iasf-milano.inaf.it
Rachele Millul	rachele.millul@brera.inaf.it
Mauro Fiorini	fiorini@lambrate.inaf.it
Salvatore Garozzo	salvatore.garozzo@oact.inaf.it
Giuseppe Sottile	sottile@ifc.inaf.it
Salvatore Giarrusso	jerry@ifc.inaf.it
ASTRI mailing list	astri@brera.inaf.it

LIST OF ACRONYMS

OACT	Osservatorio Astrofisico di Catania
IFC	Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo
COLD	Catania astrophysical Observatory Laboratory for Detectors
PCB	Printed Circuit Board
SiPM	Silicon Photo-Multiplier
MPPC	Multi Pixel Photon Counter
SST-2M	Small-Size Telescope Dual-Mirror
PDM	Photon Detection Module
ASIC	Application Specific Integrated Circuit
FEE	Front-End Electronics
BEE	Back-End Electronics
FPGA	Field Programmable Gate Array
EASIROC	Extended Analogue Silicon-pm Integrated Read-Out Chip
CITIROC	Cherenkov Imaging Telescope Integrated Read-Out Chip
I/F	Interface
LCT	Low Cross Talk
PSAU	Power Supply and Amplification Unit
PDE	Photon Detection Efficiency
SCA	Switched Capacitor Array
OCT	Optical Cross Talk
LVR	Low Voltage Reverce
LVR2	Low Voltage Reverce 2nd Version
PHD	Pulse Height Distribution

1. INTRODUCTION

The need to populate the focal plane of the ASTRI telescope with SiPM detectors that are well sensitive in the blue spectral range (Cherenkov light) but also sensitive in the infrared, demanded the using of a filter in front of the detectors to solve this problem.

The IR filter has been designed by INAF and consists of three layers of Spectrosil.

The Optical Cross-Talk (OCT) of a SiPM depends not only on the internal features (i.e trenches) and operating conditions (Over Voltage) but also on the coating and on any optical system that is placed in front of the SiPM itself.

The dependence of OCT on any optical system has led us to investigate how the filter can affect the OCT.

This document illustrates the experimental setup developed to measure the transmittance of the ASTRI filter and the cross-talk variation versus the distance between the filter and the detector.

The achieved results are also presented.

2. Transmittance measurements

In the following paragraphs we briefly describe:

a) the adopted setup based on pulsed LED sources and integrating sphere
b) the utilized pulsed LED sources with the relative central wavelength
c) the designed and realized mechanics to allow precise measurements
d) the adopted procedure to obtain the transmittance measurements

2.1 Adopted setup

We schematized the adopted setup in Figure 1. The apparatus allows transmittance measurements in the 285 - 850 nm spectral range by using 19 pulsed light sources. The wavelength of each source is reported in Table 1 of the paragraph 2.2.

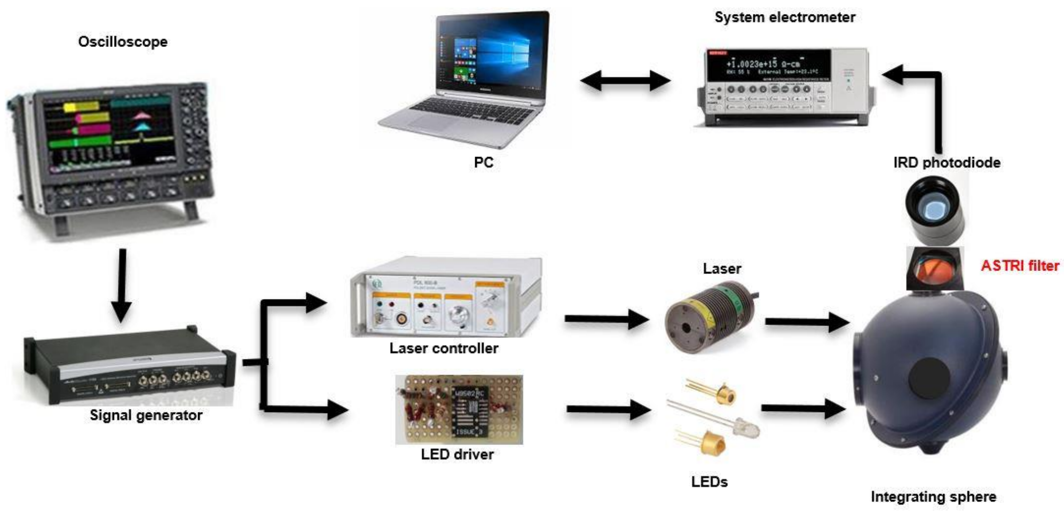


Figure 1. Set-up used for the measurements of the ASTRI IR filter transmittance.

The system is constituted by:

- Power supply Agilent E3631A
  (to supply the voltage levels to the LED driver)
- Electrometer System Keithley 6514
  (to measure the photo-current form the reference detector)
- Calibrated Photodiode IRD NIST traceable
  (to detect the luminous flux inside the integrating sphere)
- Oscilloscope LeCroy wavePro 725Zi 2.5GHz
  (to process synchro signals for the pulsed light source)
- Pulse generator LeCroy ArbStudio 1104
  (to generate synchro signals for the pulsed light source)

- LEDs Driver
  (see ASTRI-TR-OACT-3200-034 section 2.2)
- Pulsed diode laser controller PicoQuant PDL 200-B
  (to drive the lasers)
- Integrating sphere Labsphere
  (to obtain a uniform light flux on detectors surface)
- 3 LASER and 16 LED pulsed sources
  (see Table 1 section 2.1)

2.2 Pulsed light sources

The pulsed light sources available at the COLD lab are in total 19 of which 16 LED sources and 3 Laser sources. Table 1 lists the sources and their respective wavelength:

Table 1 – Lists of pulsed light sources: LED and LASER and their respective wavelength

Identifier code	Wavelength [nm]	Type
LDH-P-C-405	405	Laser
EPL-450	450	Laser
LDH-P-635	635	Laser
LED285W	285	LED
LED315W	315	LED
LED341W	341	LED
LED385L	385	LED
LED430L	430	LED
LED450L	450	LED
LED465E	465	LED
PLS-8-2-746	496	LED
LED505L	505	LED
LED525L	525	LED
LED570L	570	LED
LED591E	591	LED
LED660L	660	LED
LED680L	680	LED
LED780E	780	LED
LED851L	851	LED

2.3 Mechanical supports and filter mounting

Before to performing the measurement of transmittance we have designed and realized through a 3D printer some PLA holders that, on one side, accommodate the filter and allow the interfacing with the integrating sphere and on the other side, permit the interfacing with the calibrated photodiode. Figure 2 shows how looks like the filter mounted on the supports.
It should be noted that the supports have been designed to position the filter at the same distance from the sphere port both in presence and absence of the filter itself to avoid false measurements.

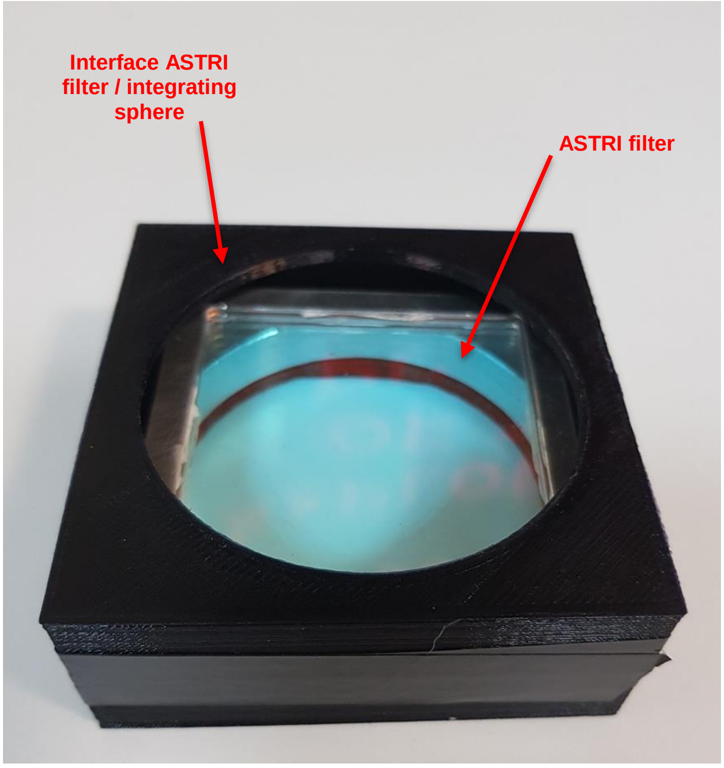


Figure 2. PLA box that accommodate the filter and is able to interface the photodiode from one side and the integrating sphere port from the other side.

Figure 3 shows the whole system mounted on the integrating sphere. It is necessary to consider that in the absence of a filter, the system essentially remains the same and allows the measurement under the same conditions both in presence and absence of the filter.

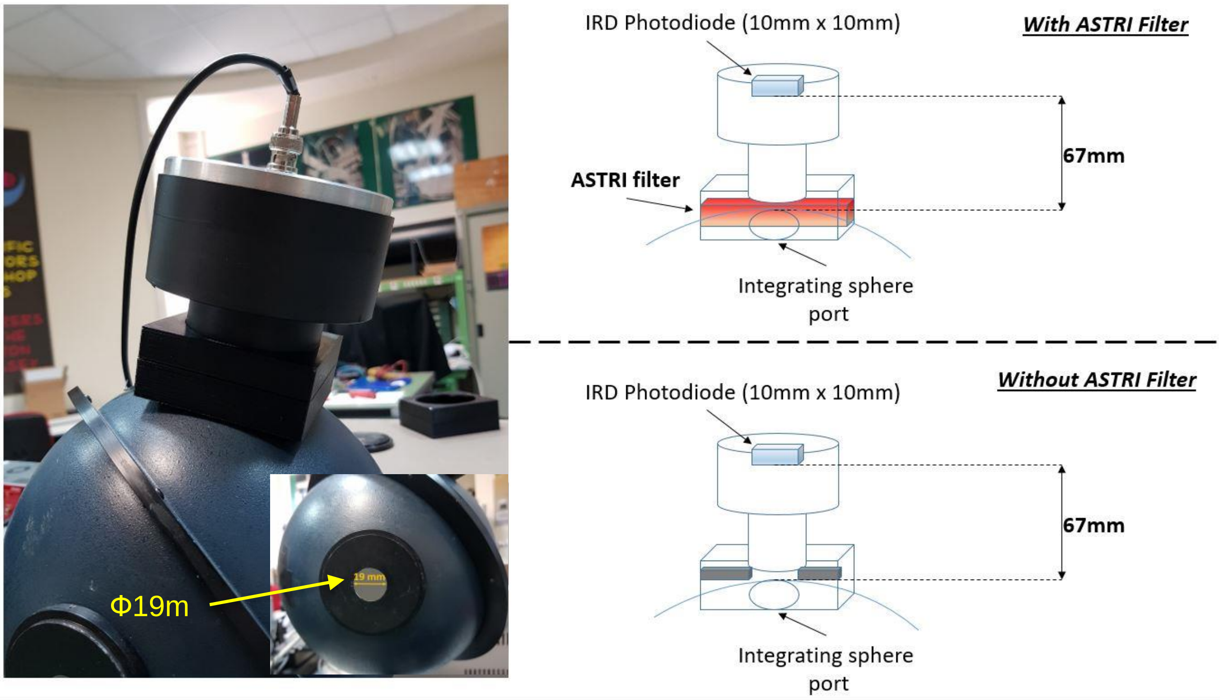


Figure 3. Left: Integrating sphere with the box hosting the filter and with on top the calibrated photodiode. Note the dimension of the diaphragm diameter (19 mm) placed in front each port. Right: Scheme of the transmittance measurements apparatus. Note that the distances between the photodiode and the integrating sphere port are the same with and without the filter.

2.4 Transmittance measurements

The measurements were carried out in an easy way by acquiring the current signal at the IRD photodiode output through the Keithley 6514 electrometer system in two successive phases:

1. with the filter interposed between the integrating sphere and the photodiode
2. removing the filter from the box.

We repeated each single measurement in different light intensity conditions changing both the voltage level and the frequency of the source and alternated the acquisition cycle on a run of 100 measurements of the photocurrent four times with and without the introduction of the ASTRI filter. The standard deviation for each set of measurements resulted less than 1%. The final transmittance value is given by the arithmetic mean of the four measurements.
Figure 4 shows the ASTRI filter transmittance curve as function of the wavelength, while Table 2 shows the result of measurements in terms of measured transmittance.

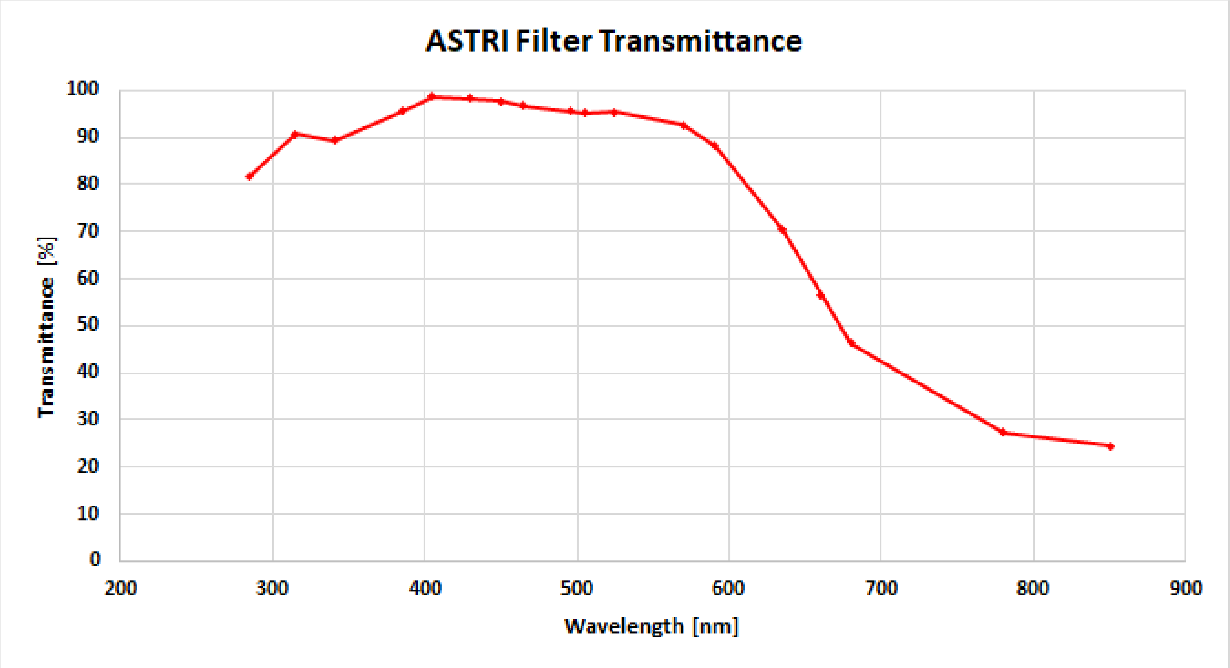


Figure 4. ASTRI IR filter transmittance

Table 2. ASTRI Filter Transmitter value

Wavelength [nm]	Trasmittance [%]
285	81,85
315	90,68
341	89,26
385	95,55
405	98,7
430	98,2
450	97,72
465	96,74
496	95,5
505	95,1
525	95,3
570	92,6
591	88,11
635	70,38
660	56,6
680	46,43
780	27,43
851	24,53

3. Cross-talk versus filter distance from SiPM

As can be easily guessable, the filter, as a reflecting element can introduce an increase of the optical cross-talk (OCT) due to reflection of the photons on its surface. And this could also be function of filter distance from SiPM because at certain distance the reflection could be negligible. So we investigated the effect of the distance of the filter from the focal plane detection modules on the OCT.

From Figure 5, provided by the mechanical design engineer of the ASTRI camera, it can be seen how the SiPM distance to the filter reaches its minimum of 1.5 mm in the central part of the focal plane. The SiPM layout on the focal plane therefore suggests to make OCT measurements depending on the SiPM distance from the filter.

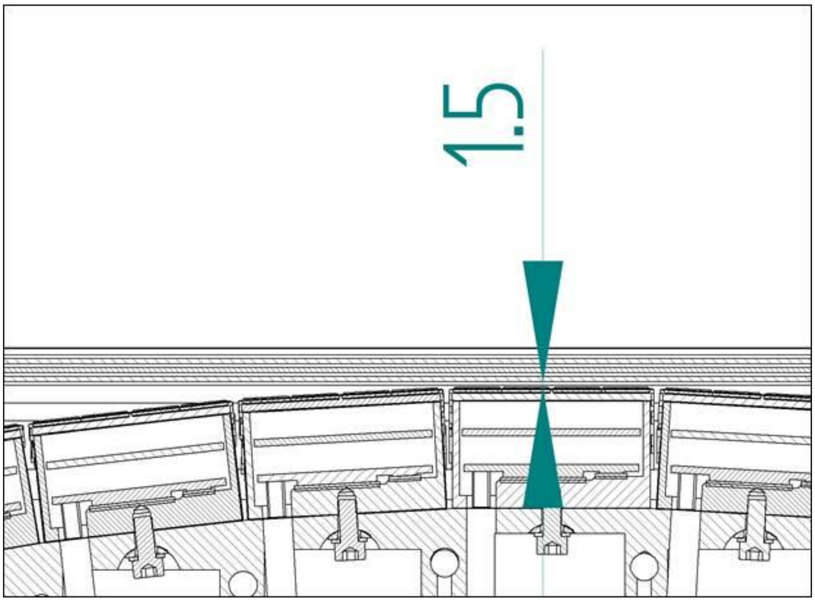


Figure 5. Minimum distance between extrados and intrados of the first sheet of Spectrosil

Furthermore, can also imagine the smaller the distance, the greater OCT. Also we can predict that there will be a condition at which the distance will no longer affect the OCT.

3.1 SiPMs used for the OCT measurements

The detectors selected for OCT measurements were four, two of 3x3 mm^2 (CS and CN type) and two of 6x6 mm^2 (CS and CN type):

- LVR2 3050 CS and CN 3x3mm^2
- LVR2 6050 CS and CN 6x6mm^2

The CS and CN marks identify respectively the presence and absence of the protective silicone coating on the surface of the SiPM. (See report ASTRI-TR-OACT-3200-034).

In this way we can determine and compare the OCT depending on the size and the type of coating.

3.2 Mechanics

Through other supports and spacers designed and created by our 3D printer, we modulated the detector's distance from the filter surface.

Figure 6 shows the boxes and all the realized supports to achieve the measurements.

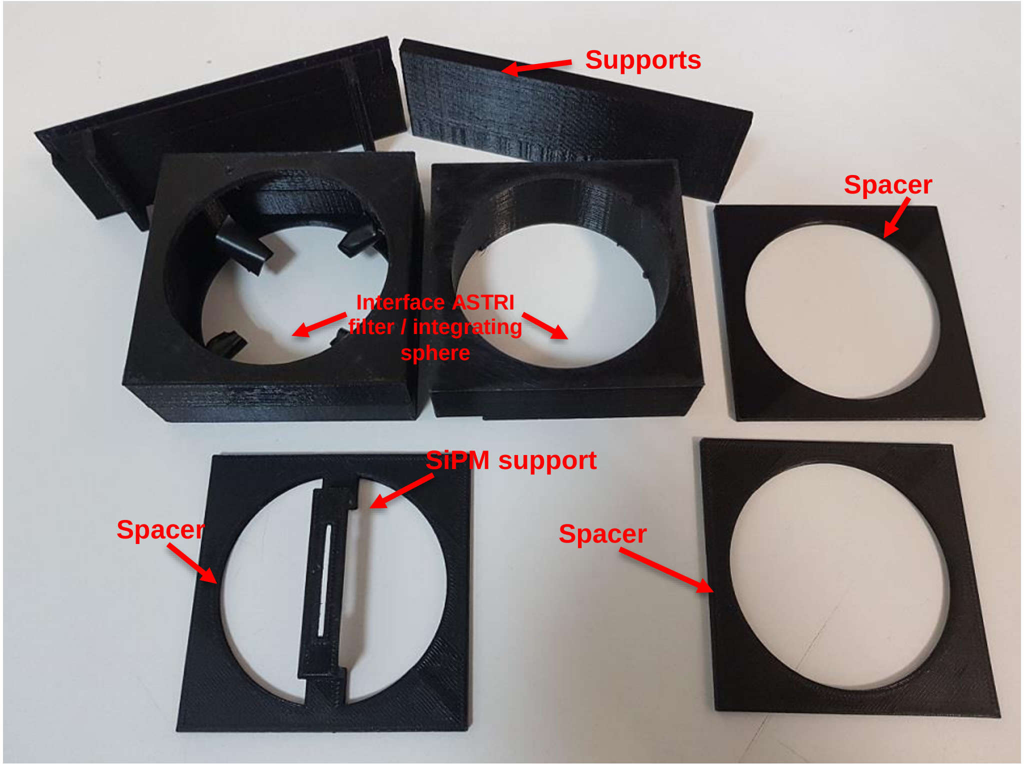


Figure 6. Supports, spacers and slots created with the 3D printer

As can be noted from the figure we also deigned a SiPM support to maintain stable and fixed the detector basement. The SiPM has been positioned and constrained to be coplanar to the filter surface as can be seen in Figure 7.

By using all possible combination of the various supports we can vary the distance of the filter from the detector and obtain the following conditions:

- Filter Absence (native OCT)
- Filter 1mm away from detector
- Filter 4 mm away from detector
- Filter 7 mm away from detector

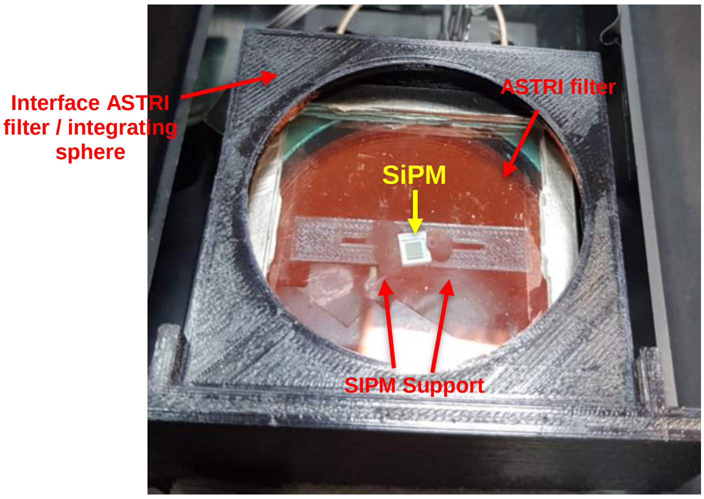


Figure 7. Locating the detector under the surface of the ASTRI filter.

3.3 OCT measurements

First case: OCT versus overvoltage measurements in absence of filter.

Figure 8 shows the cross-talk trend at different overvoltage values for the 3x3mm^2 SiPMs both CS and CN without the ASTRI filter.

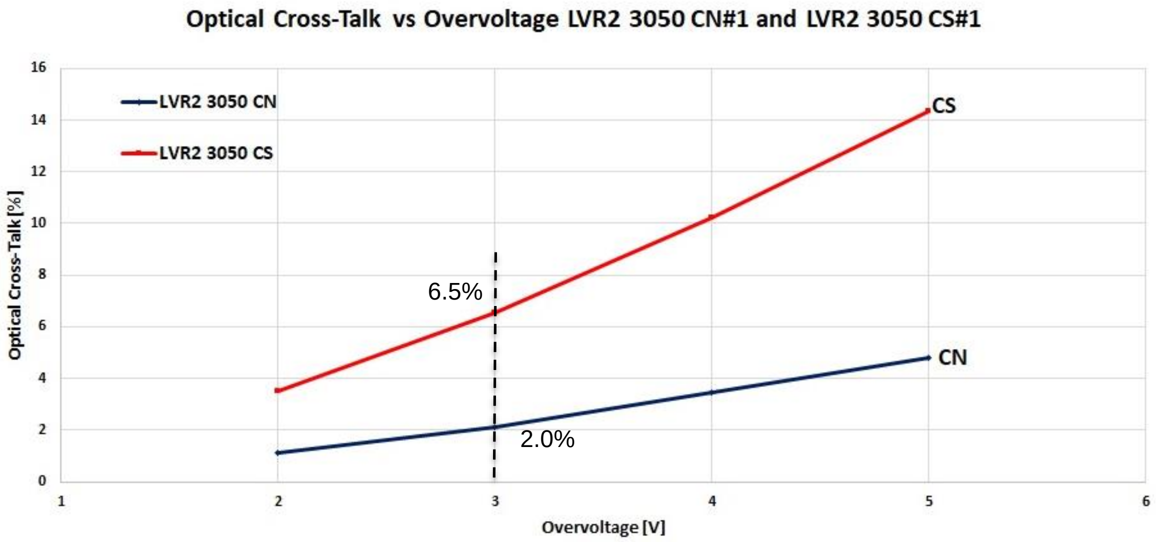


Figure 8. Optical Cross-Talk vs Overvoltage for 3x3mm^2 CS (Silicone Coating) and CN (No Coating) SiPM without ASTRI filter.

In this case, at an overvoltage of 3V, the OCT assumes 2% values for SiPM LVR2 3050 CN and 6.5% for that CS.

Figure 9 shows the cross-talk trend at different overvoltage values for the 6x6mm^2 SiPMs both CS and CN without the ASTRI filter

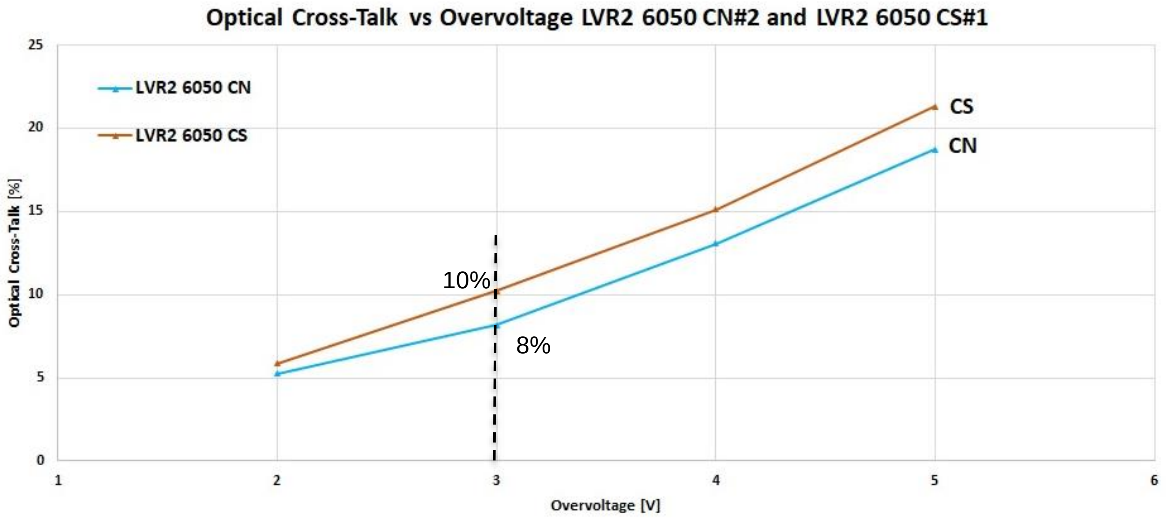


Figure 9. Optical Cross-Talk vs Overvoltage for 6x6mm^2 CS (Silicone Coating) and CN (No Coating) SiPM without ASTRI filter.

In this case, at an overvoltage of 3V, the OCT is 8% for SiPM LVR2 6050 CN and 10% for that CS.

Thus, as expected, the OCT depends on the SiPM area. The difference in OCT is more evident in the case of the CN device, in fact in this case a 6% of difference is observed.

Furthermore, we have to consider that for larger than 3x3mm^2 devices we have to cool down the operating temperature to avoid the pile-up effect due to the higher DCR.

Figures 10 and 11 show, conversely, the OCT versus overvoltage for the LVR2 3050 CN and CS SiPMs by placing the filter at different distances (as above mentioned: 1mm, 4mm and 7mm away from detector). For comparison we also include the plot in the absence of the filter.

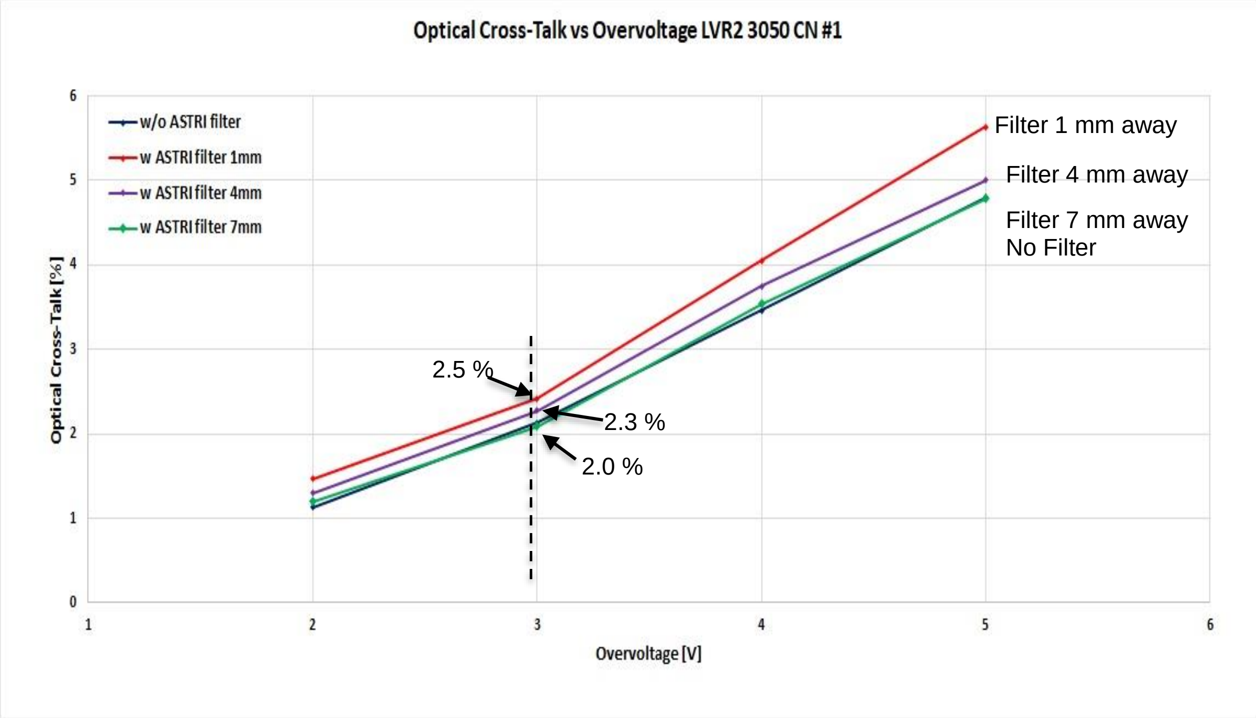


*Figure 10. Optical Cross-Talk versus overvoltage for 3x3mm² **CN** (**No Coating**) SiPM with no filter and with the filter at different distances from ASTRI filter. As can be seen, when the filter is at 1 mm from the SiPM the OCT rises of 0.5%. While at distances in the range of 1 to 7 mm the OCT assumes values in the range 2.5% to 2.0%.*

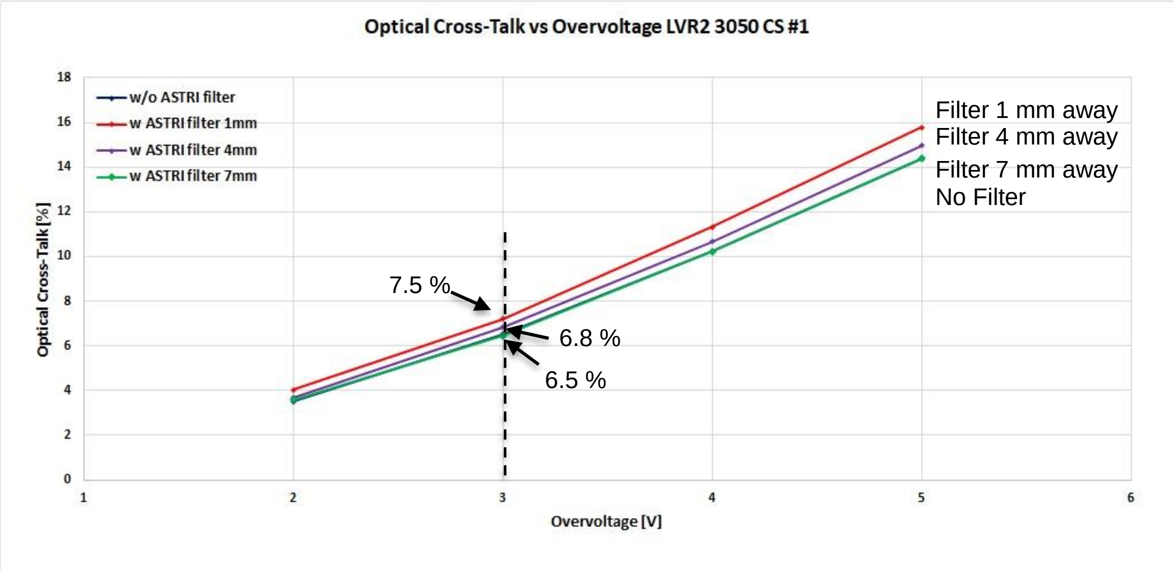


*Figure 11. Optical Cross-Talk vs Overvoltage for 3x3mm² **CS** (**Silicone Coating**) SiPM at various distance from ASTRI filter. As can be seen, when the filter is at 1 mm from the SiPM the OCT rises of 1.0%., from 6.5% to 7.5% While at distances in the range of 1 to 7 mm the OCT assumes values in the range 7.5% to 6.5%.*

From the plots it is evident that the OCT decreases with increasing distance between the filter and the SiPM. At distances greater than 7mm the filter effect is negligible on the increase of OCT. In particular, the measurement carried out at a distance of 1mm shows for the detector LVR2 3050 **CN** at an overvoltage of 3V an OCT of about **2.5%,** while an OCT of 2.0% is achieved without filter; whereas for the detector LVR2 3050 **CS** the OCT value is higher (about 5% greater) than that of the **CN** type, and rises from 6.5% (without filter or at distance greater than 7 mm), to **7.5%** at distance of about 1 mm.

As demonstrated in [ASTRI-TR-OACT-3200-034] SiPM devices larger than 3x3mm^2, have greater OCT. Furthermore, if any kind of optics is placed in their front, OCT unavoidably rises. We measured the OCT for the two devices of 6x6mm^2 LVR2 6050 CS e CN in the same conditions as the other detectors. The results are showed in Figure 12, as expected, the presence of the filter increases the OCT, and the increase is directly proportional to the proximity of the filter to the detector. We measured for the **CN type** an OCT of:

- 8.0% without filter or at distances greater or equal than 7mm
- 9.2%. at distance of 1 mm

while for the **CS type** the OCT we have:

- 10.0% without filter or at distances greater or equal than 7mm
- 11.0% at distance of 1 mm

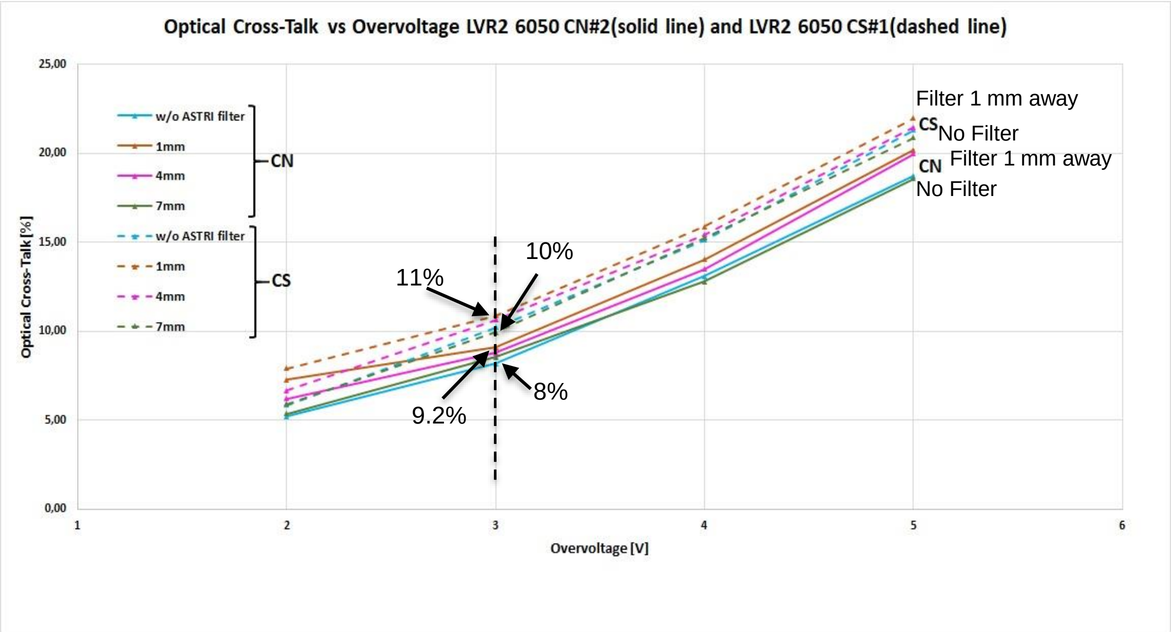


*Figure 12. Optical Cross-Talk vs Overvoltage for 6x6mm^2 **CS** (Silicone Coating) and **CN** (No Coating) SiPM at various distances of the detector from the ASTRI filter. As can be seen, for the **CN** type the OCT rises from 8.0% without filter (or at distances greater or equal than 7 mm) to 9.2%., at a distance of 1 mm while for the **CS** type the OCT rises from 10.0% without filter (or at distances greater or equal than 7 mm) to 11.0% at a distance of 1 mm.*

4. Conclusions

Here we demonstrated that the experimental setup developed to measure the transmittance of the ASTRI filter works well and is able to measure the transmittance through an integrating sphere that guarantees uniformity of illumination. The same setup with some mechanical variant allows the measurement of SiPM optical cross-talk variation with the distance between the filter and the detector itself.

We measured the variation of OCT due to the ASTRI IR filter placed at three different positions: 1 mm, 4 mm and 7 mm.

The detectors tested were Hamamatsu single pixel LVR2 type: two small (3x3 mm^2) Silicone coated (CS) and uncoated (NC) and two larger (6x6 mm^2) one CS and the other CN.

The results confirmed that:

- coated devices (CS) show higher OCT than those uncoated (CN) in fact, for example, at 3V of overvoltage the **OCT** for the 6x6mm^2 **CS type** is **10%** while for the **CN type** is **8%**
- larger pixels show higher OCT than smaller pixels, in fact at 3V of overvoltage the **OCT** for the **6x6mm^2 CS type** is **10%** while for the **3x3mm^2 CS type** is **6.5%**

and more that:

- the presence of the filter increases the OCT, and the increase is directly proportional to the proximity of the filter to the detector, in fact for the we found that the **6x6mm^2 CS type** shows an **OCT** of **10% without** filter, and an OCT of **11%** with the filter at **1mm away** from the detector
- by placing the filter from the SiPM at distances **greater** or equal to **7 mm**, the OCT becomes unaffected by the presence of the filter itself.

In the worst case, when the filter is placed at 1 mm away from the sensor we have to consider a deterioration in OCT of about 1% in both large CS and CN type devices and small CS and CN devices.

All files related to the experimental measurements presented in this report, are located in the database on the PC-LAB (COLD) site Astrophysical Observatory of Catania, path C:\Users\CCDLab1\Desktop\Romeo\Misure

5. CONTACTS

The team working on the electronic design of the ASTRI camera is composed by people from INAF's Catania Astrophysical Observatory and Palermo IASF. It is also referred to as the Electronics Camera Team.

Giovanni Bonanno	giovanni.bonanno@oact.inaf.it	OACT Catania
Giuseppe Romeo	giuseppe.romeo@oact.inaf.it	OACT Catania
Alessandro Grillo	alessandro.grillo@oact.inaf.it	OACT Catania
Salvatore Garozzo	sgarozzo@oact.inaf.it	OACT Catania
Davide Marano	dmarano@oact.inaf.it	OACT Catania
Osvaldo Catalano	osvaldo.catalano@iasf-palermo.inaf.it	IFC Palermo
Giovanni La Rosa	larosa@ifc.inaf.it	IFC Palermo
Giuseppe Sottile	sottile@ifc.inaf.it	IFC Palermo
Salvatore Giarrusso	jerry@ifc.inaf.it	IFC Palermo
Domenico Impiombato	domenico.impiombato@ifc.inaf.it	IFC Palermo