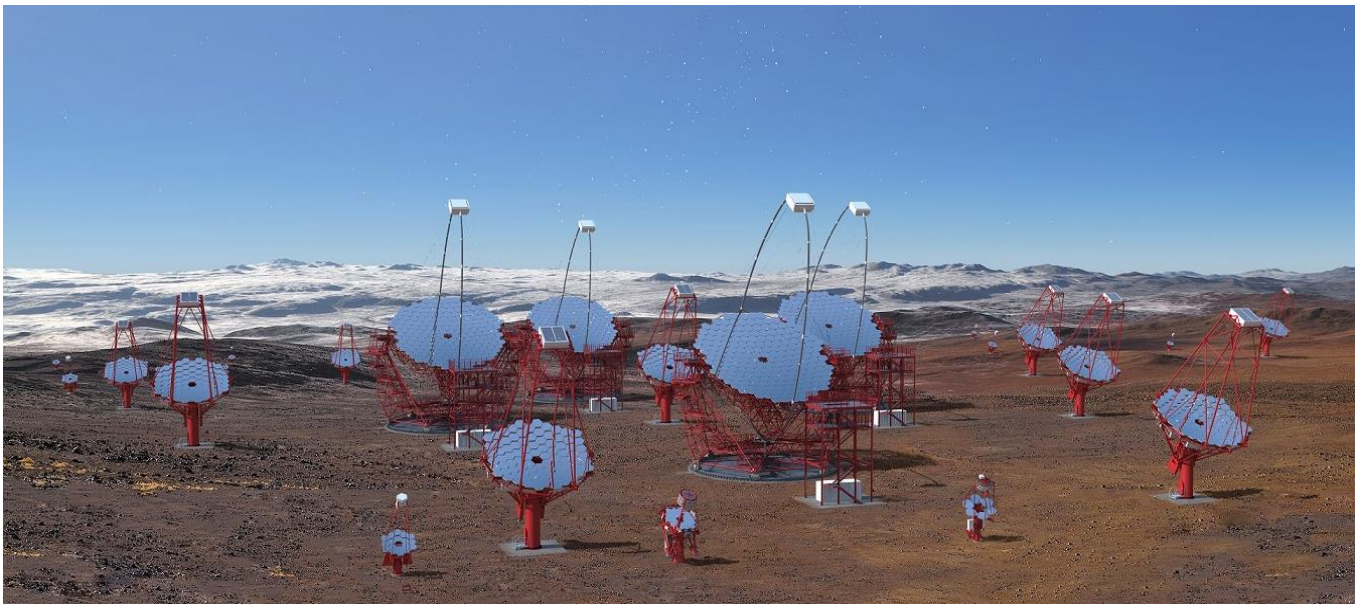
Characterization of the Hamamatsu MPPC LVR2 7075 CS, LVR2 7075 CN and LVR3 3050 CN



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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 Reverse
LVR2	Low Voltage Reverse 2nd Version
LVR3	Low Voltage Reverse 3rd Version
PHD	Pulse Height Distribution
HPK	Hamamatsu Photonics K.K.
OV	Over Voltage
PZC	Pole-Zero Cancellation

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1. INTRODUCTION

The SiPMs recently manufactured by HPK of which we carried out the characterization presented in this report, represent a very big progress to optimize the performance. In fact, the HPK succeeded in manufacturing 7x7 mm^2 with 75µm microcell devices preserving them from high DCR. Thanks to the higher fill factor, the 7075 series has higher PDE respect to the 7050 series.

Furthermore, the HPK made an effort to improve the SiPM response in the 300 – 350 nm spectral range. They produced another series named LVR3 that takes into account the improvement. We received from HPK only a 3x3mm^2 with 50µm microcell LVR3 with no coating (LVR3 3050 CN). We measured the PDE of this device and compared with the LVR2 device (same dimensions and microcell).

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2. Characterized devices: LVR2 7075 CS, LVR2 7075 CN and LVR3 3050 CN

The characterized SiPMs are:

- a 7x7 mm^2 with 75µm microcells of the LVR2 series Silicone Coated named LVR2 7075 CS
- a 7x7 mm^2 with 75µm microcells of the LVR2 series No Coated named LVR2 7075 CN
- a 3x3 mm^2 with 50µm microcells of the LVR3 series No Coated named LVR3 3050 CN

Table 1 lists the SiPMs with the relevant characteristics.

Figure 1 depicts the three characterized devices. The uncoated chip is quite simple to recognize.

Table 1

Type	Size [mm^2]	Pitch Size [µm]	Coating
LVR2 7075 CS	7x7	75	Silicone Coating
LVR2 7075 CN	7x7	75	No Coating
LVR3 3050 CN	3x3	50	No Coating

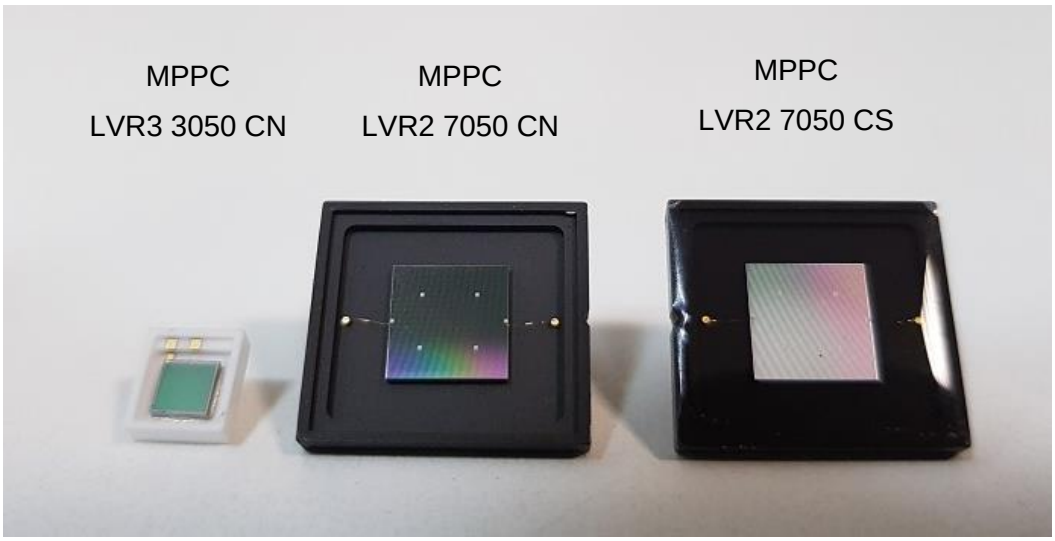

Figure 1. Picture of the three characterized SiPMs.

Form the picture is clear evident that the large central SiPM is uncoated. Instead this is less evident for the small device that is also uncoated. In the large device can be noted as the bonding wires are un protected.

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3. Optical Cross-Talk measurements

3.1 OCT dependency from DCR: pile-up effect

As explained in the report ASTRI-TR-OACT-3200-034, OCT depends on the DCR of the device that means on the operating temperature because the problem of the pile-up when the DCR is high. In this case the ratio of the counts to 1.5 pe compared to 0.5 pe is distorted because many single pe may assume levels close to or greater than 1.5 pe. For this reason, we first evaluated the OCT as a function of the temperature of the LVR2 7075 CN as all non-coating devices are characterized by a smaller OCT respect to the CS type.

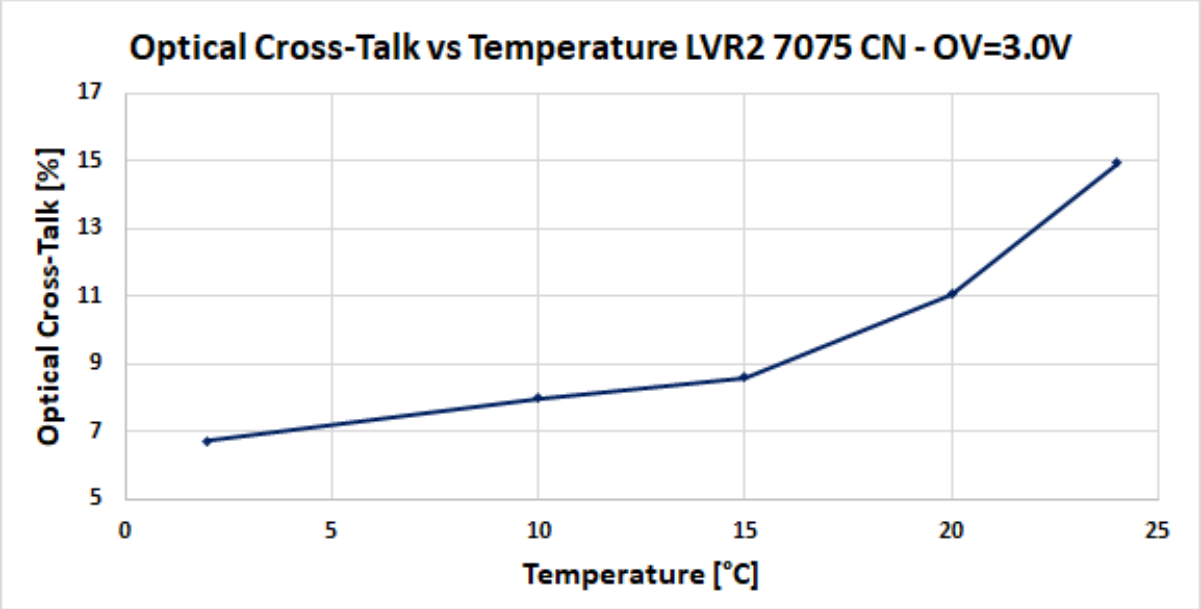

Figure 2. Optical Cross Talk at an Overvoltage of 3V versus the operating temperature for the LVR2 7075 CN MPPC.

As seen in Figure 2, the OCT from 15% at 25°C is reduced to about 7% at a temperature of 2°C. Therefore, to have a lower value of OCT, it would be necessary to operate the SiPM at temperatures lower than 5°C.

The same measurements have been done on the CS type. The result is shown in Figure 3.

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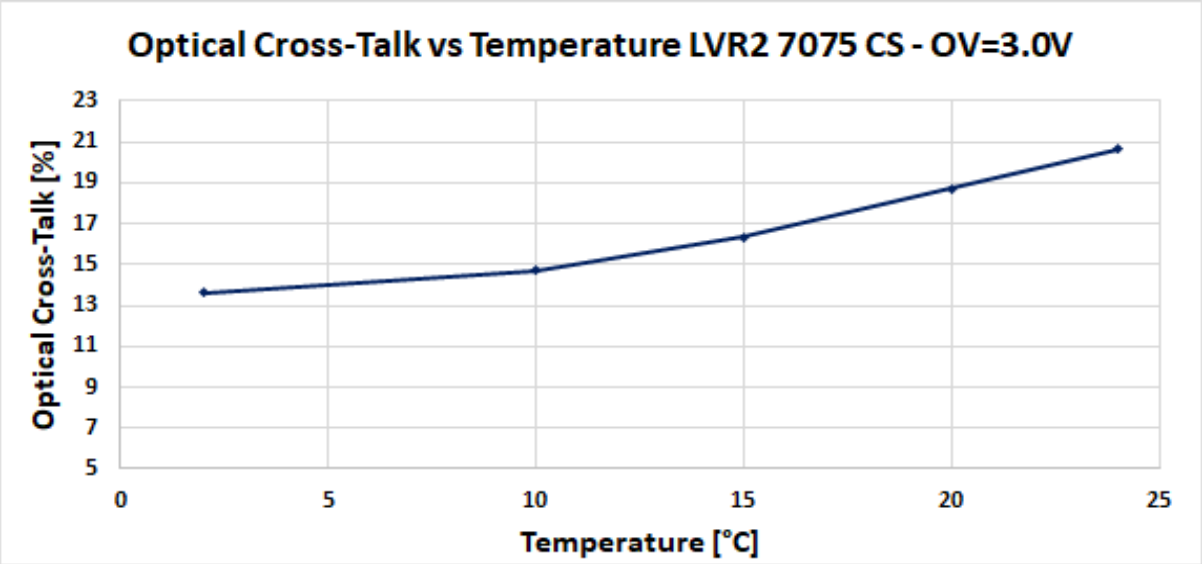

Figure 3. Optical Cross Talk at an Overvoltage of 3V versus the operating temperature for the LVR2 7075 CS MPPC

As can be seen, and as expected, the CS type shows a higher OCT respect to the CN due to the protective coating on top the sensitive surface. The OCT measured for this device is about 20% at 25°C and decreases at about 14% at a temperature of 2°C.

3.2 OCT versus Overvoltage in LVR2 7075 CS and CN

Since the operating temperature of the ASTRI camera is 15°C we have measured the OCT versus OV at both 2°C and 15°C. Figure 4 shows the comparison between the two plots.

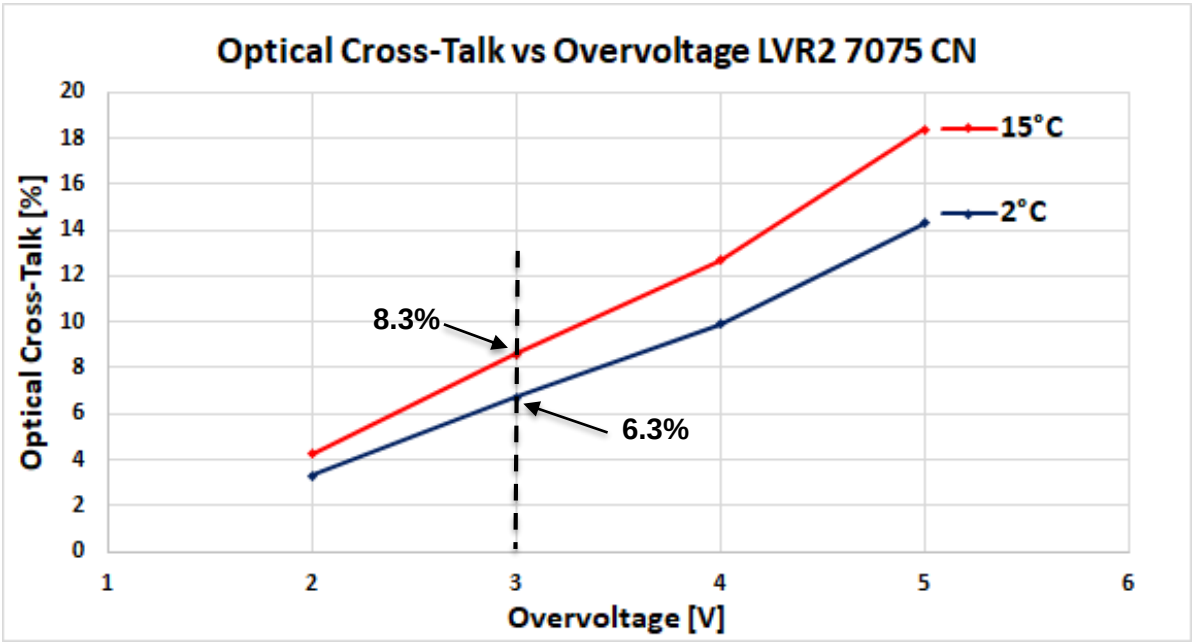

Figure 4. Optical Cross Talk versus Overvoltage for the CN type MPPC. As can be noted a difference of about 2% is obtained at 3V of OV and a slightly more at 4V of OV.

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Figure 4 shows a difference in OCT between the two operating temperatures. In particular, the difference is about 2% at 3V of OV and increases to about 4% at 5V OV. At 15°C and 3V of OV, the device has an OCT of about 8.3%, while at 2°C the OCT is around 6.3%.

Also for the CS device, the OCT values at the two temperatures have a difference between 2% and 3%. In Figure 5 are showed the results. In particular, at 3V OV and 15°C, the device has an OCT of 16% while at 2°C the OCT lowers at 14%.

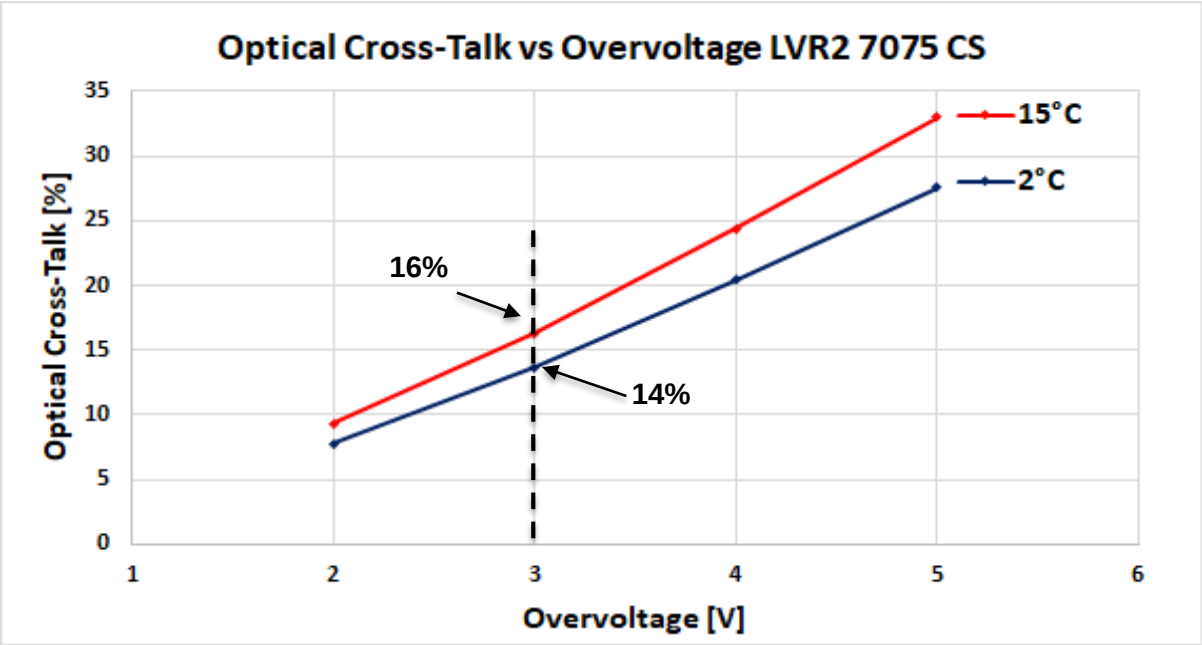

Figure 5. Optical Cross Talk versus Overvoltage for the CS type MPPC. As can be noted a difference of about 2% is obtained at 3V of OV and a slightly more at 4V of OV.

The OCT measurements of the two type of devices are compared in graph of Figure 6

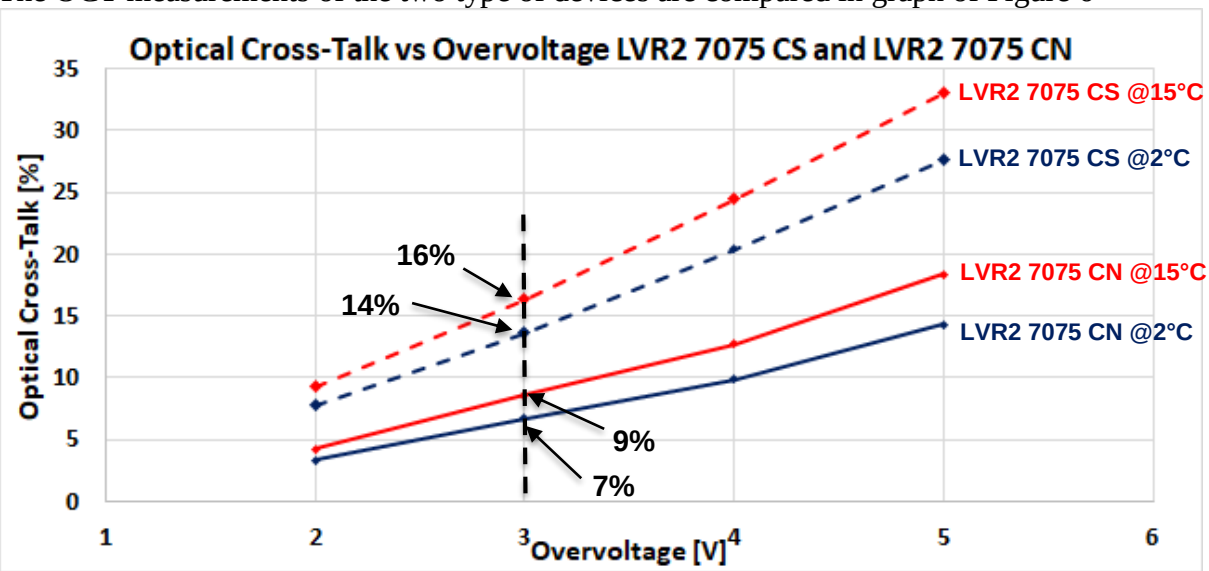

Figure 6. Optical Cross Talk versus Overvoltage comparison between the CS and the CN type MPPCs.

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3.3 OCT versus Overvoltage in 3050 CN LVR3 and LVR2

We measured the OCT also for the 3x3 mm^2 LVR3 3050 CN MPPC and compared it with that obtained for the 3x3 mm^2 same technology and same microcell LVR2 3050 CN. In this case the operating temperature doesn't affect the OCT because the DCR is relatively low and the pile-up is negligible. We operated the devices at about 20°C.
Figure 7 shows the OCT versus OV for the LVR2 3050 CN MPPC. As can be noted an OCT of about 2% is obtained at 3V of OV.

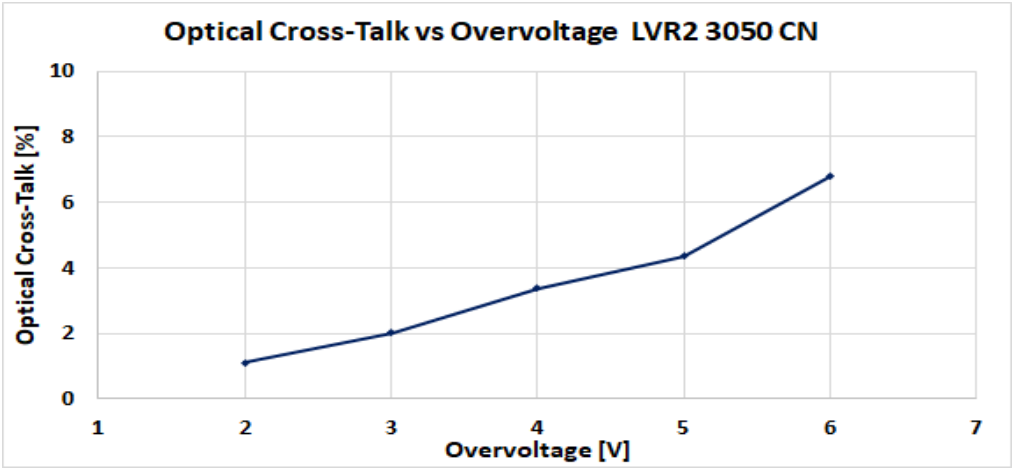

Figure 7. Optical Cross Talk versus Overvoltage for the LVR2 3050 CN MPPC. As can be noted an OCT of about 2% is obtained at 3V of OV.

Figure 8 instead, depicts the OCT versus OV for the LVR3 3050 CN MPPC. In this case, an OCT of about 3% is obtained at 3V of OV, meaning that the LVR3 technology has worsened of about 1% the OCT respect to the LVR2 technology.

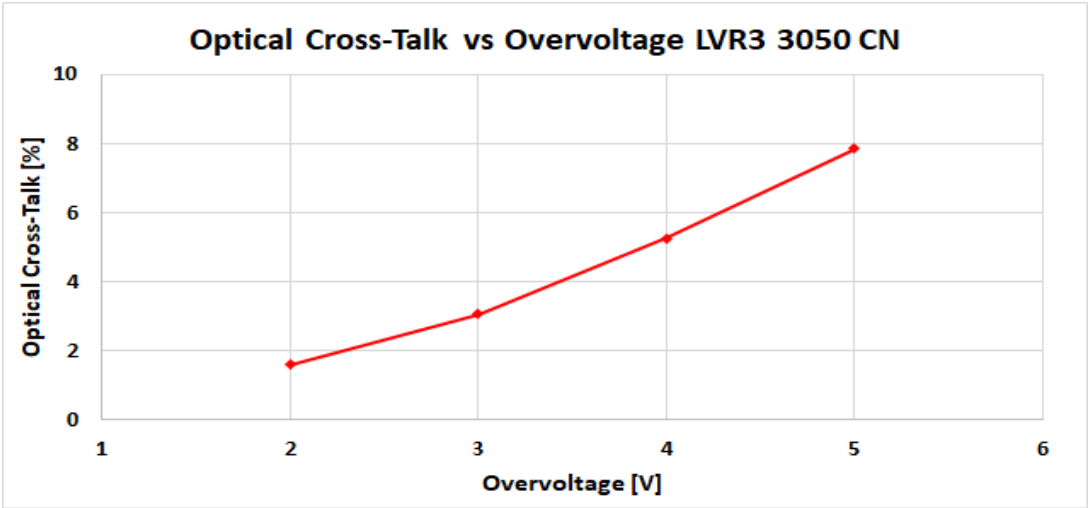

Figure 8. Optical Cross Talk versus Overvoltage for the LVR3 3050 CN MPPC. As can be noted an OCT of about 3% is obtained at 3V of OV.

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Figure 9 shows the comparison of OCT versus OV for both devices LVR2 3050 CN and LVR3 3050 CN. This comparison not only highlights an increase of 1% at 3V of OV, but also that the difference in OCT rises with the OV. In fact, at 5V of OV the LVR2 shows an OCT lower than 4% while the LVR3 an OCT of about 8%. At 4V of OV the OCT is 5.2%.

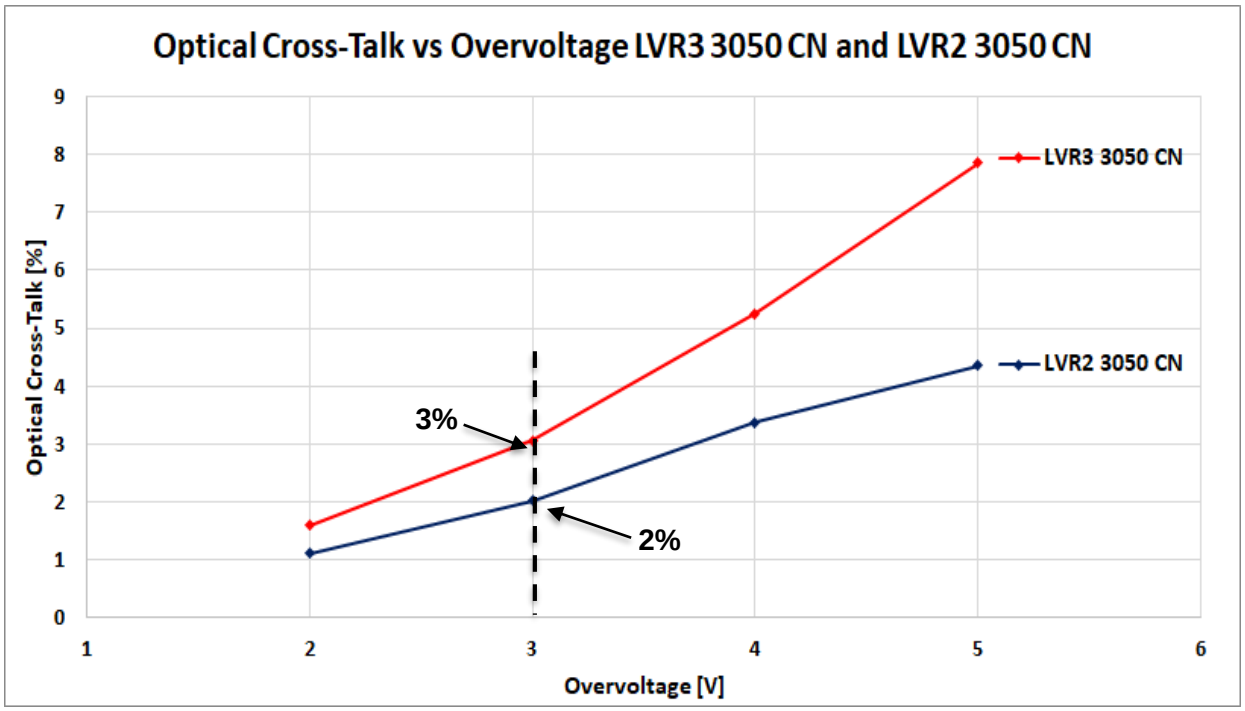

Figure 9. OCT versus OV comparison for both devices LVR2 3050 CN and LVR3 3050 CN. This comparison not only highlights an increase of 1% at 3V of OV, but also that the difference in OCT rises with the OV. In fact.at 5V of OV the LVR3 shows an OCT of about 8%, and at 4V of OV the OCT is 5.2%.

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4. PDE @ 405nm versus Overvoltage of LVR2 devices measurements

In this section we describe the results obtained on the PDE measurements carried out at our laboratory by using the method described in the report ASTRI-TR-OACT-3200-034.

We essentially measure the PDE at 405nm by varying the overvoltage from 2V to 5V in steps of 1V, and the PDE in the 280-850 nm spectral range operating each SiPM at 3V of overvoltage.

4.1 PDE versus OV of LVR2 7075 CN and CS series

Figure 10 shows the PDE at 405nm versus Overvoltage obtained for the LVR2 7075 CN and CS.

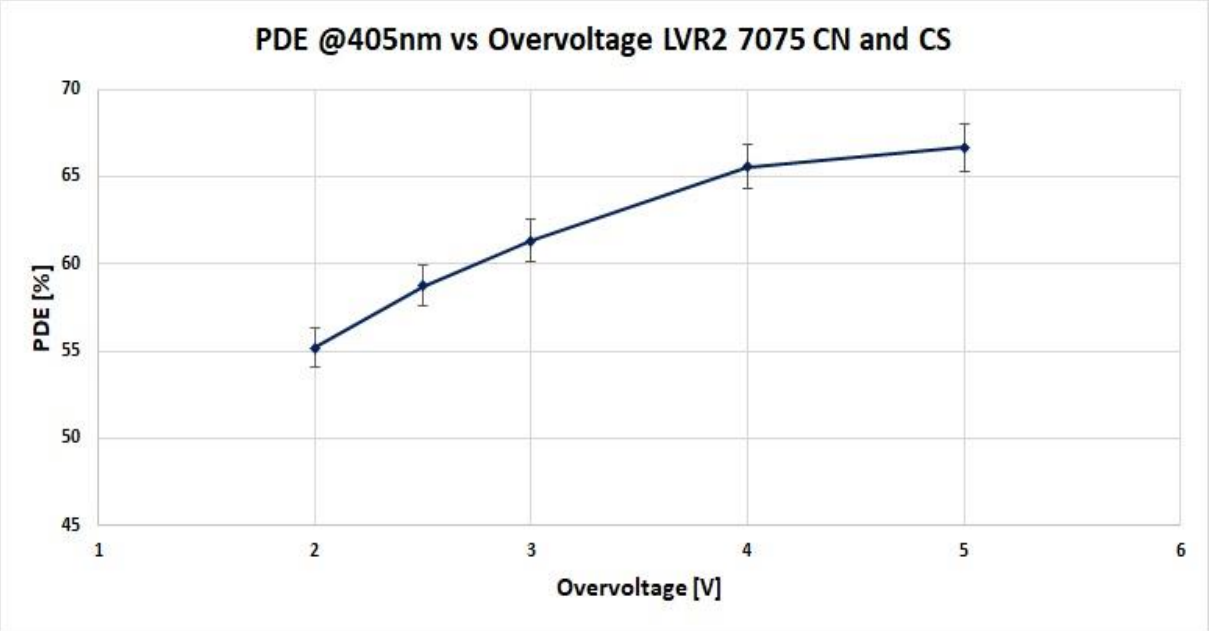

Figure 10. PDE at 405nm versus Overvoltage obtained for the LVR2 ***7075*** *CN and CS.*

The device shows an impressive PDE greater than 60% at 3V of OV and almost saturates to 67% at 5V of overvoltage. Very interesting is the PDE value of 66% at 4V of overvoltage where the OCT is reasonably low for the CTA application.

4.2 PDE versus OV of LVR2 7050 CN and CS series

Figure 11 depicts the PDE at 405nm versus Overvoltage obtained for the LVR2 7055 CN and CS. In this case, due to the lower fill factor respect to the 7075, the PDE is lower.

This device has a PDE around 48% at 3V of OV and almost saturates to 54% at 5V of overvoltage.

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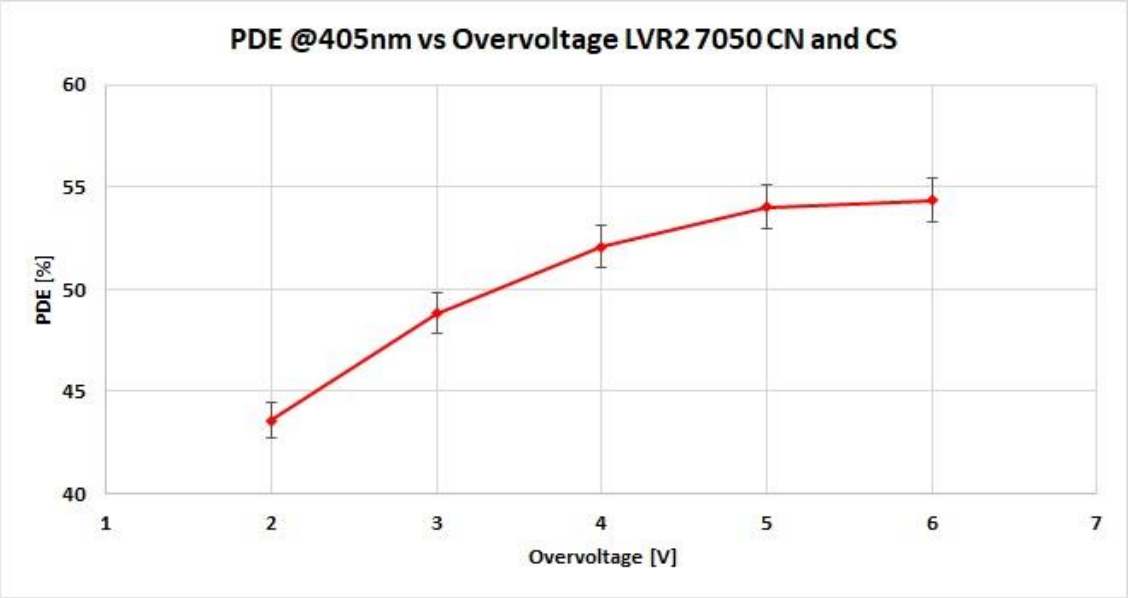

Figure 11. PDE at 405nm versus Overvoltage obtained for the LVR2 ***7050*** *CN and CS*

4.2 PDE @405nm at various OV: comparison between LVR2 7075 and 7050

Figure 12 shows the comparison in trend of PDE at 405 nm versus for 75µm and 50µm microcell MPPCs. The LVR2 7075 MPPC reaches the PDE saturation of about 67% at 5V of OV, while the LVR2 7050 MPPC reaches the PDE saturation of 48% at the same overvoltage.

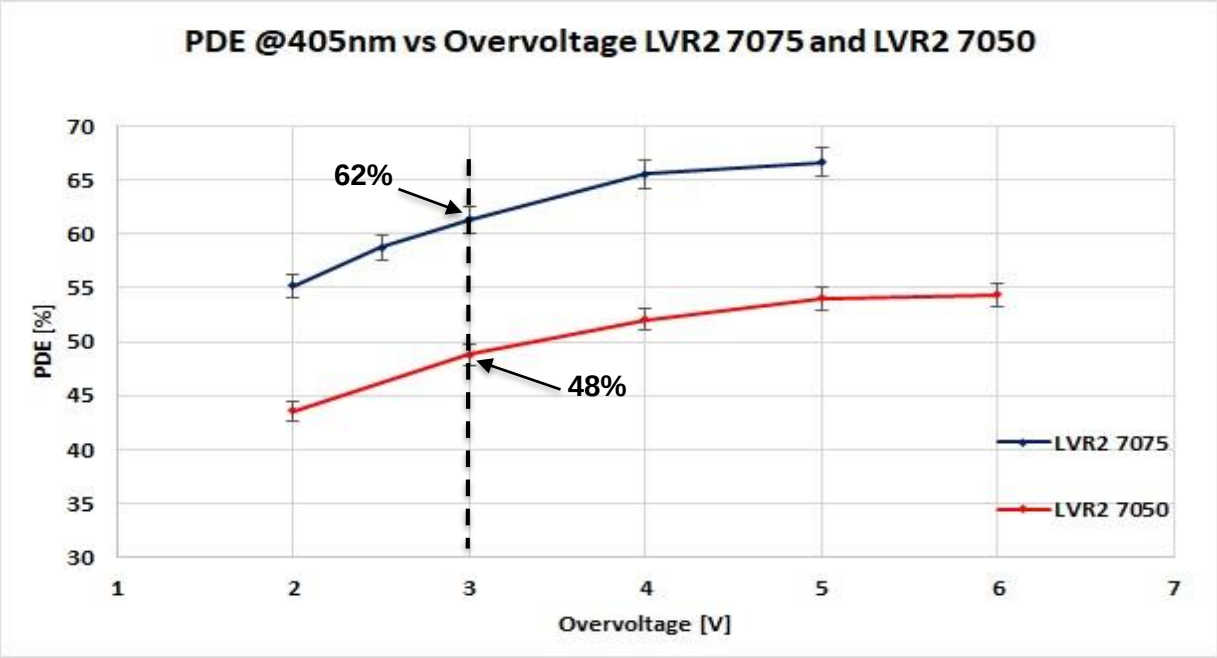

Figure 12. PDE at 405nm versus Overvoltage comparison between LVR2 ***7075*** *and LVR2* ***7050***

The figure 12 clearly shows as at all OV the PDE of the LVR2 7075 is about 10% greater than that of the LVR2 7050 at all the overvoltage in the 2 - 6 V range.

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5. PDE vs wavelength in the range 280nm – 850nm

The PDE measurements in the 285 ÷ 850 nm spectral range has been obtained by using a set of lasers and LEDs available at our laboratory and using the method described in the report ASTRI-TR-OACT-3200-034.

5.1 PDE vs wavelength at 3V of OV of the LVR2 7050 CS and CN

PDE versus wavelength in the 285 ÷ 850 nm spectral range at 3V of overvoltage of the LVR2 **7050** CS and CN is reported in figure13.

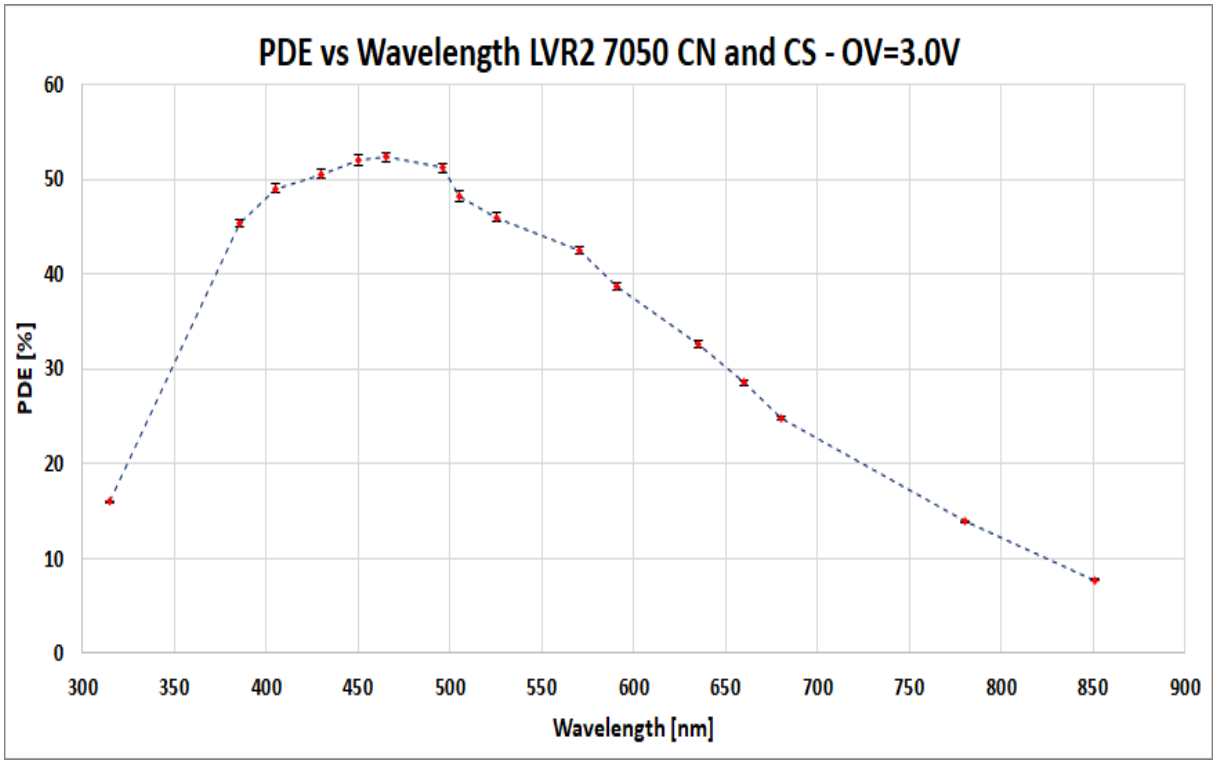

*Figure 13. PDE versus wavelength in the 280 ÷ 850 nm spectral range at 3V of overvoltage of the LVR2 **7050** CS and CN.*

As the figure clearly show the PDE of the LVR2 **7050** peaks at about 50% in the 400 ÷ 500 nm spectral range, while in the near UV region, we observe a PDE of about 15% at 280 nm.

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5.2 PDE vs wavelength at 3V and 4V of OV of the LVR2 7075 CS and CN

PDE versus wavelength in the 285 ÷ 850 nm spectral range at 3V and at 4V of overvoltage of the LVR2 7075 CS and CN are shown in Figure14.

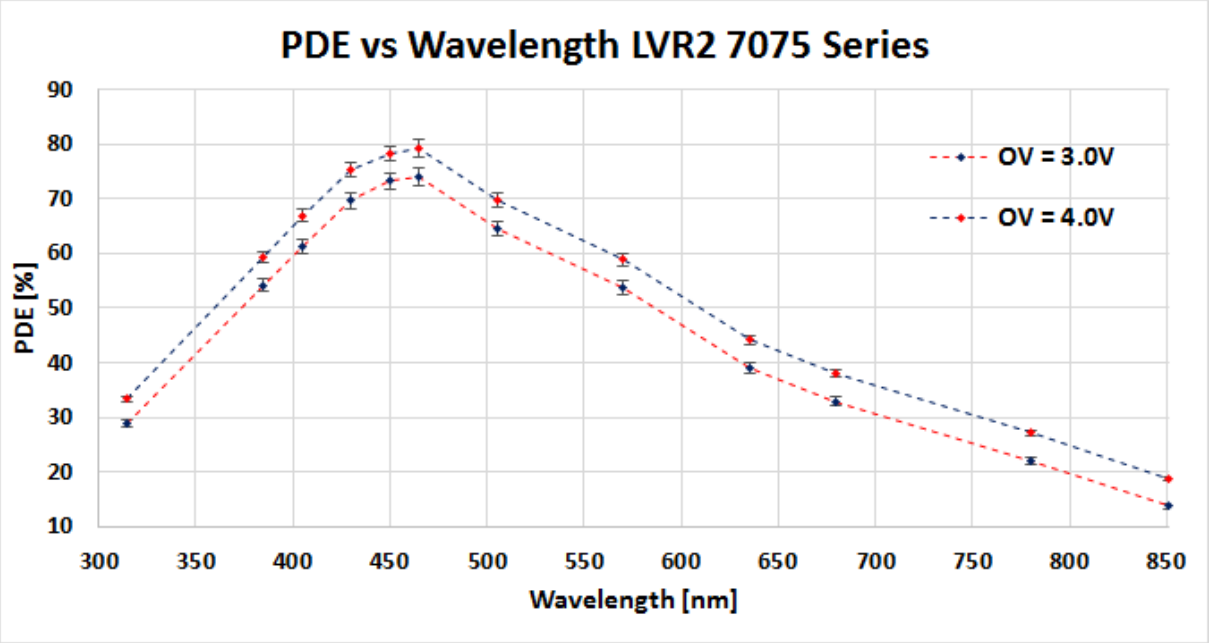

Figure 14. PDE versus wavelength in the 280 ÷ 850 nm spectral range at 3V and at 4V of overvoltage of the LVR2 ***7075*** *CS and CN. At 3V of OV a* ***75%*** *of PDE is observed at wavelengths ranging from 460nm to 470nm and at 4V of OV, where a reasonable OCT is achieved, the PDE rises to about* ***80%****.*

The PDE of the LVR2 **7075** in the case of 3V of overvoltage peaks at about **75%** in a shorter range 450 ÷ 470 nm, in the case of 4V of overvoltage, where a reasonable OCT is achieved, a peak of about **80%** (newer measured before now in any SiPM) is observed.

In the near UV region, we observe a PDE of about 28% at 280 nm.

The comparison reported in the next subsection will better emphasize the result of measurements and demonstrate the unicity of this kind of SiPM.

Thus we can conclude that HPK finally succeeded in obtaining 7x7 mm^2 with very high PDE and acceptable OCT.

This puts the basis for having a very suitable 7x7 mm^2 SiPM for the SST dual mirror telescope of the CTA project.

5.3 PDE vs wavelength: comparison between LVR2 7075 and 7050

The comparison between **7050** and **7075** is reported in Figure 15. An impressive PDE at a peak is observed either at 3V either at 4V of overvoltage.

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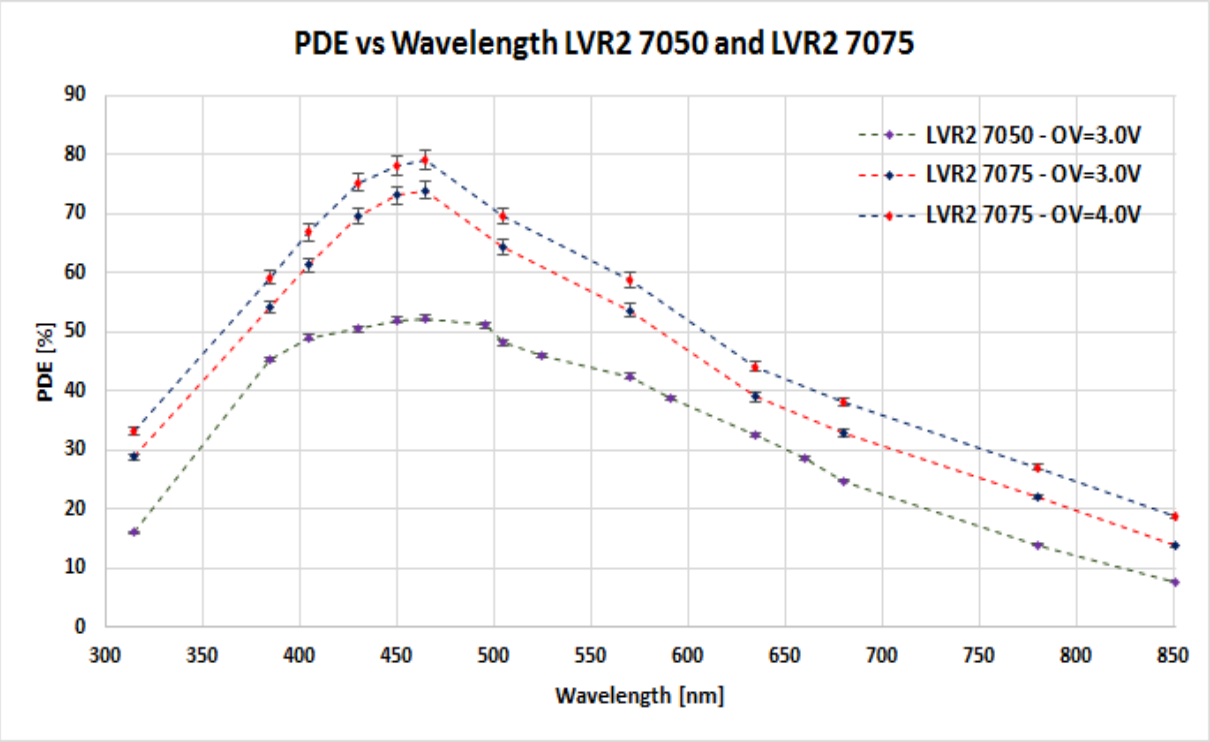

Figure 15. Comparison between LVR2 ***7050*** *and LVR2* ***7075****. A PDE peak of about 75% is observed at 3V while at 4V of overvoltage a PDE near* ***80%*** *is measured.*

5.4 PDE vs wavelength at 3V of OV of the LVR3 3050 CN

As stated above, the HPK made an effort to improve also the SiPM response in the 300 – 350 nm spectral range. They produced another series named **LVR3** that takes into account the improvement. We received from HPK only a 3x3mm^2 with 50 µm microcell LVR3 with no coating (LVR3 3050 CN). We measured the PDE of this device and we have compared with the LVR2 device (same dimensions and microcell).

Figure 16 shows the PDE versus wavelength in the 280nm – 850nm range obtained by operating the device at 3V of overvoltage. A peak in PDE of about 55% is measured in the 430 – 450 nm range while a PDE of 27% has been found at 285nm, and a PDE of 38% has been measured at 315nm.

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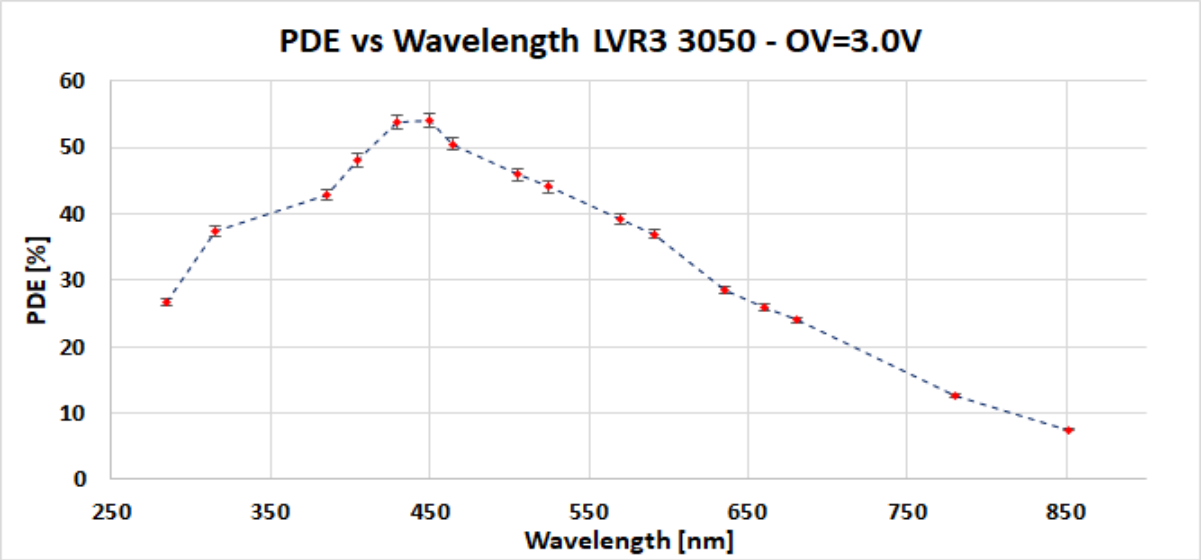

Figure 16. PDE versus wavelength in the 285nm – 850nm range obtained by operating the device at 3V of overvoltage. The PDE peaks at about 55% in the 430 – 450 nm range. We measured a PDE of 27% at 285nm, and of 38% at 315nm.

5.5 PDE vs wavelength at 3V of OV of the LVR2 3050 CN

In order to evaluate the achieved improvement in the near UV region of the LVR3 series, we measured the PDE of the LVR2 3050 CN in the 285nm – 850nm range by operating the device at 3V of overvoltage. Figure 17 shows the PDE versus wavelength in the 280nm – 850nm range obtained by operating the device at 3V of overvoltage.

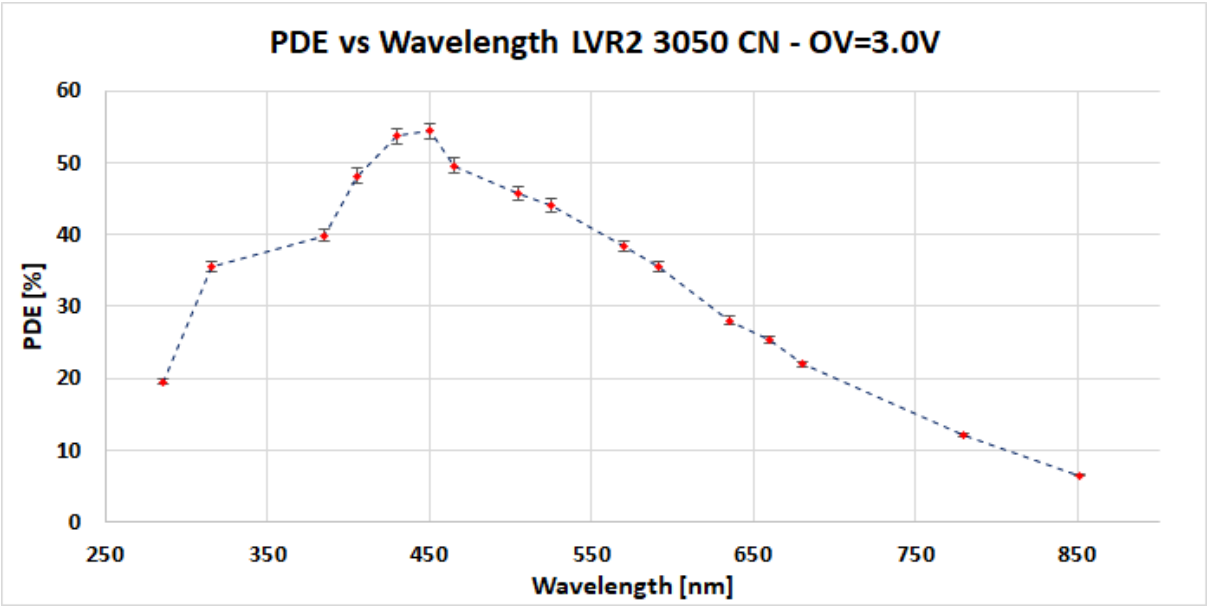

Figure 17. PDE versus wavelength in the 285nm – 850nm range obtained by operating the device at 3V of overvoltage. The PDE is exactly the same of the LVR3 in the 400 – 850 nm range. Instead we measured a PDE of 19% at 285nm, and of 35% at 315nm. These last values are lower than those obtained for the LVR3 3050 CN.

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As can be noted from Figure 17, the PDE is 19% at 285nm, and of 35% at 315nm values that are lower than those obtained for the LVR3 3050 CN at the same wavelengths.

5.6 Relative PDE of the LVR3 respect to the LVR2

In this subsection we compare the two PDE curves. Figure 18 shows the two curves superimposed one each other, while Figure 19 shows the relative PDE between the LVR3 type respect to the LVR2 type.

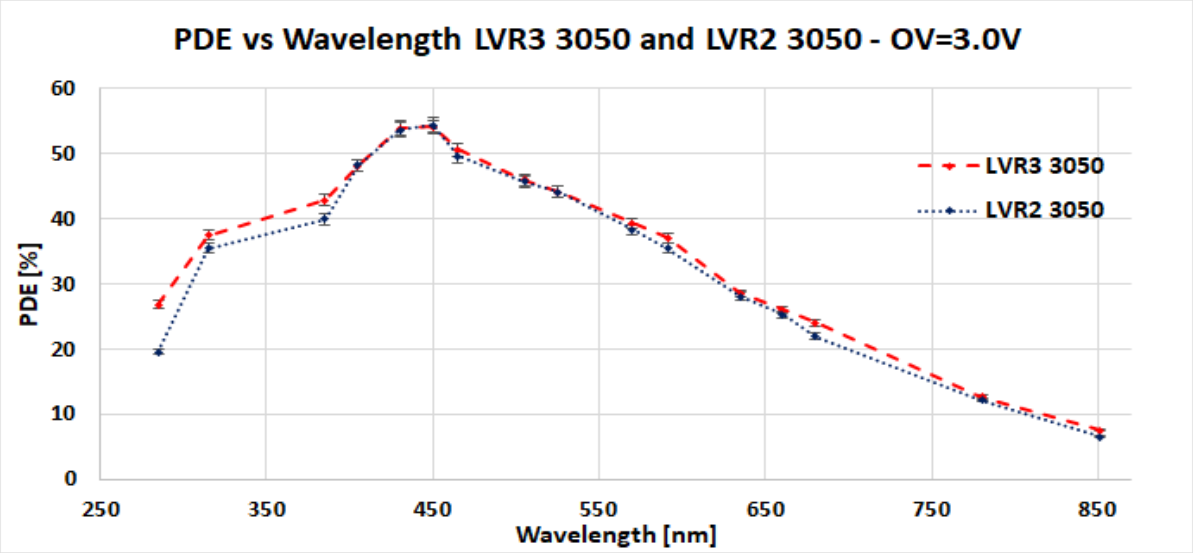

Figure 18. LVR2 and LVR3 PDE curves superimposed. The difference in the near UV region is clearly evident.

To emphasize the difference between the two technologies we plotted in figure 19 the ratio of the PDE values obtained for the two devices that in other terms is the so-called Relative PDE

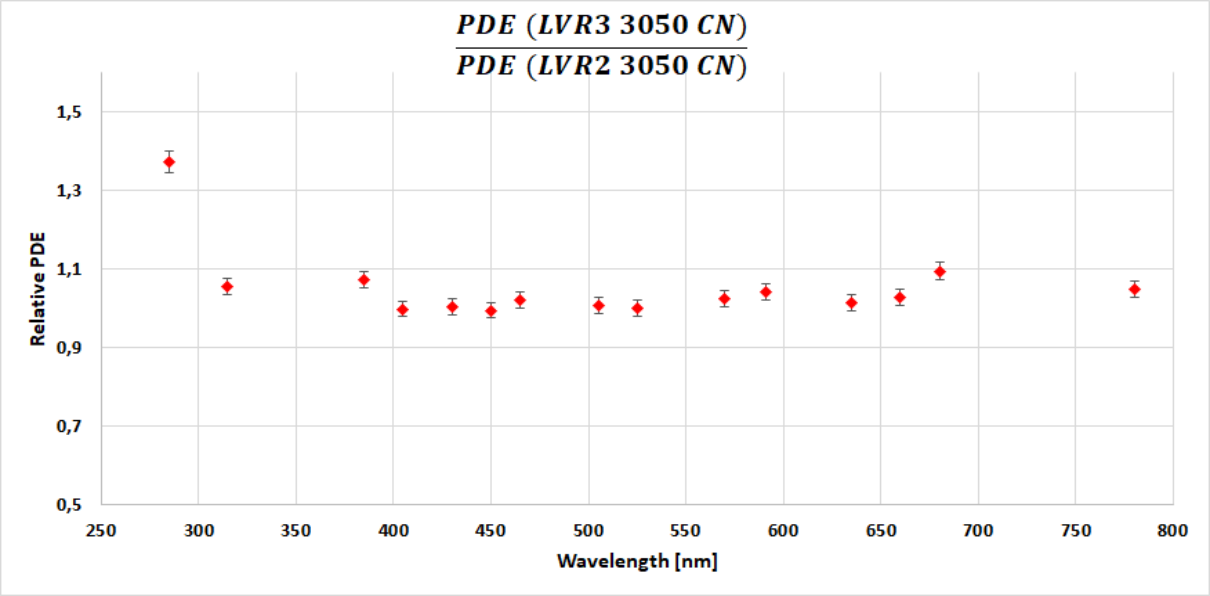

Figure 19. Relative PDE of the LVR3 3050 CN respect to the LVR2 3050 CN.

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6. PDE versus OCT: selection of the best SiPM candidate for SST

As stated above, the OCT depends on the Front End Electronics (Citiroc ASIC), or better to say on the pile-up effect that in turn depends on DCR, and thus on temperature. We measured the OCT at two different temperatures:

- 2°C where the DCR and thus the pile-up is strongly reduced
- 15°C that is the ASTRI camera working temperature.

The results in terms of PDE versus OCT for the two cases are showed in the next subsections.

6.1 PDE vs OCT at 2°C operating temperature (reduced pile-up effect)

Figure 20 reports the best achievable conditions due to the fact that we operate the SiPM at 2°C and then the OCT is the minimum obtainable. The LVR2 7075 CS and CN devices are here also compared to understand what is the final performance in both cases. Of course a better performance in terms of PDE @405nm versus OCT is achieved with the CN series because the absence of any coating that is responsible for the increasing of the OCT.

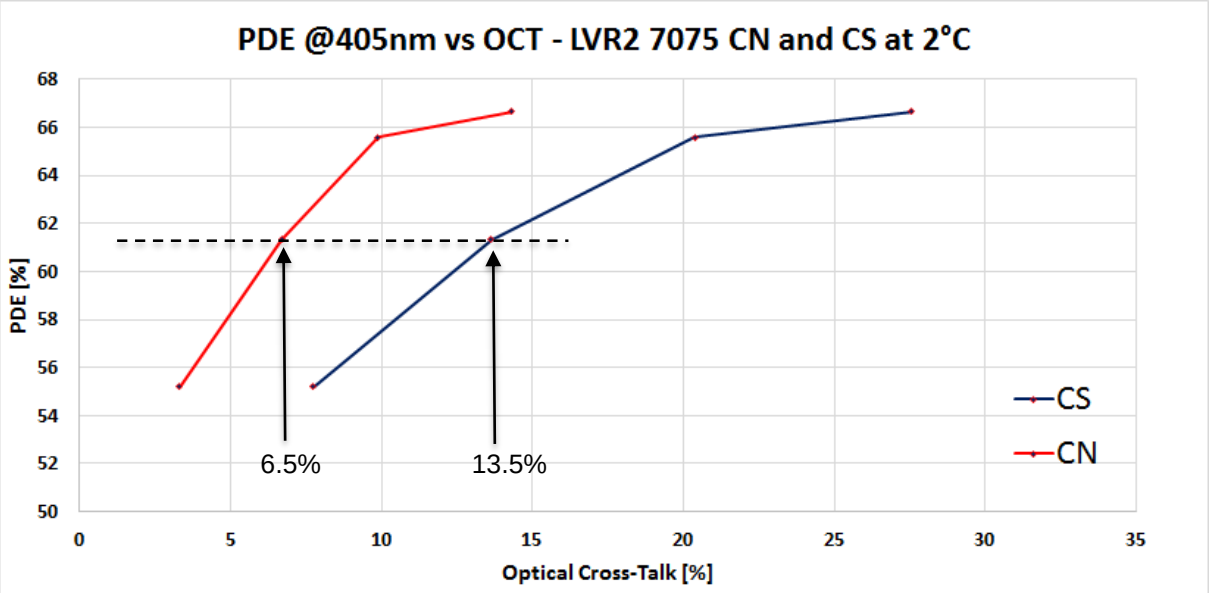

Figure 20. PDE @405nm versus OCT for the LVR2 7075 CN and CS devices at the working temperature of 2°C. The graph indicates that at 3V of overvoltage a PDE @405nm higher than 61% can be achieved, with an OCT of only 6.5% in the CN device while with an OCT of 13.5% in the CS device.

The graph of Figure 20 indicates that at 3V of overvoltage a PDE @405nm around 61% can be achieved, with an OCT of only 6.5% in the CN device while with an OCT of 13.5% in the CS device. Better situation can be considered for the CN detector if an overvoltage of 4V is selected to operate the devices, in fact a PDE @405nm of 66% can be attained with an acceptable OCT of 10%.

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To be noted that the set-up (in particular the electronics) used for the OCT measurements doesn't allow us to measure the real OCT provided by the manufacturer. In fact, the fast shaper electronics inside the ASIC chip does not allow operating a good Pole-Zero Cancellation (PZC). A Front-End electronics able to operate a good PZC will allow to obtain lower OCT independently from the operating temperature.

6.2 PDE vs OCT at 15°C, the camera ASTRI operating temperature

At the moment, the Front-End electronics based on the ASIC Citiroc 1A chip suffers from the pile-up effect (not good PZC) due to the DCR. The operating temperature of the ASTRI camera has been selected to be 15°C and thus, as stated above, we measured the OCT at 15°C. Of course a worst situation is attained. As can be seen in Figure 21, the performances in terms of PDE versus OCT are a little bit degraded.

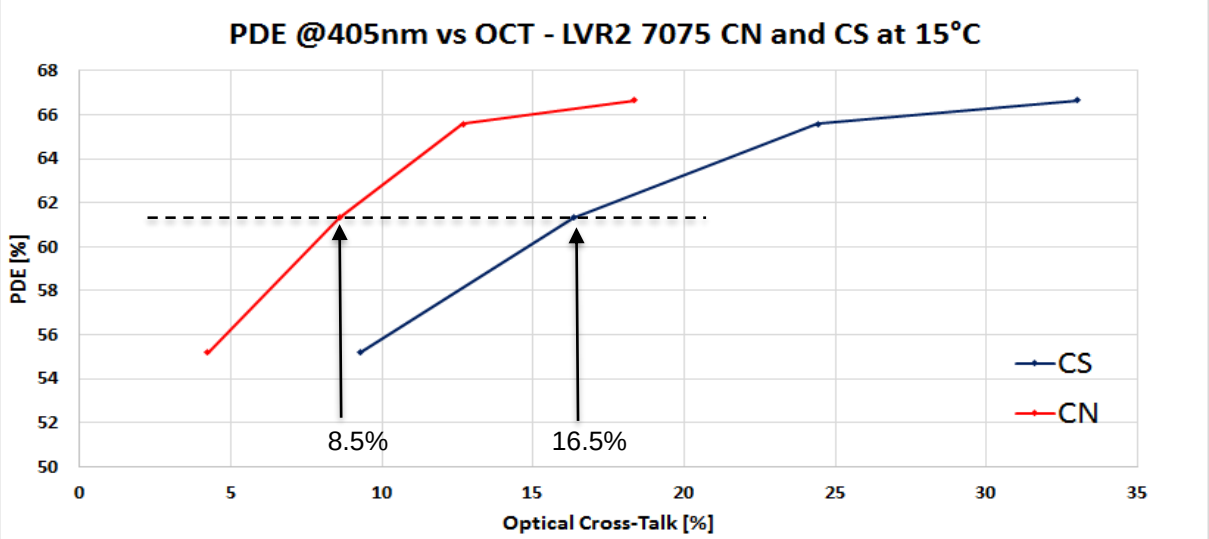

Figure 21. PDE @405nm versus OCT for the LVR2 7075 CN and CS devices at the working temperature of 15°C. The graph indicates that at 3V of overvoltage a PDE @405nm higher than 61% can be achieved, with an OCT of 8.5% in the CN device while with an OCT of 16.5% in the CS device.

The graph of Figure 21, as expected, presents a worst situation than that obtained at 2°C. At 3V of overvoltage the PDE @405nm of 61%, is reached with an OCT of 8.5% in the CN device while with an OCT of 16.5% in the CS device. At an overvoltage of 4V the PDE @405nm of 66% is reached with an OCT of 12.5%.

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7. Conclusions

The characterization presented in this report demonstrated that the 7x7 mm^2 with 75µm microcell SiPM, recently manufactured by HPK, can claim very good performances, such as very high PDE and very low OCT.

As the OCT depends on the Front End Electronics (Citiroc 1A ASIC), or better to say on the pile-up effect that in turn depends on DCR, and thus on temperature. We measured the OCT of the two type of SiPMs (CN and CS) at two different temperatures: 2°C and 15°C. We found an increasing of 2% by switching from one temperature to the other. At 2°C and 3V of overvoltage, we found, that the CS type device has an OCT of 13.5% while the CN type has an OCT of 6.5%. The situation worsens at 15°C.
The OCT essentially depends on:

1. Dimensions of the sensitive area.
2. Coating on top of the sensitive area.

And. Due to the electronics of the ASTRI camera, we have to add three more effects:

1. Pile-up due to the operating temperature or better to say to the DCR
2. Inefficient Pole-Zero Cancellation (PZC) of the Front End Electronics (FEE)
3. Optics in front of the detector (report ASTRI-TR-OACT-3200-036)

A FEE with an appropriate PZC will remove the first and the second effects.

At 3V of overvoltage a PDE of **75%** at a peak has been found, and even better at 4V, where the OCT is less than 10%, an impressive peak of about **80%** has been measured.

To better describe the performance of this kind of SiPM we reported the evaluation in terms of PDE @405nm versus OCT. As expected, a better performance is achieved by the CN series because the absence of any coating. We found a PDE@405nm of 61%, and at 2°C, an OCT of 6.5% for the CN device and 13.5% for the CS device.

Better performance at 2°C of the CN detector will be attained if an overvoltage of 4V is selected:

1. PDE @405nm of **66%** and OCT of **10%**,
2. PDE in the 450-470 nm range of **80%** and OCT of **10%**.

An FFE able to operate an efficient PZC will allow to obtain lower OCT independently from the operating temperature.

Finally, we measured the PDE of a 3x3mm^2 with 50µm microcell with no coating (**LVR3** 3050 CN) and compared the PDE result with that of the LVR2 device. The results show a real improvement in the 285 – 350 nm spectral range.

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

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8. CONTACTS

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