

# Calibration of the ASTRI-1 Cherenkov camera

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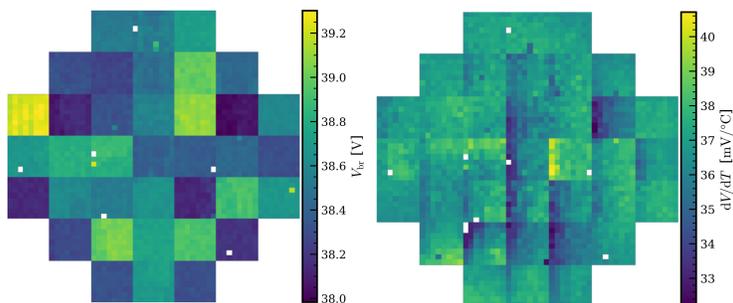
## ABSTRACT

The ASTRI Cherenkov camera is based upon Silicon Photo-Multiplier (SiPM) sensors. The focal plane is composed of 2368 pixels arranged in 37 Photon Detection Modules (PDMs) of 8x8 pixels covering a field of view of about 10.5 degree. The camera electronics is based on a peak detection circuit and is designed to perform self-trigger of the whole focal plane in order to detect and digitize Cherenkov signals while minimizing the data transfer volume. One of the nine telescopes (ASTRI-1) is already in its commissioning phase, collecting data since September 2024. In this contribution we report on the camera calibration carried out during the commissioning phase and on the system stability monitoring through on-site daily calibration runs. All the calibrations have been performed with the camera internal calibration system that allows the on-site extraction of the optimal camera configuration parameters and of the calibration coefficients needed for the data analysis.



## Introduction

The calibration of the ASTRI cameras [1] aims to ensure uniform performance across the entire focal plane. Here we describe the results of the application of the key procedures developed for this purpose [2], which include the SiPMs breakdown voltage measurement, the alignment of the trigger threshold for all ASICs channels, and the gain calibration needed to convert from analog-to-digital units to photo-electrons. These methods are designed to be performed on-site using the camera internal calibration system.



**Fig. 1: Measured breakdown voltage (left) and its linear temperature dependence (right) across the focal plane.**

## Breakdown voltage

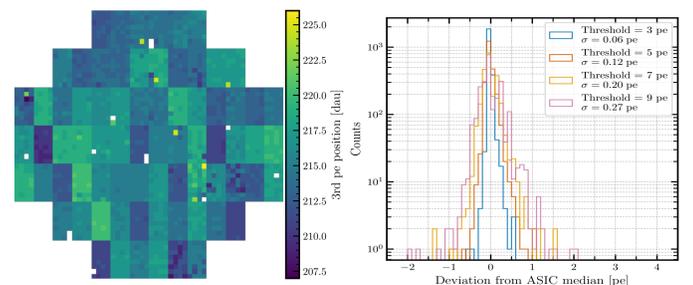
We have developed an innovative method based on measuring the signal variance as a function of bias voltage while illuminating the focal plane with a continuous light source. Then the breakdown voltage is extracted fitting a model that assumes a Borel distribution for cross-talk discharges. The calibration results (Fig. 1, left) show a small deviation of about 32 mV with respect to the median value of each module. We have also been able to measure the breakdown voltage temperature dependency on-site applying the procedure at different temperatures using the camera thermal control system (Fig. 1, right). This dependency is used to adjust the bias voltage in order to compensate for temperature fluctuations.

## ACKNOWLEDGEMENTS

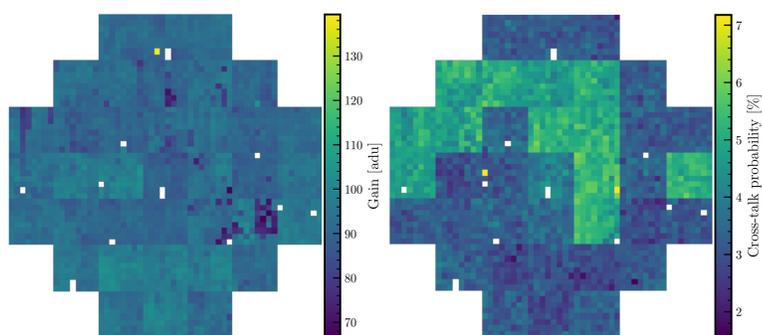
This work was conducted in the context of the ASTRI Project. We gratefully acknowledge support from the people, agencies, and organisations listed here: <http://www.astri.inaf.it/en/library/>

## Trigger alignment and calibration

A PDM utilizes two Application-Specific Integrated Circuits (ASICs). All 32 channels of each ASIC have a shared threshold, programmable by a 10-bit Digital-to-Analog Converter (DAC). Channel-to-channel variations of gain and discriminator reference voltage are expected. The trigger channels equalization can be done by means of a programmable 4-bit DAC that adjusts the discriminator reference voltage of each channel. The optimal adjustment for each channel was determined by analysing pixels *staircase curve* (dark-count rate as a function of threshold) and minimizing the number of unaligned pixels per ASIC. The aligned staircase curves are then used to extract the coefficients needed to convert each ASIC threshold from photo-electrons to the corresponding 10-bit DAC value. This procedure allowed us to align the trigger signals up to the third photo-electron (Fig. 2). At a threshold of 7 pe, a typical setting for low-zenith angle observations without moonlight [3], we get a residual misalignment of about 0.2 pe.



**Fig. 2: Measured third photo-electron after trigger alignment (left) and expected pixel threshold dispersion (right).**



**Fig. 3: Measured gain (left) and prompt cross-talk probability (right) across the focal plane.**

## Gain calibration

SiPM gain and cross-talk are obtained from Pulse-Height Distributions (PHDs) modelled by a Gaussian-smeared generalized Poisson distribution. The PHD of each SiPM is recorded illuminating the focal plane with blue light flashes with 10 ns pulses at a constant frequency of 1000 Hz. The analysis results (Fig. 3) show a gain uniformity of about 5 % across the field of view. The measured cross-talk shows a different mean value for

12 out of 37 PDMs, probably belonging to different production batches. The two batches have a mean cross-talk level of 3.2 % and 5.0 %, both with a dispersion of 0.4 %.

Gain calibration runs are taken regularly before observations to monitor the system stability. The results, from November 2024 to February 2025, show a mean gain relative dispersion of about 0.2 % and a mean cross-talk relative dispersion of about 0.4 %.