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Commissioning of SPARC4 cameras

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Abstract. INPE in partnership with the LNA is developing a new astronomical instrument called SPARC4, which will be installed on the 1.6 m telescope of the OPD. In order to characterize some subsystems of the instrument, observational missions were carried out in February, April and May 2022. The characterization of read noise and gain was performed for each camera in different observation modes. Both read noise and gain are very consistent with the value specified by the manufacturer datasheet. Images of rich fields and photometric/spectrophotometric standard stars were also gathered to obtain the signal-to-noise behavior as a function of magnitude, throughput and magnitude zero point with the direct camera of the OPD.

Resumo. O INPE em parceria com o LNA está desenvolvendo um novo instrumento astronômico chamado SPARC4, que será instalado no telescópio de 1.6 m do OPD. Com o intuito de caracterizar alguns subsistemas do instrumento, foram realizadas missões observacionais em fevereiro, abril e maio de 2022. A caracterização do *read noise* e do *gain* foi realizada para cada câmera em diferentes modos de observação. Tanto o *read noise* quanto o *gain* são bem consistentes com o valor especificado pelo fabricante. Foram obtidas também imagens de campos ricos e estrelas padrões fotométricas/espectrofotométricas para a obtenção do comportamento do sinal-ruído em função da magnitude, do *throughput* e do ponto zero de magnitude com a câmera direta do OPD.

Keywords. Instrumentation: detectors – Instrumentation: photometers – Telescopes

1. Introduction

Instituto Nacional de Pesquisas Espaciais (INPE) in partnership with *Laboratório Nacional de Astrofísica* (LNA) is developing a new astronomical instrument called Simultaneous Polarimeter and Rapid Camera in Four Bands (SPARC4, Rodrigues et al. 2012), which will be installed at the 1.6 m telescope of the Pico dos Dias Observatory (OPD). This instrument is in the final stage of development, thus enabling the beginning of the commissioning of some subsystems, in particular, the software that controls the acquisition by the scientific cameras, the cameras themselves and the Graphical User Interface (GUI).

2. Reduction software

The SPARC4 project is also developing a reduction software based on the ASTROPOP package (Campagnolo 2019), which uses the Python programming language and provides routines for the complete reduction of photometric or polarimetric data (Figueiredo et al. 2022). Commissioning data from SPARC4 cameras has been reduced using ASTROPOP. This reduction was validated through comparison with IRAF (Image Reduction and Analysis Facility).

3. Characterization of detectors

In February, April and May 2022, observational missions were carried out at the OPD, where the SPARC4 control and acquisition software was tested/used (Bernardes et al. 2022). In the February mission, a first commissioning of the four iXon Ultra 888 Andor EMCCDs cameras that will be used in SPARC4 (Bernardes, Martioli, & Rodrigues 2018) was carried out. The characterization of read noise and gain was performed for each camera in different observation modes. As an example, Table 1 lists the results of the characterization of the camera with serial number 9914 that will be used in SPARC4 as the g-channel in mode 1.0_1 (readout rate of 1 MHz and pre-amplifier gain of 1).

The read noise and gain measurements were obtained using the method described by Janesick (2001), which uses two flat-field images with the same intensity and two bias images. The expressions are:

$$\text{Gain} = \frac{(\overline{F}_1 + \overline{F}_2) - (\overline{B}_1 + \overline{B}_2)}{\sigma^2_{F_1-F_2} - \sigma^2_{B_1-B_2}}, \quad \text{Read noise} = \frac{\text{Gain}}{\sqrt{2}}\sigma_{B_1-B_2} \quad (1)$$

where $\overline{F}_1$, $\overline{F}_2$, $\overline{B}_1$ and $\overline{B}_2$ are respectively the average value of the two flat-field images and the two bias images, $\sigma_{F_1-F_2}$ and $\sigma_{B_1-B_2}$ are respectively the standard deviation of the difference between the two flat-field and bias images. Both gain and read noise are very consistent with the value specified by the manufacturer datasheet (see Table 1). To determine the linear region of the CCD and its saturation, a set of flat-fields with different exposure times was collected to map the CCD saturation together with its range of linearity. Table 1 shows the saturation and the linear region of the CCD for the exemplified case, where the regions of non-linearity are deviated from a linear fit made to the analysis set.

4. Photometric error characterization

In the April and May missions, images of rich fields and photometric standard stars were obtained to obtain the signal-to-noise behavior as a function of magnitude and also the throughput and the zero point of magnitude with the OPD's direct camera. Of course, the results themselves are different from the those expected for SPARC4 data, but those missions allowed us to test the observational procedure and to also develop the reduction procedure. In Fig. 1, the noise characterization in the four filters used is exemplified. The field used in this example is of the

Table 1. Characterization of the camera with serial number 9914 that will be used in SPARC4 as the g-channel - mode 1.0_1.

Parameters	2022feb09	2022apr14	2022apr15	2022apr16	2022apr17
Read noise (e-, datasheet)			6.66		
Read noise (e-, measured)	6.56 ± 0.06	6.61 ± 0.12	6.57 ± 0.11	6.63 ± 0.14	6.60 ± 0.13
Gain (e-/ADU, datasheet)			3.37		
Gain (e-/ADU, measured)	3.379 ± 0.0027	3.384 ± 0.015	3.377 ± 0.011	3.389 ± 0.014	3.389 ± 0.013
Saturation (ADU)			30800		
Linear region of the CCD (ADU)			up to 27000		

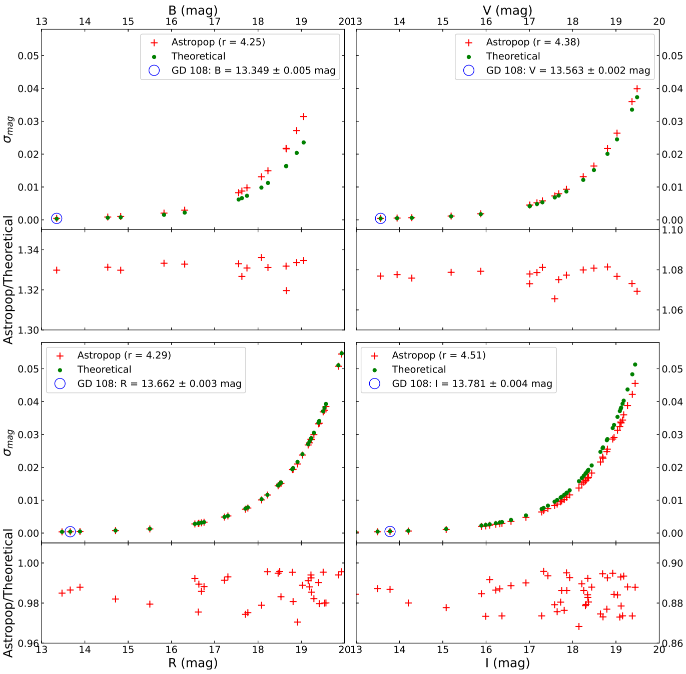

Figure 1. Photometric error of measurements using the SPARC4 camera 9914 and BVRI filters. Astropop and theoretical error are calculated as explained in the text. The top panels are σ_{mag} versus magnitude plot of the theoretical (green dots) versus ASTROPOP (red crosses) noise performance. The standard photometric star GD 108 is marked as a blue circle. The bottom panels are the division of the ASTROPOP by the theoretical σ_{mag}.

photometric standard star GD 108 and camera 9914 was used in mode 1.0_1, where the total integration time is 600, 600, 600 and 1200 s for the BVRI filters, respectively.

ASTROPOP was used to calculate the aperture photometry of the stars detected at 10σ above the background in each filter. ASTROPOP uses SEP (Barbary 2016) for the aperture photometry. To transform from instrumental magnitude to magnitude, we performed a simple displacement using the BVRI magnitudes from the literature of GD 108 (the values are listed in Fig. 1). This simple offset gives a good photometric calibration for the field compared to using astronomical catalogs (e.g., APASS and GAIA DR2), obtaining an uncertainty in the magnitude of ~ 0.1 mag.

The ASTROPOP error (aperture photometry error from SEP) is:

$$\text{FLUXERR} = \sqrt{\sum_{i\in\mathcal{A}} \left(\sigma_i^2 + \frac{p_i}{g_i}\right)} \qquad (2)$$

where $\mathcal{A}$ is the set of pixels defining the photometric aperture, σ_i is the standard deviation of noise (in ADU) estimated from the local background, p_i is the measurement image pixel value subtracted from the background and g_i is the effective detector gain in e^{-}/ADU at pixel i.

A theoretical estimate of the signal-to-noise was performed taking into account the characteristics of the instrument used and the conditions of the OPD. For this, the expression for the signal-to-noise of Janesick (2001) was adopted, where the following parameters were included in the calculation: photon noise, sky noise and read noise. The CCD response, photosphere and filters transmission were considered (see `http://www.inpe.br/etc/formCD.php`). The results obtained with ASTROPOP are in good agreement with the theoretical estimate.

With this, we can later use this knowledge for the calibration of the software that will simulate photometric and polarimetric images, which would be obtained by the EMCCDs cameras of the SPARC4. This software is called Artificial Image Simulator (AIS), which can be used to plan scientific observations to be carried out with SPARC4.

5. Conclusions and perspectives

The commissioning of the SPARC4 instrument has already begun, with the four iXon Ultra 888 Andor EMCCDs cameras being initially commissioned that will be used in the SPARC4. During the observational missions with the OPD's direct cameras, the instrument's control and acquisition software were tested. Both the gain and the read noise obtained in the characterization are very consistent with the value specified by the datasheet. Commissioning data from SPARC4 cameras was reduced using the ASTROPOP reduction software. The photometric noise was characterized for the BVRI filters with the direct cameras and is in good agreement with the theoretical estimate of the noise, and we can later use this knowledge for the calibration of the software that will simulate photometric and polarimetric images, which would be obtained by the EMCCDs cameras of the SPARC4. Finally, with the experience of commissioning the SPARC4 cameras, we have developed routines to apply in the commissioning of the integrated instrument, which occurred in November 2022 and will be described elsewhere.

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