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# Acquisition system of the SPARC4 instrument

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**Abstract.** *Instituto Nacional de Pesquisas Espaciais* (INPE), in collaboration with *Laboratório Nacional de Astrofísica* (LNA), is developing a new instrument called Simultaneous Polarimeter and Rapid Camera in Four Bands (SPARC4) that will be installed on the Perkin-Elmer telescope of 1.6 m from Pico dos Dias Observatory (in Portuguese, OPD). In this work, we present Acquisition Control System of SPARC4 (S4ACS), developed in Laboratory Virtual Instrument Engineering Workbench (LabView) programming language, together with Software Development Kit (SDK) provided by Andor Technology (manufacturer of the detectors) for controlling Charge Coupled Devices (CCDs). Each of the SPARC4 CCDs will be controlled by an instance of S4ACS installed on a dedicated computer, so that the control of the four detectors will be carried out through the communication of these instances with SPARC4 Graphical User Interface (S4GUI). S4GUI is a custom user interface for SPARC4, which is not yet finalized but is operational for image acquisition in photometric mode with the four cameras. With the current version of S4ACS, it is possible to acquire a cube of images (continuous sequence of images) with a maximum size of 1400 frames, of 1024 x 1024 pixels, with an overhead of 1.7 ms between frames. Thus, SPARC4 will allow the simultaneous and synchronized photometric and polarimetric acquisition of series of image cubes in 4 spectral bands of the Sloan Digital Sky Survey (SDSS) system: $g$, $r$, $i$ and $z$. For the polarimetric mode, it is planned that the synchronization of the involved processes (waveplate positioning, triggering the acquisition, and signaling the end of the acquisition) will be done completely via hardware as a way to reduce the overhead between these processes. During the first half of 2022, four commissioning runs of the SPARC4 acquisition system were carried out. In these runs, calibration images were obtained for the characterization of CCDs and images for astrometric and photometric calibration that will be used as input for testing the SPARC4 reduction software.

**Resumo.** O Instituto Nacional de Pesquisas Espaciais (INPE), em parceria com o Laboratório Nacional de Astrofísica (LNA), está desenvolvendo um novo instrumento chamado *Simultaneous Polarimeter and Rapid Camera in Four Bands* (SPARC4) que será instalado no telescópio Perkin-Elmer de 1,6 m do Observatório Pico dos Dias (OPD). Neste trabalho, apresentamos o *Acquisition Control System* do SPARC4 (S4ACS), desenvolvido em linguagem de programação *Laboratory Virtual Instrument Engineering Workbench* (LabView) em conjunto com o *Software Development Kit* (SDK) disponibilizado pela Andor Technology (fabricante dos detectores) para o controle dos *Charge Coupled Devices* (CCDs). Cada um dos CCDs do SPARC4 será controlado por uma instância do S4ACS instalada em um computador dedicado, de modo que o controle dos quatro detectores será realizado através da comunicação destas instâncias com o SPARC4 *Graphical User Interface* (S4GUI). O S4GUI é uma interface de usuário customizada para o SPARC4, que ainda não está finalizada mas está operacional para aquisição de imagens no modo fotométrico com as quatros câmeras. Com a versão atual do S4ACS, é possível realizar a aquisição de um cubo de imagens (sequência contínua de imagens) com um tamanho máximo de 1400 frames, de 1024 x 1024 pixels, com um tempo morto de 1,7 ms entre frames. Dessa forma, o SPARC4 permitirá a aquisição fotométrica e polarimétrica de séries de cubos de imagens de forma simultânea e sincronizada para 4 bandas espectrais do sistema *Sloan Digital Sky Survey* (SDSS): $g$, $r$, $i$ e $z$. Para o modo polarimétrico, está planejado que a sincronização dos processos envolvidos (posicionamento da lâmina, disparo da aquisição e sinalização do fim de aquisição) será feita totalmente via *hardware* como uma forma de reduzir o tempo morto entre estes processos. Durante o primeiro semestre de 2022, foram realizadas quatro missões de comissionamento do sistema de aquisição do SPARC4. Nessas missões, foram obtidas imagens de calibração para caracterização dos CCDs e imagens de campos para calibração astrométrica e fotométrica que serão usados como entrada para testes do *software* de redução do SPARC4.

**Keywords.** Instrumentation: detectors – instrumentation: photometers – instrumentation: polarimeters

## 1. Introduction

*Instituto Nacional de Pesquisas Espaciais* (INPE), in collaboration with *Laboratório Nacional de Astrofísica* (LNA), is developing a new instrument named Simultaneous Polarimeter and Rapid Camera in Four Bands (SPARC4) (Rodrigues et al. 2012). SPARC4 will be installed on the 1.6 m Perkin-Elmer telescope of *Pico dos Dias* Observatory (in Portuguese, OPD). SPARC4 will allow photometric and polarimetric acquisition in four spectral bands $g$, $r$, $i$, and $z$ of the Sloan Digital Sky Survey (SDSS) system (Doi et al. 2010). SPARC4 uses the same polarimetric technique of IAGPOL instrument (Magalhães et al. 1996; Rodrigues, Cieslinski & Steiner 1998). IAGPOL is an instrument currently in use at OPD and it contributes significantly to the productivity of the observatory. SPARC4 was designed for the observation of variable objects, like binary stars, pulsars, and exoplanets, providing synchronized image acquisition for the four bands with a time resolution of 1 s or below. The combination of the acquisition of simultaneous images in 4 bands in photometric and polarimetric modes is an advantage of SPARC4.

Following the path from the telescope, the light passes through the polarimetric module, the collimator, the dichroic mirrors, the focuser cameras, and the detectors. In the polarimetric module, there is the calibration wheel, composed of a polarizer and a depolarizer for the calibration of the instrumental polarization and the polarization efficiency. Then, the light reaches a retarder waveplate, which can be a half waveplate or a quarter waveplate. Then, the light is divided into the ordinary and the extraordinary rays using a Savart prim. The acquisition of photometric images can be done by removing these components from the optical path (Rodrigues et al. 2012). After passing through the collimator, the light is split into four bands using three dichroic mirrors, that correspond approximately to the *g*, *r*, *i*, and *z* bands (channels) of the SDSS system. A fourth mirror is used for the symmetric displacement of the detectors. For each channel, there is a camera with focuser lenses. These cameras are composed of two doublets and one singlet. Finally, the light is acquired by four iXon Ultra EMCCD cameras fabricated by the Andor Technology company. These devices have a window and a coating optimized for the region where they will operate.

SPARC4 is composed of several subsystems that need to operate together for the correct operation of the instrument. The control of each subsystem will be done by dedicated softwares. Between these softwares, one can cite Instrument Control System (S4ICS), responsible for controlling the moving mechanisms, like motors and sensors. Also, there is Auto Guider System (S4AGS), which is responsible for correcting the telescope tracking during an observation. There is Graphical User Interface (S4GUI), which is an interface between the user and the subsystems of SPARC4. Finally, there is Acquisition Control System (S4ACS), responsible for the control of the EMCCDs of the instrument.

This work presents the development of S4ACS, and the use of this software in SPARC4 commissioning runs, as well as, in scientific observations of a planetary system. This proceeding is organized as follows. Section 2 presents the structure of the acquisition system of SPARC4. Section 3 presents S4ACS. Section 4 presents the development of by-products that emerged from the S4ACS development. Section 5 presents the commissioning of the acquisition system of SPARC4. Finally, Section 6 presents the conclusion.

## 2. Structure of the acquisition system of SPARC4

Figure 1 presents the diagram of the acquisition system of SPARC4, composed of EMCCD cameras, S4ACS, S4GUI, and the sync box[1]. The sync box is a digital pulse generator fabricated by Highland Technology company, used to synchronize the acquisition between channels. In this system, each camera is connected to a different computer. In each computer, there is one instance of S4ACS, responsible for controlling the camera. Therefore, the image acquisition for the four channels is done using S4GUI to communicate with four instances of S4ACS. The communication between these softwares is done using the TCP-IP protocol. Also, S4GUI communicates with Telescope Control System of the Pico dos Dias Observatory (TCSPD) to obtain the telemetry information. This information is sent to S4ACS instances to be written into the image header.

For image acquisition in photometric mode, SPARC4 presents two synchronization modes: synchronous and asynchronous. In the asynchronous mode, each camera can be controlled individually. In the synchronous mode, the start of the kinetic series in all cameras will be synchronized. For that, there are two options for synchronization. The first one is synchronization by software. In this option, S4GUI starts the acquisition, sending a command for each instance of S4ACS. In the second option, the synchronization is done by the sync box. To start the acquisition, S4GUI sends a command for S4ACS instances to prepare the cameras for the external trigger. Then, S4GUI sends to the sync box a command to trigger four external pulses with a synchronization resolution of 12 ps. When the cameras receive these pulses, the acquisition is started.

[1] https://www.highlandtechnology.com/DSS/T560DS.shtml

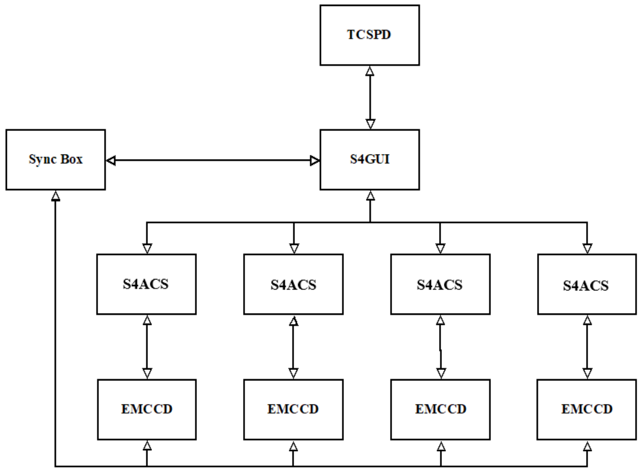


**Figure 1.** Structure of the acquisition system of SPARC4.

Acquiring a series of images using the polarimetric mode of SPARC4 is a bit more complex. Initially, the retarder waveplate must be placed in position. This is done through S4GUI communicating with S4ICS. Then, S4GUI communicates with S4ACSs to prepare the cameras. Then, it controls the sync box to trigger the external pulses. At the end of the acquisition, S4GUI sends a new command to S4ICS to move the waveplate to the next position. As can be seen, this process requires continuous communication from various components and therefore may have some delays associated with this communication.

During the development of the instrument, we verified that controlling the triggering of the pulses sent by the sync box does not necessarily need to be done via software, but it can also be done via hardware. Thus, we plan to use this characteristic so that the image acquisition through the polarimetric mode of SPARC4 is going to be done entirely via hardware, to minimize the overhead. In this process, communication will be done between the motor of the waveplate, the sync box, and the cameras. The motor will send a pulse to the sync box when it is in position. Then, the sync box will send the pulse to the cameras to start the acquisition. When the acquisitions finish, the cameras will send a signal to the motor of the waveplate to move it to the next position, starting the next cycle. The SPARC4 EMCCDs have a series of pins for inputting and outputting digital pulse signals that can be used for this purpose. Some of these signals are related to the image acquisition process and can be used to trigger external processes. Appendix A presents a study of the pulse signals of the SPARC4 cameras.

## 3. Acquisition control system of SPARC4

S4ACS is developed using the graphical programming language Laboratory Virtual Instrument Engineering Workbench (LabVIEW) 2018 and Software Development Kit (SDK)[2] version 2.104.30000.0 (02-24-2020), made available by Andor to control the SPARC4 cameras (see Fig. 2). The operating system used in the development was Windows Server 2016 standard, version 1607. The methodology used for the development was based on the works presented by Bernardes (2020) and Bernardes et al. (2019). Using S4ACS, it is possible to configure the operation mode of the cameras and acquire a series of images. The acquired data is saved in a Flexible Image Transport

[2] https://neurophysics.ucsd.edu/Manuals/Andor %20Technology/Andor_Software_Development_Kit.pdf

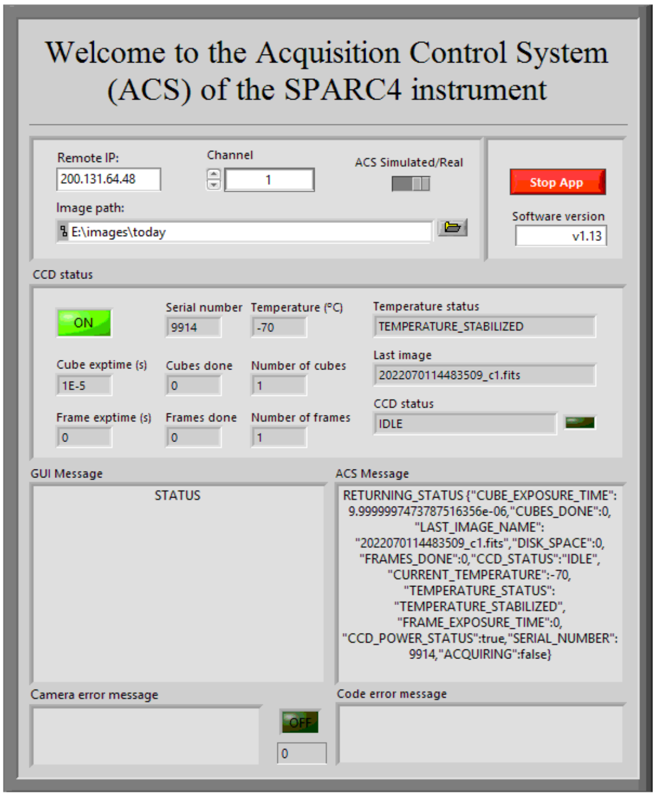


**Figure 2.** Graphical interface of S4ACS. This interface has 4 subdivisions. From top to bottom, the first one presents the parameters for the initialization of S4ACS. The second one presents the current camera status. The third one presents the content of the messages that are received and sent to S4GUI. The fourth one presents the error messages generated during the execution of the software.

System (FITS) file. All the information related to the acquisition, the instrument configuration, and its sub-systems is saved into the image header. Both the creation and the edition of the file are done by scripts developed using Python language. These scripts are executed using a Python 3.6 interpreter running in LabVIEW platform. For that, Python Integration Toolkit for LabVIEW, developed by Enthought, Inc company, was used. With the current version of S4ACS, it is possible to acquire a series with up to 1400 images of 1024 x 1024 pixels, with an overhead of 1.7 ms between images. Also, it is possible to acquire several series of images with an overhead of 140 ms.

## 4. Auxiliary developments

S4ACS is a software that can be used to communicate with any iXon camera of Andor, not necessarily the SPARC4 cameras. In particular, S4ACS was tested to control the existing direct cameras in OPD, similarly to what is done by the observatory's current software, called OPDAcquisition. Thus, by-products emerged during S4ACS development, as a way to help to control these cameras. In this section, each of these by-products is briefly discussed.

### 4.1. Filter Wheel Control System

Filter Wheel Control System (FWCS) is a software that communicates with the OPD filter wheel controller using the serial port. FWCS allows the manual control of the filter wheel and the filter selection through commands sent over the network, using the TCP-IP protocol. This is a feature not found in the observatory's current software called RodFilters.

### 4.2. Graphical Engineering Interface

S4GUI operation is quite complex and involves the control and communication of several SPARC4 subsystems, in addition to the observatory infrastructure such as the telescope itself. Thus, to help with the development of S4ACS, Graphical Engineering Interface (GEI) was developed. GEI is a reduced version of S4GUI, capable of communicating with S4ACS, configuring the CCD operating mode, and acquiring a series of images. GEI is also capable of communicating with TCSPD and FWCS. Communication with TCSPD is done via the serial port and is used to obtain telemetry information. This information is passed to ACS and added to the image header. Communication with FWCS is used for the remote control of the filter wheel.

Based on that, an iterator for the filter wheel was developed for GEI. This iterator allows the acquisition of images and the change of filters to be done sequentially and automatically. For that, the filters to be used in an iteration must be selected. For each filter, the exposure time, the number of images to be acquired, and the suffix to be inserted in the name of the image can be configured. In addition, it is possible to choose the number of iterations that should be performed. For each iteration, images will be obtained based on the configuration of each selected filter. It should be noted that this iterator was developed as an extension to GEI and it is not intended for the final SPARC4 system.

### 4.3. Use of auxiliary software in observations of the AU Mic object

On the nights of May 27 to July 6, 2022, an observing run dedicated to monitoring AU Microscopii (AU Mic) star was carried out using IAG and Zeiss telescopes of OPD. Principal Investigator (PI) of the run opted for the use of softwares OPDAcquisition, GEI, S4ACS, and FWCS. This allowed us to further test S4ACS, as described below.

AU Mic is a young planetary system, with an estimated age of 22 ± 3 Myr. Its host M1-type star is magnetically active and it has frequent flares and starspot signatures. Two Neptunian exoplanets, AU Mic b and AU Mic c, orbit around this star, with an orbit of 8.46 days and 18.86 days, respectively, and in an inclination that produces observable transits (Martioli et al. 2021). The observations carried out had the objective of constantly monitoring this system, to allow a better characterization of the events related to stellar activity and, therefore, improve the accuracy of the physical parameters found for the exoplanets.

In IAG telescope, the observations were carried out through the constant acquisition of images in the I filter, with an exposure time of 1 s, during all the time that the object was visible. In this telescope, both OPDAcquisition and the GEI/S4ACS/FWCS set were used. In Zeiss telescope, image acquisition was performed on the BVRI filters, where the filter change was performed every 1 minute, throughout the entire night. The used configuration was 3 images of 20 s in the B filter; 10 images of 6 s in the V filter; 60 images of 1 s in the R filter; 60 images of 1 s in the I filter. For that, the GEI iterator was used, together with FWCS and S4ACS. The data acquired during these nights are still being analyzed.

## 5. Acquisition system commissioning

In the first half of 2022, four commissioning runs of the SPARC4 acquisition system were carried out. As the instrument is still under development, the direct camera was used on the OPD telescopes. Table 1 presents a brief description of the configuration used.

The first run took place from 7 to 10 February, on the OPD's 60 cm IAG telescope. In this run, the four scientific cameras (one per night), an acquisition computer, and the fiber optic set, which connects the camera to the computer, were used. This system was controlled by S4ACS together with GEI. As a result of the run, we verified that the whole communication system worked perfectly. GEI allowed the acquisition of calibration images by scientific cameras, dispensing the use of OPDAcquisition. Using this data, Schlindwein et al. (2022) performed the characterization of the SPARC4 cameras to obtain their read noise and gain values in different observation modes. However, during all the nights, the bad weather conditions made it impossible to open the dome and, therefore, it was not possible to test the cameras in the sky. Some small problems were detected in the creation of FITS files, but they were already corrected and tested in the second commissioning run.

The second commissioning run took place from 14 to 17 April on the OPD's 1.6 m Perkin-Elmer telescope. The hardware used was the optical fiber set, the acquisition computer, the control computer, and the iXon Ultra 9914 camera. For communication with S4ACS, both GEI and S4GUI were used in the control computer. Communication between computers was done using the TCP-IP protocol. On the first night, several problems were detected in the communication between S4GUI and S4ACS. These issues were partially solved, and S4GUI was able to communicate with S4ACS to trigger an acquisition. However, in this run, S4GUI still did not provide a system for configuring the temperature of CCDs. For this reason, GEI was used on the other nights. Using GEI to communicate with S4ACS, it was possible to acquire images of standard photometric and spectrophotometric stars and rich fields for the remainder of the observation nights. Some of the rich fields were observed using the BVRI filters to perform field distortion measurements. Although these observations were not carried out with the instrument, the data obtained are already being reduced. For the reduction, python tools based on Astropop (Figueiredo et al. 2022) package are being developed. Despite the success of GEI and S4ACS in acquiring images for these objects, problems in the communication between these two softwares were detected. This issue has been partially fixed during the nights. The complete correction took place after the third commissioning run (see below).

The third run took place from 10 to 11 May, also on the OPD's 1.6 m telescope. The instruments used in this run were the same as in the previous run, except for the scientific camera used being the iXon Ultra 9915. In the software part, S4GUI was used to communicate with S4ACS. On the first night, rich fields were observed. In addition to these, the photometric standard star SA 109-537 was also observed. There was no observation on the second night due to bad weather. The main problem encountered on this occasion was the communication between S4GUI and S4ACS. This problem was similar to the one that occurred between GEI and S4ACS in the previous run. This problem has been corrected by implementing 2-way TCP-IP communication: one of the ways would be used to send messages from S4GUI to S4ACS, while the other way would be used to send messages from S4ACS to S4GUI.

The fourth run took place from 13 to 19 June, on the OPD's 1.6 m telescope. The hardware and software used were the same as in the previous run. For this run, S4ACS was programmed to save the frames of an image cube (array of images) taken by the camera in separate files instead of a single file. This allowed the use of the frame transfer mode, without the need to wait until the end of the cube acquisition to see the result. Some problems were found during the observations. One of them is related to the telemetry status request that S4GUI sends to TCSPD. This request was performed every 1 s and, by all indications, was causing TCSPD to malfunction. This was fixed during the run, increasing the time interval of S4GUI requests to 30 s. In the case of S4ACS, the command to abort the current acquisition left the software in an intermediate state of the acquisition. This problem appeared after the change to save the frames of an image cube in separate files. All of these issues were solved shortly after the run ended. In addition to commissioning the SPARC4 acquisition system, in this run, it was collected photometric time series of variable objects as exoplanets, cataclysmic variables, and luminous blue variables.

## 6. Conclusion

In this work, the current status of the development of S4ACS was presented. With S4ACS, it was possible to acquire a series of images with an overhead of 1.7 ms between images. Also, it was possible to acquire several series with an overhead of 140 ms between series. During this project, some by-products emerged from the development of S4ACS, which are the softwares FWCS and GEI. These softwares were used in the monitoring run of AU Mic planetary system. In this run, the set S4ACS/GEI/FWCS was used in Zeiss telescope of OPD to acquire a series of images, in the BVRI filters, with the automatic change of filter every minute. In the first half of 2022, four commissioning runs of the SPARC4 acquisition system were carried out. In this run, it was possible to use S4GUI to communicate with S4ACS and acquire a series of images of standard photometric and spectrophotometric stars, rich fields, and exoplanets. Also, during these runs, several problems related to the acquisition system were identified. Between then, the problems in communication between S4GUI and S4ACS, as well as the integration of S4GUI with TCSPD.

S4ACS is at an advanced stage of its development. In this way, the changes that arise throughout the project will be implemented in conjunction with the demand for the SPARC4 acquisition system. One example is the image header which is still in development. In addition, functional and characterization tests are planned. Functional tests involve the entire acquisition system and they were developed to test each of its functionalities. The characterization tests involve only S4ACS and they were developed for the characterization of parameters related to the image acquisition process by the cameras, such as the overhead between images and the noise of these devices.

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**Table 1.** Configuration used throughout the commissioning runs of the SPARC4 acquisition system. PE notation was used to represent the Perkin-Elmer telescope of OPD; FR column indicates whether the telescope's focal reducer was used during the run.

| Run | Date | Telescope | FR | Softwares | Camera Serial Number |
|---|---|---|---|---|---|
| 1° | 7-10 feb | IAG | No | GEI/S4ACS | 9914, 9915, 9916, 9917 |
| 2° | 14-17 apr | PE | Yes | GEI/S4GUI/S4ACS | 9914 |
| 3° | 10-11 may | PE | Yes | S4GUI/S4ACS | 9915 |
| 4° | 13-19 jun | PE | Yes | S4GUI/S4ACS | 9915 |


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Martioli, E., Hébrard, G., Correia, A. C. M., Laskar, J., Lecavelier des Etangs, A., 2021, Astronomy & Astrophysics, 649, A177

Rodrigues, C. V., Cieslinski, D., and Steiner, J. E., 1998, Astronomy and Astrophysics, 335, 979

Rodrigues, C. V., et al., 2012, in American Institute of Physics Conference Series, Hoffman, J. L., Bjorkman, J., Whitney, B., 252

Schlindwein, W., et al., 2022, Boletim da Sociedade Astronômica Brasileira, 34 (this proceedings)


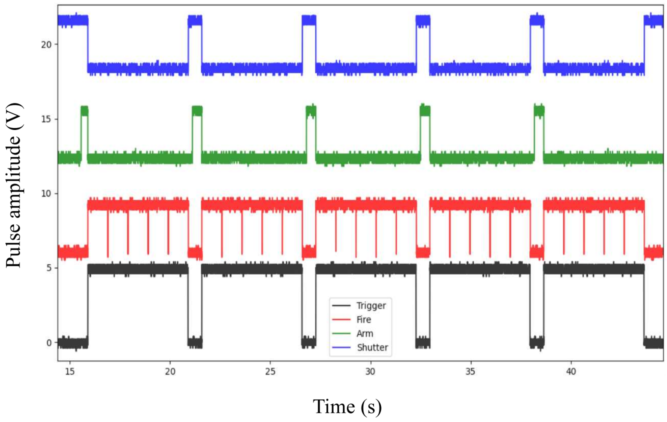


**Figure A.1.** Pulse signals *Shutter* (blue), *Arm* (green), and *Fire* (red) as a function of time. In addition to these, the external trigger signal (black) has been added as a reference.

## Appendix A: Digital pulses of the EMCCD cameras

EMCCD cameras used in SPARC4 present a set of digital pulses related to the image acquisition process. Some of them can be used in the synchronization of the image acquisition in the polarimetric mode of SPARC4. Among these signals, *Fire*, *Arm*, and *Shutter* can be highlighted. The *Fire* signal defines the time interval in which the camera's chip is exposed to the incidence of light. The *Arm* indicates when the camera is ready to receive an external signal to trigger the acquisition. The *Shutter* indicates whether the camera shutter is open or closed[3]. The rising edge of the *Fire* signal follows the start of the high state of the *Shutter*, after a delay given by the shutter opening time. The camera control system also automatically adds the shutter closing time to the *Shutter* signal at the end of an acquisition sequence.

Based on the characteristics presented, an experiment was carried out to evaluate the behavior of the *Arm*, *Fire*, and *Shutter* signals of the cameras during an acquisition. For that, the acquisition of 5 series of 5 images each was performed. Each image was acquired with an exposure time of 1 s. The external trigger mode and automatic shutter mode were used. The acquisition of the signal of each pulse was performed using an oscilloscope. The result is shown in Figure A.1. This figure shows a graph over time of the signal states of the *Shutter* (blue), *Arm* (green), *Fire* (red), and the external pulse (black), used as reference. This external pulse was programmed to be in a high state for a time interval equal to the exposure time of the series. From the graph, it can be seen that the *Shutter* signal is in a low state only during exposures. The *Arm* is in a high state when the camera is ready to receive an external pulse. The *Fire* is high when exposing and reading an image. Between two consecutive images, the *Fire* switches to the low state during a time interval of 50 ms.

Among the signals presented by Fig. A.1, the *Shutter* can be discarded, since the SPARC4 cameras will operate with the shutter always open. Therefore, it is concluded that the *Fire* pulse is the best choice to signal the end of image acquisition. To overcome the low state problem between images, an electronic filter will be used. Furthermore, the *Arm* pulse will be used to signal the sync box when the cameras are ready to receive a new external pulse. This procedure prevents a pulse from being sent to the cameras before they are ready for the next acquisition.

[3] https://neurophysics.ucsd.edu/Manuals/Andor%20Technology/iXon%20Ultra%20888%20Hardware%20Guide%201.0.pdf