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The PAU Camera

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Abstract

The PAU Camera (PAUCam) is a wide-field camera designed to be mounted at the William Herschel Telescope (WHT) prime focus, located at the Observatorio del Roque de los Muchachos in the island of La Palma (Canary Islands). Its primary function is to carry out a cosmological survey, the PAU Survey, covering an area of several hundred square degrees of sky. Its purpose is to determine positions and distances using photometric redshift techniques. To achieve accurate photo-z's, PAUCam will be equipped with 40 narrow-band filters covering the range from 450 to 850 nm, and six broad-band filters, those of the SDSS system plus the Y band. To fully cover the focal plane delivered by the telescope optics, 18 CCDs 2k $\times$ 4k are needed. The pixels are square of 15 μm size. The optical characteristics of the prime focus corrector deliver a field-of-view where eight of these CCDs will have an illumination of more than 95% covering a field of 40 arc minutes. The rest of the CCDs will occupy the vignetted region extending the field diameter to one degree. Two of the CCDs will be devoted to auto-guiding. This camera have some innovative features. Firstly, both the broad-band and the narrow-band filters will be placed in mobile trays, hosting 16 such filters at most. Those are located inside the cryostat at few millimeters in front of the CCDs when observing. Secondly, a pressurized liquid nitrogen tank outside the camera will feed a boiler inside the cryostat with a controlled massflow. The read-out electronics will use the Monsoon architecture, originally developed by NOAO, modified and manufactured by our team in the frame of the DECam project (the camera used in the DES Survey). PAUCam will also be available to the astronomical community of the WHT.

1 Introduction

PAUCam is a wide-field camera built in the framework of the PAU project, Physics of the Accelerating Universe (http://www.pausurvey.org), a *Consolider Ingenio* 2010 project coordinated by Dr. Enrique Fernández, who is also involved in the development of this instrument. The main goal of this project is to study the apparent acceleration in the expansion of the universe observed by several cosmological experimental probes.

The PAUCam will be mounted in the William Herschel Telescope (hereafter WHT) prime focus, a 4 m class telescope sited in the Observatorio del Roque de los Muchachos (La Palma, Canary Islands, Spain) and operated by the Isaac Newton Group (hereafter ING).

Simulations indicate that PAUCam at the WHT will be able to image about 2 square degrees per night in 40 narrow-band filters plus six broad-band filters to an AB magnitude depth of $i \sim 23$, providing low-resolution ($R \sim 50$) photometric spectra for around 30 000 galaxies, 5 000 stars and 1 000 quasars.

The PAU Survey will image an area of 100–200 square degrees with 40 narrow-band filters. Our simulations indicate that it is possible to obtain a redshift precision better than $0.0035(1+z)$ for 70% of the imaged galaxies. With these observations it would be possible to obtain competitive measurements of the dark-energy equation of state parameters, comparable to other much larger spectroscopic and photometric surveys now taking place or planned for the near future. The competitive edge of our approach, compared to other photometric surveys, resides in the possibility of measuring distances with the precision corresponding to the scale of the transition from linear to non-linear matter fluctuations. We want to be able to trace the linear matter fluctuations in three dimensions while the broad-band photometric surveys can only do it in two, rendering the number of independent modes that can be measured per unit surveyed area much smaller. Moreover, there are measurements such as redshift space distortions that cannot be done without precise radial distances. PAU is also competitive when compared with the current generation of spectroscopic surveys, due to the larger number of objects measured over a large volume of space extending to $z \sim 1$.

When not in use by PAU, the PAUCam will be available as a community instrument. PAUCam is able to determine spectral energy distributions (SED) of moderate resolution for a very large sample of objects, allowing the study of a variety of scientific topics beyond Cosmology. The filter system is being designed to include six broad-band filters as well as additional space for mounting possible special-purpose filters provided by the users.

2 Design

We based the design of the focal plane on three points:

- Optical telescope design: with the information provided by the ING, the unvignetted field of view in the WHT prime focus is 40 arcmin, 60 arcmin vignetting to 50%. These diameter angles on the sky correspond to a physical size of 137 and 205 mm respectively.

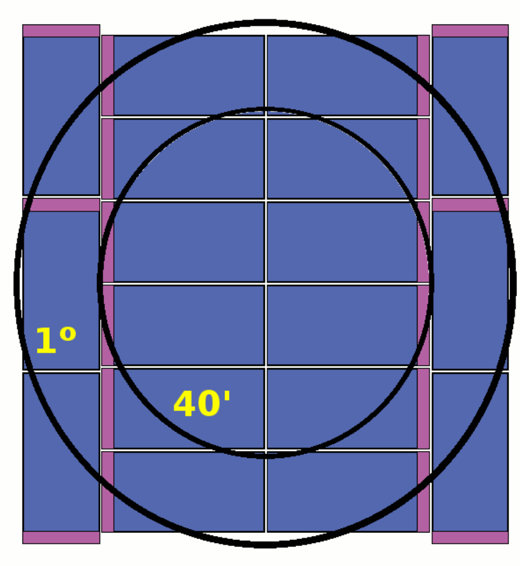

Figure 1: Distribution of the CCDs in the PAUCam instrument, optimized for a 60 arcmin field of view and the chosen detectors.

- Working wavelength: to achieve the milestones of the PAU Survey we must cover the wavelength range from 450 nm to 850 nm.
- Physical detector characteristics: in order to fill the field of view we need a detector mosaic with dead areas as small as possible. This is easier to achieve with large area detectors. A good option is to use CCD detectors with 2k $\times$ 4k with square pixel of 15 μm size. These CCD detectors are manufactured by different providers. With this pixel size, the scale at the focal plane is 0.26 arcsec/pix, sufficient to sample images taken with normal seeing conditions obtained with this telescope.

Figure 1 shows the PAUCam CCD distribution, optimized for the field of view of the WHT prime focus. This configuration allows to fill the 50% vignetted field of view and more. Two CCDs located in the vignetted area will be used for guiding. Also, a future upgrade of the WHT prime focus could allow a field of view of two degrees with the same scale [1]. With the adequate optical configuration and a new interface, PAUCam could immediately cover a field of view of one square degree.

2.1 CCD detectors

Several CCD detector manufacturers can provide devices with the suitable characteristics for the spectrographic range. That is, 2k $\times$ 4k with square pixel of 15 μm size, ratio between dead area and active area close to zero and high quantum efficiency between 450 nm and 850 nm. However, wide filter observations will require a more extended wavelength range. Both our scientific programme and the astronomical community using our instrument will benefit

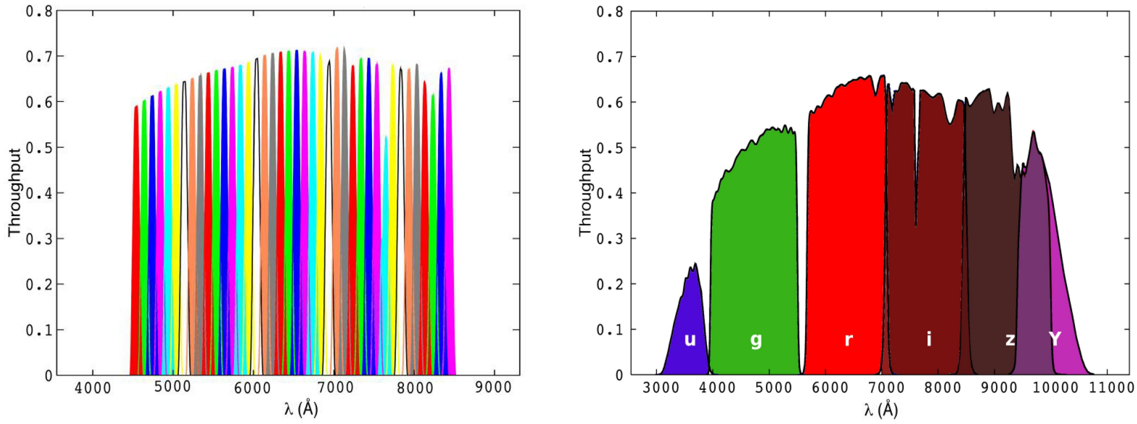

Figure 2: Theorical throughput for the forty narrow-band filters (*left*) and for the six broad-band filters (*right*). These are calculated with models of the atmosphere, telescope and filter transmision and the quantum efficiency of HPKK detectors.

from having a wavelength range from 300 nm to 1100 nm. Some manufacturers have already developed the needed multilayer coating improvements to achieve this wavelength range.

The CCD detectors manufactured by Hamamatsu Photonics (HPKK) achieve the requirements for the survey strategy in terms of readout speed and noise.

All CCD detectors will be checked for acceptance and then characterized. To do these operations, two experimental setups were built, one in Barcelona and another one in Madrid [3]). These setups are complementary facilities. One of them will work with the readout electronics involved in the PAUCam and the other one will characterize each CCD detector (i.e., readout noise, best working temperature, absolute quantum efficiency, gain, etc.).

2.2 Filters

PAUCam will incorporate narrow and broad-band filters (Fig. 2).

2.2.1 Narrow band filters

To comply with the science requirements, PAUCam should obtain a low resolution spectra ($R \sim 50$) for each pixel. To achieve this we will use 40 filters covering the range of 450 nm to 850 nm in steps of 10.0 nm. The overlap between adjacent filters must be minimum, for that, we need a filter with a transmission profile as close as possible to a Heaviside function.

We have more filters than detectors and therefore we need to be able to move the filters. In order to minimize vignetting filters must be placed very close to the detectors (a few millimiters), inside the camera. Thus, they need to work in a vacuum and a cryogenic environment.

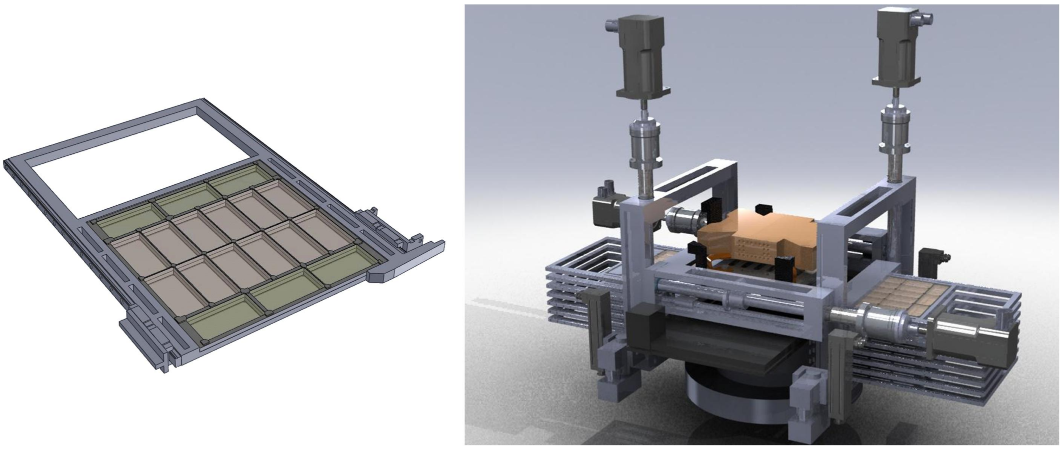

Figure 3: *Left*: One filter tray with the holders to install each narrow and broad band filter. *Right*: Filter tray interchange system with sixteen trays.

2.2.2 Broad band filters

PAUCam will have six broad-band filters: u, g, r, i, and z of SDSS and Y.

2.3 Filter trays

Filter trays are exchanged with a jukebox mechanism inside the camera. Figure 3 shows one of the trays and the mechanical system to move them. See [2] for more details.

2.4 Cooling system

We will use liquid nitrogen (LN) for the cooling system given the facilities available at the ING site. The components of the cooling system are: a deposit for 25 l for the LN, a boiler and cold plate connected by straps to the focal plate. With a controlled massflow valve, heaters and thermal sensors it is possible to adjust the temperature at an adequate value to operate the detectors with an oscillation of 0.1 K.

2.5 Electronics

The PAU project takes advantage of the know-how obtained by its supporting institutes through their collaboration at the design and production of the electronics of the DES project. Thus, the acquisition system of PAUCam will be based on an upgrade of the Monsoon system. Monsoon is a high-density electronics system designed by NOAO for a new generation of astronomical instruments.

This system was adapted to the PAUCam design. The focal plane of the PAU camera will have 18 CCDs. Thus, one Master Control Board, three 12-channel Acquisition Boards and two Clock Boards will complete the 6-slot backplane required for reading out the PAU camera detectors. In addition, it is foreseen an additional 4-slot backplane for the guiding CCDs. Also, an external interface board along with kapton cables inside the camera will be designed to redistribute video and clock signals to the 18 CCDs.

2.6 Control system

A slow control system based on a motion controller PLC will be designed. The main duties of this system will be to control the camera status, to execute commands coming from the PAUCam Control System (PCS), to generate basic camera security warnings and alarms, and to implement basic security procedures to guarantee the correct camera operation.

The slow control system is also a motion controller, which is in charge of all servomotors on the camera (filter trays, kinematic mounts and shutter).

Another main task of the slow control system is to read all sensors of the camera and to implement an interface to serve all data to the PAUCam Control System.

In a reduced number of circumstances, the Slow Control System will take complete control of the camera and enter into security mode (e.g. power failure, communication failure with PCS, etc).

To couple the telescope and the camera, a software interface called PAUCam Control System will be designed. The system should be able to read basic information from the telescope (online status), to process the data together with its own needs and to send a logic action to the telescope. All this communication is carried out between the WHT Instrument Control System (ICS) and the Observation Control System (OCS) using the CORBA standard. We plan to implement a software-based autoguider that will provide centroids directly to the Telescope Control System (TCS) through the serial port server.

Acknowledgments

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