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Commissioning, on sky performance and first operations of JPCam, a 1.2 Gpixel camera for the wide-field 2.6m Javalambre Survey Telescope

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Abstract

Commissioning results, on-sky performance and first operations of the Javalambre Panoramic Camera (JPCam) are presented in this paper. JPCam is a 1.2 Gpixel camera deployed on the 2.6m, large field-of-view Javalambre Survey Telescope (JST250) at the Observatorio Astrofísico de Javalambre (OAJ). JPCam has been conceived to perform J-PAS, a photometric survey of several thousand square degrees of the northern sky in 56 optical bands, 54 of them narrow-band filters (145 $\AA$ FWHM). To this aim, JPCam is equipped with a mosaic of 14 9.2k x 9.2k, 10μm pixel, low noise detectors from Teledyne-E2V, providing a FoV of 4.1 square degrees with a plate scale of 0.2267$''$/pix. In full frame mode, camera electronics allows read times of 10.9s at 633kHz read frequency (16.4s at 400kHz) with a readout noise of 5.5e$^-$ (4.3e$^-$). Its filter unit admits 5 filter trays, each mounting 14 filters corresponding to the 14 CCDs of the mosaic and allowing all the J-PAS filters to be permanently installed. To fully optimize image quality, position of JST250 secondary mirror and JPCam focal plane are maintained optically aligned by means of two hexapod systems. To perform this task, JPCam includes 12 auxiliary detectors, 4 for autoguiding and 8 for image quality control through wavefront sensing.

1 Introduction

The Javalambre Physics of the Accelerated Universe Astrophysical Survey (J-PAS[1]) is a Spanish-Brazilian collaboration to conduct an innovative photometric all-sky survey of thousands of square degrees of the Northern Sky [1, 2]. It will observe through a set of 54 contiguous, narrow band optical filters (145 Å width each, placed $\sim$ 100 Å apart), plus two broad band filters at the blue and red sides of the optical range to reach aperture magnitude depth of AB = 22.5 - 23.5, depending on the wavelength (5σ in 3$''$ aperture). Adjacent filters have a certain overlap ensuring a spectral measurement over the whole spectrum from about

[1] `http://j-pas.org`

320nm to over 1050nm with 56 different spectral channels without any significant modulation as a function of the redshift.

The survey will be carried out at the OAJ using the dedicated 2.55m JST250 Telescope, characterized by a very large Field of View (3 degree diameter), and the JPCam, a 1.2 Gpixel camera spanning an area of 4.1 square degrees with its 14 large format CCD mosaic.

1.1 Javalambre Survey Telescope - JST250

The main telescope at the OAJ is the JST250[3], an innovative Ritchey-Chrétien-like, alt-azimuthal, large-etendue telescope with an aperture of 2.55 m and 3 deg diameter FoV. The effective collecting area of JST250 is $3.75\,\mathrm{m}^2$, yielding an etendue of $26.5\ \mathrm{m}^2\ \mathrm{deg}^2$. Motivated by the need of optimizing the etendue, JST250 is a very fast optics telescope (F#3.5) with a plate scale of $22.67''$/mm. To guarantee the above image quality over the entire focal plane, the JST250 includes a unique field corrector of 3 lenses of fused silica, with 4 aspherical surfaces and diameters ranging from 62 to 51 cm.

In order to guarantee an optimal image quality control all over the entire FoV of the telescope, M2 is supported and controlled by a hexapod actuator. This allows to perform fine corrections of the M2 position in piston, x-y decentring and tip/tilt to compensate temperature changes and/or mechanical flexures at different telescope pointings.

2 JPCam, a 1.2Gpix camera for J-PAS

The main scientific instrument of the JST250 is the Javalambre Panoramic Camera (JPCam, Figure 1 left) [5], a 1.2 Gpixel camera conceived to perform J-PAS. The definition and procurement of JPCam was lead by CEFCA and the J-PAS Collaboration. The instrument has been funded by a consortium of several institutions from Spain (CEFCA and IAA-CSIC) and Brazil (ON, IAG/USP, and CBPF).

JPCam has been designed to maximize FoV and wavelength coverage while guaranteeing a high image quality over the whole focal plane and providing low read noise images. To this aim, JPCam is equipped with a mosaic of 14 CCD290-99 9.2k x 9.2k, $10\,\mu$m pixel, low noise detectors from Teledyne-E2V, providing an effective FoV of $4.1\mathrm{deg}^2$ with a plate scale of $0.23''$/pix. In full frame mode, camera electronics allows read times of 10.9s at 633kHz read frequency (16.4s at 400kHz) with a readout noise of $5.5e^-$ ($4.3e^-$). Its filter unit admits 5 filter trays, each mounting 14 filters corresponding to the 14 CCDs of the mosaic.

Because of the large FoV and fast optics, and to ensure optimum image quality, the JST250 secondary mirror and the JPCam focal plane are actively controlled with two hexapod actuators, the M2 hexapod and the JPCam Actuator System. This allows to perform fine corrections of the secondary mirror and instrument positions in piston, x-y decentering and tip/tilt to compensate for temperature changes and/or mechanical flexures at different telescope and instrument orientations. This is done through a wave-front curvature sensing and analysis technique developed at CEFCA [4, 5] that computes the optimal hexapod position for a given temperature and telescope pointing. To support this task, JPCam focal plane

Table 1: Main technical characteristics of the JPCam

CCD format	$14 \times 9216 \times 9232$ pix, $10\,\mu$m pix^{-1}
	1.2 Gpix camera
Pixel scale	$0.2265''$ pix^{-1}
FoV	4.1deg^2 – (14×) 0.56deg × 0,53deg
Read out time (633kHz)	10.9 s (full frame) – 6.1 s (2x2 binning)
Read out noise (633kHz)	5.5 e$^-$ (RMS)
Read out time (400kHz)	16.4 s (full frame) – 8.9 s (2x2 binning)
Read out noise (400kHz)	4.3 e$^-$ (RMS)
Gain	$2.274\, e^- ADU^{-1}$
Minimum exposure time	0.1 s
Exposure homogeneity	1 ms
Full well	$> 125\,000$ e$^-$
Dark current	0.001 e$^-$ pix^{-1} s^{-1}

includes 12 auxiliary detectors, 4 for autoguiding and 8 for image quality control through wave-front curvature sensing.

3 COMMISSIONING AND FIRST OPERATION

The three main JPCam subsystems (cryogenic camera, filter and shutter unit and actuator system) arrived at the OAJ at the end of 2016. These were independently accepted and commissioned at the OAJ, and then JPCam was fully integrated at the observatory clean room. Transportation from the clean room to the telescope and integration at the JST250

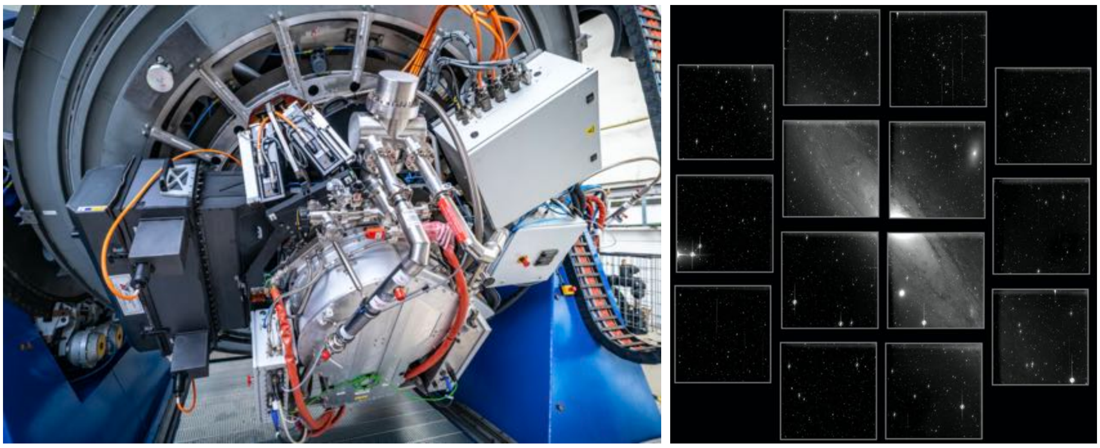

Figure 1: Left: JPCam fully integrated at the Cassegrain focus of the JST250 telescope. Right: JPCam first light image of the Andromeda (M31) local group galaxy

Cassegrain focus took place early 2020. In June 2020 JPCam observed the sky for the first time. Figure 1 (right) shows the JPCam technical first light image of M31 Galaxy.

During JPCam integration at telescope and first on-sky operation, the impact of the Covid Pandemic has been significant. During the years 2020 and 2021, the activity at the OAJ was reduced to a minimum level of maintenance to guarantee the survival of the infrastructure. In this context, development activities at the observatory, including JPCam first on-sky tests, had to be postponed until the health situation allowed them to restart safely. The other main adversity JPCam commissioning is facing is related with the control CCD electronics. During the first on-sky operation of JPCam various electronics failures have been experienced on different science drive modules. Understanding the root cause of these failures has represented a challenge to the instrument team and the cryogenic camera manufacturer due to the high complexity of JPCam electronics. The failures root cause is now understood and a modification on the JPCam electronics to correct it has been designed. The implementation of the required modification is planned for early 2023. For this reason, not all CCDs have been available and operative during JPCam commissioning and first operation, and this is why some of the on-sky performances and results shown in Section 4 are presented using 12 CCD images, instead of the 14 CCDs JPCam is equipped with. It is expected that all 14 scientific CCDs are available at the beginning of JPCam regular scientific operation in Q1 2023.

4 ON-SKY PERFORMANCES

4.1 Cryogenic stability

JPCam focal plane temperature and pressure stability tests have been performed for different telescope positions, both for the elevation axis and the instrument rotator, and over a wide ambient temperature range. Cryogenic stability has been monitored during long periods of time. Focal plane average temperature is controlled to a value of -112^{o}C with a variation across the focal plane (border to centre) of 1.27^{o}C and a stability of 1.06^{o}C p-t-v.

4.2 Image quality

Image quality of large FoV telescopes and fast optics have additional challenges and tighter tolerances than conventional telescopes. Therefore, is mandatory to check the image quality of the telescope in real time and make adjustments of the positions of the secondary mirror and instrument positions. In the case of JST250 equipped with JPCam, optimal image quality can be achieved measuring optical aberrations analyzing intra- and extra-focal images. Once aberrations are characterized, corrections are set to re-position M2 hexapod and JPCam focal plane. Figure 2 shows an example of achieved JPCam IQ during an observing run with atmospheric seeing of $\sim$0.55$''$ FWHM (left) and the cumulative distribution of achieved FWHM during the first months of operation (right)

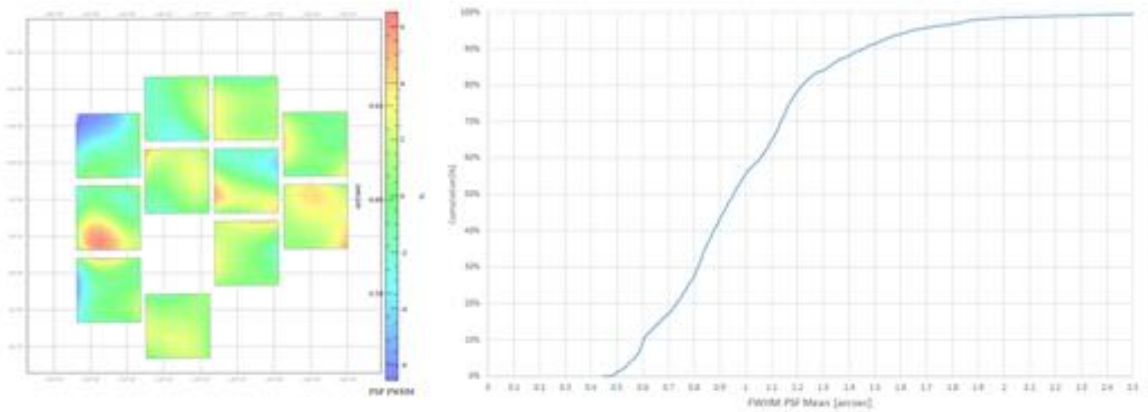

Figure 2: Left: 2D FWHM map across JPCam FoV. Note that the two areas with FWHM $\sim 0.57''$ and $\sim 0.63''$ are a surface fitting artifact due to a border effect and low star detection density around a saturated object, respectively. Atmospheric seeing during observations was $\sim 0.55''$ FWHM. Right: cumulative distribution of achieved FWHM during the first months of operation

4.3 Read-out noise

The read-out noise (RON) was measured in the two read-out frequencies, 400 kHz and 630 kHz, and in full frame and 2×2 binning configurations.

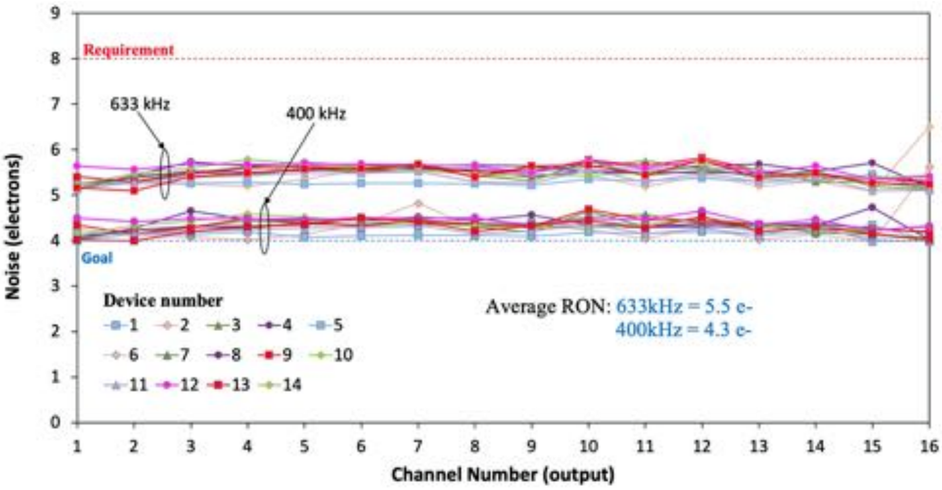

Figure 3: JPCam RON measurements. Each data point corresponds to the mean of the measurements obtained for each read-out noise, image format (full frame or binned 2×2), amplifier (from 1 to 16) and CCD device (from 1 to 14).

Results are shown in Figure 3, where the mean of the measurements in each of the 4 CCD setups, 14 CCDs and 16 amplifiers are represented by a data point. The read-out noise established in the design phase as a requirement and as the goal are shown for reference too. In full frame mode, camera electronics allows read times of 10.9s at 633kHz read frequency (16.4s at 400kHz) with a readout noise of 5.5e$^-$ (4.3e$^-$)

4.4 Zero point & limiting magnitude

We estimated the zero point of the system, noted ZP_0 and defined as the magnitude of a star that produces a flux of one electron per second in the top of the atmosphere, by including the gain of the detector and the typical extinction in the g band from the OAJ. This yielded $\mathrm{ZP}_0 = 26.15 \pm 0.05$ mag. This value is close to specifications for the analyzed g band. Additional observations are needed to minimise systematics and to estimate of the zero point for the narrow bands. The limiting magnitude of the g band calibrated images, estimated for $S/N = 5$ in a 3 arcsec diameter aperture, 60s exposure time, was $m_{\mathrm{lim}} = 23.04 \pm 0.03$ mag.

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