

## First light instrumentation for the Observatorio Astrofísico de Javalambre (OAJ)

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### Abstract

The Observatorio Astrofísico de Javalambre (OAJ) is a new astronomical facility located at the Sierra de Javalambre (Teruel, Spain) whose primary role will be to conduct all-sky astronomical surveys. The main OAJ facilities are two wide-field telescopes: the JST/T250, a 2.55 m telescope with a 3 deg diameter FoV, and the JAST/T80, a 0.83 m telescope with a 2 deg diameter FoV. These telescopes are equipped with panoramic cameras that have been designed to exploit the survey capabilities of the OAJ telescopes.

T80Cam will be mounted at the JAST/T80 and its large format CCD covers a large fraction of the JAST/T80 FoV with a pixel scale of  $0.55''\text{pix}^{-1}$ . The JST/T250 will be equipped with JPCam, a 14-CCD mosaic camera using the new e2v 9k-by-9k,  $10\ \mu\text{m}$  pixel detectors, providing a pixel scale of  $0.2''\text{pix}^{-1}$ . It is designed to perform the J-PAS, a BAO survey of the northern sky. The J-PAS survey will use 59 filters, 56 narrow-band filters (14.5 nm width) equi-spaced between 350 and 1000 nm plus 3 broad-band filters to achieve unprecedented photometric redshift accuracies for faint galaxies over  $8500\ \text{deg}^2$  of sky. In this paper, the OAJ first light instrumentation is presented.

## 1 Introduction

To carry out J-PAS [1] and J-PLUS surveys, the OAJ telescopes [2, 3, 4] will be equipped with JPCam and T80Cam, two panoramic cameras designed to exploit survey capabilities of the JST/T250 and the JAST/T80, respectively. As the overall effective etendue of a telescope plus instrument system is ultimately determined by the CCD filling factor, JPCam and T80Cam have been designed to maximize the telescopes focal plane coverage while maintaining the high image quality requirements.

JPCam and T80Cam are direct imaging instruments designed to work in a fast convergent beam at the Cassegrain foci that are based on state-of-the-art, high efficiency, low noise 9.2k-by-9.2k,  $10\ \mu\text{m}$  pixel CCDs specially developed by e2v for the J-PAS project. T80Cam will include a single CCD providing a useful FoV of  $2\ \text{deg}^2$  (65% focal plane coverage) with a plate scale of  $0.55''\text{pix}^{-1}$ . JPCam, on the other side, will include a mosaic of 14 CCDs providing a useful FoV of  $4.7\ \text{deg}^2$  (67% focal plane coverage) with a plate scale of  $0.2267''\text{pix}^{-1}$ . Moreover, JPCam will include 12 auxiliary detectors at the focal plane for guiding and wave front sensing.

The cameras are equipped with a filter unit designed to mount the complete J-PLUS and J-PAS filter sets. T80Cam includes two filter wheels with 7 positions each, this configuration allows the 12 J-PLUS filters to be permanently installed on the camera so no night-to-night filter exchange is required. Following the same low maintenance strategy, JPCam has been equipped with a filter tray magazine that includes up to five filter trays, each one mounting 14 filters. This filter unit design permits the 70 J-PAS filters to be permanently installed on JPCam.

The definition and procurement of JPCam and T80Cam is lead by a consortium of several funding institutions from Spain (CEFCA and IAA-CSIC) and Brazil (ON, IAG/USP, and CBPF). The funding of JPCam and T80Cam is guaranteed by that consortium, including the filter sets for both instruments. The commissioning of T80Cam and JPCam are planed for early of 2015 and early 2016, respectively.

## 2 T80Cam, the wide field camera for the JAST/T80 telescope

JAST/T80 will be equipped with an instrument designed to exploit the telescope survey capabilities, the T80Cam [9]. The JAST/T80 and T80Cam primary goal is to perform the photometric calibration of the JST/T250 surveys by means of the Javalambre-Photometric Local Universe Survey (J-PLUS). J-PLUS will image  $8500\ \text{deg}^2$  of the Northern Sky using 12 filters [8] in the optical range. These are a combination of narrow and broad-band filters carefully optimized to retrieve stellar parameters ( $T_{\text{eff}}$ ,  $\log g$ ,  $[\text{Fe}/\text{H}]$ ) through flux calibrated stellar models fitting [6].

T80Cam is a wide field, direct imager that will be installed at the Cassegrain focus of the JAST/T80. It is equipped with a backside illuminated e2v detector. This is a 9.2k-by-9.2k,  $10\ \mu\text{m}$  pixel, high efficiency CCD that is read from 16 ports simultaneously, allowing read times of about 12 s with a typical read noise of  $3.5\ e^-$  (RMS). This full wafer CCD covers

a large fraction of the JAST/T80 FoV with a pixel scale of  $0.55''\text{pix}^{-1}$ . Table 1 summarizes T80Cam performances.

Table 1: T80Cam performances

FoV (diameter)	1.7 deg (full performance) 2.0 deg (reduced performance)
EE50 (diameter)	$9\ \mu\text{m}$
EE80 (diameter)	$18\ \mu\text{m}$
CCD format	$9216 \times 9232\ \text{pix}$ $10\ \mu\text{m}\ \text{pix}^{-1}$
Pixel scale	$0.55''\text{pix}^{-1}$
FoV coverage	$2.0\ \text{deg}^2$ (fill factor 65%)
Read out time	12 s
Read out noise	$3.5\ \text{e}^- \text{pix}^{-1}$
Full well	$123\ 000\ \text{e}^-$
CTE	0.99995
Dark current	$0.0008\ \text{e}^- \text{pix}^{-1}\ \text{s}^{-1}$
Number of filters	12

The instrument consists of two main subsystems: the *Filter and Shutter Unit* (FSU) and the *Camera* subsystem (see Fig.1). The FSU holds two removable filter wheels and the shutter. The Camera subsystem, below, comprises the cryostat, the cooling and vacuum systems, the CCD, an optically powered entrance window and the detector electronics.

## 2.1 The Camera system

The Camera system is an 1110S camera manufactured by Spectral Instruments (Tucson, AZ, USA). It is equipped with a grade-1, backside illuminated e2v CCD, a 9.2k-by-9.2k,  $10\ \mu\text{m}$  pixel high efficiency CCD. This CCD has an image area of  $92.16\ \text{mm} \times 92.32\ \text{mm}$  and has a broadband AR coating for optimized performance from 380 to 850 nm.

Figure 2 shows the 1110S camera with an engineering CCD mounted during its manufacture at Spectral Instruments premises. The sensor is cryo-cooled to an operating temperature between  $-100$  and  $-110^\circ\text{C}$  with a cryo-tiger refrigeration system, a closed-cycle Joule-Thomson effect cryogenic refrigerator system. The chamber will be evacuated to a level of  $10^{-4}$  Torr using a turbo dry vacuum pump.

The camera entrance window is in fact the forth element of the JAST/T80 field corrector, and together with the filters, it is part of the telescope optical design optimization. The window is a 10 mm thick, weakly powered field-flattener with an 8 mm distance between its inner surface and the focal plane. The entrance window has been manufactured by Harold Johnson Optical Laboratories (Gardena, CA, USA).

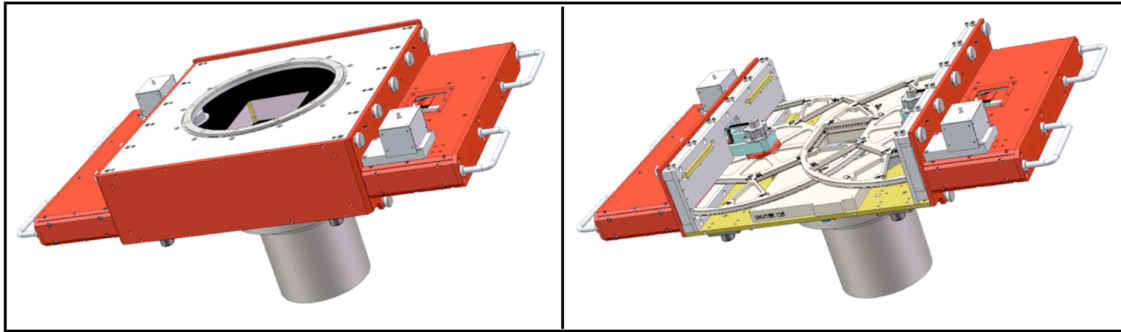


Figure 1: T80Cam design. *Left panel* shows the complete assembled instrument. The two main subsystems can be clearly identified. The top part of the instrument represents the FSU containing the shutter and the two filter wheels. The cylindrical-shaped object underneath the FSU represents the Camera subsystem. *Right panel* shows the same view of T80Cam after cover removal to show the two filter wheels and the shutter.

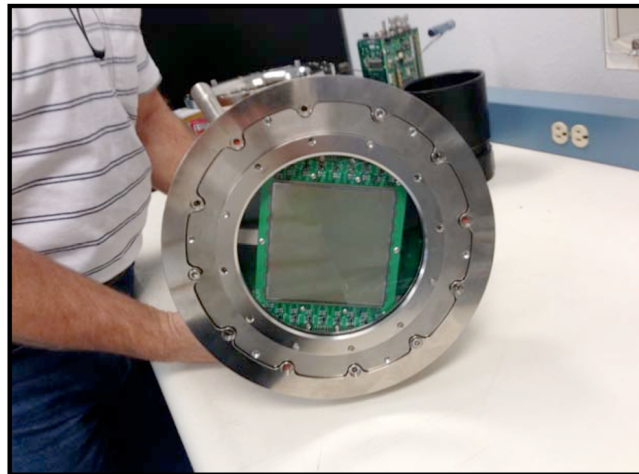


Figure 2: 1110S camera equipped with an engineering CCD during its manufacture at Spectral Instruments premises.



Figure 3: FSU during its assembly, integration and verification phase at CEFCA laboratory.

## 2.2 The Filter and Shutter Unit (FSU) system

The FSU has been designed and manufactured by the Instituto Nacional de Pesquisas Espaciais (INPE) and CEFCA. It includes the filter unit, the shutter and the cryostat support flange. The latter allows for fine alignment of the Camera system with respect to the telescope optical axis. The shutter is a 125 mm clear aperture shutter that has been acquired through the Argelander Institut für Astronomie. The FSU holds two removable filter wheels, each one capable of holding 6 filters plus an empty position. As it can be seen, filters are operating in a converging beam and close to the detector. Figure 3 shows the FSU assembly during its final stages of integration and commissioning at CEFCA premises.

Summarizing, T80Cam design has been driven by the main science goals defined by the Science Working group inside the J-PAS collaboration. The instrument has therefore been optimized to develop the J-PLUS survey. The commissioning and acceptance of T80Cam is planned for early 2015. In this time scale, the J-PLUS survey to be performed with this camera will start in the first half of 2015.

## 3 JPCam, the 1.2 Gpixel camera for the J-PAS survey

The main scientific instrument for JST/T250 is JPCam [10], a 1.2 Gpixel camera that will be installed at the Cassegrain focus. JPCam has been designed to perform the J-PAS survey, so maximizing the efficiency of FoV and wavelength coverage while guaranteeing a high image quality over the whole focal plane have been the main instrument design drivers.

JPCam is a wide field, direct imager equipped with a mosaic of 14 9.2k-by-9.2k,  $10\ \mu\text{m}$  pixel backside illuminated, low noise detectors from e2v. Each science CCD is read from 16 ports simultaneously, allowing read times of 12 s with a typical read noise of  $5\ e^-$  (RMS,

goal). Its filter unit has been designed to admit 5 filter trays, each mounting 14 square filters corresponding to the 14 CCDs of the mosaic. Each CCD will view only its corresponding filter avoiding optical cross-talk from their neighbors. The filters will operate close to, but upstream from, the dewar window in a fast converging beam. With this configuration, JPCam will cover  $4.7 \text{ deg}^2$  (67% focal plane coverage) with a plate scale of  $0.2267'' \text{ pix}^{-1}$  and will allow all the 70 required filters (59 J-PAS filters [8] plus several copies of the broad-bands) to be permanently installed on the camera, so no night-to-night filter exchange will be required.

Because of the JST/T250 very wide FoV, combined with the confirmed excellence of the OAJ intrinsic site seeing, JPCam is required to fully optimize and maintain the image quality across the full focal plane of the mosaic. Optical analysis reveals that it is necessary, not only to guide the telescope and keep it optically aligned by adjusting the position of its secondary mirror, but also of the focal plane itself [5]. To perform this task JPCam includes an hexapod actuator system that is controlled thanks to a set of wavefront sensors in the periphery of the instrument FoV. So the JPCam 14 science CCD mosaic is complemented with 12 auxiliary detectors, 4 for auto-guiding (AG) and 8 for wavefront sensing (WFS) tasks. The auxiliary detectors are e2v frame-transfer devices fed by light from broad-band filters mounted in the edges and corners of each filter tray. Table 2 summarizes JPCam performances.

Table 2: JPCam performances

FoV (diameter)	3 deg
EE50 (diameter)	11 $\mu\text{m}$
EE80 (diameter)	22 $\mu\text{m}$
CCDs format	Science: $(14 \times) 9216 \times 9232 \text{ pix}$ , $10 \mu\text{m pix}^{-1}$ Guiding: $(4 \times) 1024 \times 1024 \text{ pix}$ , $13 \mu\text{m pix}^{-1}$ Wavefront sensing: $(8 \times) 2048 \times 2048 \text{ pix}$ , $15 \mu\text{m pix}^{-1}$
Pixel scale	$0.2267'' \text{ pix}^{-1}$
FoV coverage	$4.7 \text{ deg}^2$ (fill factor 67%)
Read out time	12 s
Read out noise	$5 \text{ e}^- \text{ pix}^{-1}$
Full well	$130\,000 \text{ e}^-$
CTE	0.99995
Dark current	$0.0006 \text{ e}^- \text{ pix}^{-1} \text{ s}^{-1}$
Number of filters	70

Therefore, JPCam final design includes the following three main subsystems (see Fig. 4):

- *Hexapod Actuator Subsystem* (HAS): The HAS attaches the cryostat to the Instrument Support Structure (ISS) through the Cryostat Support Structure (CSS) and provides the required focus and tilt adjustments to the focal plane. The HAS is being designed and manufactured by the company NTE-Sener (Barcelona, Spain).
- *Filter and Shutter Unit* subsystem (FSU): The FSU is mounted directly to the ISS and comprises the filter tray exchange mechanism and the shutter. The FSU is being

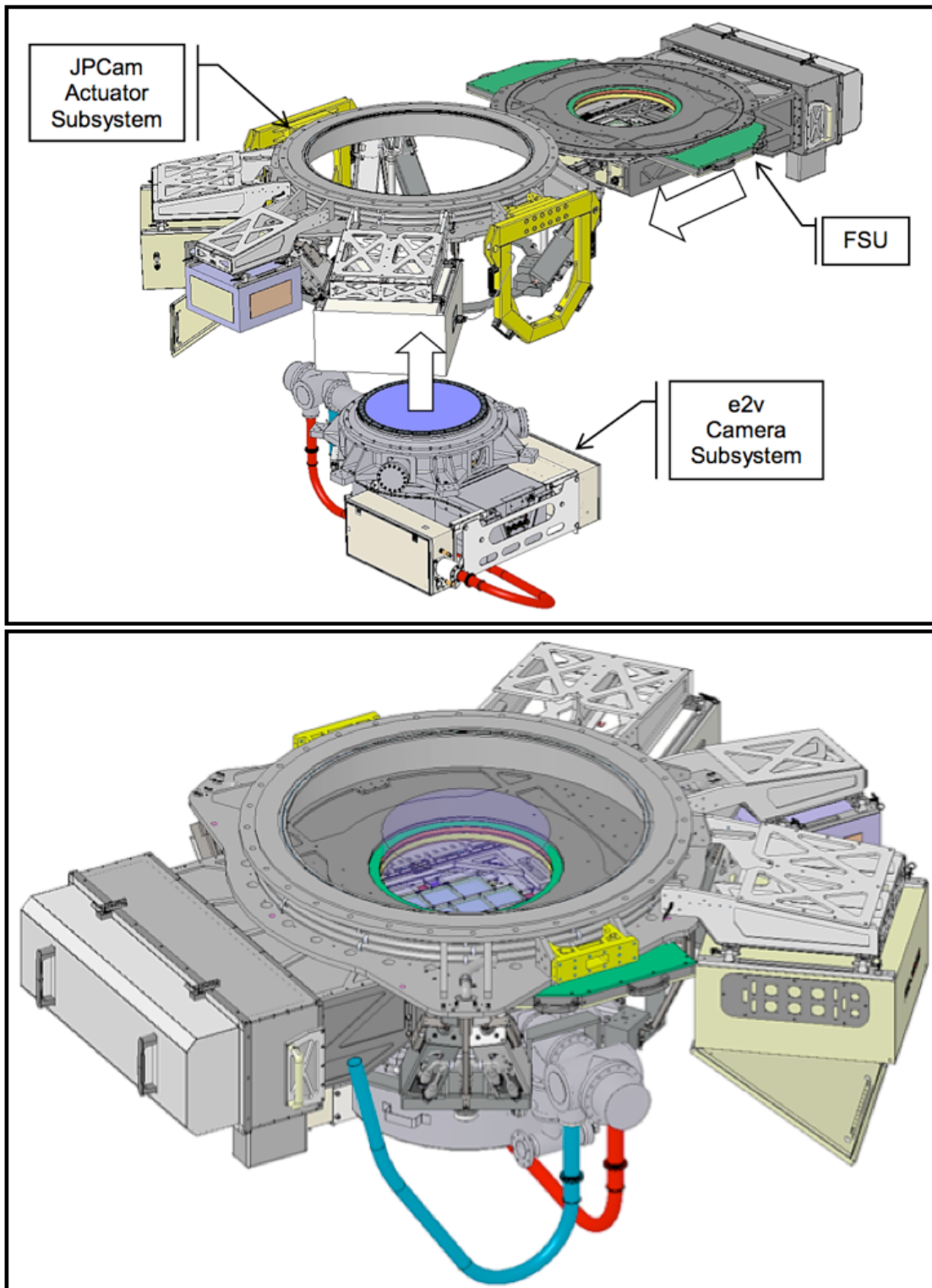


Figure 4: 3D model of JPCam. *Upper panel* shows a deployed view of the three mechanical subsystems. *Lower panel* shows the assembled instrument.

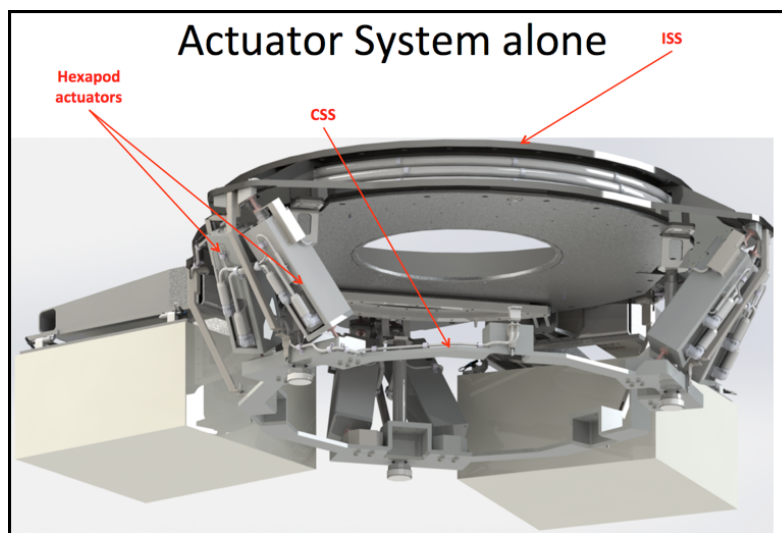


Figure 5: JPCam HAS

designed and constructed by a Brazilian-Spanish consortium led by INPE (Instituto Nacional de Pesquisas Espaciais) and CEFCA in Spain. The massive 515 mm aperture shutter is supplied by the Argelander-Institut für Astronomie, Bonn.

- *Camera* subsystem (CryoCam): The CryoCam comprises the dewar entrance window, the CCD mosaic and their associated controllers, the cooling and vacuum systems and the image acquisition electronics and control software. The CryoCam is being supplied by e2v under contract to J-PAS.

### 3.1 The Hexapod Actuator Subsystem (HAS)

The HAS is providing the CryoCam with focus and tip-tilt movement aimed to compensate the telescope deformation produced by the gravity and/or temperature changes. It will be able to move the CryoCam, whose weight is about 600 kg, with an accuracy of  $4\ \mu\text{m}$  (focus) and  $20''$  (tip-tilt). The main elements of the HAS are (see Fig. 5):

- ISS: it interfaces with the telescope flange, holds the FSU, and is the attachment to a set of actuators.
- CSS: supported by the set of actuators, it is in charge of keeping in place the CryoCam. It is the moving part of the HAS.
- Hexapod System and hexapod control electronics: six actuator assemblies attached to both the ISS and CSS configure the hexapod system.



### 3.2 The Filter and Shutter Unit (FSU) subsystem

The FSU is designed to admit 5 filter trays. All five of which contain 14 square filters each corresponding to the 14 CCDs of the detector mosaic. Additionally, the filter trays also have filter holders for broad-band filtering of the 12 auxiliary WFS and AG chips. Details of the FSU are shown in Fig. 6.

The 5 filter trays are selectable remotely so the FSU will include the motors and encoders and the control system needed for their operation. Each filter tray is designed to be easily and manually removable and exchangeable from the closed frame. Individual filters can be manually removable from their tray once the tray has been removed from the module.

The focal-plane of the T250 telescope is non-telecentric and hence, in order to retain the steepness of each intermediate-band filter bandpass profile and the uniformity of its wavelength centering, the filter must be held in each tray so as to induce a differential tilt in each of the 14 filters of the mosaic, so that each filter is perpendicular to the chief ray at its centre. Furthermore, in order to minimize the peripheral vignetting of the CCD by its corresponding filter, the distance between filters and CCDs is required to be as close as practical. A nominal gap of 4 mm between the filters and the dewar window has been chosen to allow for filter tray deployment and the necessity of pistoning the mosaic focal plane with the HAS.

The JPCam shutter has a 515 mm diameter aperture and is supplied by the Argelander-Institut für Astronomie, Bonn. It is a two-curtain shutter that guarantees an homogeneous illumination of the focal plane. It allows for exposures as short as 10 ms with an exposure uniformity better than 1 ms over the full FoV.

Finally, in order to prevent frost and/or condensation from forming on the large (about 550 mm diameter) dewar window, the FSU will be sealed and over-pressured with N<sub>2</sub>.

### 3.3 The Camera subsystem (CryoCam)

The CryoCam is being supplied by e2v [7]. The CryoCam design is shown in Fig. 7, while the layout of the focal plane cold plate is given in Fig. 8, where the 14 science sensors and 12 auxiliary guide and WFS CCDs are shown.

The data from the sensors is gathered in the Detector Electronics Box and transmitted via four Camera Link ports to three PCs, the science data, the AG and the WFS PCs. Two fibre optic channels are used to transmit the Science CCD data to reduce the data transmission time. The time to transfer a full image from JPCam to the science data PC is 8.4 s, lower than the read out time. The entire CCD is currently read out as if it were a single large image (9728 pix wide × 9265 pix high) and an additional line of status data is appended on the end.

The cryostat will cryo-cooled to an operating temperature between −100 and −110°C with LN<sub>2</sub>. A large LN<sub>2</sub> tank, mounted on the telescope fork, will feed the cryostat through routing of the flexible cooling lines via the telescope cable wraps, as required to accommodate both cassegrain and altitude rotation. The chamber will be evacuated to a level of 10<sup>−6</sup> Torr.

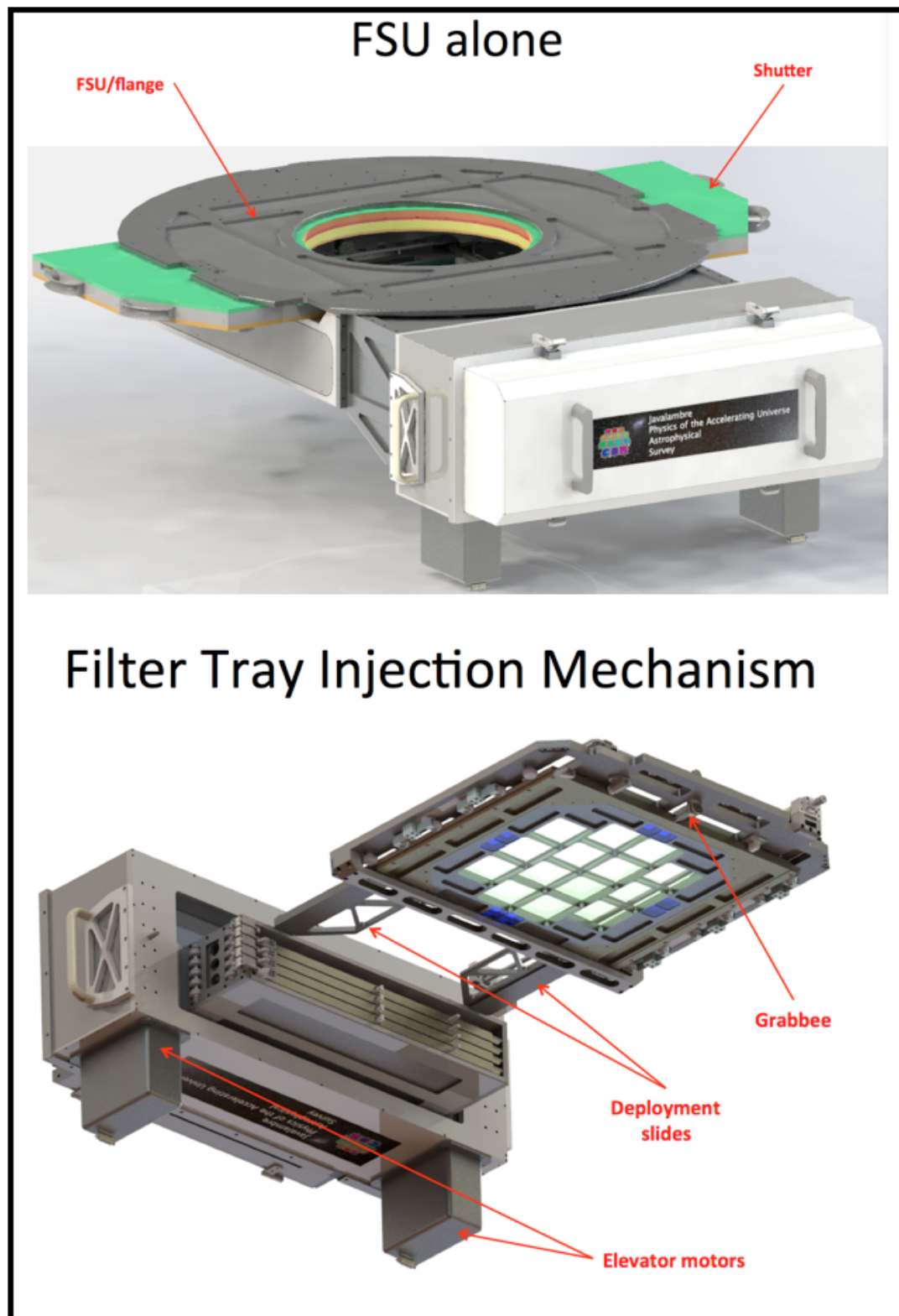


Figure 6: JPCam FSU (*top panel*) and a closer view to the filter tray injection mechanism (*bottom panel*)

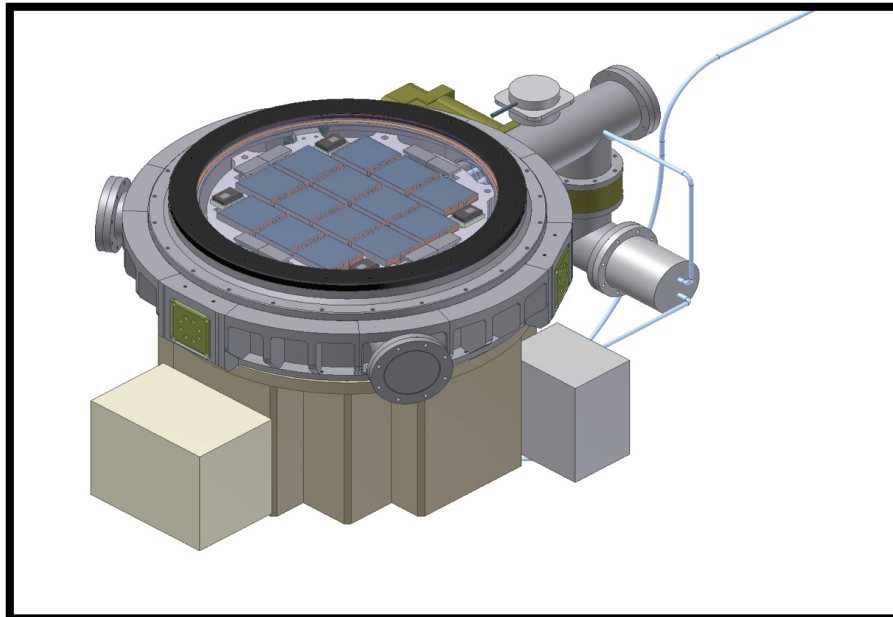


Figure 7: JPCam CryoCam 3D model.

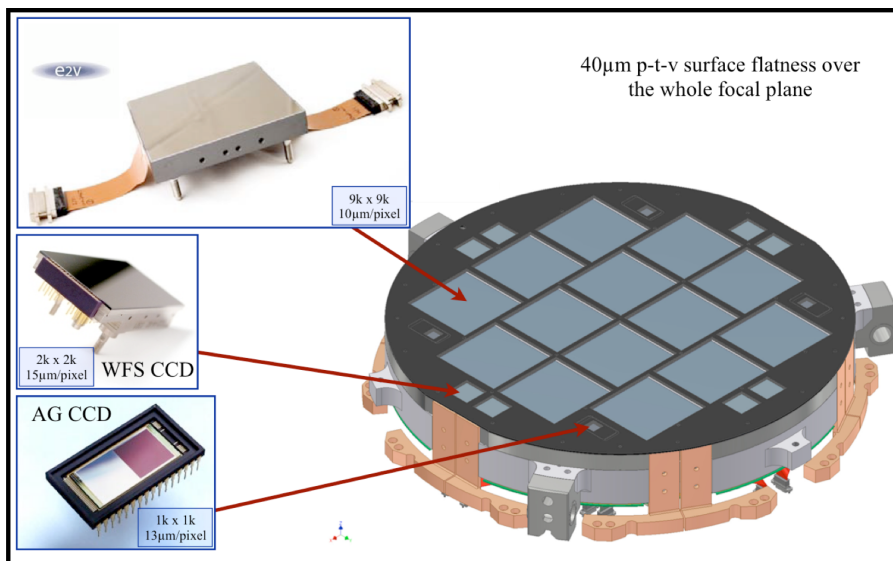


Figure 8: JPCam focal plane layout as supplied by e2v. The 14 loosely packed, full-wafer, e2v science sensors are shown mounted on the FPCP. In the periphery are mounted 4, 1k×1k frame-transfer (FT) guide CCDs and 4 pairs of 2k×2k FT WFSs. The black surface on top of the CCD mosaic is the light baffle intended to remove any undesired reflections inside the CryoCam. Thermal links are also shown.

The camera entrance window is in fact the forth element of the JST/T250 field corrector, and together with the filters, it is part of the telescope optical design optimization. The window is a 545 mm diameter and 27 mm thick, weakly powered field-flattener with an 8 mm distance between its inner surface and the focal plane mosaic.

Summarizing, JPCam design has been driven by the main science goal defined by the J-PAS collaboration, that is, the J-PAS survey. The commissioning and acceptance of JPCam is planned for late 2015, so the J-PAS survey should will start in 2016.

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