

JPCAM: A 1.2 GPIXEL CAMERA FOR THE J-PAS SURVEY

K. TAYLOR^{*}, A. MARÍN-FRANCH[†], R. LAPORTE[‡], F. G. SANTORO[§], L. MARRARA[¶],
 J. CEPAL^{||}, A. J. CENARRO[†], S. CHUECA[†], D. CRISTOBAL-HORNILLOS[†],
 A. EDEROCLITE[†], N. GRUEL[†], M. MOLES[†], F. RUEDA[†], S. RUEDA[†], J. VARELA[†],
 A. YANES[†], N. BENITEZ^{**}, R. DUPKE^{††}, A. FERNÁNDEZ-SOTO^{‡‡}, P. JORDEN^{§§},

G. LOUSBERG^{¶¶}, A. MOLINO BENITO^{**}, I. PALMER^{§§},
 C. MENDES DE OLIVEIRA^{*} and L. SODRÉ JR^{*}

^{*}Universidade de Sao Paulo, IAG
 Rua do Matao, 1226, Sao Paulo, 05508-900, Brazil

[†]Centro de Estudios de Física del Cosmos de Aragón
 Plaza San Juan 1, Planta 2, 44001 Teruel, Spain

[‡]Divisao de Astrofísica
 Instituto Nacional de Pesquisas Espaciais, Brazil

[§]New Mexico Tech/MRO
 101 East Rd, Socorro, NM, USA

[¶]TopCooler, Av. Dr. Carlos Botelho, 3526
 São Carlos/São Paulo, Brazil

^{||}Instituto de Astrofísica de Canarias
 38200 La Laguna, Tenerife, Spain

^{**}Instituto de Astrofísica de Andalucía (CSIC)
 Granada, Spain

^{††}Observatorio Nacional, Rua Gal. Jose Cristino
 20921-400, Rio de Janeiro, Brazil

^{‡‡}Instituto de Física de Cantabria (CSIC-UC)
 E-39005, Santander, Spain

^{§§}e2v Technologies
 106 Waterhouse Lane, Chelmsford, Essex, UK

^{¶¶}Advanced Mechanical and Optical Systems (AMOS)
 Rue des Chasseurs Ardennais 2, B-4031 Angleur, Liège, Belgium

Received 2013 January 23; Revised 2013 September 16; Accepted 2013 October 1; Published 2014 January 23

JPCam is a 14-CCD mosaic camera, using the new e2v 9k-by-9k 10 μ m-pixel 16-channel detectors, to be deployed on a dedicated 2.55 m wide-field telescope at the OAJ (Observatorio Astrofísico de Javalambre) in Aragon, Spain. The camera is designed to perform a Baryon Acoustic Oscillations (BAO) survey of the northern sky. The J-PAS survey strategy will use 54 relatively narrow-band (~ 13.8 nm) filters equispaced between 370 and 920 nm plus 3 broad-band filters to achieve unprecedented photometric red-shift accuracies for faint galaxies over ~ 8000 square degrees of sky. The cryostat, detector mosaic and read electronics, is being supplied by e2v under contract to J-PAS while the mechanical structure, housing the shutter and filter assembly, is being designed and constructed by a Brazilian consortium led by INPE (Instituto Nacional de Pesquisas Espaciais). The cryostat is bridged to the telescope via a hexapod actuator system to maintain image quality across the field. Four sets of 14 filters are placed in the ambient environment, just above the dewar window but directly in line with the detectors, leading to a mosaic having ~ 10 mm gaps between each CCD. The massive 500 mm aperture shutter is expected to be supplied by the Bonn-Shutter UG. We will present an overview of JPCam, from the filter configuration through to the CCD mosaic camera. A brief outline of the main J-PAS science projects will be included.

Keywords: Instrumentation, CCD camera, wide-field, Observatorio Astrofísico de Javalambre.

1. Introduction

JPCam is being developed as the primary camera for the Observatorio Astrofísico de Javalambre (Cenarro *et al.*, 2010a,b, 2012; Moles *et al.*, 2010) (OAJ), a new robotic observatory located at the Sierra de Javalambre (Teruel, Spain) whose primary role will be to conduct all-sky astronomical surveys. The OAJ's main telescope (the JST/T250) is a 2.55 m, f/3.5, telescope fitted with a 3° diameter wide-field corrector (WFC). The T250 telescope is being supplied by AMOS (Advanced Mechanical and Optical Systems, Belgium) while the WFC is sub-contracted to Tinsley Laboratories (California). The T250 will have a plate scale of 22.67"/mm with an unvignetted 3° field of view (FoV) corresponding to a diameter of 476.4 mm; JPCam itself is a 14-CCD close-packed, but not butted, mosaic of wafer-scale CCDs extended over the full FoV.

The goal of the T250 and its panoramic camera is to carry out the so called Javalambre PAU (Physics of the Accelerated Universe) Astrophysical Survey, hereafter J-PAS^(a) (Benitez *et al.*, 2009), a photometric all-sky survey of about 8,000 square degrees using 54 narrow band filters of 13.8 nm in band-width contiguously spanning a 370 to 920 nm wavelength range, plus two broad U and Z band filters (Marin-Franch *et al.*, 2012). An additional broad band R filter is also foreseen for deep imaging and weak lensing observations. The J-PAS survey will be completed in about 4–5 years from first light and is expected to reach a 3" aperture magnitude depth of AB = 22.5 — 23.5, depending on the wavelength, at a 5σ level.

JPCam has three main subsystems (see Fig. 2):

- The non-cryogenic subsystem, mounted directly to the instrument support structure (ISS), which comprises the filter exchange mechanism and shutter working at ambient temperature. In JPCam parlance, this is referred to as the filter shutter unit (or FSU);
- The cryogenic camera subsystem (or Cryo-Cam) comprising the entrance window to the dewar; the focal plane assembly, referred to here as the focal plane cold plate (FPCP), containing the science, wave-front sensors (WFSs) as well as acquisition and guide sensors (AGs) and their associated controllers; the cooling and vacuum

systems as well as the image acquisition electronics and control software;

- The Cryo-Cam is mounted neither to the FSU nor directly to the ISS but instead is bridged to the ISS via a hexapod actuator system (AS) which actuates the Cryo-Cam in response to the WFS signals from within the camera itself.

The structural layout allows the considerable weight of the Cryo-Cam to bypass the much lighter FSU which does not require to be actuated by the AS.

2. Technical Requirements and Functionality of JPCam

The goal of the system design of JPCam is to maximize the efficiency of field and wavelength coverage in the context of a system which has the 56 filters placed outside the Cryo-Cam dewar; a necessity given the number of filter exchanges required. This in turn implies that the filters are arranged in a set of filter trays where each filter isolates the light onto an individual CCD in the mosaic. Each detector then sees a subset of the 56 filters corresponding to the tray that is in use at the time. It thus becomes essential to maximize the CCD format while allowing for a significant gap between each CCD to avoid filter vignetting. Furthermore, given the required pixel sampling ($\sim 0.2''/\text{pixel}$ matched to the OAJ median seeing of 0.7"), detectors with pixels in the neighborhood of $\sim 10 \mu\text{m}$ are required. Full 6-inch wafer chips are now becoming available with formats up to $\sim 10\text{k}^2$; these are not yet fully (4-side) buttable, however they do allow JPCam to maximize its field coverage within the corrected FoV by minimizing, as much as is feasible, the optical distance between the “warm” filters and the “cold” CCD focal plane. Such geometrical considerations lead to a solution using a 14-CCD mosaic with the CCD distribution given as in Fig. 1. The FSU is consequently designed to admit 4 filter trays each containing 14 square intermediate-band filters corresponding to the 14-CCDs of the mosaic. In addition, there will be a 5th filter tray which will hold 14 identical broad-band filters for deep survey work. Each CCD will view only its corresponding filter with no cross-talk between them.

This design requires the filters to be as close as possible to the dewar window which then requires the shutter unit to be mounted above, but as close as possible, to the filters; a shutter aperture of $\sim 525 \text{ mm}$ is required. The shutter has to be able to

^a<http://j-pas.org>.

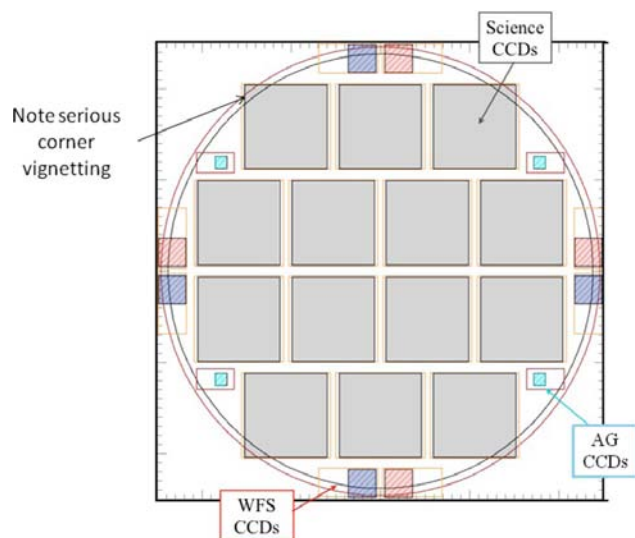


Fig. 1. (Color online) Conceptual layout of the JPCam detector focal plane prior to selecting the sensors. 14 full-frame, loosely packed, CCDs are shown populating the unvignetted FoV (black circle — the outer red circle represents the region of $<10\%$ vignetting). The small $1k^2$ CCDs (cyan) are guider chips while the larger $2k^2$ CCD pairs (blue/red) represent the intra- and extra-focal plane curvature sensors.

block and unblock the light going to the detector in such a way that the exposure times are uniform at the $>99\%$ level across the FoV. For such a large FoV, a homogeneous illumination can be achieved using “two-curtain” shutters. Similar shutters in size and requirements are produced by the Bonn University group for other large format imagers.^(b)

The science detectors were selected at the beginning of the program of work; e2v CCDs were chosen for their format ($9k^2$, $10\mu m$ pixel, 16-channel) and readout noise performance. The 14-CCD mosaic of e2v detectors can be almost completely inscribed by the FoV of the T250 telescope, as exemplified in Fig. 1. Within the periphery sectors not occupied by the detector mosaic, auxiliary CCDs are installed for guiding, focusing and wave-front sensing. The size of these auxiliary CCDs are maximized, while staying largely within the FoV of the T250 telescope and are required to have approximately the same pixel size as the science CCDs. A wave-front curvature sensing system, based on pairs of intra- and extra-focus sensors, commands the Telescope Control System (TCS) to maintain high fidelity imaging over the whole focal plane. Again e2v detectors were chosen for the guide and WFS chips.

^b<http://www.bonn-shutter.de/>.

JPCam’s control electronics is required to allow the user to modify the read-out time (up to a maximum pixel rate of ~ 2 MHz) and binning factor while defining regions of interest. The selection will be done through low-level routines controlled from a computer. Priority will be given to minimizing the read-out time, for a given read-out noise (RoN) level; to optimize this trade all 16 channels of the detector will be read out in parallel. The performance of the detector control electronics is required not to significantly degrade the intrinsic performance of the science detectors, although differential read circuitry is being carefully considered. After competitive analysis in light of JPCam’s requirements, e2v was selected to produce not only the detectors but also the full cryogenic camera system including focal plane integration and camera electronics (Jordan *et al.*, 2012). The FSU will be designed and constructed by a Brazilian consortium.

3. JPCam Structural Elements

Because of the T250 telescope’s very wide FoV combined with the confirmed excellence of the OAJ’s intrinsic site seeing, we are 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 continuously adjust the hexapod supporting the secondary (M2) mirror of the telescope, but also to supply semi-continuous positional actuation of the focal plane itself. The four curvature wave-front sensors in the periphery of the FoV, sampled every few minutes, give the information needed to correct both M2 and the camera’s focal plane, analysis of the motions of which have demonstrated the need for a further hexapod actuator system (AS) operating at the camera/telescope interface. The AS system will be supplied by the NTE-Sener group based in Barcelona, Spain.

Given the full-up ~ 650 kg weight of the cryostat holding the CCD mosaic, together with its associated electronics, cooling and vacuum system, the AS bridges directly the cryostat support structure (CSS) and the telescope’s instrument support structure (ISS), thus avoiding contact with the much lighter filter/shutter unit (FSU) whose flexure requirements are not at the level which would impact image quality. In this way, we avoid making the FSU, which carries much of the moving mechanisms of the system, structurally supportive of the

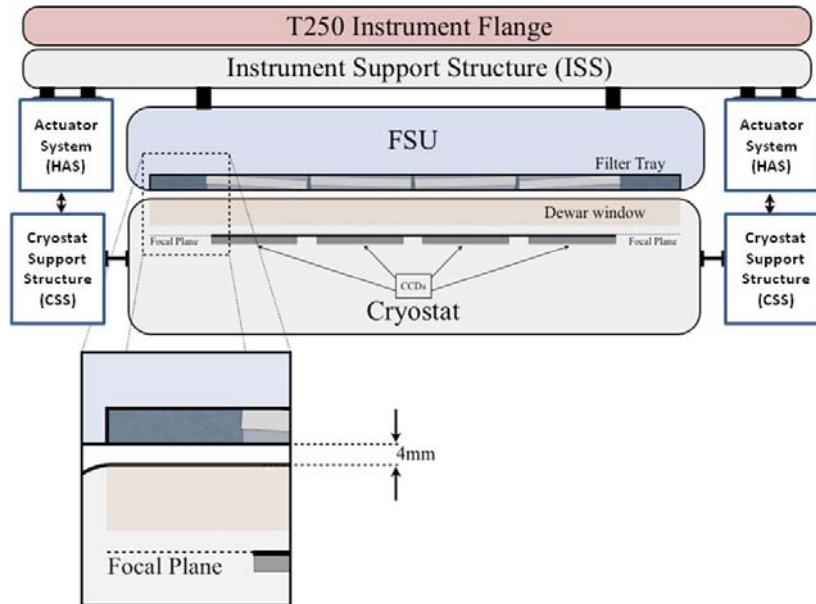


Fig. 2. The structural elements of JPCam showing the telescope interface flange directly mated with the ISS which supports the cryostat through linking the ISS with the CSS. Hexapod actuation of the cryostat with respect to the ISS is achieved through the AS which bypasses the more delicate mechanisms associated with the FSU.

much heavier cryostat. The structural assembly of JPCam is given in Fig. 2 which shows the linkages between its various elements.

Shown in the expanded view of Fig. 2 is the nominal, 4 mm, gap between the FSU filters and the cryostat window. It is this gap which is continually modified by the actuation of the AS which has a full piston range of ± 2 mm. Also to be noted is that the filters are tilted with respect to the optical axis of the system; this feature will be described in more detail in the following section.

4. The Filter/Shutter Unit

The Filter/Shutter Unit (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 wave-front sensing (8) and guider (4) chips. As shown in Fig. 1, some degree of vignetting is inevitable given the size of the science CCDs. If the gap between CCDs is increased, this then relaxes the requirement for close-packing of the filters. However, this is at the expense of an increase in vignetting at the corners of the mosaic. On the other hand, if the CCD gap is decreased, then the foot-print of the filters on their corresponding detector will give more uniform edge vignetting

around its periphery. The impact of such vignetting on the J-PAS survey efficiency was analyzed in some detail and it was concluded to reduce the CCD gap so as to minimize corner vignetting while uniformly vignetting the edges of all CCDs. In this way, the 56-deep data-cube created at each sub-field of the survey will be uniformly vignettted throughout its depth. This is in preference to the alternative of having corner vignetting which, while effecting only a subset (16) of the 56 filter images, actually compromises all 56-deep pseudo-spectra corresponding to corners throughout the data-cube; the second alternative thus actually has a much more profound degradation of the survey as a whole. The two alternatives are depicted in Fig. 3.

The focal-plane of the T250 telescope is non-telecentric and hence, in order to retain the steepness of each intermediate-band filter waveband 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 center. This amounts to a maximum tilt of $\sim 3.5^\circ$ for the outer filters of the mosaic equivalent to a ~ 6 mm departure from a flat surface. 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; as

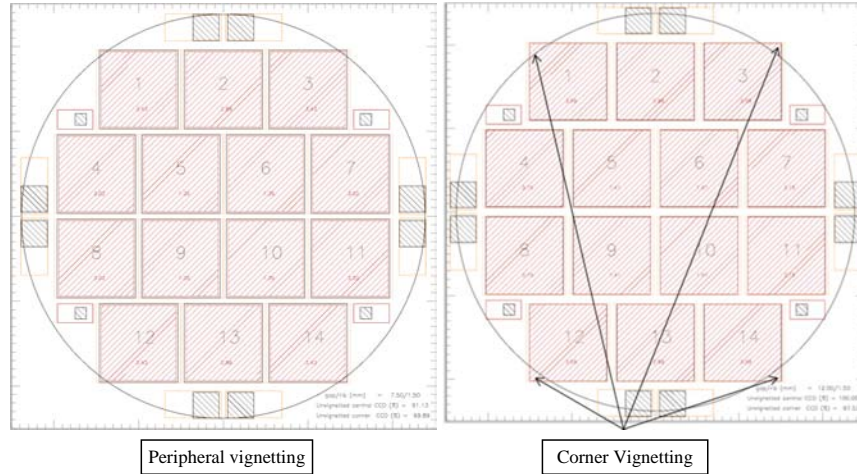


Fig. 3. (Color online) The two vignetting alternatives are shown. On the left-hand image the gap between detectors has been minimized which necessitates that the external filters are under-sized; this results in peripheral vignetting of each CCD. (The black squares represent the light sensitive areas of the detectors, while the slightly smaller, inner red squares shows the unvignetted areas.) The alternative is shown in the right-hand figure whereby the size of the filters can now be increased to permit a fully unvignetted detector (shown as red/black blended squares); in this case however, four corners of the mosaic (and the peripheral WFSs) are seriously vignetted.

stated previously, 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 AS. In order to prevent frost and/or condensation from forming on the large (~ 500 mm in diameter) dewar window, the full system from the T250 telescope's wide-field corrector through the FSU to the cryostat (as actuated by the AS) will be sealed and over-pressured with dry air or N_2 .

The 5 filter trays are selectable remotely so the FSU will include the motors, 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 remove, from their tray once the tray has been removed from the module. Details of the FSU are shown in Fig. 4 while the full system concept design, including the NTE-Sener actuator system and the e2v detector assembly is shown in Fig. 5. It should be emphasized that all these drawings are at a pre-Concept Design Review phase and hence should be regarded as work-in-progress and subject to change.

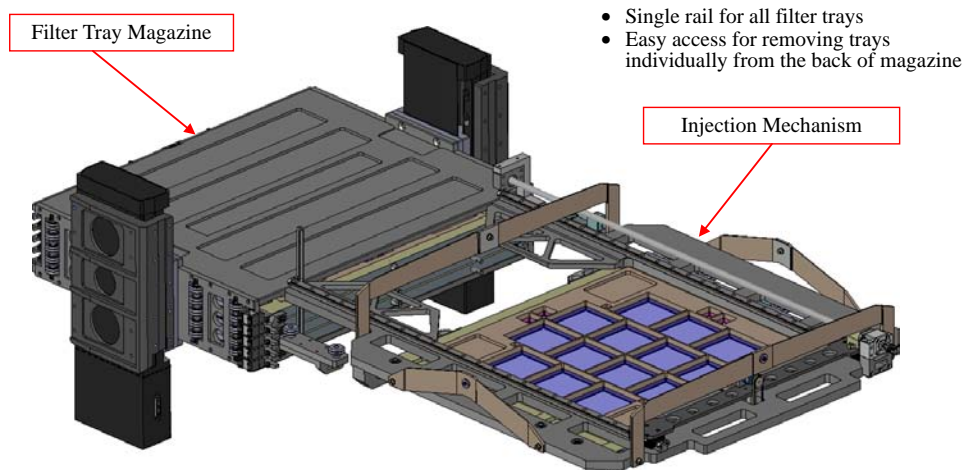


Fig. 4. Four filter trays, each containing 14, 13.8 nm bandwidth, survey filters and 12 broad-band auxiliary filters, are deployed above the focal plane using an exchange mechanism which selects the chosen filter tray from a magazine. Only the 4 filter trays, containing within them a total of 56 survey filters, are shown in the figure. Subsequent to this drawing, a requirement for an extra filter tray (5 in all) containing 14 identical broad-band R filters has been requested.

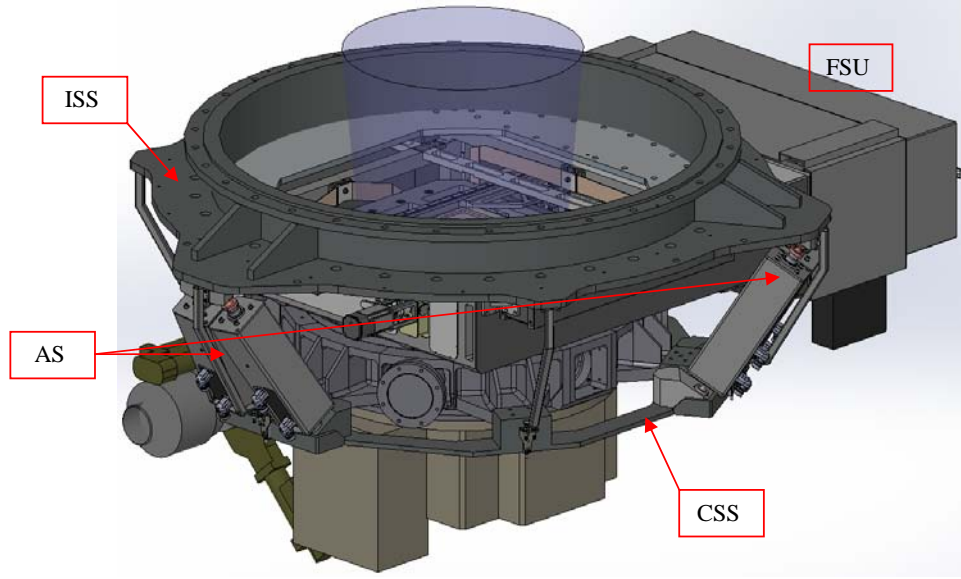


Fig. 5. The FSU module, seen from the telescope side, as mounted on the instrument support structure (ISS) which itself bolts directly to the telescope's cassegrain instrument flange. The AS actuator system is shown bridging the FSU spanning directly between the lower cryostat support structure (CSS) and the ISS.

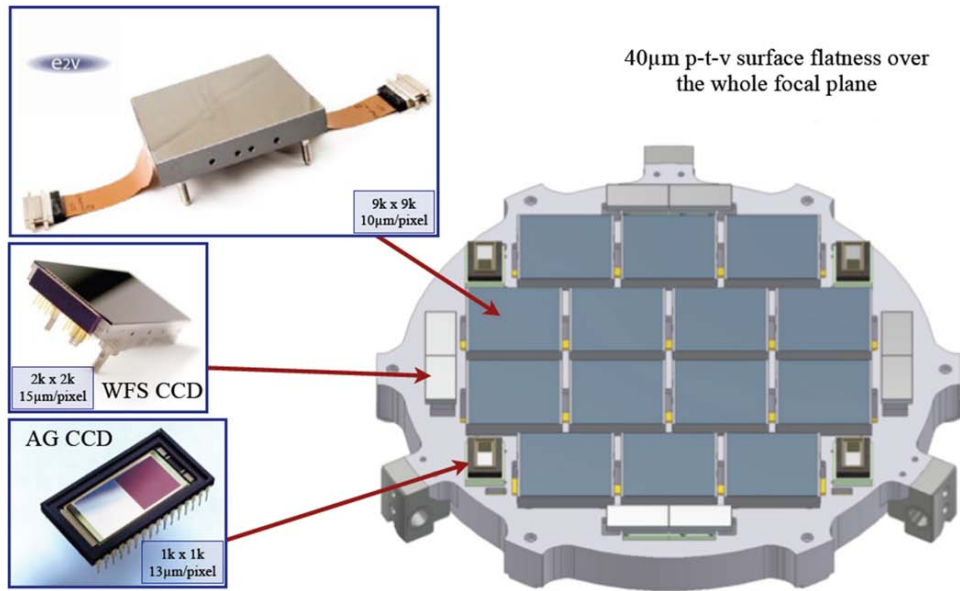


Fig. 6. JPCam's focal plane layout as supplied by e2v. The 14 loosely packed, full-wafer, e2v science sensors are shown mounted on the FPCP. In the periphery are mounted 4 $1k^2$ frame-transfer (FT) guide CCDs and 4 pairs of $2k^2$ FT WFSs.

5. Cryostat and Detector Focal Plane

The cryostat and detector focal plane for JPCam is being supplied by e2v (Jordan *et al.*, 2012). The layout of the focal plane cold plate (FPCP) is given in Fig. 6 where the 14 science sensors, 12 auxiliary guide and WFSs are shown. As a risk mitigation strategy in the context of a 4–5 year continuous survey, the cryostat will be LN_2 cooled. An large LN_2 tank will auto-feed the

cryostat through routing of the cooling lines via the telescope cable wraps and thence through two rotational couplers as required to accommodate both cassegrain and altitude rotation.

As stated previously, the cryostat is held directly to the instrument support structure (ISS) via the hexapod actuator system (AS) which is required in order to fully optimize image quality across the full FoV. In Fig. 7 we depict the curvature

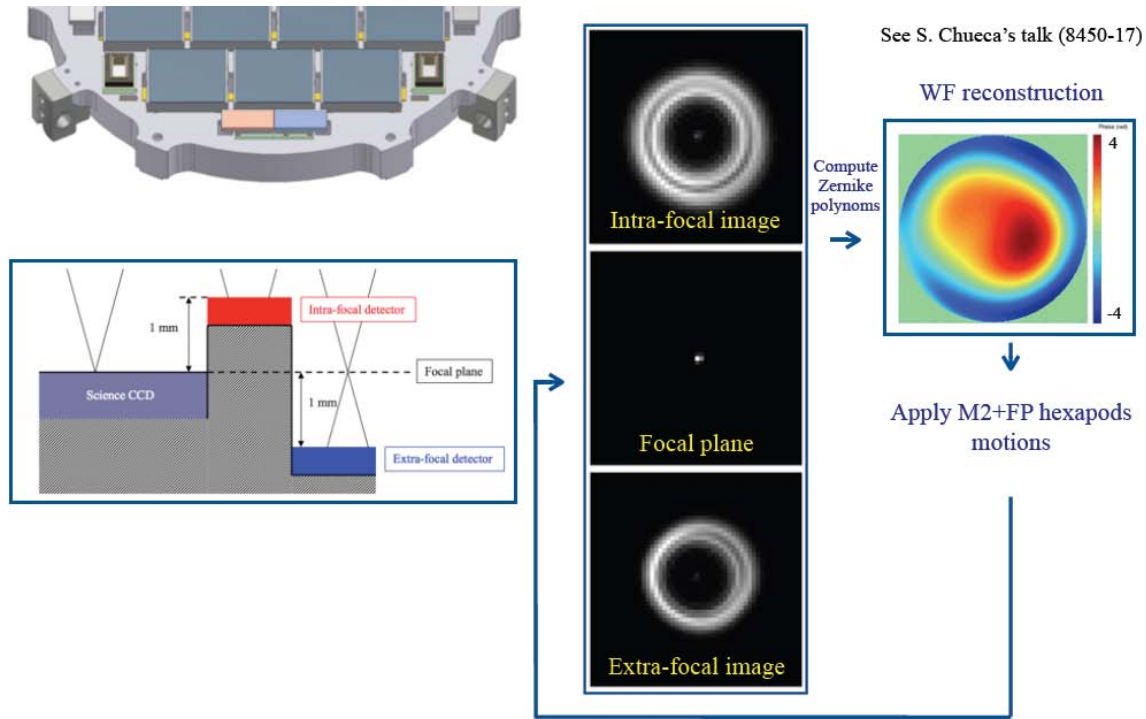


Fig. 7. Lower right depicts the intra- and extra-focal plane WFSs giving rise to alternate out-of-focus images which can be analyzed to compute Zernike polynomials which are used as inputs to the M2 hexapods and the AS.

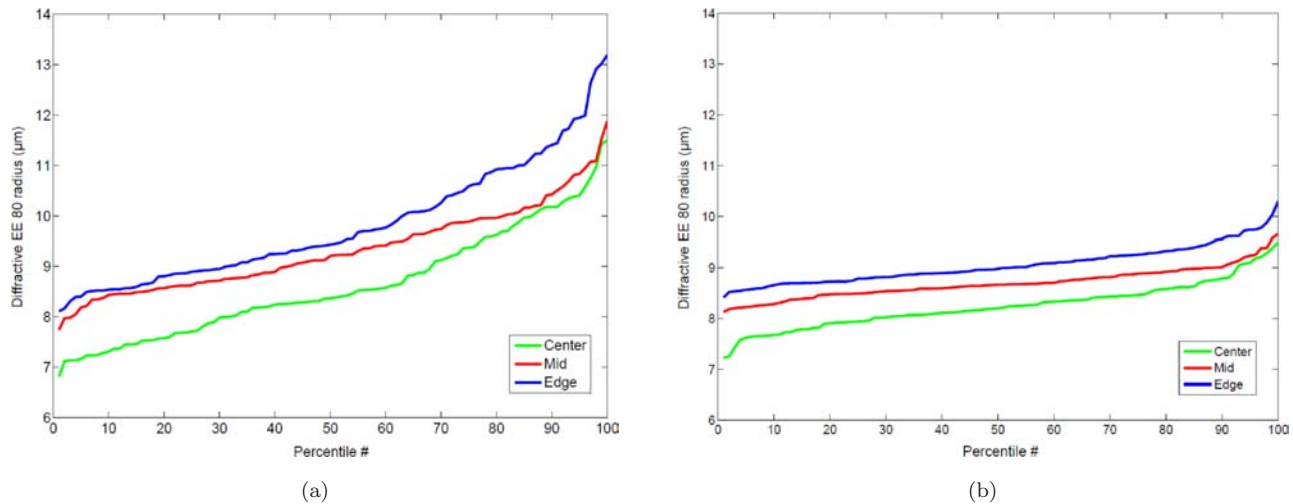


Fig. 8. The telescope performance as determined through Monte Carlo simulations of the estimated sub-system tolerances as given by AMOS; the statistical distributions are shown for three positions across the FoV. The left-hand graph shows the result of M2 actuation alone, while the right-hand graph incorporates piston correction in the focal plane, clearly demonstrating the need for the AS in order to optimize imaging performance. Tip/tilt optimization is required in both cases.

sensing method (Chueca *et al.*, 2012) that will be adopted to calculate the Zernike polynomials supplied to the M2 hexapod and the AS, while Fig. 8 shows the expected improvement in imaging performance. The 4 pairs of intra- and

extra-focal plane WFSs are offset from the focal plane by ± 1 mm; the $2k^2$ format of the WFS is sufficient to ensure the detection of several stars at the required SNR for each sensor every ~ 100 s.

6. Status and Schedule

All elements of JPCam are nearing the end of their concept design phases.

- FSU — Brazilian consortium, based in Sao Jose dos Campos, SP, Brazil;
- Cryostat camera — e2v, Chelmsford, UK;
- AS — NTE-Sener, Barcelona, Spain;
- Interface management — AMOS, Leige, Belgium.

These 4 entities came together in July 2012 to review progress and iron out critical interfaces. Once individual sub-assemblies have been through rigorous in-factory validation, we anticipate final assembly, integration and test at the T250 telescope to be scheduled to begin towards the end of 2014, with end of telescope commissioning and the beginning of J-PAS science sometime in Q1 of 2015.

Acknowledgments

We thank FAPESP and CNPq for funding of JPCam.

References

- Benitez *et al.*, 2009, *ApJ*, **691**, 241.
 Cenarro, A. J. *et al.*, 2010a, *Proc. SPIE*, **7738**.
 Cenarro, A. J. *et al.*, 2010b, *Highlights of Spanish Astrophysics*, **VI**, 680–685.
 Cenarro, A. J. *et al.*, 2012, *Proc. SPIE*, **8448**.
 Chueca, S. *et al.*, 2012, *Proc. SPIE*, **8450**.
 Jordan, P. *et al.*, 2012, *Proc. SPIE*, **8453**.
 Marín-Franch, A. *et al.*, 2012, *Proc. SPIE*, **8450**.
 Moles, M. *et al.*, 2010, *Highlights of Spanish Astrophysics*, **VI**, 73–79.