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# The Observatorio Astrofísico de Javalambre: current status and future developments

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## Abstract

The Observatorio Astrofísico de Javalambre (OAJ) is a new Spanish astronomical facility particularly conceived for carrying out large sky surveys, making use of two unprecedented telescopes of unusually large fields of view (FoV): the JST/T250, a 2.55 m telescope of 3 deg FoV, and the JAST/T80, an 83 cm telescope of 2 deg FoV. After two years of project development, JAST/T80 is already installed at the OAJ undergoing the first performance tests, and JST/T250 is fully assembled in the factory awaiting for the completion of the optics. We here provide an overall description of the project, indicating the current status of the main work packages and the next future developments.

## 1 Introduction

The OAJ [13, 2, 3, 4, 14, 5] is a new astronomical facility at the Pico del Buitre, in Teruel, promoted by the Centro de Estudios de Física del Cosmos de Aragón (CEFCA; http://www.cefca.es) to carry out large sky surveys with dedicated telescopes of very large FoV. These are the Javalambre Survey Telescope (JST/T250), a 2.55 m telescope with 3 deg FoV, and the Javalambre Auxiliary Survey Telescope (JAST/T80), an 83 cm telescope with a FoV diameter of 2 deg. The most immediate scientific goals of JST/T250 and JAST/T80 are two large sky multi-filter surveys, the Javalambre-PAU Astrophysical Survey (J-PAS; http://j-pas.org) and the Javalambre Photometric Local Universe Survey (J-PLUS), to be performed respectively with their first light panoramic cameras, namely JPCam and T80Cam.

J-PAS is an international project leaded by Spanish and Brazilian astronomical institutions that will image $\sim 8000\,\mathrm{deg}^2$ with JPCam at JST/T250, starting in 2015. J-PAS will use 54 contiguous filters of $\sim 138$ Å width (but spaced $\sim 100$ Å apart) in the range $3700-9200$ Å,

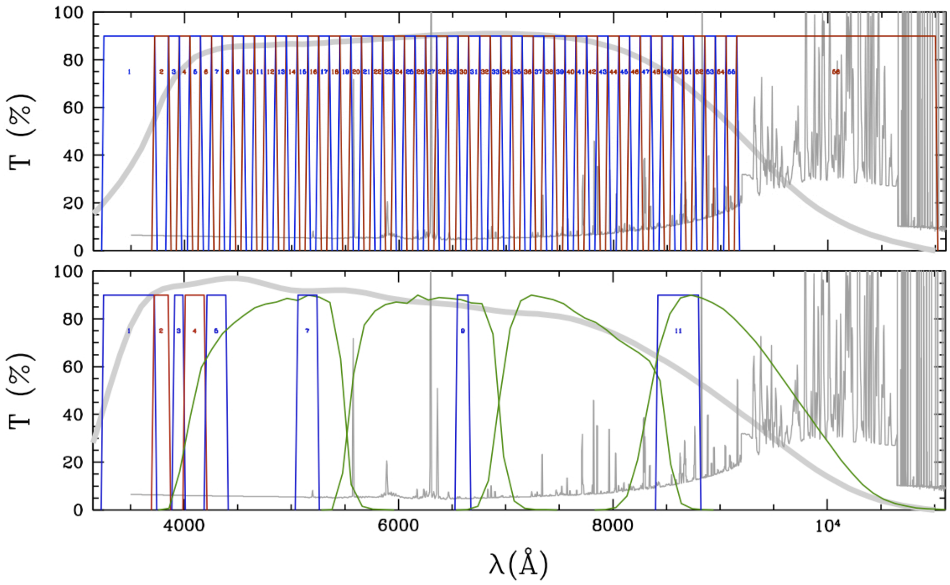


Figure 1: *Upper panel:* The set of 56 J-PAS contiguous filters. *Lower panel:* The set of 12 J-PLUS filters. Thick grey lines in both panels indicate the CCD quantum efficiency curves. Typical night-sky spectra are plotted in thin grey lines.

plus two broad $U$ and $Z$ band filters (see Fig. 1, *top*). The filter set is optimized to measure the radial scale of the Baryonic Acoustic Oscillations (BAO) as defined in [1]. With a magnitude depth ($5\sigma$; 3 arcsec aperture) of AB= $22-23$, depending on the wavelength, J-PAS will yield high-quality photo-$z$ ($\Delta z \sim 0.003(1+z)$) for around 100 million galaxies within an effective volume to measure radial BAO of $\sim$11 Gpc$^3$. In the end, the unique and most powerful characteristic of J-PAS is that it will provide a low-resolution ($R \sim 50$) spectrum for every pixel of the sky, hence behaving as an integrated field unit for the whole $\sim 8000\,\mathrm{deg}^2$ sky coverage. This fact promises important breakthroughs in many areas of Astrophysics, like e.g. large structure cosmology and Dark Energy, galaxy evolution, clusters of galaxies, stellar population studies, SNe, Milky Way structure, exoplanets, among many others.

J-PLUS constitutes the second long-term objective of the OAJ that will be performed with T80Cam at JAST/T80 during the first 2-3 years of operation. Starting in 2013, J-PLUS will cover the same sky area of J-PAS using 12 filters in the optical range (see Fig. 1, *bottom*): 4 SDSS filters ($g$,$r$,$i$,$z$)[9], which allow to anchor the photometry to that of the SDSS, 6 filters of $200-400$ Å width centered on key absorption features like H$\delta$, the G-band, Mgb/Fe lines, and the Ca triplet, for stellar classification and stellar population studies, and 2 NB filters in common with the J-PAS filter set that cover the rest-frame [OII]/$\lambda$3727 and H$\alpha$/$\lambda$6563 lines, for anchoring the J-PAS calibration and also mapping the star formation rate in nearby galaxies ($z < 0.017$). Despite the fact that the filter set is defined and optimized to carry out the photometric calibrations for J-PAS, the J-PLUS data will also allow conducting a manifold of challenging scientific programs. J-PLUS will reach $\sim 1$ mag deeper than SDSS in the 4 SDSS filters.

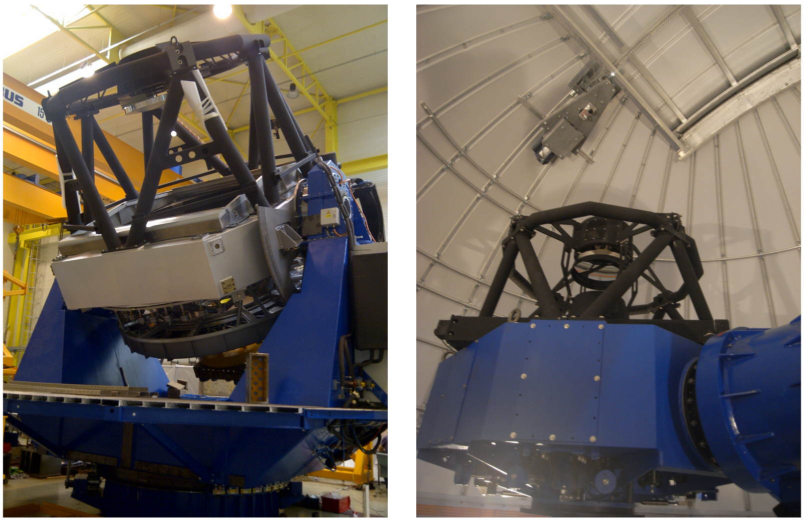

Figure 2: *Left panel:* The JST/T250 is integrated in factory with dummy optics. *Right panel:* The JAST/T80 is fully assembled at the OAJ with the final optics: aluminized mirrors and field corrector.

## 1.1 The OAJ survey telescopes

### 1.1.1 JST/T250

The centerpiece of the OAJ is the JST/T250 (Fig. 2; left), an innovative Ritchey-Chrétien-like, alt-azimuthal, large-etendue telescope with an aperture of 2.55 m and 3 deg (diameter) FoV. JST/T250 and its panoramic camera JPCam are driven by the scientific requirements to conduct J-PAS. The effective collecting area of JST/T250 is $3.75\,\mathrm{m}^2$, yielding an etendue of $26.5\,\mathrm{m}^2\mathrm{deg}^2$. With a plate scale of 22.67 arcsec/mm at the cassegrain focus, this is a very fast optics (F#3.5) and compact telescope, with a distance between M1 and M2 of only $\sim 2.2$ m. It weights $\sim 45$ tons and supports instrumentation of up to 1250 kg.

The JST/T250 design is optimized to provide a polychromatic, good image quality (EE50 $< 4.75\,\mu$m; radius) in the optical range (330–1100 nm) all over the 48 cm diameter focal plane ($7\,\mathrm{deg}^2$). For this reason it includes a field corrector of three lenses of fused silica with four aspherical surfaces and diameters of $\sim 50 - 60$ cm. The lenses are supported inside a barrel of low carbon steel specifically designed to keep their relative positions during operation using a passive hexapod structure made of INVAR. The barrel is rigidly connected to the fixed flange of the instrument rotator and sealed to the entrance window of JPCam, keeping a dry, slightly hyperbaric atmosphere around the lenses. The J-PAS filters and the JPCam entrance window are part of the optical design.

The guiding system consists of a set of four auxiliary CCDs at the edges of the JPCam focal plane. Furthermore, to keep the system in focus and preserving the image quality during the survey execution, eight additional CCDs located at the edges of the focal plane in extra and intra focal positions are foreseen to perform wave-front curvature sensing corrections in real time, as explained in [6]. The control system of JST/T250 will allow to work in continuous closed loop, analyzing the defocused images at the auxiliary CCDs and providing the Zernike coefficients to the telescope control system that converts it in M2 corrections in piston, tip and tilt to the M2 hexapod.

### 1.1.2 JAST/T80

The JAST/T80 has an 83 cm diameter M1 with a FoV of 2 deg. With a plate scale at the cassegrain focus of 55.56 arcsec/mm, is also a fast optics (F#4.5) and compact telescope, with just $\sim 830$ mm between M1 and M2. Mechanically, it has a German-equatorial mount (Fig. 2; right). With a weight of $\sim 2500$ kg, JAST/T80 supports instruments at the cassegrain focus of up to 80 kg. Together with its panoramic camera, T80Cam, JAST/T80 will be primarily devoted to perform J-PLUS and the photometric calibrations of J-PAS, although its large FoV and high sensitivity makes it ideal for many other scientific goals.

Like JST/T250, the optical design is based on a Ritchey-Chrétien configuration plus a field corrector of three spherical lenses of $150 - 170$ mm diameter. JAST/T80 is also optimized to work in the optical range, yielding a polychromatic image quality better than $4.25\,\mu$m (EE50; radius) inside the 13 cm diameter focal plane ($\sim 3.1\,\mathrm{deg}^2$), also accounting for the J-PLUS filters and the T80Cam entrance window in the optical path.

A 20 cm piggy-back telescope is attached to the JAST/T80 optical tube assembly to perform the guiding. Because of the large FoV, keeping the optics in focus and free of aberrations all over the FoV is expected to require small M2 corrections through the hexapod every few hours. For this reason, a specific procedure for wave-front curvature sensing has been designed at CEFCA, making use of the scientific CCD of T80Cam.

## 2 The OAJ panoramic cameras

To carry out J-PAS and J-PLUS, JST/T250 and JAST/T80 will be equipped with panoramic cameras, JPCam and T80Cam, based on state-of-the-art, large format CCDs. T80Cam will include a low-noise 10.5k×10.5kpix CCD of 9$\mu$m/pix by STA (http://www.sta-inc.net/), providing a useful FoV of $2\,\mathrm{deg}^2$ with a plate scale of 0.5 arcsec/pix. JPCam will include a mosaic of 14 9.2k×9.2kpix CCDs of 10 $\mu$m/pix specially developed by e2v (http://www.e2v.com/) for J-PAS, providing $\sim$70 % focal plane coverage with 0.23 arcsec/pix. Moreover, it will include 12 auxiliary e2v CCD sensors at the focal plane for guiding and wave front sensing. Overall, JPCam will have 1.3 Gpix covering $5\,\mathrm{deg}^2$, one of the largest digital camera before the arrival of the LSST camera in $\sim$ 2020. To improve the accuracy of the image quality corrections as requested by the wavefront sensing signals, an additional hexapod actuator subsystem attached to the cryostat of JPCam will allow piston and tip/tilt corrections of the focal plane. Since both cameras are designed to work in convergent beam at the cassegrain foci of the OAJ telescopes, they do not host optical elements others than the filters and the entrance windows. The filter unit for JPCam consists of a juke box of filter trays with 14 filters each. Two filter wheels with 7 filter positions each are foreseen for T80Cam. More details on the OAJ panoramic cameras and their filters can be found in [15], [11], and [12].

## 3 Current status and future developments

In May 2012, most of the OAJ civil work and buildings were received and operations at the OAJ officially started. Since then, main efforts have been focussed on the fine tuning and start up of the general installations, and of the small robotic telescopes for monitoring the seeing, the extinction and the cloud sky coverage.

The OAJ telescopes passed their preliminary and final design reviews in 2010 and 2011. At the time of writing this paper, JST/T250 is fully assembled at the contractor headquarters (AMOS; Belgium), undergoing the first functional tests (mechanical alignment and stability, main axes performance, control system, etc.) to proceed with the preliminary acceptance before the end of 2012. M1 and M2 are in very close to final polishing. The manufacturing of the three lenses of the corrector is complete at the $\sim 90\%$ level, one of them already finished, and all the mechanical components and assembly hardware for the barrel are ready for integration in the factory. According to the current schedule, the JST/T250 optics (mirrors and field corrector) will be ready for integration at the telescope at the beginning of 2013. Its arrival to the OAJ will depend on the installation of the dome at the OAJ, which is scheduled for spring 2013. In turn, JAST/T80 is finished and integrated at the OAJ, including the mirrors –already aluminized– and the field corrector. Currently we are conducting the fine alignment of the optics, after which we will proceed with the final performance tests and the scientific telescope commissioning. This will be done with a first light verification camera specifically designed and manufactured by CEFCA for this purpose.

The T80Cam mechanical design is finished and the mechanical parts are about to be fabricated. The STA 1600 CCD is already manufactured and thinned. All the electronics boards for the camera subsystem have been assembled and control software is under development. The design of the J-PLUS filters is finished and the manufacturing has started. According to our current schedule, T80Cam will be fully integrated and ready for scientific operation by March 2013. Once T80Cam is commissioned at the OAJ, JAST/T80 will start the execution of J-PLUS, which is expected to take $\sim 2$ years. Concerning JPCam, all subsystems are nearing the end of their concept design phases, and the final commissioning is planed for the end of 2014. Scientific execution of J-PAS is then scheduled to start in 2015.

A fully robotic operation of the OAJ will be possible in the future provided that JST/T250 and JAST/T80 are dedicated telescopes for J-PAS and J-PLUS, with JPCam and T80Cam being the only available instrumentation at the telescopes. Therefore, in general it will not be required the exchange of instrumentation. Also, the filter units of JPCam and T80Cam are designed to host the whole sets of survey filters simultaneously, so there will be no need for manual filter changes during the survey executions. In this sense, a significant effort is being made by CEFCA to guarantee a fully robotic and autonomous OAJ operation, both at the level of the OAJ installation and telescope control software and hardware [16] and at the level of the survey execution software manager [8], constituted by the J-PAS and J-PLUS schedulers and sequencers. Also of great importance is the automatic photometric calibration plan defined for both J-PAS and J-PLUS using the data provided by the extinction monitor [10], which will provide the extinction curve at the OAJ for every night. A crucial work package of the OAJ project aims at developing of a dedicated data center for handling, analyzing and storing in an efficient way the significant amount of data released by the OAJ telescopes during the survey execution [7]. With JPCam having $\sim 1.2$ Gpix in the 14 scientific CCDs and T80Cam amounting to $\sim 110$ Mpix, J-PAS and J-PLUS will produce 1.2 PB of data at a rate of 230 TB/year. The treatment of the $\sim 1.5$ TB per night coming from the two OAJ cameras will be performed during the day after the observations.

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## References

[1] Benítez, N., Gaztañaga, E., Miquel, R., et al. 2009, ApJ, 691, 241

[2] Cenarro, A. J., Moles, M., Cristóbal-Hornillos, D., et al. 2010, SPIE, 7738E, 26

[3] Cenarro, A. J., Cristóbal-Hornillos, D., Gruel, N., et al. 2011a, in *Highlights of Spanish Astrophysics VI*, M.R. Zapatero Osorio, J. Gorgas, J. Maíz Apellániz, J.R. Pardo, & A. Gil de Paz (eds.), p. 680

[4] Cenarro, A. J., Cristóbal-Hornillos, D., Gruel, N., et al. 2011b, in *Highlights of Spanish Astrophysics VI*, M.R. Zapatero Osorio, J. Gorgas, J. Maíz Apellániz, J.R. Pardo, & A. Gil de Paz (eds.), p. 771

[5] Cenarro, A. J., Moles, M., Cristóbal-Hornillos, D., et al. 2012, SPIE, 8444, in press

[6] Chueca, S., Marín-Franch, A., Cenarro, A. J., et al. 2012, SPIE, 8444, in press

[7] Cristóbal-Hornillos, D., Gruel, N., Varela, J., et al. 2012, SPIE, 8451, in press

[8] Ederoclite, A., Cristóbal-Hornillos, D., Moles, M., et al. 2012, SPIE, 8448, in press

[9] Fukugita, M., Ichikawa, T., Gunn, J. E., et al. 1996, AJ, 111, 1748

[10] Gruel, N., Moles, M., Varela, J., et al. 2012, SPIE, 8448, in press

[11] Marín-Franch, A., Taylor, K., Cepa, J., et al. 2012a, SPIE, 8446, in press

[12] Marín-Franch, A., Chueca, S., Moles, M., et al. 2012b, SPIE, 8450, in press

[13] Moles, M., Sánchez, S. F., Lamadrid, J. L., et al. 2010, PASP, 122, 363

[14] Moles, M., Cenarro, A. J., Cristóbal-Hornillos, D., et al. 2011, in *Highlights of Spanish Astrophysics VI*, M.R. Zapatero Osorio, J. Gorgas, J. Maíz Apellániz, J.R. Pardo, & A. Gil de Paz (eds.), p. 73

[15] Taylor, K., Marín-Franch, A., Laporte, R., et al. 2012, SPIE, 8446, in press

[16] Yanes, A., Rueda-Teruel, S., Antón, J. L., et al. 2012, SPIE, 8451, in press