

## **The *Observatorio Astrofísico de Javalambre*: telescopes and instrumentation**

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### **Abstract**

The *Observatorio Astrofísico de Javalambre* is a new observatory for professional astronomy under construction at the Sierra de Javalambre (Teruel, Spain). The observatory is mainly defined for carrying out large scale surveys in robotic mode. For this purpose there will be two main telescopes: T250, a large *étendue* telescope of 2.5 m aperture and 3 deg diameter field of view, and T80, a 0.8 m auxiliary telescope with a field of view diameter of 2 deg. The immediate objective of the T250 is to carry out the Javalambre-PAU Astrophysical Survey, a photometric survey of 8000 square degrees using 42 narrow-band filters ( $\sim 100\text{--}120\text{ \AA}$  width) in the optical spectral range. T80 will be mainly devoted to perform photometric calibrations for the survey. The two telescopes will hold panoramic cameras of large format ( $\sim 10\text{k}\times 10\text{k}$ ) CCDs located in convergent beam at their respective Cassegrain focii.

## **1 Introduction: CEFCA and the OAJ**

The *Centro de Estudios de Física del Cosmos de Aragón* (CEFCA; [www.cefca.es/](http://www.cefca.es/)) is a Center for Astrophysics and Cosmology in Spain which is in charge of the definition, design, construction and operation of the *Observatorio Astrofísico de Javalambre* (OAJ). The OAJ is a new, robotic observatory under construction at the Sierra de Javalambre, Teruel (Spain), particularly conceived and defined for conducting large scale surveys. It will host two telescopes: T250, a large *étendue* telescope with an aperture of 2.5 m diameter and 3 deg diameter field of view, and T80, a 0.8 m auxiliary telescope with a field of view diameter of 2 deg. The construction and integration of the OAJ telescopes is being carried out by the Belgian company Advanced Mechanical and Optical Systems (AMOS; [www.amos.be/](http://www.amos.be/)). More details on the project management and organization can be found in [2].

The OAJ is located at a new astronomical site: the Pico del Buitre at the Sierra de Javalambre, 1957 m above the sea level in Teruel. For more than two decades, the Pico del Buitre has been known to be a very good place for astronomical observations. Since 2007, a thorough site testing campaign carried out at the Pico del Buitre has confirmed that, indeed, it is an excellent place for ground based professional astronomy. In particular, according to the typical strengths of the sodium artificial and natural lines during a dark night, the site satisfies the International Astronomical Union (IAU) recommendations for a dark site. Also, based upon more than 100 000 seeing measurements in the last two years, the median value of the seeing in  $V$  band is  $0.71''$ , with a mode of  $0.58''$ . These and other details can be found in [3].

## 2 Scientific motivation for the OAJ

The OAJ has been defined as a joint astronomical facility to carry out surveys. It is worth noting in this sense the great capabilities of T250 for surveying the sky with an *étendue* of  $27.5 \text{ m}^2 \text{ deg}^2$ . The main astronomical survey which has motivated the design and construction of the OAJ aims at studying the Dark Energy equation of state through the analysis of the Baryonic Acoustic Oscillations (BAOs) along the line of sight, using photometric redshift for Luminous Red Galaxies (LRGs). This project has been defined within the *Consolider-Ingenio 2010* framework of the spanish *Ministerio de Ciencia e Innovación*, called “Physics of the Accelerated Universe” (PAU). This first survey, to be conducted at the OAJ, is named the Javalambre-PAU Astrophysical Survey (hereafter J-PAS). The immediate objective of the J-PAS is a photometric survey of 8000 square degrees, using 42 narrow-band filters in the whole optical range ( $\sim 100\text{--}120 \text{ \AA}$  width, from 3500 to 8500  $\text{\AA}$ ), following the specifications defined in [1]. According to recent simulations, this will allow to determine photometric redshifts for millions of LRGs with an accuracy better than  $\Delta z \sim 0.3\%$ .

In addition to the measurement of BAOs, the scientific outputs of J-PAS will be very fruitful for a wide range of topics. As a matter of fact, the J-PAS will provide low resolution ( $R \sim 30$ ) 2D spectroscopic data for all the objects within the 8000 square degrees down to  $m_{\text{AB}} < 23.5$  above the  $5\sigma$  level, with no selection bias other than the depth of the survey. More precisely, every pixel (or resolution element) of the J-PAS will have its corresponding photo-spectrum. Galaxy evolution, star formation rates at different redshifts, two-dimensional stellar population analysis, Milky Way structure studies, supernovae, gamma-ray bursts, very low mass objects, exoplanets, Solar System small bodies, etc. will highly benefit from the J-PAS data.

T80 is conceived for carrying out the necessary photometric calibrations for J-PAS. It is also foreseen that a significant percentage of the observing time will be devoted to other scientific programs such as the discovery of extragalactic tidal streams, the detection and follow-up of GRBs, the finding of extrasolar planets around  $V < 16$  stars, supernovae follow-up, studies of light curves of variable objects (QSOs, binary and variable stars), etc.

### 3 The OAJ telescopes

The main technical details of the telescopes T250 and T80 are presented in Table 1.

Table 1: Main technical characteristics of the T250 and T80 telescopes.

	T250	T80
Mount	Altazimutal	Equatorial
Configuration	Ritchey-Chrétien-like, equipped with a Field corrector and De-rotator	Ritchey-Chrétien
Focii	One axial Cassegrain	One axial Cassegrain
Aperture (M1 diameter)	2.55 m	0.826 m
Effective collecting area	3.89 m <sup>2</sup>	0.44 m <sup>2</sup>
Plate scale	22.67 arcsec/mm	55.56 arcsec/mm
Focal length	9098 mm	3712 mm
Field of view (diameter)	3.0 deg (476 mm)	1.7 deg (110 mm) full performance 2.0 deg (130 mm) reduced performance
Étendue	27.5 m <sup>2</sup> deg <sup>2</sup>	~ 1.5 m <sup>2</sup> deg <sup>2</sup>
Bandwidth	330 – 1100 nm	330 – 1100 nm
Image Quality (diameter)	50% EE ≤ 12 μm / 0.27 arcsec 80% EE ≤ 20 μm / 0.45 arcsec	50% EE ≤ 7 μm / 0.39 arcsec 80% EE ≤ 14.5 μm / 0.81 arcsec
Distortion	< 0.3%	< 1%

#### 3.1 T250

T250 is an alt-azimutal, large *étendue* telescope whose optical design is derived from a Ritchey-Chrétien configuration. The focal plane is flat and corresponds to a Cassegrain layout. The primary (M1) and secondary (M2) mirrors have an hyperbolic aspheric surface. The telescope is equipped with a field corrector to ensure the image quality all over the focal plane. It consists of 3 lenses of fused silica that combine spheric and aspheric surfaces, with diameters in the range 500–600 mm. The two mirrors and the three lenses are designed to optimize the image quality and maintain a low distortion over the entire field of view, which has a diameter of 3 degrees (476 mm).

A preliminary design view of the T250 telescope is presented in Fig. 1. In spite of its aperture, T250 is a very compact telescope because of the fast optics (F#3.5) and large field of view. The distance between M1 and M2 is only ~ 2200 mm, hence allowing the dome to be also compact (~ 9.5 m). M1 has a diameter of 2550 mm, what provides an effective collecting surface of 3.89 m<sup>2</sup> and an *étendue* of 27.5 m<sup>2</sup> deg<sup>2</sup>. The inner diameter of the M1 central hole is 1010 mm. A baffling system consisting of seven conical baffles will prevent from stray light at the focal plane, resulting either from direct glimmer on the detector or unwanted reflections on M1 and M2. The three lenses of the field corrector are supported by a barrel made of low carbon steel, designed to be stiff enough to avoid unacceptable deflection under gravity load. The corrector is rigidly connected to the fixed flange of the instrument rotator. The instrument will be supported by the rotator that compensates the field rotation. T250 will be able to support instruments of up to 1000 kg at 750 mm from the mounting flange.

T250 will have an approximate mass of 45000 kg. The structure is made of low carbon steel plates and tubes. The shape, material thickness and internal reinforcement in the box

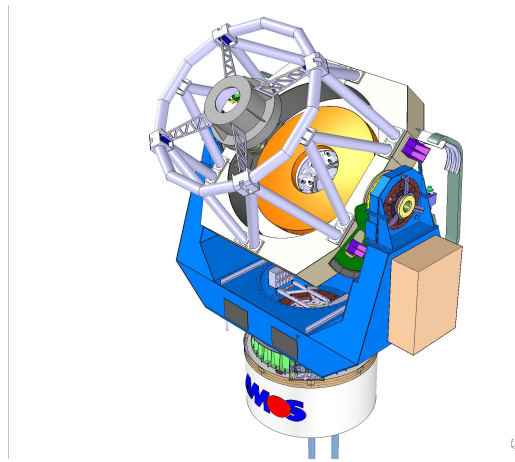


Figure 1: Preliminary design of the T250 by AMOS.

frame structures are optimized to get the highest first frequencies. The Serrurier design allows limiting the tip of M2 under gravity load. The first eigenfrequencies of the structure are above 10 Hz.

The Preliminary Design Review of the T250 was passed on October 27th, 2010. After that, it was concluded to equip T250 with a wavefront sensor (curvature sensor) and an autoguiding system at the focal plane level of the T250, for the active control of the telescope focus through the M2 hexapod. This solution is in the line of the one considered for the guiding and focus control of the Large Synoptic Survey Telescope.

### 3.2 T80

T80 has a german equatorial mount with a Ritchey-Chrétien optical configuration. The focal plane corresponds to a Cassegrain layout with a field corrector of 3 lenses. The lenses, with diameters in the range 115–140 mm, are made of fused silica and have spherical surfaces.

T80 is also a compact and fast ( $F\#4.5$ ) telescope. M1 has a diameter of 826 mm, and the distance between M1 and M2 is  $\sim 830$  mm. The T80 field of view has a diameter of 1.7 deg (110 mm) with full optical performance, reaching the 2.0 deg (130 mm) diameter with a slight ( $< 1\%$ ) vignetting. The baffling system consists of five conical baffles. The dome has a diameter of 5.5 m.

## 4 The OAJ instrumentation

The T250 and T80 instrumentation to carry out the J-PAS will consist of two panoramic CCD cameras, each containing large format CCDs of small pixel size. The base-line is using CCDs of  $\sim 10k \times 10k$  pixels and  $\sim 9\text{--}10 \mu\text{m}/\text{pixel}$ . The two cameras are designed to work at the Cassegrain focus in convergent beam, so the filters are located as close as possible to

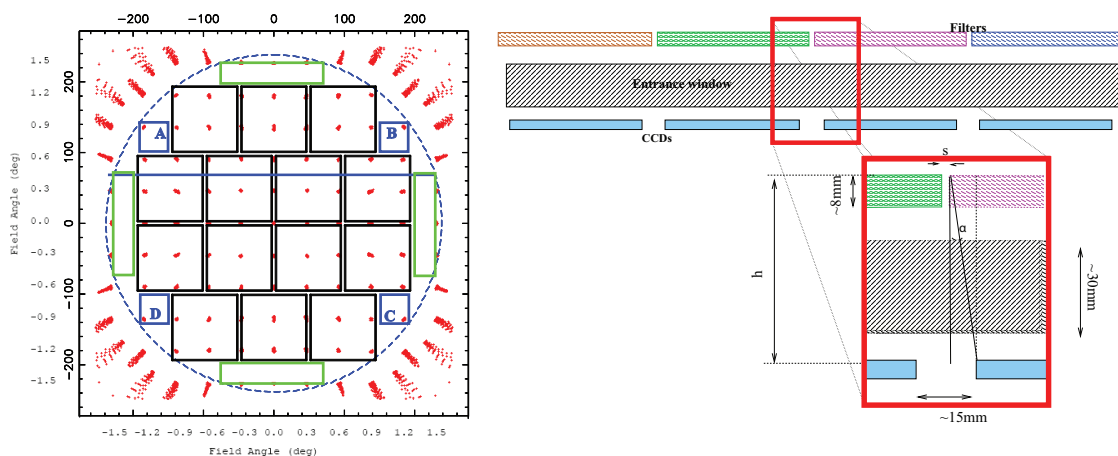


Figure 2: *Left:* A potential design of the 3 deg diameter T250 focal plane (blue dashed circle) and the placement of the 14 science CCDs (black squares). A separation of 15 mm between the CCDs has been considered. Squares A,B,C,D are planned to place auxiliary CCDs for wavefront sensing. Green regions are reserved for locating autoguiding CCDs. The spots in red illustrate the spot diagram at different locations of the focal plane. *Right:* Vertical section of the filters, entrance window and CCDs as corresponding to the blue line displayed in the left panel.

the CCDs, just separated by the cryostat entrance window.

The definition and procurement of the J-PAS cameras is lead by a consortium of several funding J-PAS institutions from Spain (CEFCA and IAA-CSIC) and Brazil (*Coordenação de Astronomia e Astrofísica (COAA) do Observatorio Nacional, Departamento de Astronomia do Instituto de Astronomia, Geofísica e Ciências Atmosféricas da Universidade de São Paulo (IAG/USP), and Coordenação de Física Teórica do Centro Brasileiro de Pesquisas Físicas*). These partners contribute at the scientific, financial and manpower levels to the development of the J-PAS project.

#### 4.1 The T250 camera

The baseline for the T250 panoramic camera is a mosaic of 14 large format CCDs, covering as much as possible the 476 mm diameter of the T250 focal plane. In this sense, the T250 camera will be the camera with the largest number of pixels ever constructed ( $\sim 1.400\text{--}1.500$  Mpix). Figure 2 (left panel) illustrates a possible location of 14 large format CCDs on the focal plane of T250. The mosaic coverage corresponds to an area on the sky of 7 square degree (3 deg diameter; blue dashed line), which is roughly equivalent to the area covered by 36 full moons.

As described in Section 2, the J-PAS will make use of 42 narrow band filters, the ones will be distributed in 3 different filter holder trays (14 filters each). The filters will be placed as close as possible to the cryostat entrance window ( $\sim 5$  mm). The right panel in Fig. 2 illustrates a vertical section (along the optical axis) of the filters, entrance window and CCDs,

as indicated by the blue line. To guarantee that each CCD only receives light beams passing through the filter above it (no contamination from adjacent filters) and to prevent vignetting due to the holders of the filter tray, the required separation between CCDs is determined by the incident chief ray angle ( $\alpha \sim 8$  deg), the filter-to-filter separation ( $s$ ), and the distance ( $h$ ) from the upper filter layer to the CCDs (see right panel in Fig. 2). The last value is in turn constrained by the thickness of the monolithic entrance window, which is expected to be in the range 2.5–3.0 cm. Using reasonable values of the above parameters, the focal panel coverage efficiency is around  $\sim 70\%$ .

The autoguiding system of the T250 will be implemented at the focal plane level, hence being part of the T250 panoramic camera. In addition, several wavefront sensors (curvature sensors) will be installed at the focal plane of the camera to feed the T250 M2 hexapod and control focus and image quality during the observations. In left panel of Fig. 2, blue squares A,B,C, and D indicate regions reserved for locating auxiliary CCDs for wavefront curvature sensing. Also, several small CCDs for autoguiding purposes will be attached inside the green rectangles. The red points indicate the typical spot diagrams at different locations of the focal plane. Inside the required 3 deg diameter field of view (blue dashed line), the image quality is highly homogeneous fulfilling the requirements in terms of EE50 and EE80.

## 4.2 The T80 camera

The T80 camera is thought as a benchmark for the T250 camera, as it is expected to use the same CCD and electronics. With a plate scale of 55.56 arcsec/mm and pixels of  $\sim 9\text{--}10 \mu$ , the pixel scale is  $\sim 0.5$  arcsec at the T80 focal plane. A single CCD suffices to cover a field of view (diameter) of 2.07 deg (the minimum required is 1.7 deg). This camera is expected to work with a set of 10–12 broad and intermediate band filters plus 2 narrow band filters in a filter exchange mechanism (filter wheel, juke-box, etc). The T80 filter definition is being optimized on the basis of the J-PAS photometric calibration tasks, for which the T80 has been conceived.

## References

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