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J-PAS & J-PLUS: large sky multi-filter surveys from the Observatorio Astrofísico de Javalambre

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Abstract

During the first years of operation, the Observatorio Astrofísico de Javalambre, in Teruel, is mostly devoted to conduct two large sky multi-filter surveys making use of two telescopes of large field of view, JST/T250 and JAST/T80, and their respective panoramic instrumentation, JPCam and T80Cam. These surveys, managed and developed within a long-term Spanish-Brazilian collaboration of astronomers who cover most fields in Astronomy and Cosmology, are the Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS) and the Javalambre Photometric Local Universe Survey (J-PLUS). J-PAS will observe 8500 deg^2 of the sky visible from Javalambre with a set of 54 narrow-band contiguous optical filters plus 5 broader ones, performing in the end as a low resolution integral field unit for the Northern hemisphere. It will provide unprecedented spectral energy distributions for every pixel of the sky, and ultimately for more than 200 million galaxies and stars. In advance, J-PLUS has started to observe the same sky area of J-PAS with 12 narrow, intermediate and broad-band filters aimed to provide the photometric calibration of J-PAS, and unprecedented multicolor data for many fields of the Astrophysics. Both J-PAS and J-PLUS will provide powerful 3D views of the Universe that will be made publicly available to the community as legacy projects. This proceeding is aimed to present the origin, motivation, characteristics and main scientific goals of the J-PAS and J-PLUS projects as well as the Spanish-Brazilian collaboration making them happen.

1 Introduction

First ideas about having a new astronomical facility in Javalambre appear in the early 1990's, when several site testing campaigns conducted at different sites in continental Spain revealed that the Pico del Buitre, at the Sierra de Javalambre in Teruel, was a potential very good site for professional astronomy. The initiative kept on hold until around 2007, when the Aragón Government decided to guarantee funding for the complete design and construction of an astronomical observatory at the site. At this time, the scientific motivation and the technical requirements for this new observatory had evolved from the very early stages into an innovative, unique facility devoted to conduct large sky astronomical surveys. In particular, based on the expertise and lessons-learned of the ALHAMBRA project ([13]), the objective was to conduct a large sky multi filter survey with more than 40 contiguous narrow-band filters aimed to measure baryon acoustic oscillations (BAOs) through the determination of photometric redshifts for millions of galaxies over several Gpc^3 up to redshift ~ 1. This led to the need of building an unprecedented telescope with a very large etendue, able to image the Universe in multiple photometric bands at very high survey speeds. With the initial goal of reaching a FoV as large as 3.5 deg, first feasibility studies concluded that the optimal configuration would be a 2.5 m telescope with a 3 deg FoV. In addition to it, a smaller aperture telescope of 0.8 m with a large FoV of 2 deg would be necessary for guaranteeing the photometric calibration of the main telescope,as well as a test bench for the overall development, operation, calibration tasks and first science at the center. In these terms, the so called Observatorio Astrofísico de Javalambre (OAJ) was proposed and supported by the former Spanish Ministry of Education and Science, the Spanish Consejo Superior de Investigaciones Científicas, and the Aragón Government.

In 2008 the Centro de Estudios de Física del Cosmos de Aragón (CEFCA) is created as a foundation of the Aragón Government, having, as a main goal, the design, construction and operation of the OAJ as well as the scientific exploitation of the astronomical data produced by the OAJ. In 2009, CEFCA was awarded with funds from the Fondo de Inversiones de Teruel (FITE) for the design and construction of the OAJ. The FITE is a regional funding channel supported at the 50% level by the Aragón Government and the Spanish Government, created for promoting the development of strategical projects in the province of Teruel. During these years, the CEFCA team concentrated efforts to finalize a proper site testing of the Pico del Buitre. The results, presented in [14], reveal that the site has excellent conditions for professional astronomy, with a median seeing of $\sim 0.7''$ and a sky brightness as dark as ~ 22 mag in V band, numbers that have been re-confirmed later on during the normal operation of the OAJ.

In 2010, additional FEDER funds were awarded to CEFCA to develop several instrumentation packages for the OAJ and a petabyte-scale data center in Teruel able to storage, reduce and analyze the vast amount of data planned to be gathered with the OAJ telescopes. At this time, the OAJ project and its scientific goals attracted several astronomical institutions in Brazil, interested in becoming part of the project by funding partially the development of the panoramic instrumentation needed for the two OAJ telescopes and participating in the scientific exploitation of the OAJ data. The main funding institutions from Brazil are the Observatorio Nacional of Rio de Janeiro and the University of Sao Paulo. This joint effort ended up in a Spanish-Brazilian collaboration of astronomers with interests in most fields in Astronomy and Cosmology, the so called Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS; http://www.j-pas.org; [3]). Since then, the collaboration has grown up to reach more than 150 members from many other countries, not only Spain and Brazil.

In this paper, I describe the main characteristics and current status of the OAJ, its telescopes and instrumentation, and the main scientific projects that have been defined within the Spanish-Brazilian collaboration for the first years of OAJ operation.

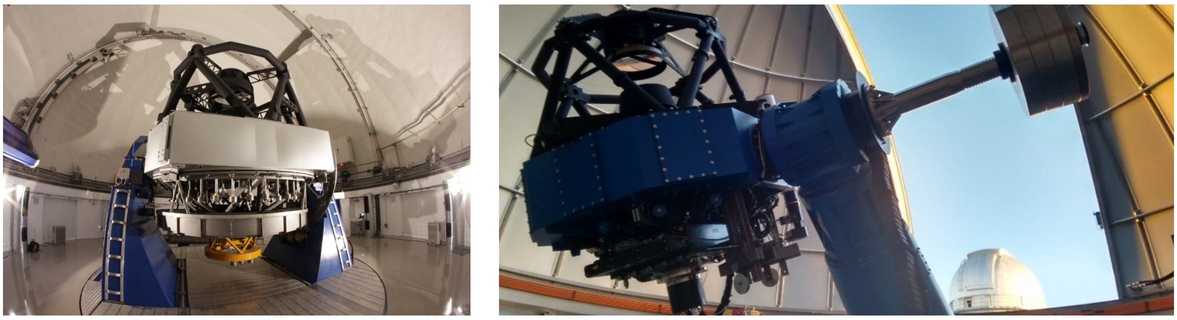

Figure 1: *Left panel*: the JST/T250 telescope. *Right panel*: the JAST/T80 telescope.

1.1 Brief summary of the OAJ characteristics and current status

The contract for the design and construction of the OAJ started in 2010. A historical progress of the project can be found in e.g. [4, 5, 6]. The OAJ contract comprised the whole civil work of the observatory, buildings, underground tunnels, general installations, the telescope domes, as well as the two main telescopes of the OAJ: the Javalambre Survey Telescope (JST/T250; see left panel in Fig. 1), an ALT-AZ 2.5 m modified Ritchey-Chretien (RC) telescope with an effective FoV of 7 deg^2, and the Javalambre Auxiliary Survey Telescope (JAST/T80; see right panel in Fig. 1), a german equatorial 0.8 m modified RC telescope with an effective FoV of 3.1 deg^2. In both cases, the RC optical design is modified with field correctors of three lenses to guarantee seeing-limited images all over the large focal plane of the telescopes. The field corrector of the JAST/T80 is made of spherical lenses. However, for the JST/T250 the lenses are extremely complicated, having 4 (out of 6) aspherical surfaces, with a diameter that ranges from 60 to 50 cm approximately. Both JST/T250 and JAST/T80 implement active optics at the level of M2, based on hexapods. An M2 control law for each telescope has been built so that the hexapod applies minor corrections in piston, decentering and tilt of M2, as a function of temperature and the pointing coordinates, to minimize optical aberrations, so that the whole system keeps optimally aligned in all cases providing an homogeneous image quality at the focal plane. The commissioning of the two telescopes has been conducted by CEFCA. More details on the particular commissioning and science verification of JAST/T80 can be found in [9].

The OAJ civil work was completed and accepted in 2015 (see Figure 2), and the OAJ contract finalized officially in February 2016 with the final acceptance of the JST/T250. During the acceptance tests of the JST/T250 conducted by CEFCA, the image quality was assessed by means of lucky imaging techniques. As illustrated in Fig. 3, the best image quality achieved during lucky imaging is $\sim 0.15''$.

The development of the instrumentation of the OAJ telescopes was not part of the OAJ contract, but managed in parallell by Spain and Brazil as part of the J-PAS collaboration. JAST/T80 is equipped with T80Cam, a camera built by CEFCA and Brazil. T80Cam consists of a cryostat equipped with a large format CCD by e2v of 9.2k$\times$9.2k pixels, with a low read-out noise of 3.4 e^- (RMS). With a pixel size of 10 μ, the plate scale of T80Cam at

Figure 2: Air view of the Observatorio Astrofísico de Javalambre.

JAST/T80 is $0.55''\text{pix}^{-1}$, providing a FoV of $2\,\text{deg}^2$. Two filter wheels host simultaneously 12 optical filters.

The main scientific camera for JST/T250 is JPCam, already designed and manufactured by CEFCA and Brazil. With around 1.2 Gpix at the focal plane, JPCam is the second largest astronomical camera in the world. It consists of a cryostat with a mosaic of 14 large format CCDs (see Fig. 4), like the ones in T80Cam, providing a plate scale of $0.23''\text{pix}^{-1}$ and an overall FoV of almost $5\,\text{deg}^2$. A set of 12 auxiliary CCDs located at the periphery of the FoV will allow guiding and performing wavefront curvature sensing analysis, which is key to feed the active optics system. JPCam hosts five filter trays with 14 filters in each tray, hence there are 70 filters available in the camera at any time. Apart from the hexapod at M2, the JST/T250 has an actuator system at the Cassegrain focus to allow corrections at the focal plane level that, together with the M2 hexapod corrections, guarantee an optimal image quality all over the focal plane. Prior to the installation of JPCam, the JST/T250 will use a replica of T80Cam modified for accommodating to the JST/T250 optics. This interim camera, namely JPAS-PF, provides a smaller FoV of $\sim 0.6\times\, 0.6\,\text{deg}^2$ and has also been built by CEFCA and Brazil to conduct the commissioning of the actuator system and the first science verification of the telescope. In this sense, JPAS-PF is a pathfinder for the J-PAS science to come with JPCam. More details about the OAJ instrumentation can be found in [11, 16, 12].

In October 2014, the OAJ was declared Spanish ICTS by the Consejo de Política Científica, Tecnológica y de Innovación of the Spanish MINECO. As such, since 2016 the OAJ offers a 20% of open time for T80Cam at JAST/T80 to the community through periodic calls, every semester. At the time of writing this proceeding, the OAJ has offered time for semesters 2016B and 2017A, in both cases with oversubscription factors larger than 1.5. JPAS-PF, already mounted on the telescope, is about to start the commissioning of the actuator system. JPCam arrived the OAJ in October 2016. Several months of verification work at the OAJ clean room are foreseen before JPCam can be taken to the telescope. This is expected to happen in 2017.

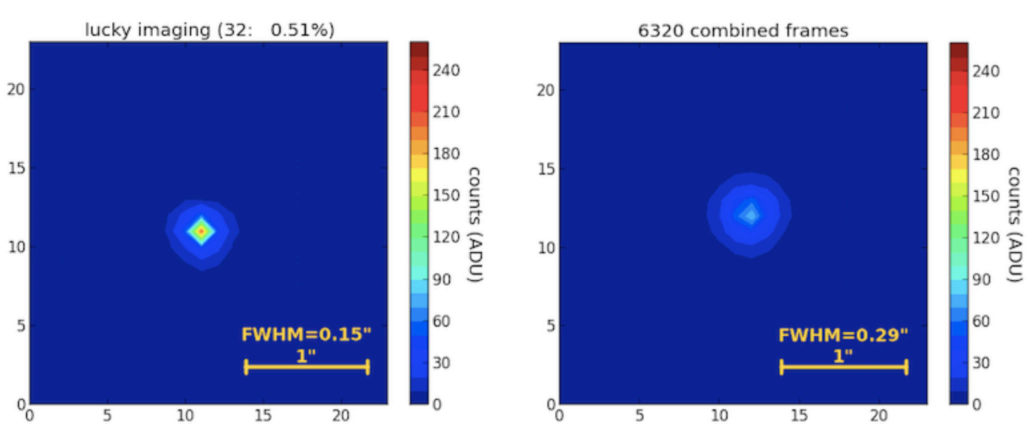

Figure 3: Assessment of the JST/T250 image quality using lucky-imaging (LI) techniques with the verification camera, in December 2nd 2015. The *left panel* shows an excellent FWHM of 0.15″ as the result of applying LI techniques for a given star, with integration times of 10 ms per frame, and aligning and stacking the best 0.5% frames according to their Strehl ratios. The *right panel* illustrates the combination (without any previous alignment) of all the frames acquired during the test, obtaining a fantastic FWHM of 0.29″. The test was performed under excellent seeing conditions, with values as low as 0.39″ in that night. This result demonstrates that the JST/T250+dome system can provide images with PSFs smaller than the seeing value measured by the DIMM monitor.

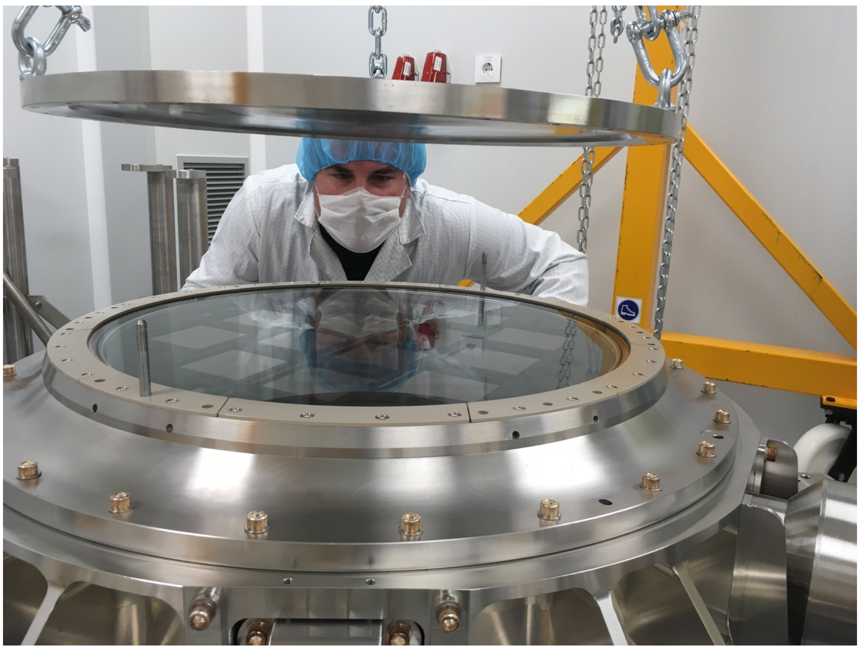

Figure 4: The cryostat and focal plane of JPCam, at the OAJ clean room.

In parallel with the design and construction of the OAJ, their telescopes and cameras, CEFCA has developed a specific data center for the handling and storage of the OAJ data. The data archiving and processing of the images collected at the OAJ is carried out in the Unit for Processing and Data Archiving (UPAD). This data center provides the hardware infrastructure needed to store, process and analyze the images, as well as keep data backup. It also provides and efficient access to the scientific database and sky images for the astronomical community and the general public. The disk system consists on a cluster with 8 nodes providing a net storage capacity $> 1\,\mathrm{PB}$ with dual parity protection. The robotic tape library amounts to 4 PB. The core network and disk storage system provide more than 5000 MB aggregated bandwidth. The software pipelines have been designed to handle the enormous data flow produced by the OAJ panoramic cameras and maximize the scientific output. The Data Management Software processes automatically the data collected during the night to check if its quality fulfills the scientific and technical requirements, update the survey's databases and feed the Scheduler to compute the telescope targets of the following nights. Full details con the hardware and software of the UPAD can be found in [7, 8].

2 The J-PAS and J-PLUS multi-filter surveys

2.1 The Javalambre Physics of the Accelerating Universe Astrophysical Survey: J-PAS

The scientific goals of J-PAS (http://www.j-pas.org) were originally defined within the framework of the CONSOLIDER-Ingenio 2010 PAU project funded by the MICINN. It is inspired in the recommendations of the Report by the ESA-ESO Working Group on "Fundamental Cosmology" ([15]). Quoting literally: "...a key element for fundamental cosmology: we need to survey a major fraction of the sky down to depths corresponding to a mean redshift of about unity, because this is the region in our visible universe where dark energy reveals its presence... "(see also [1]).

In this sense, starting in 2017 with JPAS-PF@JST/T250 and continuing later on with JPCam@JST/T250, J-PAS is defined as a photometric survey of $8.500\,\mathrm{deg}^2$ of the Northern sky in 54 narrow-band (NB) contiguous filters, spaced by $\sim 100\,\text{Å}$ but having a FWHM of $145\,\text{Å}$, spanning the optical range $\sim 3700 - 9200\,\text{Å}$, plus 1 medium-band (MB) filter that covers the UV edge, and 1 broad-band (BB) filter redwards $9100\,\text{Å}$. The J-PAS filter set is completed with 3 BB Sloan filters, g, r, and i (overall 59 filters; top panels in Fig. 5). J-PAS will be completed in 6-7 years, allowing to determine redshifts and spectral energy distributions (SEDs) for $\sim$ 200 million galaxies, with an accuracy of $\Delta z/(1+z) \leq 0.3\,\%$ for 90 million galaxies, sampling overall an effective volume of $\sim 14\,\mathrm{Gpc}^3$. Thanks to its innovative design, J-PAS can be the first experiment to reach Stage IV according to the Dark Energy Task Force classification, several years before other projects like Euclid or LSST start their operations. The instrumental development of this project requires a small fraction of the cost and complexity of a high multiplexing spectrograph, yet it will produce data which enable a much wider range of Astrophysical applications: J-PAS effectively uses a $5\,\mathrm{deg}^2$ "IFU" which will produce a 3D image of the Galactic (MW halo) and Extragalactic

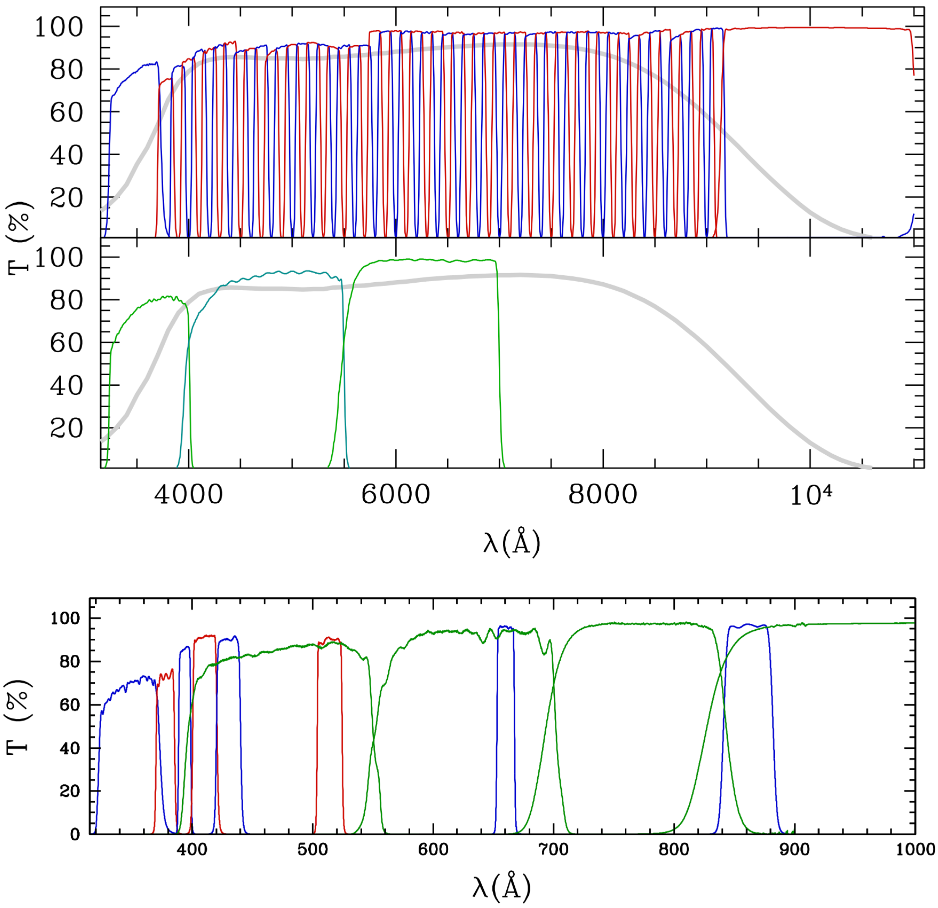

Figure 5: *Top panel*: the as-designed set of 56+3 J-PAS filters. Grey lines indicate the CCD quantum efficiency. *Bottom panel*: The as-built set of 12 J-PLUS filters (transmission curves measured at CEFCA).

Northern sky. In fact, J-PAS will provide a low-resolution (R 50) spectrum for every pixel of the sky down to AB 22 (5σ level) in the NB filters and r 24, which promises important breakthroughs in many areas of Astrophysics. Galaxy evolution and star formation rates (SFRs) at different redshifts, two-dimensional stellar population analysis, Milky Way (MW) structure studies, SNe, gamma-ray bursts, very low mass objects, exoplanets, Solar System small bodies, etc. will highly benefit from the J-PAS data. The J-PAS data will be publicly available constituting a Legacy Project.

2.2 The Javalambre Photometric Local Universe Survey: J-PLUS

J-PLUS (http://www.j-plus.es) is particularly designed to carry out the photometric calibration of J-PAS. It will observe the same sky area of J-PAS with T80Cam@JAST/T80 using a set of 12 BB, MB and NB optical filters (bottom panel in Fig. 5) that will allow to retrieve very accurate SEDs for more than 5 million stars in our Galaxy. The proposed calibration strategy lies on the reliability to determine accurate SEDs of stars out from the J-PLUS filter set. For calibration purposes, in agreement with previous work (e.g. [2, 10]), we have found that 10 intermediate-broad band filters can produce accurate enough SEDs: 4 SDSS filters (g, r, i, and z), which provide the low frequency continuum, and 6 MB filters of $200 - 400$ AA width centered on key absorption features, like uJAVA, the UV filter in common with J-PAS, J395 (Ca H+K), J410 (Hδ), J430 (the G-band), J515 (the Mgb triplet) and J861 (the Ca triplet). The J-PLUS filter set is completed with 2 NB filters also in common with the J-PAS filter set, J378 and J660, the ones are sensitive to the [OII]/λ3727 and Hα/λ6563 lines respectively. The three filters in common with J-PAS are thought as an added value for the overall calibration procedure, as they will allow second order corrections of the zero-points to anchor the J-PAS calibration.

Apart from the calibration goals of J-PLUS, it is worth noting that the filter arrangement is tuned to provide scientifically valuable data for many fields of the Astrophysics. J-PLUS is expected to reach in some fields 1 mag deeper than SDSS in the BB filters, AB$\sim$ 21.5 in the MB filters, and AB $\sim$ 22.5 in the [OII]/λ3727 and Hα/λ6563 NB filters. Since the MB filters are sensitive to the strengths of key features of old stellar populations, J-PLUS is very well suited for analyzing the stellar populations of nearby galaxies up to $z \sim 0.02$, limited by the width of the intermediate line filters. In addition, the two NB filters are ideal for mapping the star formation rates in nearby galaxies in the range $0 < z < 0.015$. The unusually large field of view of T80Cam, 2 deg^2, together with the unique width and location of some filters, turn J-PLUS into a powerful 3D view of the nearby Universe, mapping more than 20 million galaxies with reliable distance determinations and a similar number of stars of the MW halo. At a rate of 100 GB of data per night, J-PLUS will provide unprecedented multi-color images of the Universe to address a wide variety of astrophysical questions related with cosmology, large scale structure, galaxy clusters, 2D stellar populations and star formation studies in galaxies, the discovery of high redshift galaxies at specific redshift slices, QSOs, SNe, MW science and structure, and minor bodies in the Solar System. In addition, the repetition of the whole area over time in certain filters will allow to face variability studies in the time domain.

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References

[1] Albrecht, A., et al. 2006, The Dark Energy Task Force (DETF) report, arXiv:astro-ph/0609591

[2] Bailer-Jones, C. A. L. 2004, A&A, 419, 385

[3] Benítez, N., Dupke, R., Moles, M., et al. 2014, arXiv:1403.5237

[4] Cenarro, A. J., Moles, M., Cristóbal-Hornillos, D., et al. 2010, SPIE, 7738, 77380V

[5] Cenarro, A. J., Moles, M., Cristóbal-Hornillos, D., et al. 2012, SPIE, 8448, 84481A

[6] Cenarro, A. J., Moles, M., Marín-Franch, A., et al. 2014, SPIE, 9149, 91491I

[7] Cristóbal-Hornillos, D., Varela, J., Ederoclite, A., et al. 2014, SPIE, 9152, 91520O

[8] Cristóbal-Hornillos, D., Varela, J., Ederoclite, A., et al. 2015, Highlights of Spanish Astrophysics VIII, p. 798-803

[9] Ederoclite, A., et al. 2017, Highlights of Spanish Astrophysics IX, this volume.

[10] Jordi, C., Hog, E., Brown, A. G. A., et al. 2006, MNRAS, 367, 290

[11] Marín-Franch, A., Taylor, K., Cepa, J., et al. 2012, SPIE, 8446, 84466H

[12] Marín-Franch, A., et al. 2017, Highlights of Spanish Astrophysics IX, this volume.

[13] Moles, M., Benítez, N., Aguerri, J. A. L., et al. 2008, AJ, 136, 1

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

[15] Peacock, J. A., Schneider, P., Efstathiou, G., et al. 2006, arXiv:astro-ph/0610906

[16] Taylor, K., Marín-Franch, A., Laporte, R., et al. 2014, JAI, 3, 135001