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The Observatorio Astrofísico de Javalambre. A planned facility for large scale surveys

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Abstract

All-sky surveys play a fundamental role for the development of Astrophysics. The need for large-scale surveys comes from two basic motivations: one is to make an inventory of sources as complete as possible and allow for their classification in families. The other is to attack some problems demanding the sampling of large volumes to give a detectable signal. New challenges, in particular in the domain of Cosmology are giving impulse to a new kind of large-scale surveys, combining area coverage, depth and accurate enough spectral information to recover the redshift and spectral energy distribution (SED) of the detected objects. New instruments are needed to satisfy the requirements of those large-scale surveys, in particular large Etendue telescopes. The *Observatorio Astrofísico de Javalambre*, OAJ, project includes a telescope of 2.5 m aperture, with a wide field of view, 3 degrees in diameter, and excellent image quality in the whole field. Taking into account that it is going to be fully devoted to carry out surveys, it will be the highest effective Etendue telescope up to date. The project is completed with a smaller, wide field auxiliary telescope. The Observatory is being built at Pico del Buitre, Sierra de Javalambre, Teruel, a site with excellent seeing and low sky surface brightness. The institution in charge of the Observatory is the *Centro de Estudios de Física del Cosmos de Aragón*, CEFCA, a new center created in Teruel for the operation and scientific exploitation of the Javalambre Observatory. CEFCA will be also in charge of the data management and archiving. The data will be made accessible to the community. The first planned scientific project is a multi-narrow-band photometric survey covering 8,000 square degrees, designed to produce precise SEDs, and photometric redshifts accurate at the 0.3% level. A total of 42, 100–120 Å band pass filters covering most of the optical spectral range will be used. In this sense it is the development, at a much higher scale, of the ALHAMBRA survey. Its main goal is to measure the Baryonic Acoustic Oscillations to determine the equation of state of the Universe but its unbiased character and depth will produce relevant data for most domains in Astrophysics.

1 Introduction

One of the classical tasks in astronomy is to establish the census of objects, the families they define, their distribution in the sky and their properties. The status of the technological development has determined in every epoch the balance between the extension and depth of the coverage and the detail of the information on each detected object.

Undiscriminated, large area surveys require imaging in several bands to produce the spectral information. In that sense, the first systematic survey was the Palomar Observatory Sky Survey (POSS), carried out with the 48″ Schmidt telescope during the period 1950–1957. The POSS is a photographic survey of the Northern Hemisphere (later extended to the South with the UK Schmidt telescope) in two spectral bands defined by the sensitivity of the photographic plates that were used, 103aO for the "blue" and 103aF for the "red". Thus the spectral information is very limited just distinguishing between red and blue objects. For many years the POSS was the most frequently used astronomical resource, a key instrument for the development of Astrophysics. It allowed to recognize the morphology and the angular distribution of any class of objects, and to discriminate between families. All the domains, from the Solar System to galaxies and cosmology benefited of the POSS. In the domain of galaxies, beyond the grand design, regularly shaped systems, the existence of peculiar galaxies was revealed [3] opening the way to the analysis of interacting and merging systems. Clusters of Galaxies were also first identified and characterized from the POSS analysis of the distribution of galaxies showing that it is far from regular [1, 22]. Later de Vaucouleurs already hinted the existence of even larger systems of galaxies called Superclusters. The resulting view of the Universe completely changed after the POSS was available.

The very limited spectral information of the POSS prevented the determination of the Spectral Energy Distribution (SED) and the redshift of the detected objects. Getting redshifts from photometric multi-band information was first considered by [4], pushing for the use of several spectral bands to improve the accuracy on the determination of z. Different methods have been devised since them to increase the accuracy of the photo-z, the bayesian approach by [6] being one of the most reliable [15].

The next significant step forward with respect to the POSS was the Sloan Digital Sky Survey, SDSS [21], started in the 90's. The use of digital sensors and of 5 photometric bands allow for a good determination of the SED of the recorded objects and photo-z with $\sim 2-3\%$ accuracy. The gain in information is such that the impact of the SDSS in all the domains has been extraordinary.

Meanwhile, other proposed surveys have tried to improve the quality of the information by using more spectral bands or trying to go deeper than SDSS, or both. [14] were the first to propose a set of medium band filters encompassing the whole optical spectrum. The Calar Alto based projects CADIS [16] and Combo-17 [20, 5] where the first to use a combination of broad- and medium-band filters to survey a small area (about 1 square degree or less) for detailed information. Later, projects like COSMOS [19] have reached very good quality in photo-z, well below 1% in $\Delta(z)s/(1+z)$. The ALHAMBRA survey (http://www.csic.iaa.es:8080/alhambra/) was the first to propose a survey with equally spaced, top-hat response filters of 310 Å band pass [17]. It aims at covering a total of 4 square degrees to a depth of AB ~ 25 mag. The filter system includes a total of 20 contiguous, medium-band, FWHM = 310 Å, top-hat filters, that cover the complete optical range from 3500 Å to 9700 Å as prescribed in [8]. The ALHAMBRA photometric system has been characterized and compared with other existing systems in [2].The optical coverage is supplemented with the standard NIR JHKs filters. The accuracy in z is also below 1%.

The ultimate goal of the survey strategy is to get all the information needed to determine the physical properties of every detected object and even of every single resolution element. When the aim is depth and area coverage the solution is multi-band imaging photometry since spectroscopic surveys can neither go as deep as the photometric ones nor cover large enough areas. Moreover, they are defined in order to observe a restricted spectral region, producing a selection effect that is a function of the object type and redshift that can be very intricate due to the selection effects inherent to spectroscopy [13]. The spectral resolution is indeed limited but from the experience with limited projects like the above mentioned it appears that using intermediate-narrow band filters it is possible to get very accurate values of z and a precise determination of the SED of the detected objects. That accuracy can be enough to be appropriate for many of the problems in cosmology and galaxy evolution or even in stellar physics.

The development of Astrophysics in the last decade has brought into focus new problems, such as those of the dark matter, the dark energy or the overall evolution of galaxies that require new strategies based on large scale, accurate surveys. These new strategies need in turn of new and appropriate instruments to be implemented in order to make the problems affordable in limited periods of time. Within that new perspective, the *Observatorio Astrofísico de Javalambre* (OAJ) project proposes to build a dedicated telescope with a large enough Etendue to carry out a 8,000 squares degrees, multi-band photometric survey, the Javalambre-PAU Astrophysical Survey, J-PAS (see [9], and these proceedings).

2 The OAJ project

2.1 Scientific motivations

In 2007 the project *Physics of the Accelerated Universe* (PAU) was proposed and funded. Its central goal is to measure the Baryonic Acoustic Oscillations (BAO) up to $z \sim 1$ to determine the equation of state of the Universe. The project has been described in [9] (see also [7]). To measure the BAO in the radial direction the redshift has to be measured with an accuracy $\Delta(z)/(1+z) \leq 0.003$ in a large enough volume. The method proposed is to carry out a multi-band, photometric survey with 100–120 Å wide filters, over an area of about 8,000 square degrees down to AB ~ 23.5, the so called Javalambre-PAU Astrophysical Survey, J-PAS (http://www.iaa.es/∼benitez/JPAS/main.html).

Such a survey requires a devoted telescope with a large Etendue. As explained in the above reference, the project can be completed in 4-5 years with a 2 m class telescope, with a wide field of view, about 3 degrees in diameter. A project like this was proposed and eventually approved in 2009. The project is being developed with the fundings of the *Fondos Especiales de Teruel*, contributed on equal share by the *Gobierno de España* and the

Gobierno de Aragón.

Particular attention was given to the outcome of the survey other than the measurement of the BAO. Thanks to its unbiased nature (i.e., it was neither designed to detect a given class of objects nor to be precise only in some fixed spectral window), important problems other than cosmic evolution can be addressed. These include the identification and characterization of clusters of galaxies and the analysis of their number evolution with z: the analysis of the stellar content and history of all detected galaxies; the identification of several hundred thousand QSOs; the study of stellar populations in the galactic halo or the detection of debris from galactic satellites in the Milky Way halo, or even the detection of solar system minor bodies. Moreover, the ability to finely discriminate between different SEDs will permit the serendipitous detection of objects that could be classified as exotic or rare, including very high redshift galaxies.

A large collaboration is being defined to address all the aspects of the survey implementation and later scientific work on the J-PAS.

2.2 The site

The OAJ is located at the *Pico del Buitre*, *Sierra de Javalambre*, province of Teruel. The site was identified in the early 90's of the past century and preliminary studies were done at the epoch. The project was however discontinued before robust enough conclusions could be reached on its quality. Only recently, under the impulse of the new scientific proposals, the project was reactivated and a new systematic site testing campaign was started in March 2008. Dedicated seeing and extinction monitors were used as well as a 40 cm telescope equipped with a spectrograph to measure the conditions. The results for the first 1.5 years of testing have been already published [18]. The results clearly indicate that Pico del Buitre is an excellent site, with over 75% of useful time. The sky background is very low, with $B = 22.8$ mag arcsec^{-2}, $V = 22.1$ mag arcsec^{-2}, $R = 21.5$ mag arcsec^{-2}, $I = 20.4$ mag arcsec^{-2}. The median seeing is $0.71''$. It was also noticed that the seeing tends to be very stable when it is better than $0.8''$, with typical stability periods of 5 hours.

The site testing has been maintained until March 2010 when the works to build the Observatory started. We expect to resume the measurements along the springtime of 2011.

2.3 The telescopes and cameras

In 2007 a call was made for concept analysis of a large Etendue, 2 m class telescope. Several companies sent their proposals and an international committee evaluated them in 2008. On the basis of the recommendations by the committee the general requirements were established and in 2009 a call for bidders was launched. The contract was signed in March 2010 for the whole Observatory, including the civil work and the telescopes.

The main telescope OAJ telescope, ACTUEL, has been designed to have a large Etendue. This is the main driver, the goal being to have a telescope with a significantly larger Etendue than other existing instruments or similar aperture. In Table 1 we give the Etendue for telescopes up to 4 m. At the moment of this contribution the Preliminary Design

Table 1: The Etendue of small-medium size existing or planned telescopes.

Site	Telescope	Focus	Area (m^2)	FoV (deg)	AΩ	Comments
Calar Alto	T2.2m	R-C	2.94	1.116	2.88	Not implemented
Calar Alto	T3.5m	Prime	9.093	1.01	7.31	Not implemented
La Palma	INT	Prime	4.70	0.667	1.65	Wide Field Imager
La Palma	WHT	Prime	13,0	0.667	4.55	Not implemented
La Palma	NOT	R-C	4.71	0.50	0.92	Not implemented
La Silla	T3.6m	Cass	8.85	0.4	1.11	Not implemented
La Silla	NTT	R-C	9.46	0.5	1.86	Working
Las Campanas	Dupont	R-C	4.35	1.45	7.18	Not implemented
CTIO	4m Blanco	Prime	10.04	2.2	38.16	Development
Side Spring	SKYMAPPER	R-C	1.03	3	6.2	Development
Hawaii	Pann-STARRS	R-C	4×1.90	3	22.8	Development
Hawaii	Prime	CFHT	9.32	1.27	9.32	Working
Apache Point	R-C	SDSS	4	1	3.14	SDSS image
				(3.5)	14.0	Not implemented
Javalambre	T2.5m	R-C	3.78	3	26.71	Project

Review has been successfully completed and the M1 blank has been accepted. The delivery of the telescope at the OAJ site is foreseen for mid-2012.

ACTUEL has the following basic characteristics:

- Aperture: 2550 mm
- Effective collecting area: 3.78 m^2
- Field of view (FoV): 3 deg, diameter
- Nominal Etendue (considering the effective collective area): 26.71 $m^2\,deg^2$
- Image quality given by (final values, taking into account the total error budget, at any wavelength and at any position in the FoV) EED80 $\leq 0.45''$, EED50 $\leq 0.27''$

A different aspect to take into account is the fraction of the total observing time that will be devoted to carry out a given survey. In the case of ACTUEL it will be dedicated to the J-PAS and therefore the final, effective Etendue is the same as the nominal one. This makes ACTUEL a very efficient machine for surveys.

The OAJ will have another smaller, wide field telescope with the main objective of carrying out the photometric calibrations for the J-PAS. This telescope, called T80, has the following characteristics:

- Aperture: 820 mm

- Effective collecting area: 0.44 m^2

- Field of View: 1.7 deg (extended to 2 deg with slightly reduced image quality) diameter

- Image quality given by (final values, taking into account the total error budget, at any wavelength and at any position in the FoV) EED80 $\leq 0.81''$, EED50 $\leq 0.39''$

At the moment of this contribution the design has been completed and M1 is being ground. The delivery of the telescope at the OAJ site is foreseen for mid-2011.

Both telescopes will be equipped with CCD cameras. For T80 we are considering a large format, $10k\times10k$ device covering most of the FoV of the telescope. Auxiliary devices will be implemented in the focal plane for autoguiding and image quality sensing. ACTUEL will be equipped with a Panoramic Camera (Javalambre Panoramic Camera, JPCam) including 14 large format CCD. As for the T80 camera auxiliary devices will be implemented in the focal plane for autoguiding and image quality control. Presently the cameras are being designed. More details on the OAJ project, telescopes and instrumentation are presented in [10, 11].

3 The "Centro de Estudios de Física del Cosmos de Aragón"

The project is being defined and managed by the *Centro de Estudios de Física del Cosmos de Aragón*, CEFCA (http://www.cefca.es/), a recently created research center, the first devoted to Astrophysics in Aragón. CEFCA is in charge of the OAJ project and the operation, development and scientific exploitation of the Observatory. In that sense CEFCA is implementing another big facility, the *Unidad de Procesado y Archivo de Datos*, UPAD, in charge of the data handling, reduction, calibration and archiving of the data that will be produced by the OAJ telescopes (see [12]). The data of every survey will constitute a Legacy Project accessible to the whole community. A fraction of the telescopes time will be open to the community in the usual way.

CEFCA is conceived scientifically as a research institution focused in two main lines, cosmology and galaxy evolution, organized as research departments. It has been planned as a small-medium size center with a staff amounting to 40 people, including scientific research, operation and maintenance of the OAJ and UPAD.

Given the characteristics of the project the foreseen working mode of the OAJ is particular. The main activity of the OAJ will be long-term surveys as it is J-PAS. The whole OAJ project was grounded on the scientific motivations put forward by the PAU project and the J-PAS has been defined as the first survey to be carried out by the OAJ telescopes. Given the characteristics of the survey, in particular the absence of any pre-selection of the objects to observe, the data will be of the greatest importance and interest for many different domains in Astrophysics and Cosmology. To organize the scientific activity around J-PAS a call was open for collaborations on both, its central goal and the ancillary science. The 1st J-PAS meeting (http://ww.cefca.es/J-PAS) was hold in Teruel in June 2010 and the 2nd meeting will take place in Granada, beginning of December.

For future surveys, CEFCA will publish a call for proposals about 2 years before the precedent project is completed. The proposals will be considered by a committee that will propose the new survey. It is intended to organize the surveys as collaborations, as it is the case for the J-PAS. The collected data, after a short proprietary period, will be made available to the whole community.

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