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

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Abstract

J-PAS is a Spanish-Brazilian 8500 $\deg^2$ Cosmological Survey which will be carried out from the Javalambre Observatory with a purpose-built, dedicated 2.5 m telescope and a 4.7 $\deg^2$ camera with 1.2 Gpix. Starting in 2015, J-PAS will use 59 filters to measure high precision $0.003(1 + z)$ photometric redshifts for $90M$ galaxies plus several million QSOs, about 50 times more than the largest current spectroscopic survey, sampling an effective volume of $\sim 14\,\mathrm{Gpc}^3$ up to $z = 1.3$. J-PAS will not only be first radial BAO experiment to reach Stage IV; it will also detect and measure the mass of 7×10^5 galaxy clusters and groups, setting constrains on Dark Energy which rival those obtained from BAO measurements. The combination of a set of 145 Å NB filters, placed 100 Å apart, and a multi-degree field of view is a powerful "redshift machine", equivalent to a 4000 multiplexing spectrograph, but many times cheaper to build. The J-PAS camera is equivalent to a very large, 4.7 $\deg^2$ "IFU", which will produce a time-resolved, 3D image of the Northern Sky with a very wide range of scientific applications in Galaxy Evolution, Stellar Physics and the Solar System.

1 Introduction

The last decade has seen an accumulation of very large field Astrophysical Surveys (area $> 5000\,\mathrm{deg}^2$). A key factor in this development has been the undoubted success of the Sloan Digital Sky Survey (SDSS, [18]) which has spawned significant advances in almost all the fields in Astrophysics. The quest for the origin of Dark Energy has also been a powerful motivator, fostering many of the current projects like Pan-STARRS [8], DES, and BOSS [15], and also being one of the main goals of thevery large extragalactic surveys planned to start around the beginning of the next decade LSST [10], Euclid [14] and DESI [9]. Most of the observational approaches used to study Dark Energy (lensing, LSS, cluster mass function) need to obtain redshift information for massive quantities of galaxies, which means that they are often limited by the speed and accuracy of its "Redshift Machine".

There are two traditional ways of getting redshifts: relatively high precision spectroscopy (with $\frac{\delta z}{1+z} = 0.05 - 0.1\%$) and photometry yielding $\frac{\delta z}{1+z} = 1 - 10\%$. J-PAS takes photometric redshift techniques one step further, both in terms of hardware and statistical treatment reaching a "quasi-spectroscopic" precision of $\frac{\delta z}{1+z} \lesssim 0.3\%$ [3]. It can be shown [4] that for this level of accuracy, an instrumental set-up like the one used by J-PAS is about 4 times faster, in terms of survey speed, than a $\times 1000$ multiplexing spectrograph,

$$\frac{v_{\rm NB}}{v_{\rm spec}} \approx 4 \left(\frac{n_{\rm g}}{11\,000 \mathrm{galaxies/deg}^2} \right) \left(\frac{FOV}{4.7 \mathrm{deg}^2} \right) \left(\frac{1000}{N_{\rm s}} \right) \qquad (1)$$

where $n_{\rm g}$ is the galaxy density per square degree and FOV is the Field of View of the camera in square degrees. It can be seen that once, the filter system and depth is fixed (which determines the $n_{\rm g}$ for which precise photo-z can be measure) the advantage over spectroscopy comes fundamentally from the size of the camera; for smaller FOVs, e.g., $< 1\,\mathrm{deg}^2$, state-of-the-art spectrographs will be more efficient measuring redshifts than NB imaging.

J-PAS will be carried out from OAJ [11], a new observatory with a 2.54 telescope [5] specially built for the survey. Observations will partially start in 2015, using a $0.33\,\mathrm{deg}^2$ pathfinder camera, with the main $4.7\,\mathrm{deg}^2$ camera starting its operations in 2016.

2 J-PAS description

As it was shown by [3], a contiguous set of filters spaced by ~ 100Å width is able to produce photometric redshifts with a precision of $0.003(1 + z)$ for luminous red galaxies and thus measure the BAO radial scale. The basic design introduced in that paper has been optimized to maximize the overall returns of the survey in all scientific areas without compromising its main goal. The filter system (see Fig. 1) covers continuously the interval $3900 - 9100$ Å using 54 NB overlapping filters with 145 Å FWHM, set apart by 100 Å. Two additional filters complete the optical window. In addition, we include three SDSS-like broad band filters in our observations, u, g and r. The broad band filters are all contained in a single tray, which will be used only when the image quality is in the top 10% of the observatory range. Given the superb seeing at the Javalambre site, and the exquisite care being taken to make sure

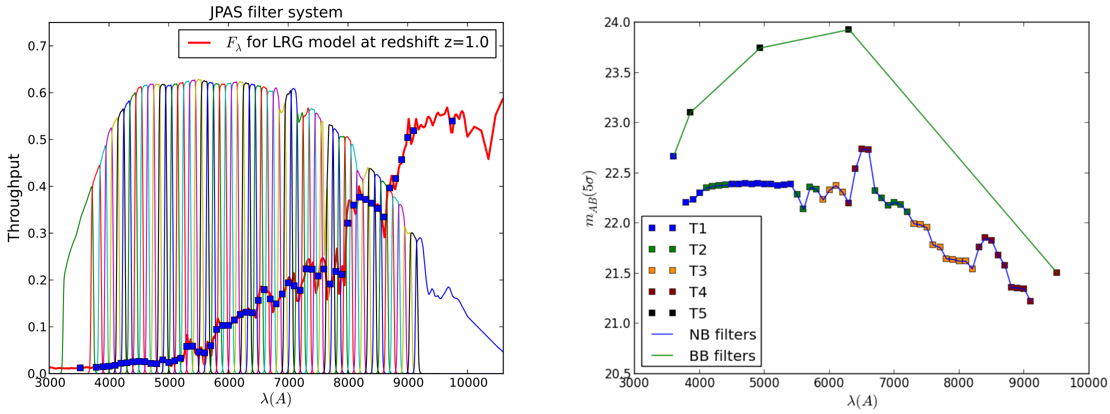

Figure 1: *Left*: The J-PAS filter system. We have included the redshifted spectrum of an early type galaxy at $z = 1.0$ from [13]. The filters are spaced by about 100 Å but have FWHM of 145 Å, what produces a significant overlap among them. The blue squares represent the flux which would be observed through the filters. Note that many spectral features apart from the 4000 Å break are resolved, which is why the precision in redshift is much larger than that which would be produced by a single break, $\Delta z/(1+z) \sim \Delta\lambda/\lambda \sim 0.02$. *Right*: Limiting AB magnitudes (5σ, $3''$ aperture) for all the filters in the survey, color coded by their tray distribution.

that neither dome nor camera significantly degrade it, we expect to get a deep $< 0.8''$ imaging of $\sim 8500\,\mathrm{deg}^2$ of the Northern Sky which will be extremely valuable for lensing analyses.

We are using a 14 CCD, $4.7\,\mathrm{deg}^2$ camera [16] and $56 + 3$ filters. It is not currently possible to build a NB filter of the required width and homogeneity over the whole $4.7\,\mathrm{deg}^2$; we therefore employ a single copy of the main 56 filters, spreading them into 4 different trays, each with 14 different filters. An additional tray contains the broad band filters. Since the filters will be distributed parallel to each other, is quite straightforward to cover the whole survey area homogeneously with all of them. It is sufficient to follow a pattern which tiles the full J-PAS sky with the CCD having the smallest effective area: that ensures that all the filters in each tray will also tile the sky with no gaps.

Despite the use of drift scan by previous surveys, as SDSS, we have decided to use a traditional "point and shoot" mosaicking strategy. We found that drift scan is only marginally more efficient (once all the factors, as overlaps, etc. are taken into account) and therefore does not warrant the loss of observing flexibility and the extremely strict requirements it imposes on both camera and telescope design. The simpler imaging strategy makes possible to re-use the reduction software of the ALHAMBRA Survey, which was mostly developed by members of the J-PAS collaboration [6, 7, 12].

Our basic exposure is 60 seconds, and we will carry out at least 4 exposures in each filter, following a $2 + 1 + 1$ pattern whenever possible, i.e. taking initially 2 almost simultaneous exposures, and then leaving an interval of a month before the 3rd and approximately 20 days between the 3rd and 4th exposures. This is close to the optimum strategy for SNeI detection,what will make J-PAS one of the most powerful ground-based SN surveys.

The total effective exposure time on any point of the sky will therefore be 1050 s (the broad band tray) + 56×240 s (one pass with all the 56 filters in the NB trays) + 14×240 s (a 2nd pass with the reddest NB tray) = 4.96 h. Since the J-PAS main camera has 4.7 deg^2, the survey speed is, therefore, $\sim 1\,\mathrm{deg}^2\,\mathrm{h}^{-1}$, and it will theoretically require ~ 9000 h to complete the full survey, a number which including realistic overheads, turns into an expected total of 12 400 h. Taking into account the experience of similar observatories we conservatively expect to be able to observe on-target effectively for at least $1800\,\mathrm{h\,yr}^{-1}$ (this is equivalent to $\sim 48\%$ useful time, similar to the values at e.g. Calar Alto). Therefore, the full completion of J-PAS will require ~ 6 yr.

3 Cosmology with J-PAS

The main goal of J-PAS is the study of Dark Energy. This is a highly competitive, area, with the two most powerful optical surveys ever undertaken starting around 2020, LSST and Euclid. However, J-PAS does not need the full filter complement to obtain unprecedented constraints on Dark Energy; the two reddest NB trays, combined with the broad band observations will provide many millions of quasi-spectroscopic redshifts (see Fig. 2) in a redshift range not previously covered by other surveys. We will prioritize the observations with these trays, and 3 years after the start of the main survey (2019, Y3 in Fig. 2) we can expect to have some of the best constraints on Dark Energy at that time, with precision increasing gradually until the survey observations finish in 2022 (Y6 in Fig. 2, left).

In addition to the BAO sample, J-PAS will also measure lower precision photometric redshifts for several hundreds of millions of galaxies, which can be used for other scientific goals, both in Cosmology and Galaxy Evolution. Figure 2 (right) shows the expected surface density of galaxies with different photo-z precisions at Y6 (end of the survey).

J-PAS will be highly competitive in all the four main DETF cosmological probes:

- SNIa. Due to its particular schedule and NB filter coverage, J-PAS is expected to detect and measure redshifts using its own imaging data for 6000 SNIa [17].

- BAO radial scale. This was the original scientific goal of the project. Apart from BAO measurements with galaxies, it will be possible to use QSO as probes [1] and also use Redshift Space Distorsions and the shape of the power spectrum as powerful cosmological tools.

- Cosmic shear. As mentioned above, we expect to be able to take a broad band image of the sky with very high PSF quality. J-PAS will measure redshifts for almost twice as many galaxies as DES, but with several times better redshift precision.

- Cluster mass function. J-PAS will not only be the most sensitive survey in terms of mass detection [4, 19], but it will be able to calibrate cluster total masses in a self-contained way, using its own lensing information.

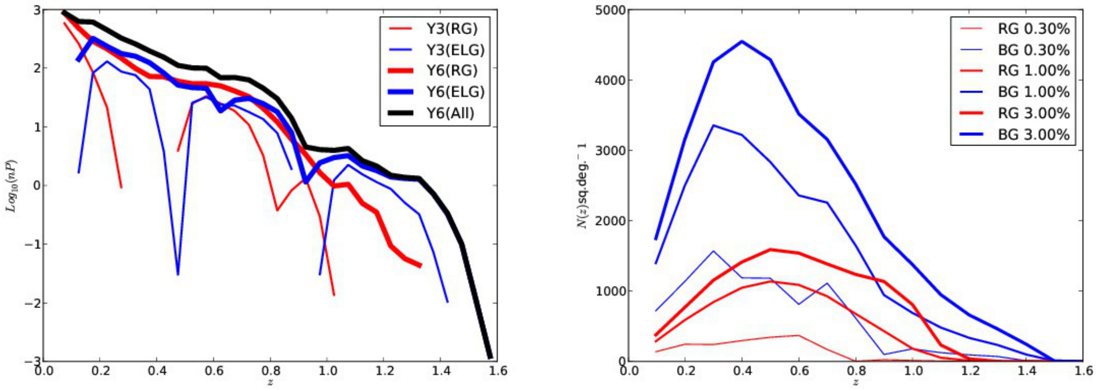

Figure 2: *Left*: Product of the galaxy density for Red Galaxies (RG) and Emission Line galaxies (ELG) with $dz/(1+z) < 0.003$ by the power spectrum (taking into account the corresponding bias) for different stages of completion of J-PAS. *Right*: Expected surface density of galaxies for different photometric redshift errors at Y6.

All these probes combined will produce DE constraints which will be only surpassed several after J-PAS has finished its observations. As an example, we list in Table 1 the forecasted DETF Figure of Merit (FoM) for several combinations of J-PAS probes.

Table 1: J-PAS Figure of Merit summary

Test	LRGs	ELGs	QSOs	All
BAOs + Planck + Stage II	87	121	100	163
BAOs + Clusters + Planck + Stage II	195	222	201	256

4 Galaxy evolution and stellar physics

J-PAS will obtain low resolution spectroscopy ($R \sim 50$) for every pixel over an SDSS-like area of the sky (and which, due to the latitude of Javalambre, will have a significant overlap with the Sloan footprint). A unique characteristic of our data is the fact that photo-spectra based on narrow-band imaging, unlike standard spectroscopy, does not suffer from systematic uncertainties in the flux calibration. Every data point of the photo-spectrum –i.e. every filter– is approximately independent, so the resulting SED is not affected by low frequency systematics in the relative flux calibration (or color terms) that can lead to biases in the derived physical properties. Multi-filter spectrophotometry thus provides accurate (low-resolution) SEDs over a wide range in wavelengths and spatial scales. J-PAS will thus be extremely competitive in several scientific areas like the nearby universe (being able to map spectroscopically the largest visible galaxies), the evolution of galaxy populations since $z \lesssim 1.3$ (providing both a full census of all massive objects and spatially resolved spectroscopical information for them), the growth or large structure and environment, the bright end of the high redshift luminosity function and Active Galactic Nuclei (J-PAS combination of spectral and time domain information will detect several million QSOs).

Extragalactic surveys cannot avoid being Galactic surveys too. Between 200 and 500 million stars are expected to be listed in the final J-PAS catalogue, which will provide one of the most detailed views of the Milky Way halos in the northern hemisphere. The J-PAS stellar catalogue will complement the Gaia space mission data, providing low-resolution SEDs for all halo stars with GAIA astrometry and velocities, greatly boosting the scientific value of both data samples. J-PAS will also be an ideal dataset to detect and study the properties of stellar streams and other tidal debris. No other survey will provide data with a similar combination of angular coverage and wavelength resolution.

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