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GALAXIES AND COSMOLOGY WITH THE PROJECTS PHYSICS OF THE ACCELERATING UNIVERSE (PAU) AND DARK ENERGY SURVEY (DES)

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Abstract. Dark energy poses one of the biggest challenges to our understanding of the universe. Currently, many projects and surveys are flourishing trying to investigate its nature. Here we briefly review the Dark Energy Survey (DES), one of the most comprehensive dark energy imaging surveys that will start observations in the near future. We also present the Physics of the Accelerating Universe (PAU) survey, which features the use of narrow band filters to obtain precise photometric redshifts to sample cosmic structure.

Keywords: cosmology, galaxy surveys, dark matter, dark energy

1 Introduction

The realization that the universe was accelerating came as a surprise more than ten years ago. Today, all cosmological observations seem to ratify this picture where the universe is dominated by some strange form of peculiar energy that drives the universe to accelerate its expansion rate. Conversely, it may happen that this acceleration is just a consequence of the laws of gravity departing from our standard understanding provided by general relativity. The investigation of what causes this accelerated expansion is driving current observational cosmological projects. In order to probe the universe we can measure its expansion rate and its growth of structure rate. The most constraining observables include supernovae, clusters of galaxies, the clustering of galaxies, weak lensing, the integrated sachs-wolfe effect (e.g., Albrecht et al. 2006). Most of them require to sample large volumes and large redshift epochs to be most efficient. For good enough statistics enough objects need to be sampled, which often means sampling many galaxies. It is also necessary to measure their distances and shapes. There are many projects focus on carrying out such extensive and comprehensive surveys. Here we will focus on two of them, the Dark Energy Survey and the Physics of the Accelerating Universe Survey.

2 The Dark Energy Survey

The Dark Energy Survey (DES*, Dark Energy Survey Collaboration 2005) is one of the most comprehensive photometric dark energy surveys planned in the near future. The DES collaboration comprises over 120 members in more than 15 institutions spread over 5 countries. The DES is constructing a new large area camera DECam (see Figure 1) to be mounted at the prime focus of the Blanco 4m telescope at Cerro Tololo, Chile. The camera includes a newly designed corrector that delivers a 2.2 degrees diameter field of view which is densely covered by 62 science CCDs, supplemented by others used for guiding, monitoring the wave front and focusing. The detectors are 2k by 4k fully depleted CCDs which make them very sensitive to red wavelengths. The camera is equipped with a set of grizY filters. DECam is now at its latest stages of construction. The installation at the 4m telescope is scheduled for January 2012. The camera is expected to be fully operational by the middle of 2012.

The DES is also implementing a data management system to handle the survey image reduction. At the same time, CTIO/NOAO is preparing the observatory and improving the telescope performance for the arrival of DECam.

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*http://www.darkenergysurvey.org

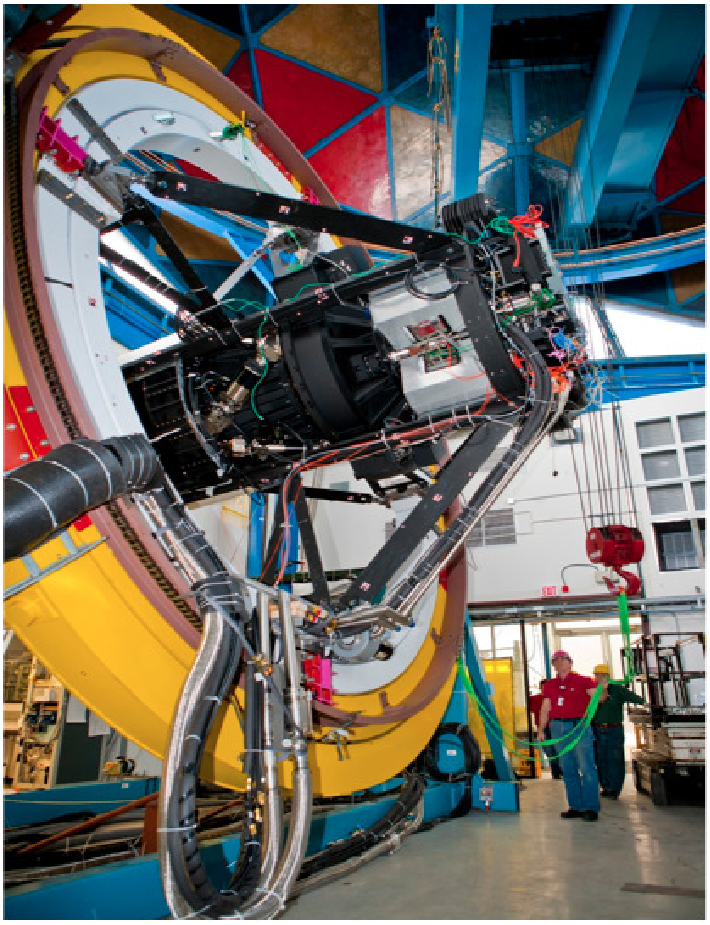

Fig. 1. DECam mounted on the Telescope Simulator at Fermilab in early 2011

The DES will use 525 nights to map 5000 deg^2 in 5 bands, grizY, down to an approximate depth of $i \sim 24$. Additionally it will sample 30 deg^2 repeatedly to search for supernovae in 10 separate fields. Two of these SNe fields will be imaged deeply and the rest will be shallower. The main science driver of DES is to characterize dark energy using four cosmological probes. DES will detect a hundred thousand galaxy clusters to redshifts $z \sim 1$ and will use the evolution of their abundance to test cosmology. For that purpose it needs to calibrate the relation between its detection method (optical searches based on colour and spatial distribution) and mass. It will overlap with the SPT SZ survey and therefore will benefit with cross checks and calibrations with the SZ decrement. Cluster weak lensing measurements will also be used to calibrate the cluster masses. Another probe will be weak lensing. DES will measure shapes for $\sim 3 \times 10^8$ galaxies at mean redshift $z \sim 0.7$ and use them to compute the cosmic shear angular power spectrum. Additionally it will use the bispectrum and the galaxy-shear signal to determine dark energy. DES will also use the clustering of galaxies to constrain cosmology. In particular, it will measure the baryon acoustic oscillation scale at different photometric redshifts bins. It will also study redshift space distortions. Another cosmological probe will be the use of supernovae. With its dual strategy search (deep and shallow) DES expects to detect around 4000 well-sampled SNe out to $z = 1$.

DES will be a photometric survey and therefore will need to rely on photometric techniques to estimate the redshift to the observed objects. The VISTA Hemisphere Survey (VHS[†]) has already started observations and will eventually map the whole DES area in the J, H and K filters. The addition of near infrared data improves the photo-z performance that is expected to have an RMS scatter below 10%. For clusters it will be lower, of the order of 2%. This precision is sufficient for the dark energy probes to be used provided that the error

[†]http://www.ast.cam.ac.uk/~rgm/vhs/

distributions are sufficiently well measured.

In order to understand the constraints that can be possible to place on dark energy, the DES team is developing a comprehensive simulation effort.

Another important component of DES is a data management system to be able to cope with the vast amounts of data that the survey will generate. In this context, a community pipeline is being developed for external users of DECam.

The DES is expected to start in September 2012 and will release their data 12 months after the data are taken.

3 The Physics of the Accelerated Universe Survey

The basics requirements for a cosmological survey are to cover large volumes, sample enough objects, measure distances and shapes and in the case of supernovae have appropriate time coverage/cadence. Photometric surveys are very efficient in sampling large volumes and many galaxy tracers. However, they perform poorly in determining redshifts. On the other hand, spectroscopic surveys can determine very accurately redshift, but struggle to obtain large number of objects and sample large volumes. The Physics of the Accelerated Universe Survey (PAU[‡]) is designed to straddle between both concepts trying to sample large volumes with good enough redshift accuracy. In fact, many cosmological applications do not require extremely accurate redshift determinations. For example, the lensing efficiency kernel is very broad and therefore individual distances need not be good. The baryon acoustic oscillations feature has an intrinsic width and sampling it with a much better distance resolution is therefore inefficient. The PAU survey intends to sample a large area of the sky using narrow band filters to obtain good photometric redshifts to constrain cosmology.

The PAU survey collaboration is building a new large field of view camera (PAUCam, Casas et al. 2010, see Figure 2) to be installed at the William Herschel Telescope (WHT) at the Observatorio del Roque de los Muchachos in La Palma, Spain. The camera will be installed at the prime focus and will use its current corrector that delivers a 1 deg diameter field of view with the inner 40arcmin without any vignetting. PAUCam will have 18 2k $\times$ 4k CCDs in its focal plane. These detectors are red sensitive fully depleted CCDs supplied by Hamamatsu. The camera will be equipped with 36 narrow band filters of 100 Å width covering the wavelength range from 4800 to 8400 Å and six standard broad band filters (ugrizY). PAUCam is currently undergoing construction that is expected to finish by the end of 2012.

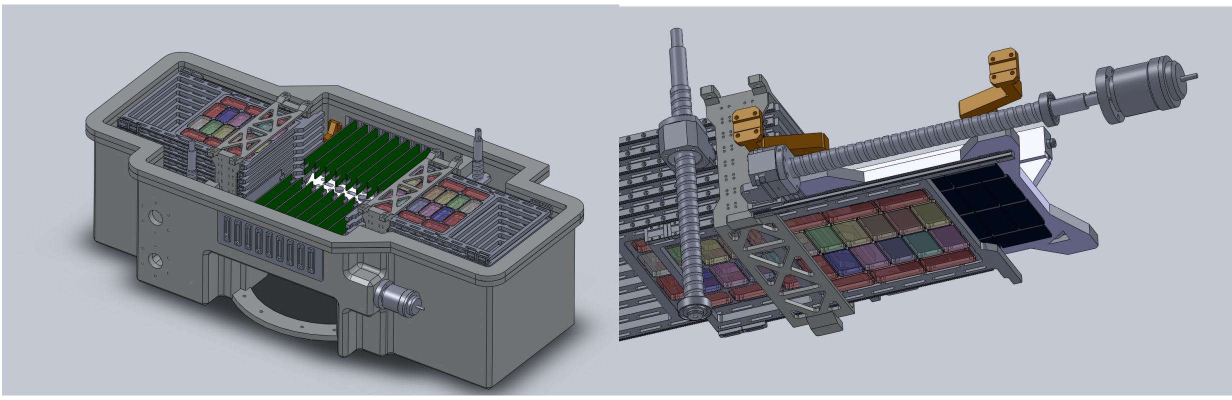

Fig. 2. Left: Rendering of the PAU Camera interior. **Right:** Image of the camera filter trays.

The PAU Camera will have a surveying power of 2 deg^2 per night imaging down to $i \sim 22.5$ in the narrow band filters and down to $i \sim 24$ in the broad band filters. The PAU survey team expects to conduct a wide area survey with all the narrow band and broad band filters in the camera of at least 200 deg^2 down to the previous quoted depth. The exact reach will depend on how much time can be used for the survey, though. Each filter tray has eighteen positions for filters, one for each CCD. We intend to place 6 narrow band and 2 broad band filters in the central eight positions (those without vignetting) of each tray. We define our survey strategy based on these eight central detectors. Nominal survey procedures with similar exposures in six different filter

[‡] http://www.pausurvey.org/

trays result in two different samples of galaxies. One shallower sample detected in the both the broad band and narrow band filters for which we would obtain photometric redshifts with $\delta z \sim 0.0035 \times (1+z)$ accuracy. And another deeper sample with galaxies just detected in the broad band filters with photometric redshift accuracy of $\delta z \sim 0.05 \times (1+z)$. We intend to study the redshift space distortions (RSD) and the weak lensing (WL) magnification of the sample and use them to place cosmological constraints. The expected performance is presented in Gaztañaga et al. (2011), where the method is explained in detail. Briefly, we will measure the RSD of the shallower sample and the WL (either by measuring magnification and/or shear) of the deeper one. We will cross-correlate different redshift bins of both samples. This technique enables to produce figure of merits on w and γ that are one order of magnitude better than if analysed separately (see Figure 3).

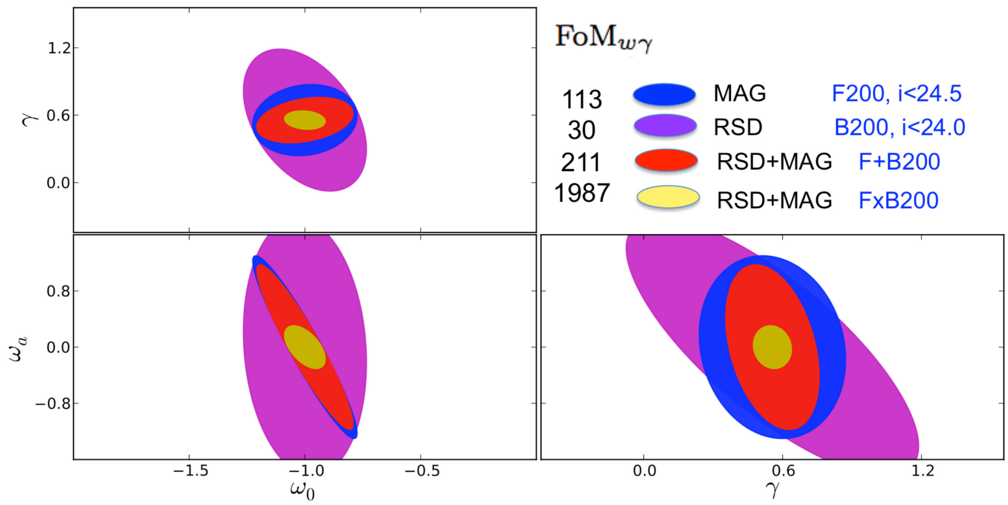

Fig. 3. Expected cosmological constraints for the dark energy equation of state (w_o and w_a) and the growth rate of structure (γ) from the PAU survey covering 200 deg^2. From Gaztañaga et al. (2011)

4 Conclusions

We have presented to upcoming surveys designed to measure the expansion rate and the growth rate of the universe to constraint dark energy. Both surveys are constructing large field of view cameras to conduct comprehensive surveys. DES will produce a photometric catalogue of 5000 deg^2 and will use four different probes to constrain dark energy. The PAU Survey straddles in between photometric and spectroscopic surveys. It will produce a shallower with good redshift determinations sample and a deeper one with poorer redshift accuracies in the same area. The PAU survey expects to exploit the benefits of conducting both surveys in the same area.

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