Intermediate Projects in Wide-Field Imaging: Supernova and Lensing activities

(Report to the IN2P3 scientific council)

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1 Introduction

A consistent picture of our Universe emerged at the turn of the century with a remarkable series of results that were published in a little less than 3 years. The detection of the accelerated expansion of the Universe [1, 2, 3] indicated that the Universe is filled with some energy density of unknown nature that acts repulsively on the large scales – called dark energy soon thereafter. The measurement of the angular size of the accoustic peak in the CMB spectrum [4], complemented with the first precise measurement of the Hubble constant H_0 delivered by the Hubble Key Project [5] favored a euclidian Universe at the critical density. Finally, the first precise measurements of the distribution of matter in the Universe [6, 7], as well as the cluster counts [8] favor a low matter density, and confirm the whole picture: the Universe is at (or very near) critical density and made principally of dark matter (25%) and dark energy (70%), the rest being essentially made of baryons. The standard model of cosmology that resulted from this remarkable series of measurements is called ΛCDM, Λ for a cosmological constant (or dark energy component), and CDM for Cold Dark Matter, the two main consistuents of the Universe – of unknown nature. Understanding the nature of dark matter and dark energy is now the central question of observational cosmology.

At the source of this revolution is another revolution in the observational techniques. The emergence and confirmation of ΛCDM is largely due to the advent of wide field imagers, i.e. mosaic of CCDs of $10^8 - 10^9$ pixels, covering up to a few degrees of sky in a single exposure. These instruments, mounted on 4-m class telescopes have allowed to finely map the matter distribution over sizable volumes of Universe ($\sim$ 1Gpc^3 for the wide survey of the CFHTLS). These instruments have also allowed to measure the expansion history through distance measurements. Essentially in parallel with these large imaging programs, the SDSS instrument has been coarsely mapping a volume of $\sim$ 10 Gpc^3 using spectroscopic techniques, and has established the Baryon Acoustic Oscillations as a major cosmological probe [9, 10, 11].

Over the last decade, the IN2P3 teams have been heavily involved in the Supernova Legacy Survey (SNLS), based on the deep component of the public CFHT Legacy survey (CFHTLS). Relying primarily on distances to supernovae, they have produced over the last ten years [12, 13, 14] the best constraints on the dark energy equation of state, and the most precise characterization of the MegaCam instrument [15, 16]. A significant know-how regarding reduction of wide-field imaging data has been gained through these activities. For the French community, the next stage is the participation to the Large Synoptic Survey Telescope (LSST) and the Euclid ESA mission. In LSST, the efforts in dark energy science are organized within the Dark Energy Science Collaboration (DESC).

The CFHT Legacy Survey observations ended in 2008. Ongoing wide field imaging survey are the Dark Energy Survey (DES), and the Subaru/HyperSuprimeCam (HSC) imaging survey. Both have a significantly larger reach than the CFHTLS, and require the development of new reduction techniques. The French community with working knowledge on wide-field imaging cosmology is not involved in either of those. Joining these collaborations as full members (with full data access) is no longer practical. The situation is different for most of our collaborators on LSST and Euclid: several European nations are involved in DES (through instrumental contributions), as well as a large fraction of LSST scientists. Some US groups were able to join the HSC survey, with a sizable entrance fee. With no contacts with the currently active wide field imaging community, the scientific return expected from the human, technical and financial investments the IN2P3 is currently putting into Euclid and LSST may be at risk.

The scientific activities described in this note aim at keeping contact with currently active teams working on fresh data, in order to maintain our technical and scientific capabilities current with the ones of our colleagues (and competitors), involved in LSST and Euclid (and sometimes both). Since we cannot enter these major collaborations, we cannot hope to compete with the key projects they are pursuing. We can however tackle subjects which have a very significant science potential, and obvious applications when LSST and Euclid see their first light.

Two such endeavors are described in this note. In §2, we describe a project to extend the supernova Hubble diagram to high redshifts using the Subaru/HSC camera. The following section (§3) deals with shear measurements, in the context of mass measurements of galaxy clusters. In the last section (§4) we outline the synergies between these two projects and the preparation of science for LSST and Euclid. We summarize the resources needed by these projects in §5, and we conclude in §6

2 Extending the Hubble diagram to high-redshifts with Subaru/HSC

2.1 Scientific context

Type Ia supernovae (SNe Ia) are among the most precise standard candles known today. With the current techniques, it is possible to measure the luminosity distance to a SN Ia with a precision better than 10%. SNe Ia allow one to constrain the late-universe luminosity-distance *vs* redshift relation, and therefore to study the integrated history of cosmic expansion. Expansion itself depends on the densities and equations of state of the cosmic fluids populating the Universe (baryons, relic photons and neutrinos, dark matter, dark energy...). The Hubble diagram of SNe Ia therefore yields one useful constrain on these cosmological parameters.

Historically, SNe Ia have allowed us to detect the acceleration of cosmic expansion [1, 2, 3]. This remarkable result, which earned its discoverers[1] the 2011 Nobel Prize for Physics, was obtained with less than 100 supernovae, at low- and intermediate-redshifts ($z \sim 0.1$ and $z \sim 0.5$ respectively).

What causes the acceleration of the expansion of the Universe is a profound mystery, central to modern cosmology. The cause is generally referred to as "dark energy". Dark energy may be a uniform and constant energy density, such as the "cosmological constant" Λ initially postulated by Einstein who later rejected it when cosmic expansion was discovered [17, 18]. It may also be a dynamical fluid of (yet) unknown nature [19]. Finally, it may be the indication that the standard cosmological model is incorrect, or even General Relativity is at fault at cosmological scales.

Experimentally, it is possible to discriminate between dark energy models by constraining the dark energy equation of state (EoS): $p = w \times \rho$. If dark energy is a cosmological constant w is equal to -1 at all times. On the other hand, dynamical dark energy models usually predict $w \neq -1$, and often a time variable equation of state ($w(a) = w_0 + (1 - a) \times w_a$, where a is the scale parameter which describes cosmic expansion). The goal of SN surveys today, and more generally of dark energy surveys, combining several probes, is to discriminate between dark energy models by measuring (w_0, w_a).

This approach has been formalized by the Dark Energy Task Force (DETF) [20], who has established a roadmap towards an accurate measurement of the dark energy EoS. Dark energy surveys are ranked according to their impact which is quantified using the DETF "figure of merit":

$$\mathrm{FoM} = |\mathrm{cov}(w_0, w_a)|^{-1/2}. \tag{1}$$

The FoM summarizes how well a survey can constrain a time-variable dark energy equation of state. Projects classified as "stage-II" by the DETF are now completed. The Supernova Legacy Survey (SNLS), described below is among them (§2.2). SNLS has obtained excellent constraints on w but is essentially insensitive to w_a (FoM ~ 15). Stage-III projects are currently on-going (§2.4). Their goal is to improve the FoM by a factor 3 w.r.t the previous generation, i.e. to detect possible variations of the dark energy equation of state. Precise measurements of the EoS will be performed by the large stage-IV surveys which will see their first light around 2020 and reach a FoM of a few hundreds (§2.3).

[1] S. Perlmutter from the Supernova Cosmology Project, B. Schmidt and A. Riess from the High-z supernova search Team.

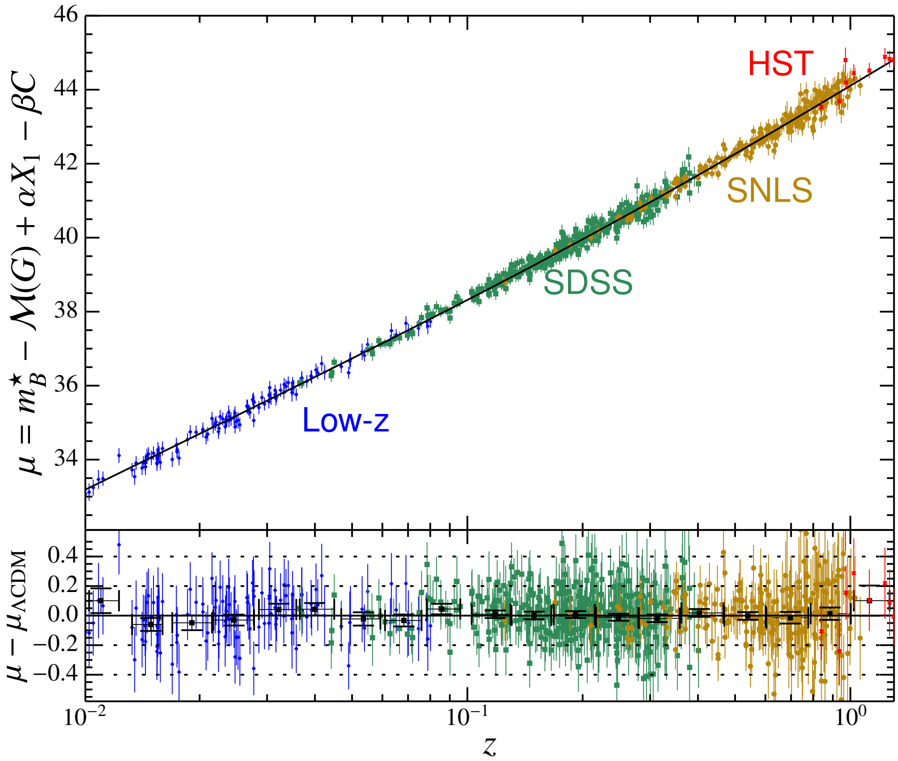

Figure 1: The Hubble diagram published by the SNLS-SDSS-II collaboration [14]. This Hubble diagram contains 740 SNe Ia. The final SNLS data release, currently in preparation will contain of the order of 1000 SNe Ia.

2.2 The recent past

Stage II projects Soon after the accelerated expansion was discovered, several teams set out to constitute the large SN Ia samples that were needed to constrain the Dark Energy equation of state. These projects have collected data during the past decade. At low-redshift, the searches led by the Center for Astrophysics (CfA, Harvard) and the Carnegie Supernova Project have gathered ~ 100 SNe Ia [21, 22, 23] (alltogether). In the intermediate redshift range the SDSS-II collaboration has populated what was then a "redshift-desert" with ~ 370 supernovae with a high-quality follow-up [24, 25, 14]. Finally, at higher redshifts, the Supernova Legacy Survey (SNLS) was able to detect, identify and follow-up ~ 450 SNe Ia in the redshift range $0.3 < z < 0.9$ [26, 27, 14]. The Hubble diagram of Type Ia supernovae now contains of the order of 1000 supernovae – more than 10 times the statistics that was available in the early 2000. It yields today the best constraints on the Dark Energy equation of state.

Involvement in SNLS & SDSS-II The IN2P3 teams have been strongly involved in SNLS, and the scientific return of this investment is remarkable. The quality of the data permitted to develop reduction, photometry and calibration techniques [15, 16, 28], to develop new supernova light curve models [29, 27] and to publish with each intermediate release of the SNLS dataset the strongest constraints on the dark energy equation of state [26, 27, 30, 31]. In 2011, SNLS and SDSS-II joined forces to reanalyze their datasets, focussing on the intercalibration of both surveys, and the potential systematics associated with the supernova empirical light curve models. This effort resulted in a series of technical papers [32, 16, 33] as well as a joint cosmology publication which improved significantly the existing constraints on w [14]. The Hubble diagram published by this project and the resulting constraints on the w-parameter are shown in figure 1 and 2. All these efforts were either led or have

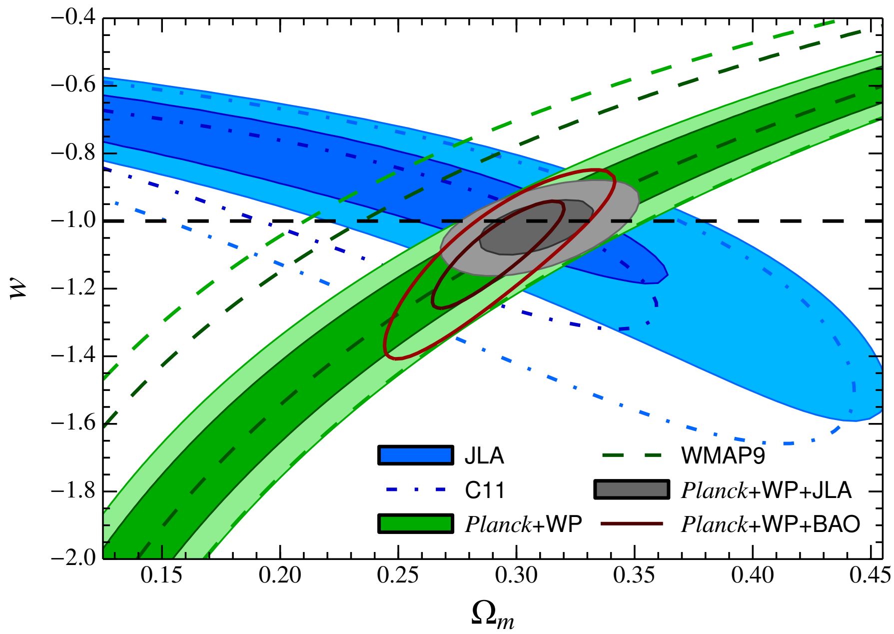

Figure 2: Constraints on the dark energy equation of state obtained by the joint SNLS-SDSS-II effort[14]. The blue region corresponds to the SN constraints (for a flat universe), the green contours are the constraints obtained from the Planck mission [34]. The combined constraints are shown in grey. The open red contours correspond to what is obtained by combining the BAO and Planck likelihoods only.

benefited from key contributions from the IN2P3 teams. SNLS is preparing its final data release, which will include its full 5-year data sample, combined with all the high-quality samples available today. This dataset, given its very high quality, will not be outdated until the end of the decade, with the advent of LSST.

2.3 The future : LSST

The science roadmap of the Large Synoptic Survey Telescope (LSST) contains a strong supernova program. LSST alone will be able to cover the full redshift range $0.05 < z < 1.2$, combining a cadenced wide and shallow survey, as well as a cadenced deep survey (a.k.a. deep drilling fields). The survey will discover and follow-up of the order of a few 10^4 SNe Ia in this redshift range, which will represent a 10-fold increase of the current statistics.

LSST alone will not be able to extend the Hubble diagram beyond a redshift of $z \sim 1.2$. Measuring the luminosity-distance of a SN Ia requires being able to infer the SN color[2] in its rest frame, from the SN flux measurements – performed in the observer frame. For a nearby object, rest-frame and observer-frame wavelength almost coincide. For an object beyond $z \sim 1.2$, most of the emitted flux will be detected in the infrared, which is not accessible to silicon light sensors such as the CCD's which equip the LSST camera.

It could however be possible to complement the LSST observations of the most distant ($z > 1.2$) supernovae with infrared observations taken from space. The Euclid satellite will be taking data during the same period. It is therefore possible to build on the complementarity between LSST and Euclid and design a joint survey for the most distant objects. This strategy has been explored in [35]. It has been shown that this approach allows to build a Hubble diagram of a few 10^4 SNe Ia up to a

[2]In astronomy, the color of an object is the (logarithm of the) ratio of the object flux in two passbands.

redshift $z \sim 1.5$. The figure of merit which can be attained this way is of ~ 200 (after combination with a geometrical Planck constraint).

Given the experience gathered in SNLS and the power of SNe Ia as a probe of the dark energy equation of state, we hope to be in a position to play a key role in the LSST working groups. This requires that we stay in contact with the new data produced by the stage-III projects currently in operation. This is where the photometry, calibration, SN light-curve fitting and more generally data-analysis techniques relevant for LSST are being developed. This is also the place where we can train the researchers that will analyze the LSST data.

2.4 The road towards LSST

As of today, the Hubble diagram comprise about 1000 well-measured objects in the redshift range $0.05 < z < 0.9$. It gives excellent constraints on w ($\sigma(w) \sim 0.055$) and is essentially insensitive to a time variable dark energy equation of state (FoM ~ 15).

To improve significantly on this situation, there are two strategies. One consists in increasing the available SN statistics by about a factor 5 in the same redshift range ($0.05 < z < 0.9$). This is the strategy followed by the Dark Energy Survey (DES). DES consists in a three-layer survey conducted over five years (500 nights) with the 3-deg^2 Dark Energy Camera (DECam) mounted on the prime focus of the 4-m Blanco telescope. Data taking started in 2013 and will last until 2017. The projects targets the four cosmological probes that are central in the LSST science program (supernovae, baryon accoustic oscillations, galaxy cluster counts and weak gravitational lensing). The DES supernova program will find of the order of 2000 SNe at redshifts comprised between 0.2 and 0.8. It prefigures the data analysis that will be performed in LSST, in the sense that the large statistics forbids to conduct a spectroscopic typing of all the discovery. For most SNe, only a spectroscopic redshift of the host galaxy will be obtained, generally well after the supernova has faded out, and only a small fraction of the detections will benefit from live spectroscopy. As a consequence, developing efficient photometric typing of the SNe Ia, as well as the control of the purity of the SN sample that enters the analysis are essential.

Very distant supernovae with Subaru/HSC An alternative approach is to leave the statistics in the $0.05 < z < 0.9$ unchanged (the SNLS/SDSS-II sample constrains this part of the Hubble diagram well) and increase instead the redshift lever-arm. The goal is then to assemble a sample of a few hundred SNe Ia in the underpopulated redshift range $0.8 < z < 1.2$, with a follow-up quality comparable to what was obtained by SNLS.

Few instruments in the world can target this redshift window. Among them is the 1.77 deg^2 HyperSuprimeCam (HSC) camera, recently mounted on the prime focus of the 8.2-m Subaru telescope (Mauna Kea). HSC has about 10 times the collecting power of MegaCam (the imager used for SNLS) in the redder part of the visible spectrum. The image quality delivered by the instrument is outstanding (0.6" of median seeing in the redder bands). We believe than HSC is the only instrument in the world that can assemble a deep SNLS-like sample by 2018 - 2020.

The HSC consortium has provisioned 300 nights to conduct a large, three layer survey. As DES, the survey targets the four main cosmology probes that will be at the core of the LSST dark energy science – with a strong emphasis on weak lensing.

We have been approached by a team of researchers from IPMU (Tokyo) involved in the HyperSuprime-Cam Imaging Survey, to work together on the design of the SN survey. Our computations have shown that a 2 semester search undertaken with HSC would be competitive with the DES supernova survey. The search itself yields a smaller number of objects (about 150 well measured SNe Ia up to a redshift $z \sim 1.2$). However, the distances to these objects are very well measured, given the large collecting power of the Subaru telescope, and the cosmological impact of these objects, once combined with the SNLS/SDSS-II sample equivalent to what is predicted for DES [36].

As discussed above for LSST (§2.3), Subaru alone cannot go beyond a redshift of 1.2. Indeed, measuring the luminosity distance to a SN Ia requires performing observations in the near-infrared. There is an option, currently under study, to extend the Hubble diagram to higher redshifts ($z \sim 1.5$). We have shown that with $\sim$ 100 HST orbits, we can complement the follow-up of a subset of the very distant SNe Ia discovered with Subaru. In that case, we would be sensitive to possible variations with redshift of the Dark Energy equation of state – as predicted by several Dark Energy models. In terms of FoM, this option can reach a FoM almost double than what is forecasted for the DES supernova program.

Discussions are currently ongoing with our IPMU collaborators on the survey design. In our current plans, data taking will take place from the end of 2016 to the first months of 2018. The idea is to publish cosmological constrains around the end of 2019. A joint paper detailing the observations and their cosmological reach is in preparation to support an observing proposal to be submitted to the HSC Time Allocation Committee. A proposal to the ESO-Very Large Telescope, to collect the redshifts of the host galaxies after the facts is in discussion. Discussions to team up with American collaborators for a higher redshift extension with HST are under way.

The details of the collaboration agreement will follow. In any case, it will include at most a handful of individuals from the IN2P3 labs.

3 Gravitational lensing

3.1 Scientific context

Gravitational lensing is regarded as the central probe of both LSST and Euclid. In both instances, the instrumentation and survey strategy were designed to enable the measurement of the shear angular correlations with the accuracy needed to take advantage of the very large sky area they both plan to cover. Both projects consider other probes; Euclid in particular will conduct a spectroscopic near infrared survey in parallel with the visible imaging survey.

The shear angular correlations are regarded as one of the most promising probes of dark energy (e.g. [20]), and have so far delivered limited constraints (e.g. [37]).This cosmological probe is sensitive to both the expansion history and the formation of structures and hence allows one to probe the latter, once the expansion history has been measured from distances to supernovae and Baryon Acoustic Oscillations (via galaxy/quasars redshift surveys). As stressed in the LSST and Euclid science cases [38, 39], confronting structure formation and expansion history is today the most sensitive way envisaged to test General Relativity on large scales. More generally, confronting different probes is the key avenue for dark energy science [20].

At variance with distances to supernovae, there is so far no know-how regarding specifics of lensing physics from imaging at IN2P3. To enter this science topic with the ambition to contribute significantly, a solid practical experience has to be acquired between now and first light, in contact with active teams. Large scale shear programs now require several hundred nights and hence gather significant collaborations. As discussed above, becoming full member of the Dark Energy Survey (DES) or of the Hyper-Suprime Cam (HSC) survey collaboration is now essentially impossible. One might consider alternatives to these two ongoing cutting-edge observing lensing programs. One such alternative is "KIDS", an ongoing survey using the 2-m VST telescope which recently produced its first release [40]: the science reach is bound to remain behind the CFHTLS because of the modest aperture of the telescope. One might also consider a proposal being setup to conduct a large program ($\sim$ 300 nights) at CFHT (the CFHT northern sky survey), mostly driven by Euclid's vital need for multi-band photometry (over the northern part of Euclid's wide survey) in order to derive photometric redshifts of galaxies. Given the overall expected time allocation, this survey is too wide and hence too shallow to allow useful shape measurements. Its expected cosmological outcome mostly consists of (partially) fulfilling Euclid's needs and contributing to DESI's targeting. Depending on the outcome of the selection process, contributing to the data reduction could be considered, but given the lack of a direct science outcome, this activity would rather belong to Euclid science preparation.

So, in order to get trained to cosmology from shear correlations, we eventually concluded that we should tackle a related but different science topic.

3.2 Gravitational lensing by galaxy clusters

Besides the two point correlation function, shear allows one to characterize large mass concentrations, and the shape distortions due to massive galaxy clusters were indeed the first detected manifestations of strong [41] and weak [42] gravitational lensing. Galaxy clusters are also currently a hot topic in cosmology, because Planck has delivered a catalog of several hundred clusters, detected via the Sunayev-Zeldovich (SZ) effect [43]. In order to constrain cosmology from cluster counts, at least a mass and a redshift estimate for each cluster are needed. Planck has delivered mass estimates, but the overall mass scale remains uncertain. Lensing is currently the best avenue to set this mass scale [44]. Planck SZ cosmology relies on this technique, and is limited by this external input [8].

Cluster lensing programs are currently conducted on most wide-field imagers, in particular DECam, HSC and Megacam on CFHT. These programs are conducted as follow-ups of either X-ray-detected clusters or (more frequently nowadays) SZ-detected clusters. The scientific aims cover detection confirmations, evaluation of cluster redshifts, and measurements of masses mostly using shear.

Regarding the origin of cluster catalogs, it is interesting to pursue both X-ray and SZ samples, because there is currently no precise knowledge of demographic biases caused by the detection method. The collaborations working on these subjects are small and focused, and obtain their observations through regular (and somehow revolving) observing proposals. These loose collaborations are open to new members, especially if those bring in observing time and/or data reduction manpower.

We have been approached by the Collaboration *Weighing the Giants* for teaming up for a CFHT proposal. The aim here is to collect masses for 12 northern X-ray clusters, in order to precisely measure their total mass. The baryon mass is derived from the X-ray luminosity, and one can then get the baryon mass fraction in these clusters. Under the reasonable assumption that this fraction does not depend on redshift, this in turn constrain distances, and hence dark energy. The same program will certainly improve the Planck cosmological constraints from cluster counts by improving the mass calibration, because all the targeted clusters belong to the Planck catalog.

We target high-quality masses, i.e. that rely on precise photometric redshifts of the sources, and on well measured galaxy shapes. This is possibly accomplished by mixing observations on CFHT and Subaru, which routinely deliver the best image quality from the ground. Our baseline is to measure galaxy colors on CFHT (typically $\sim$ 10 hours per cluster) and the shear measurement image on Subaru ($\sim$ 2 hours). We have submitted CFHT proposals for semester 15B on both the French (P.I. Astier) and Canadian (P.I van Waerbeke) agencies, which were successful on both sides. We have resubmitted very similar proposals (but for the targets!) for semester 16A. The Subaru proposal was accepted as well, and was resubmitted. The commitment, on the French side is to provide an independent reduction chain, and compare intermediate products.

While setting up the crew submitting the CFHT proposal, we tried to team up with French key actors of the galaxy cluster physics, namely M. Arnaut and N. Aghanim, both leading follow-up programs of Planck clusters. We could not agree on common targets, but agreed with M. Arnaut's group to share imaging data and compare the reductions. A first meeting of the teams has already taken place.

This cluster shear project started at spring 2015. We have collected a large image set from the Subaru public archive and started to develop the software tools required to eventually measure shear. The first needed tool is a *simultaneous* astrometry solver for a set of images of the same field, which has been written and validated, both on Megacam, Suprime-cam, and Hyper-Suprime-Cam data sets. This tool was ported by French LSST members into the LSST software framework (a.k.a "The stack"), used by the HSC survey consortium. This tool performs better than all known alternatives. We have also started the characterization of the flux-dependent PSF of Hamamatsu deep-depleted CCD's which equip the Subaru cameras, a serious issue for both shear measurements and photometry of point sources (e.g. supernovae).

The expected practical outcome of the enterprise is to learn how to measure shear and gain a working knowledge of photometric redshifts of galaxies, both with obvious applications in future programs. Several elements of the analysis chain that we have to setup could be recycled into future programs, as we have already started with the astrometry code. Scientifically, refining the cluster mass-scale of SZ catalogs to a few % precision will deliver constraints from cluster counts complementary to distance measurements.

We anticipate to submit observing proposals over $\sim$4 semesters, or more if the weather plays against us, or if we experience negative responses from time allocation committees. Assuming observing time is awarded roughly as expected, we anticipate final publications in $\sim$ 2019. We anticipate that the size of the French team cannot be more than handful of permanent researchers, to be on par with our collaborators.

4 Synergies between the supernova project, the lensing project, Euclid and LSST

The IN2P3 has a track record on the characterization of the Megacam instrument [16], in particular aspects related to the calibration of photometric measurements. Both the Subaru supernova program and the shear cluster project require such a detailed characterization of the HSC instrument. One extra complication is related to red sensitive CCDs (or deep-depleted CCDs) which equip the HSC instrument (and will equip LSST): they are affected by non-linearities (typically a flux dependent PSF) due to space charge effects [45, 46]. The tools necessary to handle the effect will be shared between the two projects, and possibly with the HSC survey collaboration.

More generally, some of the analysis tools required for the endeavors described above could make their way into the LSST software, as already started with the simultaneous astrometry package. Even if they don't, the training and know-how gained in these enterprises can only benefit to the teams that will tackle the core analyses in Euclid and LSST.

5 Required resources

The two efforts presented in this note involve groups of a few individuals, for the 3-4 years to come. No tickets nor hardware contributions are envisioned. The travel resources needed amount to a few thousand euros per (full time) individual and per year, i.e. enough to organize one workshop and two collaboration meetings per project and per year, and efficiently structure the analysis effort – because results have to come out rapidly.

6 Conclusion

We have presented two scientific projects that can allow small IN2P3 teams to remain in close contact with new data. These two projects have significant scientific promises: improve dark energy constraints by a high-redshift extension of the SN Hubble diagram, and providing the key ingredient for cosmological constraints from galaxy cluster counts. In both instances, new techniques, required for LSST are to be developed. The weak lensing project aims at opening a research avenue absent at IN2P3. We believe that conducting such activities is mandatory to allow IN2P3 teams to play an important role in the scientific analyses of Euclid and LSST. We expect that these activities will allow to train newcomers to wide-field imaging, and provide PhD students, post-docs and young researchers with actual scientific analyses. The number of people and the required resources are small and limited in time.

We have considered an alternate route, consisting in working out a reduction of the DES and/or HSC survey data, when those become public. We believe that such a goal only makes sense within some sort of international consortium. It turns out that the DESC collaboration wisely regards the reduction of these "precursor" datasets as a key test of its analysis strategies. We hence believe that DESC is the proper framework for this enterprise, which is currently being set up. This is primarily an engineering project, which consists of verifying that the LSST tools are able to extract the science already published. Some of us are involved in this effort. We believe however that it is vital to stay involved in teams producing new science.

The projects we have sketched in this note tackle science subjects that will contribute significant improvements on cosmology until Euclid and LSST first light. In addition, this tactical choice simultaneously allows our teams to maintain and develop their technical and scientific expertises at the level required to be primary actors when Euclid and LSST start observing. Besides, these projects not only have synergies between them, they also have direct synergies with (at least) LSST/DESC.

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