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Cosmology with the Rubin Observatory from the Dark Energy Science Collaboration.

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Abstract

In this contribution, we briefly present the current status of the Rubin Observatory with a focus on the activities of the DESC: the Dark Energy Science Collaboration. This group has been developing a large body of preparatory work towards maximizing the scientific output of the Legacy Survey of Space and Time (LSST) for cosmology, including dark energy and dark matter research. We will highlight some of the projects performed, including work on precursor data, development of highly detailed simulations, and sophisticated software for testing and analysis.

1 The Vera C. Rubin Observatory and the LSST

The Vera C. Rubin Observatory is a new astronomical facility being built (as of January 2023) at Cerro Pachón, in Chile. It includes the Simonyi Survey telescope, whose primary mirror has an 8.4 meter diameter and a 9.6 square degree field of view and six optical-near infrared filters (*ugrizy*).

Once construction and commissioning are complete, by mid-2024 as of current schedule, the Rubin Observatory will conduct the 10-year Legacy Survey of Space and Time (LSST), a uniform photometric survey across half of the celestial sphere up to $r \sim 27.5$, using around 800 visits per pointing. In terms of raw data volume, this amounts to nearly 20 TB/night, with hundreds of petabytes accumulated by the end of the survey, in the 2030s. The data will be publicly released in catalogs, in a cadence to be determined, after a 2 year proprietary period. However, transient alerts will be public immediately through 'broker´ systems, less than a minute after shutter closure.

Commissioning is planned to start in late 2023. Currently, a 1.2 m telescope (AuxTel) is being operated with LSST software for testing, and eventually calibration purposes. Survey strategy is being finalized after several rounds of iterations. The LSST camera (LSSTCam) is set to be shipped to the summit in the coming weeks.

1.1 The LSST science topics

The LSST science revolves around four topics [5]:

- Cosmology and fundamental physics: which includes the exploration of the dark sector of fundamental physics, the mass of the sum of the different neutrino species and the nature of gravity. This will be done using a variety of approaches available to photometric surveys, such as the measurement of supernovae of type Ia, the combination of weak lensing and large scale structure, the study of galaxy cluster counts, the study of strong lensing systems, and various studies related to nearby dwarf systems and stellar streams.

- Milky Way structure and formation: including its evolutionary history and tests against small scale predictions of cosmology; spatial maps of stellar characteristics; reaching deep into the halo (~ 100 kpc), to map billions of main sequence stars and estimate their metallicities photometrically; detect and measure tidal stream properties and origin; find new and old satellite galaxies.

- Exploration of the transient sky: variable stars, e.g., creating an RR-Lyr census up to ~ 400 kpc; a thorough search of supernovae of all types; filling the variability phase space; finding new rare, transient types; follow-up of targets of opportunity.

- Cataloging the Solar System: such as potentially hazardous asteroids; NEOs; and in general making an inventory of the Solar System.

2 The Dark Energy Science Collaboration

LSST science is mainly being developed through a federation of self-organized science collaborations. Their function is to prepare for data analysis, advise Rubin personnel in terms of the science goals, engage and train the scientific community, fundraise, develop inclusion practices, and provide software development.

In particular, the Dark Energy Science Collaboration aims at exploring the physics of the dark Universe, namely the nature of dark matter and dark energy. The core aspect of the DESC approach is firstly to have a tenfold increase in the dark energy figure of merit of Stage II experiments, according to the definitions of the Dark Energy Task Force [3] (Figure 1), but also focus on accuracy, by closing in on the systematic error budget. DESC will combine information from large scale structure and weak lensing, plus cluster count information, and in parallel incorporate supernovae and strong lensing cosmological constraints, while being open to new probes as they are developed in the coming years.

In addition, from the start, the DESC wants to focus on a collaborative approach that fosters an inclusive environment, as a core part of its way of functioning. On the other hand, DESC's procedures are being developed ensuring a continuous learning process based on experiences from previous Stage III collaborations, technically, scientifically and in terms of collaboration environment.

2.1 Technical challenges for the DESC

Following from previous experience, the DESC has been able to identify several technical aspects in which it will have to focus. The following list provides some non-exhaustive examples:

- Uniform coadded catalogs for weak lensing science will be a necessity, possibly creating new types of coadds to avoid PSF inhomogeneities. This is an intense are of research currently.
- Value added data will be needed beyond regular Rubin pipeline outputs, in particular for photometric redshifts whose systematic errors will have to be exquisitely calibrated.
- Supernovae cosmology will have to rely on photometric classifications (Ia) and on millimag level photometry using highest standards in calibration.
- Large scale structure wide area systematics have been proven (Stage III) to be thoroughly tested through several approaches.
- A new systematic source for cosmology surveys appears significantly in this dataset: blending effects (on object detection, for LSS, and photo-z, among others).

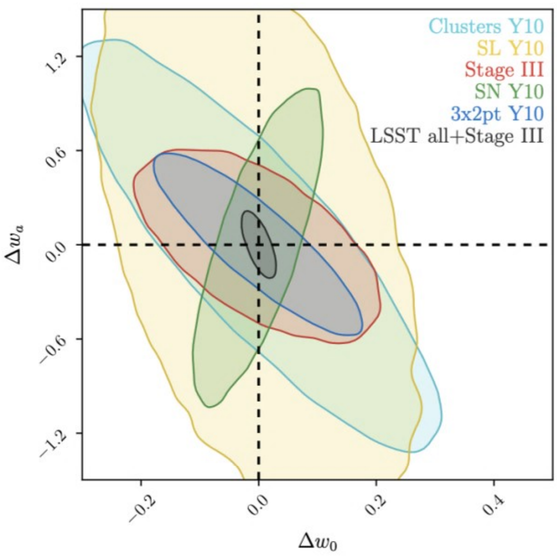

Figure 1: The forecast for dark energy constraints in $w_0 - w_a$ space (the DETF Figure of Merit) for DESC [2] using 10 years worth of data. Contours are 68% confidence intervals.

2.2 Selected DESC achievements to date

The author's biased selection of results from DESC. A full list can be found at this link:

- Simulations. A 300 square degree N-body simulation of objects with realistic colors and spatial correlations was created [1]. This included injections of supernovae and AGN light curves. The LSST observations were simulated with proper cadences, creation of images based on this cosmological simulation, and detection of sources using Rubin pipelines. The catalog testing and validation framework is described in [9] and [7]. This simulated catalog is used, among other things, to study for example optimization strategies for the tomographic binning of the combined large scale structure and weak lensing (3x2pt) measurements, as shown in [12]. A different set of simulations was used for the PLAsTiCC challenge [6] to understand the best approaches for supernova classification in the LSST area (analysis of results in [4]).

- Data Challenge 2. Various analyses groups developed and tested their science pipelines over these simulations with interesting results. An example is the realistic and rigorous analysis performed in [11] of the Difference Image Analysis pipeline of Rubin using these detailed simulations with realistic cadences and injected astrophysical transients.

- Precursor data analysis. Analyzing data from the Hyper Suprime Camera DR1 for large scale structure combined with weak lensing analyses for the first time in this data set in power spectra, as a test run for the high level DESC pipelines such as TXPipe [10] and Firecrown. Also using these pipelines to compare the cosmic shear outputs of precursor datasets [8].

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