ASSEMBLING A MAP OF THE UNIVERSE: SHAPES AND MASS DISTRIBUTION FOR THE DARK ENERGY SURVEY

Allocation: Illinois/460 Knh
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EXECUTIVE SUMMARY

The Dark Energy Survey (DES) has performed a 5,000 square-degree wide field survey in five optical bands of the southern sky and a 30 square-degree deep supernova survey with the aim of understanding the nature of dark energy and the accelerating Universe. DES used the 3 square-degree CCD (Charge-Coupled Device) camera (DECam) installed at the prime focus on the Blanco 4-m telescope with the goal of recording the positions and shapes of 500 million galaxies up to redshift 1.4. Over the course of the survey, DES produced roughly 500 TB of raw data, which has been processed with the DES Data Management system (DESDM). The Blue Waters allocation has facilitated the use of new processing algorithms that make detailed measurements of the galaxy properties (size, shape, brightness) that enable cosmological investigation into the history of structure formation in the Universe.

RESEARCH CHALLENGE

DES aims to understand the origin of cosmic acceleration and the nature of dark energy using four complementary methods: weak gravitational lensing, galaxy cluster counts, large-scale galaxy clustering (including baryon acoustic oscillations), and Type Ia supernovae. DES comprises two multiband imaging surveys: a 5,000 square-degree *g,r,i,z,Y* wide survey of the southern sky to approximately the 24th mag and a deeper time-domain 30 square-degree *g, r, i, z* deep DES Supernova Survey with a cadence of approximately five days.

METHODS & CODES

DES uses the state-of-the-art 3 square-degree DECam, a 570 megapixel camera installed at the prime focus on the Blanco 4-m telescope at the Cerro Tololo Interamerican Observatory (CTIO) in Northern Chile. DECam consists of 62 fully depleted, 250-micron-thick 2,048 × 4,096 CCDs combined with four 2,048 × 2,048 guider and eight 2,048 x 2,048 autofocus CCDs.

For 575 nights from 2013–2019, DES scanned the sky to perform a 5,000 square-degree wide field survey. Over five observing seasons, DES measured shapes, positions, fluxes, and colors for approximately 300 million galaxies and discovered and measured light curves for 3,500 supernovae, using these measurements to deliver powerful new constraints on cosmic acceleration and dark energy. Each image arrives from CTIO in Chile at the National Center for Supercomputing Applications (NCSA; Urbana, Illinois) within minutes of being observed and is usually processed by the nightly processing pipeline within the next 24 hours. These nightly pipelines are critical for the near-real-time supernovae analyses, and also provide rapid feedback about overall data quality as the survey progresses. The other cosmological probes (weak lensing and galaxy clustering) rely on the combination of all survey observations to form a data release with unprecedented depth but at the cost of averaging over instrumental changes and varying atmospheric conditions.

The DESDM software and workflows (using HTCondor) have already been implemented and exercised as part of previous allocations on Blue Waters. In addition, the atomic pieces of the DES Y6A1 release comprised 131,602 reduced, calibrated exposures and 10,169 COADD tiles and catalogs that cover the 5,000 square degree survey volume. These form the inputs for the joint analyses.

RESULTS & IMPACT

During the early years of the DES survey, new algorithms for measuring the galaxy properties were developed, but these require a joint analysis of combined images (COADDs) with the individual nightly observations that make up the survey on a per-object (galaxy) basis. The Blue Waters allocation was used to perform these analyses.

New measurement algorithms have been developed to cope with the increased astronomical survey depth, as the density of sources (stars and galaxies) projected along any line of sight in the survey volume is high enough that the projected object images overlap. Further, modern survey methodologies to obtain those depths rely on the combination of many images taken over many years in varied conditions (*e.g.*, atmospheric turbulence). Three advanced measurement algorithms have been developed by the DES Collaboration to make precise measurements based on the initial data release products. These include:

- MOF (Multi-Object Multiband Fitting), which simultaneously fits basic galaxy shapes and fluxes to each object and its neighbors;
- SOF (Single-Object Multi-Band Fitting), which performs a similar fit but masks neighboring object as a cross-check to the MOF analysis; and
- Shear, which makes a detailed shape analysis of an object and its neighbors.

These new catalogs are more precise and minimize the systematic uncertainties imprinted on the survey data. As an example of how these new catalogs will be used by the DES Collaboration, Fig. 1 shows the mass map from the first year of DES observations inferred from weak lensing measurements [1].

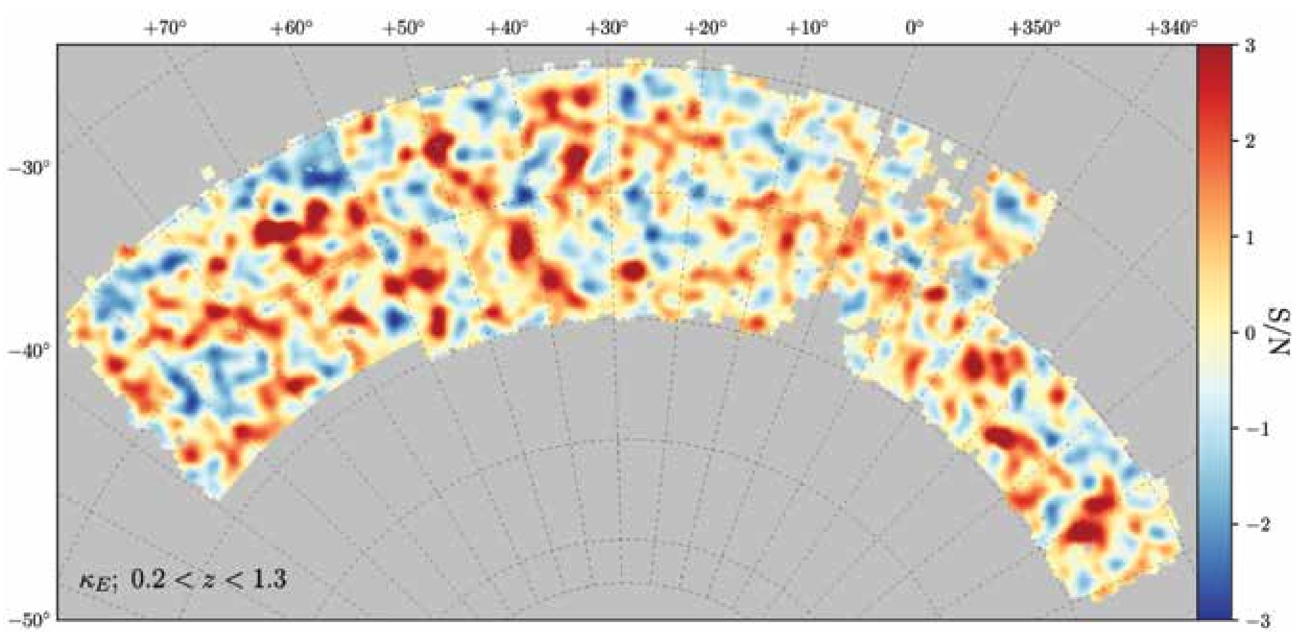

Figure 1: The mass map from the Year 1 DES observations inferred from weak lensing measurements of galaxies, where red represents higher mass density [1].

WHY BLUE WATERS

DESDM is led by NCSA, where all images are archived and served to the community. Data processing on Blue Waters is more robust and performant than distributing workloads to remote sites. Moreover, the proximity of DESDM scientists and Blue Waters staff enables rapid feedback and clear communication, which are important for the success of complex implementations. Blue Waters' primary utilization as a massively parallel resource also affords a complementary high-throughput resource by providing an elastic pool that can accommodate the intermediate demands of DES's campaign processing to obtain results within a month.

PUBLICATIONS & DATA SETS

Data set: The DES Collaboration Year 3 Annual release (Y3A1)