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PROCESSING DARK ENERGY CAMERA DATA TO MAKE THE WORLD'S BEST MAP OF THE NIGHT SKY

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EXECUTIVE SUMMARY

The Dark Energy Camera (DECam) on the Blanco 4-meter telescope has been a premier instrument for making astronomical surveys during its seven years of operation. The largest of these surveys is the Dark Energy Survey (DES), whose data was processed by the National Center for Supercomputing Applications (NCSA). In addition to DES, DECam has produced 200,000 exposures from various smaller surveys. These smaller surveys were processed with multiple pipelines, many of which have known deficiencies. In addition, their processed data are not publically available for search. The research team is processing these 200,000 exposures along with the original DES data. This meta-survey will immediately be much deeper than any survey of similar size. It will be used to study Milky Way structure, galaxy clusters, and solar system objects. It will also provide the "before" image for astronomical transients in multimessenger astronomy.

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RESEARCH CHALLENGE

The DECam has a three square degree field of view, and each image it produces contains 50 million pixels [1]. This has made it a major instrument for making astronomical surveys that cover large areas of the sky. The largest of these surveys, the Dark Energy Survey (DES) [2], was made with nearly half of the DECam observing time, and its data were processed at NCSA with a highly developed image processing pipeline. Smaller DECam surveys like the Dark Energy Camera Legacy Surveys [3] and the Dark Energy Camera Plane Survey [4] comprise months of DECam data and cover thousands of square degrees. However, they were processed with multiple pipelines that are known to be quantitatively inferior to the DES pipeline. In addition, while the raw data for these surveys are publicly available, searchable catalogs are not. The research team is processing all DECam data with the DES pipeline and releasing it publicly. For many applications, this will increase the effective DES area from 5,500 square degrees to 25,000 square degrees, or roughly 60% of the sky.

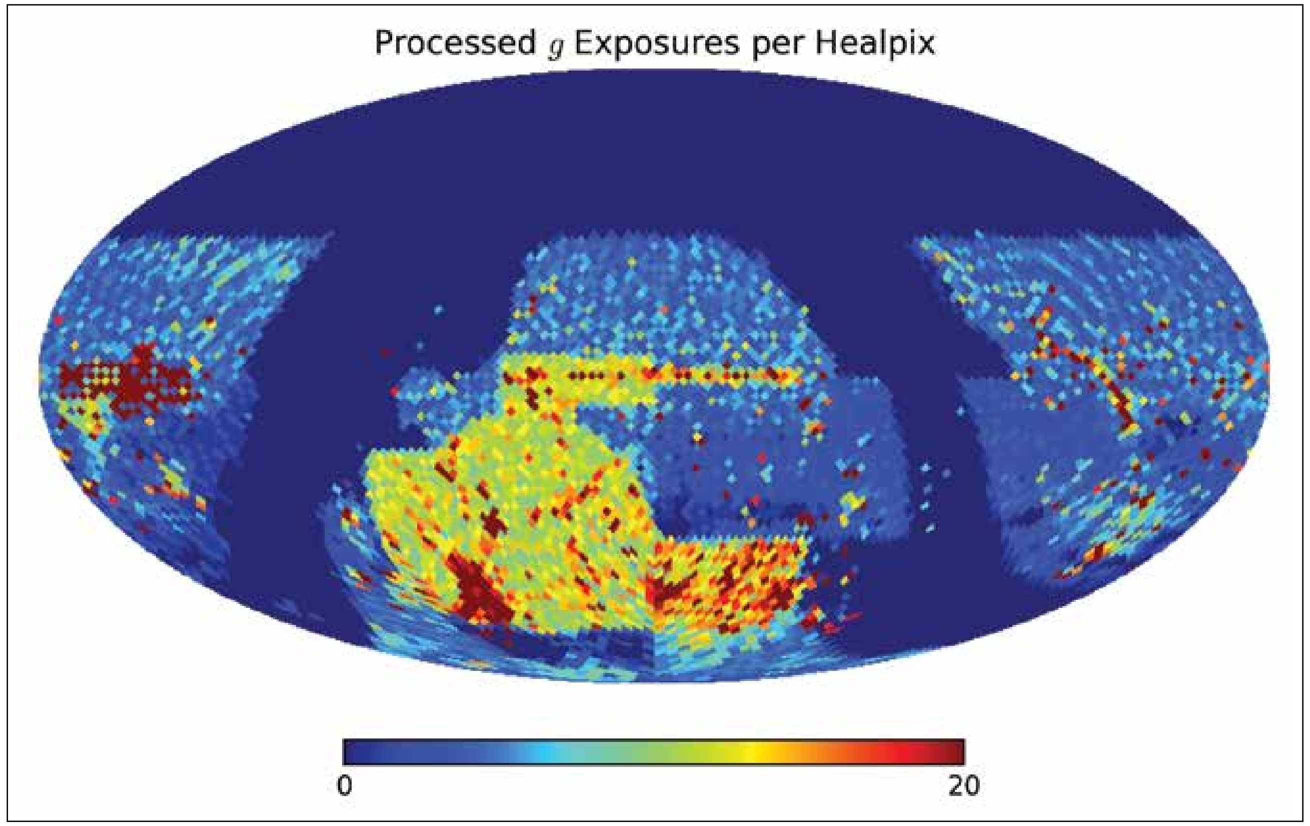

Figure 1: The spatial distribution of g band DECam data processed by the DECADE (DECam All Data Everywhere) team. These data cover half the night sky to unprecedented depth.

METHOD & CODES

The research team uses the DES image processing pipeline [5]. In addition to correcting or masking camera artifacts with the most recent proven algorithms, the pipeline uses human-inspected calibration images and a superior background subtraction method based on principle component analysis of the background [6]. The net result of these improvements is that DES reduced data have a photometric (brightness) precision of 0.5%. DECam data reduced with other pipelines have a photometric precision of between 2% and 6%, depending on the pipeline.

RESULTS & IMPACT

Using Blue Waters, the researchers have processed 66,740 DECam exposures. This comprises 33 TB of raw data turned into 100 TB of processed data. These data cover roughly 15,000 square degrees of the sky, with an average coverage of 12 exposures in any given area. These images are the deepest available over most of this new area.

The research team has given early access to these data to DES scientists. Preliminary results (with publications forthcoming) include the discovery of new outer Milky Way structures, improved observations of galaxy clusters, and the discovery of solar system objects (asteroids). The Milky Way structures will be used to trace the ancient collisions the Milky Way has had with its neighbors that have led to its current form. Images of galaxy clusters will be used to determine their masses, and through these measurements, to understand the growth of cosmological structure in the Universe. The discovery of new solar system objects helps complete a census of nearby objects, including those that may someday impact Earth. All of these discoveries required the new depth and wide area that these data provide and could not have been made had the data not been processed with Blue Waters and made available through this project.

In addition to this ongoing research, the team's survey will provide the template, or "before" image, needed to detect astronomical transients, including those initially detected with the Laser Interferometer Gravitational-Wave Observatory and other multimessenger detectors. Having archival templates will allow these objects to be studied as they are dynamic instead of hours or days later when the data have been fully analyzed.

WHY BLUE WATERS

The challenges of processing 33 TB of raw data into 100 TB of usable images and catalogs extend beyond the hundreds of thousands of core hours needed to perform the processing. This work involved the importation of a large, specialized software stack; constant transfer of large files across limited network space; and millions of calls to a central database to organize the processing and data. The Blue Waters staff showed the system's versatility by working with the research team to solve each of these problems so that data could be processed quickly with minimal human interaction and transferred back to the home system reliably. This allowed the team not only to perform the necessary computations but to present the astronomical community with a usable and exciting new data set before other groups even thought to begin to reduce the data.