1 Dark Energy Survey

DES will use measurements of gravitational lensing effects and a number of other probes to constrain the properties of Dark Energy. Erin Sheldon is a DES participant with data rights for himself, a postdoc and students. He is developing the basic software infrastructure to enable measurement of these lensing effects.

Lensing measurements are critical to the DES mission. The primary Dark Energy probes used by DES are the power spectrum of mass density fluctuations in our universe measured from gravitational lensing (cosmic shear) and the number density of galaxy clusters as a function of their mass and cosmic time. The masses of these clusters are also measured using gravitational lensing. Using the combined probes, DES will constrain the equation of state parameter w=pressure/density for Dark Energy to 3%.

The measurement of lensing effects requires working directly with the most basic data product of the survey, the CCD images. This work is considered a core infrastructure contribution to DES.

Erin Sheldon is co-leading the development of software pipelines to measure weak lensing effects in DES in collaboration with Mike Jarvis of U. Penn. BNL Postdoc Zhaoming Ma is leading the effort to characterize the Point Spread Function of the DES telescope, which is the primary source of systematic errors in lensing measurements.

Erin Sheldon is also leading the analysis effort to measure the masses of galaxy clusters in the DES, which is central to constraining Dark Energy from DES data. This cluster lensing work is a natural continuation of earlier measurements by Erin Sheldon in the Sloan Digital Sky Survey (SDSS), which are the most sensitive of this type to date. The processing pipelines for DES are an extension of those used in the SDSS, as are the analysis tools used to extract cosmological parameters. The volume and depth of DES is sufficiently large to allow these measurements to be made as a function of cosmic lookback time, with which the cosmological analysis will be extended to constrain the properties of Dark Energy.

DES will see first light in 2011. In the interim, data processing pipelines and analysis codes to measure gravitational lensing are being written and tested at BNL. Because the data management team of DES will only produce a limited number of processings of the data, development and testing must occur externally. This testing must use all available data in order to probe low level systematics, and is thus computationally intensive. BNL is providing

computing resources for this effort, which will need to ramp up when the survey data begins to flow.

The infrastructure developed for DES can be applied naturally to images from the Large Scale Synoptic Telescope (LSST), of which BNL is a member.

1.1 Progress over the Last Three Years

In FY 2008-2009 software pipelines were developed to measure gravitational shear effects in astronomical images. A framework was created to process the large amounts of DES in parallel. These codes were tested on simulated DES data designed to accurately represent real DES survey data. This code can process individual images from DES as well as combine multi-epoch data into a single best measurement for each detected astronomical object.

Development of the multi-epoch measurement code was a major milestone in DES lensing pipeline development. The DES will visit each place on the sky multiple times producing separate images at different epochs. This multi-epoch analysis is required to optimally process the data because each image is taken under different observing conditions, which results in a different Point Spread Function (PSF). As this is the dominant source of systematic error in lensing measurements, it must be treated with care. The multi epoch shear measurement code properly accounts for this effect when combining observations.

Using computers at BNL, all of the available simulated images were processed a large number of times; this quick turnaround of processing and code improvements has been important to efficient development. This processing includes the single-epoch exposures as well as the full multi-epoch simulated data. Versions of this code have been delivered regularly to the DES data management team to be used in the yearly DES "Data Challenges".

In FY 2010 further DES simulations were created and tested. These simulations are a more realistic realization of DES observations and data, and have realistic gravitational lensing effects that can be used to extract the input cosmology. Significant progress was made in testing and stabilizing the code base.

In 2010 Zhaoming Ma began developing an improved framework to determine and correct for the (PSF) of the DES telescope system. The PSF is the primary source of systematic errors in lensing measurements. This project is in the early stages, but progress has been rapid and a usable code should be available in the fall. See the FY 2011 section for more details.

1.2 Plans for the Next Three Years

1.2.1 FY 2011

At the beginning of FY 2011, the group will focus on simulating actual survey operations, where data flows continuously and must be processed in near real time. During survey operations, a large number of exposures of the sky are taken each night. This data is transferred to NCSA for basic processing by the DES Data Management (DESDM) team. The resulting "reduced" images and catalogs of stars and galaxies will then be downloaded to BNL and processed through the latest versions of the lensing measurement codes.

The lensing measurement codes are integrated into the DESDM, and are considered a key piece of survey infrastructure. However, the version of the code used to by DESDM for data releases will lag significantly behind the development version, typically by 6 months to a year. We must process the data through our pipelines externally in order to proper QA, which will find bugs and lead to improvements. This requires significant computing resources.

Further, the efficacy of development and testing of the codes will depend on the data we use as input. The simulations are a key component of this testing, but real images will provide a much richer set of conditions and sources of systematic effects. We must process all available data in a quick feedback loop with processing in order to make efficient progress in developing these codes.

As part of this testing, the group will soon go into a simulated "production mode". Images will be downloaded and processed in real time in order to smooth that process. Quality assurance will be performed automatically and this will feed back into development. This will in turn inform what checks should be performed by the QA.

The DES simulation group will also be producing new simulations in FY 2011 which will provide additional realism and challenges. These will be processed as they become available.

A key piece of infrastructure is the characterization of the Point Spread Function (PSF) of the sky and instrument, which alters the shapes of galaxies and confuses the determination of lensing effects. The PSF is normally determined on an image-by-image basis from the properties of stars, which are point-like. However, there are too few stars in an image to determine the PSF to the accuracy needed to meet DES science goals. Many of the PSF

patterns are related to the configuration of the instrument such as focus, and these patterns repeat during the survey. Thus we are developing a global solution that finds the principle components of these patterns and uses them as a basis for understanding individual images. This global solution should provide the needed accuracy.

The global PSF code must be stable enough to work in survey mode as well, incorporating new data into its solution in near real time. Postdoc Zhaoming Ma is developing this code, which should be ready for serious testing in the early part of FY 2011.

Additionally, we must be able to recover the input cosmology from our simulations at the expected accuracy. We will not have enough simulation data to test the accuracy for the full survey during FY 2011, but there are plans to produce such large simulations during the survey. We will analyze the simulations for cosmology in the mean time with the goal of producing cosmological results at the expected accuracy and precision given the simulation size.

The primary challenge for 2011-2012, however, is the processing of real DES data as it arrives in the fall. This will undoubtedly provide unexpected challenges. We must adapt the work flow of getting images, processing, and feedback into development to this real situation. Also it will become imperative to keep in as close contact as possible with DESDM in order to get important bug and stability fixes "downstream".

As stated above, it is important to have enough computing to keep a tight development-test cycle. This is because the processing is computing intensive, and we must process all available data in order to probe low level systematics. A stable version of this code, improved using many processings at BNL will be delivered to data management in time for the re-processing to be performed before the public data release. Meeting these deadlines will be a top priority for the BNL group.

1.2.2   FY 2012-2013

For FY 2012-2013, the BNL group will continue as 2011, processing data as it arrives and improving codes and calibrations. The first technical and analysis papers for lensing and cosmology will also appear at this time.

Sheldon and Ma will author technical papers based on their infrastructure work. These will become references to the community concerning how the basic processing occurs in DES. Since all data in DES are public, we must

have such references so the community can use the DES data properly.

The first analysis papers presenting cosmological results will focus on the first year of DES data. Although this is significantly less than the final data set, and final calibrations will not be in place, the results will more than compete with any previous cosmological analyses and will demonstrate survey progress.

ES will author a paper on calibrating the masses of galaxy clusters. As stated above, this is a key measurement for extracting cosmological parameters from the DES. He will also participate in the other key lensing measurements and will co-author papers on galaxy lensing and cosmic shear.