Final Scientific/Technical Report

DE-FG02-07ER41505

University of California, Davis

Optimizing New Dark Energy Experiments

PI: J. Anthony Tyson, tyson@physics.ucdavis.edu, 530-752-3830

26 August, 2013. Period covered: 9/1/2007 – 11/30/2009

HISTORY

This award was originally submitted as a multi-institutional cooperative proposal, together with a parallel proposal from DOE labs. Funding however was granted to only two of the original institutions separately: UC Davis and U. Pittsburgh. The UC Davis award initially was for one year (\$100,000) and then was supplemented at \$211,443, extending to 11/30/2009. A final financial report was submitted by UC Davis on 2/25/2010. The work begun under this proposal is ongoing, building on the progress that was made. To date there have been 5 publications based on this DOE grant which acknowledge this grant support. These publications are listed below. Some of the research begun under this award has continued under a later NSF grant which expires in 2014. This document summarizes the technical and scientific progress made under this DOE award.

SCIENTIFIC LANDSCAPE

Dark matter and dark energy offer unique windows onto fundamental physics, bridging particle physics and cosmology. Dark energy affects the cosmic history of this expansion as well as the growth in the clustering of matter over time. Understanding the nature of dark energy is one of the most fundamental questions in physics today, impacting our understanding of particle physics, cosmology, and possibly theories of gravity. As noted in the report of the Dark Energy Task Force (DETF; constituted jointly by DOE, NSF and NASA), “the nature of dark energy ranks among the very most compelling of all outstanding problems in physical science.”

Next generation “Stage IV” facilities under design during this grant, and now under construction, will enable the determination of the properties of dark energy and dark matter to unprecedented precision using multiple complementary probes. Because of this a number of ambitious wide-field optical and infrared imaging surveys have been proposed to directly measure the effects of dark energy. The most pressing challenge in these experiments is the

characterization and understanding of the systematic errors present within any given experimental configuration and the resulting impact on the accuracy of our constraints on dark energy physics. The DETF and the P5 panel in their reports recommended “Expanded support for ancillary measurements required for the long-term program and for projects that will improve our understanding and reduction of the dominant systematic measurement errors.” Looking forward to the next generation Stage IV experiments we have developed a program to address the most important potential systematic errors within these experiments. Using data from current facilities it has been feasible and timely to undertake a detailed investigation of the systematic errors. In this DOE grant we studied of the source and impact of the dominant systematic effects in dark energy measurements, and developed new analysis tools and techniques to minimize their impact. Progress under this grant is discussed briefly below. This work was a necessary precursor for the coming generations of wide-deep probes of the nature of dark energy and dark matter. The research has already had an impact on improving the efficiencies of all Stage III and IV dark energy experiments ranging from studies of baryon acoustic oscillations to weak gravitational lensing.

PERSONNEL

Senior personnel: Prof. J. Anthony Tyson, PI., Prof. Lloyd Knox, Prof. David Wittman.

Postdoctoral scholars: Dr. Michael Schneider, Dr. Samuel Schmidt, Dr. Hu Zhan.

Graduate students: James Bosch, Michael Schneider.

Effort and sources of support: All senior personnel received summer support from UCD startup funds or private gifts, except 2 weeks total on this grant for Prof. Wittman. The PI spent 0.5 - 1 months of effort per year on this project. Michael Schneider received support from this grant initially as a graduate student and then as a postdoc, and then in 2011 from an NSF grant (non-overlapping). Postdoc Hu Zhan received partial support from this grant (50%) and from a private gift. Postdoc Sam Schmidt received support from this grant and then later from an NSF grant, non overlapping. Schmidt and Zhan performed the majority of the work under this grant. Grad student Jim Bosch received most of his support from an NSF Graduate Fellowship, but his final year of support was from this grant (non-overlapping).

RESEARCH

The work accomplished under this grant covered algorithm development, experimental tests, mock data challenges, full image simulations, and studies of the robustness of the resulting dark energy probes. The research plan called for an attack on weak gravitational lensing and photometric redshift systematics (via development of novel algorithms), followed by a staged series of tests, followed by a realistic assessment of the constraining power of LSST for models of dark energy. One of the most significant advances was the development of methods for nulling systematics. As a result of this grant it was realized that particular combinations of

analysis techniques, using the same survey data, are particularly effective at nulling systematic error. Stage IV surveys like LSST are capable of probing many aspects of dark energy, beyond the familiar 2-dimensional model popularized by the DETF. There are a wide variety of possible dark energy dynamical scenarios which are not easily fit in such a 2-dimensional model.

The following figure (a product of work done under this grant) shows the precision achievable for measurement of both cosmic distances and growth of dark matter structure vs redshift when combining LSST multiple probes with the CMB. Alternative theories of the physics of dark energy, including modified gravity theories, predict significant deviations from standard model cosmology behavior of distance vs redshift and growth of structure vs redshift. These theories can then be confronted with the Stage IV experiment data, with a precision shown in the plot below (Zhan *et al.* 2009).

RESEARCH PRODUCTS

The most significant products of this research have been algorithms for estimation of weak gravitational lens shear, which correct in novel ways for the optical distortion of the atmosphere and system optics. One of these, *StackFit*, has been adopted by the LSST project as its main engine for galaxy shape measurement. In addition to the publications below, several white papers and reports to the NRC Decadal Survey were based on this work. Significant effort was spent on validation, via simulations and via application to precursor data sets. Leveraging this reduction in systematics, an additional key product has been a full analysis of the capability of LSST for probing the physics of dark energy, as shown in the figure above.

PUBLICATIONS ACKNOWLEDGING THIS DOE GRANT

[LSST: from science drivers to reference design and anticipated data products](#) Z Ivezić, JA Tyson, E Acosta, R Allsman, *et al.* - arXiv: 0805.2366, 2008, 2011

[Distance, growth factor, and dark energy constraints from photometric baryon acoustic oscillation and weak lensing measurements](#) H Zhan, L Knox, JA Tyson - The Astrophysical Journal 690 (2009) 923. doi:10.1088/0004-637X/690/1/923

[Modeling techniques for measuring galaxy properties in multi-epoch surveys](#) J Bosch – 2011 PhD Thesis. arXiv preprint arXiv:1109.1033, 2011

[Galaxy-Mass Correlations on 10 Mpc Scales in the Deep Lens Survey](#) A Choi, JA Tyson, CB Morrison, MJ Jee, SJ Schmidt, VE Margoniner, DM Wittman. - The Astrophysical Journal 759, 101, 2012; doi:10.1088/0004-637X/759/2/101

[Cosmic Shear Results from the Deep Lens Survey. I. Joint Constraints on \$\Omega_M\$ and \$\sigma_8\$ with a Two-dimensional Analysis](#) MJ Jee, JA Tyson, MD Schneider, D Wittman, S Schmidt, S Hilbert. - The Astrophysical Journal 765, 74, 2013; doi:10.1088/0004-637X/765/1/74