U. S. DEPARTMENT OF ENERGY
FIELD WORK PROPOSAL

1. B&R No. KA1301020	Contractor No.: 2010-BNL-PO095	3. Date Prepared: 20090901	4. Task Term: Begin: 10/01/2009 End: 09/30/2014

5. Work Proposal No.: N/A	6. Work Authorization No.: KACH139

7. Title: Early Career: Measuring Dark Energy with Gravitational Lensing in the Dark Energy Survey

8. Principal Investigator(s): Sheldon, Erin S. (631) 344-3117

9. Headquarters/Operations Office Program Manager: Rosenberg, Eli (301) 903-3711 eli.rosenberg@science.doe.gov	12. Headquarters Organization: Office of Science	15. HQ Organizational Code: SC
10. Operations Office Work Proposal Reviewer:	13. Operations Office: CHICAGO	16. DOE Organizational Code: CH
11. Contractor Work Proposal Manager: Ludlam, Thomas W. (631) 344-7753	14. Contractor Name: BROOKHAVEN SCIENCE ASSOCIATES BROOKHAVEN NATIONAL LABORATORY	17. Contractor Code: BN

18. Work Proposal Description (Approach, anticipated benefit in 200 words or less, suitable for public release) :

Data from the Dark Energy Survey (DES) will be used to constrain the properties of Dark Energy. The primary focus will be on measuring gravitational lensing effects to probe the expansion history and growth rate of massive structures in our universe.

Dark Energy accelerates the expansion of the universe, dramatically increasing the volume in comparison to a matter-only universe. Dark Energy also inhibits the growth of massive structures under gravitational collapse. Thus the number density of massive objects such as galaxy clusters as a function of cosmic time is directly related to the properties of Dark Energy, in particular the equation of state parameter w=pressure/density. Critical to using the number density to constrain cosmology is the masses of the clusters, which we will measure using gravitational lensing effects in DES data. Using cluster counts, lensing and other complimentary probes, the DES will measure w to about 3%.

DES will see first light in 2011. The intervening time will be spent developing data reduction pipelines and realistic simulations to test these pipelines. After first light, DES will take data for five years, during which the data will be processed as it arrives and analyses performed to extract Dark Energy parameters.

19. Principal Investigator (s) :

Signature(s) — 09/01/2009 Date

20. Contractor Work Proposal Manager: Signature — 09/01/2009 Date	21. Operations Office Review Official: _ Signature — 09/01/2009 Date

22. Detail Attachments:

( ) a. Purpose	( ) d. Future accomplishments	( ) g. Capital Equipment Request Summary
( ) b. Approach	( ) e. Relationships to other projects	( ) h. Other (Specify Topic)
( ) c. Technical progress	( ) f. Explanation of milestones	

22. Detail Attachments

a. Purpose

Analyze astronomical data from the Dark Energy Survey (DES) to constrain the properties of Dark Energy.

b. Approach

The approach is to use gravitational lensing effects in DES data to constrain the properties of Dark Energy. Erin Sheldon is a member of DES with data rights, and in collaboration with Mike Jarvis of Penn he is leading the lensing effort in DES.

Lensing measurements are critical to the goals of DES. 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%.

DES will see first light in 2011. In the interim, data processing pipelines and analysis codes to measure gravitational lensing will be written. This data will be used to calibrate the masses of the galaxy clusters used in the cosmological analyses.

This cluster lensing work is a natural continuation of earlier work 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 repeat these measurements in many bins of cosmic time, with which the cosmological analysis will be extended to constrain the properties of Dark Energy.

In contrast with cluster lensing measurements, cosmic shear is the correlation of shears across the sky independent of the location of foreground structures. Since the shear is related to mass, the cosmic shear can be used to directly infer statistics of the underlying mass distribution, the evolution of which is directly related to the properties of Dark Energy. Because the signal need not be modeled in terms of cluster halos, the interpretation of cosmic shear can be simpler than cluster lensing, but the measurement is more sensitive to systematic effects. Thus cosmic shear is quite complimentary to clusters.

The analysis and infrastructure development created for DES will also lead naturally to work on the Large Scale Synoptic Telescope (LSST) of which ES is a participating member.

This work will be in collaboration with a postdoc Zhaoming Ma who is joining BNL in Fall 2009, as well as Mike Jarvis and Bhuvnesh Jain from the University of Pennsylvania, not supported by this proposal. Erin Sheldon will be supported at 75% and Zhaoming will be supported at 100%. It is anticipated that a graduate student will also join the effort sometime late in 2009 at 100%.

This “approach” is highly compressed from the narrative. Please see that section for more details.

c. Technical Progress in FY2009 and Expected Progress FY2010

In FY 2009 software pipelines were developed to process DES simulated 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. The latter multi-epoch processing code is a major milestone in DES lensing pipeline development, as it is required to optimally process the data. Using computers at BNL, all of the currently available individual images have been processed. This Fall the full multi-epoch simulated data will be processed through the pipeline in preparation for the DES "Data Challenge Five".

In FY 2010 a much larger and more realistic DES simulation will be created. This simulation will represent a full two years of DES observations, and will have realistic gravitational lensing effects that can be used to extract the input cosmology. The primary challenge for 2010 is the processing of significantly more data and the recovery of the input cosmology. All this processing and analysis will occur in a mode that reflects real survey activities.

In FY 2010 analysis will begin on data from the Sloan Digital Sky Survey "southern stripe", a multi-epoch survey similar to the DES but smaller in data volume. This data will be a stringent test of the DES pipelines, and will lead to significant constraints on cosmological parameters such as the mean mass density.

d. Future Accomplishments

This is an outline of future DES activities starting in 2011.

Expected Progress in FY 2011

Winter/Spring
Continue analysis of SDSS data. Process DES commissioning data as it arrives. Test pipelines on real DES commissioning data, adjusting processing pipeline as needed.

Summer/Fall
Re-process the previous year's data with improved pipelines. Finish analysis of SDSS data, publish results. Process Fall/Winter DES data as it arrives.

Expected Progress in FY 2012

Winter/Spring
Process DES data as it arrives. Multiple epochs will now exist over much of the sky, first serious testing of multi-epoch shear pipeline on real DES data. Begin analysis of first year DES data for lensing.

Summer/Fall
Finalize analysis of existing DES data, incorporating recently processed data if it is ready. First publications from early DES data should emerge in summer or fall 2012.

Expected Progress in FY 2013 and FY2014

Winter 2013-Fall 2014
Activities should continue as before: Processing data as it arrives, primarily Sept-Feb of each year, incrementally improving the data pipelines and analysis codes. Analysis methods will evolve, especially as the final data are in hand and there are many epochs with which to work.

Post 2014
A re-processing of all data through the final pipelines and final analysis of the full dataset to extract cosmological information.

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U.S. Department of Energy
Summary Budget Page — SUMMARY

OMB Control No. 1910-1400

ORGANIZATION	Brookhaven National Laboratory
TITLE	EARLY CAREER: MEASURING DARK ENERGY WITH GRAVITATIONAL LENSING IN THE DARK ENERGY SURVEY
Budget Page No.:	1 of 6
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	E. Sheldon
Requested Duration:	60 (months)

A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates (List each separately with title; A.6. Show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR	Funds Requested by Applicant	Funds Granted by DOE
1. Dr. E. Sheldon	45.0	0.0	0.0	$405,232	
2.	0.0	0.0	0.0	$0	
3.					
4.					
5.					
6. ( ) Others (List individually on Budget Explanation Page)					
7. (5) Total Senior Personnel (1 - 6)	45.0	0.0	0.0	$405,232	
B. OTHER PERSONNEL (show numbers in brackets)					
1. 5 Post Doctoral Associates	60.0	0.0		$281,172	
2. 0 Other Professional	0.0				
3. 5 Graduate Students * See Subcontracts below	60.0			$0	
4. ( ) Undergraduate Students					
5. ( ) Secretarial - Clerical					
6. ( ) Others (List individually on Budget Explanation Page)					
Total Salaries and Wages (A + B)				$686,404	
C. Fringe Benefits (if charged as Direct Costs)				$231,764	
Total Salaries,Wages and Fringe Benefits (A + B + C)				$918,168	
D. Permanent Equipment (List item and dollar amount for each item)					
Total Permanent Equipment				$0	
E. Travel 1. Domestic (incl. Canada and U.S. Possessions)				$32,713	
2. Foreign				$26,020	
Total Travel				$58,733	
F. Trainee/Participant Costs					
1. Stipends (Itemize levels, tuypes and totals on budget justification page)				$0	
2. Tuition & Fees				$0	
3. Trainee Travel				$0	
4. Other (fully explain on justification page)				$0	
Total Participants ( ) Total Cost				$0	
G. Other Direct Costs					
1. Materials and Supplies				$504,792	
2. Publication Costs/Documentation/Dissemination				$0	
3. Consultant Services				$0	
4. Computer (ADPE) Services				$57,369	
5. Subcontracts for Graduate Students				$197,753	
6. Other Organizational Burden & Electric Power				$133,318	
Total Other Direct Costs				$893,232	
H. **Total Direct Costs (A through G)**				$1,870,133	
I. Indirect Costs (specify rate and base): Composite G&A rate of 39.45% on Total Modified Costs. Material Burden rate of 8.25% on purchases and travel. See Budget Explanation and Rates tab for breakdown of rates					
Total Indirect Costs				$678,897	
J. **Total Direct and Indirect Costs (H + I)**				$2,549,030	
K. Amount of any Required cost sharing from Non-federal Sources				$0	
L. **Total Cost of Project (J + K)**				$2,549,030	

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OMB Control No.
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U.S. Department of Energy
Summary Budget Page Year 1

ORGANIZATION: Brookhaven National Laboratory

TITLE: EARLY CAREER: MEASURING DARK ENERGY WITH GRAVITATIONAL LENSING IN THE DARK ENERGY SURVEY

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: E. Sheldon

Requested Duration: 12 (months)

A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates (List each separately with title; A.6. Show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR	Funds Requested by Applicant	Funds Granted by DOE
1. Dr. E. Sheldon	9.0	0.0	0.0	$74,817	
2.	0.0	0.0	0.0	$0	
3.					
4.					
5.					
6. ( ) Others (List individually on Budget Explanation Page)					
7. (1) Total Senior Personnel (1 - 6)	9.0	0.0	0.0	$74,817	
B. OTHER PERSONNEL (show numbers in brackets)					
1. 1 Dr. Zhaoming Ma	12.0	0.0		$51,912	
2. 0 Other Professional	0.0			$0	
3. 1 Graduate Students * See Subcontracts below ($38,000)	12.0			$0	
4. ( ) Undergraduate Students					
5. ( ) Secretarial - Clerical					
6. ( ) Others (List individually on Budget Explanation Page)					
Total Salaries and Wages (A + B)				$126,729	
C. Fringe Benefits (if charged as Direct Costs)				$42,015	
Total Salaries,Wages and Fringe Benefits (A + B + C)				$168,744	
D. Permanent Equipment (List item and dollar amount for each item)					
Total Permanent Equipment				$0	
E. Travel 1. Domestic (incl. Canada and U.S. Possessions)				$6,282	
2. Foreign				$5,000	
Total Travel				$11,282	
F. Trainee/Participant Costs					
1. Stipends (Itemize levels, tuypes and totals on budget justification page)				$0	
2. Tuition & Fees				$0	
3. Trainee Travel				$0	
4. Other (fully explain on justification page)				$0	
Total Participants ( ) Total Cost				$0	
G. Other Direct Costs					
1. Materials and Supplies				$97,000	
2. Publication Costs/Documentation/Dissemination					
3. Consultant Services				$0	
4. Computer (ADPE) Services				$10,532	
5. Subcontracts for Graduate Students				$38,000	
6. Other Organizational Burden & Electric Power				$24,502	
Total Other Direct Costs				$170,034	
H. **Total Direct Costs (A through G)**				$350,060	
I. Indirect Costs (specify rate and base): Composite G&A rate of 39.45% on Total Modified Costs. Material Burden rate of 8.25% on purchases and travel. See Budget Explanation and Rates tab for breakdown of rates					
Total Indirect Costs				$126,883	
J. **Total Direct and Indirect Costs (H + I)**				$476,943	
K. Amount of any Required cost sharing from Non-federal Sources					
L. **Total Cost of Project (J + K)**				$476,943	

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U.S. Department of Energy
Summary Budget Page — Year 2

ORGANIZATION: Brookhaven National Laboratory					Budget Page No.:	3 of 6
TITLE: EARLY CAREER: MEASURING DARK ENERGY WITH GRAVITATIONAL LENSING IN THE DARK ENERGY SURVEY						
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: E. Sheldon					Requested Duration:	12 (months)
A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates (List each separately with title; A.6. Show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR		Funds Requested by Applicant	Funds Granted by DOE
1. Dr. E. Sheldon	9.0	0.0	0.0		$77,809	
2.	0.0	0.0	0.0		$0	
3.						
4.						
5.						
6. ( ) Others (List individually on Budget Explanation Page)						
7. (1) Total Senior Personnel (1 - 6)	9.0	0.0	0.0		$77,809	
B. OTHER PERSONNEL (show numbers in brackets)						
1. 1 Dr. Zhaoming Ma	12.0	0.0			$53,988	
2. 0 Other Professional	0.0				$0	
3. 1 Graduate Students * See Subcontracts below ($38,760)	12.0				$0	
4. ( ) Undergraduate Students						
5. ( ) Secretarial - Clerical						
6. ( ) Others (List individually on Budget Explanation Page)						
Total Salaries and Wages (A + B)					$131,797	
C. Fringe Benefits (if charged as Direct Costs)					$44,685	
Total Salaries,Wages and Fringe Benefits (A + B + C)					$176,482	
D. Permanent Equipment (List item and dollar amount for each item)						
Total Permanent Equipment					$0	
E. Travel 1. Domestic (incl. Canada and U.S. Possessions)					$6,413	
2. Foreign					$5,100	
Total Travel					$11,513	
F. Trainee/Participant Costs						
1. Stipends (Itemize levels, tuypes and totals on budget justification page)					$0	
2. Tuition & Fees					$0	
3. Trainee Travel					$0	
4. Other (fully explain on justification page)					$0	
Total Participants ( ) Total Cost					$0	
G. Other Direct Costs						
1. Materials and Supplies					$98,940	
2. Publication Costs/Documentation/Dissemination						
3. Consultant Services					$0	
4. Computer (ADPE) Services					$10,910	
5. Subcontracts for Graduate Students					$38,760	
6. Other Organizational Burden & Electric Power					$25,625	
Total Other Direct Costs					$174,235	
H. **Total Direct Costs (A through G)**					$362,230	
I. Indirect Costs (specify rate and base): Composite G&A rate of 39.45% on Total Modified Costs. Material Burden rate of 8.25% on purchases and travel. See Budget Explanation and Rates tab for breakdown of rates						
Total Indirect Costs					$131,415	
J. **Total Direct and Indirect Costs (H + I)**					$493,645	
K. Amount of any Required cost sharing from Non-federal Sources						
L. **Total Cost of Project (J + K)**					$493,645	

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ORGANIZATION	Brookhaven National Laboratory				Budget Page No.:	4 of 6
TITLE	EARLY CAREER: MEASURING DARK ENERGY WITH GRAVITATIONAL LENSING IN THE DARK ENERGY SURVEY					
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR E. Sheldon					Requested Duration:	12 (months)
A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates (List each separately with title; A.6. Show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR		Funds Requested by Applicant	Funds Granted by DOE
1. Dr. E. Sheldon	9.0	0.0	0.0		$80,922	
2.	0.0	0.0	0.0		$0	
3.						
4.						
5.						
6. ( ) Others (List individually on Budget Explanation Page)						
7. (1) Total Senior Personnel (1 - 6)	9.0	0.0	0.0		$80,922	
B. OTHER PERSONNEL (show numbers in brackets)						
1. 1 Dr. Zhaoming Ma	12.0	0.0			$56,148	
2. 0 Other Professional	0.0				$0	
3. 1 Graduate Students * See Subcontracts below ($39,535)	12.0				$0	
4. ( ) Undergraduate Students						
5. ( ) Secretarial - Clerical						
6. ( ) Others (List individually on Budget Explanation Page)						
Total Salaries and Wages (A + B)					$137,070	
C. Fringe Benefits (if charged as Direct Costs)					$46,471	
Total Salaries,Wages and Fringe Benefits (A + B + C)					$183,541	
D. Permanent Equipment (List item and dollar amount for each item)						
Total Permanent Equipment					$0	
E. Travel 1. Domestic (incl. Canada and U.S. Possessions)					$6,541	
2. Foreign					$5,202	
Total Travel					$11,743	
F. Trainee/Participant Costs						
1. Stipends (Itemize levels, tuypes and totals on budget justification page)					$0	
2. Tuition & Fees					$0	
3. Trainee Travel					$0	
4. Other (fully explain on justification page)					$0	
Total Participants ( )	Total Cost				$0	
G. Other Direct Costs						
1. Materials and Supplies					$100,919	
2. Publication Costs/Documentation/Dissemination						
3. Consultant Services					$0	
4. Computer (ADPE) Services					$11,595	
5. Subcontracts for Graduate Students					$39,535	
6. Other Organizational Burden & Electric Power					$26,650	
Total Other Direct Costs					$178,699	
H. **Total Direct Costs (A through G)**					$373,983	
I. Indirect Costs (specify rate and base)	Composite G&A rate of 39.45% on Total Modified Costs. Material Burden rate of 8.25% on purchases and travel. See Budget Explanation and Rates tab for breakdown of rates					
Total Indirect Costs					$135,757	
J. **Total Direct and Indirect Costs (H + I)**					$509,740	
K. Amount of any Required cost sharing from Non-federal Sources						
L. **Total Cost of Project (J + K)**					$509,740	

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U.S. Department of Energy
Summary Budget Page Year 4

ORGANIZATION	Brookhaven National Laboratory				Budget Page No.:	5 of 6
TITLE	EARLY CAREER: MEASURING DARK ENERGY WITH GRAVITATIONAL LENSING IN THE DARK ENERGY SURVEY					
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR E. Sheldon					Requested Duration:	12 (months)
A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates (List each separately with title; A.6. Show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR		Funds Requested by Applicant	Funds Granted by DOE
1. Dr. E. Sheldon	9.0	0.0	0.0		$84,159	
2.	0.0	0.0	0.0		$0	
3.						
4.						
5.						
6. ( ) Others (List individually on Budget Explanation Page)						
7. (1) Total Senior Personnel (1 - 6)	9.0	0.0	0.0		$84,159	
B. OTHER PERSONNEL (show numbers in brackets)						
1. 1 Post Doc TBD	12.0	0.0			$58,394	
2. 0 Other Professional	0.0				$0	
3. 1 Graduate Students * See Subcontracts below ($40,326)	12.0				$0	
4. ( ) Undergraduate Students						
5. ( ) Secretarial - Clerical						
6. ( ) Others (List individually on Budget Explanation Page)						
Total Salaries and Wages (A + B)					$142,553	
C. Fringe Benefits (if charged as Direct Costs)					$48,330	
Total Salaries,Wages and Fringe Benefits (A + B + C)					$190,883	
D. Permanent Equipment (List item and dollar amount for each item)						
Total Permanent Equipment					$0	
E. Travel 1. Domestic (incl. Canada and U.S. Possessions)					$6,672	
2. Foreign					$5,306	
Total Travel					$11,978	
F. Trainee/Participant Costs						
1. Stipends (Itemize levels, tuypes and totals on budget justification page)					$0	
2. Tuition & Fees					$0	
3. Trainee Travel					$0	
4. Other (fully explain on justification page)					$0	
Total Participants ( )				Total Cost	$0	
G. Other Direct Costs						
1. Materials and Supplies					$102,937	
2. Publication Costs/Documentation/Dissemination						
3. Consultant Services					$0	
4. Computer (ADPE) Services					$11,971	
5. Subcontracts for Graduate Students					$40,326	
6. Other Organizational Burden & Electric Power					$27,716	
Total Other Direct Costs					$182,950	
H. **Total Direct Costs (A through G)**					$385,811	
I. Indirect Costs (specify rate and base)	Composite G&A rate of 39.45% on Total Modified Costs. Material Burden rate of 8.25% on purchases and travel. See Budget Explanation and Rates tab for breakdown of rates					
Total Indirect Costs					$140,148	
J. **Total Direct and Indirect Costs (H + I)**					$525,959	
K. Amount of any Required cost sharing from Non-federal Sources						
L. **Total Cost of Project (J + K)**					$525,959	

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Summary Budget Page **Year 5**

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ORGANIZATION	Brookhaven National Laboratory	Budget Page No.:	6 of 6
TITLE	EARLY CAREER: MEASURING DARK ENERGY WITH GRAVITATIONAL LENSING IN THE DARK ENERGY SURVEY		
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	E. Sheldon	Requested Duration:	12 (months)

A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates (List each separately with title; A.6. Show number in brackets)	DOE Funded Person-mos. CAL	ACAD	SUMR	Funds Requested by Applicant	Funds Granted by DOE
1. Dr. E. Sheldon	9.0	0.0	0.0	$87,525	
2.	0.0	0.0	0.0	$0	
3.					
4.					
5.					
6. ( ) Others (List individually on Budget Explanation Page)					
7. (1) Total Senior Personnel (1 - 6)	9.0	0.0	0.0	$87,525	
B. OTHER PERSONNEL (show numbers in brackets)					
1. 1 Post Doc TBD	12.0	0.0		$60,730	
2. 0 Other Professional	0.0			$0	
3. 1 Graduate Students * See Subcontracts below ($41,132)	12.0			$0	
4. ( ) Undergraduate Students					
5. ( ) Secretarial - Clerical					
6. ( ) Others (List individually on Budget Explanation Page)					
Total Salaries and Wages (A + B)				$148,255	
C. Fringe Benefits (if charged as Direct Costs)				$50,263	
Total Salaries,Wages and Fringe Benefits (A + B + C)				$198,518	
D. Permanent Equipment (List item and dollar amount for each item)					
Total Permanent Equipment				$0	
E. Travel 1. Domestic (incl. Canada and U.S. Possessions)				$6,805	
2. Foreign				$5,412	
Total Travel				$12,217	
F. Trainee/Participant Costs					
1. Stipends (Itemize levels, tuypes and totals on budget justification page)				$0	
2. Tuition & Fees				$0	
3. Trainee Travel				$0	
4. Other (fully explain on justification page)				$0	
Total Participants ( ) Total Cost				$0	
G. Other Direct Costs					
1. Materials and Supplies				$104,996	
2. Publication Costs/Documentation/Dissemination					
3. Consultant Services				$0	
4. Computer (ADPE) Services				$12,361	
5. Subcontracts for Graduate Students				$41,132	
6. Other Organizational Burden & Electric Power				$28,825	
Total Other Direct Costs				$187,314	
H. **Total Direct Costs (A through G)**				$398,049	
I. Indirect Costs (specify rate and base): Composite G&A rate of 39.45% on Total Modified Costs. Material Burden rate of 8.25% on purchases and travel. See Budget Explanation and Rates tab for breakdown of rates					
Total Indirect Costs				$144,694	
J. **Total Direct and Indirect Costs (H + I)**				$542,743	
K. Amount of any Required cost sharing from Non-federal Sources					
L. **Total Cost of Project (J + K)**				$542,743	

Budget Explanation

Title	Name	Role	Year 1	Year 2	Year 3	Year 4	Year 5
					FTE/Year		
Personnel							
Asst. Physicist	Dr. Erin Sheldon	Process DES & SDSS Data to constrain properties of Dark Energy	0.75	0.75	0.75	0.75	0.75
Post Doc	Dr. Zhaoming Ma	Analyze DES & SDSS data to constrain properties of Dark Energy	1.00	1.00	1.00	0.00	0.00
Post Doc	TBD	Analyze DES & SDSS data to constrain properties of Dark Energy				1.00	1.00
	Total FTE's		1.75	1.75	1.75	1.75	1.75

Salaries are escalated 4% annually starting with Year 2, estimated also reflect changes in personnel assignments.

C. Fringe and labor burden which are included in the wage pool rate

	Year 1	Year 2	Year 3	Year 4	Year 5
Scientific and Professional	38%	38%	38%	38%	38%
Post Doc	28%	28%	28%	28%	28%

D. Capital Equipment

E. Travel

Escalation rate of 2% used

F. Trainee/Participant Costs

G. Other Direct Costs

Materials and Supplies estimate with 2% escalation in the out years
Subcontracts based upon prior year estimate with a 2% escalation in the out years
ITD Allocation & Telecomm include computer services represent the computing and telecommunications per FTE.
The cost of Information Technology Department allocations is calculated at 3.4% of TMC.
Space includes direct cost of space used at laboratory published rates, plus a surcharge for fuel at 26.4% of the space charge and a deferred maintenance surcharge at FY10 25.8% and FY 11-14 24.4% of the direct space charge.
Organization burden is assessed on salary including fringe to pay for Physics Department administrative costs at 12.6%

I. Indirect Costs

		Year 1 %	Year 2 %	Year 3 %	Year 4 %	Year 5 %	
	BNL Material Burden	8.25	8.25	8.25	8.25	8.25	applied to travel, purchases and subcontracts
	PO Electric power	1.92	1.92	1.92	1.92	1.92	applied to direct salary plus fringe
Composite rate 39.45%	BNL Common G&A	24.00	24.00	24.00	24.00	24.00	applied to , direct salary plus fringe, organizational burden, purchased goods, material burden, & allocated services
Composite rate 39.45%	BNL Traditional G&A	8.25	8.25	8.25	8.25	8.25	applied to , direct salary plus fringe, organizational burden, purchased goods, and material burden
Composite rate 39.45%	BNL LDRD Burden	5.00	5.00	5.00	5.00	5.00	applied to , direct salary plus fringe, organizational burden, purchased goods, material burden, & allocated services
Composite rate 39.45%	BNL IGPP rate	2.20	2.20	2.20	2.20	2.20	applied to , direct salary plus fringe, organizational burden, purchased goods, material burden, & allocated services

Cover Page

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Early Career: Measuring Dark Energy with Gravitational Lensing in the Dark Energy Survey

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Contents

Abstract

I propose to analyze data from the Dark Energy Survey (DES) to constrain the properties of Dark Energy. My primary focus will be on measuring gravitational lensing effects to probe the expansion history and growth rate of massive structures in our universe. I am a DES member with data rights and a leader of the DES lensing effort.

Dark Energy accelerates the expansion of the universe, dramatically increasing the volume in comparison to a matter-only universe. Dark Energy also inhibits the growth of massive structures under gravitational collapse. Thus the number density of massive objects such as galaxy clusters as a function of cosmic time is directly related to the properties of Dark Energy, in particular the equation of state parameter $w =$pressure/density. Critical to using the number density to constrain cosmology is the masses of the clusters, which we will measure using gravitational lensing. Using cluster counts, lensing and other complimentary probes, the DES will measure w to $\sim$3%. This program is a natural continuation of my earlier measurements of lensing in the Sloan Digital Sky Survey (SDSS), which are most sensitive such measurements to date, and naturally leads to future work on projects such as the Large Scale Synoptic Telescope[1].

DES will see first light in 2011. In collaboration with Mike Jarvis at UPenn, I will spend the intervening time developing data reduction pipelines and realistic simulations to test these pipelines. In addition to these simulations, I will analyze existing data from the SDSS that is similar to but smaller than the final data set of DES. This analysis will produce cosmologically interesting results while stringently testing the pipelines.

After first light, DES will take data for five years, during which I will process the data as it arrives and perform analysis to extract Dark Energy parameters. These analyses will most likely produce results in two stages: an early set of results from the first year data and a second set of results from the full data set in 2014. The DES simulation and survey data will be of order a petabyte in size and will arrive in a steady stream for the next seven years. For this work I will require significant computing infrastructure and the assistance of postdocs and/or students.

Narrative

1.1 Introduction

The initial discovery of Dark Energy was made by studying the expansion history of our universe. According to General Relativity, a universe containing only ordinary matter decelerates at late times under its own gravitation, but recent studies of the brightnesses of distant supernovae indicate that our universe has begun to accelerate [2, 3]. This can happen if there is an exotic energy component in our universe with an equation of state parameter w=pressure/density that is less than -1/3.

The observational consequences of a Dark Energy component in our universe are numerous, but for our purposes the following are most relevant: 1) The expansion history follows a form quite different from that of a matter only universe, with a change in the sign of the acceleration at late times from negative to positive [4]. 2) Unlike in a matter-only universe, the growth history of massive structures through gravitation is no longer determined solely by the properties of the mass density field and the value of the present day expansion rate [5]. For example, without Dark Energy, the number density of gravitationally collapsed structures of a given mass at a given time in history is predictable essentially from the Hubble expansion constant H_0 and low order statistics of the mass field such as the mean of the density and the variance in the density as a function of scale (ignoring baryons). But in the presence of Dark Energy, the volume changes over time in a dramatically different way. The cumulative effects of Dark Energy significantly alter the predicted number of massive structures in a given volume of space.

Gravitational lensing is particularly well suited to studying this problem (e.g. [6, 7]). Lensing is the apparent bending of light as it passes massive structures. The amount of bending depends on the lens mass and the geometry of the lens-source-observer system. Thus, measurements of a large sample of lenses at various cosmological epochs tells us the expansion history of the universe, encoded in the geometry, and the growth history, encoded in the statistical distribution of the measured masses.

Lensing is more appropriate for measuring masses in an cosmological context than other techniques. The traditional technique of using orbital calculations and Kepler's laws to infer masses does not work because the timescales are too long to characterize the orbits. Velocities can only be used in a statistical way, and require assumptions about the dynamical equilibrium of the systems in question, which is often dubious on the physical scales of interest. Furthermore, interpretation based on luminous tracers is complicated by the ubiquitous presence of another mysterious substance: Dark Matter. Dark Matter dominates the mass density field, but because it is collisionless it is distributed very differently from the luminous matter. Often there are no luminous tracers in the relevant regions of space with which to infer masses. With lensing, one only needs enough background sources with which to statistically measure the lensing signal.

I propose to use data from the Dark Energy Survey (DES, [8]) to perform gravitational lensing measurements and infer the properties of Dark Energy. I am a DES member with data rights, and a leader in the DES lensing effort. My focus will be primarily on optimal measurement of the gravitational shear induced in the shapes of galaxies by lensing, and using the shear to infer statistics of the mass density field, namely the mass associated with galaxy clusters and the power spectrum of the mass density fluctuations in our universe. Both of these measurements will be highly sensitive to the properties of Dark Energy. Using a combination of techniques, we expect to constrain the equation of state parameter w to a few percent. As I will describe below, this is a natural extension of my earlier work in Gravitational Lensing using data from the Sloan Digital Sky Survey (SDSS) and will lead naturally to work on the Large Scale Synoptic Telescope [1], in which I am a participant

1.2 Previous Lensing Measurements in the SDSS

Using data from the SDSS [9], I have made highly accurate and precise measurements of gravitational shear. I have used these measurements to estimate the total mass content (normal and dark) associated with galaxies and clusters of galaxies [10, 11, 12, 13, 14]. These high quality measurements are facilitated by the excellent data and processing software of the SDSS, and our development of interpretational techniques that can extract masses from complex statistical shear measurements [15].

In these works we measured the shear from millions of background source galaxies at various projected distances from foreground lenses, from which we inferred the radial mass density profile. Because the signal is very weak, we additionally averaged the signal over many lenses. This averaging, while in principle diluting information about the individual lenses, has the positive effect of averaging out line of sight projections and "lumpiness" in the lenses, which complicates the interpretation. This in turn facilitates the extraction of accurate masses. Figure 1 shows results from [12, 13]. Plotted is mean cluster mass as a function of the number of galaxies in the cluster.

From galaxy and cluster lensing measurements we confirmed that there is an enormous amount of unseen dark matter in galaxies, and that this dark matter is in a "dark halo" that extends far beyond the concentrated bundle of stars at the center of galaxies. These measurements are completely consistent with the cold dark matter model. A number of derived results have come from these basic measurements papers, in which we have learned a great deal about the connection between the dark and visible matter in galaxies and clusters, e.g. [17, 18].

We have also used these measurements to estimate cosmological parameters. As stated in the introduction, the number density of halos of a given mass is related to the mean mass density of the universe and variance in the density. In [16] we combined the counts of galaxy clusters with our lensing mass estimates to constrain these cosmological parameters. Figure 2 shows results from [16] constraining the fractional mass density Ω_m and the relative variance in mass density on 8 Mpc scales σ_8.

While powerful in themselves, these results are also very complimentary to other measurements, breaking degeneracies in analyses of the Cosmic Microwave Background [19].

As I will describe in the next section on DES, gravitational shear measurements are central to two of that survey's primary goals. The techniques we developed in the SDSS are directly applicable to DES science, especially the study of galaxy clusters as cosmological probes. By extending the measurements backward in time with the deeper DES data, we will learn about Dark Energy as well as the Dark Matter.

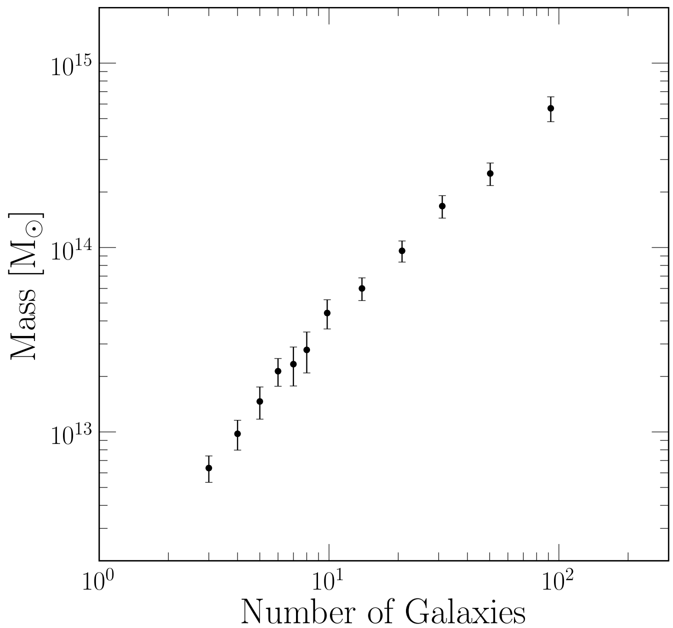

Figure 1 Mean cluster mass as a function of the number of galaxies in the cluster as measured from lensing in SDSS data [12, 13]. This calibration is critical to measuring Dark Energy with galaxy clusters.

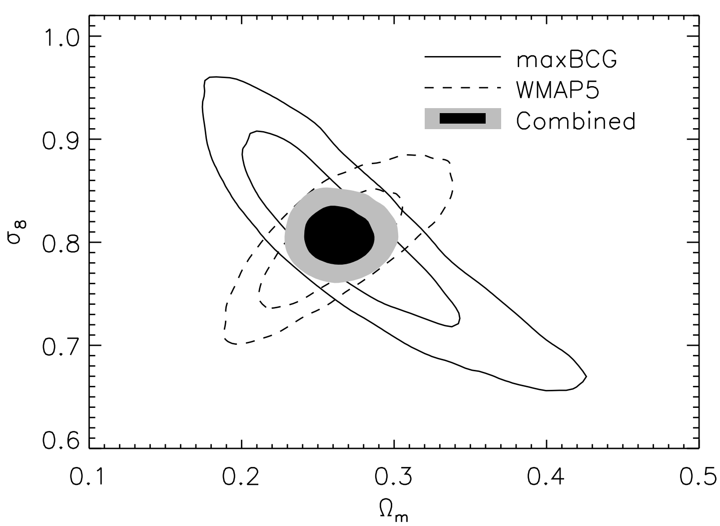

Figure 2 Constraints on the fractional mass density of our universe Ω_m and the relative variance in the density on 8 Mpc scales σ_8 as measured from SDSS data. These results [16] are derived by combining the counts of galaxy clusters with the mass calibrations from gravitational lensing as shown in Figure 1 [12, 13]. The cluster results break degeneracies with other probes such as the cosmic microwave background (WMAP). With DES we will study Dark Energy properties by extending these measurements back in time.

1.3 The Dark Energy Survey (DES)

The Dark Energy Survey (DES) is an optical, multi-band survey of 5000 square degrees using the 4-meter "Blanco" telescope at the Cerro Tololo Inter-American Observatory in Chile. A new camera is being built and the telescope repaired and upgraded. The DES will utilize gravitational lensing, an optical cluster survey, supernovae, and galaxy clustering to constrain the properties of Dark Energy. Combining the DES lensing and optical observations of galaxy clusters with observations by the South Pole Telescope (SPT, [20]) of the same galaxy clusters, greatly enhances the constraing power. These combined methods will constrain a Dark Energy equation of state parameter w to better than 3%. First light is planned for winter 2011, and the survey will run for five years. DES operations are funded in part by the U.S. Department of Energy.

The SPT will use the Sunyaev-Zel'dovich (SZ) Effect, the Compton up-scattering of light from the cosmic microwave background by the hot gas in galaxy clusters, to find a complete sample of clusters to high redshift. The goal of the SPT is to use these clusters to probe the growth of structure, and the volume of space, as a function of time. As described in the introduction, these are sensitive probes of Dark Energy. The DES will also naturally generate a huge optically selected cluster survey. Since it is the number density of clusters of a given mass that is sensitive to Dark Energy, an important part of each cluster survey will be the calibration of the mass-observable relationship via lensing. In §1.4 I will describe in detail our plans for measuring this relationship.

In addition to galaxy clusters, the DES will use a number of other probes to constrain Dark Energy properties. These include two other lensing probes: Shear-shear correlations as a function of scale and the cross-correlation between shear and known objects as a function of scale. Data are shared between cluster mass measurements and these probes, but because the correlation functions cover a much larger range of scales, they are complimentary. There is also a Supernova program that, while less constraining by itself, breaks degeneracies between certain cosmological parameters.

Table 1 shows forcasted constraints on w for various techniques employed by DES [8]. These forecasts are for DES and SPT data alone; combining with other data, for example from cosmic microwave background measurements from the Planck satellite [21], can significantly increase the precision of certain probes.

1.4 Lensing Analysis of DES Data

1.4.1 Science Analysis

In collaboration with Mike Jarvis and Bhuvnesh Jain of Penn, I am working to create data processing pipelines and analysis codes to measure gravitational lensing in DES. I will use this data to calibrate the masses of the galaxy clusters used in the cosmological analyses. I will also participate in the measurement of shear-shear correlations (cosmic shear). These are critical components of the DES mission.

As described in the introduction, the cosmological information from clusters is primarily in the number density of clusters with a given mass as a function of time. Clusters are identified not by their mass but by other indicators, such as the SZ effect from SPT data or by the clustering of visible galaxies in DES imaging data. The strength of the SZ effect and

Table 1. Projected DES Constraints on Constant w Dark Energy Models.

Method	σ_w
Clusters	
Abundance	0.13
with WL Calibration	0.09
Weak Lensing	
Cosmic Shear (CS)	0.15
Galaxy/Cluster-shear(GS) + Angular Clustering(AC)	0.08
CS + GS + AC	0.03
Angular Clustering of Galaxies	0.36
Supernovae Ia	0.34

the number of galaxies are both correlated with mass, but that correlation must be measured by a secondary method. As described in the introduction, lensing is the best method for doing this.

As described in §1.2, in our studies of SDSS lensing we have developed proven analysis techniques to calibrate the mass-observable relation of clusters (Figure 1). Using this calibration in conjunction with the number density we have inferred cosmological parameters (Figure 2). These techniques are limited only by our understanding of the systematics and characterization of the cluster selection process. The volume and depth of DES is sufficiently large that we will repeat these measurements in many bins of cosmic time, with which we will extend our cosmological analysis to constrain the properties of Dark Energy.

In contrast with cluster lensing measurements, cosmic shear is the correlation of shears across the sky independent of the location of foreground structures. Since the shear is related to mass, the cosmic shear can be used to directly infer statistics of the underlying mass distribution, the evolution of which is directly related to the properties of Dark Energy. Because the signal need not be modeled in terms of cluster halos, the interpretation of cosmic shear can be simpler than cluster lensing. However, the measurement involves directly correlating shears from many sources as a function of their separation on the sky, which can propagate systematic errors directly into the measurement. Thus cosmic shear and cluster lensing are quite complimentary.

Table 1 shows the power of lensing in the DES to constrain w as compared to other DES probes.

1.4.2 Data Reduction and Removal of Systematic Effects

Gravitational Shear alters the shapes of galaxy images, producing recognizable patterns in their ellipticities across the sky. Thus accurate shear measurements require accurate measurements of galaxy shapes. But there are a number of factors other than lensing that must be taken into account in order to extract shear signal from the shapes of galaxies. In fact these other factors are typically 10 to 100 times larger than the shear for a single galaxy.

The most dominant source of error is the intrinsic shape of the galaxy itself. While the shear may alter the ellipticity of a galaxy by less than a percent (the smallest shears measured in [12] are 10^{-4}!) the typical galaxy ellipticity is about 0.3. It is impossible to measure typical shears from a single galaxy image. However, this "shape noise" is purely random, so with enough galaxies the shear signal can be extracted using statistical techniques.

Other effects are less benign and must be explicitly accounted for in the measurements. The most serious of these is the point spread function (PSF) of the sky plus telescope optical system. The sky causes enough blurring of images to significantly alter the shapes of most galaxies, diluting the shear signal. Furthermore the optical system and instrument will significantly distort and blur the shapes of objects, producing correlations in their shapes that can mimic lensing.

There are existing techniques for removing these effects but for DES Mike Jarvis and I are developing a new pipeline designed to be nearly optimal in tracking the PSF and accounting for its effects in the shear estimation [22, 23]. Furthermore, this pipeline can make full use of the multi-epoch DES data where each area on the sky is observed many times. A prototype of this "multishear" pipeline is already in place and is being tested on simulated DES data. For the next year and a half this pipeline will undergo heavy testing and refinement in preparation for commissioning. We will further test this pipeline in a real world setting using the multi-epoch southern SDSS survey as described in section §1.5. After the survey comes online in 2011, we will process the data in real time as it arrives. The processing of simulated and real data will required significant manpower and computing resources.

1.5 New Analysis of SDSS Multi-epoch Data

Once the pipeline described in §1.4.2 reaches a state of maturity based on testing simulated data, we will process the multi-epoch data from the SDSS "southern stripe". Although this data is only 225 square degrees and somewhat shallower than the final des data, it is interesting both for testing our pipeline and performing a cosmological analysis. The data will be a more stringent test of the pipeline than DES in the sense that there are many more epochs, typically 30-40. This means many of the galaxies we use will have no detection at all on the single epoch images, requiring the multishear code to deal properly with very noisy data. But it is an excellent data set for a lensing analysis as well, being comparable or larger in volume than any existing cosmic shear study. This testing and analysis will be led by postdoc Zhaoming Ma, who is coming to BNL in October 2009. I expect at least one publication on cosmological parameters will be based on this work.

1.6 BOSS and LSST

I am a member of the Baryon Oscillation Spectroscopic Survey (BOSS, [24]), leading the spectroscopic target selection. I am also a member of LSST, working on the early stages of lensing pipeline development. Although no equipment purchases or additional manpower are required to support this work, I am contributing a total of 25% of my time to these two projects.

1.7 Resources and Budget Justification

The simulated DES data we have in hand is currently only a few terabytes, but over the next year a larger simulation, representing two years of DES data, will be generated. The total simulation data will be of order 200Tb. The DES survey proper will begin in 2011 and run for five years, generating about a petabyte of data over that time.

In order to process the simulated data and real data as it arrives we will require significant manpower and computing resources. The NSF funded DES data management (DESDM) is committed to produce a single processing of the data per year. Thus, although our lensing pipelines will be incorporated into DESDM, all development and testing must occur outside of DESDM. In order to test our pipelines and analysis codes we must process the full data set multiple times. This is because many systematics tests require essentially the full data set to explore. And only from analyzing the full data set to extract the lensing signal will we be able to feed back what we have learned into the pipelines. Working with a single processing would be highly restrictive. Thus we must have our own separate computing resources to facilitate these tests and analyses.

We do not yet know the computing power required to process the whole dataset because the multi-epoch shear fitting code is not yet mature. But based on current hardware and codes, it would take about three months to process the final petabyte of DES data on a moderate 70 node cluster with 8 cores per node.

We will also require significant resources for the science analysis, which is computationally intensive. As a reference point, the SDSS analysis presented in §1.2 required running for a week on a cluster of 80 processors. The mass and luminosity analysis of [14] is even more intensive, requiring two weeks on an 300 processor cluster (although these computers were a factor of two slower than the current generation). The DES data set will be 50 times larger.

Because of Moore's law, it makes sense to buy the computing over a period of time. To store and process the petabyte of DES data, we propose to spend about $100,000/year for five years, accruing about 200Tb of storage per year plus processing nodes. The first year we will acquire 130Tb of storage and 15 8-core nodes with 32Gb of memory each (26kSI2k, 104 HEP-SPEC 2006). In following years we will purchase more disk for the same price, and keep a trajectory to our one petabyte goal. We will assemble a system with about 70 nodes. An outline of our plans for computing purchases is shown in Table 2.

Note these prices include bulk discounts from purchasing along with other experiments through the RHIC Computing Facility at BNL.

We also ask for 75% of Erin Sheldon's salary and overhead for five years, and 100% for Zhaoming Ma for three years. It is anticipated that another postdoc will be hired after Zhaoming leaves BNL, with 100% support for two years. Additionally we anticipate a student will join us at BNL and will be covered at 100%.

The remaining funds are primarily for travel expenses. The DES collaboration is multinational and Erin Sheldon and a postdoc will most likely travel abroad to the collaboration meetings. Sheldon plans to spend three weeks each summer at a workshop in the US, such as those held at Aspen and Santa Fe. Further travel will involve attending a few conferences per year across the US for both Sheldon and Ma. Erin Sheldon will also make regular trips to the University of Pennsylvania to collaborate with Mike Jarvis and Bhuvnesh Jain.

Table 2. Projected Computing Purchases

Fiscal Year	Disk Storage [TB]	$ for Storage	Compute Servers	$ for CPU
2010	130	55,000	15	45,000
2011	162	55,000	19	45,000
2012	203	55,000	23	45,000
2013	254	55,000	29	45,000
2014	318	55,000	36	45,000
Total in 5 years	1067	275,000	122	225,000

Note. — The number of compute nodes purchased from 2011 on is based on the assumption that each node (26kSI2k, 104 HEP-SPEC 2006) would stay at the performance level of a node purchased in 2010. As the performance per node will increase over time the actual number of compute nodes after 5 years will be significantly smaller (probably O(70)), providing a combined performance of O(122) times the performance of a node purchased in 2010. Prices include bulk discounts from purchasing through the RHIC Computing Facility at BNL.

1.8 Timeline

This is an outline of the activities for the next five years. It is assumed that the primary collaborators on these activities are Erin Sheldon (ES) of BNL, Zhaoming Ma (ZM) of BNL, and Mike Jarvis (MJ) of the University of Pennsylvania. Mike Jarvis is a close collaborator but not an expense to this proposal. If a student joins us at BNL they will focus primarily on data analysis. Zhaoming may continue working on the project after he leaves BNL, but I have not explicitly included him in activities beyond summer 2012.

- **Fall 2009** Testing of the weak lensing pipeline on simulated DES data (ES, ZM and MJ). Processing of full DES simulated data set for DES data challenge 5 (ES).
- **Winter/Spring 2010** Test the lensing pipeline on SDSS multi-epoch data from the "southern stripe" (ZM). Process full SDSS data (ES, ZM).
- **Summer 2010** Begin analysis of SDSS measurements for galaxy/cluster-mass correlations and cosmic shear (ZM, ES, MJ).
- **Fall 2010** Continue analysis of SDSS data. Test pipelines on DES data challenge 6 (DC6) simulated data, which will have realistic cosmological shears (ES, ZM, MJ). Process full DC6 data. (ES)
- **Winter/Spring 2011** Continue analysis of SDSS data. Process DES commissioning data as it arrives (ES). Test pipelines on real DES commissioning data, adjusting processing pipeline as needed (ES, MJ).
- **Summer/Fall 2011** Re-process the previous year's data with improved pipelines. (ES) Finish analysis of SDSS data, publish results. Process Fall/Winter DES data as it arrives (ES).
- **Winter/Spring 2012** Process DES data as it arrives (ES). Multiple epochs will now exist over much of the sky, first serious testing of multi-epoch shear pipeline on real DES data (ES, ZM, MJ). Begin analysis of first year DES data for lensing (ES, ZM, MJ).
- **Summer/Fall 2012** Finalize analysis of existing DES data, incorporating recently processed data if it is ready (ES,ZM,MJ). First publications from early DES data should emerge in summer or fall 2012 (ES,ZM,MJ).
- **Winter 2013-Fall 2014** Activities should continue as before: Processing data as it arrives, primarily Sept-Feb of each year, incrementally improving the data pipelines and analysis codes. Analysis methods will evolve, especially as the final data are in hand and there are many epochs with which to work.
- **post 2014** A re-processing of all data through the final pipelines and final analysis of the full dataset to extract cosmological information (ES, MJ).

Appendix 1: Biographical Sketch

Erin Sheldon

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Position

Assistant Physicist, Brookhaven National Laboratory
September 2008–present

Education

University of Michigan *September 1997–August 2002*
Ph.D., Physics
Thesis advisor: Prof. Timothy McKay
Title of thesis: "Galaxies, Luminosity, and Mass: Gravitational Lensing Measurements of the Correlation between Dark and Luminous Matter"

University of Missouri *Aug 1992 – May 1997*
B.S. *Magna cum laude*, Physics and Mathematics

Research

Postdoctoral Fellow, Center for Cosmology and Particle Physics
New York University *Sep 2005–Sep 2008*
Postdoctoral Fellow, Kavli Institute for Cosmological Physics
University of Chicago *Aug 2002–Aug 2005*
Research Assistant, University of Michigan *Sep 1998–Aug 2002*
Research Assistant, Fermilab Experimental Astrophysics Group
Jun 1998–Sep 1998
Hughes Fellow, University of Missouri *May 1996–Sep 1997*
A&S Research Fellow, University of Missouri *Summer 1995*
Hughes Fellow, University of Missouri *Fall 1994–Spr 1995*

Honors/Awards

KICP Postdoctoral Fellowship *2002-05*
Michigan Space Grant Consortium grant *2000-01 and 01-02*
A&S Summer Research Fellowship, University of Missouri *Summer 1995*
Hughes Undergraduate Research Fellowship, University of Missouri
1994-95, 1995-96
O.M. Stewart Physics Scholarship, University of Missouri *1993-97*
Curators Scholarship, University of Missouri (Full Tuition Scholarship)
1992-97

Teaching **U. of Michigan, Department of Physics** *Fall 1997–Spr 1998*
Taught introductory physics labs on mechanics.

U. of Missouri, Department of Physics *Fall 1995–Spr 1997*
Taught introductory physics labs on mechanics, E&M, and thermodynamics.

U. of Chicago, Dept. of Physics and Astronomy
Summer 2004, Winter 2005
Developed and co-taught an observing lab for the Yerkes Summer Institute, a program to involve inner city kids with science.

Selected Publications for Erin Sheldon

Note Appendex 3 holds the references for the narrative.

1 E. S. Sheldon et al. Cross-correlation Weak Lensing of SDSS Galaxy Clusters III: Mass-to-light Ratios. *Accepted ApJ, appearing*, October 2009.

2 D. E. Johnston, E. S. Sheldon, et al. Cross-correlation Weak Lensing of SDSS Galaxy Clusters II: Cluster Density Profiles and the Mass–Richness Relation. *arXiv:0709.1159*, September 2007.

3 E. S. Sheldon et al. Cross-correlation Weak Lensing of SDSS Galaxy Clusters I: Measurements. *Accepted ApJ, appearing*, October 2009.

4 B. P. Koester et al. A MaxBCG Catalog of 13,823 Galaxy Clusters from the Sloan Digital Sky Survey. *ApJ*, 660:239–255, May 2007.

5 J. K. Adelman-McCarthy et al. The Fourth Data Release of the Sloan Digital Sky Survey. *ApJS*, 162:38–48, January 2006.

6 E. S. Sheldon et al. The Galaxy-Mass Correlation Function Measured from Weak Lensing in the Sloan Digital Sky Survey. *AJ*, 127:2544–2564, May 2004.

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9 E. S. Sheldon et al. Weak-Lensing Measurements of 42 SDSS/RASS Galaxy Clusters. *ApJ*, 554:881–887, June 2001.

10 P. Fischer, T. A. Mckay, E. S. Sheldon, et al. Weak Lensing with Sloan Digital Sky Survey Commissioning Data: The Galaxy-Mass Correlation Function to 1 Mpc. *AJ*, 120:1198–1208, September 2000.

Appendix 2: Current and Pending Support

Erin Sheldon is currently supported at 100% by a BNL LDRD under contract No. DE-AC02-98CH10886.

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Key: *AJ* is The Astronomical Journal, *ApJ* is The Astrophysical Journal and *MNRAS* is The Monthly Notices of the Royal Astronomical Society.

Appendix 4: Facilities and Other Resources

We plan to acquire a large amount of computing. The housing, power and cooling for these computers will be provided by the RHIC Computing Facility at Brookhaven National Lab at no additional cost to this proposal.

Appendix 5: Equipment

The equipment currently available to this project is a set of five computers purchased in January 2009, consisting of one file server and four compute nodes. The file server holds 40 Terabytes and each compute node is dual quad core with 32 Gigabytes of ram. These are housed at the RHIC Computing Facility at BNL.