Department of Energy

Review Report

For the

BigBOSS proposal

DECEMBER 2011

Executive Summary

A Department of Energy (DOE) Office of High Energy Physics (HEP) independent panel review of the proposed Big Baryon Oscillation Spectroscopic Survey (BigBOSS) project was held on December 6-7, 2011 at the Lawrence Berkeley National Laboratory (LBNL). The review was requested by Glen Crawford, Director, Research and Technology Division and was chaired by Kathleen Turner, Program Manager for the Cosmic Frontier. Nine independent scientists with expertise in the scientific, technical, cost, schedule and management aspects of the experiment served as review panel members.

The review was held in response to a Field Work Proposal (FWP) submitted to HEP by LBNL for the BigBOSS Stage IV dark energy experiment, which will study Baryon Acoustic Oscillations (BAO) and the growth of structure with an all-sky galaxy redshift survey. The BigBOSS collaboration is planning to design and fabricate a 5,000-fiber spectrograph with associated focal plane and optical corrector system to be mounted on the Mayall telescope at Kitt Peak National Observatory (KPNO). The collaboration would perform a 500-night scientific survey in partnership with the National Optical Astronomy Observatory (NOAO). The collaboration may investigate other telescopes or operating models if the Mayall telescope is not approved for continued operations.

The review panel was charged to assess the scientific and technical goals and feasibility of BigBOSS; and to assess the technical aspects, cost, schedule and management for the Research and Development (R&D) planned in the current pre-conceptual design phase.

Regarding the scientific goals of the experiment, the panel agreed that the collaboration made a compelling case that the spectroscopic survey would represent the state-of-the art in BAO measurements. Their results would be competitive with the BAO components of proposed space-based stage IV missions. In the past year, the team has succeeded in addressing almost all the concerns raised in a non-advocate review held by NOAO, significantly reducing the risk to the project. There were a number of detailed recommendations regarding studies that need to continue in order to further develop the scientific methods and goals.

Regarding the optics and mechanical aspects, the panel commented that the major risks have been identified and an R&D plan is in place to address these risks. Design studies to optimize the reference design are warranted and planned. The panel recommended studies of similar experiments to review any lessons learned.

The panel commented that the current pre-conceptual design and implementation of the focal plane system will likely meet the scientific goals. With the current design, the engineering and fabrication risks were deemed to be low. Recommendations were to further investigate design concepts and scientific goals in the near term so changes to the design can be made if needed.

Regarding the spectrograph and sensors and controls subsystems, the panel found their design to be well advanced and likely to meet or exceed the requirements. Recommendations were made to perform trade studies on the cooling system and to

determine the dynamic range requirements needed for the community science needs as well as for the BigBOSS survey.

The panel found that the current design for the computing aspects of the experiment are well developed for this stage and an R&D plan is in place to further develop the design and address major risks. The panel recommended that the computing and software development be more formally organized, and also made recommendations regarding details of the planned R&D and design.

The panel found that the estimated cost and schedule for the R&D phase are reasonable and will serve to mitigate some of the larger risks to the experiment. Recommendations were made to estimate operating costs and explore options for operations funding and define and plan the installation and commissioning tasks early in the R&D phase. A schedule with milestones at Level 1 (L1), L2 and L3 should be developed for the R&D phase. The resource loaded cost and schedule, a change control plan, interface control document milestones and other documentation should be developed to a point sufficient to support requests for CD-0 and then CD-1 approval as rapidly as possible.

The panel found that the management team is highly experienced and extremely well organized. They have tools and people in place to accomplish the planned R&D effort, which will mitigate major risks to the experiment.

The managerial structure connecting NOAO and BigBOSS should be understood prior to CD-1. In addition, the science, cost and schedule impacts of using alternative telescopes should be explored early in the R&D phase.

The science to technical requirements flowdown should be conducted and publicized within the collaboration early in the R&D phase. Continued optimization of the design within these requirements should take place during the R&D phase, instead of stopping this effort at the current reference design. Scope contingency and impacts on the science goals should be identified and understood.

Regarding foreign contributions, there were recommendations regarding roles, responsibilities and agreements with foreign institutions that should be pursued during the R&D phase. The collaboration should assign sufficient contingency to cover the additional risks and should develop tracking and reporting tools. DOE should be proactive in helping BigBOSS secure international commitments.

In summary, the panel believed that the R&D plan will lead to a mature technical design within 18 months. The panel found that the management team is clearly ready to move ahead with the project as soon as the external hurdles are cleared, including the telescope availability, and roles and responsibilities of the lead laboratories and funding agencies. The management should work with the stakeholders and agencies to bring BigBOSS to a condition where CD-0 approval can be requested expeditiously. Due to the maturity of the collaboration and design, critical decision 1 (CD-1) approval could quickly follow.

Table of Contents

Executive Summary 2

Introduction 5

Science & Survey Plan 6

Technical
a. Optics & Mechanical 10
b. Focal Plane System (incl fibers, actuators) 12
c. Spectrograph and Sensors & Control (including guiding, focus, alignment) 15
d. Computing 18

Cost & Schedule 20

Management 22

Appendices
A. Review Panel and Agency Attendees 24
B. Agenda 25
C. Review Charge 27
D. Organizational Chart 29
E. R&D Proposal summary 30

Introduction

The DOE Office of High Energy Physics independent panel review of the proposed BigBOSS project was conducted on December 6-7, 2011 at LBNL. The review was held in response to the FWP submitted by LBNL for the BigBOSS Stage IV dark energy experiment, which will study BAO and the growth of structure with an all-sky galaxy redshift survey.

The BigBOSS collaboration submitted a proposal in response to a 2009 call from the National Science Foundation's (NSF) NOAO for major new instrumentation and a 500-night scientific survey on the Mayall telescope at KPNO. The BigBOSS collaboration may investigate other telescopes or operating models if the Mayall telescope is not approved for continued operations.

The National Research Council's Astronomy and Astrophysics Decadal Survey (Astro2010) reviewed BigBOSS favorably and their August 2010 report recommended that NSF begin a mid-scale scientific projects line in which BigBOSS could compete. The October 2009 High Energy Physics Advisory Panel (HEPAP) Particle Astrophysics Science Assessment Panel (PASAG) subpanel report recommended "a portfolio of experiments that approach the astrophysical limitations for each dark energy method." DOE may consider opportunities to contribute to mid-scale ground-based projects, such as BigBOSS, as part of a coordinated dark energy program.

The BigBOSS proposal is to design, fabricate, test and deliver the instrumentation to be installed and operated on the telescope, as well as to deliver a spectroscopic pipeline and data management system. The collaboration has proposed the experiment as a partnership between DOE and NSF, with contributions from private institutions and foreign partners. Fabrication and installation of the instrumentation, which includes a new 5,000-fiber spectrograph with associated focal plane and optical corrector system, is expected to take 4 years.

BigBOSS follows the successful Sloan Digital Sky Survey III (SDSS-III) Baryon Oscillation Spectroscopic Survey (BOSS), which is currently taking data. Its spectroscopic survey will provide complementary measurements to imaging surveys that are underway or planned for this decade, including the Stage-III Dark Energy Survey (DES) and the Stage-IV Large Synoptic Survey Telescope (LSST).

The review panel was charged to assess the scientific and technical goals and feasibility of BigBOSS; and to assess the technical aspects, cost, schedule and management for the R&D planned in the current pre-conceptual design phase.

The panel's detailed findings, comments, and recommendations, for the science goals and technical, cost, schedule and managements aspects, are described in the text of this report. The review charge, participants, agenda, and list of acronyms are included as appendices along with charts on the organization and scope, cost, schedule, and funding aspects of the proposal.

<u>Science & Survey Plan</u>

Hu, Dell'Antonio, Albrecht (Subcommittee 1)

Findings:

The collaboration's proposal is to conduct a spectroscopic redshift survey aimed at measuring the BAO signal over a unique redshift range, and it would fill an important component in the portfolio of dark energy experiments. In addition to the direct measurement via BAO, the collaboration will use the redshift survey to measure redshift space distortions, a measure of the growth of clustering in the Universe.

The science goals are compelling, and the survey will make novel measurements. In particular, the radial BAO signal will measure H(z) over the redshift range $0.8<z<1.6$ and fill a hole in planned measurements of the expansion of the Universe through BAO exactly at the epoch in the Universe when the dark energy component is becoming dominant.

The collaboration will also measure the BAO signal at lower and higher redshifts, providing better constraints on cosmology at these redshifts than currently operating or immediately impending stage III experiments such as BOSS, Wiggle-z, and HETDEX. Thus, the collaboration has made a compelling case that the successful completion of their survey would represent the state-of-the art in BAO measurements, and improve the BAO contribution to the Dark Energy Task Force (DETF) Figure of Merit (FOM) by at least a factor of 10 would represent at least a factor of 10 compared to the current results from SDSS-III.

Indeed, the DETF "figure of Merit" resulting from the proposed project meeting its redshift measurement goals is competitive with the **BAO components** of space-based stage IV proposals such as Wide-Field Infrared Survey Telescope (WFIRST) and EUCLID.

In addition to proposed survey aims to measure the large-scale galaxy power spectrum to 1% precision, which will constrain other fundamental cosmological physics, from the combined neutrino masses to the validity of general relativity, as well as provide strong additional constraints to dark energy if the non-linear structure can be measured as a function of redshift.

The collaboration plans to carry out the survey by observing three distinct classes of distant objects: Luminous Red Galaxies (LRGs) (out to $z\sim1$), Emission Line Galaxies (ELGs) with ($0.7<z<1.6$), and Quasi-Stellar Objects (QSOs). For the quasars with redshift >2.2, where the Lyman-alpha forest is visible in the BigBOSS spectra, the collaboration plans to conduct an additional analysis that uses the correlation of absorption signal with redshift and position on the sky to construct a "Lyman-α" BAO measurement.

The success of the proposal's science goals depends on the successful identification and selection of target galaxies, and then on the successful measurement of redshifts of these targets. For each target type, the collaboration is relying on constructing new samples. The most critical of these samples to the success of the BigBOSS experiment is the ELG selection, because the ELGs make up about 75% of all the galaxies BigBOSS plans to observe. These galaxies are too faint to be selected in the SDSS imaging; instead, the collaboration is relying on the data from the Palomar Transient Factory (PTF) or its successor experiment (PTF2). They have established a Memorandum of Understanding (MOU) for data access with the PTF project and are actively participating as a partner institution in PTF-2, which should begin taking data in 2014.

During the non-advocate review of the BigBOSS proposal by NOAO, this selection was considered risky given the relatively shallow depth of the PTF data and the poor image quality of the delivered images. However, the survey team has done a remarkable job in the past year of using actual PTF data and validating their selection technique with spectroscopy (and with a reference catalog of ELG properties determined from the much deeper COSMOS dataset). Although some of these experiments are ongoing, it now appears very likely that they will be able to select ELG targets.

The BigBOSS team is also proposing a novel way of selecting QSO candidates, using the variability in the PTF images as an additional selection criterion. Although this was deemed merely plausible, the collaboration has taken test data to demonstrate that it is effective, and is in the process of acquiring spectra of appropriately selected targets with BOSS and MMT/Hectospec to verify the selection efficiency.

LRGs have traditionally been the main targets of BAO experiments because they are easy to select (at lower redshift) and cluster strongly, amplifying the BAO signal. The LRG selection has traditionally been performed via red optical colors. This fails for higher redshifts, because the 4000 Angstrom break redshifts out of the optical waveband. The collaboration has identified a very promising way to extend the selection to high redshift using the WISE satellite all-sky images, and has shown that this is very effective at picking out LRGs with z~1. Ironically, though, the LRG sample is currently the least well-defined of the three samples, because the current selection relies on the SDSS imaging for the optical bands. Because the BigBOSS collaboration is proposing a survey that extends considerably beyond the SDSS imaging footprint, the team needs to secure additional imaging to cover those regions. Although alternatives exist for acquiring the data (adding a third filter to the PTF2 imaging, obtaining PanSTARRS data or conducting an imaging survey with ODI/Mosaic 1.1 are all possible), the collaboration has not settled on which path to take.

In addition to the target selection, the project has to show that they will actually be able to measure redshifts for the target galaxies they collect. The collaboration is acquiring data and performing simulations to verify that the proposed BigBOSS spectrograph will successfully measure redshifts for the targeted sources. This R&D work is also extremely important for validating the science goals of the Survey. Although the R&D work to validate this is still ongoing, the collaboration has made a strong case that the

required sensitivity is attainable given small performance gains from designs of currently running projects (BOSS, SDSS3). The most challenging measurements will be those of the ELGs—the proposed spectroscopic depth will not detect the continuum strongly, instead relying on detection of the O[II] doublet in emission as the unique redshift signature. The collaboration is acquiring data with BOSS and with the FORS2 spectrograph on the Very Large Telescope (VLT) to verify the sensitivity calculations.

Although the BAO signal is theoretically well-understood, the collaboration is planning on making cosmological measurements that do depend on theoretical advances. Progress is being made in understanding how to compare power spectrum measurements with cosmological predictions at non-linear scales (a process necessary to interpreting the redshift space distortions and broad band power spectrum measurements), but theoretical work will continue to be necessary before these measurements can be exploited.

The Lyman-α forest BAO technique remains an unproven method but the first published results from BOSS that measured the broadband flux transmission correlation function have not revealed any systematic show-stoppers to date. Because the collaboration will be able to use the BOSS results as a "test-bed" to verify the technique over the next two years, their understanding of the power and systematic limitations of the technique should advance rapidly over the next year.

The BigBOSS collaboration and the DES are investigating additional gains in our understanding of Dark Energy and cosmology that would result from common analysis of the ~5,000 square degree overlap region between the two surveys.

Comments:

While demonstrating the BigBOSS FOM from BAO is comparable to the BAO FOM from other planned projects is helpful in explaining the importance of BigBOSS, any such discussion should be clear about exactly what is being compared, particularly if the other project involves other techniques that are not accounted for in the comparison.

The collaboration is planning on using the redshift-space distortions to test the nature of gravity. A more dark-energy-model independent test of the validity of general relativity (GR) would measure the curvature fluctuation generated per unit dynamical mass. This requires a comparison of the redshift space distortions from the survey with measurements of space curvature, typically from gravitational lensing, and is most powerful if done in the same field. Perhaps this is where a DES/BigBOSS overlap can be very valuable.

The progress made on validating the collaboration's plan for target identification is <u>extremely</u> impressive. In the year since the non-advocate review of the proposal by NOAO, the team has succeeded in addressing almost all the concerns raised by that review in terms of target selection, significantly reducing the risk to the project.
It is important that the R&D work proposed to verify the target selection continues to be performed. In particular, the VLT/FORS2 observations for ELG selection verification will also be very powerful in demonstrating that the proposed spectrograph sensitivity

will be sufficient to measure the redshifts of the ELGs. For the LRG target selection, it is important to test out the alternate options for acquiring the imaging data necessary for the part of the proposed BigBOSS project that does not overlap the SDSS footprint, and to select among the alternatives soon.

The limitations and biases of Lyman-alpha forest measurements of BAO are not yet completely characterized, but the BOSS data will provide a good test-bed for these studies. It is important that the collaboration continue to devote resources to analyzing the BOSS Lyman-alpha results.

The collaboration should continue its participation in PTF2, because that dataset provides the target selection for the most critical portion of the survey.

Recommendations:

Continue developing tools to model nonlinear contributions to redshift space distortions and galaxy biasing prescriptions to achieve the required precision.

Continue to address Ly-a forest astrophysical systematics for the BAO measurement using the BOSS data as it is made available.

Study the impact of other systematics in addition to star-galaxy correlation on the large scale galaxy power spectrum measurements.

Address the extent to which mock catalogs and simulations will be necessary for survey optimization and error analysis and the required computational resources.

Complete the analysis of the FORS emission line galaxies to verify the selection criteria for ELGs and provide a test of the sensitivity of BigBOSS

Use both simulations and data from BOSS to investigate the redshift-measuring efficiency expected for the ELGs.

Technical

a. Optics & Mechanical

Olivier, Dell'Antonio (SC2)

Findings:

A reference design for BigBOSS has been developed that encompasses:

- Corrector Optics/Atmospheric Dispersion Compensator (ADC)/Barrel
- Hexapod/Cage/Thermal shroud
- Spiders/Upper ring
- Interfaces

Computer-Aided Design (CAD) and Finite Element Method (FEM) models were developed, and utilized for a design study of the reference design in the following areas:

- Mass
- Volume
- Deflections and birefringence
- Dynamics
- Thermal environments
- Integration and alignment

The R&D plan proposes to increase fidelity of the models and continue to use them to analyze these areas to reduce risk.

Optics manufacturing plan, lens cell design, alignment strategy and associated tolerances were derived based on experience with Dark Energy Camera (DECam).

Further R&D work is proposed to verify optics manufacturability with vendors and to develop prototype subscale lens cell assembly.

The hexapod rotation range is +/- 2 degrees but it wasn't known if this range is available during operations, that is, whether the required focus and tip-tilt are available with this rotation range and whether this enough to compensate for telescope misalignment.

Comments:

The reference design for the optical and mechanical elements and associated implementation approach appears feasible.

The major risks have been identified and an R&D plan is in place to address these risks.

The team has the necessary technical expertise and management structure to accomplish the proposed R&D plan.

Cost and schedule were presented/reviewed separately, but team correctly identified thermal analysis as major R&D area.

The optical design goes beyond the current state of the art, so additional design studies to optimize reference design in order to potentially save cost and/or time are warranted and are planned in the proposed R&D work.

Without a large angle field rotator, it's probably worth computing if the available hexapod range is sufficient to adjust for misalignment of the telescope polar axis, etc. This adjustment could be done by repositioning the fibers, but rotation is probably easier.

Recommendations:

Hold a project meeting to review any lessons learned from DECam experience regarding optics and mechanical issues following commissioning of DECam. For example, was there any problem caused by not bringing the optics and the focal plane together earlier in the project, which might suggest a different strategy for BigBOSS.

Develop a rotation requirement with KPNO or, conversely, a scheme for using a rotation offset in fiber positioning operations, perhaps using a declination (DEC), Right Ascension (RA) table.

Technical

b. Focal Plane System (incl fibers, actuators)

Uomoto, Olivier (SC3)

Findings:

The team is sensitive to and aware of the installation problems associated with 5000+ fibers. However, the design did not take into account maintenance issues, including knowledge of how and when to replace broken fibers.

Fiber positions are tuned up using a focal plane image of the object and fiducial fibers as lit by light-emitting diodes (LEDs) at the other end. The plan for injecting light into the slithead fibers was explained only as a notion to use the non-charge-coupled device (CCD) side of a spectrograph shutter to direct LED light to the slithead.

The fiber view camera is less well-developed than the other instrument subsystems so there are a larger number of unexplored areas.

The fiber view camera concept uses a commercial Canon telephoto lens although its performance data was not available.

The fiber viewing camera is mounted at the top of the primary mirror baffle. This location is driven by KPNO operations because they do not want to remove instruments at the Cassegrain focus to accommodate this camera.

Comments:

The current pre-conceptual design and implementation of the focal plane/fiber system will likely meet the scientific goals. The technology risk is small, but successful development and deployment will require deliberate management and frequent checks against to-be-developed engineering requirements.

The major technology risk is the fiber actuator system and team has done a good job of identifying and prioritizing this risk, both by front-loading the focal plate design work and having parallel development of fiber actuator prototypes.

As a pre-conceptual design the fiber viewing camera will work but because its performance and reliability have high impact on the survey cadence, an in-system end-to-end performance analysis that includes realistic fiber illumination should be done early to confirm it is not a high-risk system.

Overall, the focal plane system is well beyond “pre-conceptual” so engineering and construction risks are low.

While fiber failures should be rare, accidents happen and it’s essential to build in the ability to replace fibers from the start. A risk assessment on science lost for various fiber

failure scenarios would allow the engineering team to apply the appropriate R&D resources to this problem.

The notional plan of illuminating the non-CCD side of a spectrograph shutter to send LED light to the slithead triggered many reviewer questions: Is there enough light (a fiber only intercepts a small fraction of the LED light even after reimaging)? Can a sufficiently light-tight shutter be made to avoid injecting light into the science data (the CCD is reading out at this time)? Where does the heat from the LED go (this is a tight space) and does it need to move?

The fiber viewing camera performance is part of a serial-time requirement for field setup so retiring its performance risk early is important.

The commercial Canon 400 mm telephoto lens in the fiber view camera would be a simple solution if it performs as needed. However, actual performance data from the manufacturer isn't available and we worry that its imaging ability might not be as good as required for this problem. This lens is designed to work with color detectors and might not be able to produce spots as small as needed in this monochromatic system. For a 400 mm focal length, it might be possible to assemble something lighter and simpler that performs better at the LED wavelength.

Placing the fiber viewing camera on top of the primary mirror baffle makes it susceptible to wind shake. Because top performance from this camera is essential for quick field setup, confirming early that this location meets specification is important.

Recommendations:

Determine from science requirements the allowable number and configuration of dead fibers. Do this before conceptual design report (CoDR) to let this information propagate throughout the collaboration and into the science planning groups.

Investigate design concepts that allow reasonable on-site repair procedures for broken focal plane fibers & actuators. This should be done now, because the focal plate design is in progress.

Investigate design concepts that allow reasonable on-site repair procedures of broken spectrograph fibers. This should be done before the spectrograph CoDR.

Learn how to illuminate the fibers from the spectrograph end so the fiber view camera can operate. Now, because the view camera design might change drastically; it also affects spectrograph design.

Confirm that the Canon 400 mm lens (or whichever lens is chosen or built) performs as required for the fiber view camera. This should be done before the view camera CoDR.

Develop a fiber viewing system that meets the performance requirements and make sure this performance is met with the wavelength and brightness of the illumination system.

Perform design integration with the spectrographs. This should be done now, because this impacts survey cadence, spectrograph design.

Confirm that the mounting location for the fiber viewing camera meets the fiber imaging specifications under windy conditions (a Finite Element Analysis [FEA], on the baffle?) or design a mounting system independent of the light baffle (can it be bolted to the mirror cell?). This should be done before the view camera CoDR (you need to be able to show that this works at CoDR).

Technical

c. Spectrograph and Sensors & Control (including guiding, focus, and alignment)

O'Connor, Uomoto (SC4)

Findings:

BigBOSS will require ten three-channel, 500 fiber spectrographs. A detailed trade study of spectrograph optical design alternatives was shown and a reference design having two dichoic beamsplitters and four doublets per arm has been chosen as the baseline. The baseline design shows acceptable image quality and the optical and mechanical layout has been developed well beyond the conceptual level.

The spectrographs will incorporate individual cryostats for each arm (30 in all), each using a single 4K x 4K CCD cooled to 140K. A linear pulse tube cryocooler technology is proposed (one per cryostat) and a detector positioning mechanism is included for aligning the detector to the optical axis to within a 30 micron tolerance band.

The Schmidt committee concerns about thin dichroics have been addressed -- the dichroics are now 20mm thick and coated on both sides. Astigmatism arising from the tilted dichroics has been corrected in the optical design as demonstrated by encircled energy analysis.

Detector requirements can be satisfied by existing CCDs: the BOSS CCD is baselined for the visible and red channels, and a commercial CCD has been identified for the blue channel.

ASIC-based frontend electronics are proposed for the video signal processing and two options are being pursued for clocking and biasing.

Four areas of CCD R&D are proposed: low noise readout, ultra-violet (UV)-enhanced window process, thick substrates for Near Infrared NIR sensitivity improvement, and buttable packaging.

The instrument will incorporate sensors (CCD or complementary metal oxide semiconductor [CMOS]) on the periphery of the focal plate for guiding, focus, and alignment. Studies of stellar density, wavefront reconstruction, Mayall tracking, and sensor alternatives were presented. The subsystem will benefit from DES guiding and alignment experience.

A well-developed plan for instrument control and data acquisition (DAQ), based on BOSS and DES experience, was presented.

Comments:

A pre-conceptual design for the LED fiber illuminator was not presented. The requirements for photon throughput and wavelength remain to be defined.

It is proposed to align detectors in the cryostats in a vertical orientation, with detectors cooled to operating temperature, and with a flat glass window replacing the doublet that will be used in the final operating condition. An analysis or experimental test needs to be performed to demonstrate that this alignment procedure is sufficiently stable to ensure proper optical performance with the cryostat in its final operating configuration.

The R&D plan includes pursuing alternative optical designs for the spectrographs, while the baseline design has been advanced to the point of manufacturer's quotations for price and delivery. It is important to set a timetable for downselecting the final spectrograph design before locking in to a particular design choice.

The linear pulse tube cryocooler is an unconventional choice and has potential cost, reliability, and vibration risk. The stated attractive features (light weight, compactness) may not outweigh these drawbacks, particularly if it is found necessary to use the Active Vibration Reduction units.

The spectrograph construction will require many high-tech, sole-sourced components and appropriate attention to schedule and cost risks will be important.

The detector choices are appropriate and appear to be low-risk. However, detailed requirements based on end-to-end throughput and image quality allocation remain to be defined.

The detector maximum signal requirement was not presented. Although BigBOSS targets are likely to be photon-starved, community science use of spare BigBOSS fibers may be limited by inability to obtain spectra of bright targets of interest with the standard operating cadence.

Noise performance and calibration of the CCDs with the proposed autoranging application-specific integrated circuit (ASIC) must be demonstrated, and a backup plan using conventional electronics should be considered.

It is unclear what risk area is addressed by the proposed R&D on CCD buttable packaging.

The guide, focus, and alignment sensor study has concentrated on feasibility assessments and fitting algorithms. Requirements have not yet been defined for most performance parameters. There is not yet a pre-conceptual design for readout electronics, control, data acquisition, mechanical support, and heat removal from these sensors.

The instrument control team is responsible to carry out an intricately-choreographed exposure sequence which includes real-time fiber mapping and actuator repositioning. The algorithms for those functions will be provided by other subsystems, and careful definition of these interfaces will be important.

The design of these subsystems of BigBOSS is well advanced and likely to meet or exceed science requirements. Most of the apparatus can be realized with relatively modest advances over previous systems. There is already a well-developed reference design for a feasible baseline spectrograph.

As with the other components of the BigBOSS instrument, the detailed performance requirements for these subsystems will be derived only after the throughput and image quality budgets have been completed with allocations to each subsystem.

Recommendations:

1. Perform a trade study on spectrograph cooling. Consider in particular the cryo/vacuum systems developed for other multi-spectrograph instruments, such as MUSE at European Southern Observatory (ESO).

2. Define the dynamic range requirement for the CCDs and readout electronics, taking into account the community science needs.

Technical

d. Computing

Lyon, Goodman (SC5)

Findings:

Computing and Software Infrastructure:
Though the actual computing requirements have yet to be determined, it seems that the needed computing infrastructure (computing hardware, databases, system layout, etc) is not particularly challenging and is an evolution of the BOSS infrastructure. The total data store size is small and is limited by the number of fibers and survey size, which are stable in the experiment design. CPU needs seem to be modest. Useful simulations can be performed on laptops. It seems that in the past the software and computing effort was loosely organized and that was good enough.

Spectra extraction algorithm:
The spectra extraction algorithm used for BOSS is not sufficient for BigBOSS because the new experiment will examine fainter targets, will have stronger susceptibility to the sky background, and will attempt the Lyman alpha forest analysis that requires a more accurate spectra model. A new more complicated "2D Point Spread Function (PSF)" extraction is under development and is a promising solution to these issues.

Simulations:
There exists a mature end-to-end simulation of BIGBOSS as well as other simulations that have already played an important role in the design and development of the experiment.

Comments:

The panel commented that that answer to the charge questions is yes: the current design and implementation approach is attainable, likely to satisfy the goals and a plan is in place to address major risks.

Computing and Software Infrastructure:
Organized computing and software management is advantageous. There are many years before the start of taking data, and computing technology and techniques will most likely change during that time. Choices made now may not be optimal for the future when improvements in speed, efficiency, maintainability, and/or collaboration may exist. Following software development processes and promptly writing documentation and process descriptions (e.g. the Pipeline Overview that Bolton showed) are crucial for a smooth running software effort.

Spectra extraction algorithm:
The NOAO non-advocate review singled out the large computational needs of the new algorithm. Those estimates have since been shown to be largely exaggerated and the concern no longer exists. But the central importance of the new algorithm to achieving

the experiment's results cannot be overstated. Fortunately, it appears that a very capable team is attacking this problem.

Recommendations:

Computing and Software Infrastructure:
Determine the computing and software requirements mentioned in work breakdown structure (WBS) 2.B.1 (Data system R&D) according to the R&D plan, starting with the physics goals of the experiment.

Create an organized computing and software development effort, with clear lines of project management and responsibilities. The effort should include the computing and software infrastructure, algorithm development, and simulations.

Investigate roles that computing and software professionals can play in the data system and pipeline development effort. Investigate computing expertise at labs and universities that may have relevance to computing challenge (e.g. parallelization).

Continue the use of a centralized point for the software repository, documentation, and issue tracking. If TRAC is not performing well, consider evaluating and migrating to a new system in a prompt manner.

Keep abreast and evaluate new computing techniques and be ready to adopt high impact improvements (e.g. can adapting the pipeline graphics processing units [GPUs] give you a big advantage?).

Spectra extraction algorithm:
Execute WBS 2.B.2 (Pipeline Reductions R&D) promptly. Make use of realistic simulations and spectra from other surveys (e.g. BOSS) to evaluate the algorithm. Find any show-stoppers quickly. As in the previous recommendation set, keep abreast of new computing technologies that could have a big impact on speed, maintainability, etc.

Work with NOAO to ensure that the official pipeline does not preclude community science.

Simulations:
These simulations seem to be well developed and in wide use by the experiment. Continue this effort.

<u>Cost & Schedule</u>

Green, Goodman (SC6)

Findings:

Strong support was expressed for BigBOSS by NOAO management. There also was strong support expressed for this survey instrument at a Community Science Meeting.

Strong support was expressed for BigBOSS by LBNL management. Good support from LBNL for the management team and the project has been shown.

R&D key activities were identified. The estimated cost was $x.xM for FY12 and $x.xM for FY13, increasing as CD-0 was assumed at the start of FY13 and CD-1 in the third quarter of FY13.

A workable baseline design was presented which serves as a reference for cost and schedule.

Memorandum of Agreements (MOA's) for R&D have been established for the major foreign partners of BigBOSS.

The BigBOSS estimated cost for the R&D phase is derived from the current R&D WBS. L2 managers were identified.

The organization chart for the R&D phase was shown and followed the WBS L2 structure.

At this pre-conceptual stage of the project, DOE base cost for the Project is estimated at $xx.xM, without contingency. Foreign costs are estimated to be $xx.xM in the DOE metric and include the corrector, focal plane and spectrograph which are complete systems.

A technically limited schedule was shown in broad brush and the Critical Path (CP) was identified. Commissioning occurs early in FY18. The corrector is the CP.

Comments:

The costs for the R&D phase appear reasonable and this schedule will produce important results that will reduce the cost uncertainty for the full proposal.

A cost estimate for R&D in FY12 and FY13 was shown. The level is about 10% of the Project cost which is roughly the expected scale.

Much of the development work is being done assuming the Mayall telescope and significant support has been provided by NOAO. The group also has excellent support from LBNL.

The group has set up well-defined milestones for each of the Level 2 WBS activities for the R&D phase. A schedule with Milestones at L1, L2 and L3 should be developed, even for the R&D phase. The cost and schedule should be derived from the resource loaded WBS.

The Interface Control Documents (ICD) are very useful in tying the subsystems of the Project together. However, there is a time dependence and ICD milestones would be a useful tool to employ.

Change control should be thought through prior to CD-1.

Operations costs should be estimated as soon as possible, and certainly prior to CD-1.

Installation and Commissioning tasks for BigBOSS should be defined and responsibilities assigned between BigBOSS and NOAO. Viable options for different operations funding modes appear to be possible.

Given the prior performance and experience of the BigBOSS team, a ~ 35% level of contingency seems appropriate – for the DOE costs.

Operations costs/funding should begin prior to the end of the Project.

The committee believes that the R&D program will lead to a mature technical design within 18 months.

The maturity of the collaboration is an opportunity to move rapidly toward CD-0 and CD-1.

In response to the charge question regarding the estimated R&D costs and schedule, the panel felt that the estimated costs for the next 2 years of R&D are reasonable and will serve to mitigate some of the larger risks to the experiment.

Recommendations:

Develop the resource loaded cost and schedule and the other documentation to a point sufficient to support requests for CD-0 then CD-1 approval as rapidly as possible.

Management

Green, Goodman (SC6)

Findings:

The Project Management team which has been put in place for BigBOSS is highly experienced and has begun to set up the appropriate tools. An R&D and a preliminary Project organization chart were shown.

The funding for BigBOSS will have a large foreign component. This represents an opportunity since the foreign partners supply a very substantial fraction of the funding.

There are several Institutions in the US and outside the US that need to coordinate for BigBOSS to succeed.

A high level schedule was shown, with CD-0 at the start of FY13.

A WBS was shown with approximately 1000 entries.

Major risks were identified.

Comments:

The R&D proposed for the next 2 years will mitigate major risks to the BigBOSS experiment.

Value engineering should be pursued beginning in the R&D phase. Readiness reviews should be scheduled and documented prior to major procurements and follow up action items should be tracked.

This is an extremely well organized project. They have all the people and organization in place. This includes the substantial foreign groups and the cooperation with the NOAO group. MOA for R&D have been established for their major foreign partners.

The managerial structure connecting NOAO and BigBOSS should be understood as soon as possible. A Memorandum of Understanding (MOU) describing the details should be developed prior to CD-1.

MOUs with the foreign BigBOSS collaborating institutions should be begun since about half the funding for BigBOSS is tied to foreign contributions.

DOE should be proactive in helping BigBOSS secure international commitments.

The ICD, the System Engineer, timely tracking and reporting and the application of contingency will help manage the foreign contributions.

Risks due to foreign contributions are large and sufficient contingency should be assigned. On the other hand, the funds contributed by the collaborating institutions and the foreign collaborators could possibly allow for forward funding and thus "earn" schedule.

The "vertical integration" or factorization with the major foreign contributions responsible for L2 subsystems should make the management task easier since interdependencies are minimized.

Tracking and reporting tools, especially with foreign contributions, should be in place by CD-1.

Scope contingency and the associated science impact should be identified, both up and down. When the cost experience of the Project becomes known, contingency can be applied to minimize the scientific impact.

The management team is clearly ready to move ahead with the project as soon as the external hurdles are cleared. (These include the issues with the telescope and NSF). The Project Management team is highly experienced and has set up the appropriate management tools.

In response to the charge question regarding the management structure and team, the panel felt that, in its current pre-conceptual R&D phase, which is prior to CD-0 or mission need, the management team and the management tools which are in place are entirely adequate and are, in fact, in advance of what is normally required.

Recommendations:

Ensure that the science to technical requirements flowdown is conducted and publicized within the collaboration early in the R&D phase to enable an optimized experimental design

Ensure that the baseline design being developed early in the R&D phase has been optimized within the science and technical requirements and that the current reference design is not the last iteration.

Explore incremental costs and schedule and science impact in using alternative telescopes early in the R&D phase.

Work with the BigBOSS stakeholders and the NOAO, NSF and DOE to bring BigBOSS management to a condition where CD-0 approval can be requested expeditiously. CD-1 could then follow quickly.

Appendix A – Review panel and Agency Attendees

Review Panel Members

Andy Albrecht	University of California, Davis
Ian Dell'Antonio	Brown University
Jordan Goodman	University of Maryland
Dan Green	Fermi National Accelerator Lab
Wayne Hu	University of Chicago
Adam Lyon	Fermi National Accelerator Lab
Paul O'Connor	Brookhaven National Lab
Scot Olivier	Lawrence Livermore National Lab
Alan Uomoto	Carnegie Observatories

Agency Representatives

Kathy Turner	Department of Energy
Jeff Pier	National Science Foundation
Jim Ulvestad	National Science Foundation
Jim Whitmore	National Science Foundation

Appendix B – Agenda

Tuesday, December 6, 2011

Plenary – Perseverance Hall (Building 54-130)

Time	Talk	Session	Speaker
8-9		Executive Session	Committee
9-9:05		Welcome	LBL Director Paul Alivisatos
9:05-10:00	P1	Science Overview	Schlegel (LBNL)
10:00-10:55	P2	Project Overview	Levi (LBNL)
		Break	
11:15-12:00	P3	Pre-conceptual Design Concepts	Sholl (UCB)
		Lunch	
1:00-1:45	P4	The BigBOSS BAO Survey	Padmanabhan(Yale)
1:45-2:30	P5	Measuring the Growth of Structure with BigBOSS	Percival (UK)
		Break	
2:45-5:00		Breakout Sessions	
5:00-6:30		Executive Sessions	Committee in 54-130 Collaboration in 50A-5132
6:30-8:00		Working Dinner (Cafeteria)	

Session 1: Survey Science Breakout (Target Selection, and Data Processing) - Perseverance Hall (54-130)

Day 1			
2:45-3:30	1.1	ELG & QSO Targets	Kneib (France)
3:30-4:00	1.2	LRG Targets	Newman (Pittsburgh)
4:00-4:30	1.3	Computing	Blanton (NYU)
4:30-5:00	1.4	Spectro Reduction	Bolton (Utah)

Session 2: Instrument R&D Breakout – 50A-5132

Day 1			
2:45-3:15	2.1	Instrument/R&D Plan	Bebek (LBL)
		----- U.S. R&D -----	
3:15-3:45	2.2	Cage & Barrel & Optics	Sholl (UCB)
4:00-4:30	2.3	Fiber system	Edelstein (UCB)
4:30-5:00	2.4	Fiber View	Baltay (Yale)

Session 3: Management Breakout – 50-4058 (General Sciences Conference Room)

Day 1			
2:45-3:15	3.1	NOAO Director's Perspective	Silva (NOAO)
3:15-3:45	3.2	Mayall Interface	Besuner (UCB)
3:45-4:30	3.3	Cost/Schedule/Management	Heetderks (UCB)
4:30-5:00	3.4	Organization/Discussion	Levi/Schlegel (LBL)

Wednesday, December 7, 2011

Time	Talk	Session	Speaker
8-8:30		Q&A with Management if needed	
8:30-12:30		Breakout Sessions	
		Working Committee Lunch	
12:30-5		Executive Session	Committee
5-6		Closeout	
		Adjourn	
7-9pm		Off-site Reception	

Session 4: Science Breakout – Perseverance Hall (Building 54-130)

Day 2			
8:30-9:15	4.1	BAO from BOSS and BigBOSS [closed session]	White (UCB)
9:15-9:45	4.2	DETF 5 years later, the big picture	Cahn (LBL)
9:45-10:30	4.3	BigBOSS Dark Energy Projections	McDonald (BNL/LBNL)
		Break	
11:00-11:30	4.4	Measuring the Neutrino Mass with BigBOSS	Slosar (BNL)
11:30-12	4.5	BigBOSS Simulation	Mostek (UCB)
12-12:30	4.6	Community Science	Dey (NOAO)

Session 5: Instrument R&D Breakout – 50A-5132

Day 2			
		U.S. R&D, Continued	
8:30-9	5.1	Instrument Control/DAQ	Honscheid (OSU)
9-9:30	5.2	Guiding/Focus	Reil (Stanford)
9:30-10	5.3	Detectors	Roe (LBL)
		---- International R&D ----	
10-10:30	5.4	Actuators	Zhai (China)
		break	
11-11:30	5.5	Spectrograph	Prieto (France)
11:30-12	5.6	Optics Manufacture & Alignment	Doel (UK)
12-12:30	5.7	Focal Plate	Prada (Spain)

Appendix C – Review Charge

U.S. Department of Energy

DATE: November 18, 2011

REPLY TO ATTN OF: Office of High Energy Physics, SC-25.1

SUBJECT: REVIEW OF THE BIGBOSS PROPOSAL

TO: Kathleen Turner, Program Manager, DOE Office of High Energy Physics

I request that you organize and conduct a review of the Big Baryon Oscillation Spectroscopic Survey (BigBOSS) proposal on December 6-7, 2011, at Lawrence Berkeley National Laboratory (LBNL). The review is in response to the Field Work Proposal (FWP) submitted by LBNL for the BigBOSS Stage IV dark energy experiment, which will study baryon acoustic oscillations and the growth of structure with an all-sky galaxy redshift survey.

BigBOSS follows the successful Sloan Digital Sky Survey III (SDSS-III) Baryon Oscillation Spectroscopic Survey (BOSS), which is currently taking data. Its spectroscopic survey will provide complementary measurements to imaging surveys that are underway or planned for this decade, including the Stage-III Dark Energy Survey (DES) and the Stage-IV Large Synoptic Survey Telescope (LSST).

The BigBOSS collaboration, led by LBNL, proposed the experiment in response to a 2009 call from the National Science Foundation's (NSF) National Optical Astronomy Observatory (NOAO) for major new instrumentation and a 500-night scientific survey on the Mayall telescope at Kitt Peak National Observatory (KPNO). The BigBOSS collaboration may investigate other telescopes or operating models if the Mayall telescope is not approved for continued operations.

The National Research Council's Astronomy and Astrophysics Decadal Survey (Astro2010) reviewed BigBOSS favorably and their August 2010 report recommended that NSF begin a mid-scale scientific projects line in which BigBOSS could compete. The October 2009 HEPAP Particle Astrophysics Science Assessment Panel (PASAG) subpanel report recommended "a portfolio of experiments that approach the astrophysical limitations for each dark energy method." DOE may consider opportunities to contribute to mid-scale ground-based projects, such as BigBOSS, as part of a coordinated dark energy program.

The BigBOSS proposal is to design, fabricate, test and deliver the instrumentation to be installed and operated on the telescope, as well as to deliver a spectroscopic pipeline and data management system. The collaboration has proposed the experiment as a partnership between DOE and NSF, with contributions from private institutions and foreign partners. Fabrication and installation of the instrumentation, which includes a

new 5,000-fiber spectrograph with associated focal plane and optical corrector system, is expected to take 4 years.

The purpose of this review is to assess the scientific and technical goals and feasibility of BigBOSS; and to assess the technical aspects, cost, schedule and management for the R&D planned during the current pre-conceptual design phase.

In carrying out its charge, the committee is requested to address the following specific items:

1. Scientific: Are the scientific goals compelling and attainable? Are they justified in relation to other existing and planned experiments?

2. Technical: Is the current pre-conceptual design and associated implementation approach attainable and likely to satisfy the scientific goals? Have the major risks been identified and is the R&D plan in place to address them?

3. Cost and Schedule: Are the estimated R&D costs and schedule reasonable and adequately justified?

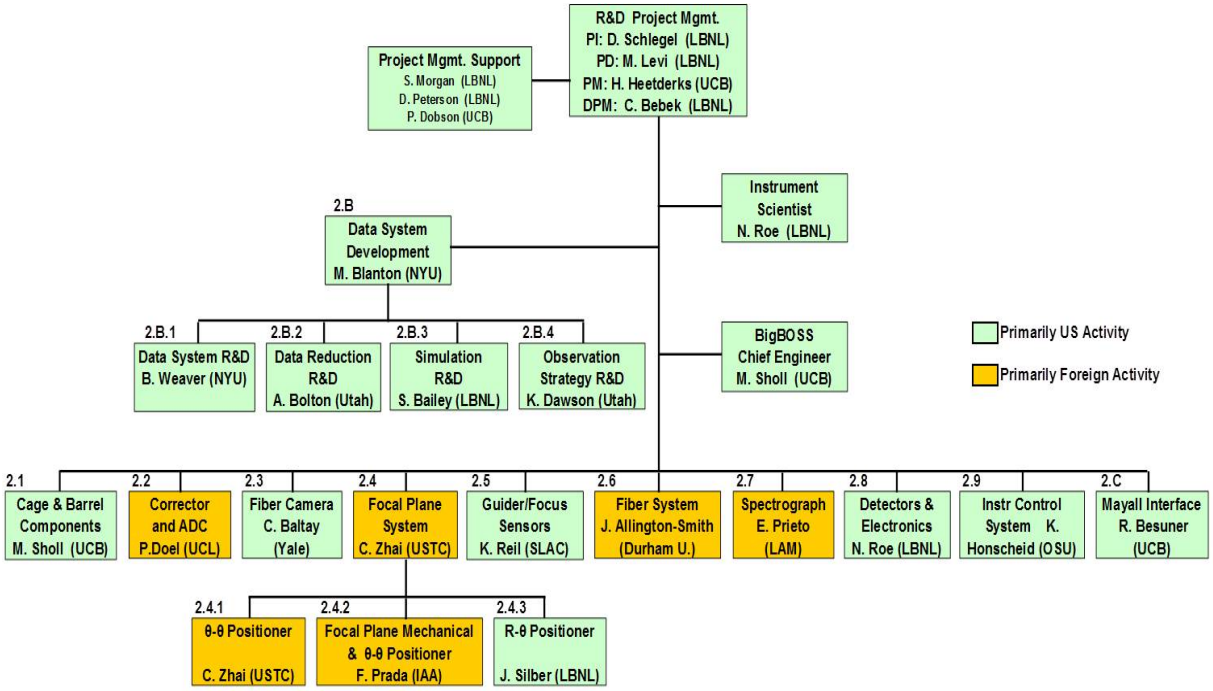
4. Management: Is the appropriate management structure and team in place for the R&D effort in the pre-conceptual design phase?

Kathleen Turner is the DOE program manager for the BigBOSS proposal and will serve as the HEP contact for the review.

As you know, these reviews play an important role in successfully executing our programs. The results of the review will be used by HEP in helping to determine the response to the BigBOSS proposal and in budget and program planning. We look forward to receiving the review report within 30 days of the review.

/S/
Glen Crawford
Director, Research and Technology Division
Office of High Energy Physics
Office of Science

Appendix D – Organization chart



Appendix E – R&D Proposal Summary

The BigBOSS collaboration has proposed to design, fabricate, test and deliver a 5,000-fiber spectrograph, with associated focal plane and optical corrector system, to be installed and operated on the Mayall telescope, as well as to deliver a spectroscopic pipeline and data management system.

BigBOSS is currently in the pre-conceptual design phase and is requesting R&D funds. The R&D phase WBS and costs are shown in Table 1 below. The R&D plan, with associated cost and schedule, is focused on retiring critical risks and developing a conceptual design by mid-FY13 and preliminary design by mid-FY14. The principal area of technical risk is the fiber actuators (WBS 2.4), and schedule and cost risks are the optical design (WBS 2.1) and spectrographs (WBS 2.7). A critical scientific risk, the target selection (WBS 2.B), is being concentrated on during the R&D phase.

In addition to US institutions, the collaboration includes participation by China, France, Spain and the U.K. The WBS lead institution or country has been chosen based on experience and strengths. In addition to the requested DOE R&D funds, substantial funds are being provided by the partners, with commitments made only for the R&D phase. In high risk areas lead by non-US partners, LBNL has effort assigned and is following the progress closely.

Table 1: R&D Phase: WBS Description and DOE Costs in $K

WBS	Description	Lead institution or country	FY12	FY13
1.0	R&D Management	LBNL		
2.1	Cage & Barrel Components R&D	FNAL		
2.2	Corrector and ADC R&D	UK		
2.3	Fiber Camera R&D	Yale University		
2.4	Focal Plane System R&D	China		
2.5	Guider/Focus Sensors R&D	SLAC		
2.6	Fiber System R&D	UK		
2.7	Spectrograph R&D	France		
2.8	Detector and Electronics R&D	LBNL		
2.9	Instrument Control System R&D	Ohio State University		
2.A	Science Requirements R&D	LBNL		
2.B	Data System R&D	New York University		
2.C	Mayall Interface R&D Studies	NOAO		
	TOTAL			

A pre-conceptual planning estimate for the total project costs from the completion of the conceptual design (Critical Decision 1) to the completion of fabrication is $xx million, in real year dollars but not including contingency, over a period of approximately 4 years. The collaboration is planning to request approximately half of this from DOE and the other half from foreign or private sources. These costs do not include any changes or upgrades needed for the telescope or operating costs after the instrumentation is delivered.

Appendix F – List of Acronyms

ADC	Atmospheric Dispersion Compensator
ASIC	Application Specific Integrated Circuit
Astro2010	National Research Council's Astronomy and Astrophysics Decadal Survey
BAO	Baryon Acoustic Oscillation
BigBOSS	Big Baryon Oscillation Spectroscopic Survey
BOSS	Baryon Oscillation Spectroscopic Survey
CAD	Computer Aided Design
CCD	Charge-Coupled Device
CD-0	Critical Decision 0
CD-1	Critical Decision 1
CMOS	Complementary Metal Oxide Semiconductor
CoDR	Conceptual Design Report
COSMOS	Cosmological Evolution Survey
CP	Critical Path
DAQ	Data Acquisition
DEC	Declination
DECam	Dark Energy Camera
DES	Dark Energy Survey
DETF	Dark Energy Task Force
DOE	Department of Energy
ELG	Emission Line Galaxies
ESO	European Southern Observatory
FEA	Finite Element Analysis
FEM	Finite Element Method
FOM	Figure of Merit
FWP	Field Work Proposal
GPU	Graphics Processing Unit
GR	General Relativity
HEP	Office of High Energy Physics
HEPAP	High Energy Physics Advisory Panel
ICD	Interface Control Documents
KPNO	Kitt Peak National Observatory
LBNL	Lawrence Berkeley National Laboratory
LED	Light-Emitting Diode
LRG	Luminous Red Galaxies
LSST	Large Synoptic Survey Telescope
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
NIR	Near Infrared
NSF	National Science Foundation
NOAO	National Optical Astronomy Observatory
PASAG	Particle Astrophysics Science Assessment Panel
PSF	Point Spread Function
PTF	Palomar Transient Factory
QSO	Quasi-Stellar Object or quasar
RA	Right Ascension
R&D	Research and Development
SDSS-III	Sloan Digital Sky Survey III
UV	Ultra Violet
VLT	Very Large Telescope
WBS	Work Breakdown Structure
WFIRST	Wide-Field Infrared Survey Telescope