Mapping the Universe with BigBOSS

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ABSTRACT

The BigBOSS experiment is a redshift survey designed to map the large scale structure of the universe and probe the nature of dark energy. Using massively-multiplexed fiber spectroscopy over 14,000 deg^2 of sky, the survey will deliver more than 20 million galaxy and quasar redshifts. The resulting three dimensional sky map will contain signatures from primordial baryon acoustic oscillations (BAO) that set a "standard ruler" distance scale. Using the BAO signature, BigBOSS will measure the cosmological distance scale to $< 1\%$ accuracy from $0.5<z<3.0$, shedding new light on the expansion history and growth of large scale structure in the Universe at a time when dark energy began to dominate. In this work, we give an overview of the BigBOSS survey goals and methodology, focusing on measuring the [O II] $\lambda3727$ emission line doublet from star-forming galaxies. We detail a new spectral simulation tool used in generating BigBOSS observations for emission-line galaxy targets. We perform a trade study of the detected galaxy redshift distribution under two observational cases relative to the baseline survey and discuss the impact on the BigBOSS science goal.

Keywords: Dark Energy, Redshift Surveys, Emission Line Spectroscopy, Spectral Simulation

1. INTRODUCTION

Extragalactic redshift surveys have played an essential role in our understanding of the structure of the Universe. The first major redshift survey to use fiber spectroscopy in the modern astronomical era was the Las Campanas Redshift Survey (LCRS).[1] Surveying $\sim 20,000$ galaxies over 700 deg^2, the LCRS revealed structures in unprecedented detail where galaxies either preferentially clustered in large filamentary structures or anti-clustered around voids. Expanding on the LCRS, the 2-degree Field Galaxy Redshift Survey (2dFGRS)[2] doubled the survey area to 1500 deg^2 in the North and South Galactic Cap and measured $\sim 250,000$ galaxies redshifts with a mean of $\bar{z}$ =0.11. Data from the 2dFGRS provided some of the first statistically significant results in computing the projected galaxy correlation function and galaxy bias on large scales[3,4] as well as a first measurement of the total mass-density of the Universe from small scale redshift space distortions.[5]

The success of the 2dFGRS survey was followed up with the Sloan Digital Sky Survey (SDSS), which from 2000 to 2008, produced a redshift map for 930,000 galaxies over 8,400 deg^2 to $z<0.15$.[6,7] Data from the SDSS has produced a wealth of information on galaxy formation and clustering in the Local universe[8,9] and has provided useful constraints on a wide variety of cosmological parameters including the geometric curvature of the universe Ω_k, the total matter density Ω_m, and the dark energy density Ω_Λ.[10] Perhaps the most intriguing discovery from both SDSS and 2dFGRS is the detection of baryon acoustic oscillations (BAO) in the galaxy power spectrum.[11,12,13] BAO are the result of sound waves that propagated in the hot plasma of the early Universe, imprinting themselves on the large scale structure of dark matter and galaxies after Recombination.[14,15] The BAO signal manifests itself as an increase of correlated galaxy power on physical scales of $\sim 100\ h^{-1}$ Mpc and can be used as a "standard ruler" in measuring both the transverse distance scale $D_A(z)$ and the line of sight distance via the Hubble parameter $H(z)$. Because measuring the BAO signal is principally limited by the survey

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volume and number density of measured galaxies, cosmological distance measures through BAO are expected to have the lowest level of systematic uncertainty relative to other known methods (such as SNIa light curves or galaxy weak lensing).[16]

Due to the unique power of BAO in determining cosmological distances, spectroscopic redshift surveys have now been designed specifically to measure galaxy BAO with <5% accuracy. WiggleZ[17] measured 130,000 star-forming emission line galaxies (ELGs) over a ~ 1 Gpc^3 volume from $z<1.0$, resulting in a 4% measurement of the volume-averaged distance scale at the survey effective redshift of $\bar{z}$=0.6.[18] Currently, the BOSS survey[19] is surveying 10,000 deg^2 of sky for luminous red galaxies (LRGs) which are more biased to the underlying dark matter distribution. The recent release of the BOSS first year results has already shown a significant improvement in the distance scale accuracy to 1.7%, besting the WiggleZ result by a factor 5 over a 2.2 Gpc^3 cosmological volume.[20]

Predicated on the success of these large-scale redshift surveys, BigBOSS[21] is a proposed survey designed to measure redshifts for >20 million galaxies over 14,000 deg^2 of sky. Located on the 4m Mayall telescope at Kitt Peak National Observatory, the BigBOSS instrument will perform massively-multiplexed fiber spectroscopy using 5000 fibers uniformly distributed across a 7 deg^2 field of view. The survey will focus on the same galaxy target types associated with both the BOSS and WiggleZ experiments at an equivalent or higher sampling density: 4 million LRGs from $0.5<z<1$, 18 million ELGs from $0.5<z<1.6$, and 2 million quasars (QSOs) from $0.5<z<3.5$. Ultimately, the scientific performance of BigBOSS relies on connecting the projected performance of the instrument to the successful production of redshifts under realistic observing conditions.

In this paper, we detail our efforts to quantify the performance of the BigBOSS instrument by measuring redshifts from simulated spectra with appropriate signal and noise characteristics of a BigBOSS galaxy observation. In particular, we focus on the detection of the [O II] λ3727 emission line doublet, which will be critical to measuring ELG redshifts beyond $z>1$. In Section 2, we will outline the overall scientific and measurement goals of the BigBOSS survey. In Section 3, we will detail the default observing conditions and inputs to the BigBOSS spectral simulation (*BBspecsim*), and we will produce spectral sensitivity for each arm of the BigBOSS spectrograph. In Section 4, we will show that the current spectrograph design meets the necessary ELG measurement requirements. We will also show the results from a Monte Carlo simulation of random ELG redshifts and [O II] line fluxes to determine the empirical relationship between the [O II] signal-to-noise and average redshift success rate. We will then use these success rates to predict the detected ELG sample for interesting conditions such as increased source and sky flux. Our conclusions will be presented in Section 5. In general, we assume a flat ΛCDM cosmology with Ω_m=0.3, Ω_Λ=0.7, σ_8=0.8, and h=0.7.

2. SURVEY GOALS

2.1 Science Goals

The top level science goals for BigBOSS are driven from the Dark Energy Task Force (DETF) Figure of Merit (FoM),[16] which is used to compare the capability of various dark energy experiments. In simplest terms, the FoM is calculated as the reciprocal of the area within an error ellipse in the $w_0 - w_a$ plane, where the dark energy equation of state is modeled as $w(a) = w_0 + (1-a)w_a$. The constraints on $w(a)$ from the DETF FoM metric is partitioned into "stages": the published knowledge circa 2000 (Stage I), the capabilities at the time of the DETF report (Stage II), the near-term capability from ongoing, medium-cost experiments (Stage III), and the future capability from planned major experiments (Stage IV). For example, if the BOSS experiment represents a Stage III BAO experiment, a Stage IV experiment would correspond to roughly a 3-fold increase in constraining the dark energy parameters. The principal BigBOSS science goal is to achieve a Stage IV level of precision in DETF FoM assuming prior information from both BOSS and *Planck* CMB experiments.[21,22] Using the projected BOSS+*Planck* FoM as a reference Stage III experiment, BigBOSS must achieve a total FoM of >90 in order to achieve the top level science goals.

For experiments that measure the cosmological distance scale through the location of the BAO peak, the relevant scaling quantity from the galaxy power spectrum to the DETF FoM is the error per Fourier mode. At a given redshift, the error per mode is given as

$$\frac{\delta P_{\rm gal}}{P_{\rm gal}} = \frac{1}{\sqrt{m}}\left(1 + \frac{1}{1+\bar{n}P_{\rm gal}}\right), \tag{1}$$

where $P_{\rm gal}$ is the auto-correlated galaxy power spectrum, $\bar{n}$ is the mean galaxy volume density, and m is the number of Fourier modes contributing to the measurement and is proportional to the total survey volume.[23] As a rule of thumb, the BOSS experiment will eventually have an effective survey volume of 6 h^{-3} Gpc^3, and therefore a 3-fold reduction in

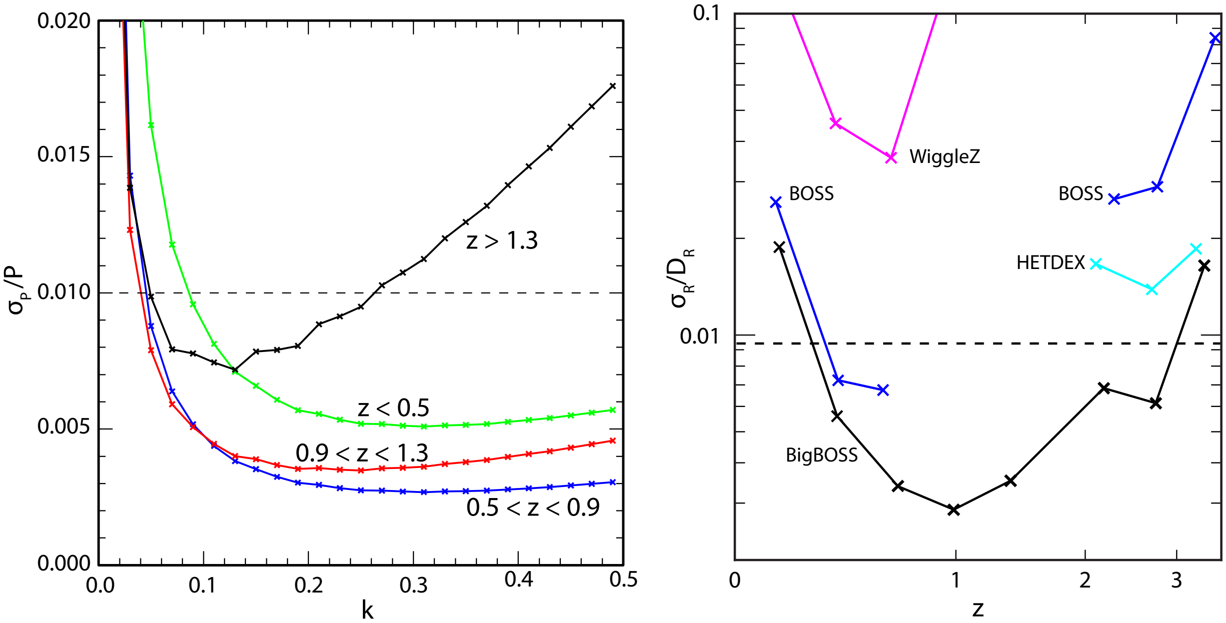


Figure 1. (left)The projected error in the BigBOSS galaxy power spectrum in four redshift bins, scale averaged in $\Delta k = 0.02$ h^{-1} Mpc bins and limiting to a $k_{\max} = 0.3$. The dashed line at σ_P/P corresponds the science goal of 1% error. (right) The angle-average distance error as a function of redshift for BOSS, WiggleZ, HETDEX, and BigBOSS. The dashed line corresponds to the BigBOSS distance error goal assuming that error values are averaged in $\Delta\ln(1+z)$ redshift bins.

the power spectrum error relative to BOSS at an equivalent volume density will require a factor of 9 in effective survey volume, or $\sim 50\ h^{-3}$ Gpc^3. For BigBOSS, the Level 1 science goal is to achieve a 1% measurement of the galaxy power spectrum to $z = 1.5$ using $\Delta_k = 0.02\ h^{-1}$ Mpc bins at a maximum $k = 0.3$. The left-hand plot in Figure 1 shows the projected error in the galaxy power spectrum from BigBOSS in four redshift bins spanning $0.5<z<1.6$.

To facilitate a direct comparison of the DETF FoM goal to both the angular diameter distance D_A and Hubble parameter $H(z)$, we translate the distance accuracy goal into the angle-averaged distance scale at a given redshift using

$$D_R = [cz(1+z)^2 D_A(z)^2 H(z)^{-1}]^{1/3}. \tag{2}$$

The right side of Figure 1 shows the projected BigBOSS distance scale error relative to several ground-based BAO surveys, including BOSS, HETDEX[24], and WiggleZ. The Level 1 distance error goal is to measure σ_R/D_R to $< 1\%$ for $0.5< z < 3.0$ assuming redshift bins of $\Delta\ln(1+z)$=0.2.

The BigBOSS Level 1 science goals also include error limits on the measured growth of large-scale structure through redshift space distortions and the overall slope of the galaxy power spectrum. These additional science goals will help measure interesting and relevant cosmological parameters, as well test General Relativity, primordial non-Gaussianity, and constrain the total mass of neutrinos. For the purposes of this study, however, the accuracy goals for the galaxy power spectrum and the distance scale are the most directly related to the DETF FoM and the required survey data.

2.2 Data Requirements

The BigBOSS project has defined a set of "Level 2" data requirements necessary to realize the aforementioned Level 1 science goals in measuring the galaxy power spectrum. The Level 2 data requirements ensure that the galaxy target distributions have sufficient volume density and redshift reach so as to produce the desired distance accuracy and error in the power spectrum. The BigBOSS experiment requires that galaxy redshifts must be measured over 14,000 deg^2 of sky with an effective volume density of $\bar{n} > 1 \times 10^{-4}\ h^3$ Mpc^{-3} from $0.5<z<1.6$. Further, the redshifts must be of good quality, with the redshift error constrained to $\sigma_z < 0.001(1+z)$ rms with a $< 5\%$ catastrophic failure rate in galaxies with a satisfactory statistical redshift error. The stringent redshift requirements force BigBOSS to be a spectroscopic galaxy redshift survey, whereas the best photometric redshift survey to date has achieved a statistical redshift error 1 order of magnitude larger than our requirement.[25]

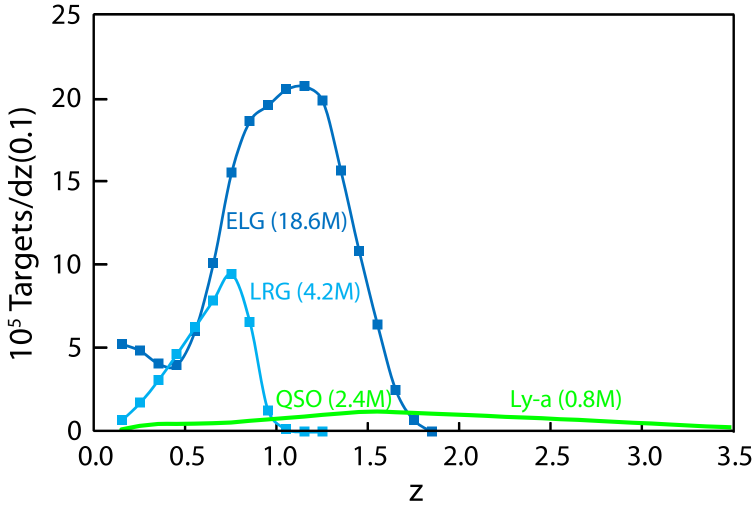


Figure 2. The target galaxy redshift distributions for BigBOSS key dark energy science.[?]

To achieve these data requirements, we have developed photometric selections to identify each galaxy target type within the required redshift range and at sufficient volume density. The specific selection techniques for LRGs and ELGs are based on a combination of optical+NIR photometry.[21] In addition to the galaxy target distributions, the BigBOSS science goals require that Lyα QSOs are sampled from $2.2<z<3.5$ with a 3-fold increase in number density. The Lyα QSOs maximize the redshift leverage in the FoM and have been used to successfully constrain relevant cosmological parameters in BOSS.[26] Figure 7 shows the BigBOSS target redshift distributions for the combined sample of LRGs, ELGs, and QSOs. Table 1 summarizes the critical parameters of the current BigBOSS survey and target requirements, as well as relevant instrument parameters designed to meet the data requirements..

3. SPECTRAL SIMULATIONS

To help formulate measurement requirements and optimize the instrument design, we have developed a spectral simulation for BigBOSS observations. The IDL-based *BBspecsim* software package combines astrophysical source spectra with site conditions at the Mayall 4m telescope and instrumental throughputs of the BigBOSS spectrographs. The code is designed to be flexible, allowing a variety of parameters to be modified at the command line, and realistic, based on the best available data for the observing conditions and instrument design. *BBspecsim* produces a single extracted 1-D spectrum and is ideally used as an exposure time calculator. As we will show in Section 4, however, the software has been already been expanded into Monte Carlo studies that address survey requirements. The following sections detail the *BBspecsim* inputs, instrumentation, and extraction processes.

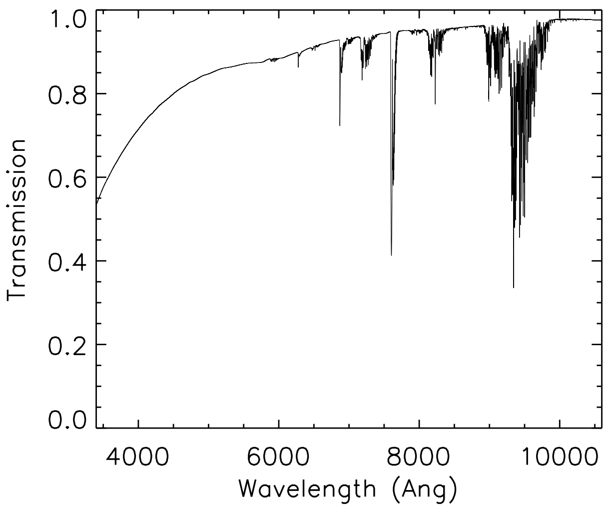
3.1 Input Source Simulation

BBspecsim allows a user to input a standard flux spectrum of any astrophysical source, either in standard cgs flux units per Angstrom or with a specified observed magnitude in a Sloan *ugriz* filter band. The simulation also accounts for atmospheric effects that both attenuate the source photons and produce additional background sky photons. The sky extinction model combines the standard Kitt Peak extinction curve with high-resolution data measured from the McMath FTS spectrograph scaled to $\sim$ 3mm of precipitable water vapor. The sky emission background is taken from the R=45,000 UVES optical sky spectrum.[27] Because most BigBOSS galaxy observations will be sky noise limited between bright OH emission lines beyond $\lambda > 7000$ Å, it is important that the continuum is not dominated by instrumental scattered light. We have cross-checked the UVES sky spectrum with the BOSS sky spectrum (R$\sim$ 3000) in clear windows between the telluric OH sky lines and and have found that both sky spectra produce $\sim 0.7 \times 10^{-17}$ ergs s^{-1} cm^{-2} arcsec^{-2} Å^{-1} in the continuum. Although BigBOSS will only observe under dark sky conditions, the sky emission spectrum is augmented with the lunar phase model[28] reflecting the solar spectrum to facilitate gray and bright time observations. Figure 3 shows the sky transmission and emission spectrum implemented in *BBspecsim*.

Along with the source input flux spectrum, the user may also specify the geometry of the source according to the half-light radius (r_e) of a Sersic exponential profile. The source profile is convolved with a seeing function appropriate for the Mayall 4m site. An internal study of archival data from the MOSAIC instrument mounted on the prime focus of

Table 1. BigBOSS overview

Parameter	Value	units
Survey		
Survey area	14,000	sq. degrees
Focal plane area	7	sq. degrees
Mean # of observations	5	per area
Max. target density	3570	per sq. degree
Number of nights	500	
Median site seeing	1.1	arcsec FWHM
Targets		
ELG target density	~ 3000	per sq. degree
ELG redshift range	$0.5<z<1.6$	
ELG min. [O II] flux	8×10^{-17}	ergs/s/cm^2
ELG min. S/N on [O II]	7	
ELG projected exp. time	20	minutes
LRG target density	~ 350	per sq. degree
LRG redshift range	$0.5<z<1.0$	
LRG min. magnitude	r=22.5	
LRG projected exp. time	30	minutes
Tracer QSO target density	~ 120	per sq. degree
Tracer QSO redshift range	$1<z<2.2$	
Lyα QSO target density	~ 90	per sq. degree
Lyα QSO redshift range	$2.2<z<3.5$	
QSO min. magnitude	g=23	
QSO projected exp. time	20-100	minutes
Continuum S/N goal	≥ 1	per Å
Instrument		
Configuration	Prime Focus	
Number of fibers	5000	
Fiber density	714	per square degree
Focal plane plate scale	82.8	μm arcsec^{-1}
Fiber actuator throw diameter	3	arcmin
Fiber diameter	1.45	arcsec
Wavelength coverage	3600 - 9800	Å
Resolution @ 3600 Å	R>1500	$\lambda/\Delta\lambda$
Resolution @ 5500 Å	R>3000	$\lambda/\Delta\lambda$
Resolution @ 6500 Å	R>4000	$\lambda/\Delta\lambda$
Detector read noise	2.5	e$^-$ pix^{-1}



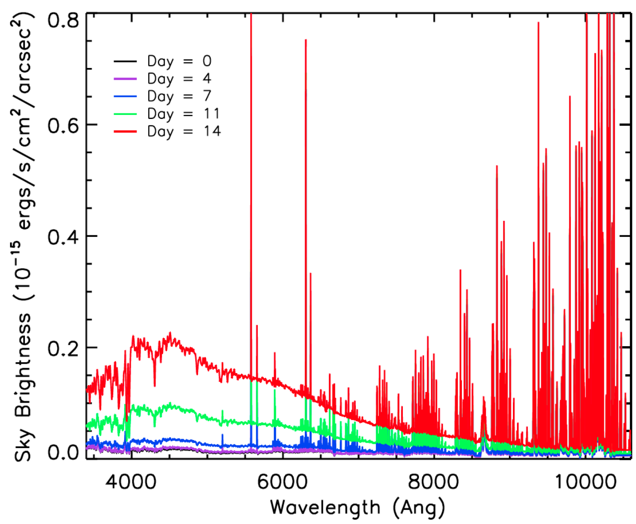


Figure 3. (left) The Kitt Peak zenith sky transmission using the standard site extinction curve provided by NOAO and high resolution data from the McMath FTS spectrograph. (right) The assumed background sky brightness taken from UVES sky spectra and augmented with a lunar phase model and a reflected solar spectrum[27,28].

the Mayall has demonstrated that a Moffat profile with FWHM=1.05" and a $\beta = 3.5$ is typical of the delivered *R*-band image quality.[29] In addition to the seeing and galaxy profiles, the simulation also adds a wavelength-dependent rms blur calculated for the BigBOSS corrector assembly. After convolution, the final spot profile is aligned on a circular fiber profile with a 1.45" diameter and a centroid offset of 0.3" to account for both the mean fiber positioner error and astrometric error. On average, the fractional encircled energy at the fiber entrance for a galaxy source with $r_e = 0.35$" under the mean observing conditions is $\sim 48\%$. Photons from the background sky are assumed to be uniformly distributed across the full fiber diameter and are not attenuated by the geometric acceptance factor.

3.2 Instrument Throughput and Spectrograph Optics

BBspecsim is designed to interface with instrument configurations released by the BigBOSS engineers. These configurations include individual component throughputs for the primary mirror, prime focus corrector, optical fibers, spectrograph optics, gratings, dichroics, and detector quantum efficiencies. We also account for geometric factors within the design, such as area-weighted vignetting on the fiber focal plane and source acceptance into the fiber. Tracking each component throughput for ongoing R&D design studies allows a high level of traceability in the BigBOSS design. All throughputs in the BigBOSS design are based on available data from previously built components or can be achieved within current vendor capabilities.

For each spectrograph design studied, two-dimensional monochromatic images are generated from third-party ray tracing software along the dispersion and spatial axes of the spectral focal plane. *BBspecsim* interpolates between these oversampled monochromatic spots for each pixel along the dispersion axis and downsamples each spot to the final detector 15 μm pixel pitch. The normalized spot data is stored and reused for iterative operations in *BBspecsim*, allowing for faster computations. A 2-D spectrum is then generated by multiplying each interpolated spot by the total expected photons in 0.1 Å wavelength bins and summing all the data along the dispersion axis.

3.3 Sky Subtraction and Spectral Extraction

Developing proper sky subtraction techniques for wide-field, multi-object fiber spectroscopy is currently an active research area.[30,31] The ultimate goal is to achieve a sky subtraction in which the residual 1-D error is minimally correlated and limited by Poisson statistics; a goal that is often thwarted by systematic flexures in the spectrograph and calibration errors. Because the BigBOSS spectrographs will be bench mounted in a stable thermal environment, we will eventually use a full 2-D extraction as advocated in Bolton & Schlegel.[31] However, *BBspecsim* currently uses a simplified sky subtraction and 1-D spectral extraction model as a conservative estimate of the BigBOSS capabilities. The standard *BBspecsim* sky spectrum is generated from the statistical mean of 25 sky fibers, therefore reducing the noise in the sky by a factor of 5. Our estimate of sky residual error is conservative; tests of the sky residuals in current BOSS reductions show that the residual noise may be a factor of 2 smaller, equivalent to 100 sky fibers. We subtract the mean 2-D sky spectrum from the 2-D object+sky spectrum to produce a final sky-subtracted object spectrum. We then extract the 1-D spectrum

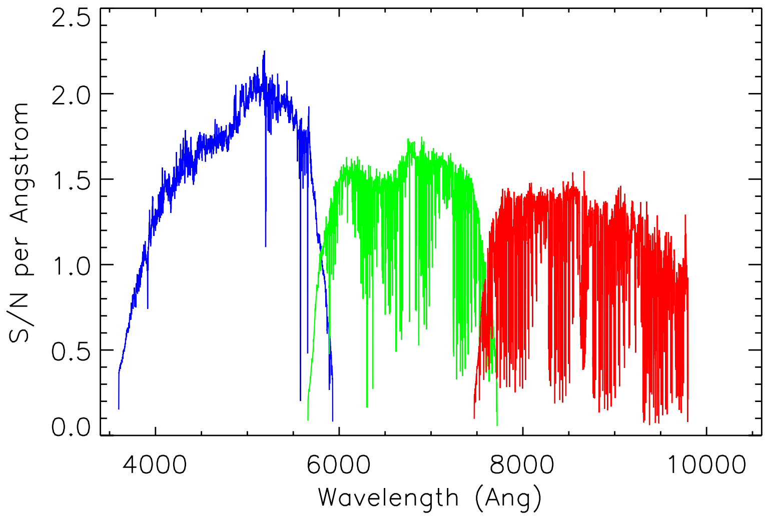


Figure 4. Average BigBOSS spectral sensitivity for a 20 minute exposure of a mag_{AB}=22 extended galaxy source with r_e=0.35".

by collapsing the input monochromatic spot profiles along the dispersion direction and creating a spatial profile for each pixel. Finally, We fit the spatial profiles to each row of the spectrum with a linear regression model (e.g. a "row-by-row" extraction). The output data is the best fit, sky-subtracted signal and formal 1-D error for each pixel of the spectrum.

Figure 4 shows the spectral sensitivity, signal-to-noise (S/N) per Angstrom, sampled at every spectral pixel for each arm of the BigBOSS spectrograph. The plotted data is for a 20 minute exposure on an extended galaxy source with r_e=0.35" with a flat mag_{AB}=22 flux spectrum. We note that the blue, red, and NIR spectrograph linear dispersions are 0.569, 0.503, and 0.569 Å pix^{-1}, respectively, and therefore the S/N per pixel will be reduced by the dispersion factors.

4. CASE STUDY: EMISSION LINE REDSHIFTS

The vast majority of possible redshifts in BigBOSS will come from emission-line galaxy targets. In total, we expect to measure redshifts for 18 million ELGs, with the bulk of the galaxy distribution between $0.5<z<1.6$. There are two primary advantages to targeting ELGs: the bright emission lines allow for efficient redshift measurement and the large volume densities at $z > 1$ provide numerous modes in the auto-correlated galaxy power spectrum. A key measurement feature for ELG targets is the availability of *multiple* emission lines which, when detected, provide unambiguous redshift identification. Figure 5 (left) shows a template ELG spectrum in the restframe with identified lines of [O II] λ3727, Hβ λ4863, [O III] λ4959+λ5007, and Hα λ6563. The figure inset shows that the [O II] emission line is actually a closely spaced doublet due to the forbidden transition between λ3726 and λ3729 of singularly ionized Oxygen.

Using *BBspecsim*, we can generate an observation of ELG galaxy spectrum in BigBOSS. The ELG template shown in Figure 5 is native to the simulation and can be redshifted, scaled by the continuum or [O II] emission line flux, and given a line velocity width. The right-hand plot of Figure 5 shows a simulated and extracted 1-D spectrum of a $z = 1.34$ [O II] doublet in a standard 20 minute BigBOSS exposure.

4.1 Redshift Success Rates

To accurately predict the fraction of targeted ELGs that will have high-confidence redshifts, we must understand the BigBOSS redshift detection efficiency for a wide range of possible redshifts. Figure 6 (left) shows the emission line S/N for the ELG template spectrum redshifted in Δz=0.001 increments over the full BigBOSS spectral range. The template spectrum assumes constant emission line flux ratios relative to F([O II])=8×10^{-17} ergs s^{-1} cm^{-2}. For $z<0.5$, the combined S/N from all emission lines is strongly enhanced by the presence of Hα. Between $0.5<z<1.0$, Hα is redshifted beyond $\lambda > 9800$ Å and a redshift must be measured from a combination of Hβ, [O III], and [O II]. The [O II] doublet will be the only emission line available for redshift measurement beyond $z > 1$, therefore requiring that the doublet is resolved for an unambiguous two-line identification in this redshift range. We also require that the combined line S/N> 7, shown as a blue dashed line, to ensure that the line is detectable above the background sky noise and has a high completeness.

We have also performed a Monte Carlo simulation of ELGs with random redshifts and emission line fluxes. By analyzing the data with a template-fitting redshift detection algorithm similar to BOSS, we compute the redshift detection

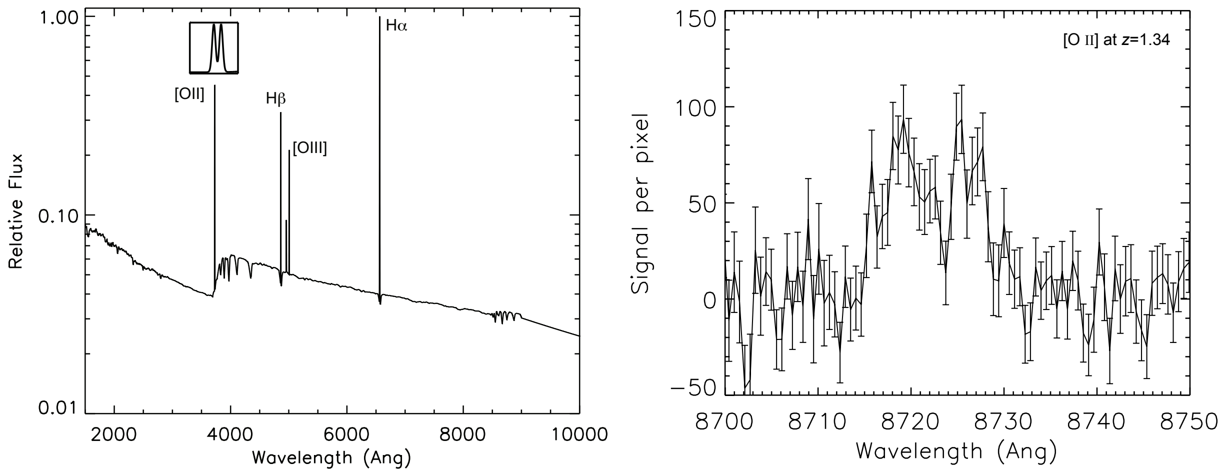


Figure 5. (left) An emission-line galaxy template spectrum at restframe wavelengths, with identified emission lines of [O II], Hβ, [O III], and Hα. (inset) The [O II] emission line centered at λ=3727 Å is actually a doublet composed of the forbidden transition between λ3726 and λ3729. (right) A *BBspecsim*-simulated [O II] emission line doublet at F([O II])=1.5×10^{-16} ergs s^{-1} cm^{-2} observed in a 20 minute exposure.The simulated emission lines have a velocity width of 70 km s^{-1}.

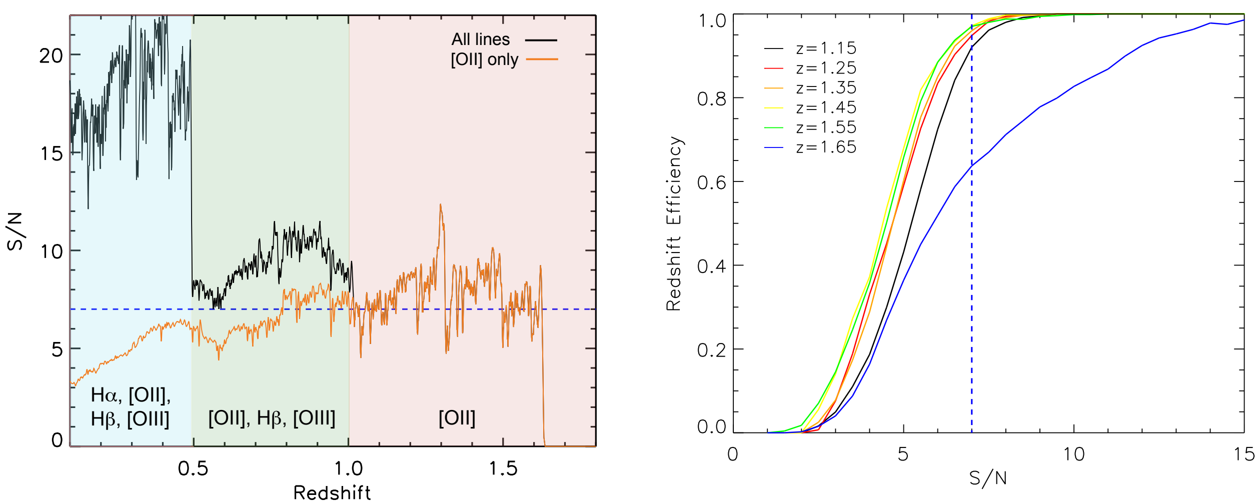


Figure 6. (left) The emission line S/N assuming constant line ratios to F([O II])=8×10^{-17} ergs s^{-1} cm^{-2} across the full BigBOSS redshift range. The black line shows the combines the S/N from all emission lines observable in the waveband, while the orange line shows the S/N only from [O II]. The horizontal blue dashed line shows the emission line S/N>7 detection goal. (right) The redshift detection efficiency for varying [O II] doublet S/N from $1.1 < z < 1.7$ and averaged in Δz=0.1 bins. The detections occur in the reddest spectrograph arm where subtracting the telluric OH sky lines is the most problematic.

efficiency as a function of redshift and [O II] emission line strength (right side of Figure 6). Because the telluric OH sky lines are the strongest at $\lambda > 7000$ Å, the simulation was restricted to the reddest spectrograph arm and averaged over Δz=0.1 bins. The redshift success rates generated in this region should conservatively estimate that success rates at shorter wavelengths where there is lower sky noise. The S/N=7 emission line requirement produces a high success rate ($> 95\%$) between $1.1<z<1.5$, proving that the requirement delivers both high redshift confidence and high completeness.

4.2 Trade Studies

In developing a conceptual design for the BigBOSS experiment, it is necessary to perform trade studies around the baseline instrument design and observation plan during the R&D phase. Ultimately, the scientific impact of these design decisions

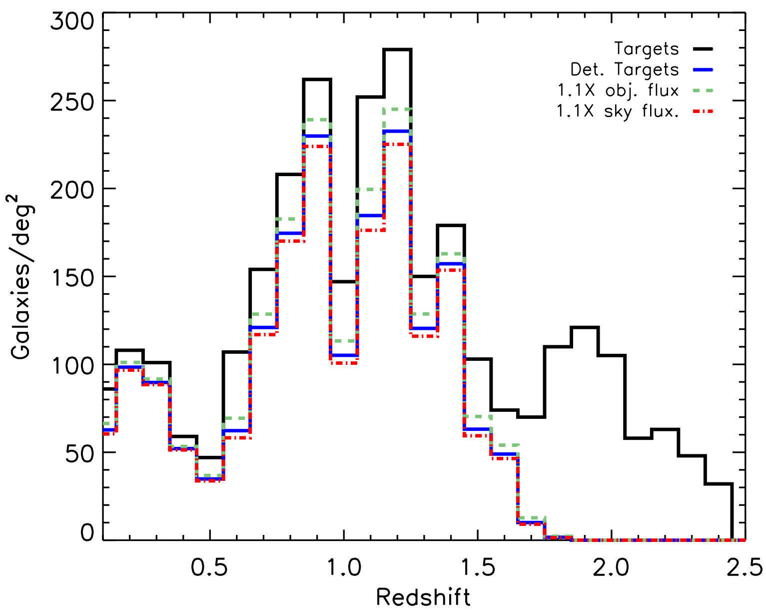


Figure 7. The BigBOSS targeted ELG redshift distribution (black line) and the detected distribution (blue line) after applying the simulated redshift success rate shown in Figure 6. The dashed lines show the detected distributions in two independent trade study cases: a 10% increase in the source flux (green) and a 10% increase in background sky (red).

must be quantified in a useful metric such as the FoM described in Section 1. In the case of BigBOSS ELGs, we have performed trade studies of the detected redshift distribution using the *BBspecsim* redshift success rates from Section 4.1 under two conditional cases. The first case is a 10% increase in the ELG source signal, which could manifest itself in the form of a brighter [O II] line flux limit or higher fiber geometric acceptance. The second case is a 10% increase in the background sky flux while maintaining a constant source flux. Such a condition could result from an increase in lunar phase or mean airmass of the survey. The results of other design modifications, such as a change to system throughput or increased exposure time, can be modeled with a combination of these two basic cases.

Figure 7 shows the targeted ELG distribution (black line) as well as the detected ELG distribution (blue line) using the average redshift success rate from in Figure 6. The detected ELG distribution is used in the baseline BigBOSS FoM projections and produces a Stage IV-level FoM$\sim$150 assuming contributions from LRGs and Lyα QSOs with priors from BOSS and *Planck*. Figure 7 also shows the two conditional cases using a 10% increase in signal and sky background (green and red dashed lines, respectively). We find that a 10% increase in the source signal for all ELGs relative to a fixed sky background would produce 4% improvement in the FoM, while a 10% increase in the sky background would produce a 2% reduction in the baseline FoM. The relatively small changes to the FoM in the presence of moderate variations in performance shows that the current experiment design is robust. We note that these factors only hold for the case of measured ELG redshifts; similar changes in the LRG and Lyα QSO measurements must also be quantified and added to the FoM. Further, the accuracy of the trade studies degrades with larger perturbations in the design. Major changes to the instrument configuration, such as the spectrograph resolution or [O II] line fluxes, requires a recomputation of the redshift success rates and baseline FoM.

5. CONCLUSIONS

The BigBOSS experiment is a next-generation galaxy redshift survey designed to measure the BAO feature and constrain the presence of dark energy in the early universe. Leveraging the experience of successful redshift surveys over the past decade, BigBOSS will use massively-multiplexed fiber spectroscopy to measure >20 million galaxy redshifts over 14,000 deg^2 of sky. BigBOSS will be a Stage IV dark energy survey in the context of the DETF FoM, improving our constraints on w_0 and w_a by at least a factor of three over BOSS.

To help in the observational planning and development of the instrument design, we have produced a simulation of BigBOSS spectra called *BBspecsim*. The simulation is principally designed to simulate emission-line galaxy spectra but is flexible to many various astrophysical and instrumental inputs. The flexibility of the simulation allows for a wide range uses and therefore is a essential tool in the R&D phase of BigBOSS. In the case of ELGs, we have used *BBspecsim* to study the emission line S/N over the expected galaxy redshift range and estimated the redshift success rate for varying S/N levels. We calculated the detected ELG redshift for the current BigBOSS design, and we investigated the effects of increased source signal and sky background on the detected redshift distribution and dark energy FoM. The *BBspecsim* simulation will be used in ongoing and future trade studies to optimize the conceptual design for BigBOSS.

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