What you can do with Millions of Galaxy Spectra: Galaxy Evolution with BigBOSS

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Abstract

Very large spectroscopic surveys such as the SDSS have been watersheds in our understanding of galaxy evolution. The power of these surveys is that their spectra enable astrophysical measurements while simultaneously having enough objects to explore the multivariate properties of the galaxy population. The BigBOSS instrument has the potential to become a similarly transformative tool for improving our understanding of how galaxies evolve. The BigBOSS Key Project will result in low signal-to-noise spectra for 20 million galaxies at z<1.7 over 14,000 square degrees, with 5-10 million "synchronous fibers" over the life of the survey that are not assigned to Key Project targets and are open for community science. Calibration fields for the Key Project will provide densely sampled and deeper exposures than the main survey, over many tens of square degrees. The BigBOSS instrument itself will be a powerful PI instrument long after the Key Project is finished. It will have 5000 rapidly positioned fibers that feed a spectrograph with high throughput from 360-1040nm over a 7 square degree field of view. Here we present a sample of example community science projects that cover the range of anticipated operating modes: 1) a measure of the distribution in galaxy properties, e.g. velocity dispersion, using large numbers of well-calibrated spectra with low signal-to-noise, 2) a large extragalactic survey aimed at understanding how stars grow within dark matter halos at z<1 as a function of environment, halo mass, and galaxy star formation history, 3) A survey of the infall regions of galaxy clusters at intermediate redshift, and 4) a search for extremely rare and bright objects that may be the most intrinsically luminous galaxies in the Universe or are strongly gravitationally lensed. These examples were raised in the BigBOSS community workshop hosted by NOAO in September 2011 and can serve as an inspiration for developing community projects with BigBOSS.

Main Survey: Modeling Large Numbers of low Signal-to-Noise spectra

In addition to phenomenal multiplexing, the BigBOSS spectrograph has moderate spectral resolution and a large wavelength range. This enables the measurement of useful absorption line properties, e.g. equivalent width and broadening, across a large range in redshift. These can in turn be used to understand the evolution in the dynamical properties and stellar populations of large samples of galaxies. The main BigBOSS survey will obtain such spectral for about 3.5 million Luminous Red Galaxies (LRG) at z<1, for which continuum detections with signal-to-noise (S/N) of a few per resolution element will be standard. Typical main survey spectra will have low to moderate S/N. Traditionally, estimating galaxy parameters like the velocity dispersion requires high signal-to-noise (S/N) spectra as noisy data can significantly bias the individual measurements. This obstacle can be overcome using Bayesian inference on large samples of galaxies with well-defined and understood noise properties and selection criteria. Such an estimator, as demonstrated with BOSS data in Shu et al. (2011), can retrieve a measurement of the mean and the scatter in the velocity dispersion distribution function as a function of galaxy mass or absolute magnitude and redshift. In contrast, frequentist stacking of galaxy spectra only yield the mean value of the line width and are susceptible to biases from the intrinsic scatter.

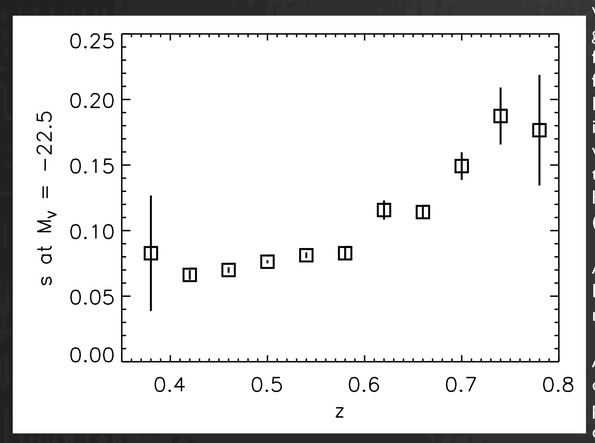


Figure 1: Shu et al. (2011) The redshift evolution in the scatter of the velocity dispersions at a fixed luminosity for BOSS "CMASS" sample galaxies (Padmanabhan et al. in prep.) assuming a log-normal shape for the velocity dispersion distribution function. This was estimated from ~300,000 massive galaxy spectra of low S/N using a hierarchical Bayesian method. The evolution to higher scatter at higher redshift is robust against errors in magnitude and redshift, and has been validated using a subset of much deeper BOSS data. It implies that the dynamical properties of the sample were more heterogeneous at higher redshift and can be used to constrain galaxy evolution models (after correction for redshift-dependent color selection effects).

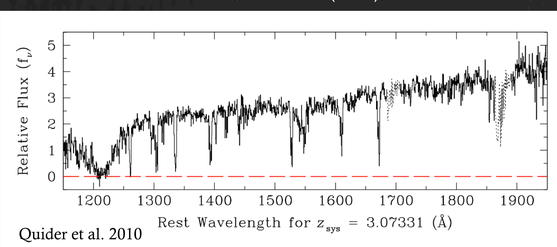
An analogous measurement can be constructed from the main BigBOSS survey using ~7 times more galaxies with higher spectral resolution and a larger redshift baseline than is possible with BOSS.

A challenge for BigBOSS will be developing techniques that can determine the distribution function for crude stellar population parameters, e.g. Balmer line strength, that are much more model dependent than the velocity dispersion.

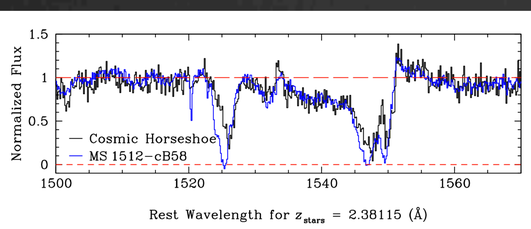
Synchronous Science: A survey of bright Lyman Break Galaxies

Very bright Lyman Break Galaxies (LBGs) are rare and may be either the intrinsically luminous end of the LBG luminosity function or lower luminosity galaxies that have been gravitationally lensed by foreground galaxies and clusters. The most dramatic existing example is the lensed LBG cB58 (Ellingson et al. 1996; Pettini et al. 2000) which enabled the first detailed abundance and ISM measurements of "typical" star-forming galaxies in the distant universe. A rest-frame UV spectrum taken from Quider et al. (2010) for the strongly-lensed "Cosmic Eye" is shown below at left demonstrates the wealth of features present the rest-frame UV. In the lower right is a blow-up around the CIV line in the "Cosmic Horseshoe" taken from Quider et al. (2009), which demonstrates the diversity among these objects. Obtaining large samples will be necessary for studying the demographics of the ISM in the star-forming galaxy population.

As part of the main BigBOSS survey, a few "synchronous" fibers per field (there will be 5-10 million of these available over the life of the survey) can be allocated to find bright galaxies with colors indicative of being LBGs. Because of the high gravitational lensing amplification (>10), these objects will be easily confirmed in the 15 minute main BigBOSS integration and can then be followed up on larger telescopes.



Quider et al. 2010

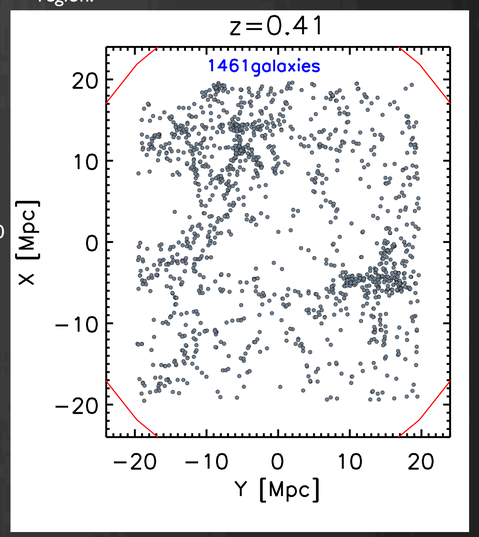


Quider et al. 2009

PI Science: The Infall regions of galaxy clusters

The large field of view of the BigBOSS spectrograph (3 deg. Diameter) makes it especially capable at mapping the infall regions of intermediate redshift clusters. By measuring galaxy redshifts for both emission and absorption-line galaxies, it will be possible to identify galaxies in infalling groups and filaments to 10s of Mpcs from the cluster core and to quantify the effects of both local and global environment on galaxy properties. While SDSS I-III has (or will have) mapped structures on these largest scales, denser observations will be needed in the cluster fields to unambiguously identify and estimate the masses of dense infalling groups and subclusters. In order to trace the quenching of star formation in a sequence from field to cluster core, observations of fainter absorption line galaxies must be sufficient to yield 4000 Angstrom break strengths, as well as Balmer line absorption to probe intermediate-age stellar populations. Fundamental plane observations for a subsample of luminous early-type galaxies will be possible by repeatedly targeting these objects during different pointings. These will provide a unique framework for understanding the merging history of galaxies in environments ranging from cluster cores to the field. A comprehensive map of a cluster and the filamentary structure in which it is embedded will require 1-2 nights of observations with BigBOSS, and 5-10 such clusters provides sufficient sample size to start disentangling galaxy-scale, group-scale, and larger than cluster-scale influences on galaxy evolution in a cosmological context.

In the figure below, a mock galaxy catalog provided by Darren Croton over a 2x2 degree area shows a set of clusters connected by filamentary structure and surrounded by infalling groups. A single BigBOSS pointing (red circle) encompasses the full range of environments in such a region.



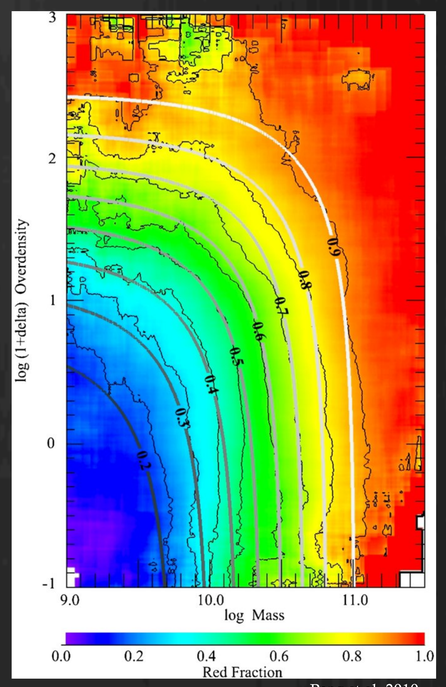
Calibration Fields: A Galaxy Evolution Survey

One of the key questions in galaxy evolution is to understand, statistically, the growth of the stellar mass of galaxies inside their dark matter halos. Accomplishing this requires accurate measures of galaxy stellar mass, star formation rates (SFRs), recent star formation, and halo masses, all over a large range in redshift. Evidence of the necessity for probing both a range of mass and environment is given in the figure at right from Peng et al. (2010). In this plot the color coding and contours represents the red fraction as a function of stellar mass and environment, which can be modeled as separable functions.

This project requires medium-depth spectroscopy to measure crude stellar population diagnostics and weak emission lines down to $10^{10} M_\odot$. It also requires a much higher spatial sampling than the default for the BigBOSS main survey (~1-2 per arcmin^2) to construct robust group catalogs (e.g. Yang et al 2007).

One model for such a survey could be conducted in the BigBOSS "calibration" fields. These are a set of ~6 fields that will be targeted multiple times during the survey to characterize the completeness and the selection function of the main survey. Hitting each field ~10 times will result in S/N of a few per pixel at R~23, which corresponds to a $10^{10} M_\odot$ limit at z=0.8. A subset of the galaxies will be hit during every (or almost every) pointing yielding ultra-deep spectra for stellar population studies.

Such a survey would contain about one hundred thousand galaxies each at z=0.5 and 0.8 and could be compared to SDSS. This sample size is sufficient to cut the sample by five bins of stellar mass, four of halo mass, five bins of star formation activity and have around a thousand objects per bin; important for both high-fidelity tracking of trends in the galaxy population as well as finding rare phases of galaxy evolution that take up only 1% of the lifetime of a galaxy (e.g., a merger or black hole accretion episode).



Peng et al. 2010

Summary

The BigBOSS instrument will provide a transformative capability for the KPNO 4-meter. Here we have presented a small sample of potential extragalactic projects that take advantage of the main anticipated modes of the BigBOSS survey and instrument. They should serve as a catalyst for vigorous community development of extragalactic observing programs. For more information on community projects, please see the BigBOSS community workshop web page at http://www.noao.edu/meetings/bigboss/

The Ground-Based Stage IV BAO Experiment
BigBOSS

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