The Deimos Spectrograph and a Planned DEEP Redshift Survey on the Keck-II Telescope

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Abstract. A second generation spectrograph for the Keck telescope is under construction at the Lick Observatory shops and will be delivered to Hawaii in 1999. Starting in the Fall of 1999, we shall begin the second phase of the DEEP project: a dense redshift survey of galaxies at $z = 1$. With each pointing of DEIMOS we shall obtain simultaneous short slit spectra of 70-100 galaxies with $m_I(AB) < 23.0$ in a field of 15' by 2'. Four regions of the sky will be studied in detail, with dense sampling in a region of 120'x15' in each region, plus outrigger fields. The galaxies for spectroscopic analysis will be selected by flux limit and by photometric redshift estimate $z_{photo} > 0.7$. The goal is to obtain high quality spectra of perhaps 30,000 galaxies over the course of 2-3 years. I here review the status of DEIMOS and the science objectives of the survey.

1 The Two Faces of DEEP

The first phase of the DEEP (Deep Extragalactic Evolutionary Probe) survey has been underway at Keck for the past several years, and has focused on the properties of faint galaxies. David Koo earlier this week summarized the status of that survey, which has been executed with the first generation Keck spectrograph, LRIS. The second phase of the DEEP survey is awaiting completion of the massive DEIMOS (DEEP Imaging Multi-Object Spectrograph) before it begins in 1999. Collaborators on the DEIMOS/DEEP survey with access to the Keck telescope are David Koo, Garth Illingworth, Tom Broadhurst, Chuck Steidel, and Mark Metzger. Additional outside collaborators are Gerard Luppino, Nick Kaiser, Alex Szalay, Andy Connolly, and Richard Kron. Drew Phillips, Nicole Vogt, and Luc Simard at UCSC, and Jeff Newman and Doug Finkbeiner at UCB are also major players in the project. Sandy Faber is principal investigator for the DEIMOS spectrograph. Current details can by found at http://www.ucolick.org/ deep/.

The DEIMOS/DEEP survey will be much more extensive than the first generation DEEP survey now underway with LRIS, and will have a number of unique features. The focus of the survey is to characterize in detail the nature of the large scale structure of the galaxy distribution at $z = 1$, while at the same time obtaining sufficiently high quality data to study the internal properties of a large sample of high redshift galaxies. Key to both projects is the high spectral resolution that DEIMOS shall deliver.

2 The DEIMOS Spectrograph

The original plan for the DEIMOS spectrograph was to clone four copies of the LRIS spectrograph together within one package, all using the same collimator. This was feasible because the field of view of LRIS is off-axis from the center of the focal plane of the Keck telescope. After a breakthrough in camera design by Harlan Epps, the original four-barreled DEIMOS evolved into a two-barreled design, with each barrel having twice the field of view of LRIS, but still sharing a common collimator. Among other virtues, this brought the fields of view closer to the optical axis and improved image quality. For budgetary reasons, only one barrel is currently under construction, and the second barrel, when eventually built, is likely to be a rather different instrument.

DEIMOS is intended for imaging and multislit spectroscopy over a field of view that is approximately a rectangle of size 15' by 5'. At the heart of DEIMOS is a monstrous 10-element refractive camera, with three aspherical surfaces and the largest piece of CaF_2 ever cast (13.5" diameter). The focal plane of the camera will be paved with silicon in an array of eight 2k-by-4k CCDs manufactured by the MIT Lincoln Laboratory, with 15μ pixels. The plate scale at the f/15 Nasmyth focus of Keck is 730μ/arcsec, which is reduced to 126μ/arcsec at the camera focus. Thus one pixel maps to 0.119 arcsec. The RMS image diameter of the spectrograph is anticipated by be $\sim 26\mu$, or 0.21 arcsec. The format at the focal plane is square, 8k by 8k pixels, and the four CCDs on the red side of the dispersion may have thicker substrates with enhanced red response.

LRIS is a Cassegrain instrument in an altitude-azimuth telescope, which requires that it rotate about the optical axis as the telescope moves across the sky. DEIMOS is too massive for the Cassegrain focus and will reside on a Nasmyth deck of the Keck-II telescope, but it must still rotate along its long axis. The time variable gravity loads on DEIMOS are only in the radial direction, and so the instrument should have considerably less flexure than LRIS. Furthermore there is an active 2-D flexure compensation system within DEIMOS in which a folding mirror and the X-coordinate of the detector package can be slightly adjusted by means of a closed cycle feedback loop. Thus we anticipate that the wavelength–to–pixel registration within DEIMOS will be stable to within 0.25 pixel RMS for long periods of time, hopefully obviating the need to take extensive calibrations on a daily basis.

Table 1: Fields Selected for the DEEP Survey

RA	dec	(epoch 2000)
14^h 17	$+52°$ 30	Groth Survey Strip
16^h 52	$+34°$ 55	last zone of low extinction
23^h 30	$+0°$ 00	on deep SDSS strip
02^h 30	$+0°$ 00	on deep SDSS strip

DEIMOS is being built as a facility instrument for Keck and will have a grating slide with room for three diffraction gratings plus a mirror for imaging. The slit masks are stored in a juke-box with room for 13 separate masks. The masks are thin aluminum plates in which slitlets will be cut by a computer controlled milling machine. The masks are stored flat but are bent to conform closely to the curved focal plane of Keck as they are inserted.

3 The DEIMOS/DEEP Redshift Survey

3.1 Fields and Photometry

Once DEIMOS is working in 1999, we shall commence a major redshift survey of faint galaxies designed to characterize galaxies and the galaxy distribution at a redshift $z = 1$. The intention is to generate a sample of uniform quality data with a well defined selection criterion that will be suitable for many different analyses.

This survey will be undertaken in four fields, as listed in Table 1. The fields were chosen as low extinction zones that are continuously observable at favorable zenith angle from Hawaii over a six month interval. One field is the Groth Survey strip, which has good HST imaging, and two of the fields are on the equatorial strip that will be deeply surveyed by the Sloan Digital Sky Survey (SDSS) project. Each of these fields is the target of a deep imaging survey by Luppino and Kaiser, whose chief goal is very deep imaging for weak lensing studies. They will use the new UH camera (8k by 12k pixels) with a field of view of 30' by 40', primarily in the V and I bands, but with B imaging as well. The imaging will be obtained in random pointings spread over a field of 3° by 3°, but with continuous coverage of a strip of length 2° in the center of each field.

Given this enormous photometric database, we shall use the color information to make photometric redshift estimates, z_{photo}. DEIMOS will be used to undertake a spectroscopic survey of galaxies with $m_I(AB) \leq 23.0$ and $z_{photo} > 0.7$. At this relatively bright flux limit, 2/3 of the galaxies will have $z < 0.7$ [1]; the photometric redshift preselection eliminates this foreground subsample, allowing the DEEP project to focus its effort on the high redshift

Universe.

3.2 Choice of Grating and Spectral Resolution

A choice of gratings is available on DEIMOS, and we anticipate that the workhorse grating for the DEEP survey will be the 900 lines/mm grating, with an anamorphic factor of 1.4. This grating will provide a spectral coverage of 3500 $\AA$ in one setting. If we use slits of width 0.75", they will project to a size of 4.6 pixels, or a wavelength interval of 2 $\AA$. Thus the resolving power of the observations will be quite high, $R \equiv \lambda/\Delta\lambda = 3700$.

The MIT-LL CCDs have exceptionally low readout noise, 1 e^-, and the system will be sky-noise limited even at high spectral resolution. The large number of pixels in the dispersion direction allows us to spread out the night sky spectrum and to obtain better sky subtraction of the bright OH sky emission lines.

We will set the grating tilt so that the region 6000-9000 $\AA$ is centered on the detector, thus assuring that the 3727 $\AA$ [OII] doublet is in range for galaxies with $0.7 < z < 1.2$. At the planned spectral resolution, the velocity resolution will be 80 km/s. The [OII] doublet will thus be resolved for all the galaxies, giving confidence to the redshift determination even if no other features are observed. With sufficient flux it should be possible to measure the velocity broadening of the lines, which will hopefully lead to an estimate of the gravitational potential-well depth of a substantial fraction of the galaxies within the survey.

3.3 Observing Strategy

In each of the four selected fields of Table 1, we shall densely target a region of 120' by 15' for DEIMOS spectroscopy. Each pointing of DEIMOS shall use a unique mask with slitlets cut over a field of size 15' by 2', with the slitlets aligned along the long axis. Our goal is 70-100 slitlets per mask, selected from the list of galaxies with $m_I(AB) \leq 23.0$ and $z_{photo} > 0.7$. The number density of candidate galaxies will slightly exceed the number of objects we can select on average, and so our survey will not be 100% complete. But this will not cause problems with the subsequent analysis if we take account of the positions of those galaxies for which we did not obtain spectroscopy.

The plan is to adjoin 60 contiguous pointings of DEIMOS into a field of extent 120' by 15', and to supplement these data with 20 additional outrigger pointings of DEIMOS within the surrouding $3° \times 3°$ field for which photometry is available. The planned integration time is one hour per pointing, broken into several shorter integrations for cosmic ray removal. Because the slitlets will be very short, we do not plan to dither the telescope. The stability of DEIMOS should allow excellent sky subtraction in spite of the short slits.

The goal of the observing program is to obtain DEIMOS spectroscopy in ≈ 320 separate fields, which should net 25,000-30,000 galaxies with $0.7 < z <$

1.2. This will require approximately 50 clear nights on Keck, which we plan to complete over a 2-3 year period. The data rate while on the telescope will be approximately 250 Mbytes/hour.

3.4 Science Goals

Each of the four DEEP surveys will enclose a densely sampled comoving volume of approximately $500 \times 60 \times 8h^{-3}$ Mpc^3 (in an Einstein–de Sitter cosmology). The densely sampled portions of the survey will thus be approximately two-dimensional, but the shortest dimension does exceed the correlation length of the galaxy clustering. The outrigger fields will yield information in a dilutely sampled cone that is well suited for detection of large scale filaments. We have a number of science goals in mind for this database:

1. Characterize the linewidths and spectral properties of galaxies versus color, luminosity, redshift, and other observables.

2. Precisely measure the two–point and three–point correlation functions of galaxies at $z = 1$ as a function of other observables, such as color, luminosity, or linewidth. For the highe–order correlations, dense sampling is essential. Recent observations of Lyman limit galaxies at $z = 3$ [2] suggest that the bias in the galaxy distribution was considerably higher in the past. Higher order correlations in the galaxy distribution are one way to estimate the presence of bias in the galaxy distribution [3]. If the galaxy bias is larger at $z = 1$ than at present, the correlation strength of different subsamples of galaxies should show more systematic variation than is observed for galaxies at $z = 0$.

3. Measure the coherence of Large Scale Structure at $z = 1$, in comparison to the structure observed at $z = 0$ from existing redshift surveys. Different cosmological models make very different predictions for the appearance of the high redshift LSS [4]. Differing degrees of bias in the galaxy distribution will be apparent in such images.

4. Measure redshift space distortions in the galaxy clustering at $z = 1$ by means of the $\xi(r_p, \pi)$ diagram and by direct measure of the small scale thermal motions of galaxies, such as suggested by [5]. The evolution of the thermal velocity dispersion is another handle that can separate the evolution of the galaxy bias from the evolution of the underlying matter distribution. The high redshift precision expected from DEIMOS will make this measurement possible.

5. Separate the Alcock-Paczynski effect [6],[7] from the redshift space distortions of the $\xi(r_p, \pi)$ diagram. This effect relates intervals of angular separation versus intervals of redshift separation as a function of redshift. An object that appears spherical at low redshift would appear elongated in redshift at $z > 0$, but the degree of elongation is a function of q_0. It is

just conceivable that the DEEP project will provide data that can measure this effect and separate it from the other expected redshift space distortions.

4 The Next Three Years

In summary, the completion of DEIMOS will signal the initiation of a massive survey of faint galaxies with the Keck telescope. This next phase of DEEP will not push to the ultimate flux limit of Keck, but will use the enormous light gathering power of the telescope combined with the unprecedented field of view to undertake a detailed examination of the state of galaxies and galaxy clustering at $z = 1$. The proposed studies require dense sampling and precision redshifts of the galaxy distribution. With these data, it should be possible to break the degeneracy between $b(z)$, $\sigma_8(z)$, and $\Omega(z)$. With a bit of luck, we may also obtain a separate measure of the deceleration parameter, q_0. The next few years promise to be extremely busy, but very exciting.

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