Pre-DEIMOS Pilot Surveys for DEEP

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Abstract.

DEEP is a multi-institutional program designed to undertake a major spectroscopic survey of 10,000+ field galaxies to $I \sim 23$ with a new instrument (DEIMOS) on the Keck II 10-m telescope. The scientific goals include exploring galaxy formation and evolution, mapping the large scale structure at moderate to high redshifts, and constraining the nature and distribution of dark matter and cosmology. DEEP is distinguished by securing spectra of sufficient quality and resolution to extract rotation curves, velocity dispersions, age estimates, and chemical abundances for a brighter subset of galaxies. While waiting for DEIMOS to be operational in 1999, the first phase of DEEP science programs has concentrated on LRIS observations of fields observed with HST. Recent highlights include redshift and kinematic studies of compact galaxies, high redshift ($z \sim 3$) galaxies, and distant spirals.

1 Introduction

The 21st century promises many faint redshift surveys with the suite of new 8-10 m class ground-based optical telescopes. Besides complementing data from space and other wavebands with critical redshifts, the high S/N and high spectral-resolution from 8-10 m class telescopes provide three new, powerful diagnostics for the analysis of distant galaxies, namely internal velocities (and hence masses when size is used), abundances, and age estimates. These parameters are clearly important, independent probes of galaxies in the early universe with solid links to theoretical simulations. Finally, because both galaxy evolution and their large scale patterns are very likely to be complex, surveys with large samples will be needed to address these problems.

2 What is DEEP?

To meet the challenge, the Deep Extragalactic Evolutionary Probe (DEEP: more details on participants and programs at URL: [http://www.ucolick.org/~deep/home.html](http://www.ucolick.org/~deep/home.html)) was initiated over 6 years ago as a project designed to gather spectral data for over 10,000 faint field galaxies [3, 4, 5] using the Keck II 10-m telescope and a new spectrograph for Keck II (DEIMOS: DEep Imaging Multi-Object Spectrograph; more information is provided at URL: [http://www.ucolick.org/~loen/Deimos/deimos.html](http://www.ucolick.org/~loen/Deimos/deimos.html) and contribution from Davis in these proceedings).
A distinguishing aspect of DEEP is that the survey aims to gather not only very faint redshifts, but also internal kinematic data in the form of rotation curves or line widths, as well as line strengths sensitive to star formation rates, gas conditions, age, and metallicity.

3 Highlights of First Phase DEEP Projects

While waiting for the completion of DEIMOS so that the major DEEP survey of 10,000+ galaxies can begin (see Davis contribution), we have been undertaking a number of smaller, pilot-style projects with the existing Low Resolution Imaging Spectrograph (LRIS: 10) to determine what is feasible with Keck and thus to help refine the scope of the main DEEP survey. To maximize the scientific returns for our relatively small samples (currently over 500 galaxies), we observed fields where HST WFPC2 images already exist, including the HDF and flanking fields 7, 8, 9, 20; the Groth Survey Strip 3, 13, and Selected Area 68. Such HST images provide morphology data and also the structure, size, and inclination data needed to convert kinematic observations from Keck into direct measures of mass. Our data is still largely being reduced, but we have already achieved a redshift completeness of 97% for a 200 galaxy sample reaching a limit of $I \sim 23$. Overall, our findings have reassured us that our major DEIMOS survey is not only feasible, but that kinematics will indeed be a powerful additional dimension of study. Our work with line strengths is not yet mature enough to be presented, so the following will focus on highlights of our kinematic surveys.

3.1 Rotation Curves of Distant Spirals

As seen in Fig. 1, we have clearly demonstrated that emission-line rotation curves of likely spirals can be observed to redshifts near $z \sim 1$ for galaxies as faint as $I \sim 22$ with one to two hour exposures 19. Based on 16 galaxies so far, we find little evidence for any major change ($< 0.6$ mag) in the zero-point of the optical Tully-Fisher relation 20. These results are in stark contrast to claims for more extensive evolution of 1.5 mag to 2.0 mag 13, 14 for very blue galaxies. Larger samples will be needed to understand the causes (e.g., luminosity or color) of these differences.

3.2 Emission Line widths

Though rotation curves are preferable, the vast majority of very faint galaxies are too small to yield more than line widths as kinematic data. Except for very bright galaxies that might yield absorption line widths, emission lines are used. Though winds, dust obscuration, and poor representation of the gravitational potential by the luminous star formation regions may all invalidate the use of the emission line widths for probing the gravitational potential, the available
Figure 1: Examples of the rotation curves measured for two high redshift galaxies, the upper with total $I \sim 21.4$ and the lower with $I \sim 22.4$.

data for compact HII galaxies, which are the most likely to suffer from these problems, nevertheless show a fairly tight correlation with a ratio of 0.7 +/- 0.1 between such optical line-width measures and radio measures of HI motions \cite{18} that should be sampling well the total mass of such systems.

Assuming line widths, after an upward correction of 40\% \cite{13}, are generally meaningful measures of the true gravitational potential, and adding HST sizes, we are able to obtain masses. At least for blue compact galaxies, we then find that luminosity alone can be a very poor gauge of their masses, i.e., the M/L ratio can vary enormously \cite{1}, \cite{12}, \cite{2}. For some, we even needed the the High Resolution Echelle Spectrograph (HIRES; see \cite{21}) to resolve velocity widths smaller than 30 km-s$^{-1}$ \cite{4}. Fortunately for the DEEP program, the vast majority of faint galaxies have line widths that should be resolved at with DEIMOS. The key point is that the lack of correlation between optical luminosity and mass, i.e. stable M/L, demonstrates the necessity, usefulness, and promise of kinematics as an important new dimension to discern the evolution of different galaxy populations.

3.3 Very High Redshift $z \sim 3$ Galaxies

A major advance with Keck has been the dramatic demonstration that very high redshift ($z \sim 3$) galaxies chosen with colors can be confirmed spectroscopically \cite{16}. The DEEP team has extended the pioneering efforts \cite{17} in the Hubble Deep Field (HDF) by pushing over one magnitude fainter, using redder “dropouts” to reach higher redshifts and higher levels of completeness,
and adopting higher spectral resolutions to improve kinematic measurements [7]. Based on the evidence so far [8], [11], the high redshift galaxies may also be small mass systems that become dwarfs today or that later merge to form more massive galaxies [7], [15] instead of being only the cores of massive galaxies.

4 Summary

Our various first phase, pilot programs with LRIS clearly show 1) the need and power of kinematics for galaxy surveys, 2) the feasibility of reaching $I \sim 23$ or fainter with respectable completeness in one to two hour exposures with Keck, and 3) the accessibility of the very high redshift universe. Thus the definition, feasibility, and value of the second phase DEIMOS DEEP program is no longer merely in the speculative proposal stage.

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