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# The Hobby-Eberly Telescope Dark Energy Experiment (HETDEX): Description and Early Pilot Survey Results

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**Abstract.** The Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) will outfit the 10 m HET with a new wide field and an array of 150 integral-field spectrographs to survey a 420 deg$^2$ area in the north Galactic cap. Each fiber-coupled unit spectrograph will cover 350-550 nm, simultaneously. This instrument, called VIRUS, will produce ∼34,000 spectra per exposure, and will open up the emission-line universe to large surveys for the first time. The survey will detect 0.8 million Lyman-alpha emitting (LAE) galaxies with $1.9<z<3.5$ and more than a million [OII] emitting galaxies with $z<0.5$.

The 3-D map of LAE galaxies in 9 cubic Gpc volume will be used to measure the expansion history at this early epoch using baryonic acoustic oscillations and the shape of the power spectrum. The aim of HETDEX is to provide a direct detection of dark energy at z∼3. The measurement will constrain the evolution of dark energy and will also provide 0.1%-level accuracy on the curvature of the Universe, ten times better than current.

The prototype of the VIRUS unit spectrograph (VIRUS-P) is a powerful instrument in its own right. Used on the McDonald 2.7 m, it covers the largest area of any integral field spectrograph, and reaches wavelengths down to 340 nm. VIRUS-P is being used for a pilot survey to better measure the properties of LAE galaxies in support of HETDEX. We report initial results from this survey.

## 1. The HETDEX Approach to the Problem of Dark Energy

Progress in understanding the physical nature of dark energy will require precision measurements of the expansion history of the Universe over the redshift range $0<z<4$. In order to make progress towards this goal, very significant surveys involving new facilities are required. Two approaches are being pursued: to refine the accuracy of the measurement at low redshift, including constraints

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on possible evolution of the dark energy equation of state, or to constrain dark energy evolution, directly, through observations at high redshift.

HETDEX (Hill et al. 2004b) has the goal of providing percent-level constraints on the expansion history of the universe (the Hubble parameter $H(z)$ and angular diameter distance $D_A(z)$) over redshifts $z$=1.9 to 3.5. HETDEX will use a combination of baryonic acoustic oscillations (e.g. Seo & Eisenstein 2007; Koehler, Schuecker, & Gebhardt 2007)) and power spectrum shape information to provide at least a 3-$\sigma$ direct detection of dark energy over these redshifts, even in the event that dark energy is a cosmological constant. To achieve this, HETDEX needs an accuracy of 0.9% on $H(z)$ at $z$=2.8. This level of accuracy requires a volume of 9 Gpc$^3$ with a density of tracers $\sim 10^{-4}$ objects per Mpc$^3$, which can be achieved by surveying 420 deg$^2$ over $1.9<z<3.5$ with 0.8 million Lyman-$\alpha$ emitting (LAE) galaxies. LAEs have high number density and are easily detected with integral field spectroscopy (as shown in Sec. 3). In addition to a direct detection of dark energy, a 0.9% measurement of $D_A$ at $z$=3 from HETDEX will determine curvature to 0.1–0.2% (Knox 2006) a factor of ten better than currently known. Nearly all of the other dark energy missions require some knowledge of curvature to disentangle the dark energy contribution. This is because at low redshifts, dark energy and curvature provide the same expansion signature.

## 2. The HET Wide Field Upgrade and VIRUS

HETDEX has three aspects: an upgrade to the HET, the instrument VIRUS, and the observing and analysis campaign. The HET has pioneered an optical design with a fixed spherical primary and a tracker to follow the motions of objects. The design is particularly effective for surveys. The wide field upgrade is needed to increase the science field-of-view from $4'$ to $22'$. This entails a new corrector, tracker, and instrument package (Booth et al. 2006).

The survey necessary to realize the desired constraints for HETDEX is a significant undertaking, and requires a telescope/spectrograph combination which can acquire the data an order of magnitude faster than current spectrographs. For such surveys to be tractable, a new approach to instrumentation is needed. Industrial replication (Hill & MacQueen 2002), promises the multiplex gains required for the next generation of instruments on very large telescopes.

The **V**isible **I**ntegral-field **R**eplicable **U**nit **S**pectrograph (VIRUS) consists of 150 integral-field spectrographs. Each VIRUS module has a fiber-coupled IFU feeding a pair of simple unit spectrographs. The VIRUS design is described in more detail in Hill et al. (2004a, 2006a,b, 2008a,b). Each VIRUS unit is fed by 224 fibers that each cover 1.8 arcsec$^2$ on the sky. The fibers feeding a two-unit module are arrayed in a 50×50 square arcseconds IFU with a 1/3 fill-factor. A dither pattern of three exposures fills in the area. The spectral resolution is 5.7Å, with coverage of 350–550 nm. The optical design is simple, using three reflective and two refractive elements. With dielectric reflective coatings optimized for the wavelength range, high throughput is obtained. The full VIRUS array will simultaneously obtain 33,600 spectra with 12 million resolution elements. The IFUs are arrayed within the $22'$ field of view of the upgraded HET with $\sim$1/7 fill factor, sufficent to detect the required density of LAEs for HETDEX. Development is proceeding with the prototype (VIRUS-P, Hill et al. (2008b)), deployed in October 2006, and pre-production prototype where value engineering is being used to reduce the cost for production (Hill et al. 2008a).

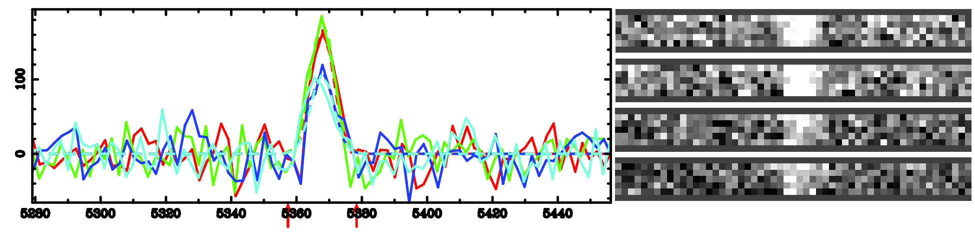


Figure 1. Example spectrum of a z=3.415 LAE in the COSMOS field from HETDEX pilot survey data obtained on the McDonald 2.7 m with VIRUS-P. The LAE is seen in four separate dithered fiber positions (shown on the right), and combined for a strong detection.

## 3. Properties of LAE Galaxies from the HETDEX Pilot Survey

The HETDEX observing campaign will take about 1400 hours on the HET (dependent on the still poorly understood properties of LAEs), which we estimate to require about 3 years to complete. Accurate measurements of the LAE luminosity function at $z = 3$ and 4 are now available from narrow-band imaging surveys and some spectroscopy to confirm candidates (e.g. Gronwall et al. 2007, and references elsewhere in these proceedings). These studies currently probe insufficient volume to measure the correlation function and bias of the LAEs, and they do not extend to the lower redshifts probed by HETDEX. To understand the properties of LAEs in more detail, to measure the contaminating fraction of low redshift galaxies, and to demonstrate the power of integral field spectroscopy for selecting large samples, we have started a pilot survey using VIRUS-P on the McDonald 2.7 m. We are targeting the MUNICS-deep, COSMOS, and GOODS-N fields, where deep imaging and other supporting data exist, allowing us to characterize the properties of detected emission-line objects. VIRUS-P is ideal for this investigation, as the IFU covers 3.5 arcmin$^2$ when fed at f/3.65 f-ratio. The individual fibers are 4.1$''$ diameter, but the sensitivity is adequate to detect significant numbers of LAEs, even on a 2 m class telescope. In comparison to narrow-band imaging surveys, VIRUS-P covers a wide redshift range, down to the uncharacterized $z$=2 epoch, and it surveys volume quickly.

To date in 80 nights, we have covered 115 arcmin$^2$ or 7.5x10$^5$ cubic Mpc co-moving volume, reaching 5-6x10$^{-17}$ erg/cm$^2$/s line flux (5-$\sigma$) in 2 hours exposure. Figure 1 presents an example LAE spectrum. Analysis of 40 arcmin$^2$ in COSMOS yields 99 emission-line objects (45 secure LAEs, 43 low redshift galaxies, one AGN, and 10 sources that are yet to be confirmed as LAEs). Separation of LAEs from [OII] emitters is based on the deep imaging available for the targeted fields. An imaging survey of moderate depth (AB$\sim$25) is needed to separate the two populations, based on emission-line equivalent width (Gronwall et al. 2007).

We are detecting significant numbers of LAEs at $z\sim 2$. Comparison of the number detected with the expected redshift distribution, based on the measured throughput of the instrument and a non-evolving $z\sim 3$ luminosity function, already gives hints about LAE evolution. An increase in the galaxy luminosity function derived from UV and IR continuum measurements of about a factor of two is seen between redshifts $z\sim 4$ and 2 (Reddy et al. 2008). Current data from the pilot survey are consistent with this trend, but analysis of the full dataset will be required for significant results. The pilot survey has proven the approach of wide-area integral field spectroscopy for HETDEX and has tested the data reduction pipeline. In another year observing we expect to refine the properties of LAEs needed for the full survey.

With 2/3 of the budget raised, HETDEX officially started in September 2007. Following the Science Requirments Review in June 2007 and Preliminary Design Review in April 2008, the project is now in the 3-year build-phase.

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