Hobby-Eberly Telescope Dark Energy Experiment (HETDEX)

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Introduction

• Case for observing baryonic oscillations at z > 2 to constrain DE
  – In comparison to z~1
• Observational parameters of HETDEX
  – Case for LAEs as tracers of large-scale structure
• Visible Integral-field Replicable Unit Spectrograph (VIRUS)
  – Massively replicated spectrograph for new wide-field corrector on HET
• Modeling of HETDEX constraints on w(z)
  – Non-parametric Monte-Carlo simulations
• Status and plans
  – Focus on contingency
• Non-linearities are negligible
  – More leverage on $w(z)$ from a given volume surveyed
Baryonic Oscillations at $2 < z < 4$

- Non-linearities are negligible
  - More leverage on $w(z)$ from a given volume surveyed

- Integral effect of $w(z)$ on $H(z)$ and $d_A(z)$
  - Results in leverage on $w$ for redshifts lower than $z_{\text{max}}$ of survey
  - Best constraints are obtained $\Delta z \sim 1$ below $z_{\text{max}}$
  - Also probes possible high redshift evolution of $w(z)$

\[
H_z = h \sqrt{\Omega_m (1 + z)^3 + \Omega_{\Lambda} \exp \left[ \frac{\int_0^z \frac{1 + w(z)}{1 + z} \, dz}{1} \right]}
\]

- It is straightforward to select tracers at $z > 1.8$
  - LBGs via photometry
  - LAEs

- At $z \sim 1-2$, [OII] is in far red and $H_\alpha$ is in J-H
  - Absorption-line redshifts are difficult
  - Selection of star-forming galaxies requires a photometric tracer over areas greater than 500 sq. degrees
Baryonic Oscillation Tracers

- Target-selection for efficient spectroscopy is a challenge in measuring DE with baryonic oscillations from ground-based observations
  - LRGs selected photometrically work well to z~0.8
    » High bias tracer already used to detect B.O. in SDSS
    » Higher redshifts require large area, deep IR photometry
    » Probably can’t press beyond z~2
    » Spectroscopic redshifts from absorption-line spectroscopy
  - [OII] and Hα emitters can work to z~2.5 with IR MOS
    » But difficult to select photometrically with any certainty
  - Lyman Break Galaxies work well for z>2.5
    » Photometric selection requires wide-field U-band photometry
    » Only ~25% show emission lines, but have high bias
  - Ly-α emitters detectable for z>1.7
    » Numerous at achievable short-exposure detection limits
    » Properties poorly understood (N(z) and bias)

HET Dark Energy Experiment

- HETDEX has the following observational parameters
  - 200 sq. degrees area; 1.8 < z < 3.7; 5.2 Gpc³ (h=0.71)
    » Two 10x10 sq. deg. fields or strip 7x30 sq. degrees
  - LAEs trace large-scale structure
    » Expect 0.5 to 1 million tracers in volume
  - LAEs detected directly by a massive IFU spectrograph
    » 20 minute exposures of each 18 arcmin diameter field, with ~1/9 fill factor on sky
    » ~110 clear dark nights to complete
  - Sufficient volume and source density to provide independent constraints on H(z) and d_A(z) at three redshifts ~1% precision
  - Unique in constraining w at low redshift while still allowing detection of higher redshift evolution
Ly-α emitters as tracers

- Properties of LAEs have been investigated through NB imaging
  - Most work has focused on \( z \sim 3 - 4 \), little is known at \( z \sim 2 \)
  - Limiting flux densities \( \sim \text{few } \epsilon^{-17} \text{ erg/cm}^2/\text{s} \)

- They are numerous
  - A few per sq. arcmin per \( \Delta z = 1 \) at \( z \sim 3 \) from numerous studies
    » But significant cosmic variance between surveys
    » 5000 – 10000 per sq. deg. Per \( \Delta z = 1 \) at \( z \sim 3 \)
  - Largest volume MUSYC survey still shows significant variance in 0.25 sq. degree areas
    » Bias of 2 – 3 inferred

- Basic properties of LAEs would make them a good tracer if they could be detected with a large area integral field spectrograph
  - Has the advantage of avoiding targeting inefficiency or bias
  - A larger range of \( z \) can be probed than is possible with LBGs

VIRUS

- Visible Integral-field Replicable Unit Spectrograph
  - Prototype of the industrial replication concept
    » Massive replication of inexpensive unit spectrograph cuts costs and development time
  - Each unit spectrograph
    » 246 fibers each 1 sq. arcsec on the sky
    » In 1/3 fill densepak IFU
    » Dither of 3 exposures gives 0.22 sq. arcmin and 340-570 nm wavelength range, \( R = 850 \)
    » ~140 VIRUS would cover
      » 30 sq. arcminutes per observation
      » Detect 14 million independent resolution elements per exposure

- Prototype is in construction
  - Delivery in April
VIRUS fits within the central obstruction of the new HET wide-field corrector.

VIRUS consists of 140 units mounted on HET.

VIRUS modules of 14 units arrayed on tracker.

Layout of ~140 IFUs with 1/9 fill factor is optimized for HETDEX:
- IFU separation is smaller than non-linear scale size
- LAEs are very numerous so no need to fill-in – want to maximize area
- Suppression of power spectrum is a small effect
  » Dithering of pointing centers removes aliasing
Predicted Number Counts

- Sensitivity of VIRUS (5-σ):
  - $2 \times 10^{-17}$ erg/cm²/s at $z=2$
  - $1 \times 10^{-17}$ erg/cm²/s at $z=3$
  - $0.8 \times 10^{-17}$ erg/cm²/s at $z=4$

- Detected # LAEs approximately constant with redshift:
  - sensitivity tracks distance modulus
  - predict $-5/\text{sq. arcmin} = 18,000/\text{sq. deg. per } \Delta z = 1$

- so with $\Delta z \approx 2$ and 1/9 fill factor, expect 3,000 LAEs per sq. degree
  - 0.6 million in 200 sq. degrees
  - sufficient to constrain the position of the BO peaks to <1% (1-D)

- this survey will require ~1100 hours exposure or ~110 good dark nights
  - needs 3 Spring trimesters to complete

Le Delliou et al., 2005

Simulating HETDEX

- Analytic prediction of $\Delta P(k)$ as a function of $k$:
  - 100 sq. degrees $\Delta z=1$ (1/4 volume)
  - Gives $\sigma_k=0.9\%$ for a one-parameter fit to realizations of the 1-D power spectrum

- One-parameter fit uses shape of power spectrum implicitly
  - 200 sq. deg. gives 0.8% precision for 1-D spectrum in each of three redshift bins $1.8 < z < 3.7$
  - Corresponds to 1.1% on $d_n(z)$ and 1.4% on $H(z)$ in each bin separating azimuthal and tangential components (Seo & Eisenstein 05)
**Baryonic oscillations** give both $H(z)$ and $d_A(z)$
- Shown relative to their values for a cosmological constant

**Baseline HETDEX dataset** should provide $\sim 1\%$ constraints on each, at three redshifts
- This is sufficient to discriminate many possible forms for $w(z)$

*Arbitrary forms for $w(z)$ to illustrate behaviour of $H(z)$ and $D_A(z)$*

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**Compare constraints on $w(z)$ obtained by SNe and HETDEX**
- Data distributed with appropriate errors about input model
- SN simulation assumes 3000 SNe each with 10% error to $z\sim 1.8$
- HETDEX assumes 0.6 million galaxies $1.8 < z < 3.7$ in 10 times SDSS volume

**Non-parametric Monte-Carlo**
- Start with input $w(z)$ and generate mock datasets
- No form for $w(z)$ is assumed in fit
- Global minimization of $\chi^2$ for $w(z)$ over 10 bins with $\Delta z=0.5$, with smoothing to prevent disjointed solutions
- 100 dataset realizations per model map out range of $w(z)$ in each $\Delta z$ bin
• Non-parametric modeling shows effect of integral constraint on \(w(z)\)
  – Considerable leverage on lower redshift \(w(z)\)
  – Best constraints come \(\Delta z \sim 1\) below maximum redshift of dataset

• Discriminatory power of HETDEX comes from the three separate measures of \(H\) and \(d_A\)
  – \(z \sim 2\) data is crucial

• Modeling of HETDEX shows that it will be as powerful as SNAP in constraining DE

• Very complimentary
  – Extends to higher redshift to test for evolution
  – Errors at lower redshift small enough to look for systematic effects in SNe distances

\[w(z) = -1\]

Simulating HETDEX

– Here \(w(z)\) is set to -1, but is modeled as variable, and is constrained to 20%
– If a prior of constant \(w\) is assumed then \(w=\text{const}\) is constrained to 2%

\[w(z) = -1\]

Simulating HETDEX

– Here \(w(z)\) is set to -1, but is modeled as variable, and is constrained to 20%
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More plots of non-parametric $w(z)$

HETDEX achieves sensitivity even if $w(z)$ evolution is at low redshift due to the integral relationship between $w(z)$ and the observables.

HETDEX strengths

- **Survey efficiency**
  - No setup time for targeting objects
  - No pre-survey to select targets

- **Data are largely self-calibrating**
  - Very good sky determination
  - Photometric calibration against SDSS stars in every observation

- **LAEs are numerous**
  - Biggest uncertainty is in $N(z \sim 2)$ and bias, but NB imaging results are encouraging
  - Need pilot survey with prototype VIRUS mounted on McDonald 2.7 m
    - Survey a large enough volume to characterize the population
    - 0.2 sq. deg $1.8 < z < 3.7$ around HDF/GOODS-N starting in April
    - ~5 million Mpc$^3$ 10x larger volume than MUSYC LAE survey
Concerns & Contingency

- Number of VIRUS modules
  - Number of modules is driven by funding but can’t exceed ~150 due to weight considerations
  - Observing time can counteract shortfall in funding
  - Little effect in simulations until number of units drops below 100
  - VIRUS design is inherently low-risk

- Contamination of sample by low z emission-line objects
  - Can tolerate 10% residual contamination
  - Selection of high EW objects against SDSS photometry will be tested in pilot survey

- Allocation of telescope time
  - Strong support for 100 night allocation from HET board and community
  - Small user community makes negotiation of time allocation straightforward

Status and Plans

- VIRUS prototype is in construction
  - Will be used for pilot survey to establish properties of LAEs

- HET wide field upgrade is mostly funded by a Congressional earmark
  - Private fundraising for VIRUS is continuing

- $25M total funding goal with ~$6.5M in hand
- CoDR in early 2006
- 2009 start for survey with funding
  - 3 years to complete
The HETDEX/VIRUS collaboration

- University of Texas at Austin
  - Design and production of VIRUS (Hill, P. MacQueen, P. Palunas, P. Segura)
  - HET Wide Field Upgrade (MacQueen, J. Booth, J. Good, Palunas, Hill)
  - Survey simulation and planning (K. Gebhardt, E. Komatsu, Hill, N. Drory)
  - Telescope operations model (HET staff)
- Universitaet-Sternwarte, Muenchen and MPE
  - Data reduction software pipeline (R. Bender, U. Hopp, C. Goessl)
  - Survey N-body simulation (P. Schuecker)
  - IFU testing (F. Grupp)
  - Mechanical design of collimator module (W. Altmann, W. Mitsch)
- Astrophysikalisches Institut, Potsdam
  - IFU prototype design, construction, testing (M. Roth, A. Kelz, S. Bauer, E. Popow)
- Instituto de Astronomia (UNAM)
  - Optical design investigation (F. Cobos, C. Tejada)
- Pennsylvania State University
  - Local galaxy contaminants (C. Gronwall and R. Ciardullo)
  - Planning for data management/dissemination (D. Schneider, D. Vanden Berk)