HETDEX & VIRUS: Panoramic Integral Field Spectroscopy with 35k fibres

Gary J. Hill, McDonald Observatory (PI, on behalf of the VIRUS team and HETDEX consortium)
Overview

- HETDEX Motivation
  - Dark Energy evolution
  - but really a vast blind integral field spectroscopic survey
- What HETDEX comprises
- VIRUS and HET upgrade status
- The HETDEX survey and example science
- HETDEX ∩ SDSS ∩ APERTIF
- Replicated spectrographs in astronomy
Hobby Eberly Telescope Dark Energy Experiment

- **HETDEX is:**
  - Upgrade of HET to have a new wide 22’ field of view
  - Deployment of the hugely replicated spectrograph, VIRUS, putting ~35,000 fibers on sky, per exposure
  - 3-5 year blind spectroscopic survey

- **HETDEX will:**
  - Map 0.8 million LAEs (1.9 < z < 3.5) and a million [OII] emitters (z < 0.5)
  - Measure expansion history to 1% precision at z~2.4
    - Direct 5-σ detection of DE if Λ
    - Strong constraint on dark energy evolution
    - Structure growth (gravity)
    - Curvature of the universe
  - Very complementary to BOSS, DES, eBOSS etc.
  - HETDEX is a unique blind spectroscopic survey with many other applications
    - In particular in galaxy evolution
    - Finds emission line objects with faint continua
• Tracker has been installed and functional for ~10 months
• Telescope control software is tracking, guiding and offsetting
HET Wide Field Upgrade

- Tracker achieves 10 μm precision over 7 m travel scale
- Ready for arrival of Wide Field Corrector
• Four mirror corrector with meter-sized optics and large aspheric departures
  – 22 arcmin diameter field of view
  – 10 m pupil diameter
  – f/3.65 and telecentric optimized for feeding fibers
• Subcontracted to the University of Arizona College of Optical Sciences
• Challenge for polishing, testing, mounting, and alignment
• High reflectivity coatings cover 350 to 1800 nm
• Unit is sealed and purged with nitrogen to protect coatings

• Pacing item in WFU
• Pre-ship Readiness Review in April
VIRUS

- VIRUS is a simple spectrograph replicated on large scale
  - 156 channel fiber-fed IFS placing 34,944 1.5” dia fibers on sky (266 μm core)
  - 350-550 nm coverage and R~700 on custom 2kx2k CCDs
  - 125 mm beamsize to accommodate catadioptric camera needed for UV coverage
  - Optimized to detect LAEs via blind integral field spectroscopy
- VIRUS prototype has been used at McDonald 2.7 m for 8 years
  - Used for HETDEX pilot survey (Adams et al 2011, Blanc et al 2011)
  - Proved the optical design, principles of the mechanical design, and the data reduction software

Lee et al. Proc SPIE 7735-140 (2010)
VIRUS hardware components

- Each unit has two channels fed by 448 fibers
- Fiber IFU production led by AIP
- Collimator production led by TAMU
- Camera production and integration led by UT Austin
- Spectrograph integration and alignment led by UT Austin

15,000 parts (not incl. fasteners)

Many mechanical parts produced by Oxford Physics and Göttingen (IAG)
Fiber IFUs at AIP

- Production at AIP with 3 vendors
- 62 of 78 with production completing in 2015
Cure data reduction software

- MPE/USM responsible for pipeline
- VIRUS is highly parallel in hardware and software
  - Prototype (VIRUS-P) tested all aspects of the system, including data reduction pipelines
- HETDEX will be processed with Cure
  - Implemented within the astrowise environment
- Have capability to simulate and process an entire VIRUS dataset
  - MPE cluster with 20 cores, 64GB Memory, 200 TB disk space
- Data volume 120 GB/night and 20 TB in three year survey

VIRUS performance

- Spectrographs and IFUs go through characterization before shipping
  - Using fiducial spectrograph or fiducial IFU as appropriate
- Image quality exceeds specifications, typically
  - Due to deterministic alignment technique using wavefront sensing
- Uniformity over IFU typically σ~3%
- 0.4% broken fibers (10x better than spec)
- Read noise within spec < 4 e⁻
  - Read time 20 seconds for 333 Mpxl
Layout on sky

Dither mechanism to fill in 1/3 fill-factor of IFUs

Input head mount plate with 78 IFUs
50 arcsec spacing within ~16 arcmin field
Spectrographs & IFUs are piling up

- 54/78 spectrograph units assembled (70%)
- Expect to complete summer 2015 (1 per week)
- First shipment to HET in May

- So need somewhere to put them.....
VIRUS infrastructure

- Enclosures for VIRUS are huge clean rooms with heat removal
- Ride on VIRUS support structure (VSS)
  - Lifted by air bearings for azimuth moves; not coupled to the telescope structure except at base
- VIRUS Cryogenic System (VCS) supplies LN to each unit to cool detectors
VIRUS Cryogenic System
- Spring field will have g-band imaging over whole area (KPNO, Subaru)
- Each 20 minute observation will detect ~125 LAEs and 150 [OII] emitters
- Survey will use all the dark time with seeing < 2.0" and extinction < 0.2 mag
- Simulations including real weather patterns show 3 years to complete
- Early 2016 start
Example science from HETDEX

**Cosmology**
- Detection of dark energy at $z \sim 2.4$
- Constrain evolution of DE
- Curvature of Universe to 0.1%
- Growth factor to test GR
- Tight upper limit on total neutrino mass
- Detection of cosmic web in emission

**Dissecting Galaxies**
- Dark matter in nearby galaxies
- Stellar populations at large radii
- Galactic structure from stellar kinematics
- Outflows and greater galaxy environment
- Map nearby galaxy clusters and groups ($z < 0.5$)
- Finding the first stars in Galaxy

**Galaxy Evolution**
- Nature of early galaxies at peak of star formation in universe and relation to environment traced by LAEs (SHELA)
- Evolution of star formation at late times ($z < 0.5$ with $\sim 1M$ [OII] emitters), particularly for low masses
- SFR vs gas for $z < 0.4$ with $\sim 0.5M$ [OII] emitters stacking HI in APERTIF (100k at $z < 0.15$ where APERTIF can expect direct detection)
- AGN/QSOs with no color selection effects up to $z \sim 3.5$ (10,000 @ $z > 2$)
Nearby stars, galaxies, & clusters

**HETDEX ∩ SDSS (survey realization)**

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<thead>
<tr>
<th>Count</th>
<th>Description</th>
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<tbody>
<tr>
<td>44714</td>
<td>stars with ( g &lt; 22 ) (S/N \approx 3)</td>
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<td>50579</td>
<td>galaxies with ( g &lt; 22 ) (S/N \approx 3)</td>
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<td>789</td>
<td>stars with SDSS spectrum in IFUs</td>
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<td>4204</td>
<td>galaxies ( g &lt; 17 ) (rotation curves)</td>
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<td>9101</td>
<td>galaxies ( g &lt; 19 ) &amp; ( D &gt; 5'' )</td>
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- VIRUS probes stars deeper and bluer than other galactic structure surveys
  - Will include tens of extremely metal poor stars
- Large sample of resolved galaxies (\( z < 0.1 \))
  - Rotation curves and dark matter distributions to SDSS surface brightness limit
  - Spatially-resolved star formation rates
  - Census of outflows
  - Cross with new Westerbork APERTIF HI survey
- Continuum spectra of stars and galaxies to \(~\)SDSS photometric limit
- 2000 Abell richness clusters covered (\( z < 0.45 \))
  - Selected blind by spectroscopic signature
  - Complements eROSITA X-ray and HSC weak lensing

\( g' = 16, z = 0.064 \)

Niv Drory
Replicable spectrographs in astronomy

- Replicable spectrograph concept now in its second decade
  - Hill & MacQueen 2002
- Beyond the specific application of VIRUS, the concept has an important future (e.g. DESI, HERMES)
- Grasp-spectral power diagram (after Bershady)
  - Excellent metric for evaluating survey instruments and IFS
  - Lines of constant number of pixels ranging up to 8kx8k
- Shaded area represents the regime of replicated instruments
  - Beyond that, mosaics of detectors are needed and instruments become physically challenging
  - It is much more cost-effective to slice the field into multiple spectrographs like in VIRUS, MUSE, and LAMOST

Replicated spectrographs on ELTs

- ELTs present particular challenges for survey spectrographs
  - Growth of instrument and detector size with aperture (at fixed camera f-ratio) becomes extreme
  - Pushes the limits of glass availability, mechanical engineering and cost
  - Will only partially be mitigated with AO for wide fields
- For example, an ELT field with GLAO has 50M spatial elements and thousands of possible targets
  - Similar to a 4 m with a three degree field
- Efficient use of detector pixels requires image slicing
  - Replication offers a cost-effective route
  - Deployable fiber IFUs allow image slicing at input and efficient use of pixels in the spectrograph

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<tr>
<th>University of Texas</th>
<th>MPE/USM</th>
<th>Texas A&amp;M</th>
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