VIRUS: a hugely replicated integral field spectrograph for HETDEX [1]

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Abstract

We present the **V**isible **I**ntegral-field **R**eplicable **U**nit **S**pectrograph (**VIRUS**), the basis of the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX); a survey of a 5 Gpc^3 volume at $1.8 < z < 3.7$ that will constrain the evolution of dark energy. VIRUS consists of 145 copies of a simple unit spectrograph, deployed on the HET. Industrial replication will allow VIRUS to be built quickly, at considerable cost-savings, with substantial risk-mitigation, compared to conventional instruments. VIRUS will cover 30 sq. arcmin. per observation and detect 14 million resolution elements per exposure, an order of magnitude larger than existing instruments. VIRUS can complete HETDEX in about 100 nights observing.

Key words: instrumentation: spectrographs (VIRUS); surveys (HETDEX); cosmological parameters; large-scale structure of Universe

Science Motivation: Large, targeted surveys of continuum selected objects are now becoming the norm, and have greatly increased our understanding in many areas of astronomy. Surveys of the emission-line universe, however, are limited currently to wide field imaging with narrow band filters or to narrower fields with Fabry-Perot etalons. Integral field (IF) spectrographs offer a huge

[1] HETDEX is led by the University of Texas at Austin with participation from the Universitäts-Sternwarte München, the Max-Planck-Institut für Extraterrestriche-Physik, and the HET consortium. http://www.as.utexas.edu/hetdex/

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gain over these techniques, providing much greater sensitivity, or much greater wavelength coverage, respectively. The current generation of IF spectrographs are well-adapted to arcminute-scale fields of view, with several thousand spatial elements, and adequate spectral coverage for targeted observations of individual extended objects. They have the grasp to detect simultaneously of order 0.5 million (spectral x spatial) resolution elements.

HETDEX(6) will map the spatial distribution of about a million Ly-α emitting galaxies (LAEs) with redshifts $1.8 < z < 3.7$ over 200 sq. deg. area (5.2 Gpc^3). This dataset will constrain the expansion history of the Universe to 1% and provide significant constraints on the *evolution* of dark energy (5; 6). The LAEs will be detected with VIRUS (5), a set of 145 IF spectrographs, covering a 20 arcmin. field. The advantage of an IF spectrograph for this project is that the tracer galaxies can be identified and have their redshifts determined in one observation. VIRUS is optimized to survey 340-570 nm over 200 sq. deg. in about 100 nights.

Industrial Replication: In order to achieve the order of magnitude increase in grasp needed for HETDEX and other wide field surveys, a scheme involving massive replication of a simple spectrograph has advantages over traditional monolithic astronomical instruments. Instruments such as MUSE (1) will use replication of up to 24 unit spectrographs, but significant additional cost savings can be realized by replicating in excess of 100 copies of a more basic spectrograph. We refer to this level of reproduction as "industrial replication" (4; 5). As monolithic instruments on VLTs reach limits of cost and weight, we need to explore industrial replication for the next generation of instruments on VLTs and ELTs (5).

The advantages of industrial replication come from the amortization of engineering costs over all the copies, and from cost savings in optics and detectors. Engineering costs can be kept below 10% of the total, whereas for a typical monolithic instrument they are 50-60%. For optics in the 150-200 mm range or below, there are many smaller optics manufacturers who can bid on fabrication of quantities of 50 or more at significant (30-40%) cost savings. Detectors in smaller formats (up to 2k x 2k) now have high enough yields that savings of 50-60% can be made, and they represent the lowest cost per pixel, currently, so long as simple replicated readout electronics are employed. A final key advantage of massive replication is that the design is prototyped, tested, and then optimized for production, following the industrial model. This reduces risk, and delivery of the full instrument can be accelerated by parallel production. For industrial replication to work, there must be tight constraints on the weight and volume of the unit spectrographs, their complexity, and stability. The failure time for a unit must be in excess of a decade, which is the typical operational lifetime of modern instruments. Finally, calibration is a challenge, so the design should be immune to changes in environment and gravity vector.

Table 1
Basic Properties of VIRUS

IFU	246 fibers, each 200 μm dia. or 1.0 sq. arcsec. area square format 29 x 29 arcsec^2, 1/3 fill-factor, hexagonal pack fed at f/3.65 at prime focus of HET
Collimator	accepts f/3.35, reverse Schmidt reflective design
Camera	f/1.33 Schmidt with 2k x 2k 15 μm pxl CCD at internal focus
Disperser	VPH grating gives 340-570 nm simultaneous coverage at R$\sim$850

The VIRUS Spectrograph and Integral Field Unit: A detailed description of the VIRUS opto-mechanical design will be given elsewhere, but is discussed in (5), and summarized in Table 1. Here we concentrate on the IFU design. It is essential to couple VIRUS to the HET with fibers due to the weight and space constraints at the prime focus of the telescope. In addition, the variable effects of the changing pupil illumination of HET during a track are mostly removed by radial scrambling along a fiber, producing much greater stability in the data calibration than is possible with an imaging spectrograph. HET has a fast focal ratio in order to couple efficiently to fibers, and VIRUS will use a densepak-type IFU (2). The layout of the fibers is in a hexagonal pack with a 1/3 fill-factor. This is most optimal for covering area, since a dither-pattern of three exposures exactly fills the field of the IFU, while maximizing the area covered per IFU. Lenslet-coupled fiber IFUs have the principal advantages of providing contiguous coverage of a small field, and allowing the slow f-ratio beams of large telescopes to be coupled efficiently to fibers. However, lenslets suffer from significant inefficiencies in the coupling between the micro-pupils created by the lenslets and the fibers, due to lens quality and diffraction effects (8). If the fiber core is oversized to mitigate these effects, then resolution is lost (5; 8). For fibers fed at the same f-ratio, the bare bundle will cover the same area of sky in three exposures as does a lenslet system, but offers significantly higher overall throughput (5).

The design of the IFU follows experience with the PPAK bundle (7), and initial tests are reported in (3). The 1/3 packing fraction at the IFU input is not naturally achieved with polyamide-buffered fiber, and softer buffer materials do not polish well, so we have investigated two approaches to establish the spacing. In the first, a matrix of thin-walled fused silica capillary tubing with appropriate inner and outer diameters (Polymicro TSP250350 250 μm ID, 360 μm OD, polyamide coated) is set up in a precision form, and then populated with Polymicro FBP200220240 fiber that has 240 μm nominal OD. In the second approach, precision holes of 0.25 mm diameter are drilled in a plastic plate, where the fiber is inserted. Both approaches have been successful in creating spacings with better than 4 μm rms error in the pitch. Manual threading of the fiber into these matrices is remarkably easy, though handling

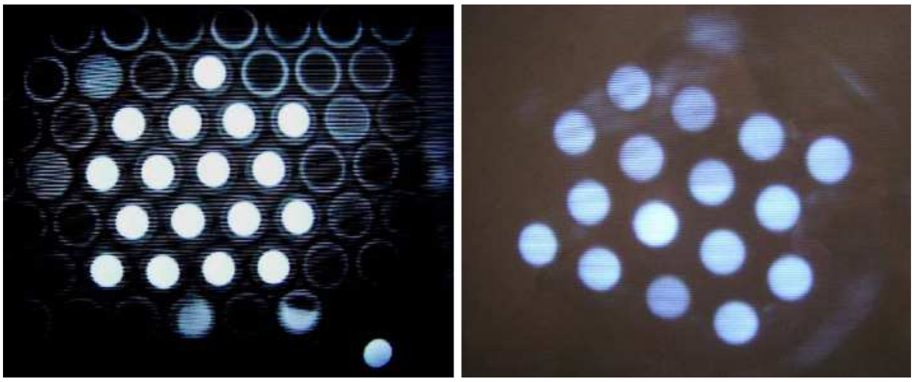

Fig. 1. Two methods for constructing the IFU head input with 1/3 fill factor. At left, fibers are threaded into a matrix of thin-walled fused silica capillary. At right they are threaded into a plastic disk precision-drilled with 0.25 mm holes. Both methods create a bundle of high quality with 4 μm rms position errors.

35,000 fibers will be a challenge. Once loaded with fiber, the head assembly is immersed in EPOTEK 301-2 low-shrinkage epoxy, which wicks up between the fibers. In the case of the capillary tubes, we find very uniform capillary action which fills the 5 μm radial clearance between the fiber and the ID of the tube (Fig 1 left panel). Following cure, the fibers are trimmed with a diamond sample saw and polished. The input end is immersed against an AR coated glass plate to improve coupling.

At the output of the fiber bundle, each of the 17 rows of the IFU layout is bonded to a slitlet, that is mounted within the IFU slit frame. The simple design of the VIRUS collimator, based on a Schmidt camera, requires that the fibers each aim normal to the spherical collimator mirror, and to facilitate this they are immersed against a cylindrical lens, with the axes of the slitlets normal to the concave surface of the lens. Within each slitlet, the fibers must also be angled so that their pupils coincide, and light-loss is minimized. This is achieved by machining precision grooves in the stainless steel slitlet substrate with accurate tilts between them. The fiber is then glued to the substrates with low shrinkage epoxy, as is normal practice. In tests, the FRD appears very similar between single fibers and each of the fiber head designs, with the capillary tube-based design showing the best uniformity in early tests. We are assembling bundles of each design for delivery at the end of the year.

VIRUS on HET: HETDEX demands the largest area coverage, but does not require a high fill-factor for the IFUs within the field (6). The 20 arcmin diameter field of the new HET corrector will be covered by 145 IFUs with $\sim$1/9 fill-factor. This is 35,670 fibers, and >14 million resolution elements per exposure. Each observation of 3 dithered exposures will observe 30 sq. arcmin. area within the 250 sq. arcmin. HET field. Estimates show a line flux limit of 1-2e-17 erg/cm^2/s in two 180s exposures per dither position. This observing sequence can be achieved in 20 minutes per field including setup time.

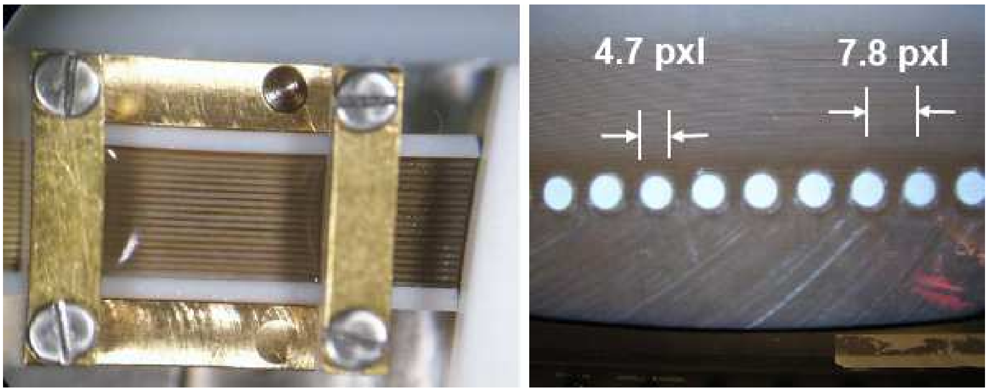

Fig. 2. Images of slitlet substrate during assembly. The left image shows the 15 fibers layed in the grooves of the stainless steel substrate, prior to bonding. The grooves radiate with an angle of 0.044 deg. with respect to one another. On the right is part of the illuminated bundle following polishing. The projected size and pitch of the fibers are indicated. Simulations show that the excellent image quality of the VIRUS optics allows clean separation of the spectra from individual fibers.

The prototype VIRUS unit spectrograph will enter use in early 2006. Costing and design for the replicated instrument will be developed from the prototype, while it is used to perform a wide-field pilot survey for LAEs. With funding in 2006, we expect to deploy the full VIRUS in late 2008, and to complete HETDEX in 2011.

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