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ABSTRACT

VIRUS is the massively replicated fiber-fed spectrograph being built for the Hobby-Eberly Telescope to support HETDEX (the Hobby-Eberly Telescope Dark Energy Experiment). The instrument consists of 156 identical channels, fed by 34,944 fibers contained in 78 integral field units, deployed in the 22 arcminute field of the upgraded HET. VIRUS covers 350-550nm at $R \approx 700$ and is built to target Lyman α emitters at $1.9 < z < 3.5$ to measure the evolution of dark energy. Here we present the assembly line construction of the VIRUS spectrographs, including their alignment and plans for characterization. We briefly discuss plans for installation on the telescope. The spectrographs are being installed on the HET in several stages, and the instrument is due for completion by the end of 2014.

Keywords: Telescopes: Hobby-Eberly, Astronomical Instrumentation: Spectrographs, Spectrographs: Integral field, Spectrographs: VIRUS

1. INTRODUCTION

VIRUS is a multiplexed spectrograph designed and built for the HETDEX (Hobby-Eberly Dark Energy Experiment) project to demonstrate the feasibility of a replicated instrument.[1] HETDEX uses the Hobby-Eberly Telescope (HET)[2] to measure and constrain the evolution of dark energy between redshifts of 2 and 4 using a broad survey of almost a million Lyman α emitters (LAEs).[3] HETDEX requires both VIRUS and a wide field upgrade to take place before the survey begins. The wide field corrector (WFC) increases the field of view of the HET from 4' to 22' using a five optic corrector.[4] This modification also requires a redesign of the the tracker (upper) portion of the HET due to the mass of the WFC.

This project is culminating, with the new tracker already installed at the Hobby-Eberly Telescope (HET) and currently undergoing testing. We await the delivery of the WFC and the VIRUS support systems (enclosures

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and cryogenic system) with planned commissioning of the full instrument early in 2015. As of the end of June 2014 we are on schedule with 38 of 78 spectrographs complete.

In this paper we focus on changes that have been made since early assembly, as well as results of parts delivered, and the projected completion schedule. We highlight where multiplexing changed our approach, and emphasize the data from receiving large sets of deliverables.

2. VIRUS OVERVIEW

The VIRUS unit design is based on a simple Schmidt camera. The optical design can be seen in Figure 1. Details of the optical design have been discussed in past proceedings.[5] All spectrograph parts have been procured and received except for a small number of collimator mirrors (which are due for delivery shortly). System characteristics can be found in Table 1. Details of the optical fiber manufacture are discussed in the current proceedings.[6]

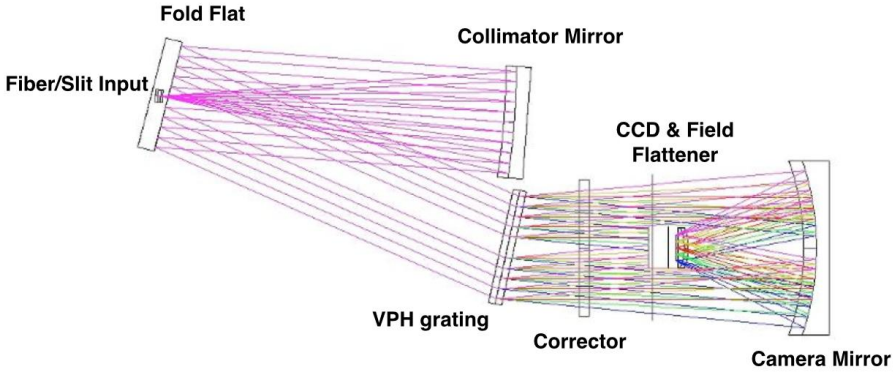


Figure 1: The Zemax layout of the VIRUS spectrographs, with components labeled.

VIRUS has been designed around the HETDEX science drivers. It is also a demonstration instrument, exploring the costs and benefits to a replicated method of instrument building.[7] At each stage - design, construction, and alignment - iterative testing reviews improved and streamlined the approach. This generally means the effort is spent earlier, to streamline the final work. Like all instrumental projects this involves constantly evaluating if one should take the "brute force" approach or the elegant redesign. Since most steps for VIRUS have been or will be done tens or hundreds of times, we have tried to invest time in simplifying individual steps and removing some of the art from assembly and alignment. The project had the advantage of beginning with the VIRUS-P(prototype), now known as the Mitchell spectrograph.[8] This pathfinder instrument tested much of the VIRUS optical design, and has become a workhorse instrument on the 2.7m telescope at McDonald Observatory.[9]

Each spectrograph has been assembled in parts along a multi-stage assembly line. The intention was to make as much of the assembly possible with lab technicians and undergraduate lab staff. This guiding principle included trying to reduce the screw diversity, considering accessibility for assembly, and limiting the number of steps that required high precision. Jigs were used when possible to limit the variation in position during assembly. We also processed parts in batches to decrease changes in method and to control for changes in conditions. We feel this principle was fairly successful. We include details below of both the assembly line and optimization.

Each VIRUS channel is optically independent. Two channels are enclosed in each unit. A baffle is placed in between the two channels in the collimator. The cryostat design limits scattering between the two channels but allows a single cable to be used for the CCDs. This creates both less vacuum cryostats (78, instead of 156), decreases the set of CCD controller electronics, and is a physically manageable unit. Combined, the unit weights roughly 150 lbs. It can be handled comfortably by two or three people during lab work and finally during installation.

Optical alignment occurs first for the detector/field flattener head. The collimators are assembled and mechanically aligned to near position,[10] and finally the camera/collimator pair is combined and aligned. Using the

Table 1: VIRUS System Characteristics (per channel, two channels per unit)

$F/\#$	3.5
R ($\lambda/\Delta\lambda$)	770
Fibers	224
Device type	Thinned Backside Illuminated
Detector size (pixels)	2064 x 2064
Pixel size	15 micron square
Dark Count	$<$ 1 e- per pixel (600s et)
Read Noise	$\leq$ 4.2 e-
Quantum Efficiency	$\geq$ 50% (350-650, wavelength dependent)

facility calibration unit (FCU), the final spectrographs are characterized as they will be used on the telescope to provide a data baseline prior to shipment to the telescope. We present the ensemble data to demonstrate the quality of the alignment, the in-situ CCD performance, and the overall system performance.

3. CURRENT STATUS

We have currently built 38 spectrographs, out of 78. The production rate and projected schedule can be seen in Figure 3. The full complement of spectrographs is expected to be complete in December 2014. The highest sustainable rate is two units (four channels) per week. This is tied directly to the cure time of the epoxy used for the detector and field flattener alignment. Each step requires 24 hours curing in the alignment setup. We have one setup for each alignment step. One could build them much faster if one invested in the infrastructure. However, the pair requires 3 CCD cameras for the alignment, which is a high initial cost. One could also imagine swapping the cameras but the setup stages are fairly intensive, and once setup the actual alignment (when parts aren't moved) is short. In early builds we did use a single rig for both steps, and moved the cameras sequentially to do first detector then field flattener alignment. It was decided to decouple the steps, as the time needed to reconfigure added considerably to the overall time budget. With practice in the new/decoupled setups, it takes less than an hour to do the field flattener and detector alignments.

All completed spectrographs are stored on site at UT Austin. A full rack (holding 9 units) can be seen in Figure 2. Five racks are currently available (45 units total) and several more locations have been identified for storage. Due to limited space at the HET, the units will be delivered to the mountain after the installation and testing of both the enclosures and the full electronics and cryogenic systems (late 2014). This requirement is driven primarily by two things - requiring installed and tested cryogenics and air handling. To test the cryogenic system, the bayonets which mate with the spectrographs must be fully deployed. With an installed spectrograph in the slot, if the bayonet is not coupled to the spectrograph, there is no stable way to fully deploy and test the bayonet. The electronics and air handling are required because the controller overheats quite quickly (on order of 10 minutes) if spectrographs are run without air flow. The placement of the controller between the two channels on the outer housing contributes significantly to this problem. It is alleviated easily by flowing air across the controller.

Because of the current production schedule, as well as the scheduled fiber delivery dates, fibers will be joined to a specific spectrograph and tested prior to shipment to the mountain. This will be the final data taken with the unit before it is integrated into the overall instrument.

4. COMPONENT DATA

Several papers have been written about the process and status of various camera components over time, including the gratings[11] and detectors.[12] We have received all the VPH gratings from Syzygy optics. The final measured values are shown in Figure 5 for reference. An image of a mounted grating is found in Figure 4. Data on the status of the fibers can also be found in these proceedings.[6]

Figure 2: Nine spectrograph units, aligned and stored at the University of Texas at Austin.

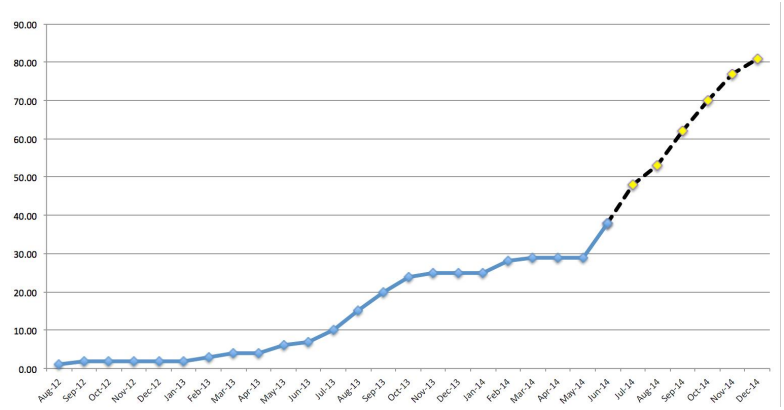


Figure 3: VIRUS Schedule. The blue line is completed units. The dotted black line is future plans. As of the end of June 2014, the assembly line is up and 2 units (4 channels) are being built every week.

4.1 Detector Data

We report on the 166 detectors received from ITL (M. Lesser) as of the end of May 2014. A small number of shipments remain to finish the detector shipments. These numbers are representative of the complete sample.

The read noise is required to be less than 4.2 e- for any pair of amplifiers. These are four amplifiers per chip, but only two are used for read out at any given time. To trade amplifier pairs, a jumper must be modified (installed or removed) in the flex cable of the detector system. Most chips meet the requirement for all for amplifiers. The read noise is shown in Figures 6 and 7.

The ensemble quantum efficiencies are shown in Figure 8. This shows both the individual detectors (measured by ITL), as well as the mean value at each wavelength. The total number included at any given data point varies, as the data provided by the vendor differed slightly between batches. The requirement is also shown in red. The distribution at each wavelength of interest is shown in Figures 9 and 10.

As one can see from the data, the performance of the detectors beats our requirements, and is quite consistent over the set. Some lessons have been learned over time. There was difficulty getting the positioning of the field flattener mount clips as precise as was initially specified. This has not been a problem, as in the end they make more than enough contact and the overall placement of the detectors with respect to the field flatteners does not vary appreciably.

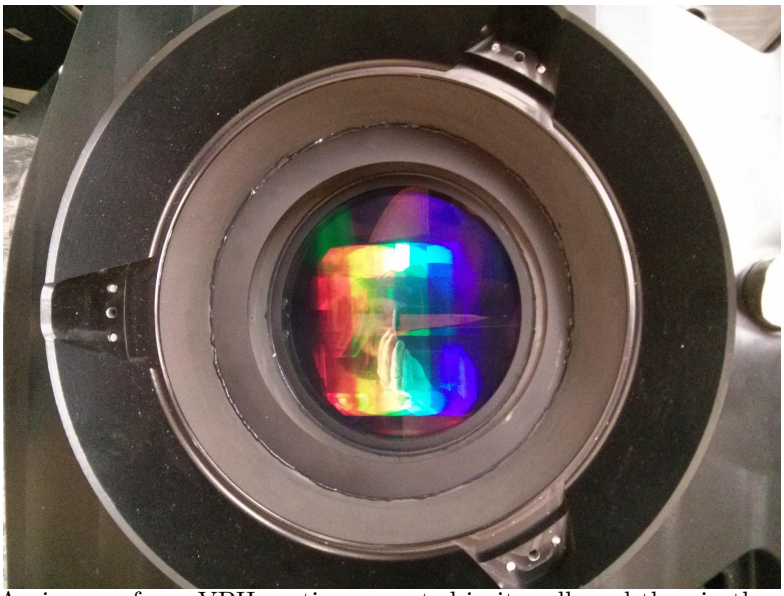


Figure 4: An image of one VPH grating mounted in its cell, and then in the collimator.

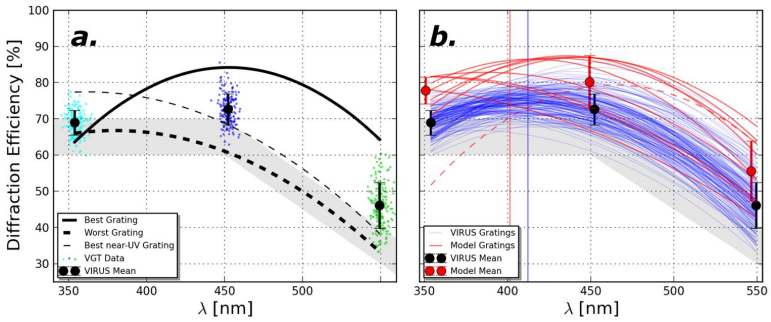


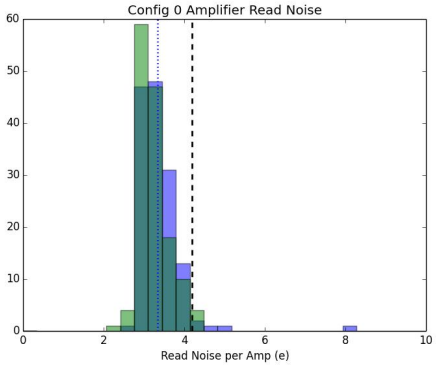
Figure 5: The delivered VPH grating efficiencies. The left plot is efficiency shown by wavelength, with the points randomly offset to show distribution of points. The grey band shows the external diffraction efficiency specification. The right shows delivered gratings versus model gratings. Details found in these proceedings.[11]

5. CAMERA ASSEMBLY

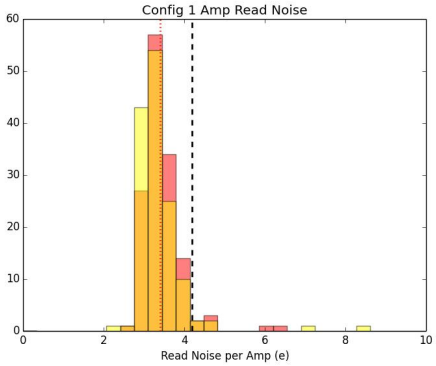
The VIRUS cameras are assembled at the University of Texas at Austin in what has become a streamlined "assembly line" process. Currently four undergraduates, a technician, and a postdoc take part. This results in roughly 2 spectrograph units (4 channels) per week. Current methods, and the occasional issue, follow.

The two main limits are the camera mirror glue up and the detector and field flattener alignment. All of these are due to both the use of permanent jigs and slow curing epoxies. All epoxies selected were selected to provide very low off-gassing (selected via the NASA off gassing database and in consultation with vendors). Especially since we are working near sensitive optics and electronics, even where the opportunity exists to heat accelerate the cure we've left it to cure at room temperature.

The detector is mounted using three screws into the spider/detector mount. The entire system is then held with a jig to position it with respect to bushings, that will eventually mount the spider into the cryostat. Once alignment is achieved, the bushings are epoxied into the spider. We align using direct imaging, both of the detector surface and a laser spot imaged on that surface (shown in Figure 11). All alignment is relative to fiducials created using a Faro Arm CMM.



(a) Read Noise Config 0



(b) Read Noise Config 1

Figure 6: Read noise from pairs of amplifiers - split into configuration 0 (standard) and configuration 1 (backup). A small number of detectors pass spec only in one configuration or the other. The specification (4.2 e-) is marked with a dashed line, and the mean with a dotted line to the left.

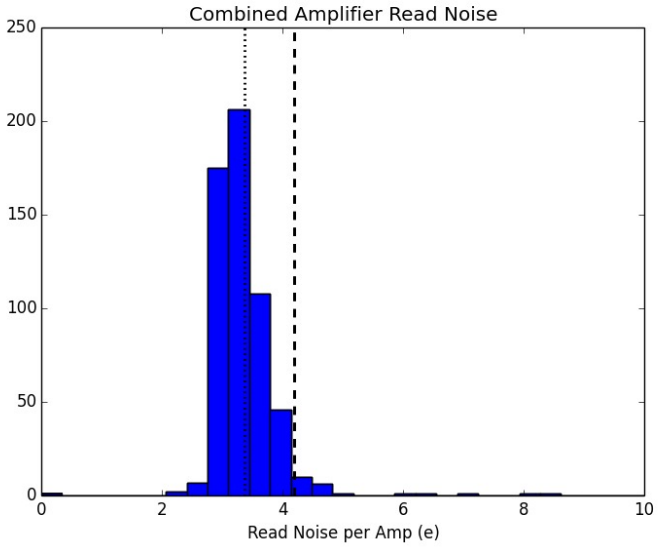


Figure 7: Distribution of all read noise values, to date. The specification is marked with the dashed line, and the mean with a dashed line to the left.

6. SPECTROGRAPH ALIGNMENT AND RESULTS

The camera is built around the aligned detector/field flattener pair. As described above this results in a semi-permanent assembly. We have successfully reclaimed spider mounts for re-use, through a mixture of mechanical and chemical means to remove the bushings. Detectors, attached with only screws, are easily removed. The field flatteners are epoxied directly onto Invar mounting clips, and removing these clips results in damage to the optic. We have not attempted to reuse them, and have a small number of spares that make it unnecessary.

The final alignment is done once a camera and collimator are combined. The alignment processes uses a moment-based wavefront sensing method developed specifically for VIRUS alignment.[13] Centroid and image size measurements are made on a set of focus-modulated images. This provides a determination of the image moments, and adjustments are then made.[14] Both the camera mirror and the collimator mirror can be pistoned during alignment. We use a modified cryostat back for the camera to allow access to the adjustment and locking screws during the process. The collimator adjusters are accessible without special modifications (as long as the outer housing is not installed). The entire system is enclosed in a baffling drape to allow access while controlling

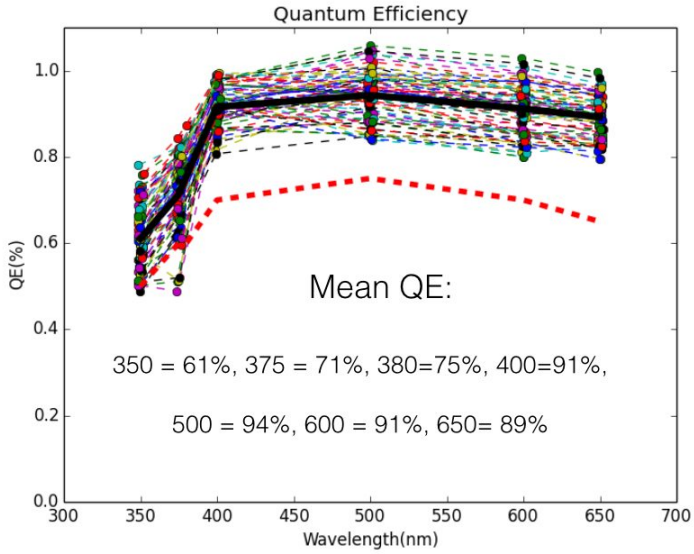


Figure 8: Measured quantum efficiencies of 166 detectors. The mean is shown by the thick black line, with values listed below the plot. The red line marks the specified minimums. The small number falling below the minimum are reporting errors due to a change in lab setup. They are currently being corrected.

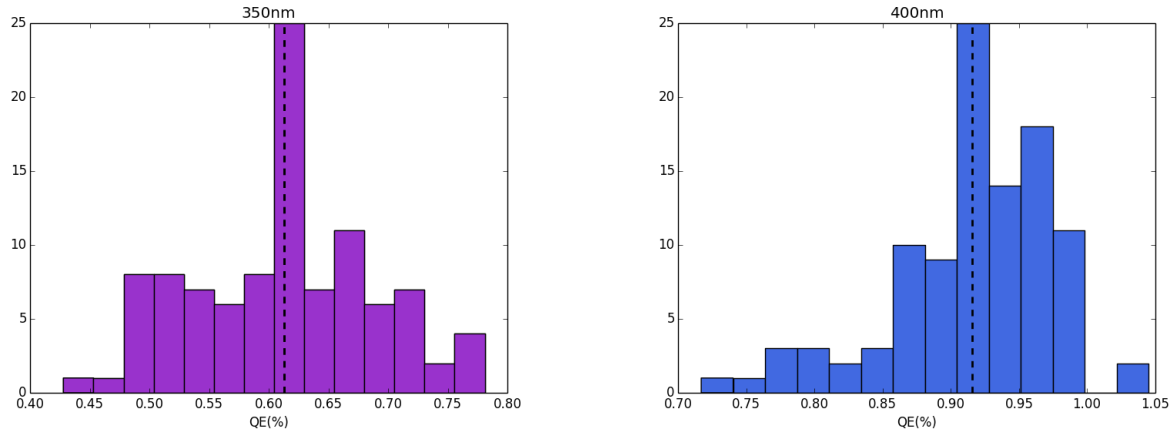


Figure 9: Distribution of the quantum efficiency of the CCD detectors, at 350nm and 400nm. The mean is marked with the dashed vertical line in each.

background illumination and scattering.

During alignment, quality control tracks several values. The first requires the center to be within a 7 pixel diameter. This is shown on Figure 12. The fiducial center is marked with the red point, and the requirement is marked with a dotted line. The cloud to the lower right is a preferential shift when the position was locked. We are now taking into account the preferential movement. The alignment requires some amount of art that has improved over time.

7. SPECTROGRAPH CHARACTERIZATION AND RESULTS

Before delivery to the mountain, each aligned spectrograph will be characterized. This will be the reference data available to both check the installation at the mountain and to use as a reference to changes over time in the instrument.

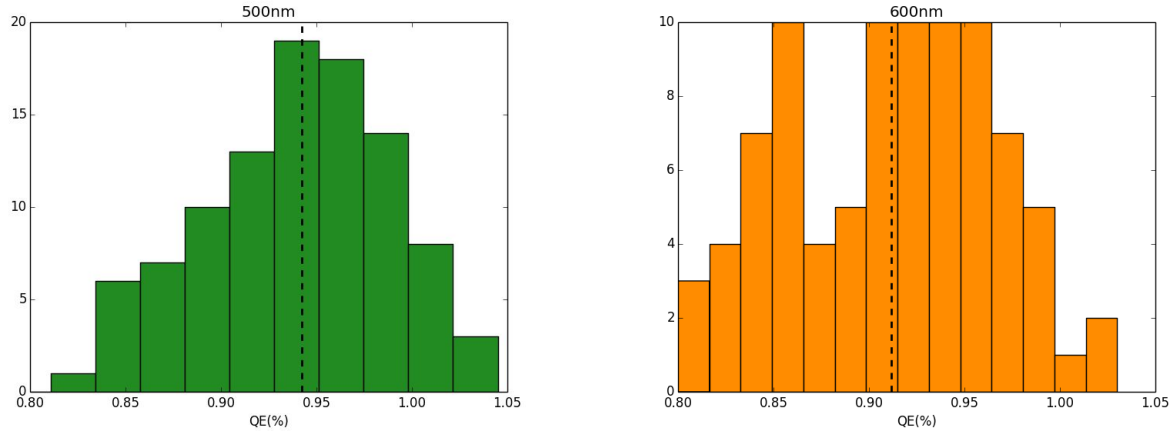


Figure 10: Distribution of the quantum efficiency of the CCD detectors, at 500nm and 600nm. The mean is marked with the dashed vertical line in each.

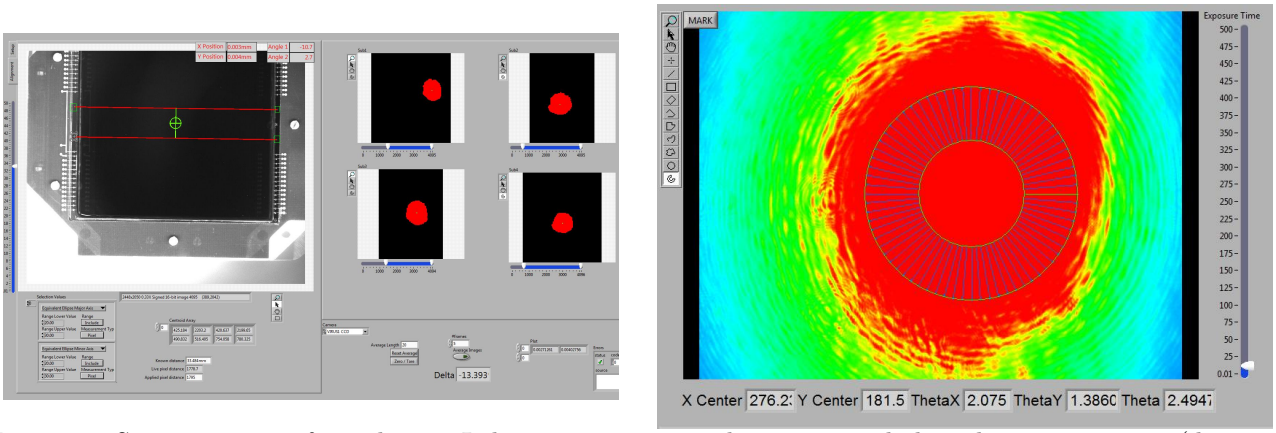


Figure 11: Screen captures from the two Labview programs used to image and align the camera optics (detector and field flattener). The left hand image shows the detector surface and uses four spots to place the XY position and rotation. The right image shows a laser return spot used to set the height and tip tilt.

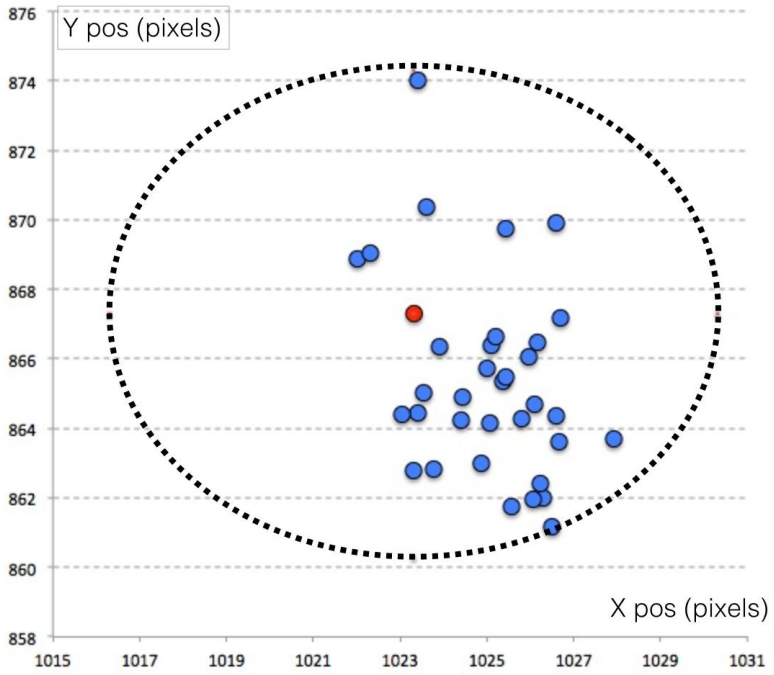


Figure 12: Center Position in camera (Pixels) with respect to fiducial

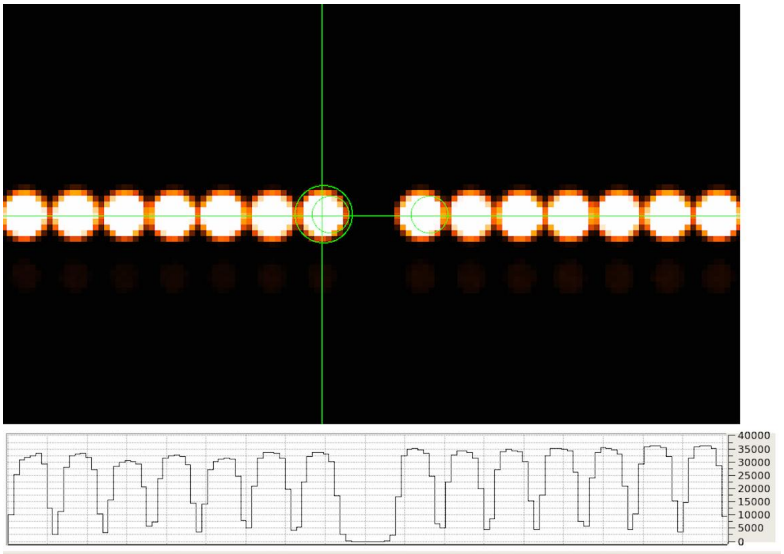


Figure 13: A close up on the center fiber images of an aligned channel. The plot below shows a sample of the fiber image shape.

We are using a QTH and deuterium combination lamp to measure a pixel flat of each detector. We will measure the read noise of the system, and characterize scattering via deep darks. We are also using a test bundle to do a final check of wavelength calibration, position, and alignment. Many of these measurements will be repeated once the spectrographs are installed as a health check on the systems. Those will also operate as a baseline for the instrument as it is monitored throughout its lifetime. This will provide indicators about possible issues with fiber bundles and detectors, controller electronics and the vacuum/cryogenic system.

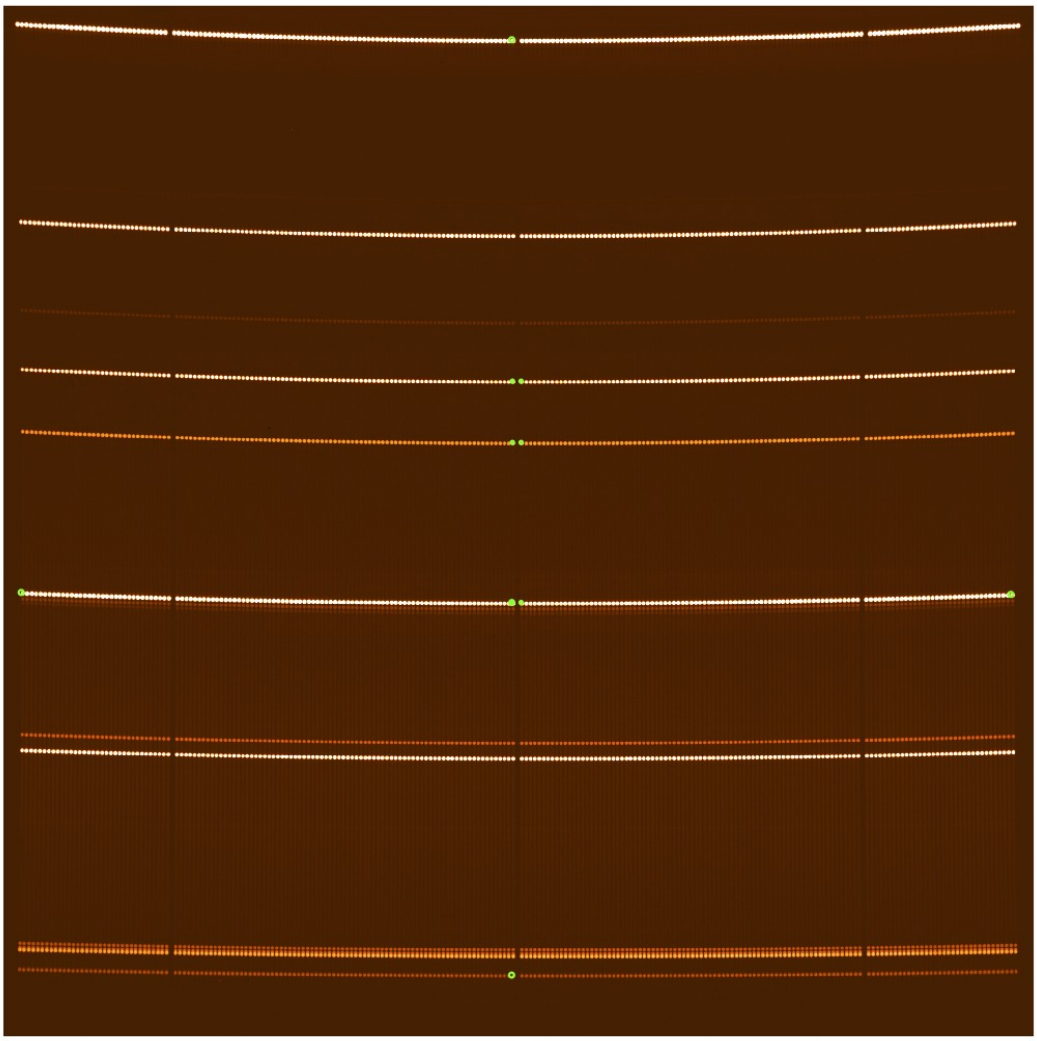


Figure 14: A full aligned VIRUS image illuminated by line lamps. Note the intentional gaps (3 spaced across the slit) to allow for a more complete characterization of the wings of the fiber profiles.

8. PLANS FOR INTEGRATION

Integration will begin once all underlying support systems have been installed and tested. Modifications have been made to the telescope system already, including the installation of the VIRUS support structure (VSS) to accommodate the enclosures that will make up the exoskeleton of VIRUS. The first side enclosures are currently being assembled at TAMU and will be delivered in the Fall of 2014.[15] The detector electronics and control systems are currently being tested together at UT as part of VIRUS characterization. VIRUS requires both cooling to the electronics (via air flow over the controllers) and cryogenic cooling for the detectors (delivered through the VIRUS cryogenic system (VCS) to operate.[16] The key elements can be seen in Figure 15.

Initial installation will consist of a single column (of eight units). This allows us to test the performance of a single standoff of the VCS before proceeding, and to develop fiber installation and handling procedures for the rest of the system. The enclosures will be populated one side at a time (39 spectrographs). Telescope performance will be tested at several intervals to confirm that motion isn't impeded or performance isn't hindered by a lopsided installation.

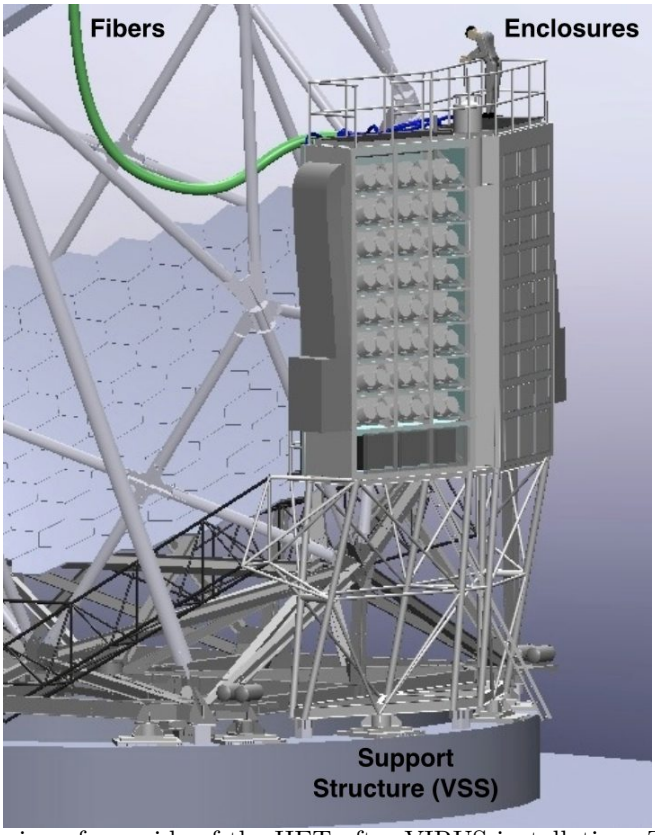


Figure 15: We show a rendering of one side of the HET after VIRUS installation. The bundle of fibers feeding the spectrographs is green, coming down from the focal plane (top left). The enclosures are shown with a person for scale at the top. The front section has the doors removed to show the spectrograph location, while the doors are shown on the second/rear portion. The enclosures rest on the VSS.

9. CONCLUSION

Half of the final complement of VIRUS units are built and initial ensemble results are shown. Delivered parts as well as assembled units are meeting desired specifications handily. We discuss some lessons learned in the first half, and look forward to plans for installation in the first half of 2015.

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