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VIRUS Instrument Collimator Assembly

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ABSTRACT

The Visual Integral-Field Replicable Unit Spectrograph (VIRUS) instrument is a baseline array 150 identical fiber fed optical spectrographs designed to support observations for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX). The collimator subassemblies of the instrument have been assembled in a production line and are now complete. Here we review the design choices and assembly practices used to produce a suite of identical low-cost spectrographs in a timely fashion using primarily unskilled labor.

Keywords: Optical instrumentation, integral field spectrographs, mass-produced instrumentation

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1. INTRODUCTION

The Hobby Eberly Telescope Dark Energy Experiment (HETDEX¹) is a project designed to probe the nature of Dark Energy using the HET telescope^a. HETDEX consists of three main parts: a major telescope upgrade including replacing the top end of the telescope to allow for a larger focal plane, the construction of the Visual Integral-Field Replicable Unit Spectrograph (VIRUS²) instrument, and the execution of a large area blind survey for Lyman alpha emitting galaxies at redshifts $z < 3.5$. The VIRUS instrument is composed of three subassemblies: the integral field unit (IFU) fiber bundle that carries the light from the focal plane of the telescope to the instrument; the collimator assemblies, described in this paper, that form the body of the spectrograph; and the camera that focuses the dispersed light onto the detector. The VIRUS instrument is currently nearing the end of the construction phase, with production of IFU units and cameras well underway. The 130 collimator assemblies described here are now completely assembled and aligned.

^a The Hobby – Eberly Telescope is operated by McDonald Observatory on behalf of the University of Texas at Austin, Pennsylvania State University, Ludwig-Maximilians-Universität München, and Georg-August-Universität, Göttingen.

Figure 1 shows a drawing of the upgraded telescope with the VIRUS mounted on the telescope in the VIRUS enclosures³. The final design of the instrument enclosures allows up to 156 VIRUS spectrographs to be installed on the telescope. Eventually the full suite of spectrographs may be completed and installed in order to carry out the survey with maximum efficiency.



Figure 1. The VIRUS spectrograph pairs will be mounted inside two climate-controlled enclosures located on either side of the telescope.

The Munneryn Astronomical Instrumentation Lab at Texas A&M has undertaken the final design, prototyping, and construction of the VIRUS collimator units^{4,5}. In this paper we describe the efficient, cost-effective assembly procedures used to complete construction of 130 collimator units.

2. DESIGN PHILOSOPHY

The VIRUS instrument consists of as many as 156 identical simple fiber-fed spectrographs mounted on the telescope structure. The VIRUS instruments are composed of a main spectrograph body (referred to as the “collimator”) and a vacuum vessel which houses the Schmidt camera. A volume phase holographic (VPH) grating provides a wavelength range of $350 < \lambda < 550$ nm. Each spectrograph is fiber-fed from the focal plane of the HET via an IFU which delivers 224 fibers to each spectrograph. The fibers are laid out in a grid pattern in the telescope focal plane. This instrument design allows large-scale spectroscopic mapping of the sky.

The spectrographs will be constructed in pairs, so that the completed VIRUS instrument will consist of up to 78 pairs of spectrographs. Figure 2 shows a drawing of one of the VIRUS spectrograph pairs.

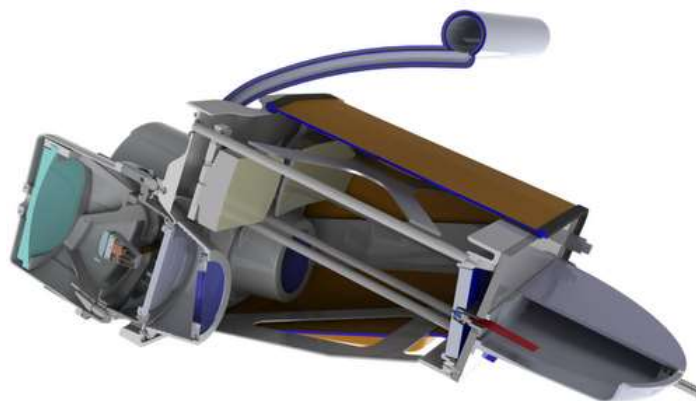


Figure 2. Section-view drawing of a pair of VIRUS spectrographs.

To facilitate the assembly line-style production of this unique instrument, the optical and mechanical designs of VIRUS have been carefully studied to make the instrument both affordable and able to be constructed in a reasonable amount of time. These studies represented a significant amount of time invested early in the project. For the collimator assembly construction described here, this early effort has now paid off and resulted in a unique set of instruments that were completed efficiently using primarily unskilled (undergraduate student worker) labor.

3. INSTRUMENT DESIGN CHOICES

In this section we provide an update on previously presented design choices⁴ for the VIRUS instrument components relevant to the collimator assemblies.

3.1 Optical design

3.1.1 Simple optics

The optical design of a VIRUS unit spectrograph is a simple off-axis Schmidt collimator coupled with a traditional Schmidt vacuum camera. The VIRUS collimator has three optics: a spherical collimator mirror, a folding flat, and a volume-phase holographic (VPH) grating. These optics proved to be relatively straightforward to manufacture by many vendors (albeit at a wide range of costs and delivery times).

3.1.2 Selection of vendors

Vendor selection was an important part of the instrument assembly process, particularly for optical vendors. We have found that while there are not large numbers of vendors who are interested in producing 100-200 optical components at a reasonable cost (the vast majority of optical vendors prefer to produce only one optic at a time or else thousands of production optics for industry), we were able to identify and work with 1-2 cost effective and capable vendors for each collimator optic. Vendor management and inventory control were important parts of this project, due to the large numbers of optics involved and the ~1 year timescale over which delivery was received.

3.2 Mechanical design

3.2.1 Fixed mechanical design

The VIRUS collimators have a simple, straightforward design with no moving parts in the instrument. Two optics in the collimator can be manually articulated to facilitate the optical alignment of the system: the collimator mirror, which is adjusted in tip/tilt/focus to optically align the instrument during construction, and the grating, whose cell is designed to be rotated in situ and then fastened in place once the grating is aligned. The fold flat is epoxied directly into the instrument and cannot be adjusted. All other mechanical structure in the instrument is simply bolted in place and cannot move once assembled.

3.2.2 Minimize castings

We initially envisioned an instrument constructed primarily of large cast aluminum components to which the optics were to be mounted. In prototyping, however, it became clear that large cast aluminum parts were quite difficult to machine: post-machining of the cast parts often left machined surfaces with holes left by inclusions in the metal caused by the casting process. In the end, castings were rejected in favor of aluminum tool plate that was machined to a similar design as the cast parts.

The final collimator design does incorporate one cast aluminum part, the housing that supports the grating. This part is roughly 6 inches in diameter by 6 inches deep and is made from a casting that is post-machined to shape since it was believed that machining the part out of solid aluminum would have been prohibitively expensive. In the end, however, the number of grating housings that were rejected due to failed castings or failed tapped holes was large enough that it might have been cost effective to machine the housings out of solid aluminum.

4. ASSEMBLY PROCEDURES

4.1 Installation of optics

The VIRUS collimator mirror, fold flat, and grating were each installed using precision metrology equipment into a cell which was then bolted into the instrument. The figures below provide some examples of the alignment fixturing and glue-up processes.

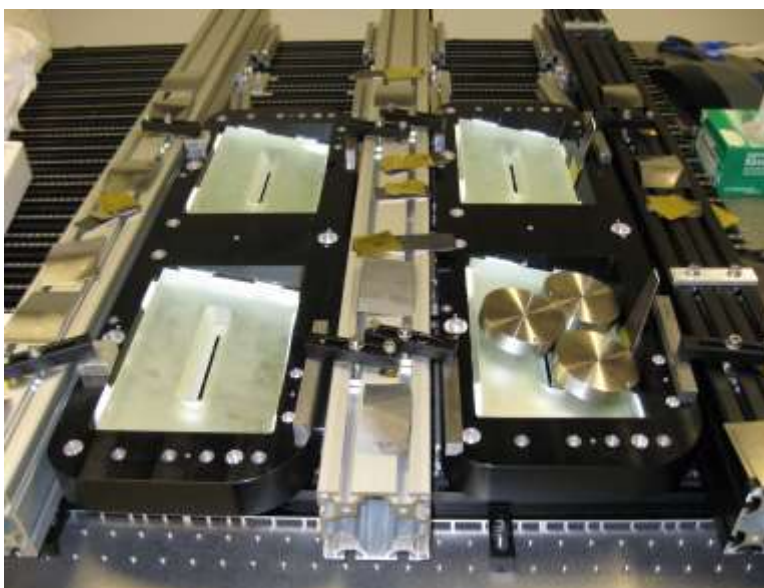


Figure 3. Installation fixture used to install folding flat into head plate. Two pairs of mirrors are installed into two head plates in one setup. The fold mirrors are precisely positioned with respect to the head plates using a Faro coordinate measuring machine (CMM) arm having a measurement accuracy of ~25 microns and are held in place with metal shims while RTV is applied around the edges of the mirror.

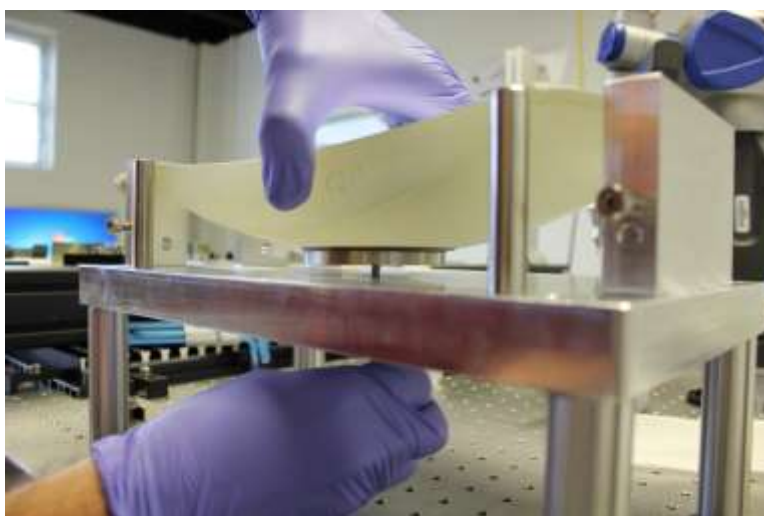


Figure 4. Collimator mirrors are installed in the instrument using an Invar mounting puck that is bonded to the back of the mirror. The puck is precisely located with respect to the edges of the mirror using an alignment fixture.

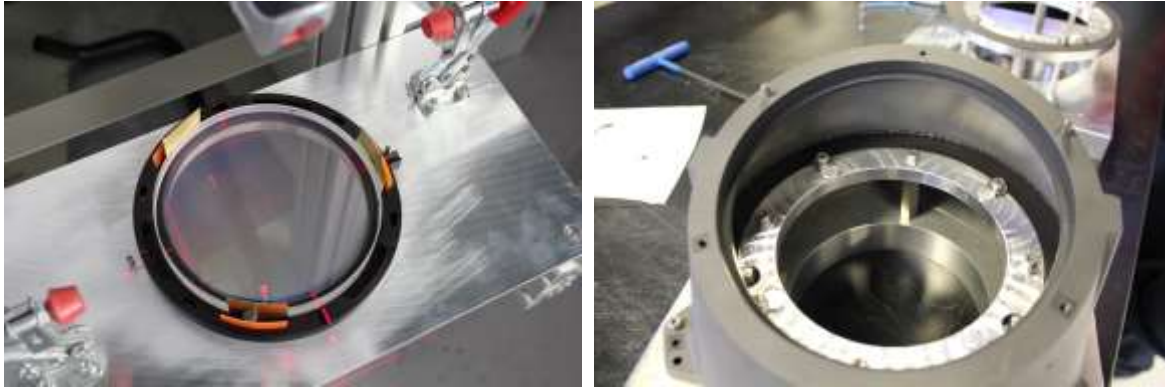


Figure 5. VPH gratings are optically aligned to the correct rotation in their cell during installation using a laser (left). Internal baffles of the grating housings are installed using a fixture (right). The grating cell is later installed on top of the housing.

4.2 Subassembly construction

The collimator subassemblies include the head plate which connects the collimator to the IFU fiber bundle, the base plate which connects the collimator to the camera, chassis plates that connect the head and base plate, and the collimator mirror mounting plate which is attached via Invar metering rods to the head and base plate to hold the collimator mirror in place in a temperature invariant way. All subassemblies were pre-assembled over approximately a one year period. Most subassembly construction was complete before the final assembly process began. Subassemblies containing optical components were protected from dust and humidity by storing them in sealed plastic bags containing desiccant packets.



Figure 6. Collimator subassemblies were pre-assembled and stored before the final collimator assembly. Shown here are the base plates (left) and side, top, and bottom plates (right). Each of these components has multiple alignment and attachment features to facilitate the final assembly. Collimator mounting plates with attached Invar metering rods can be seen on the top rack of the carts.

4.3 Final collimator assembly

In the end, the final mating of collimator subassemblies into a complete collimator unit was accomplished relatively quickly, with the final thirty pairs of collimators being assembled in just over two weeks in December 2013. The record assembly time of fifteen minutes to complete one pair of collimators is shared by the team of Nagasawa and Li. Once the final collimator assembly is complete no further optical alignment is required at this stage. The completed collimators are fitted with a plastic cover that remains with the collimators once installed on the telescope, protected from dust with plastic wrap, and finally packaged and shipped to UT-Austin for integration with the VIRUS cameras and final optical alignment.



Figure 7. Collimators were completed in batches of 10-15 at a time. This number was primarily set by the size of the assembly bench. Each set of 10-15 collimators were assembled over a 2-3 week period.



Figure 8. One complete collimator with all optics installed. Additional completed collimators (with their protective covers installed) may be seen in the background.

4.4 Optical alignment

Initially, the VIRUS instrument was designed so that each pair of VIRUS cameras would be interchangeable with any other pair of VIRUS collimator units. Unfortunately this goal was unreachable, and the final instrument will require precision alignment of each matched collimator-camera pair.

The final collimator design allows for the adjustment of the tip/tilt/focus of the collimator mirror as well as setting the precise rotation of the VPH grating. The fold flat remains fixed once installed. The process of precisely installing the optics in cells, coupled with the use of very simple fixtures (removable aluminum blocks that set the spacing between two metal surfaces were used to set the location of the collimator mirror along the length of the Invar metering rods as well as to set the final rotation of the grating) to pre-align the moveable optics in fact resulted in the collimators being assembled to within sufficient tolerances without the need of final optical alignment of each collimator before being mated with its camera. The final optical alignment of the complete spectrograph will be set for each collimator-camera pair by readjusting the position of the collimator mirror and rotation of the grating once the camera is coupled to the collimator.

5. CONCLUSIONS

The VIRUS collimator assembly process is complete for 130 collimators (65 pairs). Important considerations throughout the design and construction process included an optical design with relatively loose alignment tolerances, thoughtful vendor selection and management, careful prototyping of components followed by redesign when necessary, precision alignment of optical components within cells that can be rigidly mounted at precise locations within the instrument, preliminary subassembly construction that enabled rapid collimator unit completion, and careful attention to quality control throughout the entire process. Although the VIRUS spectrographs comprise a challengingly large instrument unlike any previously produced in astronomy, these considerations resulted in a suite of VIRUS collimators that have been completed in a cost-effective and timely manner.

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