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Production-line Assembly of 150+ VIRUS Spectrographs

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ABSTRACT

The Visual Integral-Field Replicable Unit Spectrograph (VIRUS) instrument is being built to support observations for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) project. The instrument consists of 150+ identical fiber-fed integral field optical spectrographs. This instrument provides a unique challenge in astronomical instrumentation: each of the 150+ instruments must be identical and each component must be interchangeable amongst every other spectrograph in order to ease assembly and maintenance of the instrument. In this paper we describe plans for the production-line assembly of the spectrographs. In particular, we discuss the assembly procedures and design choices that will ensure uniformity of the spectrographs and support the project schedule.

Keywords: Telescopes: Hobby-Eberly, Astronomical instrumentation: Spectrographs—VIRUS, Spectrographs: Integral Field, Spectrographs: Assembly

1. INTRODUCTION

The Hobby Eberly Telescope Dark Energy Experiment (HETDEX[1]) is a project aimed at looking for Dark Energy at high redshifts using the HET telescope. 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 (VIRUS[2]) instrument, and the execution of a large area (5000 square degrees) blind survey for Lyman alpha emitting galaxies at redshifts $z<3.5$. The VIRUS instrument is currently nearing the end of the detailed design phase, and we have begun to prototype the VIRUS production design. We are now preparing for the production-line assembly of the instrument to be completed at Texas A&M University, while the fibers to feed the instrument are being designed and constructed at Astrophysical Institute Potsdam (AIP).

VIRUS is a project unlike other modern astronomical instruments. As opposed to the traditional spectroscopic instrument for a large telescope, i.e. a single spectrograph with large and expensive optics and mechanisms that observes the entire focal plane of the telescope in one instrument, VIRUS has been designed as an array of small, inexpensive spectrographs that each sample a small piece of the focal plane. VIRUS consists of between 150 and 192 simple fiber fed optical spectrographs. The final number of VIRUS units deployed will depend on project funding. Figure 1 shows a drawing of the upgraded telescope, showing the VIRUS mounted on the telescope.

The planning process for constructing a large number of identical VIRUS spectrographs has led to specific design choices that will enable the instrument to be completed in a timely and affordable manner. In this paper we discuss these design choices and plans for assembling this unique instrument.

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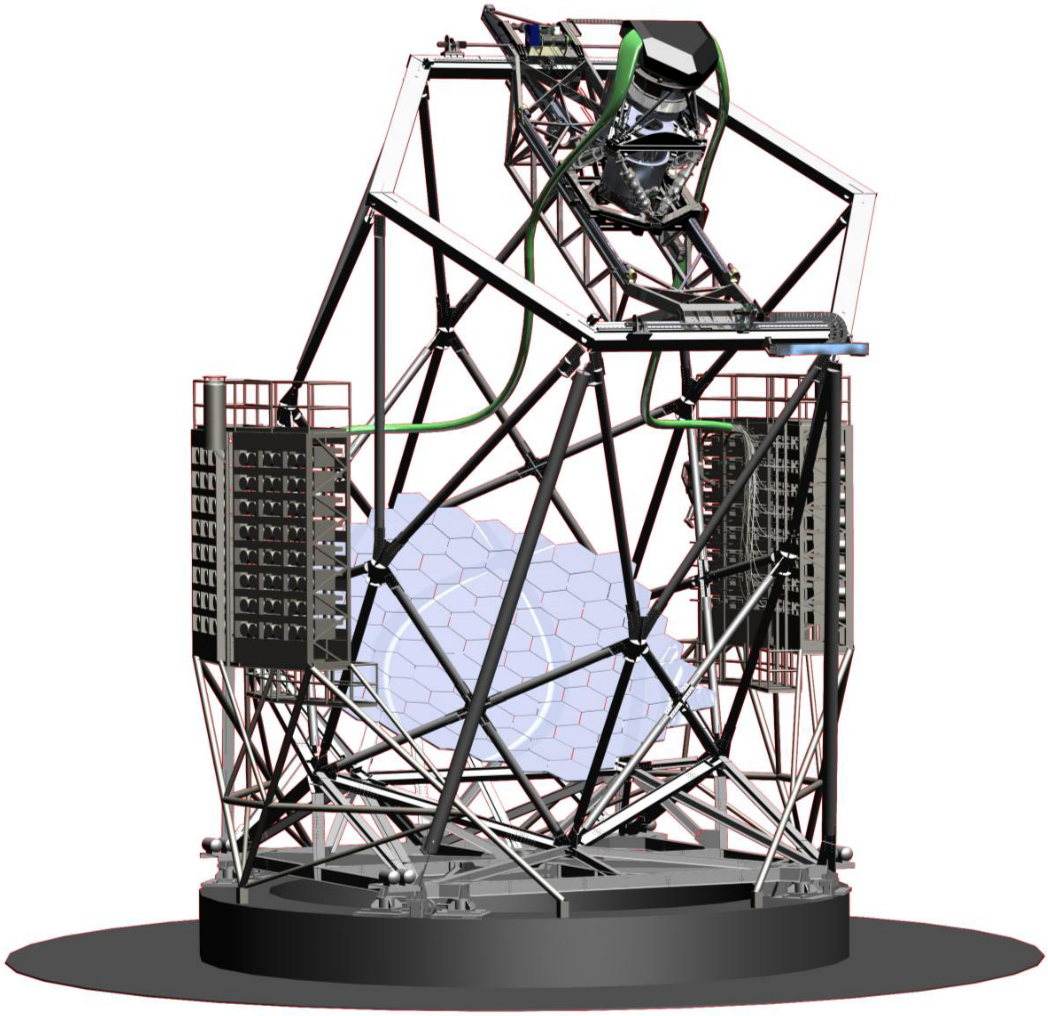

Figure 1: The 96 VIRUS spectrograph pairs will be mounted inside two climate-controlled enclosures located several meters above the base of the telescope.

2. DESIGN PHILOSOPHY

The VIRUS instrument consists of as many as 192 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 350-550 nm. The detailed optical[3] and mechanical[4] designs of the instrument are described in more detail elsewhere in these proceedings. Each spectrograph is fiber-fed from the focal plane of the HET via 224 fibers per 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 96 pairs of spectrographs. Figure 2 shows a drawing of one of the VIRUS spectrograph pairs.

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. Several themes govern the instrument design overall:

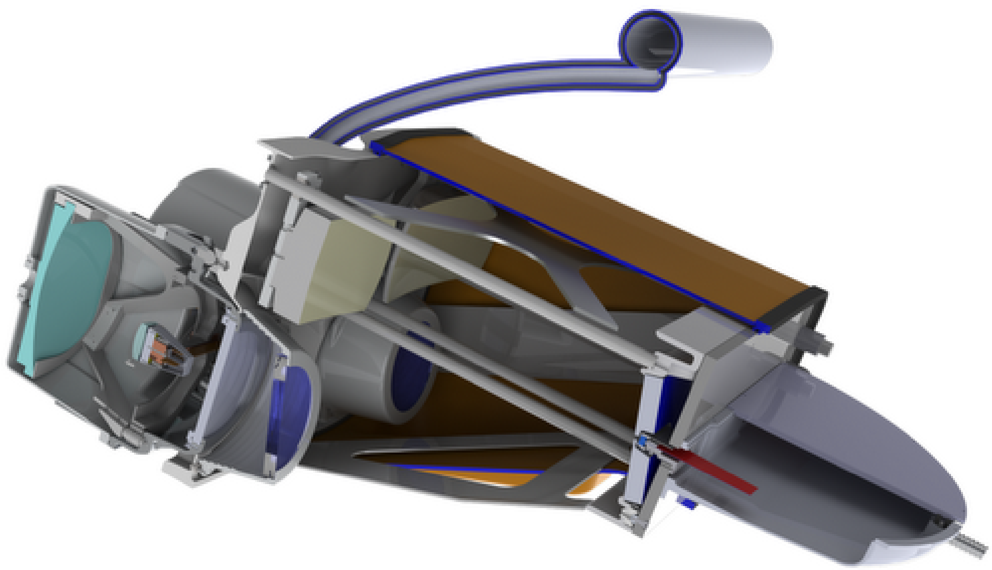

Figure 2: Section-view drawing of a pair of VIRUS spectrographs.

2.1 Interchangeable subassemblies

It is a design requirement that the camera pairs be interchangeable amongst any collimator pair once the instrument is mounted on the telescope. This requirement will enable "hot-swapping" of cameras during operations and minimize down time of the instrument in the case of failures, vacuum pump downs, etc.

2.2 Minimize number of parts

We have made an effort to minimize the number of individual parts in each VIRUS unit spectrograph. While the total number of parts is not generally a large cost or assembly time driver in an average astronomical instrument, it certainly will be a consideration in the manufacture and assembly of 150+ instruments. With this factor in mind we have made efforts to minimize the total number of manufactured parts that compose the instrument. One way this is accomplished is through the use of several use of cast aluminum part pieces, discussed in more detail below.

2.3 Maximize ease of assembly

We have spent considerable design time thinking about how to assemble the unit spectrographs in the most straightforward way. In particular, we have made an effort to minimize difficult and complicated assembly tasks, time-consuming operations, and procedures that require more than one person to complete. While these issues are rarely an issue when assembling a standard astronomical instrument since each of these things will be accomplished only once, when multiplied 192 times these considerations can quickly become major schedule drivers. Furthermore, the design allows us to precisely pre-align the optics in subassemblies which are then mounted to the instrument structure. This assembly procedure will be discussed more fully below.

2.4 Optical tolerancing

The VIRUS optics have been carefully specified to produce optics that will be interchangeable amongst any VIRUS unit. Both the optical and mechanical properties of each optic have been carefully toleranced. This will enable quick assembly of the optical assemblies and spectrograph units, and make the optical alignment process of the subassemblies and the complete instrument more straightforward.

3. INSTRUMENT DESIGN CHOICES

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 instrument has seven optics: a cylindrical fiber-coupling lens, a spherical collimator mirror, a folding flat, a volume-phase holographic (VPH) grating, an aspheric Schmidt corrector lens which forms the dewar window for the camera, a spherical camera primary, and an aspheric field flattener that sits directly in front of the detector. Note that two of the optics are spheres, two are aspheres that will be straightforward to manufacture on modern aspheric generating machines, and the remaining optics are a flat, a cylinder (both of which are straightforward to manufacture), and the VPH grating. This optical design has been carefully optimized with optics that can be easily and quickly provided by many different vendors.

3.1.2 Selection of vendors

The cost of the optics in VIRUS is, not surprisingly, a large fraction of the entire cost of the instrument. We have attempted to minimize costs and maximize optical quality by selecting appropriate optics vendors for this project. We have selected individual vendors for each of the categories of optics—this has minimized overall optics cost dramatically. It has also allowed us to specialize the design of each optic by working with vendors to maximize the manufacturability of each optic while minimizing cost. We have found many vendors who are willing to iterate with us on this effort. Obviously, purchasing the optics in large quantities at one time reduces costs as well.

3.2 Mechanical design

3.2.1 Fixed mechanical design

The VIRUS spectrographs have a simple, straightforward design with no moving parts in the instrument. Most of the optics are epoxied directly into a fixed subassembly inside the instrument; only two mirrors (the collimator mirror and camera mirror) will be adjusted in tip/tilt/focus to optically align the instrument during construction. Once optically aligned, the spectrographs will not need to be further adjusted.

3.2.2 Shared vacuums

Early in the design process the unit spectrographs were joined into pairs of spectrographs to allow the Schmidt cameras to share a single vacuum body. This decision was made to minimize pump down time of the dewars in the completed instrument as well as to save costs on vacuum fixturing on each instrument. The pairing of the spectrographs also allows a more efficient packaging of the spectrographs when they are installed on the telescope.

3.2.3 Castings

VIRUS has been designed with a minimum of parts in order to minimize costs and assembly time. This has been accomplished largely by designing several key assemblies in the instrument using cast aluminum units. The camera vacuum vessel, the grating housing, and the front and back plates of the collimator unit are all cast aluminum. The spider that holds the CCD inside the Schmidt camera is cast Invar. Each of these castings has dramatically decreased the number of individual parts to be manufactured for the instrument. We have not found any problems with structural uniformity or vacuum integrity of the castings in our prototyping and assembly tests.

3.2.4 Cooling system

An important part of the instrument design, in terms of feasibility of operations time and effort in maintaining the instrument, is the VIRUS cooling system. The system consists of a gravity-fed closed-circuit cooling system that automatically cools each of the 150+ VIRUS units while on the telescope. The design of the system allows for rapid cool-down and warm-up of the paired instruments, and allows for quick turnaround testing of the camera units in the lab. It does not require daily filling of dewars by telescope personnel. The cooling system is described in more detail elsewhere in these proceedings[5].

3.3 IFUs

In the VIRUS project, the term Integral-Field-Units (IFUs) stands for the fiber bundles that connect the telescope focal plane with the spectrographs. The use of fibers and fiber bundles provides a simple method to split-up the focal plane and to feed the light from a high number (approximate 40,000) of spatial pixels (spaxels) into a set of modular spectrographs.

In a system view, a single IFU consists of the input head, the fiber bundle run including conduit and the fiber-slit assembly. For efficiency and sampling reasons a design was chosen in which 448 fibers are being assembled in one input head and are placed in one protective conduit of 22 meters in length, while at the output the fibers fan out to feed two spectrographs to record 224 spectra each. The details of the IFU specification, design and performance are being reported elsewhere these proceedings[6]. In terms of production line assembly, this approach has the benefit that all (75-96) IFUs are identical in design and manufacture and are fully interchangeable at both the telescope and the spectrograph ends. The interface at the telescope is a multi-hole plug-plate at the focal plane, into which the IFU input heads can be inserted with high accuracy in position and tilt. At the spectrographs, the double fiber-slits are mounted to an interface plate that can be put onto any spectrograph pair (as shown in Figure 2).

The development of the fiber bundle IFUs in this project is part of the work package of the AIP. Based on its experience with the PMAS[7] and PPak[8] fiber-IFUs, AIP designed and manufactured various prototypes, called VIRUS-P[9]. Altogether four prototype versions were built, initially at AIP and later with the involvement of industrial companies. Unlike most astronomical instruments, which are unique development efforts of an institute or university department, the design for all VIRUS components always had the industrial replication in mind. AIP engaged in technology transfer with small and medium enterprises (SME) in the fiber business. Beforehand, fibers of various manufacturers were tested[10,11]. In one case, a fiber bundle was assembled, featuring fibers from four different vendors, as to obtain a direct on-sky performance comparison. Following these evaluations, selected SMEs were given contracts to build a mini-series of three IFU bundles each. The aim of this procedure was not only to obtain the first set of IFUs, but also to evaluate each company's performance with respect to manufacture within the technical specifications, to provide adequate documentation and communication, to demonstrate a quality assurance process, and to deliver within the given schedule. This approach also minimized risks, as it avoided single source dependencies and will allow a cost to quality assessment based on real performances.

While the serial production phase of fiber bundle IFUs is being outsourced, the final quality and acceptance testing is done at AIP and UT. In addition, the newly funded "center for innovation competence for fiber spectroscopy and sensing," innoFSPEC-Potsdam,[12] is engaged in the system design and the development of a quality assurance process. Amongst others, the criteria include geometric accuracy, such as fiber-to-fiber pitch, tip-tilt alignment, telecentricity, surface flatness and roughness, scratch and dig, sub-surface damage, wavelength dependent transmission and flatfield characteristics, focal ratio degradation and any defects and breakages. The findings of these tests are being fed back into the production process to ensure a high quality and reproducibility of the IFUs.

Currently, ten fiber-IFUs have been built, which is roughly 10% of the entire anticipated system (see Figure 3). Thanks to the modular approach of VIRUS, these bundles can be brought either one-by-one or in batches into operation, once they have successfully passed manufacture item acceptance. Already this subset of IFUs would be a powerful instrument for 3D-spectroscopy with the capacity to simultaneously record a high (4480) number of spectra for a uniquely large field of view (of ten times 2500 square arcseconds).

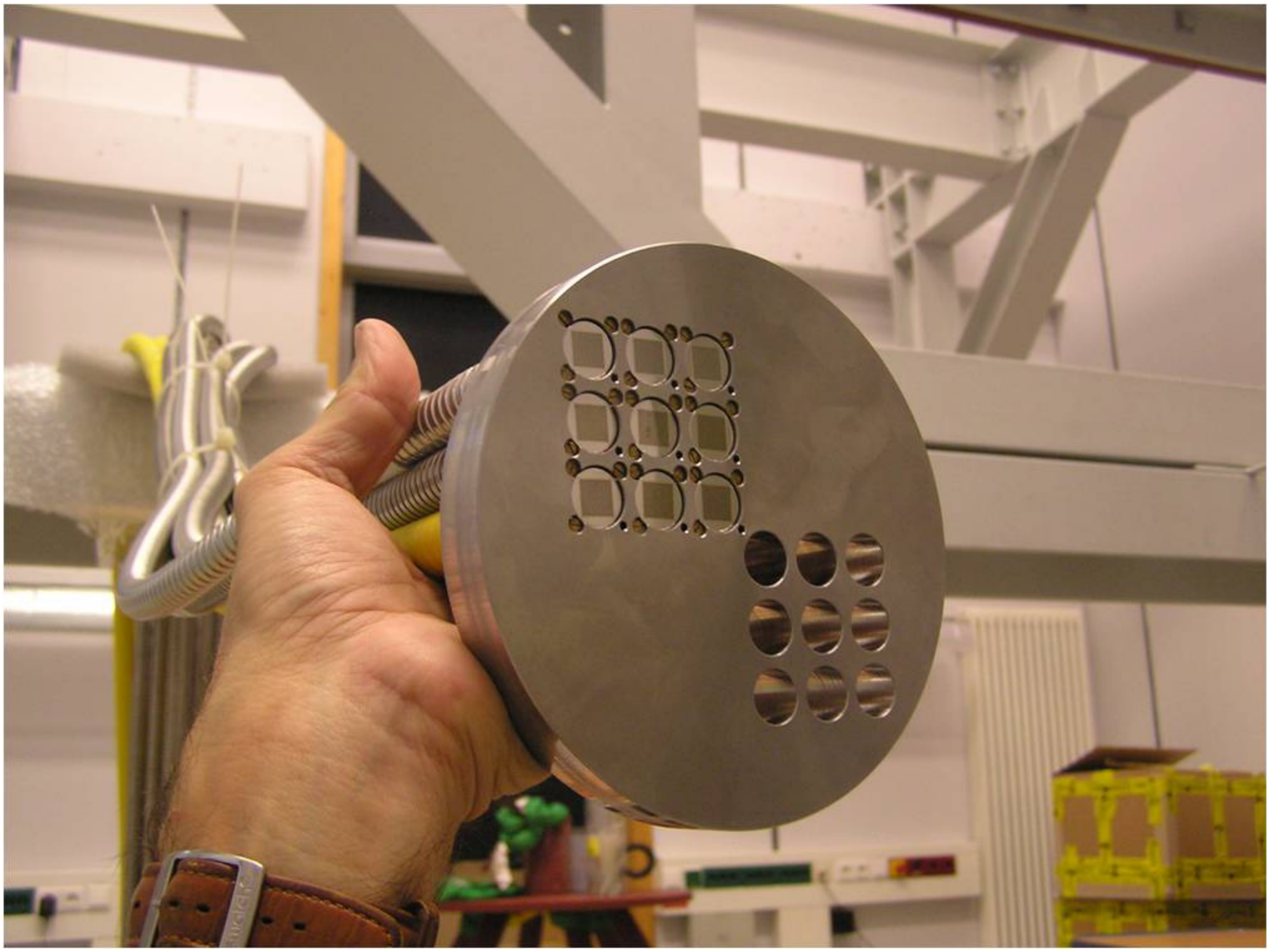

Figure 3: Picture of an IFU input head assembly in a preliminary plug plate using the first nine fiber bundles, featuring some 4000 individual fibers, which will feed 18 VIRUS-spectrographs.

4. ASSEMBLY PROCEDURES

4.1 Assembly fixtures

A main focus in the assembly procedure of the VIRUS instrument is to enable quick assembly of each unit spectrograph by precisely optically aligning each optical subassembly. Fixtures have been designed that will align each individual optical element precisely within its mount. This practice will minimize the time required to align each spectrograph and camera. The VIRUS alignment and assembly fixtures are discussed in more detail elsewhere in these proceedings[13].

4.2 Optical alignment

Each pair of VIRUS cameras is required to be interchangeable with any other pair of VIRUS collimator units. In order to meet this requirement we plan to align each VIRUS collimator with a "fiducial" camera and align each camera with a "fiducial" collimator. These fiducial units will be mechanically and optically identical to the other VIRUS units, and will provide a constant reference for the optical alignment amongst all 150+ VIRUS spectrographs.

Alignment of the collimators will be straightforward since the only optic that needs to move is the collimator. The folding flat and holographic grating will be permanently positioned (i.e., with epoxy) within their appropriate alignment tolerances in the instrument using alignment fixtures such as those described above. The instrument has been designed so that these tolerances are easily met with machine tolerances.

The camera units are aligned by changing the tip, tilt, and focus of the camera primary mirror. This is accomplished by installing a special camera vacuum vessel back cover that has feedthroughs that penetrate the vacuum and allow positioning of the camera mirror. The position is locked down, and the camera vacuum cover is changed to the permanent cover that has no vacuum feedthroughs. This process (removing the vacuum feedthroughs from the operational camera vacuum vessels) minimizes the chance of vacuum leaks and also saves cost on vacuum feedthroughs.

To speed the process of aligning the cameras we plan to create software that will transform the images produced on the CCD into instructions for tip/tilt/focus alignment moves of the camera primary mirror. The Schmidt corrector and the field flattener remain fixed during this process. This alignment procedure will be quick and straightforward so that a technician with minimal optics background can align the optics.

The collimator alignment procedure requires adjustment of the tip/tilt/focus of the collimator mirror. The folding flat and cylinder lens remain fixed. The fiducial camera will be attached to the collimator and a test fiber bundle will feed light into the instrument. This process should be sufficiently straightforward and deterministic so that we do not require software to aid in the alignment process.

5. CONCLUSION

The assembly of a multi-unit instrument such as VIRUS is a unique challenge in astronomical instrumentation. The design decisions involved in such an undertaking are numerous, but the main focus of our planning for the assembly and testing of the instrument have been to maximize efficiency of assembly in order to complete the instrument in a timely manner while minimizing cost to allow all 192 spectrographs to be built.

Texas A&M University is currently in the process of prototyping the unit spectrographs, while AIP is developing the manufacturing and testing process for the fiber bundles. Once the mechanical design of the spectrographs has been fully prototyped, by Fall 2010, we will begin production mode construction of the 150+ spectrographs. The fibers and the unit spectrographs will be installed on the telescope about 18 months after production mode construction of the spectrographs begins.

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