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Brian L. Vattiat, Gary J. Hill, Andreas Kelz, Jerry Martin, Emily Mrozinski, Thomas Jahn, Renny Spencer, "Deployment and handling of the VIRUS fiber integral field units," Proc. SPIE 10702, Ground-based and Airborne Instrumentation for Astronomy VII, 107028A (10 July 2018); doi: 10.1117/12.2314045

Event: SPIE Astronomical Telescopes + Instrumentation, 2018, Austin, Texas, United States

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ABSTRACT

The Hobby-Eberly Telescope Wide Field Upgrade includes deployment of the fiber-fed VIRUS and LRS2 spectrographs. In total, over 35,000 optical fibers of around 20m lengths are coupled to the telescope. This paper discusses the routing of those fibers, the hardware for securing them, and their deployment. Routing of the fibers to accommodate telescope motion while minimizing length and bend is presented. Hardware solutions for securing the fibers with details of the input and output terminations are included. Operations to safely install the fibers on the telescope are also covered.

Keywords: Integral Field Unit

1. INTRODUCTION

The VIRUS and LRS2 instruments utilize bundles of optical fiber to transmit light gathered from the telescope prime focus to the respective instruments. While the telescope prime focus moves in order to track celestial objects, the instruments are mounted in a stationary enclosure. Locating the instruments in a remote, stationary enclosure has several advantages; the payload carried by the telescope tracker is reduced, the instruments are placed outside of the path of light reaching the telescope primary mirror, and the gravity vector acting on the instruments remain static. However, this brings about several challenges; the fiber bundles must accommodate the tracker motion, the fiber bundles must be protected from stress due to their own weight and external forces, and the fiber bundles must be manually deployed on the telescope - spanning large distances at dangerous heights.

1.1 Hobby-Eberly Telescope

The Hobby-Eberly Telescope is a unique 10m telescope located in the Davis Mountains of west Texas. The telescope was recently upgraded for the Hobby-Eberly Telescope Dark Energy project. The upgrade includes increasing the field of view to 22 arcminutes and deploying an array of fiber-fed spectrographs. [1][2][3][4]

1.2 VIRUS and LRS2 Instruments

The VIRUS and LRS2 instruments are fiber-fed, integral field spectrographs. VIRUS consists of 75 copies of a 448 fiber, two CCD spectrograph [5-19] The LRS2 spectrograph consists of two variants of the VIRUS spectrograph with broader band pass. [20][21]

1.3 VIRUS and LRS2 Integral Field Unit

Each VIRUS and LRS2 Integral Field Unit (IFU) consist of an input head for interfacing with the telescope, an output head for interfacing with an instrument, and a fiber bundle housed in a protective conduit. At the time of writing, there are 54 VIRUS IFUs and 2 LRS2 IFUs deployed. The remainder of the VIRUS IFUs will be installed in two batches by the end of the year. The design, development, and testing of these IFUs is well documented. [22][23][24][25]

1.4 Objectives for optimal routing

The objectives for the IFU handling system were:

1. Eliminate the possibility of damage to fibers through use, even in the event of a cascade of failures of other safeguards such as tracker software and hardware limit switches.
2. Minimize the length of the IFU

Ground-based and Airborne Instrumentation for Astronomy VII, edited by Christopher J. Evans, Luc Simard, Hideki Takami, Proc. of SPIE Vol. 10702, 107028A · © 2018 SPIE · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2314045

Updated 3/20/14

3. Minimize the effect of the IFU loads due to gravity, wind, and other external forces on the stability of the science payload
4. Minimize the obscuration of the primary mirror with the IFUs and routing hardware
5. Provide a light and air seal between the dome environment and PFIP environment where the fiber bundles penetrate the PFIP enclosure

1.5 Areas of static routing, dynamic routing

When deployed, each IFU has portions of its fiber bundle that are static and portions that are dynamic. Near the input head, the fiber bundle is routed through a static tray. Near the output head, the fiber is also statically routed on the VIRUS enclosures to each instrument. The long section in between is dynamic and accommodates the tracker motions.

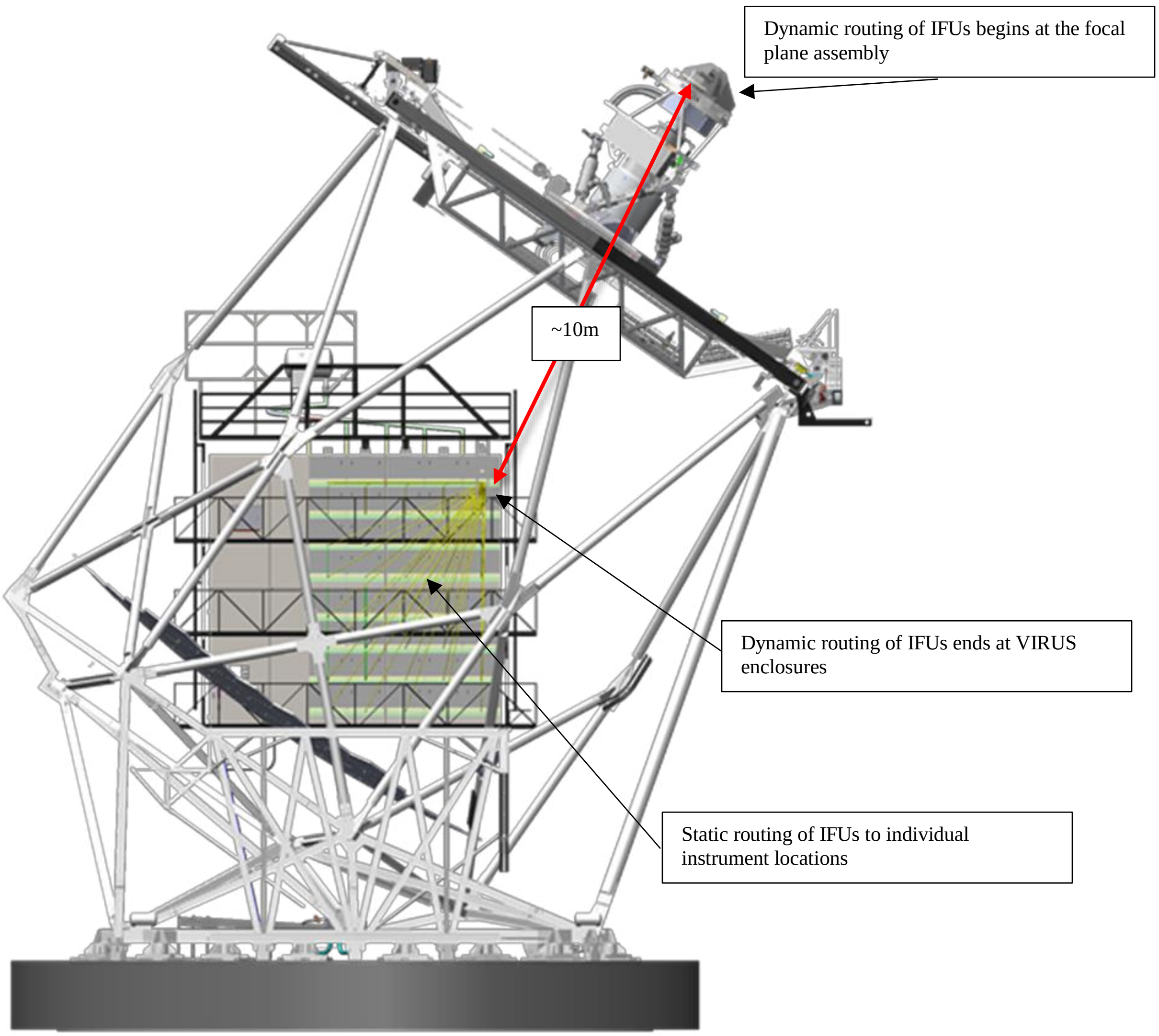


Figure 1. Side view illustration of beginning and end of dynamic run of fiber bundle.

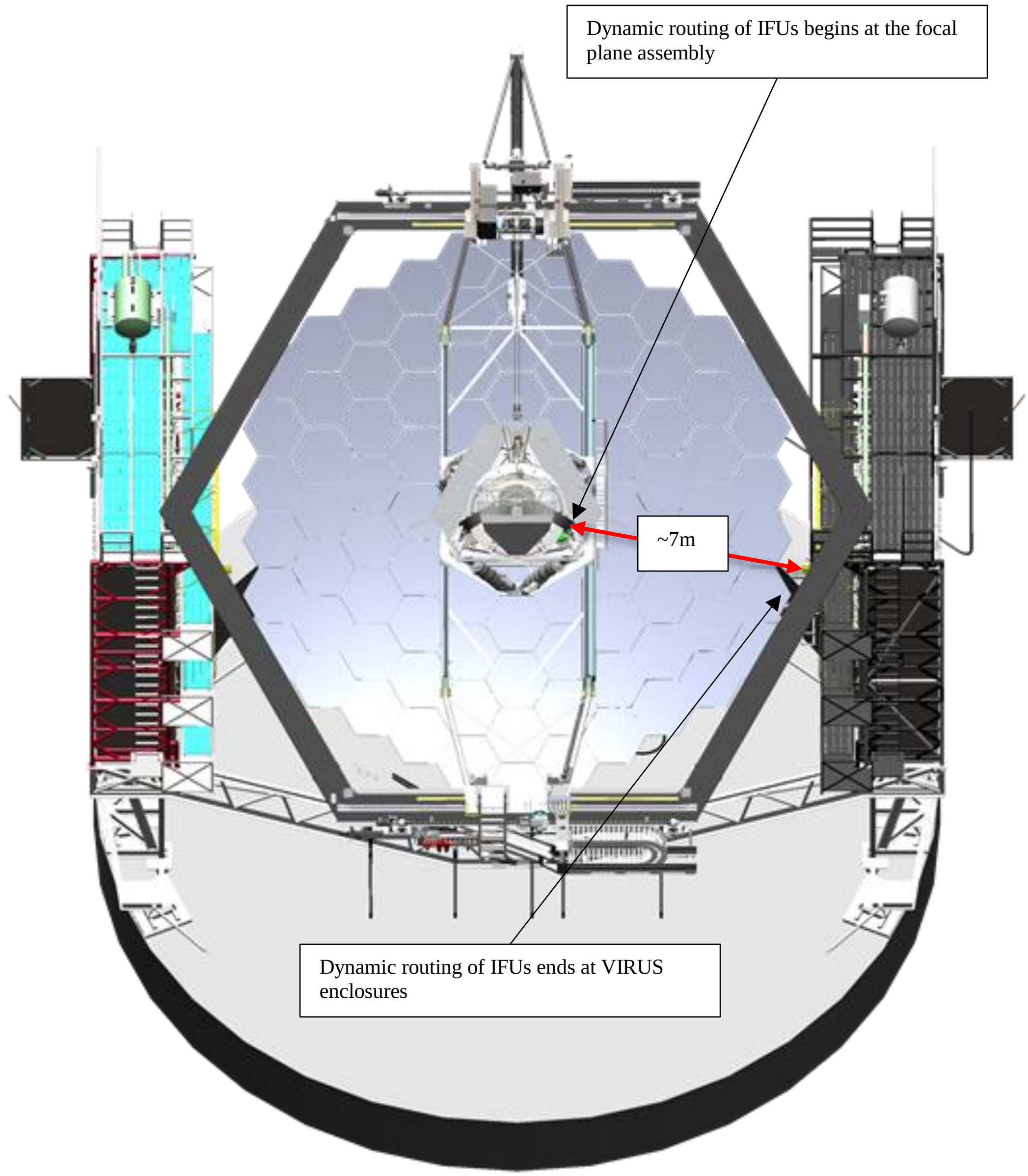


Figure 2. Top view illustration of beginning and end of dynamic run of fiber bundle.

2. TELESCOPE TRACKER MOTION

The Hobby-Eberly telescope is unique to other large telescopes in that the primary mirror is an array of spherically figured segments mounted at a fixed altitude. Tracking of celestial objects is achieved by actively positioning the Prime Focus Instrument Package (PFIP) over the stationary primary mirror [26][27]. The PFIP consists of the Wide Field Corrector (WFC) [28], metrology instrumentation for maintaining alignment and positioning of the telescope, and the science instrumentation (including the input heads for the VIRUS and LRS2 fiber bundles). The PFIP is mounted to the tracker which consists of a large two-axis stage and a hexapod (Stewart platform) [29][30]. Together, these motion platforms enable 18 degrees of spherical motion concentric with the primary mirror. For the primary mirror having a radius of curvature about 26m, the linear travel of the tracker is about 4m. In addition to the tracker spherical motion, the metrology and science instrumentation is mounted to a rotary platform needed for tracking the parallactic angle changes with diurnal motion. Total travel for the rotary platform is about 45 degrees.

3. FIBER BUNDLE ROUTING

Typical machine designs accommodate flexible cable and hose running between moving parts by using cable carrier chain. Such components are commercially available in a wide variety of capacities and lengths from suppliers such as Igus and others. In these designs, cables are routed through a series of cable carrier chains, one for each axis of motion. As a result, the lengths of cable required tends to be significantly longer than the distance of travel required, for multiple axis systems. However, for the optical fiber bundles used with VIRUS and LRS2, minimizing the total length is a high priority for design optimization. This is due to the cost of the fibers and the light loss per unit length of the fiber. Additionally, typical cable carrier chain designs rely on dynamic bends of small radii in order to provide compact designs. However, previous experience has shown that such bending can lead to migration of fibers within their protective conduit and relative to each other.

Our solution for routing a fiber bundle between the moving PFIP and the stationary instrument enclosure started with determining the straight-line length of cable needed when the PFIP is at its furthest possible position from the instrument enclosure. Making the fiber bundle anchored between these two points at least this length guaranteed that the telescope tracker could not damage the fibers in tension, assuming they are running a reasonably straight line and not caught by some other object. When the PFIP is at other positions, the excess can hang in gravity, along it's natural catenary. However, with some CAD modeling and physical mockups, it was obvious that those intermediate tracker poses could quite easily result in excess fiber bundle becoming caught in other tracker hardware. Additionally, by supporting the entire length of fiber bundle at only two positions, considerable external forces could be coupled into the metrology and science instrumentation and affect tracker stability and/or image quality issues.

Adding an additional anchor point along the length of fiber bundle ensures that excess would not become caught in other tracker hardware. By using the upper hexapod frame of the tracker as the attachment point, the effect of the fiber bundle weight and other external forces on the metrology and science instrumentation is minimized.

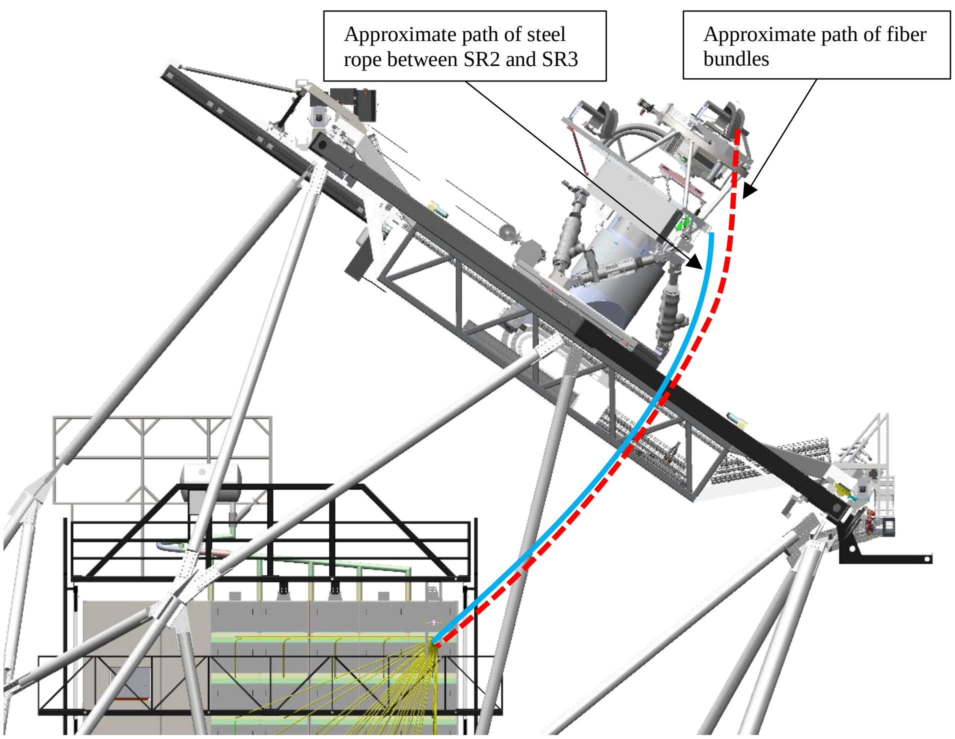


Figure 3. Illustration of approximate routing of fiber bundles viewed from the side

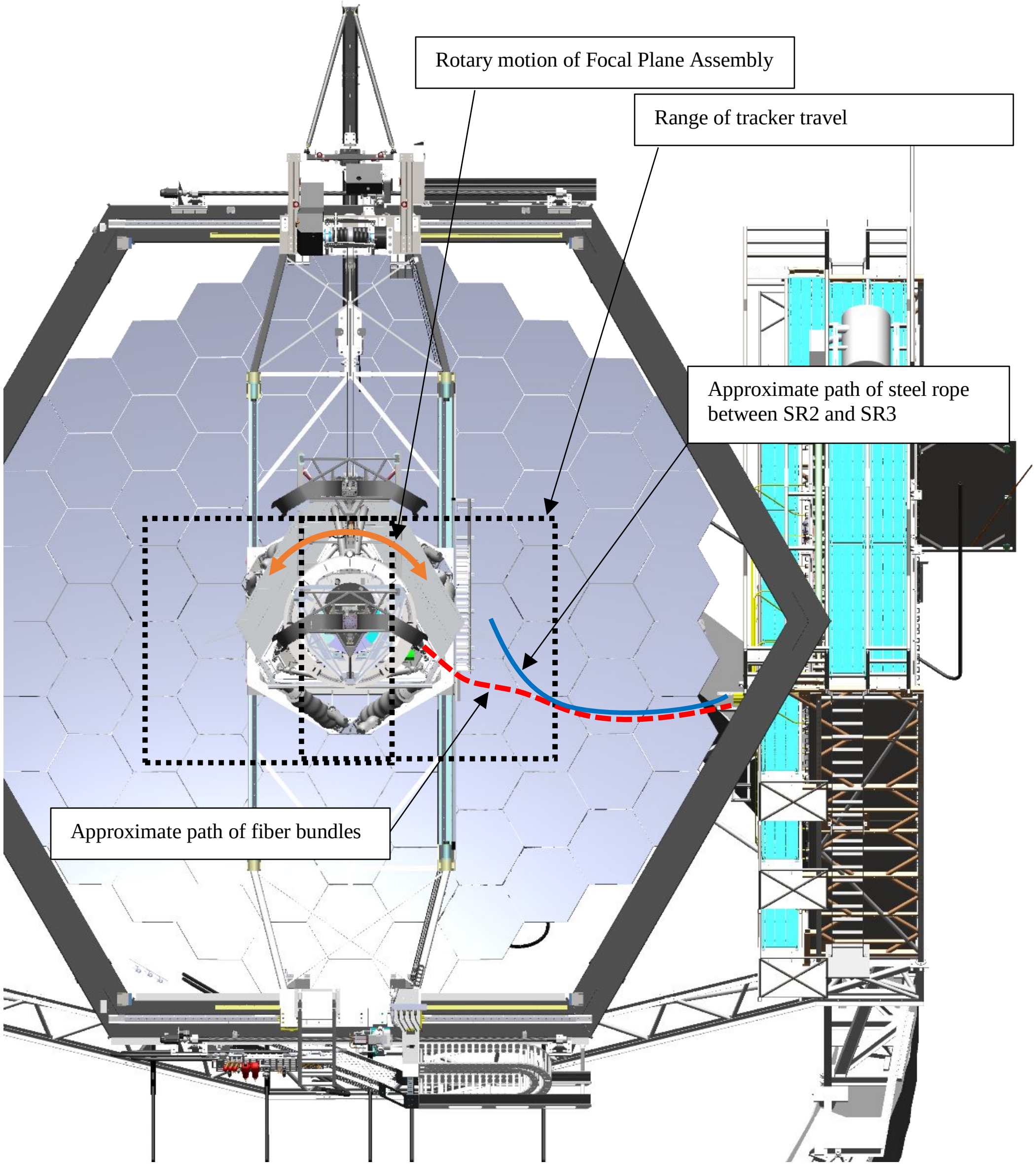


Figure 4. Illustration of approximate routing of fiber bundles viewed from top and range of motion of tracker

4. STRAIN RELIEF HARDWARE

4.1 Strain relief 1 (SR1)

Strain relief 1 consists of an Aluminum weldment mounted to the top of the PFIP. SR1 rotates with the rotary stage. The input head of each IFU is fixed to the Input Head Mount Plate (IHMP) at the telescope's focus. Here, the input face of the IFU is facing downward, toward the primary mirror. Strain relief 1 serves two purposes. The first is to provide a static fiber bundle routing, taking the fiber bundle through a ~180 degree turn starting at the input head and ending at a location outboard of the envelope of the rotary stage to which PFIP is mounted. The second purpose of SR1 is to counteract any forces imparted by the fiber bundles so that those do not couple into the science instrumentation. Each fiber bundle is secured by a collection of plastic zip-ties and aluminum bracketry. This was done in a somewhat ad-hoc and not entirely satisfactory way, making removal of an arbitrary IFU difficult or impossible. However, the arrangement is compact and any redesign will require significant rework of other hardware.

4.2 Strain relief 2 (SR2)

Strain relief 2 consists of an aluminum support to which one end of braided steel rope is anchored. The steel rope runs from its anchor point on SR2 to SR3. Strain relief 2 has two purposes. The first is to prevent excess fiber bundle from becoming caught on other hardware. The second purpose is to support the weight of the fiber bundles and to counteract other external forces transmitted by the fiber bundles. The fiber bundles are secured to the steel rope with straps spaced about 500mm apart. The fiber bundles are not secured to the steel rope in the area about 2m from the steel rope anchor point on SR2. This allows excess length of fiber bundle resulting from the rotary motion at SR1 to be taken up in the catenary curve between SR2 and SR3 rather than producing a small-radius bend near SR2

4.3 Strain relief 3 (SR3)

Strain relief 3 is the anchor point for the steel rope originating at SR2. Since the direction of the steel rope as it reaches the SR3 anchor point changes with tracker position, the anchor point is pointed to a two-axis joint. This ensures that the steel rope is in axial tension and not bending. After the last strap securing fiber bundles to steel rope, the individual fiber bundles follow diverging static routes to their respective instruments.

5. FLEXIBLE LIGHT AND AIR SEAL

The fiber bundles originate with the input head contained in the sealed and dark environment of the Focal Plane Assembly (FPA). The fiber bundles must exit the FPA enclosure and pass through the dome environment. The penetration through the FPA enclosure must also be sealed against air and light. Since the fiber bundle routing is dynamic as it leaves the FPA, a flexible seal was required. This was accomplished with a flexible fabric “sock” that secures to the FPA enclosure at one end and wraps around the fiber bundles at the other end. The fabric used is a 210 denier nylon fabric with urethane coating on one side. Hook and loop closures were sewn into the fabric and adhered to the enclosure in order to provide a means for easily removal and installation. Figure 5 shows the deployed fabric sock.

Figure 5. Fabric sock deployed over fiber bundle penetration of FPA enclosure.

6. PREPARING THE TELESCOPE FOR IFU DEPLOYMENT

Preparing the telescope for IFU deployment requires that the telescope tracker is stationary at all times. Procedures to disable and lockout the tracker must be followed once work to prepare for IFU deployment commences. The dome is a head protection required area once preparation for IFU deployment commences.

The design of the IFU input heads requires access to the underside of the IHMP in order to fasten the three screws which secure IFU input head to mounting plate. The underside of the IHMP is not normally accessible since it is surrounded by other instrumentation hardware. As a result, a service position is required for IFU deployment which allows easy access to both top and bottom of the IHMP. Since SR1 and the IHMP are constrained to each other by any previously deployed IFUs, the service position must also support the SR1 hardware in addition to the IHMP. No accessible mounting point for the IHMP and SR1 existed so a deployable work platform was designed and built.

Moving the IHMP and SR1 to the work platform requires the overhead crane which is attached to the telescope dome. Keeping the IHMP and SR1 assemblies at their nominal 35 degree angle with respect to gravity requires that a trio of lifting straps be selected and secured to SR1 and the crane hook. Additionally, since the IHMP and SR1 are constrained to each other only through the previously deployed fiber bundles, temporary hardware brackets were fabricated to secure the IHMP to SR1 during crane lifting and IFU deployment.

The length of fiber bundle between SR1 and SR2 was selected to accommodate the motion of the rotary stage on which SR1 is mounted. However, moving the IHMP and SR1 to its work platform requires a greater length of fiber. The additional length of fiber bundle is obtained by moving the excess fiber bundle between the SR2-SR3 run to the SR1-SR2 run. This can be safely done since IFU deployment operations are done at the center of tracker travel and excess fiber bundle length between SR2 and SR3 is available. Transferring the excess fiber bundle from SR2-SR3 to SR1-SR2 is accomplished with a chain winch. One end of the winch is secured to the steel rope anchor point on SR2. The other end of the winch is secured to the location of the first strap securing fiber bundles to the steel rope. When the winch is contracted, an additional 1.5-2m of fiber bundle is available for moving the IHMP and SR1 to the work platform.

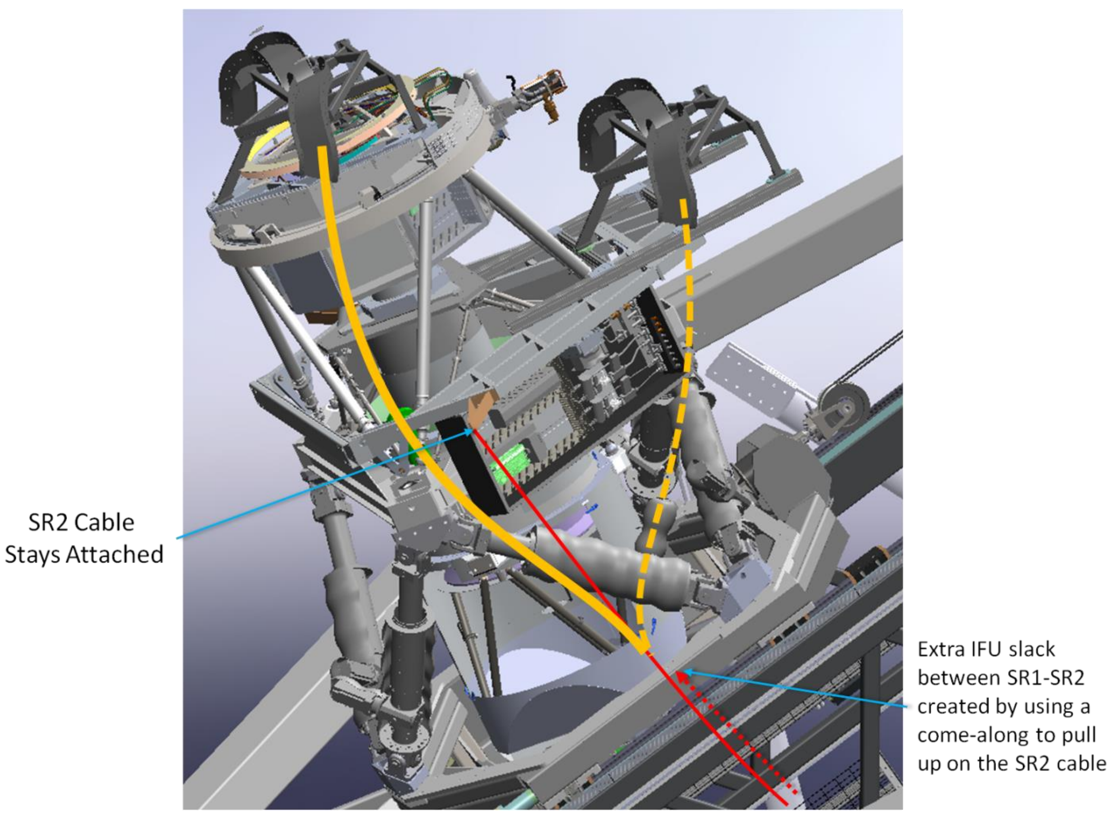


Figure 6. Illustration of the input head mount plate and strain relief 1 hardware to the work platform

Lifting and moving the IHMP and SR1 to its work platform requires three people positioned on or near the PFIP structure. One person can operate the crane controller with one hand and stabilize the load with another hand. Two other people are needed for guiding and stabilizing the payload and then securing it to the work platform. Once the IHMP and SR1 are secured to the work platform, IFU deployment can begin.

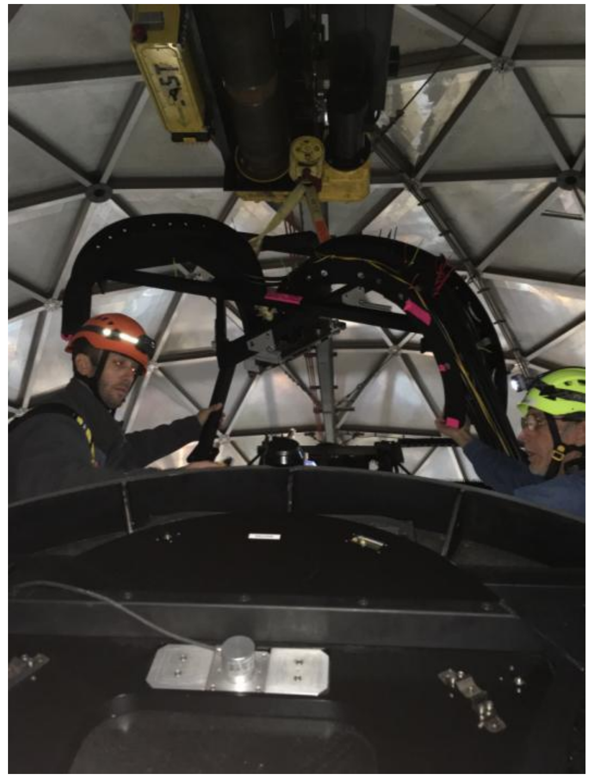
 

Figure 7. Left photo shows the IHMP and SR1 assembly being lifted from its mount on the focal plane assembly.
Figure 8. Right photo shows IHMP and SR1 assembly suspended from dome crane

7. DEPLOYMENT

7.1 IFU deployment procedure

The process of deploying IFU is as follows:

1. The IFU is wound onto a spool so that the input head is at the external end of the spool and the output head is placed onto the top of the spool, with the portion of fiber bundle that exits the output head to then be routed along the top flange of the spool into the core of the spool. Care must be taken during this step and throughout the process to avoid introducing twists into the fiber bundle as this can introduce stresses in the fibers.
2. The IFU and spool are mounted to a lifting fixture
3. The HET dome crane is used to lift the spooled IFU to the top of the VIRUS enclosure
4. The spooled IFU is removed from the lifting fixture and placed onto a de-spooling fixture secured to the top of the VIRUS enclosure
5. A HET technician passes the IFU input head to another technician waiting in an adjacent articulating boom lift.
6. The boom lift is then driven to the work platform while a technician on the VIRUS enclosure controls the IFU de-spooling

7. The IFU input head is then passed from technician in the boom lift to a technician waiting above the IHMP work platform and inserted into its assigned socket in the IHMP
8. A technician working below the IHMP work platform then installs the three M2 screws securing IFU to IHMP
9. The technician working above the IHMP secures the IFU to the SR1 structure with plastic zip ties and other brackets while the technician in the boom lift secures the IFU to the steel rope running between SR2 and SR3
10. The technician on the top of the VIRUS enclosure then passes the IFU output head to technicians on the scaffolding in the side of the VIRUS enclosure and the output head is then installed on an awaiting instrument or secured inside the enclosure for a future instrument deployment.

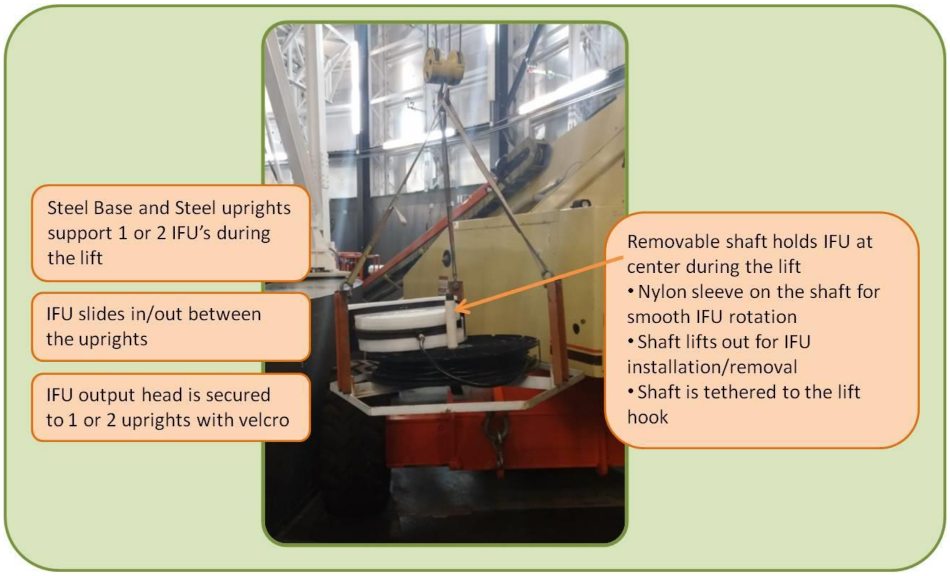


Figure 9. Fixture for lifting spooled IFU from dome floor to the top of the VIRUS enclosure with dome crane

7.2 Consideration for volume deployment

The effort required to prepare the telescope for IFU deployment is significant and so deploying multiple IFUs at once makes efficient use of that effort. Establishing an assembly-line style process for deployment results in a safe and efficient operation. Stationing technicians at each IFU handling point reduces the amount of climbing required and the potential for accidents. Deployments of 15 IFUs per day have been achieved when using as many as nine technicians at once:

- Two technicians on the dome floor, loading spooled IFUs onto the lifting fixture and operating the dome crane
- Two technicians on top of the VIRUS enclosure
- Two technicians on the VIRUS enclosure scaffolding, handling IFU output heads
- One technician riding the articulating boom lift
- One technician above the IHMP work platform
- One technician below the IHMP platform

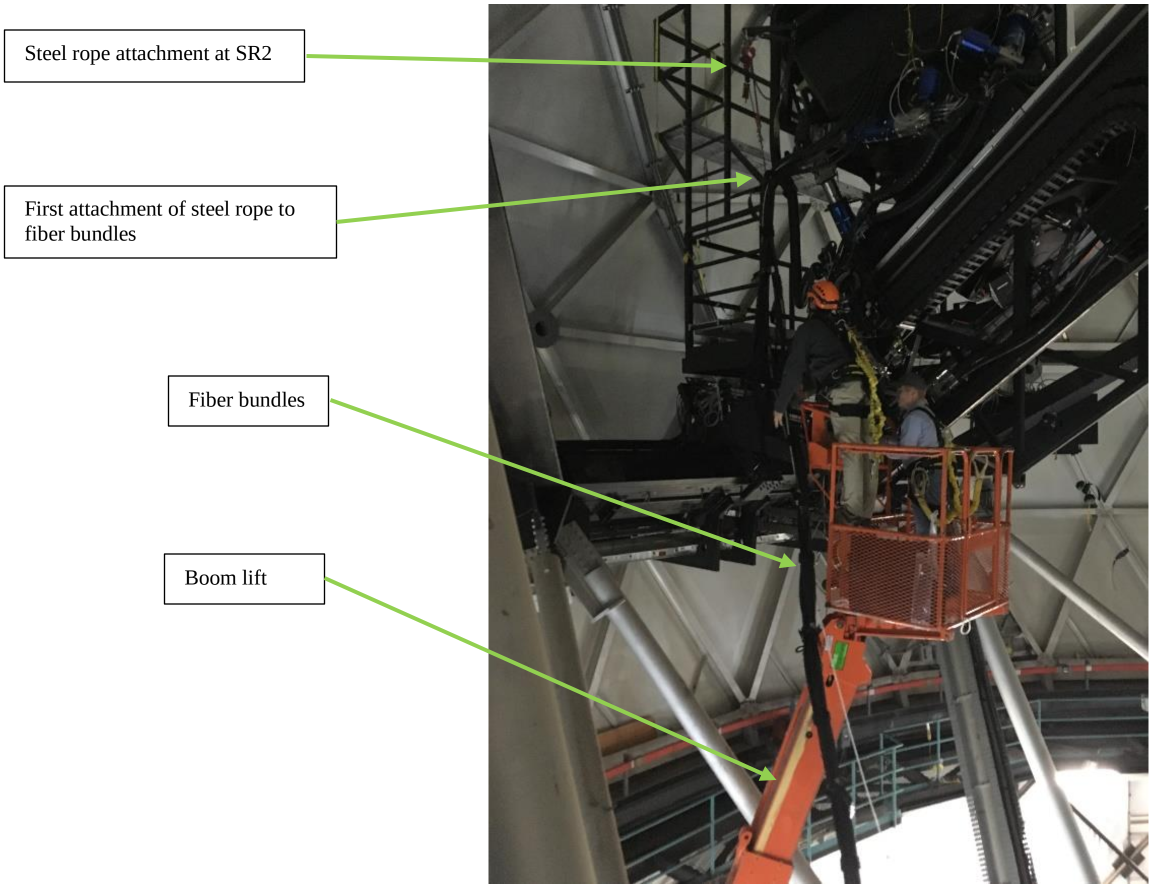
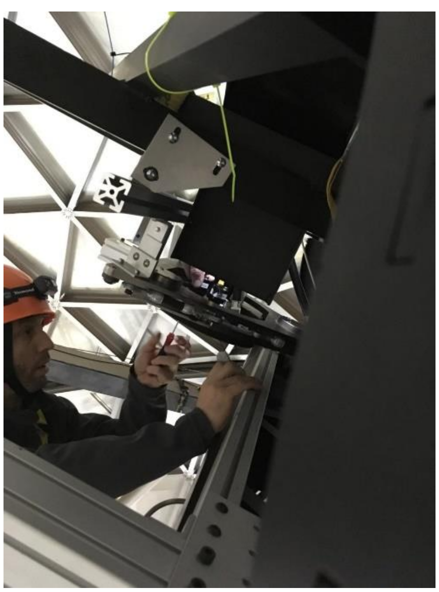


Figure 10. A boom lift being used to secure fiber bundles to the steel rope running between SR2 and SR3



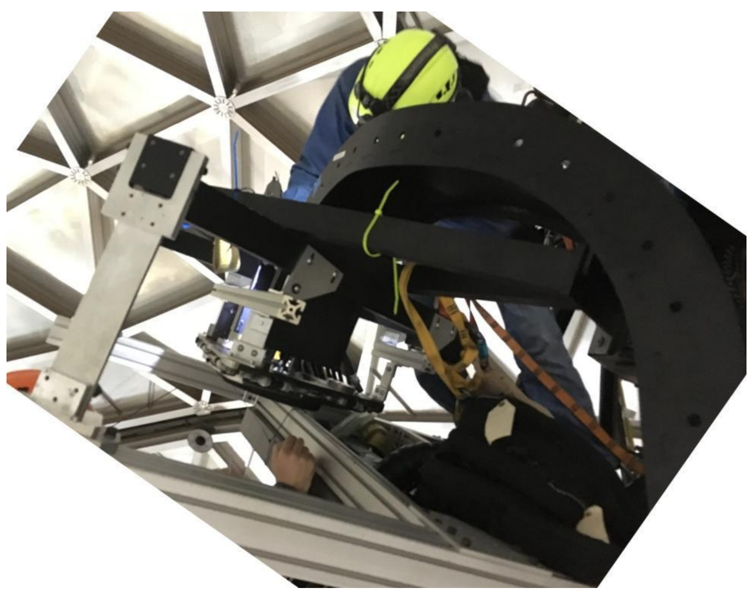


Figure 11. Left photo shows access to the bottom of the input head plate when mounted to the work platform

Figure 12. Right photo shows access to the top of the input head mount plate when mounted to the work platform

8. POST IFU DEPLOYMENT TASKS

8.1 Verification of tracker travel

Once all of the newly deployed IFUs are secured to the strain reliefs, the IHMP and SR1 must be returned from work platform to their nominal positions. This process is simply the reverse of the pre-deployment process. After each deployment, the tracker must also be exercised through its range of motion to ensure there is sufficient slack in the fiber bundles and that there are no other unforeseen problems such as slippage of the fiber bundles. The tracker XY stage is moved through its range of motion as well as the rotary stage. Normally, when the tracker is moved, the hexapod is positioned to keep the PFIP concentric with the primary mirror. However, it is possible for the hexapod to assume a pose not concentric with the primary mirror. This could occur by intentionally bypassing and/or the failure of safeguards. Such a configuration could require a greater length of fiber bundle needed to span SR1-SR2-SR3. Exercising the tracker in this manner, under controlled conditions and technicians observing from multiple angles is necessary after major IFU deployments.

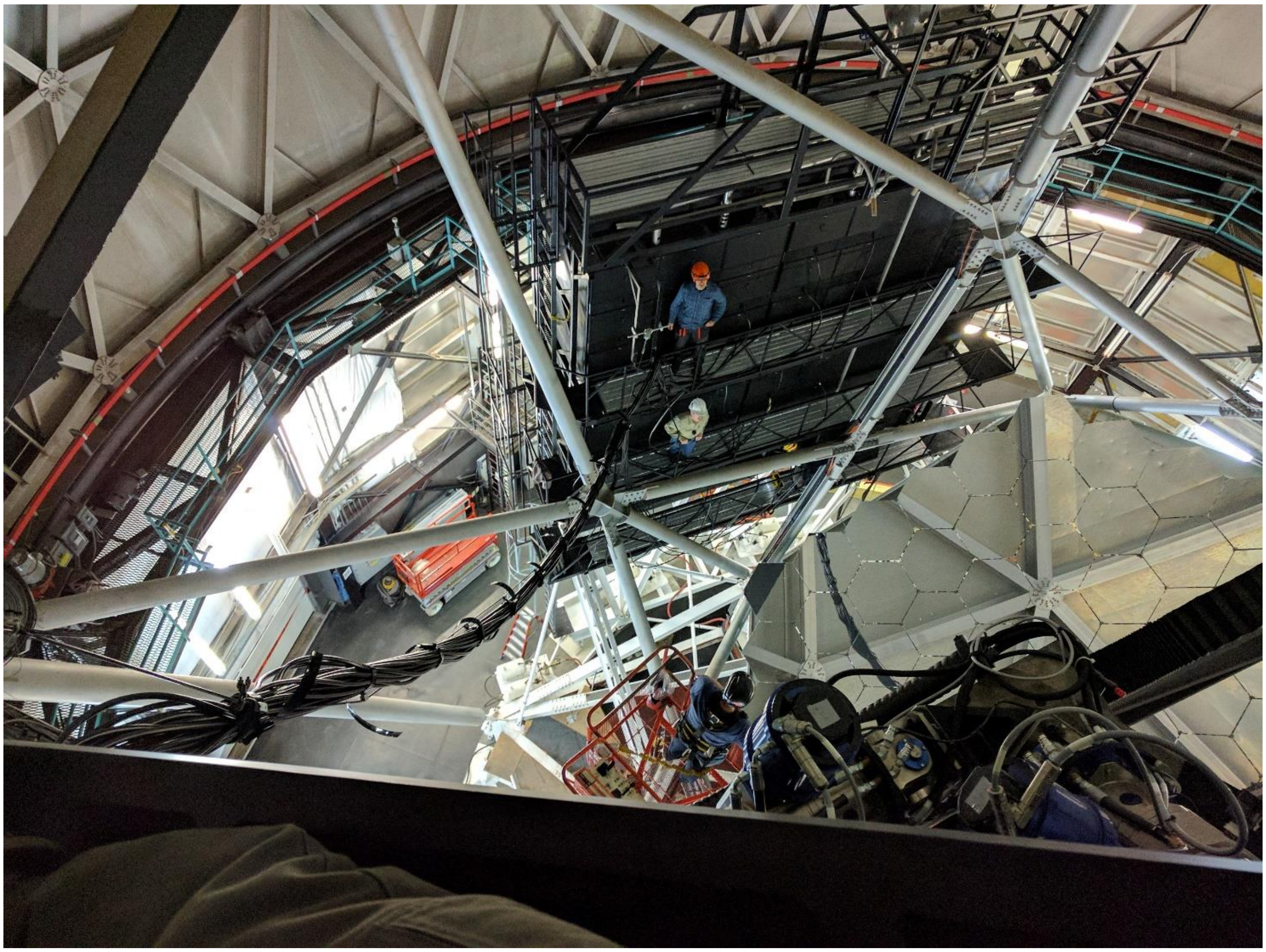


Figure 13. Photo of fiber bundles from SR2 (at left) to SR3 (image center) during test of tracker range of travel after IFU deployment

8.2 Checking IFU output head fibers

After deployment, each newly deployed IFU output head is opened to check the fibers transitioning from conduit to the pseudo-slit block. This is necessary because the protective conduit can stretch when loaded in tension. The output heads were designed such that the fibers are free from tension and form a natural curve in the area between pseudo-slit and conduit. The increase in length of the conduit can result in a migration of the fibers from the output head into the conduit and potentially stress the fibers where they attach to the pseudo-slit block. If necessary, the conduit end can be shifted in the output head to counter the effect and preserve a stress-free state of the fibers. Figure 14 shows the fibers inside of an IFU output head. In addition to post-deployment, this check is also performed periodically although no additional adjustments have been needed to date.

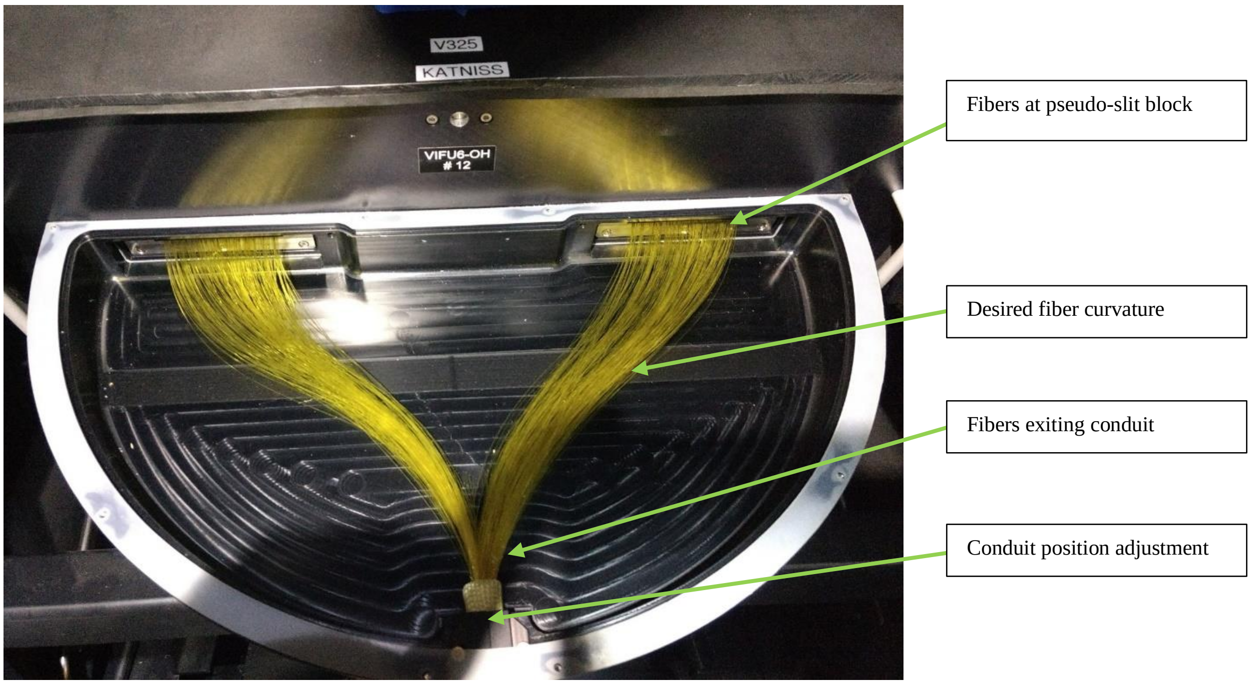


Figure 14. Photo of fibers inside IFU output head

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