Construction, testing, and commissioning of the SDSS-V Local Volume Mapper telescope system

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ABSTRACT

This paper presents an update on the construction, testing, and commissioning of the SDSS-V Local Volume Mapper (LVM) telescope system. LVM is one of three surveys that form the fifth generation of the Sloan Digital Sky Survey, and it will employ a coordinated network of four, 16-cm telescopes feeding three fiber spectrographs at the Las Campanas Observatory. The goal is to spectrally map approximately 2500 square degrees of the Galactic plane with 37” spatial resolution and R~4000 spectral resolution over the wavelength range 360-980 nm. LVM will also target the Magellanic Clouds and other Local Group galaxies.

Each of the four LVM telescopes consists of a two-mirror siderostat in alt-alt configuration feeding an optical breadboard. This produces a fixed, stable focal plane for the fiber-based Integral Field Unit (IFU). One telescope hosts the science IFU, while two others observe adjacent fields to calibrate geocoronal emission. The fourth telescope makes rapid observations of bright stars to compensate telluric absorption. The entrance slits of the spectrographs intersperse the fibers from all three types of telescope, producing truly simultaneous science and calibration exposures.

We summarize the final design of the telescope system and report on its construction, alignment and testing in the laboratory. We also describe our deployment plan for commissioning at LCO, anticipated for late 2022.

Keywords: LVM telescopes, telescope array, survey, Local Volume Mapper, SDSS-V

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1. INTRODUCTION

The Sloan Digital Sky Survey V (SDSS-V) is an all-sky spectroscopic survey of >6 million objects, designed to decode the history of the Milky Way, reveal the inner workings of stars, investigate the origin of solar systems, and track the growth of supermassive black holes across the Universe. The Local Volume Mapper (LVM) is one of three surveys that form SDSS-V. LVM seeks to map the entire Milky Way disk and nearby galaxies to understand how star formation and other processes shape the interstellar medium.

Accurately executing and calibrating a survey covering a substantial portion of the sky requires a unique type of instrument, and nowhere is this more true than with the design of the telescopes. Each of the four LVM telescopes consists of a two-mirror siderostat in horizontal, altitude-altitude configuration relaying the light to components on an optical breadboard protected by a dust-proof cover (Figure 1). This produces a fixed, stable focal plane for the microlens-based Integral Field Units (IFU's), which are connected to optical fiber bundles that convey the light to three spectrographs housed in an adjacent temperature-controlled chamber.

A custom-built enclosure with a roll-off roof protects the telescopes, IFU's, fiber bundles, and spectrographs, as well as the necessary support infrastructure, including calibration lamps, network and power, and a small observing room. The LVM Instrument is truly an international project, with contributions from five continents: North America, South America, Europe, Asia, and Australia. MPIA Heidelberg has primary responsibility for the LVM telescopes. Konidaris et al. (2020) and Herbst et al. (2020) provide further background on the LVM instrument and telescopes, respectively

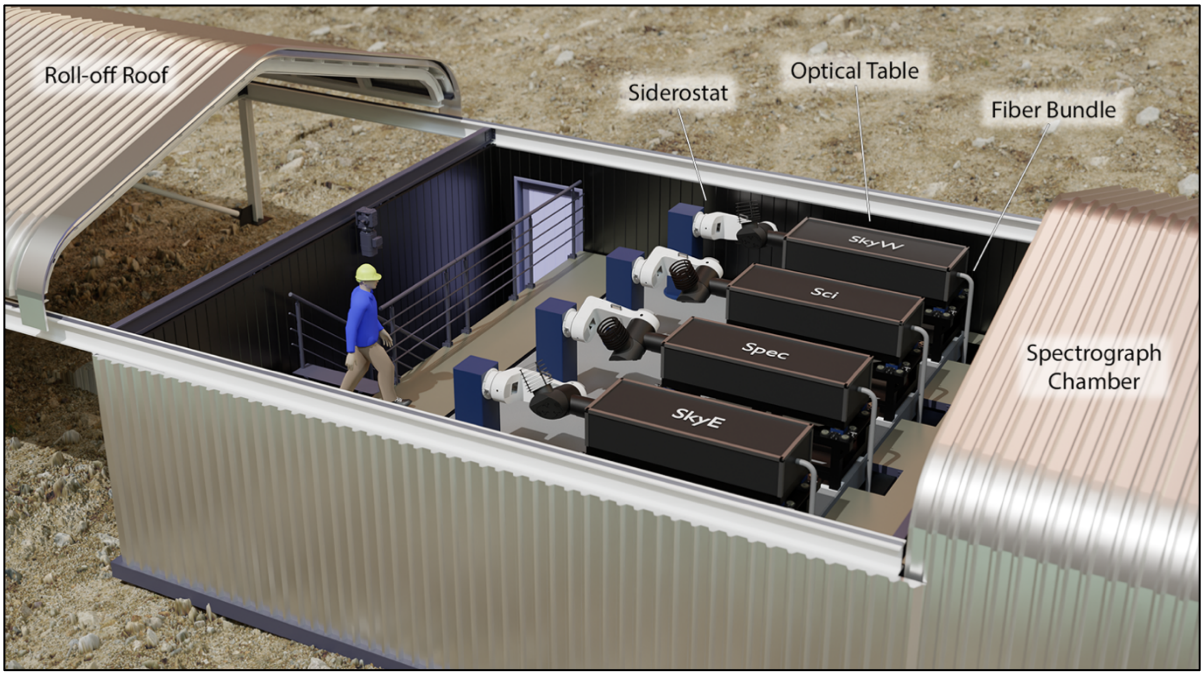

Figure 1: Each of the four LVM telescopes consists of a siderostat in horizontal, alt-alt configuration feeding fixed components on an optical table. Fiber bundles convey the light to an environmentally controlled spectrograph chamber, and a roll-off roof protects the instrument during daytime and inclement weather.

2. TELESCOPE ARCHITECTURE

As with previous Sloan surveys, the Local Volume Mapper depends on consistency in terms of both measurement and calibration to achieve its science goals, and this consistency has been a guiding principle in the design of the LVM telescopes. The overall telescope architecture was explicitly motivated by the need for simplicity and robustness in a multiyear, automated survey such as LVM. For example, with the exception of the siderostat, all elements are in a fixed, gravity invariant environment enclosed within a protective dust cover.

Error! Reference source not found. shows the telescope architecture and labels the major components. Formally, the LVM telescope system consists of all opto-mechanical elements between the sky and the microlenses of the fiber bundle. These elements include the siderostats, objective lenses, K-mirror de-rotators, Focal Plane Assemblies, and optical tables, as well as the associated electronics and low-level control software. Note that the Science and Sky calibration telescopes contain K-mirror de-rotators as shown in **Error! Reference source not found.**, while the fourth, Spectrophotometric telescope does not. It hosts a fiber selector mechanism in its focal plane for isolating the flux of individual bright stars. See Section 2.4 for details.

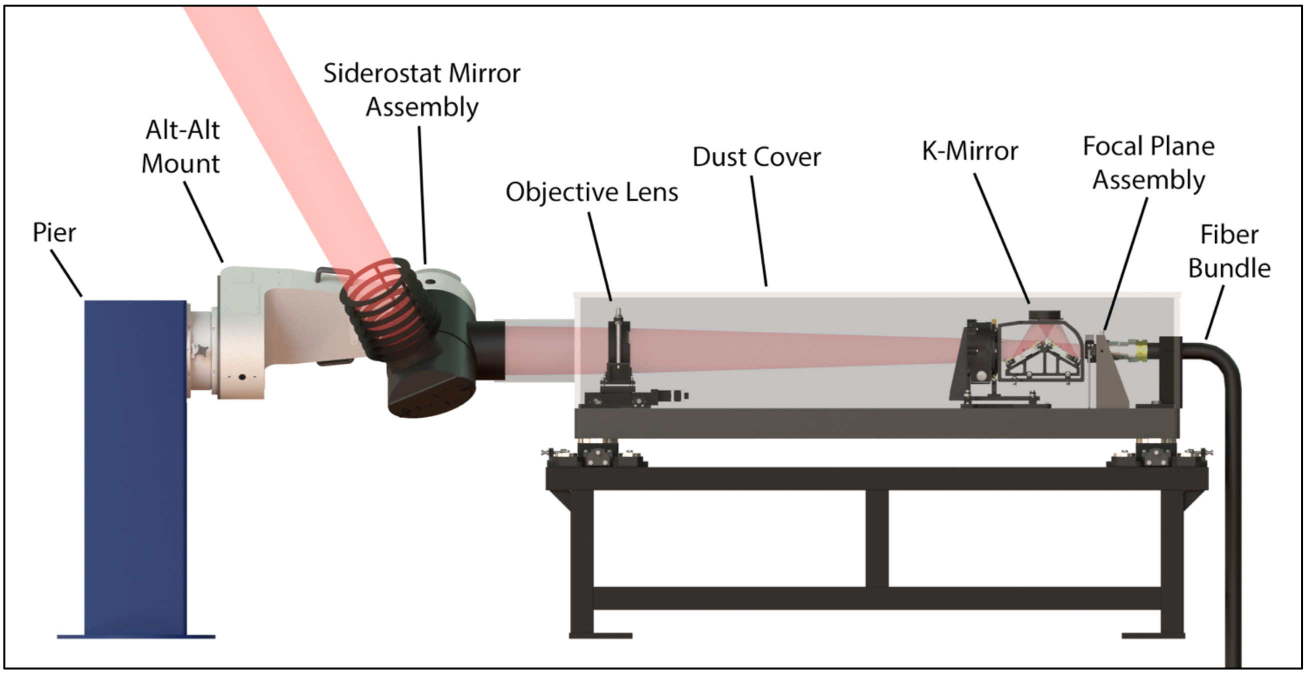

Figure 2: System architecture of the LVM telescopes. See text for details.

2.1 Siderostats

Physical motion of the IFU's and, in particular, the fiber bundles, can induce variations in focal ratio degradation and throughput that would negatively affect the global calibration of the LVM survey. As a result, the project set a requirement early on that the IFU focal plane must be fixed. This, in turn, establishes the requirement for an optical relay from the moving sky to a fixed location, in other words, a siderostat. After some exploration of alternatives, the telescope team selected the 2-mirror siderostat / optical table configuration shown in **Error! Reference source not found.**.

The LVM siderostats employ a commercial L-350 mount from Planewave Instruments (Adrian, MI, USA) operating in altitude-altitude configuration. This alt-alt architecture offers numerous advantages, including very modest requirements on sky tracking rates and the natural ability to feed a stable, horizontal instrument platform, for example, an optical table.

Pleiger Laseroptik (Witten, DE) are producing the siderostat mirrors. These are relatively large components (28 x 20cm elliptical, 5 cm thick) with protected silver coatings. The Pilot Group (Monrovia, CA, USA) have designed and are currently manufacturing the mirror cells, baffles, and piers.

2.2 Objective Lenses

LVM imposes some very demanding requirements on the powered optics: excellent image quality, extraordinarily broad wavelength coverage, and insensitivity to temperature change. The LVM objective lenses are bonded triplets of N-BAK2 glass from Schott (Mainz, DE) and monocrystalline CaF_2 elements from Hellma (Jena, DE). LVM telescope team members at Carnegie Observatories created the design, and Optimax (Ontario, NY, USA) produced and anti-reflection coated the individual lenses. Thereafter, Carnegie bonded the lenses to BAK2 – CaF_2 – BAK2 triplets using SYLGARD 184 by Dow Silicones (Midland, MI, USA), and then mounted them in a precision aluminum barrel with machined reference points for attaching the alignment target (see Section 4.1). A motorized focusing mechanism designed and built at MPIA provides the interface to the optical table.

Note that Lanz et al. (paper 12184-218, this conference) provide a complete description of the objective lens design, manufacturing, and testing.

2.3 K-Mirror De-Rotators

Conveying light from the siderostats to a fixed, stable focal plane introduces time-variable image rotation. We therefore must have an image de-rotator to both align the hexagonal footprint of the IFU correctly on the sky and to maintain that orientation during an exposure (see Figure 4). To accomplish this, the LVM telescopes use custom K-mirror de-rotators consisting of three flat mirrors mounted to a precision commercial motorized stage from Physik Instrumente (Karlsruhe, DE – see Figure 3). Kautz Engineering (Regensburg, DE) designed the mechanical components, while Materion-Balzers (Jena, DE) produced the mirrors. With conventional aluminum or silver coatings, three reflections can significantly degrade throughput, particularly at near UV wavelengths. As a result, the K-mirrors have high-performance dielectric coatings with reflectivity greater than 99.5% across the full range of LVM operating wavelengths.

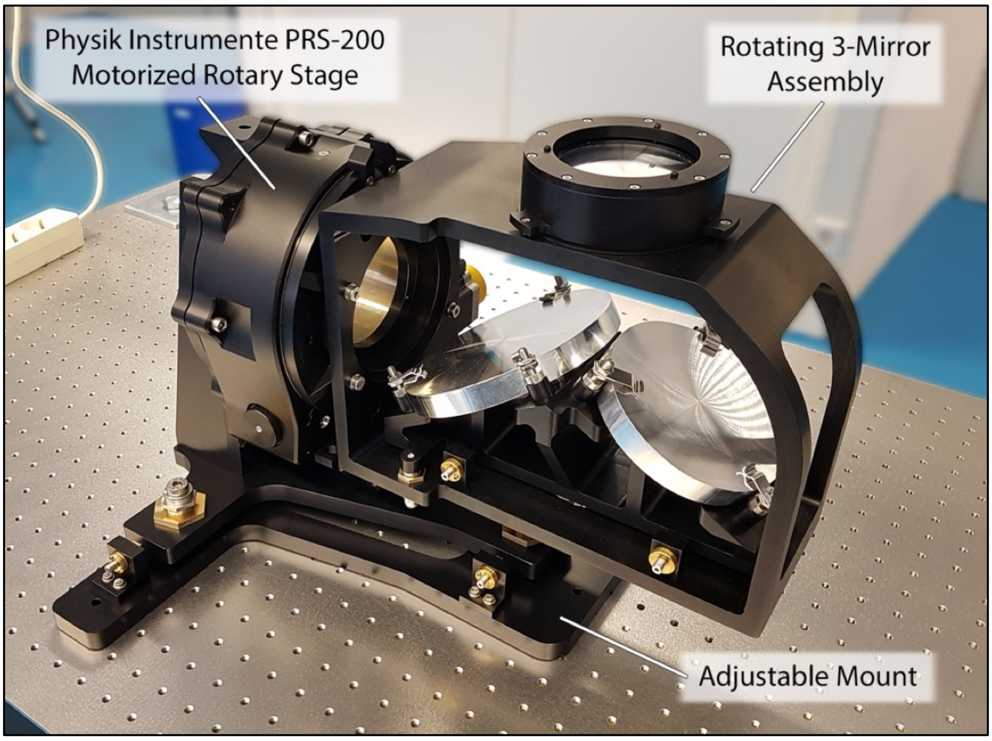

Figure 3: The K-mirror de-rotators combine three, high performance flat mirrors with a precision commercial rotary stage to cancel the field rotation induced by the combination of a moving telescope with a fixed focal plane. Note that this image shows the de-rotator with aluminum dummy mirrors used for preliminary assembly and functionality tests.

2.4 Focal Plane Assemblies

As mentioned above, the four LVM telescopes fall into two broad categories: the Sci and Sky telescopes, which require K-mirror de-rotators, and the Spec telescope, which lacks a K-mirror but has additional hardware for individual fiber selection.

Figure 4 below shows the focal plane layout for each of the telescopes. This is the view looking toward the fiber bundle, in other words, in the direction that light travels. The Sci telescope hosts a large, 16.5 mm diameter IFU with 1801 fibers and two CMOS Acquisition and Guiding (AG) sensors. The two Sky telescopes have smaller, 3.3 mm diameter IFUs, one with 60 and the other with 59 fibers, in addition to two AG sensors. Finally, the Spec telescope has an IFU identical to that in the Sci telescope, but with only 24 populated fiber locations. A hole mask sequentially selects bright reference stars on individual fibers during 12 individual pointings during an overall exposure (see Sections 2.4.2 and 3). These pointings are short (1-minute), and hence open-loop tracking suffices. As a result, the Spectrophotometric telescope hosts a single AG sensor which performs acquisition only.

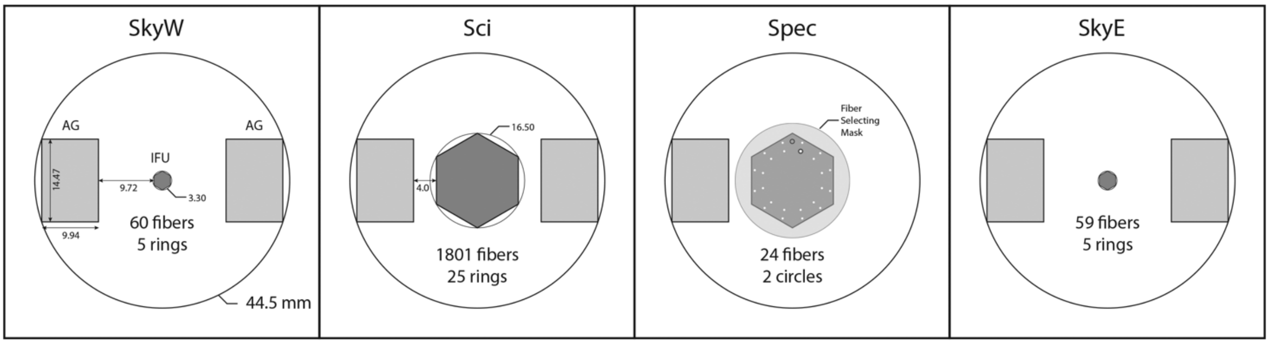

Figure 4: The focal plane layout for the four LVM telescopes. See text for details.

As of this writing (June 2022), we have manufactured two Focal Plane Assemblies (FPA), one of three for the Sci/Sky telescopes and the one for the Spec telescope (Figure 5). MPIA produced the design and manufactured all of the mechanical components.

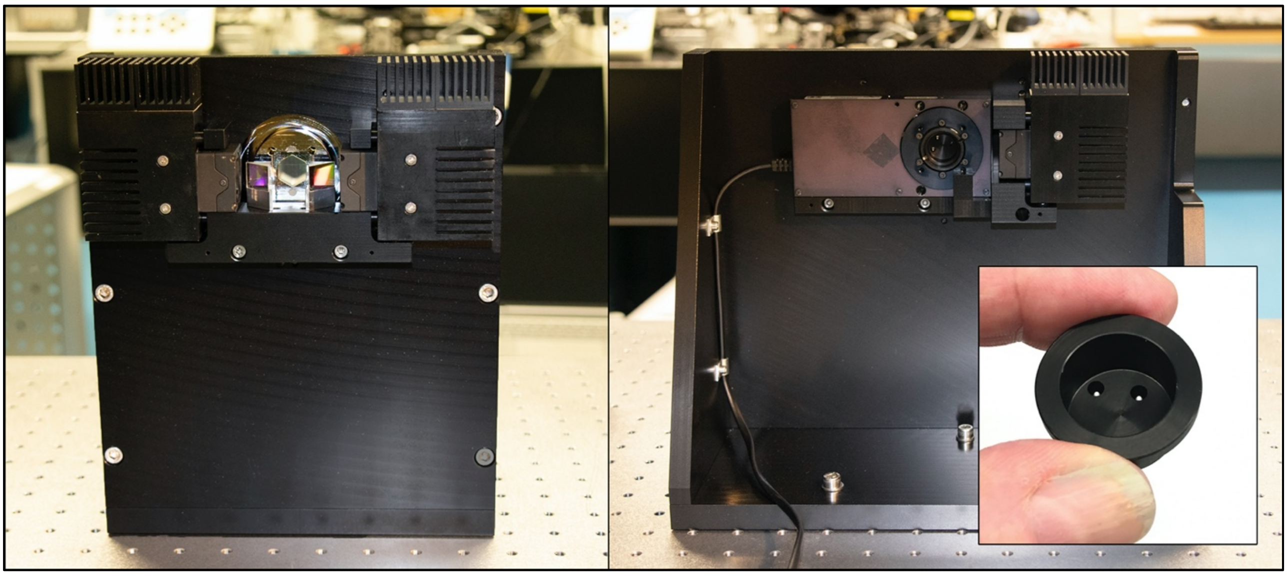

Figure 5:The Focal Plane Assemblies for the Sci/Sky telescopes (left), and the Spec telescope (right). The inset shows the rotating mask for the spectrophotometric fiber selector (see Section 2.4.2).

In addition to supporting the AG sensors and fiber selection hardware, the FPAs serve as the interface to the IFU and fiber bundles produced by LVM colleagues at Australian Astronomical Optics. And, as described in Section 4 below, the three, precision mount points for the IFU assembly form the fundamental reference for aligning the entire telescope.

2.4.1 Acquisition and Guide Hardware

To avoid partial vignetting of the beam converging to focus, the minimum gap between the large IFU and the 45° mirrors feeding the AG sensors is 4 mm. This issue also drove the requirement for a 44.5 mm or 1.4° overall delivered field of view shown in Figure 4. Although the guide fields could in principle be much closer to the IFUs for the Sky telescopes, we have prioritized standardization in the LVM project. Thus, all of the objective lenses, K-mirrors, and (where possible) focal plane hardware are the same. Note that, for compactness and precision mounting, the fold mirrors are actually BK-7 prisms from Precision Optics Gera (Gera, DE), with the hypotenuse coated with protected silver.

LVM uses seven Acquisition and Guide sensors: two each for the Sci and Sky telescopes and one for the Spec telescope. These sensors are commercial monochrome FLIR Blackfly S GigE cameras equipped with the Sony IMX432 CMOS detector. This device has a (relatively) large, 9 µm pixel pitch, which corresponds to 1 arcsec on sky, an excellent match to LVM's 3-arcsec image quality requirement. Note that the FLIR housings required modification to allow more compact packaging in the Focal Plane Assemblies.

We procured and characterized a total of nine AG cameras, including seven for deployment in the telescopes plus one spare. A final FLIR device equipped with a colour sensor will serve as an on-axis camera at the location of the IFUs for early, on-sky testing (see Section 5). Häberle et al. (paper 12184-25, this conference) describe the laboratory characterization and optimization of the AG cameras, while Kuhlberg et al. (paper 12184-261, this conference) present our planning for on-sky testing.

2.4.2 Spectrophotometric Fiber Selector

As mentioned above, the Spectrophotometric telescope makes 12 separate observations of bright stars during the 15-minute period of a single survey exposure, and, without additional hardware, each of the 12 active spectrophotometric fibers will receive unwanted light for 14 of those 15 minutes. In order to prevent excess background and contamination, a fiber selecting mask in the focal plane exposes individual fiber tips to light one at a time (Figure 5). A compact motorized rotary stage, model PR50PP from Newport, drives the selection mask.

Note that there are 24 populated fiber locations in the Spec IFU. Only twelve are used per observation; the remaining twelve are spares. See Section 3.3.4 of Herbst et al. (2020) for further details.

2.5 Optical Tables

The four optical tables are identical, and their design has heritage from the VLT Gravity instrument. A custom rigid support produced by D.H. Frank (Nußloch, DE) mates to a 210x75 cm commercial breadboard from Ametek (Meerbusch, DE). This breadboard has M6 threaded holes on a 25mm raster, allowing us to use the full complement of standard optical table equipment and infrastructure. Thanks to commercial mechanisms from Airloc (Franklin, MA, USA), this configuration provides the necessary adjustment range in XYZ position and tip-tilt (see Section 4), and it has demonstrated the required performance at the VLT, another seismically active observatory.

2.6 Electronics and Software

The LVM telescope system contains eight motorized mechanisms: four objective lens focusers, three K-mirror de-rotators, and one fiber selector. Based on successful experience in the field and in-house heritage, we are using standard MPIA motor controller units driven by our "Twice as Nice" middleware, a combination that has been deployed for several instruments at 2-8 m class telescopes. We have produced two motor units (Figure 6), giving us a hot-swappable spare at Las Campanas.

Figure 6: Front (left) and rear (middle) views of the electronics rack containing two MPIA motor controller units, and some of the cables which connect the controller to the telescopes (right). Note the woven stainless-steel sheathing to prevent damage by rodents.

3. OPERATING PRINCIPLE

As emphasized in this paper, calibration and consistency are key to the success of the LVM survey. For this reason, the 1944 fibers from the four telescopes (1801 Sci, 60 + 59 Sky, and 24 Spec) are interspersed on the entrance slits of the three spectrographs. Figure 4 of Feger et al. 2020 shows the fiber allocation scheme. Each spectrograph thus yields 644 individual traces – 600 Sci, 40 Sky, and 4 Spec taken through the same atmosphere at the same time (recall from Section 2.4.2 that only 12 of the Spec fibers are exposed). As the survey progresses, we will gather better and better understanding of the performance of each telescope, fiber, and spectrograph, allowing reliable and consistent overall calibration.

At the beginning of an observation, the four telescopes slew to and acquire their targets, and the K-mirrors move to their initial angles. Feedback from the AG cameras allows fine corrections for pointing, rotation, and focus, if necessary. The fifteen-minute survey exposure begins when all telescopes are ready. The Sci and Sky telescopes track and de-rotate on their targets for the full exposure, while the Spec telescope points at 12 different bright calibration stars for approximately 1 minute each during the 15 minutes. The rotating mask in the Spec telescope prevents contamination during calibration star acquisition. At the end of the exposure, the telescopes move to and acquire their next target during readout of the CCDs in the spectrographs. The Planewave mounts can achieve 50° per second slew speeds, so we anticipate little dead time between exposures.

4. TELESCOPE INTEGRATION AND ALIGNMENT

Figure 2 shows the overall architecture and components of the LVM telescopes. What is less obvious from the figure is that we have adopted perhaps the simplest configuration to integrate and align. All of the powered elements are contained within a single, internally-aligned lens barrel. The optical components before and after this objective lens are all flat, reducing the impact of potential decentrations. And in this arrangement, any tilts of the flat mirrors correspond essentially to pointing errors or field rotations, which will be guided out by the AG sensors or removed by offsetting the K-mirror, respectively.

We also use what are effectively standard optical breadboards, in order to exploit their flexibility in mounting and to take advantage of the vast array of alignment and measurement tools already at hand. Among these tools are custom reflecting targets, an Alignment-Autocollimator telescope (AA), and a Point Source Microscope (PSM).

4.1 Custom Reflecting Targets and Alignment Autocollimator

We employ custom reflecting targets to align most of the LVM components. These targets are diamond-turned aluminum mirrors with a precise central mark on each side. The reflecting portion acts as a mirror for the AA in autocollimator mode, allowing us to adjust the tip-tilt of the component. Adjusting the AA to finite conjugate, or alignment mode, then provides a measure of the decentration. Thus, with a single opto-mechanical configuration, we can align the component in all degrees of freedom except focus, which is uncritical, as all of the optical elements except the objective lens are flat. In total, we have three such targets: one for the objective lens and pier, one for the K-mirror, and one for the Focal Plane Assembly (Figure 8).

4.2 Point Source Microscope

The LVM survey strategy depends on accurate control of the look direction and focus of the telescope. This, in turn, means understanding the relative positions and tilts of the elements in the focal plane, namely the AG cameras, the fiber IFU, and the spectrophotometric fiber selector. We use a Point Source Microscope from Armstrong Optical (Northampton, UK) coupled with a long working-distance 10X objective from Mitutoyo for focal plane metrology (see Step 9 in Section 4.3).

4.3 Integration and Alignment Procedure

As mentioned in Section 2.4, three precision machined pads on the FPA interface plate form the fundamental reference for aligning the telescopes. This location hosts the reflective target for both the Alignment Autocollimator and the Point Source Microscope, as well as serving as the ultimate mount location for the IFU fiber bundle. The overall alignment approach requires initial placement of the hardware components within the capture range of their respective adjustment mechanism, followed by fine tuning of position and tip-tilt using either the AA or the PSM.

Figure 7 illustrates the sequence of steps for integration and alignment. As the procedure involves exploiting and then passing on the fundamental alignment reference, these steps must be executed sequentially. The following sections describe each of these steps in more detail.

Step 1. Install the optical table, FPA interface plate, and Alignment Autocollimator

After craning the optical table onto the telescope platform, we use a precision compass to align it North-South and bolt it down. We then loosely bolt the FPA interface plate in place on the breadboard and install the alignment autocollimator on a temporary table extension.

Step 2. Align the FPA interface plate to the AA

Using two simple height-of-flight targets 20 cm above the table surface, we roughly align the look direction of the alignment autocollimator. This is followed by installation of the reflecting target on the three reference pads of the FPA interface plate. We can then use the AA to make any necessary crude adjustments of the yaw of the FPA before bolting it down. At this point, the reflecting target becomes the fundamental reference. Fine adjustment of the AA in position and angle then transfers this reference to the alignment autocollimator, and we remove the reflecting target.

Step 3. Install the pier and align the optical table to it

We lift the pier onto the telescope platform and bolt it loosely into place. Using a small portable crane, we unload the pier, allowing manual repositioning. Note that the siderostat piers are simple steel weldments and offer no adjustment beyond simple shimming. Instead, we align the optical breadboard to the pier using the Airloc adjusters described in Section 2.5. We begin this alignment procedure by installing the azimuth drive of the Planewave mount on the pier and then attaching a reflecting target to the rotating portion of the drive. The alignment autocollimator then assists with fine tuning of the pier location prior to bolting it permanently in place. At this point, we use the breadboard adjusters to do the actual alignment of the table to the pier.

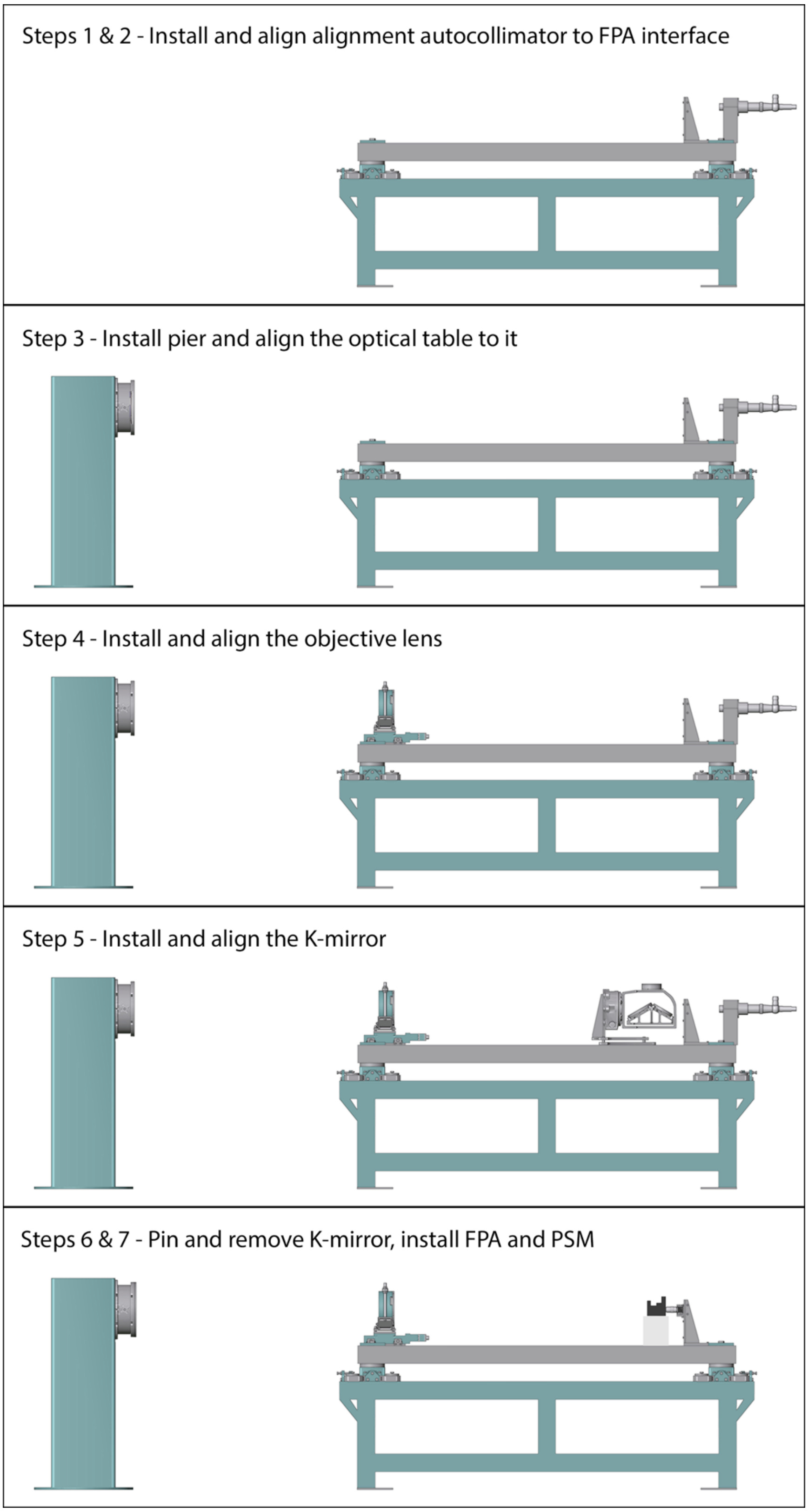

Figure 7: Integration and alignment sequence for the LVM telescopes.

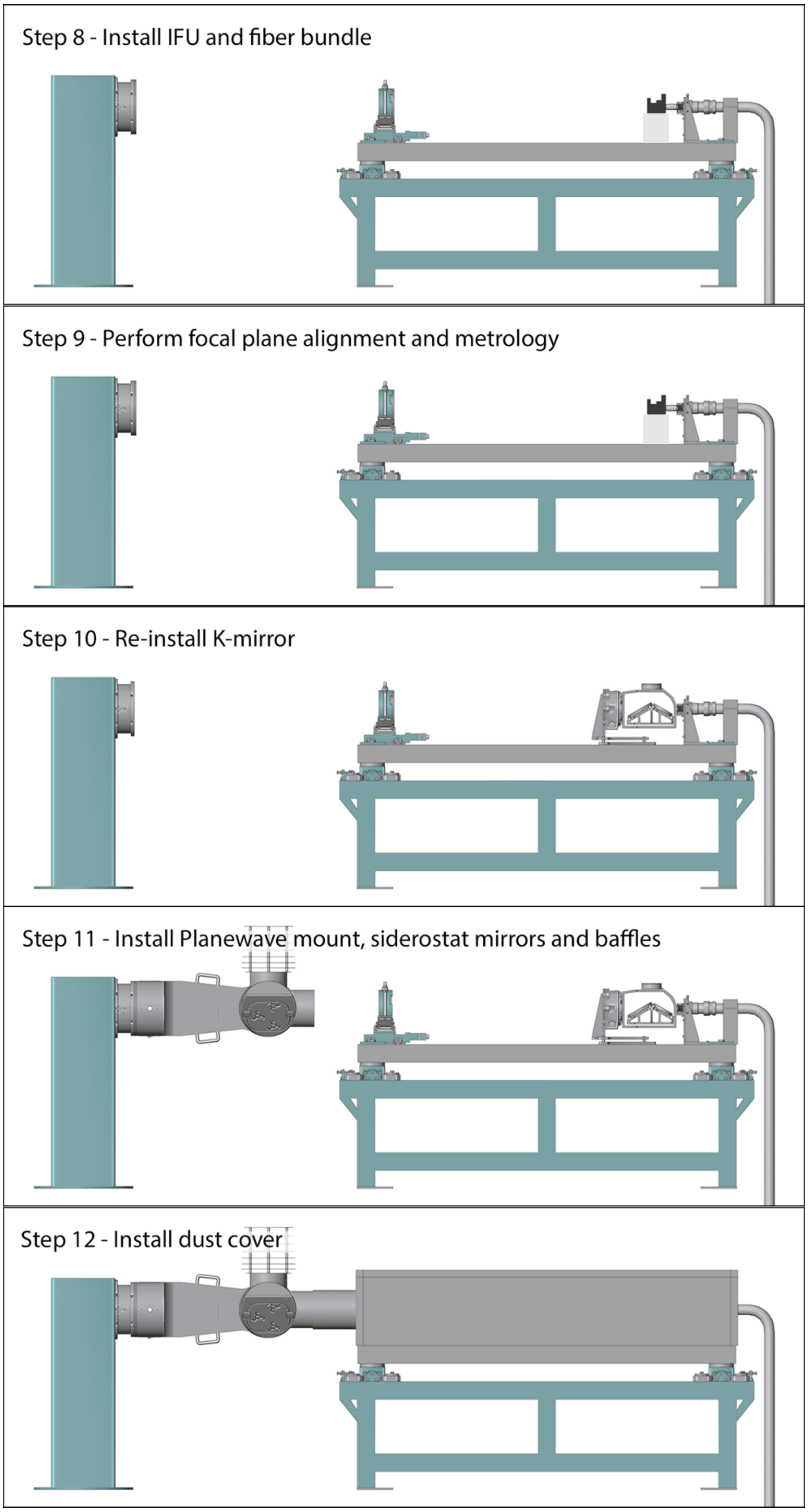

Figure 7 (continued): Integration and alignment sequence for the LVM telescopes.

Step 4. Install and align the objective lens

The reflecting target for pier/table alignment also serves as the target for the objective lens. We begin by loosely installing the focuser mechanics, clamping the lens barrel in place, and transferring the target from the pier to the three precision mount points on the lens barrel. We then iteratively adjust the lens in position and tip-tilt using the AA reference. Locking the height adjusters and attachment bolts of the focuser mechanics then completes the procedure.

Step 5. Install and align the K-mirror (Sci/Sky telescopes only)

K-mirror alignment is essentially identical to that for the objective lens. We use a reflecting target mounted in the bearing of the precision rotary drive, coupled with the fundamental AA reference, to bring the K-mirror into alignment in position and tip-tilt. Again, locking the height adjusters and attachment bolts of the mechanics completes the procedure.

Step 6. Kinematically "pin" the K-mirror and then remove it (Sci/Sky telescopes only)

The LVM focal plane is crowded, particularly for the Science and Sky telescopes. In particular, the K-mirror occupies a volume that is subsequently needed for the Point Source Microscope during the metrology procedure (Step 9 below). To address this, we install standard optical bench kinematic stops to capture the location of the K-mirror and then unbolt and remove it.

Step 7. Install the Point Source Microscope and Focal Plane Assembly components

The alignment autocollimator has served as the fundamental reference for the preceding steps. At this point, its job is done, and we re-install the FPA reflecting target and verify its alignment. We can then remove the AA and the breadboard extension. The Point Source Microscope uses three precision digital micrometers for adjustment in XYZ. We bolt the PSM assembly loosely onto the breadboard and scan the surface reflecting target to adjust its pitch and yaw (Figure 8). Bolting the microscope firmly in place and measuring the location of the target center then transfers the fundamental reference to the PSM. We can then remove the reflecting target and install the remaining FPA hardware at their nominal positions. This includes the 45° mirrors, the spectrophotometric fiber selector, and the Acquisition and Guide cameras.

Step 8. Install the IFU and fiber bundle

Installation of the IFU fiber bundle is a three-step process. We begin by bolting an x-y-rotation stage to the three reference pads of the FPA interface plate. The fiber cables are heavy – particularly in the case of the Sci telescope – and hence, we then install a bundle support block for strain relief. Finally, we connect the IFU/fiber bundle to the x-y-θ stage using its bayonet mount and tighten the clamp on the support block.

Step 9. Perform focal plane alignment and metrology

As mentioned in Step 7, the fundamental position and tip-tilt reference now resides in the Point Source Microscope. We use the measured 3-dimensional location of the IFU microlenses and the AG camera pixels to adjust their position and tip-tilt to coincide with this reference. In the case of the IFU, we measure several points around the periphery of a number of microlenses to locate their centers and hence the overall orientation of the IFU. Push bolts on the x-y-θ stage allow adjustment of the location and rotation in the focal plane, while shimming of three precision pins in the connector provide tip-tilt correction. Measuring and adjusting the AG cameras follows a similar procedure, although in this case, we illuminate individual pixels with the PSM's point source and read out the sensors to derive the 3D location. The mounting brackets of the AG cameras have 3 attachment points with pre-sized shims. Modification of these shims allows tip-tilt and focus adjustment.

Note that the AG cameras do not need to be at a particular location in the focal plane, but we do need to know where they are. Once the IFU and AG cameras are optically coplanar with the focal plane defined by the PSM, we measure their relative positions to sub-arcsecond on-sky accuracy. These measurements then allow us to use the AG images for both pointing and focus. Note that for the Spec telescope, we also calibrate and verify the positioning of the fiber selector mask. Häberle et al. (this conference) discuss the focal plane metrology in more detail.

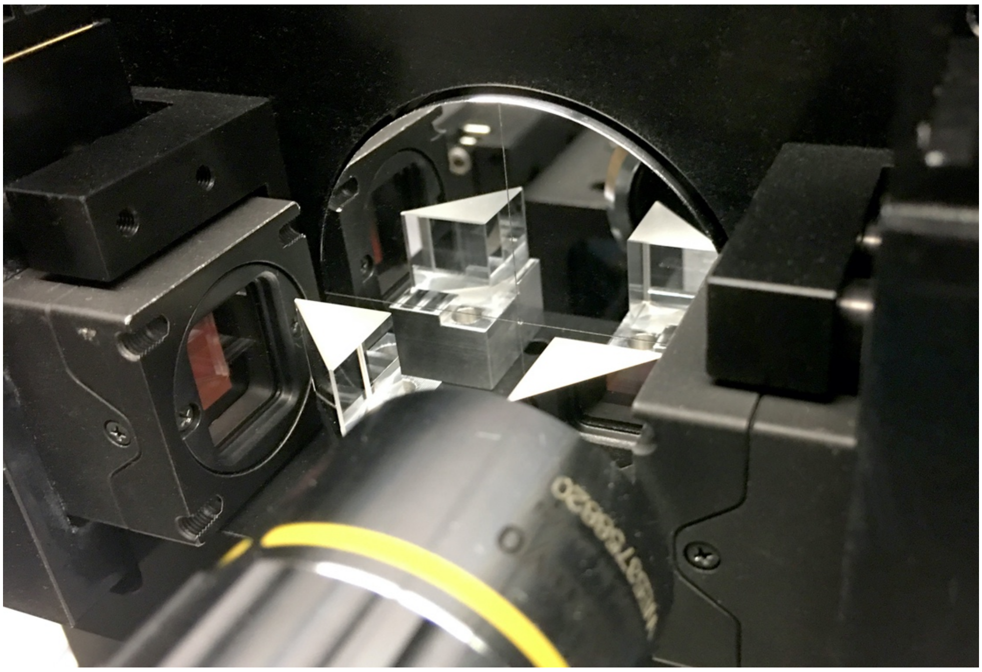

Figure 8: Scanning the surface of the reflecting target to transfer the fundamental reference to the Point Source Microscope (Step 7). Note that these prism mirrors and their mounts are temporary. The final versions will be blackened to minimize scattered light.

Step 10. Re-install the K-mirror (Sci/Sky telescopes only)

At this stage, focal plane alignment and metrology are complete, and we can remove the Point Source Microscope. We then re-install the K-mirror using the previously installed kinematic stops to return it to its correct location. The optical table is now aligned.

Step 11. Install the Planewave mount, siderostat mirrors, and baffles

With all of the components on the optical tables now in place, we turn our attention to the siderostat. Using the small mobile crane, we install the L-arm of the Planewave mount, the mirror cells, and the baffles.

Step 12. Install the dust cover

The final integration step is installation of the protective dust cover on the optical table. This cover is a modular assembly of carbon fiber panels clipped to a framework built of standard aluminum extrusions. Once the main cover is complete, we attach the cylindrical baffle extension connecting the table to the siderostat.

5. LABORATORY AND ON-SKY TESTING

We have adopted a hierarchical approach to testing of the LVM telescopes, beginning with component-level verification and subsystem tests through full telescope integration and on-sky observations. Each of the individual optical elements has or will undergo full-aperture interferometric measurements to verify as-built surface figure, and we are characterizing the opto-mechanical performance of the objective lens plus focuser, K-mirror, and Focal Plane Assemblies. Additional laboratory activities include fine tuning the thermal management of the AG cameras (see Häberle et al., this conference) and verification that the Planewave mount software operates correctly in the horizontal alt-alt configuration (Kuhlberg et al., this conference).

Despite thorough verification and testing, there will inevitably be surprises when the complete system comes together, and we have learned through difficult experience that solving problems is far more difficult and time consuming at the observatory. This challenge is particularly acute for the control software. As a result, we have planned from the beginning of the project to test a complete, integrated telescope in the laboratory and, if possible, on-sky. At the time of this conference (mid-July 2022), we are casting a 1.5 x 4m concrete platform – large enough for a single LVM telescope – just north of the main building on the MPIA campus. We will execute all of the integration, alignment, and testing operations using this facility in preparation for deployment at Las Campanas. These procedures include everything from craning the tables into place to simulating individual exposure sequences for both the Sci/Sky and Spec telescopes. Kuhlberg et al. (paper 12184-261, this conference) detail our plans for on-sky testing.

6. DEPLOYMENT AND COMMISSIONING

The Local Volume Mapper represents a completely new hardware development, from the enclosure to the telescopes to the CCD sensors of the spectrographs. Essentially all of this development work took place during the Covid 19 pandemic, and many of the collaborators on the geographically-dispersed teams have never met face to face nor visited the observatory site. Needless to say, this presents unique challenges, particularly when it comes to the assembly, integration, testing, and commissioning phases.

The current plan is to ship much of the telescope hardware to Chile by late summer of 2022. Since the telescope units are essentially identical, we will retain one optical table / siderostat pair at MPIA for ongoing testing and software development (see previous section), while the remainder get installed at Las Campanas (Figure 9).

All hardware should be in place at the observatory by December 2022, allowing a focused commissioning period before science operations begin early in 2023. An early Science Verification (SV) phase will demonstrate that the LVM instrument meets specifications. The survey itself begins concurrently with SV. Initially, all measurements will be controlled and monitored by remote observers, but we plan to migrate to increasingly robotic operations as the survey proceeds.

Finally, a map of the Local Volume cannot be entirely complete without coverage from the northern hemisphere. A sister facility, including a 1-meter telescope to map nearby galaxies, is under development for the Apache Point Observatory in New Mexico, the site of the northern components of the other SDSS-V surveys.

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Figure 9: Three of the four optical tables palletized and awaiting pickup for shipment to Chile in June 2022.

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