Current Status of the Hobby-Eberly Telescope* wide field upgrade

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ABSTRACT

The Hobby-Eberly Telescope (HET) is an innovative large telescope of 9.2 meter aperture, located in West Texas at the McDonald Observatory (MDO). The HET operates with a fixed segmented primary and has a tracker which moves the four-mirror corrector and prime focus instrument package to track the sidereal and non-sidereal motions of objects. A major upgrade of the HET is in progress that will increase the pupil size to 10 meters and the field of view to 22′ by replacing the corrector, tracker and prime focus instrument package. In addition to supporting the existing suite of instruments, this wide field upgrade will feed a revolutionary new integral field spectrograph called VIRUS, in support of the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX[‡]). This paper discusses the current status of this upgrade.

Keywords: Hobby-Eberly, telescope, HET, HETDEX, wide field corrector, tracker, spectrographs, VIRUS

1. INTRODUCTION

The HET was originally envisioned as a spectroscopic survey telescope, able to efficiently survey objects over wide areas of the sky. While the telescope has been very successful observing large samples of objects such as quasi-stellar objects (QSOs) spread over the sky with surface densities of around one per 10 sq. degrees, the HET design, coupled with a small field of view corrector, hampers programs where objects have higher sky densities. In seeking a strong niche for the HET going forward, the HET field of view will be increased from 4′ to 22′ so that it can accommodate the Visible Integral-field Replicable Unit Spectrograph (VIRUS), an innovative, highly multiplexed spectrograph that will open up the emission-line universe to systematic surveys for the first time, uncovering populations of objects selected by their line emission rather than by their continuum emission properties.

The HET wide field upgrade (WFU) includes designing, fabricating, and deploying a larger field of view corrector (referred to as the wide field corrector [WFC]) that will replace the existing spherical aberration corrector. It also includes design, fabrication, and deployment of a new prime focus instrument package (PFIP) and tracker, as well as modification to the HET's azimuth bearings, to accommodate additional weight being added to the telescope. The HET will undergo this major upgrade in 2011 to support current and future instrumentation, VIRUS, and execution of the Hobby-Eberly Telescope Dark Energy Experiment[1] (HETDEX) with the VIRUS on HET.

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[*] The Hobby-Eberly Telescope is operated by McDonald Observatory on behalf of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximillians-Universität München, and Georg-August-Universität, Göttingen

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The primary goal of the upgrade is to enable HETDEX while preserving and/or improving upon HET's current capabilities. HETDEX science requirements were scrutinized at the Science Requirements Review (SRR) in June 2007. This was followed by a Preliminary Design Review (PDR) in April 2008 which scrutinized the technical requirements that "flowed down" from the science requirements. Both independent review panels found HETDEX to be scientifically compelling, technically feasible and programmatically sound.

A thorough review of the HET (Figure 1) was presented at the 2008 SPIE Astronomical Instrumentation Conference[2]. This included a brief review of the HET so that the reader can better appreciate the differences between (1) the current and upgraded system designs, and (2) the differences between the HET and other more conventional alt-az telescopes. This review was followed by a high-level look at some of the more mature aspects of the system design as they were envisioned shortly after the PDR. Readers not familiar with the HET, WFU, HETDEX, and VIRUS are encouraged to review this 2008 paper because it contains pertinent background information that is not repeated in this paper. This paper focuses on what has transpired since PDR and is primarily limited to the status of the WFU. More detailed information about VIRUS[3 thru 12], and other aspects of the WFU[3, 13 thru 28], is contained in several other papers that are part of the 2010 SPIE Astronomical Instrumentation Conference.

Figure 1. The figure on the left shows the HET pre WFU with the dome shutter open. The figure on the right is a close up view of the top of the HET revealing the primary mirror, and telescope structure which supports the tracker and PFIP.

2. TELESCOPE CONFIGURATION

The design of the upgraded system has matured since PDR and is nearing completion. Figures 2 and 3 show CAD renderings of the telescope. The VIRUS[3] and LRS2[4] spectrograph enclosures[5] and associated fiber feeds are readily apparent in Figure 2. There are four enclosures (two on each side of the telescope). Since each enclosure contains 48 spectrographs there are a total of 192 spectrographs. More detailed information about VIRUS, LRS2, and the spectrograph enclosures can be found in References 3 through 12.

The location of the spectrograph enclosures was constrained by many factors, including:

- Desire to maximize throughput (especially in the UV) by minimizing the length of the fiber feeds
- Minimize the mechanical stress on the fiber feeds
- Maintain ample man lift access to the telescope's interior structure. This is particularly important because the mirror segments are cleaned with CO_2 several times a week, and the individual mirror segments are recoated on a regular basis.
- Prevent wind-induced motion of the spectrograph enclosures (which have an effective wind sail area on the order of 50 m^2) from shaking the telescope structure and causing image degradation

- Minimize complexity, weight, and cost of the structure which supports the spectrograph enclosures

The final enclosure locations were a compromise that was strongly influenced by the need to maintain man lift access to the primary mirror.

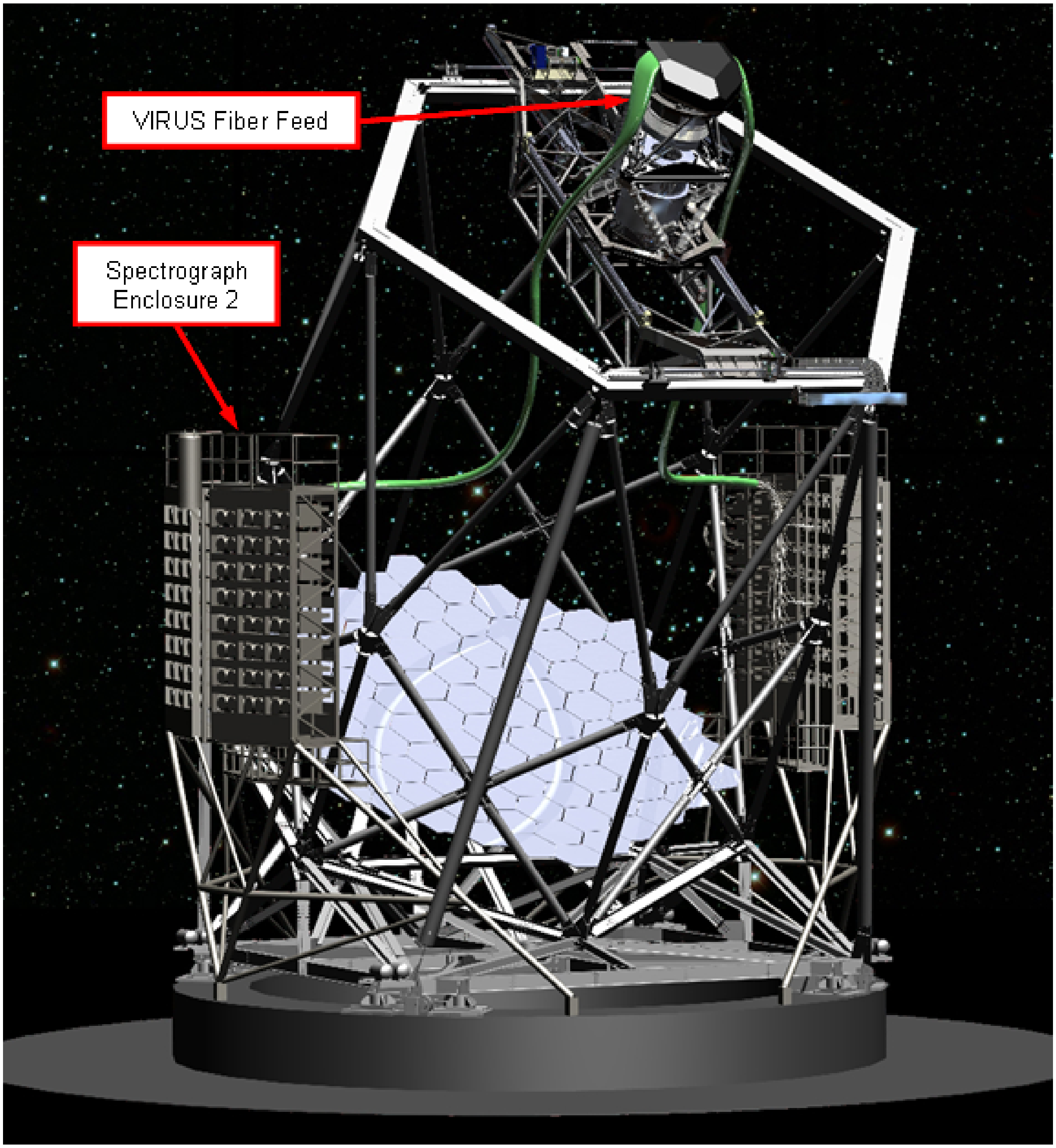

Figure 2. HET post WFU with VIRUS spectrograph enclosures installed. The spectrograph enclosures are shown with their covers removed to reveal the VIRUS spectrographs.

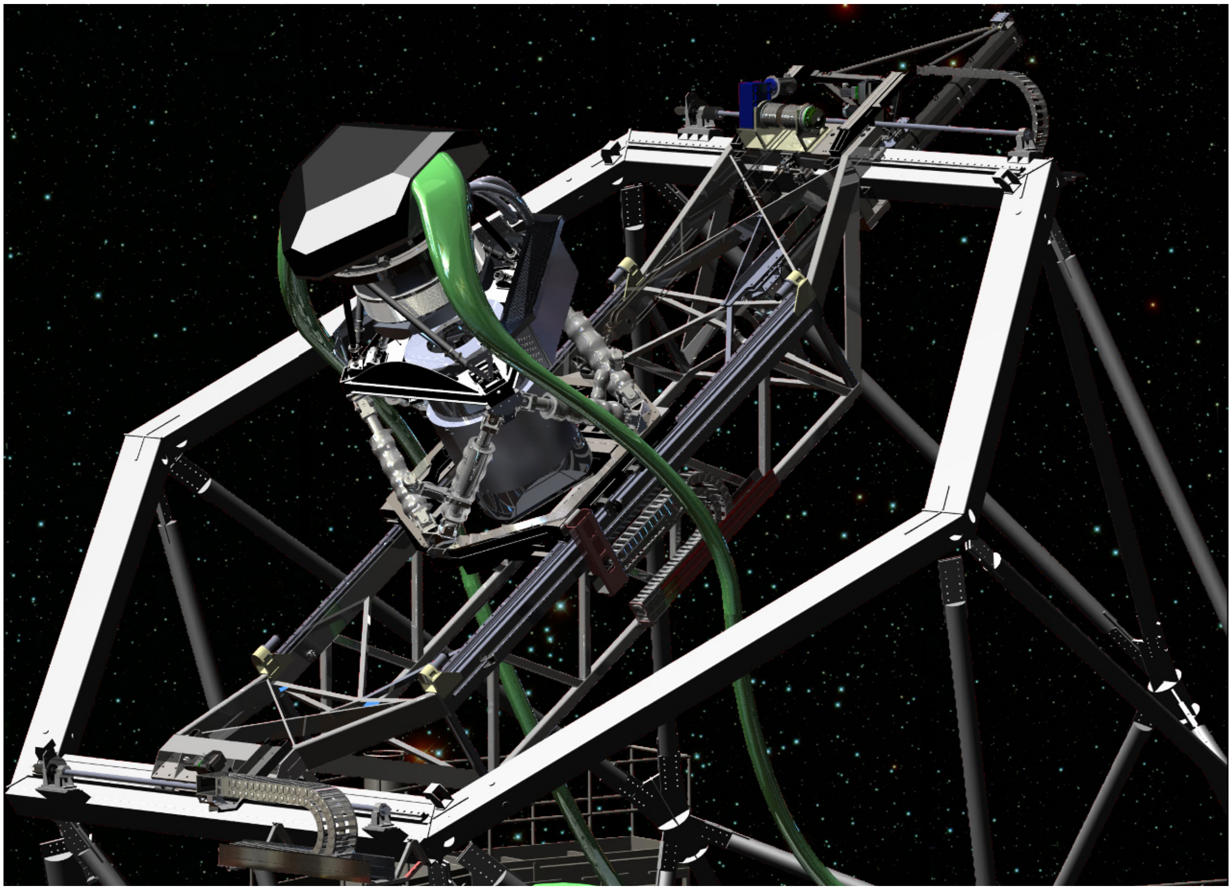

Figure 3. Close up view of the top of the telescope post WFU.

3. TRACKER

The Center for Electromechanics (CEM) was selected to design the tracker as well as other items associated with HETDEX (e.g. VIRUS spectrograph enclosures, IFU life cycle tester, and PFIP rho stage). CEM is part of the University of Texas, and is located approximately ten miles from MDO's offices at the University of Texas's main campus in Austin, Texas. CEM is an engineering research center composed of over 75 full time research staff, with over 50% of the staff being research engineers and scientist and the remainder being technicians and support staff. CEM has extensive fabrication, assembly, and testing facilities in a 140,000 square foot air conditioned high bay laboratory. Their 70 foot tall high bay features two 25 ton cranes, with an additional 25 ton crane servicing their machine shop. In addition to their high bay laboratory, they have another 10,000 square feet of air conditioned space available in eight satellite labs, along with a 1,200 square foot welding/fabrication shop.

A close up view of the tracker is shown in Figure 3. The tracker is a highly optimized machine that was subject to numerous challenging design constraints. This includes the following:

- Accurately positioning the PFIP during observations to maintain image quality. The design goal is to maintain the PFIP's position and orientation with respect to the primary mirror to within a decenter of 10μm, a defocus of 10 μm, and tip/tilt to within 4″.
- Minimizing tracker obstruction of the primary mirror with a highly optimized bridge structure[13].
- Reducing the overall weight of the tracker to keep it within the load bearing capacity of the existing telescope structure, and to achieve a fundamental mode of the entire telescope above 5 Hz.
- Accommodating the limited overhead dome crane lifting capacity and hook height constrained the maximum weight and geometry of the tracker carriage, hexapod, and PFIP components. These constraints precluded the possibility of

assembling the entire carriage/hexapod/PFIP assembly on the ground and then lifting it to the top of the telescope as a single assembly. Instead, many smaller assemblies must be lifted to the top of the telescope (one at a time) and then assembled at height over the primary mirror, a precarious process which subjects the primary mirror to increased risk of damage.

- Preventing the tracker carriage/hexapod/PFIP assembly from ever experiencing a down hill free fall along the tracker Y axis. Such an accidental event could result in catastrophic damage to the telescope. CEM conducted a thorough failure mode and effects analysis (FMEA) which resulted in a redundant design solution that has multiple layers of failure prevention. This includes the design of constant force actuator safety system[14] which is similar to the one used on the Southern African Large Telescope.
- Preventing a tracker hexapod actuator failure from damaging the PFIP/WFC. This required a thorough understanding of the volume swept out by the PFIP/WFC for all plausible combinations of the hexapod actuator lengths[15].
- Accommodating the limited straightness, flatness, and flexure of the tracker x-axis and y-axis linear bearing rail mounting surfaces, and long linear axis travel ranges (especially with regards to lead screw sag and critical speed).

More detailed information about CEM's tracker design effort can be found in References 13 through 20.

The design of the tracker is nearing completion, and many of the long lead components are being fabricated. This includes some of the larger weldments shown in Figure 4. It also includes a prototype hexapod actuator that was designed and manufactured by ADS International (Valmadrera, Italy) in collaboration with CEM and MDO[16]. The prototype actuator acceptance test was conducted at ADS in April 2009. Figure 5 contains photographs of the prototype actuator undergoing final integration and testing at ADS. Following the successful completion of the prototype actuator design, build and test, ADS International was given the go-ahead to begin fabrication and assembly of the full set of actuators for use on the HET with an expected delivery of August 2010.

Figure 4. Photographs of the tracker bridge (left) and carriage (right) weldments during fabrication.

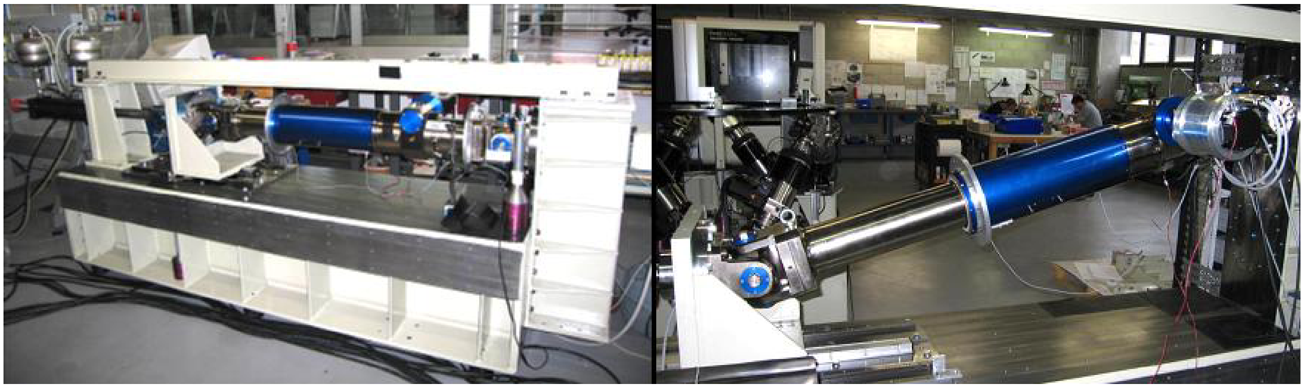

Figure 5. Photographs of the prototype hexapod actuator on the ADS test stand. The photograph on the right is a close up of the actuator being tested at angle.

4. PRIME FOCUS INSTRUMENT PACKAGE

The PFIP rides on the tracker and contains the WFC, acquisition camera, metrology equipment, and the focal surface assembly. A CAD rendering of the PFIP is shown in Figure 6 along with a close up of the WFC, and guide and wavefront sensor probe assembly.

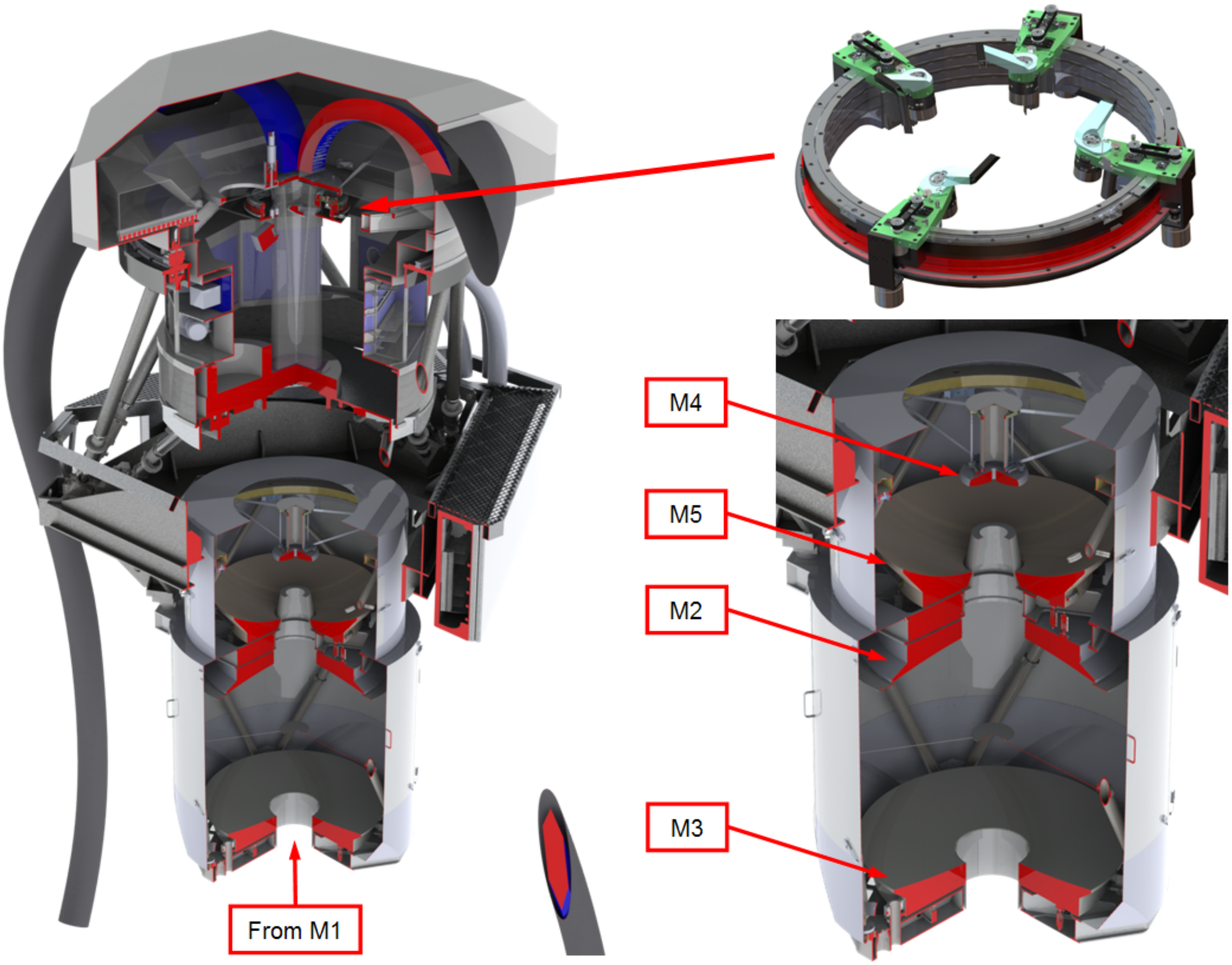

Figure 6. Close up views of the PFIP (left), WFC (lower right), and guide and wavefront sensor probe assembly (top right).

The equipment and basic configuration of the PFIP is largely unchanged from what was presented at the April 2008 PDR. However, since PDR the design has been refined. This includes:

- Structures supporting the focal plane and pupil assemblies have been optimized to improve their stiffness to weight ratio.
- Control system architecture has been finalized and hardware selected[21]. The redesigned PFIP is a stand-alone remote automation island that contains 12 subsystems and 24 motion axes. Within the PFIP, motion controllers and modular IO systems are interconnected by a local Controller Area Network (CAN) bus using the CANOpen messaging protocol. Links to ground-level systems pass through a 100 meter long cable bundle and use Ethernet over fiber optic cable exclusively. All communications between ground-level systems and PFIP subsystems are either point-to-point via Ethernet or go through Ethernet/CAN gateways that pass CANOpen messages transparently.
- Electronics cabinets and cable management hardware have been added to support the PFIP control system components.

- Maintenance platforms with personnel fall restraint tie off points have been added.
- Equipment covers have been added to contain the positively pressurized instrument air that will be used to keep the interior of the PFIP and WFC free of dust and other contaminants.
- Metrology system components (which include two guide cameras, two wavefront sensors, distance measuring interferometer, and a tip-tilt sensor) and control schemes have matured; especially with regards to the wave front sensors[22 thru 25].
- A prototype guide camera and wave front sensor probe assembly has been fabricated and is being tested.
- Three distance measuring interferometers can be accommodated. This eliminates the need to use a spherometer when aligning the primary mirror segments.
- Facility Calibration Unit (FCU) optical layout has been completed and light sources have been identified. The FCU is located at the bottom of the WFC. It injects light into the entrance of the WFC and provides field and pupil illumination which closely mimic light from the sky.

The majority of the PFIP components are being designed and fabricated by MDO personnel. Some aspects of the design are nearing completion, particularly those associated with the PFIP structure, rho stage, probe assemblies, and metrology equipment. Other aspects of the design are still at the concept level but scheduled for completion in late 2010.

For startup and testing, MDO uses hardware test benches like the one shown in Figure 7. A typical bench includes DC power supplies, motion controllers, modular I/O and an Ethernet-CAN gateway. The bench show in Figure 7 has been operational for over 6 months and is being used to facilitate the software development process.

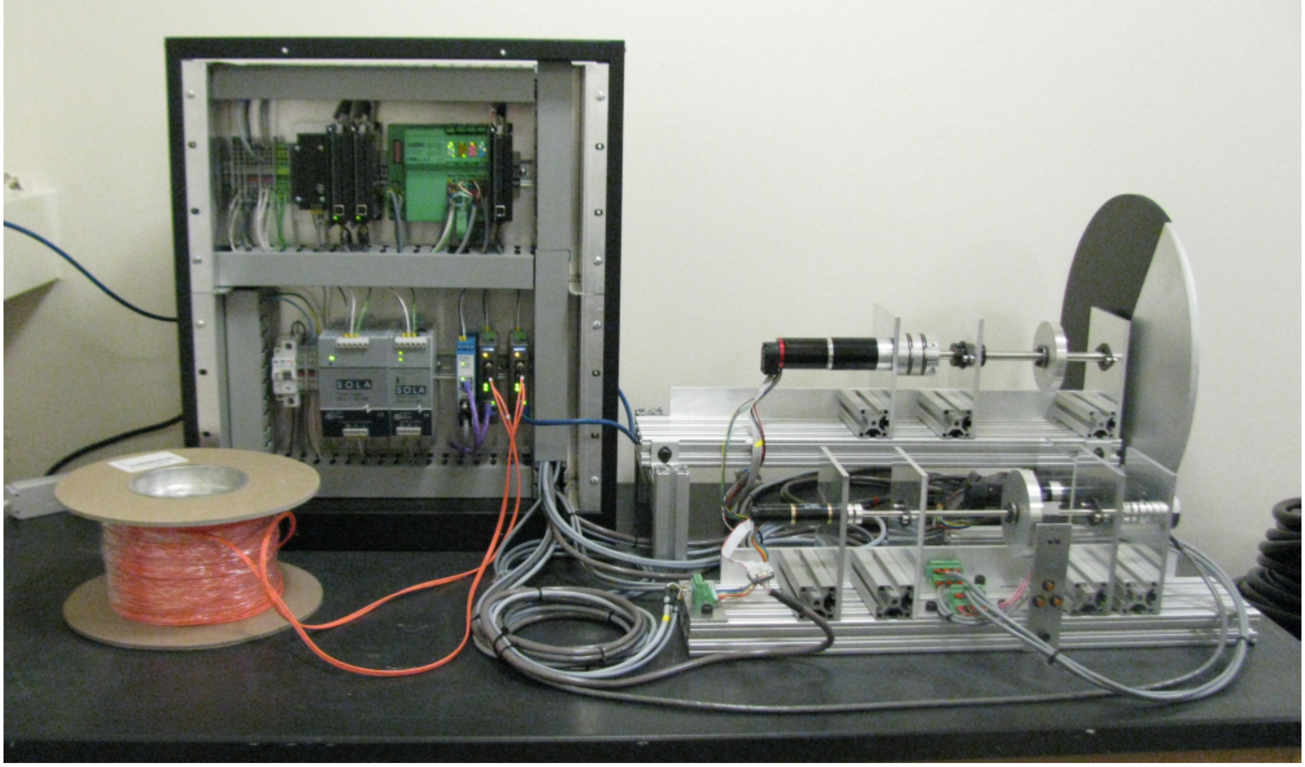

Figure 7. This multi-axis test bench is being used to test PFIP control system electronics and software. The electronic rack on the left contains power supplies, motor controllers, digital and analog IO modules. The mechanical assemblies on the right contain motors, position encoders, limit switches, and inertial loads that simulate various PFIP mechanisms.

5. WIDE FIELD CORRECTOR

In mid-2007 two parallel study contracts were issued to Sagem Défense Sécurité and the University of Arizona Optical Sciences Center (OSC) to better understand the WFC requirements, performance envelope, and cost. These studies were completed in July 2007. The starting point for each study was the baseline design developed by Phillip MacQueen which is described in Reference 26. The conclusion of both study efforts was that the WFC is a challenging but realistic design that can be built in about two years by a focused and competent contractor.

The reference design, which resulted from the two studies, was used to develop a specification and statement of work for the detailed design, fabrication and testing of a WFC. After a somewhat lengthy procurement process, a contract was awarded to OSC in October 2008. The WFC Kickoff Meeting was conducted in November 2008. This was followed by a Preliminary Design Review (PDR) in March 2009, and a Critical Design Review in August 2009. To ensure timely delivery it was necessary to order the mirror blanks in January 2009, well before the PDR.

As of May 2010 the major optical and mechanical design work[27] for the HET/WFC assembly is complete, and optical fabrication of the four mirrors and mechanical parts is well underway at OSC. Figure 8 (left) shows the 1-meter diameter M2 mirror on a robotic polishing machine at OSC. The picture shows the M2 mirror in its pre-polishing stage, where the subsurface damage generated during the grinding process is removed. The M3 and M5 mirrors are generated as aspheric shapes and have gone through the initial grinding stage and are waiting for fine grinding on a computer controlled polishing machine. The M4 mirror has gone through pre-polishing and is ready for fine figuring. Figure 8 (right) shows one of the metrology setups used to measure the highly aspheric 250 mm diameter M4 mirror. The substrate is high quality fused silica, which allows the mirror to be measured in transmission. Optical Sciences uses a separate metrology setup to calibrate the homogeneity of the substrate and retrieve the true surface figure measurement. Both of the M4 mirror metrology setups utilize phase etched CGHs used in transmission.

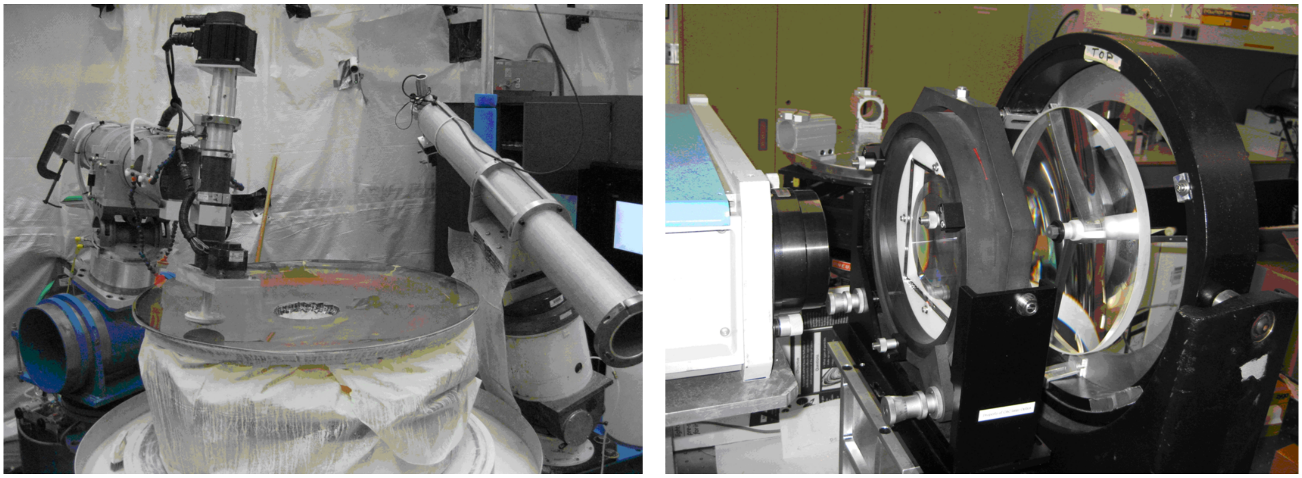

Figure 8. Pre-polished M2 mirror on 1.8-meter capacity robotic machine at OSC (left), and M4 (convex aspheric) metrology setup (right).

Mechanical parts are being fabricated and the progress shows about 85% completion. Before the mirrors are mounted in the mechanical assembly, the pre-assembled WFC structure will go through a static and dynamic performance evaluation process.

The WFC is scheduled to ship to the observatory in February 2011, shortly after the Factory Acceptance Test is completed at OSC. After the WFC arrives at MDO a Site Acceptance Test will be conducted to ensure that the alignment is intact.

Experience obtained in commissioning the HET and its sister telescope, the Southern African Large Telescope, strongly suggests that the WFC needs to be thoroughly tested as an integrated unit while subjected to the same gravity vectors encountered during deployment. This experience also suggests that the observatory must possess a means to test the WFC's internal optical alignment at the observatory (preferably while on the telescope) to facilitate troubleshooting during installation and testing, as well as years later during WFC reassembly after its mirrors have been recoated. Even though these requirements are expensive to meet, they are considered essential (to mitigating schedule risk during installation and commissioning) and are included in OSC's scope of work for the WFC. The test stand shown in Figure 9 will be used to test the WFC at OSC during the factory acceptance test, and once again at the observatory to ensure that nothing was upset in its 500 mile journey to the observatory. OSC will also be supplying metering rods, an alignment telescope/autocollimator, and mirror plugs that can be used to test the coarse alignment of the WFC while it is installed on the telescope. Figure 10 illustrates the mirror plug concept. Tests with this prototype indicate a repeatability of better than 5 micron centering. Tip/tilt repeatability tests are currently in progress.

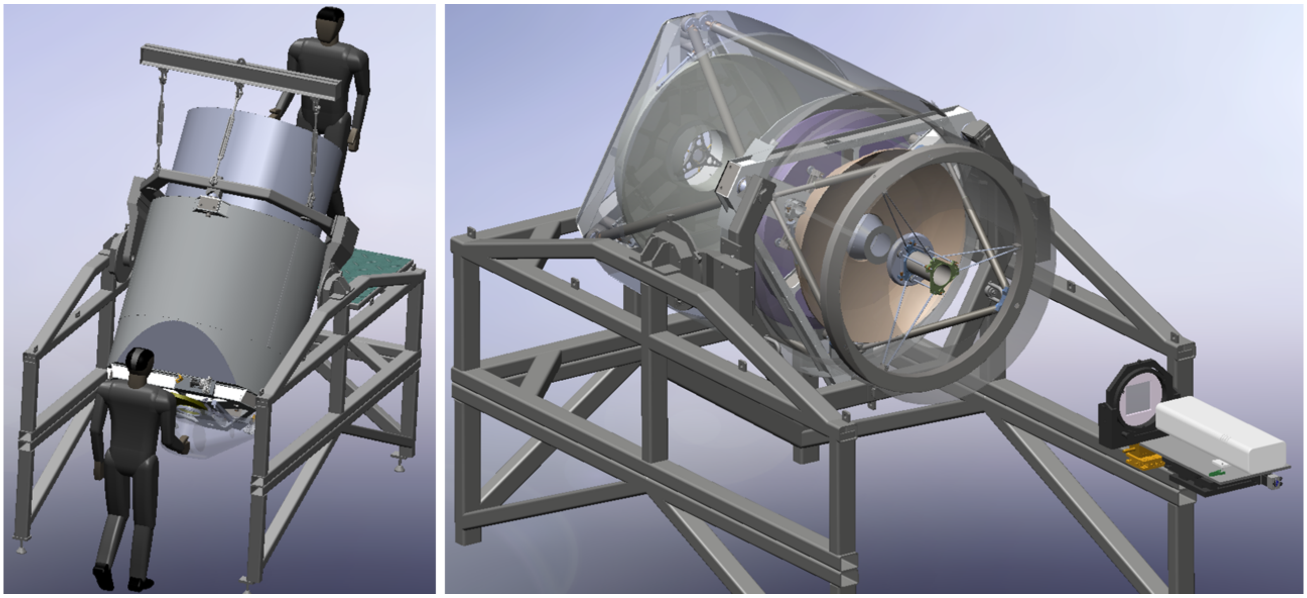

Figure 9. CAD renderings of the WFC test stand. The figure on the right shows the WFC (tipped at 90°) being tested with an interferometer and computer generated hologram.

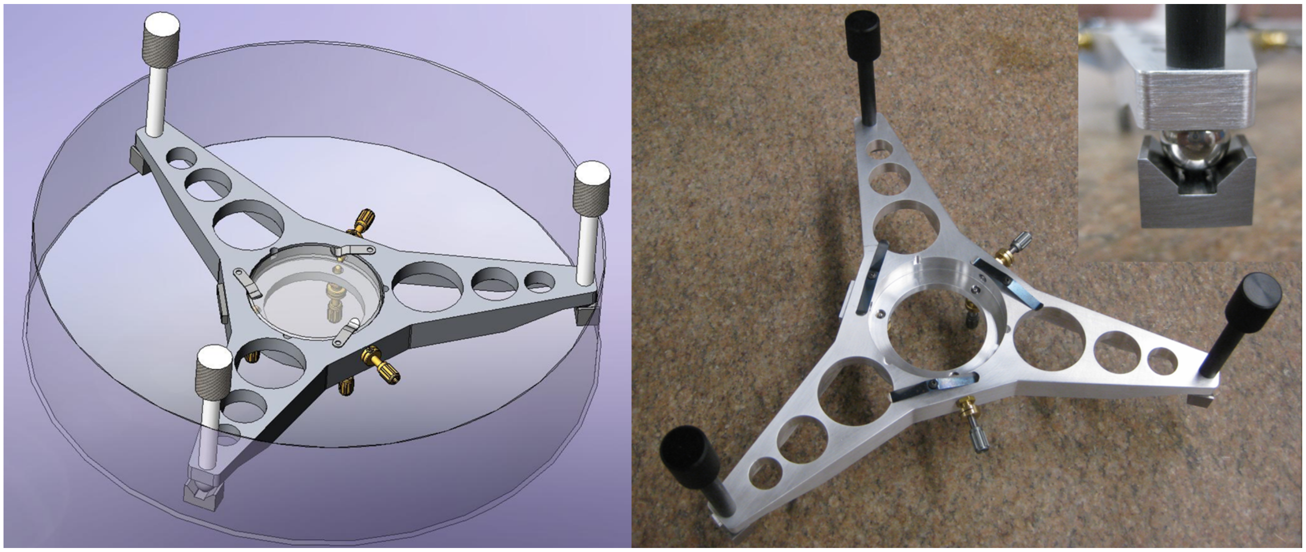

Figure 10. Mirror plug concept. The CAD rendering on the left shows the mirror plug installed in one of the WFC mirrors. The photograph on the right shows a prototype mirror plug. The inset in the top right of this photograph is a close up of one of the mirror plug's kinematic mounts.

6. SOFTWARE

The software effort is well into the implementation phase. It uses a component architecture (Figure 11) built around object oriented programming techniques. It consists of a network of control systems, each of which models a sub-set of closely coupled hardware. The control systems communicate with each other using abstract interfaces. The primary systems for the WFU and VIRUS are the Telescope CS, the Prime Focus Instrument Package CS, the Payload Alignment CS, the VIRUS Data Acquisition CS, and the Tracker CS, along with a centralized logging system. In addition to these control systems, a GUI interface will be provided which uses the Model-View pattern.

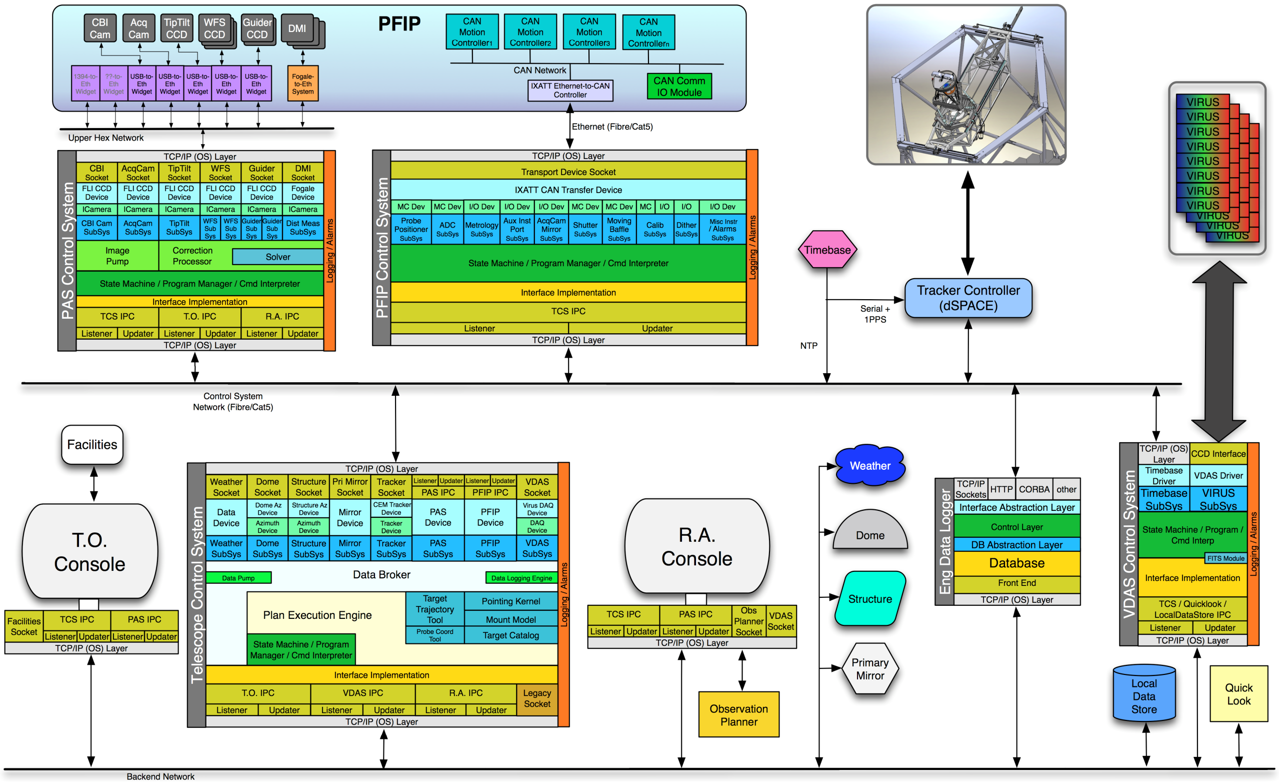

Figure 11. Software system architecture diagram.

Individually, a control system is an autonomous unit, with a state machine driven program engine and a built in scripting interpreter. They are configured at run time using a configuration script, allowing easy testing and simulation.

The primary operating system used is Red Hat Enterprise Linux 5.x, 64-bit. The tool chain consists of the following:

- Languages: C/C++, Python
- Compilers: Gnu Compiler Collection (GCC)
- Major Libraries/Technologies used:
  - OmniORB/OmniORBpy (CORBA)
  - Qt/pyQt (GUIs)
  - Log4Cplus
  - GSL (Gnu Scientific Library)
  - Scipy/Numpy
  - SWIG (Simplified Wrapper Interface Gen)
  - Slalib
  - MongoDB
  - DS9, PyDS9
  - Mayavi

7. TESTING AT CEM

One of the most significant challenges of the WFU is to minimize the down time of the HET (a functioning productive telescope) while the upgrade is being implemented. To help meet this goal the tracker and PFIP will be thoroughly tested at CEM in their 70 foot tall high bay. This includes installing the tracker and PFIP on a test stand[28] (Figure 12 left) that mimics the top structure of the telescope, and then exhaustively exercising it for several months to eliminate “infant mortality” hardware failures and to detect and fix software bugs. Prior to conducting this full system test, the hexapod will be tested on a separate test stand (Figure 12 right) with a test mass that mimics the WFC’s mass and geometric envelope. The test stands are currently being fabricated and will be available to start system testing at CEM in late 2010.

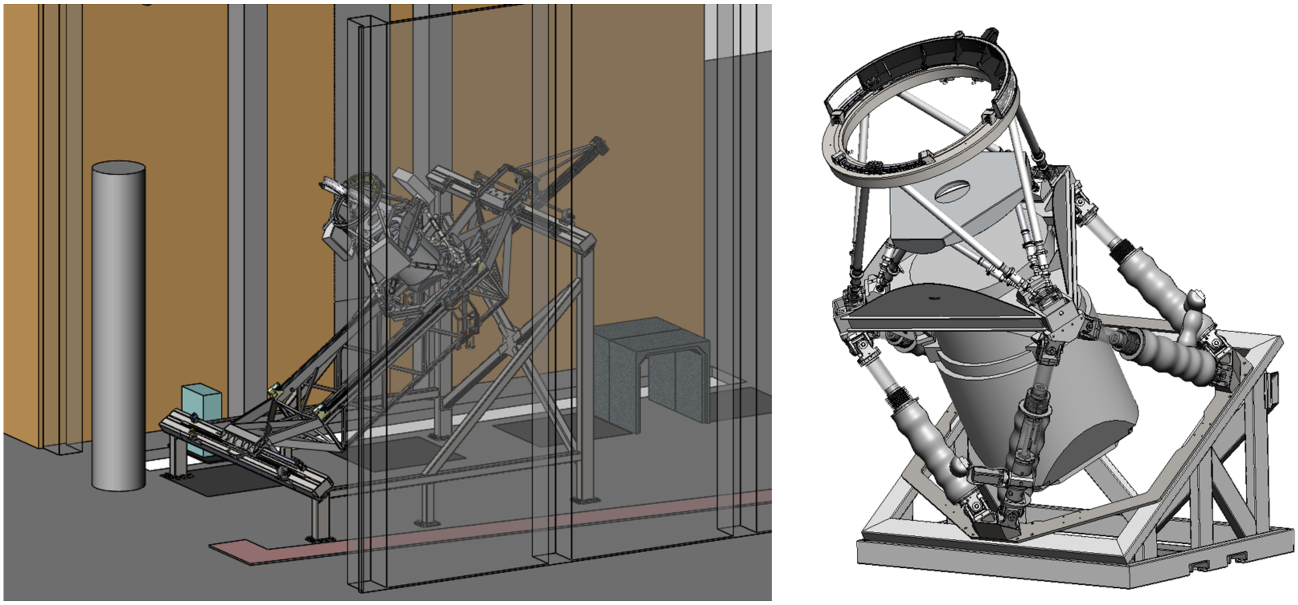

Figure 12. Tracker (left) and hexapod (right) test stands that will be used to troubleshoot and burn in the tracker at CEM.

8. SUMMARY

The HET is undergoing a major upgrade to support HETDEX and facilitate large field systematic emission-line surveys of the universe. The project is currently in the detailed design and fabrication phase with procurement of all major components underway. Integration and testing is scheduled to begin in June 2010 and will last approximately one year. This includes six months for equipment characterization and software development. Installation and commissioning at HET is anticipated to begin in the Fall of 2011 with science observations resuming in early 2012.

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