The Magdalena Ridge Observatory Interferometer: First light and deployment of the first telescope on the array

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ABSTRACT

The Magdalena Ridge Observatory Interferometer (MROI) has been under development for almost two decades. Initial funding for the facility started before the year 2000 under the Army and then Navy, and continues today through the Air Force Research Laboratory. With a projected total cost of substantially less than $200M, it represents the least expensive way to produce sub-milliarcsecond optical/near-infrared images that the astronomical community could invest in during the modern era, as compared, for instance, to extremely large telescopes or space interferometers. The MROI, when completed, will be comprised of 10 x1.4m diameter telescopes distributed on a Y-shaped array such that it will have access to spatial scales ranging from about 40 milliarcseconds down to less than 0.5 milliarcseconds. While this type of resolution is not unprecedented in the astronomical community, the ability to track fringes on and produce images of complex targets approximately 5 magnitudes fainter than is done today represents a substantial step forward. All this will be accomplished using a variety of approaches detailed in several papers from our team over the years. Together, these two factors, multiple telescopes deployed over very long-baselines coupled with fainter limiting magnitudes, will allow MROI to conduct science on a wide range and statistically meaningful samples of targets. These include pulsating and rapidly rotating stars, mass-loss via accretion and mass-transfer in interacting systems, and the highly-active environments surrounding black holes at the centers of more than 100 external galaxies. This represents a subsample of what is sure to be a tremendous and serendipitous list of science cases as we move ahead into the era of new space telescopes and synoptic surveys. Additional investigations into imaging man-made objects will be undertaken, which are of particular interest to the defense and space-industry communities as more human endeavors are moved into the space environment.

In 2016 the first MROI telescope was delivered and deployed at Magdalena Ridge in the maintenance facility. Having undergone initial check-out and fitting the system with optics and a fast tip-tilt system, we eagerly anticipate installing the telescope enclosure in 2018. The telescope and enclosure will be integrated at the facility and moved to the center of the interferometric array by late summer of 2018 with a demonstration of the performance of an entire beamline from telescope to beam combiner table shortly thereafter. At this point, deploying two more telescopes and demonstrating fringe-tracking, bootstrapping and limiting magnitudes for the facility will prove the full promise of MROI. A complete status update of all subsystems follows in the paper, as well as discussions of potential collaborative initiatives.

Keywords: interferometry, high-resolution imaging, near-infrared, telescope, dome, fringe tracker, beam combination, alignment systems

1. INTRODUCTION

The Magdalena Ridge Observatory Interferometer (MROI) was first conceived of and funded in the early 2000's as a collaboration between New Mexico Tech and the University of Cambridge. It is the most ambitious optical interferometric facility under development today with a mature design for a 10-telescope optical interferometer, a completed beam combining facility for the full array, and leveled/prepared telescope array area laid out in an equilateral Y. The facility is being built at 10,500 ft (3200 m) altitude about 20 miles (32 km) ESE of the site for the EVLA in south-central New Mexico, about a 1 hour drive from the New Mexico Tech campus in Socorro. The design for MROI has been completely optimized for an imaging mission, concentrating on the ability to image faint, complex targets that can be assessed without prior knowledge of their brightness distributions. Fringe-tracking limits of 14th magnitude at H (13.5 magnitude at K) will mean MROI is 4-5 magnitudes more sensitive than existing facilities today. Papers about the conceptual design and goals of the facility have previously discussed motivations and trade-offs for the facility design during our earlier active design phases[1,2].

1.1 Scientific Objectives

The scientific program for MROI has been presented in previous papers[3,4,5] and while the basic topics are similar to what can be imaged with other long-baseline interferometers, our approach will differ in several key ways. The sensitivity of MROI is designed to be about 4-5 magnitudes deeper than what has routinely been achieved at other facilities. This level of sensitivity is well-matched to current missions such as TESS[6] and Gaia[7] and will help complement their surveys with angular resolutions over the 0.5 to 40 milliarcsecond scale (which is sub-AU to many AU across at the distances of these surveys). Due to the polarization preserving design of the MROI system, resolved objects can be measured with high fidelity and crucial physical parameters that are typically only recognized with non-zero closure phases, such as dust distributions and material flows, will be characterized in detail for the first time. Finally, while more than a dozen AGN have been studied to date in the near and mid-infrared using long-baseline interferometers[8], MROI will be able to characterize more than 100 such systems with its deeper sensitivity, providing a statistical basis for conclusions related to unified schemes[9].

1.2 AFRL Demonstration

Funding for demonstrating MROI’s sensitivity, precision and bootstrapping capabilities is presently being provided under a cooperative agreement between New Mexico Tech and the Air Force Research Laboratory (AFRL). AFRL’s interest in the technique of long-baseline interferometric imaging stems from a need to increase Space Situational Awareness (SSA) for the many objects the U.S. community relies on in space today. As part of this cooperative agreement, MROI will be used as test-bed to validate the potential of imaging satellites in geosynchronous orbit from the ground. This work will be demonstrated on actual satellites as part of this effort and will not be confined to imaging “glints” of reflected sunlight from satellite bodies or solar panels, which can get bright enough to be fringe-tracked by existing interferometers today[10]. Because objects in geosynchronous orbit do not benefit from Earth’s rotation for aperture synthesis, true images at high-resolution can only be produced when many telescopes are combined over both short and long-baselines simultaneously in order to access all relevant spatial scales of the objects. See Young et al. [11,12] for simulations of MROI’s anticipated performance on geosynchronous satellites.

1.3 Long-term Plans for Facility

Most initial imaging work by long-baseline interferometers has combined only 4 telescopes at a time, even when more telescopes are part of the interferometric array. Aperture masking and speckle imaging are superior in terms of their imaging capability to characterize the uv-plane quickly, but lack both the sensitivity and baseline lengths to make complex images of anything but a handful of the brightest examples of many classes of targets using present-day telescopes. Only recently have long-baseline interferometers considered combining more than 4 combined telescope beams during one “integration time” (typically a few minutes of acquisition, system phasing up, fringe tracking an calibration data collection)[13,14]. Because the number of independent closure phases increases quickly as more telescopes are combined, we are striving to develop multi-way beam combiner designs with fast-switching capabilities in order to sample 8 and eventually 10 telescopes in the MROI system during one “integration time”[15].

New Mexico Tech, the lead institution for the MROI work, is ultimately interested in retaining only a fraction of the array’s available observing time for the institution. It is expected that the best science will come from a facility which is used by many investigators, both for astronomical science as well as investigations of man-made objects. It is for this reason that we are actively seeking partnerships with other universities and scientific consortia, as well as eventually applying for more community access through something like the NSF MSIP program, which is currently offering community access to the CHARA array[16]. With deeper limiting sensitivities than other long-baseline facilities, we anticipate that new science will be routinely accomplished as soon as four telescopes are available in the MROI array. Additionally, we have maintained throughout the design and build of the MROI facility a 4th optical table location in the

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inner beam combining area (BCA) which will be available for visitor instruments. Most long-baseline interferometers have several different beam combining instruments installed, to the mutual benefit of the communities they serve; we do not anticipate any difference in the MROI operation's model. A bottom-up budget has been calculated for the facility which projects a nightly cost that benefits from multiple similar systems and is much less than the canonical 10% of full facility cost for yearly operations. Partners joining early in the life of the facility will benefit from early access to these new capabilities and the ability to help shape future decisions about the MROI facility development.

2. TELESCOPE AND ENCLOSURE

2.1 Unit Telescope Mount (UTM)

The MROI Unit Telescope Mounts (UTM) are being designed and built by AMOS in Liege, Belgium[17]. The UTM are an altitude-altitude mount, with a design based on laser range-finding telescopes, and use only three mirrors in the system (Figure 1). This design saves reflections and scattering due to having fewer mirrors than a typical altitude-azimuth design. It also permits the telescope beam to come out at a fixed height across the Nasmyth table, which allows for fast tip-tilt correction using the UTM secondary (below) and makes controlling and directing the 100 mm collimated beam into the beam-transport system an easier prospect than would be the case with more reflections.

2.2 Unit Telescope Enclosure (UTE)

The Unit Telescope Enclosures (UTEs) are being designed by EIE Group in Venice, Italy and built under subcontract to EIE by a team of local Italian firms[18]. Each UTE both protects and is used to transport the UTM between telescope stations on the array. The design of the UTE is squat to allow for 6 hour tracks for any objects 30^{o} above the horizon while in the most compact telescope configuration (7.8 meters on centers) without vignetting on neighboring UTEs. The telescope slits are sized so that no tracking or dome motion of the UTEs is required during integration (less than 10 minutes) in order to prevent vibrations from degrading the scientific measurements. The first UTE passed Factory Acceptance Testing (FAT) in January, 2018 and was shipped to the MROI Visitor Center and Maintenance Facility (VCMF) in May, 2018 where it is being assembled today (see Figure 2). After preliminary Site Acceptance Testing (SAT) at the VCMF, it will be integrated with a UTM and fully tested on the interferometric array.

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Figure 1: UTM in the maintenance facility during preliminary testing. Photo by Colleen Gino.

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2.3 Integration and Installation on Array

We expect to integrate the first UTM and UTE later this summer (Sept 2018) on an integration station, which is a minimally functional telescope pad directly outside the VCMF (see Figure 3). After this activity, we expect to move them as a unit telescope (UT) to the array on one of the fully functional interferometer telescope stations. These telescope stations have mechanically separated UTM and UTE foundations so that wind-buffeting and other motions of the enclosures will not affect the telescopes. A variety of tests, such as software control, integrated system tracking, and a full-sky pointing model will also be undertaken initially. Once the system is nominally functional, we will assess the throughput, pointing, sensitivity and other measureable quantities of the first beamline of the MROI. Fine-tuning of system parameters will be undertaken, as well as further array and beam combining lab preparations, while we await completion of the second UTM and UTE. For a complete discussion of the preparation and details associated with this several-week process, see Olivares et al. [19].

Figure 2: The first UTE under assembly in the maintenance facility at the Magdalena Ridge.

3. OPTICS/OPTICAL SUBSYSTEMS

Several optical subsystems are being purchased now under the AFRL contract so that testing of the first beam train can be undertaken once the UT is installed on the array. Because the overall system throughput and error budget does not allow for us to overlook performance requirements on any subsystem, we track carefully the effects introduced by even the simplest pieces of hardware in the system, with a particular eye to overall precision, stability, throughput, and the overall interferometric sensitivity.

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Figure 3: Integration station under construction located outside maintenance facility.
The first UTM and UTE will be integrated on this station later this fall.

3.1 Telescope Optics

The system sensitivity and error budget for MROI requires no more than 63 nm RMS of wavefront error in the beam after reflection from the telescope tertiary mirror. Early in the development of the program 6 full sets of mirror blanks for MROI were purchased and a contract for figuring them was started with a local company (OST in Albuquerque, NM). The secondaries and tertiaries for the first 6 telescopes were completed and delivered to the project about 5 years ago. The 1.4 meter primaries, which required new infrastructure for the OST company, were completed more slowly. Unfortunately the company went bankrupt during the recession a few years ago, and only the first UT's primary was completed before the company folded. Recently a new contract was started with AOS in Tucson, AZ to complete the primary mirrors for the second and third UTs (Figure 4). The current Environmental Impact Survey (EIS) for Magdalena Ridge does not permit for re-coating of mirrors on the summit, and thus we are in the process of identifying a regular protected aluminum coater for the primary mirrors, which we anticipate recoating on a biennial basis. Ongoing discussions within the project continue regarding which protected silver coatings will be used for the secondary and tertiary mirrors in the system. Presently the first UT has all the mirrors coated with protected aluminum by Howard Clausing in Peoria, IL.

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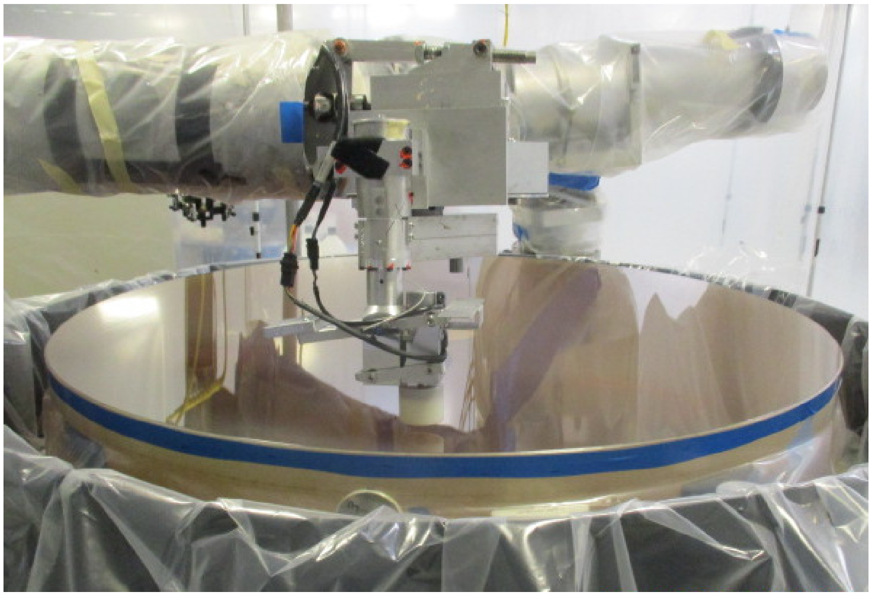

Figure 4: Primary mirror of MROI UT1 under measurement at AOS. Photo courtesy of AOS.

3.2 Mersenne Beam Condensers

The Mersenne condensing telescopes transform the 95 mm beam that exits the delay line to an 13 mm collimated beam at a lower height in the inner beam combining laboratory. These condensing telescopes have to be stable (to pointing and collimation errors) over the temperature range in the beam combining lab (nominal operational range of 18-22^{o} C), as well as compact and easily aligned to the rest of the beam train to within a few 10s of arcseconds. The condensers must also not introduce polarization affects on the beams, thus the angles of incidence and coatings must be controlled as prescribed in the system error budget. Finally, vibration is always of concern, and thus testing over a broad range of potentially detrimental vibrational frequencies is required for the condenser telescopes that will ultimately be used at MROI (see Figure 5 for a cartoon). Mounting to the optical table will be performed via custom mounts built by the MROI team designed to allow precision alignment of the system. An initial design is being developed by OSL in Kenley, UK to be tested in the MROI BCA on the first beam train later this year.

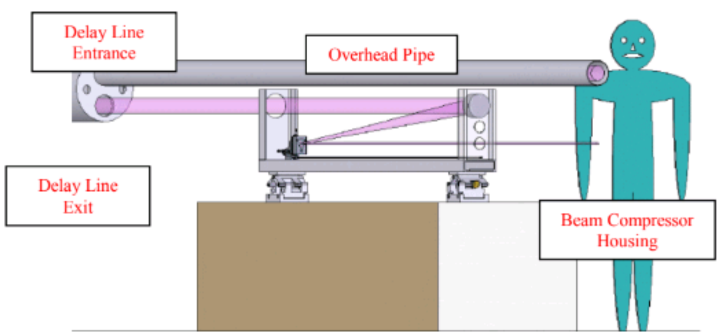

Figure 5: A cartoon of the layout of the beam condenser in the inner BCA. The light from the telescopes enters right to left in vacuum pipes, and the condensers must mount beneath them for clearance.

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4. ARRAY INFRASTRUCTURE AND BEAM RELAY SYSTEM

4.1 Integration Station

The telescope integration station (a kinematic concrete pad system) was developed and poured outside of the VCMF earlier this year. This station, unlike the actual telescope array infrastructure, is not intended for long-term use of a UT, merely for safe integration and basic functionality tests before the UT is moved to the array. As such, the integration station is not divided into an inner and outer foundation for the UTM and UTE respectively. Minimal functionality will be provided via extended power, chiller and ethernet lines/cables from within the VCMF to outside at the station. Lightning protection equipment is also installed and grounded to the station. These lines/cables are the same ones presently being used for partial SAT of the UTM in the VCMF facility. The integration station, however, was required to be poured deep enough to support the full mass of the UTM and UTE during the final integration step. A choice was made to place this station close to the building so that some basic wind protections could be provided to the telescope during the few hours between when it is placed outdoors, and the UTE is placed on top of it. For more details of the integration process, see Olivares et al.[19] and Figure 3 above.

Figure 6: Artist's conception of completed MROI interferometer in extended configuration (everything except full array arms/pipes and telescopes are currently installed on site). The arm positions, labeled clockwise from the top of the picture, are S, W and N. Photo by Tyson Eakman.

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4.2 Array Infrastructure

When completed, the full array infrastructure for MROI will include 28 stations on the array, laid out in an equilateral Y with one central station and 9 more along each arm – referred to as West, North and South (see Figure 6). Each station provides compressed air, chilled liquid, power, ethernet and lightning protection. The heat is effluxed away from the telescopes through the chilled water system that vents to a building downwind from the array (to the northeast). Today 7 of the 28 stations have been installed, with conduit and lightning protection, mostly along the West arm. Stations range from 7.8m separation in the most compact spacings, to 347m for the largest separations between telescopes on the ends of separate arms (see Figure 7). Spacings were chosen to approximately double the spatial resolution along an arm as the scopes are moved out to their next logical location. After the three reflections through the telescope, the light crosses the Nasmyth table, where tip-tilt correction is determined using the fast tip-tilt system (see more below). At each station location is an entrance window into the beam relay system (see next section). After the light is corrected for tip and tilt errors, it is directed by a 4th mirror in the MROI beam train into the vacuum system, which sends the light into the beam combining facility.

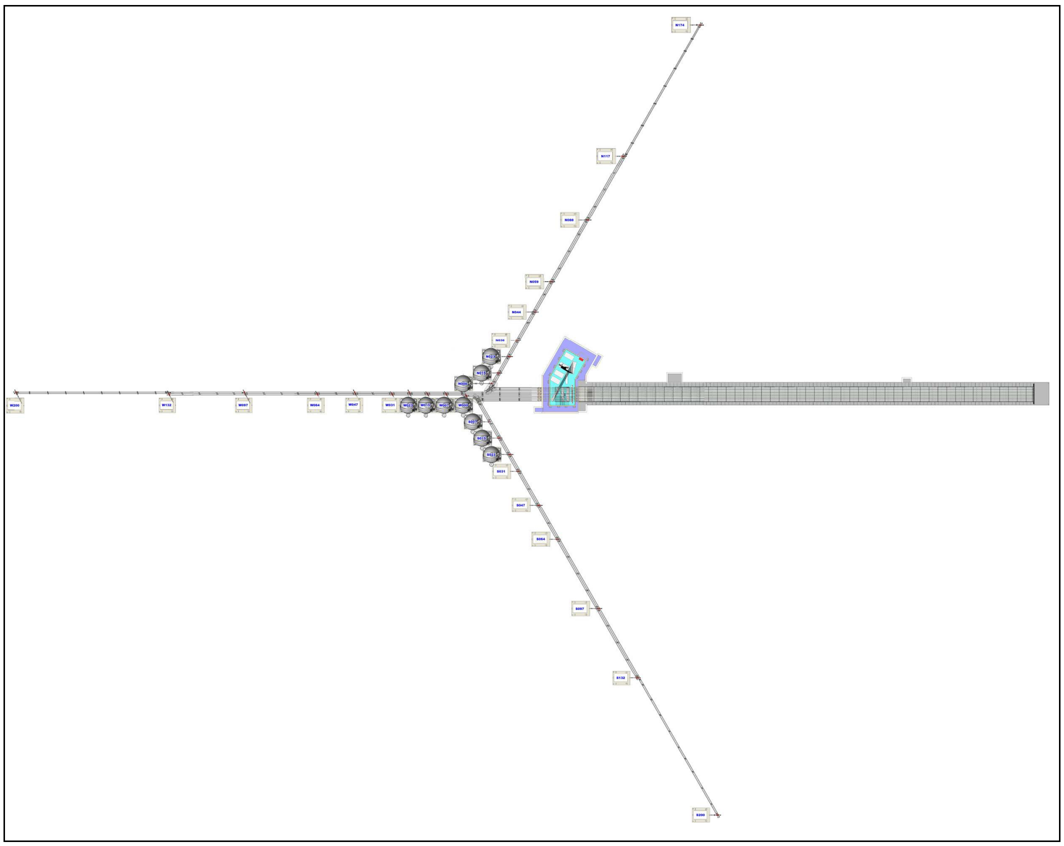

Figure 7: The layout of all the pads on the MROI along with the building, including delay line area (to the right) and beam combining building (blue section near center). North is up in this drawing. The scale of the layout is approximately 420m from the left to right hand side and 350m from top to bottom of the picture.

4.3 Beam Relay/Vacuum Pipes

Each station's mirror configuration takes the corrected light from the UT to an articulated mirror in the beam relay vacuum can of the beam relay system. The incident angles for this redirection of the beam are less than 20^{o} in order to preserve the polarization properties of the light. These mirrors direct the light into the beam combining facility through pipes maintaining a fairly soft vacuum (~1 millibars), in order to cut down on longitudinal dispersion and tip-tilt fluctuations caused by air and water vapor along the path. The vacuum cans, designed and built in-house, have been extensively tested for vacuum integrity under daily solar illumination and hold vacuum for many weeks without issue.

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The pipes are attached to the mirror cans via compliant bellows to minimize diurnal forcing of the system (Figure 8). Extensive testing using a pilot laser beam launched from and then returned to the inner beam combining area, which is then focused onto a camera, is being undertaken to determine both the amplitude and direction of any beam motion in order to learn if diurnal heating, wind, ground motions due to temperature/seasonal changes, etc. are likely to require nighttime correction. These tests will quantify the frequency and scale of these corrections which we will automate during operations. See below for more discussion of the automation of this realignment during regular operations.

Figure 8: Beam relay vacuum can and support piers under test on MROI array.

5. AUTOMATED ALIGNMENT SYSTEM

5.1 Overall Philosophy

The automation of the alignment of a large and distributed optical system like MROI is important for several reasons. Foremost is the efficiency of the scientific observations, which cannot be optimized without a remote way of controlling all the mirrors in the beam train to direct the light where it is needed. Second is the sheer scale of the facility, which would be difficult to align daily, or even within an observing session, without several trained technicians available at all times. Finally, many components in the system are within vacuum chambers or in rooms where temperatures are strictly controlled, which necessitates remote access to these components. Given all these reasons, MROI has maintained and developed a concept for automated alignment of all moving optical components from its inception. The most recent developments in the automated alignment system (AAS) are given by Luis et al.[21] in these proceedings, but we summarize here the basic elements of how the system fits into the MROI as a whole.

Conceptually, the tasks required for automated alignment are fairly easy to track. The entire interferometer is tied to the position and direction (in a 3D mechanical space) of the delay lines in the MROI. We build out from this fiducial position represented by the delay lines, both upstream and downstream, to the telescopes and fringe tracking instrument

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respectively. Each alignment sub-section requires the ability to control both tilt and shear in its respective location, and so care must be taken to produce this level of control without over-constraining any one sub-system. Finally, a way to tie all these systems together is needed. This is provided in the way of artificial light sources which can be seen across all wavebands of the system and from one end of the MROI through the longest beampath we might implement, with sufficient SNR so that alignments that support the overall error budget (in terms of tilt and shear and their affect on system visibility) are maintained. See Figure 9 for the concept of how we will implement this at MROI.

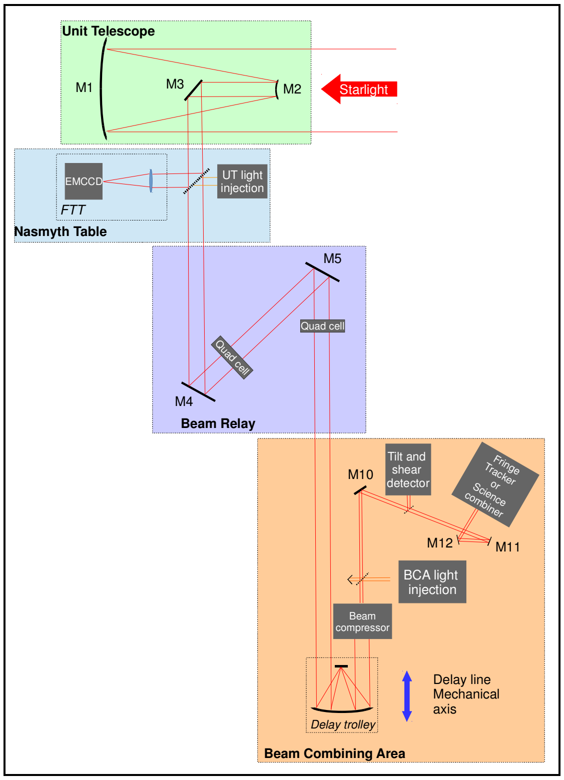

Figure 9: Conceptual layout of the shear/tilt actuation paths in the MROI beam train. All optical systems are tied to the mechanical axis of the delay lines. See below or Luis et al.[21] for a complete discussion of the information in this figure.

Some of the detailed components in the implementation of the AAS at MROI include the following: a) a fast tip-tilt system located at each telescope Nasmyth table and operating at optical wavelengths which directly controls the secondary of the telescope, b) a light injection system (UTLIS) which can send artificial light from the telescope back to the inner beam combining area for aligning intermediate mirrors, c) pop-up quad cells on intermediate mirrors to sense the beam location at each optic in the beam train, d) a light injection system after the Mersenne condensers (MOB – see Shtromberg et al.[20]) to inject light both towards the telescopes and also towards the beam combiners, e) a Shack-Hartmann type shear and tilt measuring device (BEASST) near the beam combiners in the inner BCA which can work on either starlight or the artificial light from the UTLIS to determine the overall quality of the interferometric beam. Results from all of these components will be used to initially align and then further correct drifts in alignment throughout the observing period for all ten telescopes in the array. Below we focus on two new and rapidly maturing systems that are crucial to the AAS.

5.2 Fast Tip-tilt System

The fast tip-tilt (FTT) system is being designed and built by our collaborators at Cambridge University[22]. The system is located on the Nasmyth table of the unit telescope and uses the "bluest" light for sensing and correction of the pointing of the UT light in real-time into the beam train to correct for the lowest order aberrations of the wavefront of the light.

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When MROI is operating in the infrared for science, this “bluest” light will be from 600 to 1000 nm; when operating in the optical, it will be from 400 to 600 nm. This is done with the explicit intention of not “sharing” light between different subsystems of the interferometer so as to maintain the highest sensitivity possible for each observation. The FTT works at a bandwidth up to 50 Hz to control the secondary mirror. Factory acceptance tests (FAT) of the FTT were run in the lab in Cambridge to demonstrate closed-loop correction performance, heat dissipation, beam and vibrational stability. The FTT was initially brought to MROI in the fall of 2017 and minimally used on the existing UT Nasmyth in the VCMF to check alignment, throughput, and determine basic functionality of the software system (see Figure 10). Limited on-sky testing has been undertaken which shows that the FTT system is functional, but needs some tuning to control the telescope optimally under MROI system computer control. A full SAT will be conducted of the FTT on the first UT once the telescope is located on the array later this fall.

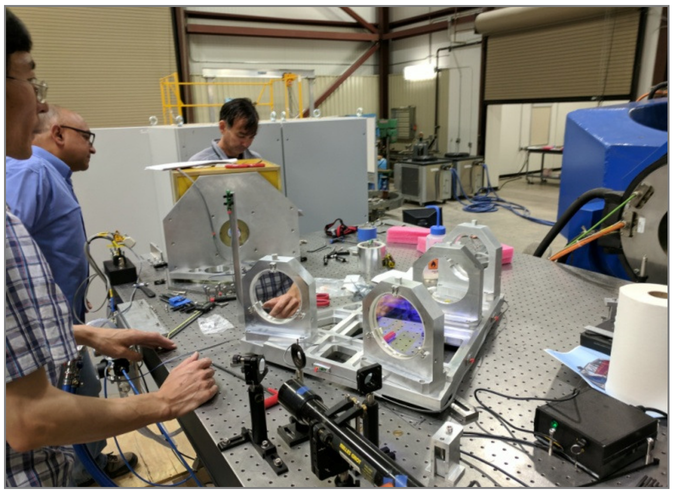

Figure 10: FTT system under initial installation on the Nasmyth table of UTM1 in the maintenance facility.

5.3 BEASST

BEASST (Back-End Active Stabilization of Shear and Tilt) is a Shack-Hartmann system being built by Cambridge University. BEASST’s purpose is to sense and feed information back to the AAS control algorithms about beam quality in the interferometer. It will be located in the inner BCA just before the fringe-tracker or other science instruments in the beam train. BEASST will work at long-red or near-infrared wavelengths (around 1550 nm) and uses an array of microlenses and a commercial grade CMOS camera . A prototype of BEASST is presently under test at Cambridge and will be used for first fringes at MROI in a few years. See Luis et al.[21] for complete details of the system.

5.4 Other components

As alluded to above, other components of the MROI AAS include the MOB, pop-up quad cells and other system sensors. Much of that work was already completed (Shtromberg et al.[23]) and will not be repeated here in much detail. Briefly, the pop-up quad cells are made from off-the-shelf photovoltaic material, custom cut and fit to simple current-balance type electronics architecture to determine the centration of the 100 mm beams in the vacuum cans of the beam train along the long paths traveled from the UTs to the delay lines. The MOB (Magical Optical Box) is a beam launch system that is intended to send both optical and infrared light, coaligned in the beam launch infrastructure, throughout the beam train of MROI. A recommendation was made as part of the previous thesis work that the current version of this launch system, using lasers/LEDs and fibers, was neither sufficiently bright enough nor broad-band enough to send enough photons out to the telescopes from the launch location in the inner BCA. A re-evaluation of the MOB design is underway and we expect to test various versions of this system in the coming 2 years. Finally, some work has been undertaken on testing custom capacitive sensors (Bowman and Buscher[24]) for sensing and potentially controlling the mirrors in the beam relay system cans. Currently the capacitive sensors do not have the required stability over a wide-range of temperatures to be used as absolute measuring devices, so schemes are being investigated for using them for relative measurements. These schemes include investigations of differential approaches using pairs of sensors, or

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developing capacitive material with better stability over a wide range of temperatures expected in the beam relay cans, which are mostly located outside and subjected to diurnal cycling.

6. FRINGE TRACKER AND INITIAL SCIENCE CAMERA

6.1 ICoNN

ICoNN is the ***I***nfrared ***Co***herencing ***N***earest ***N***eighbors combiner, a nearest-neighboring-telescope style fringe tracker for the MROI (Jurgenson et al.[25]). Each ICoNN cryostat accepts up to 5 combined beams from the 10-way fringe tracking beam combiner off of one side of the set of dichroics. Ultimately, we will need to build 4 identical ICoNN dewars/detector systems to collect all the light from the fringe-tracking beam combiner. Each ICoNN dewar works at H or K_s at low spectral resolution (using direct vision prisms) to locate and stabilize the fringe packets between telescopes in order to phase up the array. The nearest-neighbors approach for fringe-tracking is used in order to obtain the highest possible SNR between each neighboring telescope pair thus preserving the best possible sensitivity of the array. Originally designed to operate with Teledyne PICNIC detectors, we are switching ICoNN's detector readout system and making minor modifications to the present optics now that small-format, high-speed photon counting detectors are available, specifically the Selex SAPHIRA detector (Buscher et al [26]; Finger et al. [27]). Because the pixel pitch and the format of the full array carrier for the SAPHIRA are significantly different than for the PICNIC, several compromises have to be made with this first dewar to make the system functional for first light. These design trade-offs and initial tests are being undertaken today in anticipation of moving the beam combiner and ICoNN to Magdalena Ridge in about one year. See Ligon et al.[28] for full details of the work.

6.2 FOURIER

A new first-science infrared beam combiner is under concept design at Cambridge University to be used for the initial AFRL demonstrations and to do simple near-infrared science when only two or three telescopes exist in the array. This instrument, ***F***ree-space ***O***ptical multi-apert***U***re combine***R*** for ***I***nterf***ER***ometry (FOURIER), will use a model for beam combination that maximizes the sensitivity of the system with low to moderate spectral resolutions. It is anticipated that we will use a SAPHIRA detector for this instrument as well, maximizing on our internal expertise with these systems. See Mortimer and Buscher[29] for a discussion of the basic design trade-offs and optimizations that are being considered.

6.3 Visitor Instruments

MROI has always maintained space in the inner BCA for visitor instruments in the sense of our overall designs and the existence of a fourth optical table in the room. The inner BCA table layout is undergoing some rethinking due to the use of better detectors and fast switch-yards to enable mixing of all beams during the interferometric measurement cadence of a few minutes (see Buscher[15]). We intend to maintain the presence of the visitor table and will produce a white paper in the next year that will detail all the system design parameters so that collaborators can anticipate potential instrument designs that will work at MROI. Potential collaborators should contact the first author for more information about testing/deploying their instruments on the Ridge.

7. SOFTWARE AND OTHER PROGRESS ON THE RIDGE

7.1 Interferometer Supervisory System and Testing

The Interferometer Supervisory System (ISS) is an overarching software system that communicates with each subsystem (e.g. UTM, UTE, delay lines, etc.) via a database publish/subscribe architecture. The platform for all the subsystems is a combination of Linux and Real-time Linux for the real-time subsystems (mainly fast tip-tilt, fringe-tracking and delay lines). Basic Graphical User Interfaces (GUIs) are being developed for each subsystem with the anticipation of an overarching GUI for engineering once data are being taken on the array. A simulation environment has been developed and used to exercise the software to determine system rates and CPU loads for the initial implementation of the MROI. Limited testing has been undertaken with the UTM and FTT systems in the VCMF facility, with much more anticipated once the UT is moved to the array later this fall. Astronomical catalogues today mainly rely on Hipparcos stellar catalogues, and a science database is being planned for in order to archive all observations. All astronomical data will be maintained in OIFITS2 format and permanently archived by the observatory. For more information on the ISS and software development at MROI see Farris et al.[30,31].

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7.2 Long-term Weather Statistics

Weather statistics on Magdalena Ridge have been archived and maintained for nearly 20 years on a variety of different platforms. All-sky images are also available for a portion of this time period (about 7 years) and will become available again soon with the deployment of a refurbished all-sky camera (we believe lightning took out the previous one). A short paper gathering basic statistics on the Ridge was prepared by Klinglesmith et al. [32], with a longer paper including statistical analyses to be published in the next year. Some basic statistics include yearly temperature excursions, wind directions and maxima, dew point/humidity trends and percentages of cloudy/cloud-free nights. The future refereed paper will attempt to correlate known requirements for operating the interferometer with historical data to produce a fuller picture of the available observing time and best observing seasons at the site. This may also be of interest for potential collaborators because a third location for another observing facility was identified and approved in the original EIS for Magdalena Ridge. This location does not presently have infrastructure developed for it, but would clearly benefit from the existing power, water, ethernet and roadway infrastructure already on the Ridge.

7.3 Horizontal Scintillometry

We are undertaking an assessment of the horizontal seeing at the MROI. The intention is to determine if there are certain weather conditions or locations on the Ridge along the arms of the array that are more likely to have highly variable ground-layer seeing directly above the telescopes. The approach uses the Kipp & Zonnen scintillometers that are often used by the hydrological community to assess radiant heat flux off the Earth's surface for ground-truth in remote sensing applications. Because these instruments measure the seeing via recording the C_n^2 , it is possible, though not typical, to operate their data loggers at very high rates allowing one to measure seeing on timescales meaningful/comparable to the interferometric measurement time. A pair of scintillometers has been installed to examine the atmosphere above the center of the MROI array a few meters higher than the telescopes will be positioned. Diurnal cycling is clearly evident in the PSDs of the data, and further tests are ongoing to determine if other frequencies dominate and are correlated with other weather measures, such as wind direction or speed. If this approach proves feasible it may present a low-cost way to assess seeing over large mirrors, such as being used in the ELTs. See Dooley and Creech-Eakman[34] for further details.

8. CONCLUSIONS AND ACKNOWLEDGEMENTS

The MROI has been under design and development for more than 15 years now. After many funding challenges, we are now operating under a $25M cooperative agreement with the AFRL and are close to integrating the first telescope at the interferometer site. With luck, in about 2 years we will be attempting to combine light from two telescopes to get first fringes at MROI. At that time, we hope to demonstrate the promise and feasibility of faint fringe-tracking on complex targets. With the completion of MROI's ten-telescope facility, we will be the most ambitious optical/infrared interferometer built to date. The total cost of the interferometric facility can be estimated to be around $150M (in today's dollars), considerably less expensive than either extremely large telescopes or most space-based facilities capable of high angular resolution imaging.

We would like to thank our administration at New Mexico Tech, including especially our new President Dr. Stephen Wells, who has been incredibly supportive of our endeavor these past two years. We also extend a special thanks to our congressional staff who help tremendously with securing the funding for this project that comes to us via the AFRL cooperative agreement.

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