The Magdalena Ridge Observatory interferometer: a status update

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ABSTRACT

The Magdalena Ridge Observatory Interferometer has been designed to be a 10 × 1.4 m aperture long-baseline optical/near-infrared interferometer in an equilateral "Y" configuration, and is being deployed west of Socorro, NM on the Magdalena Ridge. Unfortunately, first light for the facility has been delayed due to the current difficult funding regime, but during the past two years we have made substantial progress on many of the key subsystems for the array. The design of all these subsystems is largely complete, and laboratory assembly and testing, and the installation of many of its components on the Ridge are now underway. This paper serves as an overview and update on the facility's present status, and the plans for future funding and eventual operations of the facilities.

Keywords: Optical interferometer, telescope facilities, high-resolution imaging, fringe tracking, beam combiners, delay lines, alignment systems

1. MAGDALENA RIDGE OBSERVATORY INTERFEROMETER OVERVIEW

The Magdalena Ridge Observatory (MRO) is a Federally and institutionally funded facility being built and managed by New Mexico Institute of Mining and Technology (NMT). NMT also serves as host for the observatory offices at its campus in Socorro, NM. The observatory consists of two major facilities: a fast-tracking 2.4 m telescope and a multi-element optical/infrared interferometric array. The interferometer is being designed and built in collaboration with partners at the University of Cambridge, UK. Many details of both the general design of the array, its specific subsystems and its scientific foci have been discussed in the last several SPIE topical meetings on optical interferometry, and so this paper will serve as a status update on the facilities since the SPIE 2010 paper (Creech-Eakman et al. 2010). In the following sections below we discuss the project's progress over the past two years and present our current plans for the future facility deployment and its operational phase given the current uncertain funding climate for science worldwide.

2. PROGRESS ON INDIVIDUAL SUBSYSTEMS

The MRO interferometer (MROI) design and build activities are managed under a Work Breakdown Structure (WBS) which includes 18 separate major packages. Each of these packages includes a set of design requirements, a group of design memos and implementation decisions, and a series of formal reviews, frequently using external experts for validation of the team's conclusions, and finally resulting in a system design for each WBS item. As part of the verification of a package, risk-reduction experiments or prototype hardware may be built before a final design is agreed upon. Each full system design also requires a comprehensive assembly, integration and verification plan (AIV) so that necessary equipment and personnel resources can be predicted well in advance of deploying equipment on the mountain. Software control, which is integrated into all of the MROI's subsystems, is managed centrally and had been designed to allow for upgrades and improvements to be deployed easily throughout the life of the facility (see Farris et al., 2010). A comprehensive software system simulation framework is being developed to support testing of individual systems as they are delivered to the observatory. The current status of these 18 major work packages is that the majority have passed their final design review (FDR), and only the Fast Tip-Tilt system, Automated Alignment system, Telescope Transporter and Scientific Commissioning work have yet to be taken to the FDR level. Below, we provide updates on several of the major WBS items, especially those where there has been significant progress over the past two years.

2.1. Unit Telescopes and Optics

Each MROI unit telescope (UT) consists of a 1.4 m diameter telescope on an altitude-altitude mount utilizing only a primary, secondary and tertiary mirror to inject the starlight into the fast tip-tilt system (mounted on a Nasmyth table and controlling the secondary mirror) and then into the beam transport system (see below). The telescopes are being built by AMOS in Liege, Belgium. Six full sets of optics have been procured for the program and have been partially fabricated at OST in Albuquerque, NM. When polished and coated, the telescope optics will produce beams with a total RMS wavefront error of 63 nm, which includes a contribution from all alignment errors. The reader can refer to Pirnay et al. 2008 and Pirnay et al. 2010 for details of the design and assembly, and integration and testing of the telescope mounts.

The first MROI telescope is now complete and has passed its factory acceptance tests using dummy weights to simulate the load of the mirrors. We are waiting for transportation of telescope 1 to a new MRO maintenance facility (see below) for integration with the mirrors and site-acceptance testing. This is now expected in 2013. Procurement and construction of the large components for the second and third telescopes has begin, as has initial integration of the largest parts, but additional funding is needed to bring these to a completed state (Figure 1). The optics for UT #1 are nearing completion, while the primary mirrors for telescopes 2 and 3 still requiring several months of work. However, all the secondary and tertiary mirrors for UTs #1 through #6 are complete and meet the required surface specifications. The six sets of optics are presently being warehoused at the NMT campus as we investigate other large optics finishing companies to complete the work since the previous company fell victim to the US economic downturn.

Figure 1: Telescope mounts and optics for the MROI: At left are the bases for UTS #2 and #3 at the AMOS factory; at center their corresponding two top ends; at the right UT #1's primary mirror is shown at the OST polishing facilities. Pictures are courtesy of AMOS and OST.

2.2. Unit Telescope Enclosures and Visitor's Center

The unit telescope enclosures (UTEs) for the MROI have an unusual and novel design which serves three different purposes simultaneously: 1) they protect the telescopes and their instrumentation from environmental influences, 2) they allow for the field-of-view and field-of-regard requirements for the array, especially during observations in a close-packed configuration when telescopes are separated by 7.8m on centers, and 3) they allow for protected transportation of the telescopes to new configurations on the ridge to match different scientific goals (Figure 2). The UTEs have been designed by EIE in Venice, Italy (see Busatta, A. et al. 2010 and Payne, Marchiori & Busatta, 2010). In 2011 the fabrication vendor, Berengo-Galbiati in Lecco, Italy, was competitively selected to undertake the build and deployment of the UTEs. We anticipate approximately 12 months of activity to produce the first UTE, which will commence as soon as funds become available.

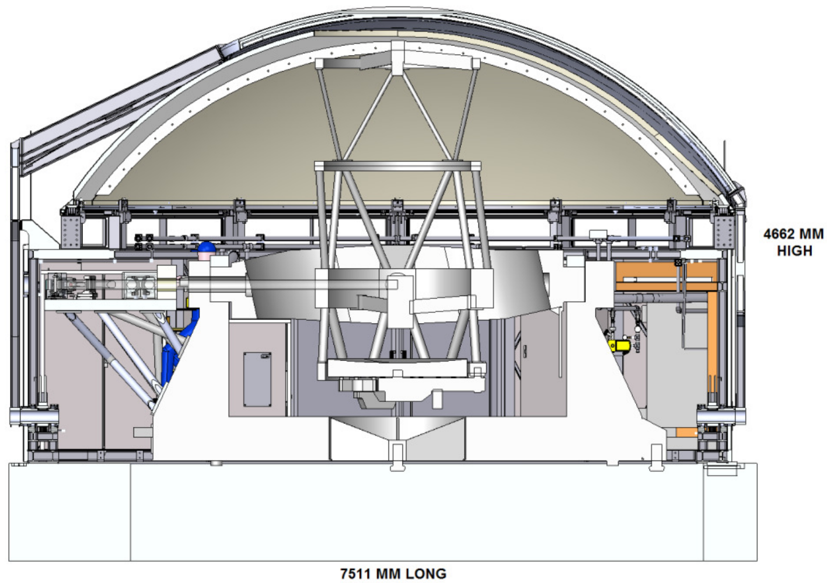

Figure 2: A cross-section of an MROI UT enclosure. Note, in particular, the extremely efficient use of interior space, the "squat" design of the enclosure to meet the field-of-view requirements for the array, and the separated foundations for the telescope and enclosure mounts. This design drawing is courtesy of EIE.

A competitively selected proposal within the state of New Mexico for a Visitor's Center at Magdalena Ridge was awarded to NMT/MRO in 2011. The visitor's center will also include a co-located maintenance facility for observatory equipment within the building. This facility will house a servicing location for large scientific equipment from the observatory, including a mounting platform and roll-off roof section for testing/debugging the MROI unit telescopes with starlight (Figure 3). The design is being undertaken by URS Corporation and their sub-contractor SMPC Architects in Albuquerque, NM. The observatory has released a request for proposals for the construction and has already pre-qualified five contractors for bidding on the completed design. This procedure is expected to start later this year. When completed in 2013, we anticipate testing the first MROI telescope on-site in this facility, prior to receiving the first UTE.

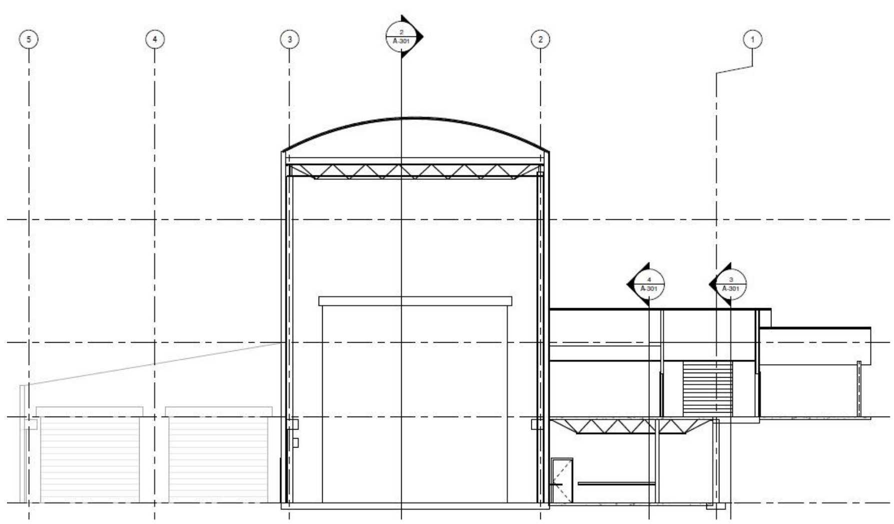

Figure 3: A cross-section of the new MRO visitor's center and maintenance facility. At left are garage doors for vehicles and at center is the maintenance bay for large equipment. The initial tests of telescopes and servicing of large equipment will use these facilities on the Ridge.

2.3. Array Infrastructure and Beam Relay Systems

When fully completed, the MROI array infrastructure will include 28 separate telescope mounting platforms for the full ten-telescope complement of the MROI, over 2 kilometers of vacuum transport pipe for the stellar beams, and close to 30 custom vacuum beam relay containers. These will be mounted on specialized platforms with stringent subsidence and vibrational stability requirements, and each will contain a beam turning mirror and its associated components required for the automated alignment system (see below). Each telescope foundation location will contain infrastructure for separate electrical, Ethernet and glycol cooling connections. Importantly, at each UT location, the UTs and UTEs will have physically decoupled kinematic mounts and foundations so that any wind-buffeting of the enclosures will not be coupled directly to the telescopes and degrade the interferometric observations.

In situ-testing and analysis of prototype components for the vacuum beam relay system demonstrated that these would not be able to meet the very stringent thermal and vibrational stability requirements needed to support the array-wide error budget. As a result, the beam relay system, which includes relay pipe supports, vacuum anchors, cross-over cans and their supports, and the mounts for mirrors 4 and 5 in the MROI beam train (the mirrors which immediately follow the telescope optics) have all undergone a complete redesign since the last SPIE meeting (see Santoro et al. 2012, these proceedings). Several of these new prototypes are now undergoing on-site or in-lab testing, including thermal stability tests of mirrors 4 and 5, and vacuum integrity tests of many of the different can designs (Figure 4). We have recently begun on-site tests of the vacuum beam relay system from the beam combining facility to the vertex of the array infrastructure, with vacuum integrity performing at or near specifications.

Figure 4: Components of the beam relay system under prototype and test in the lab and on-site at MROI.

Design of the array infrastructure components has been a collaborative project between the observatory and M3 in Tucson, AZ, who designed the MROI beam-combining facilities (see Creech-Eakman, et al. 2008). To date, seven of the inner central telescope pads have been installed at MROI since the 2010 SPIE conference (see Figure 5), and it is expected that three of these pads will be fully populated with all the necessary service connections by the end of the year. Ongoing installation will exploit in-house effort at NMT/MRO as more funding becomes available.

Figure 5: A view along the west array arm of the interferometer toward the beam combining facilities. Four of the telescope and enclosure foundations are shown together with the beam relay and vacuum can piers running along the left-hand side of the photo.

2.4. Fast Tip-Tilt and Acquisition Systems

The MROI combined fast tip-tilt/narrow-field acquisition systems are located on the Nasmyth platform of the unit telescopes. The role of the systems is to perform initial acquisition of an observational target, and subsequently to maintain the telescope pointing and remove low-order atmospheric tip-tilt perturbations by actuating the telescope's secondary mirror throughout the scientific observation. All sensing for this part of the MROI system will occur at optical wavelengths (400-1000 nm) so that near-infrared light is preserved for fringe-tracking and initial science. Future MROI science observations at optical wavelengths will likely involve the bluest light of this band (up to ~600 nm) being used for tip-tilt sensing.

The fast tip-tilt and narrow-field acquisition systems are being designed and prototyped by the University of Cambridge. The contract was only recently awarded to this group and a great deal of progress has been made during the past two years. Figure 6 shows the conceptual design of the system and some of the prototype hardware, and further details can be found in Young et al. 2012 (these proceedings). The design uses a transmissive focusing optic which gives a high optical throughput and has much more relaxed alignment tolerances than an off-axis parabola. As a result, it has been possible to realize opto-mechanical design contains no actuated alignment components. The system is designed around a COTS Andor electron-multiplying CCD and has a predicted V-band sensitivity of 16th magnitude: in fact it will be able to operate with even fainter targets, but will then not satisfy its requirement to deliver a two-axis residual tilt error of no more than 36 milli-arcseconds. A full-scale prototype is presently under test at Cambridge.

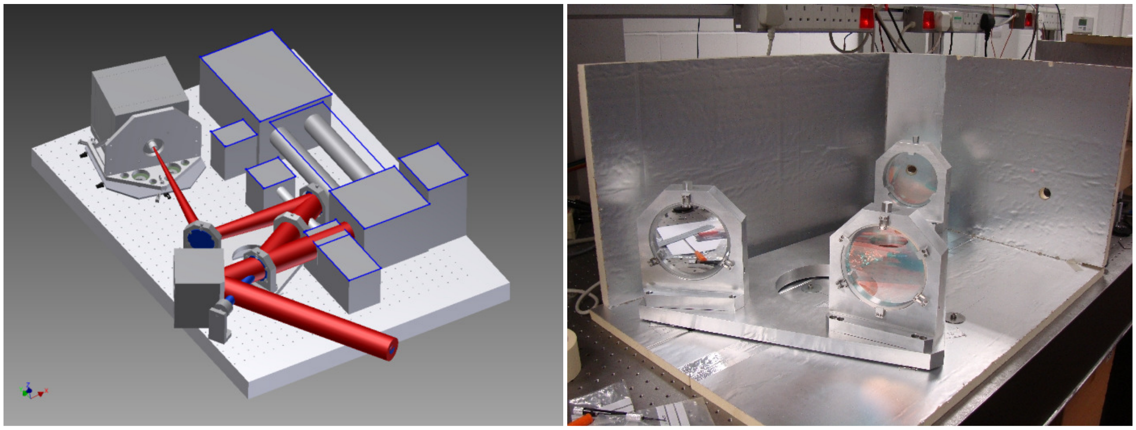

Figure 6: Preliminary design of the fast tip-tilt system. On the left is an isoplanatic view of the fast tip-tilt system on the Nasmyth table of the telescope, and on the right is a portion of the system under test at the Cavendish lab in Cambridge.

2.5. Delay Lines

The delay lines and associated carts or trolleys are a completely new system in the field of optical/infrared interferometry and are being designed and fabricated by the University of Cambridge (see Fisher et al. 2010 for details). Risk reduction experiments and tests of a prototype trolley were initially undertaken in Cambridge, resulting in the present trolley final design. This design is the only one in existence which allows a continuous delay stroke of up to 380 meters in vacuum. The MROI delay lines feature innovations in three major areas: 1) the trolleys have compliant wheels and actuated secondaries (in a cat's eye design) such that they can run directly on standard 16 inch diameter aluminum pipe, with closed-loop correction of beam shear due to pipe irregularities, 2) the opto-mechanical and control system design surpasses all requirements for optical path length jitter, including when passing over pipe joints in the system, and 3) the use of inductive pick-up along the bottom of the vacuum pipe and wireless communication with the on-board computer avoids the need to drag cables behind the trolley.

In late 2010, 100 m of delay line pipe were installed and fully aligned to local fiducial markers inside and outside the beam combining facility using theodolites and the MROI metrology system (Figure 7). The stability of this system has been regularly monitored over the intervening period and shows excellent stability: there has been less than 0.5 mm of motion of the 100 m length of pipe over the span of 12 months. In addition, the metrology laser beam stability has been better than 0.5 seconds of arcs over periods of several weeks. Several dozen pipe sections for the second and third delay lines have been purchased and installation will begin as soon funds become available.

Figure 7: The current delay line pipe installation at MROI. On the left is the first 100m of delay line pipe for trolley #1 in the MROI beam combining facility, while at right is shown the metrology launch table within the inner beam combining area.

At present, the first production delay line trolley is complete and has passed factory acceptance testing in Cambridge (Figure 8). We are awaiting clearance at US Customs to ship the trolley to MROI, where it is expected to undergo site acceptance testing shortly. Procurement of all the long-lead items for trolley 2 has begun, with completion and factory testing of the second trolley anticipated well in advance of the arrival of UT #2.

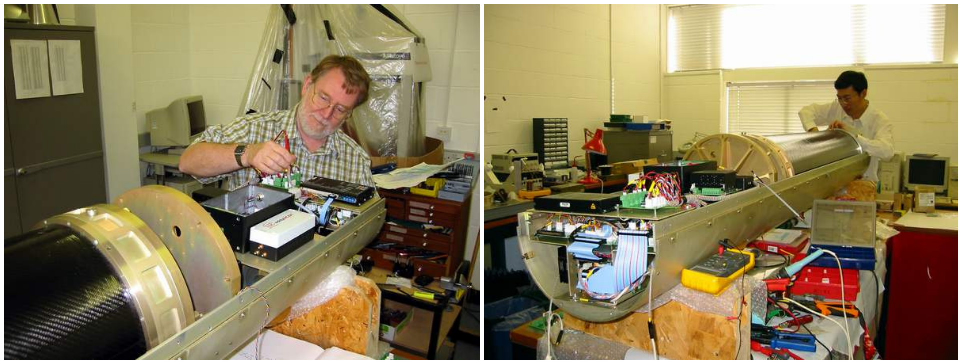

Figure 8: A delay line trolley under test at Cambridge. At left is the back end of the delay line trolley, where the onboard control electronics and wireless communication are located, while at right you see the full length of the trolley during final assembly at the Cavendish Lab in Cambridge. The long black structure seen in both images – most clearly to the bottom left of the left hand panel – is the custom carbon-fiber barrel of the principal optical tube assembly.

2.6. Automated Alignment System

The MROI alignment system will be a fully computer automated optical alignment system which will be used to feed and align "white" and laser light simultaneously through the fringe tracker and science instruments, and as well along the beam relay system and delay lines out to the unit telescopes. The use of the system will greatly improve the efficiency of the initial alignment of the interferometer, and will be key to rapidly re-locating the starlight beams and getting back on-sky if an alignment fault occurs during the night (see Shtromberg et al. 2010). The prototype system underwent major testing in 2010 and has been mechanically redesigned to improve its optical throughput and to defeat a vignetting problem (Figure 9). Automated "smart" alignment algorithms have been developed and are currently under test in the laboratory as a part of the closed-loop fringe experiment (see below).

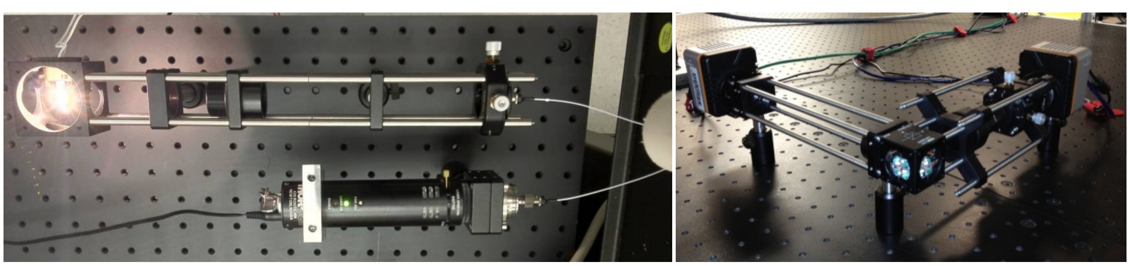

Figure 9: Components of the automated alignment system. At left are the fiber injectors for the white-light and near-infrared/visible laser alignment beams and at right are the optical components and cameras for the sensing unit that measured the beam direction and location simultaneously.

2.7. Fringe-Tracker System

The MROI fringe-tracker ICoNN (Infrared Coherencing Nearest Neighbor tracker) is a nearest neighbor style pairwise beam combiner that can mix and sense the full complement of 10 telescope beams of the MROI. The design has been developed to allow the interferometer fringe phase to be detected and tracked at either the H or K infrared bandpasses for any distribution of neighboring telescopes, while at the same time a separate science beam combiner(s) will works at other infrared or optical wavelengths to sense the fringes from the beams from all combinations of telescopes (i.e. not just the nearest neighbor pairs). The ultra-stable MROI design is completely non-actuated save for its modulating mirrors, and has demonstrated excellent opto-mechanical stability even when tested in a laboratory with no temperature or vibration control. Based on this performance we anticipate very little need for routine re-alignment of the fringe-tracker system in the beam combining facility at MROI where high vibrational stability and thermal changes controlled to within 0.1^{o} C diurnally are the norm. For more details the reader is referred to Jurgenson et al 2008, McCracken et al 2012 (these proceedings – for fringe-tracking simulation and performance) and Santoro et al 2012 (these proceedings – for opto-mechanics) for more details of the MROI fringe-tracker opto-mechanical design and its fabrication and assembly progress.

Since the last SPIE meeting the cold spectrograph/camera system for ICoNN has been manufactured (Figure 10) and delivered to the MROI lab. Vacuum hold times are excellent and cryotesting of all the opto-mechanics in the system was started early this year. We are presently integrating and testing a PICNIC detector and a set of ARC (Leach) electronics in the system. Later this year, we will commence closed-loop testing of the entire fringe tracking system using a "dummy" atmosphere and real-time optical path difference control of actuated components to simulate on-sky observations. Only after these tests are complete will we ship the fringe-tracker combiner and spectrograph to the Ridge for installation in the optical laboratory.

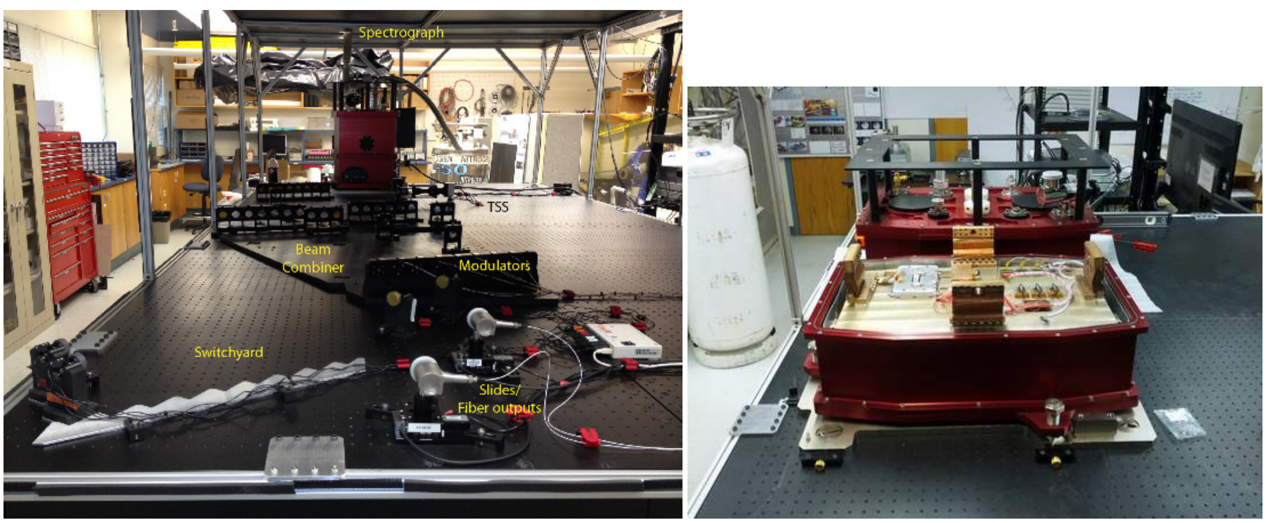

Figure 10: The MROI fringe tracker, ICoNN, under test in the lab. The left hand panel shows the beam combiner, spectrograph, modulators and switchyard being fiber-fed by the alignment system light in the foreground of the picture. The right hand panel shows the cryogenic optical bench of the ICoNN spectrograph in the foreground and to the rear of the picture the top portion of the cryostat.

3. FUNDING AND THE SCHEDULE FOR FIRST LIGHT

The schedule for first-light with the MROI is intimately tied to the observatory funding profile. At present we are pursuing multiple avenues of funding including Federal, State, institutional and philanthropic sources. Toward this goal, we are also pursuing private funding with potential industry partners by examining the role that the MROI will be able to play in the imaging of geosynchronous satellites (c.f. Young et al. 2012 these proceedings). A best-case funding profile, with the goal of attaining four-telescope imaging in as short a time as possible, will allow us to reach the following milestones for the observatory over the next few years:

- 2013: Receiving and installing the first telescope and the first delay line trolley. Completing the visitor's and maintenance facility. Completing the beam-relay system for a selection of telescope foundations. Fabrication of the first telescope enclosure and the second delay line trolley;

- 2014: Receiving and installing the first two telescope enclosures and telescope number two, installation of the second delay line pipe and trolley at the Ridge, installation of all the necessary beam combining facility infrastructure (e.g. computers, vacuum system, fast tip-tilt components, beam relay pipes and optics, automated alignment system infrastructure, metrology systems) to support two telescope fringe measurements;

- 2015: Receiving and installing telescope and enclosure number three, and installation of all of its associated beam relay and delay infrastructure. Attaining first fringes with the first two MROI telescopes;

- 2016: Receiving and installing telescope and enclosure number four, and installation of all of its associated beam relay and delay infrastructure. Completing an infrared scientific beam combiner. Attaining closure phase/fringe measurements using four MROI telescopes.

The business plan and operational model for the MROI facility is currently being revised given the recent and anticipated changes in the funding landscape in the US as a result of the economic downturn and outcomes from the Astrophysics 2010 Decadal Survey. We are presently favoring a consortium-style model for operations of the facility such that individual investigators, university partners, and private groups can all attain access to MROI's capabilities. We anticipate initial operations beginning coincident with the deployment of the scientific beam combiner instrument at MROI. Interested parties should contract the observatory directly to initiate informal discussions.

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