The Magdalena Ridge Observatory Interferometer: upcoming important milestones towards first fringes

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ABSTRACT

The Magdalena Ridge Observatory Interferometer has been conceived to be the most ambitious optical/near-infrared long-baseline imaging interferometer in the world today. We anticipate receiving the second telescope mount and enclosure and associated beamline infrastructure to enable us to attempt first fringes measurements early in 2023. Having reached this important milestone, we anticipate receiving the third copy of all beamline components about one year later and attempting closure phase measurements thereafter. We will present a status update and plans under the new Cooperative Agreement with AFRL for the next phases of the project.

Keywords: long-baseline optical infrared interferometry; telescopes; delay lines; fast tip-tilt; fringe tracking; interferometric imaging; geosynchronous objects; space domain awareness

1. INTRODUCTION

The Magdalena Ridge Observatory Interferometer (MROI) is a long-baseline optical-infrared interferometer being built in the mountains of central New Mexico. It has been under development for about 2 decades, and when completed is envisioned to consist of ten 1.4m diameter movable telescopes in an equilateral–Y configuration which has been optimized for an imaging mission. The principal developers of the MROI are New Mexico Institute of Mining and Technology and investigators at the Cavendish Laboratory, University of Cambridge. While the key science mission is centered around astrophysics of faint and complex objects, the MROI will also be capable of imaging man-made objects in geosynchronous orbits and beyond. For more information on the facility and its science and imaging capabilities see our prior papers[1,2,3] and references therein. See figure 1 for recent pictures of the first telescope on the array.

After a recent funding hiatus of 18 months, the MROI facility is funded under a $25 million, five-year cooperative agreement with the Air Force Research Laboratory (AFRL) to achieve several goals toward developing imaging capabilities on man-made objects. These include: completion and installation of the second and third telescopes and their enclosures at the facility, development and expansion of the inner array infrastructure out to 13 telescope stations, development of the second and third beamlines including fast tip-tilt, automated alignment systems, delay lines and atmospheric dispersion correctors, software to operate the facility and finally an upgrade of the fringe-tracking system, ICoNN, and deployment of the infrared science combiner system, FOURIER. Below follows a brief status update of each of these systems and plans for the remaining time on the cooperative agreement.

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Figure 1: On the left is a night-time long-exposure of the first telescope in the MROI array positioned on the W7 foundation. The telescope, built by AMOS, can be seen inside the enclosure, built by EIE, via the internally illuminated structure. On the right is an overhead view of the same telescope seen next to the yellow lifting mechanism, which will be deployed during relocation of the telescopes between various foundations.

2. MRO INTERFEROMETER SUBSYTEM STATUS

The majority of the MROI subsystems have been reported on in prior SPIE and other publications (e.g. delay lines[4], fringe tracker[5], telescope[6], enclosure[7]). This report will serve as an update of work on those subsystems that we have made progress on since the last SPIE report in 2020[8], which was during our funding hiatus (March 2020-Oct 2021).

2.1 Telescope Mount

The telescope mounts for MROI are being built by AMOS in Liege, Belgium[9]. The second telescope mount was about 6 months from deployment at the MROI facilities when funding was halted. We have restarted this contract and will be undergoing Factory Acceptance Testing (FAT) in September, 2022. The mount will then be disassembled, shipped to NM, and reassembled on the Magdalena Ridge in a maintenance facility before being deployed on the array in station W7, where it will undergo Site Acceptance Testing (SAT) and then be used in beamline testing before attempting fringes in spring of 2023. The primary mirror for the second telescope for MROI was completed and coated in aluminum by AOS in Tucson, AZ which unfortunately closed shop during the pandemic.

2.2 Telescope Enclosure

The telescope enclosure for MROI is being built by the EIE Group in Venice, Italy[10]. The second telescope enclosure was similarly about 6 months from deployment when the funding hiatus started. This contract has been restarted but has suffered more delays due to sourcing of critical components, which had to be re-initiated following Covid-19 issues and subsequent loss of some sub-supplier companies in Italy. We anticipate FAT in the September to October timeframe this year, followed by shipping, re-assembly at the MROI facilities, and integration with the second telescope mount and optics. SAT on the array will take place simultaneously with SAT for the second mount, after which time installation of final components, such as the fast tip-tilt system, will occur in advance of beamline testing and fringes.

2.3 Fast tip-tilt system

The fast tip-tilt (FTT) system for MROI is being designed and built by the University of Cambridge part of the MROI team[11]. Deployment and SAT testing of the first FTT unit on the array took place in November of 2018 and has not been reported previously in the literature. The design of the FTT is to allow for tip-tilt correction across the entire optical waveband (450-800nm) when the MROI is undertaking infrared science observations, or just over the blue part of the optical waveband (450-600nm) when the MROI is undertaking optical science observations. The assessment of the initial FTT performance during the nights of November 8-9, 2018 was accompanied by independent seeing measurements performed on-site by J. Briggs using a small seeing monitor he developed and markets, who found good to moderate seeing (0.7"- 1.5") over this time period. The FTT is designed to correct to 16th magnitude in the optical. See figure 2 below for initial first-light performance of the FTT. A new dichroic coating is being developed to improve performance for subsequent units.

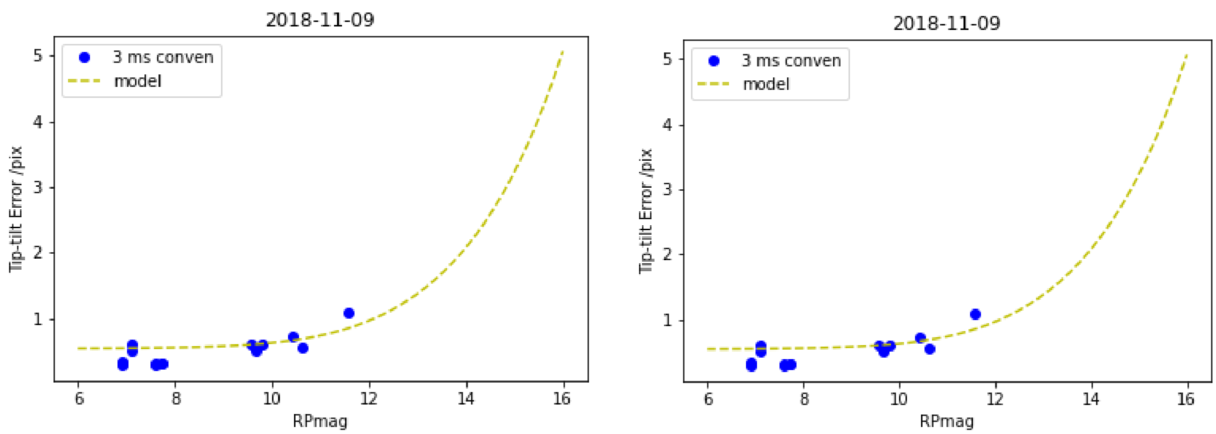

Figure 2: Results of tip-tilt residual errors vs. Gaia RP magnitudes of each stellar target on the first two nights of tip-tilt operations in Nov, 2018. The dashed line is an empirical noise model for the measured performance. Each pixel represents 0.15" on the sky.

2.4 Facilities and infrastructure at MROI

The expansion of the external facilities along the MROI array arms to 13 stations will enable the interferometer to undertake initial science observations with baselines up to 32m along an arm and 54.5m between outer stations. The facility presently has 7 partially-completed telescope foundations, in the sense that the concrete and conduit work has been completed, but not all power, fiber optics and ethernet have yet been installed. Additionally, each telescope station requires a pier nearby on which is housed a beam-relay system vacuum can and associated vacuum pipe for beam transport. It is our goal during this phase of the cooperative agreement with AFRL to complete the inner 13 telescope foundations and as much of the infrastructure as we can afford. This will include an upgrade of the chiller system which is used to maintain the internal temperature of the telescope enclosures during the day and provide a cooling loop at night to send heat (generated by internal electronics) away from the telescopes. As such, a small civil engineering team from New Mexico Tech has joined the project to help with the deployment of these facilities and the oversight of the contracted concrete work, likely during the summer or fall of 2023 but dependent on yearly funding allocations. Internal to the facility, all infrastructure for 3 beamlines is being installed including multiple optical tables, precisely placed on concrete legs (to reduce vibrations) and sited in using a laser tracker. Also to be installed and aligned are the delay line pipes and metrology systems as well as beam compressors to reduce the 100mm beams to a more manageable 18mm within the inner beam combining facility. See figure 3 for external and internal view of the beam transport areas and the inner beam combining area.

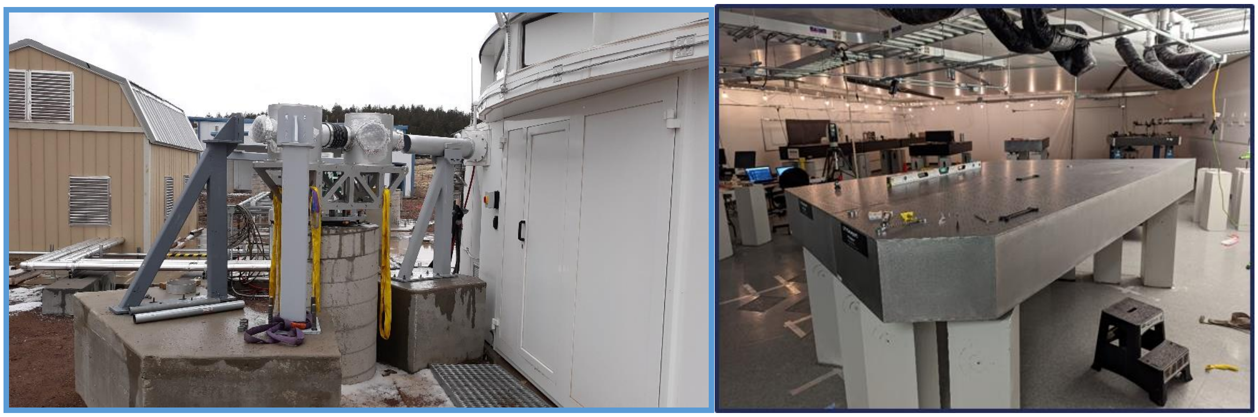

Figure 3: On the left is the first unit telescope with vacuum beam pipes entering the turning can in the center of the picture. The light is then directed into the beam combining facility. On the left side of the picture is a temporary chiller unit used to produce cooling fluid for the first unit telescope and associated electronics. On the right is a picture of the inner beam combining area where optical table installation is ongoing. Custom concrete legs have been designed for the tables to help lower the natural vibrational frequencies. Overhead cable trays and venting systems are visible at the top of the photo.

2.5 Automated Alignment System (AAS) and associated hardware and software

During the funding hiatus it was the project's philosophy to try to support ongoing student work on the project as much as could be accomplished using internal funds at New Mexico Tech and the University of Cambridge. Much of the progress on the Automated Alignment System (AAS) was due to this student work and the support we could provide from faculty and staff at the two institutions. The AAS[12] is an end-to-end alignment system for the MROI that launches artificial beams in the optical and infrared from within the inner beam combining facility upstream toward the telescopes (through beam compressors and delay lines) and downstream toward the fringe tracker and science instruments. Included as part of the AAS is BEASST (Back-End Active Stabilization of Shear and Tilt), a custom Shack-Hartmann system to detect and stabilize the incoming beams at the start of the night and between science observations. An extensive paper in this proceedings on the dissertation work of J. Luis[13] discusses the status of this work to date.

In 2019 testing of the light from the external beam vacuum cans into the inner beam combining facility identified large-scale diurnal motions of external beam cans or mirrors most likely due to solar insolation. We have undertaken detailed thermal studies and mitigation plans to assess and correct for this motion as part of the development of the AAS. This has necessitated planning for the possibility of a "smart" alignment system using thermal data from the external beam pier, vacuum cans and mounts to predict and move optics in anticipation of the motion, especially at the start of the night when the most rapid cooling post sunset is expected.

Master's thesis work by S. Norouzi relating to the AAS was undertaken and completed[14] during the hiatus. This work applied machine learning to solve the problem that BEASST's shear measurement precision is reduced by atmospheric seeing when it views starlight. A conventional approach is to capture and average hundreds of frames to smooth the image prior to reduction, but this reduces the efficiency of gathering science data. Initial results show that a neural network solution can outperform the averaging approach when only a small number of frames is collected.

2.6 Software

The MROI software system consists of an interferometer control system run under Linux, with both hard real-time (e.g. fringe-tracking and delay line software) using Xenomai, as well as conventional software for individual subsystems that is controlled by local software written mainly in C or Java, or a local driver depending on the status and needs of each hardware component. Additional stand-alone systems, such as an Environmental Monitoring and Supervisory System (EMSS), catalogs the weather and temperature and lightning monitoring systems across the Ridge facilities. The software is all monitored via an Interferometer Supervisory System (ISS) which is used to start and stop the entire system and records status of all subsystems in a database, reporting alarms or faults as needed. The ISS is a custom software suite and has been reported on in the past[15]. New effort on the software has included development of a telescope “umbrella system”, a more robust EMSS to include more remote components on the mountain, and simulation systems to practice operating the array components and develop user GUIs. Figure 4 shows a mosaic of several of these operational GUIs under development for the unit telescopes and enclosures.

2.7 Atmospheric Dispersion Correctors

Early in the development of MROI it was recognized that Atmospheric Dispersion Correctors (ADCs) would be required to be able to correct the interferometer beams for tilt and shear across the 0.60 - 2.4 micron operational bandwidth to within 30 degrees of the horizon for scientific studies. Development of these ADCs was recently re-initiated during the hiatus as a theoretical paper study, and is now continuing in terms of identifying actual components and developing a design toward a Conceptual Design Review (CoDR) in late 2022 or early 2023. The location of the ADCs will be on the Nasmyth table of the telescopes and will consist of two pairs of counter-rotating prisms. Custom control software will be developed as part of this effort. We anticipate deploying and testing a prototype, and then the building and installing the final ADC systems for three telescopes during the duration of this cooperative agreement.

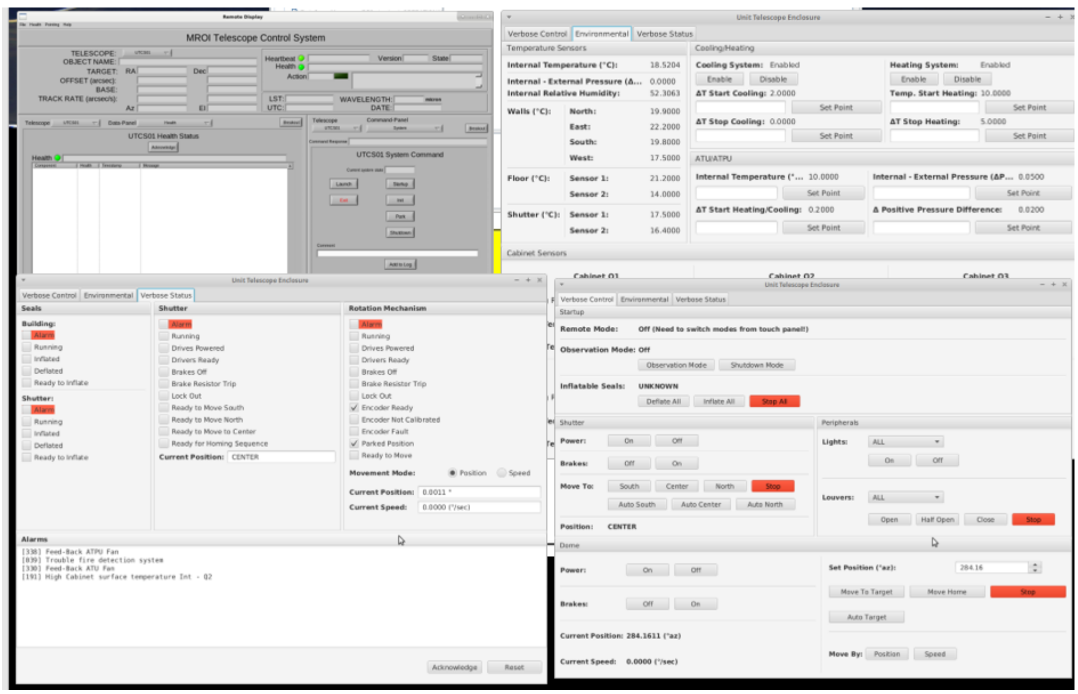

Figure 4: GUIs for controlling the telescope and enclosure. These GUIs are currently integrated with both actual hardware and also a simulation system (under development) to allow for testing software in advance of deployment of new systems.

2.8 FOURIER

It was initially planned that first-fringes measurements with MROI would use the ICoNN fringe-tracker[5] by replacing the current PICNIC detector system with the relatively new SAPHIRA detector developed by Leonardo and readout electronics developed by ESO[16]. Unfortunately, the funding hiatus made it impossible to execute that plan, and so a re-baselining of first fringes will occur using the FOURIER instrument which was built as part of a dissertation project of D. Mortimer[17] at the University of Cambridge and was able to purchase and install a SAPHIRA and electronics prior to and during the hiatus. FOURIER is a low-to-moderate resolution J, H or K 3-beam image plane combining system for first science observations with MROI and is being reported on elsewhere in these proceedings[18]. FOURIER will be delivered to MROI and installed in time for first fringes observations in early 2023.

3. PLANS MOVING FORWARD

The new cooperative agreement for MROI with AFRL will take us to a three-telescope facility with both a fringe tracker and infrared science instrument, all under computer control and employing fast tip-tilt correction, an automated alignment system and employing custom delay lines. This is made possible due to the AFRL's interest in potentially deploying a system like MROI for imaging man-made objects in geosynchronous orbit and beyond. In furtherance of this effort, we are working with Tau Technologies in Albuquerque, NM to develop use cases and do modeling of a variety of man-made targets for first-light investigations with MROI. These investigations will not be able to produce images with only 2 or 3 telescopes operational, but they will allow MROI to demonstrate sensitivity in both visibility and closure phase precision on some man-made objects and astronomical objects of similar brightness to demonstrate MROI's capabilities in supporting Space Domain Awareness (SDA) studies. Initial work led in our group by J. Young[19,20] has shown the promise of an MROI-like facility, potentially deploying more than 10 telescopes, for SDA imaging needs in support of national security and general health of the satellite assets at geosynchronous orbit and beyond.

Future funding for MROI beyond the initial 3-telescope deployment highlighted here has not yet been secured. However, the US's 2020 Astrophysics Decadal Survey highlighted the need for long-baseline optical interferometers to undertake many key science questions of interest to the astrophysics community, with MROI being one of the facilities specifically called out. We have begun initial queries with funding agencies towards these goals of a fully funded and completed facility which could be accomplished for modest funding levels by the close of the 2020 decade.

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