The Magdalena Ridge Observatory Interferometer

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Outline

1 Introduction
  - The MROI project
  - Science and technology drivers
  - Technical requirements

2 Conceptual Design

3 Accomplishments and Current Status
  - Unit Telescopes
  - Fast Tip-Tilt Systems
  - Beam Relay
  - Delay Lines
  - Beam Combiners
  - Alignment
  - Controls

4 Conclusions

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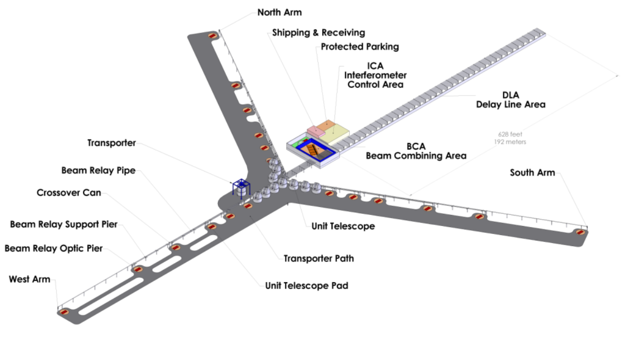
The What, Who, Where and Why of MROI

What is MROI?

The Magdalena Ridge Observatory Interferometer:
A telescope array dedicated to optical/IR synthesis imaging



Unique Features of MROI

- Focus on **model-independent imaging**
- Operation at **visible and near-IR** wavelengths
- **Baselines up to 350 m**
- Limiting sensitivity **goal H=14**

Who is working on MROI?

- New Mexico Tech
  - Project Office
  - Engineering team –
    Allen Farris, Andres Olivares, Chris Salcido
  - Site
- University of Cambridge
  - Vision
  - System Architects – Chris Haniff, David Buscher
  - Sub-system development

Science and technology drivers

- Capitalise on proven strengths of existing interferometers
- Improve on their limitations, where tractable
- Science case built on **model-independent imaging** and realistic enhancements in limiting sensitivity and observing efficiency

Science case

- AGN astrophysics
  - Verification of the unified model, nuclear and extra-nuclear starbursts, BLR dynamics, jet counterparts
- Star and planet formation
  - Protostellar accretion, disk clearing as evidence for planet formation, emission line imaging of jets, outflows and magnetically channeled accretion. Detection of sub-stellar companions
- Mass-loss and dynamical systems
  - Convection and impact on mass loss, wind and shock geometries. Mass-loss in binaries. Stellar pulsations

Top-level science requirements

- Imaging with 5×5 resels for resolved-core objects, 10×10 resels for compact-core objects
- Image dynamic range 100:1
- Point source fringe tracking sensitivity $H = 14$
- Wavelength coverage 0.6–2.4 µm
- Spectral resolution $R \approx 30, \approx 300, \gtrsim 5000$
- Automated sequencing and operation (operator on site)

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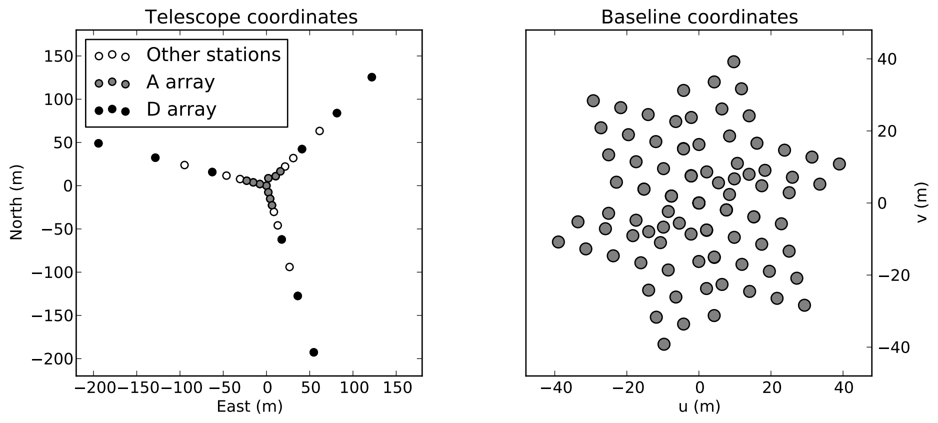
Array configuration



Telescopes and AO

- 2–3r_0-sized telescopes without AO beyond tip-tilt
  - Optimum size for tip-tilt corrected sensitivity
  - Larger AO-equipped telescopes would conflict with need to close-pack telescopes
  - Laser guide stars would be required for good AO sky coverage; cost of this conflicts with need for enough telescopes to image reliably
- 2–3r_0 in near-IR is 1–2 m

Beam relay

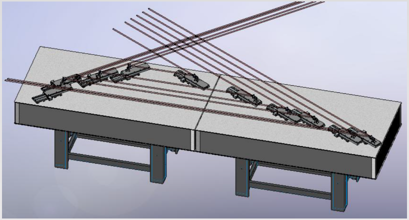
- Vacuum free-space beam transport
  - Avoids losses incurred by splitting bandpass and injecting into optical fibres
- Large beam size for long-distance propagation; small beam after delay lines to reduce cost and footprint

Delay lines

- Single stage, continously-variable system to minimize reflections and avoid switching overheads
  - Contrast with CHARA, NPOI scheme of switchable fixed delays plus short continuously-variable delay

Science instruments

- Visible ($\lambda < 1$ μm) and near-IR combiners
- Space for "guest" instrument
- Beam combiner concepts based on parallel combiners fed by a reconfigurable "fast switchyard"



Fringe tracking

- Group delay method allows coherencing on sources $\sim 10\times$ fainter than cophasing methods
  - Short exposures needed in science beam combiners
- Separate fringe tracking and science combiners to allow optimization for their respective roles

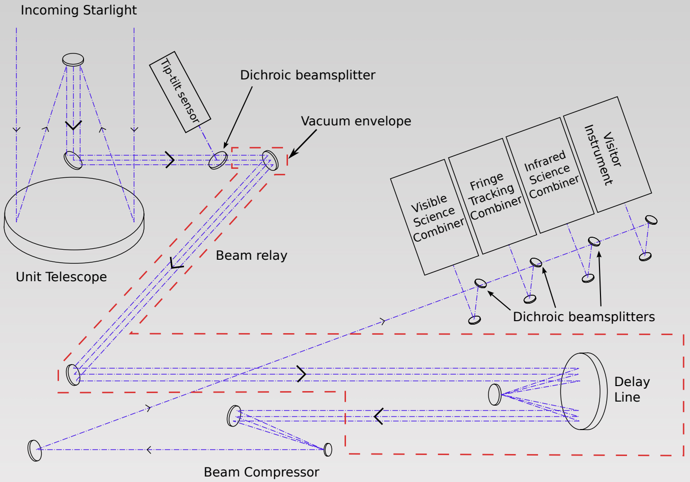
Alignment

- Automated nightly alignment
- Parallel alignment of beam trains

Control software

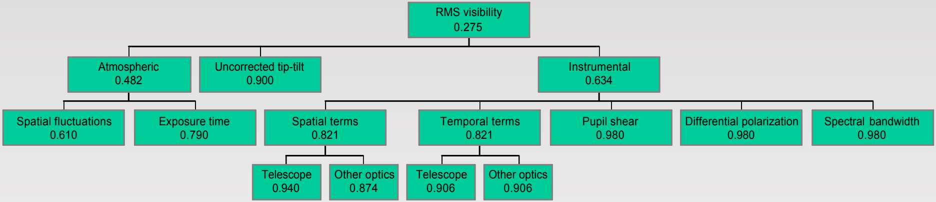
- Automated operation
- Continuous collection and storage of engineering data
- Independently-developed subsystems integrated to form a distributed control system using custom protocols over Ethernet
- Central supervisory system handles configuration, sequencing and data collection

Optical train



Error budget

- Detailed error budget used to apportion losses between optical surfaces
- Overall visibility loss factor 0.276 at *H* band
- Overall throughput 13%



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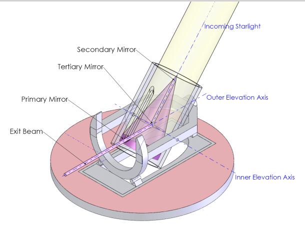
Accomplishments

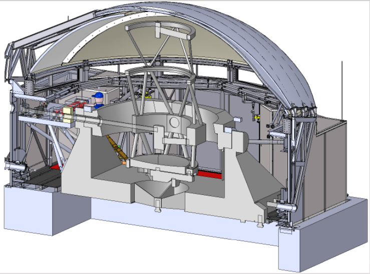
- Observatory site and infrastructure prepared
- Successful design, tendering and construction of:
  - Beam Combining Facility
  - Unit Telescope #1
  - Telescope and beam relay piers close to array vertex
- Mitigated risks of innovative sub-system designs
  - Unit telescopes
  - Delay lines
  - Fast tip-tilt systems

Unit Telescopes



- Three mirror elevation-over-elevation mount
- Factory verification of pupil motion, vibration induced optical path fluctuations, M1/M2/M3 stability
    - Final WFE 62 nm rms

Telescope Enclosures



- Final design allows minimum 7.8 m UT spacing
- Enclosure supports telescope during relocation

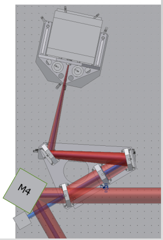
Unit Telescopes Status

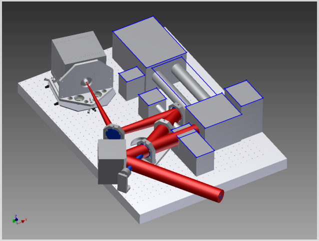
- UT#1 passed FATs, on-site integration in visitor and maintenance facility mid 2014
- UT#2 and UT#3 part-fabricated
- UT Enclosures designed

Fast Tip-Tilt Systems

- One system per UT, mounted on Nasmyth optical table
- Uses “visible” light 350–1000 nm
- Fast tip-tilt correction using UT actuated secondary mirror
    - Tip-tilt zero point on FTT camera defined at start of night as part of interferometer automated alignment
- Narrow-field (60″) target acquisition

FTT Optical Design and Layout





- Transmissive design with custom cemented triplet lens
  - Angular stability tolerance 20× that for OAP mirror
  - Temperature-dependent focal length compensates for expansion of steel table top

FTT Status

- Prototypes of critical system components have been built and tested
- Laboratory test results validate design approach
  - Optomechanical stability within factor 2–3 of demanding requirements already demonstrated
  - Camera test results predict 49.6 Hz closed loop bandwidth at 900 Hz frame rate
- Final design and fabrication of first system underway
- Preliminary version of real-time control software done

Beam Relay System

- Beam diameters 95 mm outside and through delay lines, 13 mm for beam combiners
- Engineering of support piers for MROI environment challenging; final design is bulky and hence expensive

Beam Relay Status

- Partial Beam Relay System under test on site

Delay Lines

- Delay range 0 to 380 m in vacuum, realized in single stroke with only three reflections
- Multiple innovations needed to make system affordable:
  - Delay carriage runs directly on inner surface of vacuum vessel; necessitates additional active control
  - Wireless communications
  - Inductive power supply

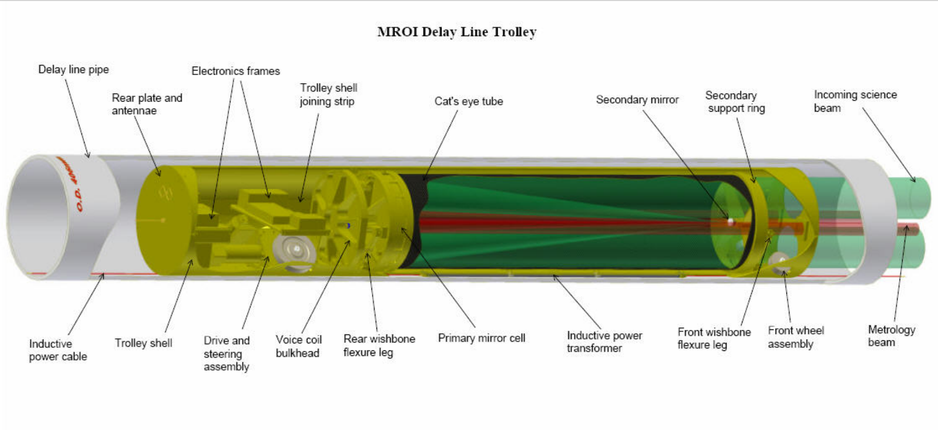
Demonstrated Performance

- **Delay jitter < 15 nm rms over 10 ms**; < 41 nm rms over 35 ms; < 55 nm rms over 50 ms ($\lambda/40$ rms over $2t_0$)
- **Intra-night delay repeatability < 10 µm**; night-to-night < 100 µm
- Slew speed: **30 m delay change in 30 s**; full reposition in 5 min

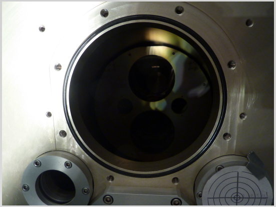
The MROI Delay Line Trolley

- Trolley comprises **cat's eye** retroreflector flexure-mounted to motorised **carriage**
- Cat's-eye driven by voice coil
- Carriage runs inside a 200 m evacuated pipe

The "Photon Torpedo"



Delay Lines Status

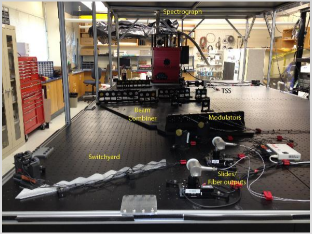


- First production trolley installed at MROI July 2013
- Site Acceptance Tests Oct/Nov 2013
- Rework and manufacture of second production trolley in progress

Fringe Tracking Beam Combiner

- **ICoNN**: Infrared Coherencing Nearest-Neighbour tracker
- Nearest-neighbour combiner: only mixes beams from adjacent telescopes
- Design allows for up to 10 input beams
- Handles three nearest-neighbours in central telescope in “Y”

ICoNN Status



- Beam combiner complete
- Final spectrograph optics due shortly
- Lab demonstration of closed-loop tracking in progress

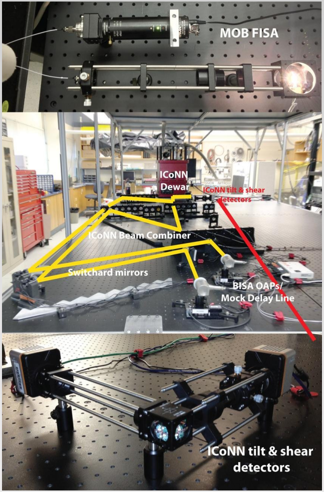
Science Beam Combiner

- MROI will eventually have “visible” (0.6–1.0 µm) and near-IR (*JHK*) science combiners
- Development of near-IR combiner prioritized
- Various design concepts have been compared
- Designs use a fast optical switchyard to select subsets of beams, to maximize instantaneous signal-to-noise

Alignment

- Scheme designed for nightly correction and beam tilt and shear
- Optical train split into three independent “sub-trains” whose optical axes must be co-aligned:
  - Inner rotation axis of unit telescope
  - Line of motion of delay line
  - Optical axes of beam combiner
- A pair of flat mirrors between each sub-train provides the necessary degrees of freedom

Alignment Status



- Preliminary design complete
- Prototype components built and tested

Controls

- Main issue was integrating many diverse systems
- Solved by using standardised interface software automatically generated from a simple high-level description of the system
- Generated interface code provides functionality for:
    - Object construction and destruction
    - System configuration using data from a central database
    - Receiving commands
    - Publishing engineering monitor data, faults and alerts

Controls Status

- Initial versions of supervisory system components and graphical user interfaces
- Java version of system interface framework complete
- C version of system interface framework nearly complete

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MROI Schedule and Funding

- Pursuing Federal, State, and philanthropic sources
- Aim to demonstrate performance (esp. sensitivity) and possibly conduct a limited science programme
- Optimistic schedule:
    - 2014 UT #1 (inc. FTT #1) in **visitor and maintenance facility**
    - 2015 Enclosures #1 & #2, UT #2
    - 2016 UT #3, **first fringes** with fringe tracking beam combiner
    - 2017 UT #4, IR science beam combiner

Conclusions

- MROI concept found to be realizable as a detailed design
  - Relocatable telescopes, 350 m maximum baseline
  - Beam train with 13 reflections from sky to combiner input
- Observatory infrastructure in place
- Major procurements and civil engineering done
- Biggest design risks (UTs, delay lines) retired
- Design and prototyping complete for most systems needed for first fringes

Forward Look

- Schedule dependent on funding
- Partners welcome!
- Initial goal is to demonstrate performance with a compact sub-array on ∼2016 timescale
- Leading to fundraising for an operationally-viable array
- Possible job opportunities in a few months