Update on the Status of the Magdalena Ridge Observatory Interferometer

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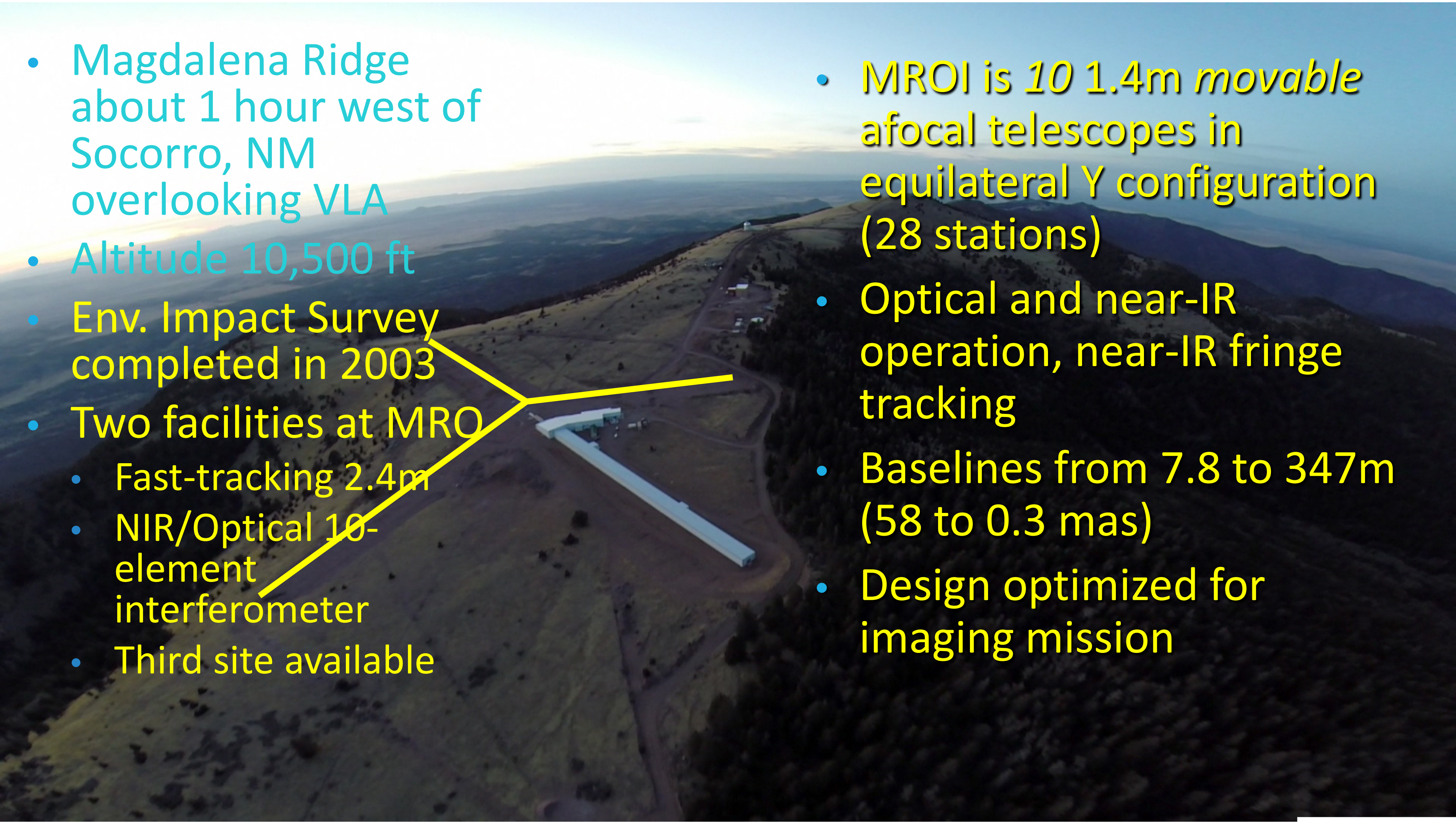
On behalf of NMT and Cambridge teams

Overview of the Observatory

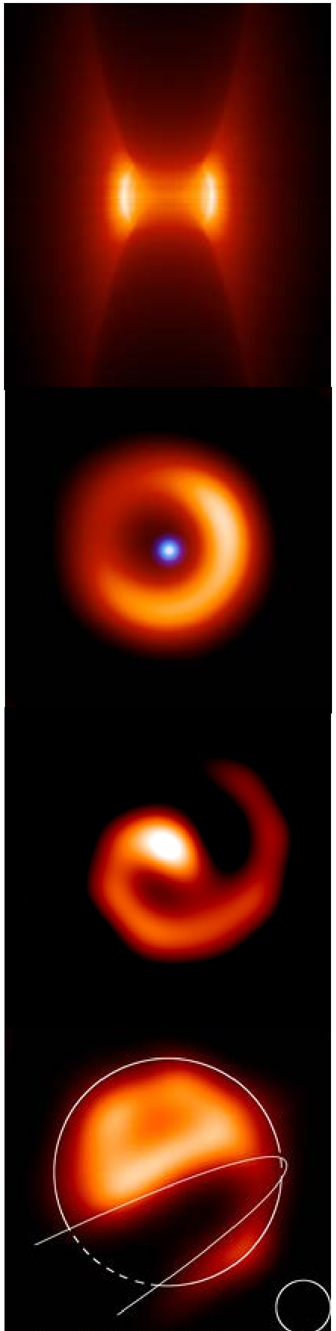


- Magdalena Ridge about 1 hour west of Socorro, NM overlooking VLA
- Altitude 10,500 ft
- Env. Impact Survey completed in 2003
- Two facilities at MRO
  - Fast-tracking 2.4m
  - NIR/Optical 10-element interferometer
  - Third site available

- MROI is *10* 1.4m *movable* afocal telescopes in equilateral Y configuration (28 stations)
- Optical and near-IR operation, near-IR fringe tracking
- Baselines from 7.8 to 347m (58 to 0.3 mas)
- Design optimized for imaging mission

MROI Science Case

- AGN:
  - Verification of the unified model.
  - Determination of nature of nuclear/extra-nuclear starbursts.
  - H = 14 gives >100 targets.
- Star and planet formation:
  - Protostellar accretion, imaging of dust disks, disk clearing as evidence for planet formation.
  - Emission line imaging of jets, outflows and magnetically channeled accretion.
  - Detection of sub-stellar companions.
- Stellar accretion, mass loss and B fields/circulation:
  - Convection, mass loss and mass transfer in single and multi-star systems.
  - Bipolarity and collimation of circumstellar material, wind and shock geometries, interacting binary systems
  - Pulsations in Cepheids, Miras, RV Tauris, etc.
  - Star spots, oblateness, asymmetric properties



Flow Down for Requirements

- Telescope diameter of 1.4 m
  - H magnitude = 14th for group delay tracking limit
- Spatial scales of 0.3 to 58 mas
  - Baselines from 7.8 to 347 m (for 0.6-2.4 microns)
- Moderate-to-high spectral resolutions
  - Separate fringe tracking and science cameras
- High throughput to achieve sensitivity limit
  - Fifteen reflections from primary to detectors (13% throughput)
  - Optimized coatings (polarization, phase, reflectivity) for 0.6-2.4 microns
- Large number of telescopes rapidly combined/movable
  - Optimized for model-independent imaging

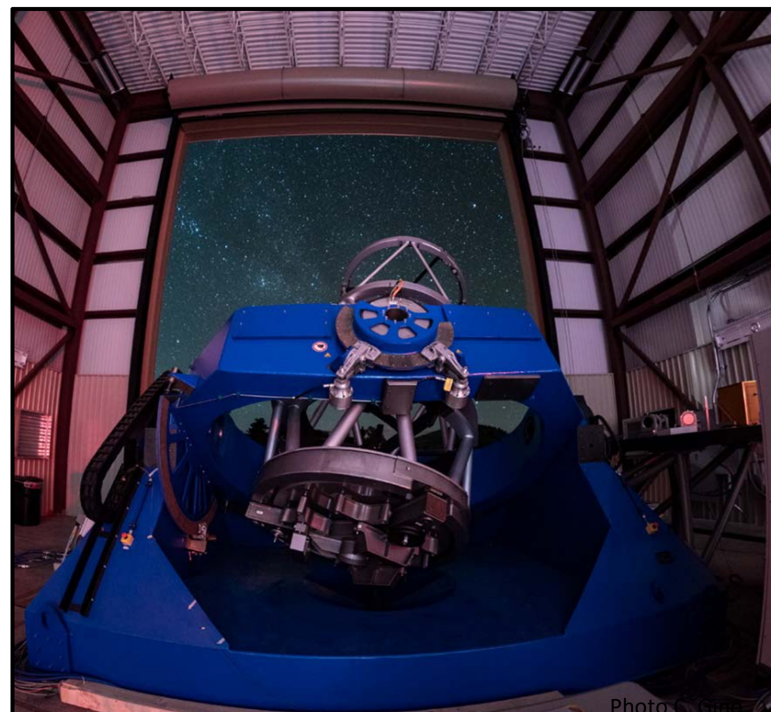
Photo T. Eakman, Array layout: A. Olivares

Try to apply lessons learned from other interferometric facilities whenever possible.

Team has experience with hardware at: COAST, SUSI, KI, CHARA, NPOI and PTI

Telescope #1 first light 4 years ago

- AMOS 1.4m diameter alt-alt telescopes
  - 62nm rms wavefront after 3 reflections
  - Polarization preserving design
  - Tip-tilt secondary on PI hexapod - reduce number of reflections & achieve low-order AO correction
  - First light in VCMF in Nov ’16



First Enclosure (+Scope) on the Array

- EIE enclosures house and transport telescope
  - Squat design - 6 hours continuous tracking in close-packed configuration (7.8m on centers)
  - Louvered design for venting & embedded metal mesh for lightning protection
  - MROI team programmed dome automation with telescopes
  - Moved with crane, preferably reach stacker in future – see movies at MROI website
  - First light on array in Nov 2018 with FTT

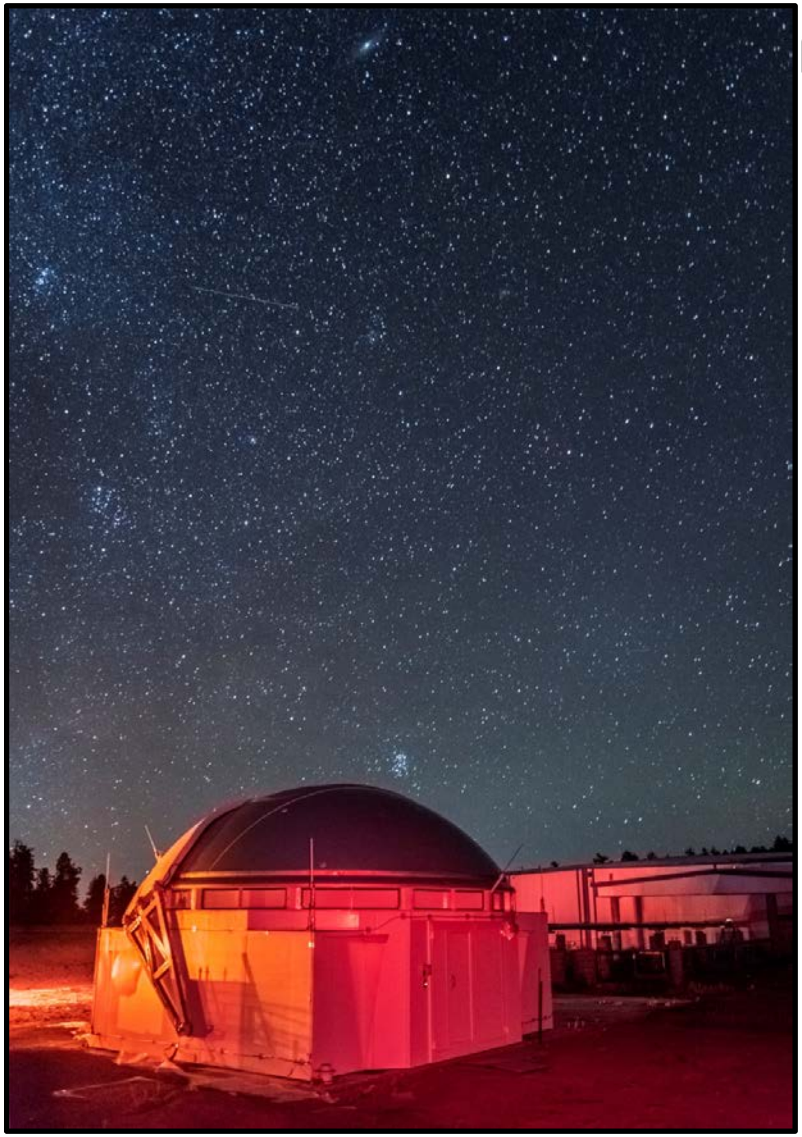
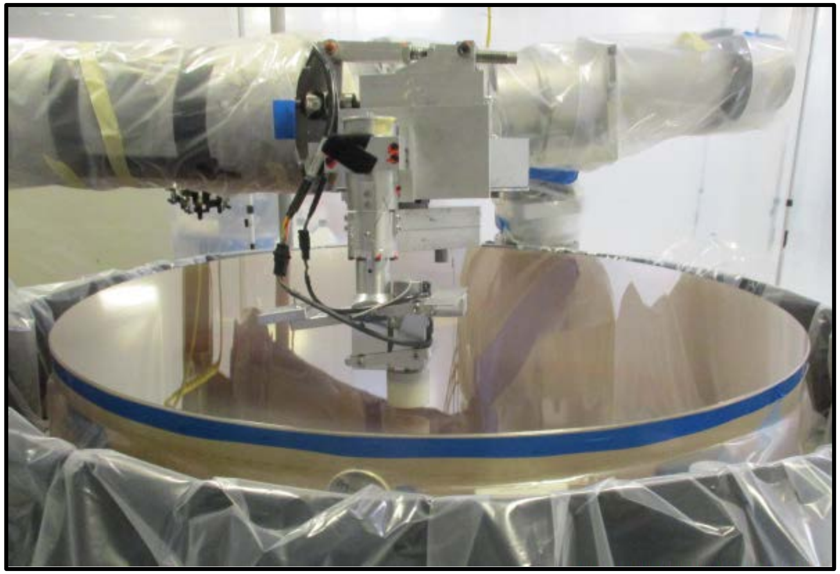
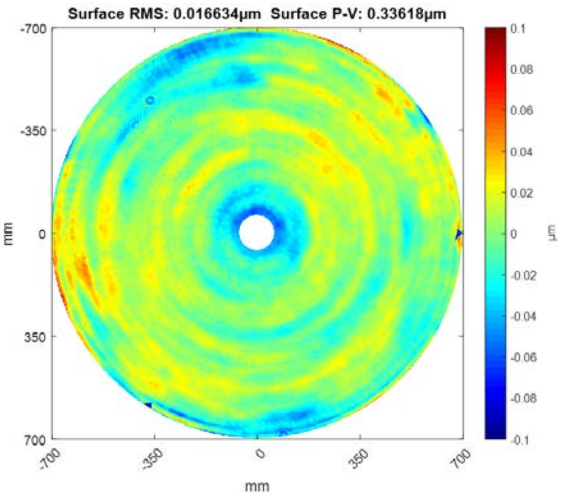


Photo C. Gino

Telescope Primary for UT#2 Done Polishing

- 6 full sets of optics purchased a decade+ ago
- Secondaries and tertiaries all finished before original company went bankrupt during Great Recession
- Measured rms WFE on 2nd primary is 16.6nm (19.5nm is requirement)
- Using CGH vertically in the mirror mount to match all systems
- Coating completed and WFE remains within tolerances
- 3rd primary polishing was about half completed in March 2020 – anticipate 6 more months of work to complete

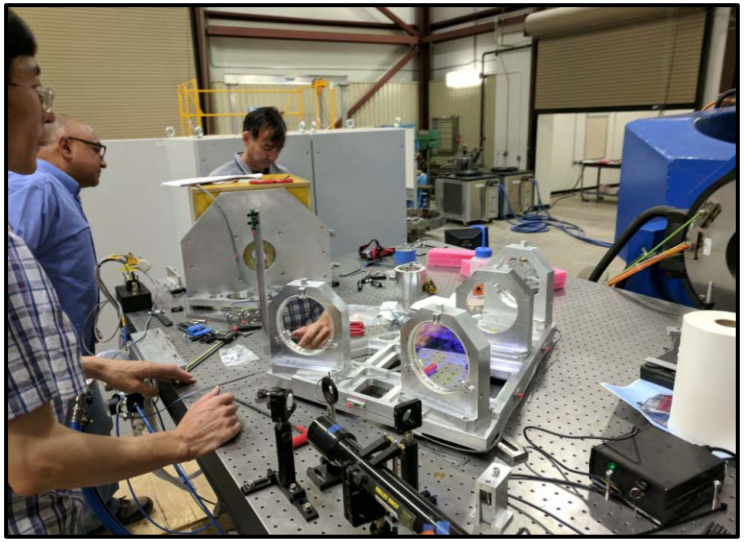




Magdalena Ridge Observatory

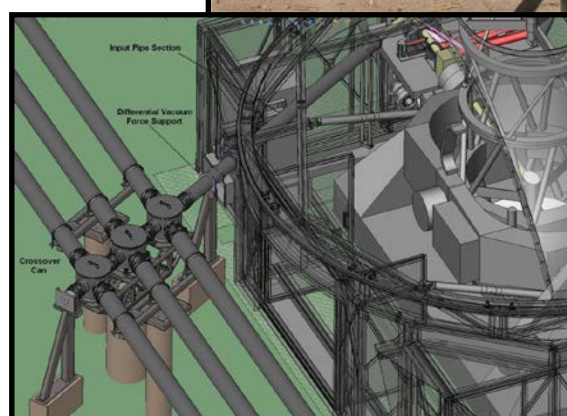
Fast Tip-Tilt System Closed the Loop

- Designed and built by Cambridge University
  - Passive design to minimize moving parts
  - Sensing in “blue” end of spectrum to at least V=16 (V=14 tested in lab)
  - Fast tip-tilt deployed on Nasmyth table controls telescope secondary
  - <60 mas 2-axis T/T jitter in Nov 2018 on V=12 objects in mediocre (1.5”) seeing
  - Retested on several occasions thereafter reaching V~15.5
  - SPIE Presentations on Xenomai control software by Eugene Seneta in Dec 2020



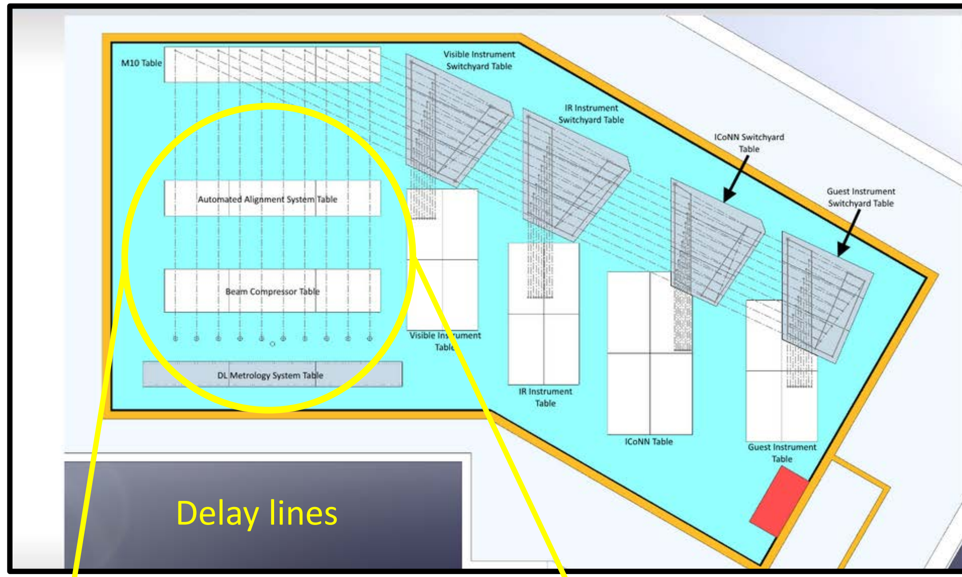
Beam Relay System being Extended

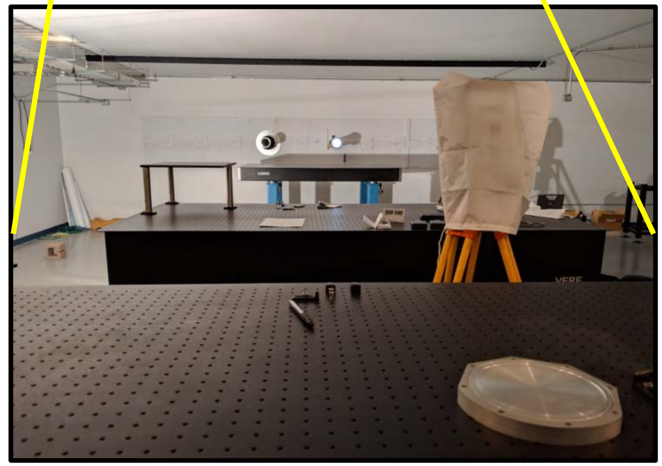
- All designed and built at NMT
- Array infrastructure includes 28 telescope locations – 7 partially completed; 2 exterior beam lines installed on W arm
- Continuous light transport via 1 mbar vacuum from telescope to beam combining room
- Designed to minimize subsidence and prevent lightning strikes from getting “into” the building
- Testing of full-beam line stability into the building began early 2019 – diurnal/thermal cycling



Beam Combining Facility being Populated

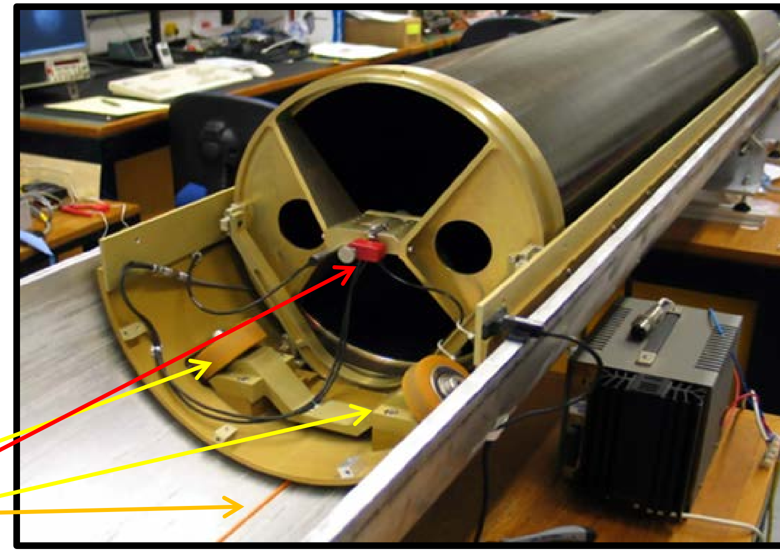
- Completed in 2008 to support full facility including 10 delay lines and 4 instrument tables
- Continuous single stroke delay; "dead air" in beam combining room; tested vibrationally and thermally
- Redesign of internal layout for tables in 2019
- Installation of several tables today using laser tracker

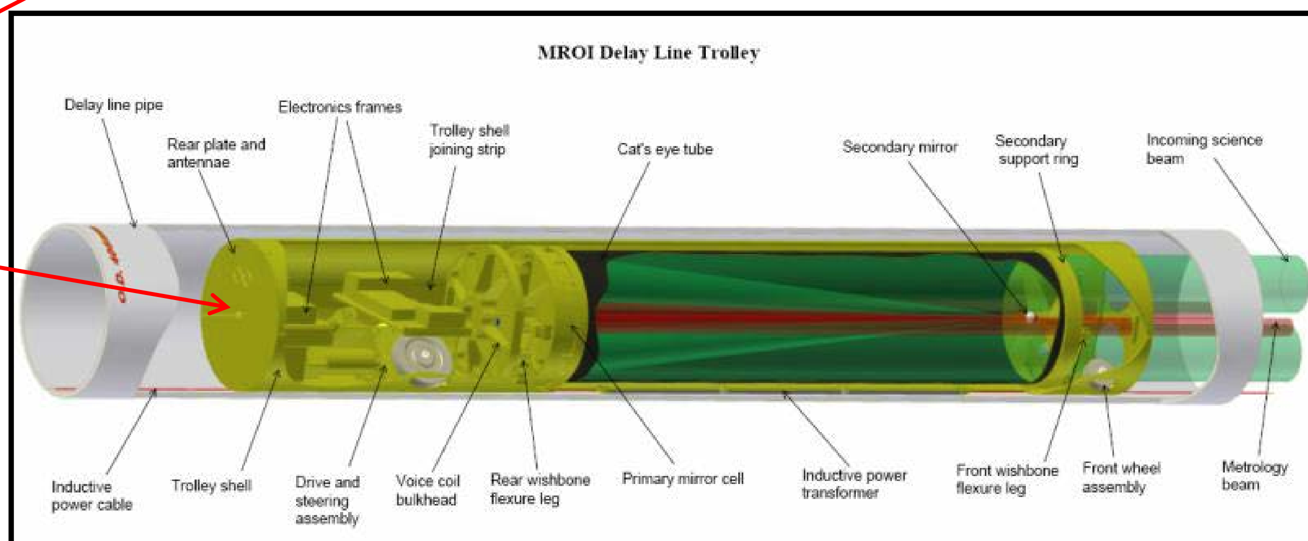




Delay Lines Trolleys Operational

- Innovative redesign compared to other facilities
- Delay line carts/trolleys – cat's eye vacuum system designed/tested by Cambridge
- Inductive pick-up
- Compliant wheels
- Tip-tilt secondary
- Wireless to computer





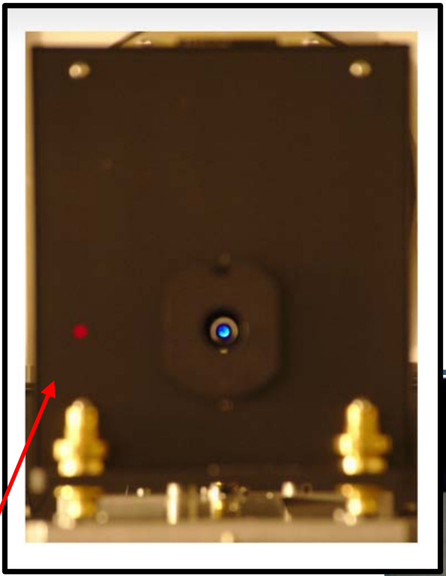
Delay Line Pipes

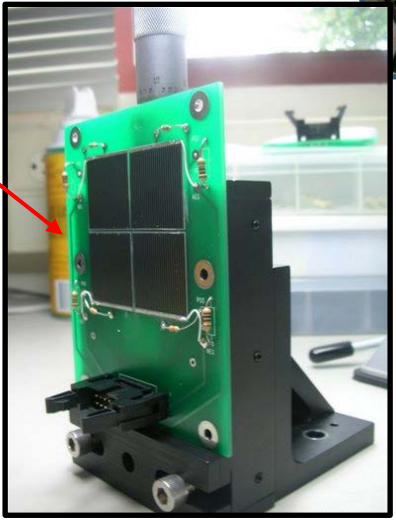
- 190m continuous vacuum delay using off-the-shelf pipe
- Installed on a technical slab separated from outer building footings/walls
- Trolley compensates for sidereal positions & atmospheric turbulence
- Holds vacuum (~1 mbar) for weeks without issue
- Trolley 2 ready to ship – OPD jitter < 15nm in any 10ms interval - demonstrated in COAST DL pipes

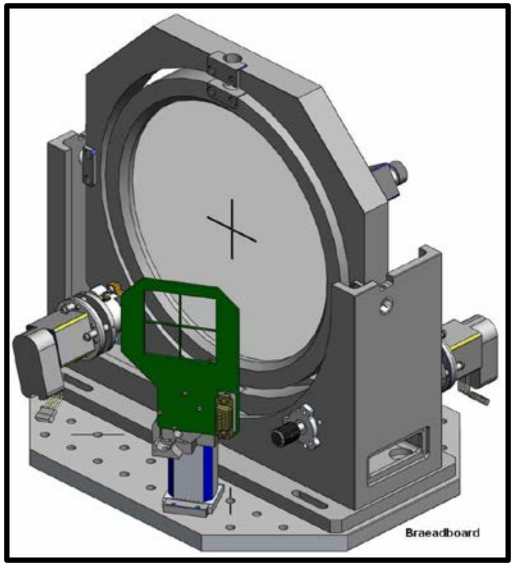
Photo by C.Gino

Automated Alignment System

- End-to-end alignment of interferometer as needed during day/night
- Quad-cell photovoltaic "pop-ups" for beam location – working with group at INOAE for new quad cell design
- Optical/infrared beam launchers for "fake stars"
- BEASST WFS installed 2019 – tested on starlight
- SPIE Presentation by James Luis in Dec 2020

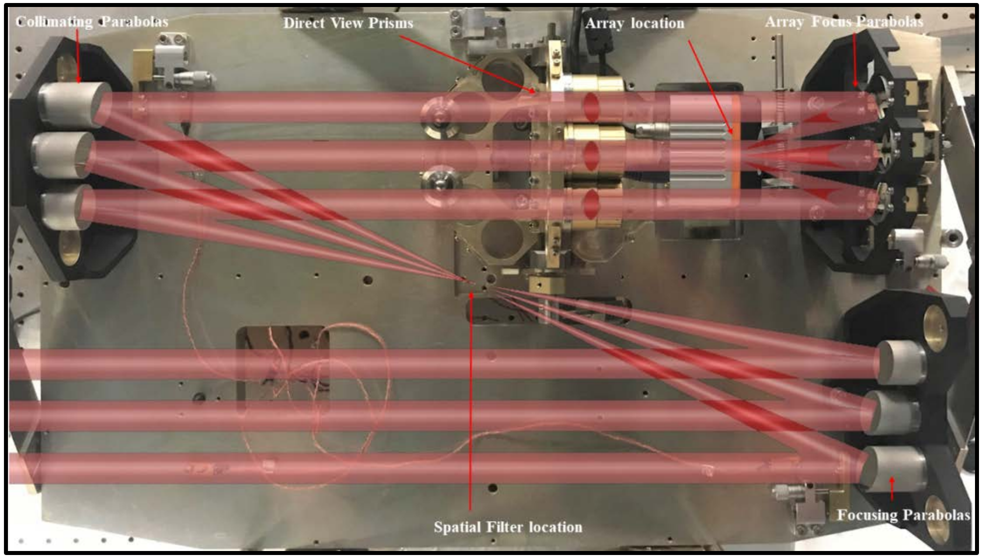


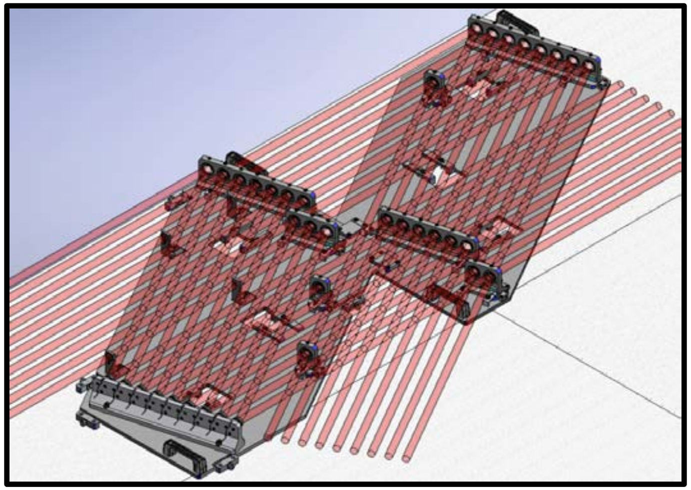


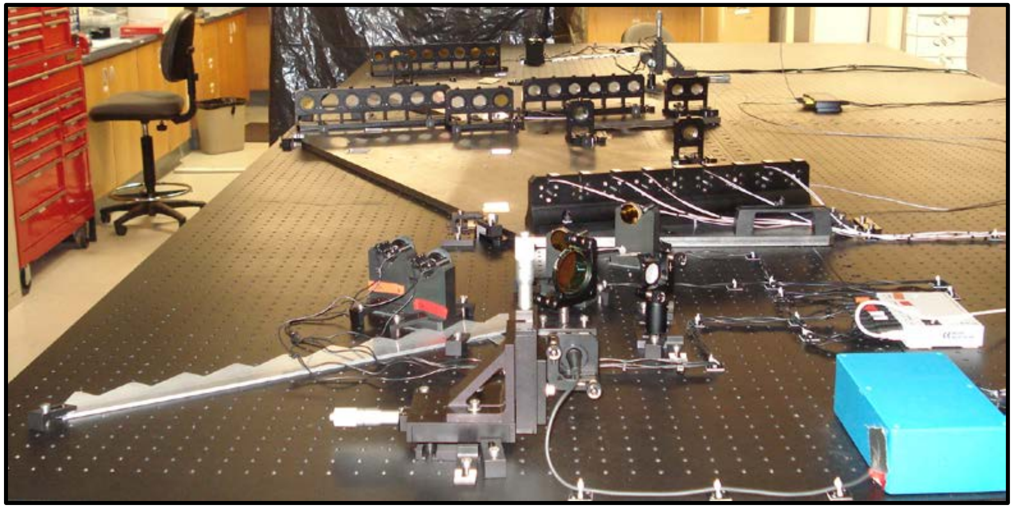


Beam Combiner and Fringe Tracker (ICoNN)

- Nearest-neighbors style fringe tracking; DVPs for dispersion
- Beam combiner accepts all 10 beams – 5 go into each dewar
- Inner 6 beam trains tested and populated with optics
- Upgrading with SAPHIRA detector (photon-counting IR MCT array) and ESO controller

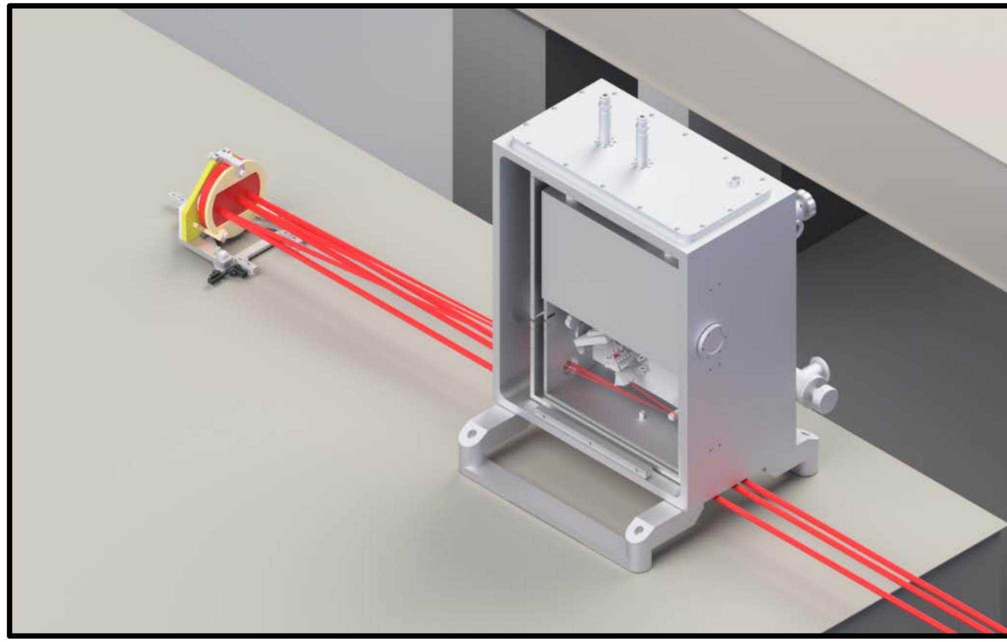






First Science with FOURIER

- Simple 3-beam image plane combiner being designed by Cambridge PhD student Mortimer
- Uses SAPHIRA detector + ESO controller; J, H or K at low spectral resolutions (R~75-90)
- 11th magnitude in any band
- Free-space propagation, anamorphic optics and spatial filtering with slits
- Passed FDR at MROI in December 2019; under assembly in lab today
- SPIE Presentation by Dan Mortimer in Dec 2020



Universal Cryogenics

Magdalena Ridge Observatory

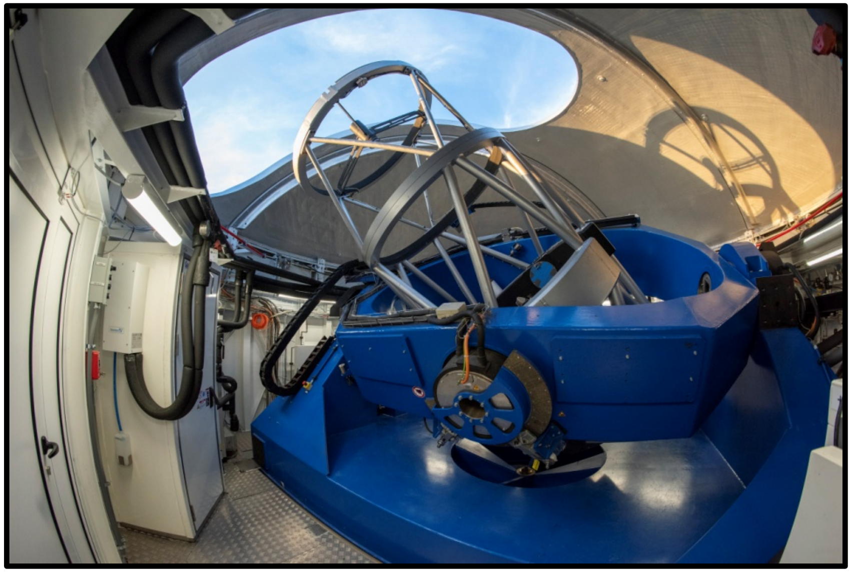
Funding and Fringes Timeline

Simulated image Direct-TV Satellite #9 accomplished in 2 hours using 10-element MROI plus 2.4m scope with aperture masking

- Funding via AFRL under CA with university for $20M through FY20 has ended
    - Temporary shutdown of project in March 2020 due to Congressional funding snafoo
- New DoD funding contract for another 5 years is being negotiated this week -- $6.5M already appropriated for FY21
- Future funding after 3 beamlines is TBD – *looking for partners, public funding or philanthropic support*
- Awaiting Decadal Survey results to determine a path forward for US community – told by AURA folks that likely to be released in June/July
- Cost ~$8M/beamline for hardware – *entire facility* could be finished for less than ~$100M
- Initial science after first fringes with deep initial magnitudes
- Anticipate making time available to astronomical community via NOIRLab around deployment of UT4 if NSF funding
- *New faculty member at NMT* to assist in MROI work – Ryan Norris
- 2023 AAS June meeting is in Albuquerque, NM – anticipate MROI tours

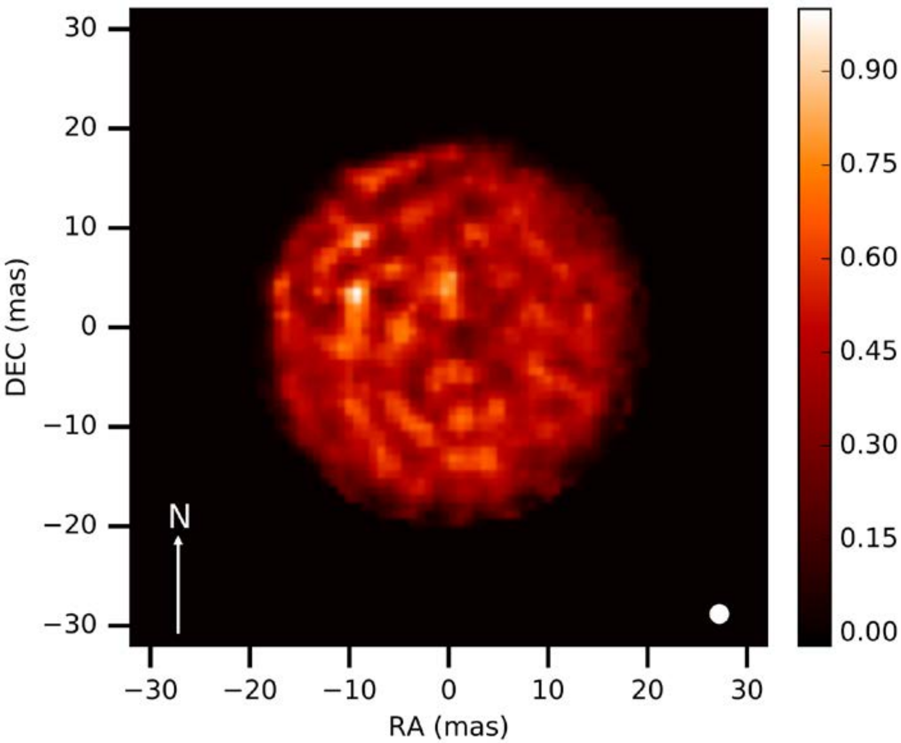
Potential Early Science with MROI

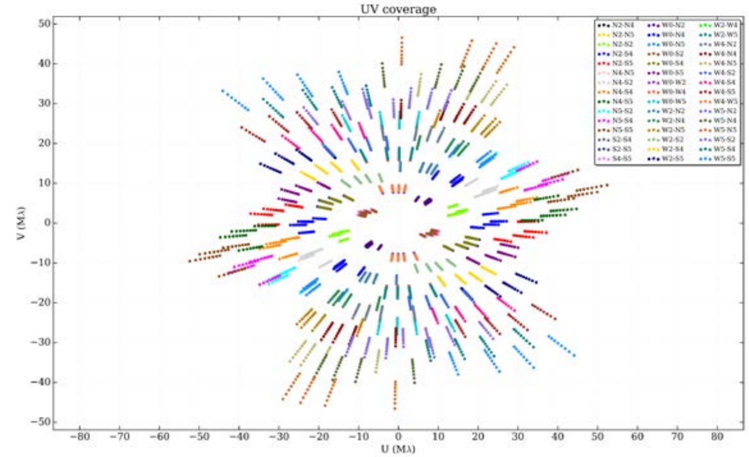
- Two scopes:
  - Assume deeper magnitudes
  - Binarity in faint systems – several different applications
  - AGN reverberation mapping
  - Diameters/limb-darkening of faint dwarfs/exoplanet host stars
  - Stellar pulsations
- Three scopes:
  - Assume closure phase capability
  - CVs/Novae in active phases
  - Stellar rotational elongation
  - Non-radial stellar pulsations
  - YSO disks/openings

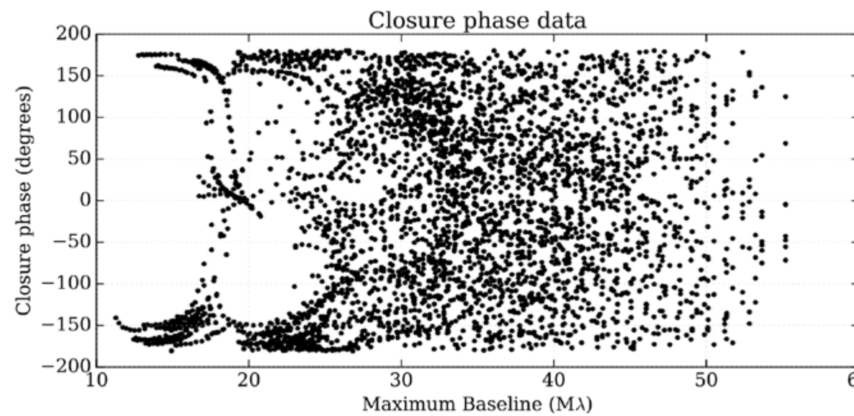


Photos C. Gino

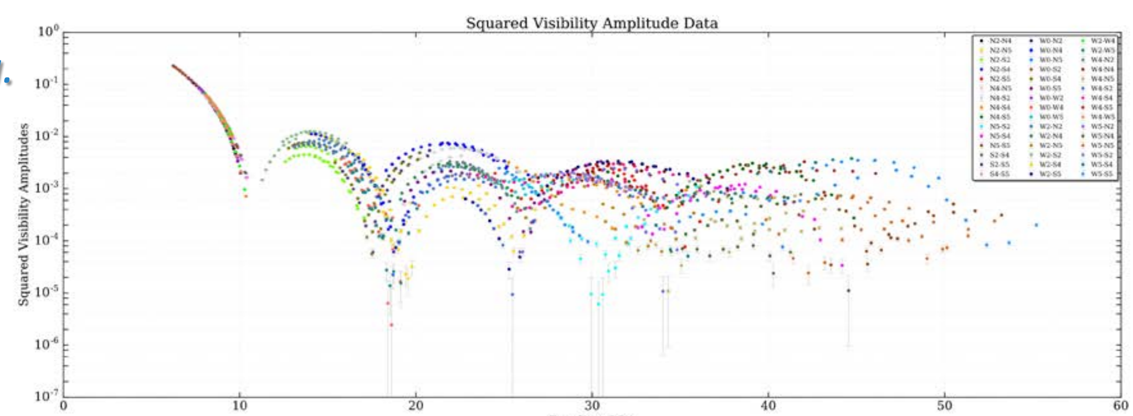
The Promise of MROI







One night of MROI 10-telescope data.



Courtesy of Ryan Norris,
collaborating with Baron and Young

MRO
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Thank you for your attention and patience while we get going again:

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