MRO Interferometer: Prelude to First Fringes

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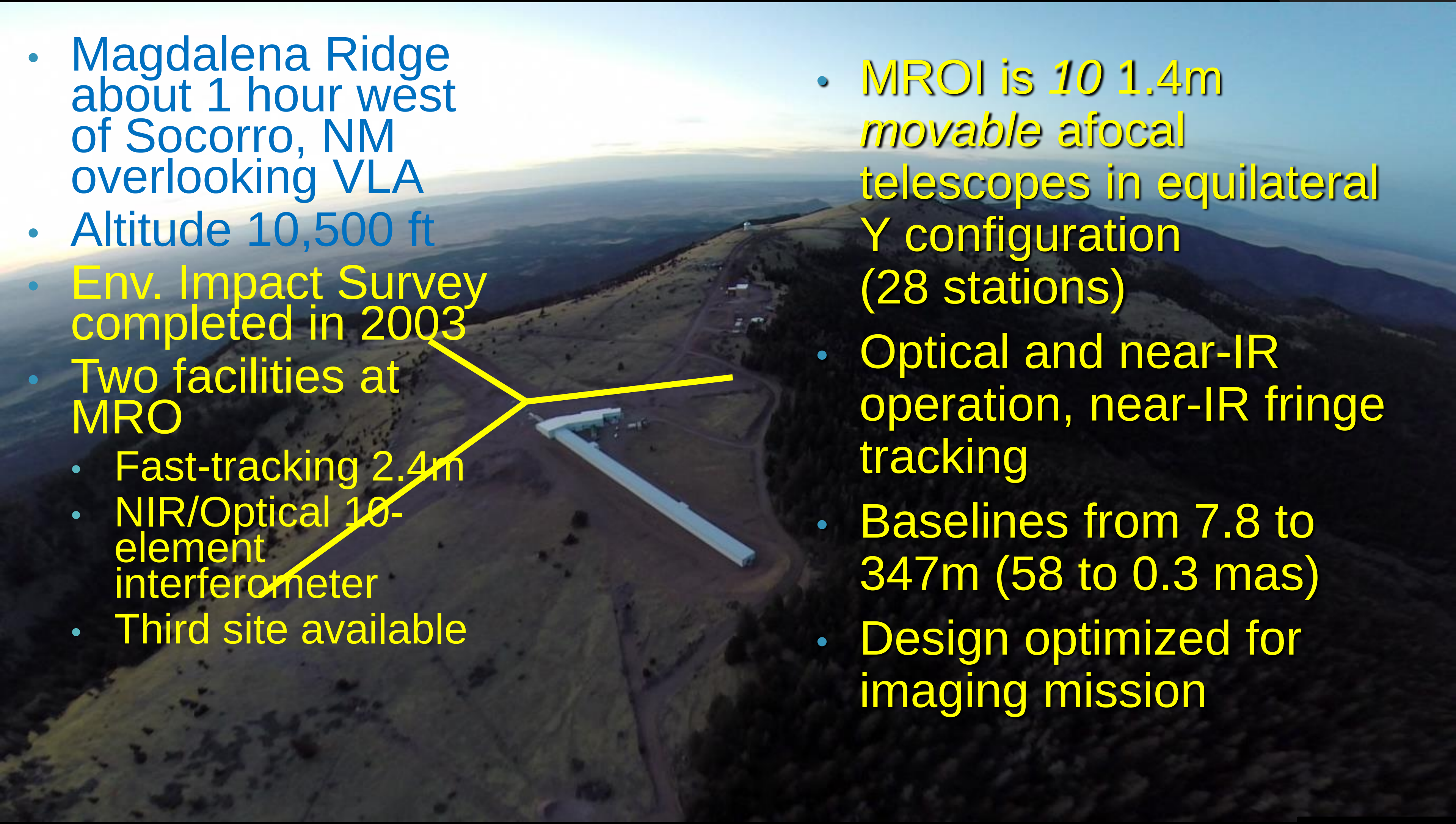
Overview of the Observatory

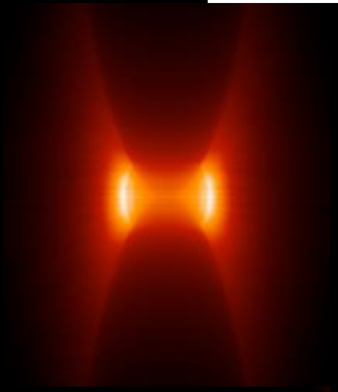


- Magdalena Ridge about 1 hour west of Socorro, NM overlooking VLA
- Altitude 10,500 ft
- Env. Impact Survey completed in 2003
- Two facilities at MRO
  - Fast-tracking 2.4m
  - NIR/Optical 10-element interferometer
  - Third site available

- 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

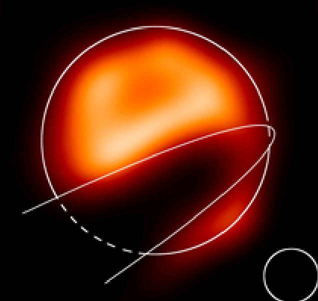
MROI Science Case

- 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, NPOI and PTI

Telescope #1 first light 2+ 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 light on the array in ‘18

Photos C. Gino

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 to equilibrate rapidly
  - Embedded metal mesh for lightning protection
  - Lifting with crane, preferably reach stacker –see movies
  - Factory Testing completed in Jan; Site Testing completed Oct '18; First light on array in Nov '18 with FTT; multiple observing runs in 2019

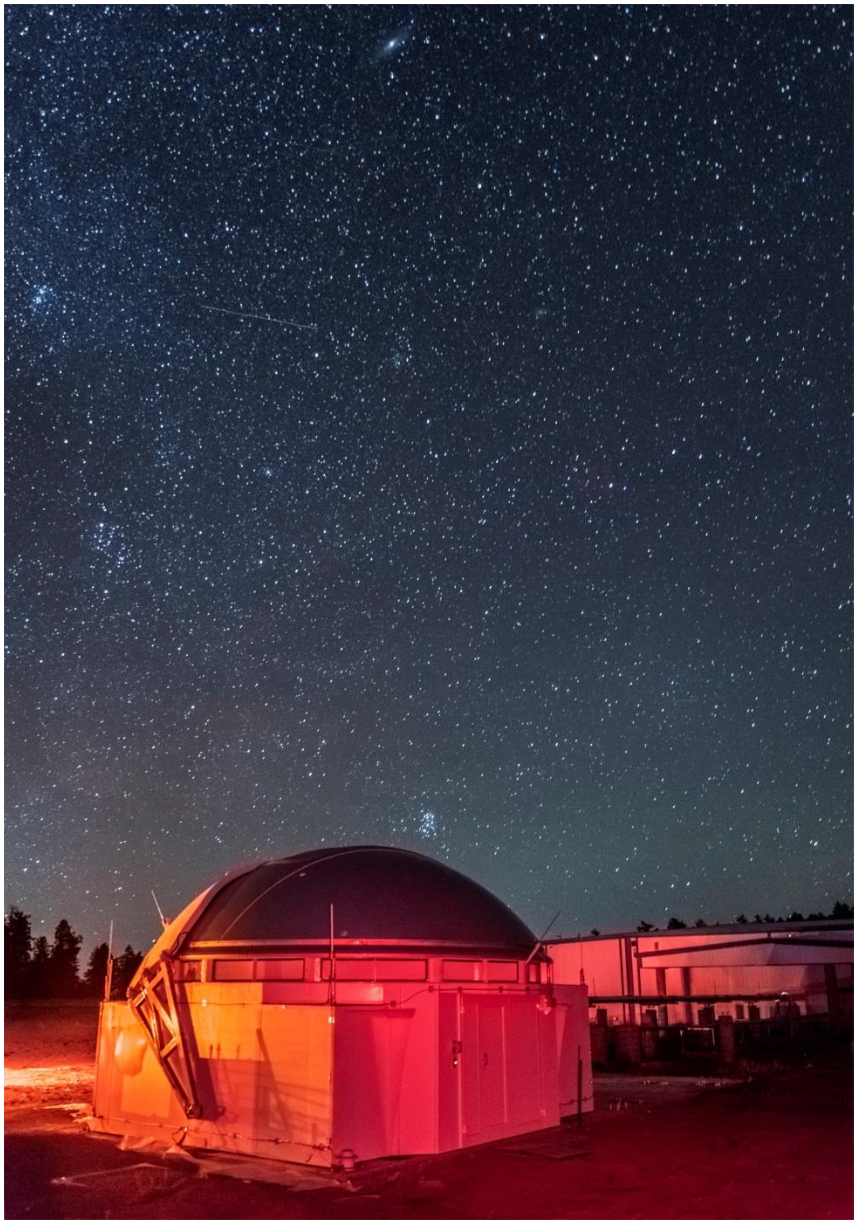
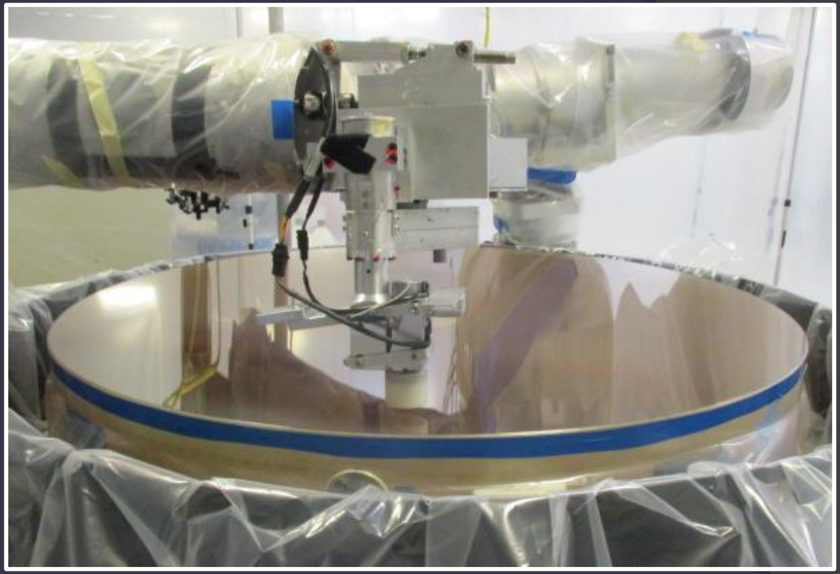
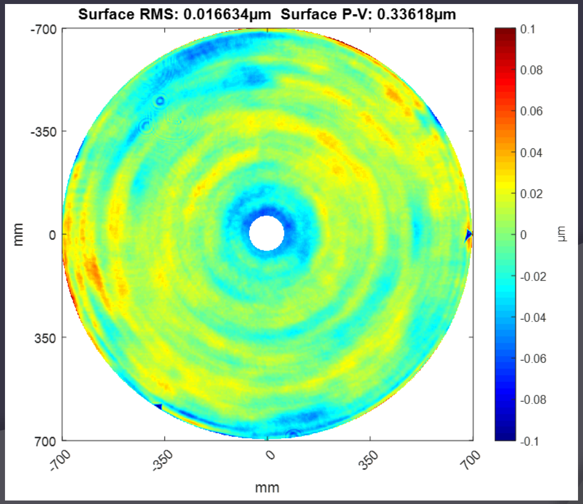


Photo C. Gino

Telescope Primary for UT#2 Done Polishing

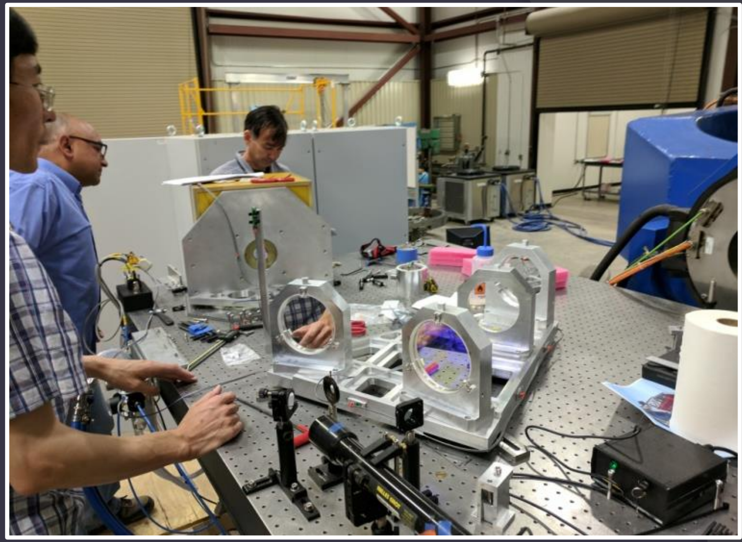
- 6 full sets of optics purchased a decade ago
- Secondaries and tertiaries all finished before original company went bankrupt – now at AOS
- Measured rms WFE on 2nd primary is 16.6nm (19.5nm is requirement)
- Using CGH vertically in the mirror mount to match all primaries
- Polishing of 3rd primary started 6 weeks ago
- Plan to swap out 3rd primary with 1st primary if done by Fall '20





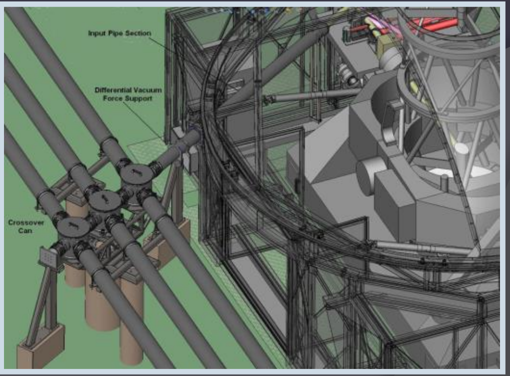
Fast Tip-Tilt System Closed the Loop

- Designed and built by Cambridge University
  - Passive design to minimize moving parts
  - Sensing in “blue” end of spectrum to at least V=16
  - Fast tip-tilt deployed on Nasmyth table controls telescope secondary
  - <60 mas 2-axis T/T jitter in Nov ‘19 on V=12 objects in mediocre (1.5”) seeing



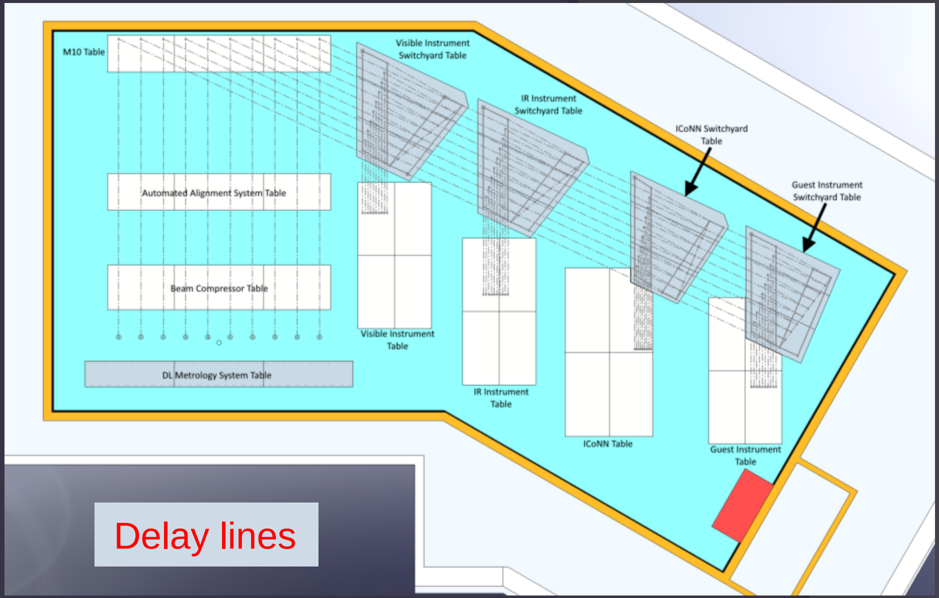
Beam Relay System being Extended

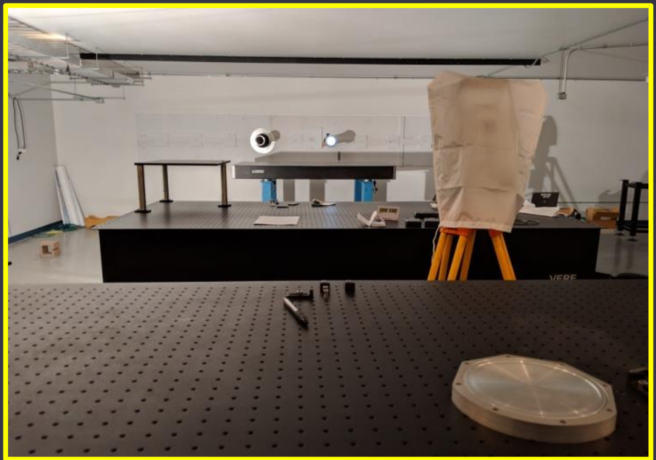
- All designed/built at NMT
- Array infrastructure includes 28 telescope locations – 7 partially completed; 2 exterior beam lines installed on W arm
- Continuous light transport via ~1 mbar vacuum from telescope to beam combining room
- Designed to minimize subsidence and prevent lightning strikes from getting “into” the building
- Full-beam line light into inner BCA in fall; complete testing in a few months



Beam Combining Facility being Populated

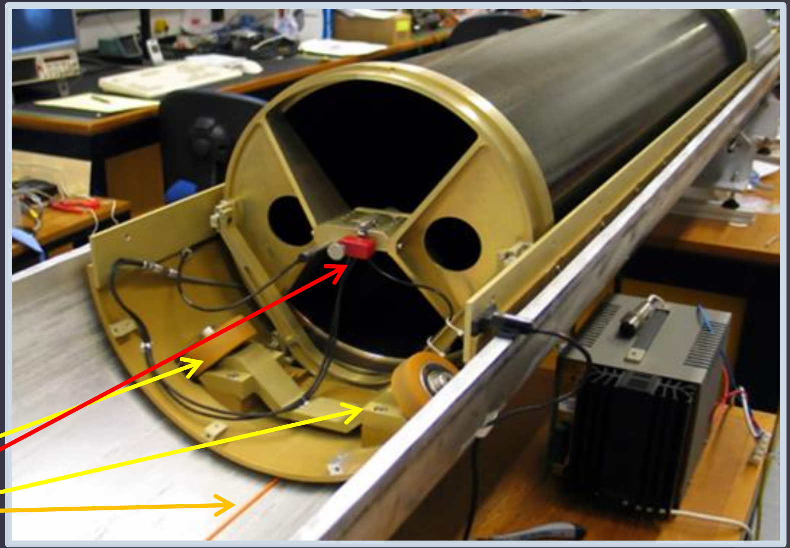
- Completed in 2008 to support full facility including 10 delay lines and 4 instrument tables
- Continuous single stroke delay; “dead air” in beam combining room
- Tested for thermal/vibrational stability
- Installation of several tables using laser tracker



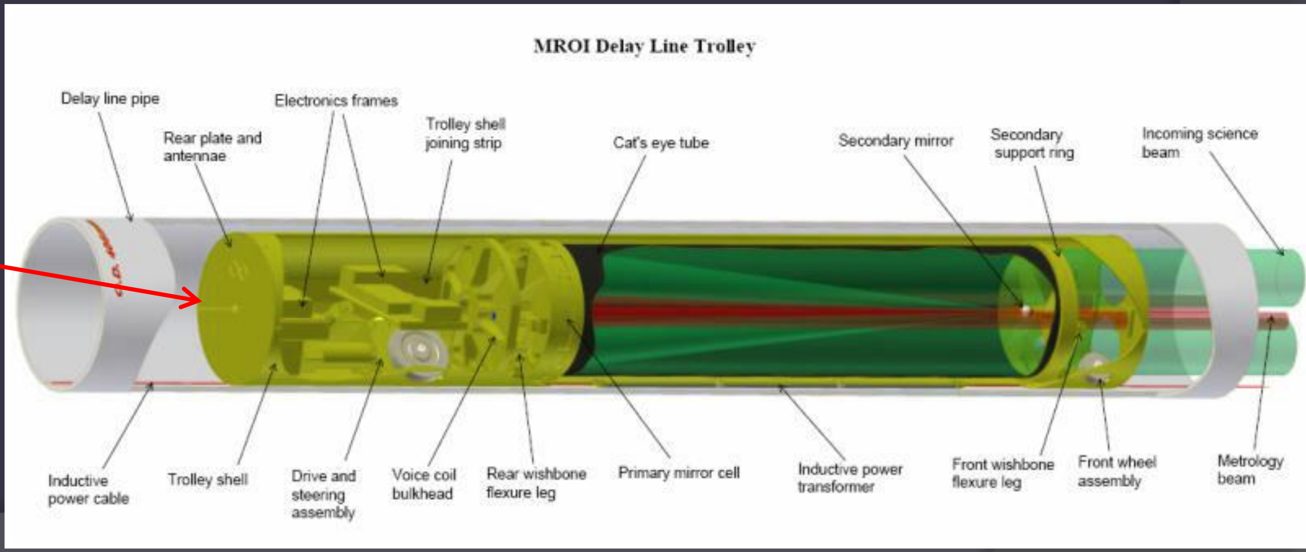


Delay Lines Trolleys Operational

- 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



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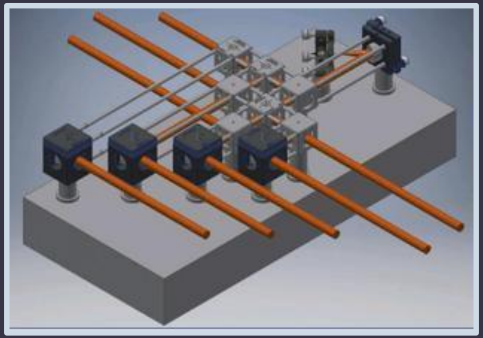
Magdalena Ridge Observatory

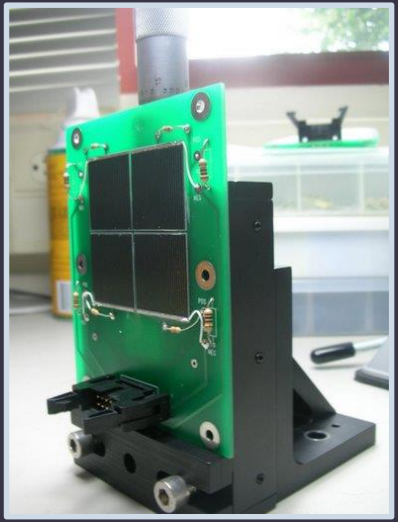
Delay Line Pipes

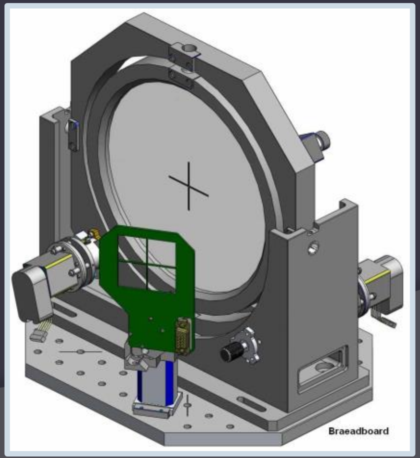
- 190m continuous vacuum delay using off-the-shelf pipe
- Installed on a technical slab separated from outer building footings/walls
- Compensates for sidereal positions & atmospheric turbulence
- Holds vacuum (~1 mbar) for weeks without issue
- 2nd pipe install next month
- Trolley 2 being shipped shortly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

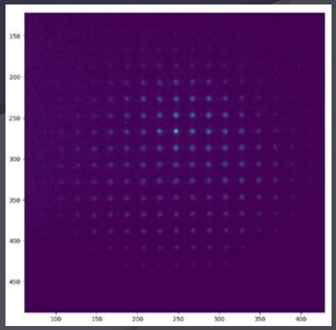
Automated Alignment System

- End-to-end alignment of interferometer as needed during day/night
- Quad-cell photovoltaic “pop-ups” for beam location
- Optical/infrared beam launchers for “fake stars”
- BEASST WFS installed in summer ‘19
- 2nd pipe and optics line being installed shortly
- Requires beam stability/alignment at fractions of arcsecond and less than 1% of beam width throughout interferometric observation



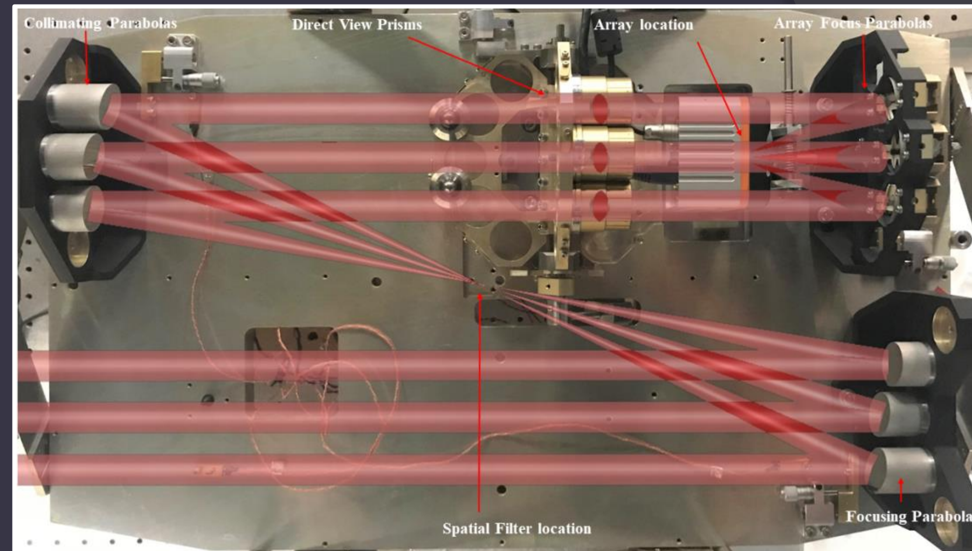


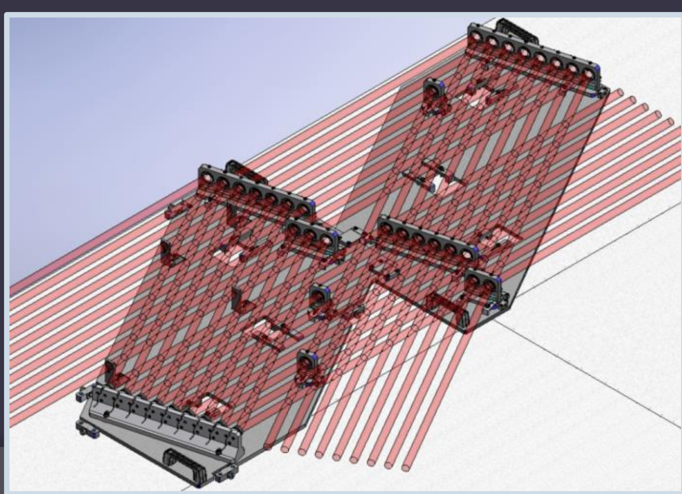


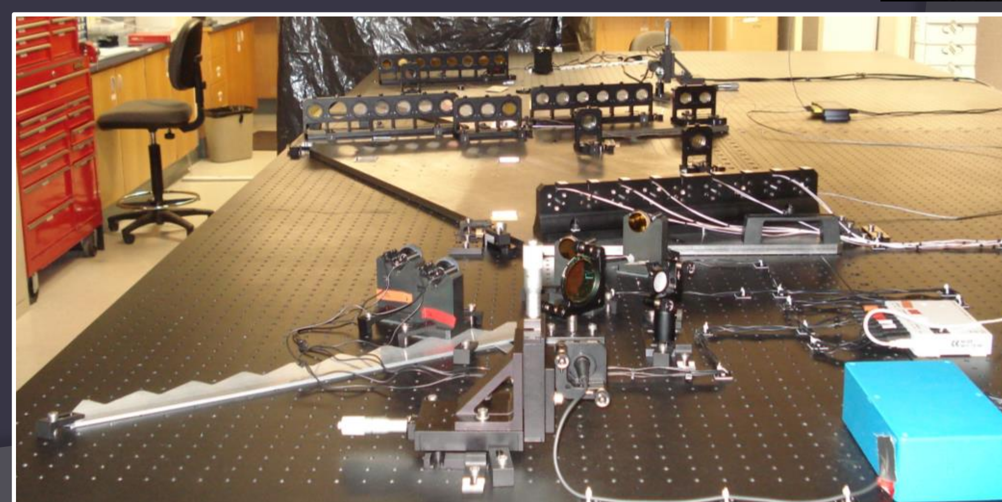


Beam Combiner and Fringe Tracker (ICoNN)

- 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 this spring

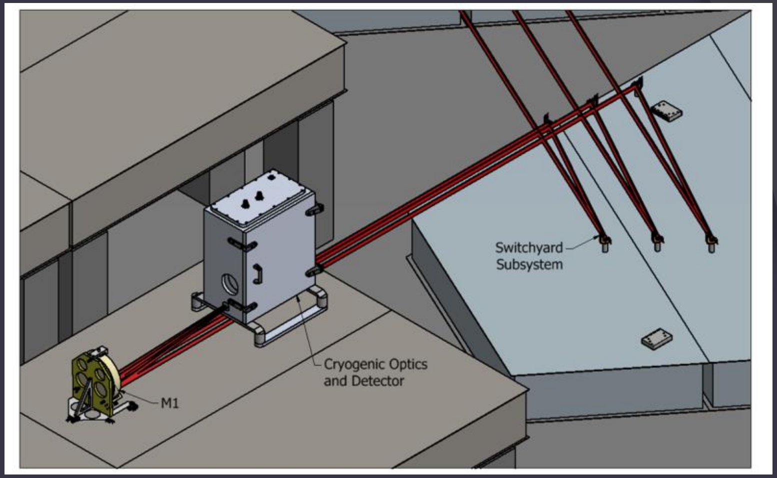


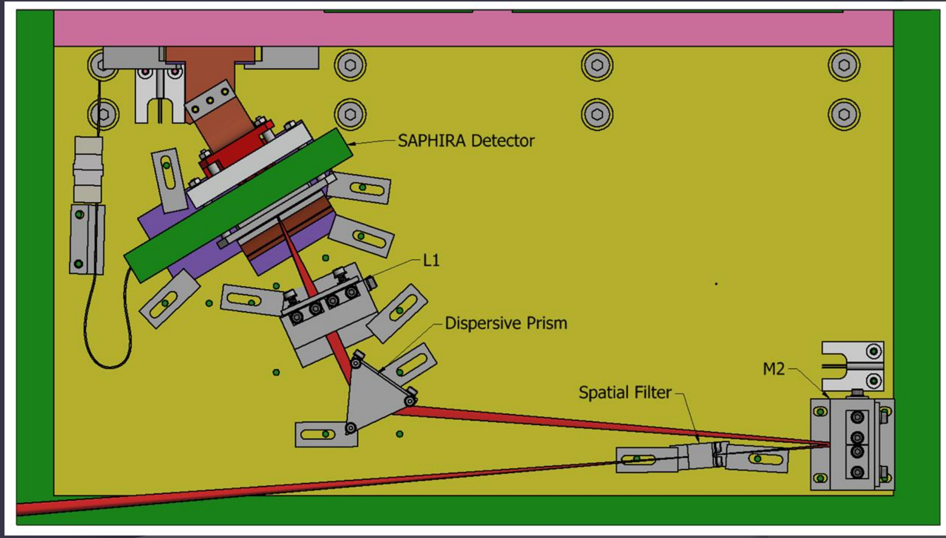




First Science with FOURIER

- Simple 3-beam image plane combiner being designed by Cambridge PhD student
- Uses SAPHIRA detector + ESO controller; J, H or K at moderate spectral resolution (R~100)
- Free-space propagation, anamorphic optics and spatial filtering with slits
- FDR at MROI in Dec ‘19; delivery early 2021





Potential Early Science with MROI

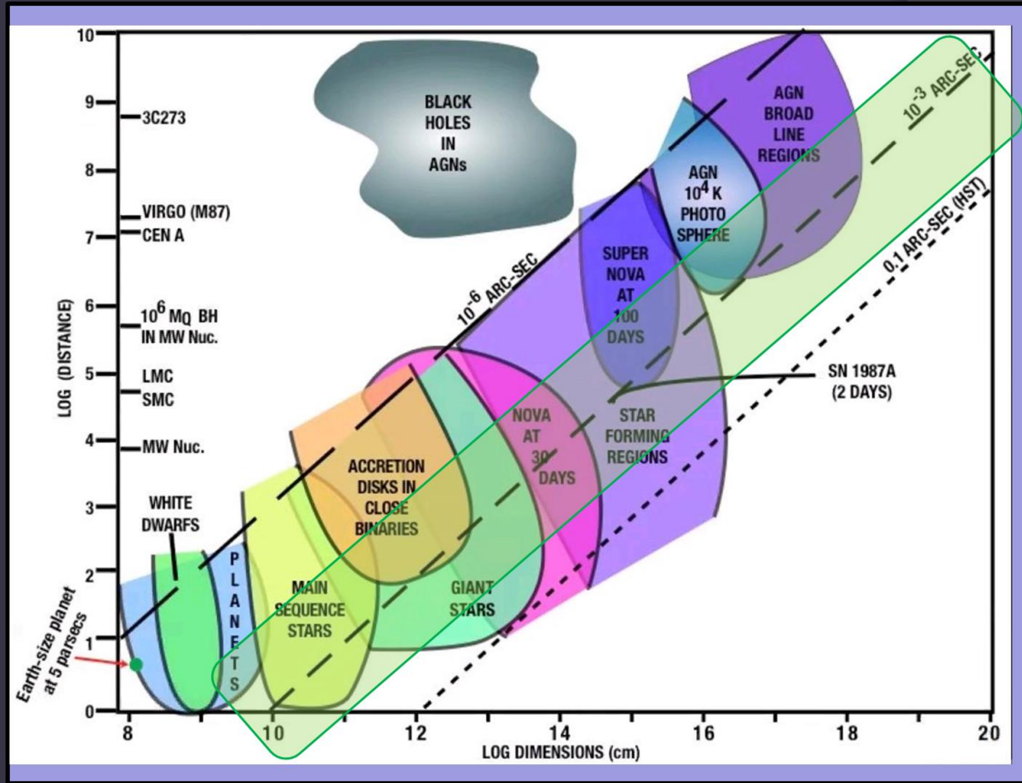


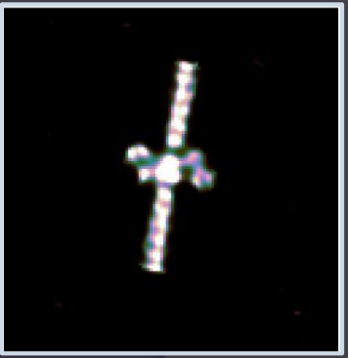
Fig. courtesy of S. Rinehart

- 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

Funding and Fringes Timeline

- Funding via AFRL under CA with university for $25M through 2021
  - Get first fringes and do GEO risk reduction demos on this timeline
- Future funding after 3 telescopes is TBD – *looking for partners, public or philanthropic support*
- Cost ~$8.5M/beamline for hardware – entire facility plus start-up of operations pitched to Decadal for $110M
- Initial science after first fringes with deeper magnitudes than possible today

- Near-Term Timeline:
  - Anticipate fringes in ~12 months – late 2020/early 2021
  - 3rd UT may be ordered in a few months
  - Schedule thereafter is funding dependent
  - Delivery time for future telescope+enclosure is 15-18 months (can build in pairs)
- Anticipate making time available to astronomical community via NOAO around deployment of UT4 & 5
- 2023 AAS June meeting is in Albuquerque – anticipate MROI tours



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

The Extended Team:

- Van Romero – PI
- Ifan Payne – Director
- Chris Haniff & David Buscher – System Architects
- Michelle Creech-Eakman – Project Scientist
- Rob Ligon – Instrument Scientist
- Andres Olivares – Lead Mechanical Engineer
- Allen Farris – Lead Software
- NMT Team: Robert Collins, Chuck Dahl, Dipanjan Das Roy, Dylan Etscorn, Shelbi Etscorn, Colleen Gino, Omid Hosseni, Stephen Jojola, Jennie Maes, Danielle Ochoa, Juan Pino, Chris Salcido, Isaac Salayandia, Amanda Sanchez
- Cambridge Team: John Young, Bodie Seneta, David Sun, Martin Fisher
- Recent and Current Students at both: Dooley, Erica, James, Andrew, Louis, Caylin, Brandon, Mariam, Ratna, Mateo, Sarah, Elizabeth, William, Julianna, Dan, Siavash

Thank you for your attention!

We miss our dear friend and colleague Dan Klinglesmith

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MRO Magdalena Ridge Observatory

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