The CHARA Array

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Associate Director

CHARA Array of
Georgia State University

Center for High Angular Resolution Astronomy (CHARA)

- Center for High Angular Resolution Astronomy
  - Georgia State University, Atlanta
  - Director: Douglas Gies
  - 6 faculty/staff, 6 graduate students
- CHARA Array
  - Mount Wilson Observatory, California
  - Director: Theo ten Brummelaar
  - 15 staff members onsite
  - Funded through the National Science Foundation and GSU

CHARA Collaboration

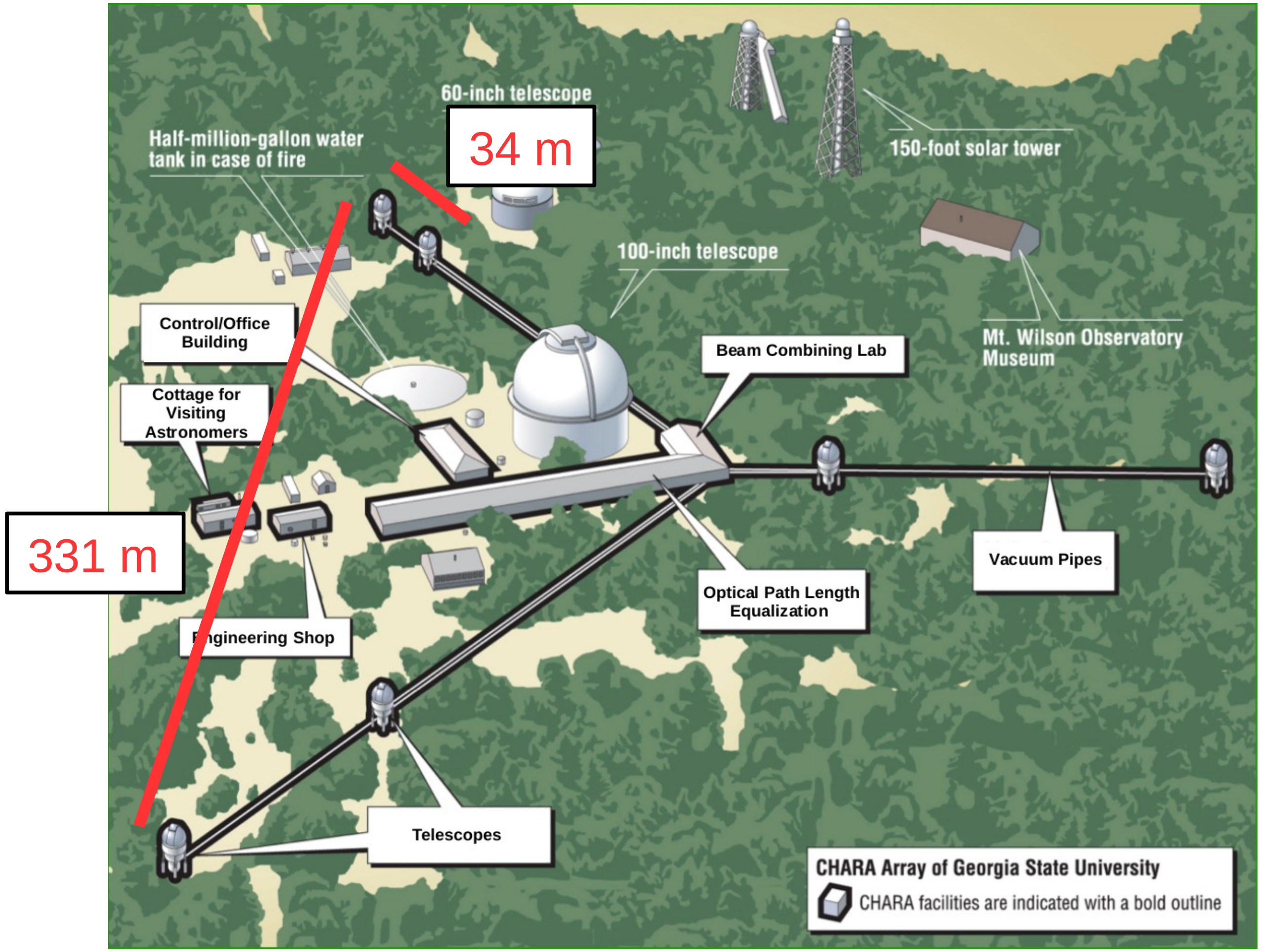
- Operated by Georgia State University
- CHARA Collaboration
  - University of Michigan (MIRC-X, MYSTIC)
  - University of Exeter (MIRC-X)
  - l’Observatoire de la Côte d’Azur (VEGA, SPICA)
  - Australian National University, University of Sydney (PAVO)
  - L’Observatoire de Paris (FLUOR/JouFLU)
  - Université Limoges (ALOHA)
- Open Access
  - Available through NOIRLab

The CHARA Array
Mount Wilson Observatory, California

- 1996: Ground Breaking
- 1999: First Fringes
- 2005: Routine science operations

- 210 Refereed publications

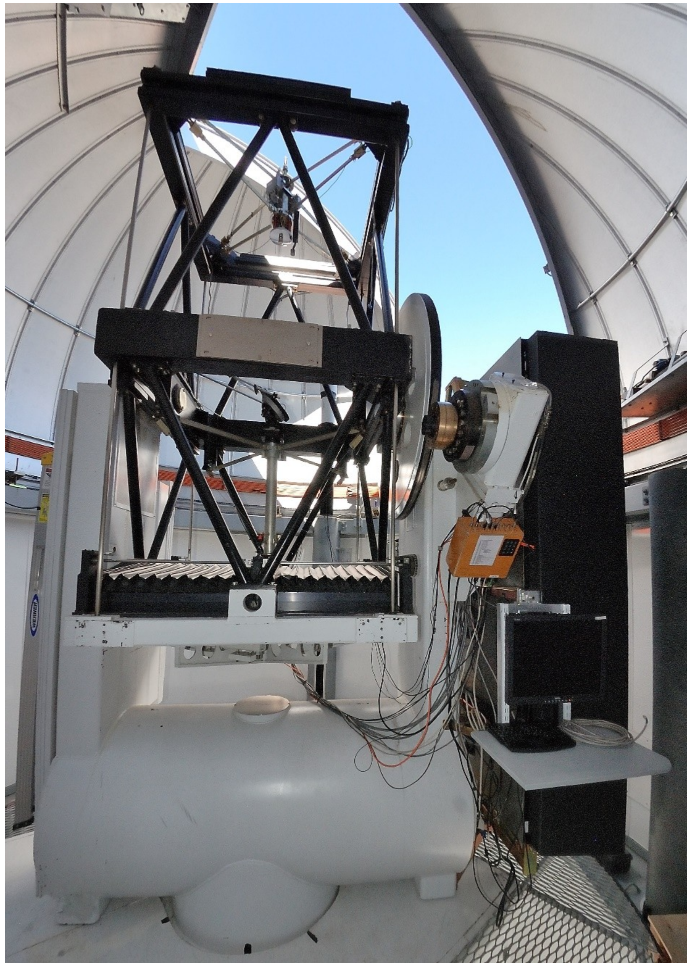
The CHARA Array
Mount Wilson Observatory, California



- Six 1-meter telescopes
- Baselines ranging from 34 m to 331 m
- Spatial resolution
  - 0.20 mas at R (650 nm)
  - 0.52 mas at H (1.67 μm)
  - 0.66 mas at K (2.13 μm)

Six 1-meter Telescopes

Vacuum Tubes Transport Light to Laboratory

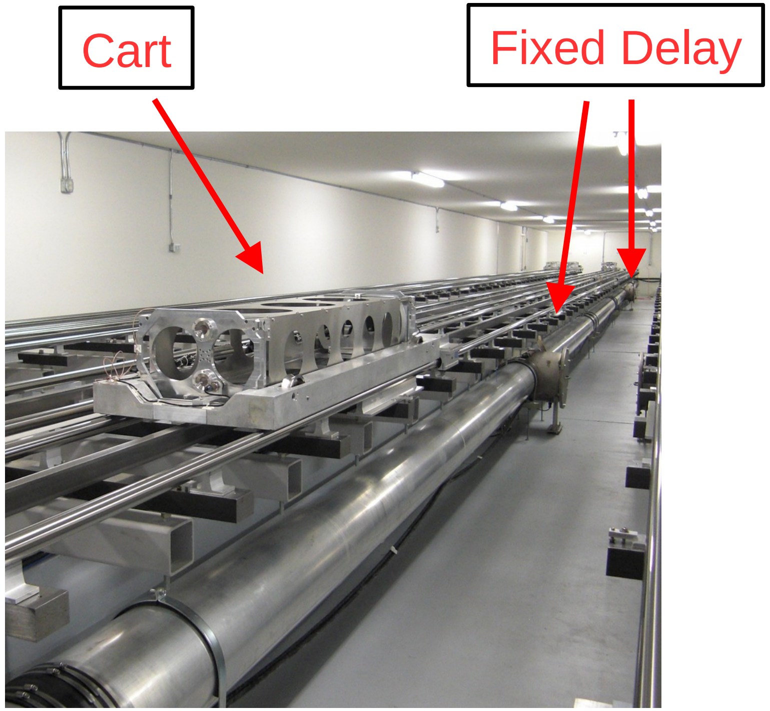


Light from Three Arms of Array
Transported to Beam Combining Lab

Vacuum Turning Boxes

Makes 6 lines parallel while preserving polarizations

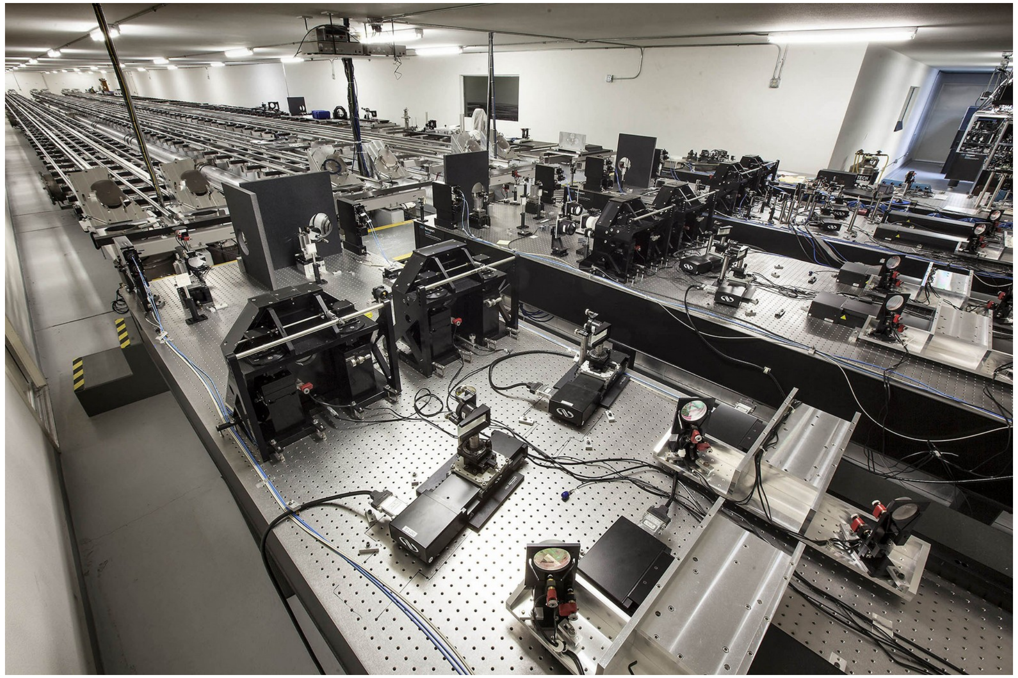
Delay Lines and Carts

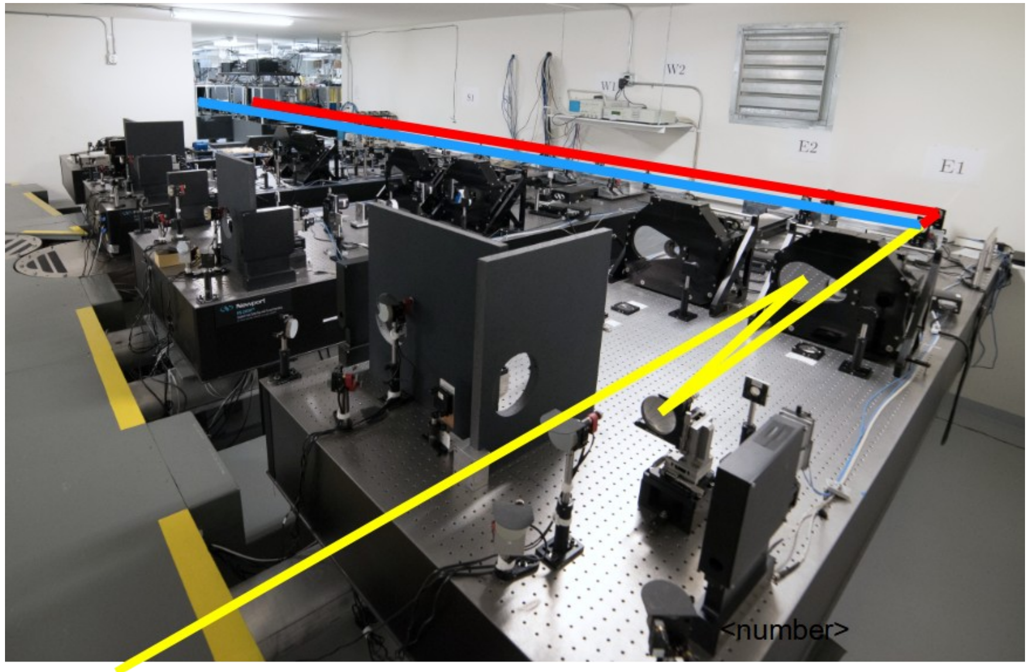


- Fixed delay added using POP mirrors in vacuum tubes
- Continuously variable delay by carts on rails

Beam Management

Beam Reducing Telescope and Dichroic to Separate Visible and Infrared Light





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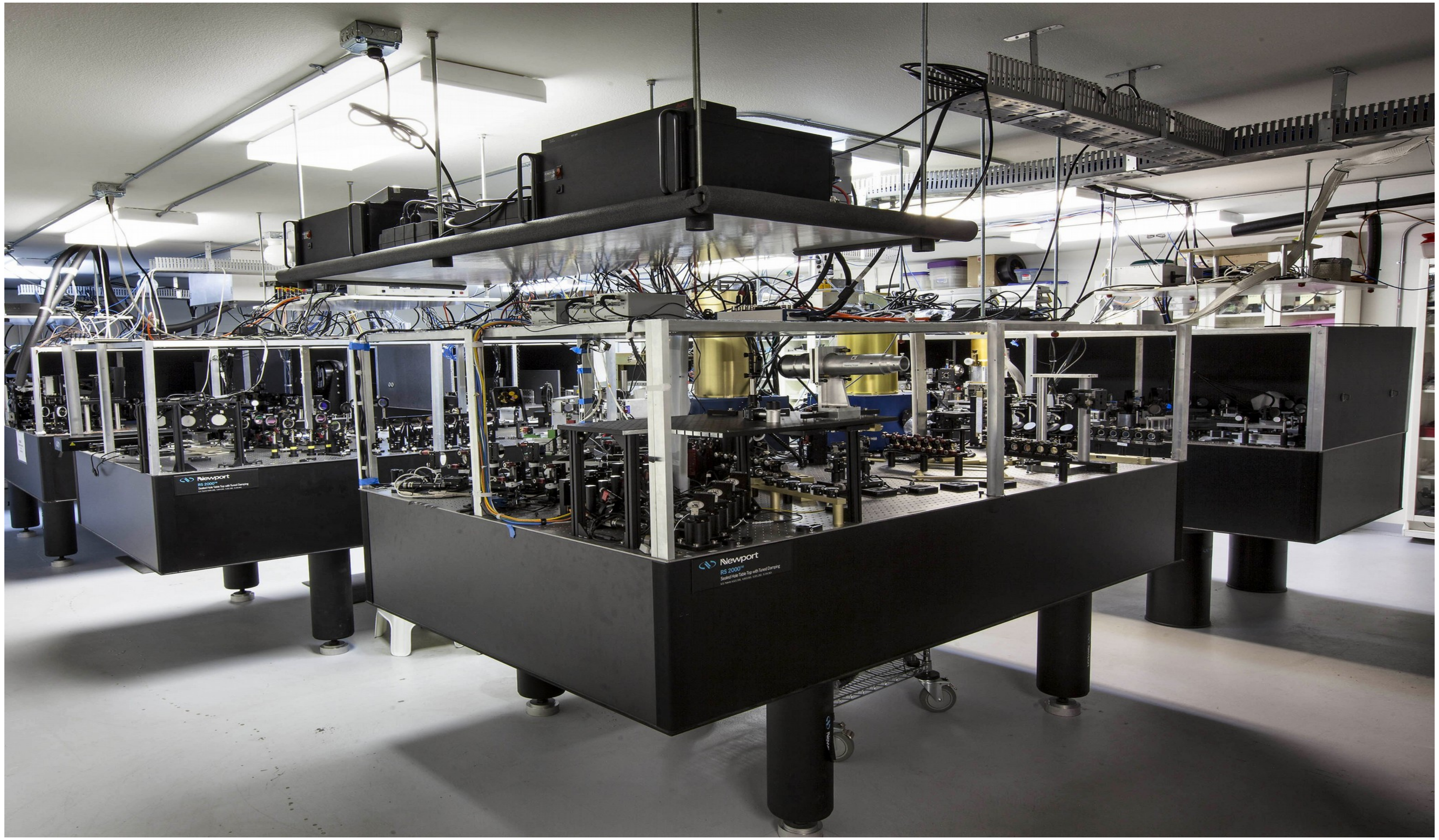
Beam Combiners



Beam Combiners

Current Instruments:

MIRC-X
6T, H-band (J)
Prism R=50, H < 6.5 – 7.5
Grism R=190, H < 5.5 – 6.5

CLASSIC/CLIMB
JHK, Broadband
2T: K < 7.0 – 8.0
3T: K < 6.0 – 7.0

PAVO
2T
630-900 nm, R=30
Rmag < 7.0 – 8.0

Upcoming Instruments:

MYSTIC
6T, K-band

Commissioning: 2021B

SPICA
6T, 600 – 860 nm
R = 140, 4400, 13000
Commissioning: 2022A

CLASSIC/CLIMB++
2T/3T, JHK
Improved sensitivity
Commissioning: 2022?

Past Instruments:

VEGA
2T – 4T, 450 – 850 nm
R = 1700, 6000, 30000
Operational: 2007 – 2020

FLUOR/JouFLU
2T, K-band

Operational: 2002 – 2018

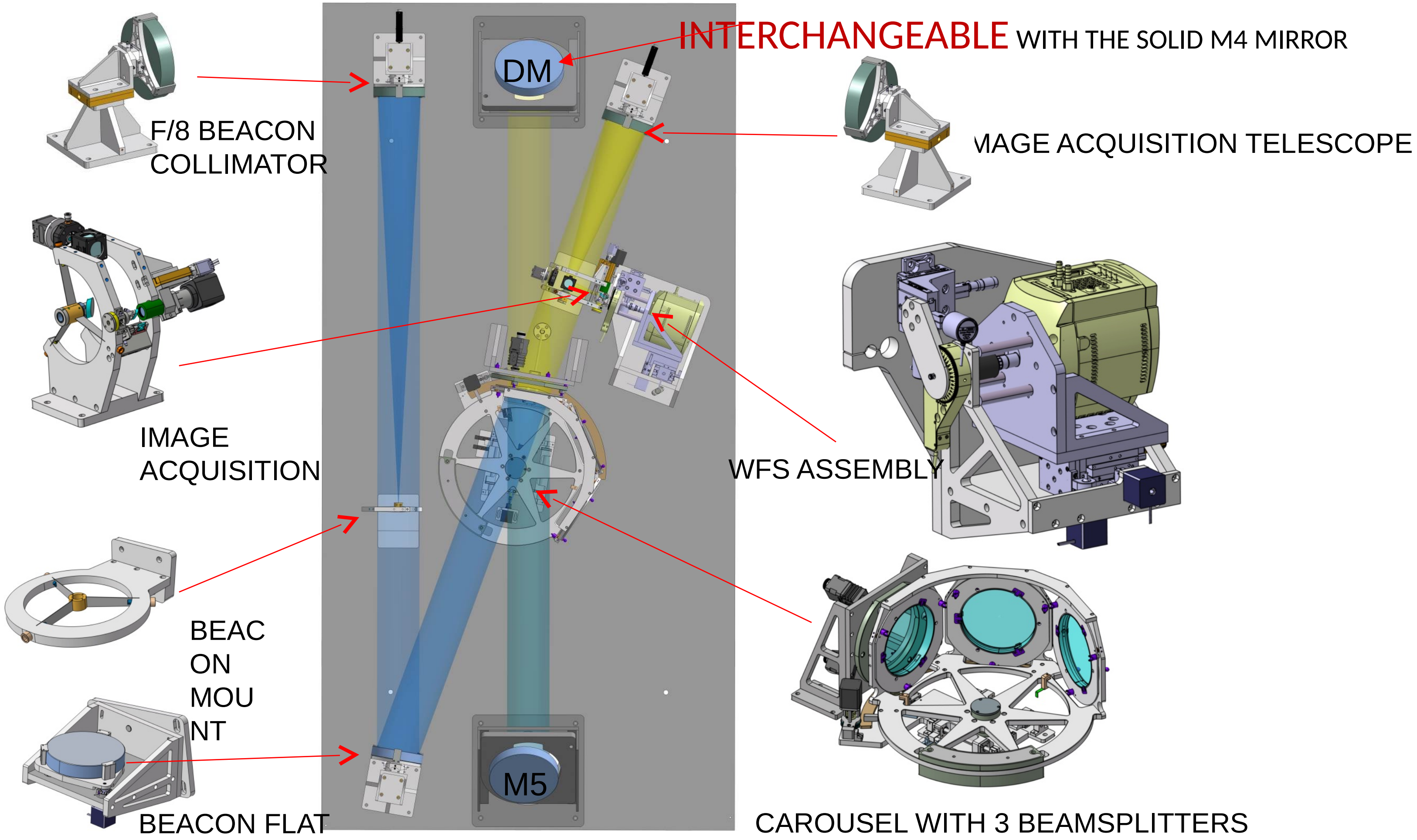
AO/Tiptilt Tracking: V < 12 mag

Magnitude limits are given as a range from typical to best case sensitivities.

Adaptive Optics at CHARA

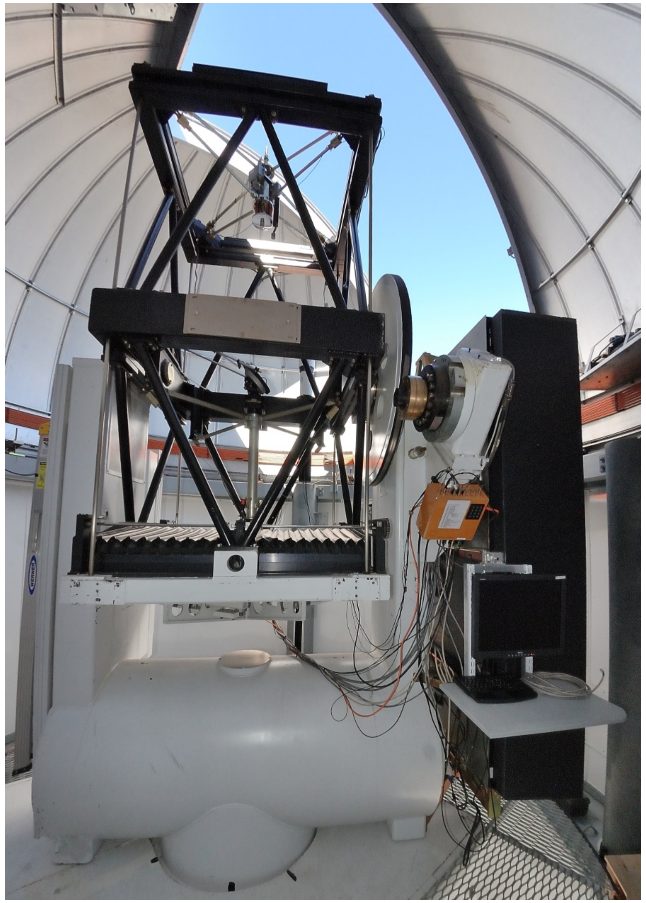
- Goals
  - Improve efficiency – increase number of nights with high quality seeing
  - Improve sensitivity by ~ 1 mag on the best nights
- Telescope AO
  - Fast correction for atmospheric distortion
  - Tiptilt corrections
- Lab AO
  - Slow correction for non-common path errors between telescope and laboratory

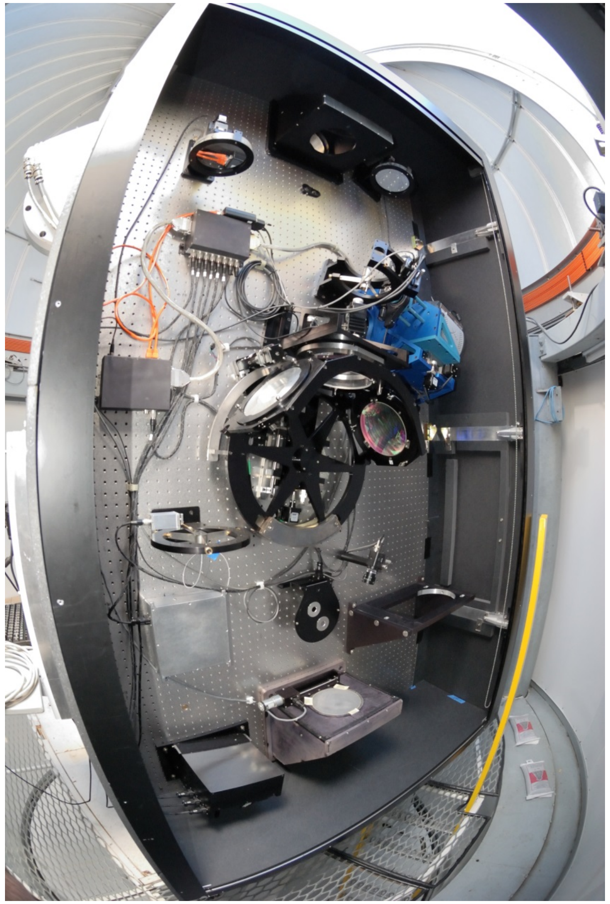
Telescope Adaptive Optics



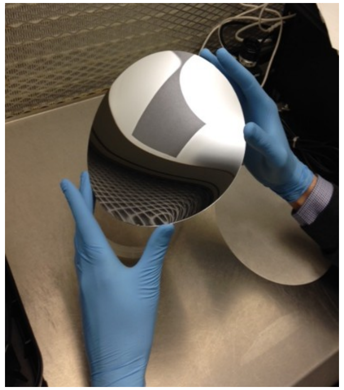
Telescope Adaptive Optics

CURRENT VIEW OF THE TELESCOPE AO SYSTEM ON ITS PROTECTIVE ENCLOSURE



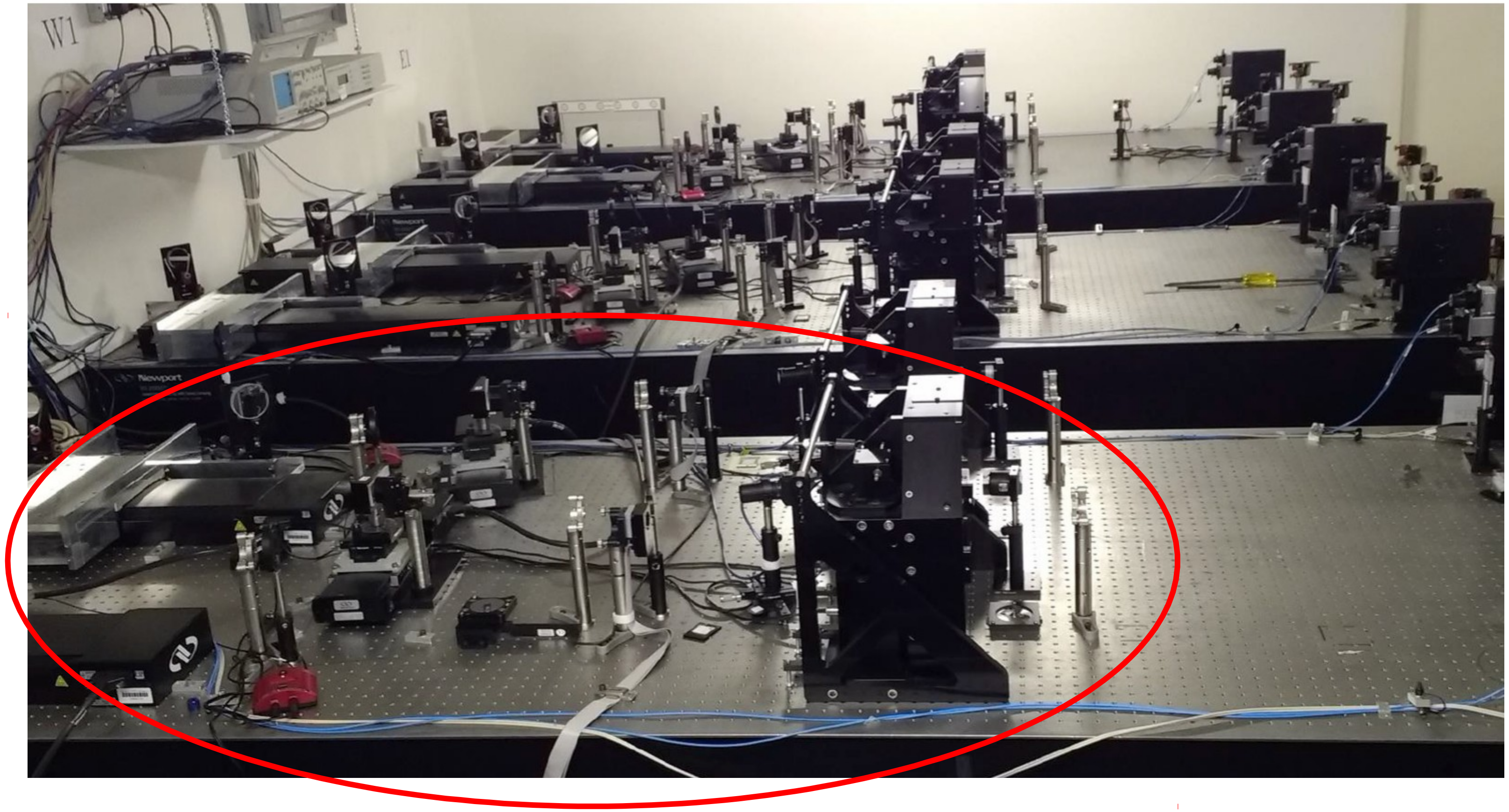


ALPAO



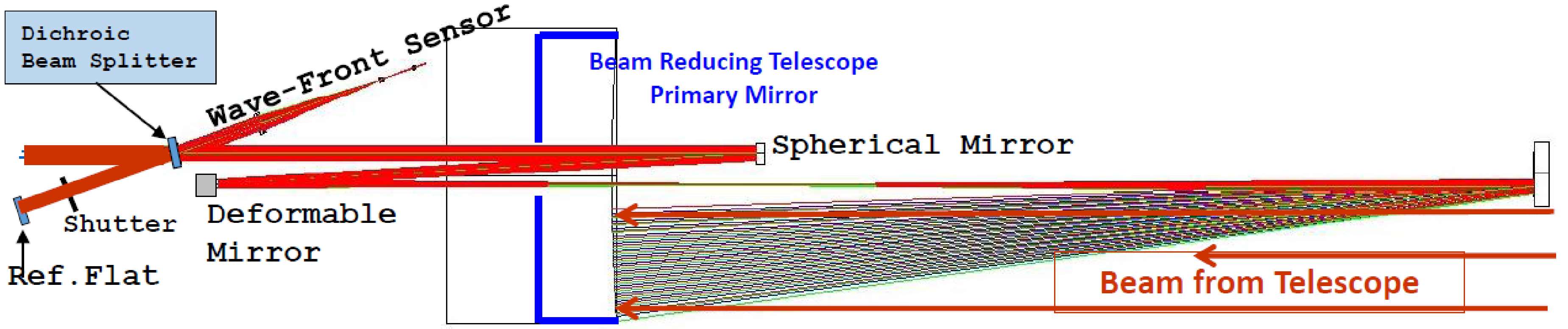
- 60 actuators
- 17.7 cm x 12.5 cm
- 45° angle of incidence

Laboratory Adaptive Optics



Laboratory Adaptive Optics

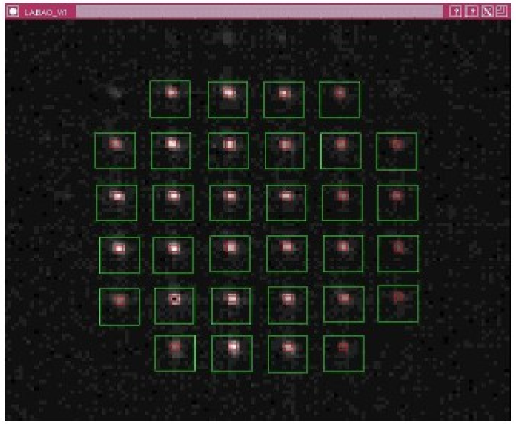
Beam Switcher

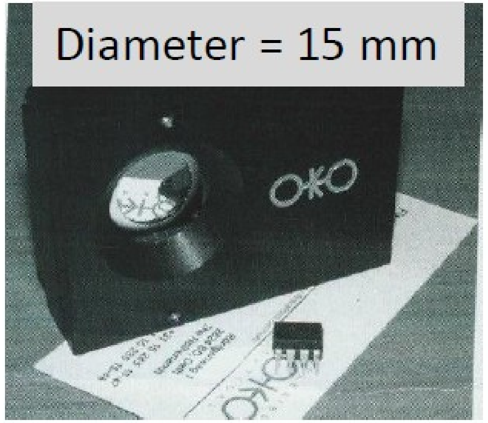


Delay Line Cart

Shack Hartmann Wavefront Sensor + Deformable Mirror

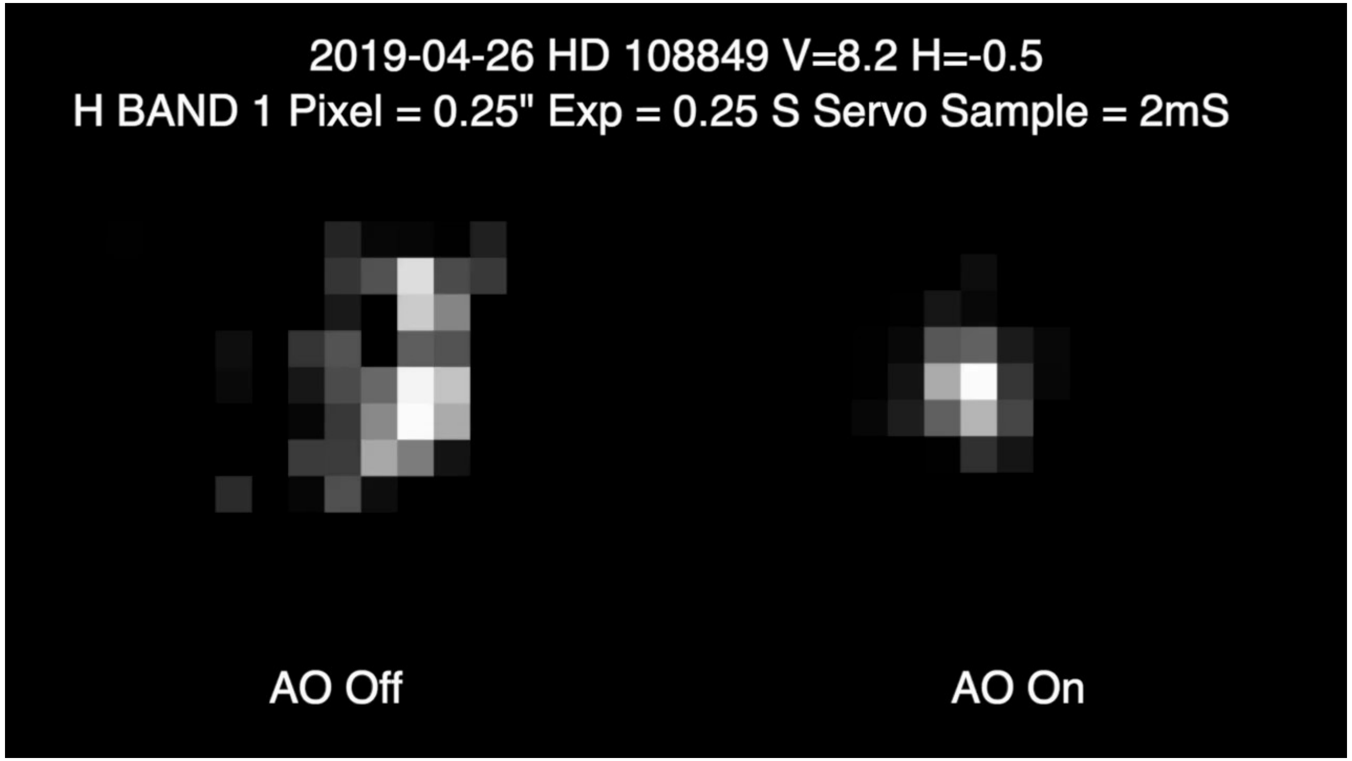
Lenslet Array
10 mm x 10 mm square grid





OKO Deformable Mirror
15 mm
37 actuators

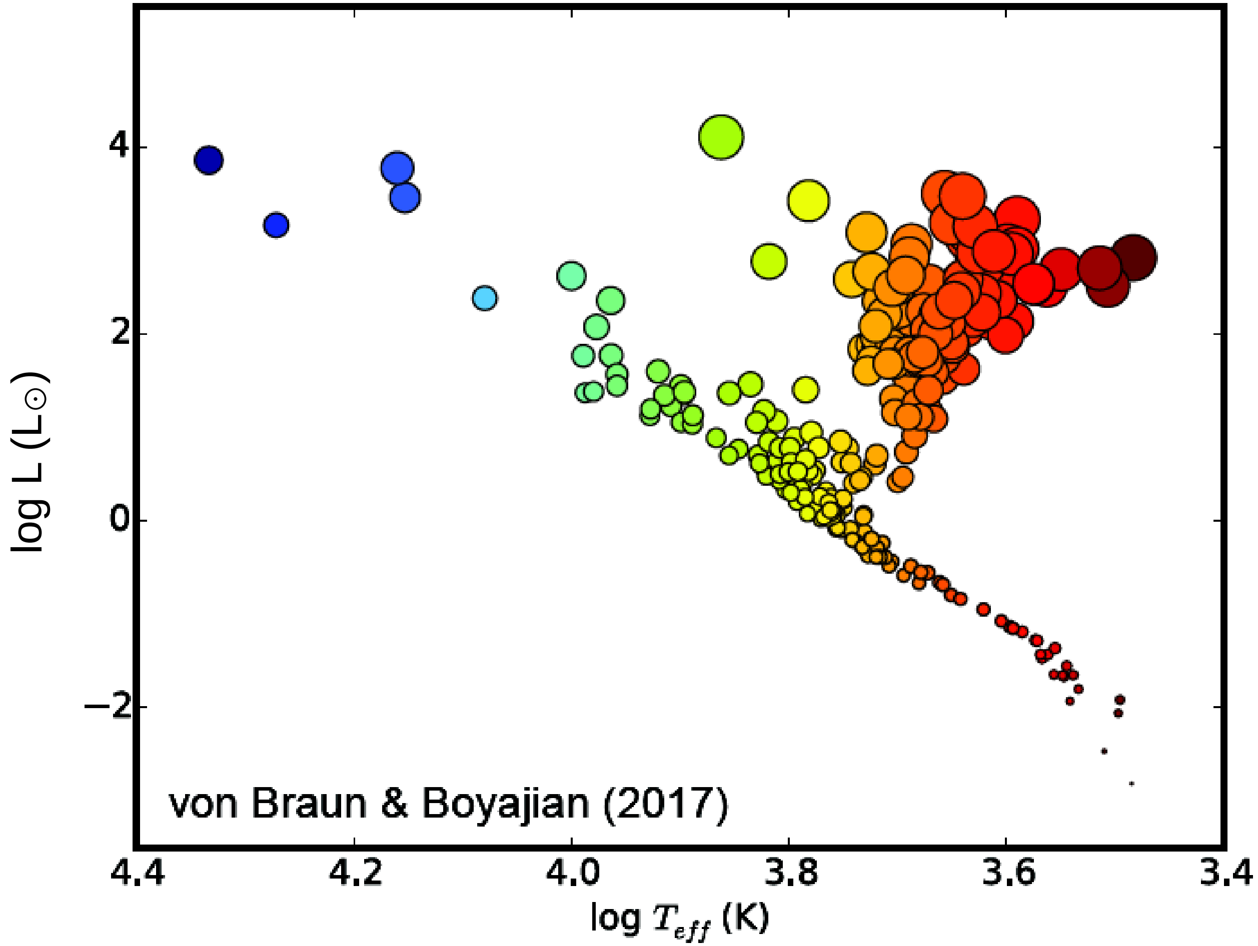
CHARA AO On Sky Performance



- LabAO installed on all 6 beams.
- Deformable mirrors installed and running full AO on two telescopes.
- Improving performance of remaining DMs.

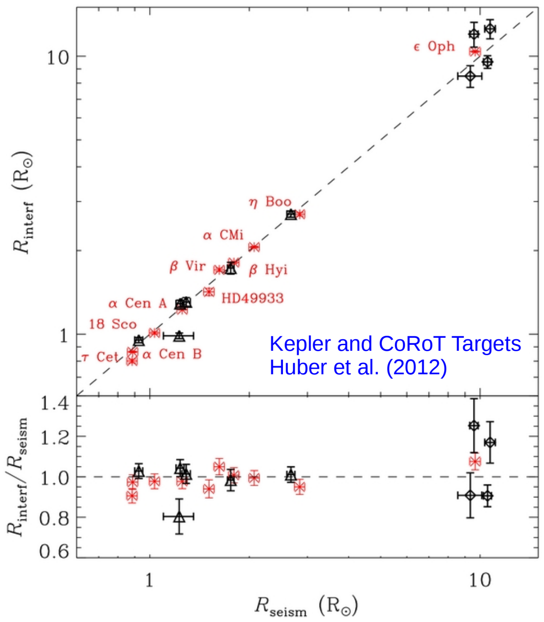
Overview of CHARA Science Results

Stellar Diameters



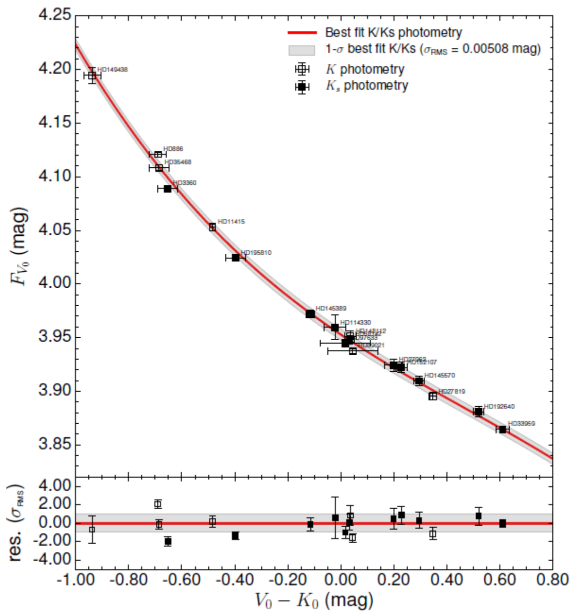
- Empirical HR Diagram
- ~ 290 stars, σ_θ < 5%
- Angular Diameter + Parallax
  - Linear Radius
- Diameter + Bolometric Flux
  - Effective Temperature

Stellar Diameters



Asteroseismology

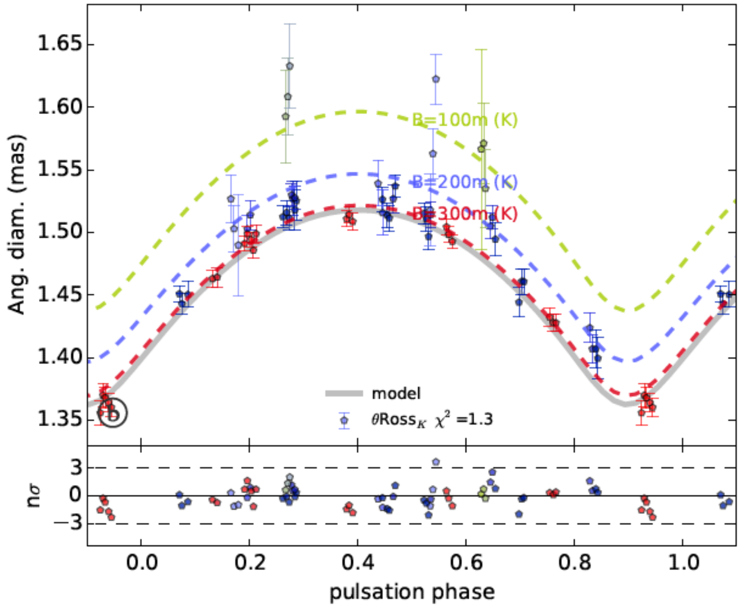
- Asteroseismology probes density and internal structure
- Test asteroseismic scaling relations
- Huber et al. (2012)



Surface Brightness Color Relations

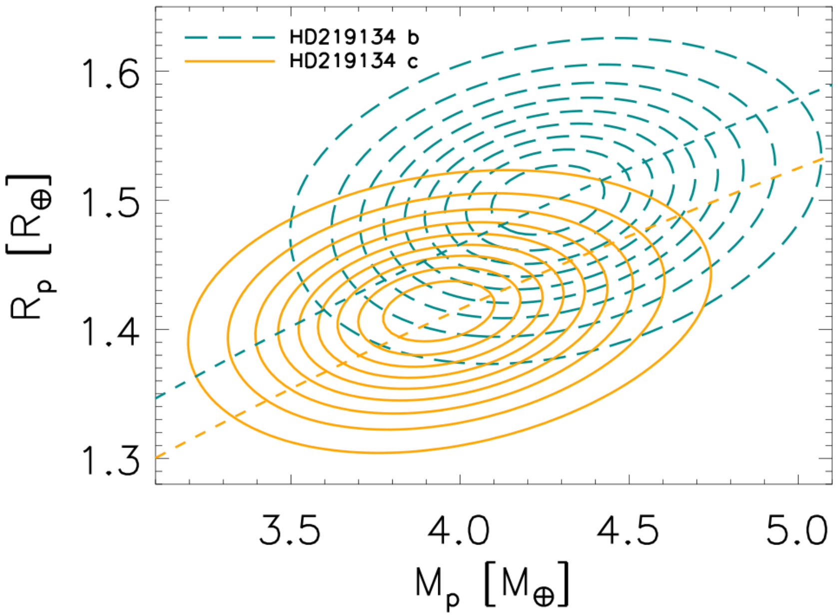
- Calibration for early and late-type stars
- Derive diameters with 1-2% precision
- Salsi et al. (2021)

Stellar Diameters



Stellar Pulsations

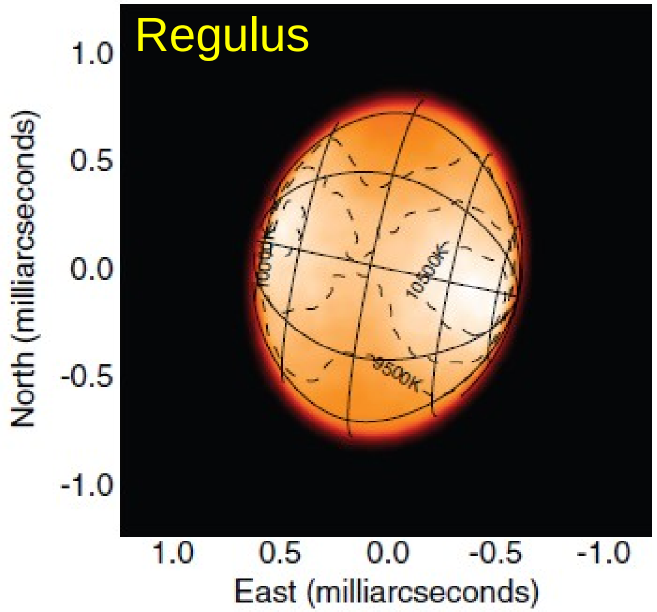
- Cepheid - δ Cep
- Pulsation Parallax
- Merand et al. (2015)



Exoplanet Host Stars

- Radius of transiting planets
- Size of habitable zones
- Ligi et al. (2019)

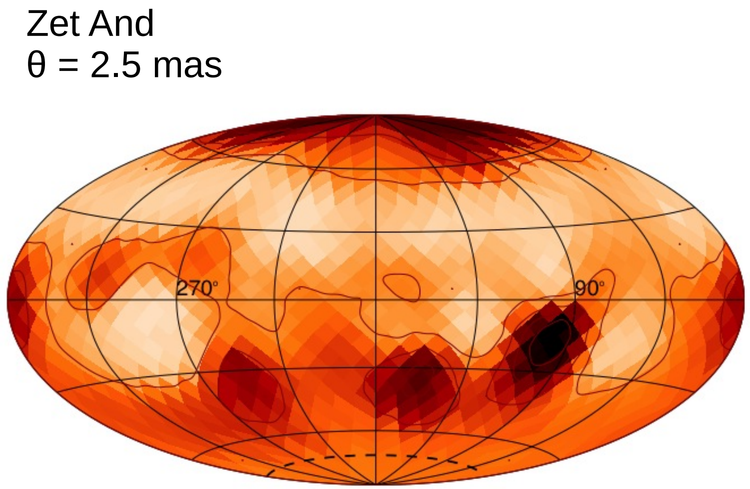
Imaging Stellar Surfaces



Rapid Rotators

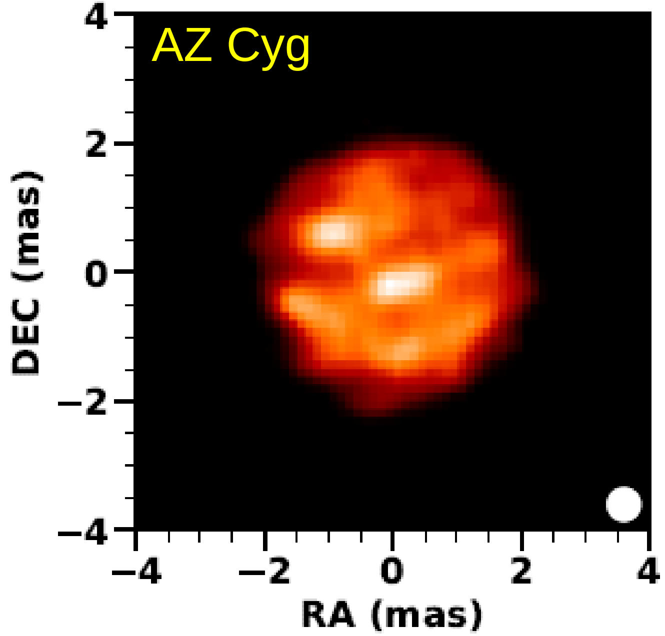
- Oblateness
- Limb-darkening
- Gravity-darkening

Che et al. (2011)



Starspots

Roettenbacher et al. (2016)

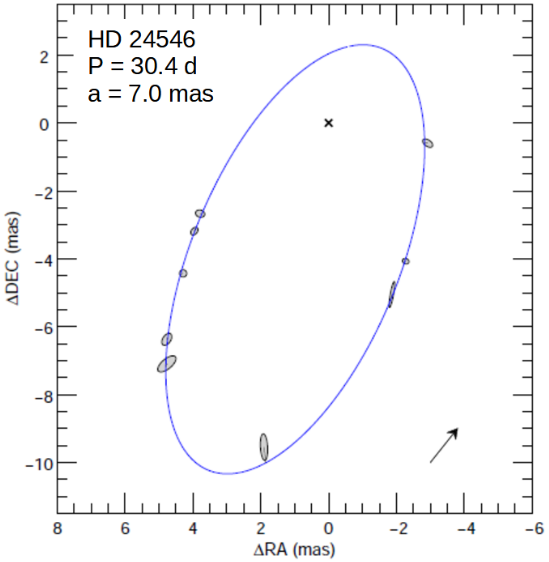


Convection on Supergiants

Norris et al. (submitted)

Binary Stars

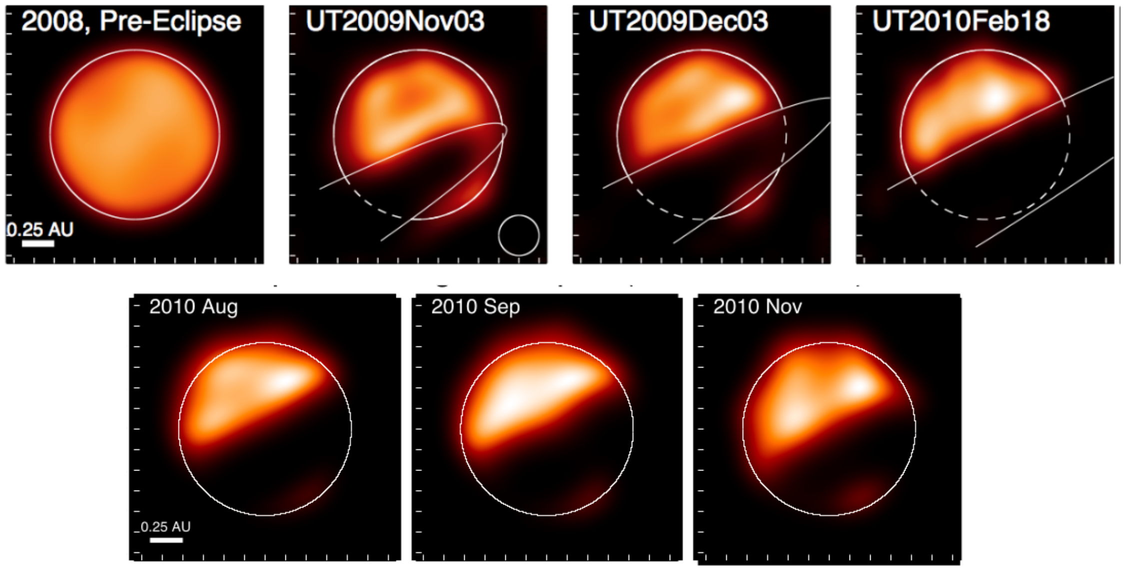
Lester et al. (2020)

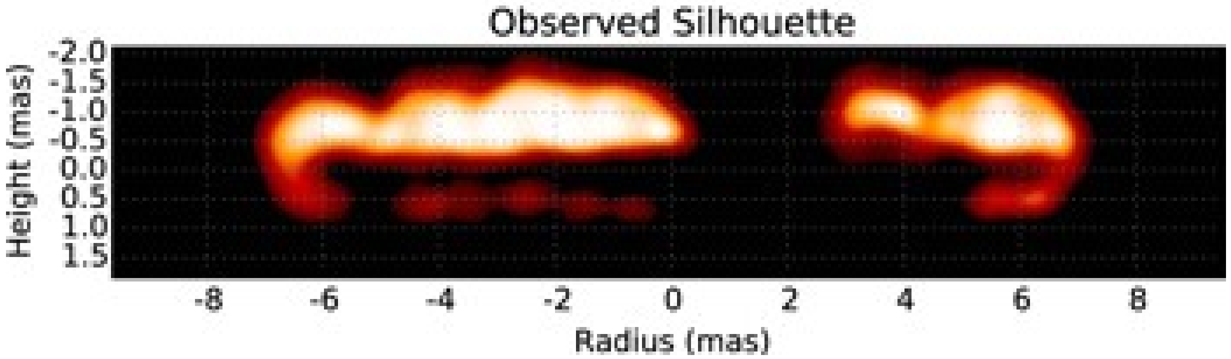


Zhao et al. (2008)

- Spatially resolved orbits of spectroscopic binaries
  - Masses and distances with 1-3% precision
- High contrast companions
  - Separations 0.5 – 50 mas
  - ΔH < 6 mag
- Mass transfer and tidal distortions in interacting binaries

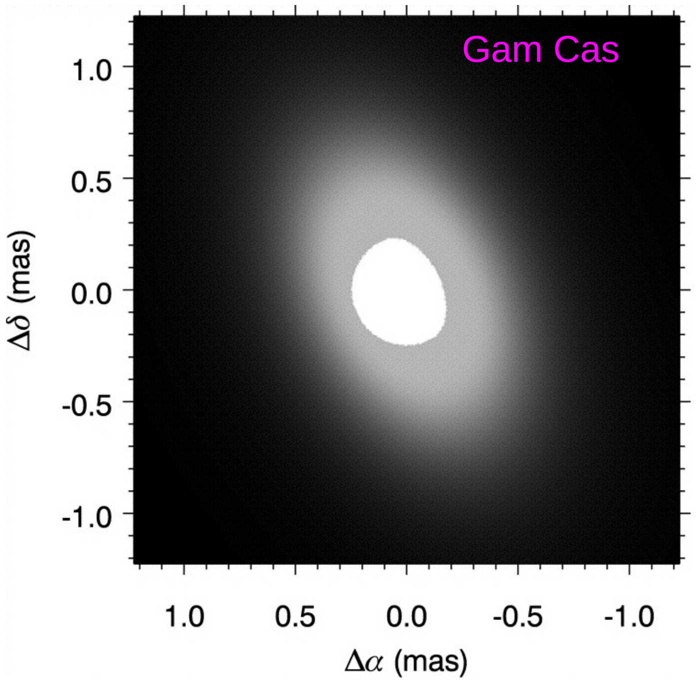
Eclipsing Binary: Epsilon Aurigae

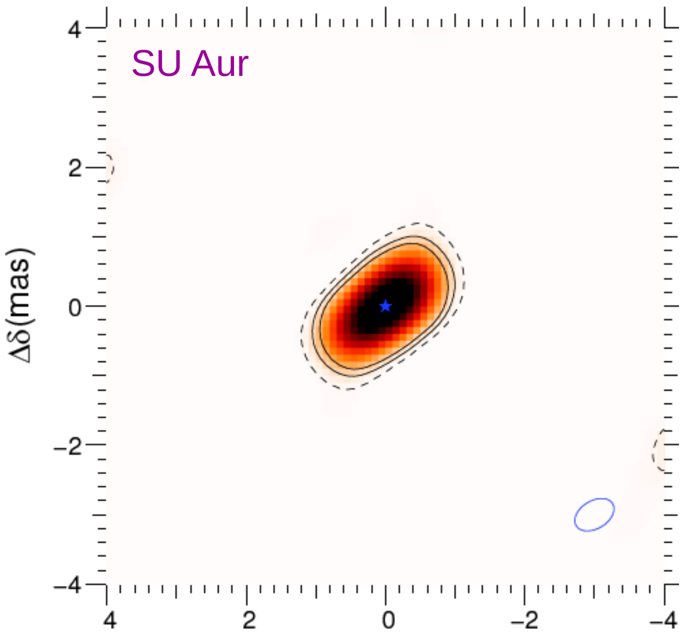




Kloppenborg et al. (2010, 2015)

Circumstellar Disks





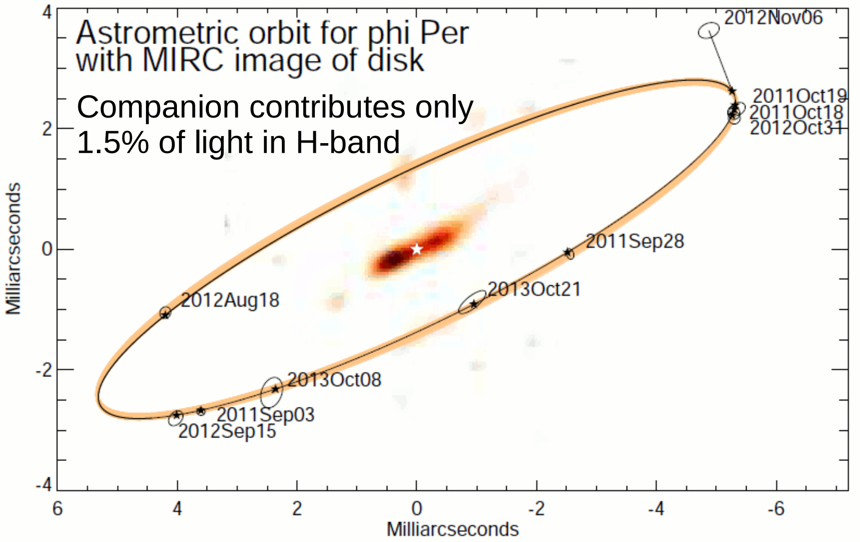
Rapidly Rotating Be Stars

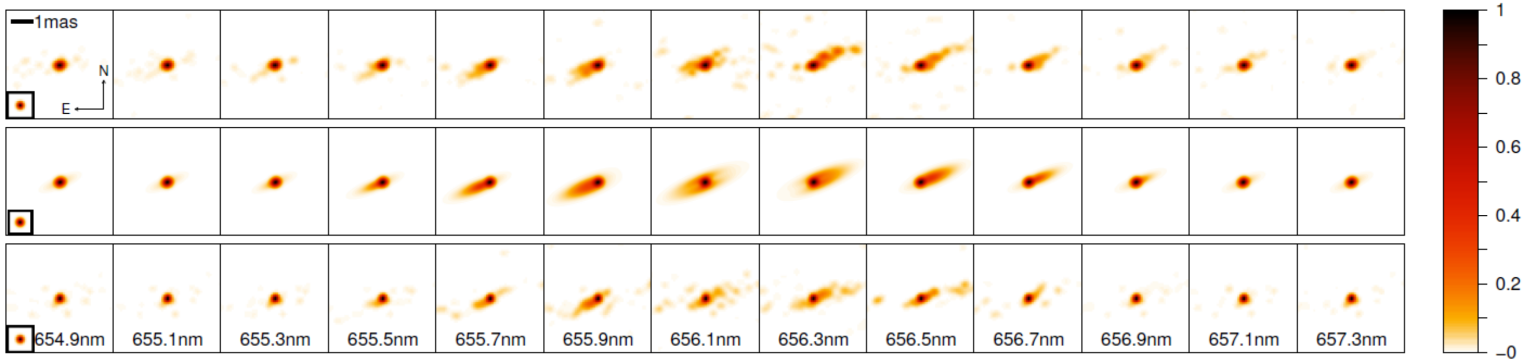
- Gies et al. (2007)

Young Stellar Objects

- Labdon et al. (2019)

Kinematics of Disks and Outflows





Spectrally dispersed images of Phi Per Disk

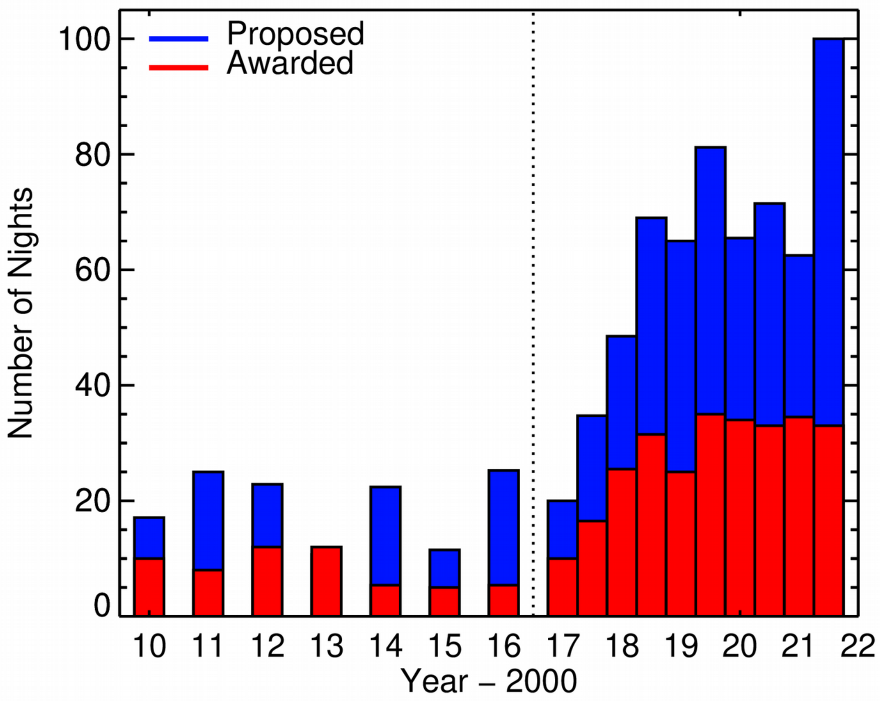
- VEGA beam combiner
- Mourard et al. (2015)

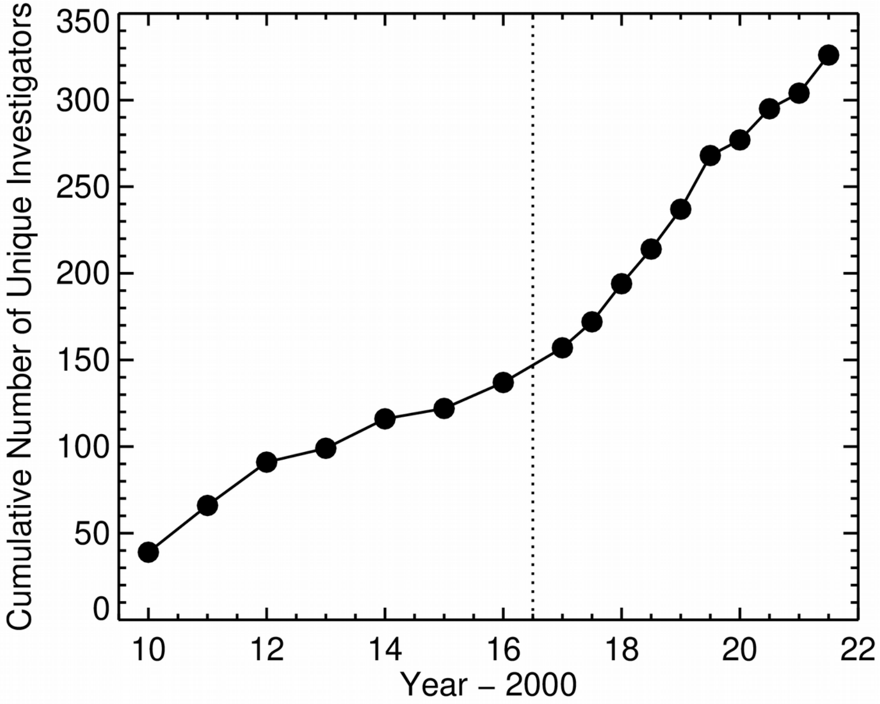
Open Access Time

- Trial program began in 2010
  - Initially 5-10 nights per year
- Support from NSF Midscale Innovations Program in 2017
- Currently offer 60 nights per year to the community
  - Expand to 100 nights per year over the next 3 years
- Time offered through NOIR Lab call for proposals
  - Semester A (Feb – Jul): due end of September
  - Semester B (Aug – Dec): due end of March

Open Access Statistics

- Average over-subscription rate of ~ 2.4
- Over 320 astronomers have applied for open access time.





How to Apply for Open Access Time

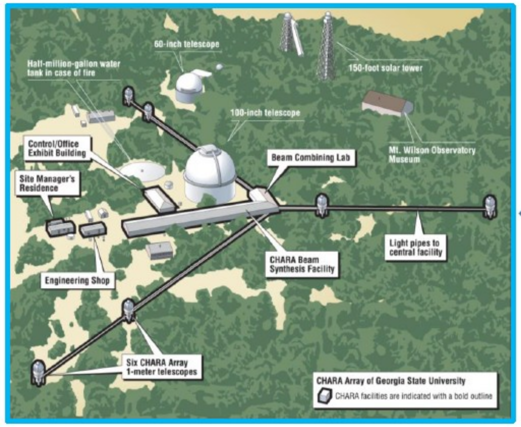
- Applying for CHARA time
  - http://www.chara.gsu.edu/observers/applying-for-chara-time
- Open access proposals are submitted through NOIRLab
  - http://ast.noao.edu/observing/proposal-info
- Planning observations
  - http://www.chara.gsu.edu/observers/planning-an-observation
  - ASPRO2 can be used to plan CHARA observations (JMMC)
  - Select instrument and telescope configuration
  - Select POP delay settings (access to different parts of sky)
- CHARA staff can help with planning, data collection, and reduction.

CHARA Data Center

- Located at GSU Data Center in Atlanta
- 3 Virtual Machines on CHARA Server
  - Remote Observing
  - Data Reduction
  - Data Archive
- Searchable Database Coming Soon!

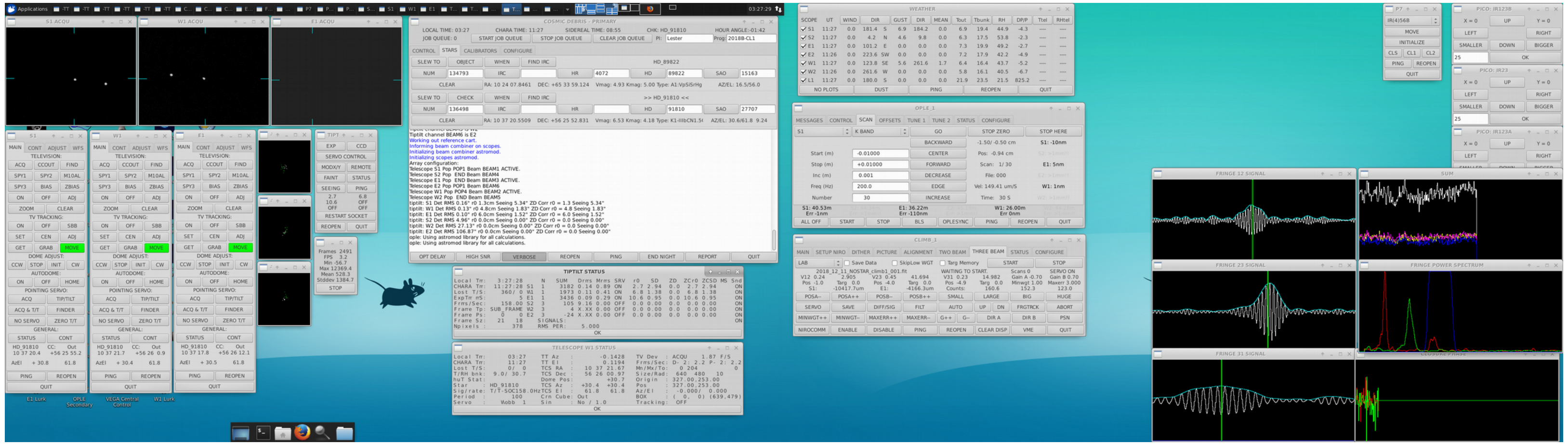
Remote Observing

- Connect to Atlanta machine using VNC.
- Atlanta machine connects to mountain using SSH tunnel.
- Active and view-only modes available.
- Remote-only observing during pandemic.



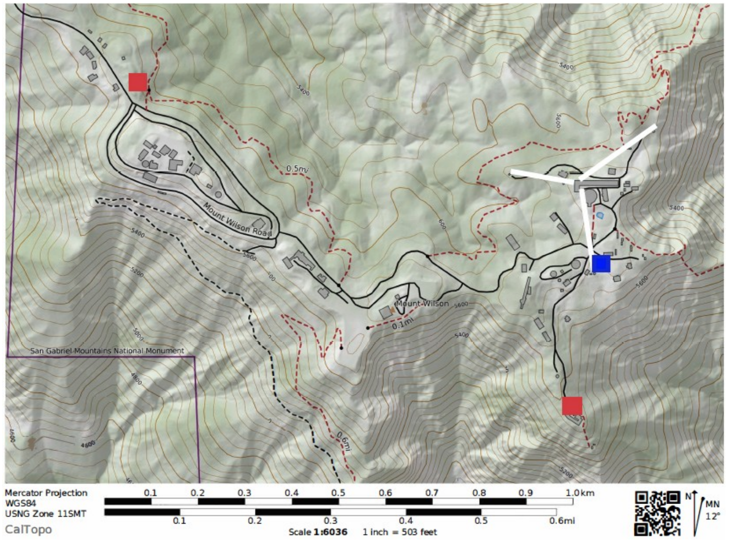
ssh tunnel

VNC



Future Expansion: Mobile Telescope Project

PlaneWave 1000 at NPOI (Gerard van Belle)



- Funded through National Science Foundation – Major Research Instrumentation program
- PI: Douglas Gies
- Mobile 7th telescope connected by fiber optics
- Short baselines for imaging large stars
- Long baselines for resolving exoplanet host stars and distant massive stars
- Pathfinder for future expansion of the CHARA Array

Summary – CHARA Array

- Next generation instrumentation
  - MIRC-X, MYSTIC, SPICA, CLASSIC++/CLIMB++
  - Improved sensitivity
  - Six telescope combination at visible and near-infrared wavelengths
- Mobile Telescope project
  - Longer baselines, additional uv coverage, fiber optic relays
- Open access time available through NOIRLab
  - Next proposal deadline – September 2021