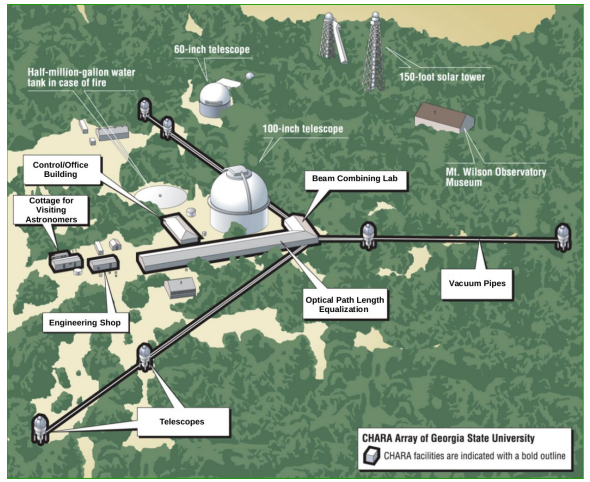
An Optical Interferometry Science Briefing

Gail Schaefer

Director of the CHARA Array
Georgia State University

Current Long Baseline Optical Interferometers



CHARA Array
Mount Wilson, CA
Six 1 m telescopes
330 m max baseline
Visible + Near IR

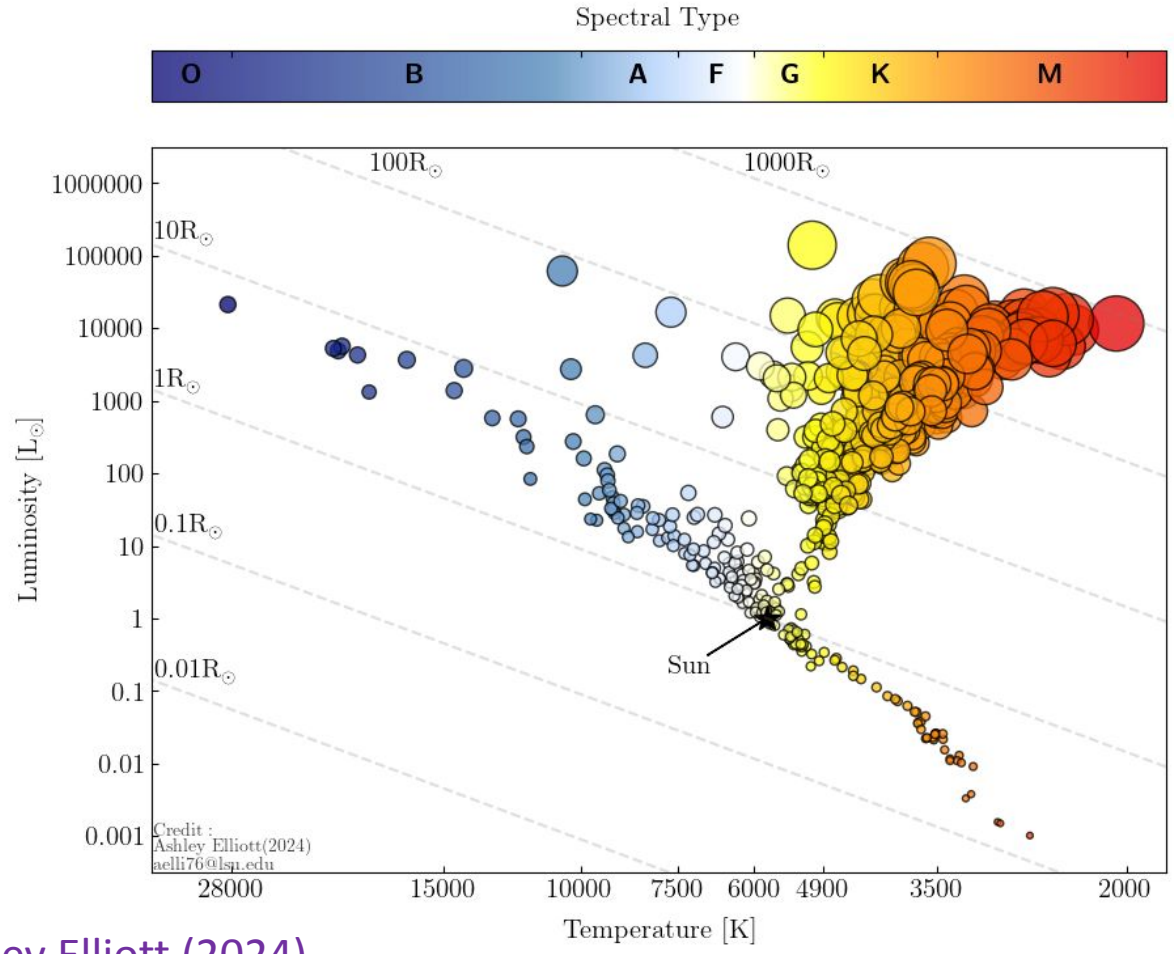
VLTI
Paranal, Chile
Four 8-m UTs:
130 m max baseline
Four 1.8 m ATs:
200 m max baseline
Near + mid IR

NPOI
Anderson Mesa, AZ
Six 12.5 cm apertures
100 m max baseline
Visible

LBTI
Mount Graham, AZ
Two 8 m telescopes
23 m max baseline
Mid IR

MROI
Magdalena, NM
Planned: Ten 1.4 m telescopes
Planned: 340 m max baseline
Near IR
UNDER CONSTRUCTION

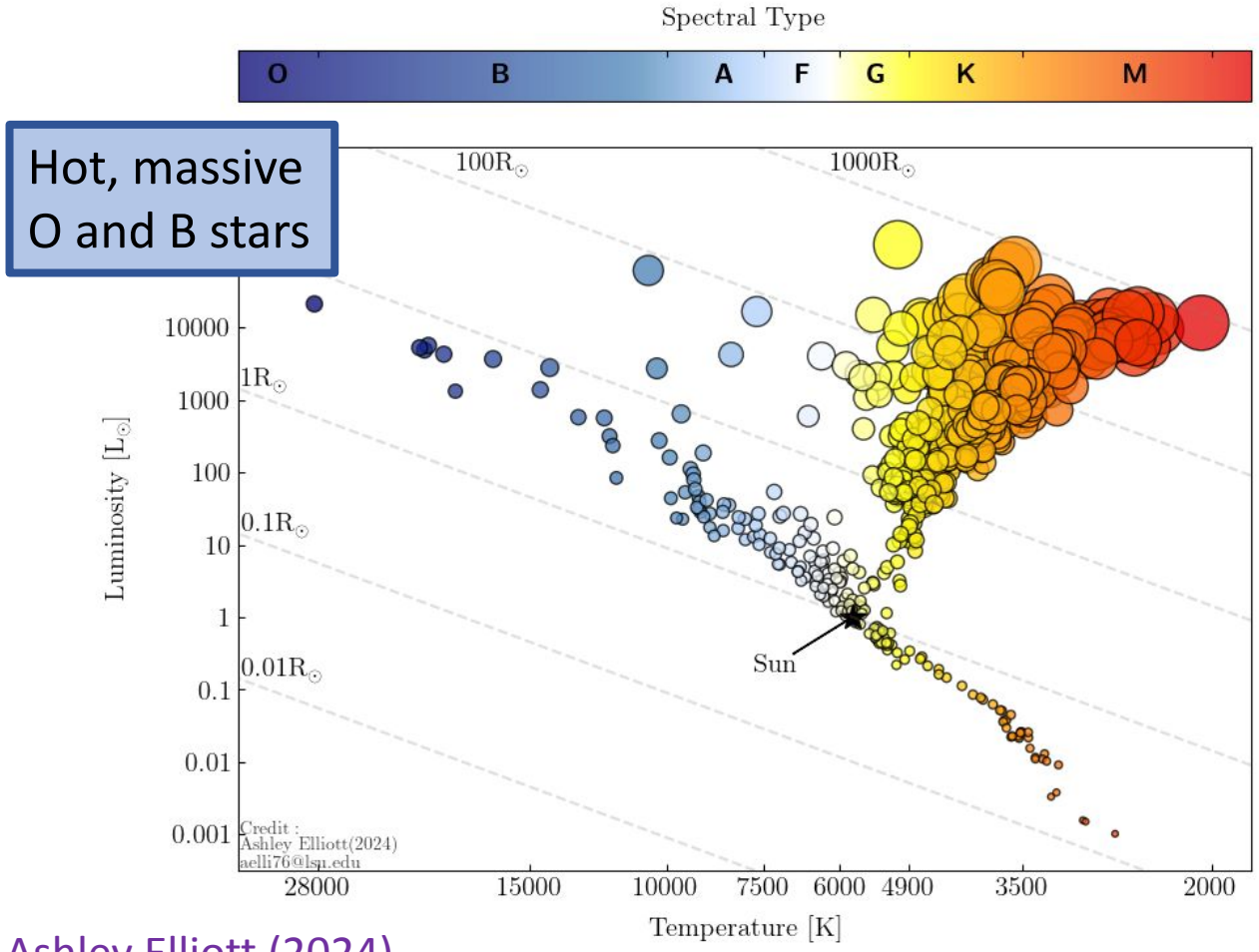
Stellar Diameters



- Empirical HR Diagram
- 693 stars, $\sigma_\theta < 5\%$
- Angular Diameter + Parallax
  - Linear Radius
- Diameter + Bolometric Flux
  - Effective Temperature

Ashley Elliott (2024)

Stellar Diameters



Ashley Elliott (2024)

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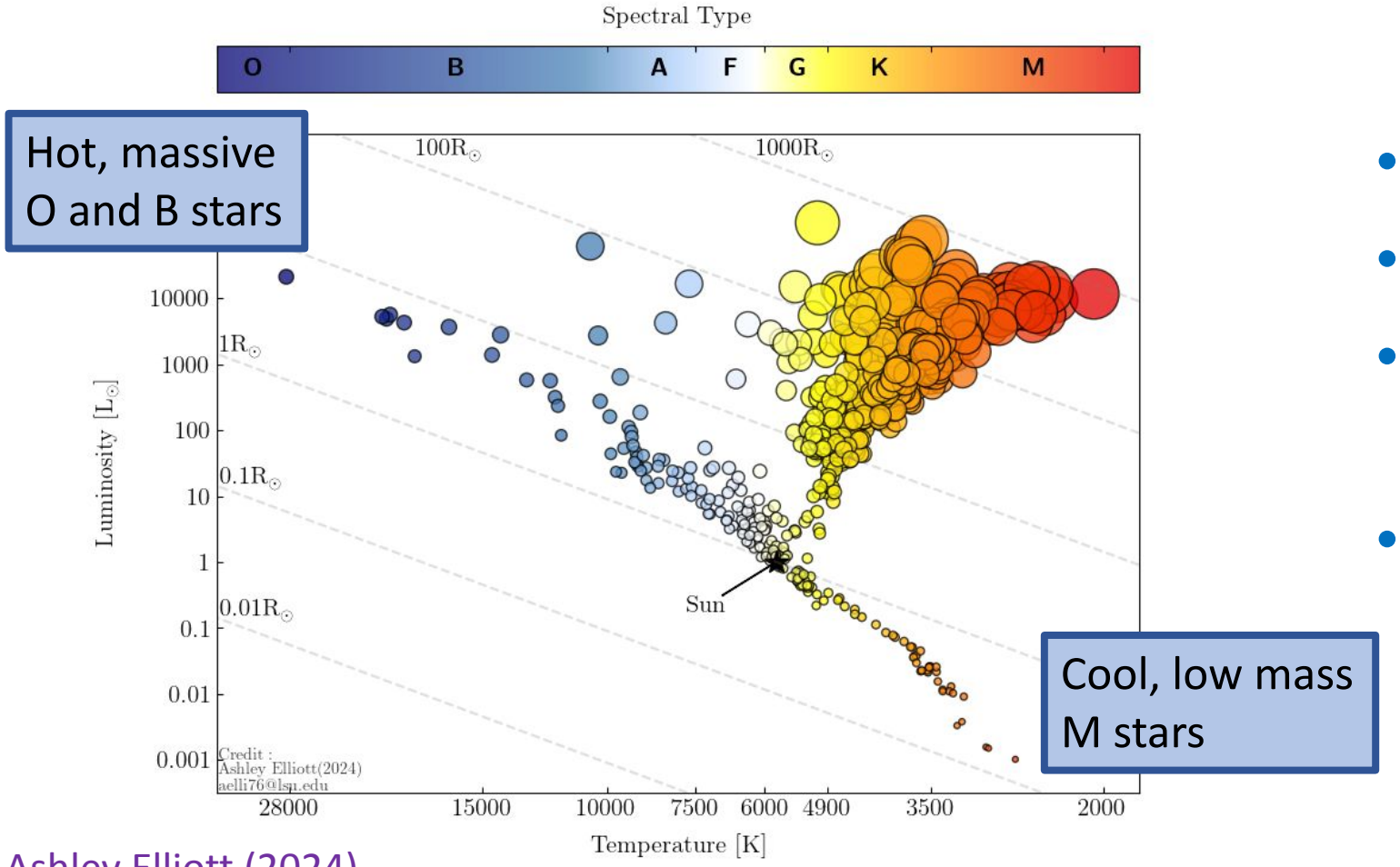
Stellar Diameters



Hot, massive
O and B stars

Cool, low mass
M stars

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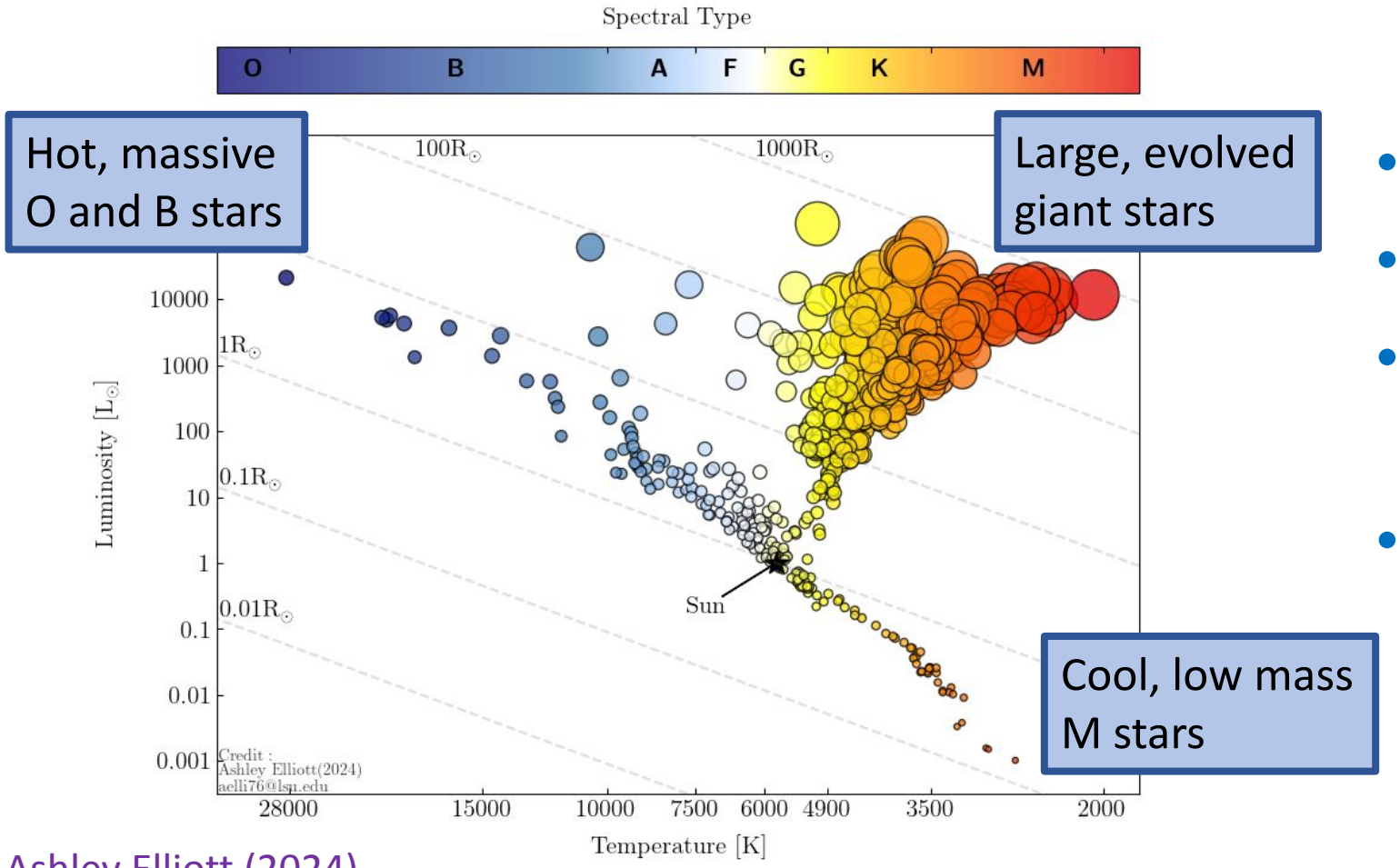
Ashley Elliott (2024)

Stellar Diameters



Ashley Elliott (2024)

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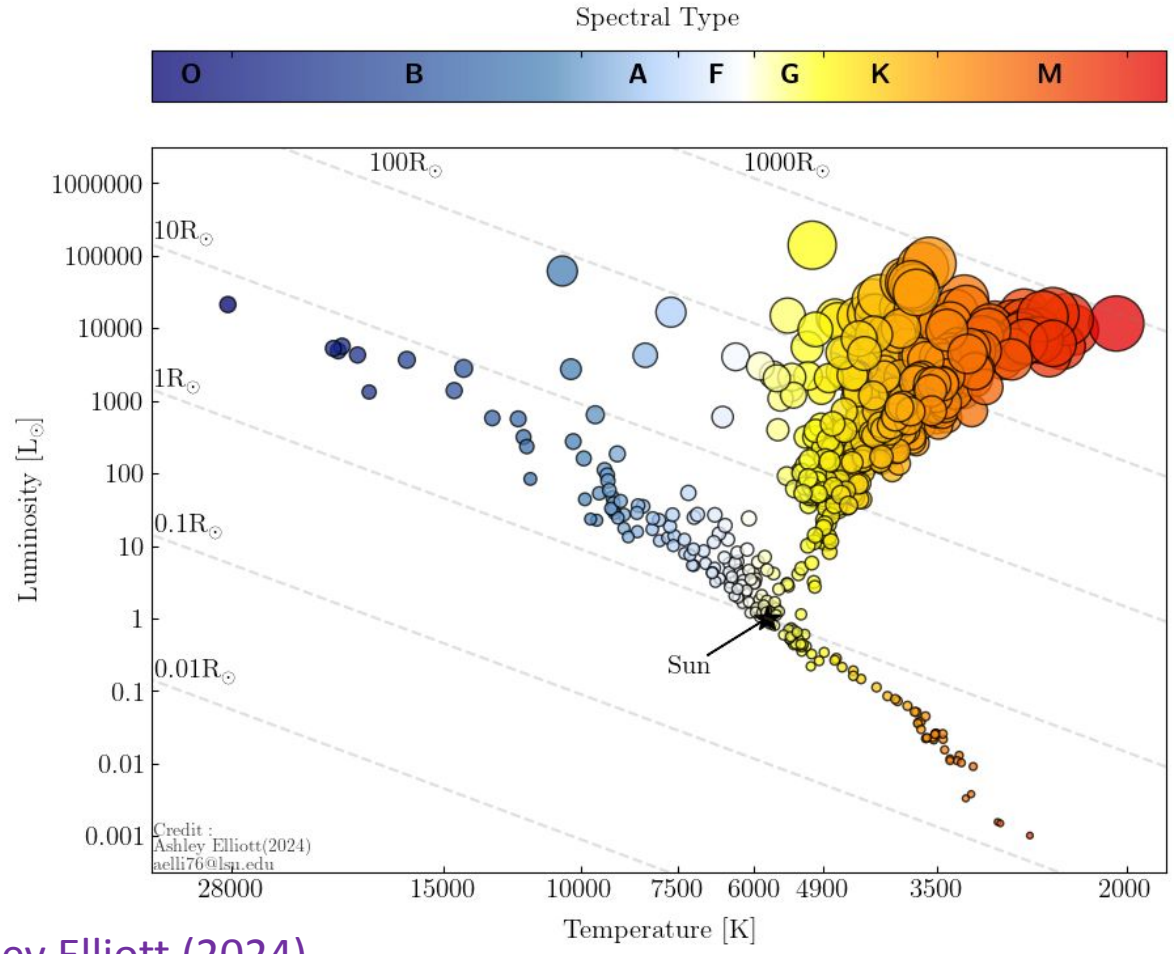
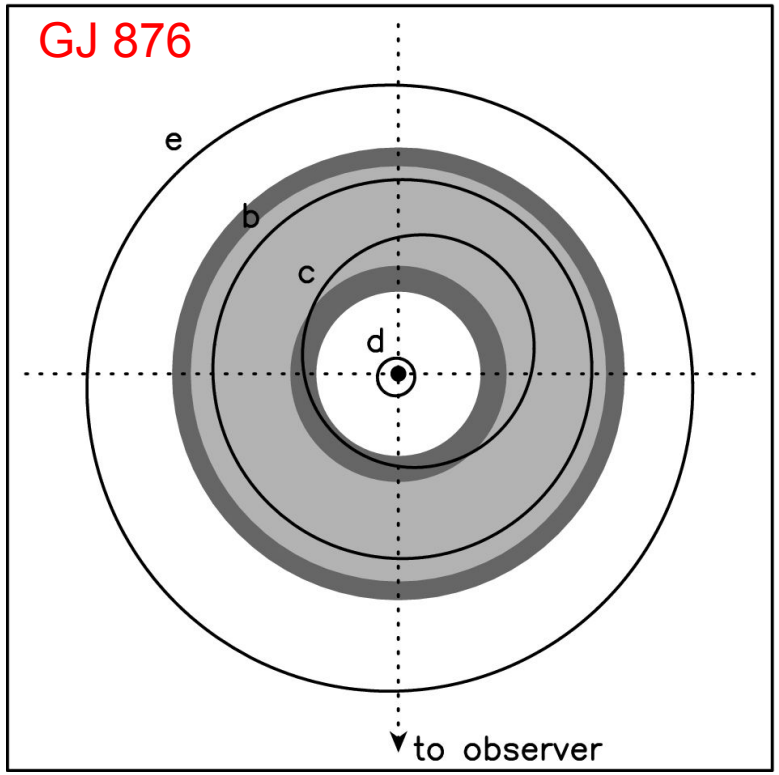
Stellar Diameters



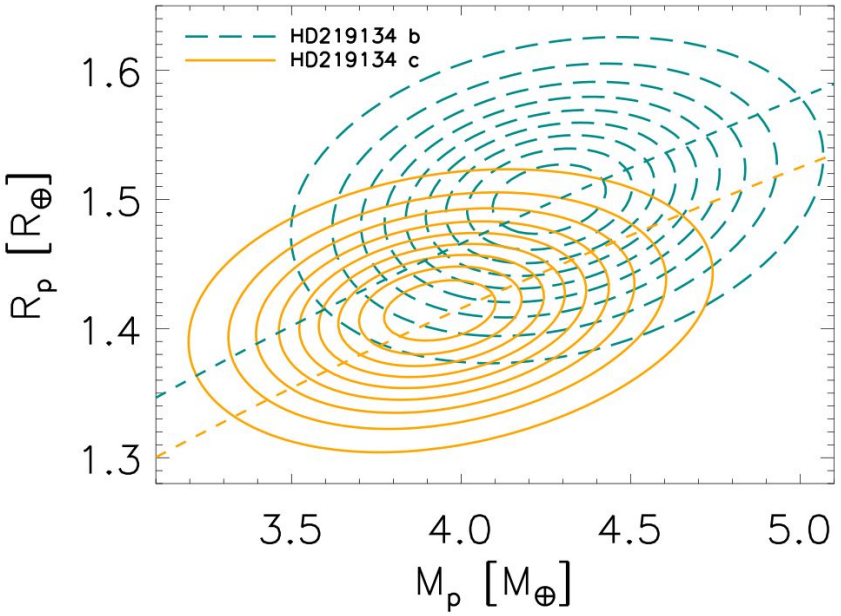
- Compute masses and ages from evolutionary tracks/isochrones
- Test evolutionary models
- Refine color-magnitude relations
- Refine surface brightness relations
- Test asteroseismic scaling relations

Ashley Elliott (2024)

Exoplanet Host Stars

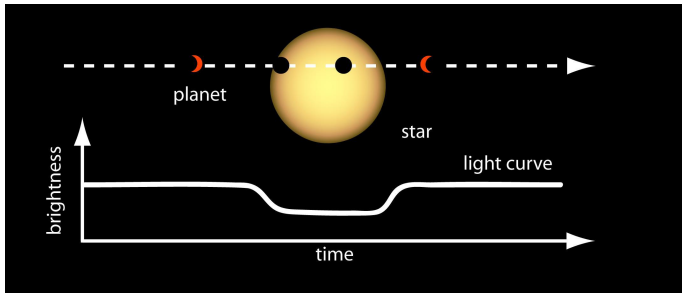


von Braun et al. 2014



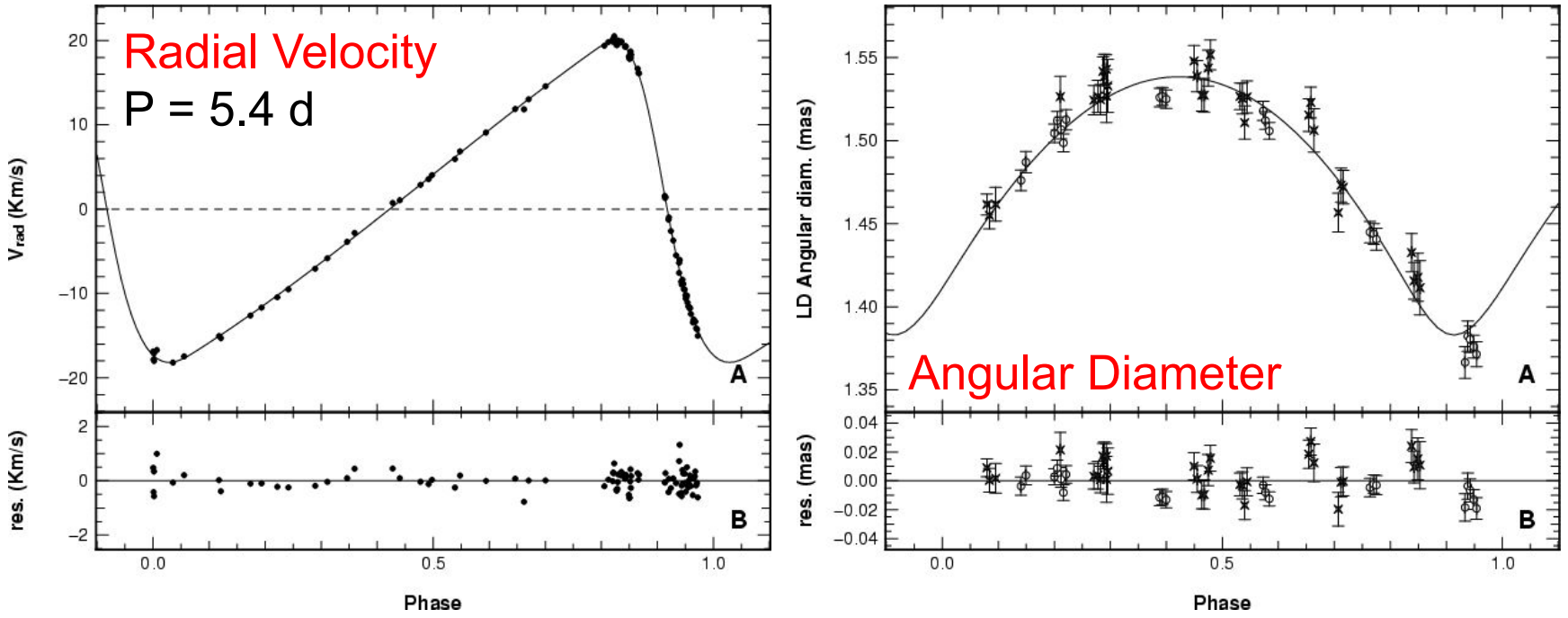
Ligi et al. 2019

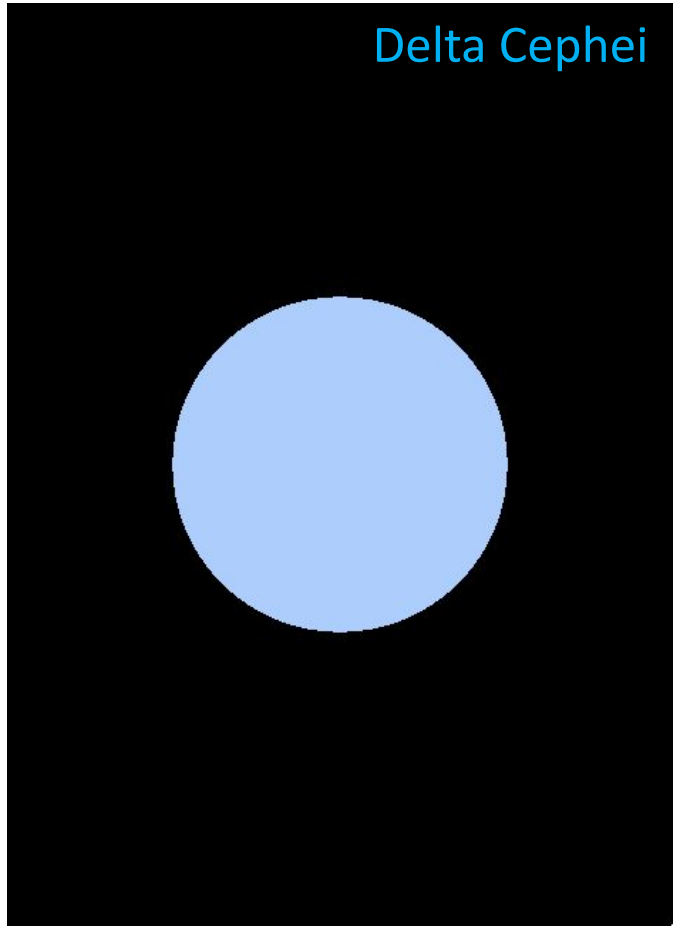
- Radius and Teff of host
  - Mass + age from evolutionary tracks
- Size of habitable zone
- Radius of transiting planets



NASA Ames

Pulsating Cepheid Variables



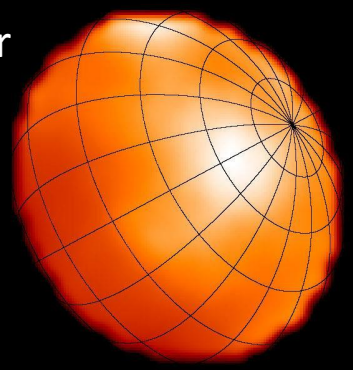


- Radial velocity and angular diameter variations
- Pulsation Parallax - Merand et al. (2005, 2015)

Imaging Stellar Surfaces

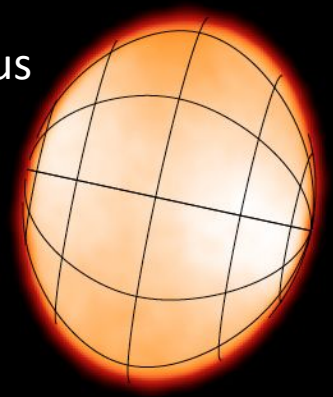
Rapid Rotation

Altair



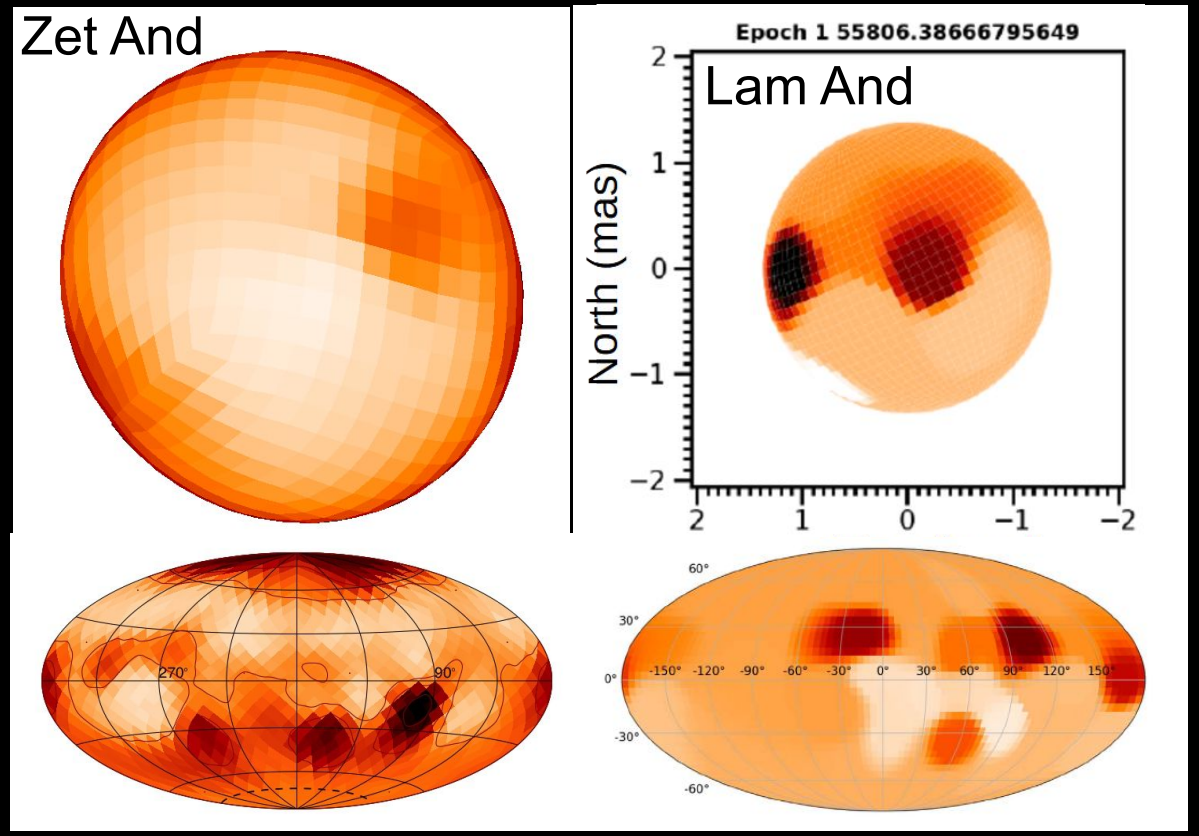
Monnier et al. (2007)

Regulus



Che et al. (2011)

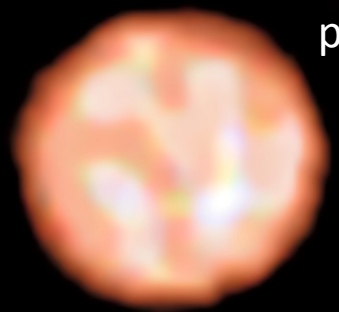
Starspots



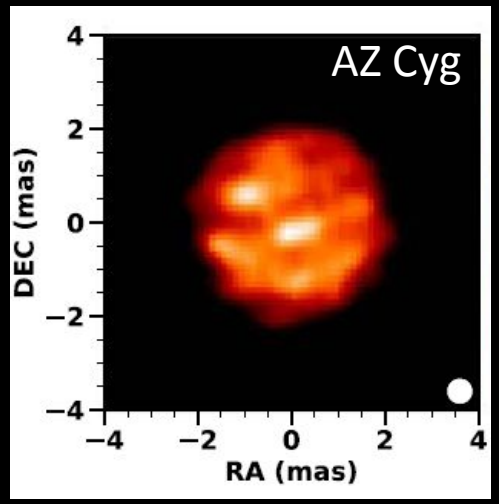
Roettenbacher et al. (2016) Martinez et al. (2021)

Convection

pi1 Gru

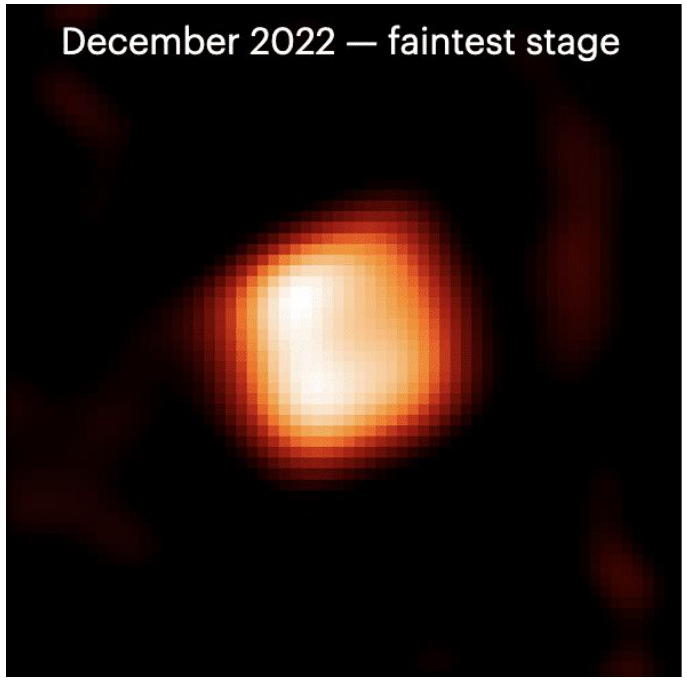


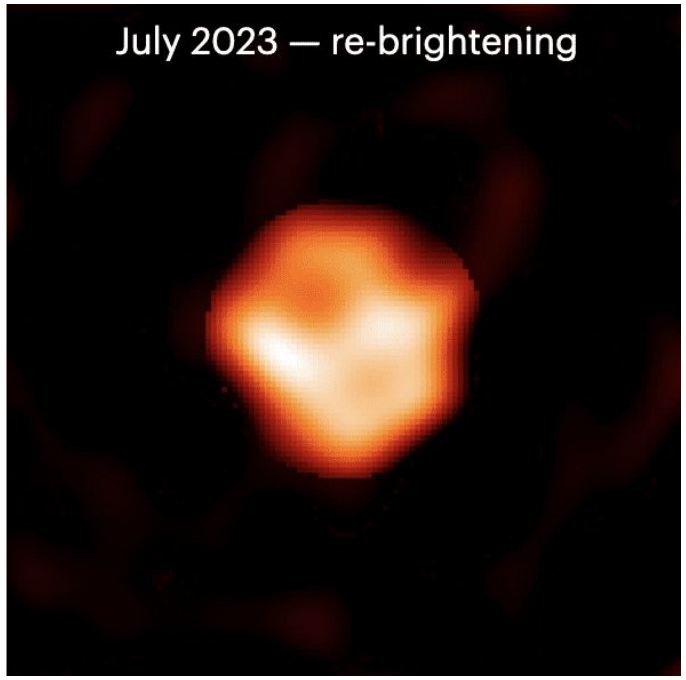
Paladini et al. (2018)

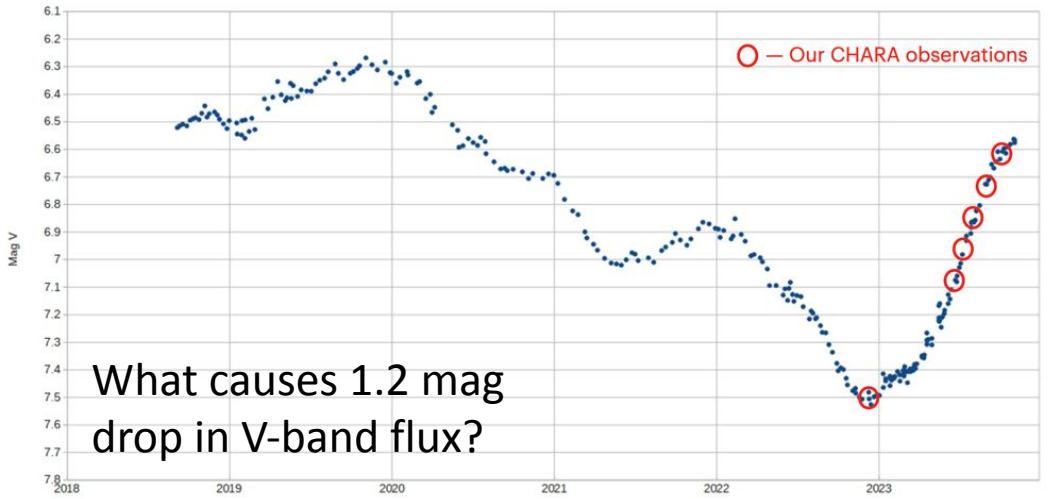


Norris et al. (2021)

Great Dimming of RW Cep







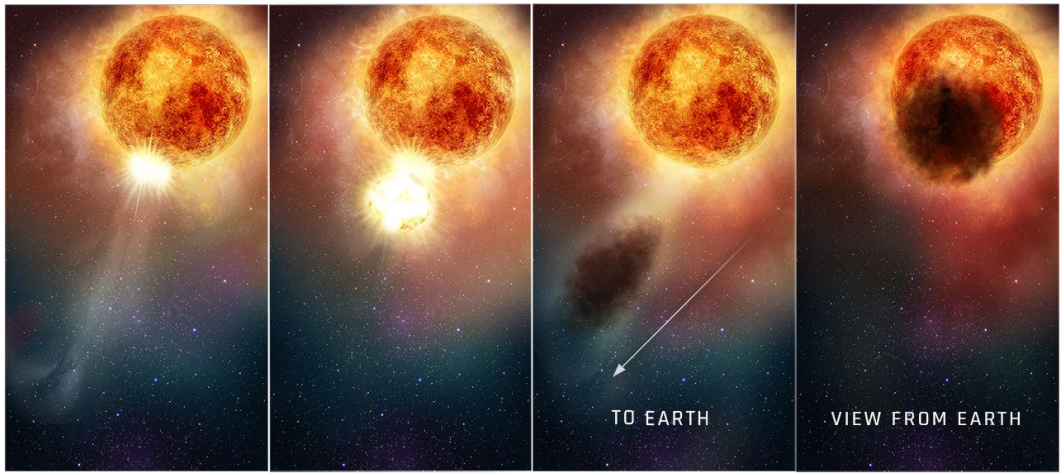
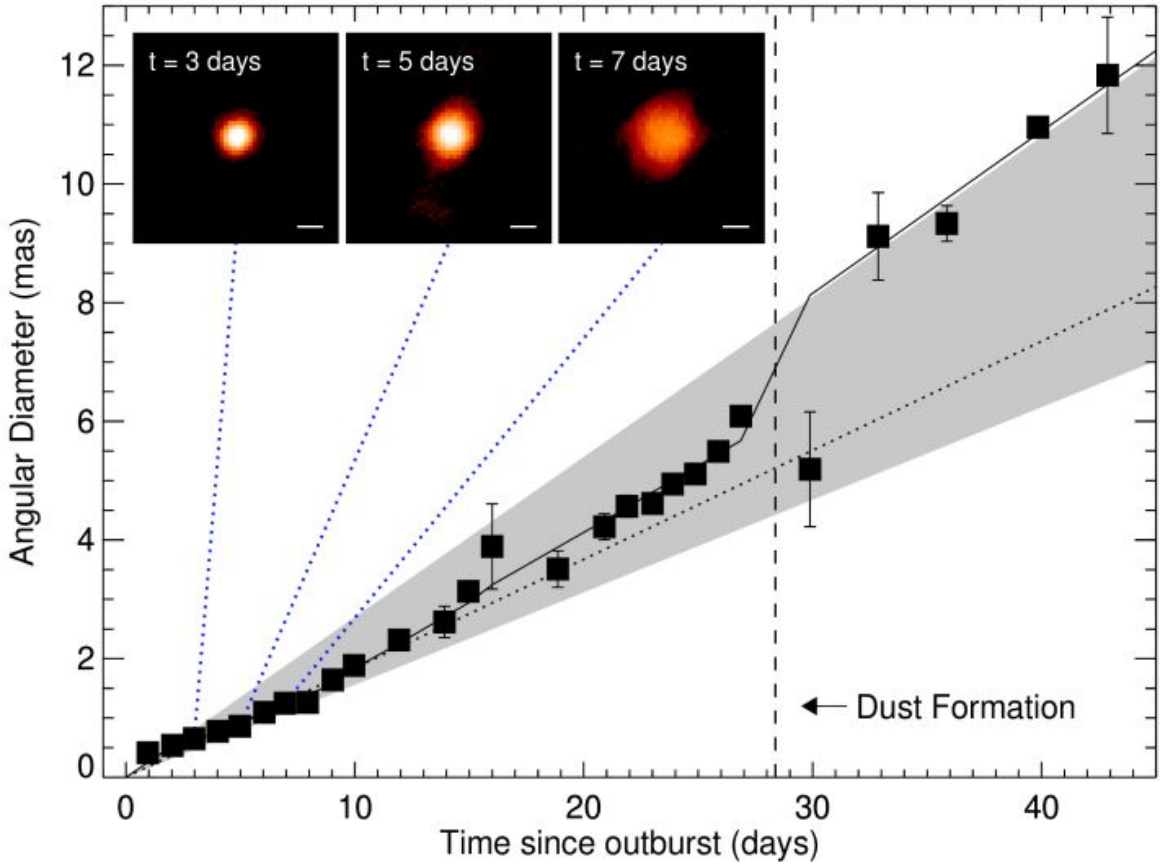


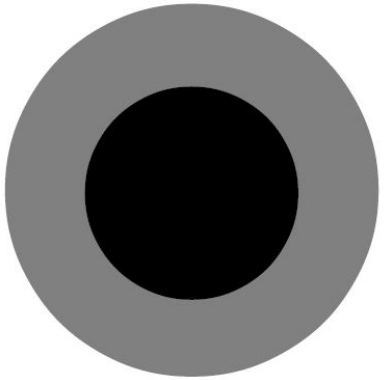
Illustration credit: NASA, ESA, and E. Wheatley (STScI)

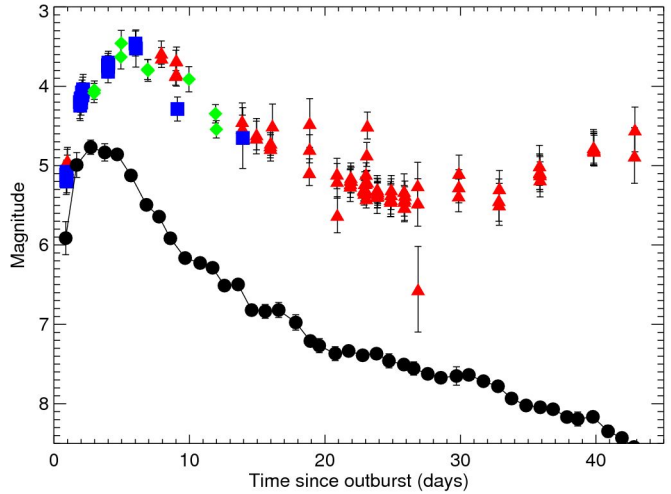
- Patchy appearance results from dust created by a huge ejection from the star
- Anugu et al. (2023)

Classical Nova Explosions
Nova Delphini 2013



Schaefer et al. (2014)



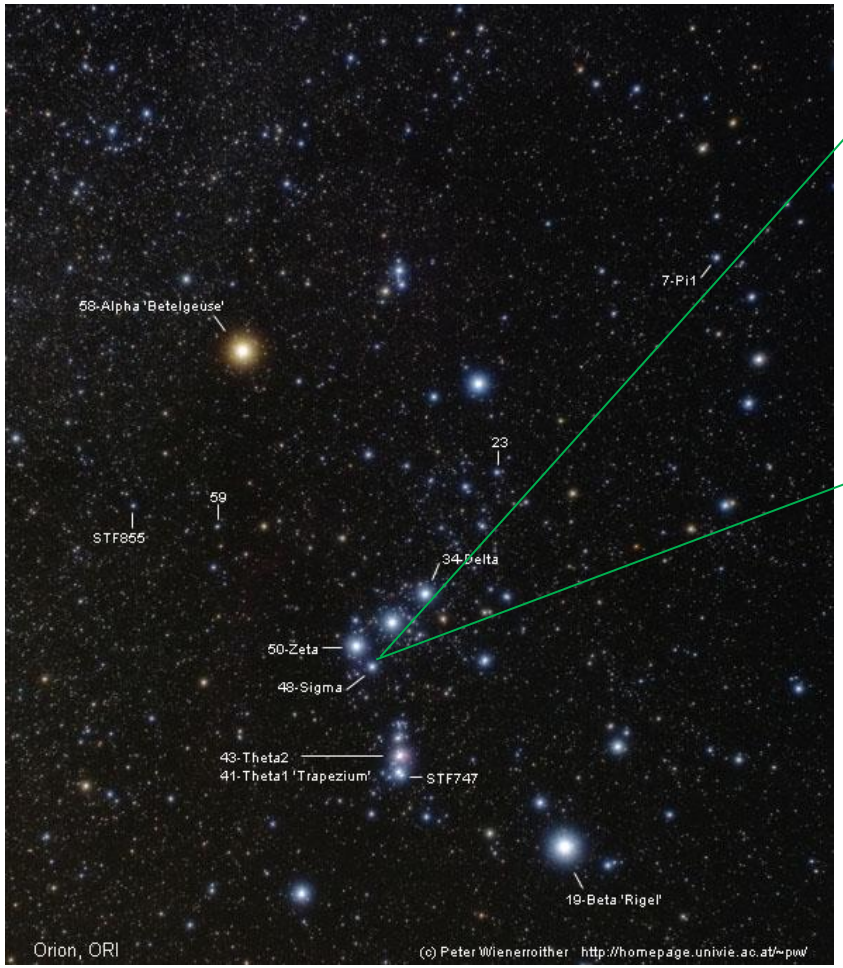


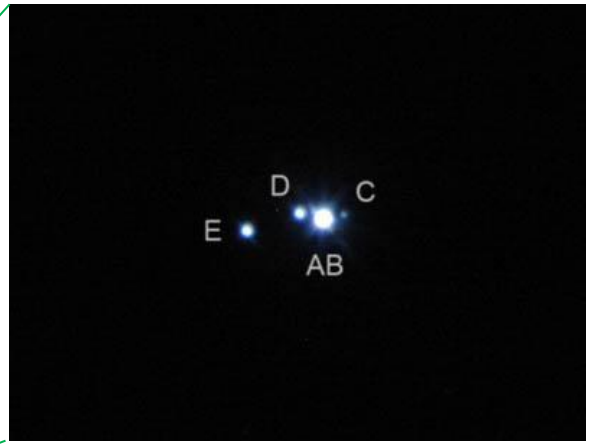
H+K (CHARA)

V (AAVSO)

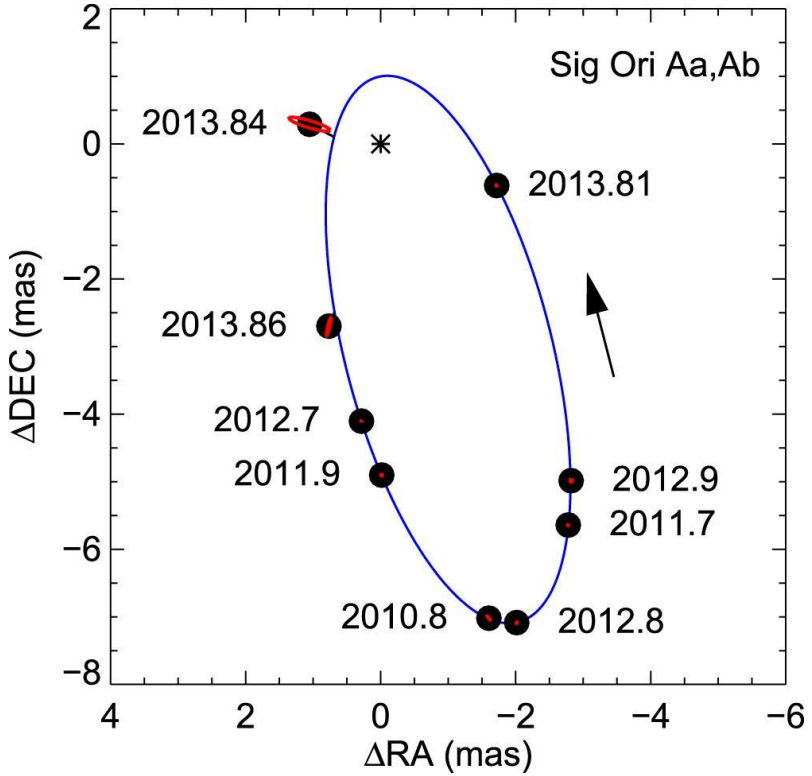
- Changes in apparent expansion – optically thick core surrounded by diffuse envelope that cools over time
- Geometric disk: 4.5 kpc
- Asymmetric shape detected as early as t=2d

Binary Stars: Stellar Masses



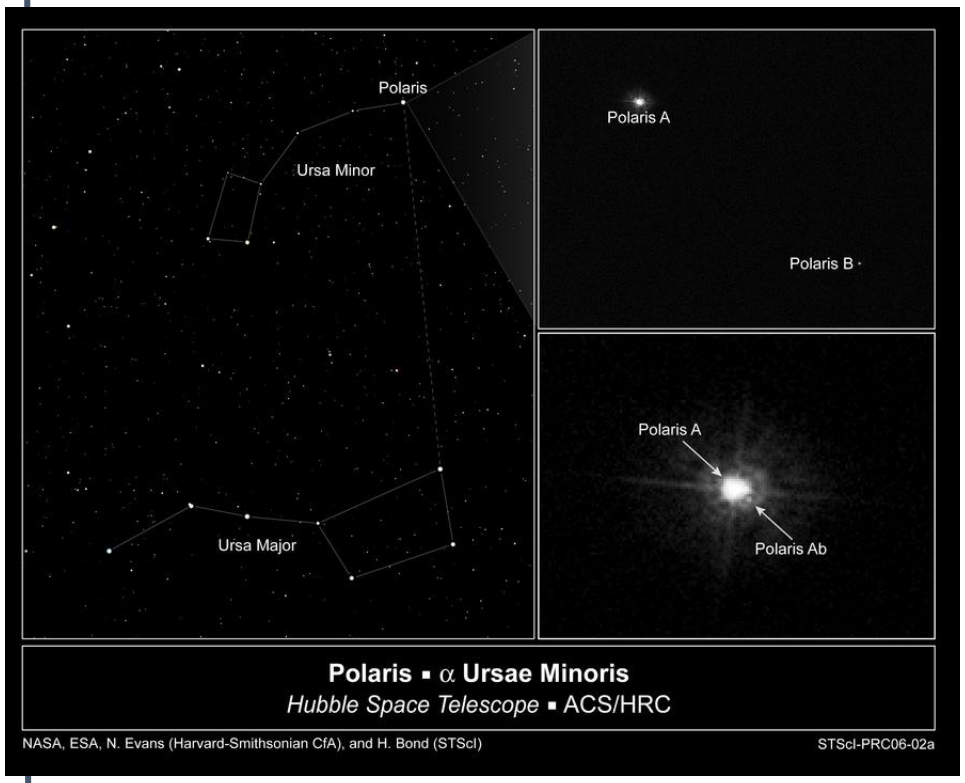


- Spatially resolved orbits of spectroscopic binaries
- Masses and distances with 1-3% precision

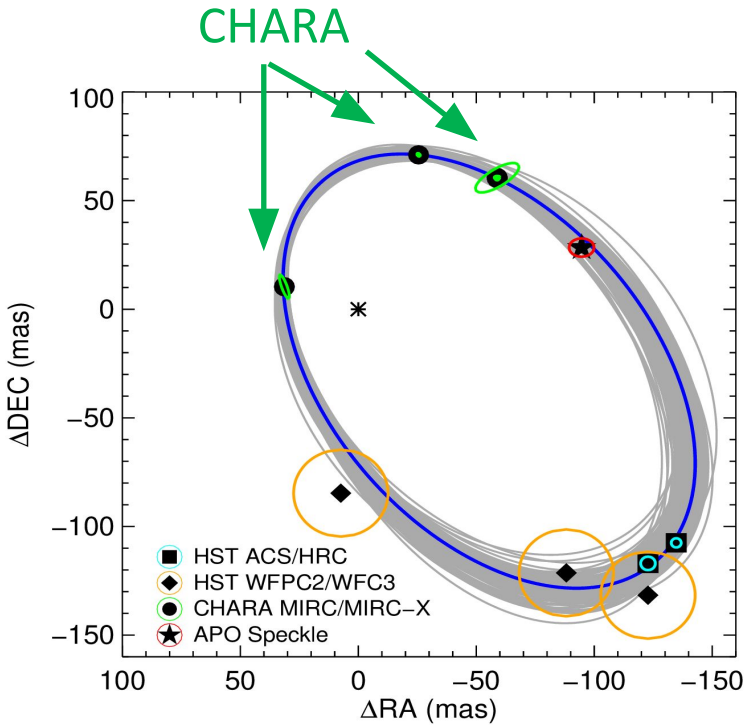


Period: 143 days
Semi-major axis: 4.3 mas
17 and 13 solar masses
Schaefer et al. (2016)

Polaris – Nearest and Brightest Cepheid Variable

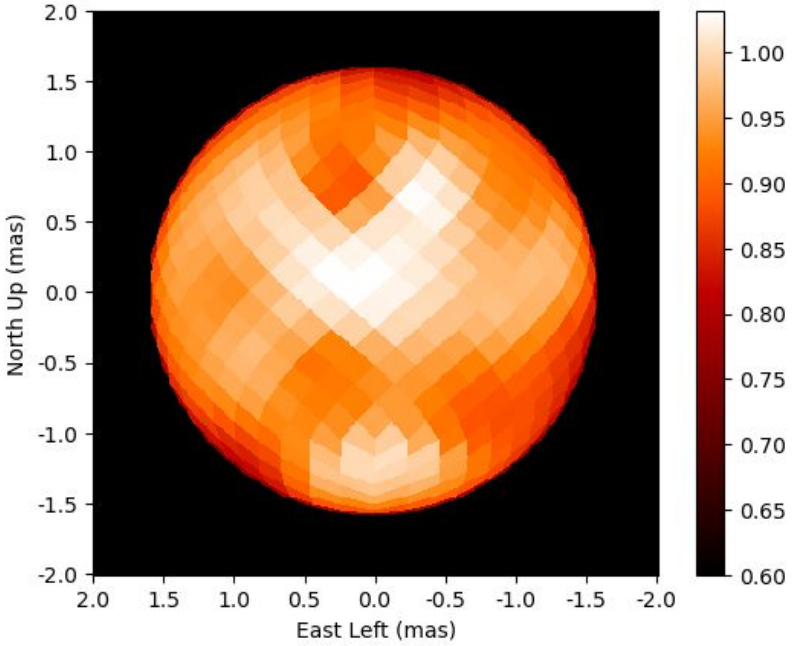


High contrast close companion orbits Polaris every 30 years



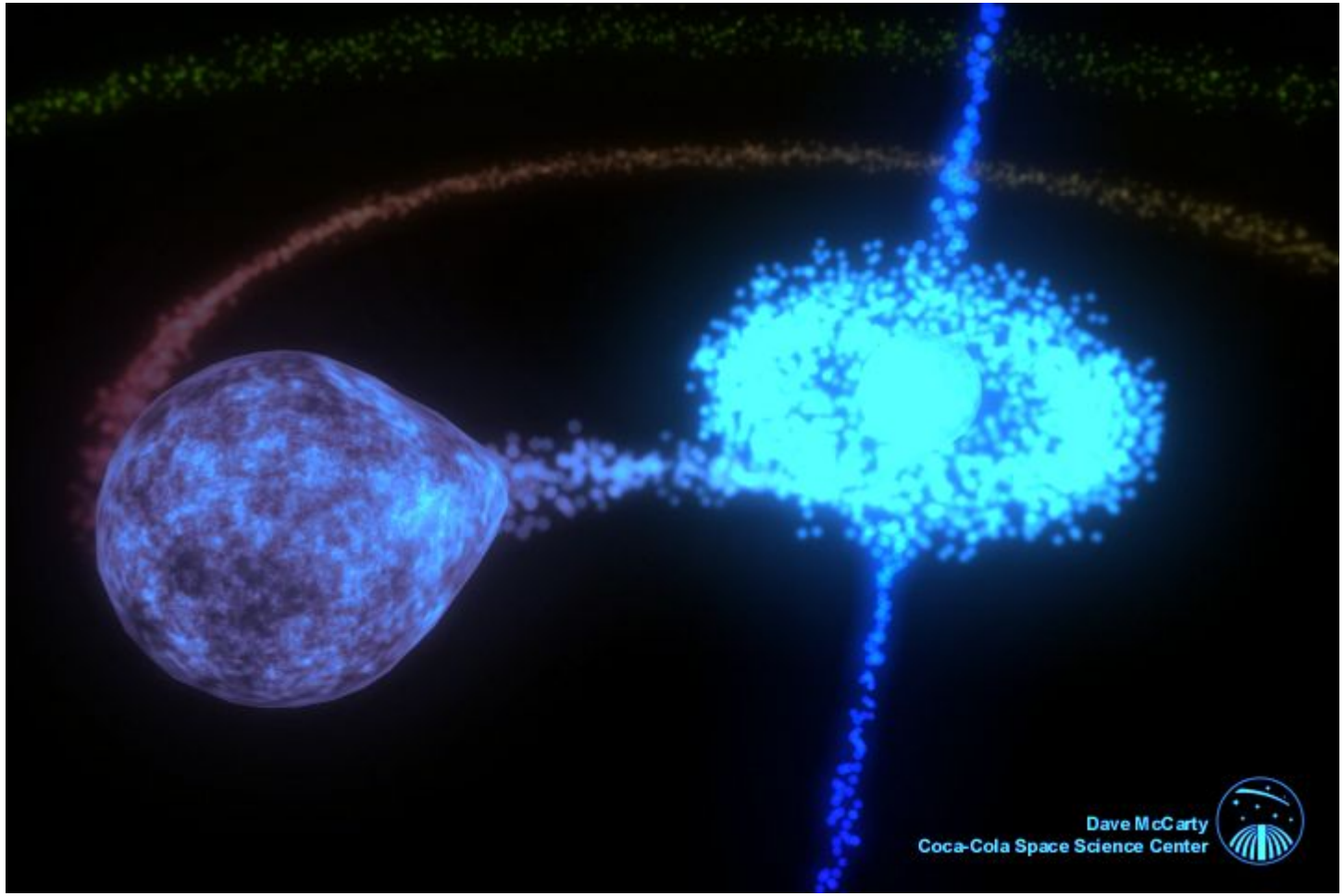
Cepheid mass 5.1 ± 0.3 M☐
More luminous than predicted

Evans et al. (2024)

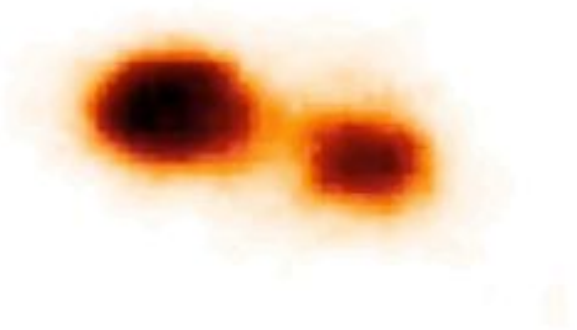


Spots on the surface of Polaris!

Mass Transfer in Interacting Binaries

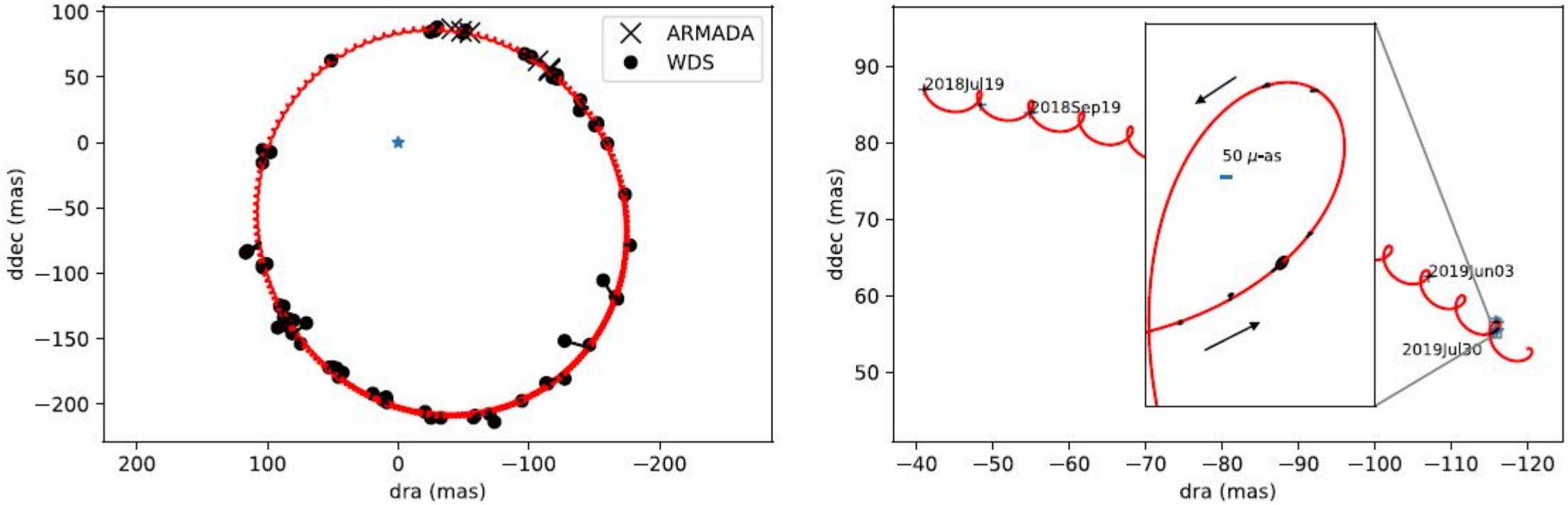


Beta Lyrae
P = 12.9 d
a = 0.87 mas



Zhao et al. (2008)

Astrometric Wobble from additional companions



Gardner et al. (2021)

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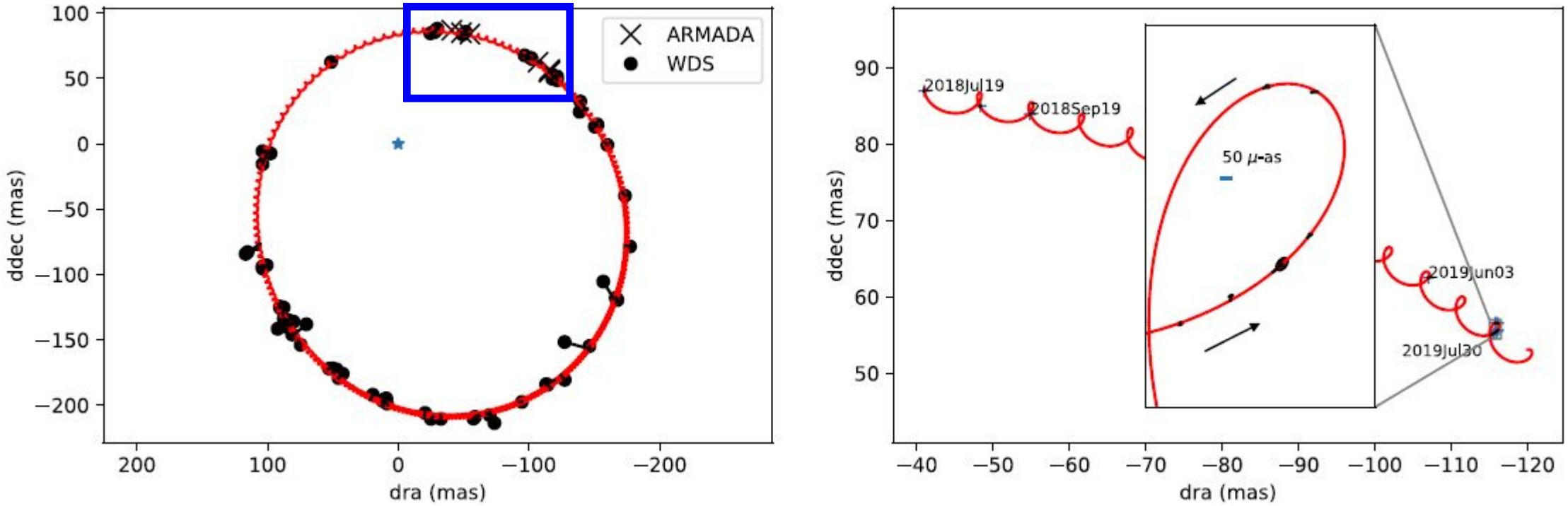
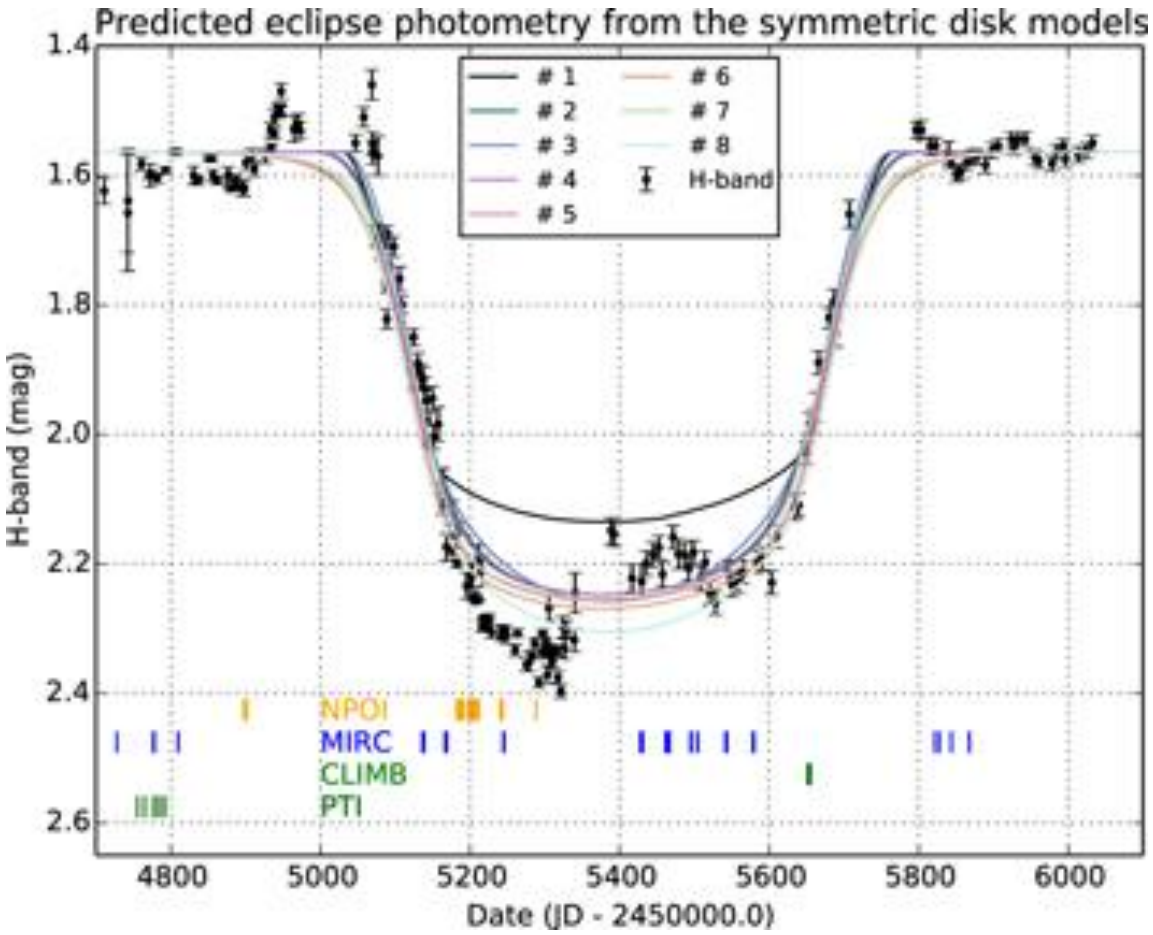


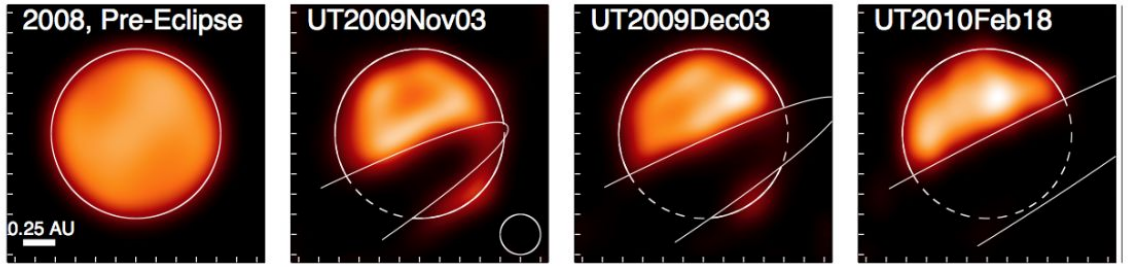
Gardner et al. (2021)

Eclipsing Binary: Epsilon Aurigae

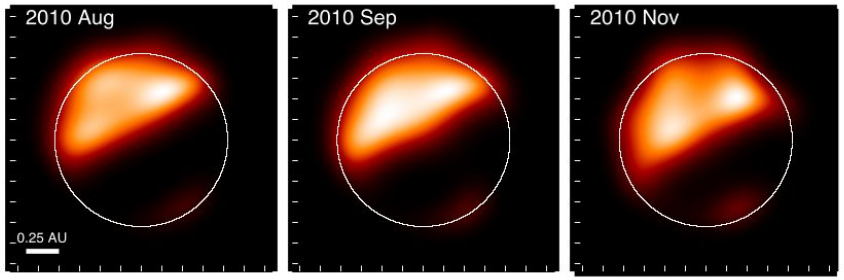


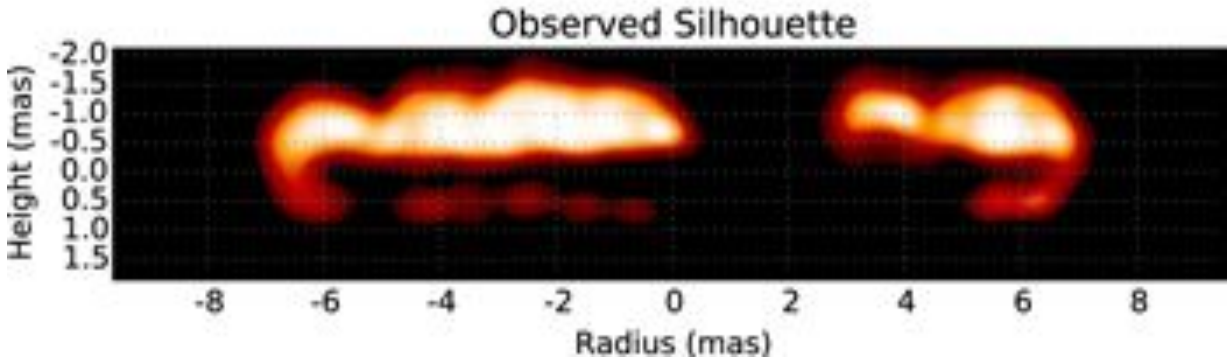
Kloppenborg et al. (2010, 2015)
AAVSO, Hopkins et al. (2012)

Eclipsing Binary: Epsilon Aurigae



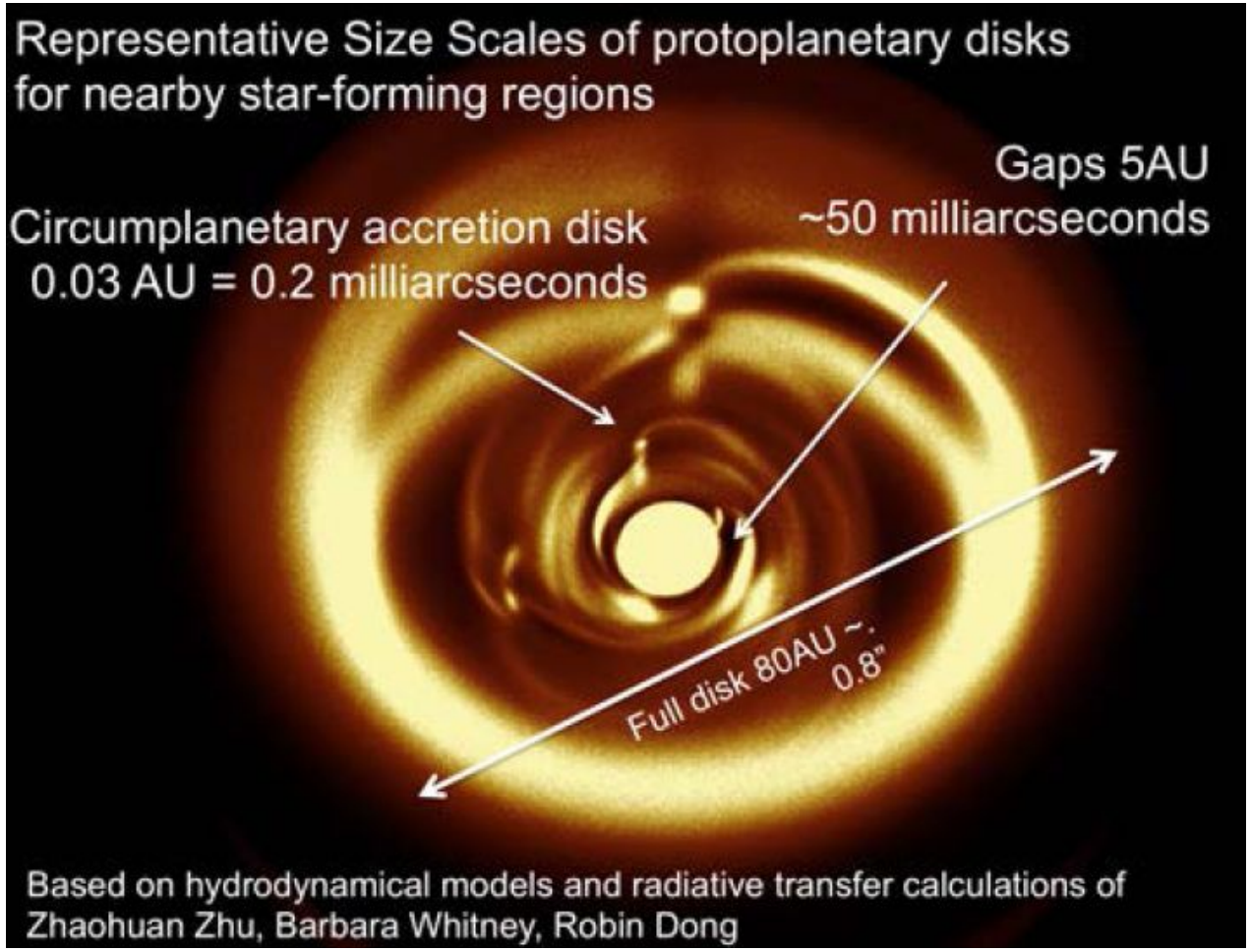
θ = 2.2 mas





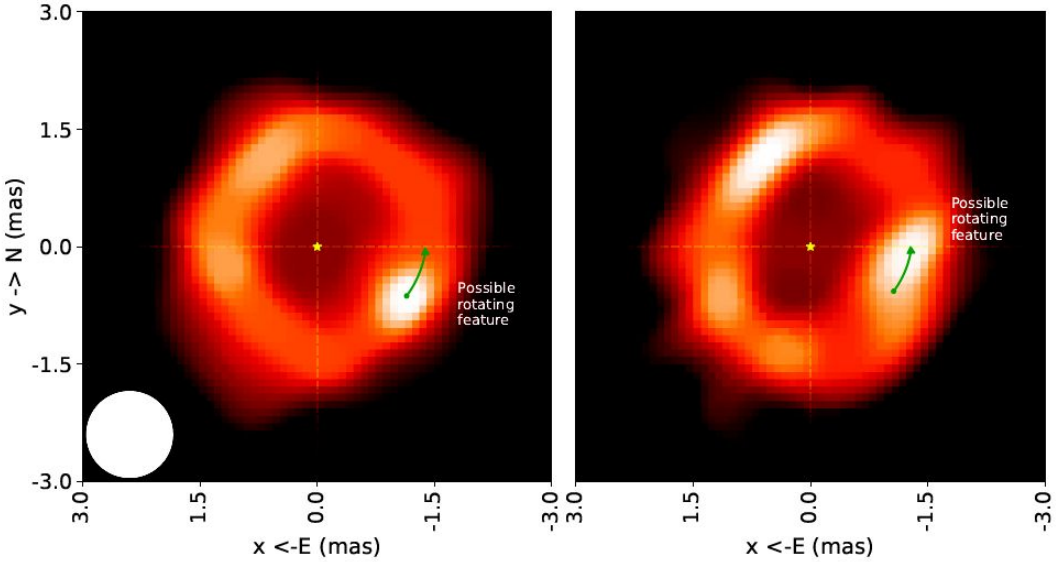
Kloppenborg et al. (2010, 2015)

Protoplanetary Disks and Planet Formation

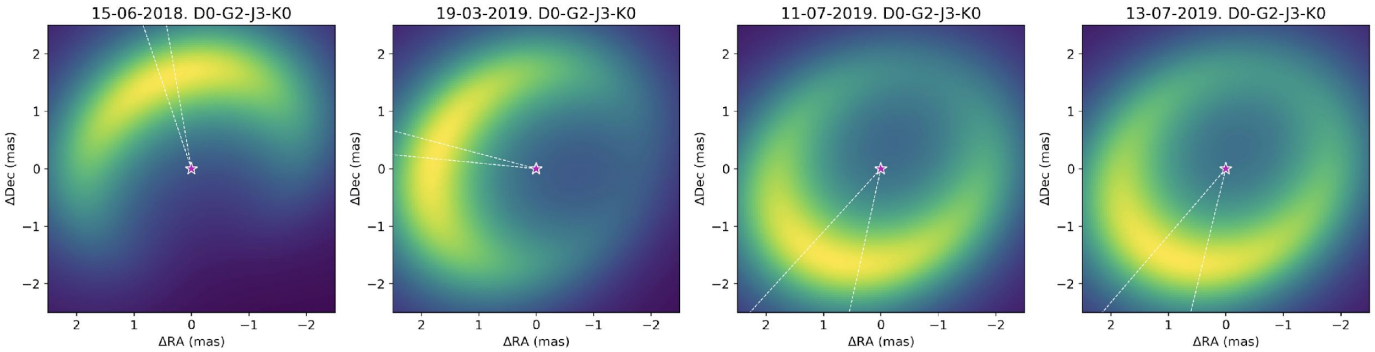


Monnier et al. (2019)

Planet Forming Disks around Young Stars

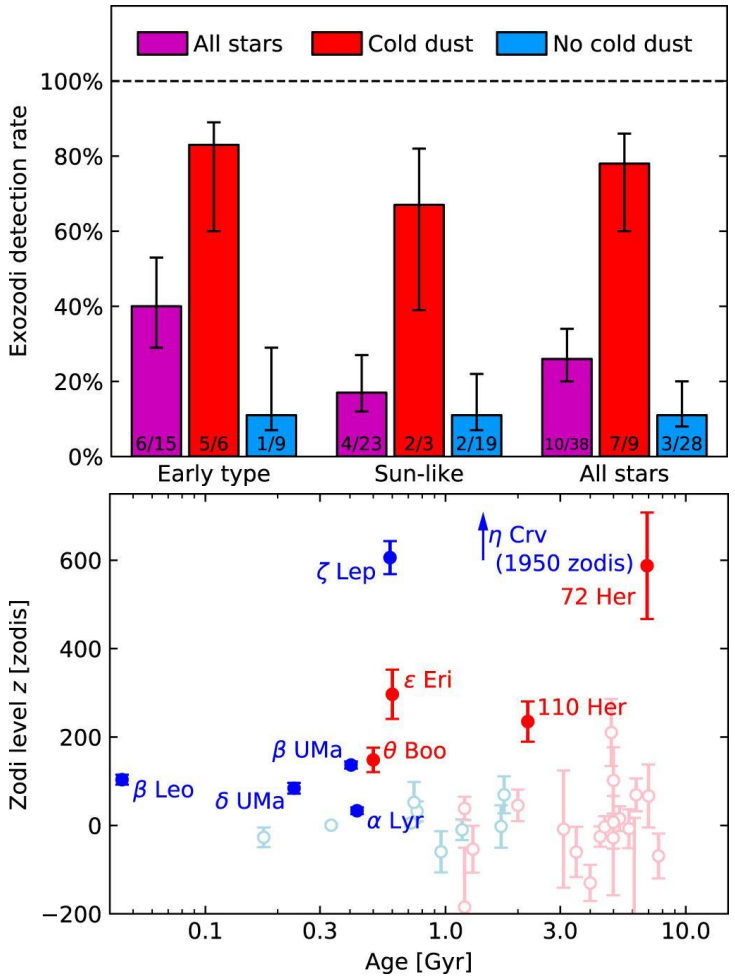


V1925 Aql – CHARA + VLTI
Ibrahim et al. (2023)



HD 98922 – VLTI GRAVITY
GRAVITY Collaboration et al. (2024)

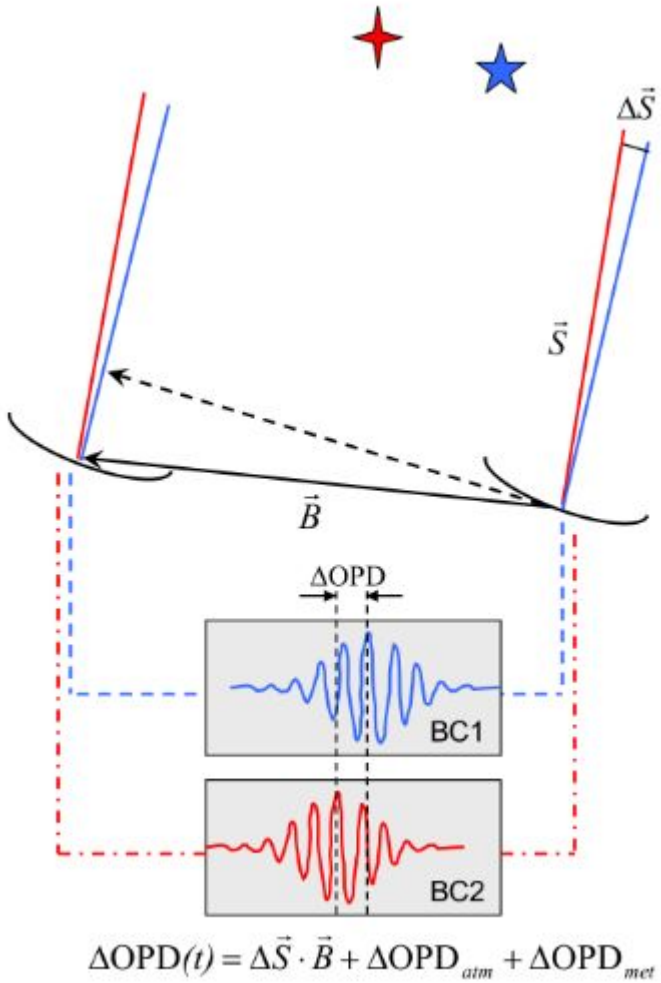
Hosts Survey for Exozodiacal Dust



- Nulling with LBTI – N-band (8-13 μm)
- Suppress starlight – probe faint circumstellar emission
- Sample of 38 stars – 10 show significant excess
- Correlation of our detections with the presence of cold dust, but not with stellar spectral type or age
- Sun-like stars have relatively low HZ dust levels
  - Not a major limitation to direct imaging of Earth-like planets

Ertel et al. (2020)

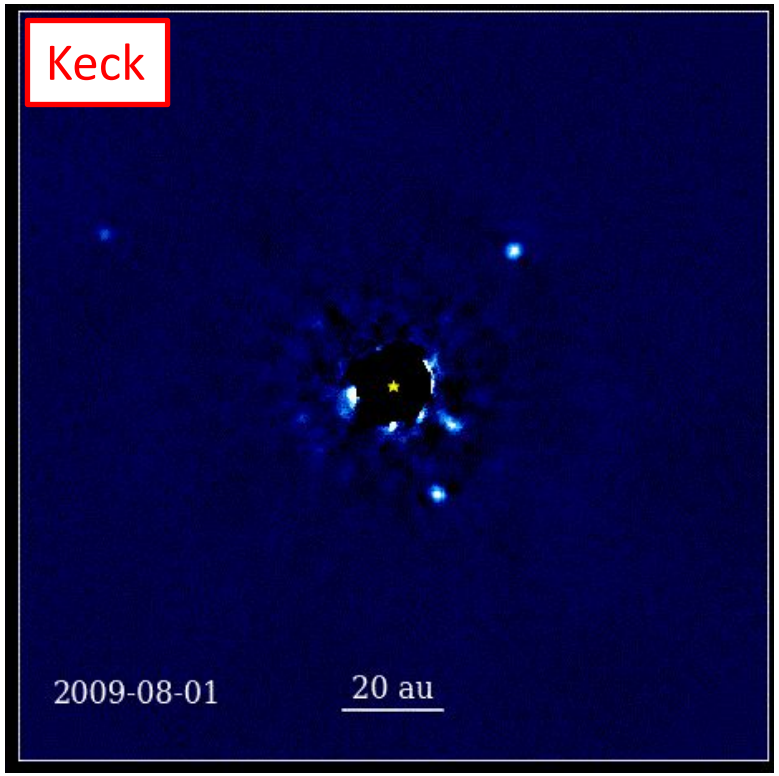
Dual Field Mode



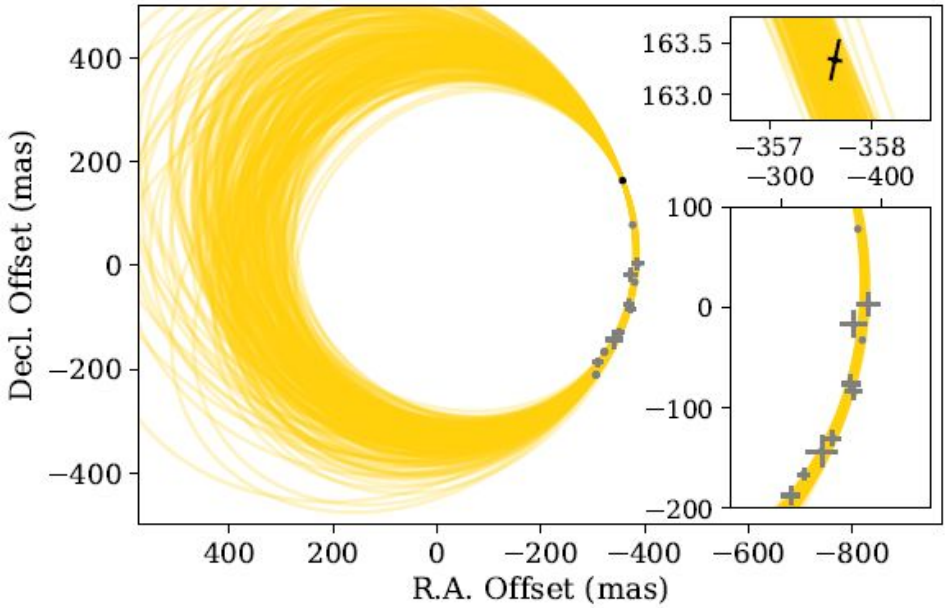
- Difference in the fringe envelope position of the two objects as seen by the beam combiners is a measure of the object separation on sky
- VLTI/GRAVITY – extends field of view out to 2’’ (UT) and 4’’ (AT)
- GRAVITY wide – out to 30’’

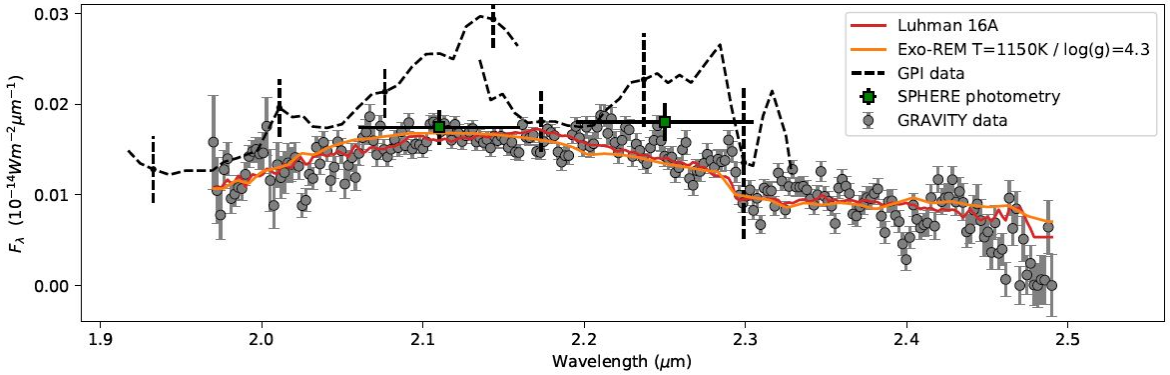
Pfuhl et al. (2021), Glindemann et al. (2003)

Exoplanet Astrometry with VLTI/GRAVITY



Credit: Jason Wang (Northwestern)/William Thompson (UVic)/Christian Marois (NRC Herzberg)/Quinn Konopacky (UCSD)

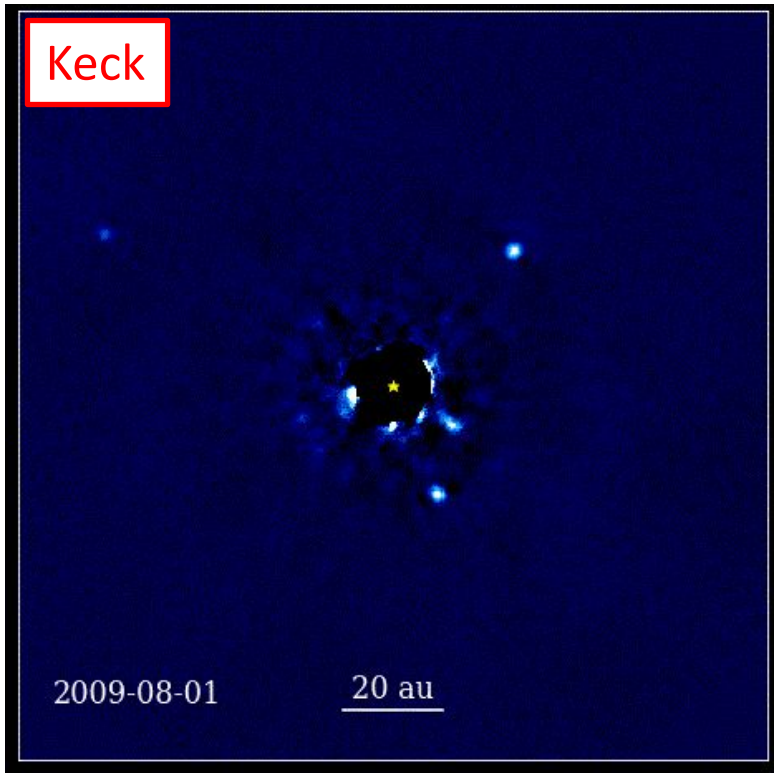




- Keplerian orbit of HR 8799 e.
- GRAVITY K band spectrum of HR8799 e (R ~ 500)

GRAVITY Collaboration et al. (2018b)

Exoplanet Astrometry with VLTI/GRAVITY



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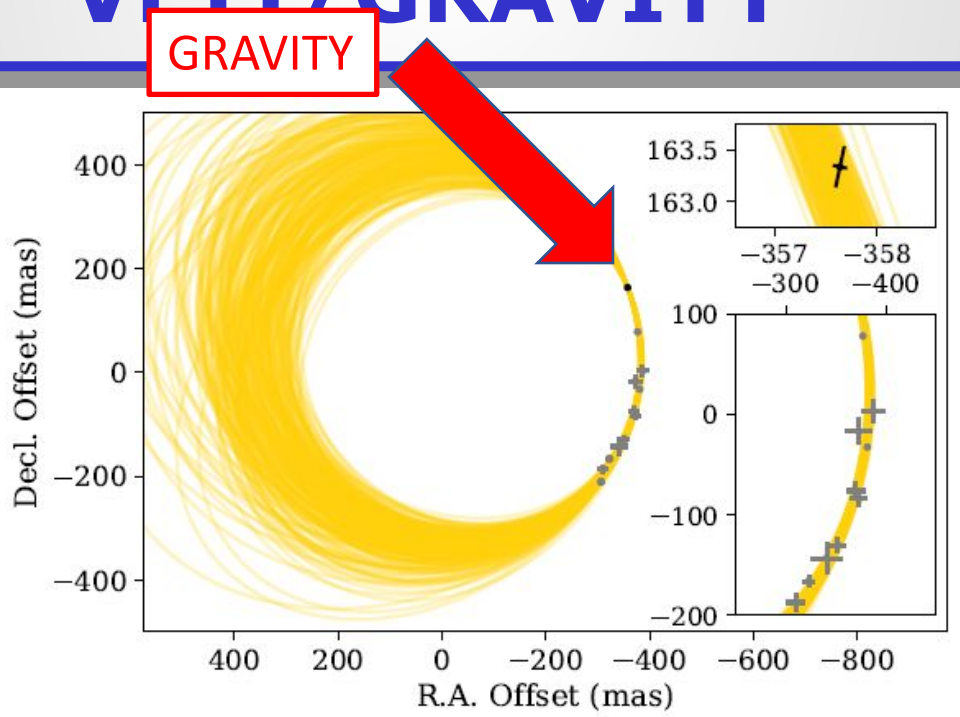

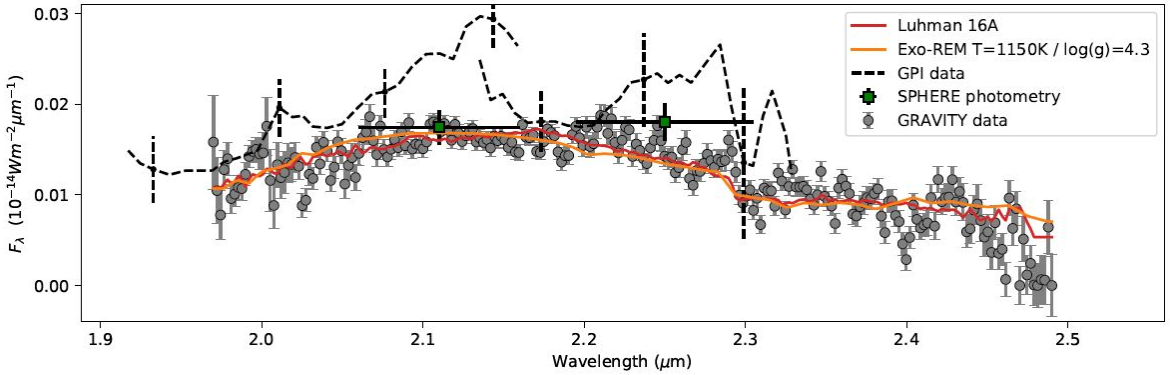

- Keplerian orbit of HR 8799 e.
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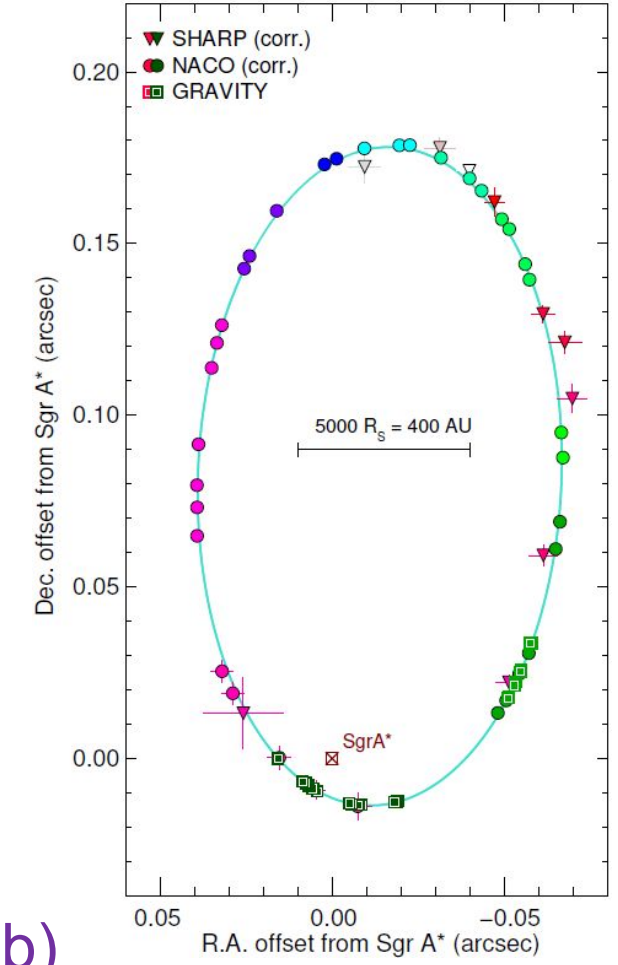
GRAVITY Collaboration et al. (2018b)

VLTI Gravity: Galactic Center

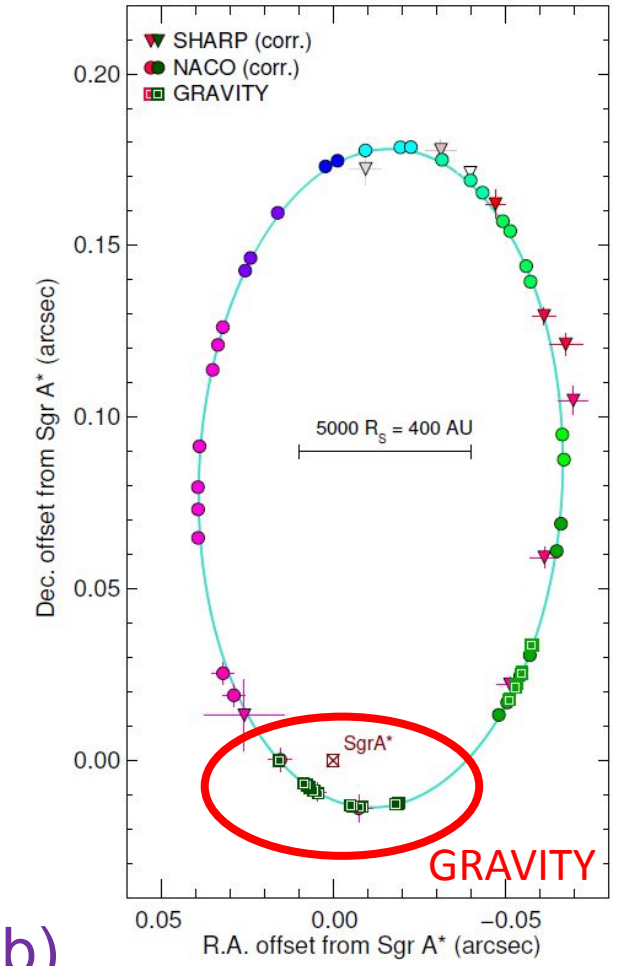
50 mas



GRAVITY Collaboration et al. (2018a, 2022a, 2022b)

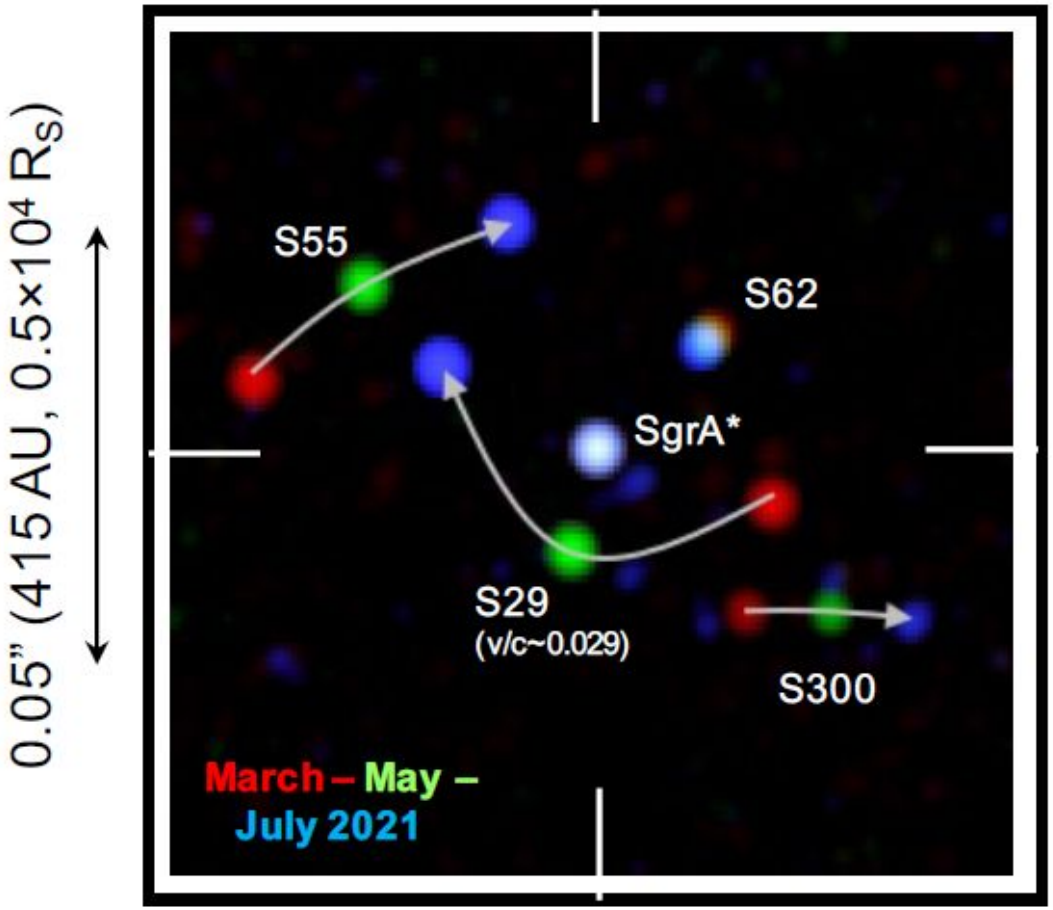
VLTI Gravity: Galactic Center

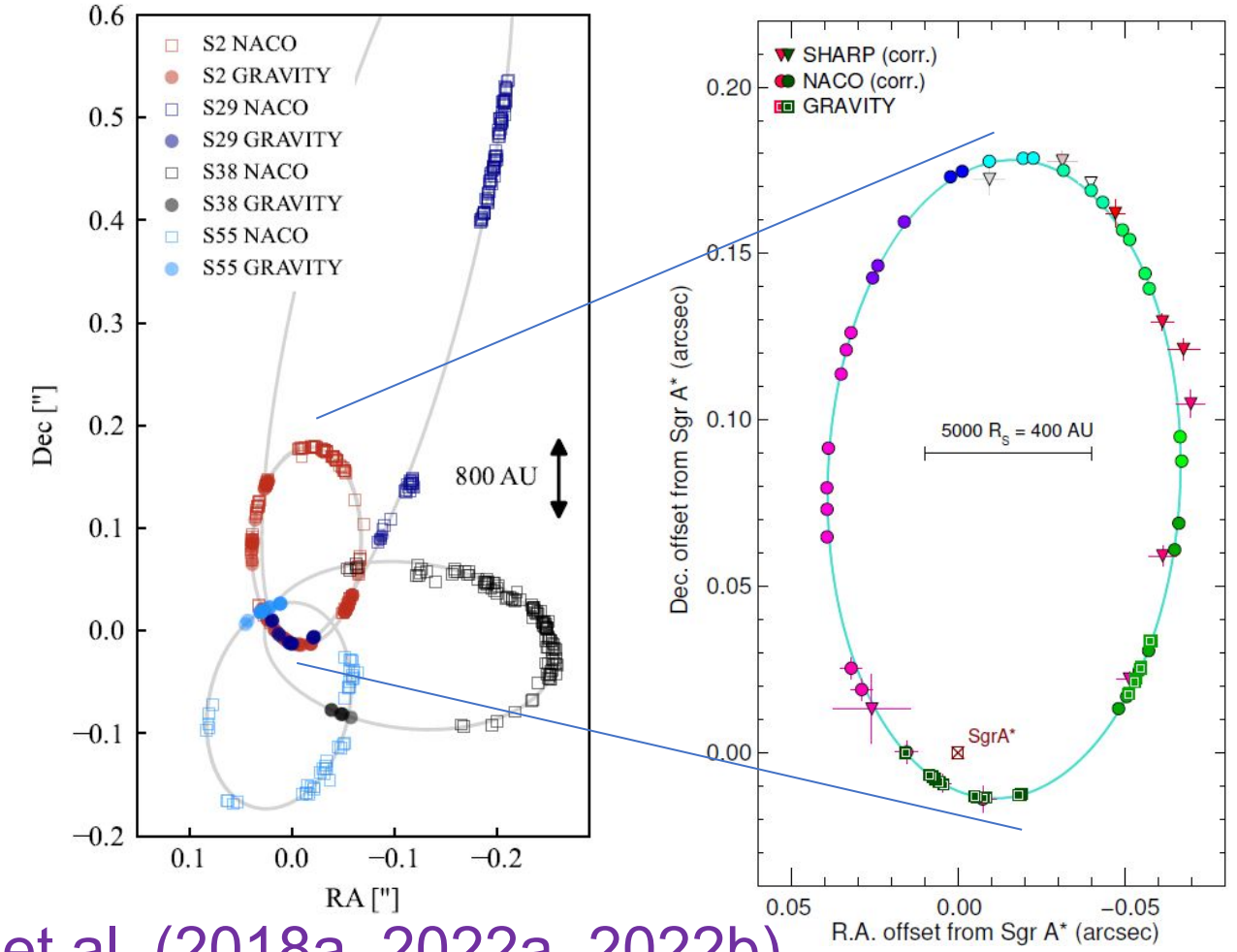
50 mas



GRAVITY Collaboration et al. (2018a, 2022a, 2022b)

VLTI Gravity: Galactic Center

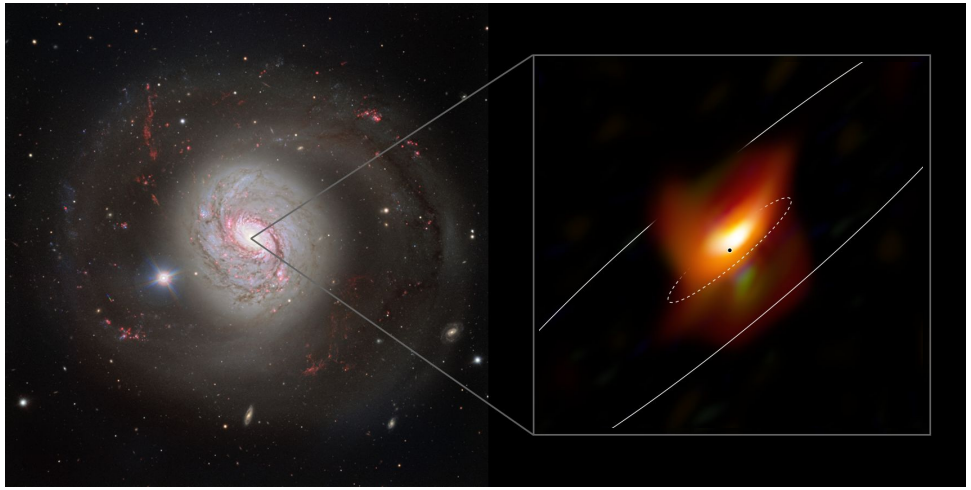




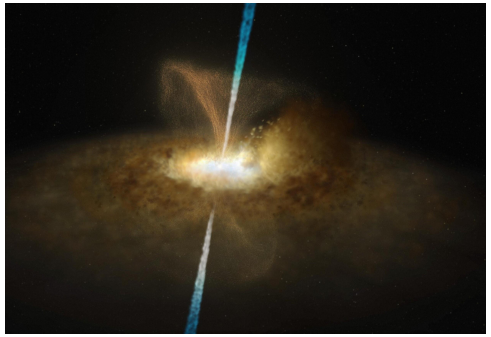
GRAVITY Collaboration et al. (2018a, 2022a, 2022b)

Active Galactic Nuclei
Central Supermassive Black Hole

Type 2 AGN – Edge On

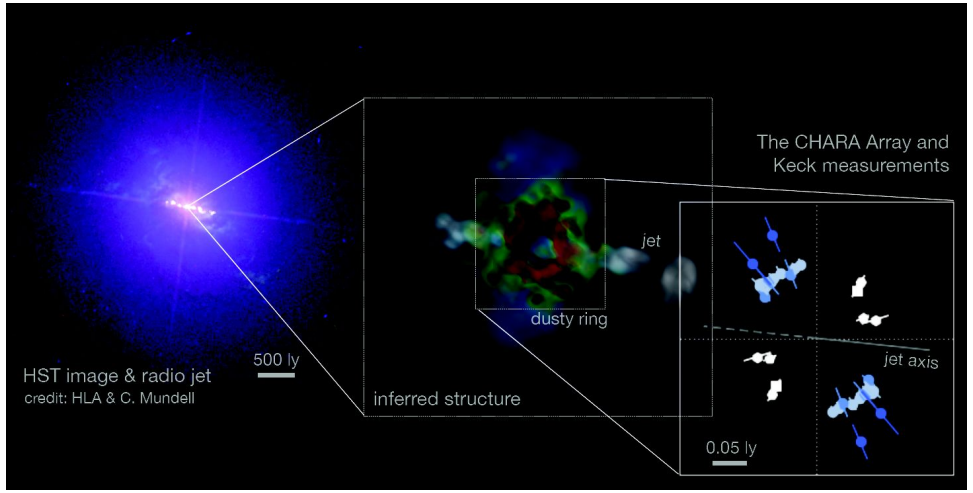


M77 – NGC 1068: VLTI MATISSE
Dusty disk obscures dust sublimation ring



Gámez-Rosas et al. (2022)
Leftley et a. (2024): 2-10 μm
https://www.eso.org/public/news/eso2203/

Type 1 AGN – Face On

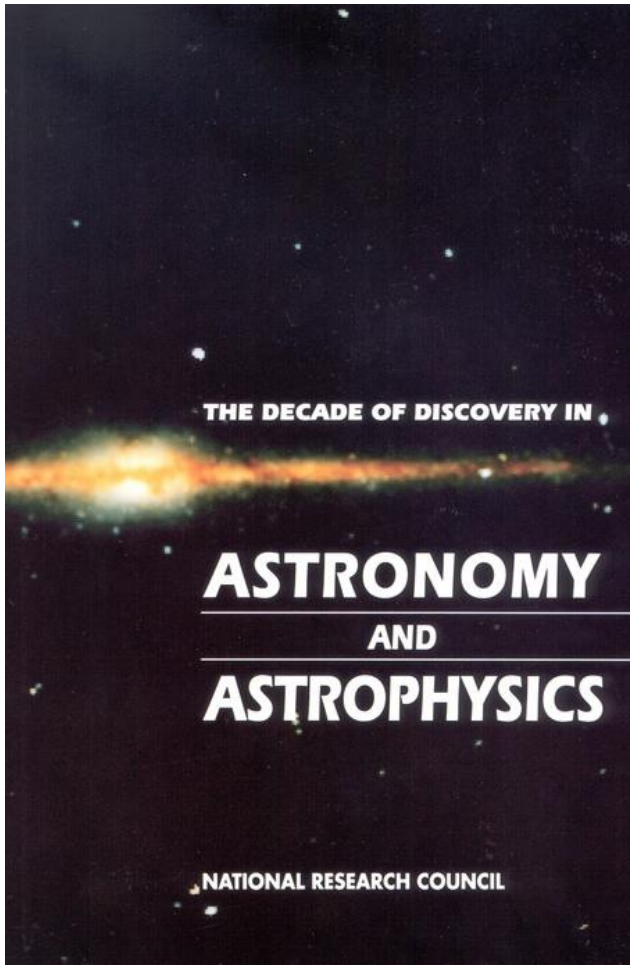


NGC 4151: CHARA + Keck
Innermost dusty ring perpendicular to jet
Kishimoto et al. (2022)

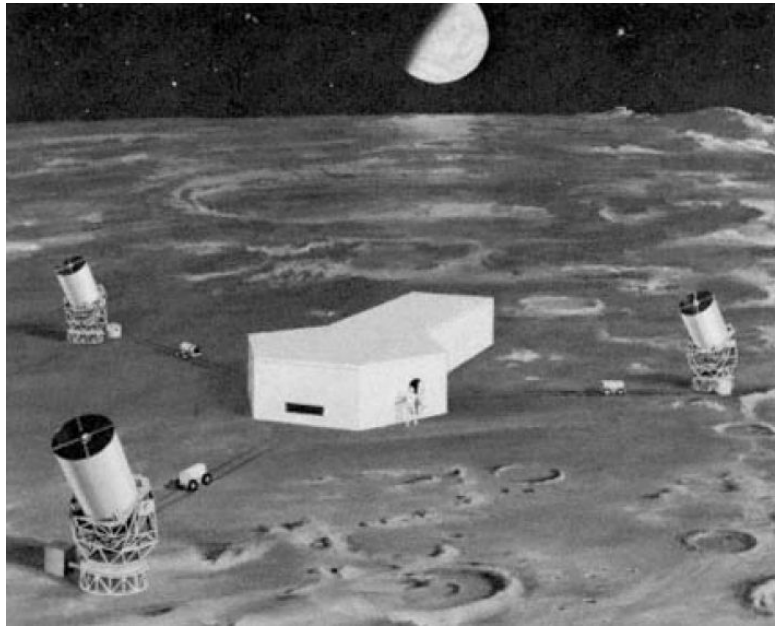
A look back and forward:

Past and Future Priorities for Optical Long Baseline Interferometry in Astronomy Decadal Surveys

Decadal Survey for the 1990s

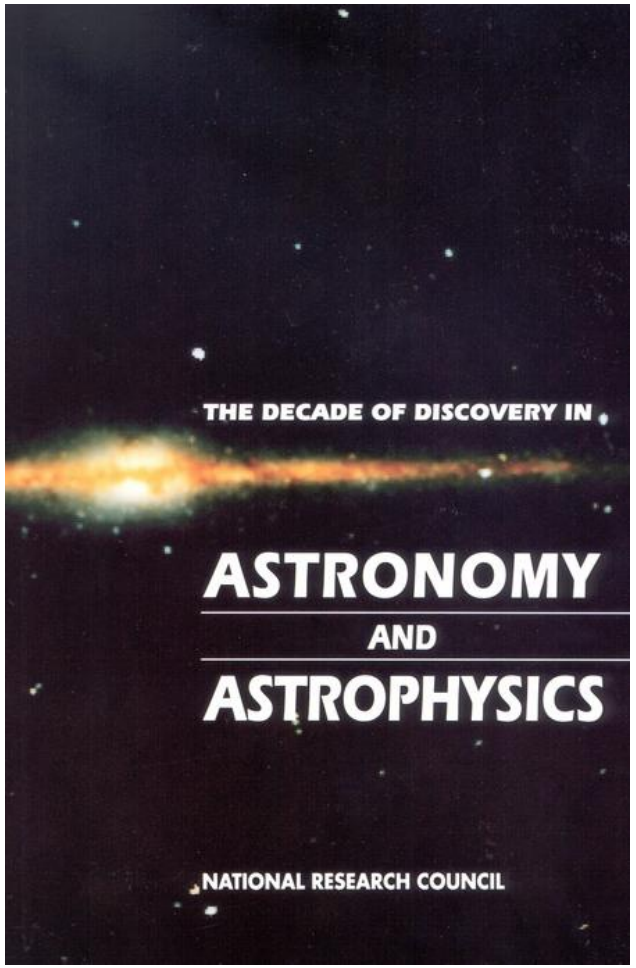


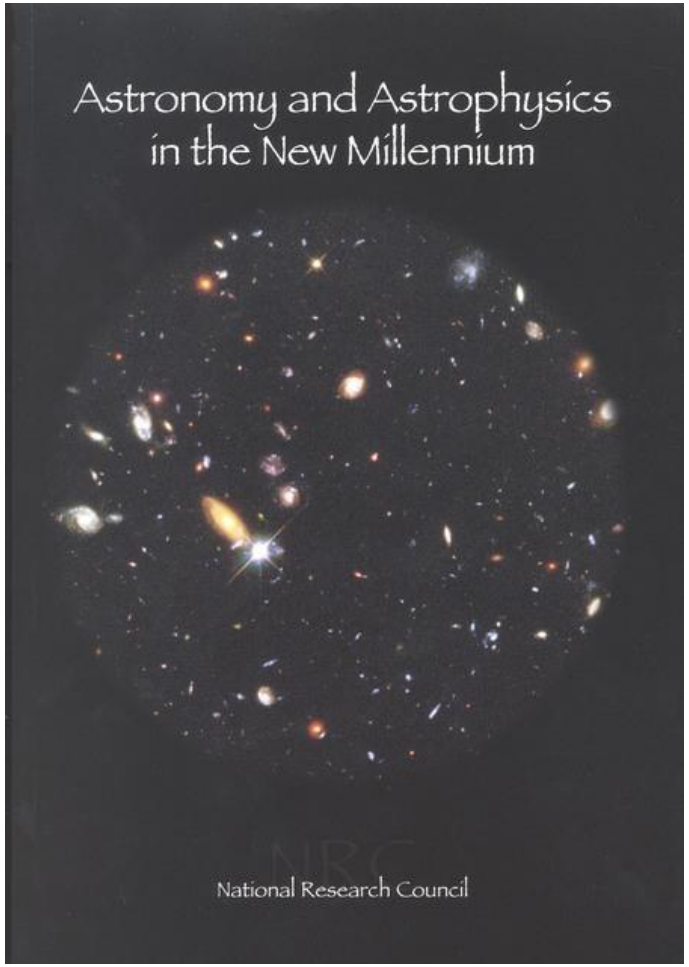
- Ground-based Priorities – Moderate Programs
  - Adaptive Optics
  - Interferometry
- "The Moon as an Observatory Site"
  - High sensitivity
  - Kilometer-sized baselines
  - No terrestrial atmosphere
  - No spacecraft positioning



Artist Conception of Lunar Interferometer in 1990 Decadal Survey

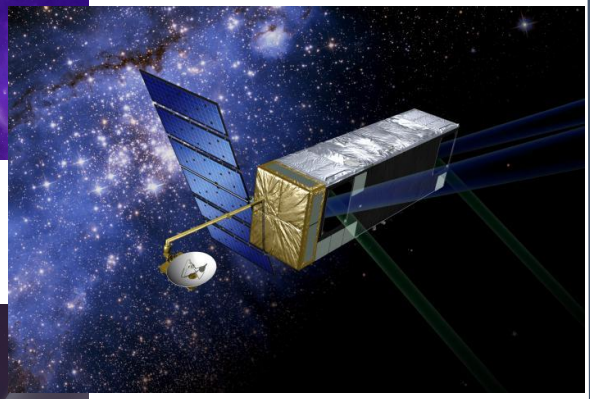
Astro 1990+2000 Decadal Surveys
Space-based Priorities

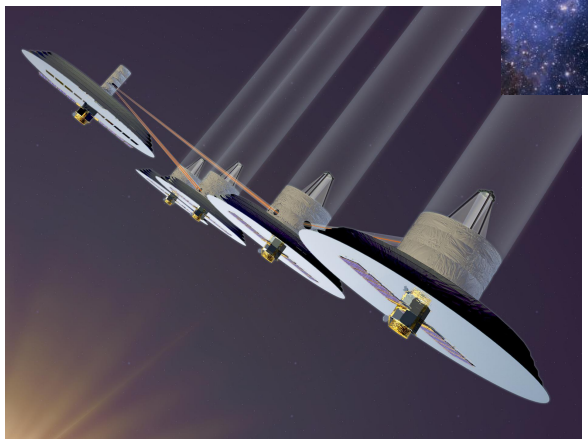




Space Interferometry Mission (SIM)

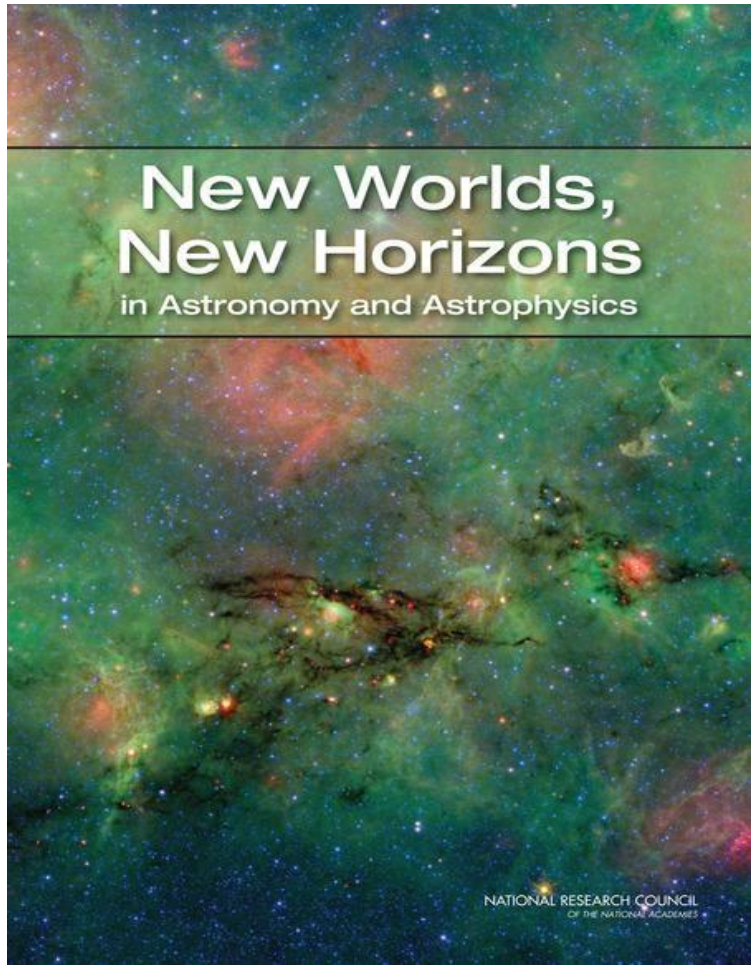
SIM Lite





Terrestrial Planet Finder (TPF)

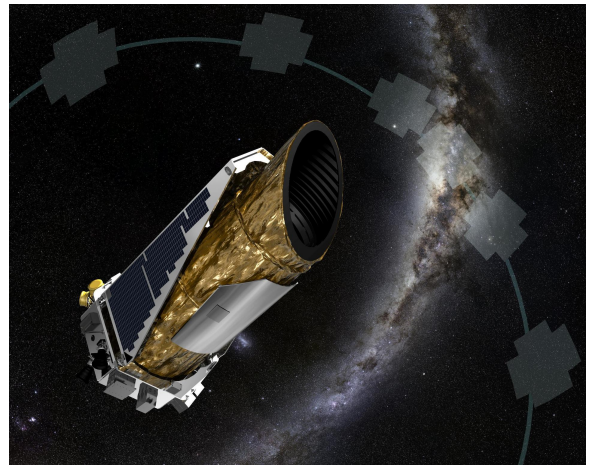
Astro2010 Decadal Survey



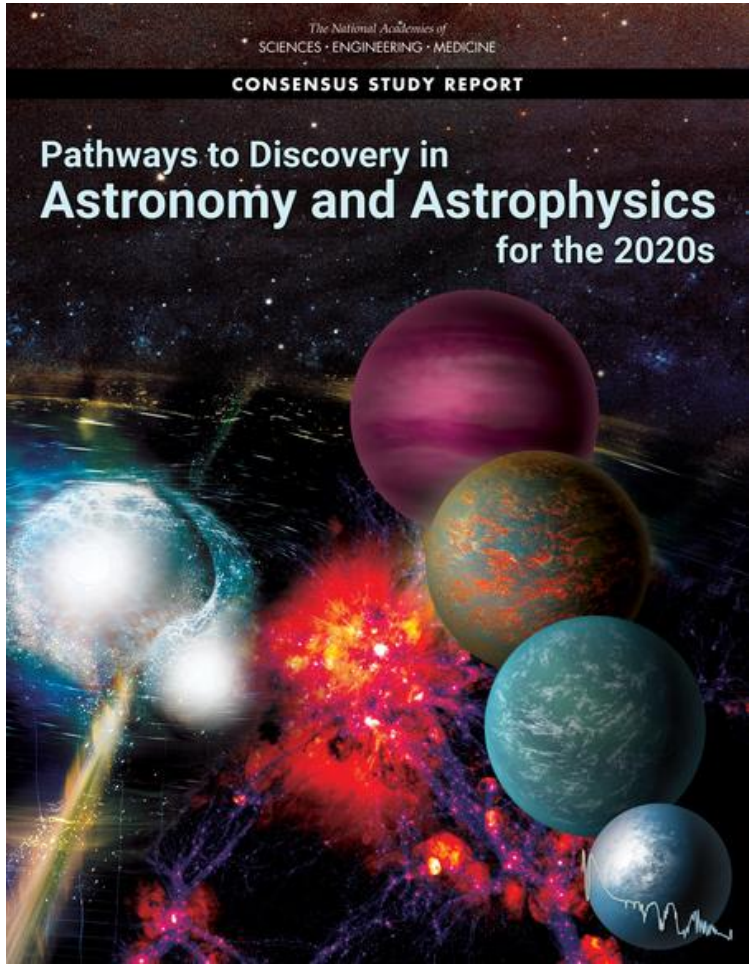
- "In considering possible exoplanet missions for the next decade, the committee gave serious consideration to SIMLite but decided against recommending it."
  - Large cost ($1.9 billion)
  - Long time to launch
  - Success of Kepler – planet detection efficiency

SIM Lite

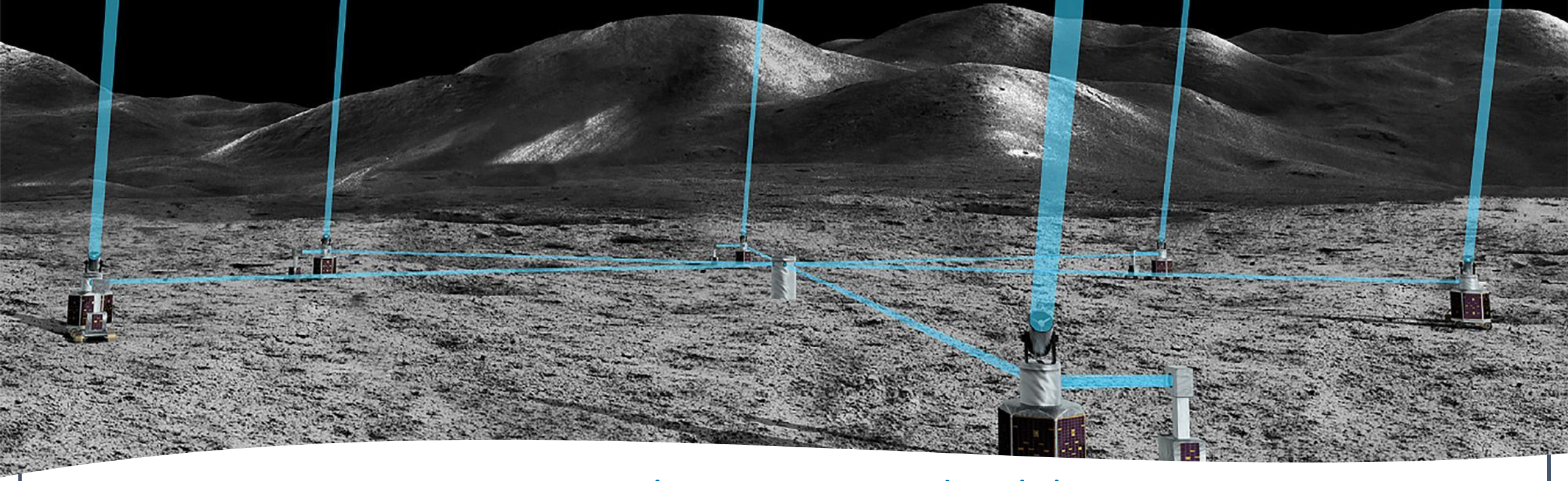
Kepler



Astro2020 Decadal Survey



- Search For Life on Exoplanets
  - Mid-IR interferometry: temperature, radii, and atmospheric features of planets around FGKM stars
- Stars, the Sun, and Stellar Populations
  - Maintaining and expanding the leading U.S. capabilities in optical long-baseline interferometry, such as the CHARA Array, NPOI and MROI.
  - Future Needs: 1 km baselines, 2–3 m aperture telescopes, 0.9–1 μm instrumentation
  - Characterizing full stellar and brown dwarf radii
- Optical/IR Observations from the Ground
  - NSF funding realities – unlikely to support all 3
  - US Interferometry community: formulate plan for collective goal



Opportunities for milli- to micro-arcsecond spatial resolution

- High sensitivity and stability
- Radii of the coolest stars and brown dwarfs
- Close companions around planet hosting stars
- Radii and inner regions of young stellar objects
- Sizes of newborn stars
- Active galactic Nuclei