Dual-Star Interferometry at the CHARA Array

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CHARA Science Meeting 2025, Apr 28-30, Nice (France)

CHARA Sensitivity

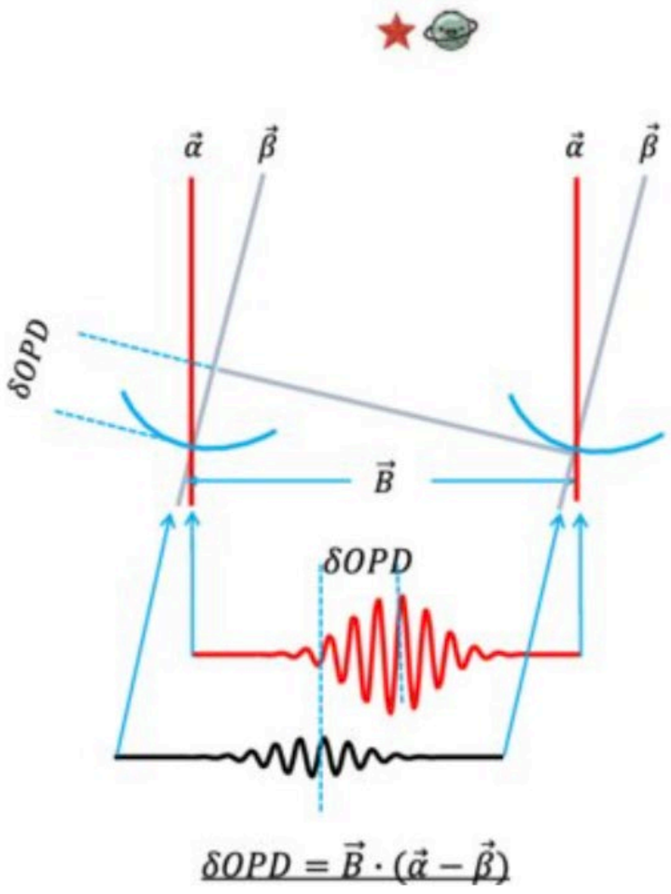
- Current sensitivity: H/K ≈ 8–9 magnitudes
- Fringe Tracker $\mathrm{SNR} \propto \sqrt{t}$ (t = exposure)
- Current coherent integration time at CHARA: 20–40 ms at H-band
- Although, there are several ways to improve the sensitivity (increase D and good AO), taking long exposures is one of the easy ways to improve sensitivity
- Example: Increase exposure from 20 ms → 2 s (×100 longer)
- Expected sensitivity gain (assuming no thermal noise): Δmag=$2.5\log_{10}(\sqrt{100})$=2.5 mag

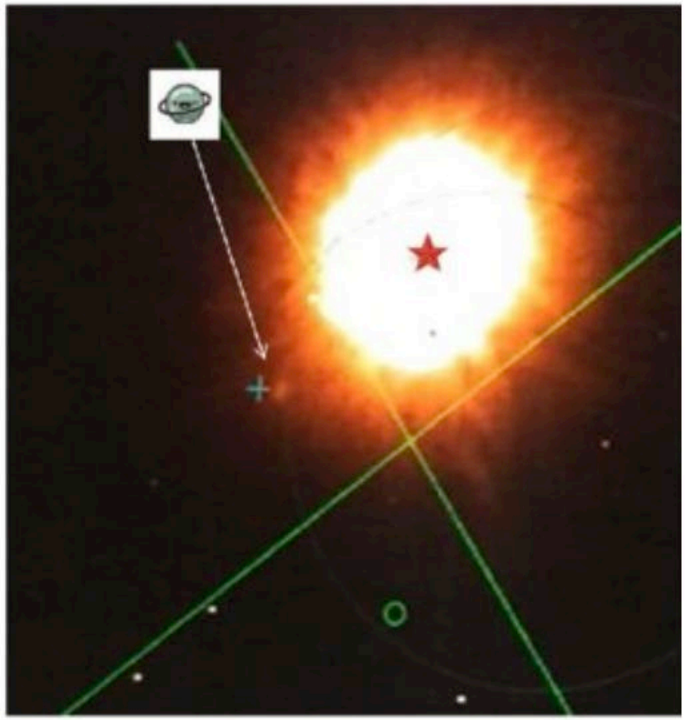
GRAVITY on ATs:

Single-field on-axis = 9 mag

Dual-field off-axis = 16 mag

Dual Field Interferometry

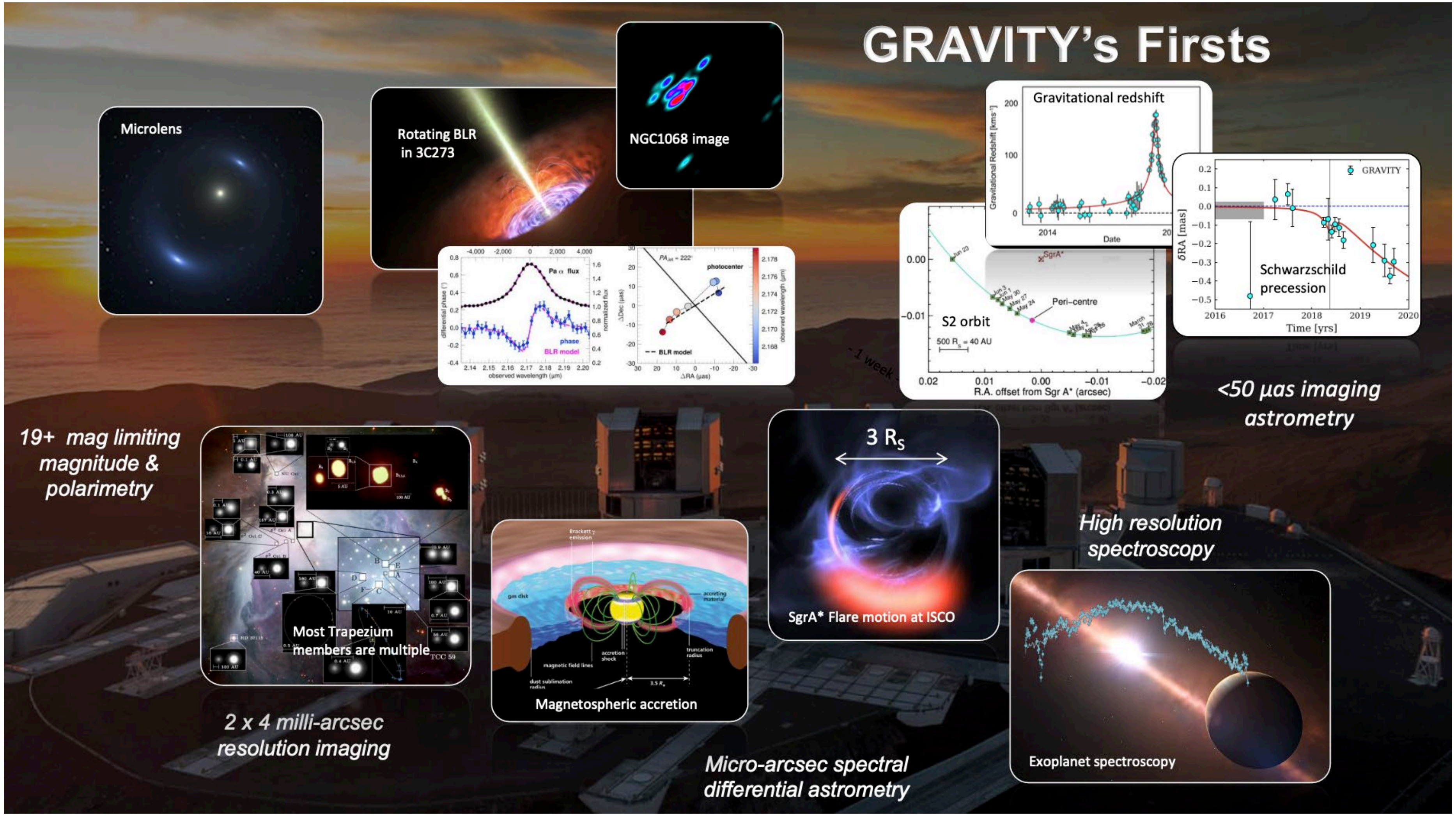




- Track fringes using bright star
- Long exposures on faint star on science beam combiner
- High contrast companion detection:
  (i) Single mode spatial filtering
  (ii) Coherent flux of companion
- Astrometry

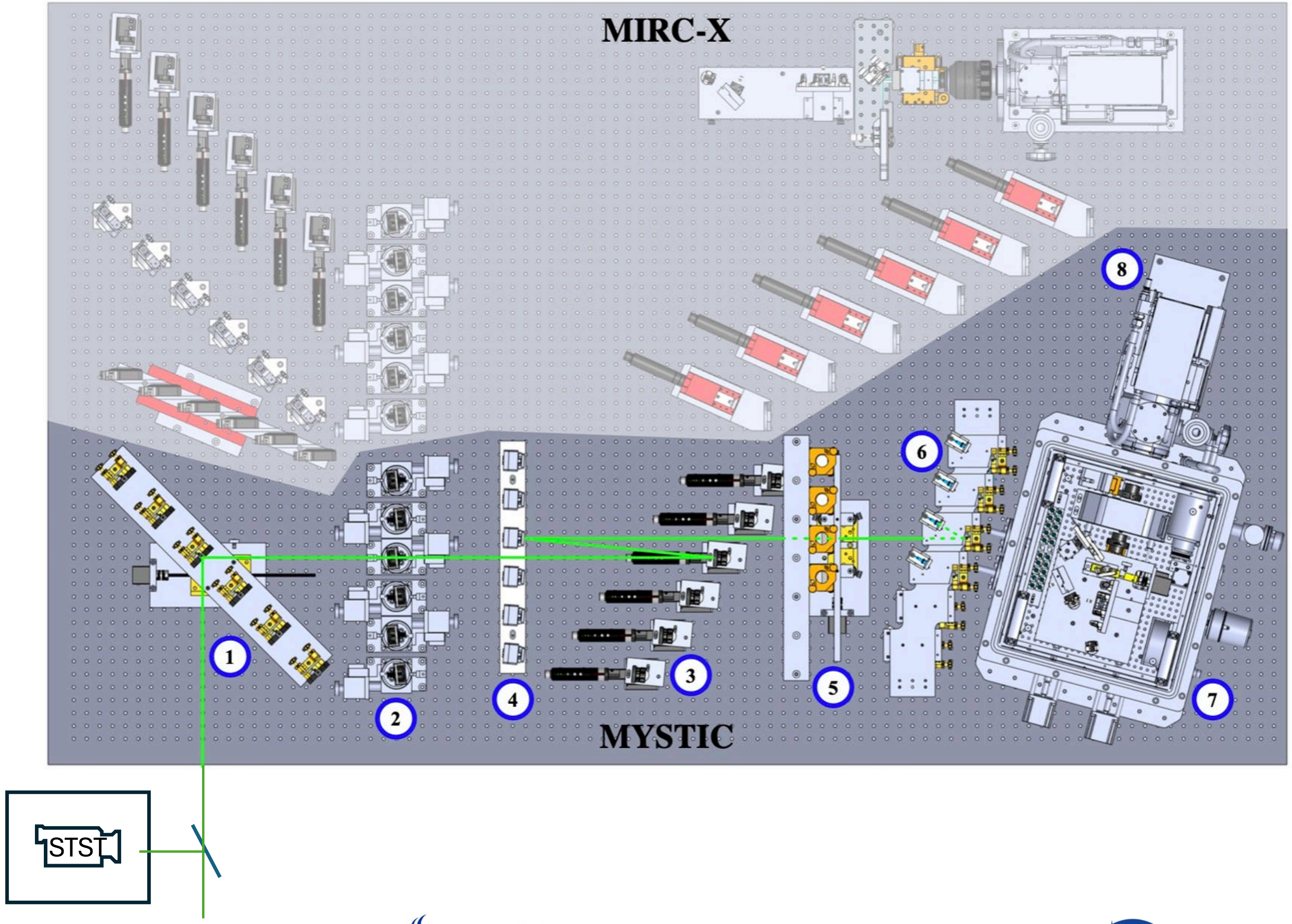
Credit: Lacour 2023

GRAVITY Success

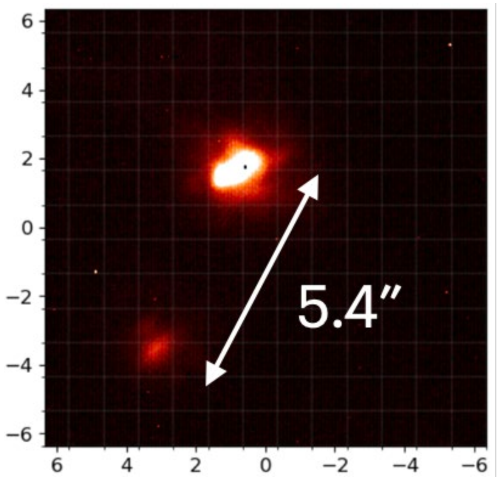


Credit: Frank Eisenhauer

1. Implementation at CHARA: FT and SC

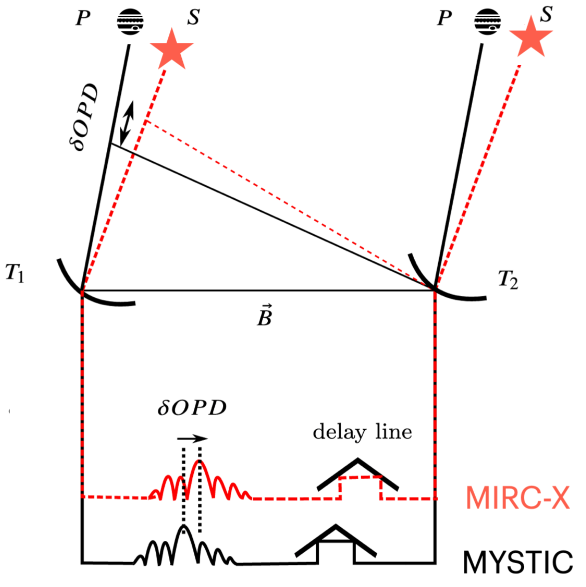


- GRAVITY FT = MIRC-X
- GRAVITY SC = MYSTIC
- GRAVITY acquisition camera = Six Telescope Star Tracker (STST)

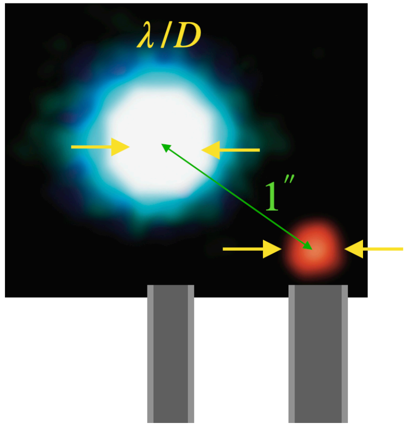


STST acquisition

2. Implementation at CHARA: double star injection into fibers

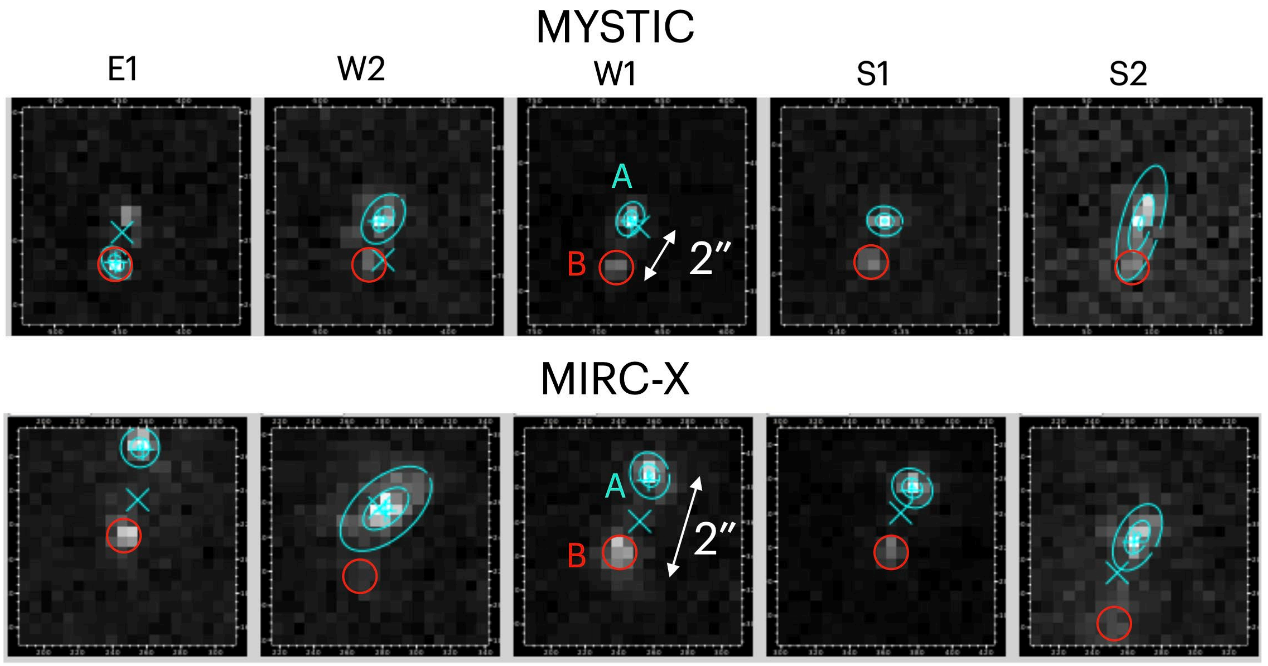


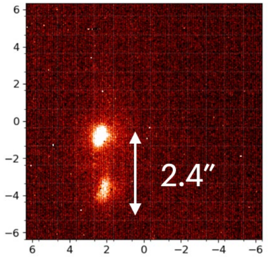
$$\delta OPD = \vec{B}\,.(\vec{S} - \vec{P})$$



MIRC-X Fiber size 340 mas at H-band

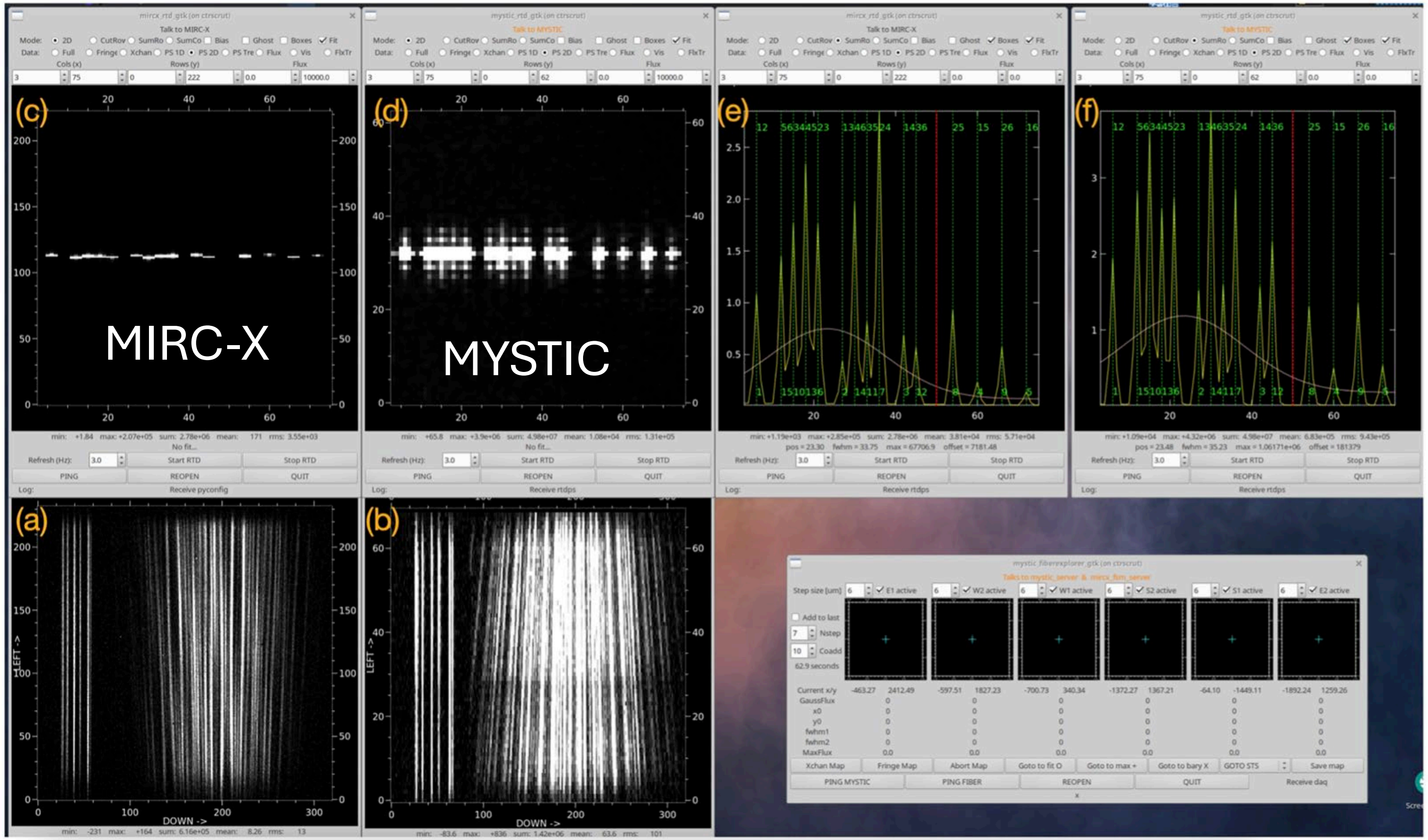
MYSTIC Fiber size 450 mas at K-band

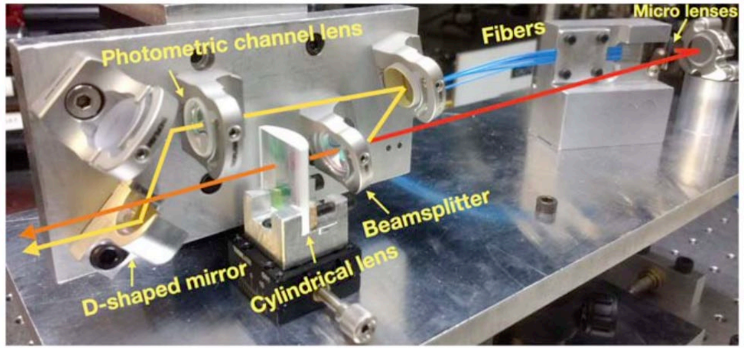




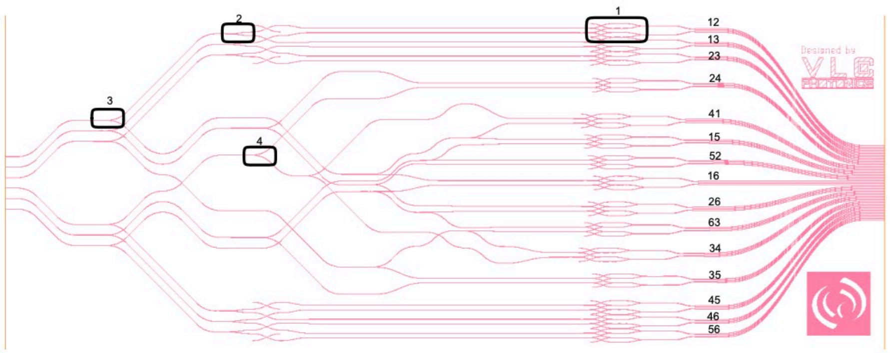
Using STST, we select stars and inject into fibers of MIRC-X and MYSTIC

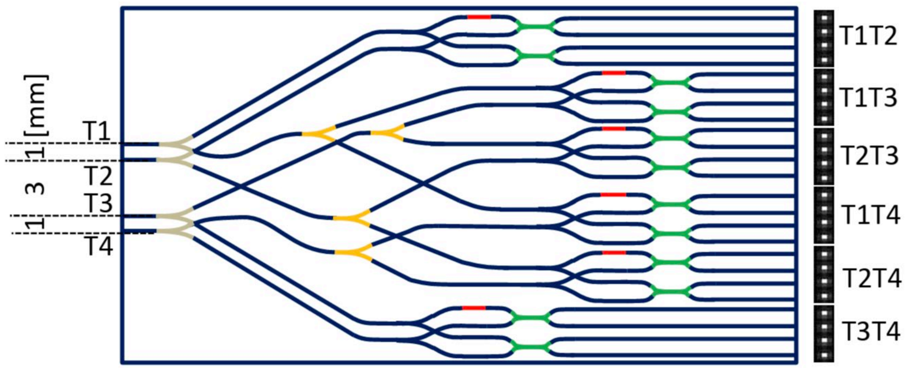
1. MIRC-X and MYSTIC provide: All-in-one or ABCD combination

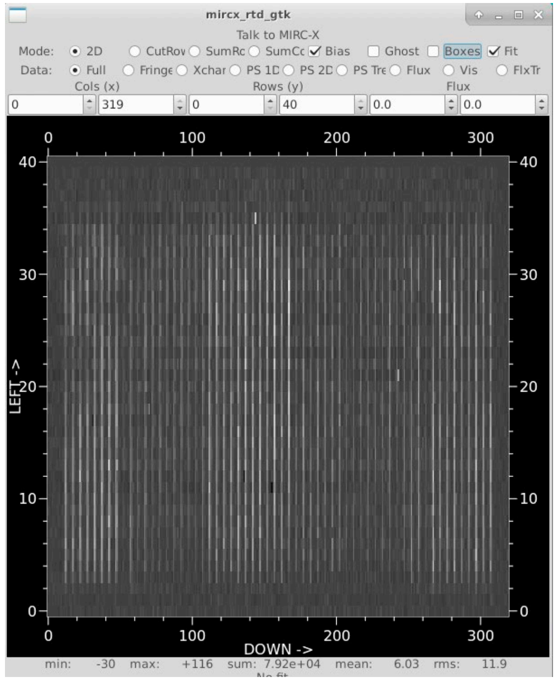




2: MIRC-X and MYSTIC provide: All-in-one or ABCD combination



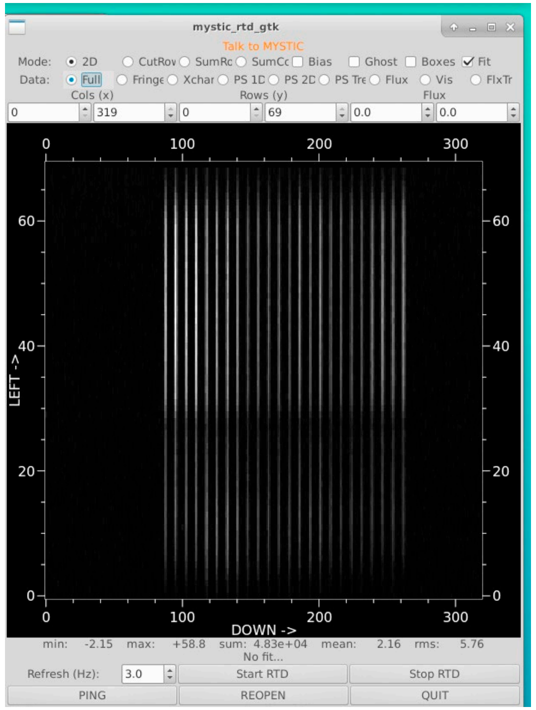




MIRC-X:

6 tel ABCD chip

(SPICA-FT)

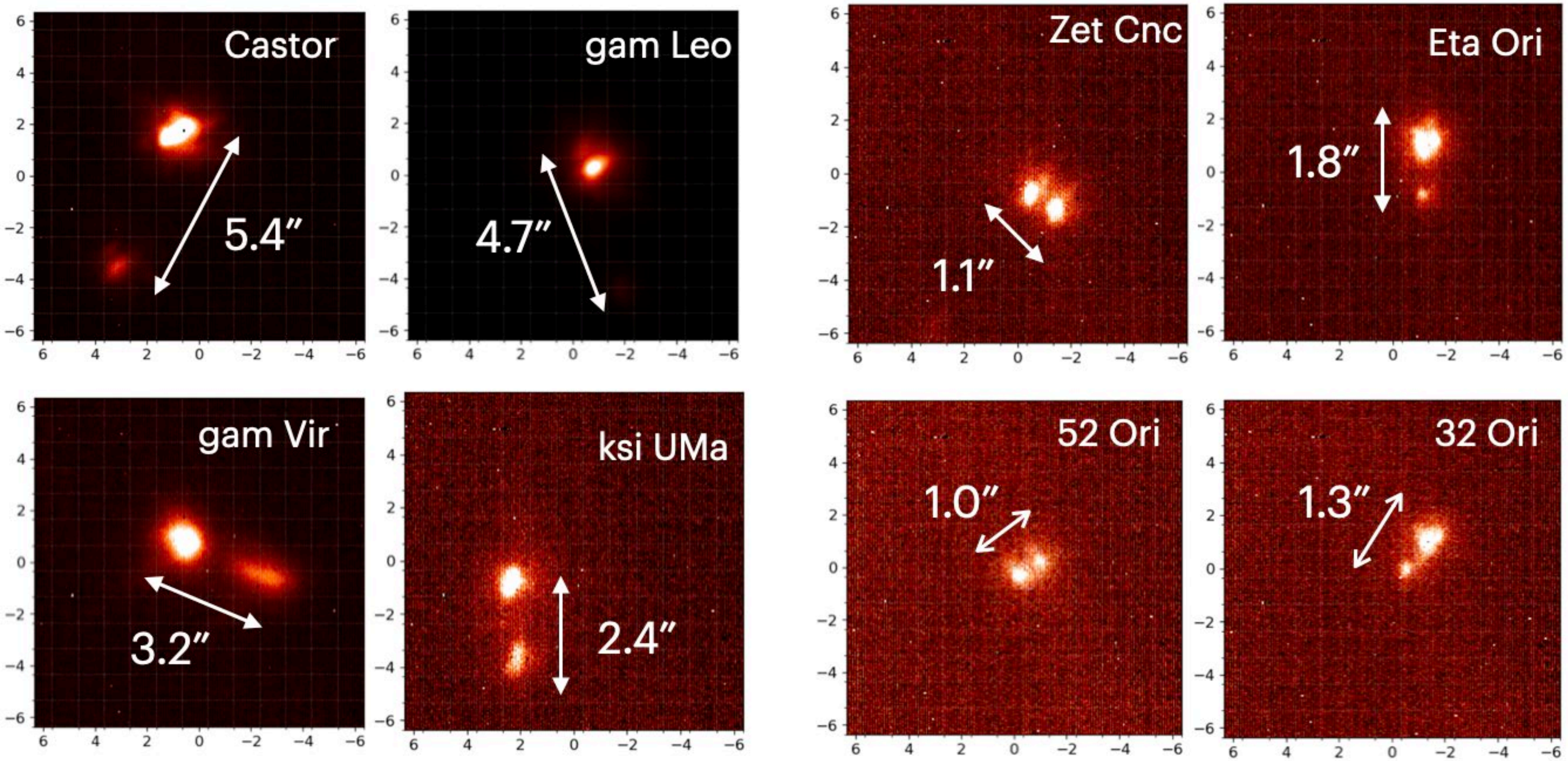


MYSTIC:

GRAVITY

Spare chip

CHARA Dual Star Field of View



Seen on the Six Telescope Star Tracker in the lab, next to MIRC-X and MYSTIC

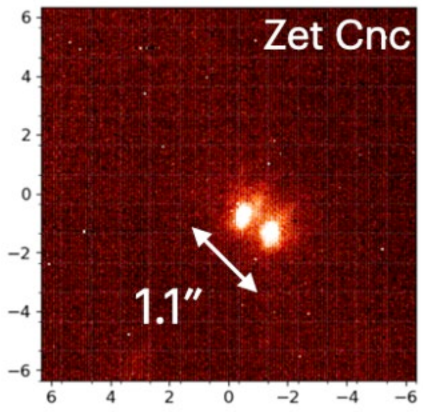
Any show stoppers?

Currently MIRC-X and MYSTIC standardly observe as FT and, both observe the on-axis bright star

In dual-star mode:

- The **fainter star** is injected into the **science beam combiner (SC)**
- Internal delay lines are adjusted to match the **astrometric separation** between the two stars

Adaptive optics plays a critical role resolving two stars



1. Implementation differences: Wavelength

- GRAVITY: FT and SC both in K-band
- CHARA MIRC-X (J+H band) and MYSTIC (K-band) operate different wavelengths

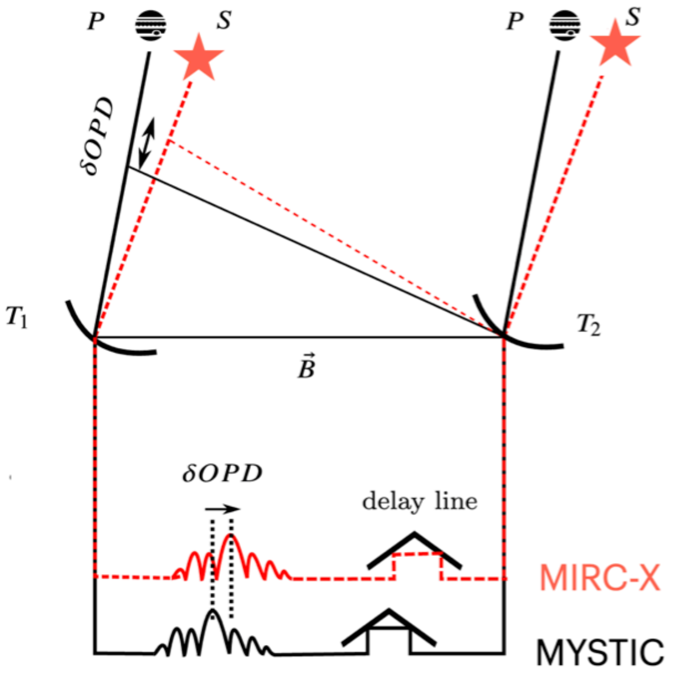
Advantage:

Flexibility to select FT and SC either in H or K-bands based on angular resolution requirements

Challenges:

- Longitudinal wavelength dispersion corrections between H and K. We have it.
- FT and SC are different wavelengths, nee to consider water vapor effects. Perhaps, adapt working principles from GRAV4MAT

2. Implementation differences: Astrometry



$$\delta OPD = \vec{B}.(\vec{S} - \vec{P})$$

- GRAVITY equip with precise metrology enable ~20 us astrometry
- CHARA MIRC-X and MYSTIC: no metrology, we expect the ~100-200 us astrometry
- The precision of astrometry depends on the precision of the differential delay lines (DDLs), we need to upgrade them
- Current DDLs are zabor motors they have range for 5” astrometric separation field of view. Repeatability is not good.

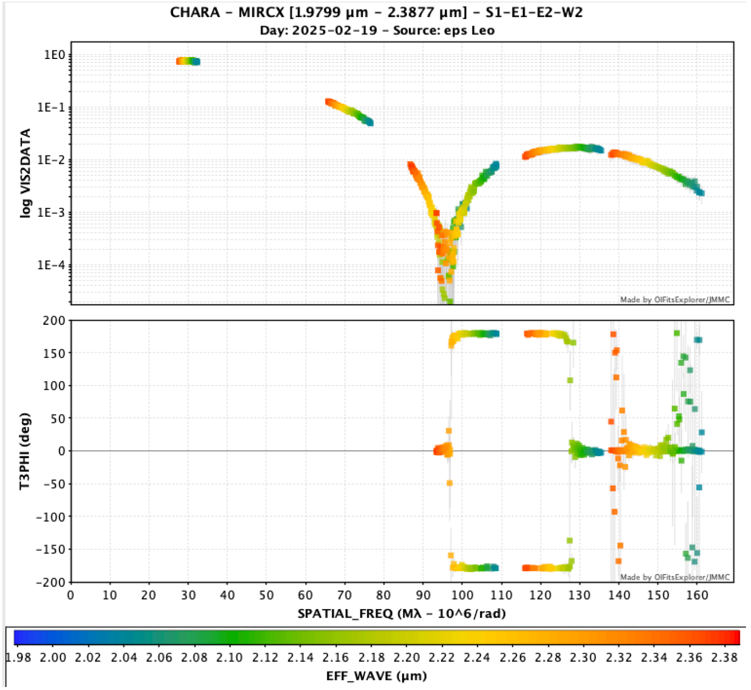
First light planned August 2025

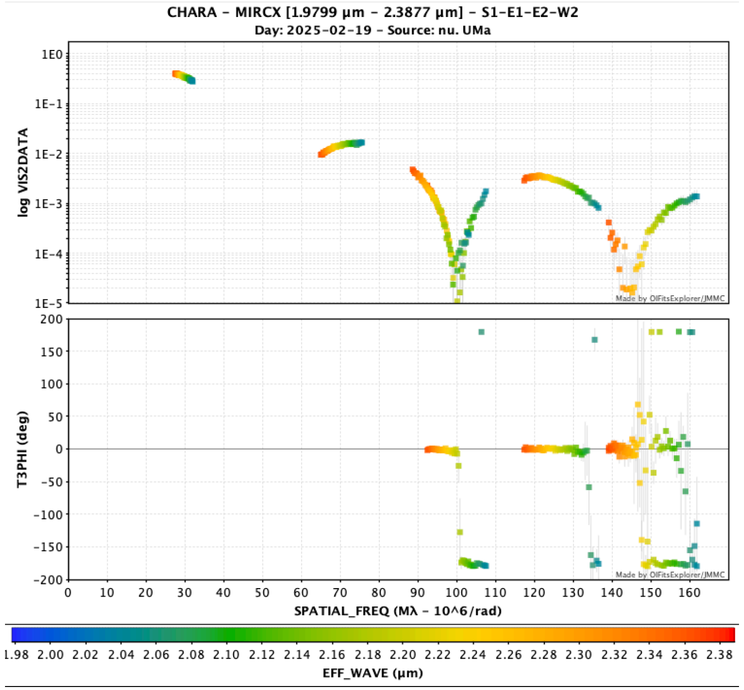
- Commission with double stars
- Fiber injection based on STST and astrometric separation and projection angle
- Fringe acquisition in dual field mode (on-axis and off-axis)

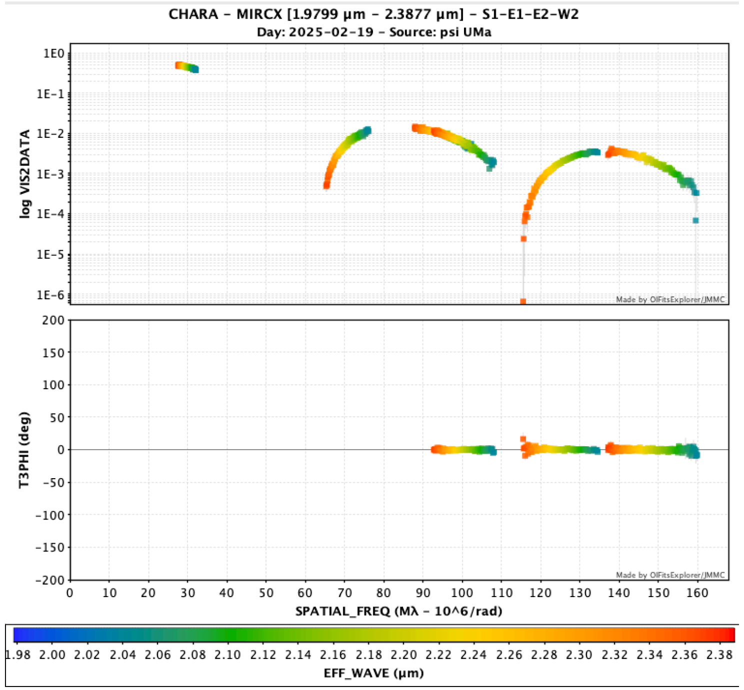
- SPICA-FT phase tracker is almost ready (led by D. Mourard)
- MIRC-X camera upgraded (led by S. Kraus; expected up to 1 mag sensitivity)

Delay lines problems fixed

See Nils talk

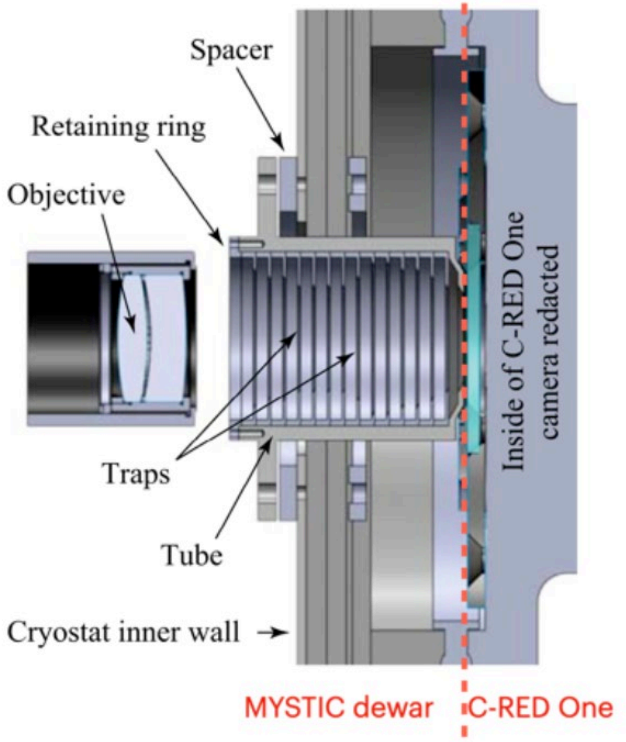






Funding request to upgrade MYSTIC camera: goal high contrast science

- Upgrade the MYSTIC camera: new sensor, lower dark current
- Connect MYSTIC camera and beam combiner cryostat for lessor thermal backgrounds
- Faster and accurate delay lines



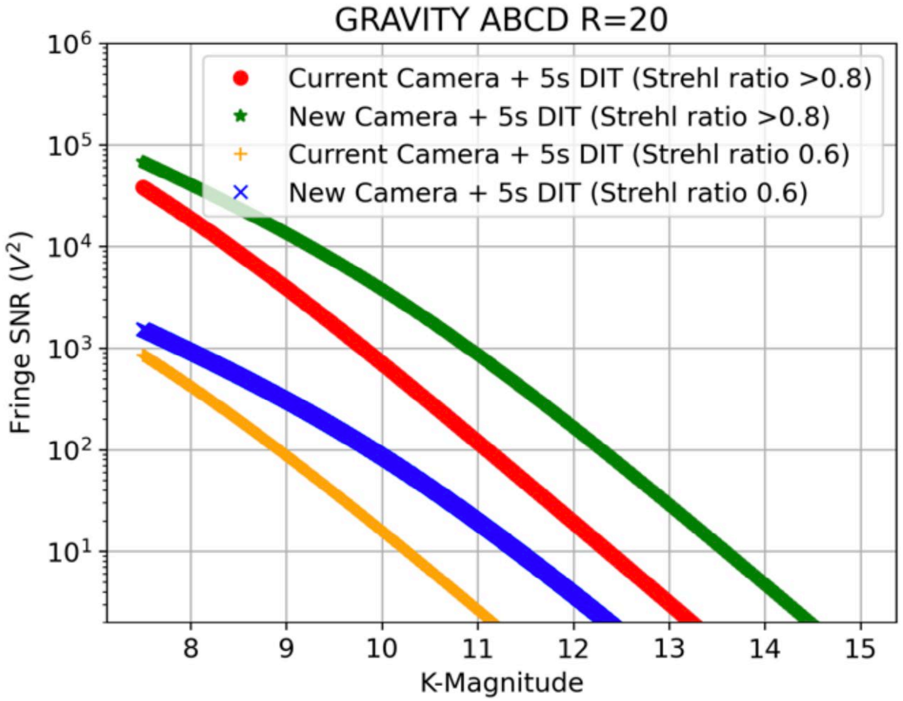
Funding request to upgrade MYSTIC camera: goal high contrast science

5-Second Integrations: Sensitivity Estimates

Calculations suggest reaching K = 11–14 magnitudes, depending on:

- Adaptive Optics (AO) correction with best quality
- How effectively we handle thermal leakage with the newer camera

Is that just a dream?
We are about to find out!

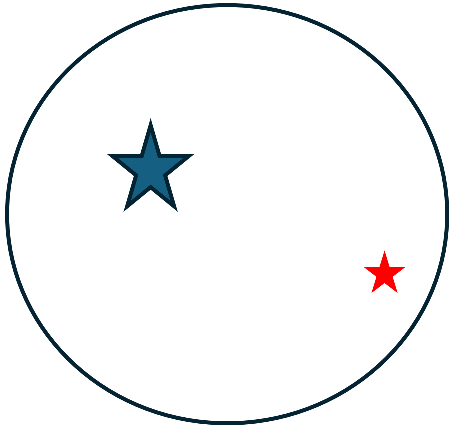


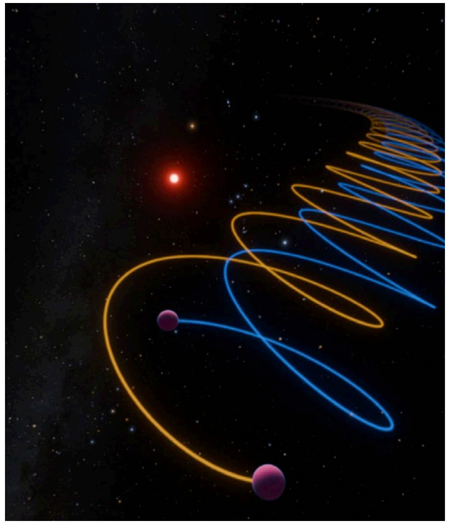
1. Science cases

Expect 2.5 mag sensitivity improvement within 5” field of view of primary

- **Double Stars within 5" Field of View**
  → Currently challenging: AO tracking struggles on faint, off-axis stars
- **Multiplicity Studies & Detection of Faint Companions**
  → Enable off-axis fringe tracking on secondary components
- **Wide Binary Astrometry**
  → High-precision relative astrometry of wide pairs
  → Search for wobbles in astrometric orbits (indicating unseen third components)
- AGN, YSO, white dwarfs ..??

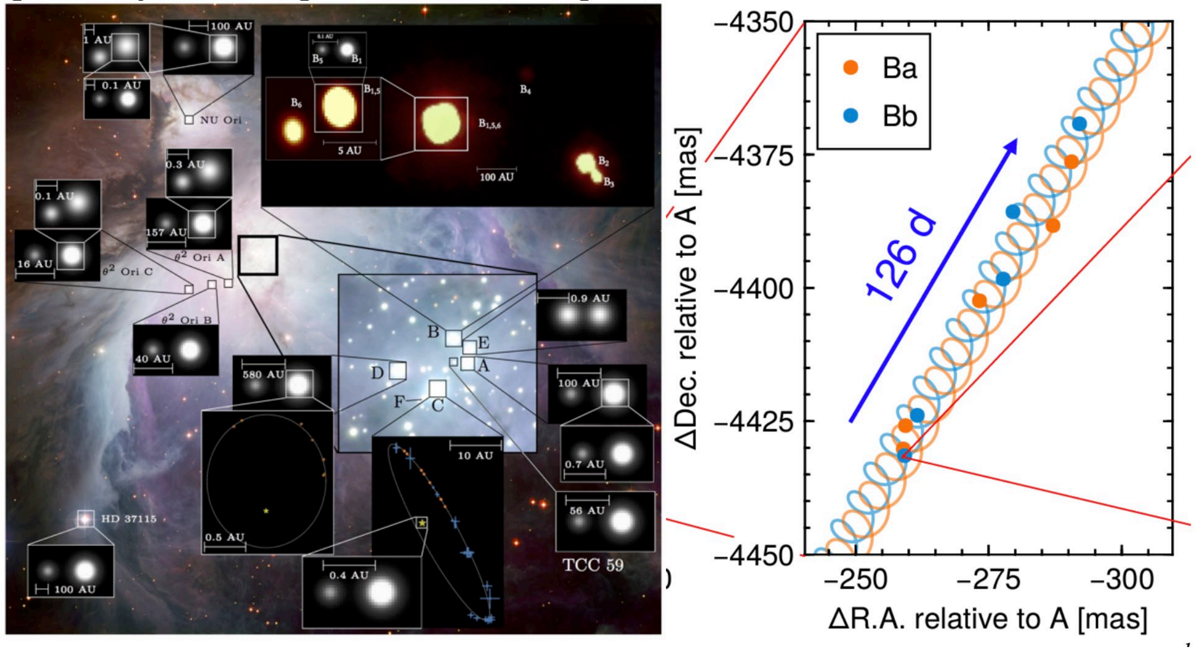
5” field of view





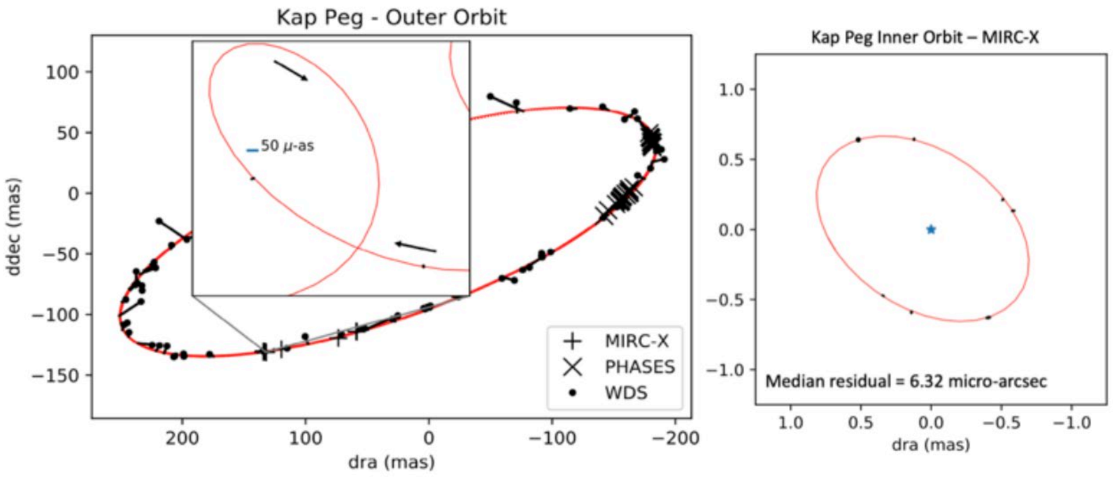
credit: K. Miller / R. Hurt / Caltech / IPAC.

1. Science cases



Multiples systems detected in the Orion Nebula including Trapezium Cluster (GRAVITY Collaboration, Karl et al. 2018)

Off-axis observation of cool brown dwarf Gliese 229 B revealing it’s a binary (Xuan et al. 2024, Nature)



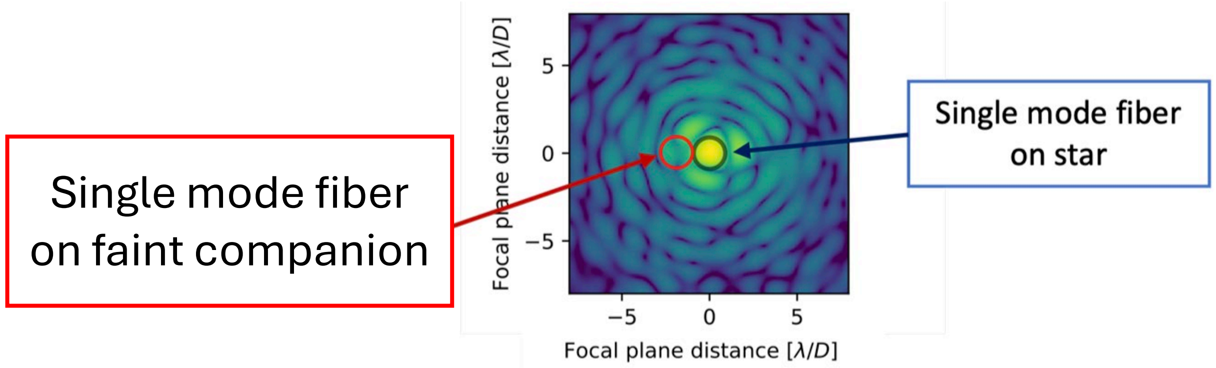
ARMADA survey: on-axis (Gardner et al. 2022)

Pursue similar science on wide binaries with dual field.

2. Science cases: high contrast companions

This mode achieves high contrast with two levels of star flux filtering.
(i) Spatial filtering using a single-mode fiber
(ii) Coherent flux filtering to separate companion signal from star flux

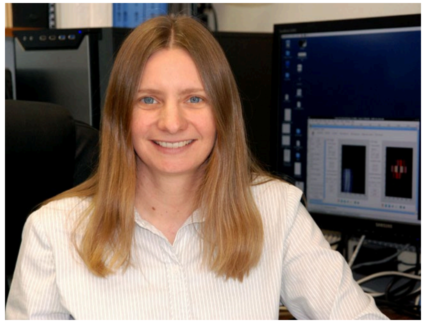
(Lacour 2023)



(Lacour et al 2025)

Team

Software/ observing lead



CHARA director

PI MYSTIC

PI MIRC-X

PI FT

+ CHARA collaboration