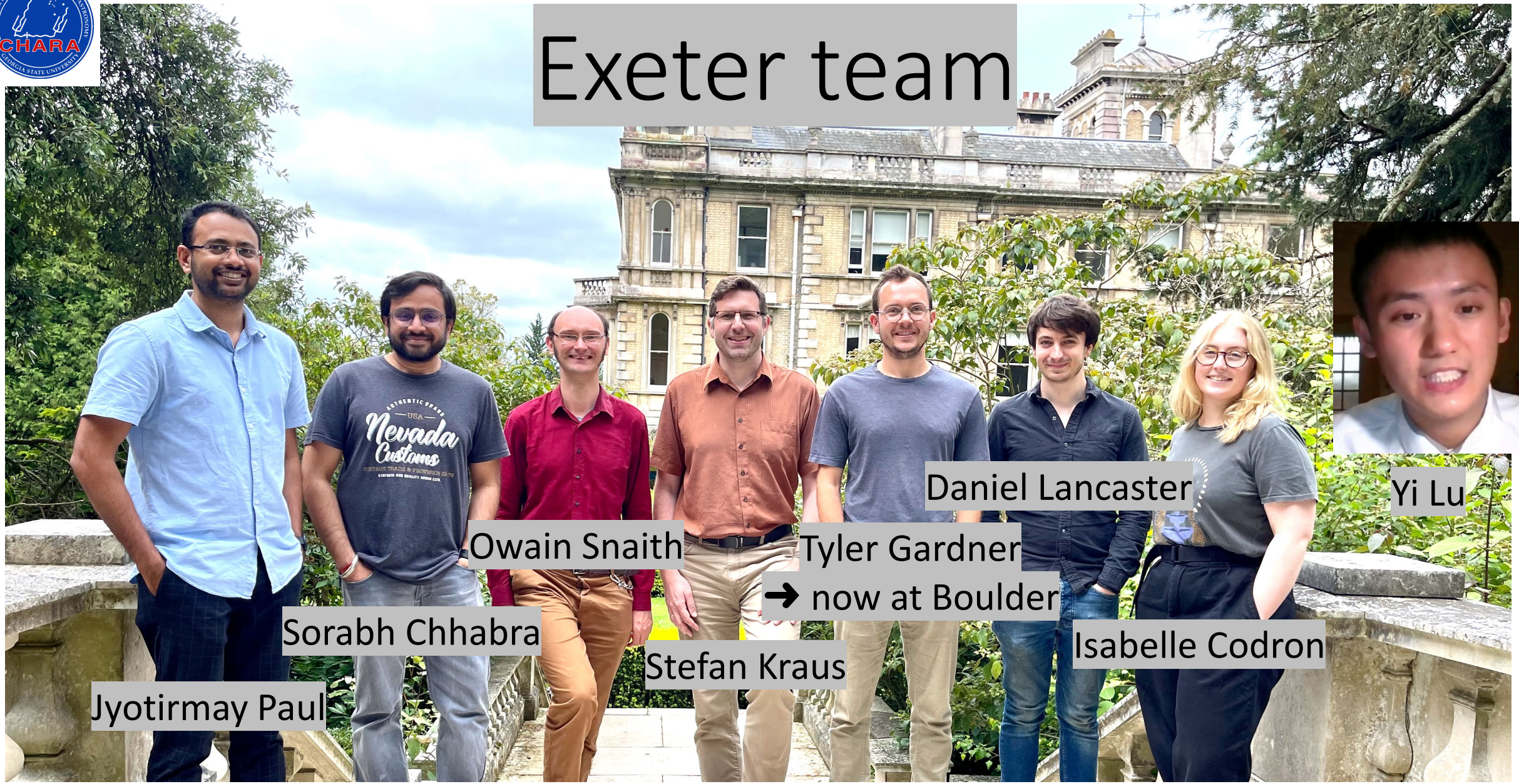
Updates from the Exeter group: MIRC-X upgrades and science

Stefan Kraus, Dan Lancaster, Isabelle Codron, Tyler Gardner,
Sorabh Chhabra, Jyotirmay Paul, Owain Snaith

and CHARA, UM & INAF colleagues, incl. Narsi Anugu, Andrea Bianco & Michele Frangiamore

University of Exeter

Exeter team


Nevada Customs
Owain Snaith
Tyler Gardner
➜ now at Boulder
Daniel Lancaster
Yi Lu
Sorabh Chhabra
Stefan Kraus
Isabelle Codron
Jyotirmay Paul

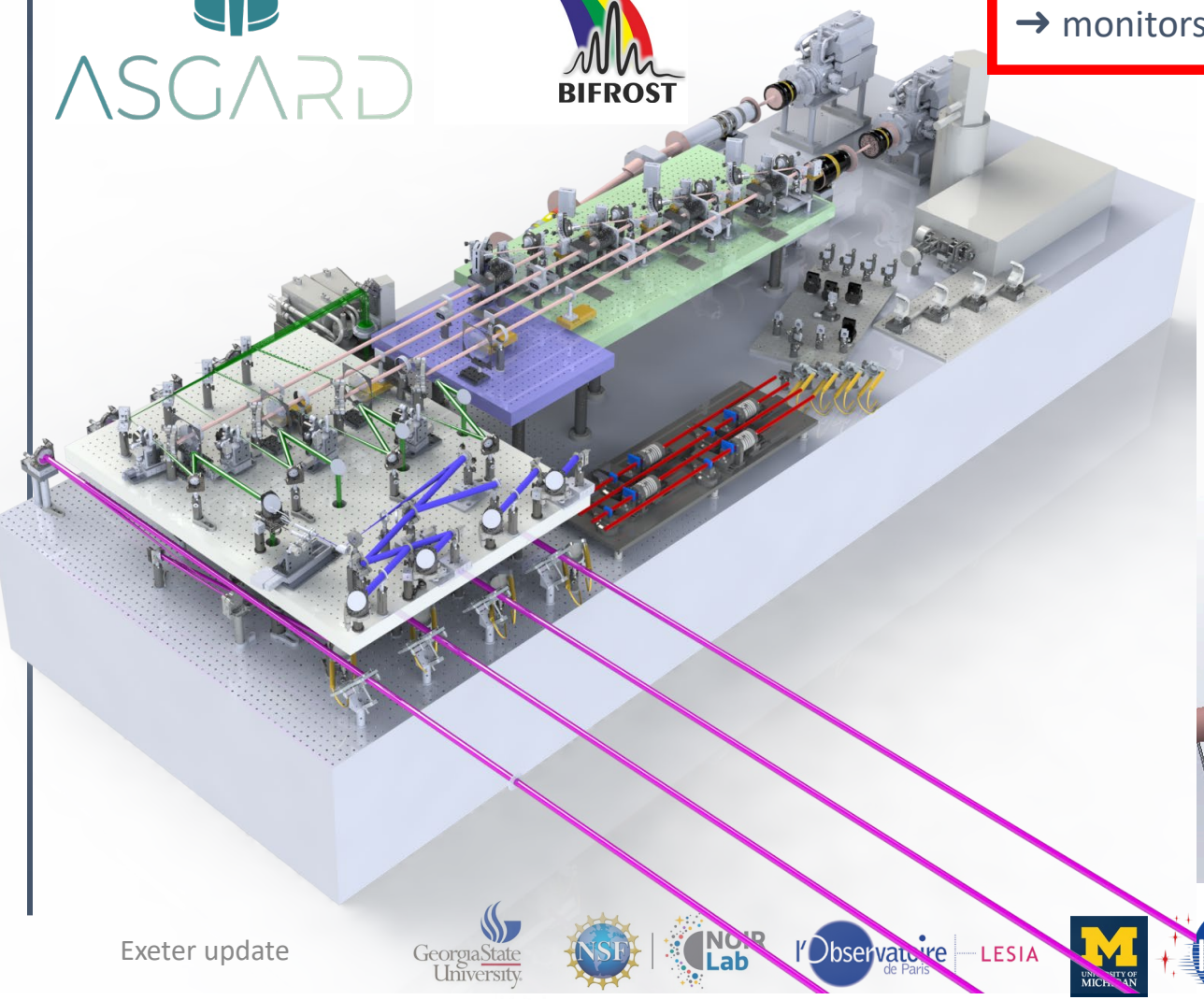
MIRC-X / BIFROST synergie

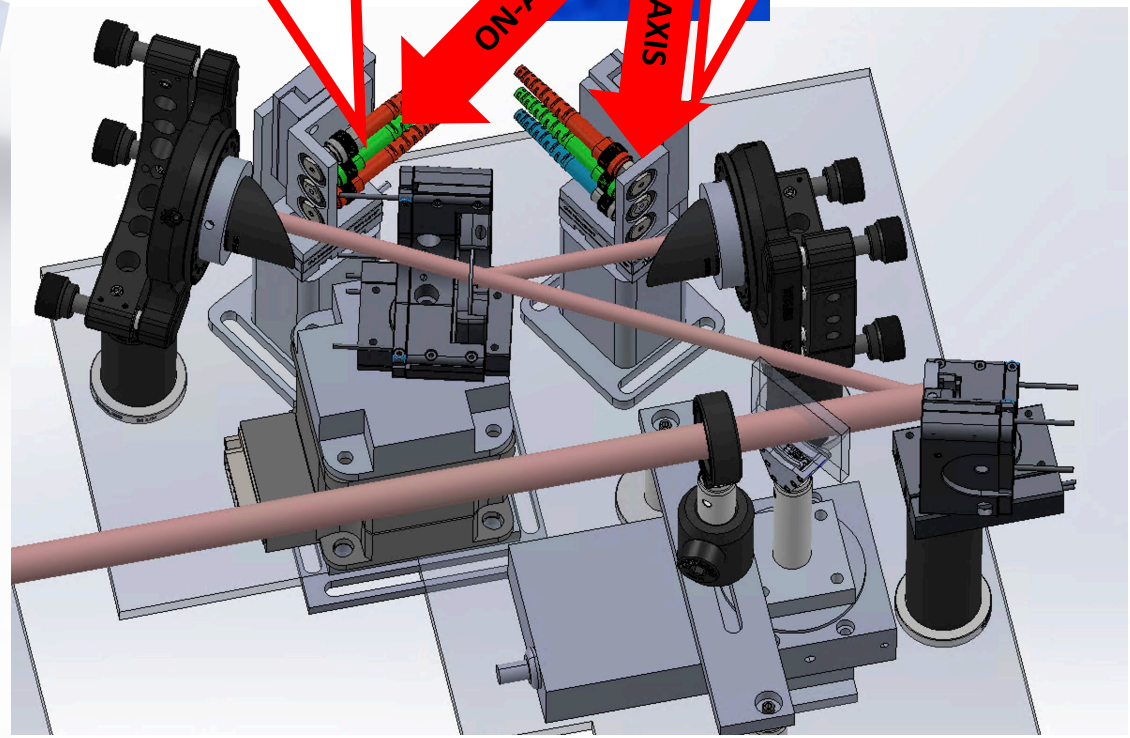
ON-AXIS ARM (LR spectrograph):
→ calibrates continuum visibilities
→ monitors phase; feedback to FT

OFF-AXIS ARM (HR spectrograph):
→ records spectrally dispersed Interferograms
→ can point to off-axis source within 1” FOV

ASGARD

BIFROST





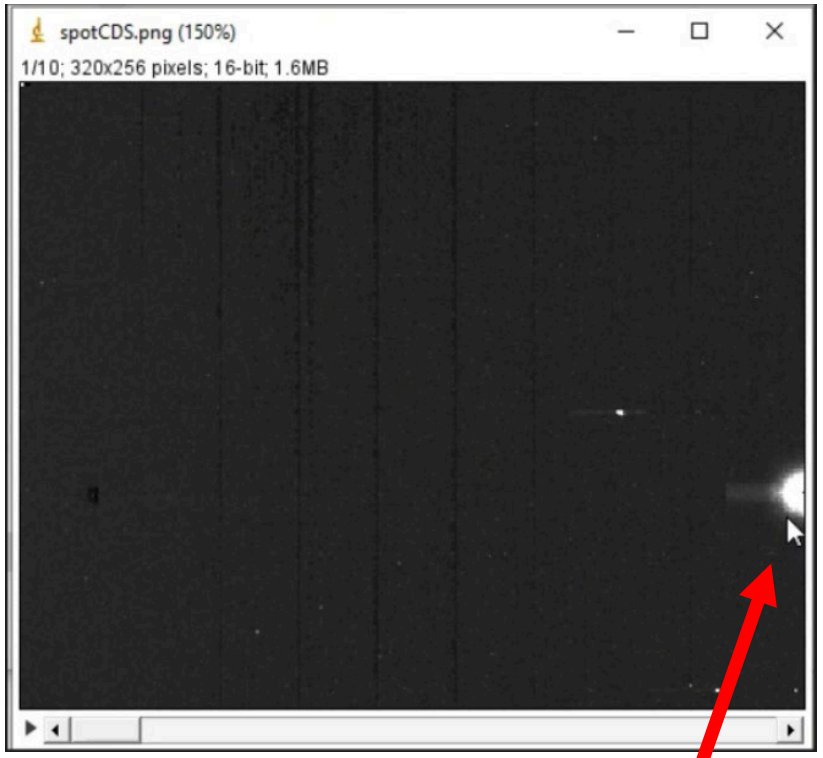
MIRC-X / BIFROST synergies

- Subsystem Design / Manufacturing:
  - APD cameras (low-dark optimization, long-wavelength suppression, …)
  - VPH gratings
  - Photonics combiners
- Methodology:
  - Optical designs to reduce thermal background
  - Dual-field interferometry (see also Narsi's talk)
  - Cophasing in data processing
- Pipeline:
  - ABCD pipeline (also needed for SPICA-FT and MYSTIC GRAVITY chip)

MIRC-X: C-RED One upgrade

- Camera shipped to France: Dec 28 ➜ April 3
- Special thanks to Craig, Narsi, Cyprien, Rob, … and to science users for their patience!
- Installation of new sensor and read-out electronics
- Rapid iteration in March to decide on optimal filter combination + read-out mode:
  ➜ adopted low-risk filter strategy
  (HKHK filter, “high-speed”)

MIRC-X camera sensor before upgrade



Saturation-related damage?

MIRC-X: C-RED One upgrade

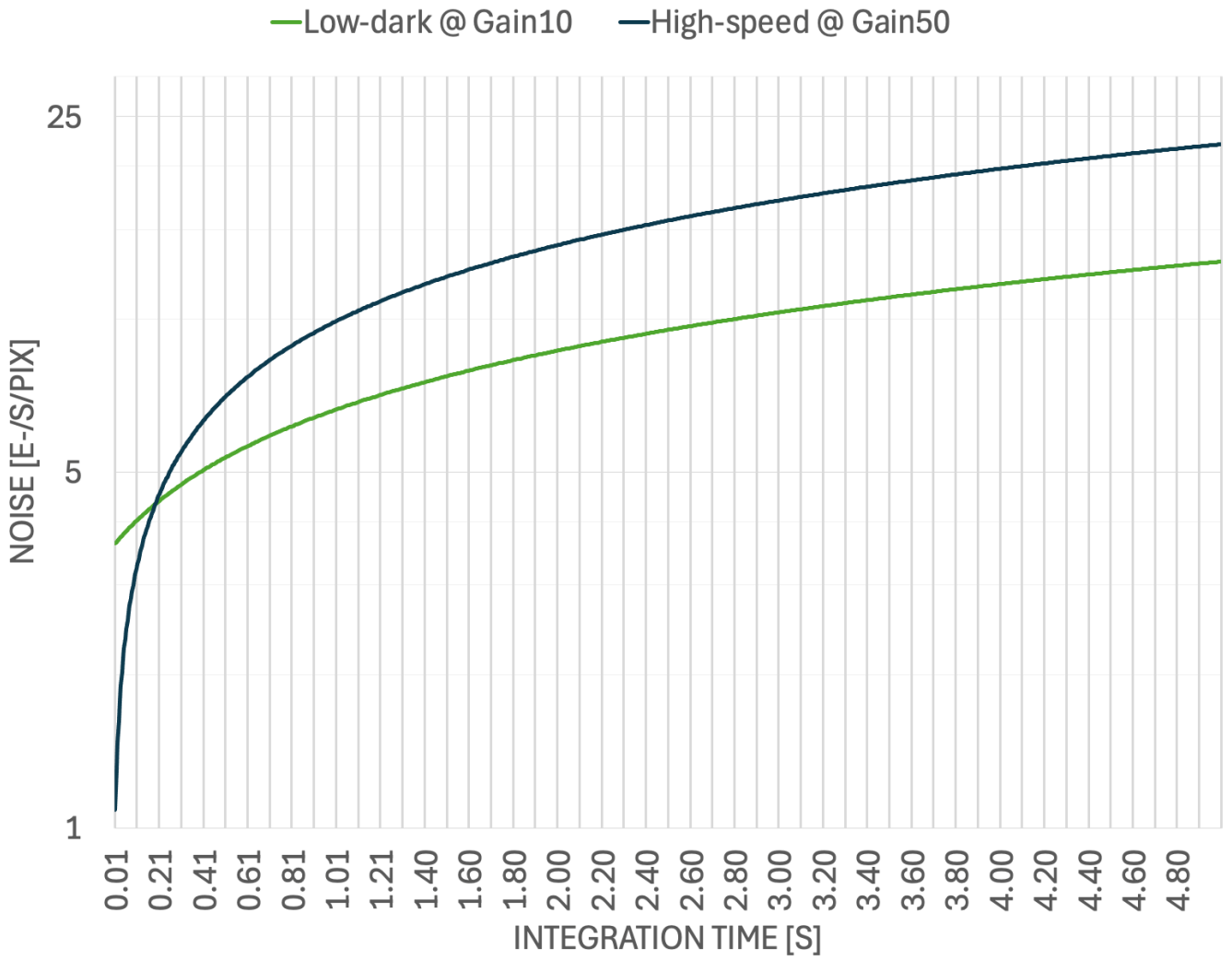
- New sensor, latest APD generation; reduced vibration imparted to the detector
- Not limited by dark current anymore
  ➜ Essential for realizing long DITs needed for high-spectral resolution & dual-field
- Now limited by thermal background, set by cold stop size needed for AIO combiner
- Sensitivity gains to be quantified

		Dark Current w/cold stop [e-/s/pix]	Dark Current + Thermal BG [e-/s/pix]	Read noise [e-/pix]
"Low dark" (max 868 fps)	Gain 10	3.6	31.0	3.6
	Gain 50	27.7	70.4	0.8
"High speed" (max 3440 fps)	Gain 10	7.2	45.3	3.8
	Gain 50	39.8	97	0.8

Reduced from ~100 e-/s/pix

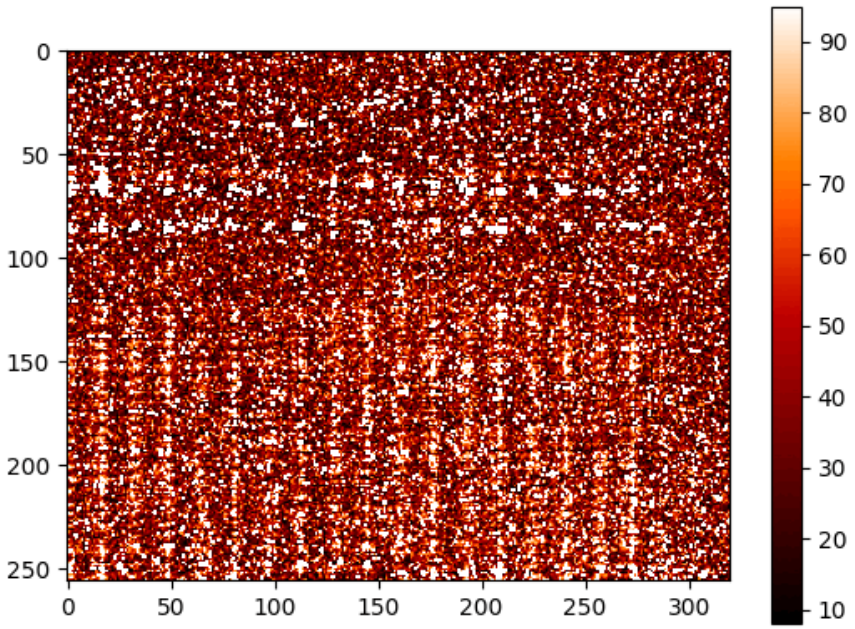
Reduced from ~200 e-/s/pix

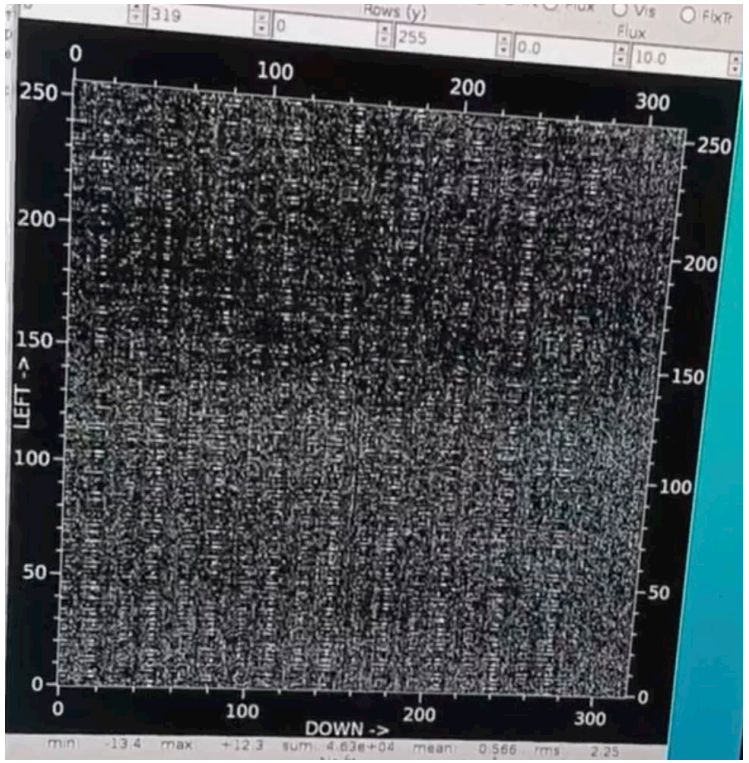
MIRC-X: C-RED One upgrade

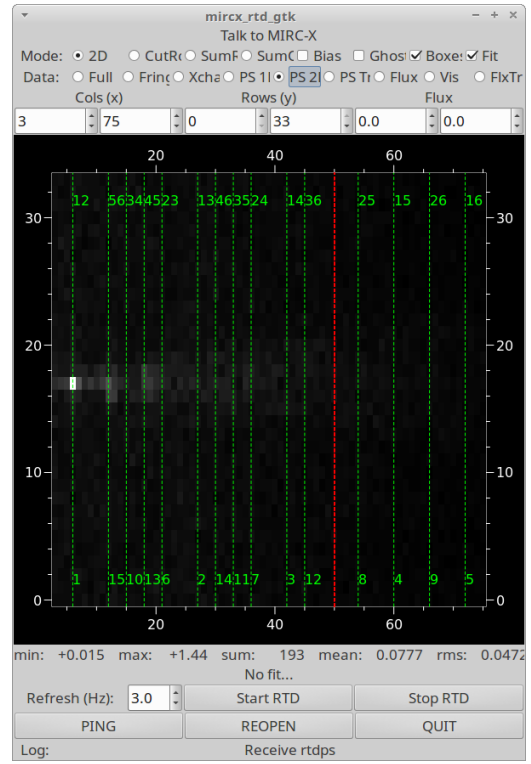


MIRC-X: C-RED One upgrade

Report of correlated noise (developing after few minutes)
➜ to be discussed with manufacturer
➜ monitor problem & observers please report back to us!



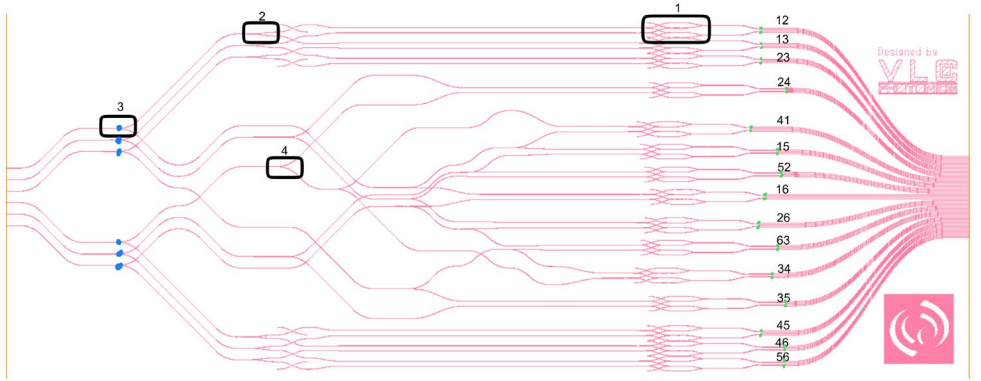




MIRC-X: development roadmap

Goals:

- realizing full sensitivity gain from new camera
- improving calibration accuracy

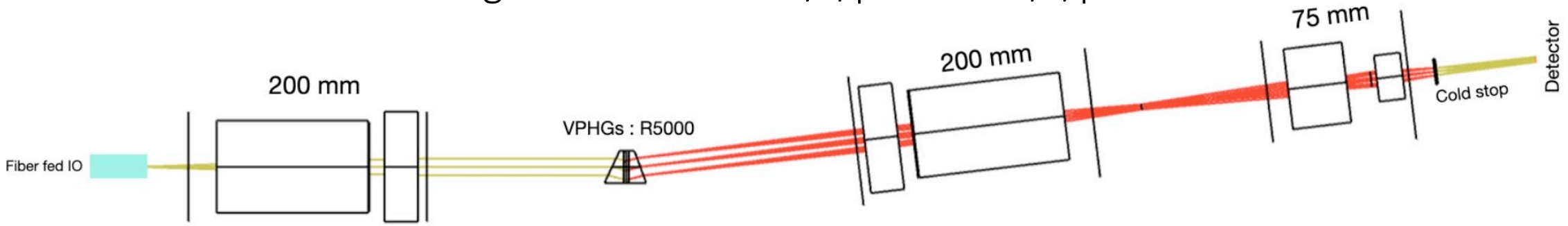


SPICA-FT (H-band)

Implementation pathway #1: cryogenic MIRC-X

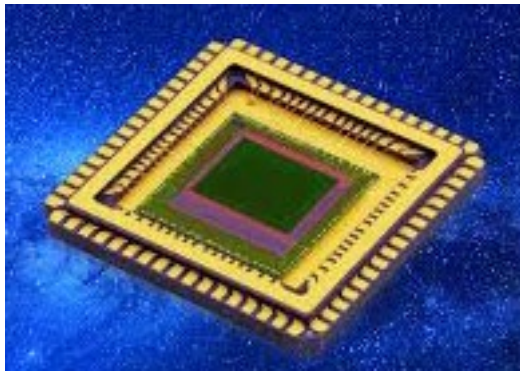
Implementation pathway #2:

- Ultra-broadband PIC device: J + H band simultaneously
- Change optical layout to reimage grating onto cold stop
  ➜ allow reducing the cold stop size from f/4 to f/12
  ➜ reduce thermal background from 82 e-/s/pix to 4 e-/s/pix

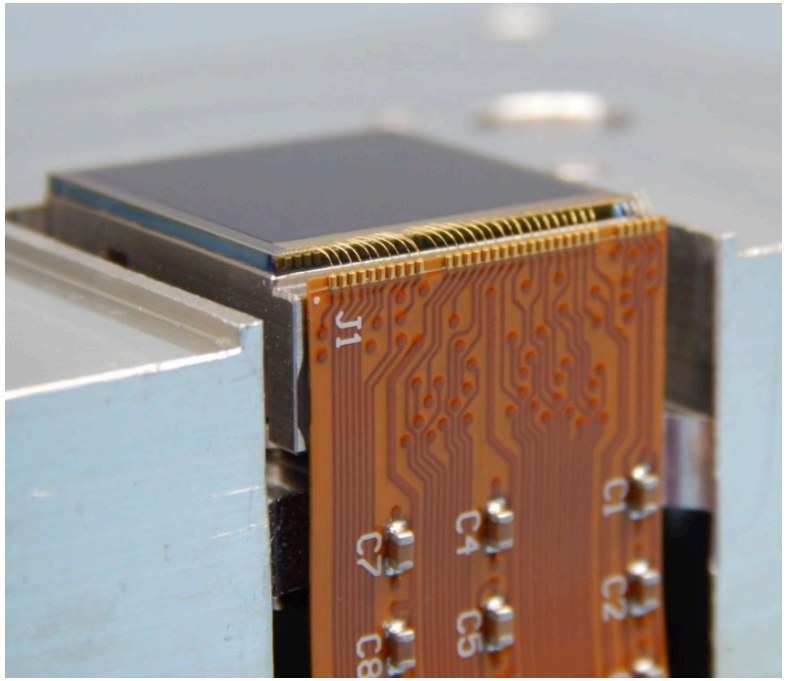


MIRC-X: development roadmap

Camera developments under consideration:



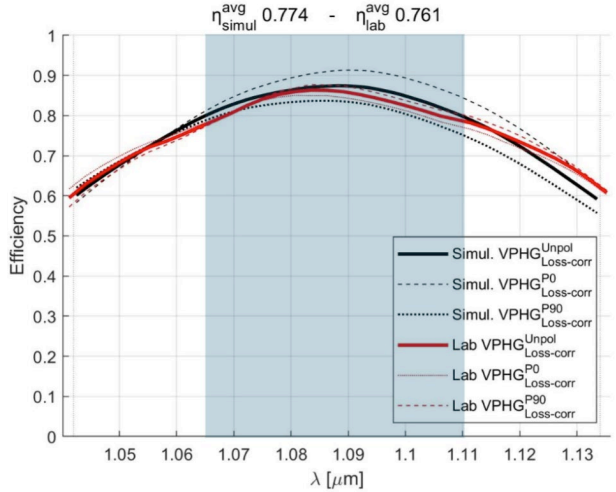
Left-over Saphira sensor from MIRC-X camera
➜ camera for STST?



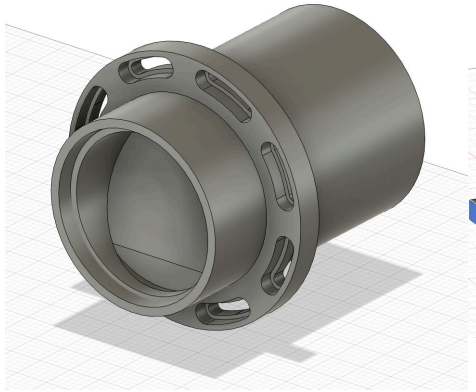
Science-grade ‘Ike Pono’ device with 1k×1k pixels procured
➜ future MIRC-X science camera?

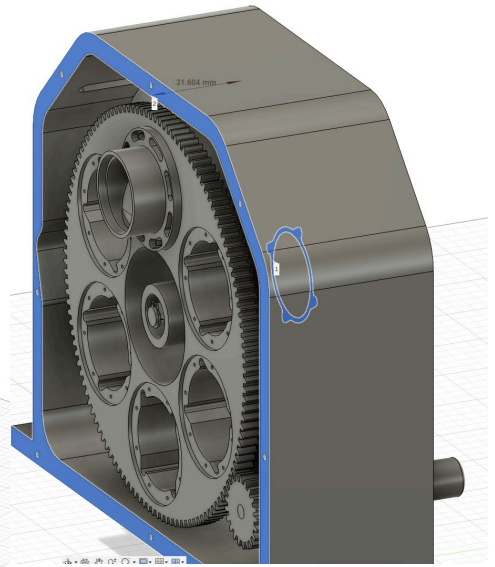
MIRC-X: VPH R=6000 gratings

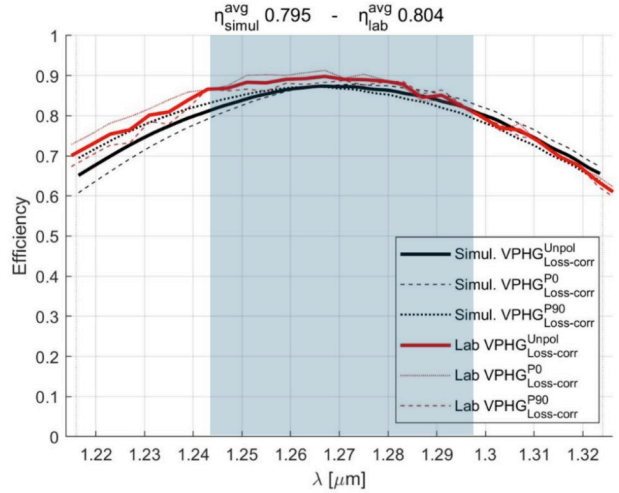
- R=6000 gratings:
  He I 1.08µm
  Paβ 1.28µm
- High-efficiency 75...80%
- Manufactured by INAF team:
  Andrea Bianco + Michele Frangiamore
- To be installed by Dan Lancaster,
  initially for 4T operations;
  later 6T with 75mm lens



Wheel 1 (29 mm)	Wheel 2 (15 mm)
Empty	Empty
R22	Wollaston
R50	R182
R102	R625
R2314	R1170
Empty (Future VPH)	Empty



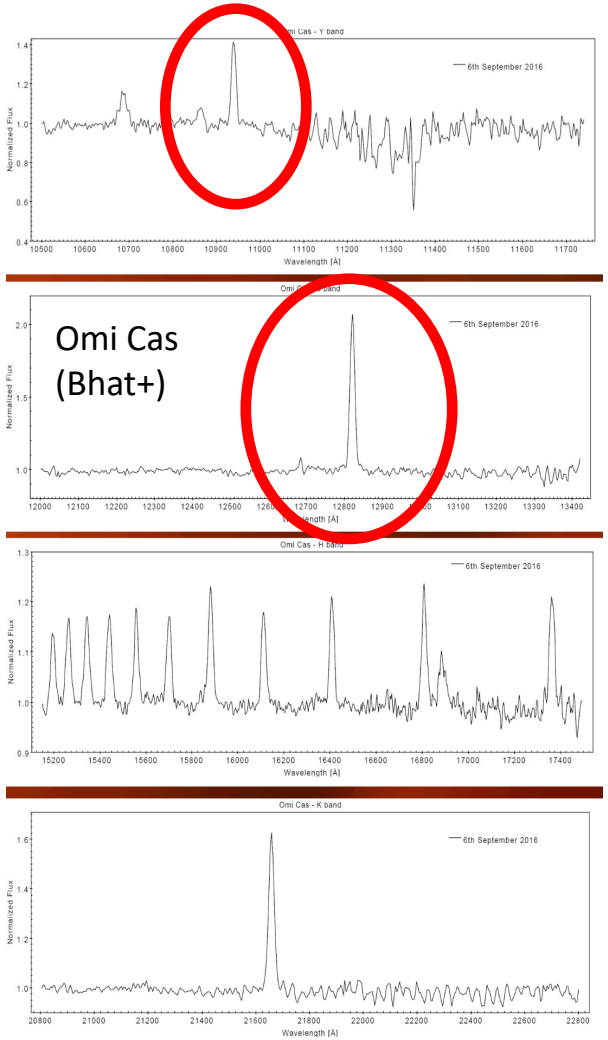


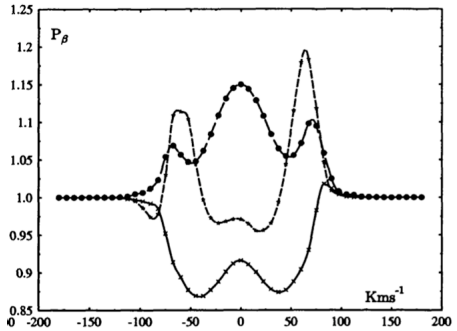


Frangiamore+ 2024

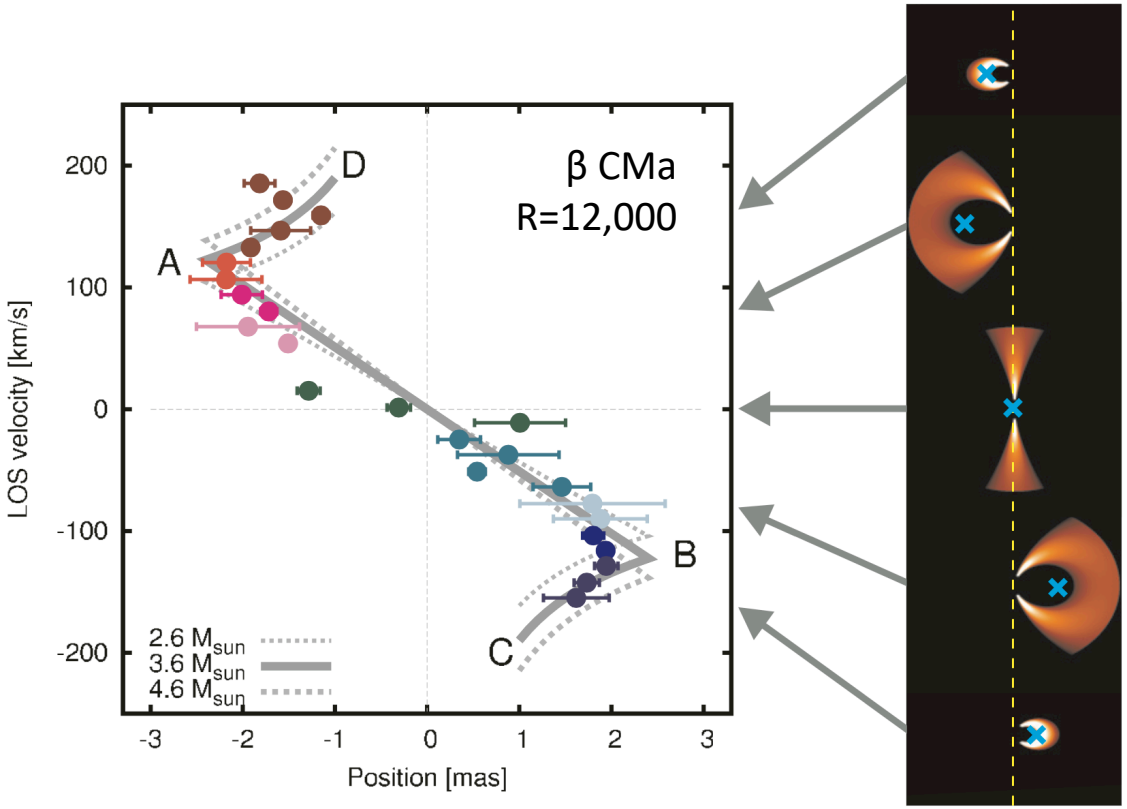
Science: High spectral dispersion

(1) Classical Be stars





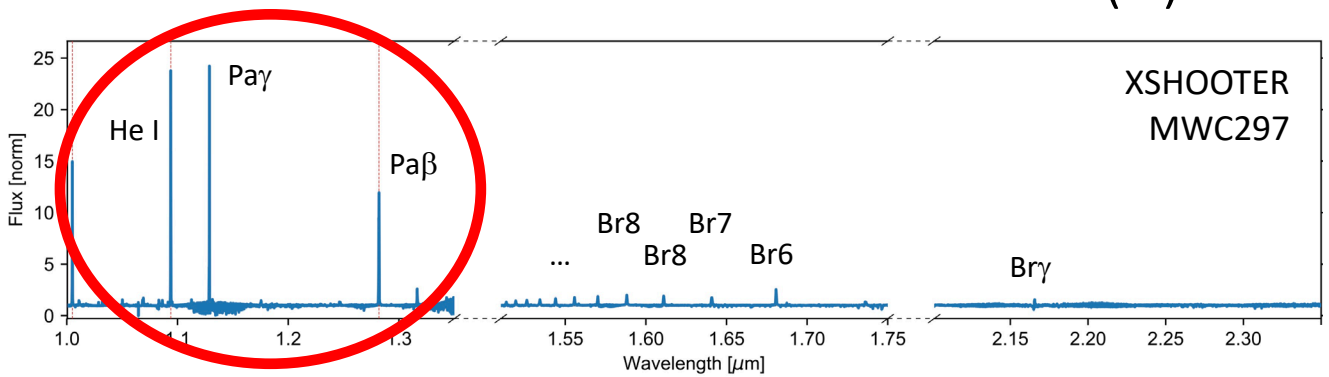
Be star model
(Cidale+ 2000)

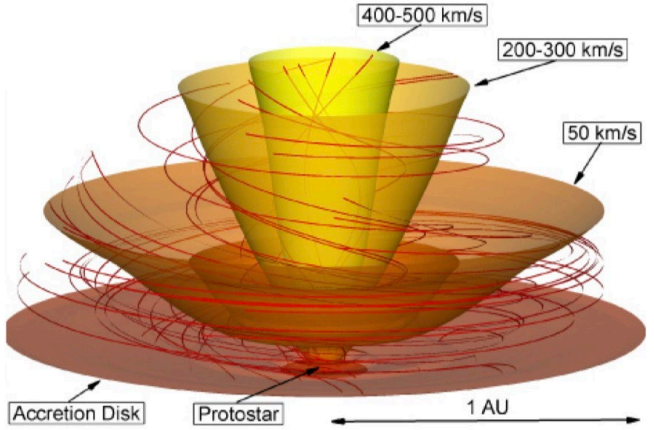


Detailed kinematical studies
(Kraus+ 2012)

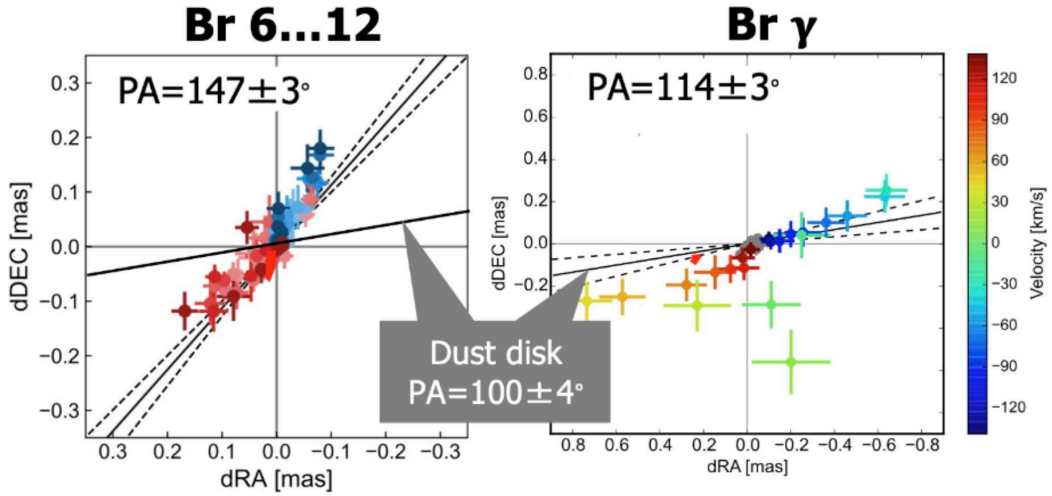
Science: High spectral dispersion

(2) YSO



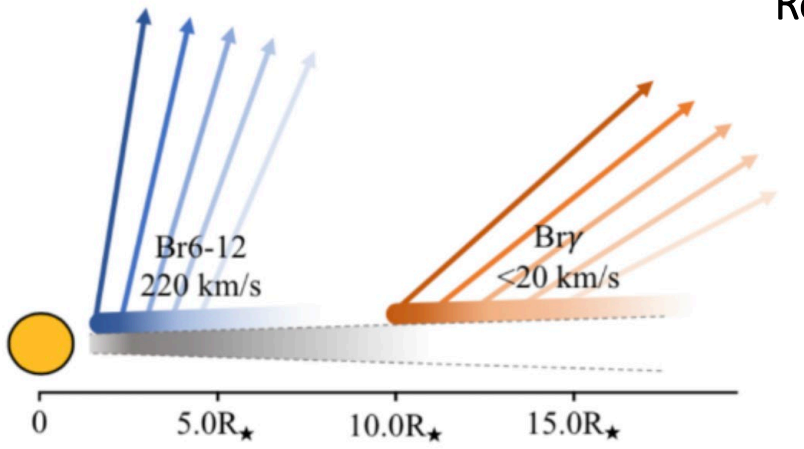


Romanova



~ 3 $R_\odot$ with v_z=220 km/s
steep (near-polar) stream-line

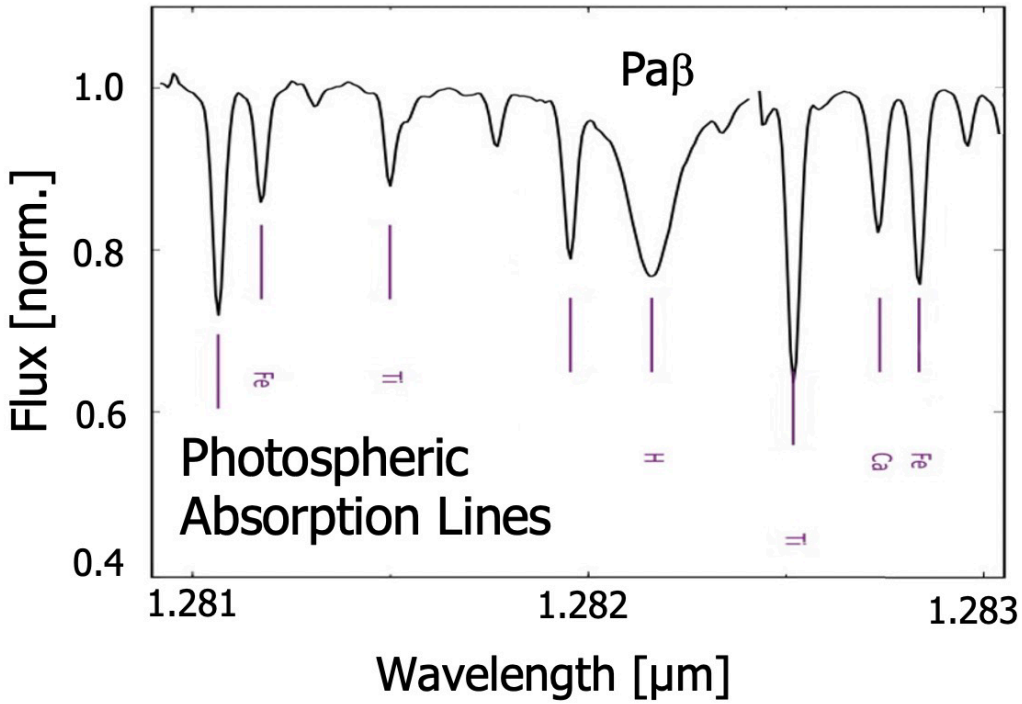
~ 12 $R_\odot$ with v_z<20 km/s
shallow stream-line



Hone 2020

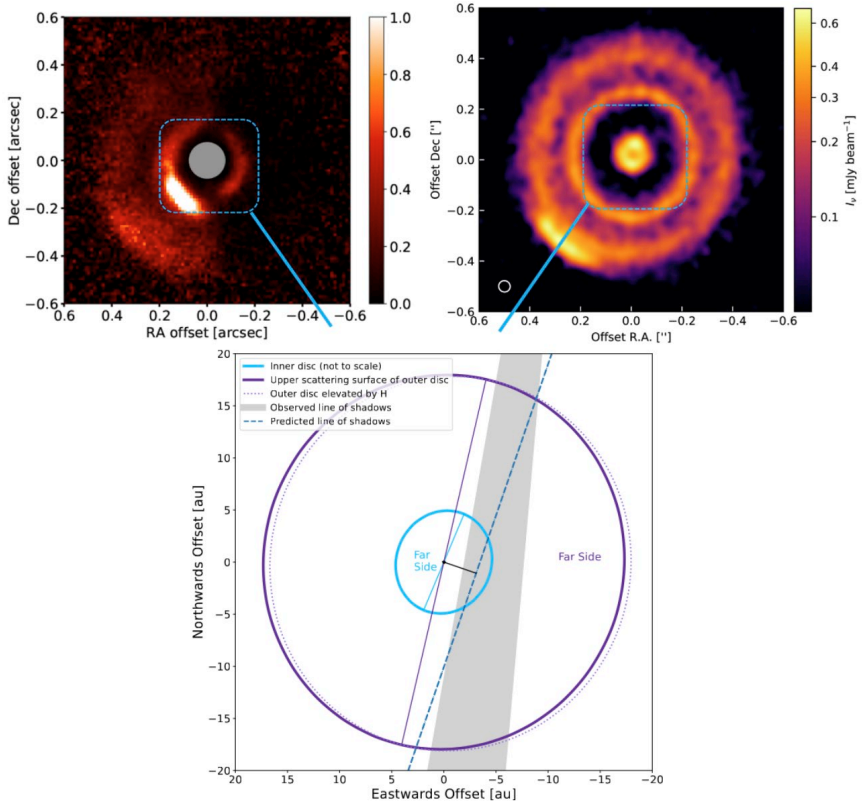
Science: High spectral dispersion

(3) Companion detection / spectral classification



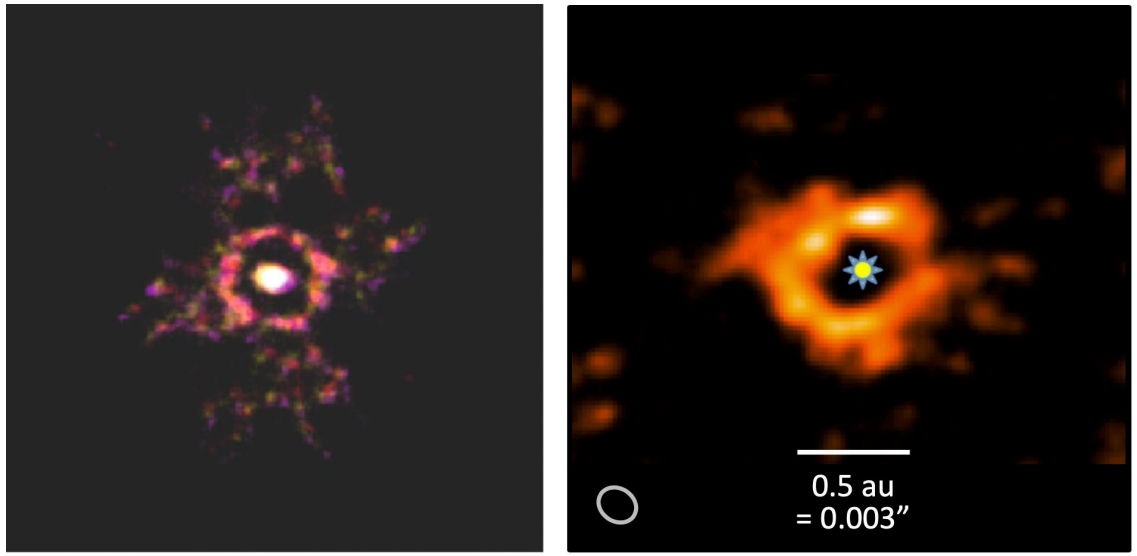
Science: Survey on Herbig stars

Inner/outer disk misalignments & origin of shadows



Isabelle Codron

Temporal variability near the dust sublimation rim

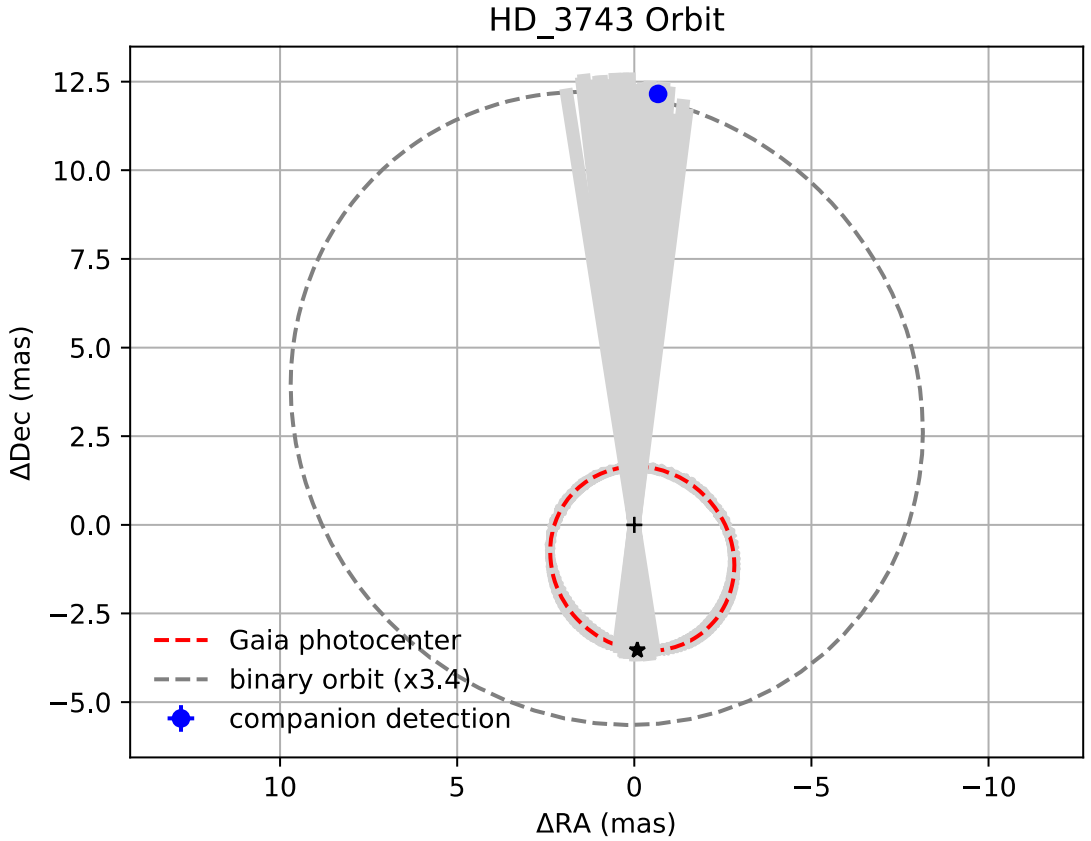


Jyotirmay Paul

Stefan Kraus

Owain Snaith

Science: Gaia binaries



- Orbital elements from Gaia
- Scale between Gaia orbit and our data point gives semi-major axis → **Dynamical Mass** of system
  - Better – include our data point in fitting!
  - Not possible without epoch data from Gaia
- Flux ratio and photocenter orbit
  → can get **individual masses**

$$(M1+M2)^{1/3}\, P^{2/3} [M2 / (M1+M2) - f / (1+f)] = a_{photo} / plx$$

For all binaries:

$$M1 + M2 = a_{semi}^{3} / P^{2}$$

With SB1:

$$K_1 = 2\pi a_1 \sin(i) / [P (1-e^2)^{1/2}]$$
$$a_{semi} = a_1 + a_2$$
$$a_1 / a_2 = M_2 / M_1$$

With SB2:

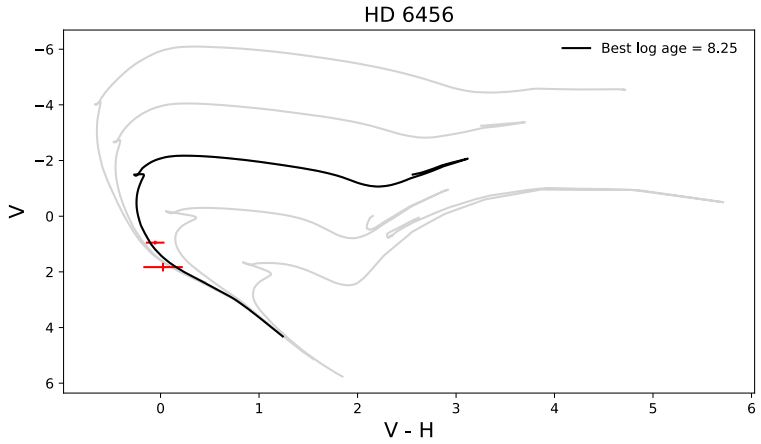
$$K_1 / K_2 = M_2 / M_1$$

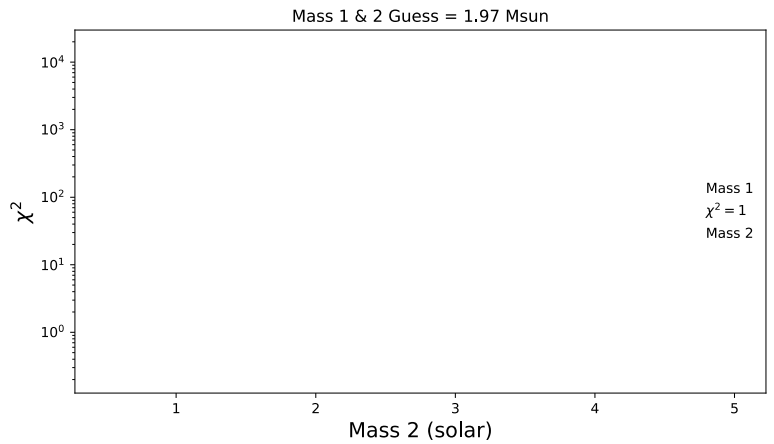
<u>Measured masses:</u>

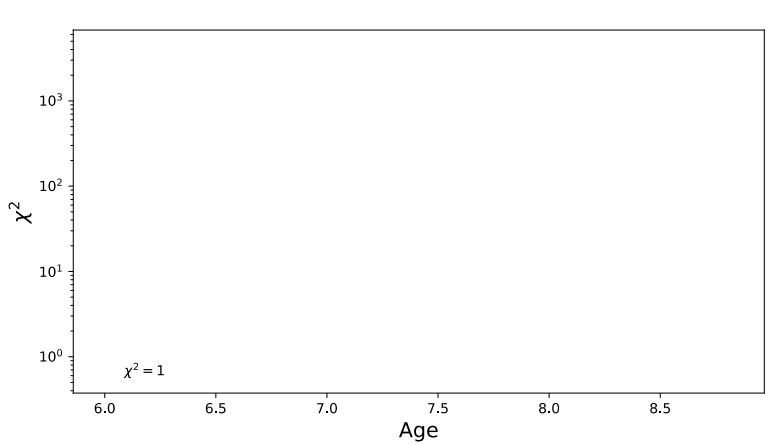
$M1 = 2.19 +/- 0.44\ M_{sun}$

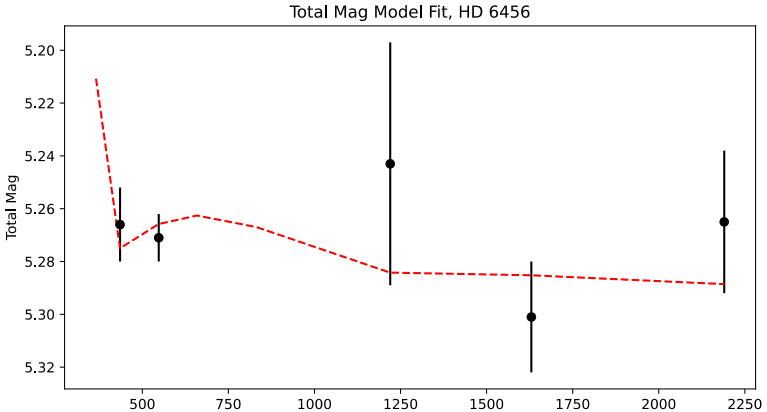
$M2 = 1.43 +/- 0.22\ M_{sun}$

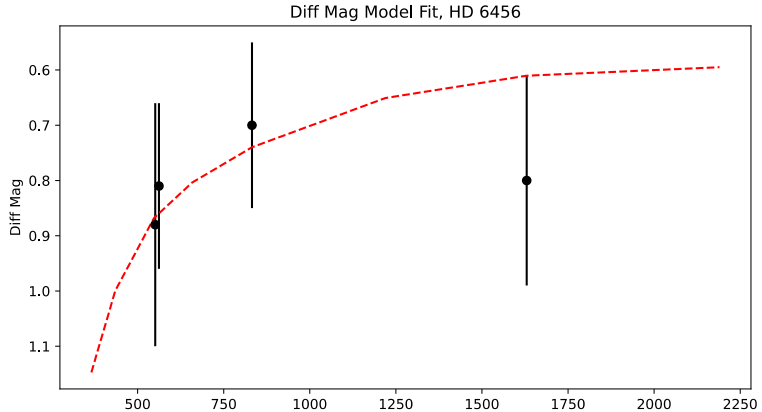
Science: Gaia binaries

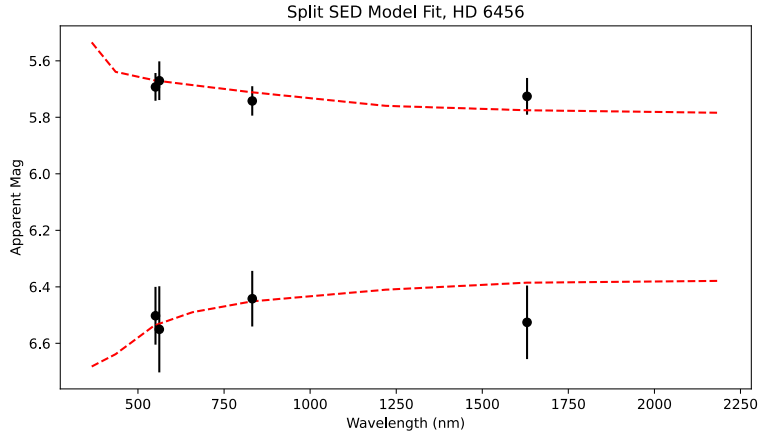






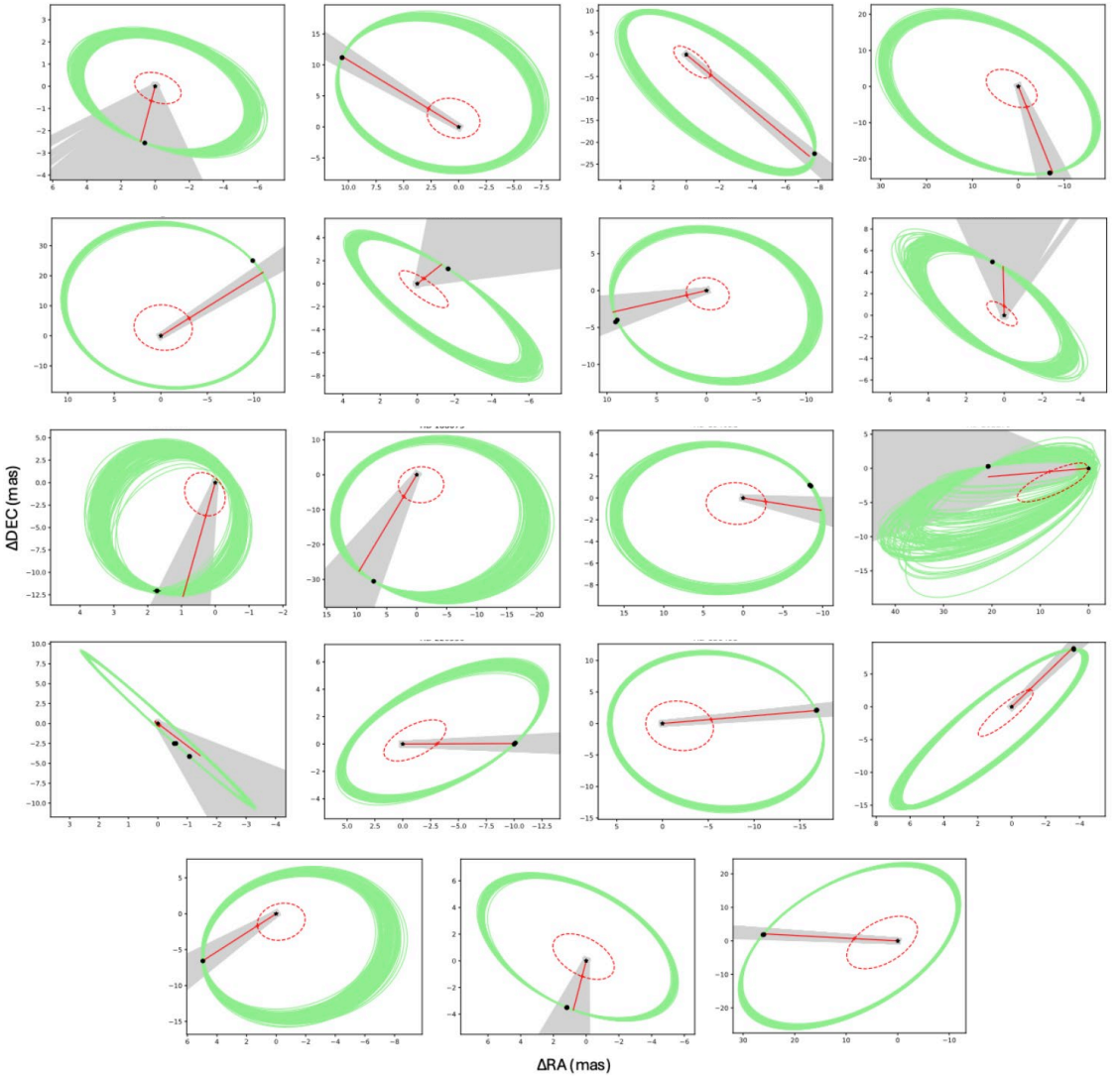


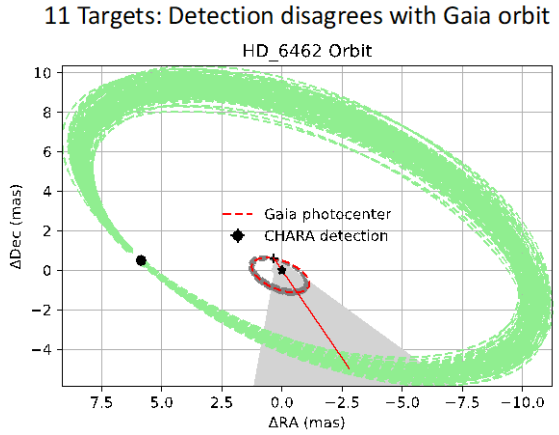




Science: Gaia binaries

- Intermediate-mass binaries
- Asteroseismology and low-metallicity targets (see Yi's talk)





Summary

MIRC-X:

- Camera future-proofed:
  moderate sensitivity gain now; large gain in future;
  work needed on correlated noise
- VPHG R=6000 for Paβ and HeI line to be installed in June
- Plans for J+H photonics beam combiner upgrade

Science:

- YSO multi-epoch imaging (Codron, Stefan, Jyotirmay, Owain)
- Gaia binaries (Yi, Tyler)
- High-spectral dispersion companion detection/characterization (Dan)