Visible-light high-contrast imaging polarimetry at Subaru

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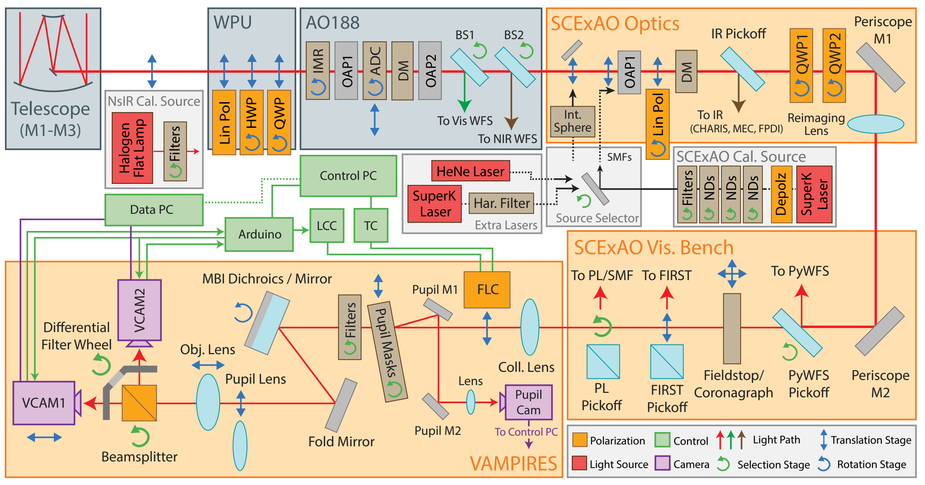
High-contrast instrumentation, polarimetry, circumstellar disks, exoplanets, low-mass companions

Introduction to VAMPIRES

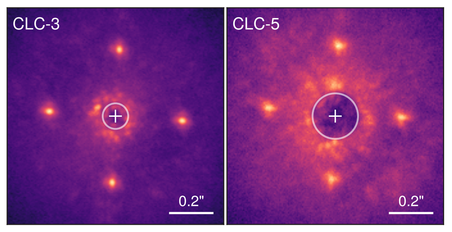
- SCExAO/VAMPIRES: Visible Aperture-Masking Imager/Interferometer for Resolving Exoplanetary Signatures
- 8.2 m telescope combined with multi-stage extreme adaptive optics (AO188 + SCExAO) enables high angular resolution (17 mas to 21 mas), diffraction-limited imaging from 600nm to 800nm
- 3”x3” FOV; dual-cam polarimetry; sparse aperture masking interferometry; narrowband differential imaging (Hα and SII)
- Upgraded in June 2023 with new detectors, multiband imaging, visible-light coronagraphs, and an achromatic FLC

Instrument Schematic

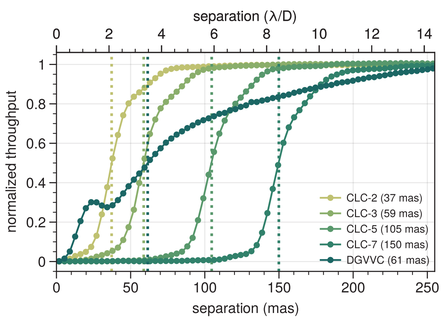


Coronagraphy

VAMPIRES is equipped with four classic Lyot-style coronagraphs and a double-grating vector vortex (DGVVC)

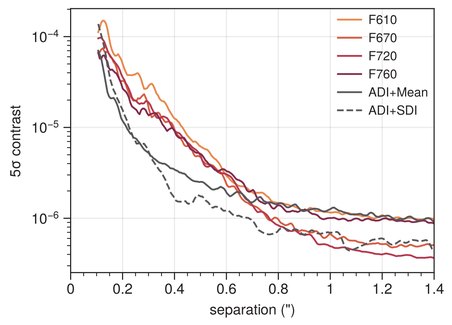


(Above) On-sky coronagraphic PSFs with the CLC-3 and CLC-5 masks. The astrogrid creates calibration speckles for astrometric and photometric calibration



(Above) Throughput curves for each focal plane mask along with the inner working angle

(Below) 5σ throughput-corrected contrast curves from 60 minutes of data (m^R=6, 10° PA rotation) in median conditions (seeing 0.5” ± 0.2”)



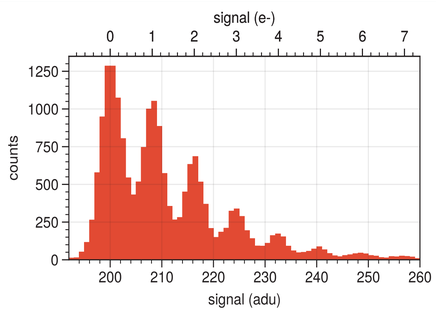
Photon Number Resolving CMOS Detectors

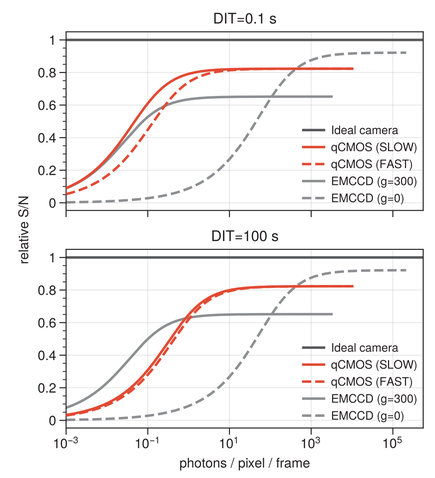
Replaced two Andor iXon Ultra 897 EMCCDs with Hamamatsu ORCA-Quest C15550-20UP qCMOS detectors

Low read noise (0.22 - 0.4 e^-), high dynamic range (85 - 90 dB), high framerate (506 Hz at 3”x3” FOV), low dark current (4x10^{-3} e^-/px/s), simpler to operate, smaller

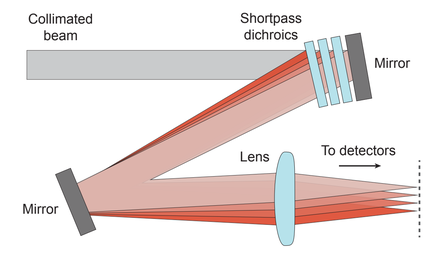
(Top right) histogram of 10^4 pixels in SLOW mode (RN=0.25 e^-). The Poisson peaks are clearly resolved, allowing the unambiguous estimation of the photon number, which is free of read noise.

(Bottom right) signal-to-noise ratio curves, normalized to an ideal camera, for both cameras with two different exposure times. The qCMOS detectors outperform the EMCCDs except for long exposures limited by the higher dark current



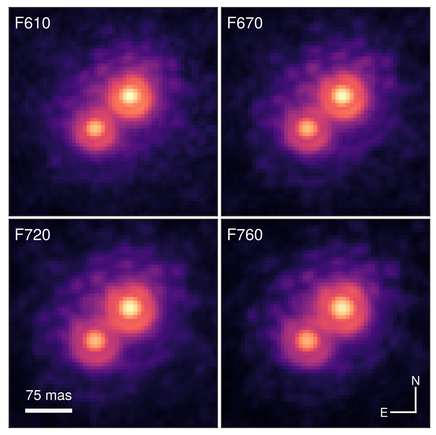


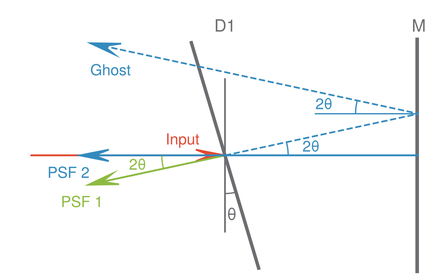
Multiband Imaging

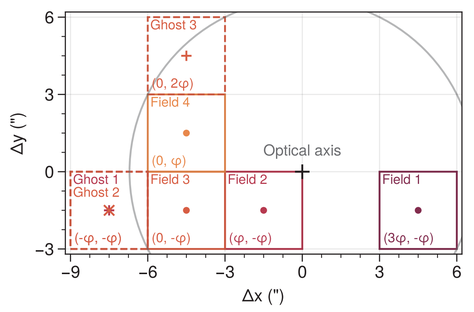


(Above) stack of low angle-of-incidence dichroics splits beam into four fields by wavelength

(Right) On-sky observations of a 75 mas separation binary with multiband imaging







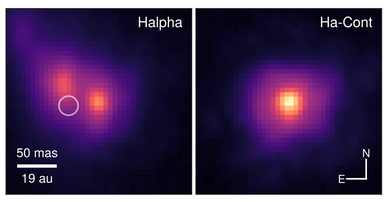
(Left) Ghosts are created by repeated reflections. **(Right)** Geometry is optimized so all ghosts fall outside the four primary fields

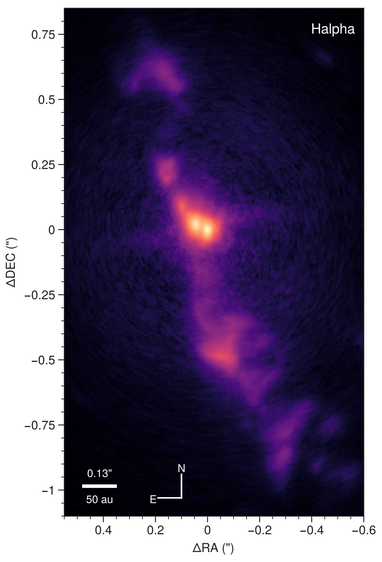
R Aqr Binary + Jet

Symbiotic star comprising a compact accretion disk around a white dwarf (WD) fed by a giant Mira variable star

Hα imaging with 26 mas angular resolution enables direct imaging of the jet emission separate from the AGB star

(Below) expected location of WD is marked with a circle, showing asymmetric emission from the jet



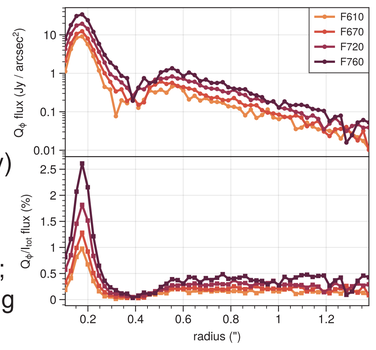


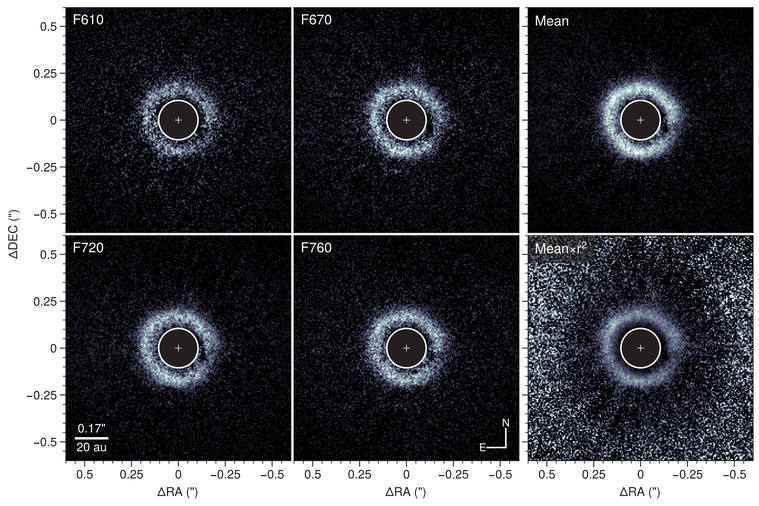
HD 169142 Transition Disk

Measuring wavelength-dependent scattering with multiband imaging plus polarimetry

50 minutes of coronagraphic data without FLC (double-difference only) in okay conditions (0.8” seeing, average LWE)

Clearly resolve inner and outer ring; radial profiles show higher scattering at longer wavelengths



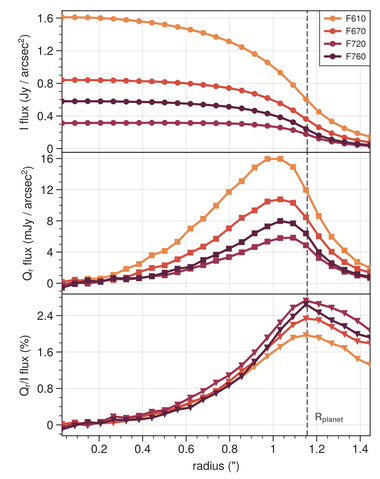


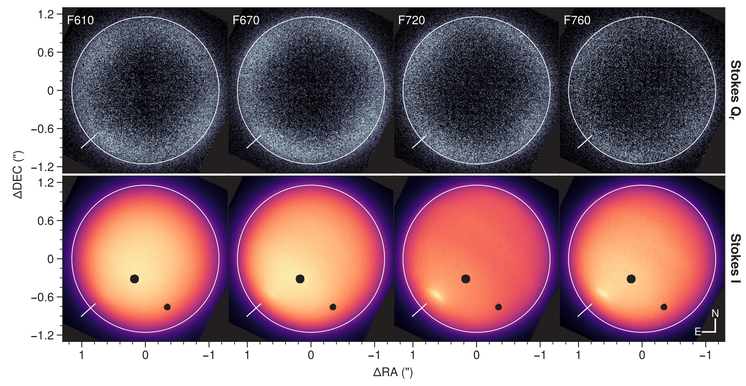
Neptune

20 minutes of data without FLC (double-difference only) in okay conditions (0.8” seeing, average LWE), poor correction due to extended object

(Right) Radial profiles shows wavelength-dependent intensity and scattering

(Bottom) Clear limb-polarization from multiple-scattering in the gaseous atmosphere. The Great white spot and some absorption bands visible in total intensity



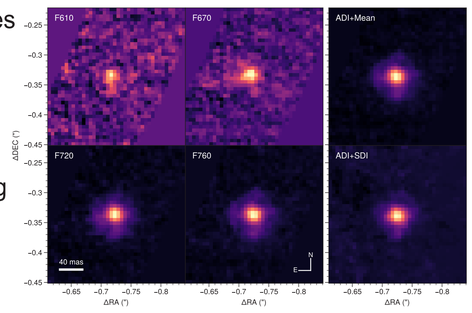


Low-Mass Companion HD 1160 B

Short sequence: 10 minutes of coronagraphic data with 15° of parallactic angle rotation in median seeing (0.6” ± 0.1”)

Angular differential imaging plus spectral differential imaging enabled with multiband imaging

Companion astrometry and SED can be extracted (spectral resolution ~13)



(Above) low-mass companion (M5 to M7 spectral type) at 0.794” separation

Results

- Coronagraphs and low-noise qCMOS detectors enable 10^{-4} to 10^{-6} contrast
- Multiband imaging enables spectral differential imaging, spectro-polarimetry, and SEDs; 4x improvement in observing efficiency
- Polarization well constrained (Zhang+ 2023); characterization for the new instrument is planned work; preliminary results show a ~20% improvement in polarimetric efficiency
- New control framework improves observing efficiency up to 2x thanks to asynchronous device control and FITS operations

Future Prospects

- Near-IR PyWFS + AO3K (Lozi+ 2022) is very exciting for young, dusty, red stars (e.g., circumstellar disk hosts)
- Implement coronagraphic low-order wavefront sensor using reflective Lyot stop and pupil camera (Singh+ 2014)
- First major release of data processing pipeline
- Further evaluation of DGVVC (Doelman+ 2023) and RAP (Leboulleux+ 2022)
- Incorporating focal plane wavefront sensing techniques to address low-wind effect (Ahn+ 2021, Vievard+ 2020)

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