Synergies of Subaru and CGI

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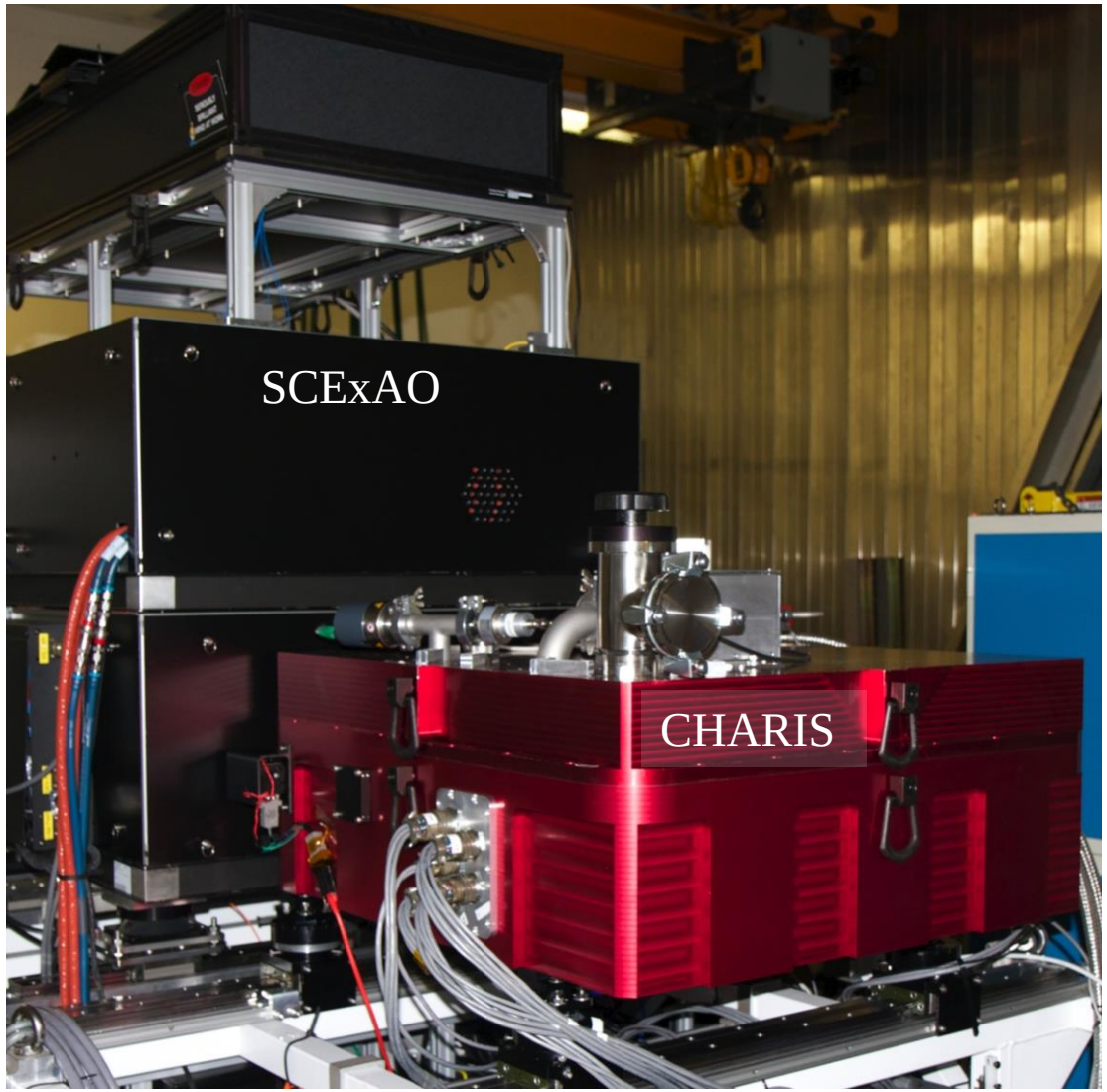
SCExAO and CHARIS

- Major Science Objective:
  - Spectral characterization
    - Exoplanets
    - Disks
    - Brown dwarfs
  - Supports Coronagraph IWA = 3 λ/D = 90 mas
    Current coronagraphs are pushing inside
  - 2.07”x2.07” FOV
  - R~19, J+H+K Band
    - ~53% Throughput
  - R~65-85: J,H, and K Bands
    - ~40% Throughput

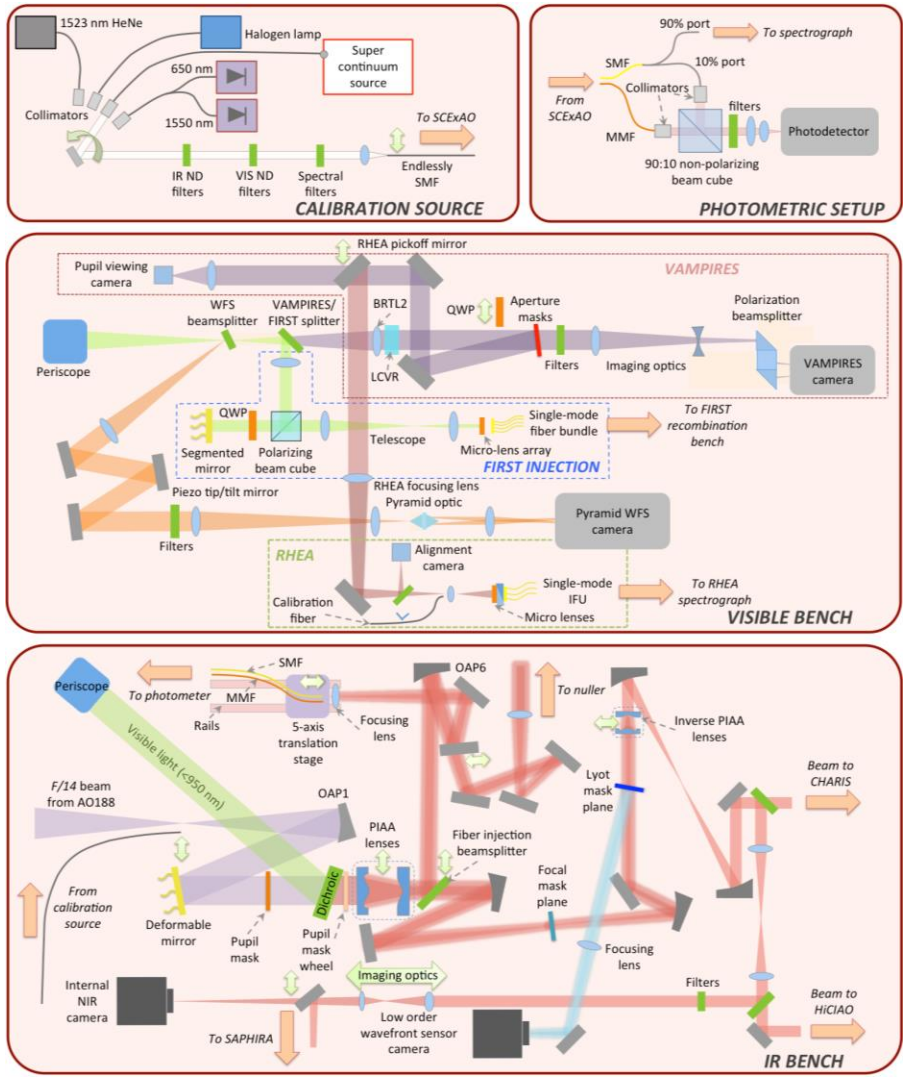


CHARIS work was performed under a Grant-in-Aid for Scientific Research on
Innovative Areas from MEXT of the Japanese government (Number 23103002) (Hayashi, Kasdin)

Subaru's SCExAO Modules and Current Capabilities

The wavefront control feeds a high Strehl PSF to various modules, from 600 nm to K band.

- **Visible (600 – 950 nm):**
  - VAMPIRES, non-redundant masking, polarimetry, with spectral differential imaging capability (h-alpha, SII)
  - FIRST, non-redundant remapping interferometer, with spectroscopic analysis
  - RHEA, single mode fiber injection, high-res spectroscopy, high-spatial resolution on resolved stars
- **IR (950-2400 nm):**
  - HiCIAO - high contrast image (y to K-band)
  - SAPHIRA - high-speed photon counting imager, (H-band for now)
  - CHARIS - IFS (J to K-band)
  - MEC - MKIDs detector, high-speed, energy discriminating photon counting imager (y to J-band)
  - NIR single mode injection, high throughput high resolution spectroscopy. Soon will be connected to the new IRD
  - Various small IWA (1-3 l/D) coronagraphs for high contrast imaging – PIAA, vector vortex, 8OPM
  - GLINT - NIR nulling interferometer based on photonics



Courtesy Nemanja Jovanovic

Jovanovic et al, PASP, 127, 890 (2015)

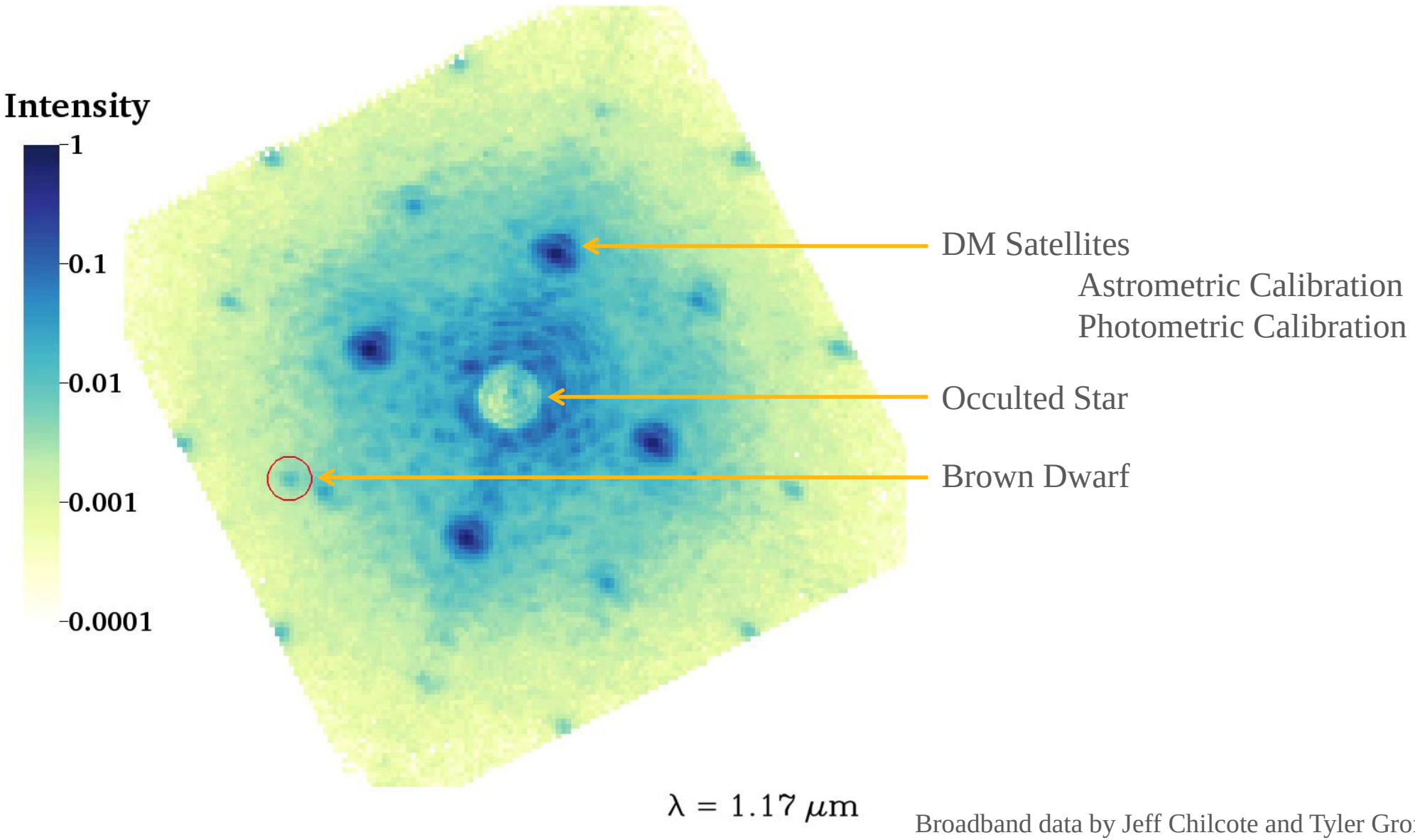
High Level "What can Subaru observations do for CGI"

- Precursor Observations with extreme adaptive optics (ExAO)
  - Any CGI targets of opportunity are Vmag~5, which is well within the wheelhouse of target brightness for Subaru's SCExAO modules. If observable from Mauna Kea they are highly complementary
  - Detection and characterization of binaries and bright (>5e-6 contrast) companions in the near-infrared
    - Potentially some value added science
    - Vetting of targets
  - Disk detection
- Small inner working angle detections using VAMPIRES module
- Conventional AO detection of background objects ahead of CGI observations
  - IRCS

Instrument Phasing with CGI observations

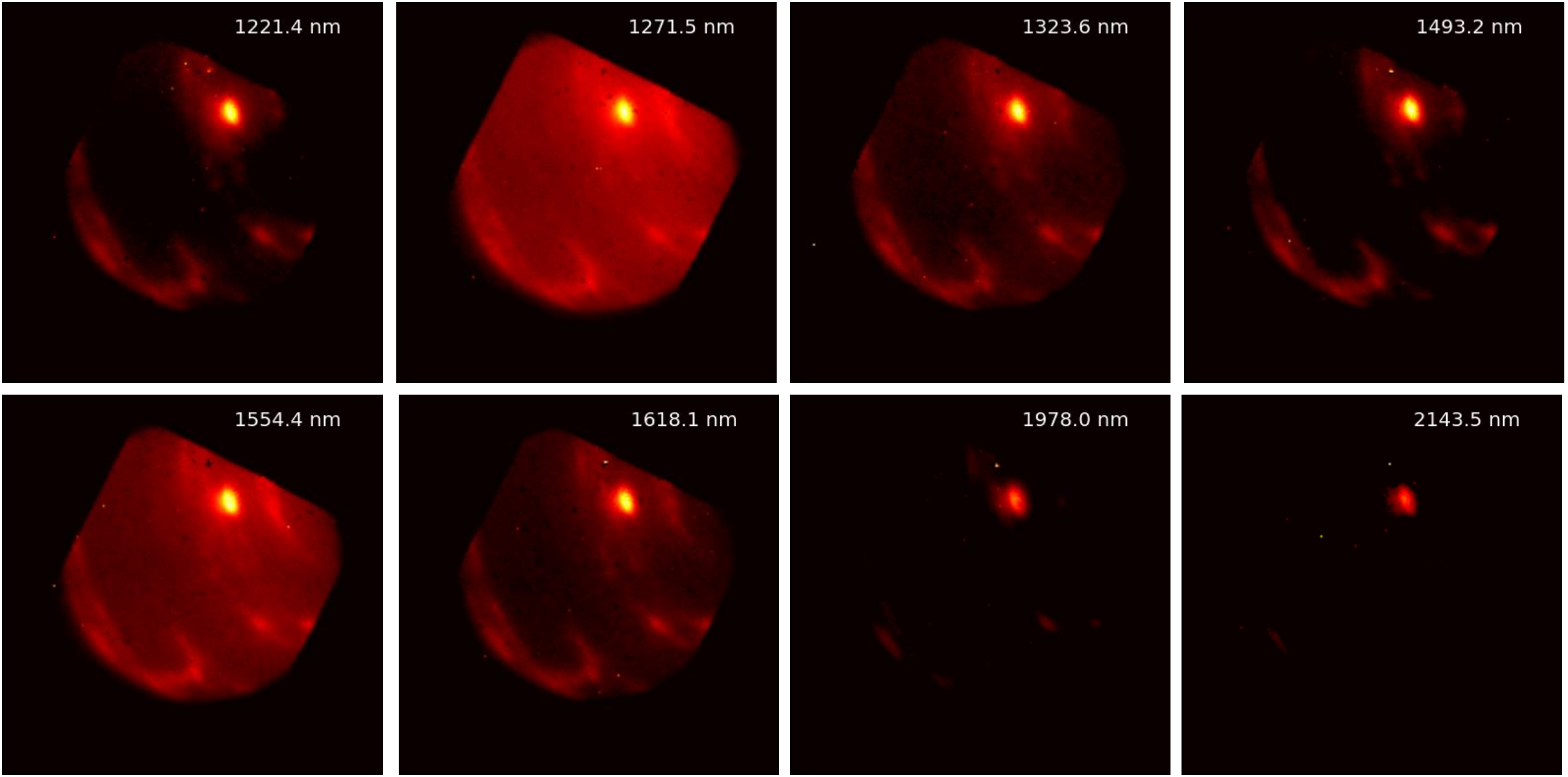
- SCExAO+CHARIS and modules are PI instruments, with a 3-year phasing and re-evaluation
- SCExAO+CHARIS will not longer exist at Subaru by 2026
- Plan is to evolve SCExAO+CHARIS into a TMT instrument by the time CGI observations and potential GO/Starshade missions are in operation
- Consequence
  - Subaru/SCExAO observations of CGI strategic targets would have to be identified and observed in the next few years
  - Assuming a US-Japan collaboration on developing SCExAO+CHARIS for TMT, observations could be planned with CGI to both vet targets and do follow up science if the GO program happens and/or CGI finds something interesting during the technology demonstration
  - The TMT US-Japan collaboration would provide a healthy base for data processing and analysis if CGI has a GO program

Brown Dwarf HD 1160



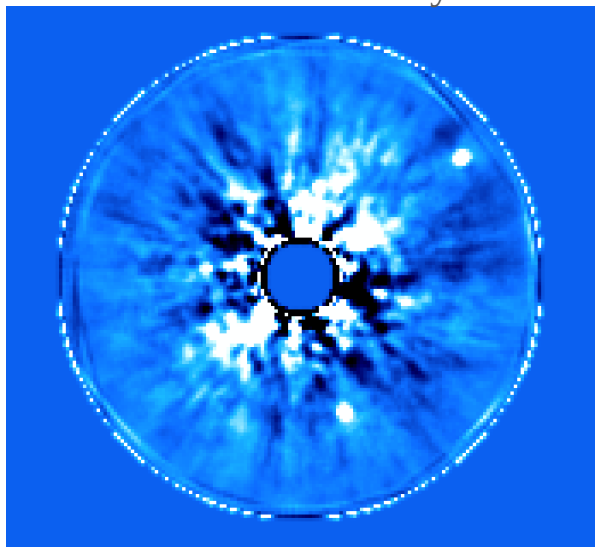
Broadband data by Jeff Chilcote and Tyler Groff
Pretty GIF made by Tim BRandt

Example CHARIS image with Neptune

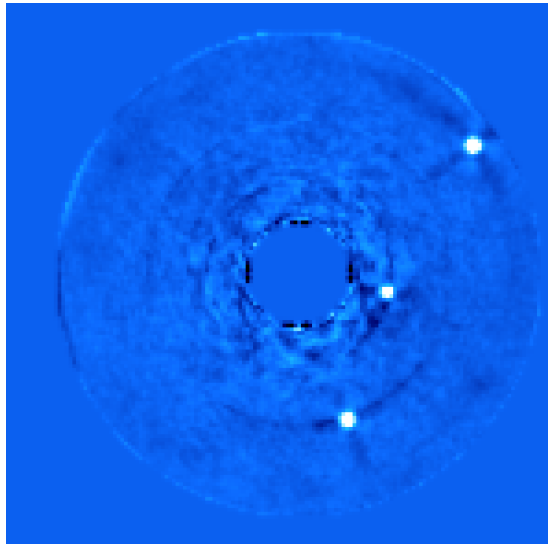


CHARIS First Detections and Analysis by the Team

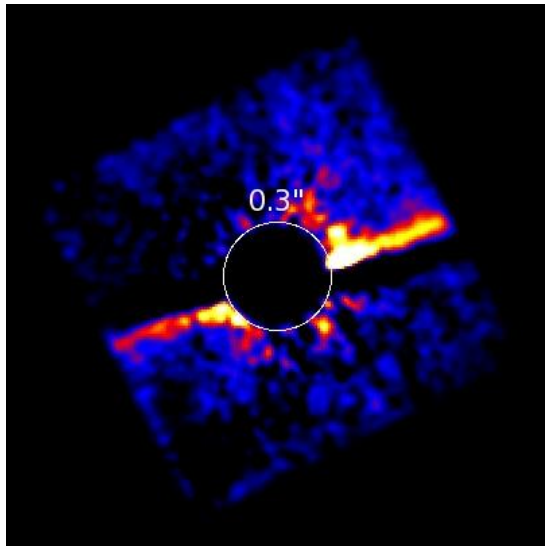
HR8799 ADI only



HR8799 ADI + SDI

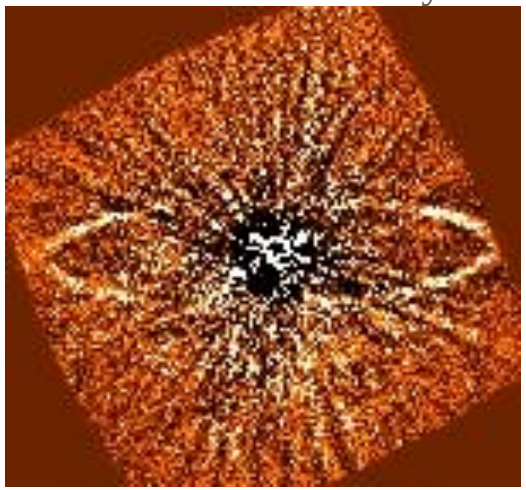


HD32297 Roll Subtracted

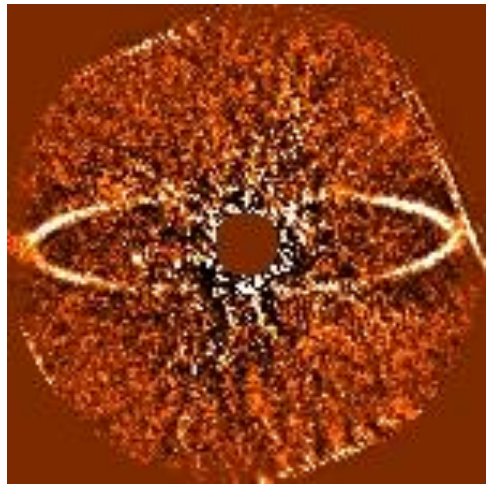


ADI+SDI detection of HR8799 c,d,e at SNR of 50, 35, and 15 respectively (~2-3 x 10^{-5})

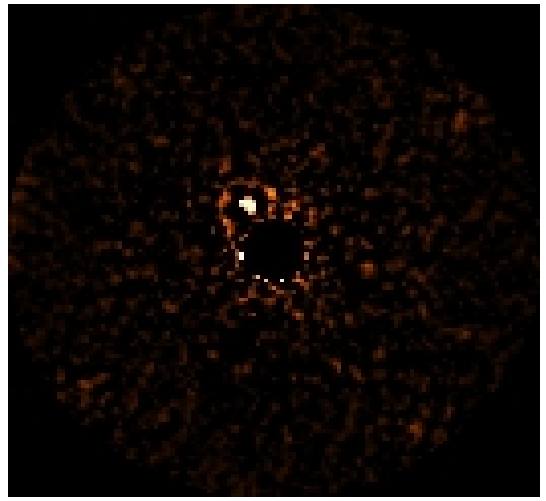
HR4796A - ADI only



HR4796A – ADI+SDI



HD91312 K-band Slice



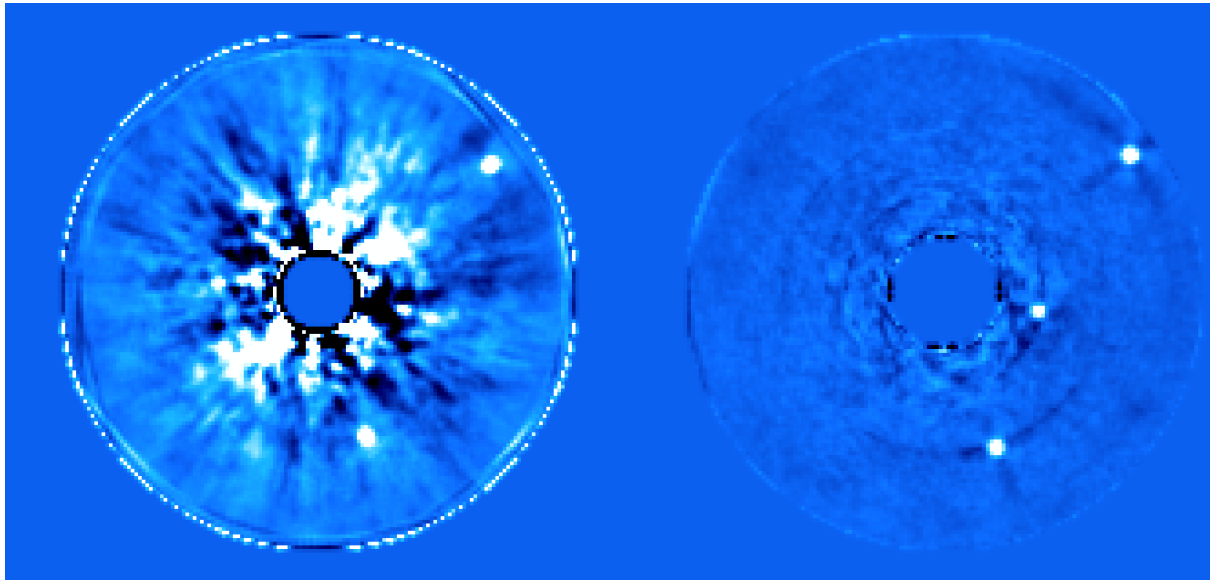
HR8799 preliminary data processing by Tim Brandt, HD32297 Processing by Thayne Currie, Quick HR4796A and HD91312 analysis by M. Rizzo et al.

Post-Processing on ground data

- Post-processing techniques are being assumed for the flight IFS
- Great successes with this on the ground
- Need to test on WFIRST models
  - Interested to see how this could help/demand more from the IFS
  - The Data challenges will be very helpful in answer this

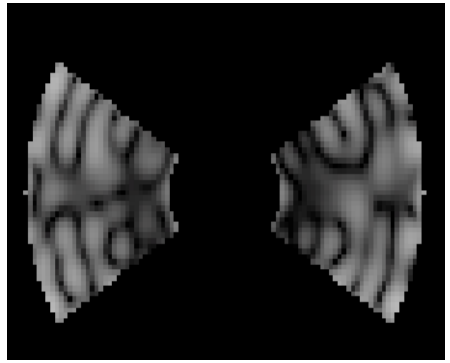
HR8799 ADI only

HR8799 ADI + SDI

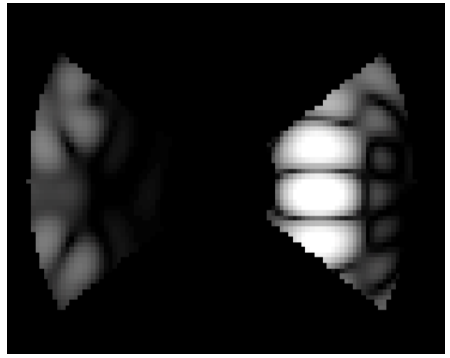


Commissioning data, post-processing by Tim Brandt

SP Image Plane

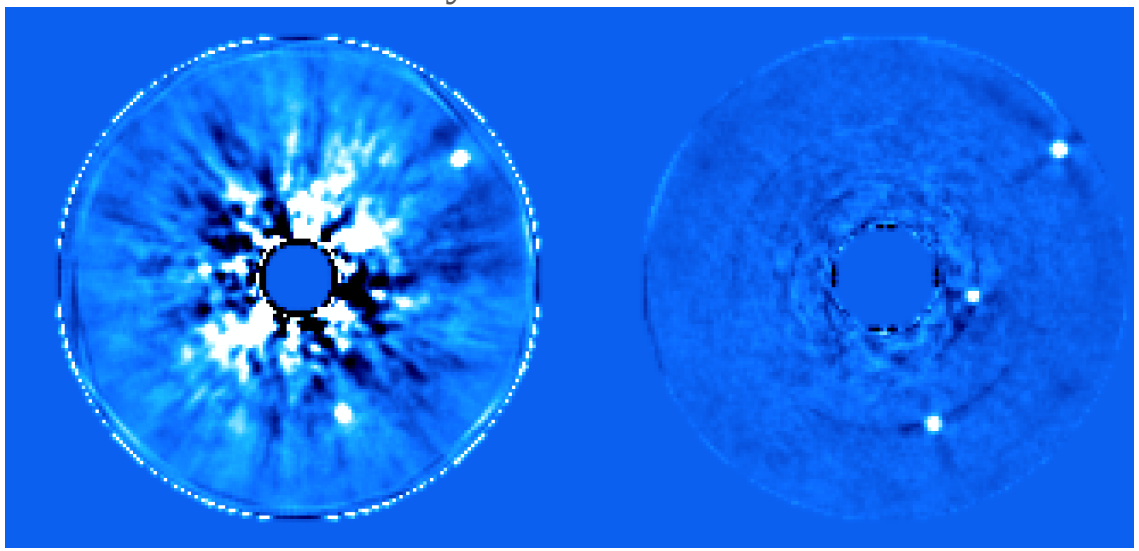


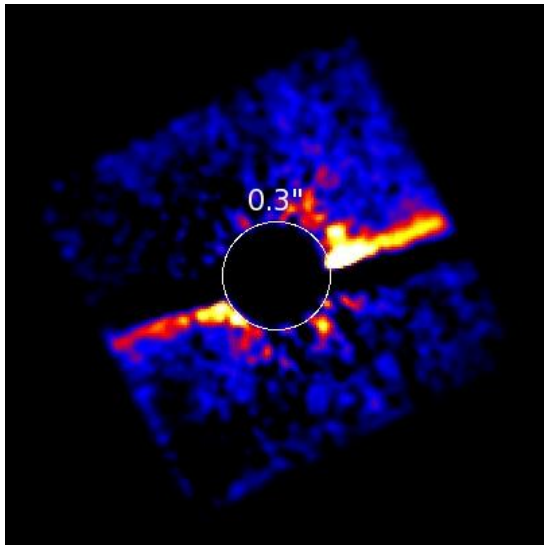
a (bright) planet



Example Subaru Data Products: CHARIS First detections

HR8799 ADI only HR8799 ADI + SDI HD32297 Roll Subtracted





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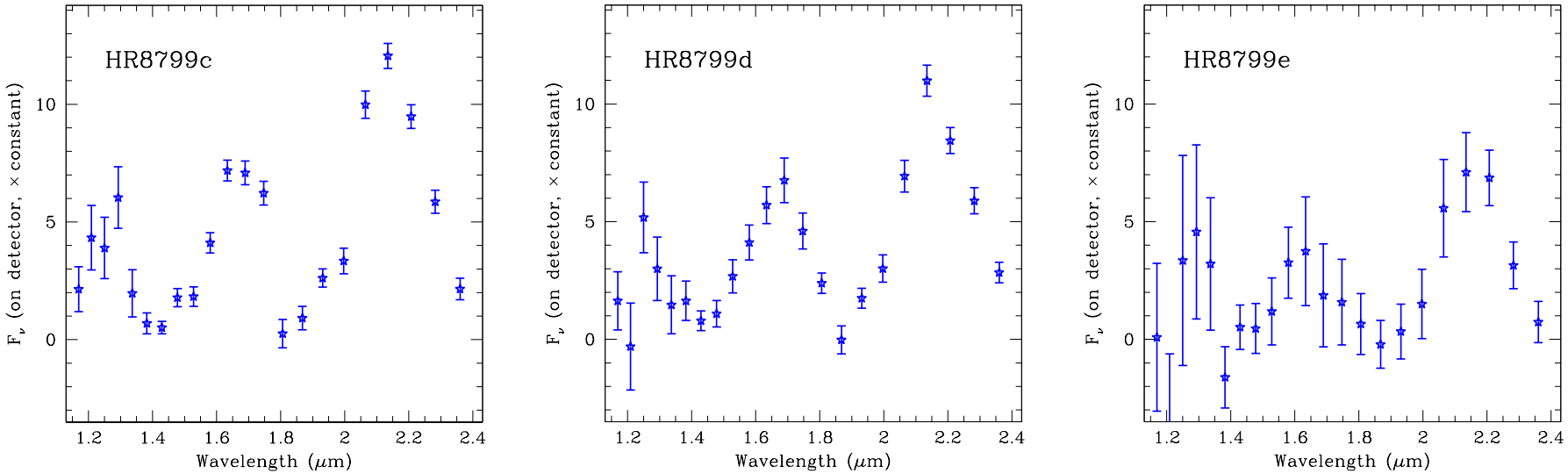
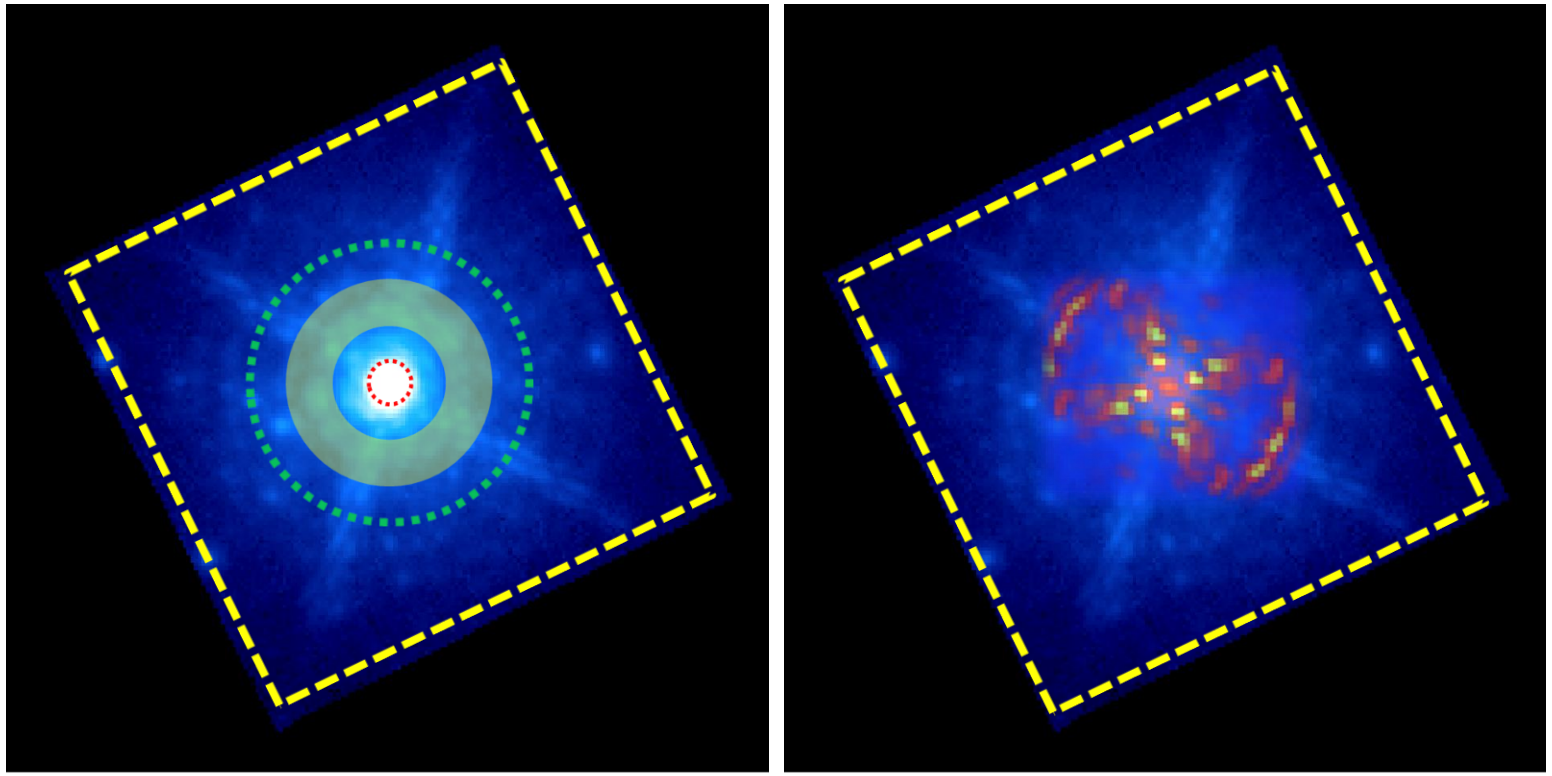


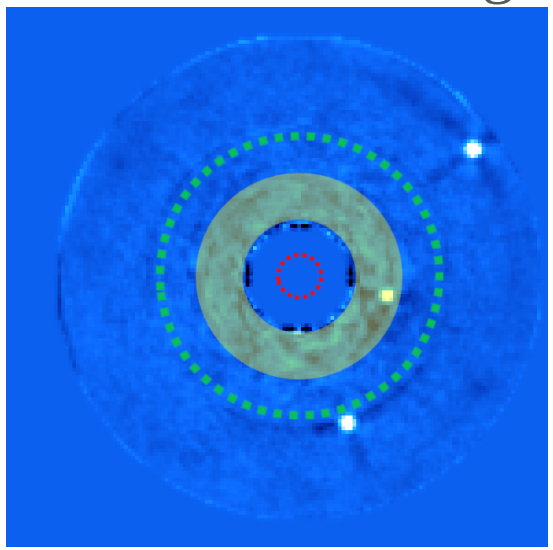
HR8799 preliminary data processing by Tim Brandt, HD32297 Processing by Thayne Currie

Example Observational Overlap

M5 Globular Cluster



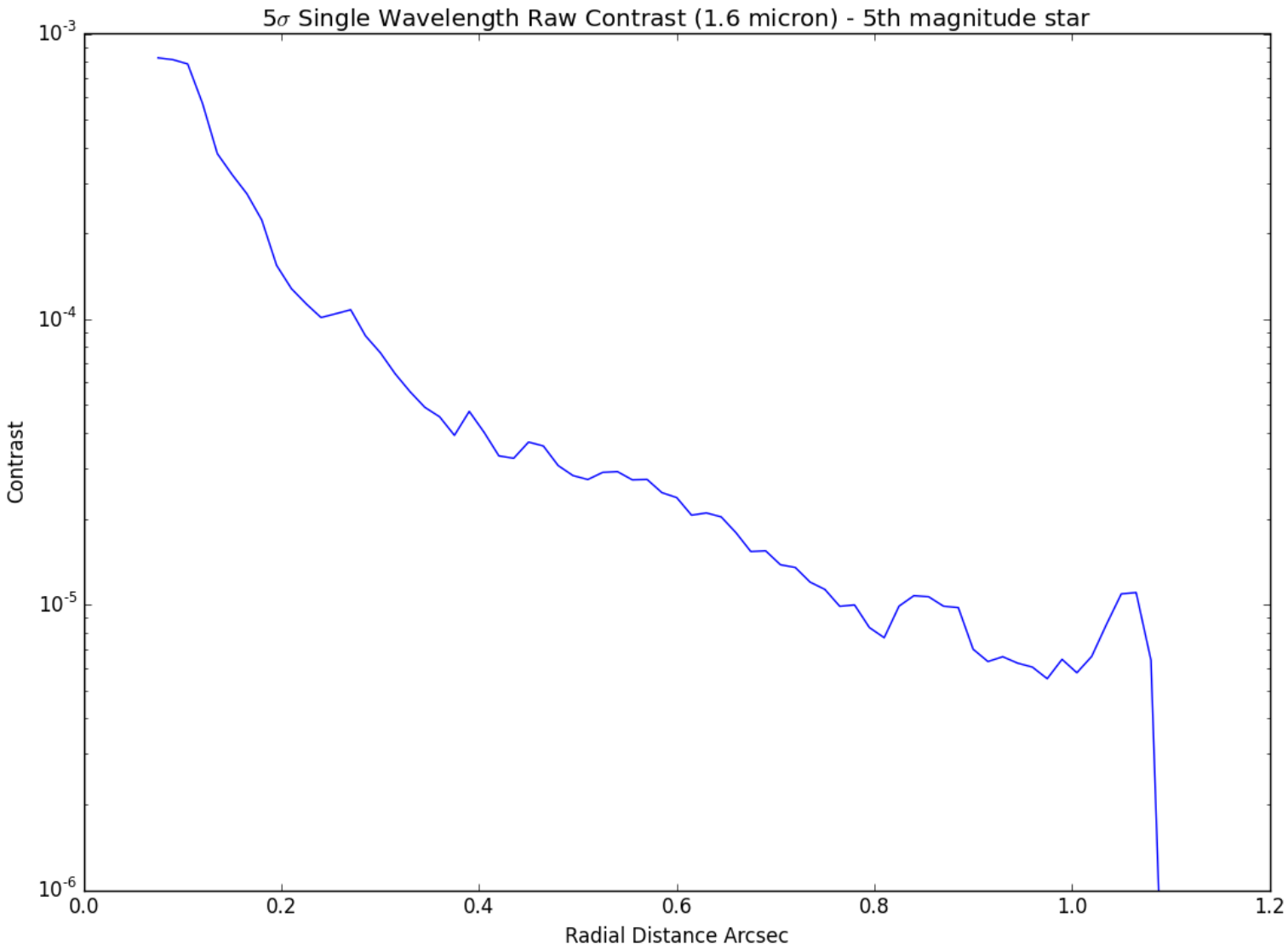
HR8799
w/Post-Processing



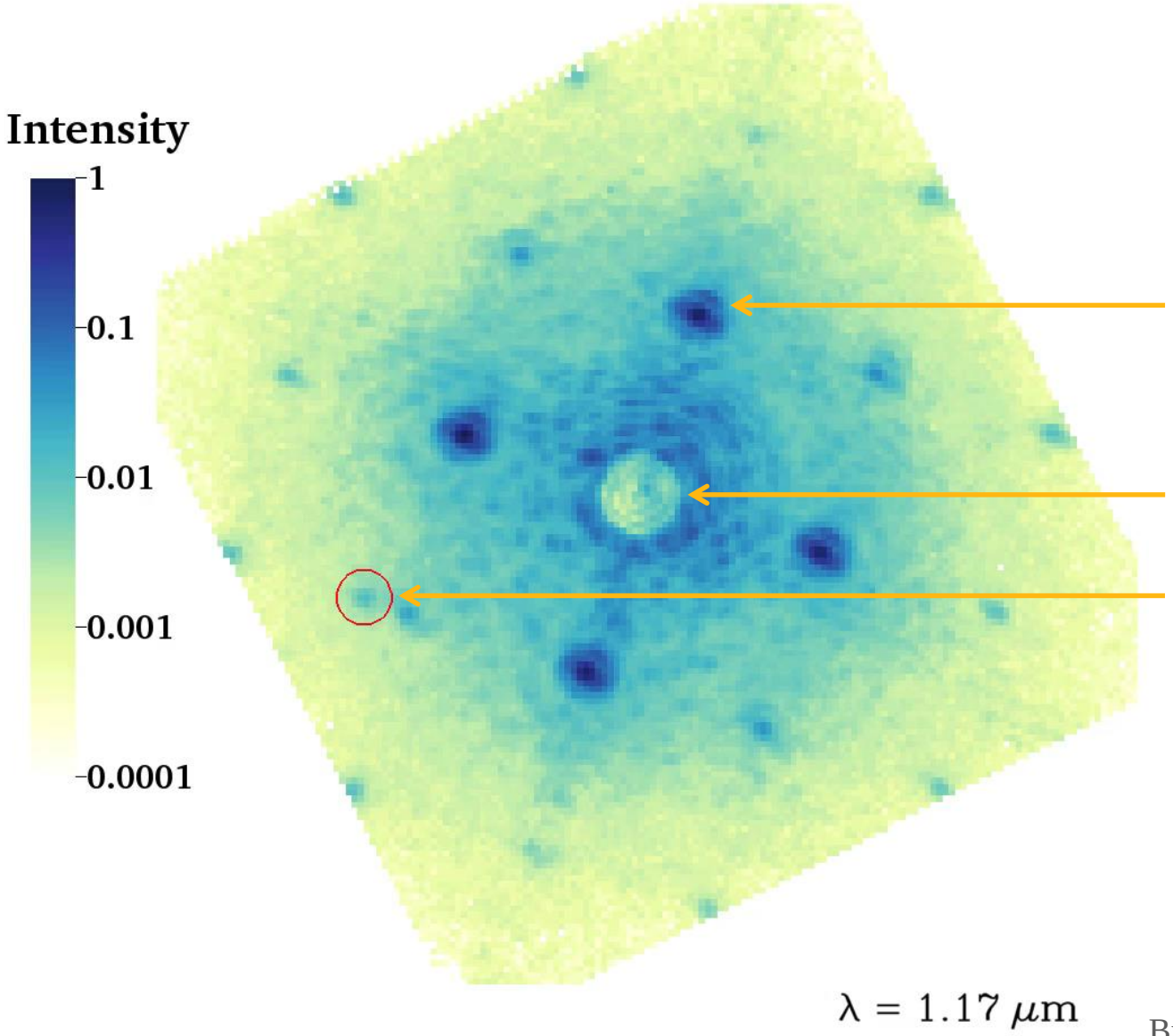
Published CGI FOV overlaid onto a CHARIS image from the Subaru telescope

- Detector field of view
- 10 λ/D (~0.5”) Coronagraph outer working angle
- 3 λ/D radial inner working angle
- Angular separation where requirements are set

Example of capability: First Light Contrast Curve



Brown Dwarf HD1160



DM Satellites
Astrometric and Photometric Calibration

Occulted Star

Brown Dwarf

Broadband data by Jeff and Tyler
Pretty GIF made by Tim

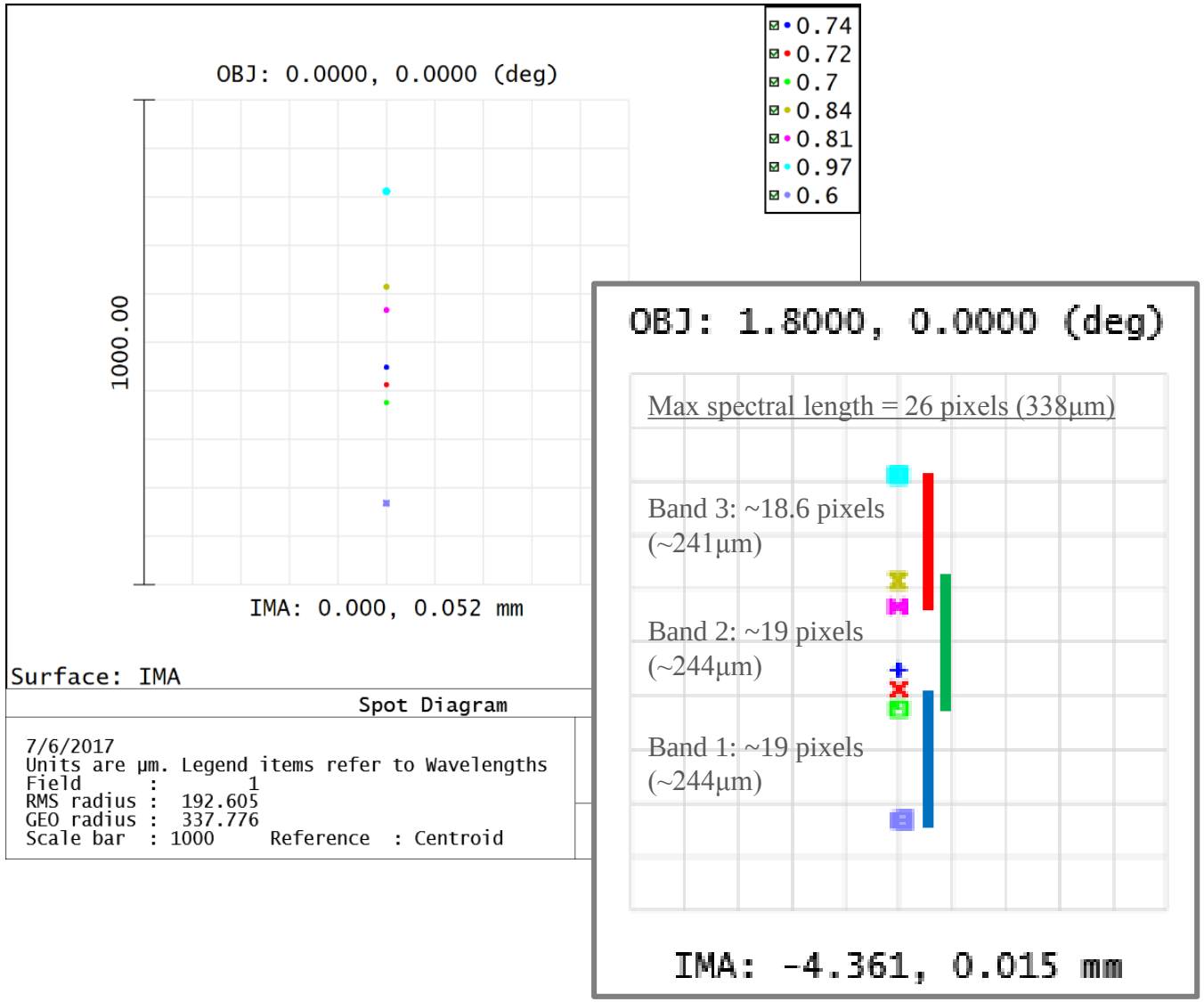
Current Flight IFS Bandpasses

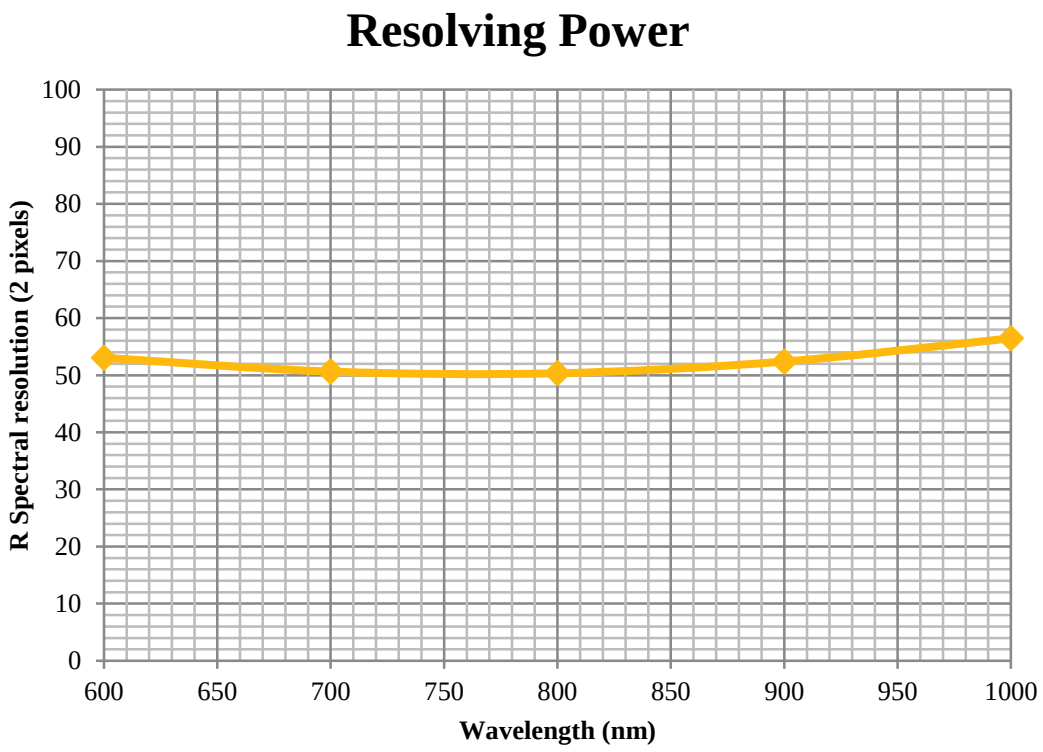
	Center	Cut-on	Cut-off	Bandwidth %
CGI Band 1 (Shaped Pupil)	660	600	720	18.2
CGI Band 2 (Shaped Pupil)	770	700	840	18.2
CGI Band 3 (Shaped Pupil)	890	810	970	18.0
Occulter Band 1	728	656	800	20
Occulter Band 2	910	820	1000	20

- CGI bands are likely to change, and only 1 band will be tested and verified for the technology demonstraiton
- Possibility of a future Starshade mission
  - Compatibility has been an interesting challenge
- These are fundamental drivers in the complexity of the instrument necessary achieve the scientific goals of the coronagraph instrument

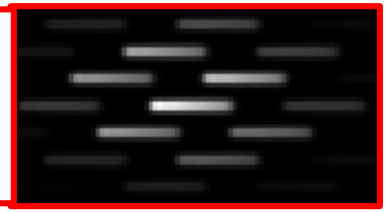
Backup

Baseline IFS Spectral resolution





Visualization of Spectra on Detector



Simulations and Calibration Strategies

- 2D Simulations
  - Noise, detector traps, flux rates, exposure times, and co-adding
  - Includes Reference differential image (RDI)
    Model accepts J.Krist dyanamic data (currently OS5 data)
    Useful in setting constraints on lenslet sampling of PSF
  - Matched filter spectral extraction
    Used to simulate the science product for SITs and modelers
- IFS Calibrations
  - Dispersion and lenslet PSF templates characterized pre-launch
  - On-orbit calibration is to re-register image on detector (x,y,θ)
  - Wavelength verifications requires astrophysical standards
  - Developing method to calibrate detector registration on-orbit.
    - Reduce risk of not having a calibration source.
    - Improves efficiency of IFS operations
  - Calibration operations that rely only on DM commands
    - Reduces stability requirements
    - No need to re-point telescope to calibrate IFS
    - Increases frequency that we could recalibrate