Synergies of Subaru and CGI

Tyler D. Groff
SCExAO and CHARIS

- Major Science Objective:
  - Spectral characterization
  - Exoplanets
  - Disks
  - Brown dwarfs

- Supports Coronagraph IWA = 3 $\lambda/D = 90$ 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)
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 – PIIAA, vector vortex, 8OPM
  - GLINT - NIR nulling interferometer based on photonics

**Courtesy Nemanja Jovanovic**
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
SCExAO+CHARIS and modules are PI instruments, with a 3-year phasing and re-evaluation.

SCExAO+CHARIS will no 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.
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

Commissioning data, post-processing by Tim Brandt

SP Image Plane

HR8799 ADI only

HR8799 ADI + SDI

a (bright) planet
Example Subaru Data Products: CHARIS First detections

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)

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 \( \lambda/D \) (~0.5") Coronagraph outer working angle
- 3 \( \lambda/D \) radial inner working angle

Angular separation where requirements are set
Example of capability: First Light Contrast Curve
Brown Dwarf HD1160

Intensity

DM Satellites
Astrometric and Photometric Calibration

Occulted Star

Brown Dwarf

$\lambda = 1.17 \mu m$

Broadband data by Jeff and Tyler
Pretty GIF made by Tim
Current Flight IFS Bandpasses

<table>
<thead>
<tr>
<th></th>
<th>Center</th>
<th>Cut-on</th>
<th>Cut-off</th>
<th>Bandwidth %</th>
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<td>660</td>
<td>600</td>
<td>720</td>
<td>18.2</td>
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<tr>
<td>Occulter Band 2</td>
<td>910</td>
<td>820</td>
<td>1000</td>
<td>20</td>
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- 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 to achieve the scientific goals of the coronagraph instrument
Baseline IFS Spectral resolution

Resolving Power

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 dynamic 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