SCExAO: Enabling Deep Contrast Exoplanet Observations at the Diffraction Limit with New Technologies

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TEAMS: **GLINT, FIRST, VAMPIRES, NIR-PL, MEC, SPIDERS, AO3k**

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OVERVIEW

Due tti the extreme contrast between exoplanets and their host stars, direct imaging and spectroscopy of exoplanets poses significant technical challenges. The SCExAO system is actively participating in the development of promising new technologies to meet this challenge and provide unique capabilities to Subaru users.

Detectors:
- MEC (upgrade ongoing at UCSB)
- CRED1 now permanently installed for fPDI and photonic spectrograph

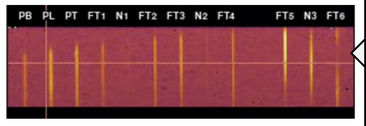
Astrophotonics:
- GLINT nuller operated in NIR
- Photonic spectrograph used by GLINT and NIR-PL, shared camera with fPDI
- Photonic lantern -> see poster P27

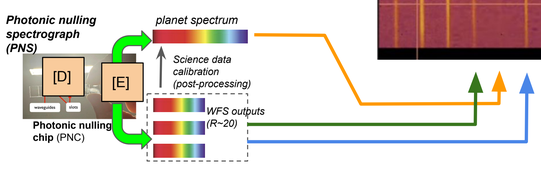
Wavefront control and Speckle control:
- Algorithms: PSF reconstruction, Optimal AO control
- SPIDERS

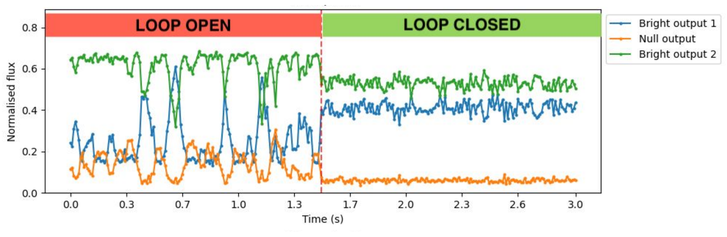
RECENT HIGHLIGHTS - GLINT

On-sky demonstration of active nulling using signal from photonic chip
GLINT chip used for both nulling and WFS
Null stabilized by control loop

GLINT team (Rossini-Bryson et al. 2025), in prep

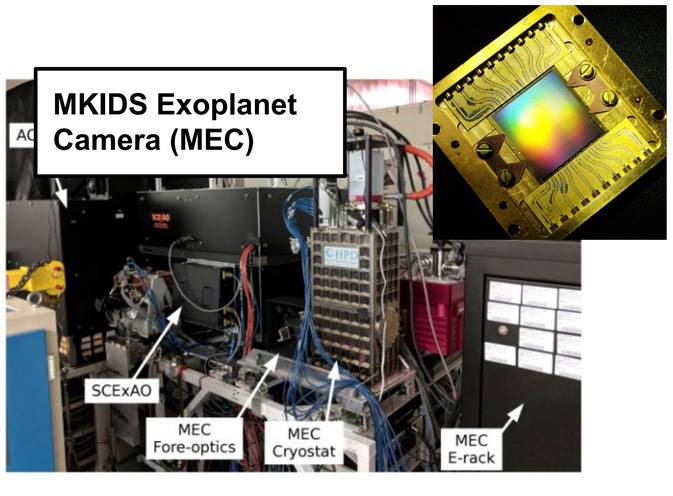






DETECTORS

- Photonic Spectrograph now using ImAPD technology (CRED1)
- MEC camera (using MKIDS) currently undergoing upgrades at UCSB - will be shipped back to Subaru in ~1.5yr

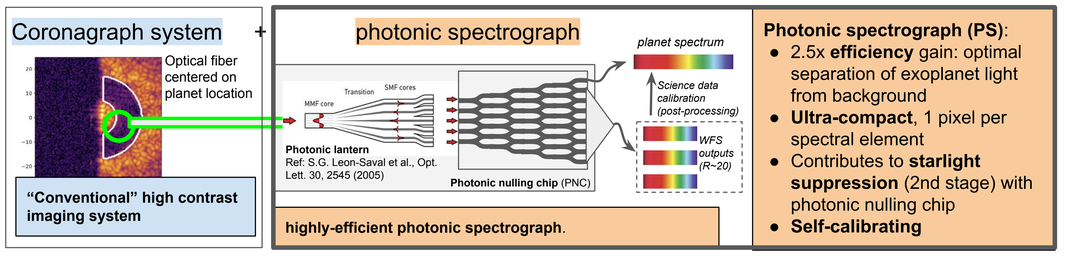


PHOTONIC SPECTROGRAPH CONCEPT

INJECTION INTO PHOTONIC DEVICE
Direct or post-coronagraph
Lenslet array (GLINT), or PL (FIRST)

PHOTONIC PROCESSING
Nulling (GLINT)
WFS (GLINT, FIRST)
Spectro-imaging (FIRST, ExoNINJA)

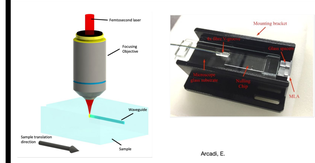
SPECTROGRAPH
Array of SMFs dispersed on detector



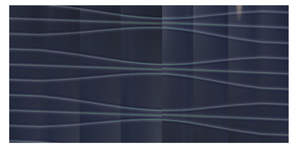
Photonic spectrograph (PS):
- 2.5x **efficiency** gain: optimal separation of exoplanet light from background
- **Ultra-compact**, 1 pixel per spectral element
- Contributes to **starlight suppression** (2nd stage) with photonic nulling chip
- **Self-calibrating**

Example architecture optimized for exoplanet spectroscopy (for Subaru, HWO and TMT)

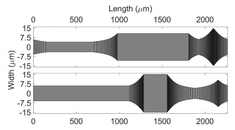
GLINT PHOTONIC CHIP



Photonic Chip is 3D written by ultrafast laser inscription (ULI)



Tricouplers allow for symmetric light combination

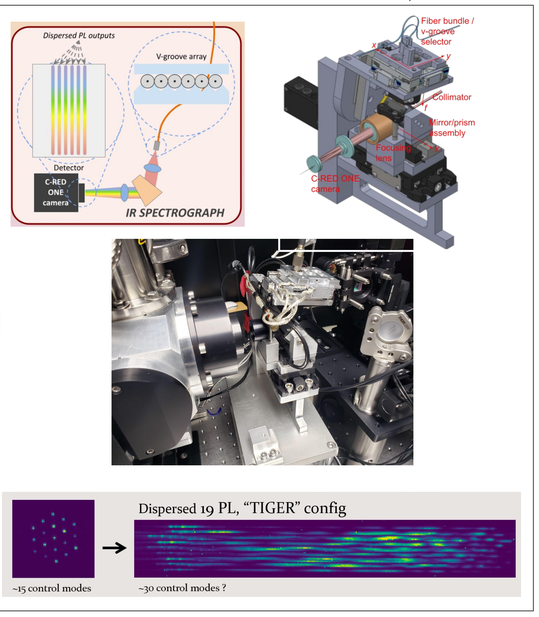


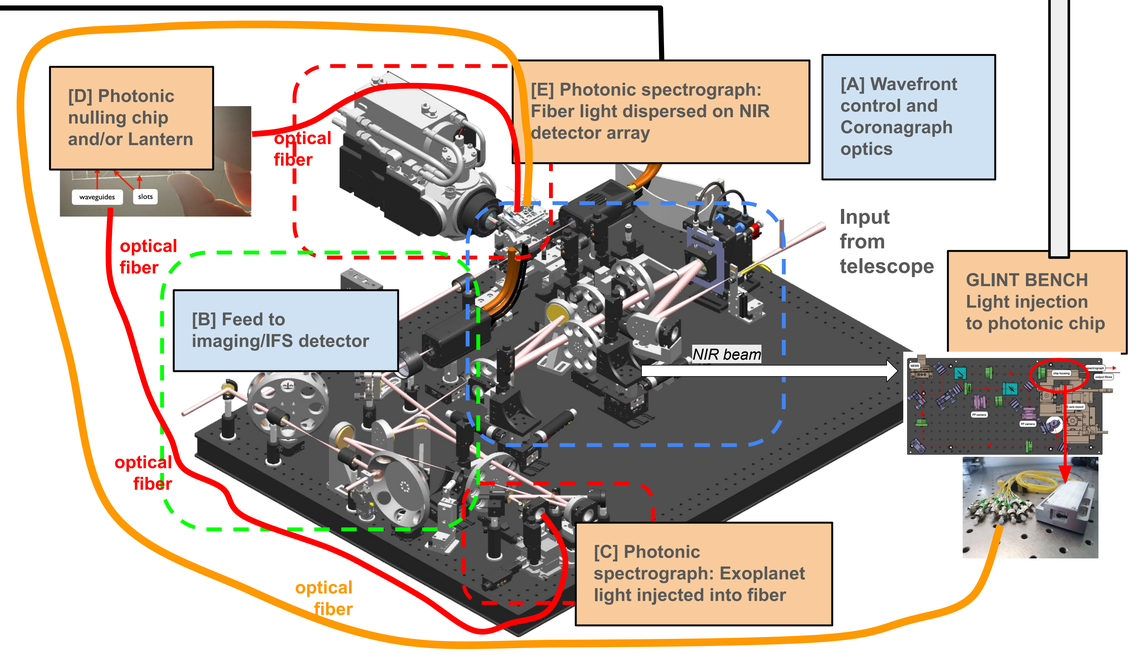
Achromatic phase shifters maintain broadband null

UPCOMING: Thermal-actuated phase shifters

PHOTONIC SPECTROGRAPH IMPLEMENTATION ON SCExAO (NIR)

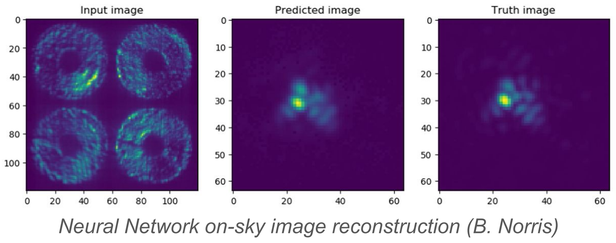
SPECTROGRAPH



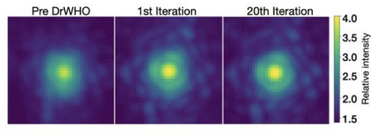


PSF RECONSTRUCTION

GOALS:
- **Calibrate and remove speckle noise from science data**
  -> access deeper contrast for exoplanet imaging and spectroscopy
  "speckles" refers here to unwanted starlight in both focal plane imaging and photonic spectrograph
- **Deep speckle nulling** on-sky



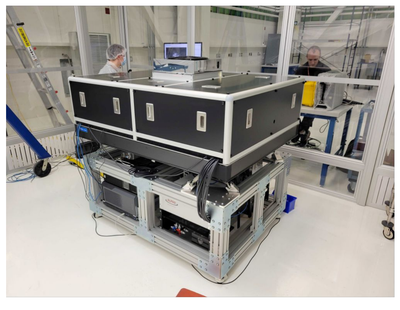
Neural Network on-sky image reconstruction (B. Norris)

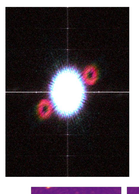


AO WFS referencing (N. Skaf et al 2022)

SCExAO system optimized for telemetry data acquisition and synchronization for PSF reconstruction. Able to acquire ~100 TB/night. Algorithm development ongoing.

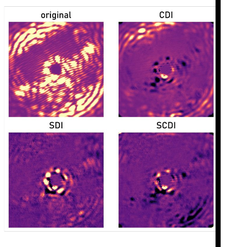
REVEALING NATURE OF SPECKLES WITH SPIDERS

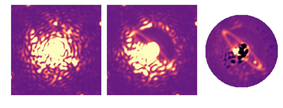




Spectro-Coherent Differential Imaging

- Suppress speckles using DM at one wavelength
- Record fringed images at all wavelengths
- Use spectral differential imaging and coherent differential imaging on the same dataset





SPIDERS (PI: C. Marois) will measure speckles in coherent light, at high speed and high spectral resolution -> will establish limits to high contrast imaging on Subaru and guide future developments

Acknowledgements

The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Maunakea has always had within the Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain.
The development of SCExAO was supported by the National Astronomical Observatory of Japan (NAOJ), the Astrobiology Center of the National Institutes of Natural Sciences, Japan, the Subaru Telescope, the Japan Society for the Promotion of Science (Grant-in-Aid for Research #23340051, #26220704, #23103002, #19H00703 & #19H00695), and the Mt Cuba Foundation.
Wavefront control R&D activities received support from the Heising-Simons foundation and NASA (Grant #80NSSC19K0336). LDFC development is supported by NASA Strategic Astrophysics Technology grant #80NSSC19K0121. NS acknowledges support from the PSL Iris-OCAV project.