SCExAO / GLINT and NIR photonics

Olivier Guyon[a,b,c], Julien Lozi[a], Sebastien Vievard[a,d], Garima Singh[a], Sandrine Juliard[a,c]
Peter Tuthill[e], Barnaby Norris[e], Simon Gross[f], Stephanie Rossini-Bryson[e], Elizabeth Arcadi[f], Glen Douglas[f], Matteo Columbo[e], Mona El Morsy[g], Yoo-Jung Kim[h,i], Nemanja Jovanovic[i], Sergio Leon-Saval[e], Yinzi Xin[i,j], Mike Fitzgerald[h]

[a] *Subaru telescope,* [b] *Astrobiology Center,* [c] *Univ. of Arizona,* [d] *Univ. of Hawaii,* [e] *Univ. of Sydney,* [f] *Macquarie Univ,* [g] *Univ. of Texas San Antonio,* [h] *UCLA,* [i] *Caltech,* [j] *Leiden Univ.*

Contact: guyon@naoj.org

OVERVIEW

The SCExAO system is supporting new development in NIR photonics to enable detection and spectroscopic characterization of exoplanets with sensitivity and precision superior to what can be realized with conventional optics. the main science drivers for these activities are:

- Detection and characterization of exoplanets at small angular separation, reaching into the habitable zones of stars
- Access to lower mass and older planets at deeper contrast levels

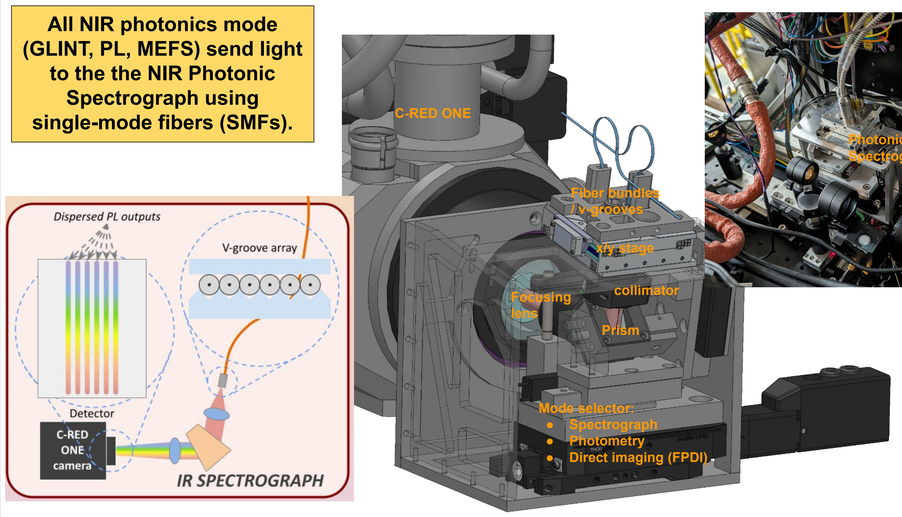
Photonic technologies also provide higher precision measurements.

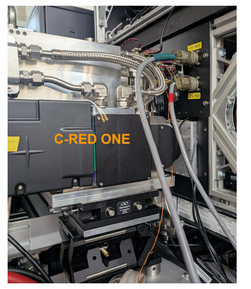
This poster provides an overview of these activities in the nearIR:

- The **GLINT instrument module** integrates wavefront control and starlight suppression using a photonic nulling chip
- The **NIR photonic lantern (PL)** provides high-fidelity wavefront sensing and image reconstruction, as well as spectro-astrometry.
- Photonic devices are enabling high-efficiency exoplanet spectroscopy. We are maturing the **Matched Electric Field Spectroscopy (MEFS)** concept to enable high-performance exoplanet spectroscopy for Subaru as well as future missions/projects (HWO, TMT).

NIR Photonic Spectrograph

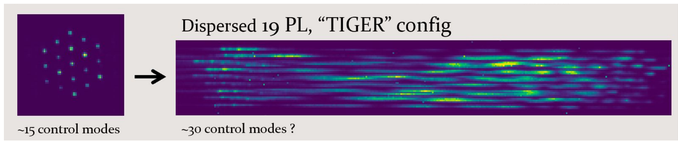
All NIR photonics mode (GLINT, PL, MEFS) send light to the the NIR Photonic Spectrograph using single-mode fibers (SMFs).





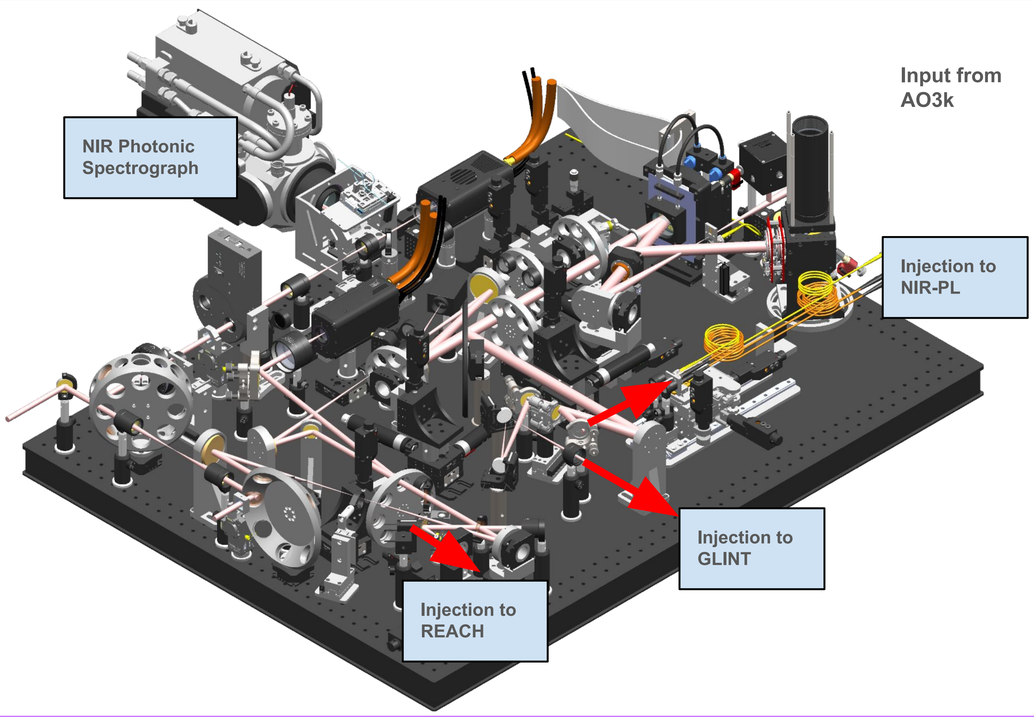
NIR Photonic Spectrograph Design

Takes as input a 1D or 2D compact array of single-mode fibers (SMFs). Spectral dispersion by prism. Detector is a low-noise high frame rate MCT array with in-pixel amplification to approach photon-counting performance.
Max # of channels: ~50
Spectral range: 0.9-1.7um
Spectral resolution: ~200



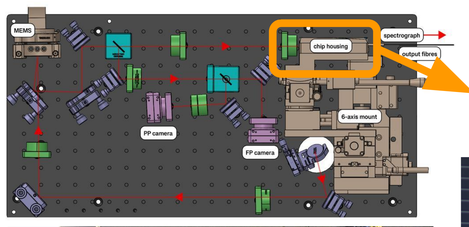
Funding by NAOJ/TMT dev. fund, JSPS/GLINT
Design+realization: J. Lozi

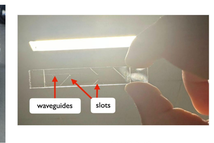
NIR PHOTONIC INFRASTRUCTURE @ SCExAO



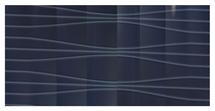
GLINT

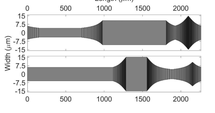
GLINT integrates wavefront sensing, control, and starlight suppression (nulling) in a photonic chip. It can detect exoplanet light at smaller angular separation than conventional coronagraphs thanks to interferometric nulling and self-calibration. ***GLINT will be offered to Subaru observers for exoplanet detection and spectroscopy.***



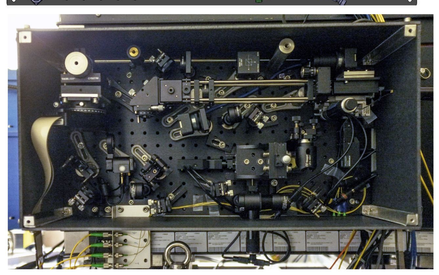


The photonic nulling chip (PNC) is laser-inscribed in glass (right). Left: The PNC is connected to single-mode fibers (SMFs) that direct light to the photonic spectrograph.



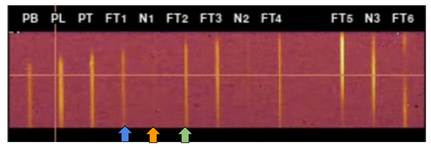


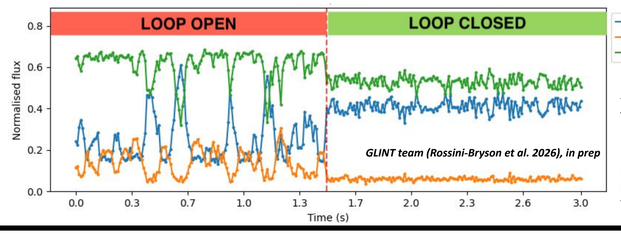
To deliver broadband starlight suppression, GLINT's PNC relies on the symmetry provided by tricouplers (left) and fine chromatic control of phase with achromatic phase shifters (right).



The GLINT optical bench injects light in a photonic nulling chip that performs wavefront sensing and starlight suppression. Wavefront correction is done with a segmented deformable mirror, visible here at the top right of the bench. Top: CAD, bottom: image.

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





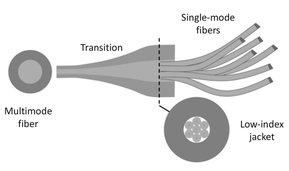
Top: Photonic spectrograp raw image. Vertical axis is wavelength (1 to 1.7 um) Each vertical line is a dispersed SMF output.

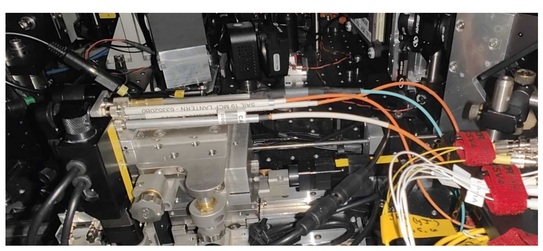
Left: On-sky close loop validation. The FT1 and FT2 outputs are driving a real-time control loop by upstream DM actuation to cancel starlight in the science (null) output N1.

NIR Photonic Lanterns

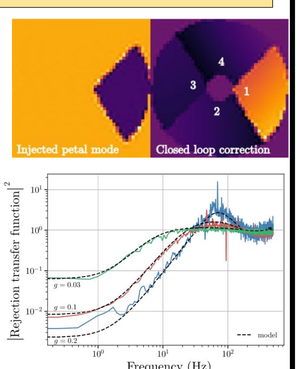
NIR-PL is uniquely powerful for wavefront sensing and specro-imaging/astrometry at and below the telescope diffraction limit. ***NIR-PL's interferometric output provides measurement accuracy not possible with conventional bulk optics.***

In a PL, light transitions adiabatically (no loss) from the MMF input to multiple SMF outputs. **The PL performs a modal decomposition of the input electric field** over a small FOV.





Several NIR PLs are mounted on a 5-axis precision motorized stage for injection. Light enters from the left into the PLs (straight sections) and exists to the right as multiple SMFs, connected to the photonic spectrograph. This injection is pre- coronagraph..



Demonstration of adaptive optics control using the NIR-PL as a wavefront sensor on SCExAO. Lin et. al 2023

Matched Electric Field Spectrograph (MEFS)

MEFS uses coronagraphy + photonics to enable high efficiency spectroscopy of exoplanets at small angular separation. Its active photonic circuit concentrates exoplanet light into a single mode fiber (SMF) before sending it to the photonic spectrograph. ***MEFS is our proposed architecture for future exoplanet spectroscopy with Subaru, TMT and HWO, and is under active development.***

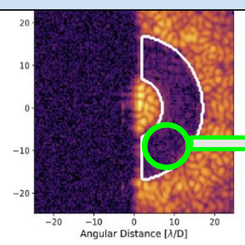
"Conventional" high contrast imaging system, optimized for efficiency and IWA
~1e-7 contrast over ~50% spectral bandwidth

Wavelength splitting to multiple photonic circuits, each processing a ~5% or broader spectral range

Photonic Layer
Concentrates and separates planet light from residual starlight
Improves contrast by ~100x
Operates in ~ >5% spectral band

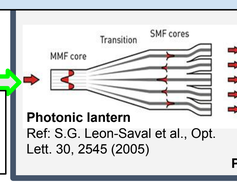
Single Mode Spectrograph

Single mode fiber (SMF)



Photonic circuit matches planet EF to spectrograph SMF

Small field centered on planet location is coherently coupled to photonic circuit



Photonic lantern
Ref: S.G. Leon-Saval et al., Opt. Lett. 30, 2545 (2005)

Photonic nulling chip (PNC)

planet spectrum

I_0 I_1 I_2

Non-planet light used for wavefront sensing / control and signal calibration

MEFS as proposed for HWO mission
Credit: MEFS team

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 and the Mt Cuba Foundation.