

# Dark Hole Algorithms Working Group

## 3/10/2021: Wavefront sensing on SCExAO and system ID

Link to presentation file:

[DAWG\\_2021-03-10\\_Deo\\_Pairwise.pdf](#)

Our goal for this meeting was to address the idea of integrating low-order wavefront sensor telemetry into the overall control and sensing strategy. With the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), Olivier's team has been developing a strategy combining AO WFS and science focal plane sensing.

We began the meeting with a presentation by Olivier on SCExAO.

- SCExAO is both a technology testbed and a scientific instrument.
- one major difference from space coronagraphy is that ground-based coronagraph like SCExAO tend to rely more on empirical calibration of the system response (G matrix) than models.
- Some key research areas at SCExAO are sensor fusion, alternative wavefront sensor designs, and post-processing calibration.
- The team is also looking at spatial light modulators for high-contrast imaging.
- Integrated SAPHIRA and MKIDS detectors
- Using photonic chips for WFS
- Some weaknesses of the testbed: less stable (in air) and no high-fidelity mode  
Strengths: flexibility, large number of sensors and modes, and a natural path to on-sky testing

- Speckle control with focal plane sensor has been demonstrated with an internal source.
- Also testing interferometric wavefront sensing and nulling - with waveguides etched in a chip - FIRST (visible) and GLINT (NIR).
- Comment from Laurent Pueyo: In terms of WFS/telemetry there might be a sweet spot application for low-noise detector technologies that might not be ready to be used as a science detector (say "not enough" pixels or smallish spectral bandpass) but could be tremendously useful for DH maintenance/post processing with future missions.

Vincent presented a HOWFS experiment underway at the NASA Ames PIAA testbed, in which pairwise probe data are used for model ID.

- Goal is to identify linear relationships between DM wavefront and focal plane field to eliminate cumbersome numerical modeling step. Plan to apply the method to SCExAO.
- Ames has been providing probe cubes from their PIAA testbed.
- The probes are redundant (smaller phase shift than typical) to enable fitting E0 and the changes in the field due to the DM probes.
- Choose Fourier pairs to probe entire space of the DM response; with a fast DM measurement cycle as on SCExAO, can quickly re-build the model.
- Different data sets analyzed with and without the coronagraph. There is an unresolved problem with the coronagraphic data set, speckles that don't respond as expected.
- Also working on numerical simulations to improve algorithm efficiency
- Next steps to attempt iterative G matrix learning method

#### General discussion

Olivier - for CGI context, probably most interesting to explore what Vincent described, but also the Zernike WFS and post-processing calibration opportunity.

Complexity measure for computing the G matrix? Depends on number of Fourier pairs, number of pixels. It helps to pose the problem as linear least squares as opposed to nonlinear.

Photon noise will be a constraint in probing. The operation scenario is something we need to look at.

Question from Rus about waveguide coronagraph - what is performance status, maturity?

GLINT - single mode fibers from subapertures. Waveguide chip is designed to produce achromatic destructive null. You simultaneously measure the null channel (where planet's light would be) and multiple channels capturing the state of the wavefront. The bright channels are analogous to the Zernike WFS output.

On GLINT, is the DM control in the loop with the bright channel data? Not implemented yet but that is the plan. The main performance advantage is at small angular separations close to  $1 \lambda/D$ . But for most exoplanet imaging observations at larger angular separations, you would need many more fibers. Also the nulls are not very deep, but technology is improving. The overall approach is closely related to the Palomar nulling coronagraph by Bertrand Mennesson and Gene Serabyn.

Will CGI use DM probes to build system response?

Eric - CGI is not baselining an empirical probe approach. Will use phase retrieval and pupil imaging for identifying necessary system parameters. Note also CGI cannot run DMs at high rates, it takes a few seconds per actuator move.

Laurent - if we wanted to experiment with different probes, could someone propose collecting a few hours of data? What do the ops allow? It's possible, but the experiment needs to be specified and go through quality check.

Olivier - motivation for considering Vincent's method is not just digging the dark hole, but rather coherent differential imaging. To be quantitative about the light that is left.

Leonid - Have you used the wavefront sensor data for post-processing?

Olivier - we have used Pyramid wavefront sensor data to predict PSF with neural net (Barnaby Norris / U. Sydney). However, at very high contrasts, the non-common path can limit this approach.

Hanying - Question about separating coherent and incoherent light.

Olivier - Three fundamental sources of incoherent light: polarization mismatch, wavelength diversity within bandpass, temporal variation within your exposure. Model error can lead you to incorrectly estimate the incoherent component. Temporal decoherencing is also an issue in space, in spite of the stability, due to the long exposure times needed.

#### Related links

Olivier Guyon's SPIE presentation/paper: <https://doi.org/10.1117/12.2562723>