

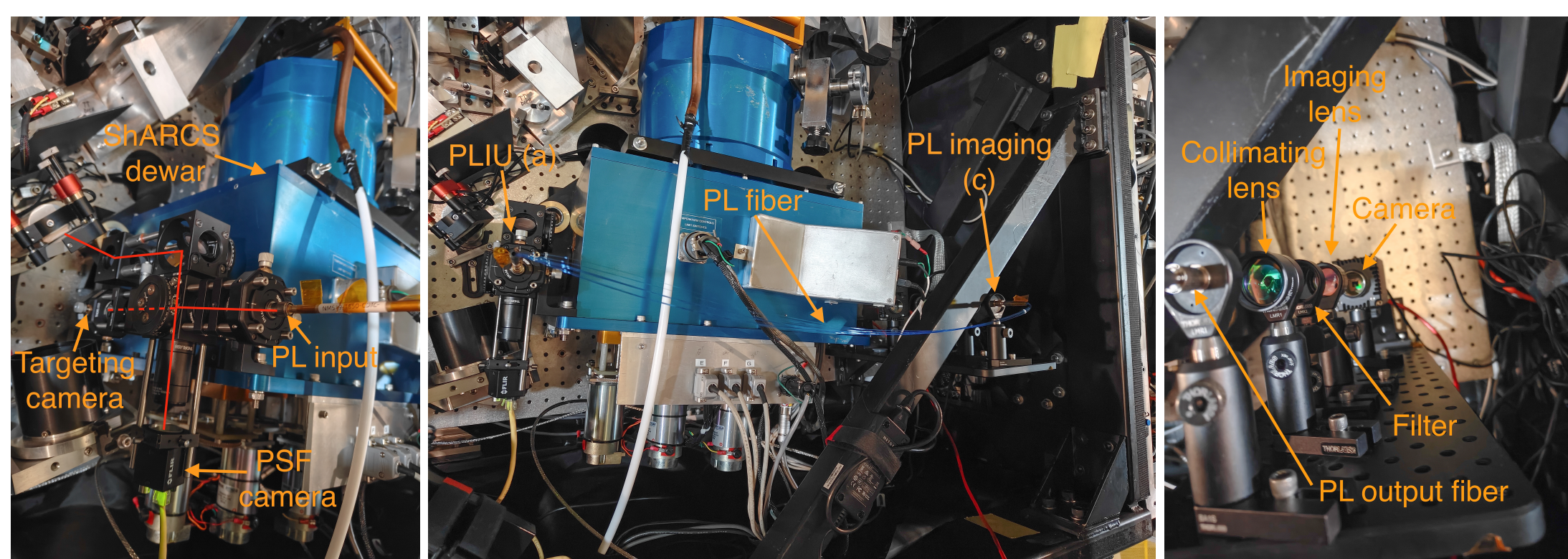


On-sky demonstration of second-stage wavefront control with a photonic lantern



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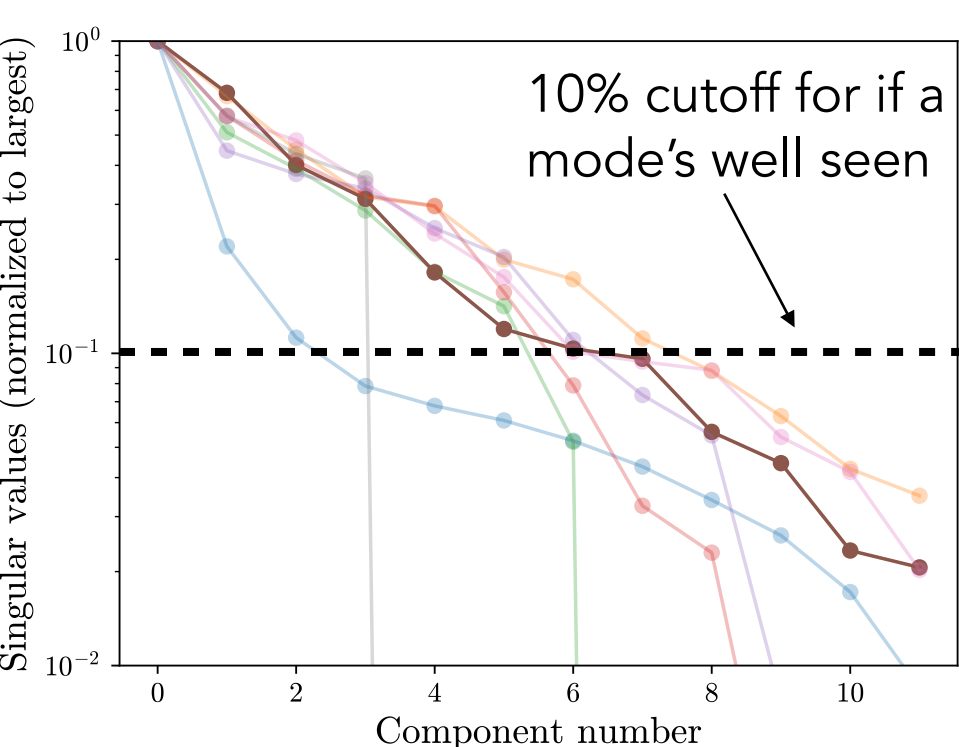
AO for high-contrast imaging is often limited by non-common-path aberrations (NCPAs) seen only in the science plane. These can be sensed by focal-plane wavefront sensors (WFSs) like the photonic lantern (PL). We installed a non-dispersed PL on the Shane 3m telescope at Lick Observatory as a second-stage WFS and demonstrated closed-loop control of residual wavefront errors. PLs enable improvements to existing AO systems via minor retrofits!



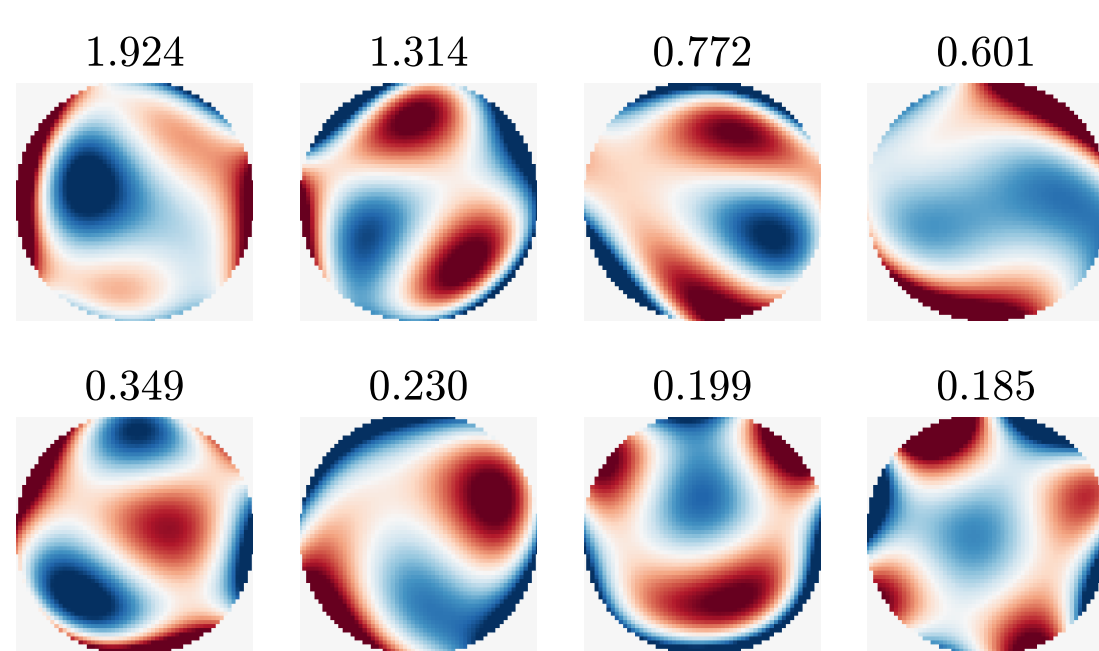
Integration at ShaneAO: we pick off light going into the science camera ShARCS; split across targeting, PSF, and lantern input. The lantern stretches over and across the ShARCS dewar. At output, reimaging and narrow-band (1550 ± 30 nm) filter, to Goldeye short-wave IR camera, to my personal laptop for image reduction and SSH DM interface.

Why undispersed PL spots + narrow band? NCPAs have low spatial orders, which is well matched to the PL; showing one wavelength is sufficient for second-stage control frees up other wavelengths for simultaneous science imaging!

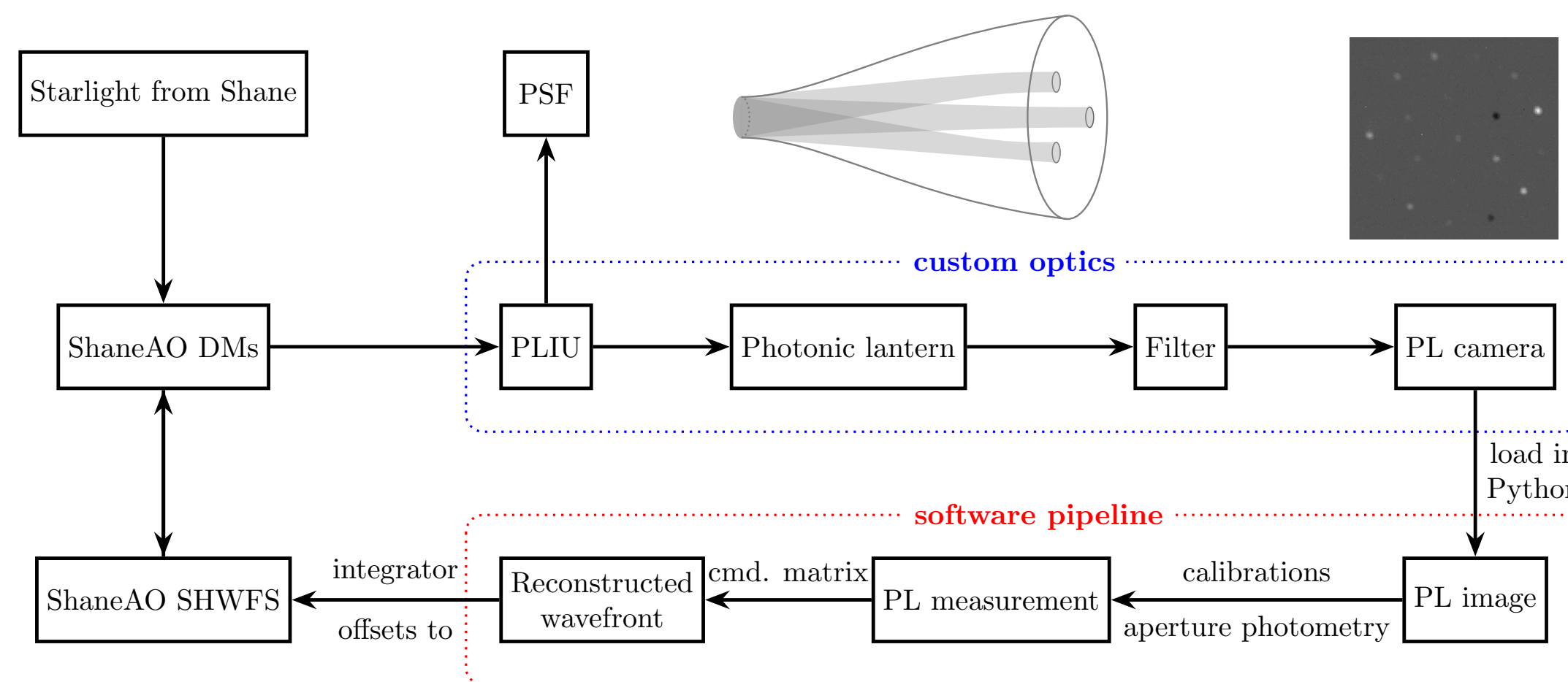
Off-sky setup: joint optimization of PSF shape and PL throughput (total flux and uniformity), port identification and creating image masks for aperture photometry, interaction and command matrices on the ShaneAO calibration source.



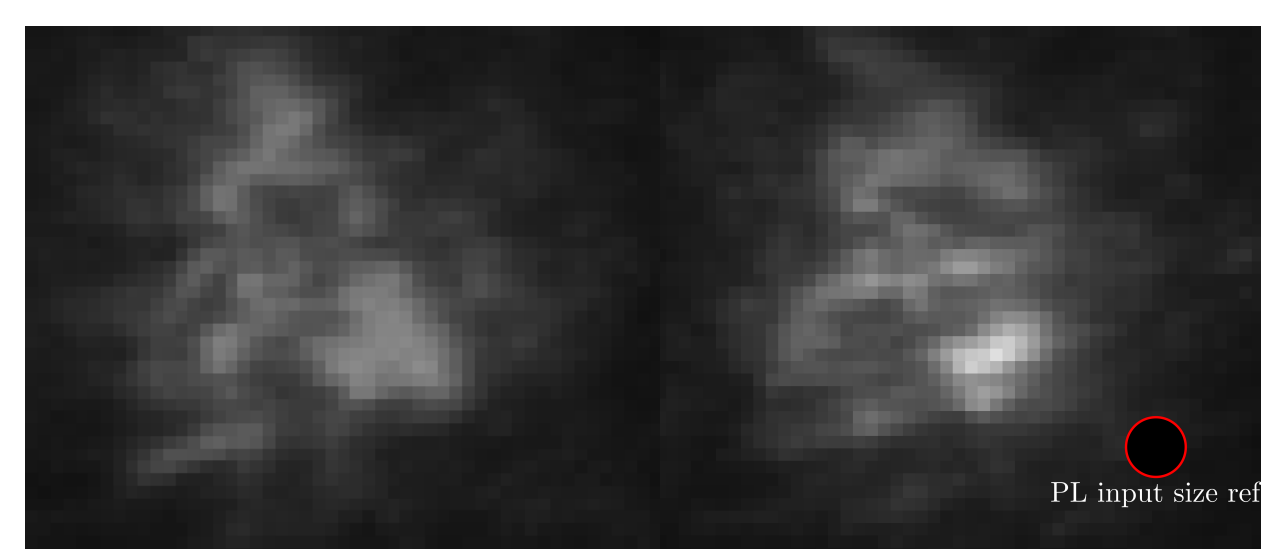
Identified 3-8 usable control modes depending on alignment + poke amplitude. Low orders with edge features (sharp cutoff at PL entrance?)



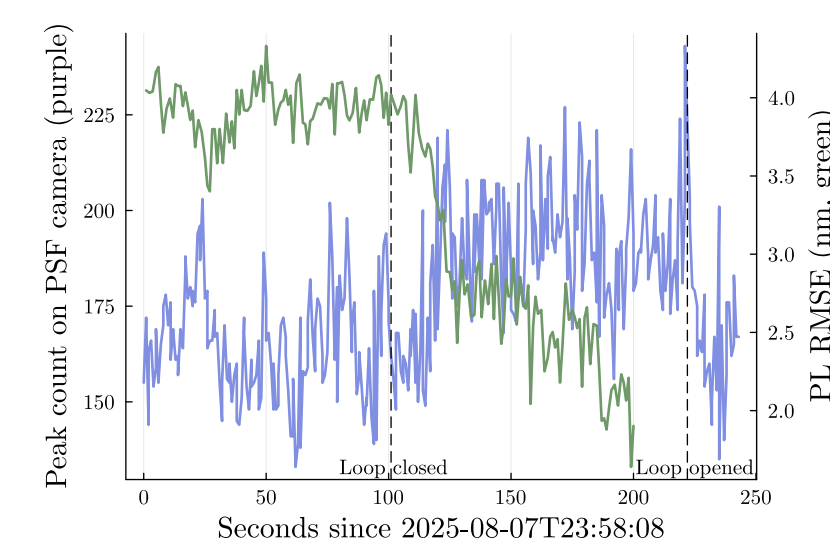
This work published as Sengupta et al. 2026 AJ 171 65.



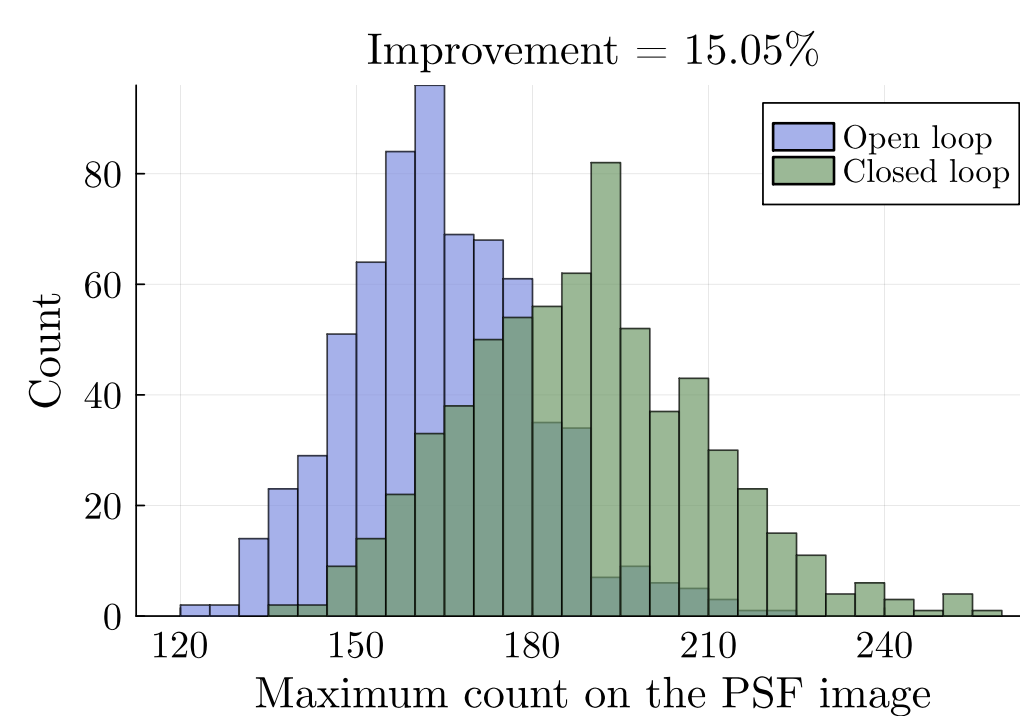
On-sky experiment: open loop spiral search in tip/tilt to optimize coupling (no tip/tilt control access), vary exposure time/stacking to avoid saturation, check reconstruction stays stable over time, close loop (integrator, $g = 0.3$, $l = 0.95$).



Open loop PSF Closed loop PSF



PSF quality and our measured PL error



We successfully closed the loop nine times! We observe image quality improvement over the size scale of the lantern's input, as expected.

Facilitating photonic lantern wavefront sensing is feasible!

- Injection/alignment was very suboptimal — next-gen testbed APALO got ~3x our throughput at first light! Better stability would help iterate on WFS performance over time (e.g. couldn't reuse interaction matrix over multiple days due to drift)
- Better integration with real-time control to bring down DM latency, to catch the evolution timescale of first-stage atmospheric residuals as well as NCPAs
- Nonlinear wavefront reconstruction, simultaneous WFS and imaging, noise sensitivity: tests ongoing in the lab at UCSC (see this summer's SPIE!)

Faster two-stage one-DM control

Bonus: New paper (Sengupta et al. 2026, accepted PASP) developing control algorithms for focal-plane WFS without an additional DM!



Like this experiment, but higher speed: see also REDWOODS by Gerard, Sanchez, Sengupta et al. in this conference

