Towards On-Sky Focal Plane Wavefront Control of Residual Atmospheric Speckles

Wavefront Sensing in the VLT/ELT Era VII

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LLNL-PRES-841090

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Lawrence Livermore National Laboratory

CDI (coherent differential imaging) workshop: in Meudon, France just before AO4ELT7

Announcement just went out; 3 day workshop, just 1 day of talks.
Stay tuned and let me know if you're interested!

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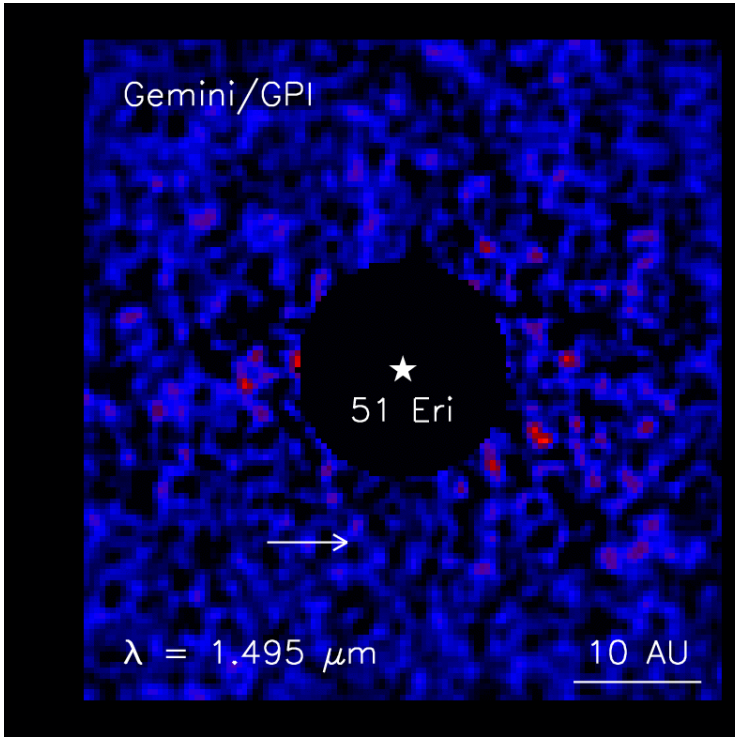
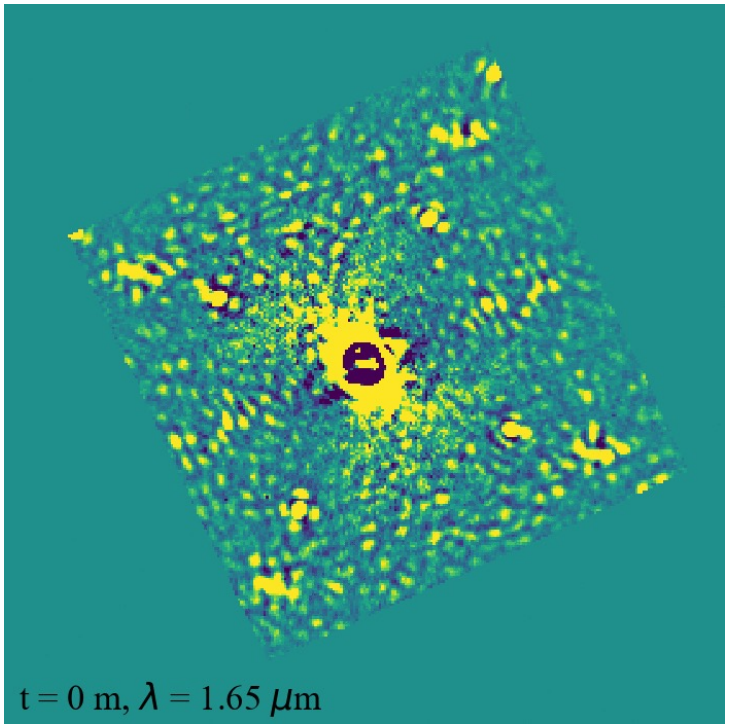
Residual speckles limit exoplanet imaging



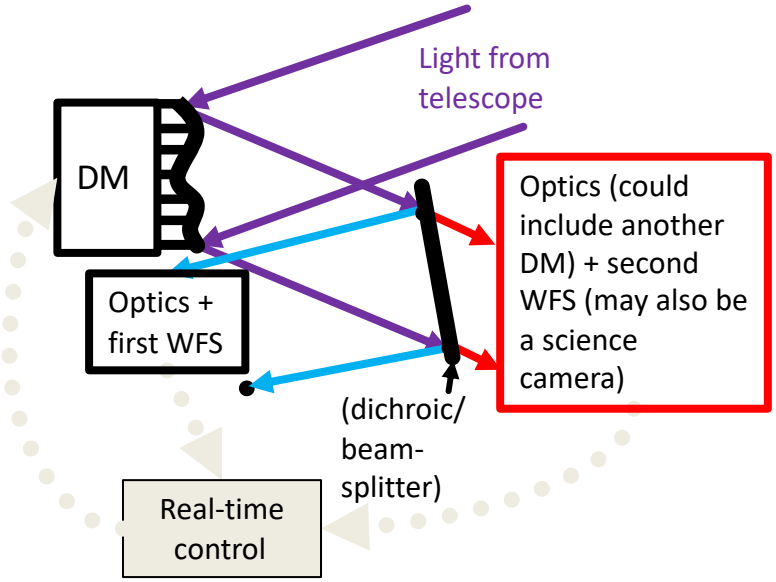
(Macintosh et al. 2015)



(Gerard et al. 2020)

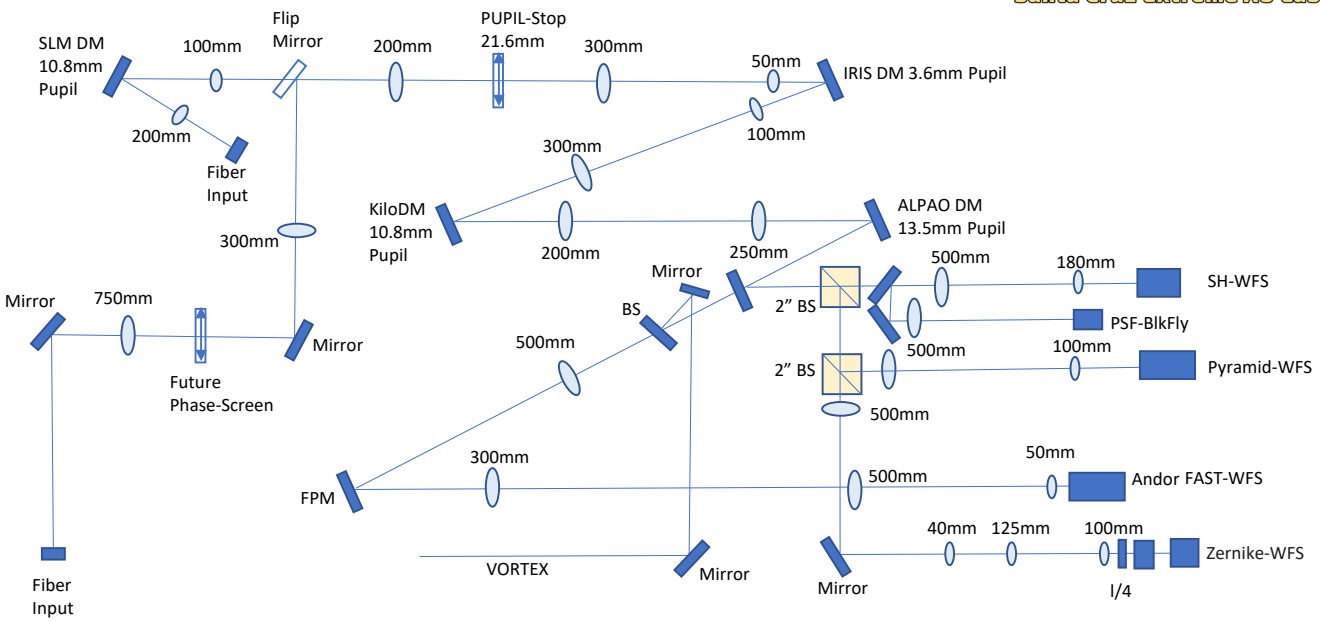
Talk Overview: multi-WFS AO

- Alternative RTC from slope offsets for high-speed multi-WFS AO (including focal plane WFS)
- SEAL lab demo! 🤞



SEAL (Santa Cruz Extreme AO Lab) testbed overview

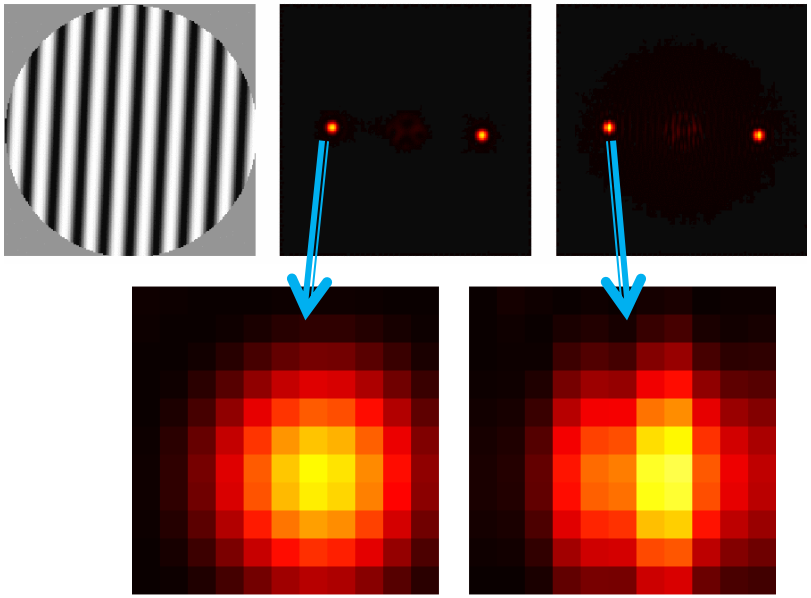
- 4 DMs: Meadowlark SLM, IrisAO segmented DM, BMC kiloDM*, ALPAO DM97
- 6 WFS arms: SHWFS, 3 sided PyWFS, FAST/4 sided PyWFS, ZWFS, PSF camera, vector vortex
- RTC: Keck II NIR PyWFS "clone" (S. Cetre et al.); all high-level code in Python!



(R. Jensen-Clem, P. Hinz, D. Dillon, C. Cetre, R. Kupke, B. Gerard, M. Salama, M. van Kooten, V. Chambouleyron, D. Sanchez, J. Fowler, A. Sengupta, J. Soto)

FAST—Fast Atmospheric Self-coherent camera (SCC) Technique

- Normal science image does not measure wavefront's relative phase
- SCC image does
- But classical SCC fringe visibility (fringed vs. un-fringed image components) is too low to enable a high-speed AO loop
- FAST enables ~10^6 x greater fringe visibilities, making AO residual wavefront control possible



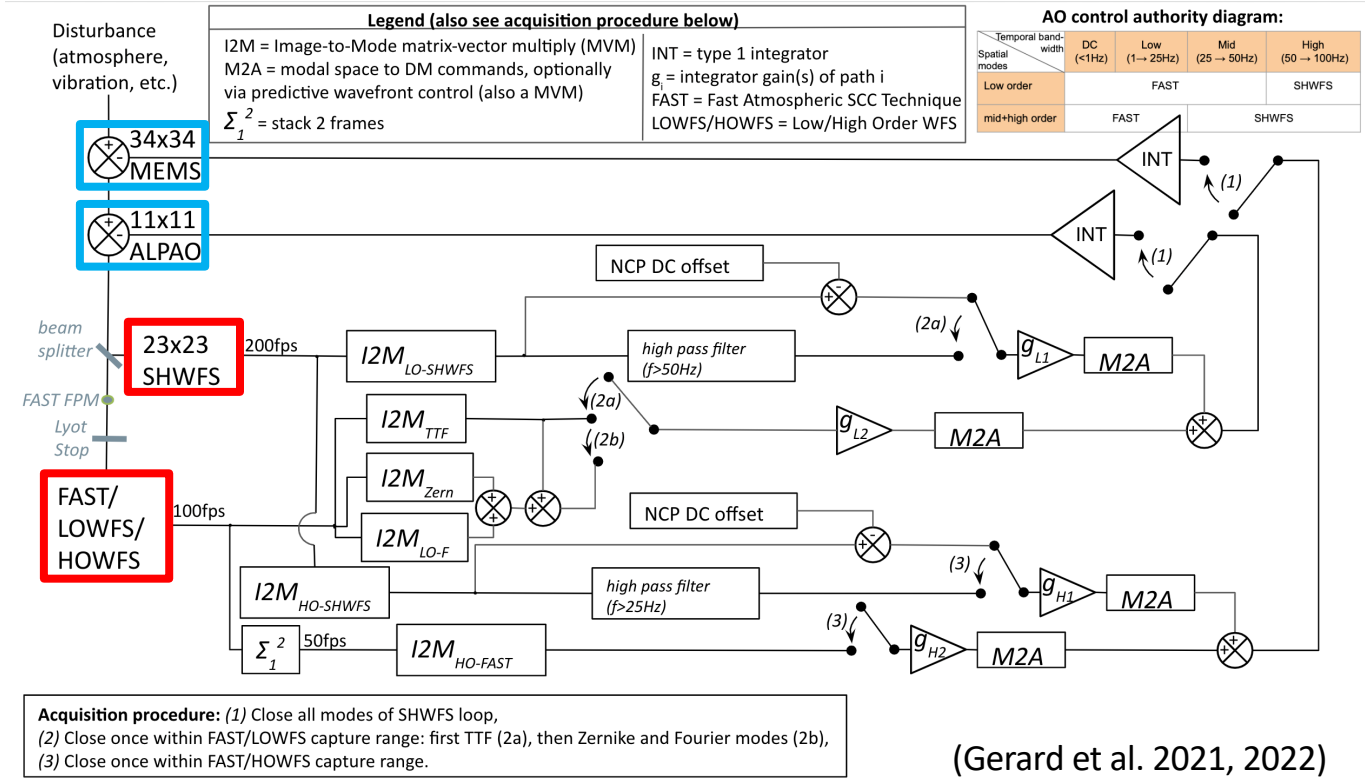
(Baudoz, Galicher, Mazoyer, Delorme, Gerard, Singh, Bos, Potier, Haffert, **Thompson!** et al.)

Multi-WFS AO concept

How to get:

- 2 DMs and
- 2 WFSs

to work together (with both WFSs pointing at the same guide star):



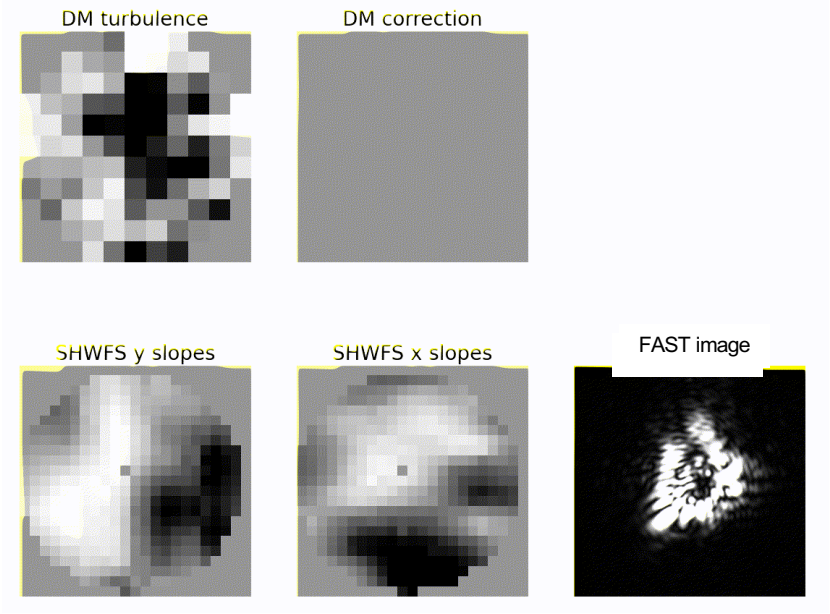
(Gerard et al. 2021, 2022)

SEAL Demo!

LLNL-PRES-841090

FAST SEAL backup figures

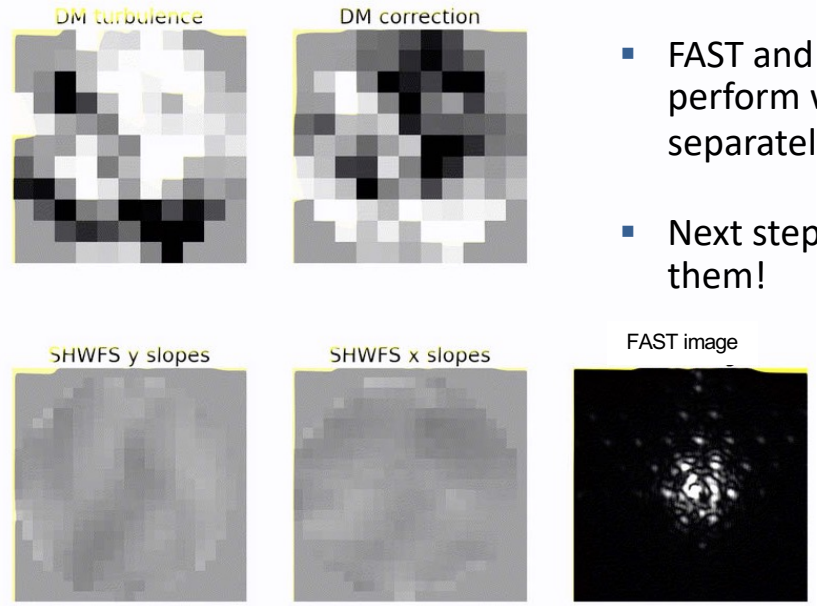
SHWFS AO loop (200 Hz)



(Gerard et al. 2022, JATIS, SPIE, more in prep)

FAST SEAL backup figures

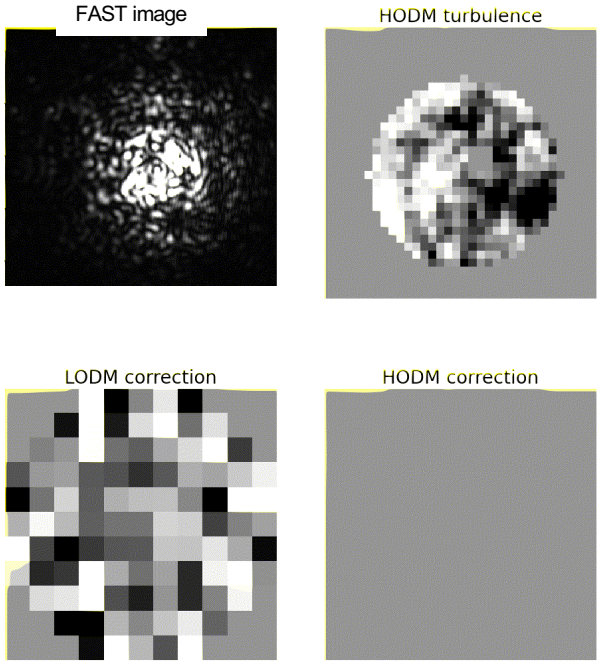
SHWFS AO loop (200 Hz)



- FAST and SHWFS perform well, separately
- Next step: combine them!

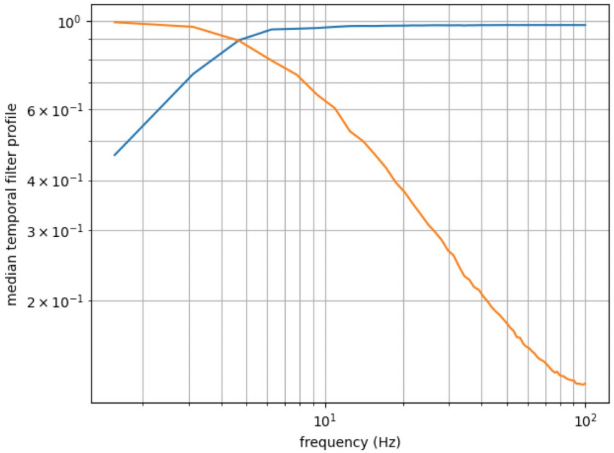
(Gerard et al. 2022, JATIS, SPIE, more in prep)

FAST residual AO loop (100 Hz)

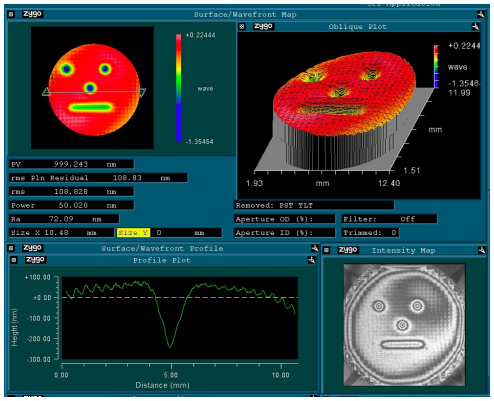


FAST SEAL backup figures (only LODM)

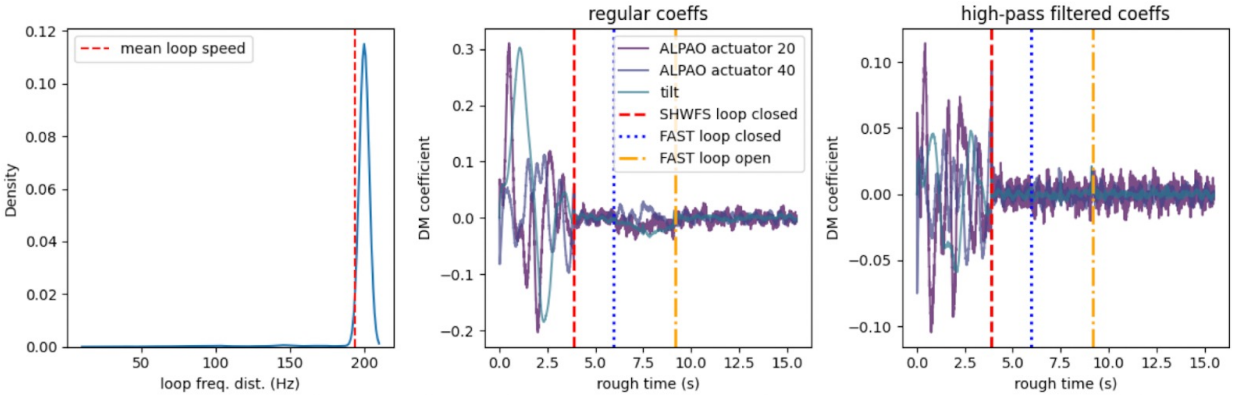
bandpasses:



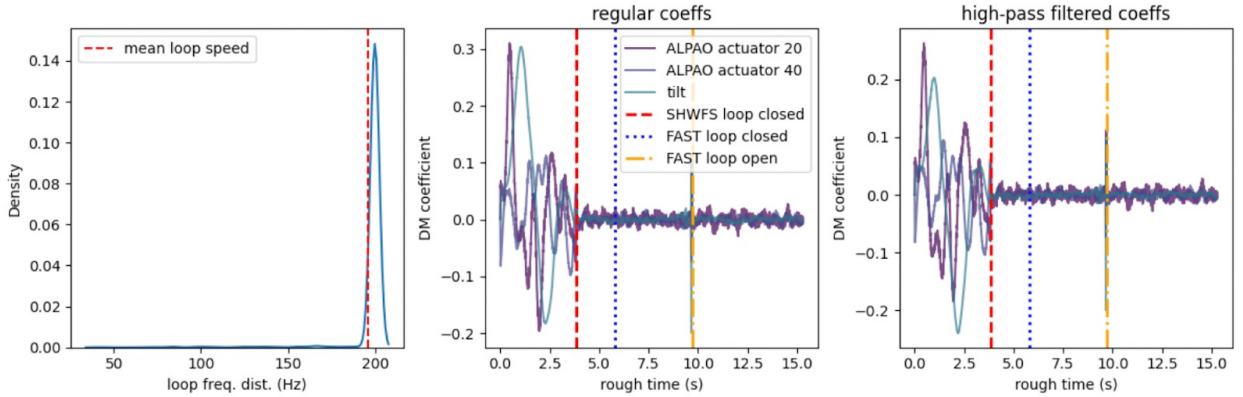
New BMC 28x28 HODM results coming soon!

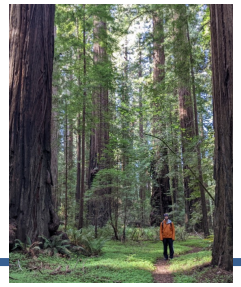


w/FAST loop open:



w/FAST loop closed:

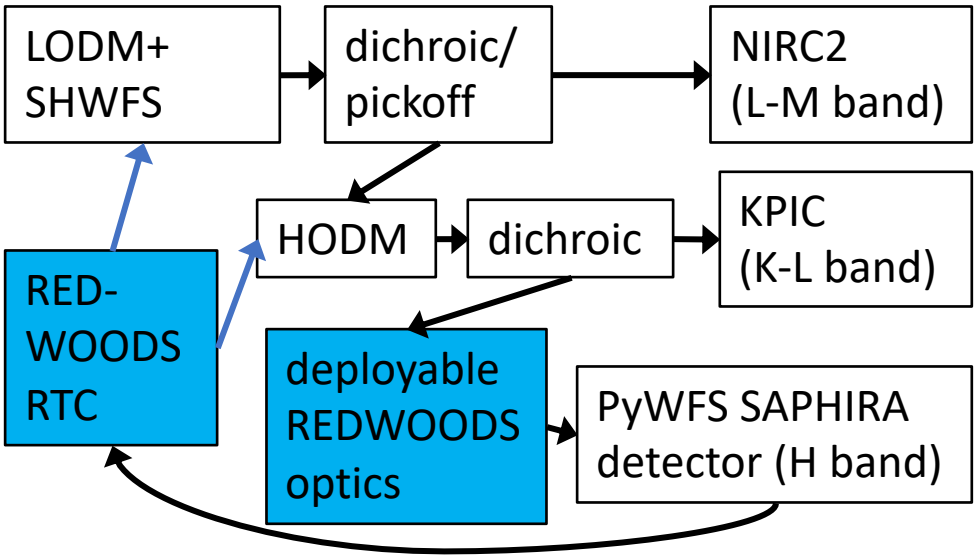




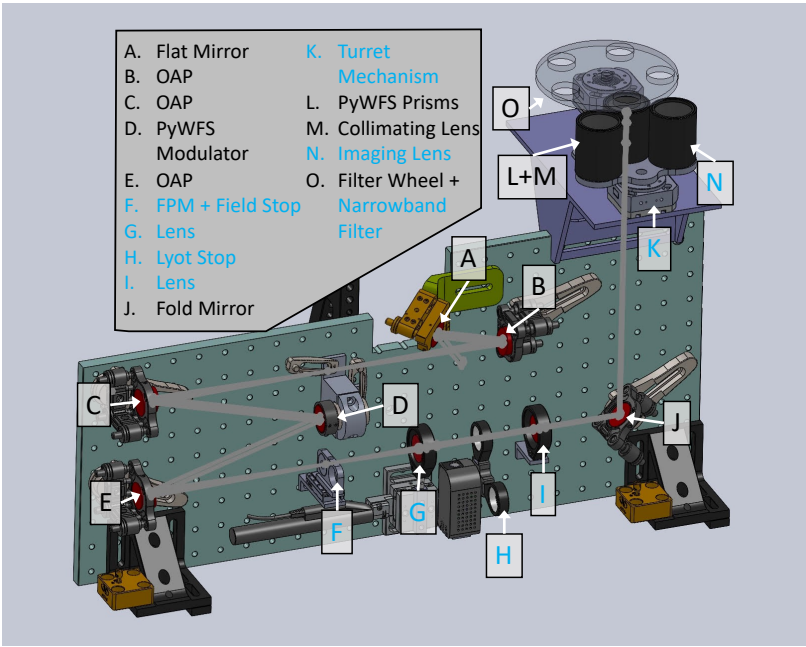
REDWOODS: Realtime Exoplanet Direct imaging via Wavefront control Of Optical DefectS (logo, and funding, pending)

PI: B. Gerard, co-Is: J. Delorme, R. Jensen-Clem, P. Wizinowich

Could implement multi-WFS AO w/ (1) SHWFS+FAST, (2) SHWFS+DM-based chopping, (3) SHWFS+PyWFS, or (4) SHWFS+bright PyWFS



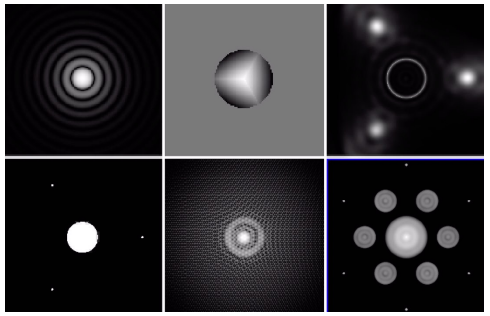
(unpublished, from proposal)



Multi-WFS SCAO discussion topics

- High-speed FAST: is it worth it? FAST areas for improvement:
  - multi-reference and/or Wynne corrector FAST (enabling broadband WFS → higher speed, lower measurement noise);
  - optimal linear FAST coronagraph (improving non-linearities);
  - LLOWFS + FAST (lower measurement noise)
- DM-based optical chopping (Gerard et al. 2022, SPIE)
- Multi-WFS AO with other WFSs. Worth pursuing? Kulscar et al?

multi-reference FAST



(Gerard et al. 2020, dissertation)

Spatial modes \ Temporal band-width	Low (< 50Hz)	Mid (50→ 250Hz)	High (250→ 600Hz)
Low order	WFS2		WFS1
mid+high order	WFS2	WFS1