Comparative Performance of a 3-Sided and 4-Sided Pyramid Wavefront Sensor

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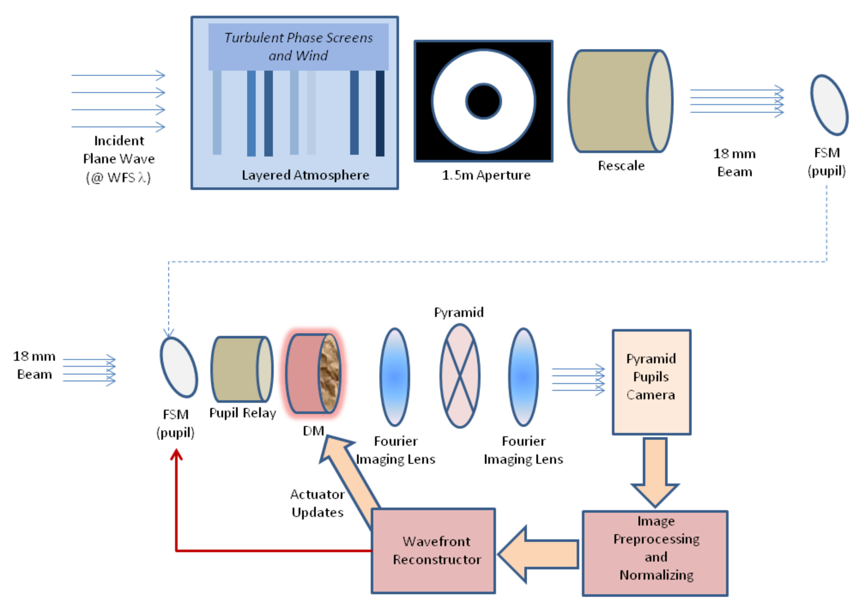
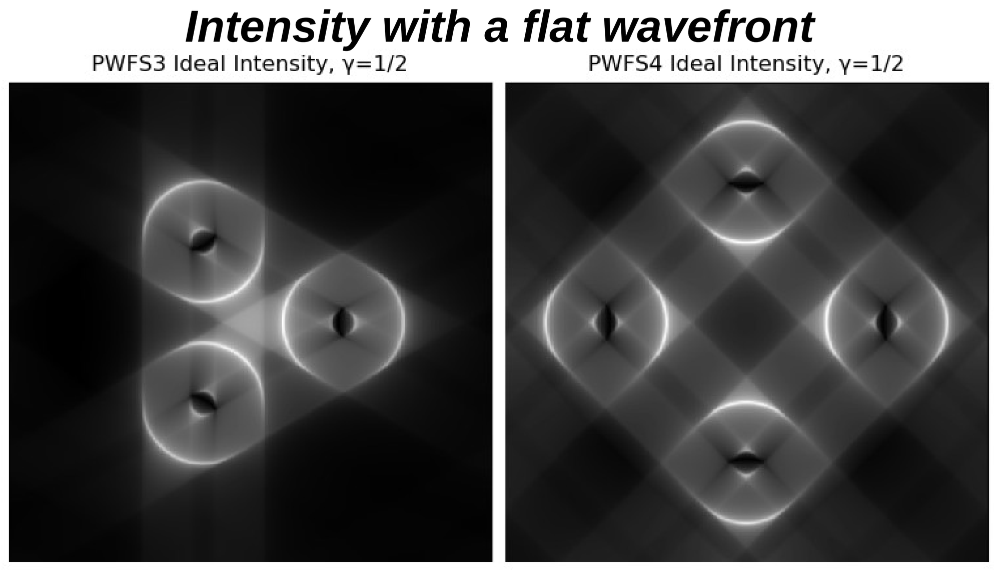
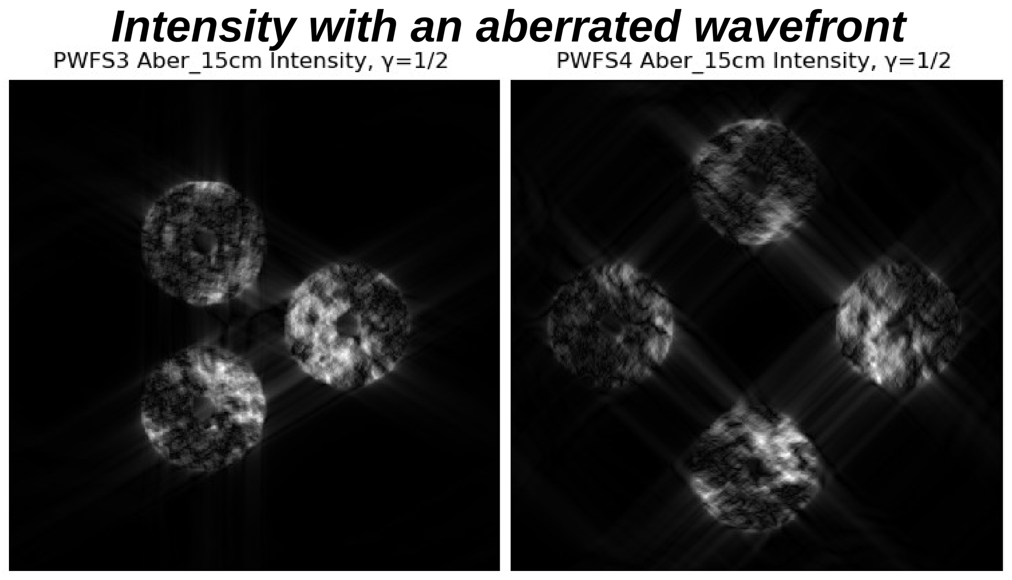
Pyramid WFS Simulation Block Diagram



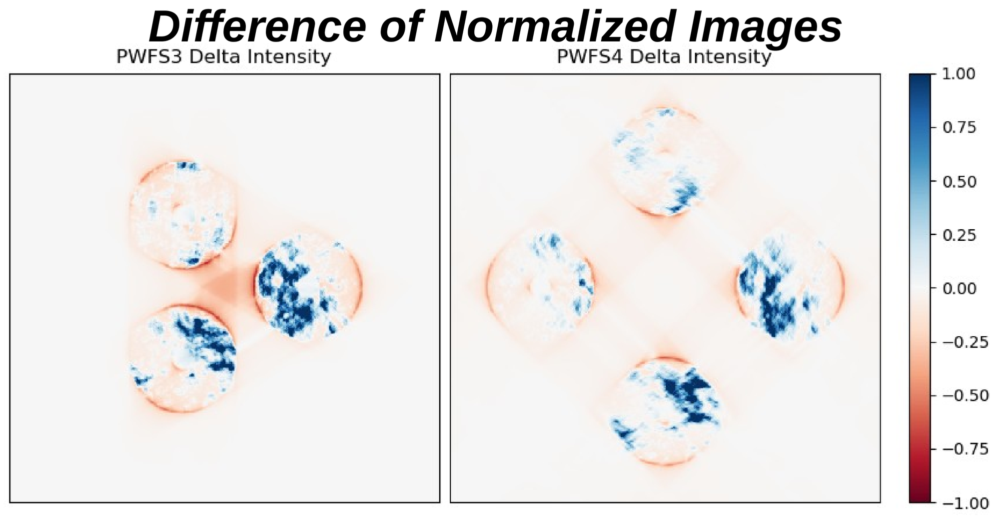
Intensity with a flat wavefront



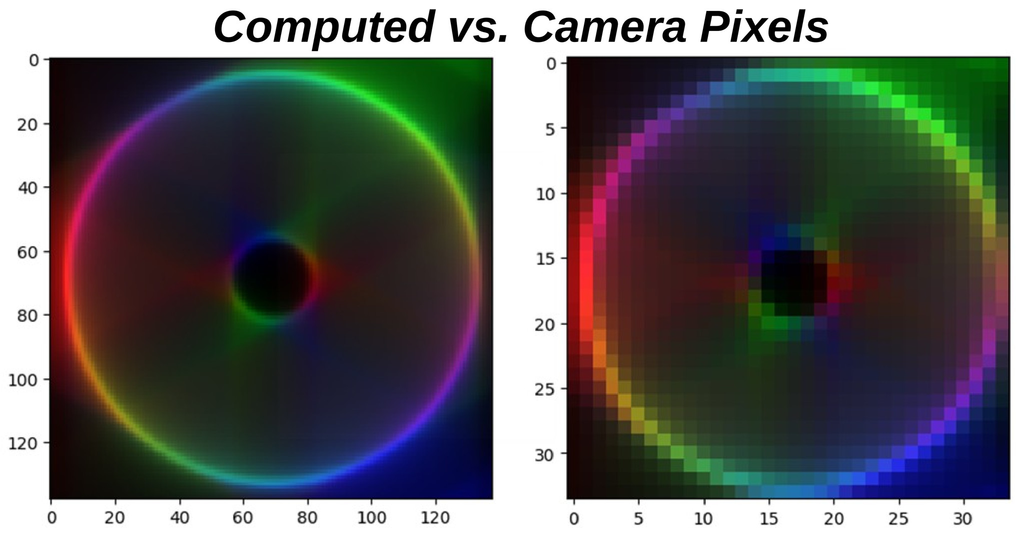
Intensity with an aberrated wavefront



Difference of Normalized Images



Computed vs. Camera Pixels



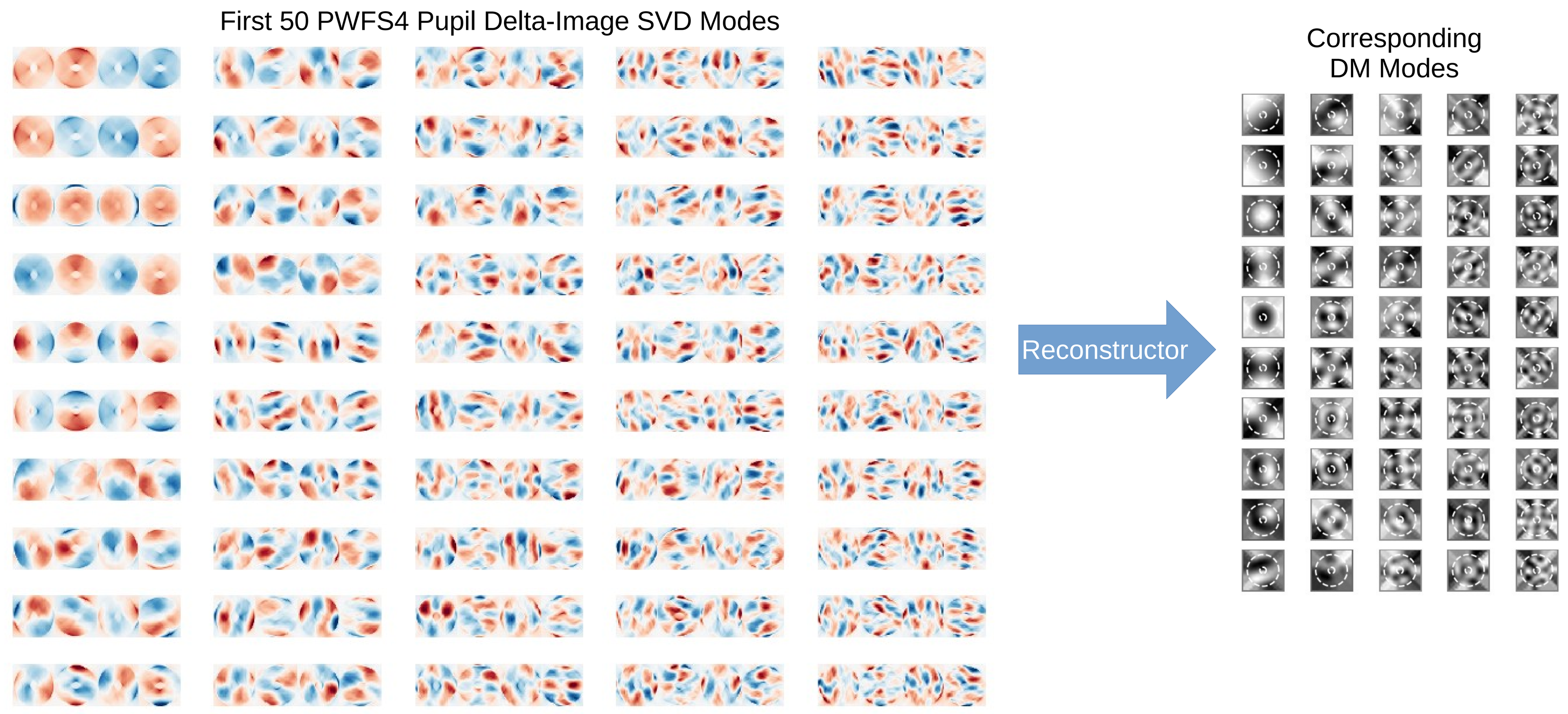
Region around each pupil image is extracted.
A small surrounding region is also kept.
Plotted as RGB stack for alignment visualization.
Perfect alignment case is normalized and kept as a "zero" reference.

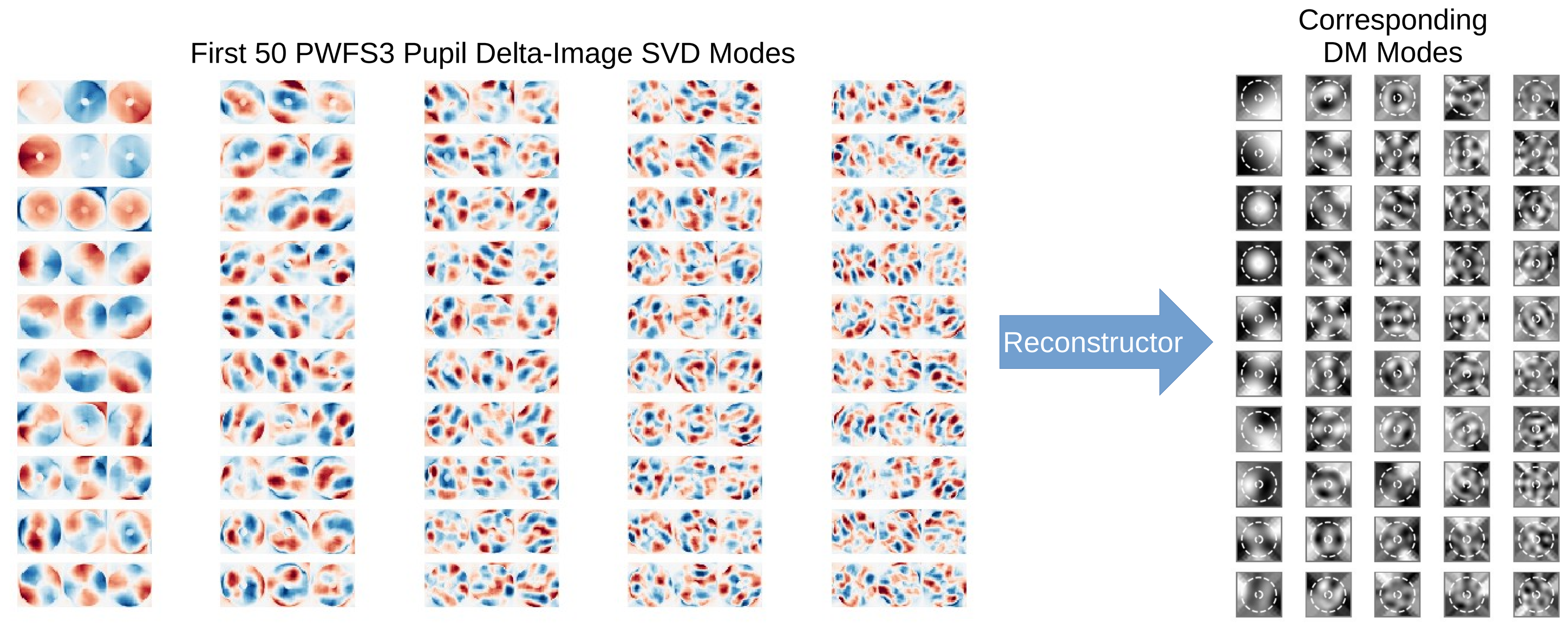
Each image is decimated to 32 pixels across pupil.
Wavefront reconstruction uses this minus the zero reference.

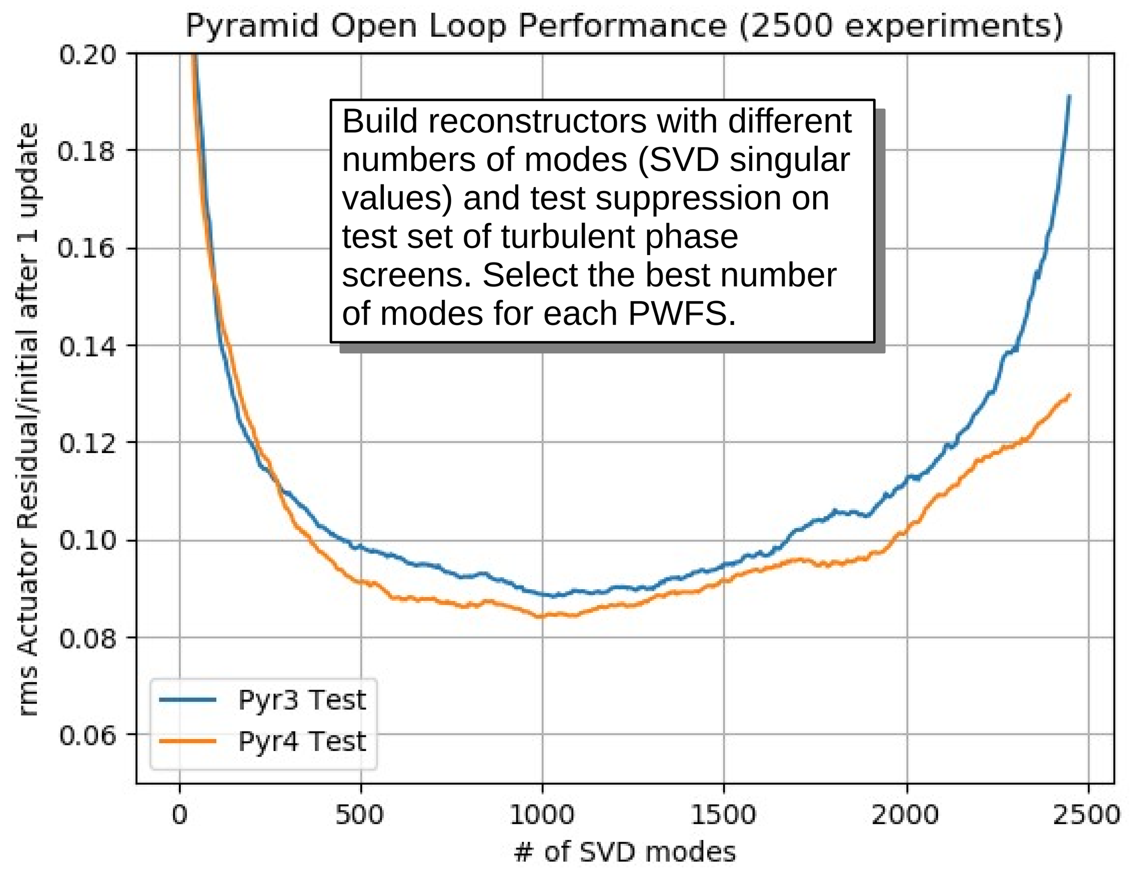
Use the simulation with 2500 Kolmogorov phase screens to estimate an SVD reconstructor. Test on 100 extra screens.

- 1.5 m telescope
- 12×12 DM (center 12 of 16×16)
- Phase screen ensemble rms WFE: 100 nm
- No pyramid modulation (assume we are operating in closed loop with rms WFE ~100-150 nm)
- Wavefront sensor wavelength: 700 nm
- Record phase screen displacement at DM actuators and PWFS pixel intensities.

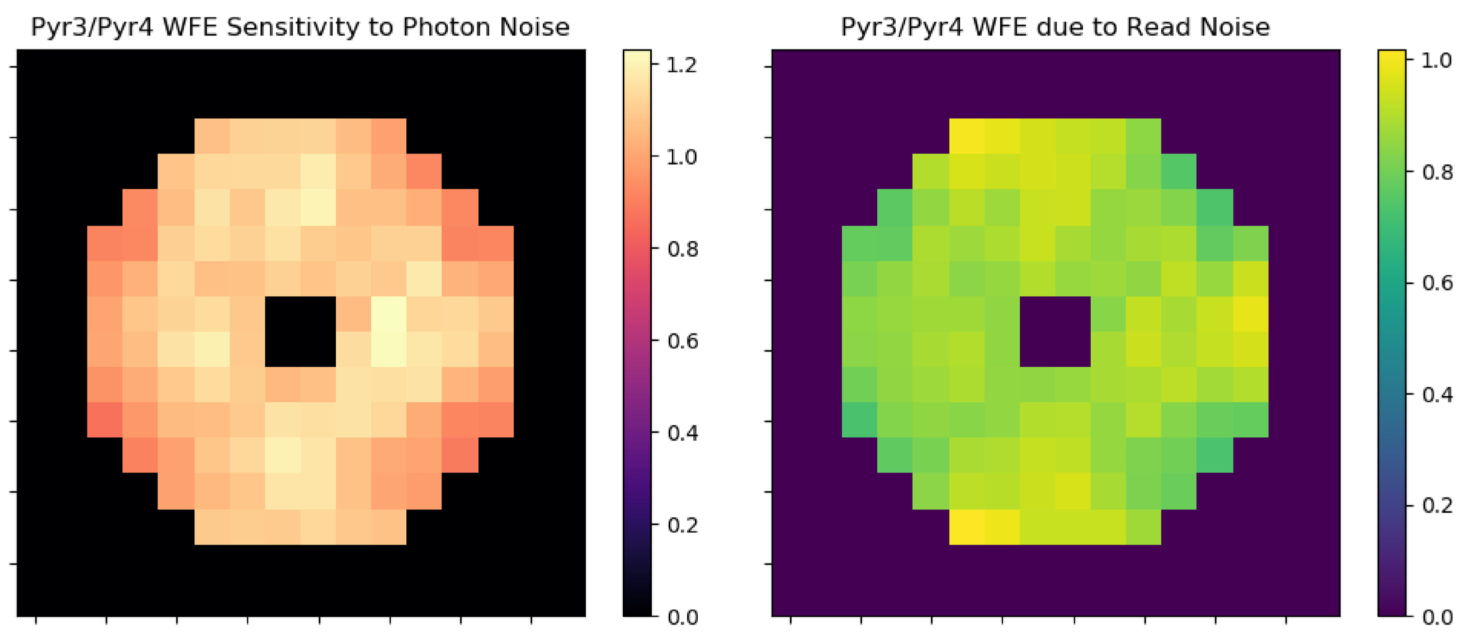
SVD Reconstructors for PWFS3 & PWFS4





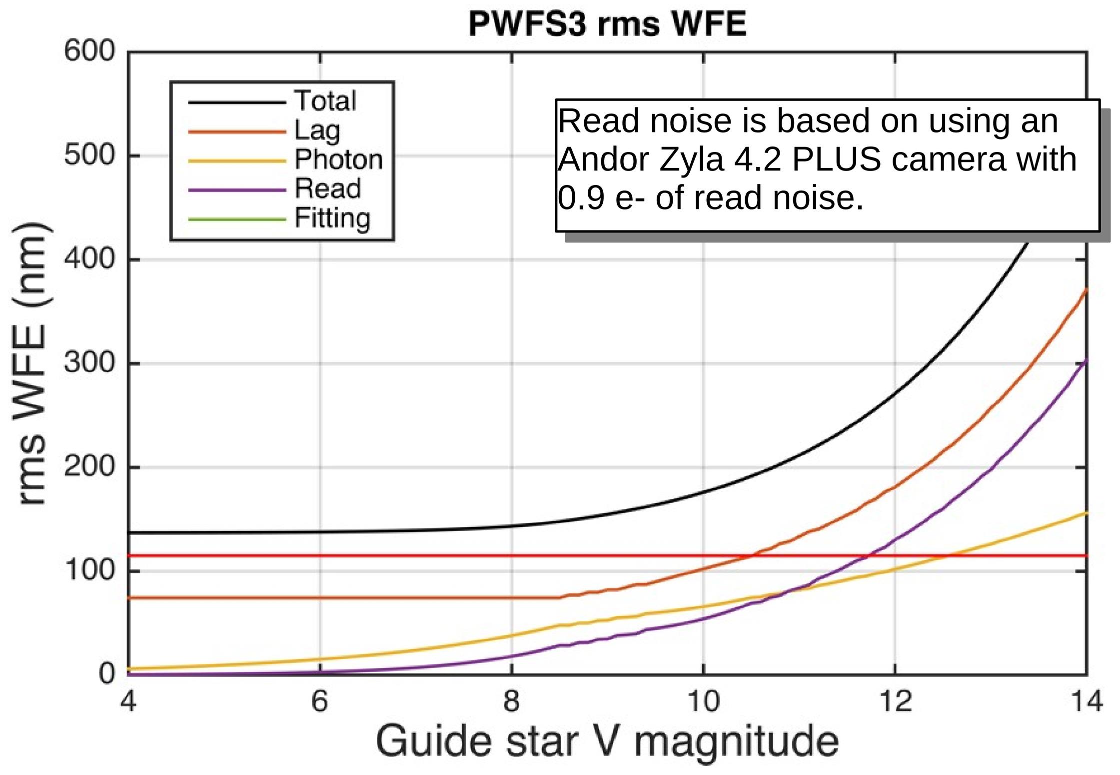


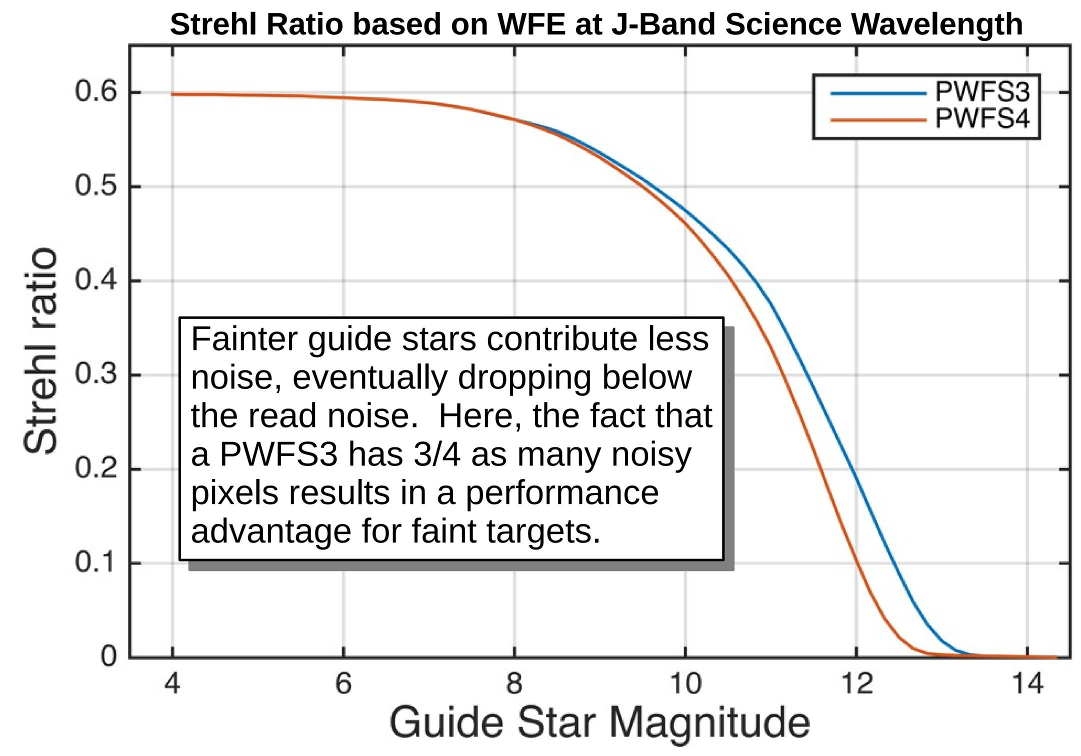
Use the reconstructors and ideal intensity patterns to determine the ratio of the sensitivities to photon noise and read noise.



Plots of the PWFS3/PWFS4 ratios of rms WFE due to photon noise (left) and read noise (right). On the average, the photon noise sensitivity is worse for the PWFS3, whit the read noise sensitivity is less. The photon noise ratio follows the relative open-loop suppression of the two reconstructors, while the read noise sensitivity is consistent with there being fewer noisy pixels in the PWFS3 relative to PWFS4. Due to the difference in scaling with guide star brightness, the read noise advantage becomes the more important effect with fainter targets.

Implications for Closed-Loop Performance





Conclusions

The comparative PWFS simulation and analysis in the *noise-free case* indicates that at least for non-iterated open loop wavefront aberration suppression, the performance of the 4-sided and 3-sided pyramids is nearly the same, with the PWFS4 suppressing about 0.5% better. However, it is our experience that such a small difference in open loop suppression would not translate to performance gains in closed loop.

The more important performance difference is in noise sensitivity, where for faint sources the PWFS3 showed a reduction of 13% compared to the PWFS4. This is attributable to the fewer pixels used by the PWFS3. The importance of this reduction in the faint guide star limit where read noise begins to dominate is close to twice that value in terms of residual WFE because of the knock-on effects of balancing other error sources. The closed-loop advantage of PWFS3 becomes even more pronounced with noisier detectors.

The regime where the PWFS3 excels is exactly where GEO satellites are found. Because these objects are of an angular size substantially smaller than the seeing limit, an AO system based around a PWFS3 will be able to exploit the coherence of the light and will be optimally suited to correcting the image to the highest possible Strehl ratio. The contrast ratio in the vicinity of the GEO will also be maximized with a PWFS3, allowing enhanced detection of faint closely-spaced objects (CSO) compared to AO systems using either a Shack-Hartmann WFS or a PWFS4. The PWFS3 is therefore a better choice for SSA applications involving GEO objects.

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