# Effect of segmented telescope phasing errors on adaptive optics performance

Marcos van Dam
*Flat Wavefronts*

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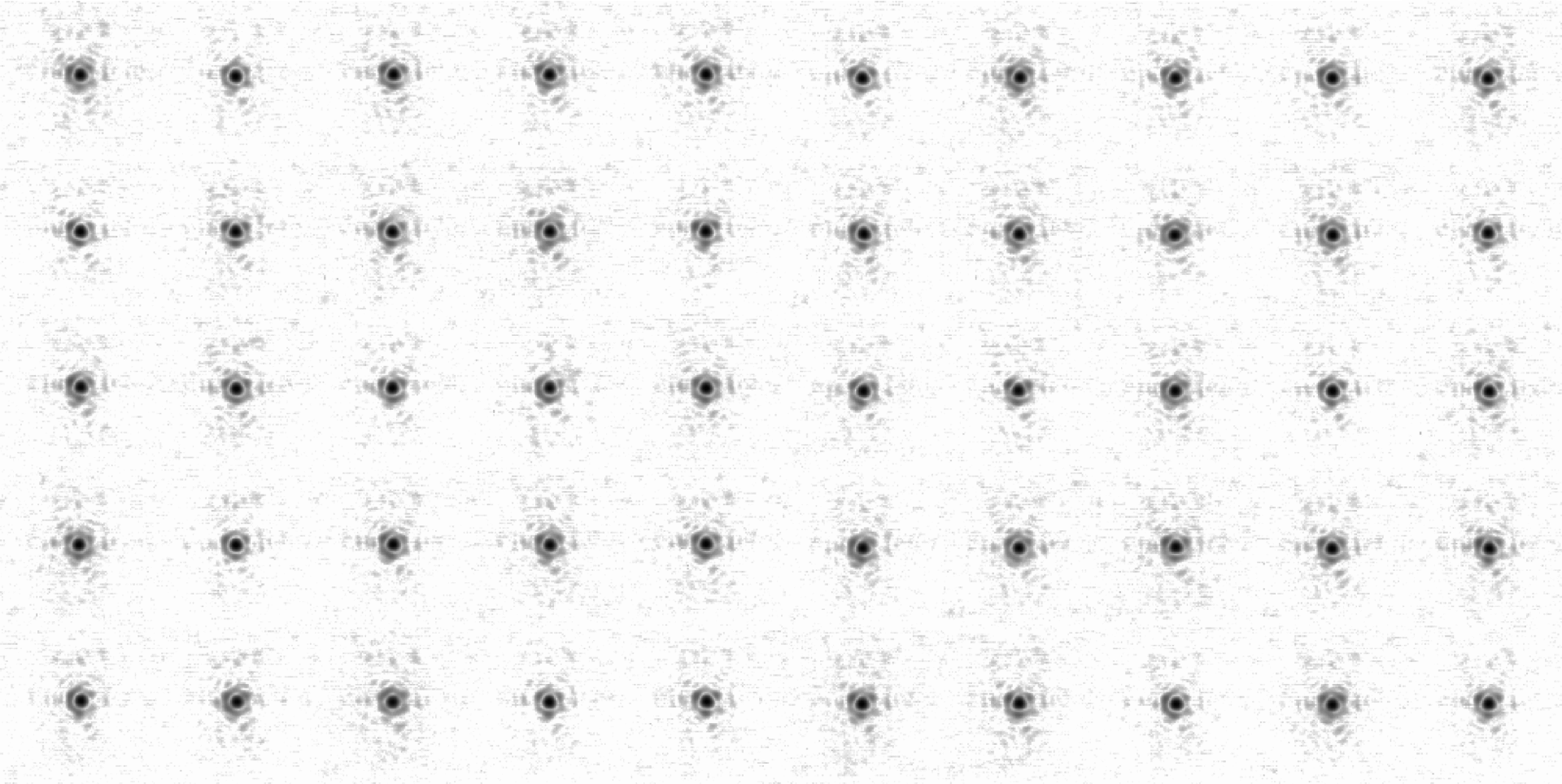
*W.M. Keck Observatory*



# Motivation

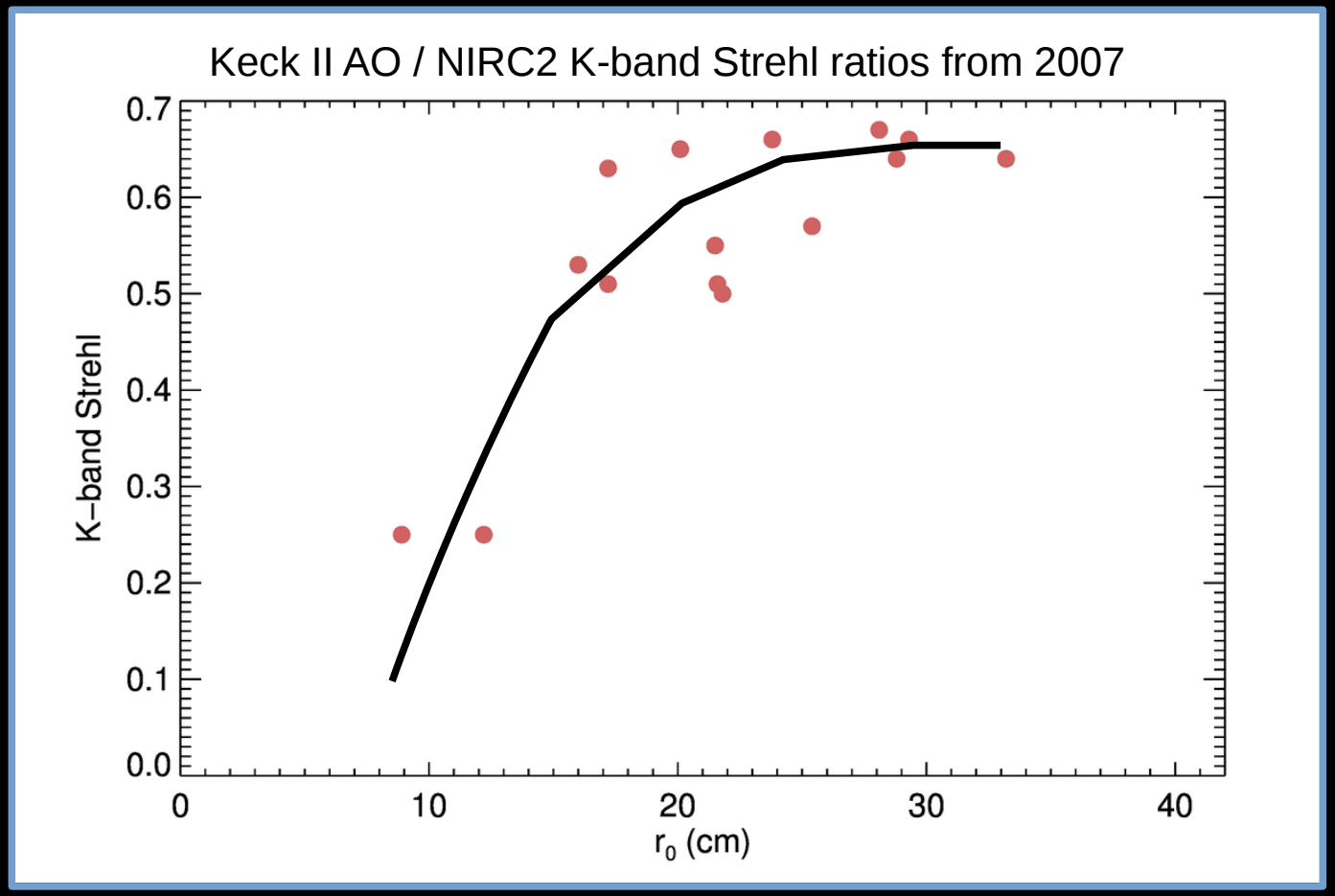
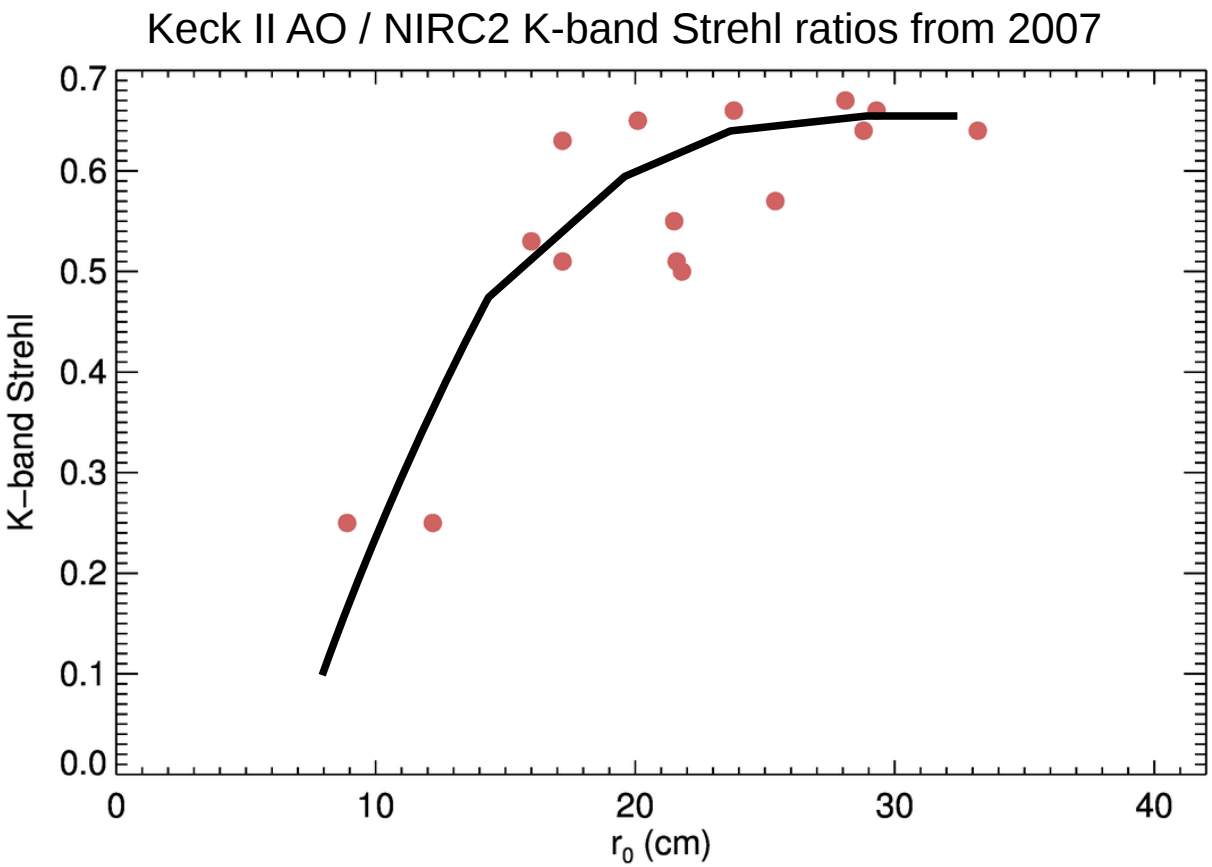
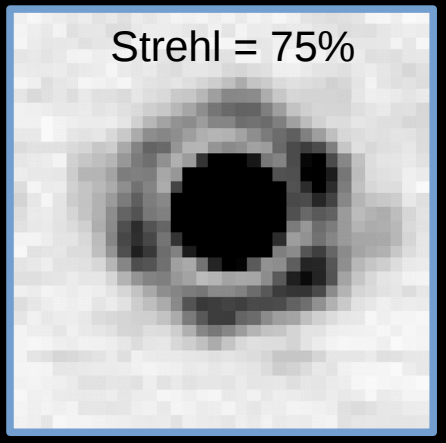



Image quality limited by error terms independent of seeing!

# Motivation




Best images have low order static aberrations!

# Outline of Talk

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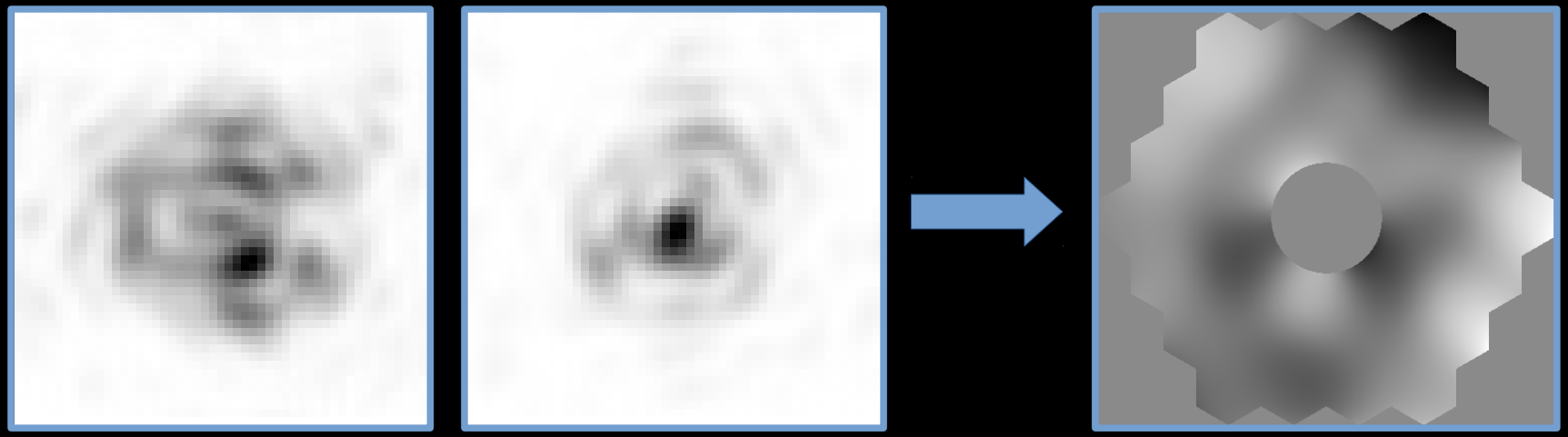
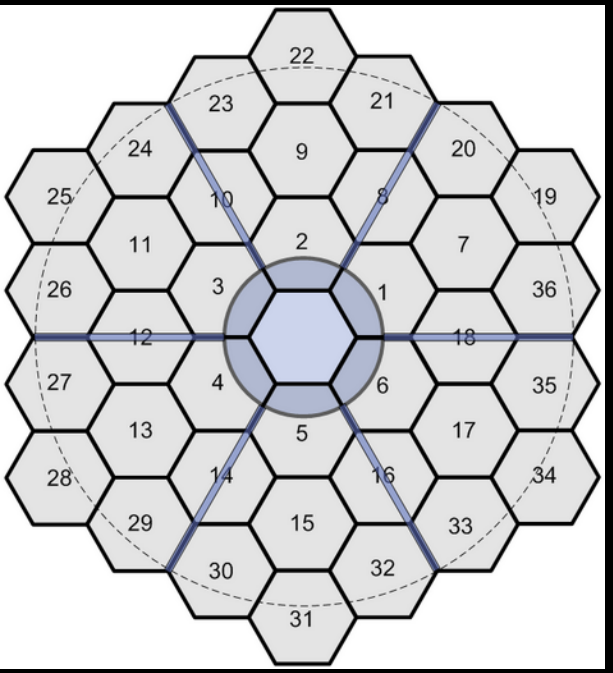
- Results of on-sky phase retrieval experiments

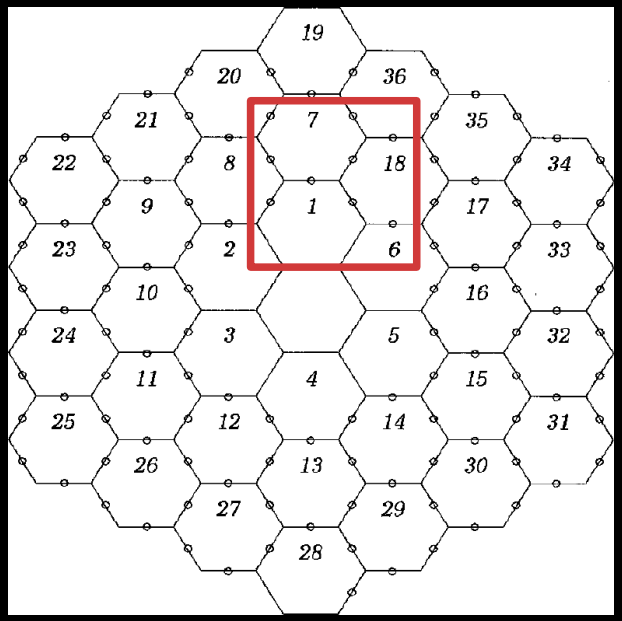


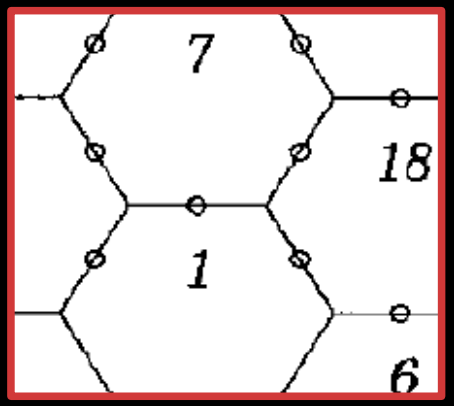
# Keck Telescopes

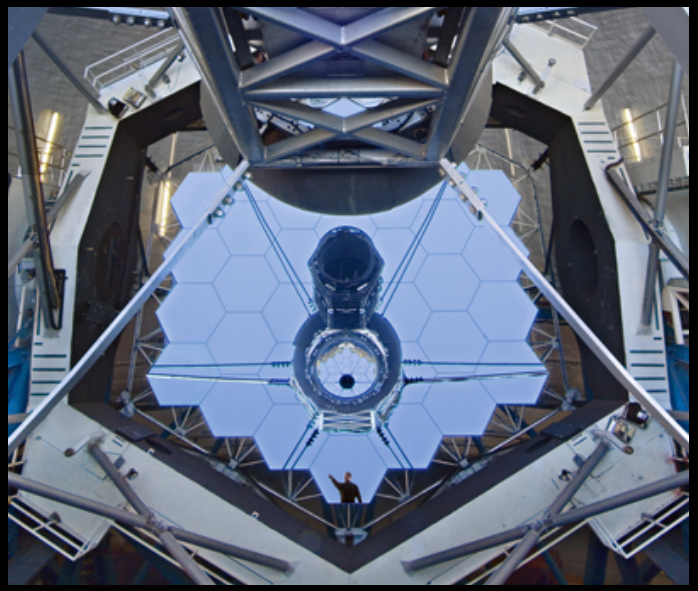



- Two twin 10-m telescopes on Mauna Kea
- 36 hexagonal segments
- NGS/LGS AO on both telescopes

# Phasing Camera



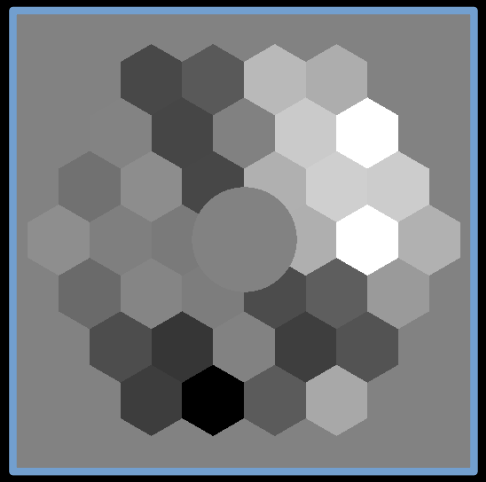



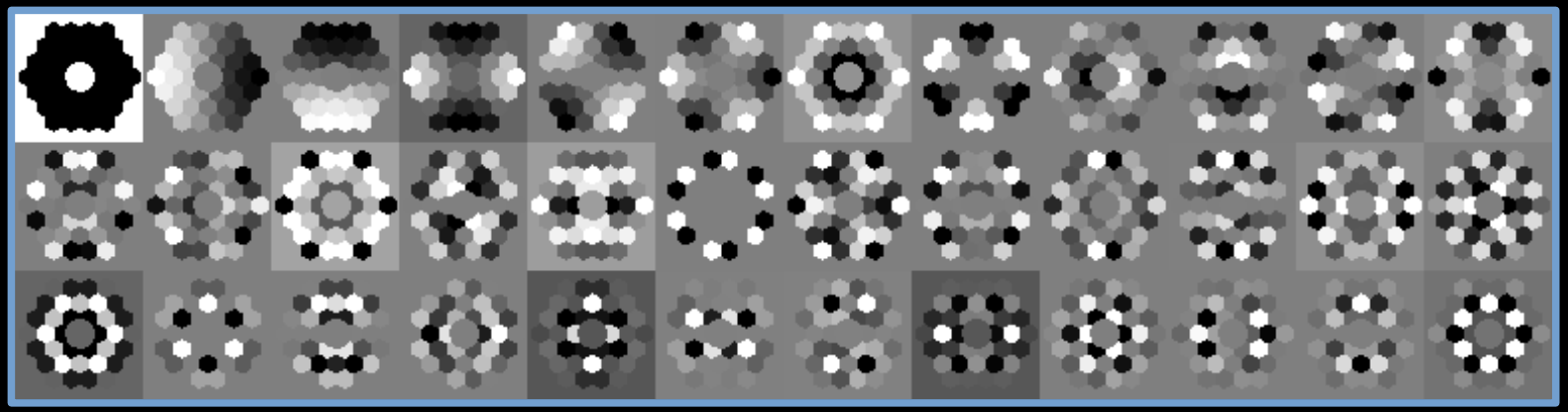



- Optically measures phase between adjacent segments
- 78 measurements used to contrain 36 segment pistons
- Phase is maintained with capacitive edge sensors aided by look-up tables
- Temporal stability of phasing not well understood

# Phasing Errors

- Random errors in phase measurements lead to low spatial frequency segment piston errors

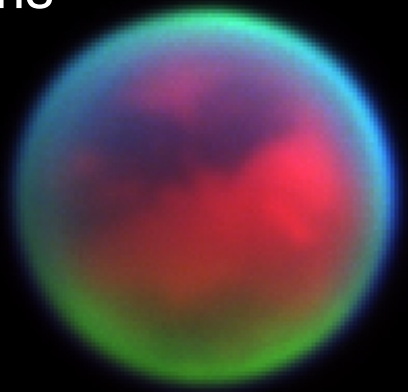




Eigenmodes

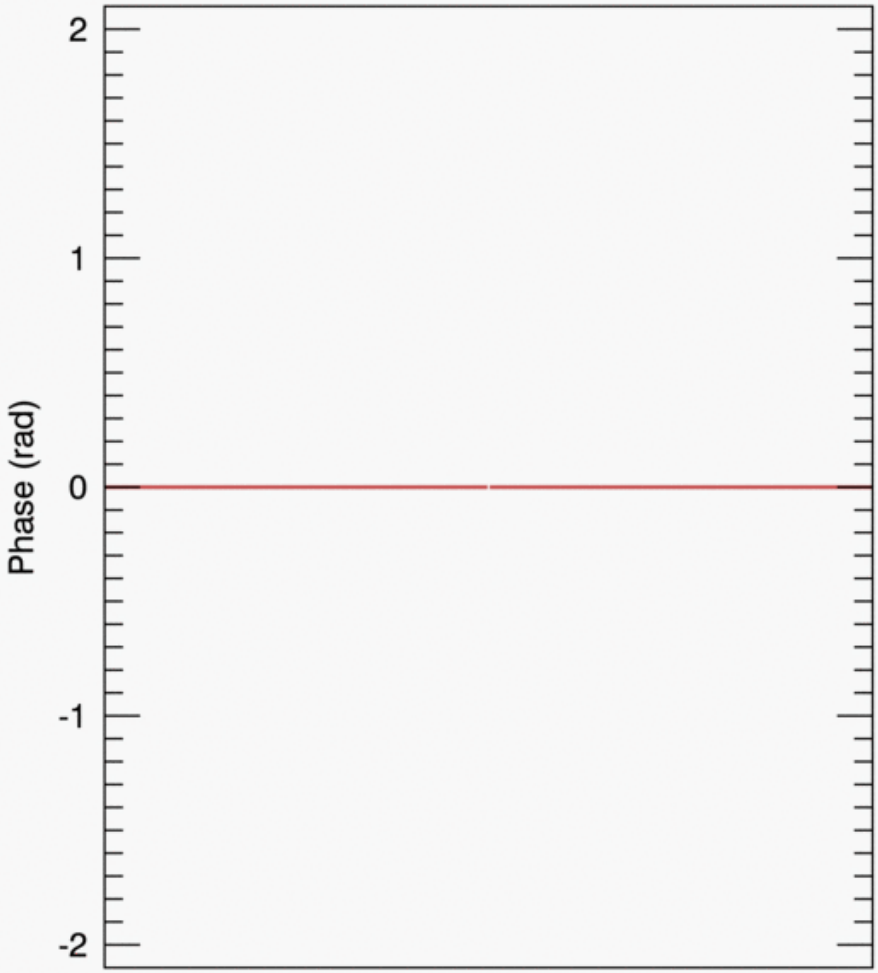
# AO systems

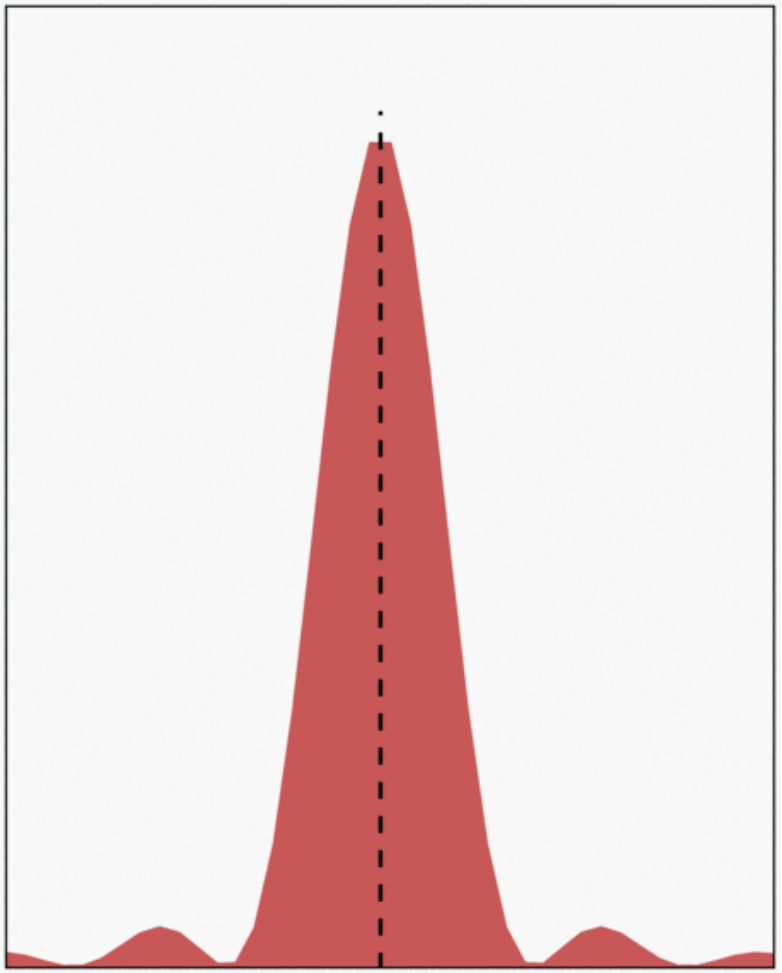
- Both telescopes have almost indentical AO systems
- 20x20 Shack-Hartmann WFS with quad cells
- NGS and LGS
- 21x21 actuator Xinetics DM (349 actuators)



# Response of SH WFS to phase discontinuities

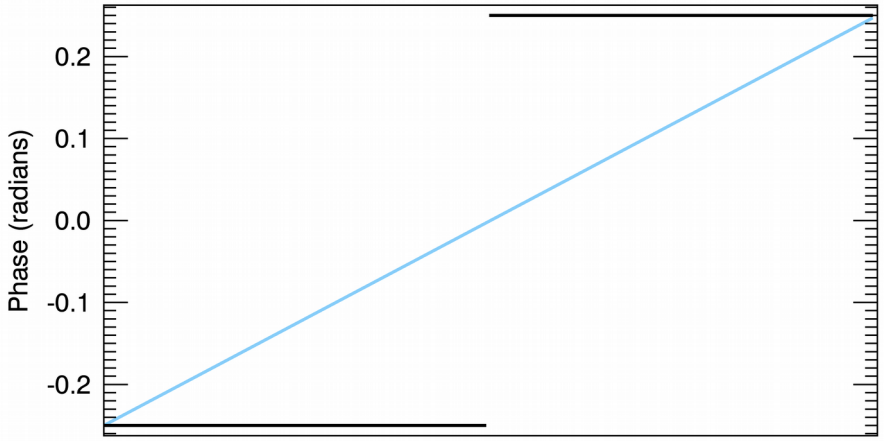
## Centroid changes in response to phase discontinuity

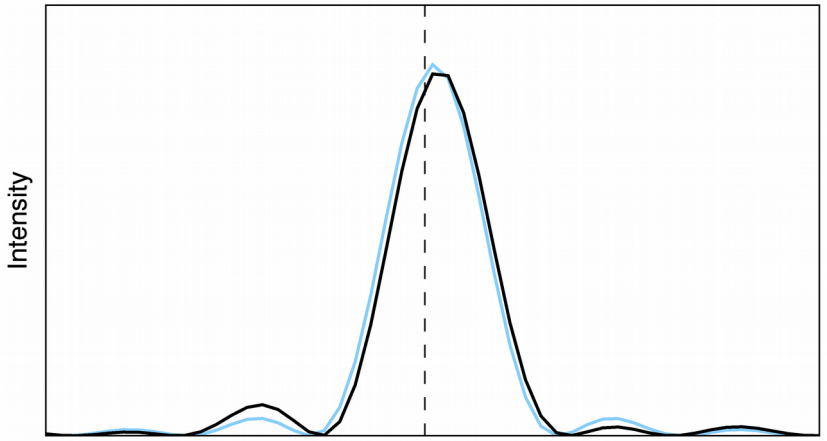


# Response of SH WFS to phase discontinuities

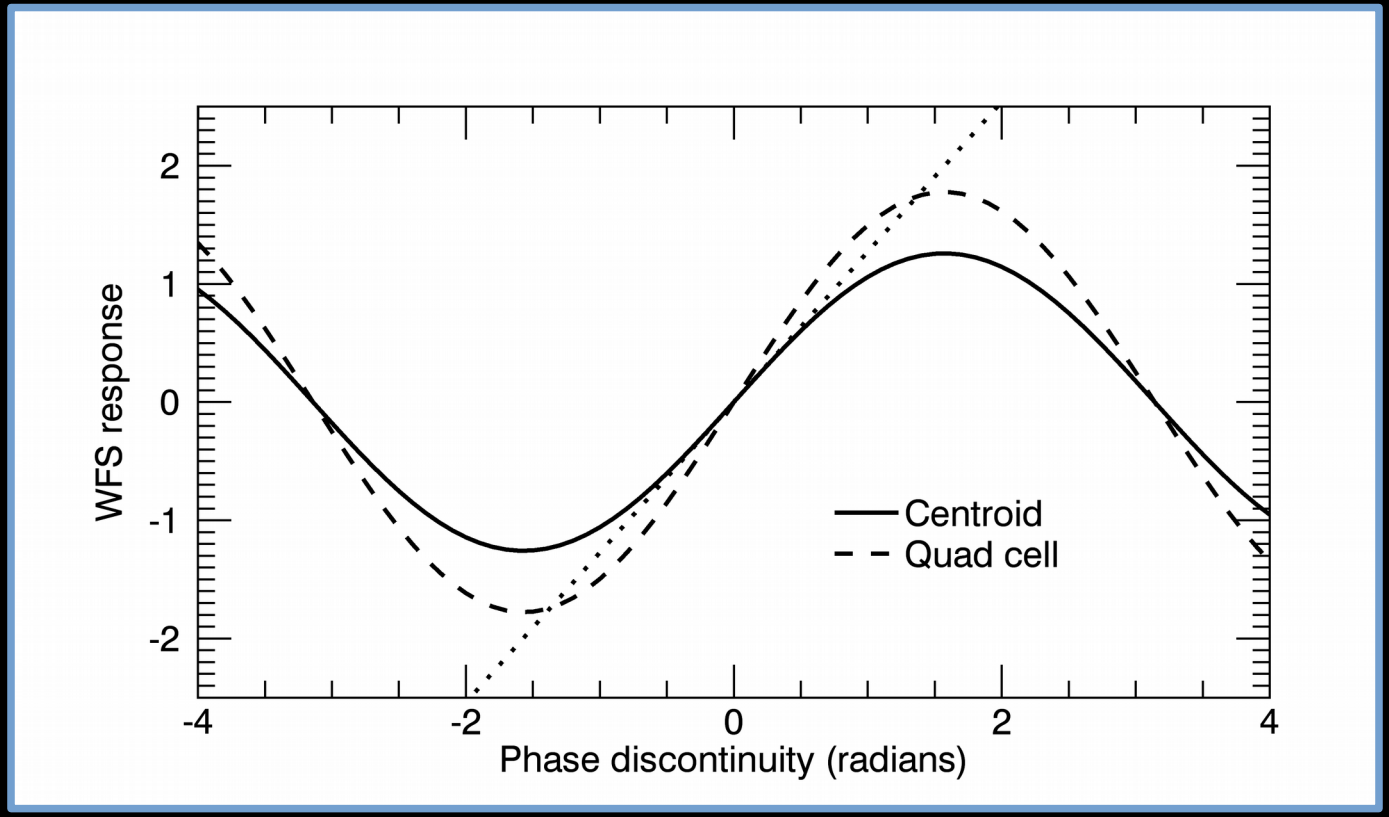
Centroid is exactly the same for a discontinuity as for a constant slope



# Response of SH WFS to phase discontinuities

Quad cell is even more sensitive to phase discontinuities



# Response of SH WFS to phase discontinuities

End-to-end simulations were run in yao to see effect of phasing errors on image quality

| RMS phasing error (nm) | 0 | 50 | 75 | 100 | 125 | 150 | 175 |
|---|---|---|---|---|---|---|---|
| H-band Strehl ratio | 0.733 | 0.729 | 0.724 | 0.708 | 0.672 | 0.603 | 0.512 |

Applied phasing errors

# Response of SH WFS to phase discontinuities

End-to-end simulations were run in yao to see effect of phasing errors on image quality

| RMS phasing error (nm) | 0 | 50 | 75 | 100 | 125 | 150 | 175 |
|---|---|---|---|---|---|---|---|
| Additional wavefront error (nm) | 0 | 19 | 29 | 49 | 77 | 116 | 157 |

Marechal approximation

Phasing error partially corrected

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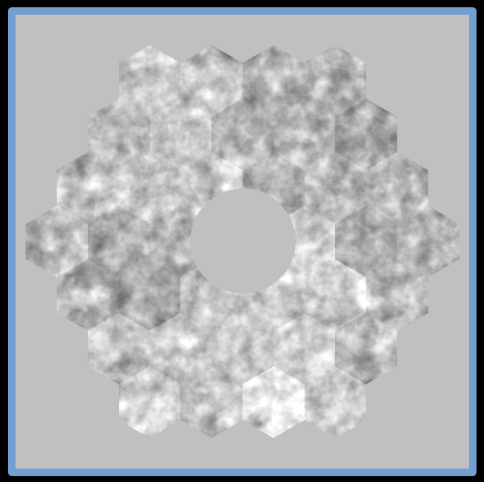
Applied telescope phase

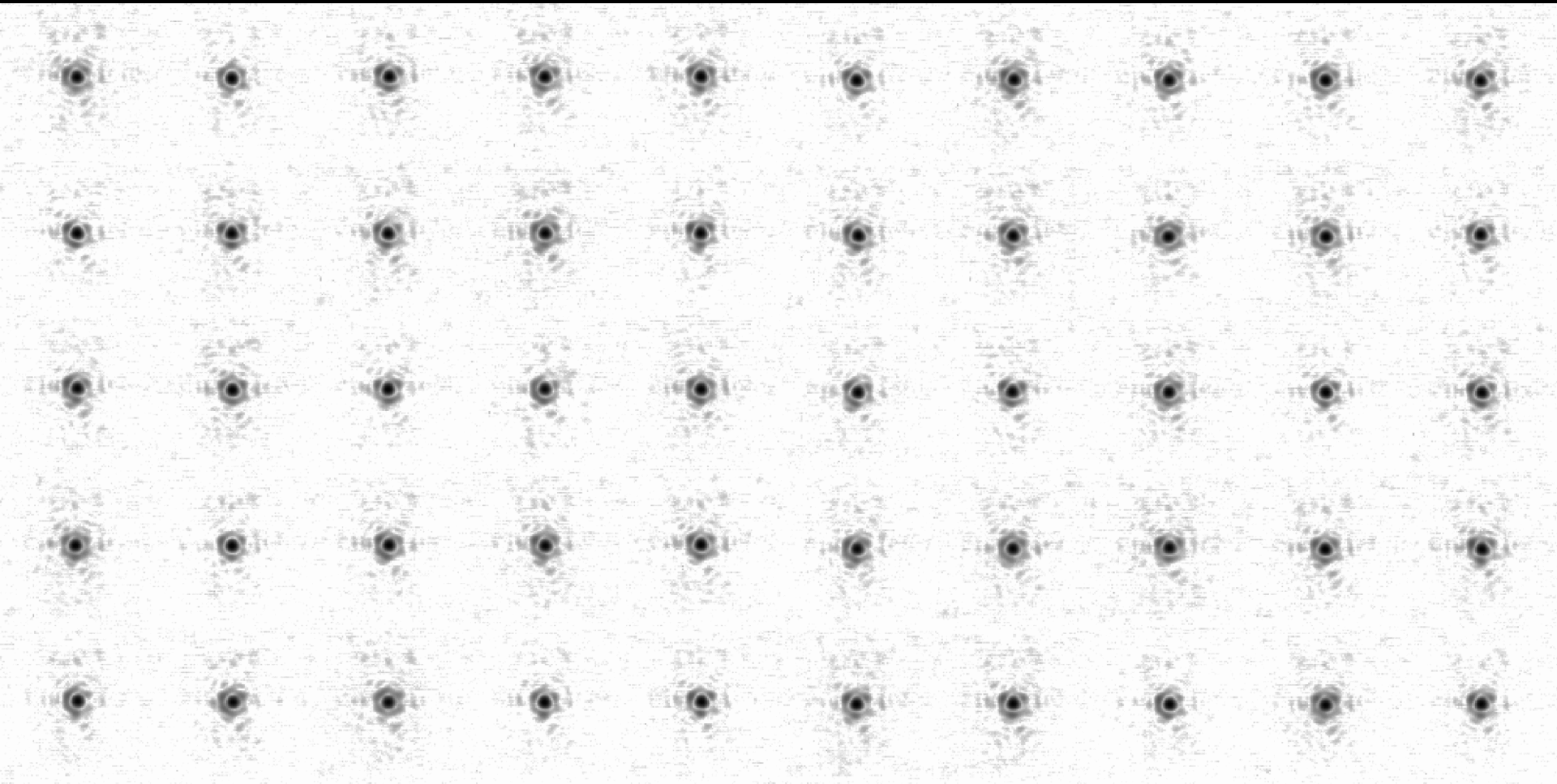
Residual error



Take home message:
Small phasing errors are measured and partially corrected, large errors are not!

# Phase retrieval from images

- 50 short-exposure images were taken in focus
- Modified Gerchberg-Saxton algorithm used to reconstruct phase



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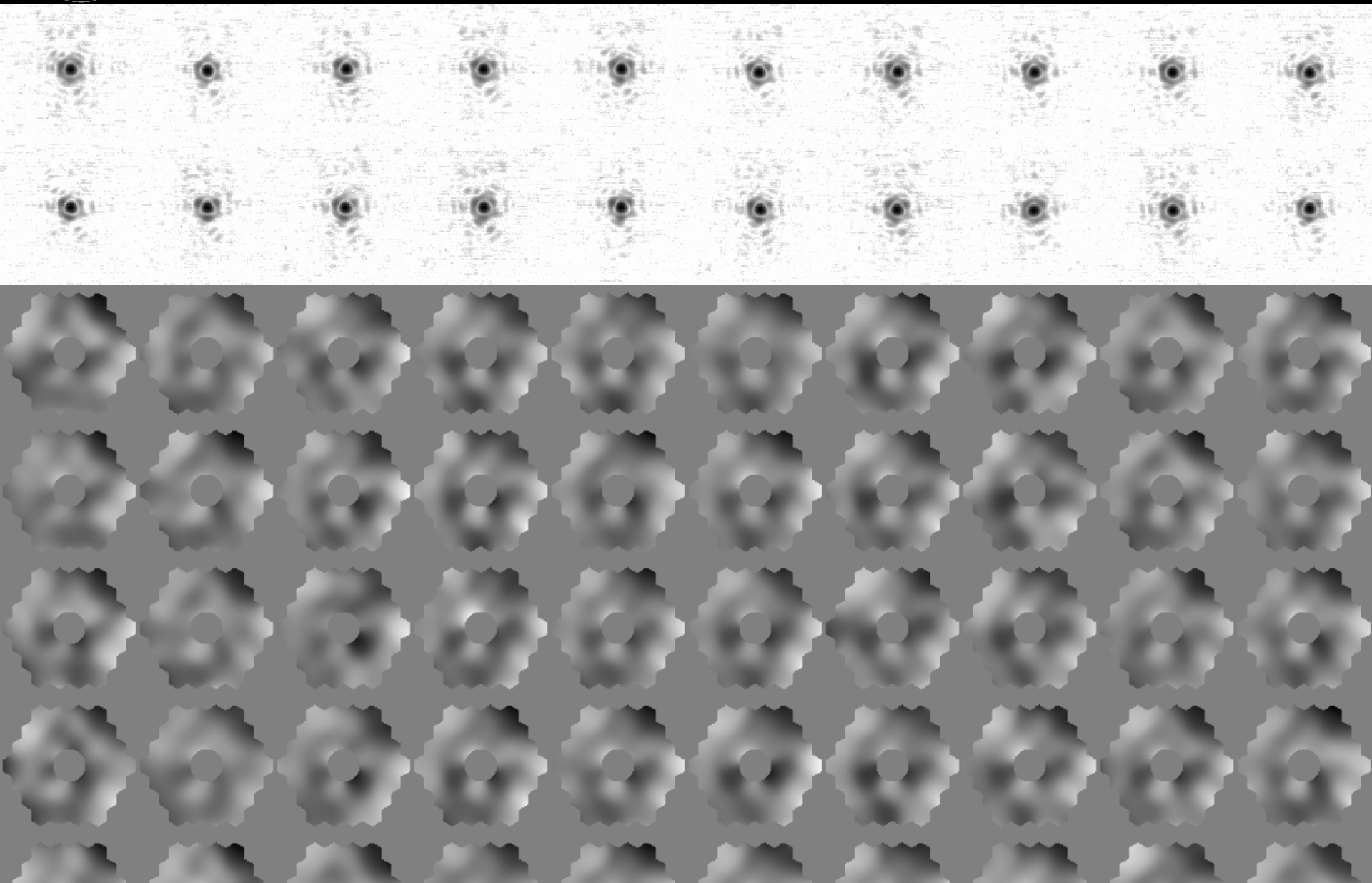
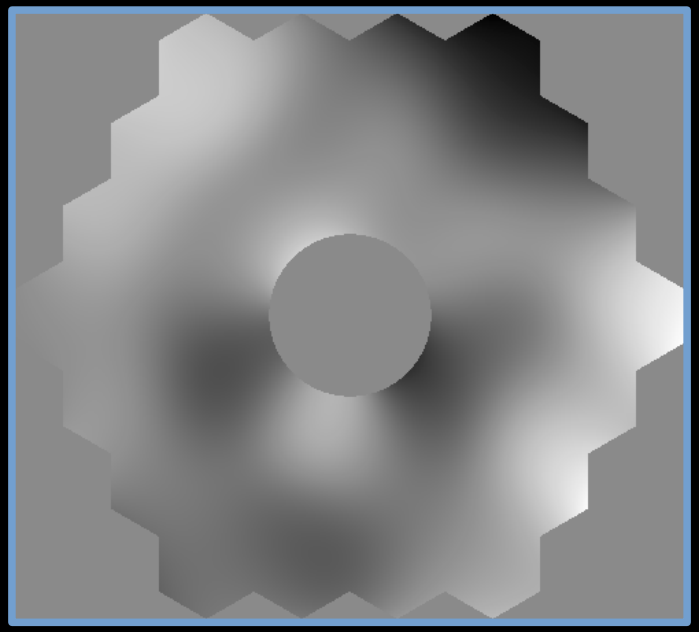
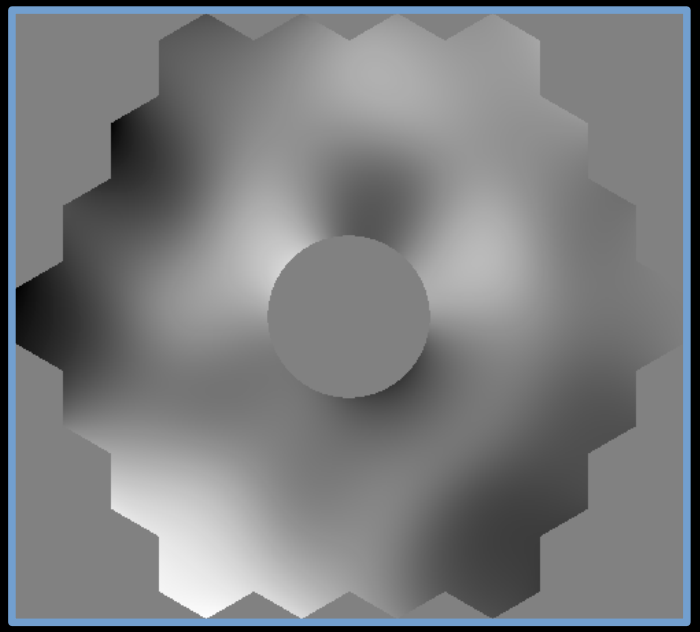


# Phase retrieval from images

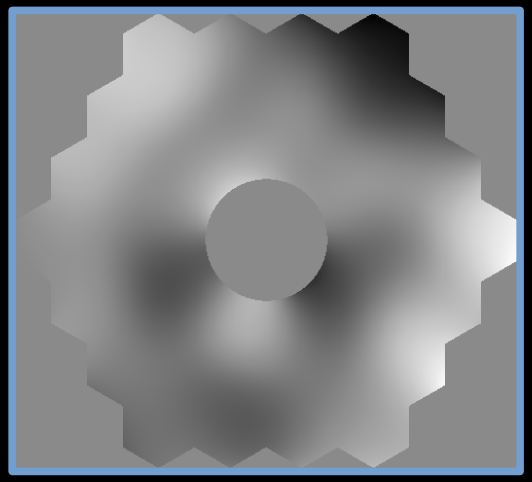
- 50 short-exposure images were taken in focus
- Modified Gerchberg-Saxton algorithm used to reconstruct phase
- Average the reconstructed phases, but there is a phase ambiguity due to the pupil symmetry





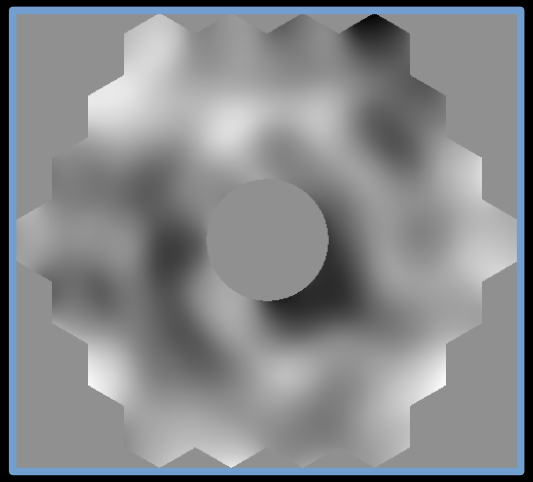
# Phase retrieval from defocused images

- 50 short-exposure images were taken either side of focus
- Used two different methods to reconstruct:
  - Modified Gerchberg-Saxton algorithm
  - Non-linear minimization in yorick-opra software
- Results are almost identical, with RMS value of 112 nm



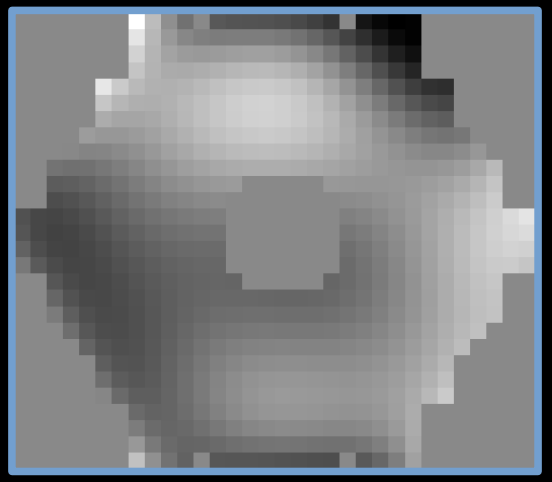
In-focus images

Modified Gerchberg-Saxton



Defocused images

Modified Gerchberg-Saxton

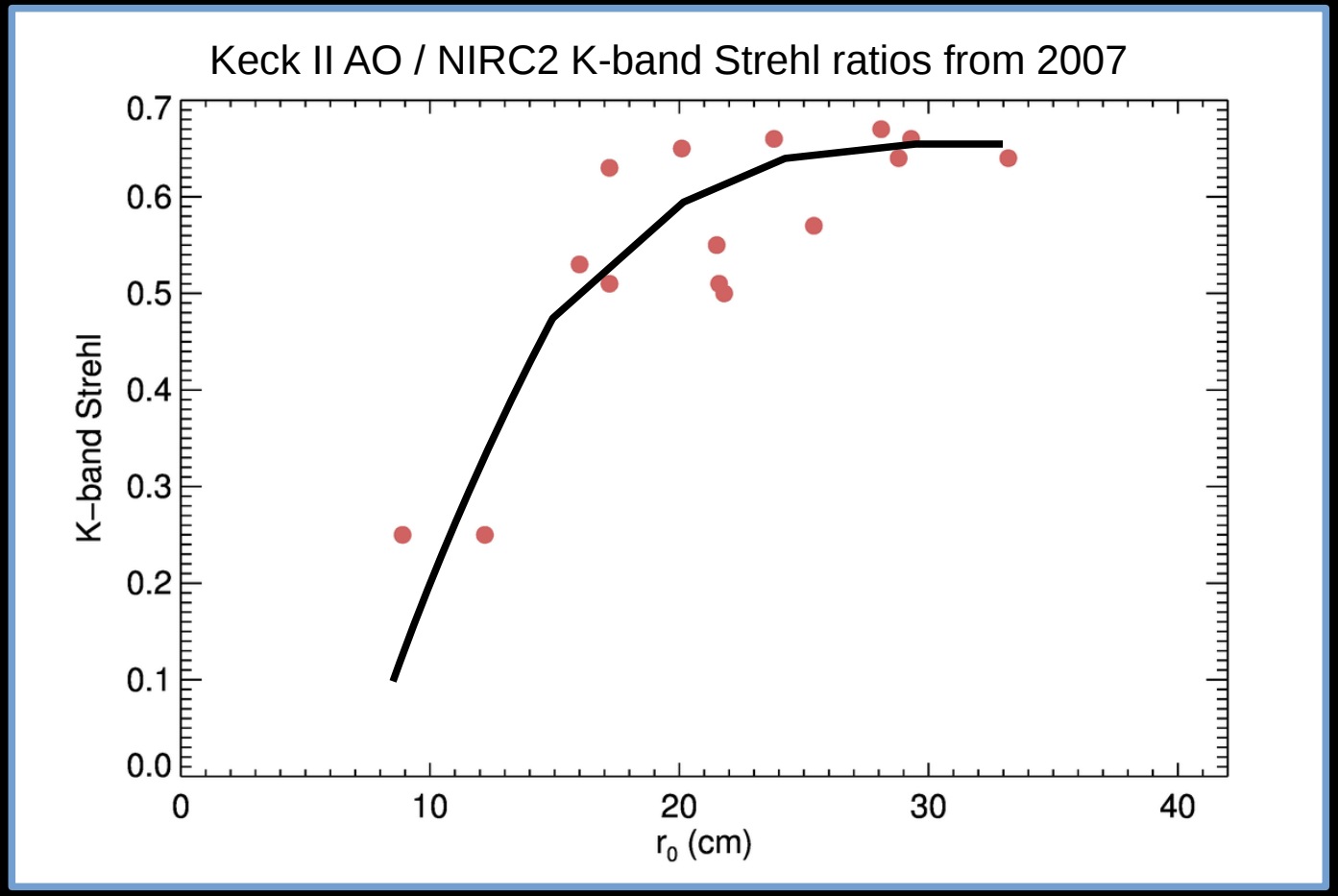


Defocused images

yorick-opra

# Conclusions

- Performance of Keck AO systems on bright stars is limited by phasing errors



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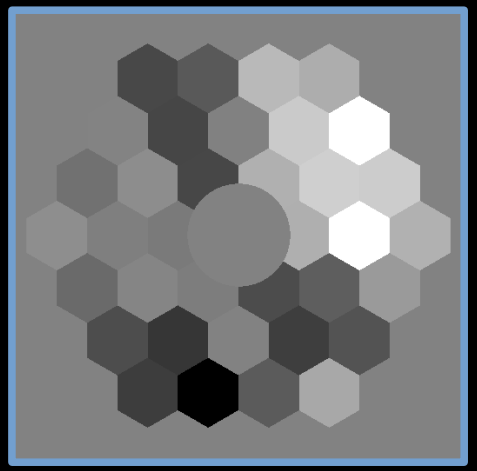
- Performance of Keck AO systems on bright stars is limited by phasing errors
- Random phase errors in segmented telescope lead to low-order phase errors





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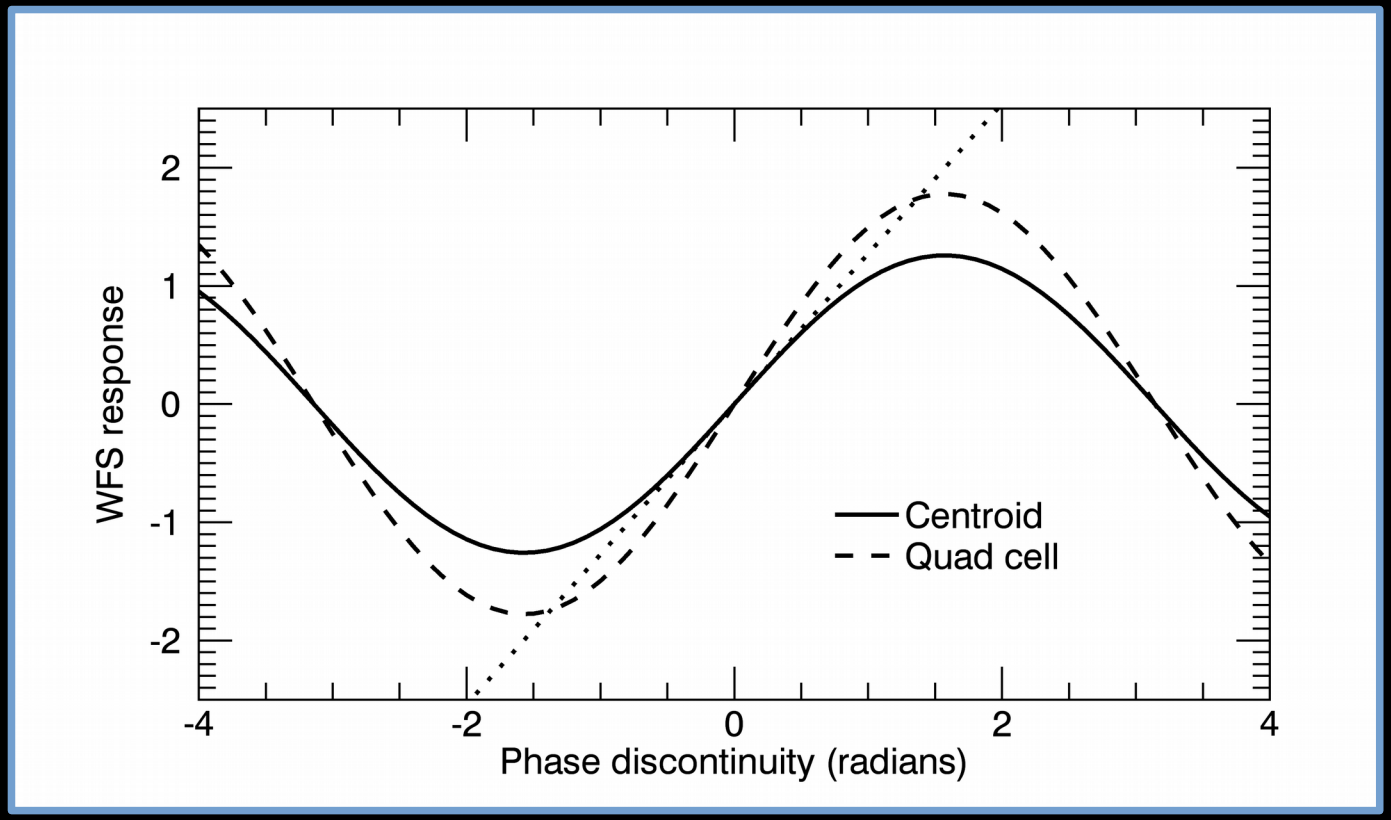
- Random phase errors in segmented telescope lead to low-order phase errors
- Shack-Hartmann WFS can measure ~100 nm RMS segment piston



# Conclusions

- Performance of Keck AO systems on bright stars is limited by phasing errors
- Random phase errors in segmented telescope lead to low-order phase errors
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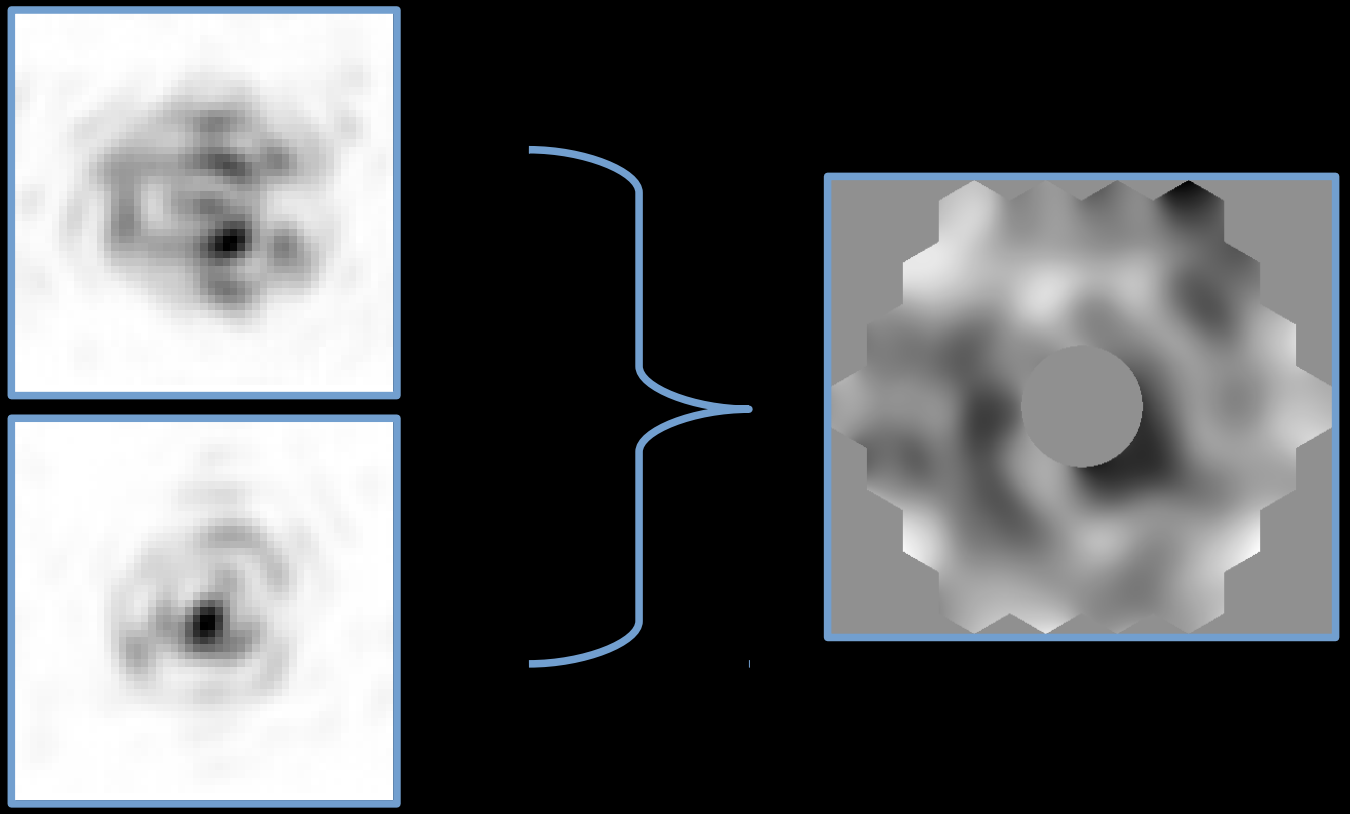
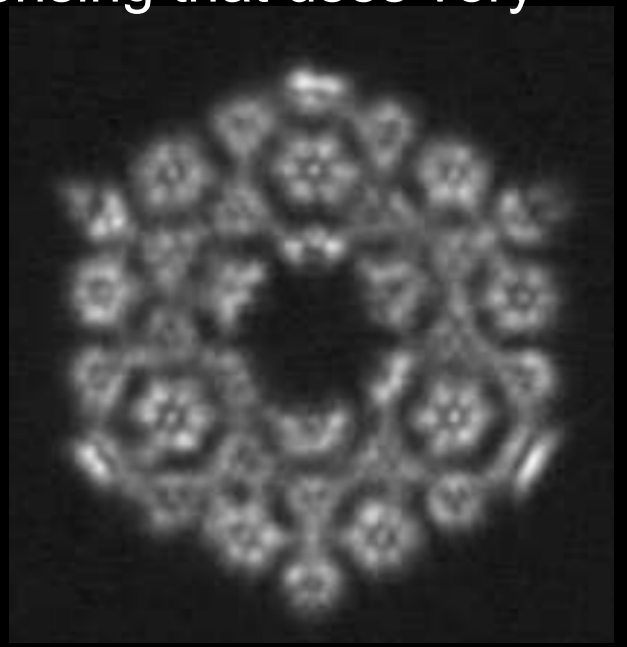
- Phasing errors can be estimated from AO-corrected images at or near focal plane



# Future work

- Test a method called phase discontinuity sensing that uses very defocused images.



- Use the output of the phase reconstruction to update the telescope segment phasing