Effect of segmented telescope phasing errors on adaptive optics performance

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*Flat Wavefronts*

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Motivation

Keck II AO / NIRC2 K-band Strehl ratios from 2007

Image quality limited by error terms independent of seeing!
Motivation

Keck II AO / NIRC2 K-band Strehl ratios from 2007

Best images have low order static aberrations!

Strehl = 75%
Outline of Talk

Review of Keck telescopes, phasing and AO systems
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- Review of Keck telescopes, phasing and AO systems
- Measuring phase discontinuities with a Shack-Hartmann WFS
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- Review of Keck telescopes, phasing and AO systems
- Measuring phase discontinuities with a Shack-Hartmann WFS
- 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 constrain 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
Both telescopes have almost identical 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

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<thead>
<tr>
<th>RMS phasing error (nm)</th>
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<th>75</th>
<th>100</th>
<th>125</th>
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<td>H-band Strehl ratio</td>
<td>0.733</td>
<td>0.729</td>
<td>0.724</td>
<td>0.708</td>
<td>0.672</td>
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Applied phasing errors
Response of SH WFS to phase discontinuities

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Marechal approximation

Phasing error partially corrected
Response of SH WFS to phase discontinuities

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

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- 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.