Pyramid WFS Performance Tolerance Study for NFIRAOS

Lianqi Wang
Jean-Pierre Veran, and Brent Ellerbroek

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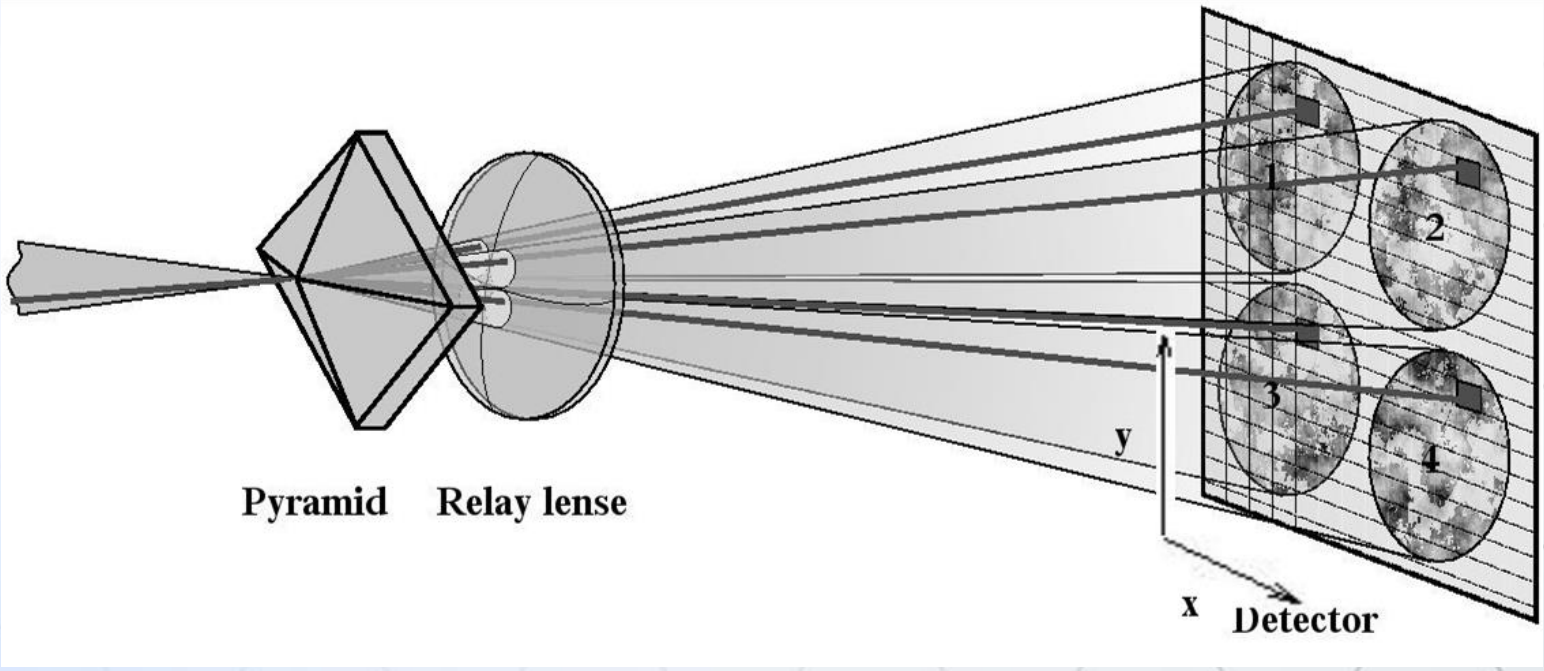
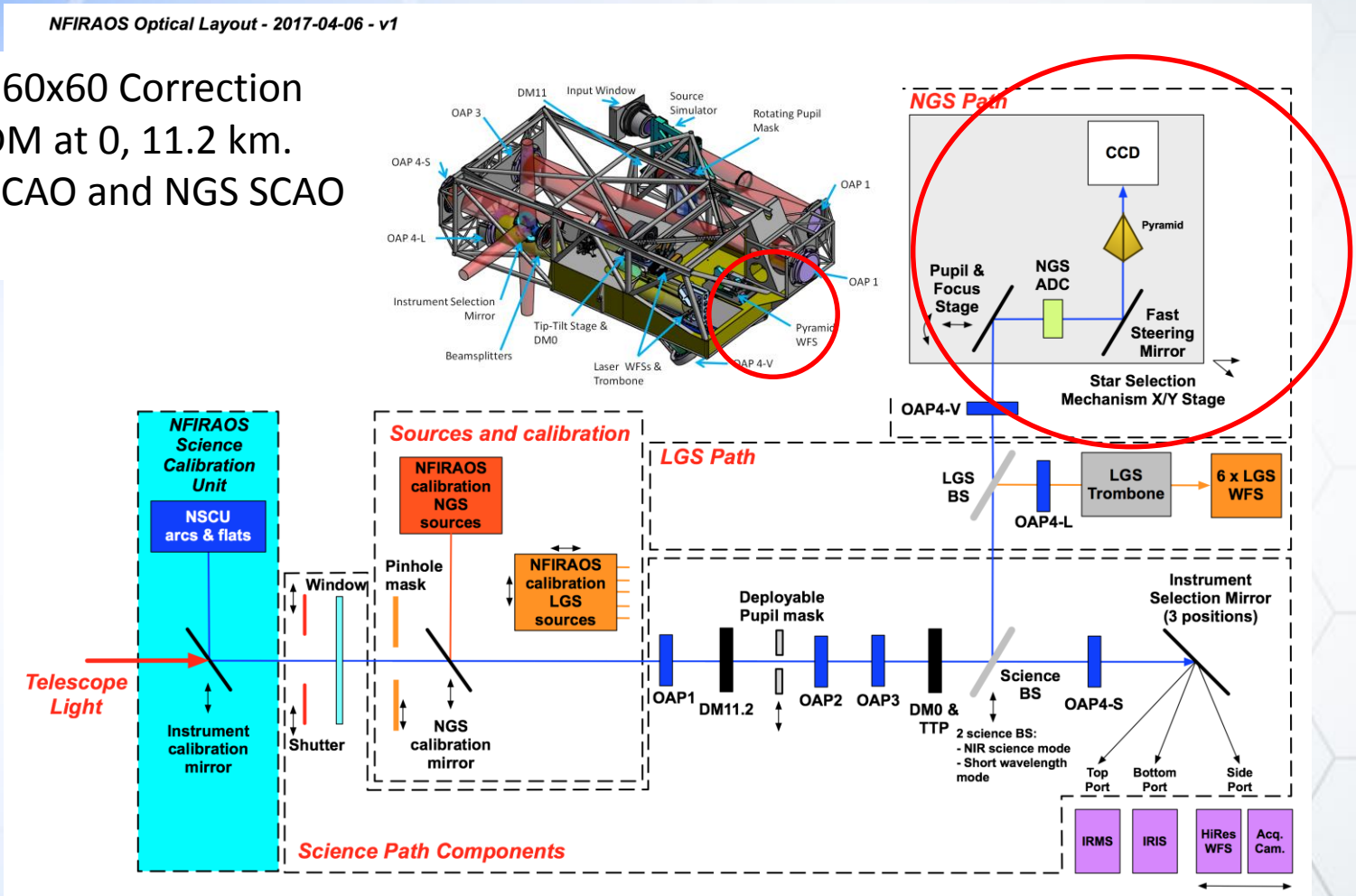
Outline

- PWFS in TMT NFIRAOS
- Simulated performance
- Implementation error tolerance
- Interaction matrix

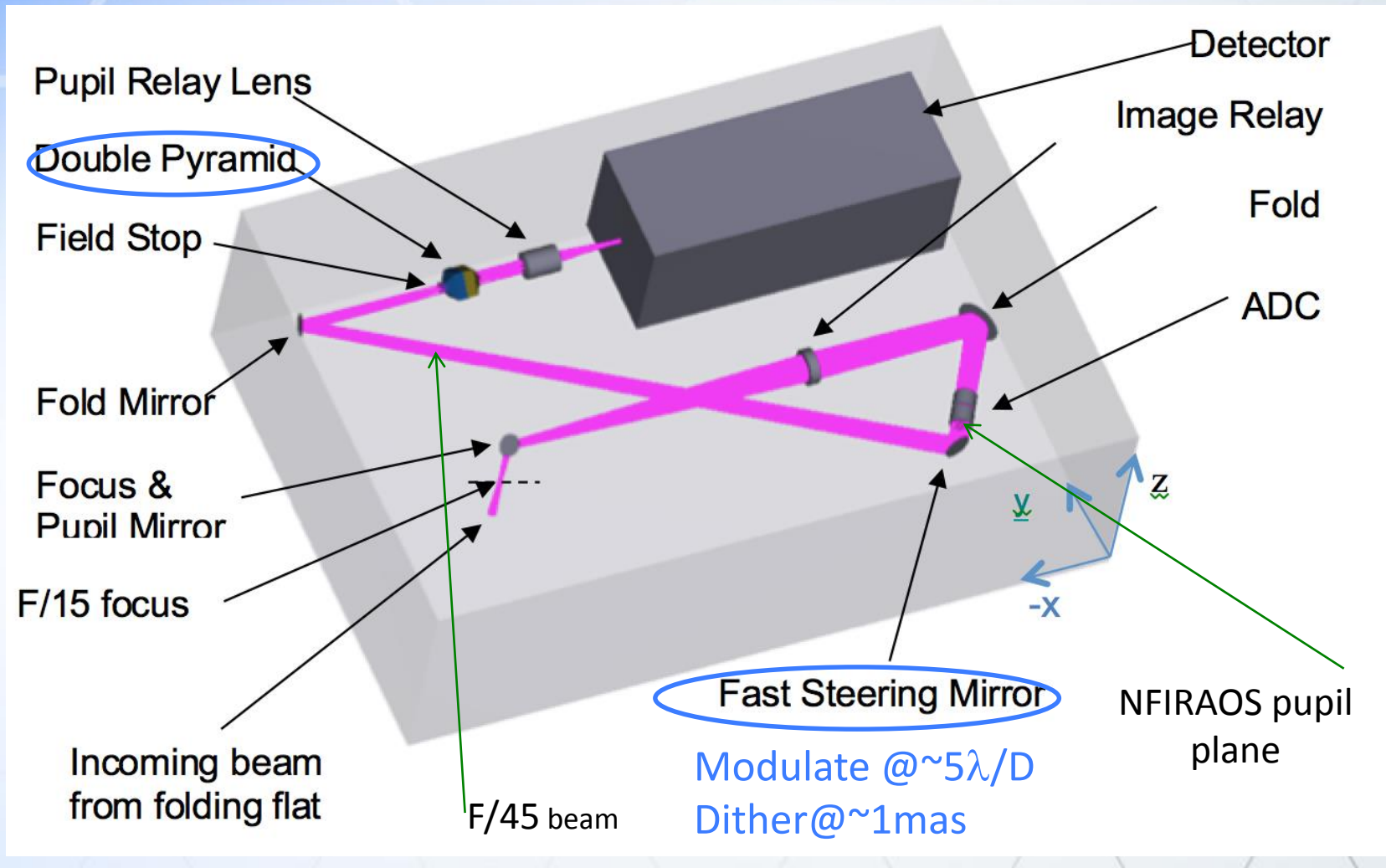


NFIRAOS

- Order 60x60 Correction
- Dual DM at 0, 11.2 km.
- LGS MCAO and NGS SCAO



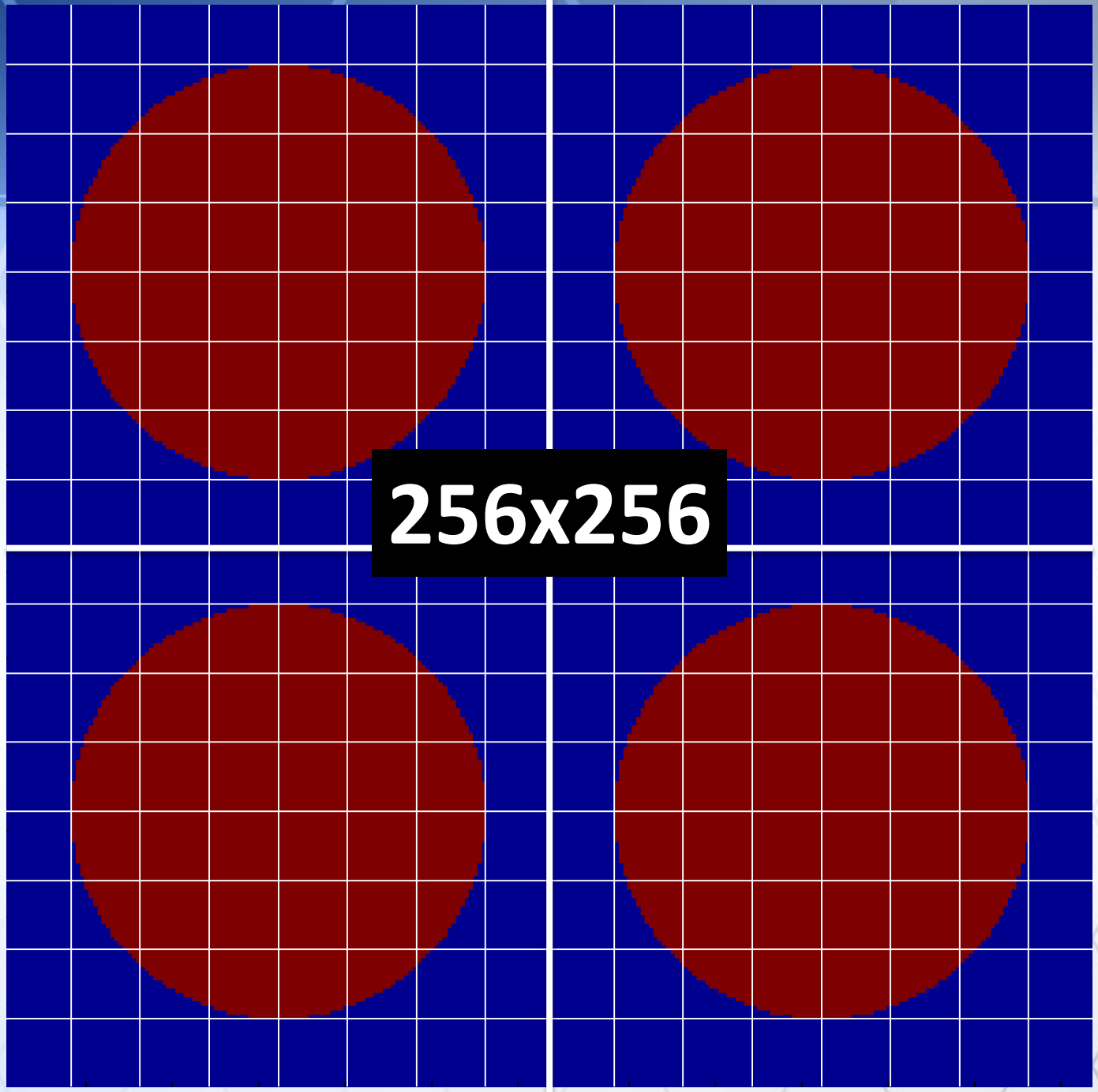
NFIRAOS PWFS on x/y Stage



PWFS Detector

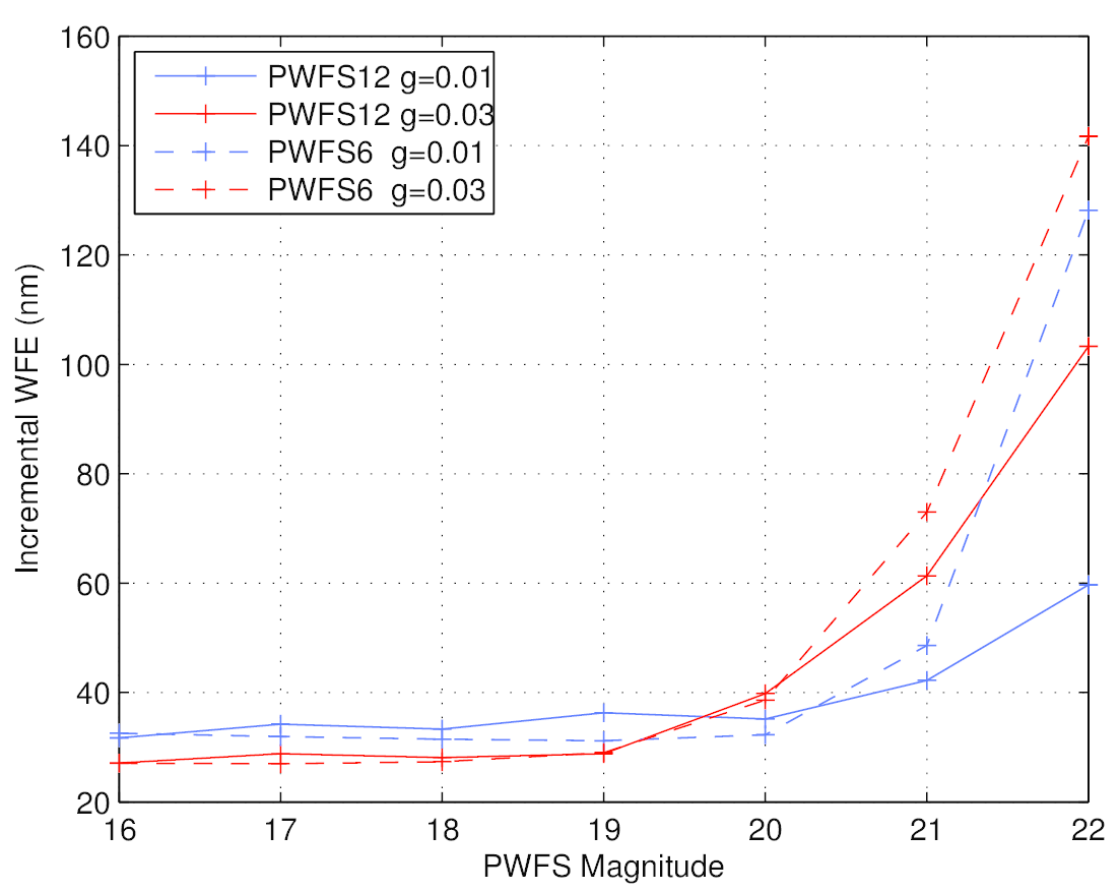
- 96x96 pupil sampling
  - <1e^- RoN: negligible noise penalty
  - Reduces aliasing error
  - Various binning modes: 48x48, 32x32, 24x24, 12x12, 6x6, etc.
  - Oversampling helps to relax sub-pupil tolerance

TMT
Thirty Meter Telescope



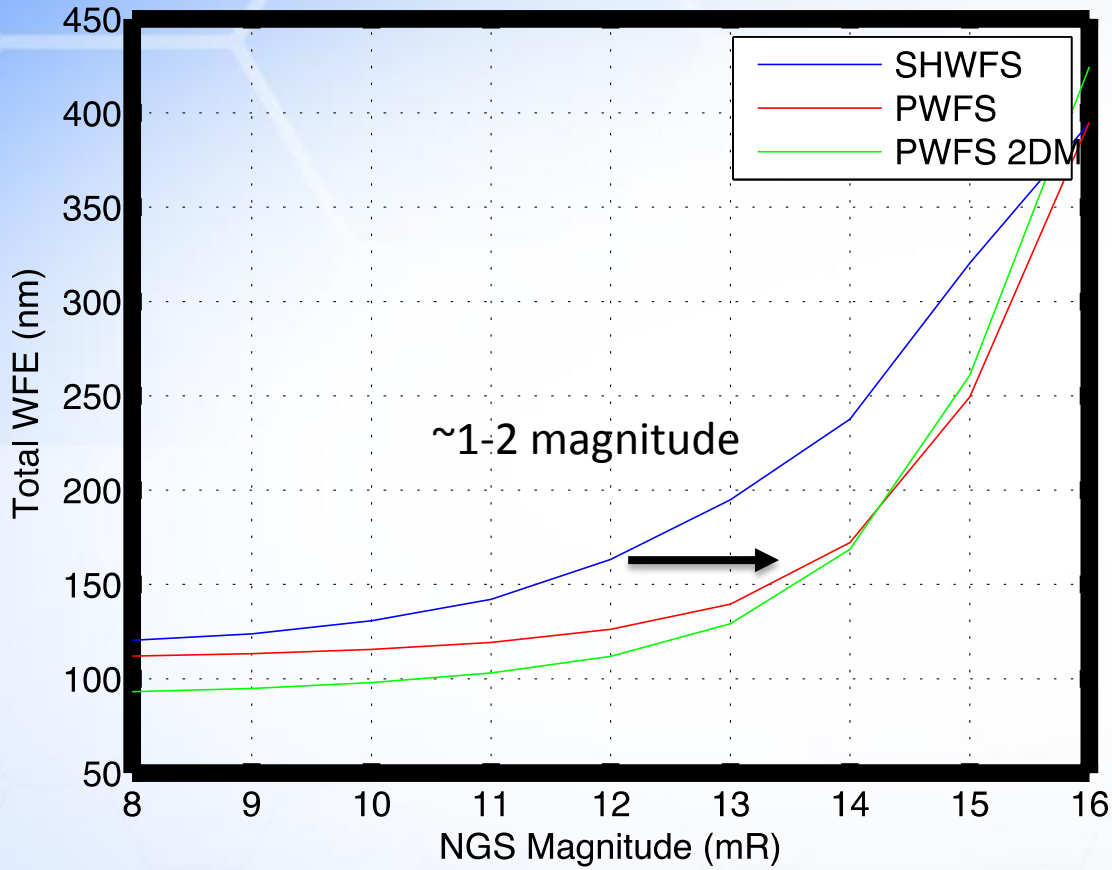
Three Major Functions

PWFS Function 1/3
Truth WFS for LGS MCAO



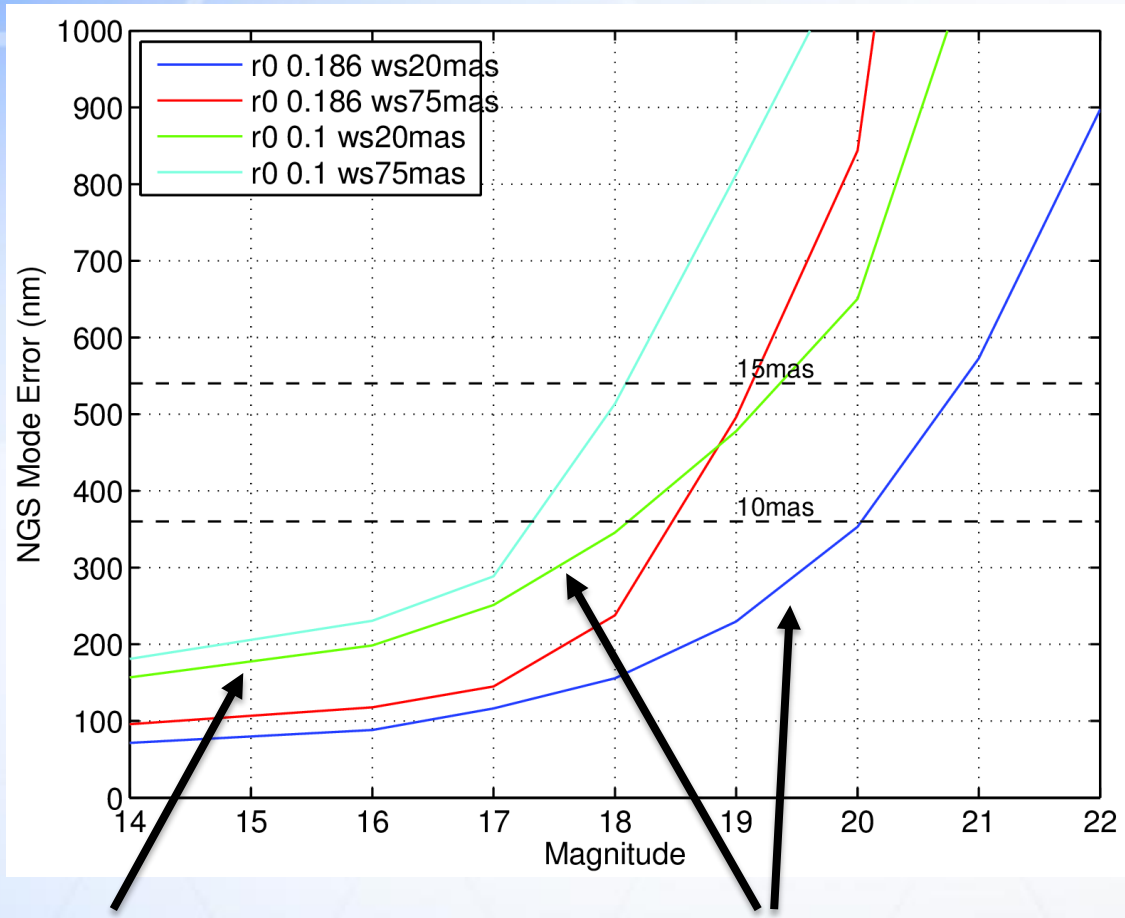
- Corrects bias error due to sodium profile evolution.
  - center launch
  - radial order modes only
- Versatile binning helps magnitude limit (mR=22)
  - Minimum at 8 Hz (TBC) to enable optical gain tracking
  - ~100% sky coverage

PWFS Function 2/3
Classic AO



- Simulation
  - SHWFS@60x60 with 4x4 pix
  - PWFS @ order 96x96
  - 1 vs 2 DM control
    - ~60 nm reduction
  - Dim NGS (m_R>=15)
    - Increased modulation
    - Binning detector (not done yet)
- Other configuration
  - Assuming 150 nm alignment error (astigmatism) + 70 nm polishing error
  - Excludes other implementation error

PWFS Function 3/3 as Tip/Tilt WFS



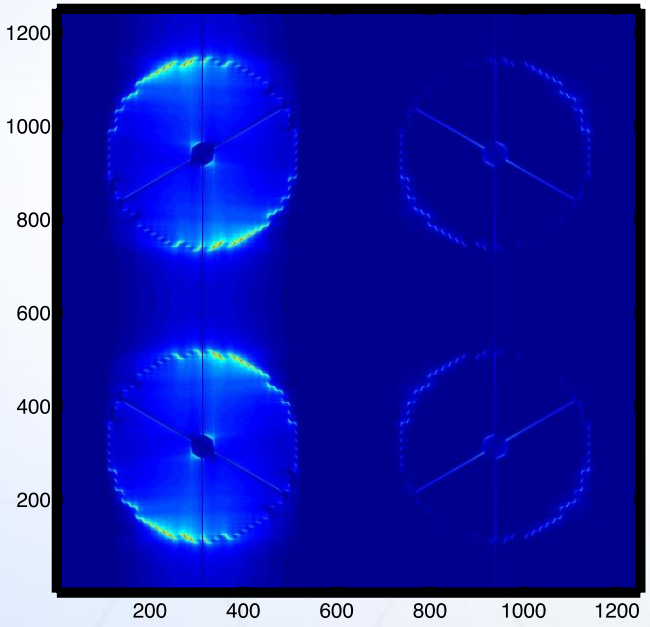
- Stabilizes tip/tilt to simplify OIWFS/ODGW acquisition
  - wind shake
  - turbulence
- m_R<18-20
- 80 percentile Mauna Kea sky background

Worst seeing

75 percentile wind

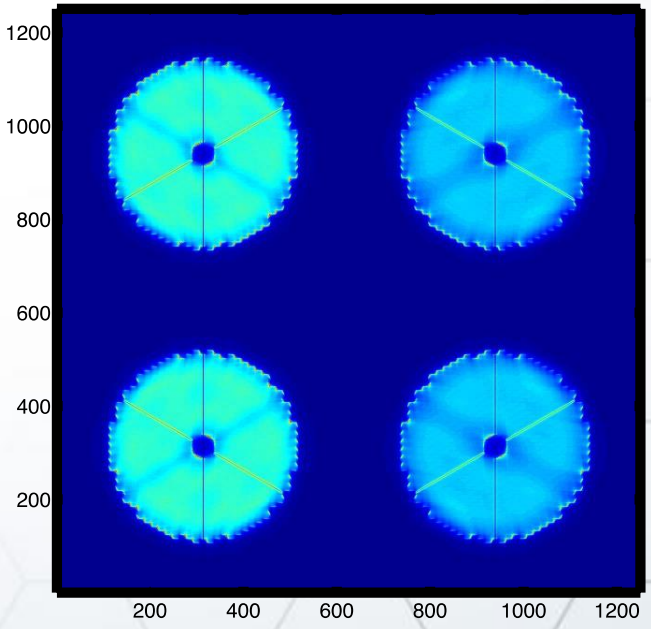
Simulation of PWFS in MAOS (1)

- Simulation of PWFS in our AO simulator (MAOS)
  - Complex pupil function with 3x embedding factor
  - FFT → Apply Pyramid Phase → Inverse FFT→ABS2
  - Repeat with Pyramid vertex at each modulation position or sampling an extended object



Without Modulation

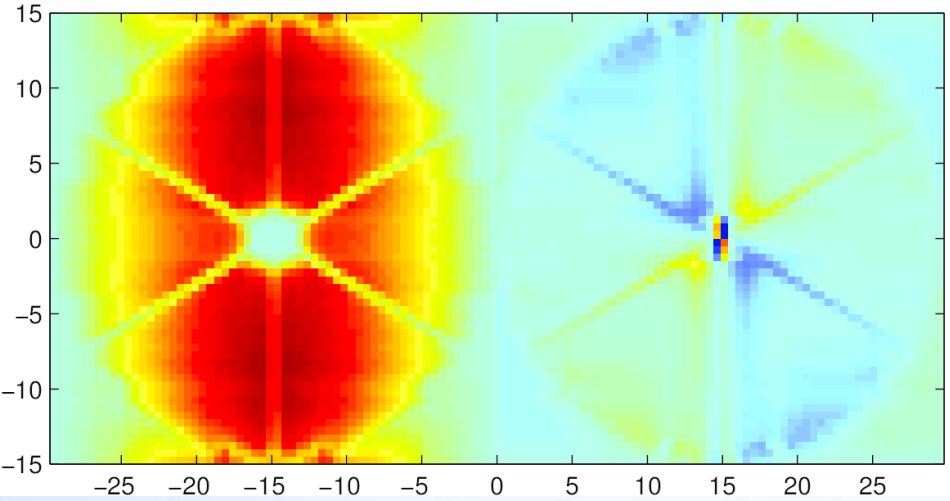
Tilt mode



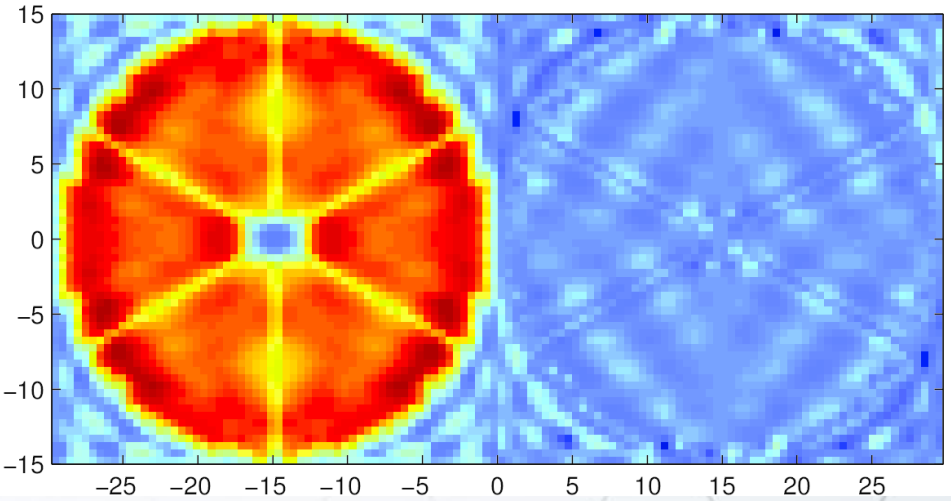
With 5λ/D Modulation

Simulation of PWFS in MAOS (2)

- Simulation of PWFS in our AO simulator (MAOS)
  - Sample Images onto detector
  - Extract sub-pupils using thresholding of sum of sub-pupils
  - Compute Gradients using quad-cell algorithm



Without Modulation

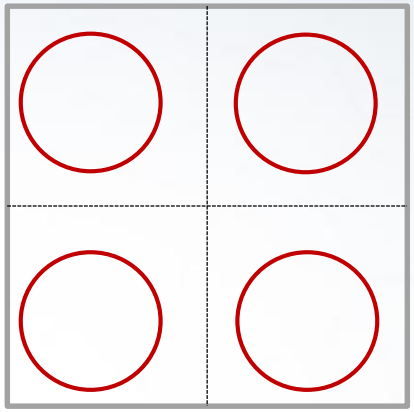


With 5λ/D Modulation

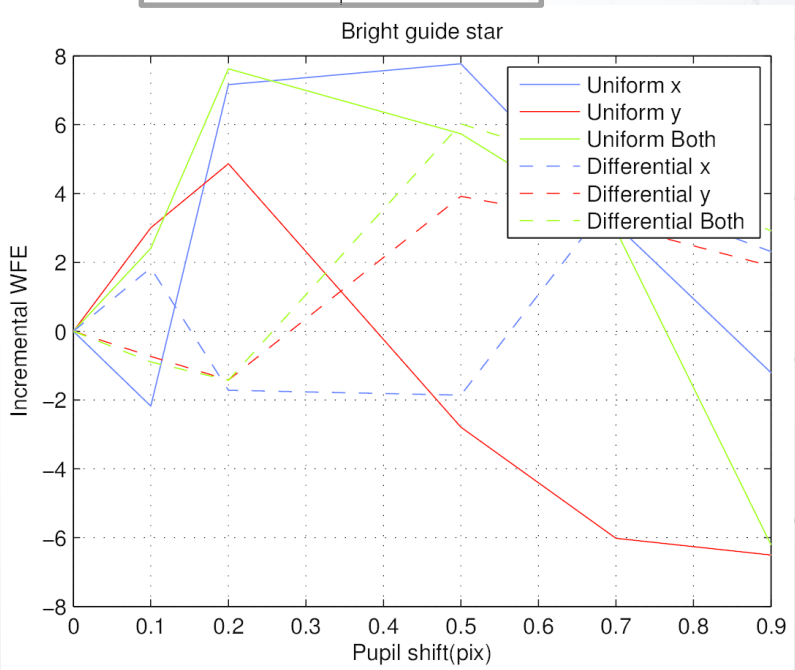
All Kinds of Implementation Errors

Implementation Errors (1) Geometry

- Pupil Location error
  - Vertex angle error
  - PWFS to CCD misregistration
  - Solution:
    - Measuring the actual pupil
    - No need to be separated by specific integer number of pixels
- Pupil magnification error
  - Affects order of sensing
  - Negligible effect
- Common pupil distortion
  - Caused by OAPs.
  - Negligible effect

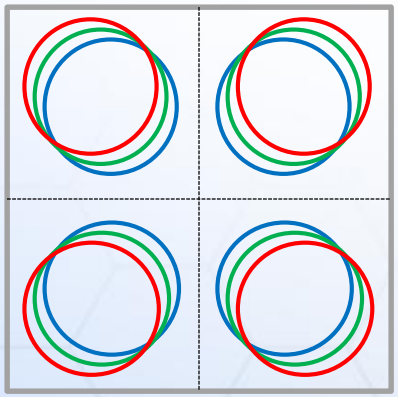


(credit: O. Lardiere)



Implementation Errors (2) Blurring

- Flat edge and vertex
  - Should be smaller than λ/D (31.5 micron in f/45 beam).
  - We simulated 22 micron width of flat edge and vertex.
  - 16 nm WFE penalty.
- Sub-pupil blurring
  - Detector charge diffusion
  - Pyramid chromatic effect
  - Relay optics blurring
  - Modulation mirror smearing



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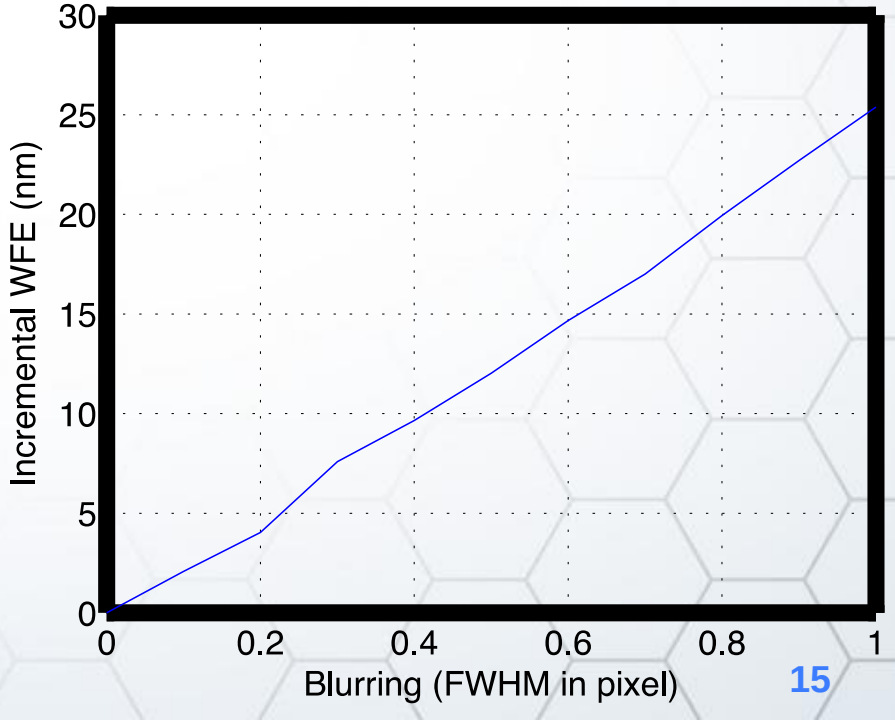
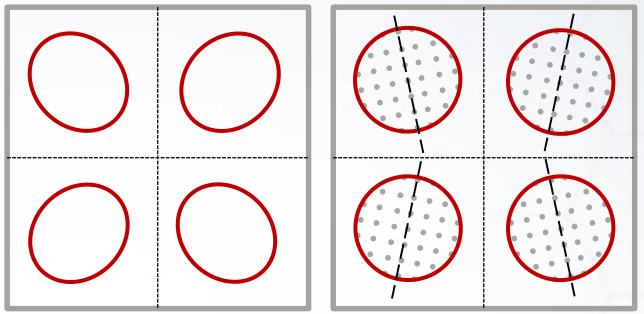


Implementation Errors (3)
Pupil distortion

- Differential distortion
  - Radial elongation
  - Sub-pupil rotation
  - Cannot be compensated by redefining the pupil
  - Negligible up to 1 pixel offset



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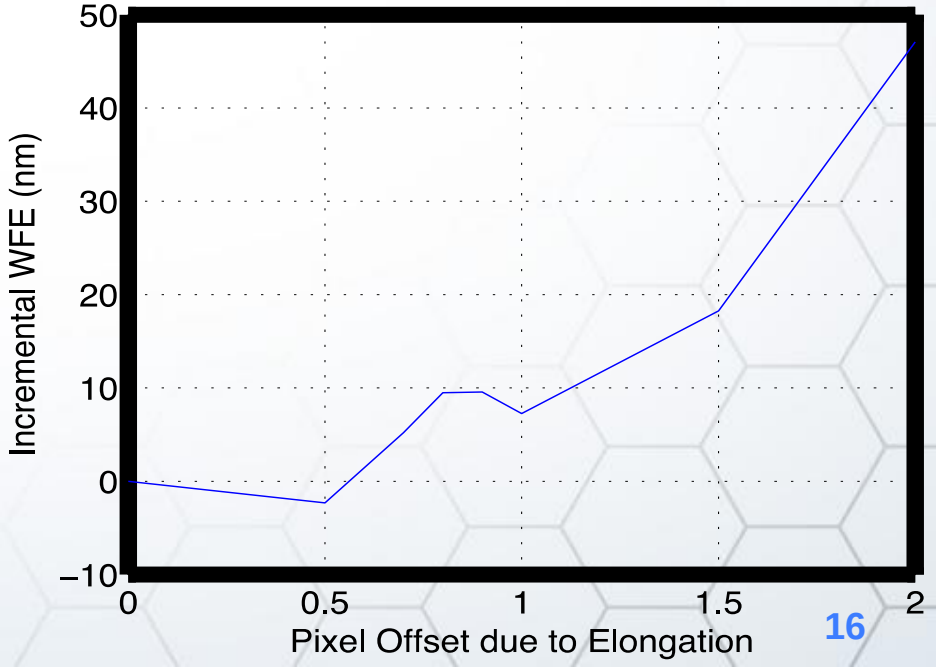
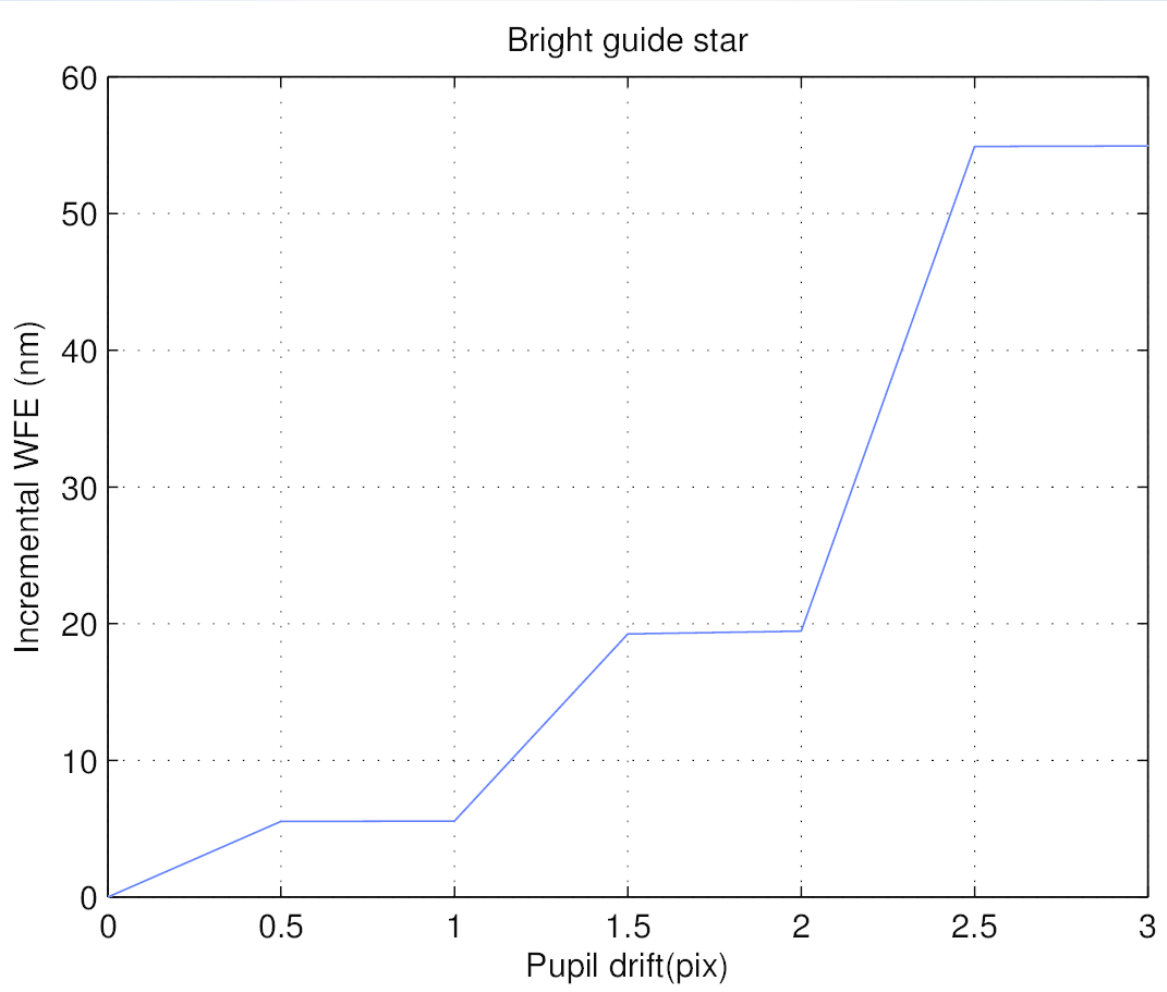


Implementation Errors (4)
Pupil Drift

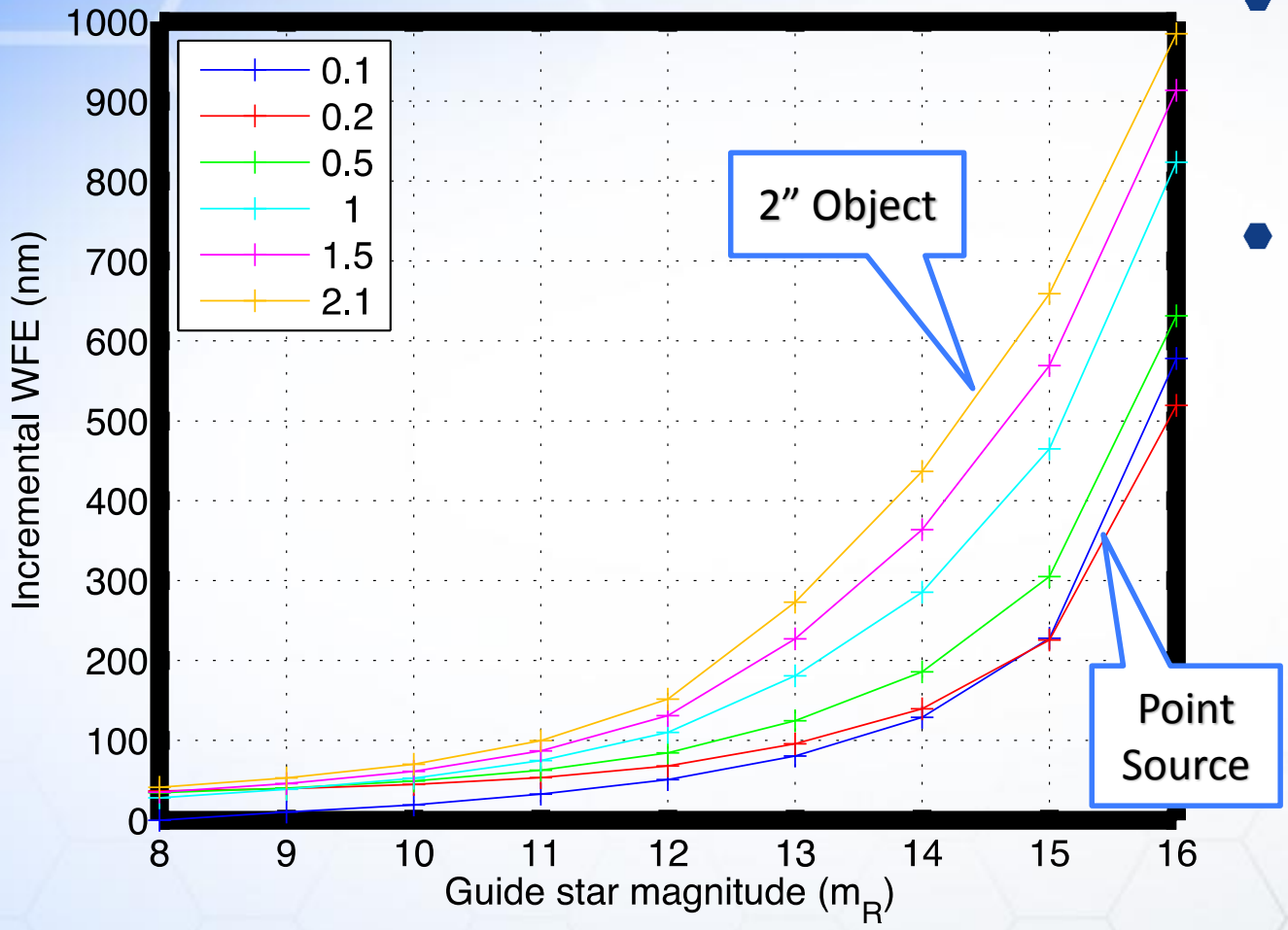
- Pupil drift cannot be compensated
  - <~1 pixel
- PWFS is used for to feed back TMT pupil error
  - <~0.1 pixel



Implementation Errors (5)
Focal Plane Effects

- Modulation error due to steering mirror position accuracy.
  - 32 point modulation with PI FSM mirror
  - Tip/tilt error
- None point source
  - Atmospheric dispersion corrector (ADC) residual
  - Extended guide object
  - Like increased modulation: reduces sensitivity.

Extended Object Classic AO



- 2 magnitude penalty for 2" spot
- Simulated by modulation

Implementation Errors Tolerance Summary

Term	Tolerance	Impact to WFE
Common pupil distortion	0.2 pix RMS	0
Differential pupil distortion	0.4 pix p/v	16
Pupil image location	A few pixels	12
Imperfect Pyramid	22 micron flat edge/vertex	16
Pupil image quality (blur)	0.6 pix FWHM	16
Charge diffusion (blur)	0.7 pix FWHM	17
Modulation error	<2 uas	0
Pupil drift	<0.1 pixel	0
Total		35

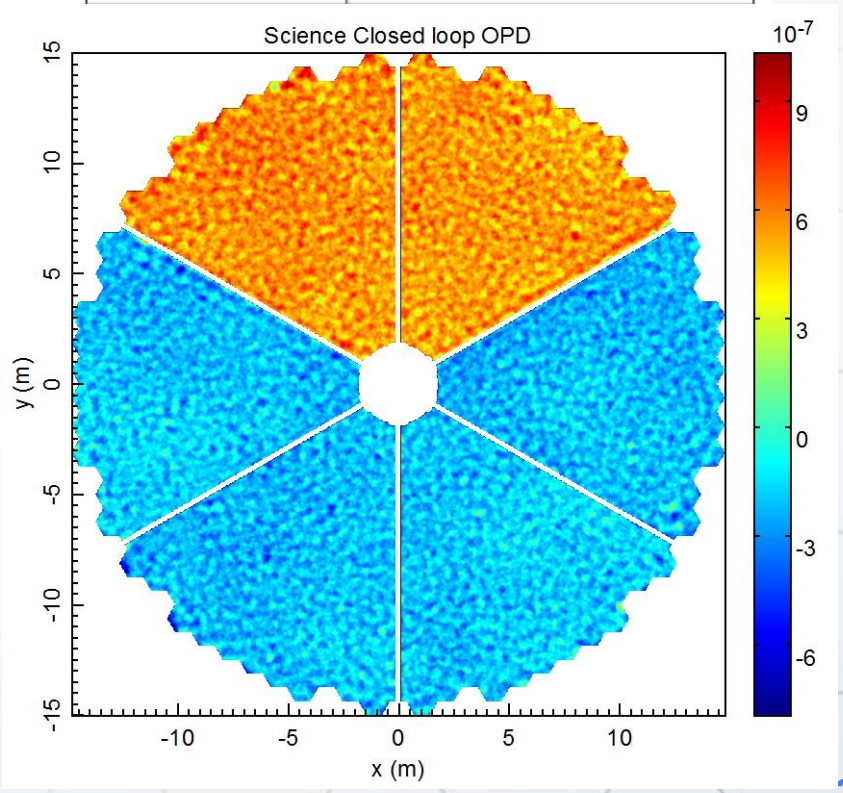
Interaction Matrix Complications

Interaction Matrix Measured

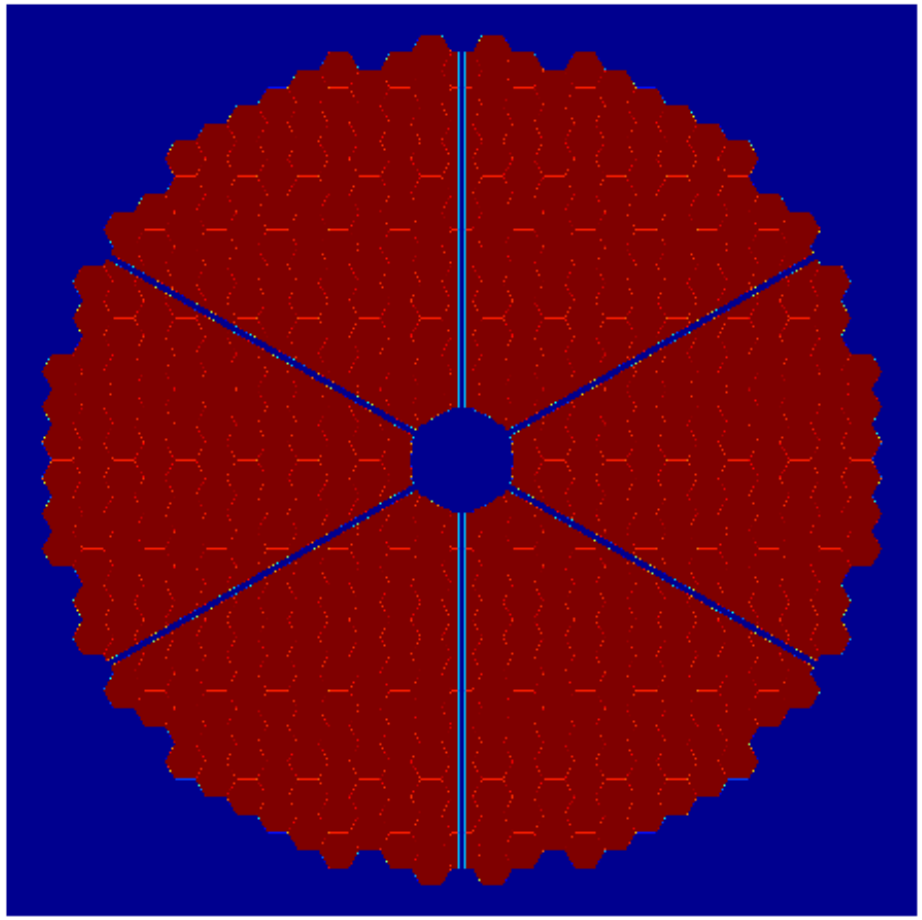
- Includes error due to DM hysteresis, photon noise, implementation error, etc.
- Need precise pupil mask with uniform illumination
- Need one IA every half degree of pupil rotation

	Incremental WFE (nm)
TMT_10%	14.2
TMT_20%	19.4
Circular	30.9
Circular_10%	35.2
Circular_20%	36.6

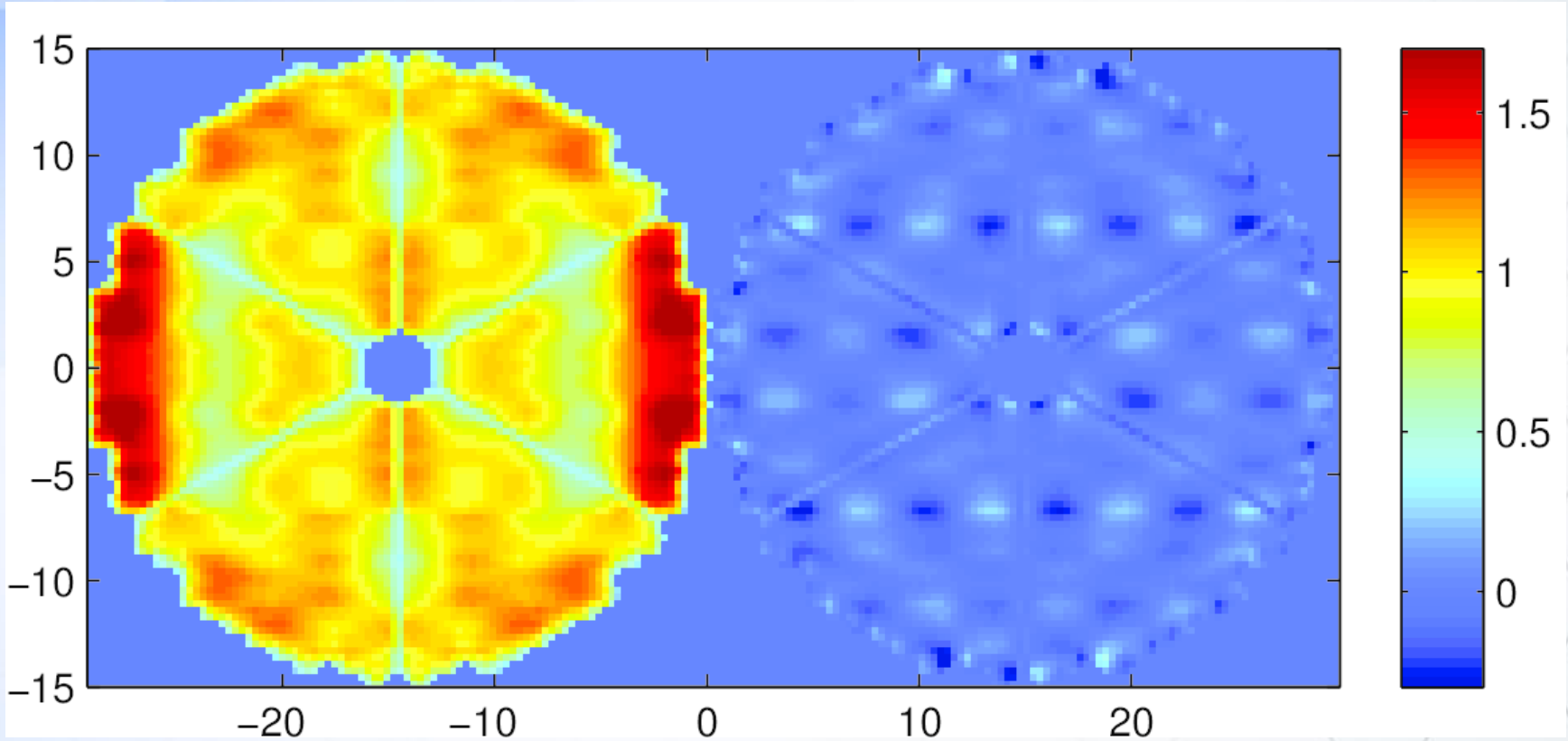
Pupil angle difference (degree)	Incremental WFE (nm)
0.4	5.8
0.5	9.1
0.6	10.6
0.7	170.5
0.8	174.3
0.9	178.2
1	183.3



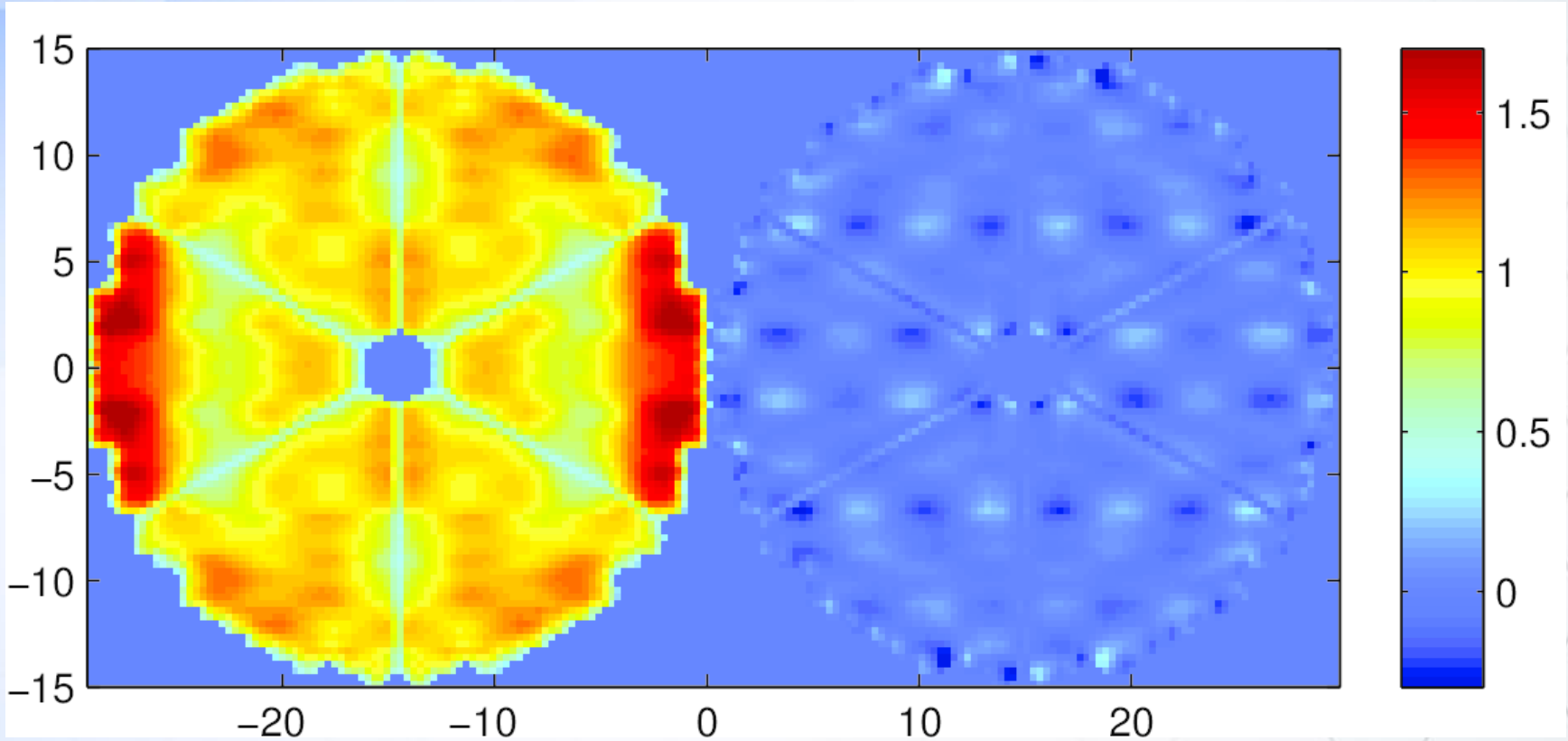
TMT Pupil



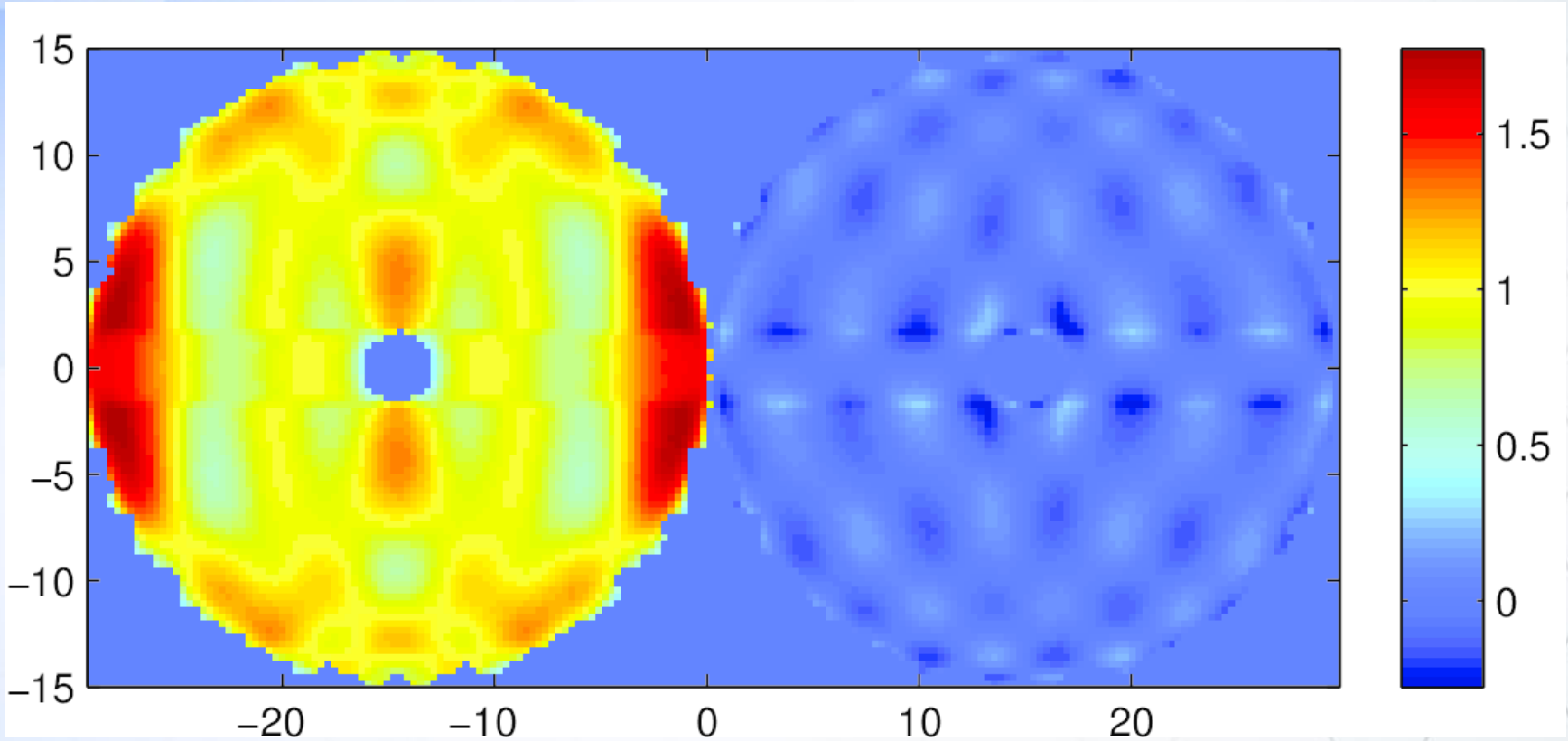
Interaction Matrix (TMT)
Tilt mode



Interaction Matrix
TMT+20% variation



Interaction Matrix
Circular Pupil



Interaction Matrix via Simulation

- Numerical interaction matrix via simulation
  - Free of measurement noise.
  - Needs precise knowledge all aspects of the system
    - Actual telescope pupil
    - Optics distortion information (from measured IA)
    - DM actuator influence function
    - PWFS prescription and defect
    - Precise sub-pupil location and shape on the detector.
    - Any pupil blurring
    - Modulation parameters
    - ...
  - Will it work well on sky?
- On line measurement?
  - A lot of modes to measure: ~7000 actuators.

Acknowledgments

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