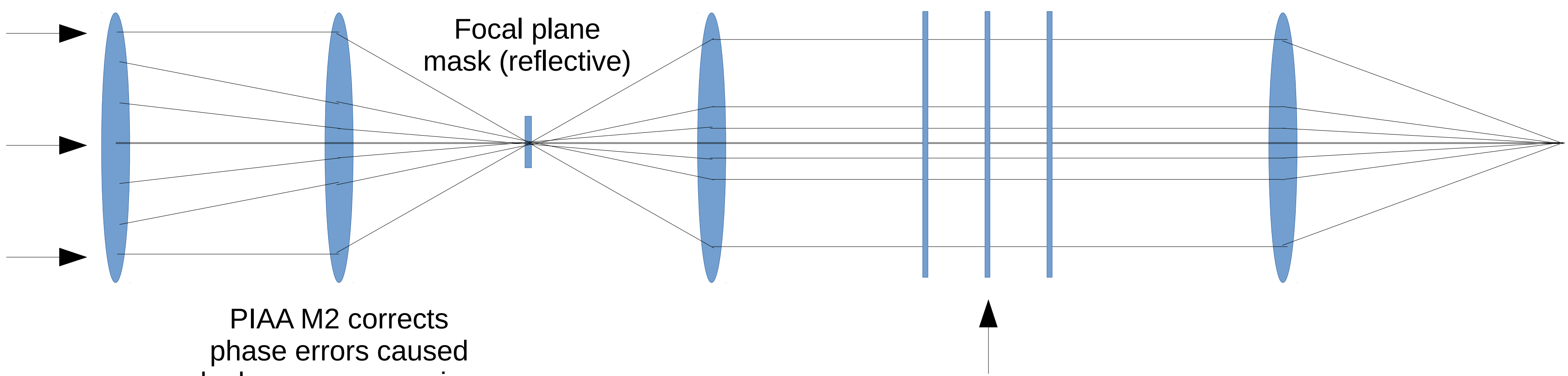
AFTA PIAACMC 3rd Genenration (PIAACMC-20150322) Modeling Results including OS3 Time Series

John Krist (JPL)
26 March 2015

PIAACMC Schematic



No inverse PIAA optics in AFTA design for simplicity.

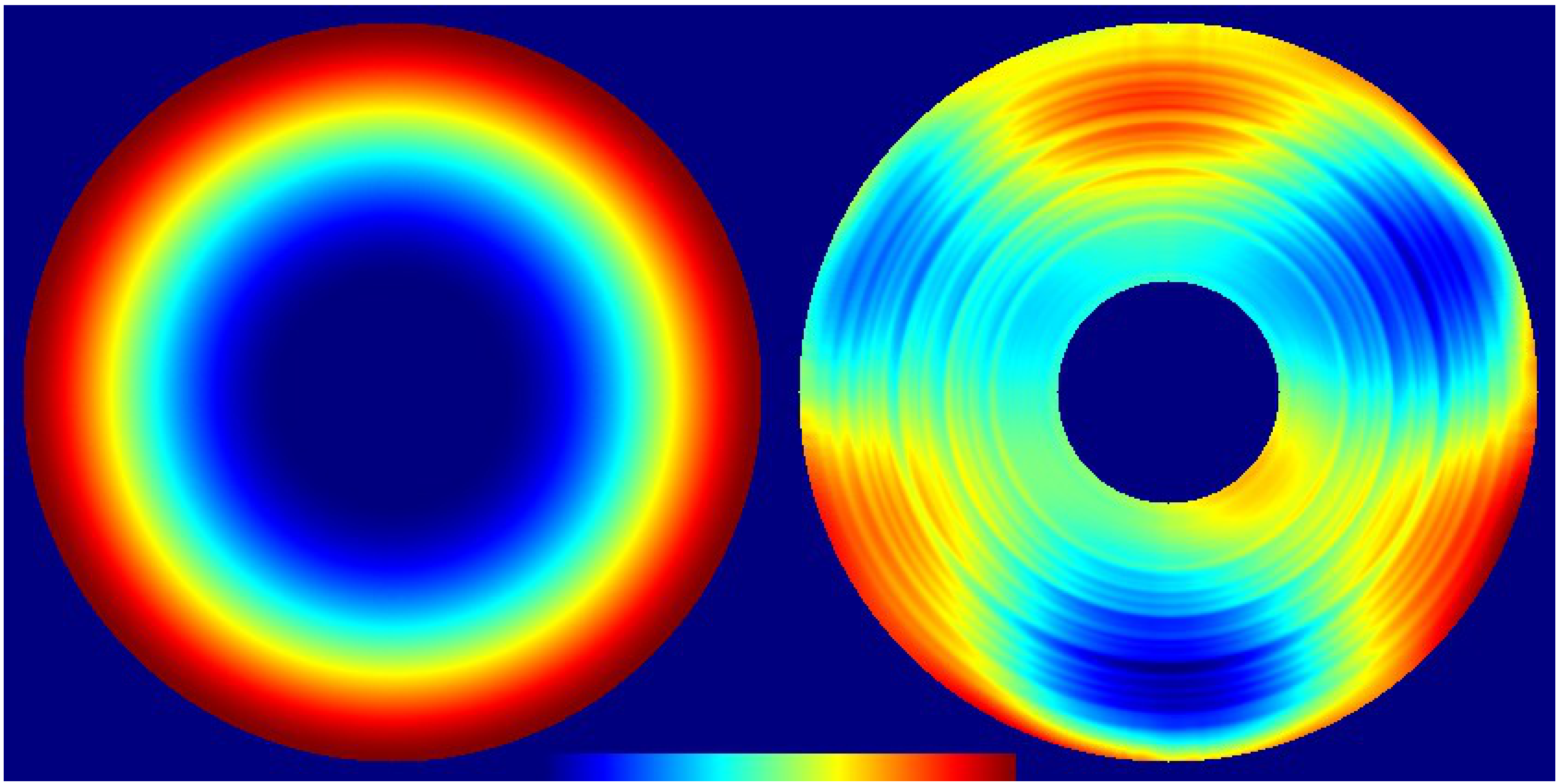
PIAACMC Gen 3 Modeling

- Inputs provided by Guyon
  - Cycle 5 pupil used (i.e., no bumps along central obscuration)
  - PIAA M1 & M2 optic 2-D surface profiles (not circularly symmetric)
    - 1.2x angular magnification
  - focal plane mask 2-D surface profile (reflective)
  - 4 Lyot stops
    - Lyot stops placed at different Z locations along optical axis
    - Two of the stops were combined and used at an intermediate location, as specified by Guyon
  - entrance beam diameter is 44 mm
  - No inverse PIAA
  - no design-defined OWA
  - operating bandwidth is 10% centered at 550 nm
  - single polarization only
    - Gen 2 results demonstrated polarization-induced aberrations degrade contrast too much
    - wavefront control optimization for a single polarization
  - high-res sampling at focal plane mask using DFT
  - EFC ran for an r = 1.2 – 9 λ/D (sky) half-sided dark hole
    - a larger dark hole (e.g., <18 λ/D) is possible without much performance degradation, based on Gen 2 results
- Brian Kern is working on optimizing jitter sensitivity using DM

PIAACMC Gen 3 M1 Surface

M1 Surface Map
(excludes OAP component)

Mean radial profile subtracted



8.3 μm surface deviation

16 nm surface deviation
(groves are sampling artifacts)

PIAACMC M1 surface does the apodization and includes asymmetry due to spiders.
M2 optic flattens phase error introduced by M1.

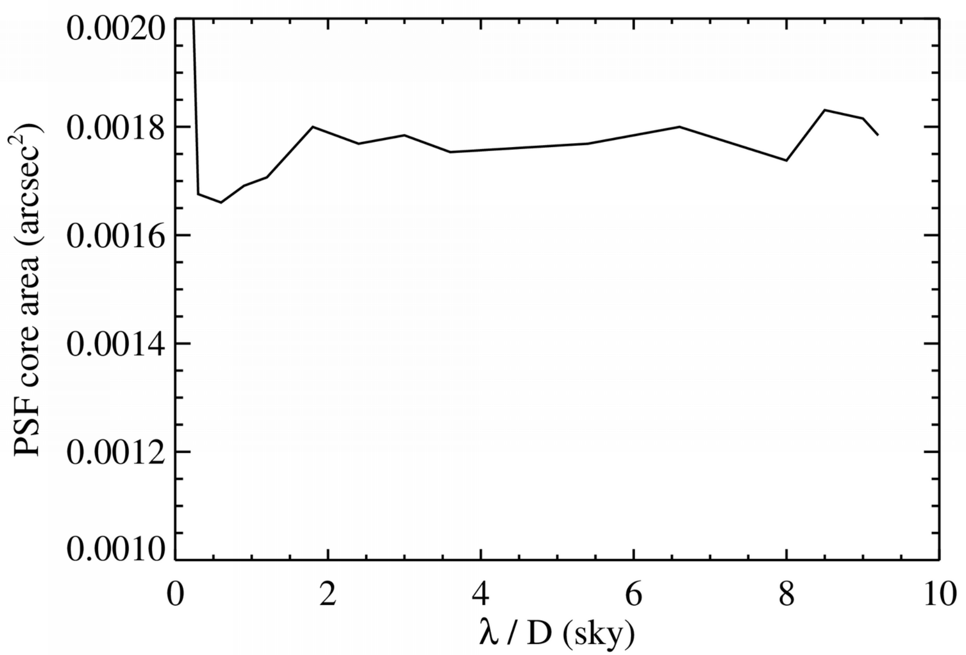
PIAACMC Gen 3 Focal Plane Mask

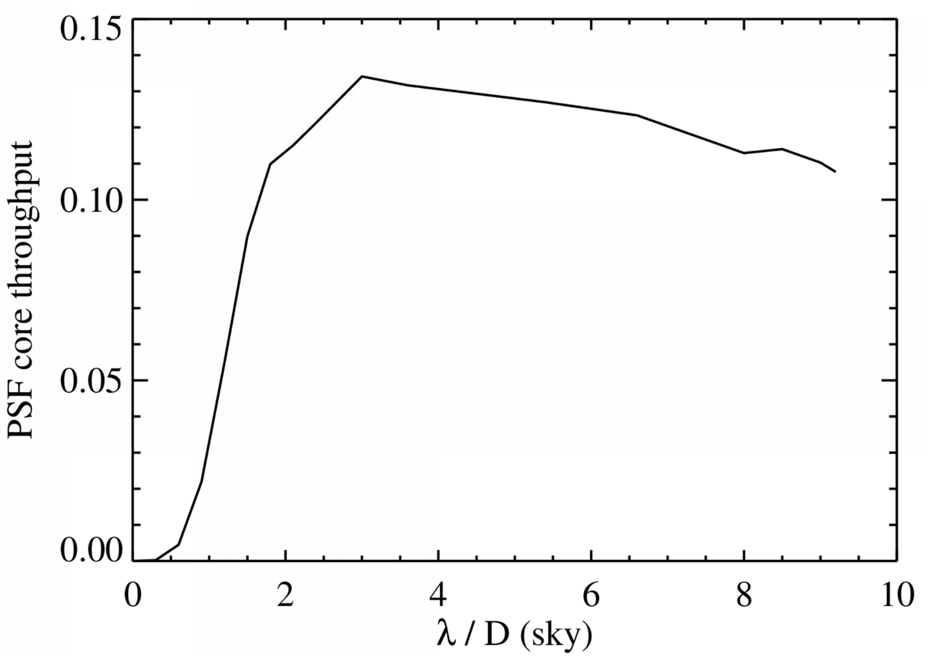
fpm_zone21_16_022_20_best

3.2 λ_c/D diameter (λ_c = 550 nm)

Mask is reflective.
-339 nm to +355 nm surface.

PIAACMC Gen 3 Throughput
(ignoring losses from reflections, filters, polarizer, etc.)

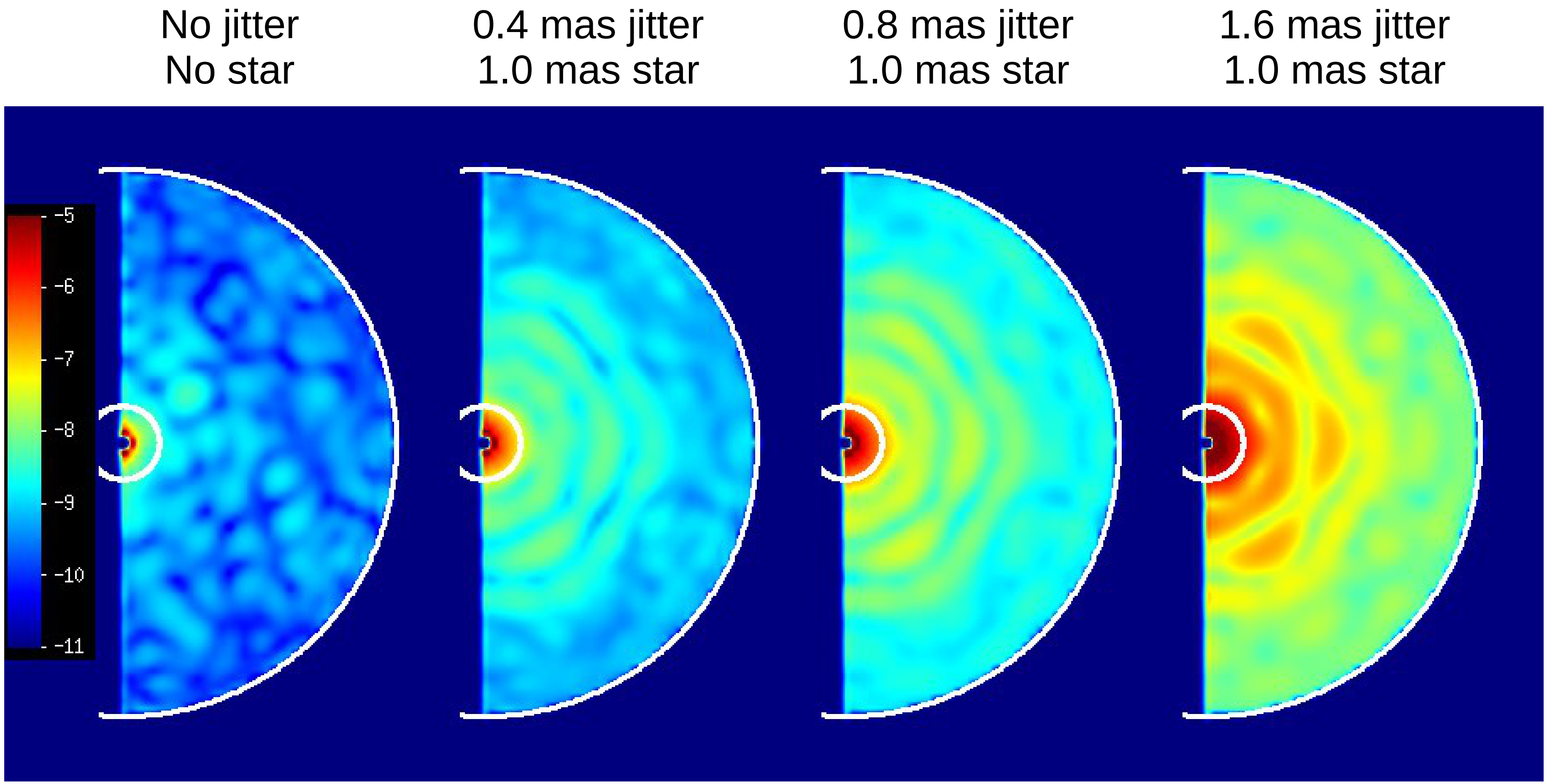




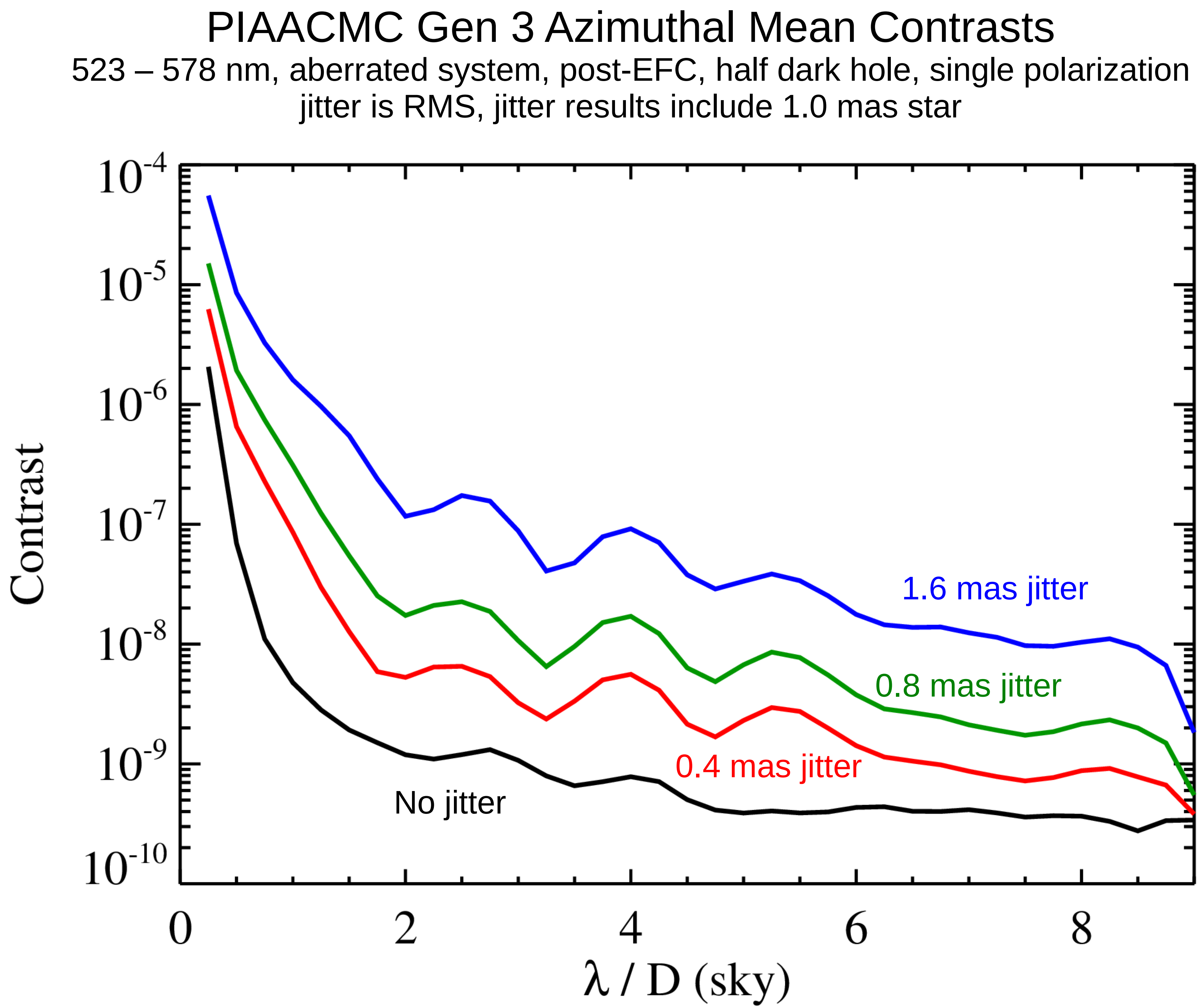
PSF core throughput = flux inside planet FWHM region / flux at AFTA primary
(for AFTA without a coronagraph this is 0.34)
Peak relative throughput = 0.14 / 0.34 = 41% (gen2 design was 50%)
PSF core area (FWHM area) ≈ 0.00175 arcsec^2
(for AFTA without a coronagraph this would be 0.00165 arcsec^2)
Coronagraph transmission = 58%

PIAACMC Gen 3 Contrast Maps

523 – 578 nm, aberrated system with EFC, single polarization, jitter added after EFC, jitter is RMS

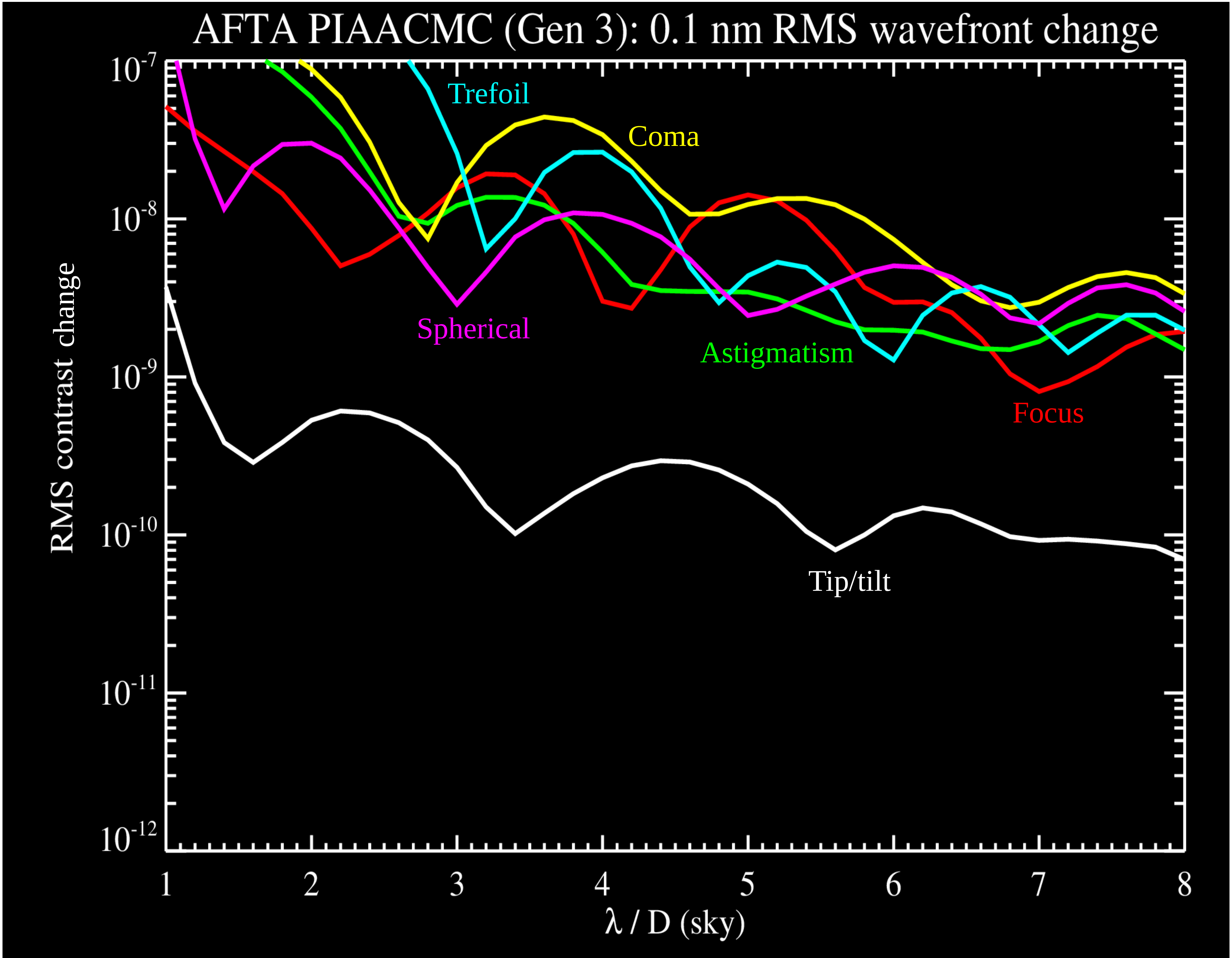


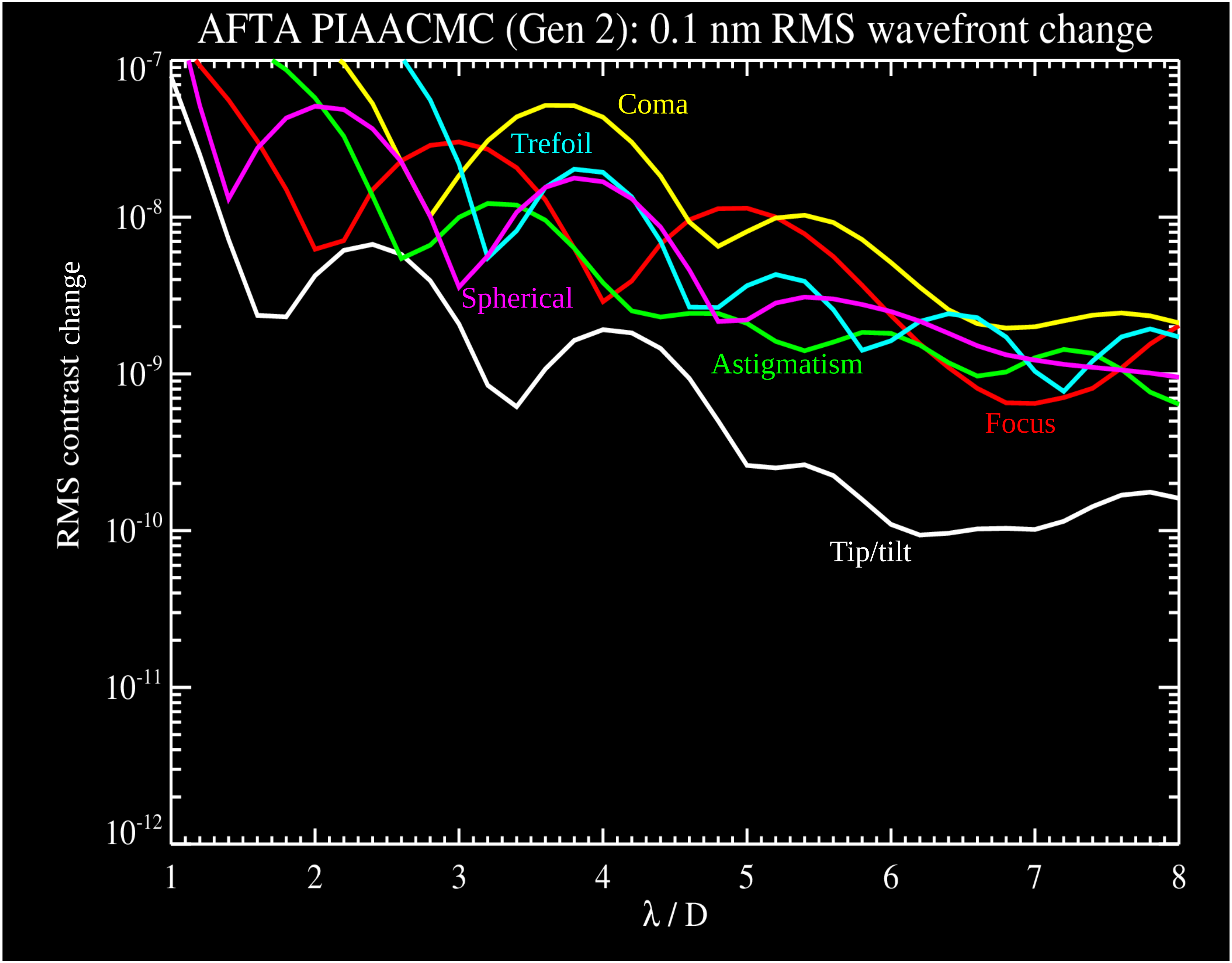
Arcs are r = 1.2 & 9 λ/D (sky)


PIAACMC Gen 3 Azimuthal Mean Contrasts
523 – 578 nm, aberrated system, post-EFC, half dark hole, single polarization
jitter is RMS, jitter results include 1.0 mas star
Contrast
λ / D (sky)
1.6 mas jitter
0.8 mas jitter
0.4 mas jitter
No jitter

Sensitivity Plots

- Plots for 550 nm (monochromatic)
- 100 pm of individual aberrations were inserted at the primary mirror and propagated through the system with no wavefront control
- The RMS of the difference between the aberrated and unaberrated intensity fields was computed in 0.4 λ/D-wide annuli of different radii
- Gen 2 results also shown for comparison
- Gen 3 design is about an order of magnitude better in tip/tilt sensitivity than Gen 2, but other aberrations are generally unchanged (optimization was for tip/tilt only)


AFTA PIAACMC (Gen 3): 0.1 nm RMS wavefront change
RMS contrast change
λ / D (sky)
Trefoil
Coma
Spherical
Astigmatism
Focus
Tip/tilt
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
1
2
3
4
5
6
7
8


AFTA PIAACMC (Gen 2): 0.1 nm RMS wavefront change
RMS contrast change
λ / D
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
1
2
3
4
5
6
7
8
Coma
Trefoil
Spherical
Astigmatism
Focus
Tip/tilt

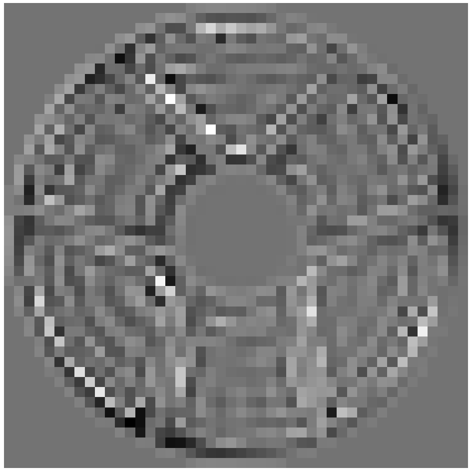
Performance Improvement Using DM?

In an ***unaberrated*** system, can EFC use the DM to improve upon the design performance of PIAACMC? Yes, contrast is improved by a factor of a few.

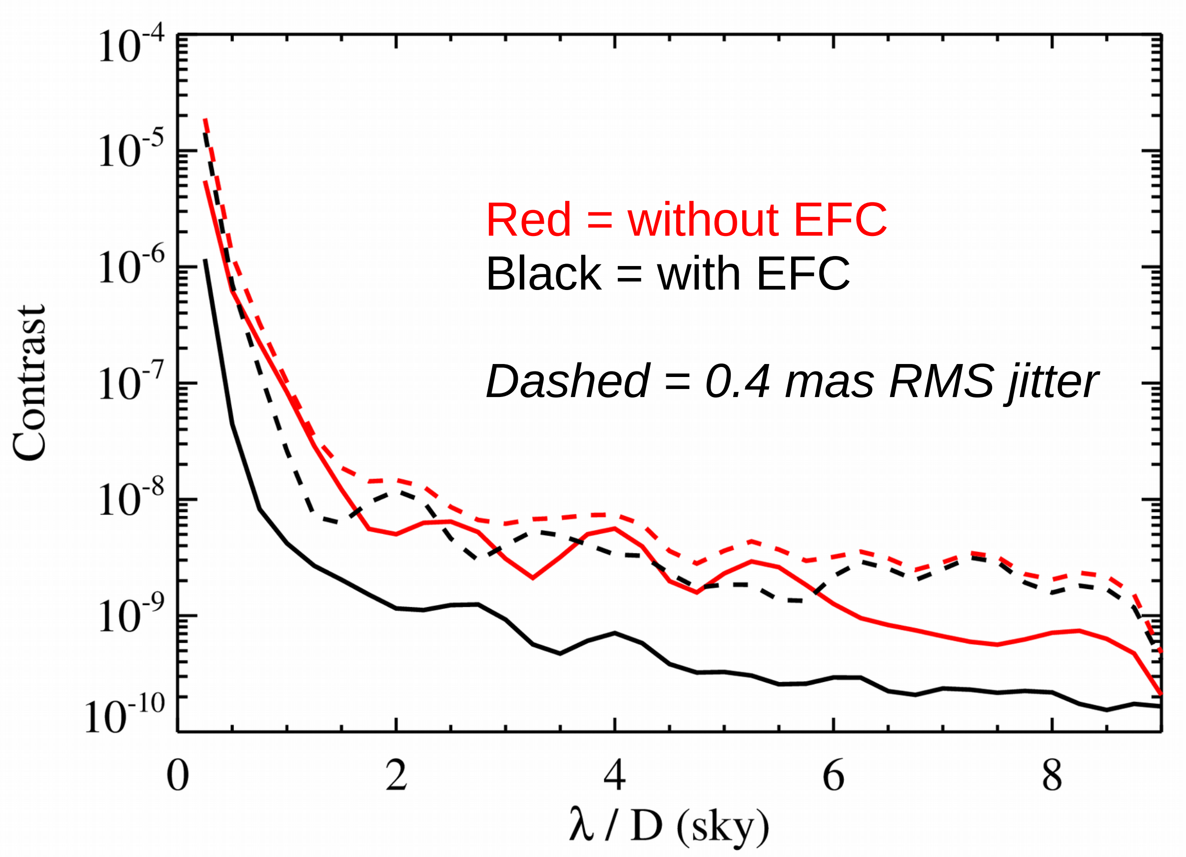
Does it matter once jitter is added? Not nearly as much.

Note: this does not address improving jitter performance with the DM, just static performance.

DM pattern from EFC on an unaberrated system



Stroke = ±2 nm



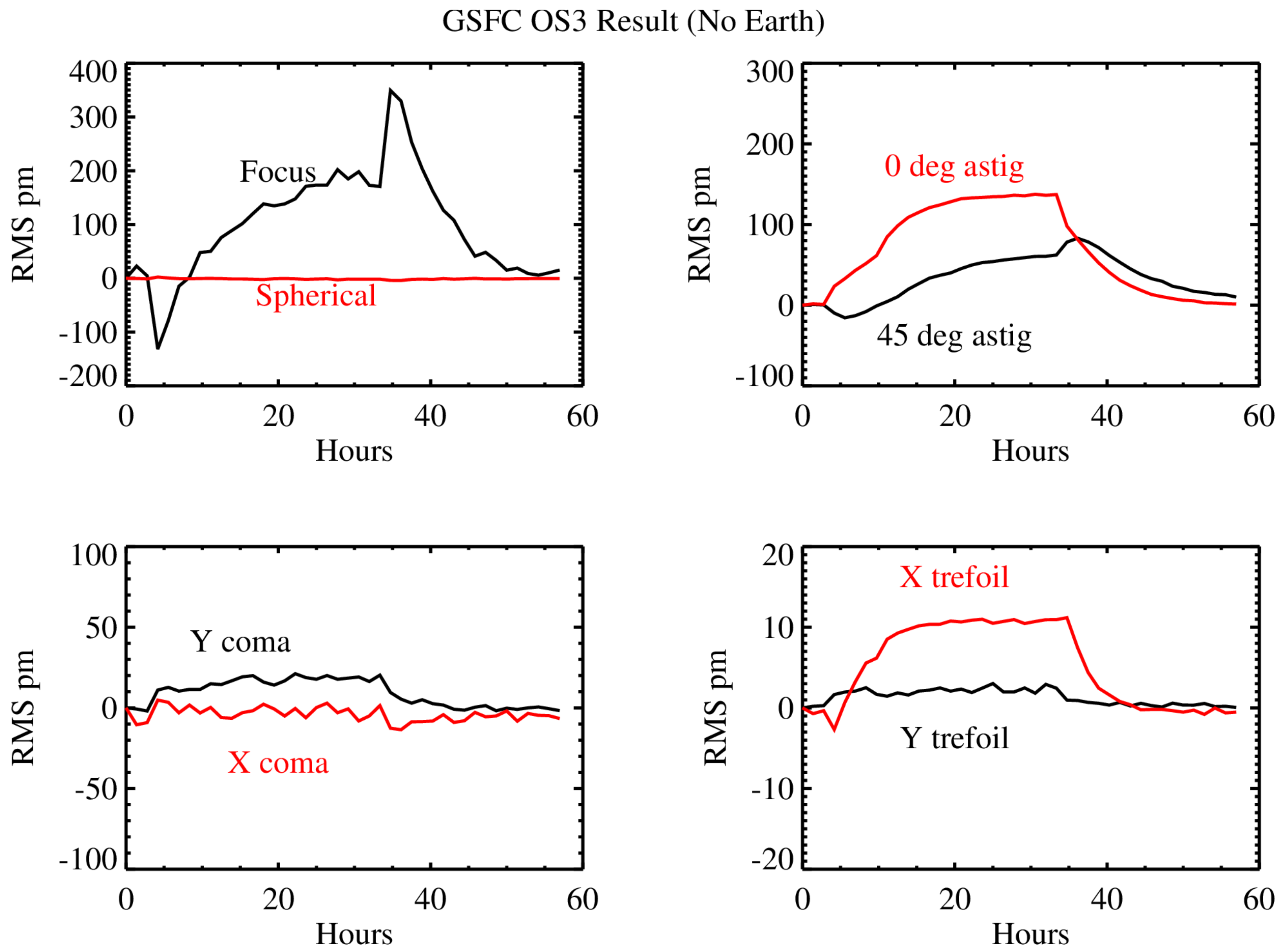
PIAACMC OS3 Time Series Models

- Earth not included (quasi-L2)
- Thermal+structural models generated by GSFC at 5000 sec intervals encompassing observations of β UMa (V=2.37, A1IV, 40 ksec), 47 UMa (V=5.04, G1V, 85 ksec), and 61 UMa (V=5.34, G8V, 85 ksec)
  - model uncertainty factors included
- Wavefront maps sent to JPL, Zernikes fitted by Krist
- Zernikes used as inputs to Xu Wang's LOWFS model with noise to obtain “sensed” Zernikes at each time step
  - model assumes reflection from patterned dielectric coating on **HLC** occulter
  - **PIAACMC** would require different scheme using light reflected from Lyot stop (unexplored)
- “sensed” Zernikes used by Erkin Sidick to define DM1 low-order corrections for Z5-Z11
  - static and time-dependent DM actuator gain errors included
  - correction errors incorporated into next iterations wavefront error
- tip/tilt & focus assumed to be perfectly corrected in no-LOWFC case, focus correction errors included in LOWFC case
- DM correction patterns sent to John Krist for speckle field time series generation and analysis
- Evaluated with and without DM LOWFC for quasi-L2 (no Earth)

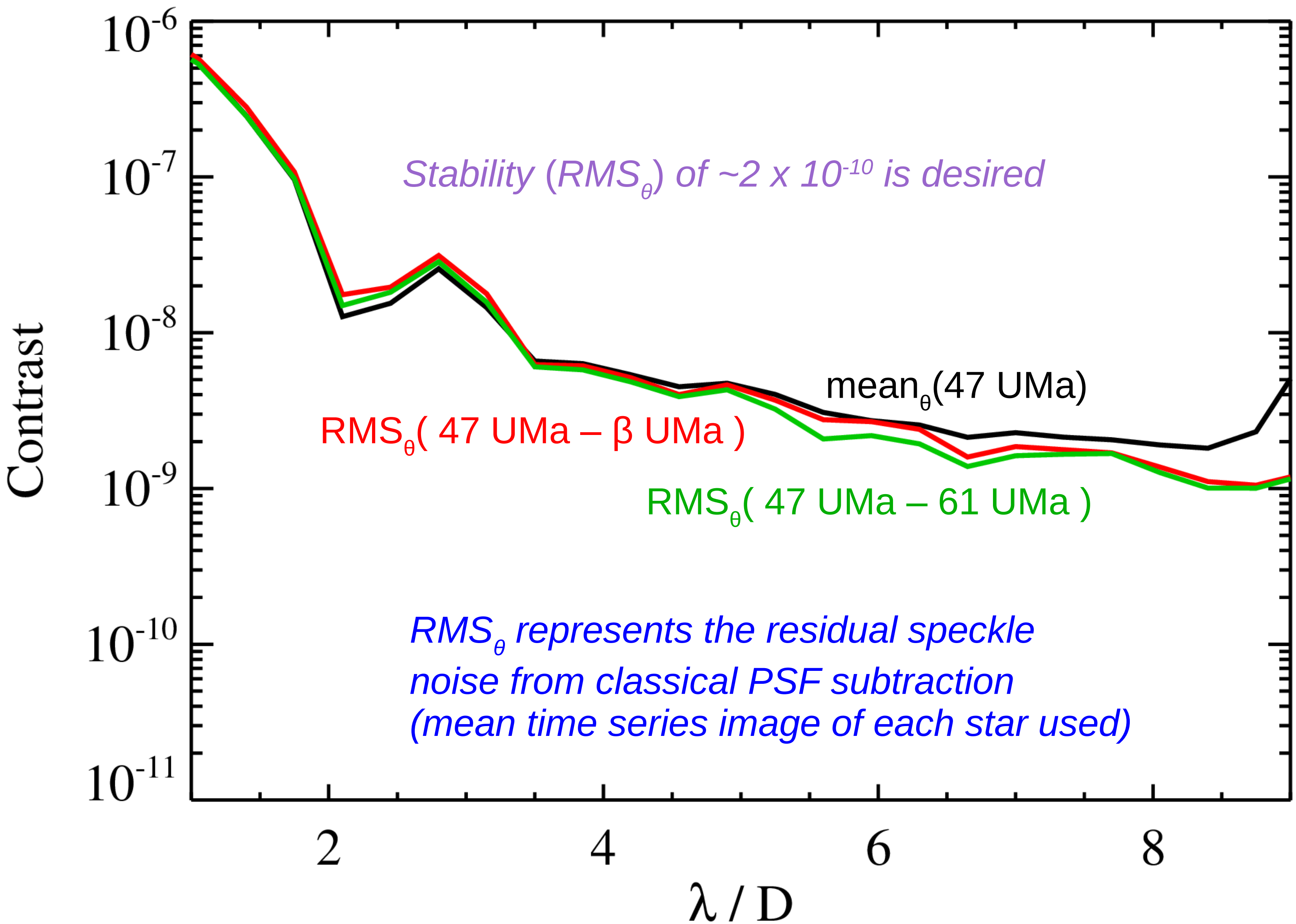
Simulation Parameters

- Broadband 523-578 nm images constructed using 9 monochromatic images weighted by stellar spectrum appropriate for each star
- No noise
- No jitter (tip/tilt errors are assumed to be perfectly removed with FSM)
- Focus corrected with piston mirror (measurement error is included)
- No further EFC after low order aberrations applied
- For each star, time-step images were coadded (assume the entire time was spent in the one filter)
- Planets added to 47 UMa (same planets as used in OS1 simulations)

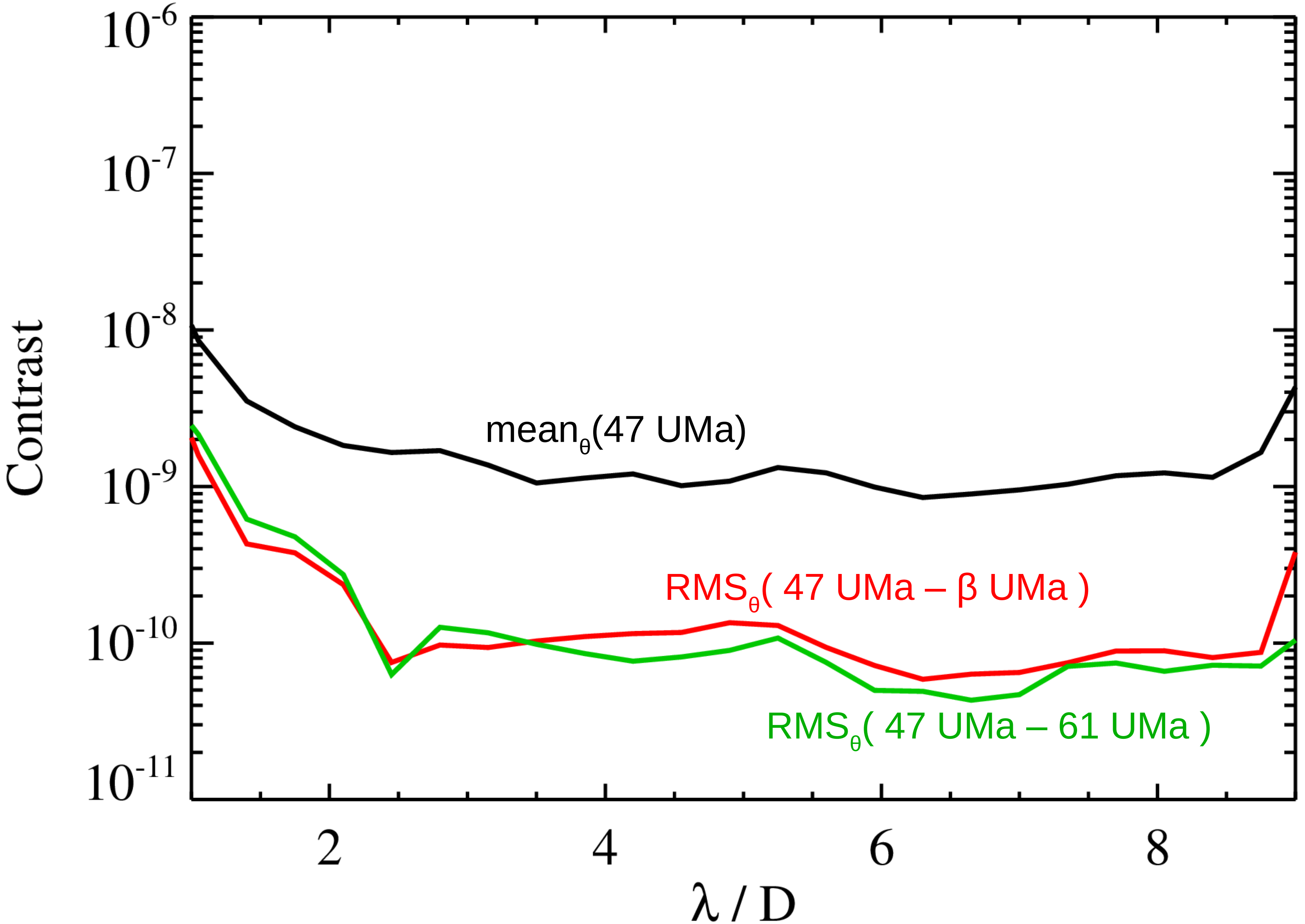
OS3 aberrations (No Earth)



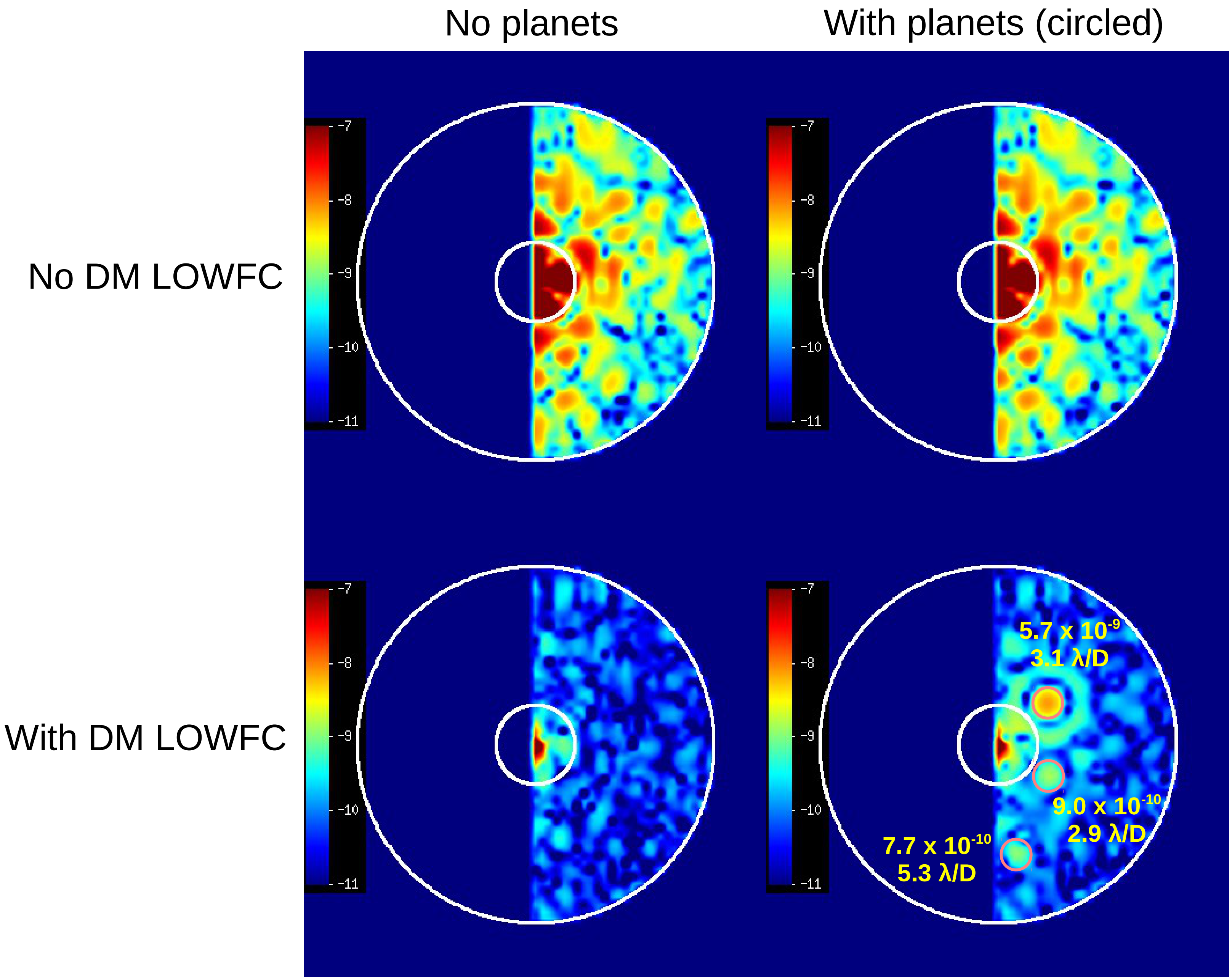
Residual speckle noise levels without DM LOWFC



Residual speckle noise levels with DM LOWFC



Absolute differences of 47 Uma - β Uma (OS3, no Earth)



Circles are r = 2 & 9 λ/D (sky)

Speckle Time Series Movie

- piaacmc_no_earth_os3_time_series.gif
- Speckle fields with/without deformable mirror low order wavefront control of Z5-Z11
- brightness = $(\text{Contrast} > 10^{-11} < 10^{-8})^{1/4}$
- PIAACMC shows larger variations without DM LOWFC than HLC, probably due to astigmatism correction errors
  - astigmatism varies by about ~150 pm
  - PIAACMC is nearly 100x more sensitive to astigmatism than HLC

Summary

- Gen 3 design provides 5x - 15x improvement in jitter sensitivity over Gen 2 design
  - with 0.4 mas jitter and 1.0 mas star, contrast at 2 λ/D is 5×10^{-9} with Gen 3 vs. 1×10^{-7} with Gen 2
- Sensitivity to other aberrations generally unchanged
- Effective throughput (amount of light in PSF core) is a little less than Gen 2 due to more aggressive Lyot stops