Is WFIRST Coronagraph Polarization Splitting Really Needed? Polarization Effect vs Wavlength & Jitter

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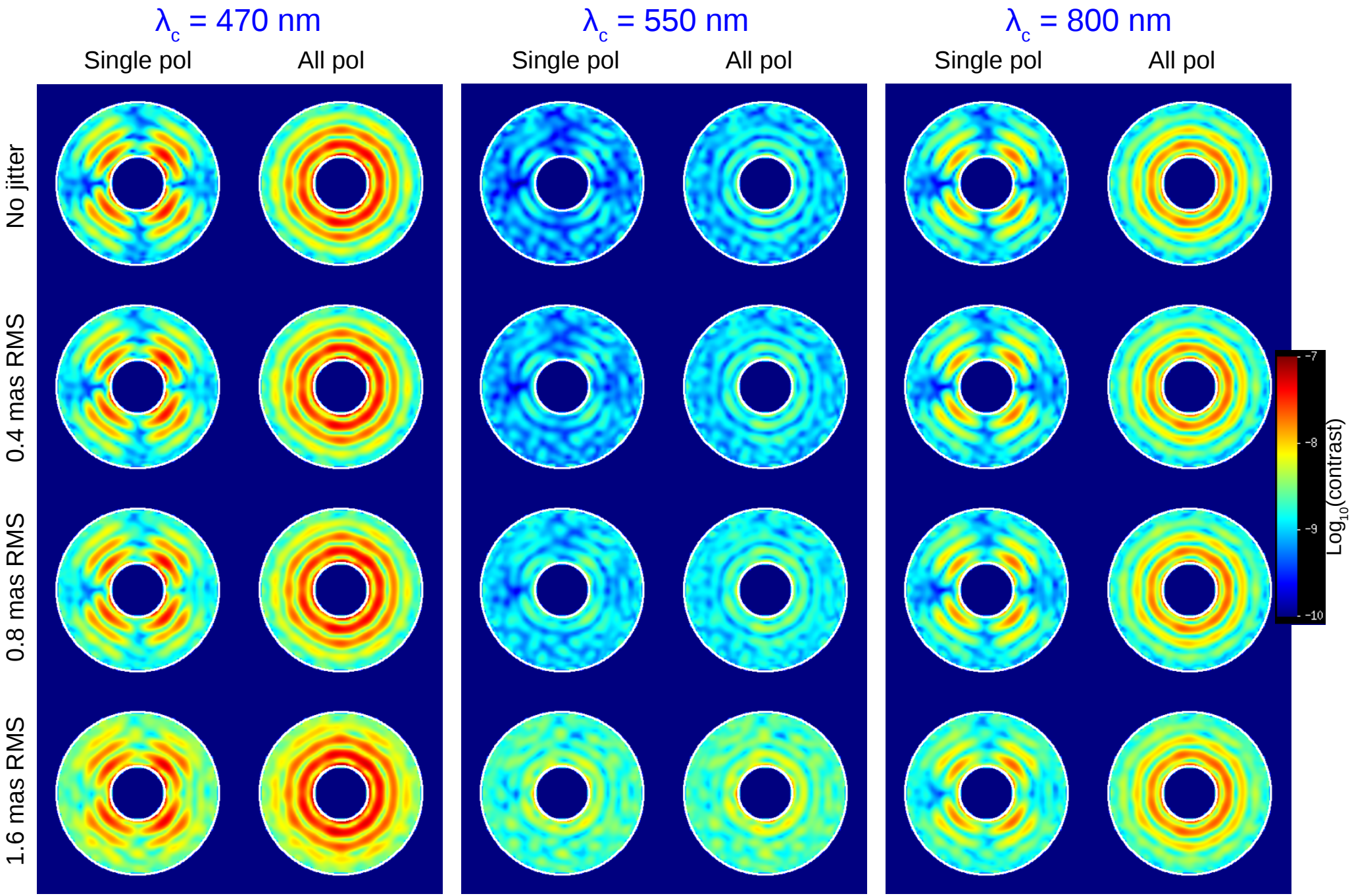
Basic Conditions & Questions

- The best speckle contrast is achieved using a single polarization
- Without polarization splitting the speckles are brighter but there is no ~50% throughput loss due to splitting
- In the presence of expected levels of jitter, does the single polarization's improved contrast outweigh the 2x throughput gain from not splitting, in terms of yield?
  - Current assumptions are that the imaging channel is polarization split and the wavefront is optimized for a single polarization

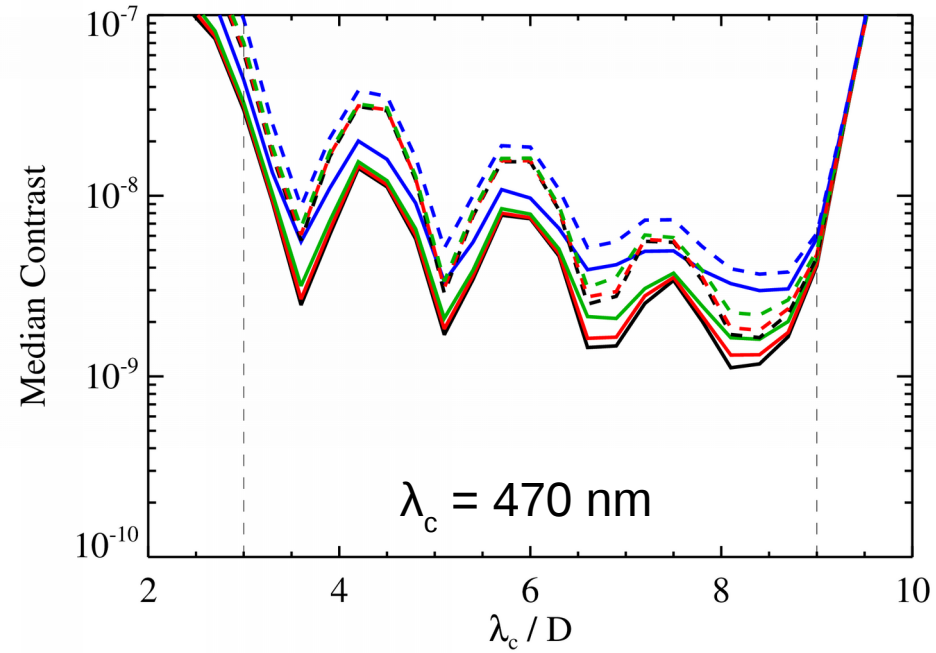
Modeling Runs

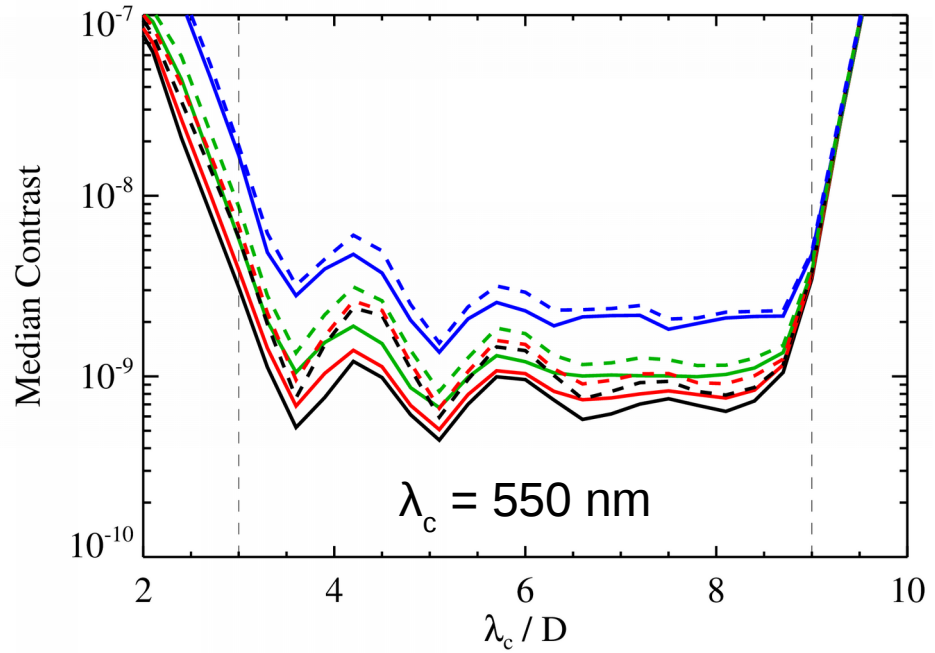
- HLC 20160129
  - circularly symmetric dielectric & nickel focal plane mask patterns
    - more recent HLC designs with azimuthally-varying patterns have similar astigmatism sensitivities and would produce similar results
    - astigmatism sensitivity is now being used as a constraint in HLC design, so future versions may provide some significant reduction in polarization aberration sensitivity
- 10% bandpass (λ = 522.5 – 577.5 nm)
  - Lacking longer and shorter bandpass designs, polarization aberrations at other wavelengths are used in this bandpass (e.g., if the polarization WFE at 470 nm is *x* waves, then *x* waves of WFE is used at 550 nm), assuming similar aberration sensitivity in terms of waves
    - jitter is also scaled to be appropriate for the assumed bandpass, in terms of λ/D
      - current expected post-FSM jitter is 0.4 – 1.6 mas RMS/axis
    - 1 mas diameter star also included
      - contrast effect from star of diameter *D* is equivalent to RMS jitter of 4 x *D*
- EFC using DM probing over 3 x 3.3% finite bandpasses with 0.3 λ_c/D finite pixels
  - prior analyses show same results using 0.5 λ_c/D pixels
- Current flight aberration assumptions used for optical surface errors
- DMs initially set to Dwight's patterns without matching exactly
  - initial field contrast after wavefront flattening and before EFC = 10^{-5}

HLC with Polarization, Jitter & 1 mas Star



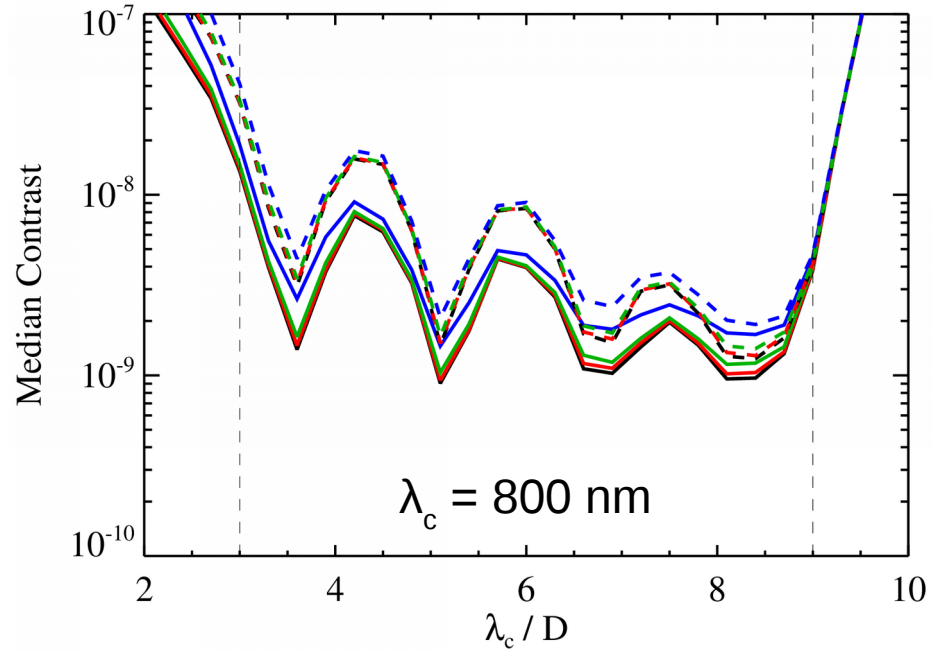
Circles are r = 3 & 9 λ_c/D





1.6 mas RMS
0.8 mas RMS
0.4 mas RMS
No jitter

Solid = Single polarization
Dashed = Dual polarization



Quick n' Dirty SNR Calculations

$$SNR = \frac{S_{planet}\sqrt{t}}{\sqrt{B}}$$

SNR = planet *detection* SNR (in Bijan's terms)
S_{planet} = planet flux rate within planet PSF core
t = integration time
B = background signal (speckle) rate within planet PSF core

$$S_{planet} = F_{star} C_{planet} T_{core} POL$$

F_{star} = stellar flux rate
C_{planet} = planet contrast
T_{core} = PSF core throughput
POL = 0.5 if single polarization, else 1.0

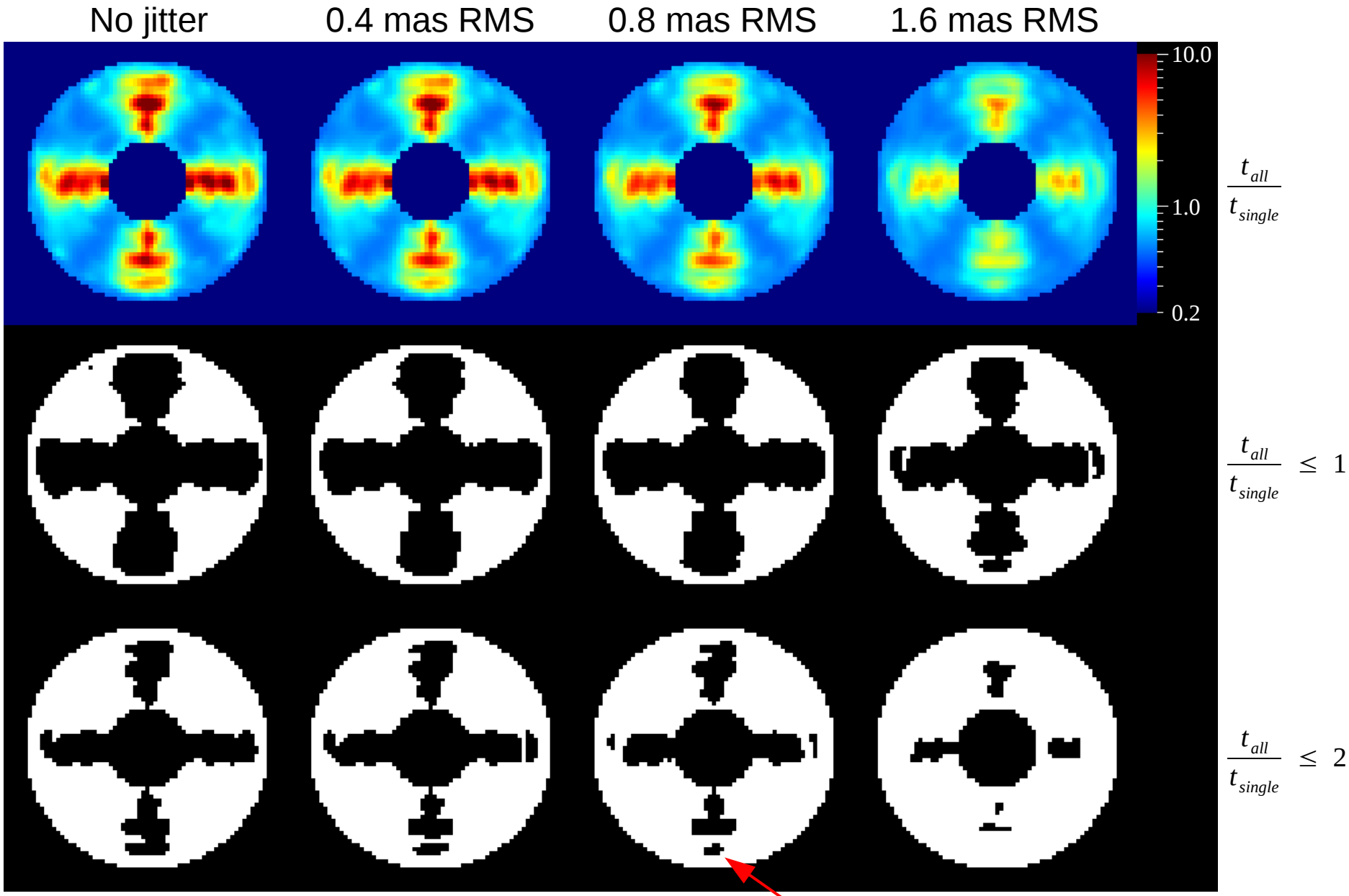
$$B = I_{speckle} A_{core} POL$$

$I_{speckle(all\ or\ single)}$ = speckle surface brightness in given polarization
A_{core} = area of planet PSF core
NOTE: in the maps that follow, $I_{speckle} A_{core}$ is computed by convolving the speckle field with an aperture of area A_{core}

$$\frac{t_{all}}{t_{single}} = \frac{I_{speckle(all)}}{2 I_{speckle(single)}}$$

for any given desired detection SNR.

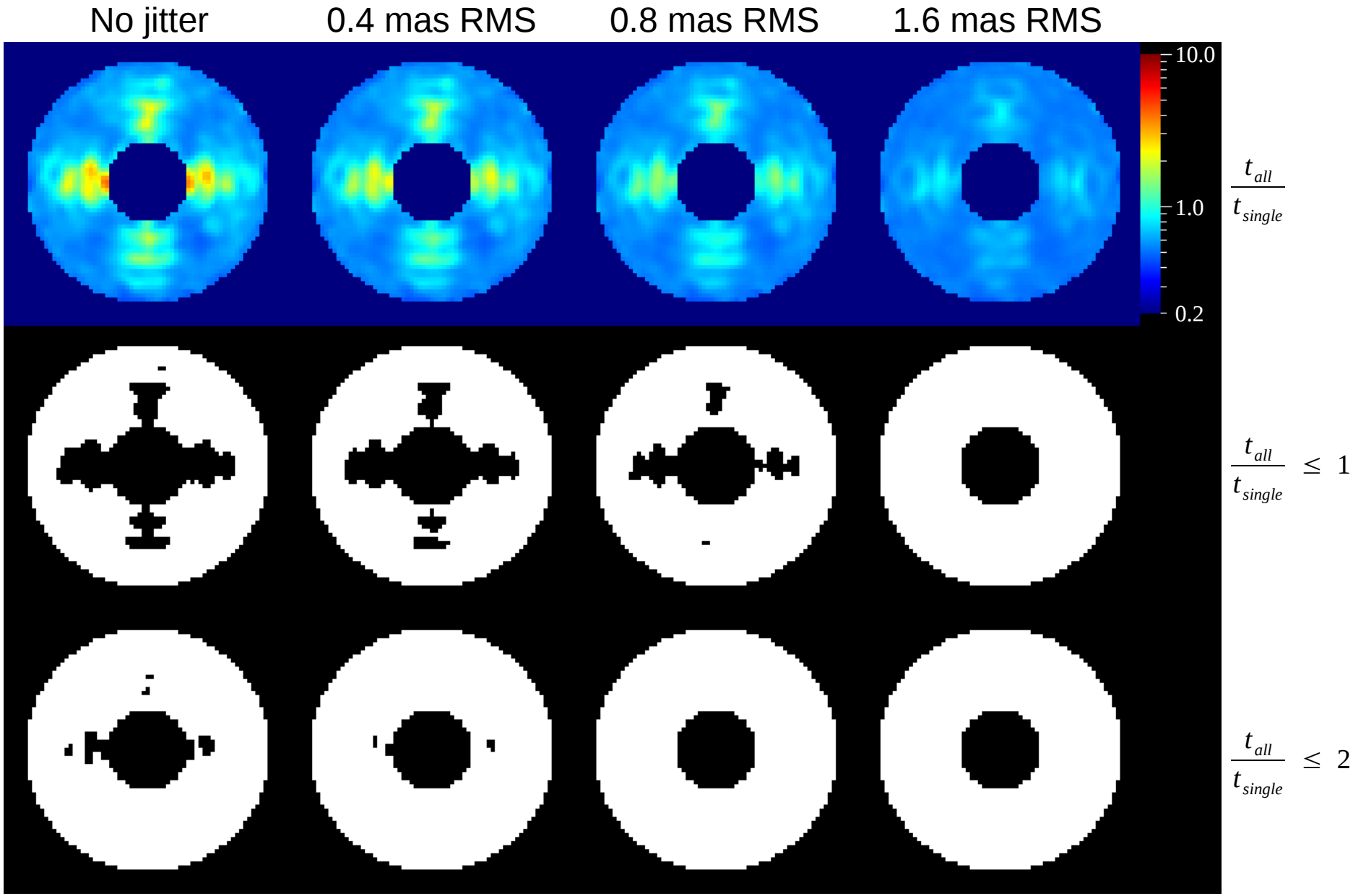
Time to get the same SNR: λ_c=470 nm



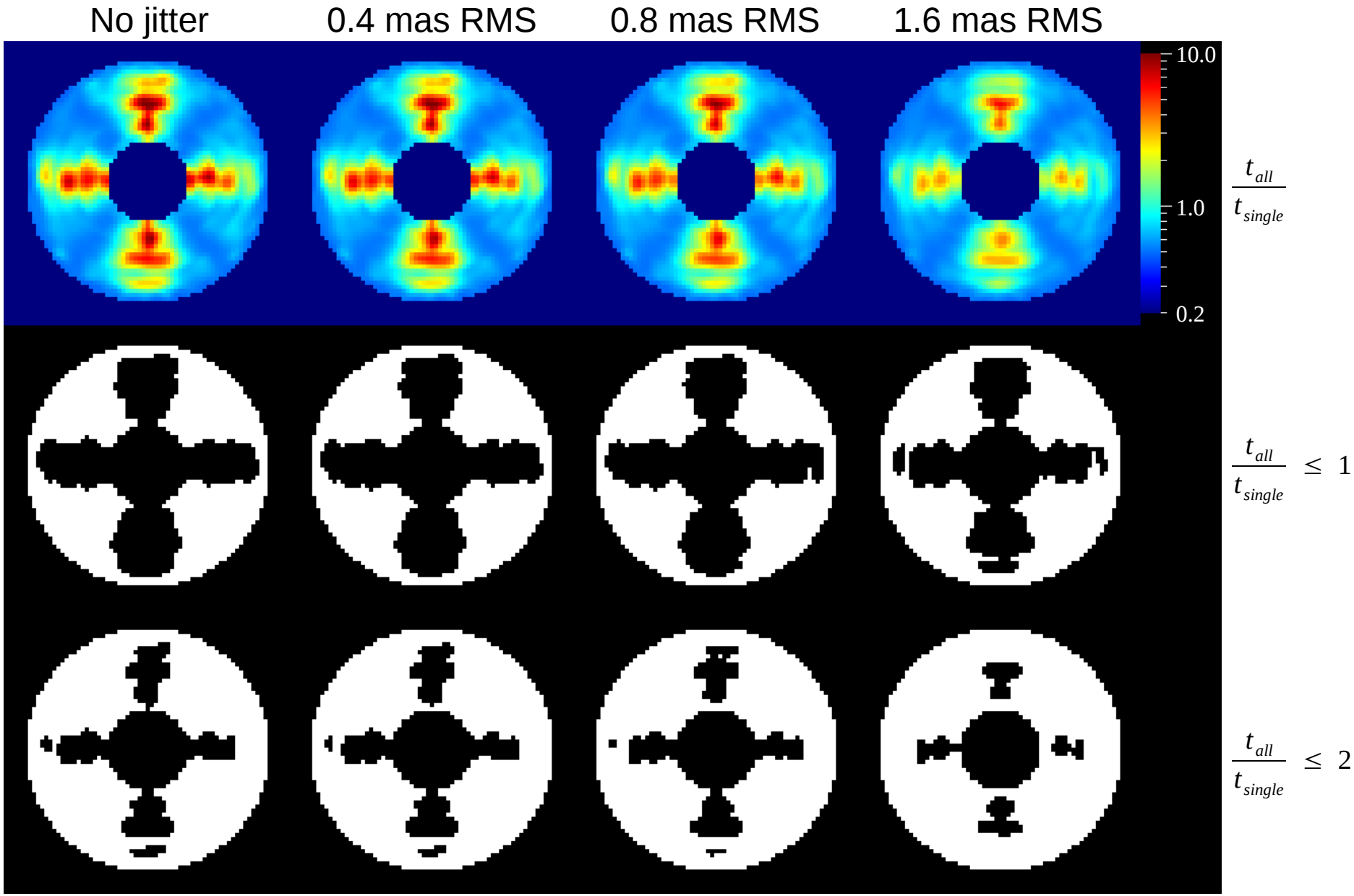
White regions are where it takes less or equal time to get the same SNR without polarization splitting (t_{all}) than in a single polarization channel (t_{single})

Gap along edge is artifact from convolving near field stop edge with core area kernel

Time to get the same SNR: λ_c=550 nm



Time to get the same SNR: λ_c=800 nm



Summary

- In the 10%, λ_c=550 nm bandpass the large majority of the field can get to the same SNR without polarization splitting in less time than in a single polarization for all jitters
- In the 10%, λ_c=470 nm & 800 nm bandpasses, slightly more than half of the field can get to the same SNR without splitting
- With more advanced SNR calculations, including planet shot noise, the gain of not splitting will increase
- Yield estimates using 2-D maps rather than azimuthal mean profiles will be necessary to settle the question
  - estimates should wait until next round of astigmatism optimization of HLC is done
- If splitting is deleted and insertable polarizers are added, the dark hole would be dug without a polarizer
  - inserting a polarizer will not degrade contrast, but since the speckles are polarization dependent the dark hole speckle pattern will be unique to each polarizer
    - reference images will have to be obtained at each polarization along with the science images whenever polarizers are used