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California Institute of Technology

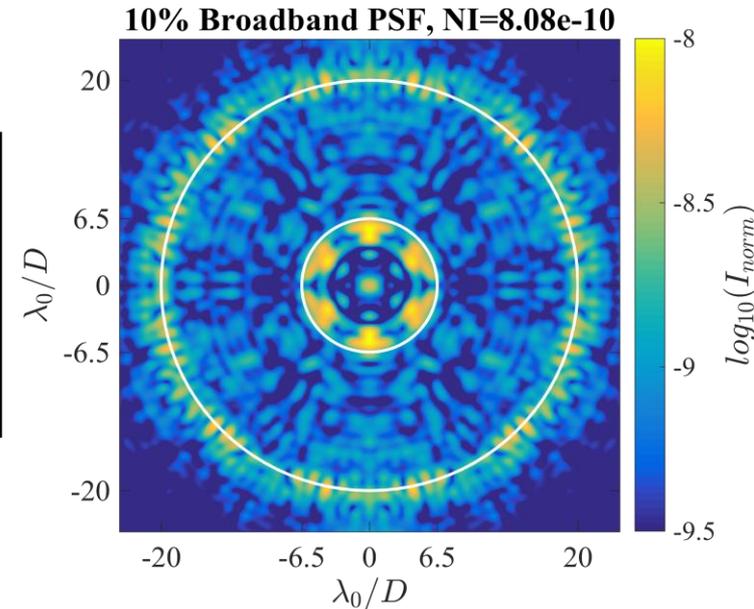
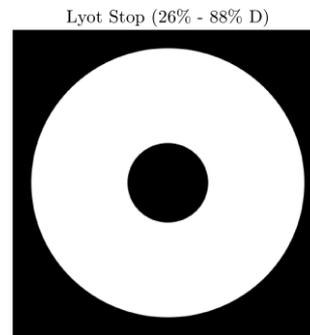
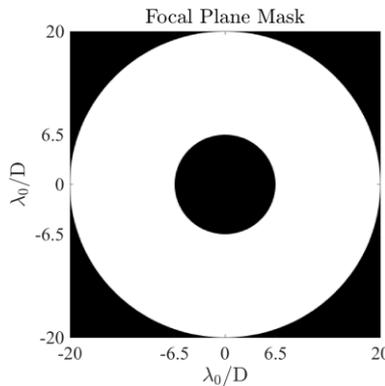
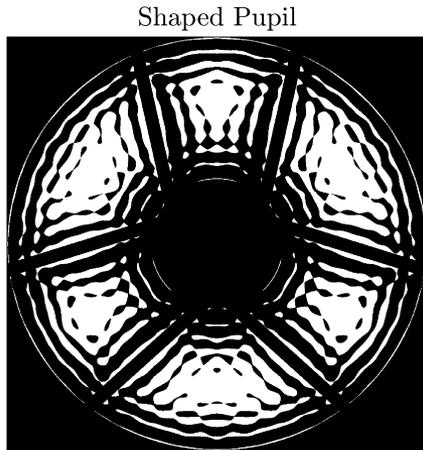


# Updated WFIRST CGI SPC Design for Disk Science: Discussion on Minimum SP Feature Size

A.J. Riggs and Neil Zimmerman

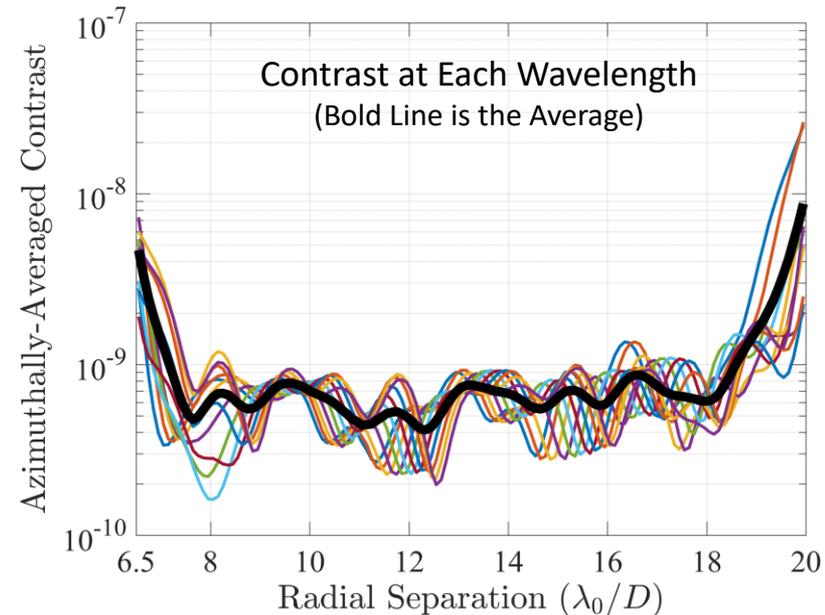
January 30, 2017

# New Design (*SPC\_disk\_20170130*)

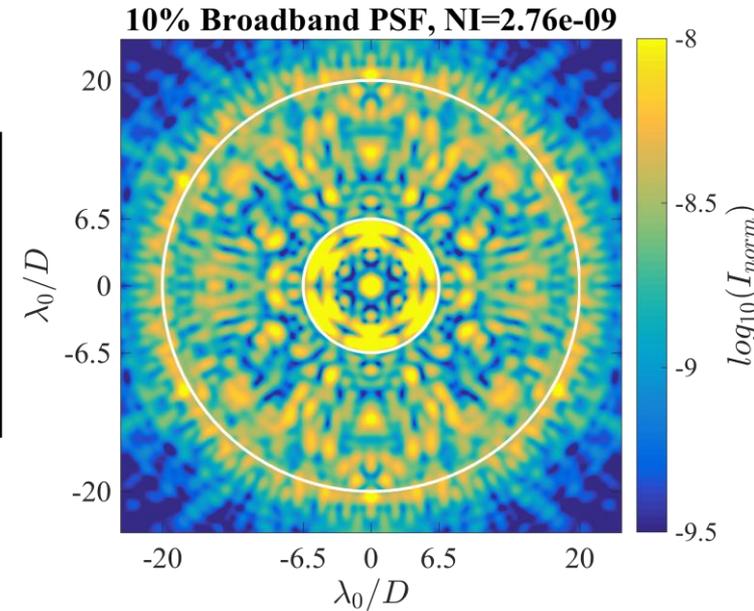
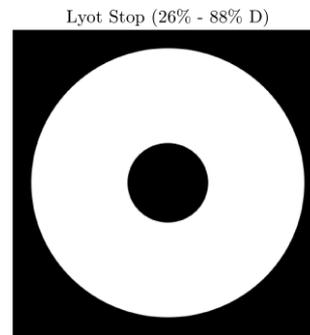
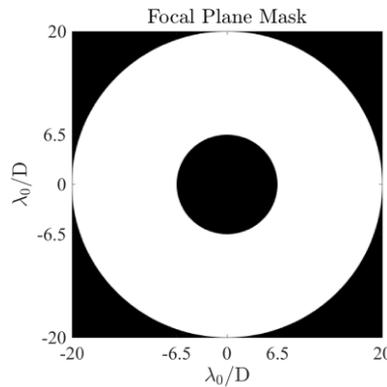
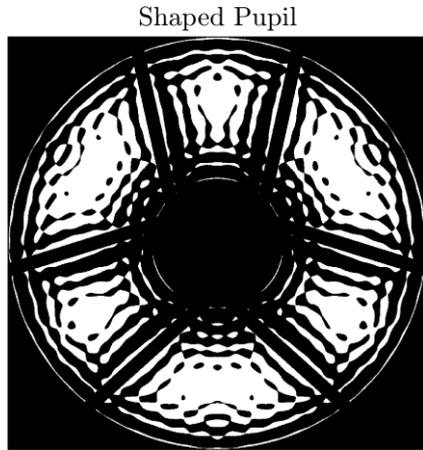


## Specs:

- $8.9 \times 10^{-10}$  contrast
- FWHM core throughput = 5.53%
- 6.5-20  $\lambda_0/D$  open area
  - IWA =  $6.8 \lambda_0/D$  (half-max point)
  - OWA =  $19.8 \lambda_0/D$  (half-max point)
- 360-degree FOV
- 10% Broadband
- minimum SP feature size:  $D/2000$
- 0.2% D pupil padding
- Cycle 6 (2016-03-02) pupil used

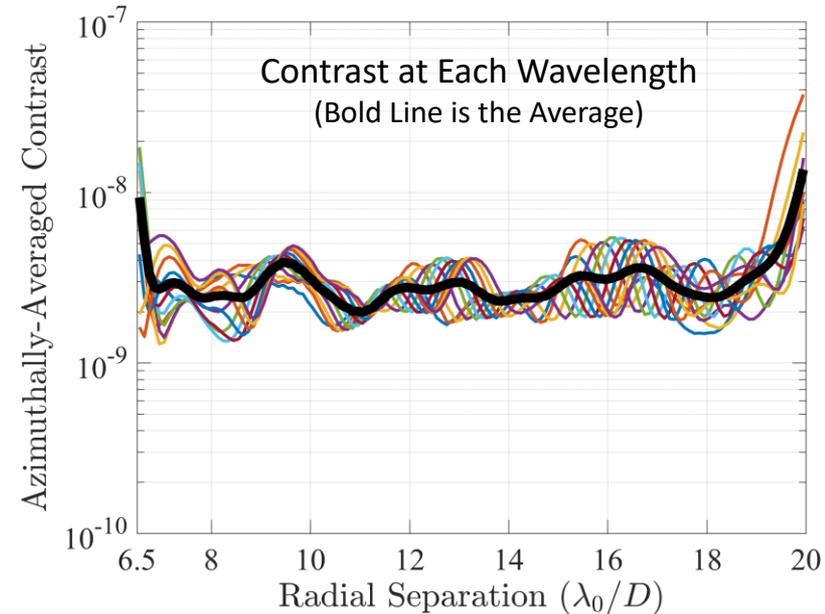


# Previous Design (*August 2015*)



## Specs:

- **$3.0 \times 10^{-9}$**  contrast
- FWHM core throughput = 5.67%
- 6.5-20  $\lambda_0/D$  open area
  - IWA = 6.8  $\lambda_0/D$  (half-max point)
  - OWA = 19.8  $\lambda_0/D$  (half-max point)
- 360-degree FOV
- 10% Broadband
- minimum SP feature size: **D/1000**
- 0.2%-D, x-y-translational pupil padding
- Cycle 5v2 pupil used

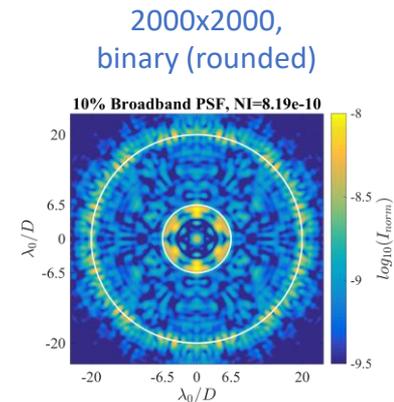
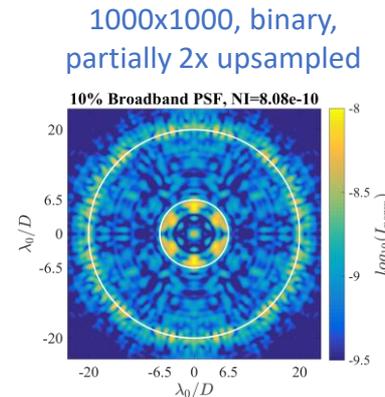
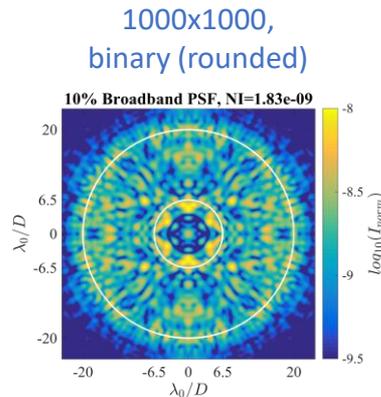
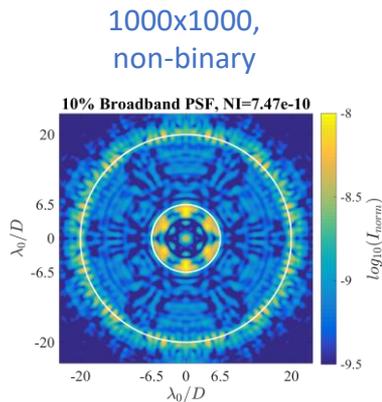


# SP Sampling Choice

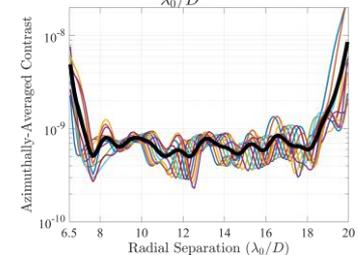
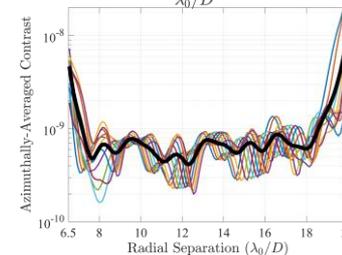
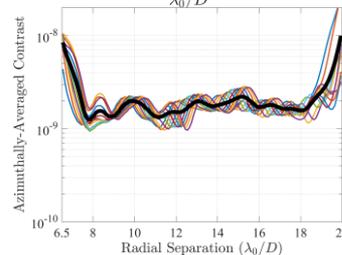
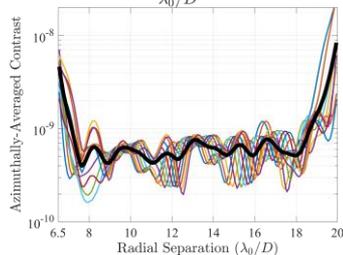
Issue with old design: Higher SP resolution needed to maintain design contrast.

- SP designs come out of linear optimizations as *almost* binary
  - Need binary (0 or 1) SP “pixel” values to manufacture the mask.
  - Rounding the non-binary values can hurt the contrast if the apodizer resolution is too low
    - August 2015 disk science mask design had 1000x1000 SP resolution --> Too low
- Options:
  - Preference 1: Upsample each non-binary point in the 1000x1000 array into a 2x2 binary array.
    - Only affects 924 of 649330 pixels (**0.14%**) in the 1000x1000 pupil.
    - Easier for modeling team to use (as a 1000x1000 array instead of a 2000x2000 array).
  - Preference 2: Use rounded 2000x2000 result.
    - Has many more small features. Unclear if this many small features could cause waveguiding effects.

Design  
PSF



Radial  
Contrast



Summary

- Good contrast
- Not manufacturable

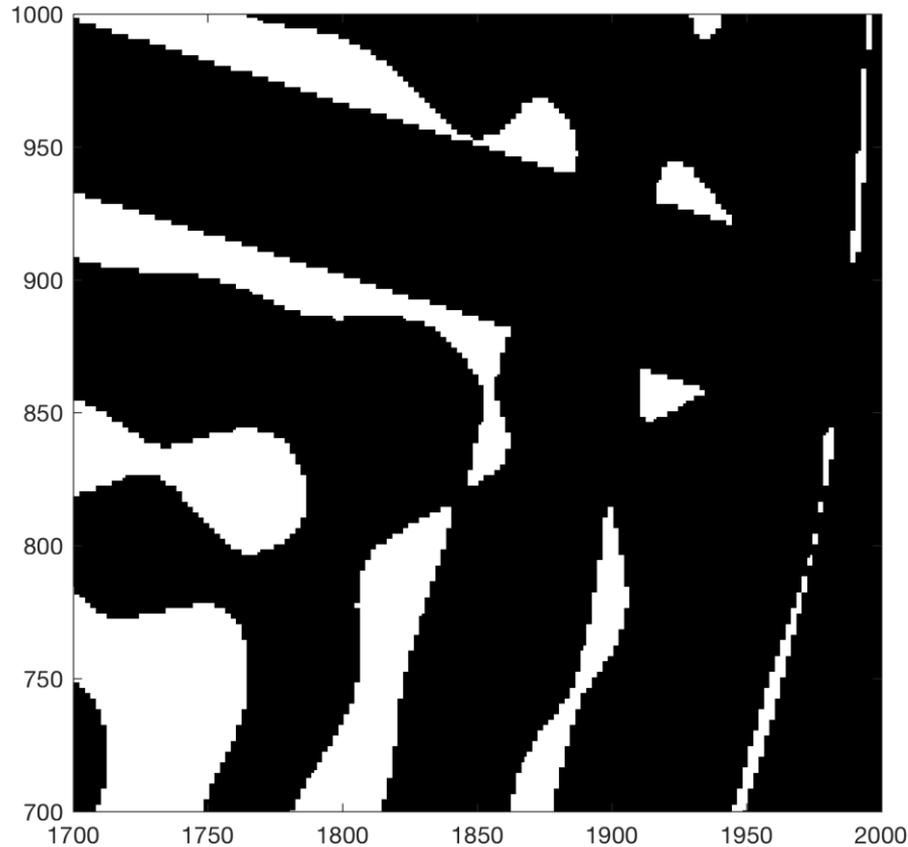
- Worse contrast
- Manufacturable
- 20-micron features

- Good contrast
- Manufacturable
- Mostly 20-micron features

- Good contrast
- Manufacturable
- 10-micron features

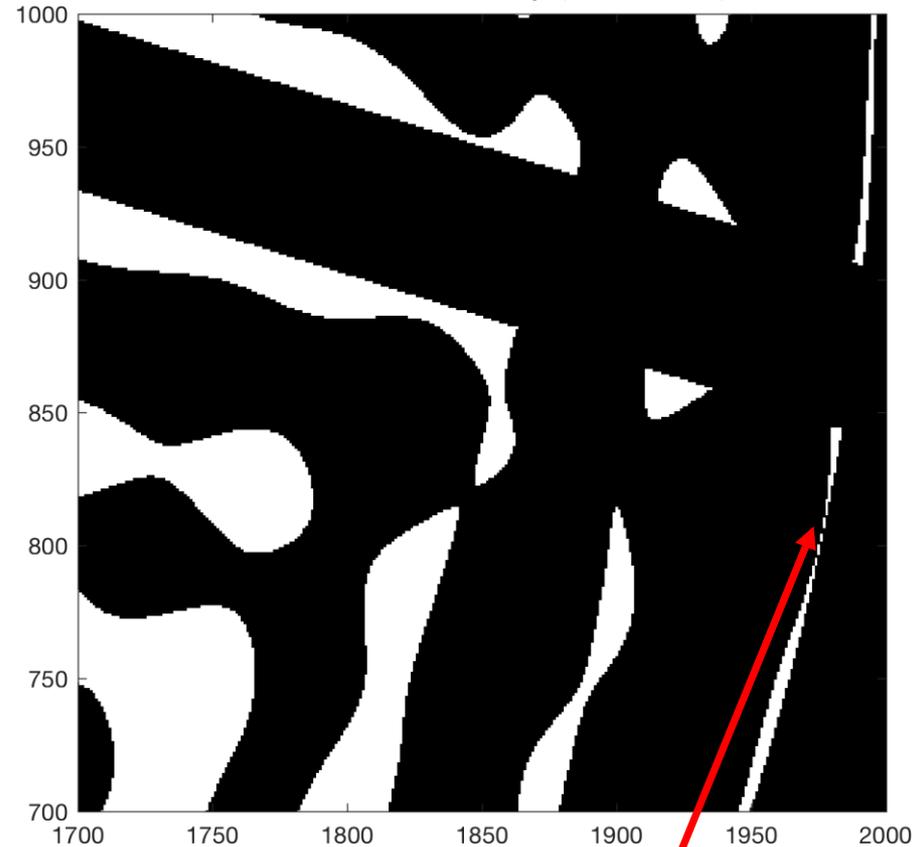
# Zoomed in SPs at Different Resolutions

1000x1000, binary, partially 2x upsampled



- Min feature size  $>20 \times$  wavelength
  - Waveguiding should not be an issue

2000x2000, binary (rounded)



- Min feature size  $>10 \times$  wavelength
  - Main waveguiding worries are in the thin ring along the pupil's outer edge

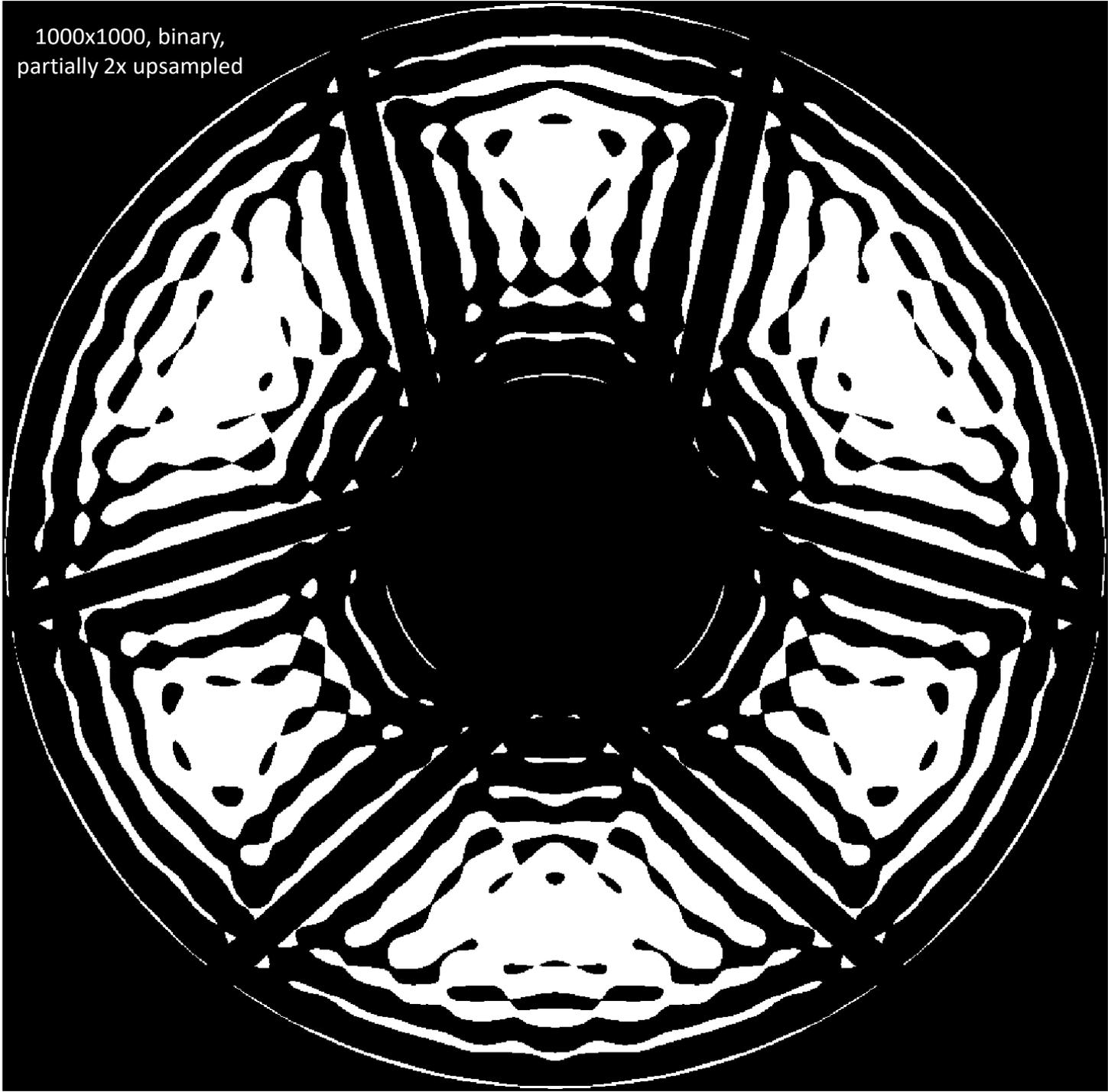
# Key Questions

Context:

- Tradeoff between min features size and contrast
  - Want  $\leq 10$   $\mu\text{m}$  feature size for contrast
  - Want  $>10(?)$   $\mu\text{m}$  feature size for manufacturing accuracy and to avoid waveguiding
- 
- What is the minimum allowable feature size to avoid sufficiently adverse waveguiding effects?
    - Is this even a major concern since only a few regions in the shaped pupil are even at the minimum resolution?  
(Waveguiding should only be an issue in very narrow regions, not along the edges of large features.)
    - How can we model vector diffraction of the reflective SP to answer this question?
      - Should we answer the question by:
        1. Modeling a lone reflective square (e.g.,  $10\mu\text{m} \times 10\mu\text{m}$ ) with vector propagation software to determine the effects
        2. Including those effects into a scalar model with wavefront correction
      - Or should we just agree on a large enough min resolution that we know should be safe (e.g.,  $10\text{-}20\mu\text{m}$ )?
        - $\sim 20\mu\text{m}$  shown to give  $\sim 4\text{e-}9$  contrast for SPC in MCB testbed.

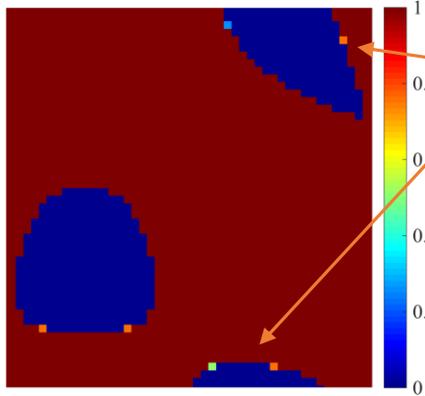
# Backup Slides

1000x1000, binary,  
partially 2x upsampled



# 1x1 --> 2x2 Upsampling

(Zoomed in region of SP)



**Problem:** Initial SP has some non-binary values that cannot be rounded at 1x resolution.

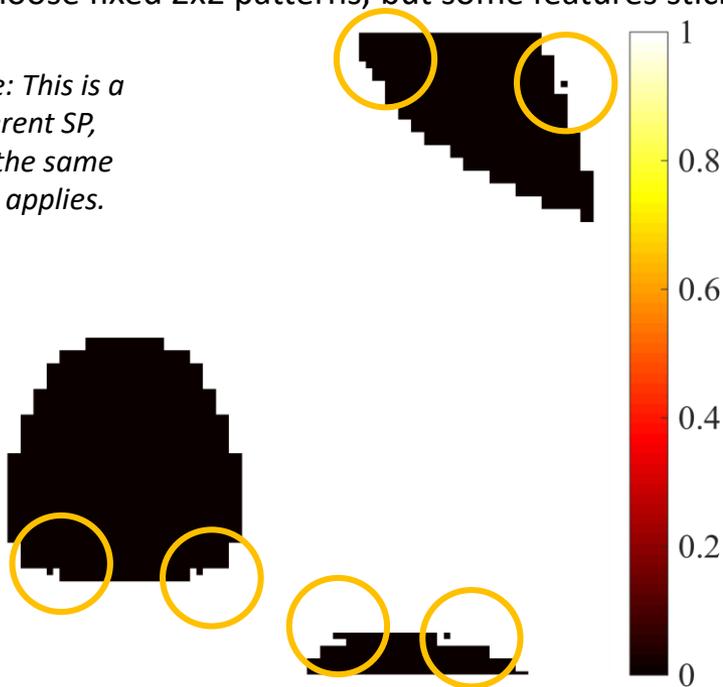
**2x Upsampling Steps:**

- Round values to nearest 1/4:  $SP = 1/4 * \text{round}(4 * SP)$
- Replace 1/4-valued pixels with 2x2 block having 1 of 4 pixels transmissive. Do similarly for values of 1/2 and 3/4.

**Simple 2x2 upsampling:**

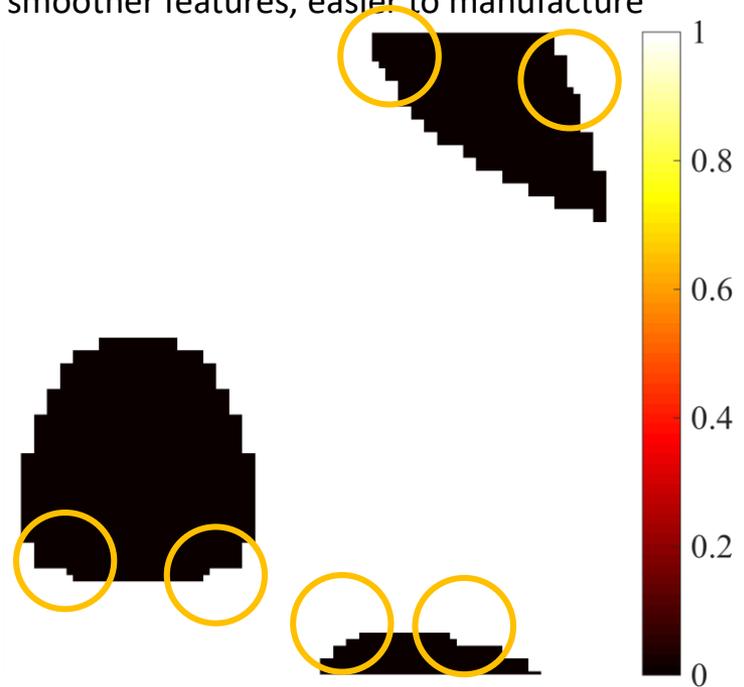
Choose fixed 2x2 patterns, but some features stick out

*Note: This is a different SP, but the same idea applies.*



**Neighborhood 2x2 upsampling:**

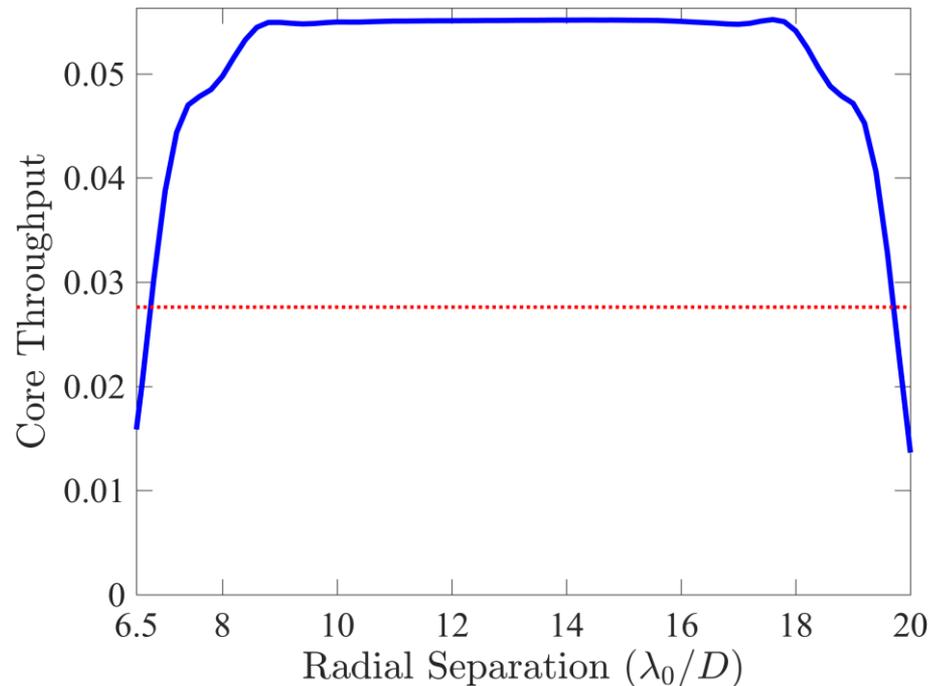
Force new values to stick with their neighbors  
→ smoother features, easier to manufacture



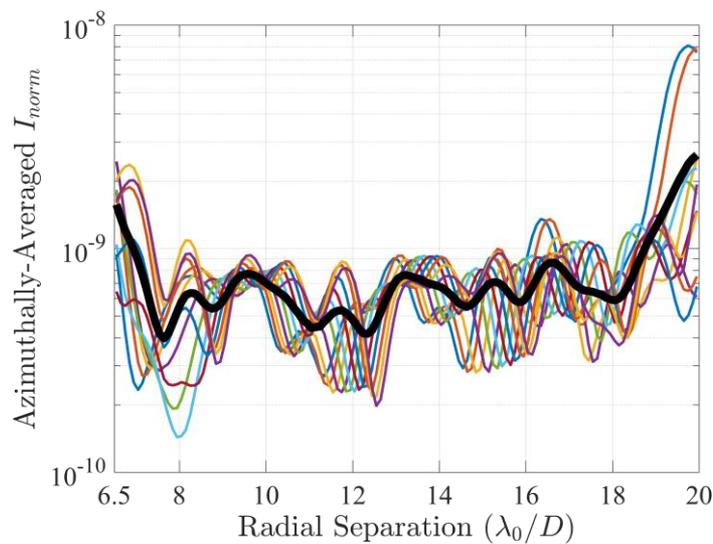
# Throughput of New Design

(*SPC\_disk\_20170130*)

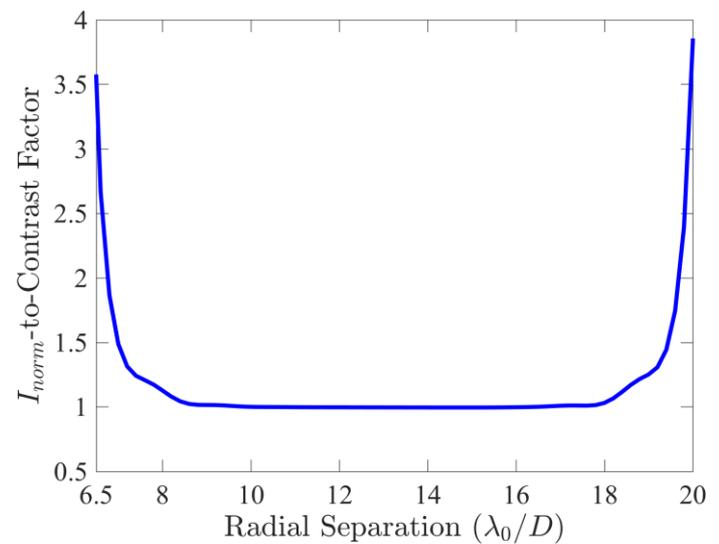
- Max core throughput = 5.5%
- IWA =  $6.8 \lambda_0/D$  (half-max point)
- OWA =  $19.8 \lambda_0/D$  (half-max point)



# $I_{\text{norm}}$ to Contrast Conversion



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