Validating and Testing a Convolutional Model for Extended 3D Objects: An Application to the Pyramid Wavefront Sensor with Laser Guide Stars

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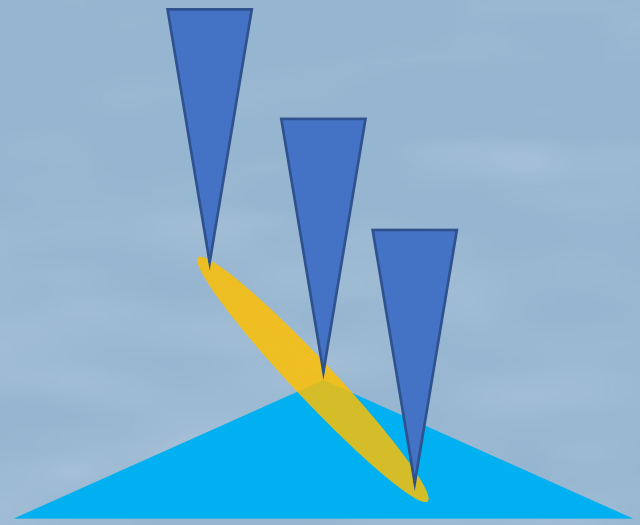
FIRST LIGHT
ADVANCED IMAGERY

RÉGION SUD
PROVENCE ALPES CÔTE D'AZUR

NGS and LGS with PWFS

NGS



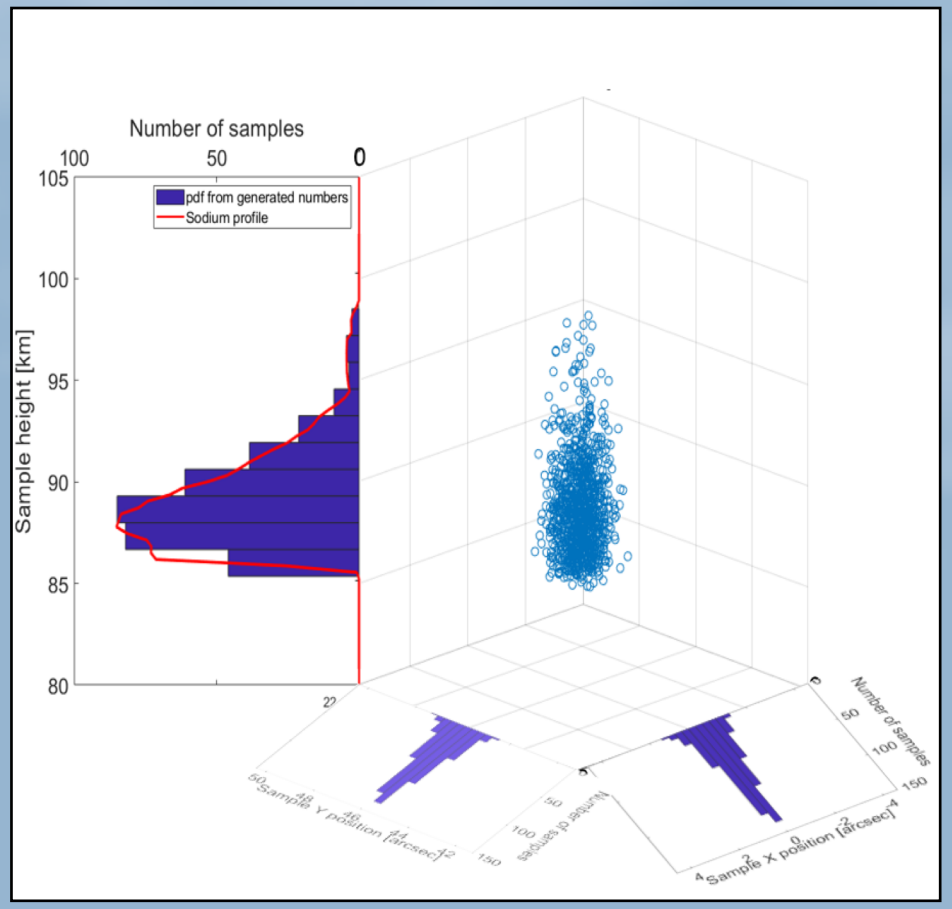
LGS

Glass pyramid

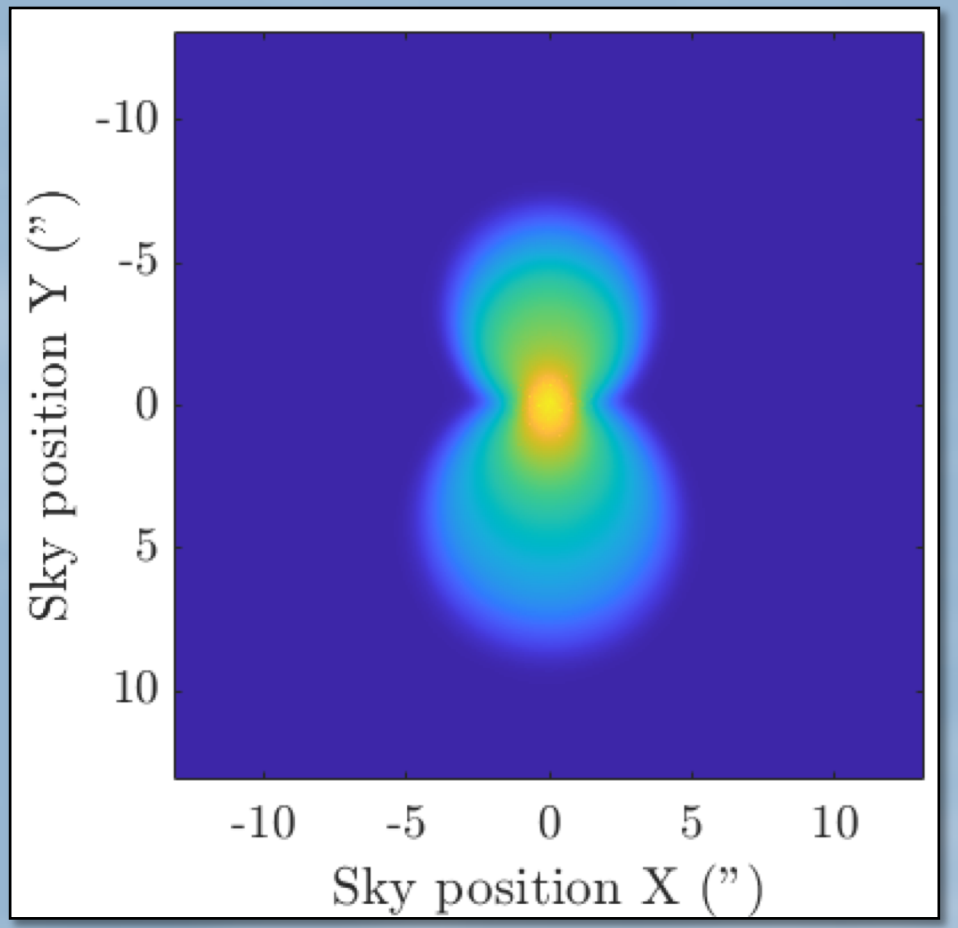
Light beam

Spot image

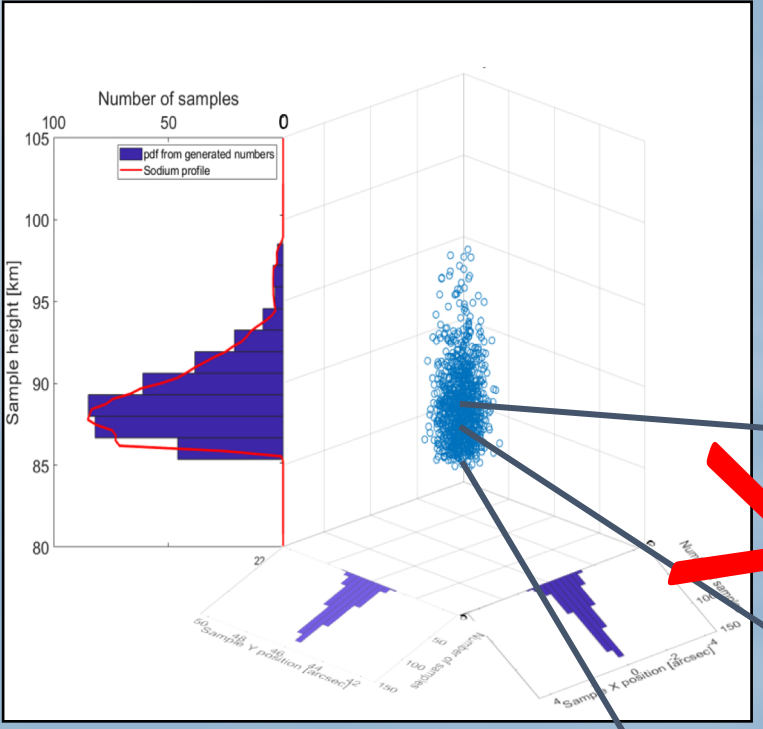
LGS modeling



LGS modelation: point source sampling

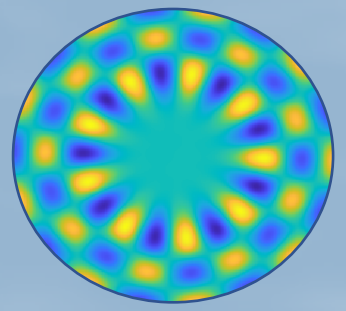


Focal plane image of LGS with 40 m telescope

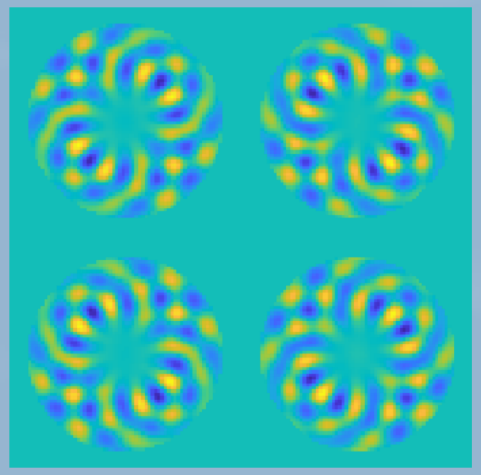

Number of samples
100
50
0
105
100
95
90
85
80
Sample height [km]
pdf from generated numbers
Sodium profile

>60x faster!

NGS vs LGS signal

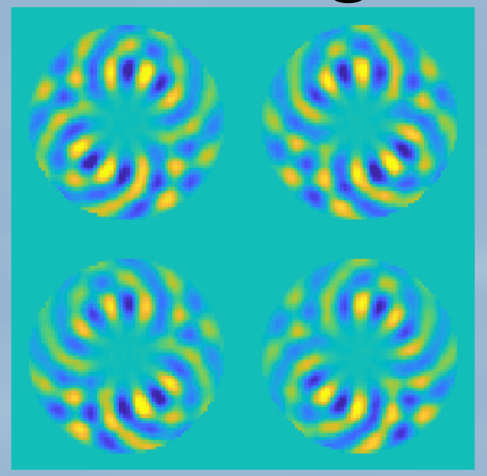
$\phi =$ 

NGS



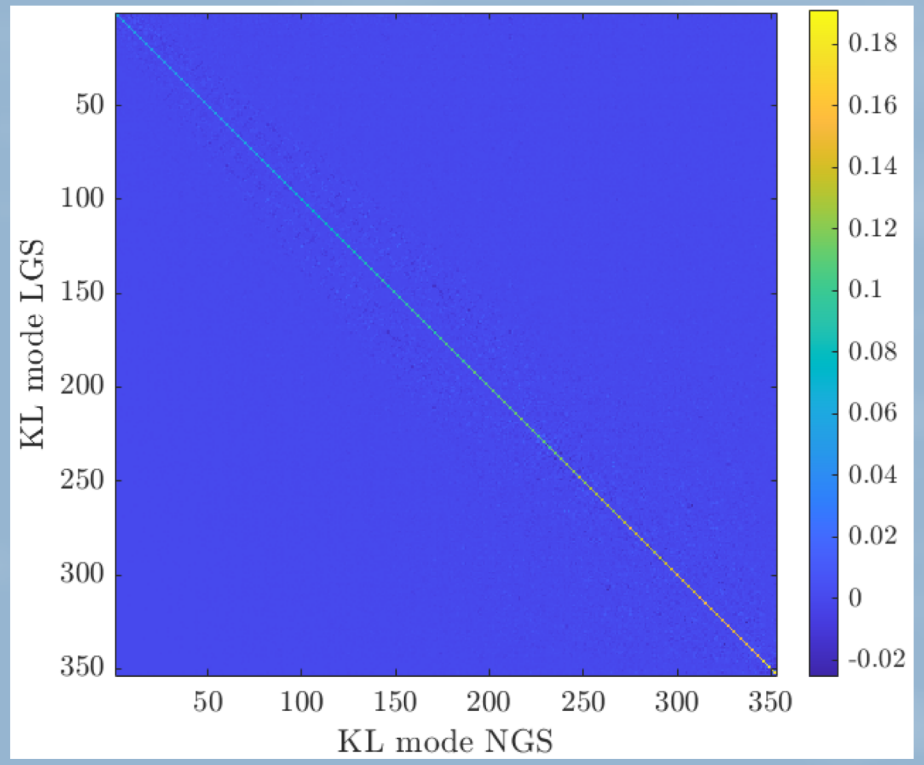
LGS

$LGS \cdot g$



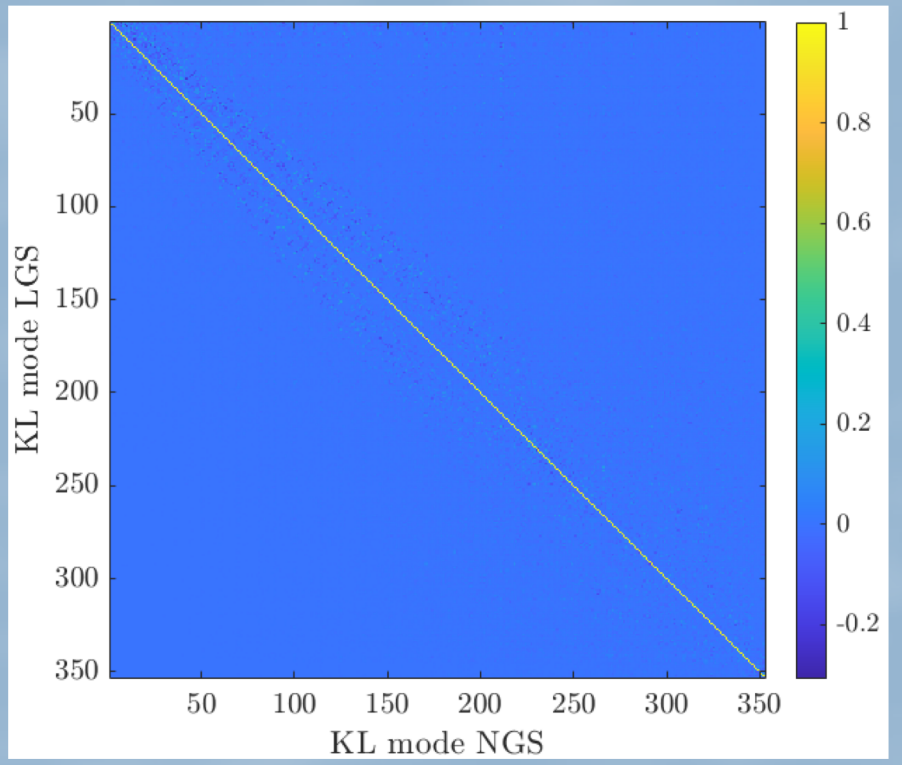
NGS vs LGS signal

$(iMat_{NGS})^{\dagger} \cdot iMat_{LGS}$



Optical gains

$(iMat_{NGS} \cdot OG)^{\dagger} \cdot iMat_{LGS}$



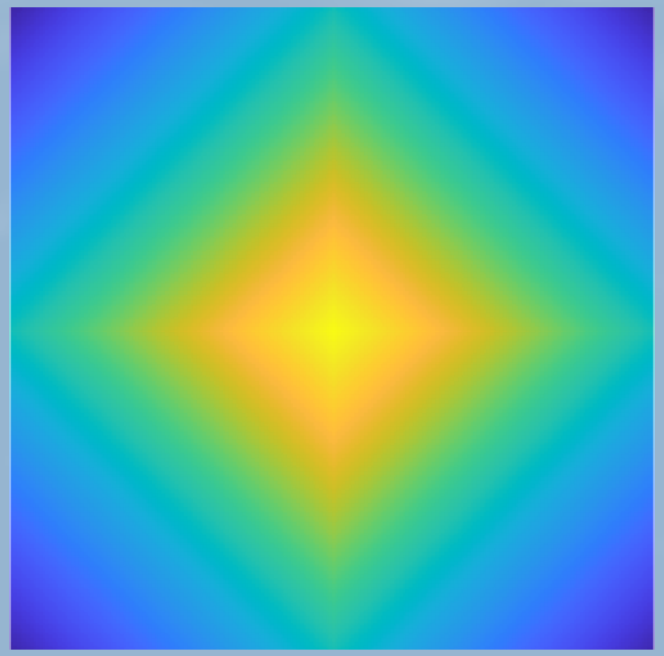
Issues for 40 m telescopes

- Single frame: ≈ 10 000 seconds
- 80x80 DM: ≈ 5000 actuators
- Interaction Matrix: ≈ 4 years to compute
- We don’t have access to the $iMat_{LGS}$

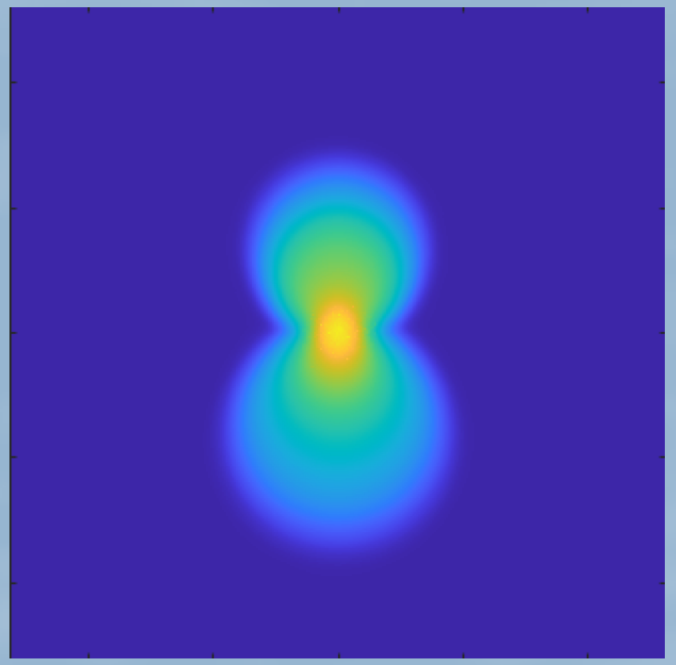
Convolutional model [1]

$$IR = 2\,Im\left[\overline{\hat{m}}\,(\widehat{m\,\omega})\right]$$

arg(m)



ω



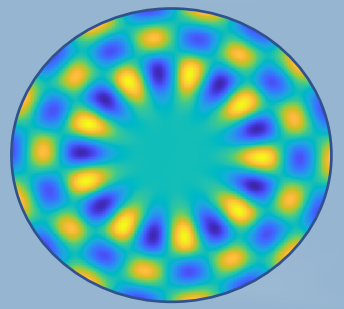
1) Fauvarque, O., Janin-Potiron, P., Correia, C., et al. 2019, J. Opt. Soc. Am. A, 36, 1241

Convolutional model

>1.000x faster!

$$IR = 2\,Im\left[\bar{\hat{m}}\,\hat{m}(\phi)\right]$$

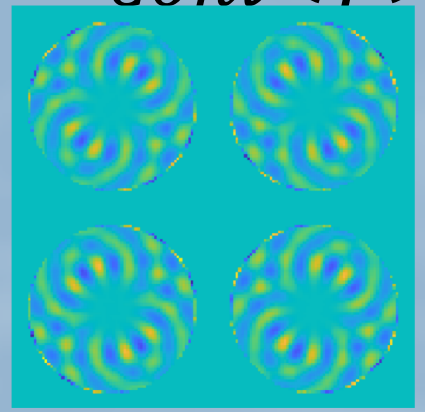
$$\Delta I(\phi) = (\phi \mathbb{I}_p) * \mathrm{IR}$$

$\phi =$ 

10.000 s

10 s

$\Delta I_{E2E}(\phi)$ 

$\Delta I_{Conv}(\phi)$ 

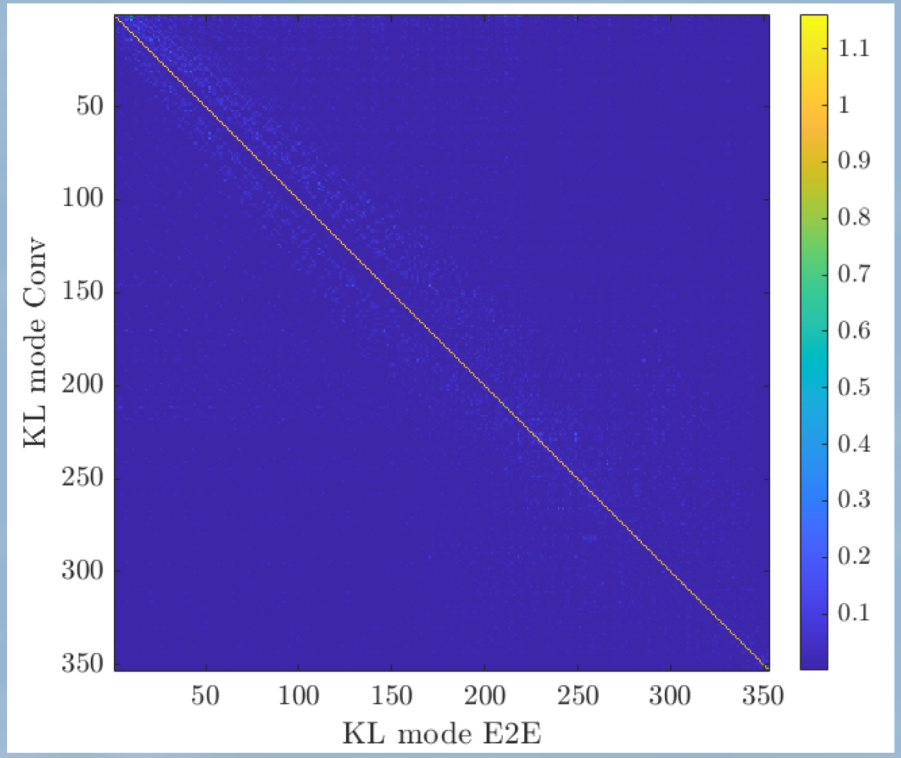
Convolutional model

$$IR = 2\,Im\left[\bar{\hat{m}}\,(\hat{m}\,\hat{\omega})\right]$$

$$\Delta I(\phi) = \left(\phi \mathbb{I}_{\mathrm{p}}\right) * \mathrm{IR}$$

$$\mathrm{iMat} = \left[\Delta I(\phi_1) \ldots \Delta I(\phi_i) \ldots \Delta I(\phi_N)\right]$$

$$(iMat_{E2E})^{\dagger} \cdot iMat_{Conv}$$



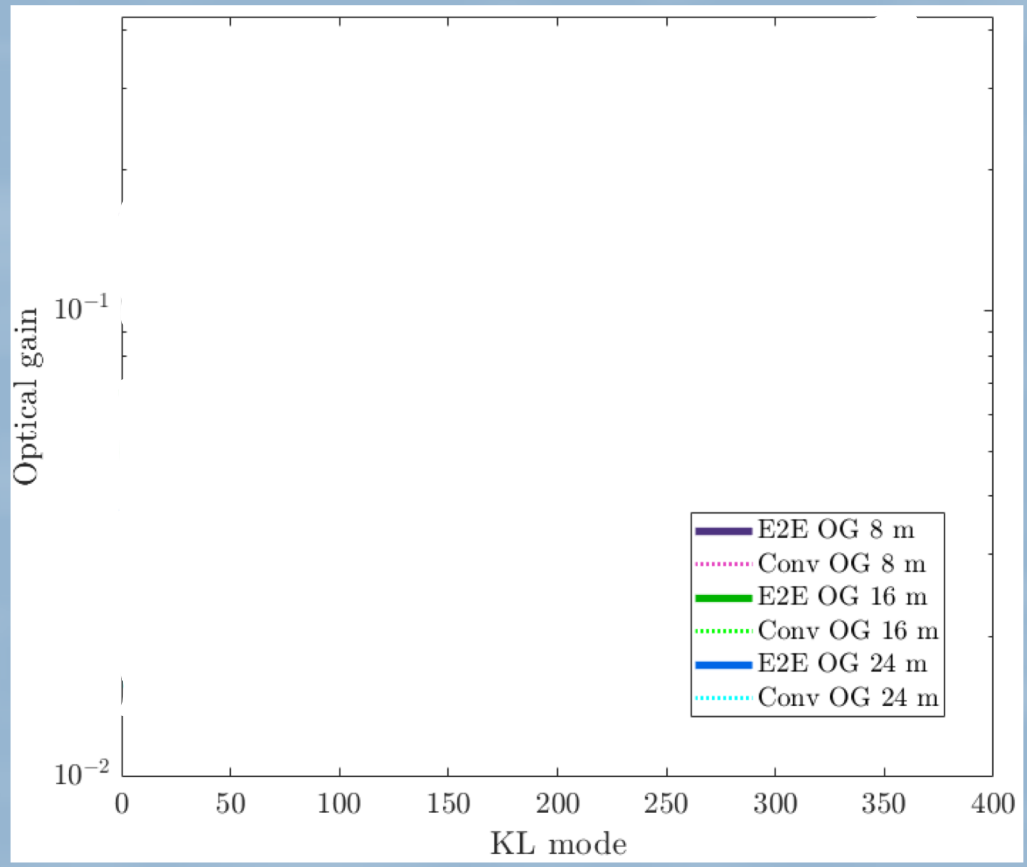
Convolutional model

$$IR = 2\,Im\left[\overline{\hat{m}}\,(\widehat{m\omega})\right]$$

$$\Delta I(\phi) = \left(\phi \mathbb{I}_{\mathrm{p}}\right) * \mathrm{IR}$$

$$\mathrm{iMat} = \left[\Delta I(\phi_1) \ldots \Delta I(\phi_i) \ldots \Delta I(\phi_N)\right]$$

$$OG = diag\left((iMat_{NGS})^{\dagger} \cdot iMat_{LGS}\right)$$



NGS vs LGS signal

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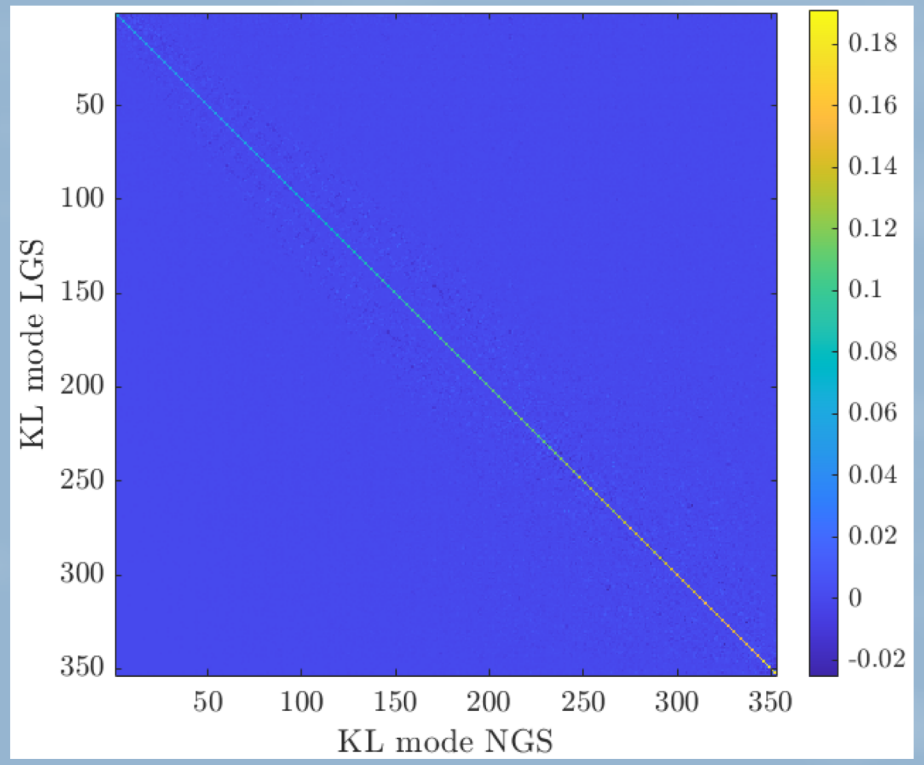
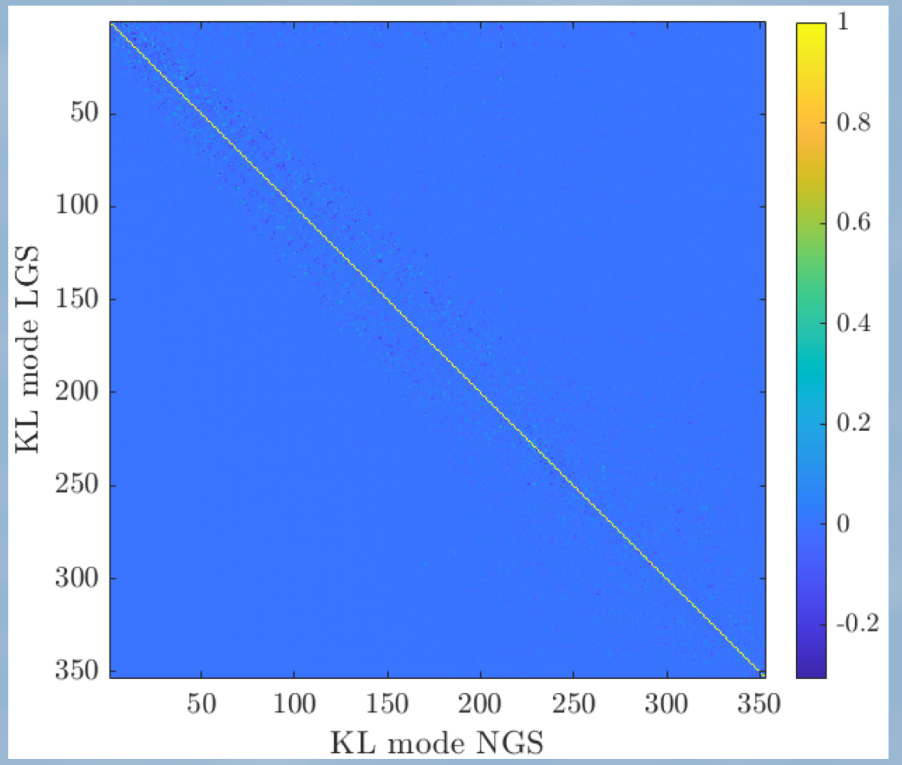


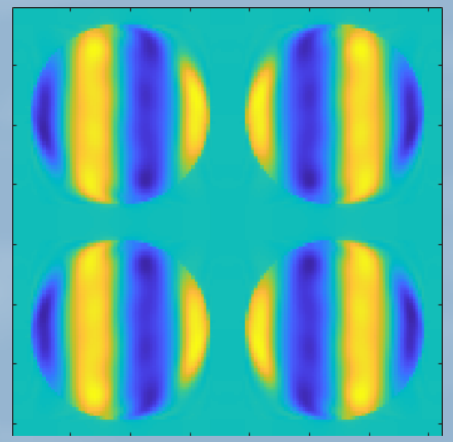
Optical gains

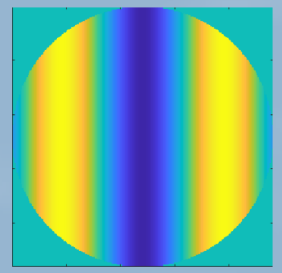
$(iMat_{NGS} \cdot OG)^{\dagger} \cdot iMat_{LGS}$

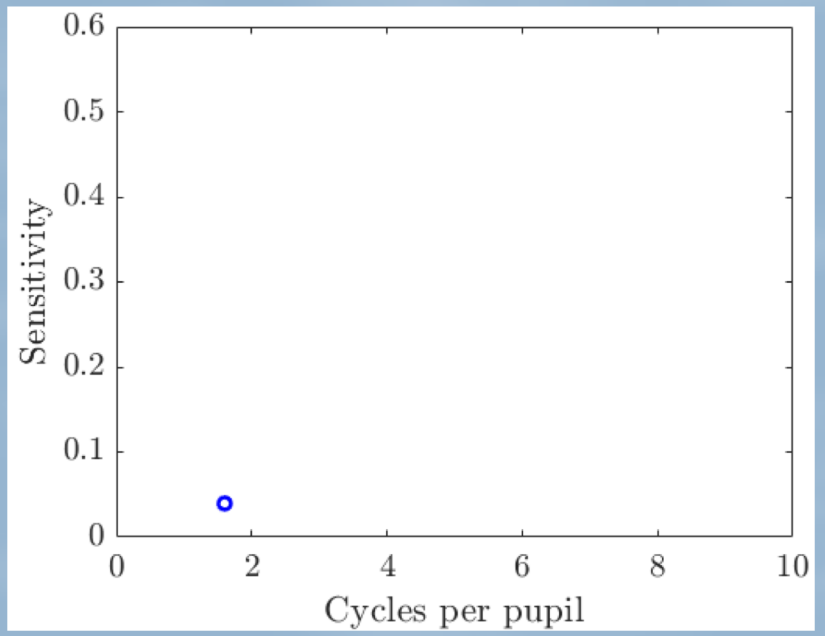


Sensitivity computation

$$S_{\phi_i} = \frac{\left\| \quad \right\|_2}{\left\| \quad \right\|_2}$$

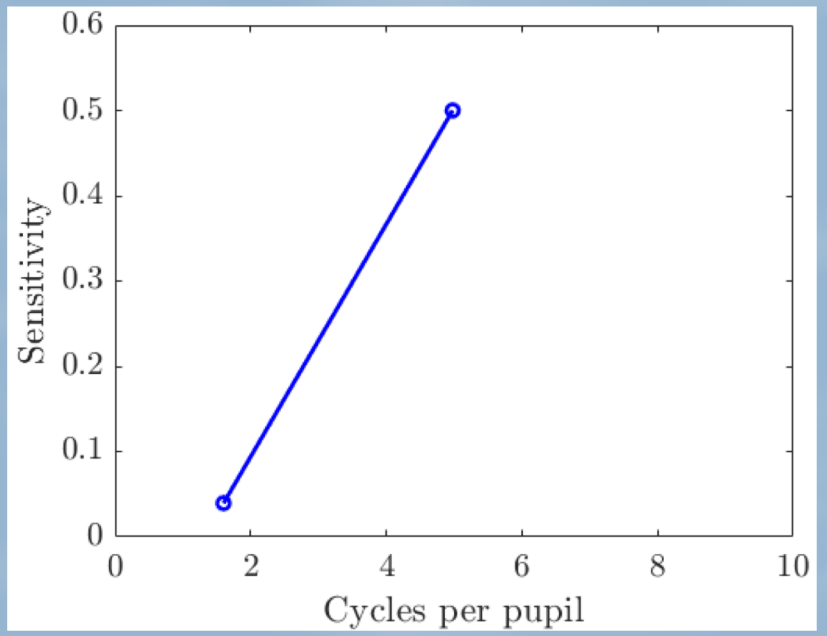






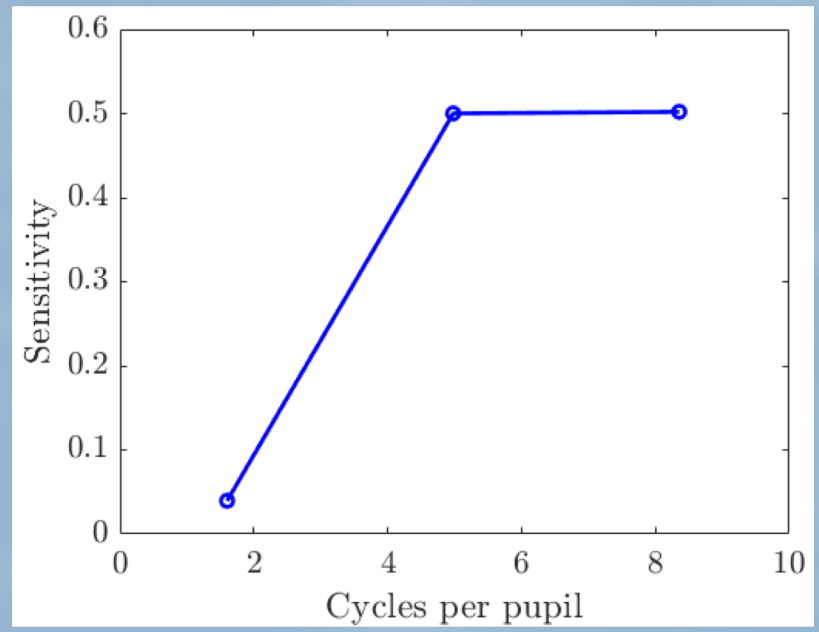
Sensitivity computation

$$S_{\phi_i} = \frac{\left\| \text{[four-circle grating]} \right\|_2}{\left\| \text{[single-circle grating]} \right\|_2}$$



Sensitivity computation

$$S_{\phi_i} = \frac{\left\| \text{[four-lobe pattern]} \right\|_2}{\left\| \text{[single-lobe pattern]} \right\|_2}$$



Transfer function

$$TF(u,v) = \widehat{IR}$$

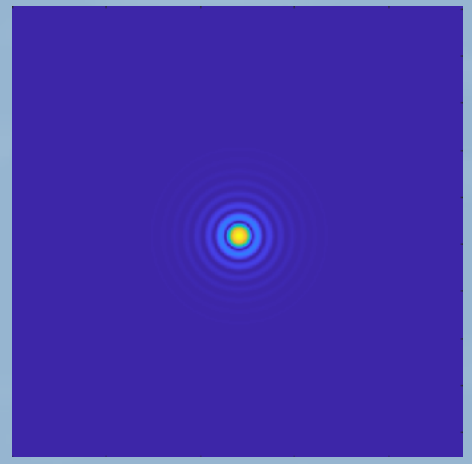
$$s_f = \frac{1}{\sqrt{2}}\left(s\left(cos_f\right)^2 + s\left(sin_f\right)^2\right)$$

$$s_f = \sqrt{|TF|^2 * PSF}$$

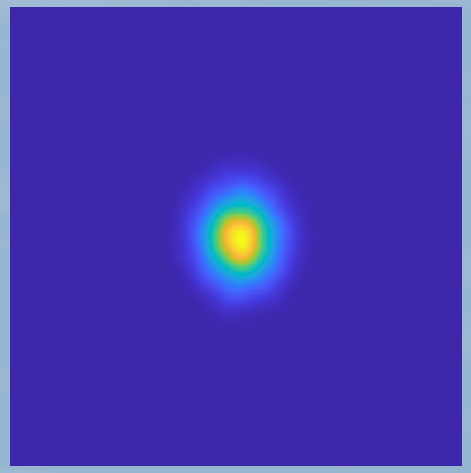
Sensitivity maps

$$s_f = \sqrt{|TF|^2 * PSF}$$

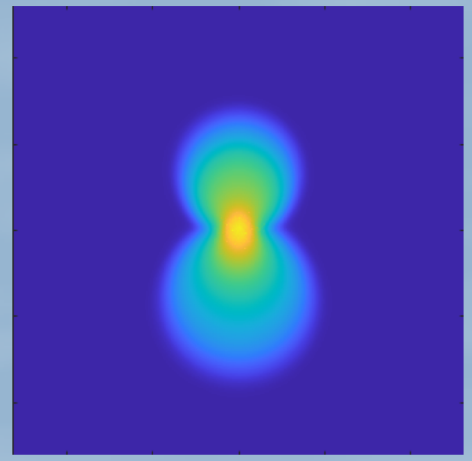
Diffraction limited spot (zoom x300)



Laser launch telescope limited 1” spot



Full 3D LGS structure



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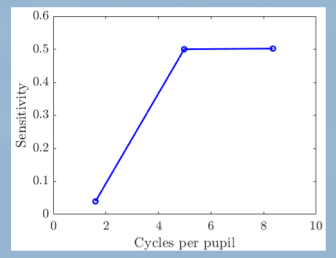

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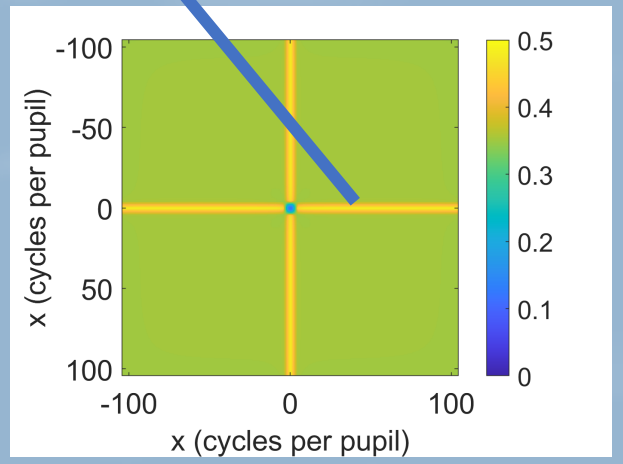

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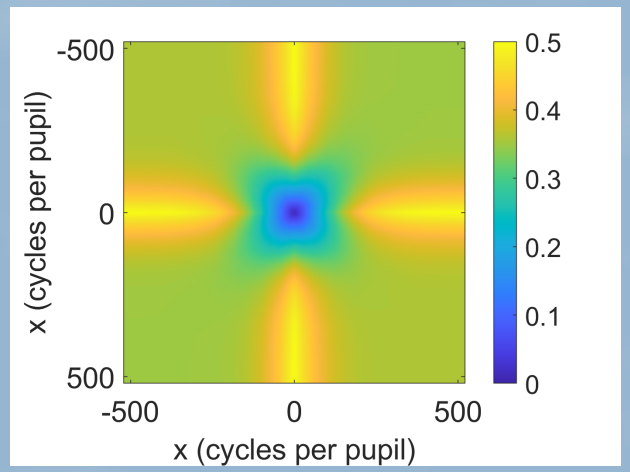
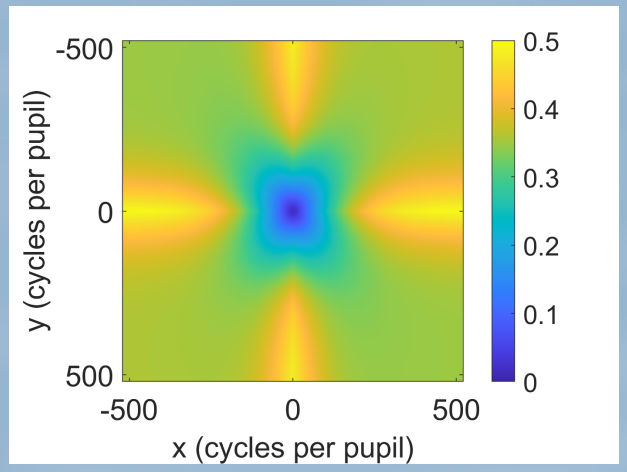


Full 3D LGS structure

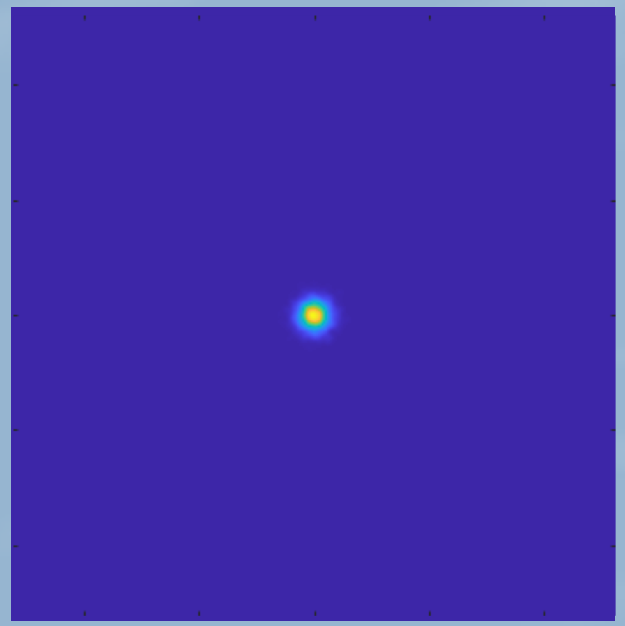


40 m telescope

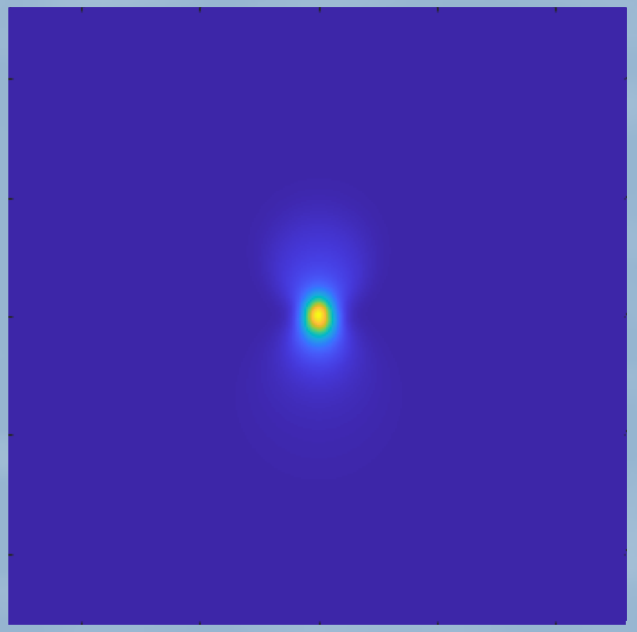
Sensitivity maps

$$s_f = \sqrt{|TF|^2 * PSF}$$

Laser launch telescope limited
1” spot



Full 3D LGS structure



40 m telescope

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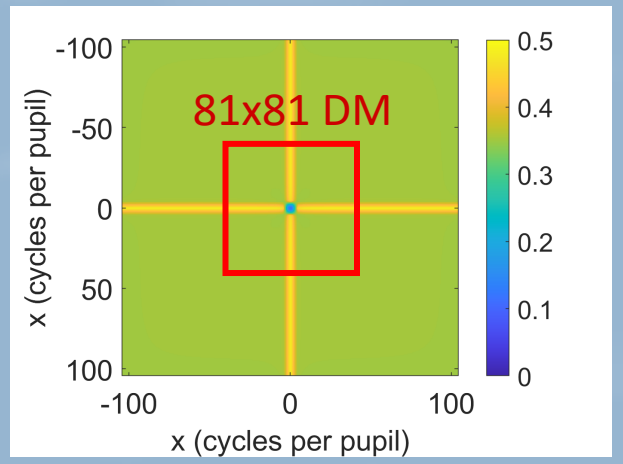
Diffraction limited spot (zoom x300)



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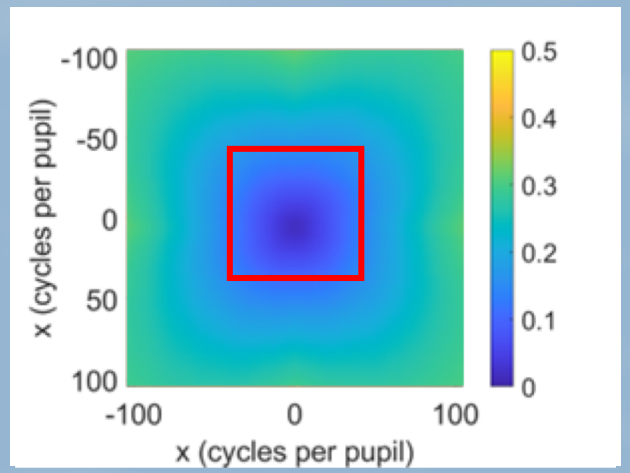

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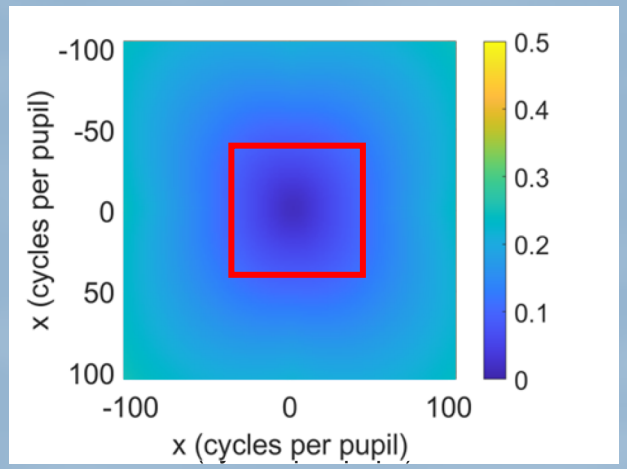
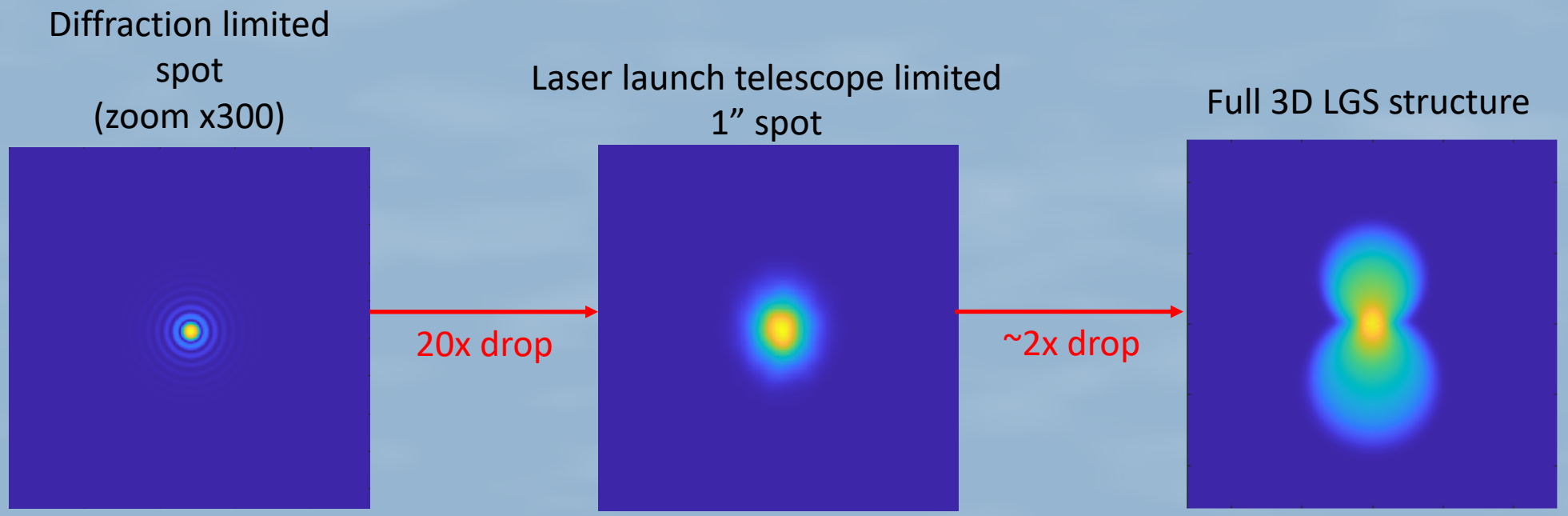


40 m telescope

Sensitivity



Conclusion

- Successfully developed a method 60+ times faster than traditional ways of simulating LGS.
- Validated and tested the use of a convolutional model to further speed up the process 1000+ times.
- The width of the laser beam is more important than the elongation in terms of noise propagation

Thank you!

- Questions?