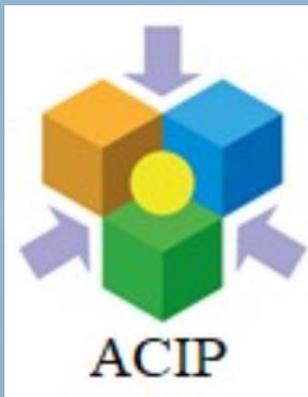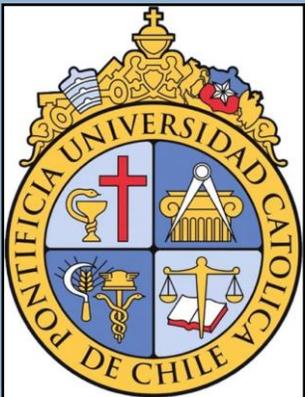# Fourier filter LGS wavefront sensing for ELT sized telescopes: comparison of Pyramid and Ingot
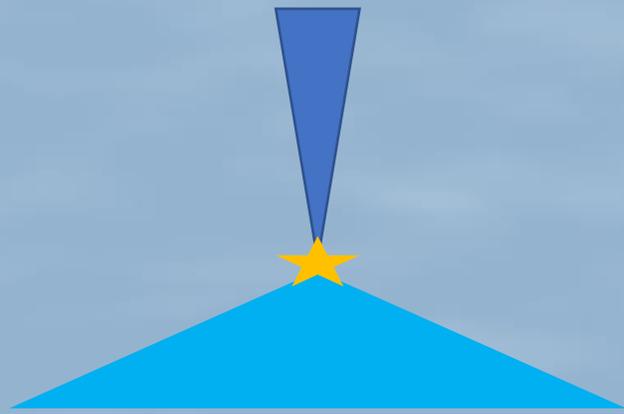
*Francisco Oyarzún[1], Vincent Chambouleyron[2], **Benoit Neichel**[2], Thierry Fusco[2], Andrés Guesalaga[1]*

[1]*Departamento de Ingeniería Eléctrica, Pontificia Universidad Católica de Chile, Santiago, Chile*
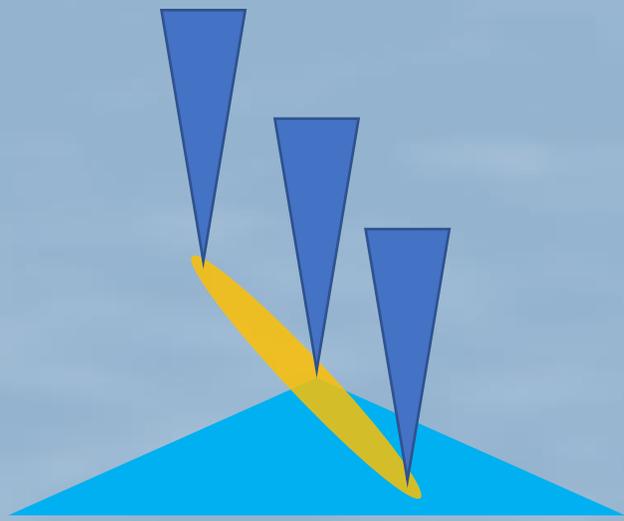
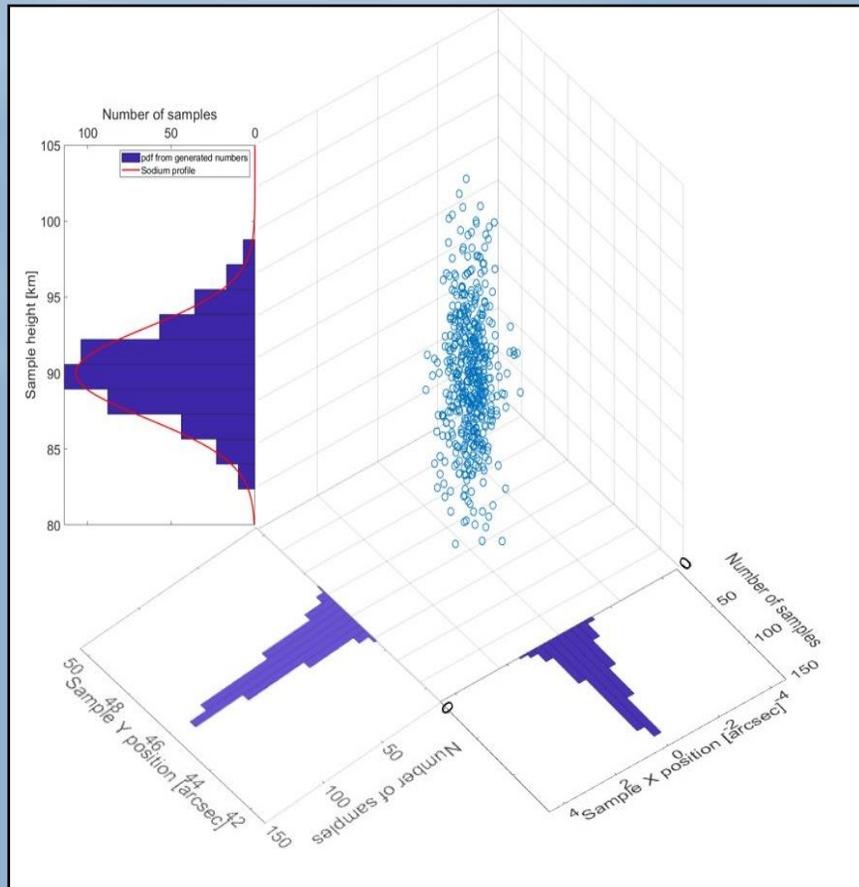[2]*Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France*
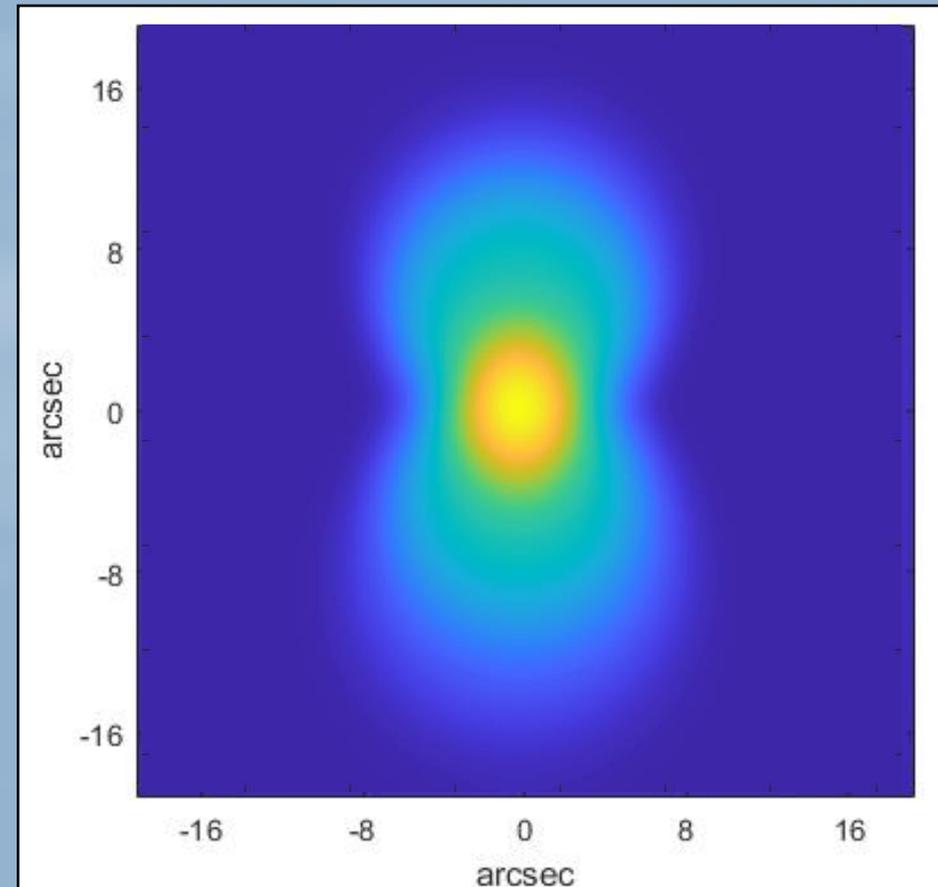
Pyramid + LGS

NGS

LGS

Glass pyramid

Light beam
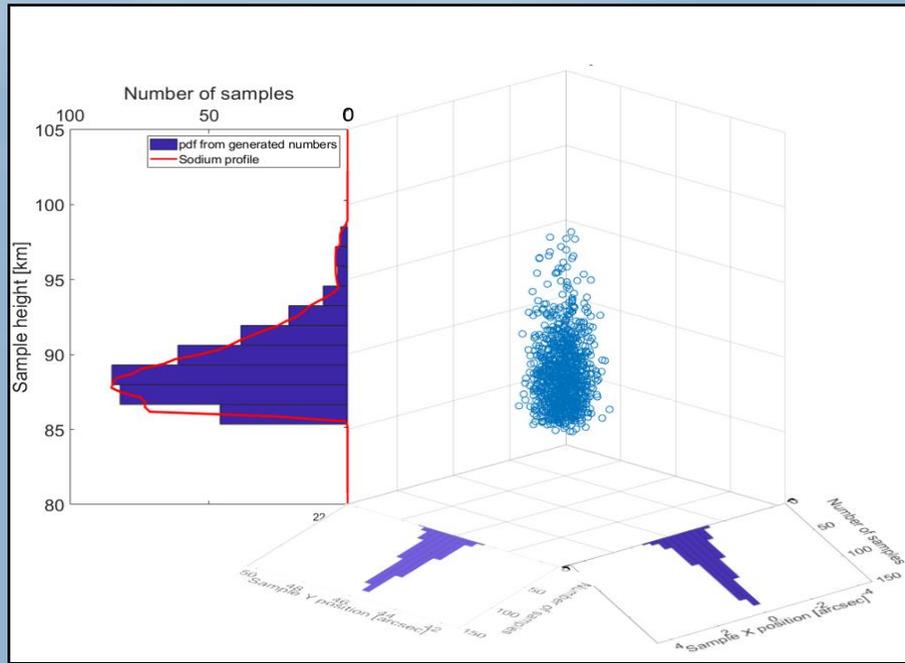
Spot image

LGS modeling

LGS modelation: point source sampling

LGS image as seen through the telescope

LGS modeling

LGS modelation: point source sampling

LGS image as seen through the telescope

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>60x faster!
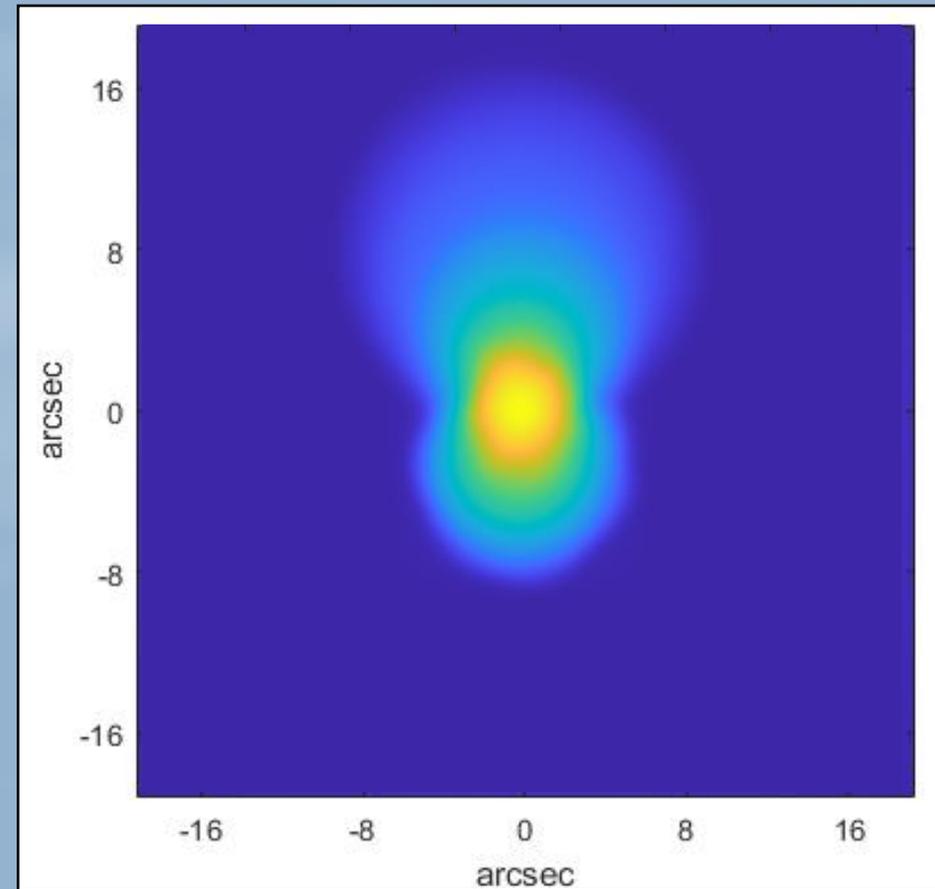
Tested FFWFS for 40 m telescope

Pyramid

Ingot

LGS as seen by the WFS   **Phase mask**   **Pupil images**

DoF : Depth of Focus
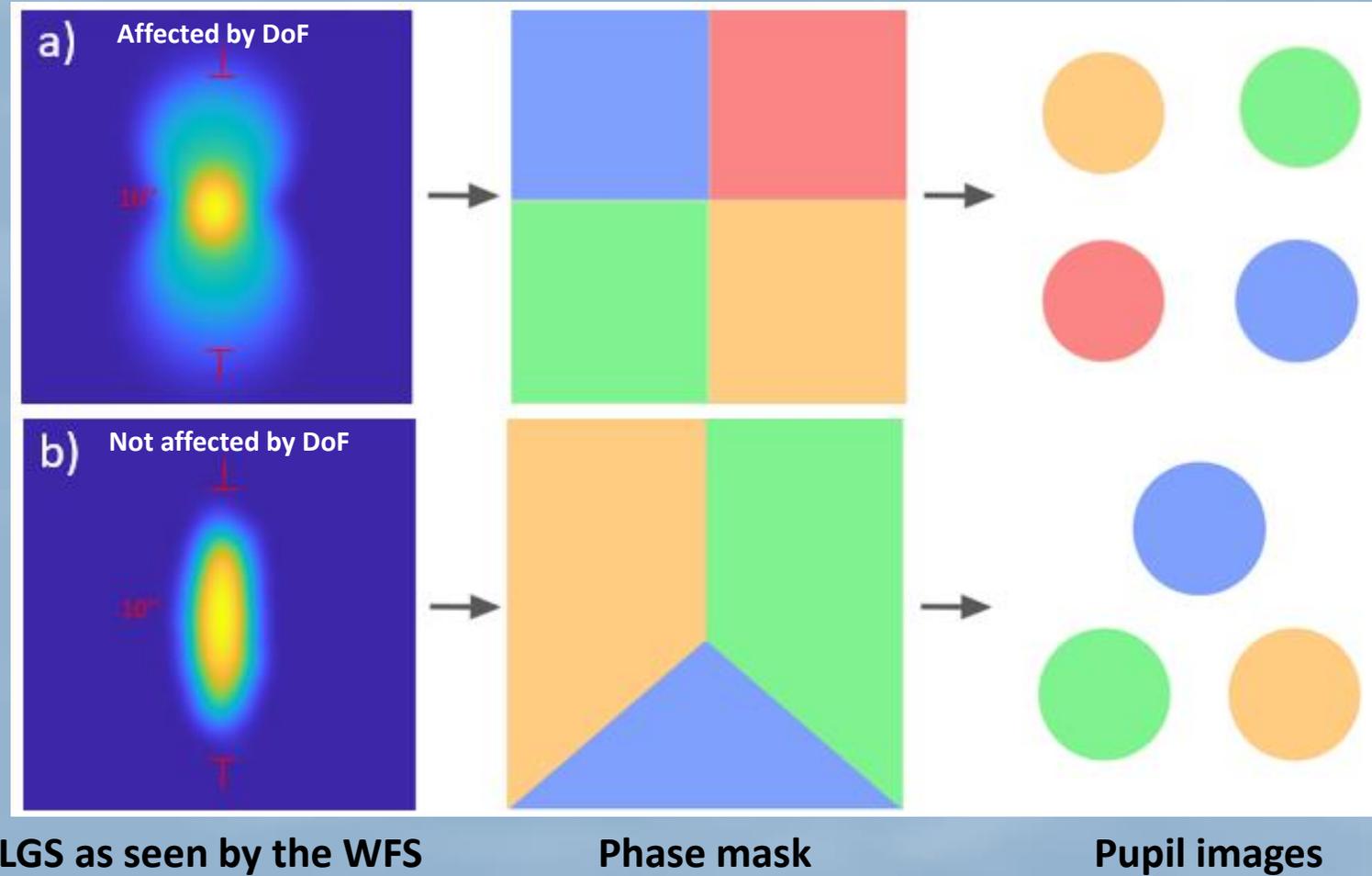
Photon noise sensitivity computation

$$S_{\phi_i \gamma} = \left\| \frac{\text{}}{\sqrt{\text{}}} \right\|^2$$

Photon noise & Sensitivity

$$\sigma^2_{\phi_i\,\gamma} = \frac{1}{s^2_{\phi_i\,\gamma}\,N_\gamma}$$

$$\sigma^2_{\gamma-noise} = \sum \sigma^2_{\phi_i\,\gamma}$$

Photon noise sensitivity

✳ = vertical
◇ = horizontal

✳ Diffraction limited 3Pyramid

Sensitivity

Spatial frequency (cicles per pupil)

Diffraction limited
3 mas spot
(zoom x300)

N_γ : Number of photons

$\sigma^2_{\gamma-noise}$: Photon noise contribution to EB

$s_{\phi_i\,\gamma}$: Sensitivity to mode ϕ_i

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Photon noise & Sensitivity

$$\sigma^2_{\phi_i\,\gamma} = \frac{1}{s^2_{\phi_i\,\gamma}\,N_\gamma}$$

$$\sigma^2_{\gamma-noise} = \sum \sigma^2_{\phi_i\,\gamma}$$

Photon noise sensitivity

20x drop
~ 6.5 mag

✳ = vertical
◇ = horizontal

Sensitivity

Spatial frequency (cicles per pupil)

* Diffraction limited 3Pyramid
* Laser 1" spot limited 3Pyramid
* Laser 1" spot limited 4Pyramid

Diffraction limited
3 mas spot
(zoom x300)

Laser launch telescope limited
1" spot

N_γ : Number of photons

$\sigma^2_{\gamma-noise}$: Photon noise contribution to EB

$s_{\phi_i\,\gamma}$: Sensitivity to mode ϕ_i
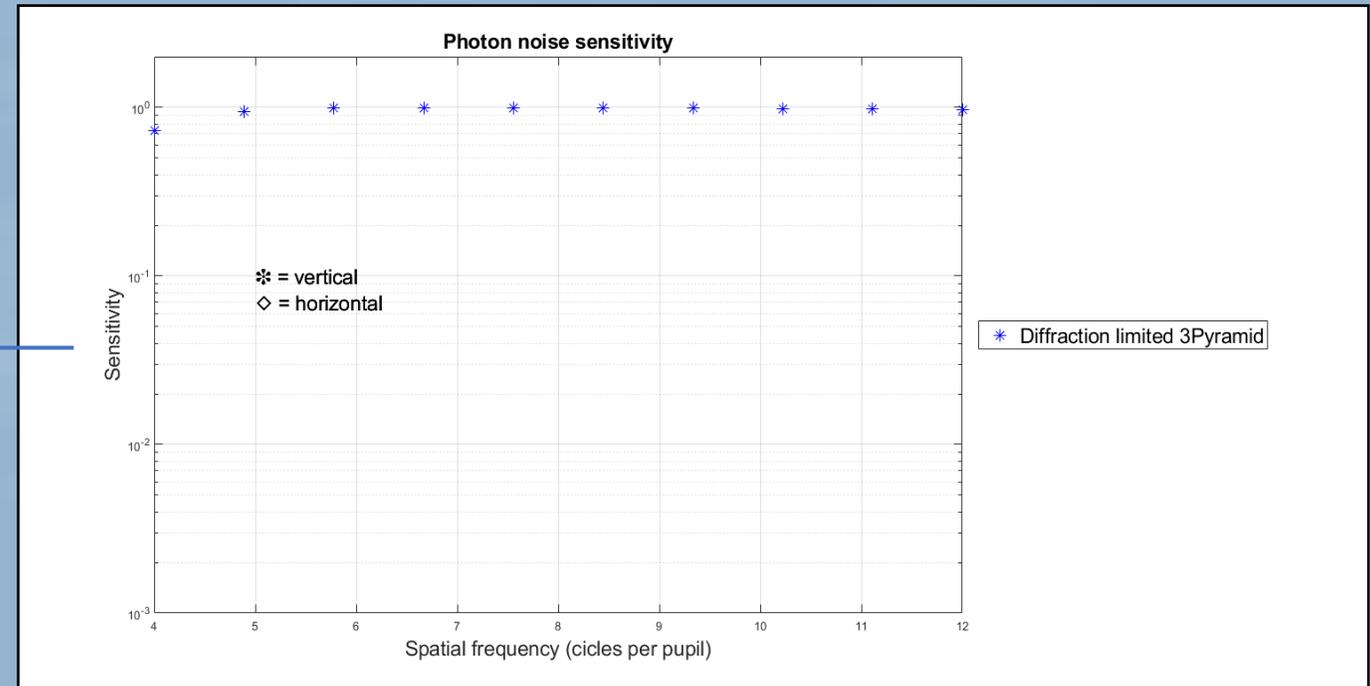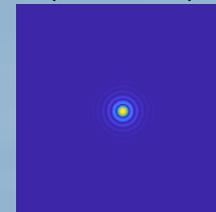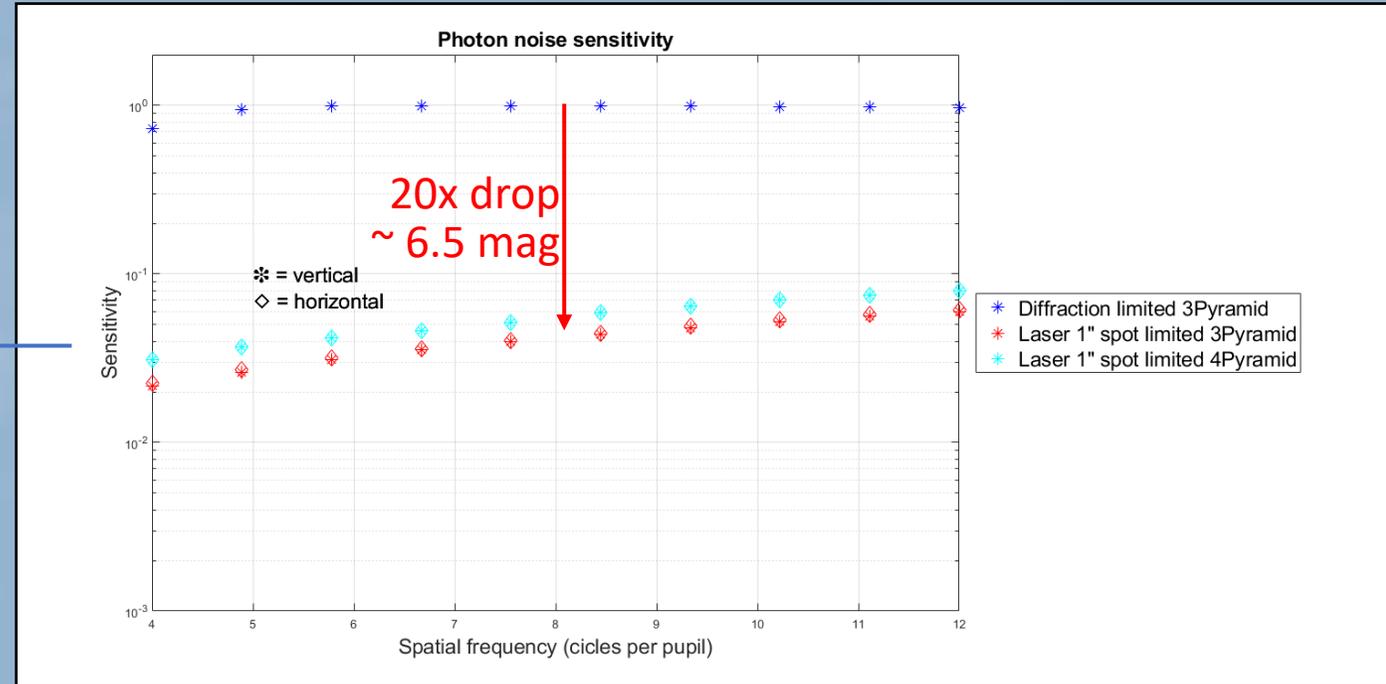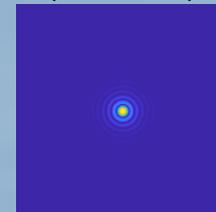
9

Photon noise & Sensitivity

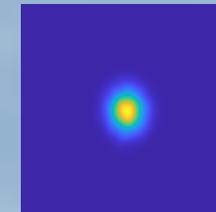$$\sigma^2_{\phi_i \gamma} = \frac{1}{s^2_{\phi_i \gamma} N_\gamma}$$

$$\sigma^2_{\gamma-noise} = \sum \sigma^2_{\phi_i \gamma}$$
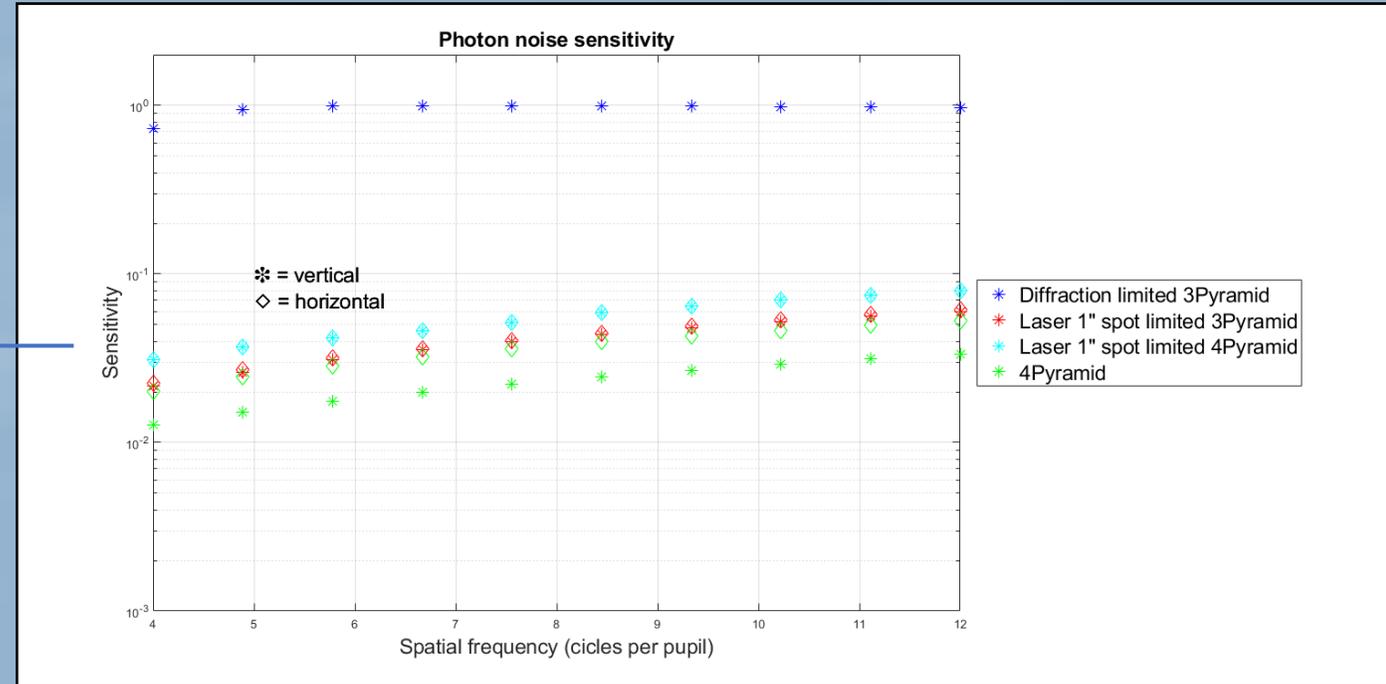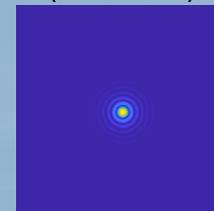
N_γ : Number of photons

$\sigma^2_{\gamma-noise}$: Photon noise contribution to EB

$s_{\phi_i \gamma}$: Sensitivity to mode ϕ_i

Photon noise sensitivity

✳ = vertical
◇ = horizontal

Diffraction limited 3Pyramid
Laser 1" spot limited 3Pyramid
Laser 1" spot limited 4Pyramid
4Pyramid

Sensitivity

Spatial frequency (cicles per pupil)

Diffraction limited
3 mas spot
(zoom x300)

Laser launch telescope limited
1" spot

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Photon noise & Sensitivity

$$\sigma^2_{\phi_i \, \gamma} = \frac{1}{s^2_{\phi_i \, \gamma} \, N_\gamma}$$

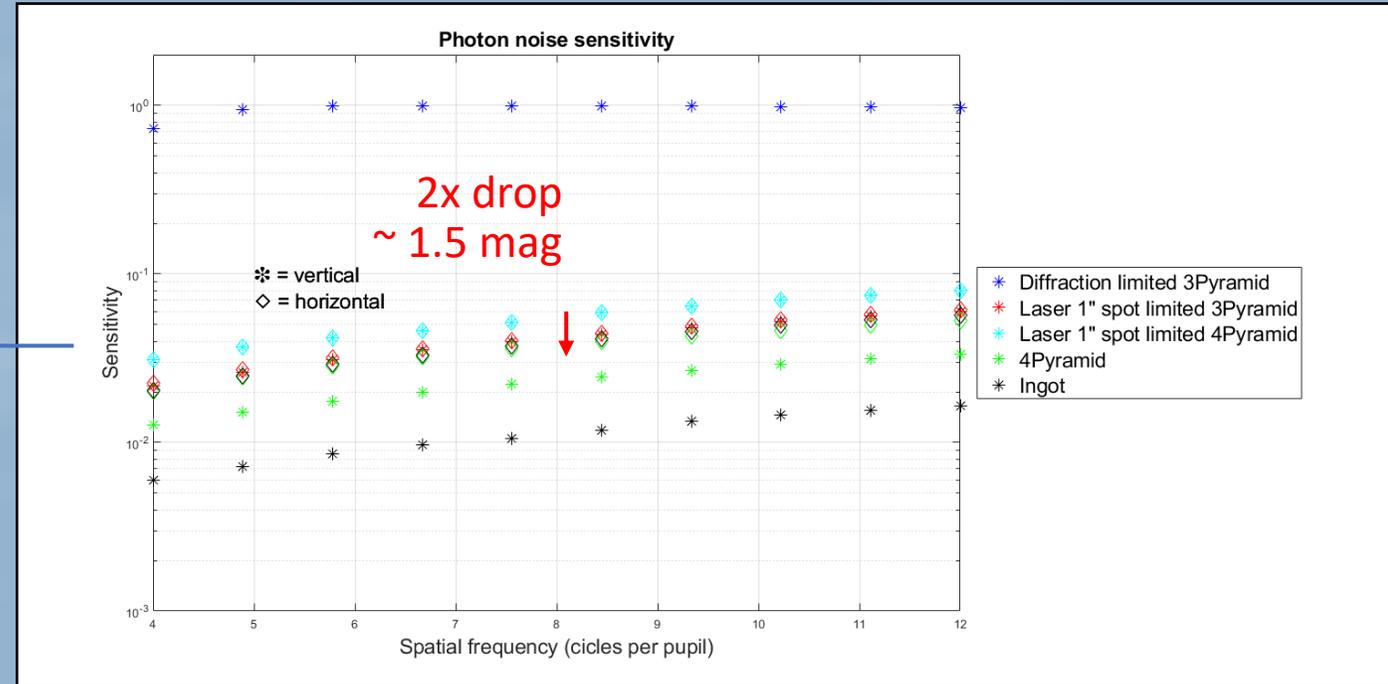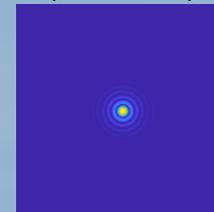$$\sigma^2_{\gamma-noise} = \sum \sigma^2_{\phi_i \, \gamma}$$

N_γ : Number of photons

$\sigma^2_{\gamma-noise}$: Photon noise contribution to EB

$s_{\phi_i \, \gamma}$: Sensitivity to mode ϕ_i

Photon noise sensitivity

2x drop
~ 1.5 mag

✳ = vertical
◇ = horizontal

* Diffraction limited 3Pyramid
* Laser 1" spot limited 3Pyramid
* Laser 1" spot limited 4Pyramid
* 4Pyramid
* Ingot

Sensitivity

Spatial frequency (cicles per pupil)

Diffraction limited
3 mas spot
(zoom x300)

Laser launch telescope limited
1" spot

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Photon noise Sensitivity

Diffraction limited
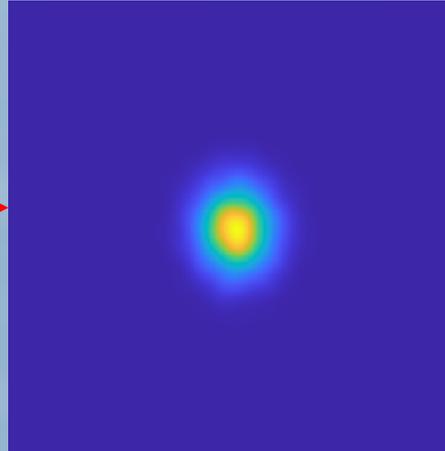3 mas spot
(zoom x300)
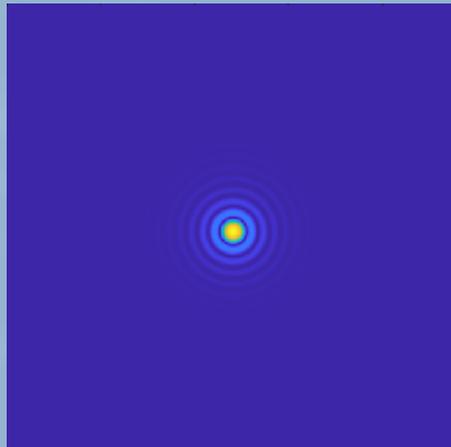
Laser launch telescope limited
1" spot

Full 3D LGS structure
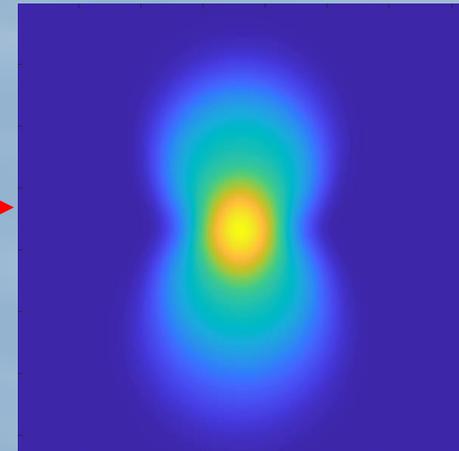
20x drop

~2x drop

Closed loop verification on 8 m telescope

- **400 KL modes**
- **Expected SR = 42 %**

- **@ 8m the sensitivity analysis predicts 4.6 mag drop when using pyramid+LGS**

SR evolution with magnitude and wind for an 8 m telescope and $r_0 = 0.15$

- NGS 0 m/s wind
- NGS 5 m/s wind
- NGS 10 m/s wind
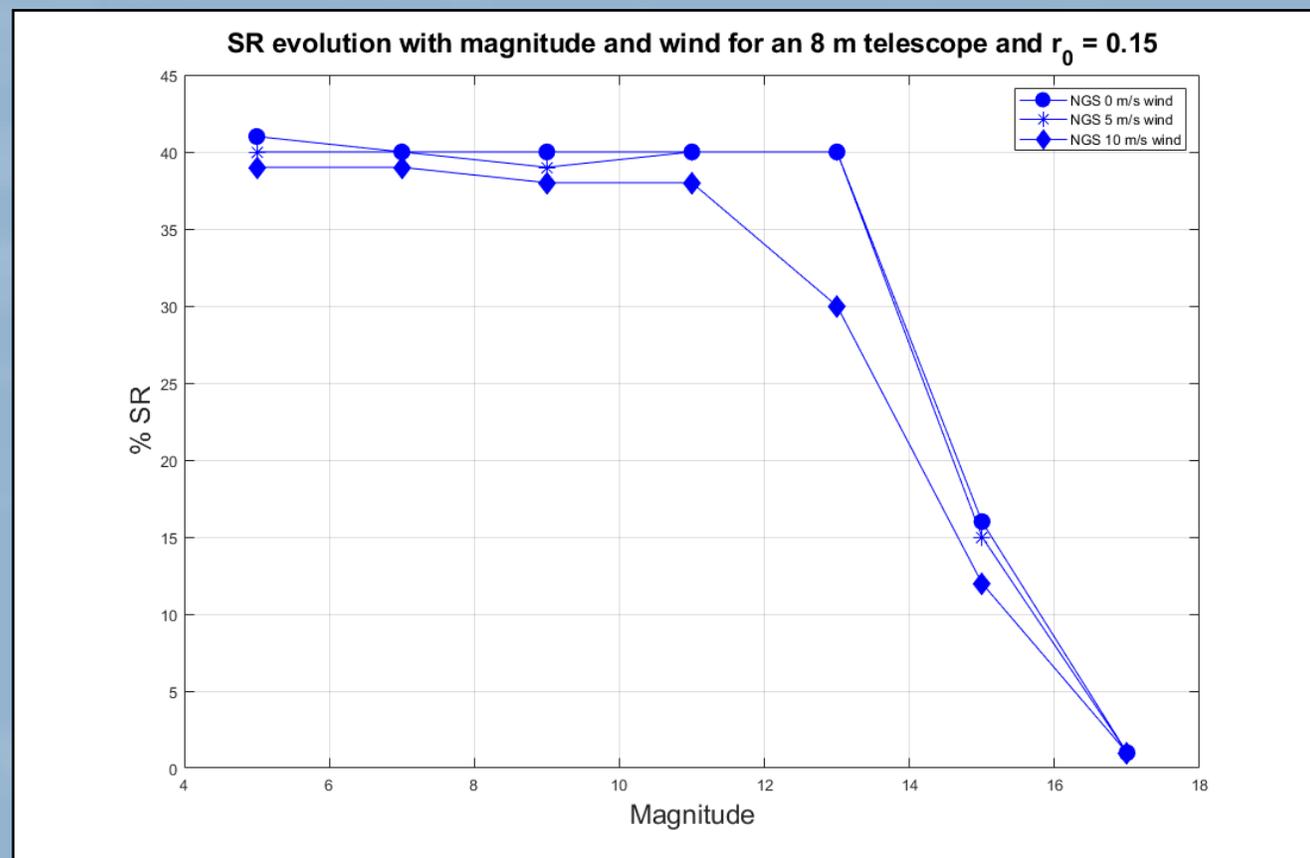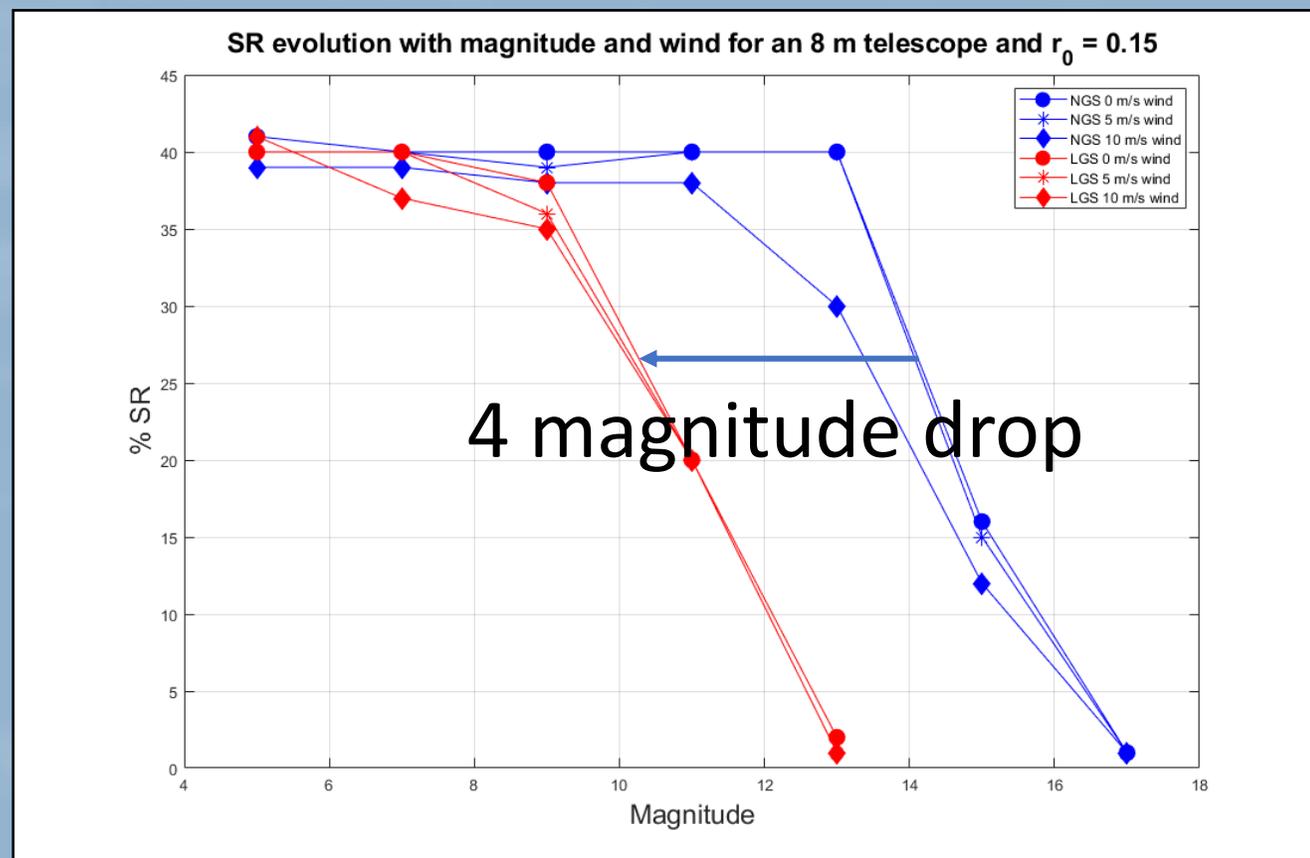
Closed loop verification on 8 m telescope

- **400 KL modes**
- **Expected SR = 42 %**

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SR evolution with magnitude and wind for an 8 m telescope and $r_0 = 0.15$

Legend: NGS 0 m/s wind; NGS 5 m/s wind; NGS 10 m/s wind; LGS 0 m/s wind; LGS 5 m/s wind; LGS 10 m/s wind

4 magnitude drop

Conclusion

- Successfully developed a method 60+ times faster than traditional ways of simulating LGS.

- Pyramid and Ingot have similar sensitivities.

- The main source of lost sensitivity might be the width of the LASER.

Future work

- Laboratory demonstration with PULPOS @ PUCV

Thank you!

- Questions?