INGOT WFS FOR LGS: ON-GOING FEASIBILITY STUDY

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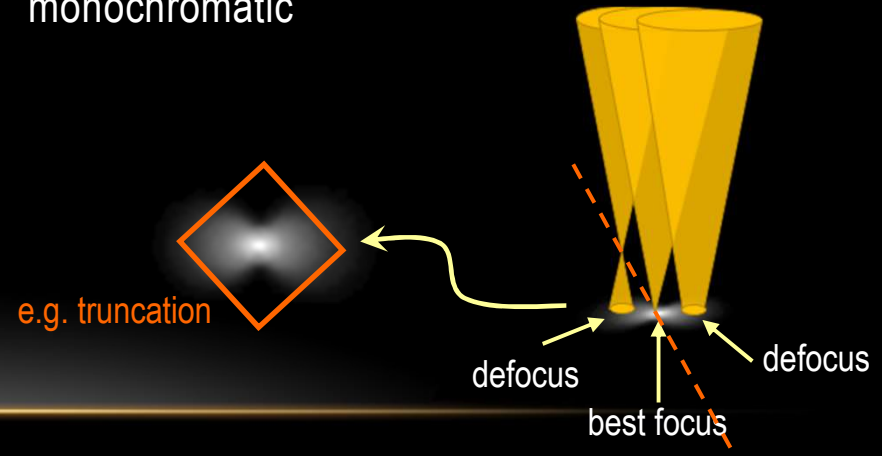
LASER GUIDE STAR - A SOURCE FOR AO

LGS PECULIARITIES:

- not a point-like source
- located at finite distance
- monochromatic

volume
~~3D image plane~~



INGOT DESIGN CONCEPT

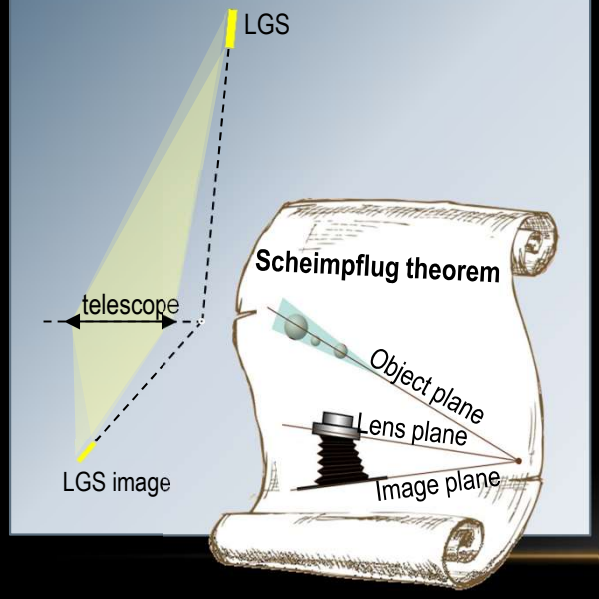
MAIN FUNCTIONALITIES/DESIDERATA:

1) Shall discriminate (on the FP) incoming WF local TT

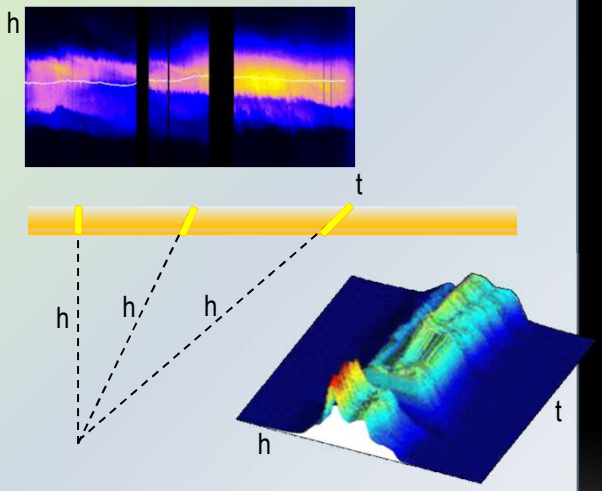
LGS PECULIARITIES:

- not a point-like source
- located at finite distance
- monochromatic

2) Shall match LGS image geometry



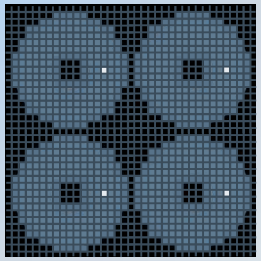
3) Shall allow to cope with Na layer variations



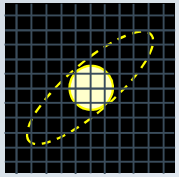
4) If possible, PP WFS…

Pixels occupation:
- PP WFS: few pixels per sub-ap (4px)
- FP WFS: higher img sampl. (~10x10px)

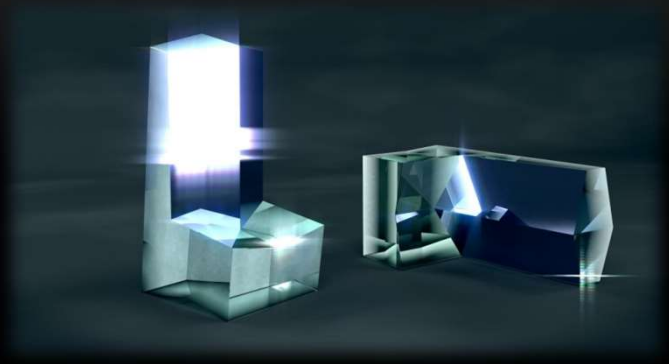
e.g. P-WFS



e.g. SH-WFS

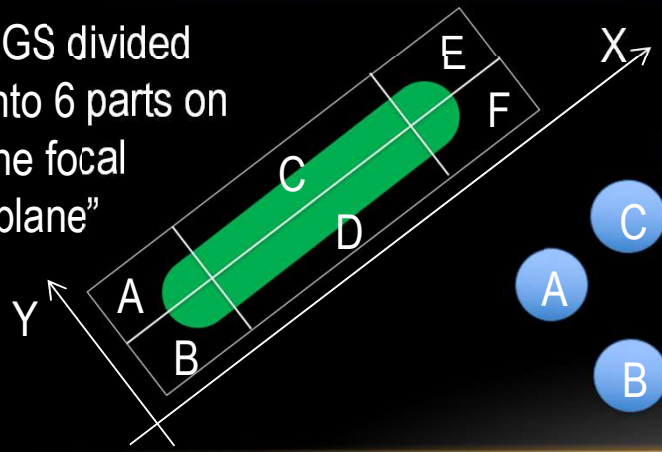


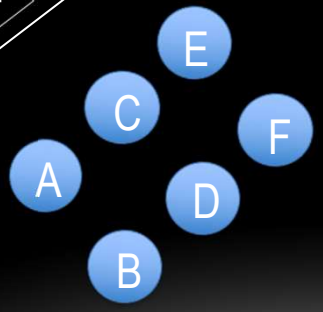
INGOT DESIGN CONCEPT



"WFS in the VLT and ELT era II"

LGS divided into 6 parts on the focal "plane"



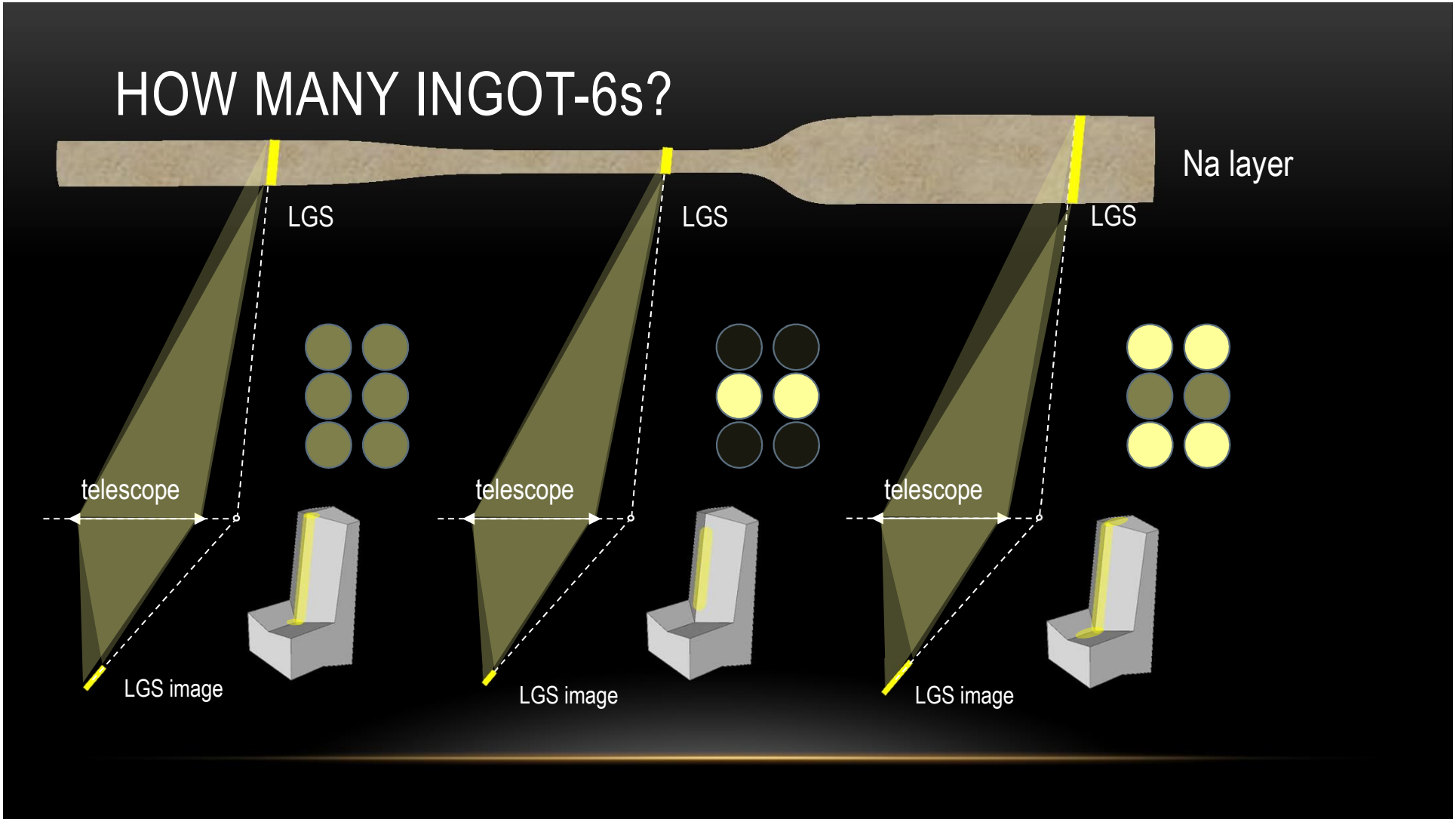


6 re-imaged pupils to be treated in a "6-quad-like" style

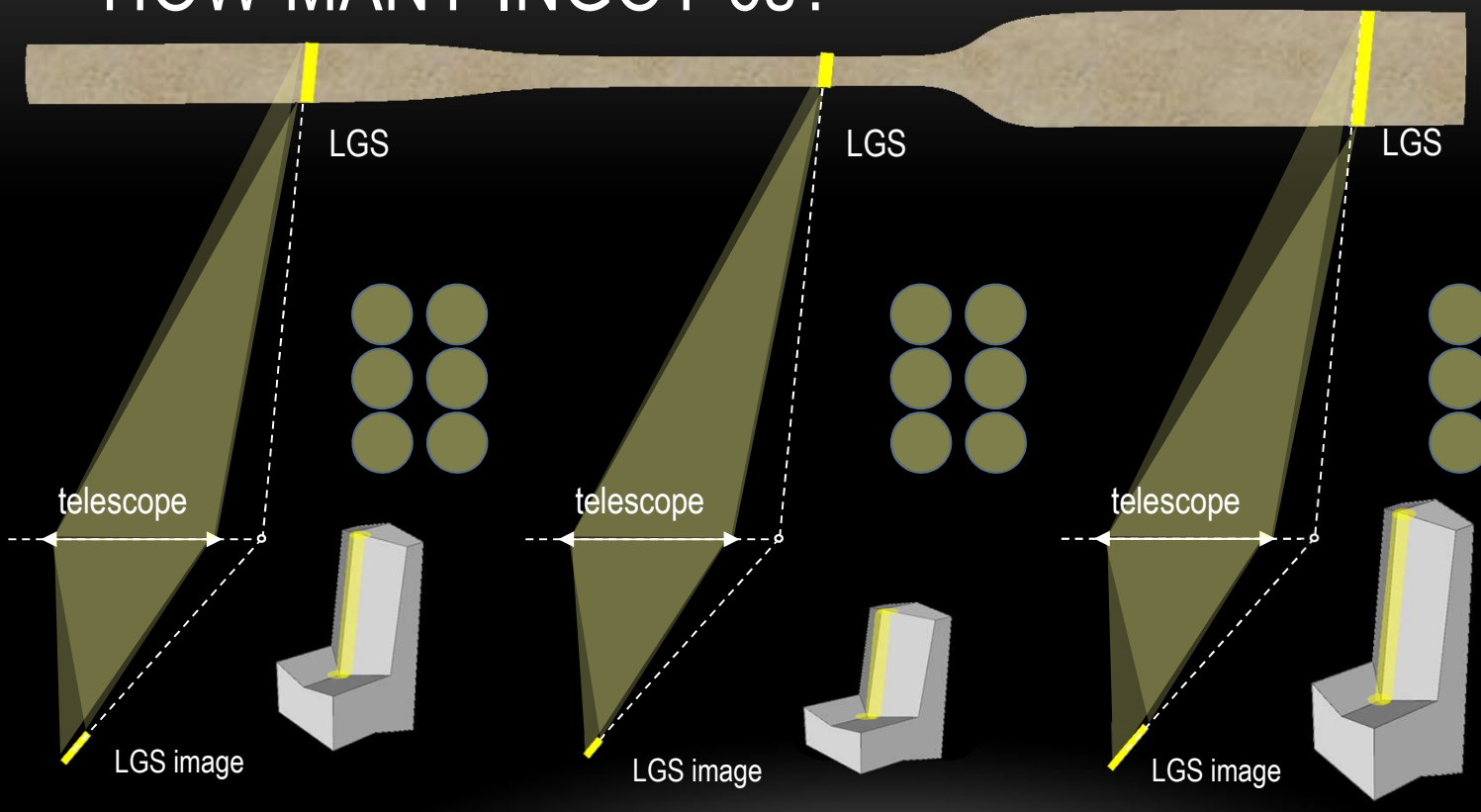
$$S_X \sim \frac{E+F-A-B}{A+B+E+F}$$

$$S_Y \sim \frac{A+C+E-B-D-F}{A+B+C+D+E+F}$$

HOW MANY INGOT-6s?

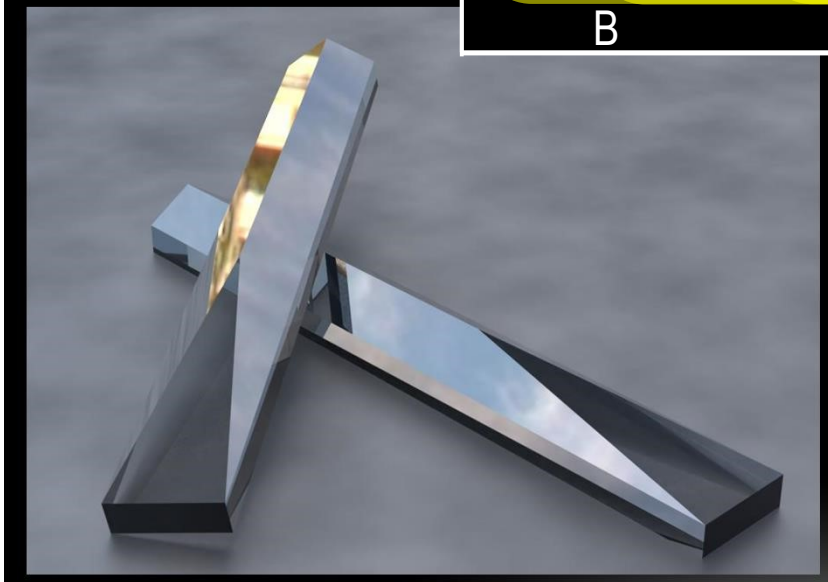


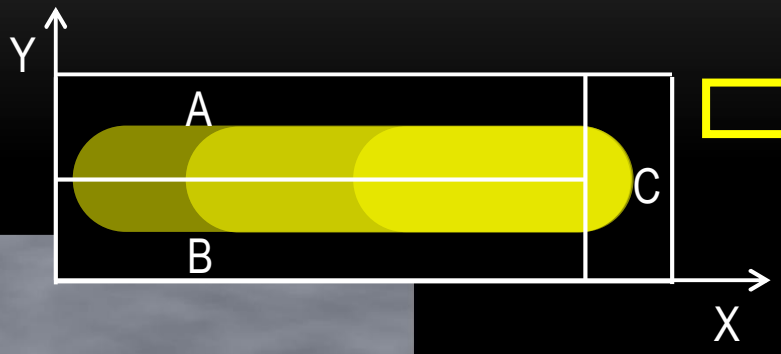
HOW MANY INGOT-6s?

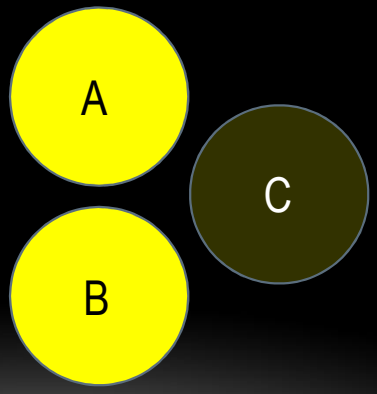


INGOT prism should be exchanged depending on Na layer thickness

A DIFFERENT “FLAVOR”: INGOT-3



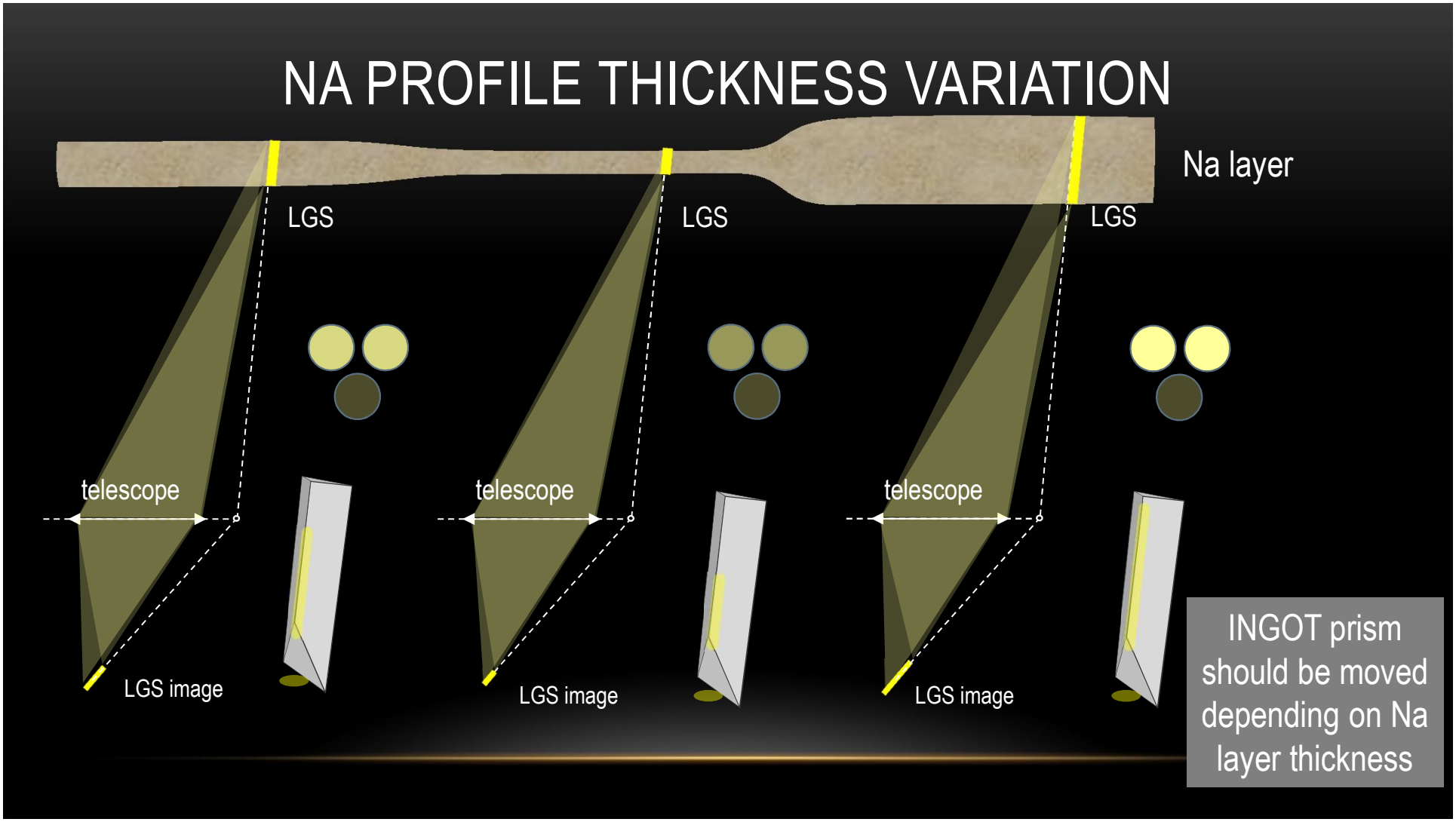




- The INGOT is constrained to the Na layer lower (sharper) edge
- Easier to manufacture
- No more INGOT exchangeability required to match Na layer

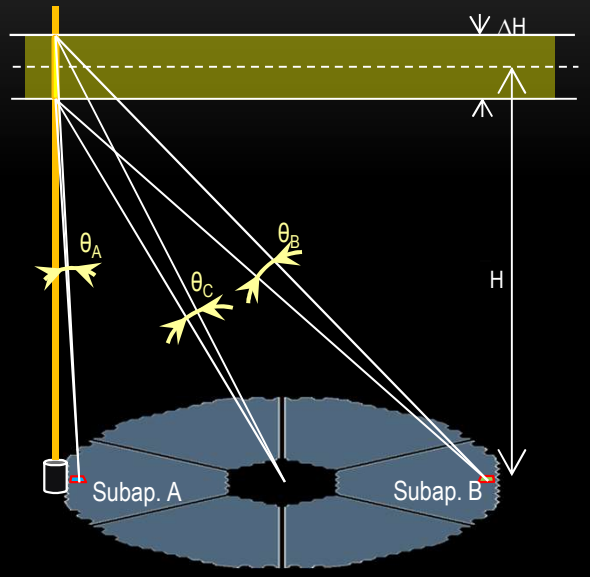
$$S_X \propto \frac{C}{Total} \qquad S_Y \propto \frac{A-B}{Total}$$

NA PROFILE THICKNESS VARIATION



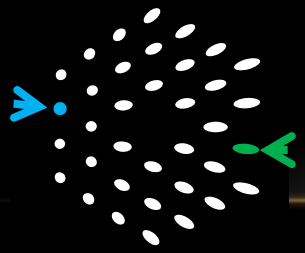
PECULIARITIES OF LGS/INGOT PROJECTIONS

LGS:

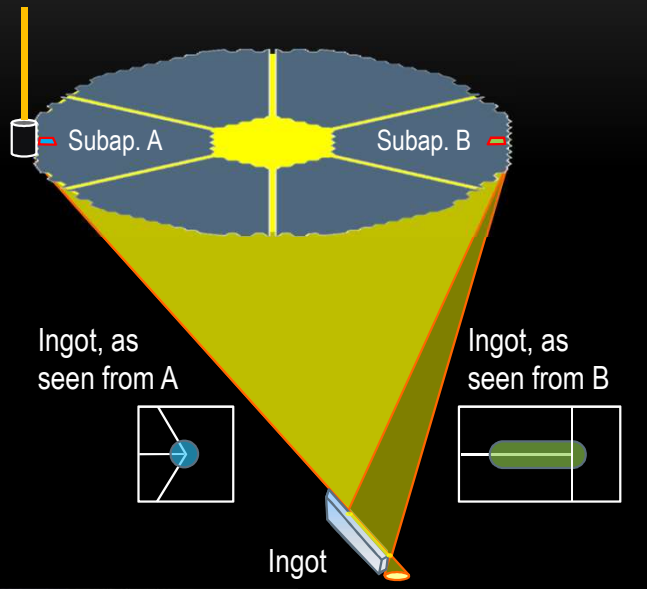


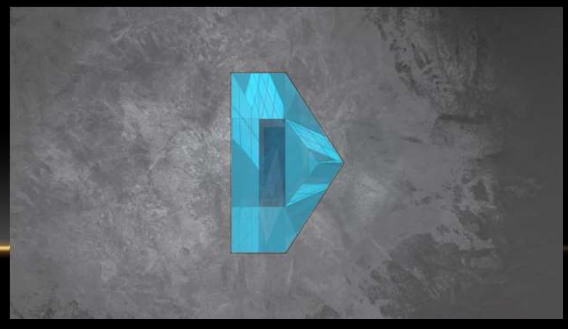
$\theta_A < \theta_C < \theta_B$

on a S-H WFS focal plane:



INGOT:

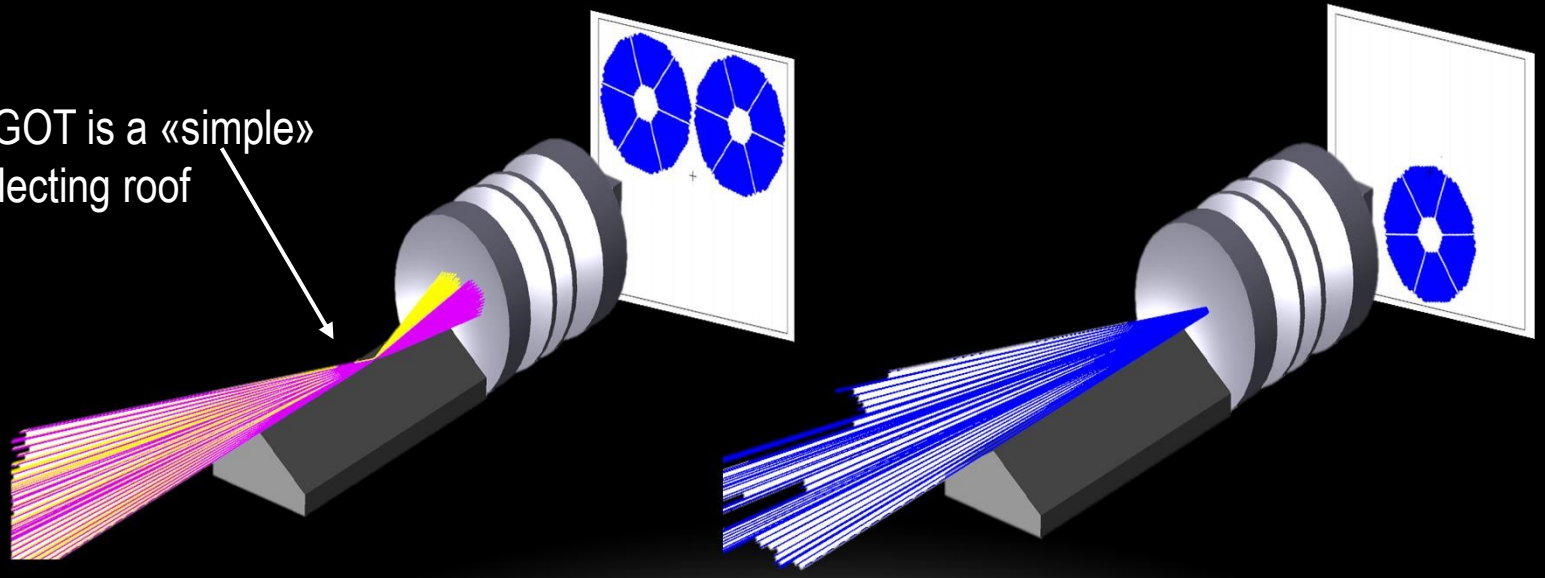




INGOT-3 OPTICAL DESIGN

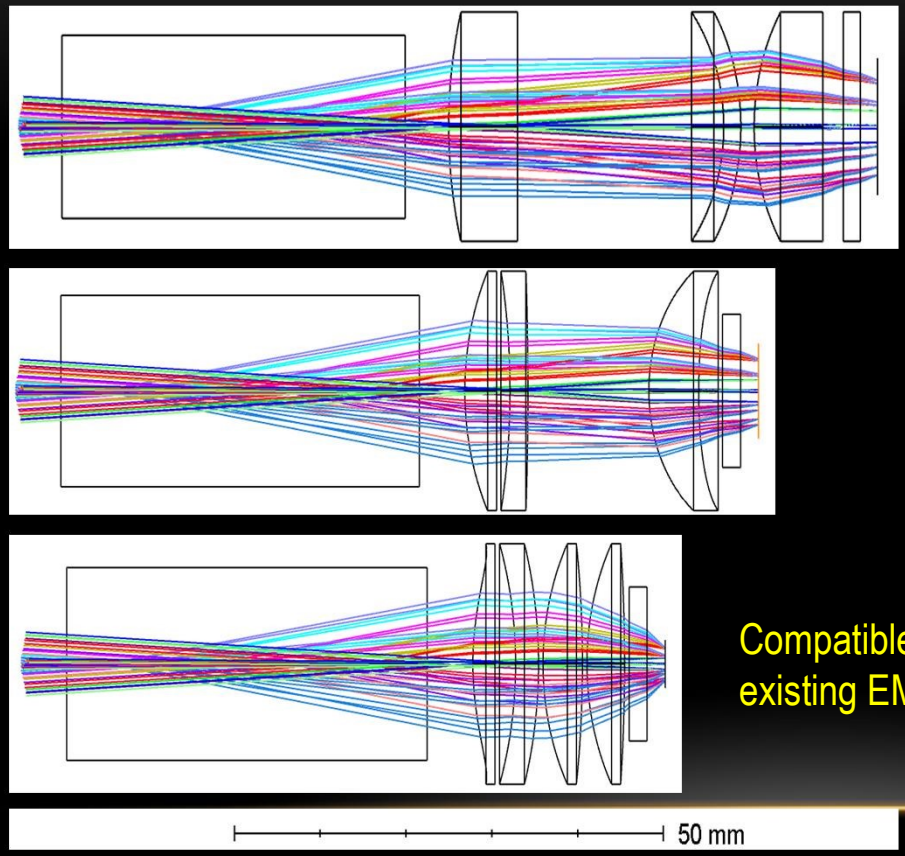
Pupil C is transmitted
w/o intersecting the prism

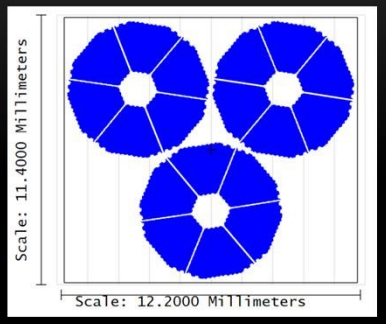
INGOT is a «simple»
reflecting roof



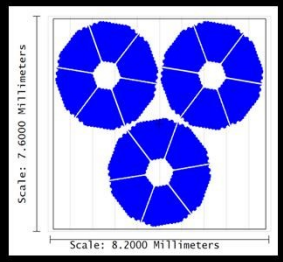
INGOT-3 OPTICAL DESIGN

10km sodium thickness



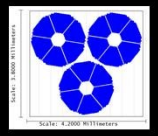


3px/sub-ap.



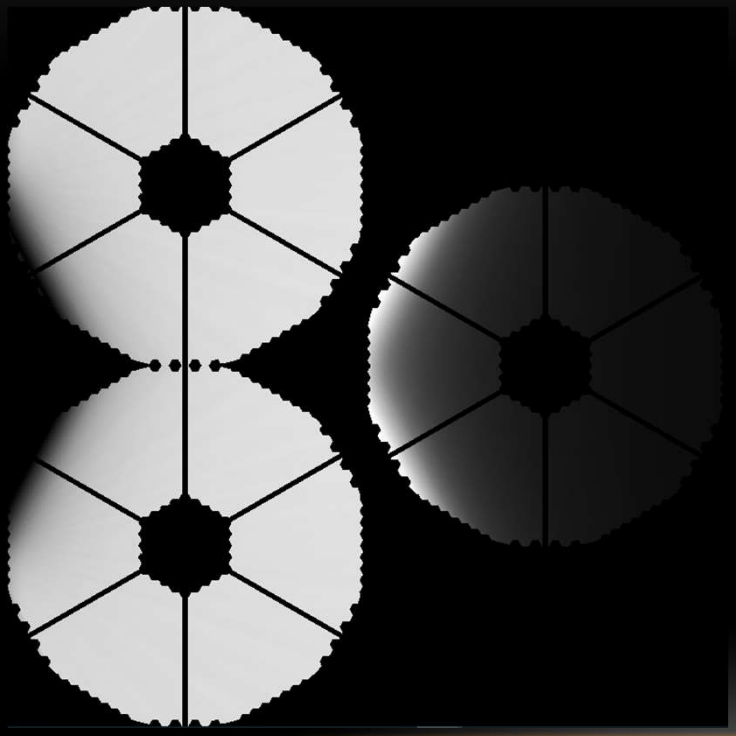
2px/sub-ap.

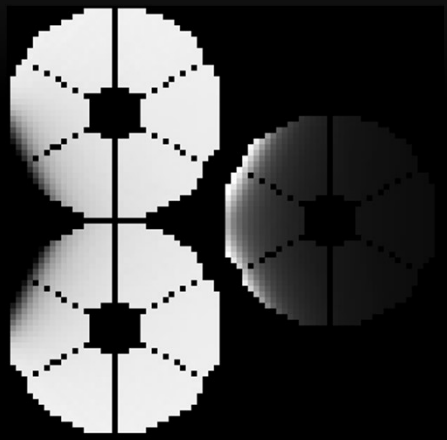
Compatible with currently existing EMCCD (240x240 px)

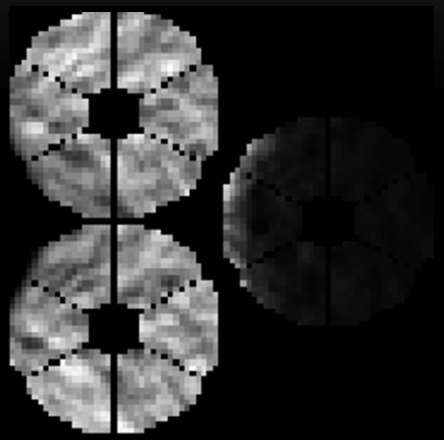


1px/sub-ap.
156x166px

INGOT PUPILS AND SIGNALS:



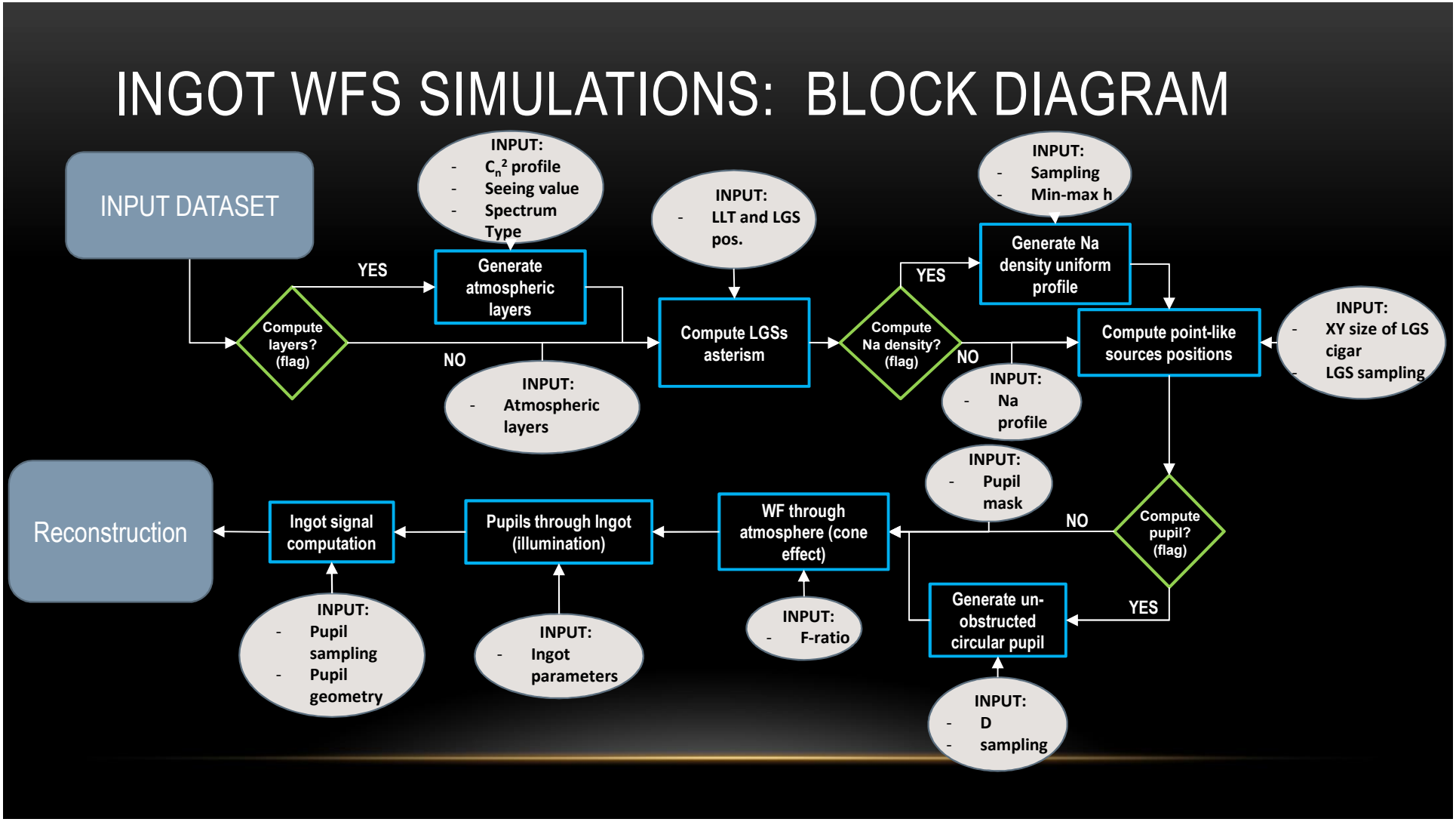




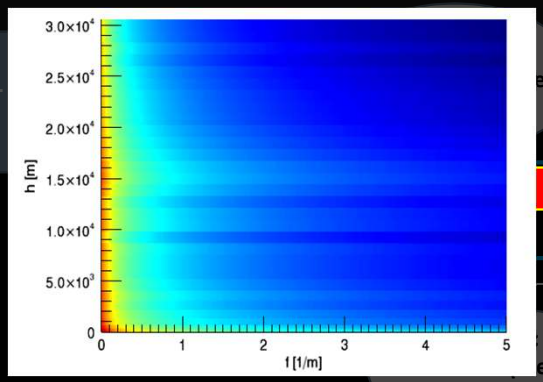
$$S_X = \frac{C}{< A+B >_{\sim seconds}} \cdot \eta \qquad \eta = \frac{< A+B >_{\sim hour}}{< C >_{\sim hour}}$$

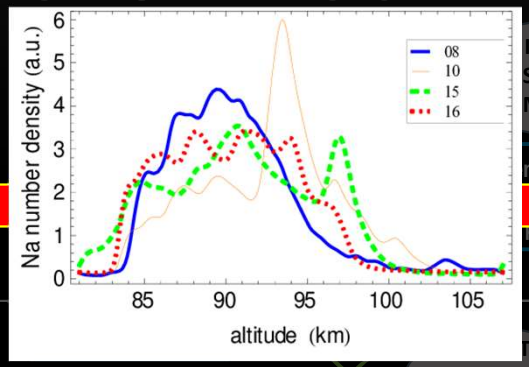
$$S_Y = \frac{A-B}{< A+B >_{\sim seconds}}$$

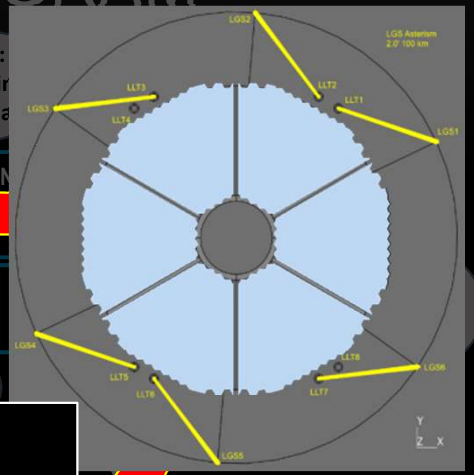
INGOT WFS SIMULATIONS: BLOCK DIAGRAM

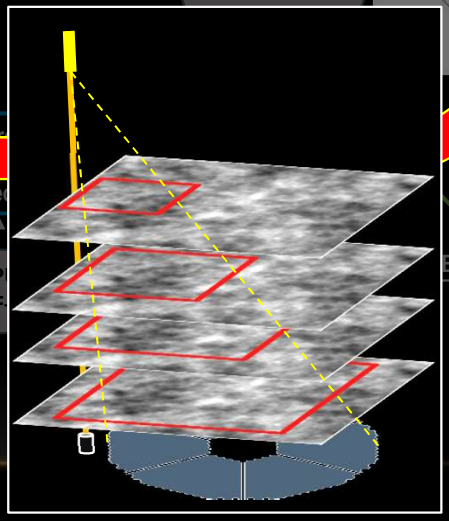


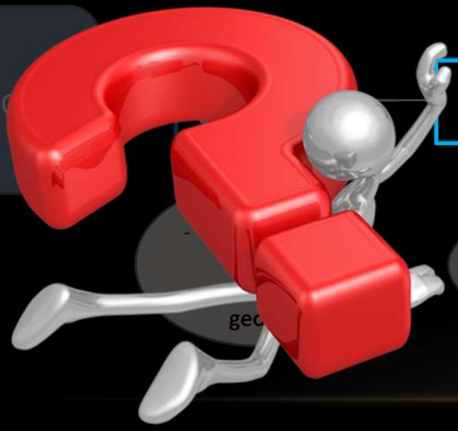
INGOT WFS SIMULATIONS: BLOCK DIAGRAM











Pupils through Ingot (illumination)

INPUT:
- Ingot parameters

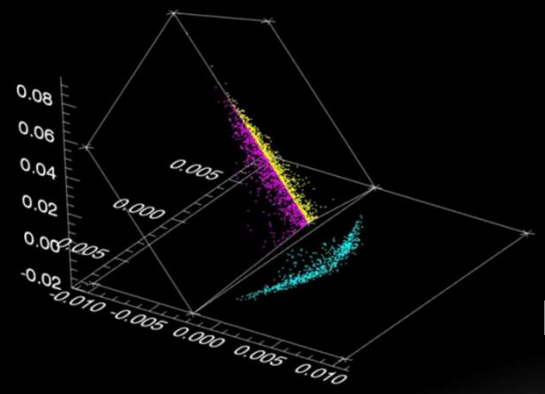
INPUT:
- Na

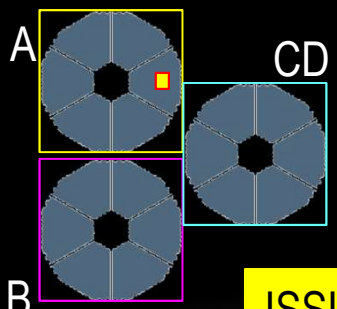
layers

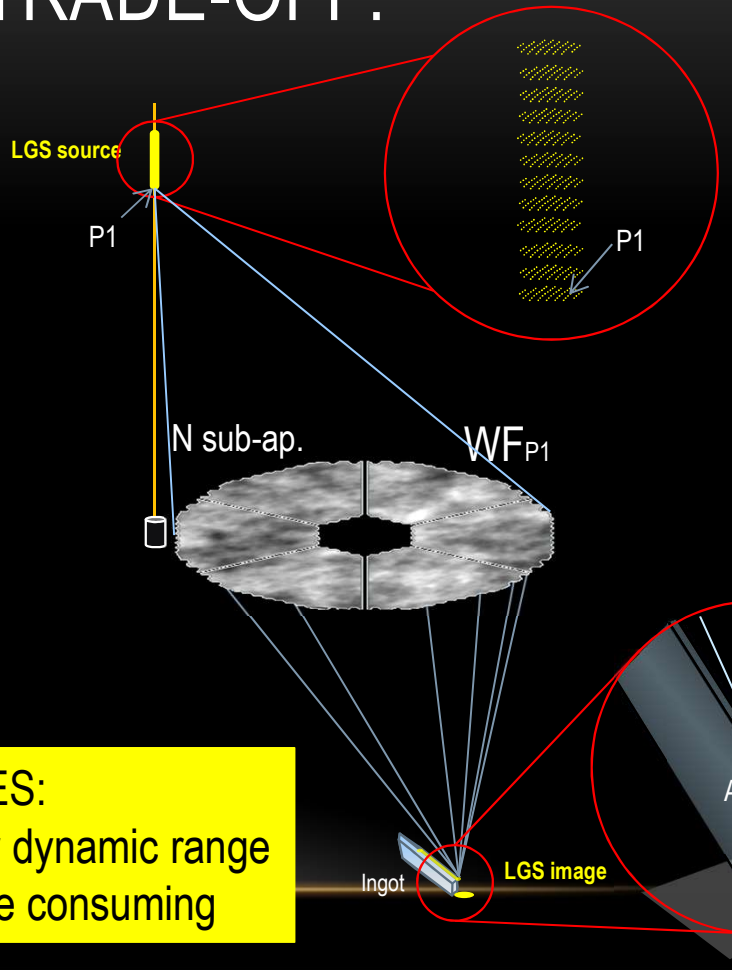
LGS IMAGE APPROACH TRADE-OFF:

Approach 1: pure ray-tracing

- LGS sampled (P points)
- P different WFs enter the pupil
- NxP rays traced to the Ingot
- NxP total counts onto the 3 pupils







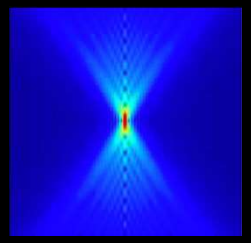
ISSUES:

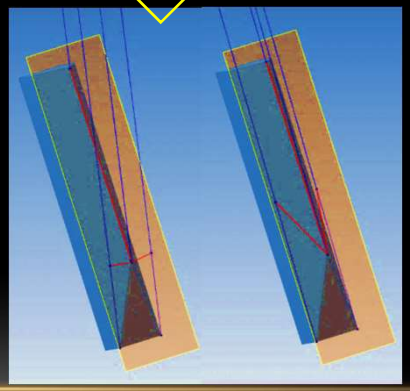
- Low dynamic range
- Time consuming

LGS IMAGE APPROACH TRADE-OFF:

Approach 2: Fourier Transforms + P-WFS-like masking

- P Fourier Transf. to get Electr. Field
- PSF stretched to Sch. plane
- 3 Ingot masks
- 3xP FT to get back to pupil images





ISSUES:

- PSF along Z
- ≠ mask ∀ sub-ap.

DIFFRACTION VS GEOMETRICAL OPTICS

Assumptions: D = 38.542 m
λ = 0.589 um

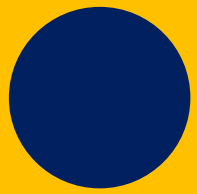
	LGS ∅	Diffr. FWHM	Linear ratio	Area ratio
INGOT	1.5”	0.003”	0.2%	4ppm
S-H	1.5”	0.24”	16%	2.5%

Compared with PHOTON NOISE CONTRIBUTION:

1) Flux = 200 ph/sub-ap/integr. time
   Photon noise = 7%
2) Flux = 1000 ph/sub-ap/integr. time
   Photon noise = 3%

Non-elongated LGS size
(due to upward laser propagation

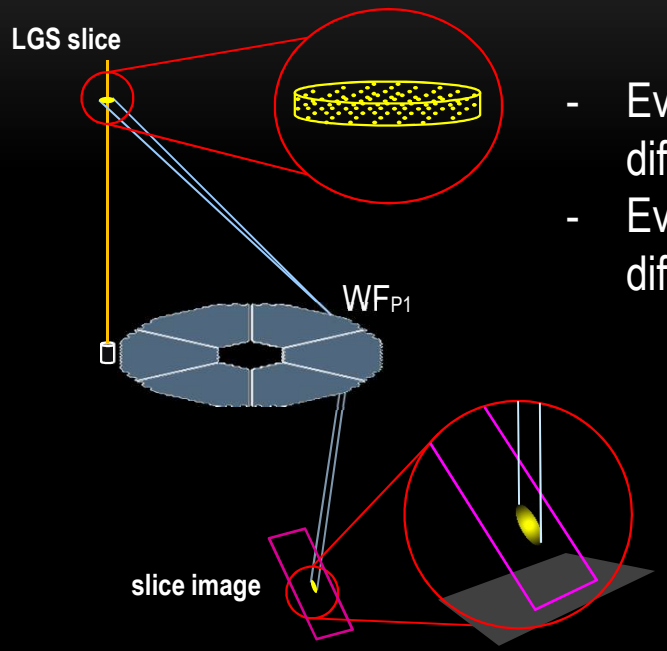
→ INGOT convolution PSF



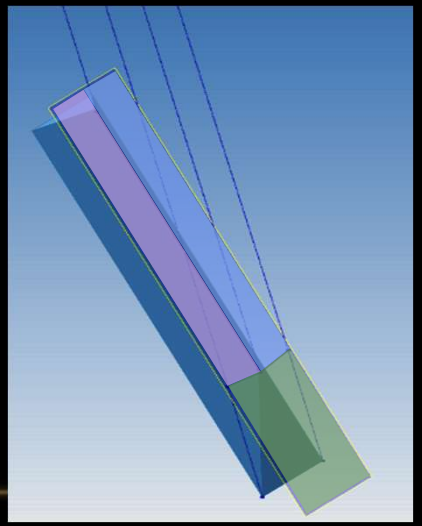
→ SH convolution PSF

2-STEPS SIMULATIONS APPROACH (CURRENT):

1) PRELIMINARY GEOMETRY
- Representative LGS-slice re-imaged onto Sch. plane with RAY-TRACING
- N LGS-slice images STORED
- N Ingot projections onto Sch. plane STORED



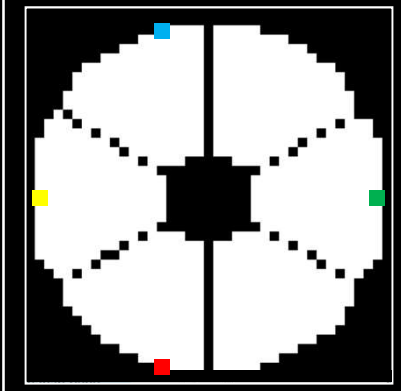
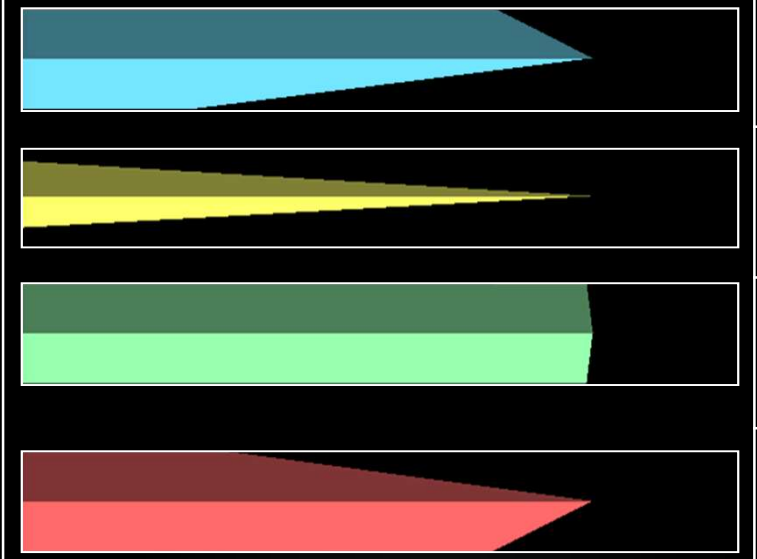
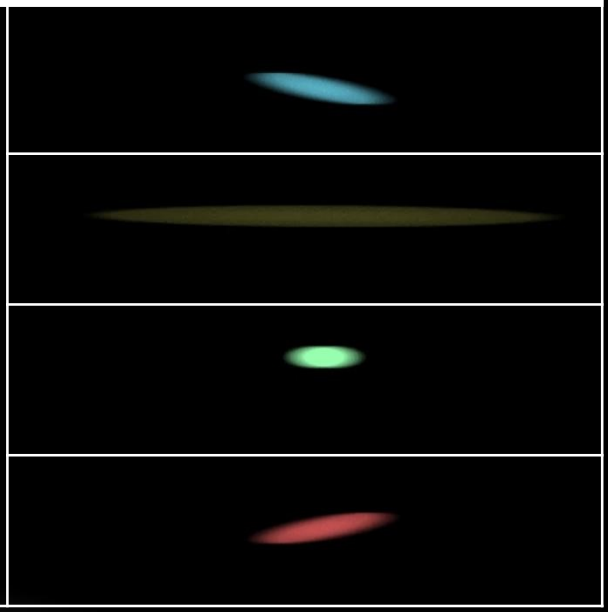
- Every sub-ap produces a different disk image
- Every sub-ap produces a different ingot mask



ARE THEY SO DIFFERENT?

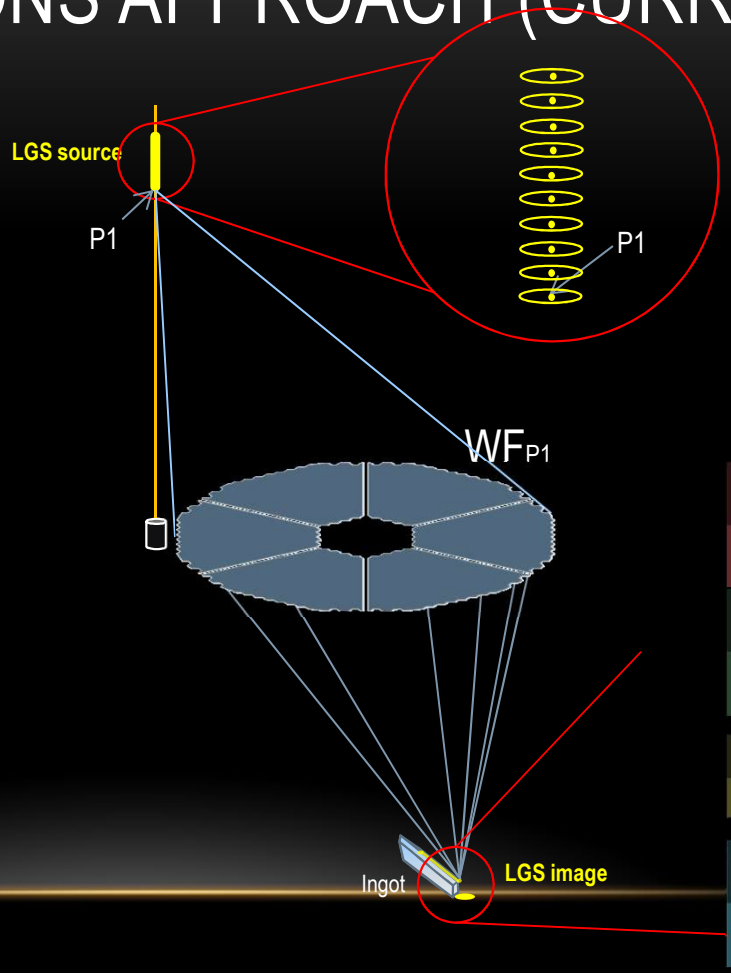
- N slice images
- N ingot masks

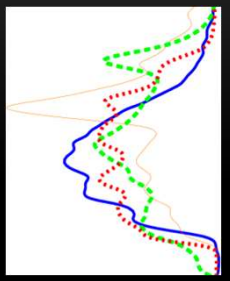
STORED DISK IMAGES AND INGOT MASKS

e.g. sub-apertures	MASKS (ingot projections):	Slice image on Sch. Plane:
		

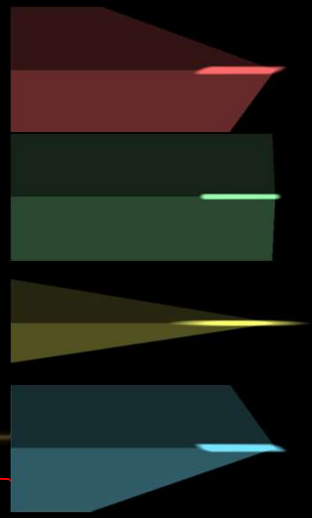
YES, they are…

2-STEPS SIMULATIONS APPROACH (CURRENT):





Full LGS w/o atm.

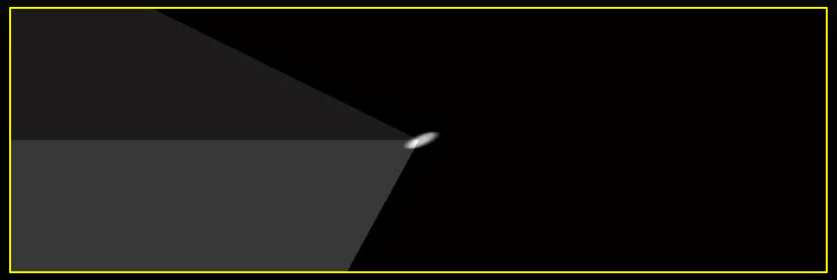


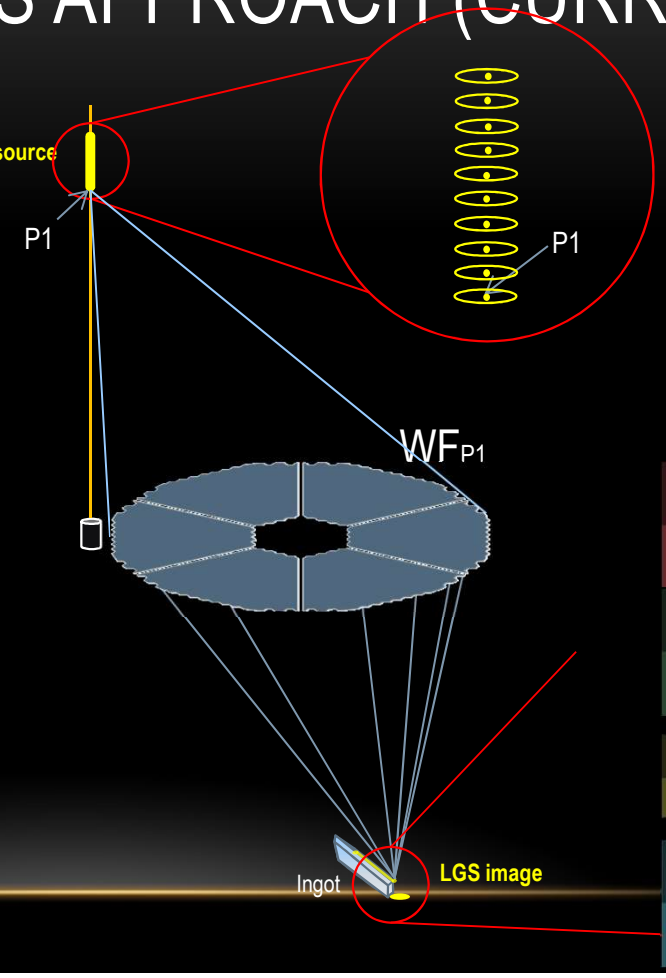
2) MAIN SIMULATION:

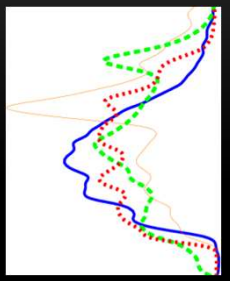
- LGS sampled in 1D (P'<<P points)
- P' different WFs enter the pupil
- NxP' rays traced to the Sch. plane
- Convolution with stored disk image
- Through stored Ingot masks

2-STEPS SIMULATIONS APPROACH (CURRENT):

P1 slice image with atm. (subap. 0 to 985):







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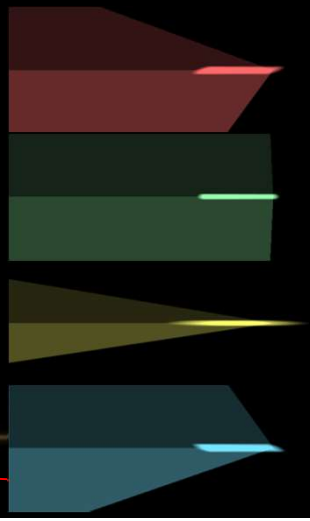

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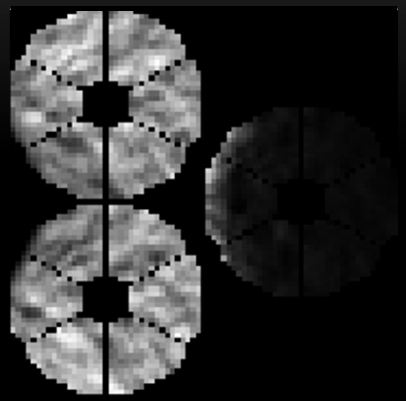
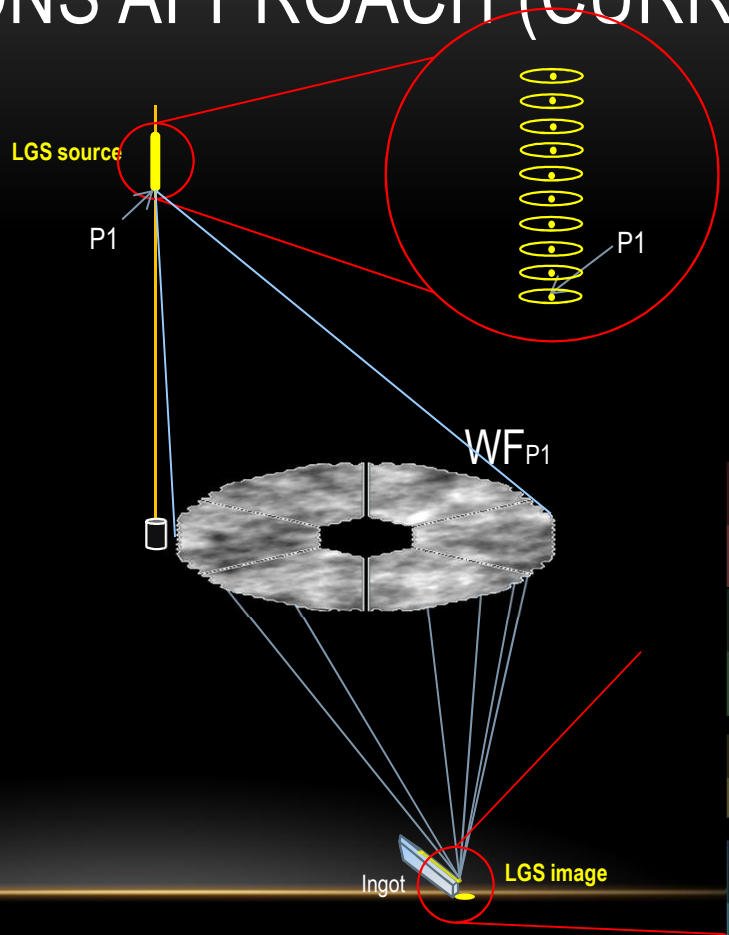
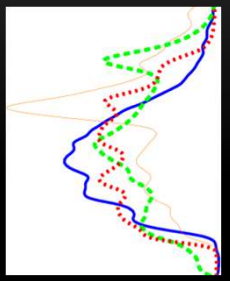
- LGS sampled in 1D (P'<<P points)
- P' different WFs enter the pupil
- NxP' rays traced to the Sch. plane
- Convolution with stored disk image
- Through stored Ingot masks

2-STEPS SIMULATIONS APPROACH (CURRENT):

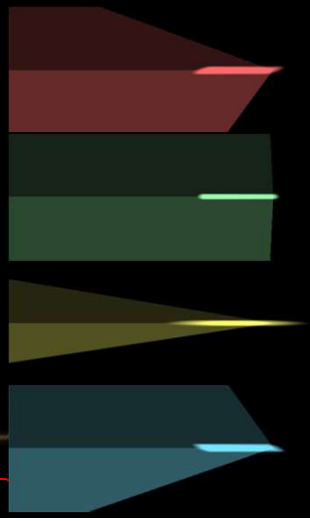
All integrated…
PUPILS!!!!!







Full LGS w/o atm.



2) MAIN SIMULATION:
- LGS sampled in 1D (P'<<P points)
- P' different WFs enter the pupil
- NxP' rays traced to the Sch. plane
- Convolution with stored disk image
- Through stored Ingot masks

FIRST RECONSTRUCTORS

Zernike high-order (100 modes…) reconstr. tested with **pure ray tracing** approach…

Open loop

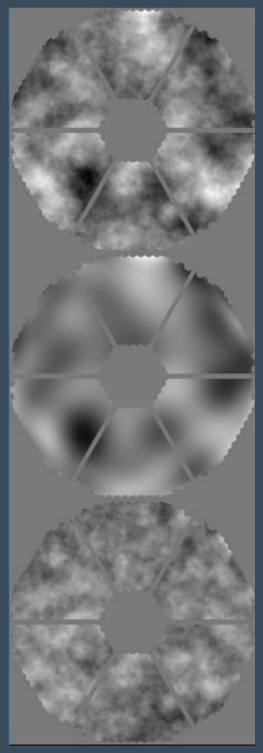
Full turbulence:

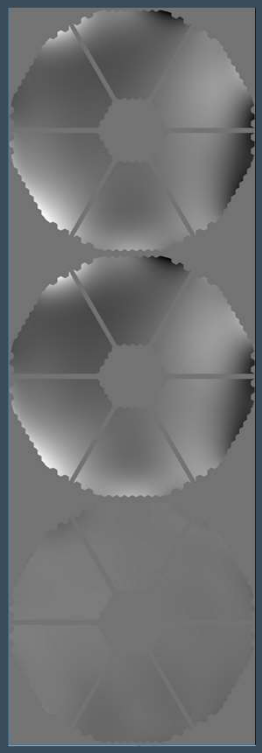
100 modes:

Input WF

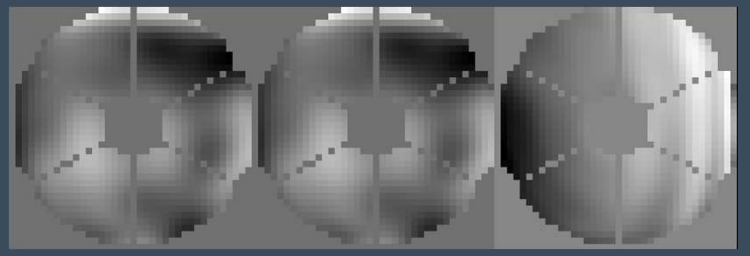
Reconstr. WF

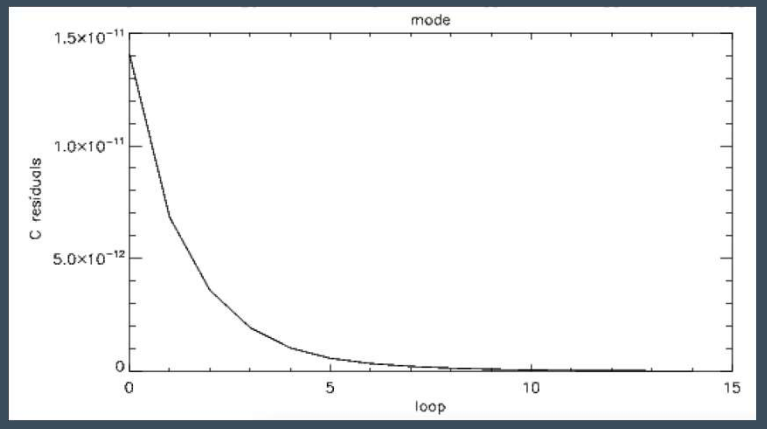
Residuals



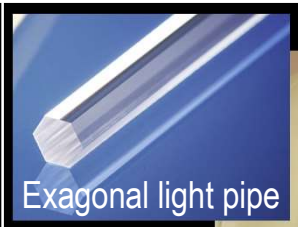
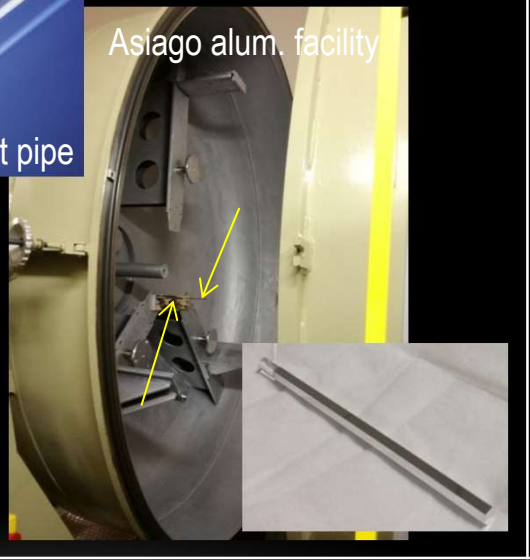


100 modes: Closed loop





LABORATORY ACTIVITIES:

Source	Telescope	Ingot	WFS
	 2’ ∅ lens F/8.6 f = 430 mm	 	«Ingot» + 6-axis stages  50 mm objective + Prosilica GT3300

LABORATORY ACTIVITIES:

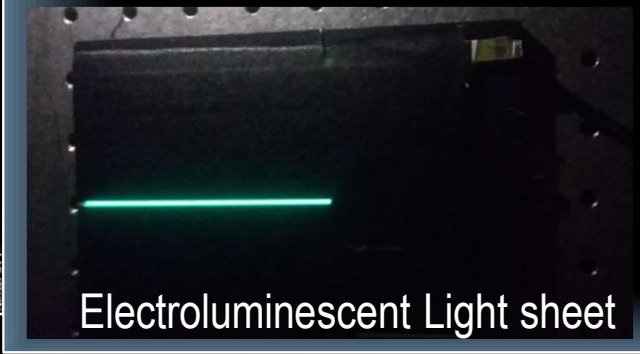
Source

LGS-like source beauty contest 2018

Laptop

Hg lamp

Bare fiber



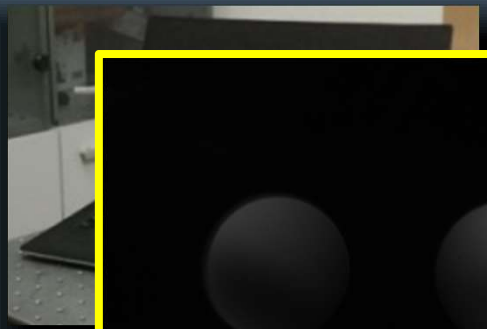
Electroluminescent Light sheet

Special guest

LABORATORY ACTIVITIES:

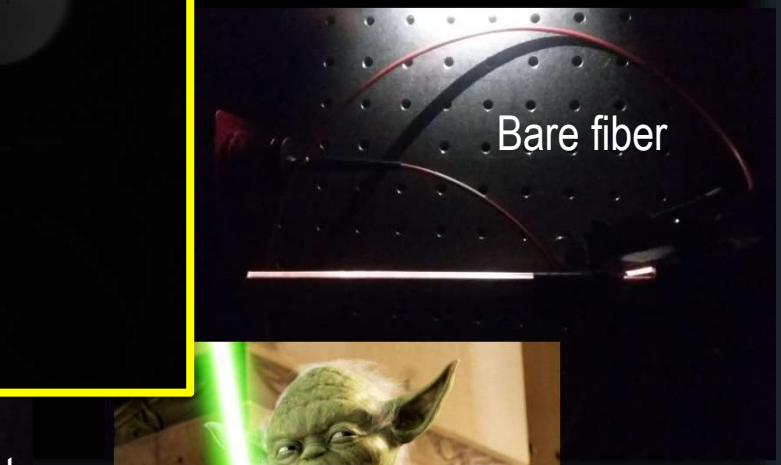
Source

LGS-like source beauty contest 2018



Lapto

Electroluminescent Light sheet



Bare fiber

Special guest

NEXT STEPS

SIMULATIONS:

- Debug/complete the E2E simulator:
  - through ingot → parametric
  - build new reconstructor, open/closed loop
- Run with realistic parameters (to get sensitivities)

PROTOTYPE:

- Complete setup
- Test with induced known aberrations
- Sensitivity to different simulated Na profiles

PROCUREMENT:

- Ask feasibility from companies

Wednesday 14.30:
Roberto Ragazzoni
*«***Pupil plane wavefront sensing with 3D perturbators***»*