LGS spot truncation mitigation in ELTs: optimizing the pixel usage

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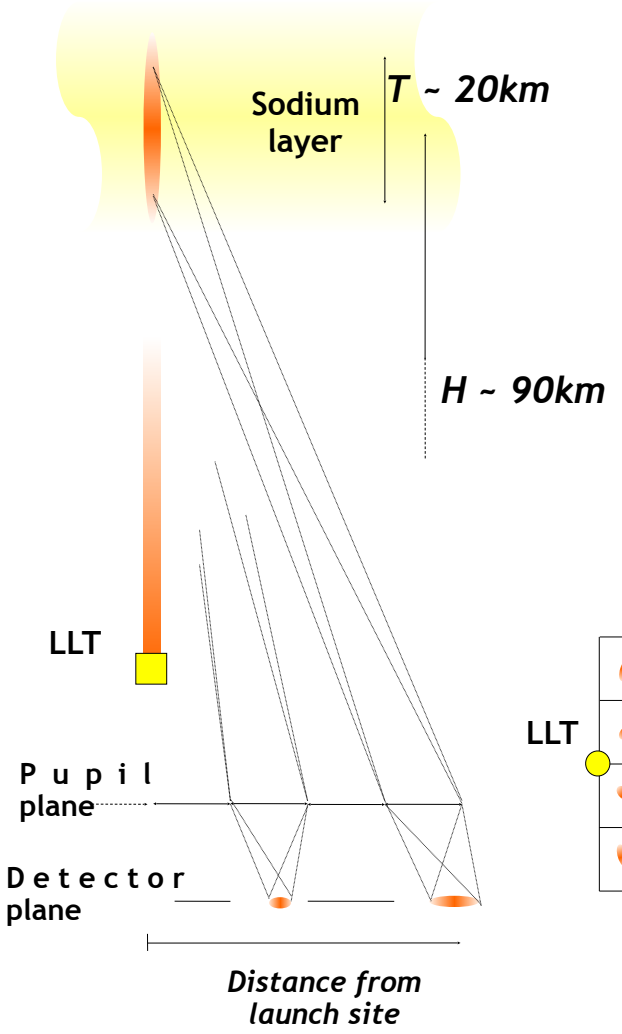
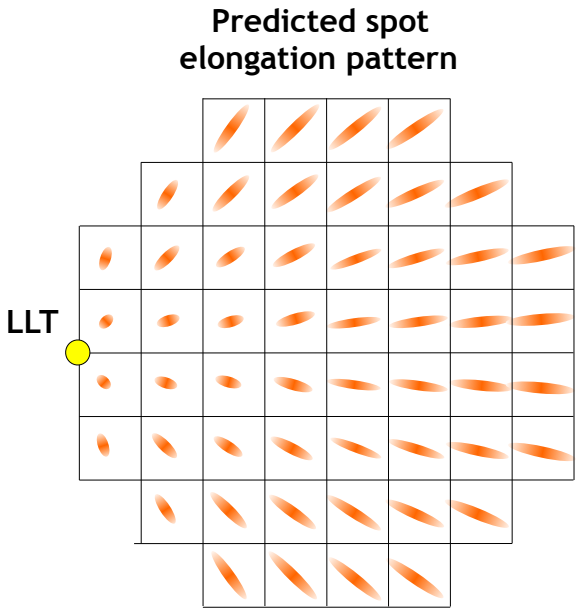
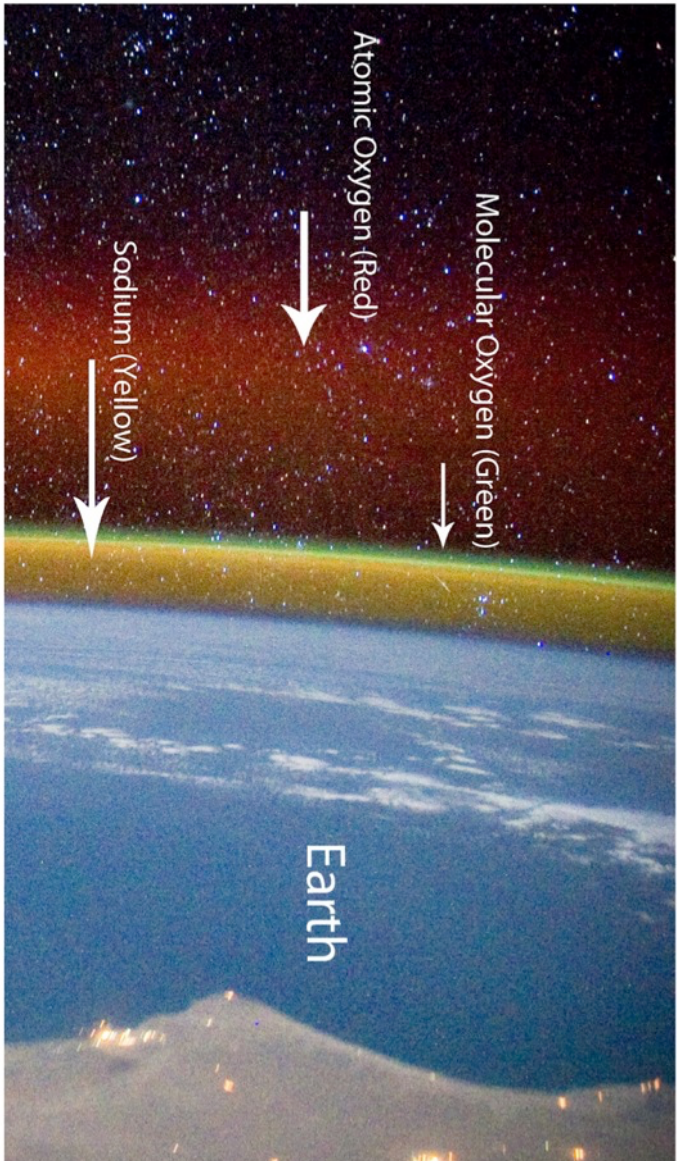
2 ONERA - The French Aerospace Lab

LGS Spot elongation

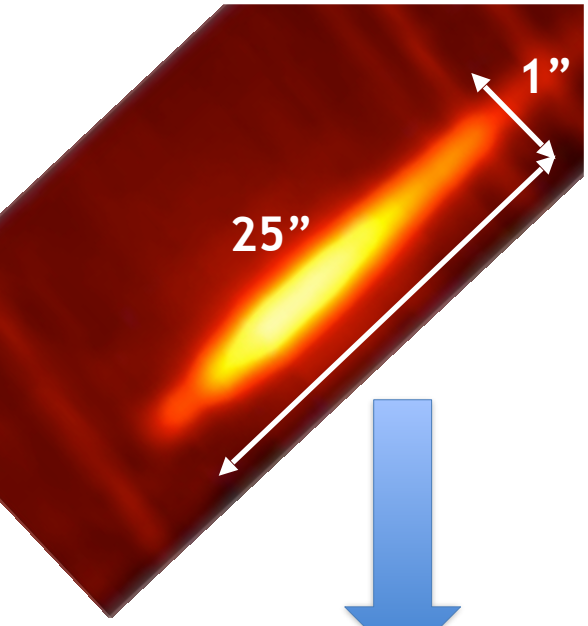






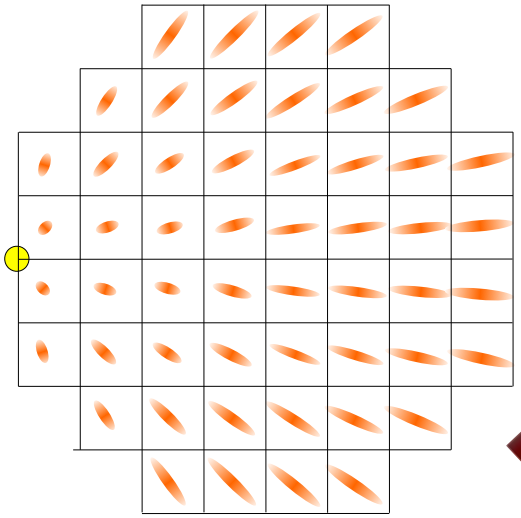
LGS Spot elongation

On a ~40m telescope

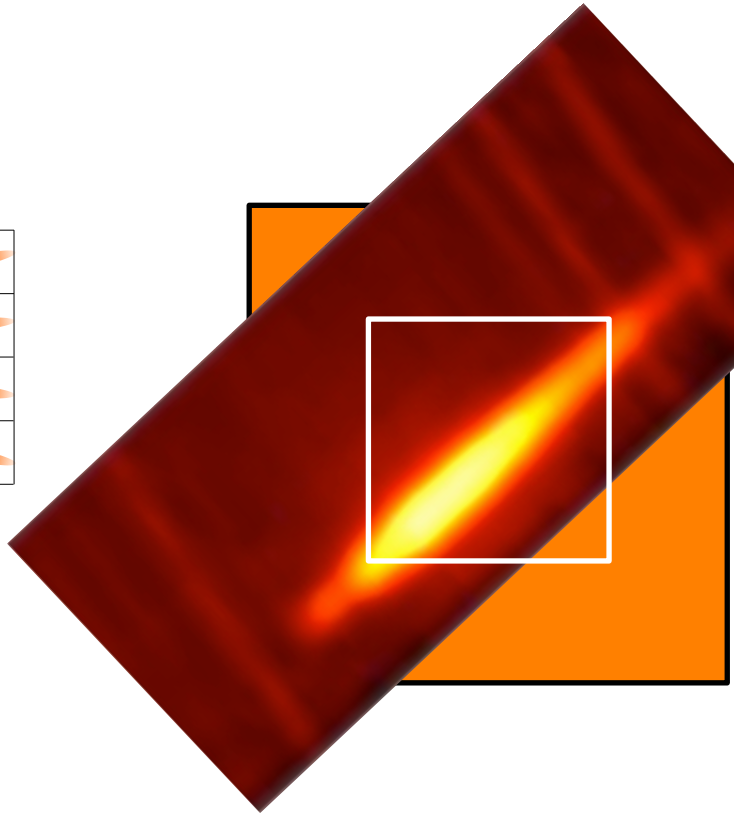


Ideally, we need subapertures with 25x25 pixels of ~1”

For 80x80 subapertures, we need 2000 x 2000 pixels

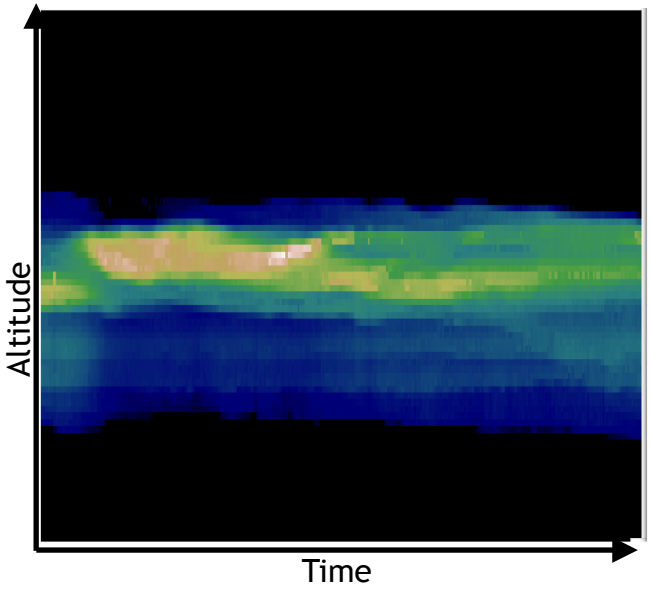


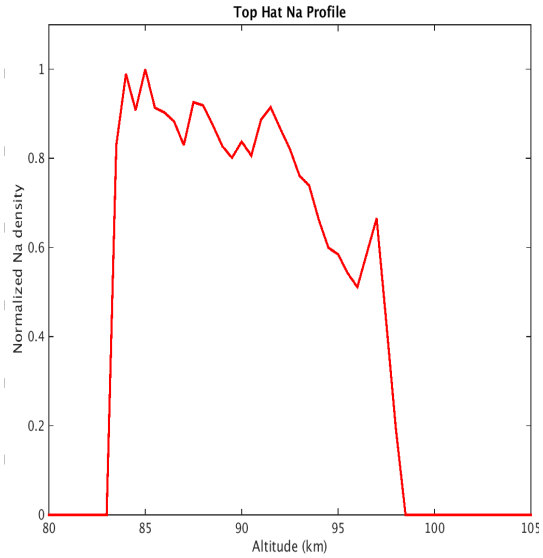
Most likely, we will have no more than 10x10 pixels



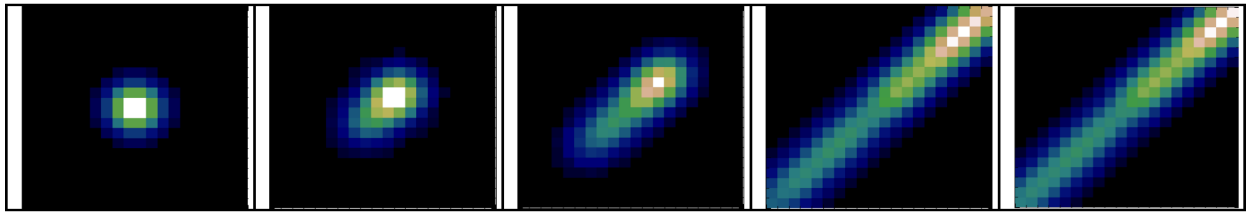
Strong truncation

Impact of truncation on a single WFS





- *À la* Diolaiti/Schreiber, we simulate elongated spots (normalized by the Na profile intensity)
- Compute the centroid of each sub-aperture, and project the resulting wave-front on Zernikes
- No elongation: no aberration
- No truncation: Tip/Tilt/Focus only



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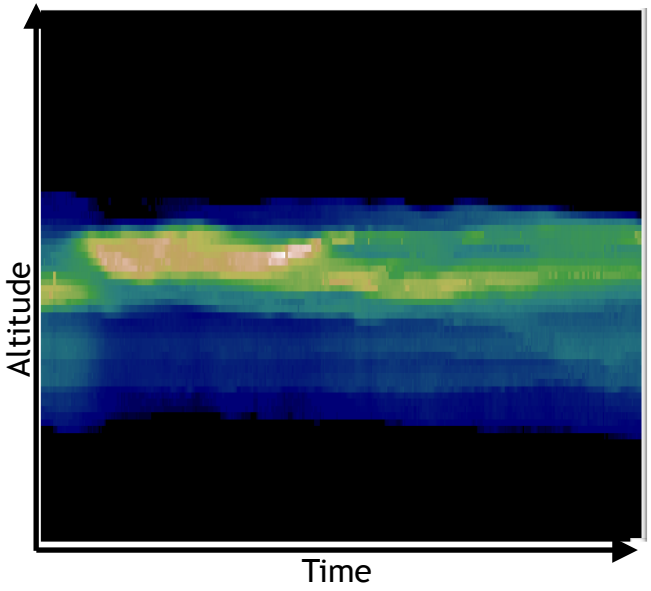
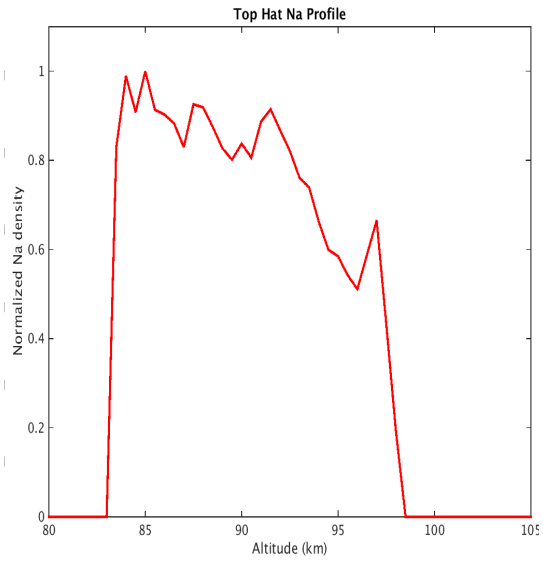
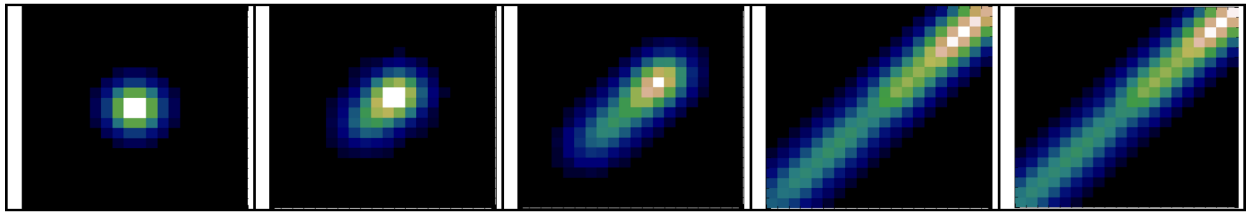
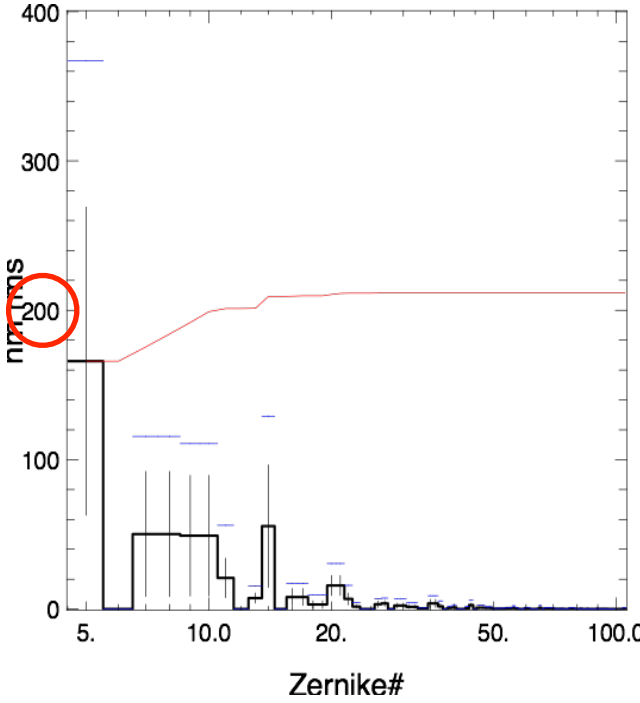




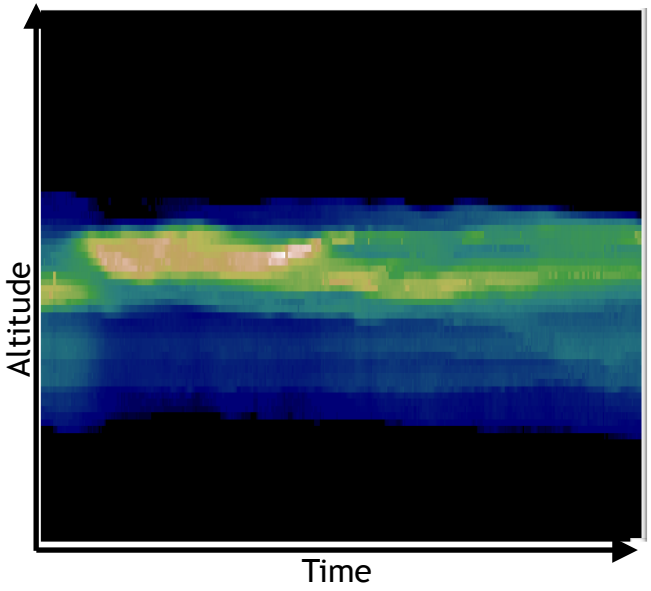


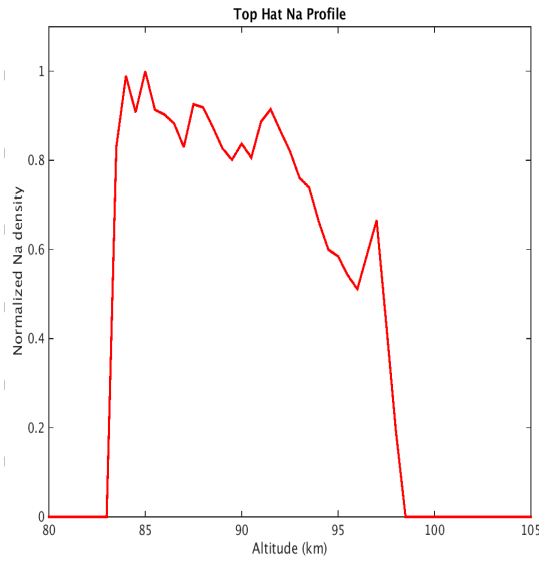
- Select 11 Na profiles showing a large variety of configurations
- For each profile, and each time, compute the residual aberrations (for a single WFS)



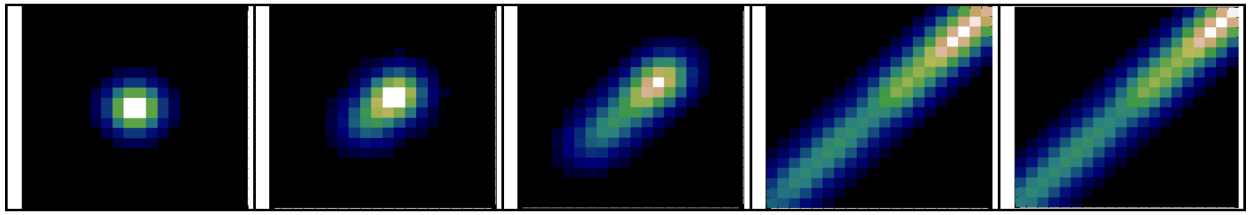
(blue = peak; error bar = rms ; histogram = avg ; red = cumulative of avg)

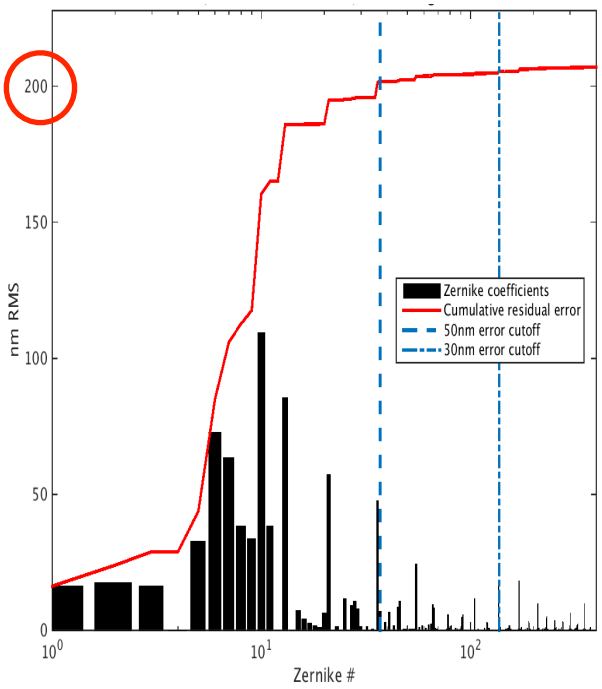
Impact of truncation on LTAO





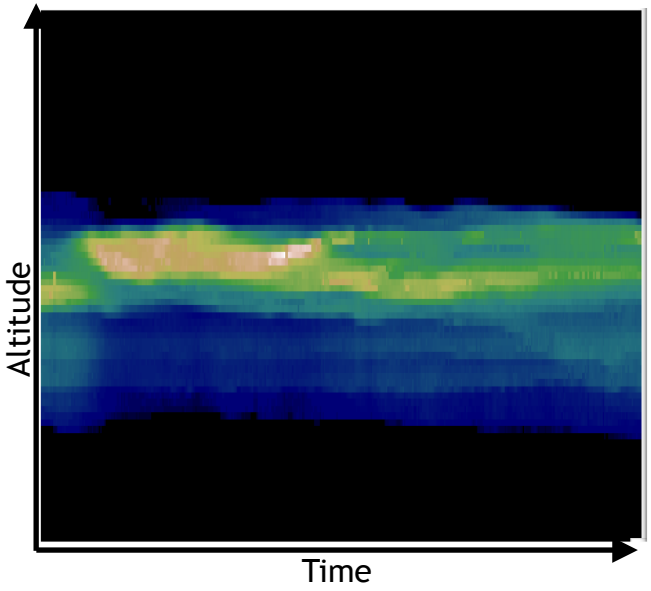
- 6 LGS
- No turbulence
- MMSE reconstructor
- 42'' radius asterism

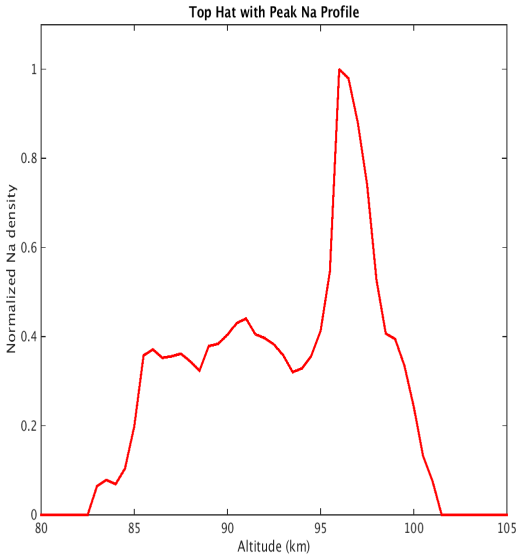




(histogram = avg ; red = cumulative of avg ; blue = 30nm and 50nm cutoff)

Impact of truncation on LTAO





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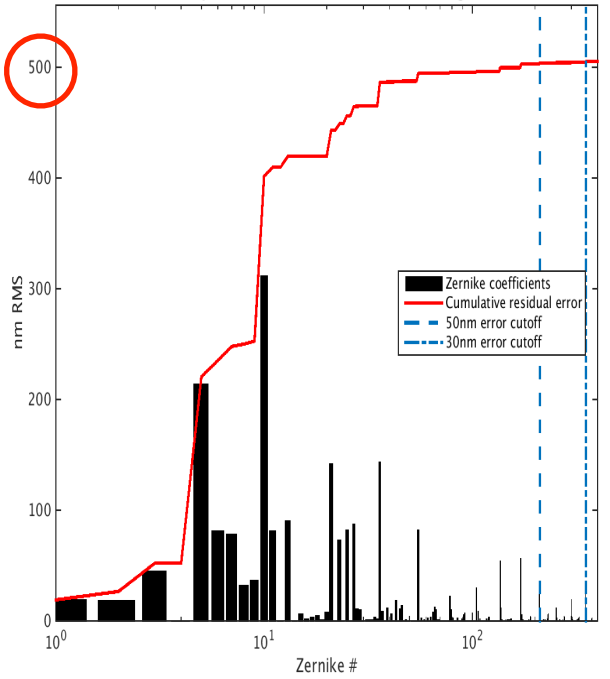

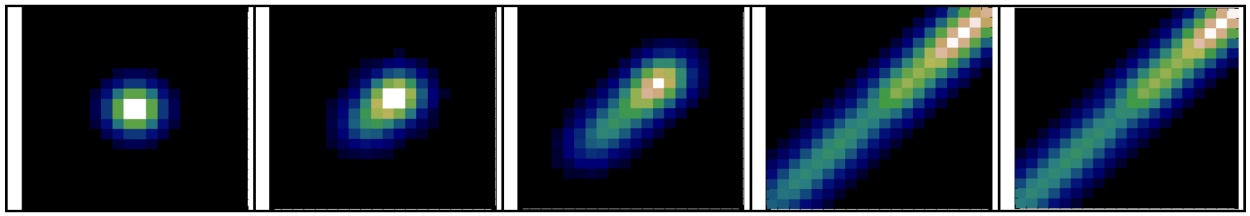

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Need for a Truth Sensor but aberrations are mostly low order => 10x10 subapertures on a truth sensor should be enough on average but on very perturbed profiles…

(more on tomographic errors in T. Fusco's talk this afternoon)

Elongated spots cropping

What if we completely discarded the biased measurements from the subapertures with the most truncated spots ?

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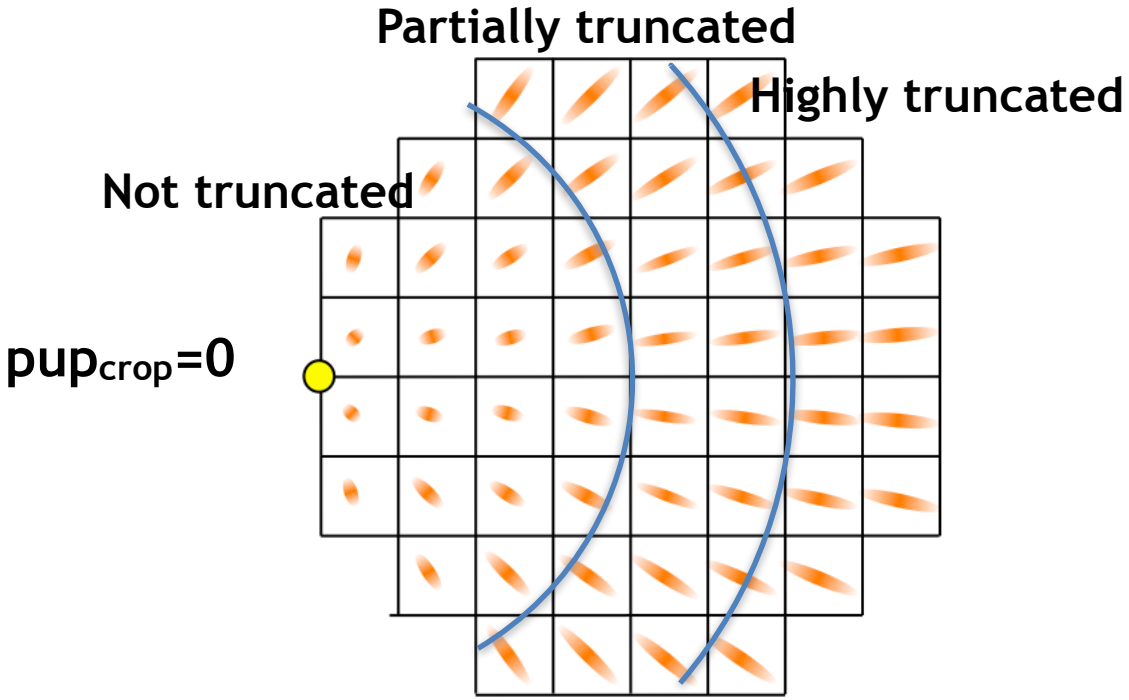
Spot elongation $\propto$ distance from laser launch telescope D_{LLT}

->we 'crop' the subapertures at $D_{LLT} > D \times (1\text{-}pup_{crop})$



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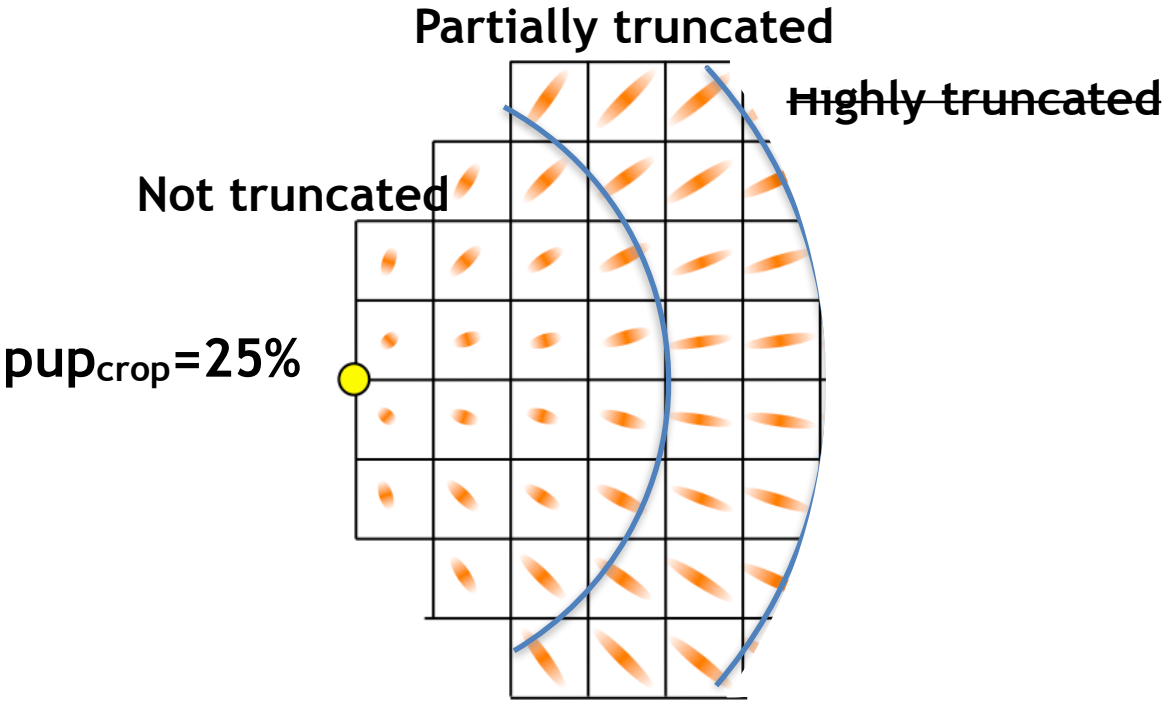

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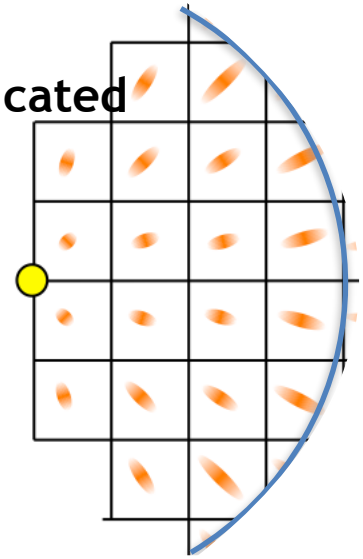
->we 'crop' the subapertures at D_{LLT} > D x (1-pup_{crop})

~~Partially truncated~~

~~Highly truncated~~

Not truncated

pup_{crop}=50%



Killer for 1 WFS…

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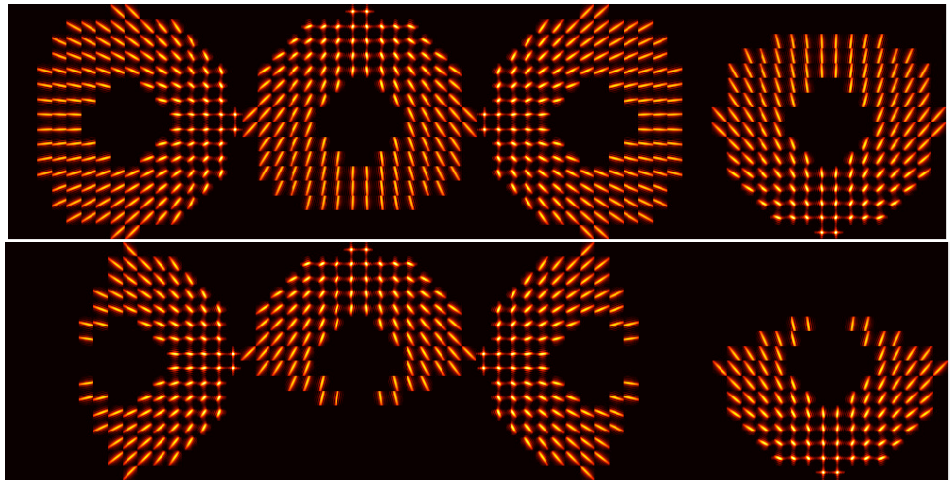
But we have redundancy

pup_{crop}=10%

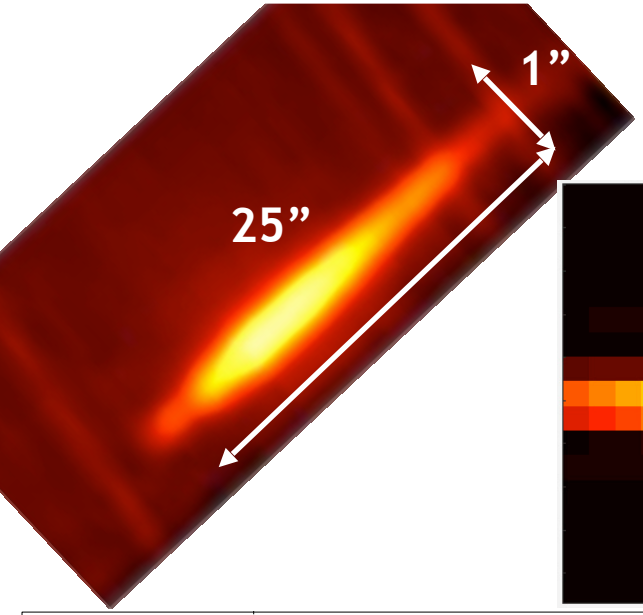
pup_{crop}=30%

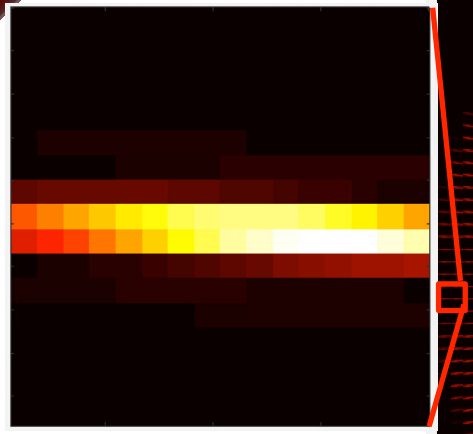


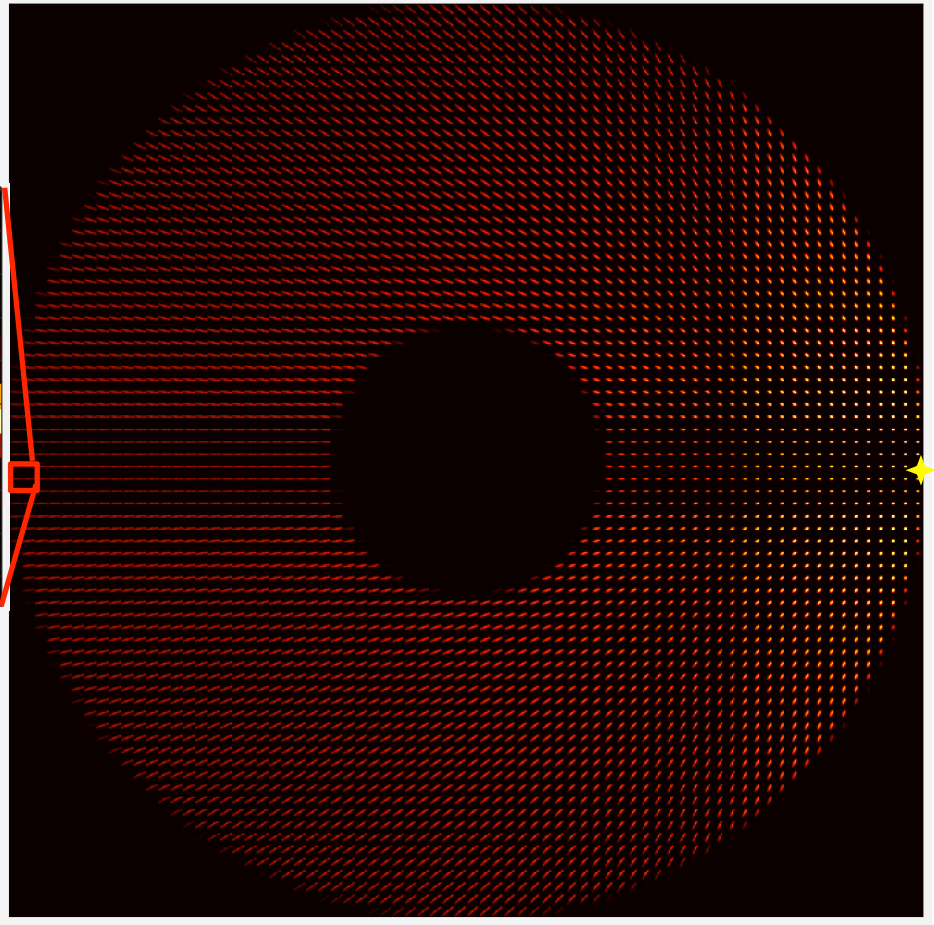
WFS_1 WFS_2 WFS_3 WFS_4

E2E simulations (OOMAO)

On a ~40m telescope

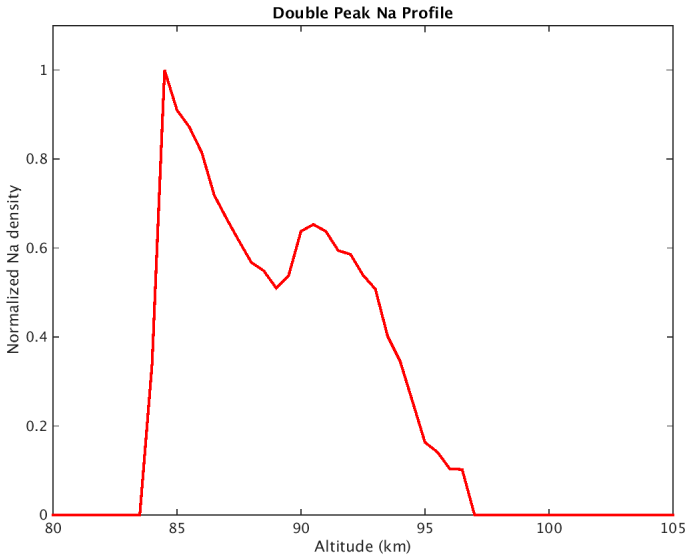


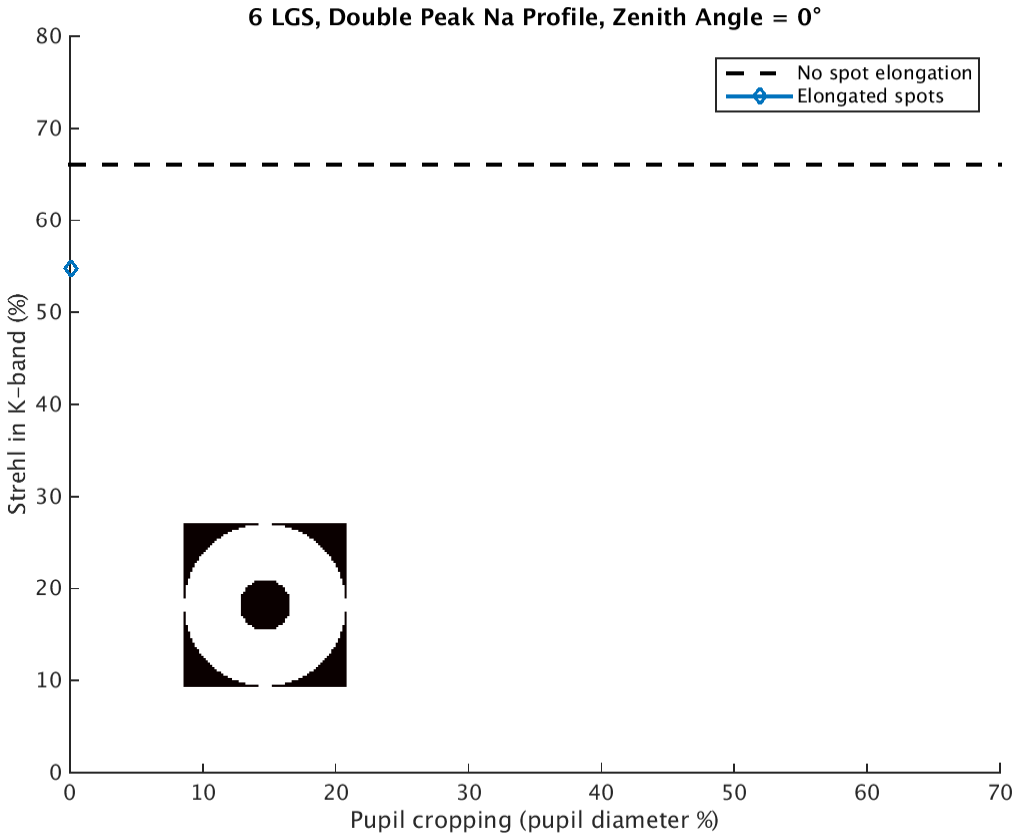




Full E-ELT simulation:
Pupil diameter : 37m
74x74 SH LGS WFS
75x75 actuator DM (Fried geometry)
Subaperture pitch : 50cm
Subaperture FOV : 10” (1” pixels)
6 LGS-Asterism diameter : 42”
30% central obscuration
(Y. Ono poster P3059, Thursday)

Elongated spots cropping





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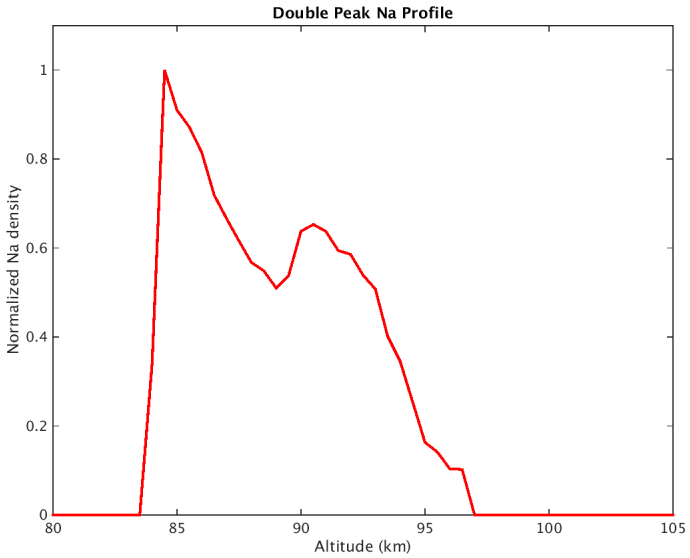

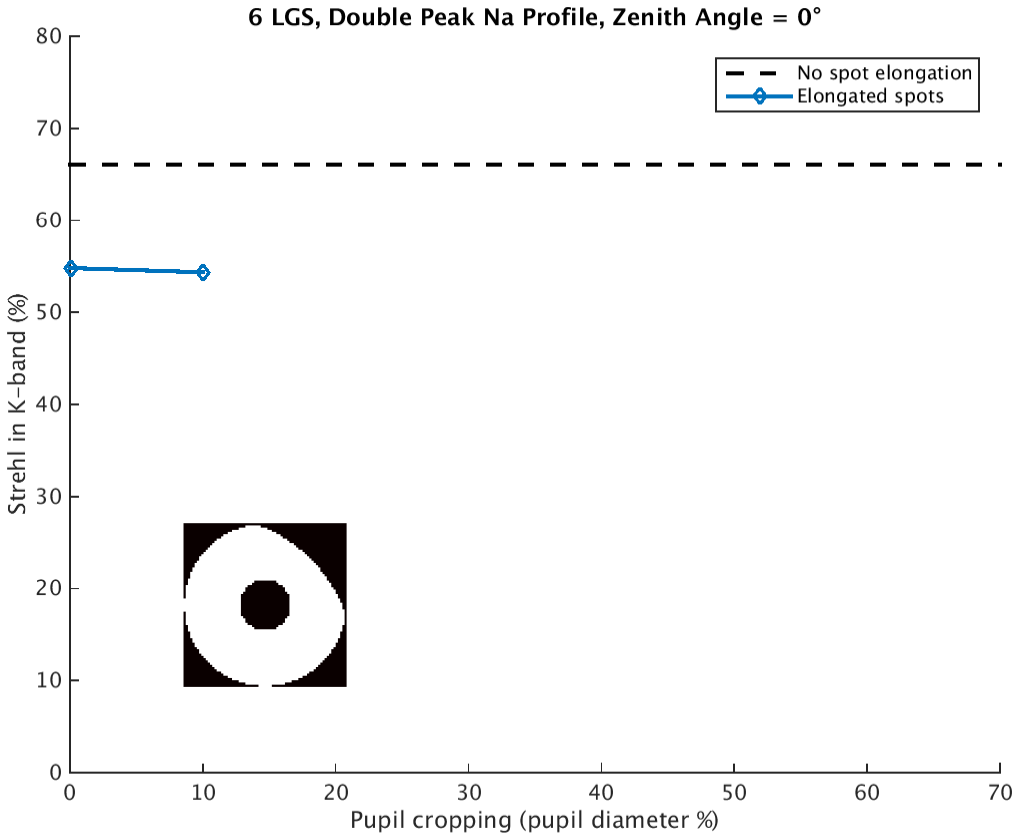

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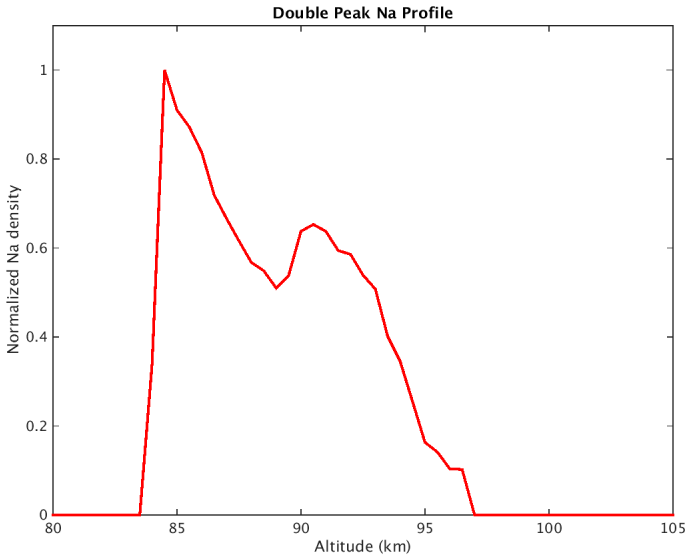

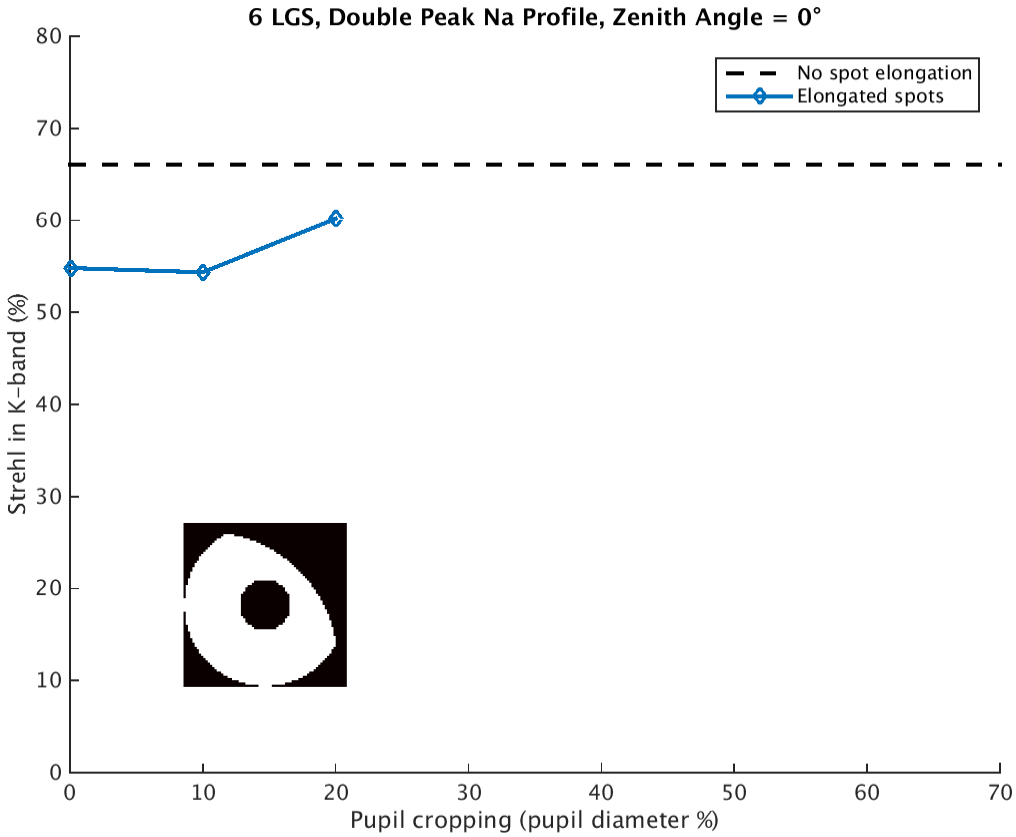

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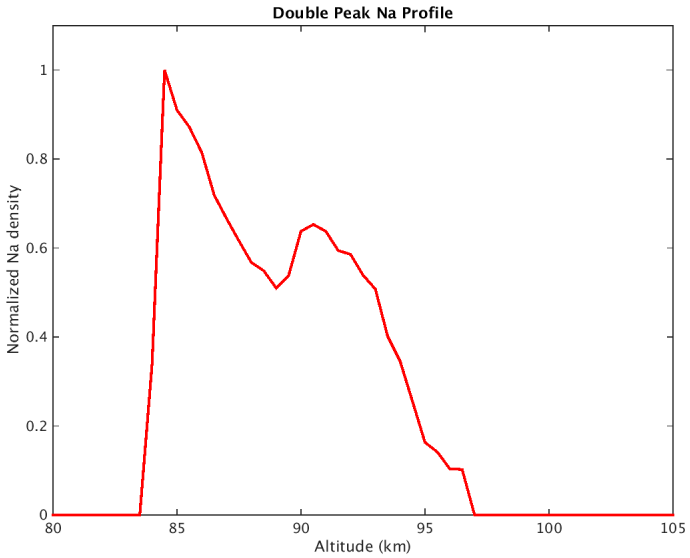

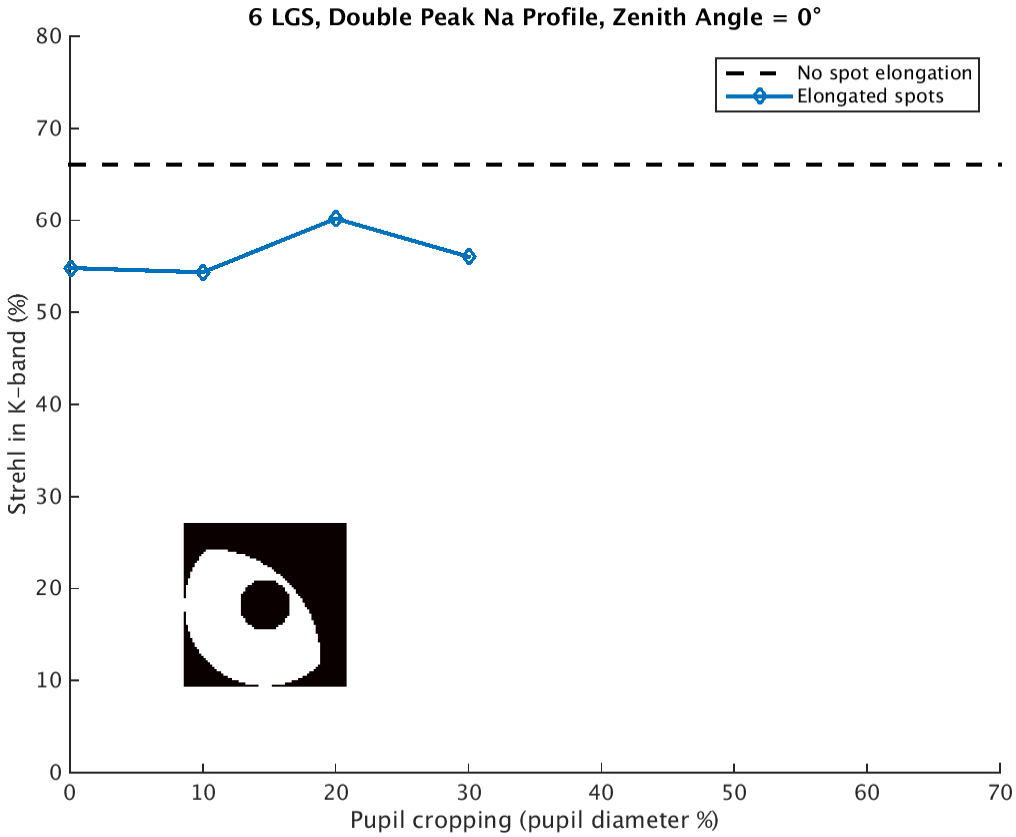

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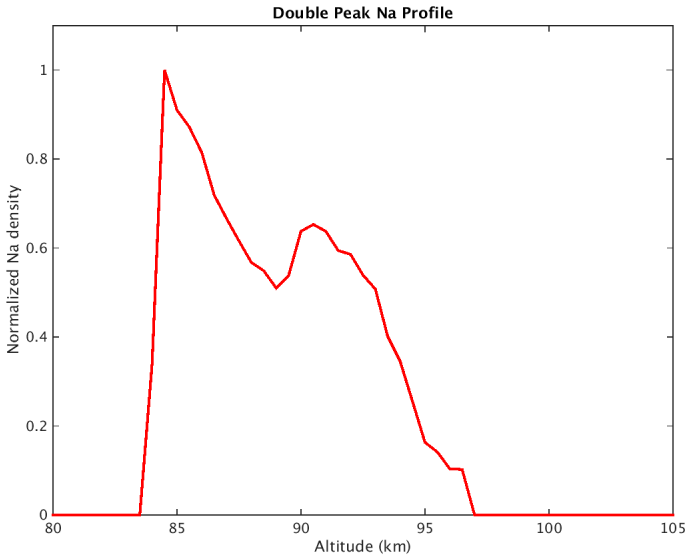

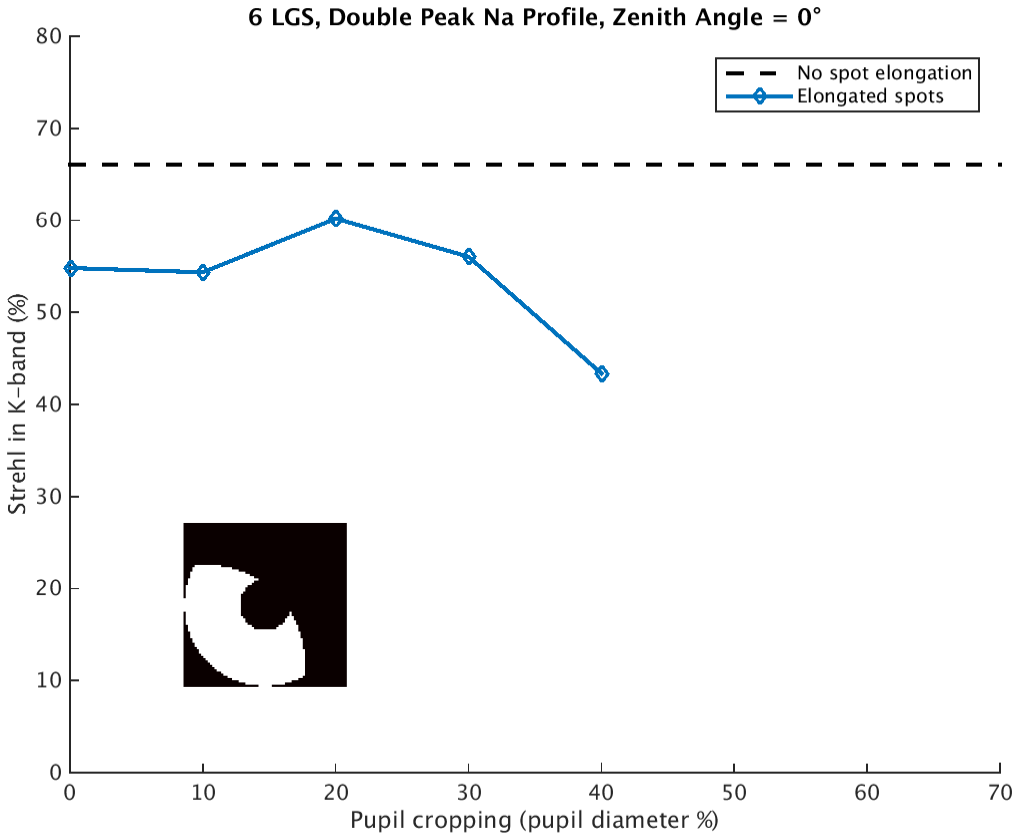

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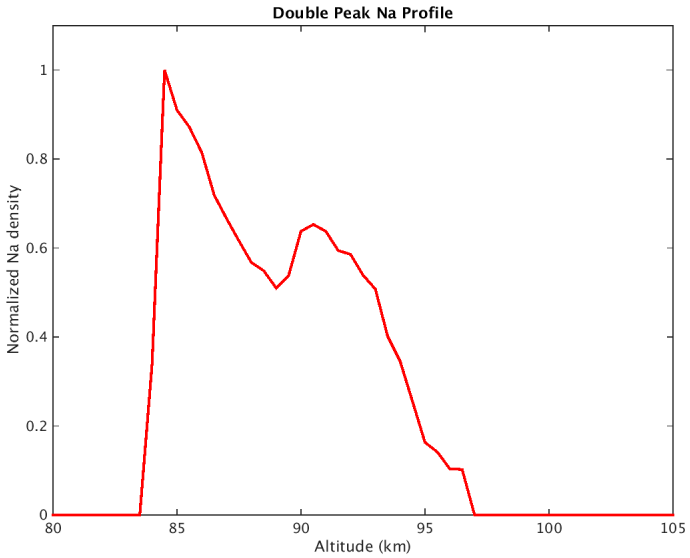

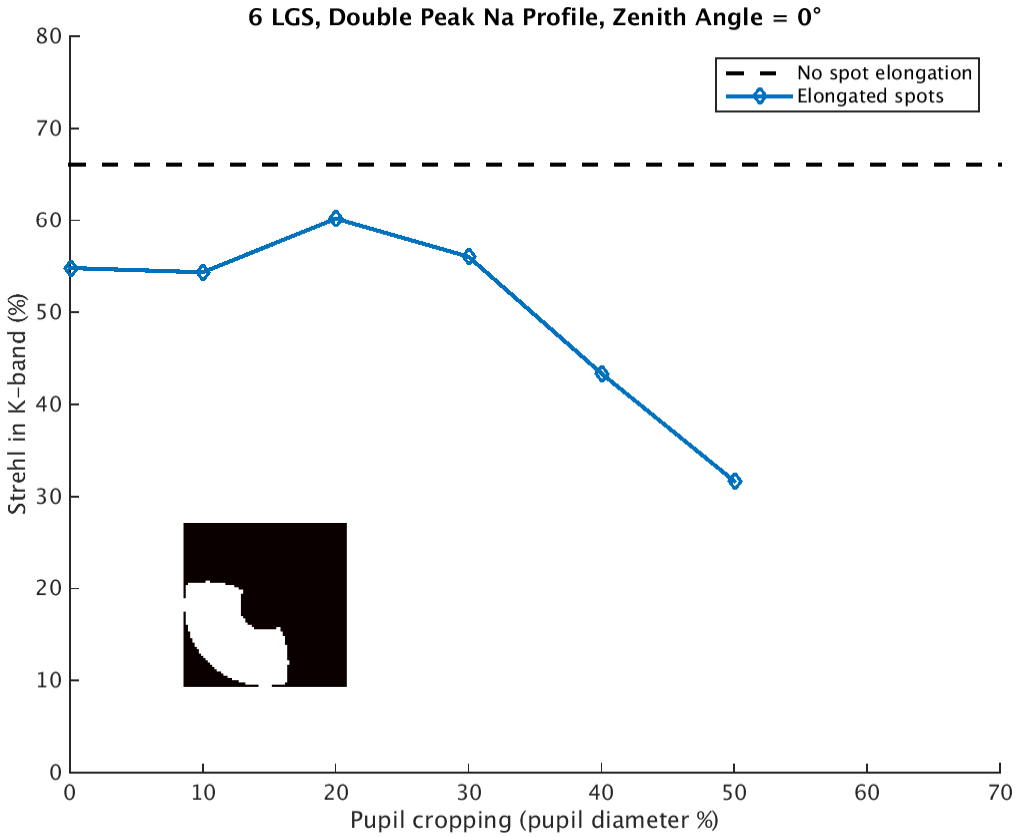

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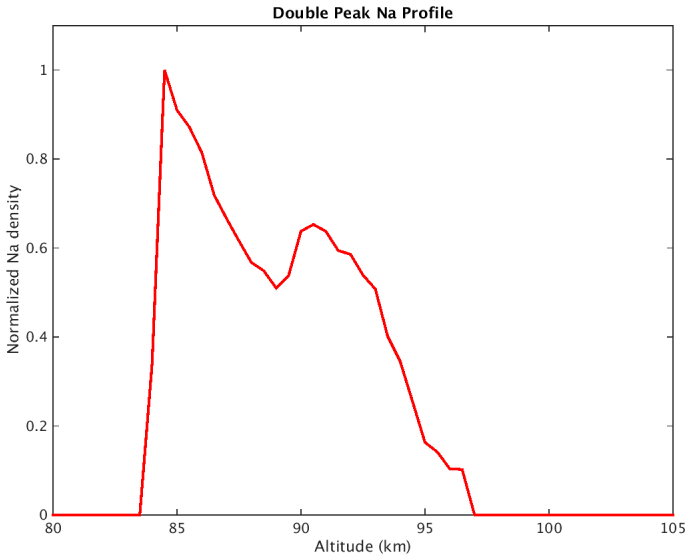

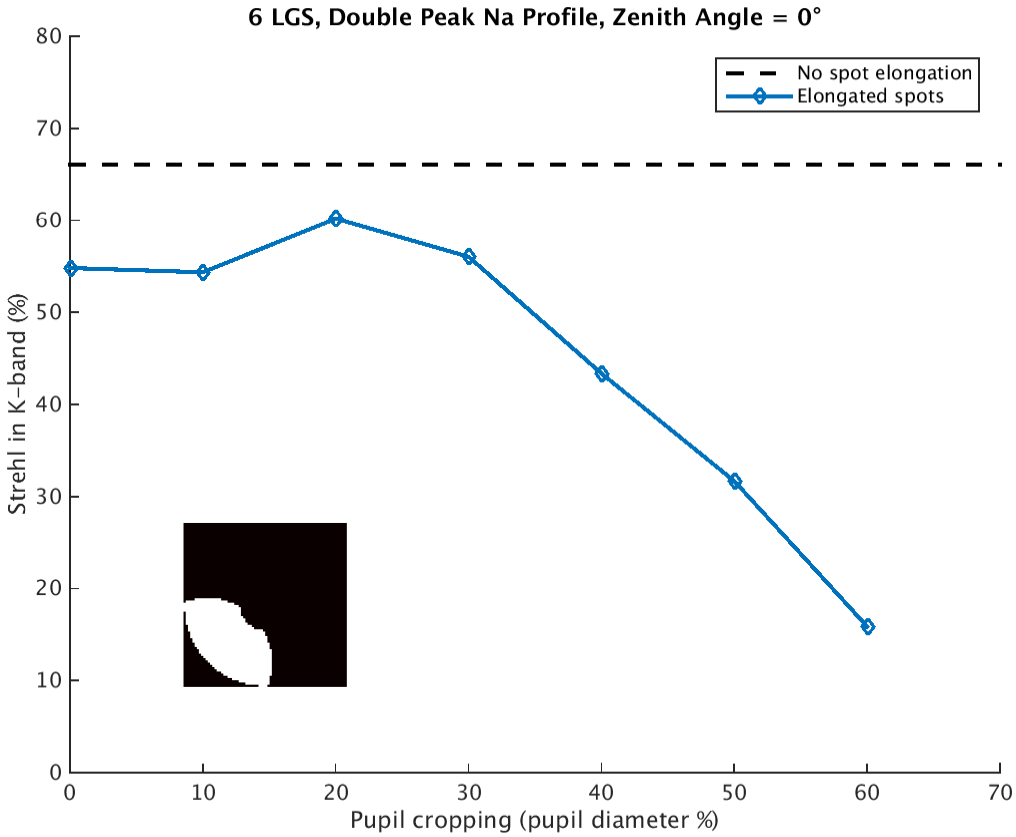

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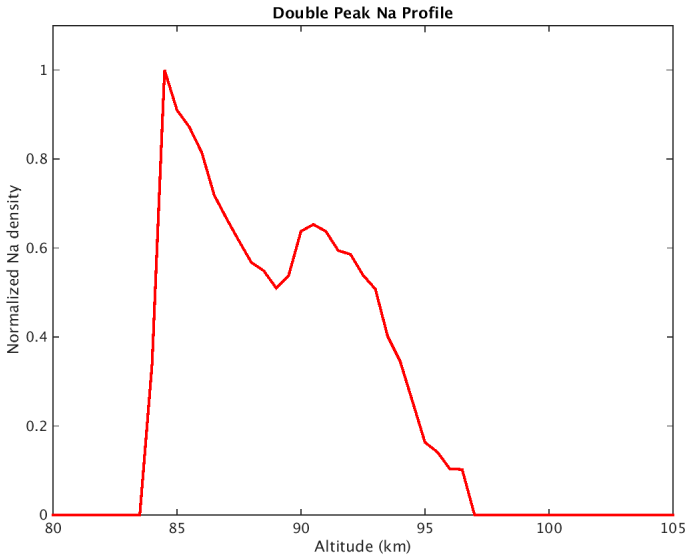

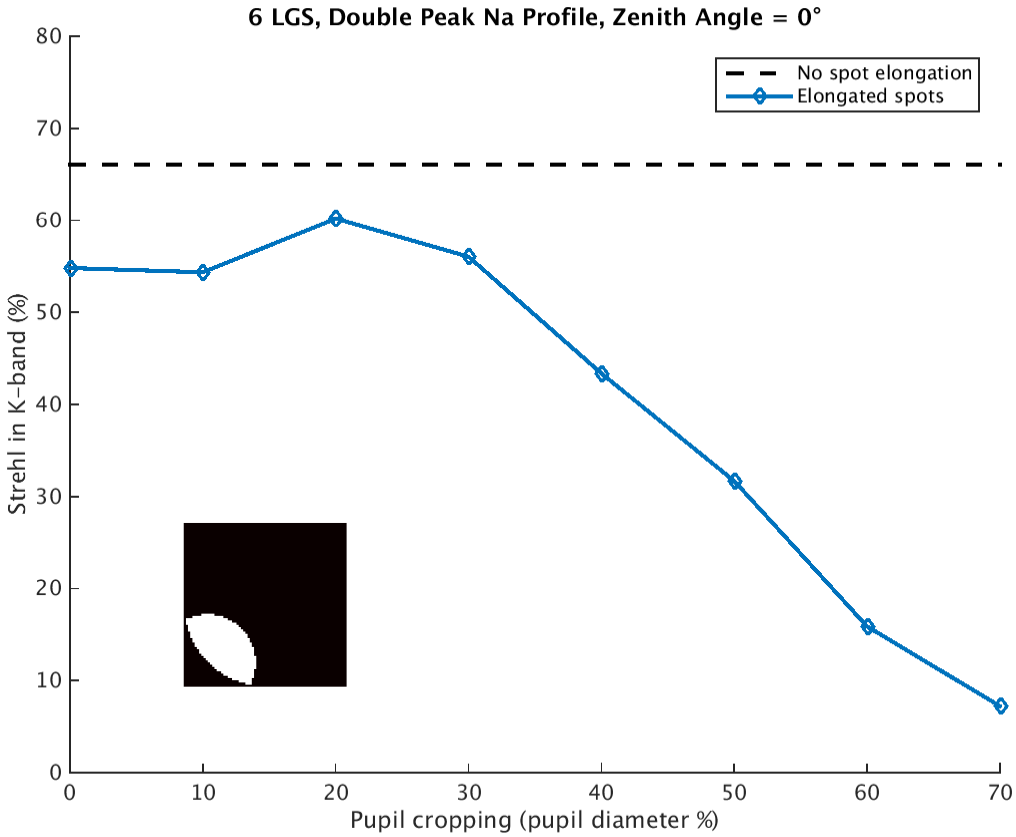

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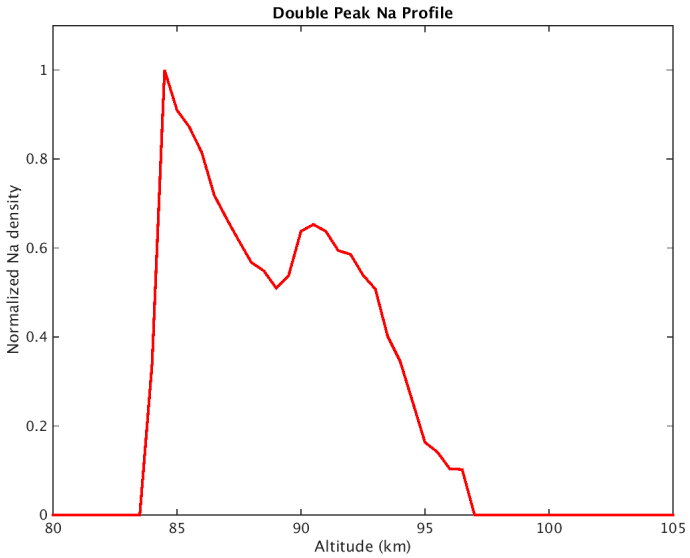

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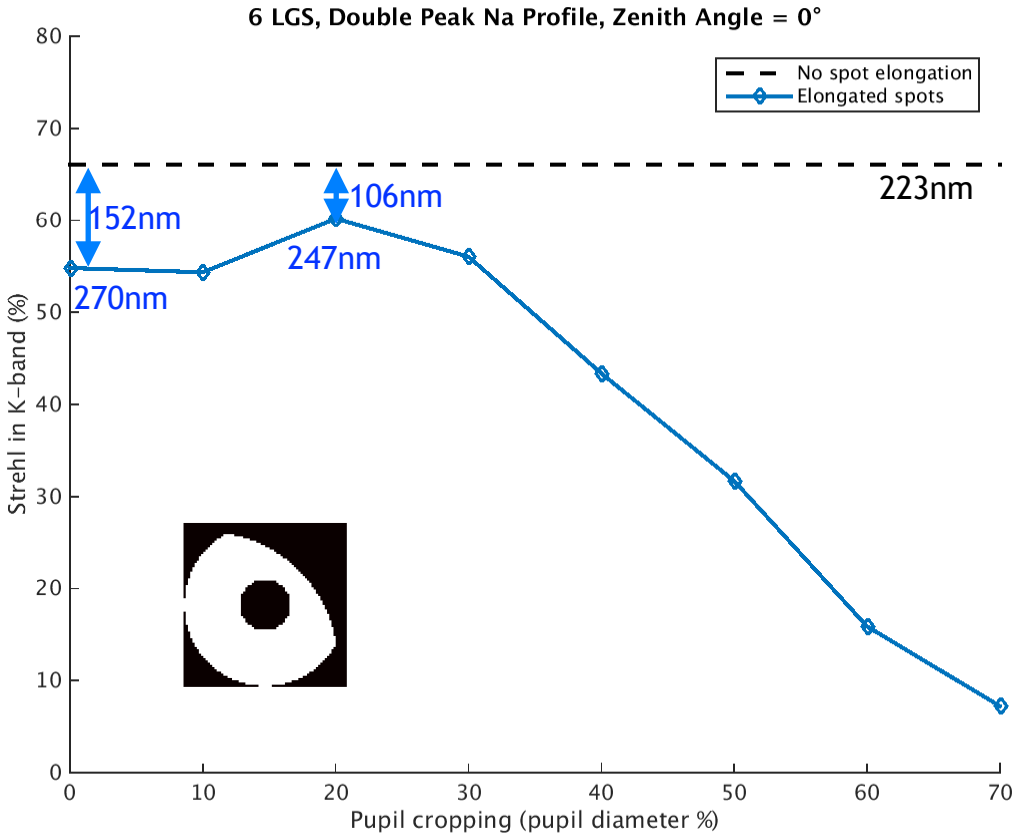
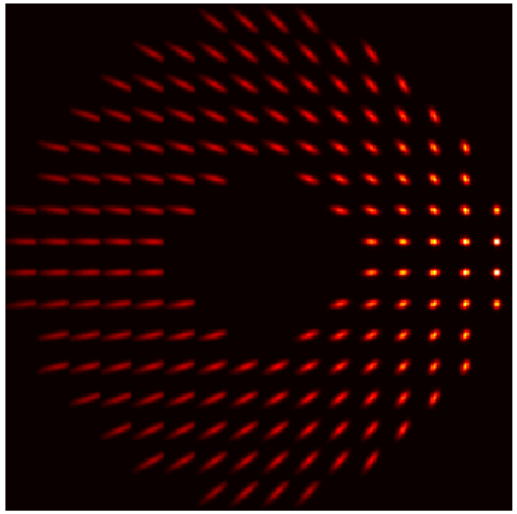


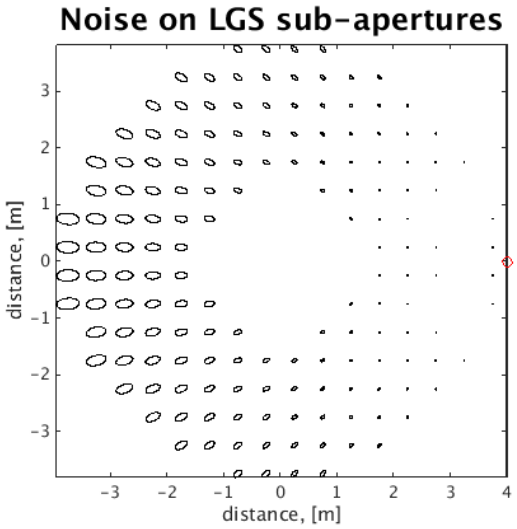
Performance increases as we discard subapertures with too large an elongation/truncation

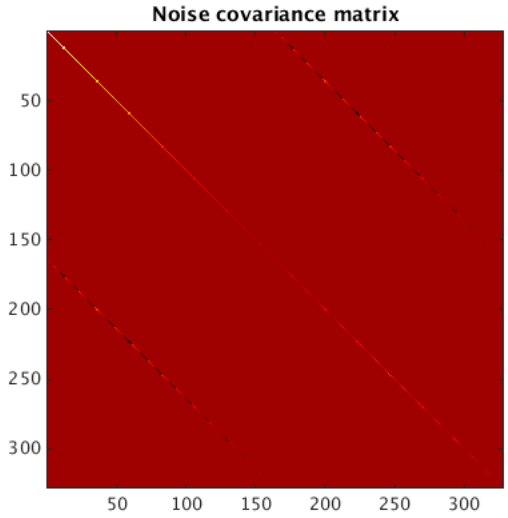
WFE due to elongation reduced from 152nm to 106nm RMS

Differential subaperture weighting

- *à la* Tallon 2008/Robert 2010
- Takes into account the elongation in the noise covariance matrix
- Takes into account cross-coupling between X and Y slopes

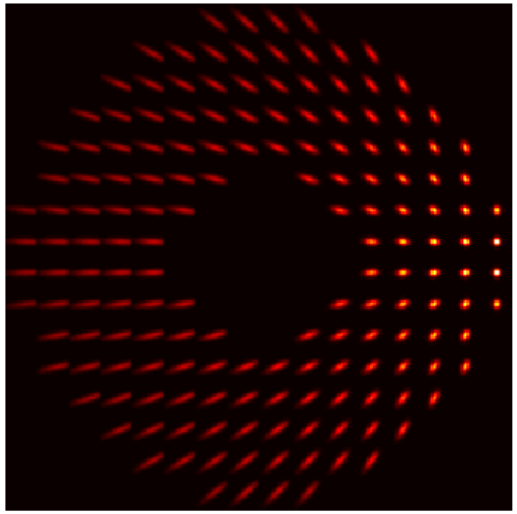


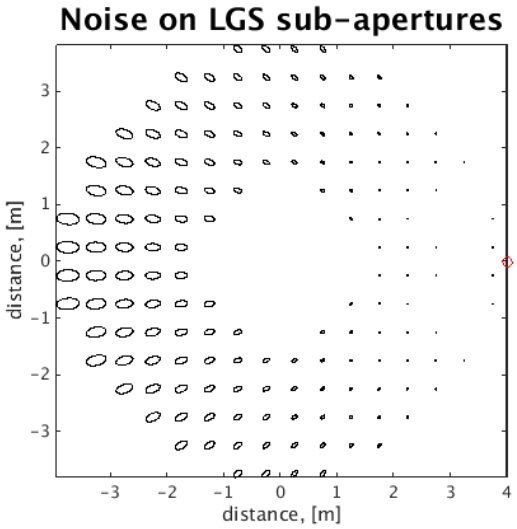


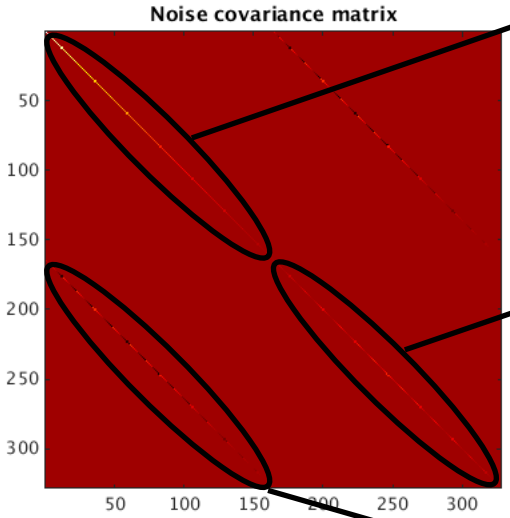


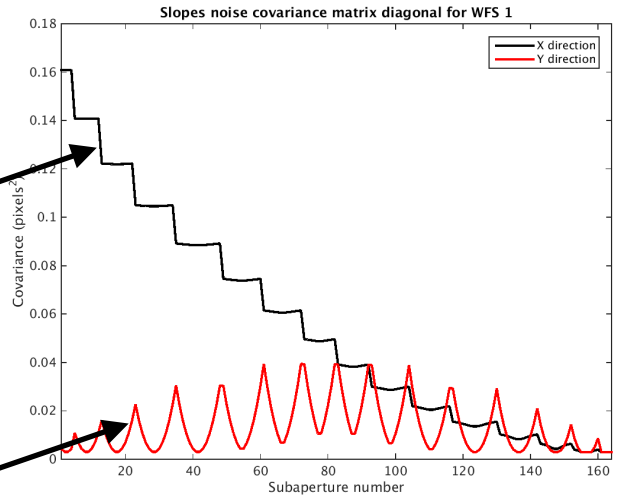
Differential subaperture weighting

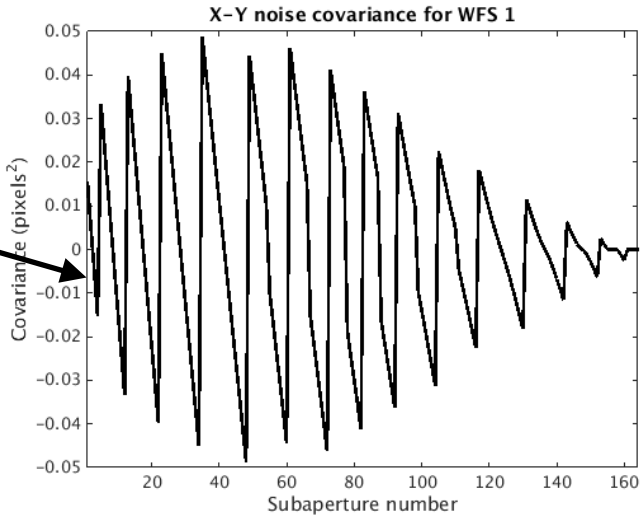
- Tallon 2008/Robert 2010
- Takes into account the elongation in the noise covariance matrix
- Takes into account cross-coupling between X and Y slopes











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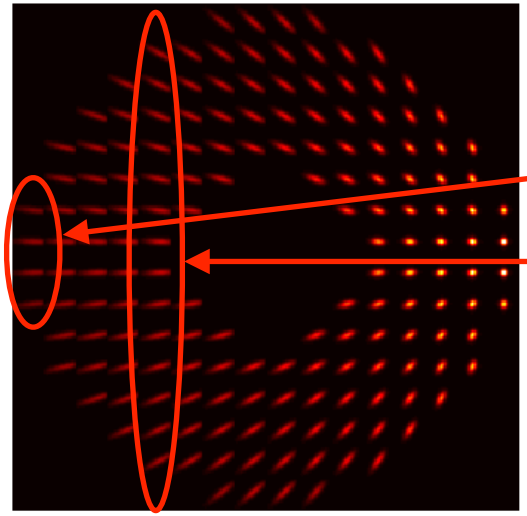

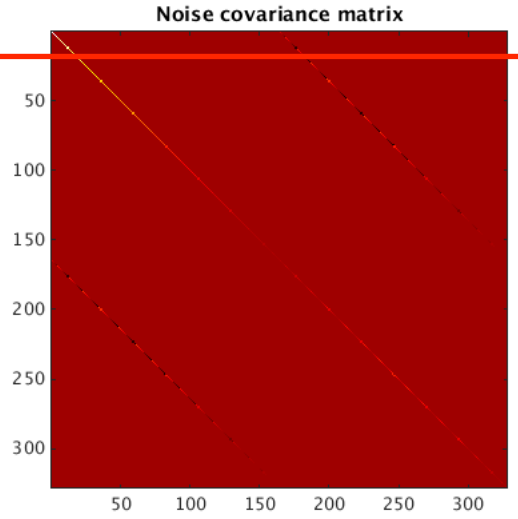

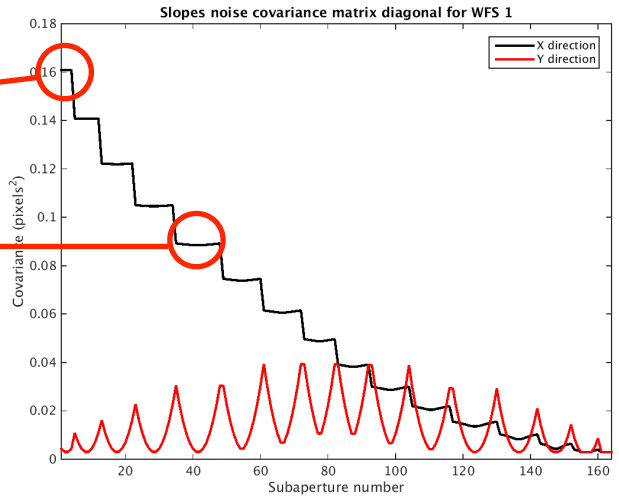

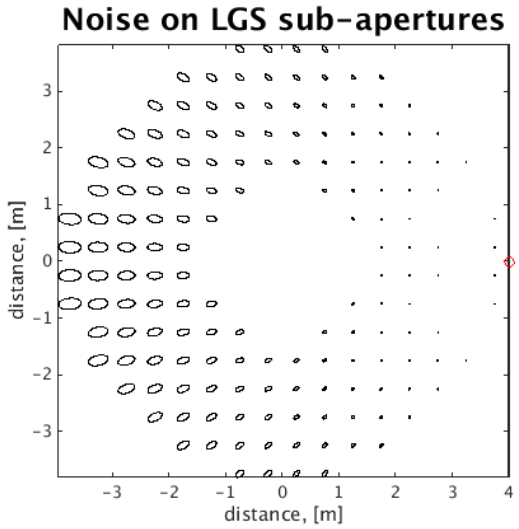

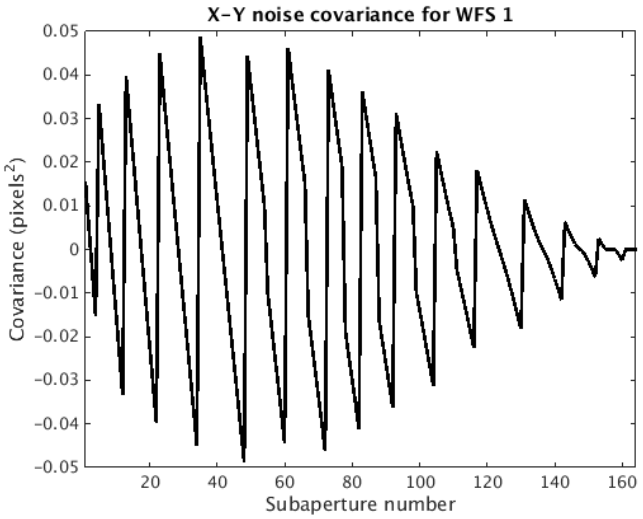

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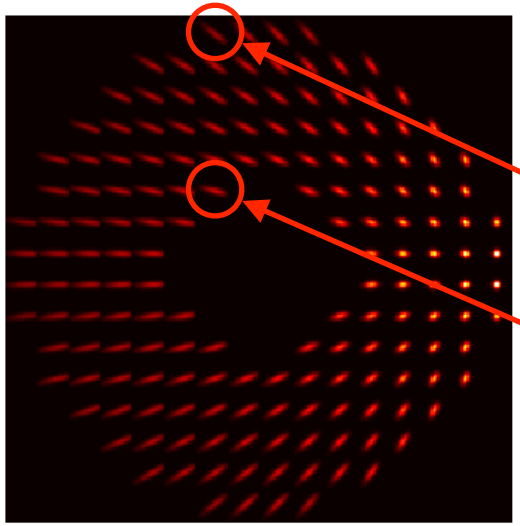
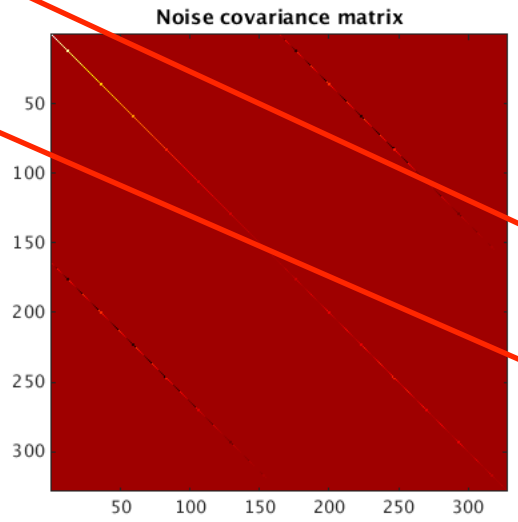
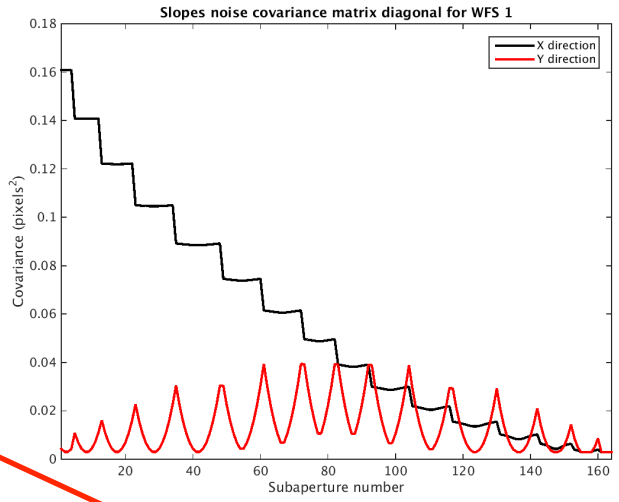
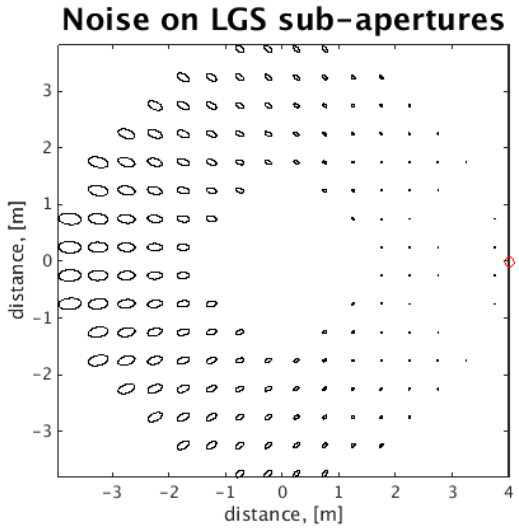
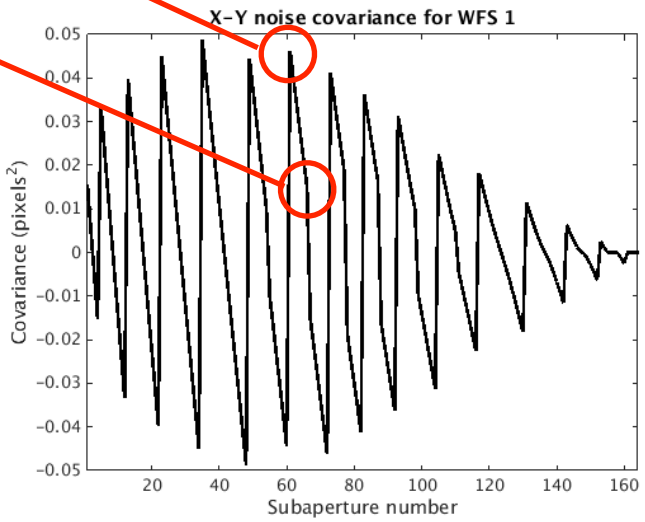


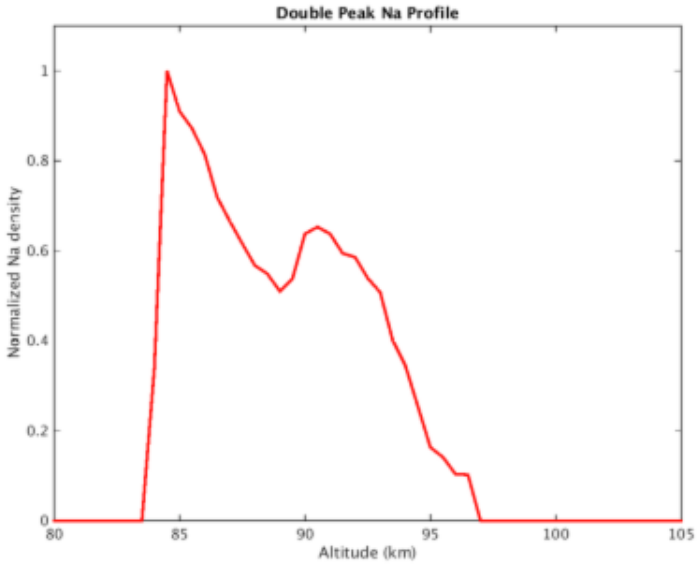




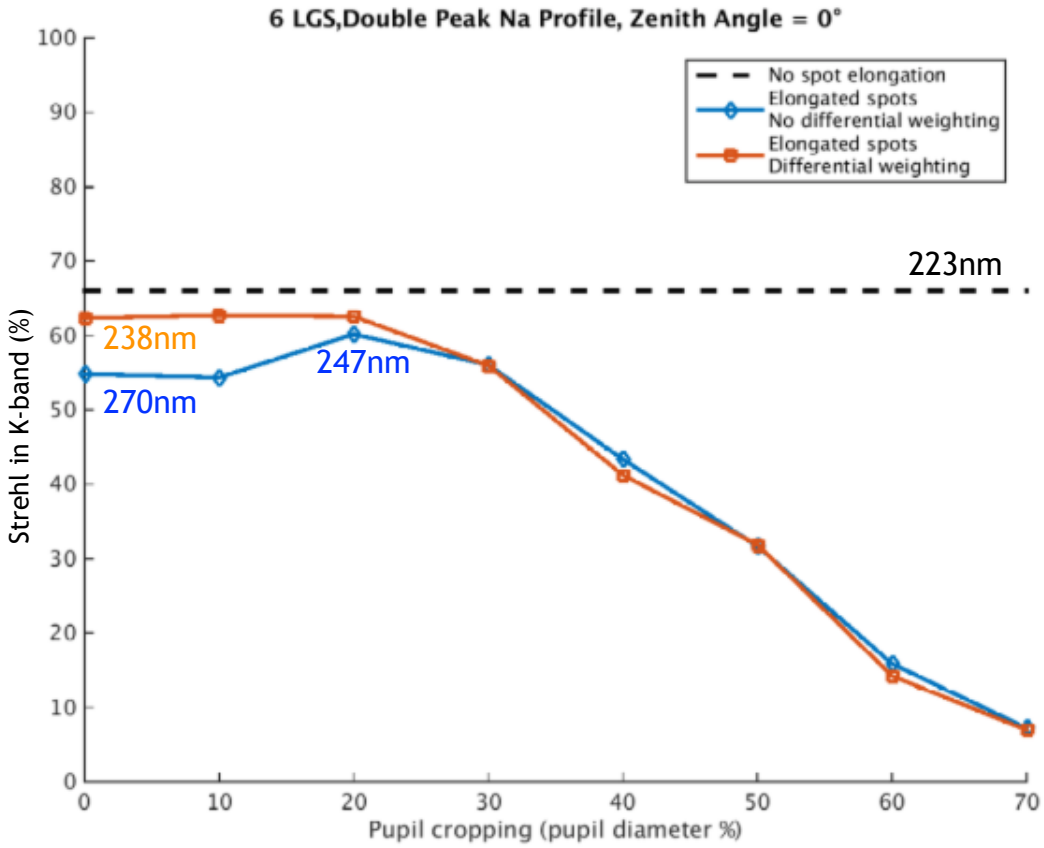




Subaperture weighting+cropping



Full E-ELT simulation:
Pupil diameter : 37m
74x74 SH LGS WFS
75x75 actuator DM
Subaperture pitch : 50cm
Subaperture FOV : 10" (1" pixels)
6 LGS-Asterism diameter : 42"
30% central obscuration
High flux

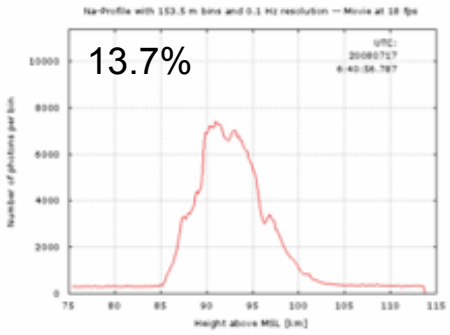


WFE due to elongation reduced from 152nm to 83nm RMS when using subaperture differential weighting

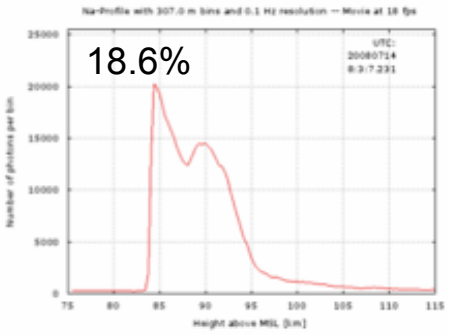
but Na profile not always bimodal !

Subaperture weighting+cropping

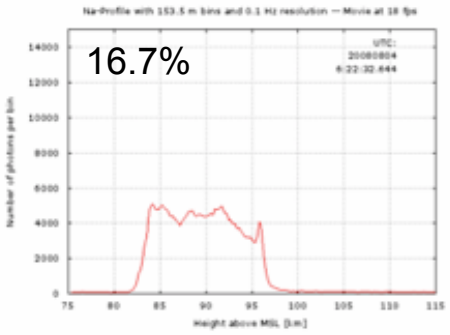
Single peak



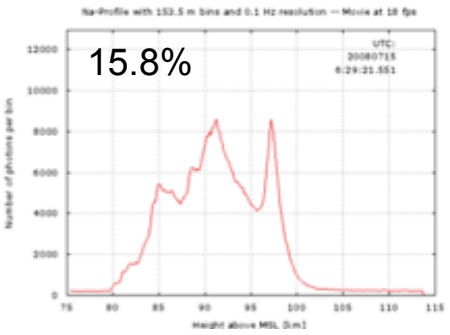
Double peak



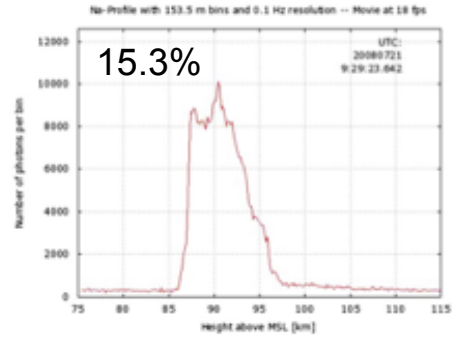
Top hat



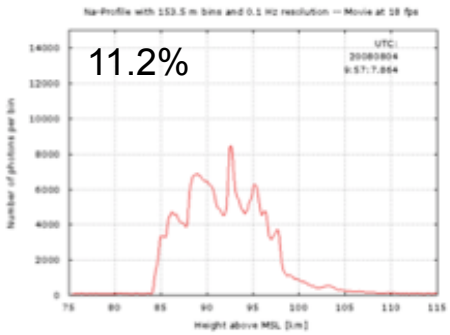
Very wide



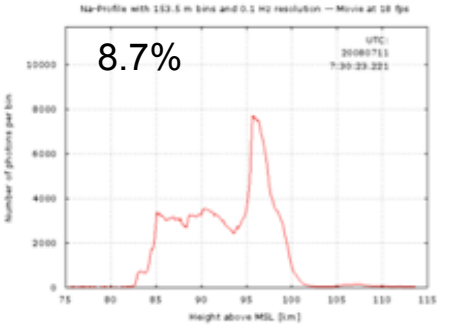
Very narrow



Multi peak

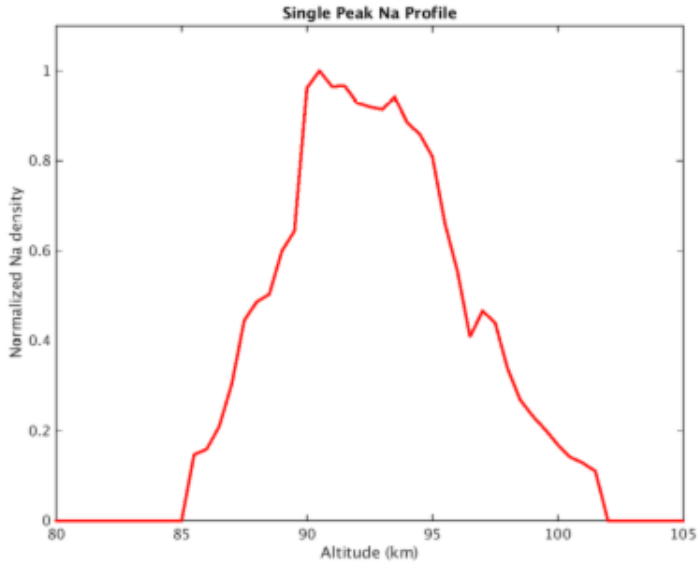


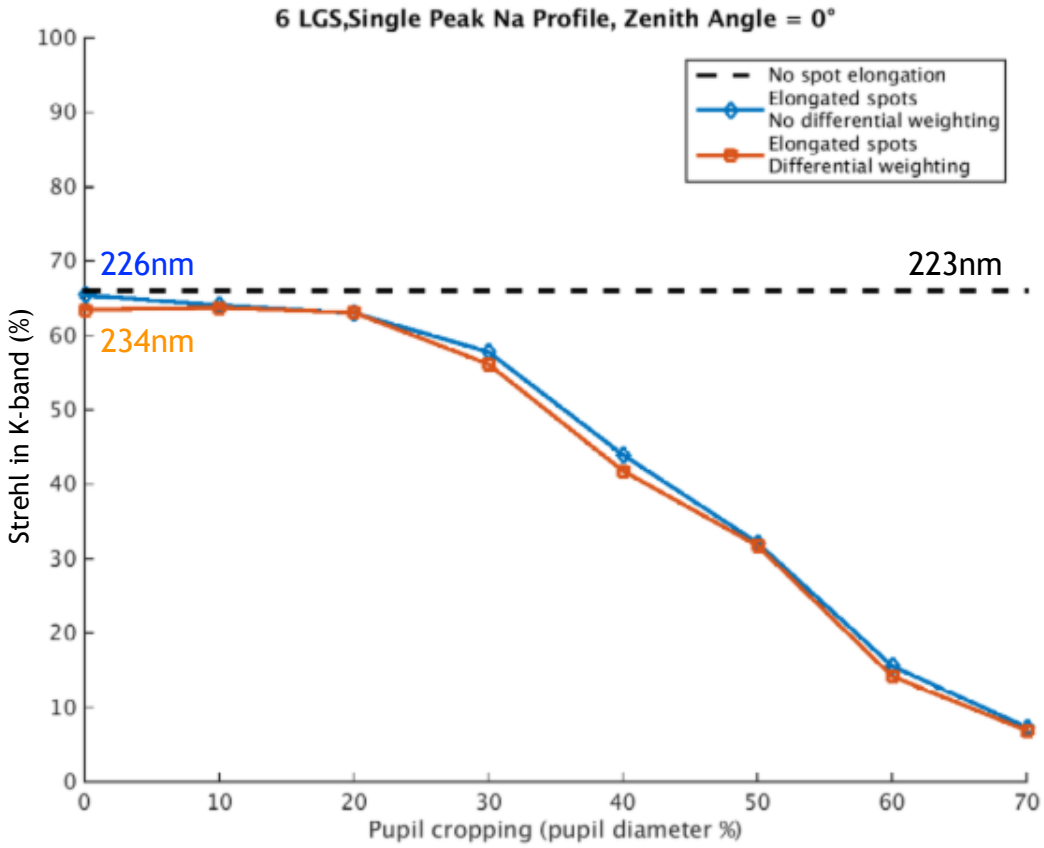
Top hat with pk.



Pfrommer and Hickson 2011

Subaperture weighting+cropping



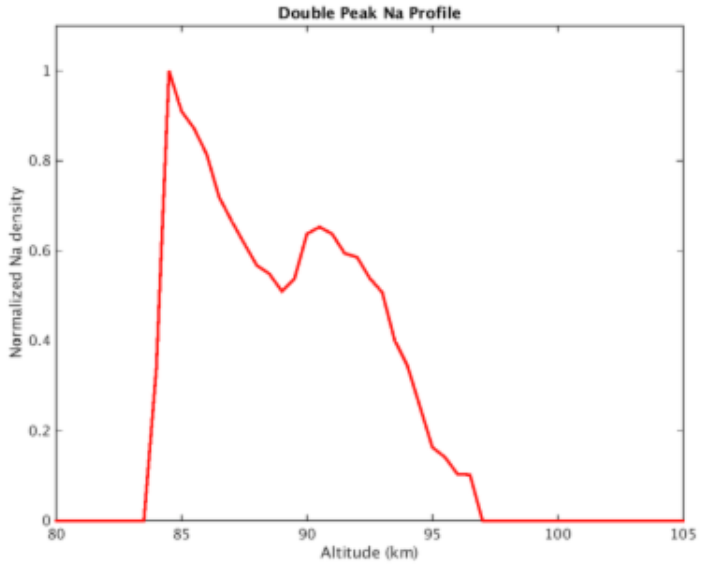


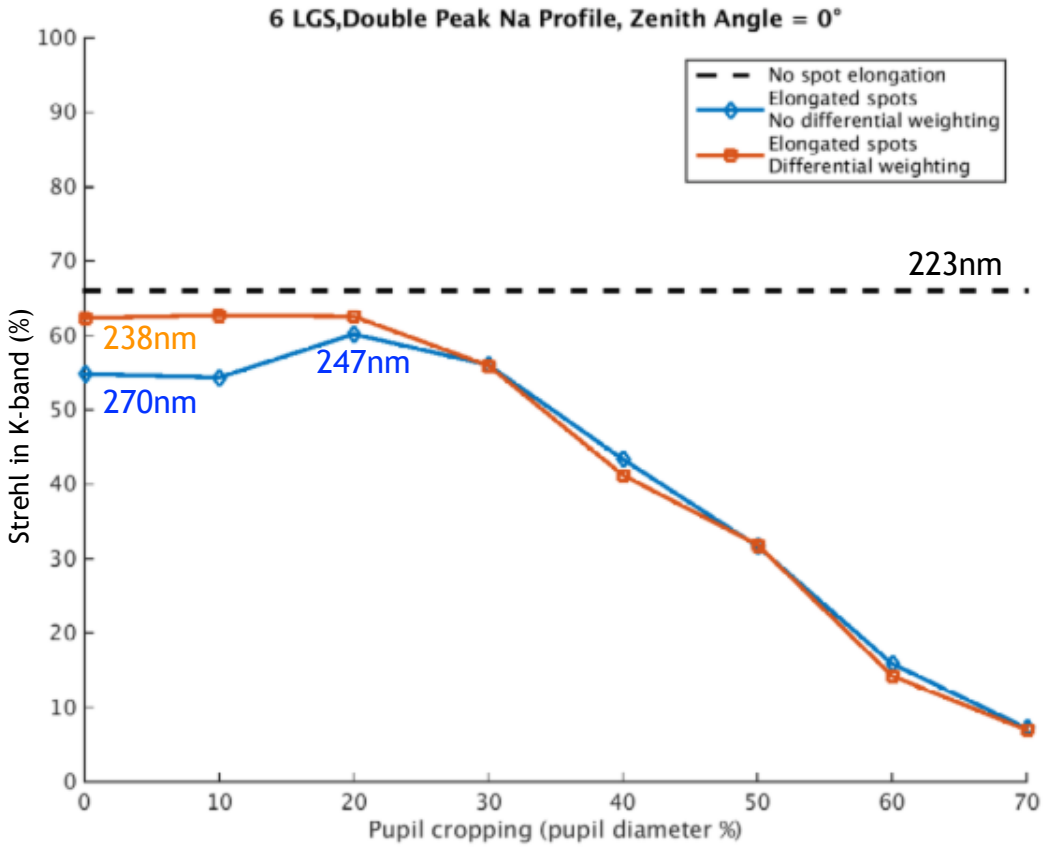
Full E-ELT simulation:
Pupil diameter : 37m
74x74 SH LGS WFS
75x75 actuator DM
Subaperture pitch : 50cm
Subaperture FOV : 10" (1" pixels)
6 LGS-Asterism diameter : 42"
30% central obscuration
High flux

Narrow spot mostly within the subaperture even opposite from LLT

Weighting over-regularizes already good information

Subaperture weighting+cropping





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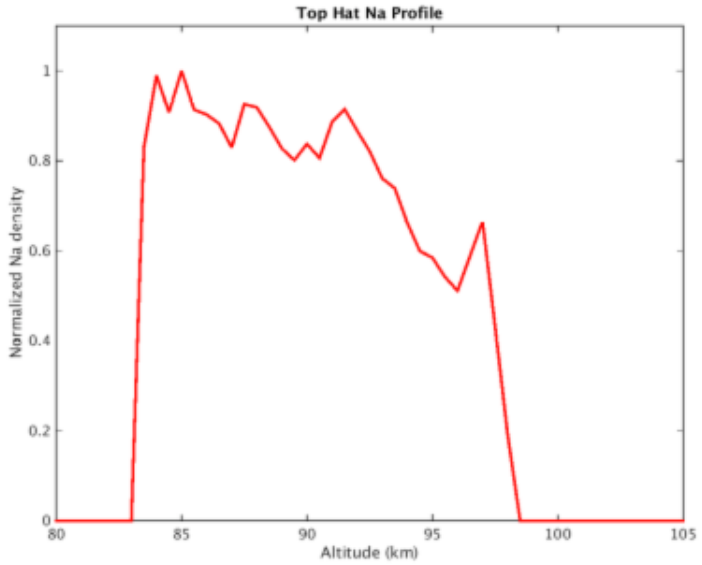
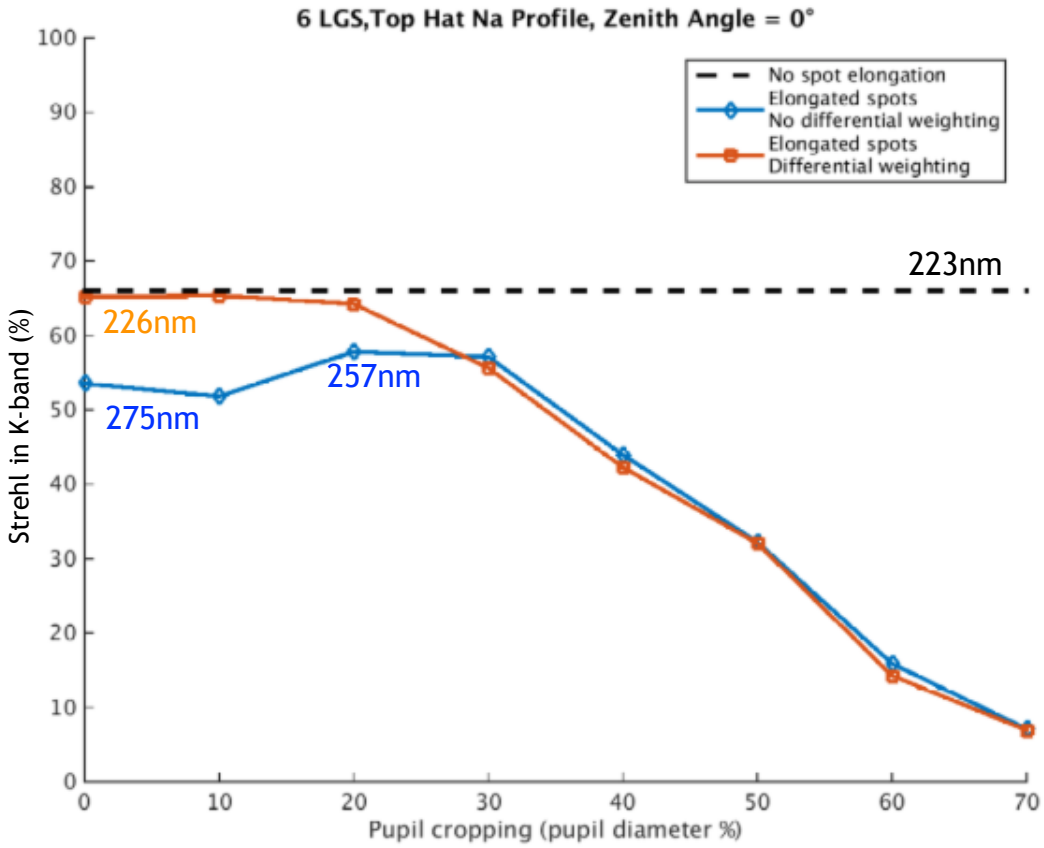
WFE due to elongation reduced from 152nm to 83nm RMS when using subaperture differential weighting

Subaperture weighting+cropping





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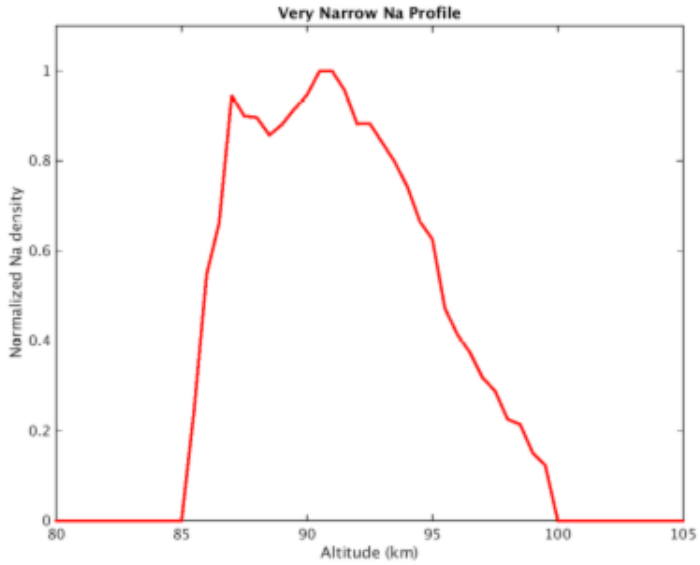
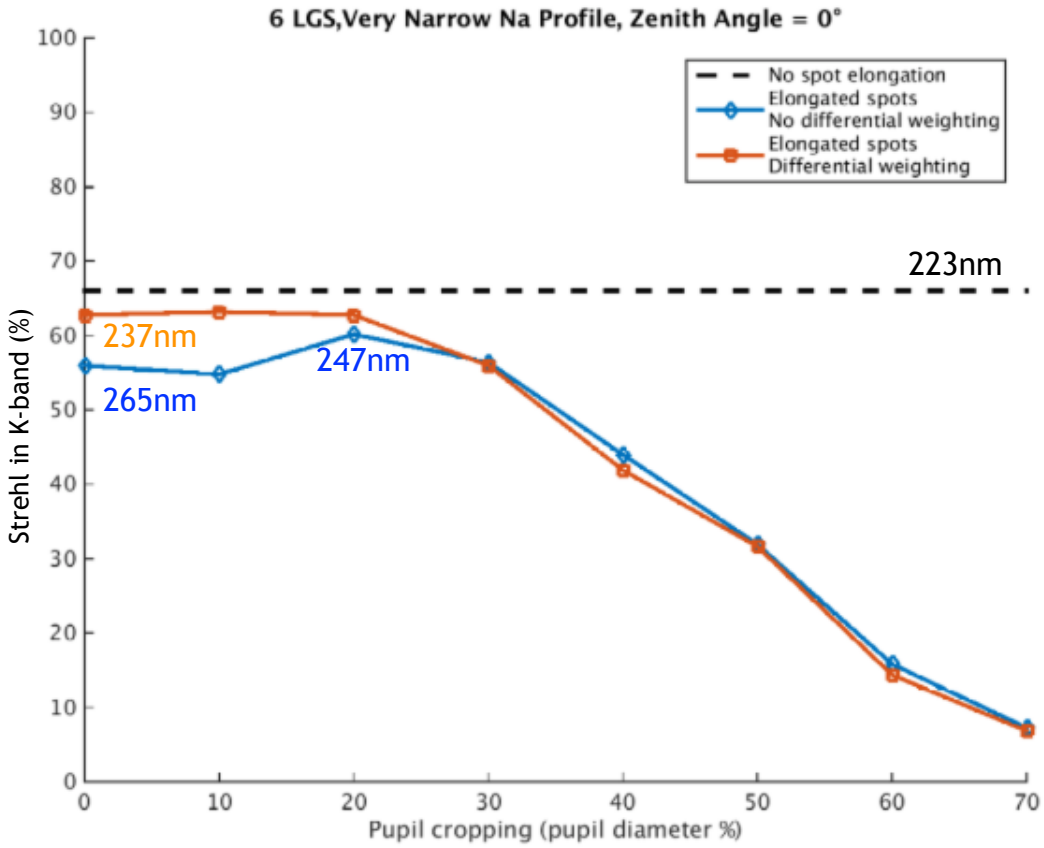
75x75 actuator DM
Subaperture pitch : 50cm
Subaperture FOV : 10” (1” pixels)
6 LGS-Asterism diameter : 42”
30% central obscuration
High flux

Differential weighting gives almost ideal performance

Subaperture weighting+cropping





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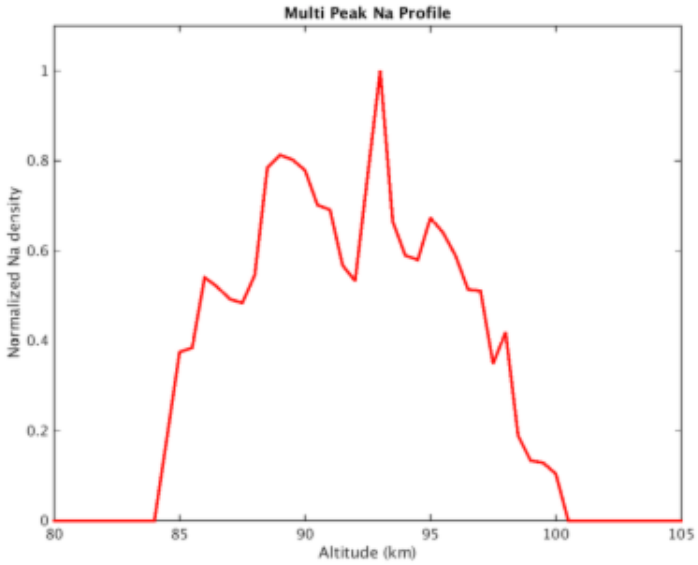
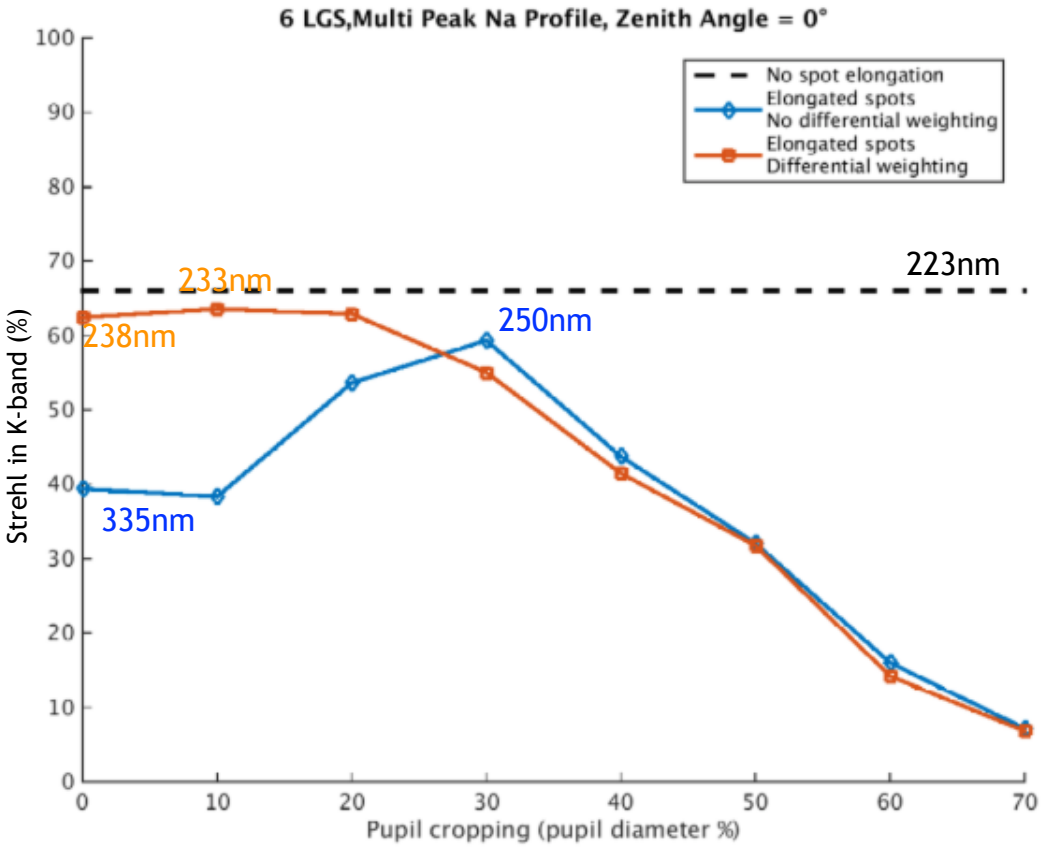
30% central obscuration
High flux

WFE due to elongation reduced from 143nm to 80nm RMS when using subaperture differential weighting

Best ‘cropping’ (20%)
WFE due to elongation =106nm

Subaperture weighting+cropping





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75x75 actuator DM
Subaperture pitch : 50cm
Subaperture FOV : 10” (1” pixels)
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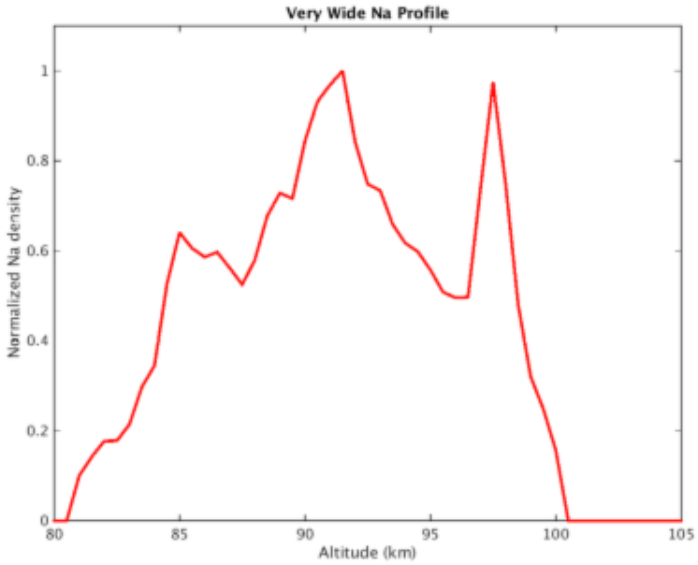
30% central obscuration
High flux

WFE due to elongation reduced from 250nm to 83nm RMS when using subaperture differential weighting

WFE reduced to 67nm RMS when combining weighting and cropping

Subaperture weighting+cropping



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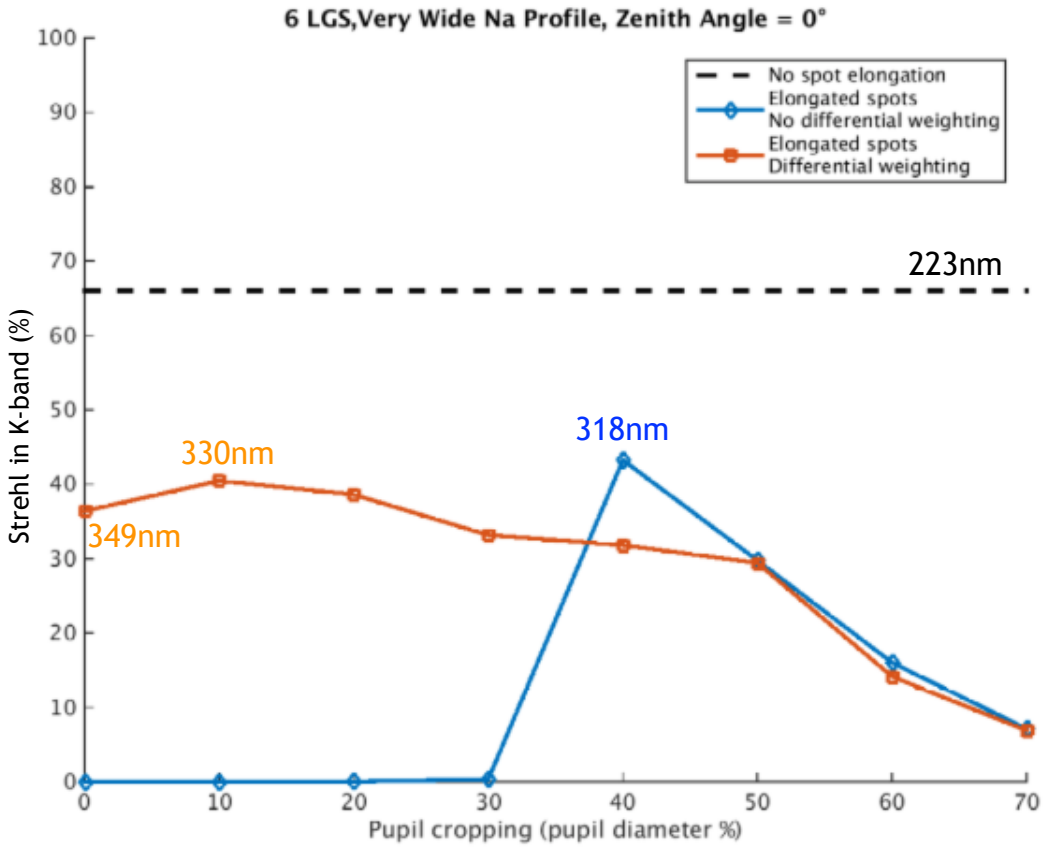
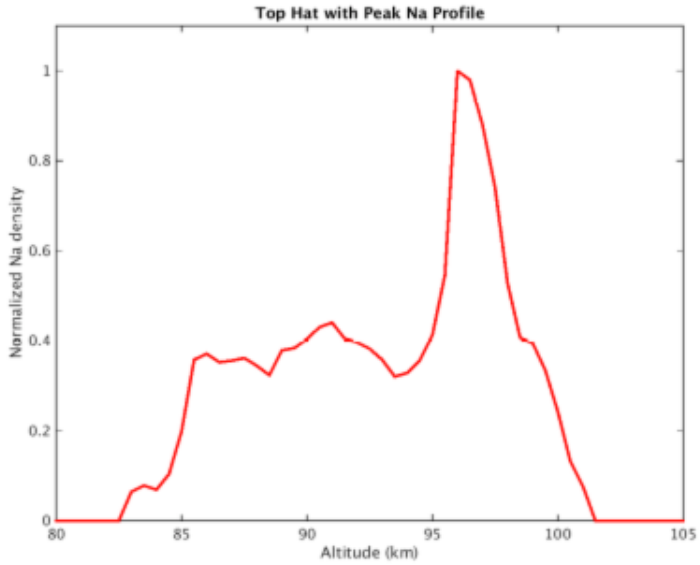
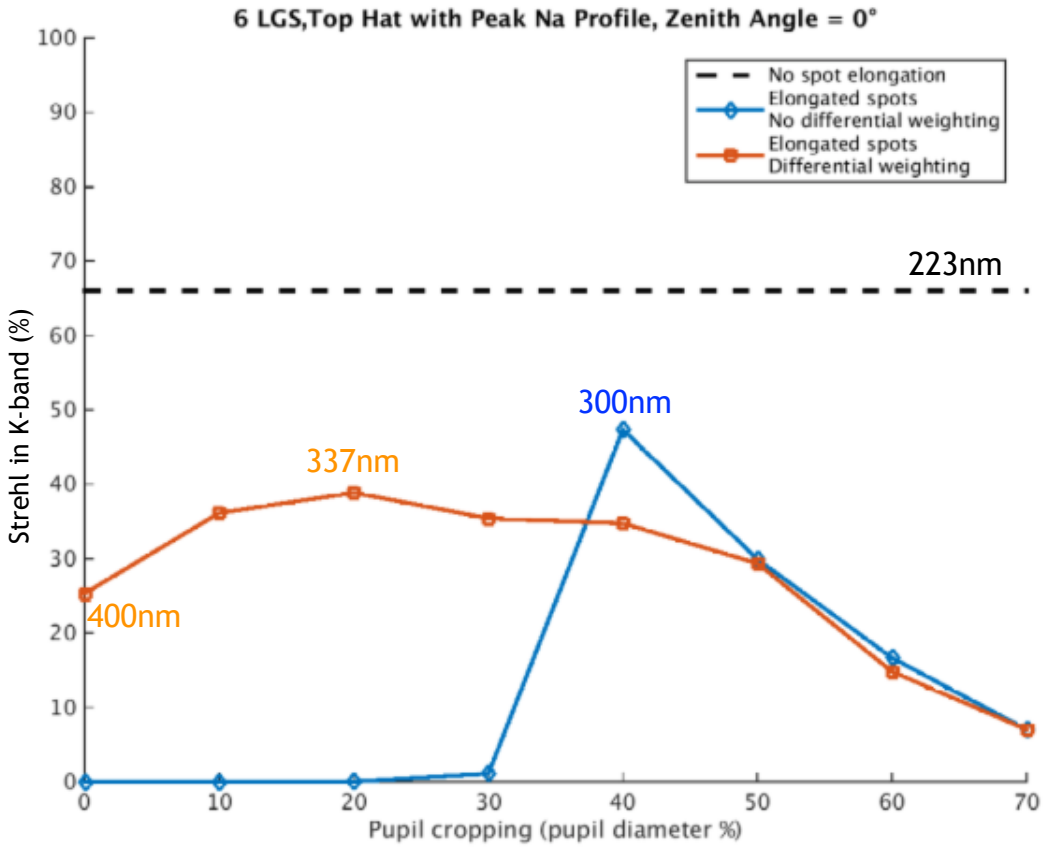
High flux



Very perturbed profile with sharp peak at high altitude
Unstable loop when taking into account all subapertures
Weighting mandatory for full pupil
High cropping (40%) improves performance over weighting but far from ideal

Subaperture weighting+cropping





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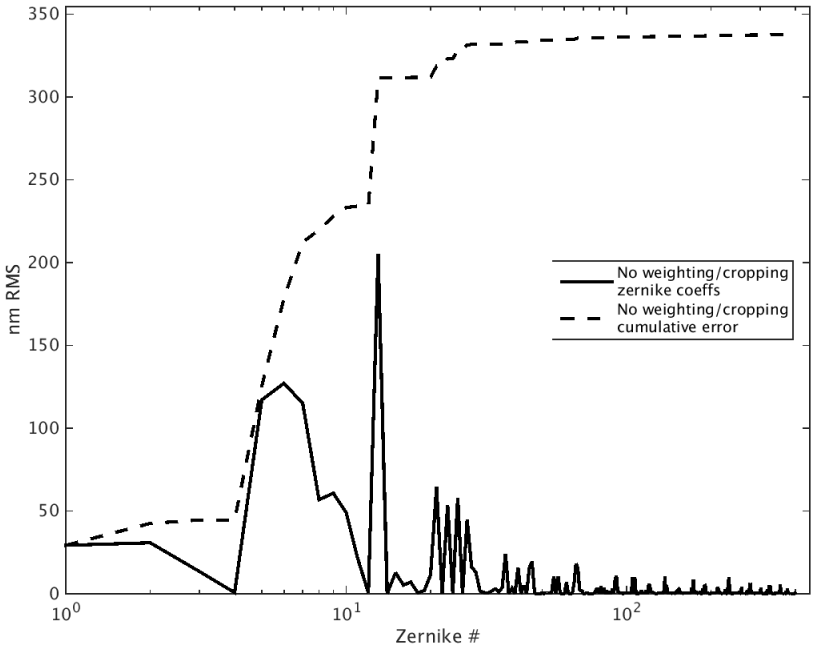
Truth sensor

How many modes do we need to measure to remain below a prescribed WFE due to spot elongation ?



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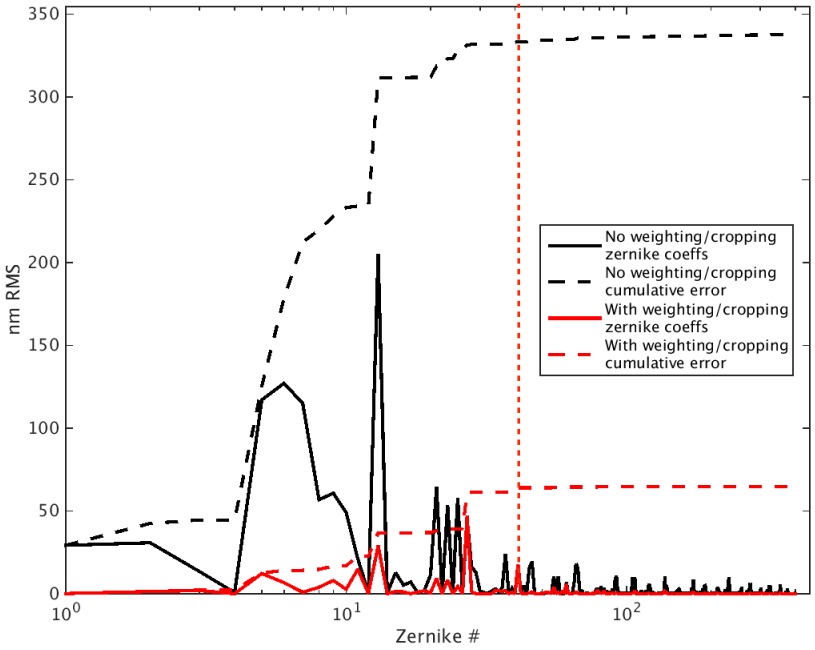

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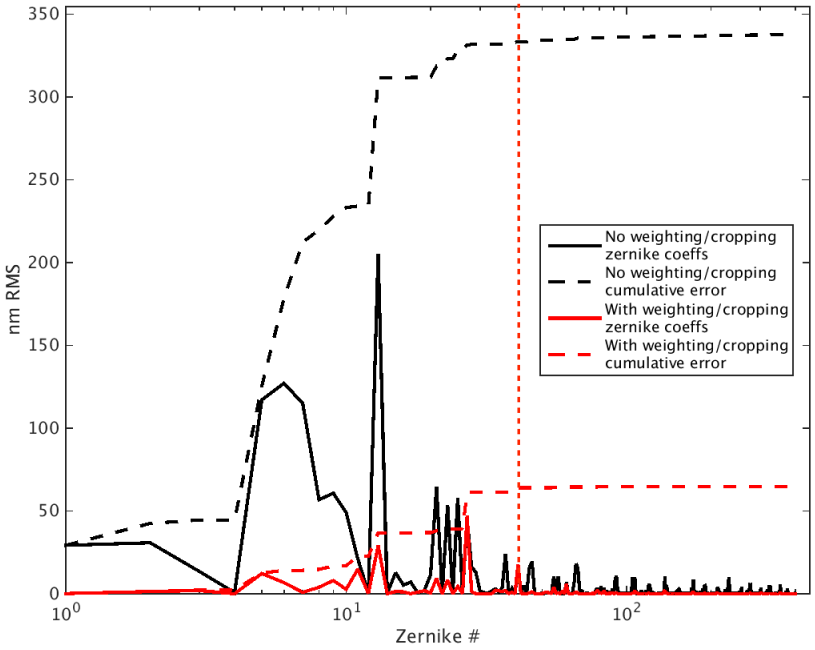
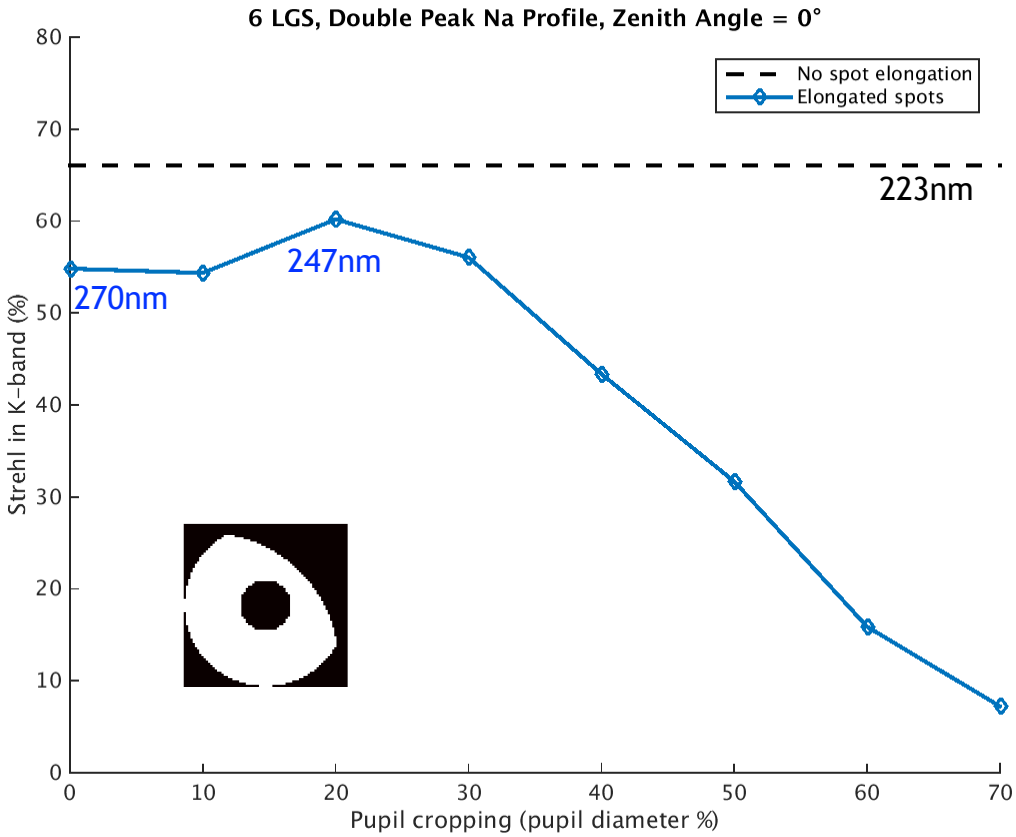


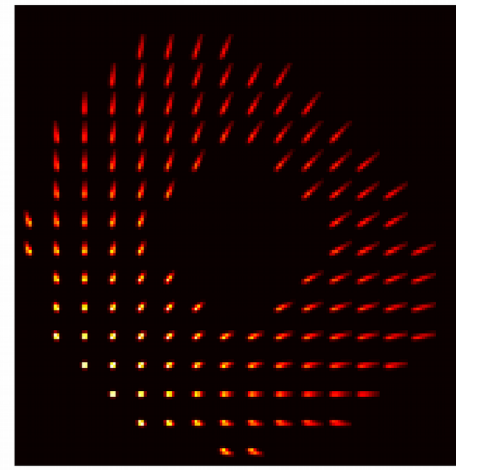
	Single	Top hat	Double	Very narrow	Multi peak	Very wide	Top hat +peak
10nm	z1	z10	z14	z14	z28	z42	z56
20nm	z1	z1	z1	z1	z1	z42	z42
30nm	z1	z1	z1	z1	z1	z42	z42
40nm	z1	z1	z1	z1	z1	z28	z28
50nm	z1	z1	z1	z1	z1	z28	z28

8x8 truth sensor sufficient to remain below 10nm at all times

Corner Shack-Hartmann

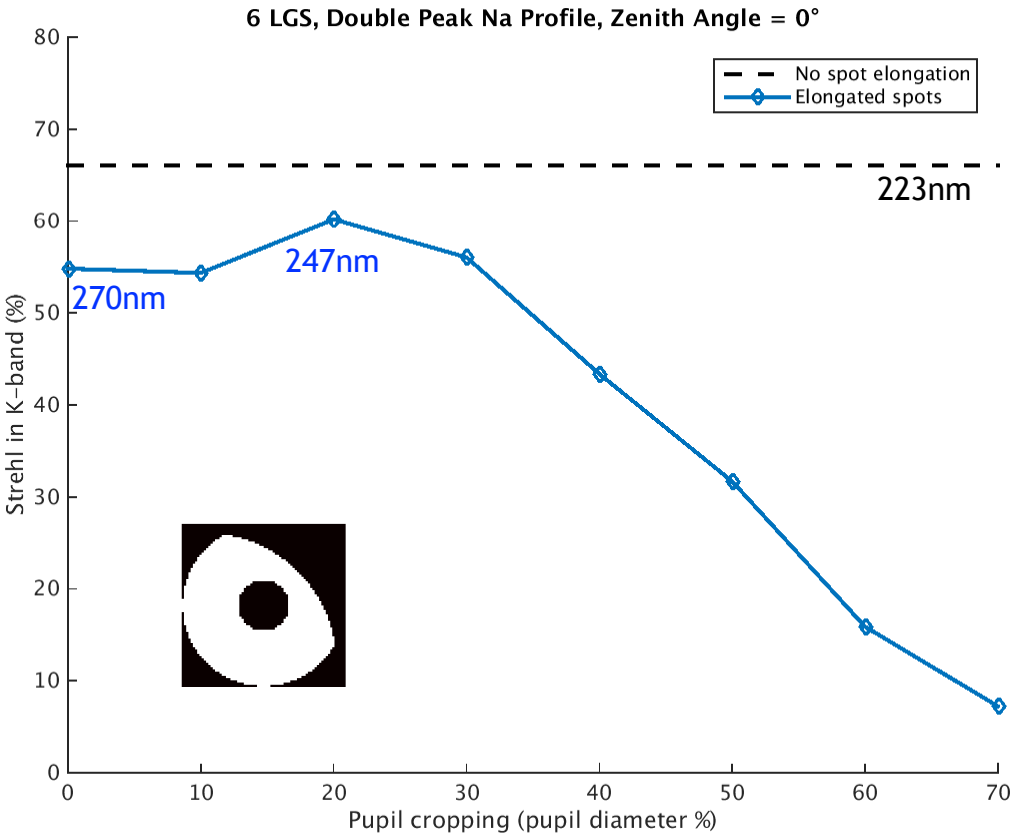


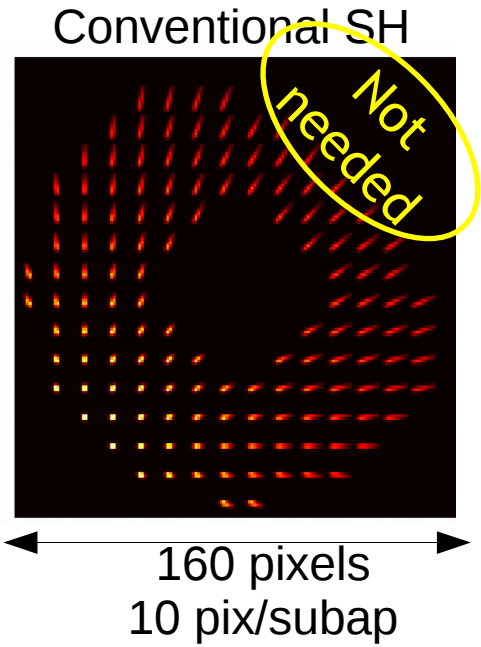
Conventional SH



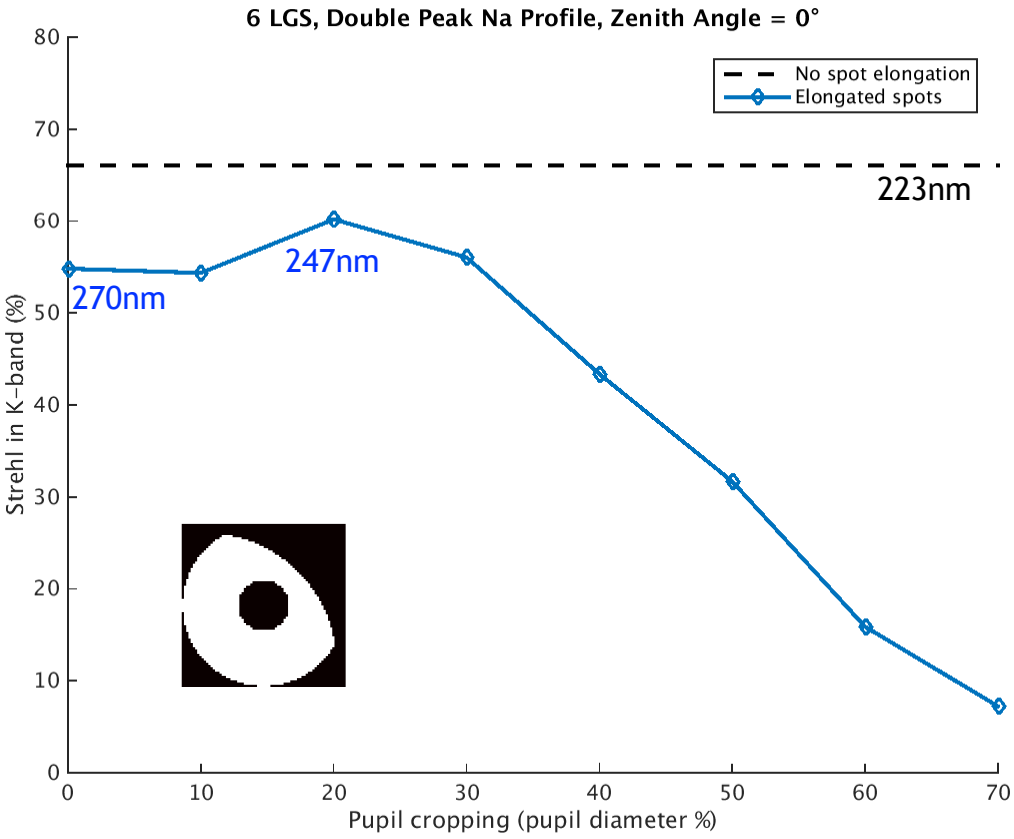
160 pixels
10 pix/subap

Corner Shack-Hartmann





Corner Shack-Hartmann



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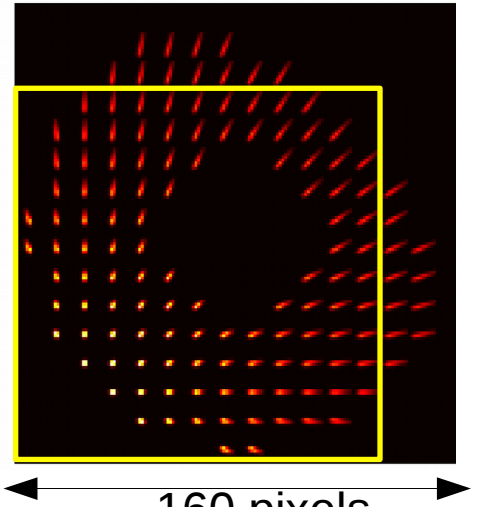

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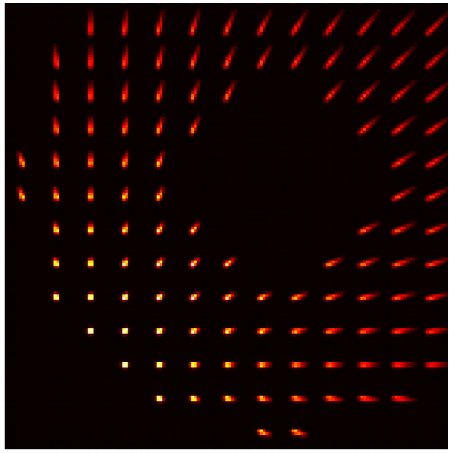

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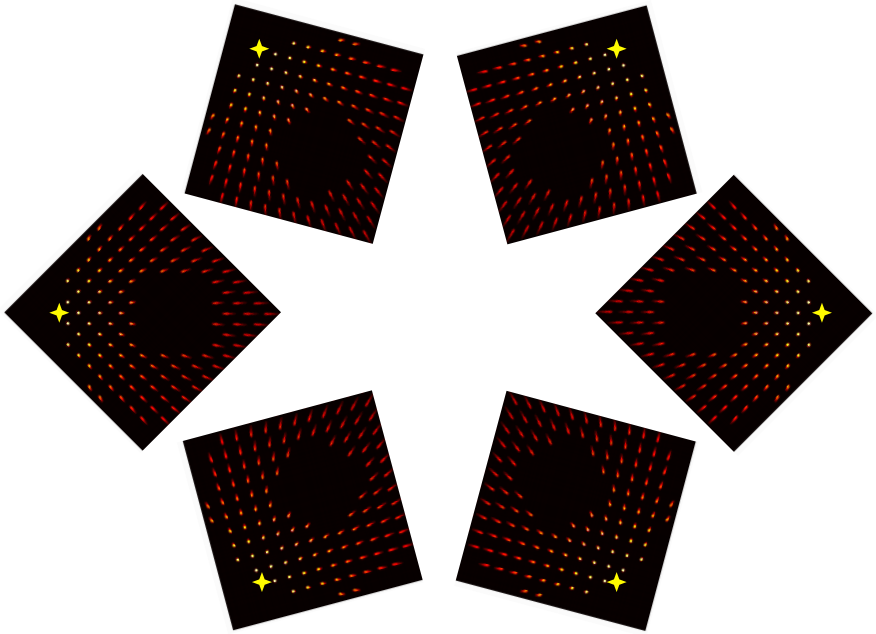
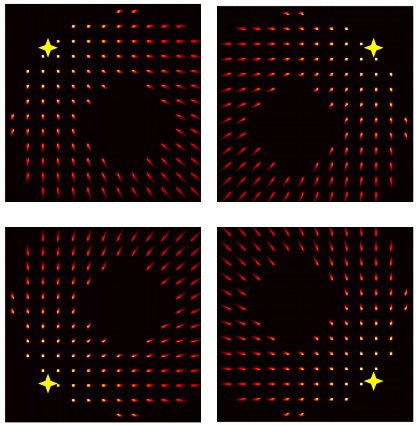
12 pix/subap

Corner Shack-Hartmann

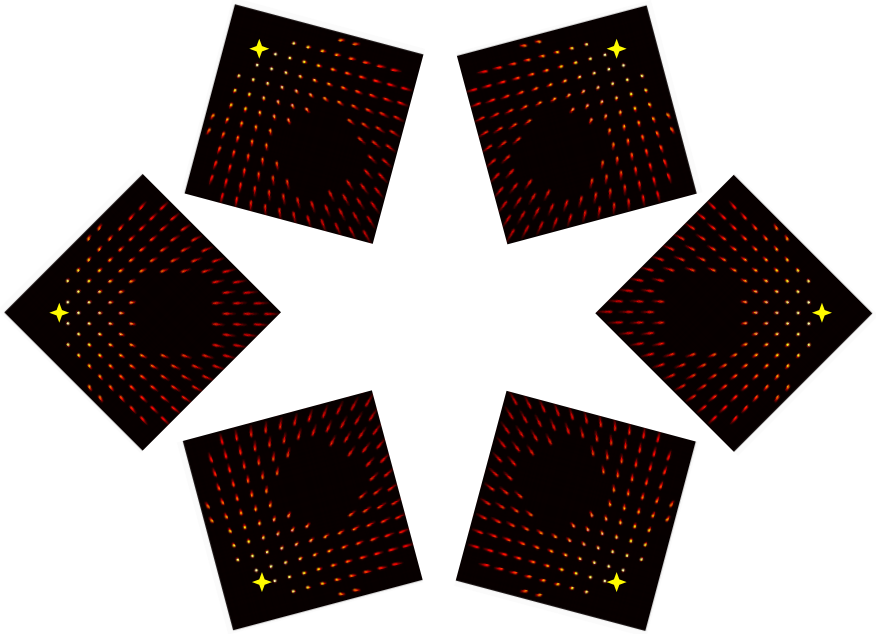


6 LGS configuration



4 LGS configuration

Corner Shack-Hartmann



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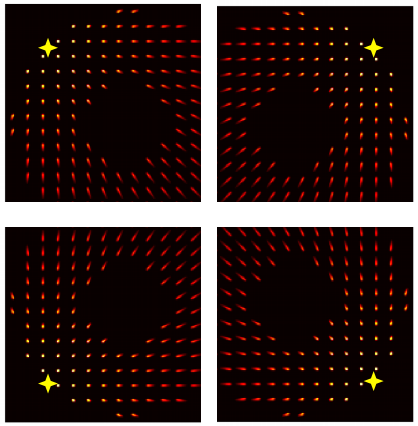

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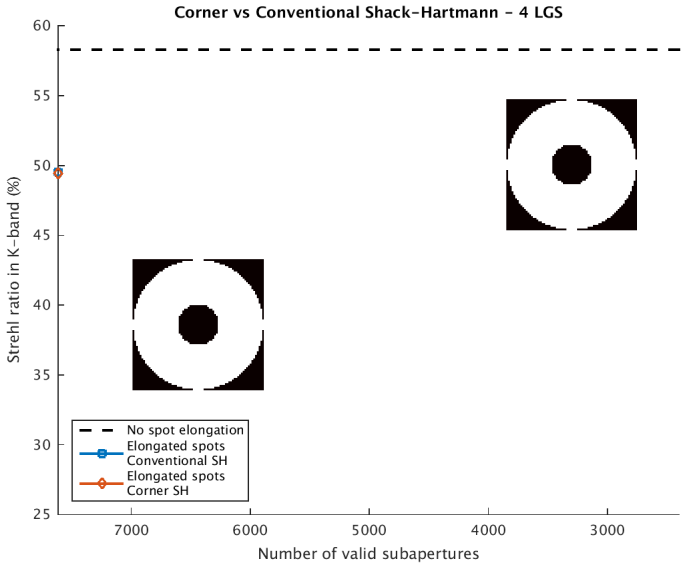

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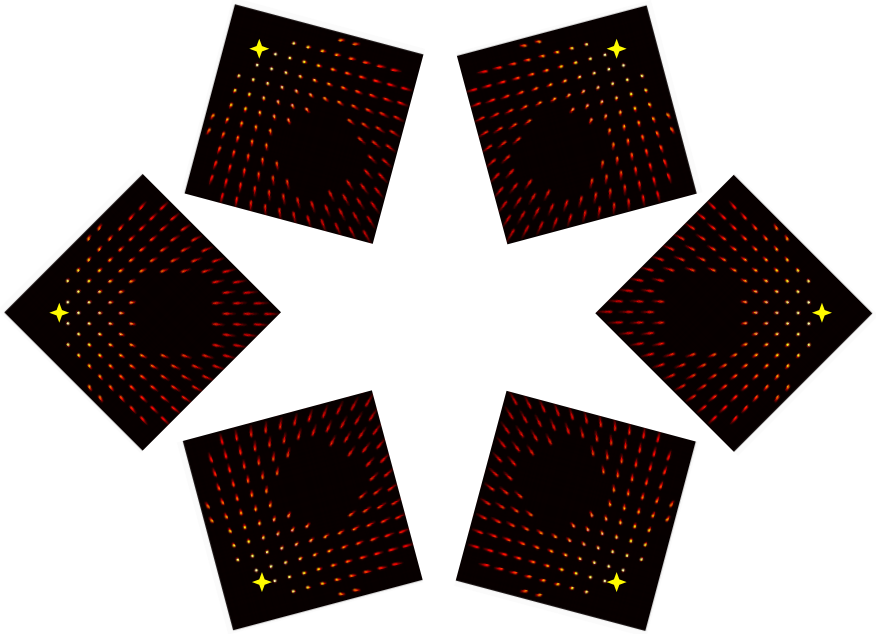

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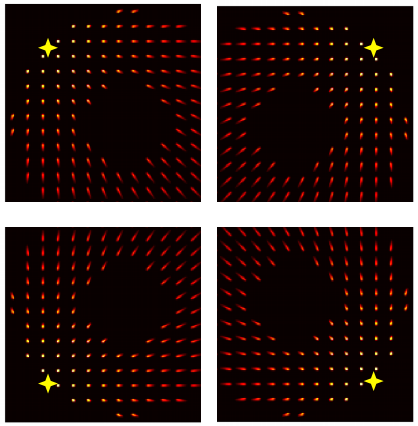

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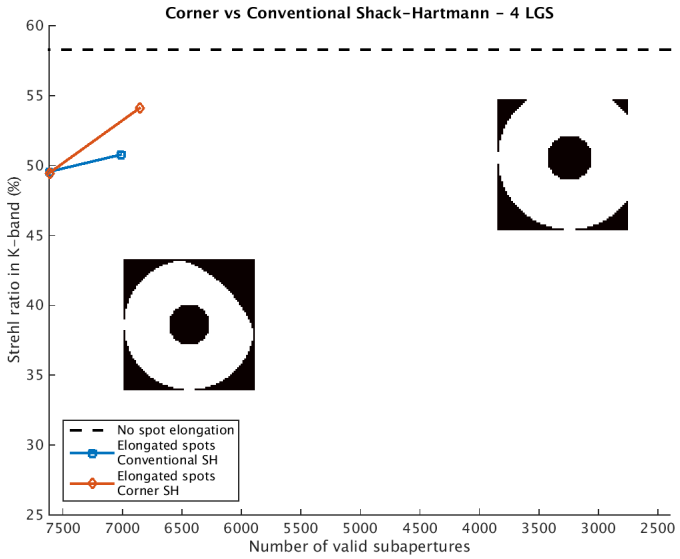

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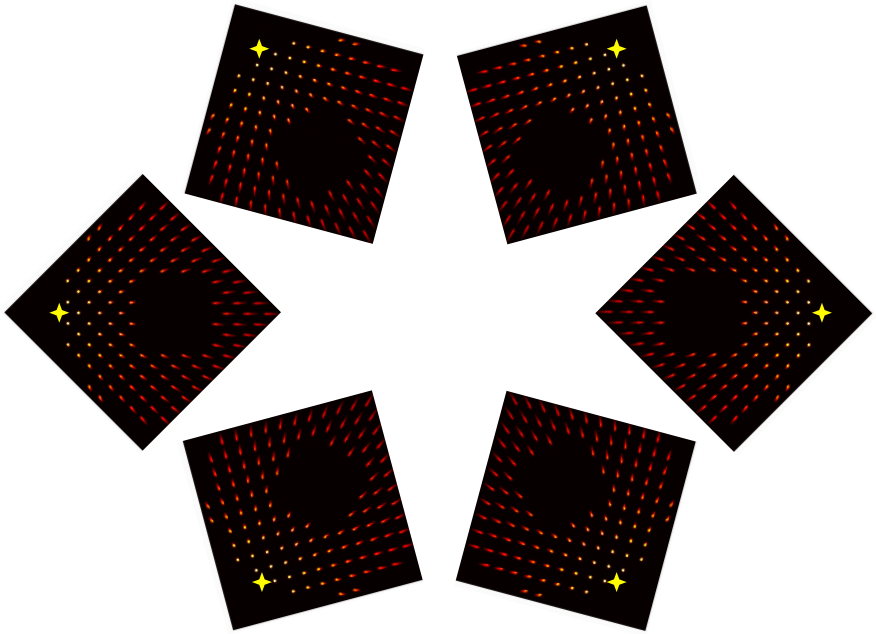

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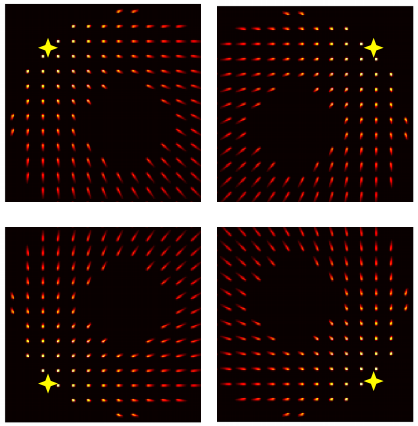

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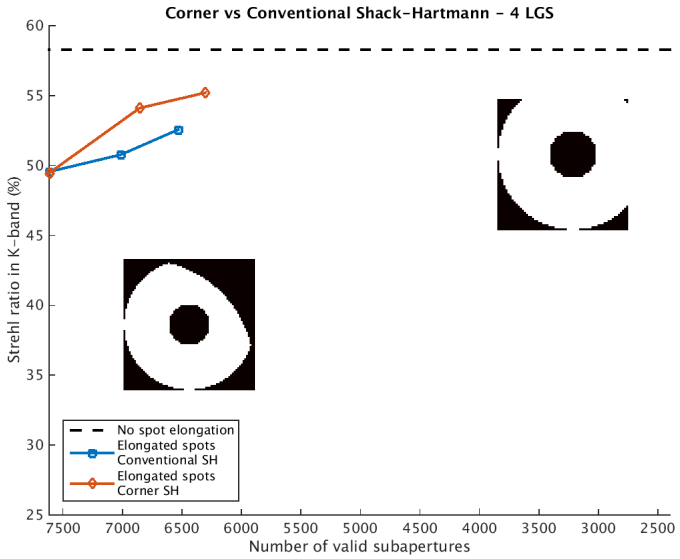

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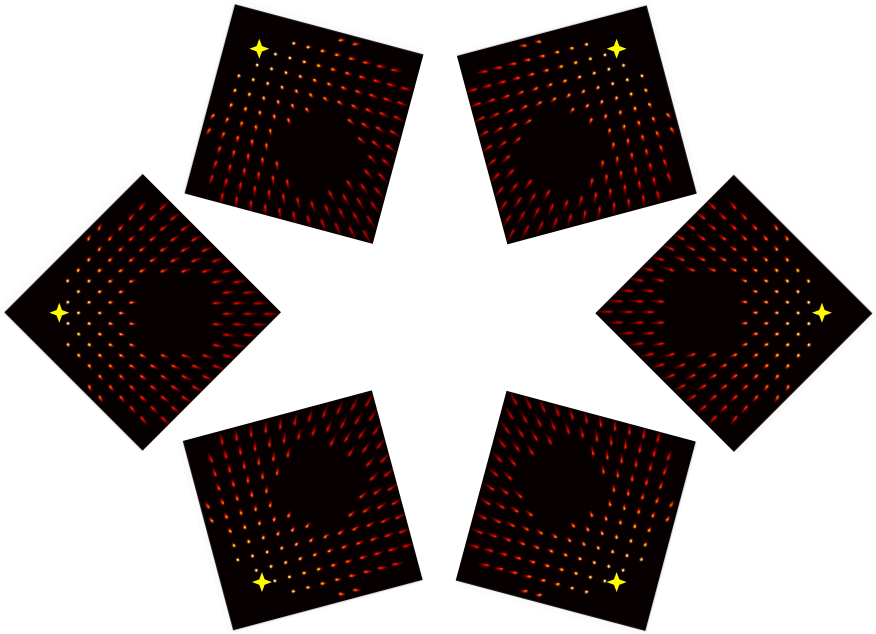

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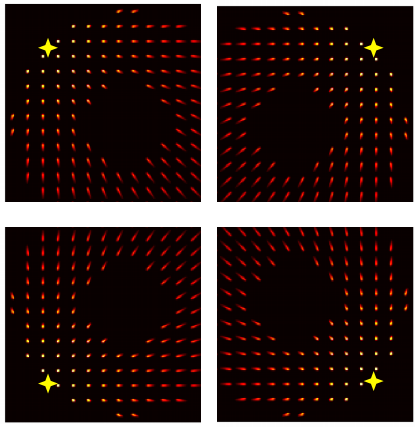

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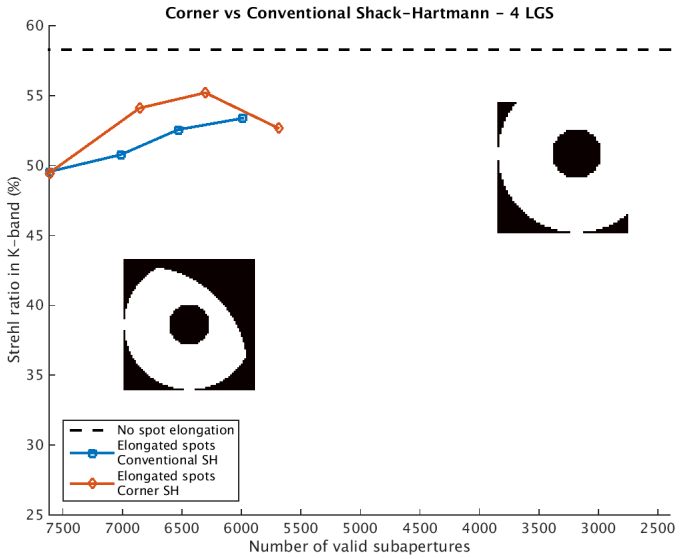

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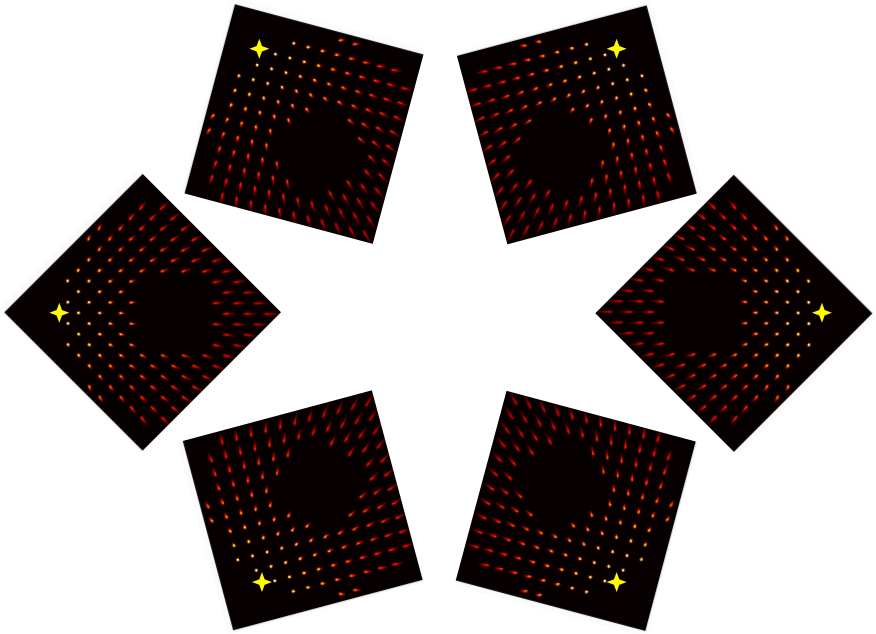

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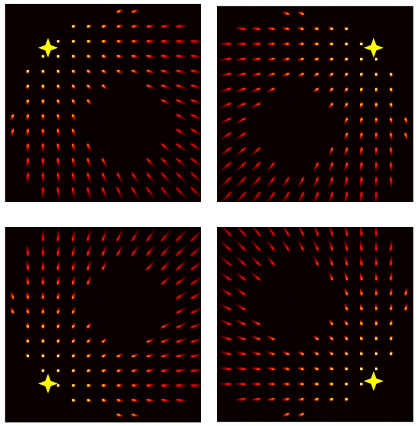

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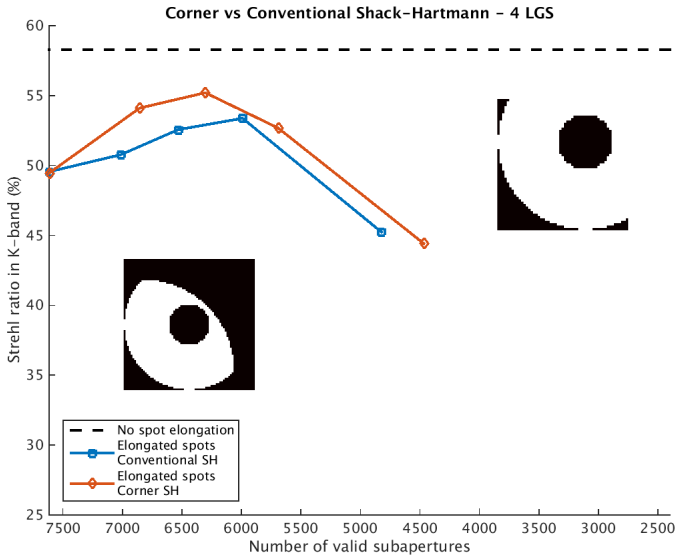

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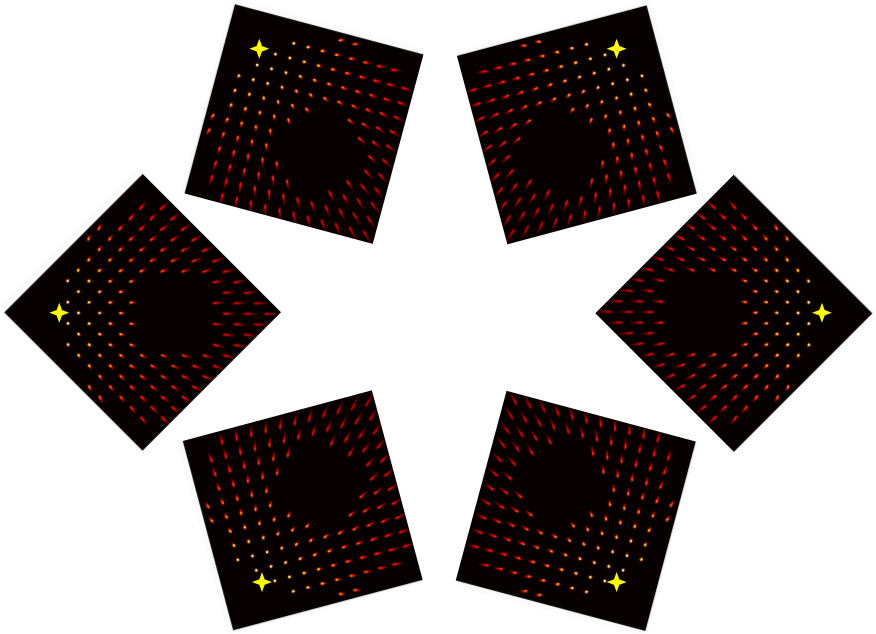

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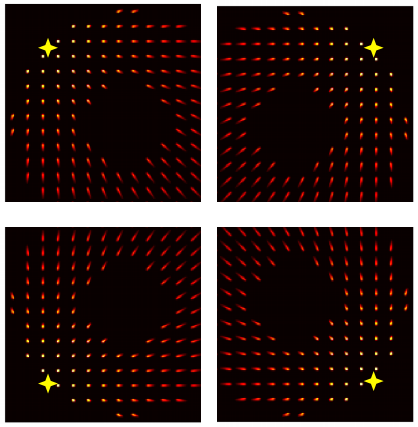

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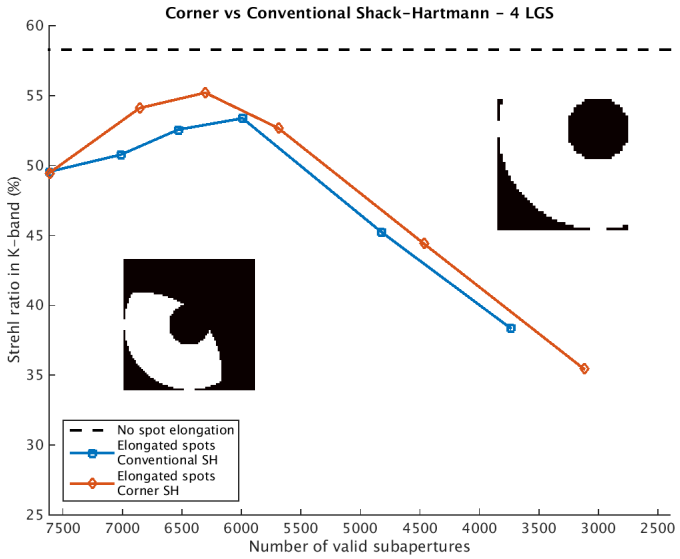

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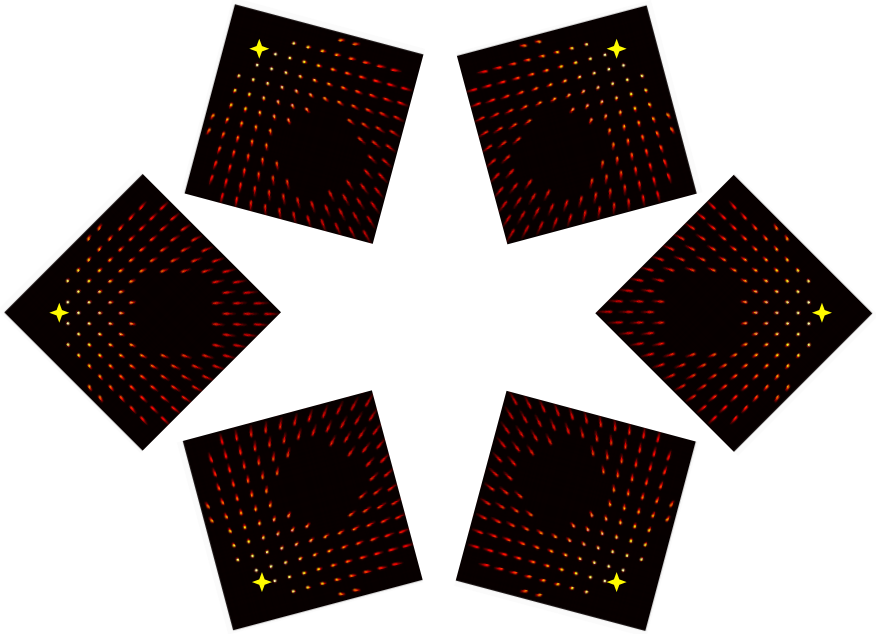

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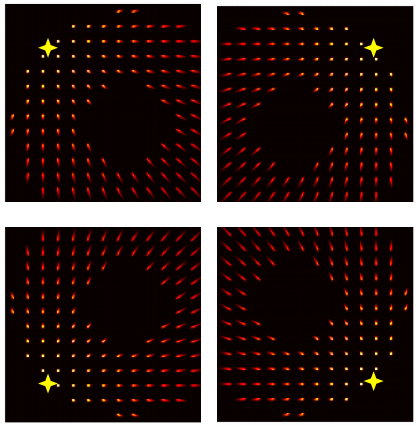

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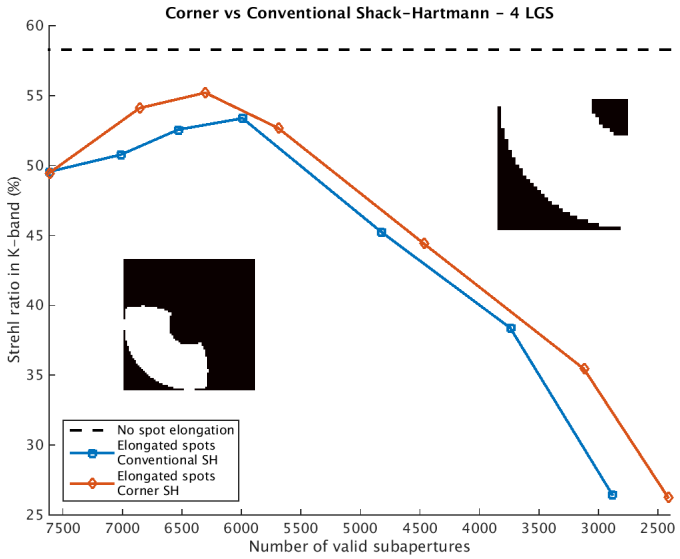

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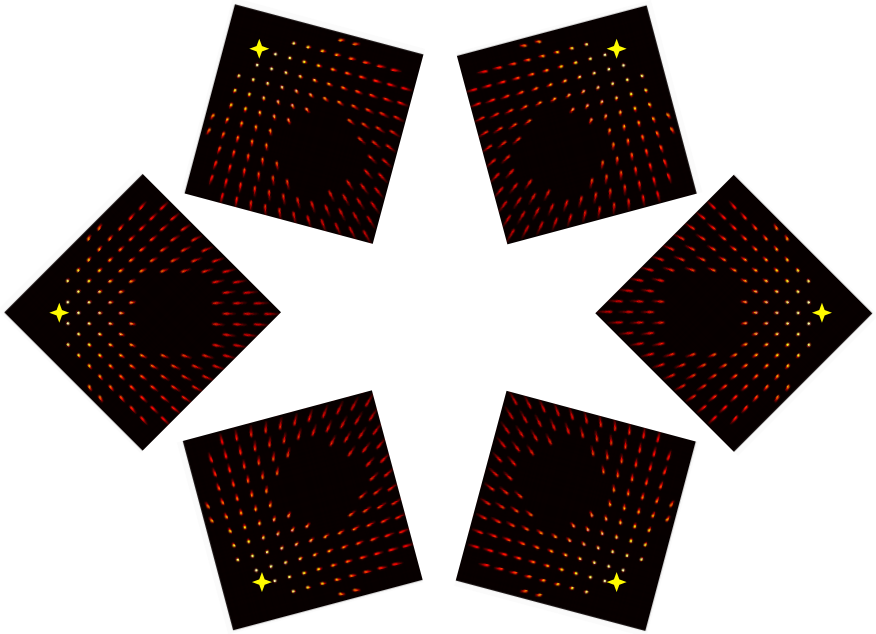

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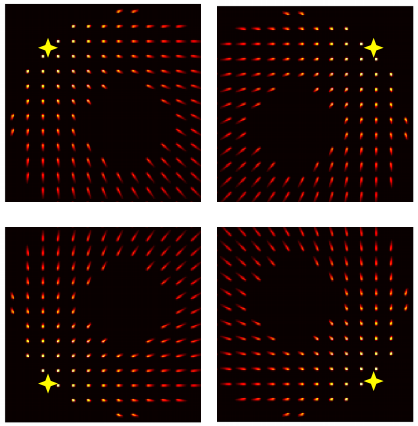
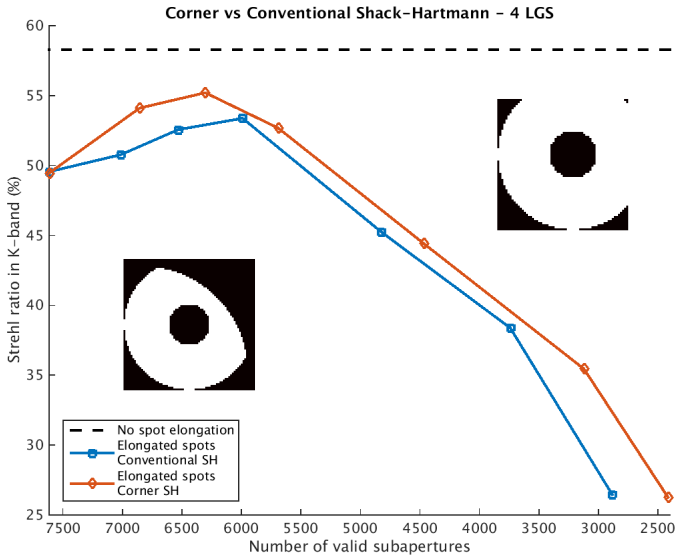


4 LGS configuration

Corner SH always better
than conventional SH
for a given # of subapertures



Conclusion

->Completely discarding 10-40% of the truncated subapertures actually increases Strehl Ratio (depending on Sodium profiles)

->Combining subaperture differential weighting and cropping allow us to reach quasi-ideal performance on most sodium profiles

-> Help release constraints on Truth Sensor design: 8(x8) is enough !

-> Corner Shack-Hartmann to optimize pixel usage

On-going work

- Thorough analysis of more parameters (truncation, d/r0, central obscuration, asterism diameter, #LGS…)

- Advanced centroiding algorithms/strategies

- Actual ELT M4 geometry (see N. Schwartz talk tomorrow 12:30)

- Temporal aspects, sodium profil evolution during the night

Gracias

The authors thanks the European Research Council for its support through the grant ERC-STG-2015 ICARUS 678777