LGS spot truncation mitigation in ELT Wide Field Adaptive Optics

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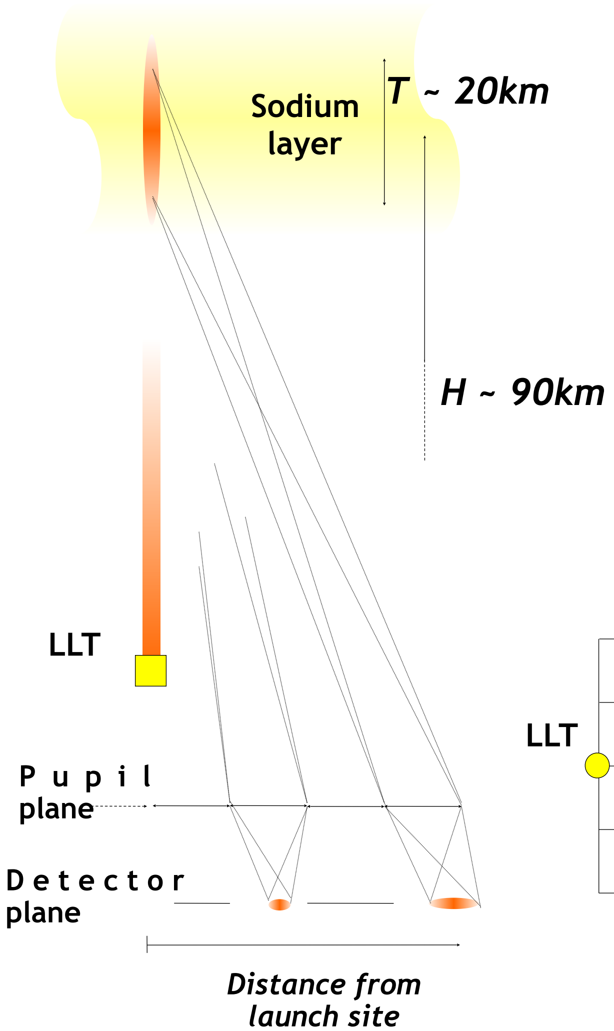
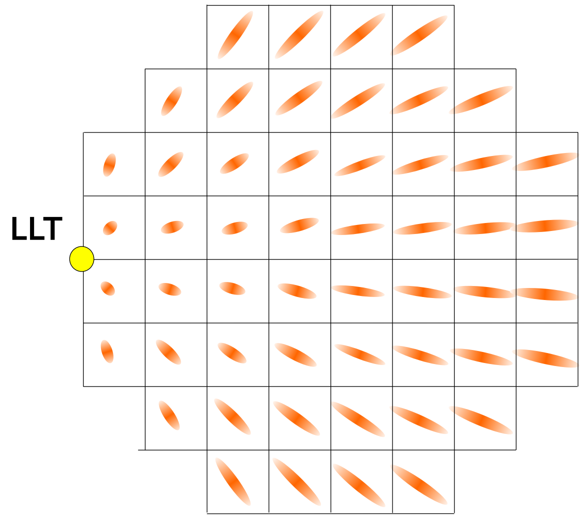
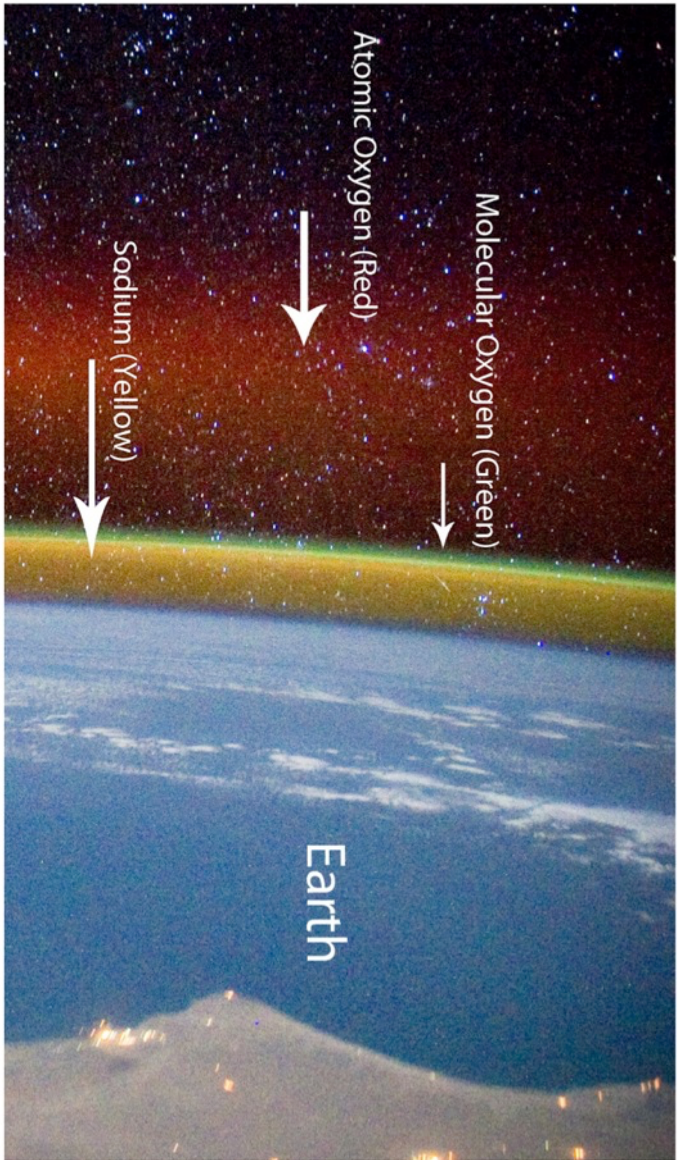
2 ONERA - The French Aerospace Lab

LGS Spot elongation



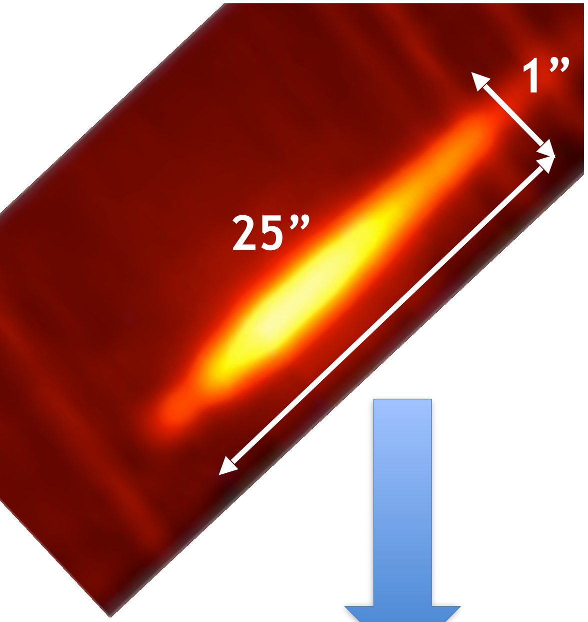
Predicted spot
elongation pattern





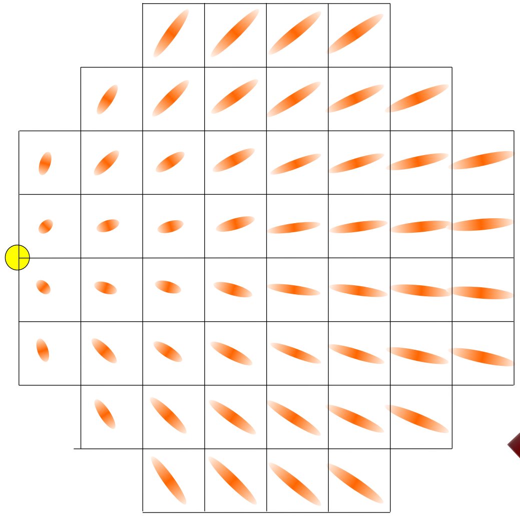
LGS Spot elongation

On a ~40m telescope

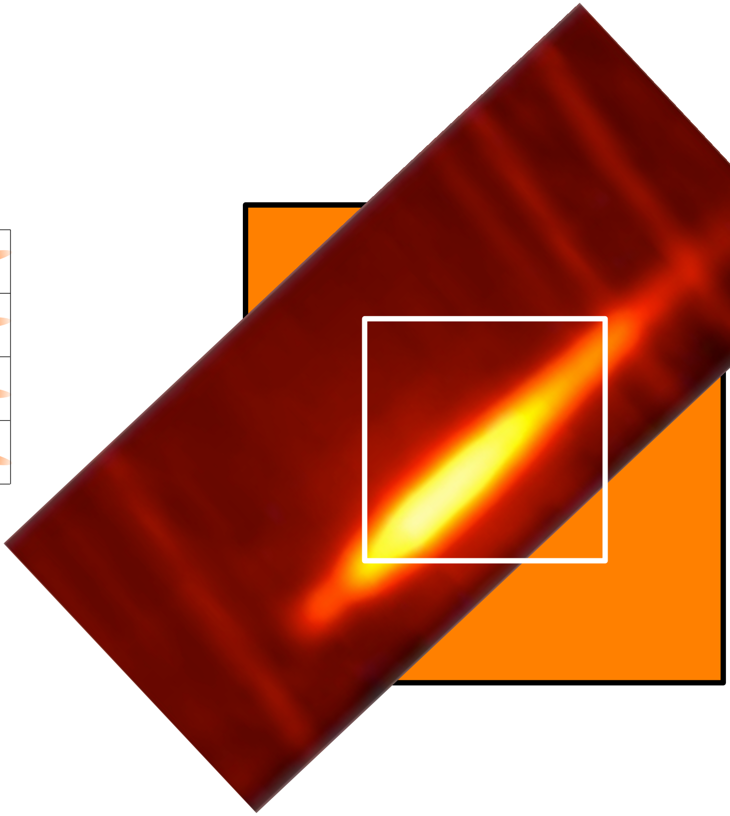


Ideally, we need subapertures with 25x25 pixels of ~1”

For 80x80 subapertures, we need 2000 x 2000 pixels



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



Strong truncation

Elongated spots cropping

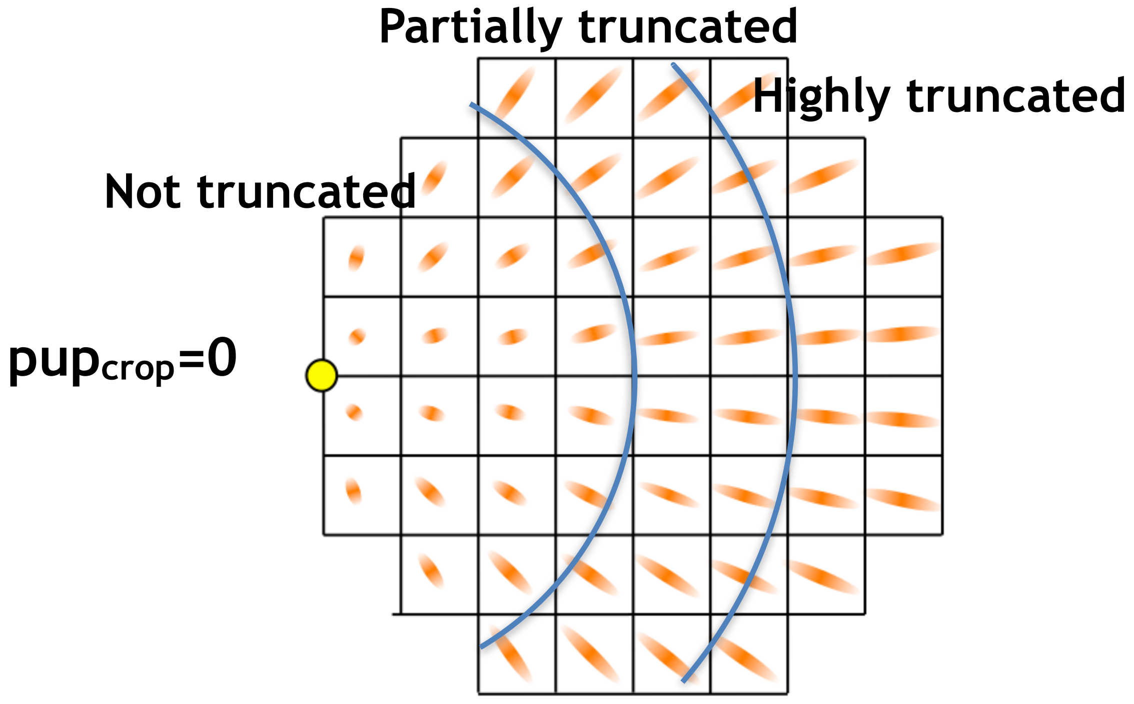
What if we completely discarded the biased measurements from the subapertures with the most truncated spots ?

Elongated spots cropping

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

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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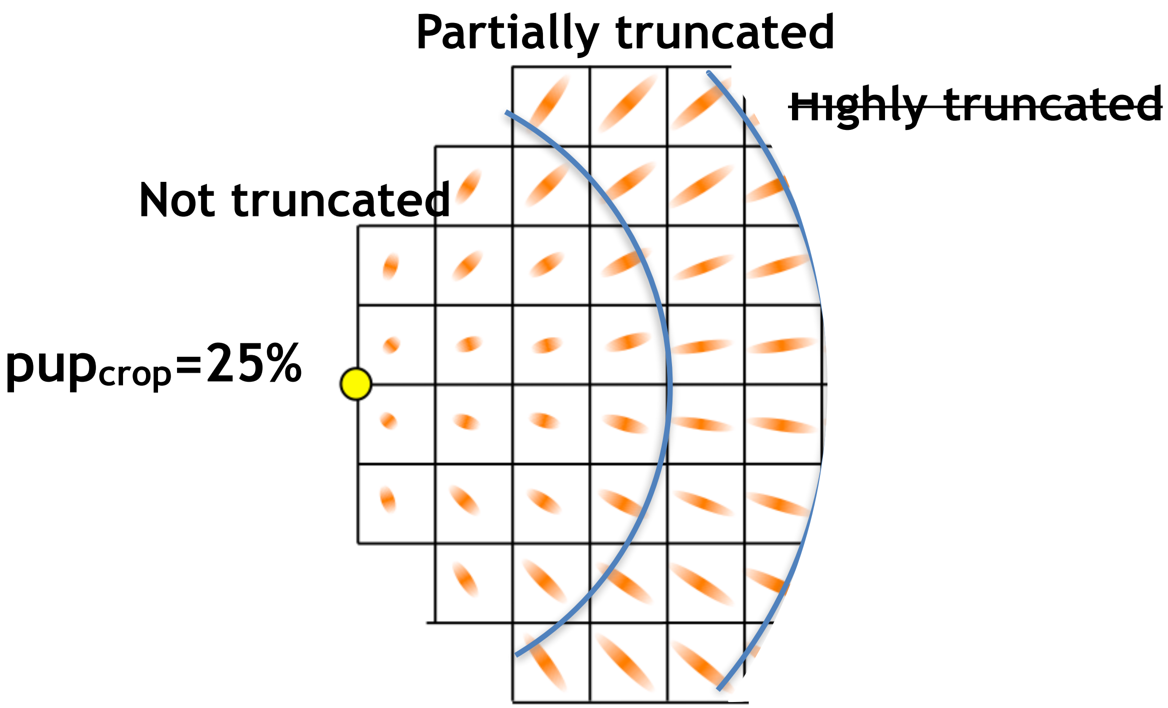

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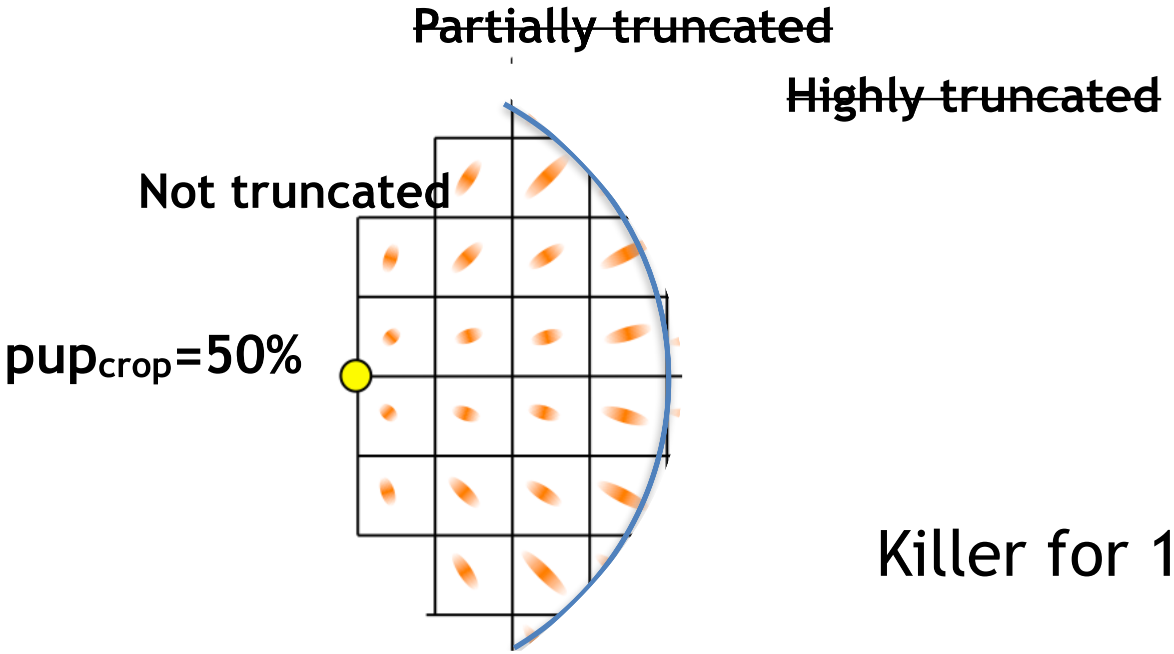

Killer for 1 WFS…

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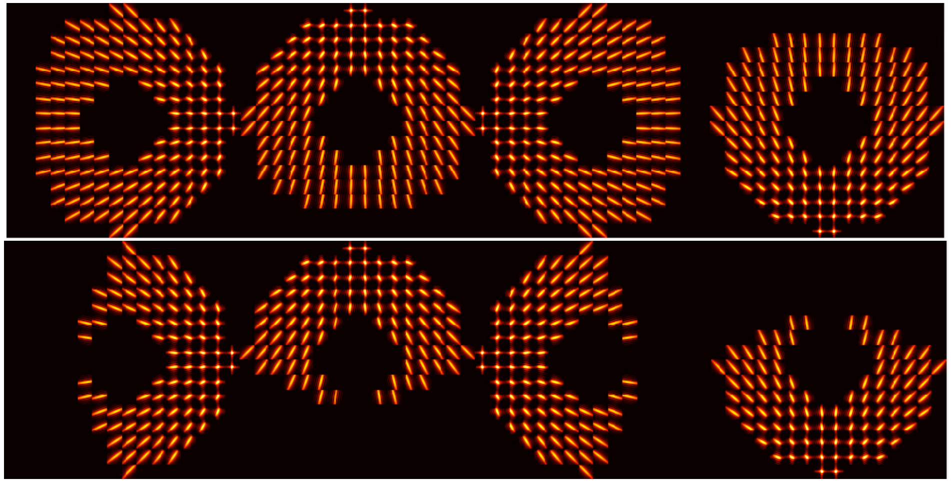
But we have redundancy

pup_{crop}=10%

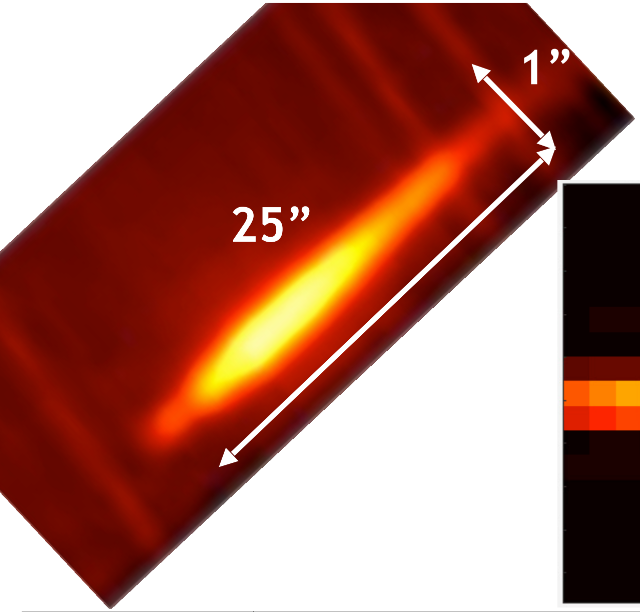
pup_{crop}=30%

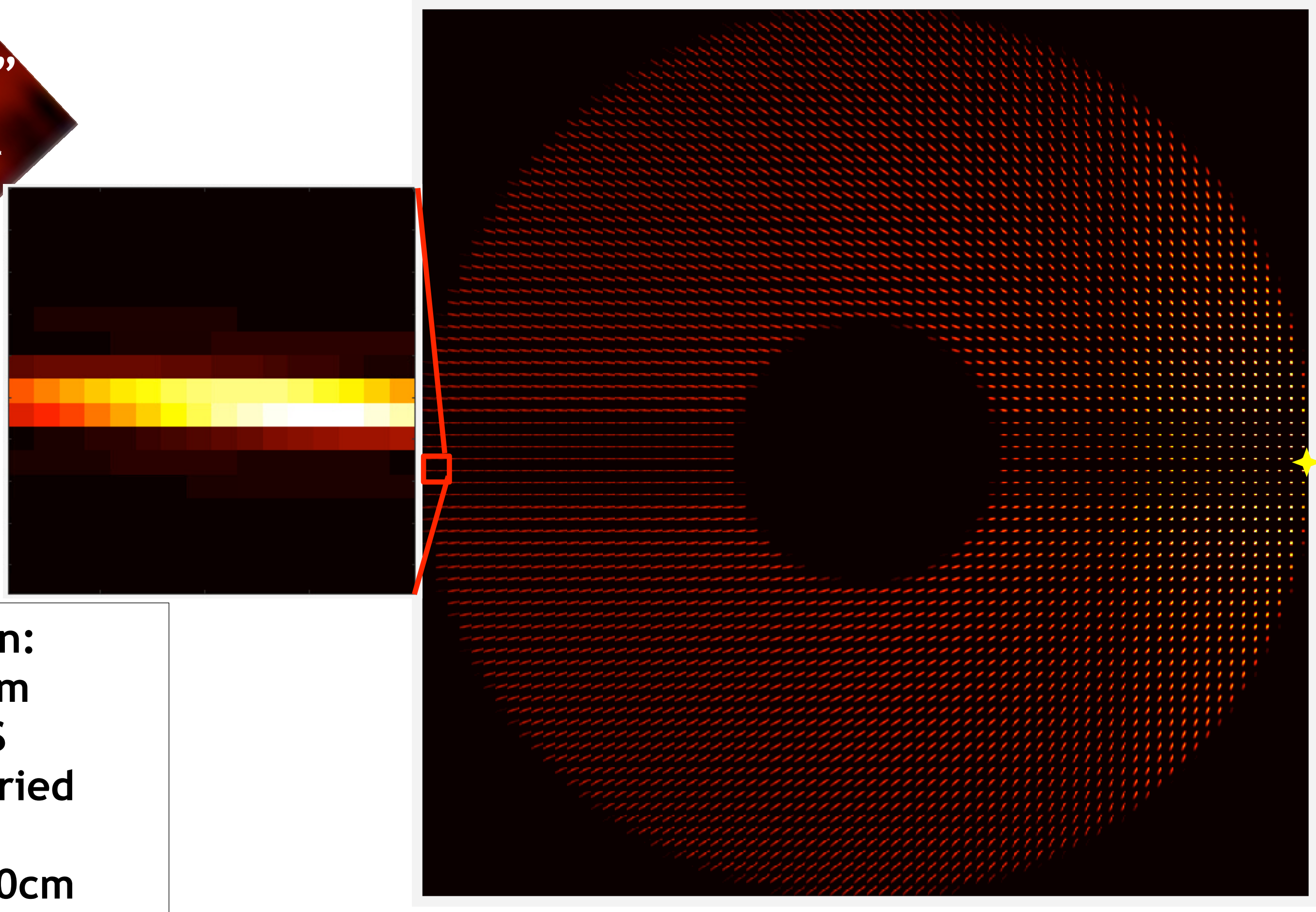


WFS$_1$ WFS$_2$ WFS$_3$ WFS$_4$

E2E simulations (OOMAO)

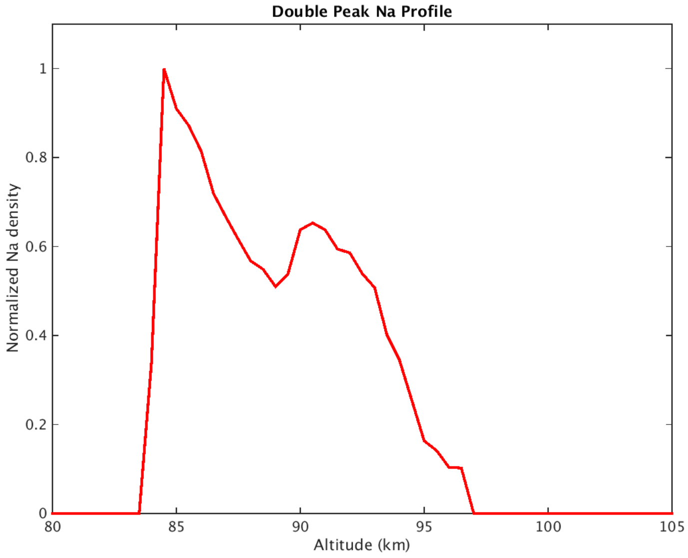
On a ~40m telescope





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

Elongated spots cropping



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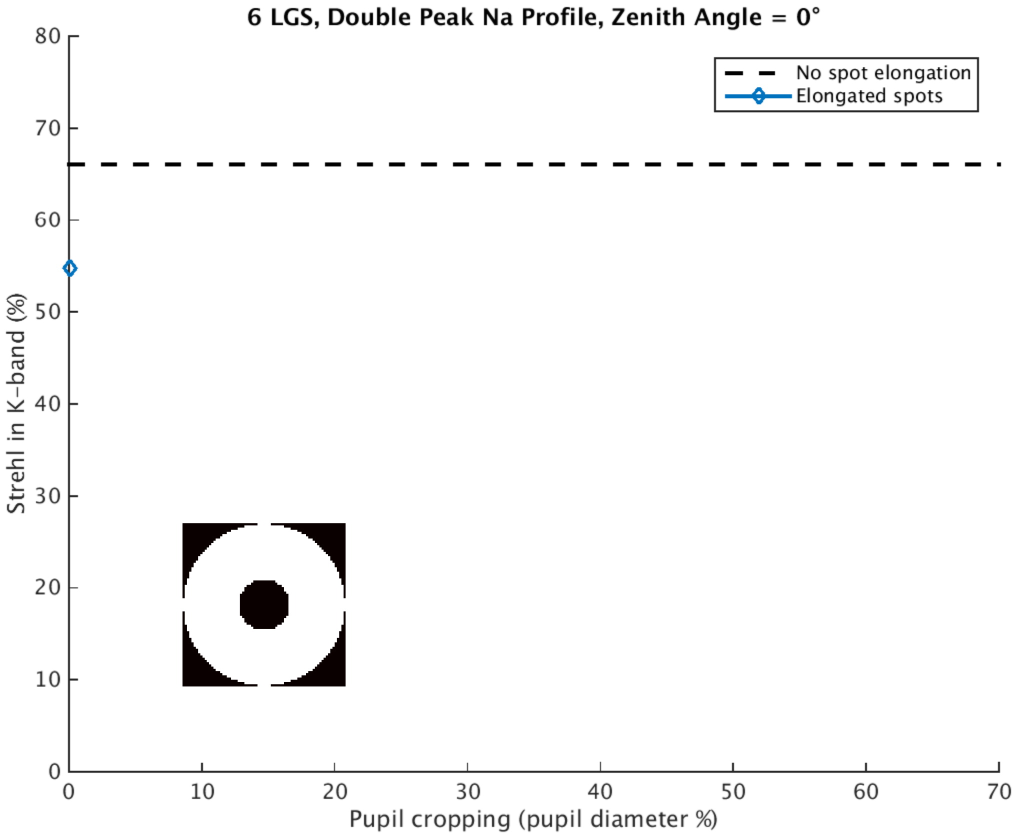

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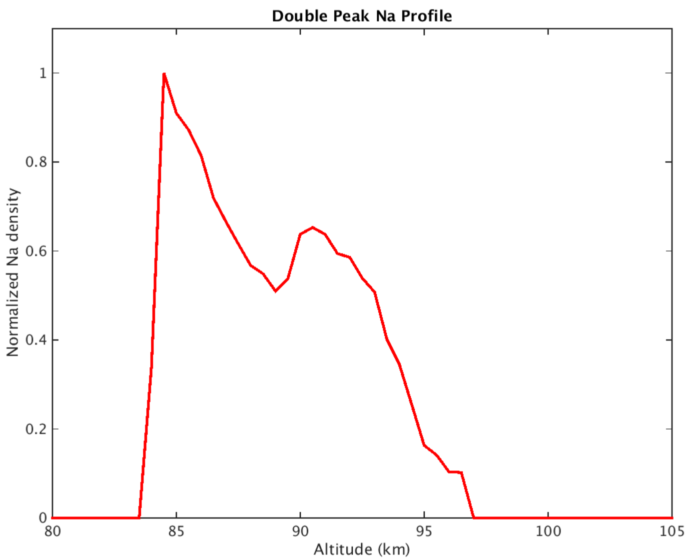

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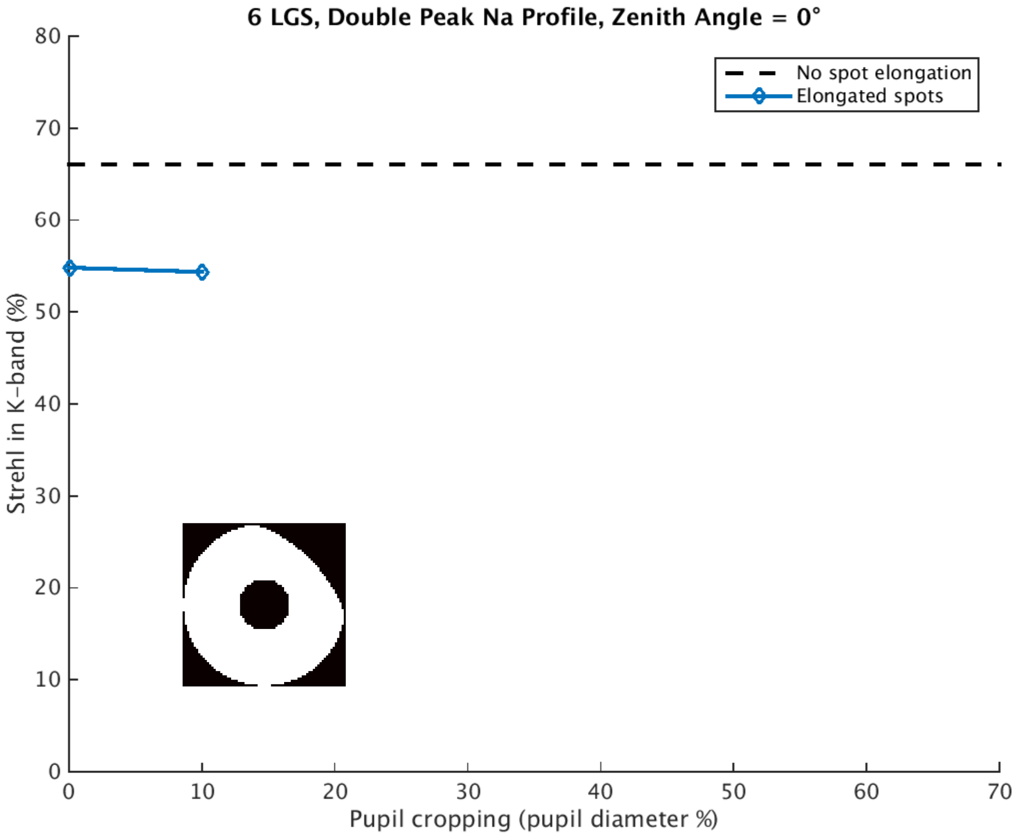

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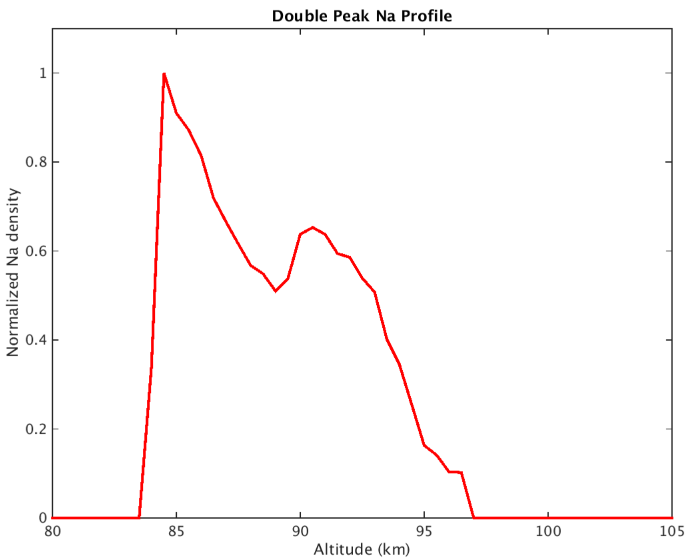

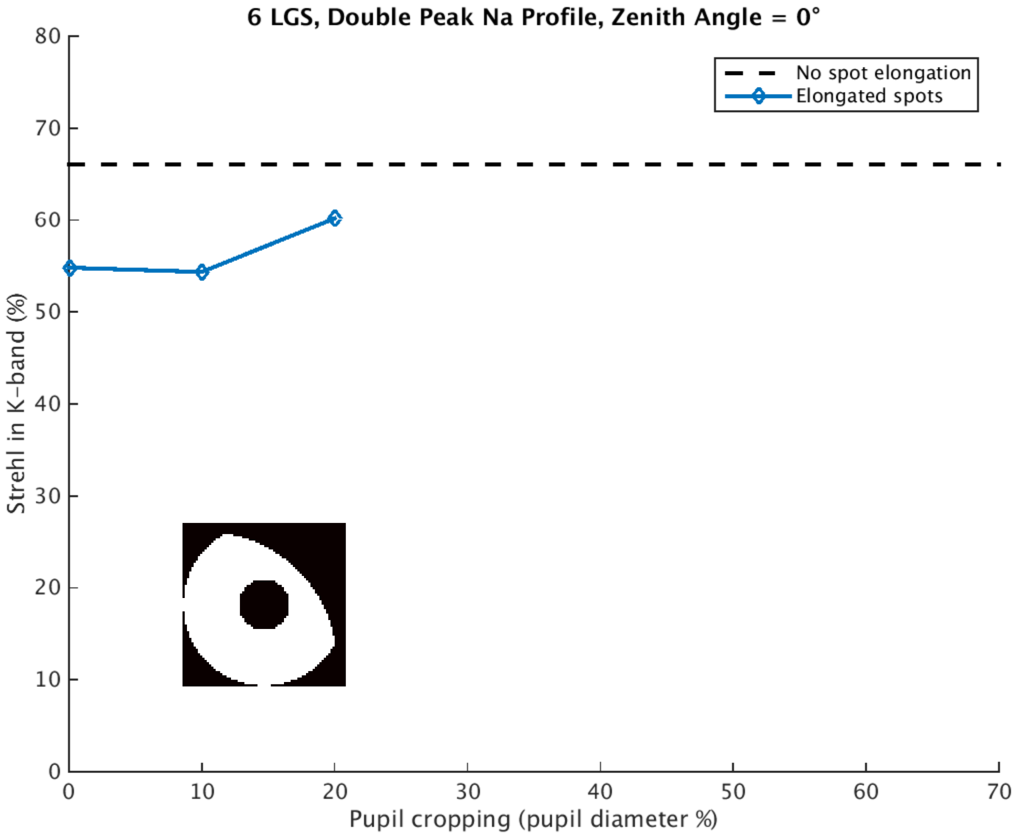

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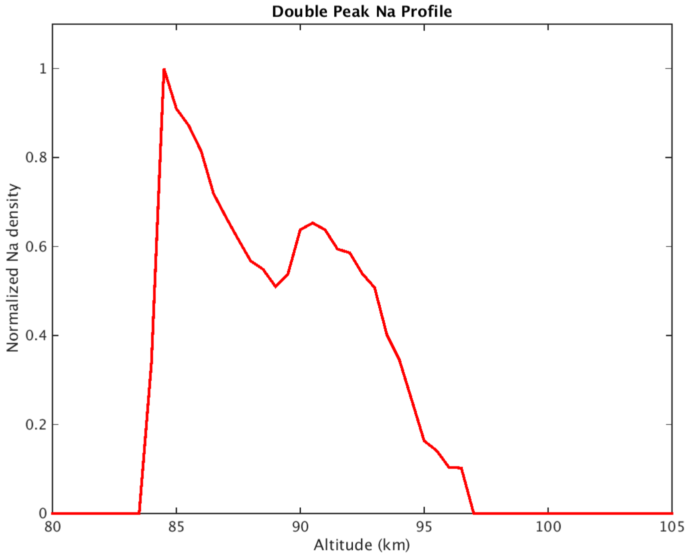

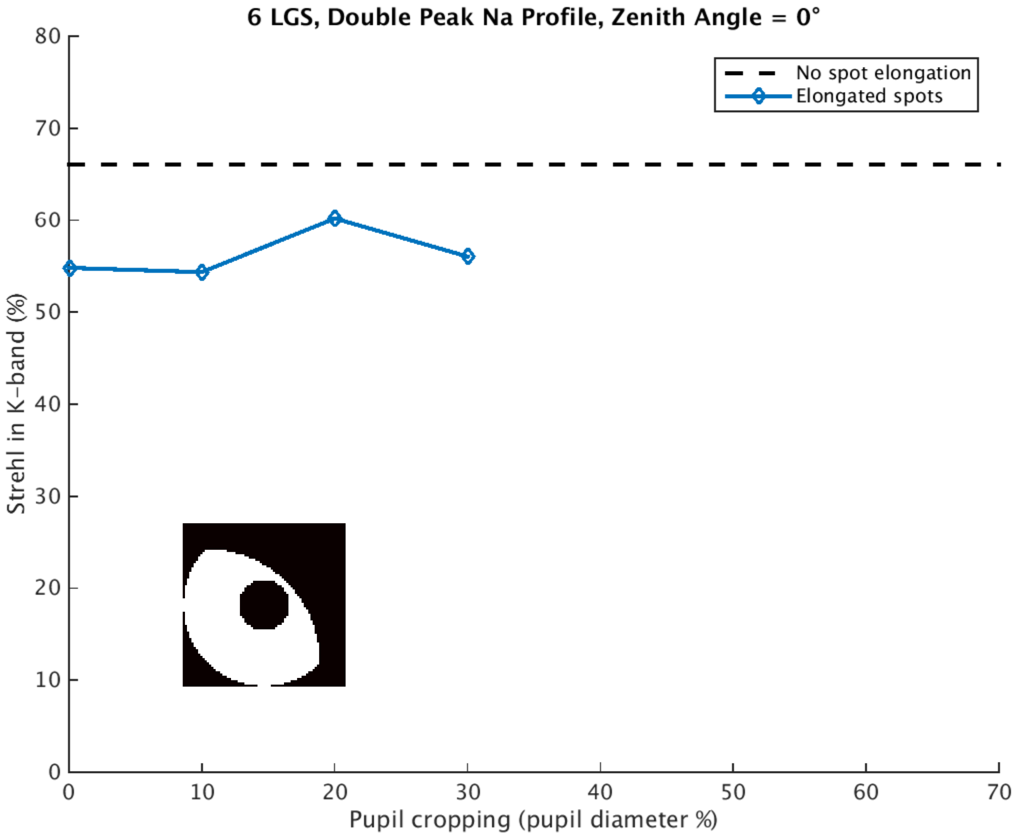

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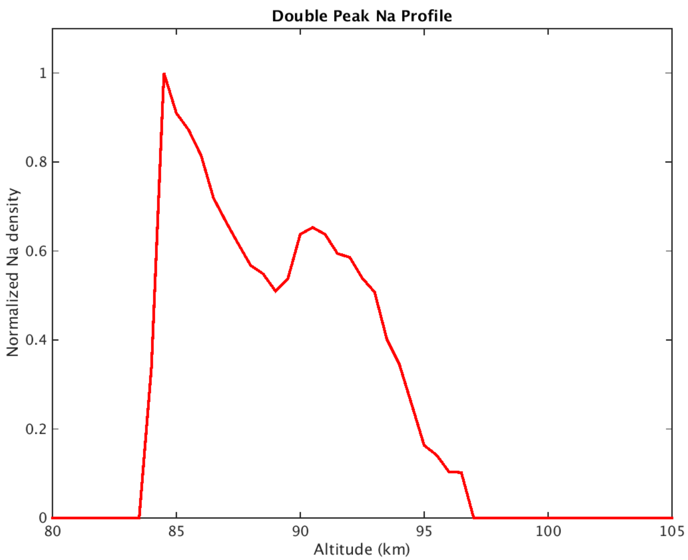

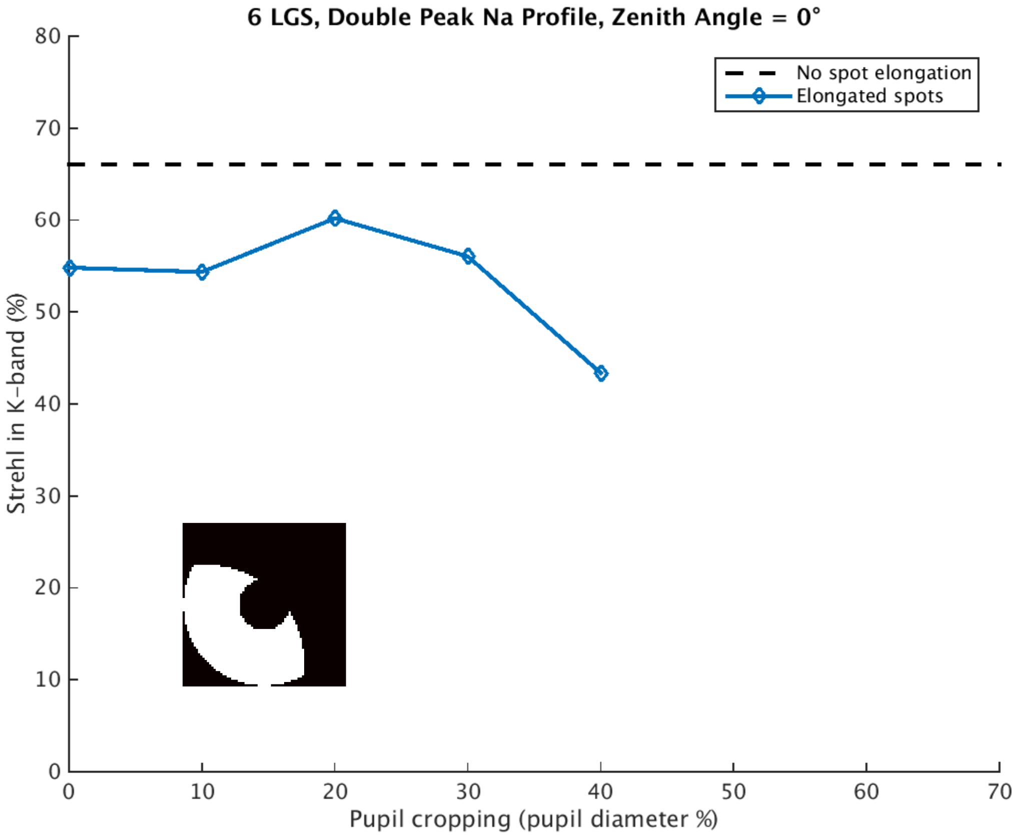

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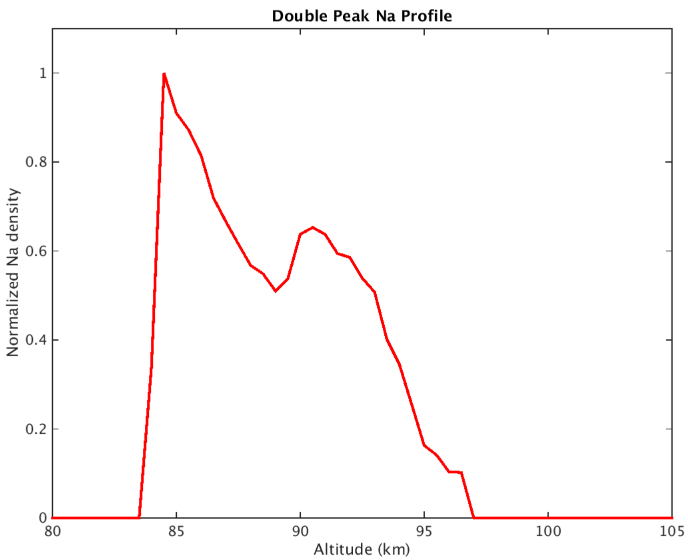

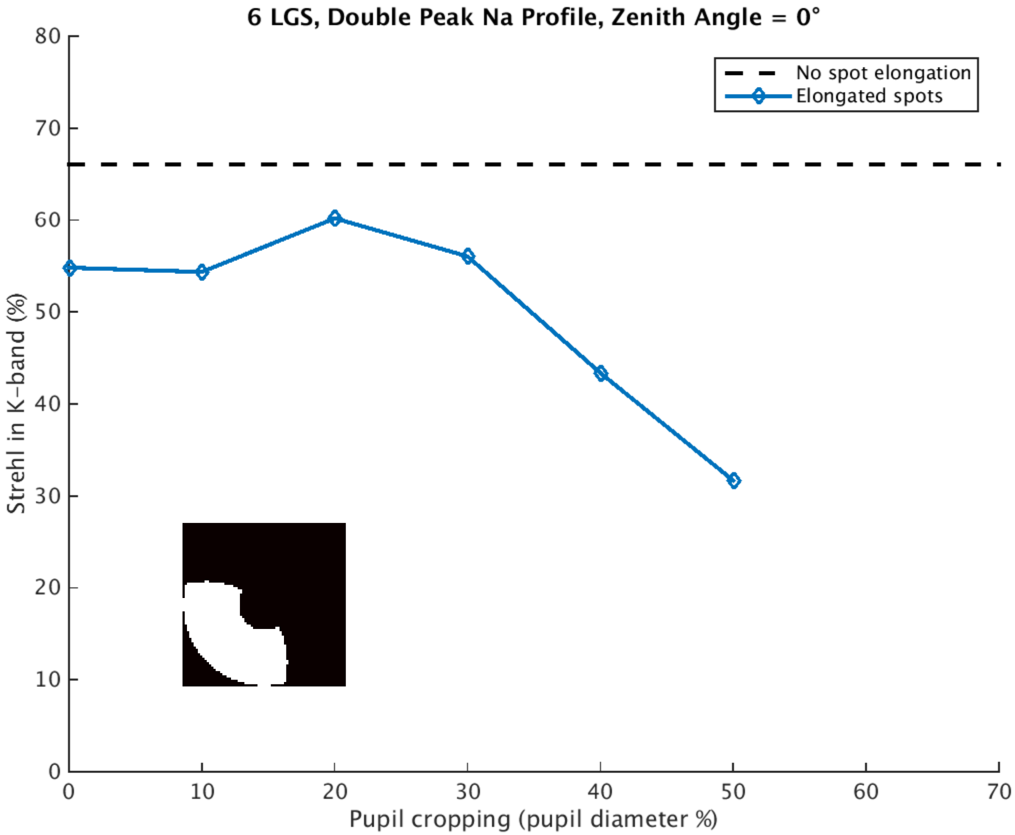

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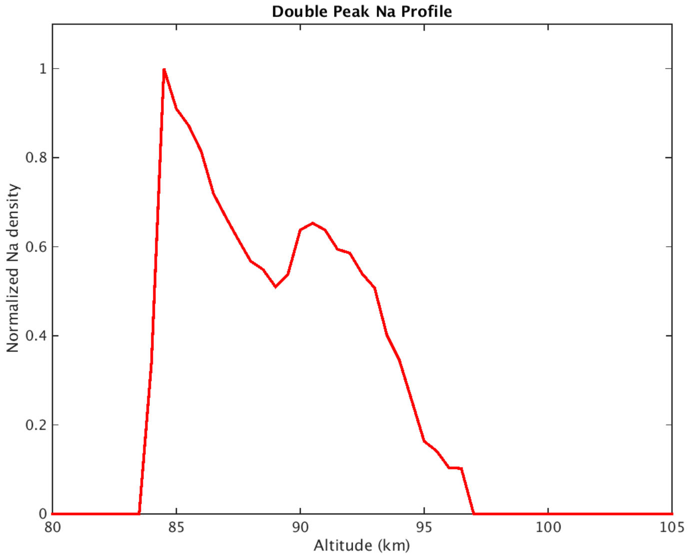

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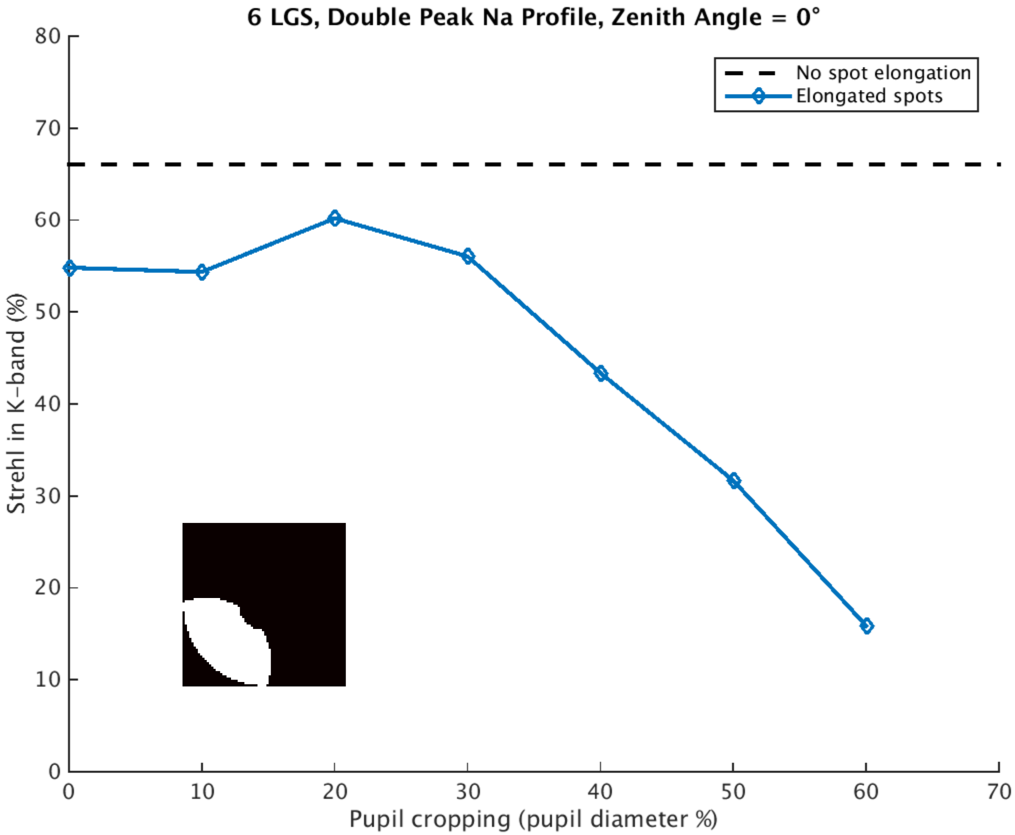

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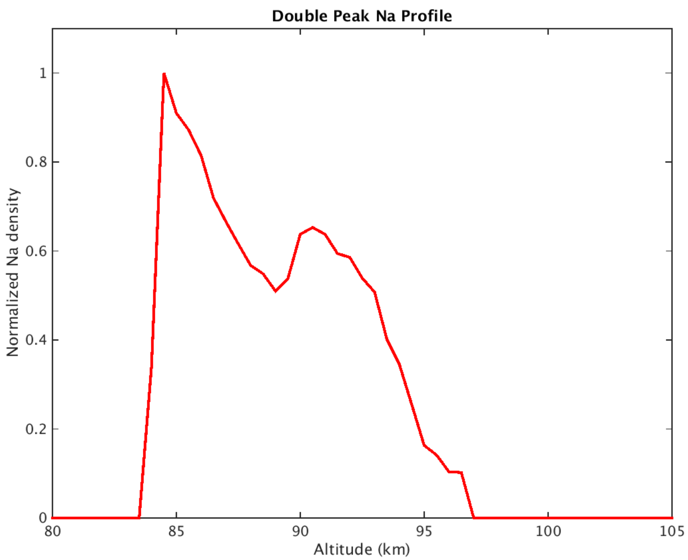

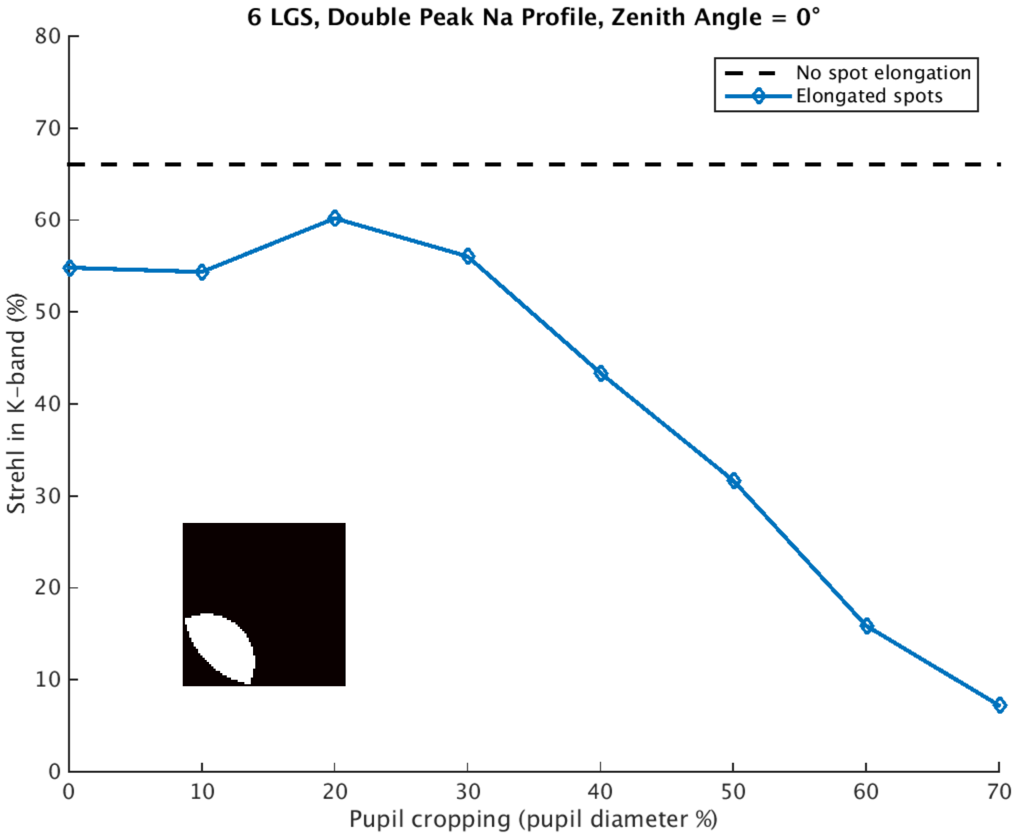

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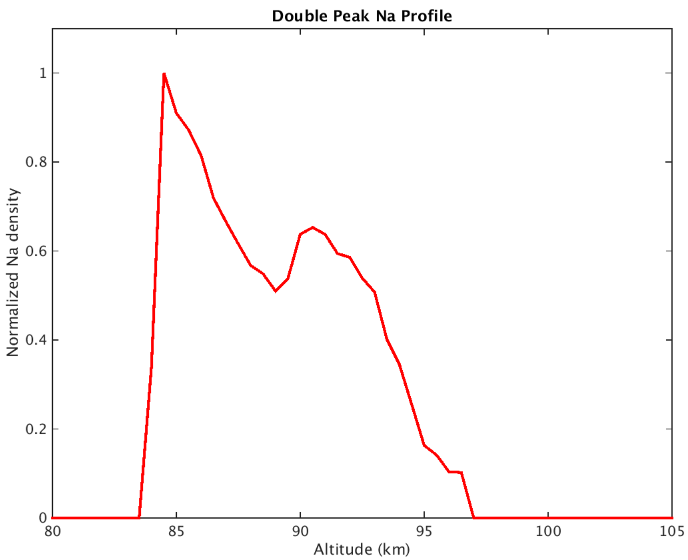

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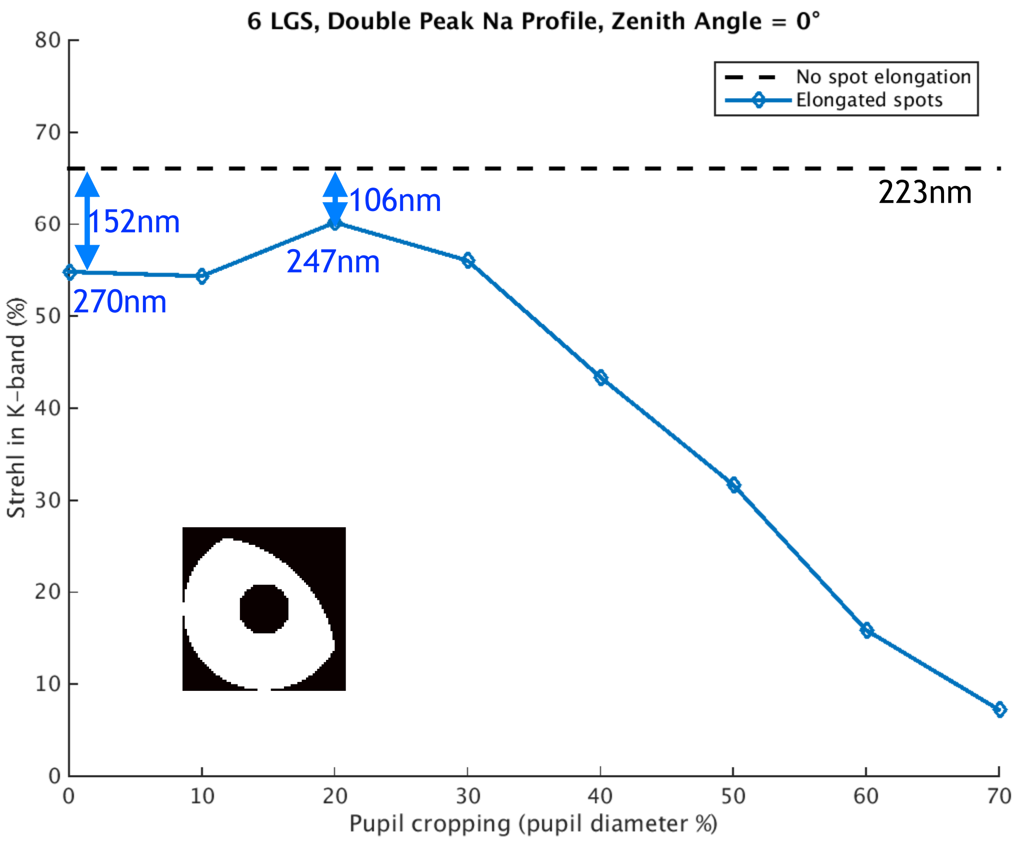
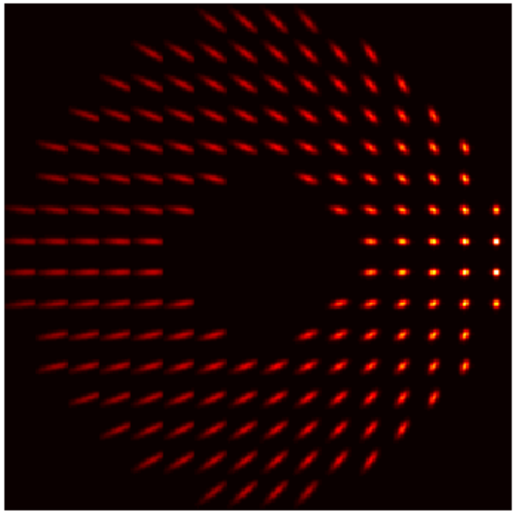


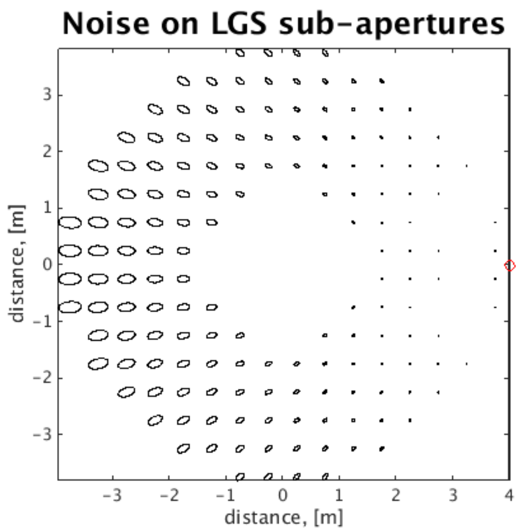
Performance increases as we discard subapertures with too large an elongation/truncation

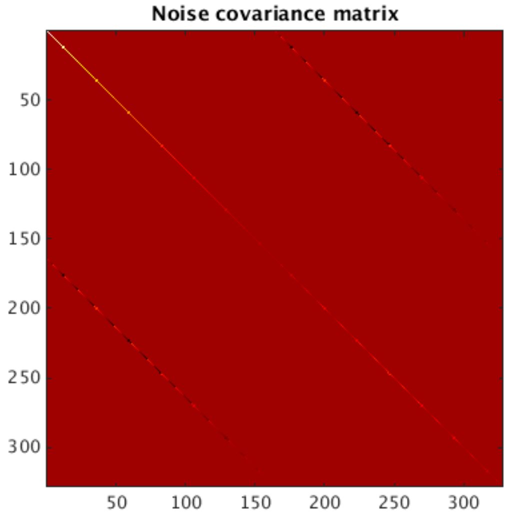
WFE due to elongation reduced from 152nm to 106nm RMS

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







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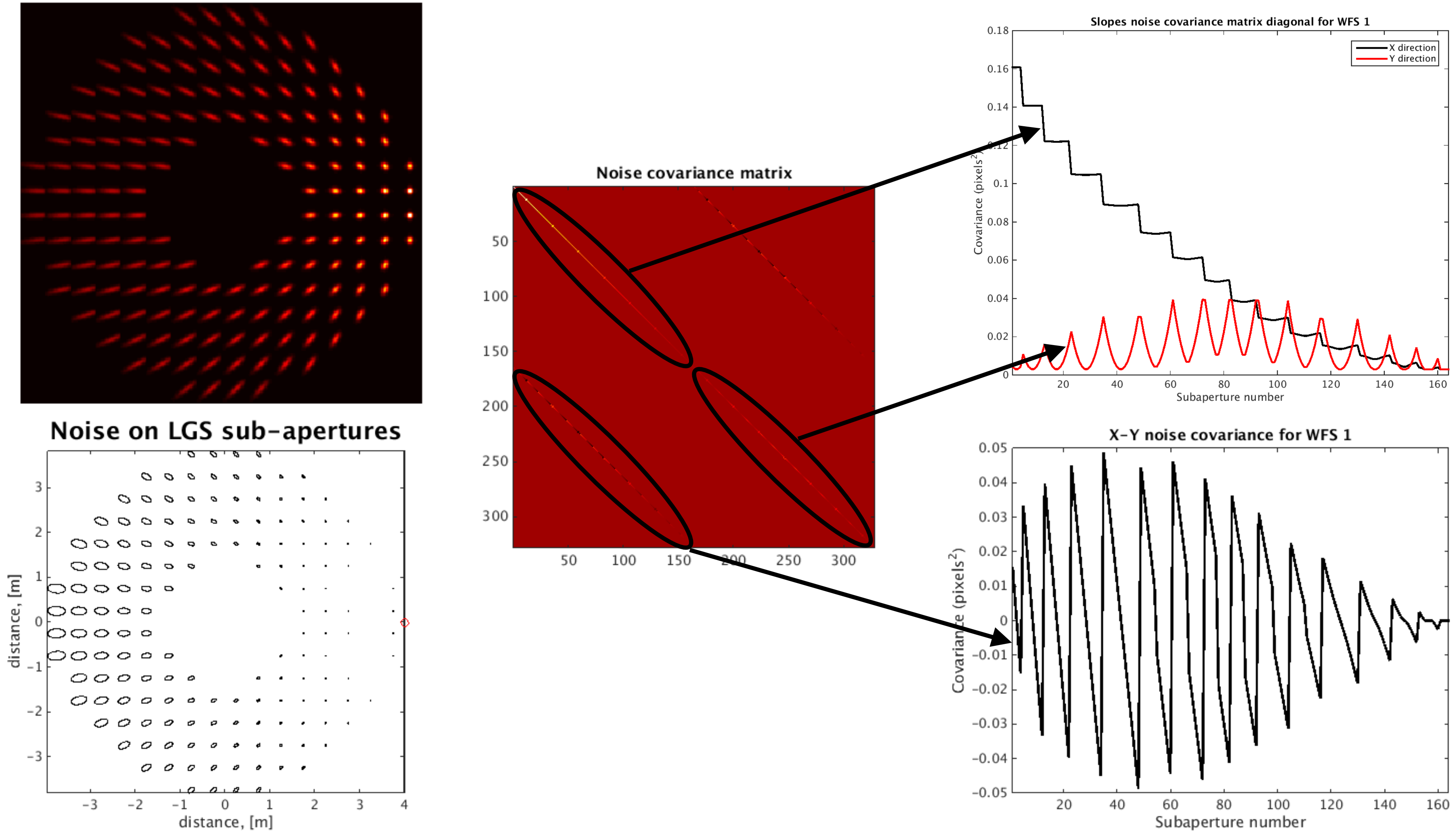

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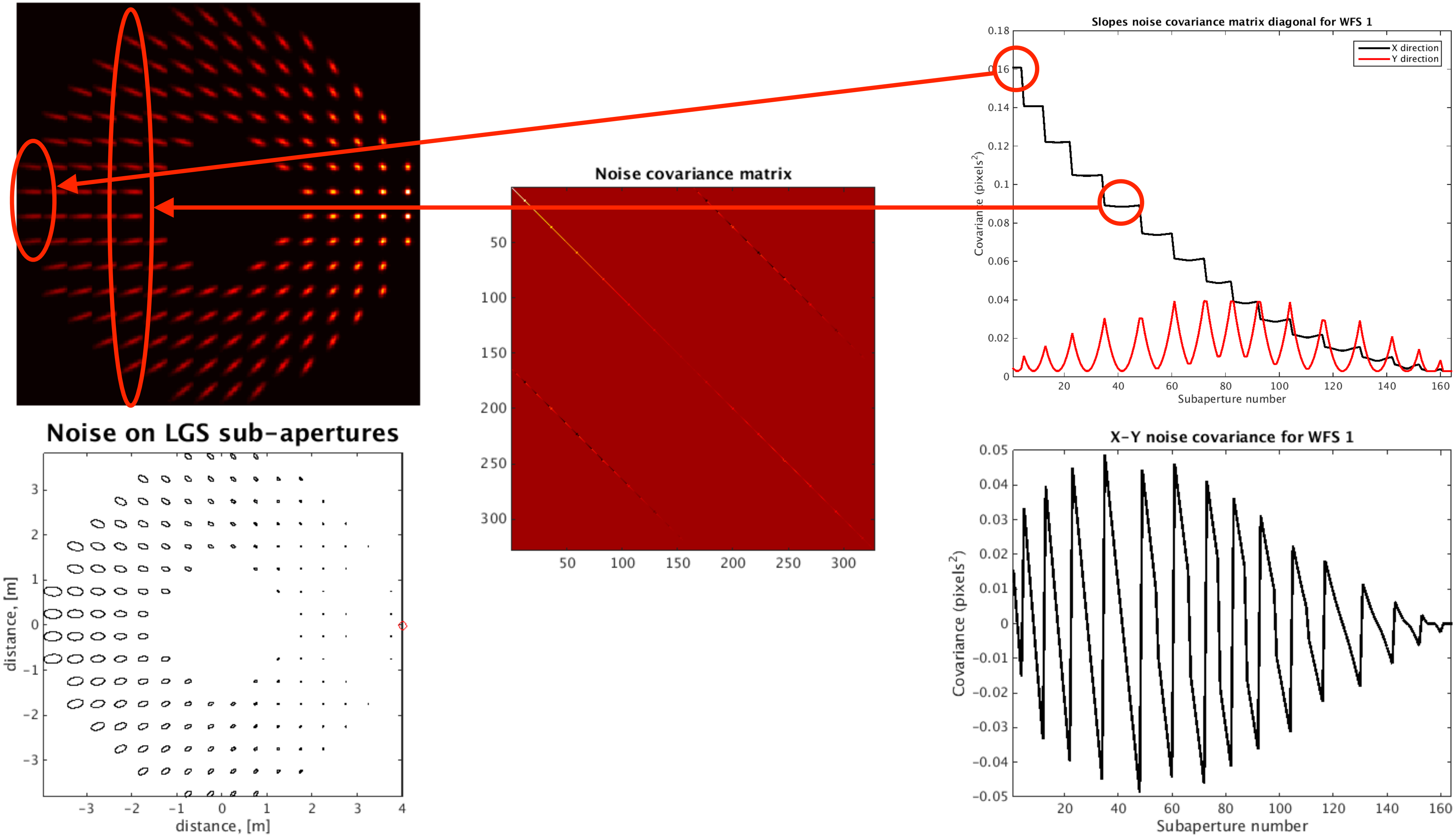

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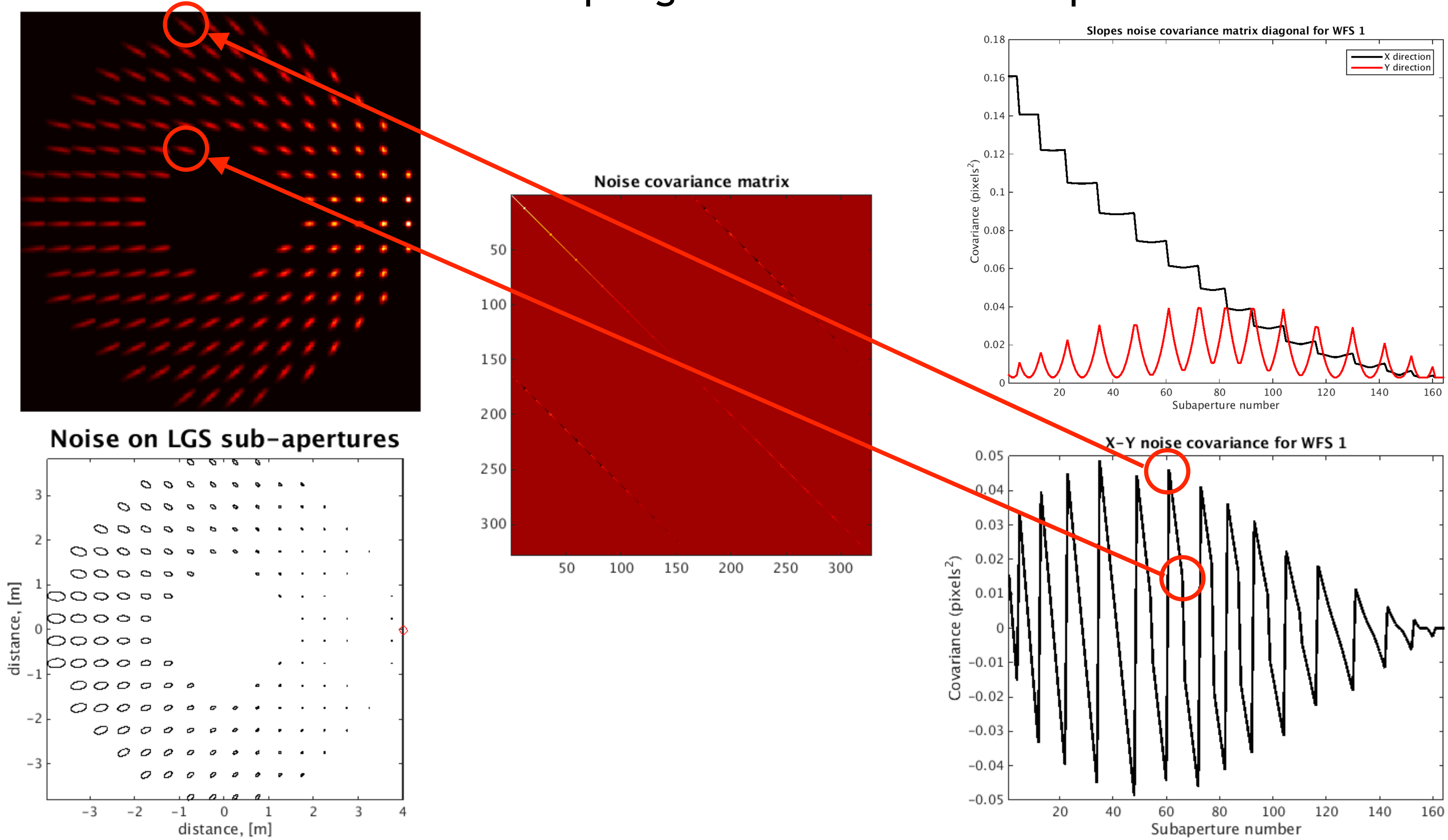
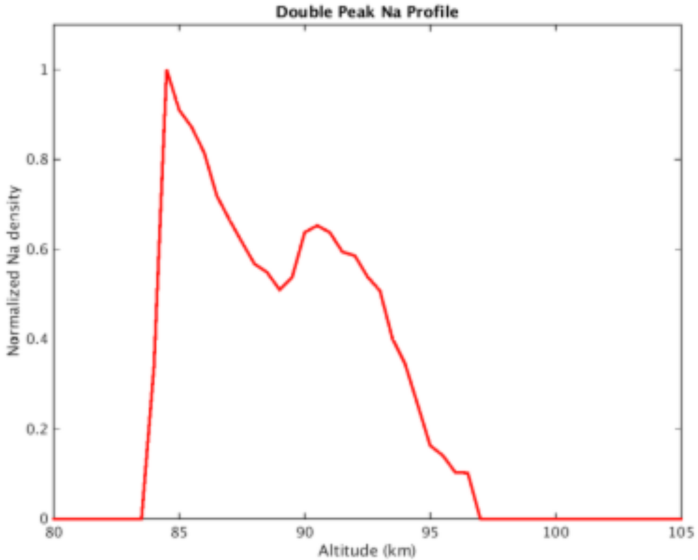
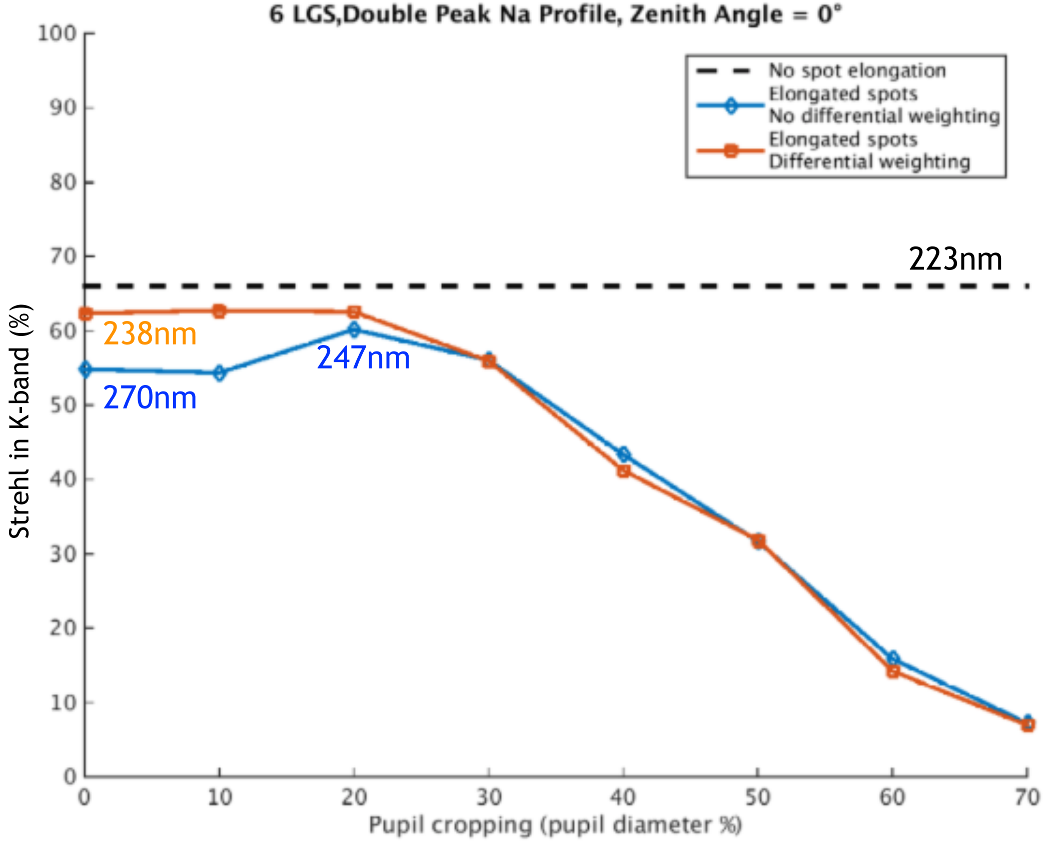


Subaperture weighting+cropping





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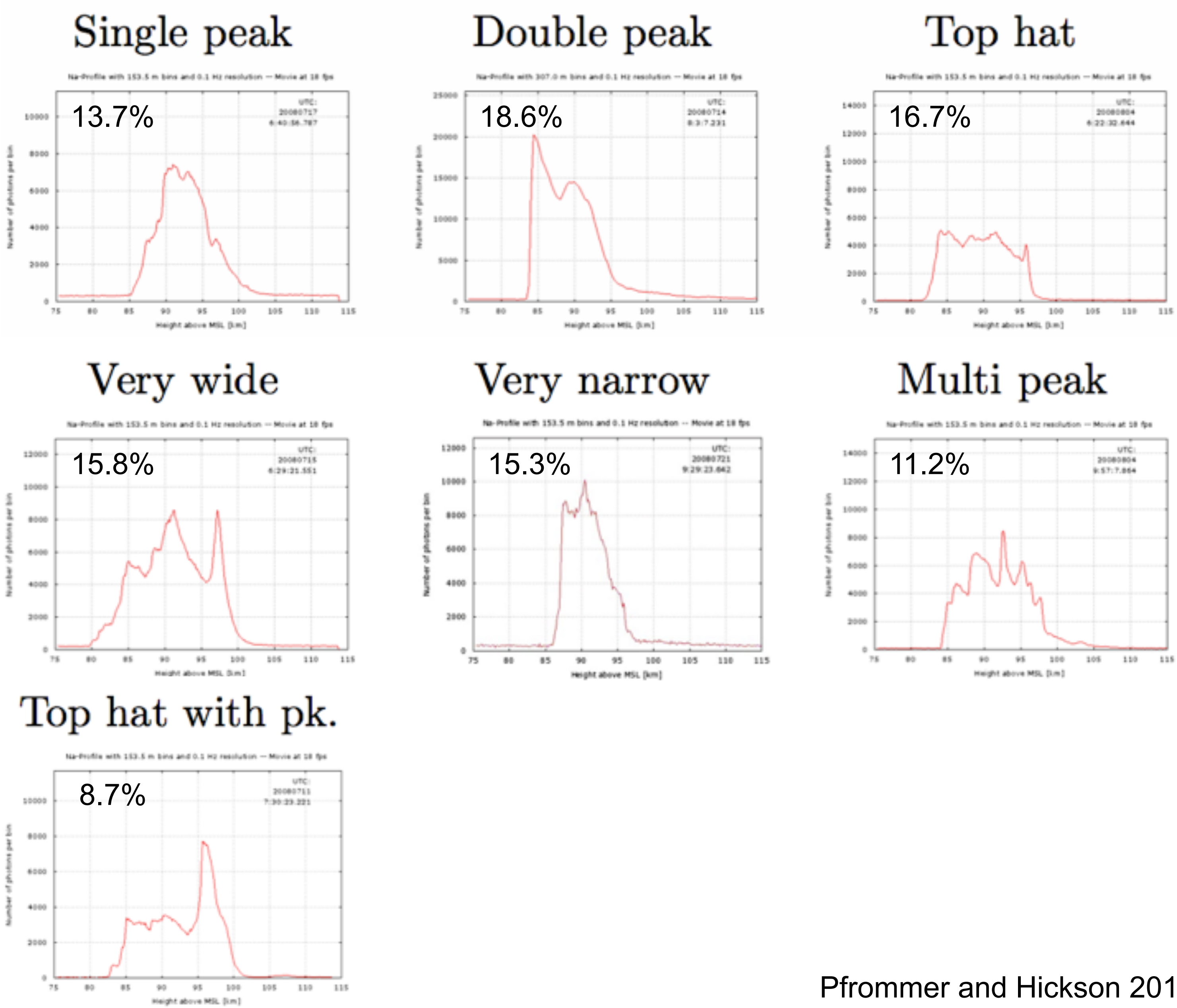
30% central obscuration
High flux

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

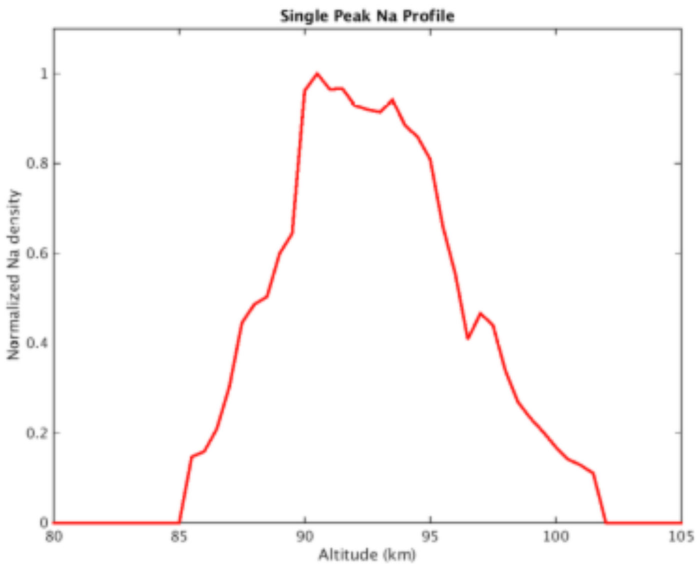
but Na profile not always bimodal !

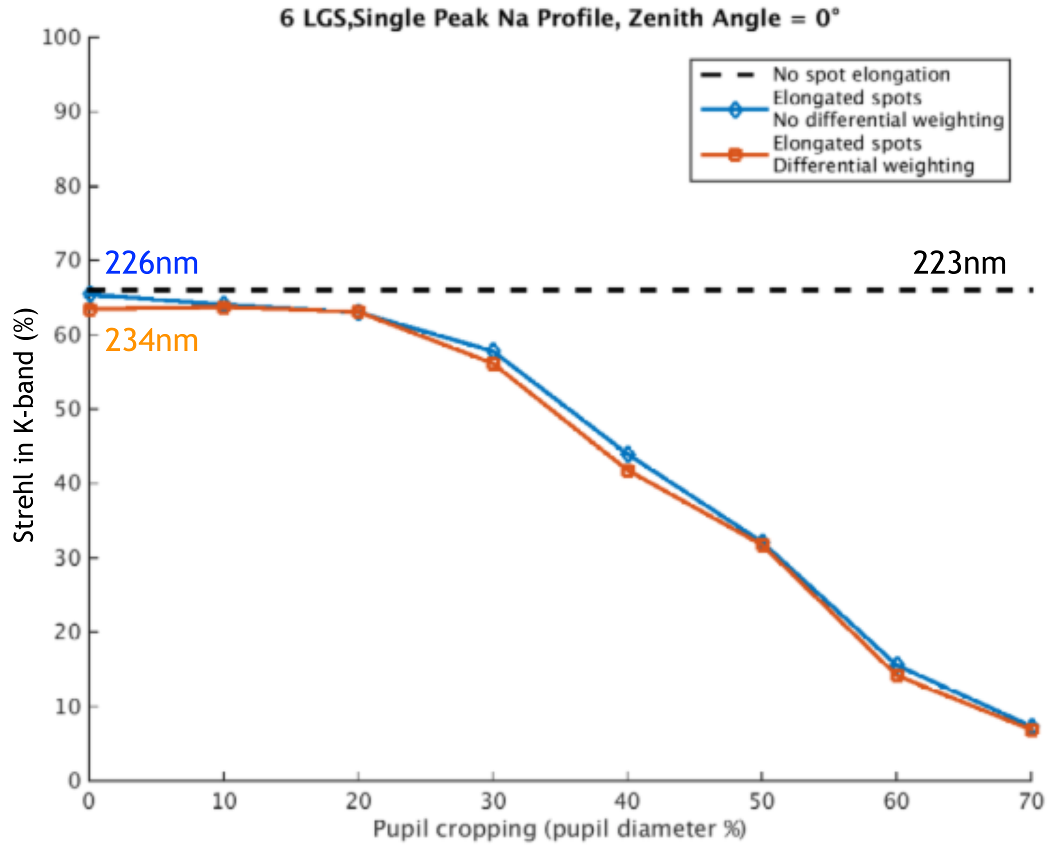
Subaperture weighting+cropping



Pfrommer and Hickson 2011

Subaperture weighting+cropping





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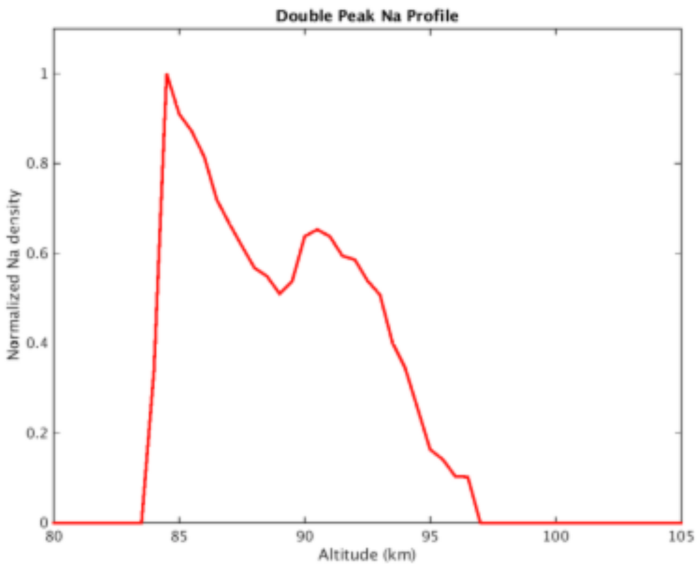
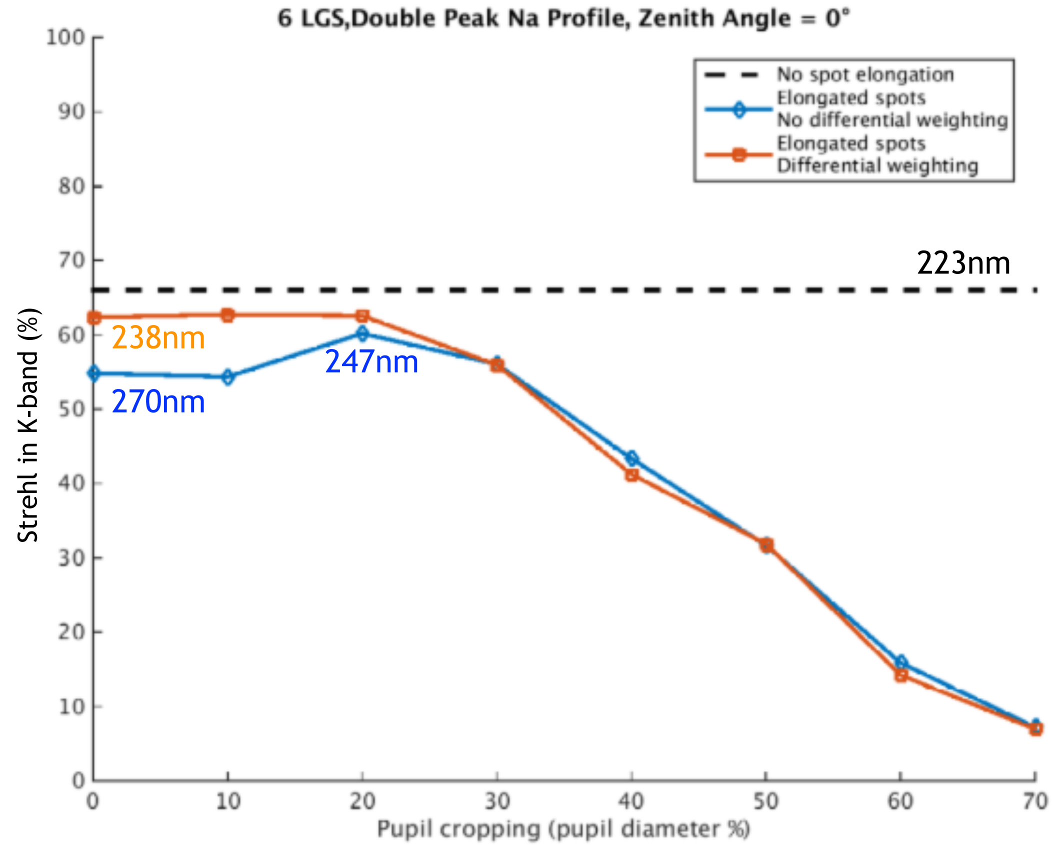
Narrow spot mostly within the subaperture even opposite from LLT

Weighting over-regularizes already good information

Subaperture weighting+cropping





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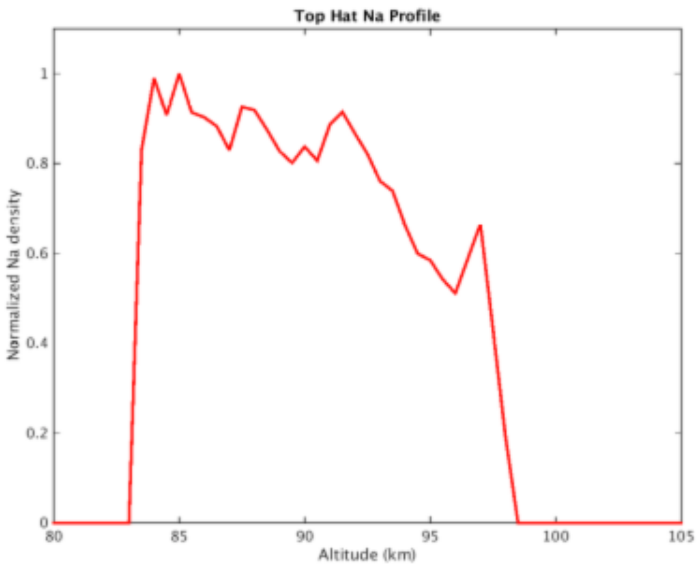
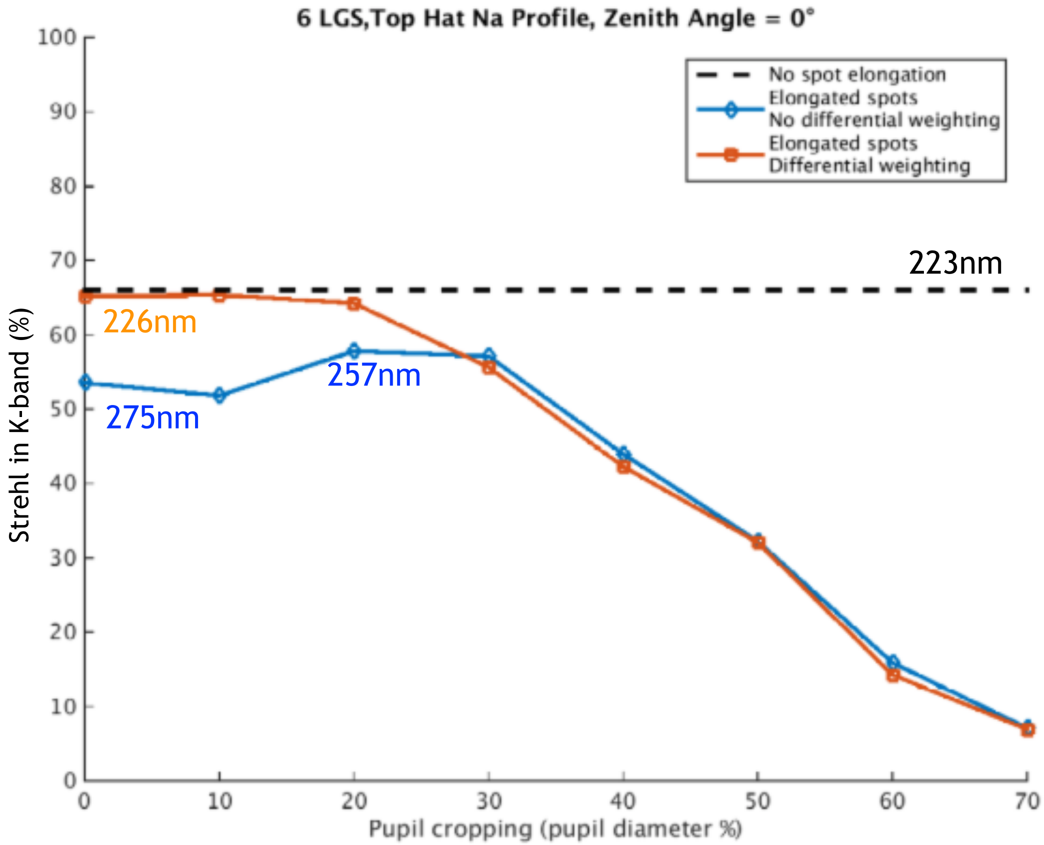
Subaperture weighting+cropping





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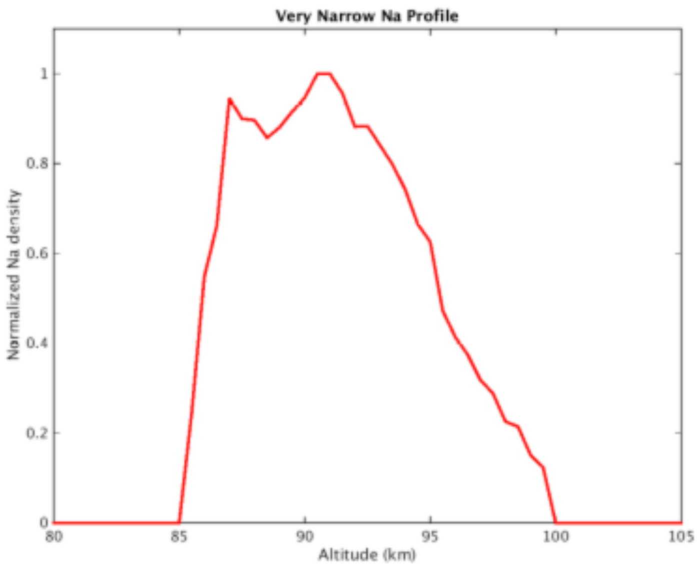
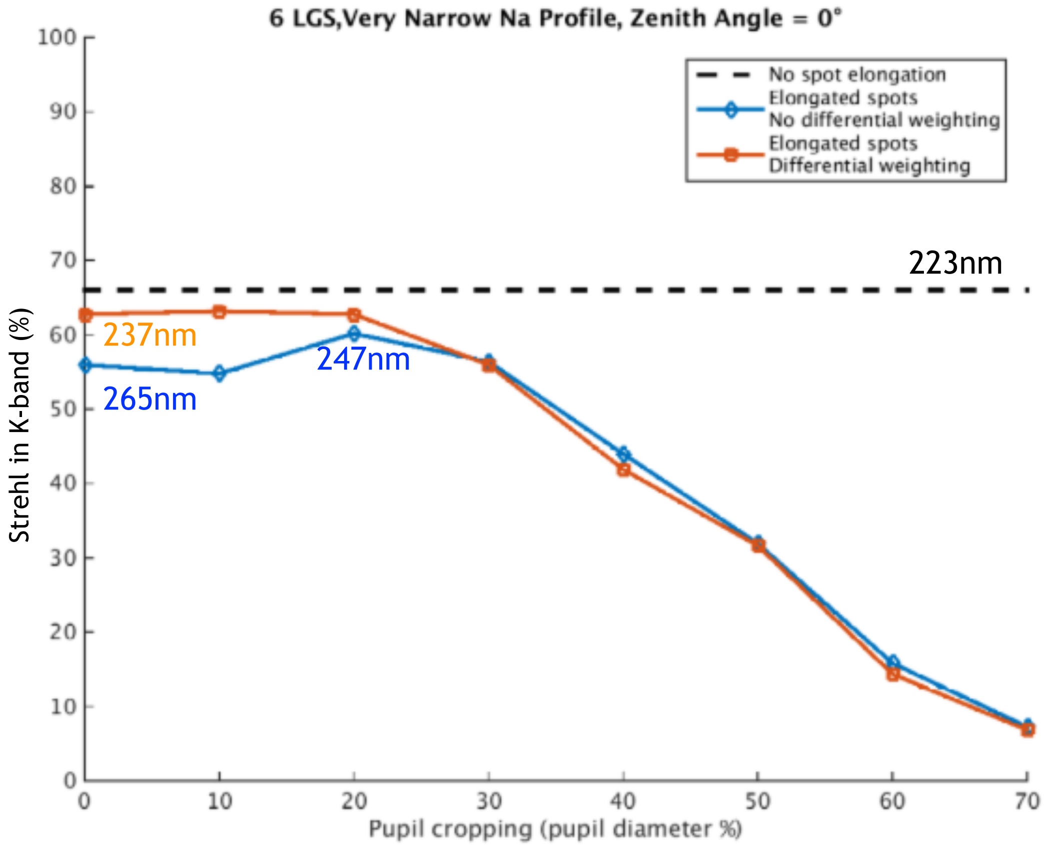
Differential weighting gives almost ideal performance

Subaperture weighting+cropping





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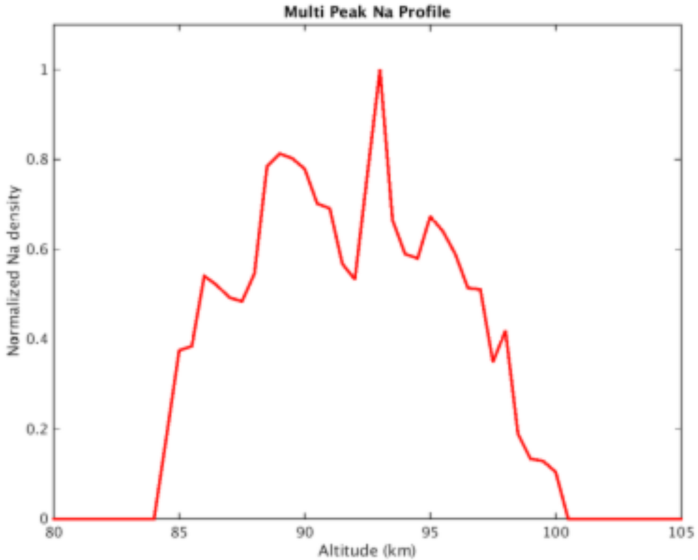
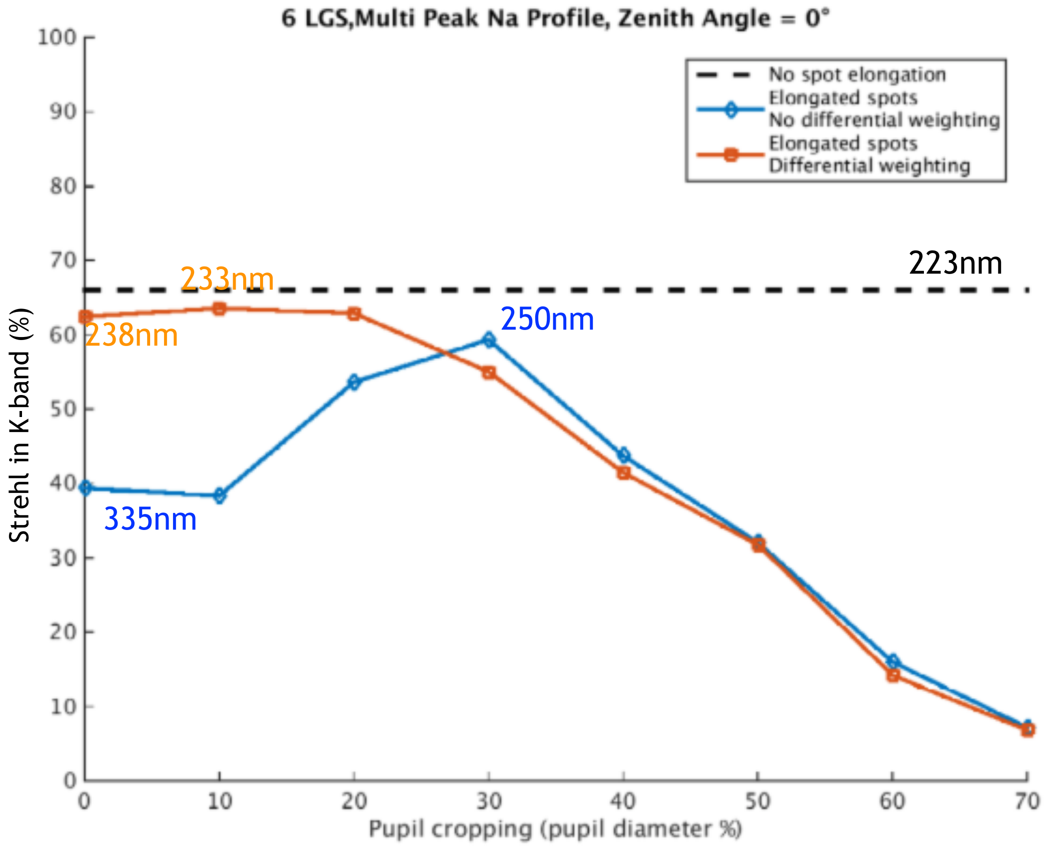
WFE due to elongation reduced from 143nm to 80nm RMS when using subaperture differential weighting

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

Subaperture weighting+cropping





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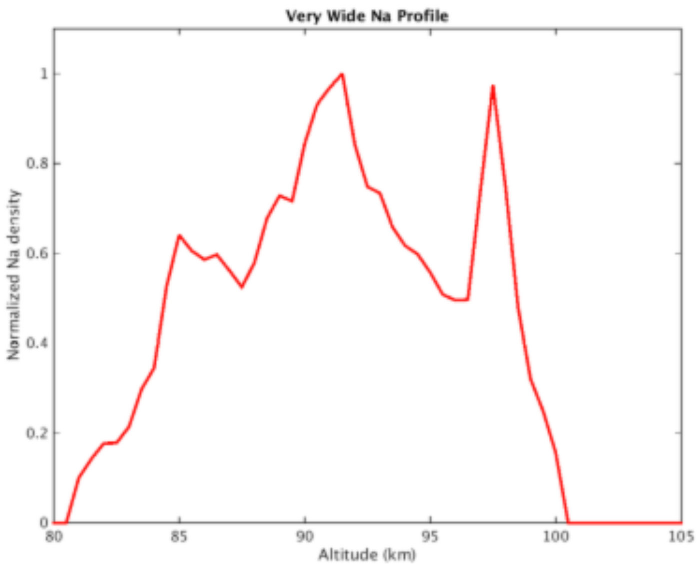
WFE due to elongation reduced from 250nm to 83nm RMS when using subaperture differential weighting

WFE reduced to 67nm RMS when combining weighting and cropping

Subaperture weighting+cropping



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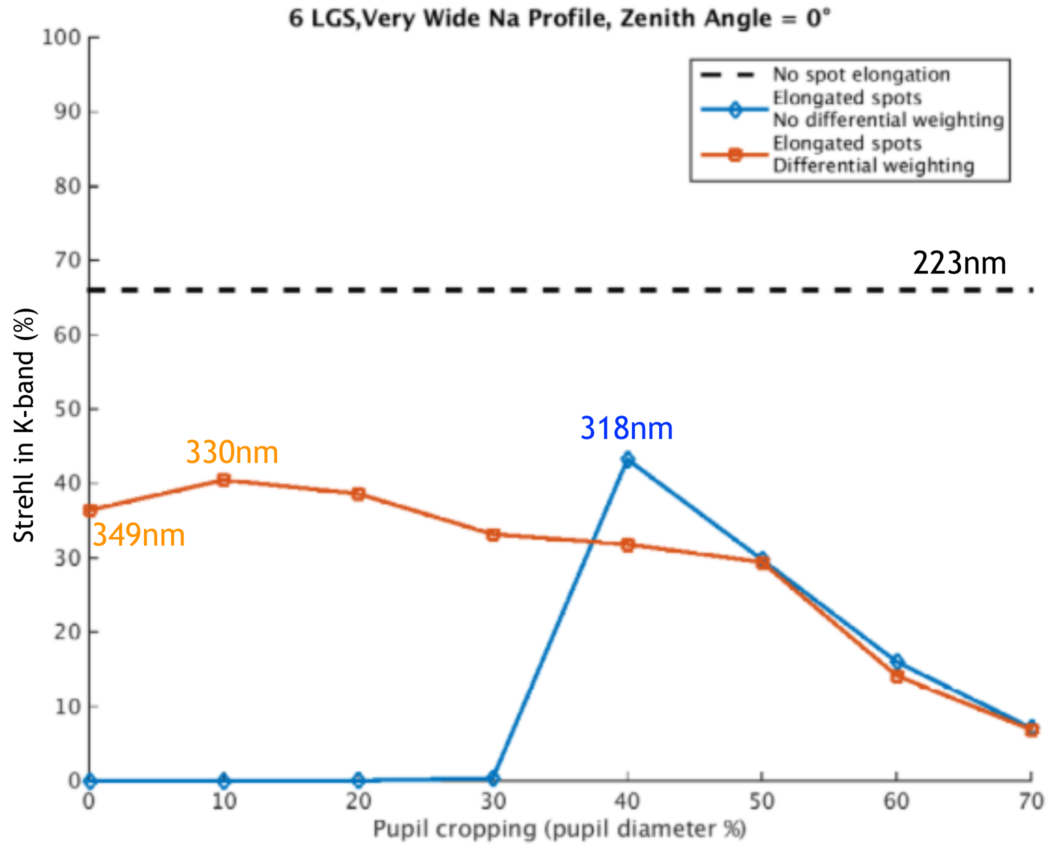
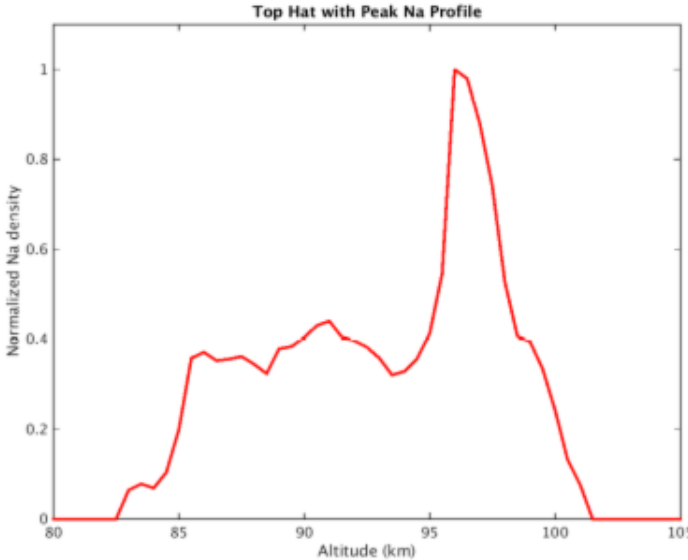
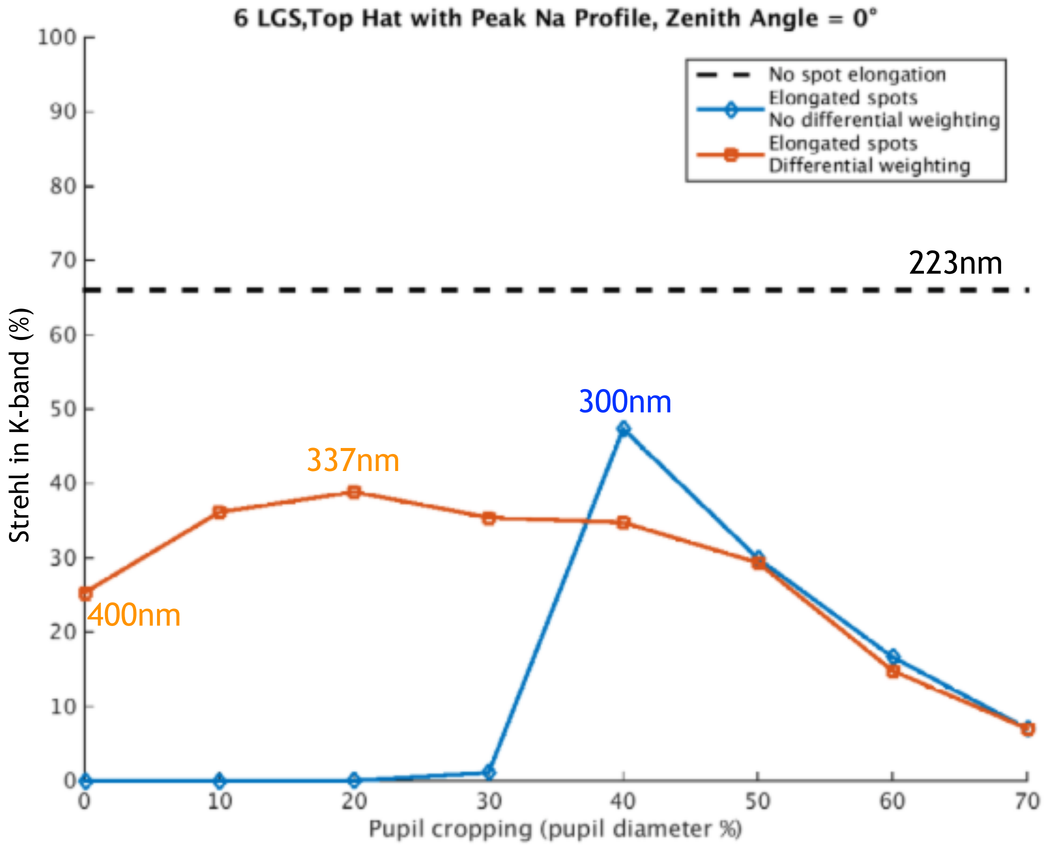


Very perturbed profile with sharp peak at high altitude
Unstable loop when taking into account all subapertures
Weighting mandatory for full pupil
High cropping (40%) improves performance over weighting but far from ideal

Subaperture weighting+cropping

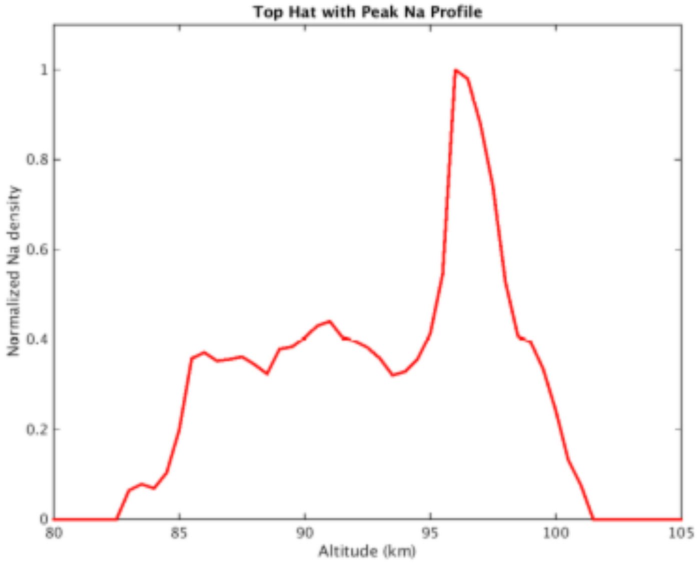




Full E-ELT simulation:
Pupil diameter : 37m
74x74 SH LGS WFS
75x75 actuator DM
Subaperture pitch : 50cm
Subaperture FOV : 10'' (1'' pixels)
6 LGS-Asterism diameter : 42''
30% central obscuration
High flux

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

Non-cooperative Na profile



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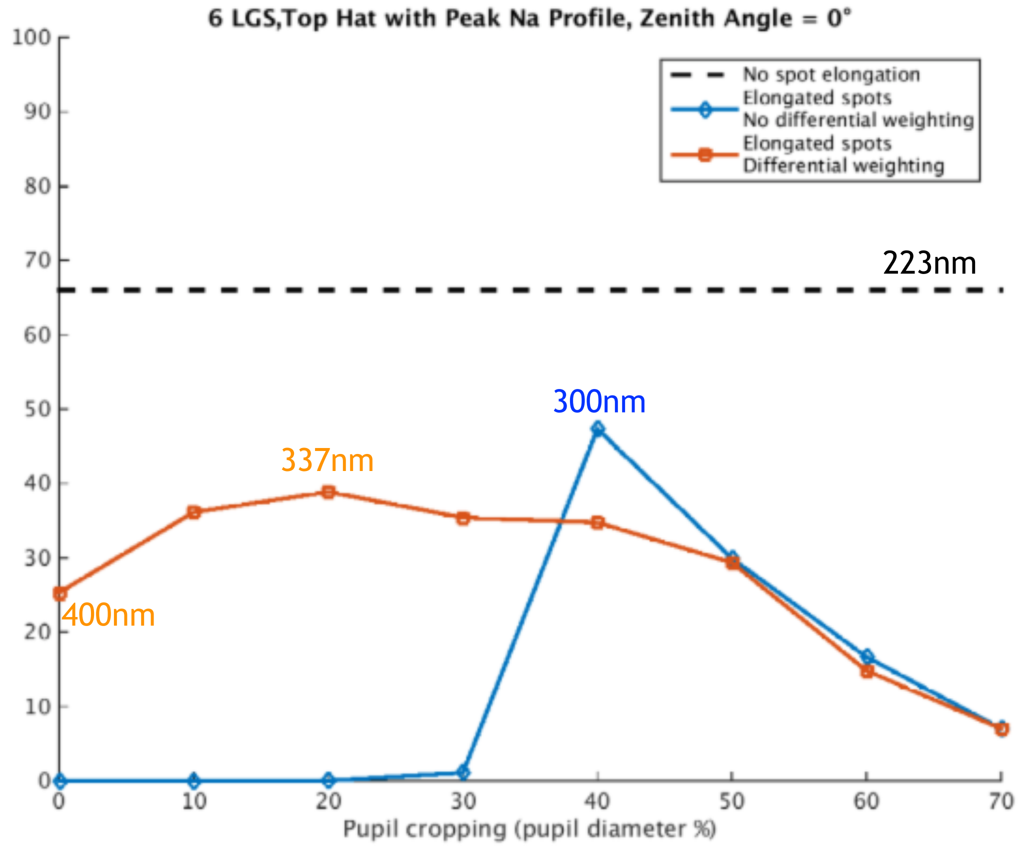

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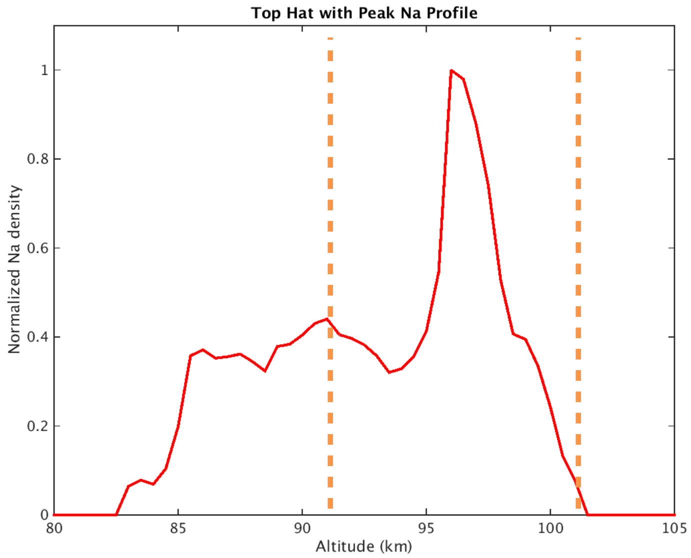

Isolating the high frequency component ->conjugation at 96km + 20 brightest pixels

SR = 8% :(

Brightest pixels amplifies bias inducing high order aberrations

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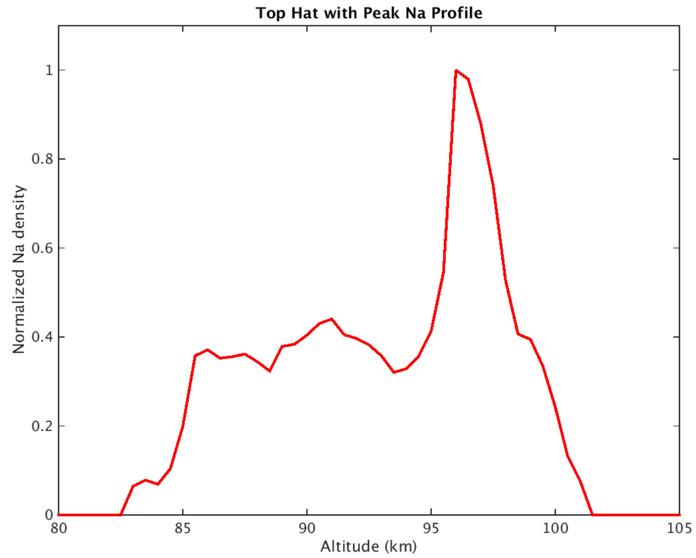
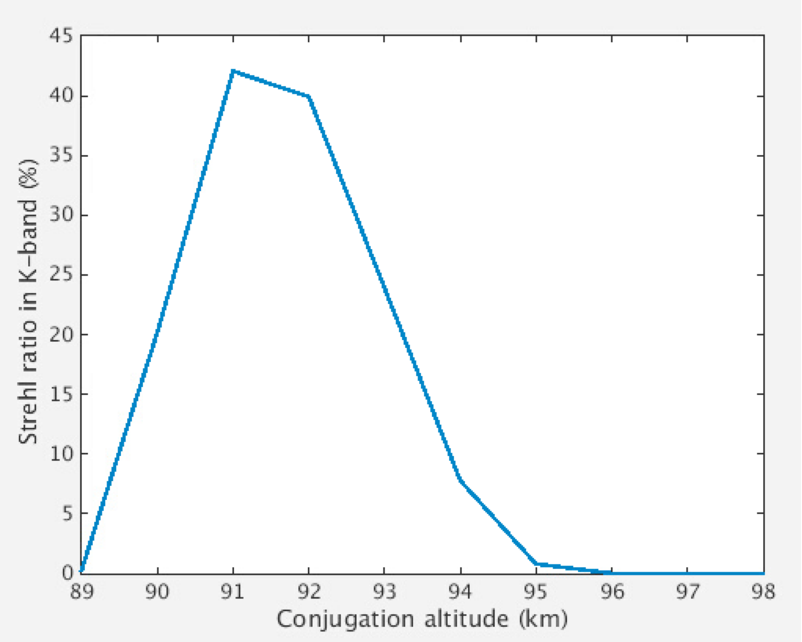
Non-cooperative Na profile : dependance on altitude conjugation





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With spot truncation, conjugation altitude is critical

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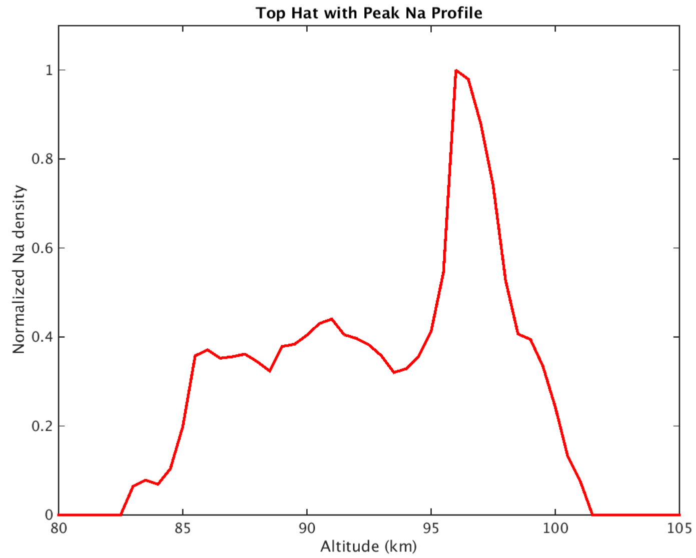

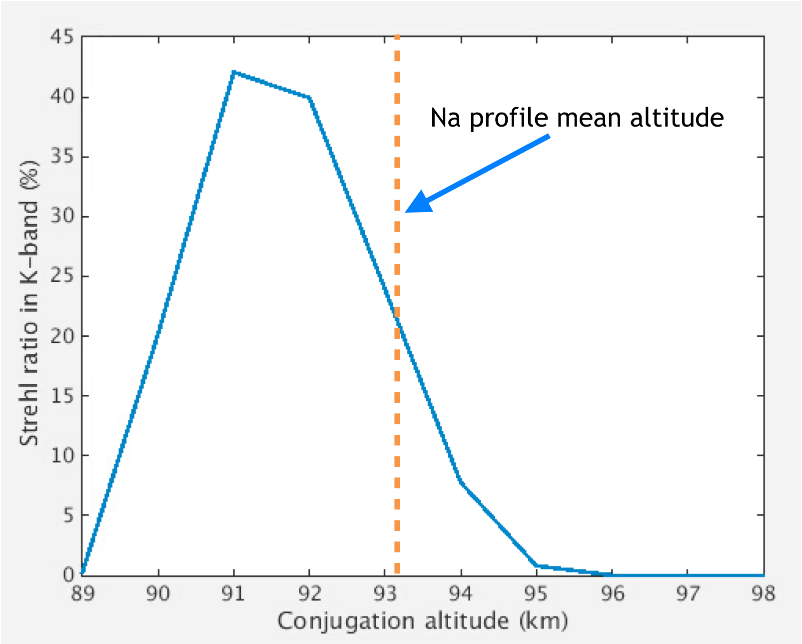

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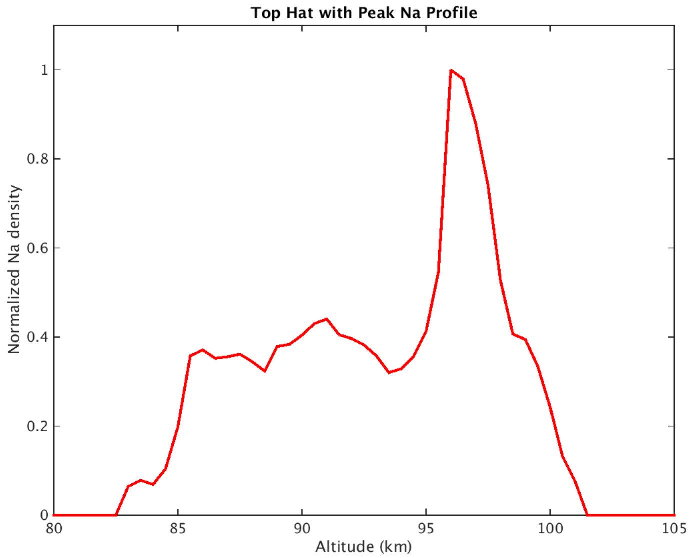
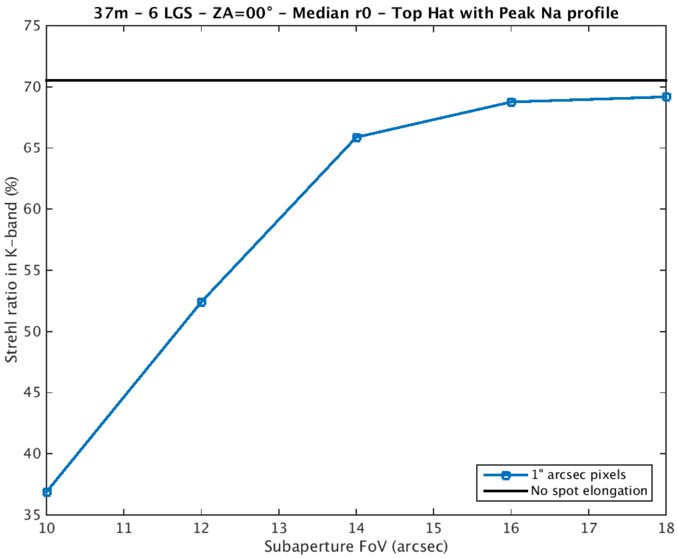
With spot truncation, conjugation altitude is critical but not trivial

Non-cooperative Na profile : expanding the Field-of-View





Full E-ELT simulation:
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Subaperture pitch : 50cm
Subaperture FOV : variable
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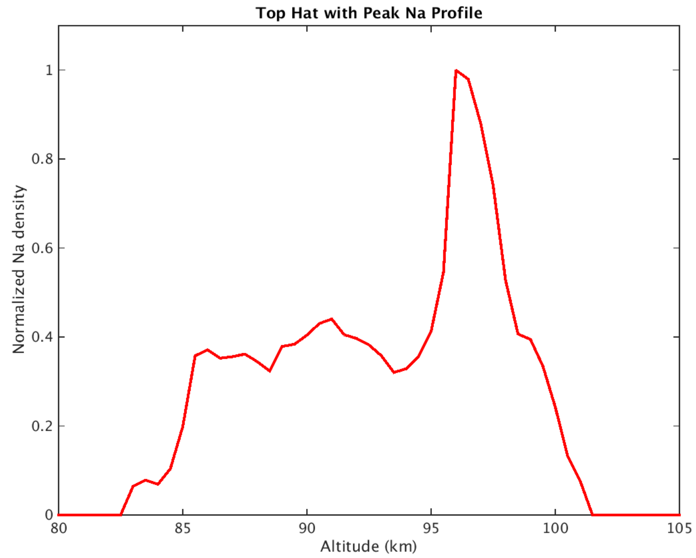
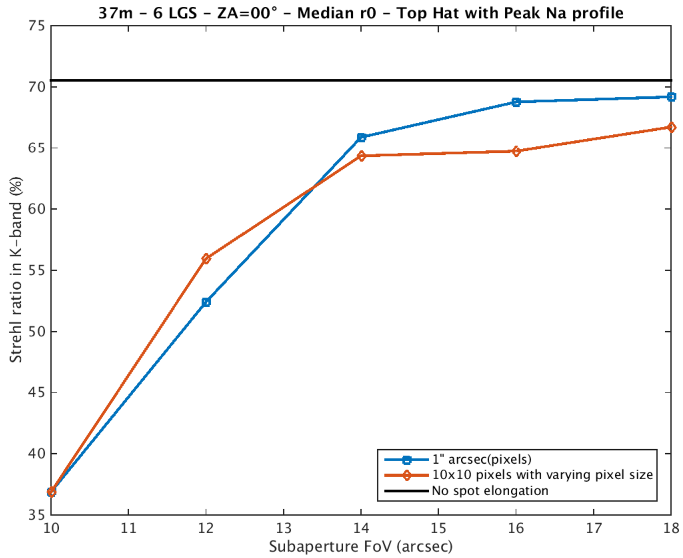
Expanding the FoV removes truncation

Performance close to the non-elongated case

Non-cooperative Na profile : expanding the Field-of-View





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30% central obscuration
High flux

Expanding the FoV removes truncation

Performance close to the non-elongated case

Expanding the FoV by increasing the pixel size (and the LGS FWHM) only slightly degrades the performance

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

-> Freak Sodium profiles exist

-> Not an issue when no truncation

-> More small pixels is the best

-> Larger pixels are a good compromise to remove truncation

-> Increase pinhole size, separate the spots, software subaps

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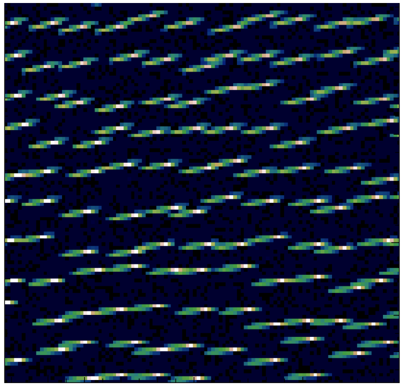

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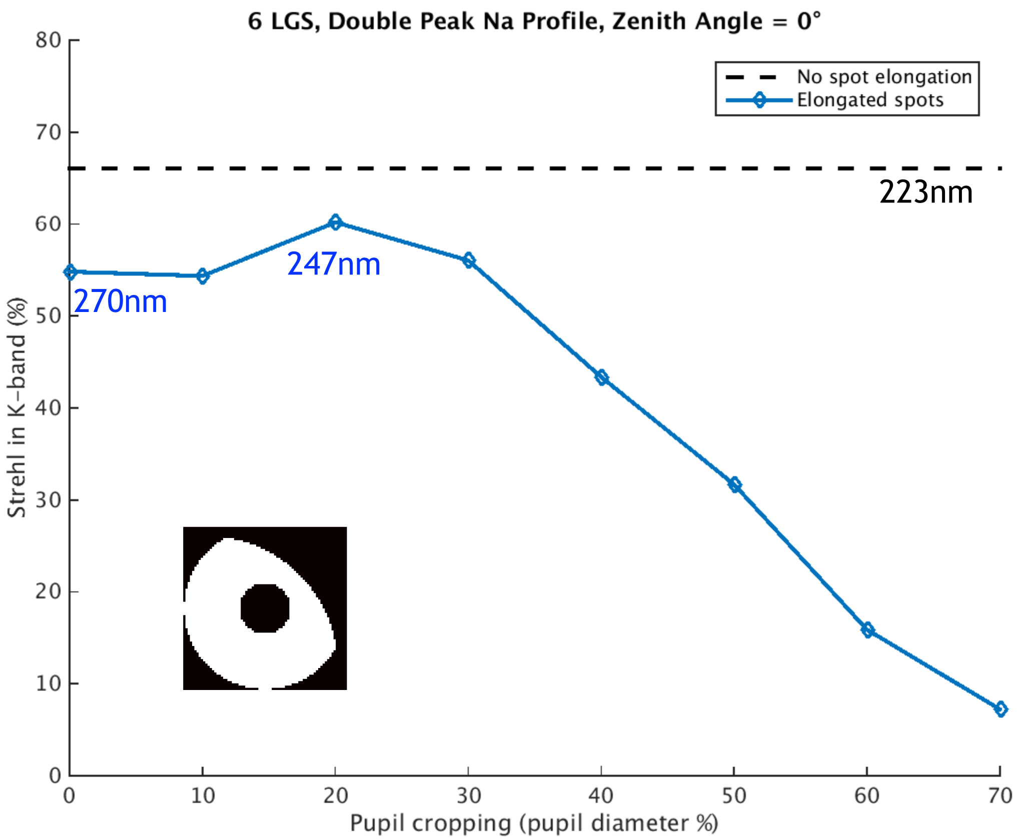
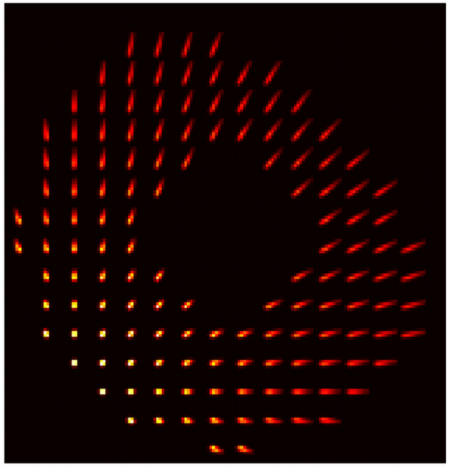
Grazie

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

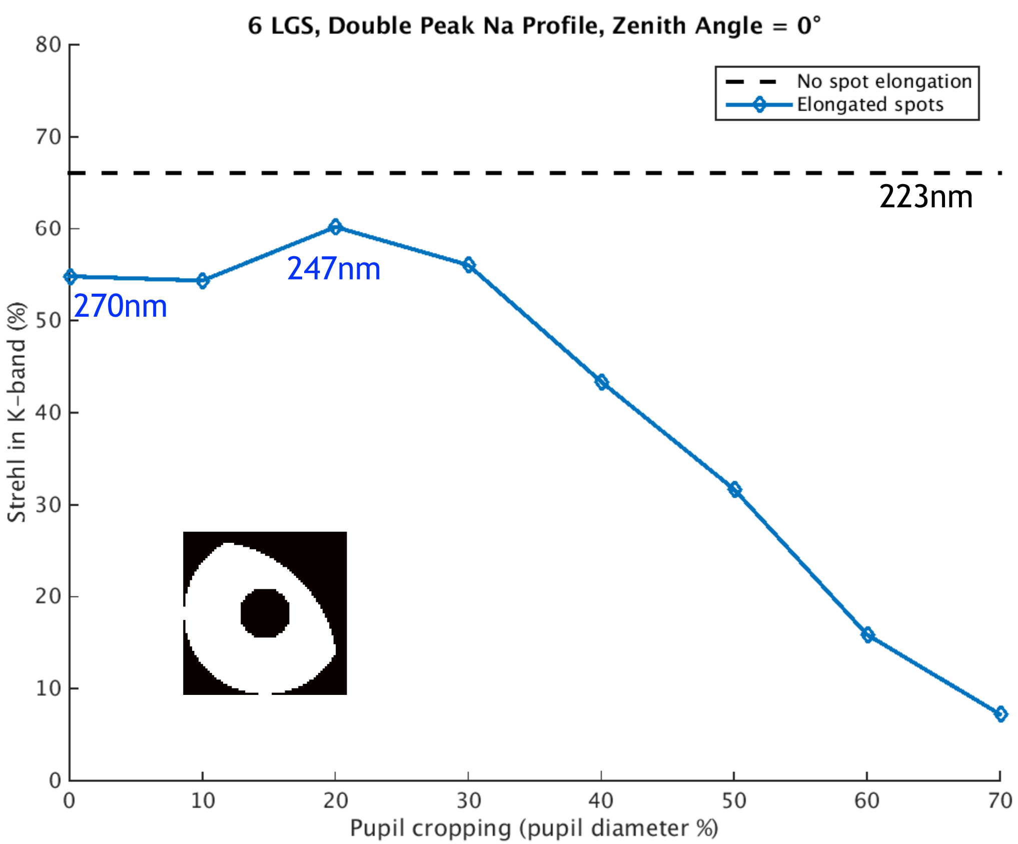
Corner Shack-Hartmann



Conventional SH



160 pixels
10 pix/subap



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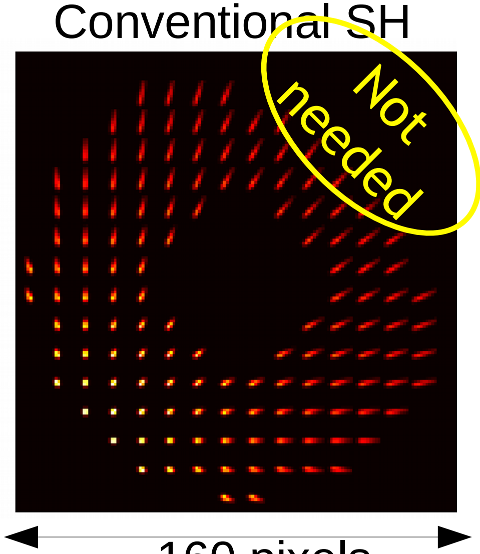

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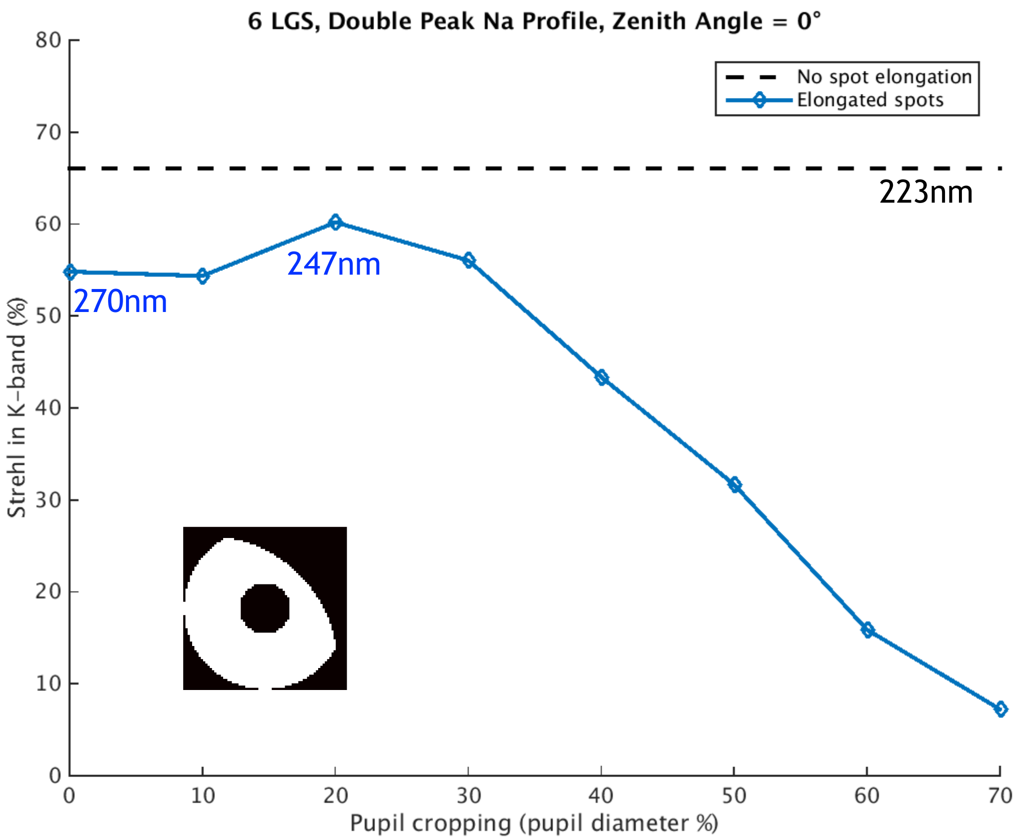

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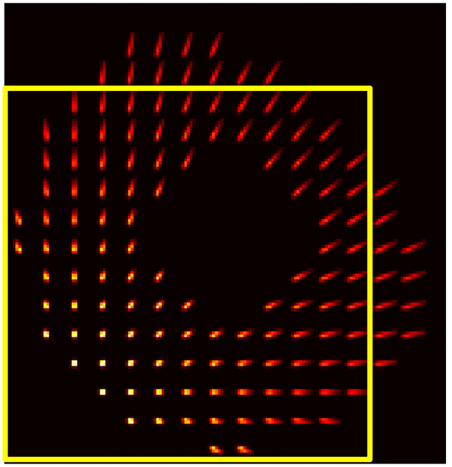

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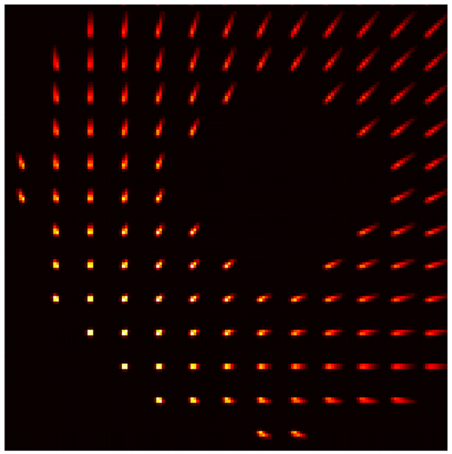
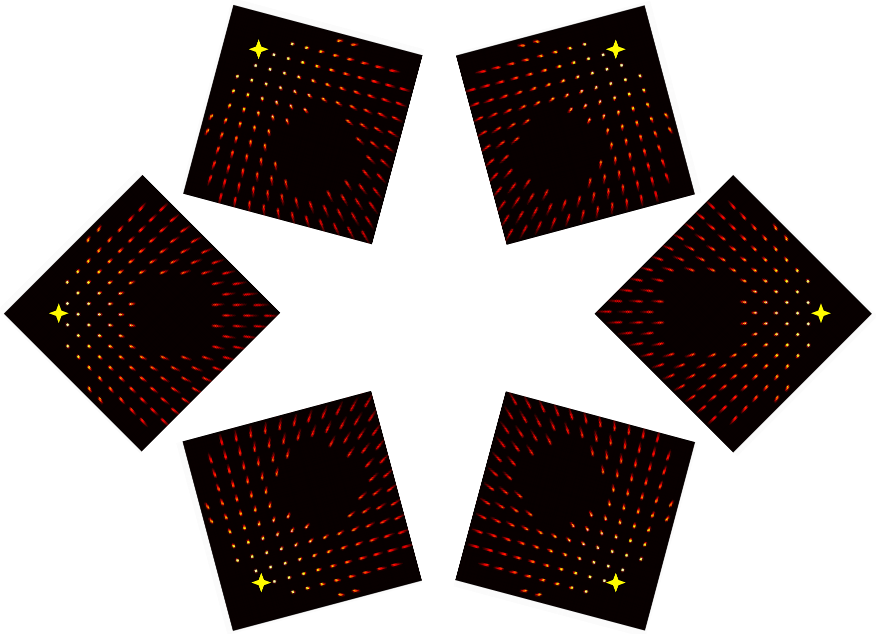
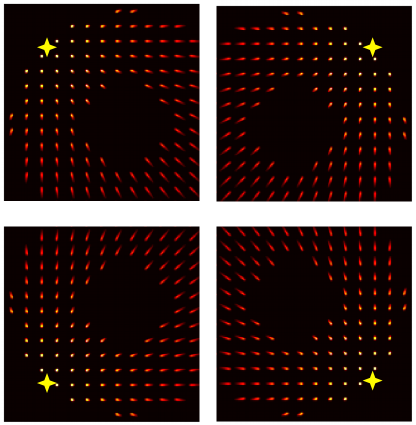


160 pixels
12 pix/subap

Corner Shack-Hartmann

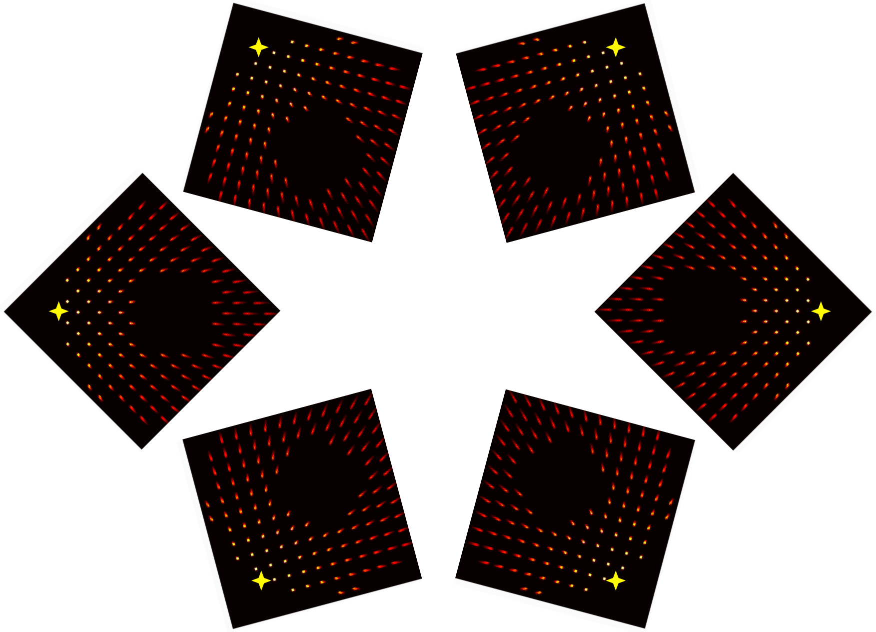


6 LGS configuration



4 LGS configuration

Corner Shack-Hartmann



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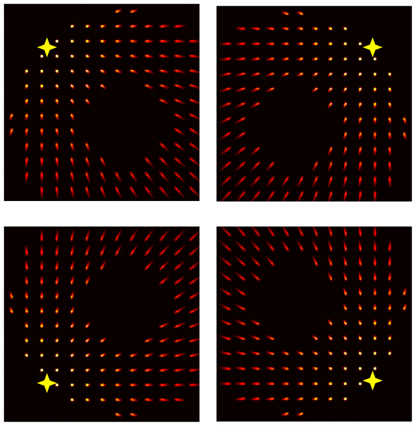

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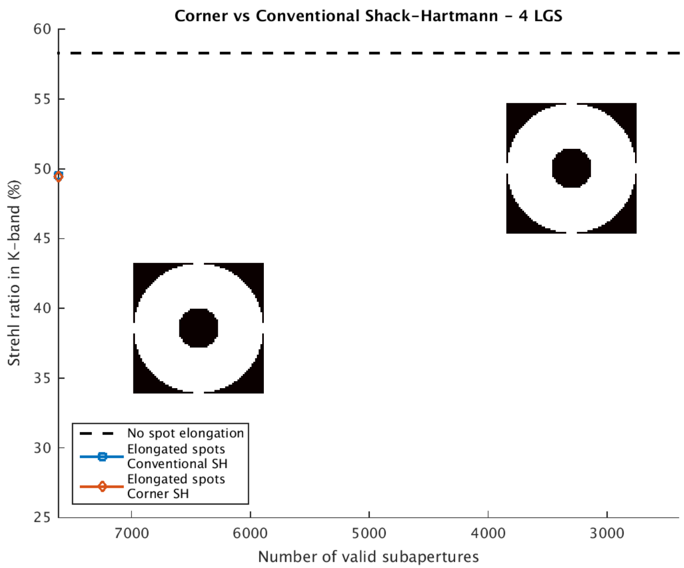

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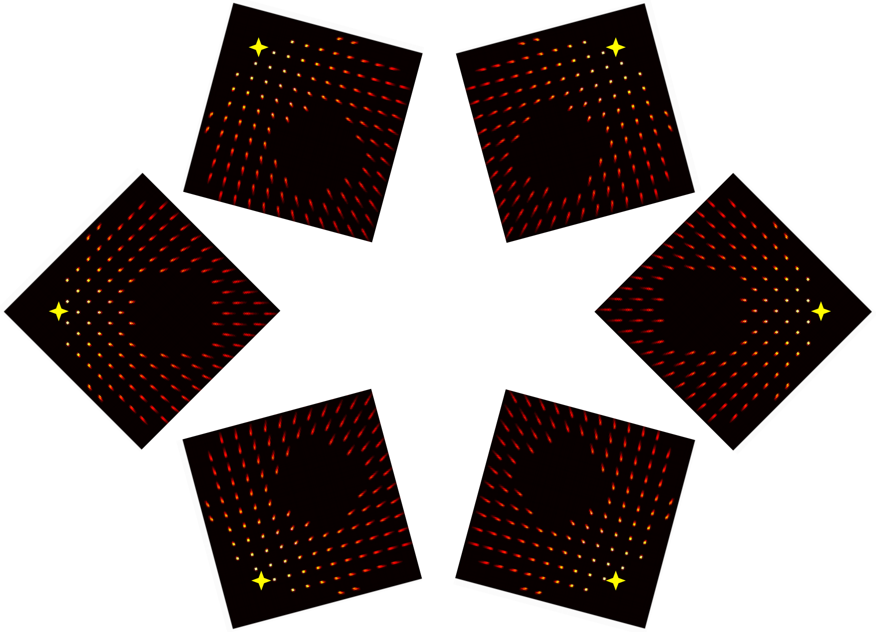

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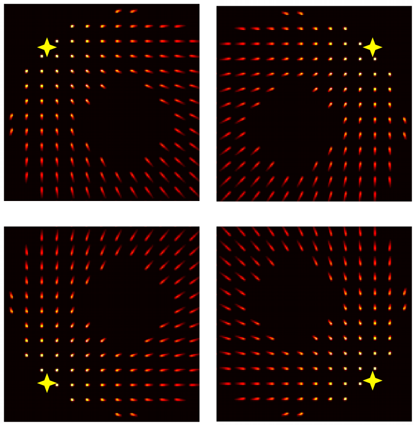

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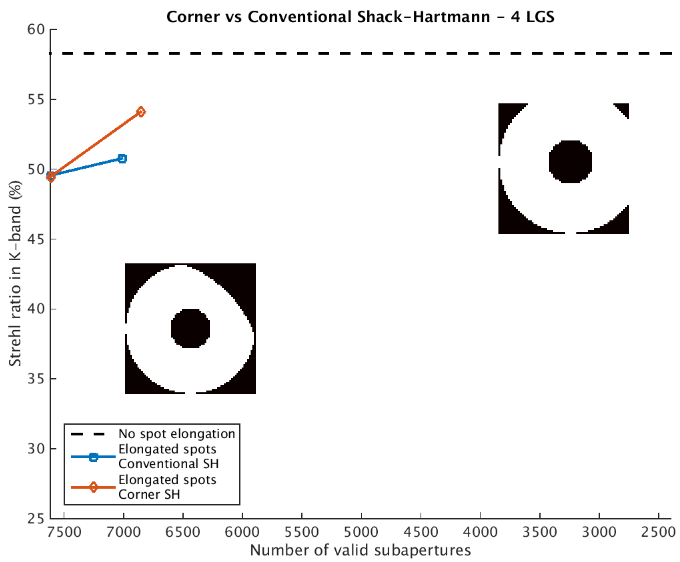

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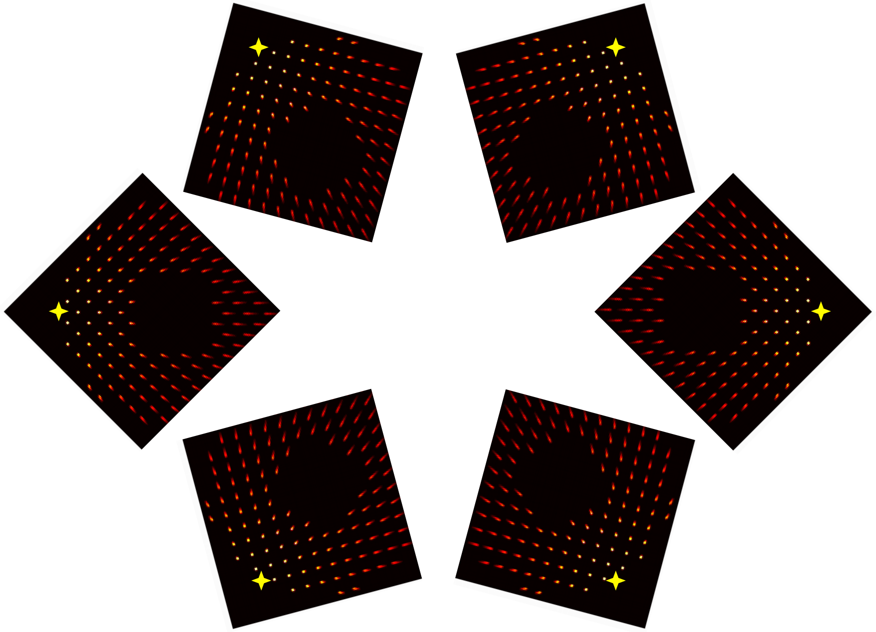

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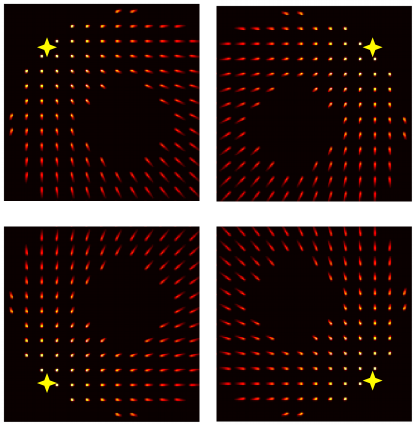

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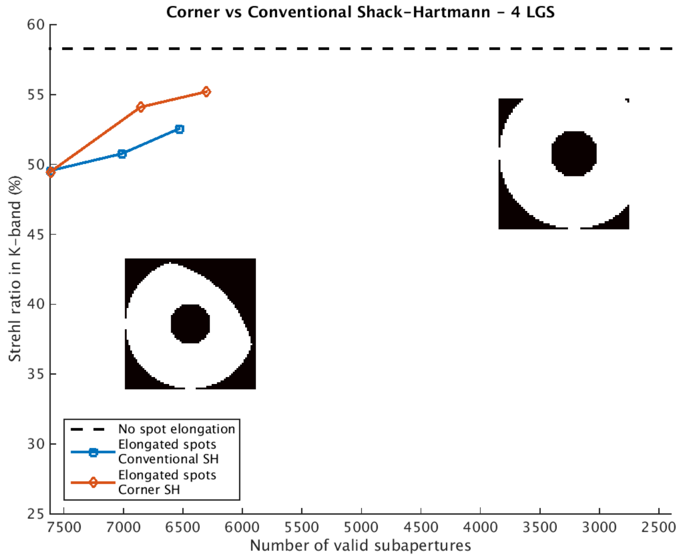

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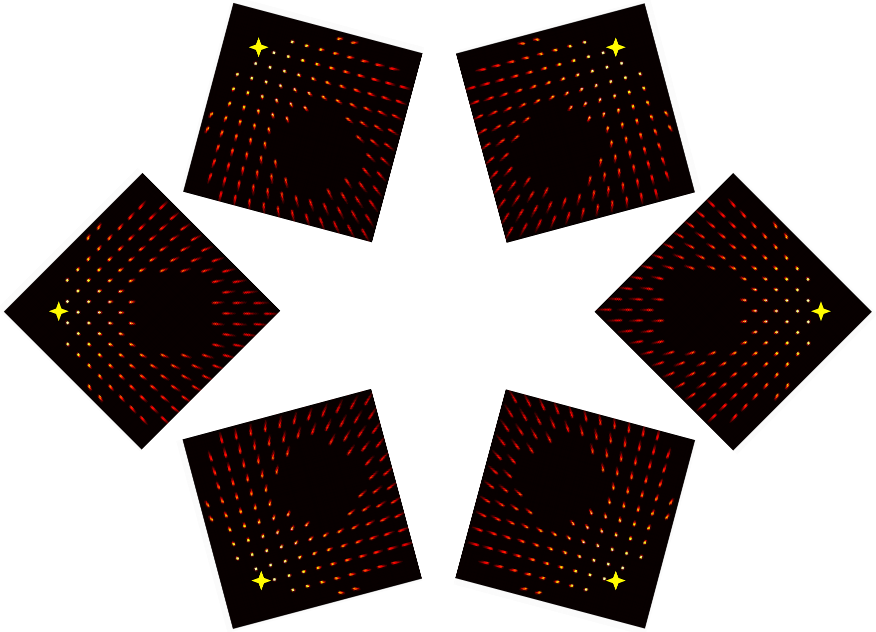

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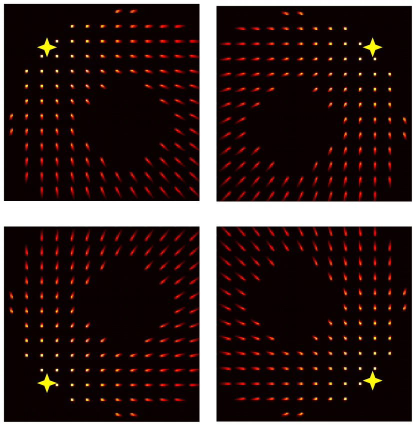

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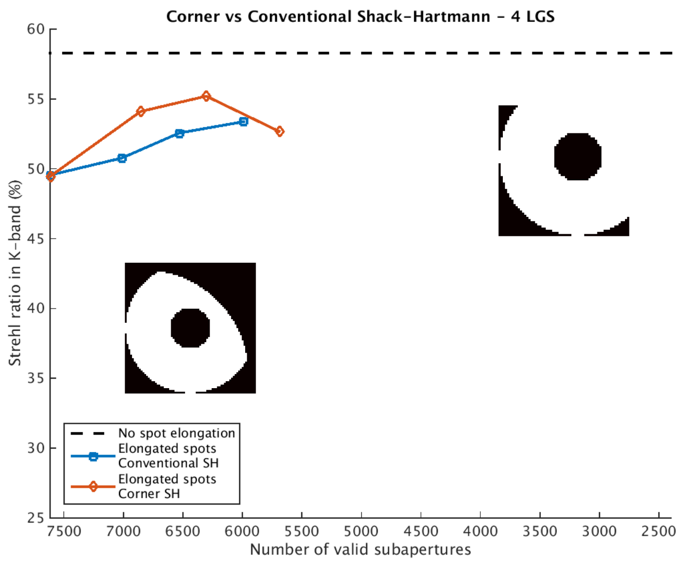

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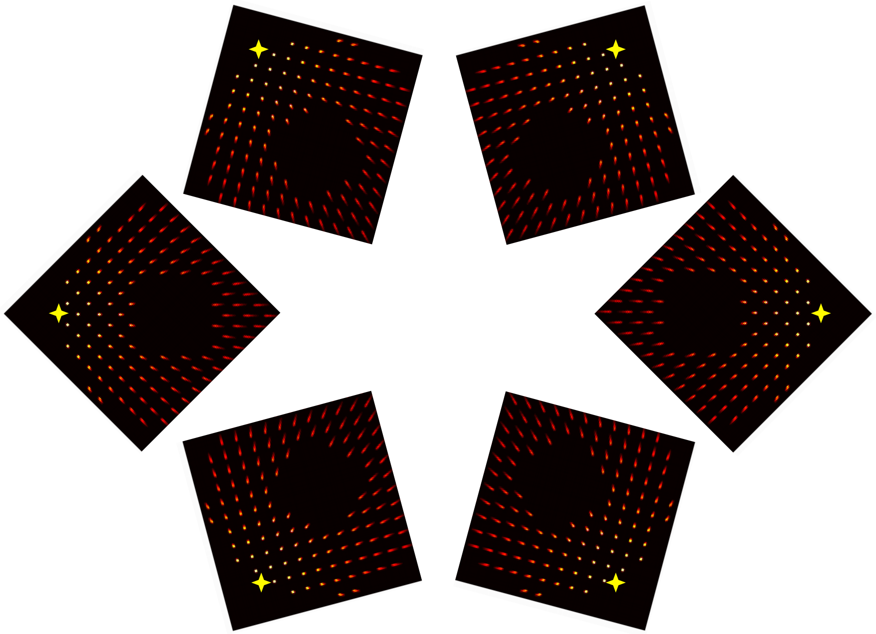

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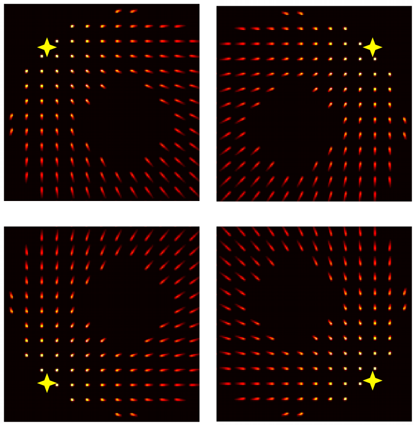

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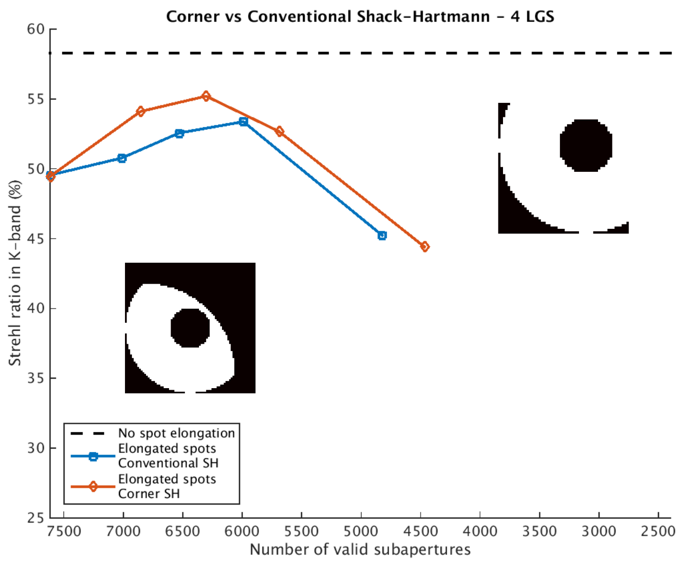

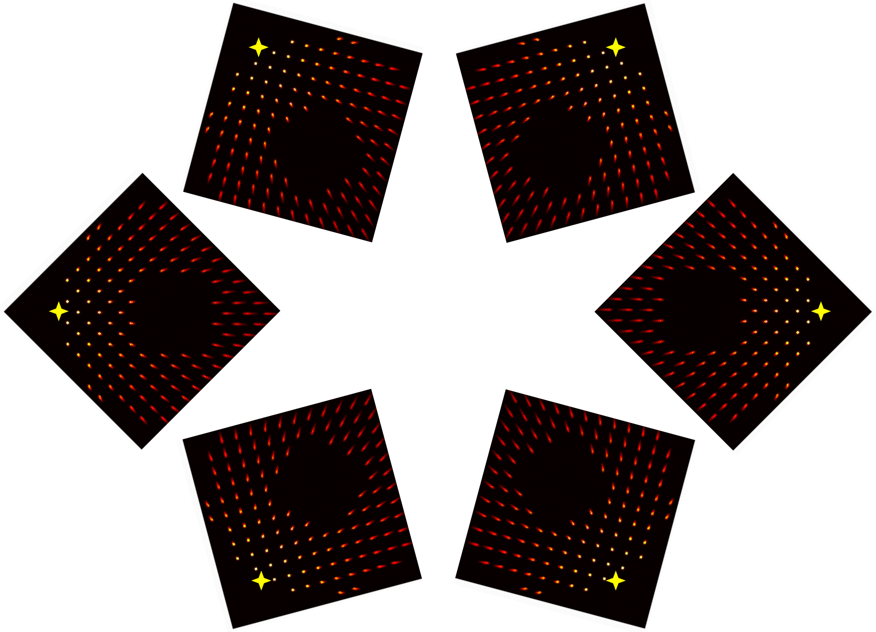

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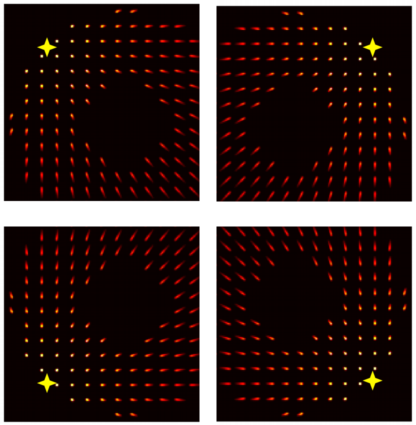

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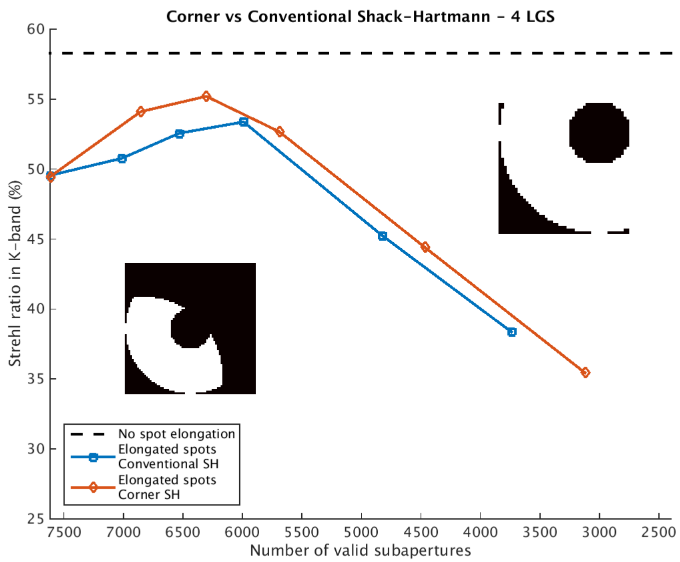

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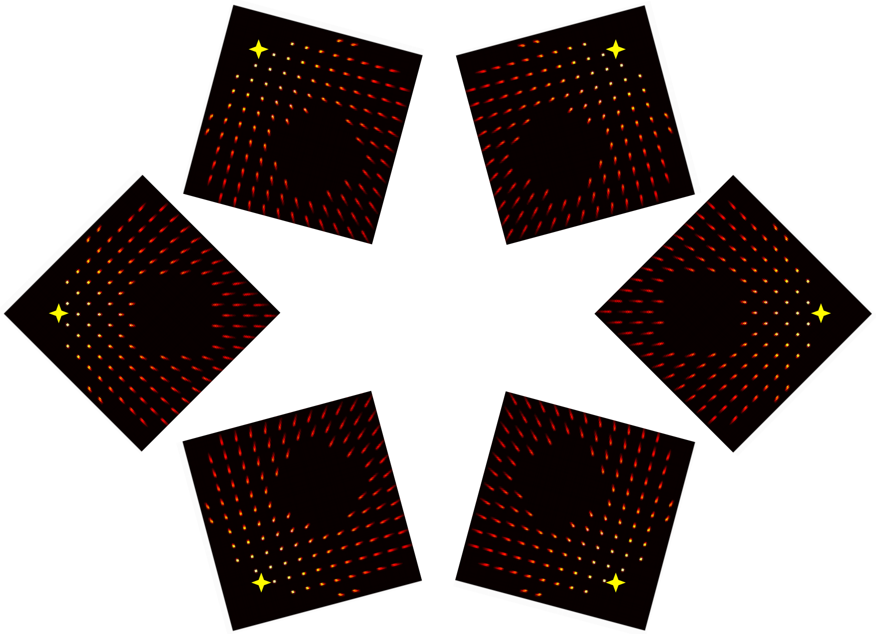

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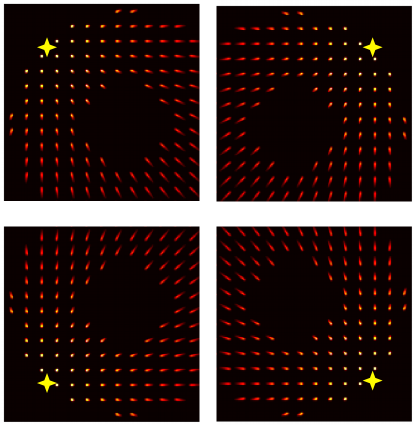

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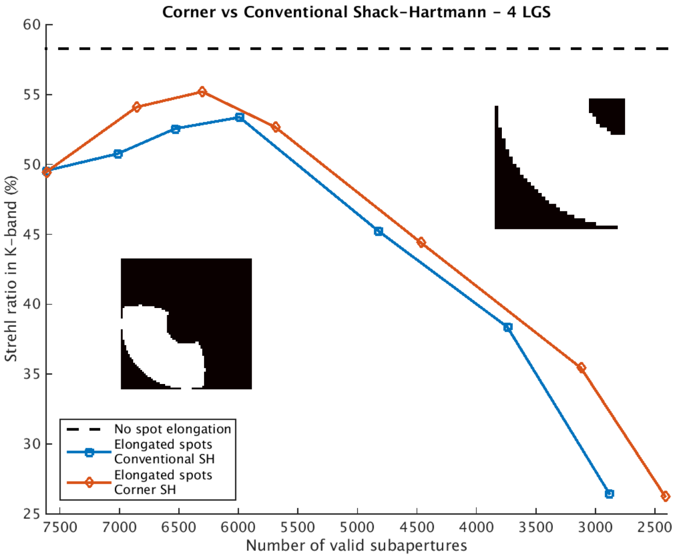

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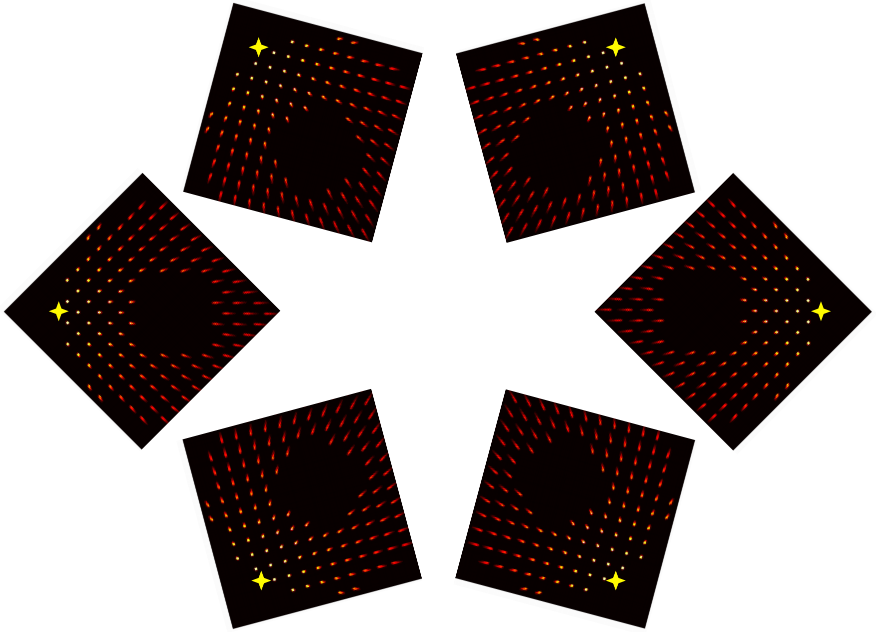

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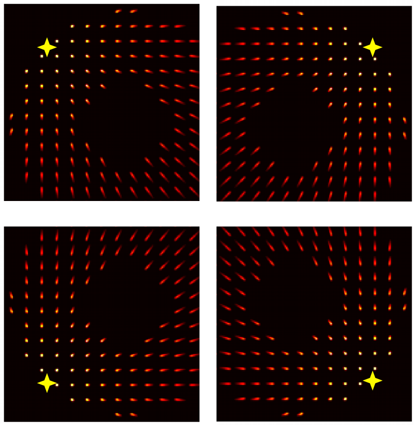

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Corner SH always better than conventional SH for a given # of subapertures