Multiple spatial frequency wavefront sensing with a Pyramid

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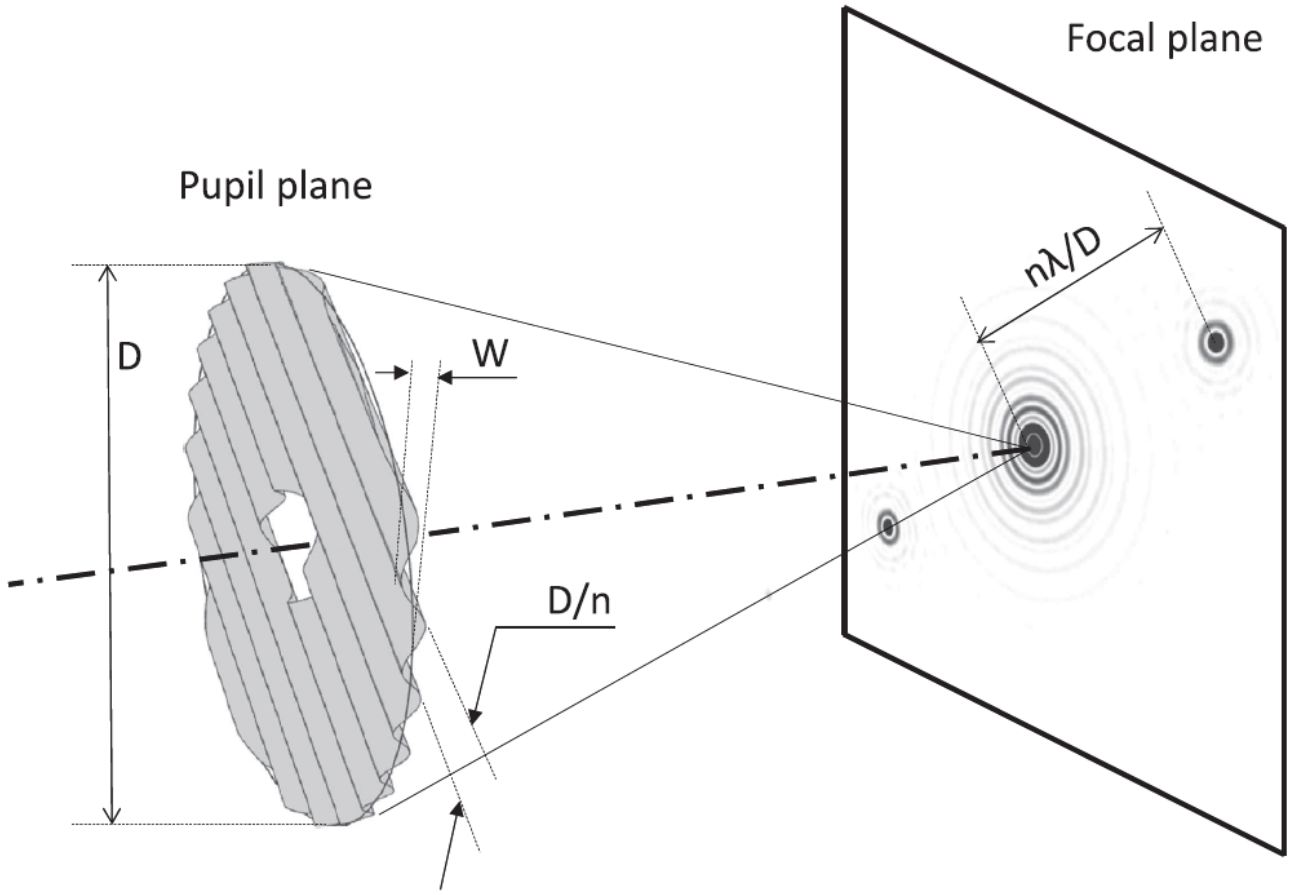
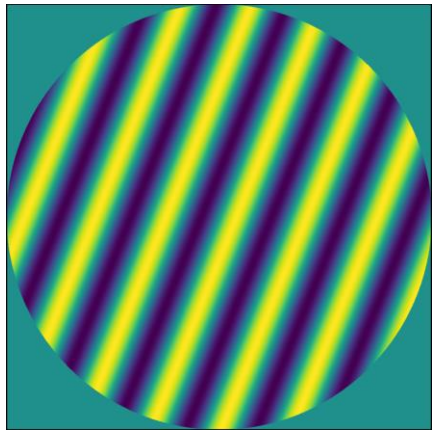
Demetrio Magrin, Luca Marafatto

The simple sine-wave case

- A sine-wave perturbation with n cycles/pupil will produce two speckles at nλ/D
- The intensity of the speckles is proportional to the square of the wave amplitude W



Adding another frequency



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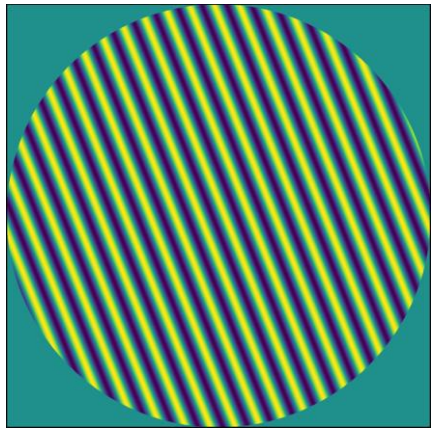
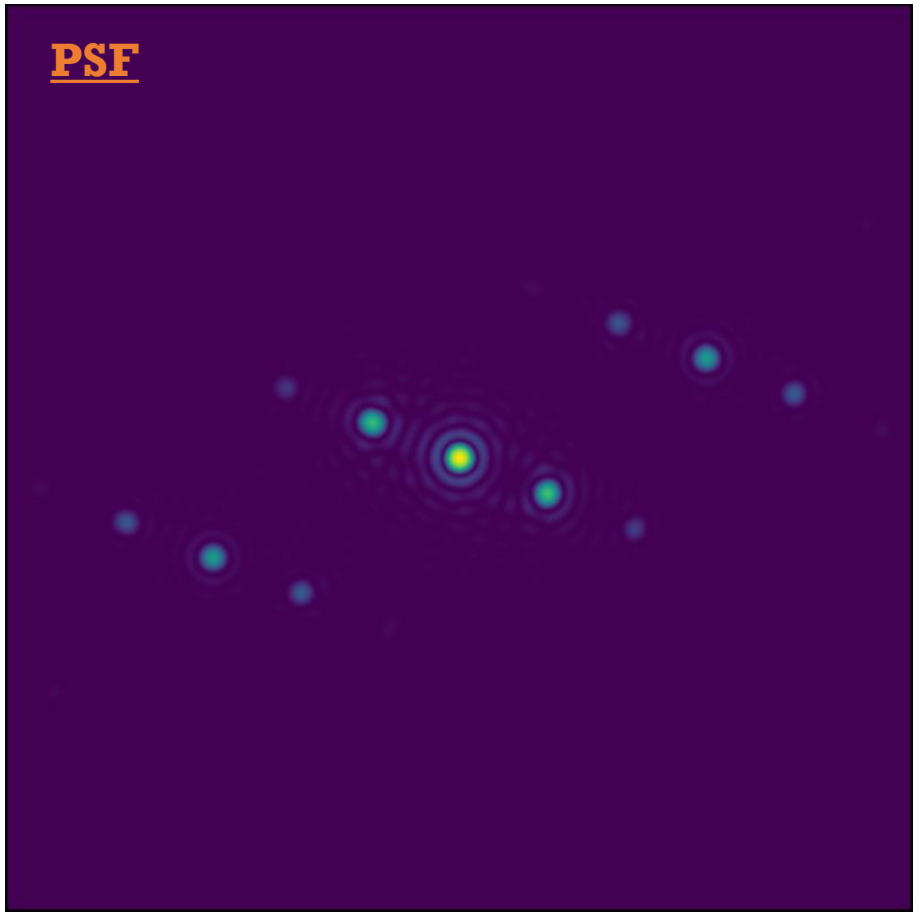


Phase 1

Amplitude: W_1=100nm
Frequency: n_1=6.5 cycle/pup

Phase 2

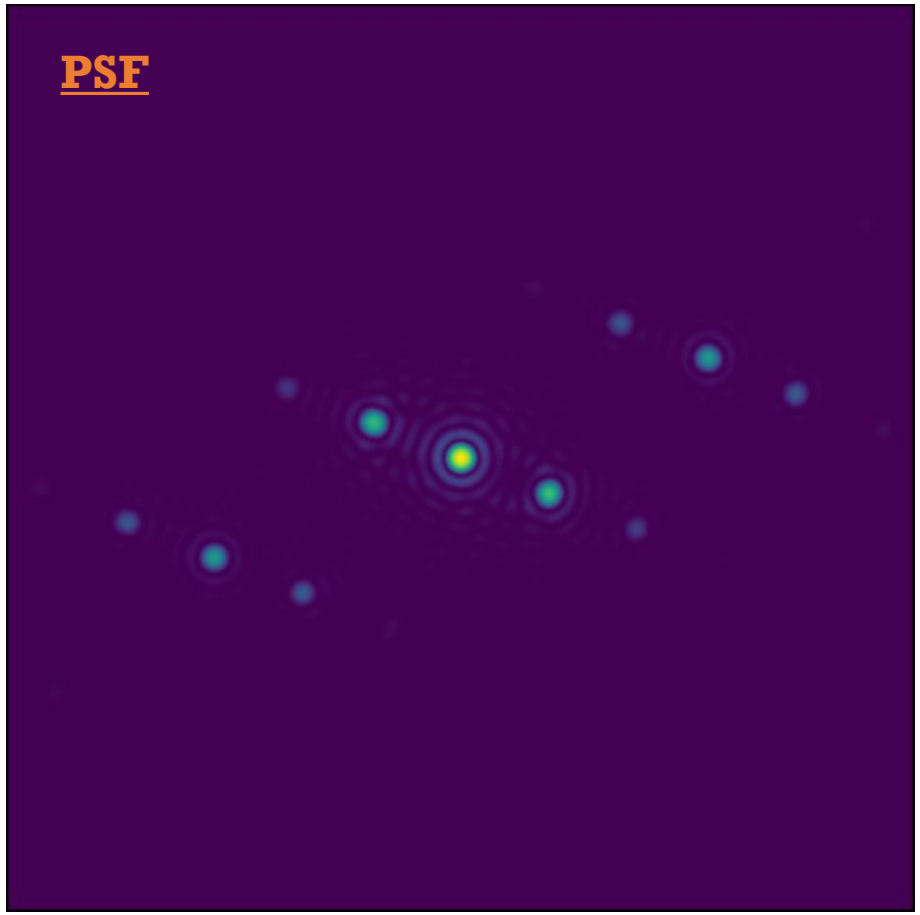
Amplitude: W_2=75nm
Frequency: n_2=18.3 cycle/pup



Noise and information

If I want to sense only the low frequency…

where is the low frequency information and where is the noise?



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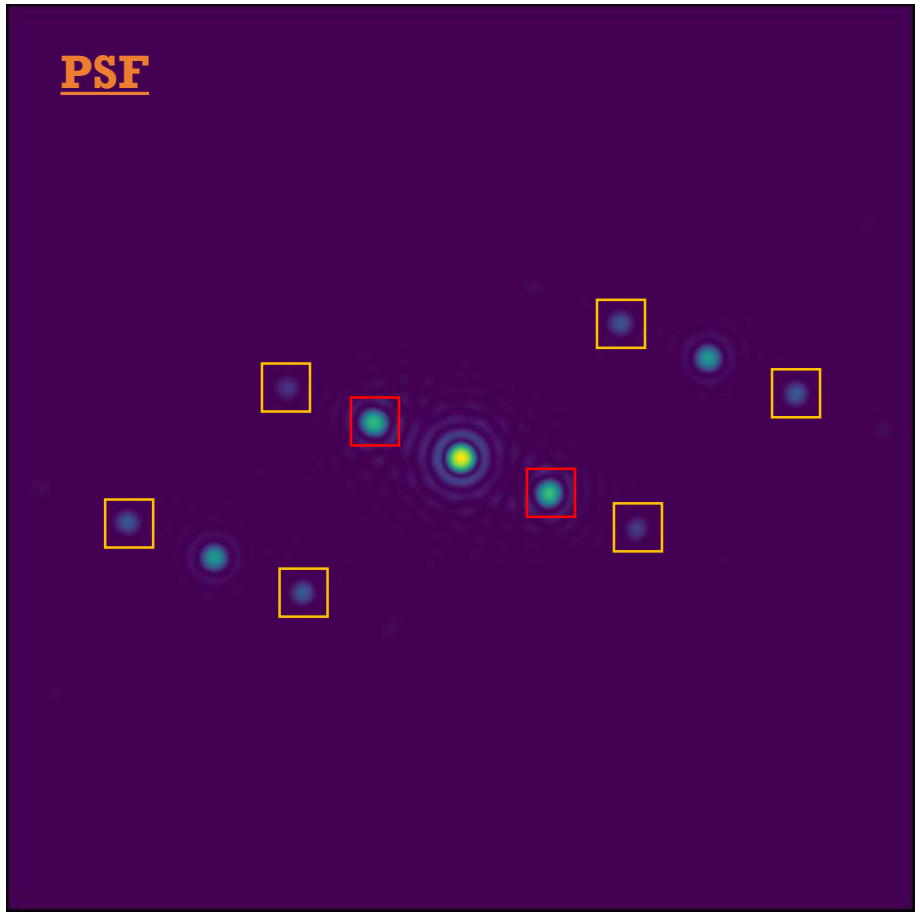
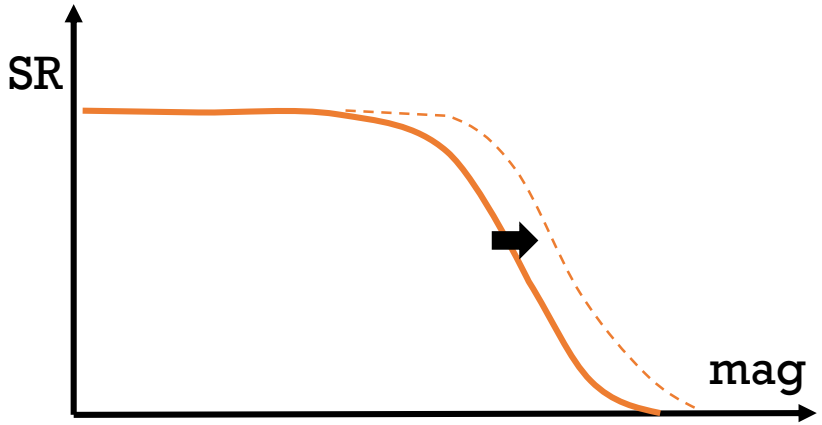


What we would like

- **High sensitivity** = get rid of the noise sources



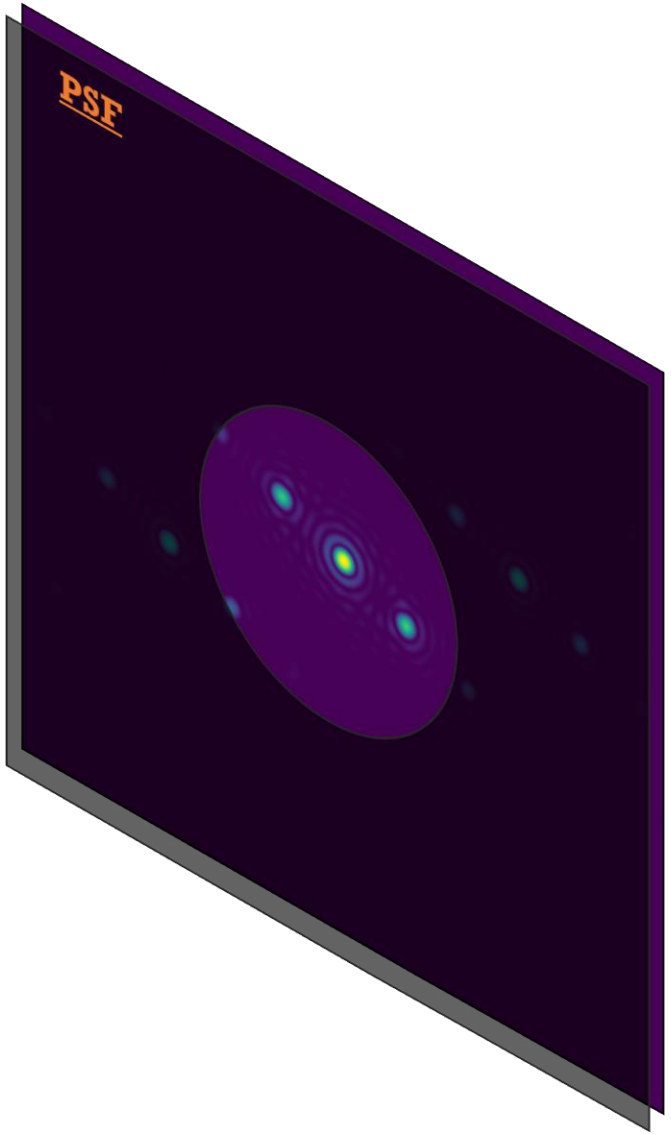
- **High precision** = get access to the high spatial frequency information (e.g. AO in the visible)

Getting rid of the noise (spatial filtering)

Mask-out the light from high-order frequencies to increase the S/N ratio in the sensing of the low-order frequencies

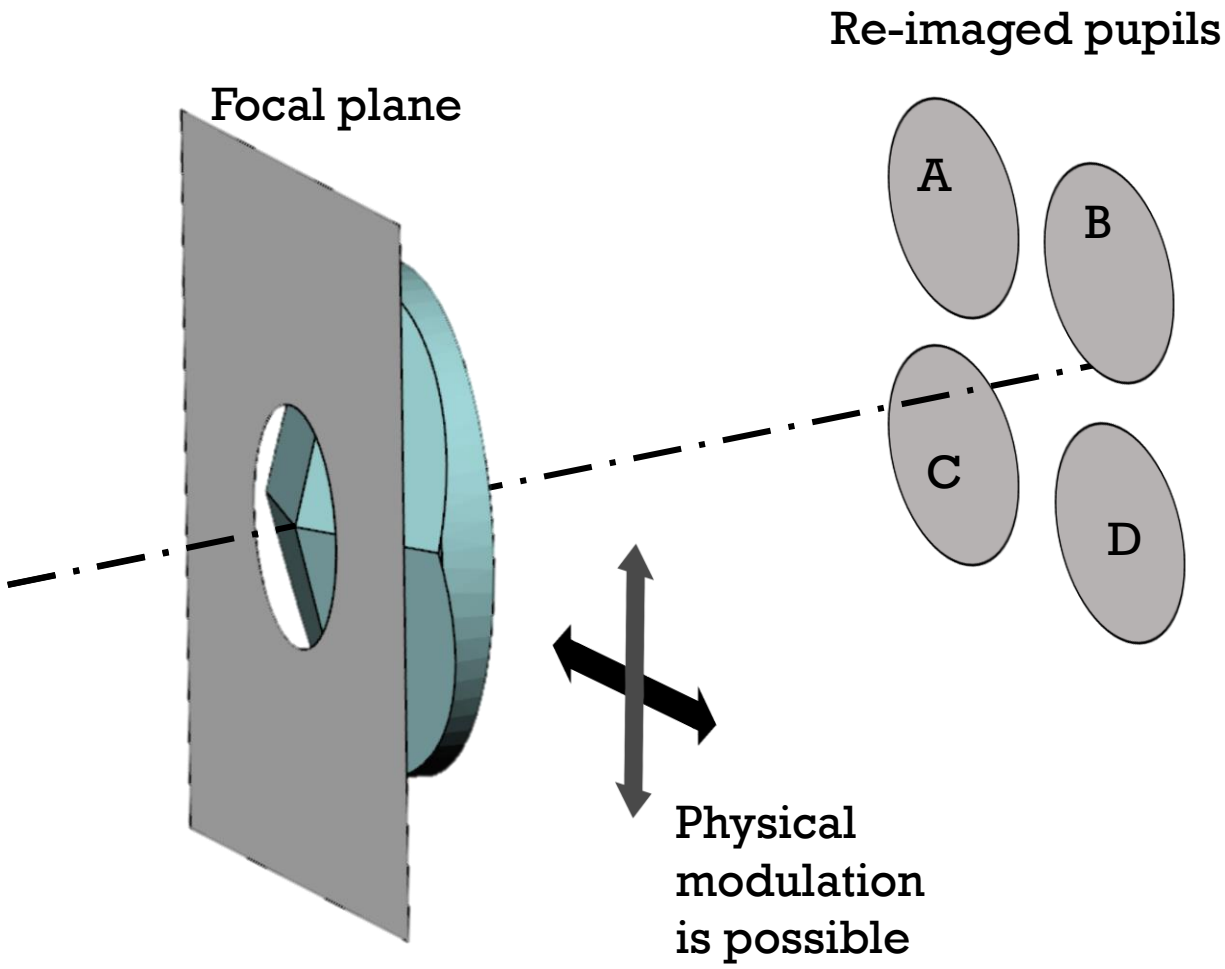
Particularly relevant in closed loop when low-order aberrations are beeing corrected and the associated signal is smaller than that of high-order frequencies

Already done in other instruments (e.g. SPHERE @ VLT)

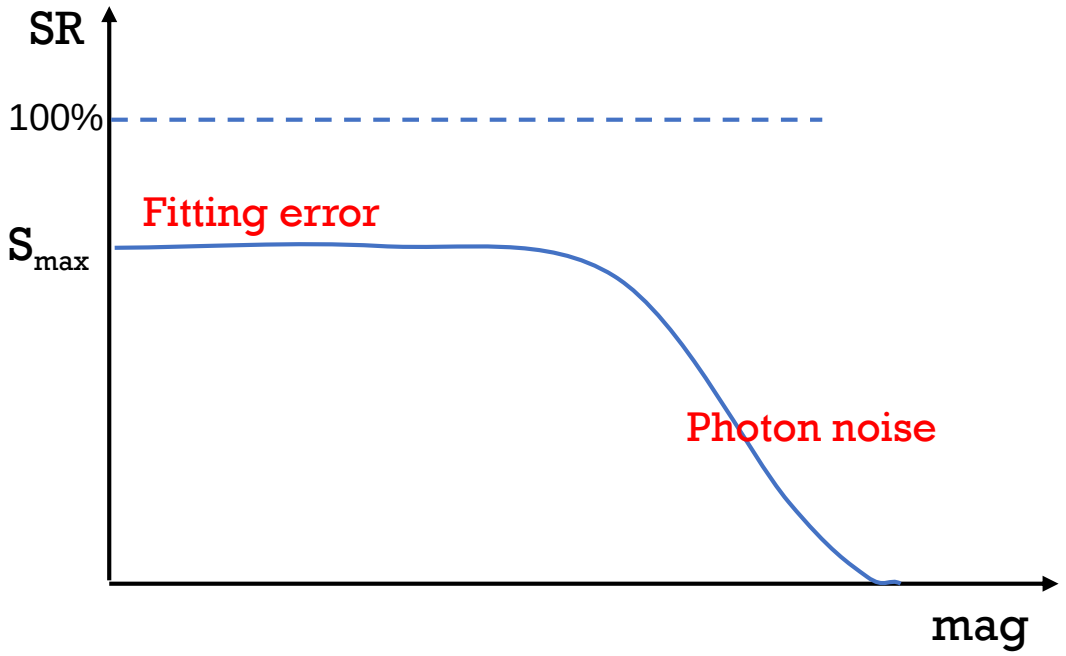


Pyramid - Filtering out the high frequencies

- Spatial filter in front of the pyramid
- Active modulation is still possible



Pyramid – filtering out the high frequencies



Noisy background intensity

$$I_B = I(1 - S_{max})$$

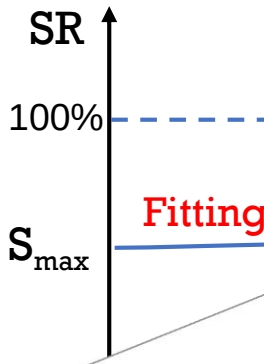
Signal intensity on the pupils

$$I_0 = I\frac{S_{max}}{2}$$

Filtering out the high frequency, the noisy background is removed and the same S/N is obtained with a smaller intensity reference star

$$\Delta m = 2.5log\left(1 + 2\frac{1 - S_{max}}{S_{max}}\right)$$

Pyramid – filtering out the high fr es



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Multiple Spatial Frequencies Pyramid WaveFront Sensing

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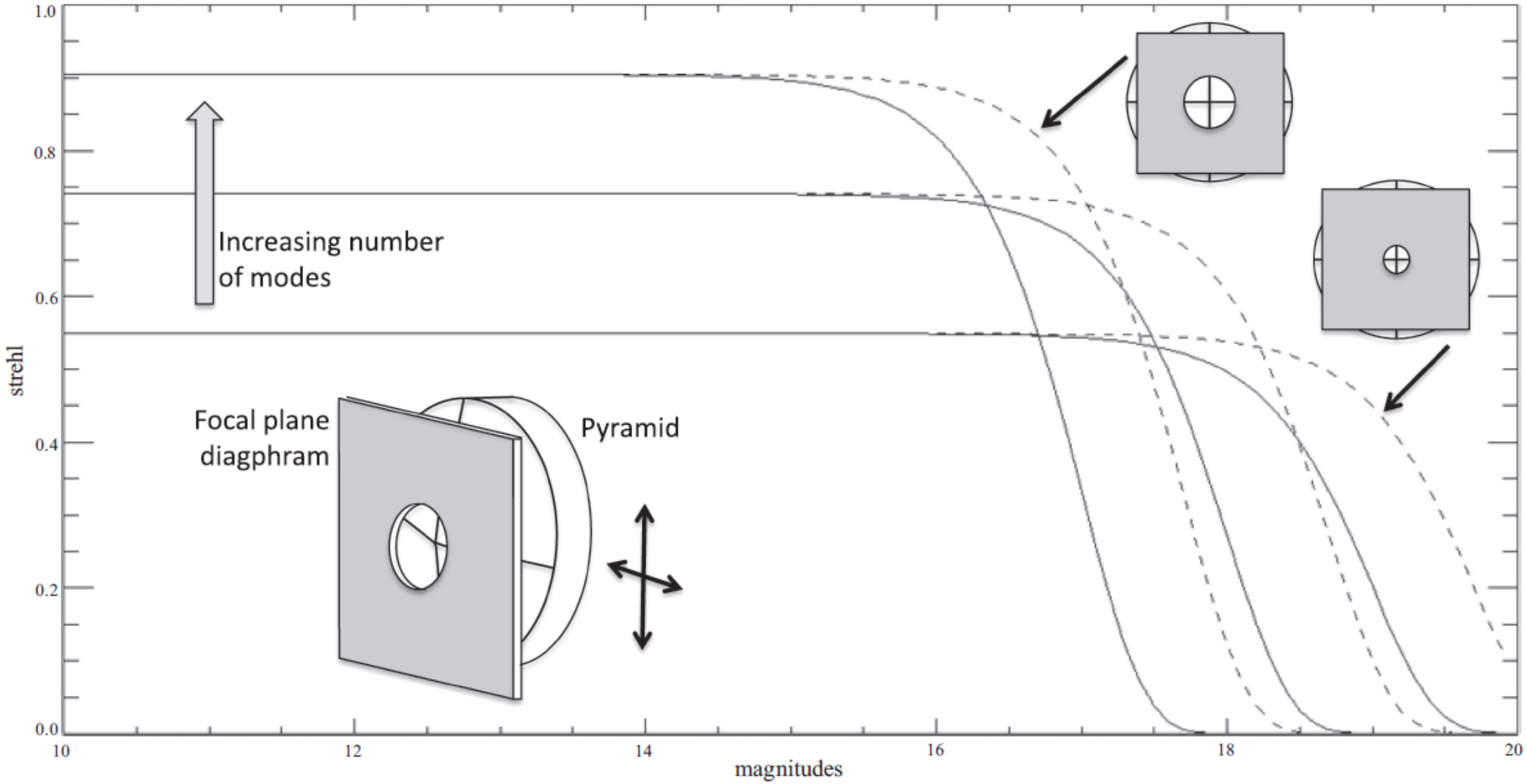
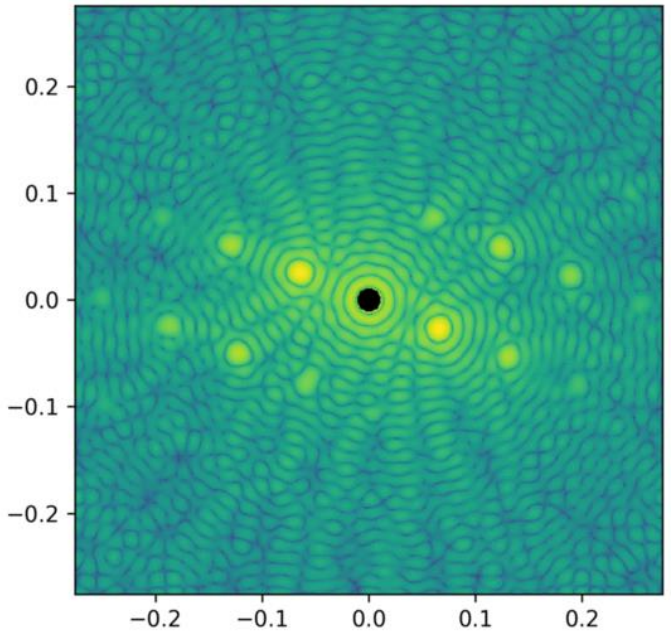
Pyramid – filtering out the high frequencies

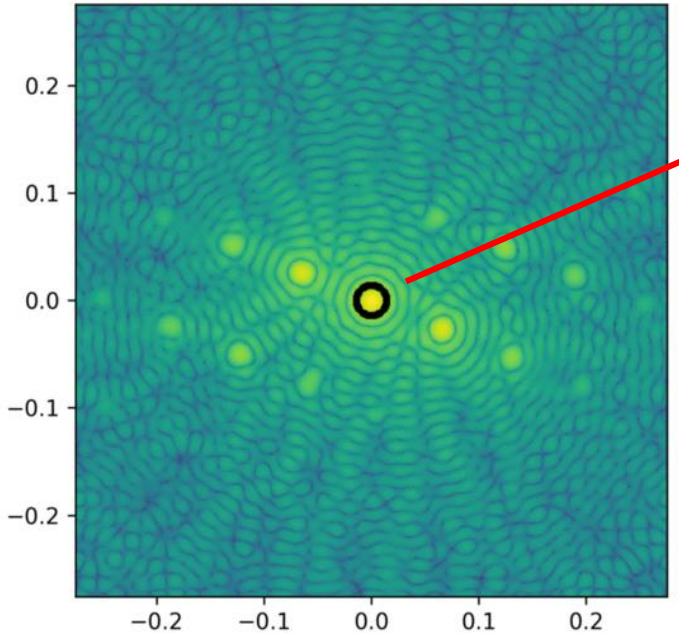


Pyramid - Filtering out the low frequencies

The inefficient way…

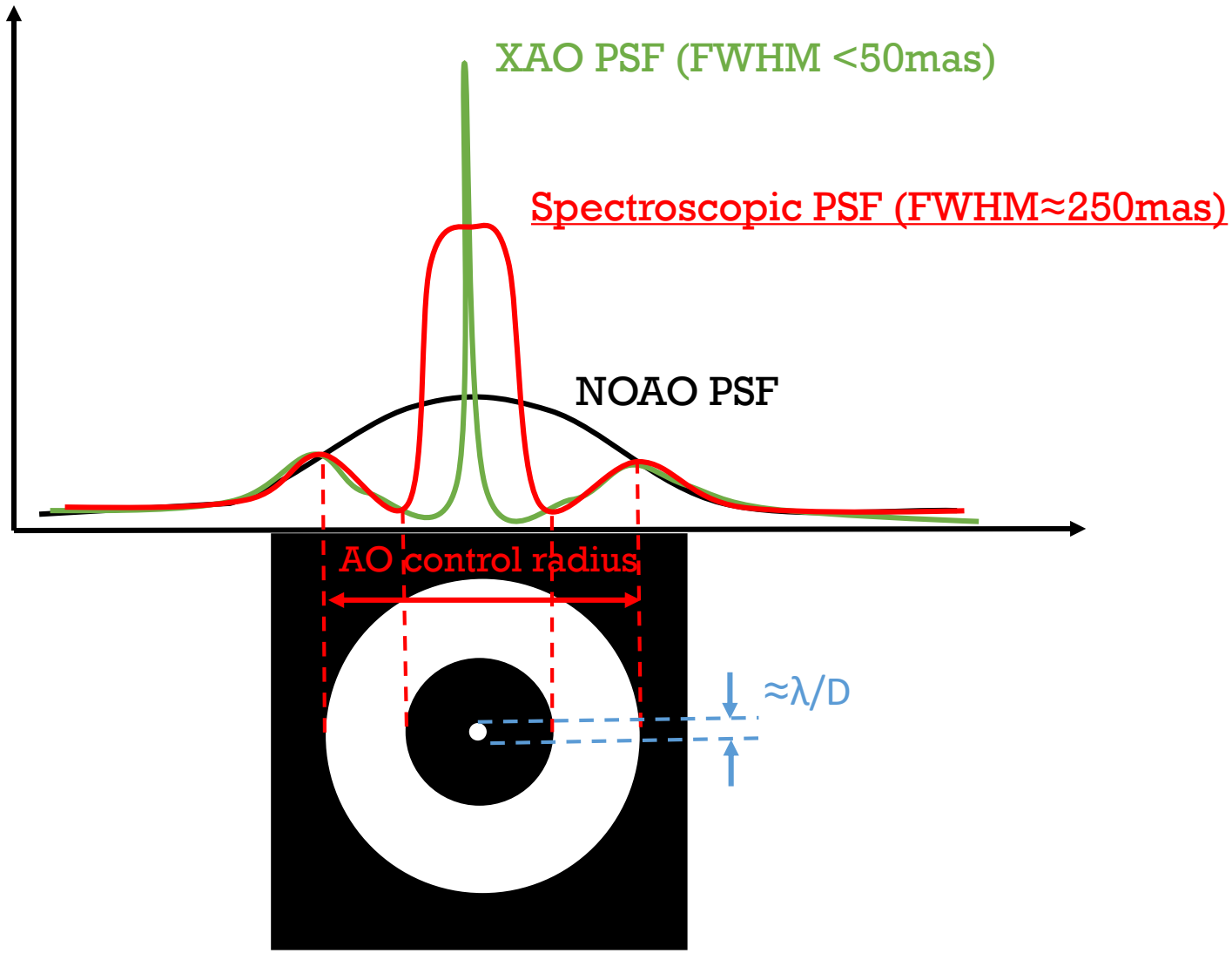


The smart way…



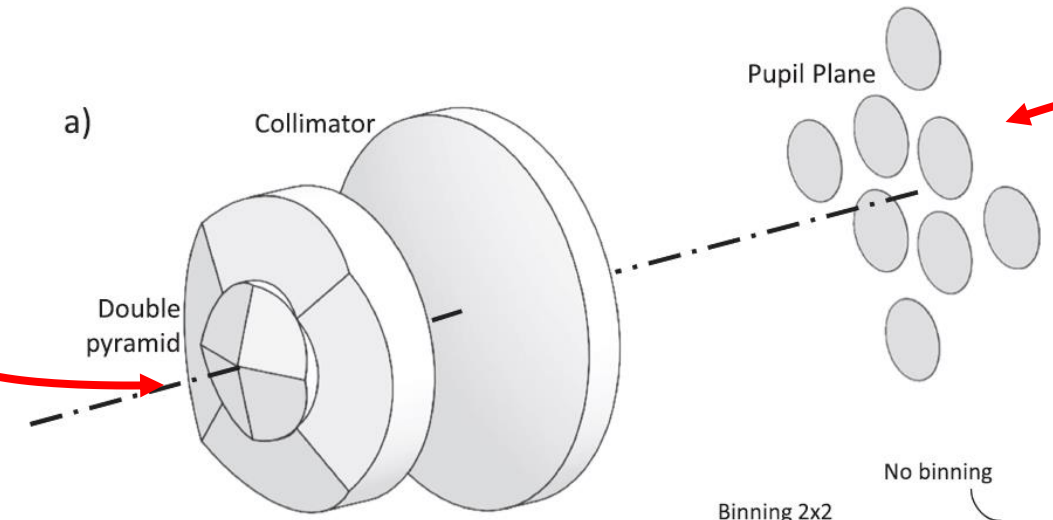
Keep light from the central peak (or part of it)

Low-frequency filtering: an application

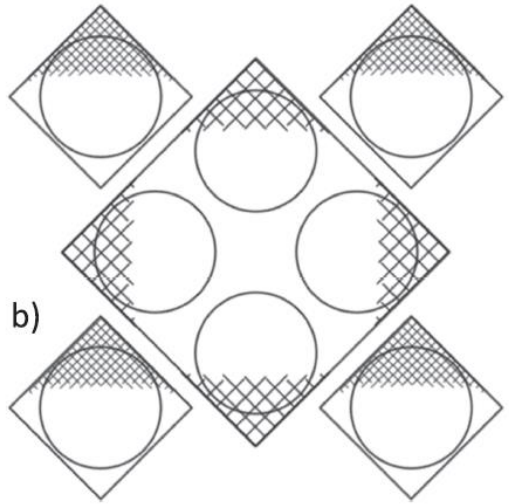


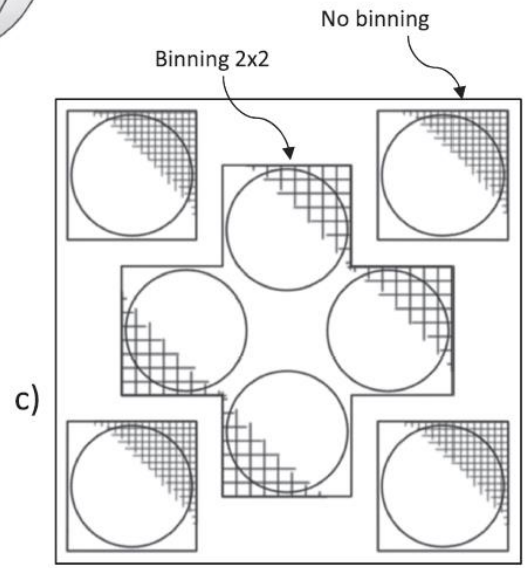
Multiple spatial frequency pyramid sensor

Central peak goes to low-freq. pupils (non optimal for the sensing of high-freq.)



Double pyramid splits the light in 8 pupils

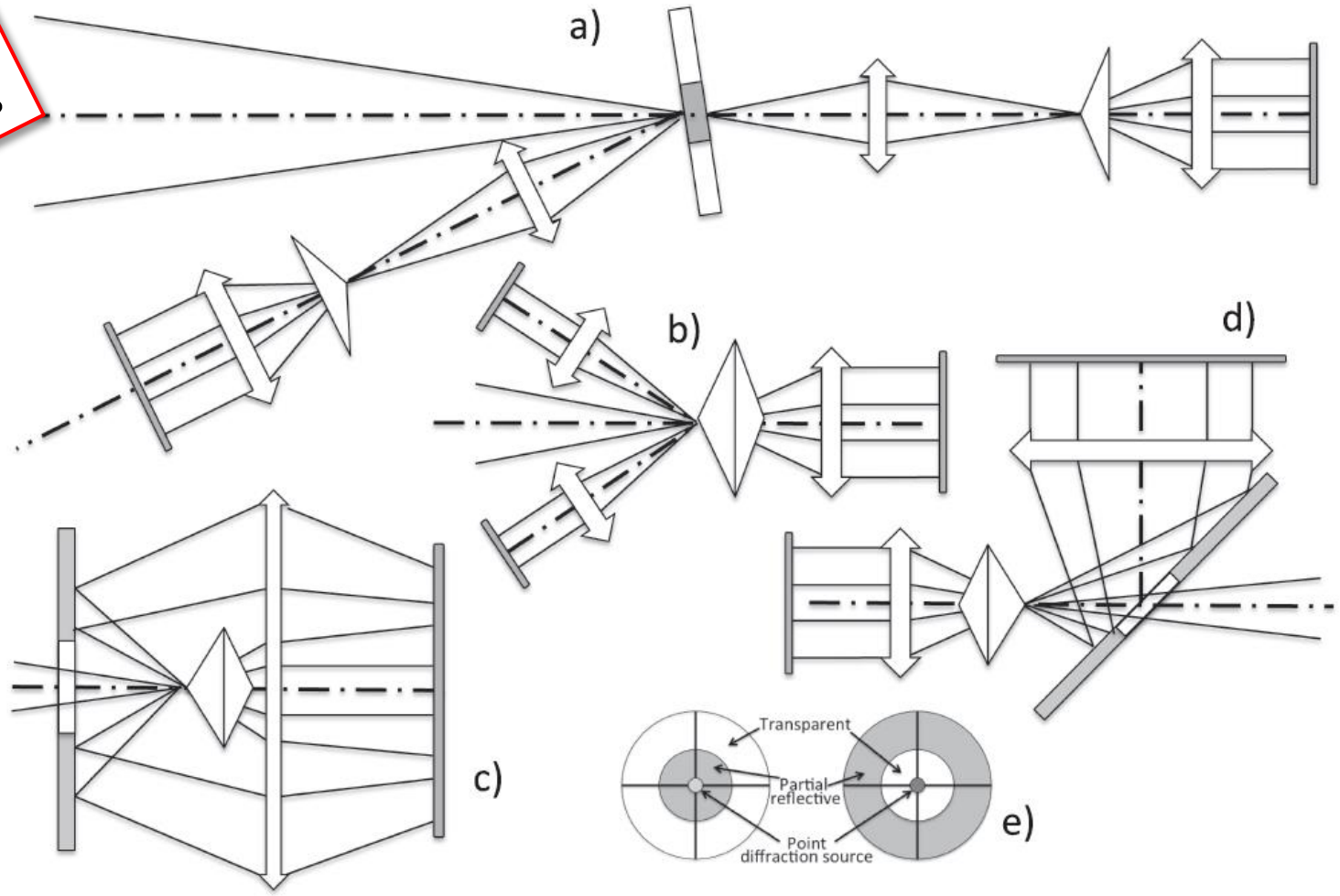




Higher pupil sampling for high spatial frequencies

Multiple spatial frequency pyramid sensor

Some optical schemes to convey part of the light from the central peak to the high frequency pupils



Spatial filtering in the real world…

- More than two spatial frequencies
- White-light condition
- Temporal evolution (closed loop Vs. open loop)

- E2E simulations are needed to assess real magnitude gains and performance improvements
- Many parameters to play with and adjust based on the scientific purpose