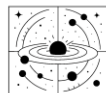


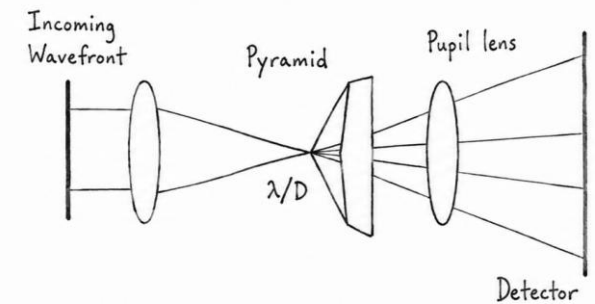
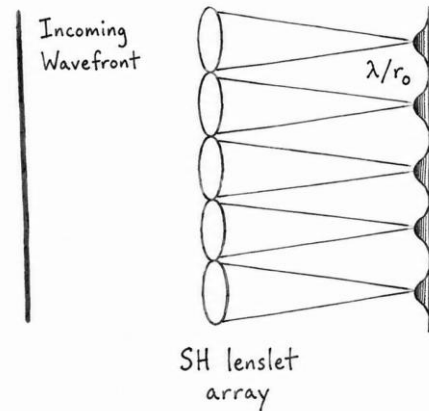
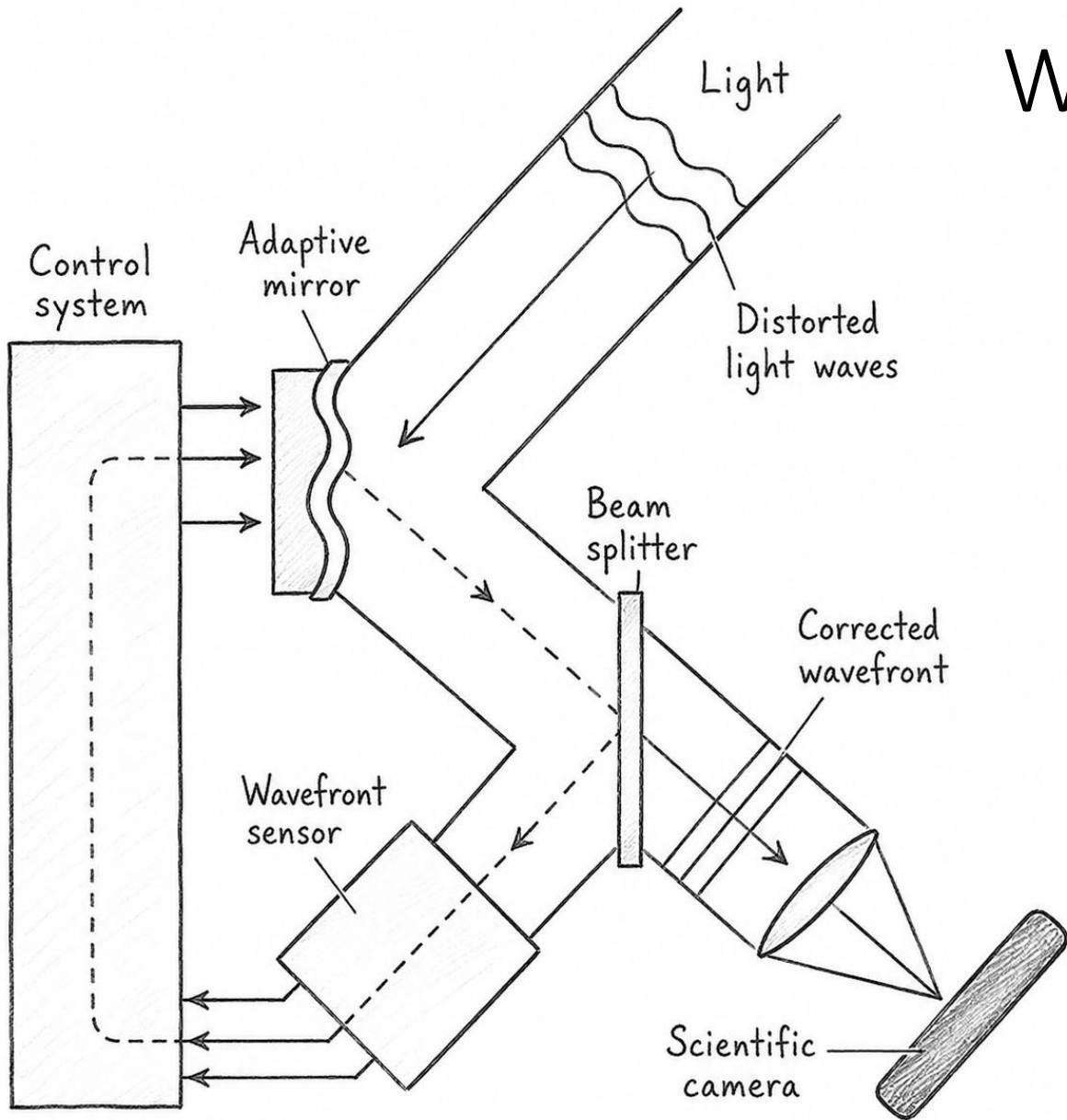
# Novel Types of Wavefront Sensors for the ELT **P**lanetary **C**amera and **S**pectrograph

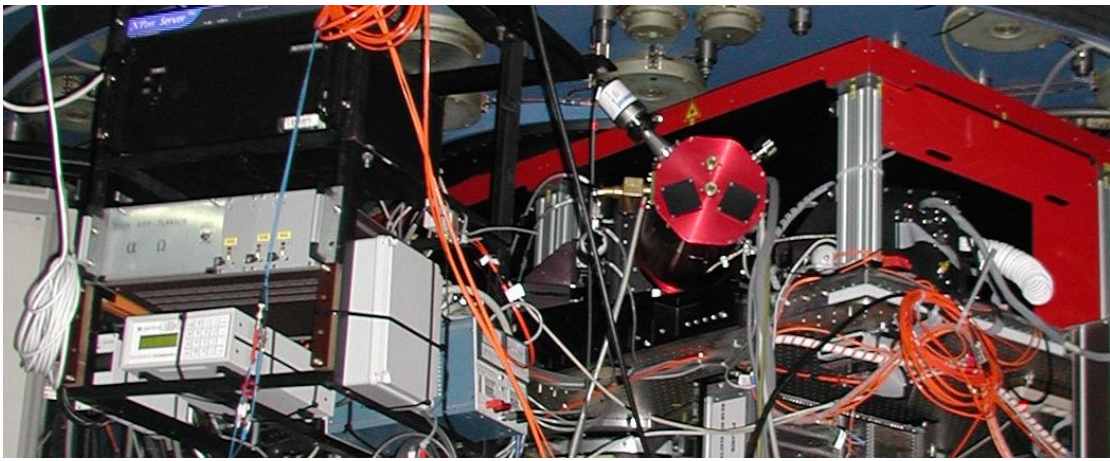
From PYRAMIR to PCS

Markus Feldt



# What is a Wavefront Sensor?



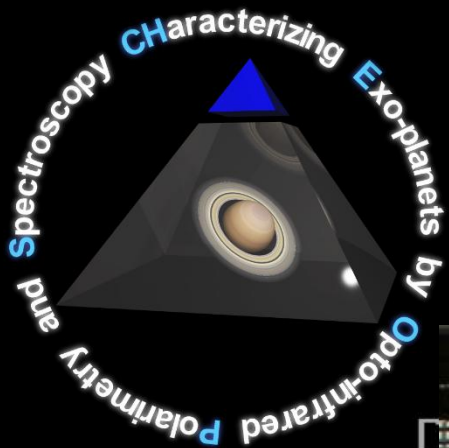


# A Bit of History (I)

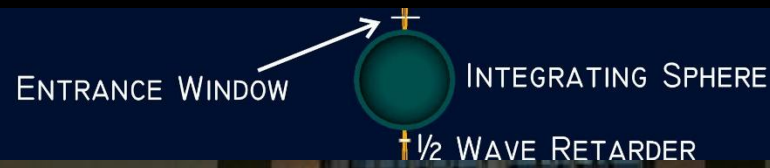
# PYRAM<sup>IR</sup>





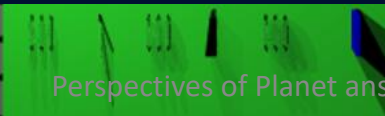


VLT Nasmyth A



Parab

Dic



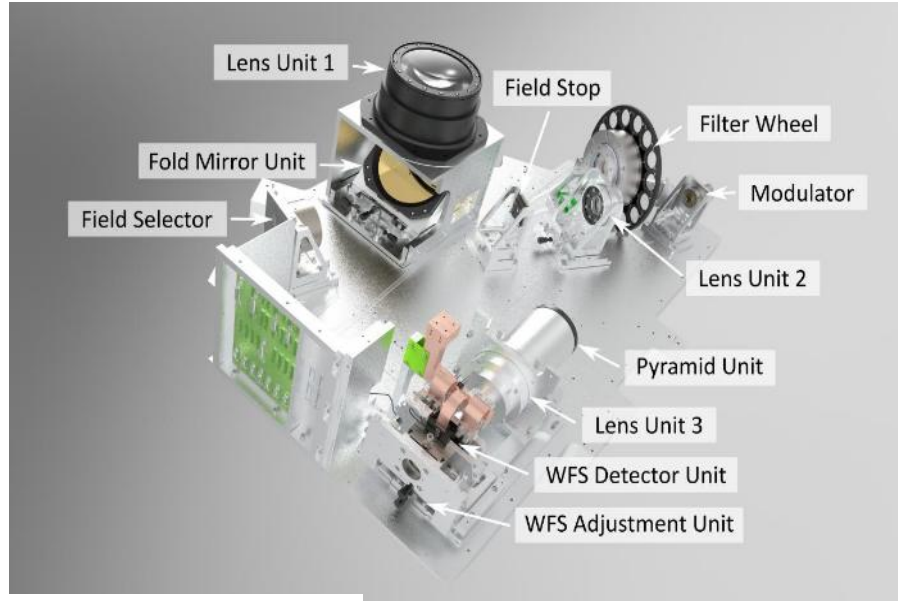
NIR IFU

Perspectives of Planet and Star Formation



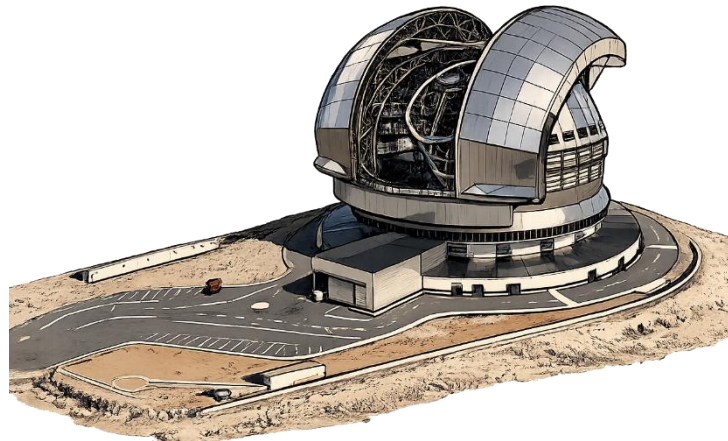
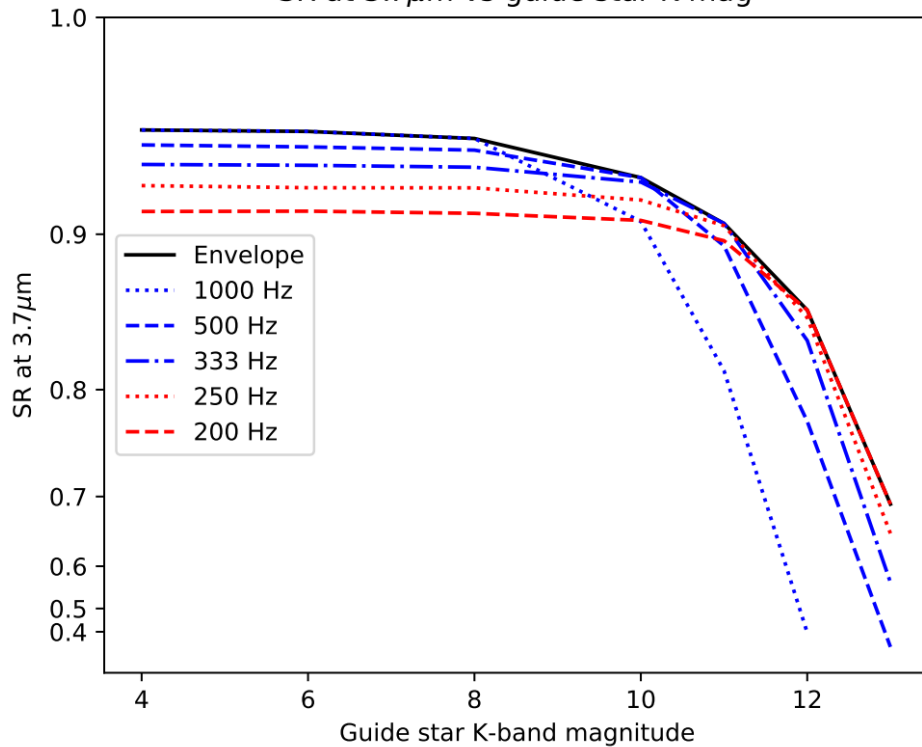
# METIS

Mid-infrared  
ELT Imager and  
Spectrograph

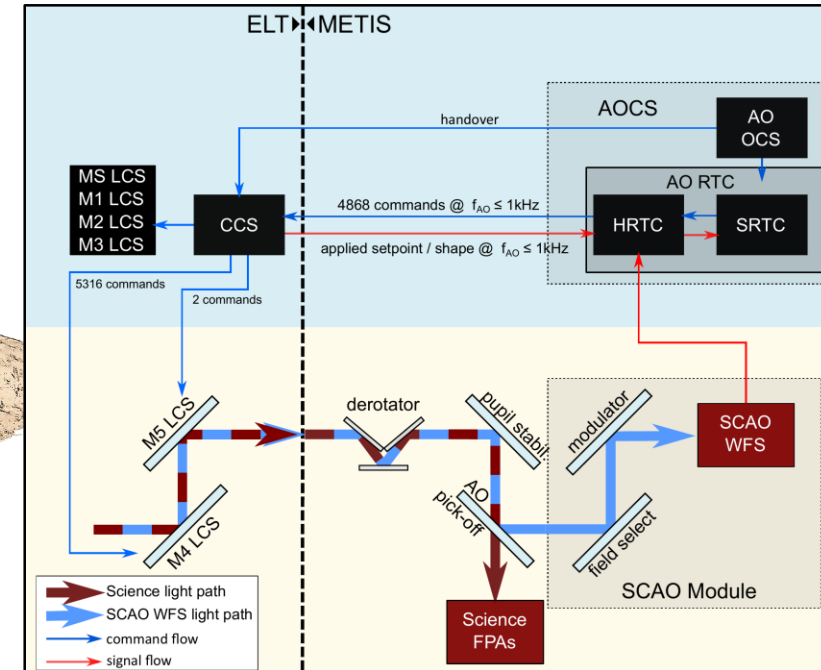


## A Bit of History (III)

SR at  $3.7\mu\text{m}$  vs guide star K-mag



Perspectives of Planet and Star Formation



Contrast requirements:

| Distance [mas]<br>Lim. <i>I</i> Mag. | 30                                   | 100                                   | 300                                             |
|--------------------------------------|--------------------------------------|---------------------------------------|-------------------------------------------------|
| 5 (goal 6)                           | $2 \times 10^{-9}$ (goal $10^{-9}$ ) | $10^{-9}$ (goal $4 \times 10^{-10}$ ) | $5 \times 10^{-10}$ (goal $2 \times 10^{-10}$ ) |
| 7 (goal 8)                           | $10^{-8}$                            | $10^{-9}$                             | $10^{-9}$                                       |
| 9 (goal 10)                          | $10^{-6}$                            | $10^{-6}$                             | $10^{-6}$                                       |

| Distance [mas] | 10        | 20                  | 30         |
|----------------|-----------|---------------------|------------|
| Contrast       | $10^{-8}$ | $3 \times 10^{-10}$ | $10^{-10}$ |

Loosely translated to AO performance:

**Req-2** The extreme AO system of EPICS shall deliver a Strehl Ratio (SR) of 85% in *H*-band under reference seeing conditions. (This corresponds to a wavefront error of  $\sim$  **100 nm rms**)

**Req-3** Limiting magnitude to fulfil requirement *Req-2*  $I < 9$  mag (goal:  $I = 13$  mag at SR=60%)

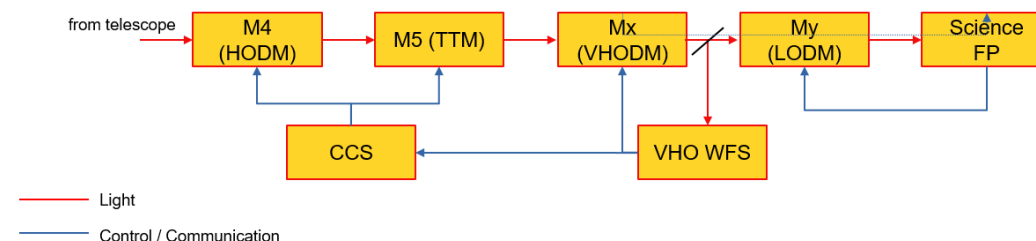
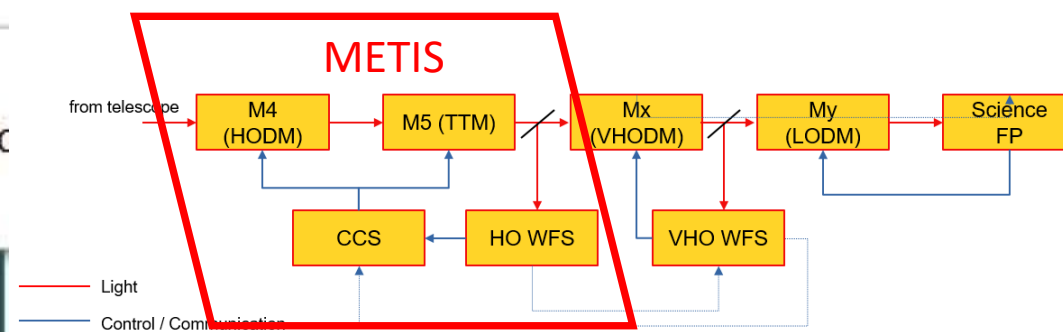
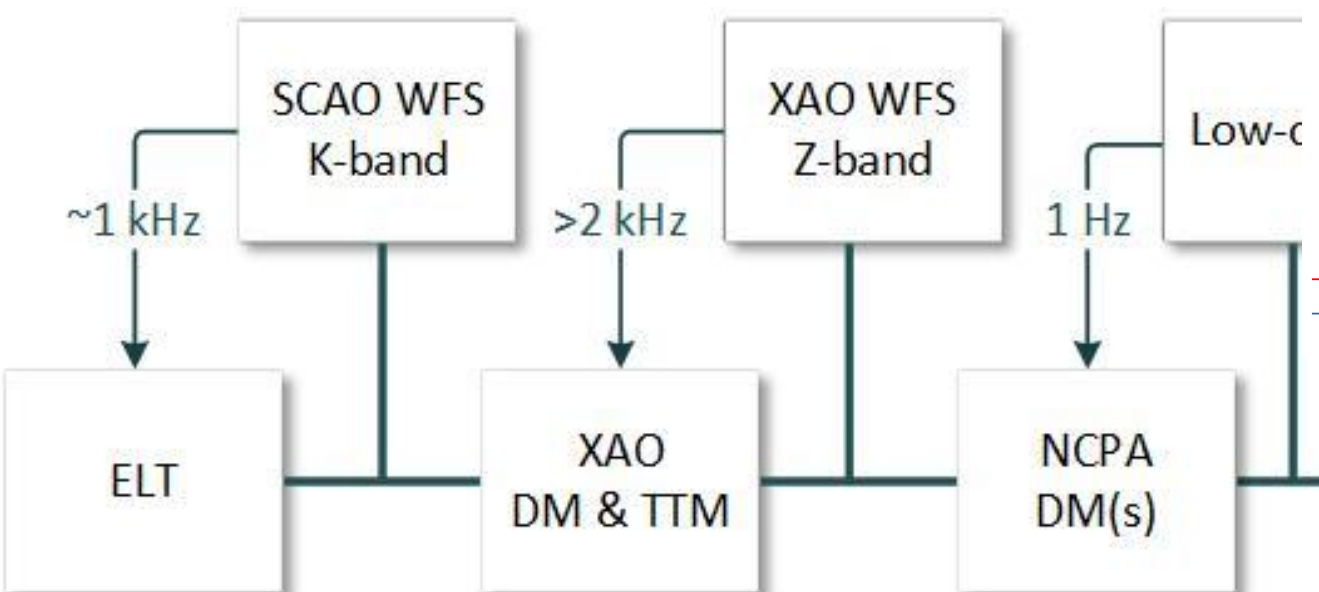
**Req-4** The extreme AO system of EPICS shall deliver a Strehl ratio of >55% in the *R*-band for very bright stars  $R < 5$  mag ( $\sim$ WFE **<80 nm rms**)



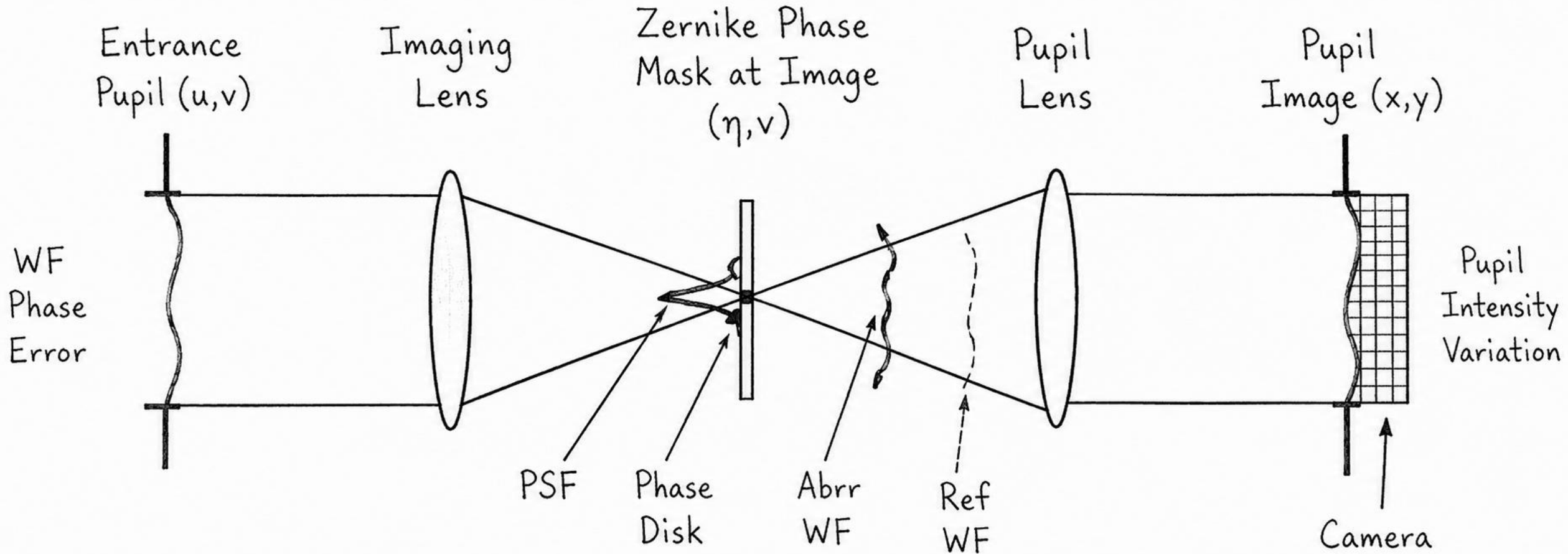
# PCS

## Cascaded AO

## Woofer-tweeter AO

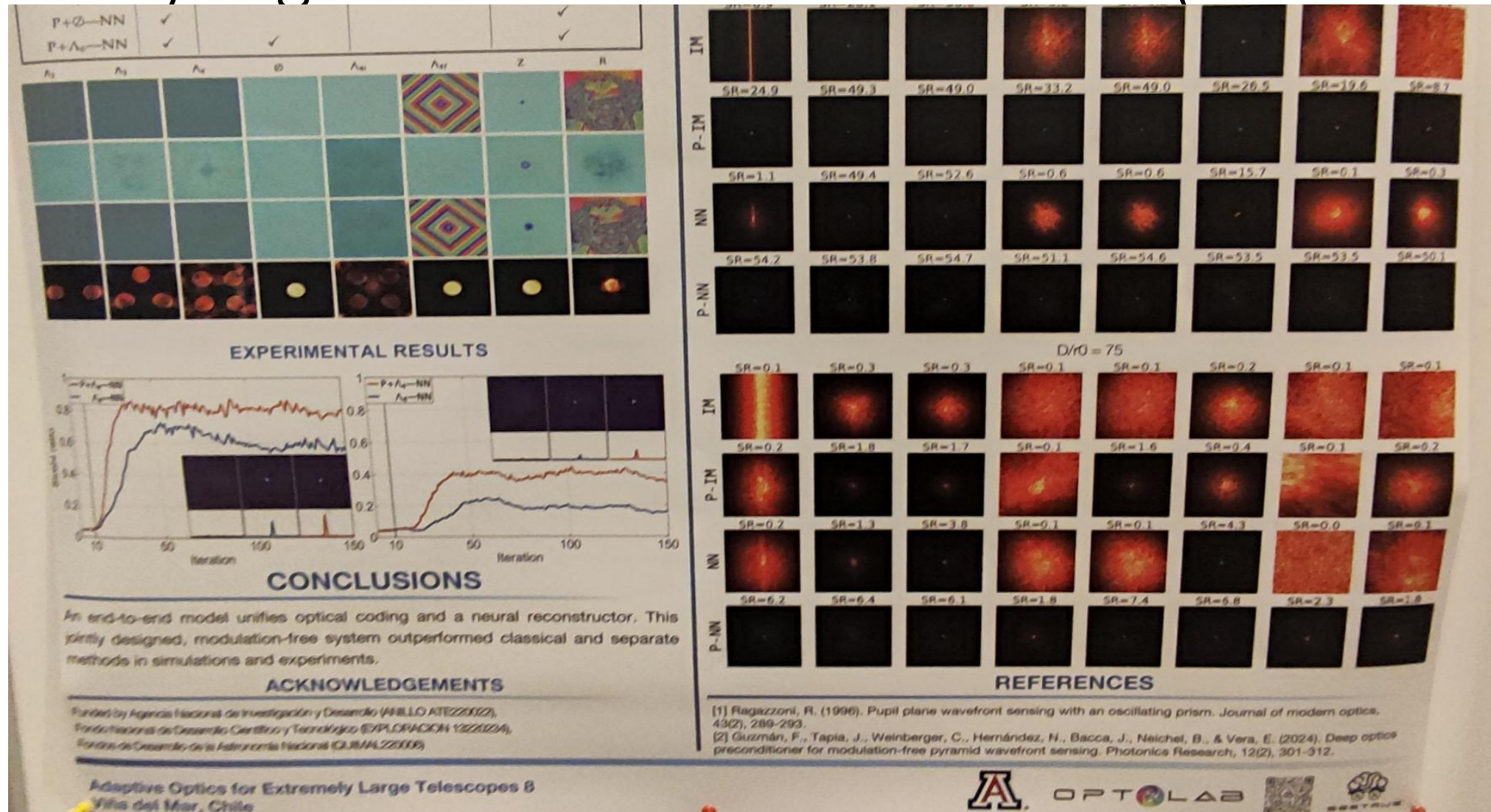


# Very High Order Wavefront Sensor (VHO WFS)

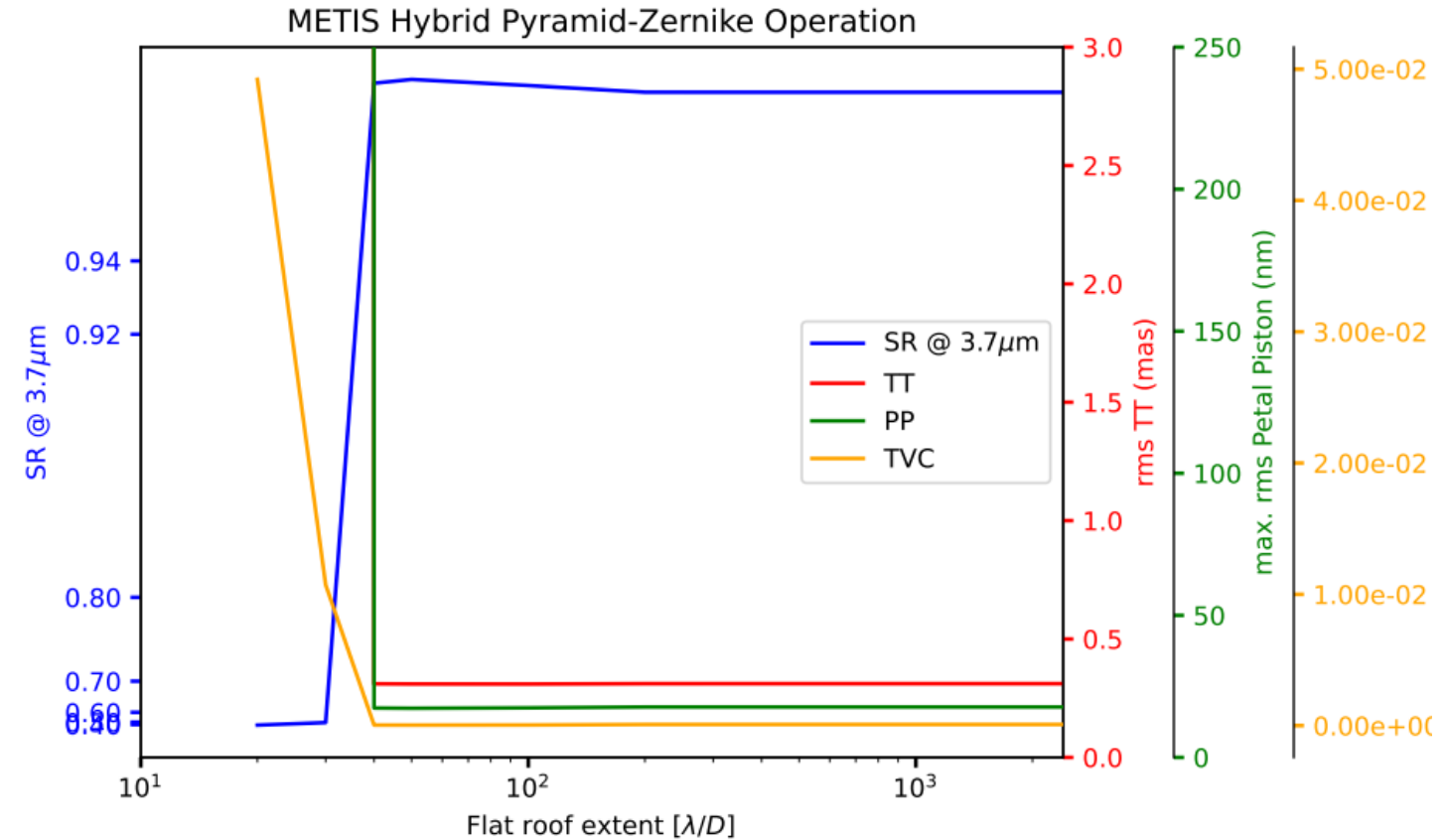
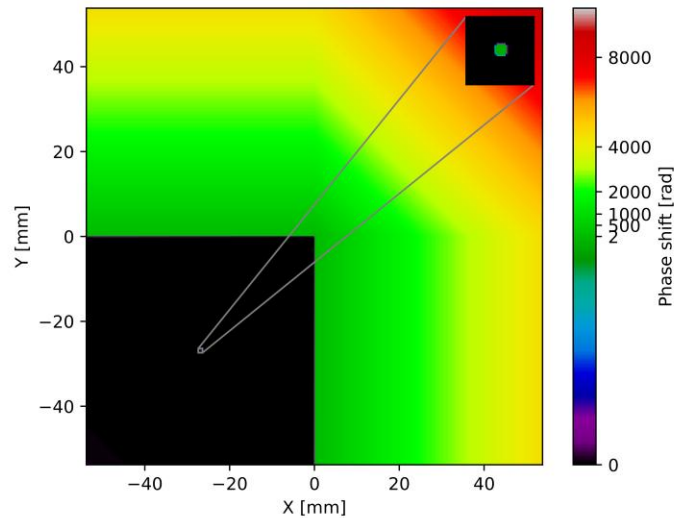
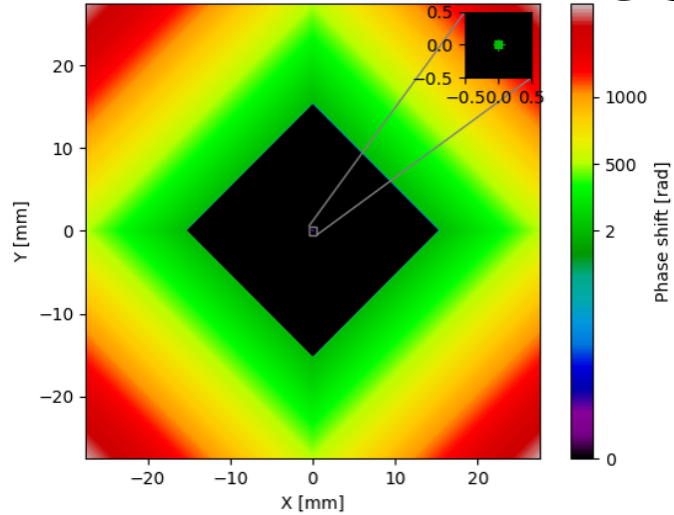




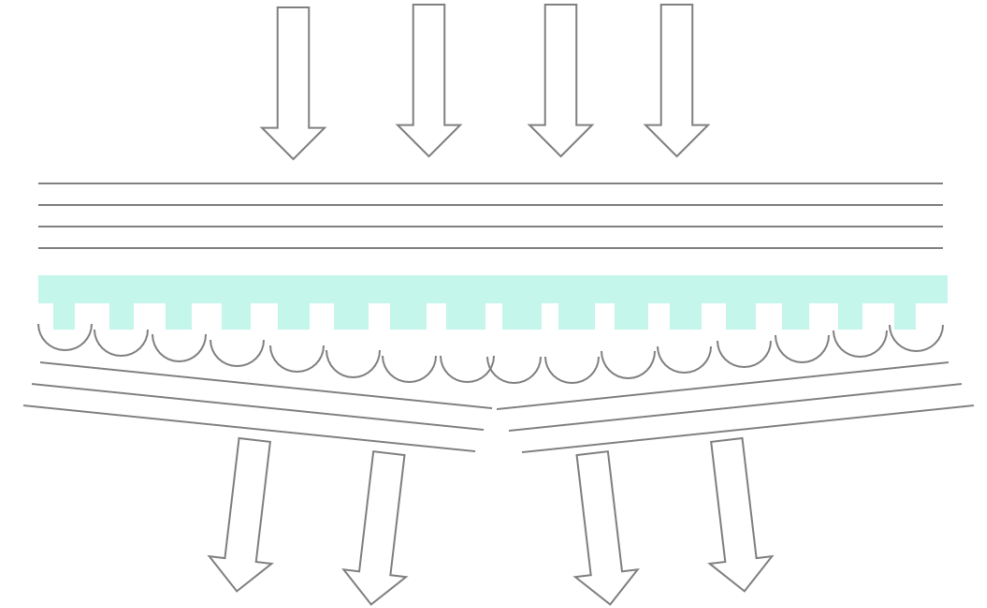
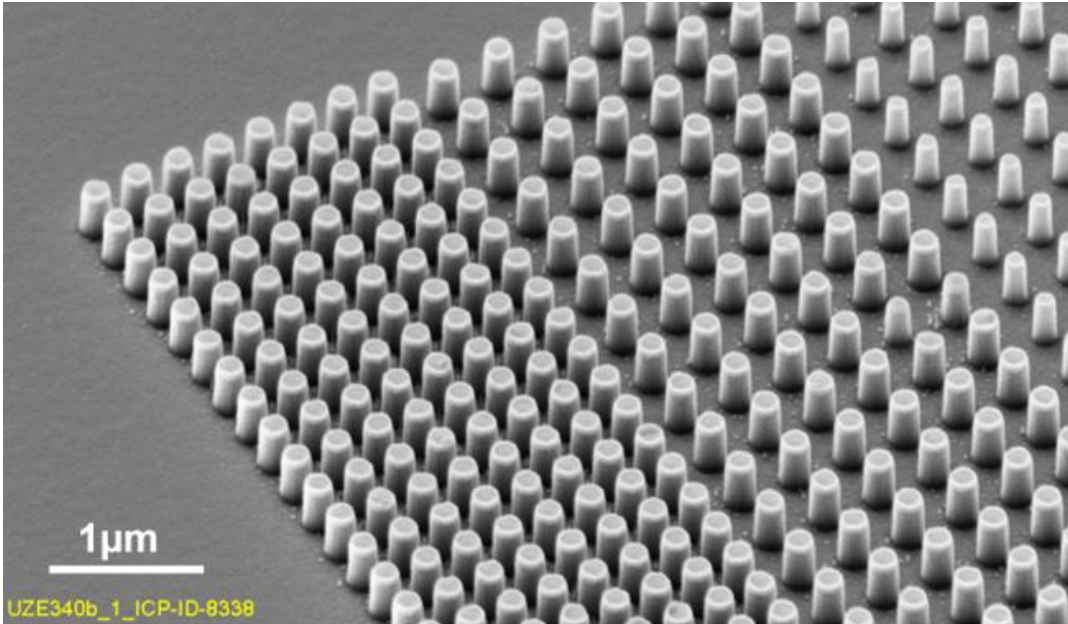
# Very High Order Wavefront Sensor (VHO WFS)



# Combining a Pyramid and a Zernike?

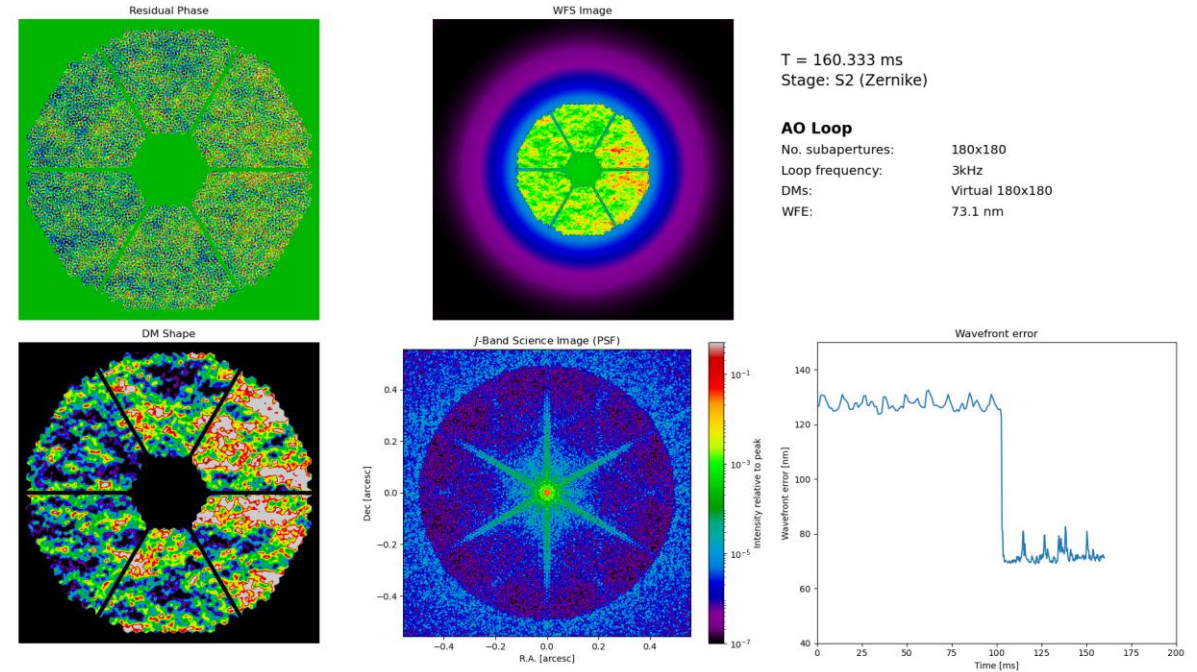
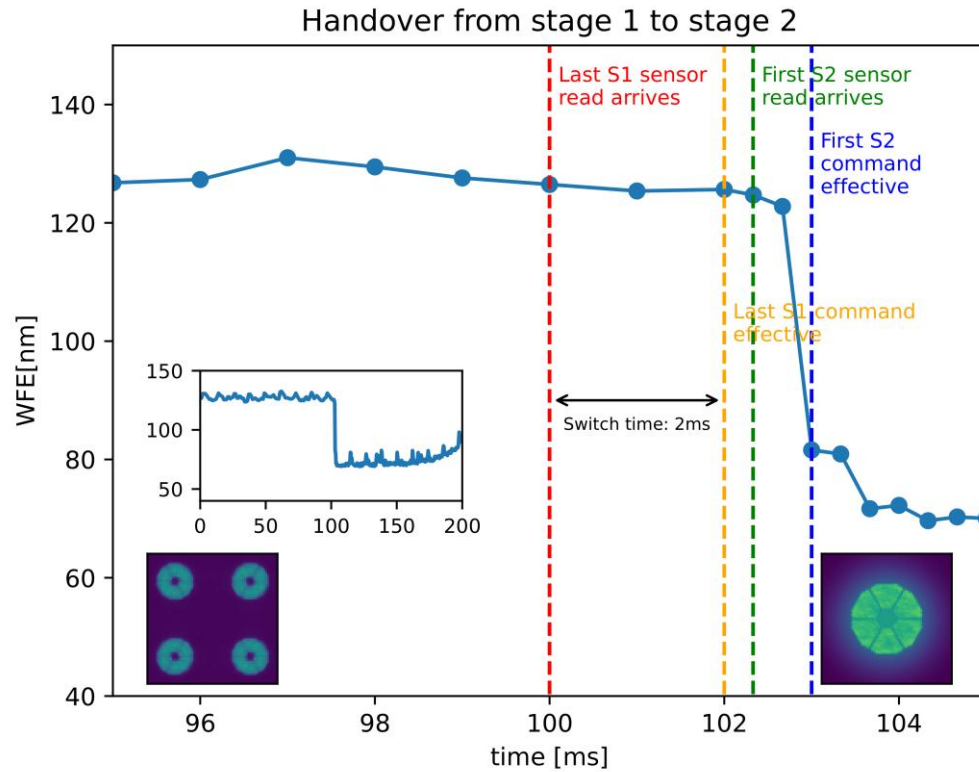


# Combining a Pyramid and a Zernike?





# Sequential Operation

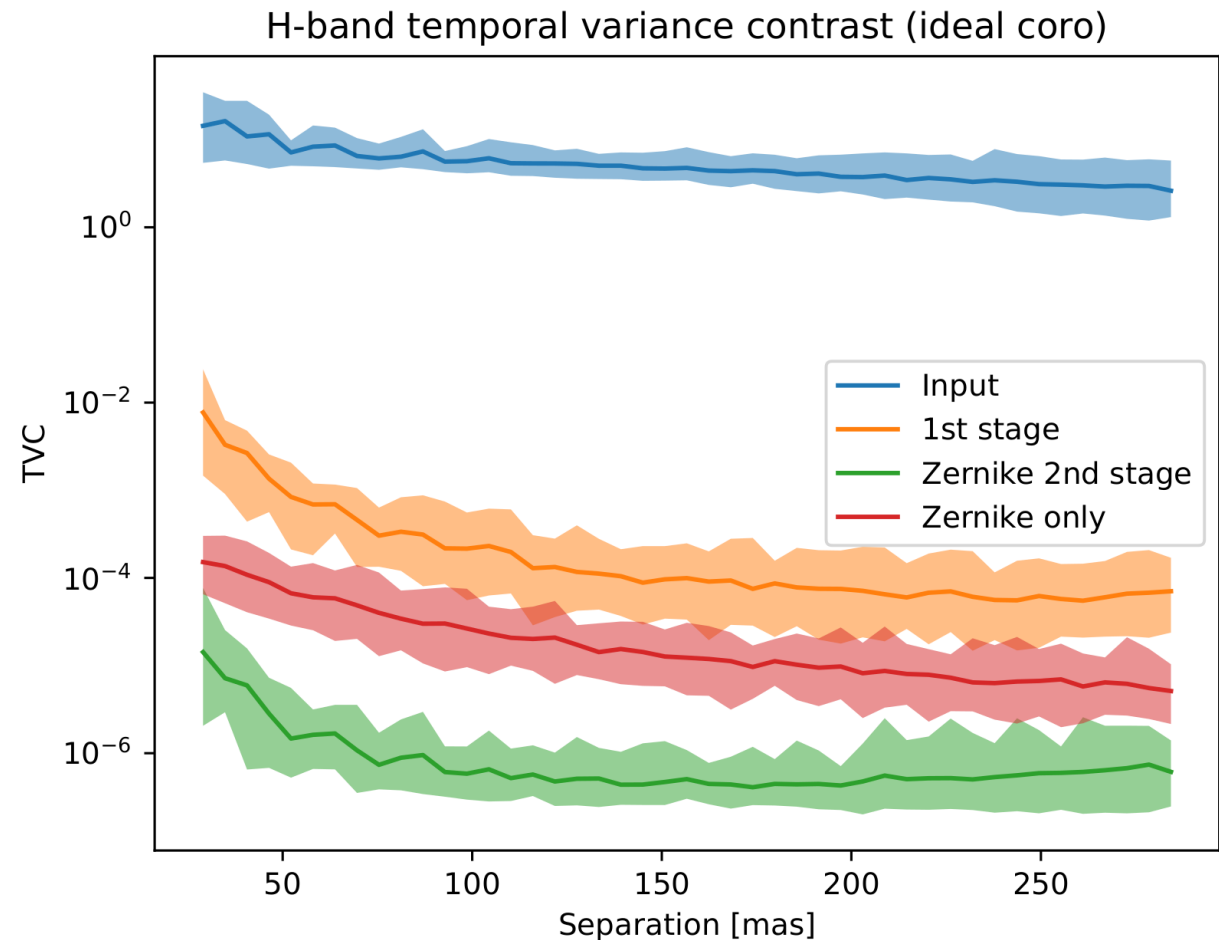


# Parallel vs. Sequential Operation

## Simulating 2stage PCS system

- 1st stage METIS,
- 2nd stage 180x180, 3kHz
- Q2 seeing, bright star

| Correction scheme | Residual WFE (nm) |
|-------------------|-------------------|
| 1 stage           | 143               |
| Zernike as 2nd    | 56                |
| Zernike only      | 155               |



# Take Home Messages

- ▶ New WFS types can come too early
- ▶ PCS can either be operated with one or two sensors simultaneously
- ▶ Fourier sensors offer a variety of possibilities
- ▶ Zernike sensor offers excellent performance as second stage, has trouble alone