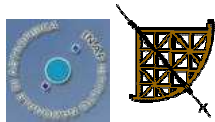


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# MAORY

## E-ELT multi-conjugate adaptive optics module

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# Requirements

- **Location and functions**

- MCAO module located on Nasmyth platform
- Relay telescope focal plane
- Host post-focal deformable mirrors

- **Client instrument MICADO**

- Wavelength range: 0.8 - 2.4  $\mu\text{m}$
- Field of View: 53"×53"
- AO correction: **uniform** over field with high **sky coverage**
- Astrometry: 50  $\mu\text{as}$  relative accuracy across full field
- Photometry: 0.03 mag relative accuracy
- MAORY thermal background: < 50% (telescope + sky) @Ks
- Field derotation: mechanical on gravity invariant port

- **Other client instruments?**

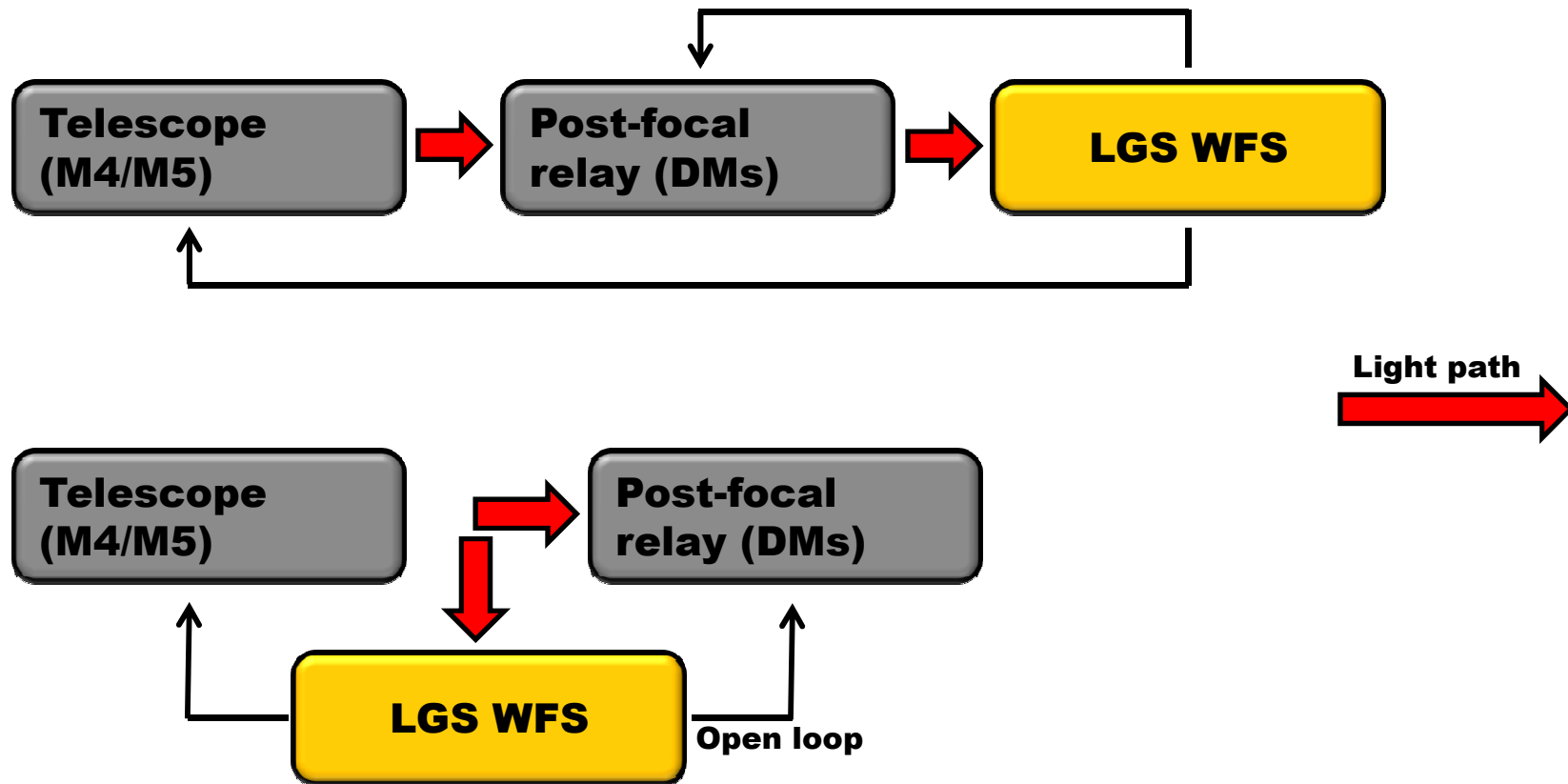
- SIMPLE (single-object high spectral resolution spectrograph)
- Design and performance optimized for MICADO

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# Baseline design overview

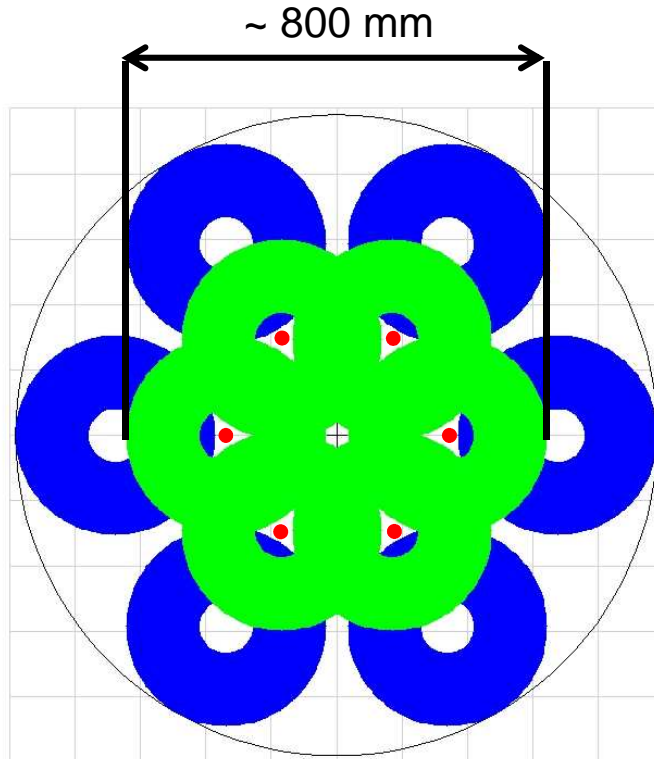
- **Corrected field of view**
  - AO performance optimized over 53"x53" unvignetted field for MICADO
  - Maximum unvignetted scientific field  $\varnothing$  2 arcmin
  - Technical field  $\varnothing$  2.6 arcmin for Natural Guide Star search
- **Wavefront sensing**
  - 6 Sodium LGS WFS (sky coverage, uniformity of correction)
    - 2 arcmin angular diameter
    - LGS projected from M1 edge
  - 3 NGS WFS
- **Wavefront correction**
  - Telescope M4 + M5
  - 2 post-focal deformable mirrors (4  $\mu$ m, 12.7  $\mu$ m)

# Design choice: LGS WFS location



**Not just a matter of location!**  
**Closed vs. open loop**  
(For MAORY Phase-A we choose closed loop)

# Design choice: LGS WFS location



**Laser Guide Stars FoV 4 arcmin**

**Laser Guide Stars FoV 2 arcmin**

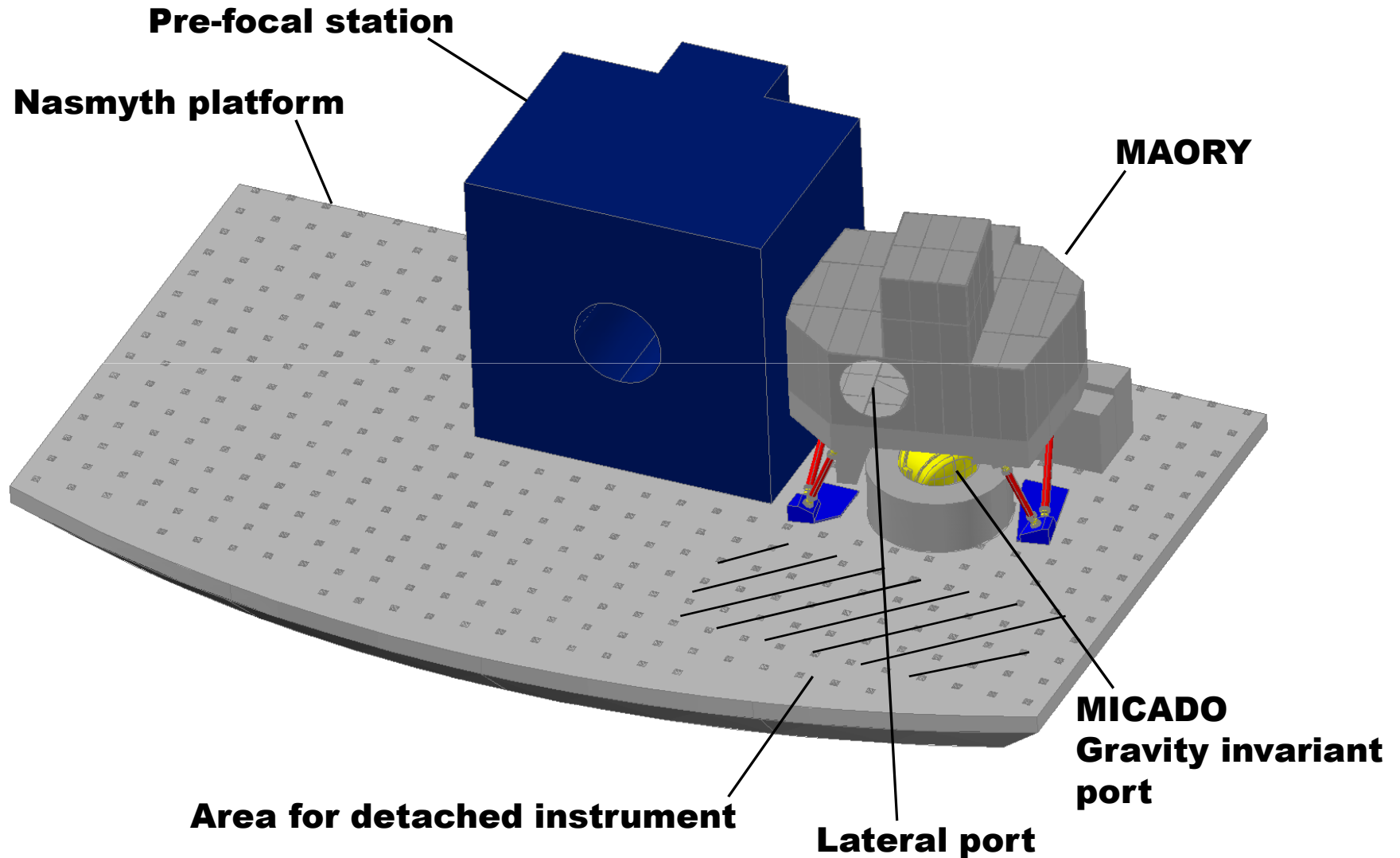
**Science field 2 arcmin**

**Footprints on E-ELT focal plane**

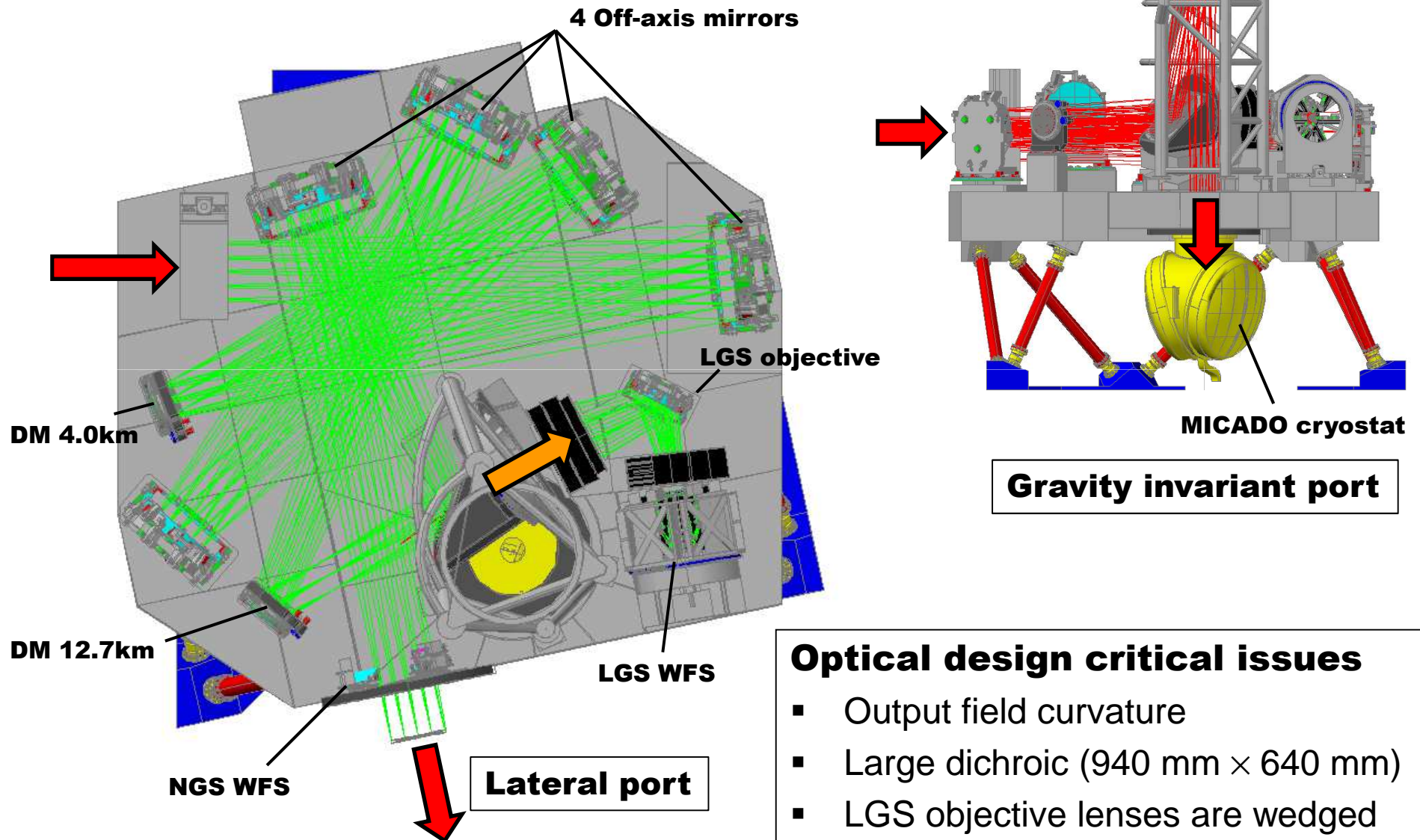
## **Laser / Science optical beam separation issue**

- LGS on 2 arcmin FoV → Large dichroic (~1.2 m × 0.8 m)
- LGS on 4 arcmin FoV → LGS beams picked-off easily, but...
  - Optical layer-oriented viewpoint → “FoV vs. Thickness” rule
  - Tomographic viewpoint → Sensitivity to knowledge of Cn2 profile

# Layout on E-ELT Nasmyth platform

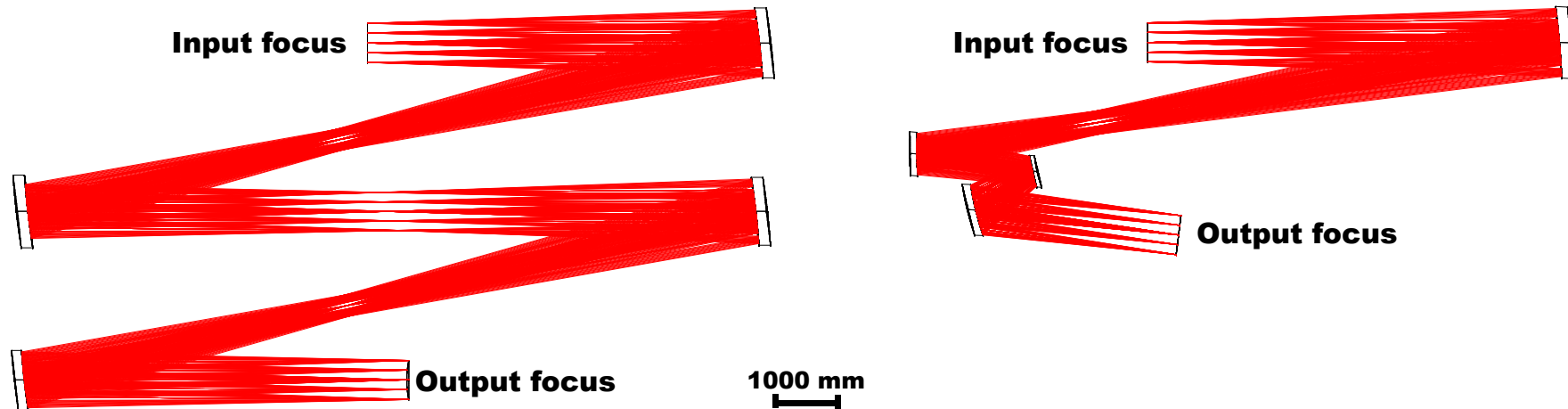


# Post-focal relay



- Optical design critical issues**
- Output field curvature
  - Large dichroic (940 mm × 640 mm)
  - LGS objective lenses are wedged

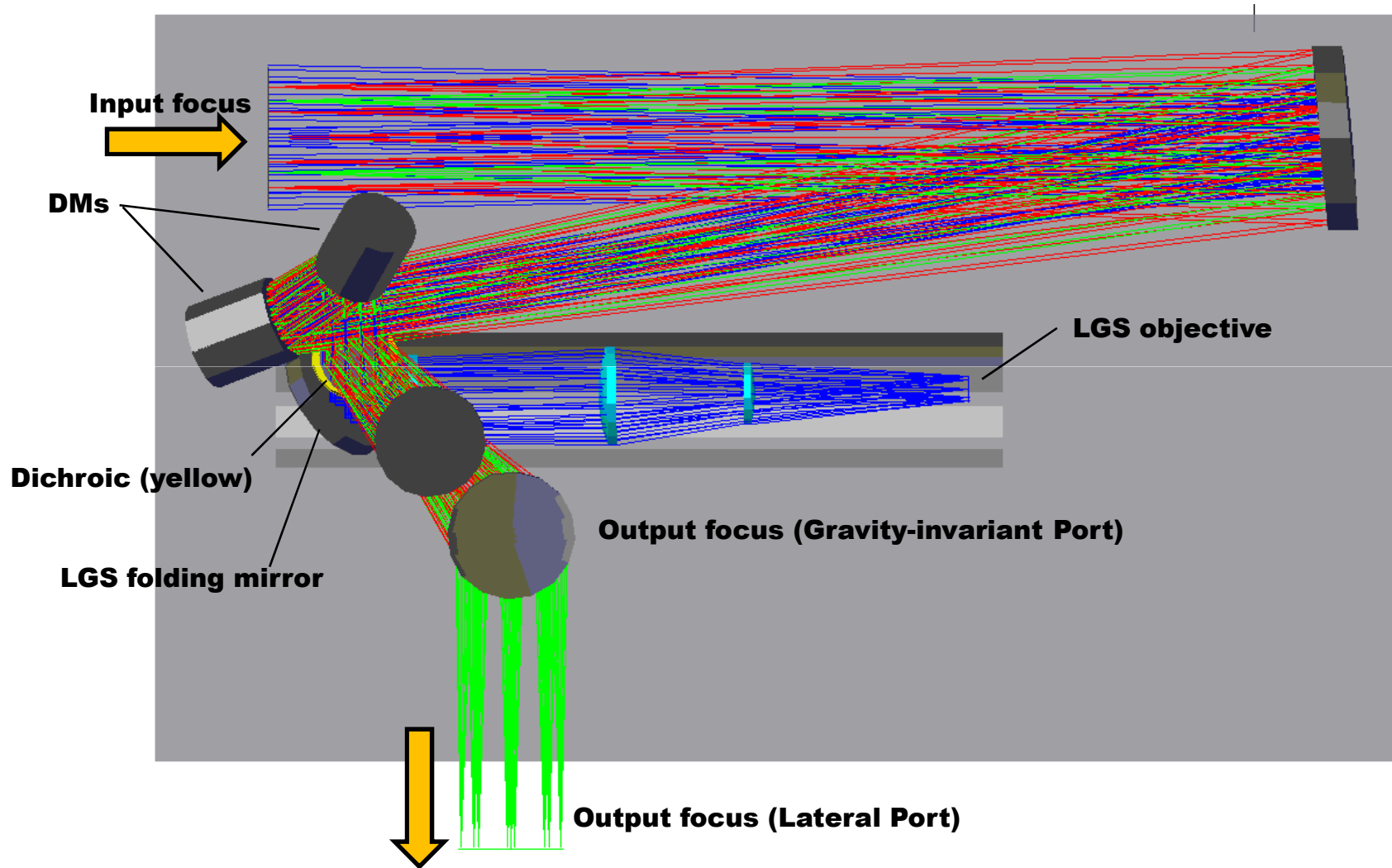
# Two optical design options



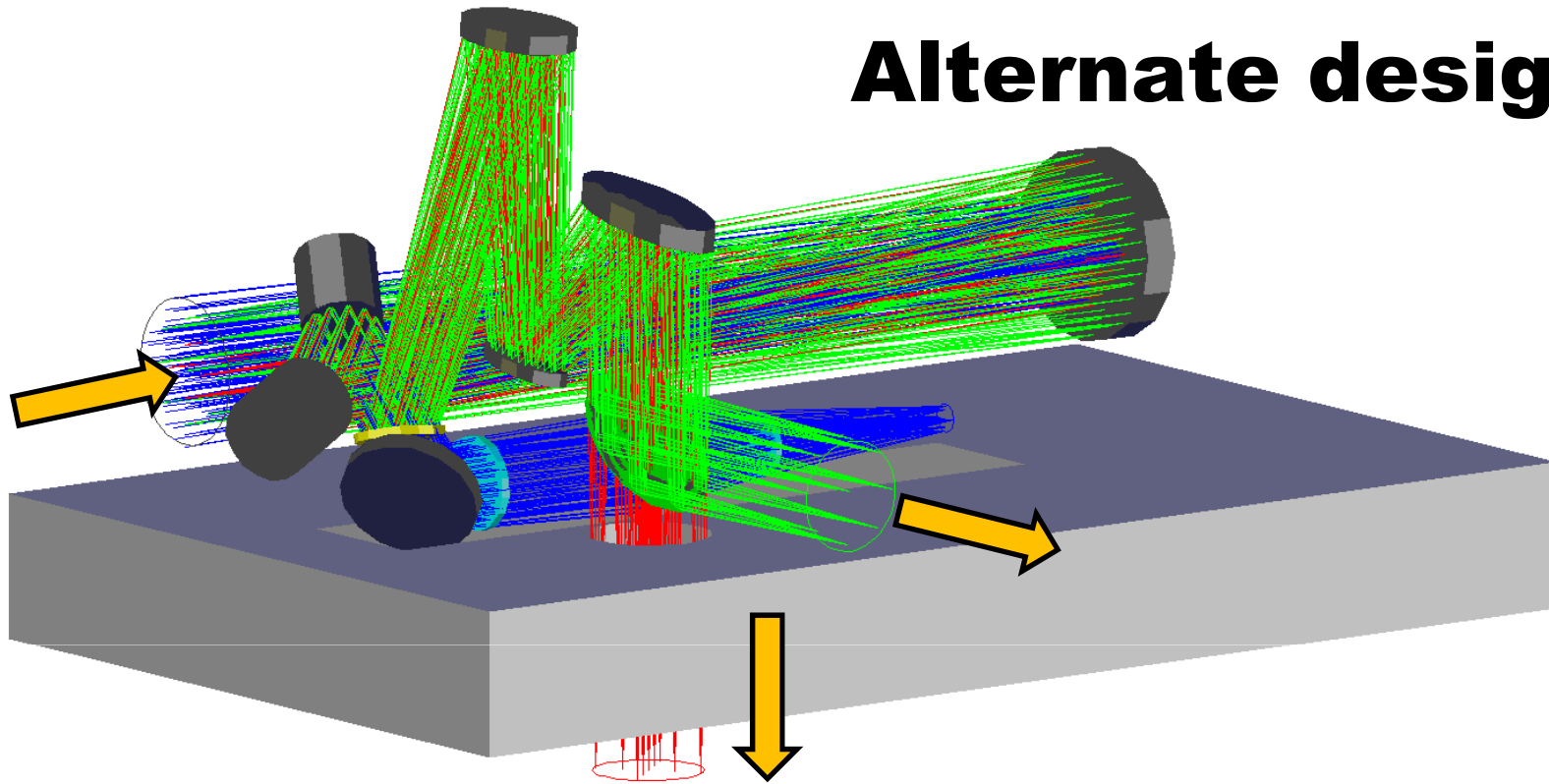
- Intermediate focal plane tilted with respect to chief ray
  - 2 pupil images (required if DMs are conjugated close one to each other)
  - Optical surfaces all concave → strong field curvature
- 1 pupil image
  - Optical surfaces: 3 concave + 1 convex → no field curvature
  - Larger asphericity of 2 mirrors



# Alternate design



# Alternate design



	Phase-A Design	Alternate Design
Number of reflections	8	7-8
Dichroic size	940 mm × 640 mm	480 mm × 420 mm
Max. LGS objective lens diameter	810 mm	610 mm
LGS objective lenses wedged?	Yes	No
Output field curvature radius	1425 mm	43800 mm
Average wavefront error FoV Ø60"	19 nm	48 nm
Max. geometric distortion FoV Ø60"	2.8 mas	0.2 mas
Total volume	7.4 m×7.2 m×8.0 m	7.2 m×4.3 m×6.4 m

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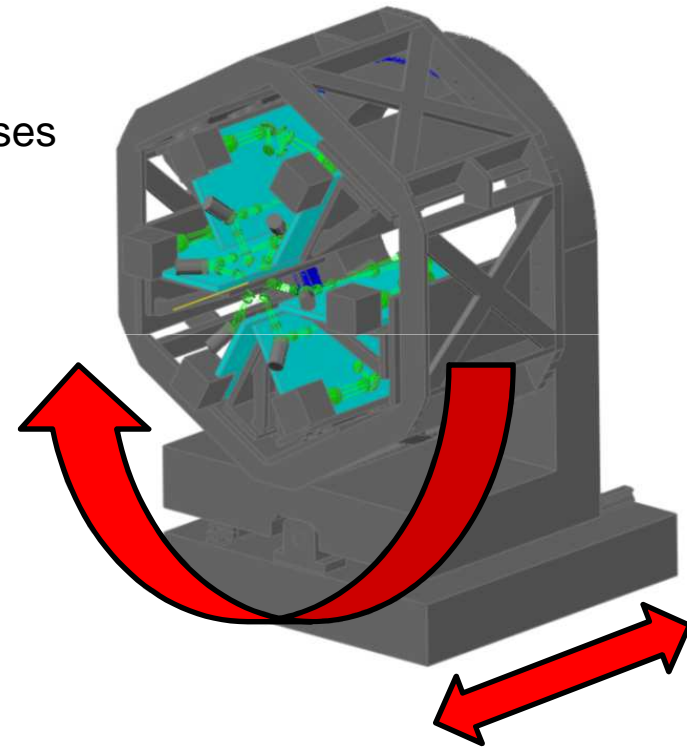
# LGS Wavefront Sensor

## Functions

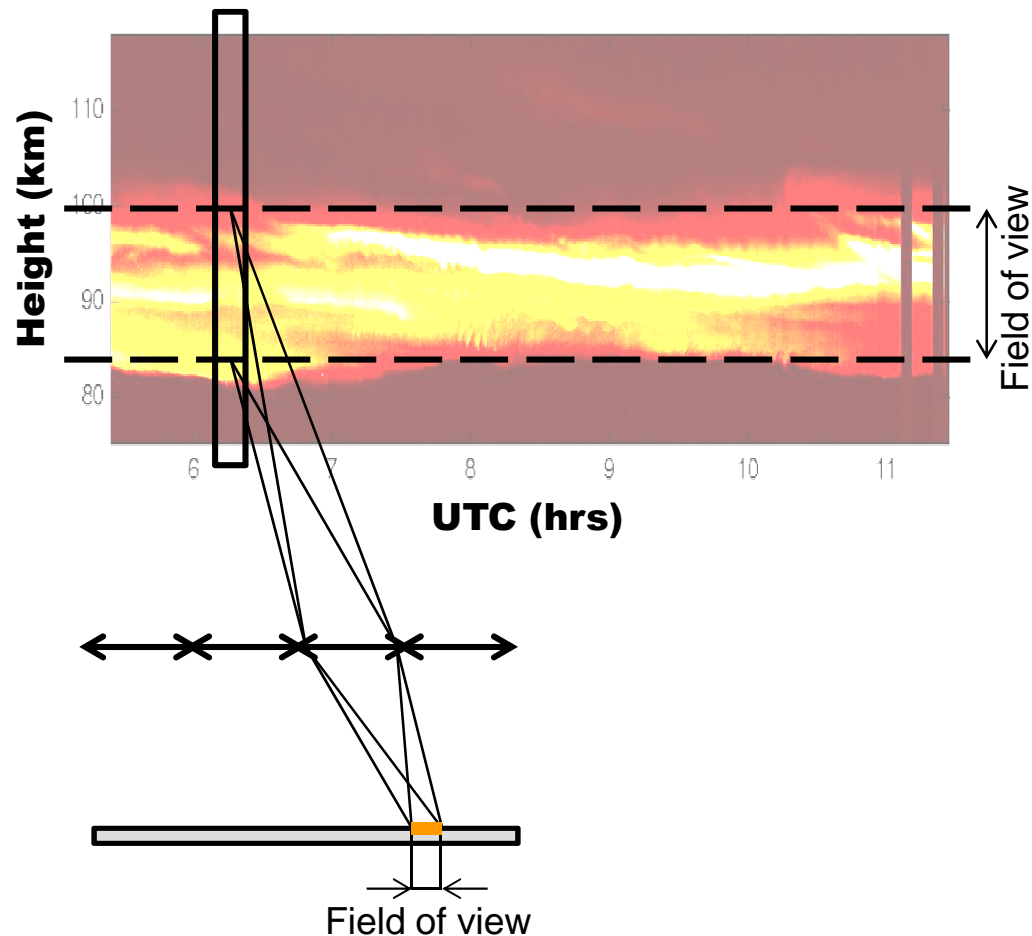
- Global focus (slow) to track the Sodium layer
  - Phase-A design: by moving WFS assembly
  - Alternate design: by moving LGS objective lenses
- Mechanical derotation (elevation only)
- Jitter compensation (one per probe)
- Differential (slow) focus (one per probe)

## Wavefront Sensor features

- Shack-Hartmann baseline  
84×84 subapertures (for 42 m E-ELT)
- Must account for LGS non-common path aberrations due to optics and Sodium layer effects



# Sodium special effects



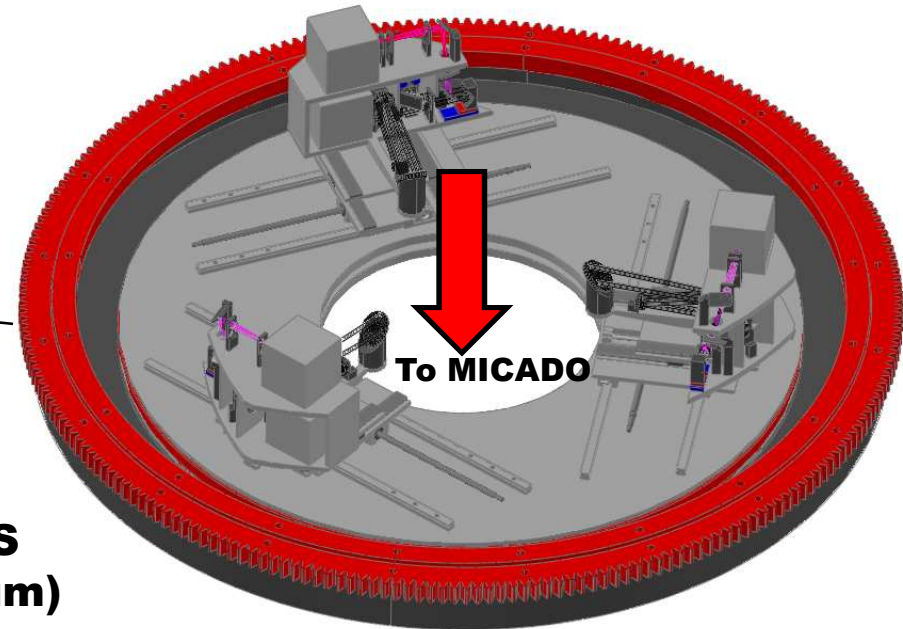
**Sodium data kindly provided by  
Paul Hickson, University of British Columbia**

- No truncation → Focus + Tip-tilt (edge proj.)
- Finite FoV → Time-variable low-order non-common path aberration
- NGS Reference WFS required
- 20+ nights of data analyzed
- Preliminary results
  - LGS WFS FoV: 10 arcsec small, 15-20 arcsec acceptable for side projection
  - NGS Reference WFS: ~10×10 subapertures ~0.1 Hz
  - Error contribution: few 10 nm RMS residual wavefront (warning: photon noise contribution in Sodium data!)

**(L. Schreiber, in prep.)**

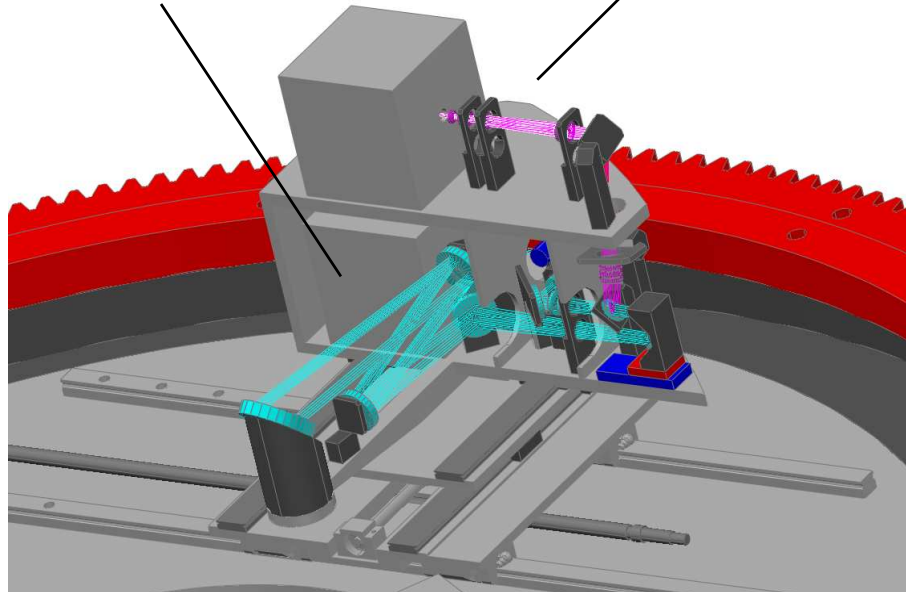
# NGS WFS

Gravity invariant port  
Instrument derotator



Tip-Tilt & Focus WFS  
(1.5  $\mu\text{m}$  – 1.8  $\mu\text{m}$ )

Reference WFS  
(0.6  $\mu\text{m}$  – 0.9  $\mu\text{m}$ )



## Tip-Tilt & Focus channel

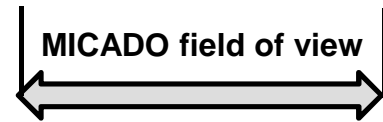
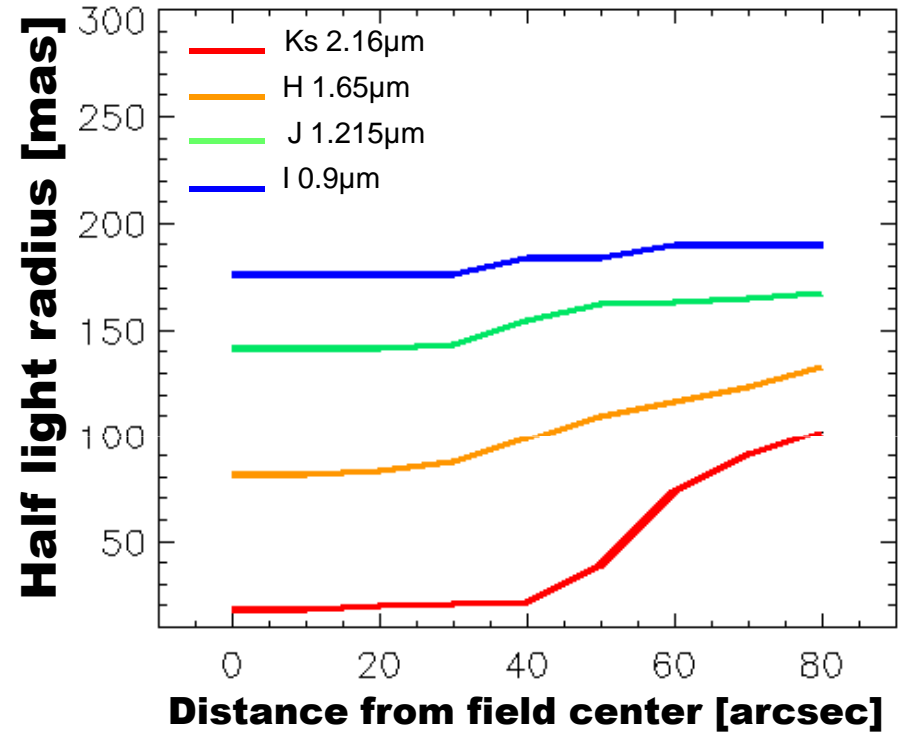
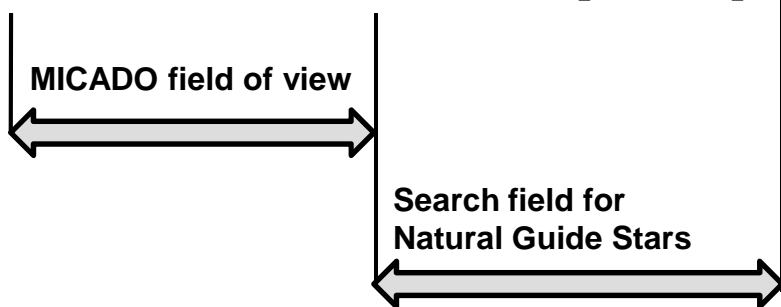
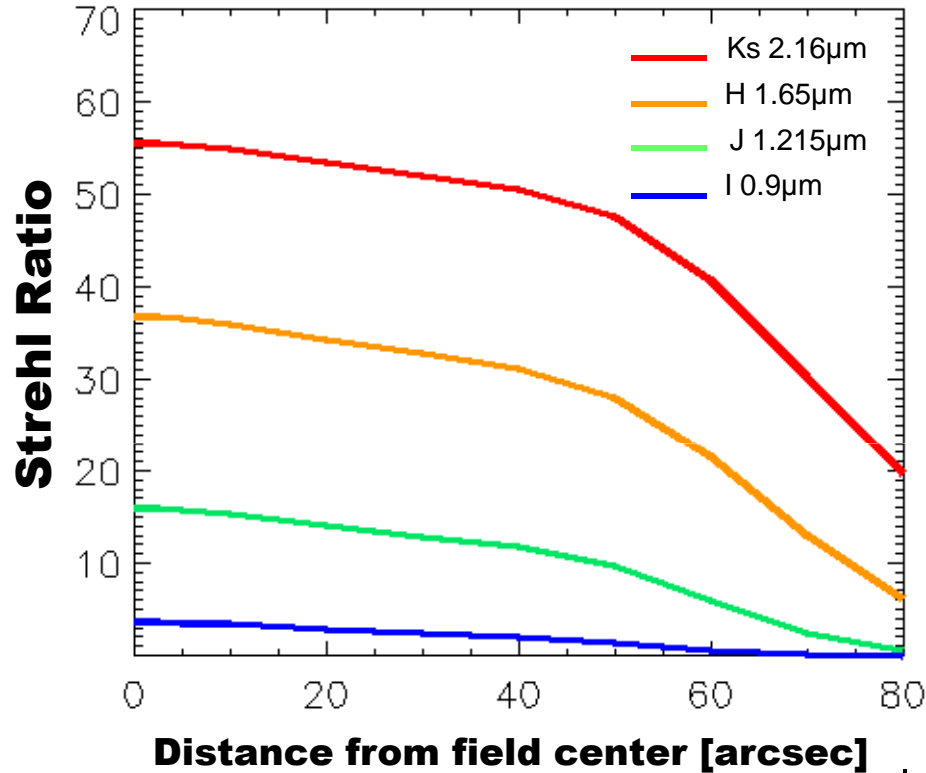
- 2 TT + 1 TTF or 3 TTF  $\rightarrow$  choice depends on Sodium focus properties (see T. Pfrommer's talk)
- Shack-Hartmann, 2 $\times$ 2 subap
- Alternative WFS: LIFT (S. Meimon's talk)

## Reference channel

- $\sim$ 10 $\times$ 10 subap,  $\sim$ 0.1 Hz
- Pyramid WFS

# Performance

Median atmospheric conditions  
Seeing 0.8",  $\tau_0 = 2.5$  ms,  $L_0 = 25$  m

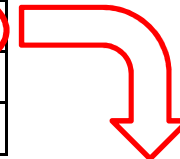


# Sky coverage (North Galactic Pole, median seeing)

- Random star counts generated by TRILEGAL code
- All possible 3-NGS asterisms are formed for each trial
- Best asterism chosen according to figure of merit accounting for measurement noise, temporal error, anisoplanatic error
- Observables: tip-tilt (all 3 NGS), focus (1 NGS or all 3 NGS)
- Each star is assigned the Strehl Ratio value corresponding to its position in the field
- Strehl Ratio comes from closed loop MCAO correction
- Infrared background rejection comes from spot windowing

## Sky coverage with 2 TT WFS + 1 TTF WFS

Minimum field-averaged Strehl Ratio (*)				Sky Coverage
2.16 $\mu\text{m}$ Ks	1.65 $\mu\text{m}$ H	1.215 $\mu\text{m}$ J	0.9 $\mu\text{m}$ I	
0.53	0.34	0.14	0.03	39%
0.51	0.32	0.13	0.03	50%
0.49	0.30	0.11	0.02	60%
0.47	0.27	0.09	<0.01	70%
0.41	0.22	0.06	<0.01	80%



(\*) MICADO FoV 53"×53"

50% if 3 NGS measure focus