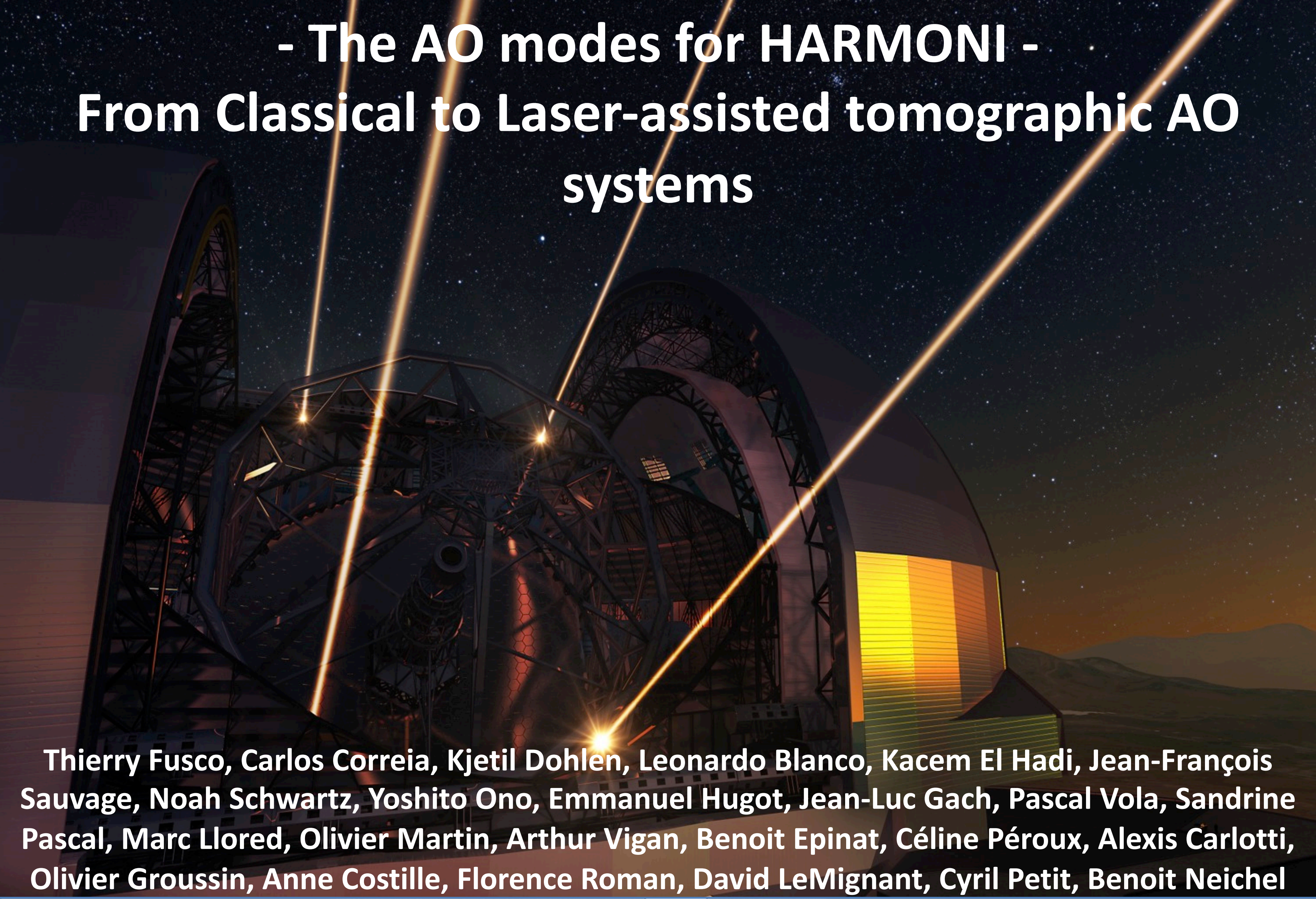


- The AO modes for HARMONI - From Classical to Laser-assisted tomographic AO systems

Thierry Fusco, Carlos Correia, Kjetil Dohlen, Leonardo Blanco, Kacem El Hadi, Jean-François Sauvage, Noah Schwartz, Yoshito Ono, Emmanuel Hugot, Jean-Luc Gach, Pascal Vola, Sandrine Pascal, Marc Llored, Olivier Martin, Arthur Vigan, Benoit Epinat, Céline Péroux, Alexis Carlotti, Olivier Groussin, Anne Costille, Florence Roman, David LeMignant, Cyril Petit, Benoit Neichel

Outline –

- General presentation of the E-ELT
- HARMONI
  - General overview
  - Science cases
  - The two AO systems
    - Single Conjugate AO (SCAO)
    - Laser Tomography AO (LTAO)

The E-ELT

Five-mirror design —
Three-mirror on-axis + two fold mirrors used for adaptive optics

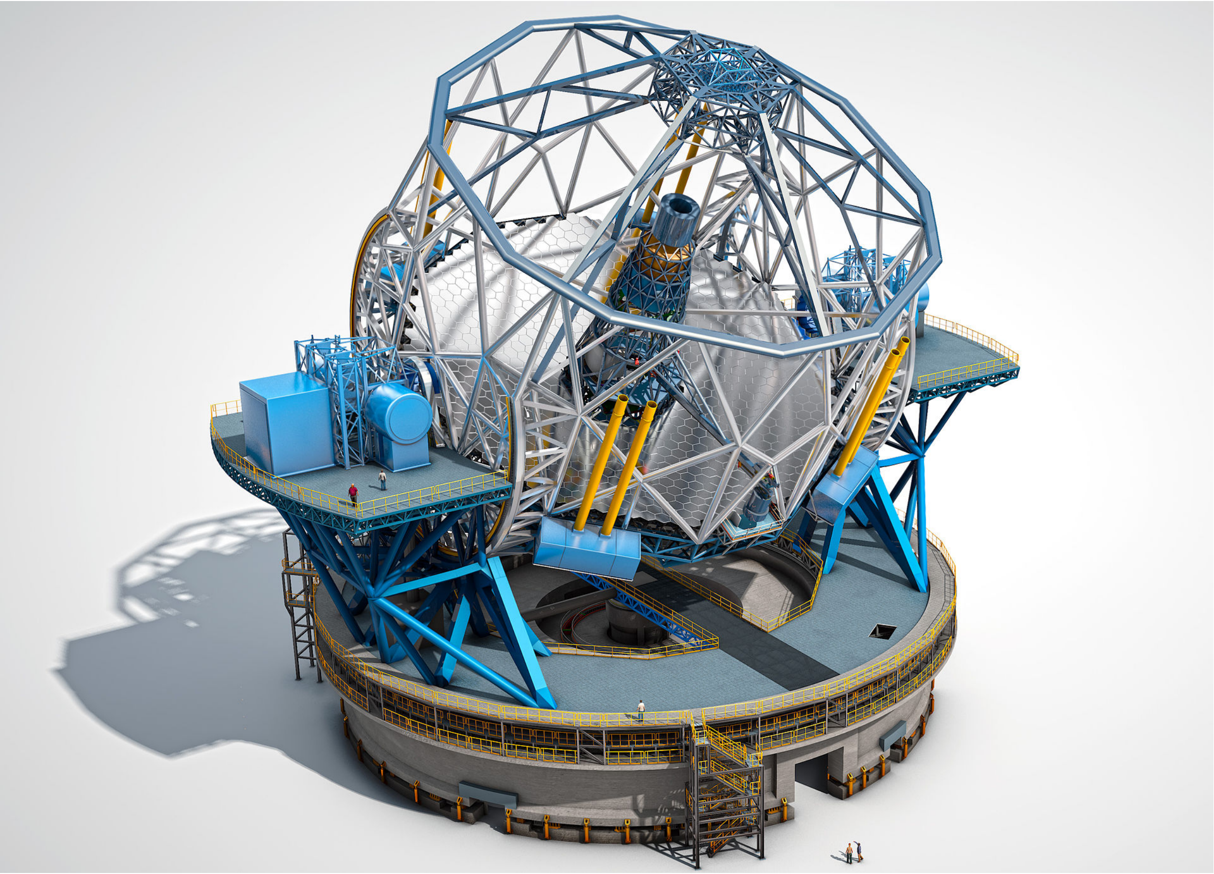
M1 = 39 m (798 hexagonal 1.4 m mirror segments)

M2 = 4m

M3 = 3.75m

M4 = 2.40m (deformable mirror) – 5806 actuators

M5 = 2.6m (TT mirror)



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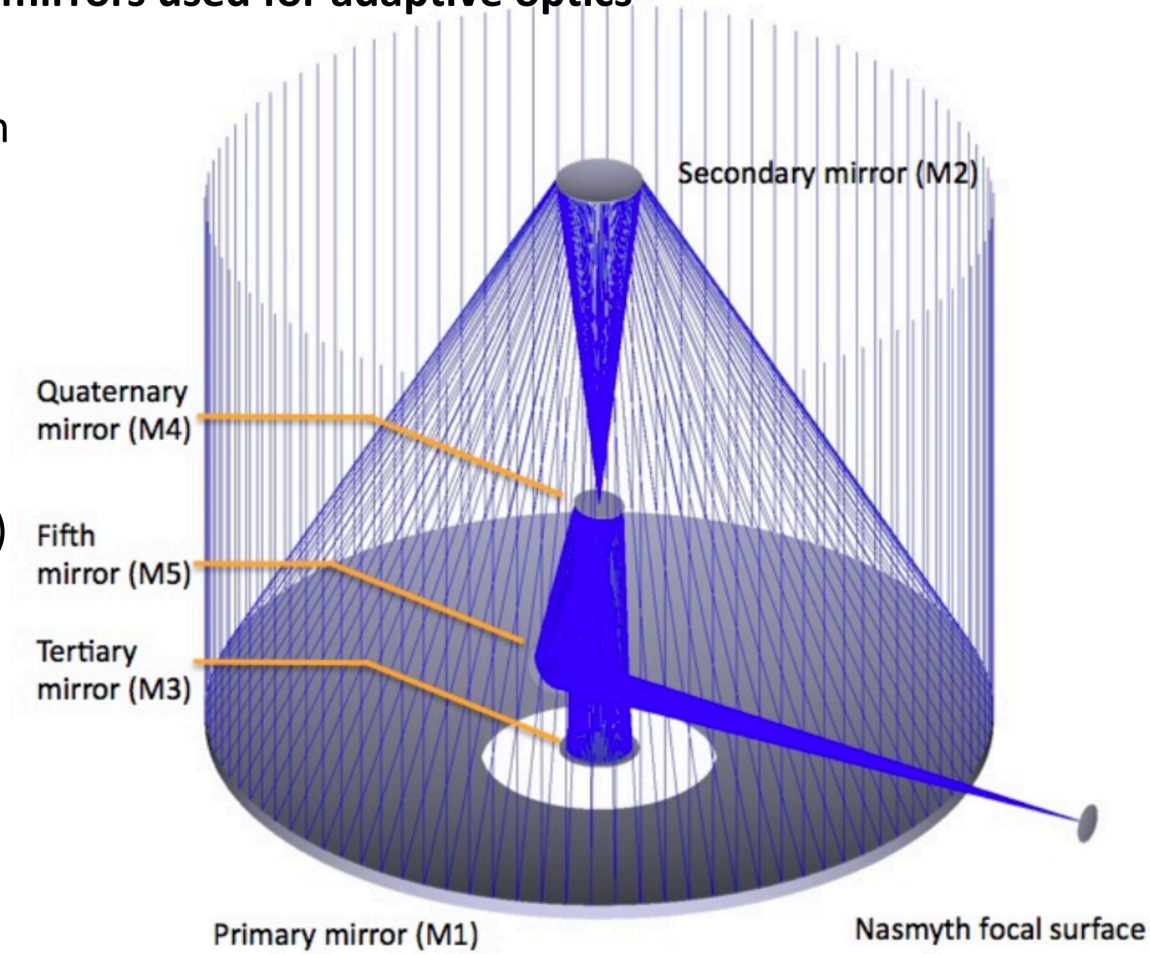
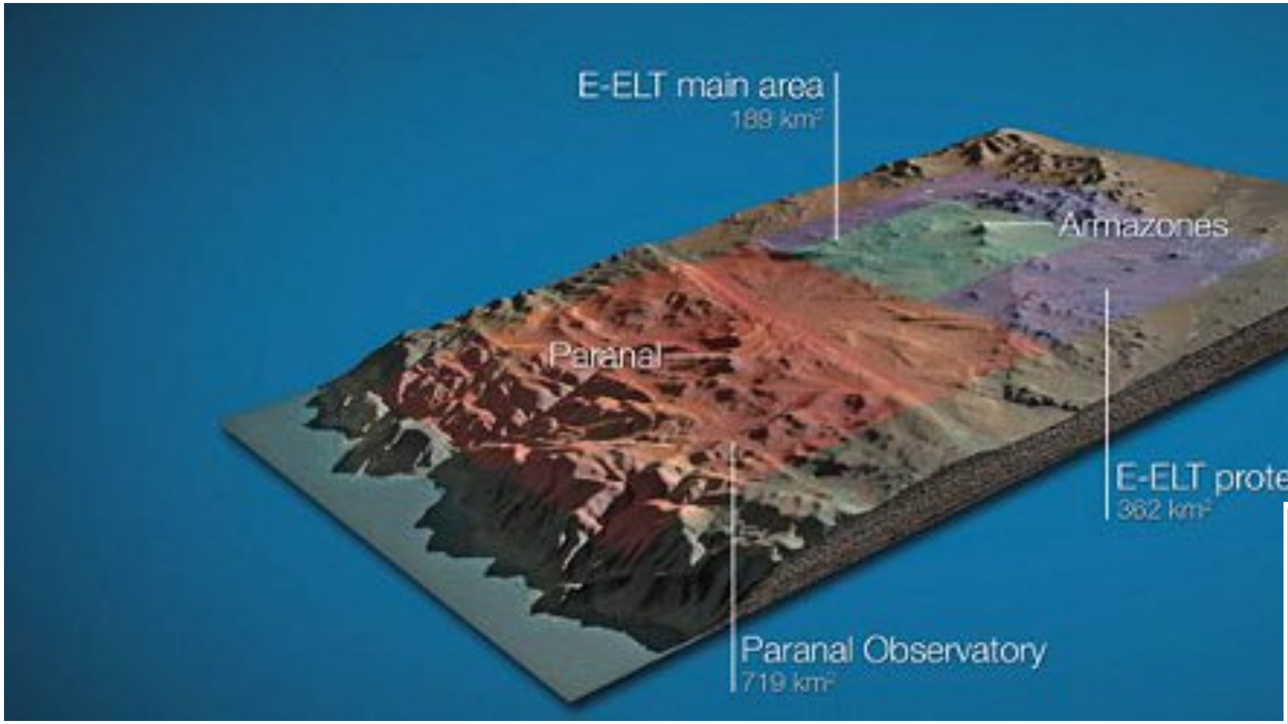
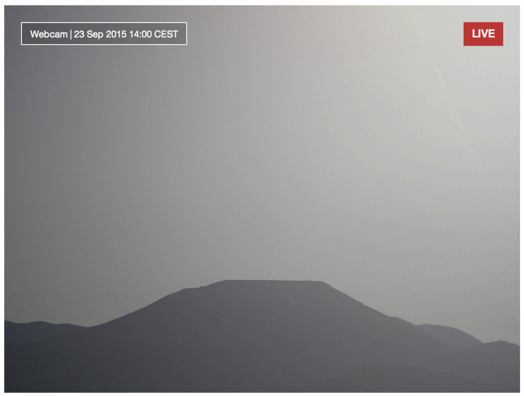


CNRS INSU Observer & comprendre | LAM Laboratoire d'Astrophysique de Marseille | ONERA The French Aerospace Lab | Aix*Marseille Université

The E-ELT





Cerro Armazones: 3060-metres high mountain in the central part of Chile's Atacama Desert, about 20 kilometres from Cerro Paranal, home of ESO's Very Large Telescope.

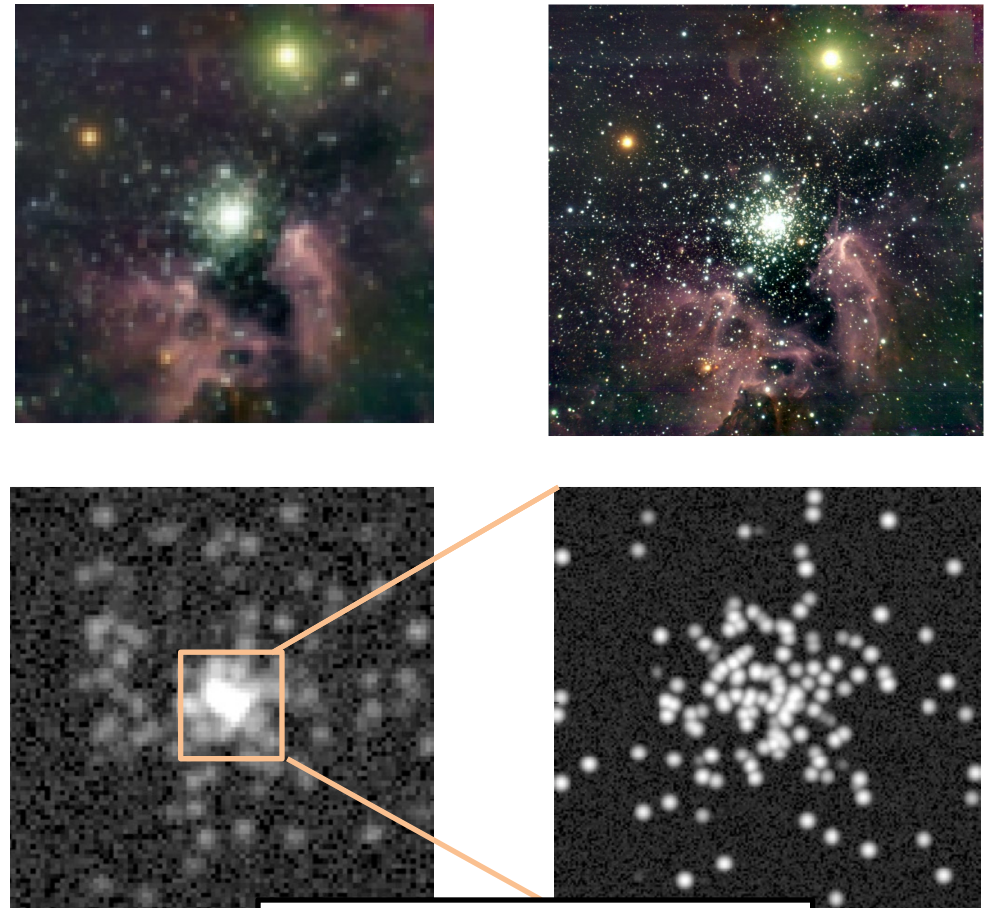
eso1716 — Organisation Release

First Stone Ceremony for ESO's Extremely Large Telescope

Start of ELT dome and telescope construction

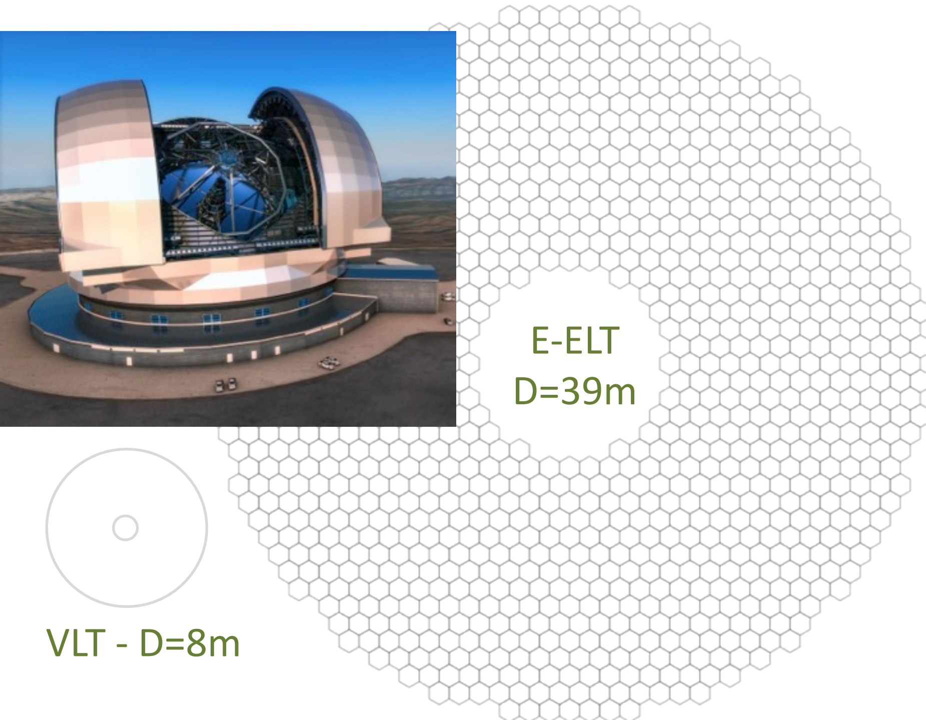
26 May 2017

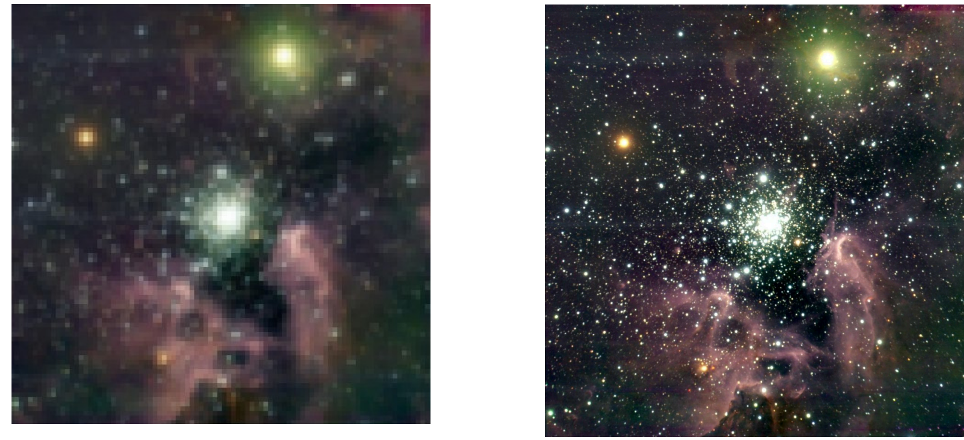
The E-ELT

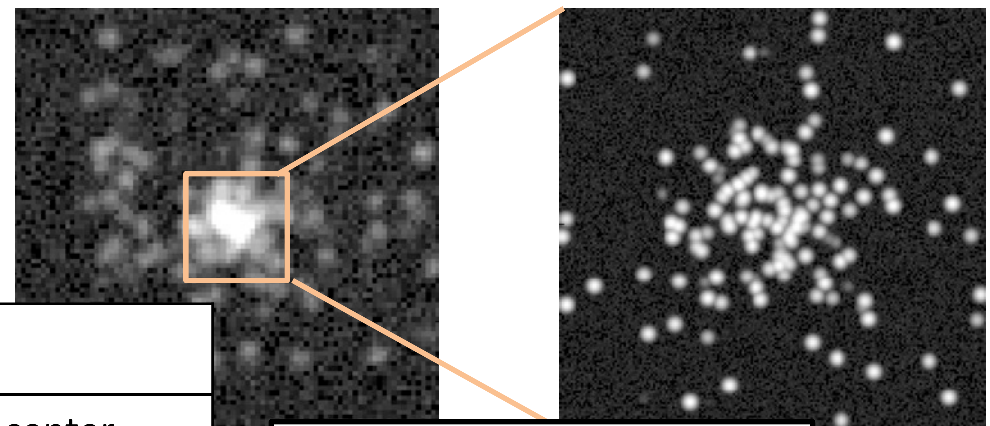


Gain en résolution x 5
Gain en sensitivity x 5^4

The E-ELT





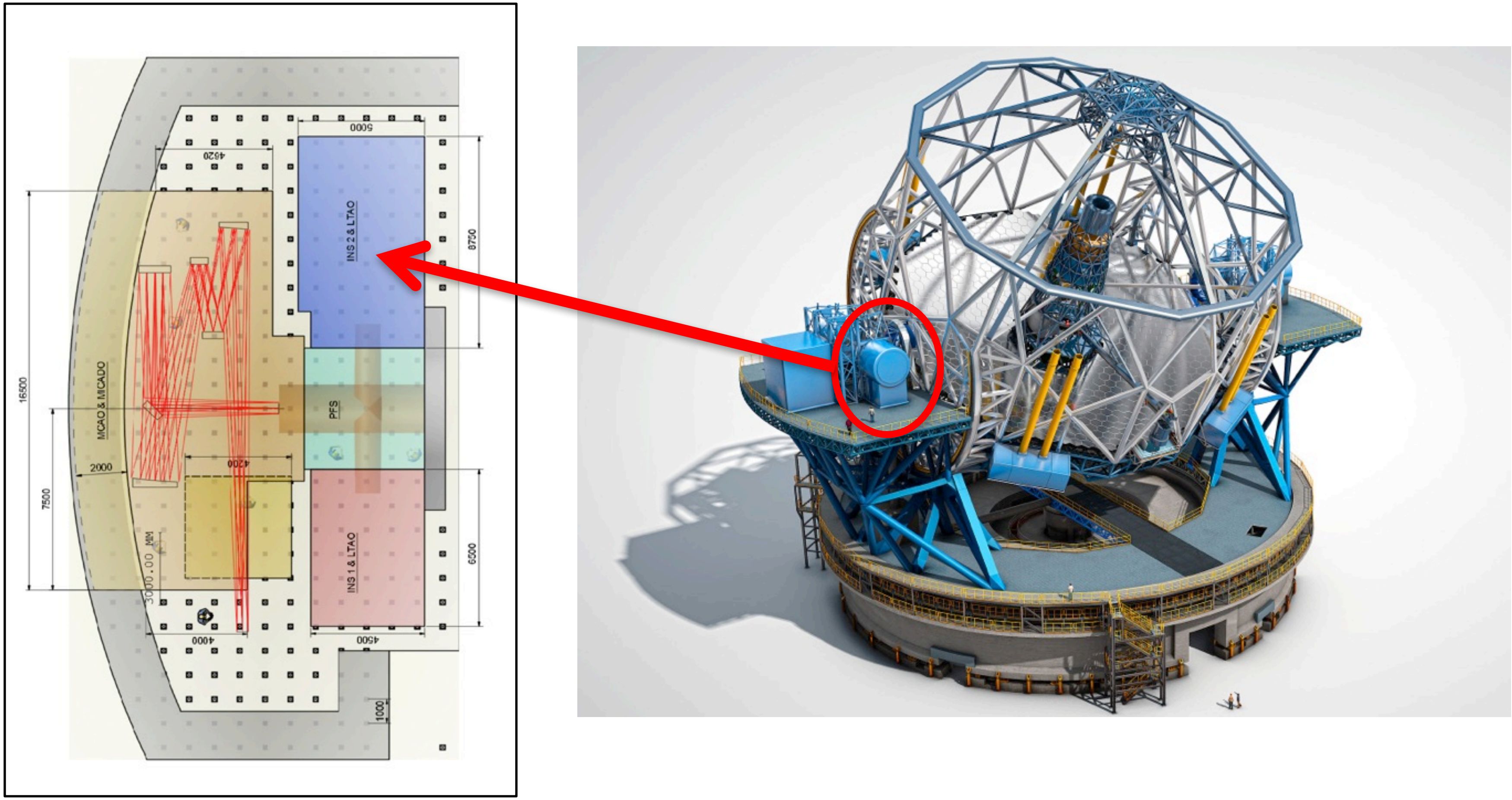


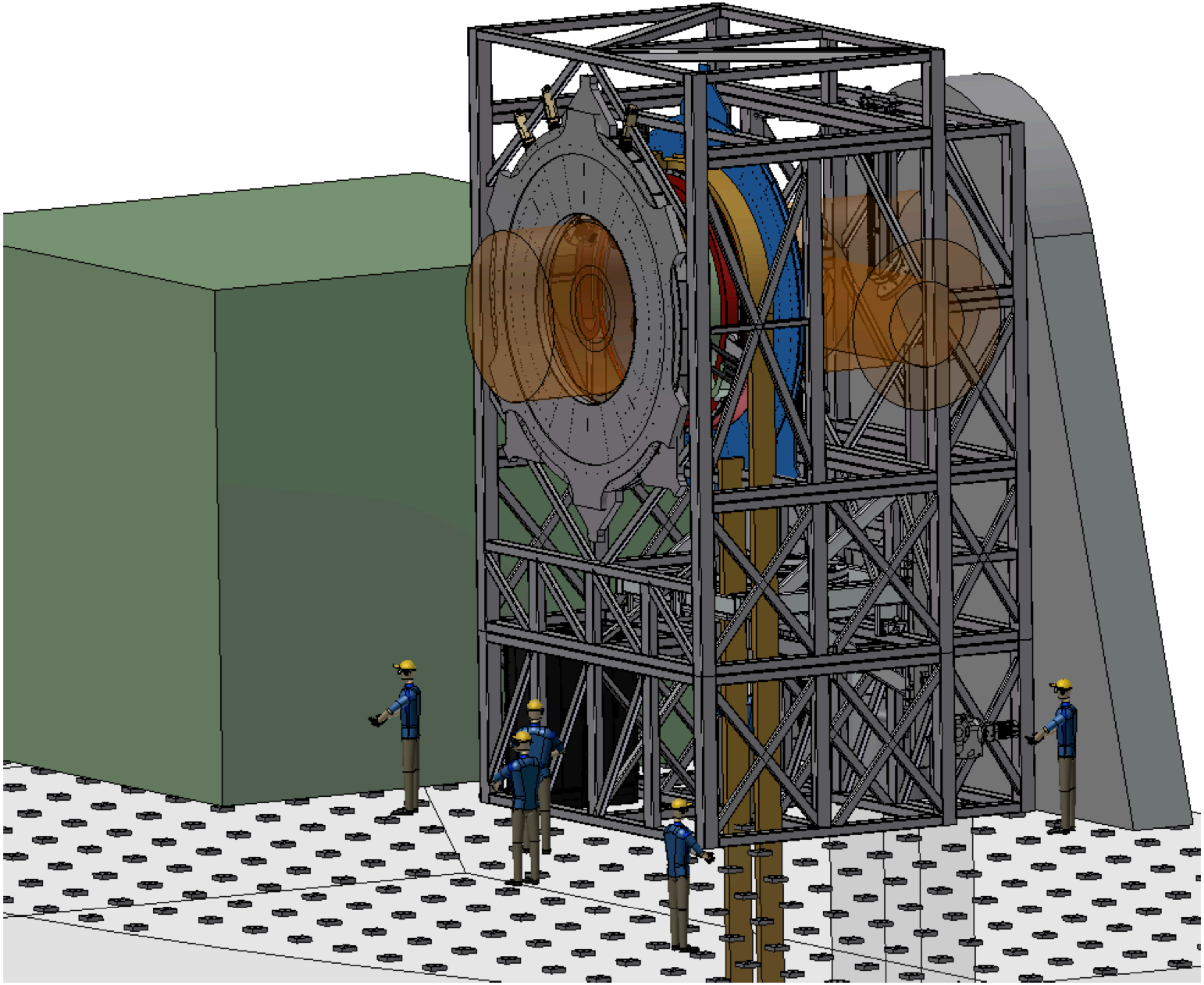
First light instruments		
MICADO	Spectro-imageur NIR	Galactic center High-z galaxies
METIS	Spectro-imageur MIR	Planet & disks High-z galaxies
HARMONI	IFU Visible - NIR	Stellar pop. High-z galaxies

Gain in resolution x 5
Gain in sensitivity x 5^4

HARMONI Overview

First light ELT instrument





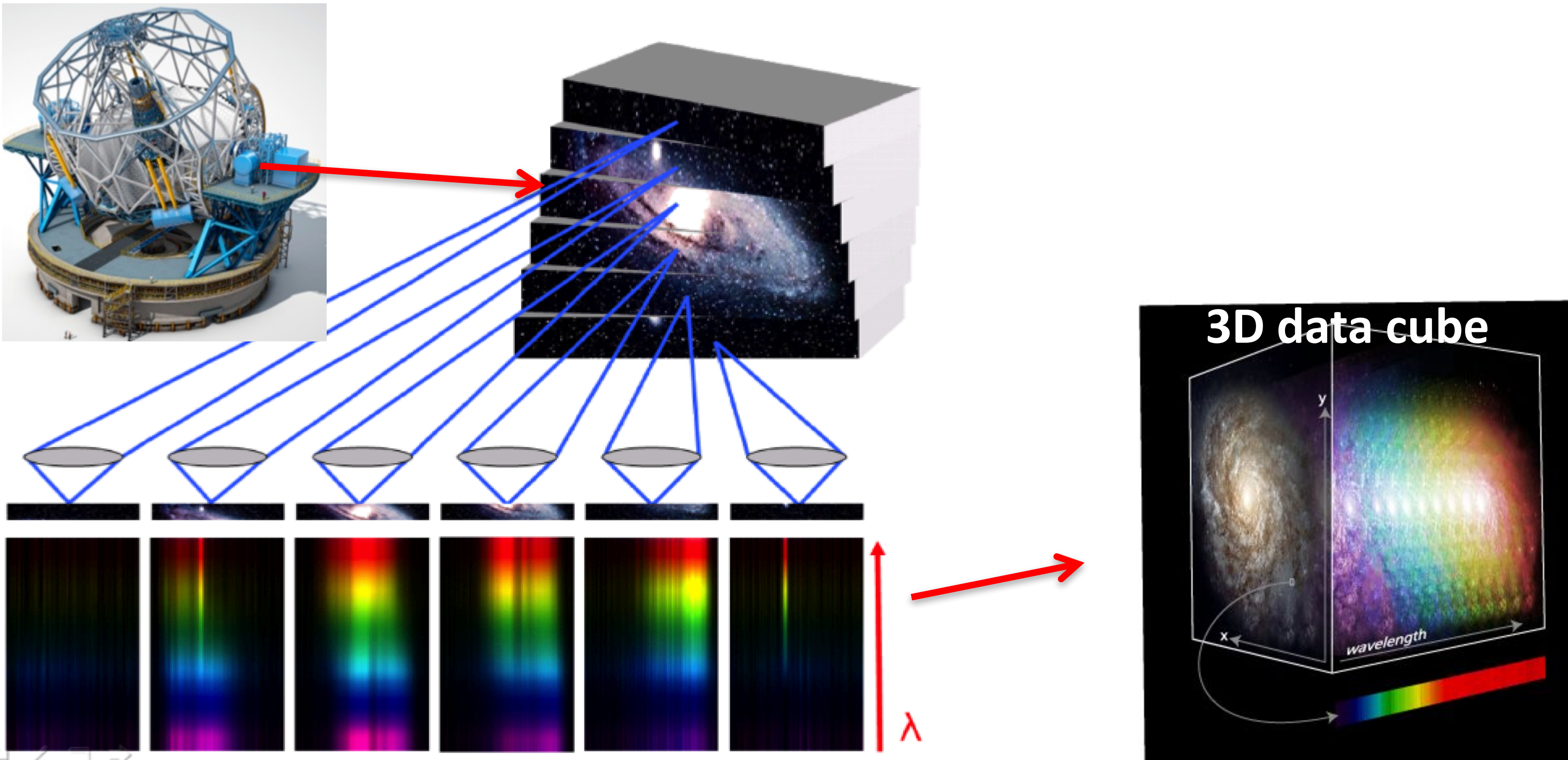
HARMONI Overview

HARMONI = High Angular Resolution - Monolithic - Optical and Near-infrared - Integral field spectrograph

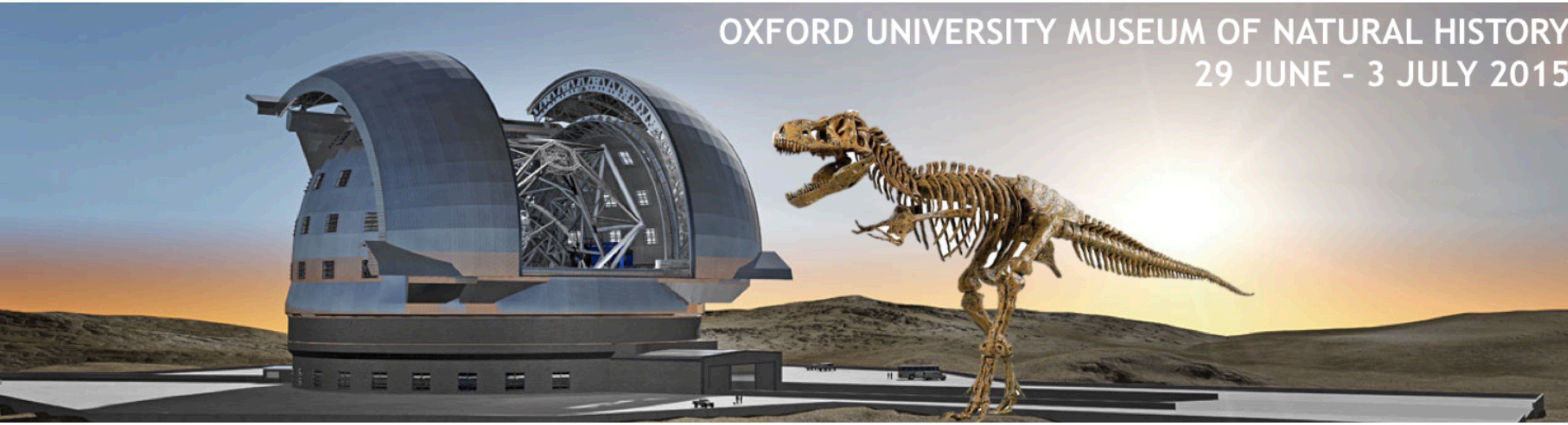
First light ELT instrument

Workhorse instrument - visible and near-infrared spectroscopy (0.5–2.4 μm)

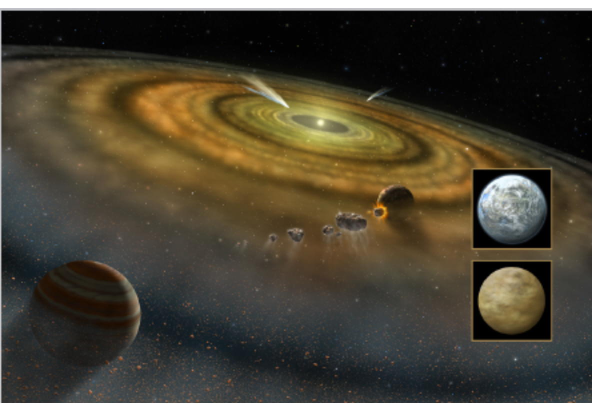
Integral Field Spectrograph – providing ~ 30 000 spectra per exposure



HARMONI – Science Case



http://harmoni2015.physics.ox.ac.uk/programme.php

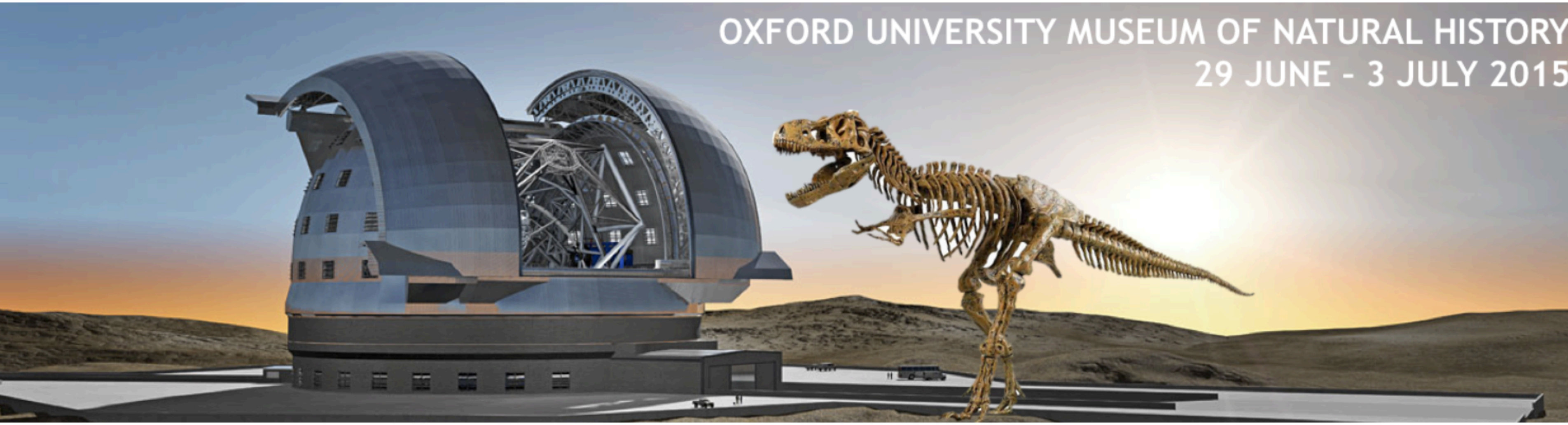


Planet and Stars

Stars and galaxies

Galaxies and cosmology

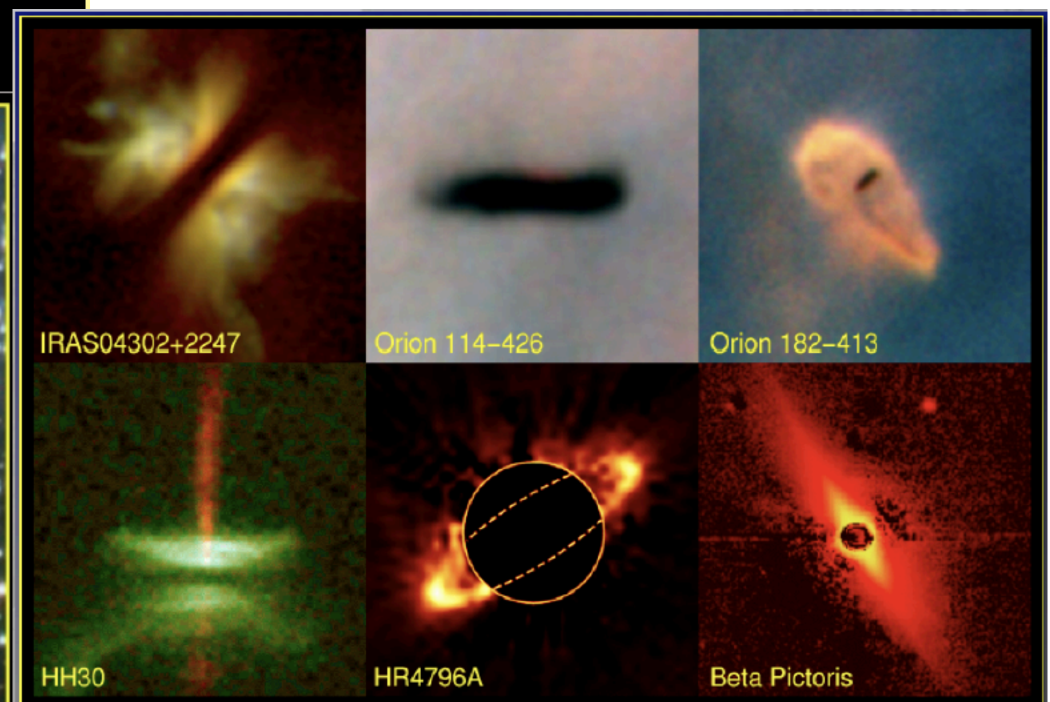
HARMONI – Science Case



http://harmoni2015.physics.ox.ac.uk/programme.php

HARMONI – Science Case

- **Direct detection of exoplanets via HC**
- **Indirect detection with radial velocity**
- **Circumstellar disks**
- **Young clusters and IMFs**

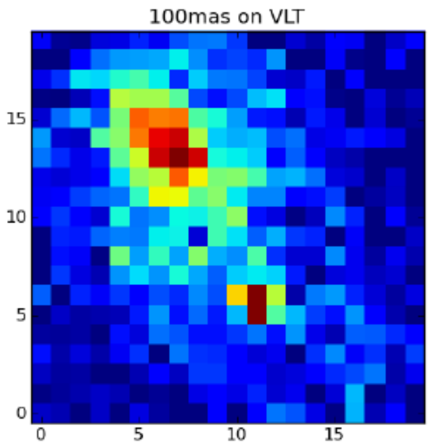


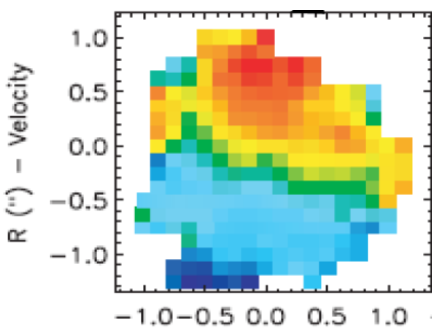
ONERA
THE FRENCH AEROSPACE LAB

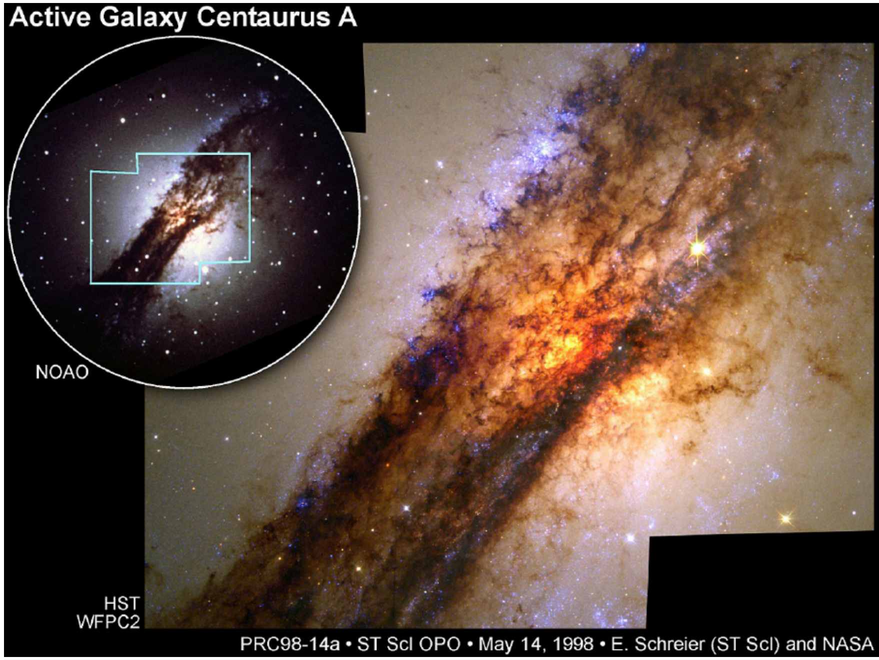
Aix*Marseille université

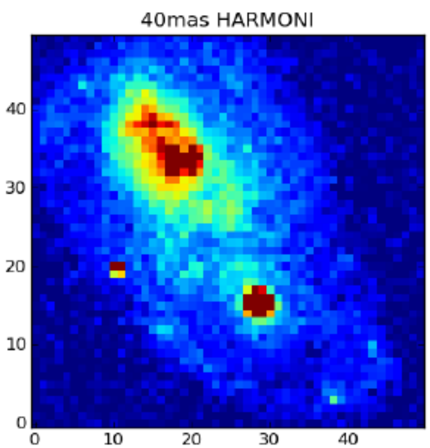
HARMONI – Science Case

- **Extragalactic resolved stellar population**
- **High-z dynamical masses / kinematics / chemical composition / Modes of star formation**



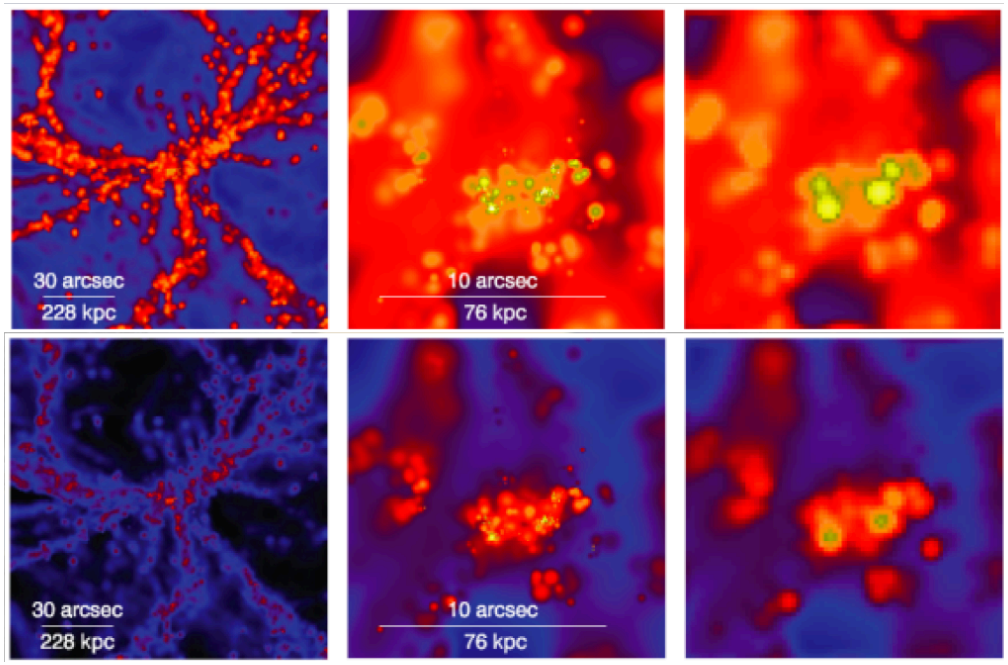






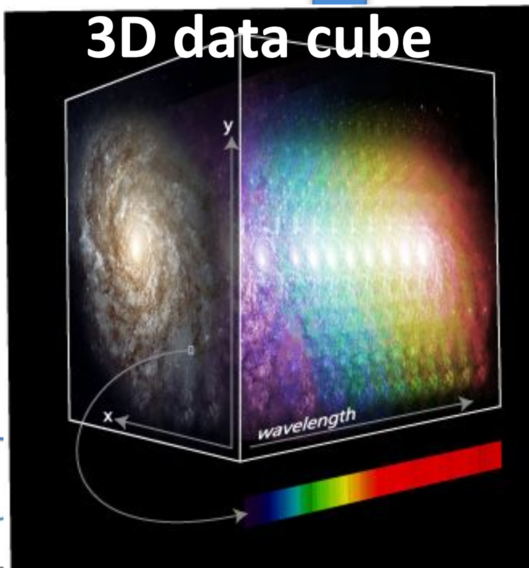
HARMONI – Science Case

- **Detecting the formation of MW like galaxies at z=10.**
- **Pop III - the first stars**
- **Detect first enrichment of IGM**
- **What re-ionised the Universe?**

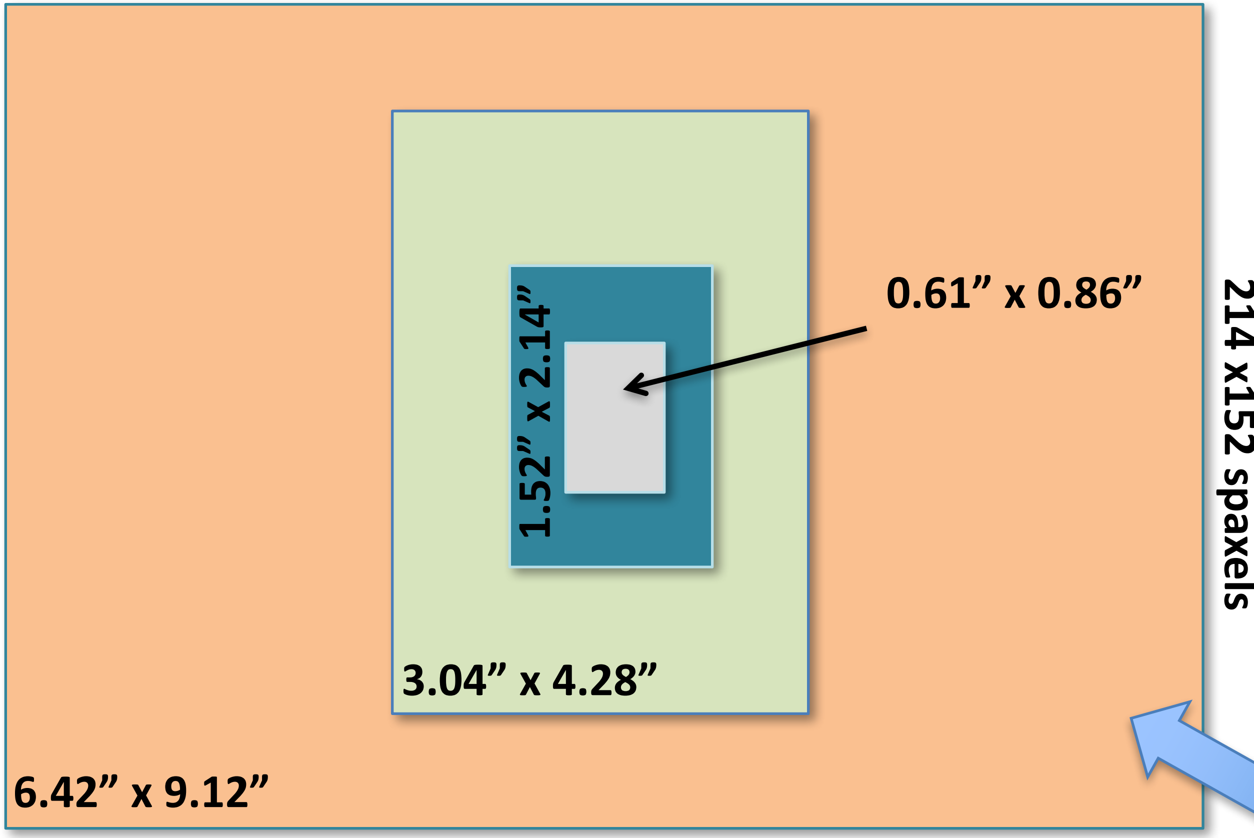


HARMONI = 3 resolving powers

Bands	Wavelengths (µm)	R
"V+R" or "I+z+J" or "H+K"	0.45-0.8, 0.8-1.35, 1.45-2.45	**~3000**
"I+z" or "J" or "H" or "K"	0.8-1.0, 1.1-1.35, 1.45-1.85, 1.95-2.45	**~7500**
"Z" or "J_high" or "H_high" or "K_high"	0.9, 1.2, 1.65, 2.2 (TBD)	**~20000**



HARMONI = 4 spatial scales

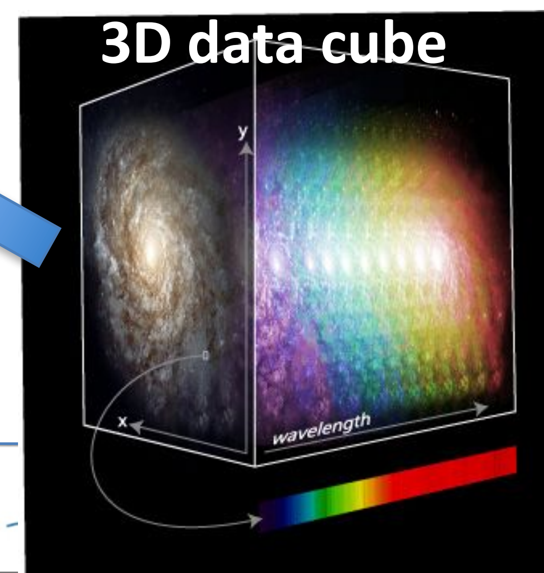


60 x 30 mas

20 mas

10 mas

4 mas



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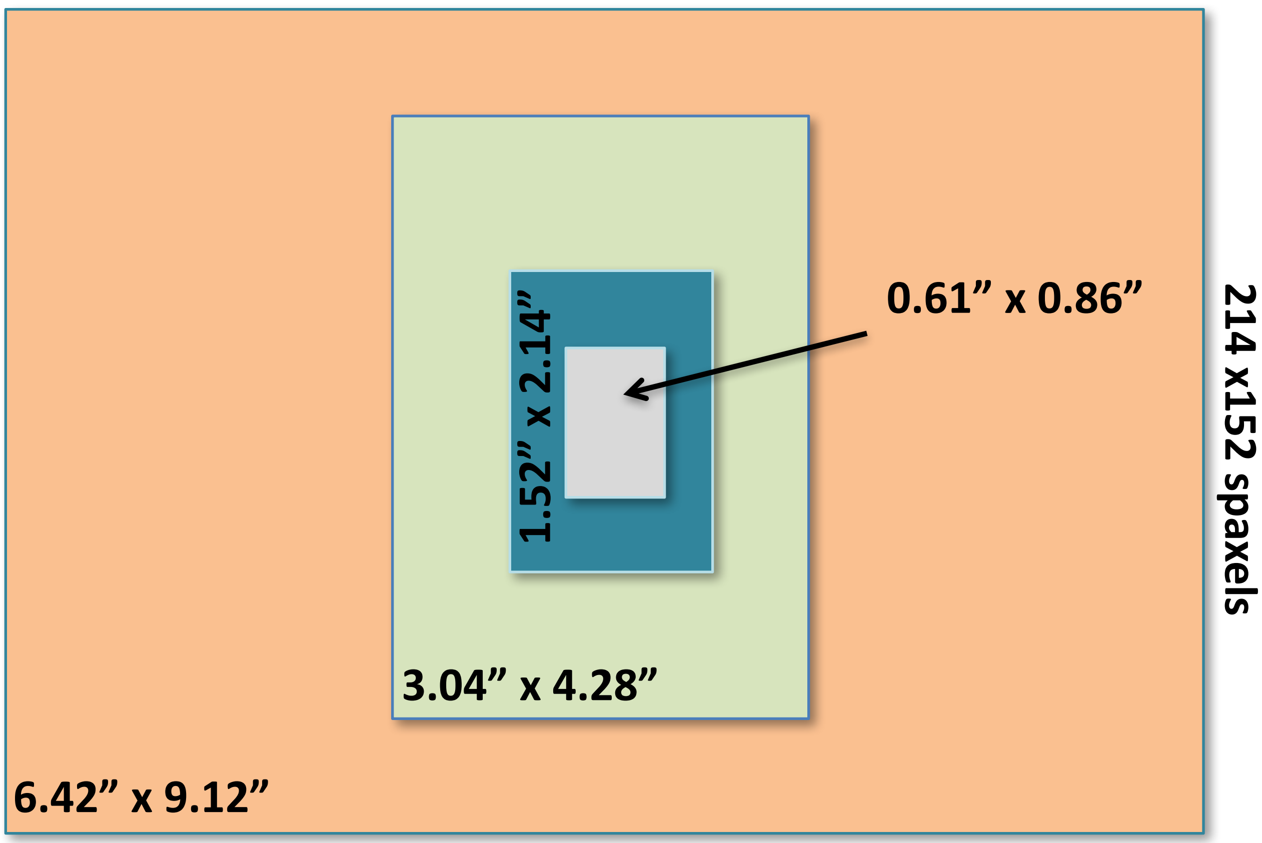
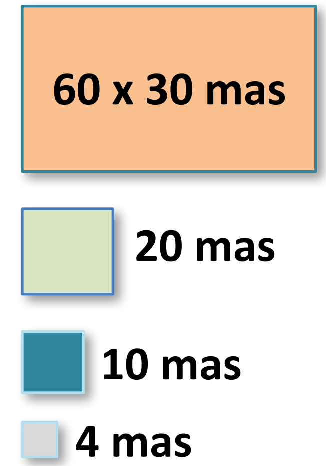
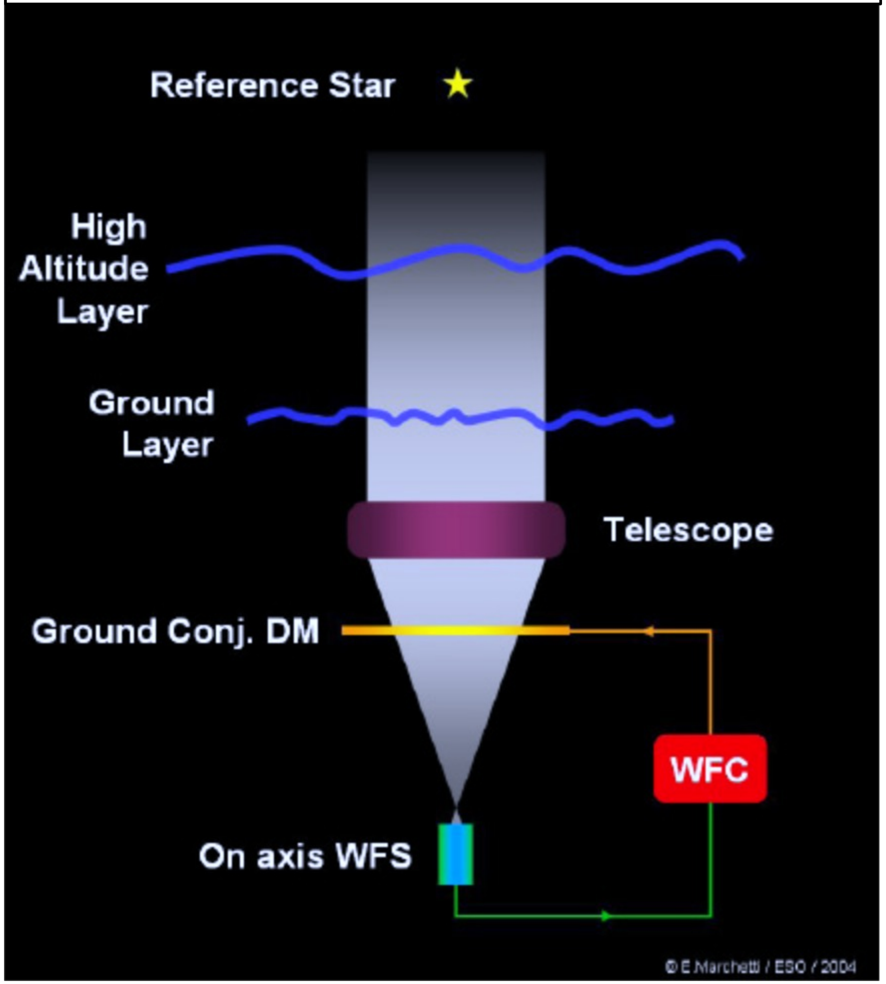




Assisted with Adaptive Optics

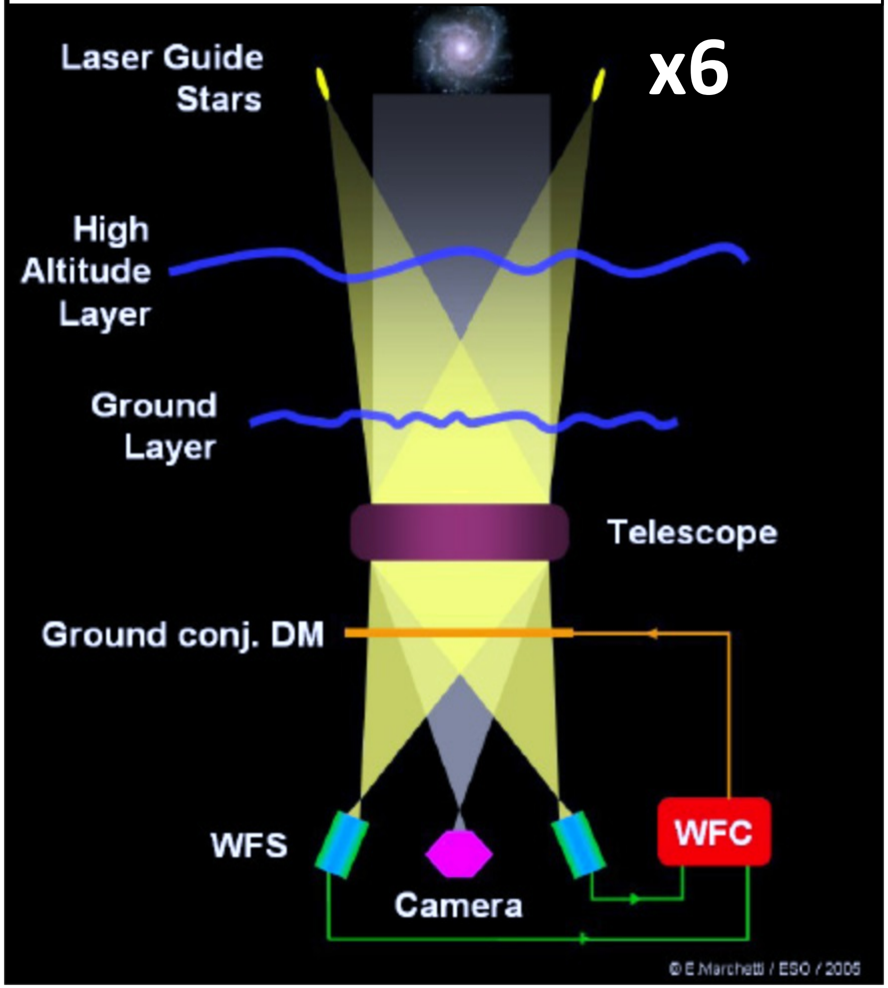
HARMONI: Two AO modes

Single Conjugated AO



High-Performance – Low sky coverage

Laser Tomography AO

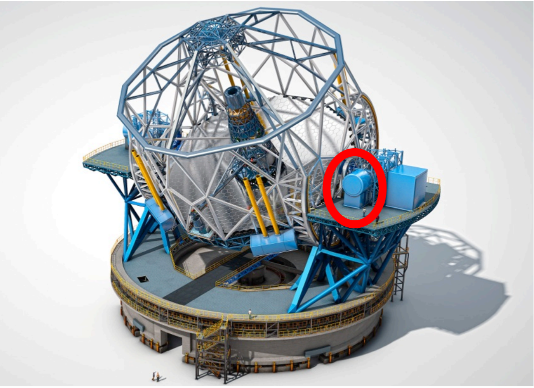


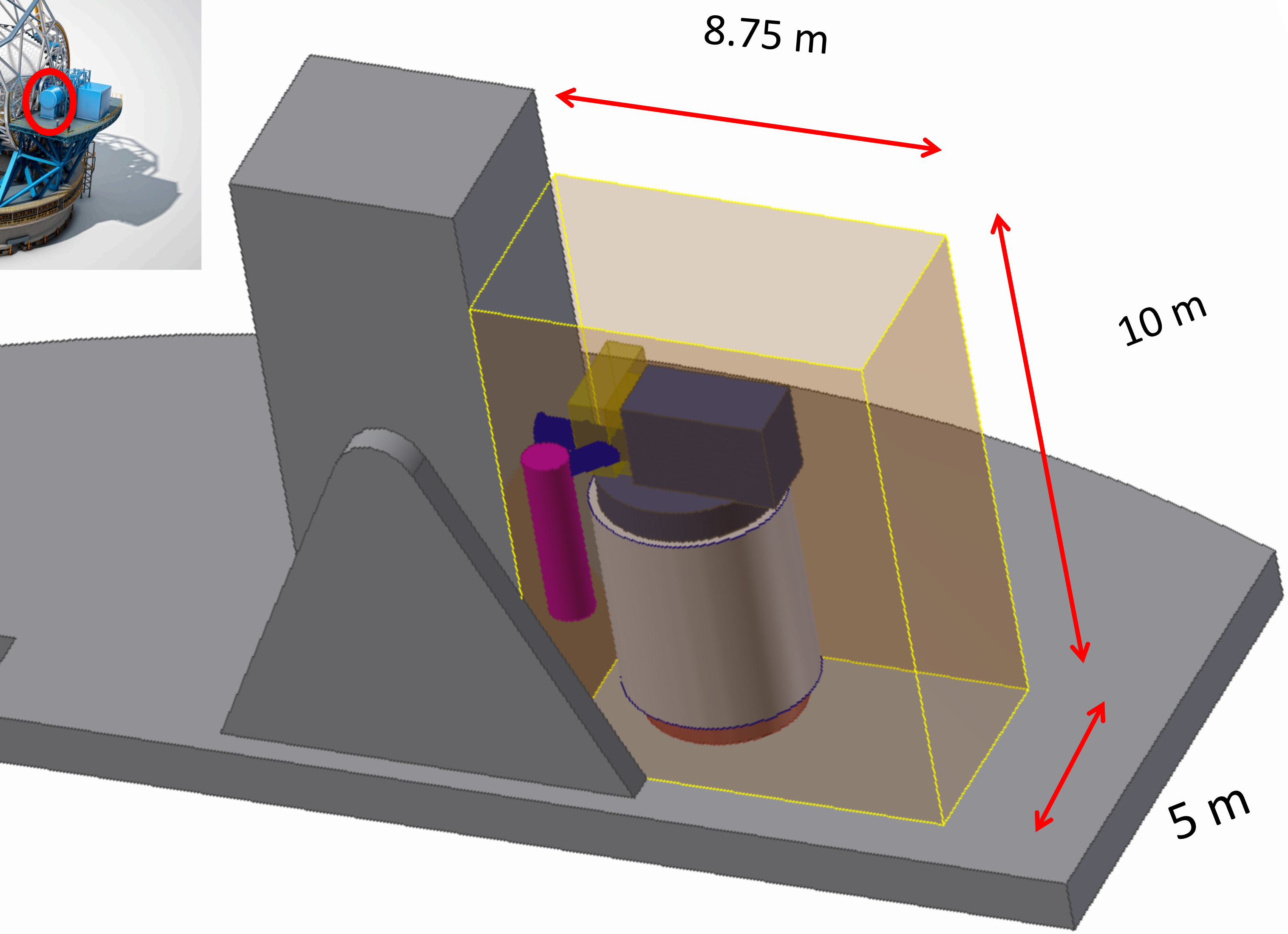
High-Performance & sky coverage

HARMONI Consortium

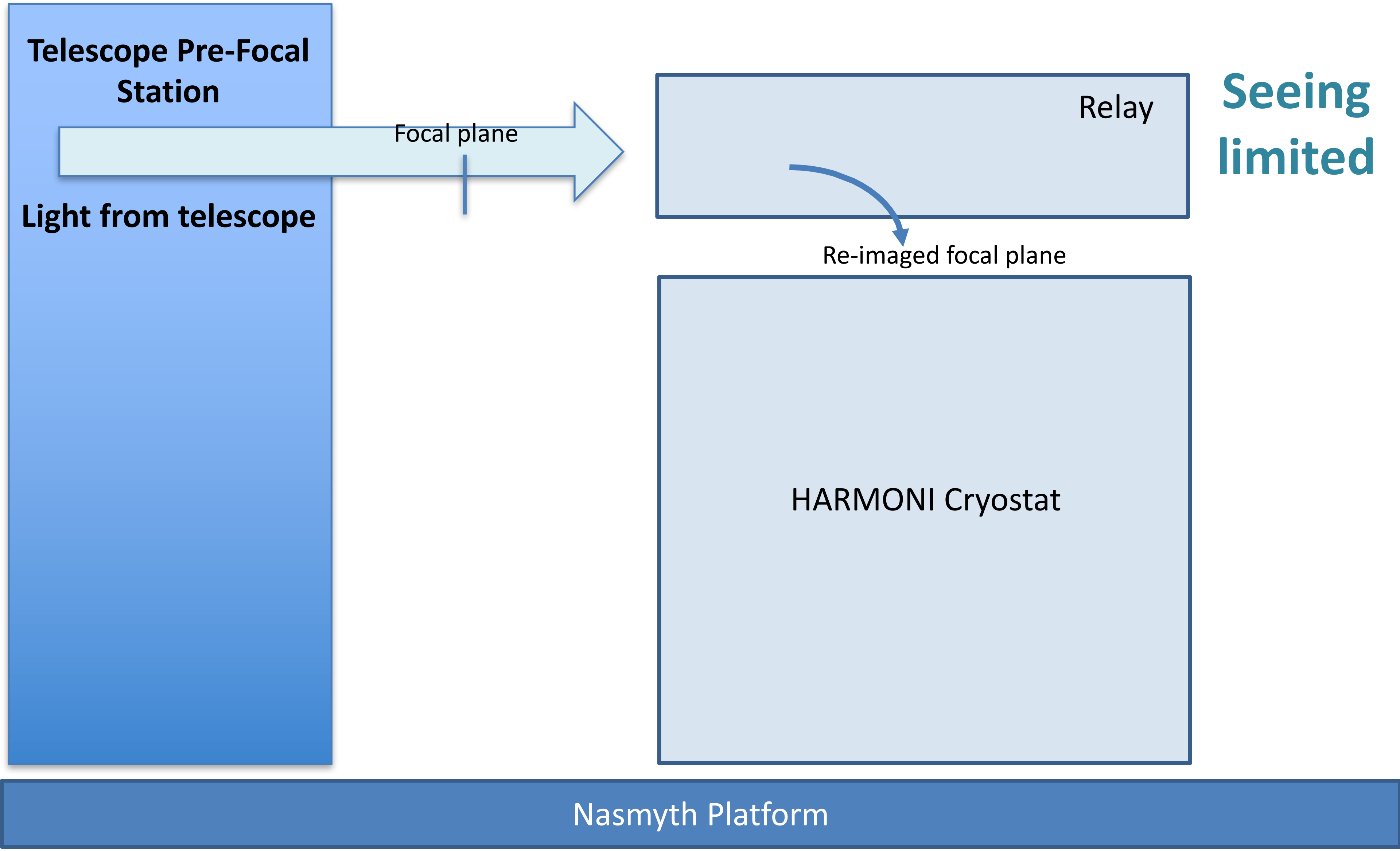
Partner	Associate Partner	Responsibilities
University of Oxford	STFC – RAL Space	Spectrographs & Obs. Prep
STFC – UK ATC Edinburgh	Univ. of Durham	Cryostat, AIV, Rotator, LTAO
IAC, Tenerife		Pre-optics & Electronics
CSIC – CAB (INTA), Madrid		Calibration & Sec. guiding
CRAL, Lyon	IPAG, Grenoble IRAP, Toulouse	IFU & Software
LAM, Marseille	ONERA, Paris IPAG, Grenoble	SCAO, LTAO, High Contrast

HARMONI, SCAO & LTAO implementation





HARMONI, SCAO & LTAO implementation



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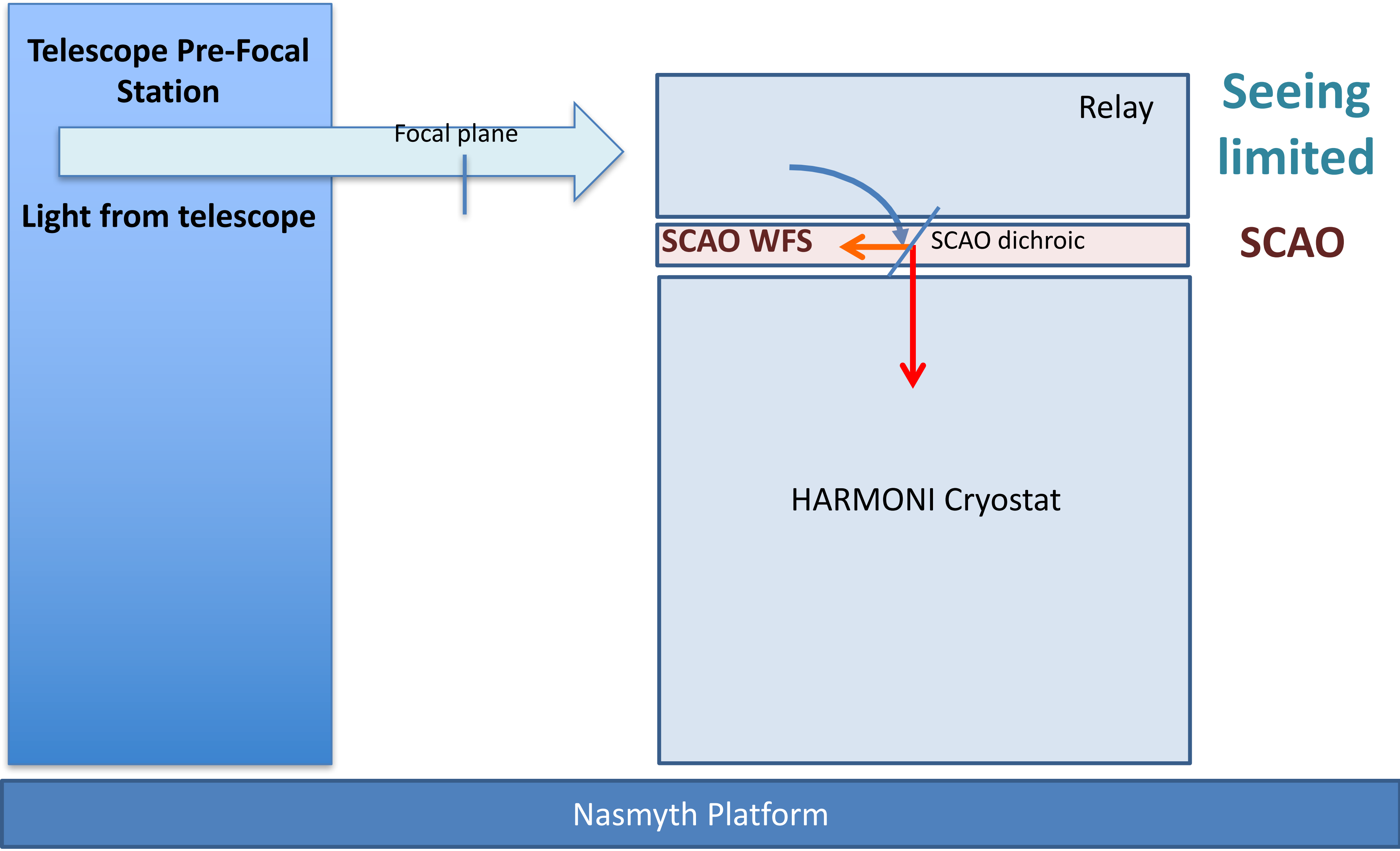

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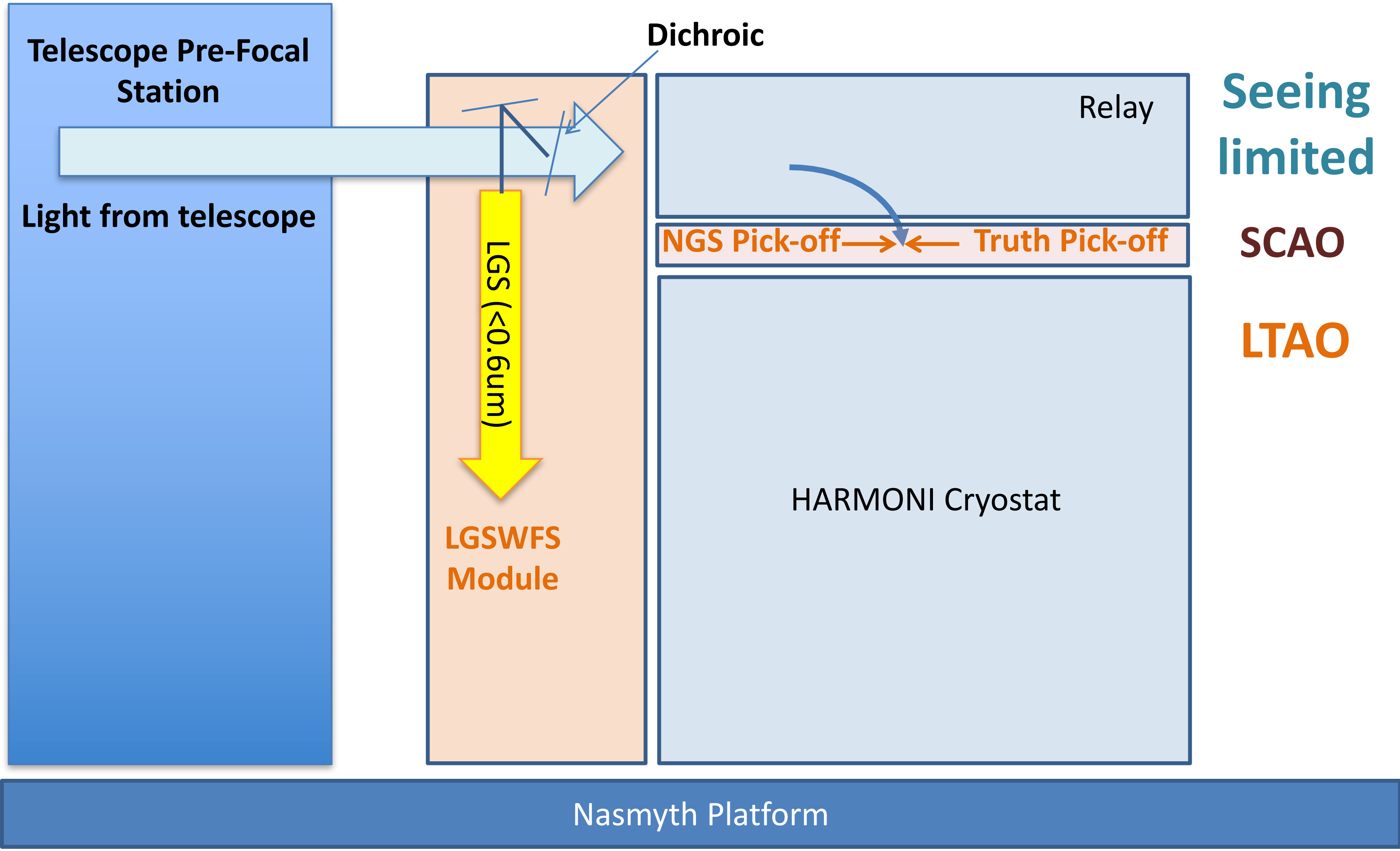

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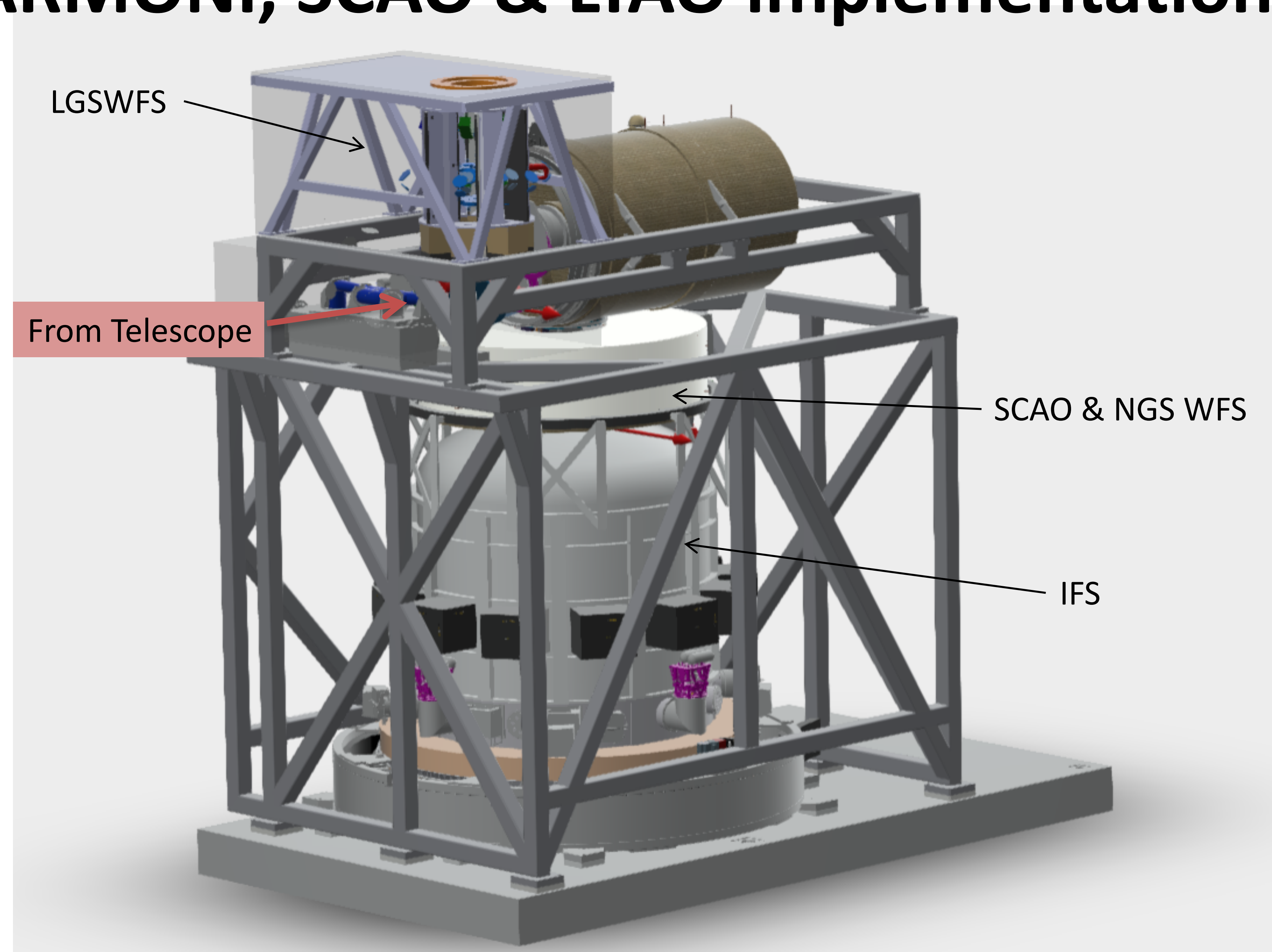
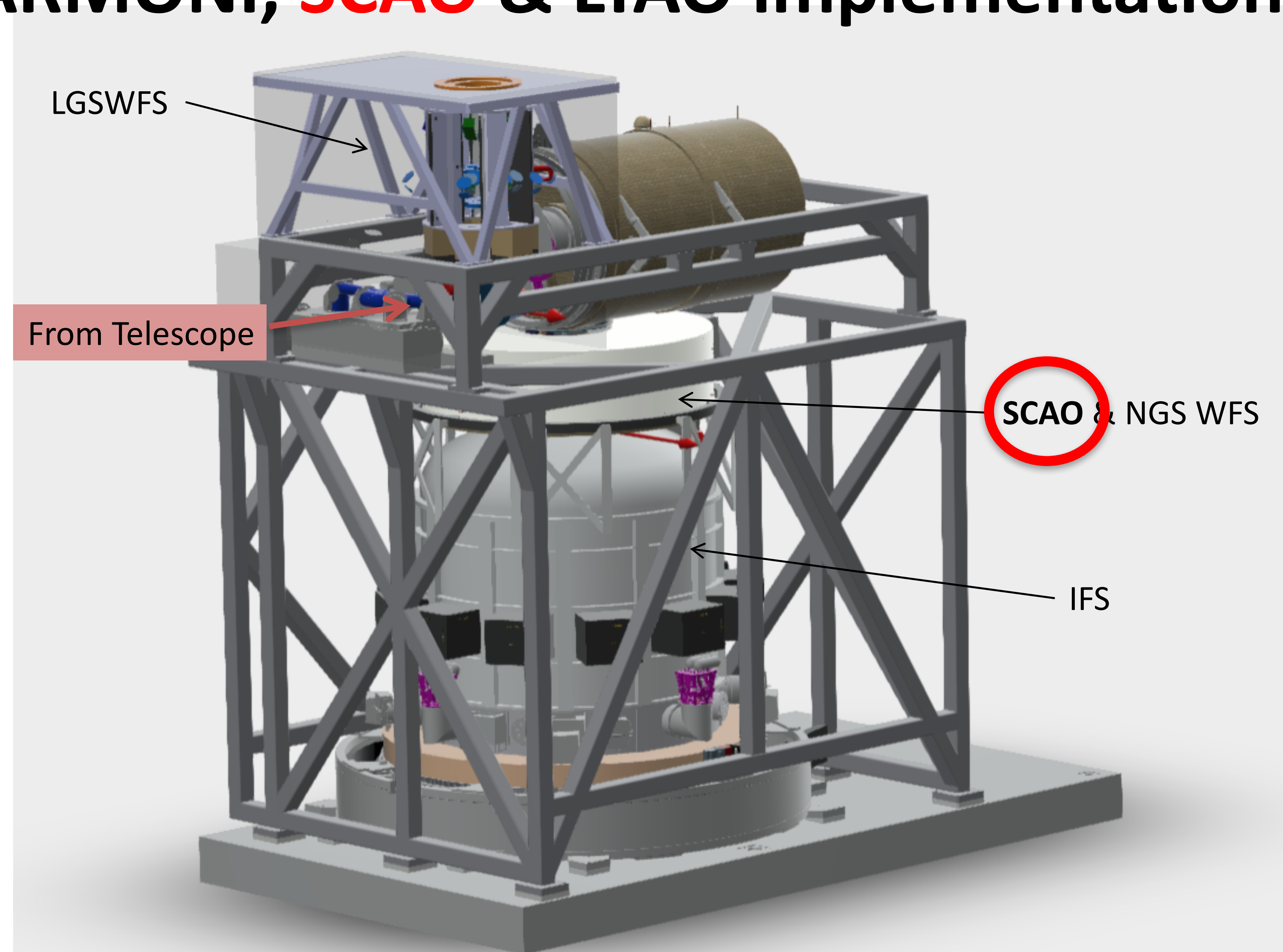


HARMONI, SCAO & LTAO implementation



SCAO system baseline is to use a pyramid WFS:

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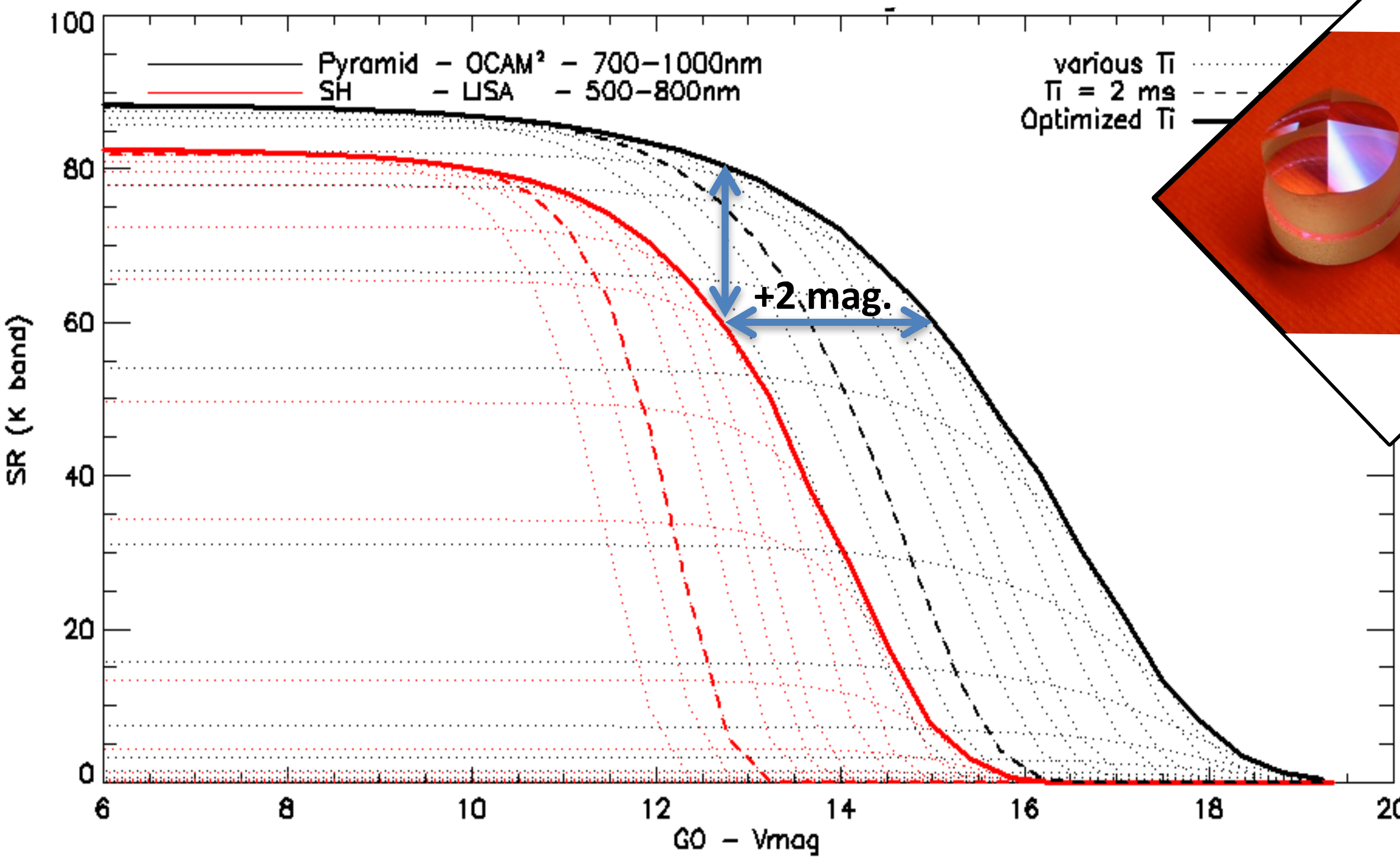
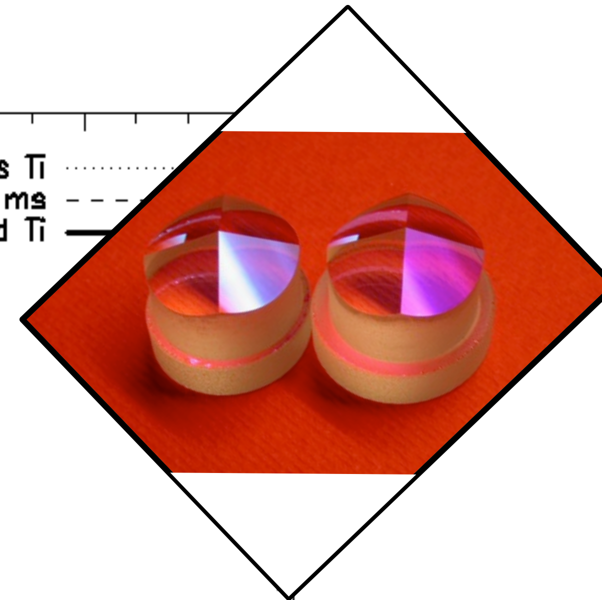
- Better performance & better sensitivity





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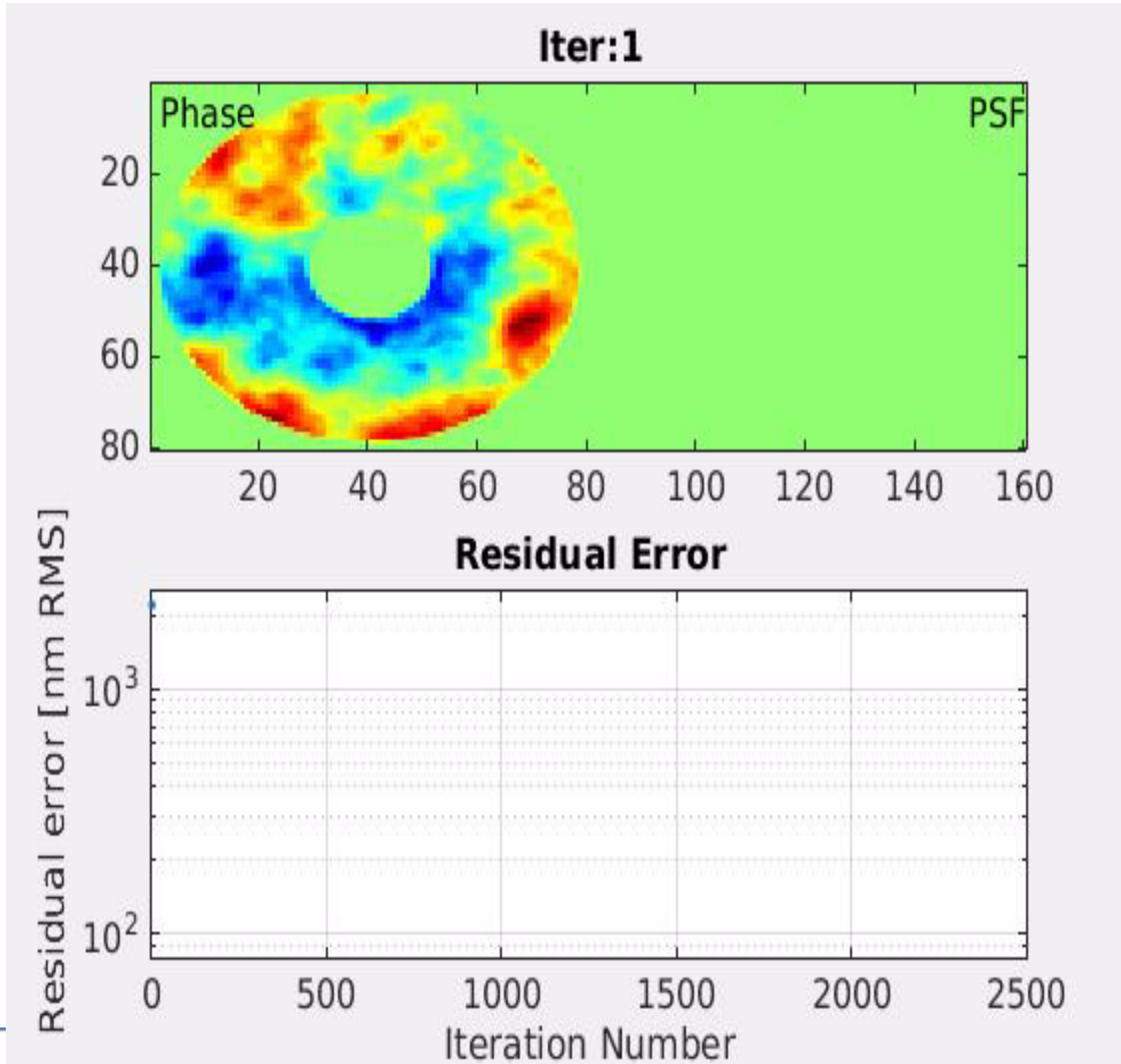
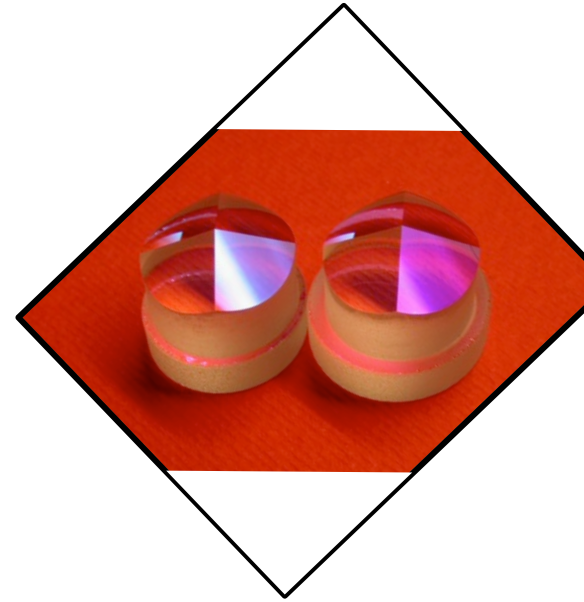
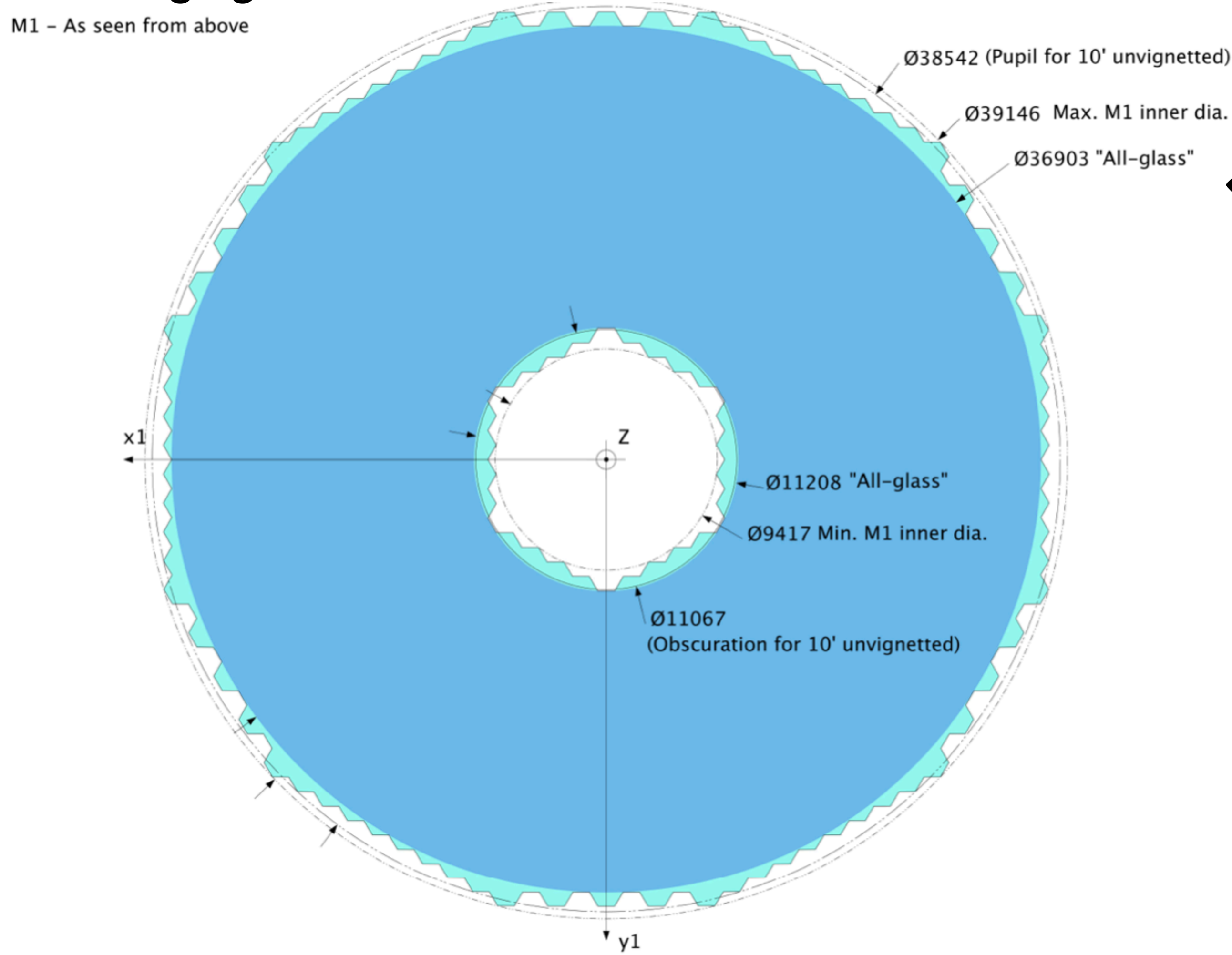
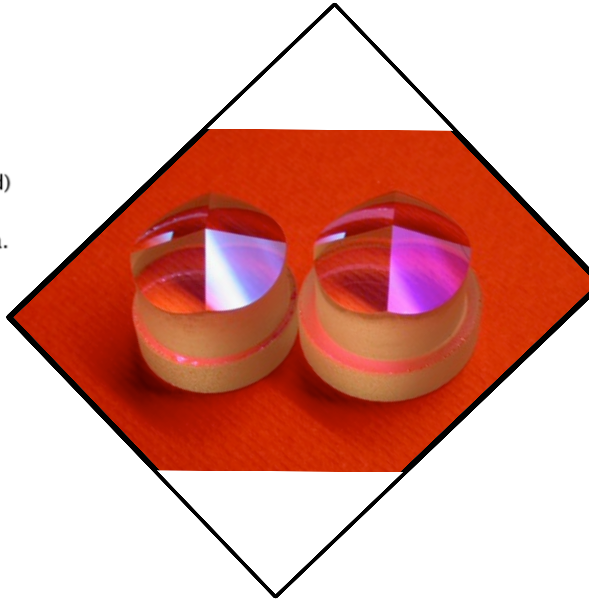




SCAO system baseline is to use a pyramid WFS

- Better performance & better sensitivity
- Managing the “Island” effect

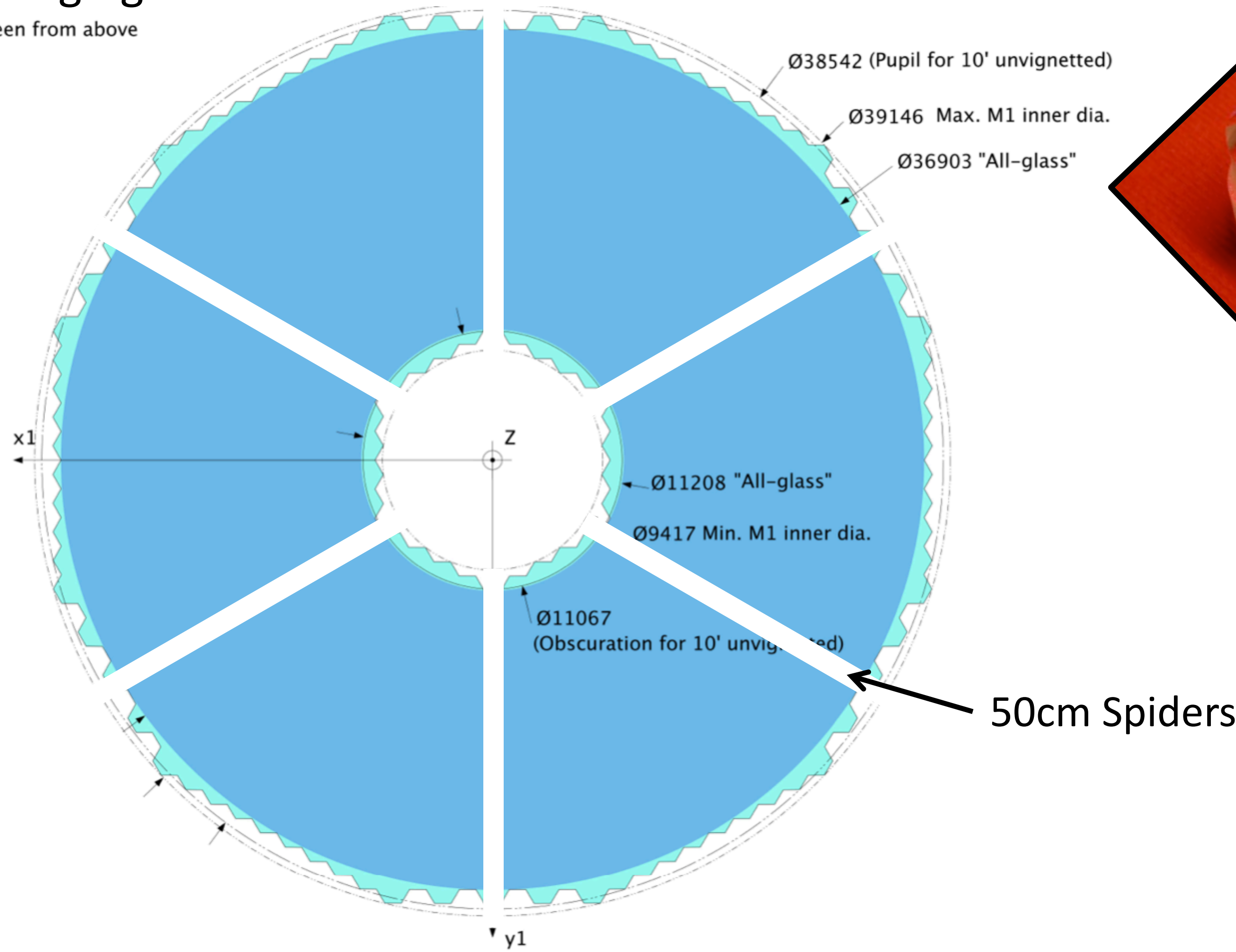


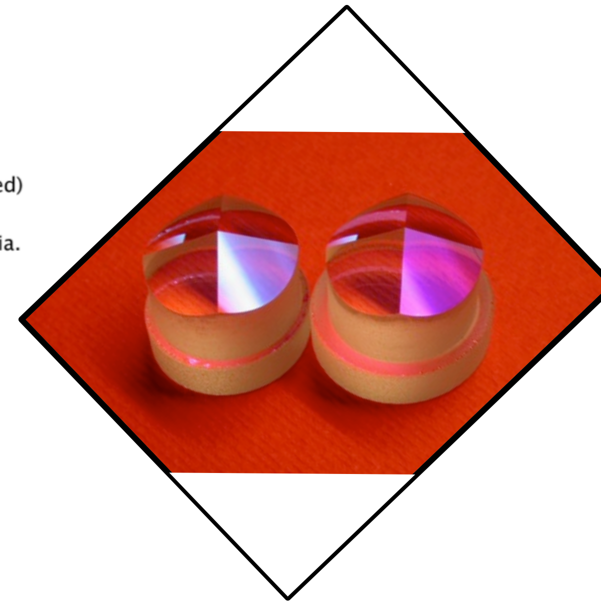


SCAO system baseline is to use a pyramid WFS

- Better performance & better sensitivity
- Managing the "Island" effect

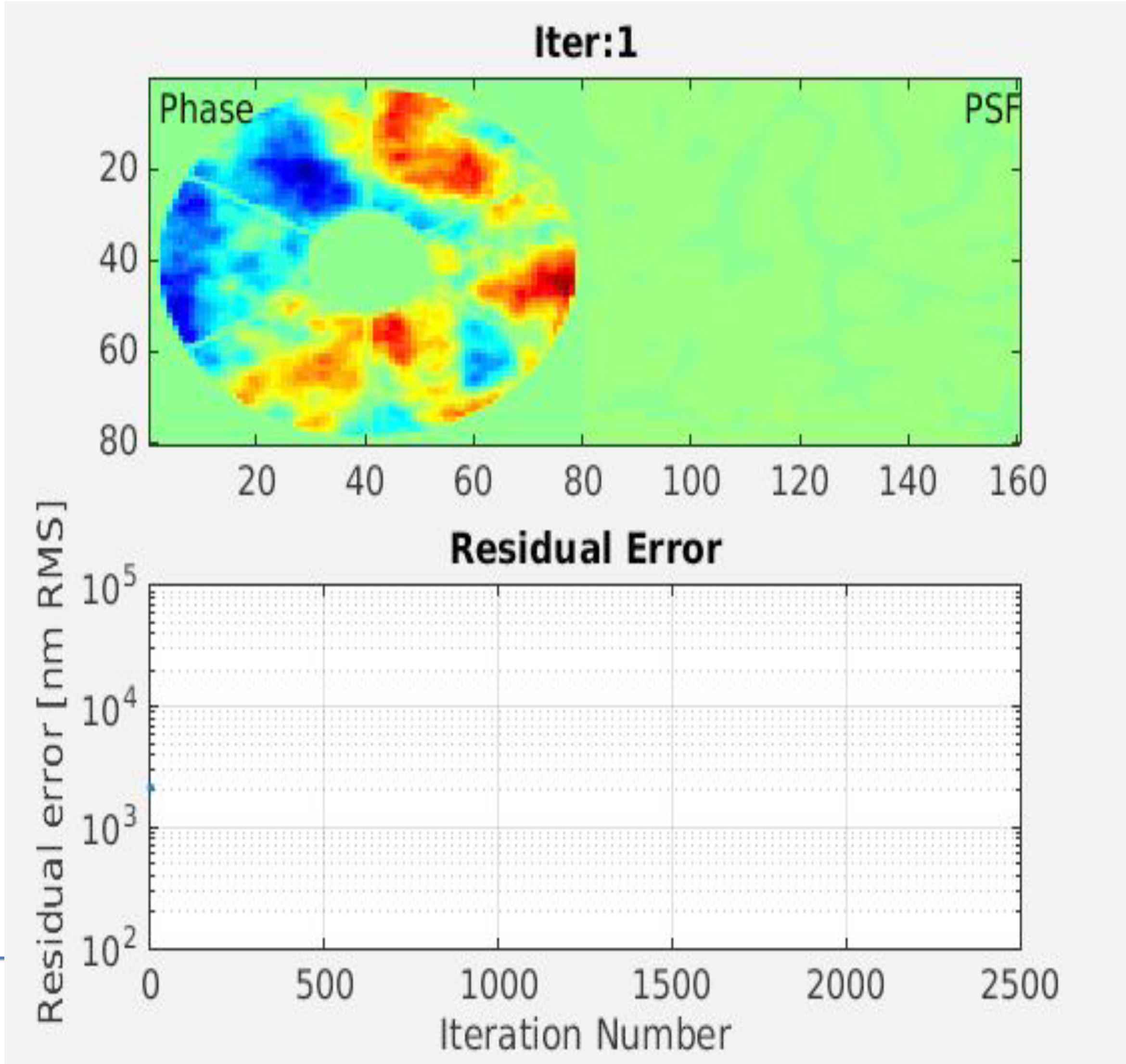
M1 – As seen from above





SCAO system baseline is to use a pyramid WFS

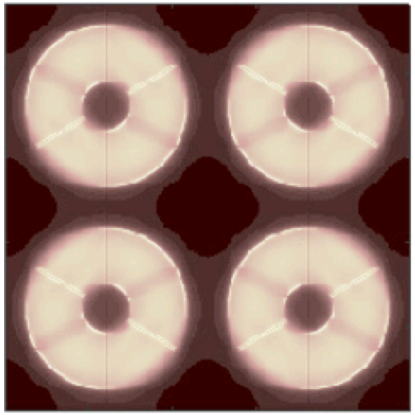
- Better performance & better sensitivity
- Managing the "Island" effect



SCAO system baseline is to use a pyramid WFS

- Better performance & better sensitivity
- Managing the “Island” effect

Small modulation provides information on what’s behind the spider

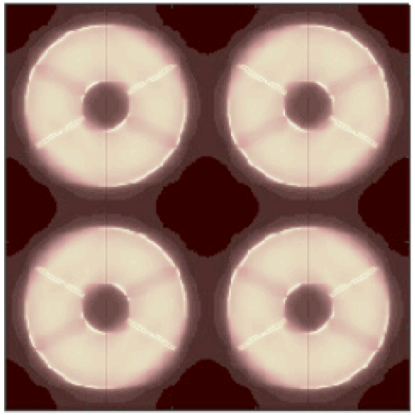


+ Secret ingredient
See Noah Schwartz talk on Friday

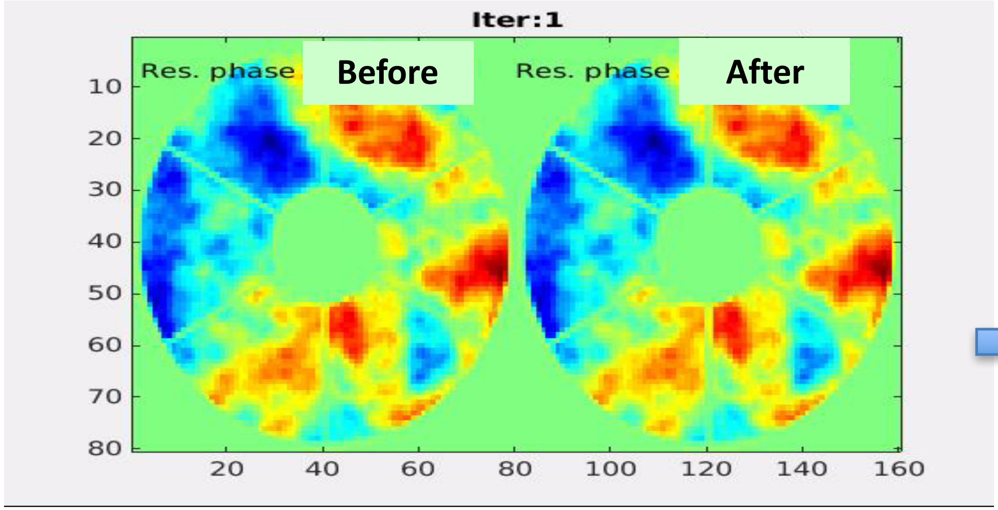
SCAO system baseline is to use a pyramid WFS

- Better performance & better sensitivity
- Managing the "Island" effect

Small modulation provides information on what's behind the spider



See Noah Schwartz AO4ELT5



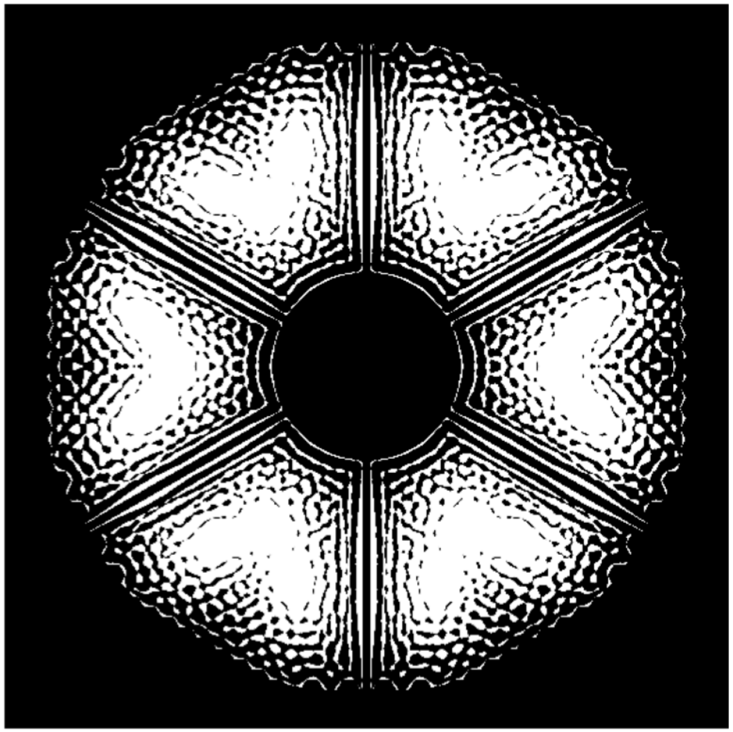
Residuals less than 50nm

SCAO will provide a SR of >70% in K-band

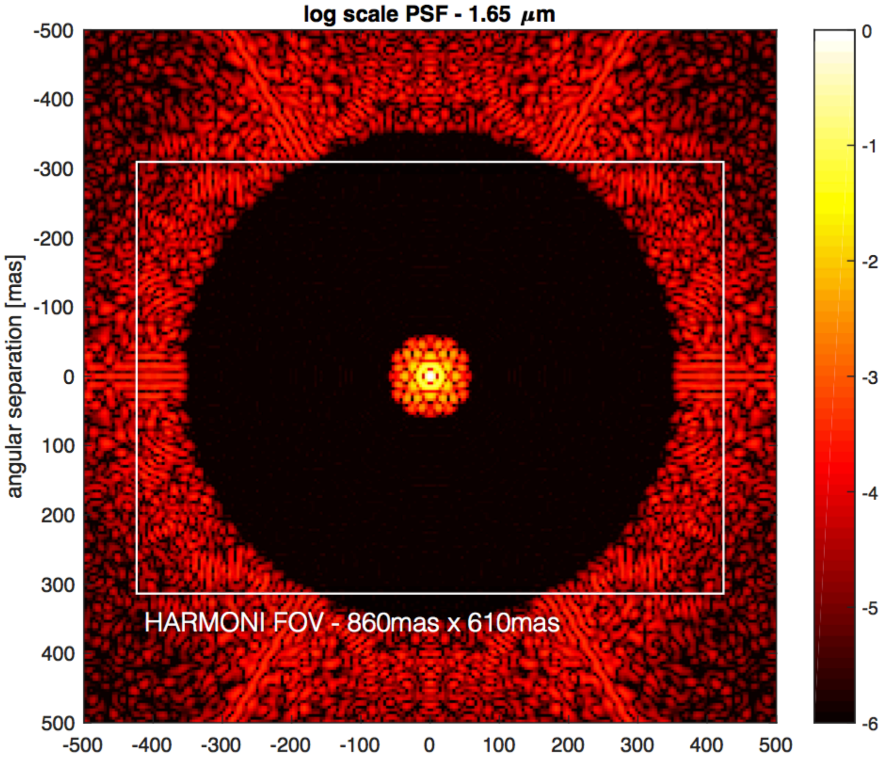
High Contrast :

Spectral characterization of young Jupiters around nearby stars in H & K bands at R=3000-20000, with **a 10-6 contrast at 200mas**.

Shaped pupil transmission



From A. Carlotti, A. Vigan, D. Mouillet, M. Bonnefois

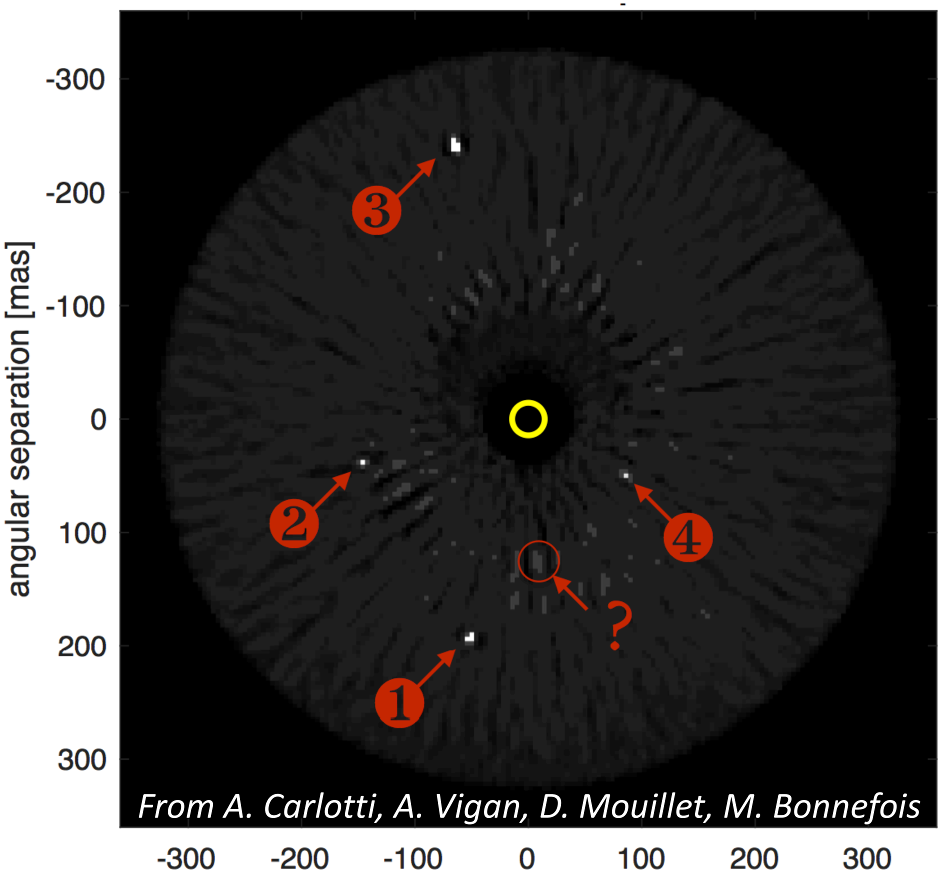


HARMONI SCAO

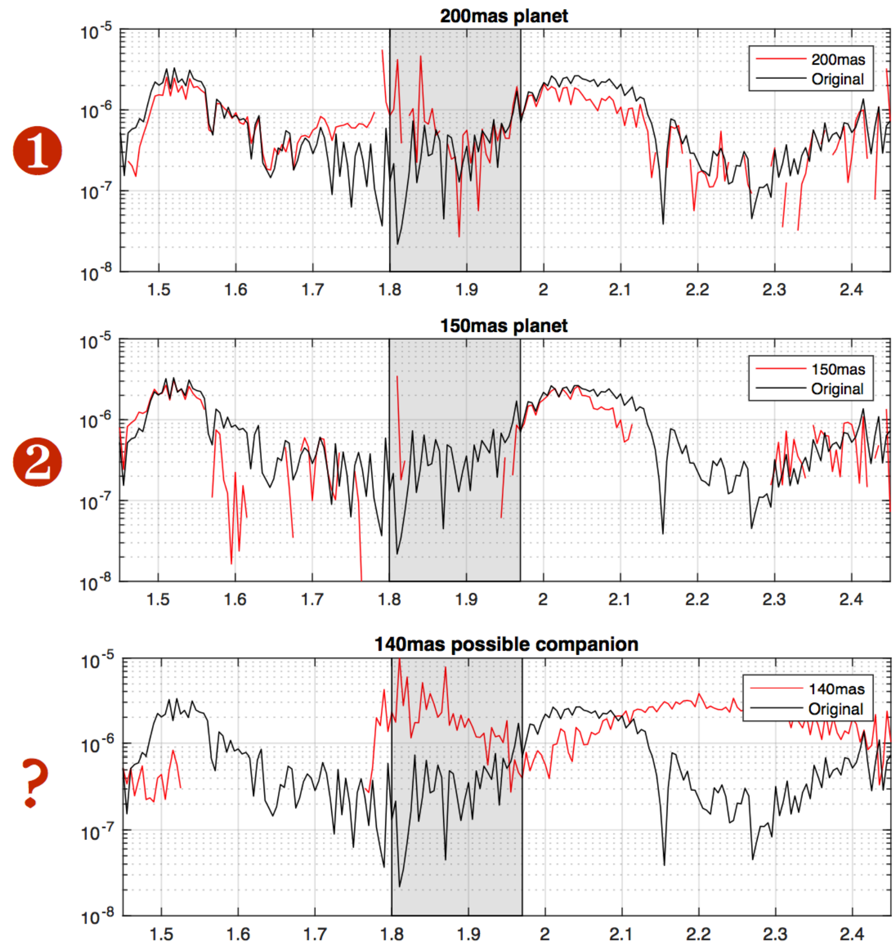
High Contrast :

Simulated data of 4 planets w/ 10-6 planets contrast & 51 Eri b-like synthetic spectrum (2h exp. with H=6 star).

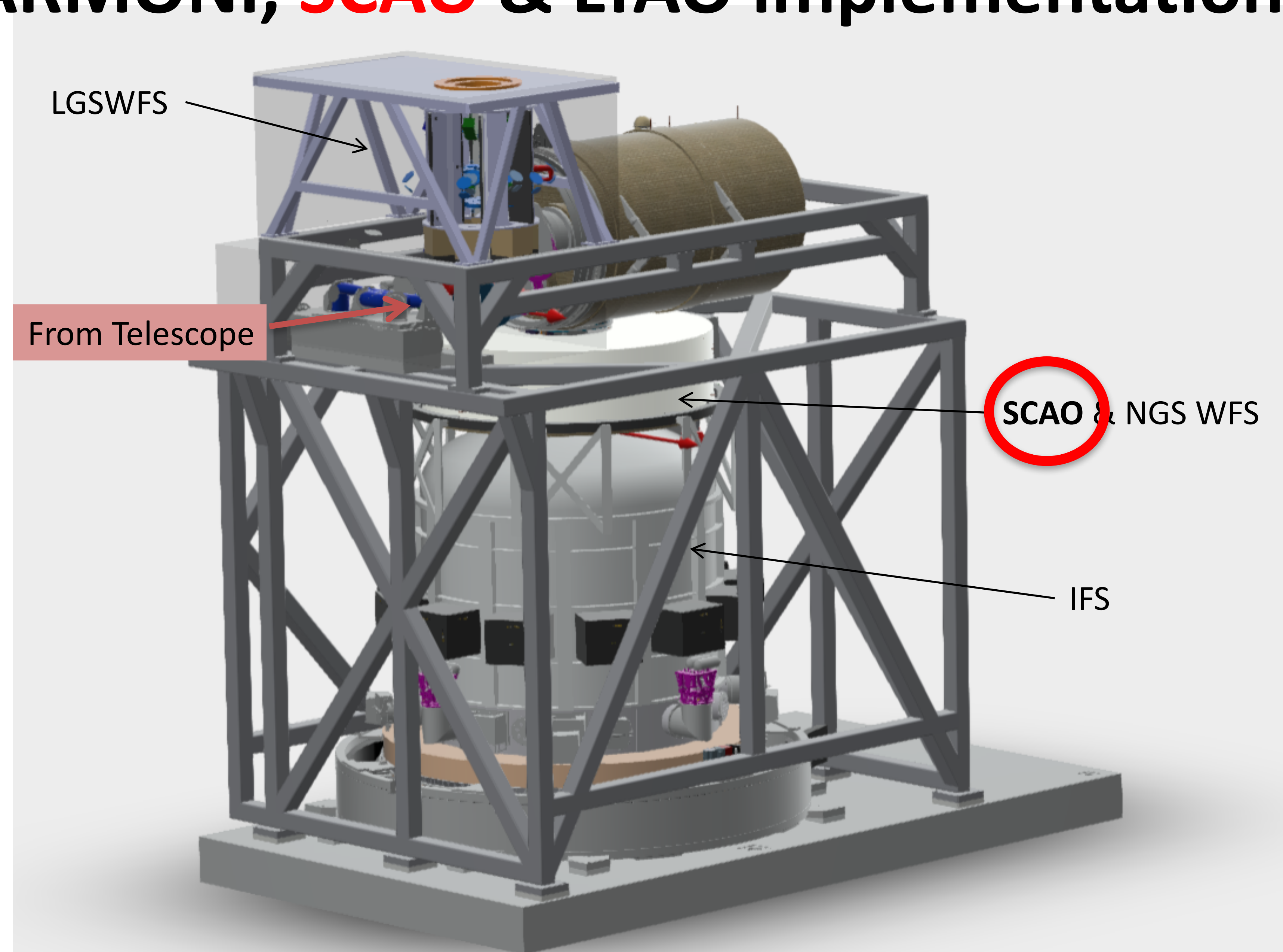
The 4 planets appear in the detection map

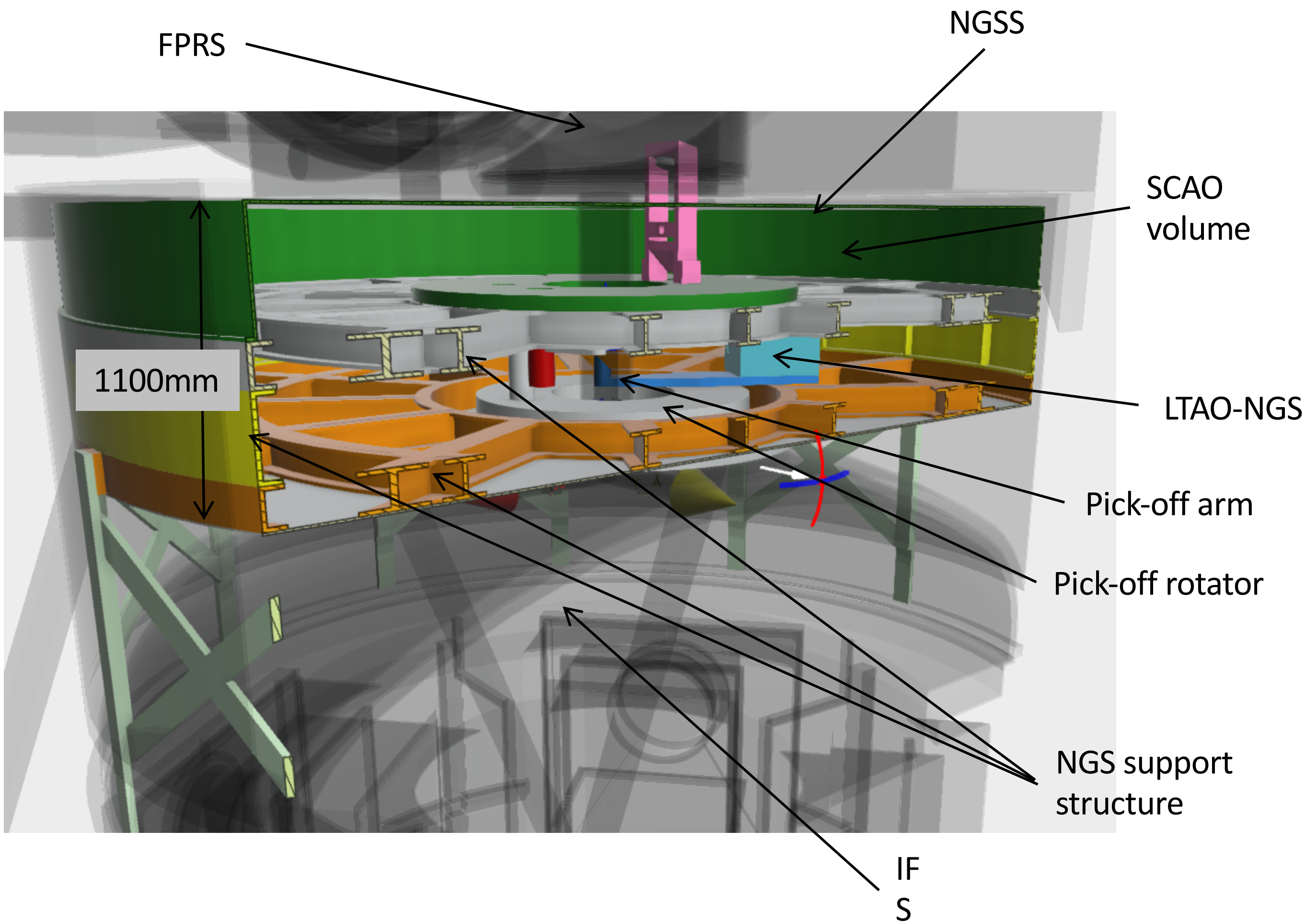


Extracted spectra



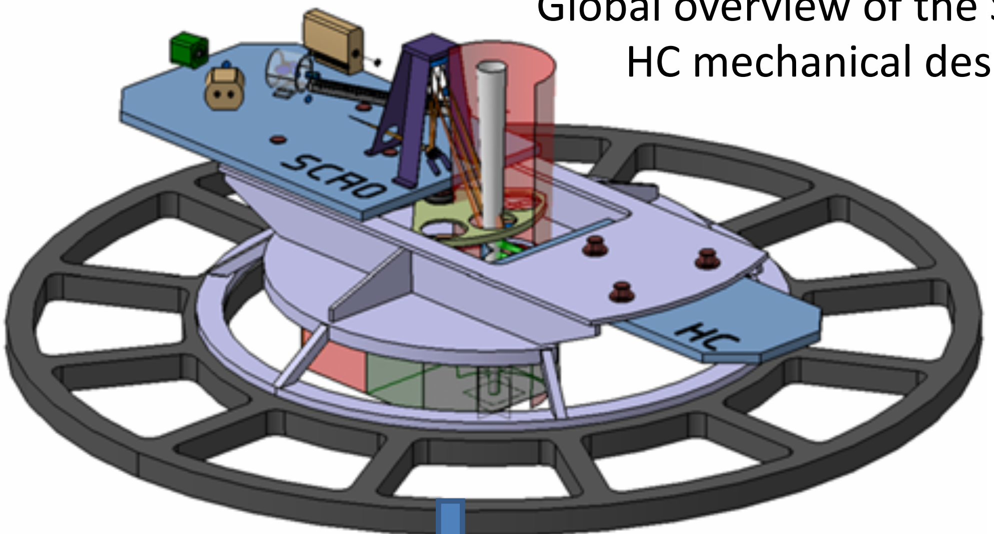
HARMONI, SCAO & LTAO implementation

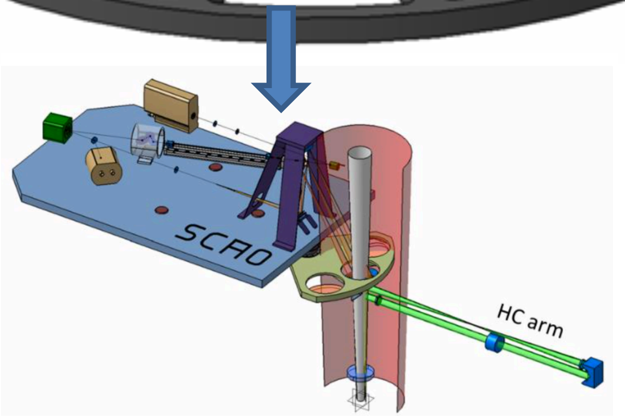




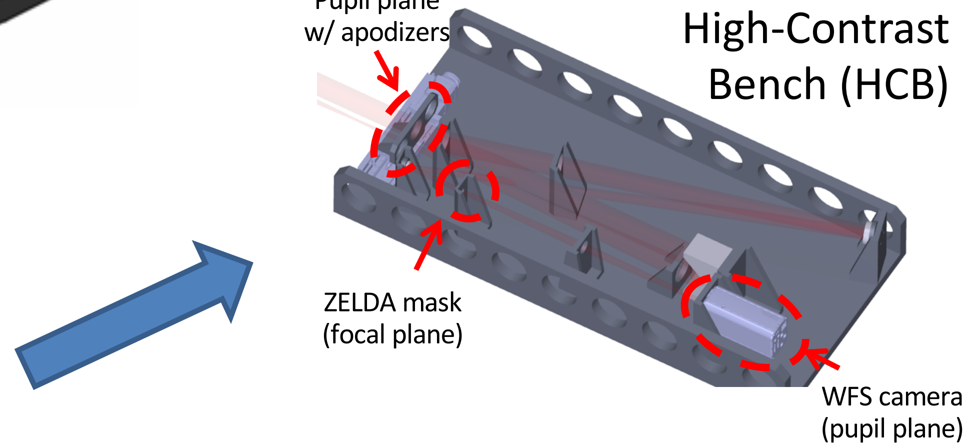
FPRS
NGSS
SCAO
volume
1100mm
LTAO-NGS
Pick-off arm
Pick-off rotator
NGS support
structure
IF
S

Global overview of the SCAO &
HC mechanical design



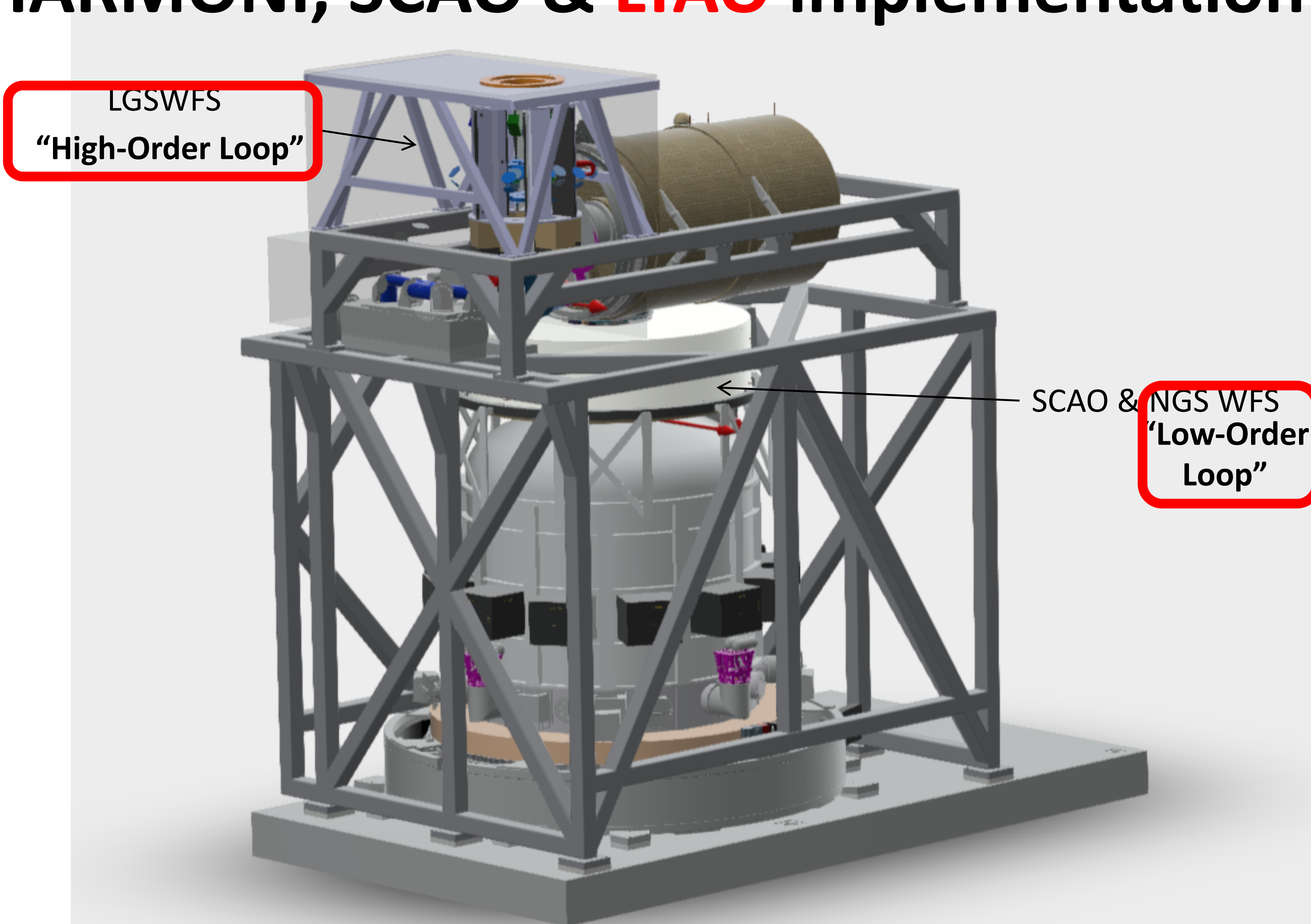


High-Contrast
Bench (HCB)

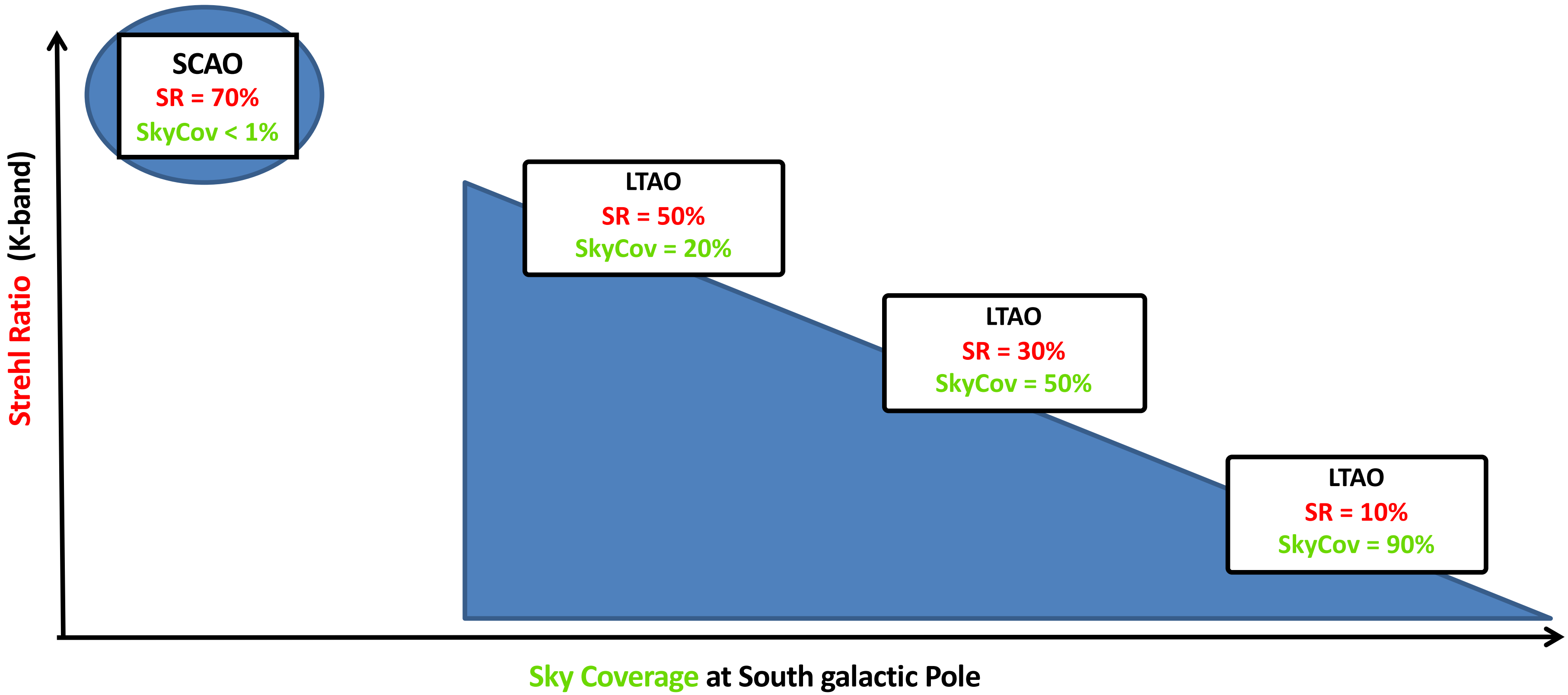


Ask P. Vola, S. Pascal, K. Dohlen for more details on the opto-mechanical design !

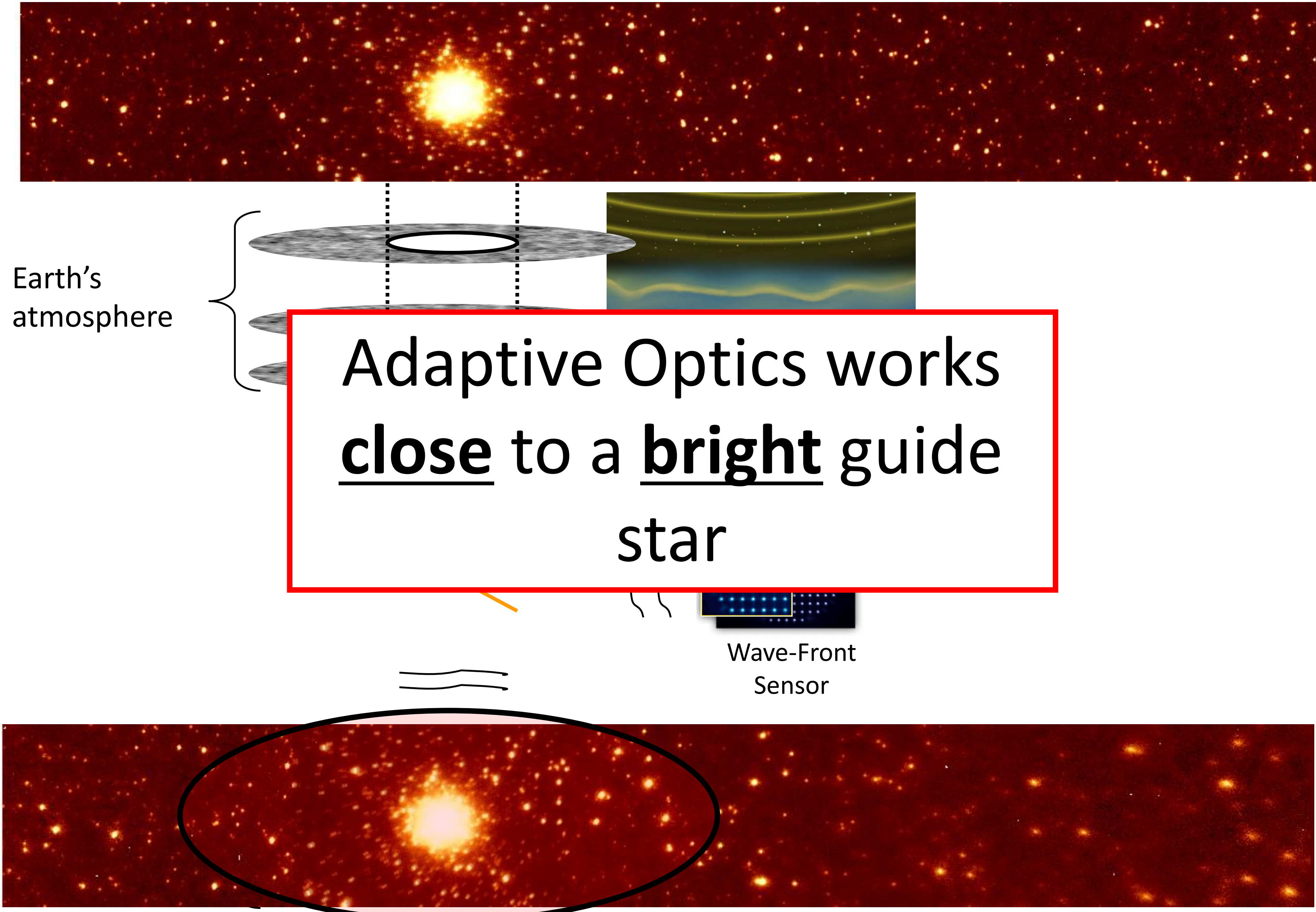
HARMONI, SCAO & LTAO implementation



HARMONI LTAO:
Main Objective = provide sky coverage to HARMONI !



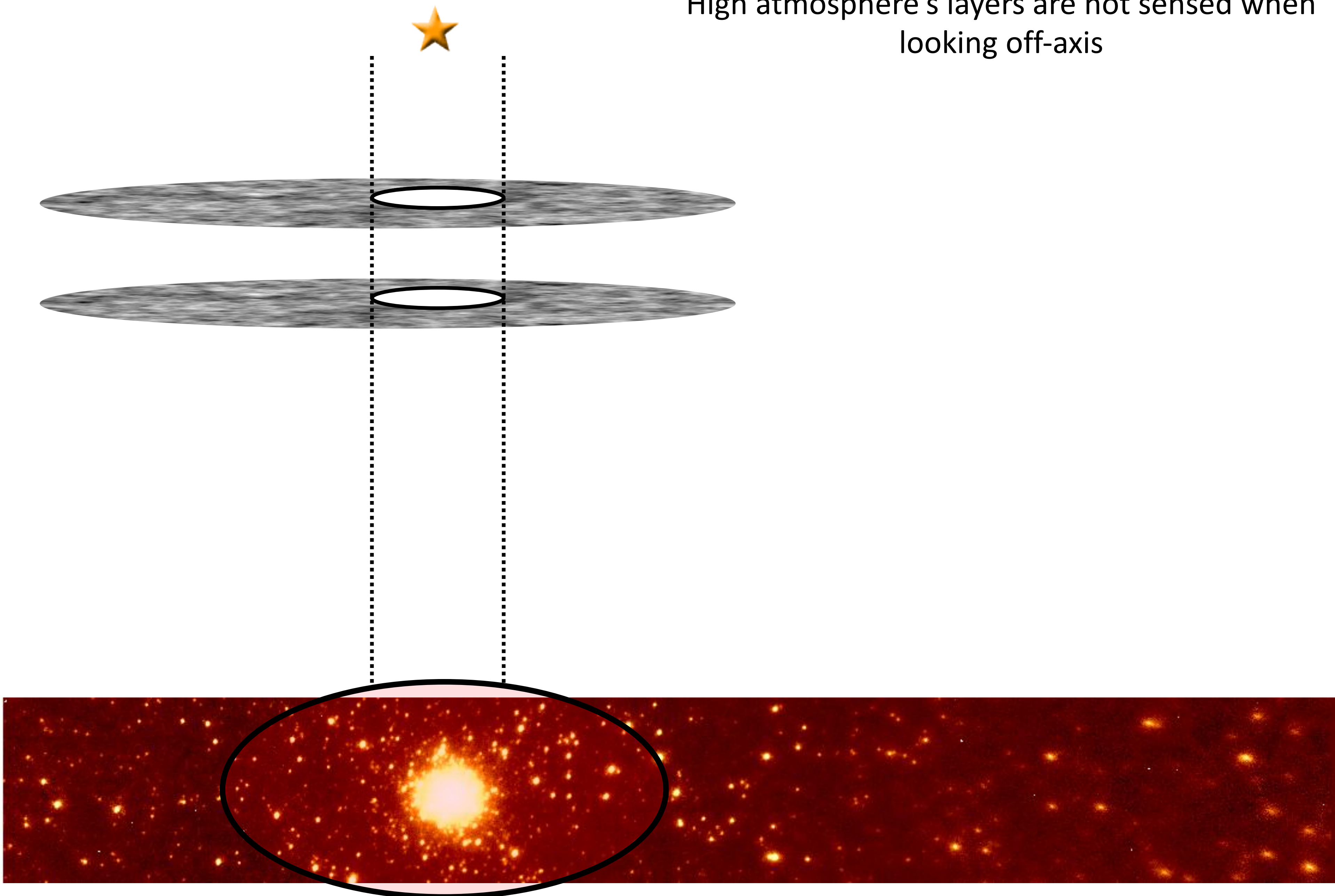
Adaptive Optics



Adaptive Optics works **close** to a **bright** guide star

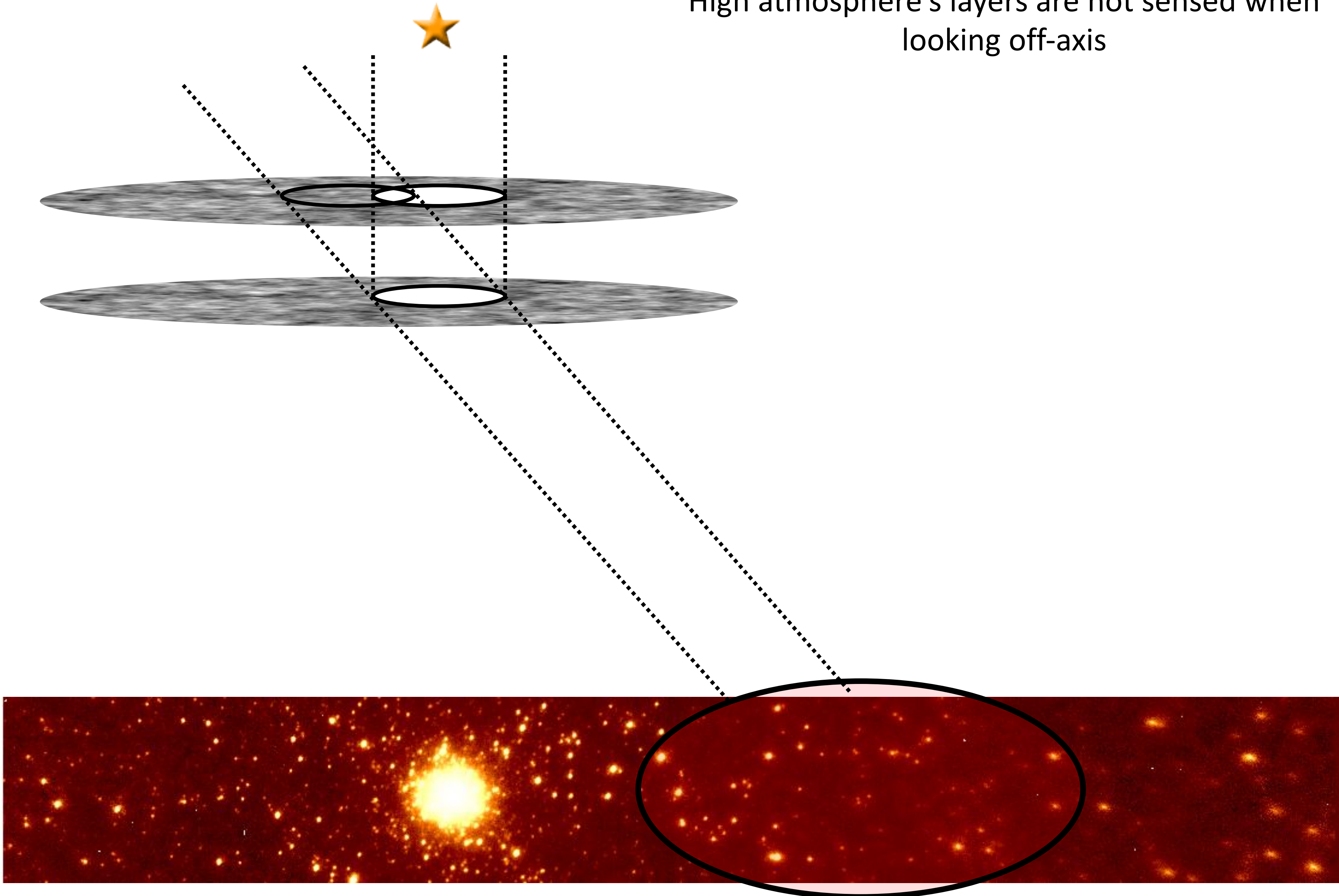
Anisoplanatism

High atmosphere's layers are not sensed when looking off-axis



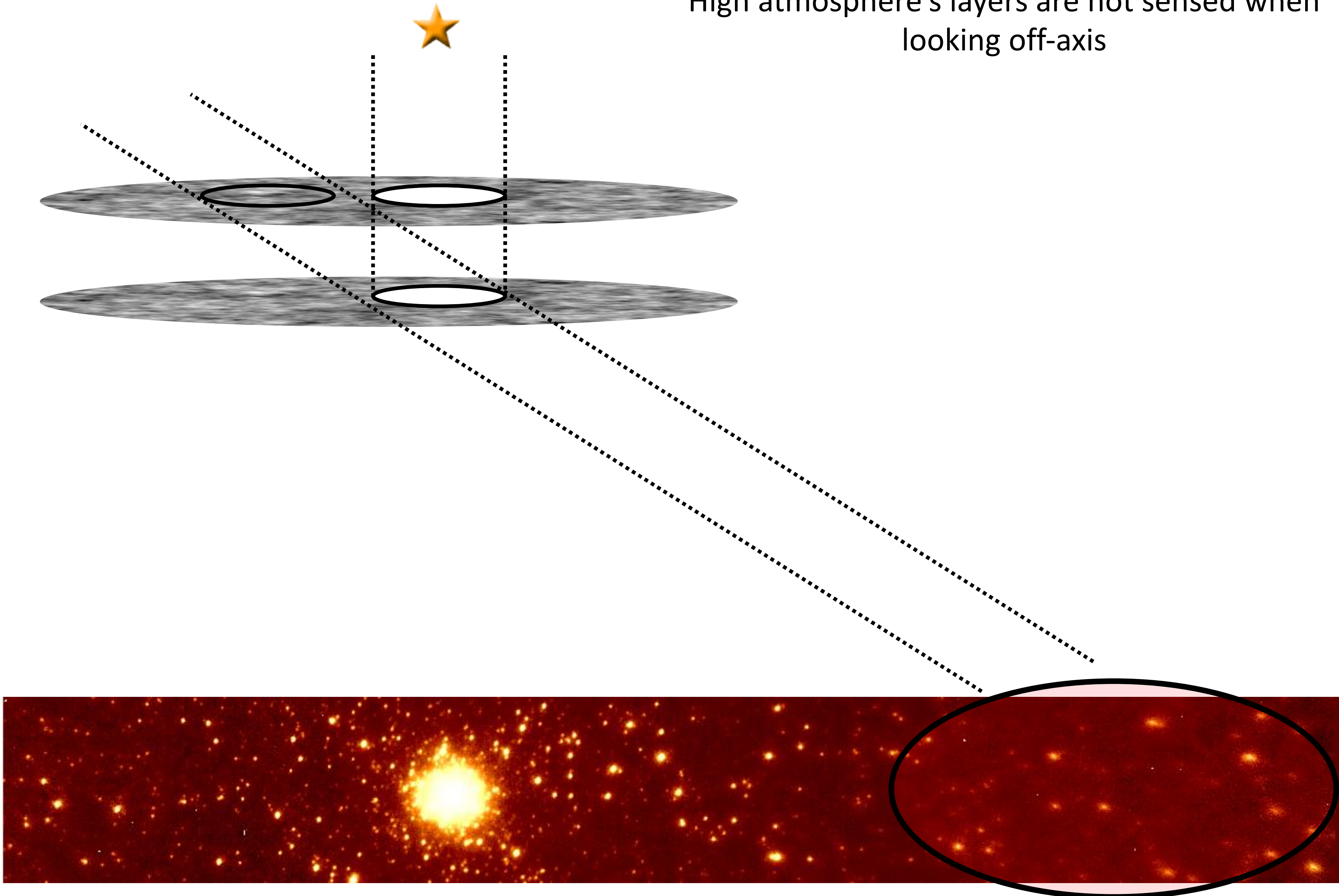
Anisoplanatism

High atmosphere's layers are not sensed when looking off-axis

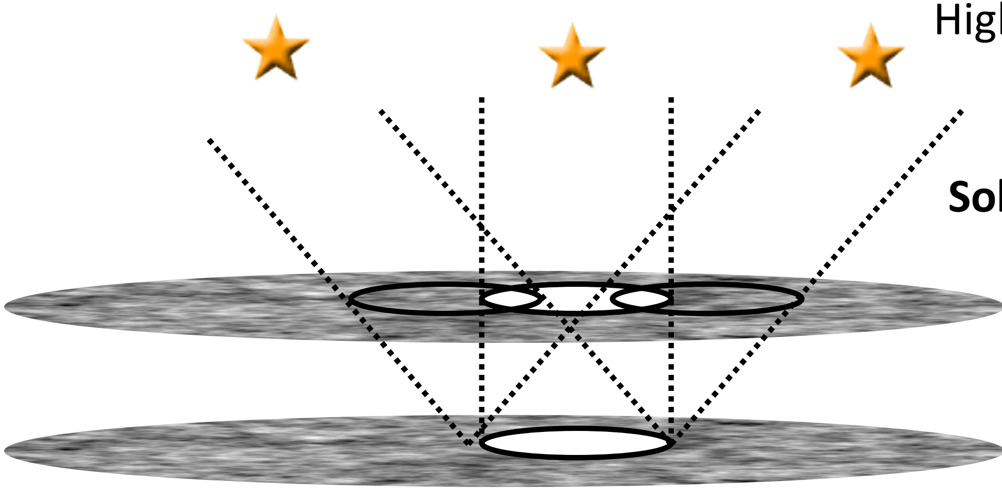


Anisoplanatism

High atmosphere's layers are not sensed when looking off-axis

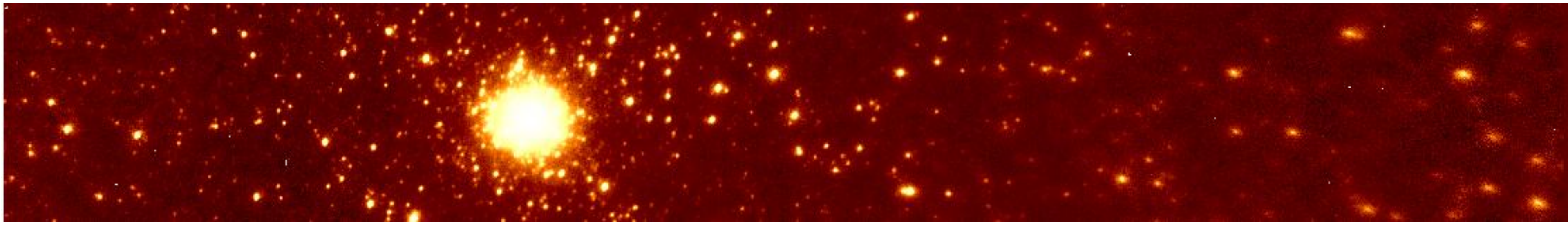


Tomography

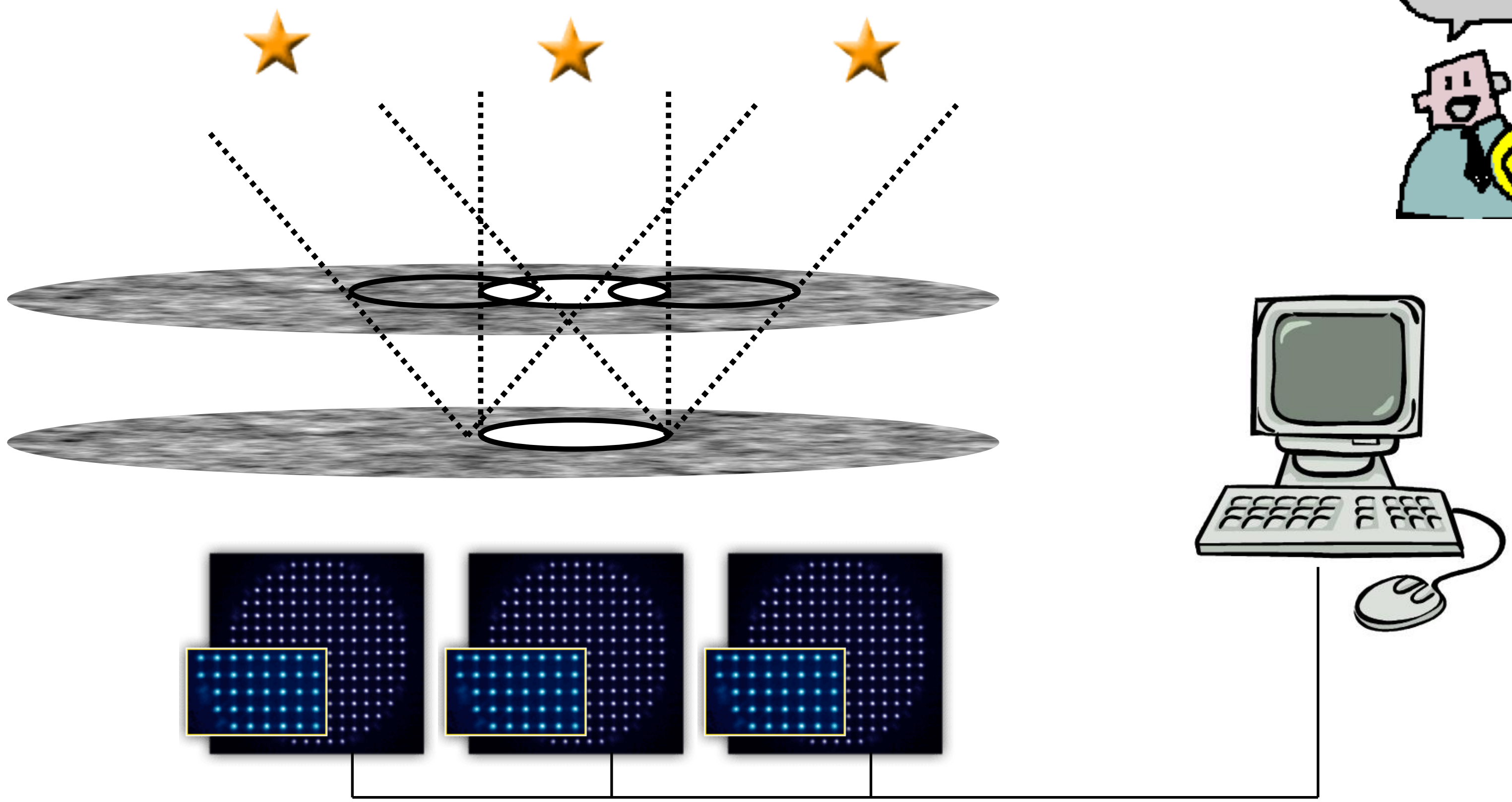


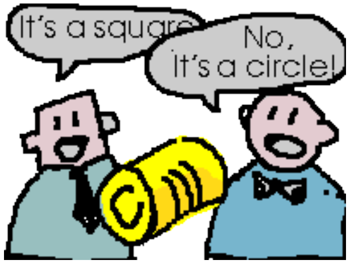
High atmosphere's layers are not sensed when looking off-axis

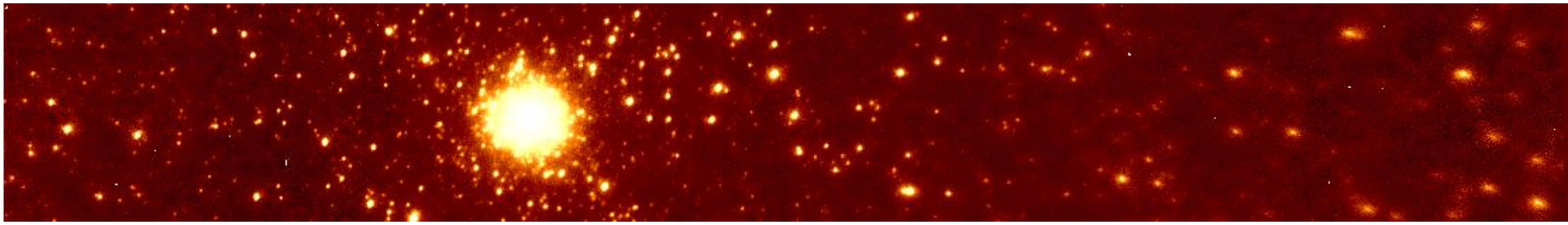
Solution => Combine off-axis measurements



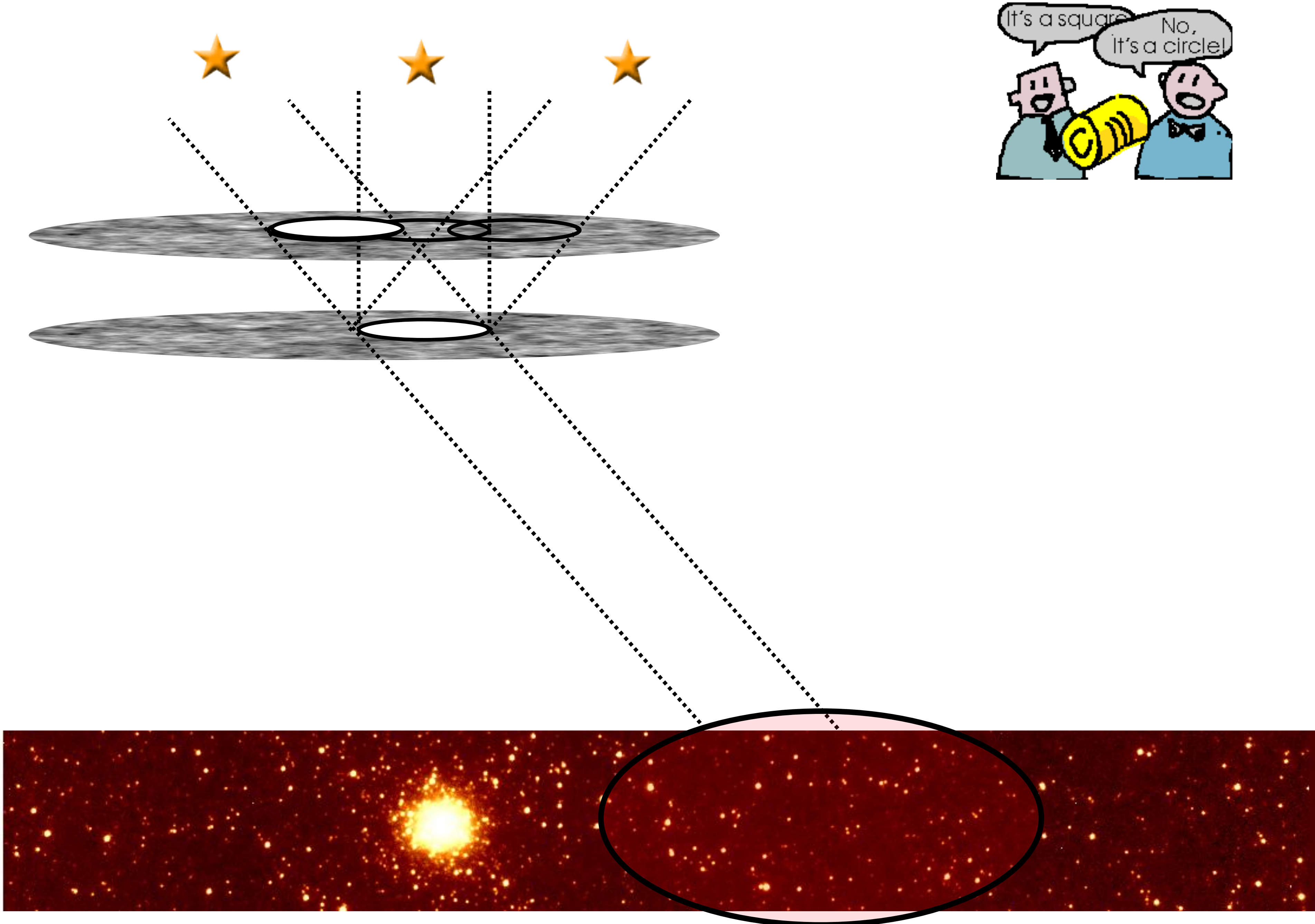
Tomography







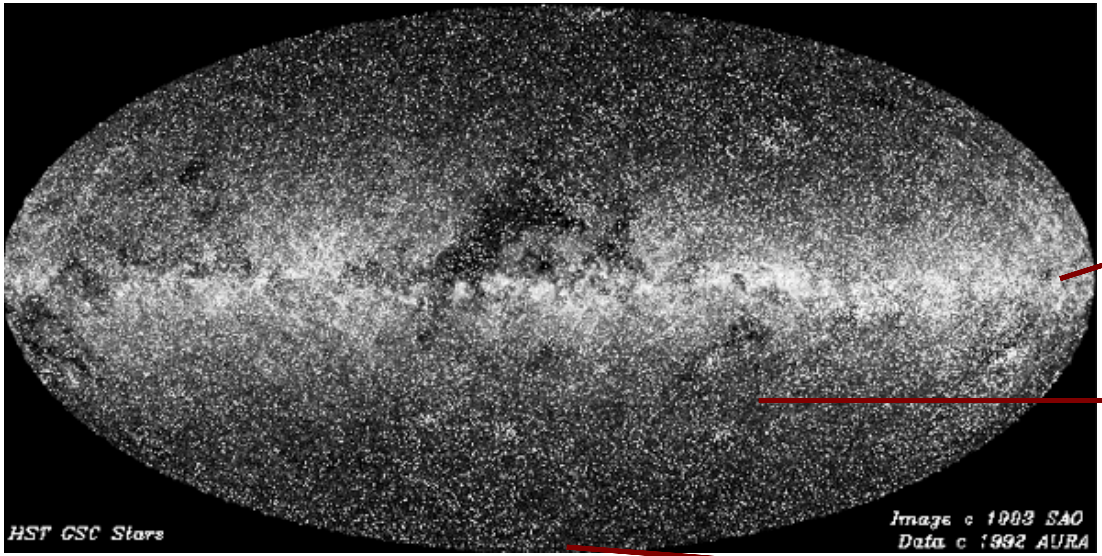
Tomography



Sky Coverage

Adaptive Optics works <u>close</u> to a <u>bright</u> guide star

How many Guide Stars are available ?



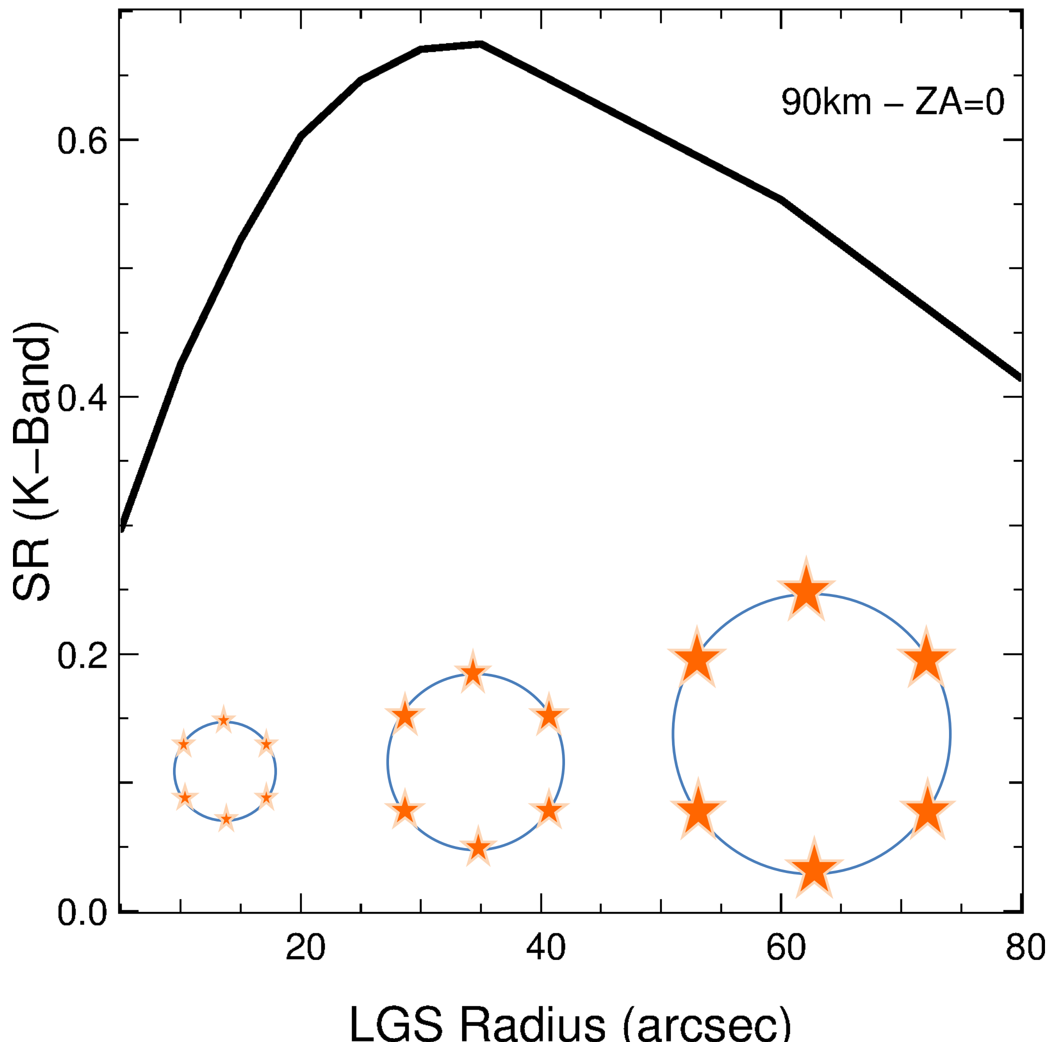
3 stars with R < 16 in a 2 arcmin FoV

10%

1%

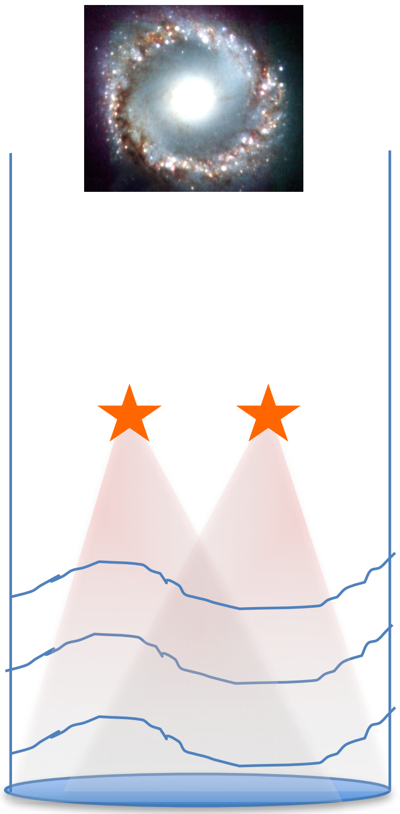
0.1%

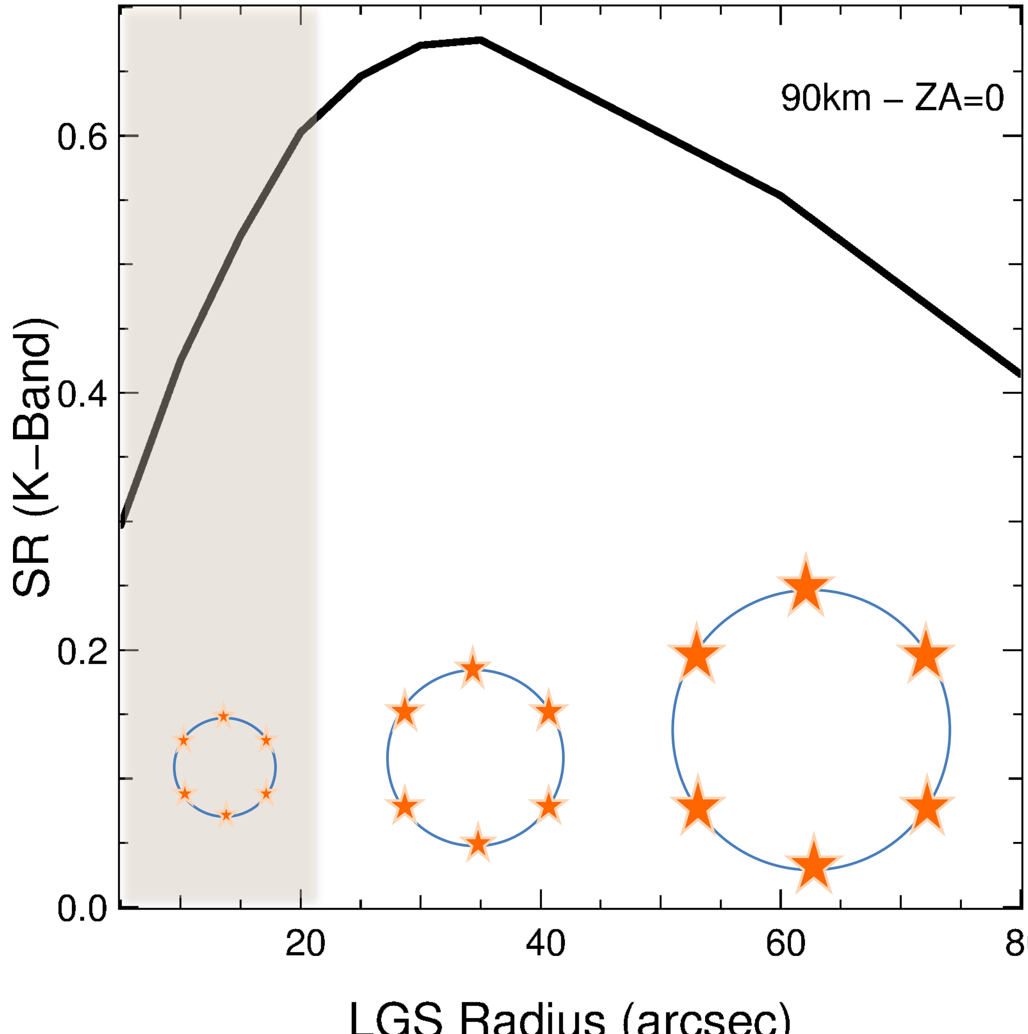
Impact of LGS constellation



Simulation E2E from Miska Lelouarn (ESO – OCTOPUS), Carlos Correia (OOMAO) and Fourier from T. Fusco

Impact of LGS constellation





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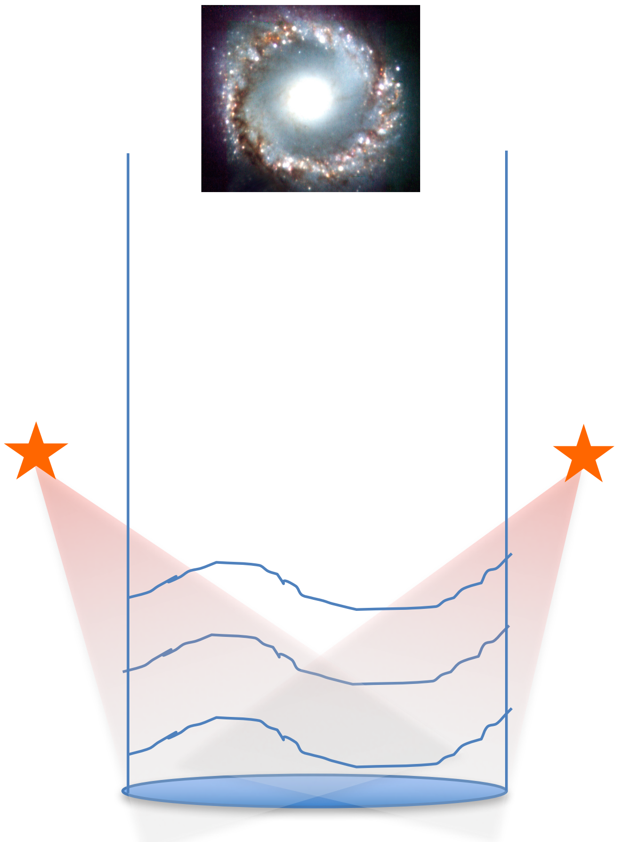

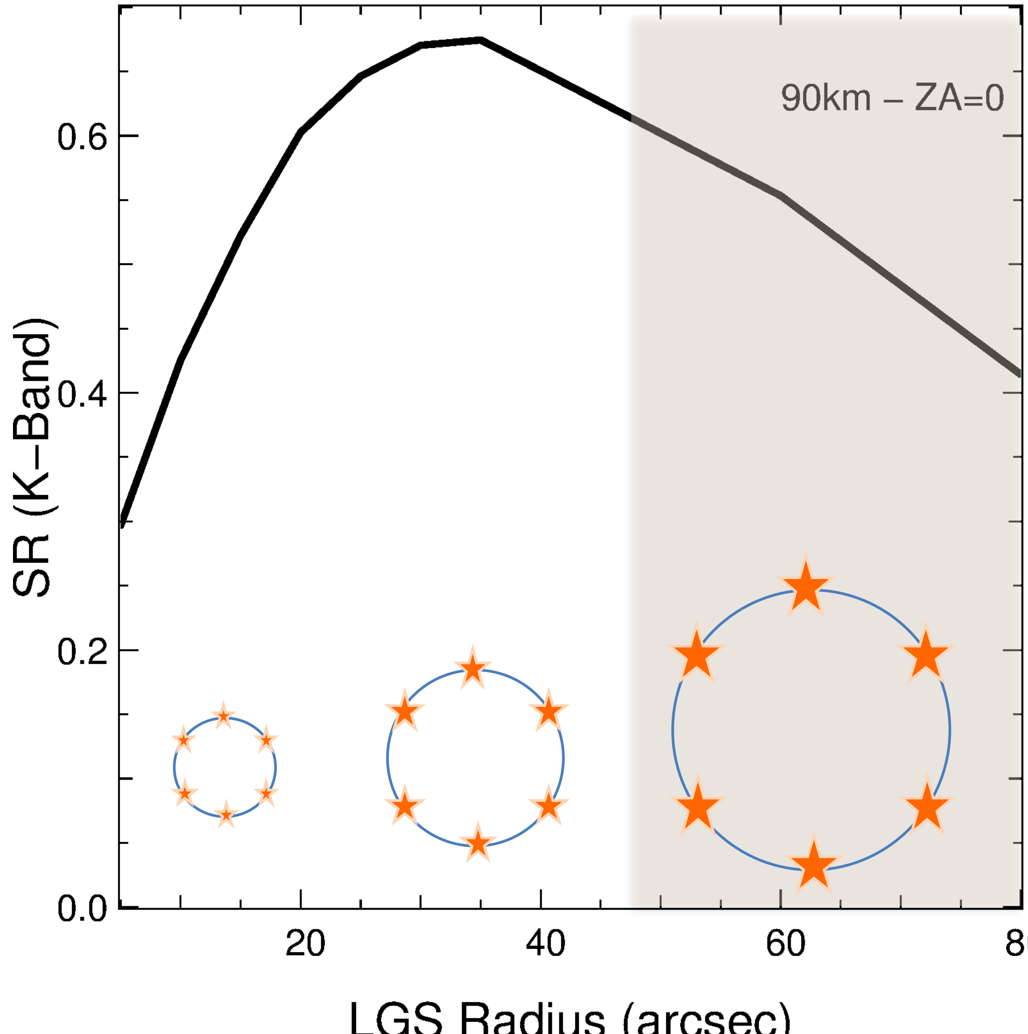

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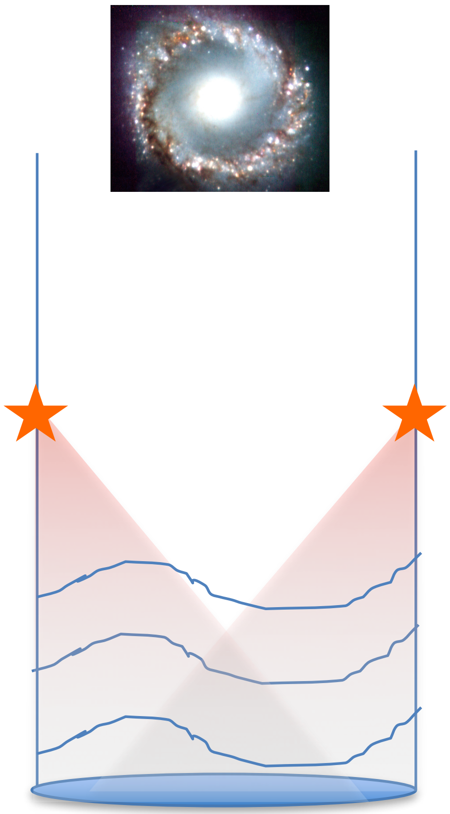

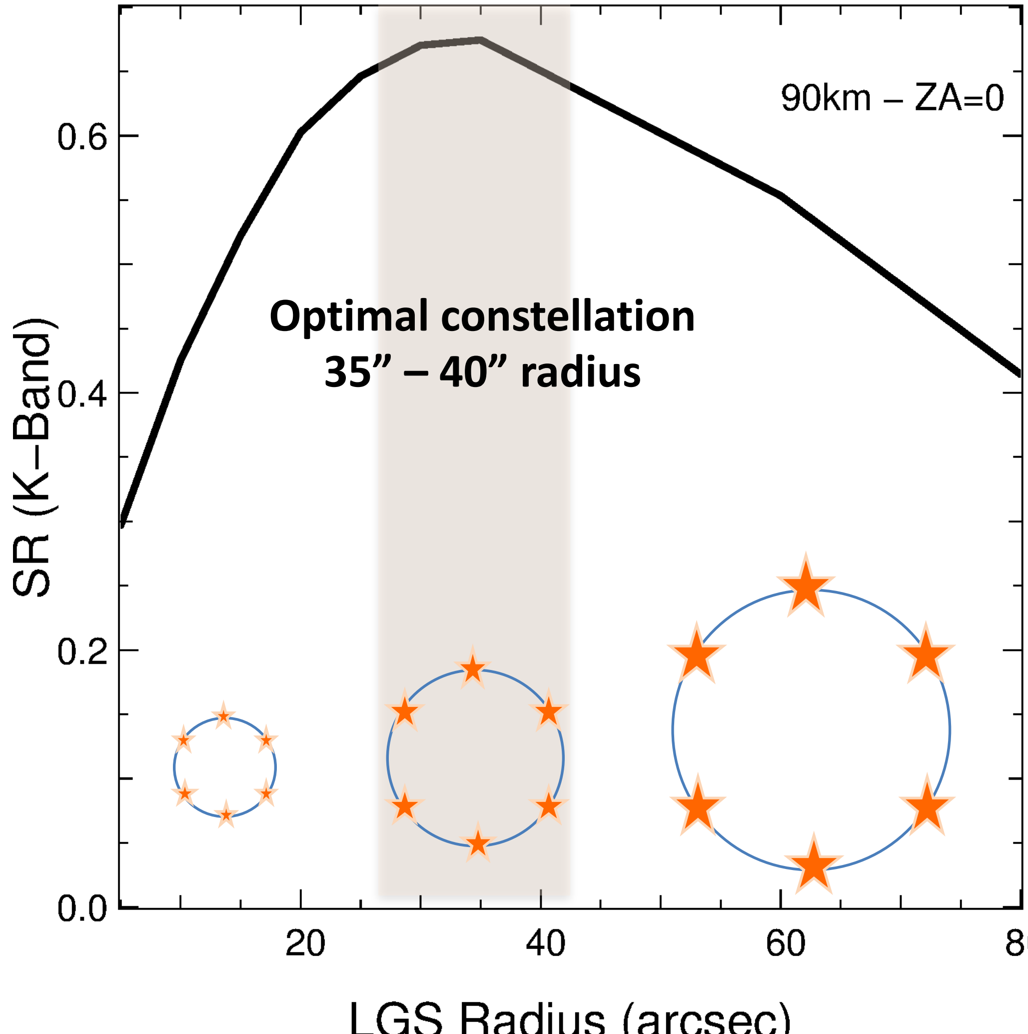

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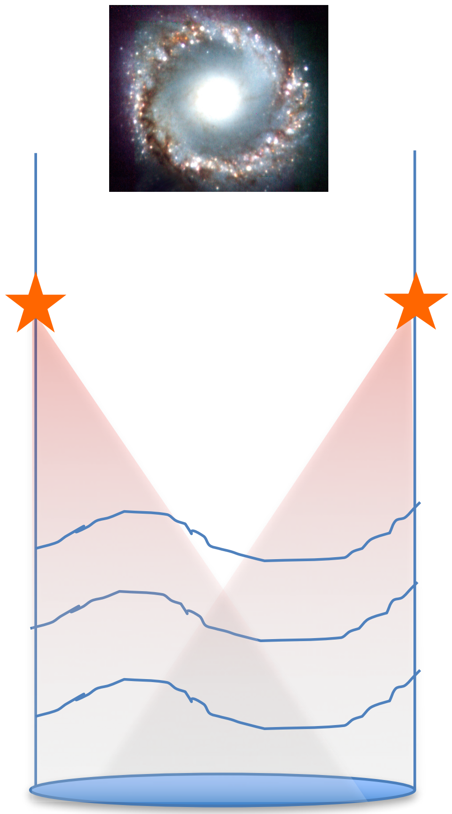
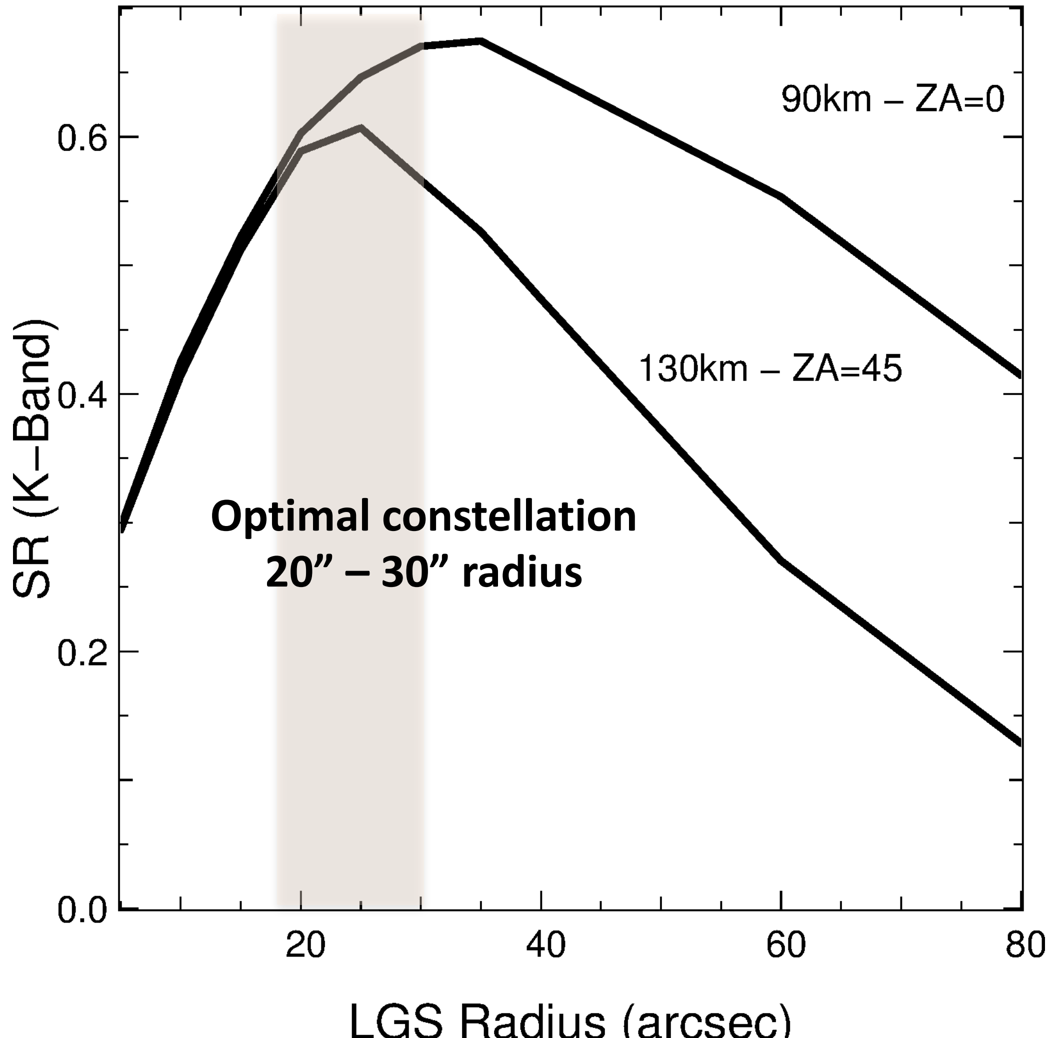
Impact of LGS constellation





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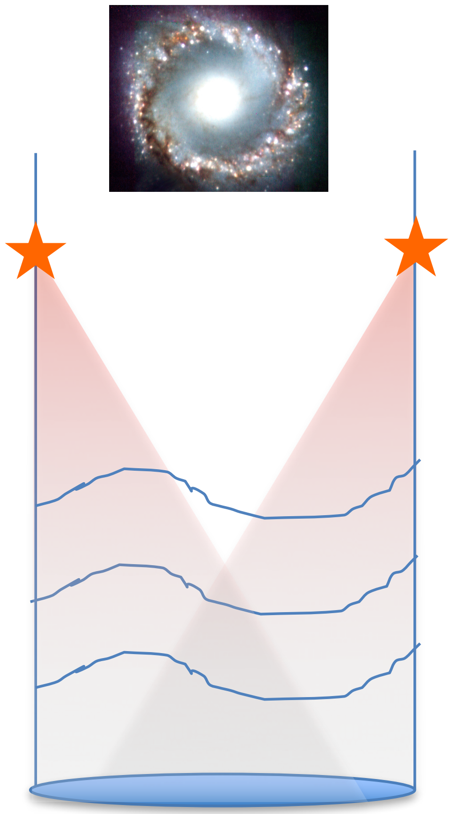
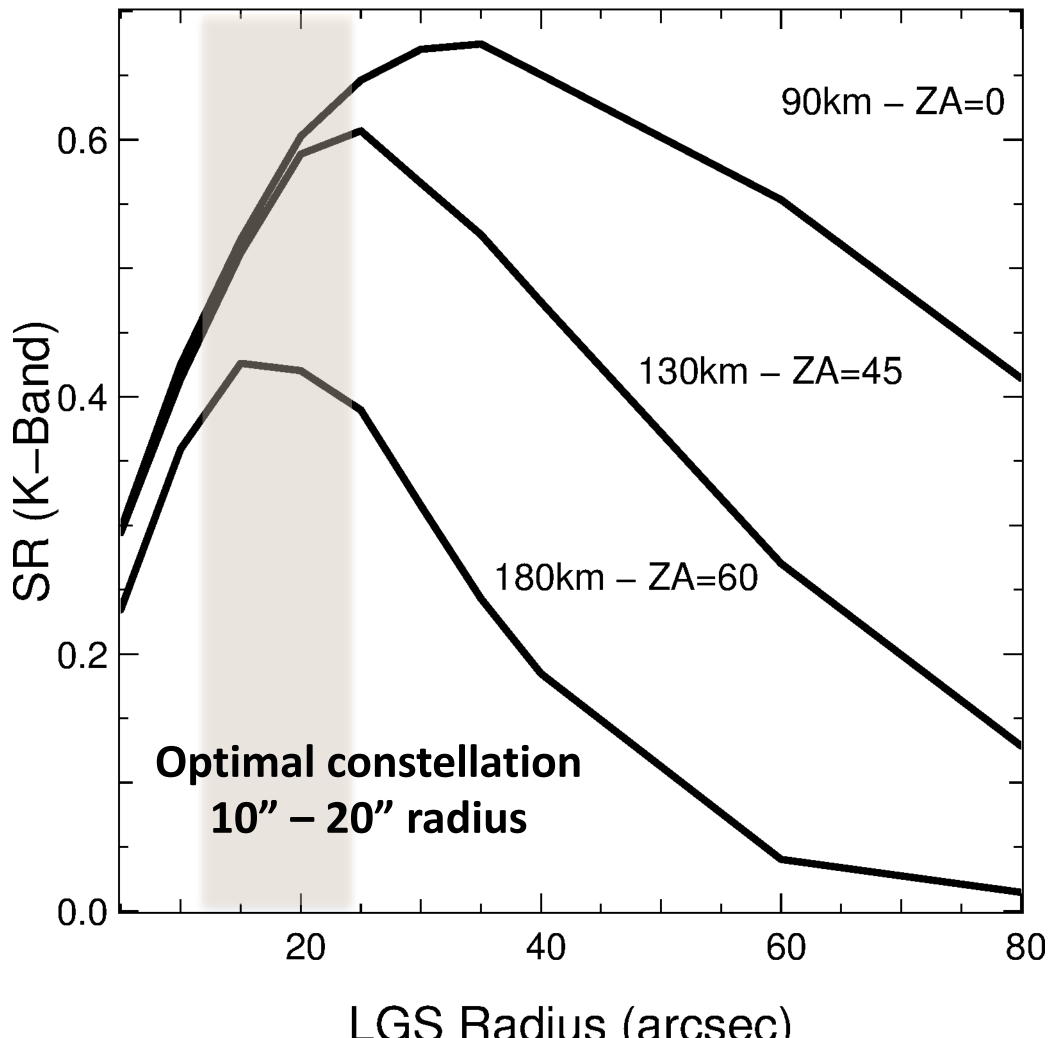
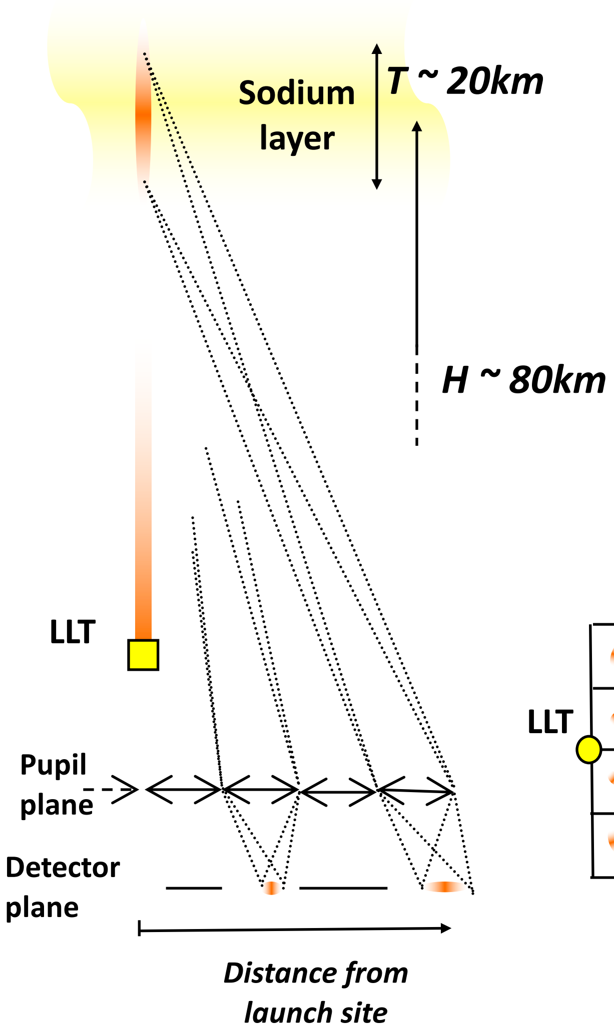


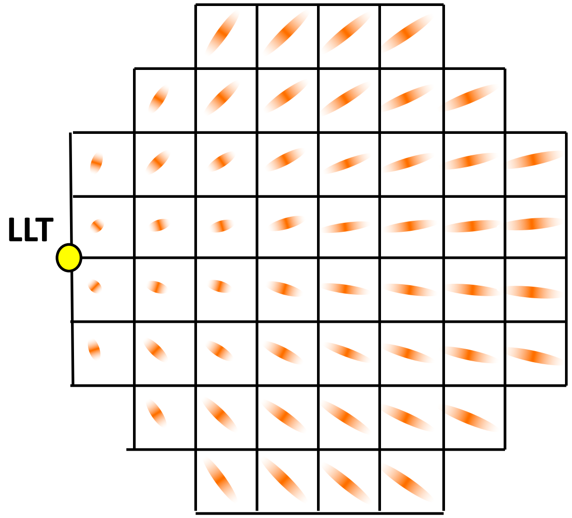


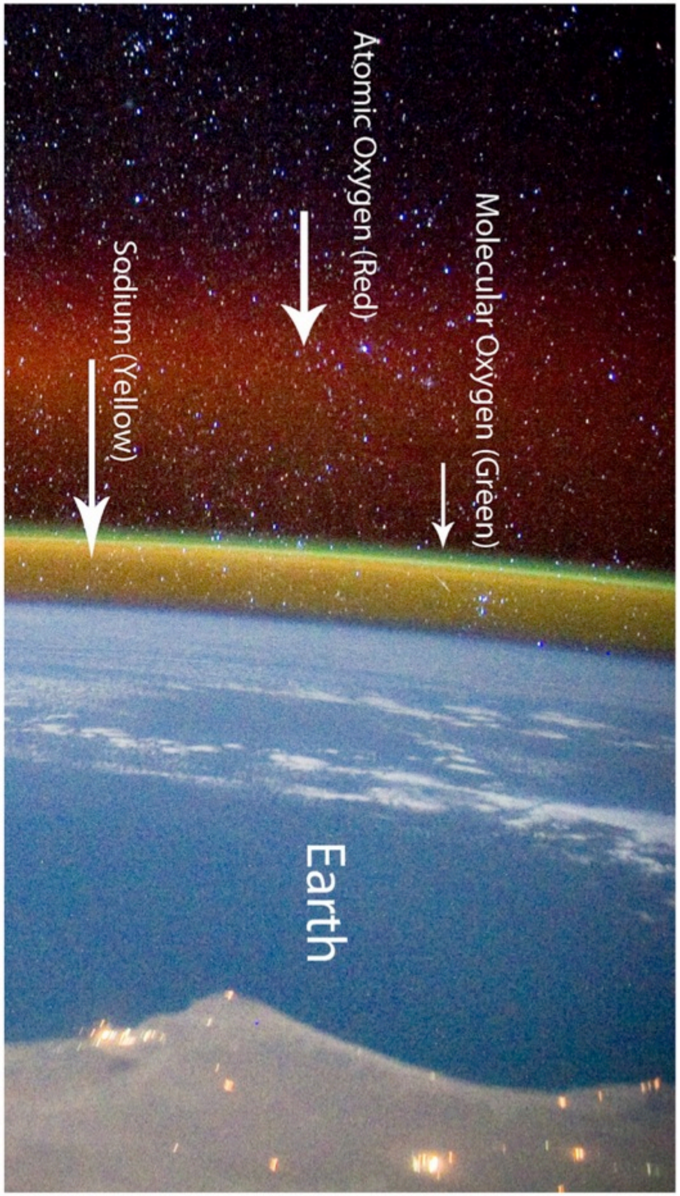
Simulation E2E from Miska Lelouarn (ESO – OCTOPUS), Carlos Correia (OOMAO) and Fourier from T. Fusco

Sensing on LGS

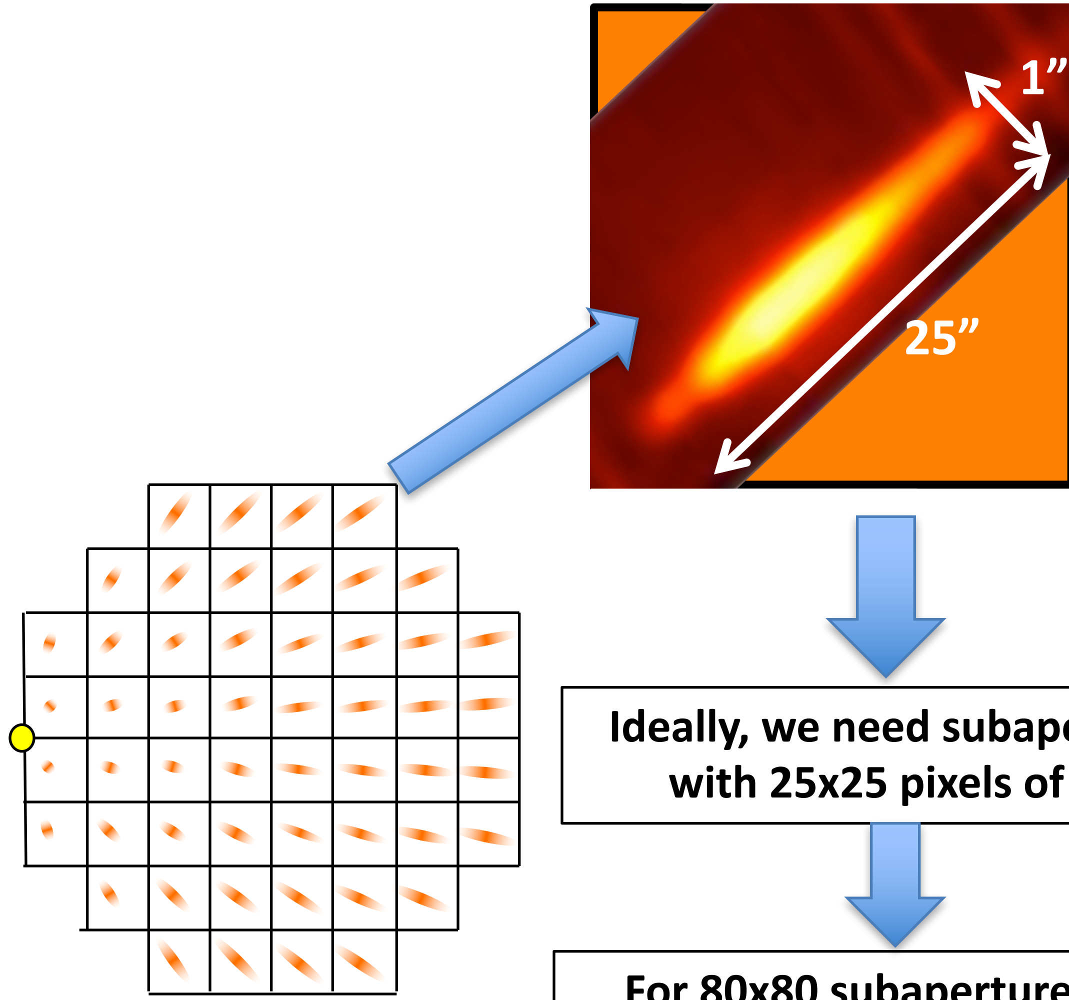


Predicted spot
elongation pattern





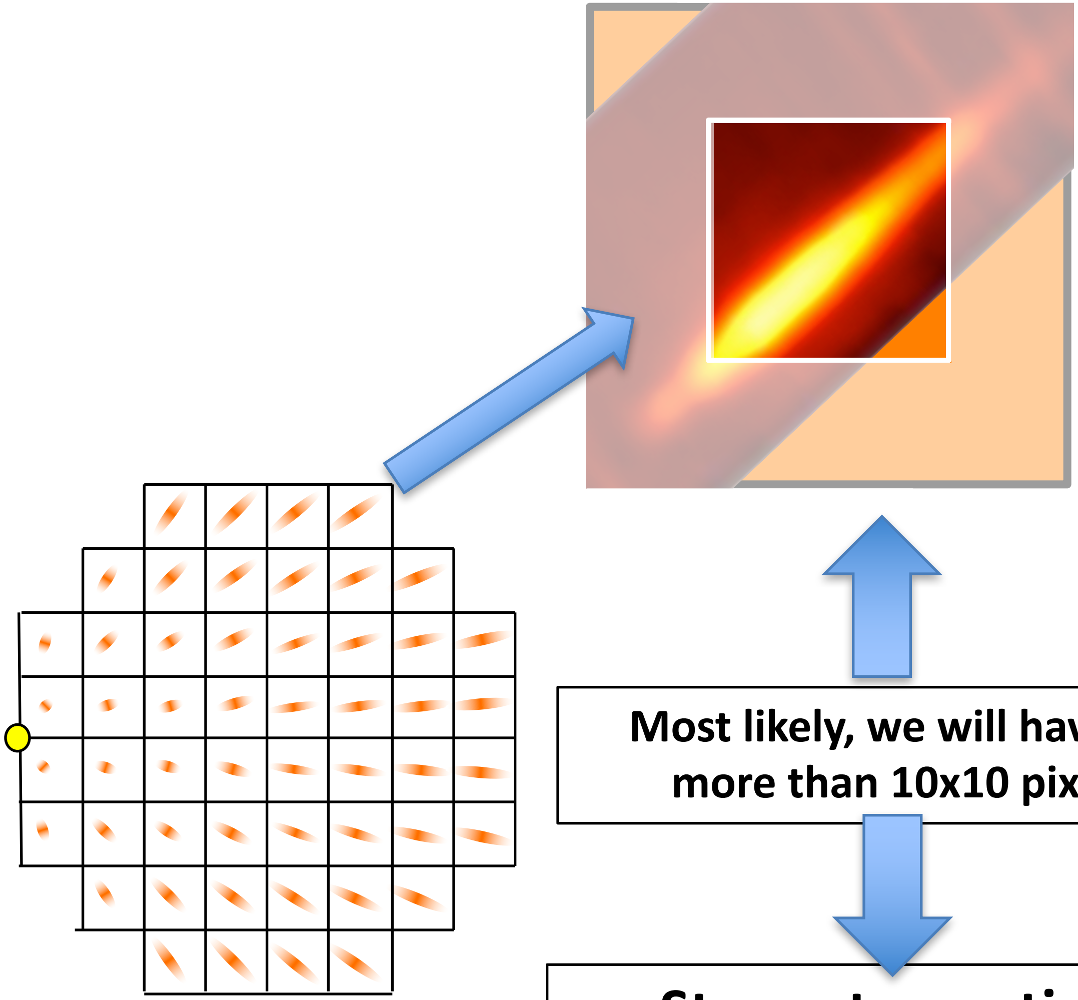
Dealing with spot elongation



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

For 80x80 subapertures, we need 2000 x 2000 pixels

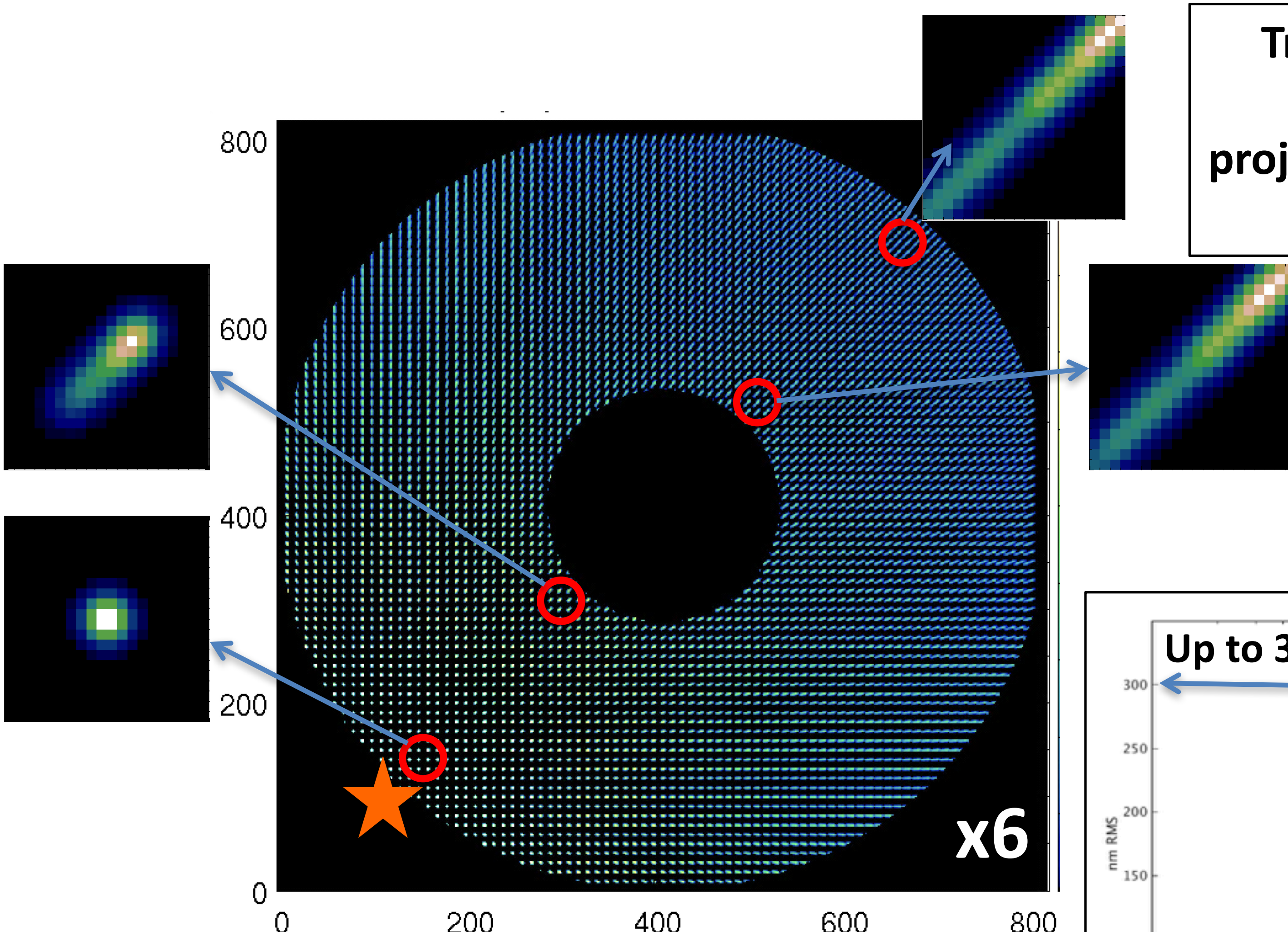
Dealing with spot truncation



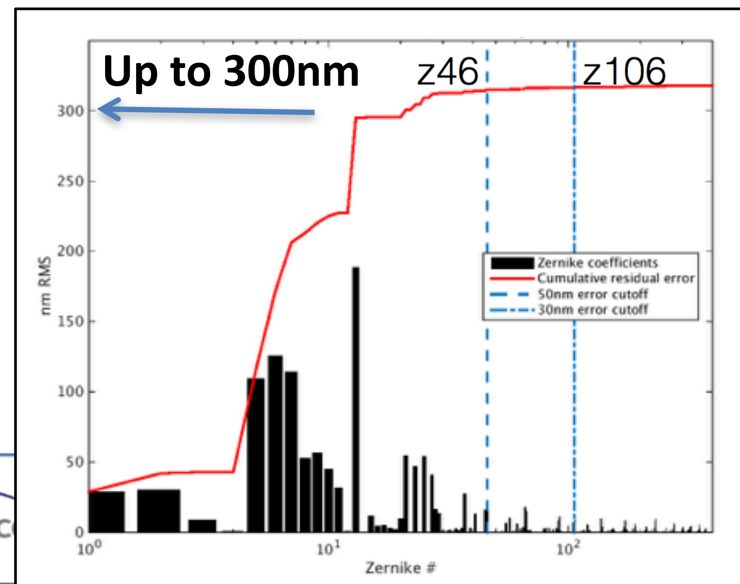
Most likely, we will have no more than 10x10 pixels

Strong truncation

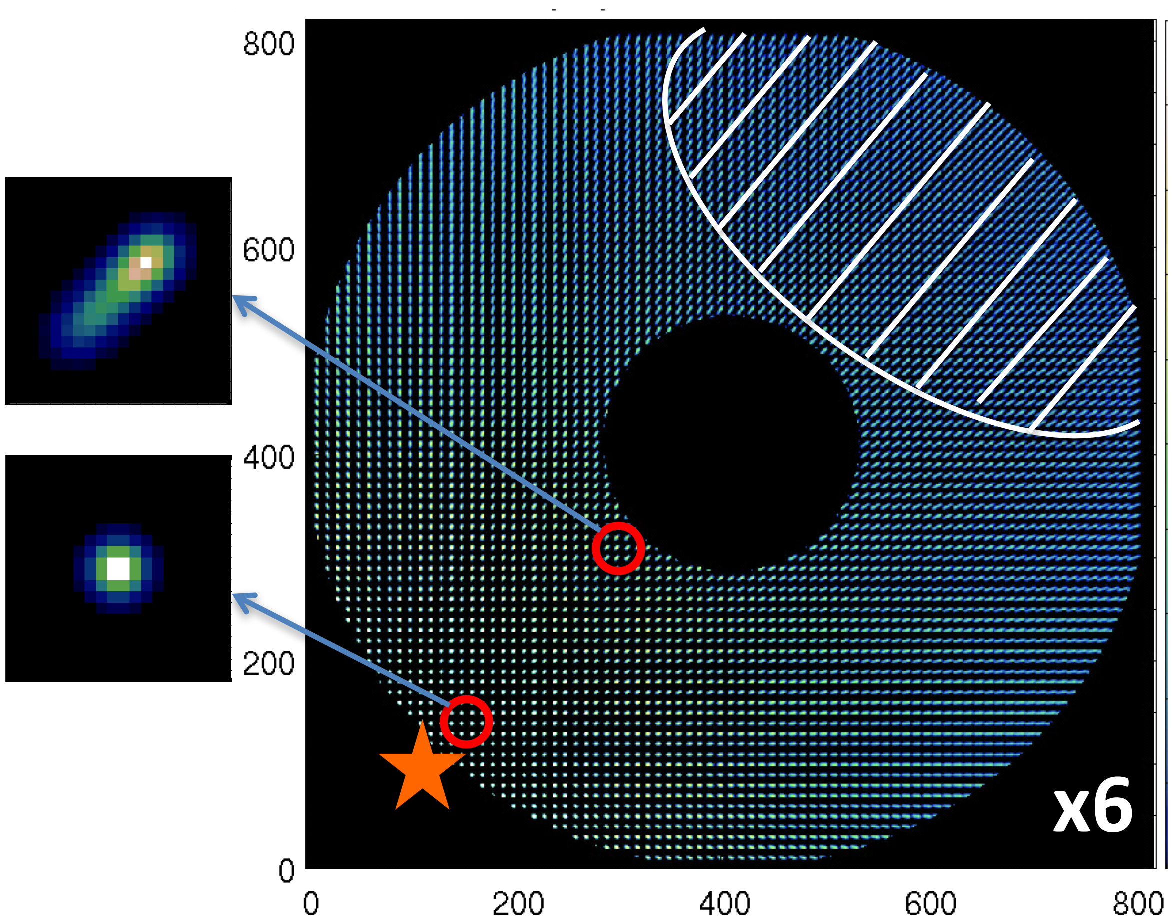
Dealing with spot truncation



Truncation induces biases that are projected on-axis by the Tomography

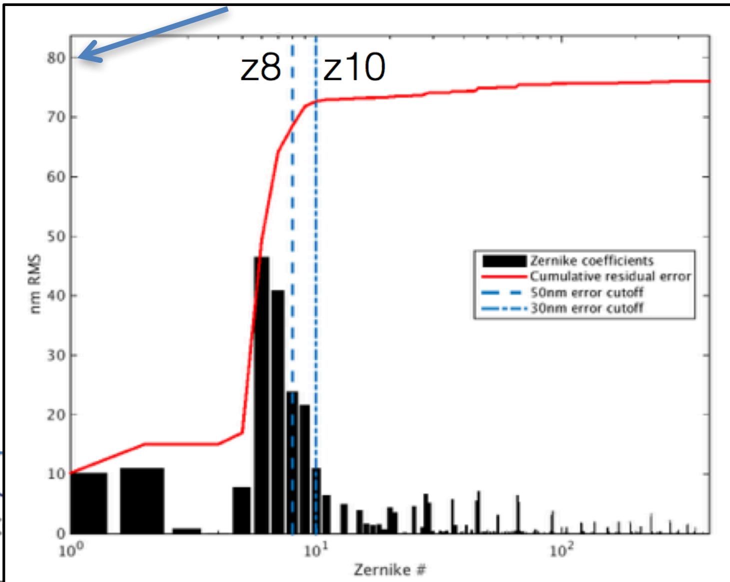


Dealing with spot truncation

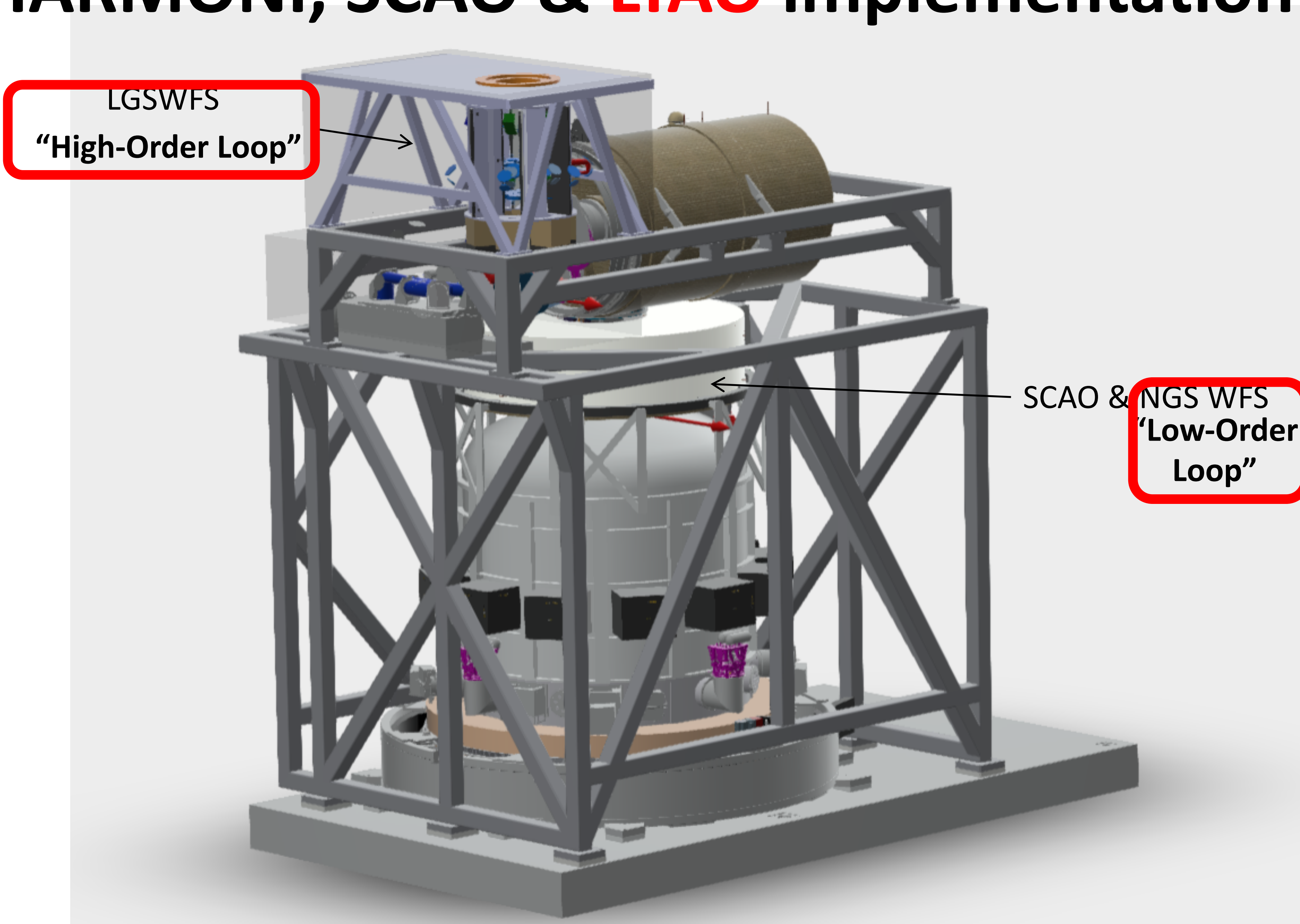


One way to reduce this impact is to reject the truncated measurements

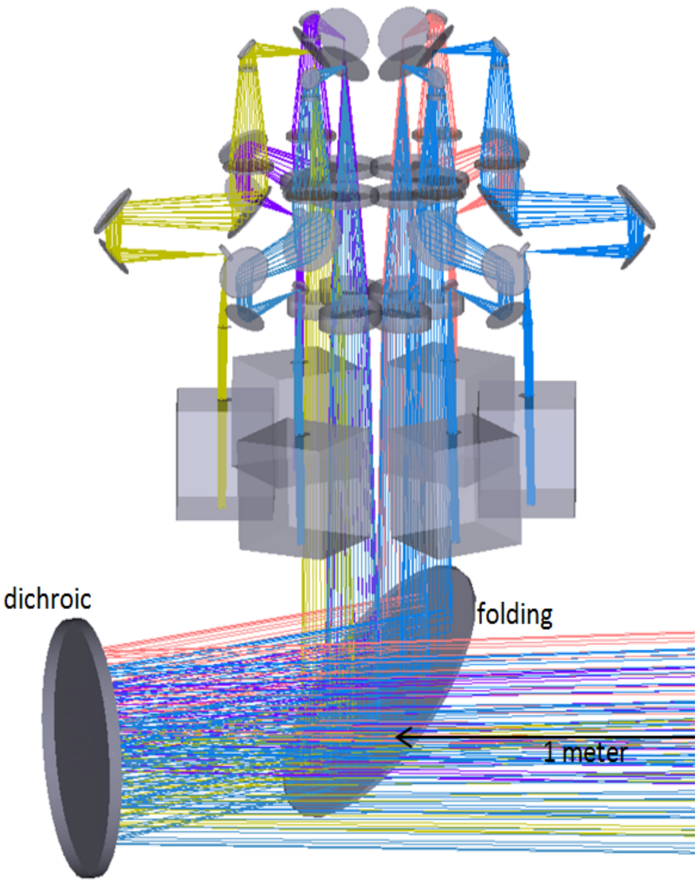
Down to 80nm

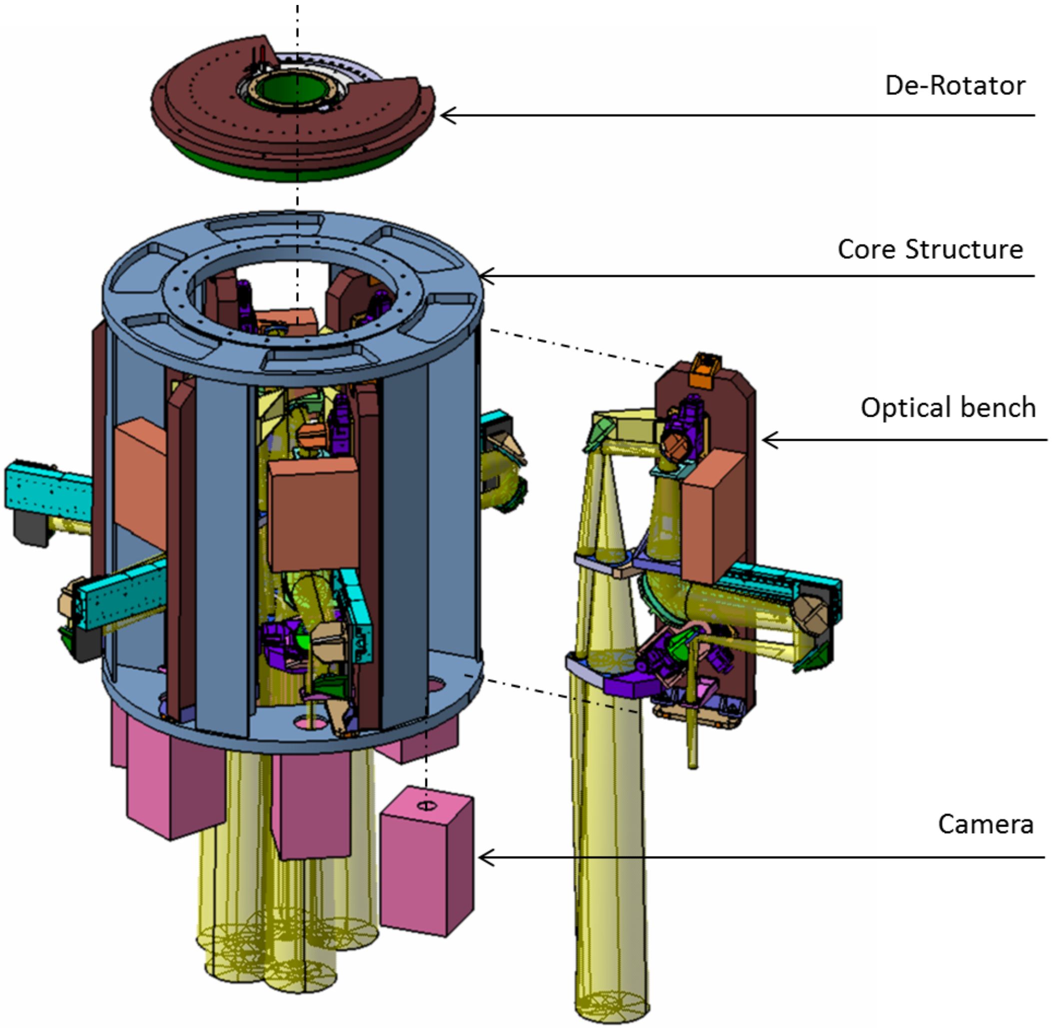


HARMONI, SCAO & LTAO implementation



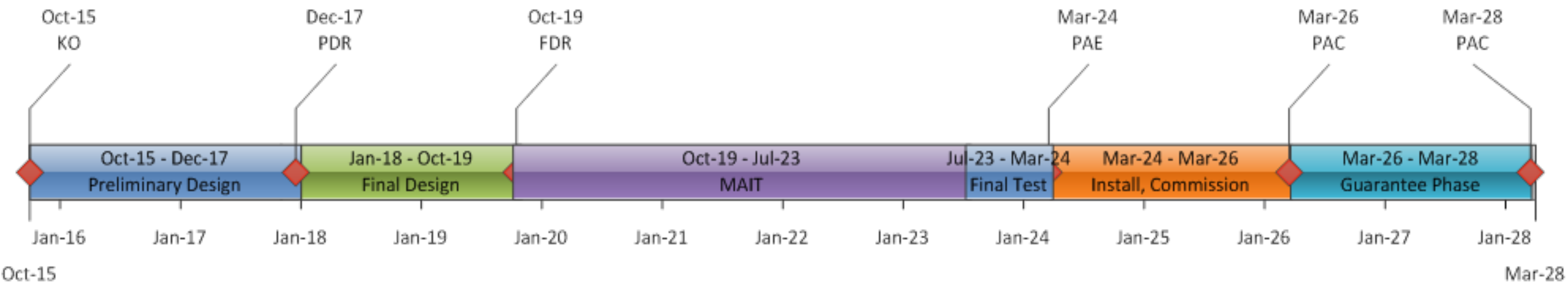
LGSWFS



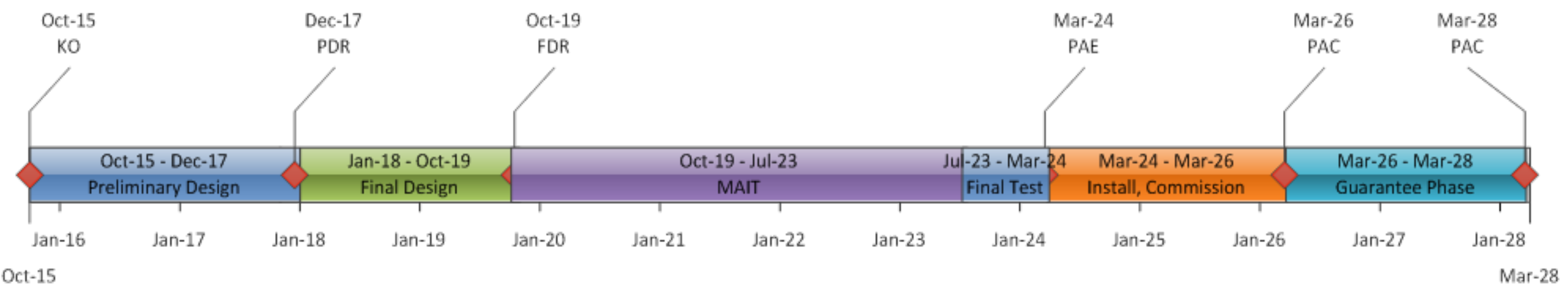


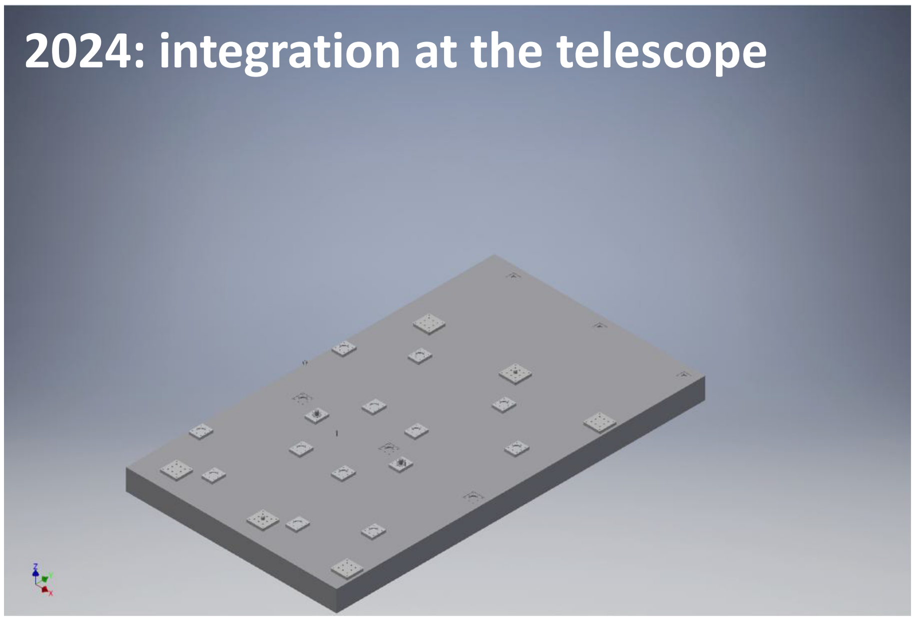
Ask P. Vola, S. Pascal, K. Dohlen for more details on the opto-mechanical design !

Conclusion: HARMONI schedule



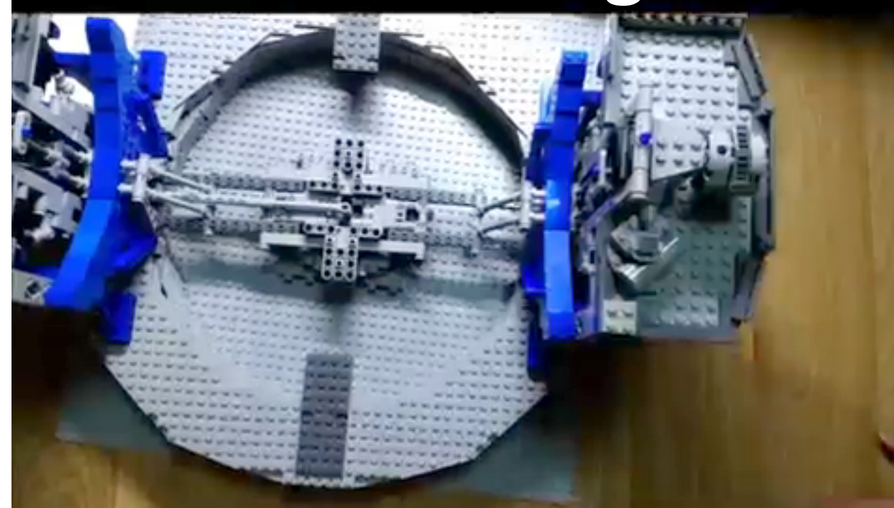
Conclusion: HARMONI schedule





HARMONI

2024: 1st light !



Dr. Frans Snik

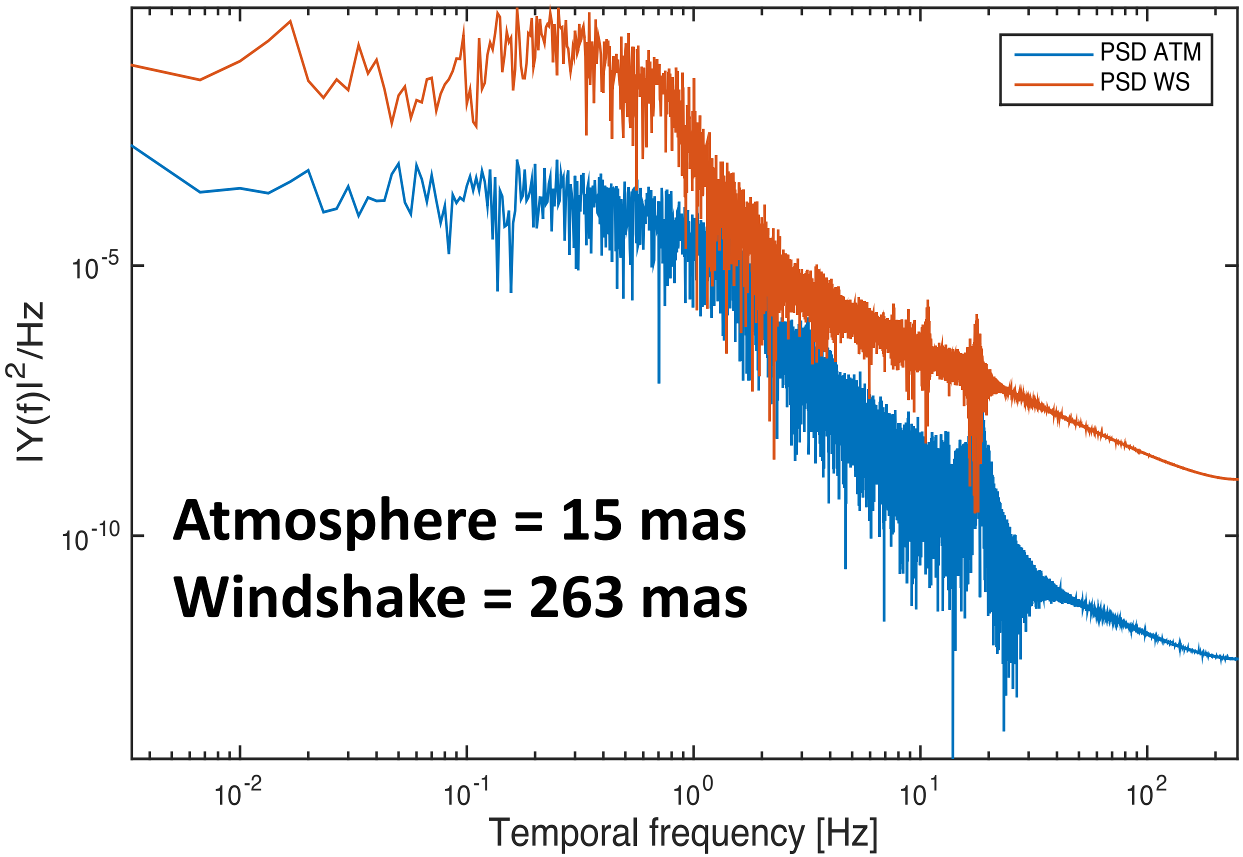
Thanks to:

Thierry Fusco, Carlos Correia, Kjetil Dohlen, Leonardo Blanco, Kacem El Hadi, Jean-François Sauvage, Noah Schwartz, Yoshito Ono, Emmanuel Hugot, Jean-Luc Gach, Pascal Vola, Sandrine Pascal, Marc Llored, Olivier Martin, Arthur Vigan, Benoit Epinat, Alexis Carlotti, Céline Péroux, David Le Mignant, Olivier Groussin, Anne Costille, Florence Roman, Cyril Petit

Extra-Slides

Sensing on NGS

Main offender is the telescope Windshake



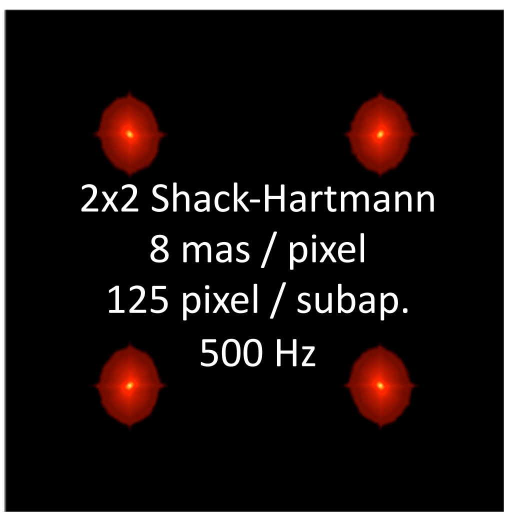
But windshake is isoplanatic: we can use the telescope WFS to reduce it

Sensing on NGS

Jitter control strategy:

- Use "bright but far" stars to compensate windshake with telescope WFS
- Use "faint but close" star to compensate atmospheric jitter

1.2 to 2.2 microns



Sensing on NGS

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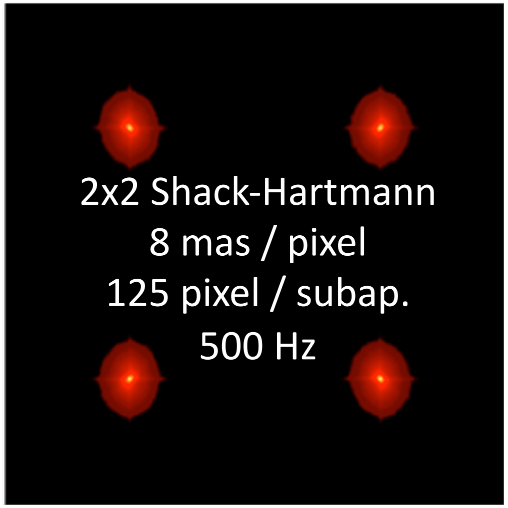
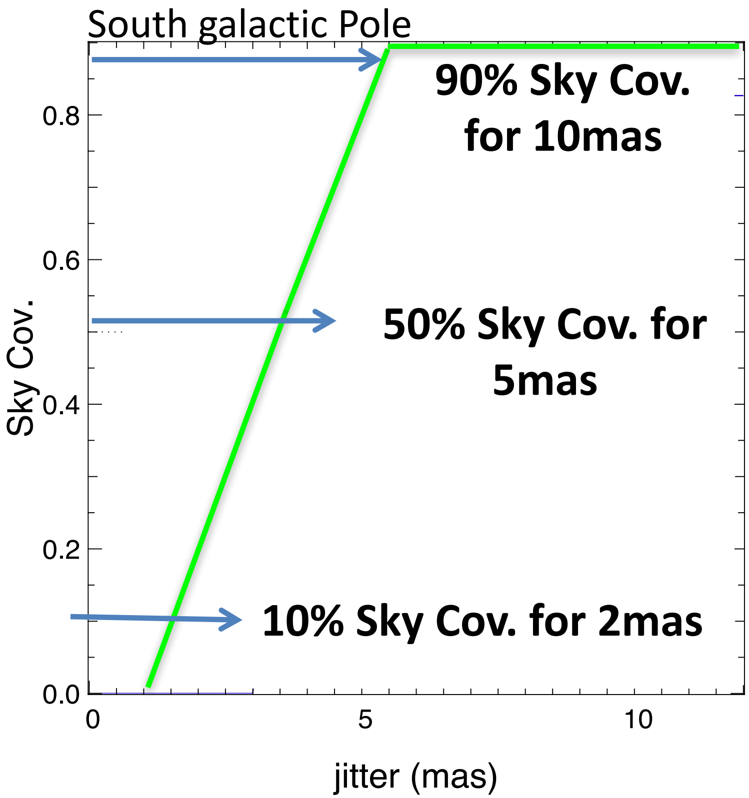
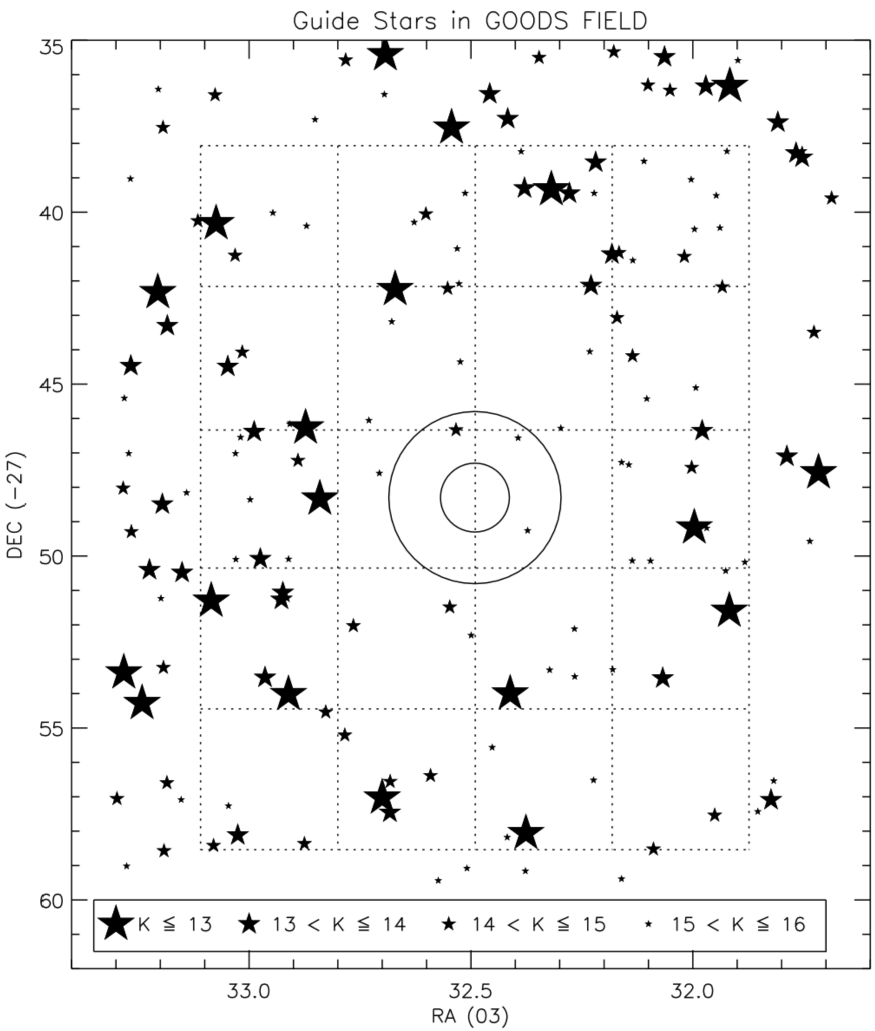
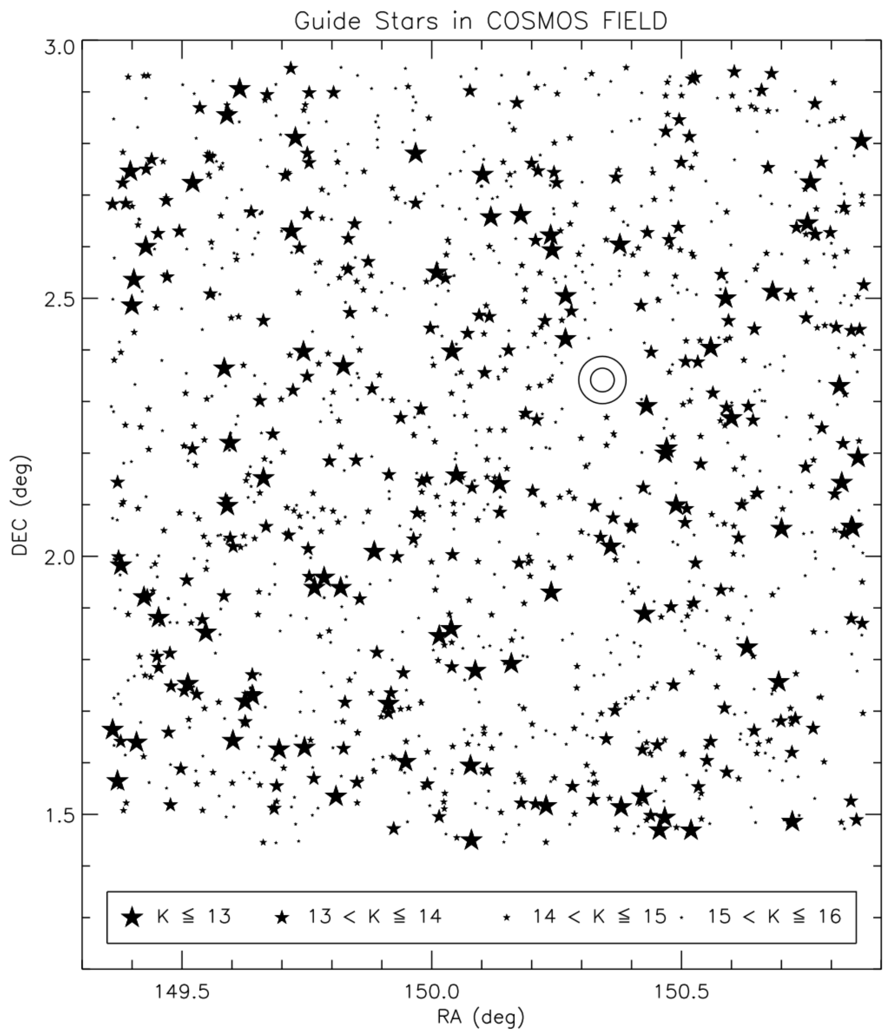




See Carlos Correia poster on Thursday

Sensing on NGS





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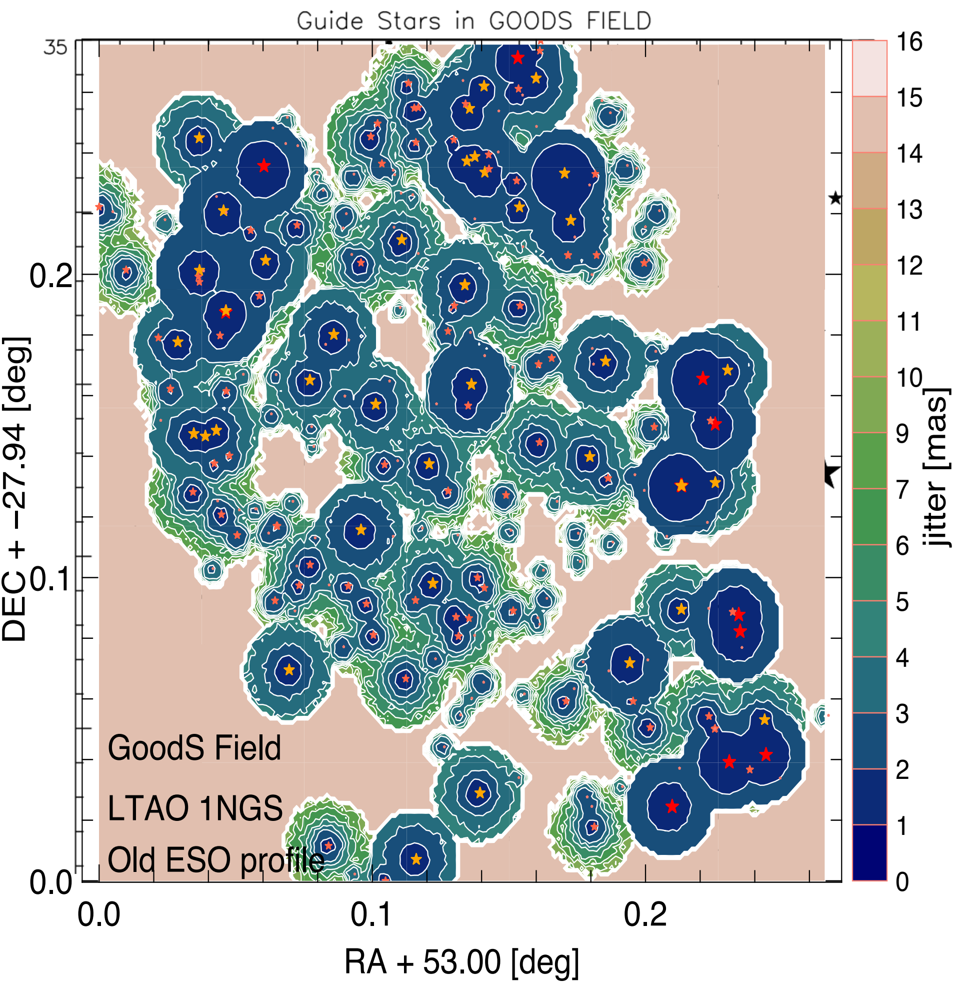
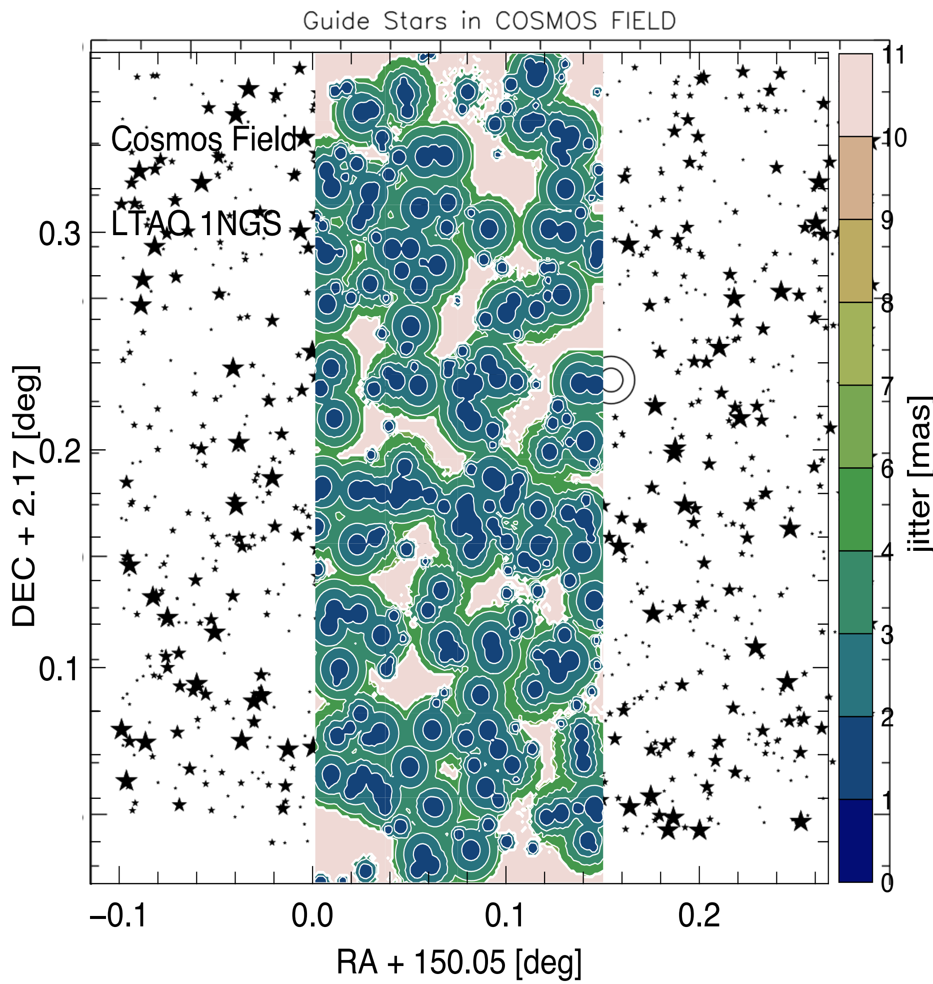
Sensing on NGS





The NGS strategy fulfills the science requirements for all observations