MAVIS : *M*cao *A*ssisted *V*isible *I*mager and *S*pectrograph

a MCAO module for the VLT-AOF:
Toward wide field visible observations

Yoann Brûlé - LAM
17th May 2018
LAM R&D Seminar

Overview

- What is MAVIS ?
  - Multi-Conjugate Adaptive Optics ?
  - Why go to the visible ?
  - Is visible/MCAO do-able ?
- MCAO simulations @ LAM
  - Fourier / E2E
  - E2E MCAO code (OOMAO)
    - Principle
    - Validation
  - MAVIS dimensioning
- Prospects

What is MAVIS?

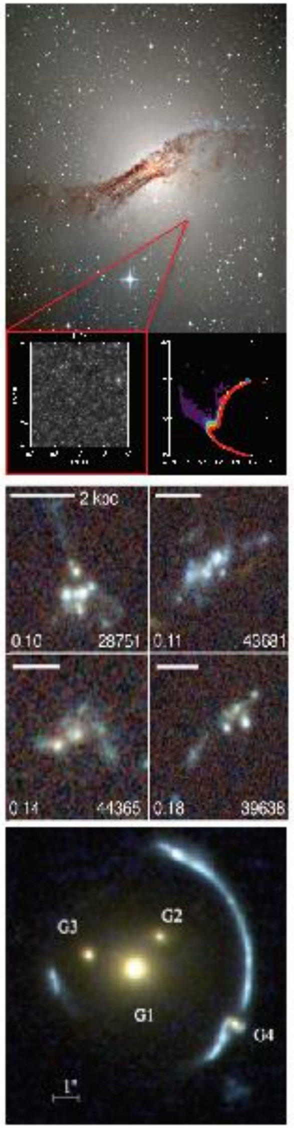
MAVIS (MCAO-Assisted Visible Imager & Spectrograph) is a proposed instrument for ESO's VLT Adaptive Optics Facility that will provide near-diffraction limited image quality over a large field of view using Multi-Conjugate Adaptive Optics. MAVIS is an Australian-European project.
More information at http://mavis-ao.org/mavis.

Science with MAVIS

- Star formation histories of the local volume through resolved stellar populations
- Local group internal dynamics via proper motions and crowded field spectroscopy
- Resolving star formation clumps to high redshift
- Dark matter substructure via lensing
- Monitoring solar system bodies

Strawman MAVIS Requirements

Field of view	30"x30"
Angular resolution	FWHM ~ 20mas at V band
Wavelength coverage	VRI, extended to UBz
Strehl ratio	15% at V under median seeing conditions
Sky coverage	> 50% at Galactic Poles
Imager	~ 7mas pixel size. Broad and narrow band filters. Tuneable filters - to be explored
Spectrograph	Fibre + Starbug concepts to be explored: Highly multiplexed point-source capabilities Multiplexed compact IFUs (0.5" FoV) and larger FoV IFUs. R=5,000-10,000. Alternatively, 3"x3" image slicer IFU with 25mas spaxels.



CONSORTIUM

R. Ragazzoni

Software
Opto-mechanics

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V. Viotto
D. Magrin

S. Esposito

M. Bonaglia
L. Busoni
G. Agapito

AO system engineering
Opto-mechanics
NGS WFS

C. Jenkins

Australian National University

R. McDermid

Macquarie

Management
LGS WFS
RTC

F. Rigaut

T. Fusco

Simulations
Post-processing
AO Control

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

ONERA THE FRENCH AEROSPACE LAB

B. Neichel
C. Correia

AAO

Post-focal instrumentation

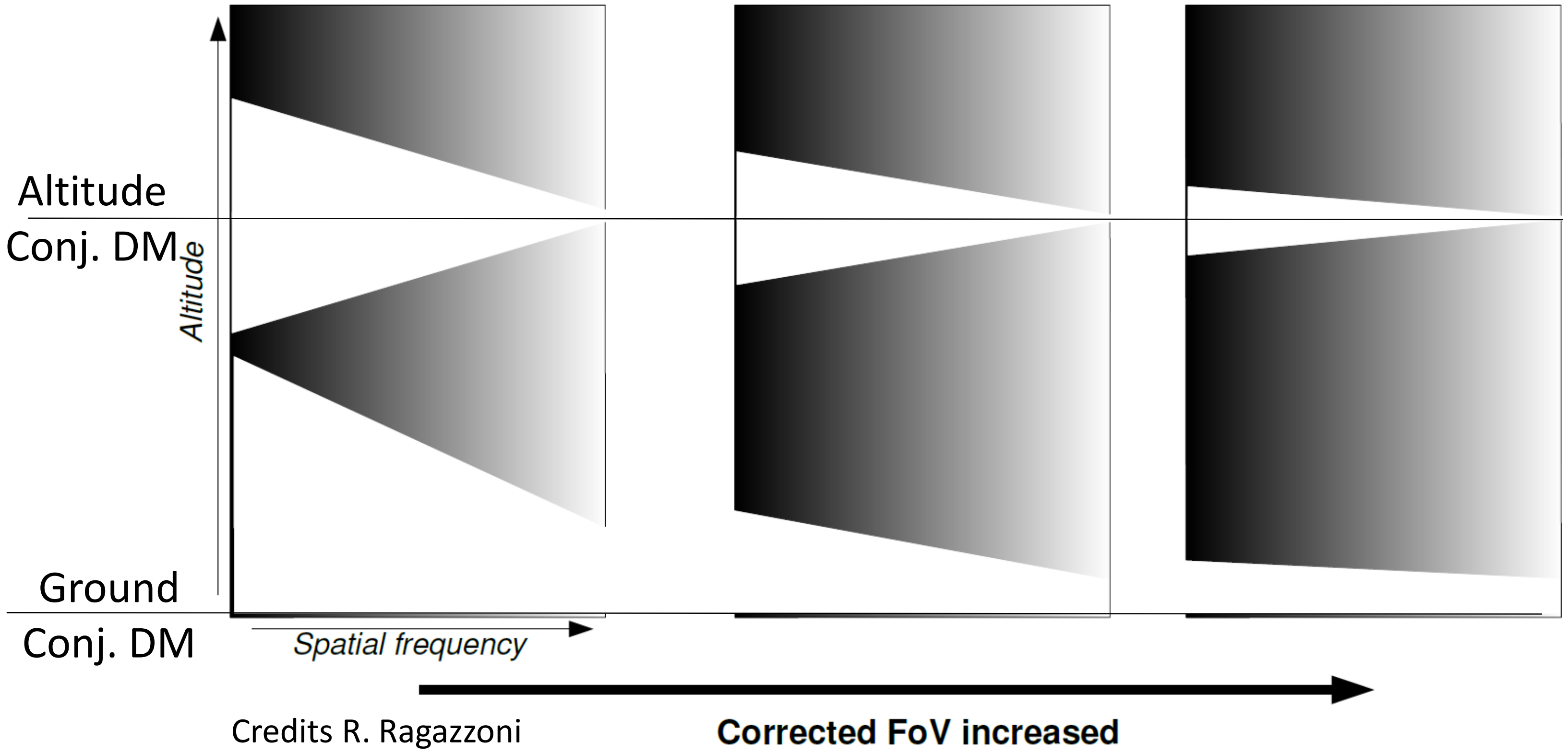
J. Lawrence

S. Ellis

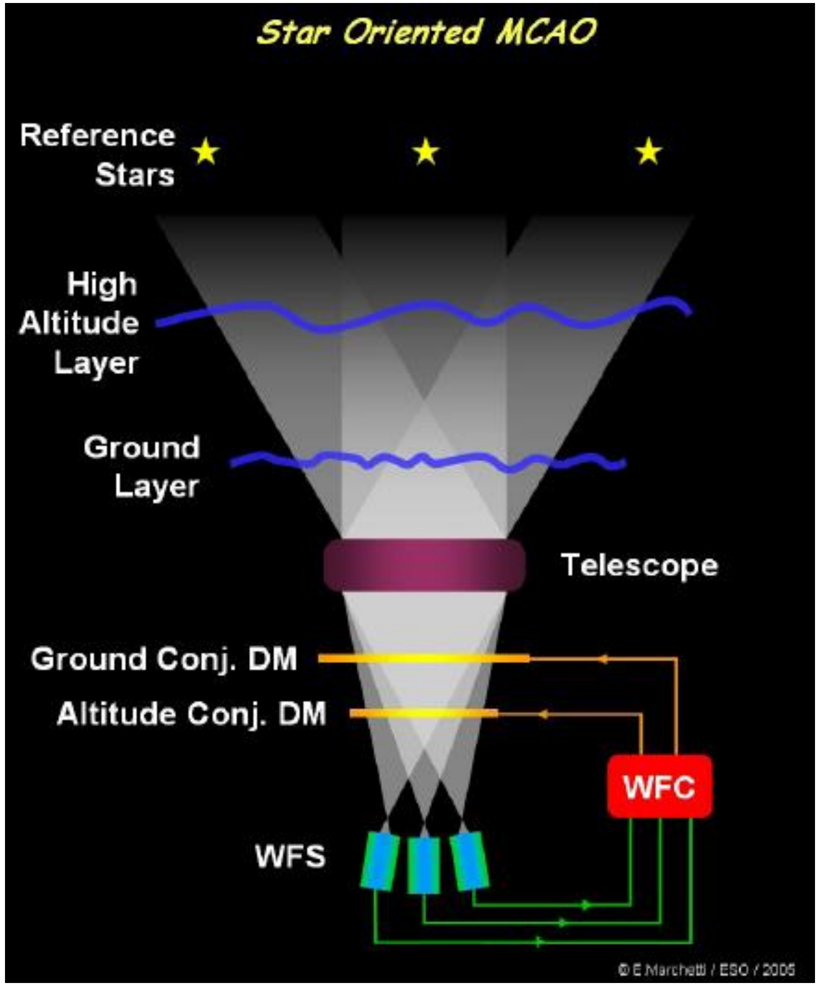
http://mavis-ao.org/mavis

Multi-Conjugate Adaptive Optics (MCAO)

- Several DMs conjugated at different altitudes
- Increased the corrected field of view beyond limitations of natural angular anisoplanatism



Credits R. Ragazzoni



Credits E. Marchetti

Why go to the visible ?

- Science and physical arguments compared to NIR
  - Sky background is much smaller (1000 to 10000 darker than K)
  - Most of the action is in the visible (atomic lines) !
  - 500 nm on an 8-m VLT ➔ same angular resolution as 2 µm on an 39-m ELT
  - A lot more …

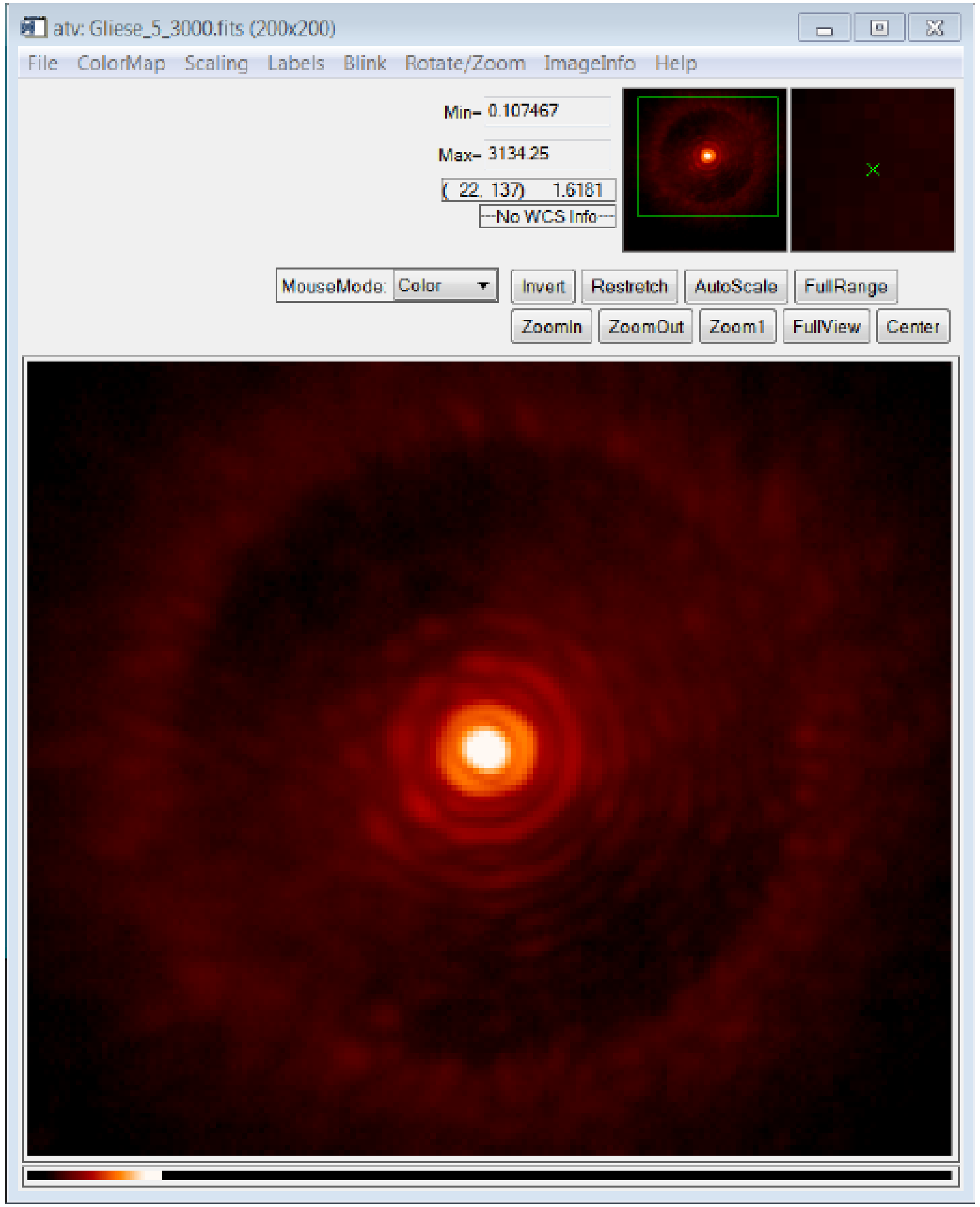
- Technological arguments compared to NIR
  - Large visible detectors are cheap and detector quality is much better
  - Low noise (<1e- RON), large (4kx4k) and fast (10 frames/s) detectors exist

Is VISIBLE do-able ?

- SCAO correction in the visible exists
  - 650 nm images from Forerunner @ LBT
    - 0.8” seeing
    - 50% Strehl ratio !
    - 18 milliarcsec FWHM

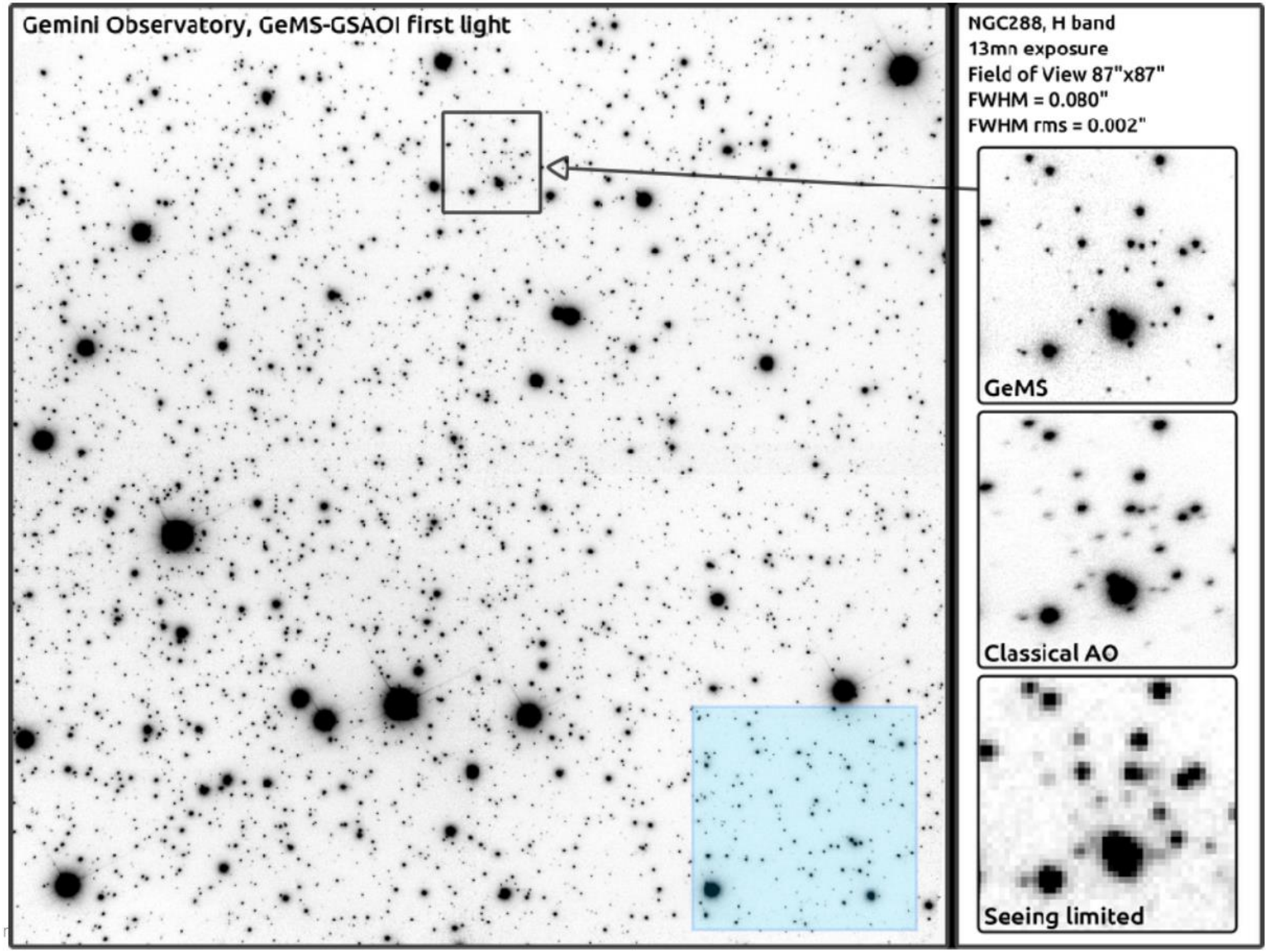
- There are similar images from SPHERE @ VLT (95% Strehl @ K-band → 37% @ V band)

YES



Is MCAO do-able ? YES

MCAO in the NIR : GEMS @GEMINI

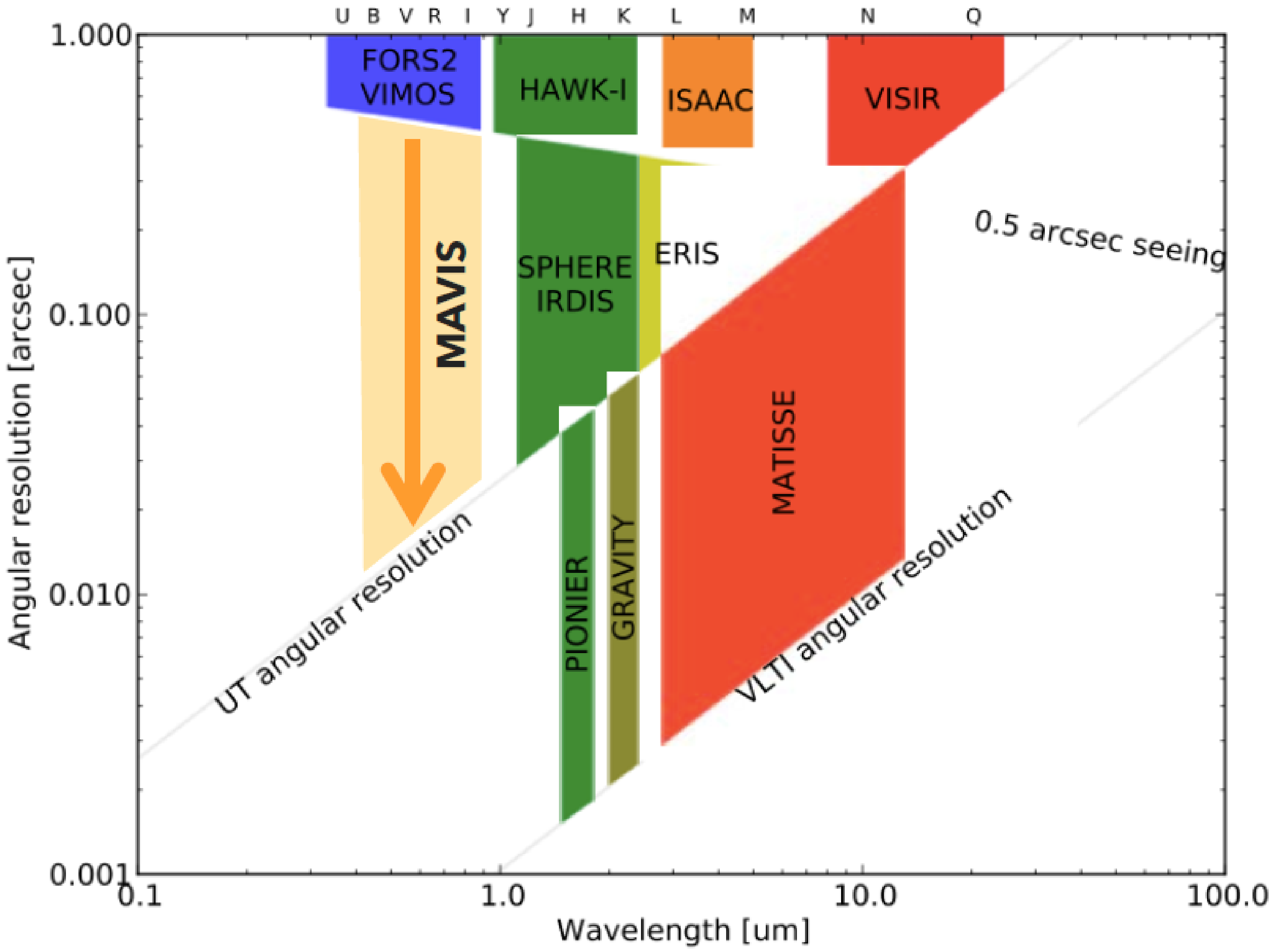


VISIBLE + MCAO

≈

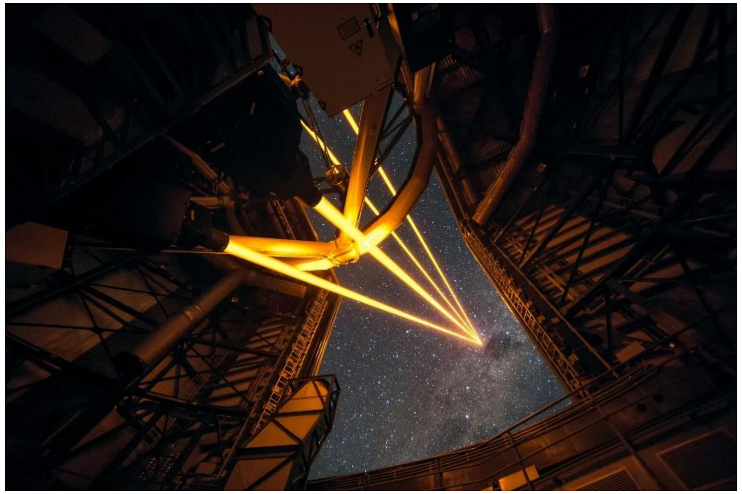
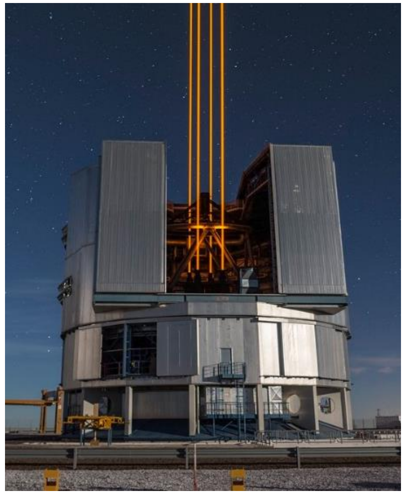
DO-ABLE

Filling a resolution gap of current VLT/I instrumentation



The AOF (VLT-UT4)

- The existing facilites :
  - A Deformable Secondary Mirror (DSM) with 1170 actuators conjugated to the ground (≈20 cm actuator pitch projected on M1)
  - Four 20W Laser Guide Stars associated to 4 SH WFS 40x40 for GLAO

  - Appropriate to push correction to the visible wavelength
- What would be missing for MAVIS ?
  - 2/3 post focal DMs
  - 3 NGS SH WFSs with low RON infrared detectors for Tip/Tilt Anisoplanatism
  - *1/2 LGS + 1/2 SH WFS 40x40 with low RON detector ?*

MCAO simulations

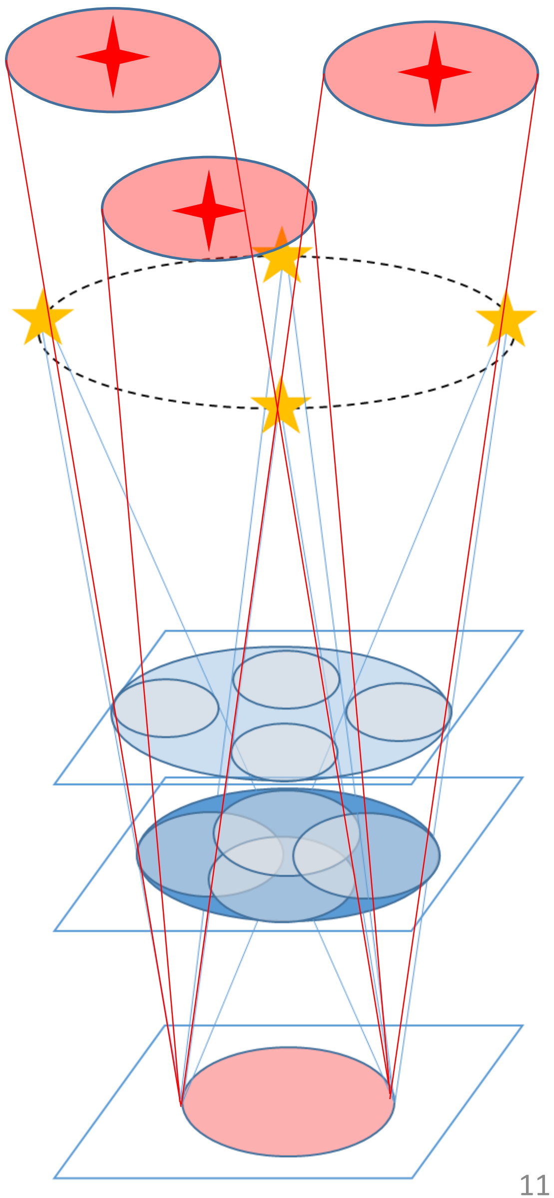
- Fourier simulations (T. Fusco)
  - Independant realisation of phase screens in the Fourier space
    ➔ white noise colored by the spectrum of the turbulence
  - Each operator (propagation/measure/tomography/correction) acts as linear spatial filter
  - Difficulties to deal with edge effects (infinite pupil)
  - No conical propagation (no LGS)
  - Fast computation (≈1s)

- E2E simulation with OOMAO

MCAO E2E simulations in a nutshell

- Tomographic reconstruction of the turbulent volume
  - LGS wavefront sensing (does not apply to Tip/Tilt)
    ➔ Reconstruction of the HO zernike modes (>3)
  - NGS wavefront sensing for Tip/Tilt Anisoplanatism (TTA)
    ➔ need for 3 well spread natural stars to be effective

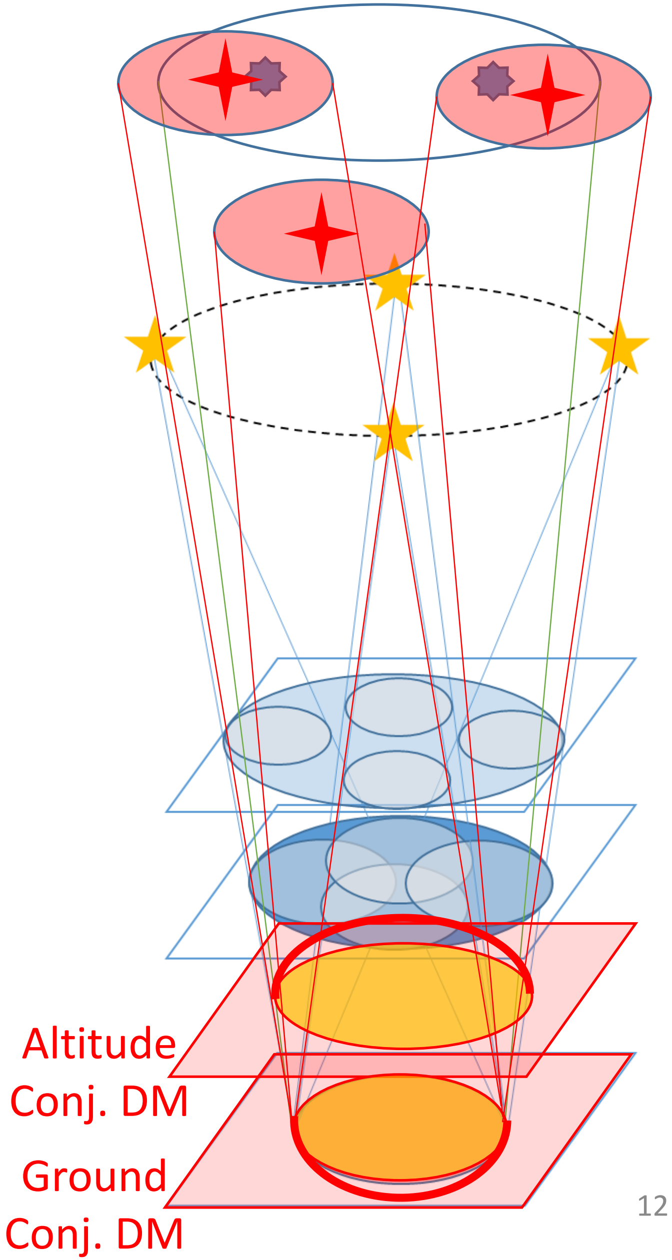
Tomographic error
(number and configuration of LGS and NGS)



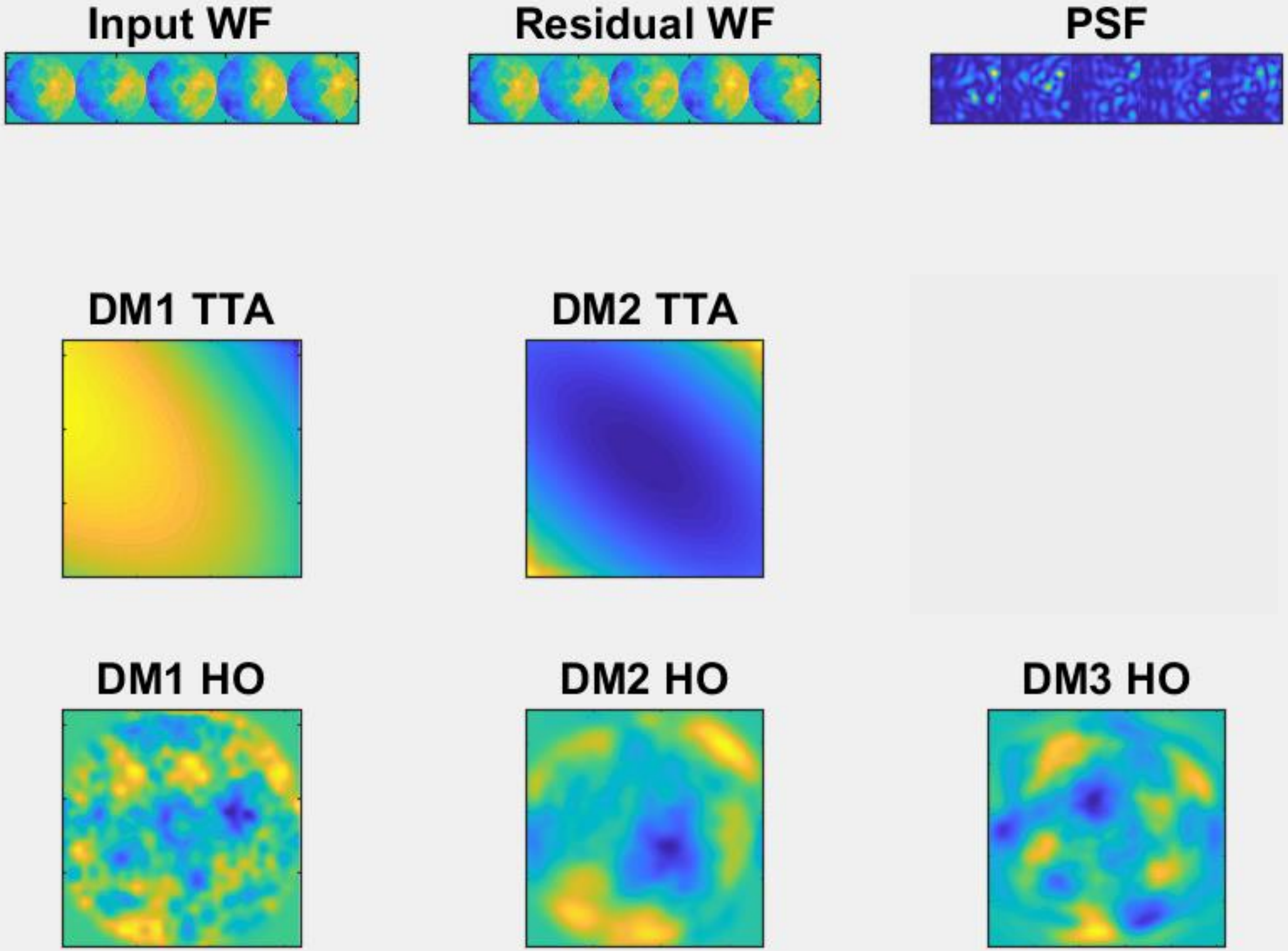
MCAO E2E simulations in a nutshell

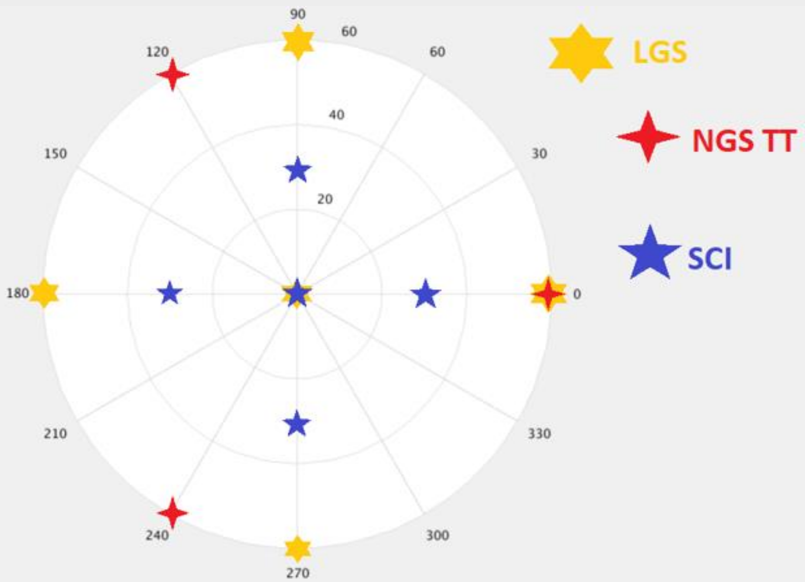
- Projection of the turbulent volume onto the DMs (fitting step) through split tomography
  - HO projections depends on :
    - the number of DMs and their conjugation altitudes
    - the « optimized » FoV/directions of the sky that as to be correct
  - TTA modeled through a 5 quadratic « null modes » space projected on the first two DMs

Generalized fitting errors (number of DMs, pitch, conjugation altitudes)



Example : O AO Implantation





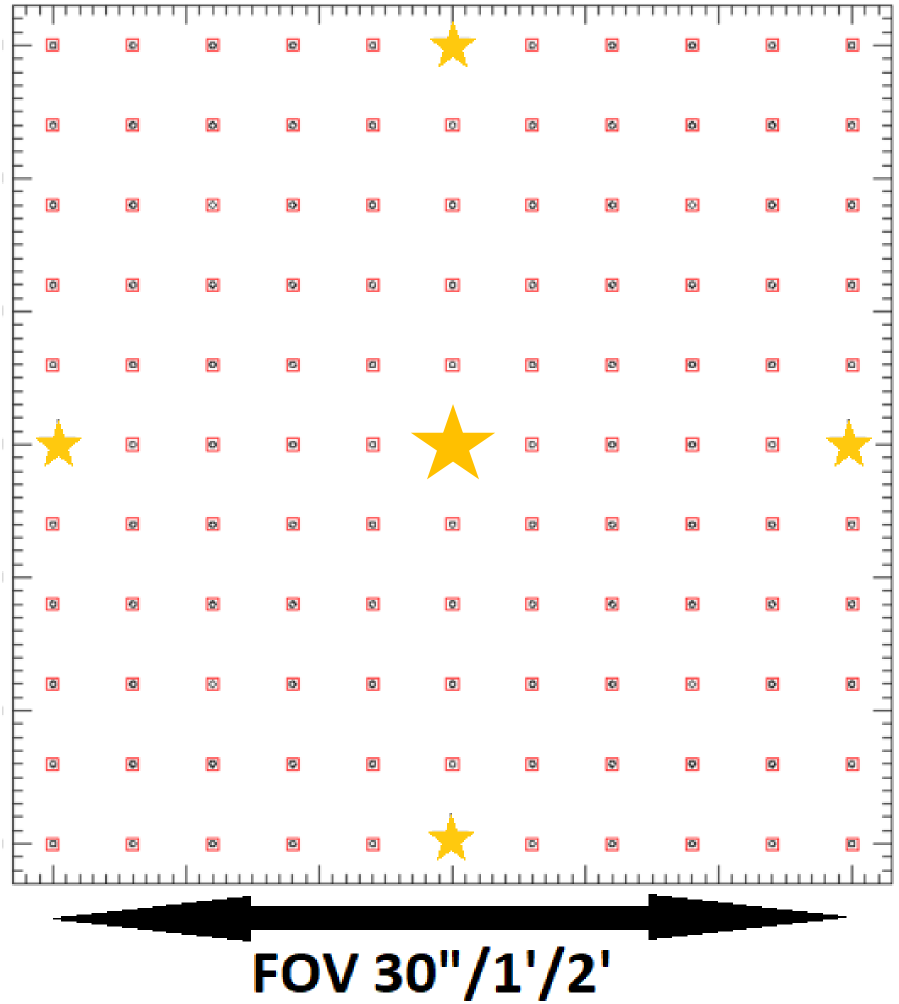
5 LGS:
- 4 LGS asterism @ 60’’ radius
- + 1 centered

3 NGS:
- Asterism @ 60’’ radius

3 DMS:
- @ 0km : DSM 20 cm actuator pitch
- @ 1,3km : 40 cm actuator pitch
- @ 8,5km : 40 cm actuator pitch
- Fitting with a 11x11 optimization grid on a 120’’ square

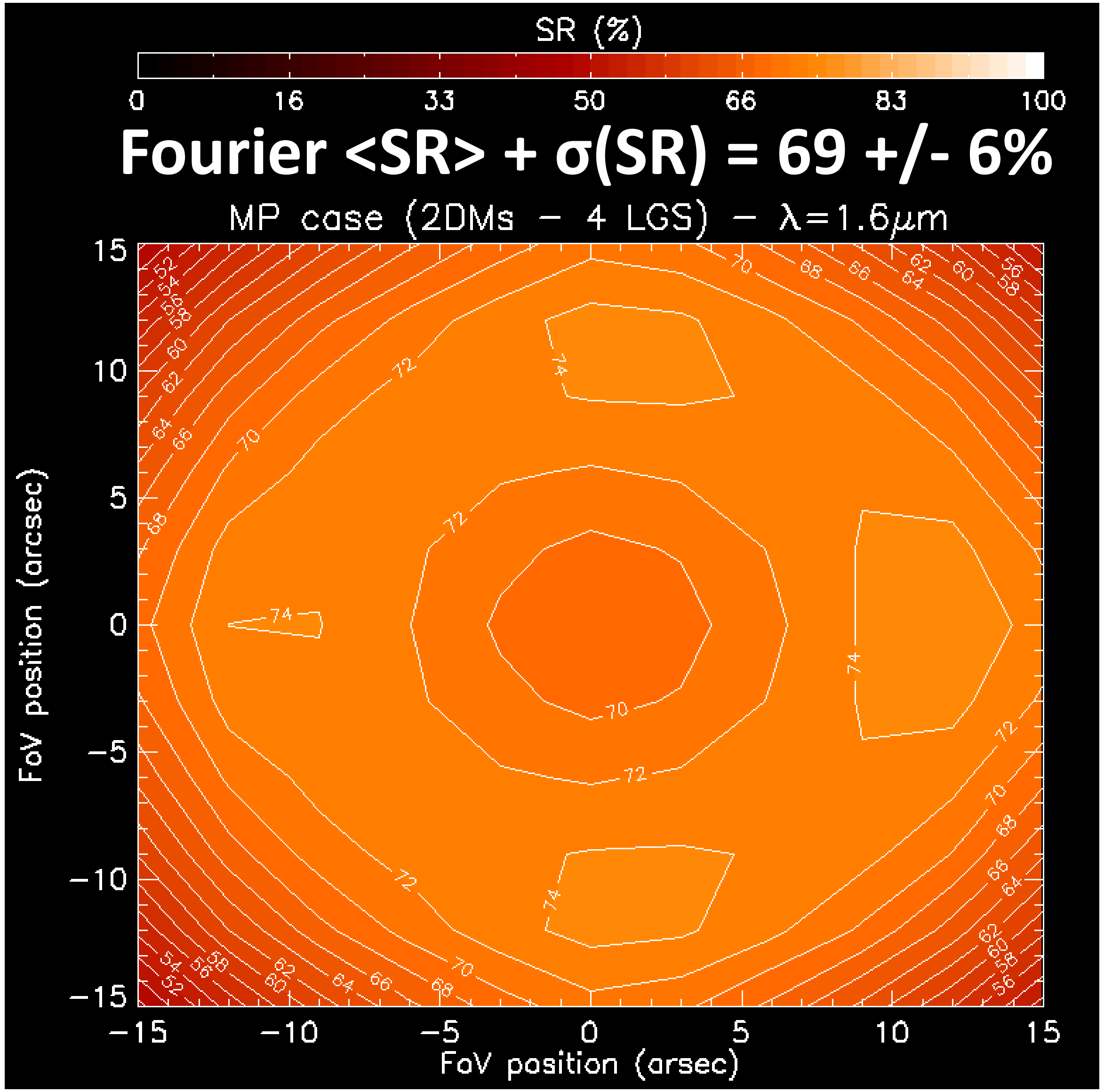
Validation : Fourier versus E2E simulations

- Fourier simulations by T. Fusco
  - Atmosphere:
    - Seeing (at Zenith) 0.8”
    - Zenith angle 30°
    - L_0 25m
    - Cn^2 profile on 10 layers
    - Mean wind speed ≈ 10 $m.s^{-1}$
  - 4 (Baseline) or 5 LGS (Goal)
    - On the edges of the FoV
    - One at the center
  - 2 (Baseline) or 3 (Goal) DMs:
    - 0km, 25 cm pitch / 8km, 40 cm pitch
    - 0km, 25 cm pitch / 1.3km, 40cm pitch / 8.5km, 40 cm pitch
- E2E simulations
  - 1 kHz pseudo open-loop simulation of 2s
  - Full tomography on LGS (no TTA)
    - Point spot @ 90 km, conical propagation
    - 32x32 SH WFS with 10x10 pixels/s.a. with no noise detector
- Output :
  - Strehl map on the FoV in H band

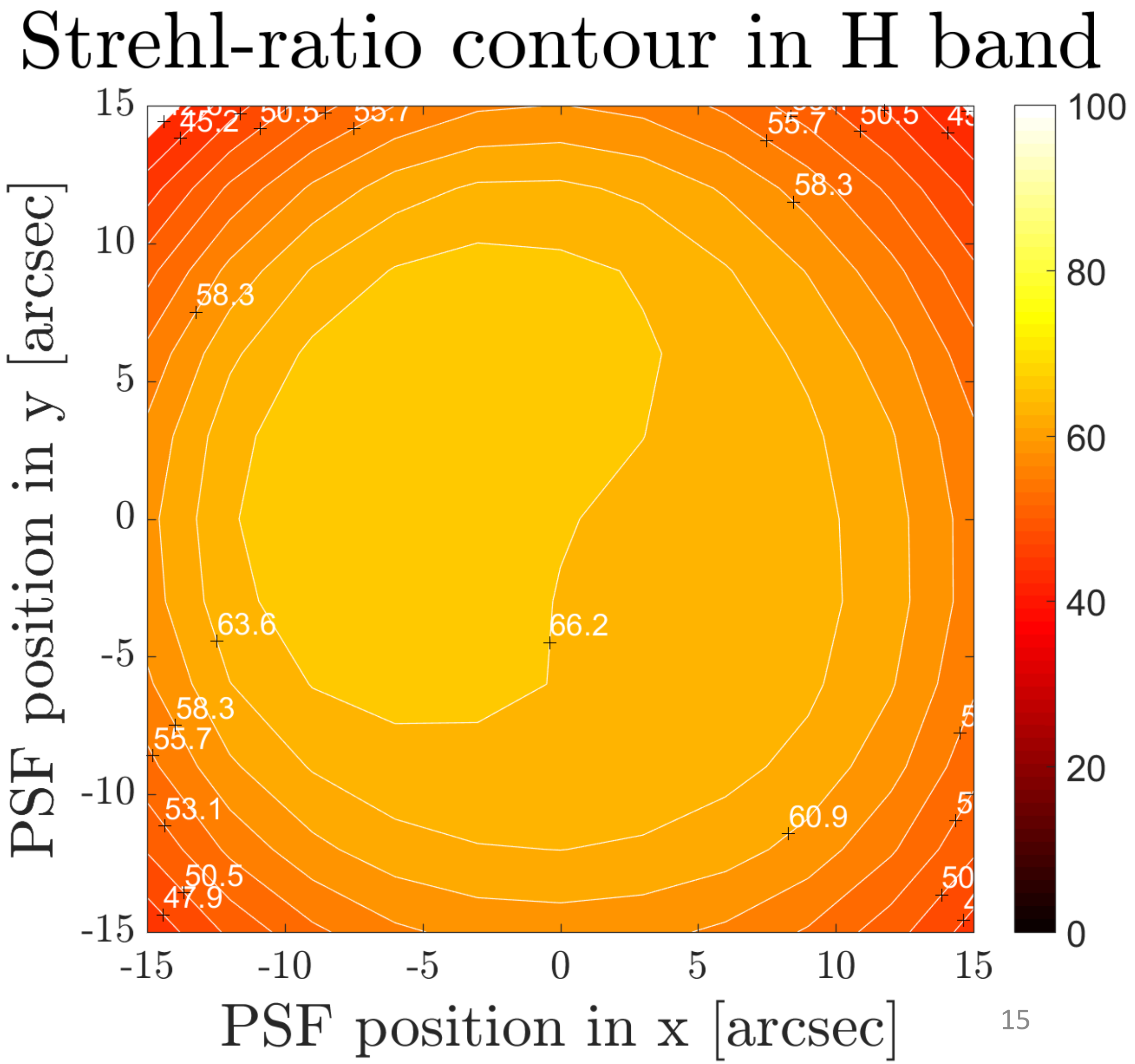


Baseline configuration 2 DMs / 4 LGS / FoV 30''

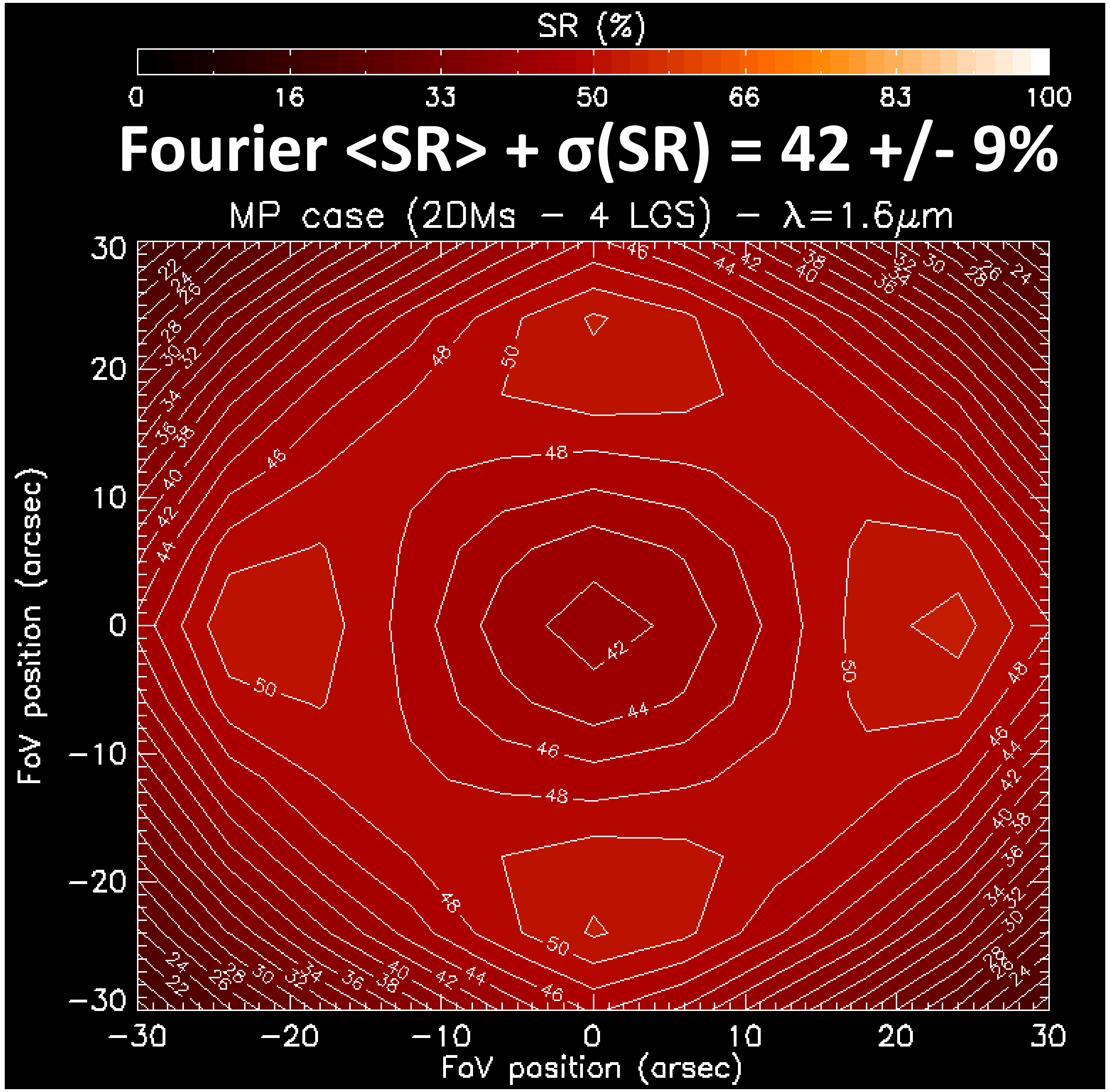
Fourier <SR> + σ(SR) = 69 +/- 6%



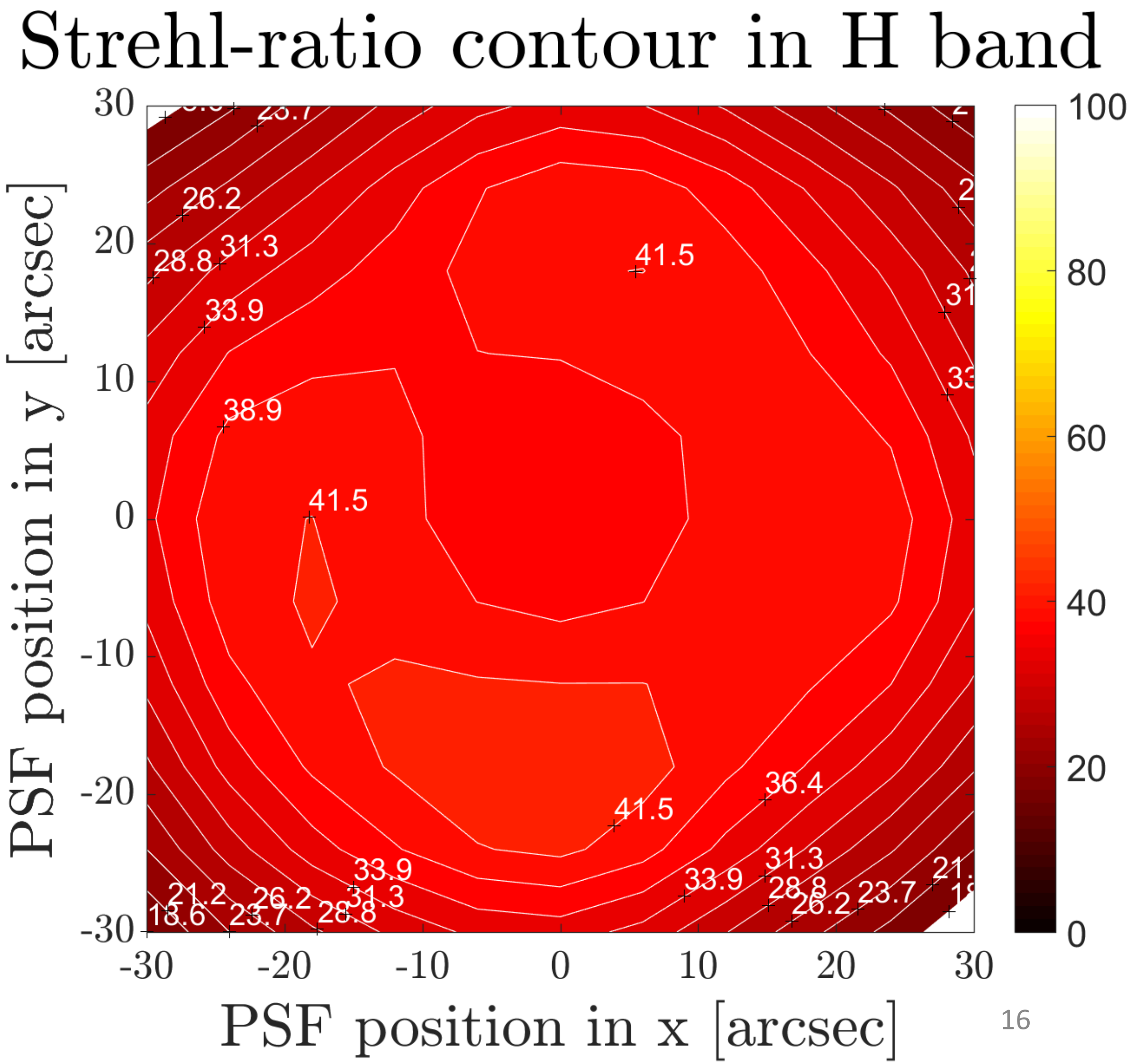
E2E <SR> + σ(SR) = 61 +/- 6%



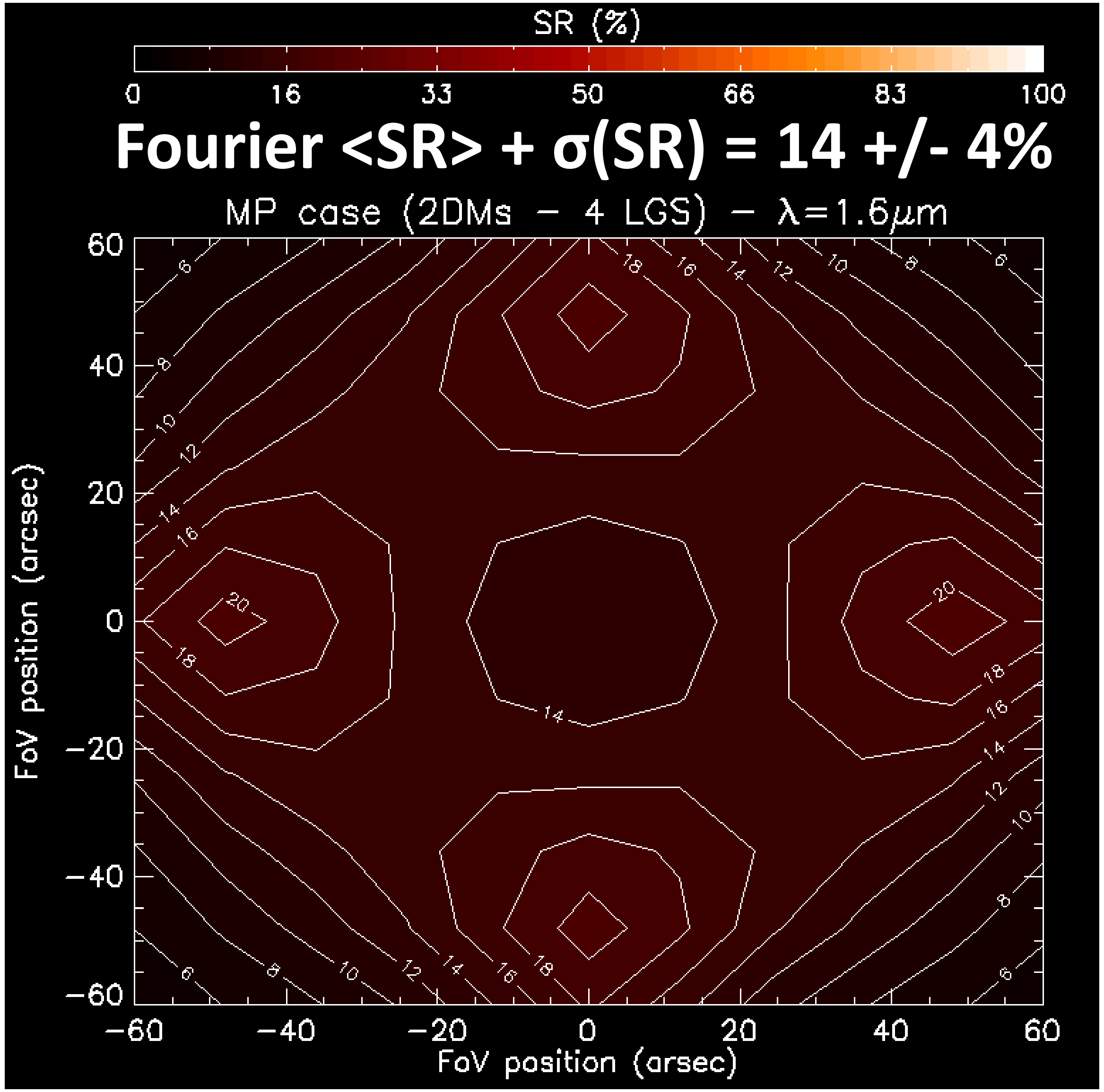
Baseline configuration 2 DMs / 4 LGS / FoV 60''



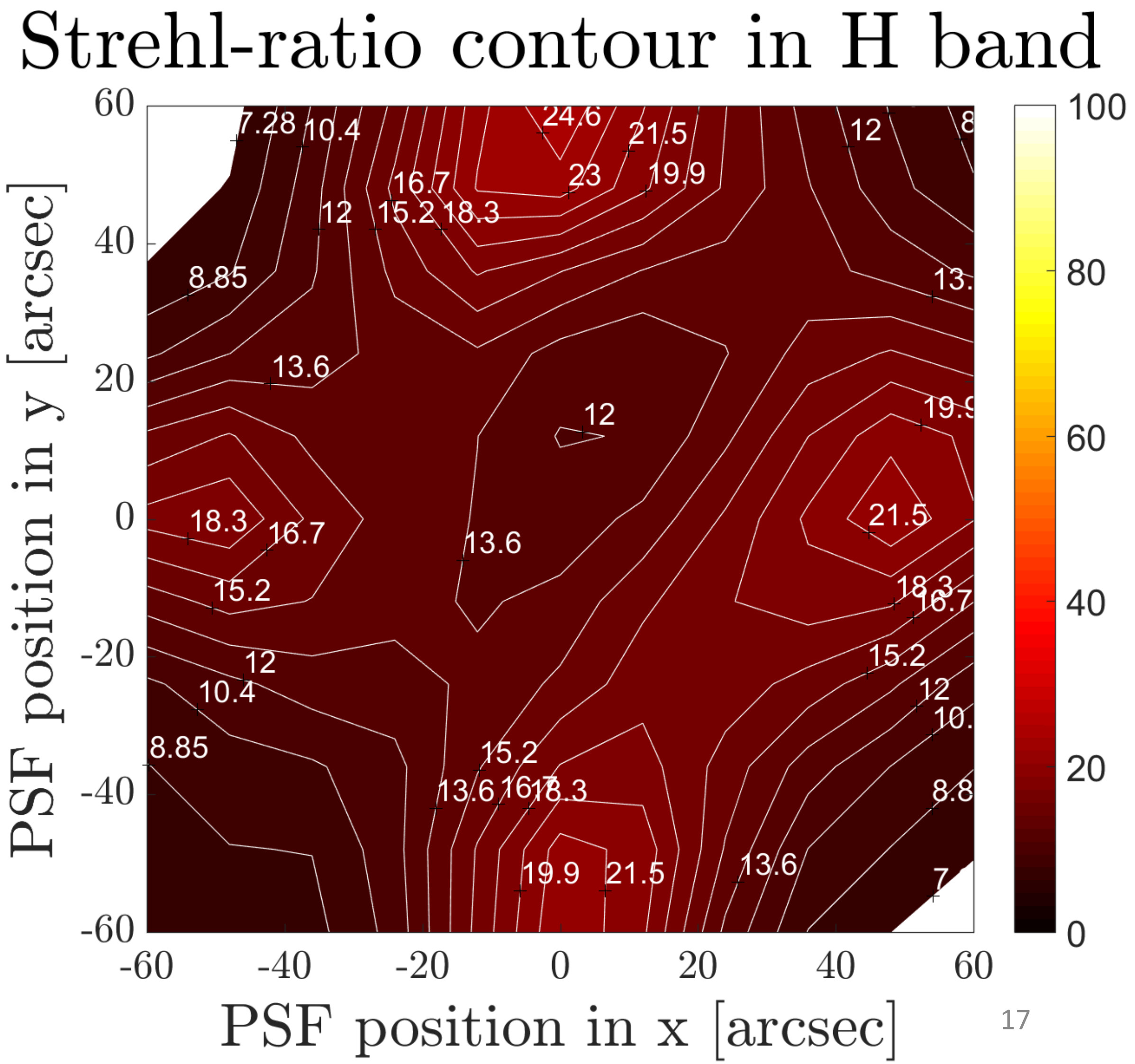
E2E <SR> + σ(SR) = 35 +/- 7%



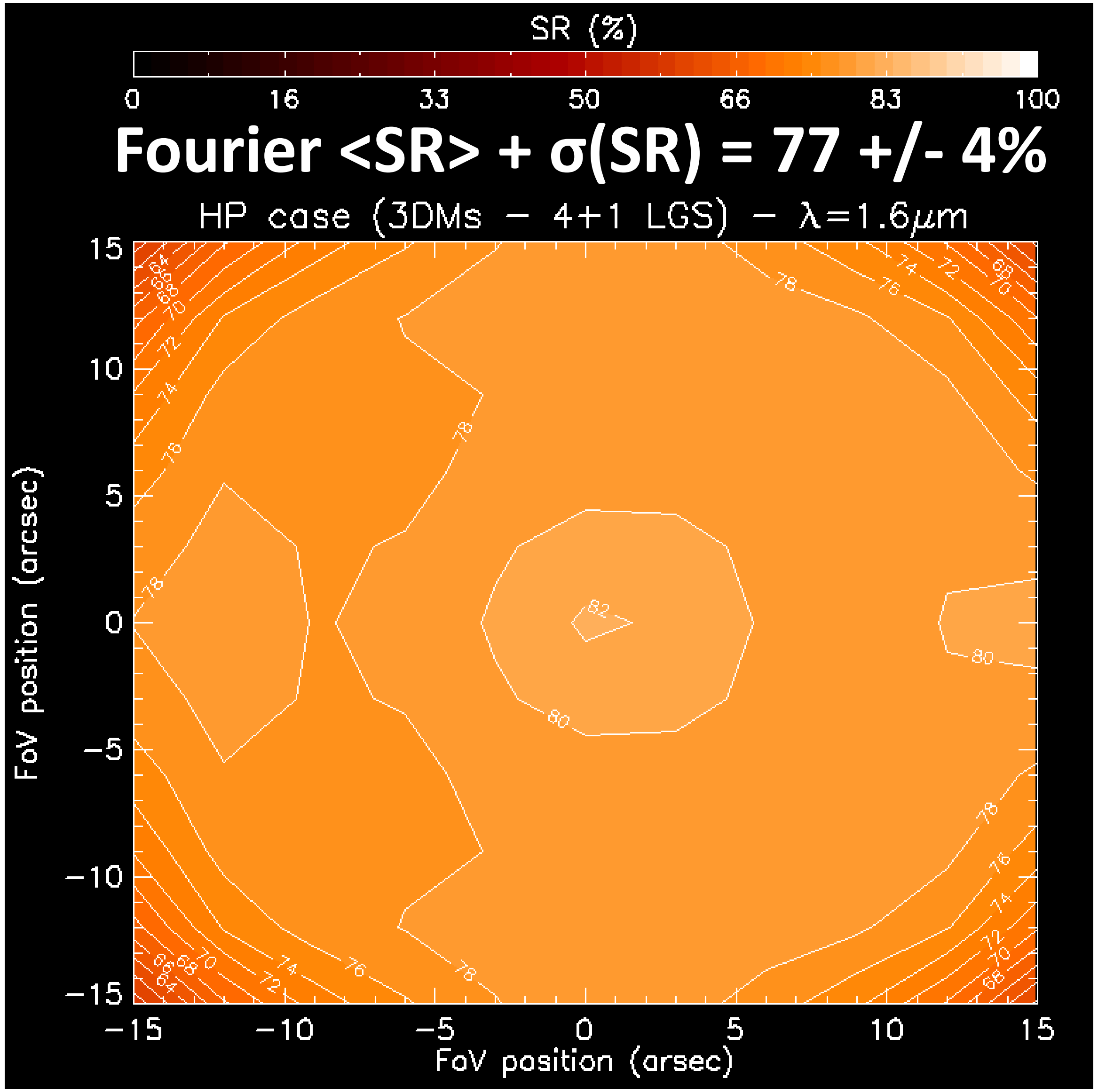
Baseline configuration 2 DMs / 4 LGS / FoV 120’’



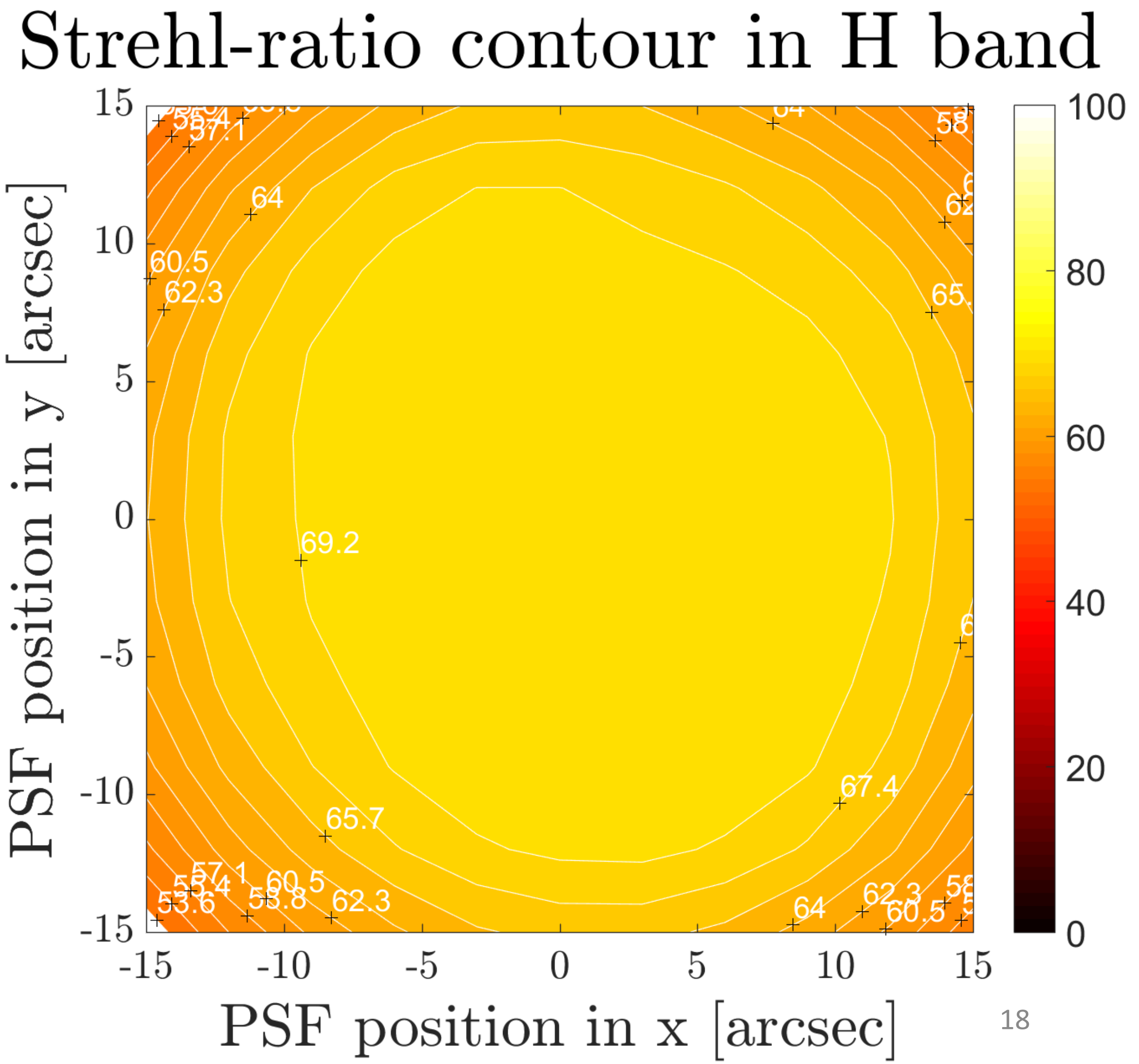
E2E <SR> + σ(SR) = 14 +/- 4%



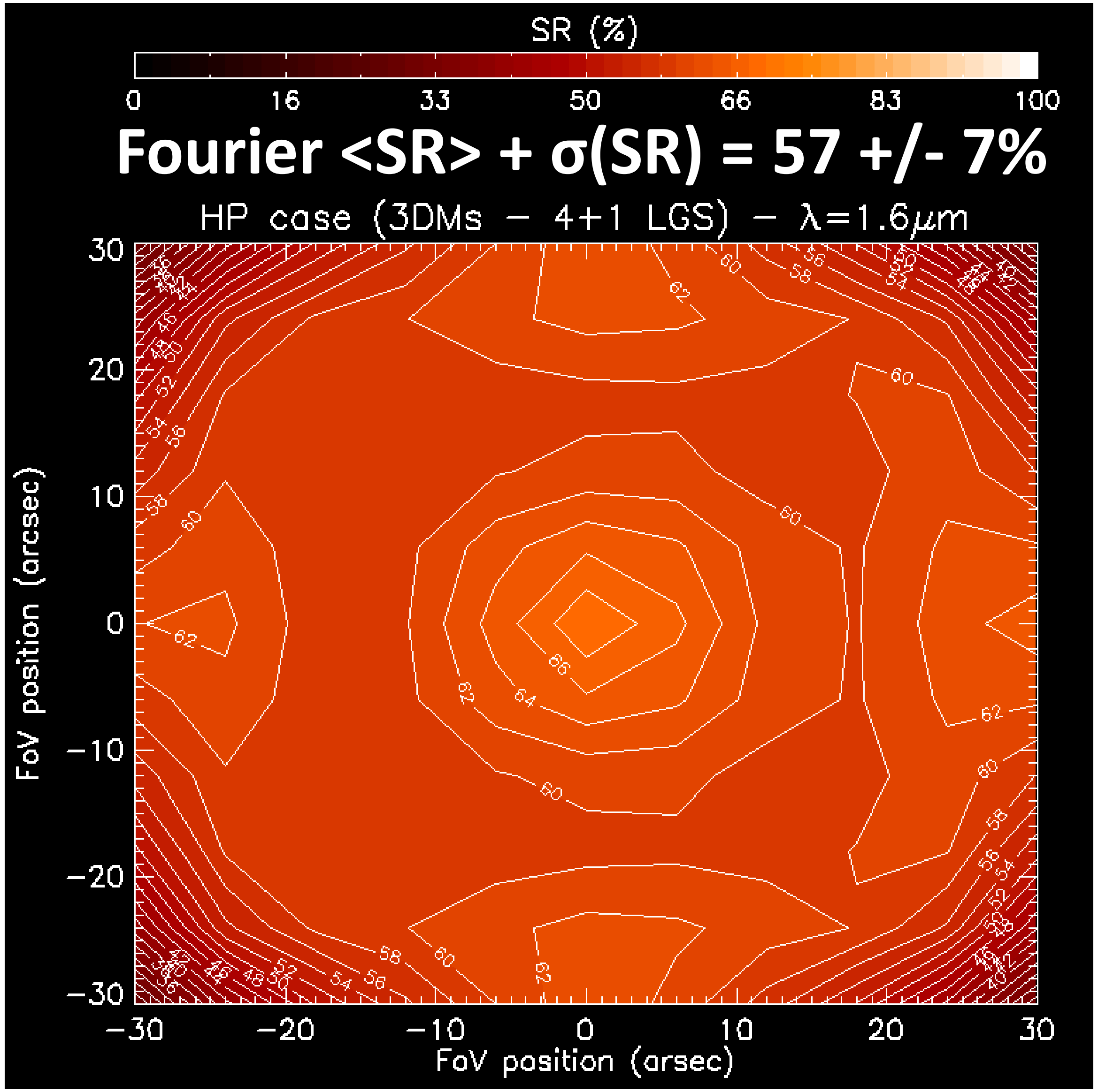
Goal configuration 3 DMs / 5 LGS / FoV 30’’



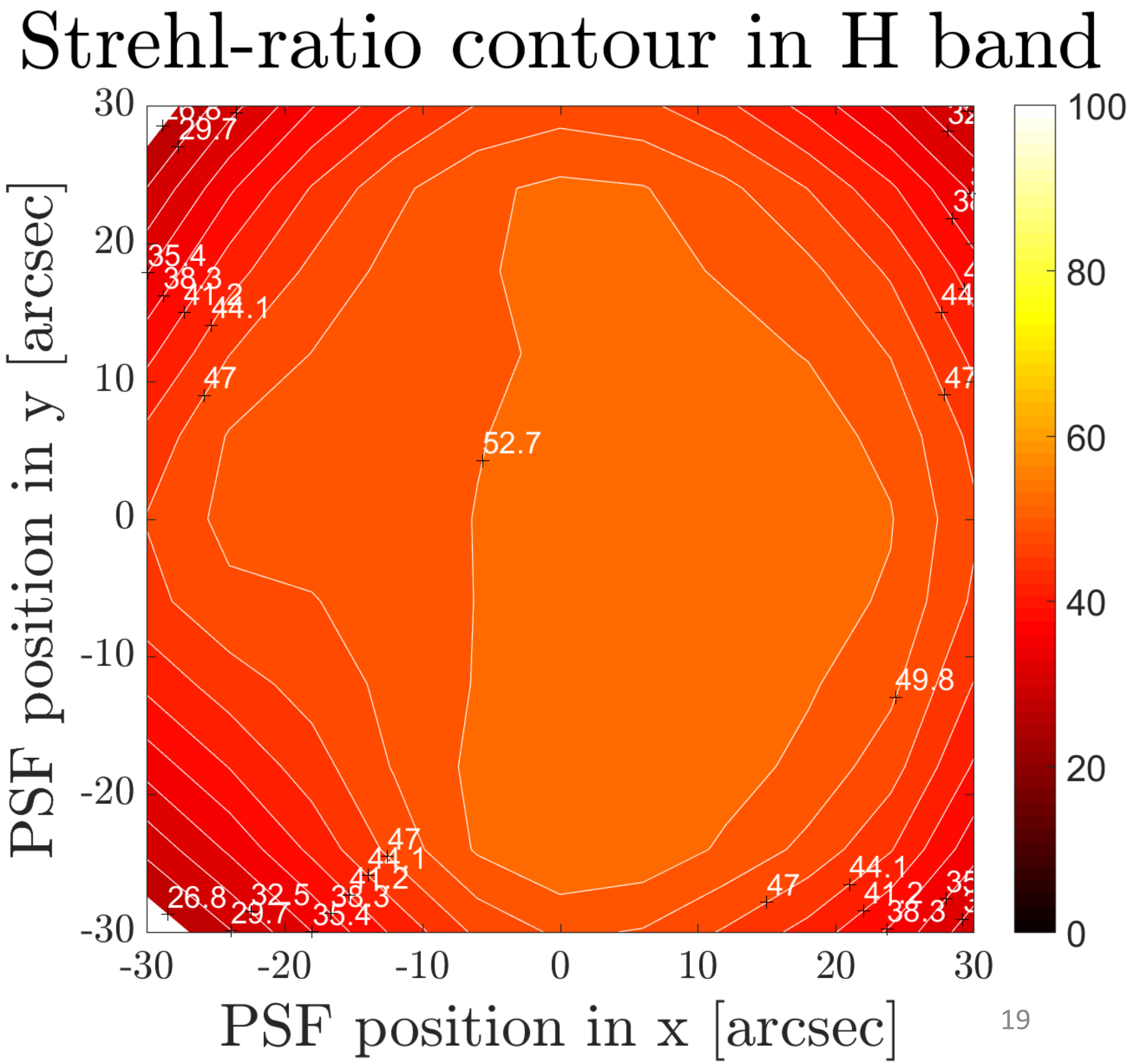
E2E <SR> + σ(SR) = 66 +/- 4%



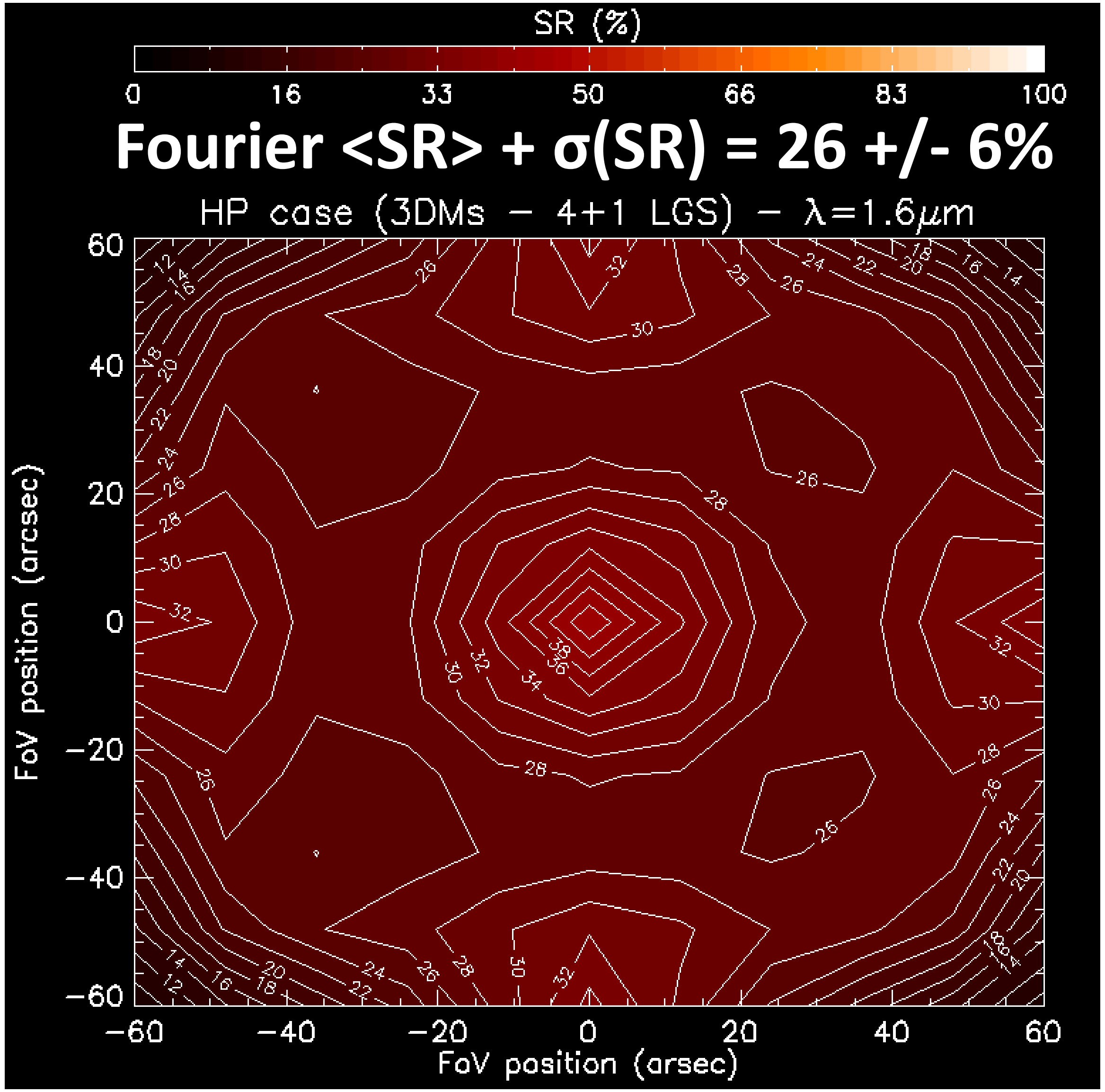
Goal configuration 3 DMs / 5 LGS / FoV 60’’



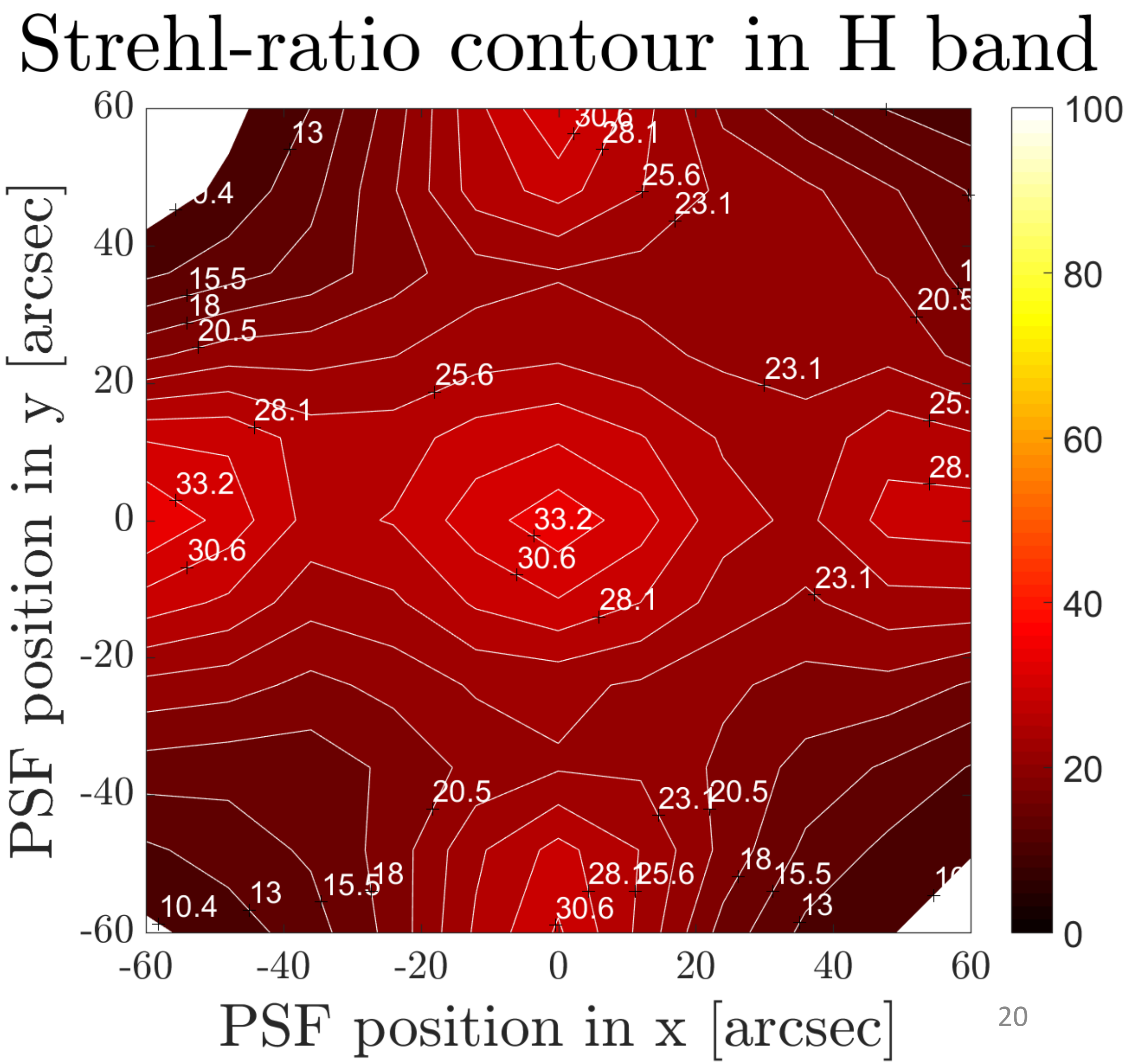
E2E <SR> + σ(SR) = 47 +/- 7%



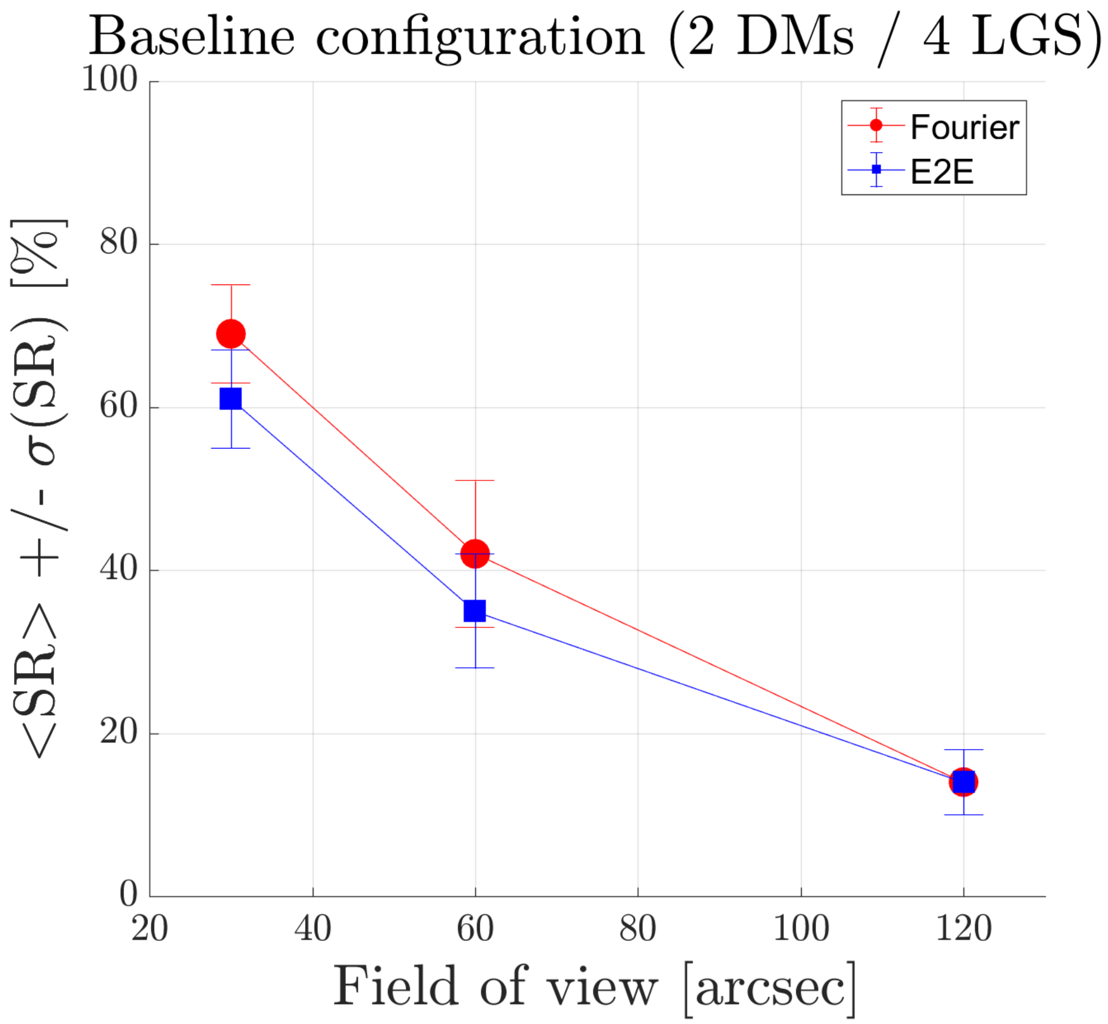
Goal configuration 3 DMs / 5 LGS / FoV 120''

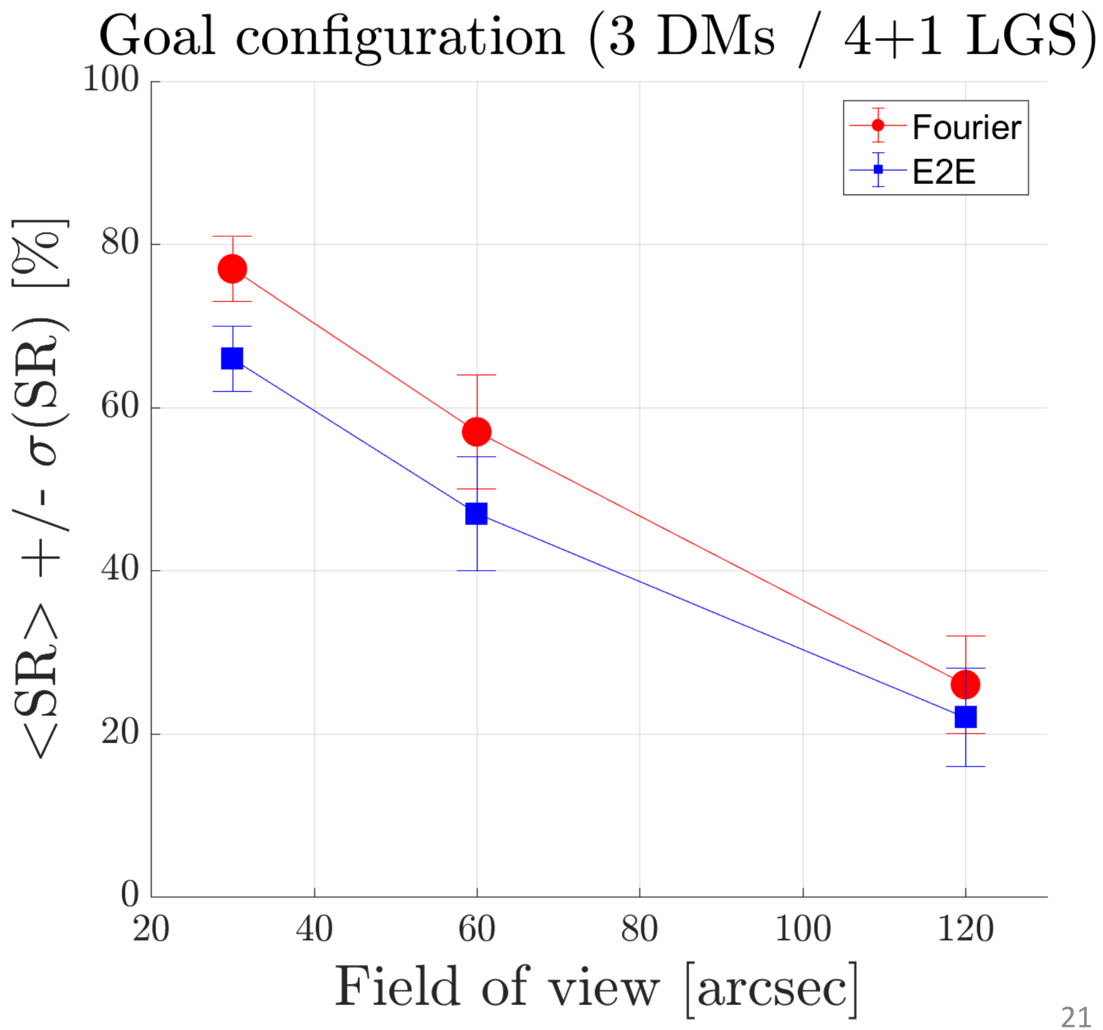


E2E <SR> + σ(SR) = 22 +/- 6%



Summary : discrepancies ?

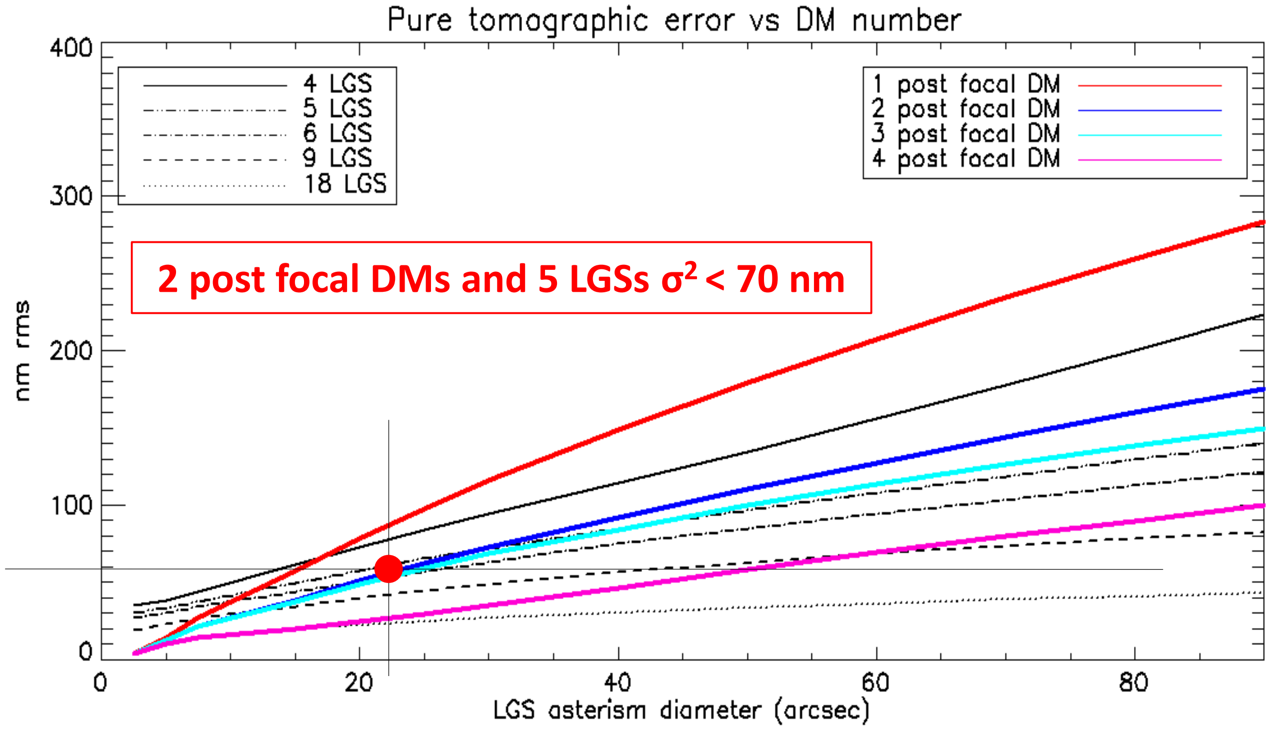




MAVIS dimensioning

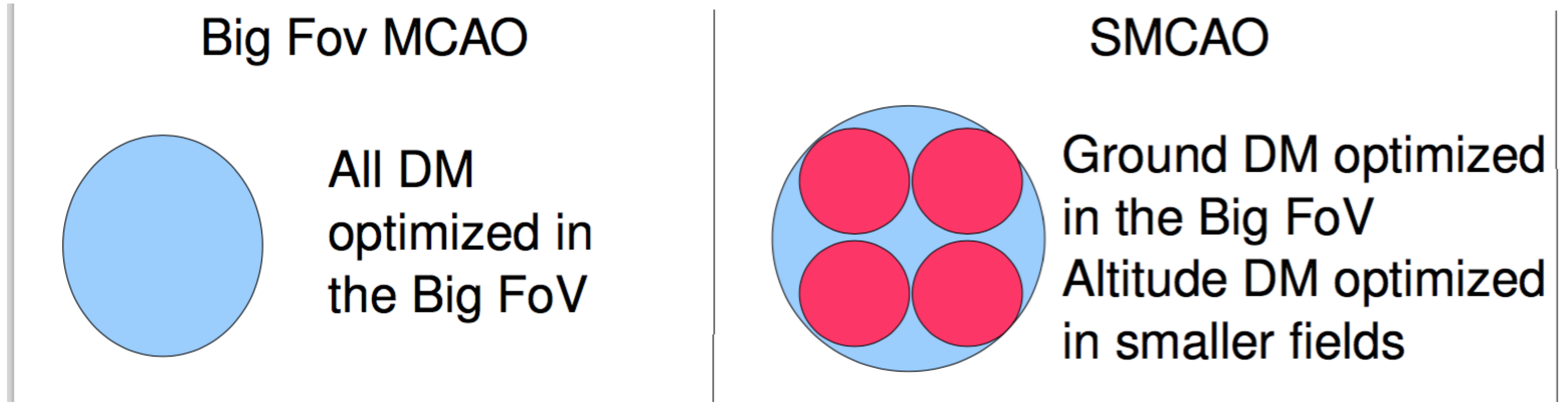
- Initial configuration from Fourier simulations (T. Fusco)
  - Number and position of LGS and corresponding tomographic error
  - Number, pitch, and conjugation altitudes of DMs and corresponding fitting error
- Refinement with E2E simulations :
  - WFS noise impact (NGS and LGSF)
  - **Sky coverage studies (TTA)**
    - **NGS positions and magnitude (H band)**
    - **Slow NGS wavefront sensing**

In progress



Prospects

- Use of Paranal Cn^2 profile (J. Osborn & O. Farrel) to optimize DMs conjugation altitudes with Fourier code (tomographic error)
- MOAO with micro DMs for NGS WFS (Sky coverage improvement)
- Other concepts (Star Oriented Segmented-MCAO)
- …



Scheme B. Neichel

MAVIS

Thank you for your attention !

http://mavis-ao.org/