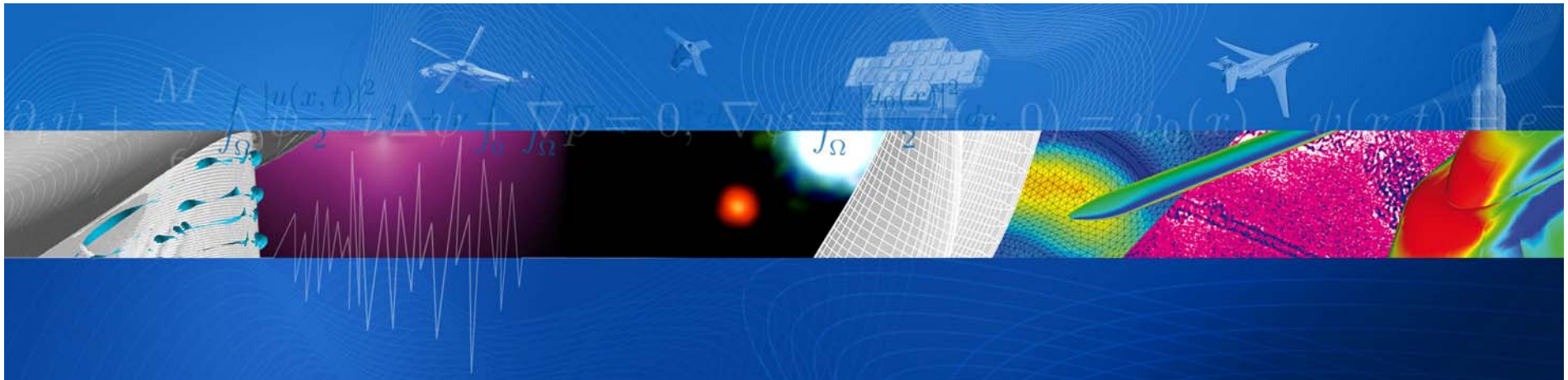


Experimental demonstration of Wide Field Adaptive Optics concepts for the ELT

Amélie Parisot, Cyril Petit, Thierry Fusco, Jean-Marc Conan

ONERA
THE FRENCH AEROSPACE LAB

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

retour sur innovation

Outline

1. The HOMER bench
2. Bench calibration
3. Tomography on the HOMER bench

Goals of the bench

- Implementation and tests of tomographic AO concepts (LTAO, MCAO…)

  Estimation of performance

  Analysis on natural/laser guide stars (configuration, star number …)

- Comparison of control laws (integrator, LQG, POLC…)

  Integrator control : Least square reconstructor, integrator control

  Control equation : $u_{n+1} = u_n + gM_{com}\, y_n$

  u_n is the voltage applied to the DM

  M_{com} is the generalized inverse of the interaction matrix of the system (link between $u_{(DM)}$ and slopes $_{(WFS)}$)

  Optimal control (LQG) : Estimation and prediction of the turbulent volume, based on a Kalman filter

  Projection of the estimated turbulence on the DMs for the correction

  Other solutions (POLC, Virtual DM…):

- Study of calibration strategies in tomographic AO

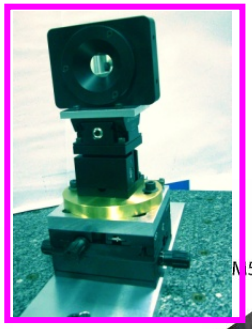
Experimental setup of HOMER bench

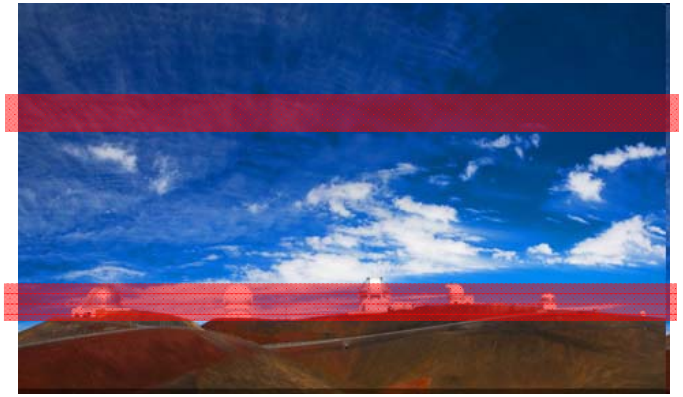
Turbulent module :
3 phase screens in rotation generating a realistic turbulence

Light source with 7x7 reconfigurable positions of laser (635 nm)

Experimental setup of HOMER bench

1er DM (ALPAO) conjugated with the pupil.
52 actuators in the pupil.





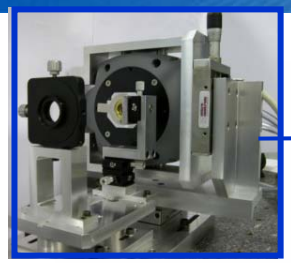
Adaptive Optics loop

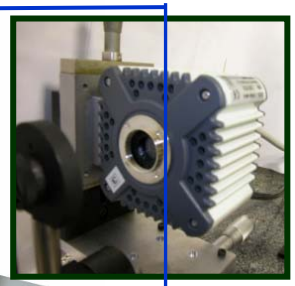
Second DM

(88 act, ALPAO) can be translated to be conjugated with different altitudes

Experimental setup of HOMER bench

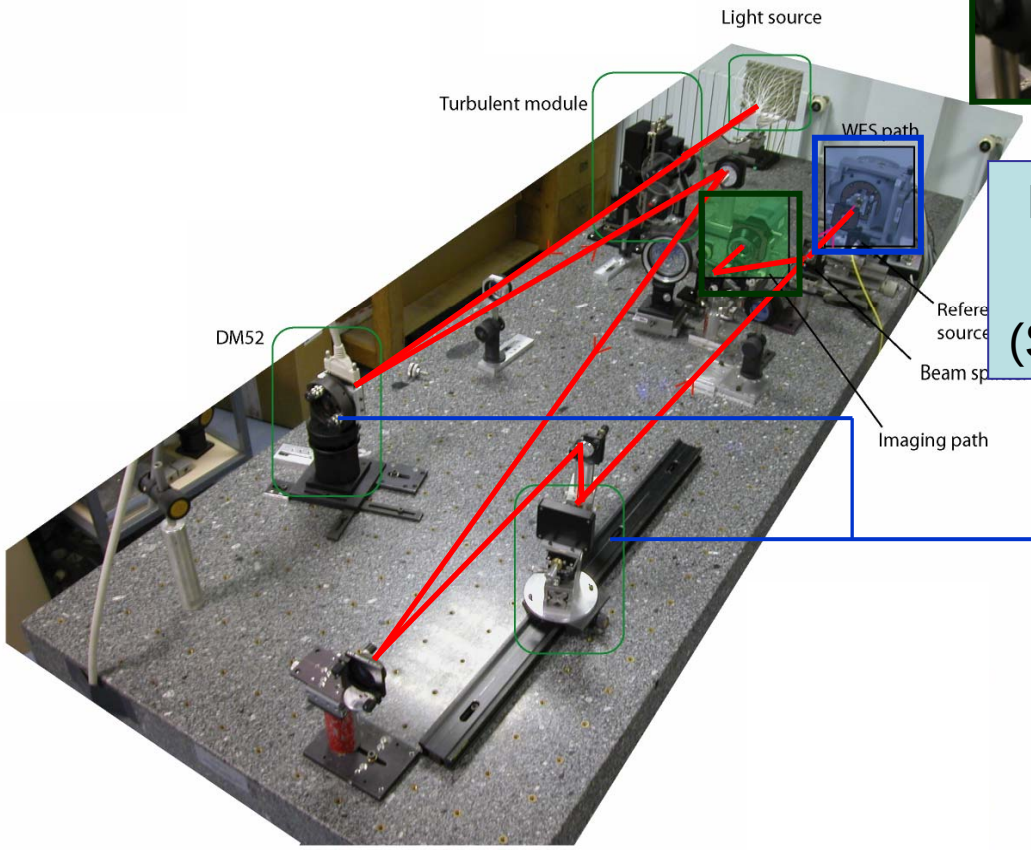
Multi-directional Shack-Hartmann based WFS 7x7 sub-apertures (ANDOR EMCCD, 1002x1004 pixels)





Visible Imaging camera

1344x1024 pixels (HAMAMATSU)



Real Time Computer (Shaktiware)

Bench optimisation

2 main limitations

Optical quality
of the bench

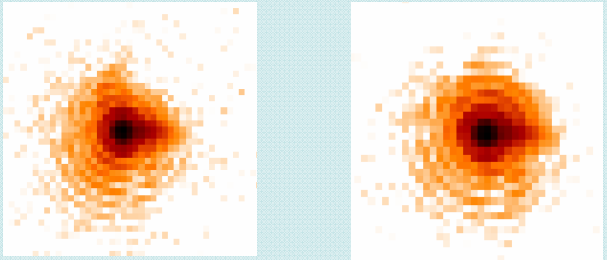
Model errors in the matrices
used in tomographic control law
=> sub-optimal correction

Bench optimisation

2 main limitations

Need of accurate calibrations

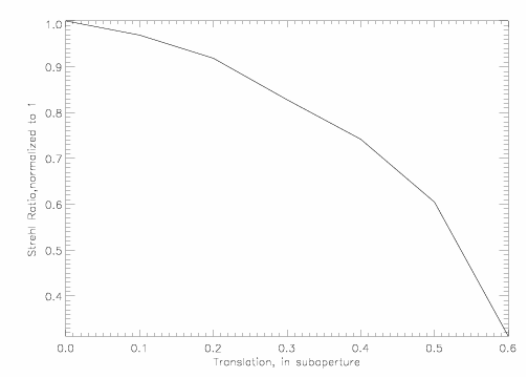
Of non-common path aberrations



SR=92% SR=98%

J.-F. Sauvage, et al, JOSA 24, 2007.

Of relative geometry of the bench components



Bench optimisation

WFS/DM mismatch : 4 parameters to identify :

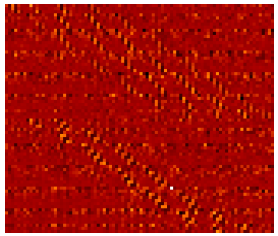
X-Y translations
Rotation
Magnification

\+ Directions of analysis & altitude

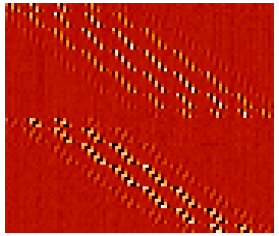
✓ Joint estimation thanks to the interaction matrix – Levenberg-Maquardt type algorithm

✓ Estimation of noise impact

SNR=max(Mint)/σ(Mint(unused subpup))



SNR=4



SNR=40

Bench optimisation

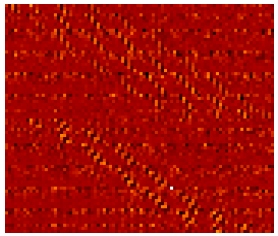
WFS/DM mismatch : 4 parameters to identify :
- X-Y translations
- Rotation
- Magnification

\+ Directions of analysis & altitude

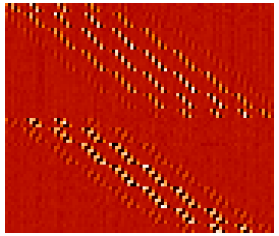
✓ Joint estimation thanks to the interaction matrix – Levenberg-Maquardt type algorithm

✓ Estimation of noise impact

SNR=max(Mint)/σ(Mint(unused subpup))



SNR=4



SNR=40

✓ **Numerical validation** of the identification algorithm : Precision better than :

- 0.1% sub-pupil on rotation and translation
- 0.05'' on direction of analysis
- 60m on altitude

Bench optimisation

WFS/DM mismatch : 4 parameters to identify :

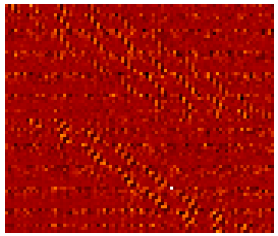
X-Y translations
Rotation
Magnification

\+ Directions of analysis & altitude

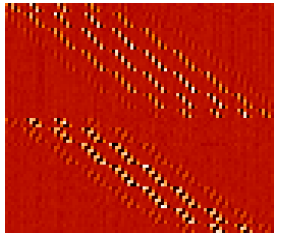
✓ Joint estimation thanks to the interaction matrix – Levenberg-Maquardt type algorithm

✓ Estimation of noise impact

SNR=max(Mint)/σ(Mint(unused subpup))



SNR=4

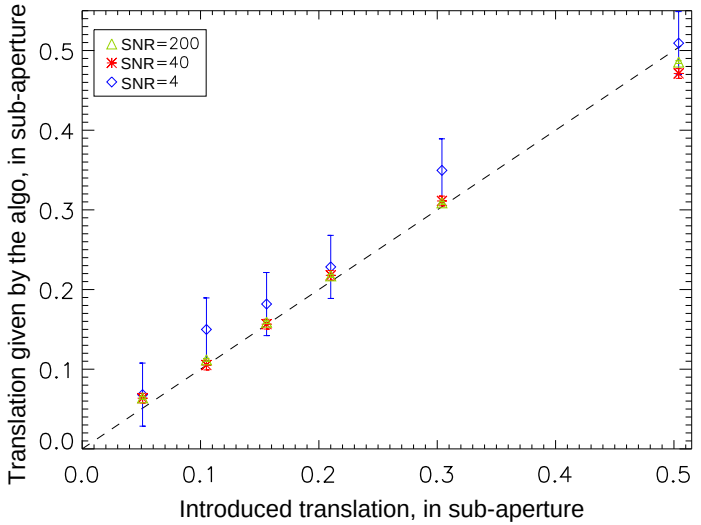


SNR=40

✓ **Experimental validation**

Precision better than :

1/20° sub-pupil on rotation and translation



The HOMER bench

Conclusion :

✓ Integrated and working bench

-> and now optimised / optimisable

Goal :

Implementation and tests of control laws

- with NGS
- then with LGS

Tomography with HOMER bench – Tomography AO control

- **GLAO :** integrator controller : $u_k = u_{k-1} + R^{glao}\, y_k$

$R^{glao} = gM_{com}$; g=gain M_{com}=generalized inverse of interaction matrix

=> No tomographic abilities

Tomography with HOMER bench – Tomography AO control

- **GLAO :** Ground Layer Adaptive Optics

- **POLC :** Pseudo-Open Loop Control : static minimum variance reconstructor, adapted to dynamic closed-loop by pseudo open-loop measurement computation

Tomography with HOMER bench – Tomography AO control

- **GLAO :** Ground Layer Adaptive Optics
- **POLC :** Pseudo-Open Loop Control
- **LQG :** Linear Quadratic Gaussian

  optimal solution according to minimum residual phase variance of the dynamic closed-loop control problem

Tomography with HOMER bench

Comparison of performance – GLAO, POLC, LQG - , wrt the field of view for several SNR

LTAO

- ✓ in simulation
- ✓ implemented on the bench

Case of study :

1 DM

4 natural guide stars

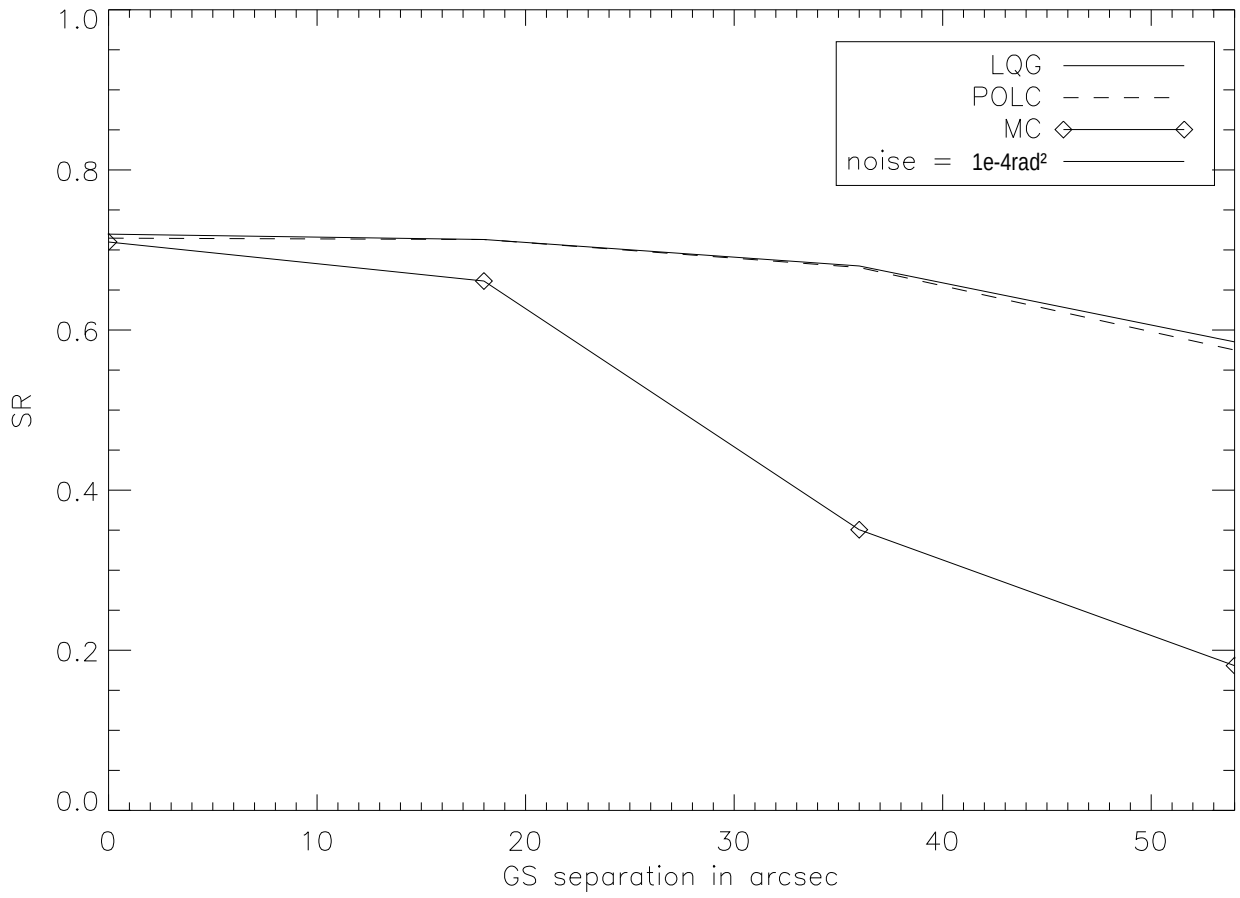
3 turbulent layers (phase screeens)

h=[0, 6, 10] km ; v_{wind} = [9, 5, 20] $m.s^{-1}$

$\%C^2_n$= [0.52, 0.32, 0.16] ; d/r0=1.2

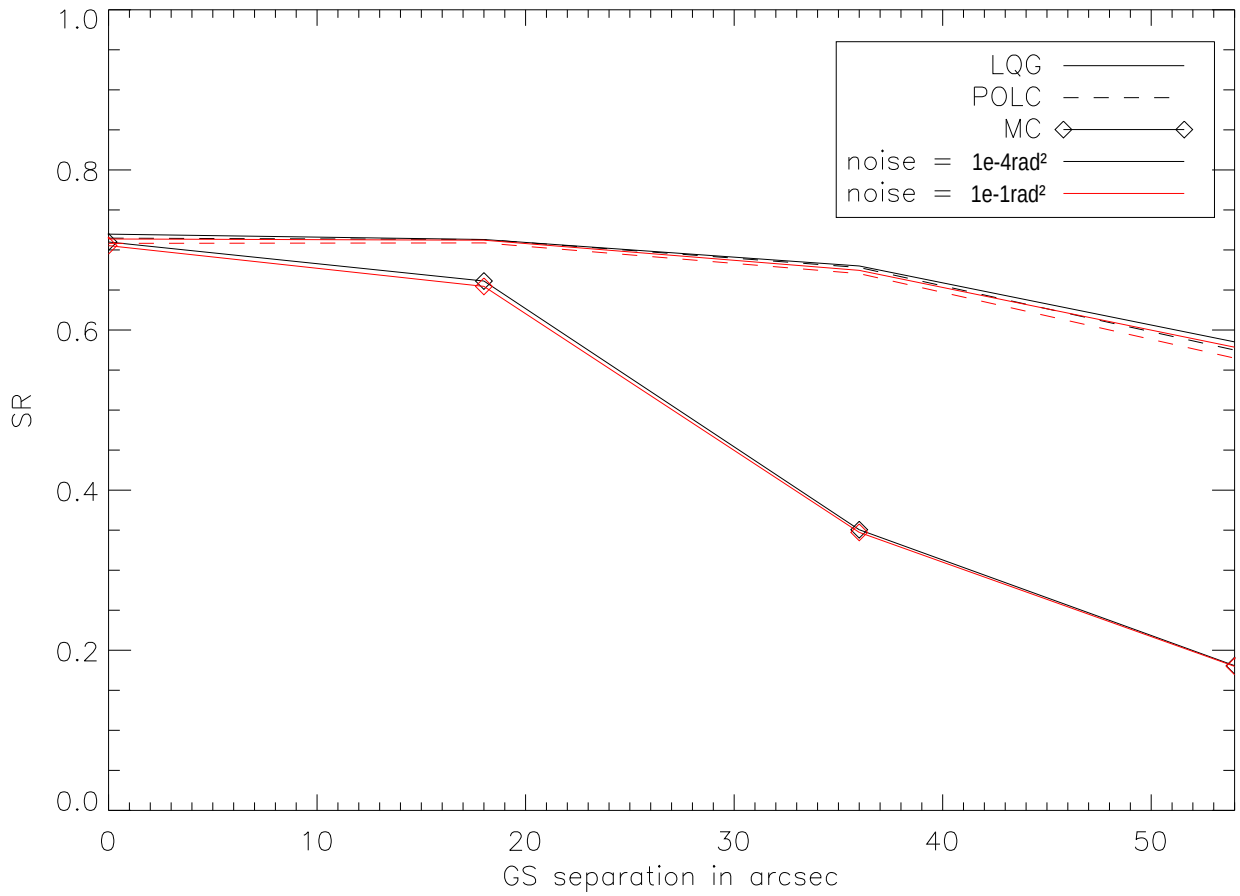
F_{bench}=12Hz => $F_{samp\ (equivalent)}$ = 500Hz

Tomography with HOMER bench - Simulation

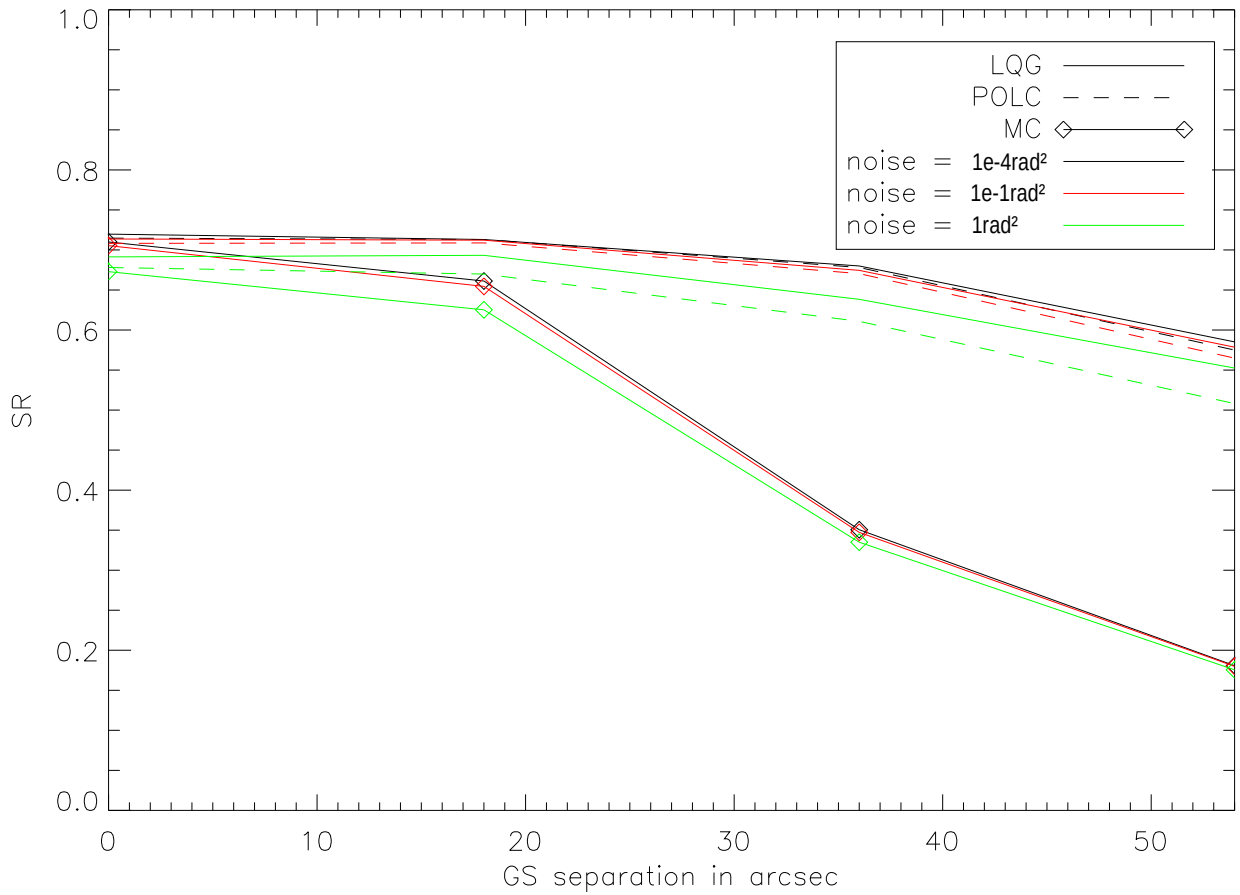


On-axis Strehl

Tomography with HOMER bench - Simulation



Tomography with HOMER bench - Simulation



LQG best perf.

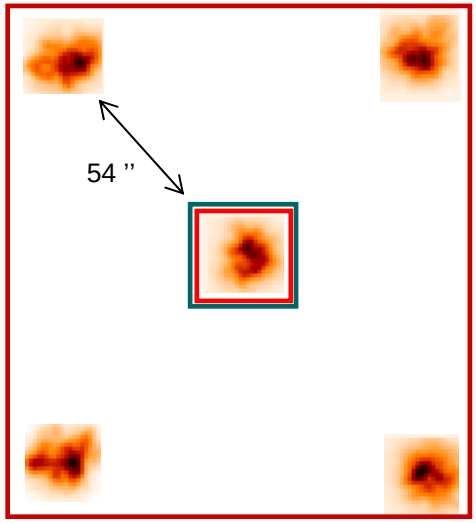
POLC gives equivalent perf for medium or high SNR

lower performance for low SNR

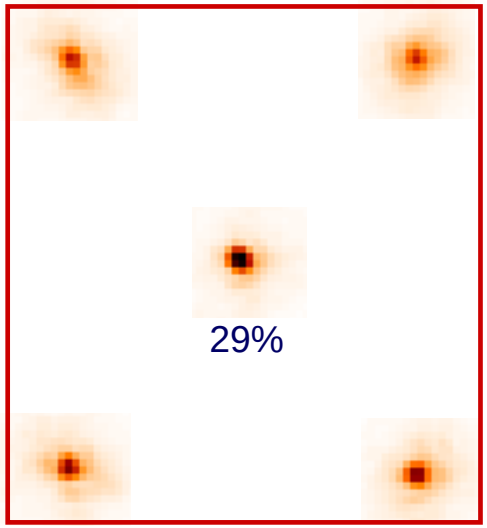
Tomography with HOMER bench – Experimental results

Guide stars

Scientific targets

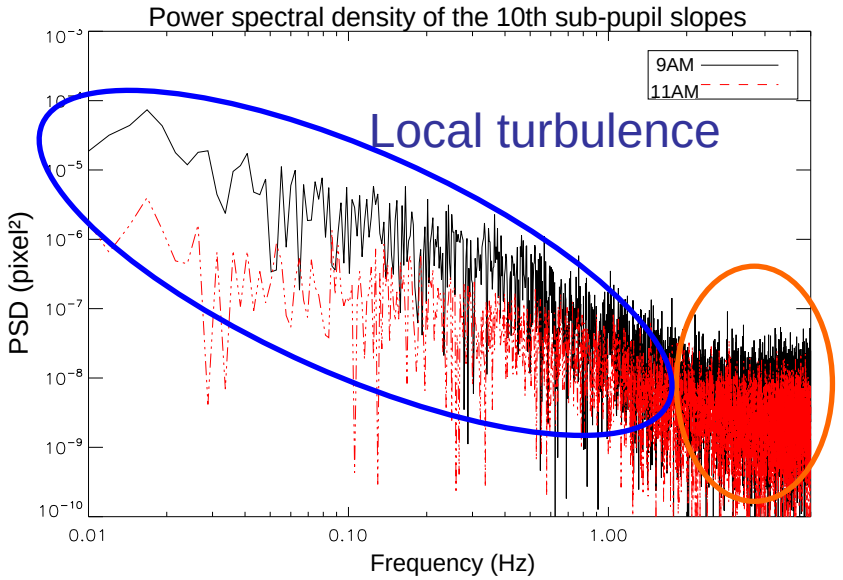


SCAO



Performance limitation

- Strong local turbulence

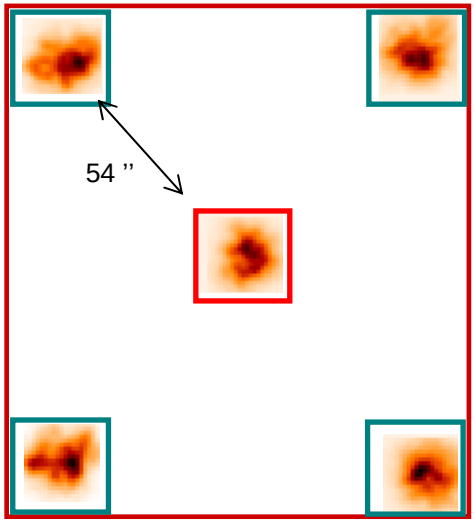


Noise level

Tomography with HOMER bench – Experimental results

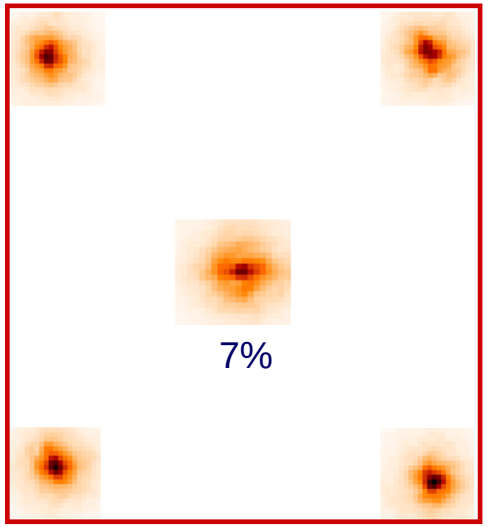
Guide stars

Scientific targets

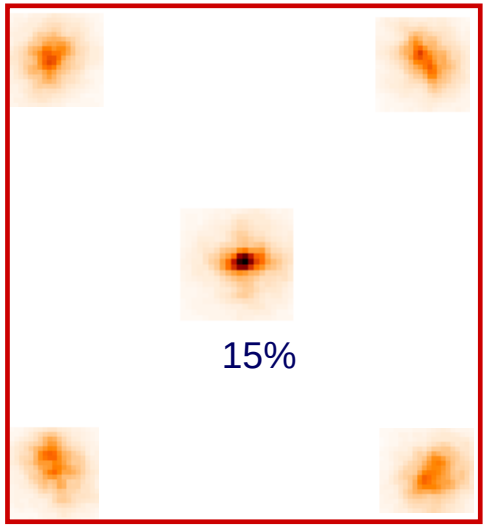


SCAO : SR=29%

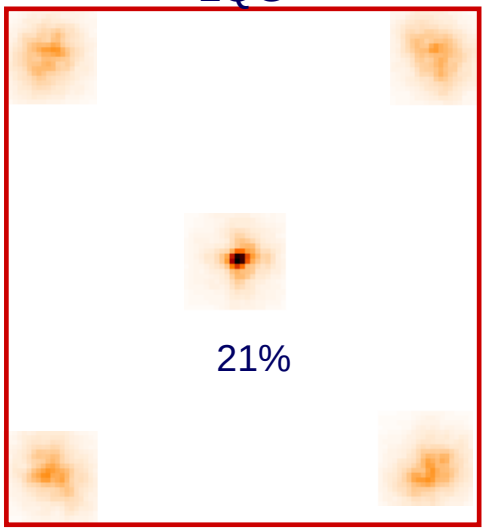
GLAO



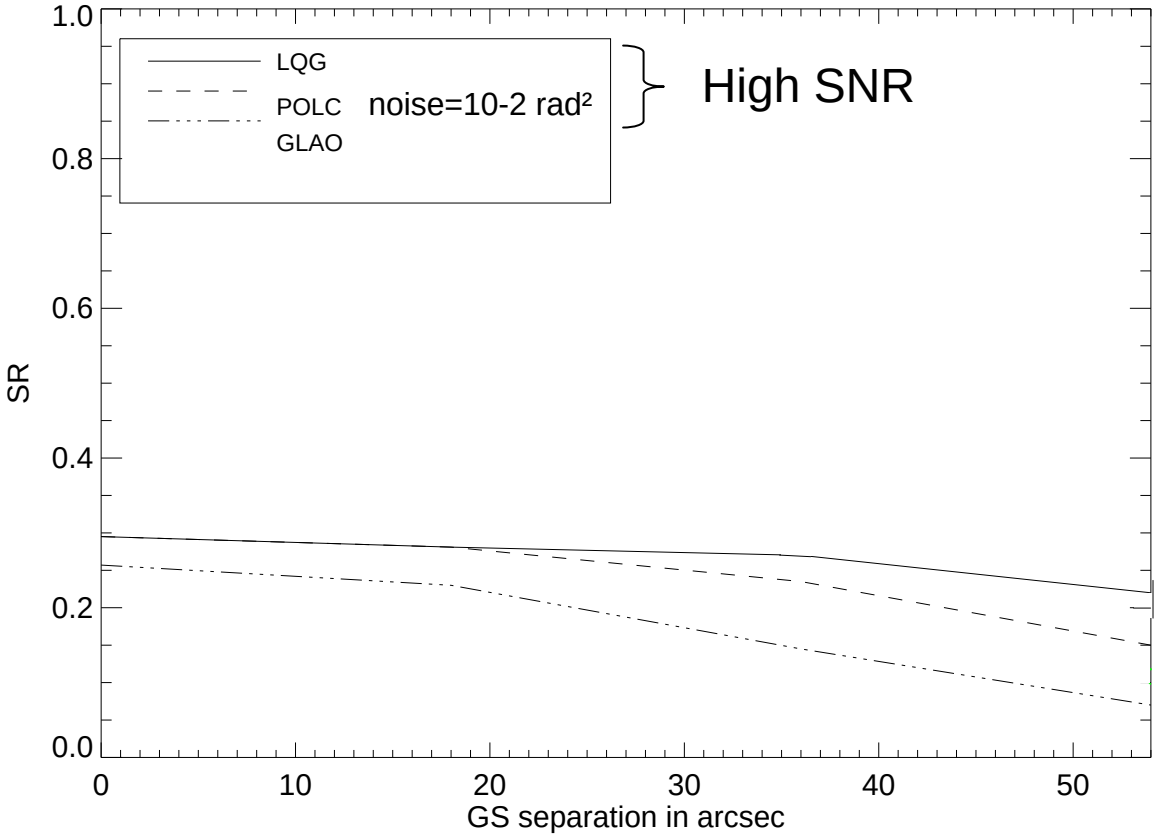
POLC



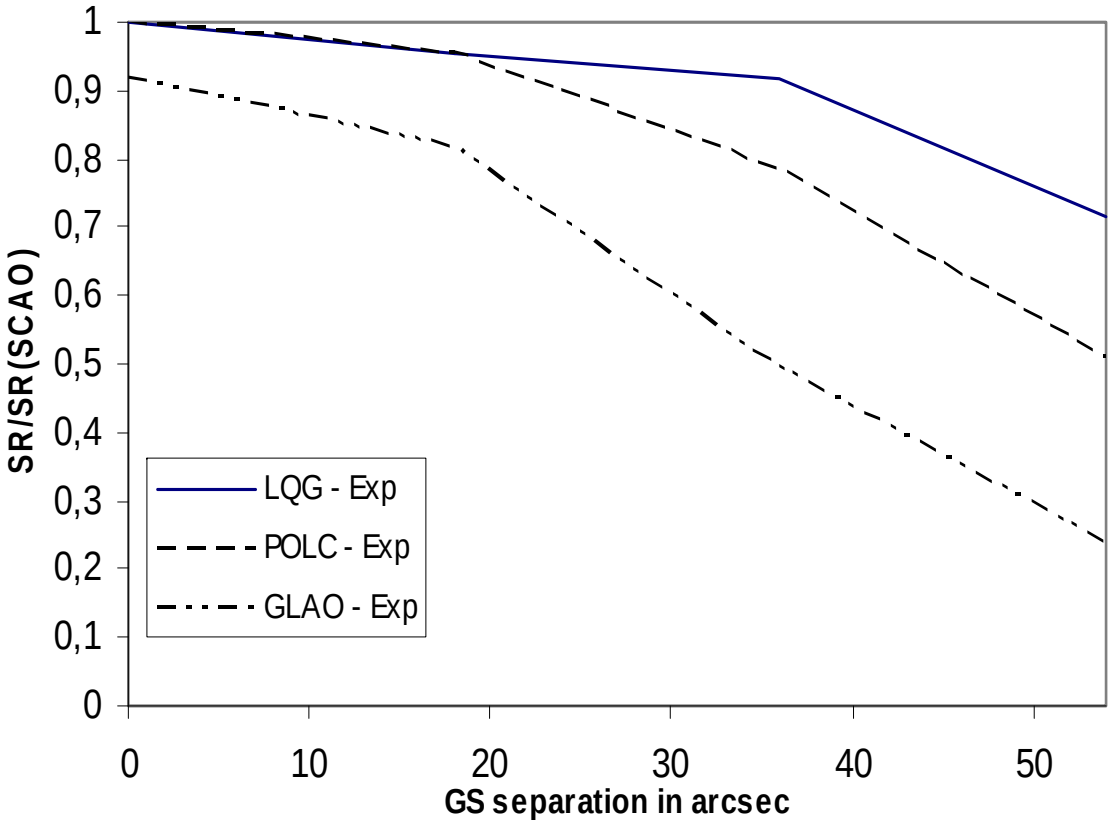
LQG



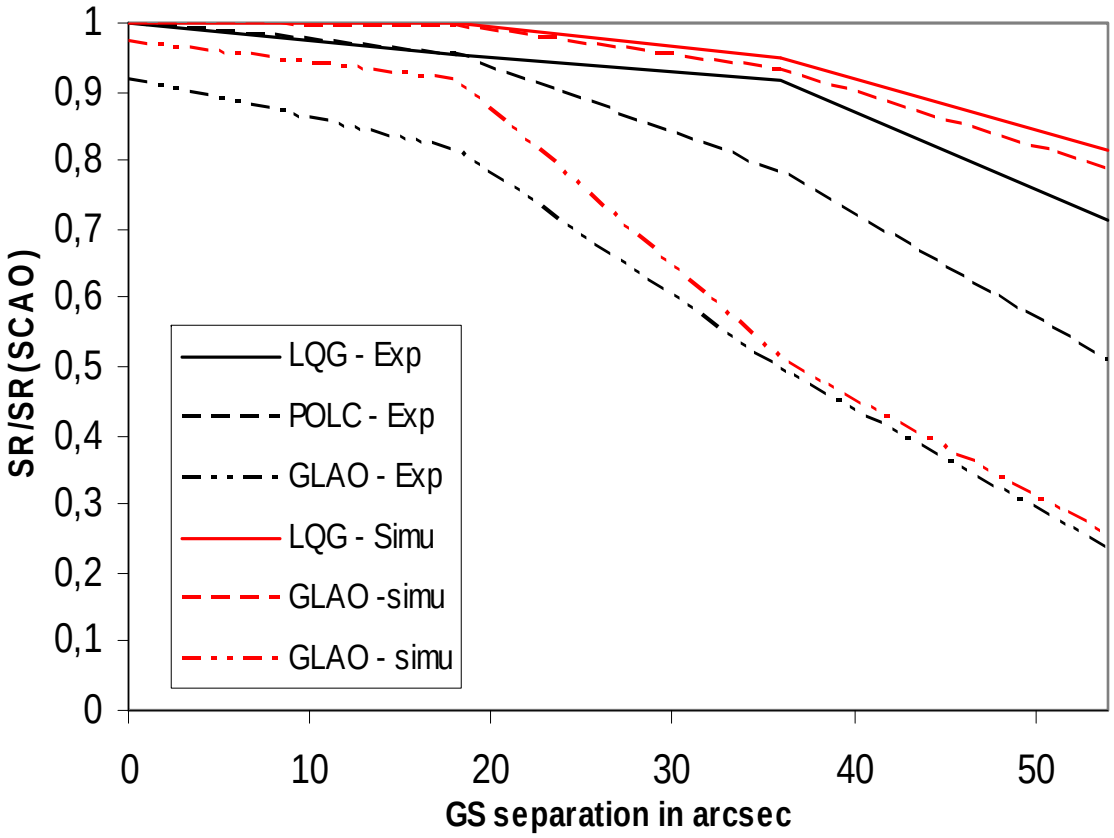
Tomography with HOMER bench – Experimental results



Tomography with HOMER bench – Experimental results

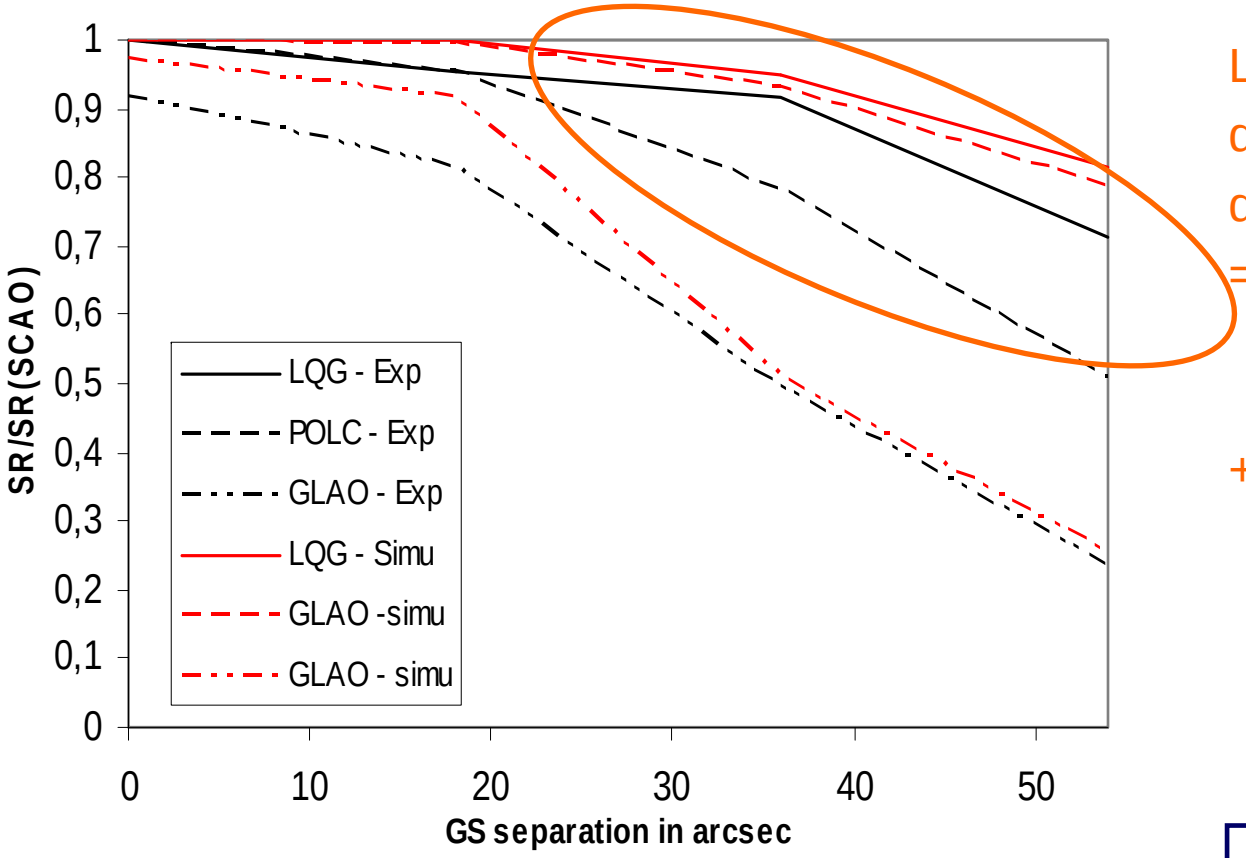


Tomography with HOMER bench – Experimental results



Same trend

Tomography with HOMER bench – Experimental results

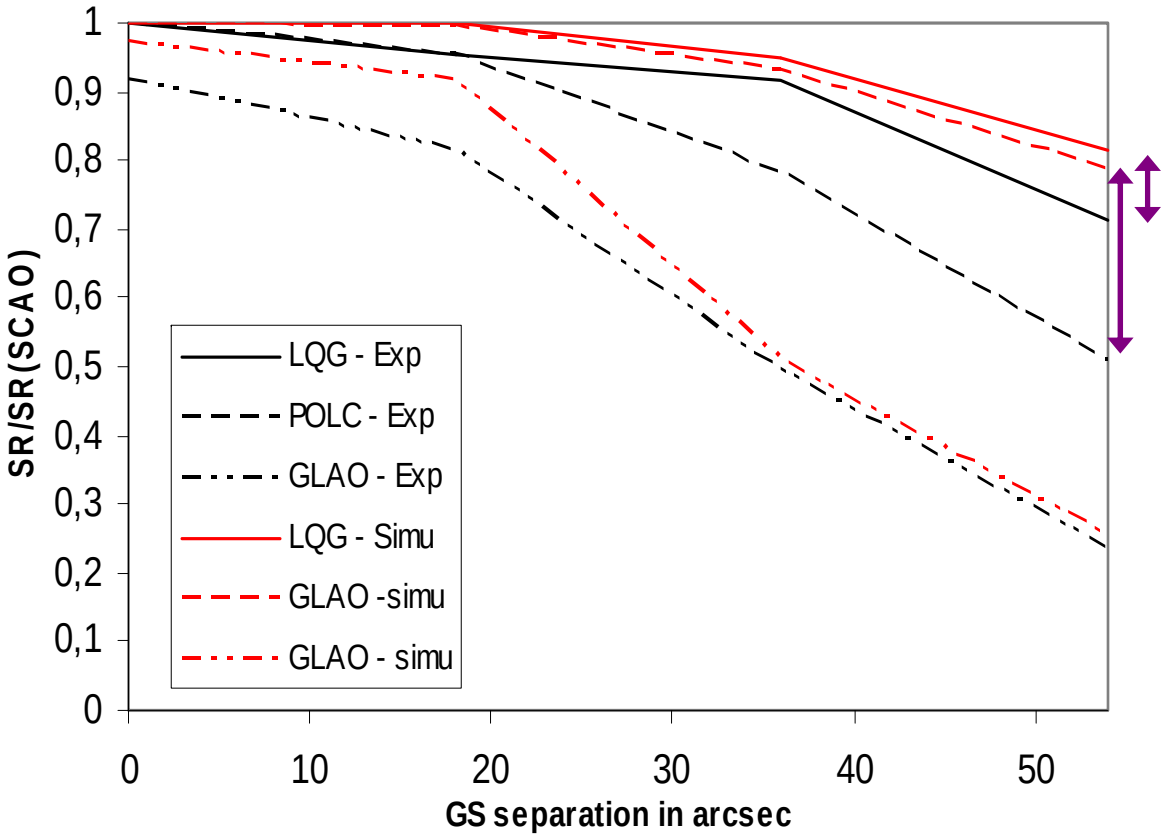


Local turbulence distributed at different altitudes
=>effect on tomography

+ Model errors

Same trend

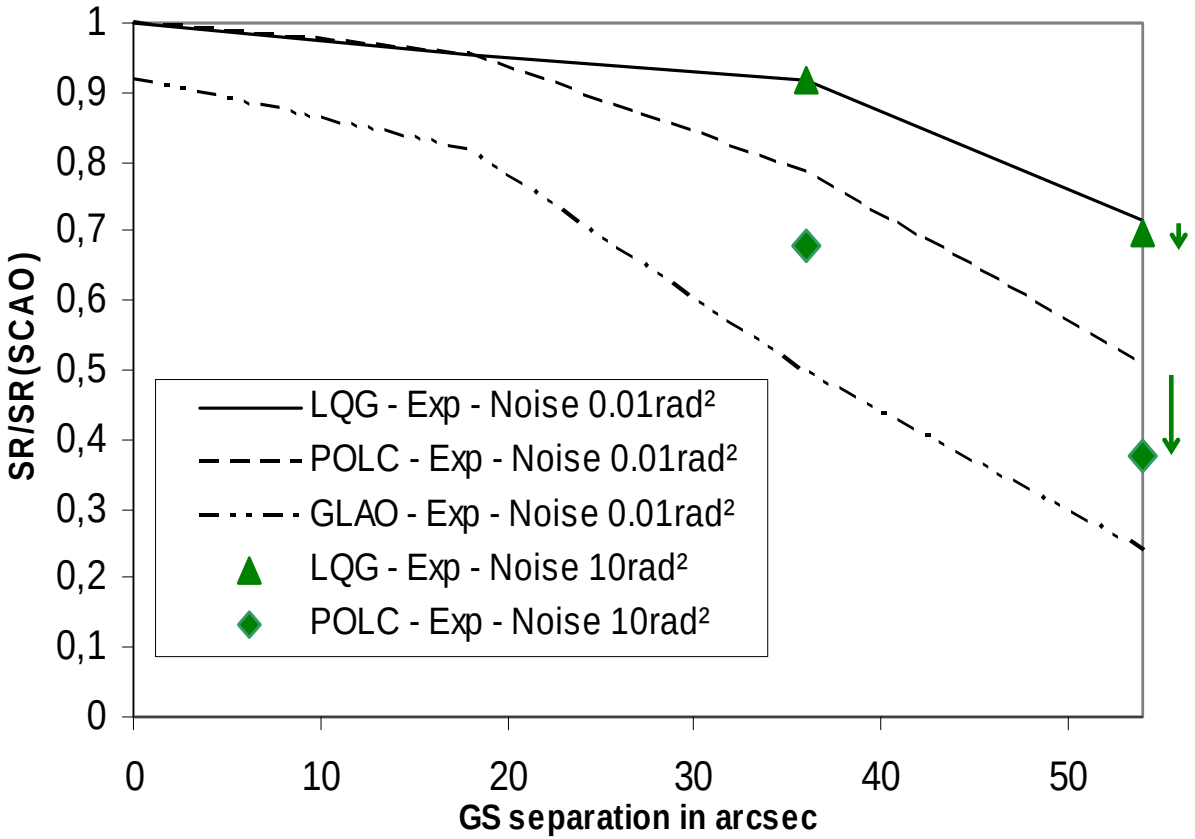
Tomography with HOMER bench – Experimental results



POLC less robust to model errors than LQG ?

Same trend

Tomography with HOMER bench – Experimental results



POLC more sensitive to SNR

Conclusion/Perspectives

- HOMER : a working tomographic AO bench
  - ✓ 1st experimental demonstration of tomographic AO in closed loop with LQG control law
  - ✓ POLC implemented and tested in LTAO
- Optimization and complete calibration of the bench
  - ✓ Numerical and experimental validation of the algorithm of system parameters identification
  - ✓ Experimental validation of the relative geometry WFS/GS in progress
  - ✓ Correction of non common path aberration : done on axis, in progress in the field
- Implementation and comparison of different control laws and Wide Field AO concepts (in particular, in low SNR)
  - ✓ Integrator, LQG, POLC are implemented and validated
  - ✓ Other control laws (VDM, DLQG) : to do (see Cyril Petit's talk)
- Analysis+control on natural/laser guide stars

To prepare futur VLT/ELT systems …