



The European RTN (Research Training Network) on AO for ELTs

M. Le Louarn

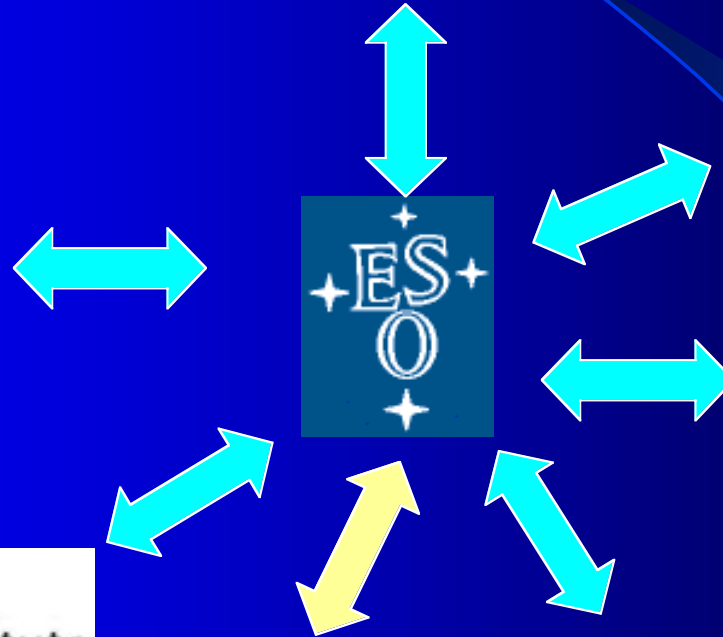
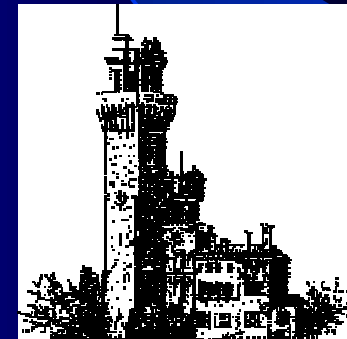


NETWORK PARTNERS

Funding:



LUND
UNIVERSITY





Key areas addressed by the RTN

WP 2

3D-Wavefront sensing:
Tomography

WP 3

New wavefront sensors

Multi-conjugate
AO

WP 5

Micro-mirror
R&D

Network activities
AO for ELT

Cophasing of
large segmented
mirrors

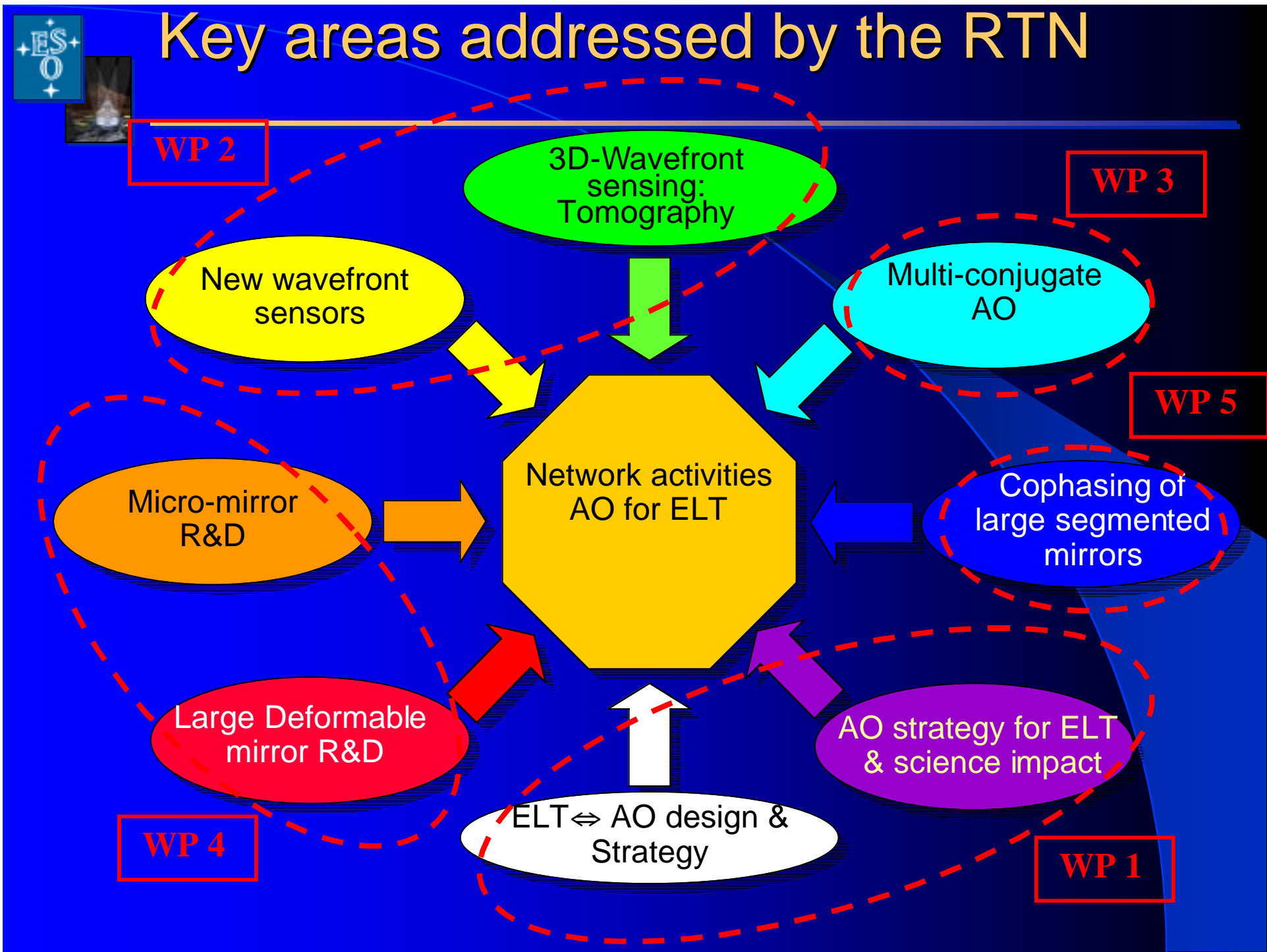
Large Deformable
mirror R&D

AO strategy for ELT
& science impact

WP 4

ELT \Leftrightarrow AO design &
Strategy

WP 1





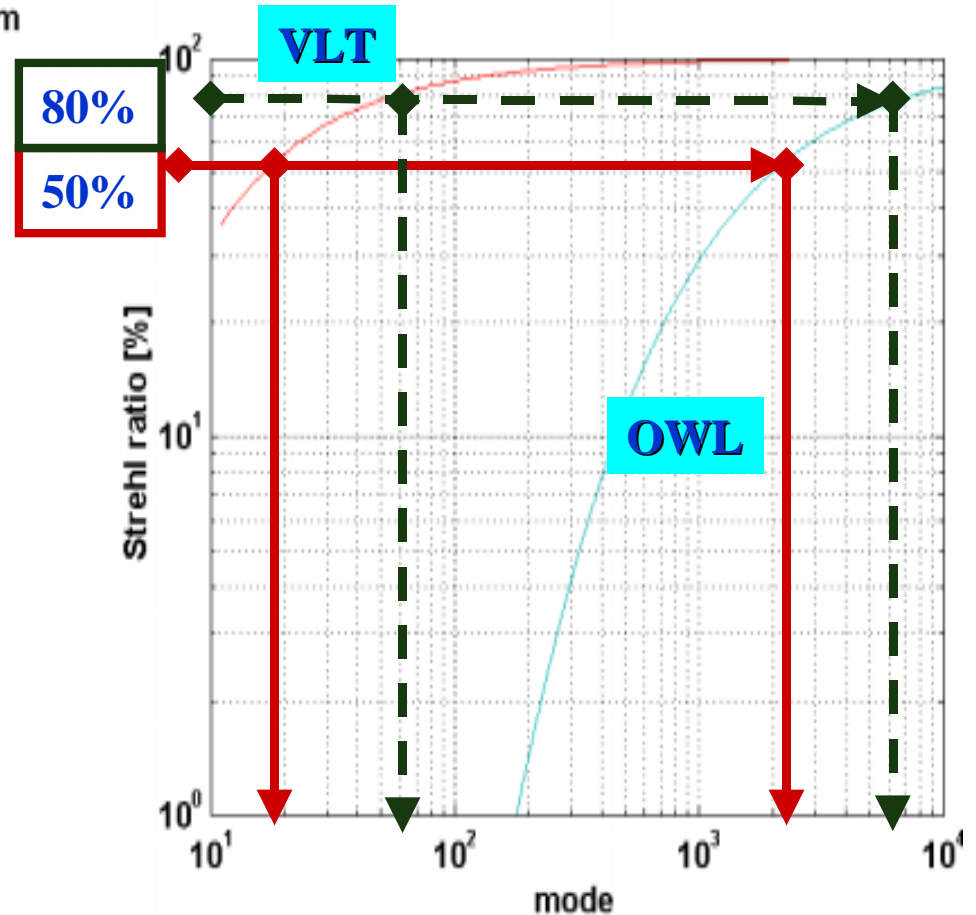
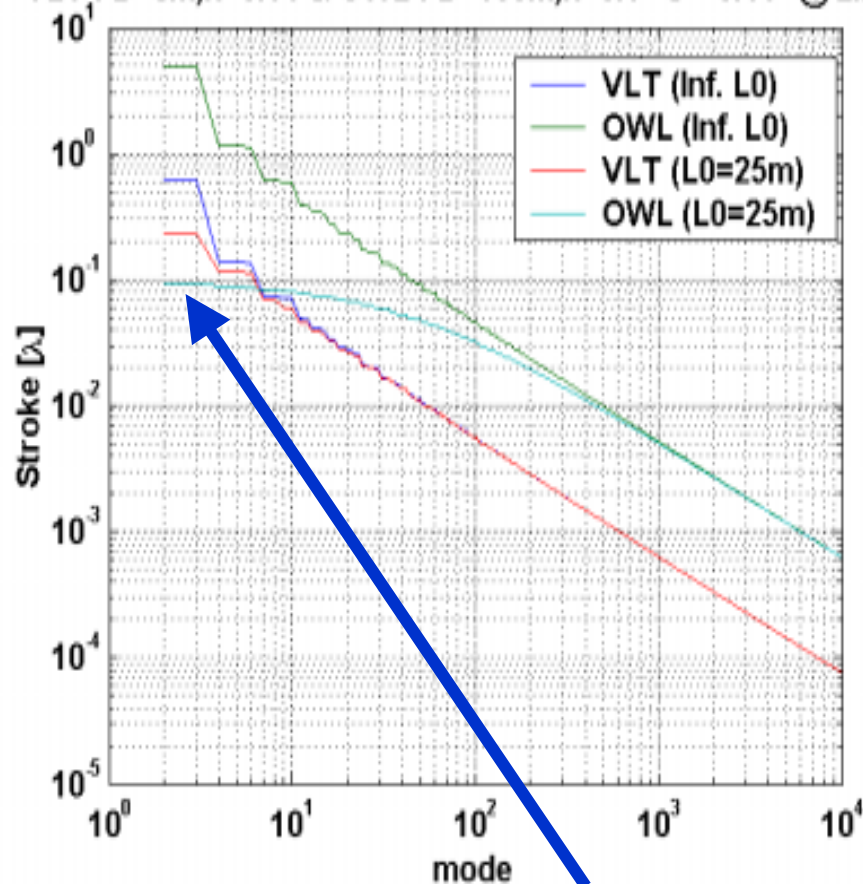
WP1 Science & Networking

Top level requirements
ELT design and AO constrains
Finite outer scale effect
Deformable mirror requirements
Knowledge of the atmosphere
Preliminary road-map for AO on
ELTs



Analytic AO simulation : L0 effect

VLT : $D=8m, r_i=0.14$ & OWL : $D=100m, r_i=0.1 - \varepsilon = 0.44'' @ 2.2\mu m$

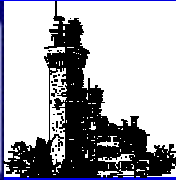


Effect of a finite outer scale of turbulence on the turbulent modes to be corrected: **100 first modes are much attenuated for OWL**

R. Conan et al. 2002



WP2 & 3 Science & Networking



ONERA



Max Planck Institute
for Astronomy

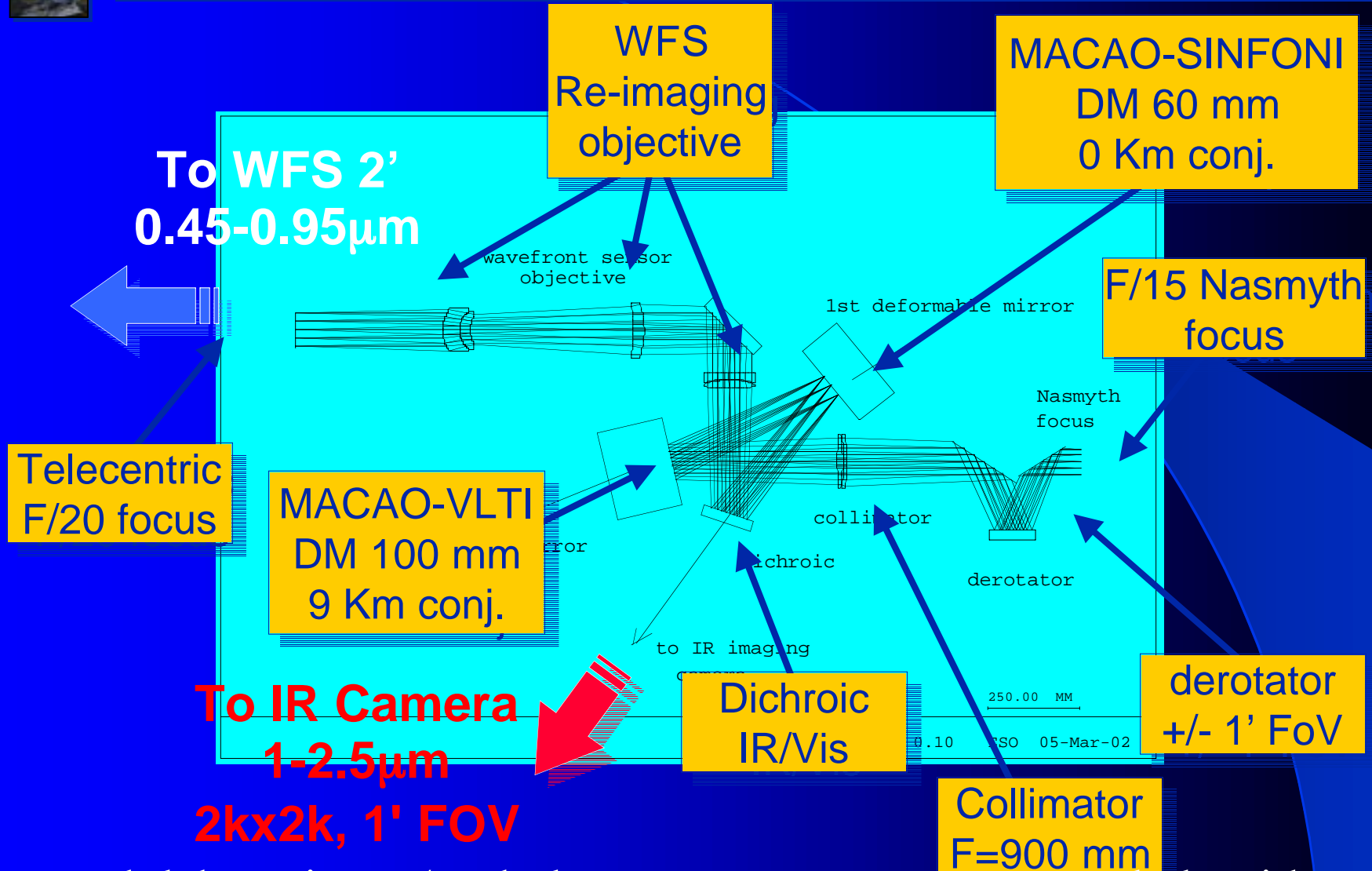


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Adaptive Optics Tomography
Wavefront sensing and 3 D WFS
Multi-Conjugate Adaptive Optics (MCAO)
Star oriented MCAO
Layer oriented MCAO
Multi-FOV Layer Oriented MCAO
LGS MCAO



MAD optical design

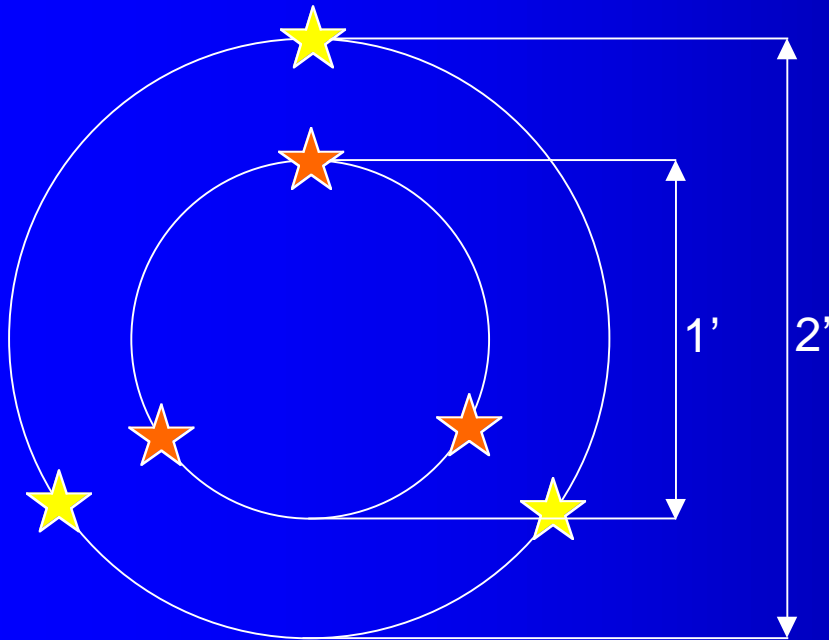


Thorough lab testing w/ turbulence generator to test control algorithms + understand MCAO. Compare Star and Layer oriented approaches

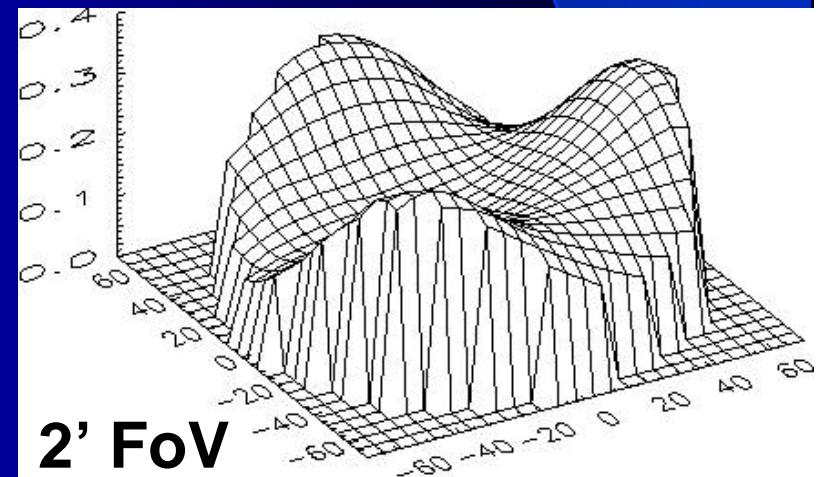
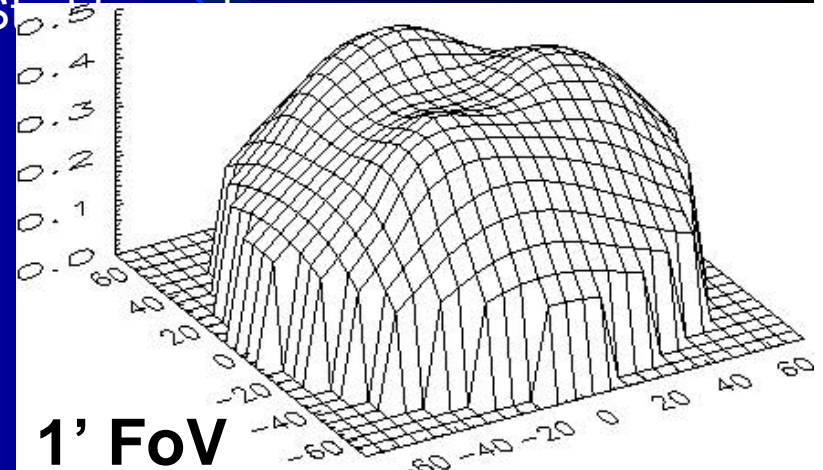


MAD Star Oriented expected performance

- Numerical simulations
- 7 layers atmosphere, seeing 0.65" at zenith and 30° from zenith
- MAD system, 3 Natural Guide Stars
- Performance in K band (2.2 μm): Peak Strehl / Strehl Ratio



FoV	Zenith	30°
1'	0.45/0.13	0.42/0.21
2'	0.31/0.13	0.28/0.21

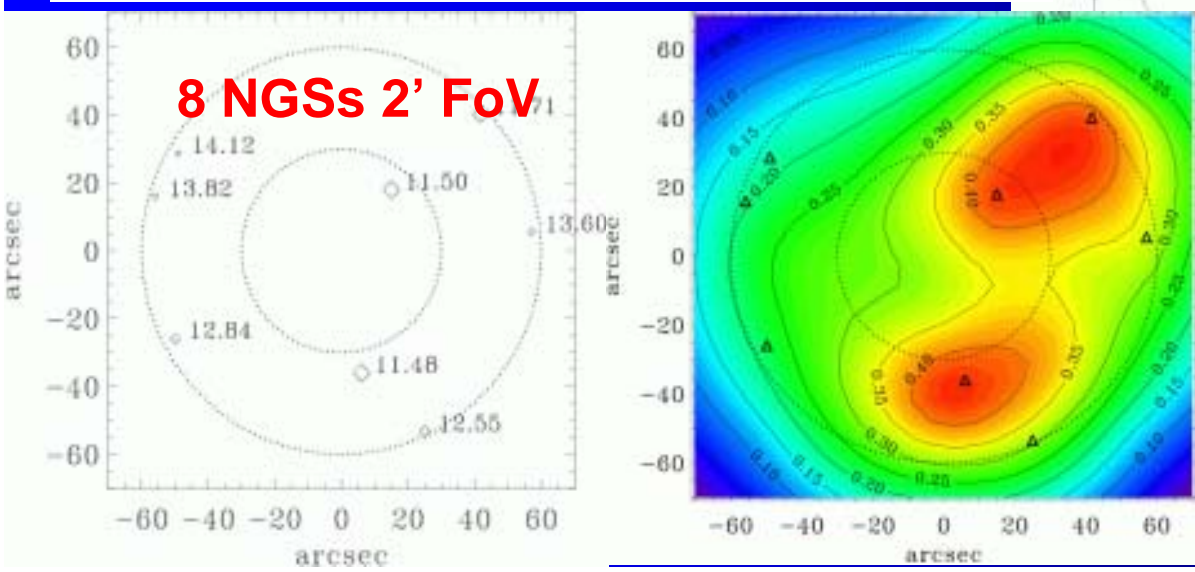
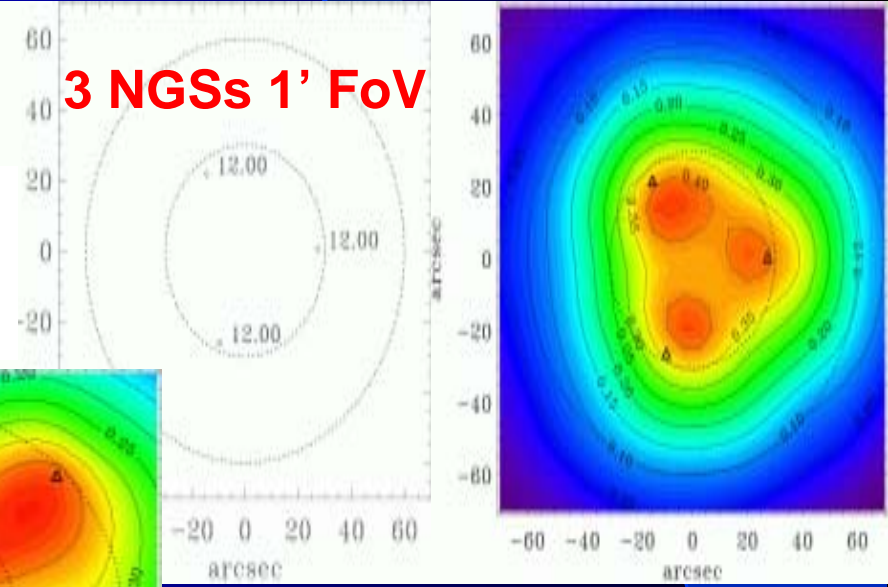




Layer Oriented expected performance

- Numerical simulations
- 7 layers atmosphere, seeing 0.67", no outer scale, at 30° (no zenith)
- MAD system, 3-8 NGSs integrated magnitude $m_v < 14$
- Performance in K band (2.2 μm): Peak Strehl / Strehl rms

# NGS	1' FoV	2' FoV	
3 NGS	0.43/0.05	0.31/0.06	
# NGS-2' FoV	$m_{\text{int}:10}$	12	14
6 NGS	0.43/0.09	0.40/0.05	0.29/0.05
8 NGS	0.44/0.06	0.41/0.06	0.28/0.06





WP4 Science and Networking



High Density deformable mirrors
Large deformable mirrors
High density micro-mirrors



Adaptive "secondaries" (Arcetri)

- A cost-effective design optimised for MCAO and for low sensitivity to error sources
- **Prototype adapt. second. @ VLT ?**

M2 - Flat, 33.4-m, segmented

M4 - Aspheric, 8.1-m, thin active meniscus

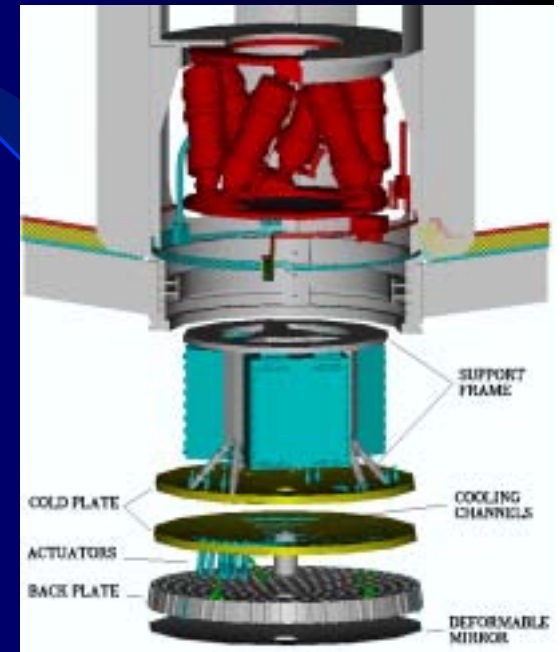
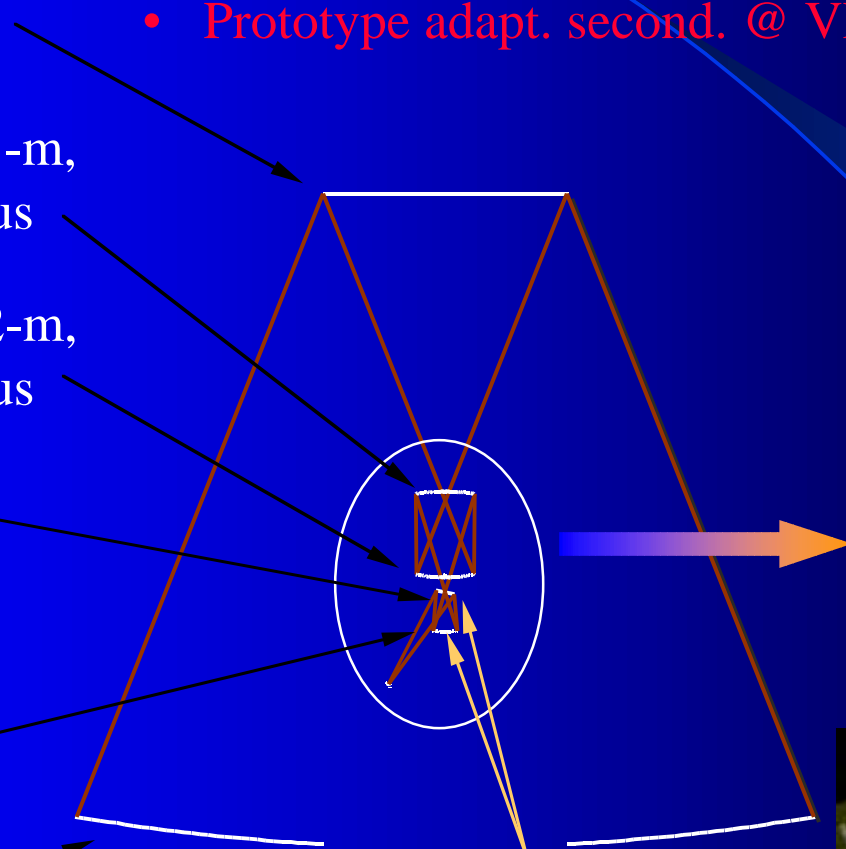
M3 - Aspheric, 8.2-m, thin active meniscus

M6 - Flat, 2.5-m, Exit pupil, field stabilization

M5 - Aspheric, 4.0-m, Focusing

M1 - Spherical, 100-m, f/1.42, segmented

Adaptive mirrors
(conjugated to 0, 8 km)
7000-20000 actuators





MOEMS (obs. Marseille)

◆ MDM conception, realization and characterization, since 2001

- Collaboration with LAAS (Toulouse-France)
- Manpower: LAM (2 p. + PhD student);
LAAS (2 p. + Post-Doc (AO-ELT, starting this fall))
- Device characterization
 - Characterization bench under development
 - Tests on prototypes developed by LAAS

◆ Projects

- VLT 2nd generation
 - PF (LAOG, LAM, Obs. Paris-Meudon, Obs. Nice, ...)
 - FALCON (Obs. Paris-Meudon, LAM)
- OWL
 - AO-ELT network



Science and Networking WP5



Large segmented mirrors
Effect of segmentation cophasing
Point Spread Function quality
Wavefront sensing for cophasing
Mach Zehnder, curvature, Shack
Hartmann, Pyramid.....

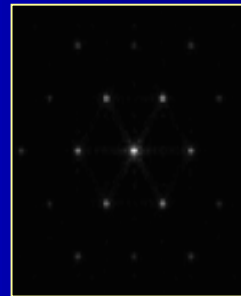


Segmentation *PSF* errors

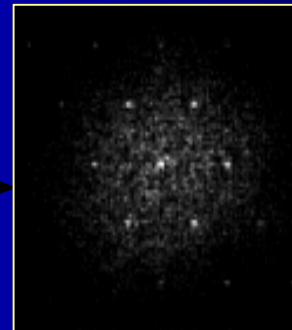
Gaps



Edge misfigure



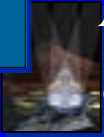
Tip-tilt error



Piston error



Diffraction peaks



All effects: Strehl ratio and relative intensity of the first order diffraction peaks

Effect	Critical parameters	Typical value	Strehl ratio		Relative intensity of A ₁ peaks	
			Expression	Value	Expression	Value
Gap	gap size, δ segment size d	12mm 1.5m	$(1-\delta/d)^4$	0.98	$0.7(\delta/d)^2$	$4 \cdot 10^{-5}$
Turned edges	depth, ε width, η	0.25 μ m (WF) 20 -10mm	$> 1-3.3 \cdot (2\eta/d) + 4.5 \cdot (2\eta/d)^2$	0.94 – 0.97	$< 0.5(\eta/d)^2$	$7 \cdot 10^{-5} - 3 \cdot 10^{-4}$
Tip-tilt	rms segments, N	$\lambda/30$ (WF) 3300	$1-rms^2 + rms^4(2.34+2/N)/4$	0.96	$0.013rms^4$	$2.5 \cdot 10^{-5}$
Piston	rms segments, N	$\lambda/30$ (WF) 3300	$\exp(-rms^2)$	0.96	—	—

	Shack-Hartman	Curvature	Mach-Zender	Pyramid
1-Cycle-Piston-Step-Precision (at the wavefront)	~17nm rms measured ^b ~5nm rms simulated	≤360nm measured ^c ≤150nm (30nm rms) sim.	TBD	
End-Precision (Piston rms at mirror surface)	~2nm simulated	66nm measured ^d ~4nm simulated	TBD	25nm ^e (sim., seeing ltd) 13nm (sim., diff. ltd)
Range (Piston _{max} at the mirror surface)	±30μm (broadband, Keck) ±1μm (2-λ) ±100μm (3-λ) TBC	± ≥5μm (3-λ) TBC	±20-30μm TBC	±0.6μm (3-λ) TBC
Sensibility to seeing	low	low (adjustable!)	very low	high ^f
Sensibility to edges	no ^g	low TBC ^h	high (show stopper?)	low, TBC
Sens. to atmp. dispersion	dispersion may help	low, TBC	high (broadband)	low, TBC
Magnitude limit (1min exposure per cycle)	11-12(+)	14+ ⁱ	14+	TBD
Fabrication Complexity	high	easy	easy (TBC)	easy
Alignment Complexity	high	low	low	low
Detector Size (OWL)	2k	2k-4k	2k-4k	~1k
Phase 2 mirrors?	difficult	yes ^j (TBC)	yes (Fourier Filter)	TBD
Use observation time?	no	no ^k	no	no
Iterations needed?	no perhaps yes for 2 mirrors	yes (~5) no if Piston < ±λ/30(MS)	no (weakly)	yes (10-20)
Wavelength	650nm, 850nm (Keck, GTC) visible - IR	3μm (Keck) visible - IR	visible - IR	visible - near IR

^aPrecision (measured at the wavefront) of one single piston step measurement when the piston step is within the non-ambiguity range ($[-\lambda/2, +\lambda/2]$ or $[-\lambda/4, +\lambda/4]$). For simulations following conditions are assumed: r_0 (@ 500nm)=24cm, 1 Min exposure time (photonic noise included).

^bKeck result: Chanan et. al report 12-nm mirror surface rms differences between measurements performed at different wavelengths. This results in $12 \times 2/\sqrt{2} \text{nm} = 17\text{-nm}$ rms wavefront error for one wavelength. The given error therefore excludes errors due to segment aberrations, just like the simulations. The better precision of the simulation is due to a different analysis method – using an analysis similar to Keck, one achieves comparable results.

^cKeck result; $\lambda=3.31\mu\text{m}$

^d $\lambda=3.31\mu\text{m}$. Keck result: This is the difference between C and S-H measurements and is believed to arise from segment aberrations; the repeatability of C is stated as 40nm(@MS). This bad repeatability may be due to a weak analysis method. The simulation was done with seeing and photon noise included, but excluding segment aberrations (like edge effects); using a smaller wavelength enhances end precision; increasing the exposure time, the rms error tends to zero

^esimulation differs to Curv. and S-H: no photon noise included; atmospheric turbulence introduced by different phase screens vs. convolution

^fhigh precision with AO, low precision without

^gusing a mask to block the gap/edge. This mask at the same time relaxes requirements on alignment accuracy and distortion in the pupil imaging

^hshould be low, because large part of the segment surface contributes to the signal. But not yet included into simulations