LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

cnrs

Space Active/Adaptive Optics @ LAM

Deformable Mirrors

Research/Developement and Characterization

Aix*Marseille université

Context

- LAM expertise on development of **Active/Adaptive Optics** techniques for **large ground-based telescopes** for **40 years**

- LAM is one of the 5 French "**Space-Lab**", with a **strong expertise on space optics** and long list of realizations for CNES, ESA and NASA missions (SOHO, COROT, HERSCHEL, GALEX, ROSETTA, etc..)

- **As an evidence** the combination of know-how and the development of Space Active/Adaptive Optics started @ LAM in late 2000's :
  - Active corrector (MADRAS collaboration with Thales-Alenia-Space) 2008-2013
  - Wave-front sensors (RASCASSE project with TAS, ONERA and CNES) 2012-2015
  - Control strategies (open/close loop, narrow/wide field WFS, etc..) 2012 - ..
  - Dedicated characterization optical bench 2012 - ..

- **Numerous collaborations with international/industrial partners** on new missions design, research and development and technological transfer.
  - Space Telescope Science Institute and JPL (Benches , WFIRST, LUVOIR/Habex, etc..)
  - Thales Alenia Space : space active/adaptive optics and MOEMS-based space systems
  - DMs manufacturers (CILAS, ALP'AO, IRIS AO, etc…) on devices characterization

Today/Tomorrow LAM hosts a French workshop on High Contrast Imaging techniques for future space missions (NASA Decadal), with STScI and CNES representatives.

MADRAS project

Space active mirror technological demonstrator

- ✓ 2006-2008 conceptual study for CNES from LAM new idea.
- ✓ 2009-2013 from concept to TRL4 - Research project / M. Laslandes Ph.D
- ✓ 2014-2018 from TRL4 to TRL7 - Industrial Partnership with THALES / CNES

Study case: > 3 m class future space telescopes

- ✓ Data from flying telescopes
- ✓ Modeling of future missions

} Active system specifications

- *Correction of first Zernike*
- *Efficient but simple*
- *Light and small*
- *Resistant*
- *Low power consuming*

Contributors to the WFE

- ✓ Integration and alignment errors
- ✓ Thermo-elastic and gravity effects

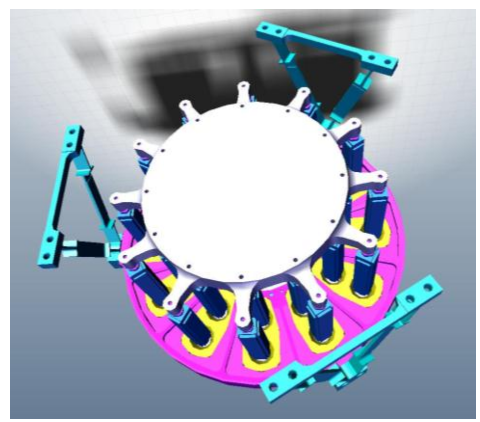
Residual WFE after correction

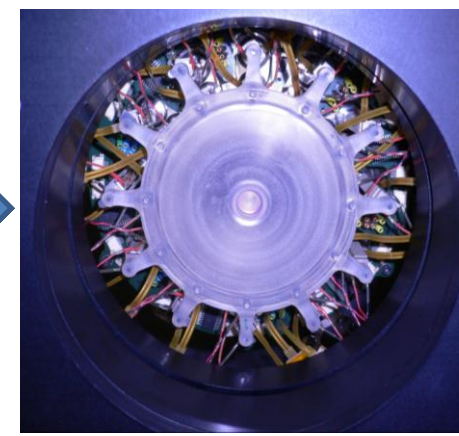
< 5 nm rms per mode

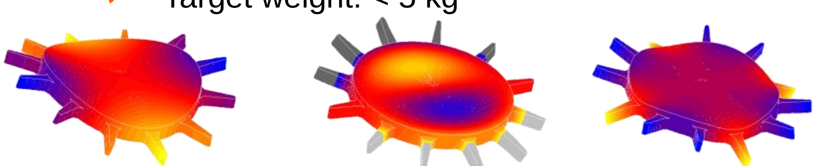
< 10 nm rms for global WFE

Active mirror dimension

- ✓ Exit pupil: 90 mm diameter
- ✓ Target weight: < 5 kg







MADRAS 2 integrated in THALES/CNES study on new generation space telescope (2015-2017)

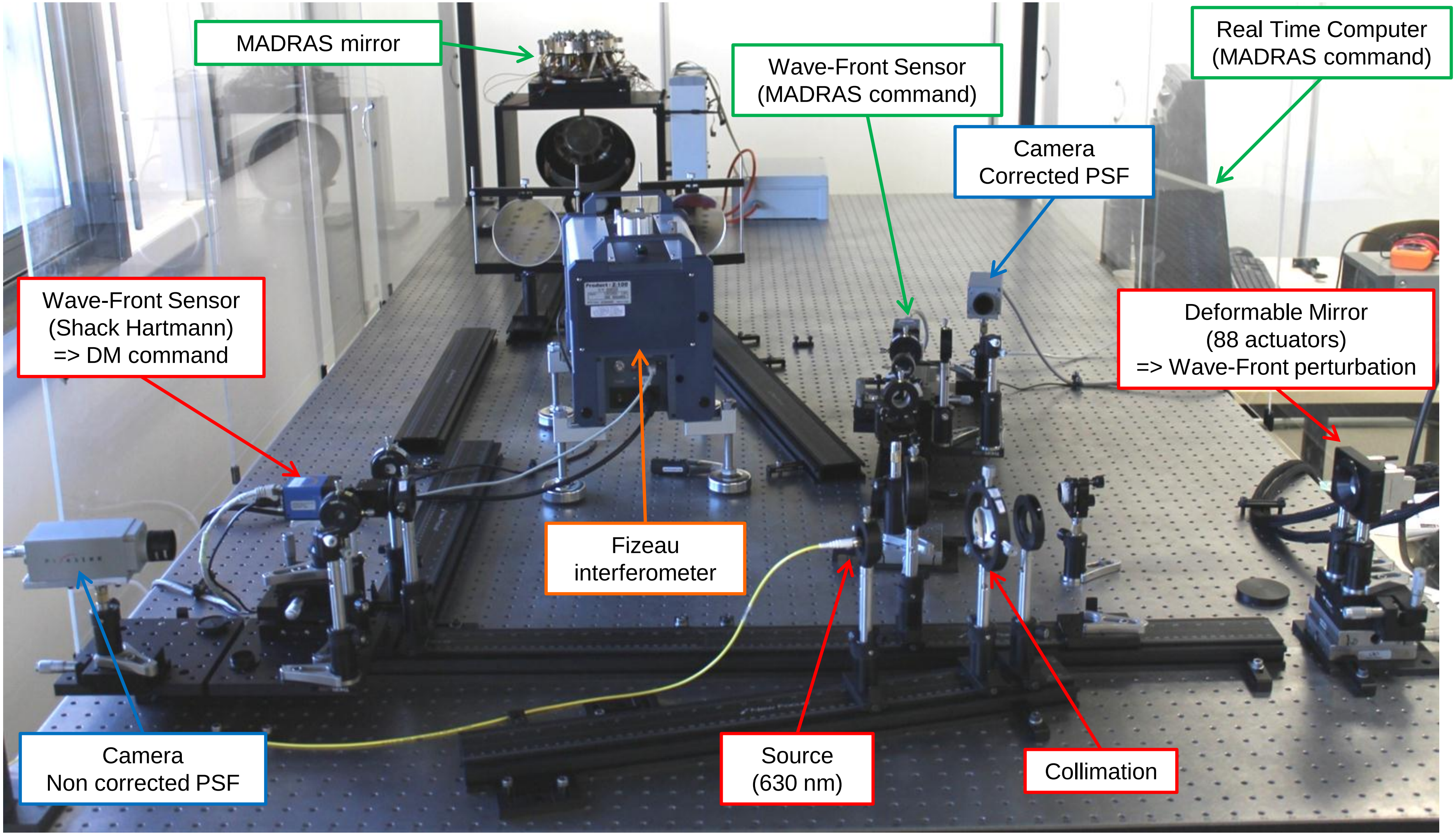
MADRAS test bench

Telescope simulator

Active correcting loop

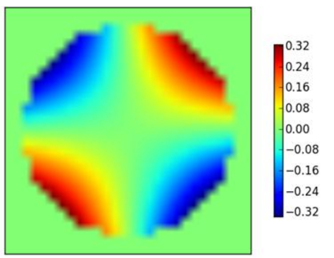
PSF imaging

Surface deformation monitoring

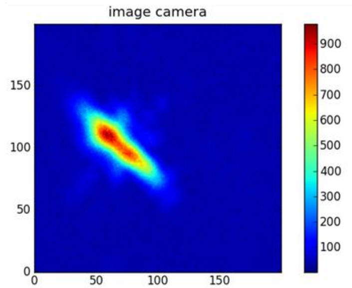


Closed loop mode correction: Astm3 example

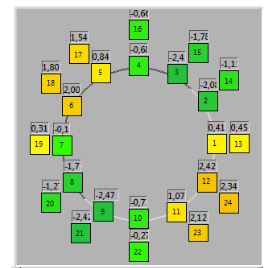
Injected WFE
150 nm rms



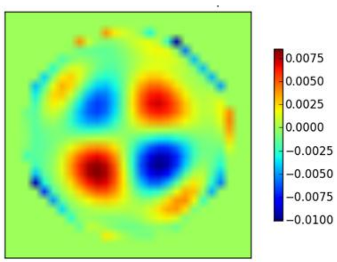
PSF before correction



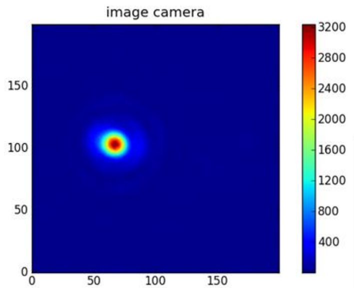
Commands



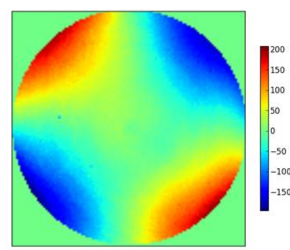
Residual WFE
3.3 nm rms

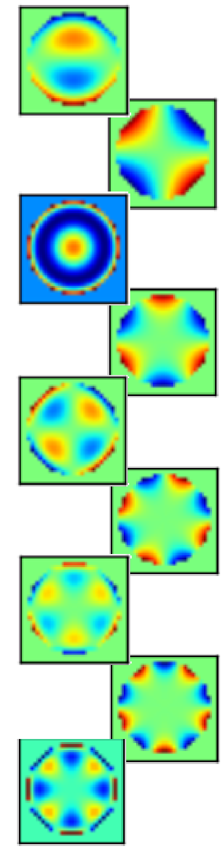


PSF after correction

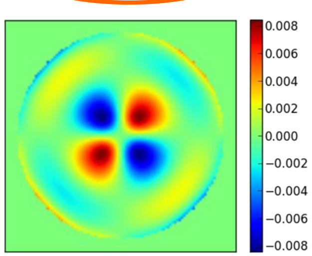


Mirror deformation (interf)
76 nm rms





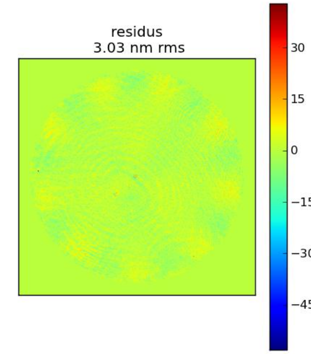
Residues expected from FEA
2.5 nm rms



Global performance: sum of the individual modes

- Worst case: Residual WFE = 14.3 nm rms
- Representative case: Mean residual WFE = 8.2 nm rms

Mirror best flat
~ 8nm RMS on D100,
< 6nm RMS on D90



Space Active/Adaptive Optics Testing Facility

All components addressed :

- Characterization of active/adaptive mirrors
- Characterization of wave-front sensors
- Characterization of control algorithms

Perfectly characterized in term of performance / stability

Considered as a CNES reference testing facility for space active optics

Adjustable configuration :

- Adjustable entrance and DM pupils dimensions
- Image/Pupil planes wave-front sensors
- Static or dynamic WFE generation
- Controlled environment (temperature, vibrations, stray light, etc.)
- Automated bench : optical configuration, entrance scenes, data acquisition, etc..

MOEMS Testing Facility

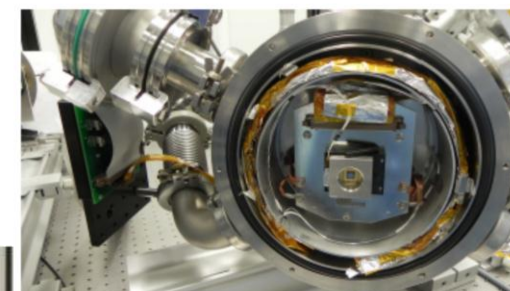
Different characterization benches:

- Interferometric bench with 2µm resolution in X-Y and subnanometric in Z
- Small cryogenic chamber option available
- Dedicated cryogenic facility (~40K) for small optical systems

Measurements :

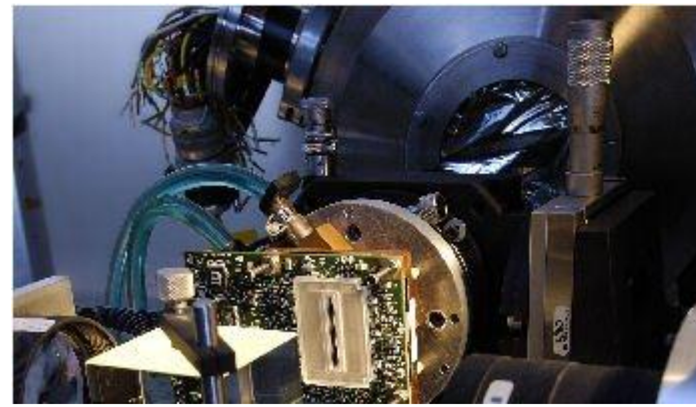
- Surface deformation,
- Stroke,
- Influence function,
- Dynamic behaviour,
- Repetability, stability

See also F. Zamkotsian presentation on MOEMS

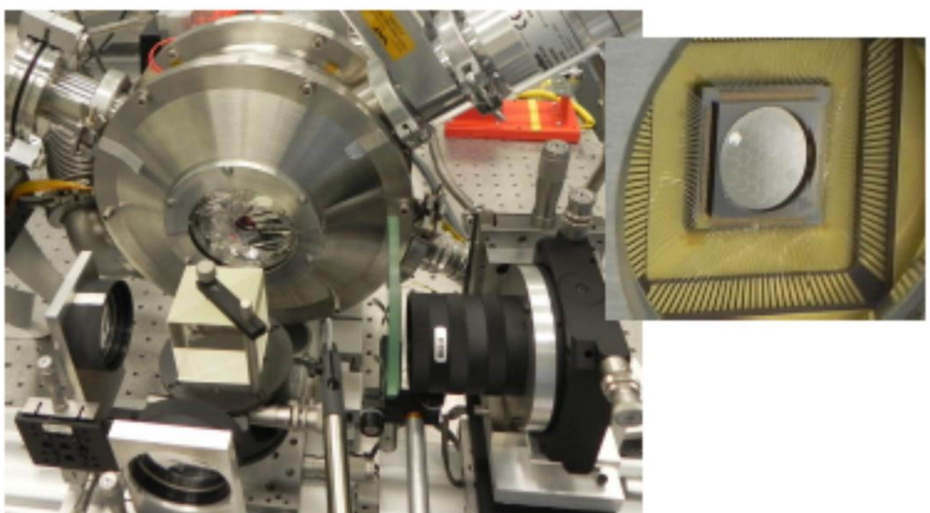


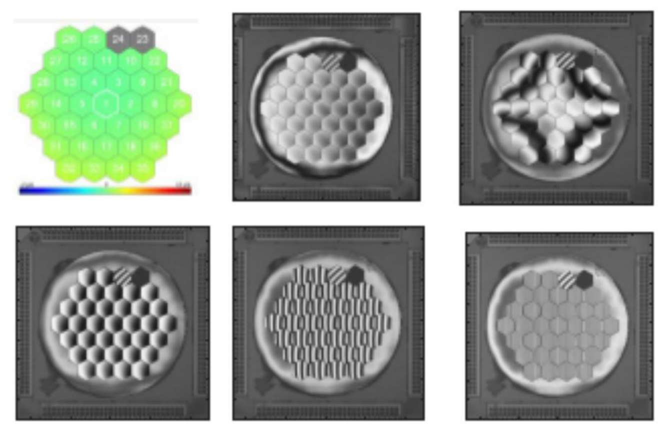
Characterization of Deformable Mirrors

- **Tests on multiple continuous membrane devices at ambient temperature :**
  - LAAS DM,
  - OKO (electrostatic and piezo),
  - ALPAO,
  - Boston Micromachines (1k DM)



- **Tests in cryogenic environment (160K)** :
  - IRIS AO segmented DM: PTT111





On-going developments / collaborations

Support to space industry for components development :

- From TRL4 to TRL7-8
- Expertise in design/conception, characterization, etc..

Strong PhD research program with renowned partners:

- *Space active optics for high angular resolution observation – Wavefront control strategy*
  PhD funded by CNES/ ONERA (2012-2015)
- *Optical space complex systems for high angular resolution imaging*
  PhD funded by DGA (Defense Ministry) / Aix-Marseille Univ. (2014-2017)
- *Space Active Optics strategies for wide field telescopes*
  PhD funded by NASA/STScI and ONERA (2015-2018)
- *High contrast and co-phasing strategies for segmented space telescopes*
  PhD funded by NASA/STScI and ONERA (2015-2018)
- *Large lightweight space mirrors manufacturing*
  PhD funded by Thales Alenia Space (2017-2020)

ONERA
THE FRENCH AEROSPACE LAB

SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

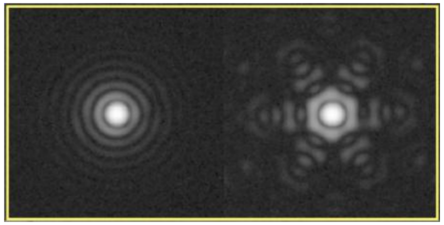
Close collaboration with NASA/AURA STScI (Baltimore)

- High contrast imaging, complex apertures, co-phasing and alignment strategies, ...

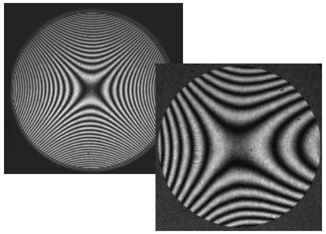
  → Strong involvement in future space instrumentation : WFIRST, + LUVOIR/HabEX ? .

High quality aspherics / off-axis optics

- ✓ Instrument static and quasi-static speckles impact the high contrast performance of coronagraphic images
  - Low spatial frequency (LoF) (→ Nact/2) are corrected by DMs
  - MiF and HiF remain in the coronagraphic image



- ✓ Importance to minimize these errors at the polishing state
  - Relaxes requirements on the WFS
  - Improve final contrast, bandwidth, effective IWA..

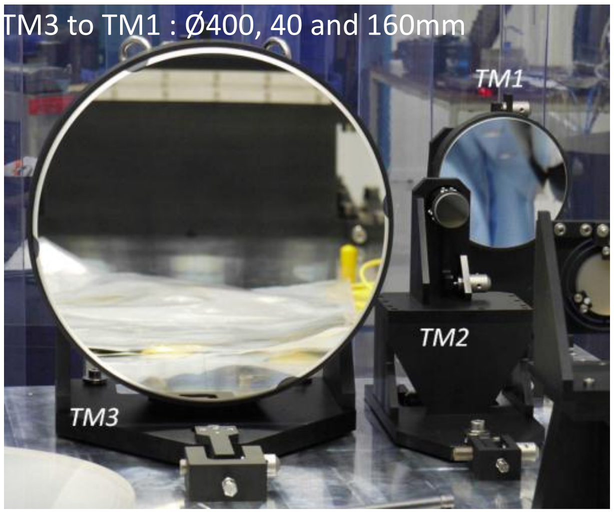


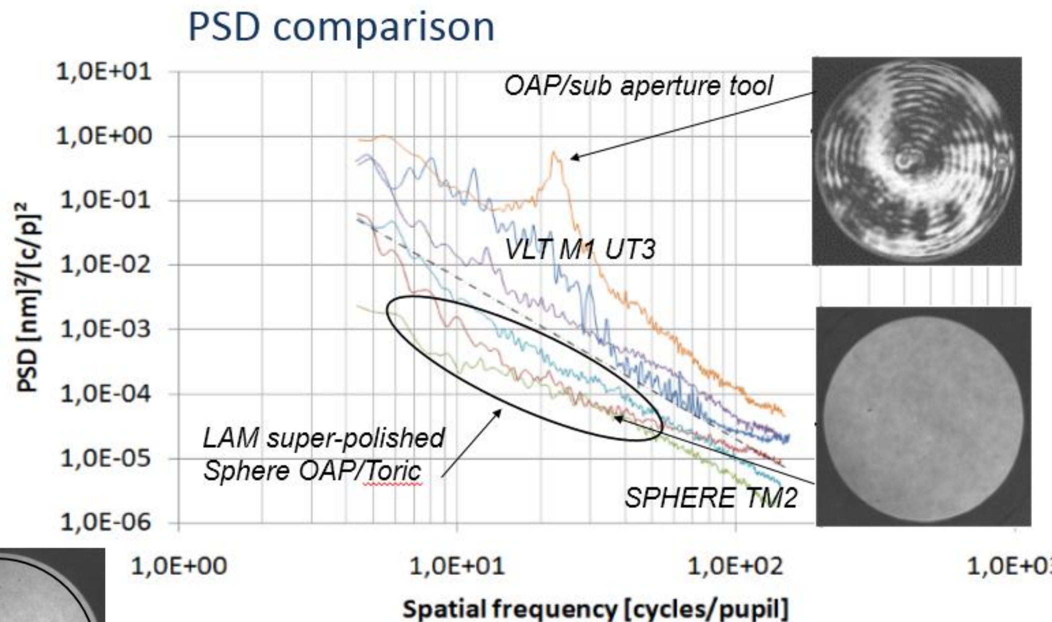
LAM developed a dedicated optical fabrication method, using active polishing

- Perfectly suited for Toric mirrors, Off-axis parabolas, etc.. (Sph3 + Ast, Com, Tri, …)
- Exquisite results : LoF <10 – 20 nm rms (including form error)
  MiF / HiF ~ 1- 2nm rms
  Roughness ~ 2 – 5 Å rms
- Available up to 450 mm Ø mirrors [F/5 - F/3 optics] with off-axis distance up to 3 times diameter

Super polished off-axis optics already delivered to
ESO VLT-SPHERE instrument and HiCat bench @ STScI

High quality aspherics / off-axis optics

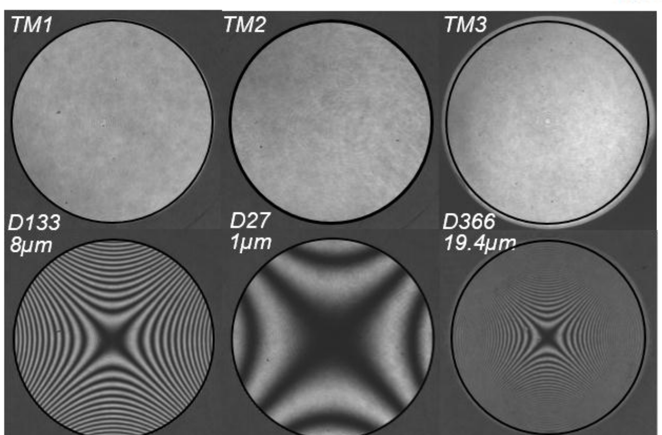




Polishing under stress →

Toricity

Aspherical relaxed state →



		TM1	TM2	TM3
Optical quality	*LF*	9.0nm	7.5nm	22.0 nm
	MF	1.3nm	1.1nm	2.5nm
	HF	1.1nm	--	1.6nm
Roughness		**5 Å**	**2 Å**	**9 Å**

VLT SPHERE toric mirrors

Delivered to SPHERE in 2011

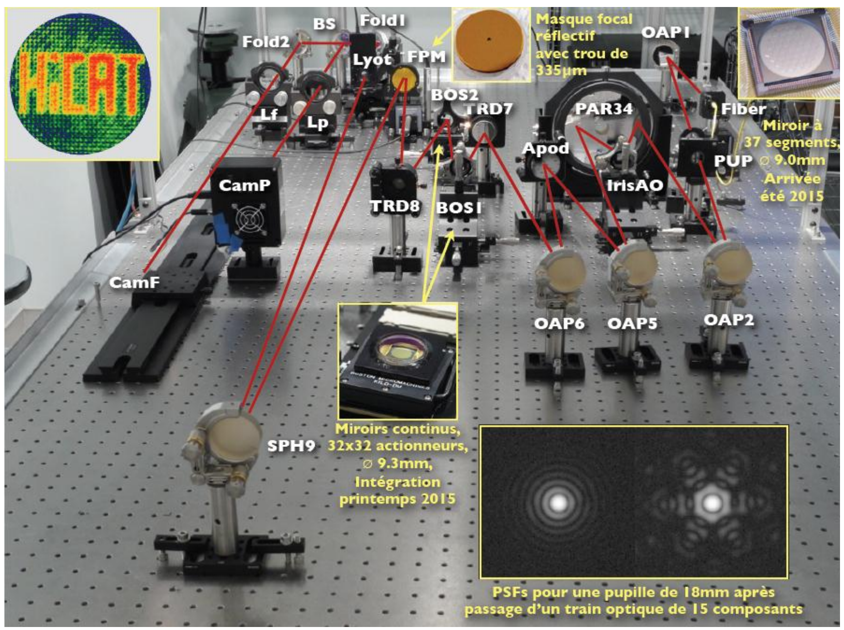
+ one spare in 2013

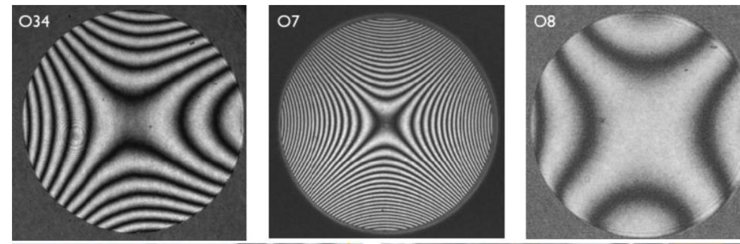
Hugot + 2009 (Ap.Opt) ; Hugot + 2012 (A&A)

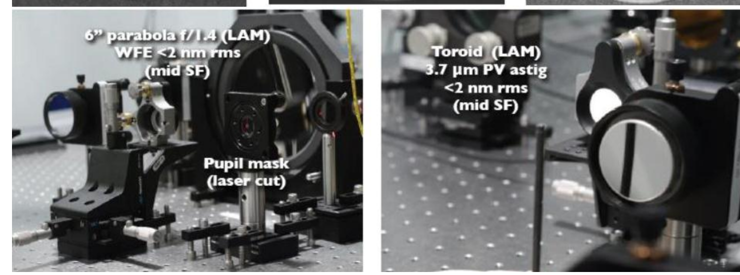
High quality aspherics / off-axis optics

NASA-STScI / HiCat mirrors
High contrast platform @ STScI

- ✓ Same challenges as SPHERE, in terms of surface quality
- ✓ Delivery of 3 super-polished off-axis mirrors in 2013







	O34	O7	O8
LoF WFE [nm]	13.0	7.0	6.4
MiF WFE [nm]	1.5	2.0	1.5
HiF WFE [nm]	1.3	2.2	1.6
Roughness [nm]	0.4	0.5	0.4

Exquisite results (without AO !)

HiCat WFE only 12nm rms after 15 optics

N'Diaye, Soummer+ 2014

On-going discussion with NASA-WFIRST and CNES for delivery of all CGI OAPs