The next leap in LUVOIR space Astronomy

R&D activities undertaken at LAM

Dr Emmanuel HUGOT

Aix Marseille University, CNRS

Laboratoire d'Astrophysique de Marseille

On behalf of the LAM R&D optics group

www.lam.fr/optique-instrumentation

Beyond JWST: challenges

Narrow Field

- ✓ Ultra stability: 10 picometers over 10-20min exposures
- ✓ Segments vibration control, pointing jitter
- ✓ Ultra-smooth exotic optics

Wide field

- ✓ High throughput → less optics
- ✓ High angular resolution
- ✓ PSF uniformity in the field

And more:

- ✓ Multiplex, Broad wavelength range
- ✓ Low noise/large formats photon counting detectors
- ✓ Lightweight, active structures and mirrors
- ✓ …

A VLT-SPHERE on-sky exposure
A few nm stability over 20min

A GeMS wide field pic of N159W (LMC)

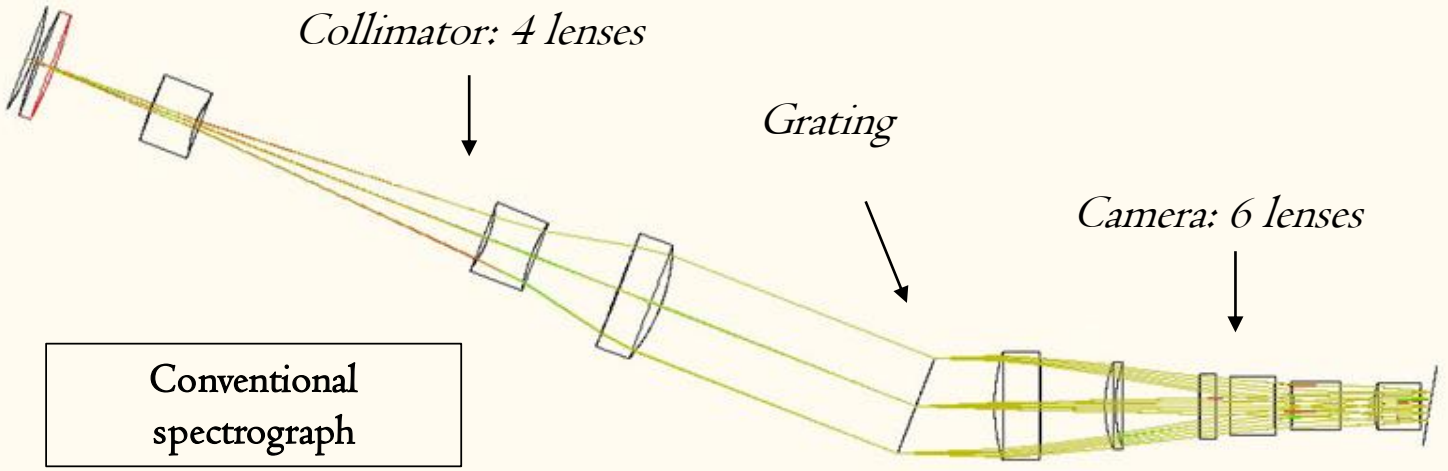
Bernard, Neichel et al 2016 (in prep)

TOWARDS COST-EFFECTIVE INSTRUMENTATION

INNOVATIVE OPTICAL DESIGN
OPTICAL FABRICATION AND TESTING
INNOVATIVE DETECTORS

Innovative optical design

From Cuby+ 2006



Conventional spectrograph

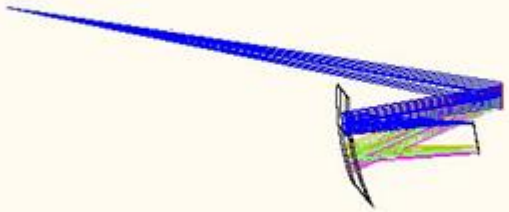
Length: 2.0 m

Only 2 mirrors

- ✓ **Volume** gain x5
- ✓ **Throughput** gain 20%
- ✓ No chromaticity
- ✓ Simplified AIT phase

Length: 0.6m

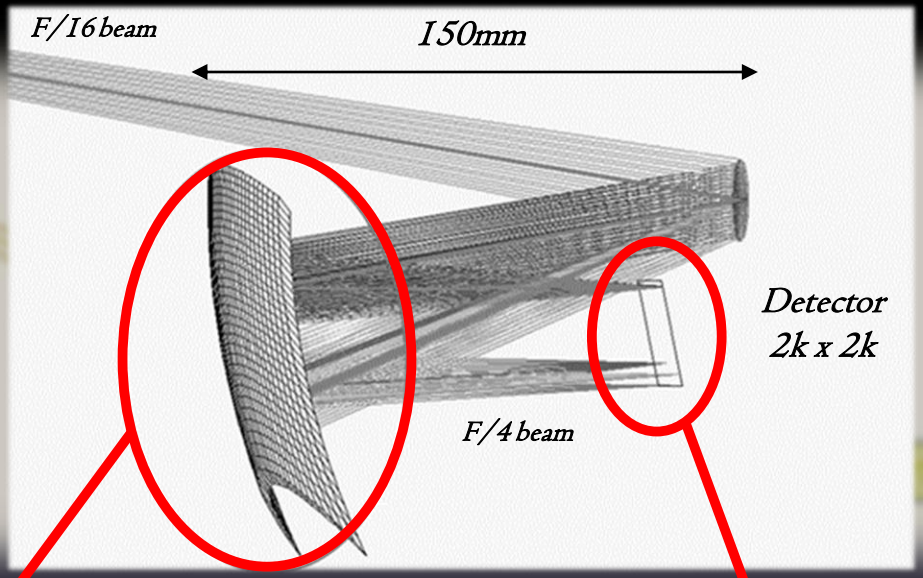
No collimator



Grating

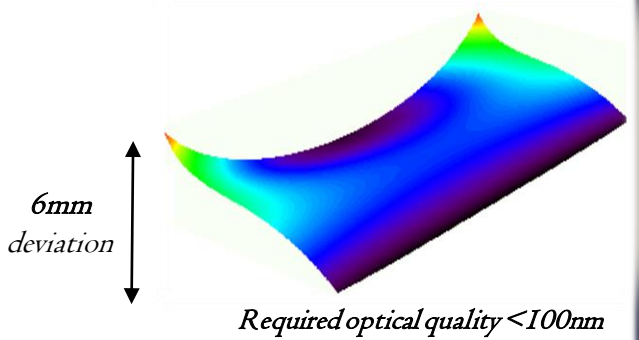
Camera: 1 freeform(!)

The price to pay



1. Extreme freeform shape

10 times higher than state of the art



2. Flat field, large detector

Increased optics complexity

Overcome fabrication limits

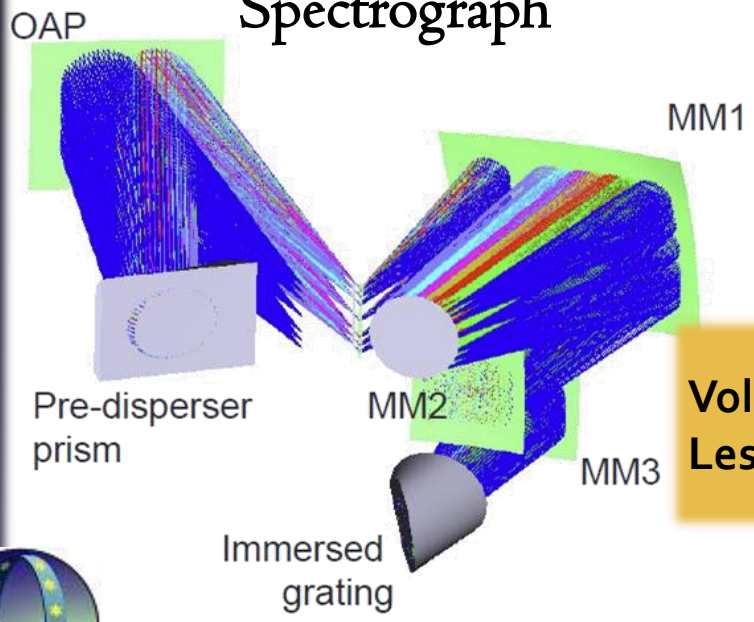
→ Make them active

→ Curve the focal plane

Innovative optical design

- **Develop** - Mathematical descriptions
  - Optimization methods
- **Perform** Comparative studies on existing instruments

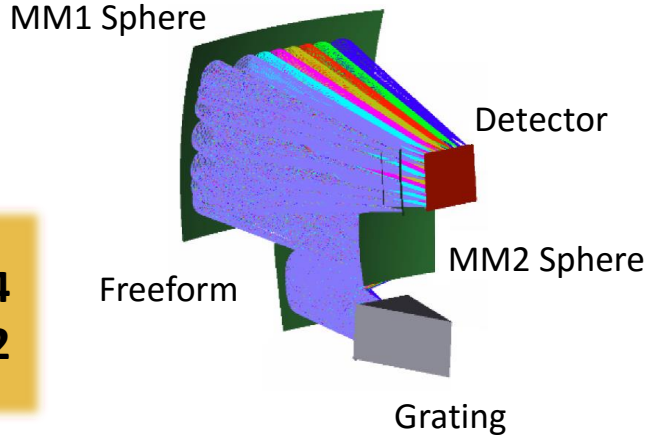
The E-ELT METIS Spectrograph



Volume gain x 4
Less optics x 2

Agocs et al. SPIE 2014
Hugot et al. SPIE 2014

Preliminary study



Only one complex element!

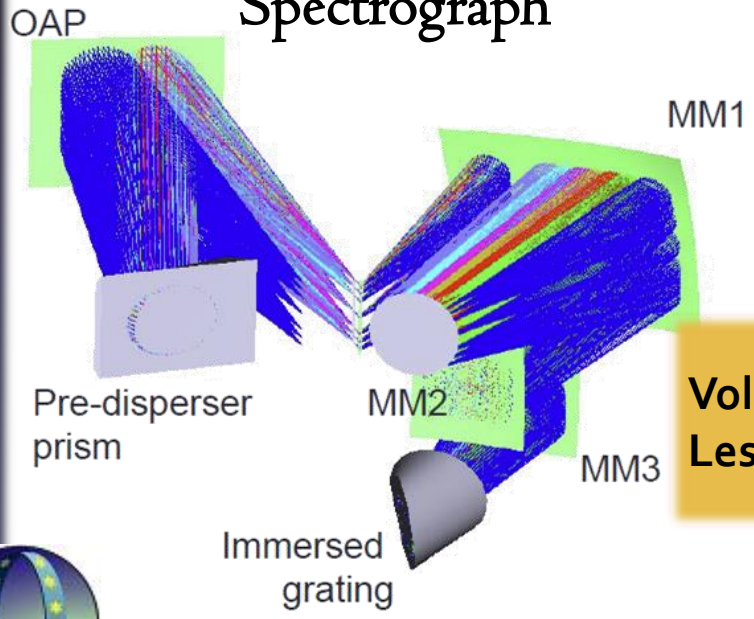
Innovative optical design

- **Develop** - Mathematical descriptions
  - Optimization methods
- **Perform** Comparative studies on existing instruments

Post doc Eduard Muslimov (2017-18, LAM) on innovative optical design

The E-ELT MOS Spectrograph

Puget et al. SPIE 2014



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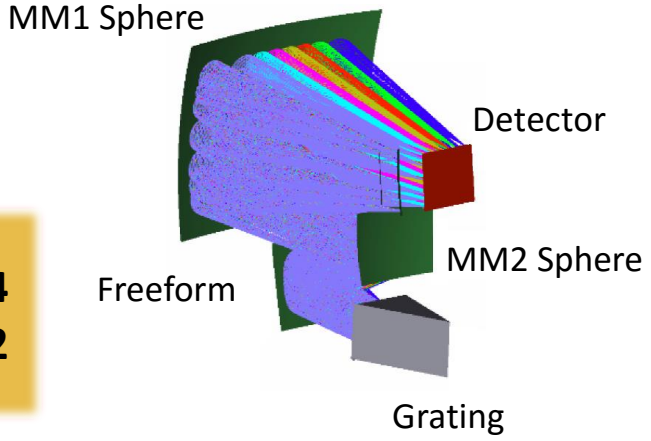


Only one complex element!

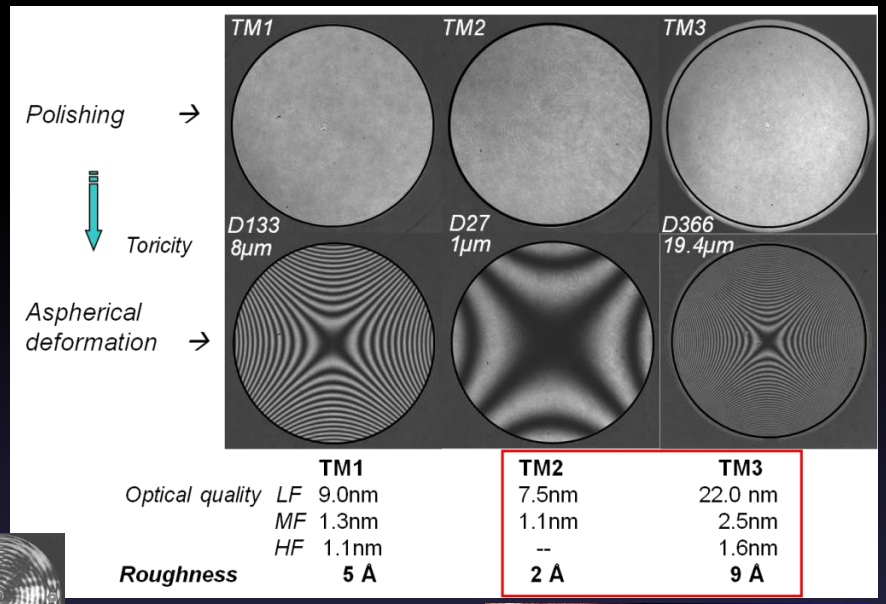
Super-polishing of the SPHERE OAPs

Exquisite results

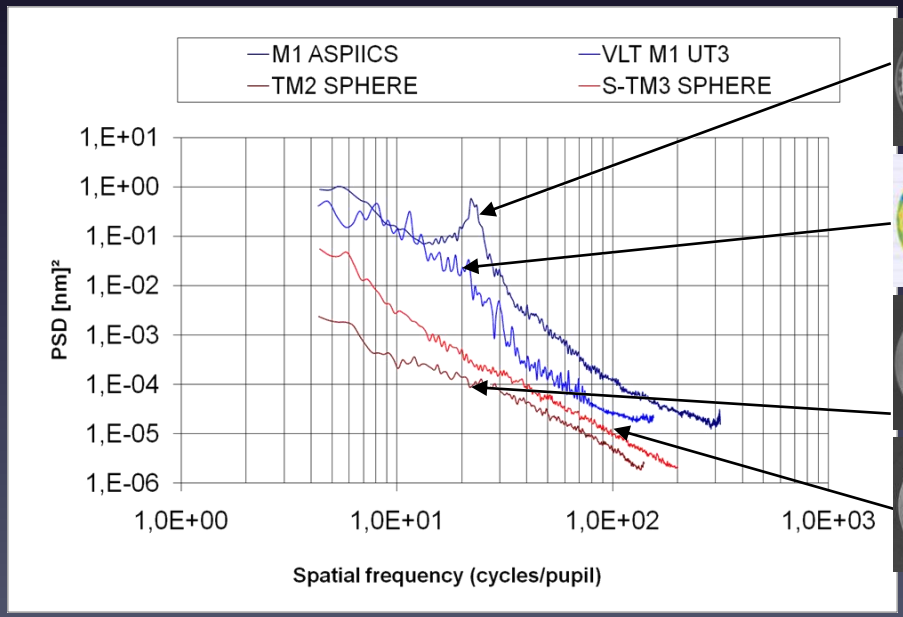
- Form errors ~10-20nm RMS
- Ultra-low HF level ~1-2nm RMS
- Sub-nm roughness ~5 Angströms

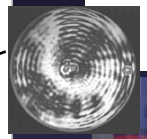
Delivered to SPHERE in 2011
+ one spare in 2013

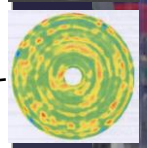
Hugot+2009 (App. Opt.)
Hugot+2012 (A&A)

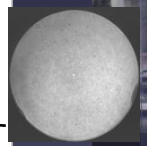


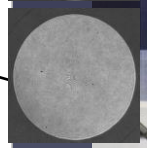
		TM1	TM2	TM3
Optical quality	LF	9.0nm	7.5nm	22.0 nm
	MF	1.3nm	1.1nm	2.5nm
	HF	1.1nm	--	1.6nm
Roughness		**5 Å**	**2 Å**	**9 Å**

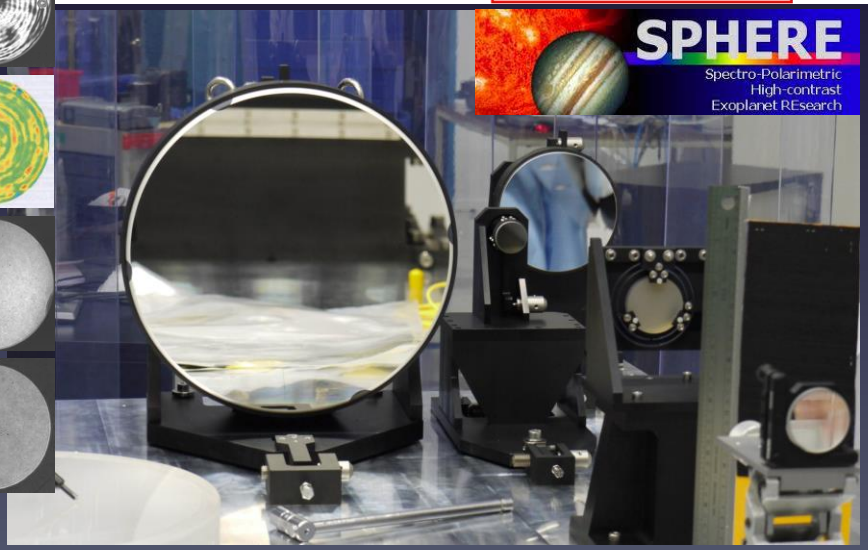








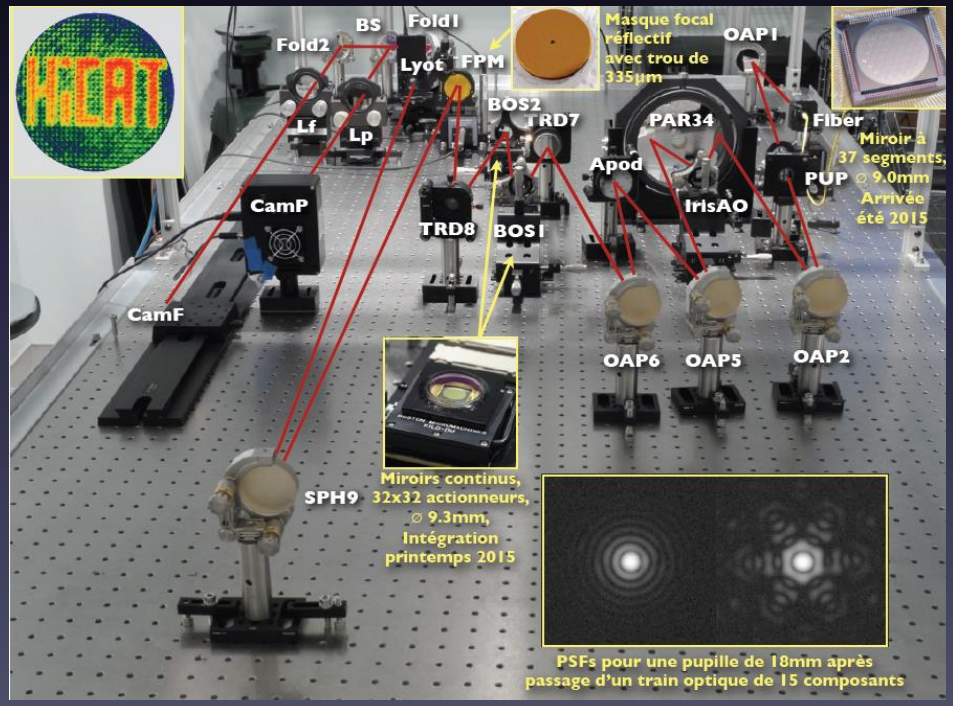


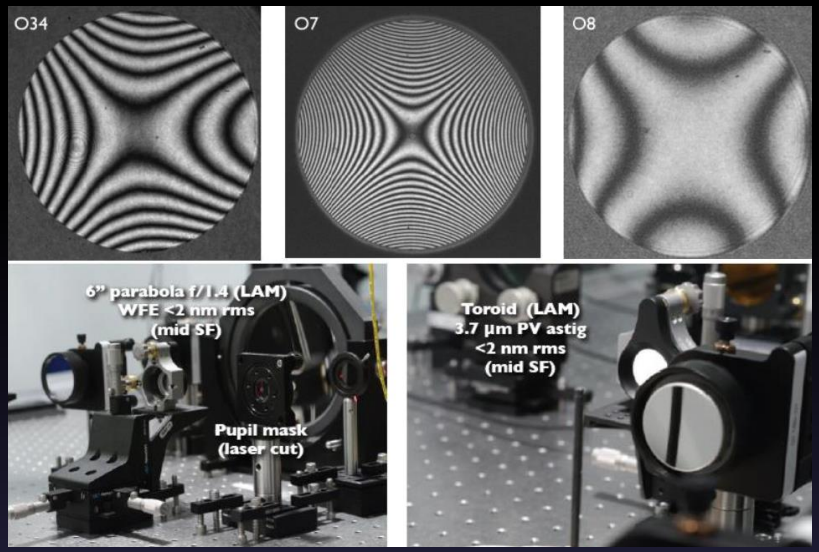


NASA-STScI / HiCat off axis mirrors

HiCat = high contrast platform @ STScI

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





Exquisite results too:

Only 12nm WFE after 15 optics!

	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

N'Diaye, Soummer + 2014
Leboulleux+ 2016

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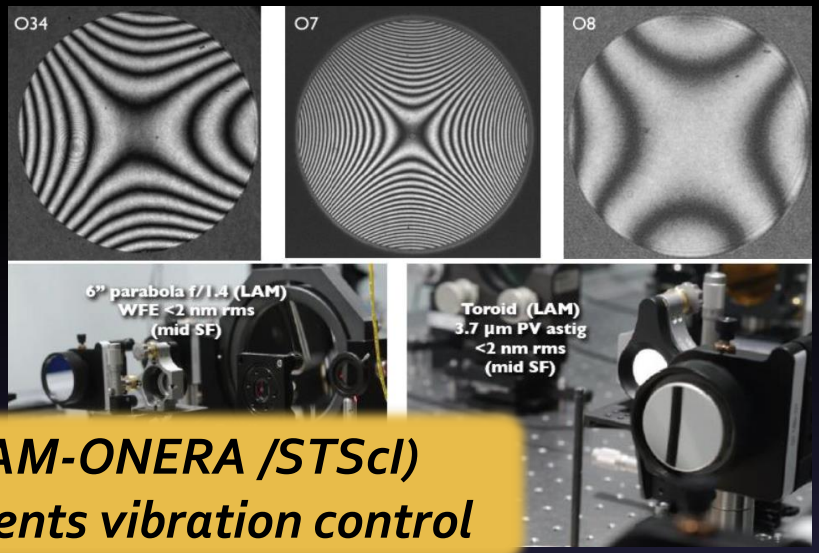

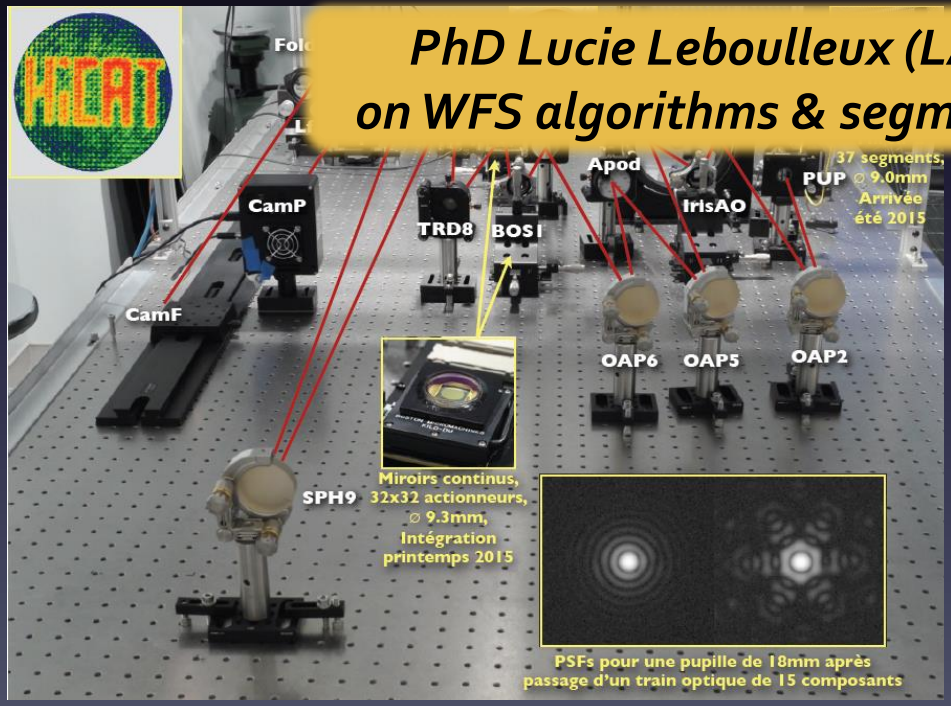

PhD Lucie Leboulleux (LAM-ONERA /STScI) on WFS algorithms & segments vibration control

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Fast low noise detectors

OCAM – OCAM2
SPHERE and SCExAO WFS

- 240x240pixs
- 3 500 Hz frame rate
- 0.3 e- Read out Noise

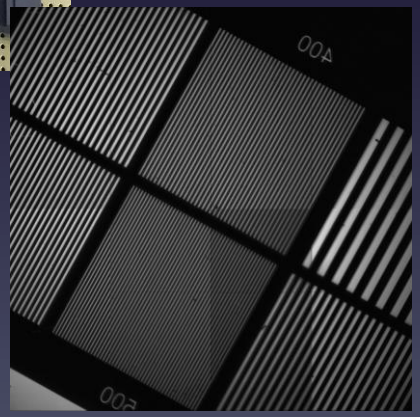
FIRST LIGHT ADVANCED IMAGERY

> 30 OCAM2 cameras delivered by FLI for AO application and others since 2011

4k x 4k EMCCD 282
Ultra low noise + photon counting!

- Chip size : 125 mm ! 20µm flatness
- 4k x 4k frame transfer image
- Noise <1 e- (!!) -5fps

Univ Montreal
LAM
E2V



First image @ -60°C
(Courtesy E2V)

Contact:
Jean-luc.gach@lam.fr

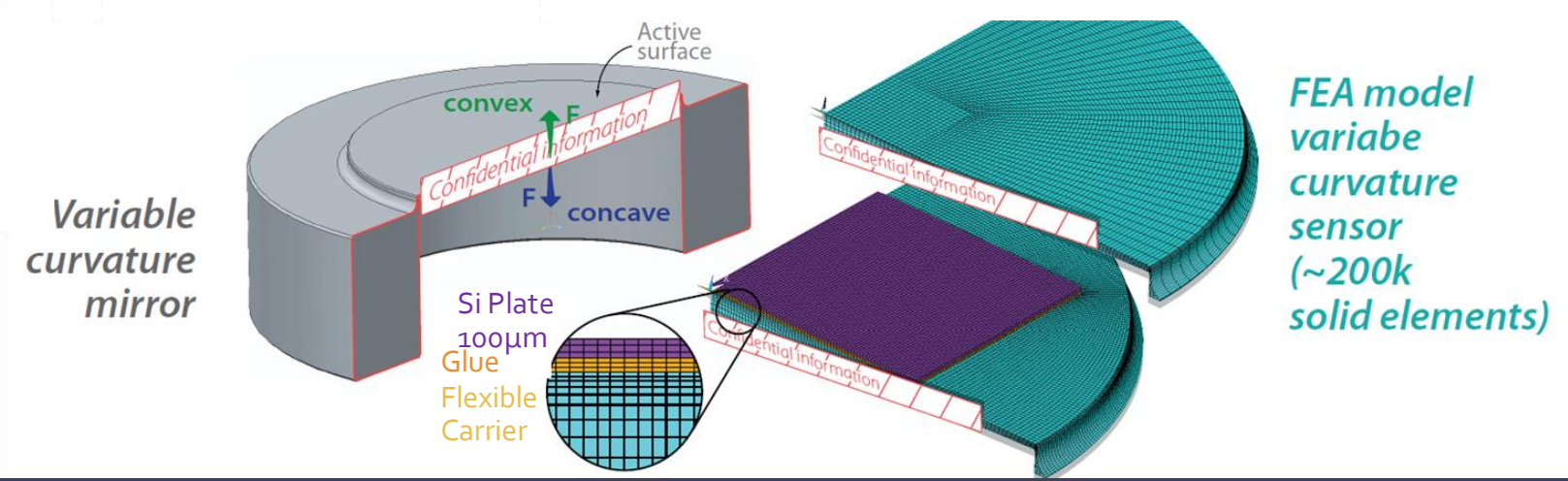
11

Flexible focal plane arrays

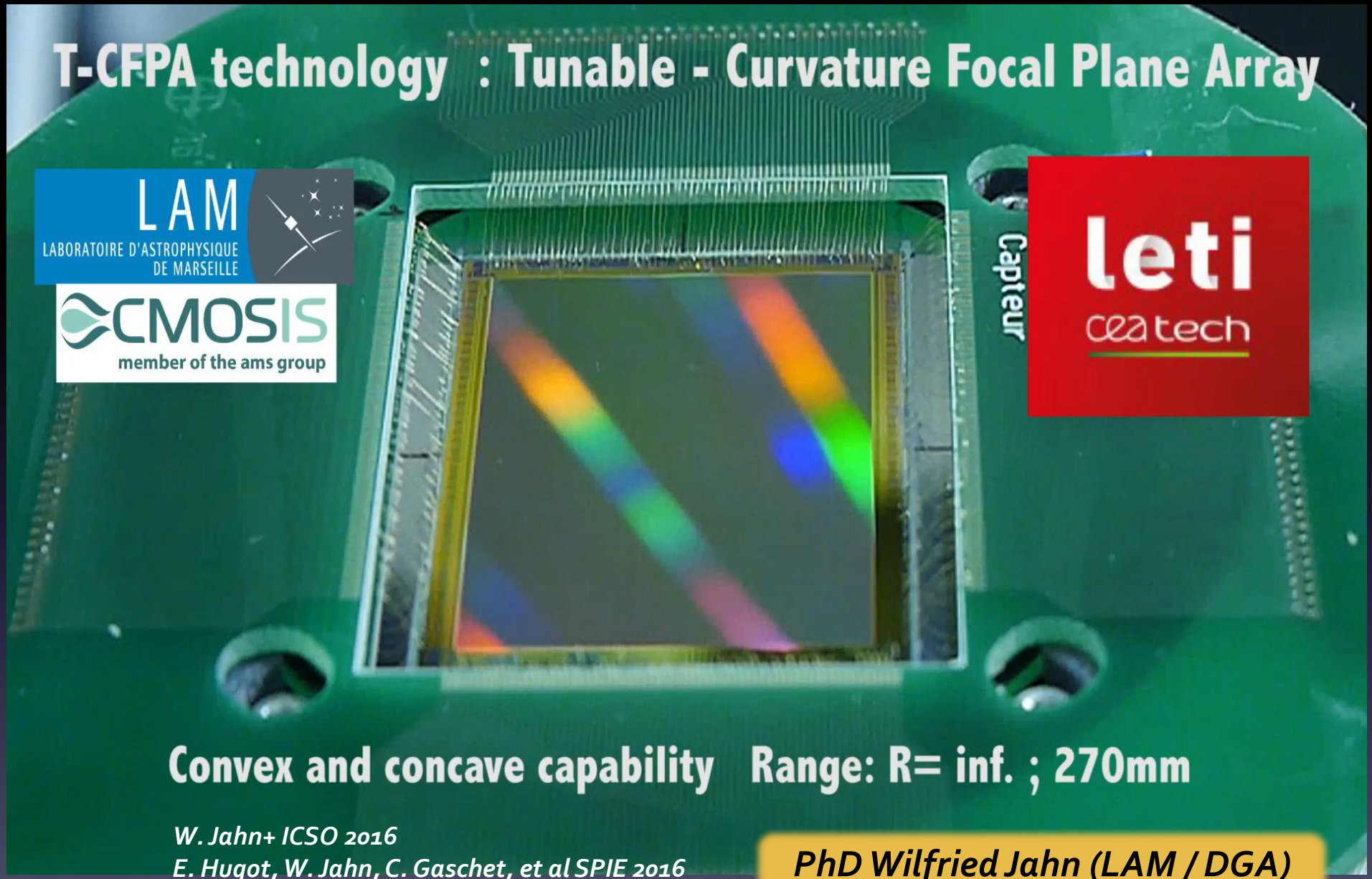
Principle:
Combine active mirrors and flexible arrays

Gain

- Control the bending of the substrates
- Reach any curvature before breakage
- Test performance over a broad range of curvature
- Simplify manufacturing process?



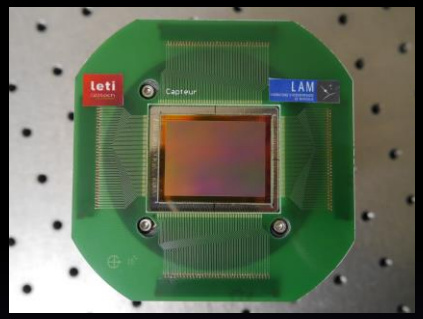
Ferrari 1998, A&A → *Variable Curvature mirrors for the VLTI*



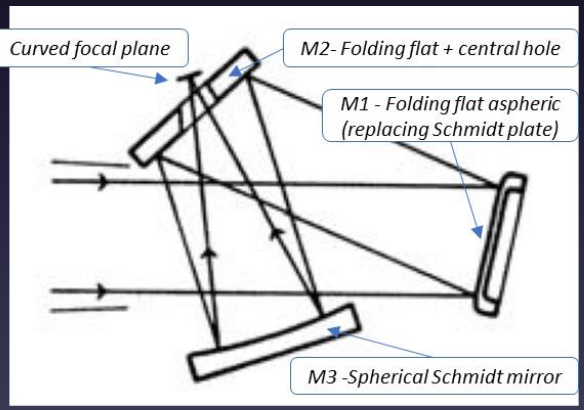
W. Jahn+ ICSO 2016
E. Hugot, W. Jahn, C. Gaschet, et al SPIE 2016

PhD Wilfried Jahn (LAM / DGA) on innovative focal plane arrays

Towards a ground-based demonstrator



- **ERC program 2016-2021**
  - PhD and Post doc positions
  - A 350k CFT to be issued for prototypes realization next year
  - Leverage to structure activity with ESO and ESA



- **Program 2017-2020**
  - Ground based VIS demonstrator (50cm, F/2)
  - Opportunity to have a psychological impact with an on-sky system (Collab D. Valls-Gabaud)

Post doc Simona Lombardo (2017-18, LAM) on system optimization vs science return

TELESCOPE-WISE APPROACHES

CO-PHASING TECHNIQUES FOR SEGMENTED APERTURES
ULTRA LIGHTWEIGHT LARGE MIRRORS
SPACE ACTIVE OPTICS

Cophasing techniques

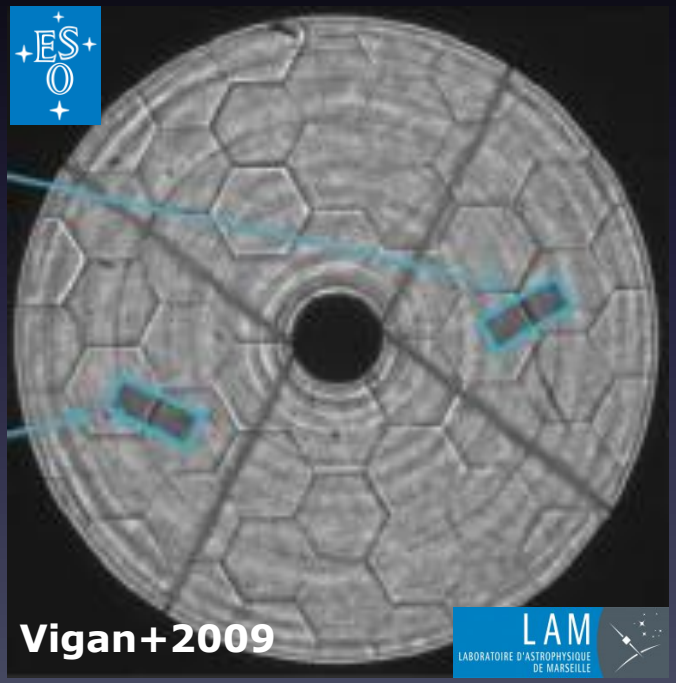
The ESO/APE demonstrator

APE = Active Phasing Experiment (2008-2009)

- Fine phasing through the turbulence
  <10nm RMS with the Zernike Sensor
- 30 nights of qualification and tests @VLT

Segmented pupil relay

Pupil image @VLT



Scalable for space use

- *AIT on ground*
- *Fine phasing in flight mode*

Increased performance in turbulence-free environment

Contact:
Arthur.vigan@lam.fr

Cophasing techniques

The ESO / PEACE platform

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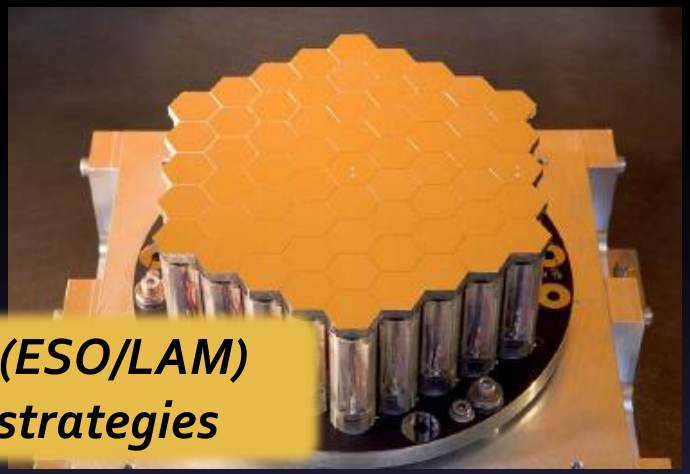

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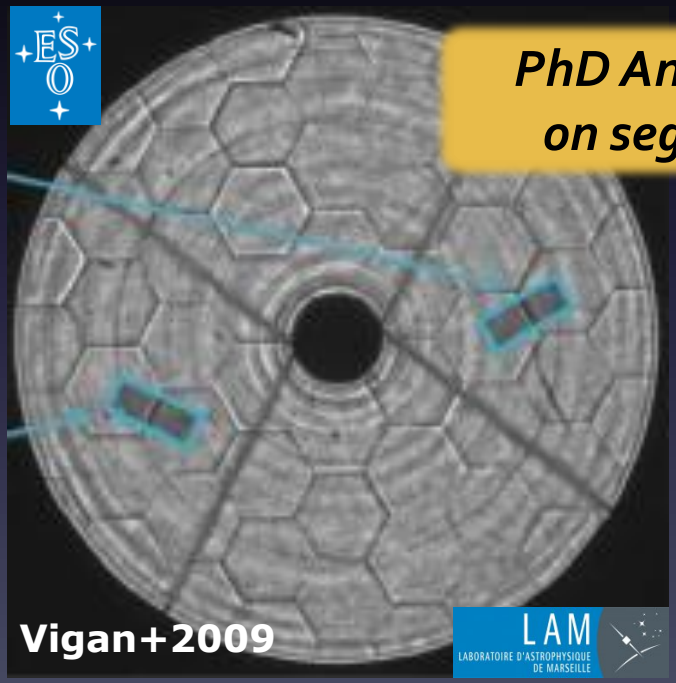

PhD Anne-Laure Cheffot (ESO/LAM) on segments cophasing strategies

Scalable for space use

- *AIT on ground*
- *Fine phasing in flight mode*

Increased performance in turbulence-free environment

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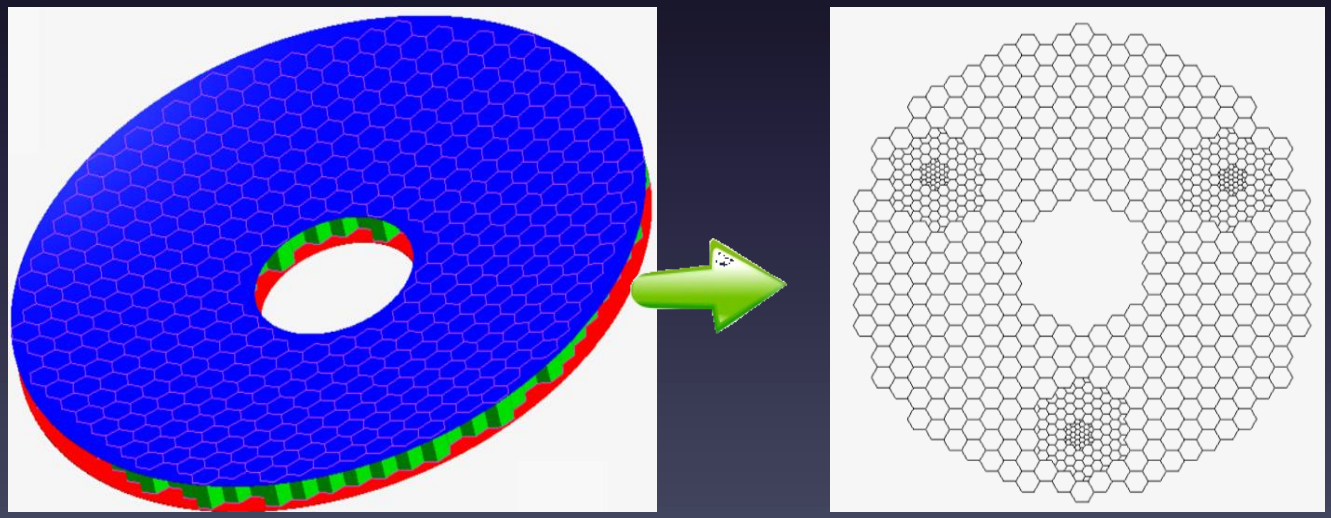
Ultra-lightweight large mirrors

Large mirrors from 1.5m to 4m class:

- Sandwich like mirror structure
- From regular pattern to locally increased honeycomb density
- FEA simulation to extract print through effect



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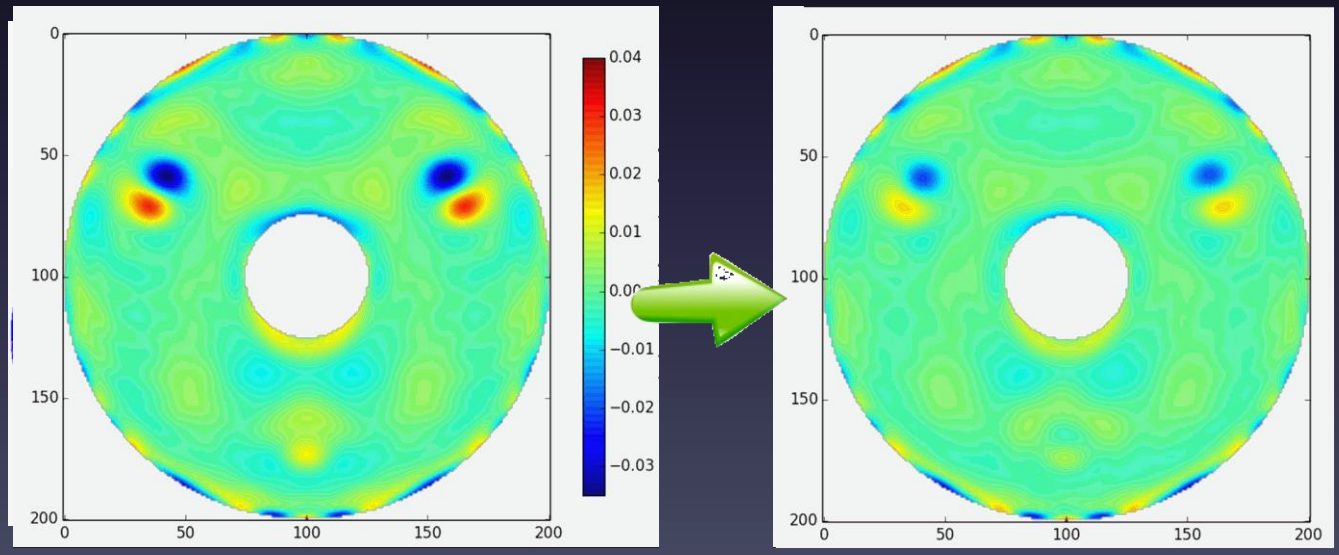

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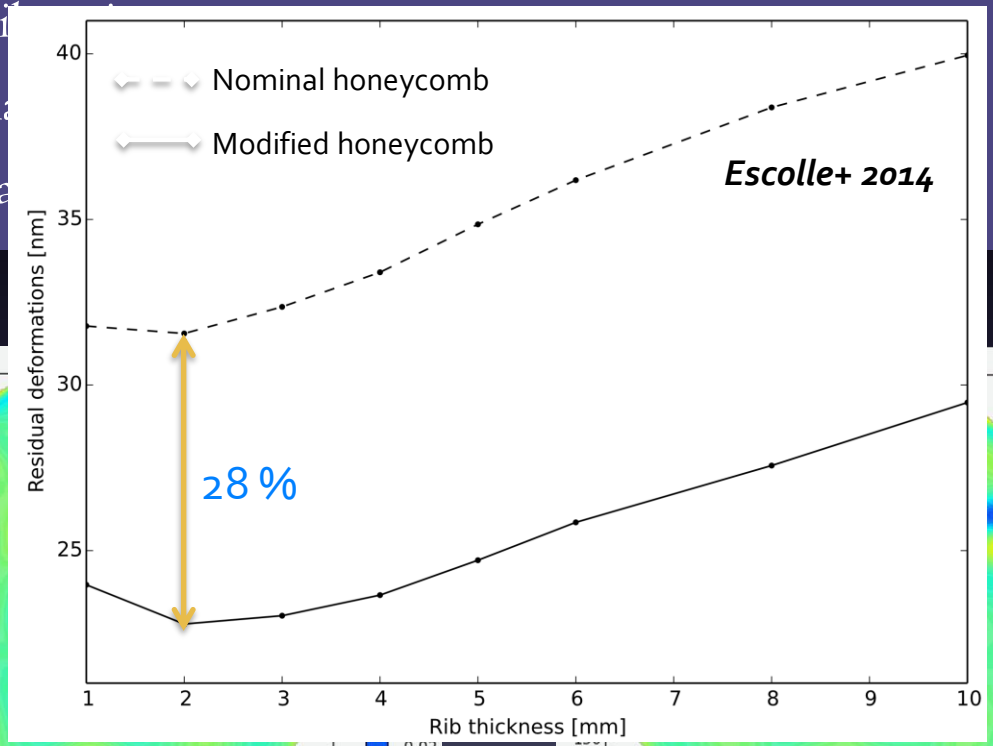


PhD Sabri Lemared (2017-2019, LAM) on ultralightweight large mirrors manufacturing

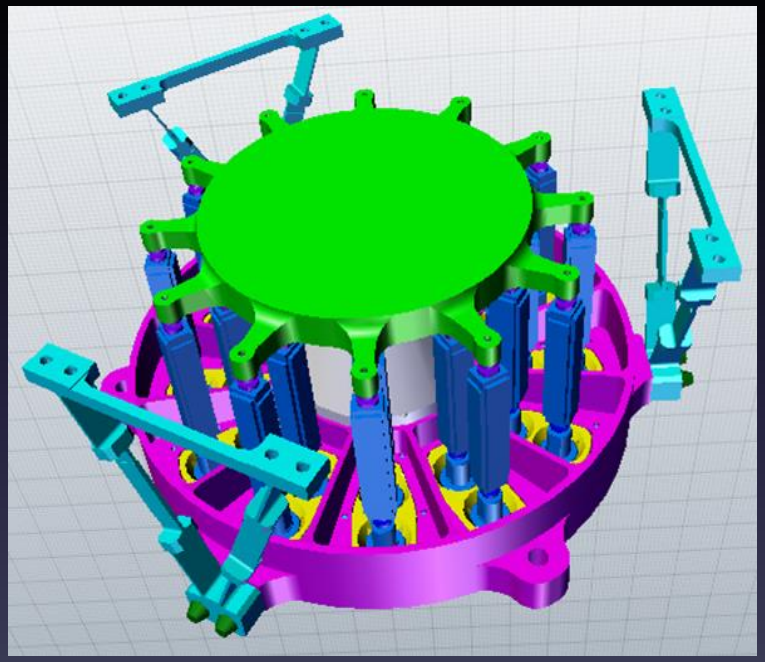
Space Active Optics: MADRAS

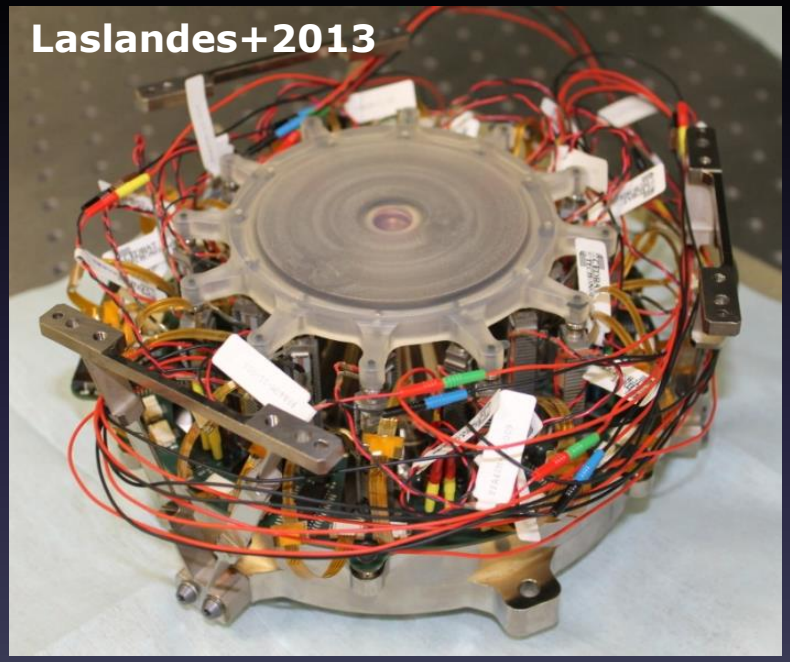
Mirror **A**ctively **D**eformed and **R**egulated for **A**pplications in **S**pace

Boundary actuation → *No actuator print-through*

100mm diameter - 24 external actuators

Number of actuators *not* driven by the mirror size!





MADRAS CAD model and prototype

Co-Optimisation of the **mirror+ harness for an utmost performance**

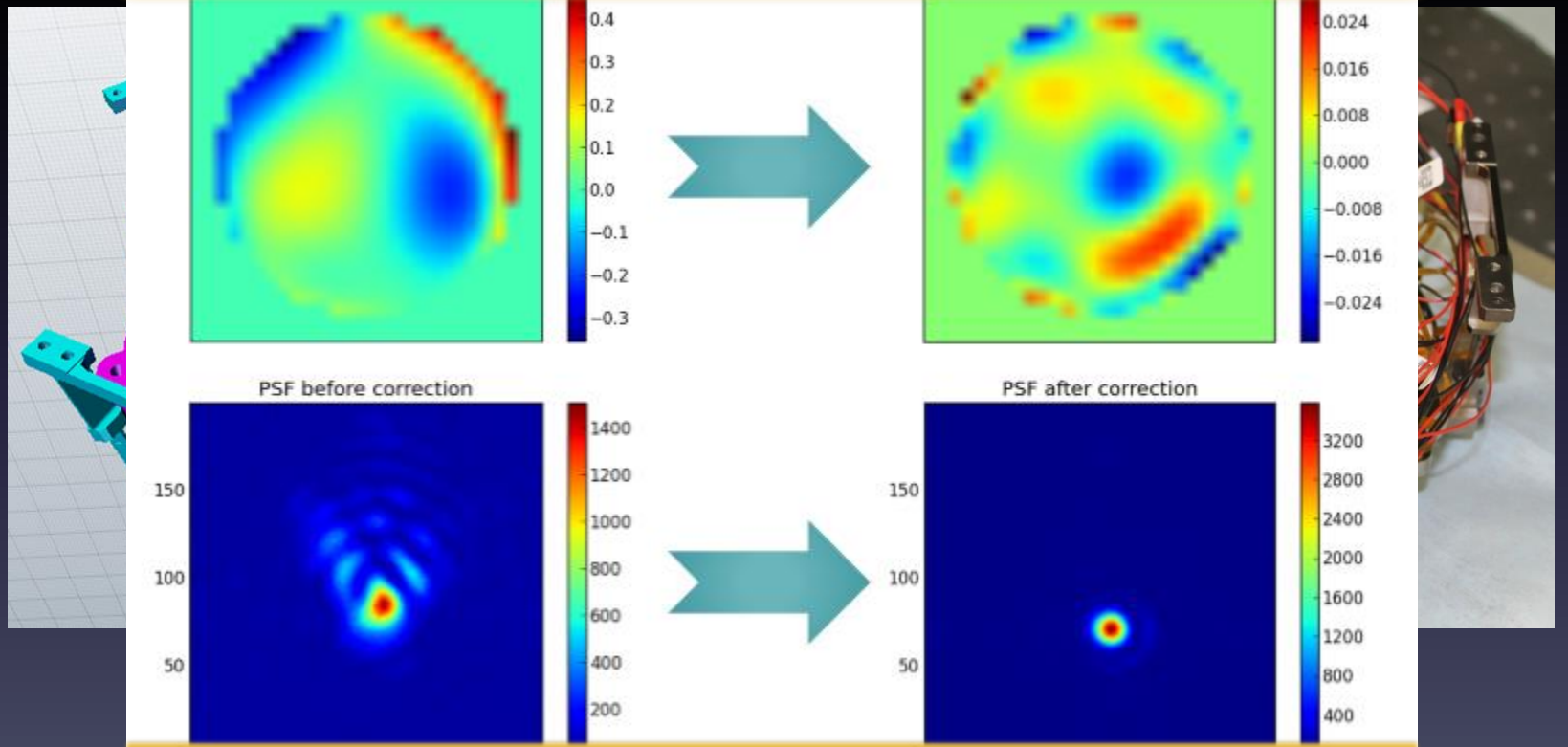
Contact:
Marc.ferrari@lam.fr

Space Active Optics: MADRAS

Mirror **A**ctively **D**eformed and **R**egulated for **A**pplications in **S**pace

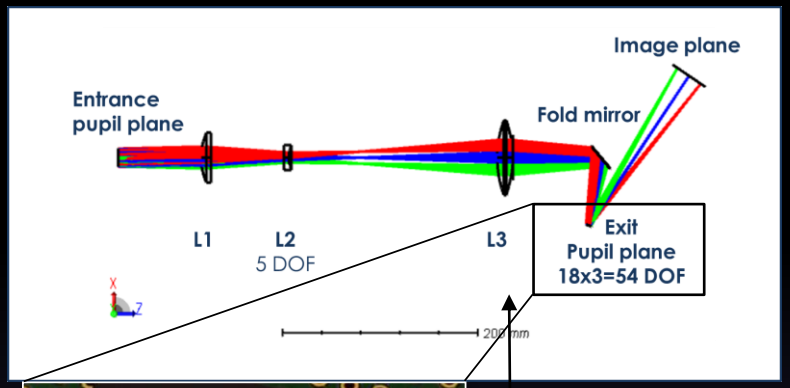
PhD Marie Laslandes 2012 (LAM / CNES/THALES) on space active optics

→TRL6 in 2017



WFE and PSF - before and after correction

Wide field active telescopes



JOST (JWST Optical Simulator Testbed)

- FoV: 3.4°x3.4°
- F#: 30.2
- <20nmRMS

SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

Alignment strategies for a wide field active telescope

PhD Sylvain Egron (LAM-ONERA/STScI) on control strategies over wide fields

Egron et al SPIE & ICSO 2016

Contacts:
egron@stsci.edu
marc.ferrari@lam.fr
soummer@stsci.edu

Wrap up

Towards cost-effective instrumentation

➢ Innovative optical Design	→ Post Doc Eduard Muslimov	ERC
➢ Optical fabrication	→ PhD Sabri Lemared	THALES
➢ Curved detectors	→ PhD Wilfried Jahn	DGA
	→ Post Doc Simona Lombardo	ERC

➢ Telescope - wise approach

➢ HC with complex apertures	→ PhD Lucie Leboulleux	STScI/ONERA
➢ Cophasing techniques	→ PhD Anne-Laure Cheffot	ESO/LAM
➢ Space Active Optics 2016-17: MADRAS → TRL6, 2018: Industrial knowledge transfer	→ PhD Marie Laslandes	
➢ Wide field Active Telescope	→ PhD Sylvain Egron	STScI/ONERA