R&D Testbenches In France
For High Contrast Imaging In Space

ASHRA/CNES meeting

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Raphaël Galicher
Maud Langlois
Jean-François Sauvage
Patrice Martinez
Alexis Carlotti

Needs For Astrophysics And Needed Studies

Needs for astrophysics

High contrast levels: ~ 1e-10 contrast
Large spectral band: >200nm in visible ; >500nm in NIR

Needed studies

Coronagraphs

Chromatism	Segmentation/Obscuration
Pupil apodization	Post-coronographic apodization
Small IWA	Adaptative components

Wavefront control

Chromatism	Segmentation	Phase&amplitude
HOWFS	LOWFS	
Jitter	SLM	micro-miroirs

A posteriori speckle calibration

Coherence	Statistics

Space TRL

Free @ Ipag bench

Objective

Measurement and control of Fresnel effects using Electric Field Conjugation (EFC)
Coronagraph characterization

Main components

- Polychromatic (Nir)
- Focal phase mask + pupil apodization
- 32X32 BMC (at ESO today)

Not usable since 2015

Activities

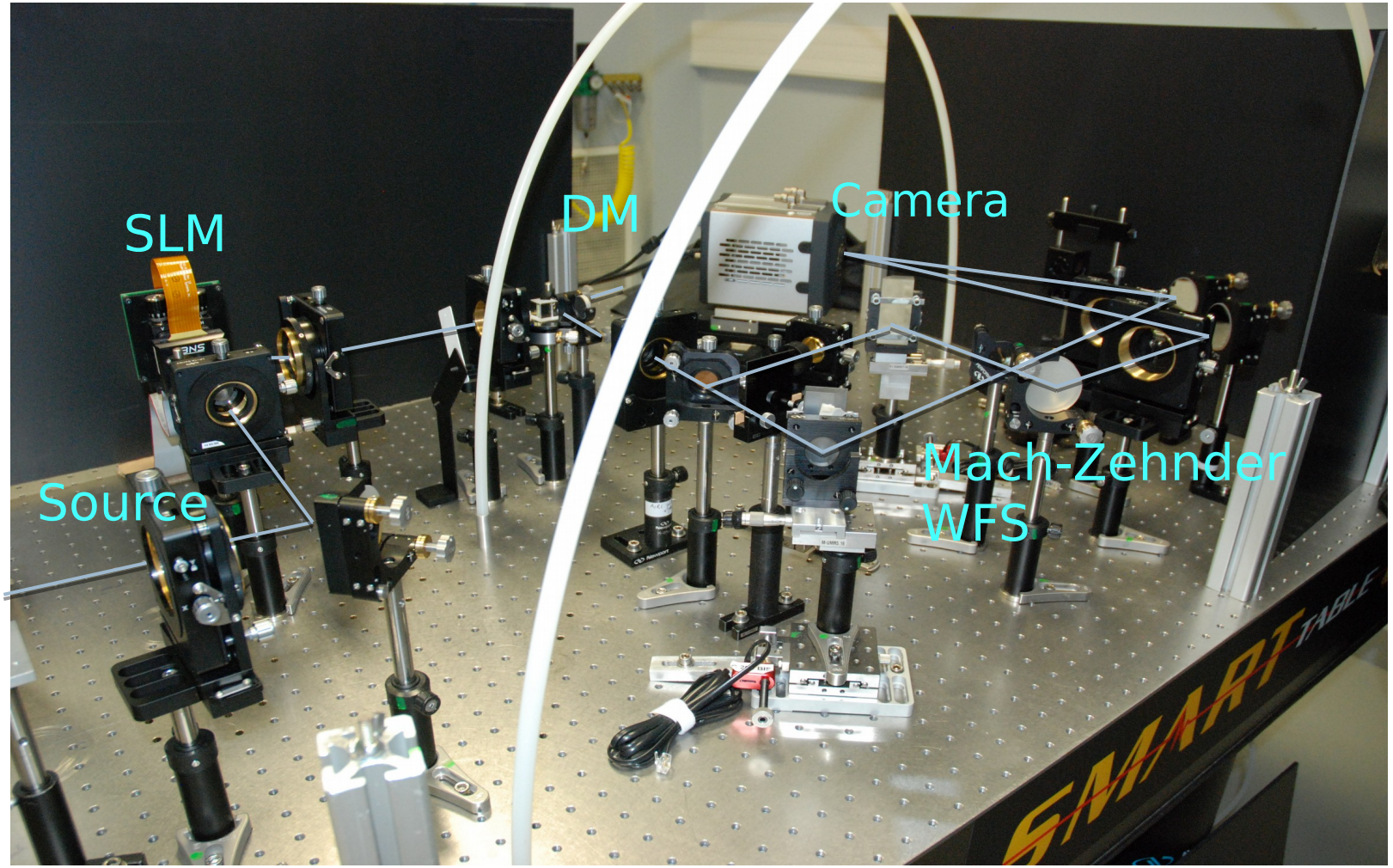
- Measurement via EFC (tested @ Sphere : gain of 12 on internal source and 5 on-sky)
- Control loop of HOWFS

Perspectives

- 2017: characterization of Shark/LBT coronagraphs (throughput, defects, PSF properties)
- 2018: micro-mirror matrices (amplitude correction, pupil apodization) + LO DM

Vérinaud et al. 2011 ; Kasper&Vérinaud, In prep (?)

XAO-CRAL bench



XAO-CRAL: Objective, Activities & Perspectives

Objective

New concepts for XAO for ELT but possibly useful for space mission.

Main components

- Polychromatic light
- 512x512 SLM
- 12x12 BMC DM
- Atmosphere (phase mask) + telescope simulator (ELT)

Activities

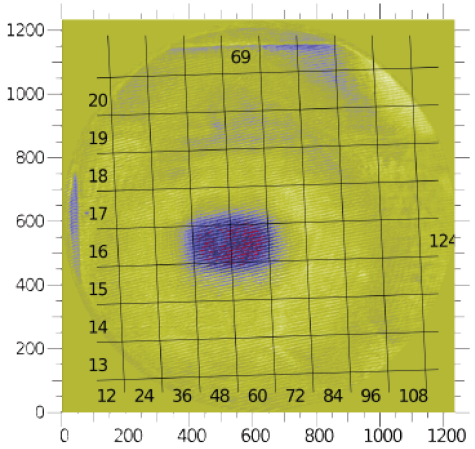
- WFS : Mach-Zehnder interferometer in broadband
- Woofer/tweeter (DM+SLM)

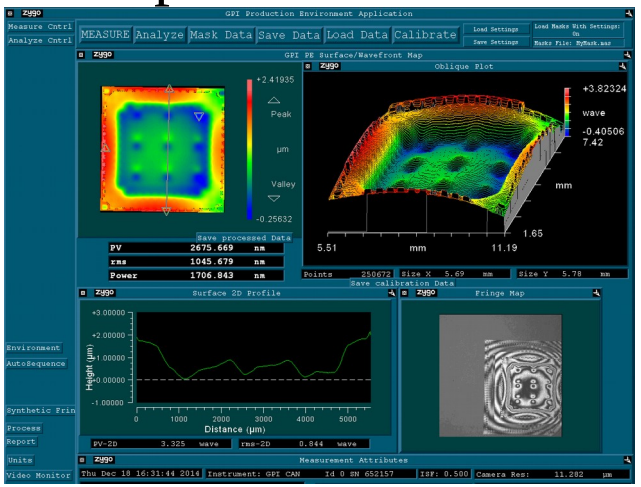
Perspectives

- Control closed-loop (>kHz)
- Spider and segment impact
- Segment co-phasing
- A posteriori speckle calibration (post-processing techniques)

XAO-CRAL results

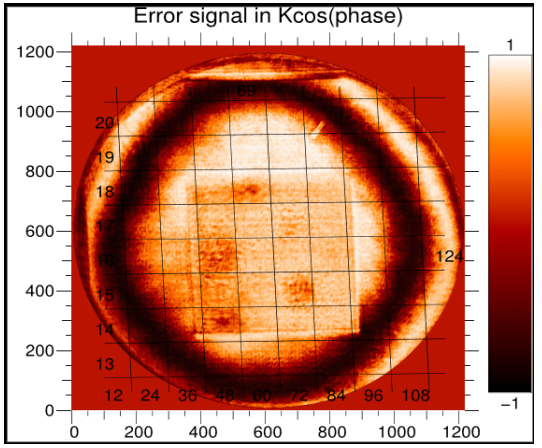
WFS Mach-Zehnder phase estimation

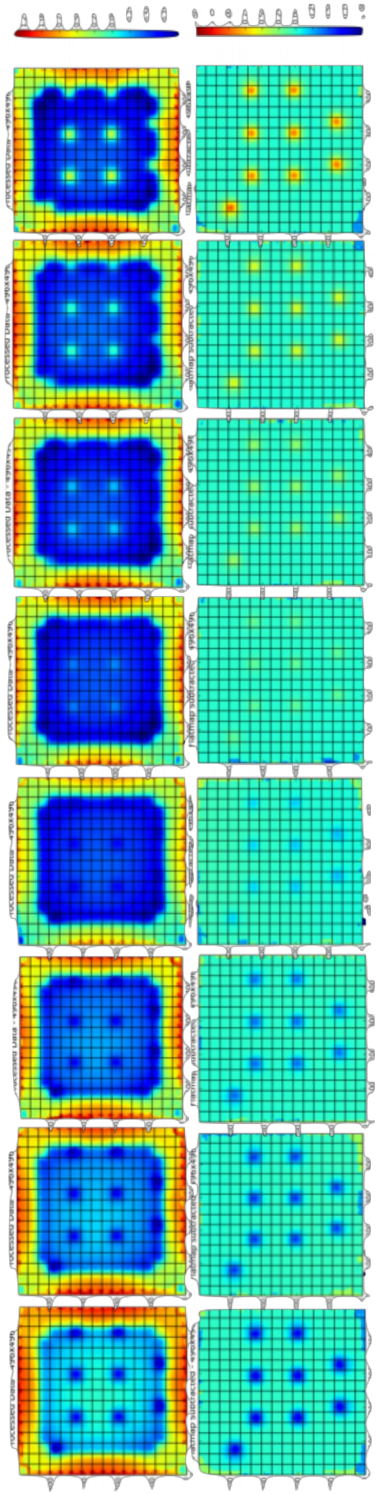




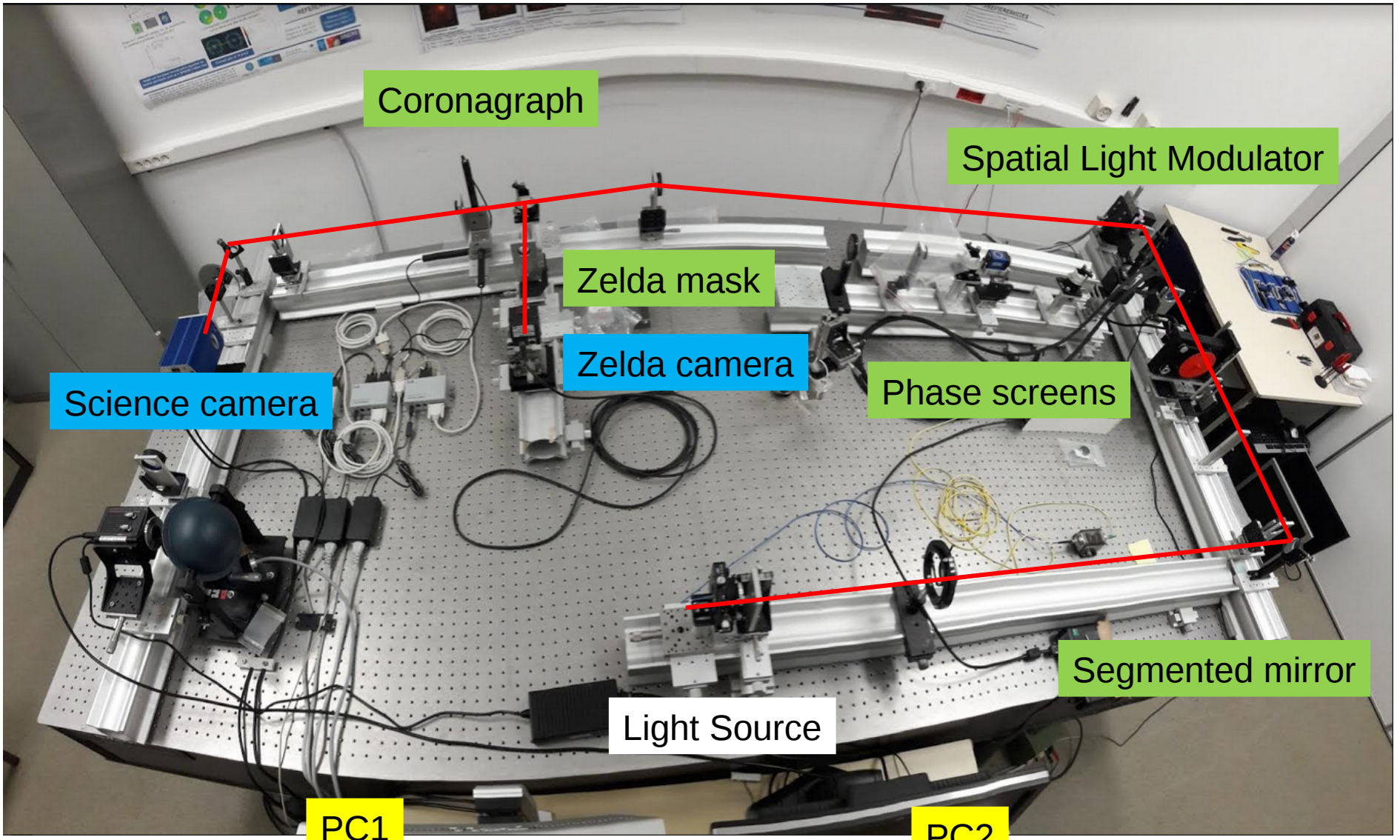
Loupias et al. 2016

1/ **phase** error induced by DM
2/ **correction using SLM**





Mithic @ Lam bench



Mithic @ Lam: Objectives & Activities

Objective

Space and ground-based telescope: non-linear dark hole, segmentation, LOWFS+HOWFS

Main components

- Monochromatic / Polarized light
- Roddier&Roddier coronagraph + pupil apodization
- Phase mask + Wheel :
    - Atmosphere simulator (XAO residual)
    - Static patterns (segments, LO, HO)
- SLM modelizing a Sphere DM
- WFS : Haso / Coffee / Zelda

Activities

- Non linear dark hole
- Zelda: closed-loop NCPA stabilization
- Zelda: coupling with Coffee
- A posteriori speckle calibration
- Coffee: to prepare on-sky tests
- Low wind effect: validation of WFS procedures

Mithic @ Lam: Results & Perspectives

Results

• "Quantifying telescope phase discontinuities external to AO-systems by use of Phase Diversity and Focal Plane Sharpening"

• Characterisation of a turbulent module for the MITHIC high-contrast imaging testbed, *Vigan et al. 2016*

Perspectives

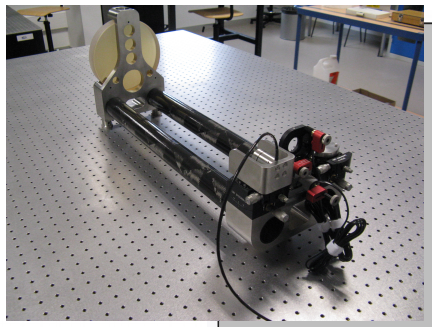
• Rough cover on imaging path (mainly for light pollution)

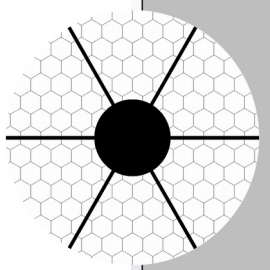
• Control / command : development of an IHM for controlling easily all devices

• Segmented mirror : PTT111 for basic tests

Speed @ Lagrange

E-ELT like pupil





Martinez et al. 2016

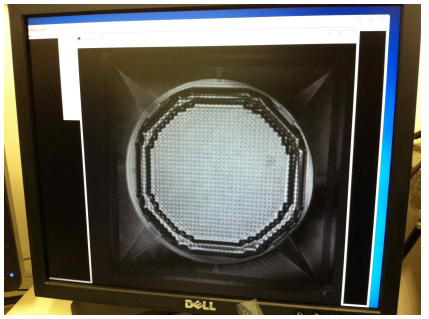
Speed @ Lagrange: Objectives & Activities

Objective

Amplitude correction with segmented pupil
Small IWA coronagraphs

Main components

- NIR + VIS
- E-ELT like pupil
- PIAAMC (IWA = 1L/D)
- Detectors
    - Nir: Rasoir – Eso
    - Vis: Apogee
- IRIS AO PTT489 (163 segments)
- 2 BMC Kilo-C DMs
- 1 Tip/Tilt (PI)

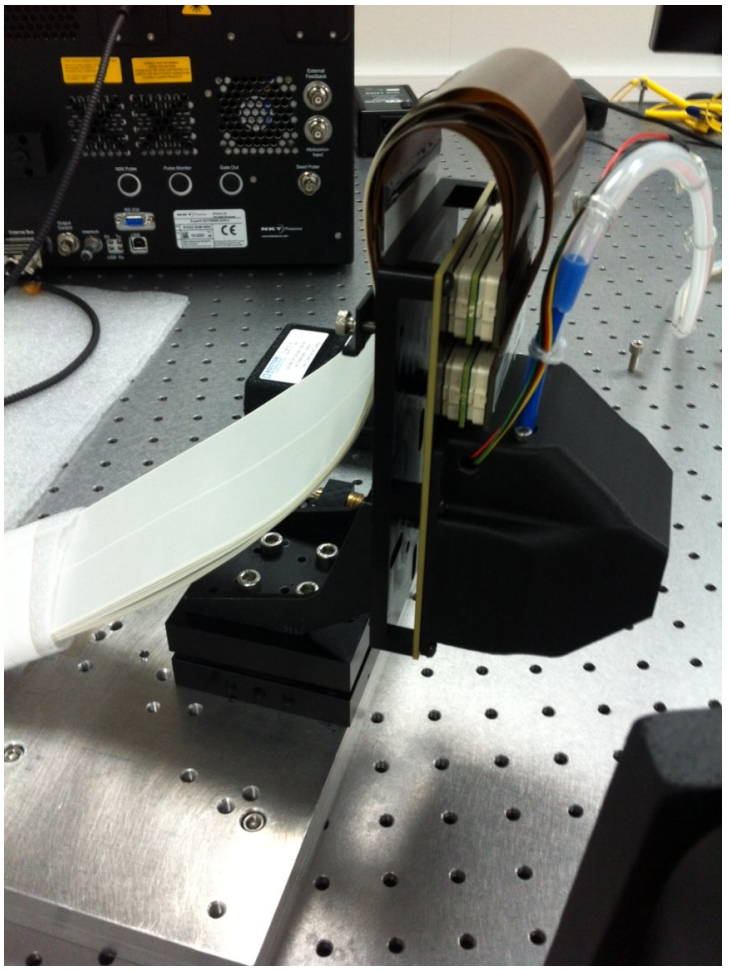


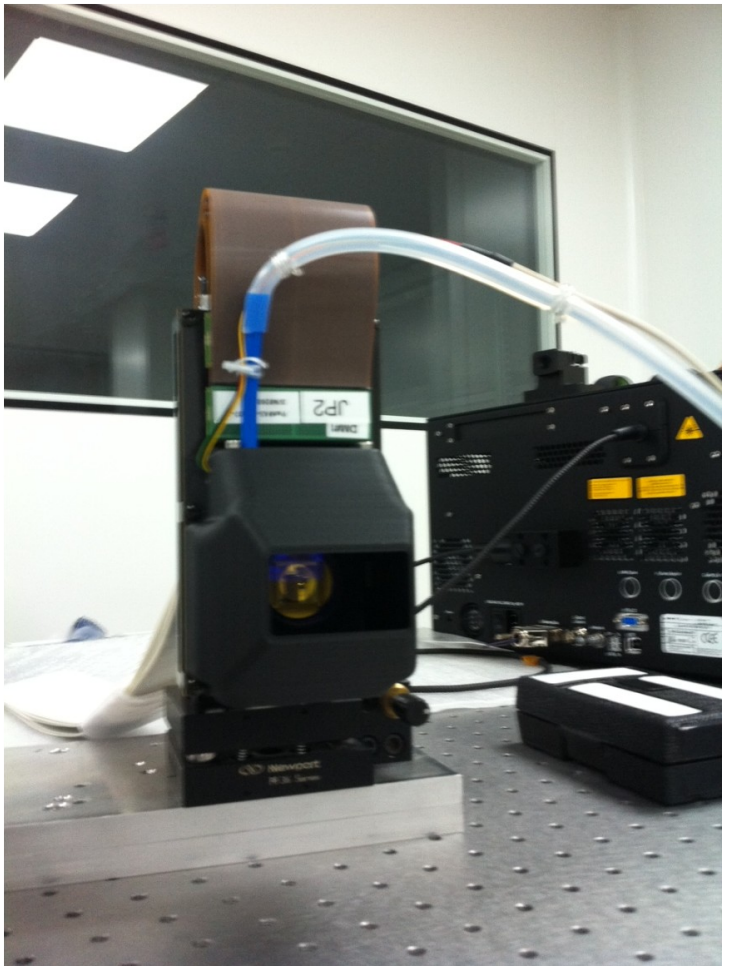
Activities

- 2 separated testbeds currently in use (cophasing & Fresnel/DMs calibration) SCC-PS, Zelda-PS
- Sept 2017 – early 2018 : Vis path alignment
- mid-2018 – … : Nir path alignment

Speed @ Lagrange: BMC & Humidity

ISO 7 room humidity : 55 % +/-10 % > DM requirements = 40 %
→ dedicated system for humidity < 20-30 %





Speed @ Lagrange: Results & Perspectives

Results

OI#1 : SCC-PS (w/Lesia) & Zelda-PS (w/Lam) *Janin-Potiron et al. 2016/2017*
OI#9 & #10: *Beaulieu et al. 2017*
OI#5 & #8: Cnes R&T (small IWA coronagraph w/ Lesia & O. Guyon)

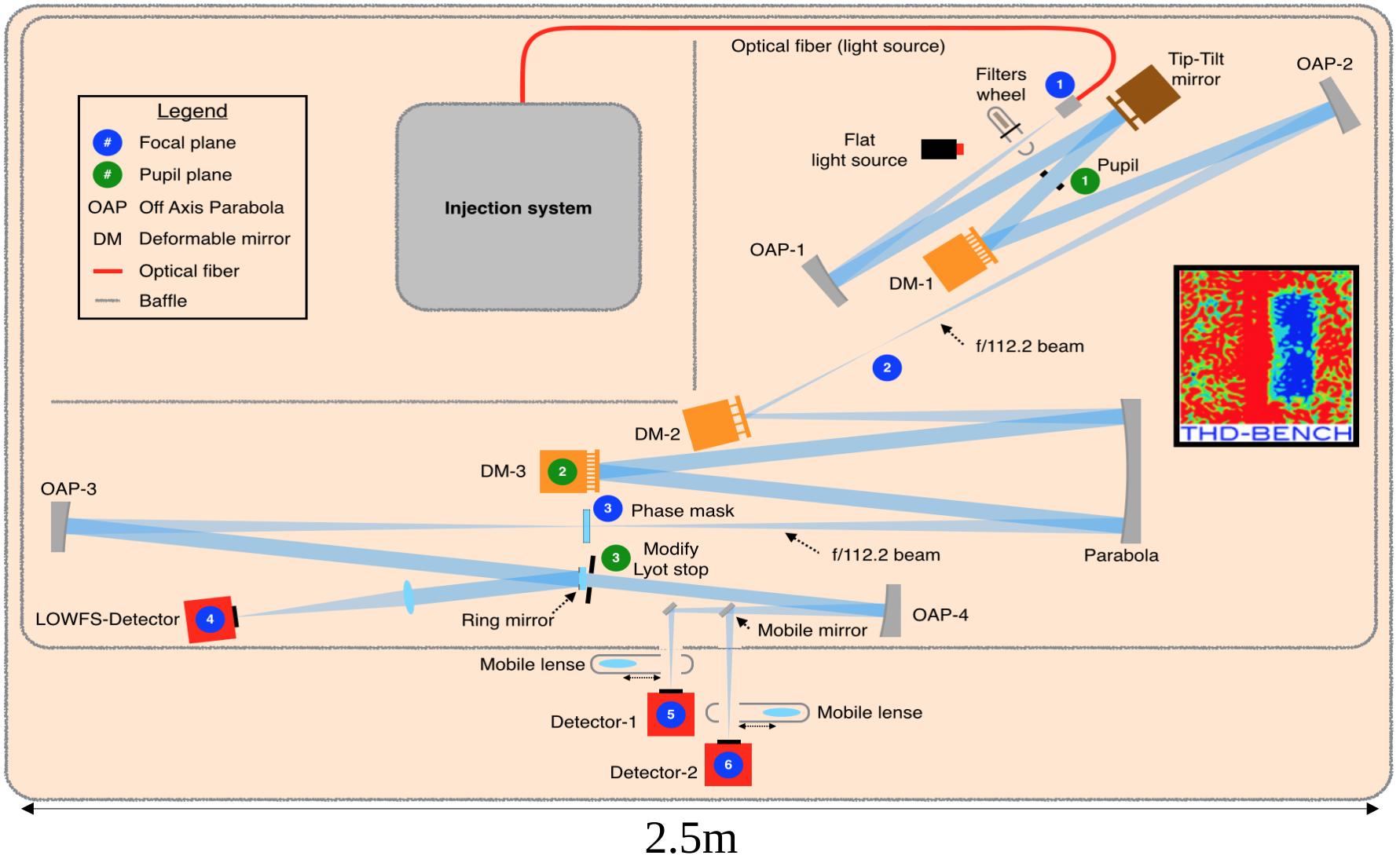
Perspectives

Objectifs	OI#1	OI#2	OI#3	OI#4	OI#5	OI#6	OI#7	OI#8	OI#9	OI#10
Avancement	✓			...	...			...	✓	✓

Tasks

- OI#1 : Development of novel(s) instrument-level phasing technics
- OI#2 : Study segment misalignments propagation error and impact for high-contrast imaging
- OI#3 : Development of strategies for fine-phasing from post-AO wavefront measurements
- OI#4 : Phasing systems comparison (zernike-based sensor, APFWS, Phase diversity, novels)
- OI#5 : Development of a PIAACMC reaching 10^{-7} raw contrast at 1 λ/D
- OI#6 : Analysis of missing segments impacts on high-contrast imaging performance
- OI#7 : Appraise non-linear solution for wavefront shaping combined with coronagraphy
- OI#8 : Study stellar resolution impact with stellar size up to 0.5 mas
- OI#9 : Study of Fresnel effect and thorough understanding in instrumental and contrast design
- OI#10 : In-depth mastering of multi-DMs architecture considering Fresnel/Talbot effects

THD2 @ Lesia

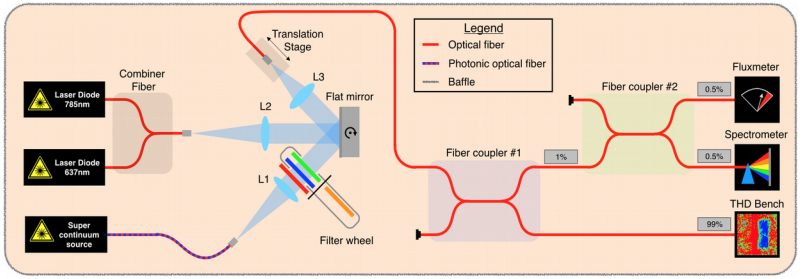

Legend
Focal plane
Pupil plane
OAP Off Axis Parabola
DM Deformable mirror
Optical fiber
Baffle
Injection system
Optical fiber (light source)
Filters wheel
Tip-Tilt mirror
OAP-2
Flat light source
Pupil
OAP-1
DM-1
f/112.2 beam
THD-BENCH
DM-2
DM-3
OAP-3
Phase mask
Modify Lyot stop
f/112.2 beam
Parabola
LOWFS-Detector
Ring mirror
Mobile mirror
OAP-4
Mobile lense
Detector-1
Mobile lense
Detector-2
1.5m
2.5m

THD2 @ Lesia: Objective & Main components

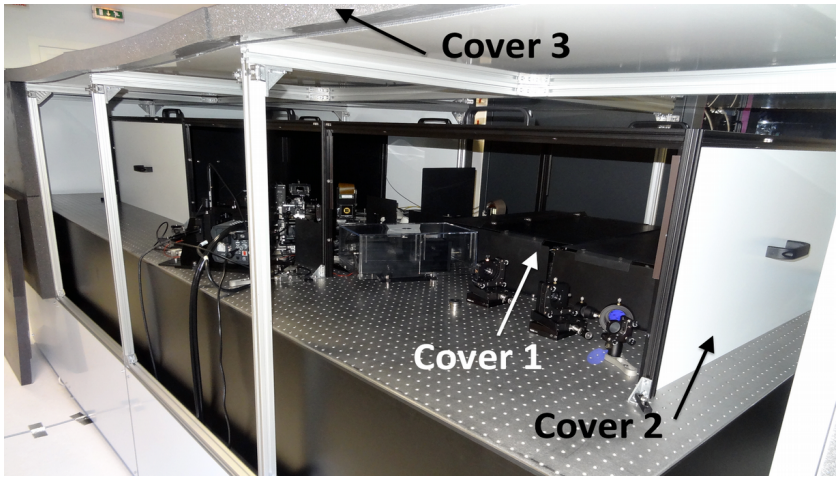
Objective

Compare high contrast imaging techniques (coronagraphs, WF sensing/control, a posteriori speckle calibration) and optimize their associations

Main components



- Vis: 3 Laser diodes + Supercontinuum source
- Pupil apodization
- Focal plane mask
- LOWF: TT
- HOWF: 32x32 BMC + 34x34 BMC + 12x12 BMC in cascade
- Stable over months with ~10pm accuracy:
  - Cleam room (iso7)
  - 3 covers (temperature, acoustics, turbulence)
  - Motorized alignment
  - Temperature/humidity measurements
  - Control room outside the clean room

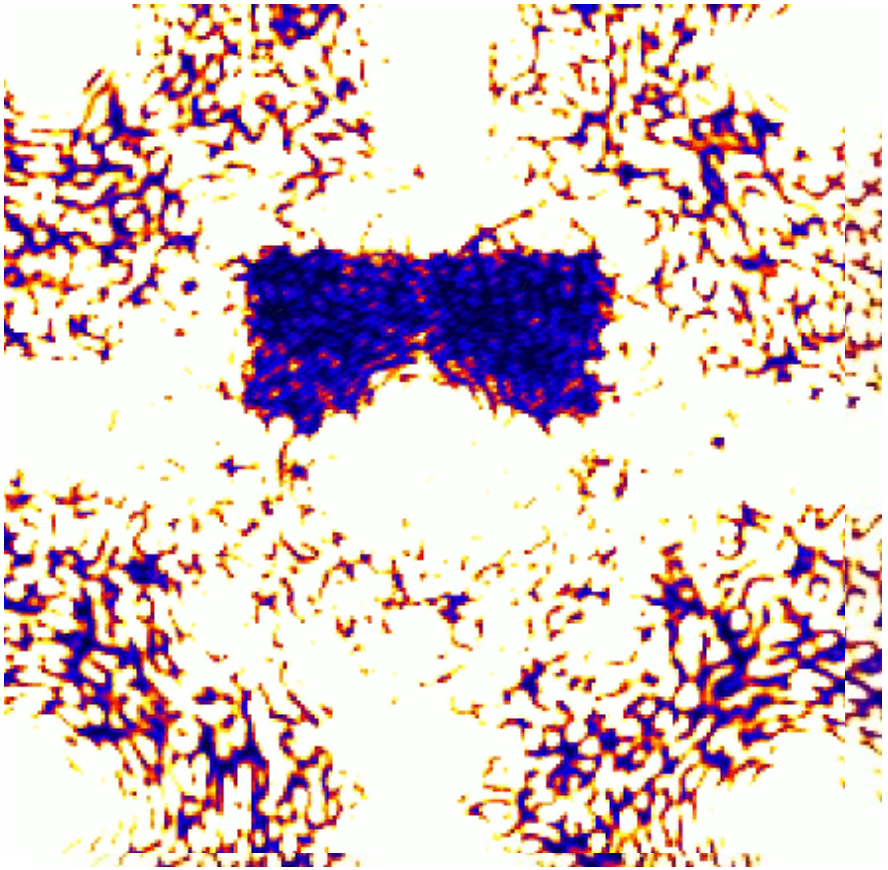


Tip-Tilt 32x32 12x12 34x34

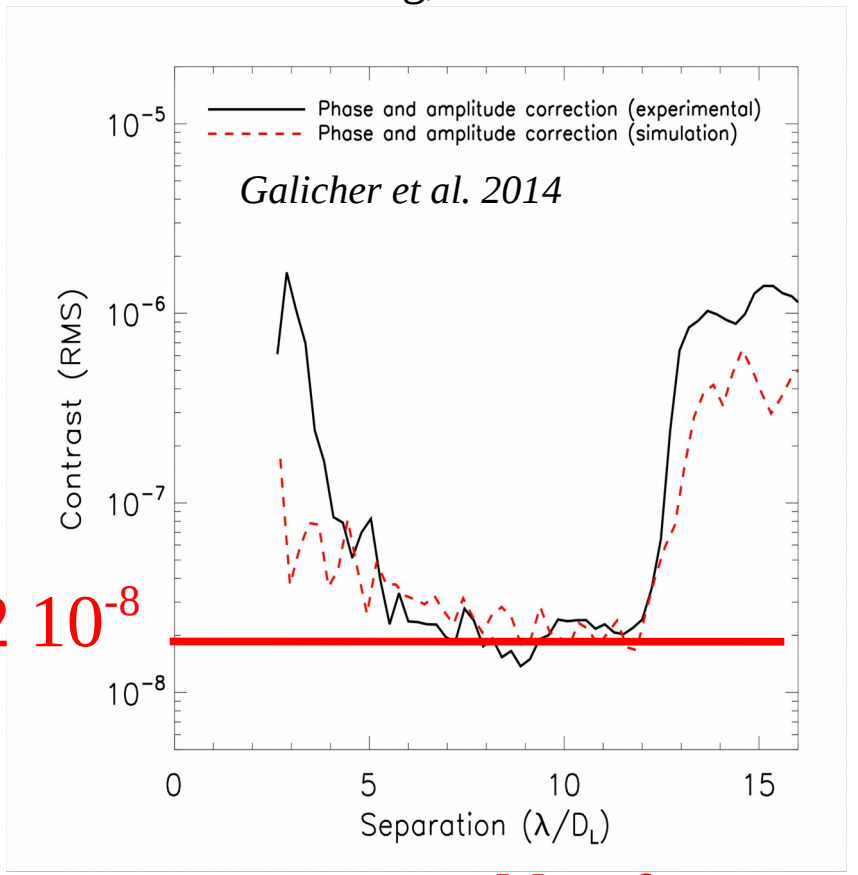
THD2 @ Lesia: Results (1/)

Monochromatic light + 1DM

640nm laser light; FQPM coronagraph, Self-coherent camera WF sensing, one deformable mirror



28 λ/D



2 10^{-8}

Star is attenuated by factor of 50 million in raw images

Limitation: amplitude aberrations

THD2 @ Lesia: Results (2/)

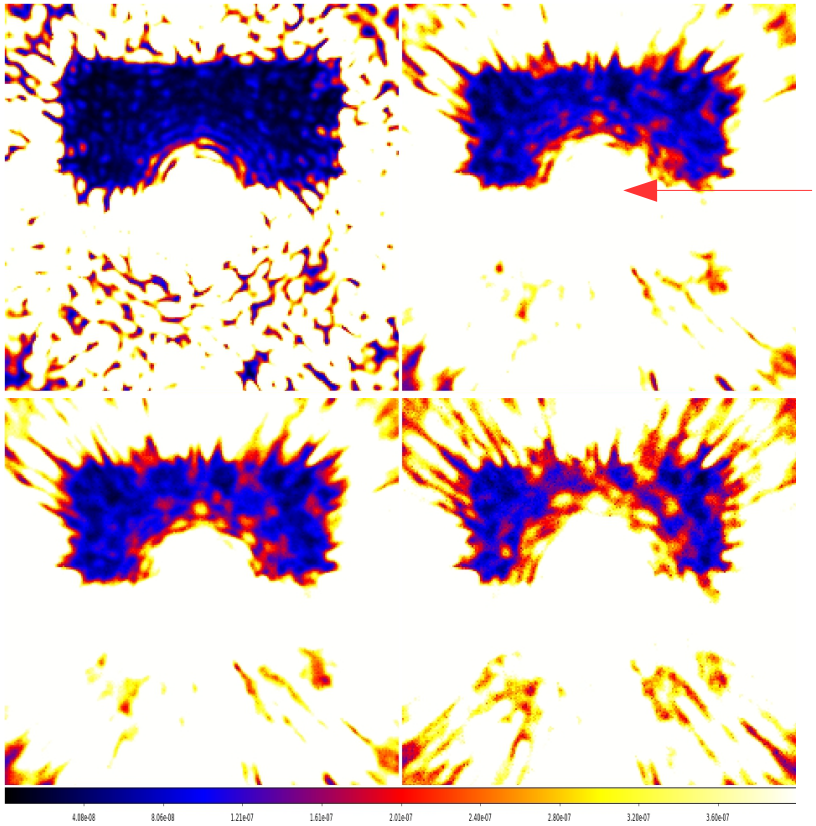
Highly achromatic coronagraphs based on phase masks

DZPM coronagraph in visible, Self-coherent camera WF sensing, one deformable mirror

Collaboration : Lam

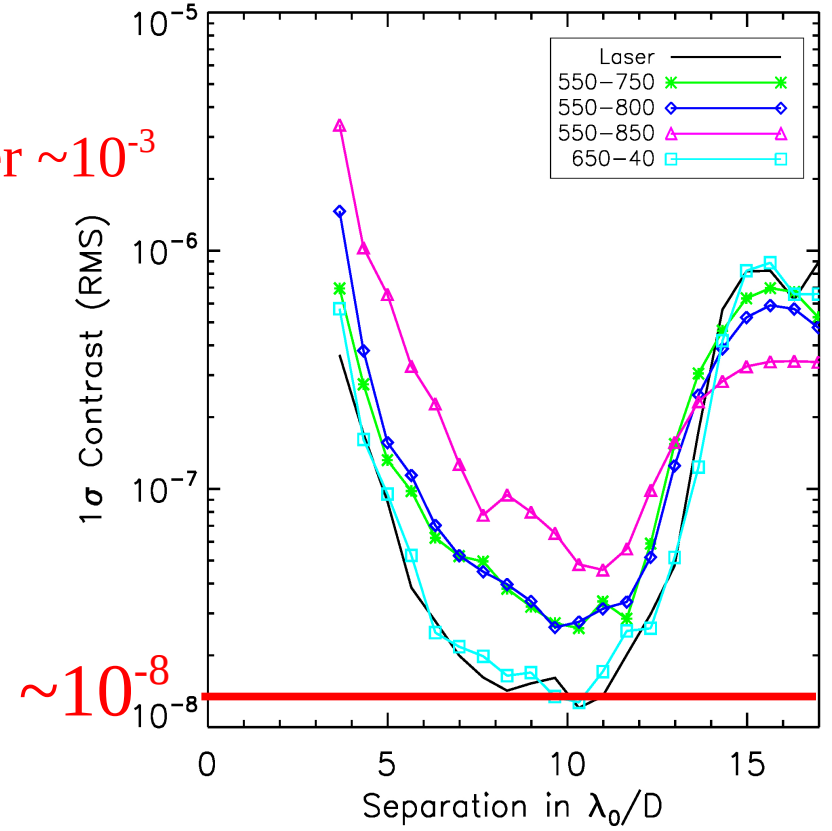
Galicher et al. 2014
Delorme et al. 2016a

Δλ = 30nm (5%) Δλ = 200nm (31%)



center ~10^{-3}

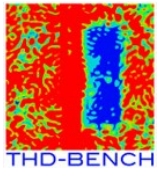
Δλ = 250nm (39%) Δλ = 300nm (47%)



~10^{-8}

raw contrast

THD2 @ Lesia: Results (4/)

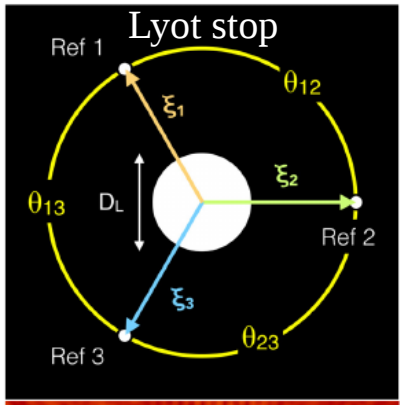


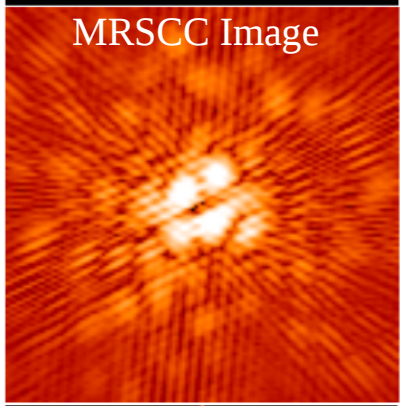
Highly achromatic coronagraphs based on phase masks

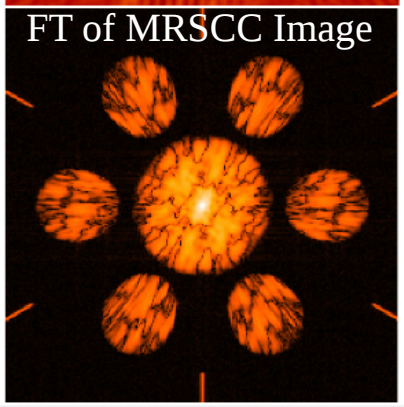
Type	Techno	Collaboration	Comment for future		
DZPM	Glass plate	Lam	Need test with smaller IWA	✓	*Delorme et al. 2016a*
VVC	Photonic layers	NAOJ	Mitigated results		
EOPM	Photonic layers	Hokkaido Univ.	Mitigated results		*Komuro et al. In prep*
VVC	Liquid crystal polymer		Techno is not ready	✓	*Baudoz et al, In prep*
SLPM	Glass plate	Shanghai Univ.	In progress		*Patru et al. In prep*
Continuous function	Glass plate	Shanghai Univ. / Paris Obs.	In progress		

THD2 @ Lesia: Results (5/)

Achromatization of focal plane WFS

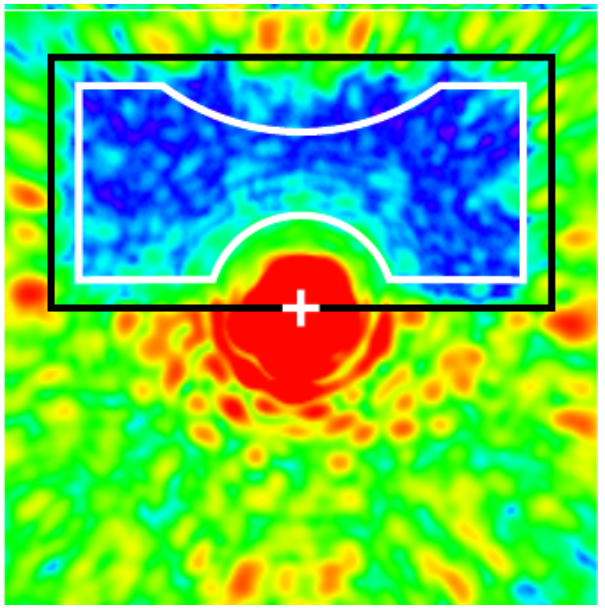




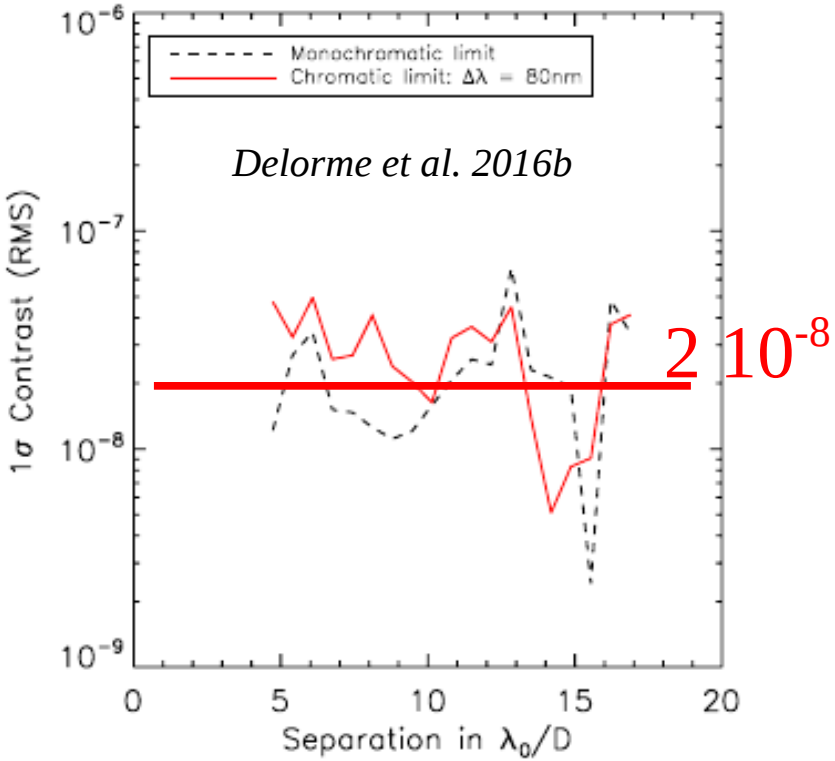


Multi-reference self-coherent camera (MRSCC)

600-680nm light; DZPM coronagraph, 1DM



MRSCC: spatial modulation, not model dependent, one image per correction, proven close-loop at 10Hz



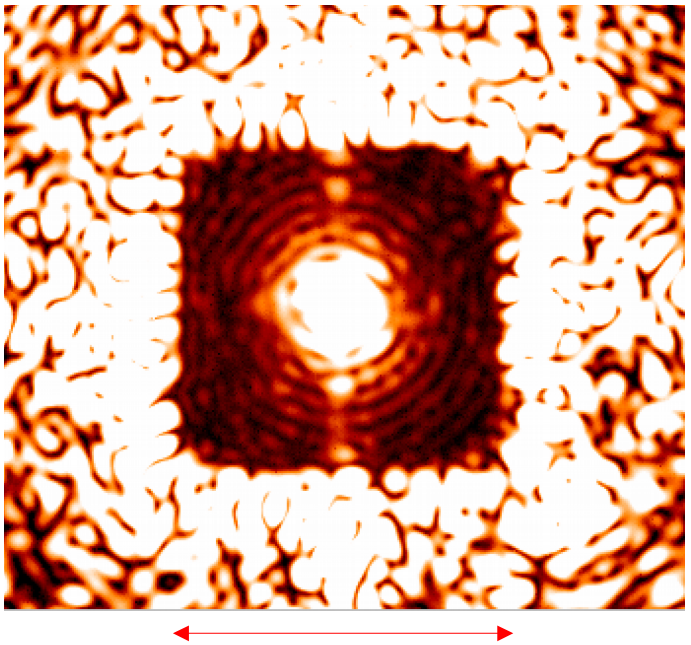
Same performance in monochromatic light and with 12.5 % bandpass (600-680nm)

THD2 @ Lesia: Results (6/)

Monochromatic light + 2DMs : amplitude&phase control

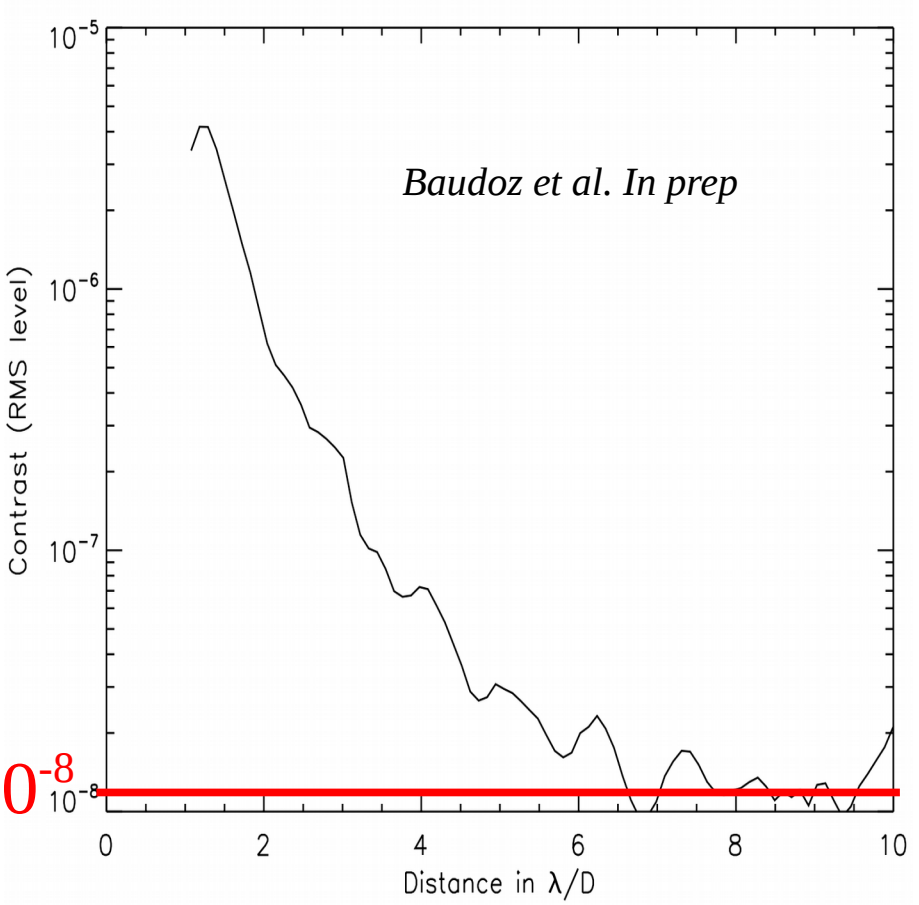
700nm laser light; FQPM coronagraph, Self-coherent camera WF sensing,two deformable mirrors

Collaboration : Lagrange



20 λ/D

Full Fov cleaned from speckles



10^-8

THD2 @ Lesia: Results & Perspectives

Coronagraphic components	Advancement	Collaboration
Four Quadrant Phase Mask	✓	GEPI, France
Multi-Four Quadrant PM	✓	GEPI, France
Apodized Dual Zone PM	✓	LAM, France
8-Octant Phase Mask	09/2015 =>	Hokkaido Univ., Japan
Vector Vortex (photonic layers)	09/2015 =>	NAOJ, Japan
Vector Vortex (Liquid cristal)	✓	Lesia, France
6-Level Phase Mask	11/2016 =>	Shanghai Univ., China & GEPI, France
Achromatic Phase Mask	11/2016 =>	Shanghai Univ., China & Lesia, France
Multi-star coronagraph	2017 =>	Loma/Bordeaux, France

Wavefront control	Advancement	Collaboration
Monochromatic & Polychromatic Self-Coherent Camera	✓	Lesia, France
Amplitude & Chromatism correction	12/2015 =>	Lesia, France & Lagrange, France
Coronograph & Phase diversity (COFFEE algorithm)	01/2016 =>	Onera, France
Optimization of algorithms, system study	10/2016 =>	SRON, Netherlands
Stability of a high contrast imager	01/2017 =>	Lesia, France
Electric field conjugation	2018 (TBC) =>	IPAG, France
Zelda technique	2018 (TBC) =>	LAM, France

Needs For Astrophysics And Needed Studies

Needs for astrophysics

High contrast levels: ~ 1e-10 contrast

Large spectral band: >200nm in visible ; >500nm in NIR

Needed studies

Coronagraphs

Chromatism

Segmentation/Obscuration

Pupil apodization

Post-coronagraphic apodization

Small IWA

Adaptative components

Wavefront control

Chromatism

Segmentation

Phase&amplitude

HOWFS

LOWFS

Jitter

SLMs

Micro-mirrors

A posteriori speckle calibration

Coherence

Statistics

Others

Micro-vibration / stability

Cnes

Cral

Ipag

Lam

Lesia

Lagrange

The French High Contrast Testbench Map

THD2 @ Lesia

XAO @ Cral

FREE @ Ipag

SPEED @ Lagrange

Cnes-Bench @ CNES

MITHIC @ Lam