Exoplanet Imaging with the Luvoir telescope

12th January 2017

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R&D At The Paris Observatory For High Contrast Imaging

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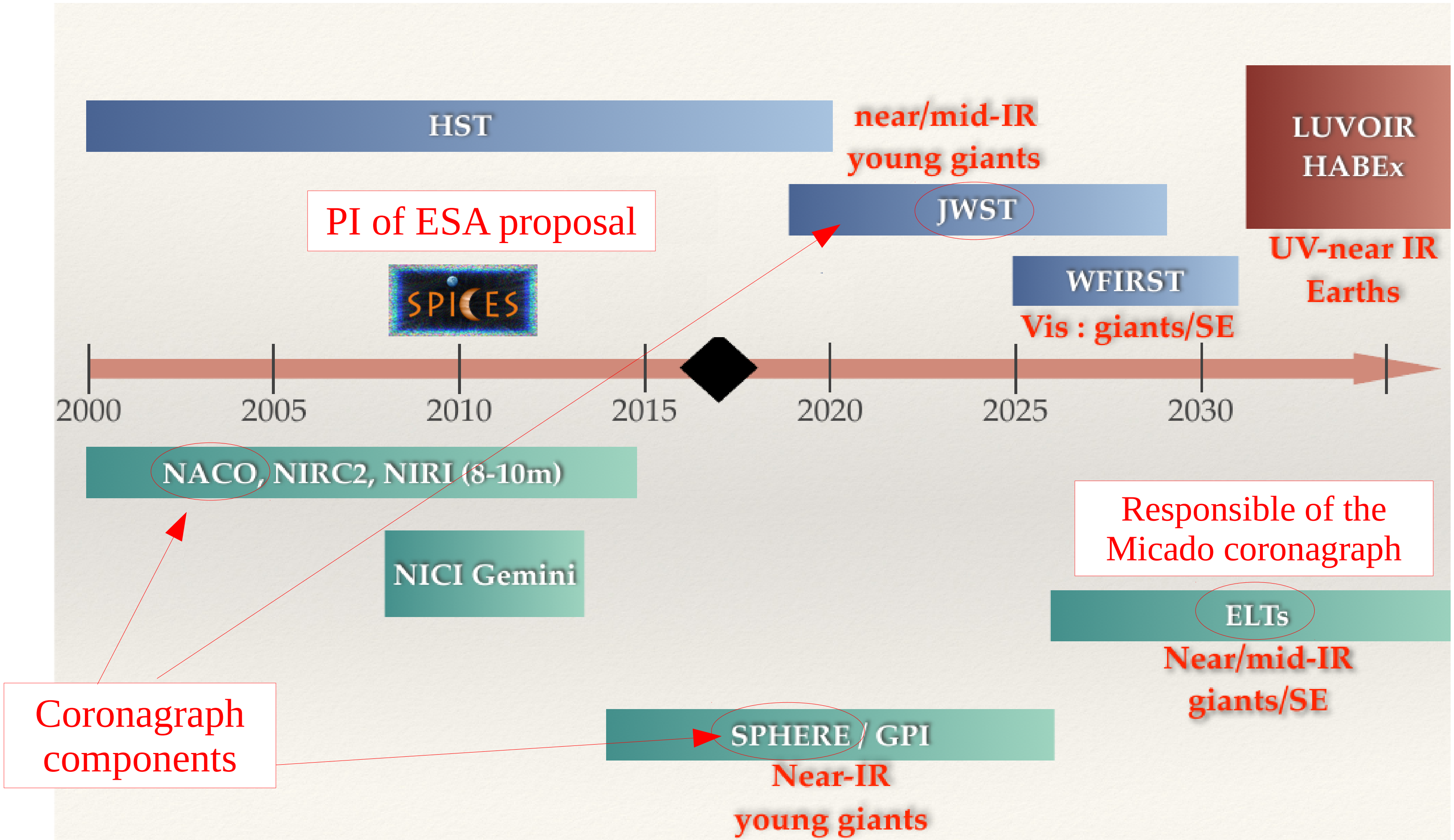
High contrast imaging and the Paris Observatory



And lots of R&D in laboratory

The Luvoir Optical/Near IR coronagraph

Specifications from Science goals

Shawn Domagal, Jan. 11th 2017, Meudon

Contrast < 10^{-10} to observe ExoEarths

Low resolution spectroscopy (R>150)

Baseline bandpass : 0.4 µm to 1.8 µm
Ambitious bandpass : 0.2 µm to 2.4 µm

The Luvoir Optical/Near IR coronagraph

Specifications from Science goals

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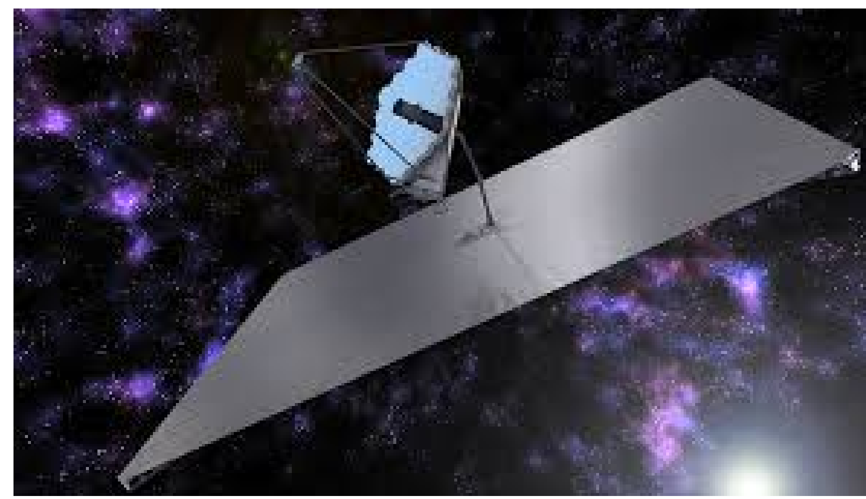


Contrast **10^{-11}** to observe ExoEarths

Low resolution spectroscopy (R>150)

Baseline bandpass : 0.4 µm to 1.8 µm
Ambitious bandpass : 0.2 µm to 2.4 µm

The Luvoir Optical/Near IR coronagraph

What are the challenges ?

Contrast 10^{-11} to observe ExoEarths → Best in laboratory is a few 10^{-10} under « perfect » conditions

Low resolution spectroscopy (R>150) → R<100 for SPHERE & GPI

Baseline bandpass : 0.4 µm to 1.8 µm
Ambitious bandpass : 0.2 µm to 2.4 µm → need for achromatic coronagraph and control of chromatic aberrations

What do we need for the Luvoir instrument?

1/ Attenuate the star light down to 10^{-10}: **coronagraph**
→ efficient over a large bandpass
→ robust to real conditions (jitter, segmented/obscurated pupil, etc)

2/ **Wavefront errors** down to 1pm rms over the pupil
→ Wavefront **sensing** in the science image
→ Active **control** of phase and amplitude aberrations simultaneously?
→ Active control of chromatic aberrations (Fresnel effects)?

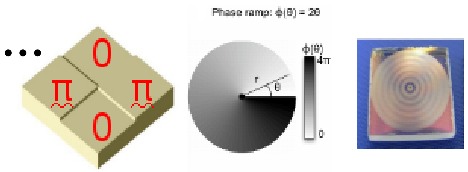
3/ **Stabilization** of the aberrations to enable a 10 factor a posteriori calibration

4/ Only one technical solution for all the science cases?
photometry and spectrometry of exoplanets and circumstellar disks → 4 instruments?

Lots Of Techniques/Ideas Exist !

1/ **Coronagraphs**

→ FQPM, EOPM, Vortex, APLC, Band limited, DZPM, SLPM, ...



2/ **High accuracy wavefront sensing**

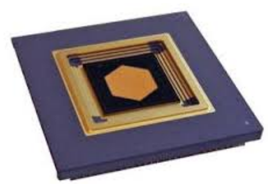
→ LOWFS: *Mas et al. 2012, Singh et al. 2015, Shi et al. 2015, ...*

→ HOWFS: Self-coherent camera, Coffee, Electric Field Conjugation, ...

3/ **Wavefront control**

→ Deformable mirrors

→ Spatial Light Modulators



4/ **A posteriori calibration**

→ roll telescope

→ spectral differential imaging

→ coherence differential imaging

How to determine the best configuration/strategy ?

Need a laboratory to compare and associate the techniques

The THD2 bench

Banc Très Haute Dynamique
Terrifically High Dynamic bench

<u>Objectives</u>

For future space- and ground-based telescopes

+ Compare high contrast imaging techniques under the same conditions
+ Test several associations of these techniques
+ Find the best instrumental configuration for each science case

THD2 bench is a R&D laboratory bench working in Vis/NIR

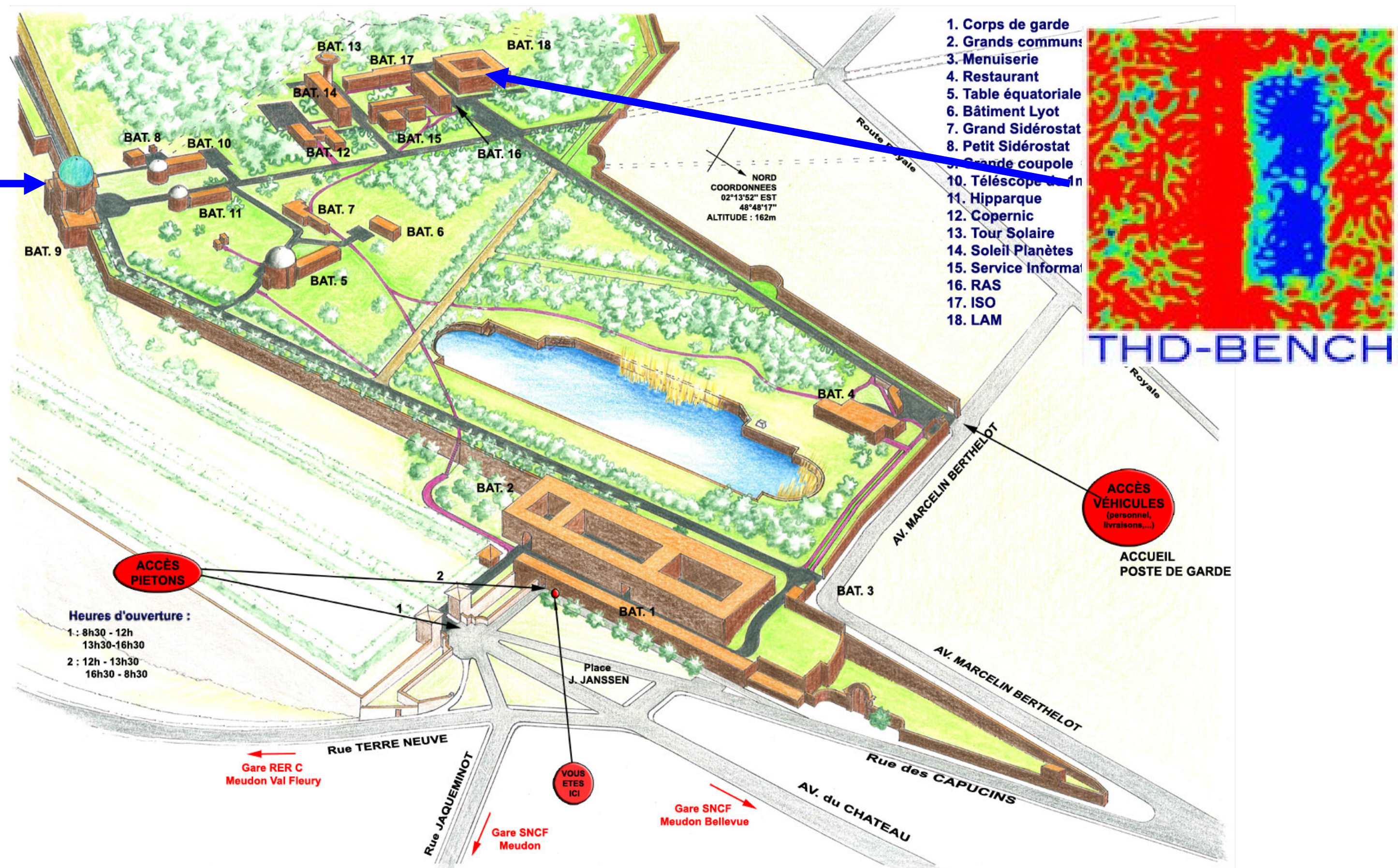
→ Accessible

→ Reproductible

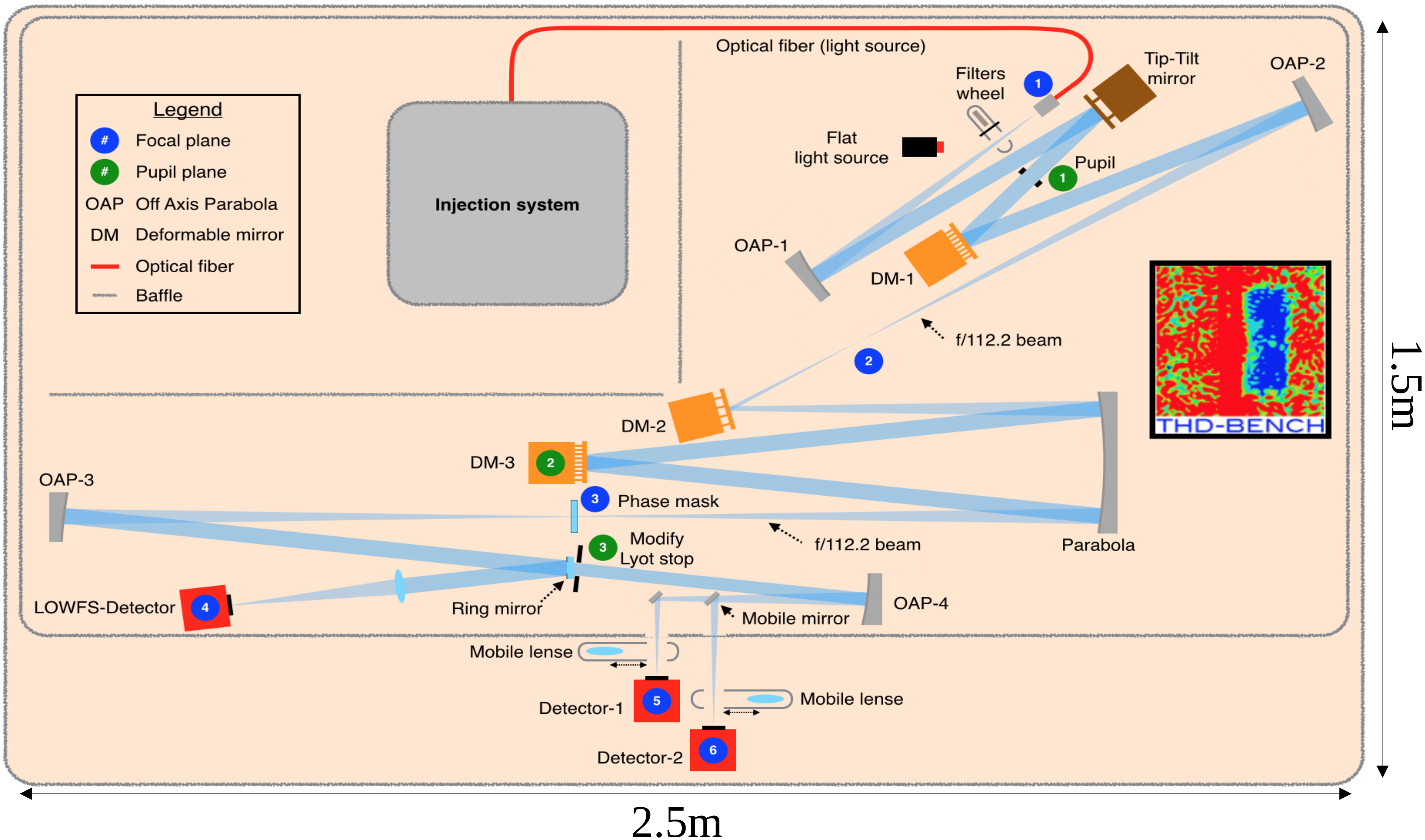
→ Versatile

Where is the THD2 bench ?

We are here



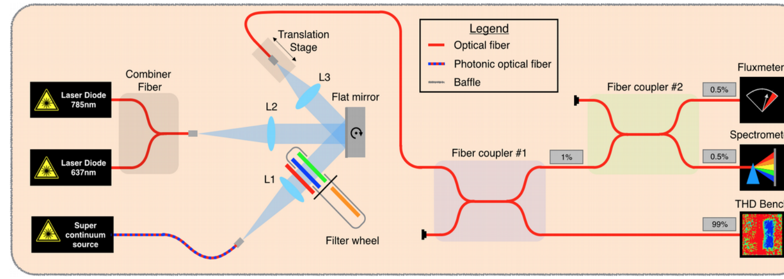
THD2 bench optical design



THD2 bench main characteristics

Sources

3 lasers, visible/NIR supercontinuum source



Active elements for LOWF+HOWF

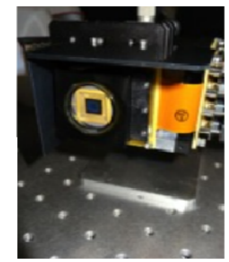
1 tip-tilt mirror

3 deformable mirrors (in cascade)

Tip-Tilt

32x32

12x12



34x34

Stable over months with ~10pm accuracy

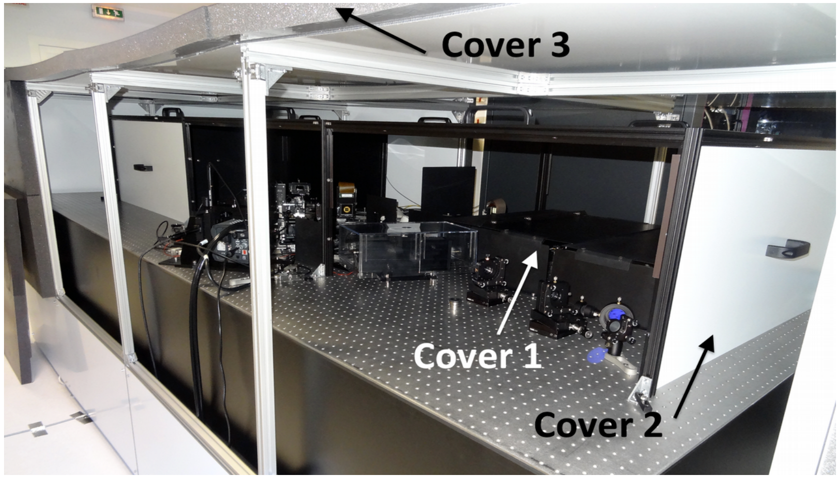
Clean room

3 covers (temperature, acoustic, turbulence)

Motorized alignment

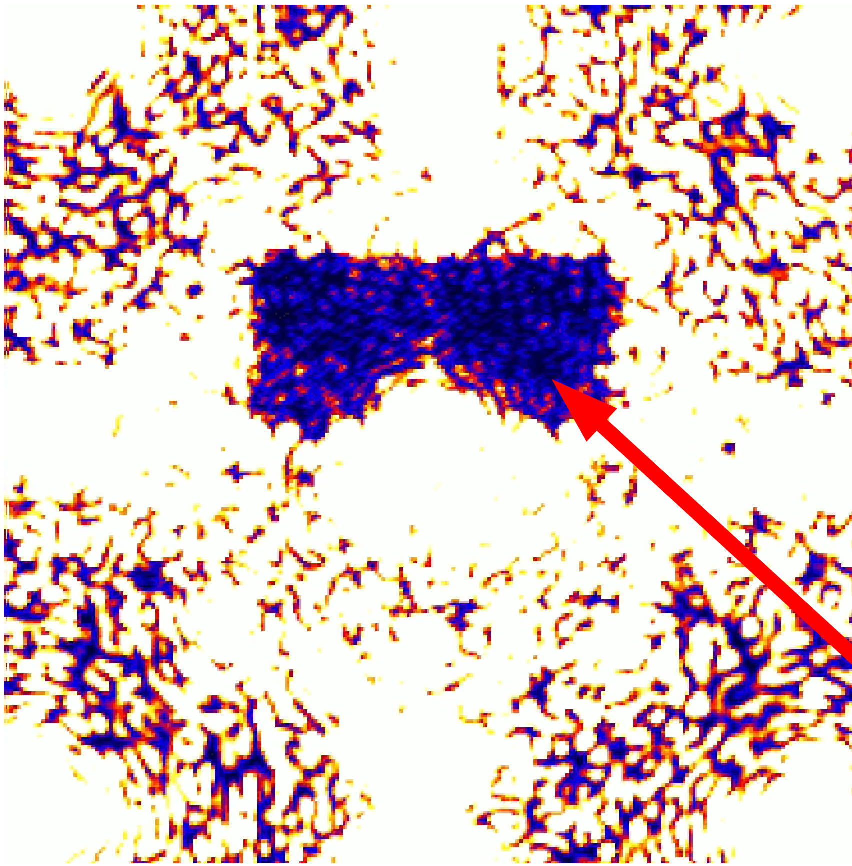
Temperature, humidity measurements

Control room

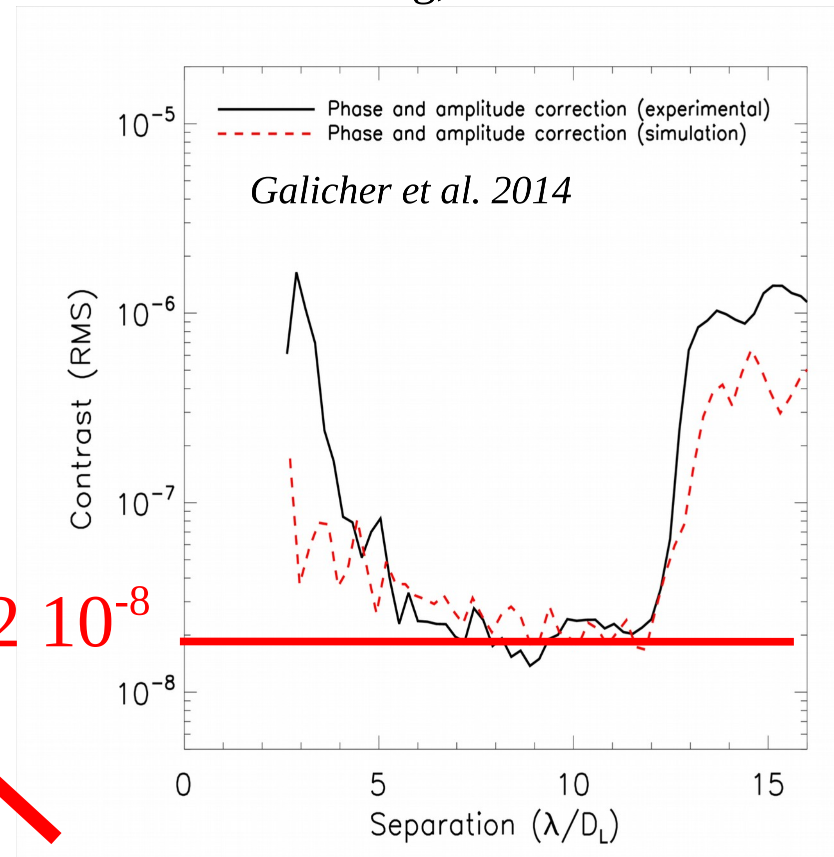


THD2 bench : monochromatic light

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



28 λ/D



$2\ 10^{-8}$

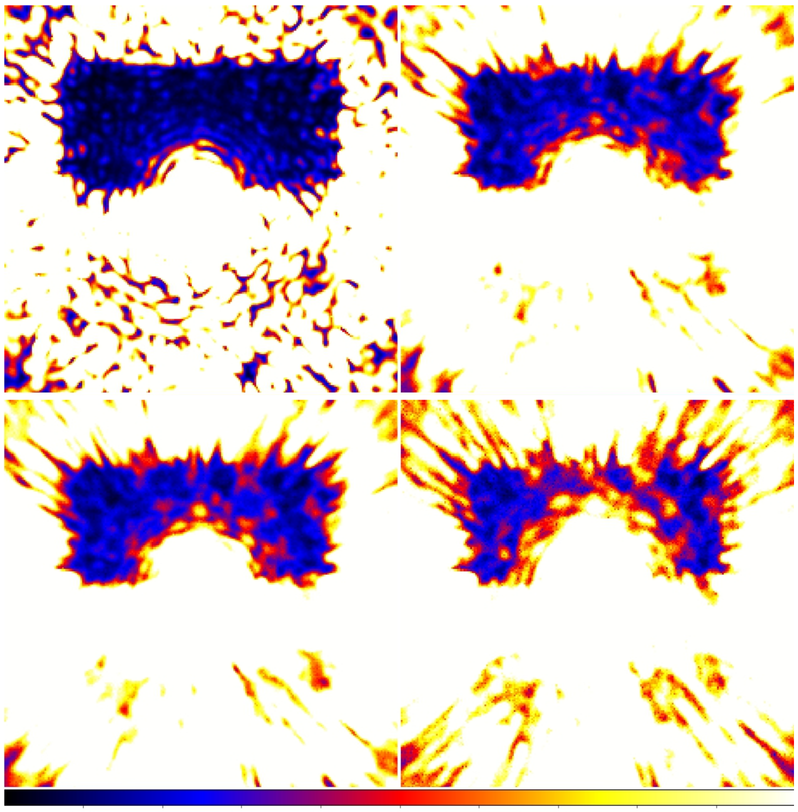
Star is attenuated by factor of 50 million in raw images

Limitation: amplitude aberrations

THD2 bench : large bandpass

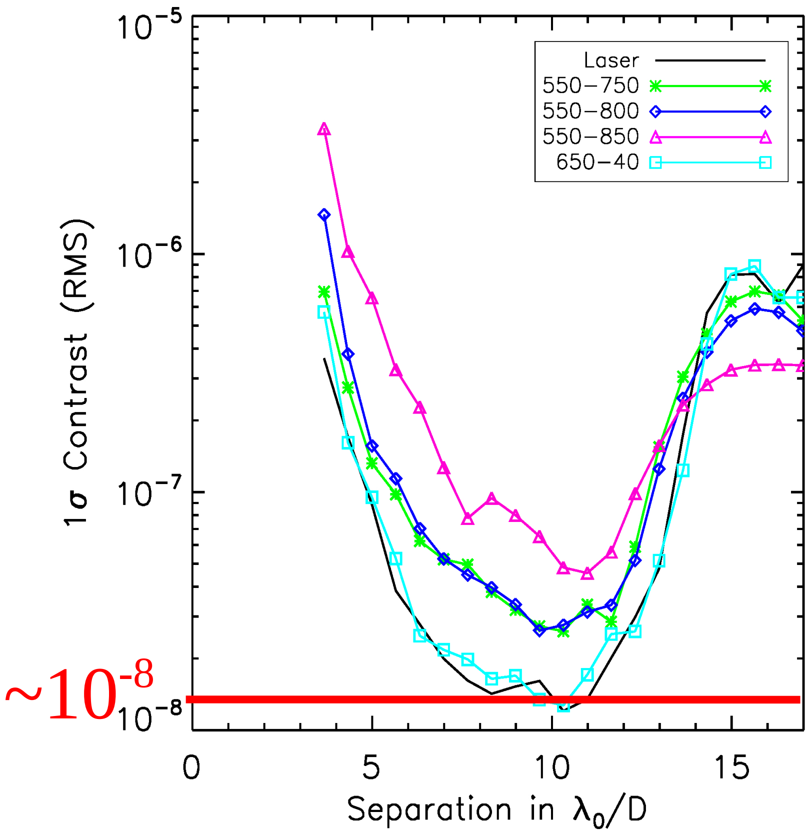
DZPM coronagraph in visible, Self-coherent camera WF sensing, one deformable mirror

$\Delta\lambda$ = 30nm (5%) $\Delta\lambda$ = 200nm (31%)



$\Delta\lambda$ = 250nm (39%) $\Delta\lambda$ = 300nm (47%)

Galicher et al. 2014



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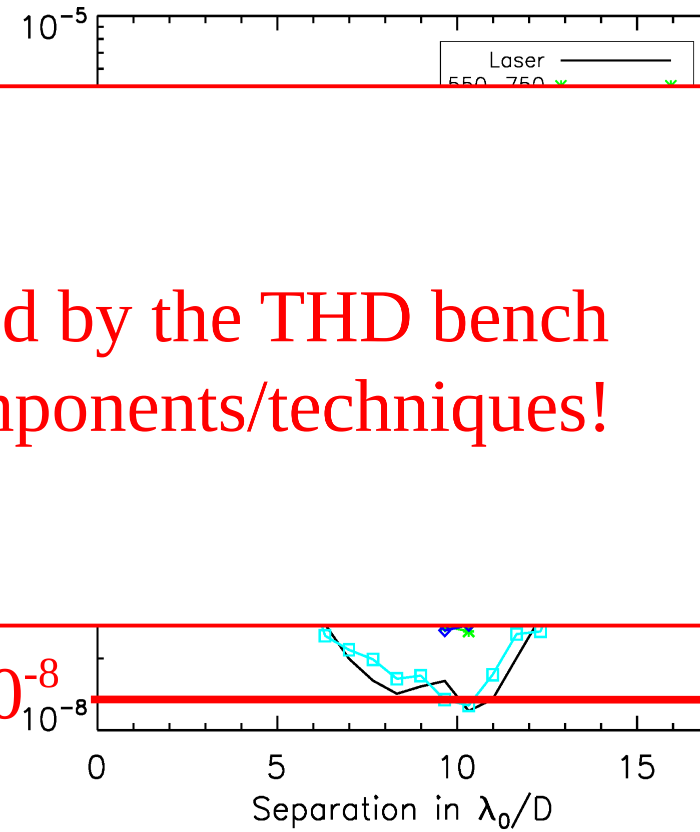


Almost no chromatism induced by the THD bench

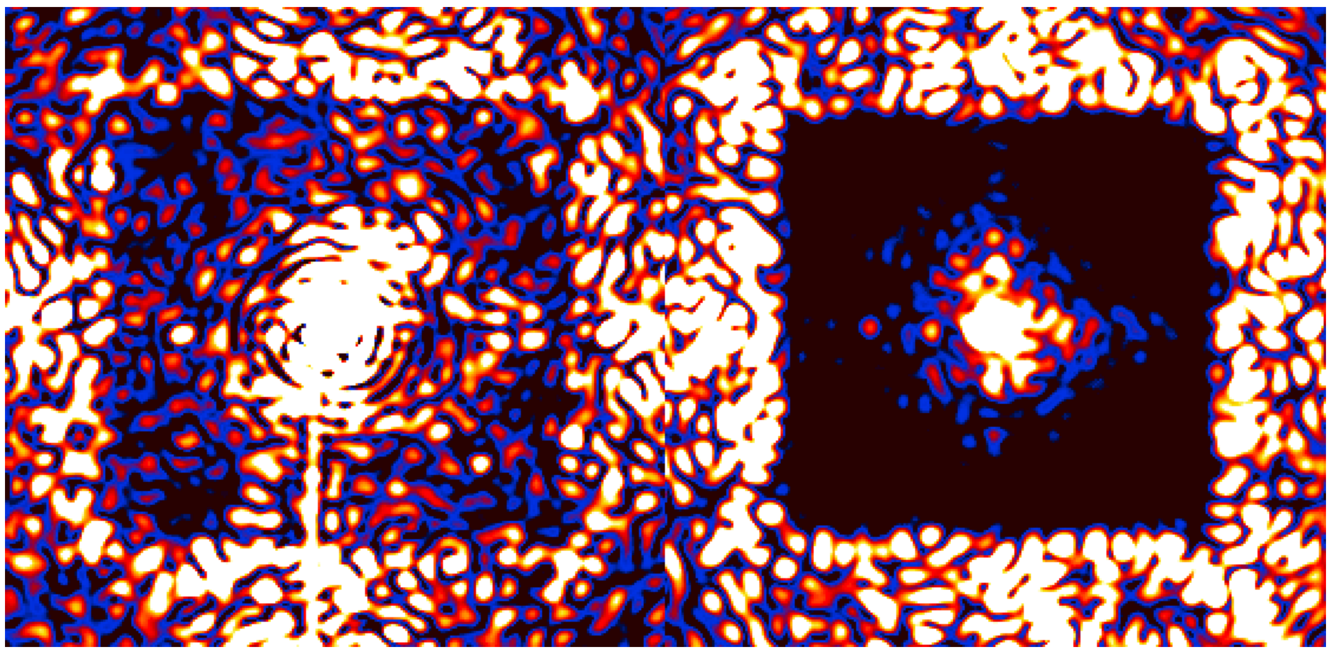
→ can test chromatism of components/techniques!

THD2 bench : phase, amplitude, chromatic aberrations

FWPM coronagraph, Self-coherent camera WF sensing

Phase control | **Phase + amplitude control**

miroirs déformables : 1 | # miroirs déformables : 2



→ **Full field-of-view with 10^{-8} raw contrast level**

→ In future : control of chromatic aberrations

THD2 bench : collaborations

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	09/2015 =>	NAOJ, Japan
6-Level Phase Mask	11/2016 =>	Shanghai Univ., China & GEPI, France
Achromatic Phase Mask	11/2016 =>	Shanghai Univ., China

Wavefront control	Advancement	Collaboration
Monochromatic & Polychromatic Self-Coherent Camera	✓	Lesia, France
Amplitude & Chromatism correction	12/2015 =>	Lesia, & 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	2017 =>	IPAG, France
Zelda technique	2017 (TBC) =>	LAM, France

Conclusions

The Paris Observatory has a long history in high contrast imaging
→ Several contribution to space- and ground- based instruments
→ Lots of R&D

There is no demonstrated solution that can get the required coronagraphic contrast for measuring the spectrum of an Earth-twin planet

BUT

There are a lots of technical solutions
→ TPF, WFIRST context

The THD2 bench is a unique R&D facility for preparing the LUVOIR coronagraph
→ Designed for preparing space missions
→ Already lost of collaborations that the Luvoir project could benefit of

Thank you