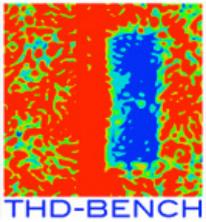


# THD 2 bench : A unique testbed in Europe for high contrast imaging

Baudoz, P., Galicher, R.  
and THD team

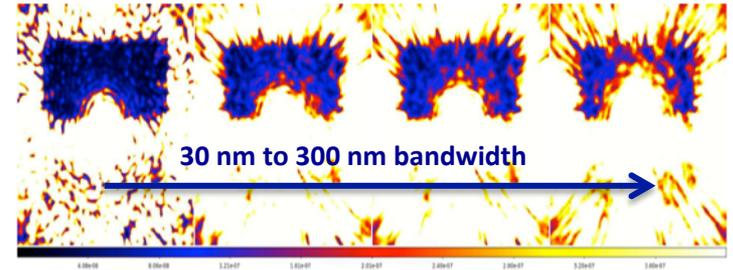
**Main Funding : CNES, CNRS, Paris Observatory**



# THD 2 Description

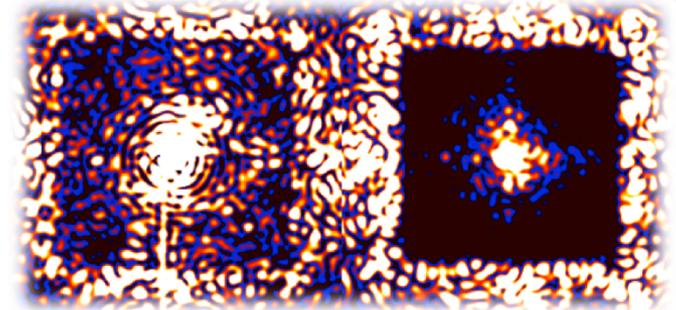
## Same capabilities than THD 1:

- ✓ Achromatic design (mirrors)
- ✓ Compatible with many coronagraphs
- ✓ Not in vacuum but stabilized environment and fully motorized
- ✓ Low-order wavefront sensor (tip-tilt control)



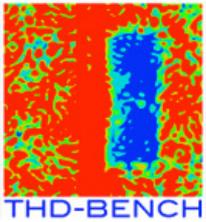
## Upgrade implemented on THD 2 :

- ✓ Correction of phase and amplitude  
⇒ 3 Deformable Mirrors
- ✓ Improved environment stabilization
- ✓ Improved calibration and housekeeping data recording

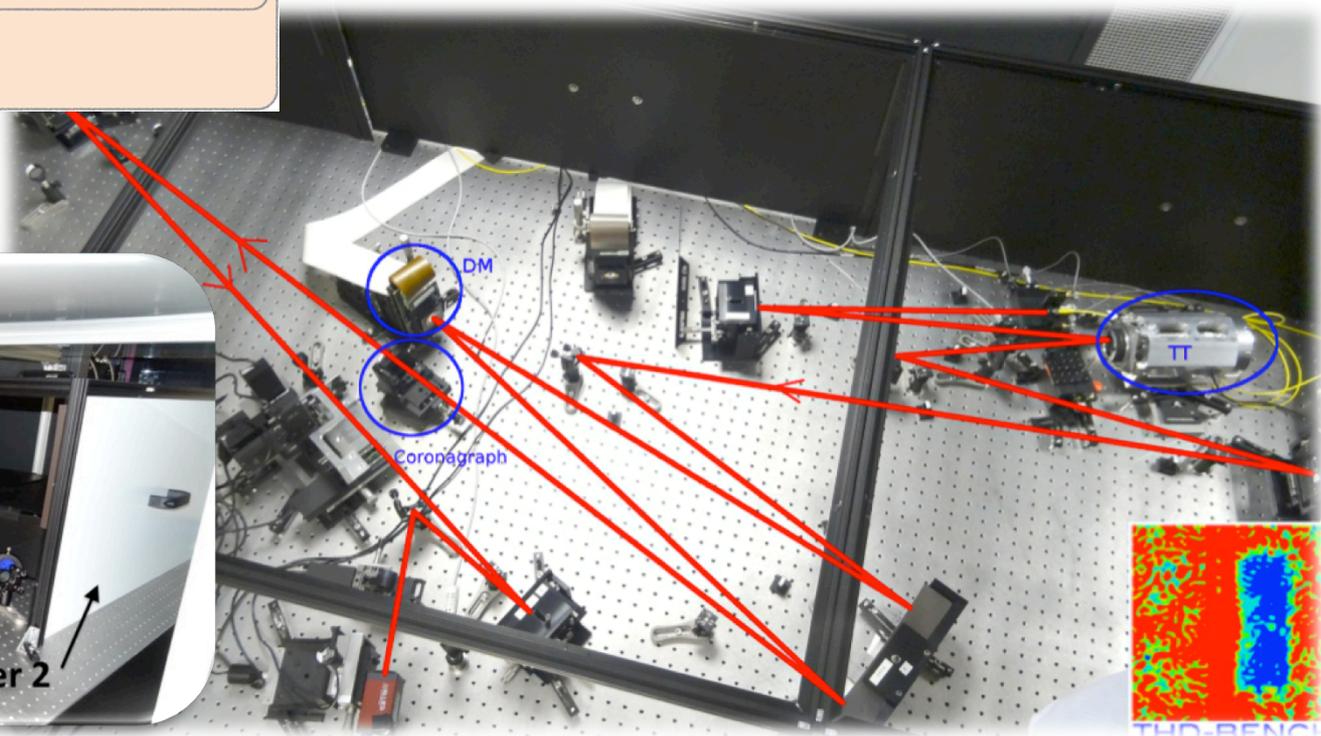
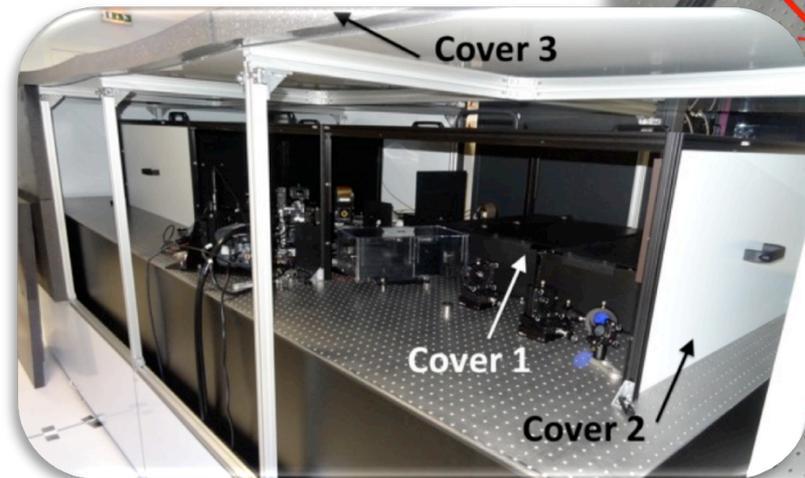
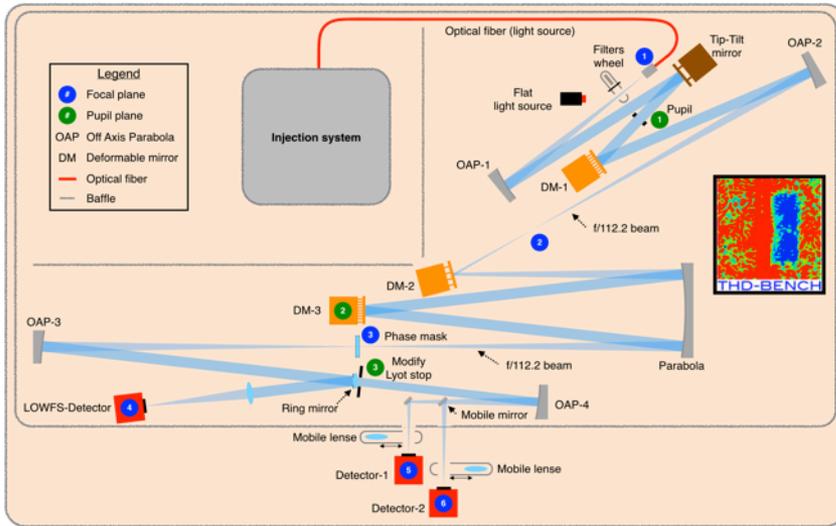


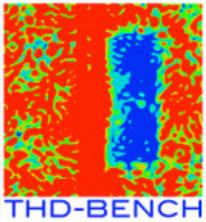
THD 1 (1 DM)

THD 2 (with 2 DM only)



# Optical design and setup





# A very complete testbed

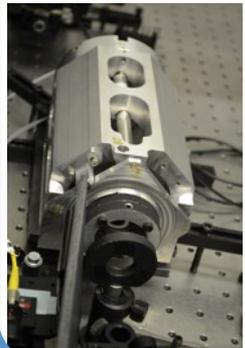
## Source unit : visible light from monochromatic to large bandwidth $> 300$ nm

- Broadband (450 to 950 nm) supercontinuum source + filter wheel
- Laser diode @ 638 nm & 785 nm
- Flat-Field source @ 650 nm
- Fluxmeter, Spectrometer



## Active mirrors

Tip Tilt mirror  
(SPHERE  
prototype)

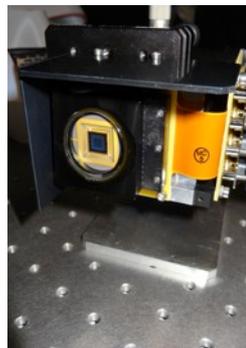


### 3 Deformable Mirrors

34x34  
actuators



12x12  
actuators



32x32  
actuators



## Cameras & Sensors

Science + Self-  
Coherent Camera

- 100 Hz
- 3 e- RON



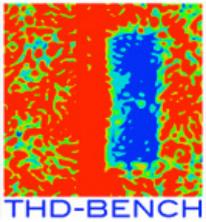
Low-order  
wavefront Sensor

- 500 Hz
- 18 e- RON



## Calibration & Housekeeping

Recording simultaneously : **images** from cameras, **applied controls** to active mirrors, **total flux and spectrum** of input light, **temperature & humidity** sensors ( $\approx 10$  sensors), working configuration, ...



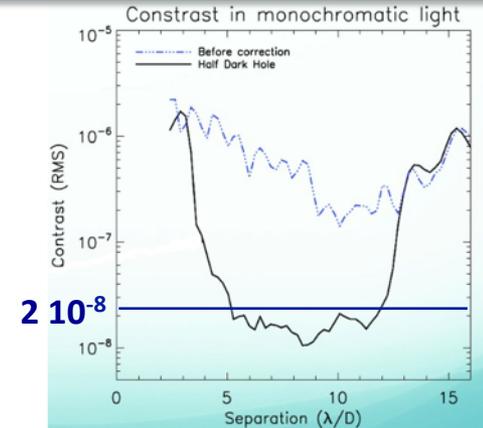
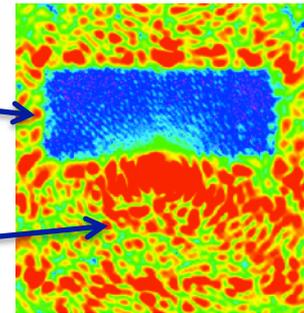
# Examples of Performance

More than 15 Publications (5 refereed or accepted papers)

## Monochromatic (bandwidth <10 nm) results

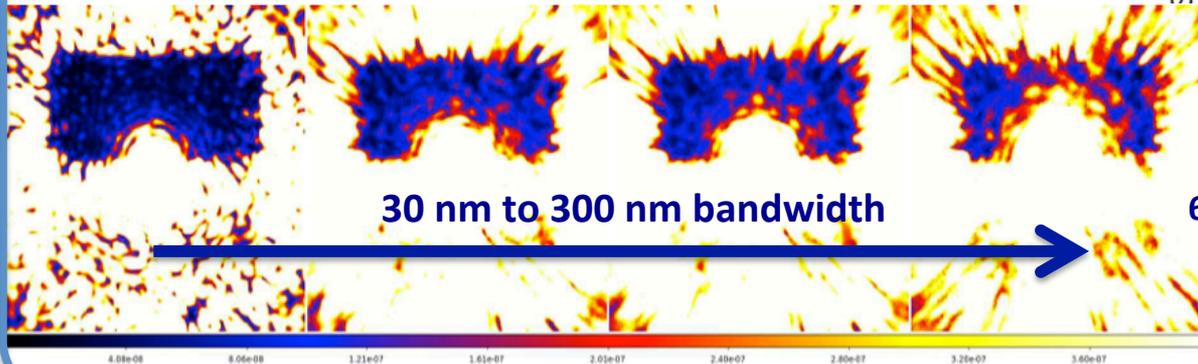
Contrast:  $< 2 \cdot 10^{-8}$  between  $5 \lambda/D$  and  $12 \lambda/D$

THD1 Limitation = amplitude errors  
Reduced by a factor  $>20$  on THD2

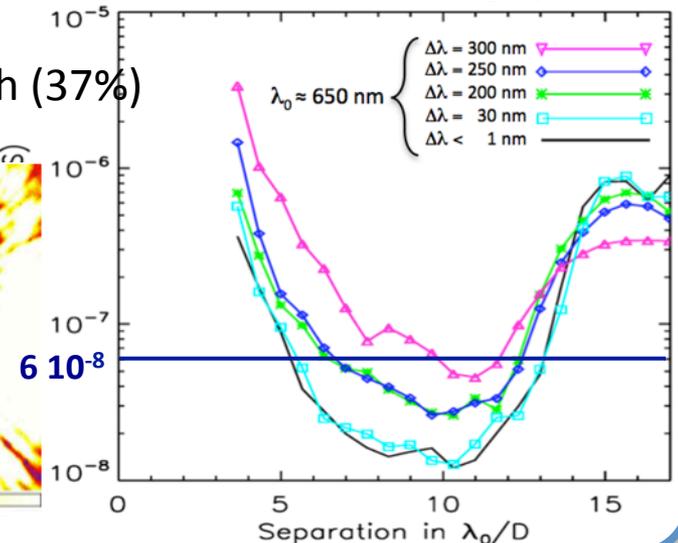


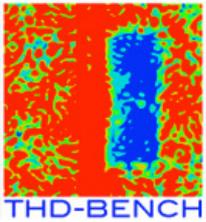
## Achromaticity of the testbed

Contrast degrades by only a factor 3 for 250 nm bandwidth (37%)



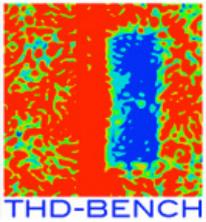
## DZPM coronagraph





# A versatile and open testbed

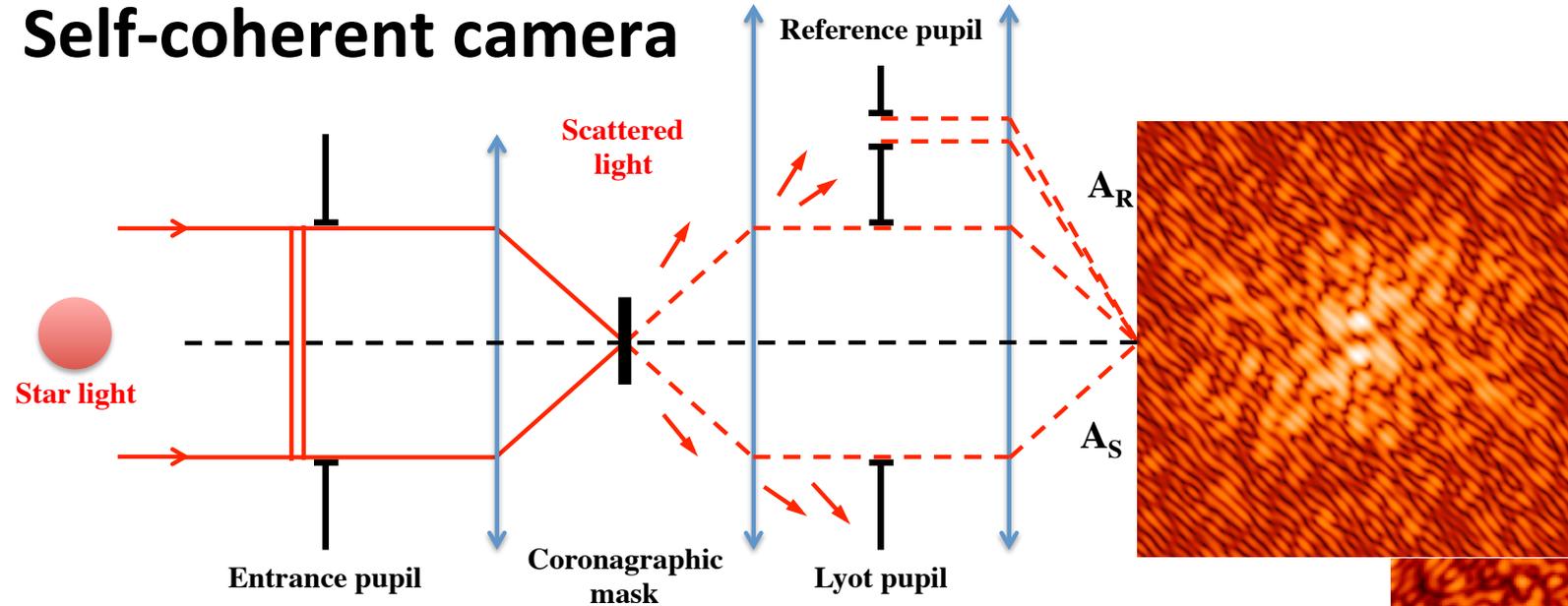
Tests of coronagraphic components	Advancement	Collaboration
Four Quadrant Phase Mask	✓	Dvlpt at Paris Obs. + GEPI, France
Multi-Four Quadrant PM	✓	Dvlpt at Paris Obs. + GEPI, France
Apodized Dual Zone PM	✓	M. N'Diaye (LAM, France)
8-Octant Phase Mask	09/2015 =>	N. Murakami (Hokkaido Univ.)
Vector Vortex	09/2015 =>	J. Nishikawa (NAOJ)
6-Layers Phase Mask	09/2016 =>	Q. Cao ( Shanghai Univ.)
<b>Wavefront control</b>		
Monochromatic & Polychromatic Self-Coherent Camera	✓	Dvlpt at Paris Obs.
Amplitude & Chromatism correction	12/2015 =>	Dvlpt at Paris Obs. + Lagrange, France
Coronagraphic diversity (COFFEE algorithm)	01/2016 =>	L. Mugnier, J.F. Sauvage (ONERA, France)
Optimization of algorithms, system study, etc...	2016 (TBC) =>	SRON (Netherlands)



# Wavefront sensing on the THD bench

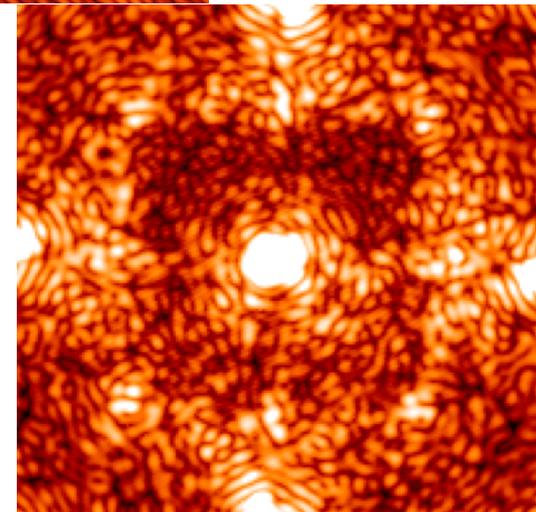
Telescope      Pupil plane      Focal plane      Pupil plane      Focal plane

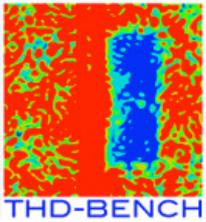
## Self-coherent camera



### Spatial encoding of the *speckles* in focal plane :

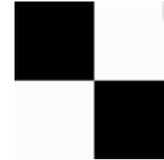
- Estimation of the **complex field**
- Not model dependent
- **One SCC image (= science image) per loop**
- Closed-loop correction (**few Hz**, goal 100 Hz)
- Correction in **large bandwidth** (80 nm in visible)





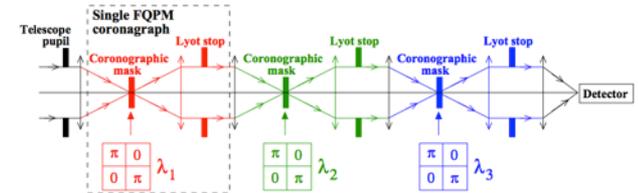
# Tested coronagraphs on THD/THD2

## 1) Monochromatic FQPM



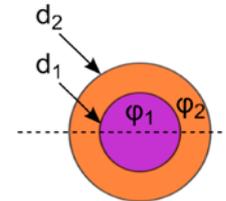
## 2) Multi-FQPM

3 FQPM optimized for  $\lambda_0 = 650$  nm and  $\Delta\lambda = 200$  nm (30 %)



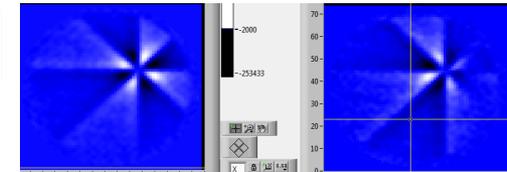
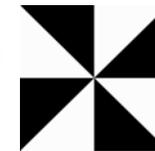
## 3) Dual Zone Phase Mask (LAM collaboration)

Mask and apodizer optimized for 1-10  $\lambda/D$  for  $\lambda_0 = 665$  nm and  $\Delta\lambda = 133$  nm (20%)



## 4) Eight Octant Phase Mask (Hokkaido Univ. & NAOJ collab.)

Monochromatic and achromatic 3 layers components



## 5) Vector Vortex (Hokkaido Univ. & NAOJ collab)

Monochromatic and achromatic 3 layers components

