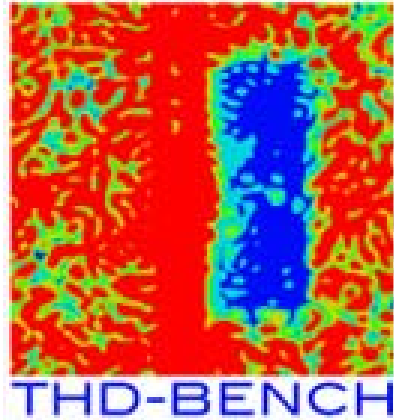




Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique



THD2
LHDS (Très Haute dynamique)

a **high contrast imaging** testbed
for future instruments to characterize **exoplanets**

Fabien Patru (ESEP postdoc)

Pierre Baudoz, Raphaël Galicher & the THD team

ESEP day

29/11/2016

Outline

- High contrast imaging for exoplanet science



- The THD2 bench



- Plan for the next 2 years



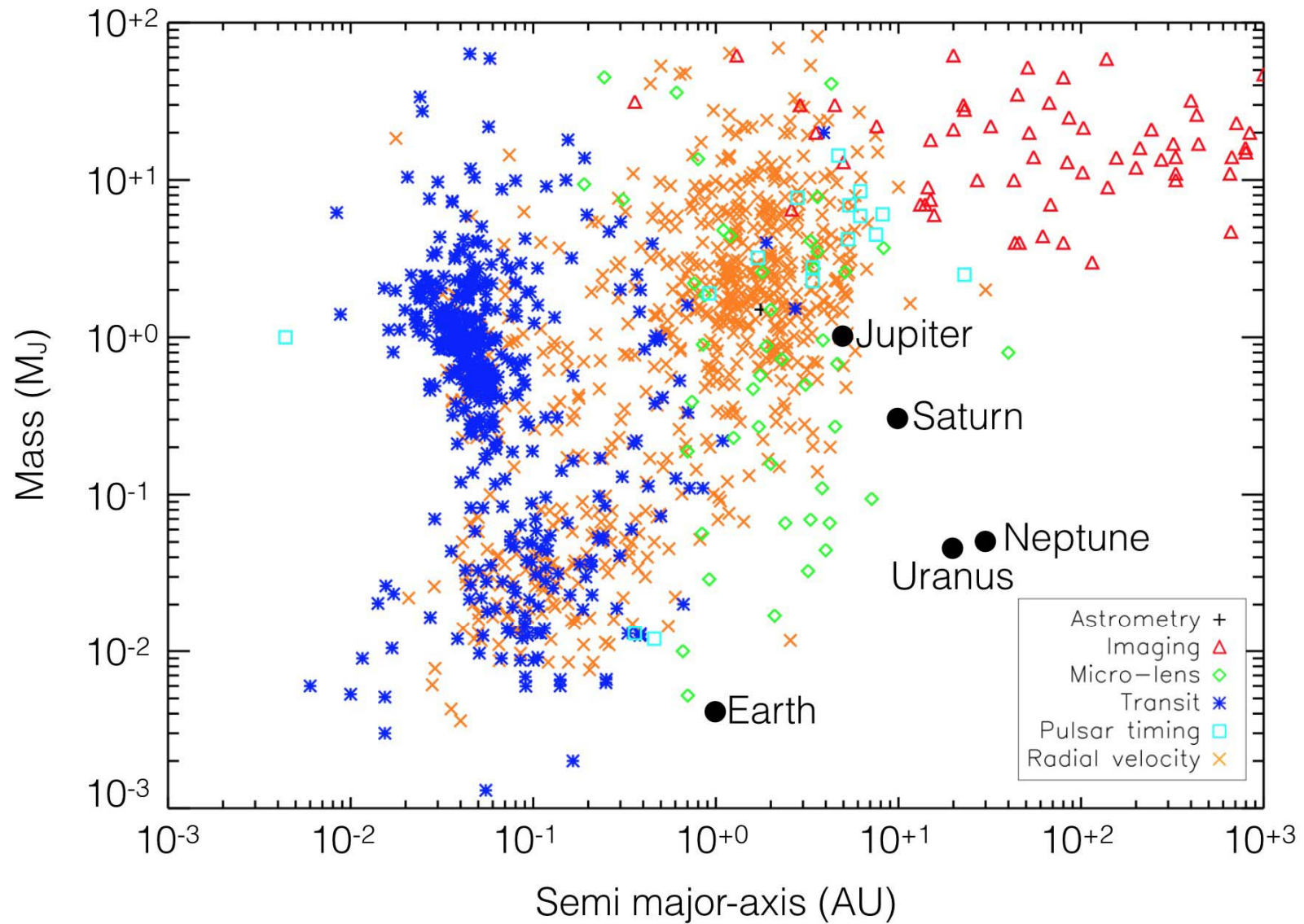
Outline

- High contrast imaging for exoplanet science



- The THD2 bench
- Plan for the next 2 years

Scientific context



The exoplanets, new world of science

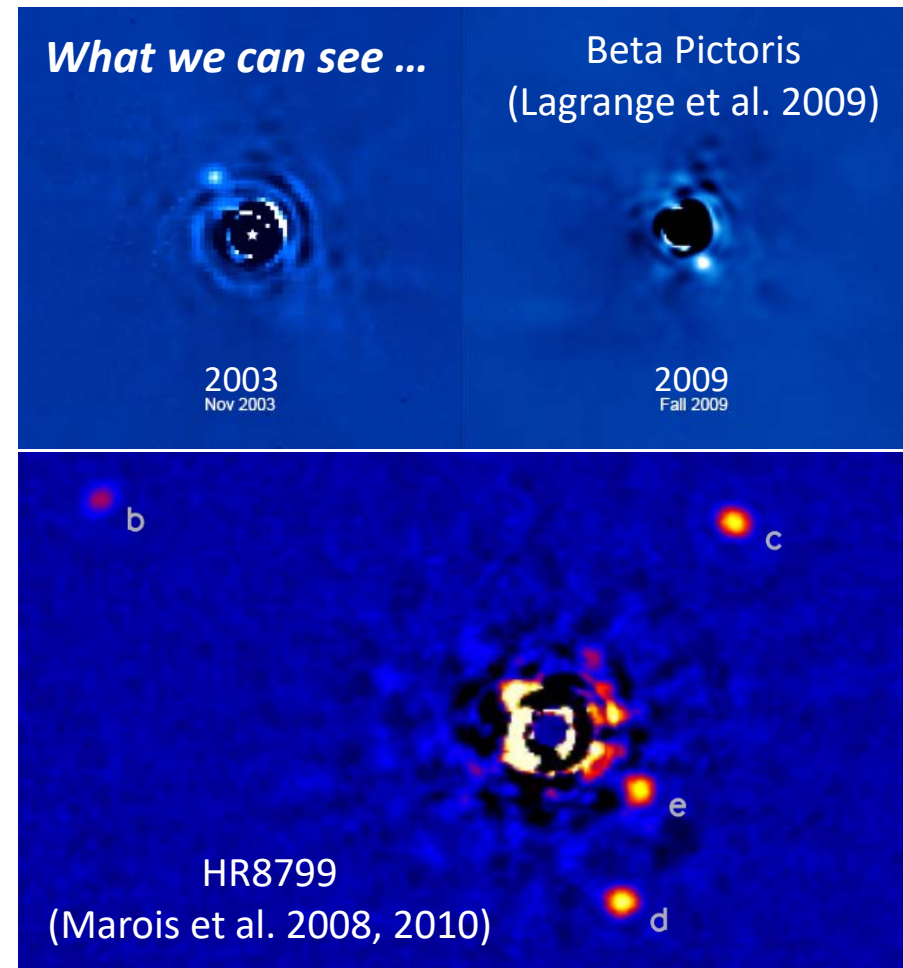


Need of **high spectral resolution**

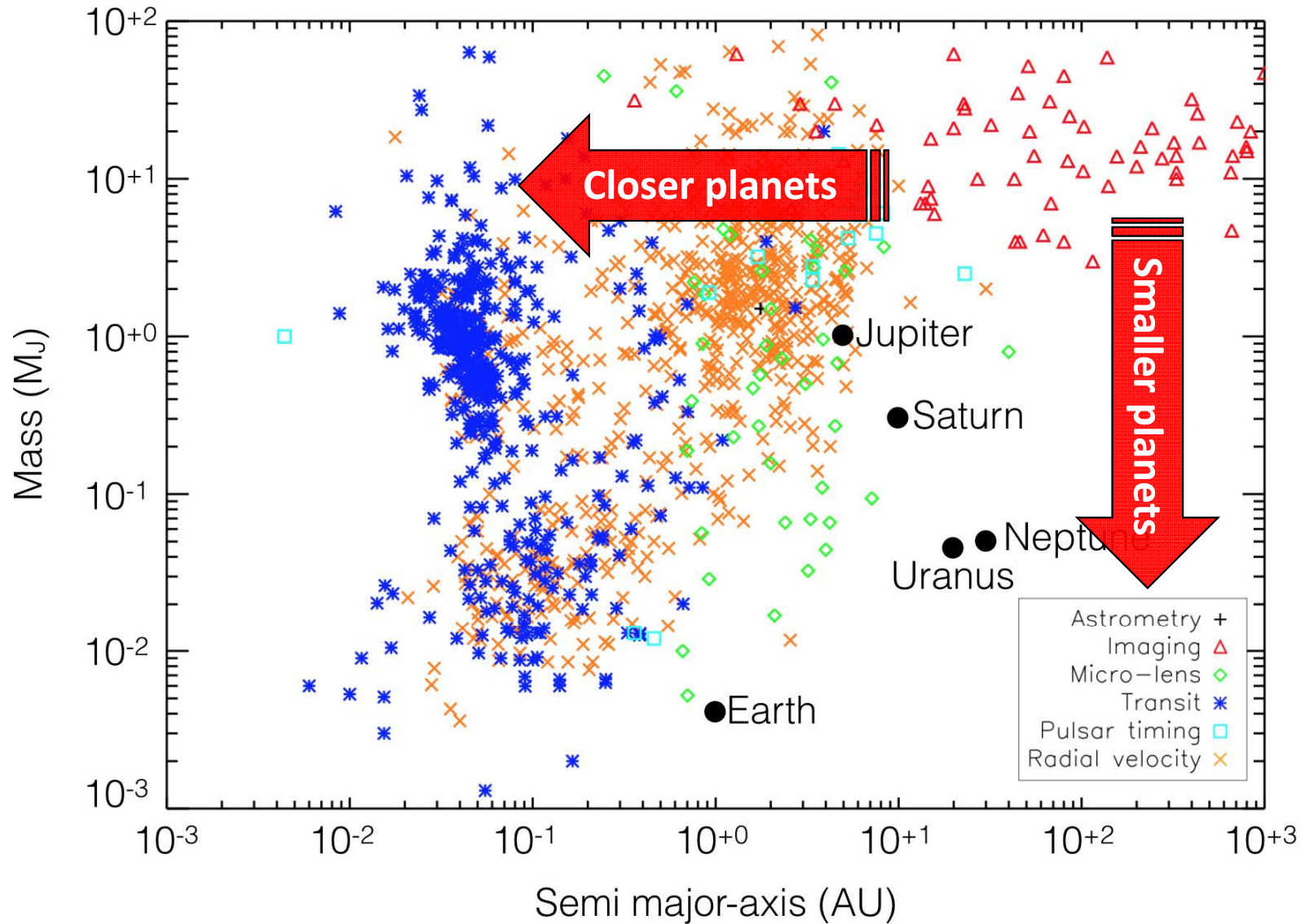
Direct imaging (=> Direct spectrum)

requires :

- High **spatial resolution** to detect close planet (< 1 arcsec)
- High **contrast** to detect faint planets (10^{-4} to 10^{-10})

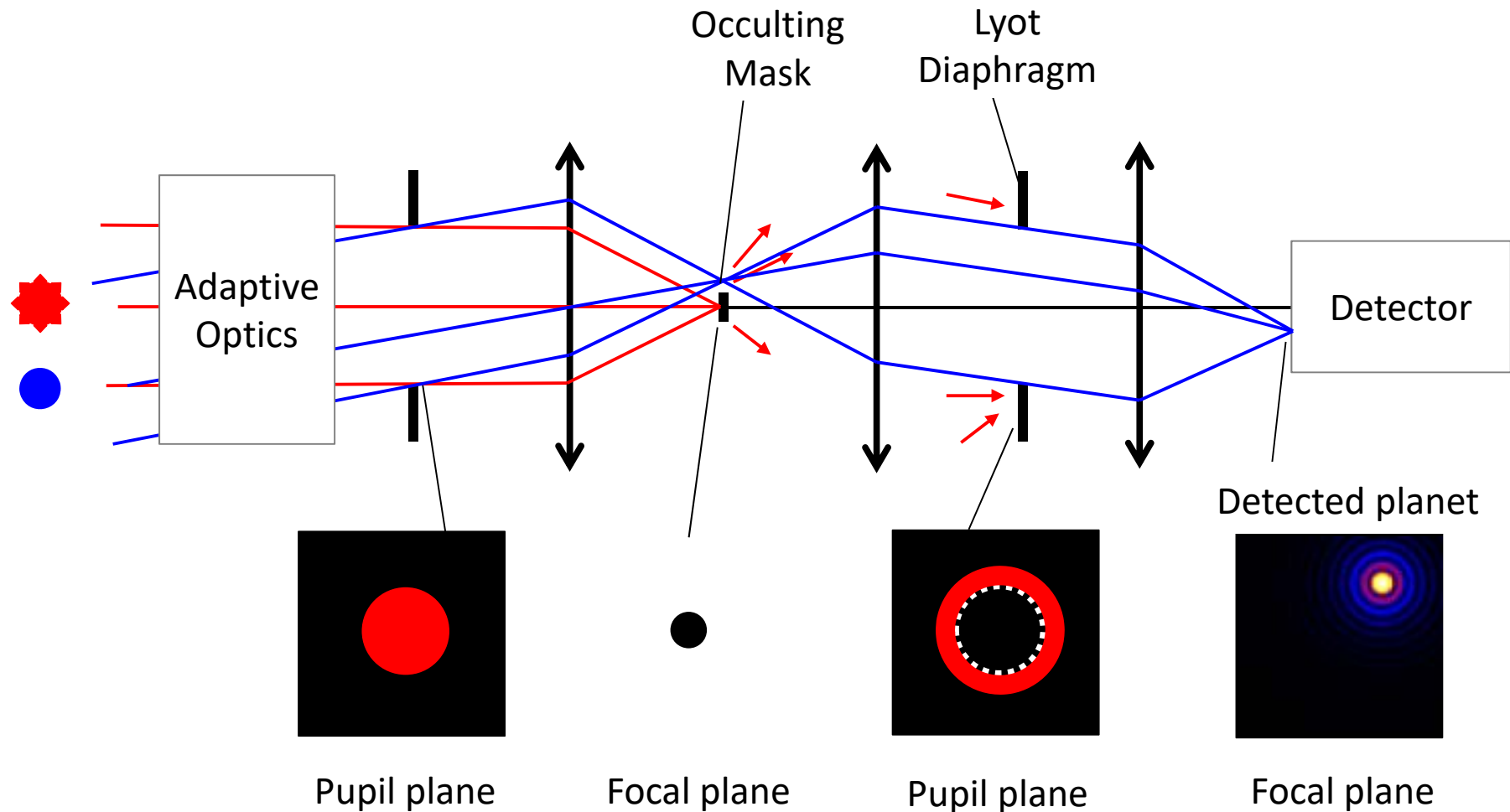


Scientific context



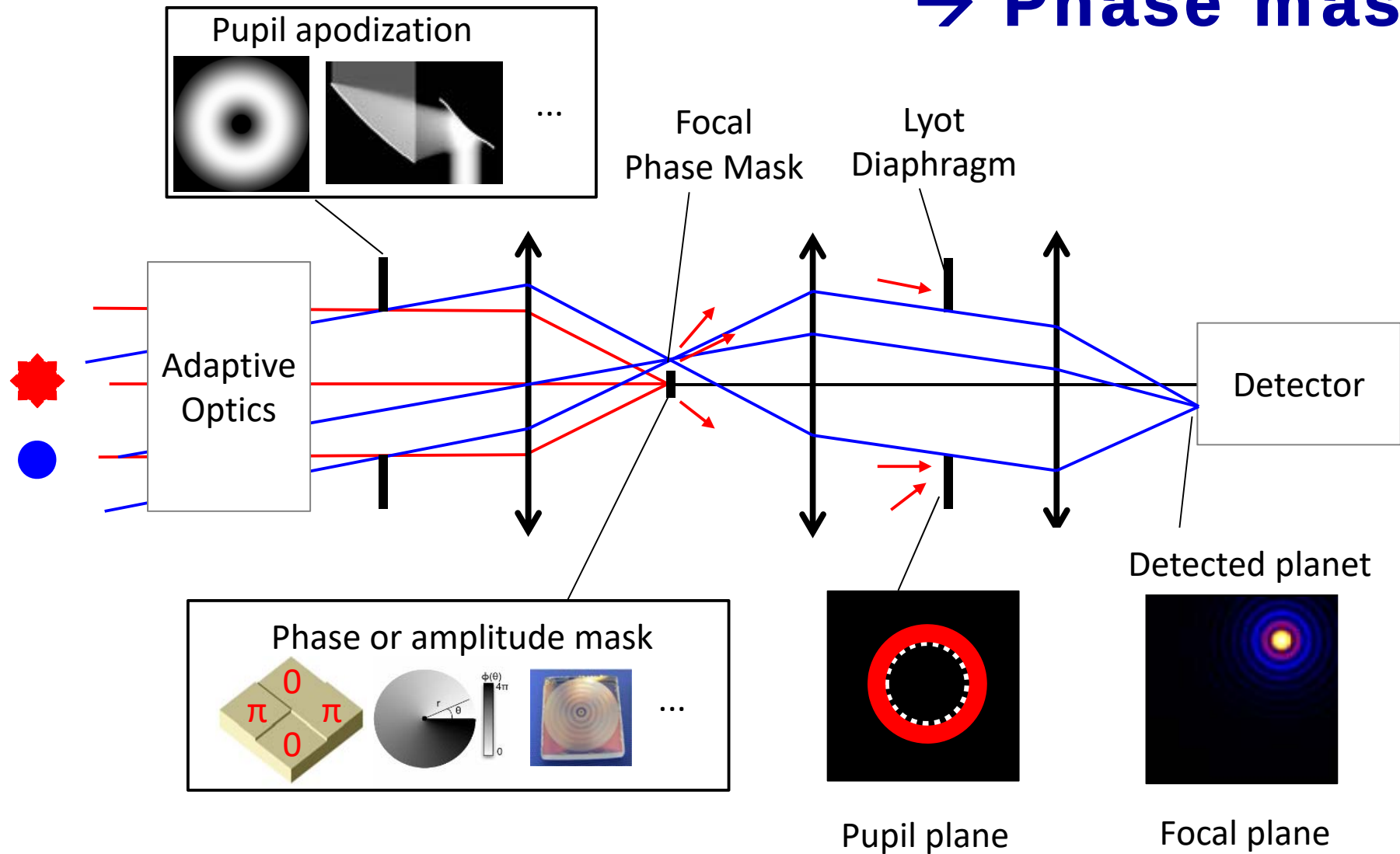
Stellar coronagraphy

→ Lyot mask



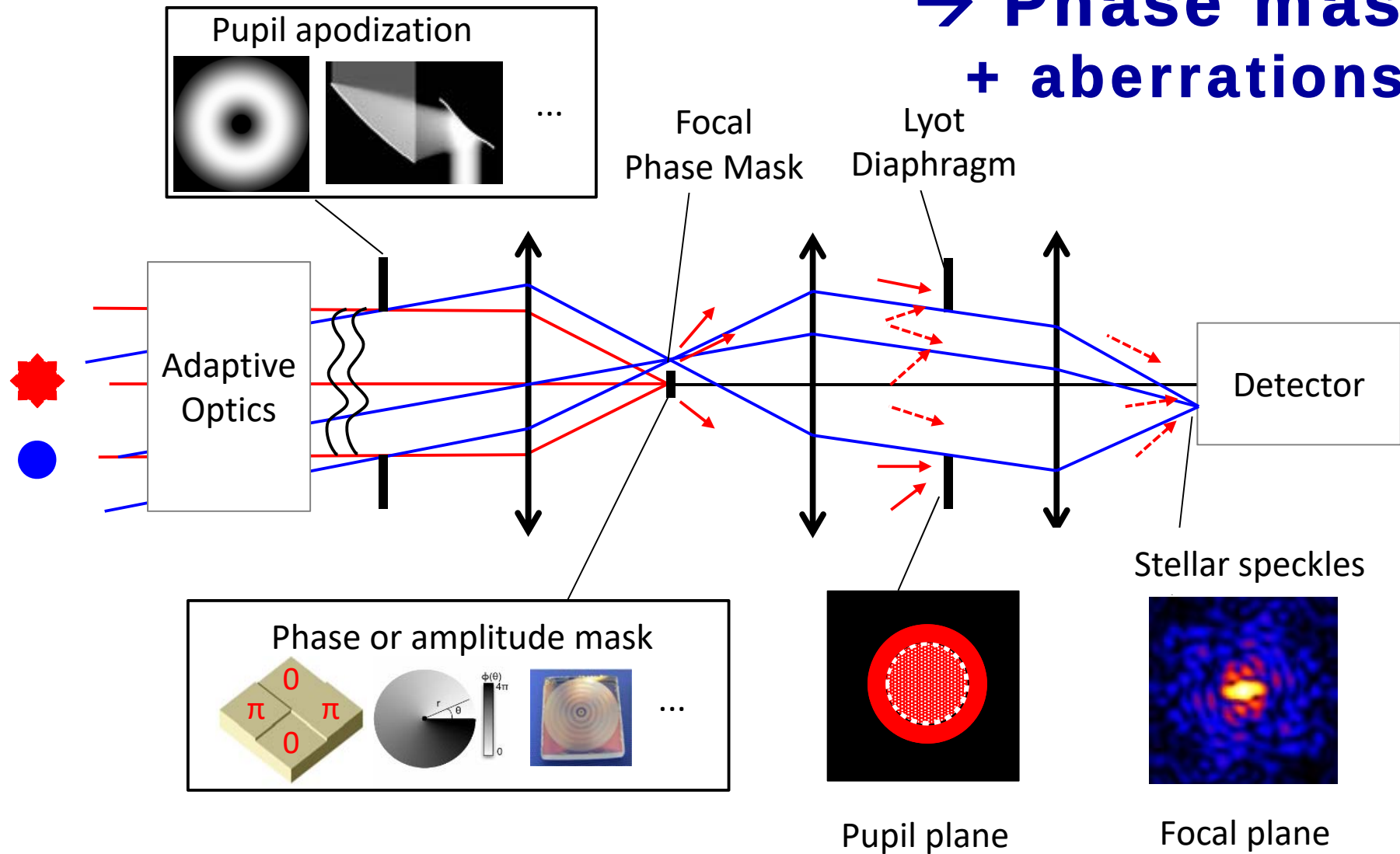
Stellar coronagraphy

→ Phase mask

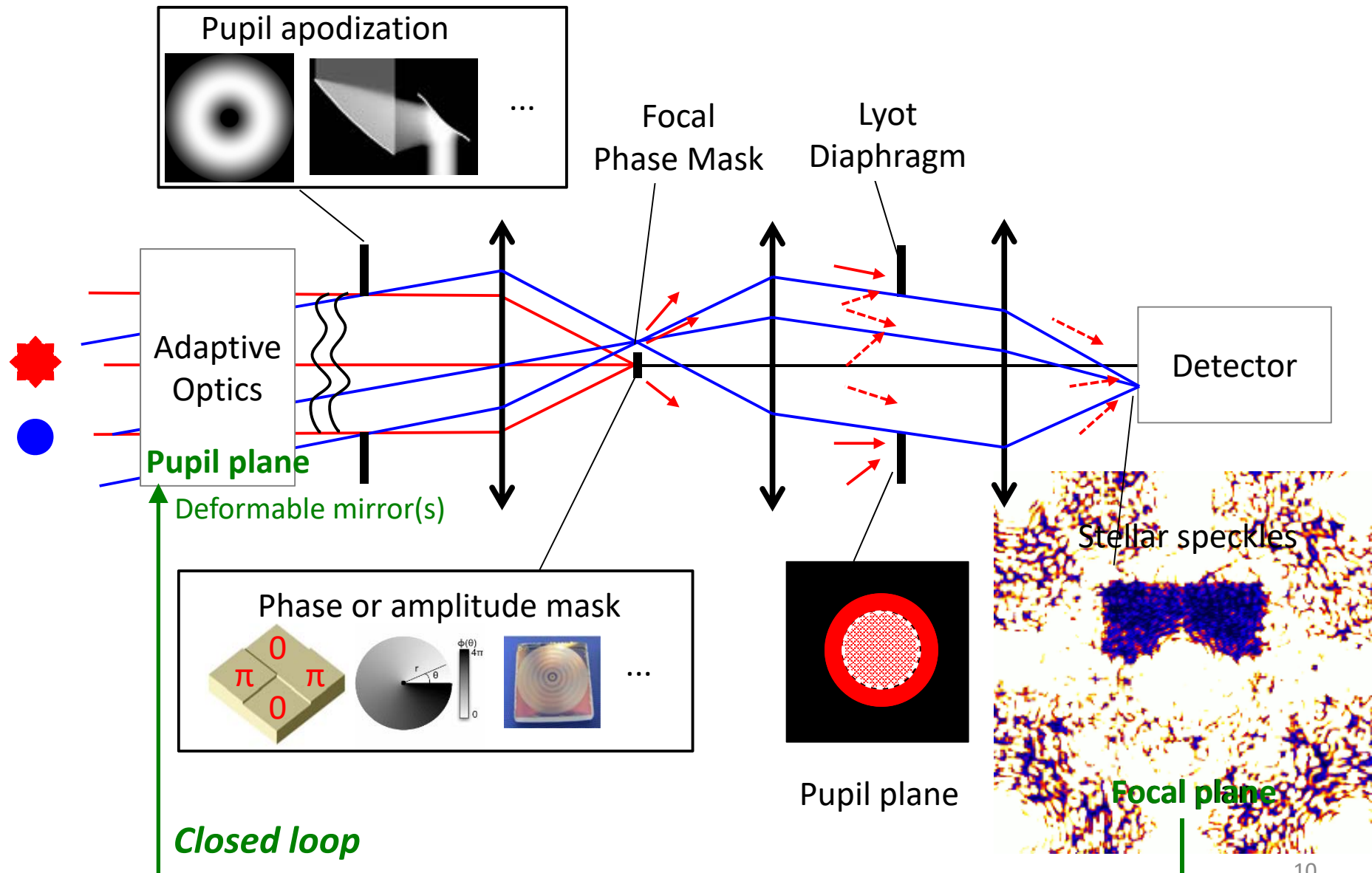


Stellar coronagraphy

→ Phase mask
+ aberrations



Active control of the speckles



(Courtesy of Raphaël Galicher)

Outline

- High contrast imaging for exoplanet science

- The THD2 bench



- Plan for the next 2 years

Future projects

- Many **projects** for exoplanet imaging

- Current instruments (e.g. VLT/SPHERE upgrade)



- Future instruments (e.g. E-ELT/PCS, W-FIRST, LUVOIR, etc.)

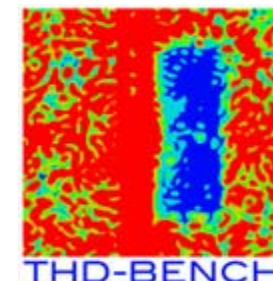


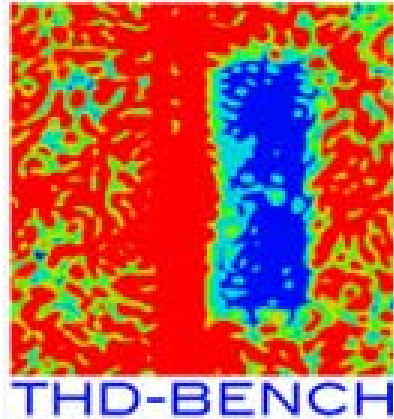
- Many possible **techniques** for high contrast imaging

- Coronagraphy, wavefront sensing, etc...

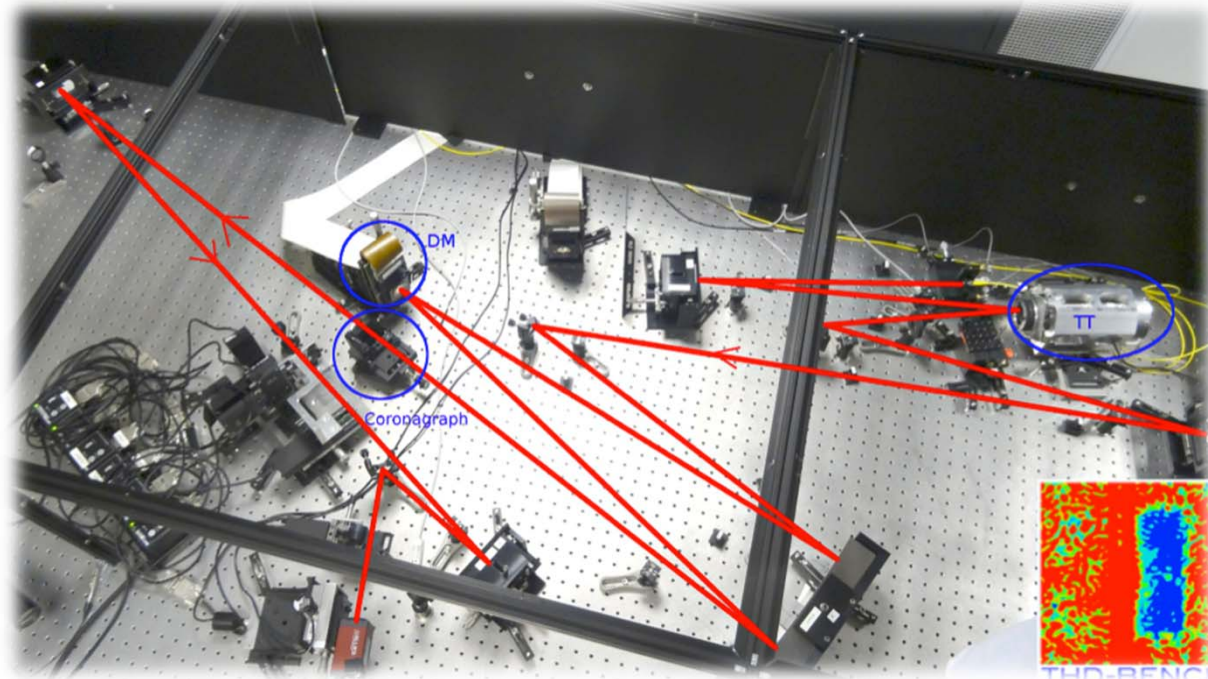
- How to choose the best techniques *w.r.t.* the project ?

- Tests & comparisons in laboratory => **THD2 bench**

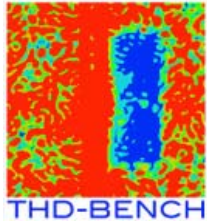




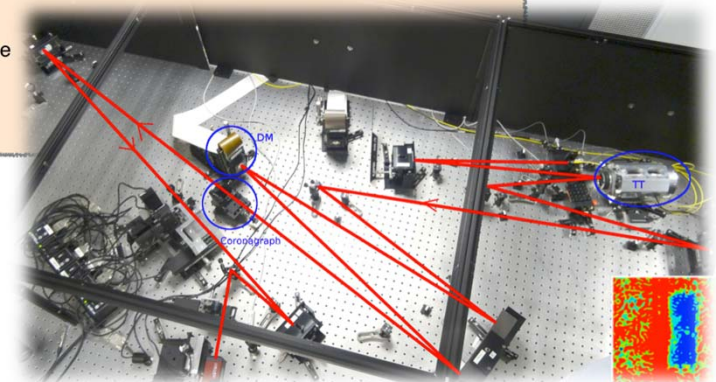
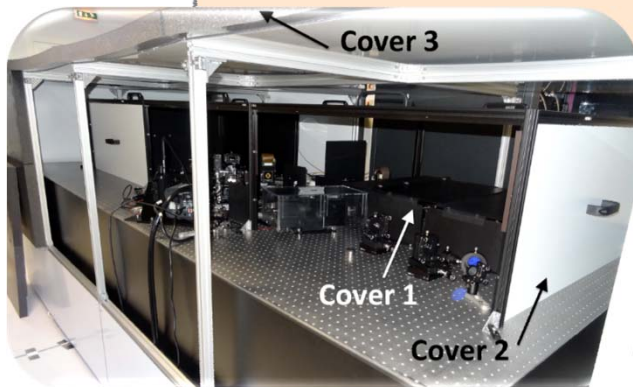
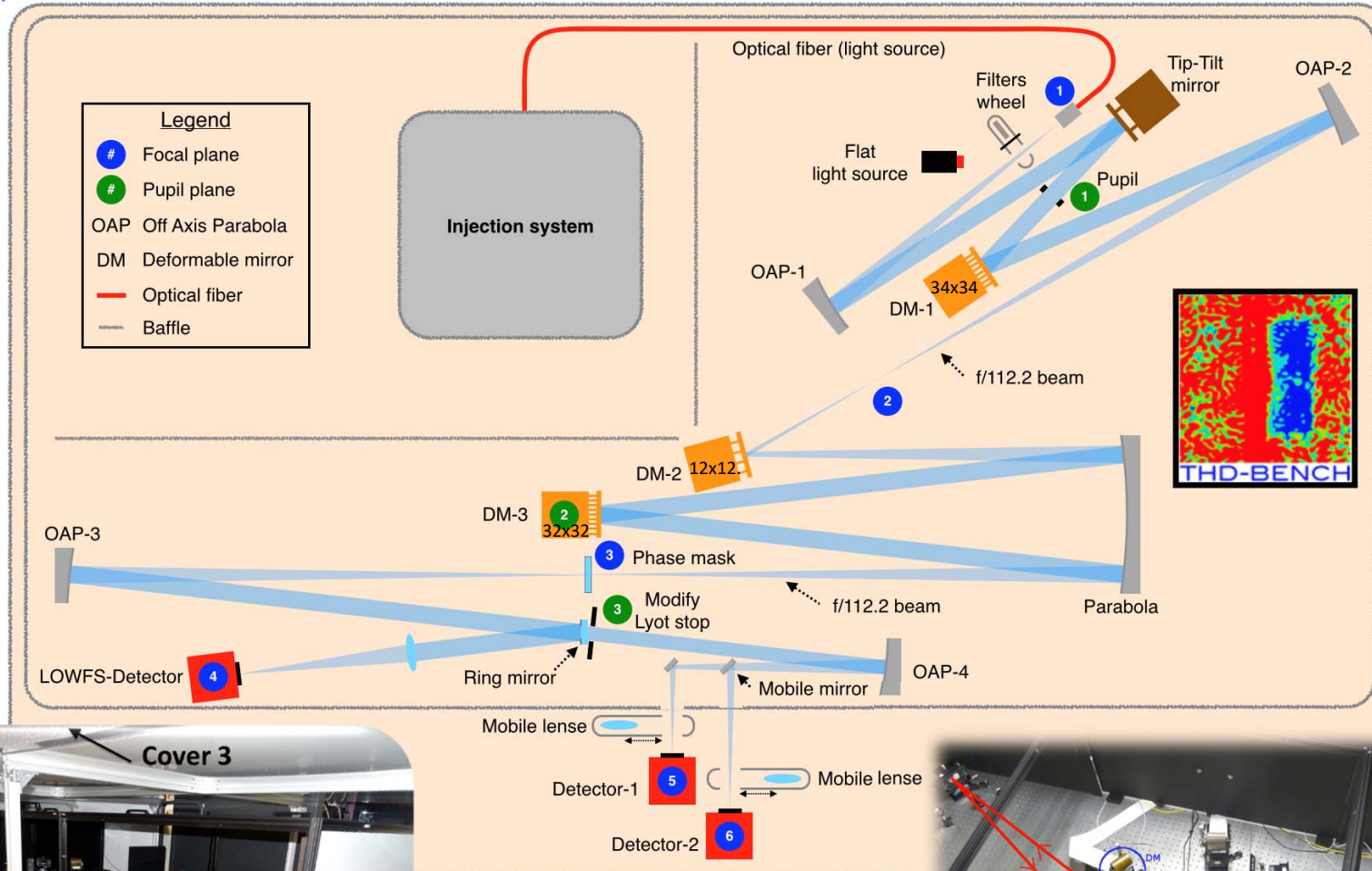
Strategy & objectives on THD2

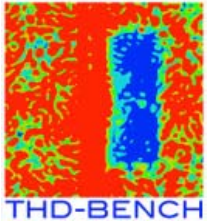


- **Test several concepts for high contrast imaging under the same conditions**
 - Coronagraphs, apodizers,
 - Focal plane wavefront sensors
 - Focal plane speckle techniques
- **Open facility for the community**
 - International collaborations
 - Flexible interface
 - Accessible pupil & focal planes
 - Phase & amplitude correction



Optical design and setup





A very complete testbed

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
- 60000 ADU



Neo

Low-order wavefront Sensor

- 500 Hz
- 18 e- RON
- 16400 ADU



Pike

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



Calibration & Housekeeping

Recording simultaneously : **images** from cameras, **applied controls** to active mirrors, **total flux and spectrum of input light**, **temperature & humidity** sensors (≈ 10 sensors), working configuration, ... ¹⁵



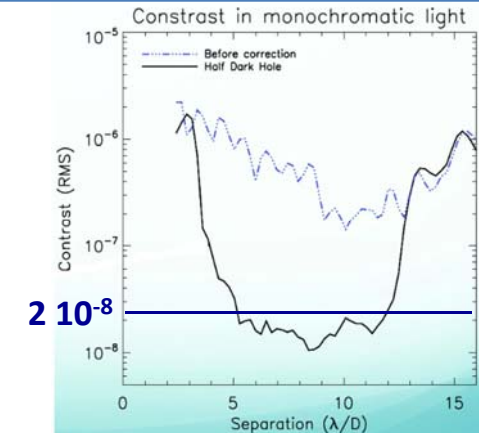
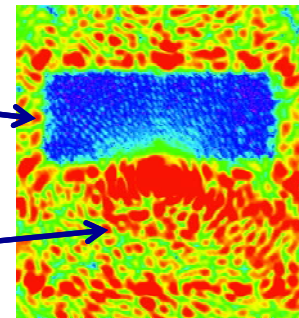
Examples of Performance

More than 15 Publications (5 refereed or accepted papers)

Monochromatic (bandwidth <10 nm) results

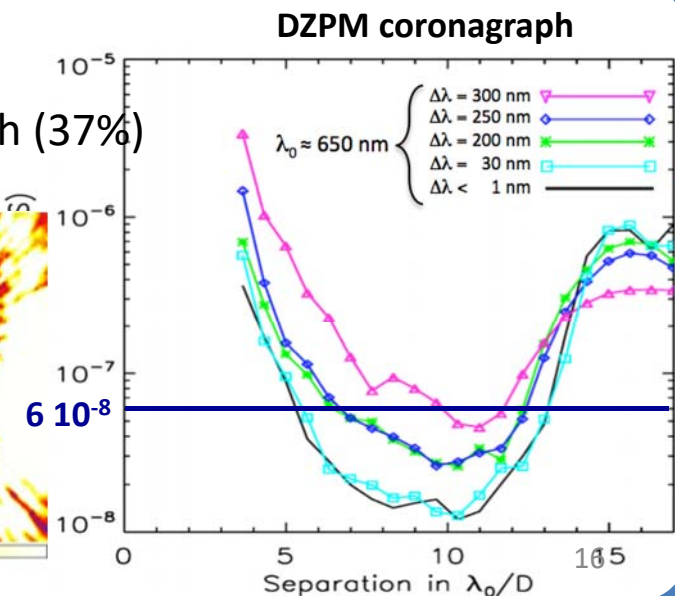
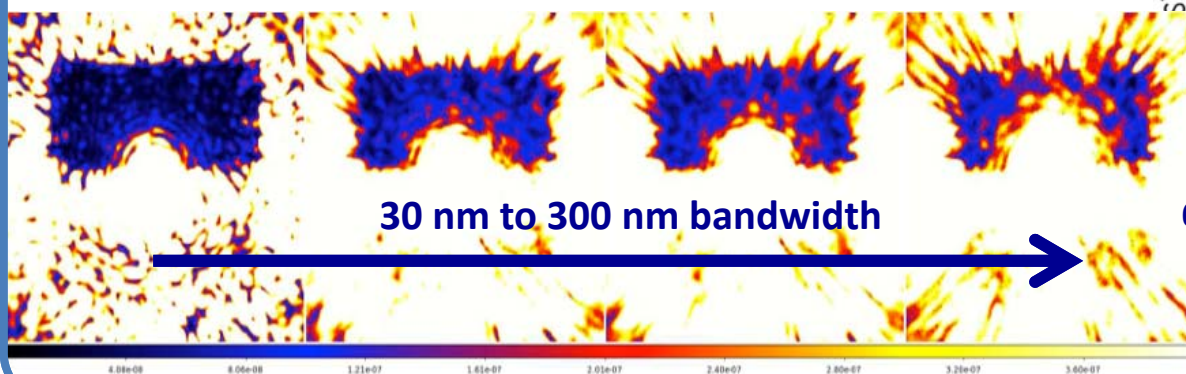
Contrast: $< 2 \cdot 10^{-8}$ between $5 \lambda/D$ and $12 \lambda/D$

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



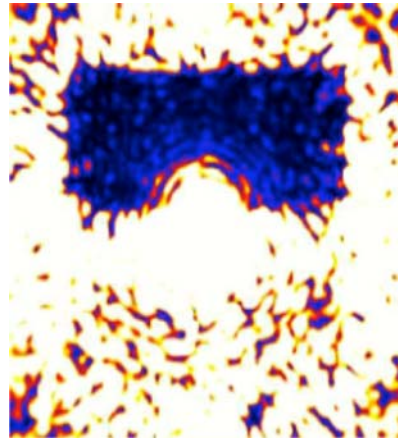
Achromaticity of the testbed

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

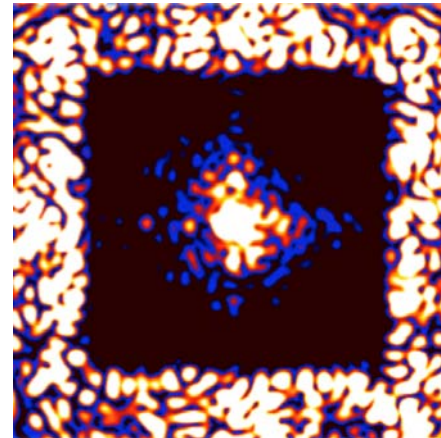




Examples of Performance



THD 1 (1 DM only)



THD 2 (2 DMs)

Full-field
Correction

<i>Coronagraphic components</i>	<i>Collaborations</i>
4-Quadrant Phase Mask (PM)	Dvlpt at Paris Obs. + GEPI, France
Multi-4 Quadrant PM	Dvlpt at Paris Obs. + GEPI, France
Apodized Dual Zone PM	M. N'Diaye (LAM , France)
8-Octants PM	N. Murakami (Hokkaido Univ.)
Photonic Crystal Vortex PM	J. Nishikawa (NAOJ , Japan)
<i>Focal plane wavefront control</i>	<i>Collaborations</i>
SCC & MR-SCC Wavefront Sensor	Dvlpt at Paris Obs.

Outline

- High contrast imaging for exoplanet science
- The THD2 bench
- Plan for the next 2 years



WHEN ?

A versatile and open testbed

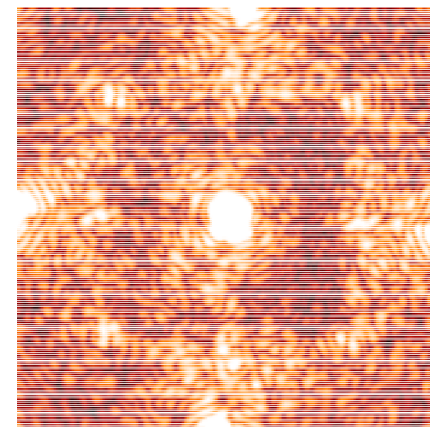
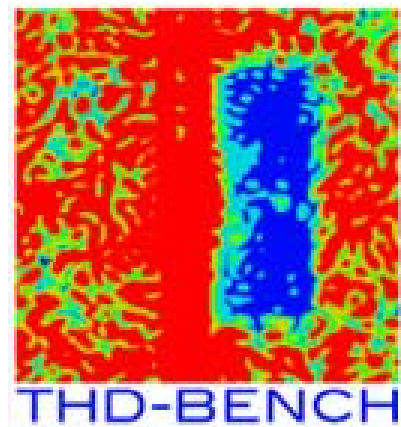
<i>Coronagraphic components</i>	<i>Collaborations</i>	<i>Planning</i>
Liquid Crystal Polymer Vector Vortex PM	THD team (LESIA , France)	(Purchased soon)
8-Octant PM	N. Murakami (Hokkaido Univ. , Japan)	January 2017 (PhD, 1 month)
Photonic Crystal Vortex PM	J. Nishikawa (NAOJ , Japan)	January 2017 ?
6-Layers PM (from GEPI) Focal plane phasing techniques	Q. Cao, K. Wang, D. Teng (Shanghai univ. , China)	March 2017 (Student, 1 week)
<i>Focal plane wavefront control</i>	<i>Collaborations</i>	<i>Planning</i>
Post-coronagraphic diversity algorithm (COFFEE)	L. Mugnier, J.F. Sauvage (ONERA, LAM , France)	February 2017
Electric Field Conjugation (EFC)	C. Vérinaud (IPAG , France)	TBD
Zernike sensor (Zelda)	A. Vigan, K. Dohlen (LAM , France)	TBD
<i>Other studies</i>	<i>Collaborations</i>	<i>Planning</i>
Optimization of algorithms Chromatic aberrations study System study, etc...	C. de Jonge (SRON , Netherlands)	March, May 2017 (PhD, 2 weeks + 6 month ?)
Amplitude & chromatism correction	(Paris Obs., OCA Lagrange , France)	TBD

Main tasks during my post-doc

- **Management:**
 - Technical THD team (regular meetings, bench occupation vs Gantt, etc.)
 - Master students, PhD, postdocs
 - External manufacturers, providers
 - **International collaborations** (Japan, China, Netherlands, France, to be continued...)
- **Experiments on the THD2 bench:**
 - Test and integrate **a new vortex cornagraph**
 - Optimize the control loop with 2 DMs
 - Add a 12x12 DM to control **amplitude aberrations** at low spatial frequency
 - Sense and correct **chromatic aberrations** by using 3 DMs
 - Contribute to **Focal Plane WFS** comparison for **speckle** sensing and correction
- **To go further: Understand the limitations from 10^{-8} to 10^{-9} , 10^{-10} , ... ?**
 - Thermal effects, diffusion, etc.
 - New methods based on **interferometry** (aperture masking, aperture discretization)

Conclusion

- **Objectives**: Prepare the future instruments for ground and space projects
- **Needs**: Tests in laboratory of various techniques and their associations
- **A new tool**: The THD2 bench
 - A unique testbed in Europe
 - International collaborations
 - Several coronagraphs and Focal Plane wavefront sensing techniques
(already tested or TBD)



End

Thank you for your attention

THD2, pushing the contrast to the limit