imagine optic™

Experts in adaptive optics for ultra intense lasers

Latest developments of adaptive optics for ultra intense lasers and plasma diagnostics.

Xavier Levecq

Target to Plasma 2015

Outline

- Adaptive optics introduction

- Full correction strategy
    - Standard adaptive optics principle
    - Phase retrieval adaptive optics

- Plasma diagnostics
    - Wavefront diagnostics
    - Example of dense plasma diagnosis with EUV light source

- Conclusion

nlefaudeux@imagine-optic.com

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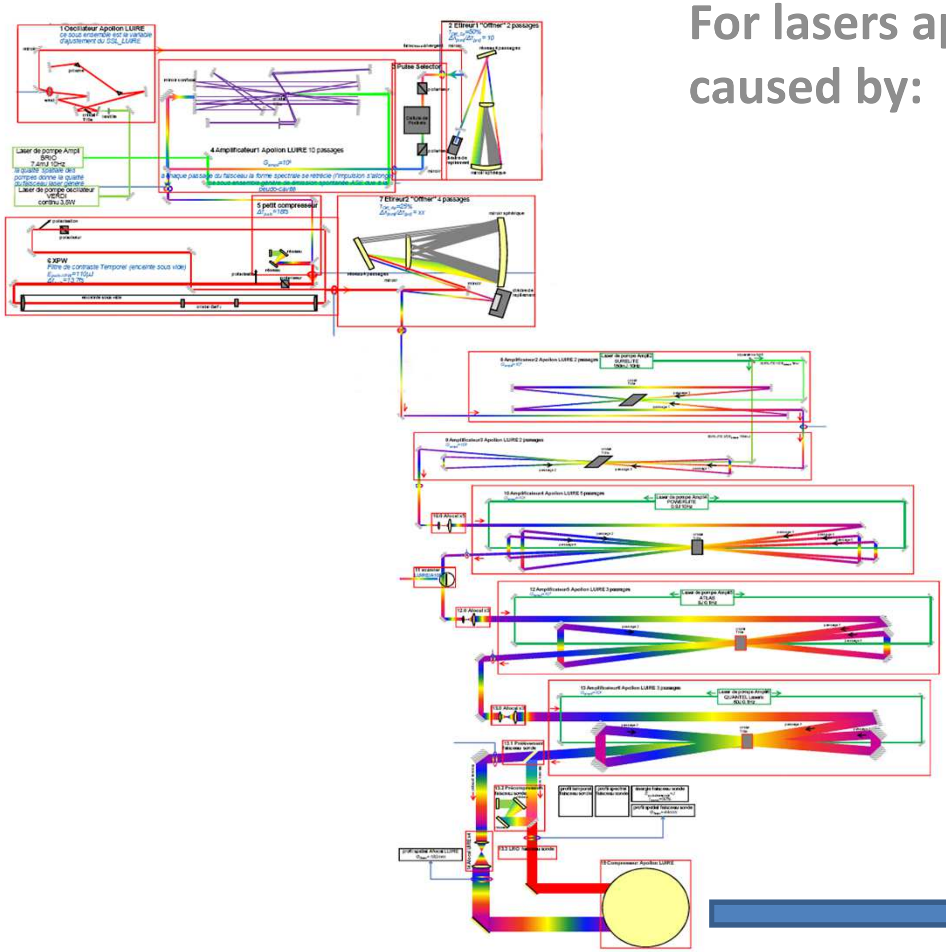
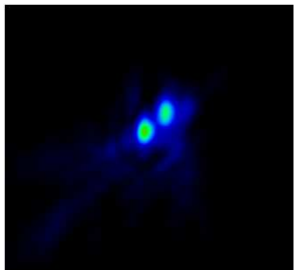
Adaptive optics introduction



For lasers applications, the wavefront distortions are caused by:

- *very high number optical elements*
- *misalignment of optical elements (beam expanders, …)*
- *Thermal effects in the amplifiers*
- *mechanical constraints on large optical elements*

These wavefront distortions degrade the focused beam and decrease the maximum focused intensity



Outline

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- **Full correction strategy**
    - Standard adaptive optics principle
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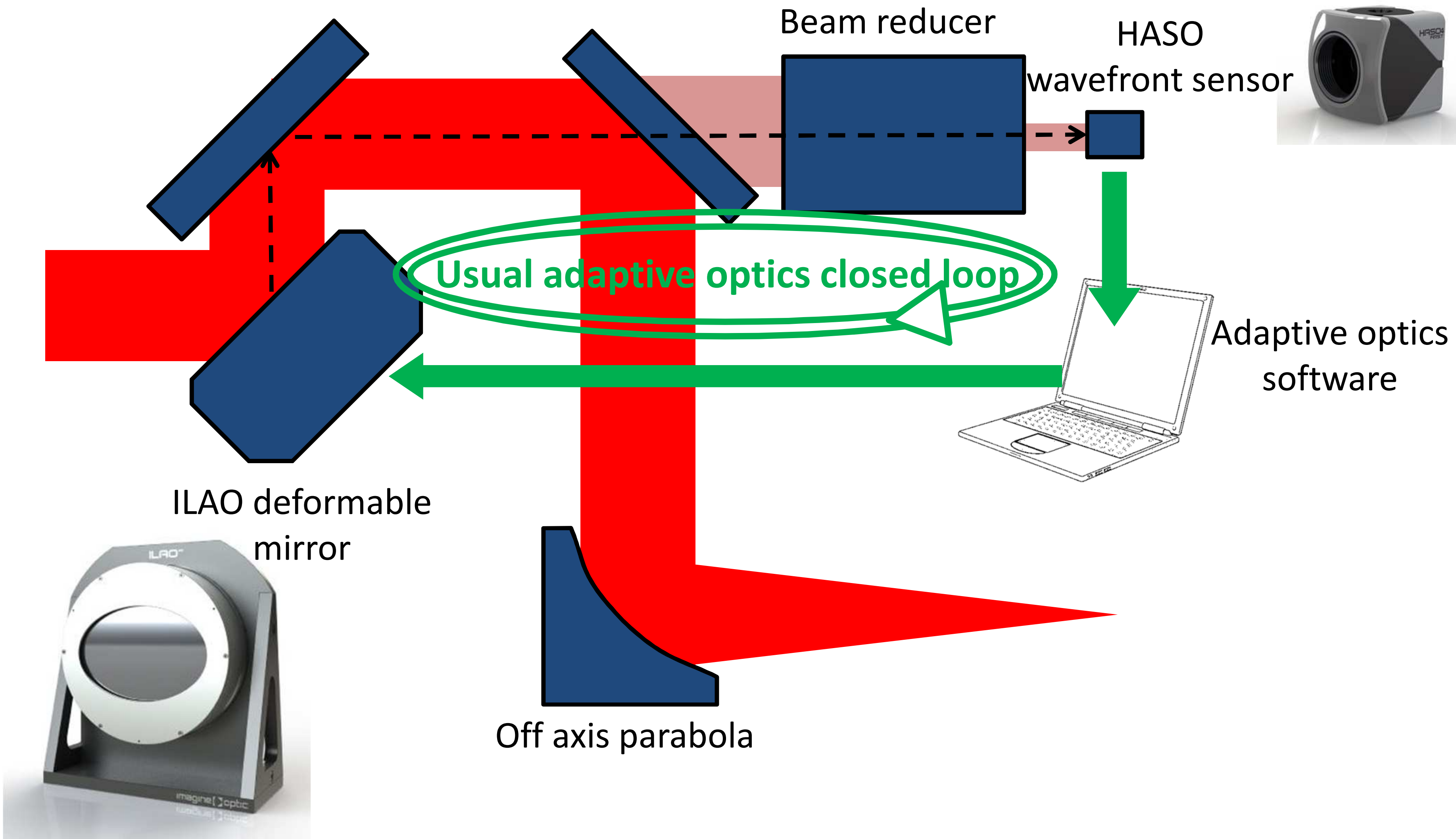
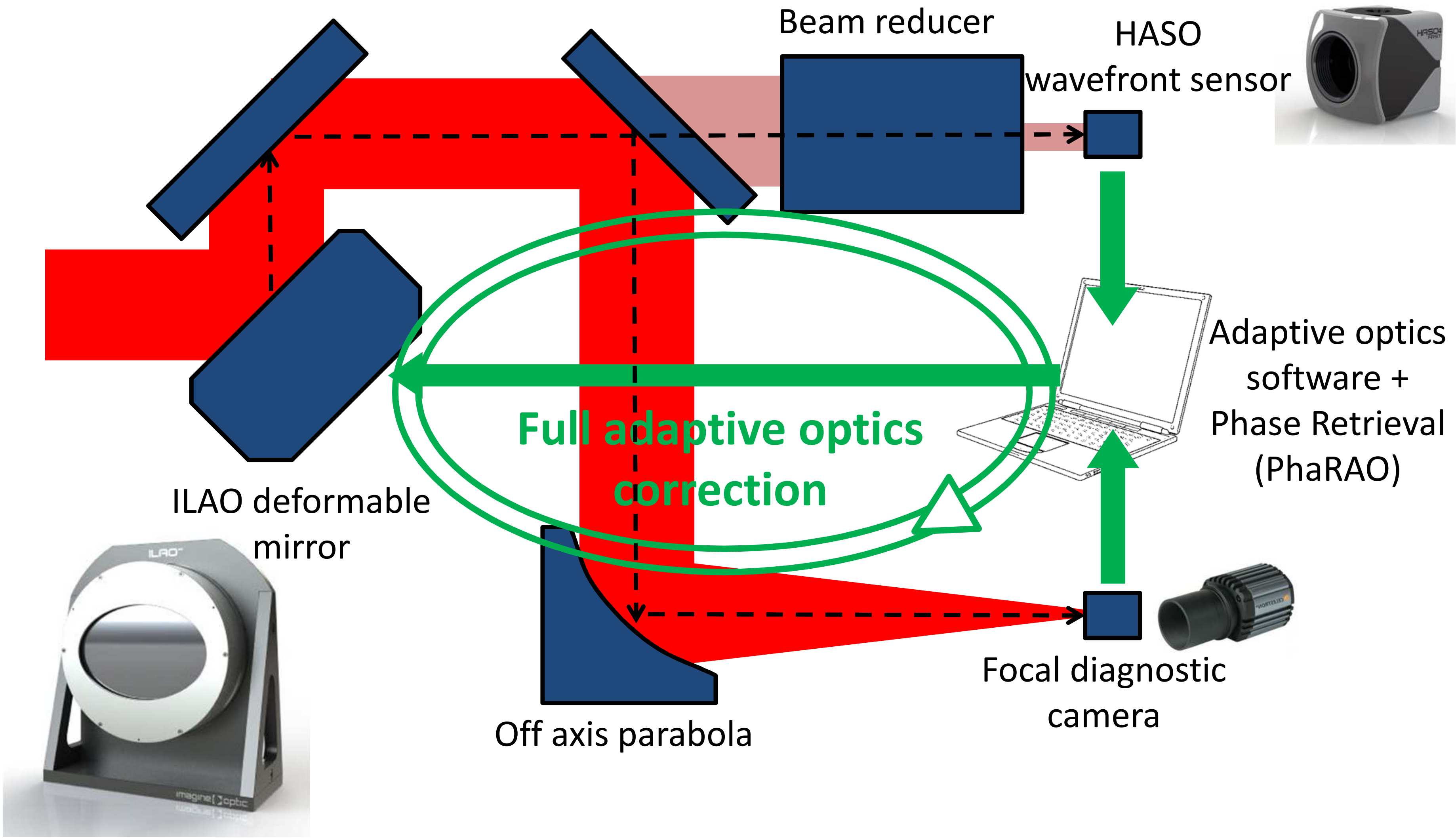
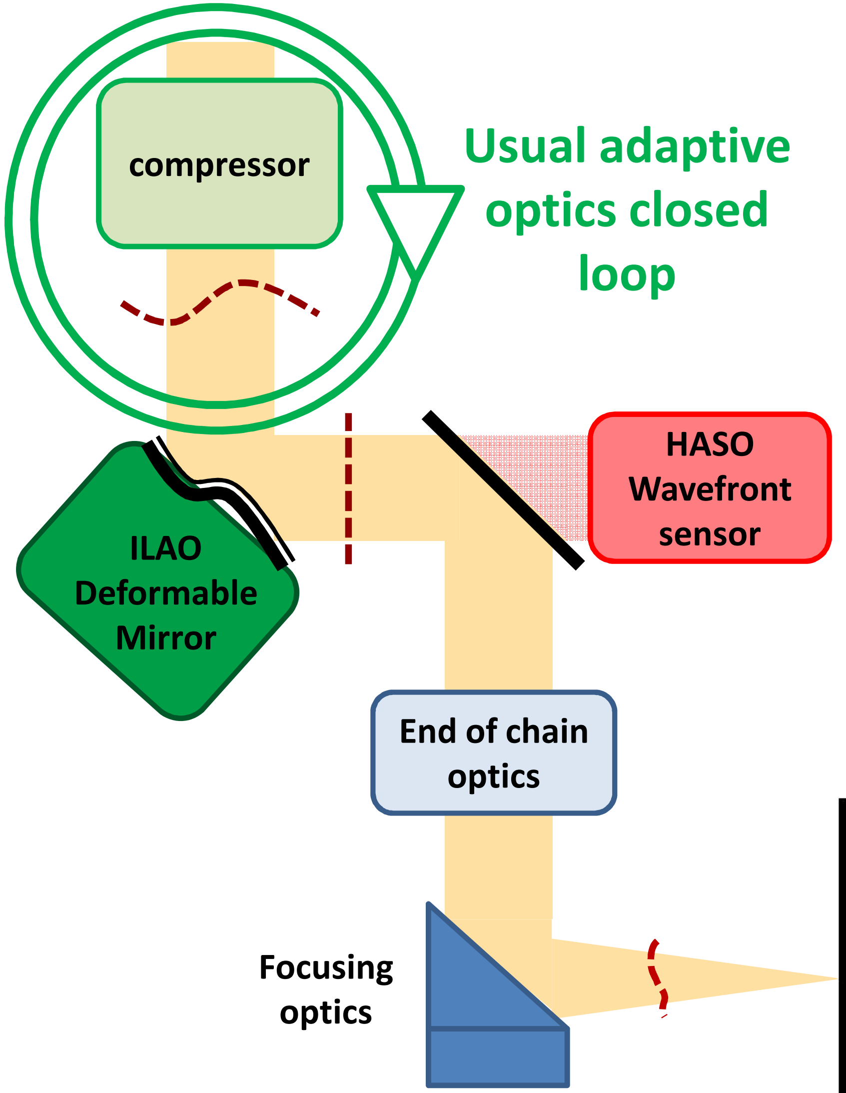
Standard adaptive optics principle



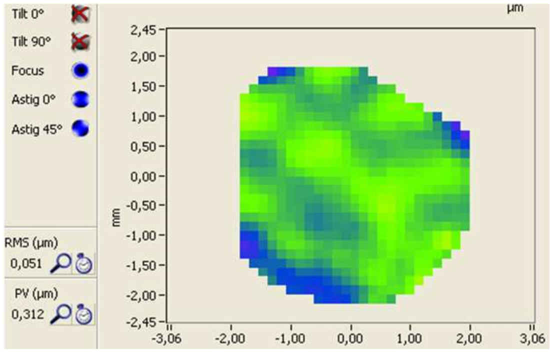
Full correction adaptive optics strategy

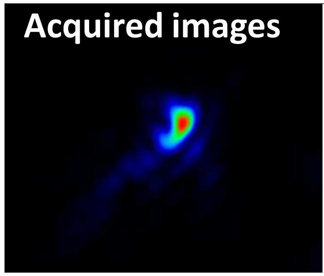


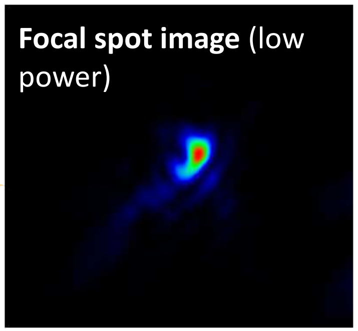
Full correction adaptive optics strategy : step 1, acquisition



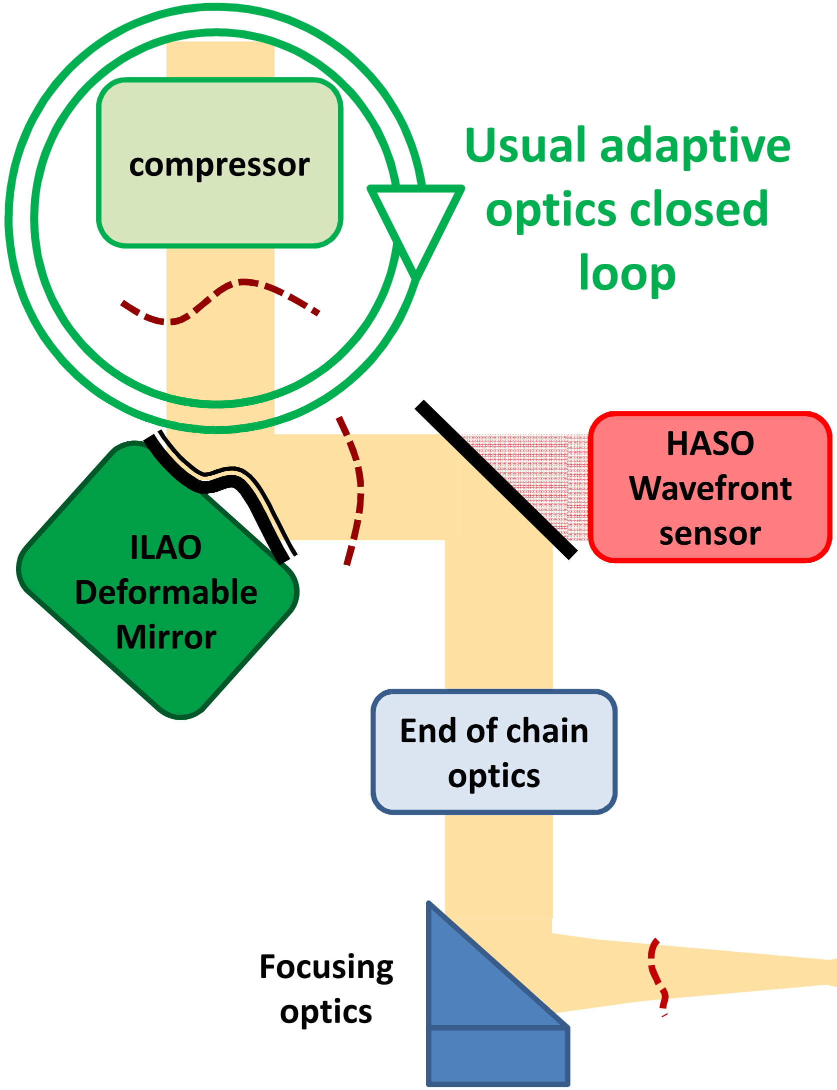
Wavefront
50 nm RMS



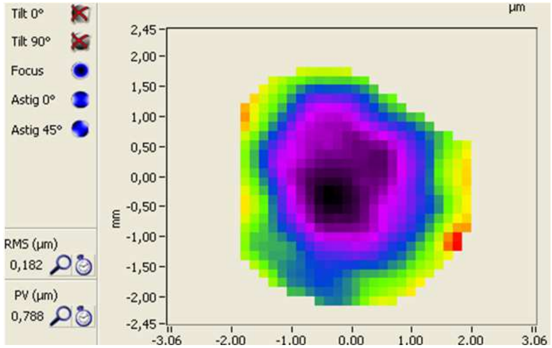


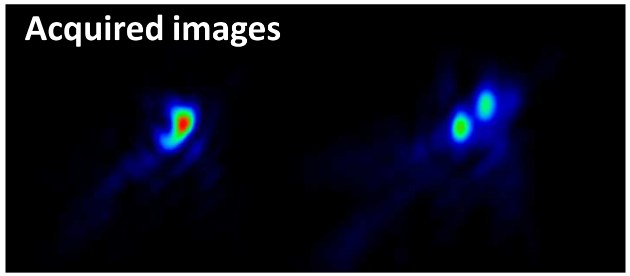


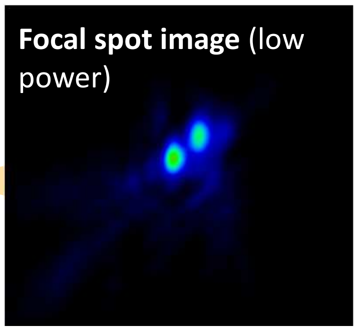
Full correction adaptive optics strategy : step 1, acquisition



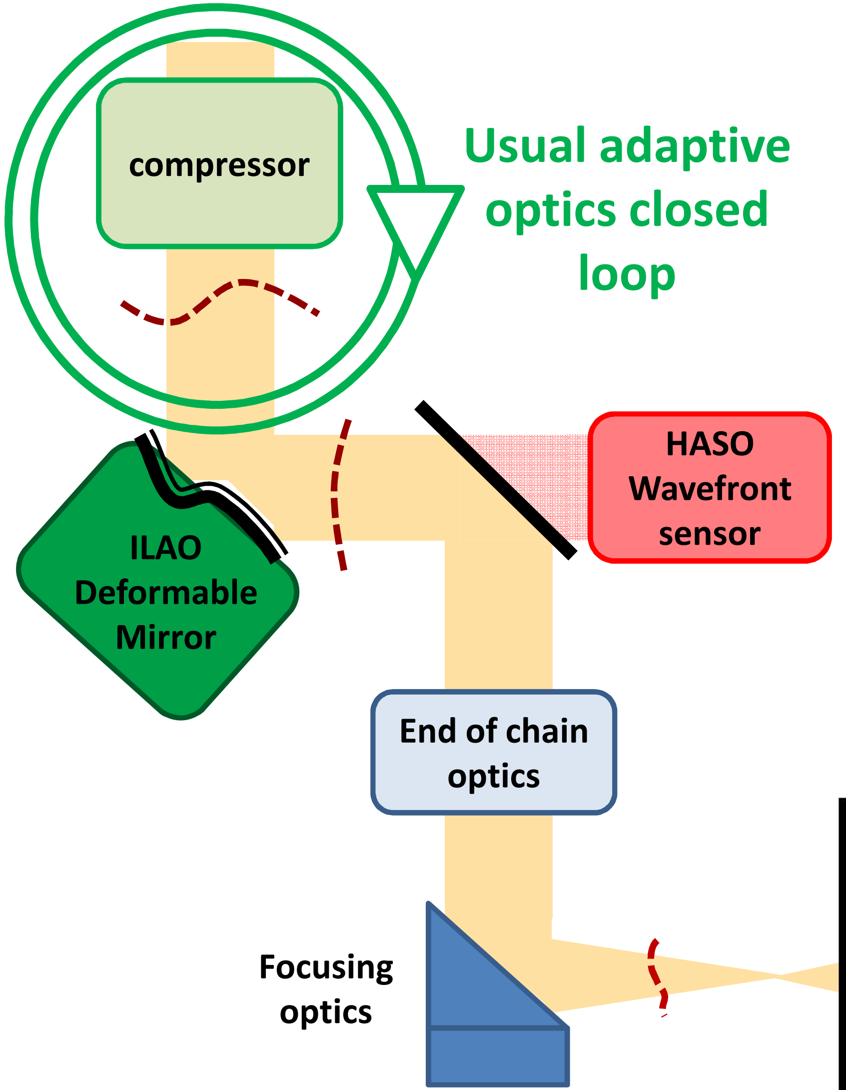
Wavefront
182 nm RMS



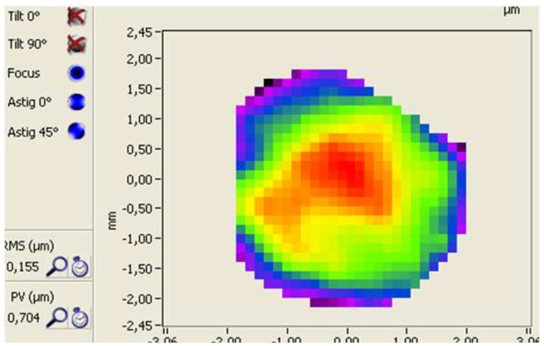


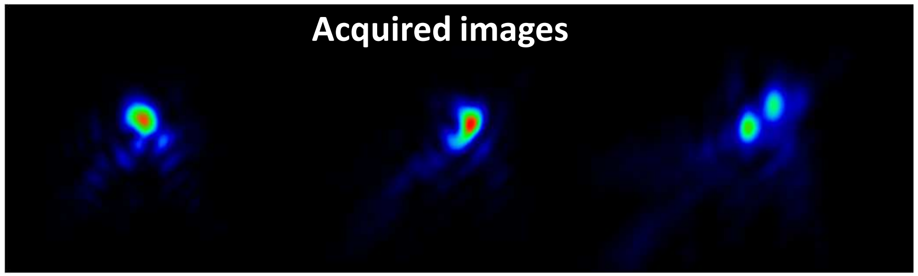


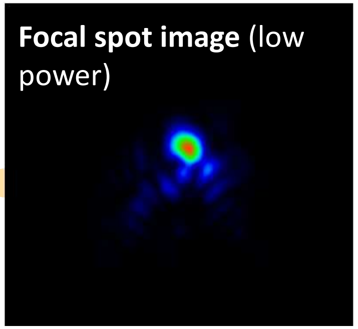
Full correction adaptive optics strategy : step 1, acquisition



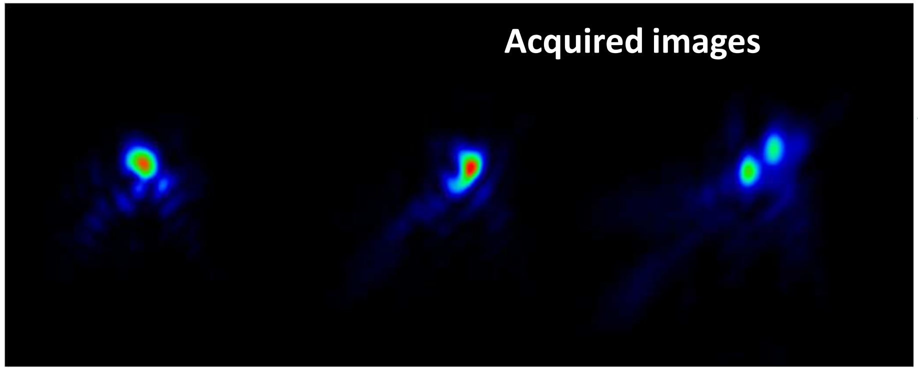
Wavefront
155 nm RMS



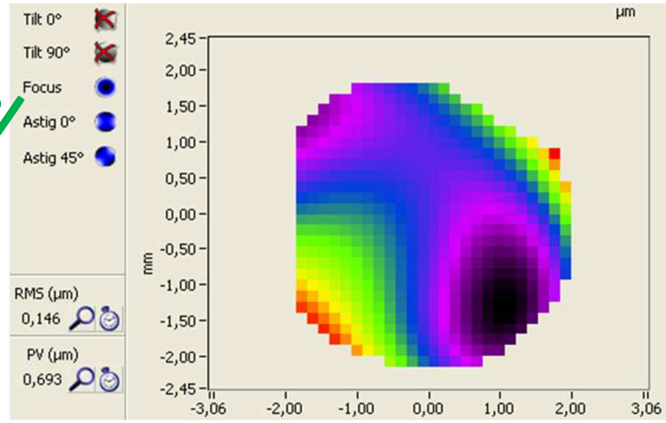




Full correction adaptive optics strategy : step 2 , calculation

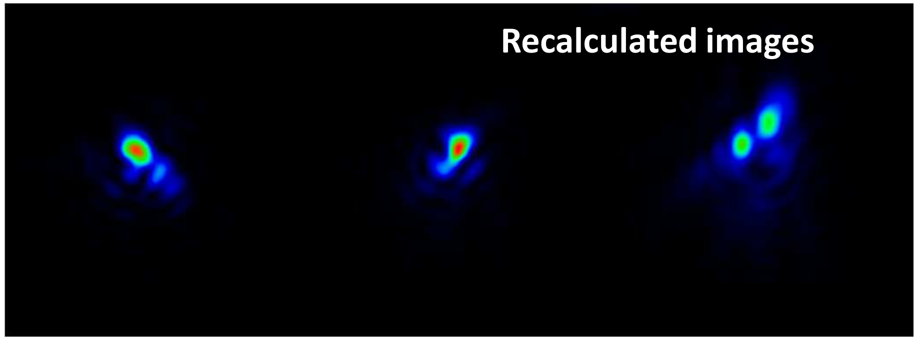


Phase retrieval



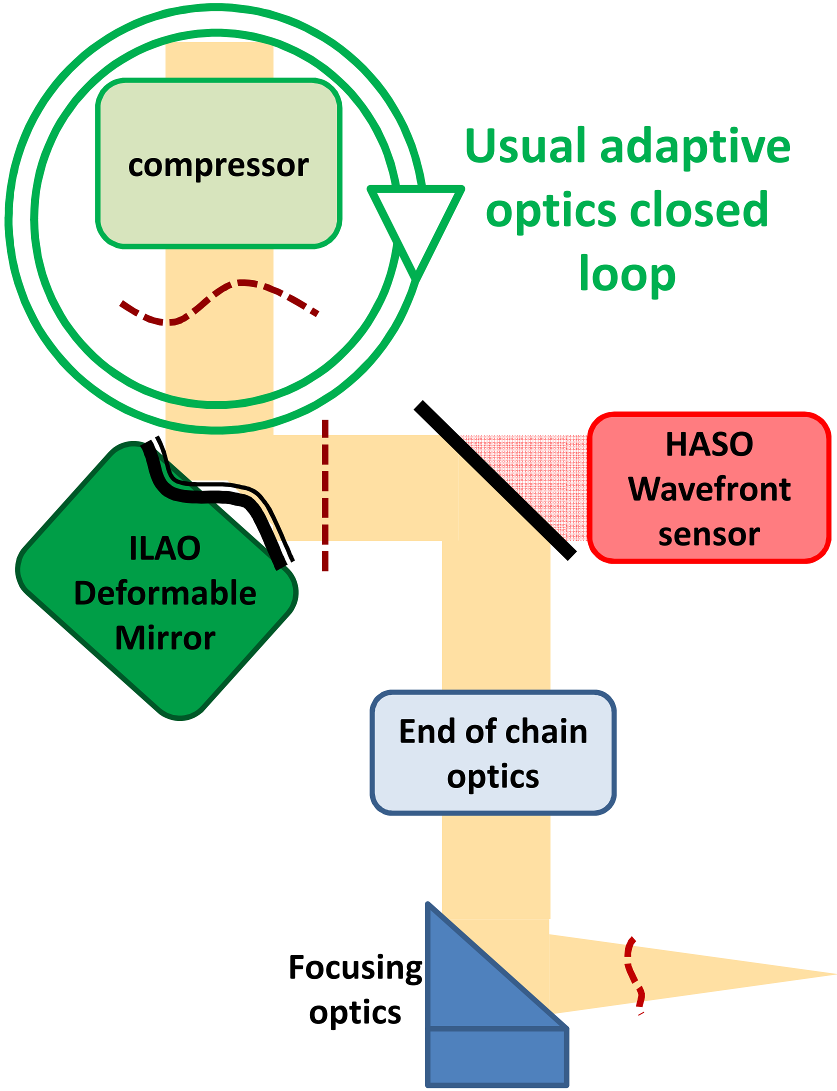
Wavefront responsible of the focal spot aberrations = 146nm RMS

Simple Fourier transform to check Phase Retrieval result

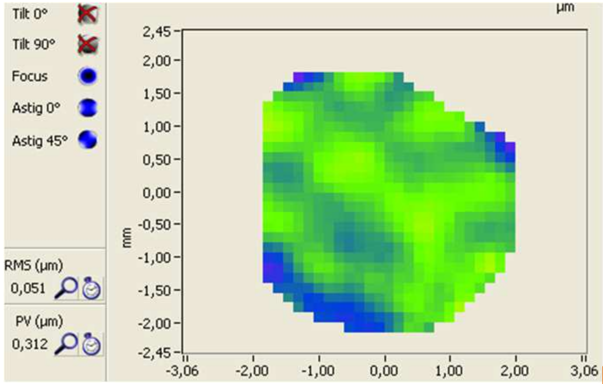


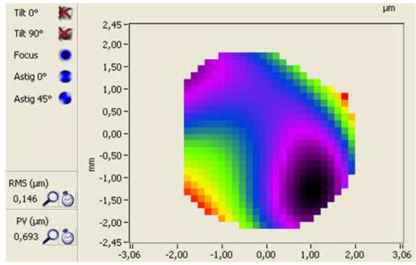
Experts in adaptive optics for ultra intense lasers

Full correction adaptive optics strategy : step 3, correction



Wavefront 50nm RMS

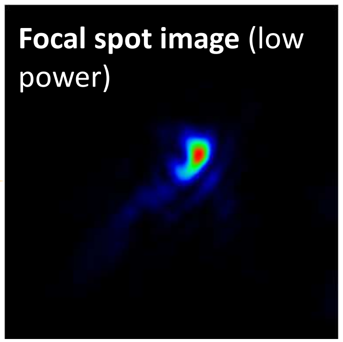




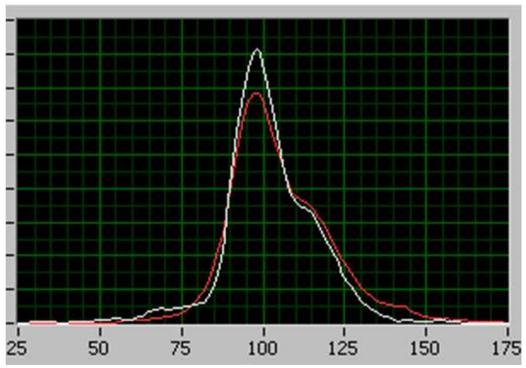
Phase retrieval result

Estimated Strehl : 45%

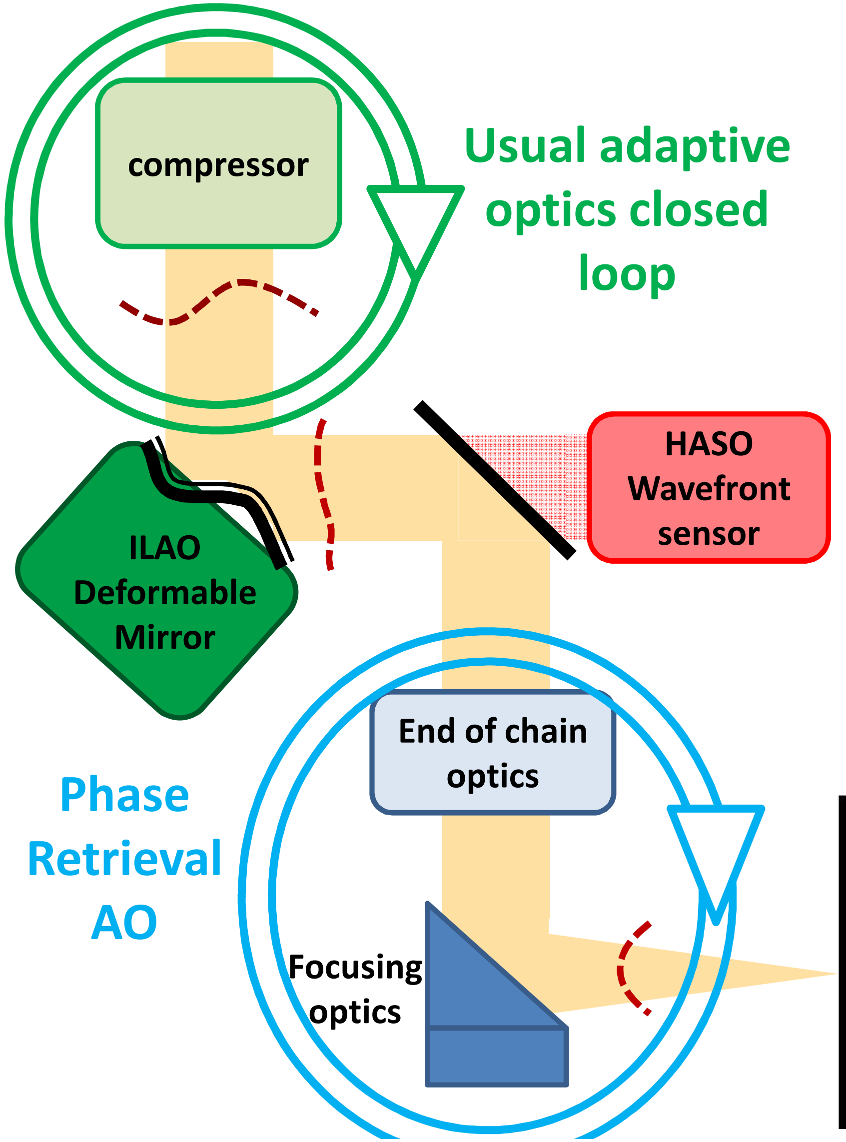
46% of energy in 28µm diameter disk



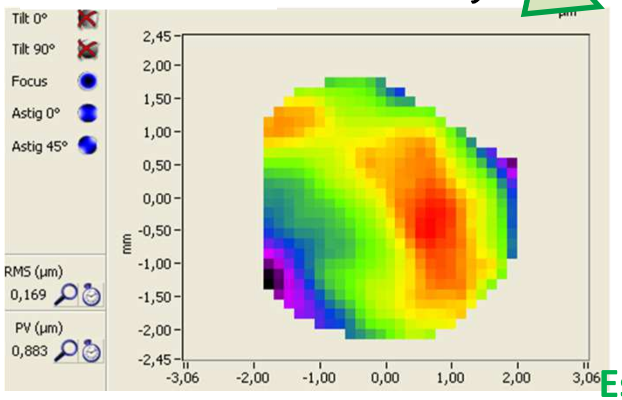
Focal spot image (low power)



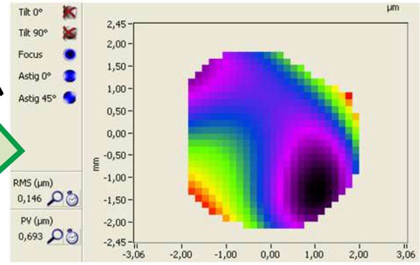
Full correction adaptive optics strategy : step 3, correction



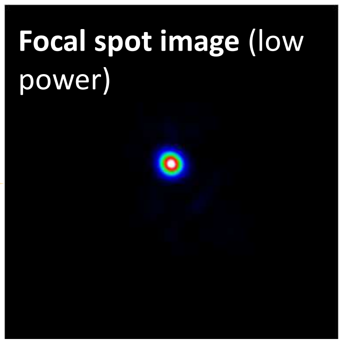
Wavefront 169nm RMS



Opposite sent to DM

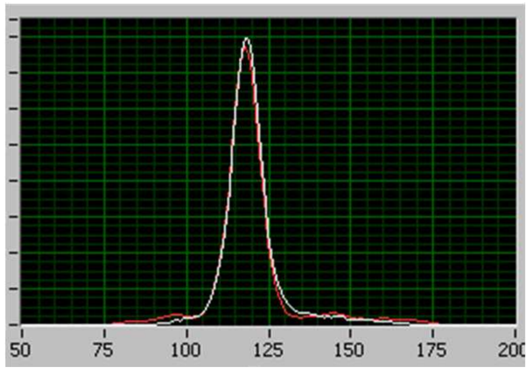


Phase retrieval result



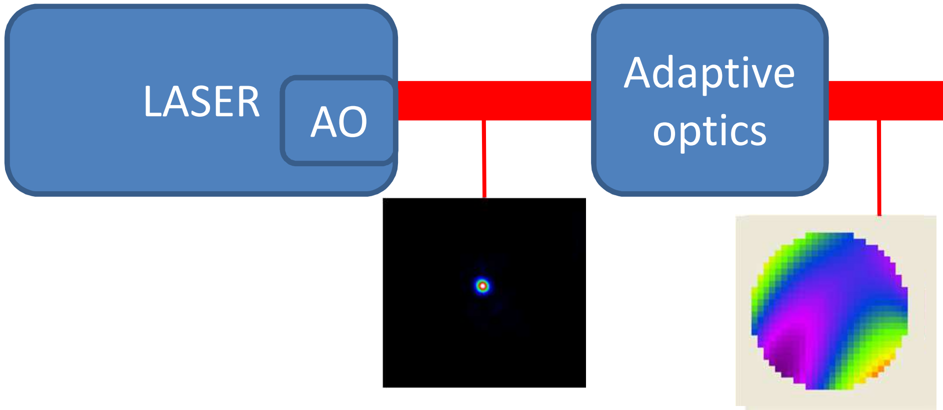
Estimated Strehl : 93%

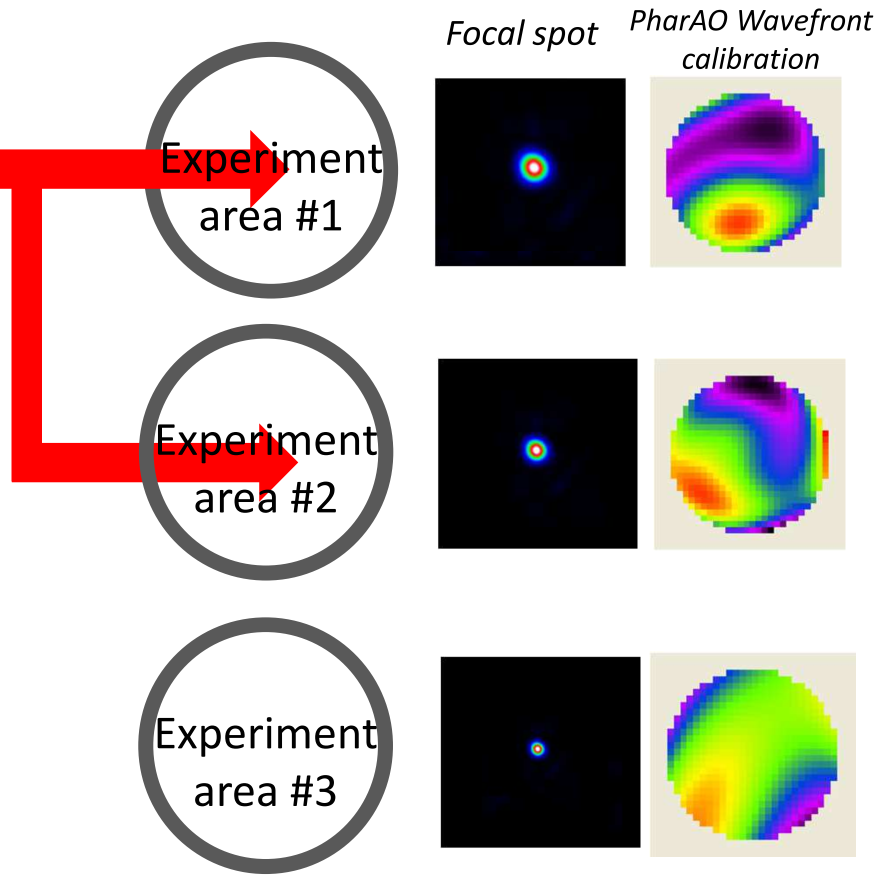
81% of energy in 28µm diameter disk



Near Future : new AO strategies dedicated to laser users

In the near future, a single laser will be used for multiple experiment areas.





Addition of another adaptive optics system

Use of the focal spot cameras + Phase Retrieval Adaptive Optics (the « PharAO ») in order to measure the focal spot aberrations.

Daily use of the laser using AO with calibrated the wavefront of each experiment area.

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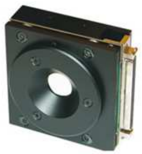
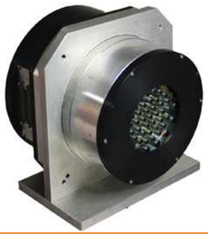
Adaptive optics at Imagine Optic

Imagine Optic provides and manufacture complete adaptive optics solutions

WAVEFRONT SENSORS

- EUV (6 to 60 nm), UV (193-266 nm), VISIBLE, **NIR (600-1100nm)**
- X (up to 25 keV) synchrotron applications

DEFORMABLE MIRRORS

- *MIRAO 52-e : low power, magnetic mirror: microscopy applications*
- **ILAO : high power, mechanical mirror: laser application**

SOFTWARE

- **Wave View** *: Metrology tools*
- **Wave Tune** *: usual « close loop » adaptive optics*
- **PhaRAO** *: specific adaptive optics*
- *WaveTune : AO software with focal spot camera*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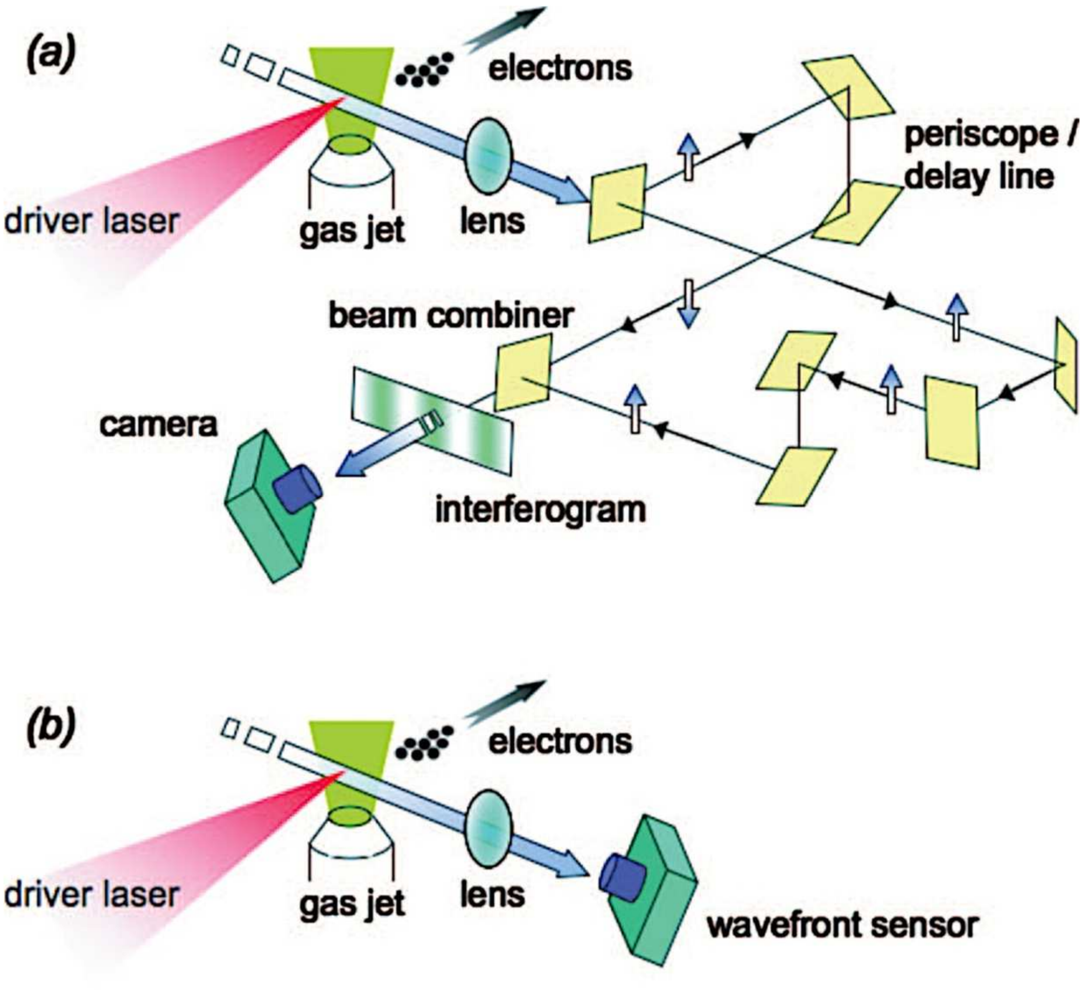
Plasma Diagnostic : interferometry or wavefront sensor



G.R. Plateau et al, Rev. Sci. Instrum. **81**, 033108 2010

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Plasma Diagnostic : which wavelength?

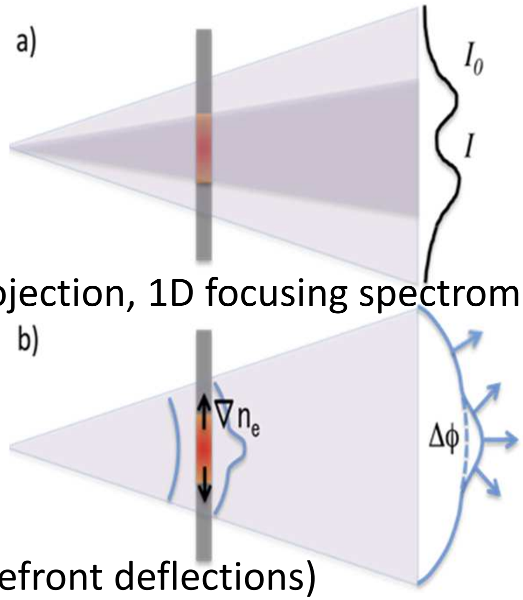
- Sub critical density < 10^{20} e-/cm^3
  Wavelength : UV or visible

- Dense plasma between 10^{20} and 10^{20} e-/cm^3
  Wavelength : EUV (5 – 100 nm)

- Overdense plasma > 10^{23} e-/cm^3
  Wavelength : X-ray (5 – 25 keV)

Plasma Diagnostic : Dense plasma with EUV

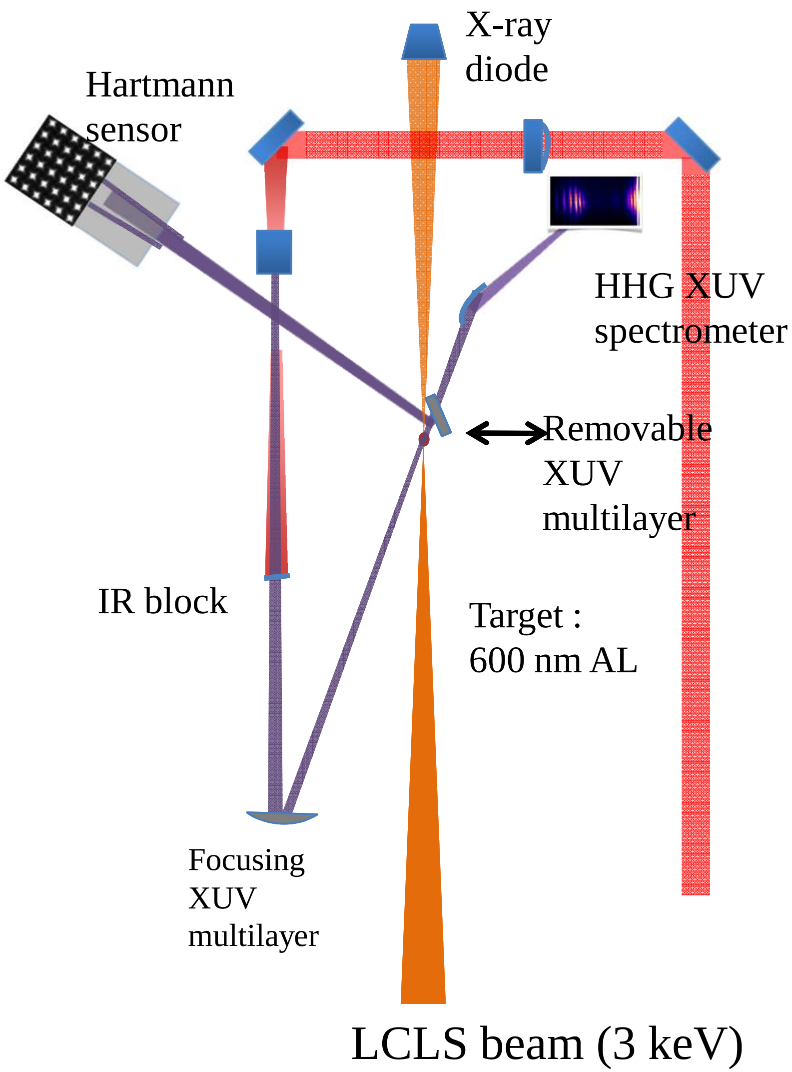
Main Diagnostics:



Opacity
(Point projection, 1D focusing spectrometer)

Refraction
(HHG wavefront deflections)

EUV probe beam: 32 nm

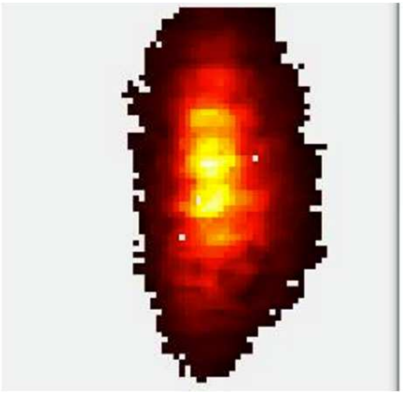


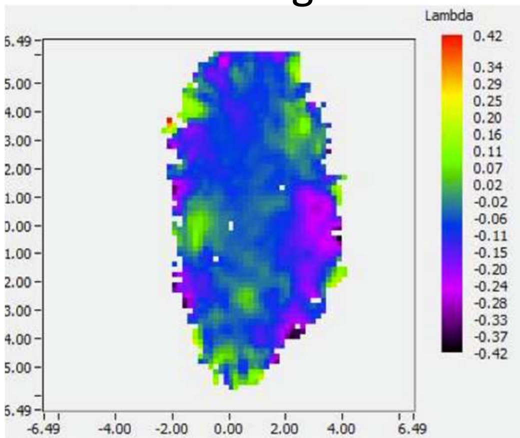
Courtesy : Philippe Zeitoun and Marta Fajardo

Plasma Diagnostic : Dense plasma with EUV

Intensity through target

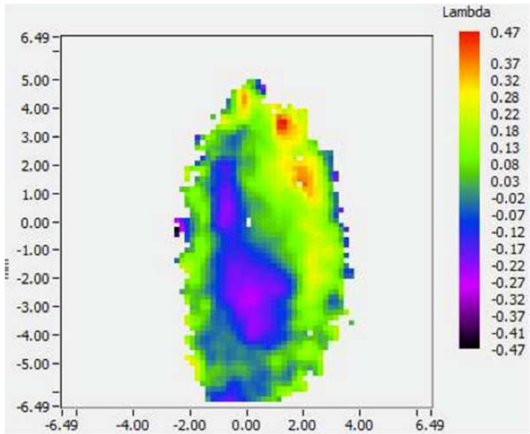
Phase changes





T<0ps

HHG arriving before the LCLS: no changes in phase compared to reference front



T=5ps

Refraction is apparent in intensity profile going through plasma and visible in phase shifts

Ongoing data analysis:

- Re-tracing HHG propagation to know spot profile at plasma

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Experts in adaptive optics for ultra intense lasers

Conclusions

Imagine Optic is strongly committed in the development of adaptive optics solutions for High Power Laser applications:

- ***ILAO mechanical deformable mirror has been developpped to respond to specific needs of adaptive optics for demanding laser applications***
  Coatings, replacable substrate, Diameters 50 to 335mm, High quality, stable correction

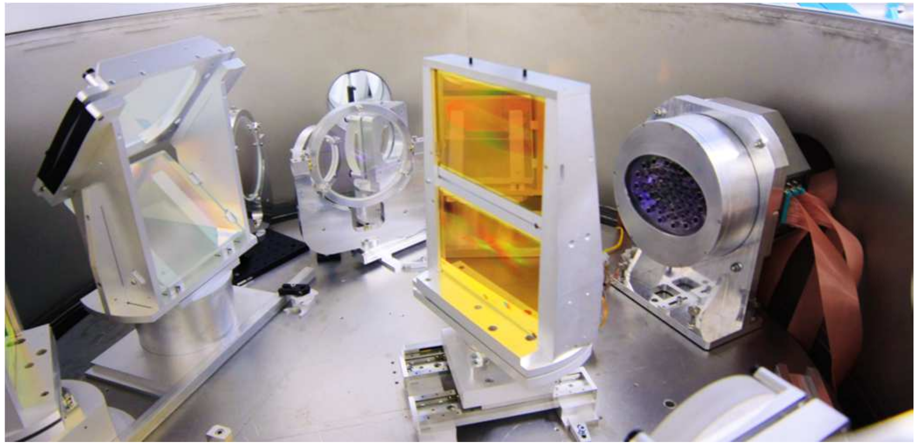
- ***New adaptive optics correction strategies are being developed for High Power Laser users***
  Phase Retrieval adaptive optics : *Direct (no iterations) and fully automated method (no complex user operation)*

- ***Beam diagnostic systems,***

- ***Plasma diagnostic tools***

- ***Complete support and consulting***

- ***and more to come in the future …***



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Thank you for your attention

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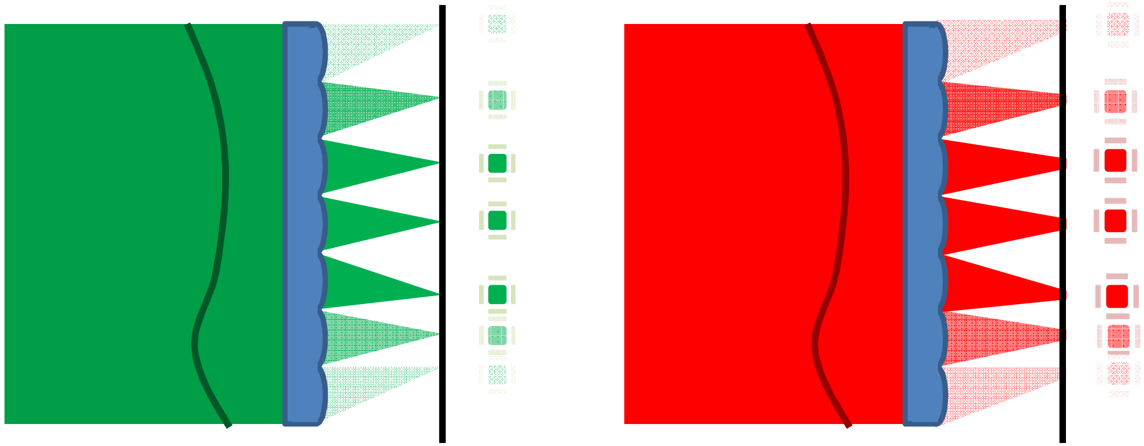
Achromaticity of Shack Hartmann WFS

SH wavefront sensor is strictly achromatic



When the wavelength changes, the spots are not at the perfect focus on the CCD.

However, the spot position remains the same (What matters is not the focal lenght of the microlenses but the distance between the microlenses and CCD).

Same spot postion → same WF measurement = SH wavefront sensor is achromatic.

SH is used in astronomy on sources with blackbody spectrum

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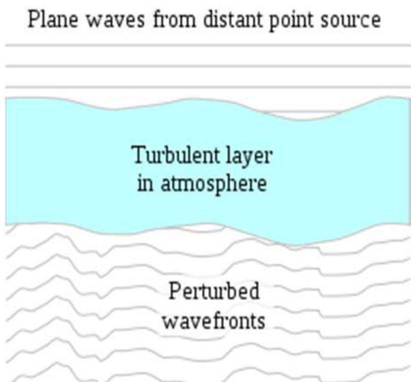
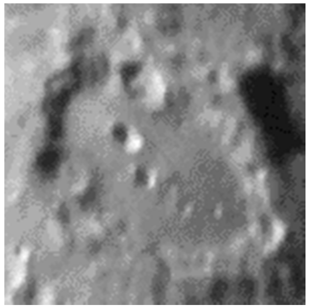
Adaptive optics developed for astronomy

Atmospheric turbulence creates wavefront distortion.

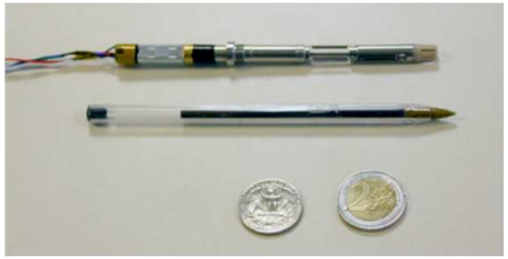
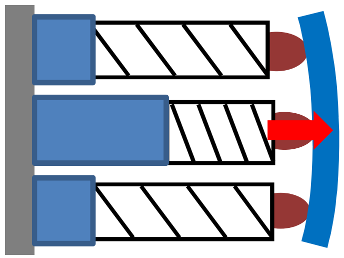
Wavefront distortion decreases **image resolution** in ground-based telescopes.



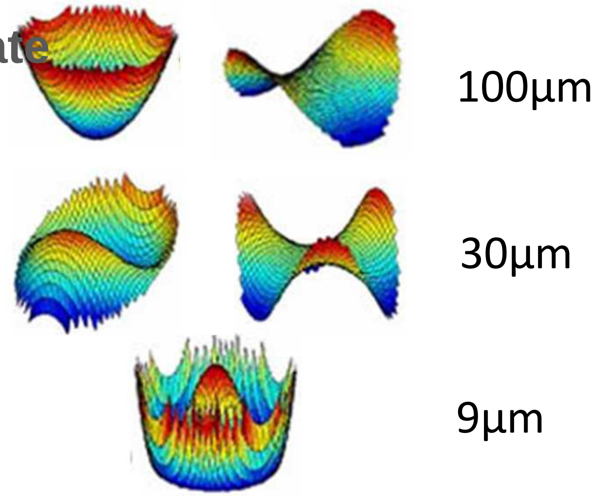


Deformable mirror : mechanical actuators technology

Principle : generation of a force at the back of a substrate

→ ***Conversion of macroscopic displacements in microscopic shape change***



52 actuators

Integrated with High Power dielectric coating from state of the art manufacturer

Deformable mirror : Mechanical actuators technology

Features :

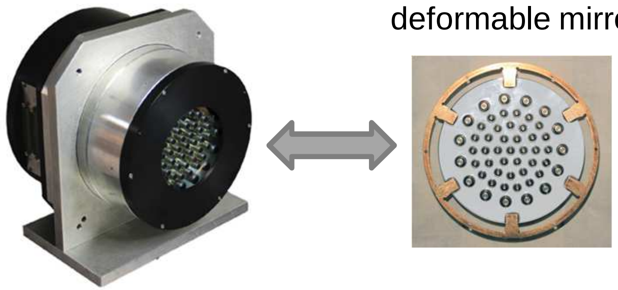
- Number of actuators : ~10 –> ~100 (between 30 – 55 typical)
- Stroke : 100 µm
- Size : 30 – 600 mm in diameter (no technological higher limit)
- Optical quality : 10 – 20 nm rms WFE
- Compatible with any coating : Metal, Hybrid, Dielectric (usual manufacturers

Advantage :

- Scalability
- Stability (even unpowered)
- EMC immunity
- Simple maintenance (actuators and reflective substrate)

Drawbacks :

- Speed (<0.5Hz)
- Backlash compensation



Reflective surface detached from the deformable mirror

Outline

- Adaptive optics introduction

- **Overview of the state of the art of adaptive optics components**
  - Deformable mirror
  - **Wavefront sensor**

- Perspectives for near future and next generation laser facilities
  - Software developments : use of a focal spot camera
  - Software development : Tango and Epics control
  - Hardware development : Beam reducer

- Conclusion

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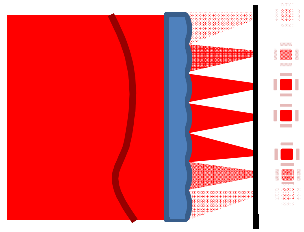
Overview of the adaptive optics components : wavefront sensor

Imagine Optics manufactures Shack Hartmann wavefront sensors

Shack Hartmann wavefront sensors are:

- ***achromatic***
- ***insensitive to vibrations***
- ***large dynamic range***
- ***measure wavefront everywhere there are photons***
  (no assumption on laser beam pupil shape)



Shack Hartmann : everywhere there are photons

→Spots on the CCD →phase and intensity is measured

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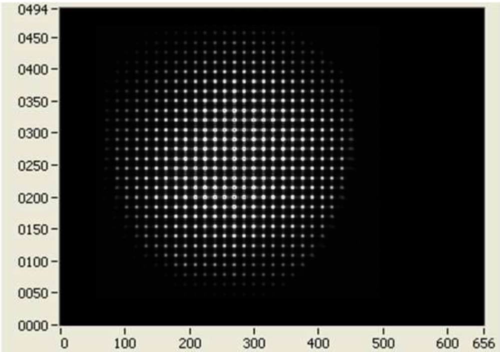
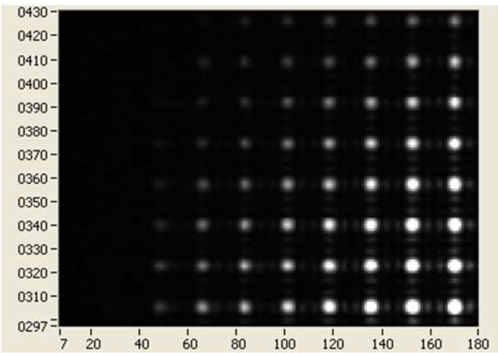
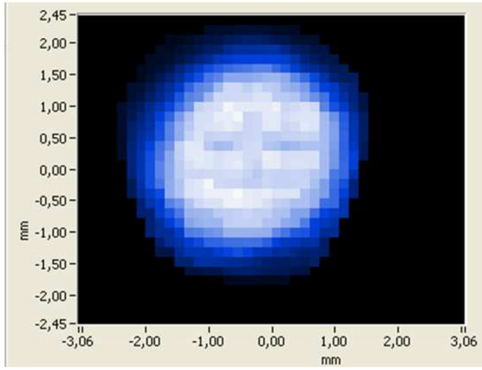
Typical laser beam measurement

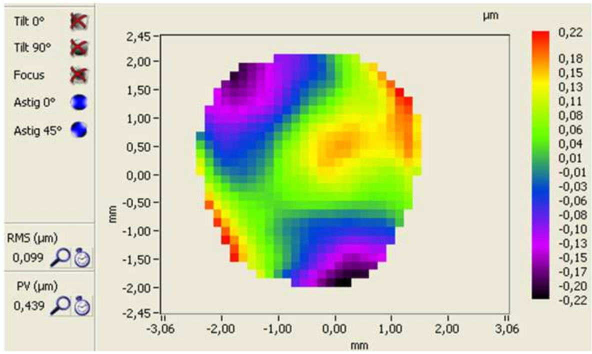


Raw signal on the CCD sensor

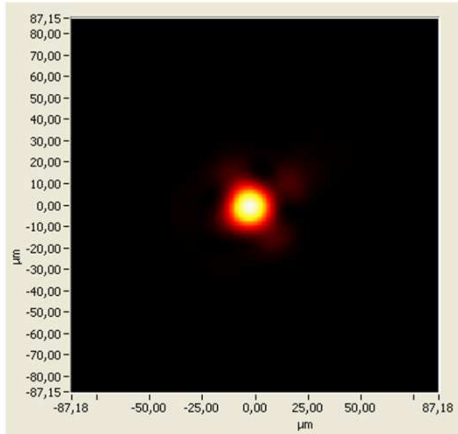




Measured intensity profile



Measured wavefront



Calculated focus

!!! Accurate focal spot correction requires to measure the extreme edge of the beam without assumptions on the beam shape !!!

Wavefront and intensity are measured even at the extreme edge of the beam.

- *Independant of beam shape*
- *Whole beam taken into account*

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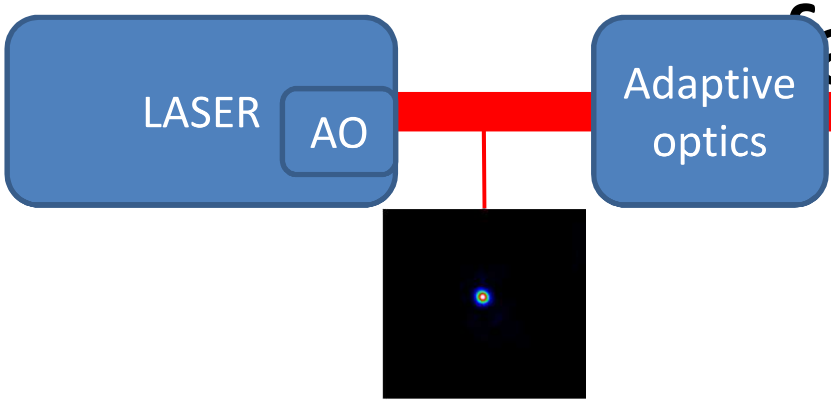
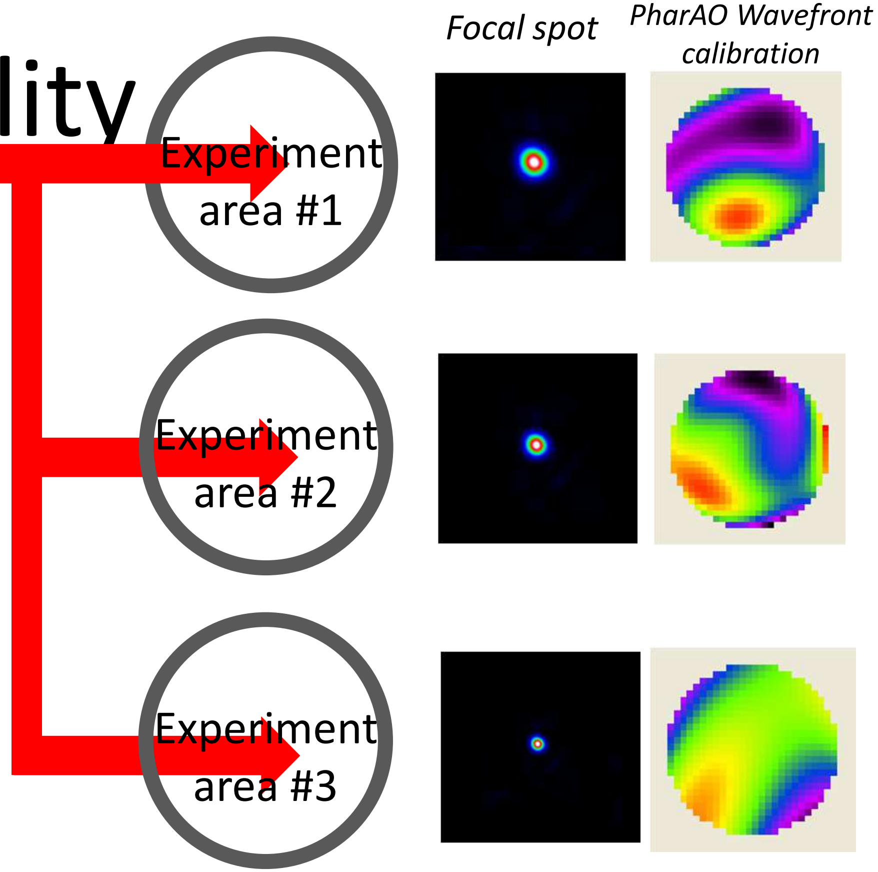
Near Future: total integration of the AO in the control command of the facility





In order for such a use of AO to be realistic, AO system has to be fully integrated in the control command of the laser facility.

→ *A big work has to be done on in order to have a AO system that can be fully and easily controlled through TANGO or EPICS systems.*

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