LESIA l'Observatoire de Paris | PSL

SCExAO

Subaru Coronagraphic Extreme Adaptive Optics

すばるコロナグラフ極限補償光学装置

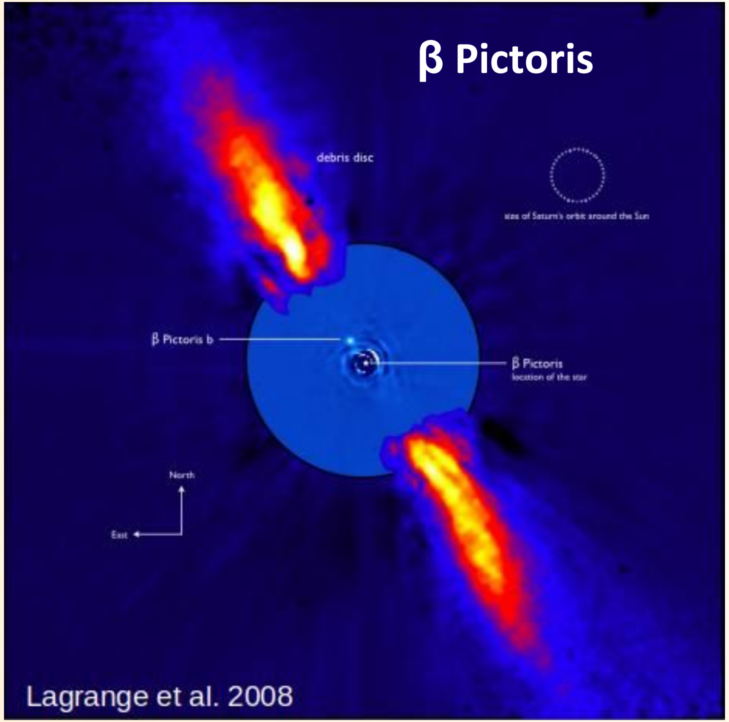
IPAG Institut de Planétologie et d'Astrophysique de Grenoble

Interferometric approach to spectral wavefront sensing with the FIRST instrument on the Subaru Telescope

Kevin Barjot, Sebastien Vievard, Vincent Deo, Olivier Guyon, Elsa Huby, Sylvestre Lacour, Nick Cvetojevic, Martin Foin, Richard Frazin, Takayuki Kotani, Vincent Lapeyrere, Julien Lozi, Franck Marchis, Guillermo Martin, Pierre-Louis Mayeur, Barnaby Norris, Guy Perrin, Daniel Rouan

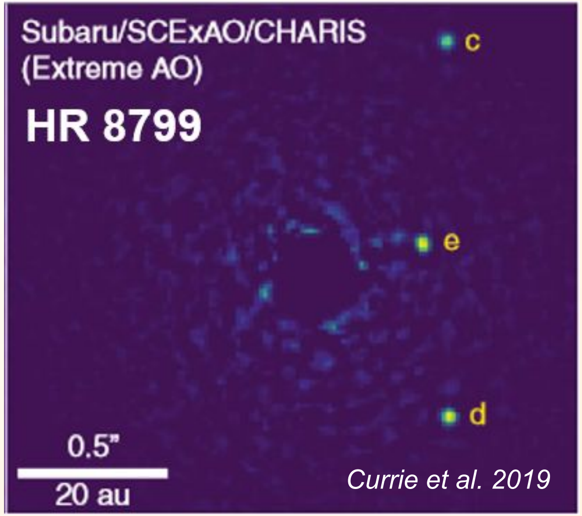
SCExAO High contrast imaging

→ For protoplanetary disks and substellar companions study



Two performance goals:

- High contrast 10^{-6} - 10^{-10}
- High resolution 10 - 100 mas

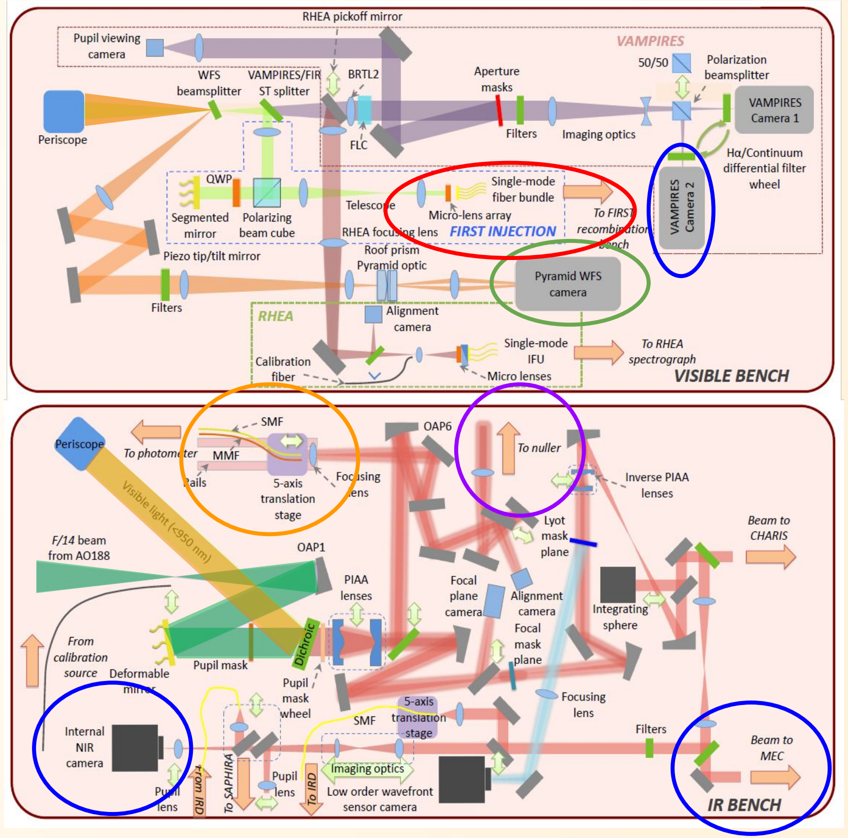


Wavefront sensing in the SCExAO bench

SCExAO = Extreme AO with a **Pyramid Wavefront Sensor (WFS)**

Many WFS techniques under development:

- Focal plane wavefront sensing (See S. Bos, N. Skaf, S. Vievard talks)
- Interferometric approach to WFS
  - In the IR : GLINT (on-chip nulling interfero) + Photonic lantern (see B. Norris talk)
  - in the Vis : FIRST → our focus on this talk



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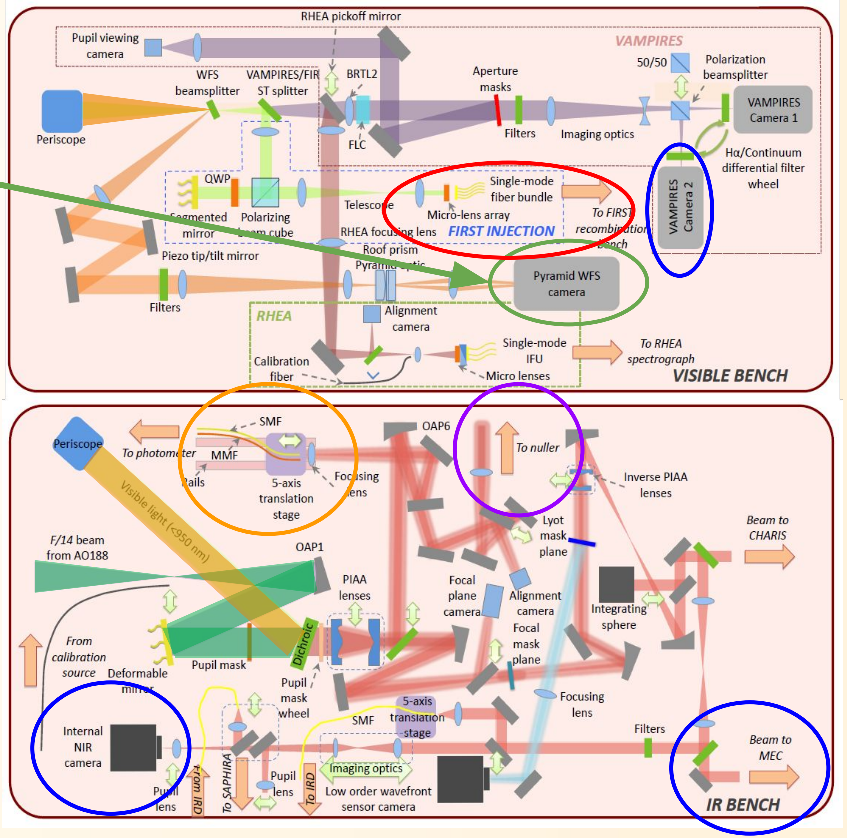

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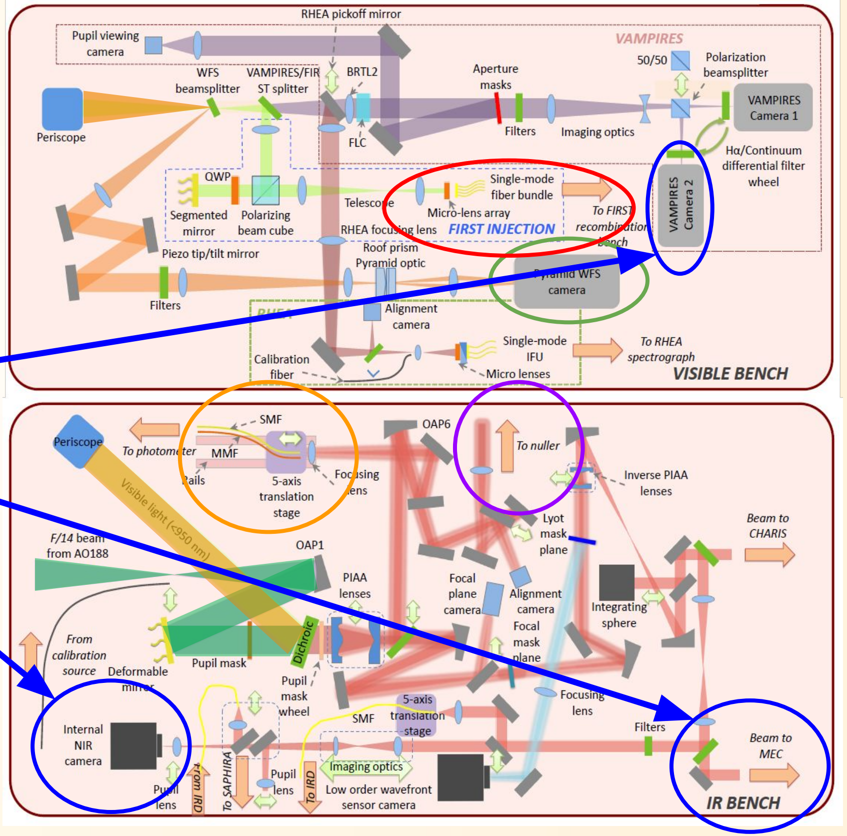

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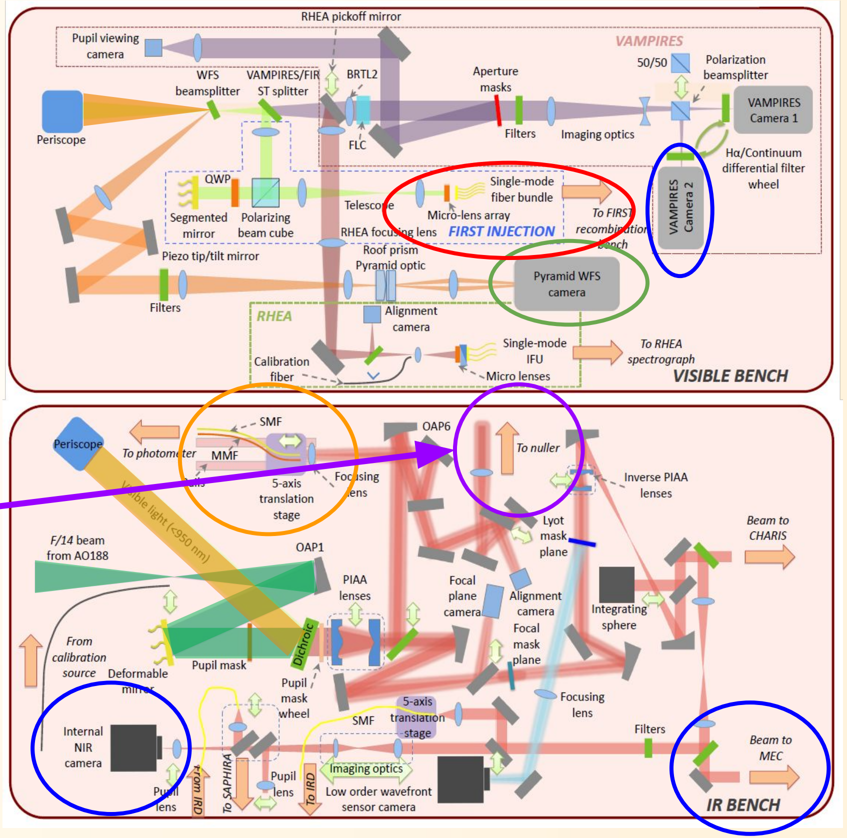

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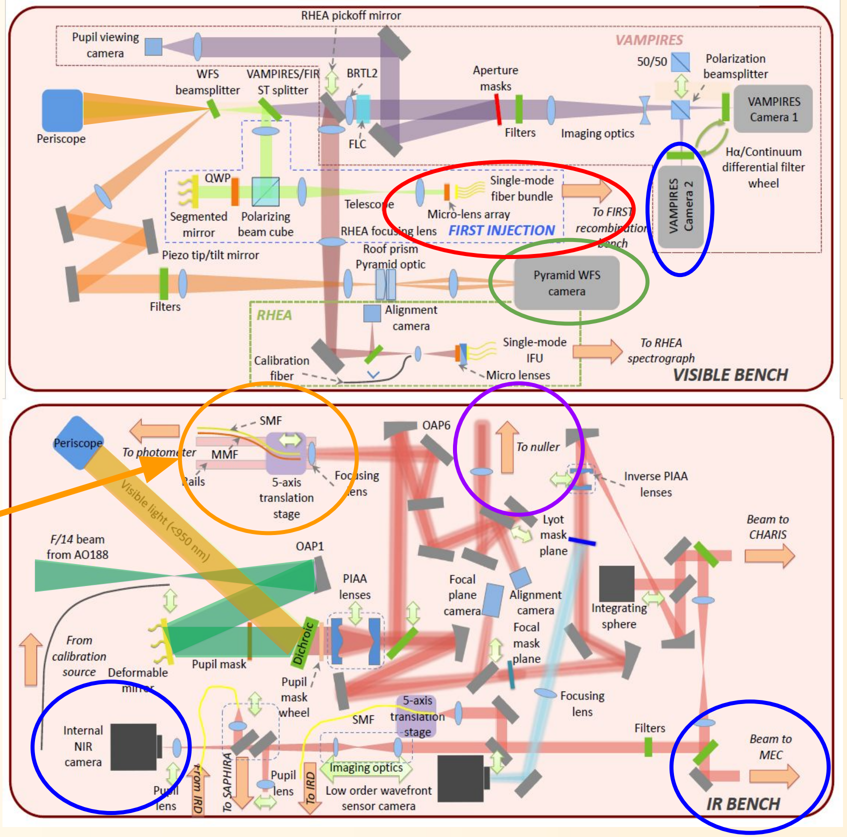

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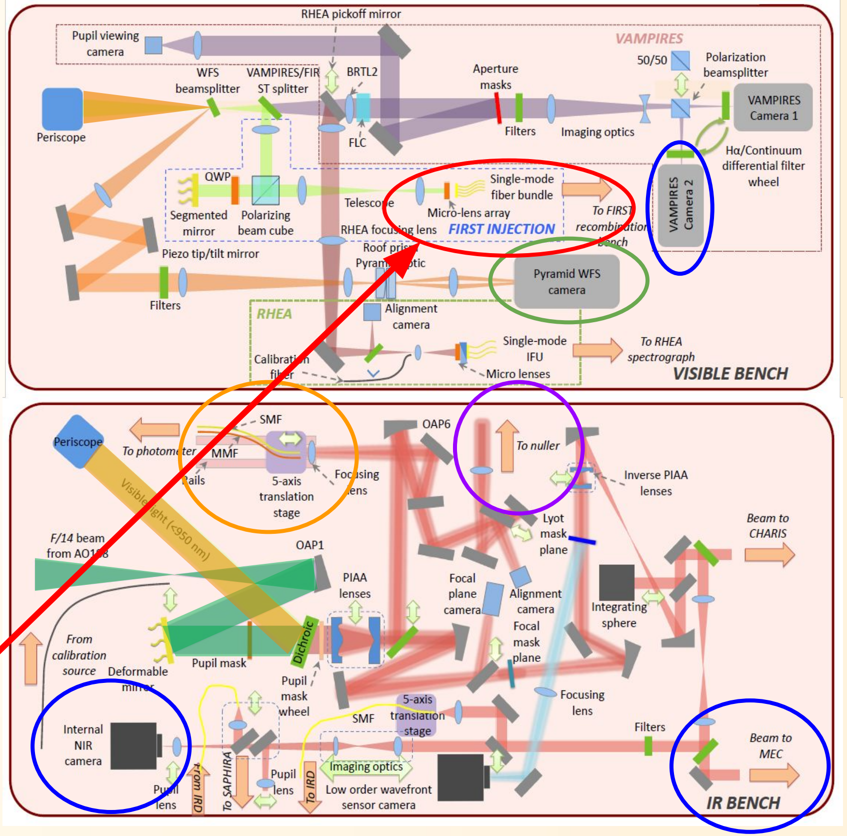
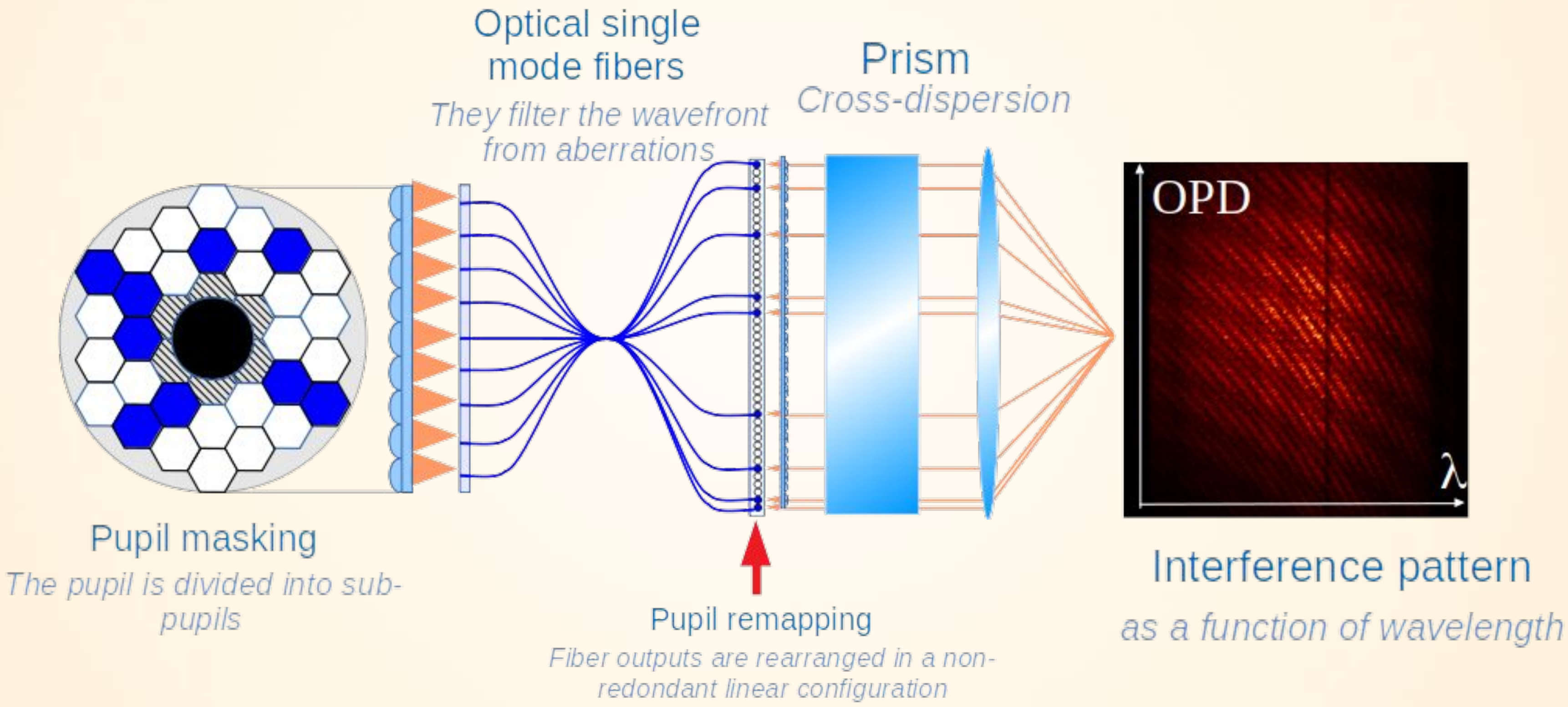


Fibered Imager foR a Single Telescope



FIRST as an interferometric WFS

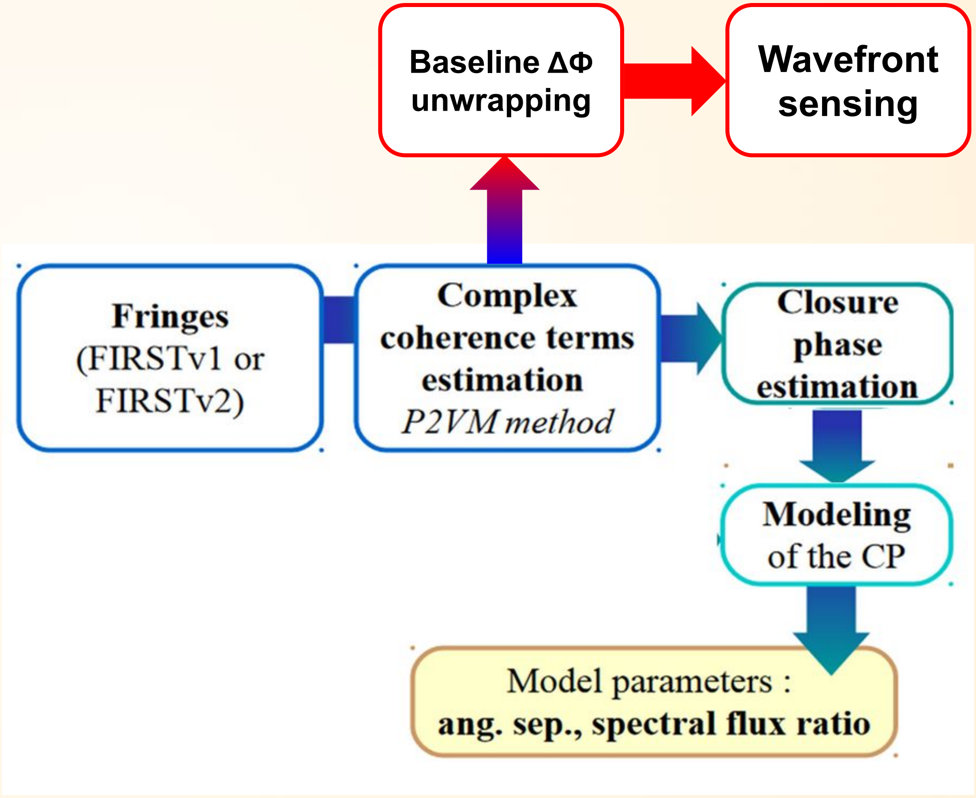
Complex coherence of i-j baseline:

$$\mu_{ij} = |V_{ij}|e^{i\varphi_{ij}} A_i A_j e^{i\Delta\Phi_{ij}}$$

Complex visibility from observed object

Amplitude pupil *i* and *j*

Differential piston



FIRST WFS:

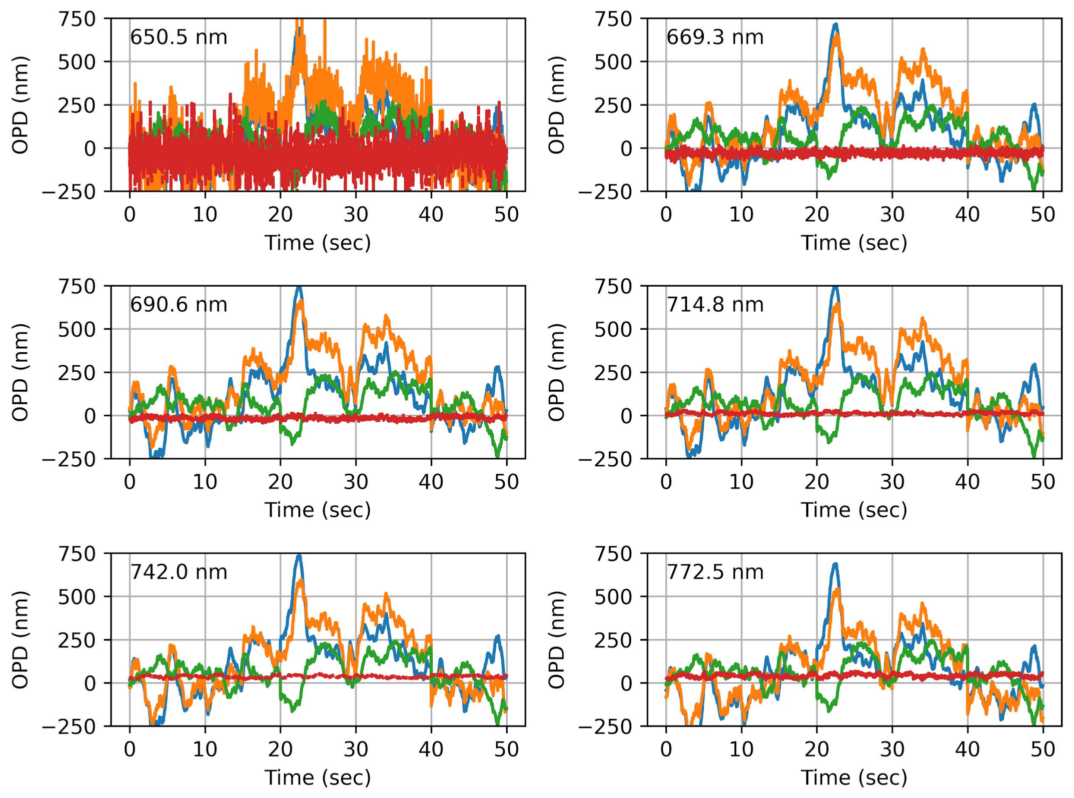
- With > 100 spectral channels
- With near infinite dynamic range (200+ µm)
- Providing an absolute OPD measurement
- Concept can be optically tuned to be fast and optimally sensitive (new sensor, revisit design, ...)

First attempts at wavefront sensing

OPD measurements on 3 baselines after subtracting the mean (fiber mismatch) OPD, for 6 spectral channels.

Very good consistency w/ wavelength ! Even the noisier 650 nm channel

Significant fluctuations (more than can be accounted from WF):
the physical causes of this are under investigations



Conclusion

- SCExAO is a testbed proposing many ways to develop new WFS to get to higher contrast and resolution in direct imaging astrophysics adapted to forthcoming ELT-like complex pupils
- With FIRST we use CP measurements for science, rejecting differential pistons which are seen to be very useful for WFS
- Lot of efforts are put on algorithms to:
  - Retrieve absolute OPD between sub-pupils
  - Understand the big values seen until now and determine how we will benefit from the forthcoming upgrade of FIRST
- FIRST is a promising instrument that will be able to perform astrophysic measurements at the same time of wavefront control on photonics

Making FIRST into a WFS

FIRST for science: output is the CP, mapped to object structure

FIRST WFS: leverage for WFS retrieval - new initiative exploring the current capabilities

Complex coherence from the science reduction pipeline:

$$\mu_{ij}(\lambda) = |V_{ij}|e^{i\phi_{ij}} A_i A_j e^{i\Delta\Phi_{ij}}$$

Object visibility assumed = 1 for now (ie point source)

Possibility for measuring scintillation

OPD on baseline i-j
Need to be extracted and properly unwrapped

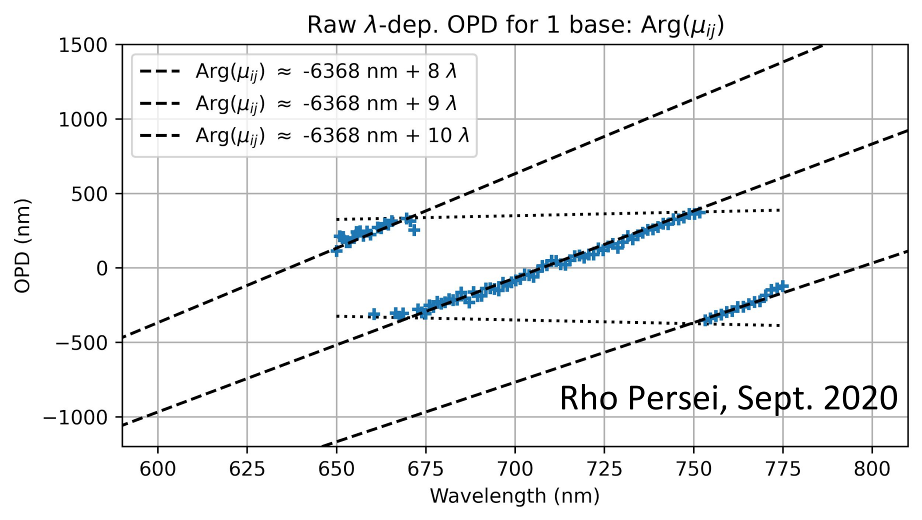
FIRST WFS: candidate for an interferometric wavefront sensor

- With > 100 spectral channels
- With near infinite dynamic range (200+ µm)
- Providing an absolute OPD measurement
- Concept can be optically tuned to be fast and optimally sensitive (new sensor, revisit design, ...)

Absolute OPD retrieval

Use wavelength channels of FIRST to find the absolute OPD on all baselines
Large OPDs (10s - 100 µm) due to fibers

Example: integer slope fitted is due to wraps in phase readout… far from white fringe !
Fit intercept gives OPD on baseline… here 6.37 µm !



Various caveats being worked on:

- WF chromaticity vs. phase wraps ?
- Data most often not that clean
- Must be performed and made consistent across all baselines, all frames
- Integer optimization is hard and inefficient

But soon enough:

Will achieve a software “fringe tracking”, equivalent assuming a slow temporal / chromatic evolution of the WF

Absolute OPD retrieval

Wavelength-dependent information most useful for absolute OPD inference

But… integer (phase jumps) optimizations problems are hard. OPDs over a triangle of baselines often sum to ±720 nm (med. wavelength) instead of 0. Must be fixed in a second pass. Same with 1st order chromaticity, which is entangled with this method.

Large OPDs (up to 100 µm) due to fibers. We're working on characterizing their temporal variations (thermal, vibrations, strain)