Focal Plane Wavefront Sensing on SUBARU/SCExAO

S. Vievard, S.P. Bos , F. Cassaing , T. Currie, V. Deo, O. Guyon , N. Jovanovic, C. U. Keller, M. Lamb, C. Lopez, J. Lozi, F. Martinache, D. Mary, K. Miller, A. Montmerle-Bonnefois, L. Mugnier, M. N'Diaye , B. Norris, A. Sahoo, JF. Sauvage, N. Skaf, F. Snik , M. J. Wilby , A. Wong

Subaru telescope , Leiden observatory, University of Sidney, Observatoire de la Cote d'Azur, ONERA, Caltech,Univ. of Toronto

Context : Instrumental limitations to High Contrast Imager performance

➢ **The Island Effect**

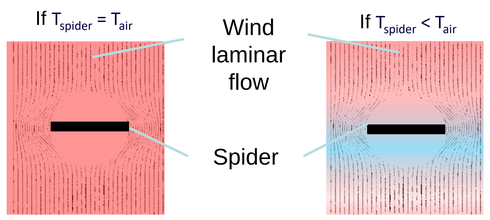
Fragmentation of the pupil

→ Differential piston effect, segmentation…

Low Wind Effect

→ A thermal effect (see Fig. on the right):

- The temperature differential between ambient air and spider induces radiative exchanges that create refractive index gradient near spiders when the wind speed is low (typically < 3m.s^{-1})

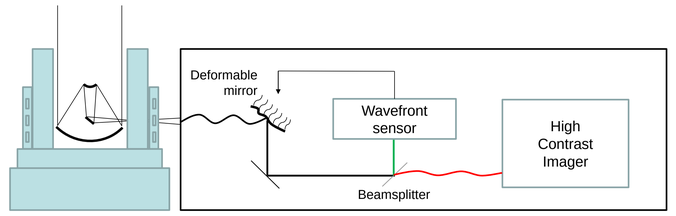


The LWE : explanation of the radiative exchanges between ambient air and the spider

➢ **The Non-Common Path Aberrations**

Wavefront sensor light path differs from **science light path**

→ Aberrations in the science path are not corrected by the wavefront sensor



The science light path contains **parts** that are not seen, therefore not corrected, by the wavefront sensor

→ Sources of aberrations which limit the achievable contrast or resolution of high contrast imagers

Zernike Asymetric Pupil (ZAP)

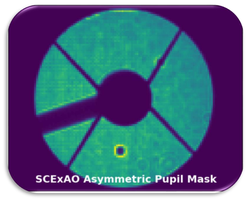
➢ **Principle**

→ **Phase retrieval with asymmetric pupil mask**

➢ **Hardware requirements**

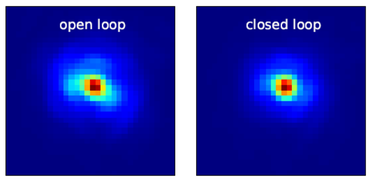
→ Asymmetric pupil mask

→ Focal plane image



➢ **Latest results**

→ On-sky loop closure : 37% gain in Strehl



M. N'Diaye et al., A&A, 2018

Phase retrieval with vAPP

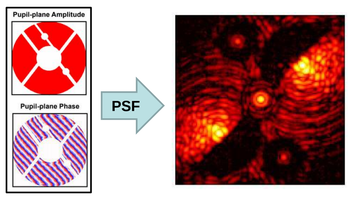
➢ **Principle**

→ **Phase retrieval on PSF copies generated by the vector Apodizing Phase Plate (vAPP)**

➢ **Hardware requirements**

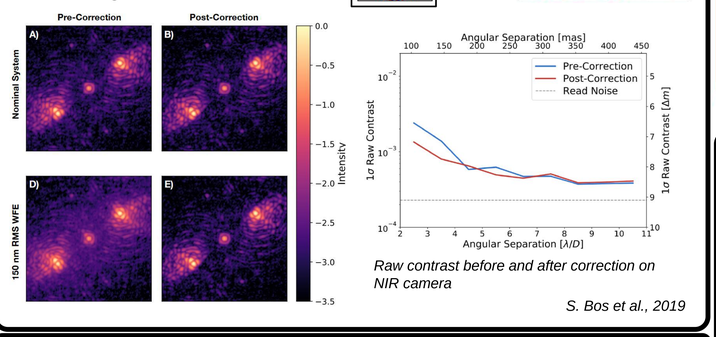
→ Pupil mask : vAPP

→ Focal plane image



➢ **Latest results**

→ On-sky loop closure : 6% gain in Strehl



Raw contrast before and after correction on NIR camera

S. Bos et al., 2019

DR WHO

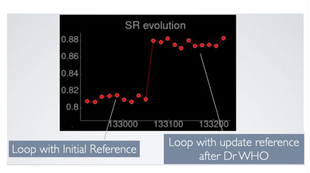
➢ **Principle**

→ **Direct Reinforcement Wavefront Heuristic Optimization (DR WHO). Updating PyWFS reference using lucky imaging.**

➢ **Hardware requirements**

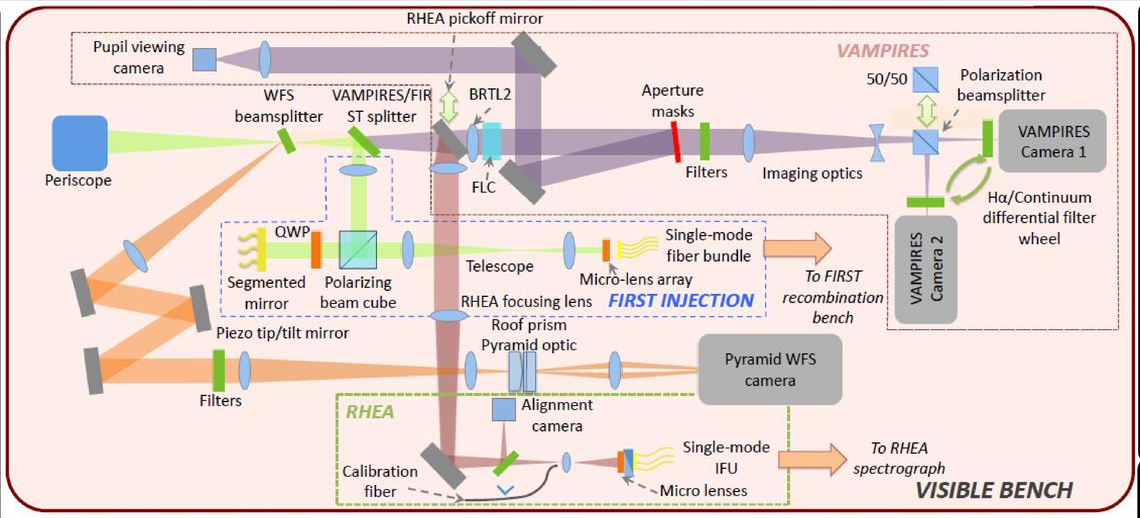
→ Pyramid Wavefront sensor

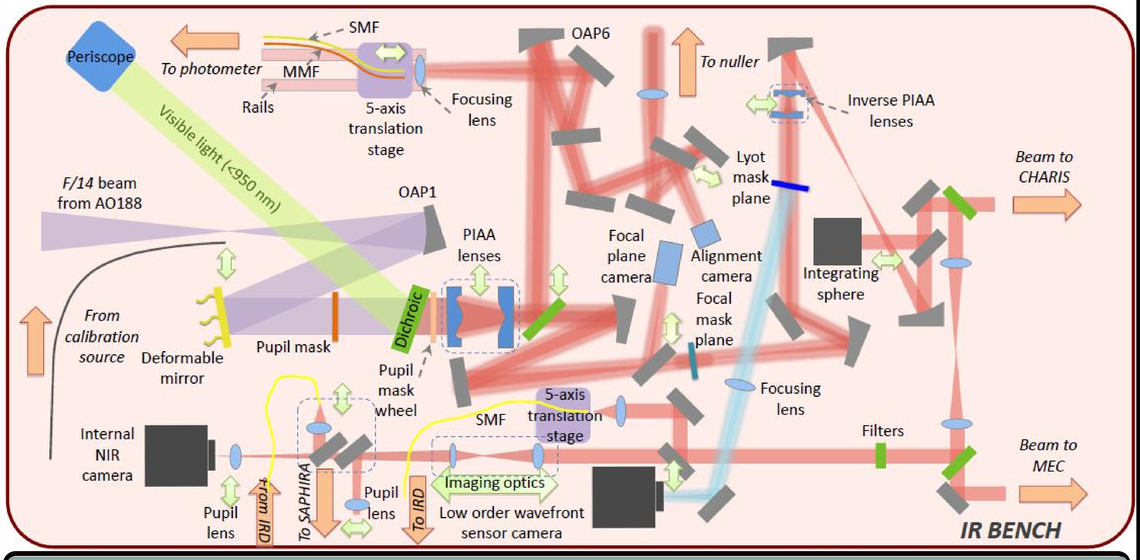
→ Focal plane image



➢ **Latest results**

→ **Simulation: Gain of 8% in SR**





Fast and Furious

➢ **Principle**

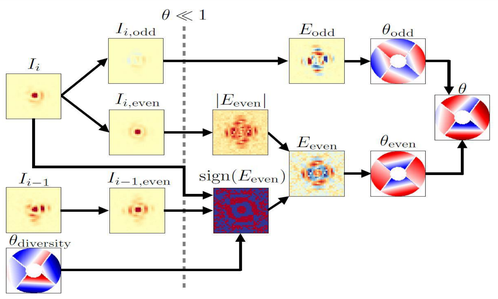
→ **Sequential Phase diversity.** Estimation of odd and even modes in a focal plane. Even mode sign ambiguity lifted with temporal diversity

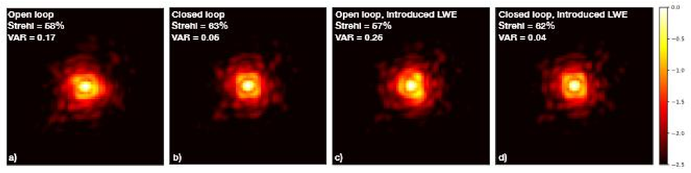
➢ **Hardware requirements**

→ Focal plane image

➢ **Latest results**

→ On-sky loop closure : 5% gain in Strehl





S. Bos et al., 2020

Linearized Analytic Phase Diversity (LAPD)

➢ **Principle**

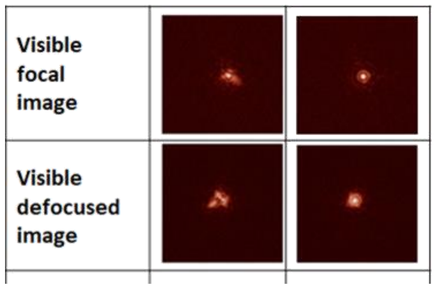
→ **Linearized phase diversity with extended capture range**

S. Vievard et al., 2020

➢ **Hardware requirements**

→ Focal plane image

→ Defocused image



➢ **Latest results**

→ **Lab** loop closure

PSF reconstruction using Neural Network

➢ **Principle**

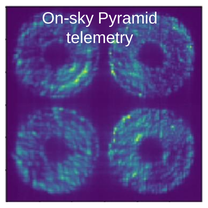
→ **Train deep neural network with synchronized Pyramid Wavefront Sensor telemetry and focal plane image**

→ Real-time PSF prediction using the PyWFS telemetry

➢ **Hardware requirements**

→ Pyramid Wavefront Sensor telemetry

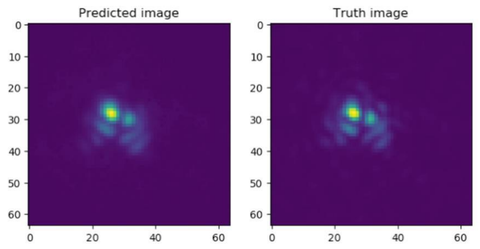
→ Focal plane image



➢ **Latest results**

→ On-sky :

- PSF prediction from Pyramid telemetry



B. Norris, A. Wong, 2019

Single image Phase Diversity

➢ **Principle**

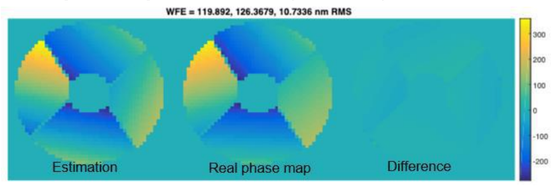
→ **Assumption of point source and large defocus : apply PD to one image**

➢ **Hardware requirements**

→ Defocused image

➢ **Latest results**

→ **Lab open-loop estimation** (*M. Lamb*)



Conclusion and perspectives

Algorithm	ZAP	vAPP PR	LAPD	Fast and Furious	Single image PD	Neural network	DR WHO
Hardware	Pupil mask Focal plane	vAPP Focal plane	Focal plane Defocused plane	Focal plane	Defocused plane	PyWFS image Focal plane	PyWFS Focal plane
Simulation	✓	✓	✓	✓	✓	✓	✓
On-bench	✓	✓	✓	✓	✓	✓	In progress…
On-sky	✓	✓	In progress…	✓	In progress…	In progress…	To do…

➢ **Multiple options available to increase the wavefront quality, depending on the observing mode**

➢ **SCExAO: key platform to test and validate new concepts/algorithms**

➢ **Key for future challenges on Extremely Large Telescopes**