

Strategy to validate the deep learning methods for focal-plane wavefront sensing in the lab and on the sky

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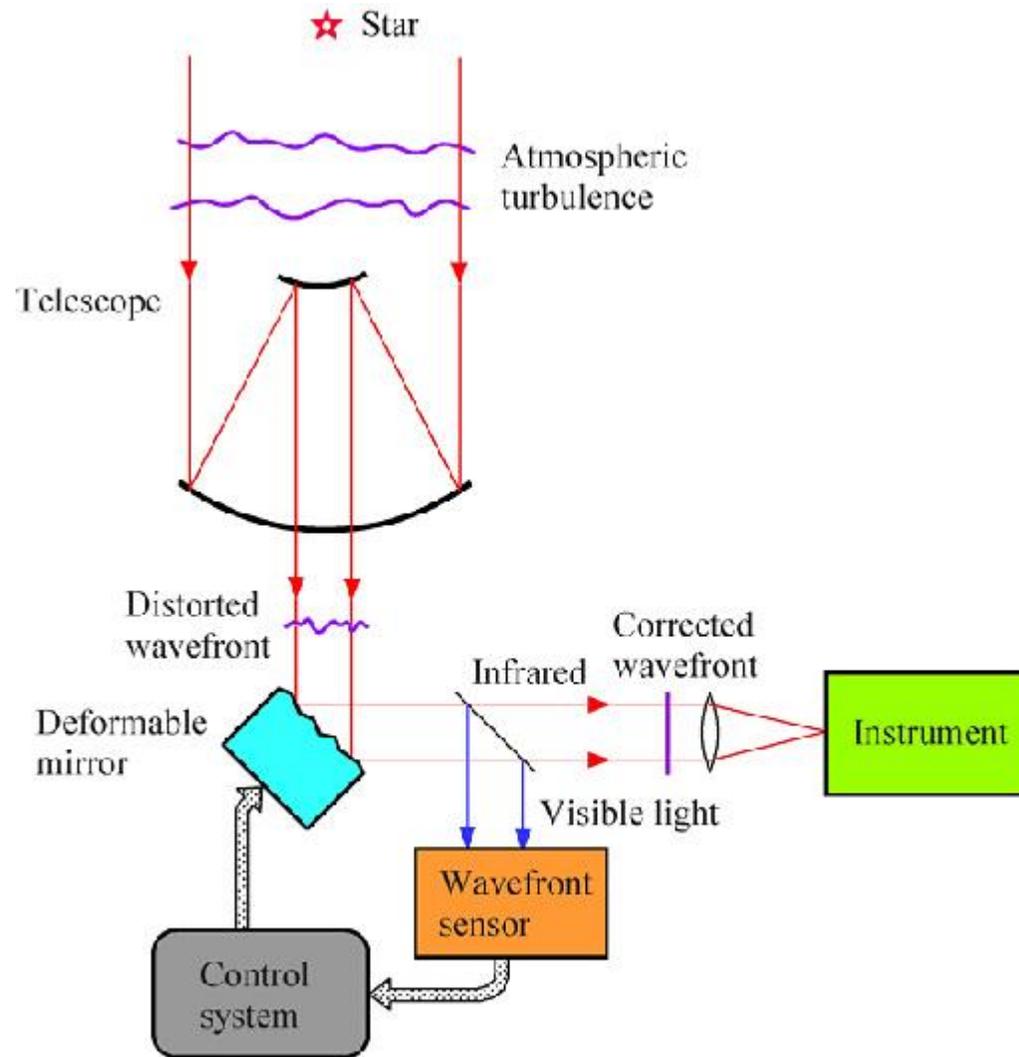
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2 Montefiore Institute of Electrical Engineering and Computer Science, University of Liège

WFS 2022, Porto

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Adaptive Optics

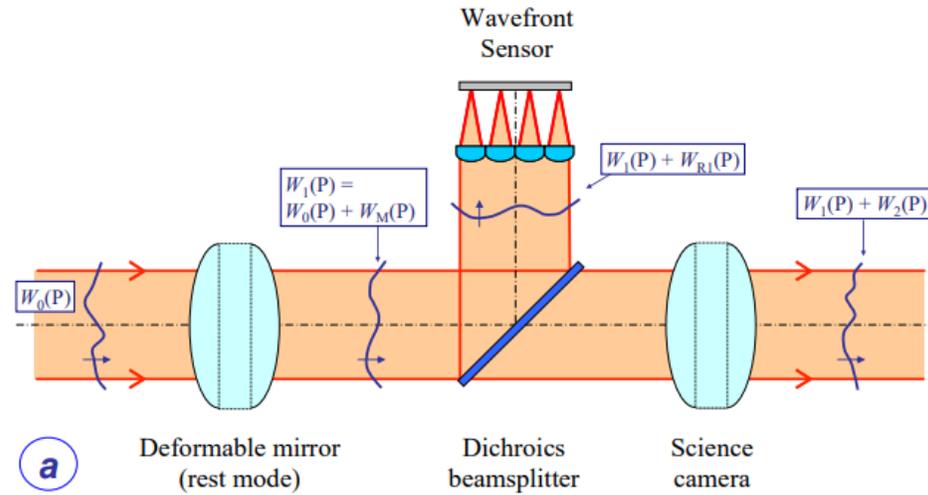


- High resolution system
- HCI system

PC: Subaru Telescope
 (<https://subarutelescope.org/en/about/instrument/ao36/index.html>)

Schematic diagram of adaptive optics

Non Common Path Aberration

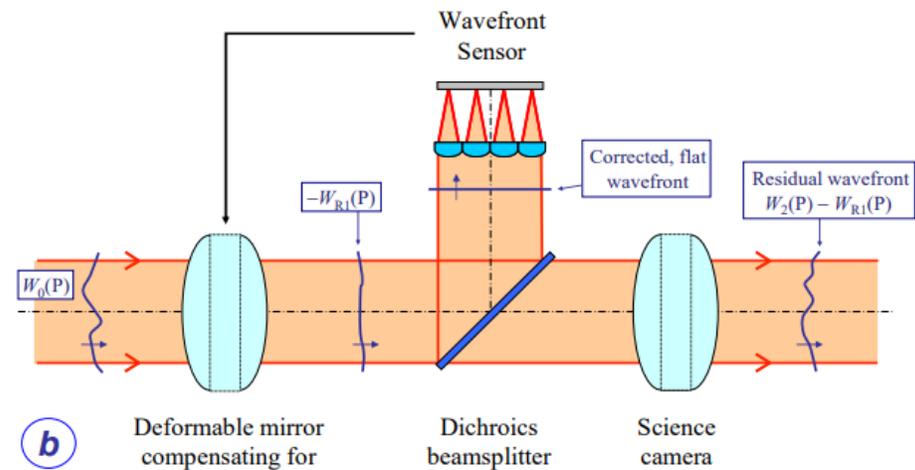


a

Deformable mirror
(rest mode)

Dichroics
beamsplitter

Science
camera



b

Deformable mirror
compensating for
 $W_1(P) + W_{R1}(P)$. Paul

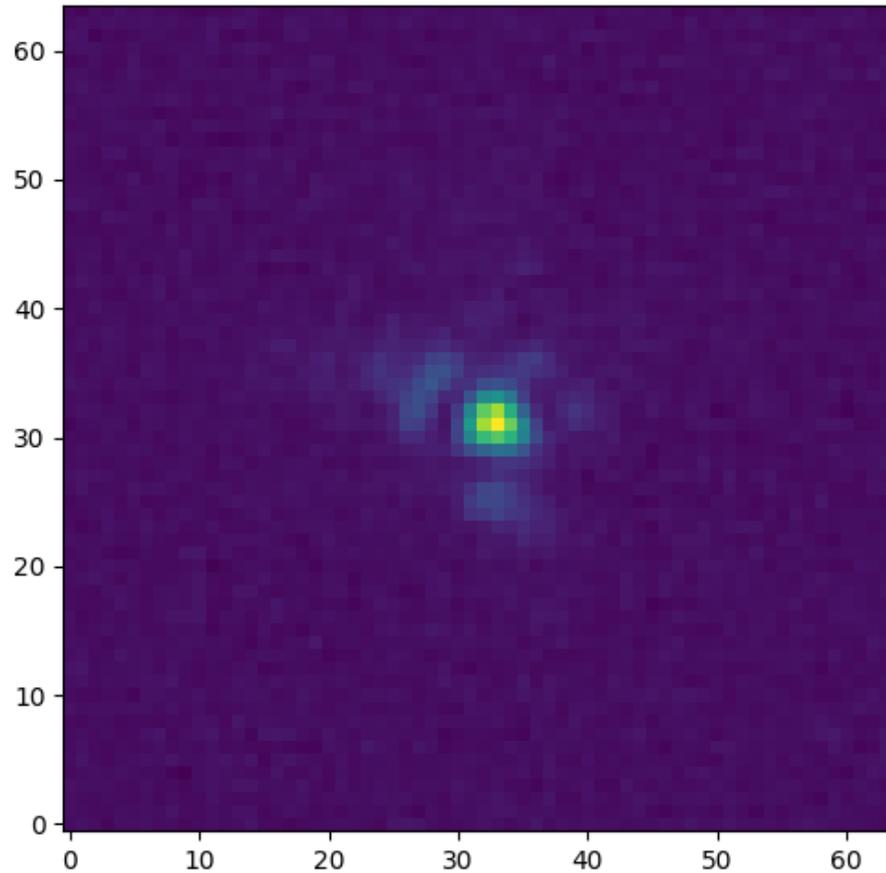
Dichroics
beamsplitter

Science
camera

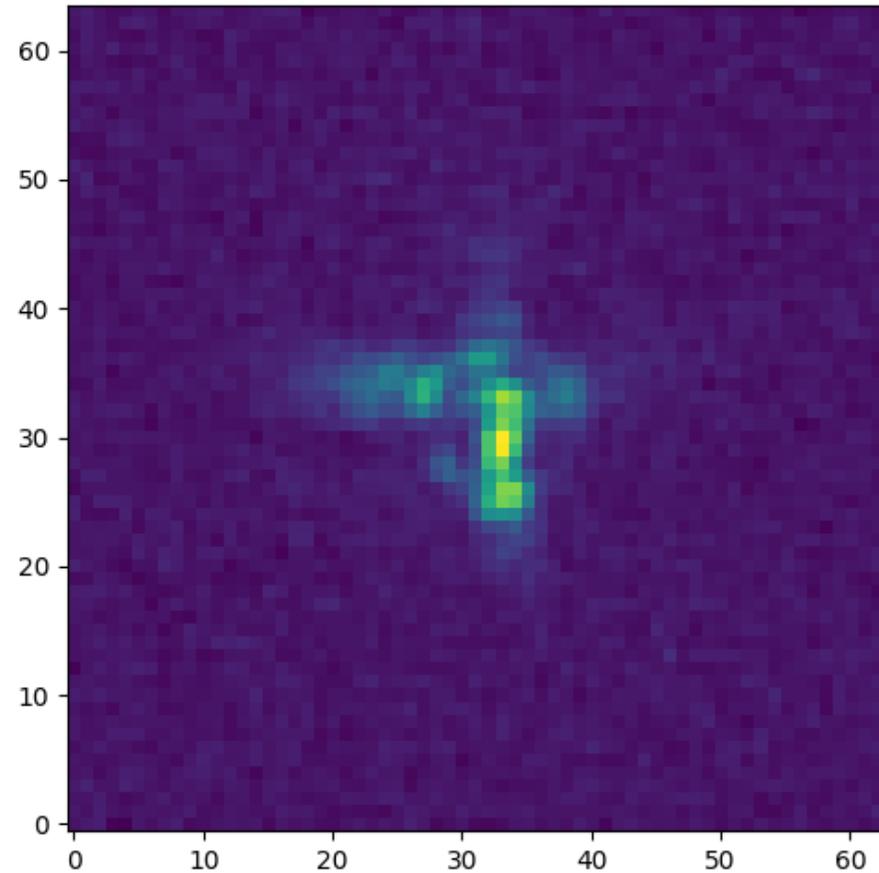
François Hénault 2019

Focal Plane Wavefront Sensing

CAMERA 1 (vcamim1) Focal image



CAMERA 0 (vcamim0) Defocused image

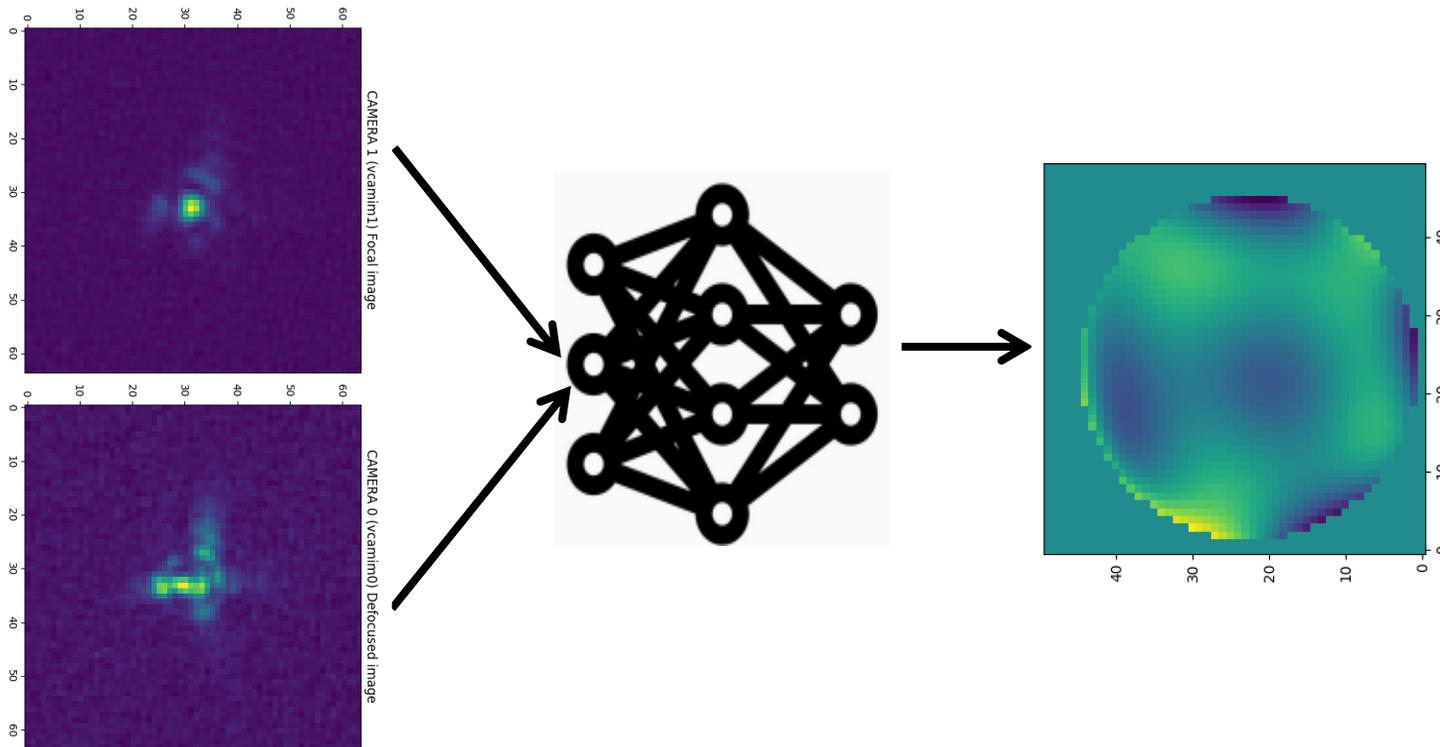


Gerchberg and Saxton (1972)

Gonsalves (1976)

Part 1
Deep learning based
focal-plane wavefront sensing with standard
images

Deep learning methods for focal-plane wavefront sensing



Quesnel et al. 2020
Orban de Xivry et al. 2021

scexao2

scexao2(scexao control) (scexao2: (scexao)) - VNC viewer

network power switches

NPS1 ports 1-4	VAMPIRES CAMERA	SCExAO2 POWER	HIGH-VOLTAGE TT	VAMPIRES CAMERA
NPS2 ports 1-4	SOURCE BOX	DM ELECTRONICS	VAMPIRES SYNC	TUNKNOWM?
NPS2 ports 5-8	GLINT CREZD	DM VACUUM PUMP	FIRST SCI CAM	FIRST NEON SRC
NPS2 ports 9-12	VAMP DIFFRACTION	DM VACUUM PUMP	FIRST SCI CAM	TUNKNOWM?
NPS2 ports 13-16	OCAM POWER	RAMMERS POWER	GLINT PICOMOTOR	CHUCKCAM POWER
NPS3 ports 1-4	SCExAO2 POWER	DM ELECTRONICS	HIGH-VOLTAGE TT	VAMPIRES CAMERA
NPS3 ports 5-8	SOURCE BOX	DM ELECTRONICS	VAMPIRES SYNC	TUNKNOWM?

calibration source

Cal source: **LN** (w: 9.03 mm, y: 22.91 mm)

Source type: SuperX broadband (w: 43.00 deg)

Source IR ND: 00 3.0

Source Opt ND: 00 3.0

Source Filter: 00 4.0 (vis)

Integ. Sphere: OUT

Comp. plate: OUT

FRONT IR BENCH AND CORONAGRAPH

DAP1	COLLS	(t: 17.80 deg, p: 46.03 deg, f: 195000 stp)
Dichroic	LN	(w: 0.00 deg, x: 65200 stp, y: 67100 stp)
Pupil Mask	Open	(w: 270.00 deg, x: 62250 stp, y: 41000 stp)
PIA1	Open	(w: 270.00 deg, x: 60050 stp, y: 12210 stp, f: 75000 stp)
PIA2	Open	(w: 180.00 deg, x: 65000 stp, y: 110000 stp, f: 60000 stp)
Focal Plane Mask	Open (default)	(w: 0.00 deg, x: 11750 stp, y: 135000 stp)
Lytet Mask	UNKNOWN	(x: 0.00 mm, y: 0.00 mm, t: 50 stp, p: 182 stp)
Inverse PIA:	UNKNOWN	

BACK IR BENCH AND IR CAMS

DAP1 Pickoff	OUT	(t: 2.80 deg, p: 15.07 deg)
DAP1	On-axis	(t: 0.00 deg, p: 0.19 deg)
Steering mirror	On-axis	(w: 181.40 deg, t: 1.20 deg)
CHARIS Pickoff	Gold mirror	(w: 91.34 deg, t: 1.85 deg)
WKIDS Pickoff	Gold mirror	(x: 3.10 mm, y: 13.50 mm)
IR Cam Pup Mask	Open	
IR Cam Filter	OPEN	
IR Cam Block	OUT	
IR Cam Focus	ChuckCam focus	(f1:290000 stp, f2: 18.00 mm)
CHUCKCAM Pupil	OUT	
CHUCKCAM Pup Fcs	PUPIL	(f: 4.50 mm)
BUFFYCAM Pickoff	OUT	(x: 0.00 mm)
BUFFYCAM Pupil	OUT	
LLWFS Block	OUT	
LLWFS Focus	OUT	(f: 0 stp)

IR BENCH POLARIZATION

IR Cam OMP	OUT	
Field Stop	OUT	(x: 0.00 mm, y: 0.00 mm)
IR Cam FLC	OUT	(t: -0.00 deg)
IR Cam HWP	OUT	(t: -0.00 deg)
IR Cam Wollaston	OUT	

IR BENCH FIBER INJECTIONS

GLINT Pickoff	OUT	(x: 0.00 mm)
Fib Inj Pickoff	LN	(x: 27.00 mm)
Fib Inj Fiber	UNKNOWN	(x: 254307 stp, y: 10 stp, f: 165300 stp)
Fib Inj Carriage	UNKNOWN	(f: 550000 stp)
REACH Pickoff	OUT	(x: 20.00 mm)
REACH OAP	UNKNOWN	(t: -0.16 deg, p: 0.06 deg)
REACH Fiber	UNKNOWN	(x: 109500.00 mm, y: 107000.00 mm, t: 0.00 deg)

VISIBLE BENCH

PyWFS Pickoff	800 nm SP (dILT)	(w: 180.00 deg)
PyWFS Field Stop	1.24 arcsec	(x: 15.75 mm, y: 9.27 mm)
PyWFS Filter	BLOCK	
PyWFS Col. Lens	BLOCK	(f: 140000 stp)
PyWFS Focus	BLOCK	(f: 105000 stp)
PyWFS Fcs pickoff	OUT	
PyWFS Pupil Lens	OUT	(x: 148200 stp, y: 24300 stp)
VAMP Field Stop	Open (Default)	(x: 13.57 mm, y: 13.50 mm)
FIRST Pickoff	OUT	(x: 17.50 mm)
FIRST Injection	UNKNOWN	(x: 40700 stp, y: 116200 stp, f: 181.00 mm)
FIRST Photometry	OUT	(x: 15.00 mm)
RHEA Pickoff	NOT CONNECTED	(x: 188.00 mm)

PyWFS LOOP STATUS

PyWFS loop status	0	PyWFS loop frequency	3000 Hz
PyWFS calibration status	19	PyWFS loop gain	1.000
PyWFS pupil alignment loop	OPEN	PyWFS loop leak	0.054
PyWFS flux centering loop	OPEN	PyWFS modulation radius	0.000 max
PyWFS DM offload	OPEN		

LLWFS LOOP STATUS

LLWFS loop status	59	LLWFS loop frequency	107 Hz
LLWFS mode type	43	LLWFS loop gain	164.000
LLWFS number of modes	62	LLWFS loop leak	129.000

SPECKLE NULLING LOOP STATUS

Speckle Nulling loop status	OFF	Speckle Nulling loop freq.	165 Hz
Speckle Nulling loop gain	30		
	185.000		

ZAP LOOP STATUS

ZAP loop status	146	ZAP loop frequency	13 Hz
ZAP mode type	110	ZAP loop gain	130.000
ZAP number of modes	77		

ASTROGRID LOOP STATUS

ASTROGRID loop status	OFF	ASTROGRID modulation freq.	2000 Hz
ASTROGRID separation	15.500 1/D	ASTROGRID amplitude	0.050 um

LOGGING STATUS

Logging ChuckCam images	OFF	Acquiring ChuckCam darks	OFF
Logging BuffyCam images	OFF	Acquiring BuffyCam darks	OFF
Aligning PSF on the hotspot	OFF		

MANAGE CONFIGURATION 13

```

00 Coronagraph : 13 Occulter 113mas
01 Lyot : 2 Lyot coro stop
02 Move the shaped pupil in
03 Manual pupil alignment
04 Move the selected FPM in
05 Manual FPM alignment
06 Move FPM sideways
07 Move the Lyot in
08 Manual Lyot alignment
09 Move shaped pupil out
10 Move Lyot out
11 Image size : 28 pixels
12 No average : 100 images
13 [1] Get crop parameters (./GetCrop) -> conf lowfscrop.txt
14 [1] Apply crop parameters (./cropshim) -> /tmp/ircam2crop.in.sh
15 [0] Take all darks (./takeDark) -> dark
16 [0] Take single dark (./takeSingleDark) -> dark

```

scexao@scexao:~\$

LOAD MODULES SHARED ALL /src/cacao/lib [CLI_ADD_LIBS] not supported

27 modules, 316

cacao > loadfits 'tmp' Unprocessed string : [50,50] -32 1.000000 0.0 [MILK_SHM_DIR] '/tmp [MILK_SHM_DIR] '/tmp read shared mem image size 1

cacao > cp dm0 dm0disp

cacao > exit

Closing PID 13974 (prom)

channel #10: min=0.000, max=0.000, mean=0.000, std=0.000

Python: home/scexao

```

(base) scexao@scexao5:~$

```

PALILA camera display!

APAPANE camera display!

PALILA camera viewer

```

For help, press [h]
h0,v0 = 160,108  sh,sv = 820,286
s = 12.7 us FPS = 830 NDR = 32
tms = 18.7 us min,max = -197, 227HS
mouse = 140,184 flux = -17
non-linear // bias

```

APAPANE camera viewer

```

For help, press [h]
h0,v0 = 64, 48  sh,sv = 160,160
s = 10.1 us FPS = 905 NDR = 32
tms = 3.24 us min,max = -1507,004526
mouse = 104, 80 flux = 7
non-linear // bias

```

xterm

```

Warning: src_flux requires "src_power on" - or you will get a thorlabs wheel error.
scexao@scexao2:~/Documents/OPES src_flux optnd 4
Warning: src_flux requires "src_power on" - or you will get a thorlabs wheel error.
scexao@scexao2:~/Documents/OPES src_flux filter 6
Warning: src_flux requires "src_power on" - or you will get a thorlabs wheel error.
scexao@scexao2:~/Documents/OPES src_flux filter 1
Warning: src_flux requires "src_power on" - or you will get a thorlabs wheel error.
scexao@scexao2:~/Documents/OPES

```

xterm

```

Warning: src_flux requires "src_power on" - or you will get a thorlabs wheel error.
[0.56399834, -0.06450999, True]
x: 10
27837
[0.54652226, -0.048666365, True]
x: 10
27847
[0.5199028, -0.048558815, True]
x: 10
27857
(base) scexao@scexao2:~/Documents/OPES src_flux off
src_power is OFF
Warning: src_flux requires "src_power on" - or you will get a thorlabs wheel error.
scexao@scexao2:~/Documents/OPES

```

20/10/2022

J. Paul

WF5 2022, Porto

Workspace 1

xterm

02:56 AM

VAMPIRE

VAMPIRES (sonne:1 (lestat)) - VNC Viewer

MATLAB R2021b - academic use

vCamControl

ARCHIVE TO Gen2

HWP Enabled

HWP wait for CHARIS

Frames/HWP: 1 Log File: defaultLogFile.txt

Steer Im/Pup
Stop Video

Cur Cam: 1

Log view

Clip Hi: 0 Clip Low: 0

Abort!

Snapshot

Camera Cooling: On Off

Temp Set: -85

Temp 1: -85 Temp 2: -84

Timing File: fastFT15

Readout Mode: NFT FT

Execute Acquisition

Acquisition Series: Ex. Ha Series: 1

Execute Series: Loop

Quarter-wave Plates: Plate 1: 128 Plate 2: 167.99

Filter Wheel: Preset File: defaultFilterPresets Filter: 725-50

Move Filter Wheel

Calibration: Polariser: 00 00 In Out

Run topQWP Cal

Run pQWP Grid (W/P) Run AO188 pQWP Grid

Waveplate: QWPs Subtract

Subtract-o-matic: Store Image Subtract

FLC Temperature: On Off

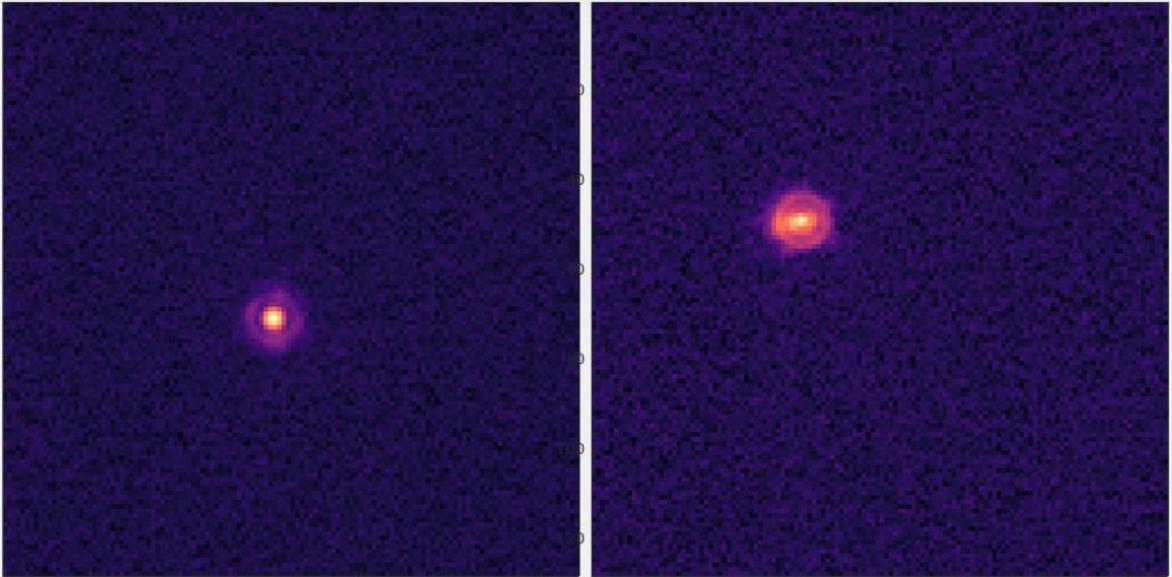
Temp Set: 45 Cur Temp: 17.3

Soft Acq (Unsync'd): 1 1 nCubes Cubes/

Sequence vals: 0

None Filter Abs fo... Diff foC...

Acquire n Cubes



Output path/file:

filename

Click Location: Cam 1 73.62 135.3 Cam 2 365 383

Set Line Profile: Show line

Peak Flux: 4030

Box flux: 1661

Prof. max: 15000

00 00 00 00

Displaying live video

Exit

```

(base) lestat@sonne:~/code/vControl$ milk-shaimon vcam0
[ FAILED ] File /milk/shm/vcam0.im.shm not found
REQUIRED FILE NOT FOUND: EXITING
(base) lestat@sonne:~/code/vControl$ milk-shaimon vcamim0
[ FAILED ] File /milk/shm/vcamim0.im.shm not found
REQUIRED FILE NOT FOUND: EXITING
(base) lestat@sonne:~/code/vControl$
  
```

tCropmode =
20002

tCropmode =
20002

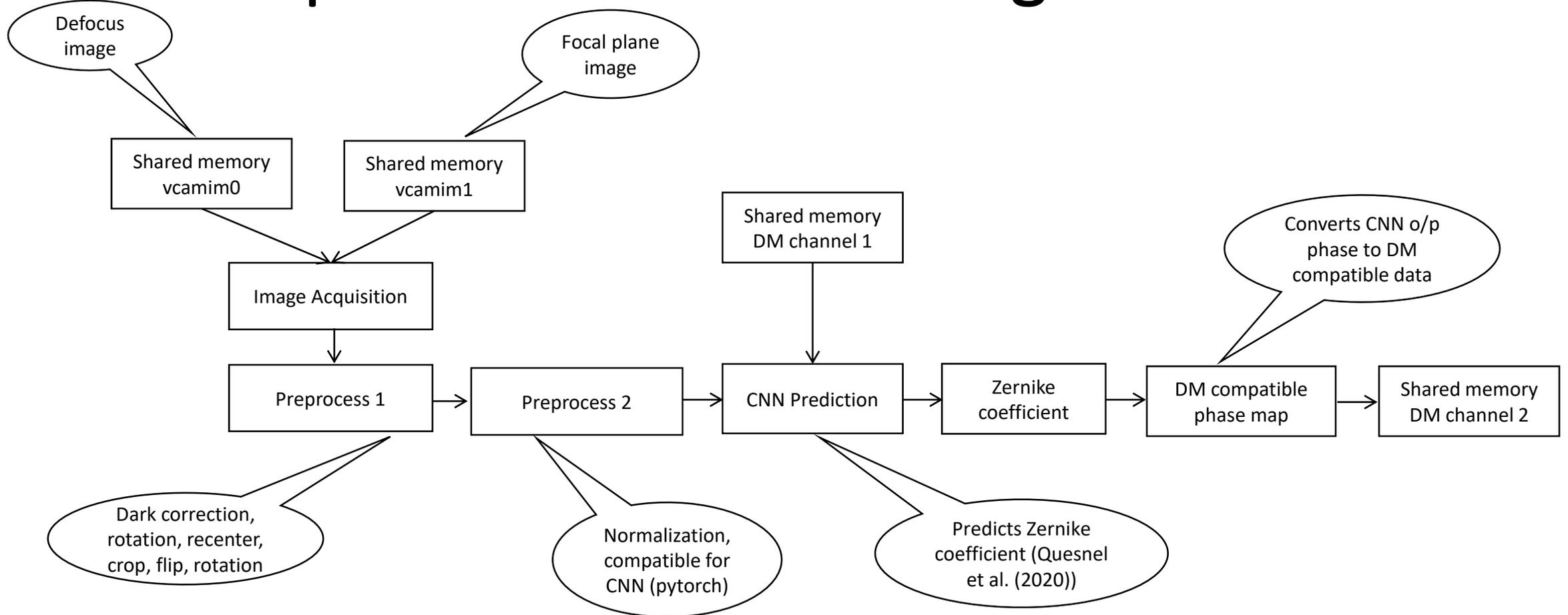
20/10/2022

J. Paul

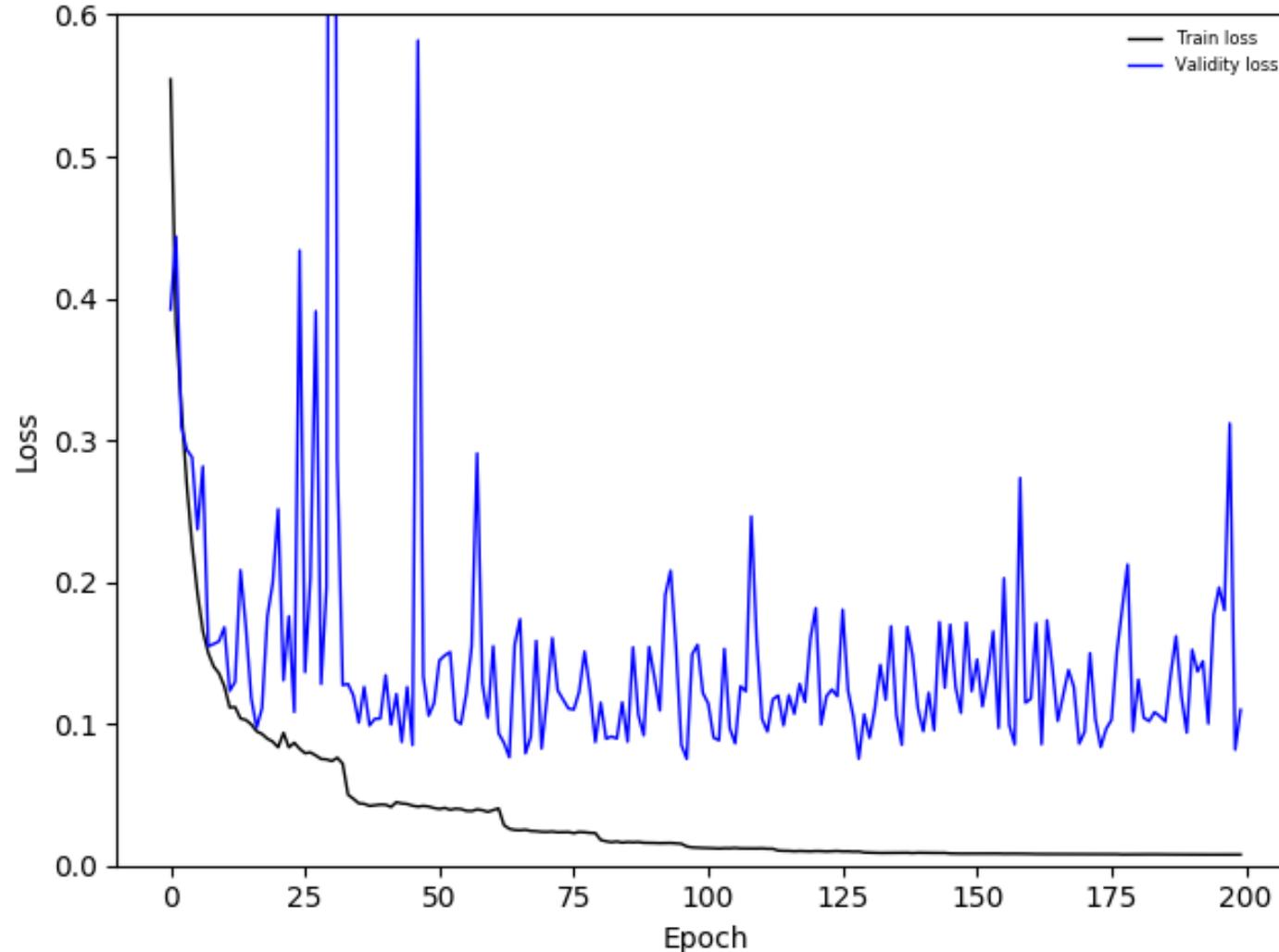
WFS 2022, Porto

lestat@sonne: ~... MATLAB R2021b... Command Window vCamControl lestat@sonne: ~ 22:28

Flow chart: CNN based focal-plane wavefront sensing at SCExAO

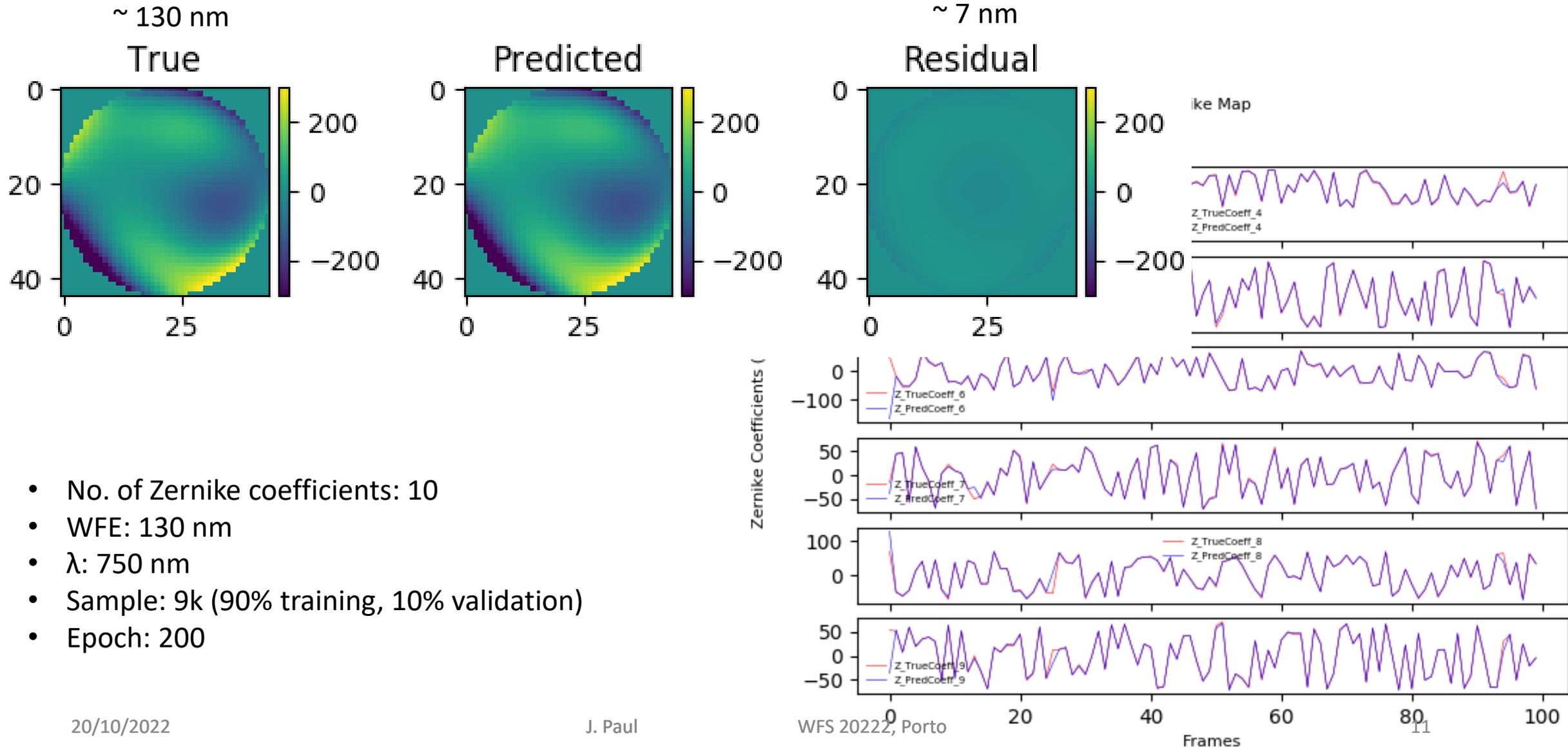


Training Loss



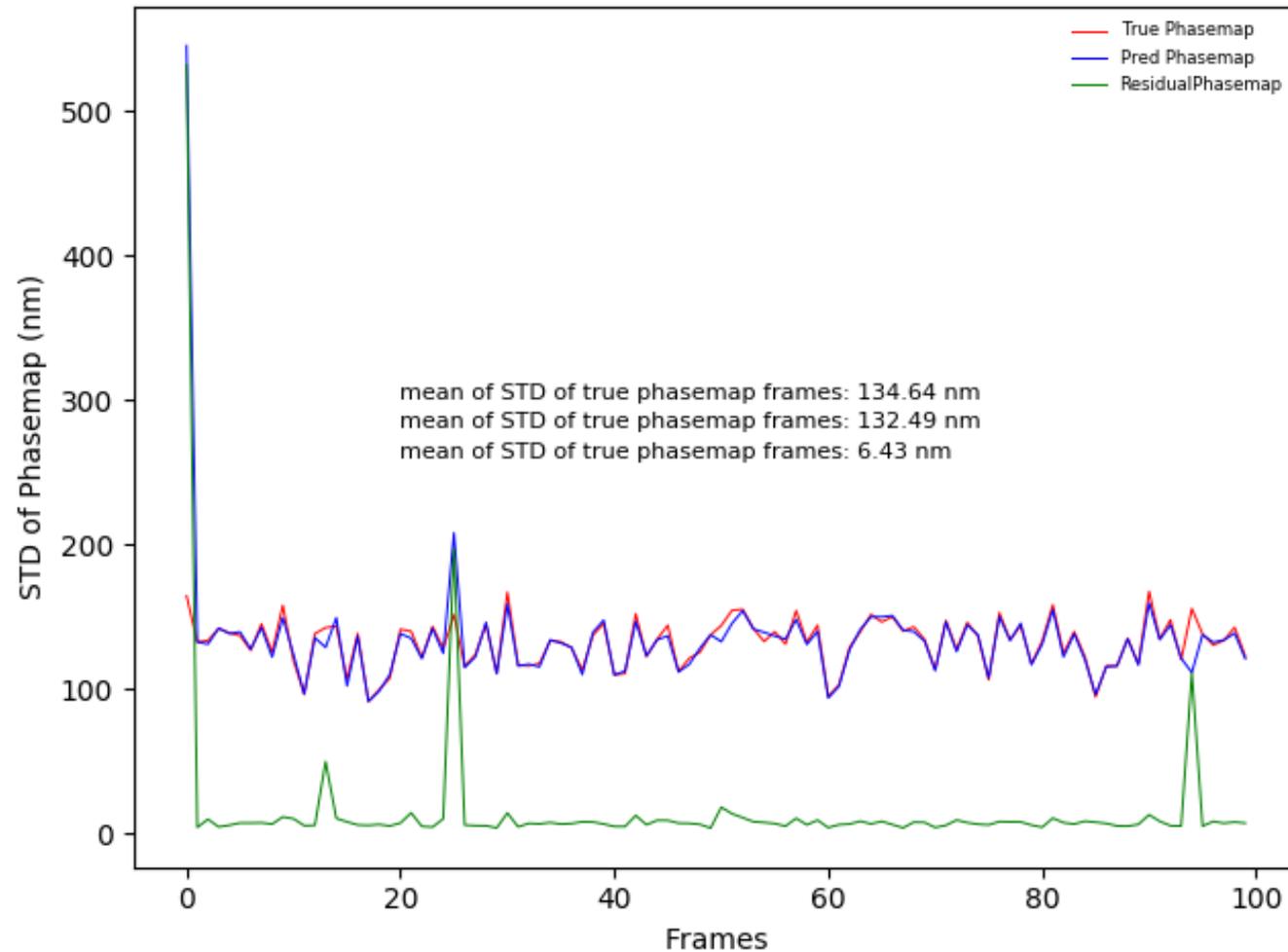
- No. of Zernike coefficients: 10
- WFE: 130 nm
- λ : 750 nm
- Sample: 9k (90% training, 10% validation)
- Epoch: 200
- ~ 3.0 hours

Prediction

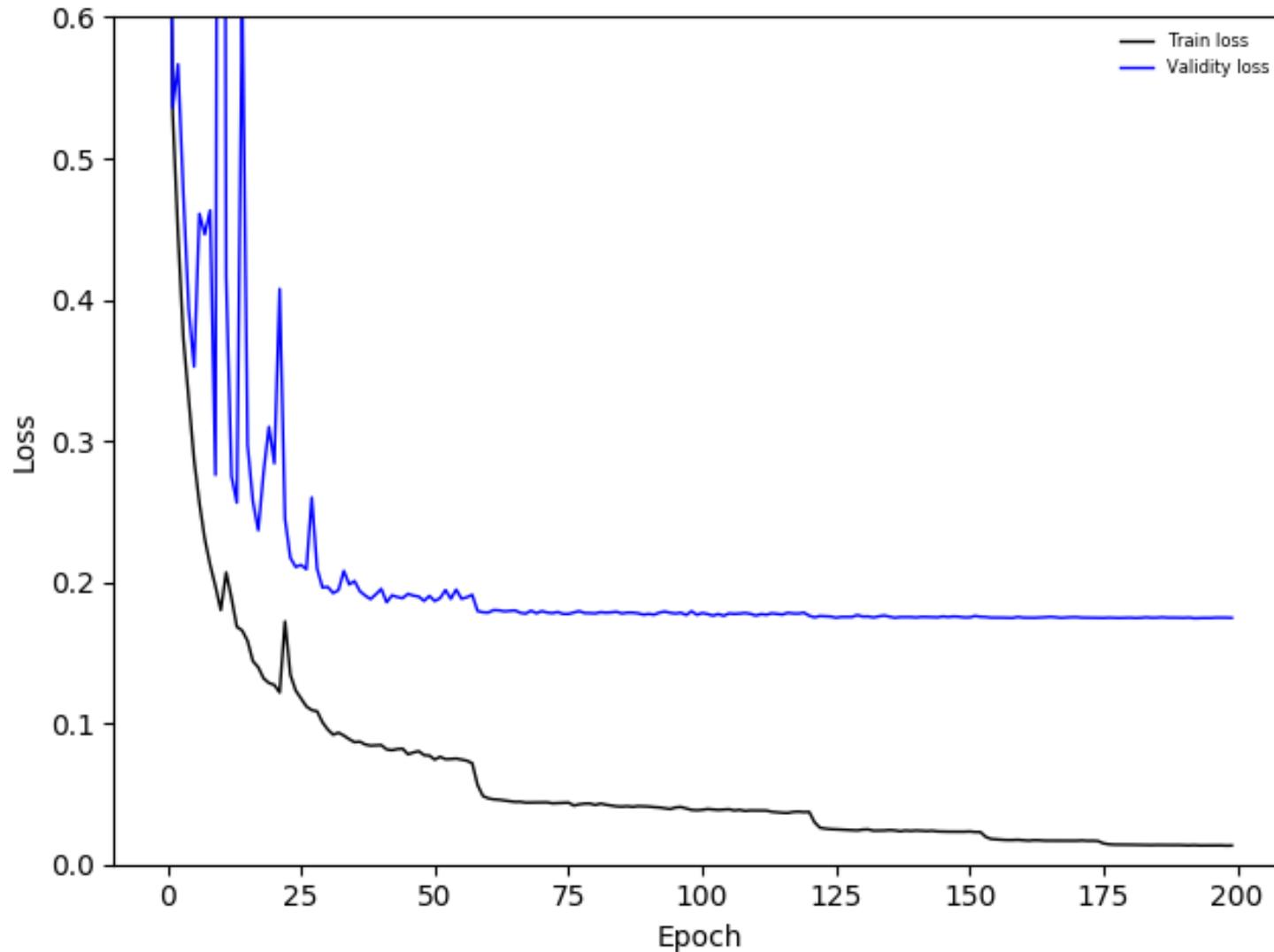


- No. of Zernike coefficients: 10
- WFE: 130 nm
- λ : 750 nm
- Sample: 9k (90% training, 10% validation)
- Epoch: 200

Evolution of Zernike coefficients (z: 10)

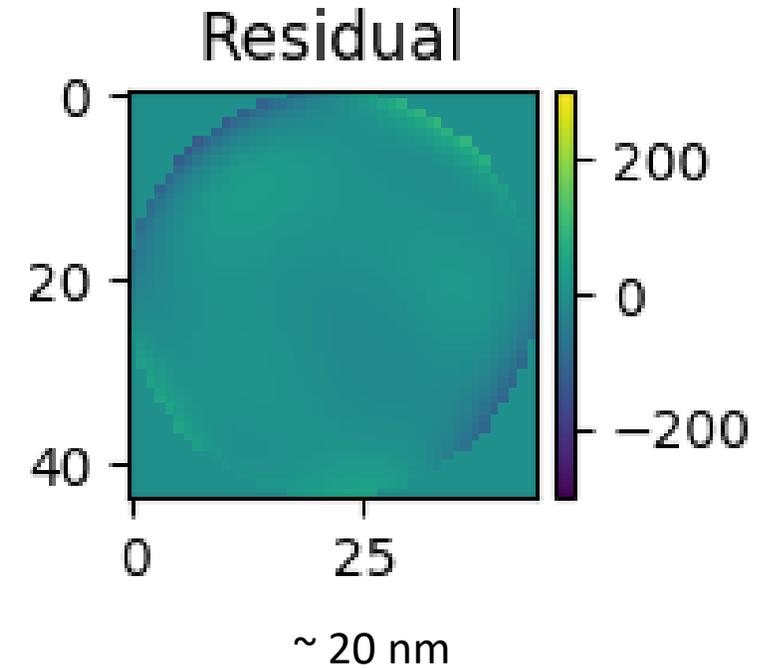
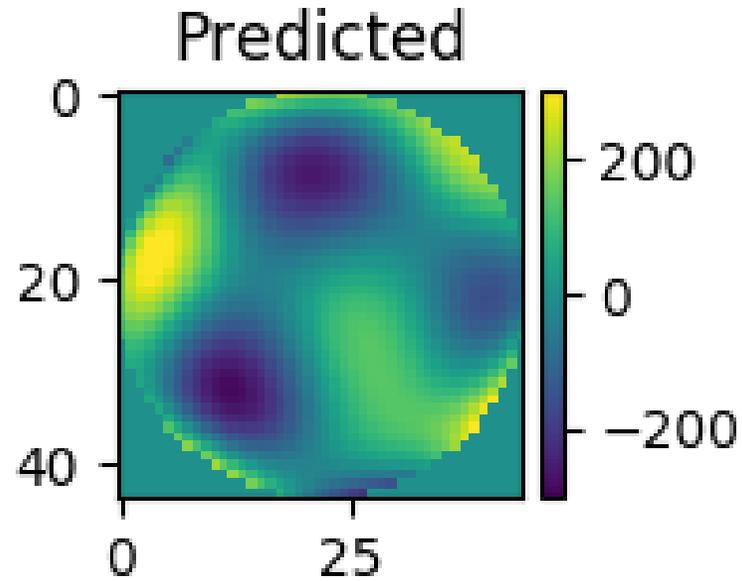
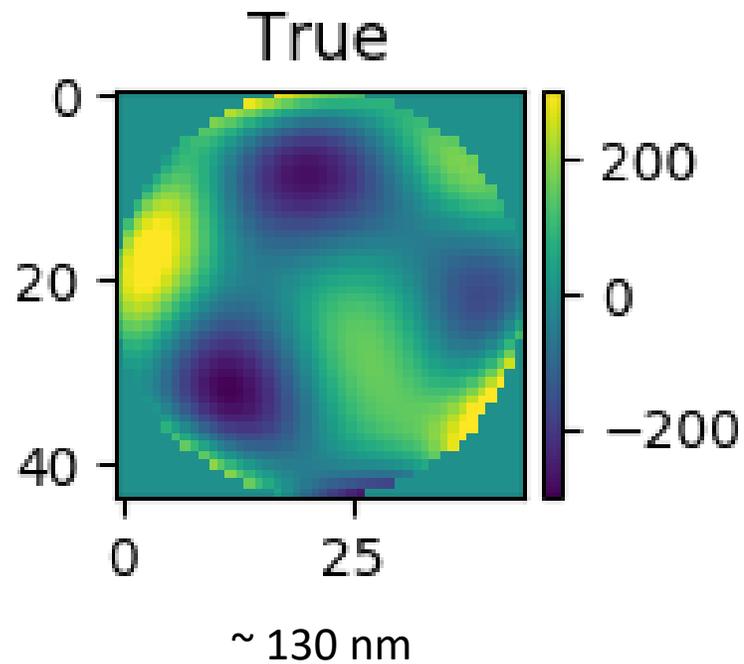


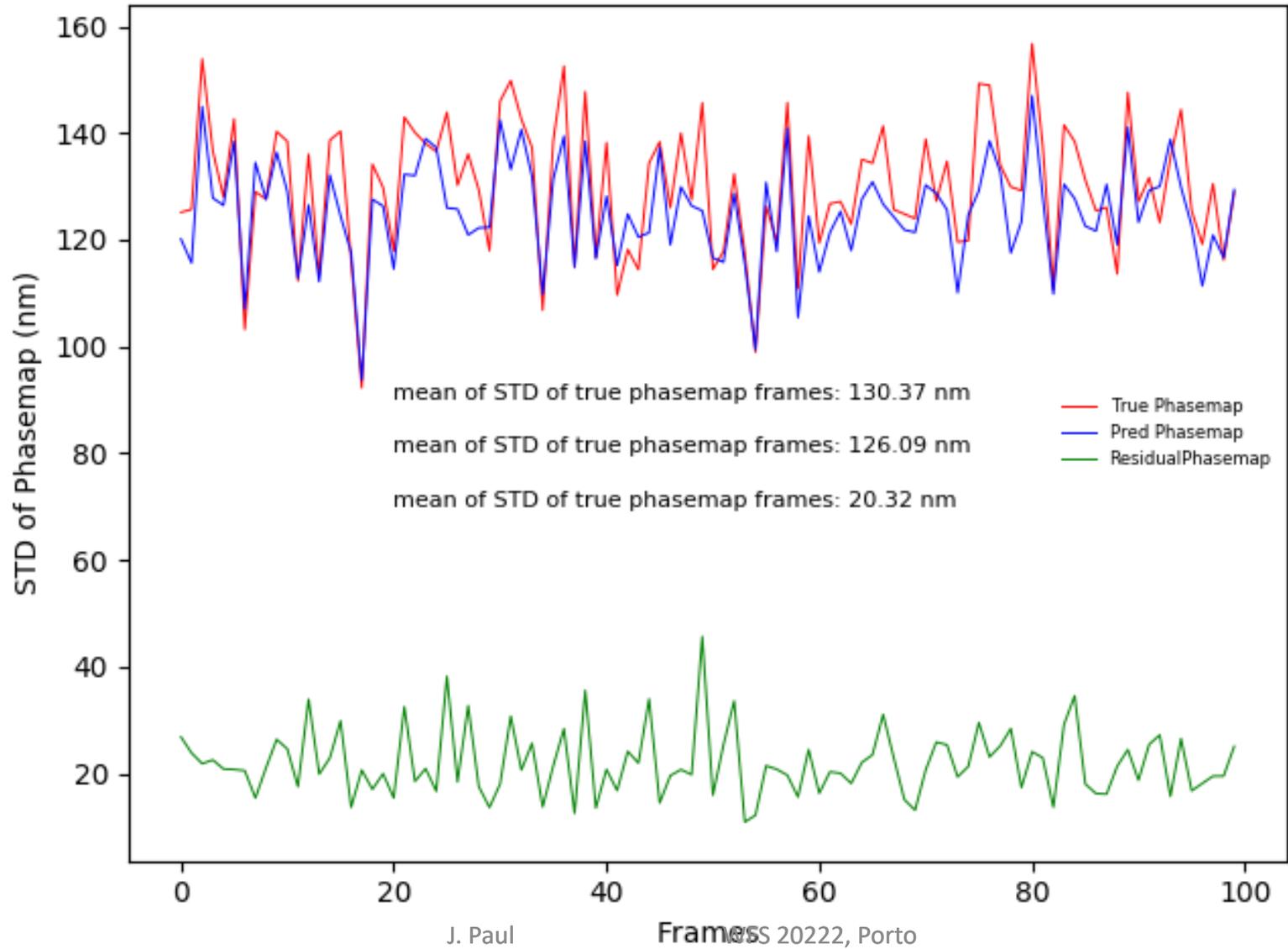
Training Loss



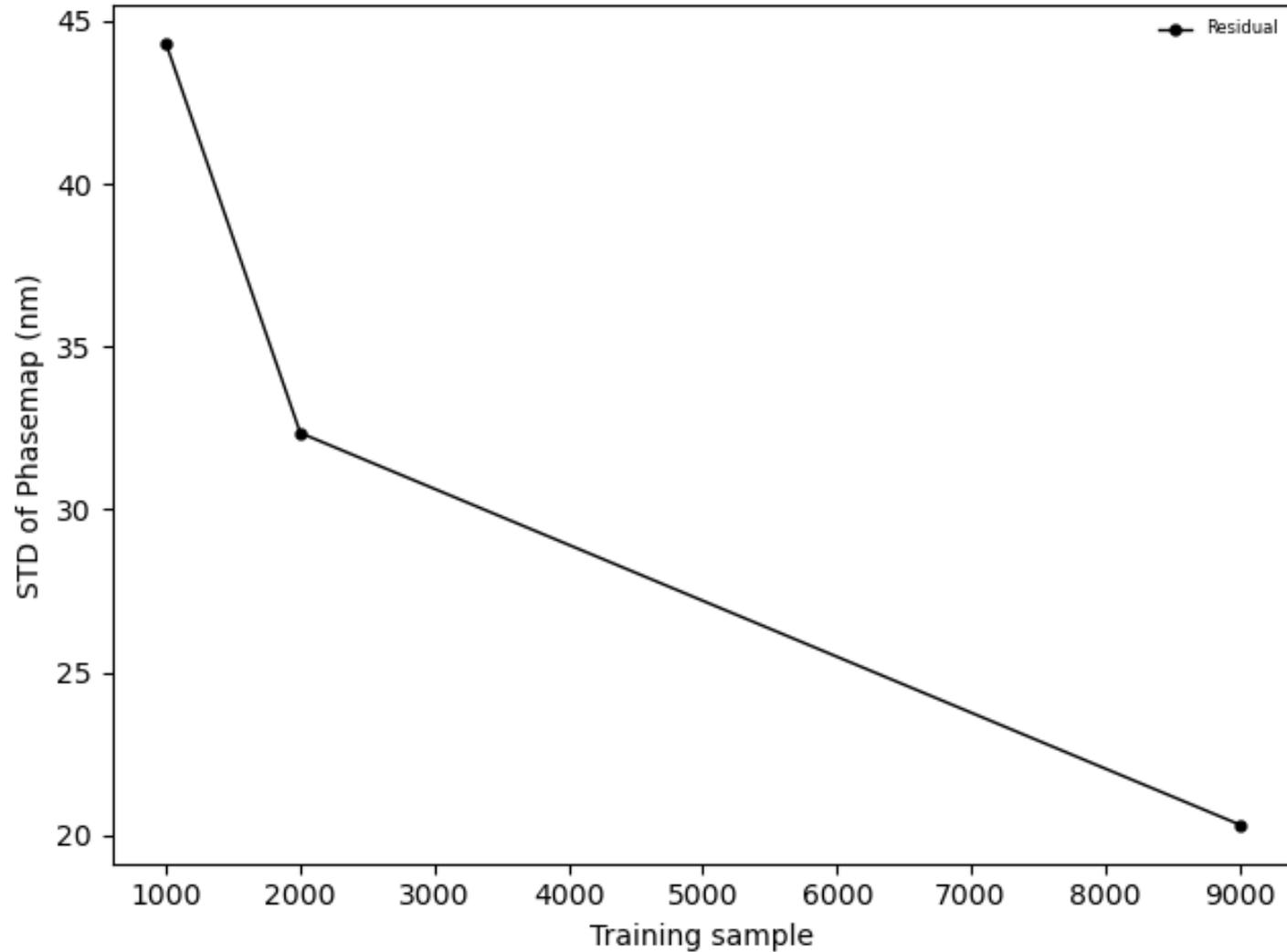
- No. of Zernike coefficients: 20
- WFE: 130 nm
- λ : 750 nm
- Sample: 9k (90% training, 10% validation)
- Epoch: 200
- ~ 3.0 hours

Prediction





Training dataset size



- No. of Zernike coefficients: 20
- WFE: 130 nm
- λ : 750 nm
- Sample: 90% training, 10% validation

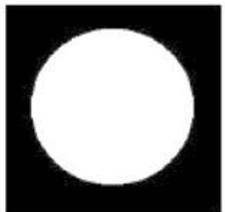
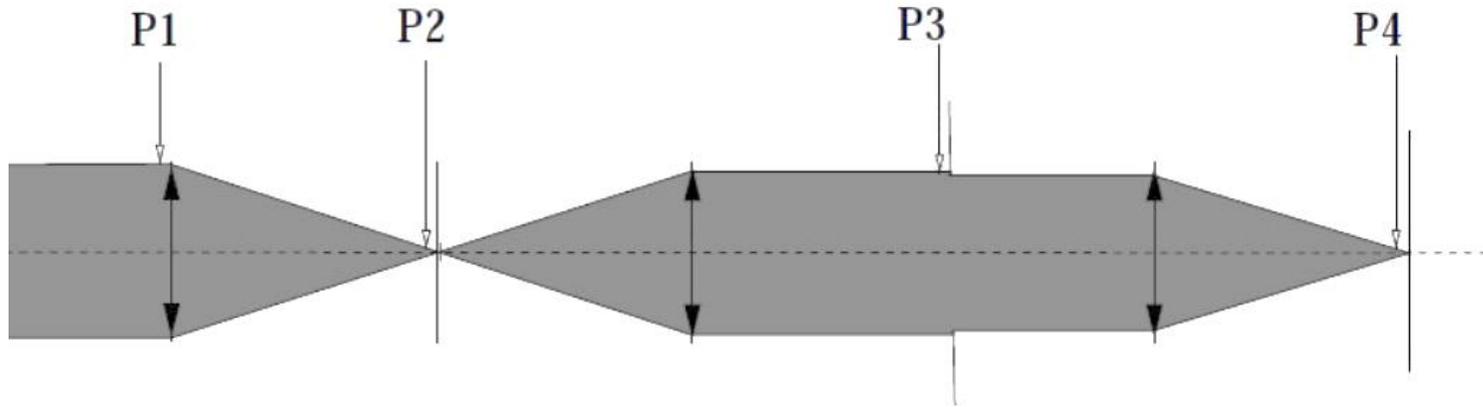
Future steps

- Real time correction in scexao testbench
 - Introduction of static aberration in one of the DM channel
 - Apply correction at the different DM channel
- Onsky implementation
 - NCPA and AO residual

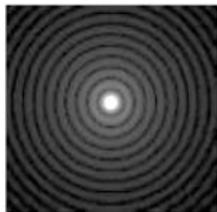
Part 2

Dual polarization based focal plane wavefront sensing, VODCA

Principles of Coronagraph

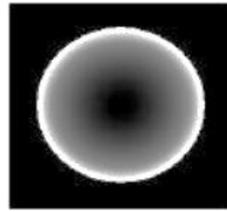


P1

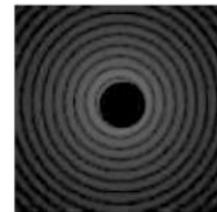


P2

Lyot
coronagraph

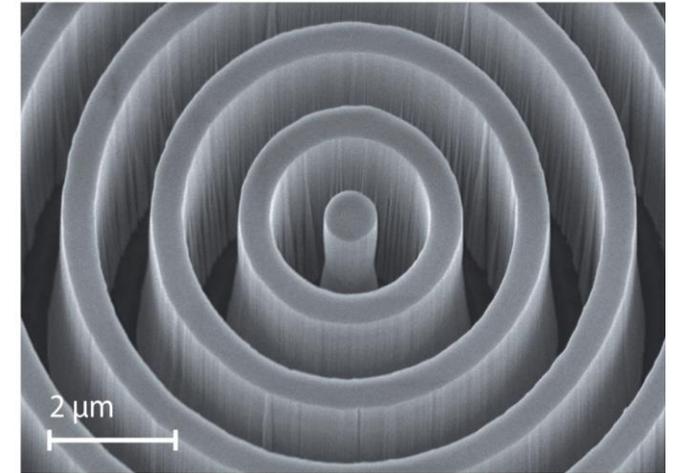


P3



P4

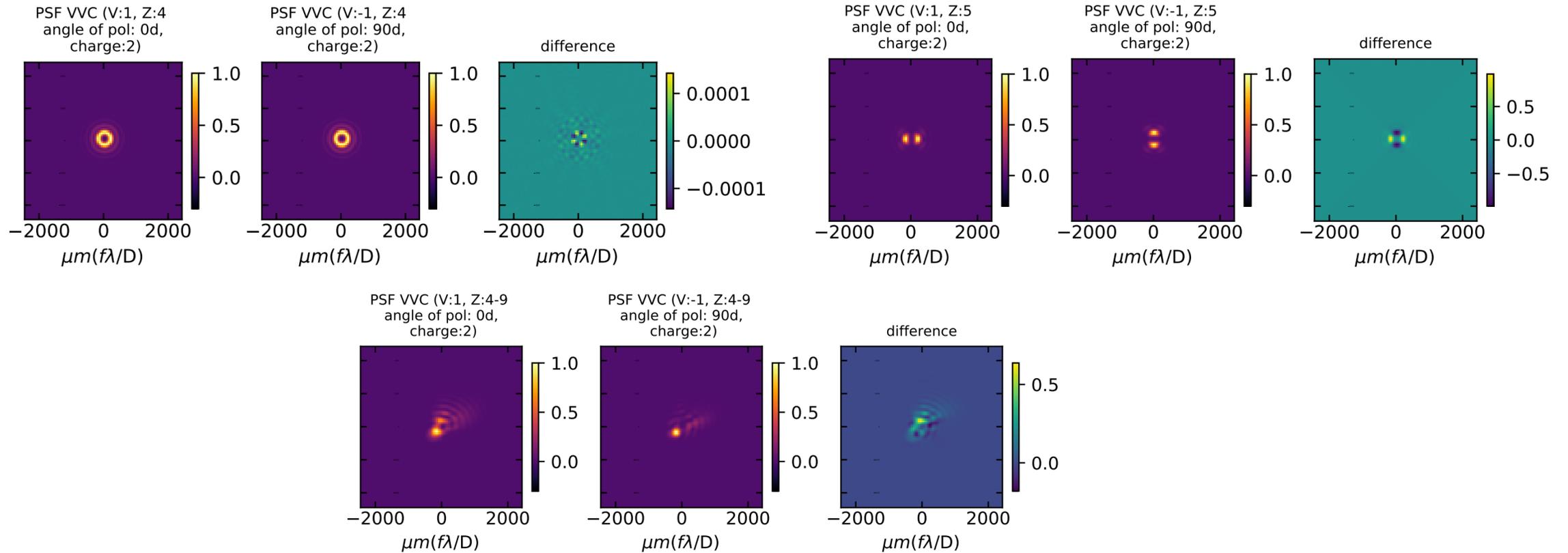
Guyon et al. (1999).



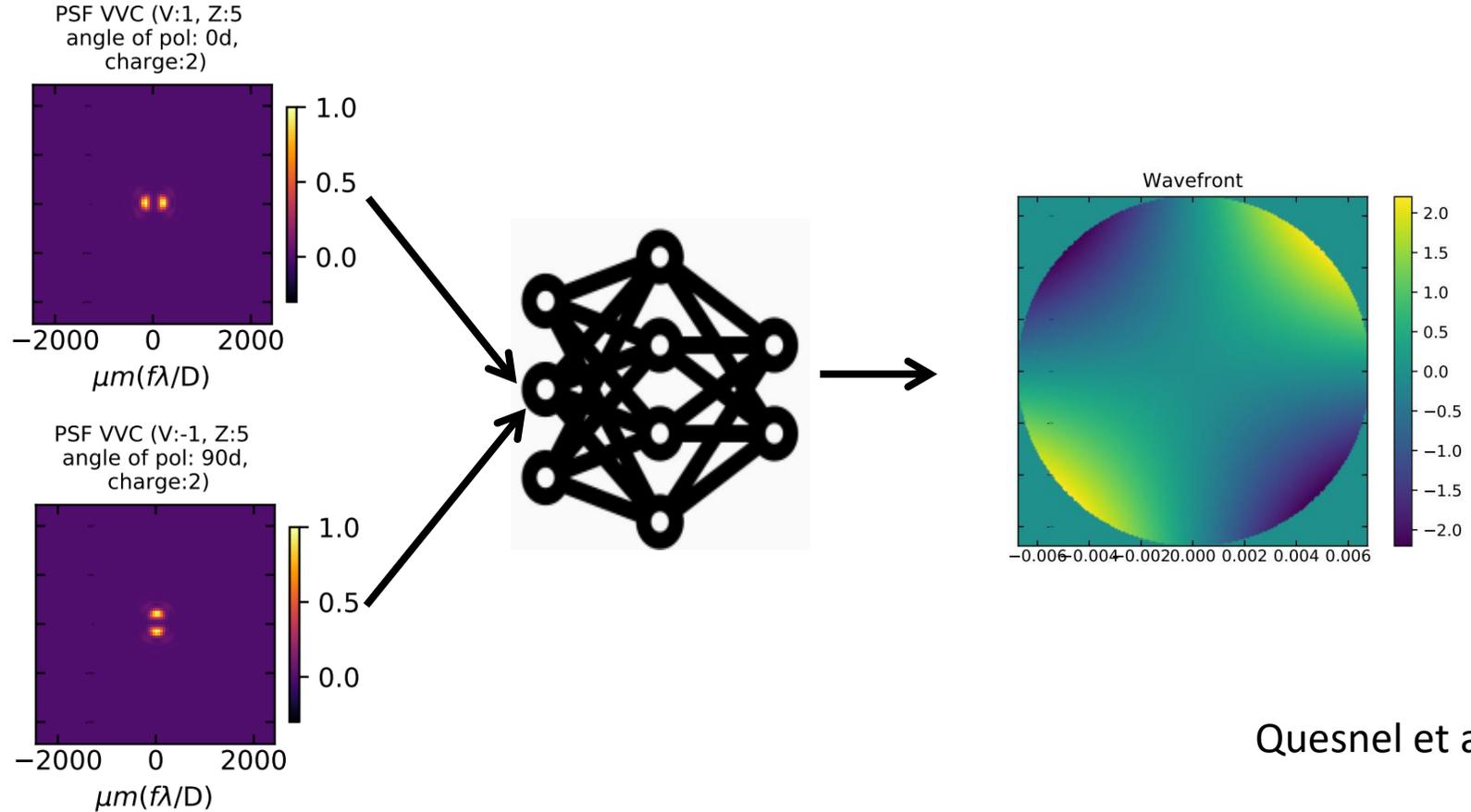
Vector Vortex Coronagraph

Delacroix et al. 2013

Phase diversity due to polarization

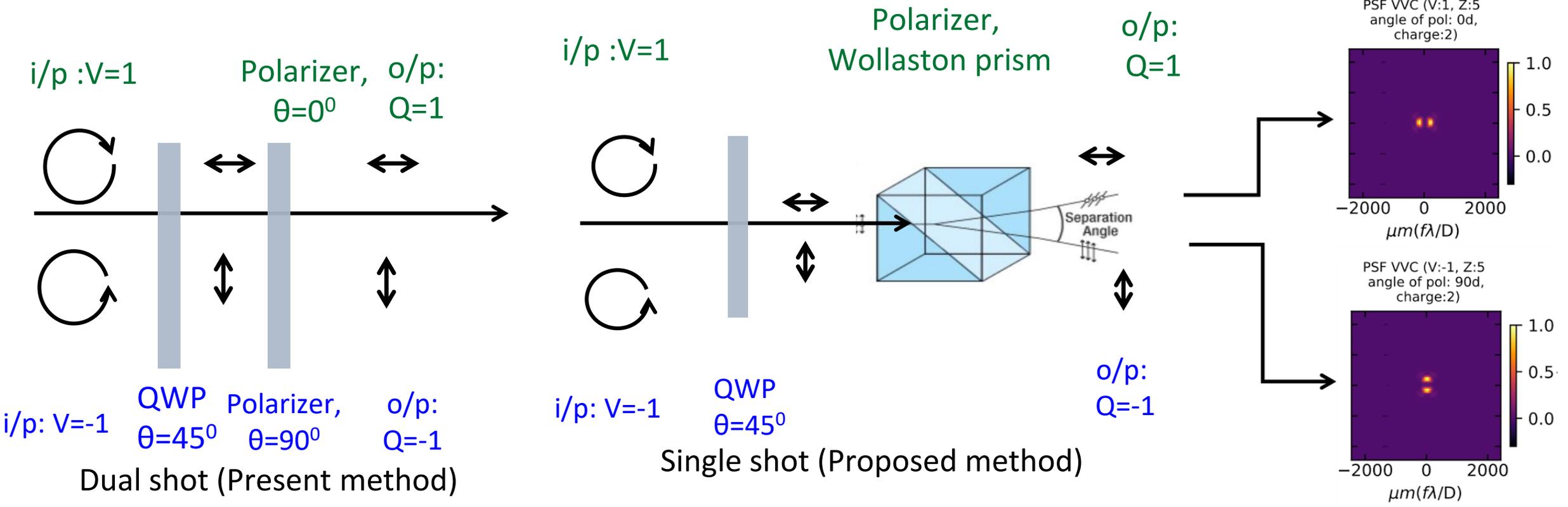


Dual polarization based focal plane wavefront sensing, VODCA

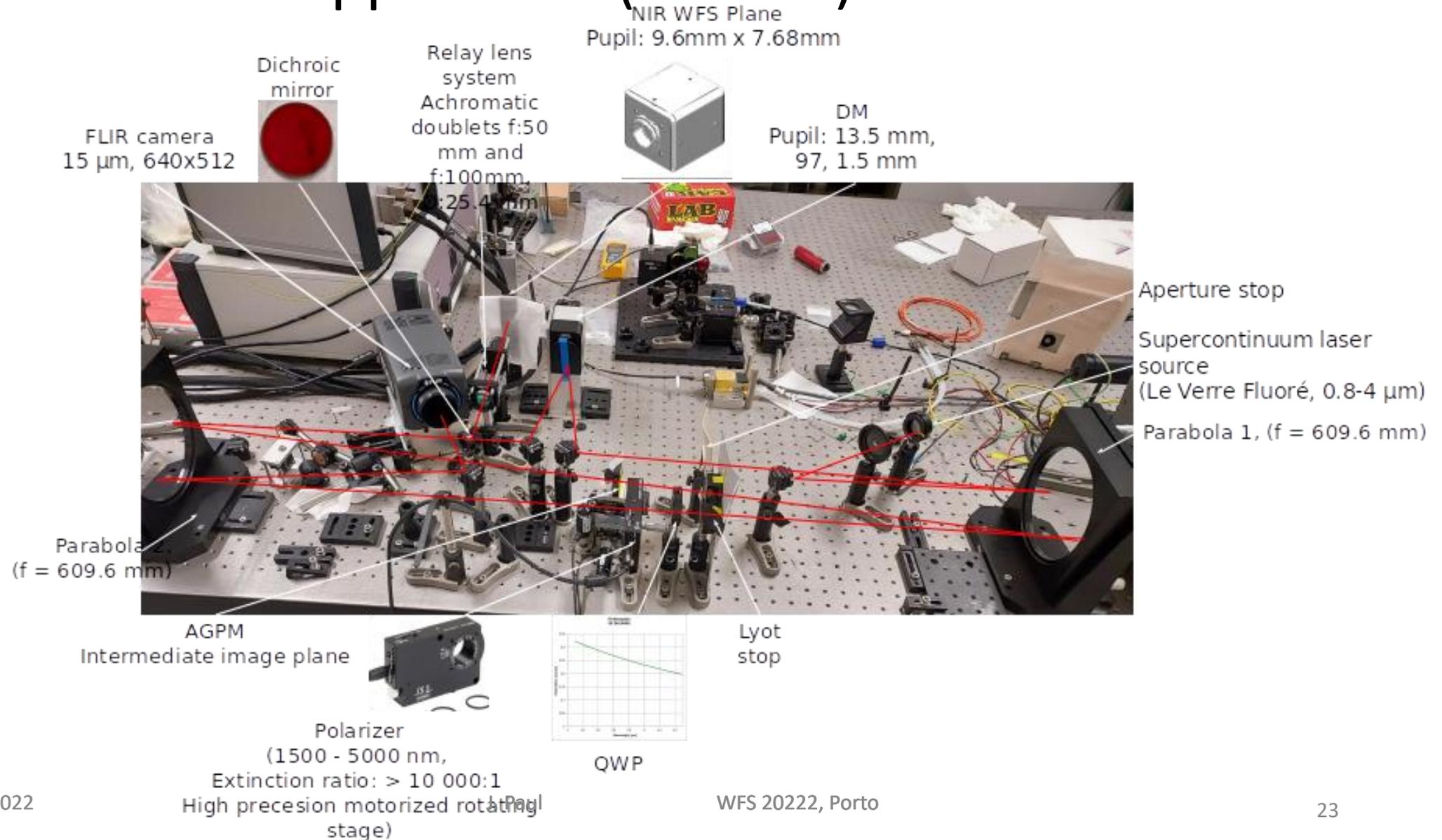


Quesnel et al. 2022 (accepted)

Filtering the PSF corresponds to different circular polarized light



Vortex Optical Demonstrator for Coronagraphic Application (VODCA) test bench



Thanks