

Lab Notebook

Pupil Reconstruction

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Contents

1 PL Information Determination	2
1.1 The data	2
1.1.1 Atmospheric aberration related	2
1.1.2 Zernike modes related	4
1.2 The models	12
1.2.1 Atmospheric aberration related models	13
1.2.2 Zernike modes related models	14

1 PL Information Determination

1.1 The data

There are two groups of datasets.

1.1.1 Atmospheric aberration related

There are 4 datasets composed by PSFs and their corresponding PL intensities.

PSFs The PSFs' electric fields are stored in a 3d matrix of depth 2: depth 1 and 2 represent the real and imaginary value of the electric field in a point.

- **Original sized PSFs:** A dataset of 70000 electric fields stored in 128x128x2 matrixes.

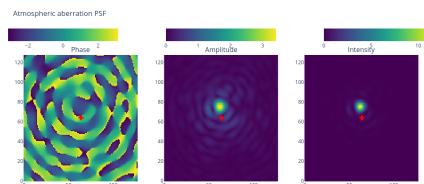


Figure 1: Example original sized PSF

- **Cropped sized PSFs:** A dataset of 70000 electric fields stored in 64x64x2 matrixes. These cropped PSFs correspond to the central pixels from the Original sized PSFs.
- **Original sized predicted PSFs:** A dataset of 70000 predicted electric fields stored in 128x128x2 matrices. These predicted PSFs are the outputs of a model trained with the Original PSFs dataset and their corresponding PL intensities.

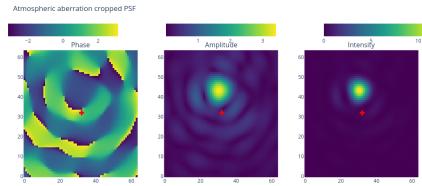


Figure 2: Example Cropped sized PSF

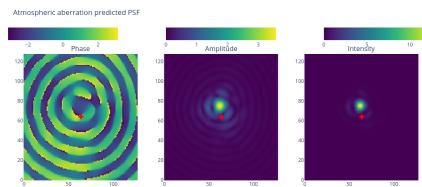


Figure 3: Example original sized predicted PSF

- **Cropped sized predicted PSF:** A dataset of 70000 predicted electric fields stored in 64x64x2 matrices. These cropped predicted PSFs are the outputs of a model trained with the Cropped sized PSFs dataset and their corresponding PL intensities (which are the same output intensities from the Original sized PSFs dataset).

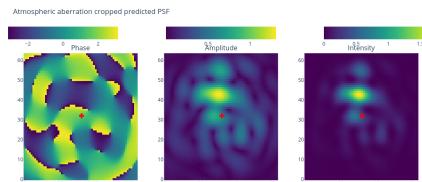


Figure 4: Example cropped sized predicted PSF

PL intensities The same dataset of PL output intensities are used for every PSF dataset. The intensities are computed multiplying the LP coefficients by the transfer matrix of the **19 mode PL**. This dataset has 70000 datapoints, each datapoint being

a vector of 19 elements.

1.1.2 Zernike modes related

There are 5 subgroups of datasets: PSFs generated with 2, 5, 9, 14 and 20 zernike modes. Each subgroup is divided in original sized, cropped sized, predicted and cropped predicted as in the case of the atmospheric aberration PSFs.

PSFs

- **Original sized 2 modes PSFs:** A dataset of 70000 electric fields stored in 128x128x2 matrixes. The aberration by a 2 modes zernike basis.

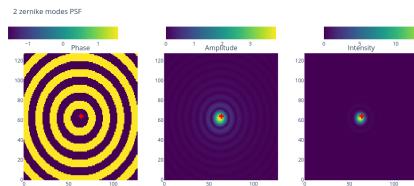


Figure 5: Example original sized 2 modes PSF

- **Cropped sized 2 modes PSFs:** A dataset of 70000 electric fields stored in 64x64x2 matrixes. These cropped PSFs correspond to the central pixels from the Original sized 2 modes PSFs.

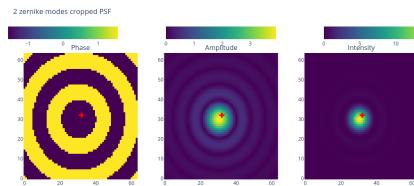


Figure 6: Example Cropped sized 2 modes PSF

- **Original sized predicted 2 modes PSFs:** A dataset of 70000 predicted electric fields stored in 128x128x2 matrices. These predicted PSFs are the outputs of a model trained with the Original sized 2 modes PSFs dataset and their corresponding PL intensities.

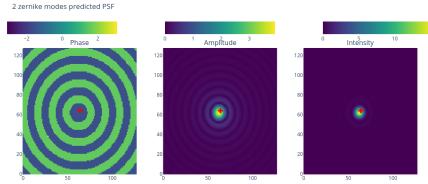


Figure 7: Example original sized predicted 2 modes PSF

- **Cropped sized predicted 2 modes PSF:** A dataset of 70000 predicted electric fields stored in 64x64x2 matrices. These cropped predicted PSFs are the outputs of a model trained with the Cropped sized 2 modes PSFs dataset and their corresponding PL intensities (which are the same output intensities from the Original sized 2 modes PSFs dataset).

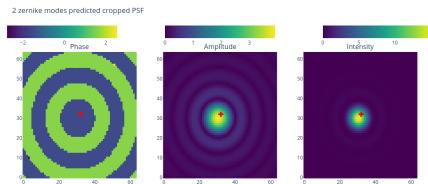


Figure 8: Example cropped sized predicted 2 modes PSF

- **Original sized 5 modes PSFs:** A dataset of 70000 electric fields stored in 128x128x2 matrixes. The aberration by a 5 modes zernike basis.
- **Cropped sized 5 modes PSFs:** A dataset of 70000 electric fields stored in 64x64x2 matrixes. These cropped PSFs correspond to the central pixels from the Original sized 5 modes PSFs.

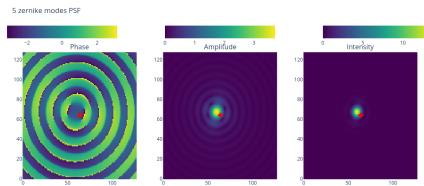


Figure 9: Example original sized 5 modes PSF

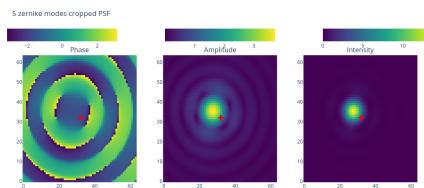


Figure 10: Example Cropped sized 5 modes PSF

- **Original sized predicted 5 modes PSFs:** A dataset of 70000 predicted electric fields stored in 128x128x2 matrices. These predicted PSFs are the outputs of a model trained with the Original sized 5 modes PSFs dataset and their corresponding PL intensities.

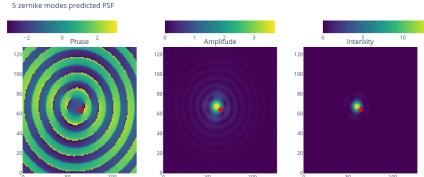


Figure 11: Example original sized predicted 5 modes PSF

- **Cropped sized predicted 5 modes PSF:** A dataset of 70000 predicted electric fields stored in 64x64x2 matrices. These cropped predicted PSFs are the outputs of a model trained with the Cropped sized 5 modes PSFs dataset and their corresponding PL intensities (which are the same output intensities from the Original sized 5 modes PSFs dataset).

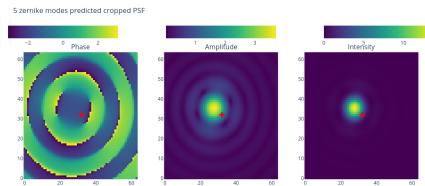


Figure 12: Example cropped sized predicted 5 modes PSF

- **Original sized 9 modes PSFs:** A dataset of 70000 electric fields stored in 128x128x2 matrixes. The aberration by a 9 modes zernike basis.

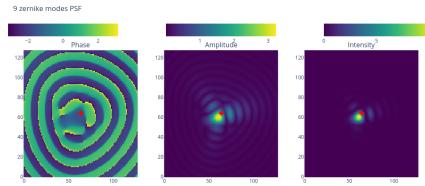


Figure 13: Example original sized 9 modes PSF

- **Cropped sized 9 modes PSFs:** A dataset of 70000 electric fields stored in 64x64x2 matrixes. These cropped PSFs correspond to the central pixels from the Original sized 9 modes PSFs.

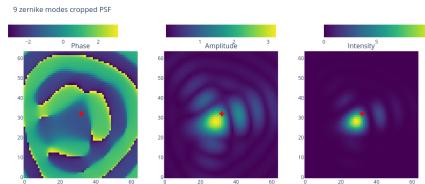


Figure 14: Example Cropped sized 9 modes PSF

- **Original sized predicted 9 modes PSFs:** A dataset of 70000 predicted electric fields stored in 128x128x2 matrices. These predicted PSFs are the

outputs of a model trained with the Original sized 9 modes PSFs dataset and their corresponding PL intensities.

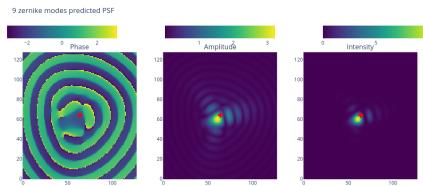


Figure 15: Example original sized predicted 9 modes PSF

- **Cropped sized predicted 9 modes PSF:** A dataset of 70000 predicted electric fields stored in 64x64x2 matrices. These cropped predicted PSFs are the outputs of a model trained with the Cropped sized 9 modes PSFs dataset and their corresponding PL intensities (which are the same output intensities from the Original sized 9 modes PSFs dataset).

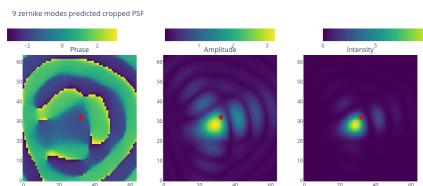


Figure 16: Example cropped sized predicted 9 modes PSF

- **Original sized 14 modes PSFs:** A dataset of 70000 electric fields stored in 128x128x2 matrixes. The aberration by a 14 modes zernike basis.
- **Cropped sized 14 modes PSFs:** A dataset of 70000 electric fields stored in 64x64x2 matrixes. These cropped PSFs correspond to the central pixels from the Original sized 14 modes PSFs.
- **Original sized predicted 14 modes PSFs:** A dataset of 70000 predicted electric fields stored in 128x128x2 matrixes. These predicted PSFs are the

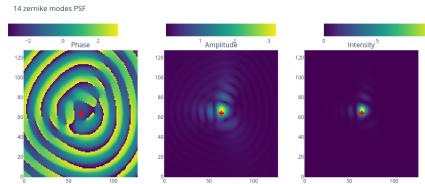


Figure 17: Example original sized 14 modes PSF

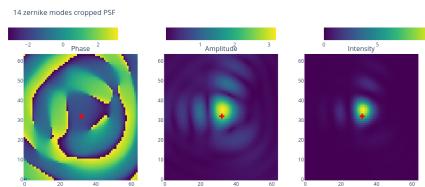


Figure 18: Example Cropped sized 14 modes PSF

outputs of a model trained with the Original sized 14 modes PSFs dataset and their corresponding PL intensities.

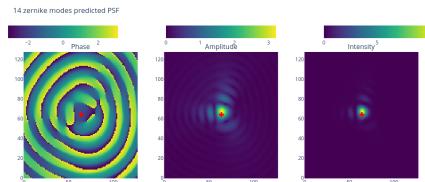


Figure 19: Example original sized predicted 14 modes PSF

- **Cropped sized predicted 14 modes PSF:** A dataset of 70000 predicted electric fields stored in 64x64x2 matrices. These cropped predicted PSFs are the outputs of a model trained with the Cropped sized 14 modes PSFs dataset and their corresponding PL intensities (which are the same output intensities from the Original sized 14 modes PSFs dataset).

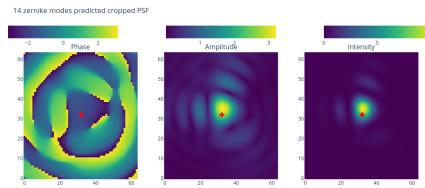


Figure 20: Example cropped sized predicted 14 modes PSF

- **Original sized 20 modes PSFs:** A dataset of 70000 electric fields stored in 128x128x2 matrixes. The aberration by a 20 modes zernike basis.

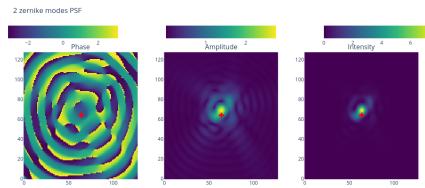


Figure 21: Example original sized 20 modes PSF

- **Cropped sized 20 modes PSFs:** A dataset of 70000 electric fields stored in 64x64x2 matrixes. These cropped PSFs correspond to the central pixels from the Original sized 20 modes PSFs.

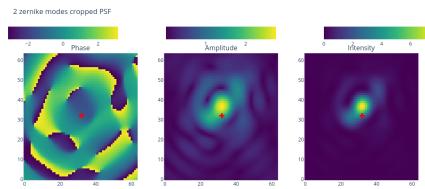


Figure 22: Example Cropped sized 20 modes PSF

- **Original sized predicted 20 modes PSFs:** A dataset of 70000 predicted electric fields stored in 128x128x2 matrices. These predicted PSFs are the

outputs of a model trained with the Original sized 20 modes PSFs dataset and their corresponding PL intensities.

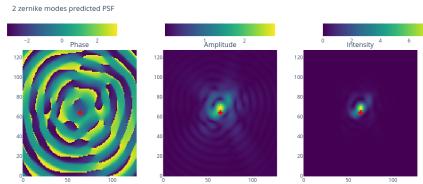


Figure 23: Example original sized predicted 20 modes PSF

- **Cropped sized predicted 20 modes PSF:** A dataset of 70000 predicted electric fields stored in 64x64x2 matrices. These cropped predicted PSFs are the outputs of a model trained with the Cropped sized 20 modes PSFs dataset and their corresponding PL intensities (which are the same output intensities from the Original sized 20 modes PSFs dataset).

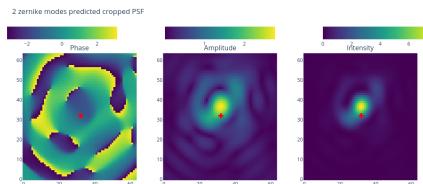


Figure 24: Example cropped sized predicted 20 modes PSF

LP mode coefficients There is one PL intensities dataset per Zernike aberration PSF subgroup: LP modes coefficients for 2, 5, 9, 14, 20 modes PSFs. Each of the dataset has 70000 datapoints each datapoint being the complex coefficients stored in a 19x2 matrix that separates the real and imaginary part of the coefficients.

PL intensities There is one PL intensities dataset per Zernike aberration PSF subgroup: PL intensities for 2, 5, 9, 14, 20 modes PSFs. Each of the dataset has

70000 datapoints each datapoint being the 19 intensities corresponding to the PSF

1.2 The models

For all the datasets a model with the following configuration has been trained. The inputs of the model are the PL intensities and the outputs are the flattened matrices that represent the PSFs' complex fields.

HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:  
-Fully Connected  
-Input shape: 19  
-Output shape: 32768  
-Hidden layers: [1024, 1024, 1024, 1024, 1024, 1024]  
-Regularizer: None  
-Hidden Layers Activation: relu  
-Output Layer Activation: linear  
-Batch Normalization: False  
-Dropout: False, 0.2
```

```
*COMPILATION HYPERPARAMETERS:  
-Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999  
-Loss Function: MSE  
-Metric: MSE
```

```
* TRAINING HYPERPARAMETERS :
-Epochs: 200
-Batch size: 32
-Callbacks:
-ReduceLROnPlateau: MSE 20 x0.1
-Early Stop: MSE 50
```

The exception is the model trained for the Atmospheric Aberration Cropped PSF which has Batch Normalization activated.

1.2.1 Atmospheric aberration related models

Original sized PSF :

```
-Train MSE: 0.004607476759701967
-Validation MSE: 0.056021399796009064
```

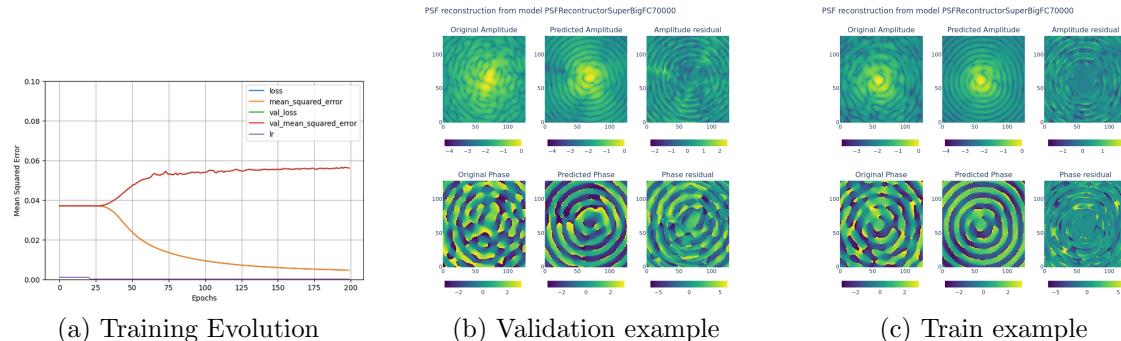


Figure 25: Results of training the model PSFReconstructorSuperBigFC70000-1

Cropped sized PSF :

```
-Train MSE: 0.008466990664601326
-Validation MSE: 0.20970138907432556
```

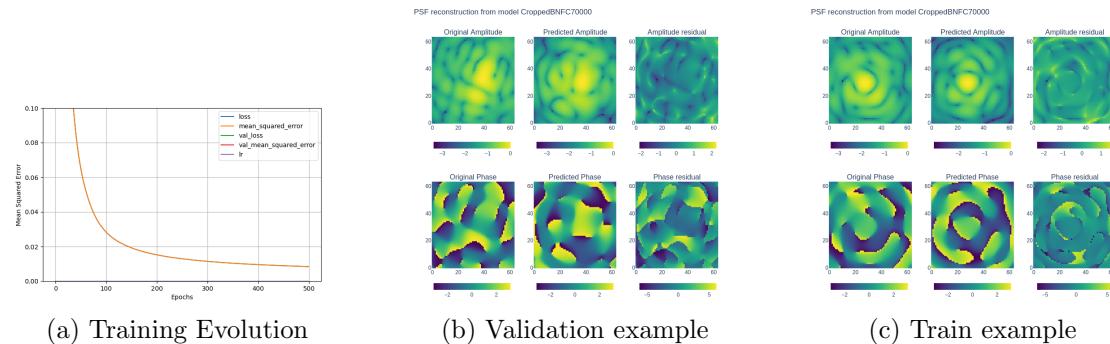


Figure 26: Results of training the model PSFRecontructorSuperBigFC70000-1

1.2.2 Zernike modes related models

Original sized 2 modes PSFs :

```
-Train MSE: 0.0000000895368188480461
-Validation MSE: 0.034455109387636185
```

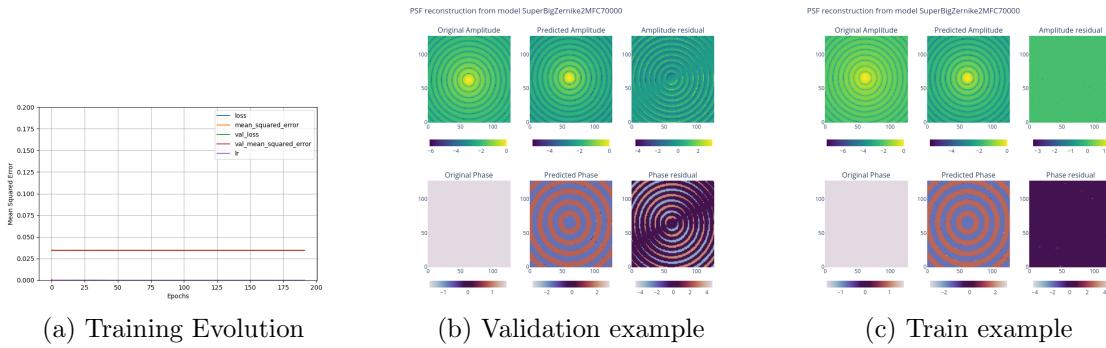


Figure 27: Model training for original sized 2 zernike modes PSFs

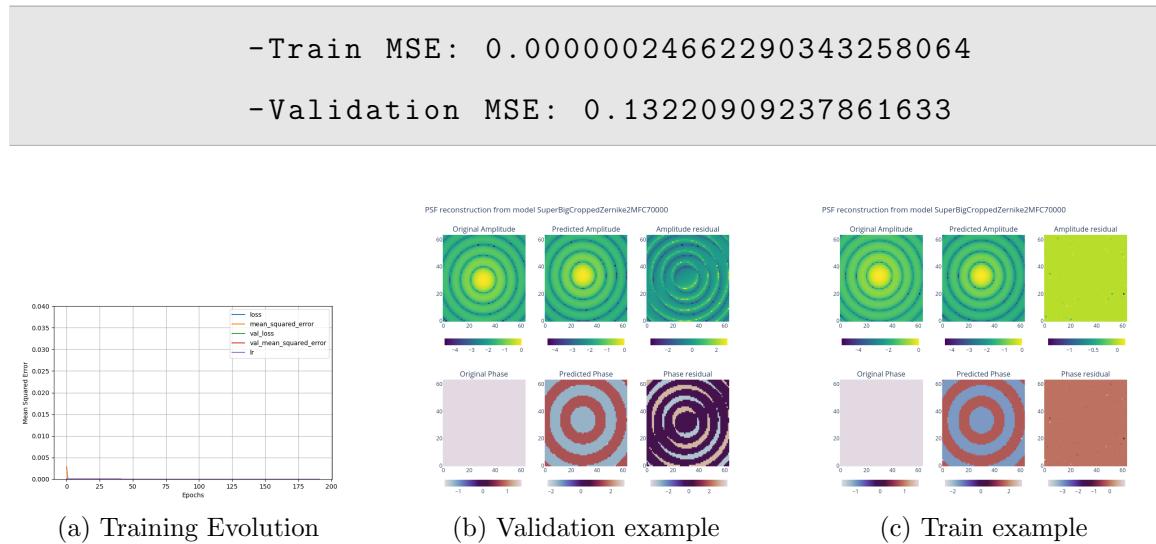
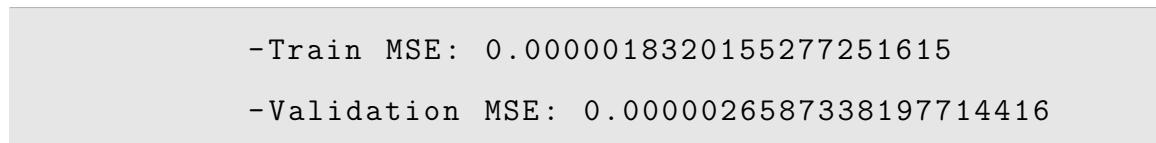
Cropped sized 2 modes PSFs :

Figure 28: Model training for cropped sized 2 zernike modes PSFs

Original sized 5 modes PSFs :

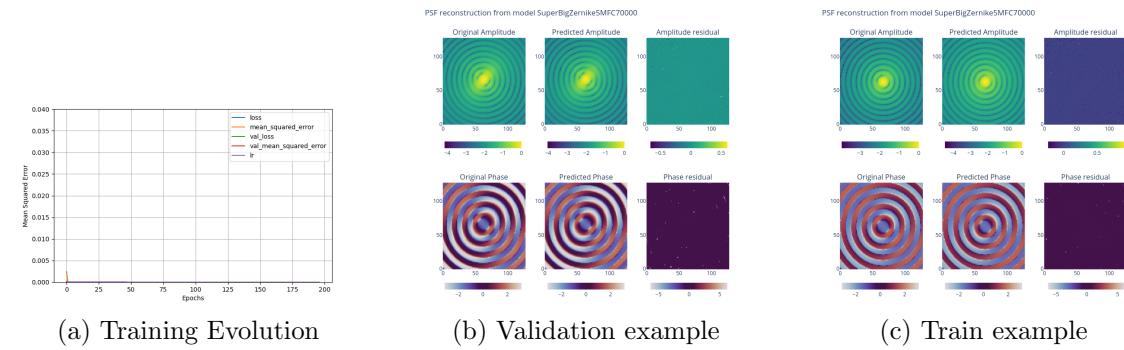


Figure 29: Model training for original sized 5 zernike modes PSFs

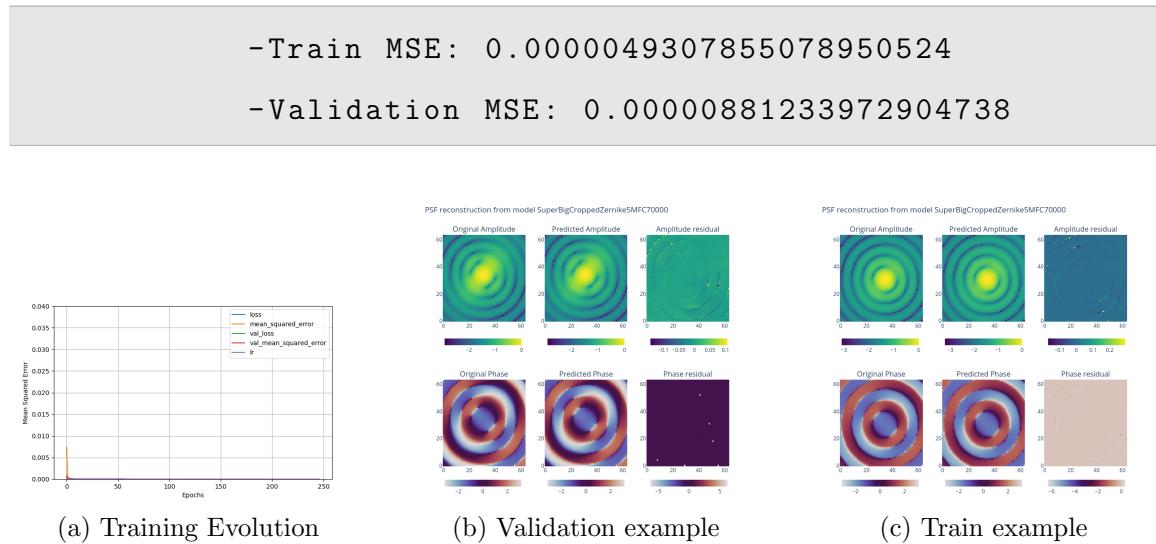
Cropped sized 5 modes PSFs :

Figure 30: Model training for cropped sized 5 zernike modes PSFs

Original sized 9 modes PSFs :

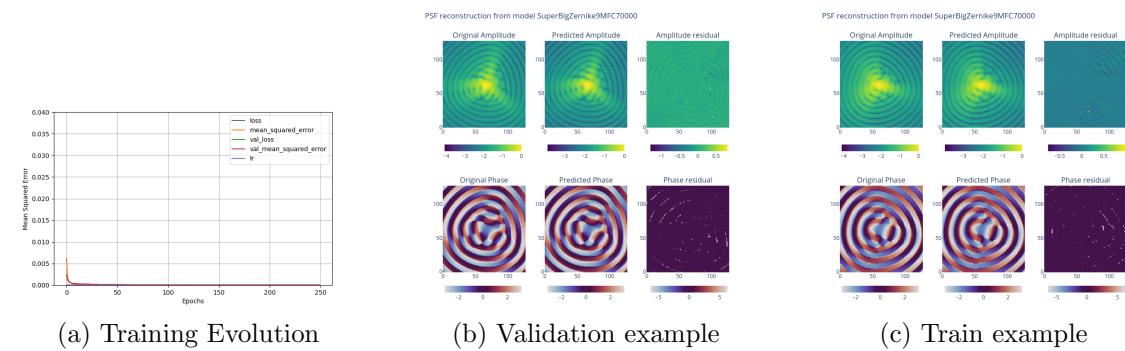


Figure 31: Model training for original sized 9 zernike modes PSFs

Cropped sized 9 modes PSFs :

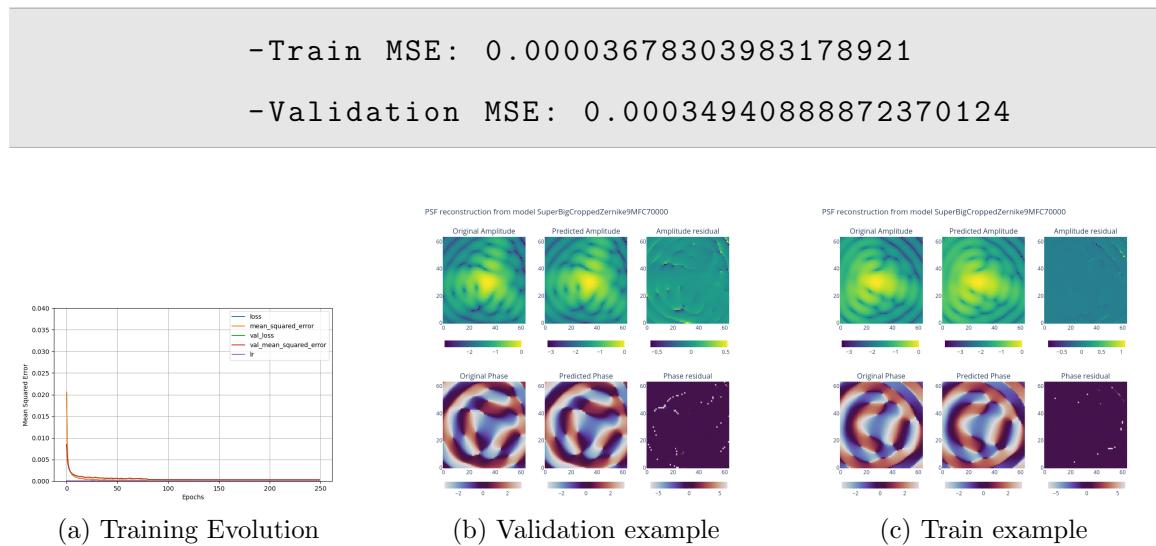


Figure 32: Model training for cropped sized 9 zernike modes PSFs

Original sized 14 modes PSFs :



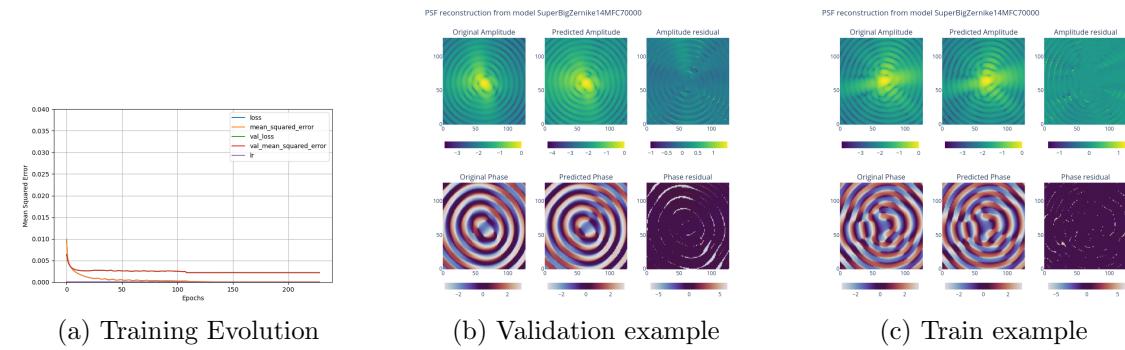


Figure 33: Model training for original sized 14 zernike modes PSFs

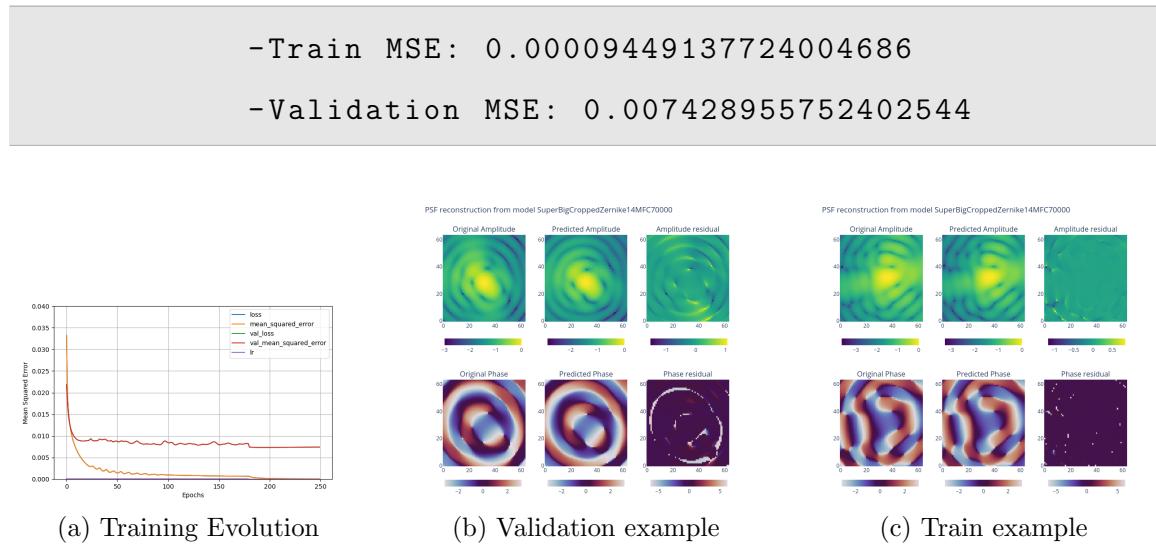
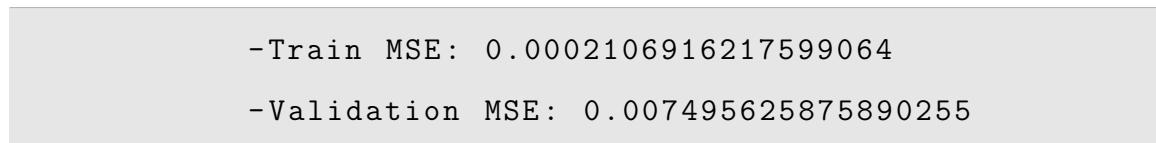
Cropped sized 14 modes PSFs :

Figure 34: Model training for cropped sized 14 zernike modes PSFs

Original sized 20 modes PSFs :

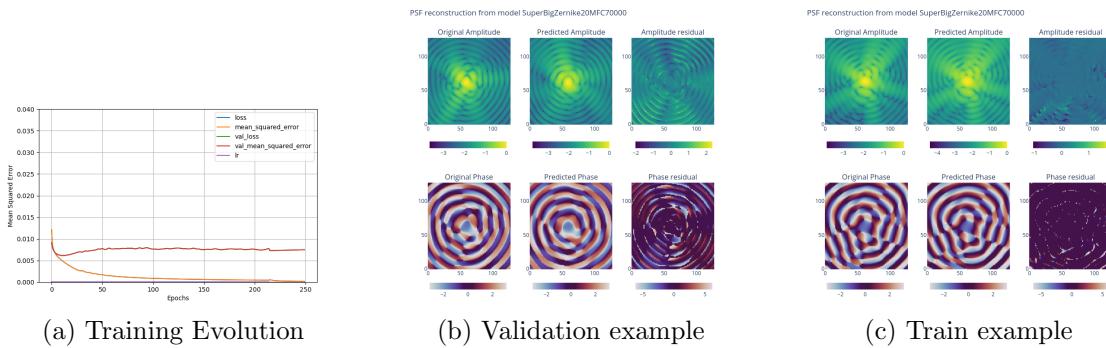


Figure 35: Model training for original sized 20 zernike modes PSFs

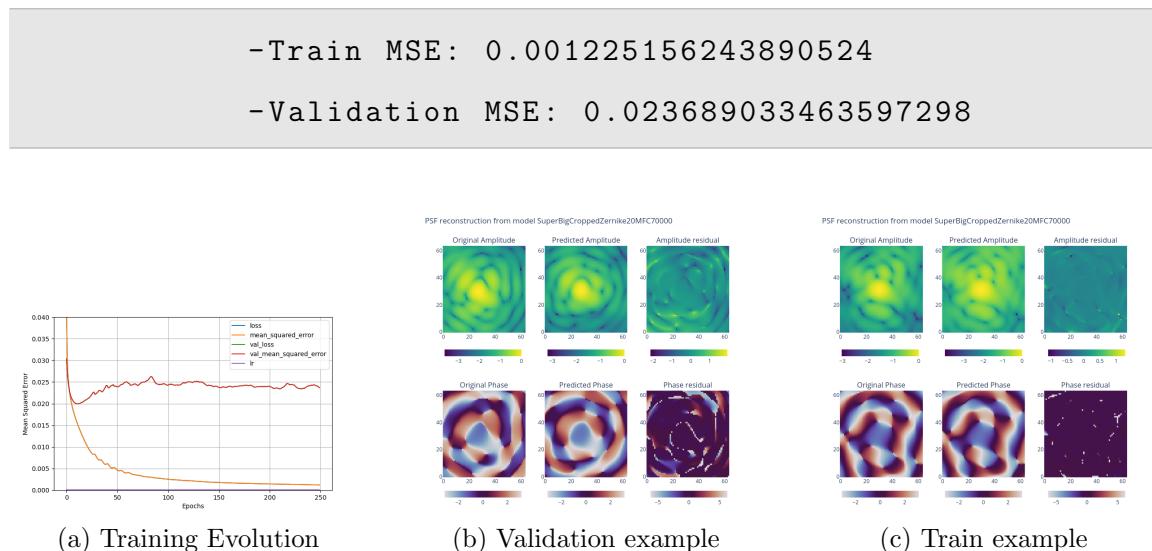
Cropped sized 20 modes PSFs :

Figure 36: Model training for cropped sized 20 zernike modes PSFs

A summary of the MSE evolution over the Zernike PSFs datasets. The fact that the validation MSE for 2 modes is the worse may be because the neural network is not able to understand traslations.



Figure 37: MSE evolution over the Zernike PSFs datasets