

# Lab Notebook

## Pupil Reconstruction

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# 1 Amplitude and Phase Reconstruction

16 February 2024

- Create new github branch: `AmpPhaseReconstructionRetraining`
  - Download the following the files from Morgana:
    - `superK_slmcube_20230625_complsines-01sp_07`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file00`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file01`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file02`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file03`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file04`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file05`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file06`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file07`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file08`
    - `slmcube_20230625_complsines-01sp_07_PSFWFs_file09`
  - Data processing for Fully Convolutional NN training
  - One fast experiment for each file: very good results, around 0.05 validation mse
-

**19 February 2024**

- Remove normalization from amplitude and phase for the fully connected experiments

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## **EXPERIMENT NewFC10000-Processed 2**

HYPERPARAMETERS:

**\*ARCHITECTURE HYPERPARAMETERS:**

- Fully Connected
- Input shape: 1320
- Output shape: (2, 96, 96)
- Hidden layers: [2000, 2000, 2000, 2000]
- Regularizer: None
- Hidden Layers Activation: relu
- Output Layer Activation: linear
- Batch Normalization: False
- Dropout: False, 0.2

**\*COMPILE 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: 64
- Callbacks:
  - ReduceLROnPlateau: MSE 10 x0.1
  - Early Stop: MSE 25

**VISUALIZATION:****\*RESULTS :**

- Train MSE: 0.035130929201841354
- Validation MSE: 0.0786573588848114

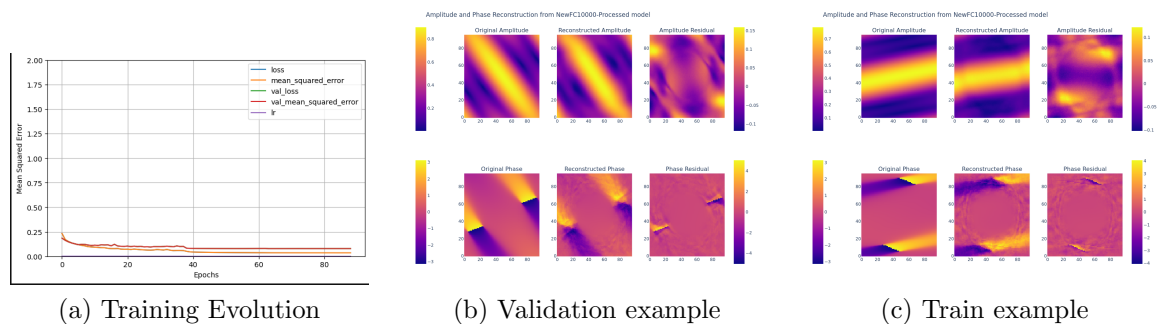


Figure 1: Results of training the model NewFC10000-Processed 2

**EXPERIMENT NewFC30000-Processed-1**

## HYPERPARAMETERS:

**\*ARCHITECTURE HYPERPARAMETERS:**

- Fully Connected
- Input shape: 1320
- Output shape: (2, 96, 96)
- Hidden layers: [2000, 2000, 2000, 2000]
- Regularizer: None
- Hidden Layers Activation: relu
- Output Layer Activation: linear
- Batch Normalization: False
- Dropout: False, 0.2

**\*COMPILE 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: 64
- Callbacks:
  - ReduceLROnPlateau: MSE 10 x0.1
  - Early Stop: MSE 25

## VISUALIZATION:

**\*RESULTS :**

-Train MSE: 0.0357743538916111

-Validation MSE: 0.057852283120155334

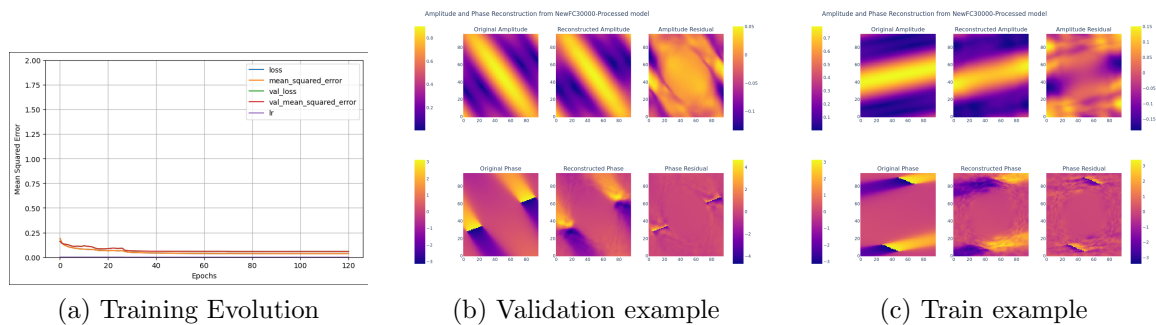


Figure 2: Results of training the model NewFC30000-Processed-1

**EXPERIMENT NewFC80000-Processed-1**

## HYPERPARAMETERS:

**\*ARCHITECTURE HYPERPARAMETERS :**

- Fully Connected
- Input shape: 1320
- Output shape: (2, 96, 96)
- Hidden layers: [2000, 2000, 2000, 2000]
- 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: 64
```

```
-Callbacks:
```

```
-ReduceLROnPlateau: MSE 10 x0.1
```

```
-Early Stop: MSE 25
```

## VISUALIZATION:

```
*RESULTS:
```

```
-Train MSE: 0.03301804140210152
```

```
-Validation MSE: 0.04487497732043266
```



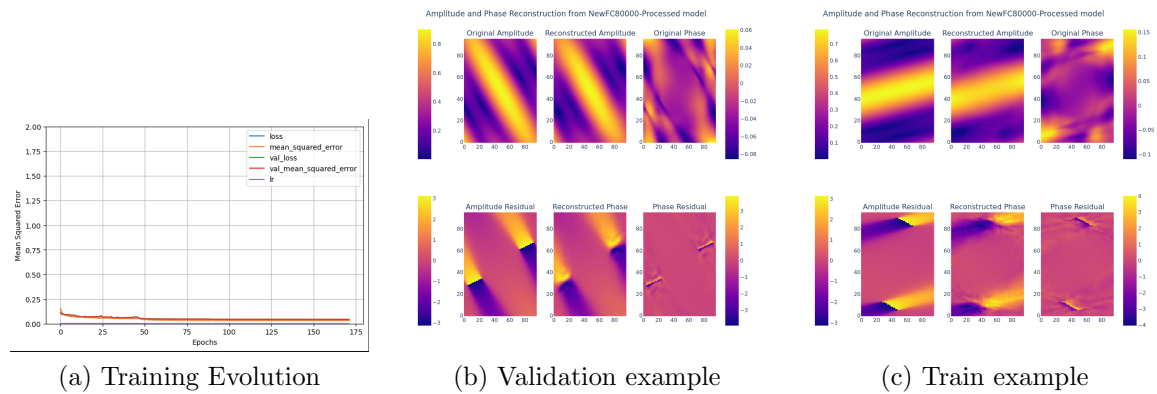


Figure 3: Results of training the model NewFC80000-Processed-1

- Normalize and split fluxes in train, validation and test files
- Stack amplitude and phase arrays and save in train, validation and test files

## EXPERIMENT NewConv10000-1

HYPERPARAMETERS:

\*ARCHITECTURE HYPERPARAMETERS :

-Convolutional

-Input shape: (55, 24, 1)

-Output shape: (96, 96, 2)

-Convolutional Layers: [128, 256, 512]

-Convolutonal Kernels: [(3, 3), (3, 3), (3, 3)]

```
-Fully Connected Hidden layers: [4096, 2048, 2048, 1024, 1024, 1024]
-Regularizer: None
-Convolutional Activation: relu
-Hidden Layers Activation: relu
-Output Layer Activation: linear
-Batch Normalization: True
```

**\*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 15 x0.1
  -Early Stop: MSE 50
```

**VISUALIZATION:**

**\*RESULTS:**

```
-Train MSE: 0.031087761744856834
-Validation MSE: 0.09376049041748047
```

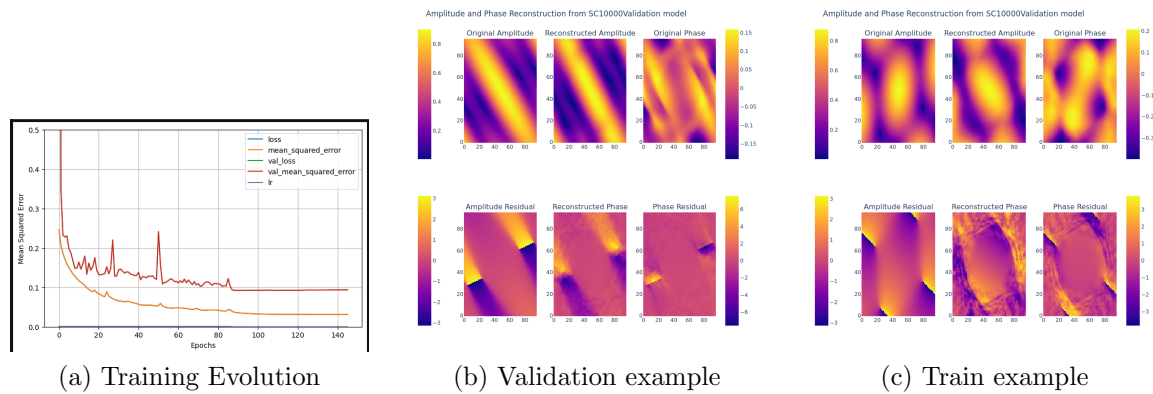


Figure 4: Results of training the model NewConv10000-1

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## EXPERIMENT NewConv30000-1

HYPERPARAMETERS:

\*ARCHITECTURE HYPERPARAMETERS:

- Convolutional
- Input shape: (55, 24, 1)
- Output shape: (96, 96, 2)
- Convolutional Layers: [128, 256, 512]
- Convolutonal Kernels: [(3, 3), (3, 3), (3, 3)]

```
-Fully Connected Hidden layers: [4096, 2048, 2048, 1024, 1024, 1024]
-Regularizer: None
-Convolutional Activation: relu
-Hidden Layers Activation: relu
-Output Layer Activation: linear
-Batch Normalization: True
```

**\*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 15 x0.1
  -Early Stop: MSE 50
```

**VISUALIZATION:**

**\*RESULTS:**

```
-Train MSE: 0.03819489851593971
-Validation MSE: 0.06443119794130325
```

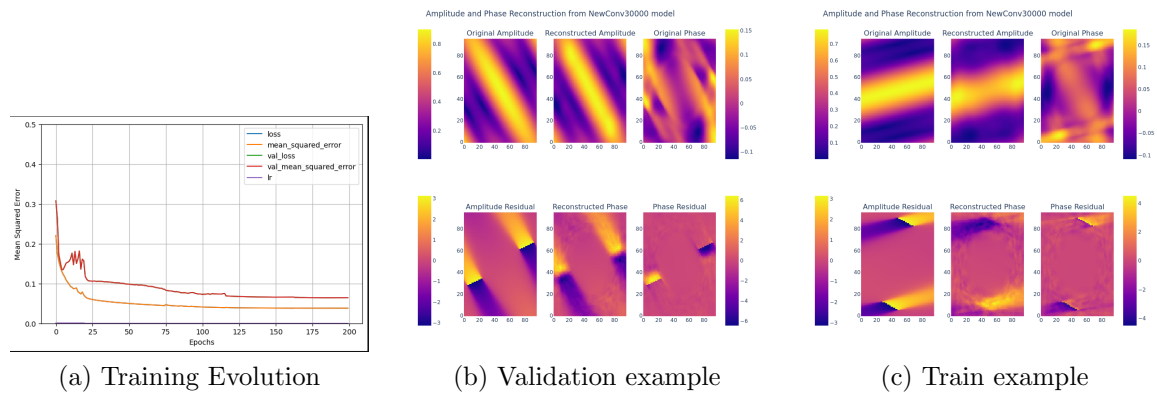


Figure 5: Results of training the model NewConv30000-1

## EXPERIMENT NewConv30000-1

### HYPERPARAMETERS:

#### \*ARCHITECTURE HYPERPARAMETERS:

-Convolutional

-Input shape: (55, 24, 1)

-Output shape: (96, 96, 2)

-Convolutional Layers: [128, 256, 512]

-Convolutonal Kernels: [(3, 3), (3, 3), (3, 3)]

-Fully Connected Hidden layers: [4096, 2048, 2048, 1024, 1024, 1024]

-Regularizer: None

-Convolutional Activation: relu

-Hidden Layers Activation: relu

```
-Output Layer Activation: linear
-Batch Normalization: True

*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 15 x0.1
    -Early Stop: MSE 50
```

#### VISUALIZATION:

```
*RESULTS:
  -Train MSE: 0.030630357563495636
  -Validation MSE: 0.08355200290679932
```

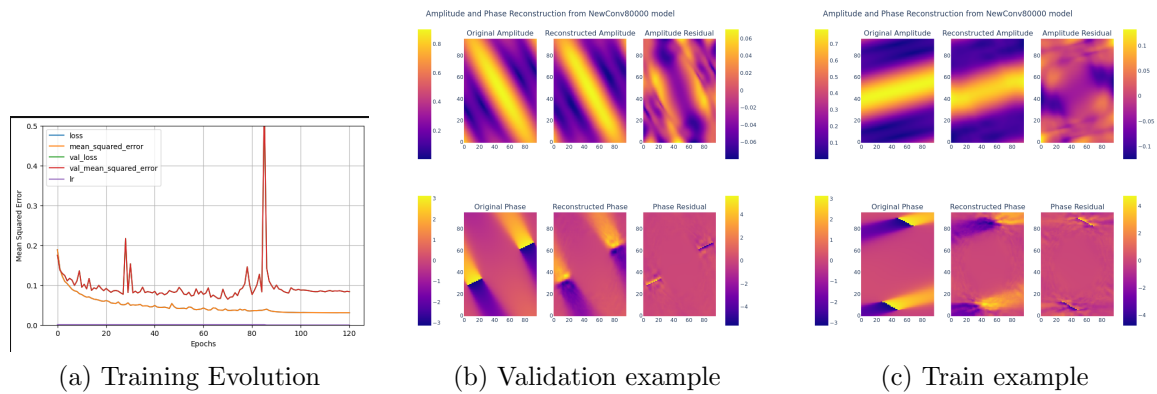


Figure 6: Results of training the model NewConv80000-1

- Normalize flux data and add padding for flux autoencoder
- Stack amplitude and phase and add padding for encoder+convolutional model

## EXPERIMENT NewFluxAutoencoder10000-1

HYPERPARAMETERS:

\*ARCHITECTURE HYPERPARAMETERS :

-Autoencoder

-Input shape: (56, 24, 1)

-Convolutional Layers: [512, 128, 64, 8]

(Inverse in the decoder)

-Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]

```
(Inverse in the decoder)

-Convolucional Activation: relu
-Output Layer Activation: linear
-Padding: same
-Use Batch Normalization: True

*COMPILATION HYPERPARAMETERS:

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

*TRAINING HYPERPARAMETERS:

-Epochs: 75
-Batch size: 32
-Callbacks:
  -ReduceLROnPlateau: MSE 8 x0.1
  -Early Stop: MSE 15
```

#### VISUALIZATION:

```
*RESULTS:

-Train MSE: 0.0018673702143132687
-Validation MSE: 0.005482238717377186
```



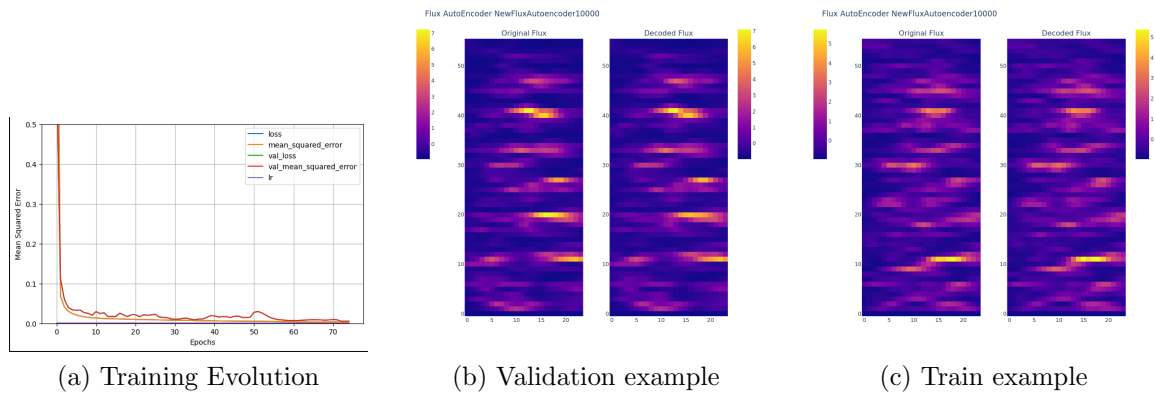


Figure 7: Results of training the model NewFluxAutoencoder10000-1

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## EXPERIMENT NewFluxAutoencoder80000-1

HYPERPARAMETERS:

\*ARCHITECTURE HYPERPARAMETERS :

-Autoencoder

-Input shape: (56, 24, 1)

-Convolutional Layers: [512, 128, 64, 8]

(Inverse in the decoder)

```
-Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]
```

```
(Inverse in the decoder)
```

```
-Convolutional Activation: relu
```

```
-Output Layer Activation: linear
```

```
-Padding: same
```

```
-Use Batch Normalization: True
```

```
*COMPILATION HYPERPARAMETERS:
```

```
-Optimizer: ADAM lr=0.001, beta_1=0.9, beta_2=0.999
```

```
-Loss Function: MSE
```

```
-Metric: MSE
```

```
*TRAINING HYPERPARAMETERS:
```

```
-Epochs: 75
```

```
-Batch size: 32
```

```
-Callbacks:
```

```
-ReduceLROnPlateau: MSE 8 x0.1
```

```
-Early Stop: MSE 15
```

## VISUALIZATION:

```
-Train MSE: 0.024667566642165184
```

```
-Validation MSE: 0.0158506091684103
```

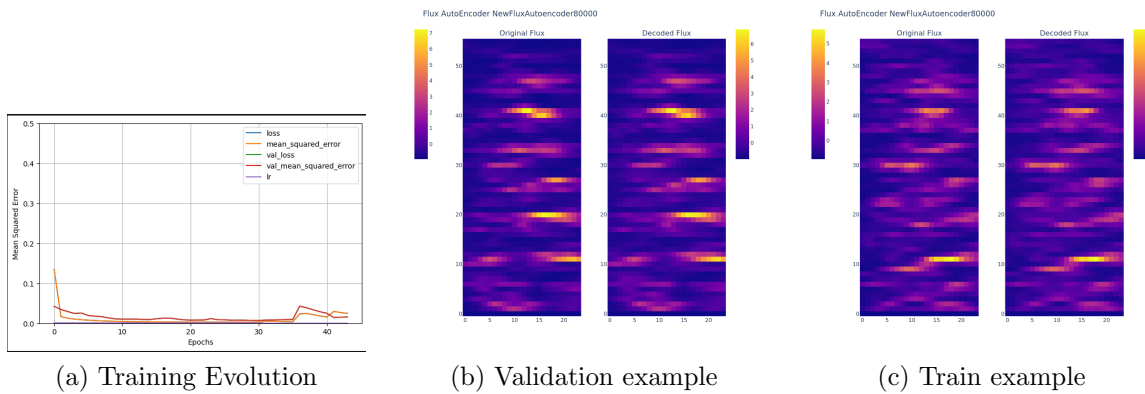


Figure 8: Results of training the model NewFluxAutoencoder10000-1

## EXPERIMENT NewEncConv10000-1

### HYPERPARAMETERS:

#### \*ARCHITECTURE HYPERPARAMETERS:

- Encoder + Convolutional
- Convolutional Layers: [1024, 512, 256, 256]
- Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]
- Convolutional Activation: relu
- Output Layer Activation: linear

#### \*COMPILE HYPERPARAMETERS:

- Optimizer: ADAM lr=0.0001, beta\_1=0.9, beta\_2=0.999
- Loss Function: MSE

-Metric: MSE

\* TRAINING HYPERPARAMETERS:

-Epochs: 100

-Batch size: 32

-Callbacks:

-ReduceLROnPlateau: MSE 8 x0.1

-Early Stop: MSE 15

VISUALIZATION:

\*RESULTS:

-Train MSE: 0.011328332126140594

-Validation MSE: 0.06024651601910591

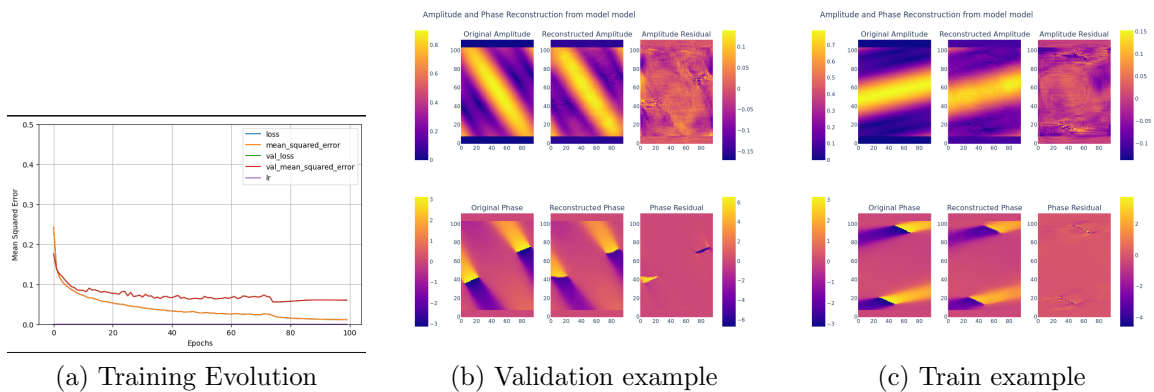


Figure 9: Results of training the model NewEncConv10000-1

## EXPERIMENT NewEncConv30000-1

### HYPERPARAMETERS:

```
*ARCHITECTURE HYPERPARAMETERS:
  -Encoder + Convolutional
  -Convolutional Layers: [1024, 512, 256, 256]
  -Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]
  -Convolutional Activation: relu
  -Output Layer Activation: linear

*COMPILE HYPERPARAMETERS:
  -Optimizer: ADAM lr=0.0001, beta_1=0.9, beta_2=0.999
  -Loss Function: MSE
  -Metric: MSE

* TRAINING HYPERPARAMETERS:
  -Epochs: 100
  -Batch size: 32
  -Callbacks:
    -ReduceLROnPlateau: MSE 8 x0.1
    -Early Stop: MSE 15
```

### VISUALIZATION:

```
*RESULTS:
  -Train MSE: 0.016221819445490837
```

-Validation MSE: 0.05662507936358452

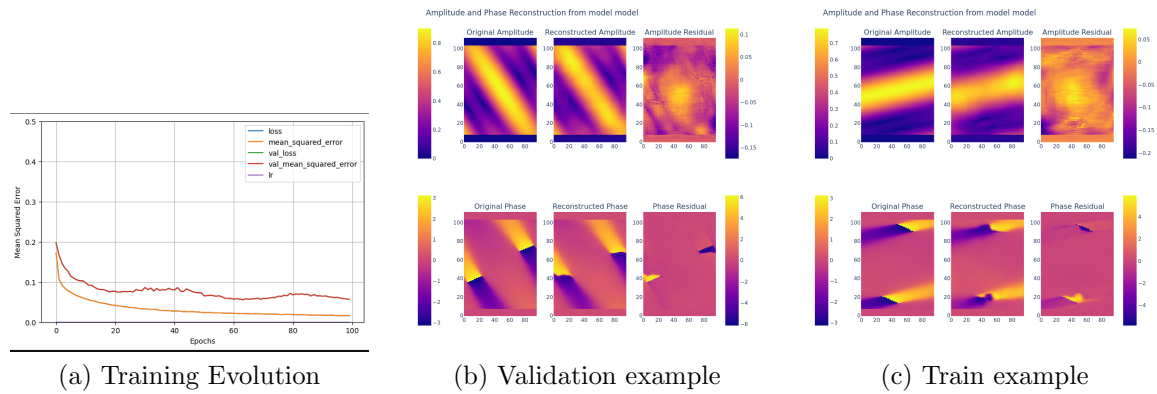


Figure 10: Results of training the model NewEncConv30000-1

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## EXPERIMENT NewEncConv80000-1

HYPERPARAMETERS:

\*ARCHITECTURE HYPERPARAMETERS:

-Encoder + Convolutional

-Convolutional Layers: [1024, 512, 256, 256]

```
-Convolutonal Kernels: [(3, 3), (3, 3), (3, 3), (3, 3)]  
-Convolutional Activation: relu  
-Output Layer Activation: linear
```

**\*COMPILATION HYPERPARAMETERS:**

```
-Optimizer: ADAM lr=0.0001, beta_1=0.9, beta_2=0.999  
-Loss Function: MSE  
-Metric: MSE
```

**\* TRAINING HYPERPARAMETERS:**

```
-Epochs: 100  
-Batch size: 32  
-Callbacks:  
  -ReduceLROnPlateau: MSE 8 x0.1  
  -Early Stop: MSE 15
```

**VISUALIZATION:**

**\*RESULTS:**

```
-Train MSE: 0.0163  
-Validation MSE: 0.0369
```

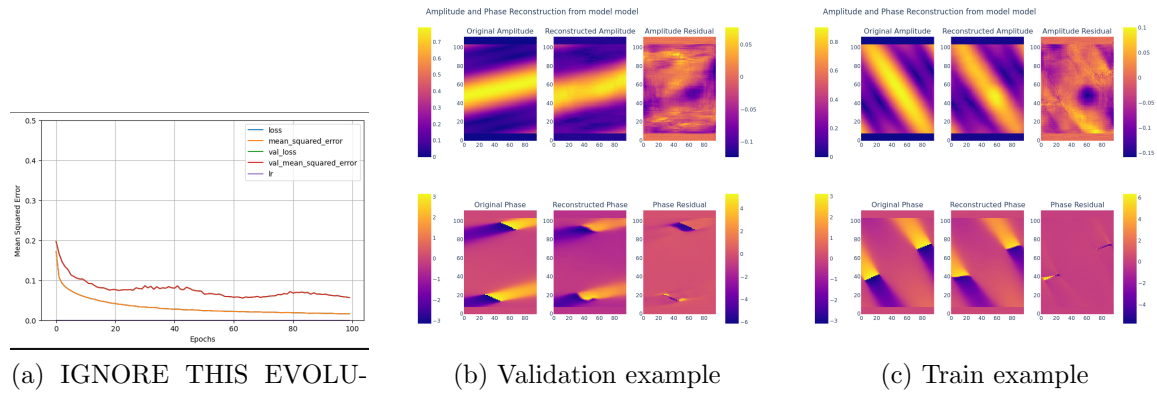


Figure 11: Results of training the model NewEncConv80000-1

## 2 PSF Reconstruction

20 February 2024

- Create custom dynamic dataloader for PL output flux and PSF complex field for PSF reconstruction



**26 February 2024**

- Create a dataloader to dynamically load flux and psf
  - Normalize electric fields, real and imaginary parts independently
  - Normalize PL output fluxes
  - Train a fully connected nn with horrible results, train mse keeps stable at 1, will have to look at the data
- 

**27 February 2024**

- Create plotting functions to show amplitude, phase and intensity from an electric field
  - Normalize electric field, this time dividing the complex number matrix by a constant (50.000 in this case)
  - Redo output flux calculation with the normalized electric fields through the transfer matrix of the 19 fibre PL
-

28 February 2024

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## EXPERIMENT PSF-FC-Reconstructor-1

HYPERPARAMETERS:

**\*ARCHITECTURE HYPERPARAMETERS:**

- Fully Connected
- Input shape: 19
- Output shape: 32768
- Hidden layers: [2000, 2000, 2000, 2000]
- Regularizer: None
- Hidden Layers Activation: relu
- Output Layer Activation: linear
- Batch Normalization: False
- Dropout: False, 0.2

**\*COMPILE 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: 64

-Callbacks:

-ReduceLROnPlateau: MSE 10 x0.1

-Early Stop: MSE 25

```

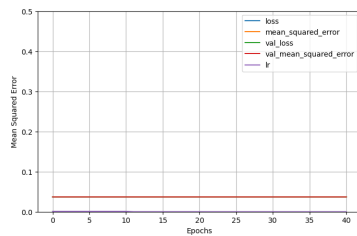
### VISUALIZATION:

```

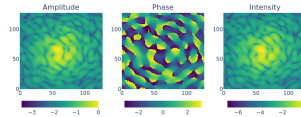
-Train MSE: 0.03701553866267204

-Validation MSE: 0.03701810911297798

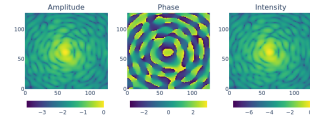
```



(a) Training Evolution



(b) Validation prediction



(c) Validation original

Figure 12: Results of training the model PSF-FC-Reconstructor-1

## 29 February 2024

- Create a function to plot amplitude and phase predictions and residuals from a complex field
- Create evaluation notebook
- Since in yesterday's experiment the model does not learn at all, I design two different experiments, to check if there is a problem with the network:

1. A model that sums the output flux of the PL
  2. A model that sums the scalars of the complex numbers array containing the electric fields at the pupil.
- 

## EXPERIMENT Flux-Sum-1

This model performs a sum of all the output fluxes from the PL

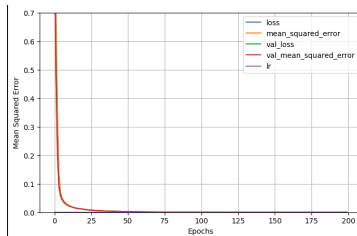
HYPERPARAMETERS:

**\*ARCHITECTURE HYPERPARAMETERS :**

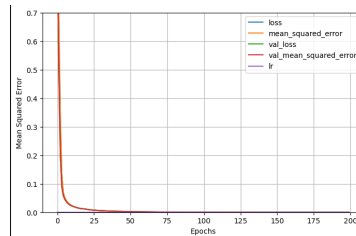
- Fully Connected
- Input shape: 19
- Output shape: 1
- Hidden layers: [100, 100]
- Regularizer: None
- Hidden Layers Activation: relu
- Output Layer Activation: linear
- Batch Normalization: False
- Dropout: False, 0.2

**\*COMPILE HYPERPARAMETERS :**

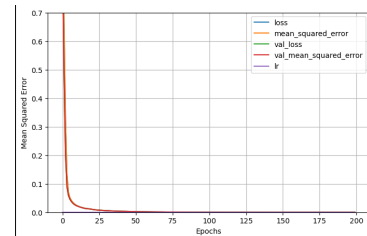
- Optimizer: ADAM lr=0.0001, beta\_1=0.9, beta\_2=0.999
- Loss Function: MSE
- Metric: MSE

**\*TRAINING HYPERPARAMETERS :****-Epochs: 200****-Batch size: 64****-Callbacks :****-ReduceLROnPlateau: MSE 10 x0.1****-Early Stop: MSE 25****VISUALIZATION:****\*RESULTS :****-Train MSE: 0.00018273142632097006****-Validation MSE: 0.00018727070710156113**

(a) Training Evolution



(b) Training Evolution



(c) Training Evolution

Figure 13: Results of training the model Flux-Sum-1

**EXPERIMENT ElectricField-Sum-1**

This model performs a sum of all the output fluxes from the PL

## HYPERPARAMETERS:

**\*ARCHITECTURE HYPERPARAMETERS:**

- Fully Connected
- Input shape: 32768
- Output shape: 1
- Hidden layers: [100, 100, 100]
- Regularizer: None
- Hidden Layers Activation: relu
- Output Layer Activation: linear
- Batch Normalization: False
- Dropout: False, 0.2

**\*COMPILE HYPERPARAMETERS:**

- Optimizer: ADAM lr=0.0001, beta\_1=0.9, beta\_2=0.999
- Loss Function: MSE
- Metric: MSE

**\*TRAINING HYPERPARAMETERS:**

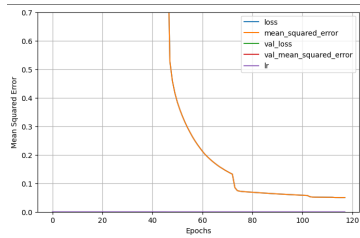
- Epochs: 200
- Batch size: 64
- Callbacks:
  - ReduceLROnPlateau: MSE 10 x0.1
  - Early Stop: MSE 25

## VISUALIZATION:

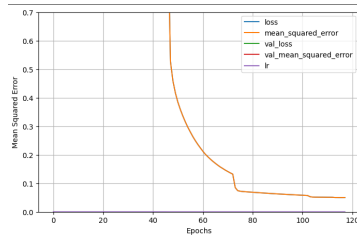
**\*RESULTS :**

-Train MSE: 0.050156451761722565

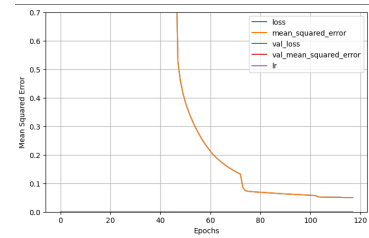
-Validation MSE: 0.8189939856529236



(a) Training Evolution



(b) Training Evolution



(c) Training Evolution

Figure 14: Results of training the model ElectricField-Sum-1

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**01 May 2024**

- Today I decide to train a model with just one datapoint and see if is able to learn the PSF from one flux and one electric field
- 

**EXPERIMENT TestWith1DataPoint-1**

HYPERPARAMETERS:

**\*ARCHITECTURE HYPERPARAMETERS :**

```
-Fully Connected
-Input shape: 19
-Output shape: 32768
-Hidden layers: [1000, 1000, 1000, 1000]
-Regularizer: None
-Hidden Layers Activation: relu
-Output Layer Activation: linear
-Batch Normalization: False
-Dropout: False, 0.2

*COMPILATION HYPERPARAMETERS:
-Optimizer: ADAM lr=0.01, beta_1=0.9, beta_2=0.999
-Loss Function: MSE
-Metric: MSE

*TRAINING HYPERPARAMETERS:
-Epochs: 1000
-Batch size: 64
-Callbacks:
-ReduceLROnPlateau: MSE 10 x0.1
-Early Stop: MSE 25
```

#### VISUALIZATION:

```
-Train MSE: 0.03701553866267204
-Validation MSE: 0.03701810911297798
```



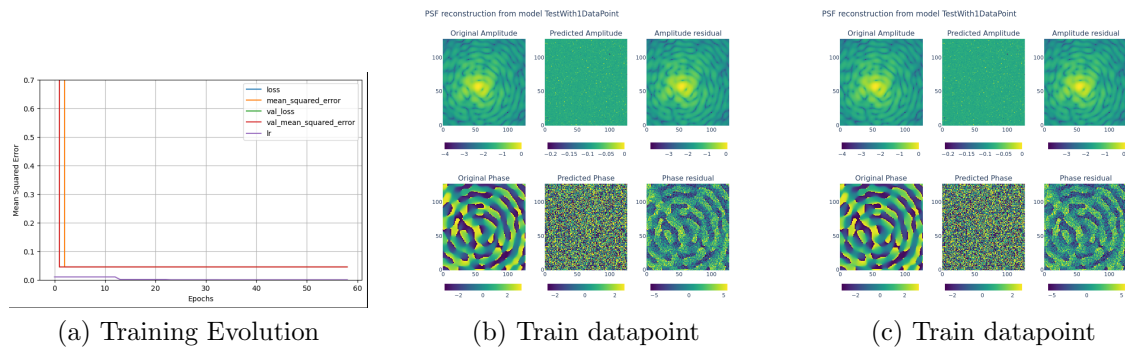


Figure 15: Results of training the model TestWith1DataPoint-1