

# Beam Spot Position Modeling via Machine Learning

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Nadezhda Dimitrova

Group: Rana Adhikari

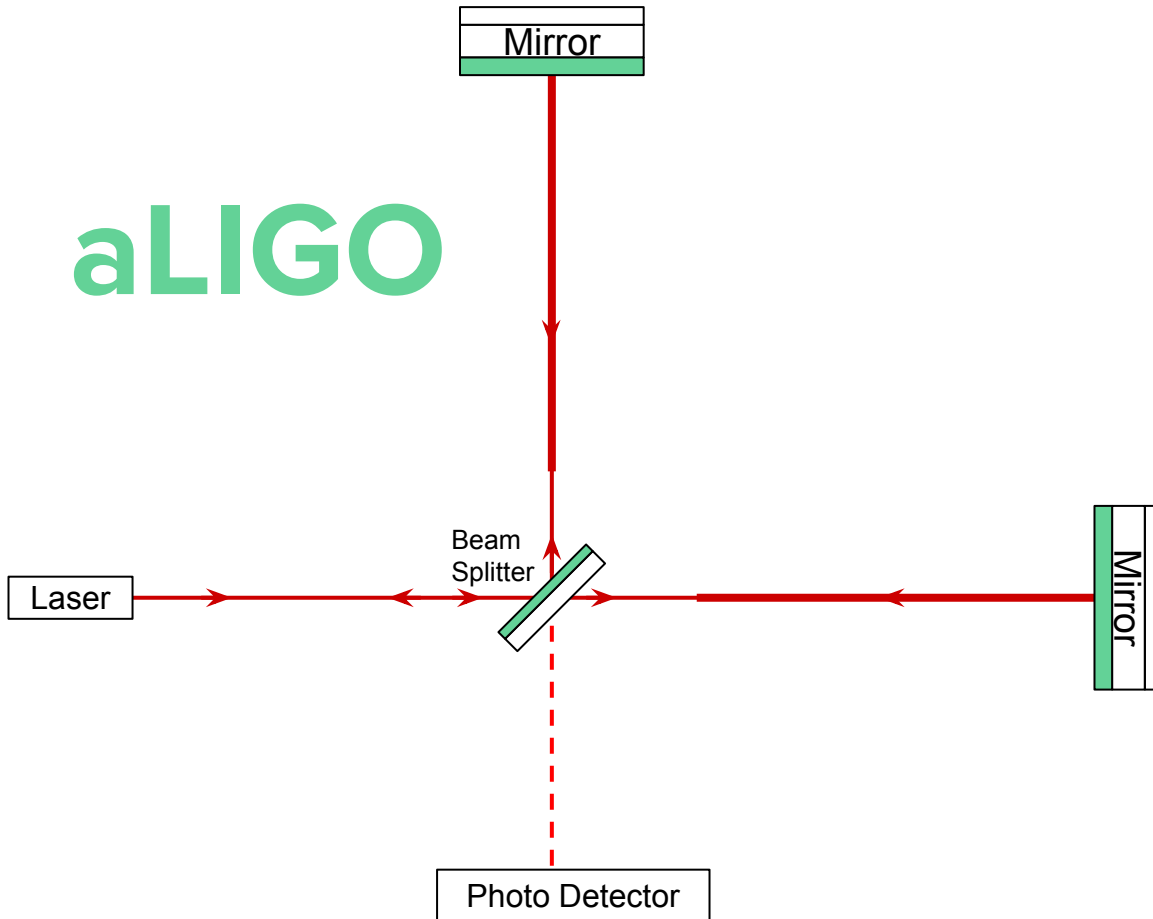
Mentor: Hang Yu



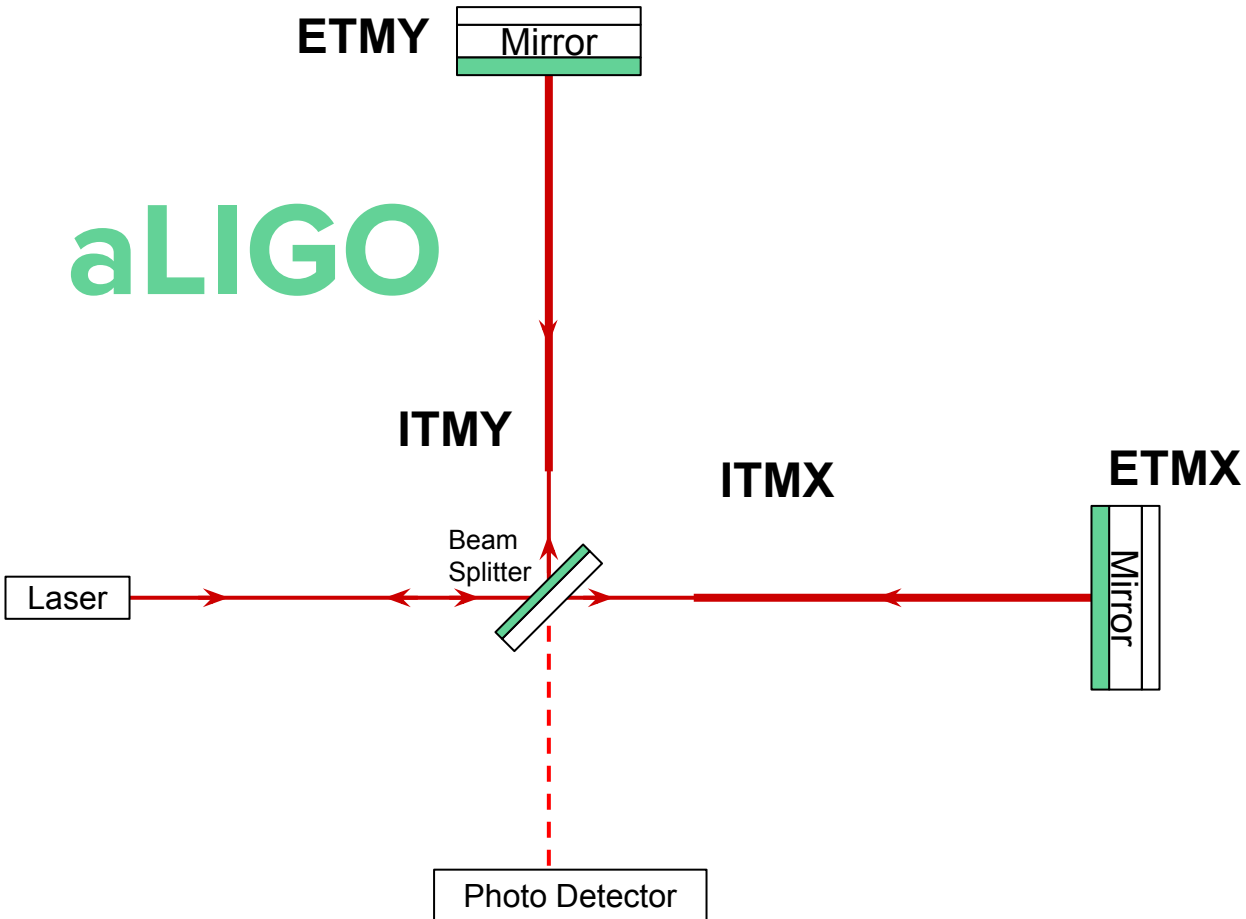
**LIGO**



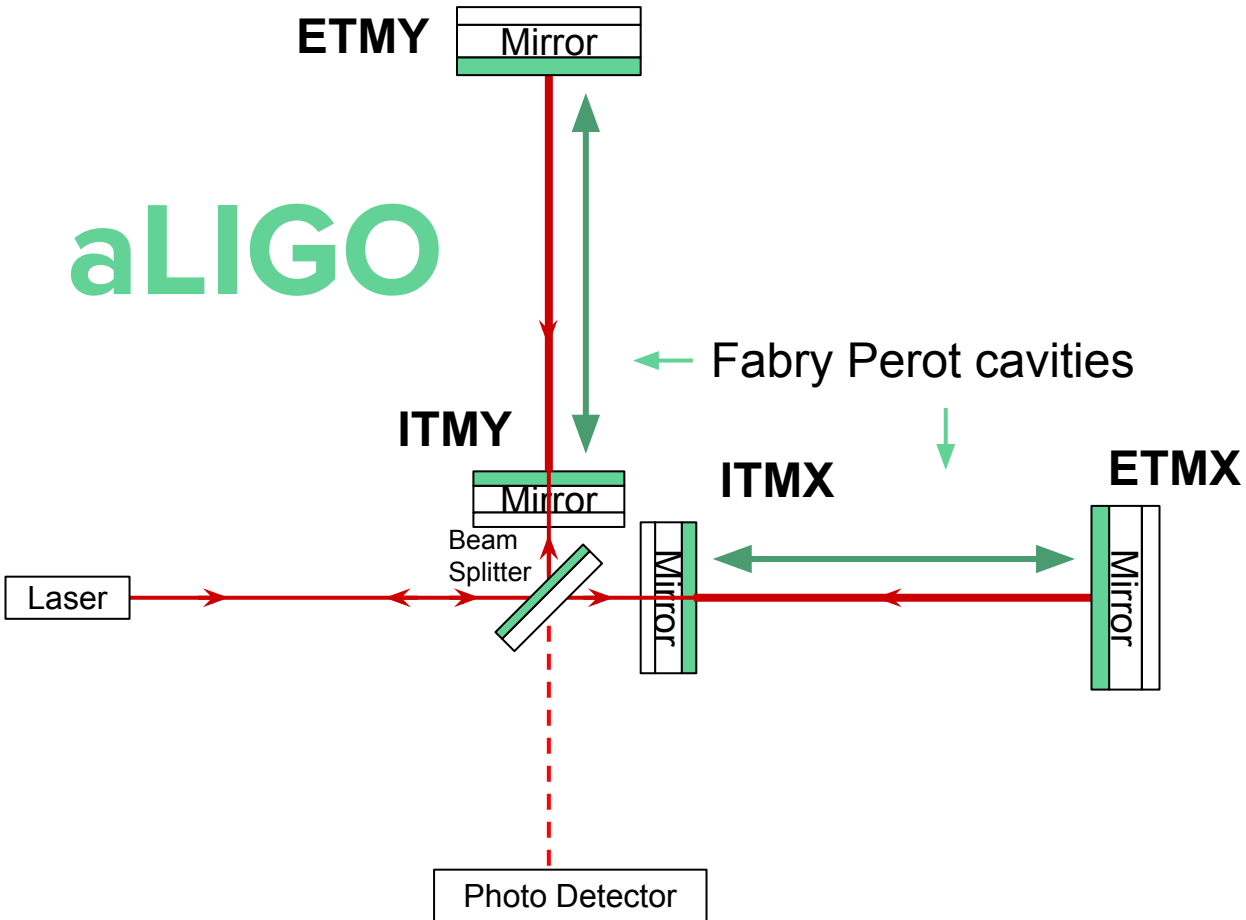
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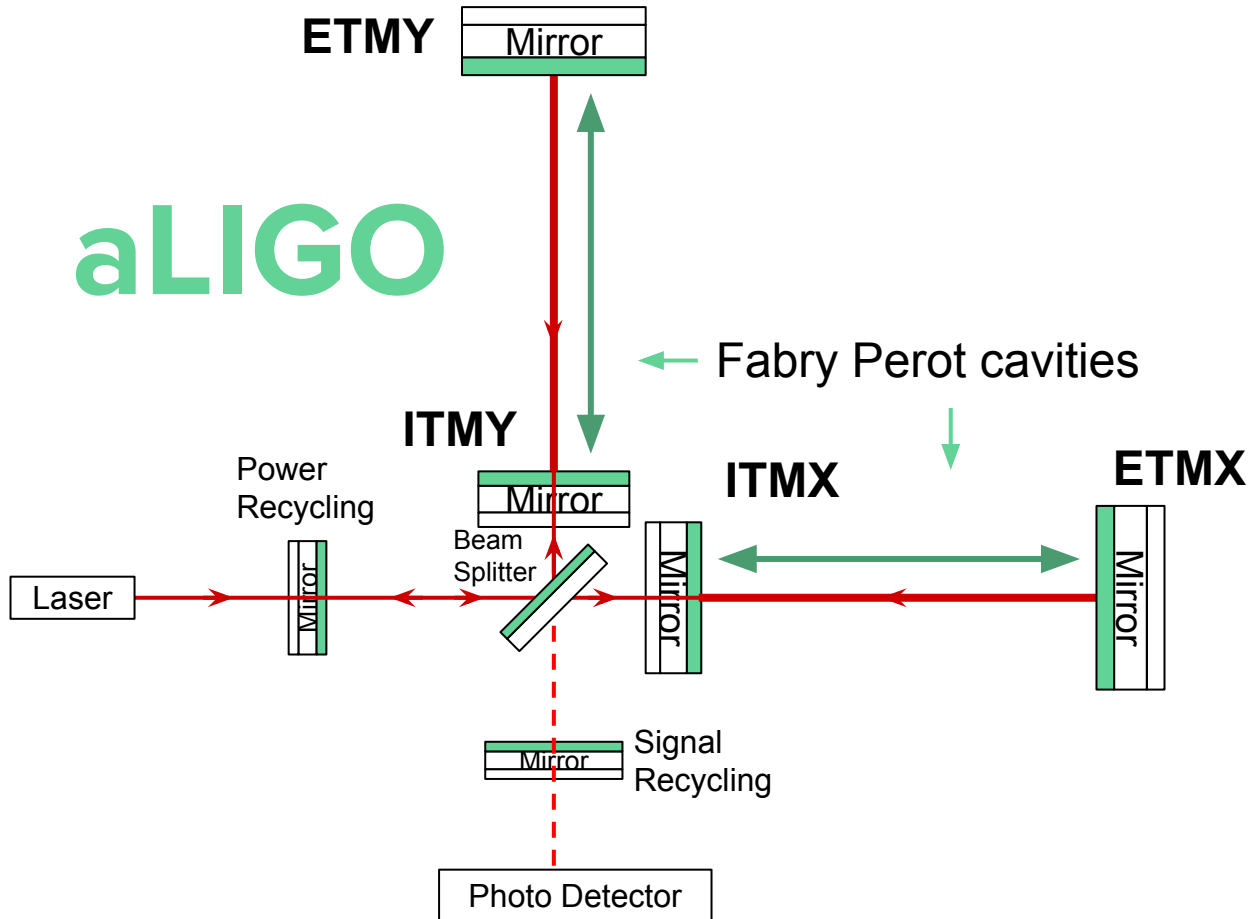
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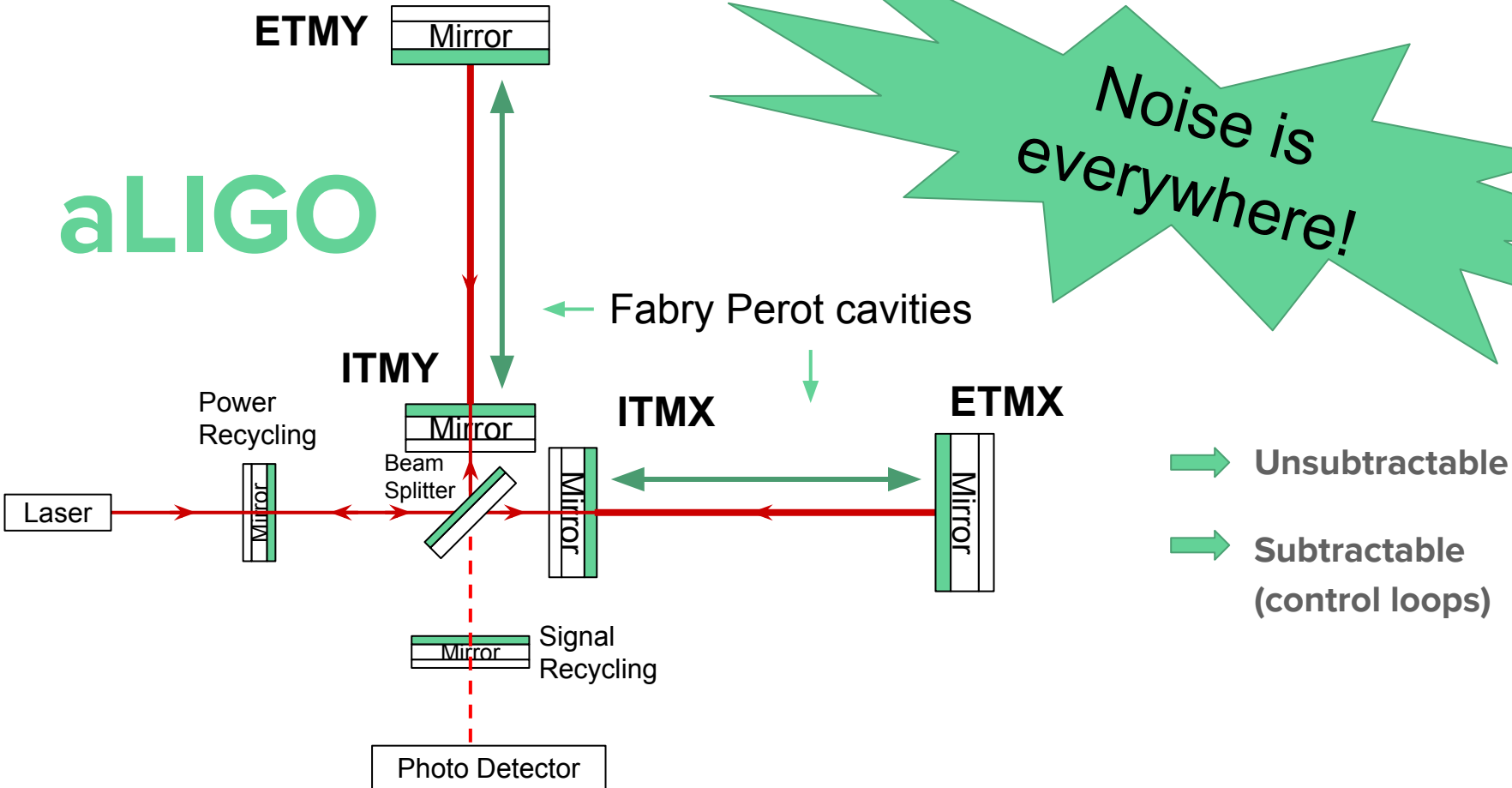
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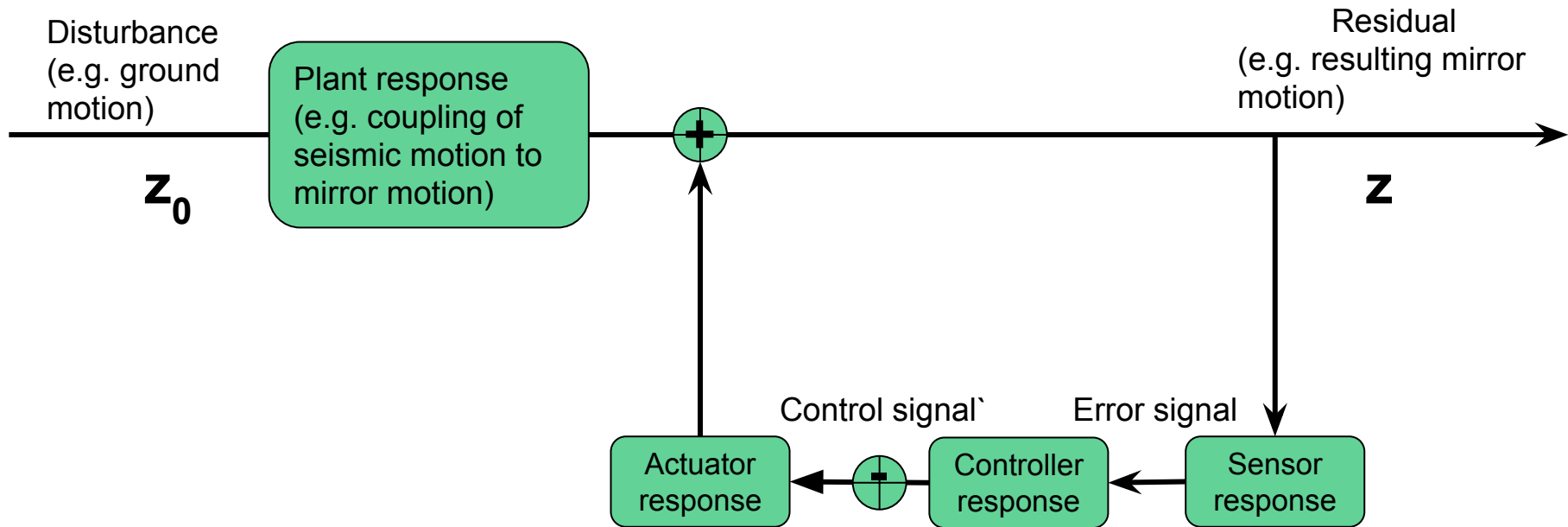


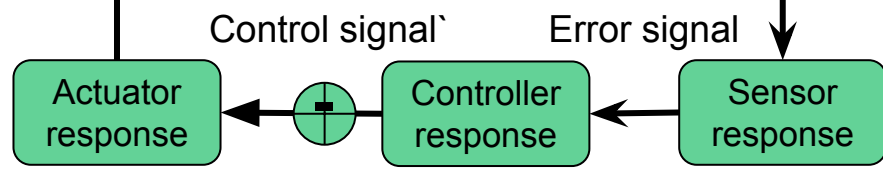
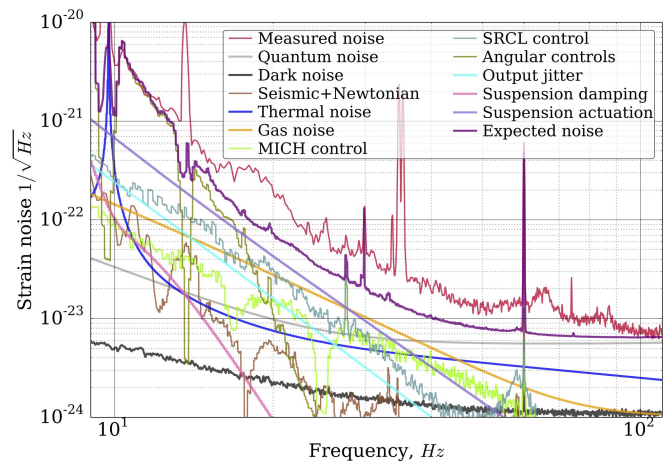
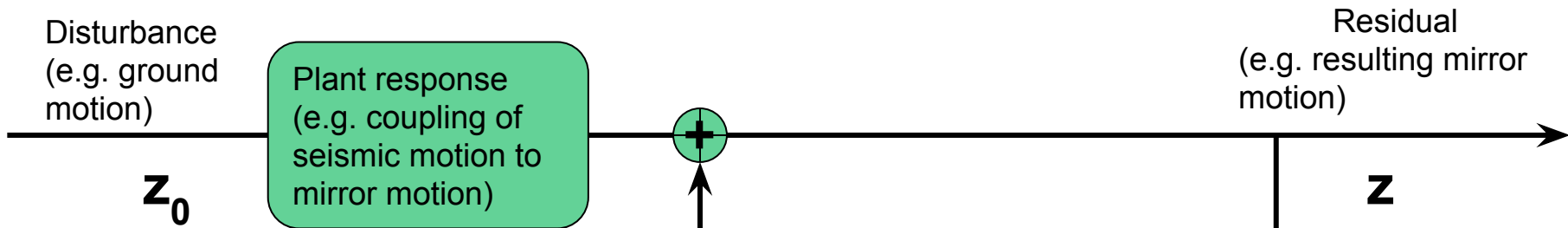
# aLIGO



# aLIGO







**Current Wiener Filtering:**  
 MSE-based regression model to reduce **linearly** coupled noises



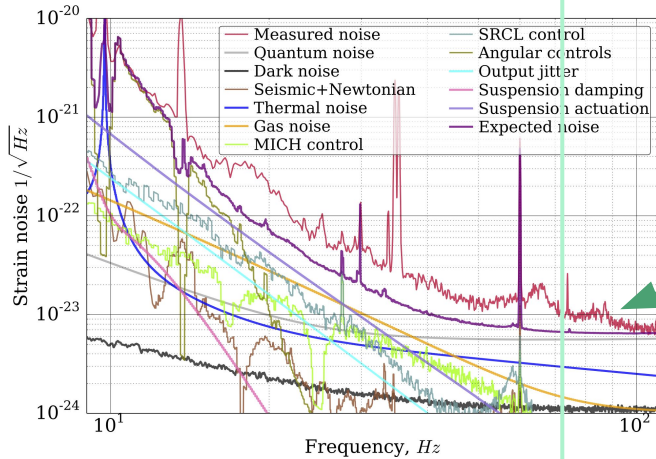
Disturbance  
(e.g. ground motion)

$z_0$

Plant response  
(e.g. coupling of seismic motion to mirror motion)

Residual  
(e.g. resulting mirror motion)

$z$



Actuator response

Control signal



Controller response

Error signal

Sensor response

### Current Wiener Filtering:

MSE-based regression model to reduce **linearly** coupled noises

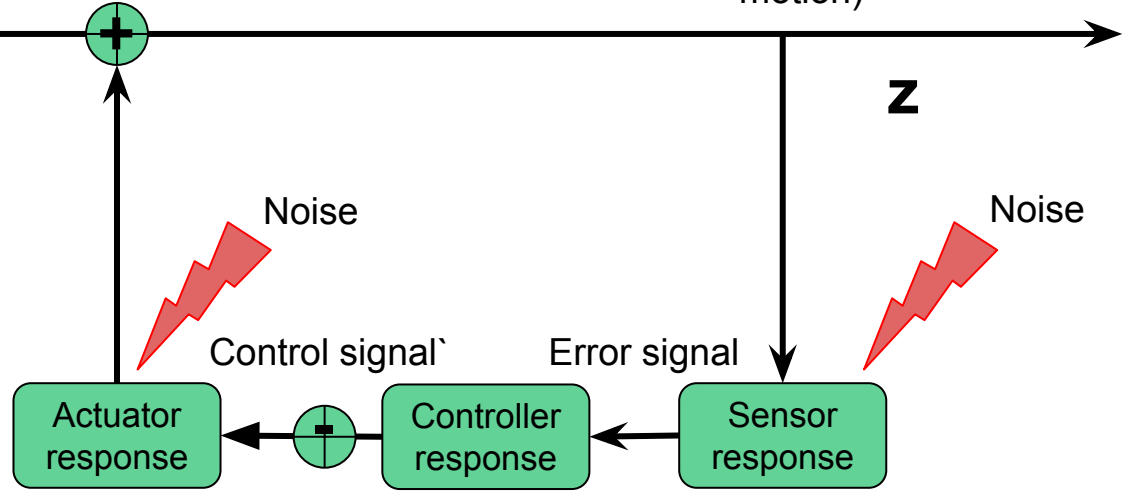
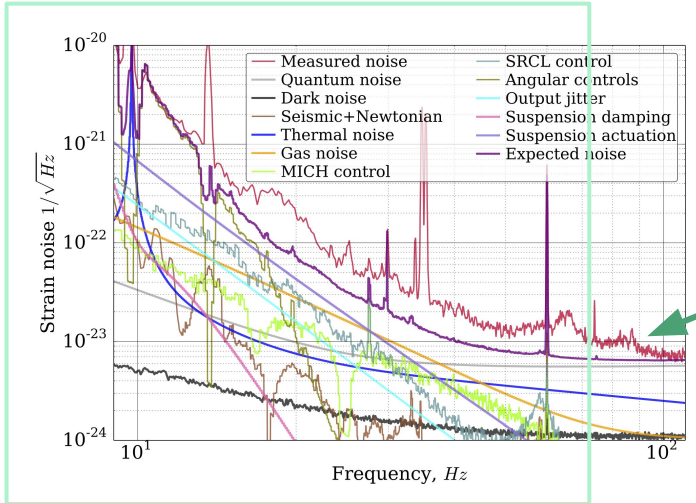
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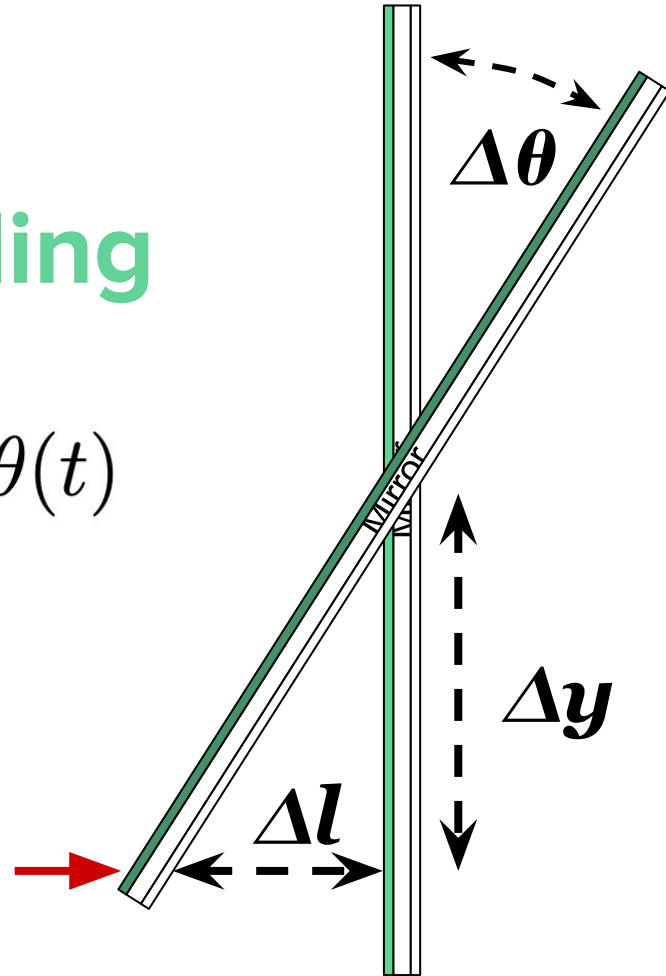
### Current Wiener Filtering:

MSE-based regression model to reduce linearly coupled noises

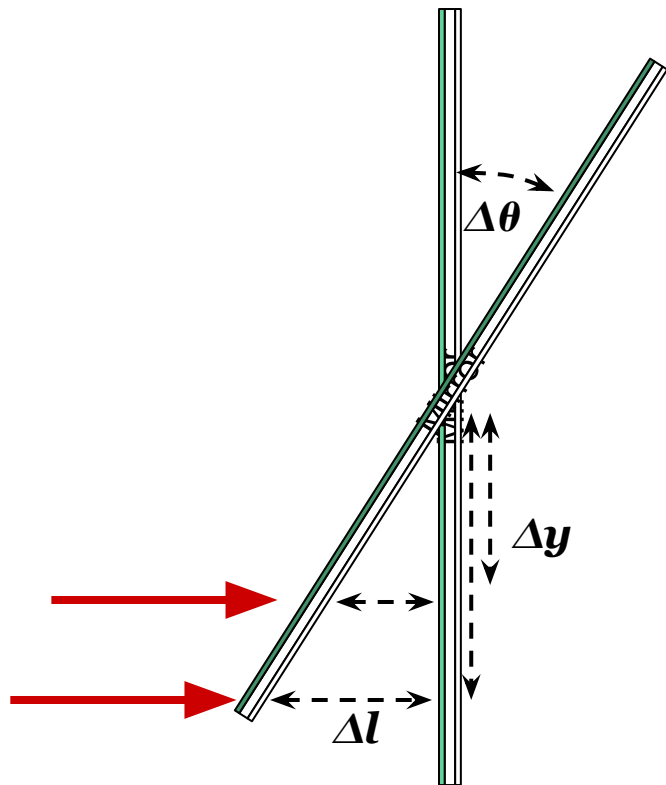
# Motivation

# Bilinear Coupling

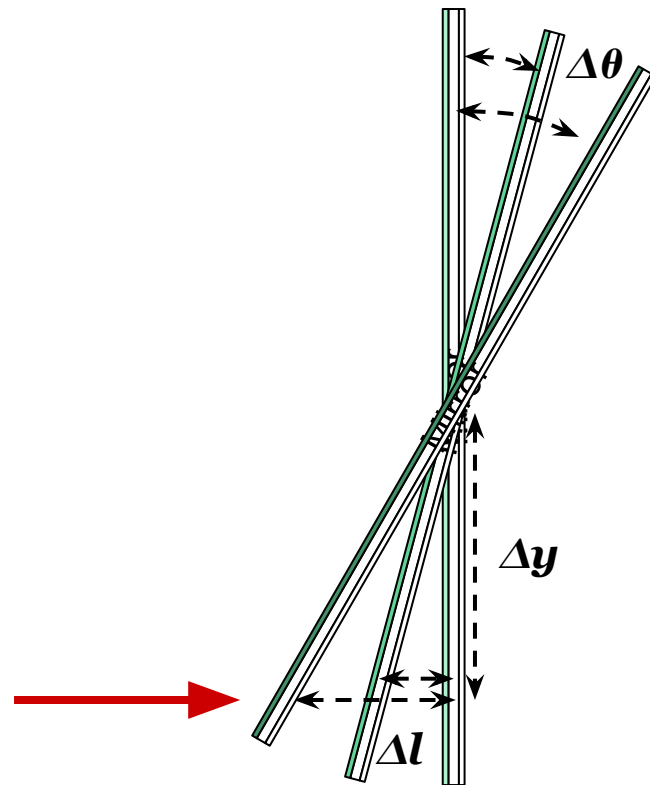
$$\Delta l(t) = \Delta y(t) \times \Delta \theta(t)$$



$$\Delta l(t) \propto \Delta y(t), \quad \Delta \theta(t) = \text{const}$$

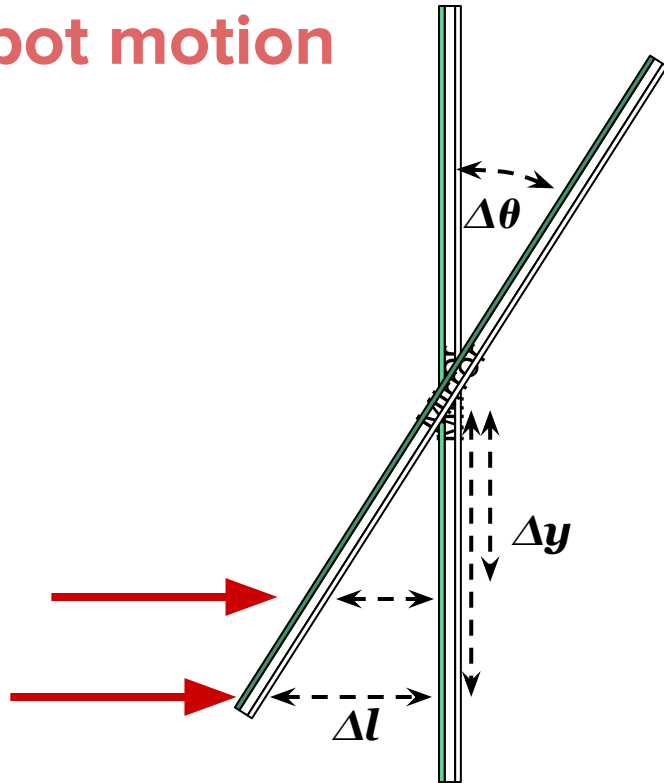


$$\Delta l(t) \propto \Delta \theta(t), \quad \Delta y(t) = \text{const}$$



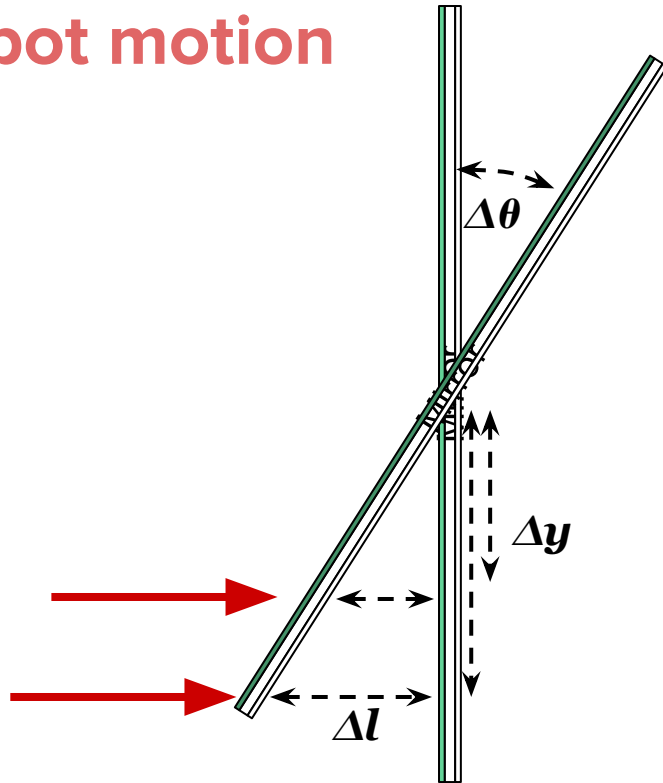
$$\Delta l(t) \propto \Delta y(t), \quad \Delta \theta(t) = \text{const}$$

## Spot motion




$$\Delta l(t) \propto \Delta y(t), \quad \Delta\theta(t) = \text{const}$$

## Spot motion



Test mass rotation  $\rightarrow$  Beam spot movement

 only depends on data witnessed at current time step

# Witnesses



**Physical effects**

**Ground Disturbances**

# Physical effects

ADS

Laser beam position on the test masses

TR

Beam position on ETM transmission  
DC offset

DHARD/CHARD

Error signal to common / differential arm

Alignment Sensing and Control (ASC)

# Ground Disturbances

# Physical effects

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Laser beam position on the test masses

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# Ground Disturbances

OPLEV

Suspension angular motion by optical lever

Suspension System (SUS)

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# Ground Disturbances

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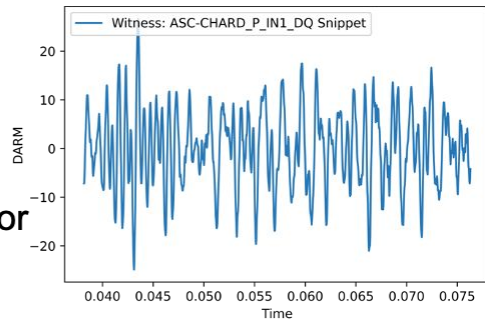
CAL\_CART  
Vibration isolation table displacement

Internal Seismic Isolation platforms (ISI)

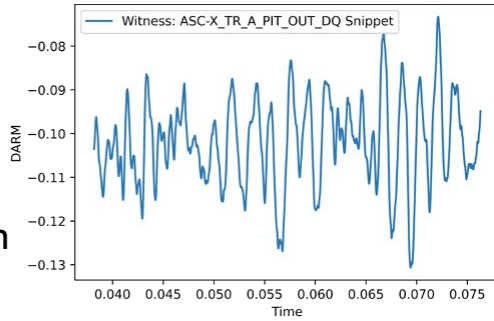
# Data

# Timeseries Snippets - Witness Data

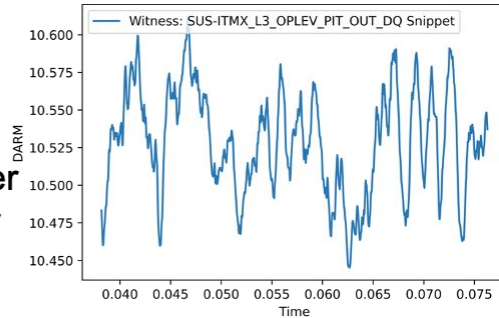
WIT 1  
arm error



WIT 5  
beam  
position

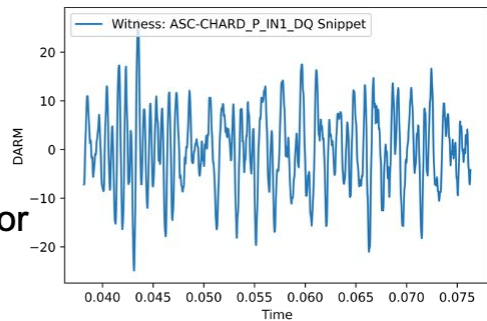


WIT 13  
op. lever  
angular  
motion

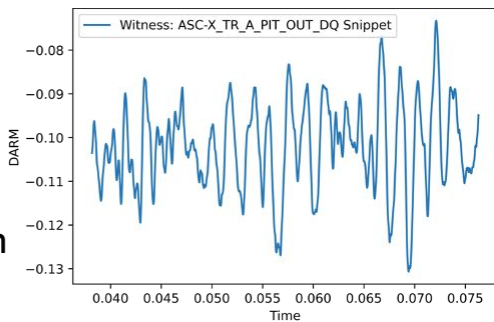


# Timeseries Snippets - Target Data

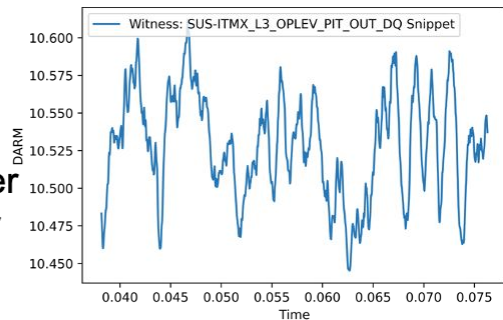
WIT 1  
arm error



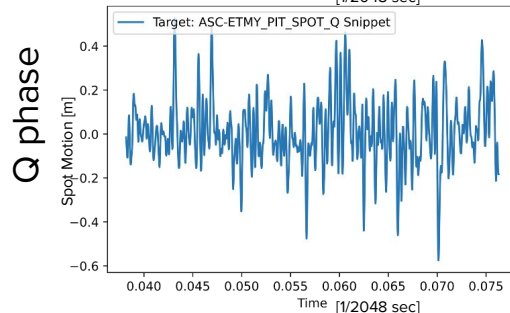
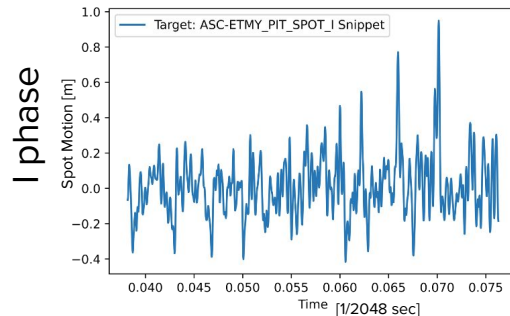
WIT 5  
beam  
position



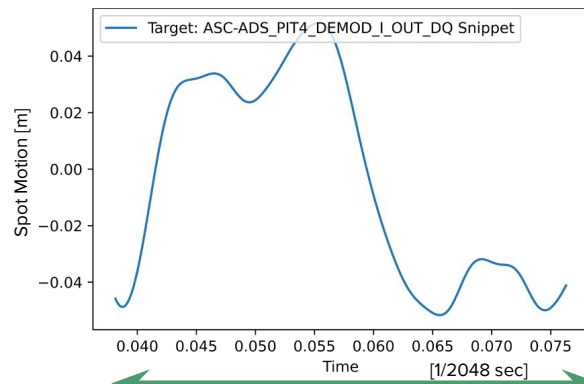
WIT 13  
op. lever  
angular  
motion



ETMY  
Reconstructed Spot Motion

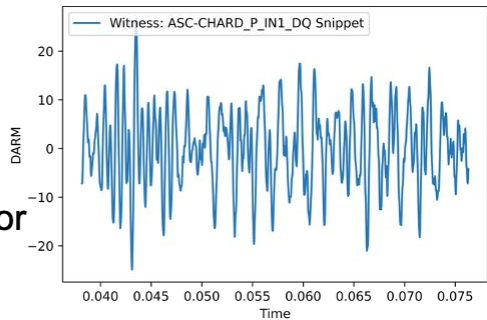


ETMY  
Measured Spot Motion

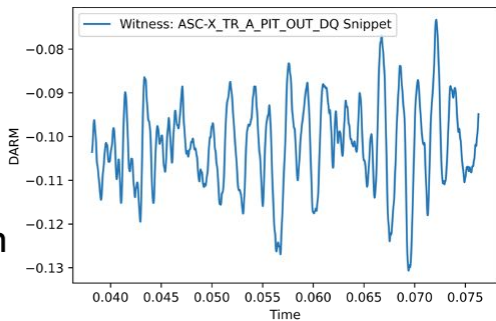


# Microseismic Motion

WIT 1  
arm error



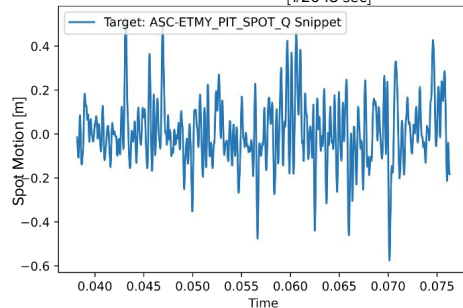
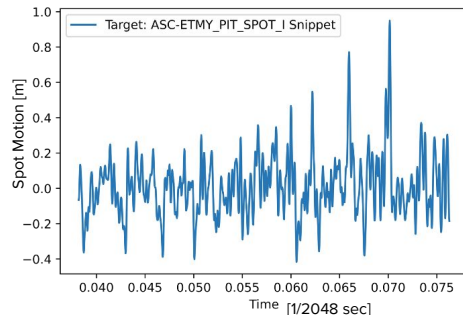
WIT 5  
beam  
position



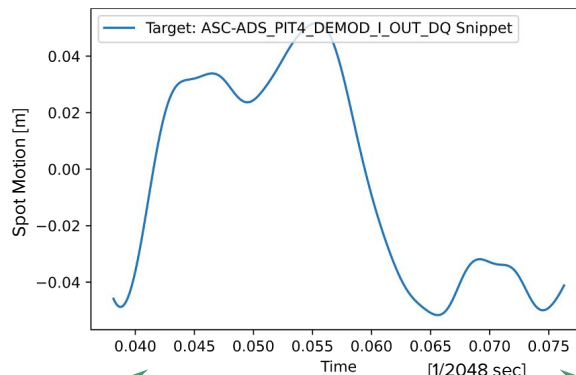
WIT 13  
op. lever  
angular  
motion



ETMY  
Reconstructed Spot Motion



ETMY  
Measured Spot Motion



**75 sec snippet**



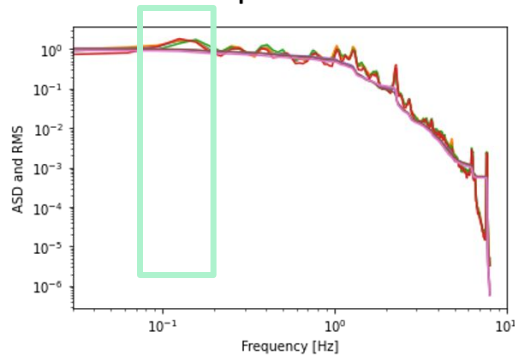
Time Scales:  
10-20 secs  
Freq desired:  
0.05-0.2 Hz



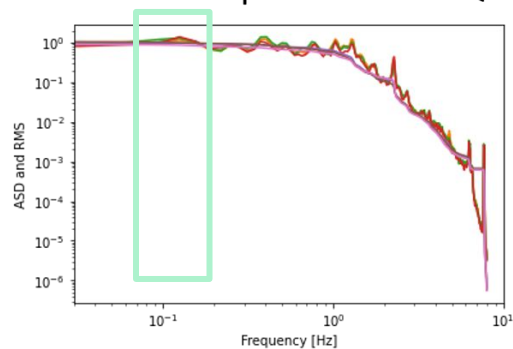
# Power Spectra

# Microseismic Motion

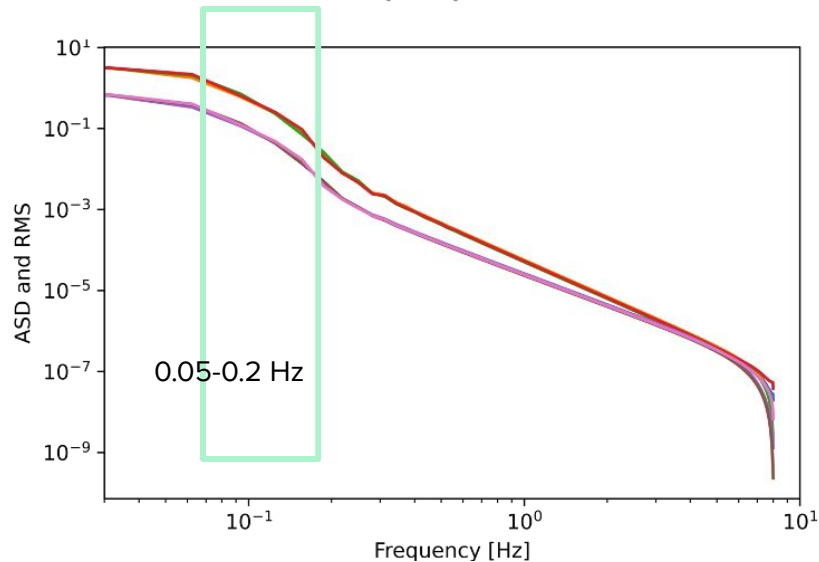
Reconstructed spot ETMY Pitch I Phase



Reconstructed spot ETMY Pitch Q Phase

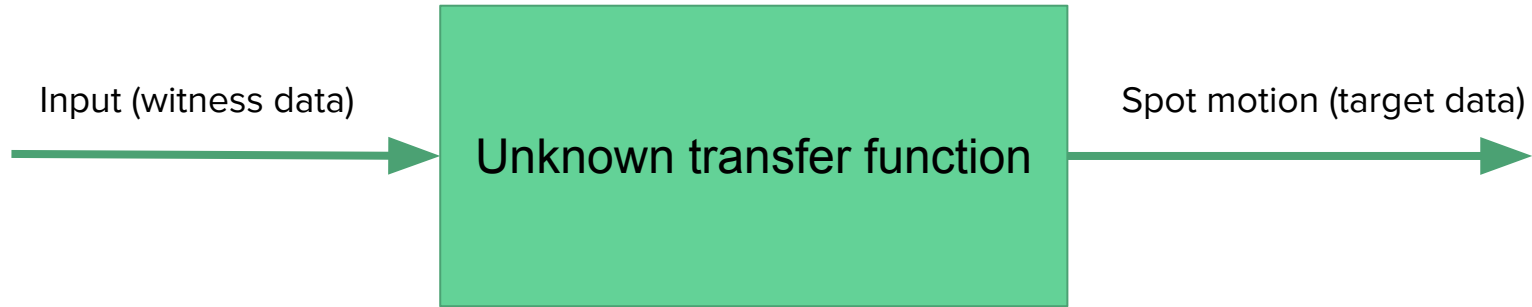


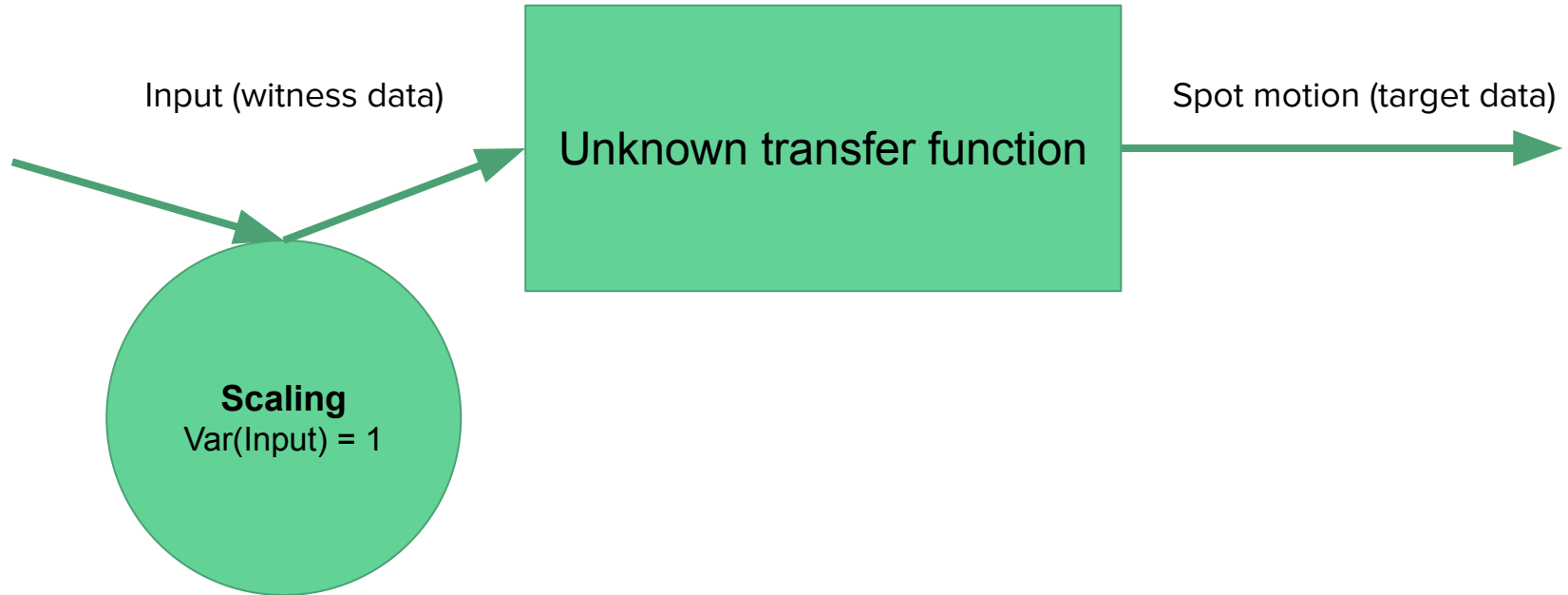
ADS Demodulated spot position ETMY Pitch I phase

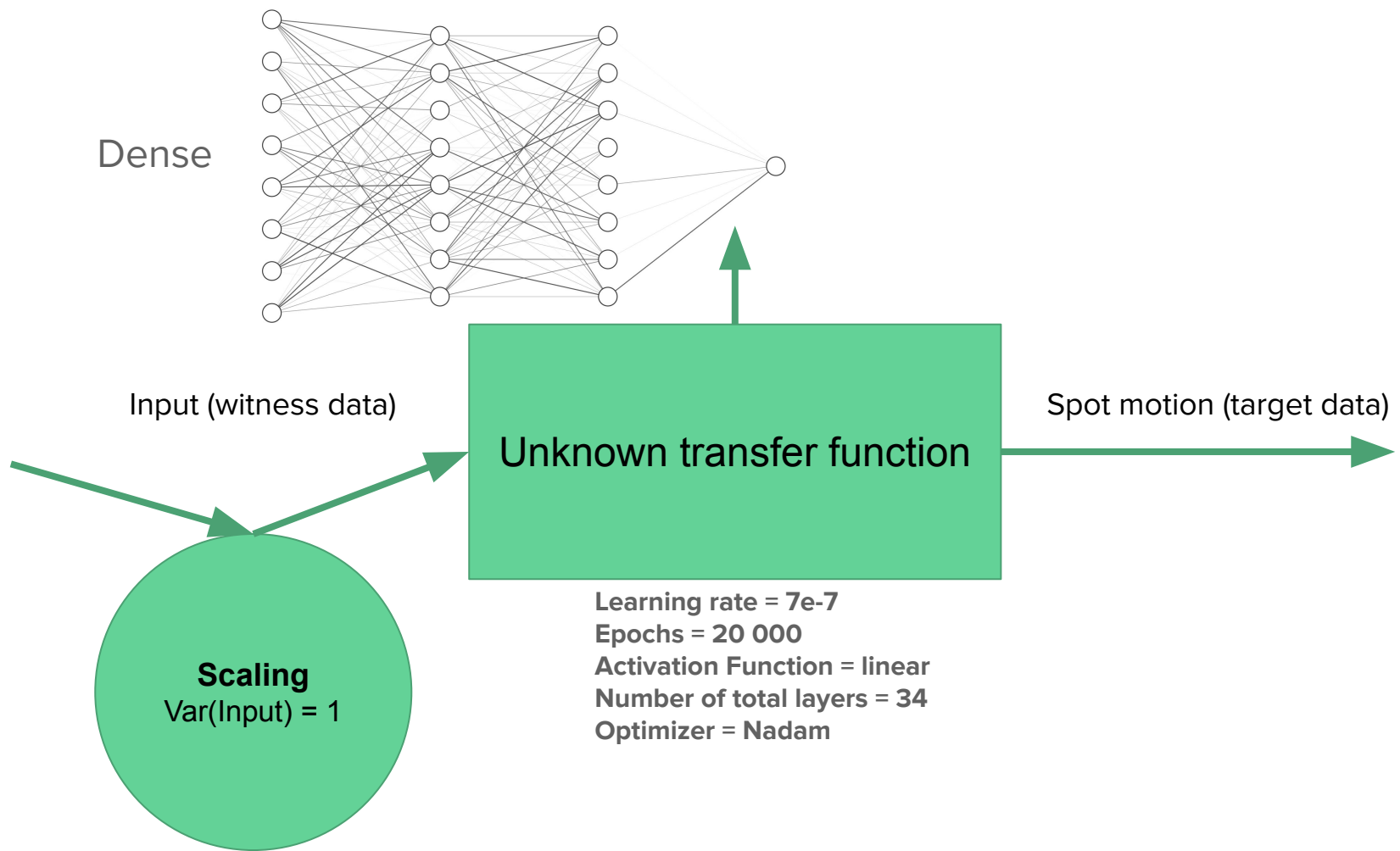


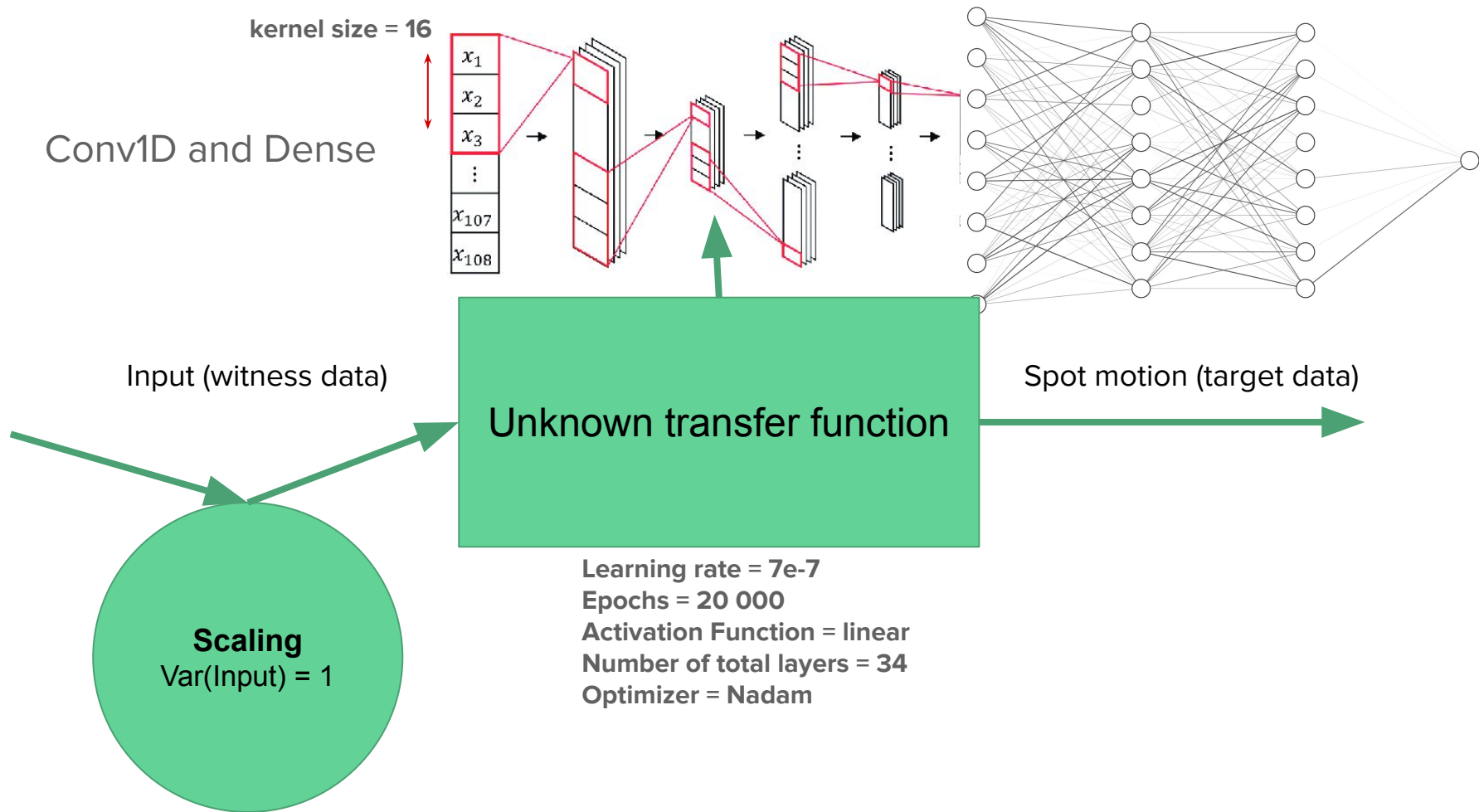
# Networks

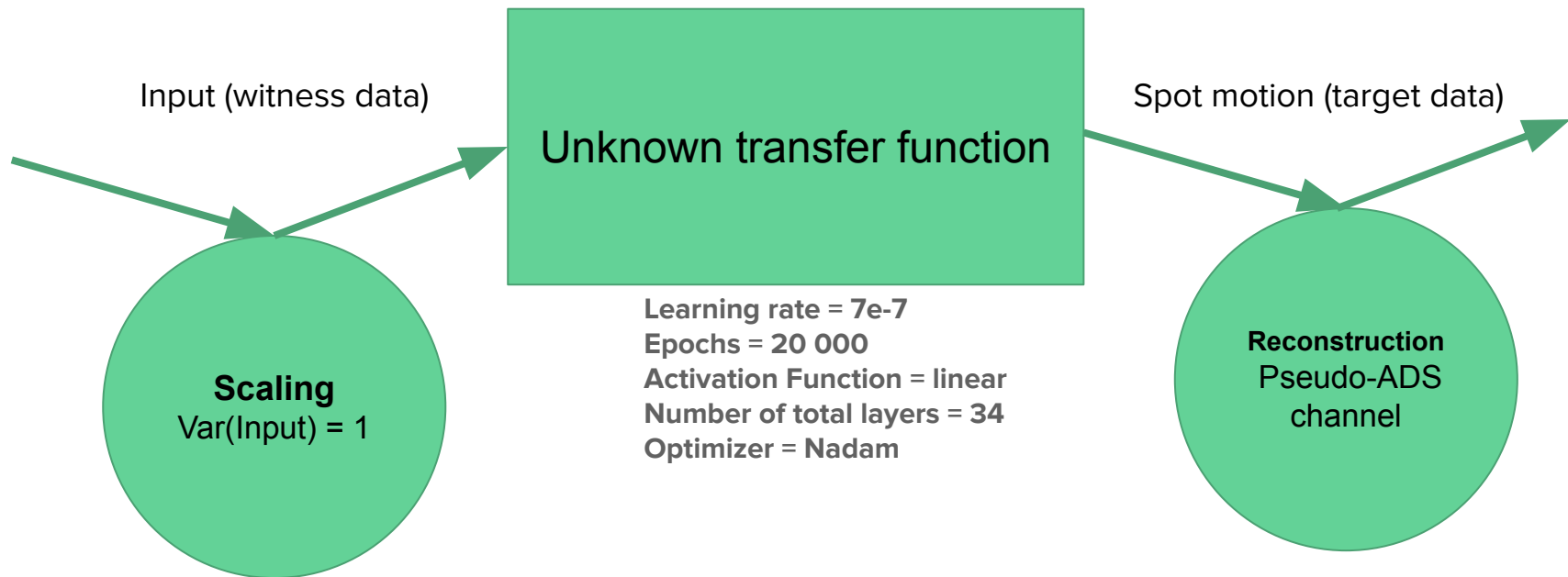
# What is a machine learning model?



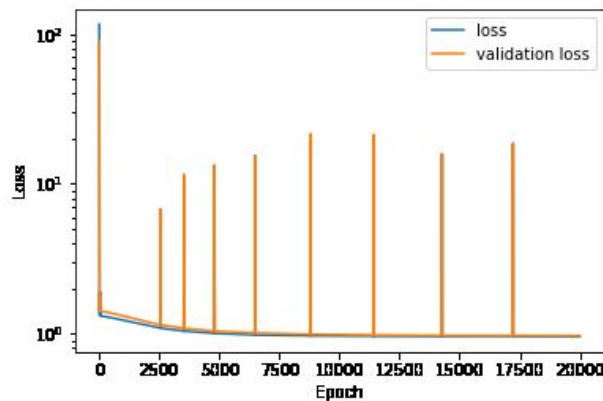
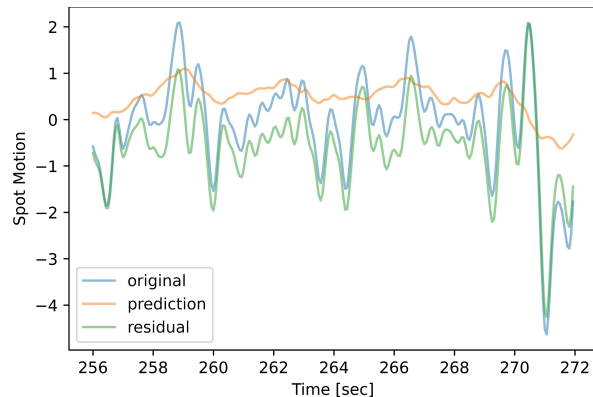
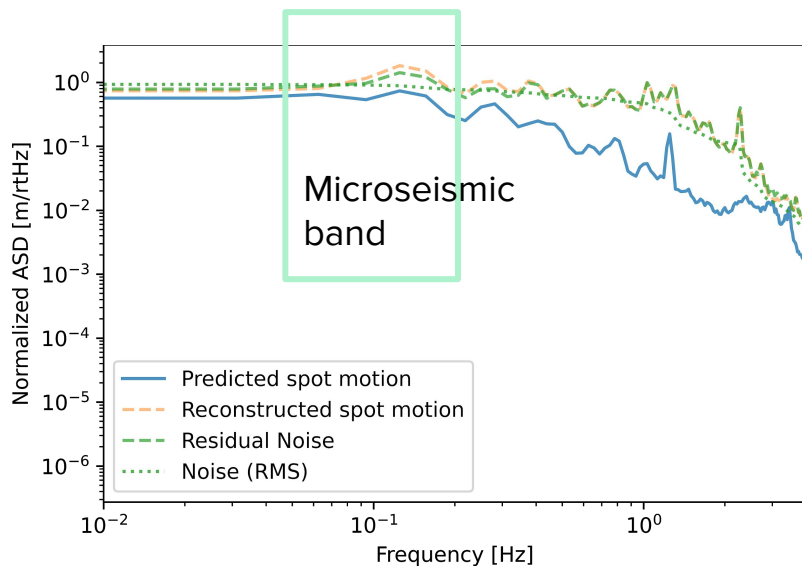






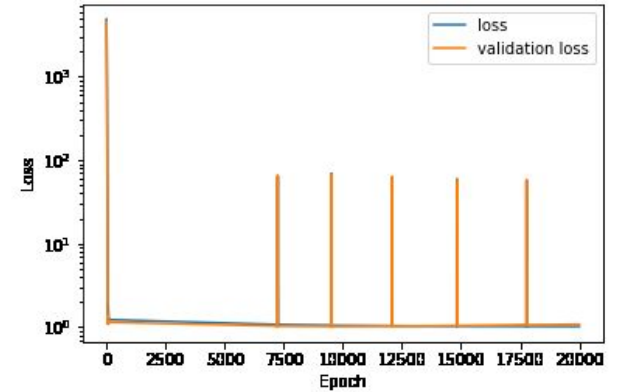
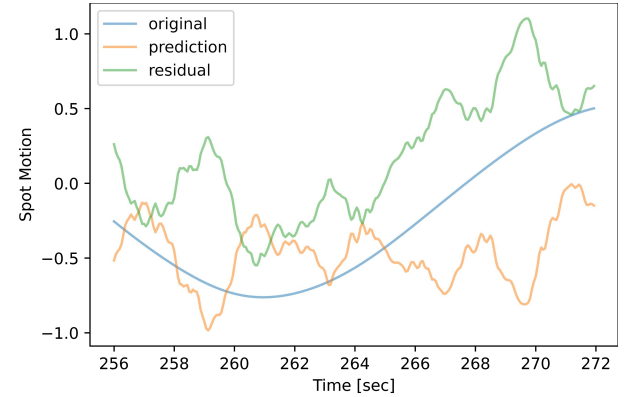
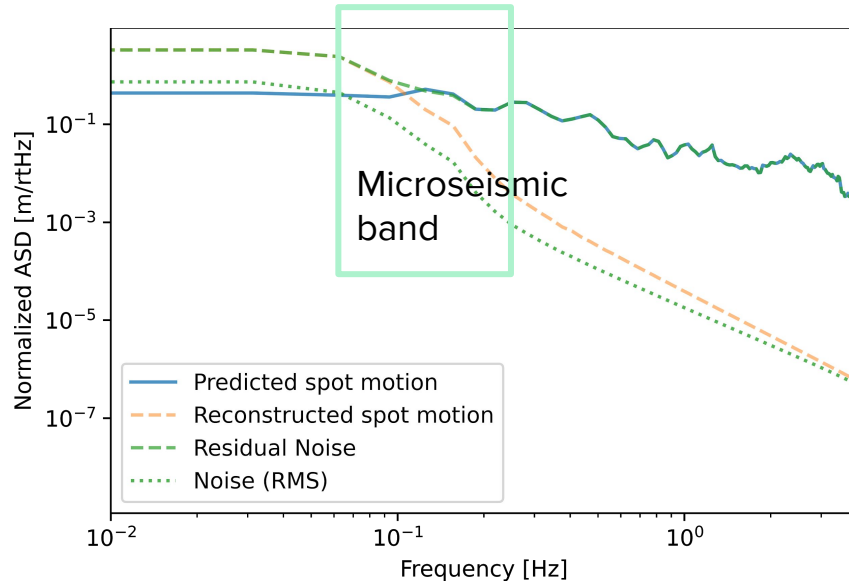


# Reconstructed Spot Position - Dense

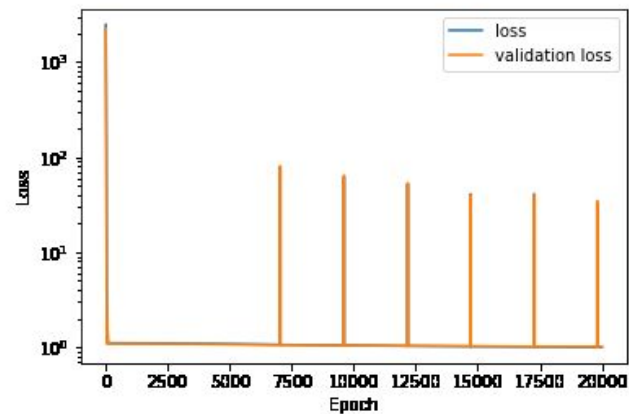
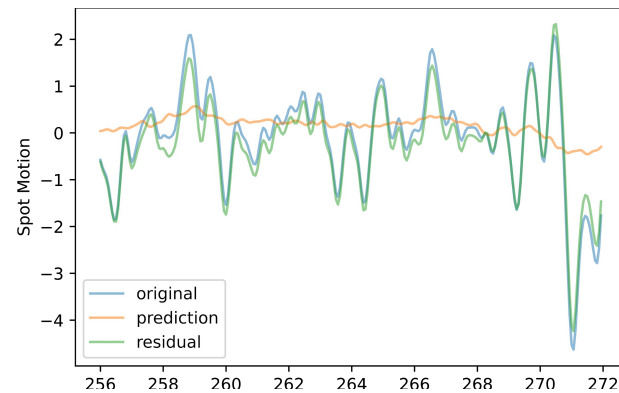
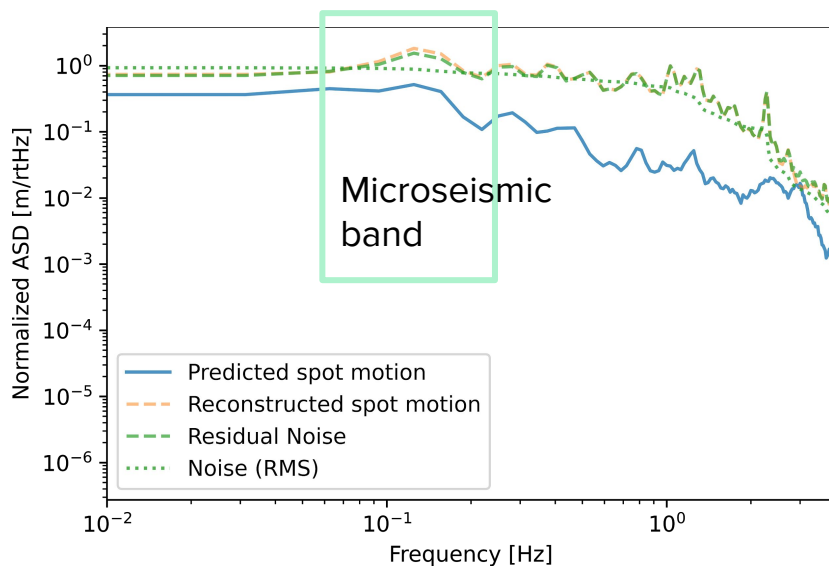




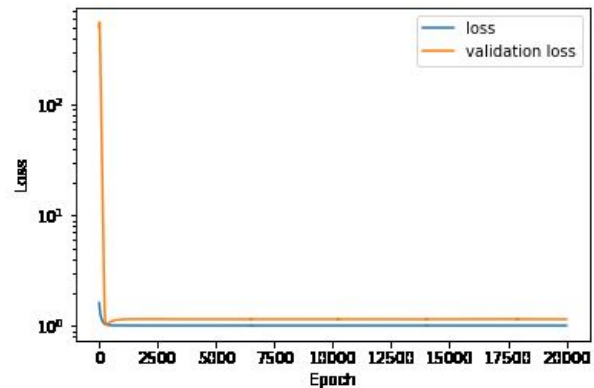
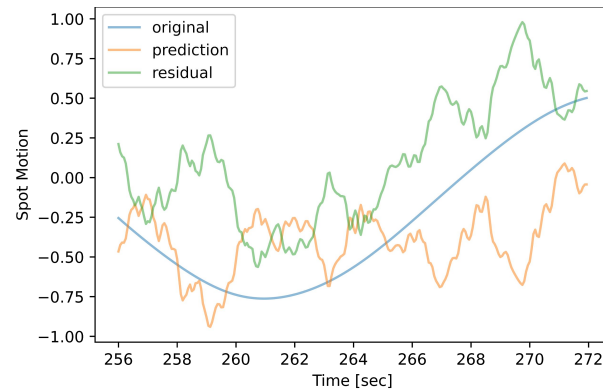
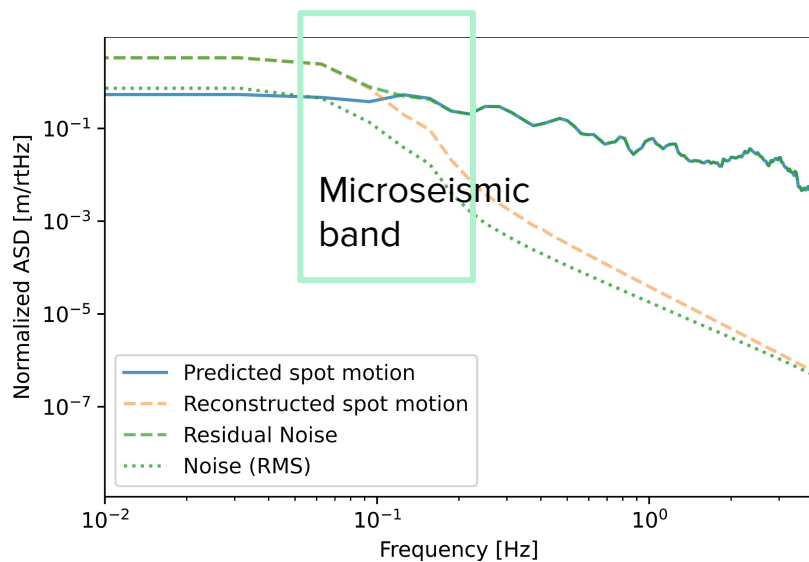
# Measured Spot Position - Dense



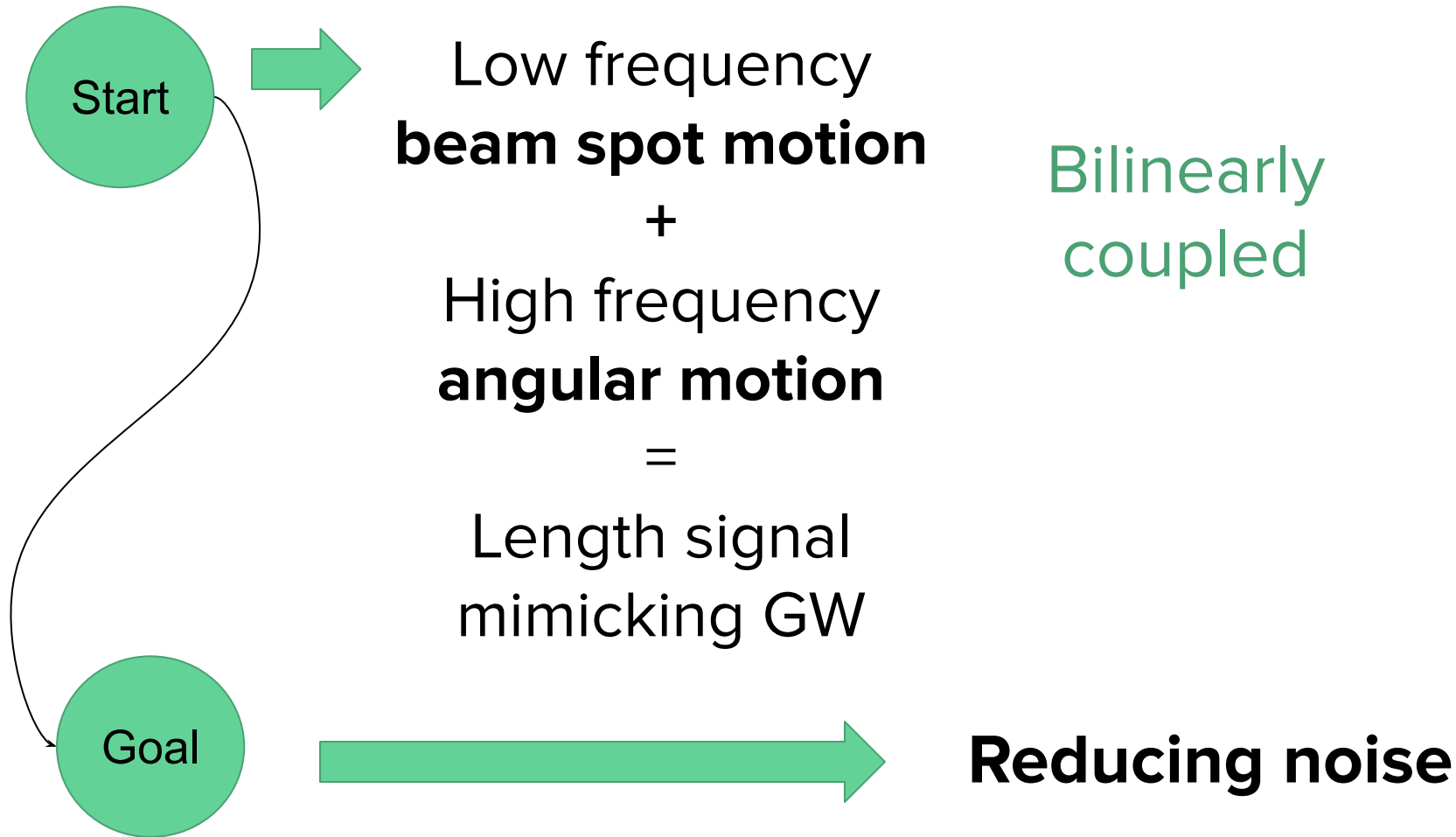
# Reconstructed Spot Position - Conv + Dense



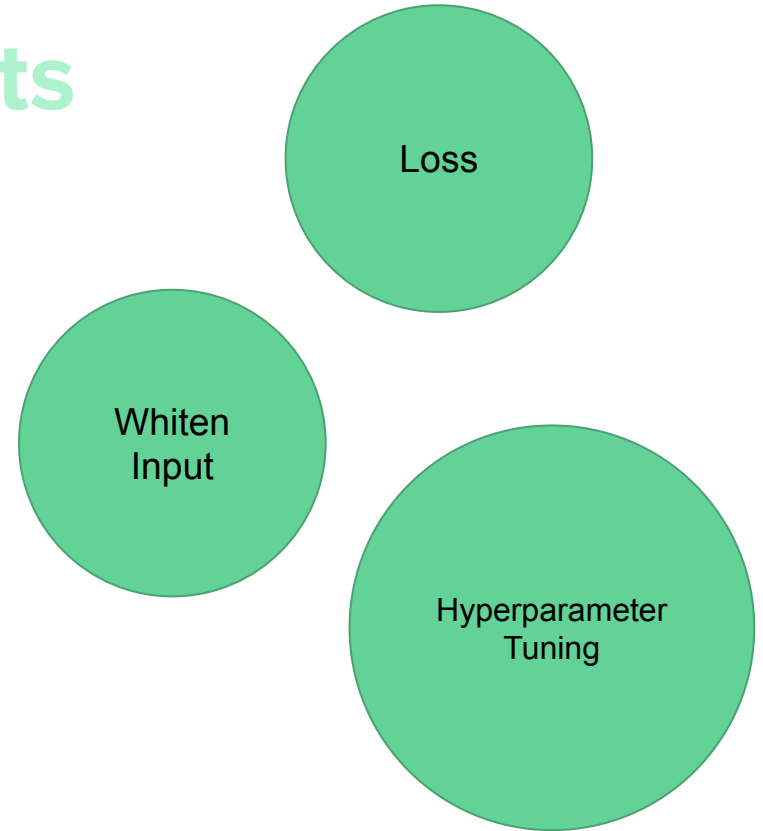
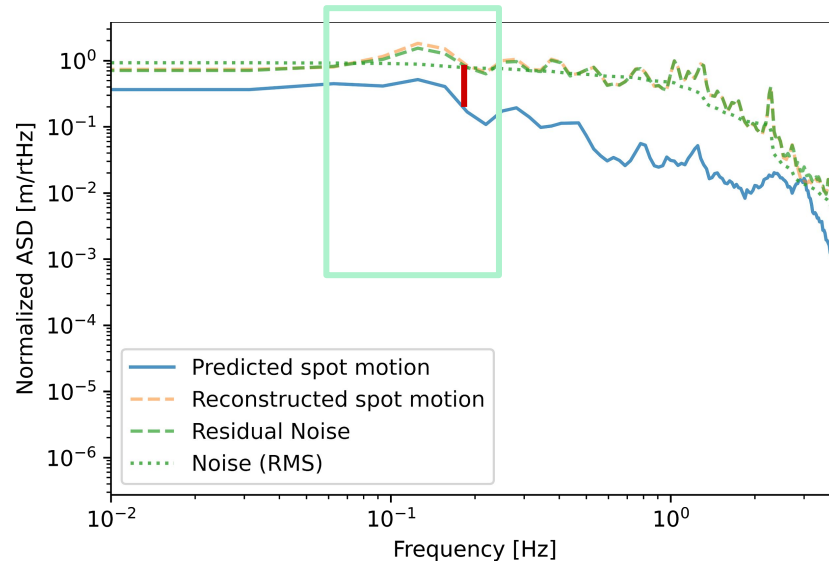
# Measured Spot Position - Conv + Dense



# Conclusion



# Future Developments



**Thank you for  
a wonderful summer!**

**Questions?**