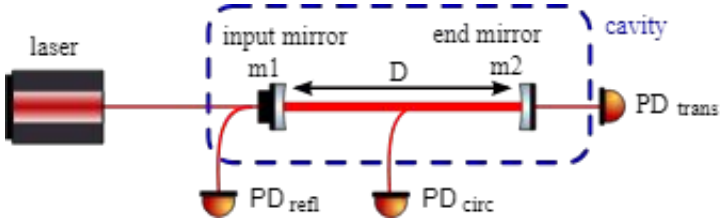
Reinforcement Learning for Lock Acquisition

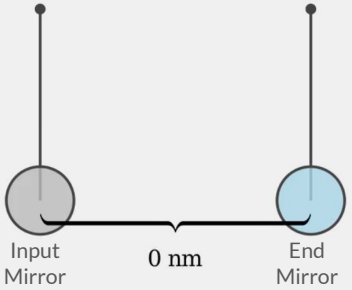
Kenny Moc | Supervisor: Rana X. Adhikari

Caltech

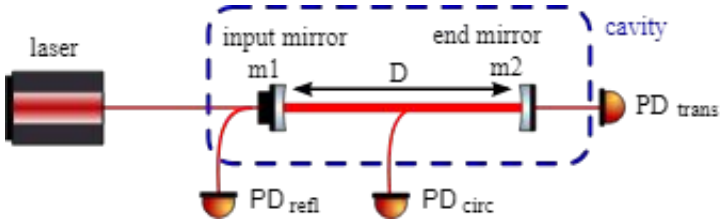
The Problem: Loss of Lock

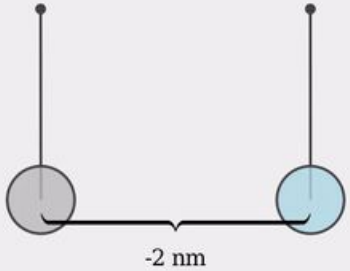
The Fabry-Perot Cavity





Noise Forces Bring it Out of Resonance





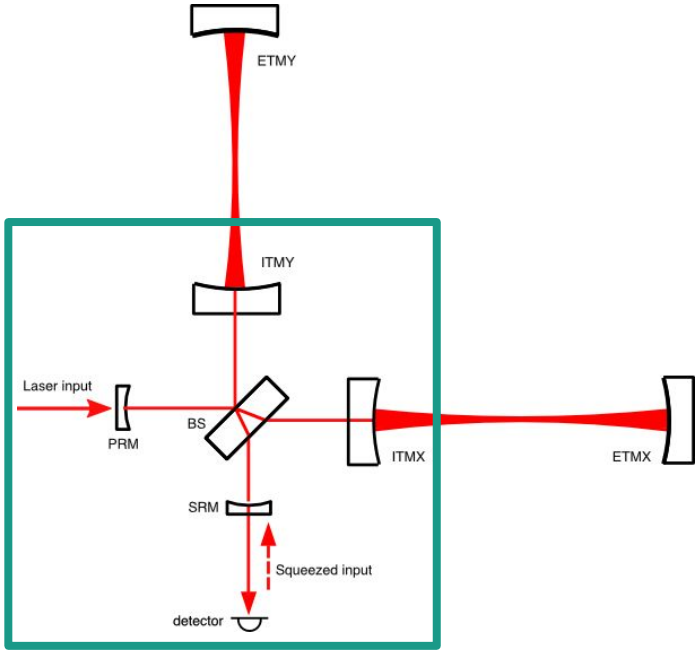
Lost lock! Can take O(1 hour) at the sites to bring the cavities back to lock

Network Topology

Power-Recycled Michelson Interferometer (PRMI)

- Mirrors: PRM, BS, ITMY, ITMX, SRM
- Power detector signals available:
  - REFL: reflected power at PRM
  - POP: power built up in cavity
  - AS: power going to SRM
  - POX: power going into x-arm
  - POY: power going into y-arm

We also “demodulate” REFL, POP, and AS to get more information to get more information.



Simplified sketch of the interferometer

Image: https://www.gwoptics.org/finesse/examples/aligo_sensitivity.php

Degrees of Freedom – PRCL and MICH

- **Michelson Length (MICH)**
  - Difference in lengths from BS to each ITM
- **Power Recycling Cavity Length (PRCI)**
  - Average length between PRM and ITMs

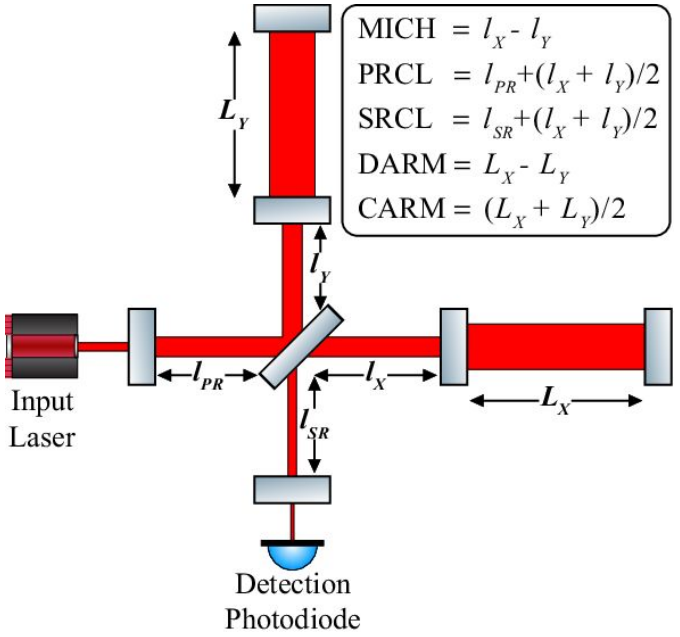
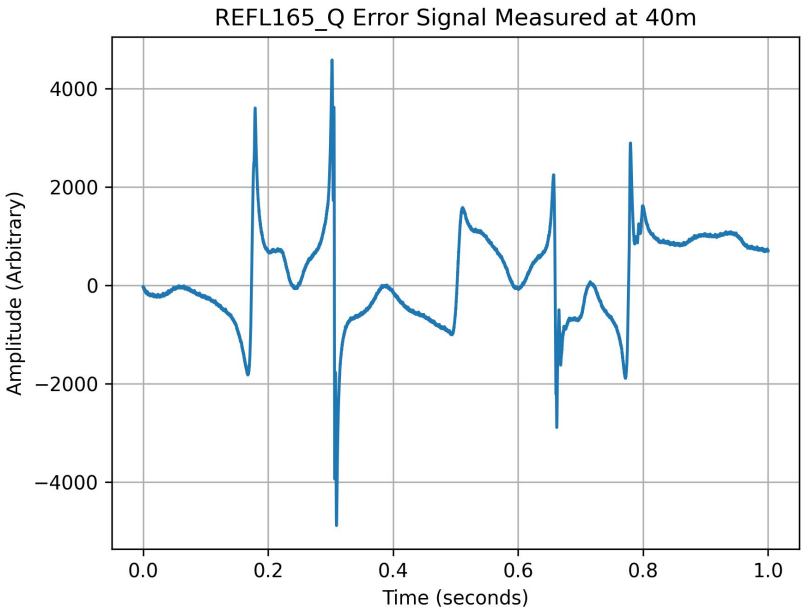


Image: https://www.semanticscholar.org/paper/Arm-length-stabilisation-for-interferometric-using-Mullavey-Slagmolen/198344e2fcd450273222e298ecc75f2c586f948e

Current Method

Pound–Drever–Hall (PDH) Locking Linear Controller

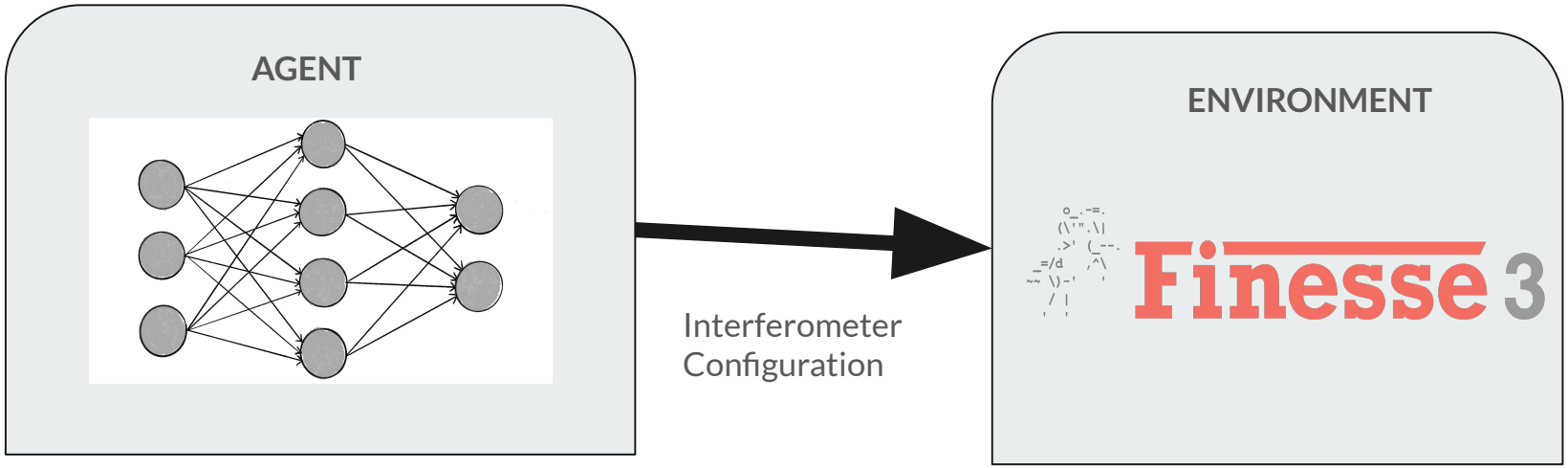
- We use an error signal from demodulating our power detector
- Great in the linear regime
- Not so good in the nonlinear regime
- Solution: wait until it is in the linear regime.



Real signal measured at the 40m

Can this be improved?

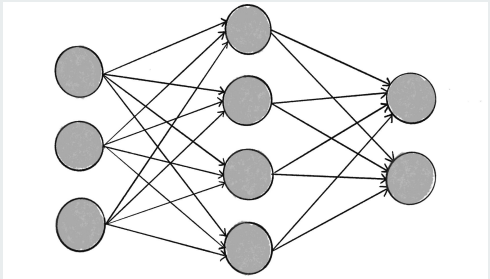
Reinforcement Learning



Reinforcement Learning

Thinking...thinking...

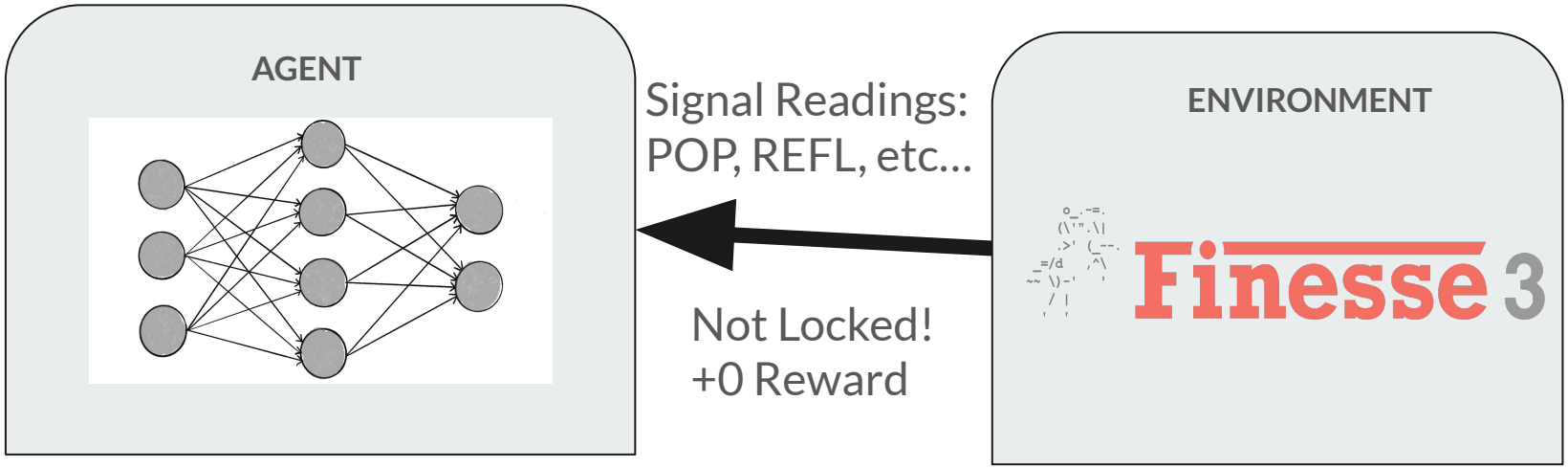
AGENT



ENVIRONMENT

Finesse 3

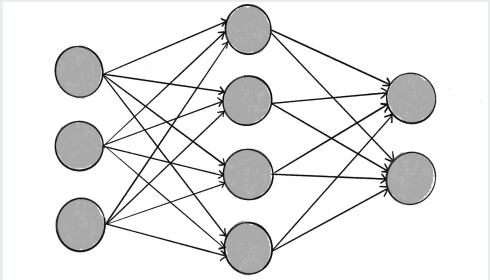
Reinforcement Learning



Reinforcement Learning

Updating…

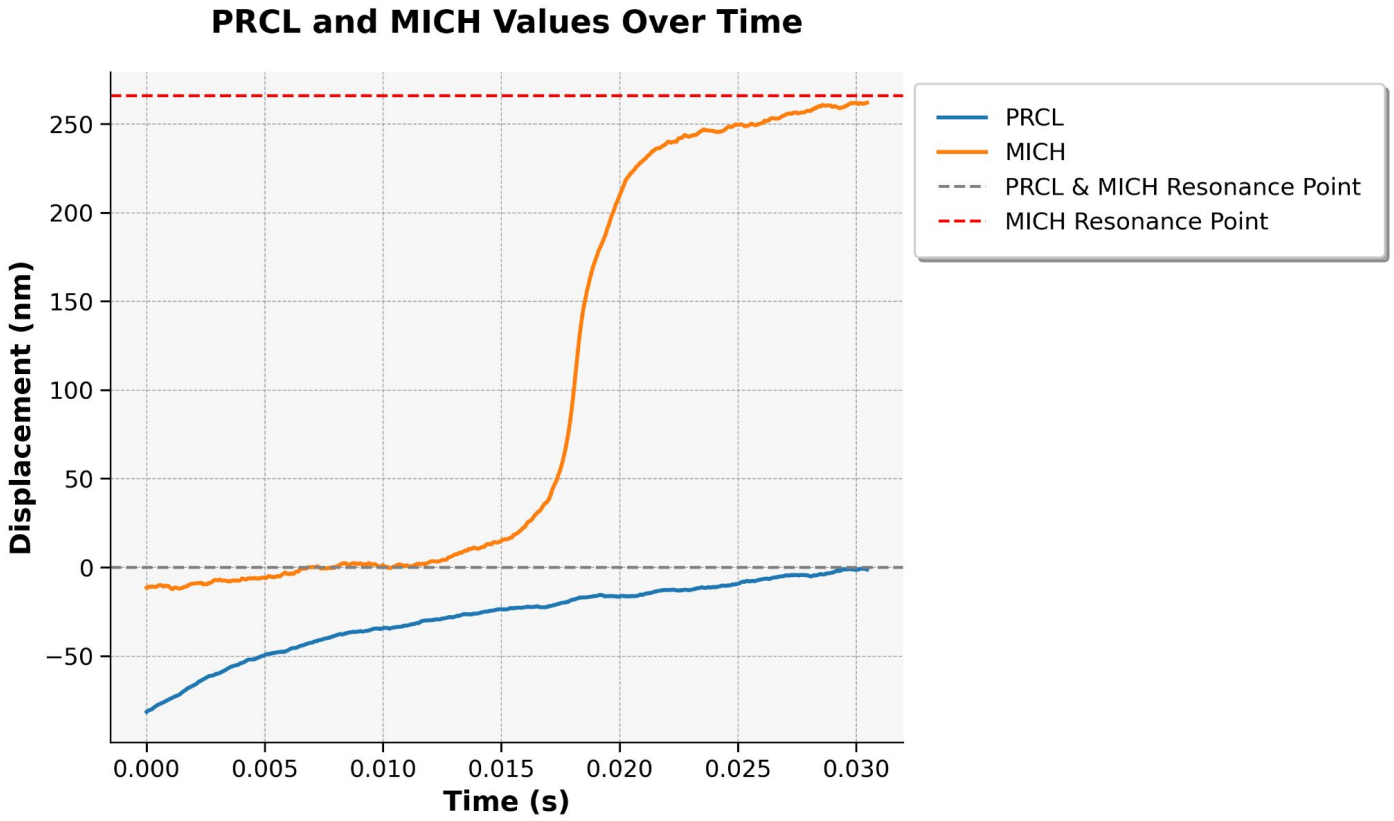
AGENT



ENVIRONMENT

Finesse 3

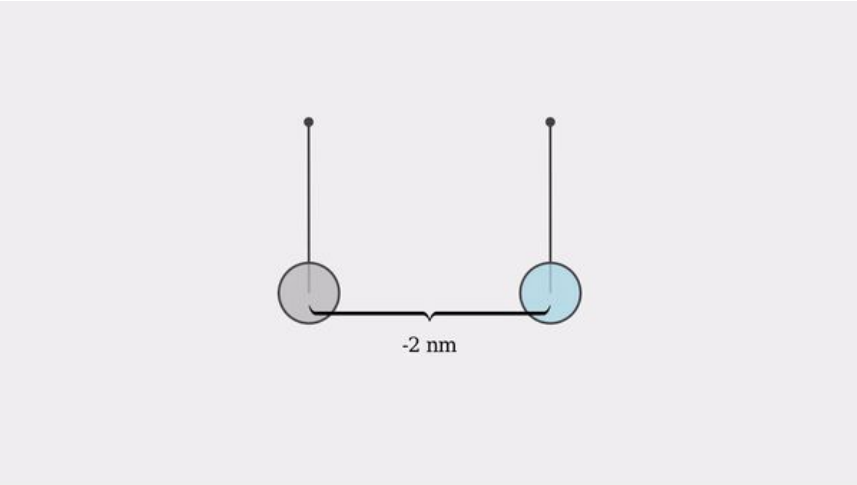
Note: we used a PPO agent.

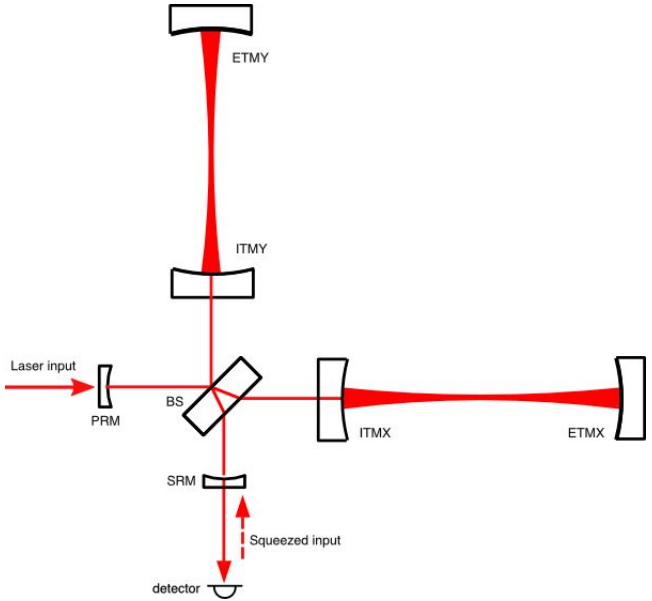


PPO Agent Locking Static Interferometer

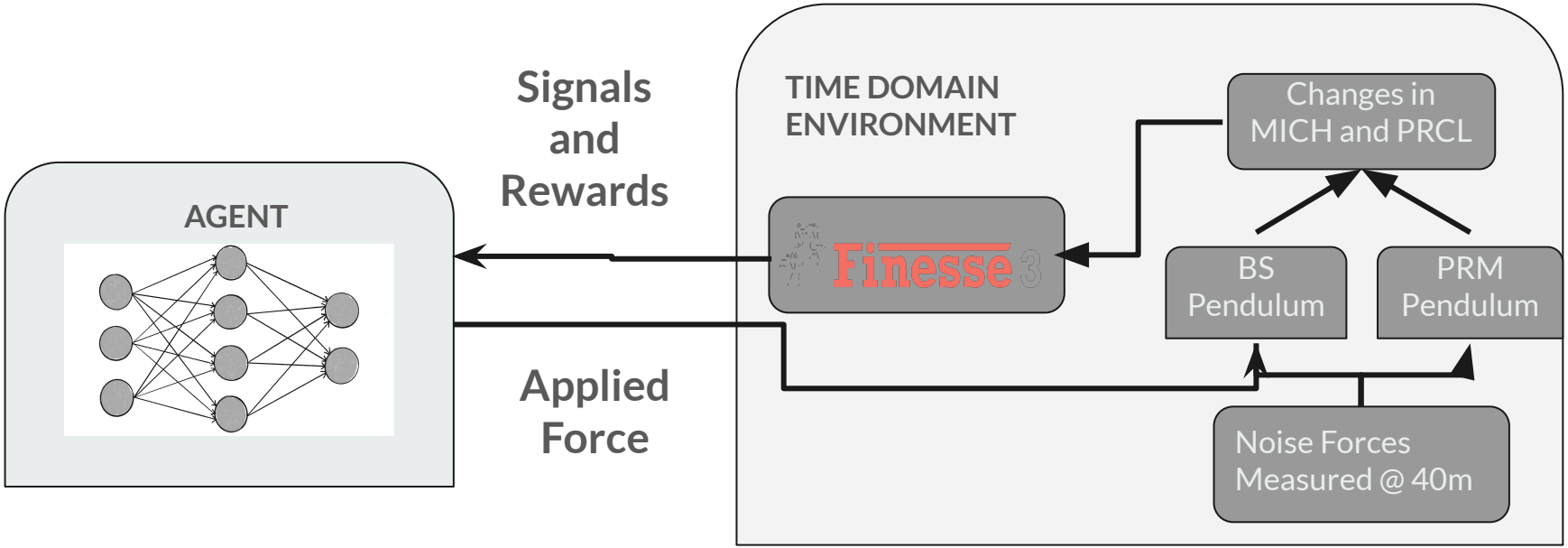
It’s possible…but not realistic

Not Static – We have Pendulums and Noise Forces





Time-Domain Simulation



Specifics

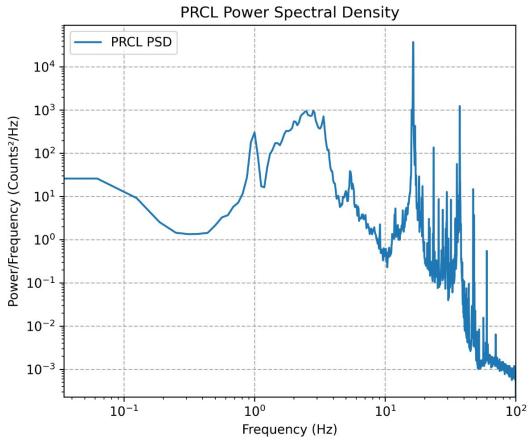
Pendulums

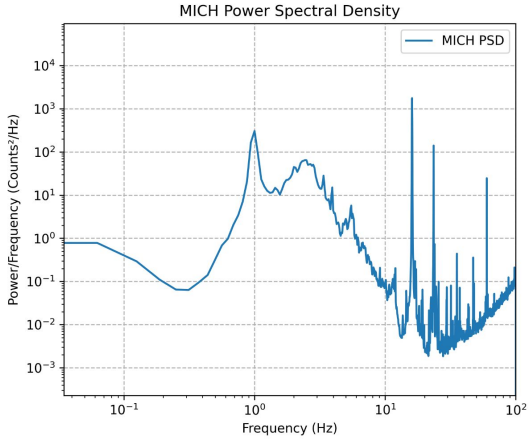
- Dynamics integrated by Runge-Kutta
- Velocity damped
- Frequency of 1Hz

Noise Forces

- Control signals measured (while locked) at 40m act as proxy for noise forces
- PSD Estimation with Welch
- Frequencies above 100 Hz are cut off

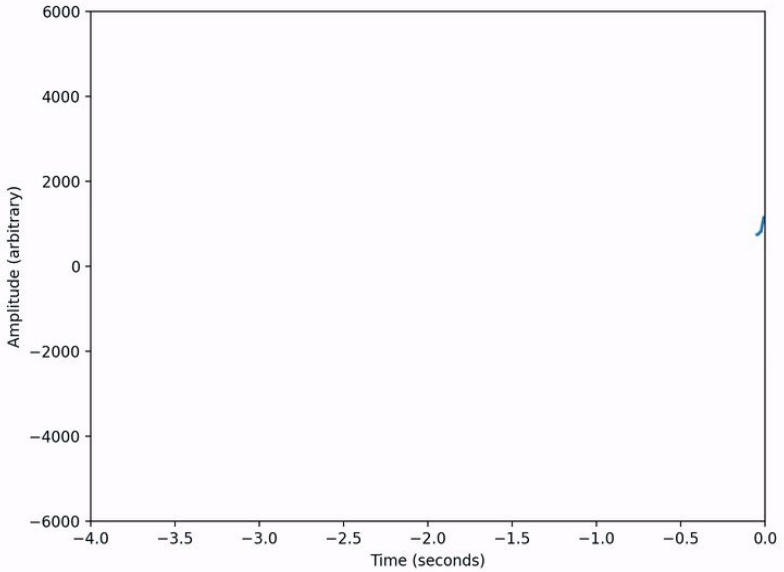
Sounds complicated…**does it work**?



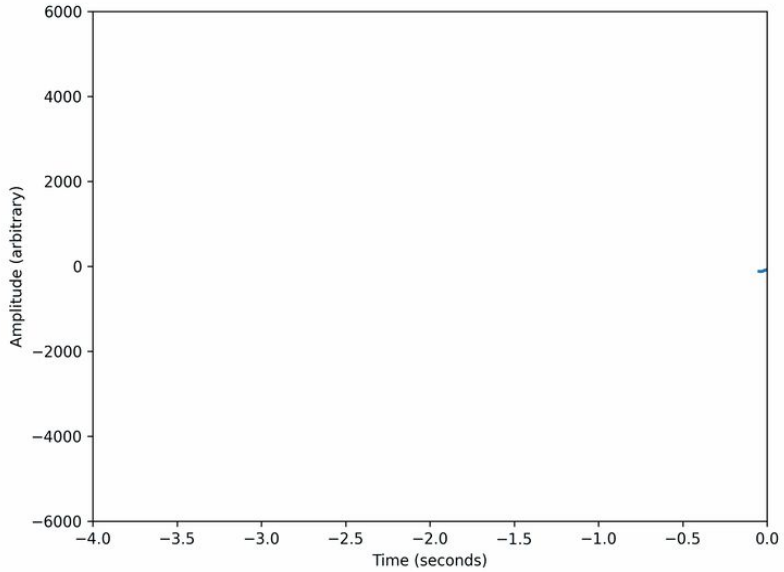


Simulation Results and Measured Results (real time)

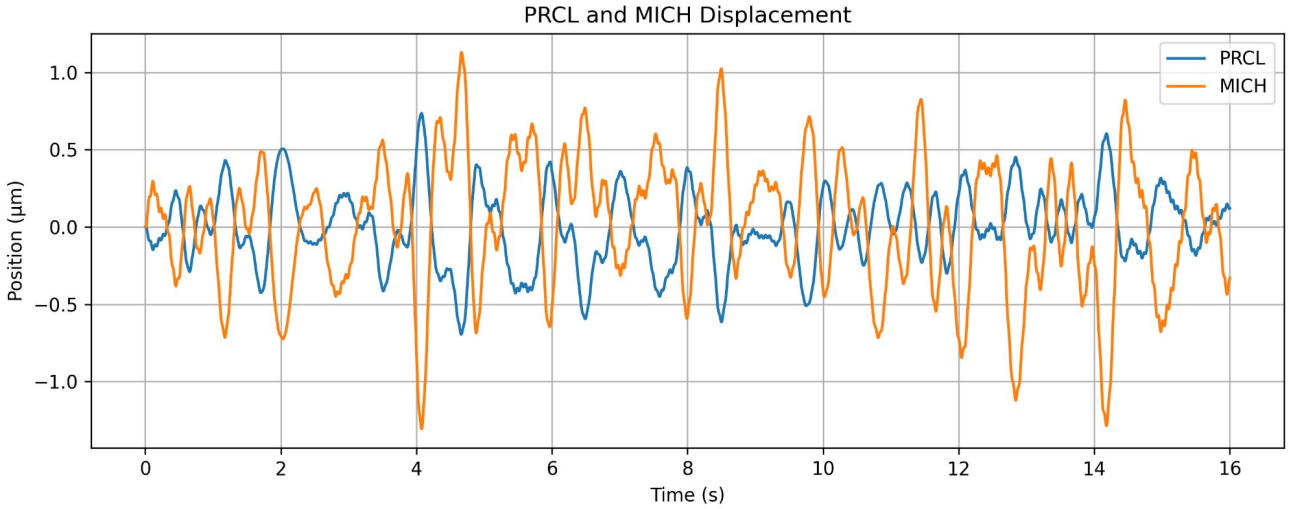
REFL165_Q Signal

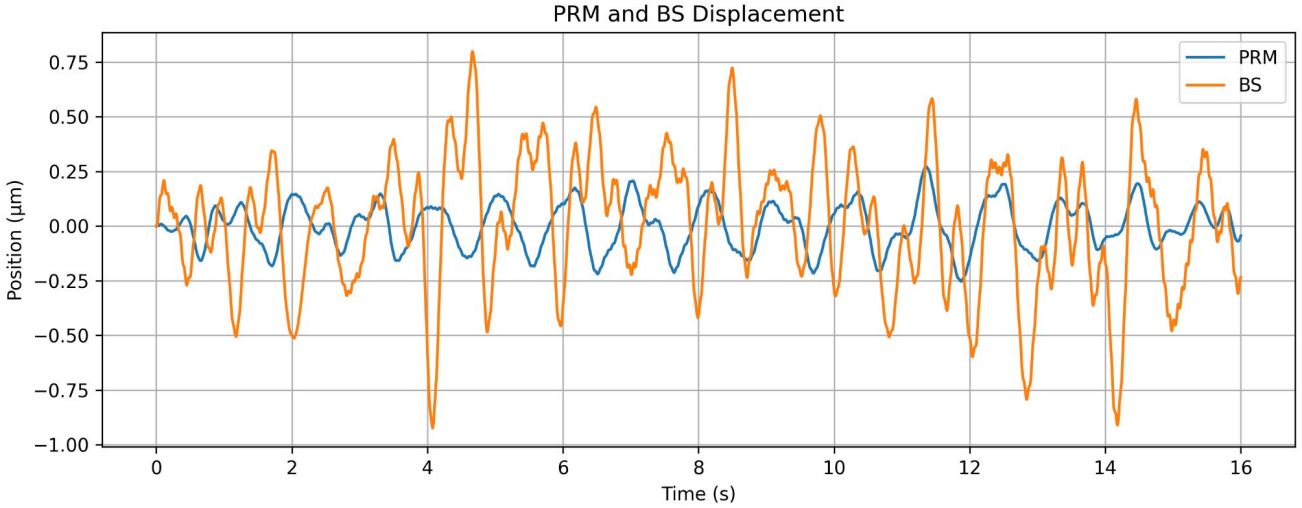


REAL Data measured at 40m



DEEPFAKE


PRCL and MICH Displacement
PRCL
MICH
Position (μm)
1.0
0.5
0.0
−0.5
−1.0
0
2
4
6
8
10
12
14
16
Time (s)


PRM and BS Displacement
PRM
BS
Position (μm)
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
0
2
4
6
8
10
12
14
16
Time (s)

Speedup!

Naive approach:

```
[20]: %timeit model.run()

      343 ms ± 2.4 ms per loop (mean ± std. dev. of 7 runs, 1 loop each)
```

~2.9 iterations/second

(w/o pendulum dynamics)

Expert approach:

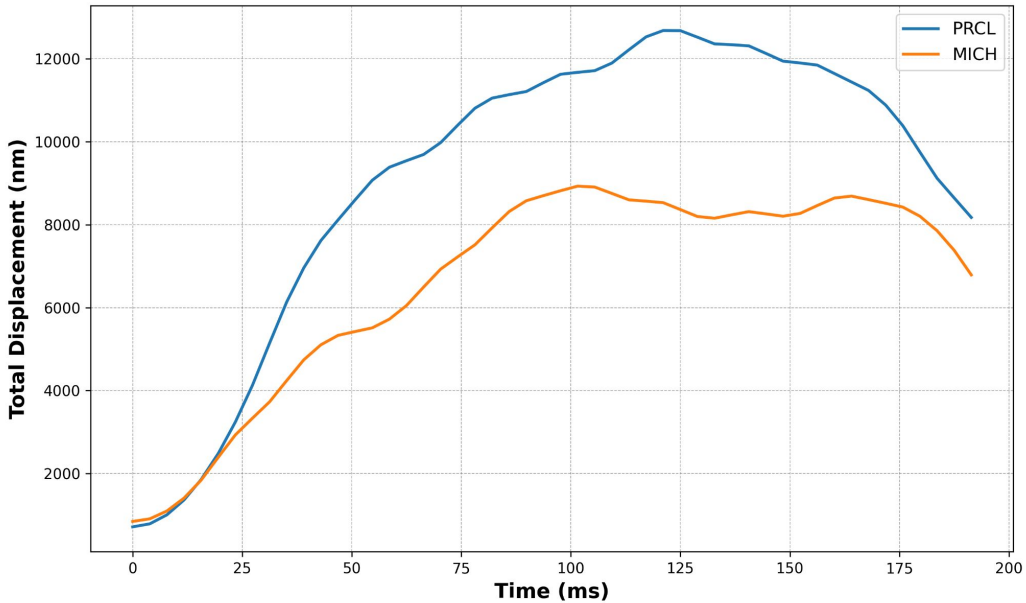
```
[7]: # sampling rate is 16384Hz, dt = 1/16384
     # runtime is in number of points
     sim = Simulation(model, runtime=16384*16)

[*]: results = sim.run()

     xaxis:  16%|▌| 41121/262145 [00:51<04:3  802.03it/s]
```

~800 iterations/second

(with pendulum dynamics!!!)

Good job Kenny!

Does It Work?



PPO with CNN to Extract Features – Actuating on BS and PRM at 256 Hz

NO!

- Agent needs to learn finer control
- Resonance conditions repeat every O(100 nm)
- Agent is moving through thousands of nm in a few ms

Summary and Future Work

Summary

- We showed that RL **can** lock some toy model of the 40m interferometer from observing power detector and PDH error signals only
- We developed a faithful time-domain simulation of the 40m interferometer
- We tried locking this simulation and we failed…for now

Future Direction

- Lock the time-domain simulation of the interferometer

Acknowledgements

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