First demonstration of neural sensing and control in a kilometer-scale gravitational wave observatory

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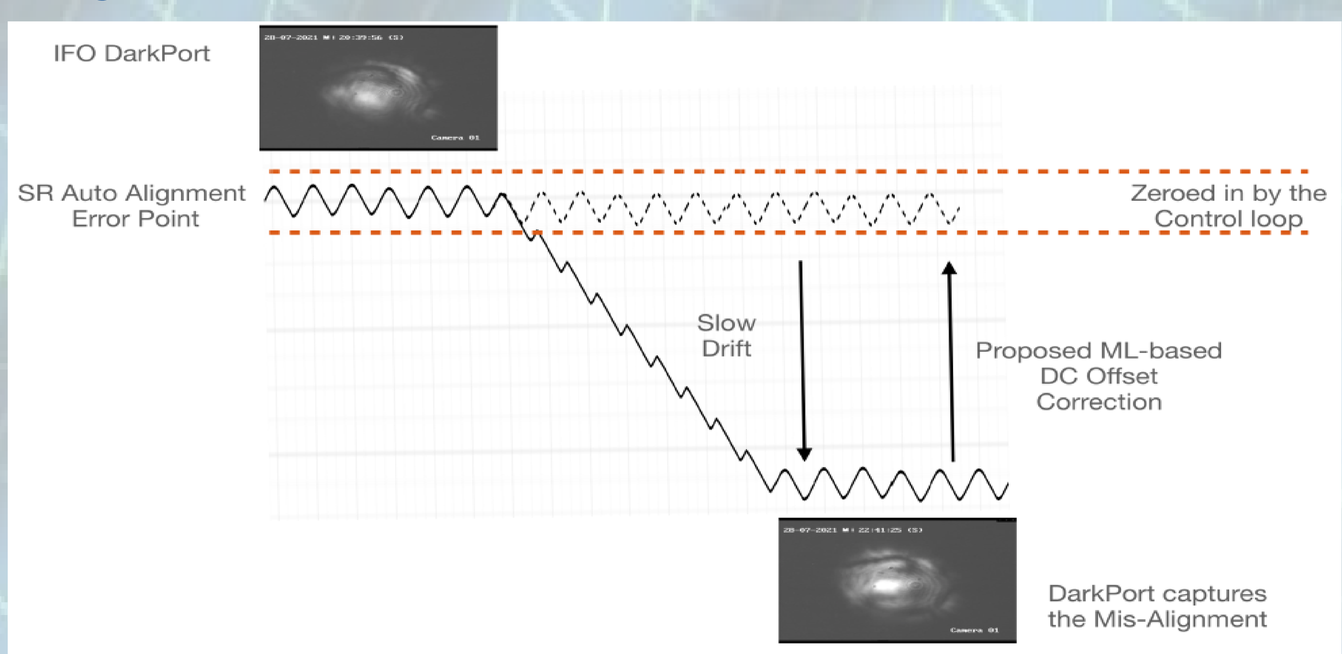
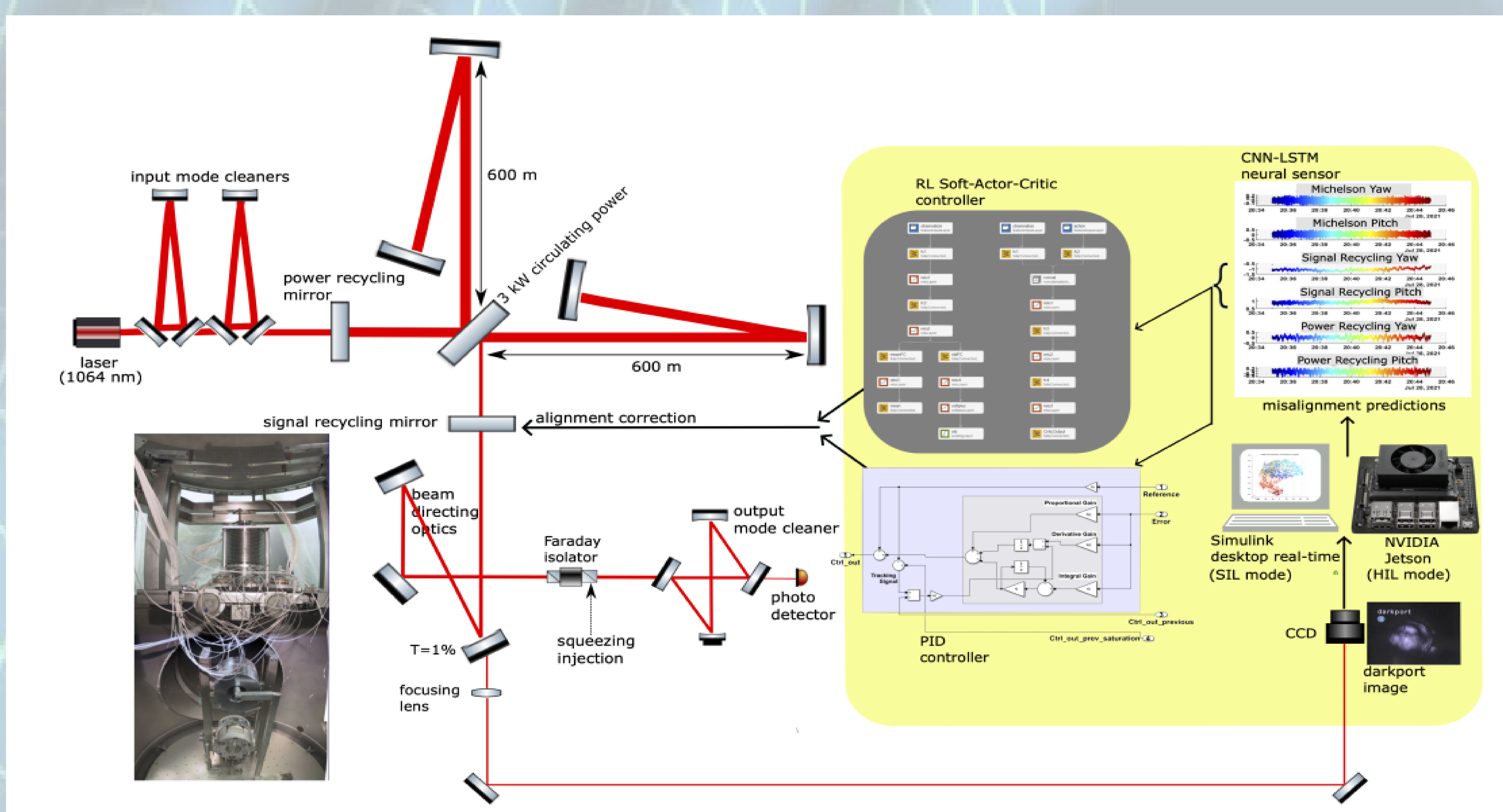
1. Motivation - automatic alignment problems

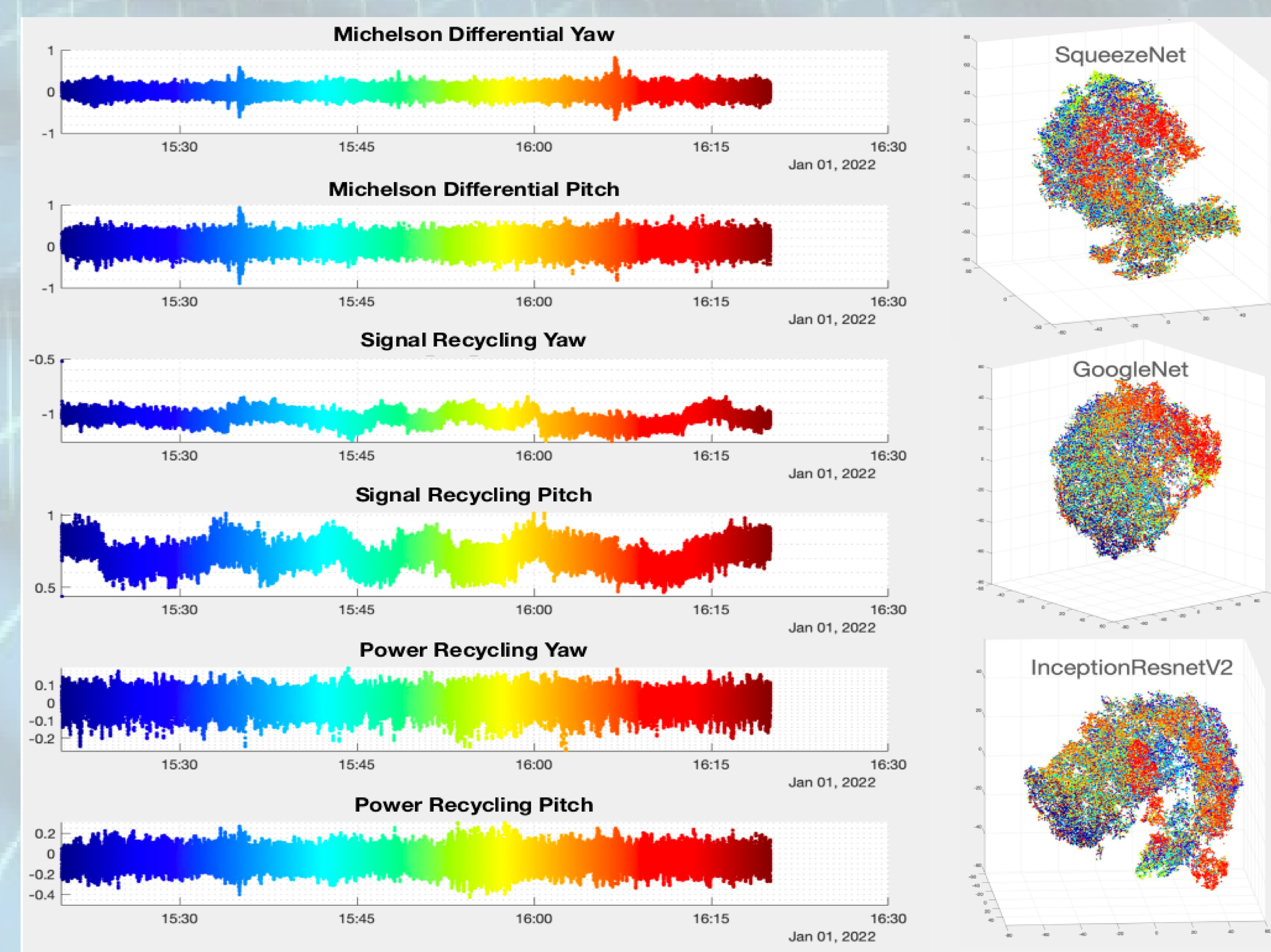
- Suspended optics susceptible to alignment perturbations
- Slow drifts over time due to variations in temperature and seismic levels
- Interference with the suite of optical squeezing and thermal compensation experiments carried out at GEO
- Critical to attain optimal sensitivity and maintain long lock stretches



- Video camera images of the darkport beam contain much information about the IFO state
- One-to-one mapping between the state of the IFO and the darkport image – image-to-time-series regression problem
- Neural sensor architecture – CNN-LSTM
- CNN architecture based on transfer learning
- Feature extraction capability and comparing the response to the temporal evolution of darkport images

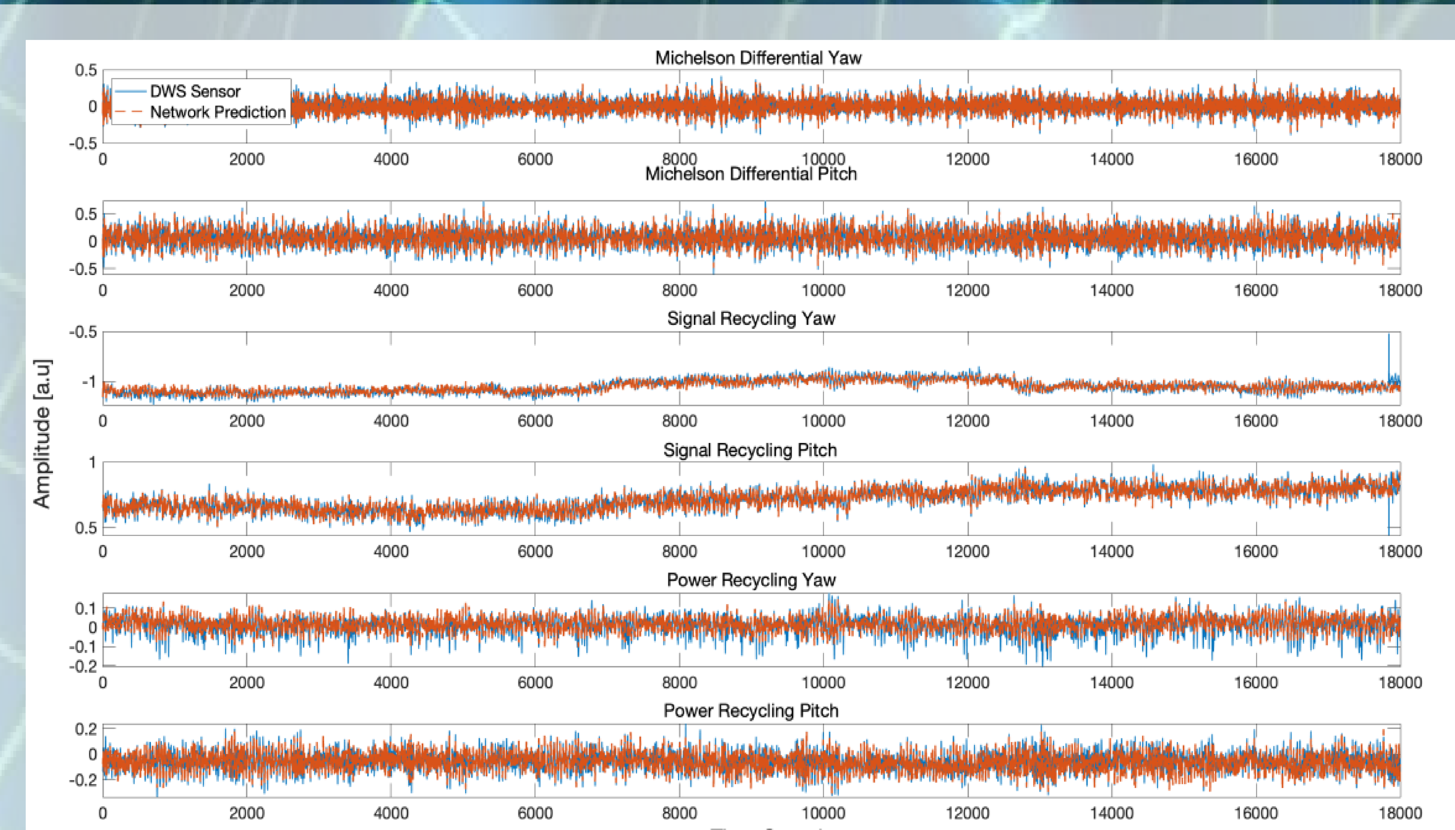


2. Neural sensing and control

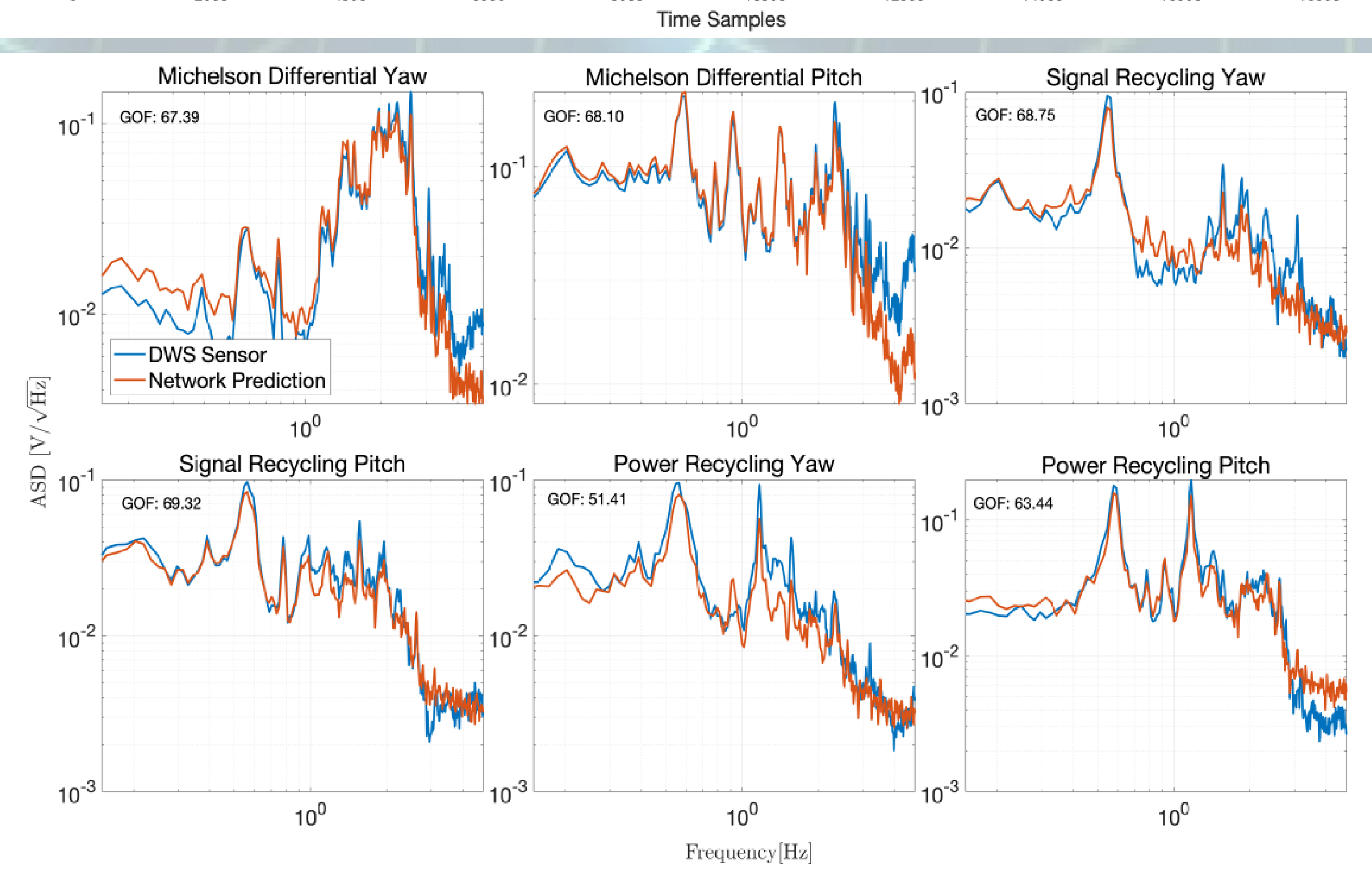


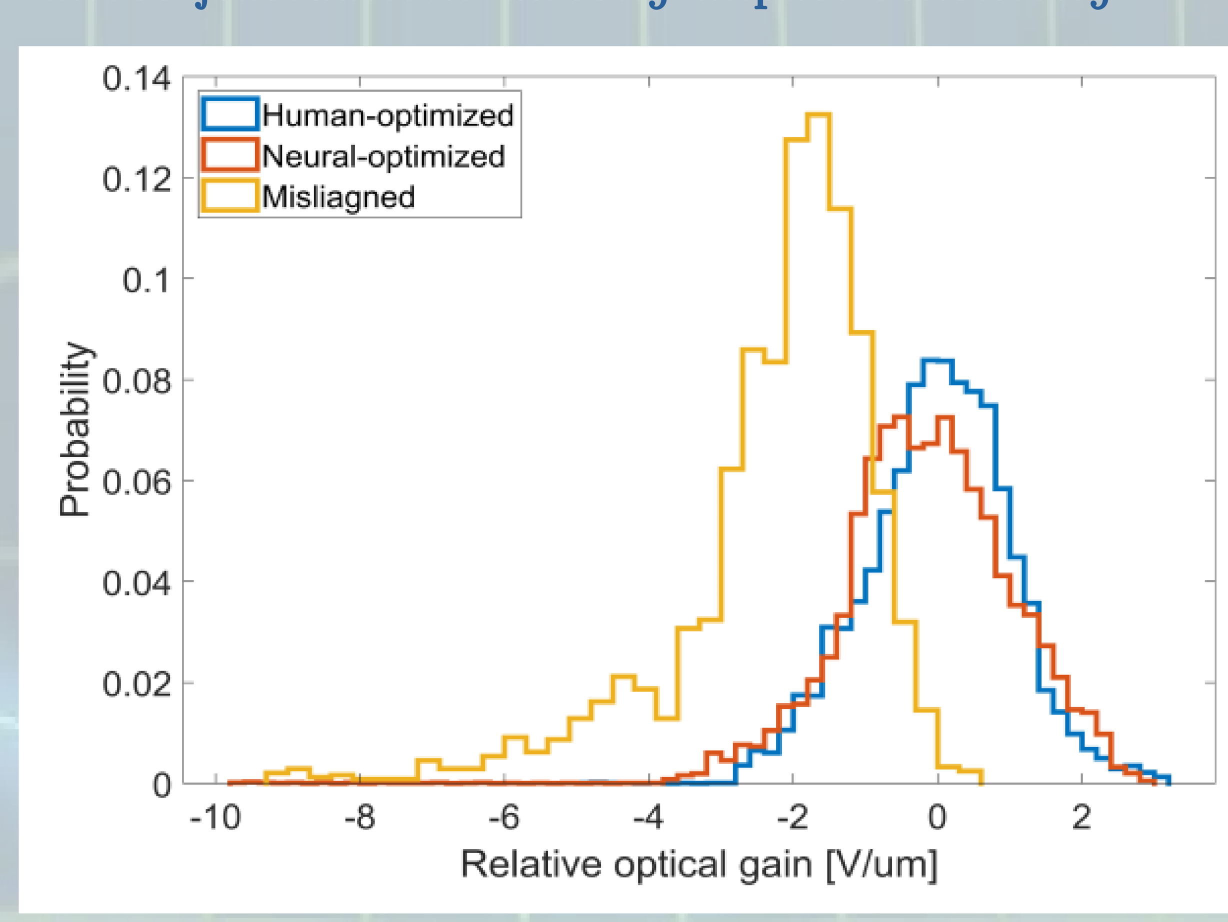
- The performance of different CNN-LSTM networks across different metrics
- Goal – predict the new error points whenever the detector gets into a misaligned state – PID and RL agent can set it to the last known "good" state
- Low integral error of PID and the faster response of RL
- Soft-Actor-Critic – fast learning rate, lower sensitivity to hyperparameters, ability to reuse fast experience, balanced trade-off between exploration and exploitation

3. Results



- One hour of darkport images
- Training on InceptionResnetV2-LSTM
- Comparison of neural network alignment predictions for the key optics in time and frequency domain with the measurements from the differential wavefront sensor
- The network has the ability to capture most of the spectral features
- A robust way to assess the neural system's performance is the interferometric optical gain, whose fluctuations directly impact sensitivity





4. Conclusions and outlook

- AI-assisted autonomous sensing and control will play a major role in the operation of IFOs, including automated alignment and multi-cavity locking
- Development of a deep neural network scheme to extract meaningful information about the state of the IFO and reconstructed the alignment error signal using the data from the GEO600 observatory
- Implementation of a control loop that uses this neural sensor and achieved drift control of the signal recycling mirror using deep RL, leading to improved overall sensitivity
- This work is the first of its kind of control, where ML-based control is applied to a km-scale GW IFO
- One of the future goals – higher bandwidth version of this neural scheme

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