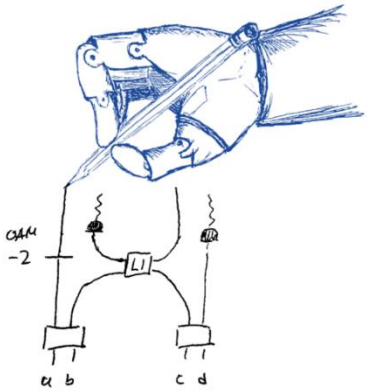
GWADW, Elba, Italy, 23.05.2023

Digital Discovery of Interferometric Gravitational Wave Detectors

with Yehonathan Drori, Rana X. Adhikari (Caltech, LIGO)



MAX PLANCK INSTITUTE
FOR THE SCIENCE OF LIGHT

Mario Krenn

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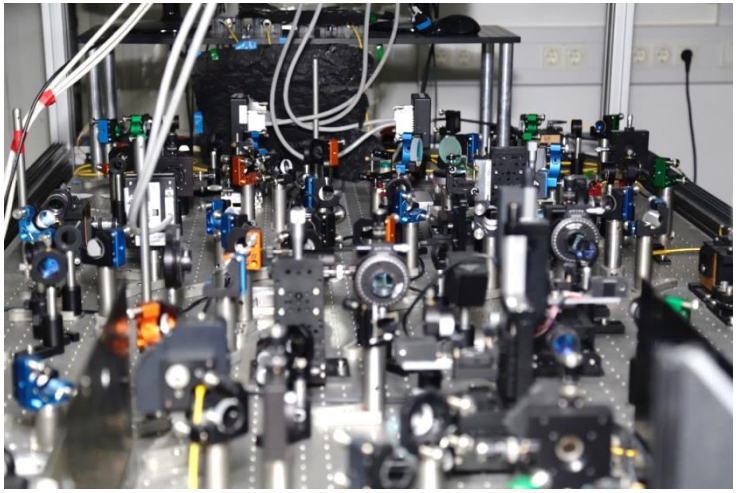
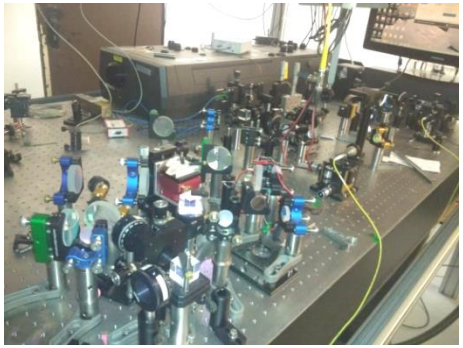
Computer-designed quantum experiments

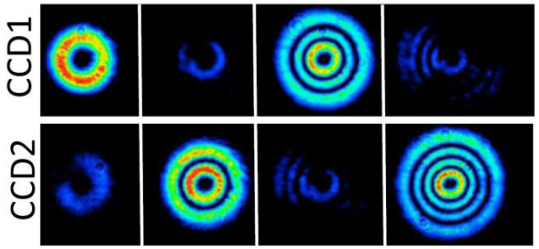
MK, Malik, Fickler, Lapkiewicz, Zeilinger, *PRL* **116**, 090405 (2016).
MK, Erhard, Zeilinger, *Nature Reviews Physics* **2**, 649 (2020).

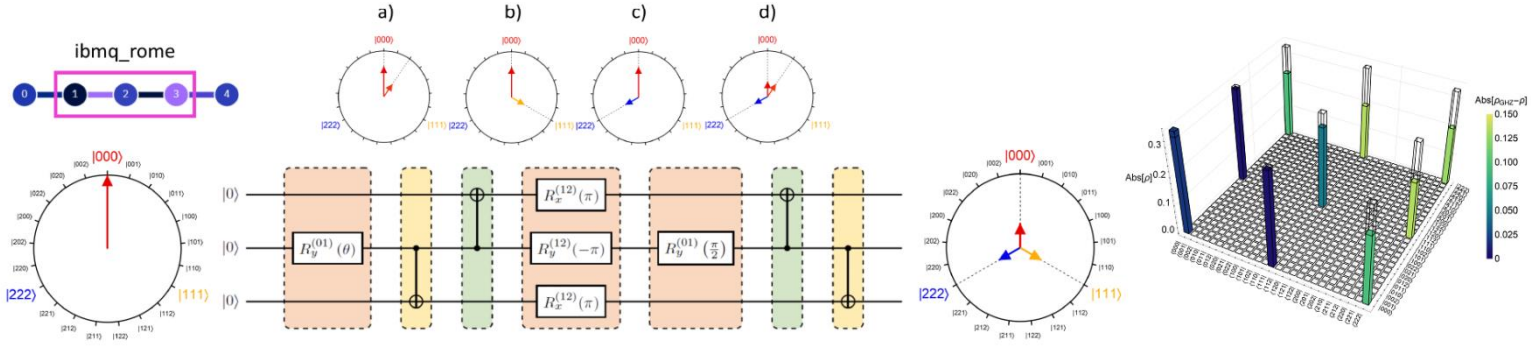
First experimental multipartite high-dimensional entanglement



New ways to control & measure photons







First multipartite high-dim entanglement in superconducting Quantum Computer

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Computer-designed GW detectors: The enormous search space

Some examples (without symmetry):

3 lasers, 3 BS, 3 detectors: 1000 combinations

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Computer-designed GW detectors: The enormous search space

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3 lasers, 3 BS, 3 detectors: 1000 combinations

5 lasers, 5 BS, 5 detectors: 81,000 combinations (!)

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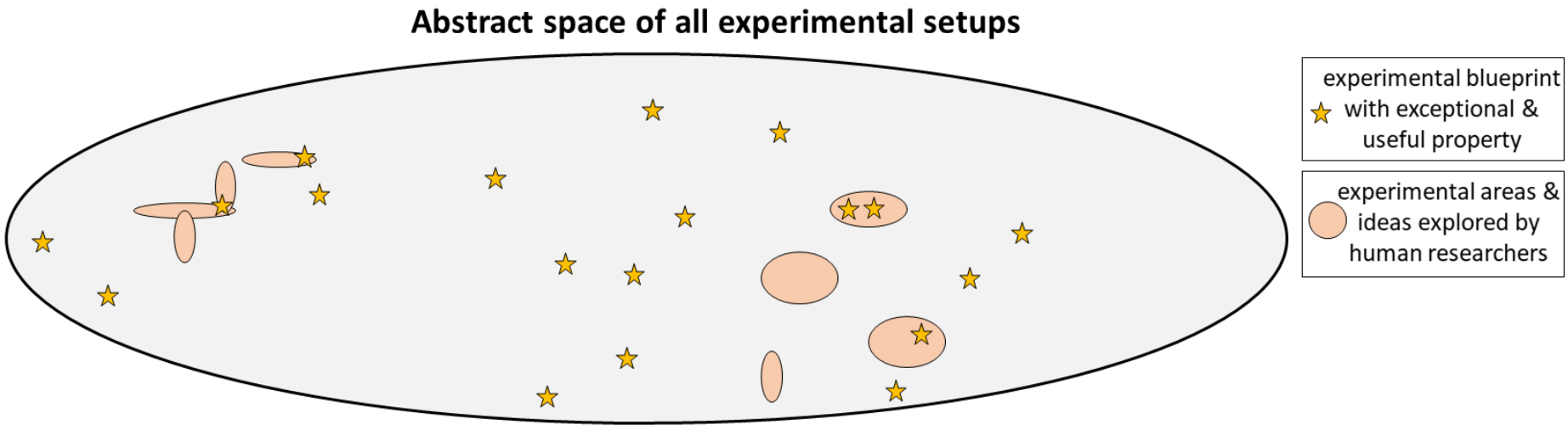
Computer-designed GW detectors: The enormous search space



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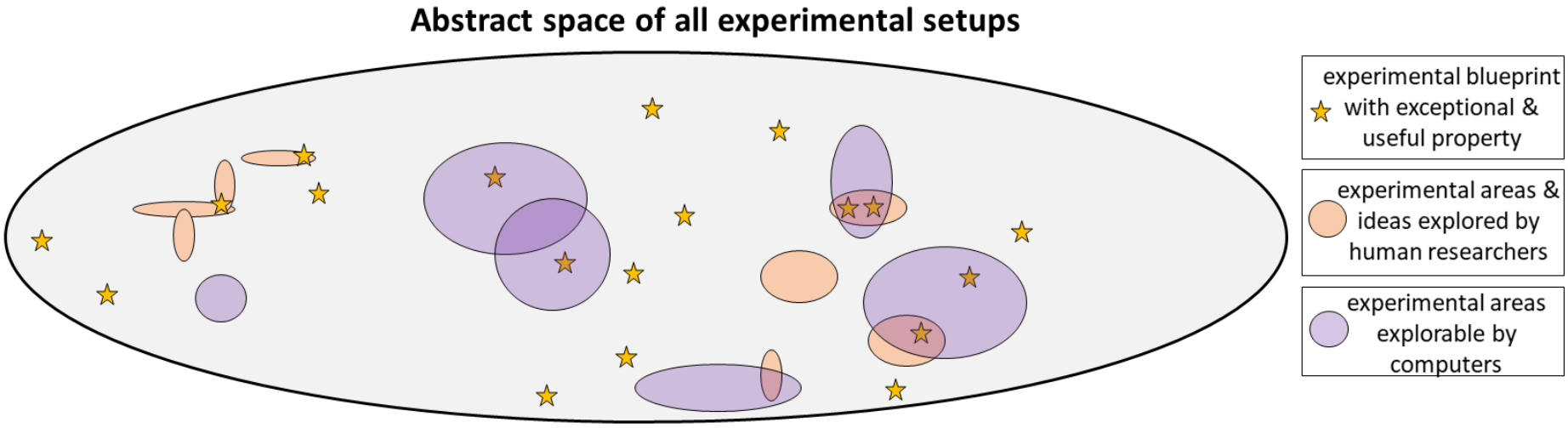

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Computer-designed GW detectors:

Discrete & continuous optimization problem:

Finding suitable topology and parameters

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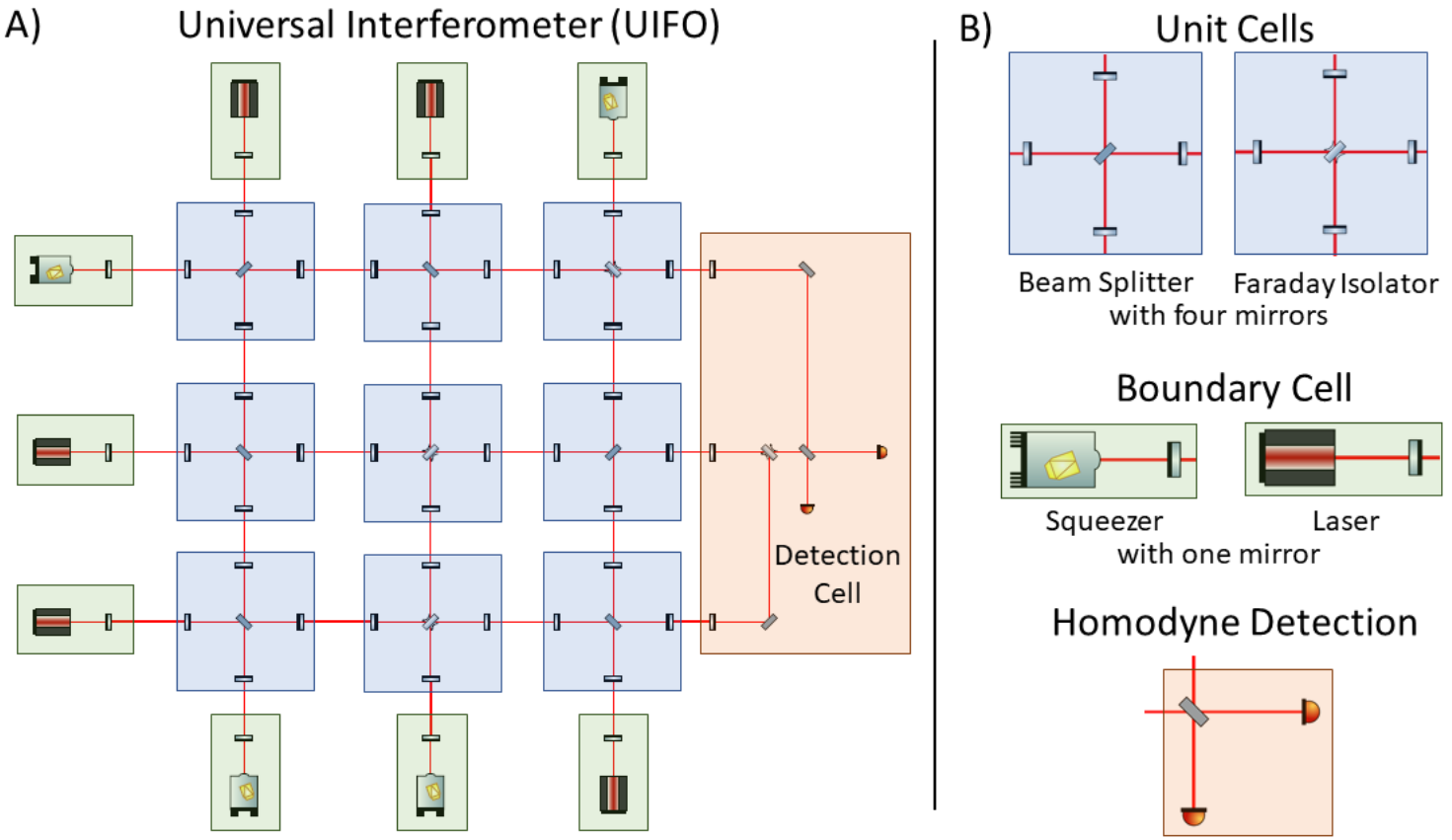
Computer-designed GW detectors:

Discrete & continuous optimization problem:

Finding suitable topology and parameters

Reformulation as quasi-continuous problem



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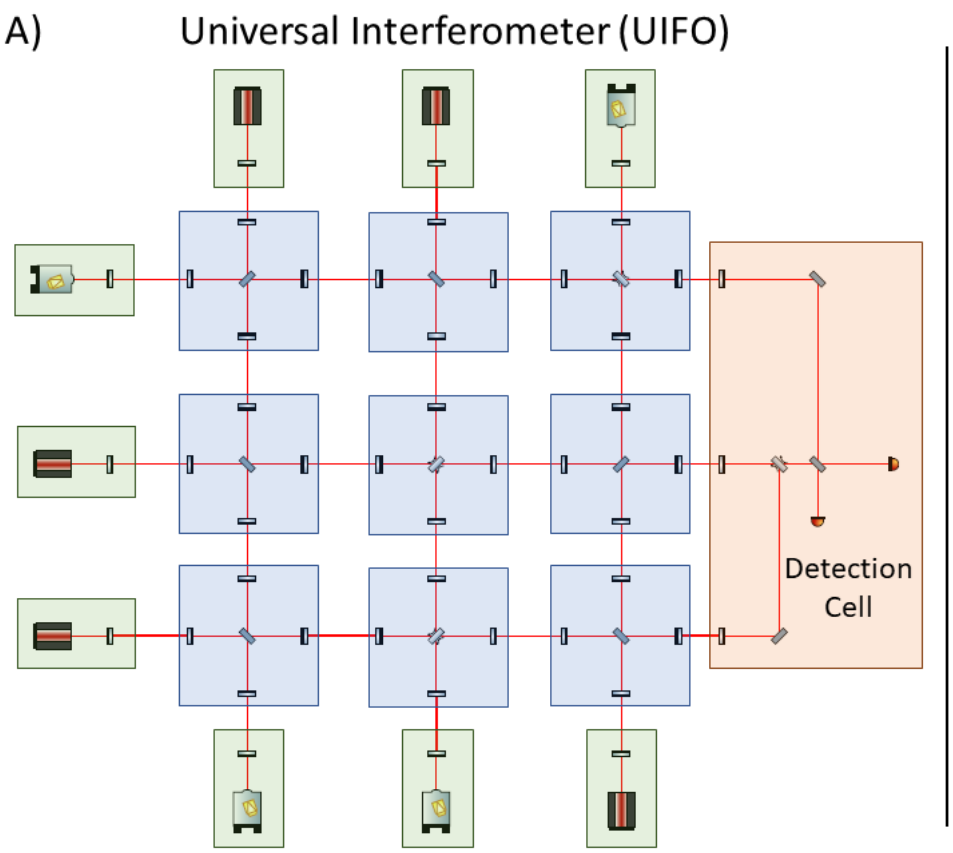
Computer-designed GW detectors:

Discrete & continuous optimization problem:

Finding suitable topology and parameters



Voyager-like constraints

	Min	Max
Optical path	1 cm	4 km
Mass	10 g	200 kg
Loss	5 ppm	
Transmissivity	15 ppm	
Squeezing		10 dB
Power Transmission		2 kW
Circulating power		3.5 MW

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Computer-designed GW detectors: Simulation assumptions

Finesse2 (assuming plane wave, assuming free masses, single carrier frequency)

$$Sensitivity = \frac{response}{noise}$$

Response: modulating the spaces & measuring the demodulated signal at the readout

Quantum Noise: computed by Finesse

Classical noise: projecting laser noises (taken from O3 performance paper [PRD *102*(6), 062003, 2020]) of all the sources on to the readout. Thermal and seismic noise added to noise budget, from same paper.

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Computer-designed GW detectors: Global & Local optimization

Maximization of strain sensitivity in frequency range, under constraints

- Pool of 1000s initial conditions
- Simultaneous 1000 **local** optimization of parameter
  (gradients & higher-order derivatives, similar to NN)

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Compare to: Voyager and Voyager local optimized
every improvement must be new superior topology.

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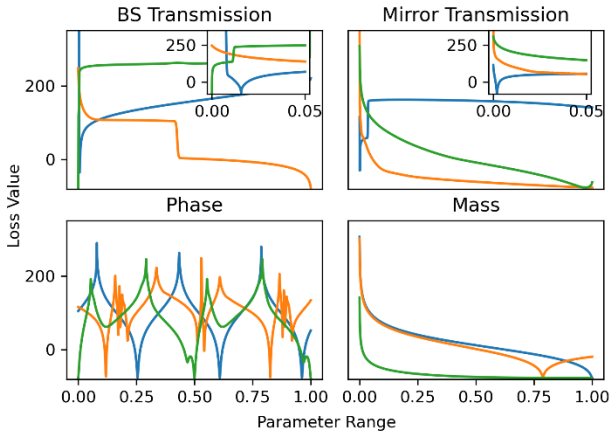

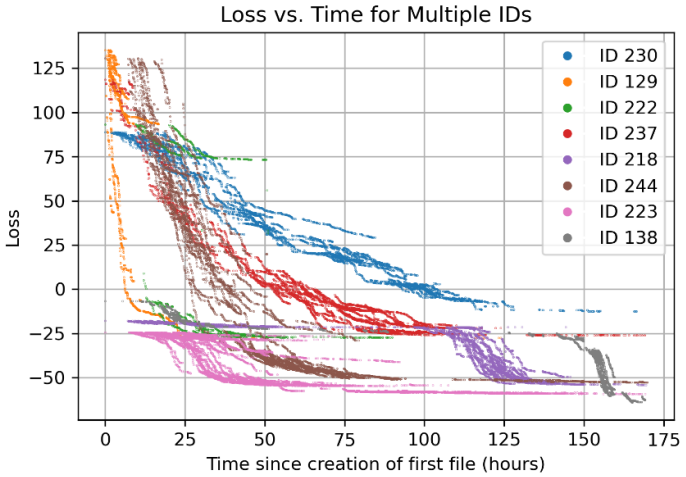

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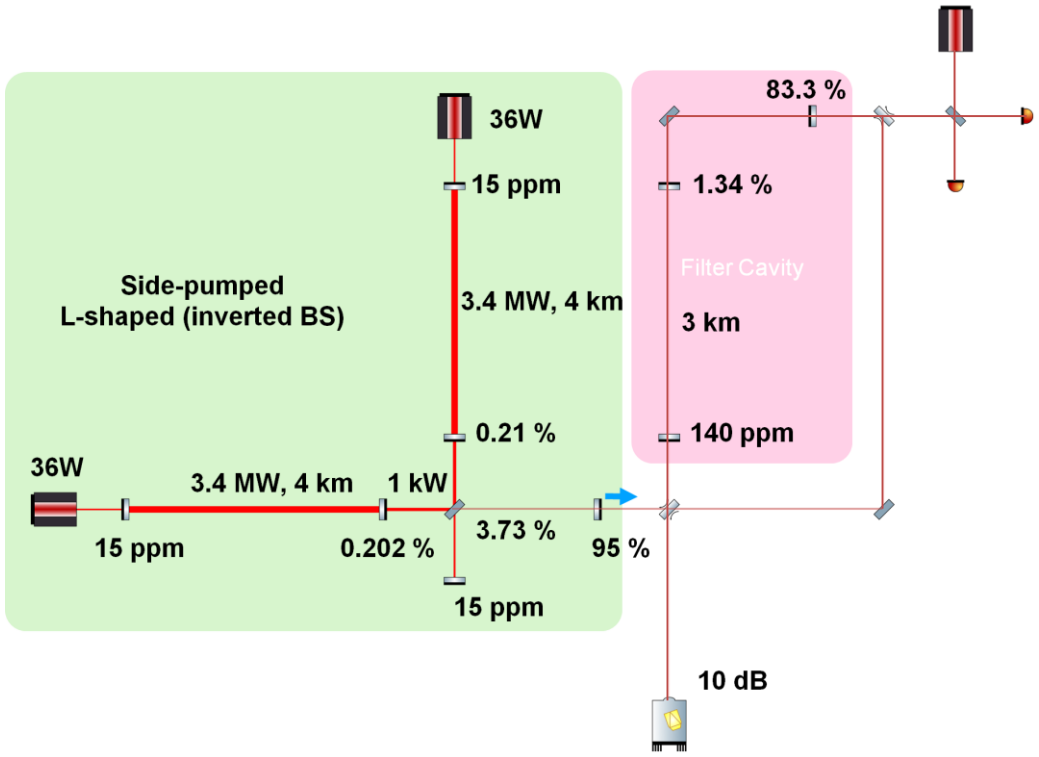
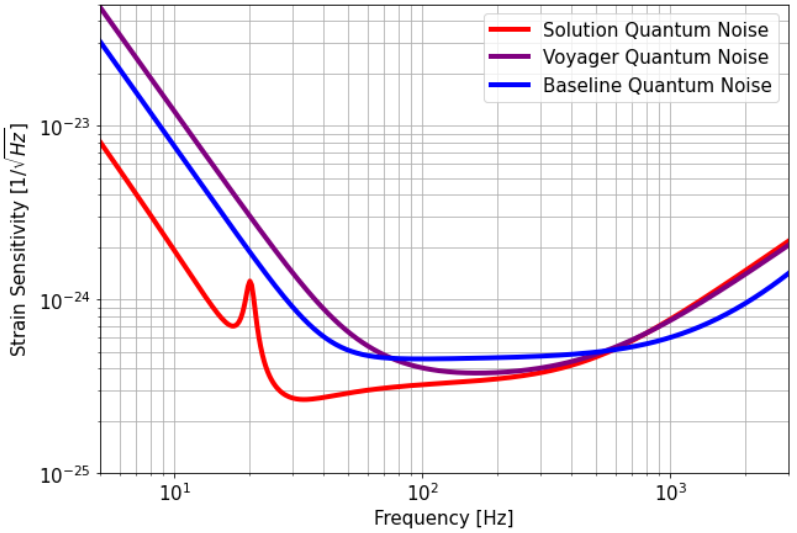
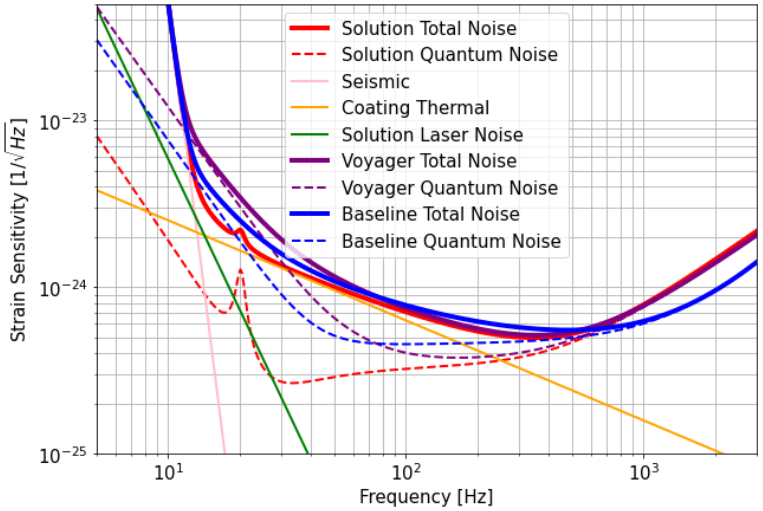
Computer-designed GW detectors: Results: 20Hz-5kHz







Coating thermal noise limits this improvement

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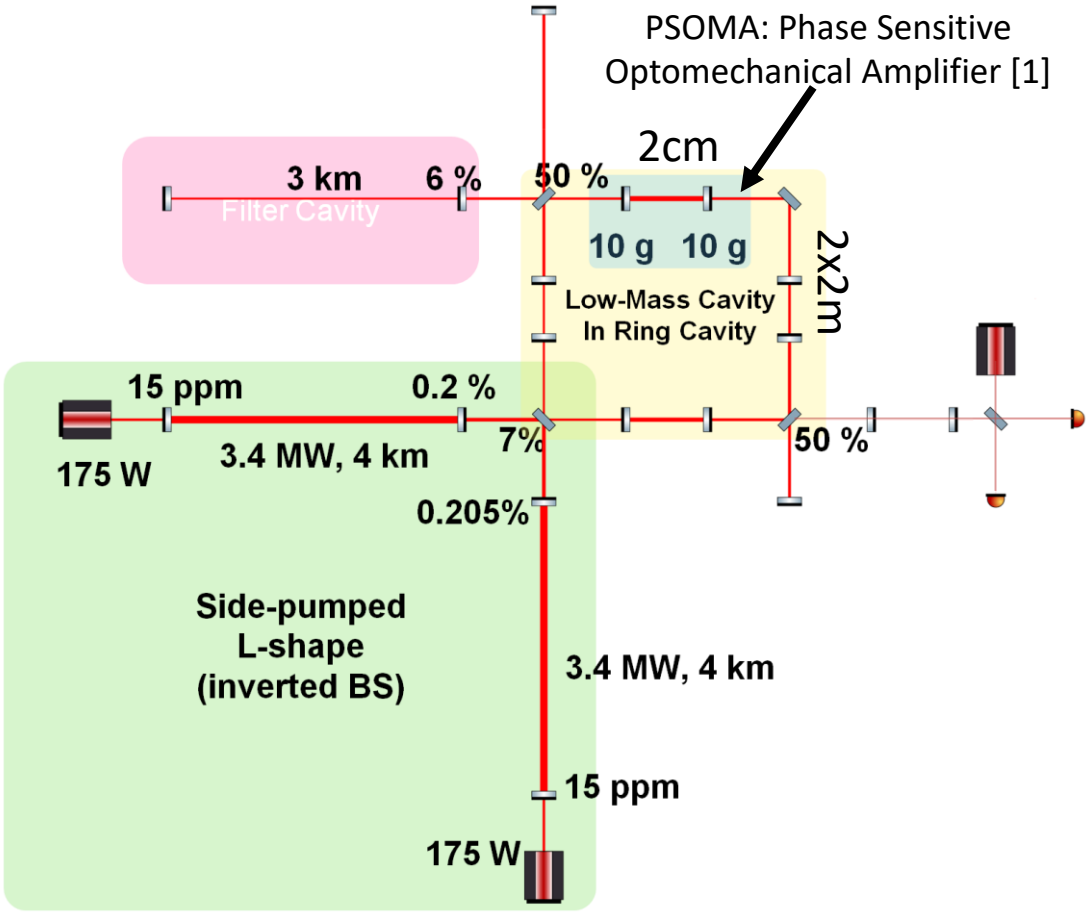
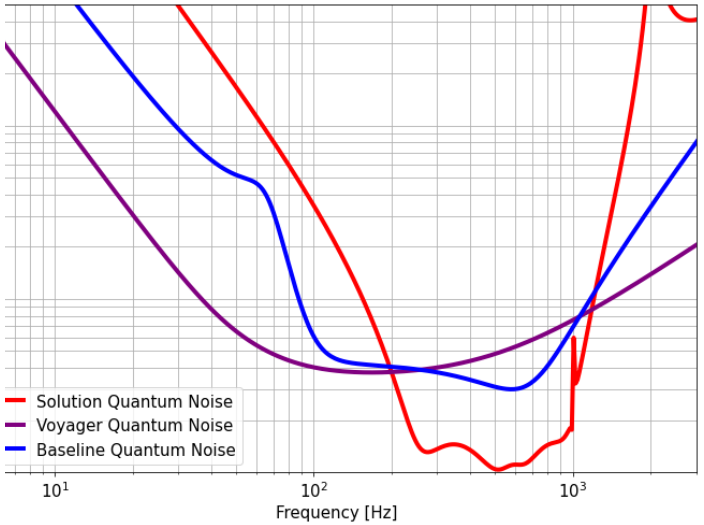
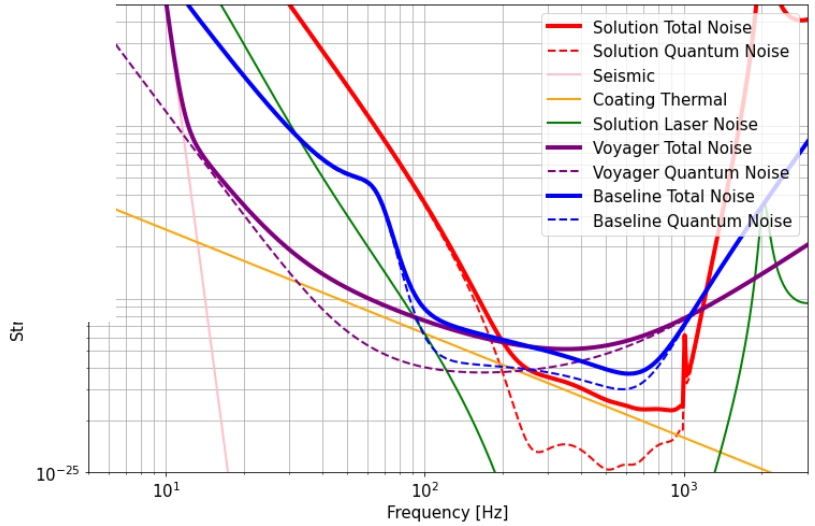
Computer-designed GW detectors: Results: 200Hz-1kHz







[1] Bai, et al., *PRA* **102**(2), 023507 (2020).

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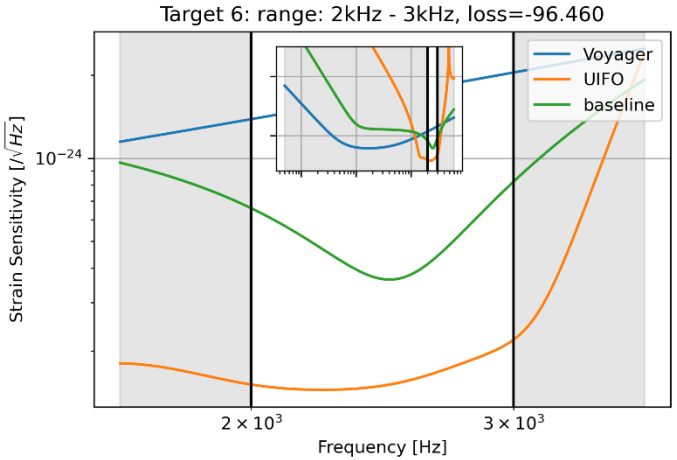
Computer-designed GW detectors: Results

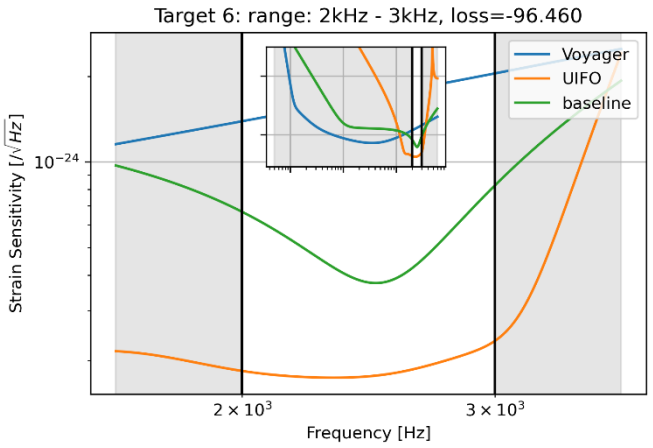
2kHz-3kHz

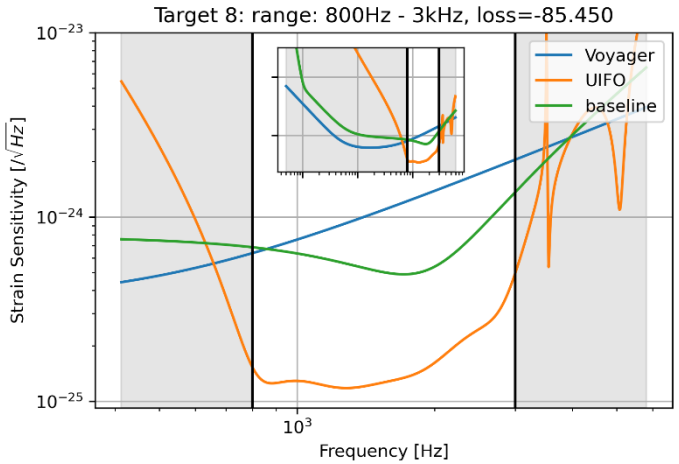
800Hz-3kHz

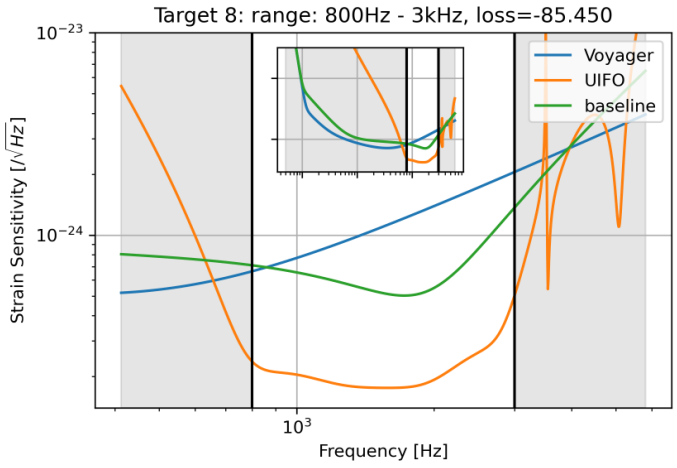
quantum, frequency, intensity noise

including thermal, seismic noise









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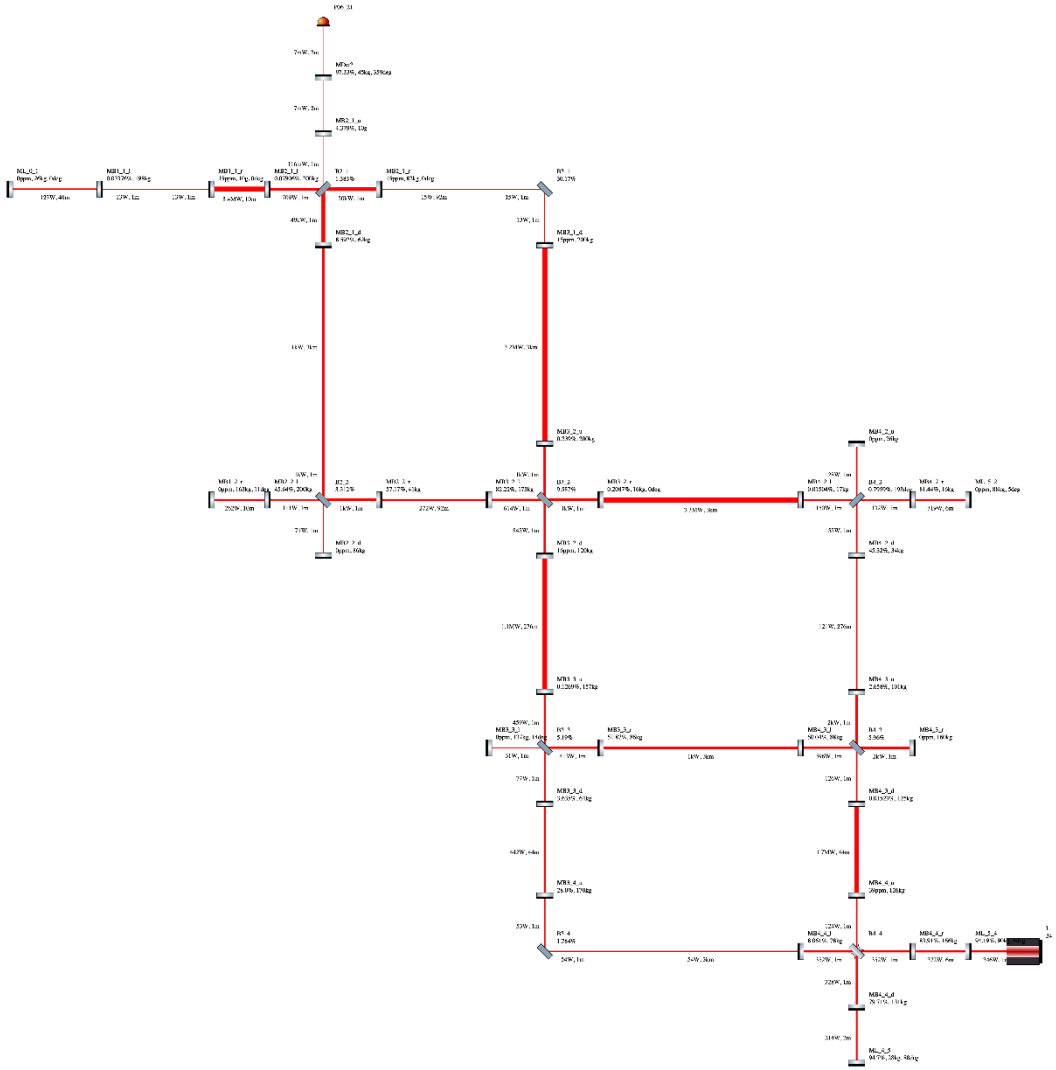
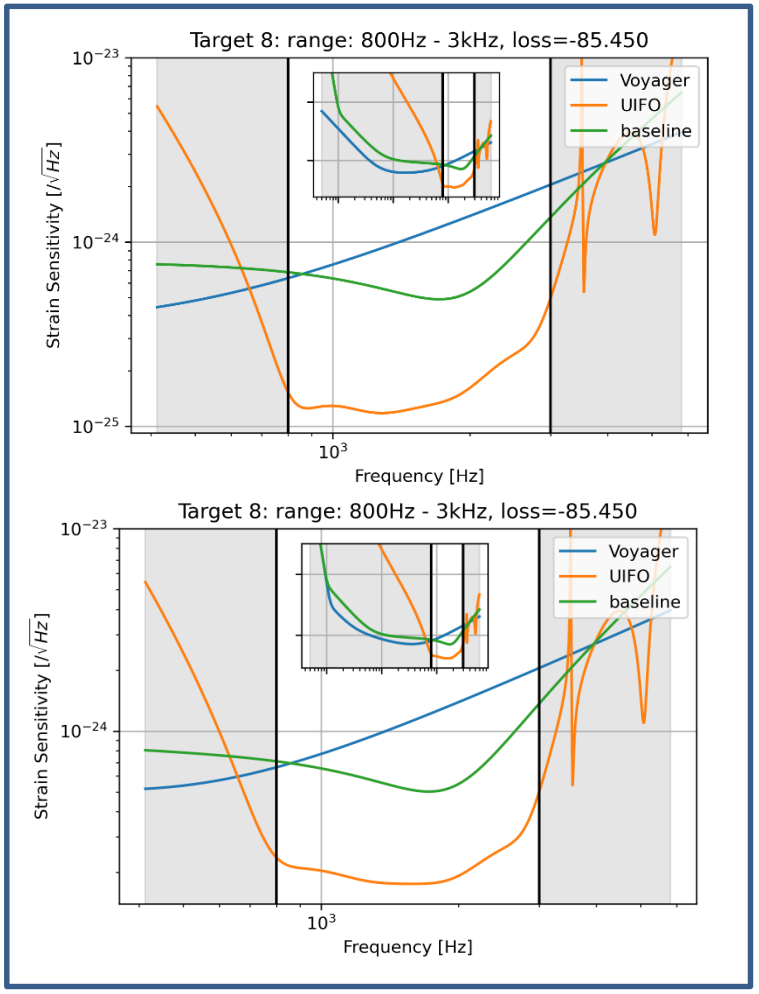
Computer-designed GW detectors: Results



800Hz-3kHz



Computer-designed GW detectors: Conclusion

Top-Solution Setups:

Can they be conceptualized?
Are they new?
Are they useful?

We have about 100 different solutions each might contain new ideas we could discover.

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The larger and more complex the search space, the larger the chances for *highly unorthodox solutions*

- Beyond free masses
- Beyond single carrier frequency
- Generalized measurements
- Two-mode squeezing & entanglement
- Nonlinear optics

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Speed-up exploration

- Finesse-based speedup? Other simulation frameworks?
- ML-based speedup: Effective neural-network surrogate model, large language models for suggesting initial conditions

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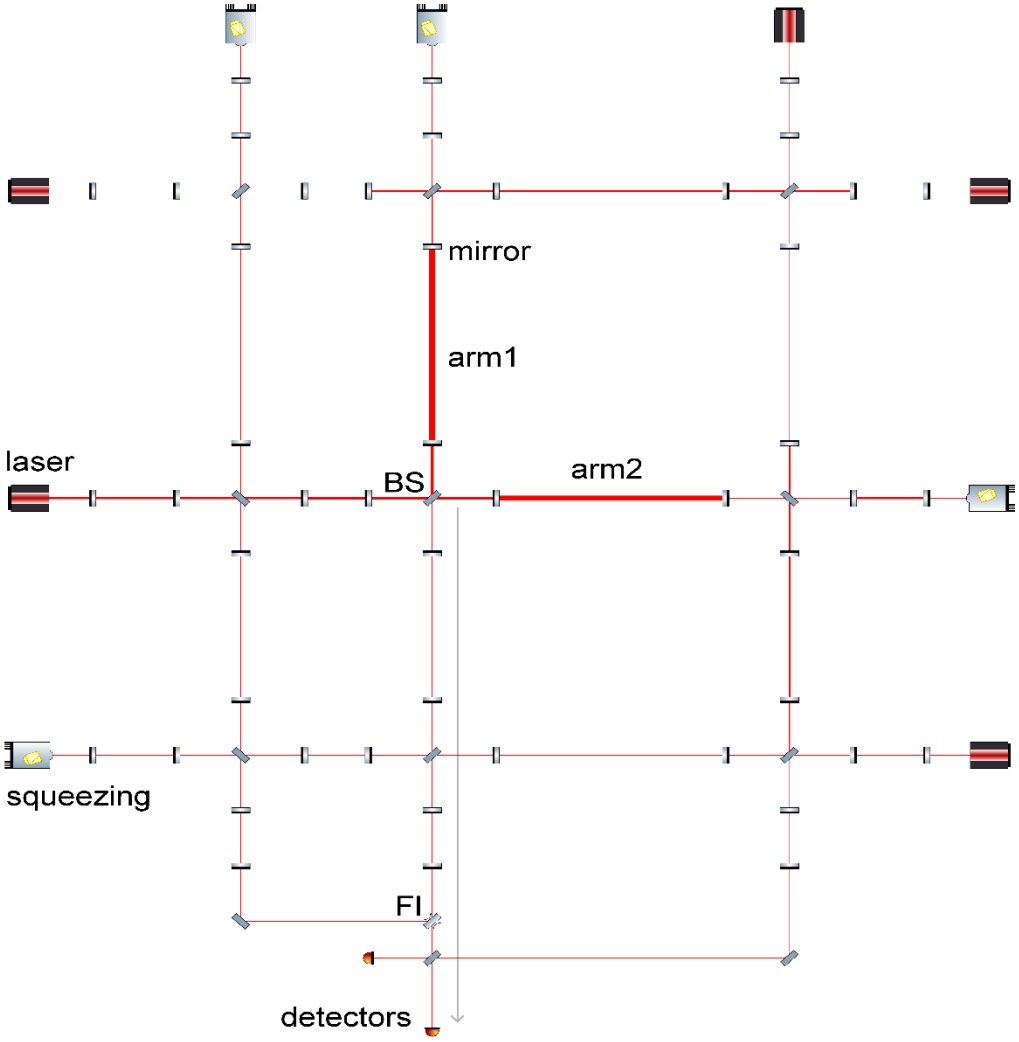
Computer-designed GW detectors: aLIGO in UIFO



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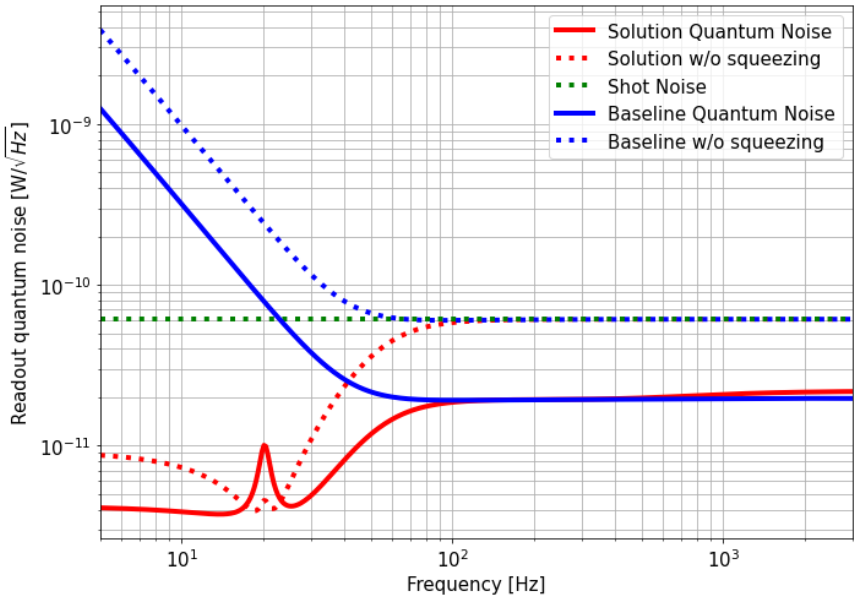
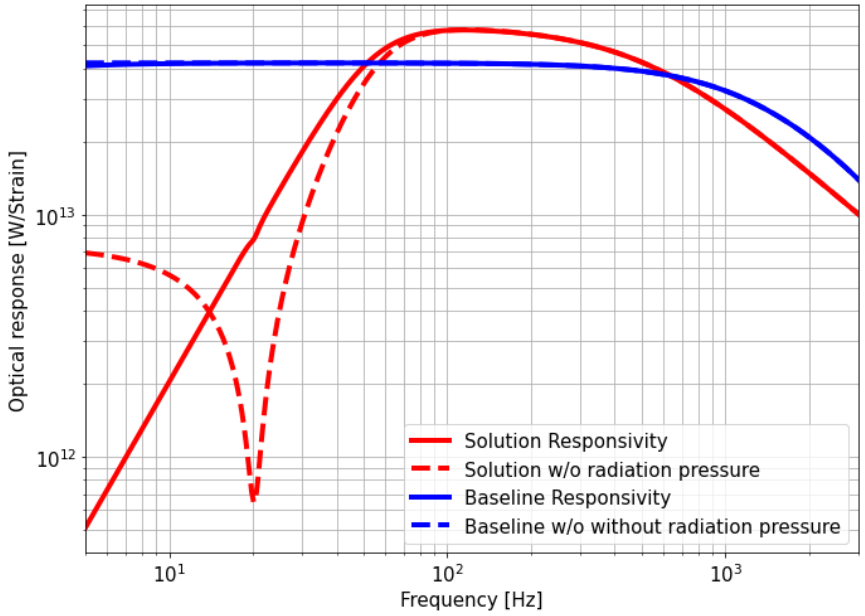
Computer-designed GW detectors: Noise and responsivity (Broadband)





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Computer-designed GW detectors: Noise and responsivity (Narrow Band)