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Lightsaber: A simulator of the angular sensing and control system in LIGO

Tomislav Andrić

Jan Harms

Hang Yu

Rana X. Adhikari

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Program

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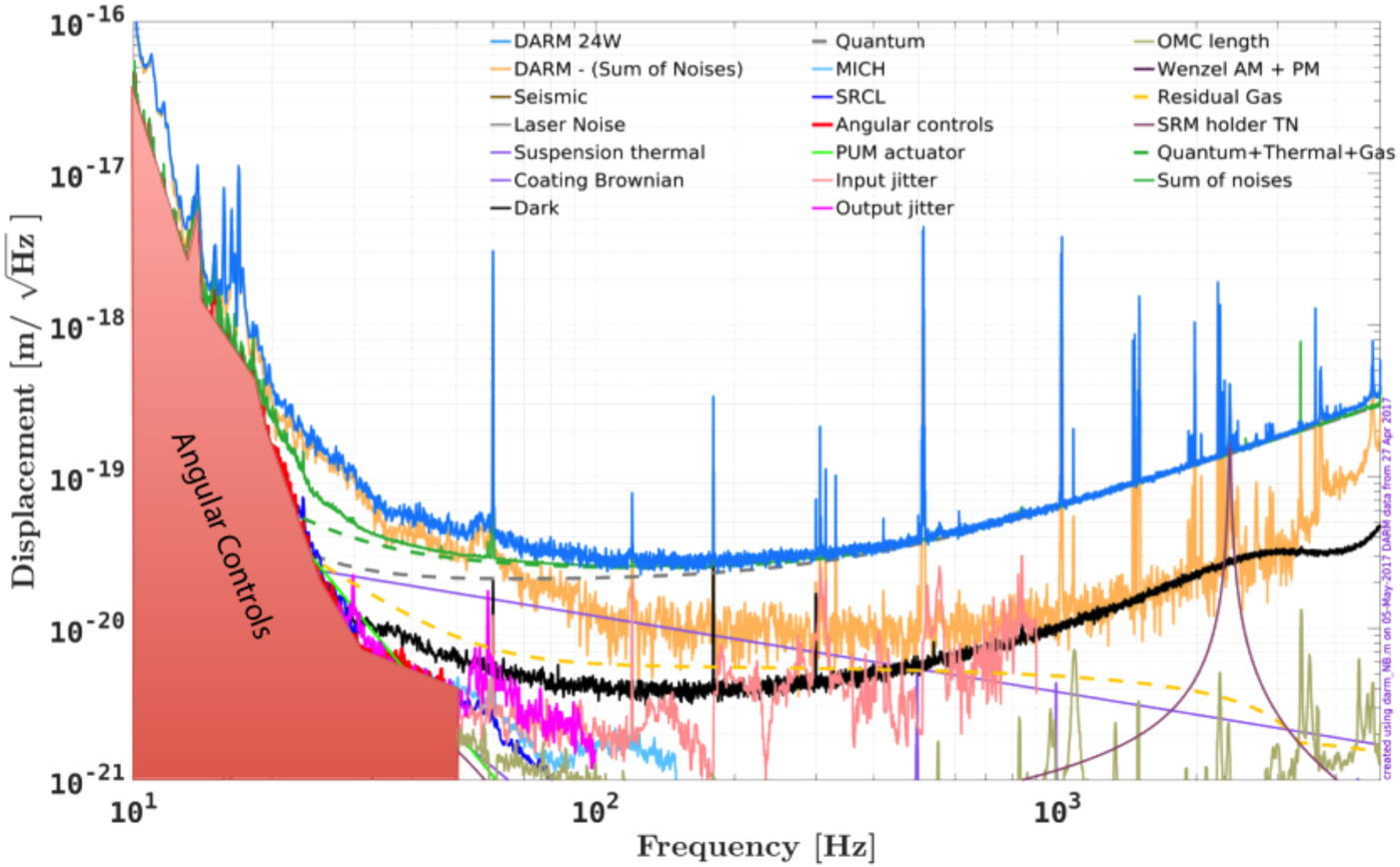
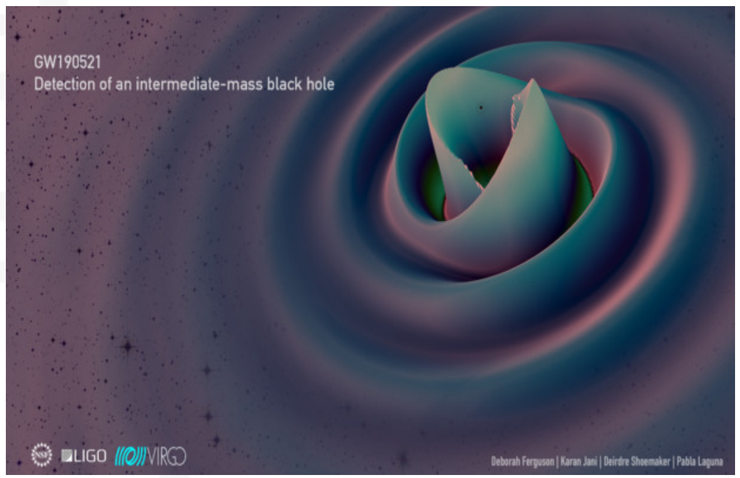
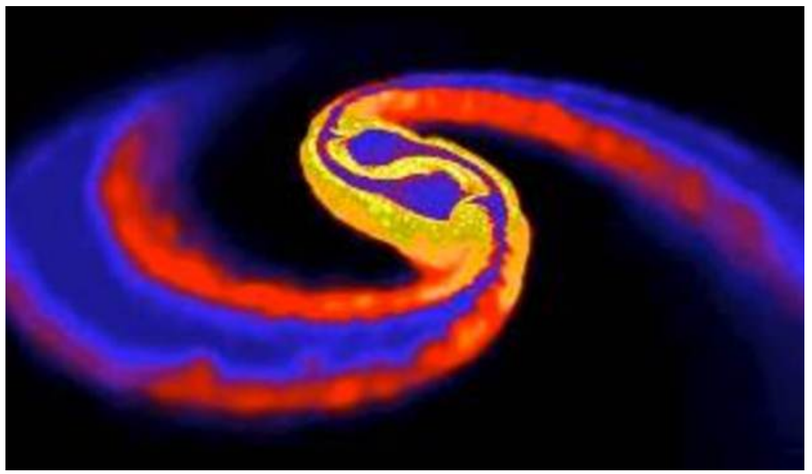
Importance and requirements

- LIGO – limited by ASC noise
- No straight-forward solution
- ET – issue needs to be addressed already with its design
- Low light power, increased mass of TM (reduce the angular optomechanical instabilities)

- Requirements:
  1. 1 nrad RMS
  2. Lowest possible noise above 10 Hz

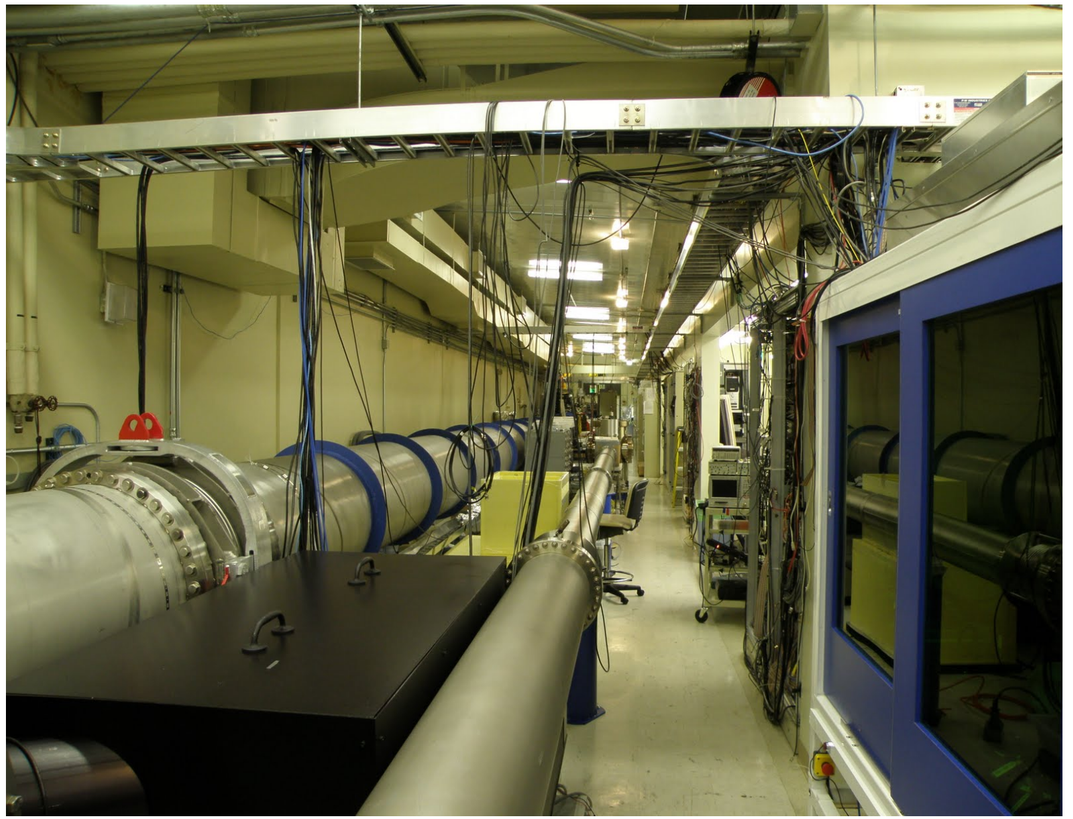


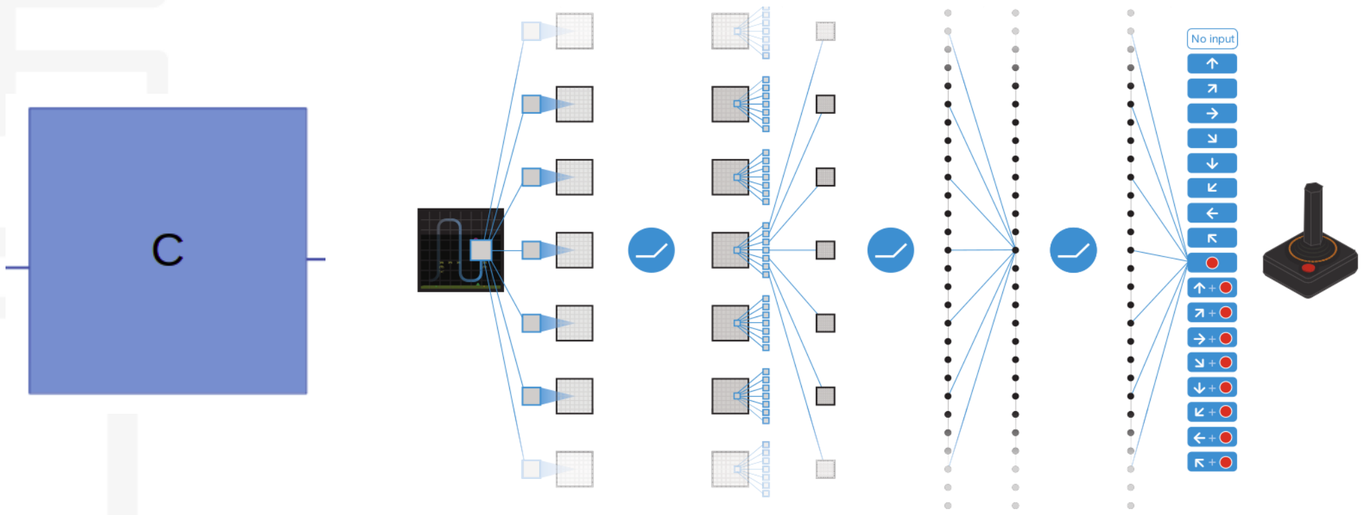


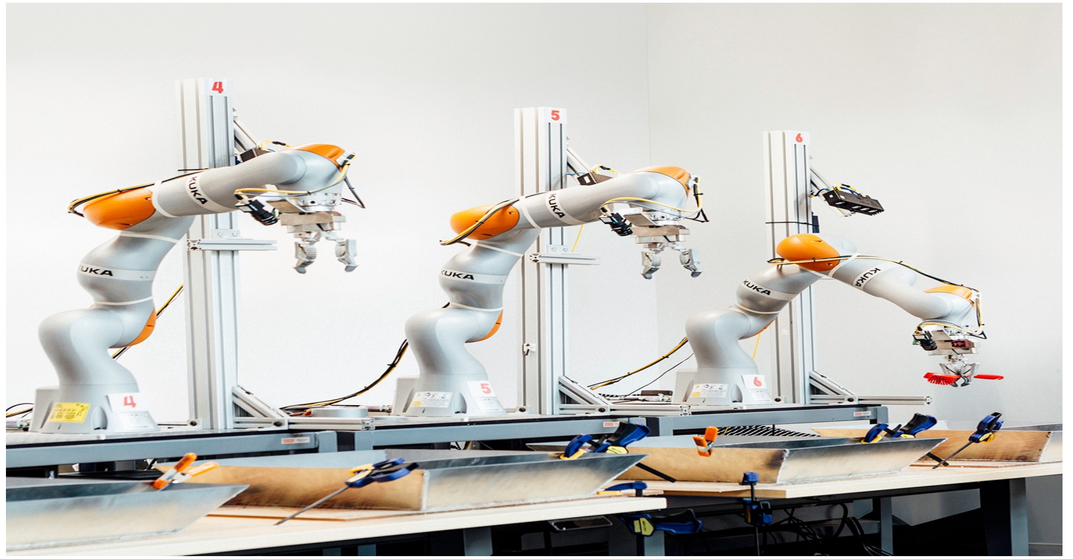


Ongoing activities and motivation

- Time domain simulations of the ASC – A2L coupling and strain noise
- Currently feedback is done by linear filter designed by commissioners
- ML to improve our feedback control
- Test nonlinear feedback control such as reinforcement learning – high demands (robust, stable and optimal) – will be developed and tested with the time-domain simulations
- Caltech 40m prototype – first experimental test
- DeepMind and Caltech

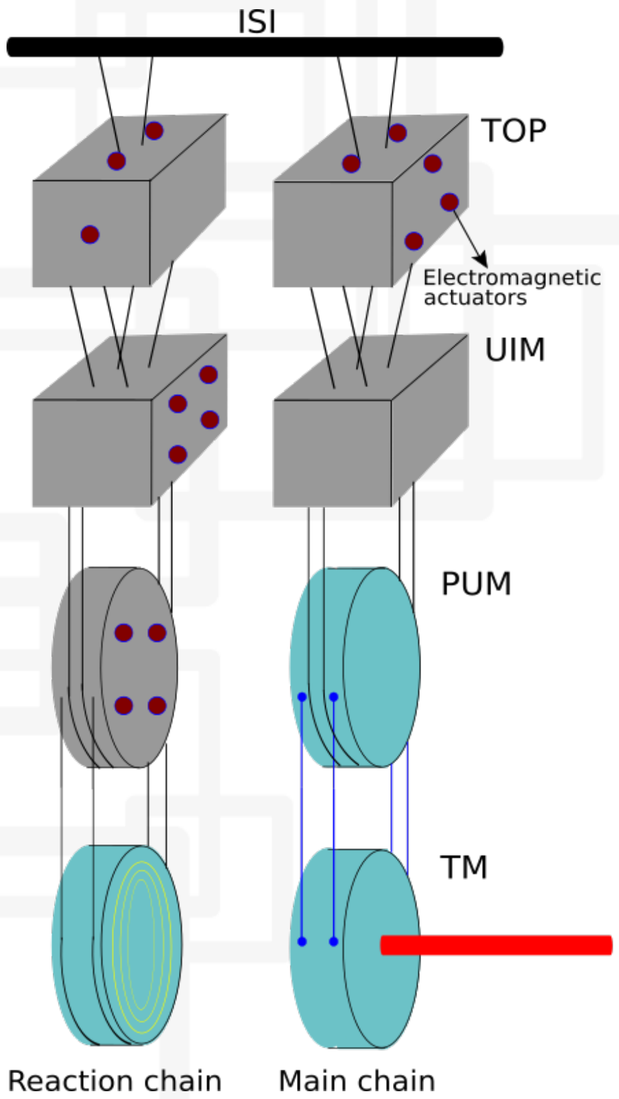


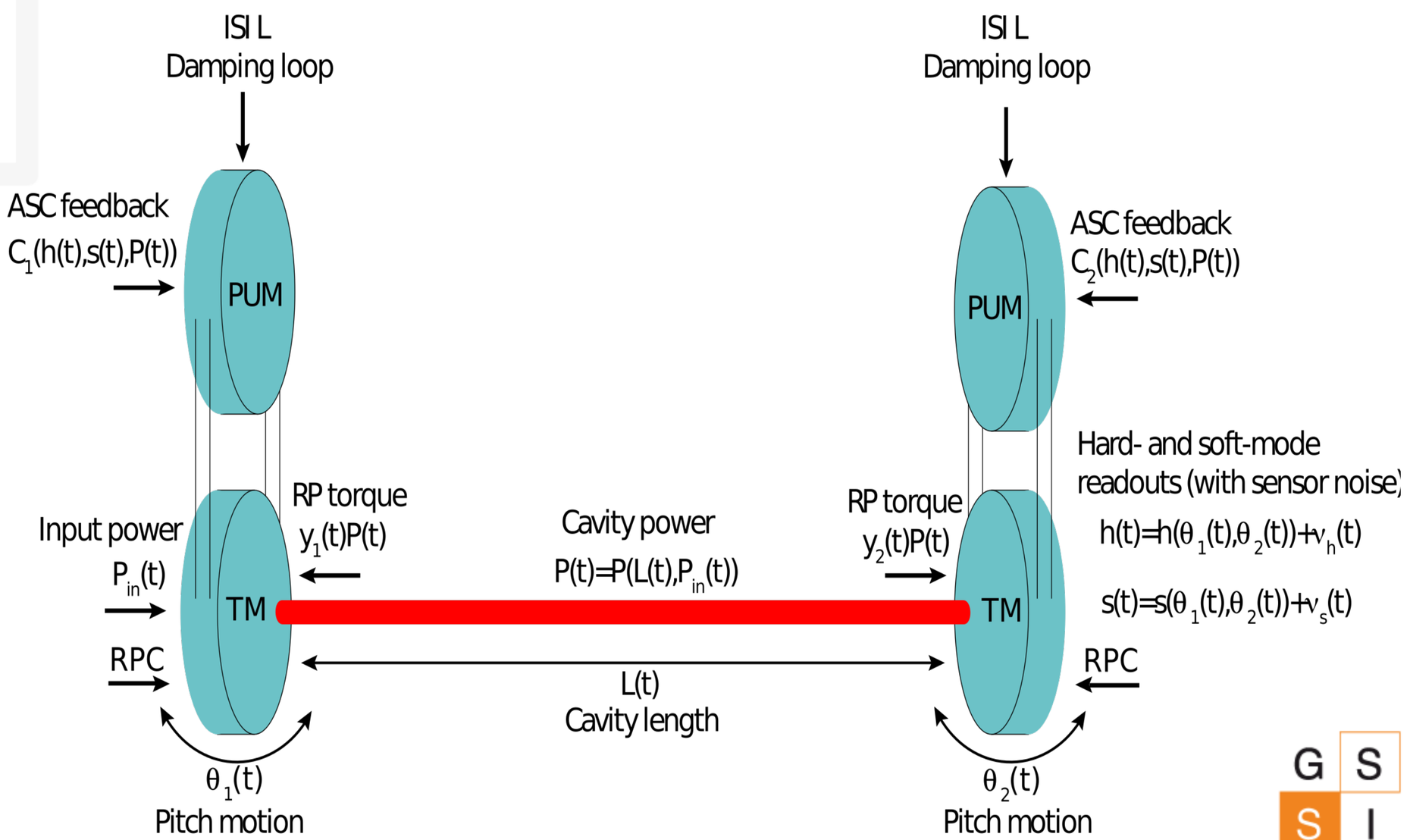




Overview

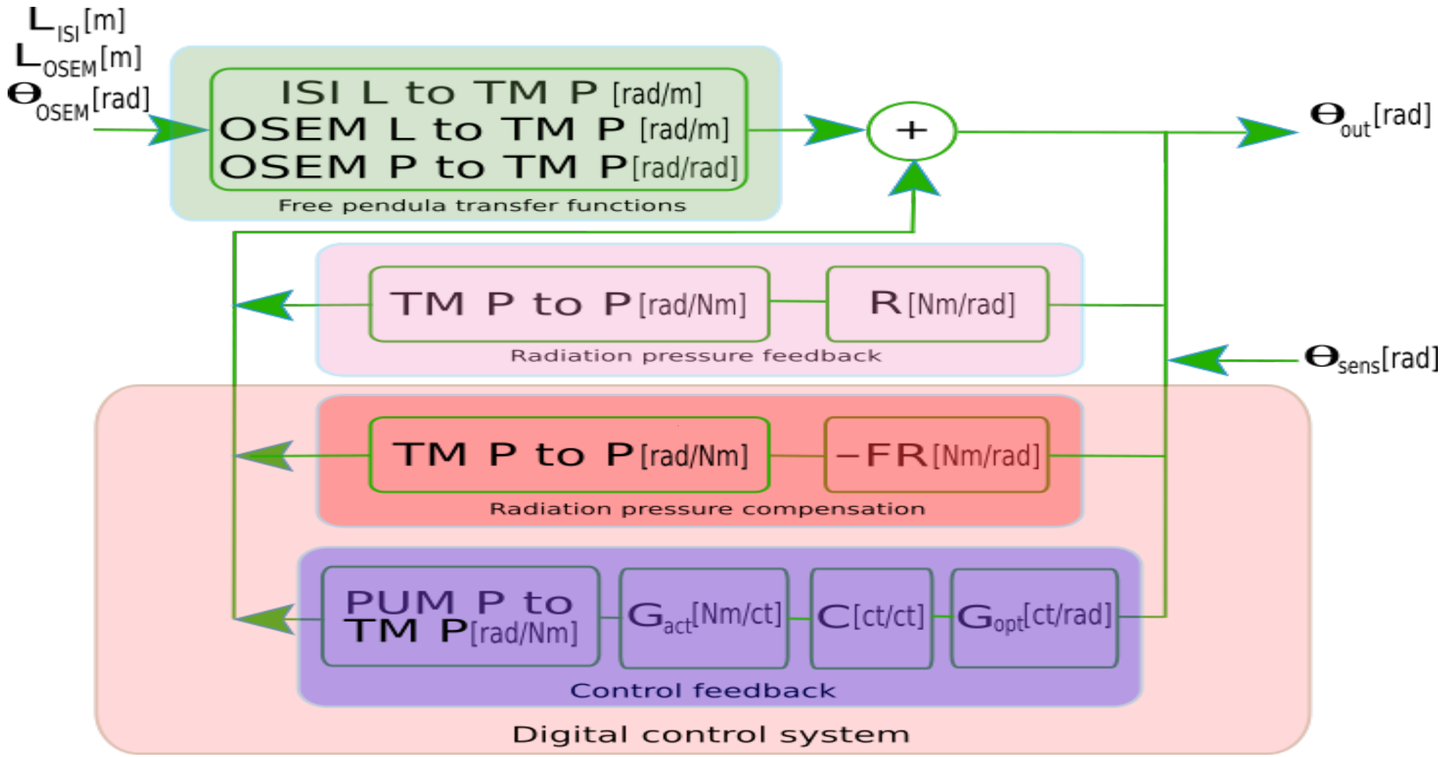
- The linear couplings of the simulation are based on state-space models, which means that also the zpk specifications of control filters are internally converted into state-space models

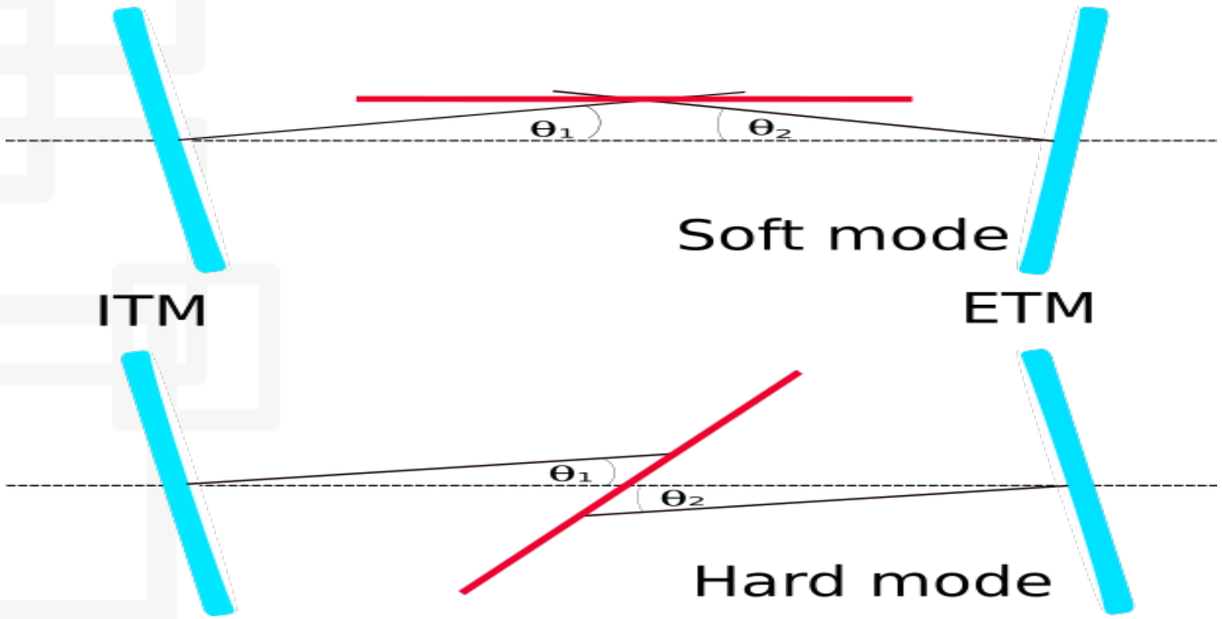


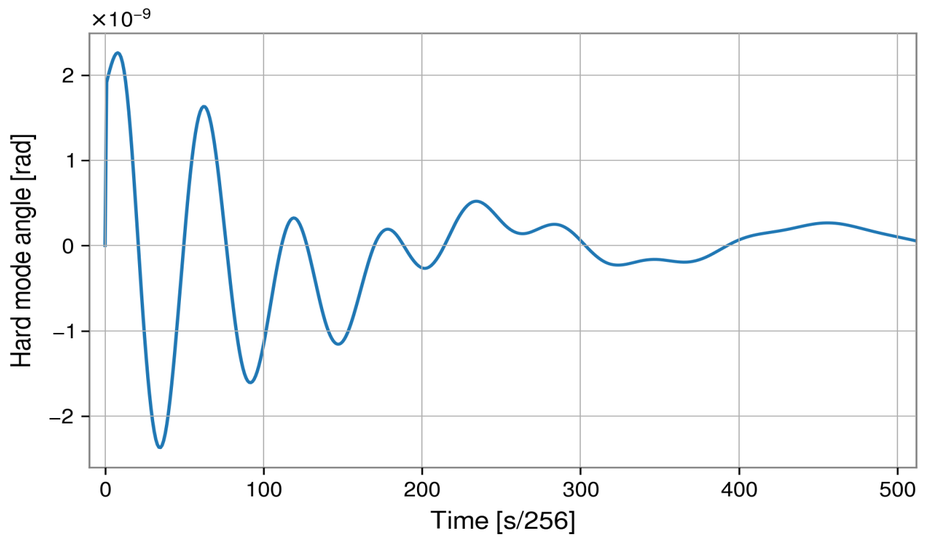


Optomechanical system

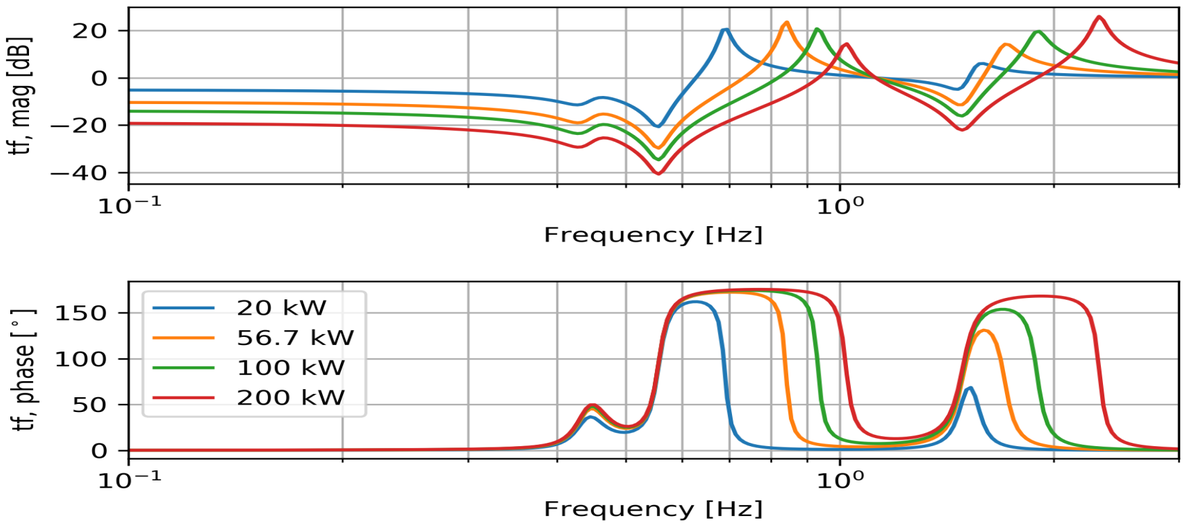
- Radiation pressure exerts torque on the suspended mirrors, adding to the fixed restoring torque of the suspension
- ASC allows us to operate IFO with angular mechanics dominated by RP
- Normal mode basis which decouples the effects of RP in 2 independent modes
- Sidles-Sigg effect



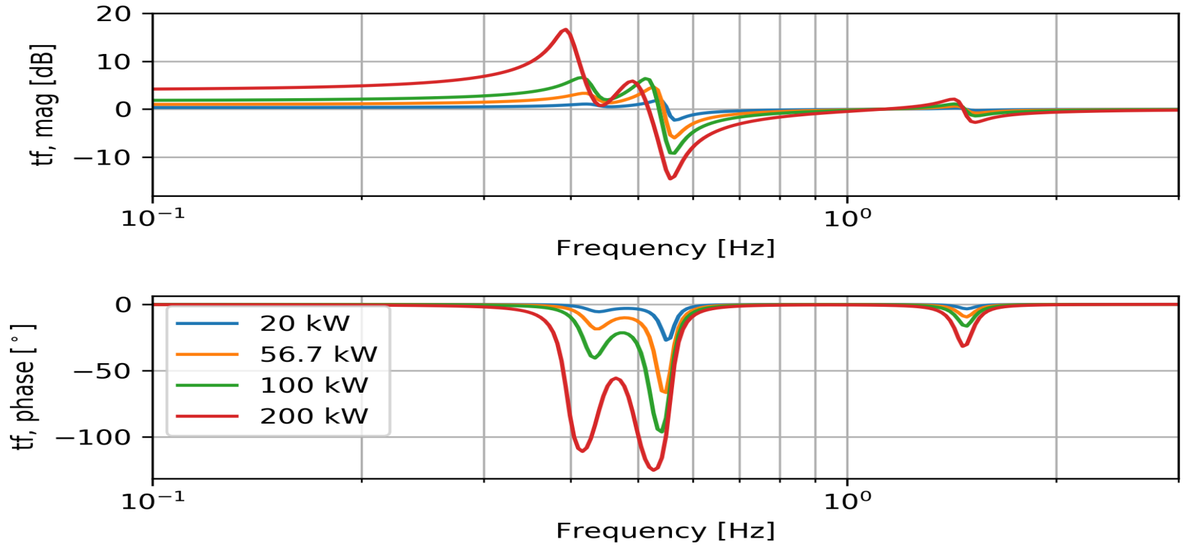




Optomechanical system

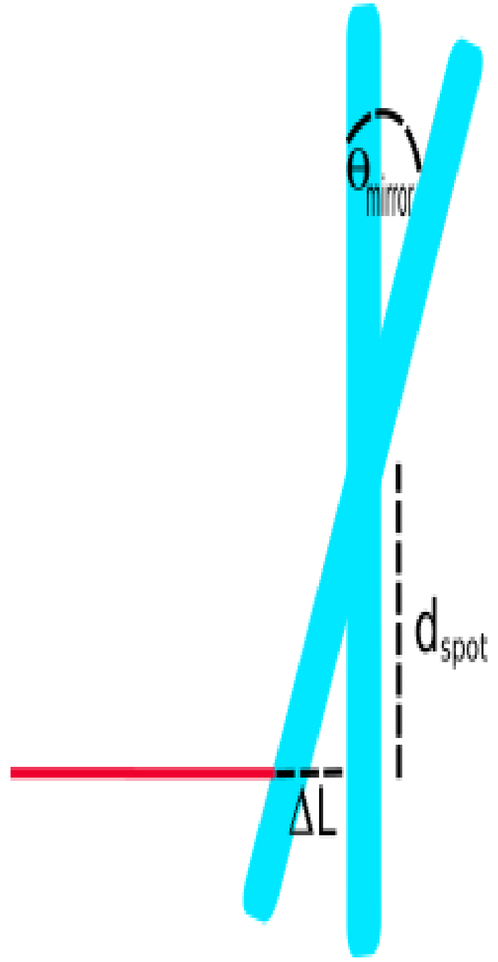


a) Hard mode



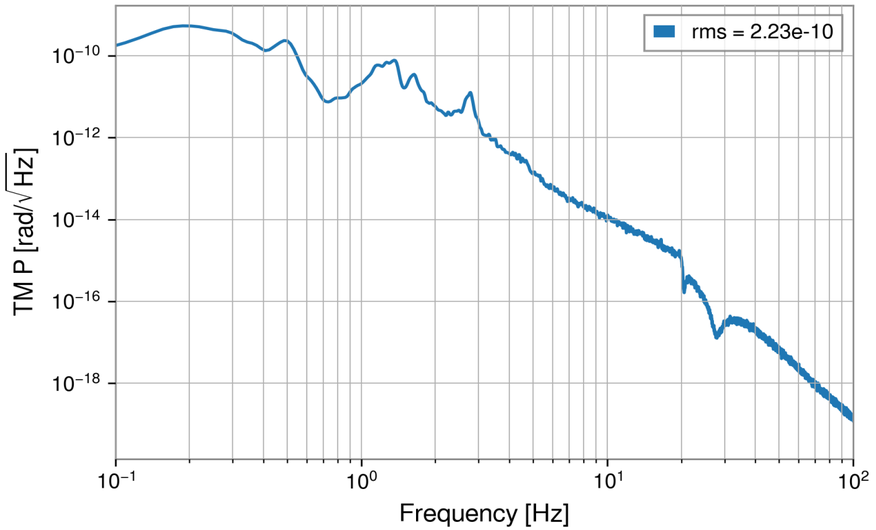
b) Soft mode

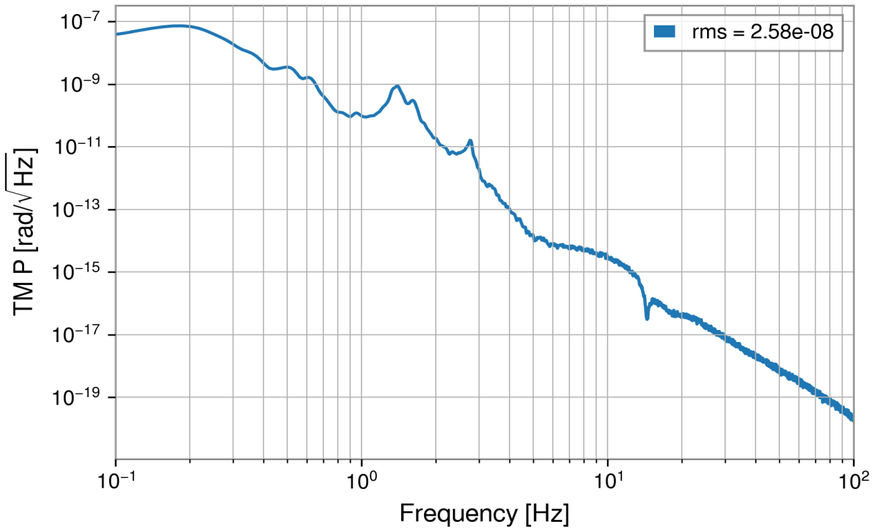
- Bode plot of Sidles-Sigg feedback transfer function changing the arm cavity power
- The most significant coupling of angular motion to cavity length occurs when the beam spot is off-center from the mirror's axis of rotation
- Results in an increase in the sensed longitudinal motion

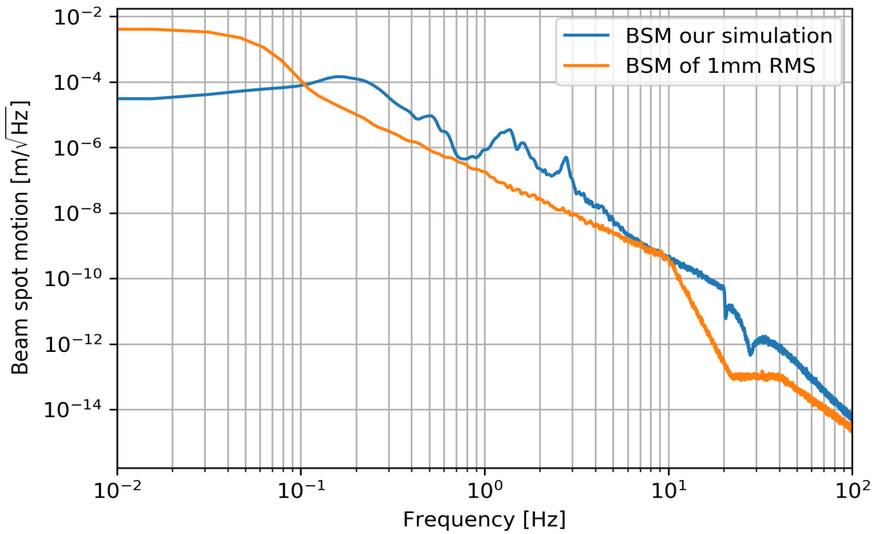


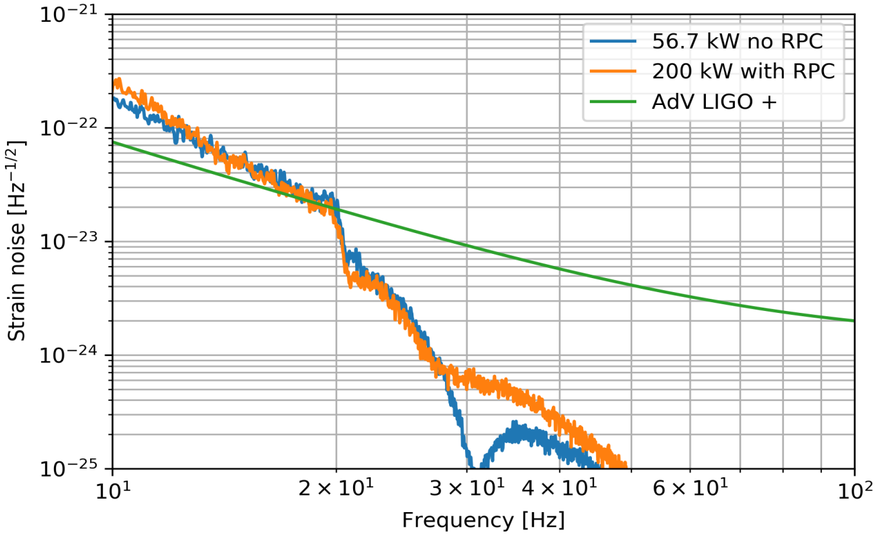
$$\Delta l(t) = d_{spot}(t) \times \theta_{mirror}(t)$$

Some results









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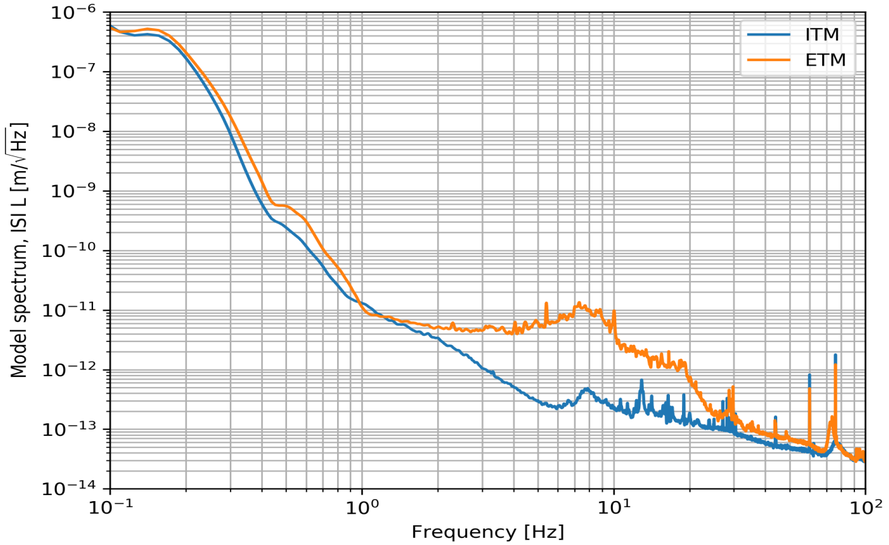
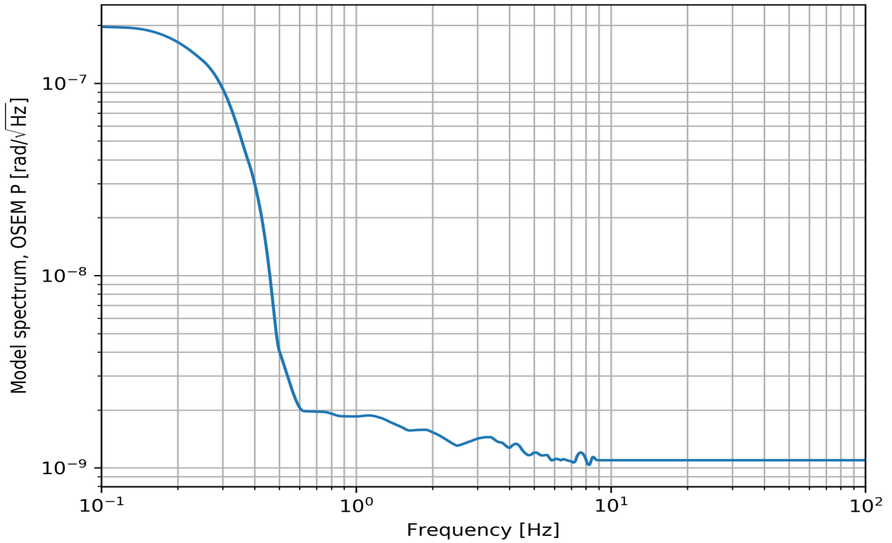
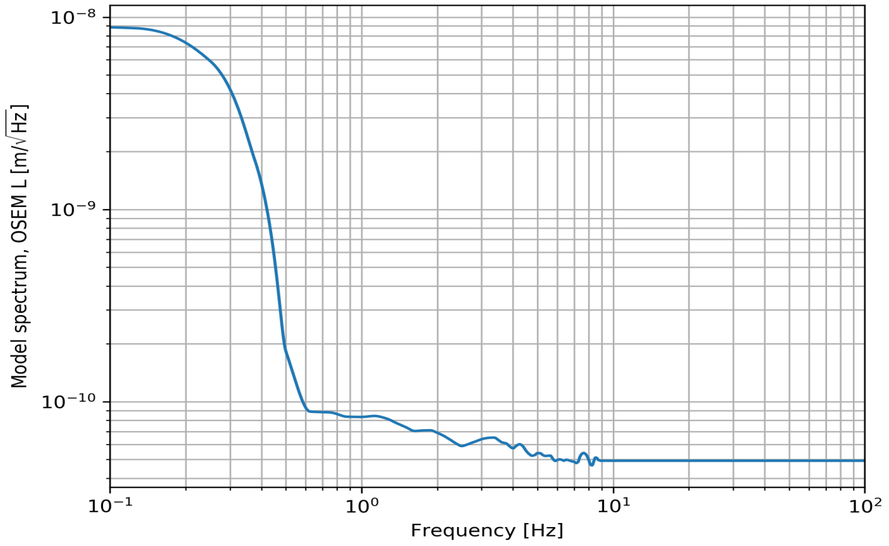
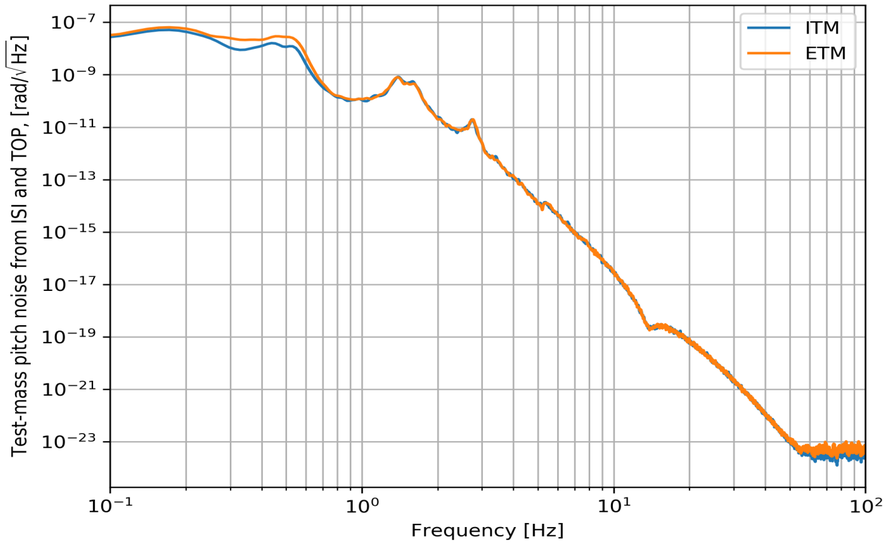
BACKUP SLIDES

External noises and overall noise

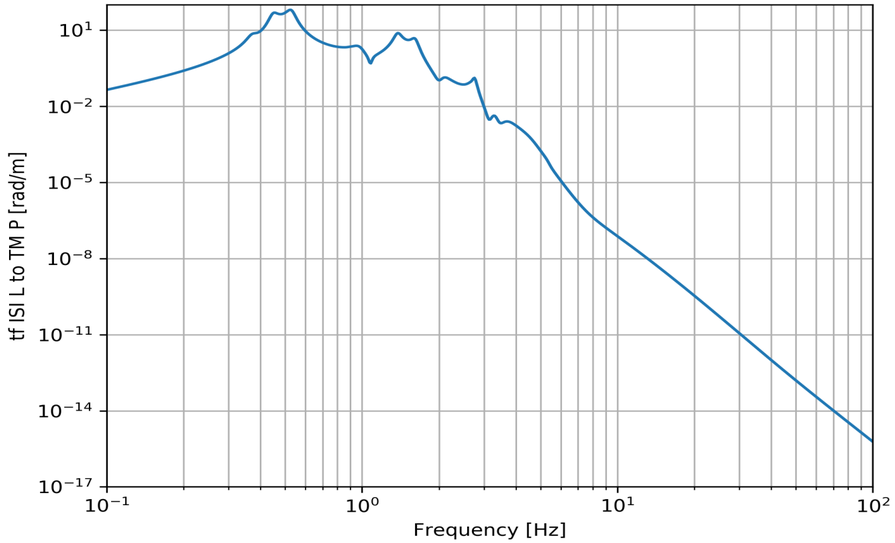


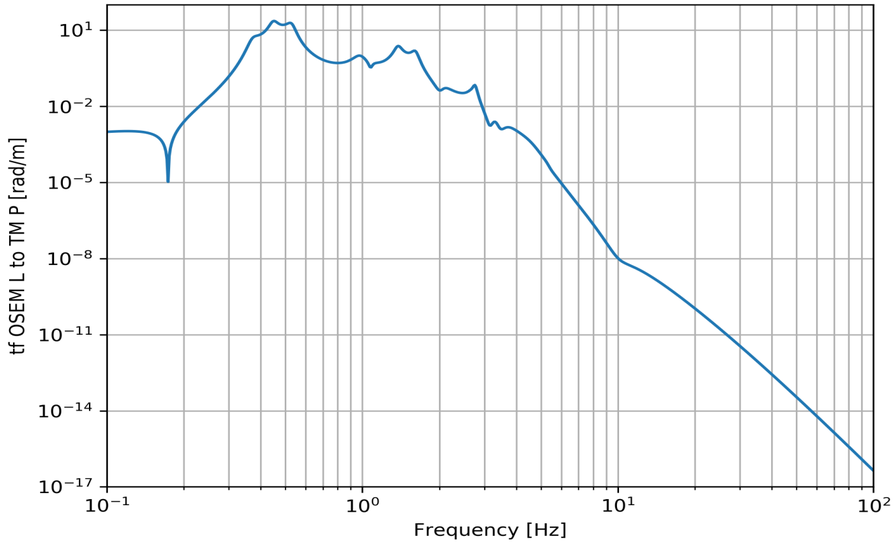


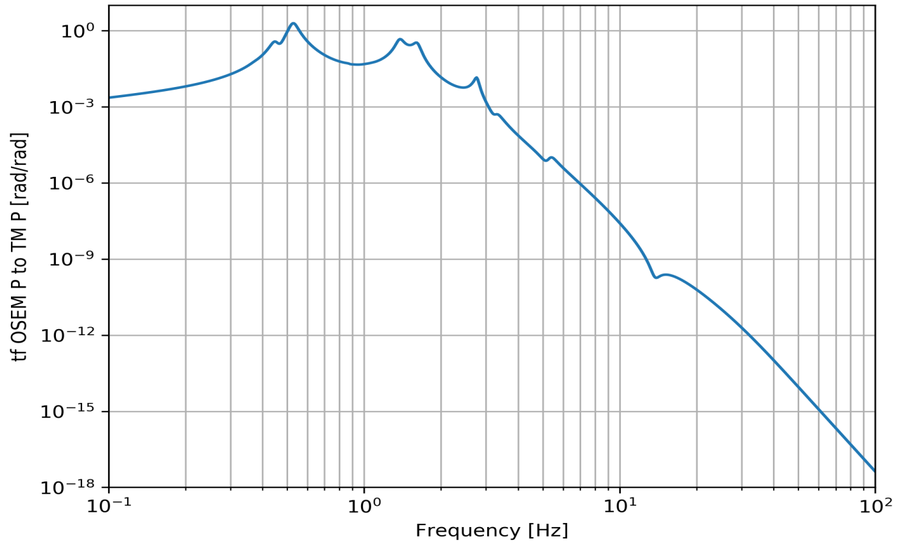




Transfer functions







Bode plots and PSD of power fluctuations