Optomechanical Instability in the KAGRA Gravitational Wave Telescope

KAGRA

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Abstract

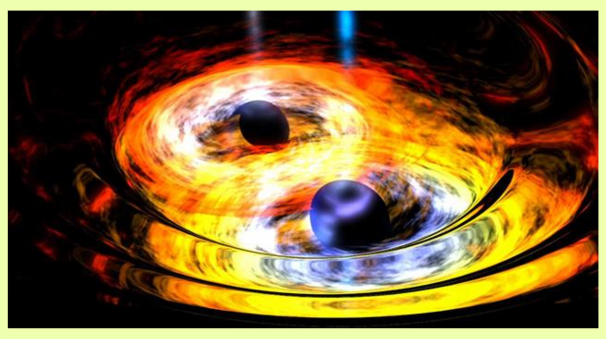
KAGRA is a 3-km interferometric gravitational wave telescope which started construction in 2010 at Kamioka, Japan [1]. We reduce seismic noise by constructing the interferometer in the quiet underground site, and we reduce thermal noise by cooling down the test mass mirrors to 20 K. These advanced technologies help KAGRA detect gravitational waves from binary neutron stars more than 200 Mpc away.

In order to achieve such a high sensitivity, longitudinal and angular motions of the mirrors must be finely controlled. However, the alignment control will be one of the most challenging issue because of the optomechanical instability of the arm cavities [2,3].

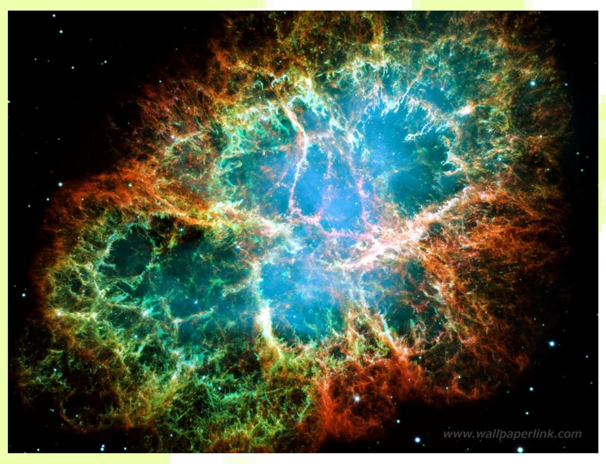
Here, we present our interferometer design to reduce this instability, and show angular noise estimate from the interferometer modeling.

1. Gravitational wave and its detection

binary neutron star



binary black hole

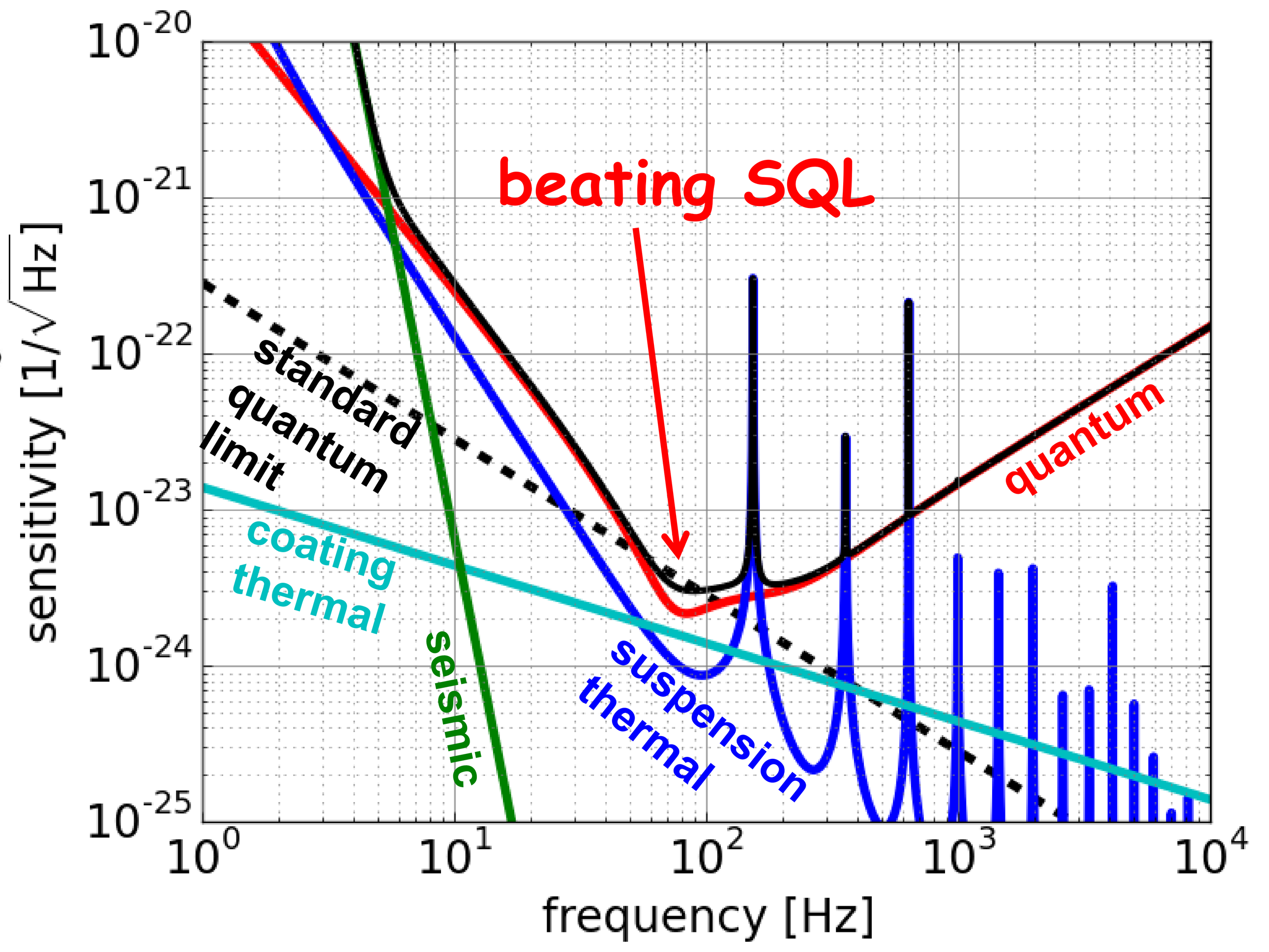


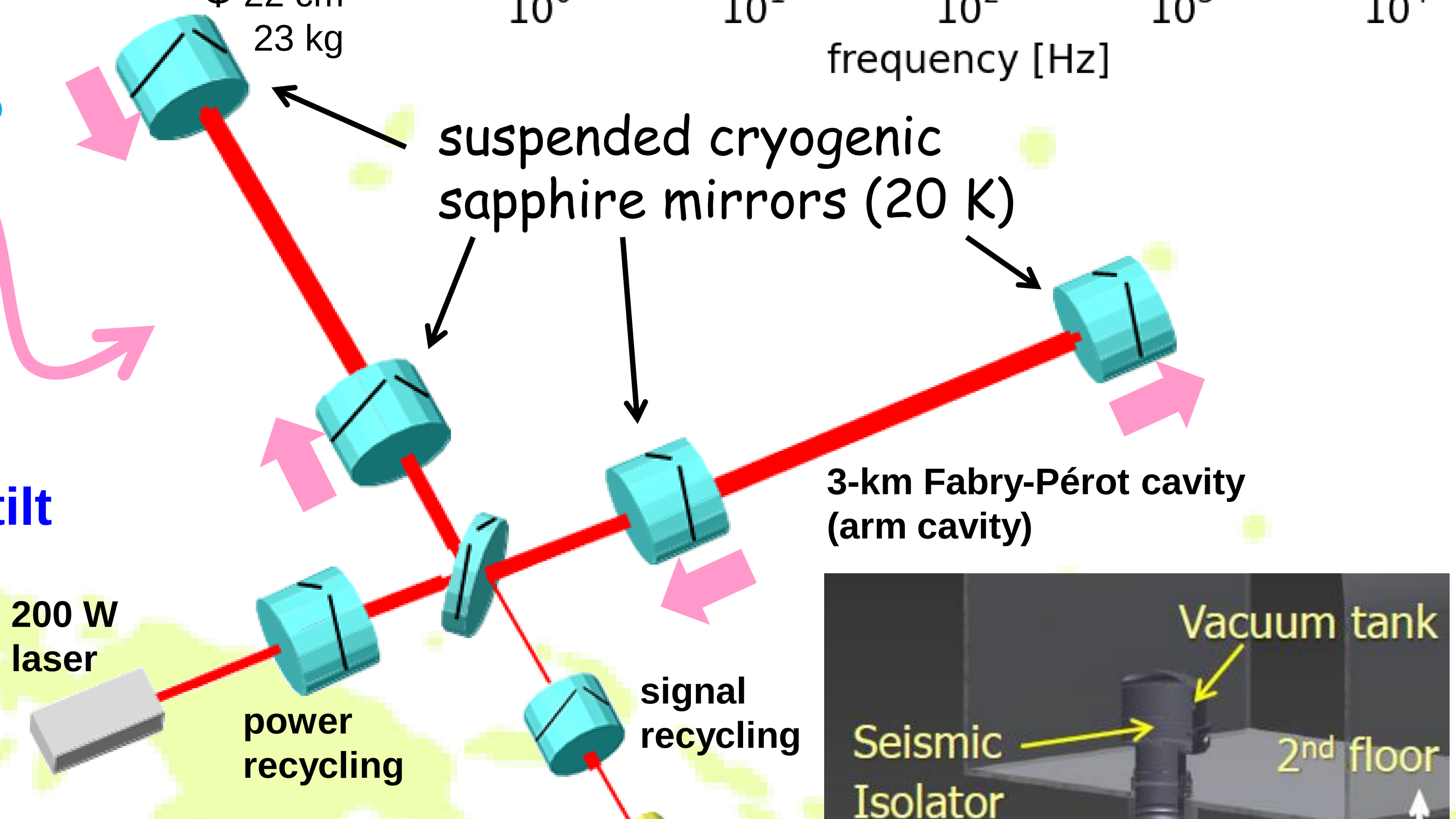
supernova

Gravitational wave
- ripples in spacetime
- quadrupole
- propagates at the speed of light

GW telescope
= Dual Recycled Fabry-Pérot Michelson Interferometer

Φ 22 cm
23 kg

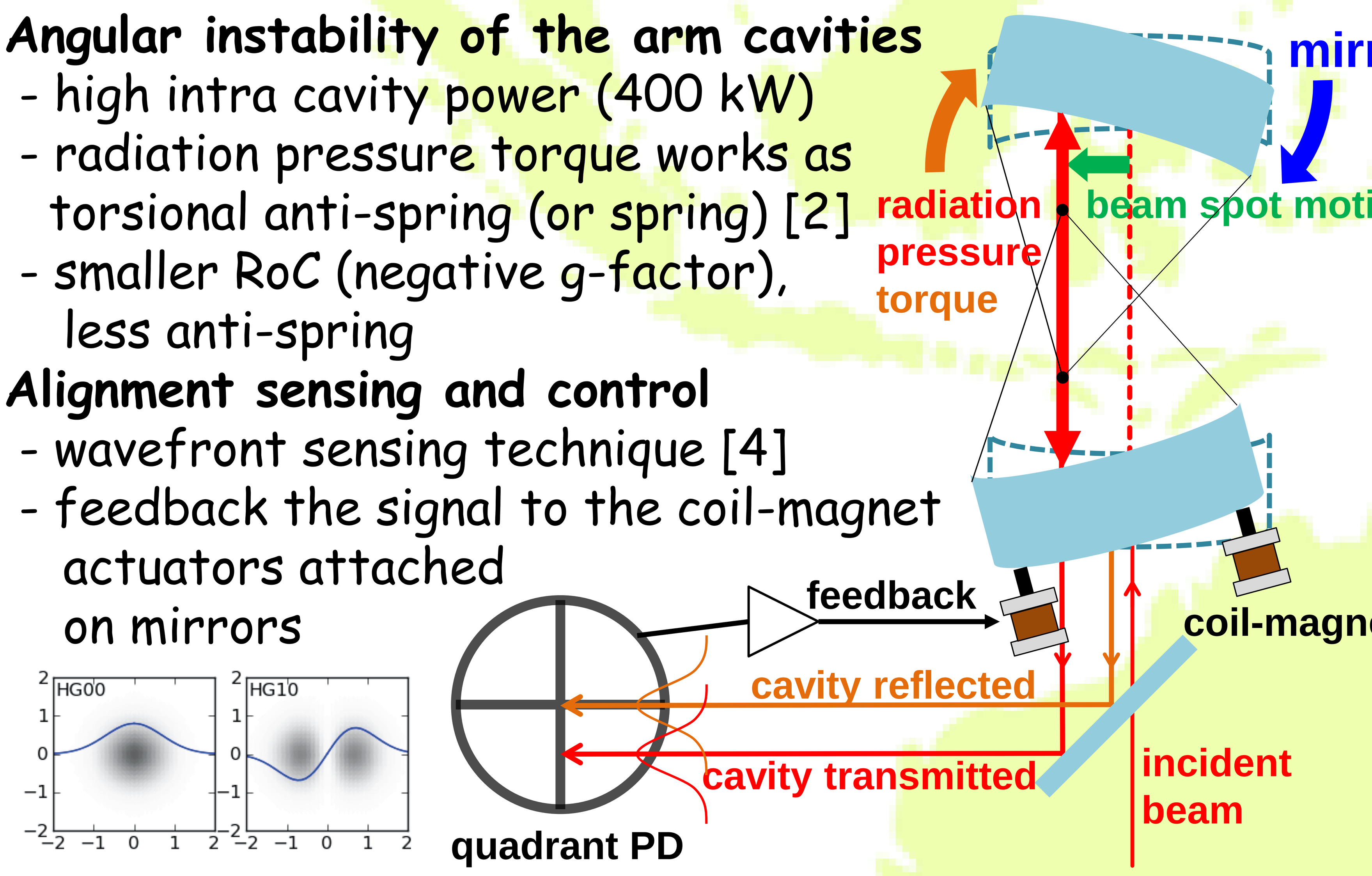


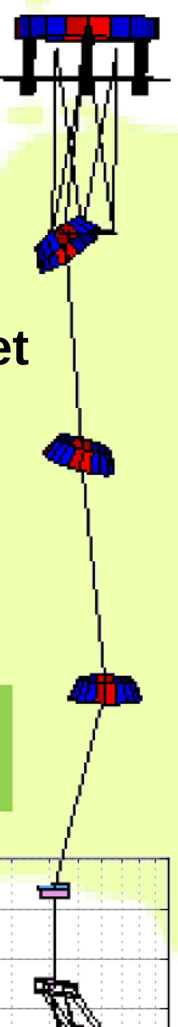


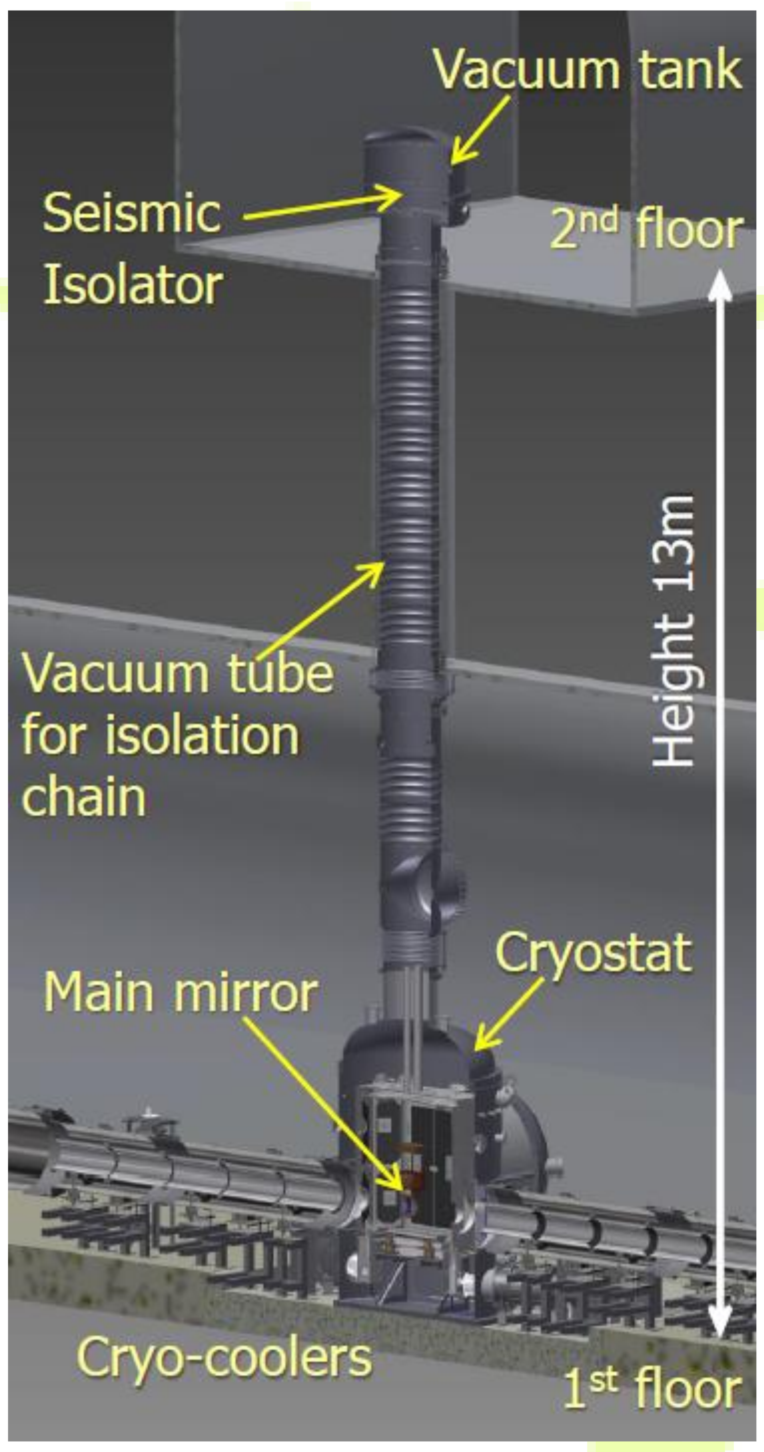
2. Optomechanical angular instability

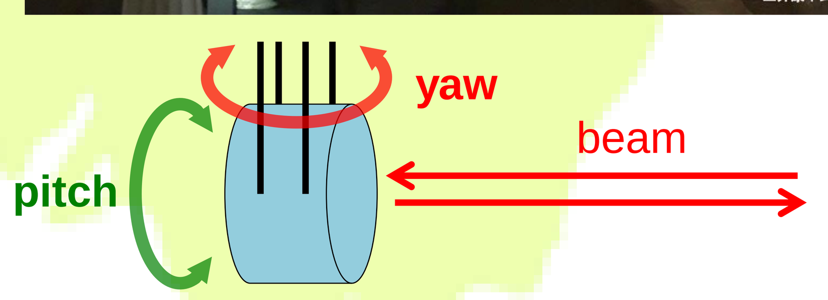
Angular instability of the arm cavities
- high intra cavity power (400 kW)
- radiation pressure torque works as torsional anti-spring (or spring) [2]
- smaller RoC (negative g-factor), less anti-spring

Alignment sensing and control
- wavefront sensing technique [4]
- feedback the signal to the coil-magnet actuators attached on mirrors









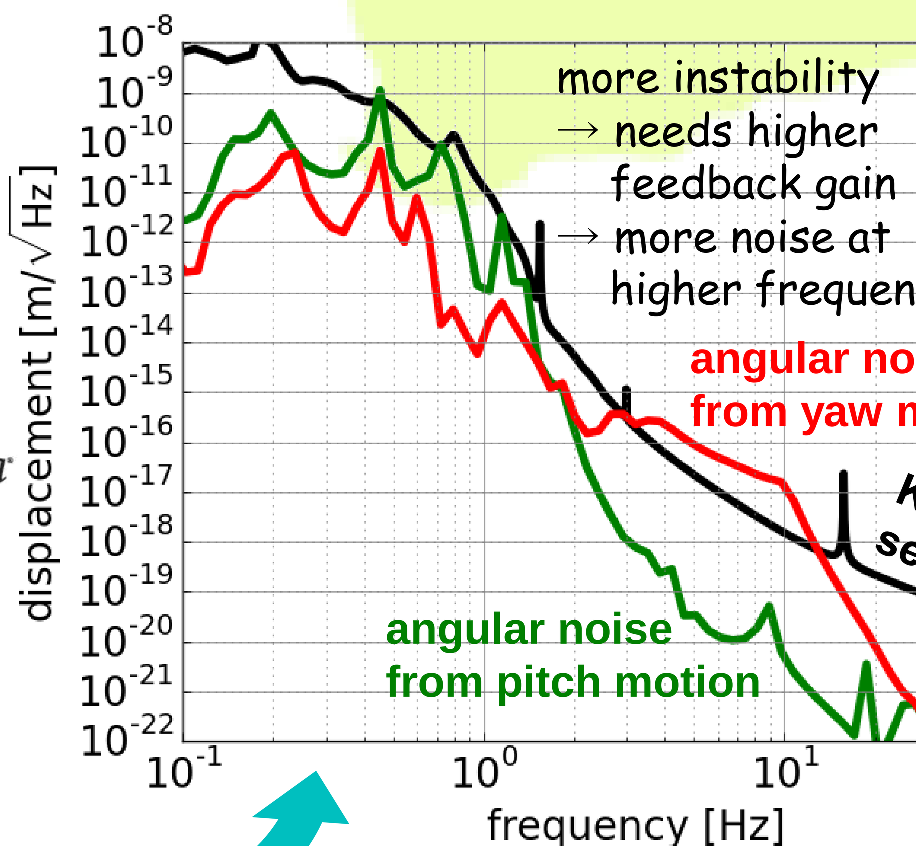
3. Angular noise estimate

Interferometer modeling
- 3D rigid body model for simulating mechanical responses of test mass mirror suspensions

\+ Wolfram Mathematica

- Optickle [5] frequency domain quantum-optomechanics simulation tool

MATLAB



References

[1] Y. Aso, Y. Michimura, K. Somiya *et al.*, Phys. Rev. D **88**, 043007 (2013)
[2] J. A. Sidles and D. Sigg, Phys. Lett. A **354**, 167 (2006)
[3] L. Barsotti *et al.*, Class. Quatum Grav. **27**, 084026 (2010)
[4] E. Morrison et al., Appl. Opt. **33**, 5041 (1994)
[5] M. Evans *et al.*, https://github.com/Optickle/Optickle

KAGRA drawings and photos are taken from JGW-G1503311 by S. Kawamura
Mathematica 3D rigid body suspension model is made by T. Sekiguchi
Drawings of GW sources are from
http://youtu.be/g8s81MzzJ5c
http://www.astroarts.co.jp/news/2013/12/04binary_bh/
http://en.wikipedia.org/wiki/Supernova