Optomechanical Alignment Instability in LIGO Mode Cleaners

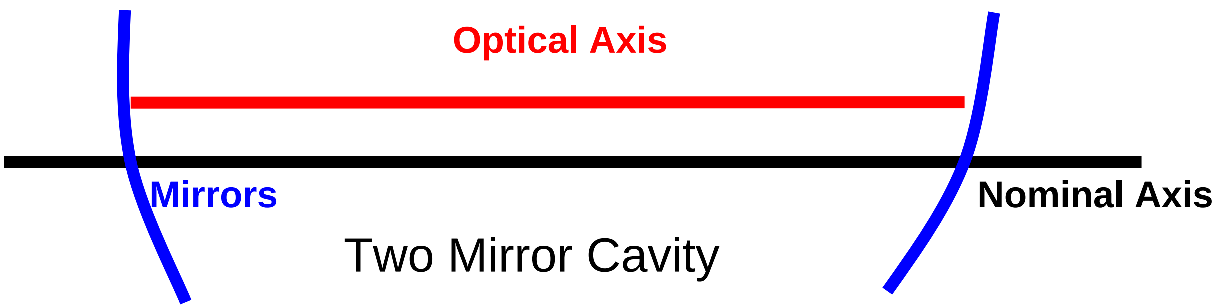
Jenne Driggers

LIGO 40m Prototype

Mentor: Alan Weinstein

Co-Mentor: Rana Adhikari

Angular Instability in the Mode Cleaner



- Laser light can push the mirrors out of alignment
- If the torque due to the light is greater than the restoring torques of the pendulum and the servo, then the cavity can become unstable
- Mode Cleaner cavities have been modeled to determine what laser powers will cause instability
- The 40m Mode Cleaner has been measured to ensure the model and calculations match reality

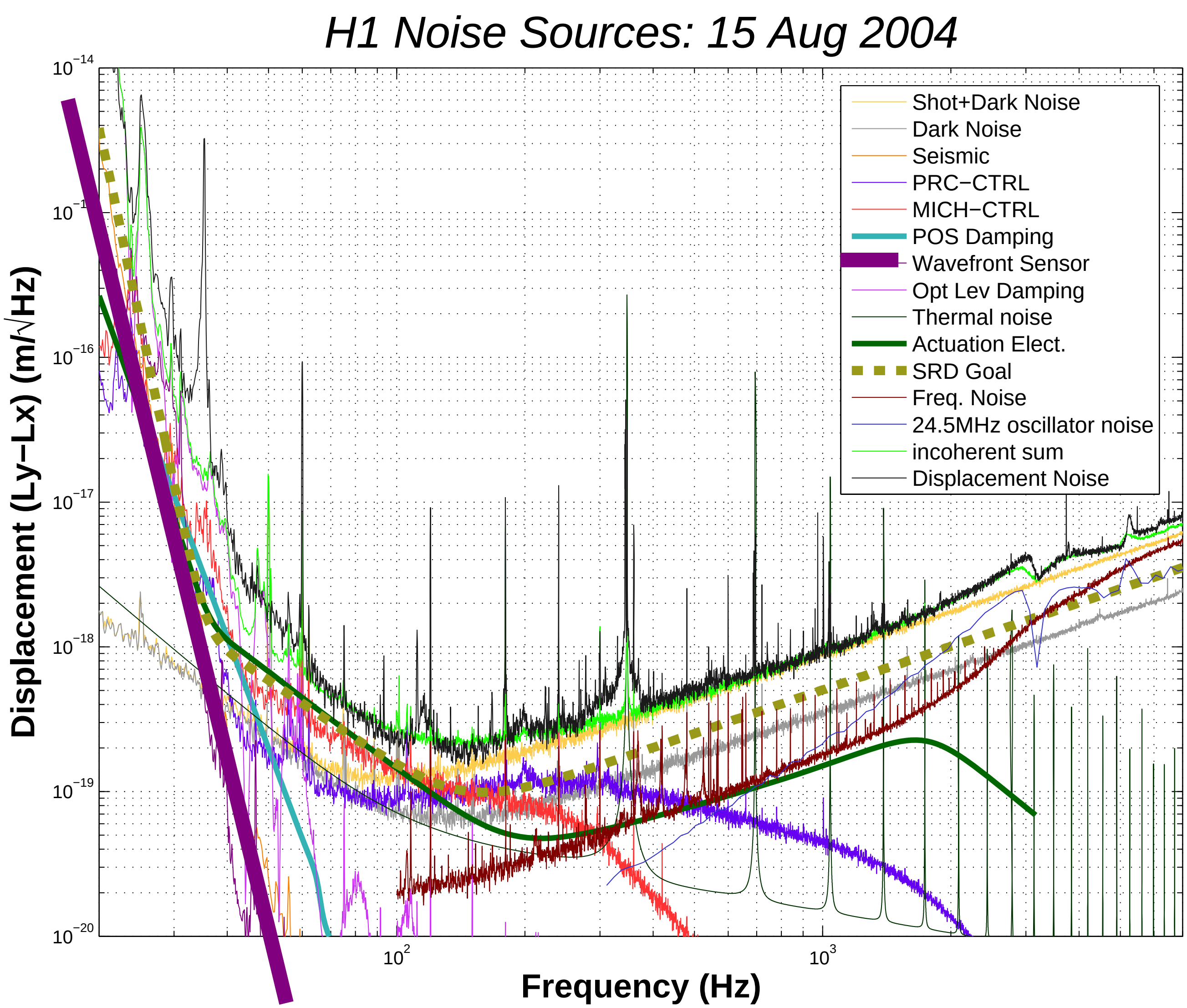
Where do Instabilities Potentially Exist (Without Controls Servos)?

	Mode Cleaner	Arms
Initial LIGO	Stable	Unstable First seen in H2
Middle LIGO	???	Unstable
Advanced LIGO	???	Unstable

Can We Lock the Interferometers?

- Yes, it is believed possible to create servos strong enough to keep the interferometers in lock.
- The problem will be to keep the noise on the servos as low as possible, so it does not limit sensitivity.

Potential Servo Noise Problems



- Currently, the noise from the Wavefront Sensors is just below the wall of Seismic noise.
- High WFS bandwidth is necessary to control the Interferometer, but makes it very difficult to push the noise level down.
- For Advanced LIGO, work needs to be done to ensure that we will not be limited by this servo noise.

Analytic Calculations to Check Model

$$\tau_{opt} = \frac{2Px}{c}$$

$$\tau_{pendulum} = \alpha I \omega_{pendulum}{}^2$$

•Stability depends strongly on the g-factor of the cavity. As $|g| \to 1$, the cavity becomes more and more unstable, where

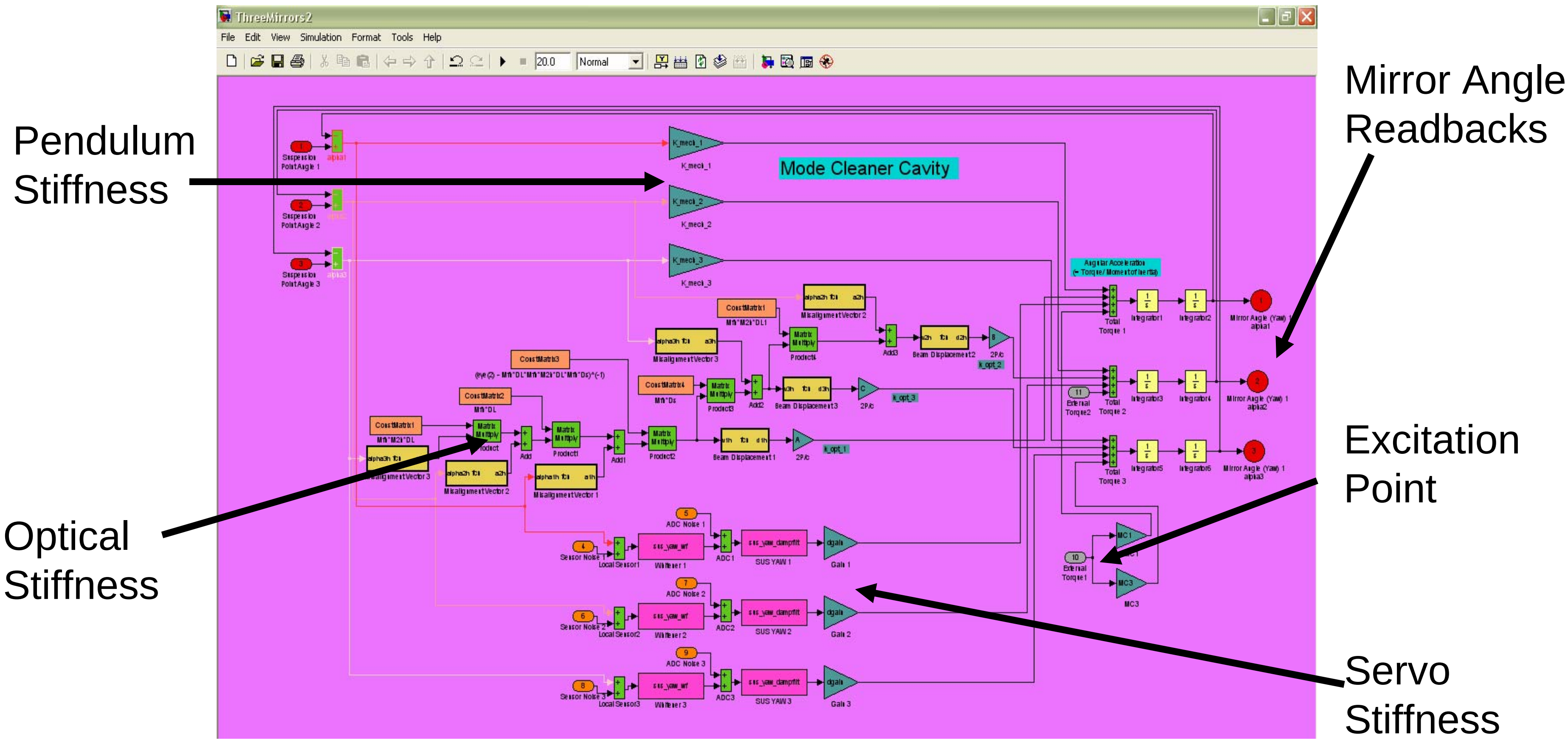
$$g = 1 - \frac{L_{cavity}}{R_{RadiusofCurvature}}$$

•For Initial LIGO Arms, g_{ETM}=0.46 and g_{ITM}=0.73.
•For AdLIGO Arms, g_{ETM}= g_{ITM}= -.80
•If the Initial LIGO mirrors are misaligned by 1 degree, with 14kW of power circulating,

- $\tau_{opt\ on\ ITM}$=0.0143 N*m
- $\tau_{pendulum}$=0.0082 N*m

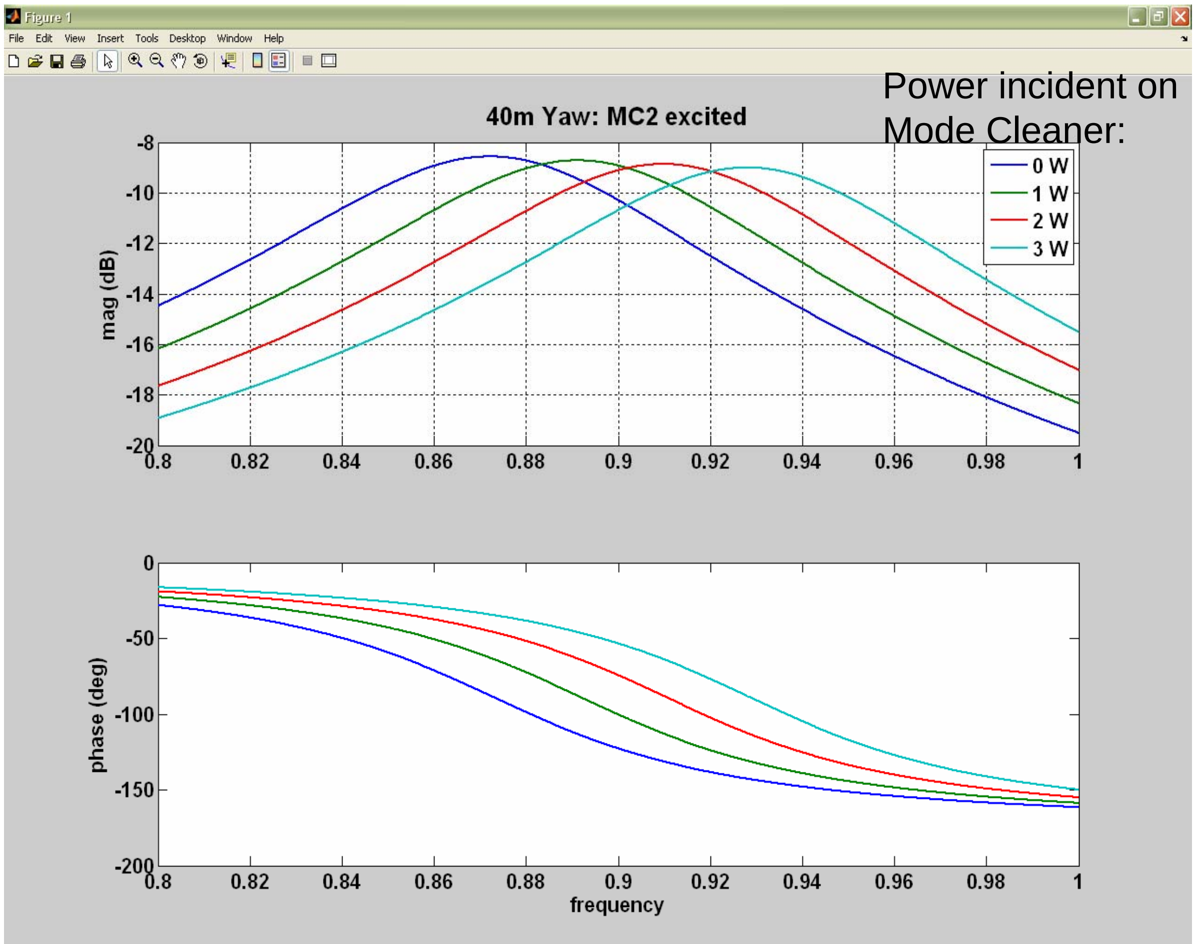
•Further calculations confirmed that the model matches literature: LIGO Documents T030120, T030275 by Daniel Sigg.

Simulink Model of MC Cavity



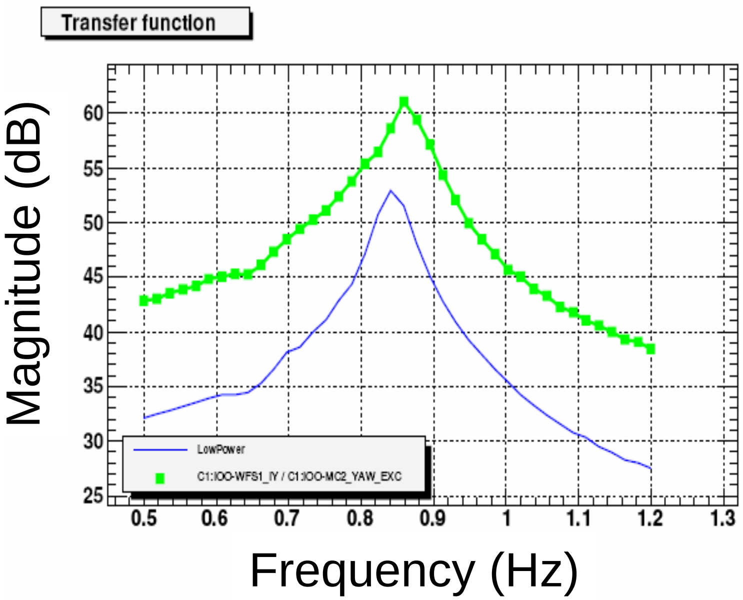
Simulink is a time-domain modeling function in MATLAB

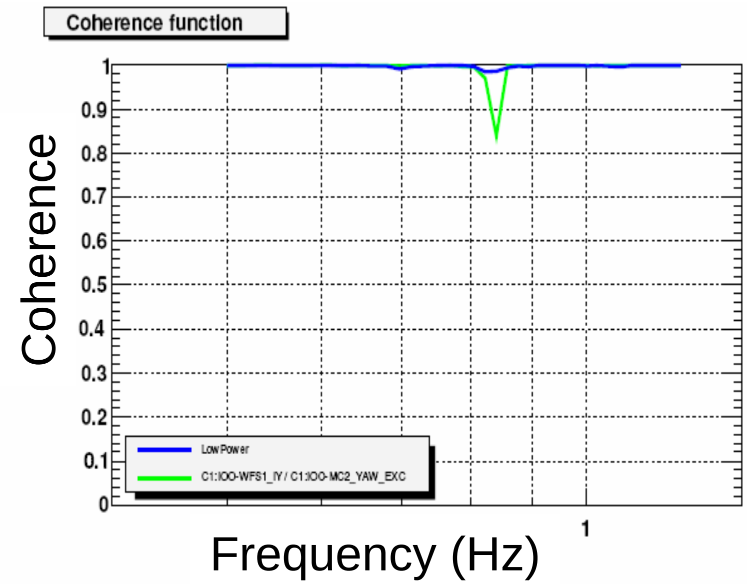
Modeling the 40m Mode Cleaner: Yaw DOF

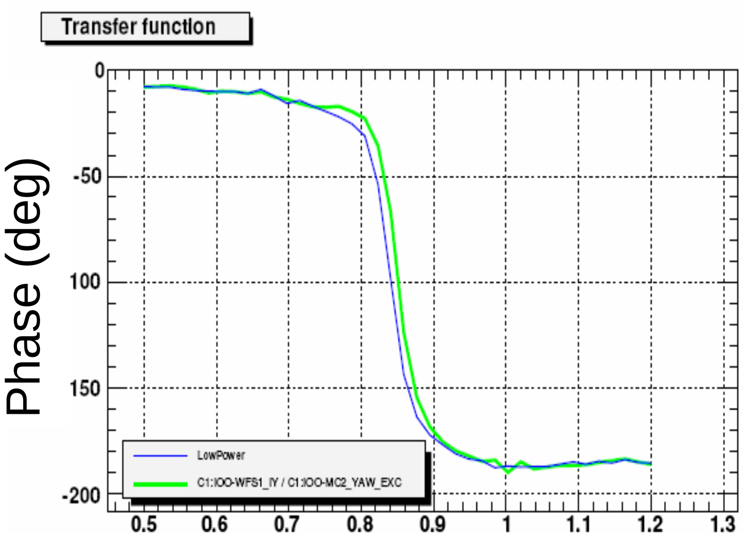


According to this model, we expect the resonant peak of the 40m Mode Cleaner to shift to higher frequency with higher incident power.

40m Mode Cleaner Measurements





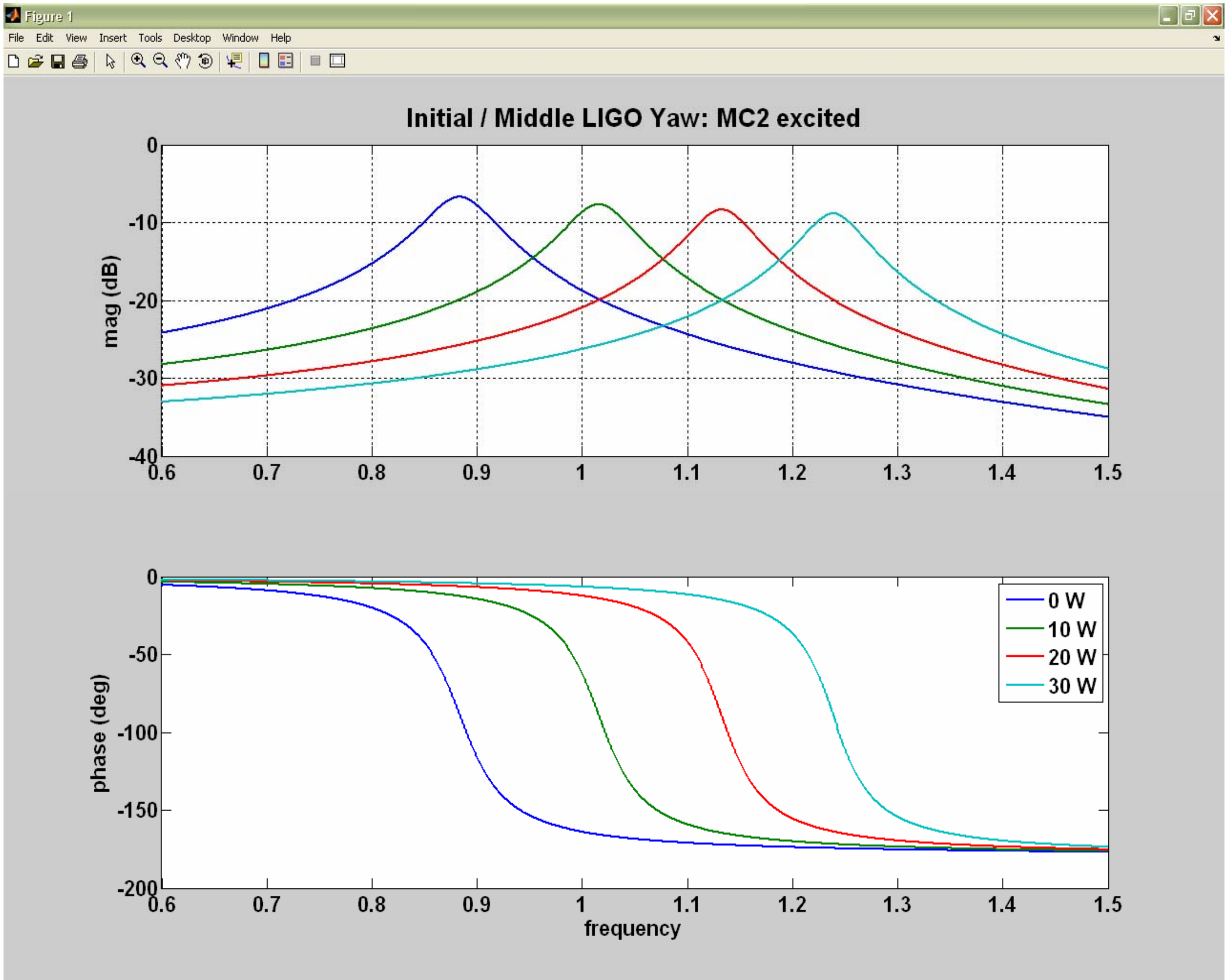


0.322 W Incident on Mode Cleaner

0.974W Incident on Mode Cleaner

- MC2 excited in Yaw with swept sine, response seen on Wavefront Sensors.
- With higher power, the resonant peak did indeed shift to a higher frequency.
- Further work: measure yaw at higher power, repeat all measurements for pitch.

Initial and Middle LIGOs

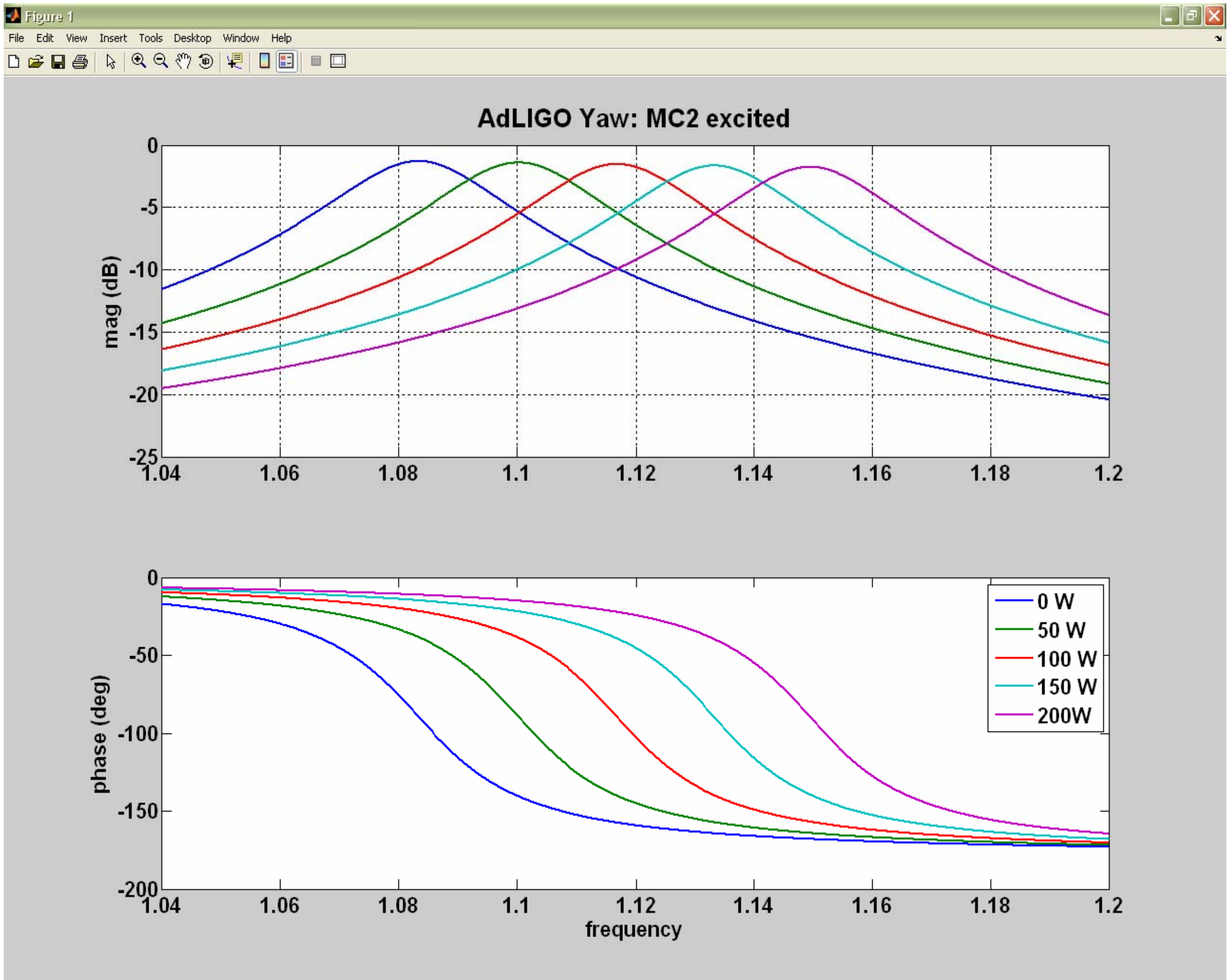


- Same parameters, different incident powers
- Initial LIGO laser = 10W
- Middle LIGO laser = 30W

- Very small peak movement for Initial LIGO.
- More pronounced for Middle LIGO

Implications for Advanced LIGO

- This model uses single, not quad pendulums
- The instability will be visible with a 200W laser, but should be controllable with servos



Thank You

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- Alan Weinstein
- Rana Adhikari
- Sam Waldman
- 40m Lab

Along the way…AM Laser assembled to test RF Photodiodes, including those in Mode Cleaner Servo

QUESTIONS?