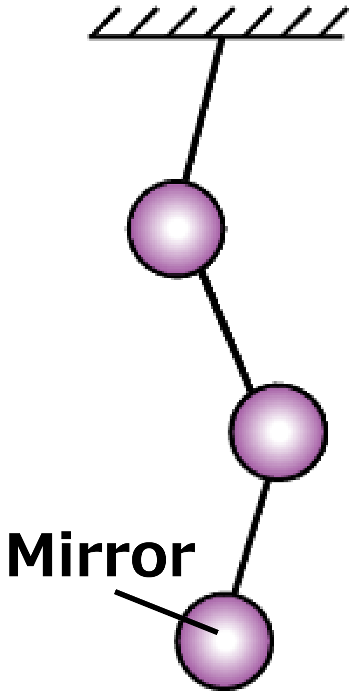
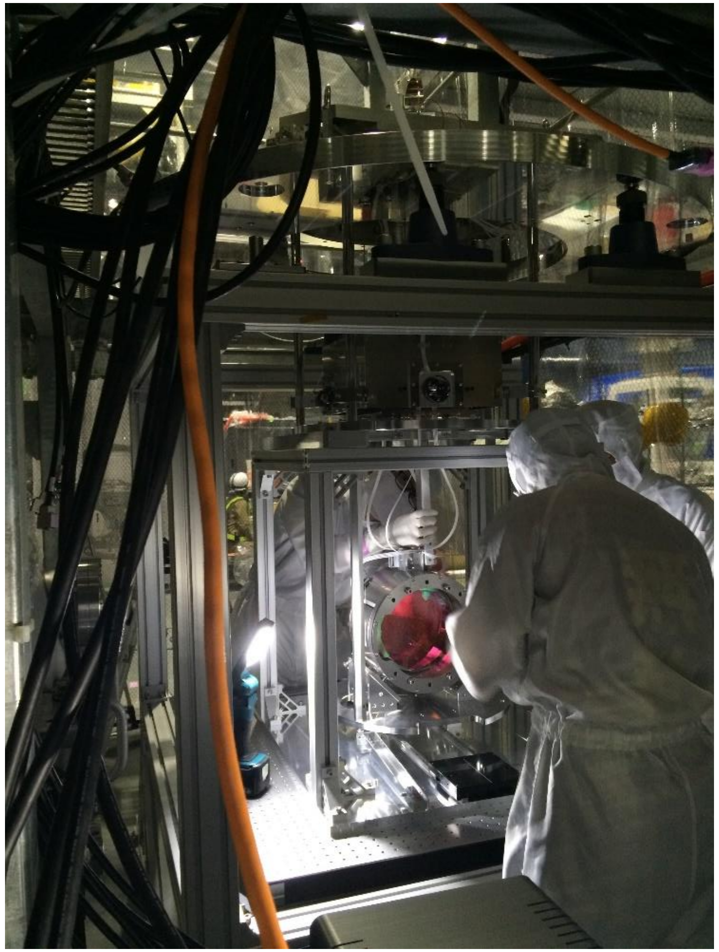
DRAFT

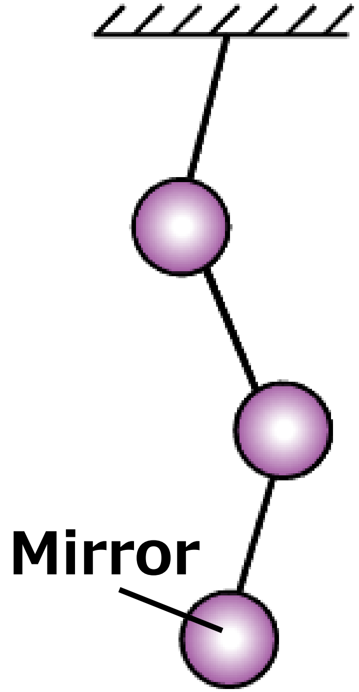
Quick manual for operating suspensions





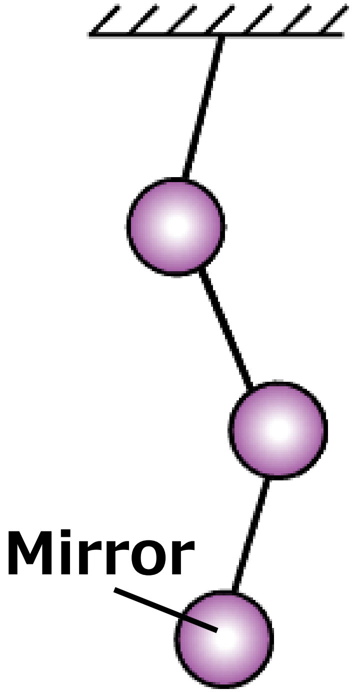
In the first place,

why suspension is needed?



1. In order to let mirrors move
   as free particles in a horizontal plane.

2. In order to suppress ***seismic motion.***



Seismic noise

Typical noise sources

- Quantum noise
- Thermal noise

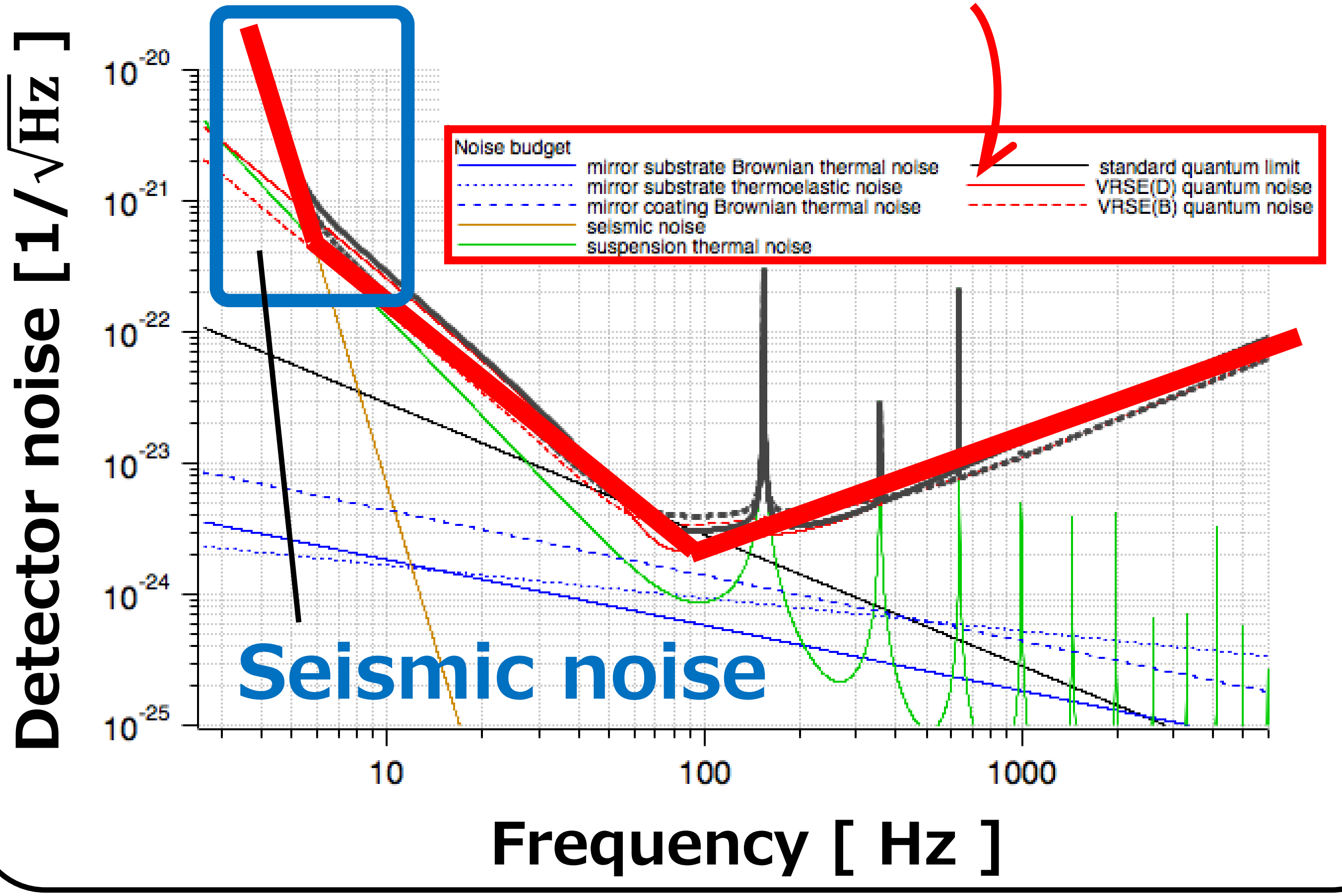
…

- **Seismic noise**

Seismic motion induces low-frequency oscillation of mirrors.

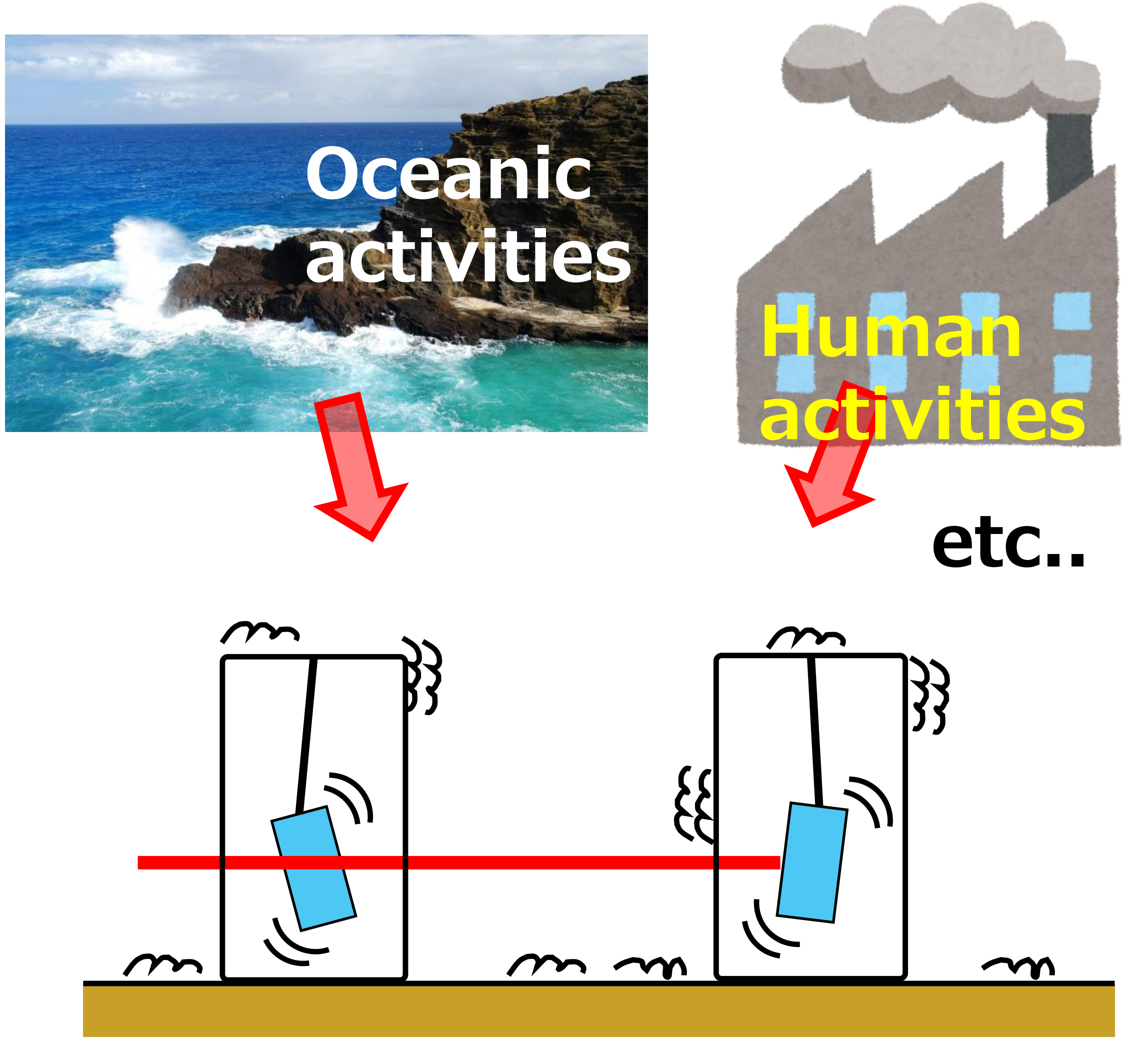
→ *Necessary to suppress*

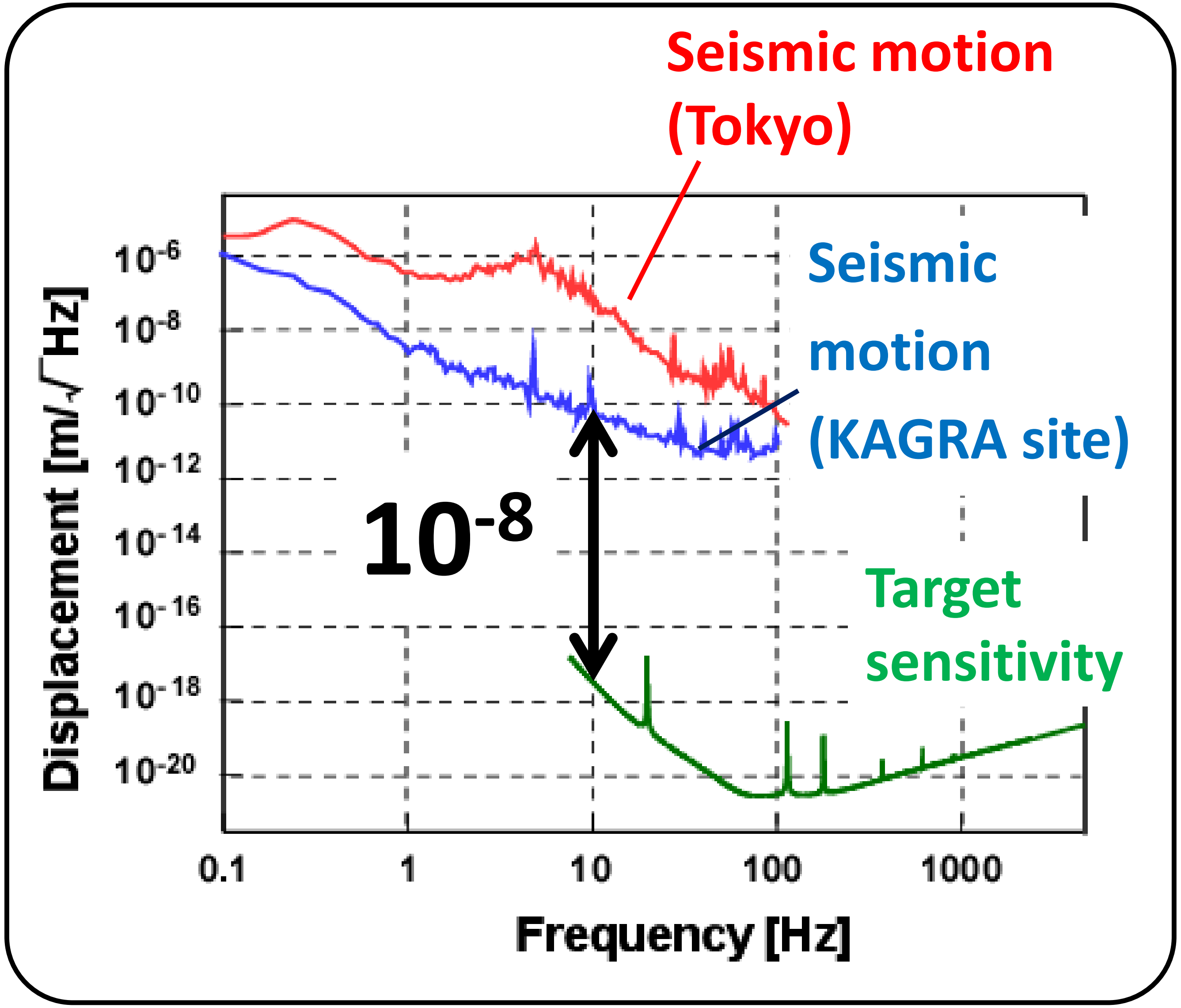
So many noise sources..



In case of KAGRA

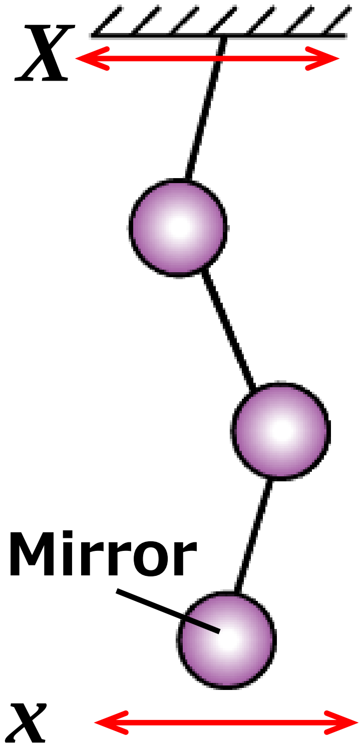
Where comes from?

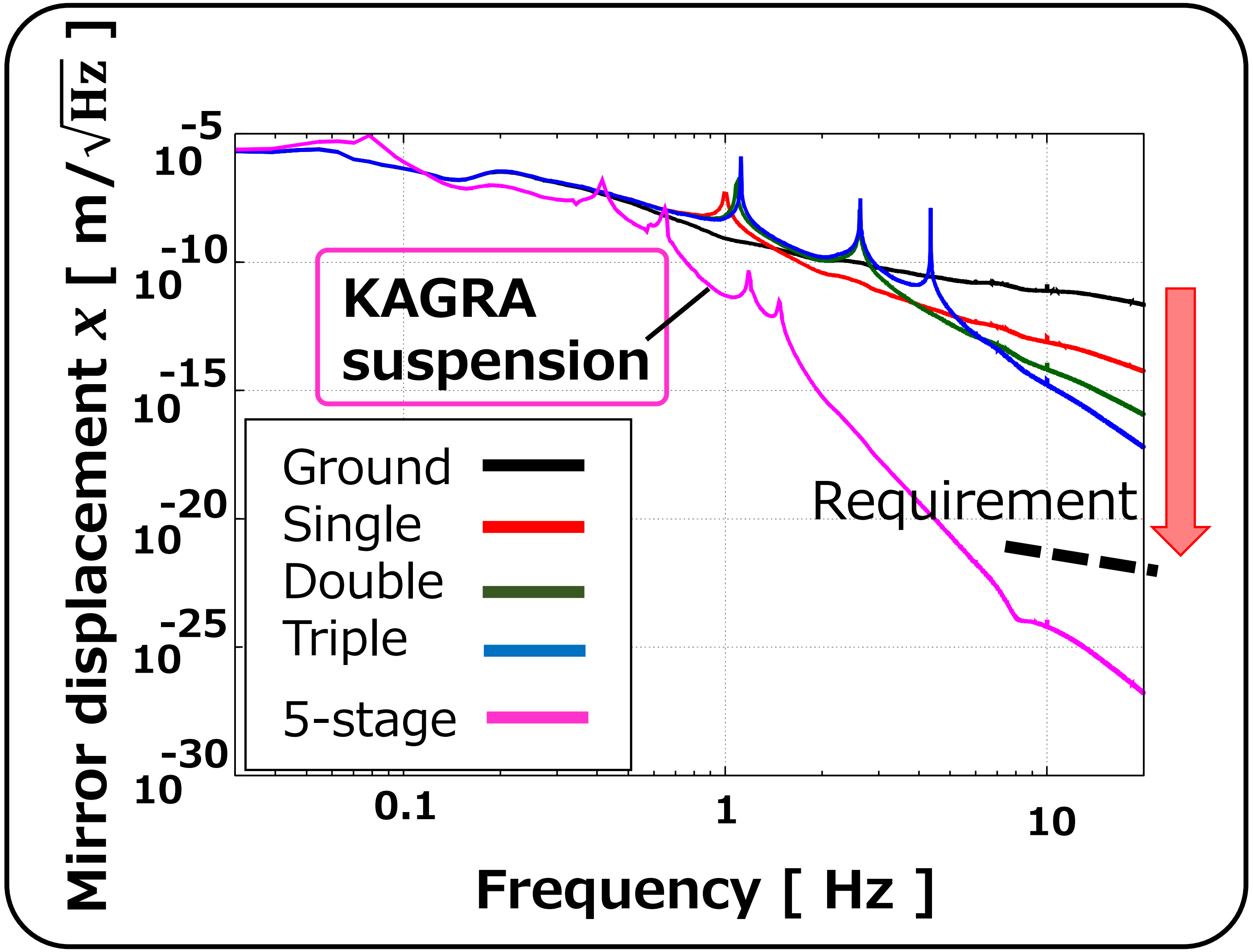


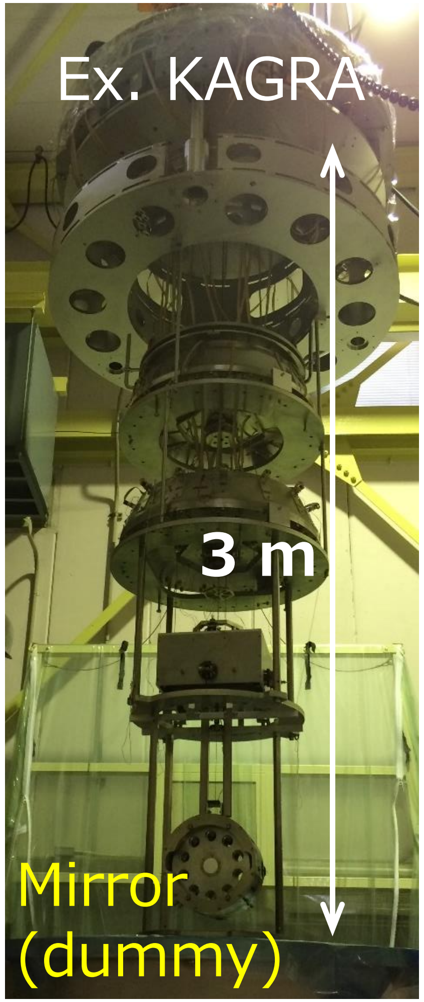


→ *We have to attenuate this seismic motion!*

Seismic attenuation



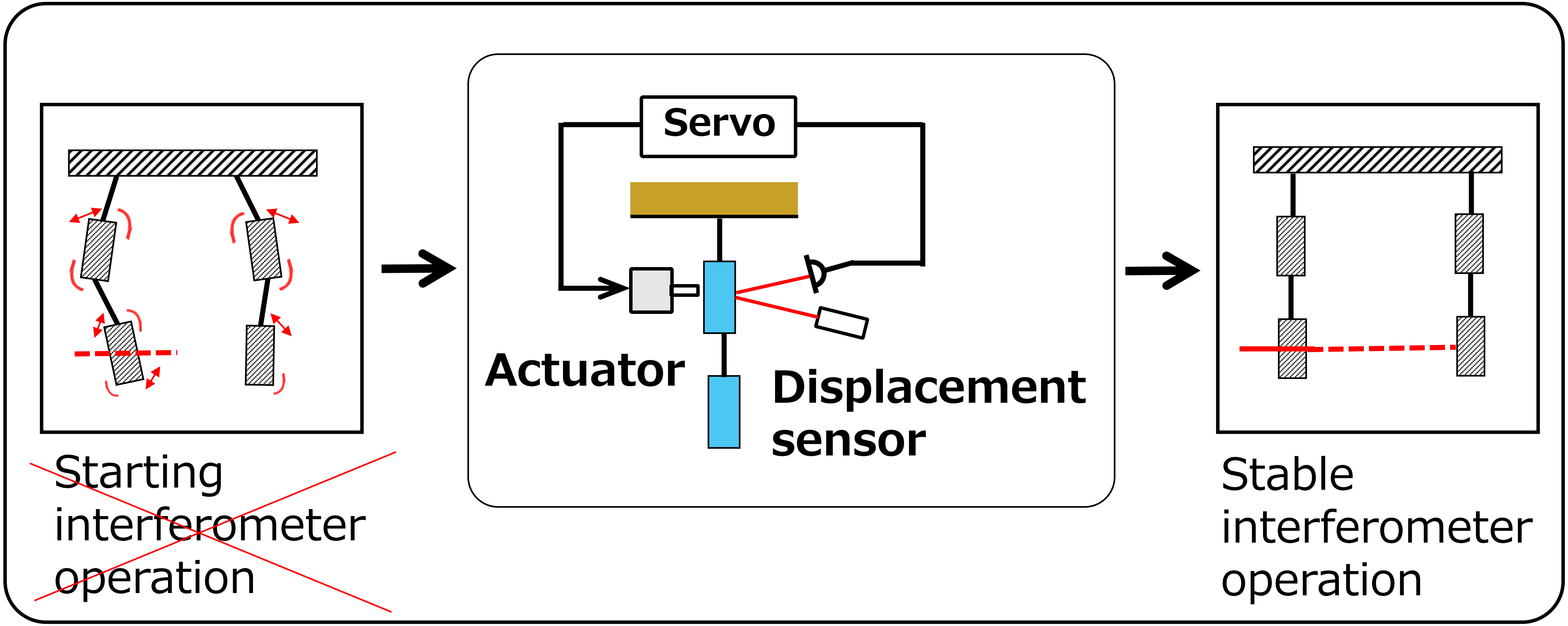




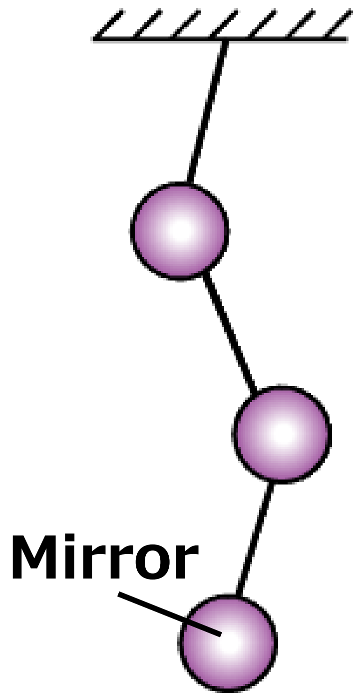
→ ***Suspension system based on multi-stage pendulum.***

Resonance damping

→ *Active control for stable interferometer operation.*



"Why suspension is needed?"

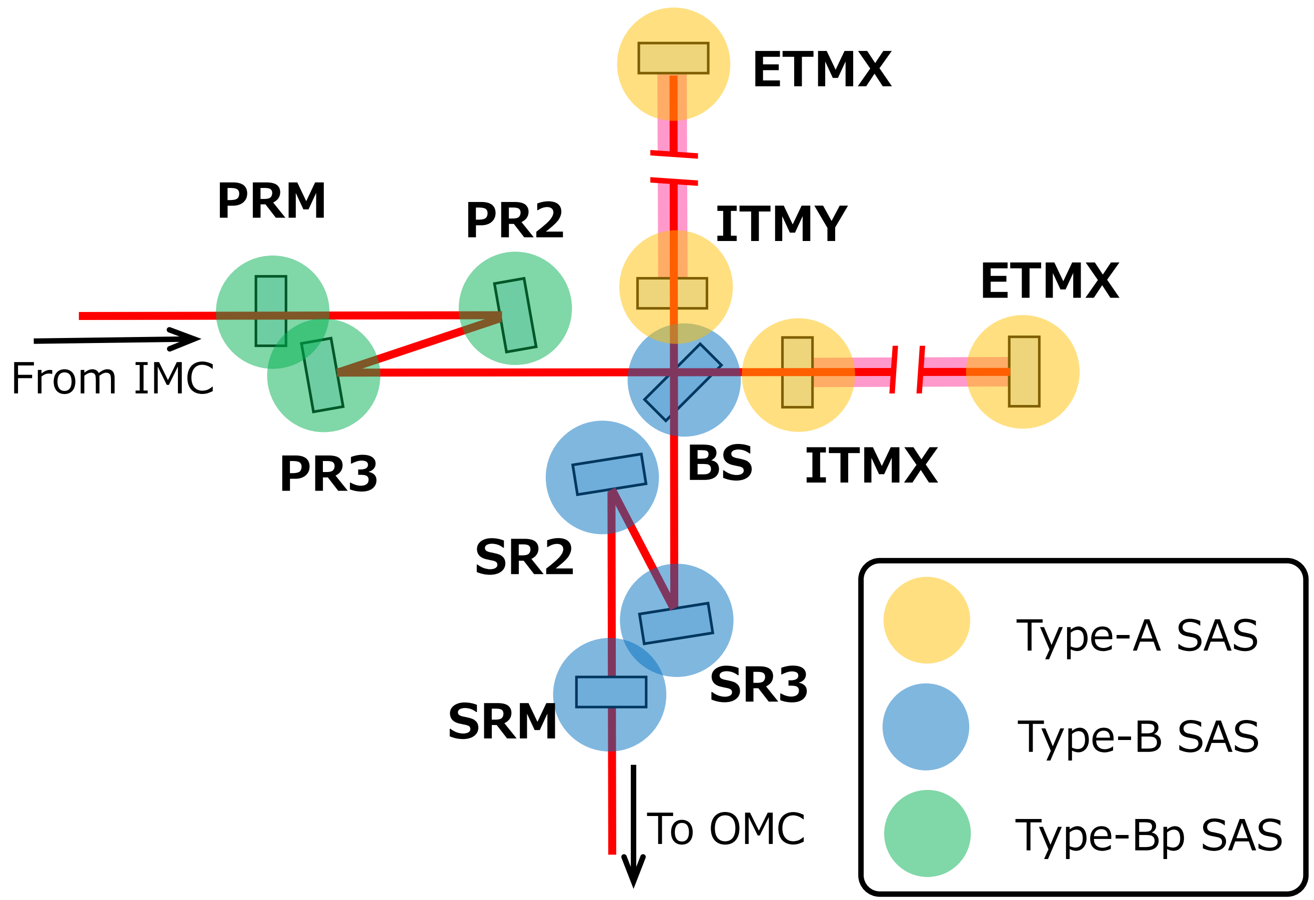


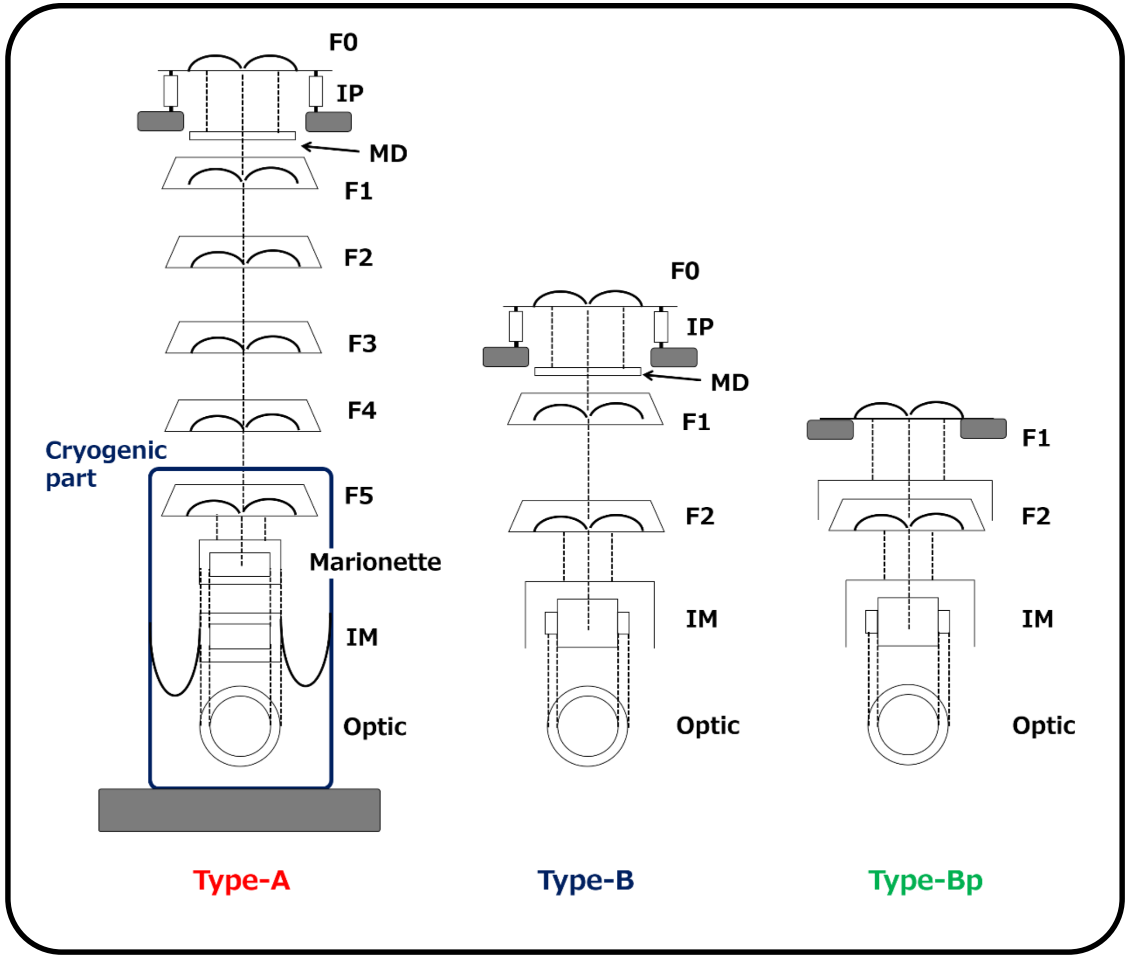
1. In order to let mirrors move
   as free particles in a horizontal plane.

2. In order to suppress ***seismic noise***.
   → *Attenuate seismic noise by adopting suspensions based on multi-stage pendulum.*

   → *Damp mechanical resonances of the suspensions for stable interferometer operation by active controls with sensors and actuators.*

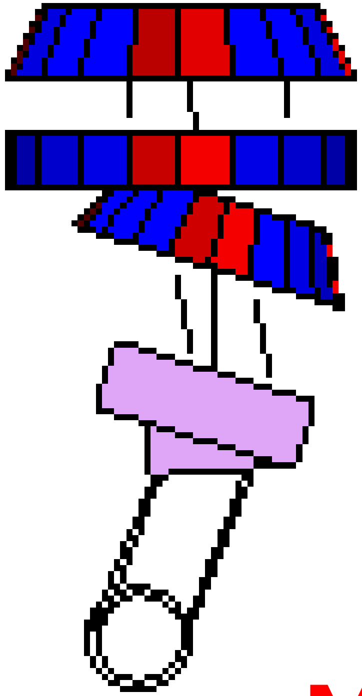
..How do KAGRA suspensions look like?



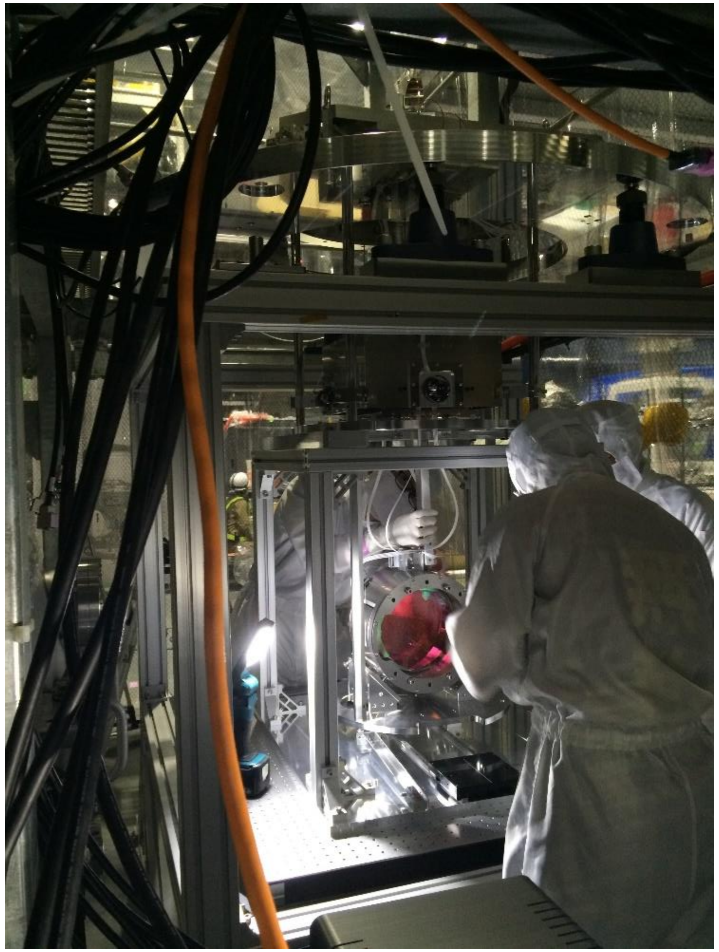


KAGRA detector has 3 seismic attenuation systems.

1. Simulation



2. Experiment

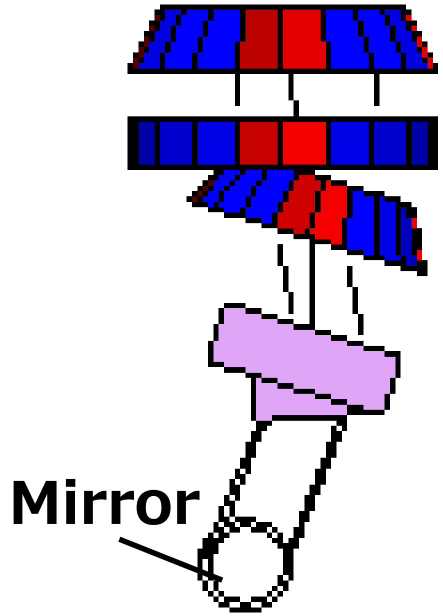


Main topic

Then, for designing

1. mechanics of suspensions
2. ***active control systems (servo systems),***

→ *we need simulation!*



What system do we want to realize by using active controls?

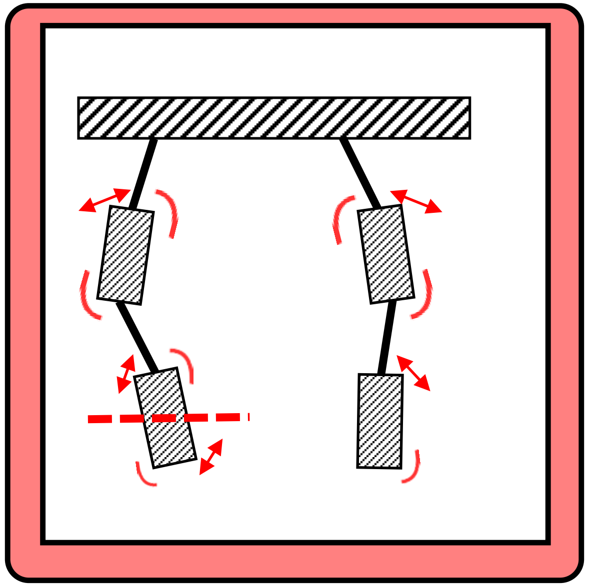
→ *1. System which damps all the resonances (which can disturb the interferometer operation).*

→ *2. System which reduces RMS velocity & RMS angle so that one can lock the interferometer.*

→ *3. System which induces low control noise.*

Like this: Steps for observation

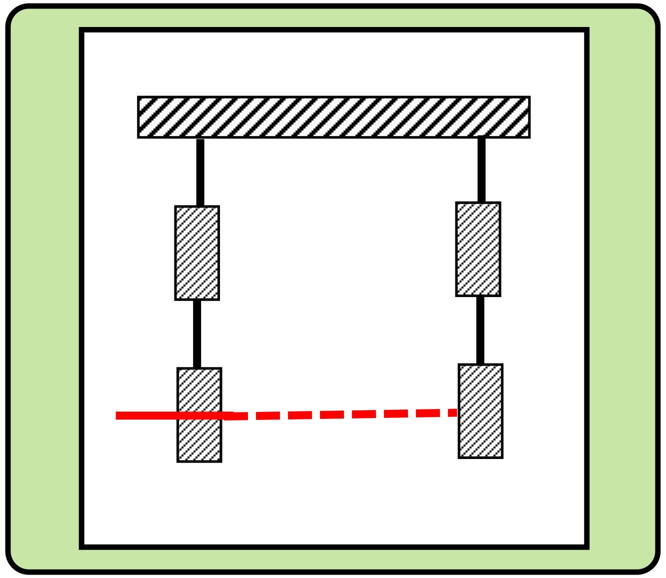
1. Calm-down phase



To do

Damp mechanical resonances

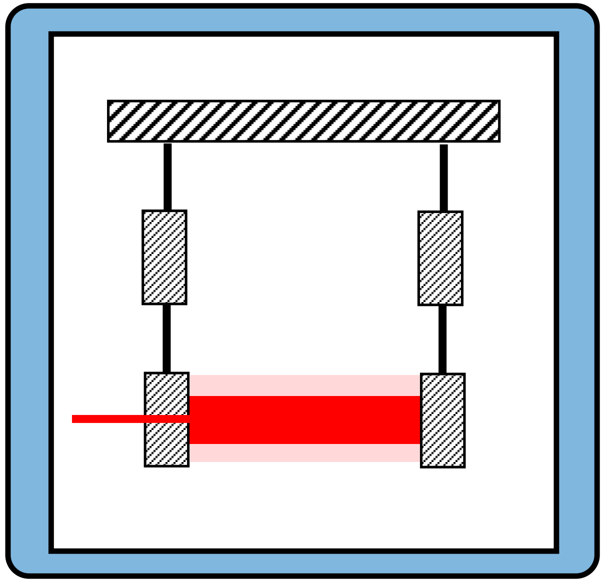
2. Lock-acquisition phase



To do

Reduce RMS velocity & RMS angle

3. Observation phase



To do

Keep mirror position with low control noise

What should we know for designing active control systems?

→ *1. Suspension responses without control (Mechanical responses)*

→ *2. Suspension responses with control*

What should we know more in detail?

→ *1. Responses without control*

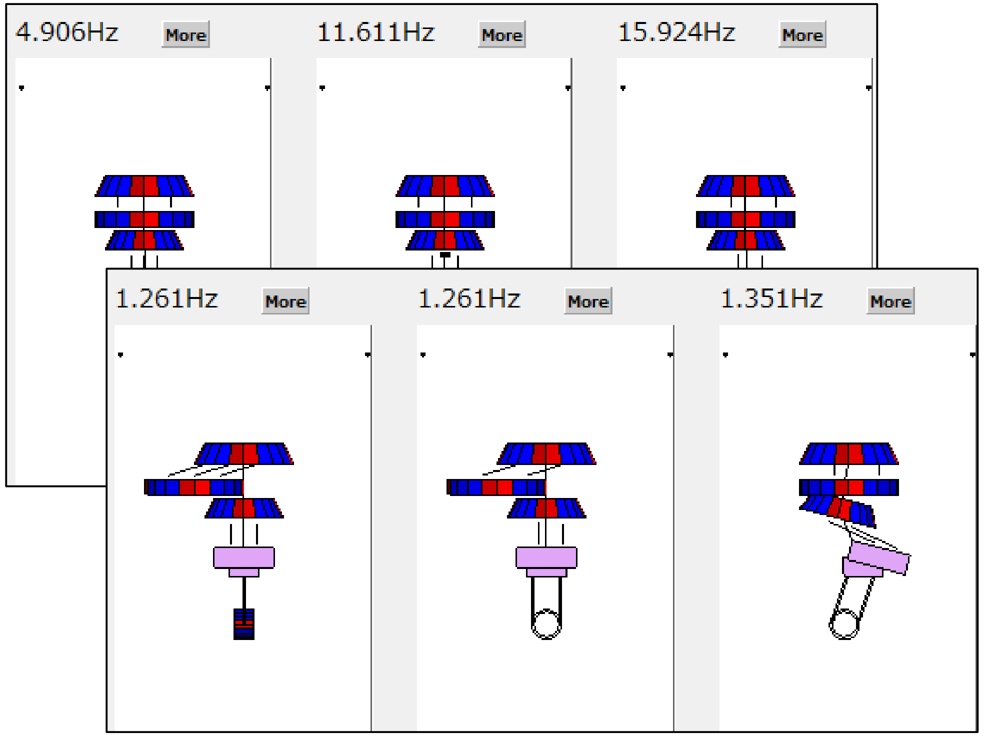
Necessary to know how the resonances look like:
1-1. Eigen mode shapes
1-2. Transfer functions

→ *2. Responses with control*

Necessary to know:
2-1. Damping performance
2-2. Root-Mean-Square velocity & angle etc.
2-3. Control noise coupling

1. Suspension responses without control

1-1. Eigenmode shapes

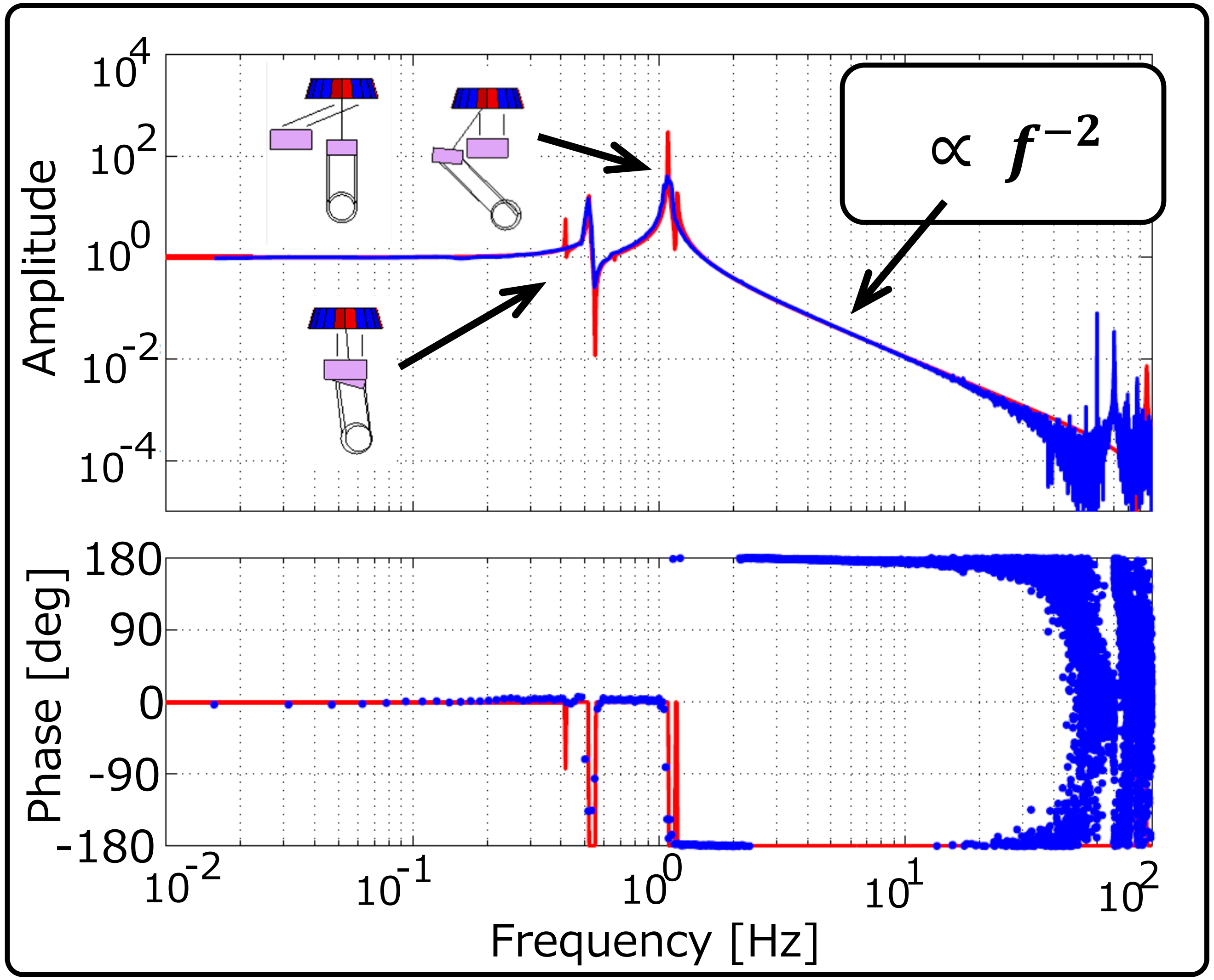


main components of a resonance.

→

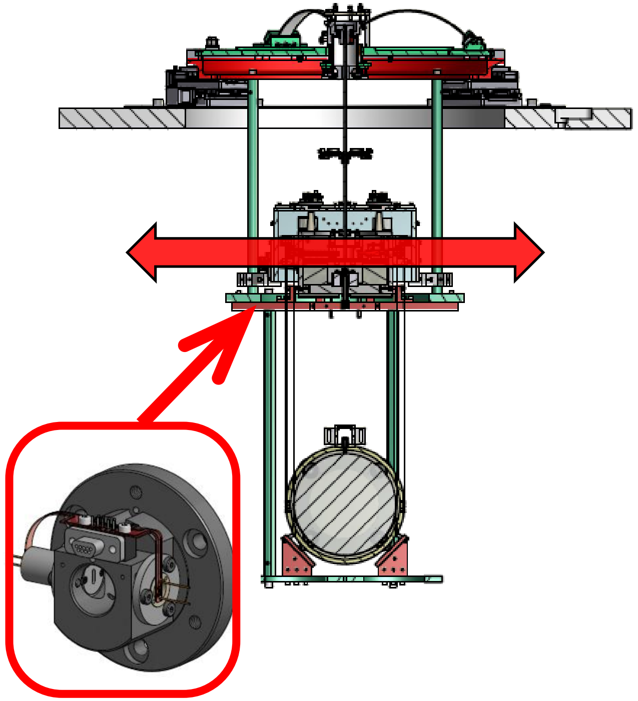
1. Suspension responses without control

1-2. Transfer functions



How is frequency response?

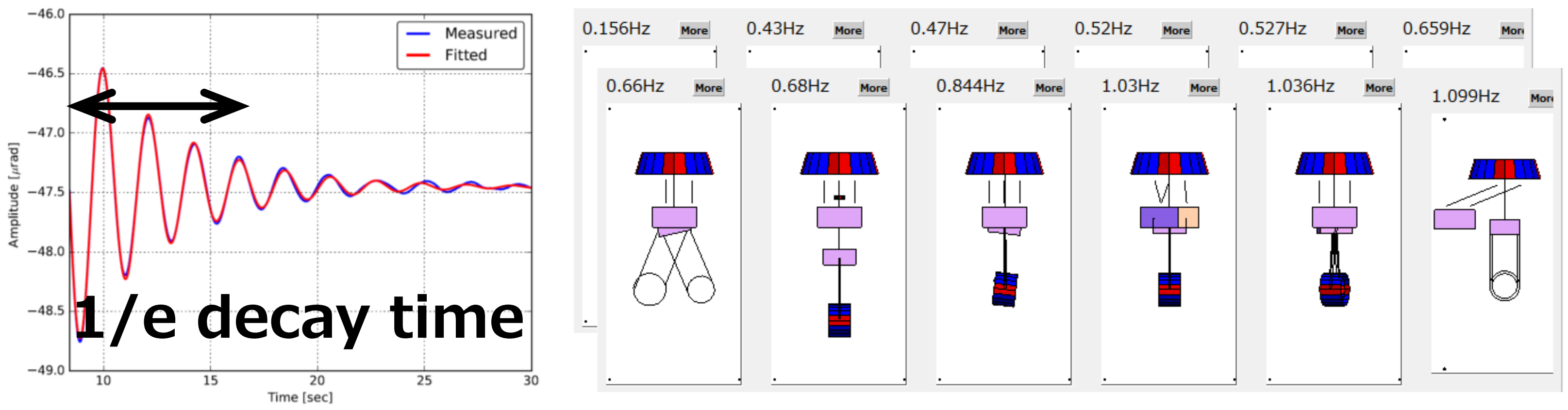
(for each components, DoF)



2. Suspension responses with control

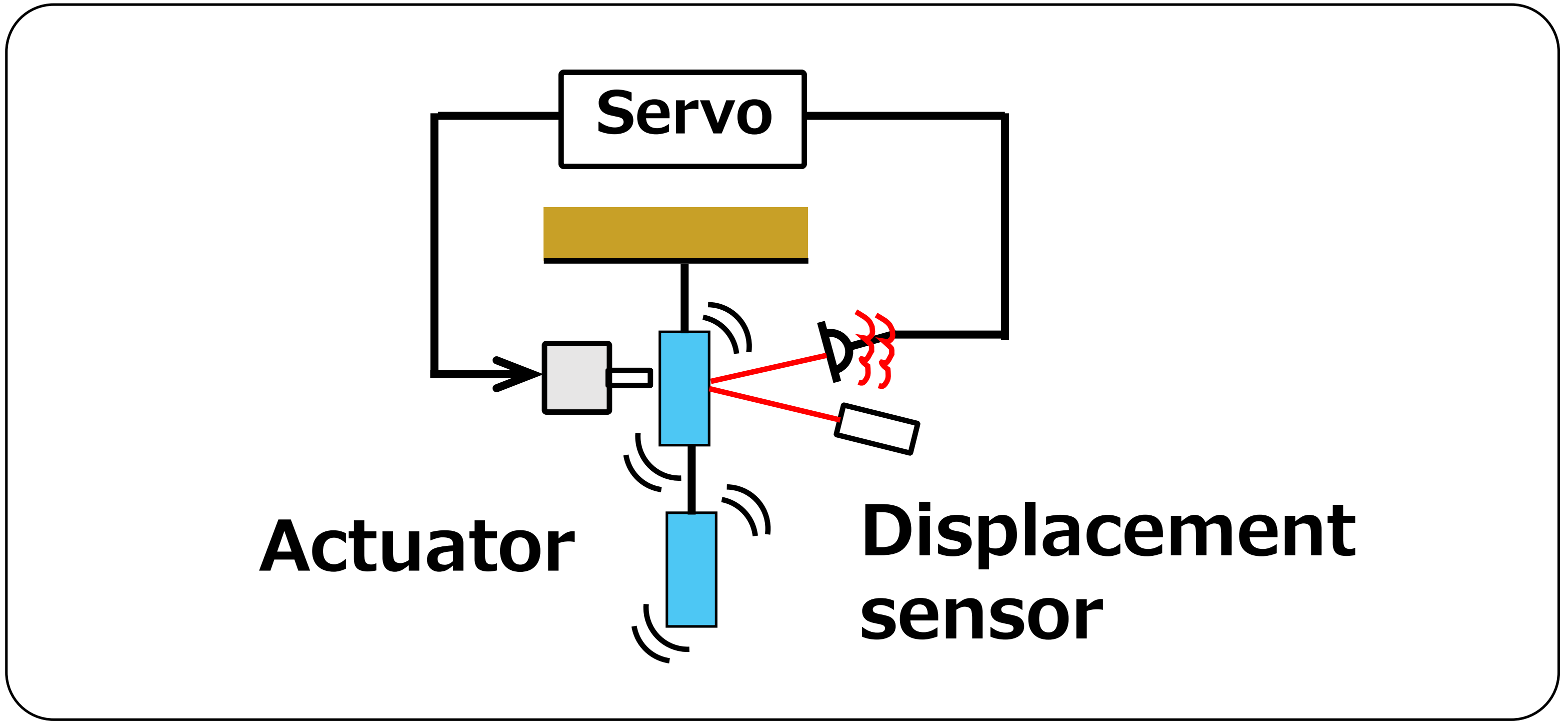
2-1. Damping performances

For damping resonances



2. Suspension responses with control

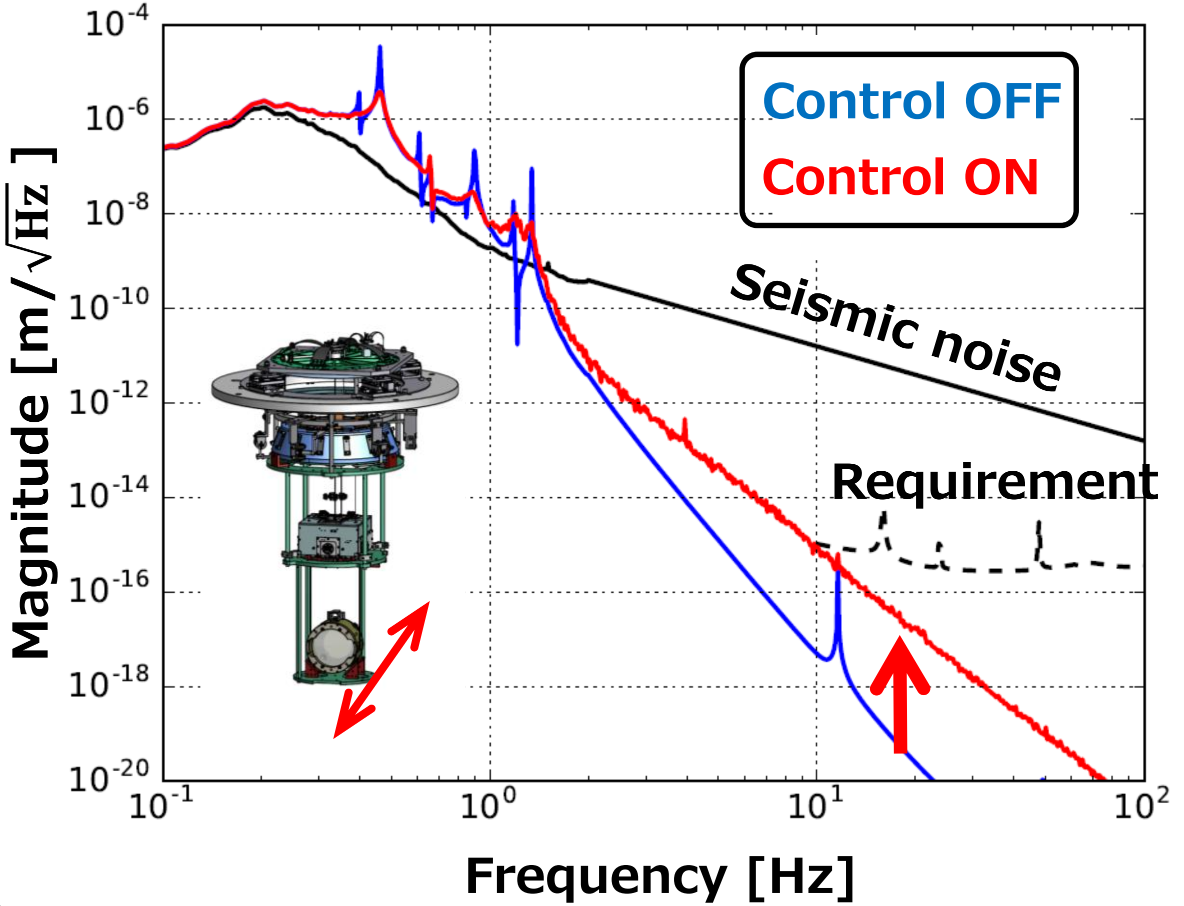
2-3. Since actuation is exerted by referencing sensor signals, sensor noise can induce external vibration. → ***control noise***



2. Suspension responses with control

2-3. Since actuation is exerted by referencing sensor signals, sensor noise can induce external vibration. → ***control noise***

Ex. Mirror oscillation (beam axis):



At high frequencies (> 2 Hz):
Displacement amplitude with ctrl becomes larger because of sensor noise.

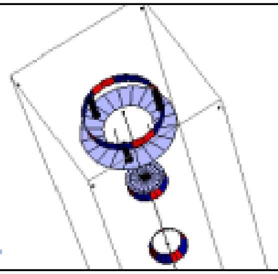
↓

We have to design the servo so that the control noise is smaller than the requirements.

What tools do we have?

SUMCON *in Mathematica*

spension odel structor



&

MATLAB

SIMULINK

Again, what should we know in detail?

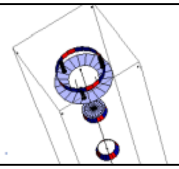
→ 1. Responses without control

Necessary to know how the resonances look like:

1-1. Eigen mode shapes

1-2. Transfer functions

SUMCON spension odel structor in *Mathematica*



MATLAB SIMULINK

→ 2. Responses with control

Necessary to know:

2-1. Damping performance

2-2. Root-Mean-Square velocity & angle etc.

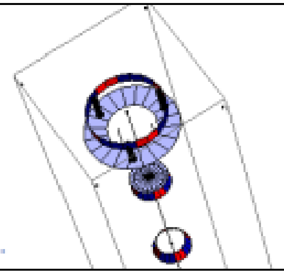
2-3. Control noise coupling

MATLAB SIMULINK

For mechanical response:

SUMCON *in Mathematica*

spension odel structor



Source files:

http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=3729

Quick manual:

http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=5034

You can visit the quick manual if you want to use SUMCON!

For** mechanical response & **response with control:

MATLAB SIMULINK

Reference files:

https://granite.phys.s.u-tokyo.ac.jp/svn/LCGT/trunk/VIS/SuspensionControlModel/

Quick manual:

http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=6284

You can visit the quick manual if you want to use this tool!

What is required for active control systems?

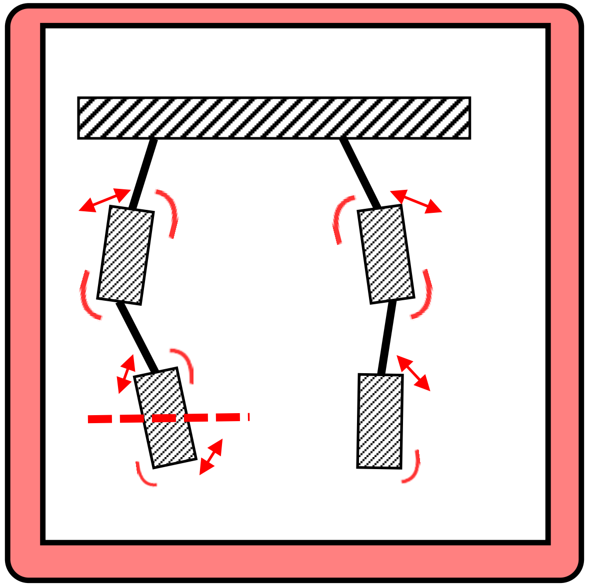
→ 1. To damp all the resonances
(which can disturb the interferometer operation).

→ 2. To reduces RMS velocity & RMS angle
so that one can lock the interferometer.

→ 3. To induces control noise as low as possible.

More in detail?

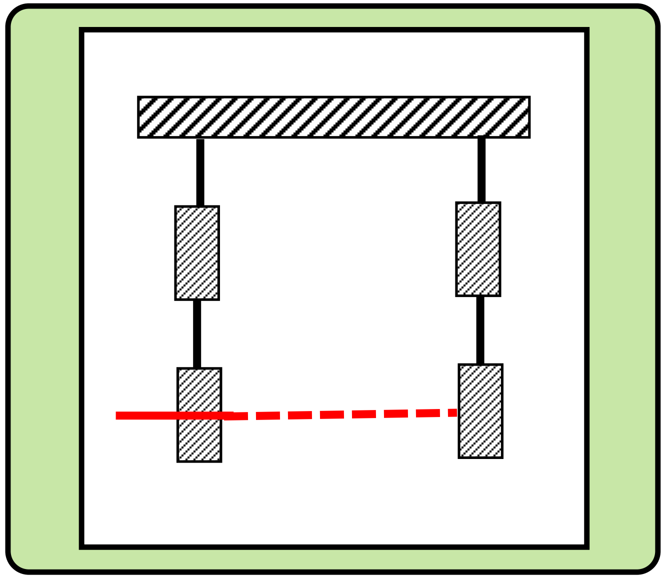
1. Calm-down phase



To do

Damp mechanical resonances

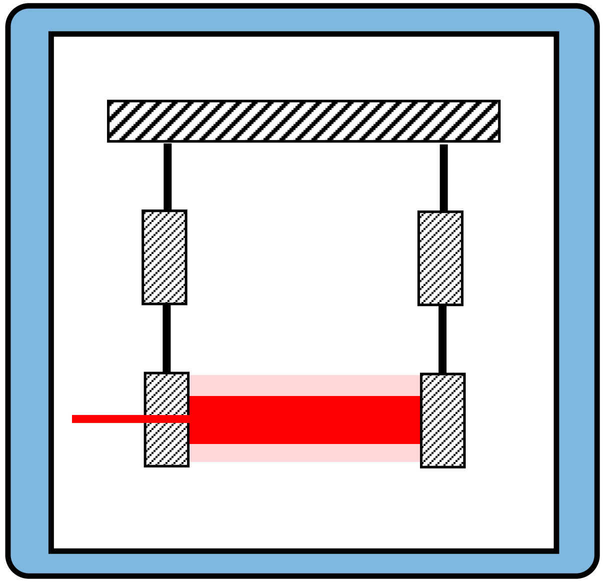
2. Lock-acquisition phase



To do

Reduce RMS velocity & RMS angle

3. Observation phase

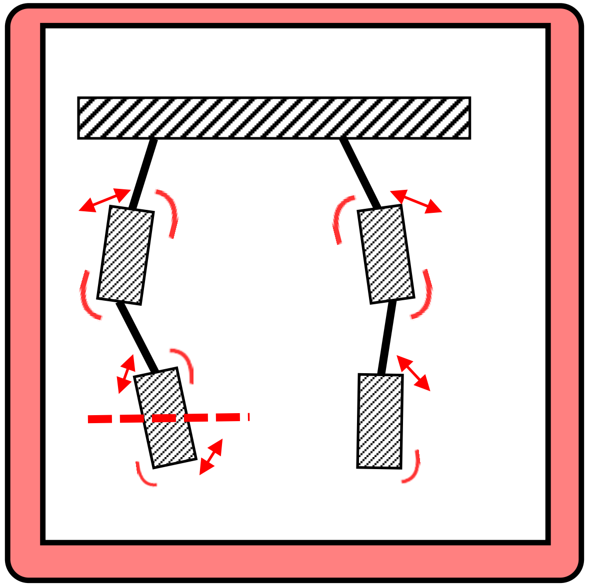


To do

Keep mirror position with low control noise

More in detail?

1. Calm-down phase



Requirement

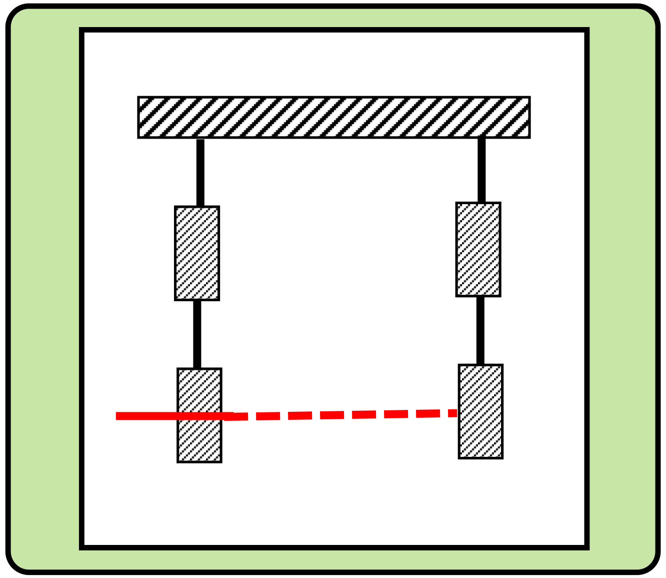
1/e decay time < 1 min.
(for each resonances which can disturb locking.)

To do

Damp mechanical resonances

More in detail?

2. Lock-acquisition phase



To do

Reduce RMS velocity & RMS angle

Requirements on type-Bp

1. RMS velocity (L) < 5 um/sec.
2. RMS displacement (T, V) < 1 mm
3. RMS displacement (P, Y) < 2 urad

Requirements on type-B

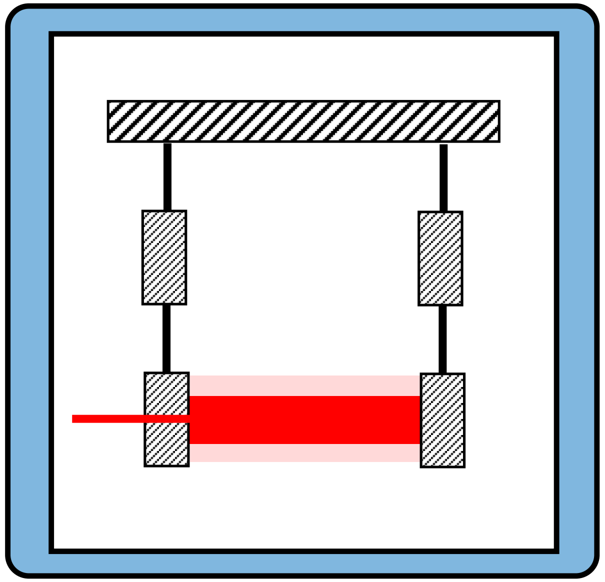
1. RMS velocity (L) < 0.5 um/sec.
2. RMS displacement (T, V) < 1 mm
3. RMS displacement (P, Y) < 1 urad

Requirements on type-A

1. RMS velocity (L) < 0.5 um/sec.
2. RMS displacement (T, V) < 1 mm
3. RMS displacement (P, Y) < 0.2 urad

More in detail?

3. Observation phase



To do

Keep mirror position with low control noise

Requirements on type-Bp

1. Displacement (L) < 1e-15 m at 10 Hz
2. RMS displacement (L) < 70 um
3. RMS displacement (T, V) < 1 mm
4. RMS displacement (P, Y) < 2 urad

Requirements on type-B

1. Displacement (L) < 5e-18 m at 10 Hz
2. RMS displacement (L) < 0.4 um
3. RMS displacement (T, V) < 1 mm
4. RMS displacement (P, Y) < 1 urad

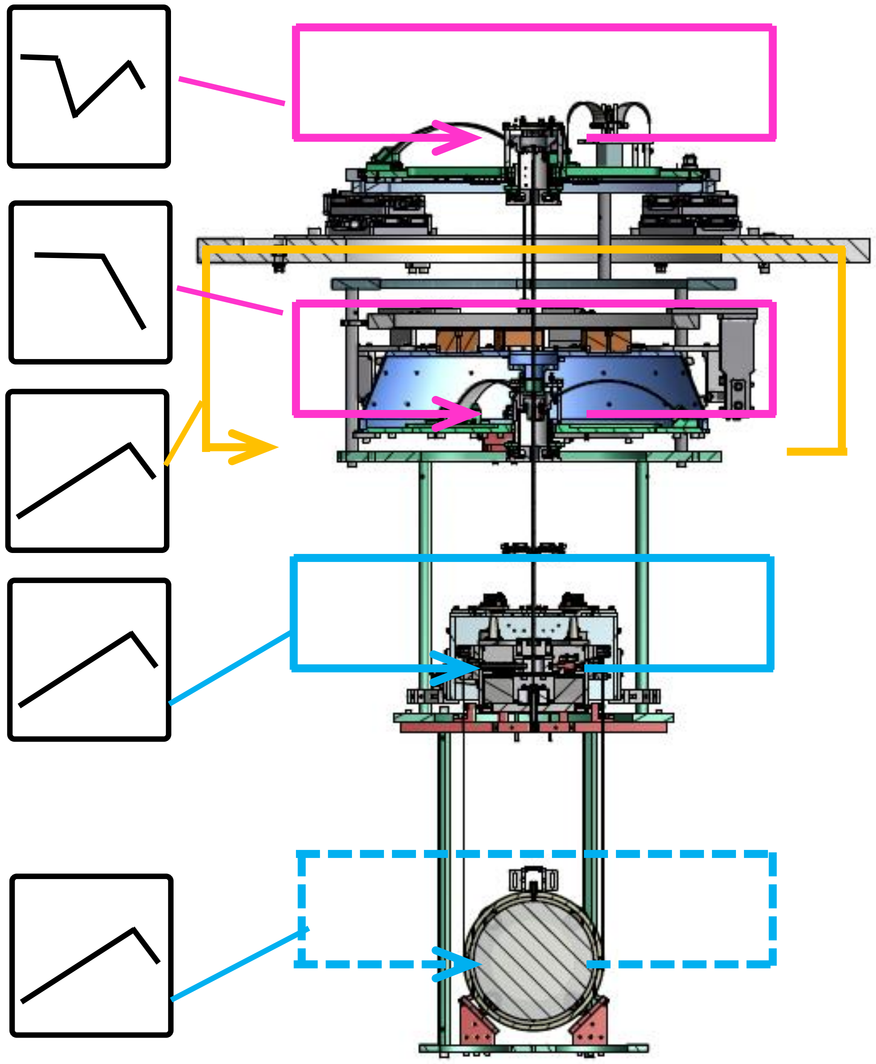
Requirements on type-A

1. Displacement (L) < 1e-19 m at 10 Hz
2. RMS displacement (L) < 2 nm
3. RMS displacement (T, V) < 1 mm
4. RMS displacement (P, Y) < 0.2 urad

Example: Active control system for type-Bp suspension

Degree of freedom:	*Sensors:*
L = Longitudinal	*F1, F2 LVDT*
T = Transversal	*→ relatively vertical motion between GAS-keystone and frame*
V = Vertical	*BF LVDT*
R = Roll	*→ Relative motion between BF and its recoil mass*
P = Pitch	*OSEM*
Y = Yaw	*→ Relative motion between IM and its recoil mass*
	OpLev
	→ Angular sensor for optics
	LnSen
	→ Longitudinal sensor for optics

1. Calm-down phase



GAS Control

F1 LVDT $\xrightarrow{\text{DC + Damp}}$ F1 Actuator

F2 LVDT $\xrightarrow{\text{DC}}$ F2 Actuator

BF Control

BF LVDT $\xrightarrow[L,\ T,\ V,\ R,\ P,\ Y]{\text{Damp}}$ BF Actuator

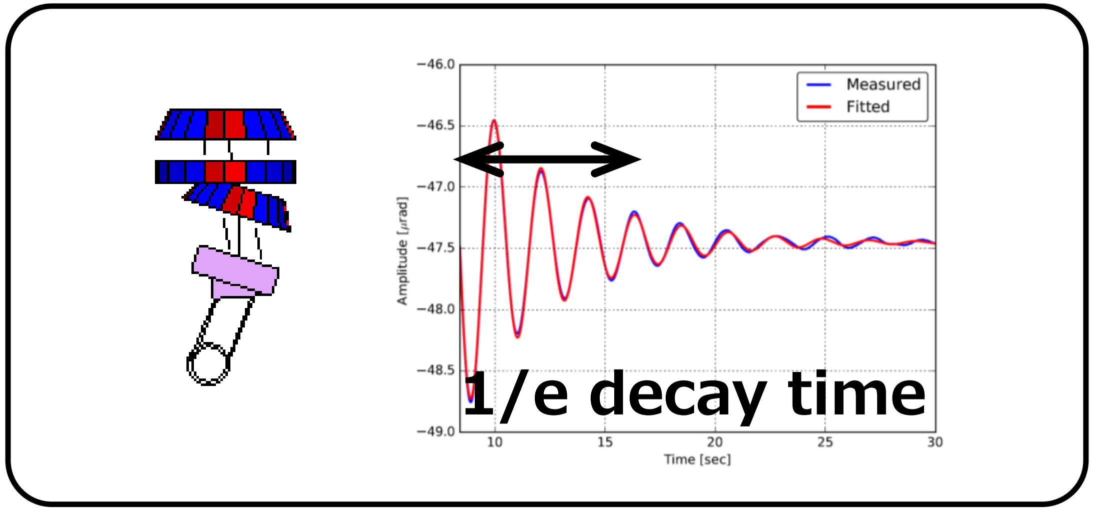
Payload Control

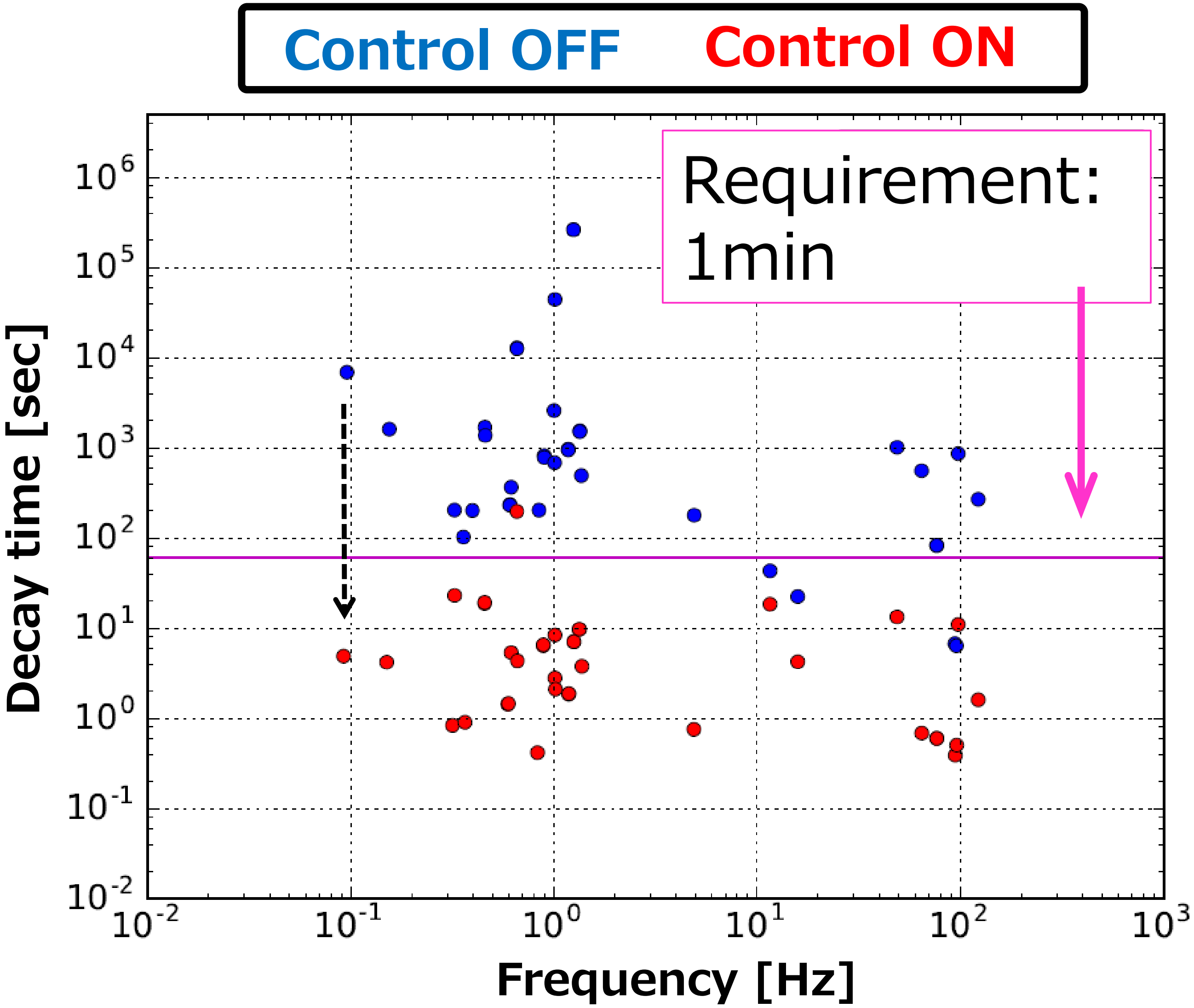
IM OSEM $\xrightarrow[L,\ T,\ V,\ R,\ P,\ Y]{\text{Damp}}$ IM Actuator

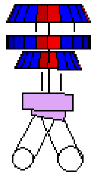
TM OpLev
TM LnSen $\xrightarrow[L,\ P,\ Y]{\text{Damp}}$ TM Actuator

1. Calm-down phase

Suppress large disturbance

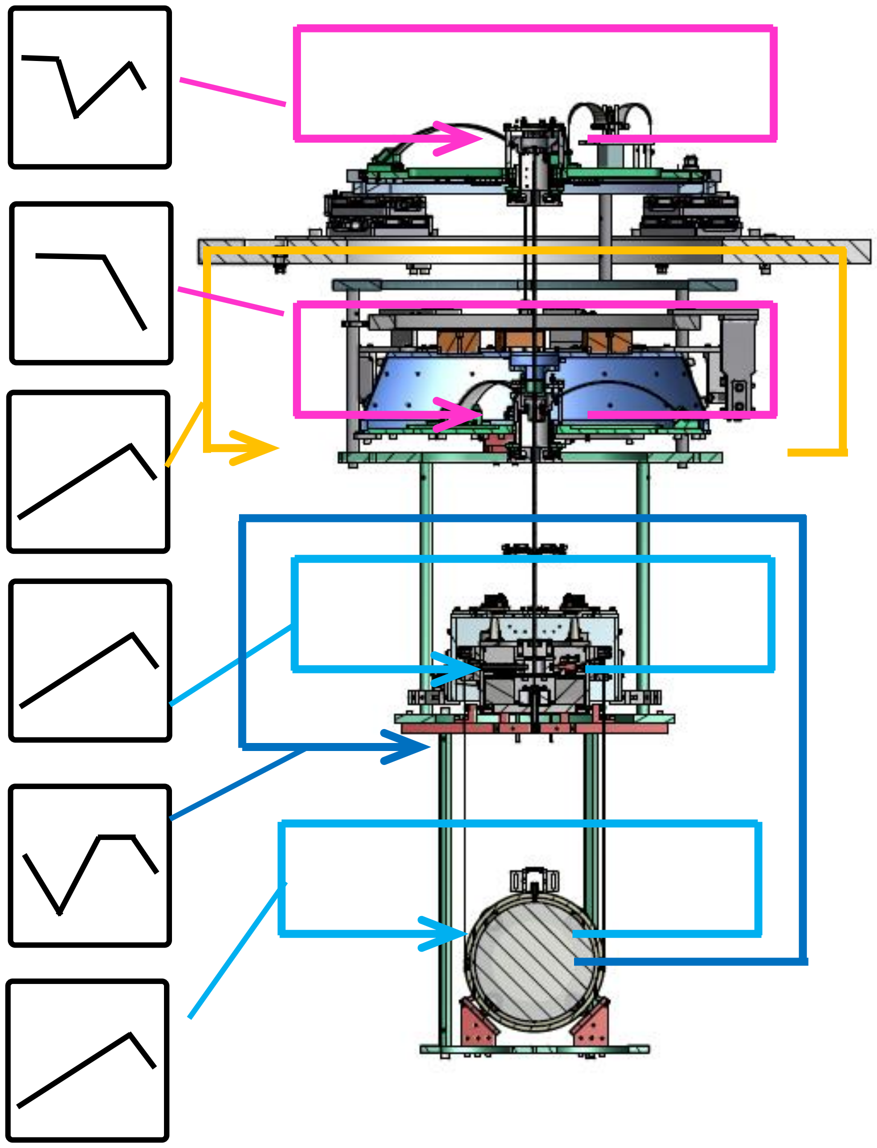






Not disturb operation
→ No problem.

2. *Lock-acquisition phase*



GAS Control

F1 LVDT $\xrightarrow{\text{DC + Damp}}$ F1 Actuator

F2 LVDT $\xrightarrow{\text{DC}}$ F2 Actuator

BF Control

BF LVDT $\xrightarrow[L,\ T,\ V,\ R,\ P,\ Y]{\text{Damp}}$ BF Actuator

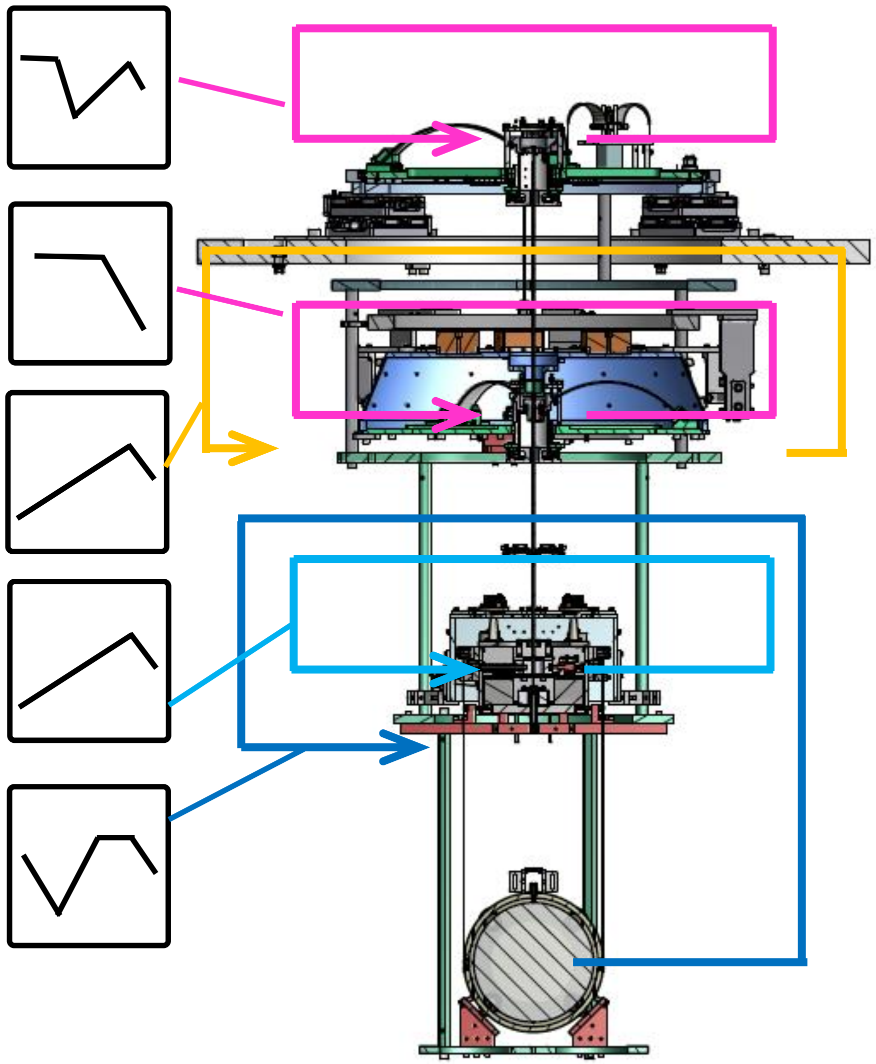
Payload Control

IM OSEM $\xrightarrow[L,\ T,\ V,\ R]{\text{Damp}}$ IM Actuator

TM OpLev $\xrightarrow[P,\ Y]{\text{DC + Damp}}$ IM Actuator

TM LnSen $\xrightarrow[L]{\text{Damp}}$ TM Actuator

3. Observation phase



GAS Control

F1 LVDT $\xrightarrow{\text{DC + Damp}}$ F1 Actuator

F2 LVDT $\xrightarrow{\text{DC}}$ F2 Actuator

BF Control

BF LVDT $\xrightarrow[\textit{L, T, R, P, Y}]{\text{Damp}}$ BF Actuator

Payload Control

IM OSEM $\xrightarrow[\textit{L, T, R}]{\text{Damp}}$ IM Actuator

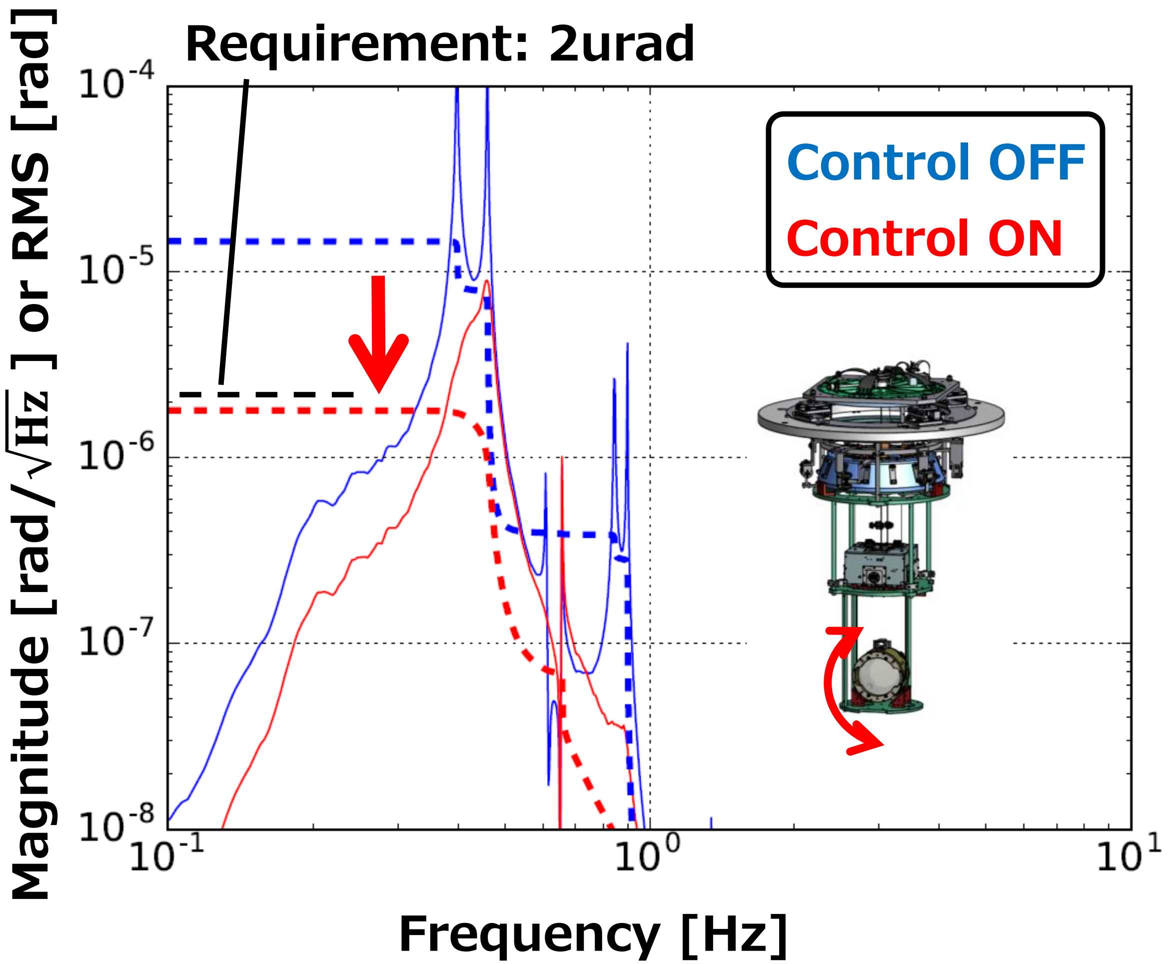
WFS $\xrightarrow[\textit{P, Y}]{\text{DC + Damp}}$ IM Actuator

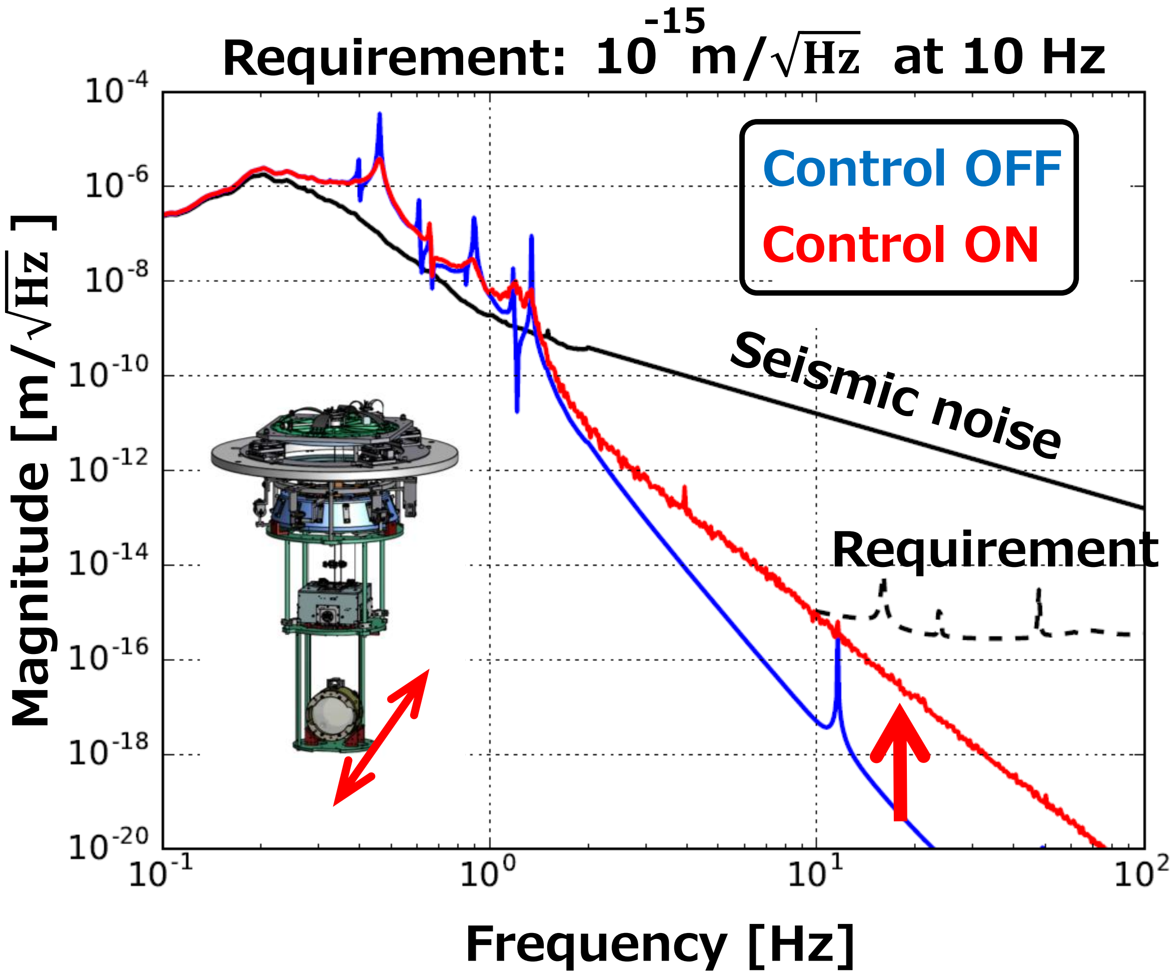
TM OpLev

TM LnSen $\rightarrow$ TM Actuator

3. Observation phase

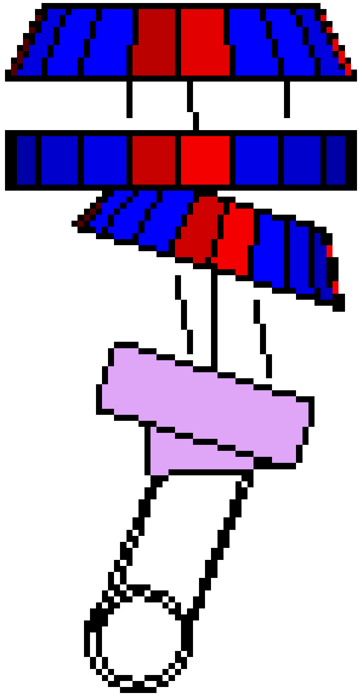
Suppress RMS (Root Mean Square) & **control noise**

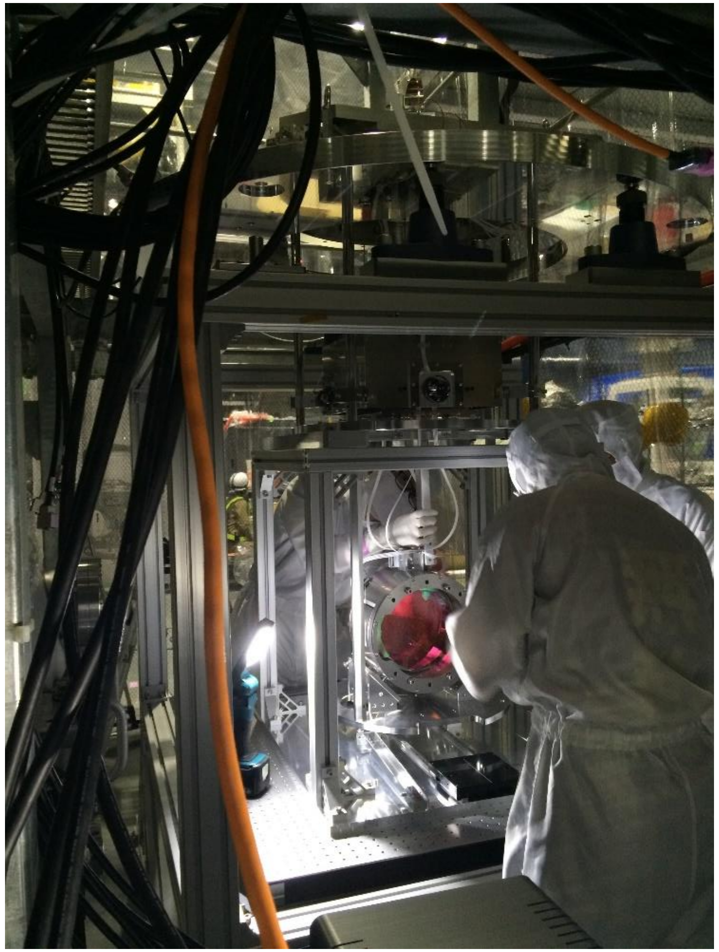




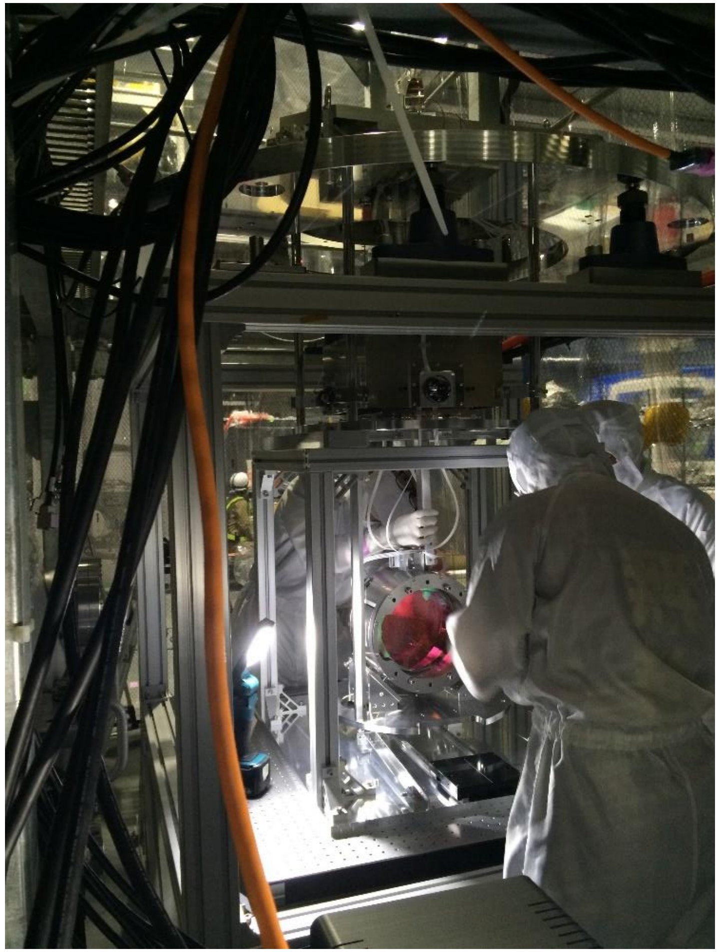
Heat link issue

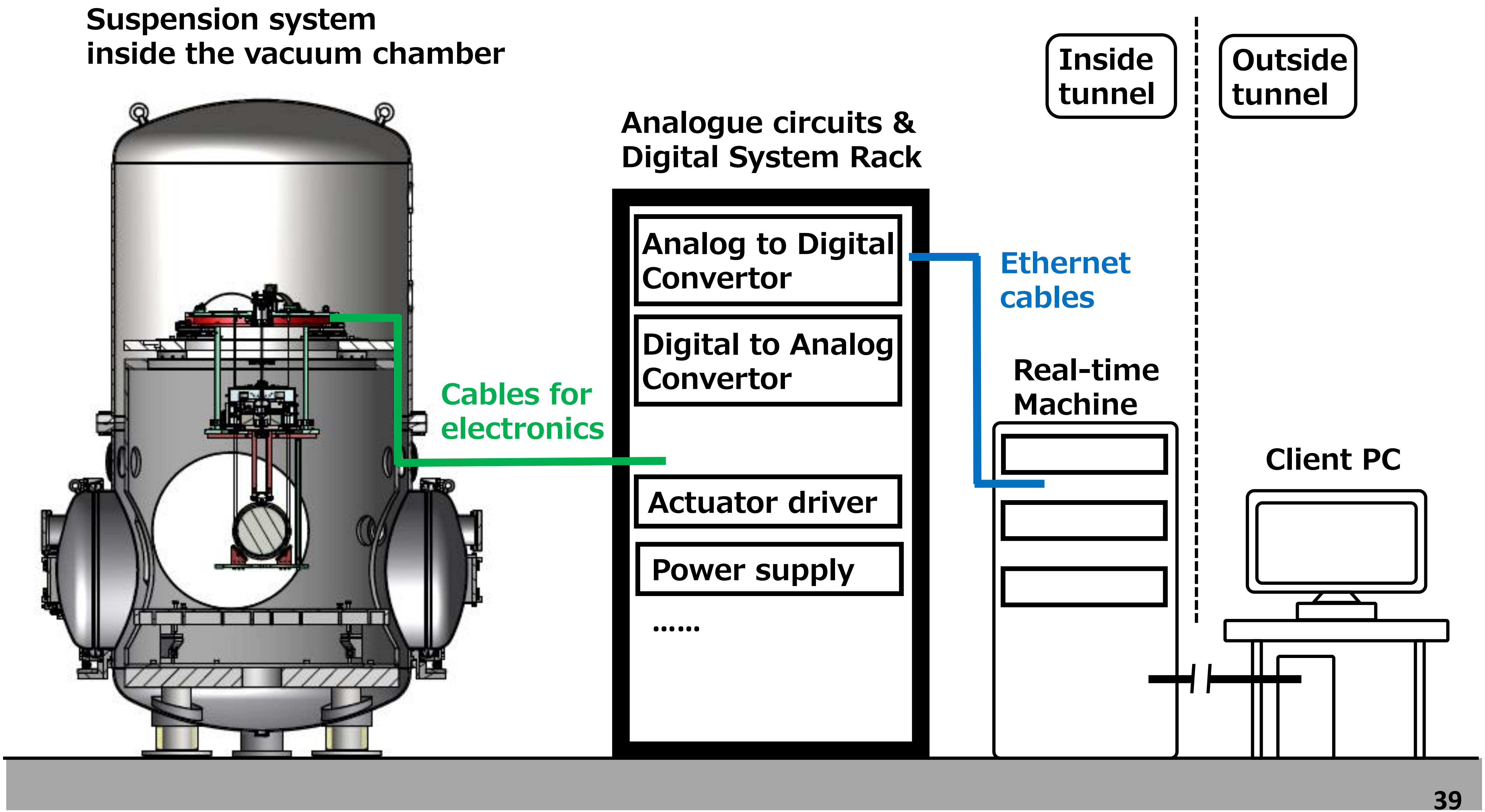
1. Simulation → 2. Experiment





After assembly..

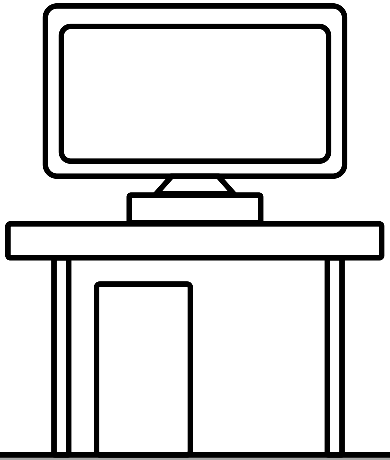



Suspension system
inside the vacuum chamber
Analogue circuits &
Digital System Rack
Inside
tunnel
Outside
tunnel
Analog to Digital
Convertor
Digital to Analog
Convertor
Actuator driver
Power supply
……
Ethernet
cables
Cables for
electronics
Real-time
Machine
Client PC

What do we do through PC?

Outside tunnel

Client PC



→ play with suspensions!

1. Measure spectra, transfer functions, Mechanical Q factors, and so on.
→ diaggui, dataviewer, etc.

2. Implement servo filters
→ foton, medm, etc

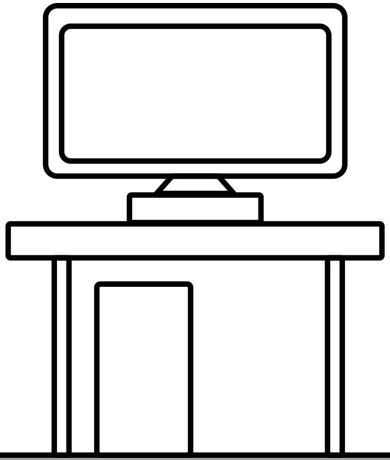
NOTE: Do remember that suspension is so delicate.

What do we do through PC?

→ *play with suspensions!*

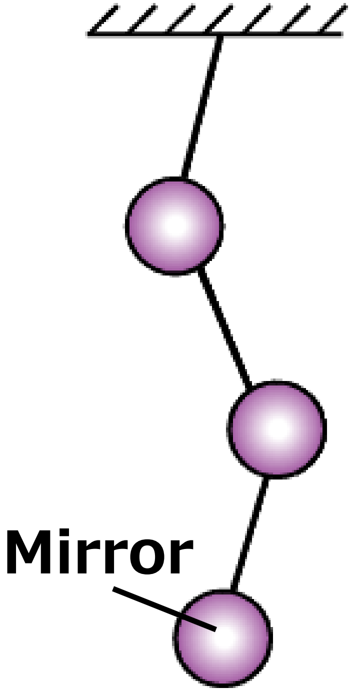
Outside tunnel

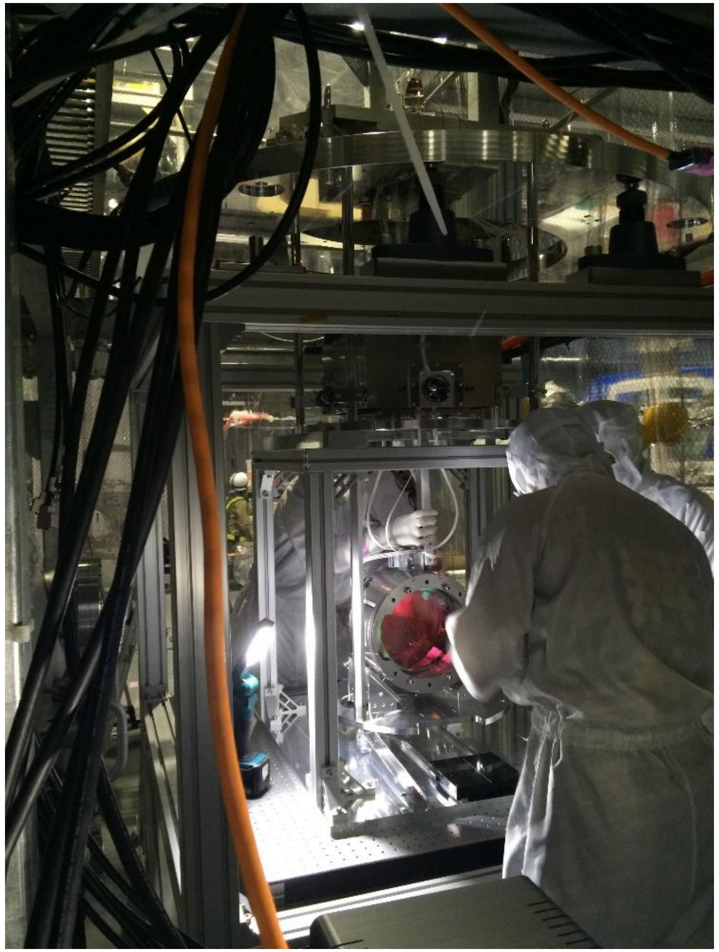
Client PC



1. "Calculator & Real time model" by Yamamoto-san.
   http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=5910
2. "How to use KAGRA Data Tools" by Miyo-kun.
   http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=5910
3. "Epics, MEDM, Strip tools" by Sasaki-kun.
   http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=5910

Notes





NOTE: Do remember that suspension is so delicate.

1. Too large actuation force can easily break some components like OSEM flags.

2. Too quick DC alignment can damage the system.