

KAGRA 用防振装置の開発 XVII (インストール)

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麻生洋一(国立天文台), 奥富弘基(総研大), Ettore Majorana(INFN Rome),
Joris van Heijningen, 我妻一博(NIKHEF), Riccardo DeSalvo(Univ. Sannio),
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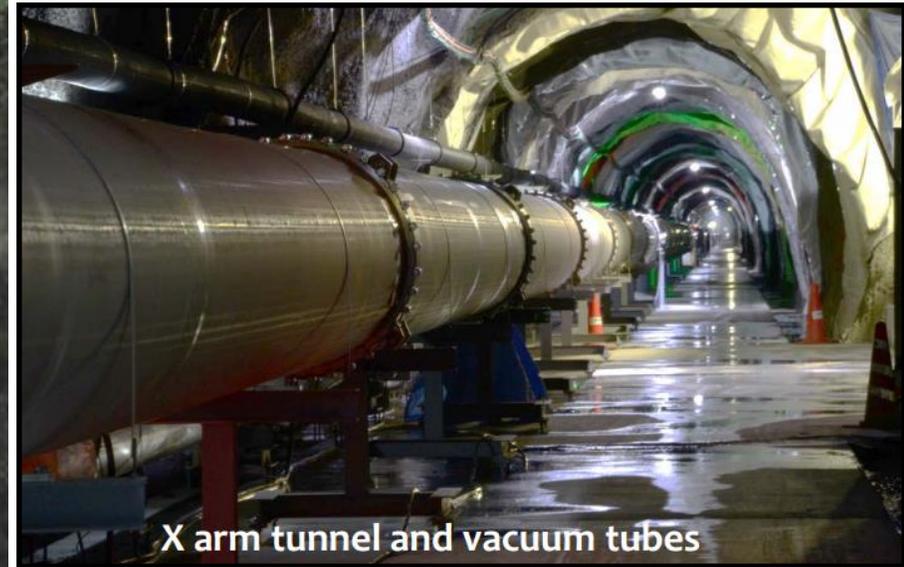
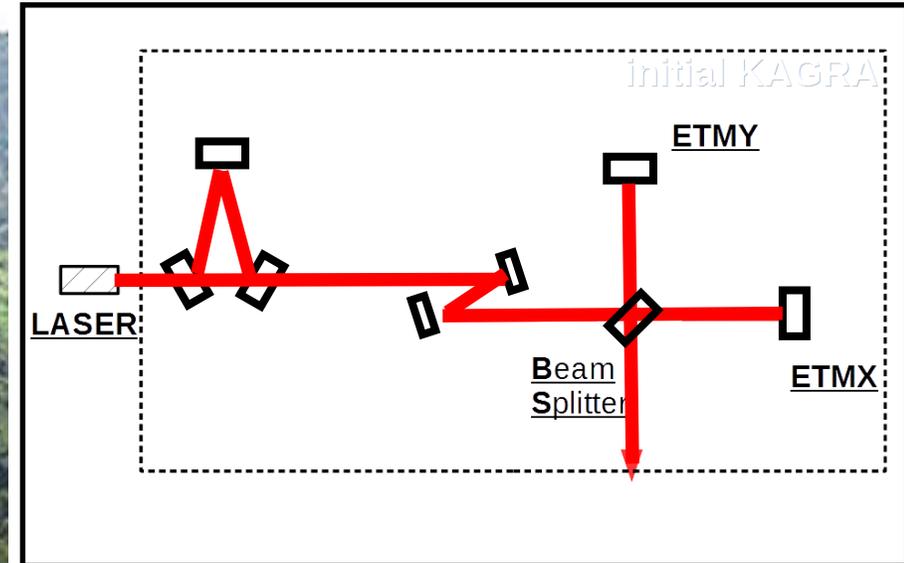
□ まとめ

❖はじめに : KAGRA

大型低温重力波検出器 KAGRA

* 2016年3月末に試運転開始予定
(iKAGRA)

→ 3 km のマイケルソン干渉計

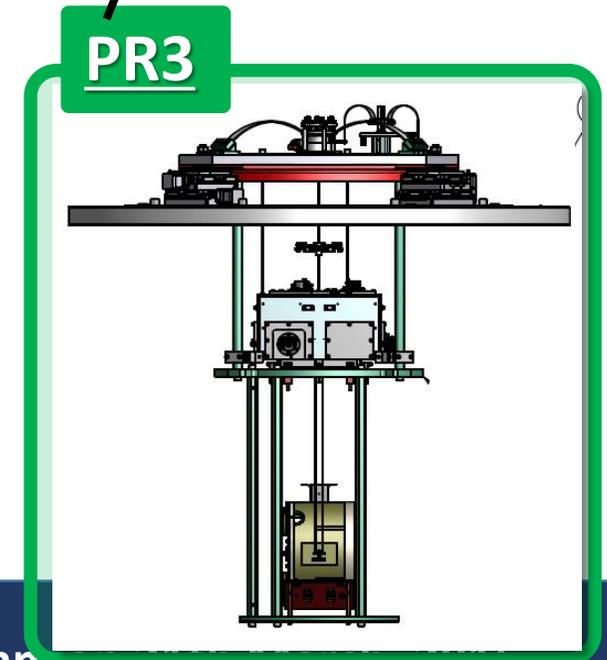
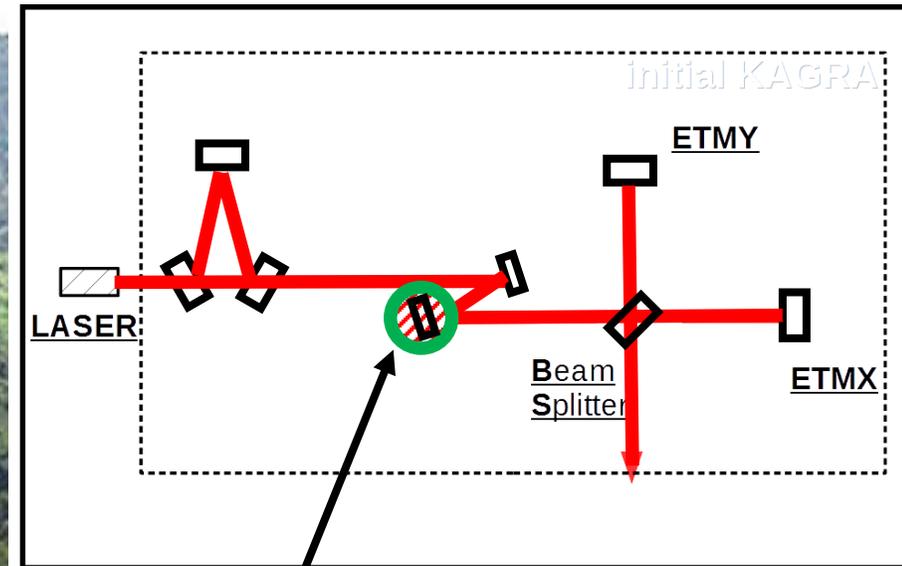


◆はじめに : KAGRA

今回は iKAGRA 干渉計の調整用鏡 PR3 の installation について。

目的 :

- 1) 調整用鏡をインストール → 使用
- 2) KAGRAの防振装置のインストール手順の確認



Contents

□ はじめに / KAGRA

◆ PR3 防振装置

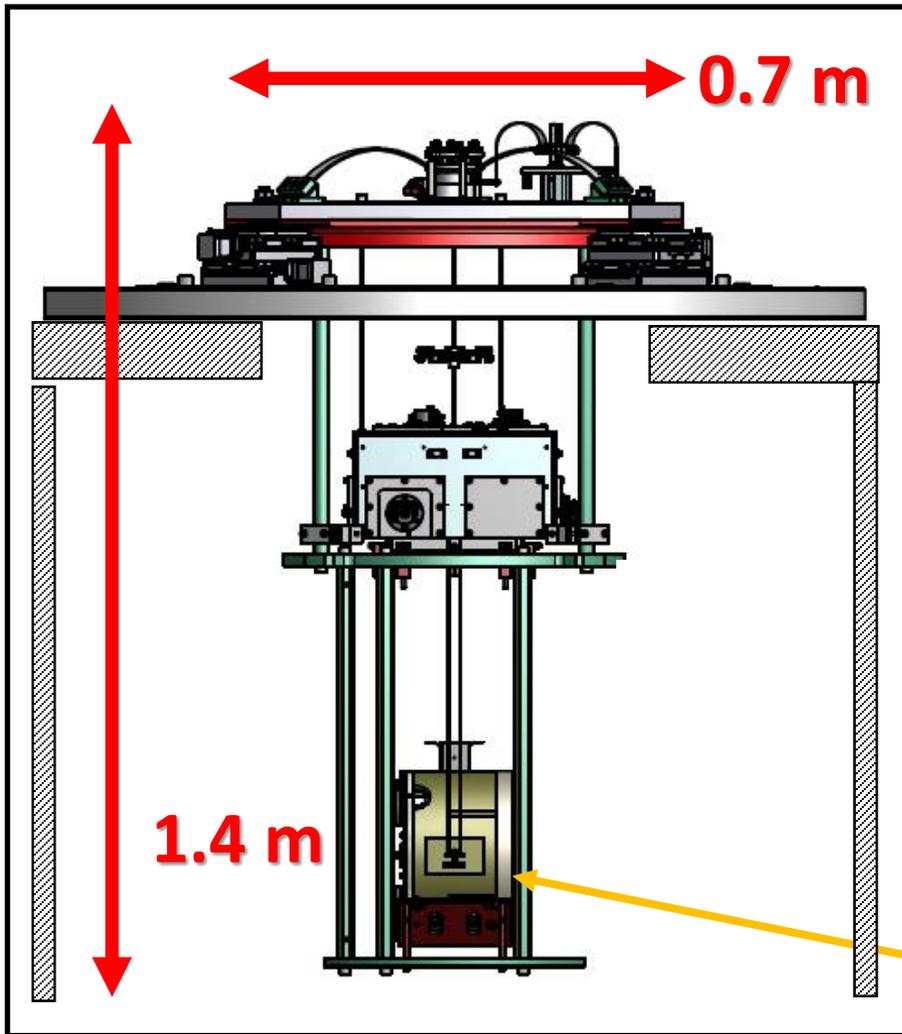
□ Installation @ 神岡KAGRAサイト

□ 組み立て手順

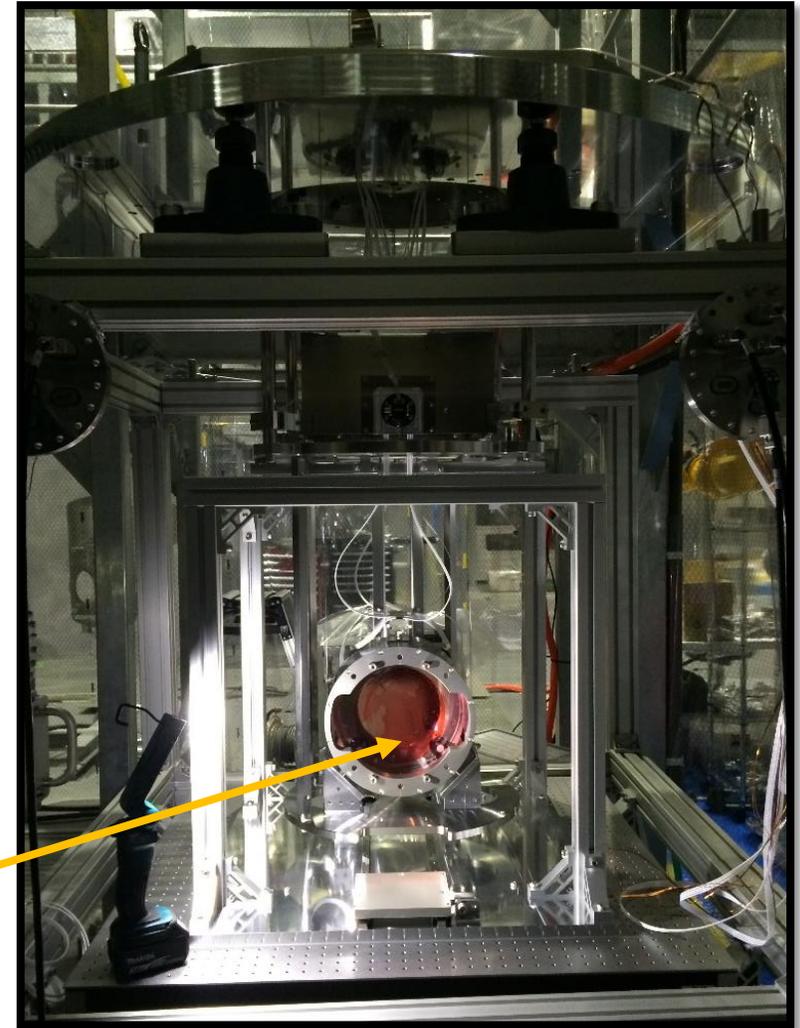
□ 干渉計での利用

□ まとめ

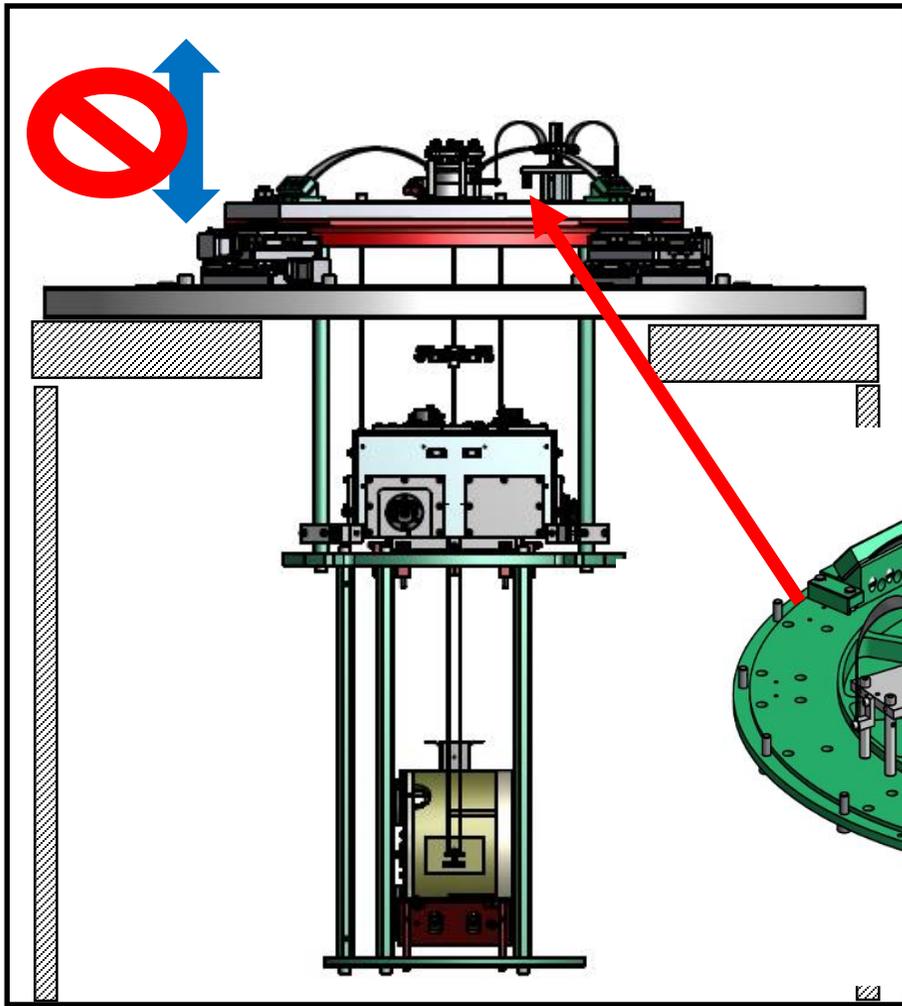
◆ PR3 防振装置 / メカの構成



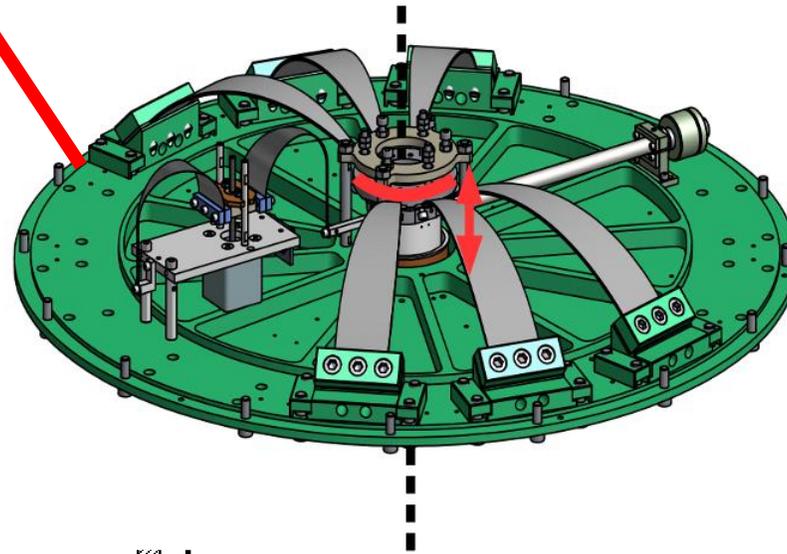
iKAGRA での
PR3用 防振装置
(TypeBp')



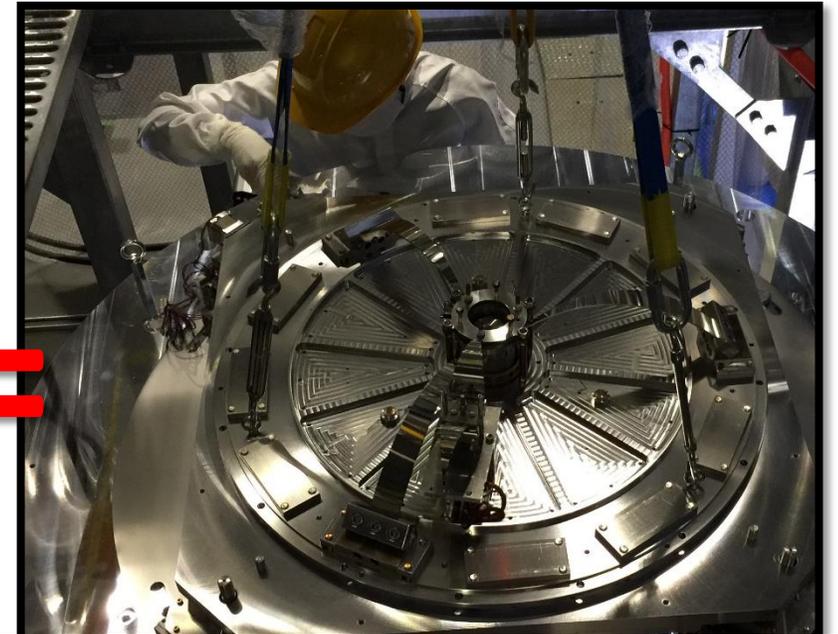
❖ PR3 防振装置 / メカの構成



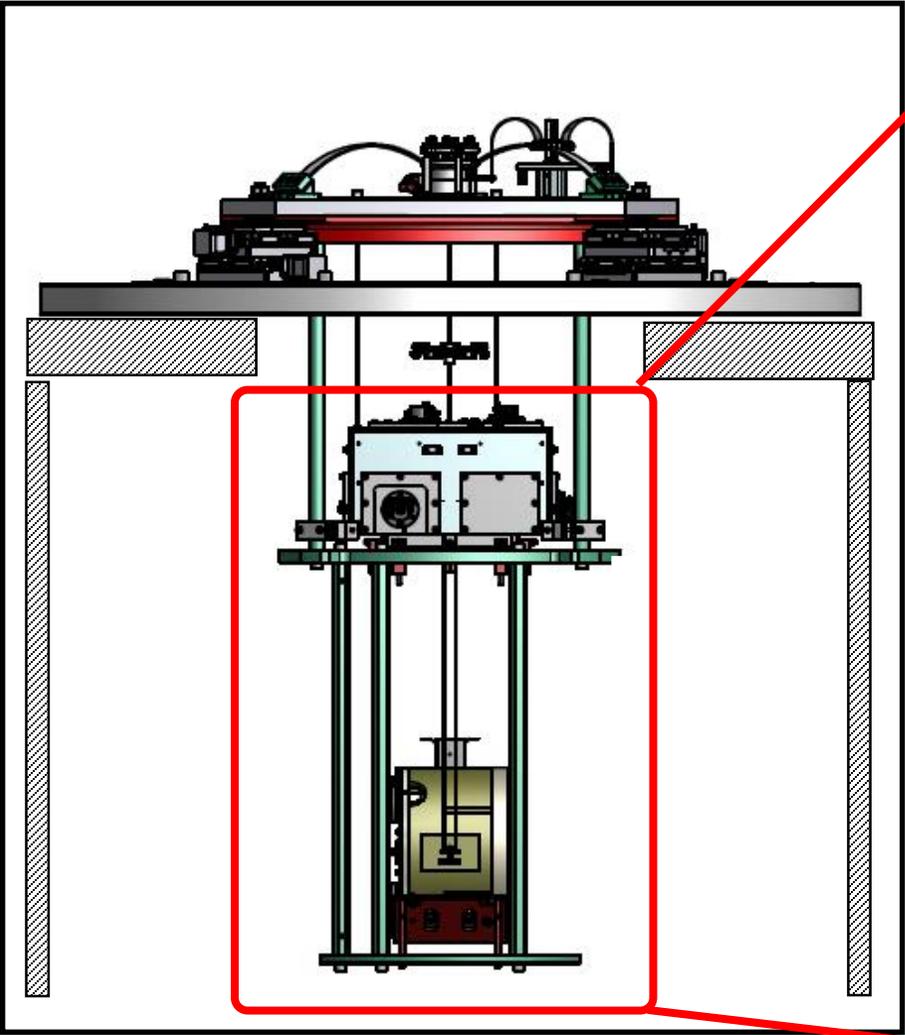
Geometric Anti-Spring(GAS) Filter ;
垂直方向の防振に必要。1 段使用



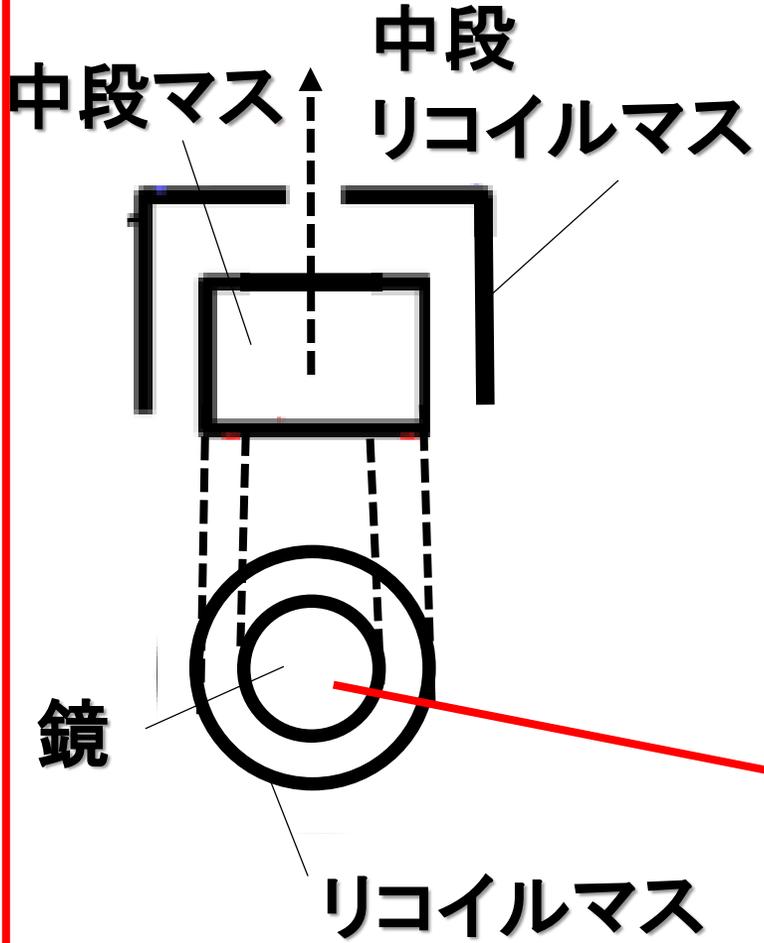
=



◆ PR3 防振装置 / メカの構成



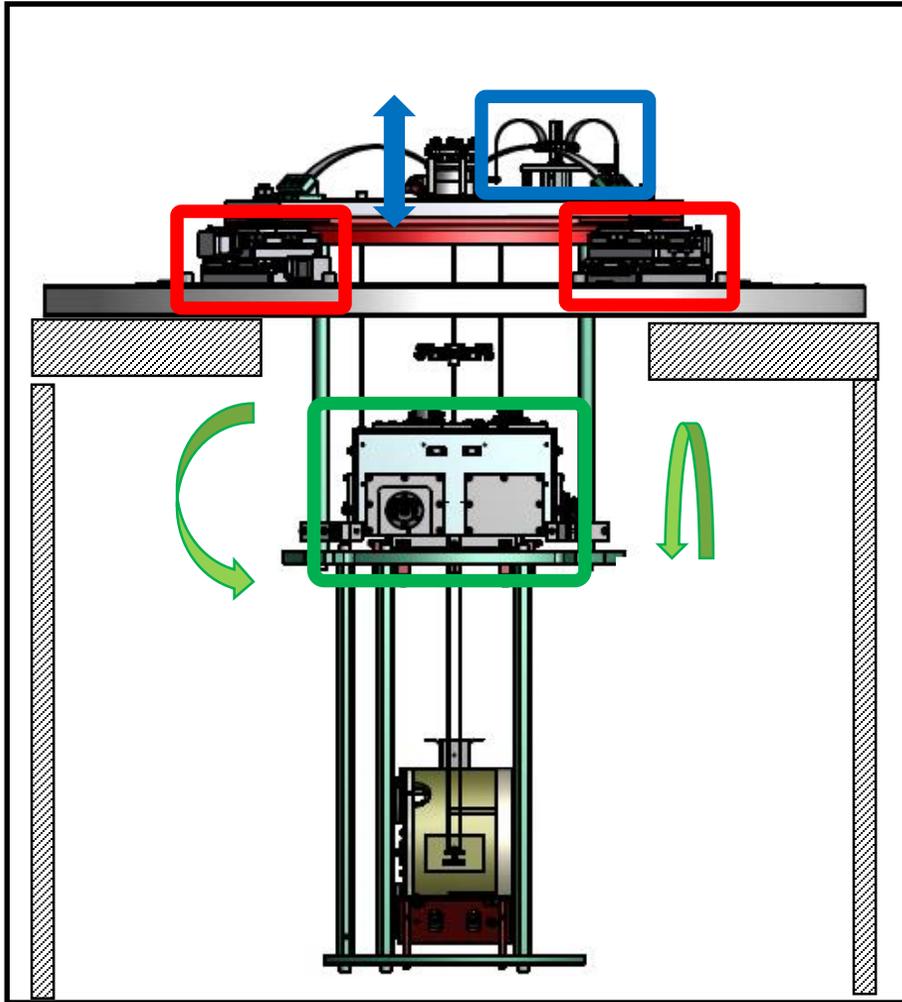
“Payload”



鏡とその覆いとの、
相対的な傾き・姿勢の
微調整を行う。

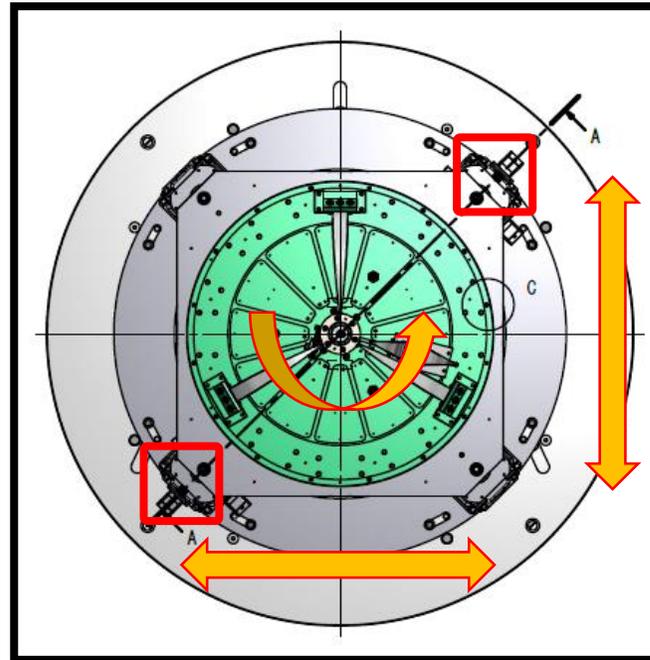
現在鏡は
リコイルマスに
固定。

◆ PR3 防振装置 / 初期アライメント機構



“Traverser”

防振装置全体の
並進2軸方向と
垂直軸周りの回転方向



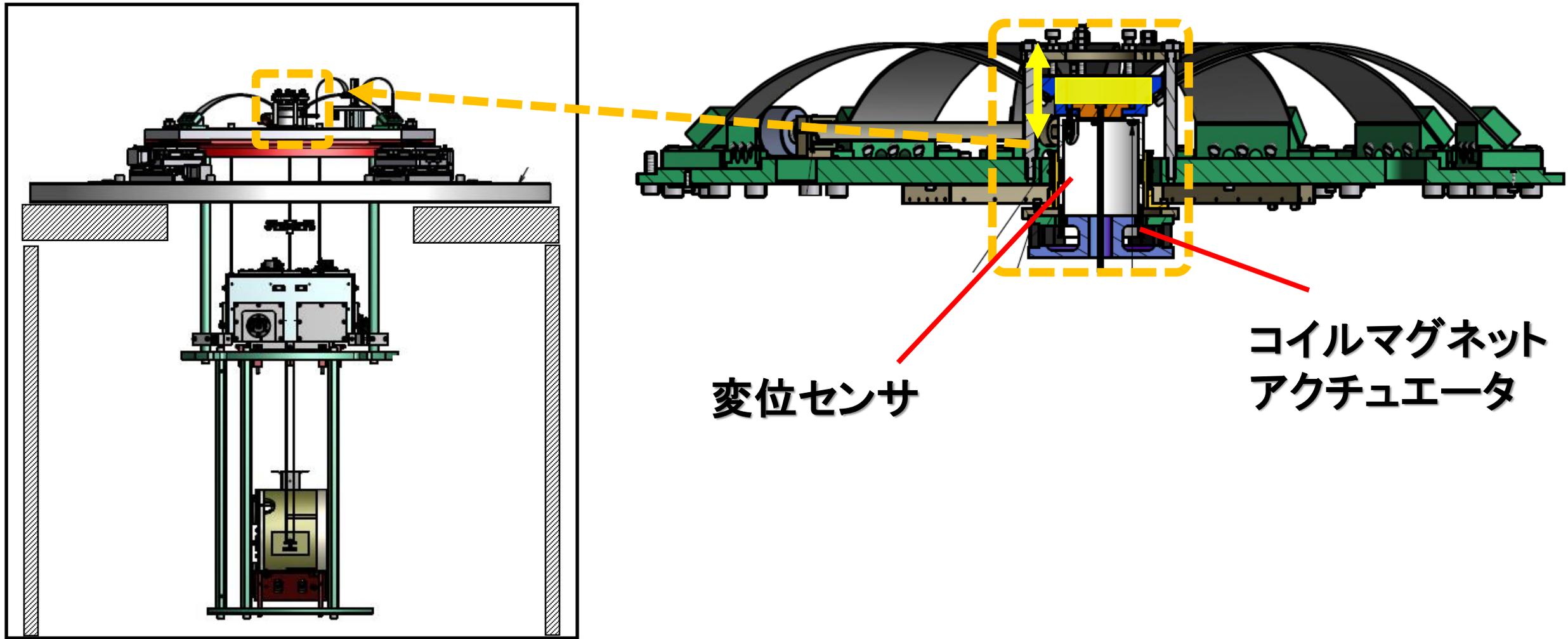
“Fishing rod”

鏡の垂直軸方向

DC tilt adjustment

中段マスの回転
2方向

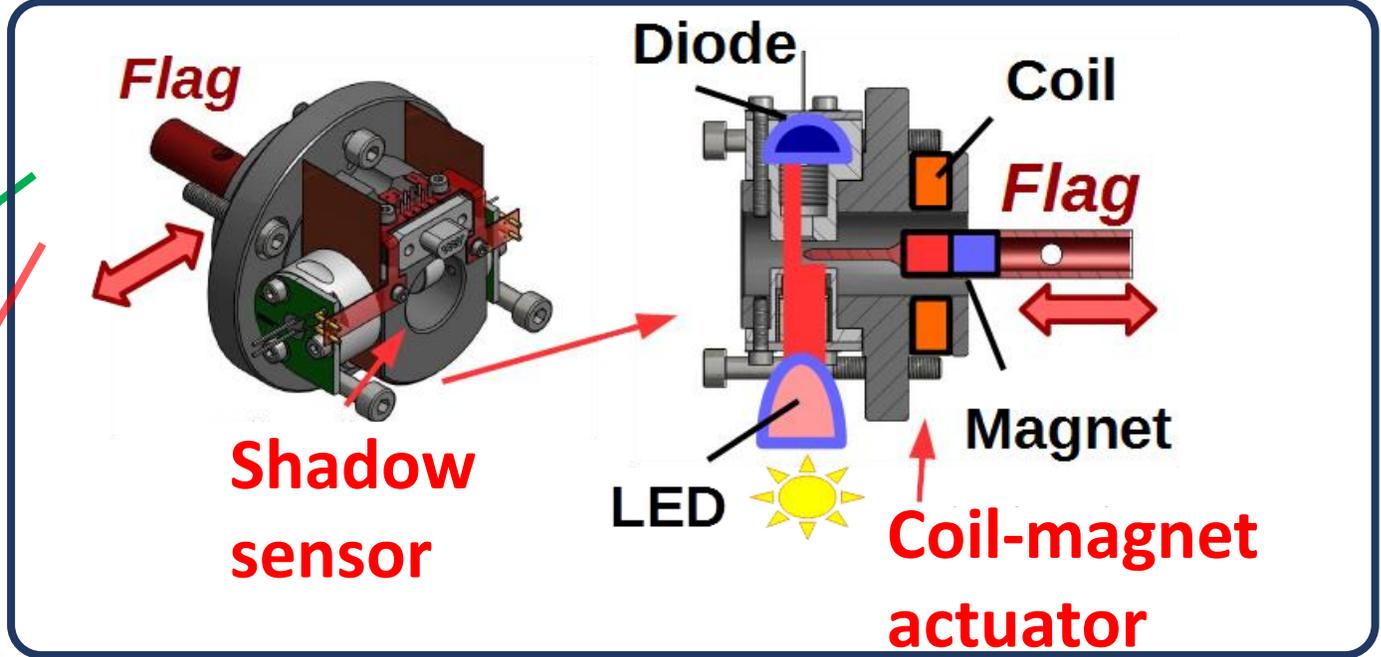
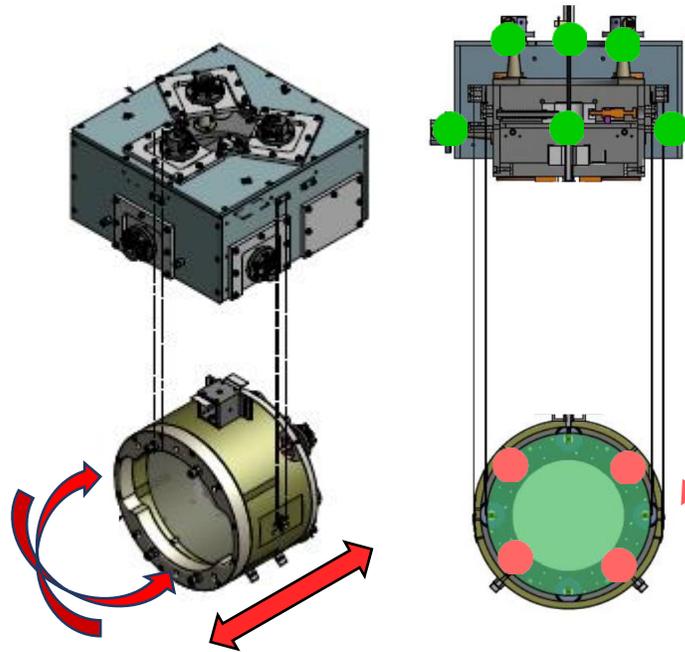
◆ PR3 防振装置 / センサ, アクチュエータ



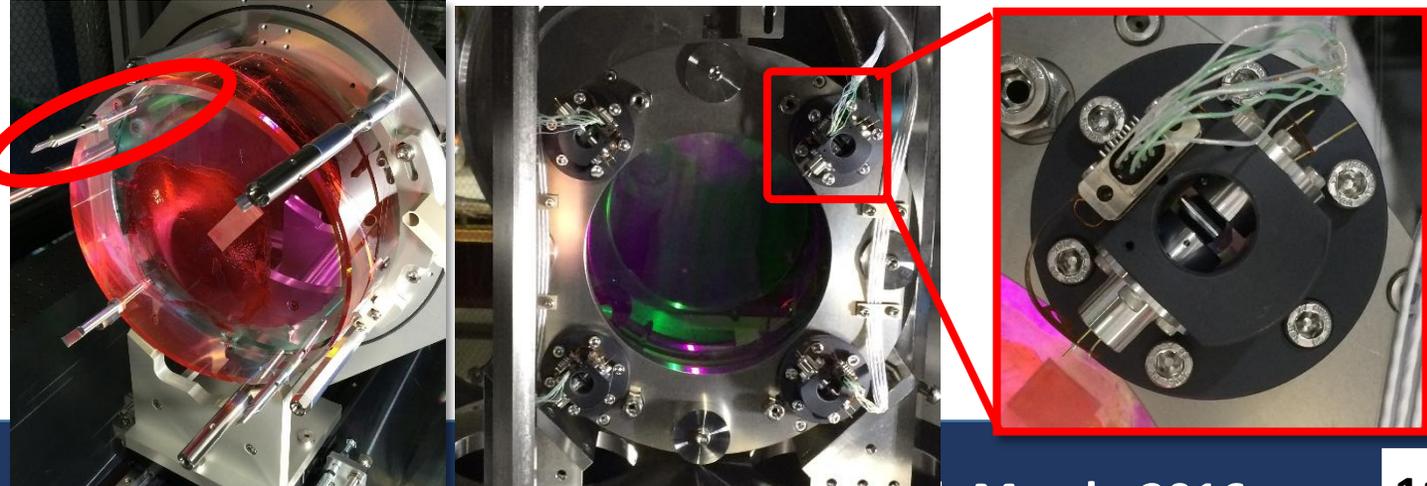
❖ PR3 防振装置 / センサ, アクチュエータ

Optical Sensors and Electro-Magnetic Actuators

→ シャドウセンサ & コイルマグネット アクチュエータ



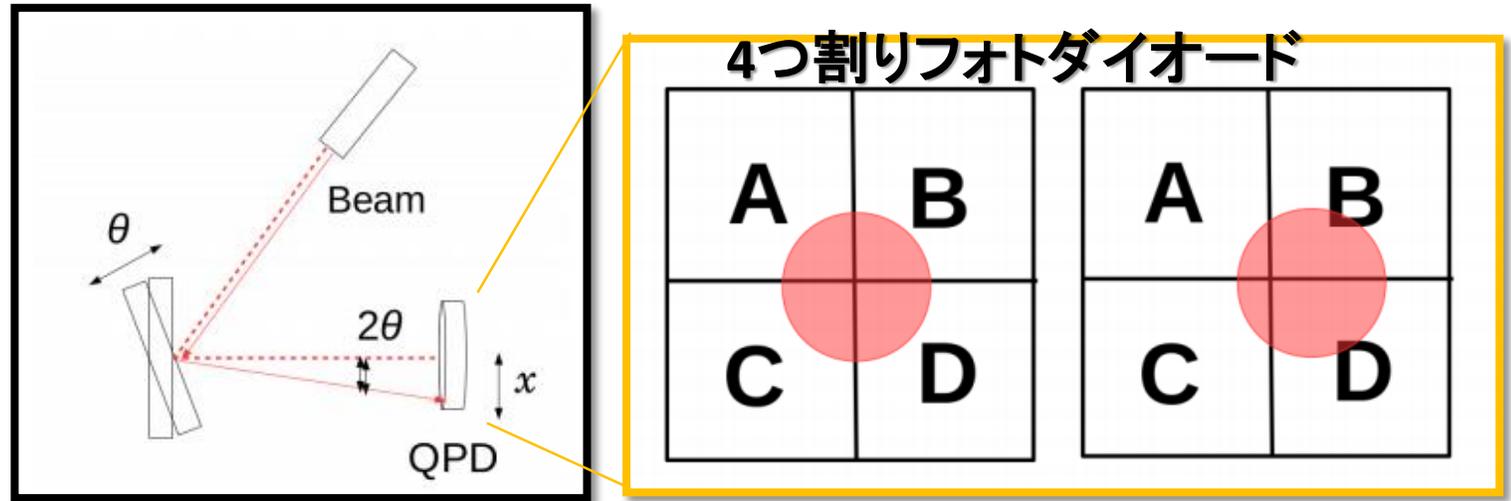
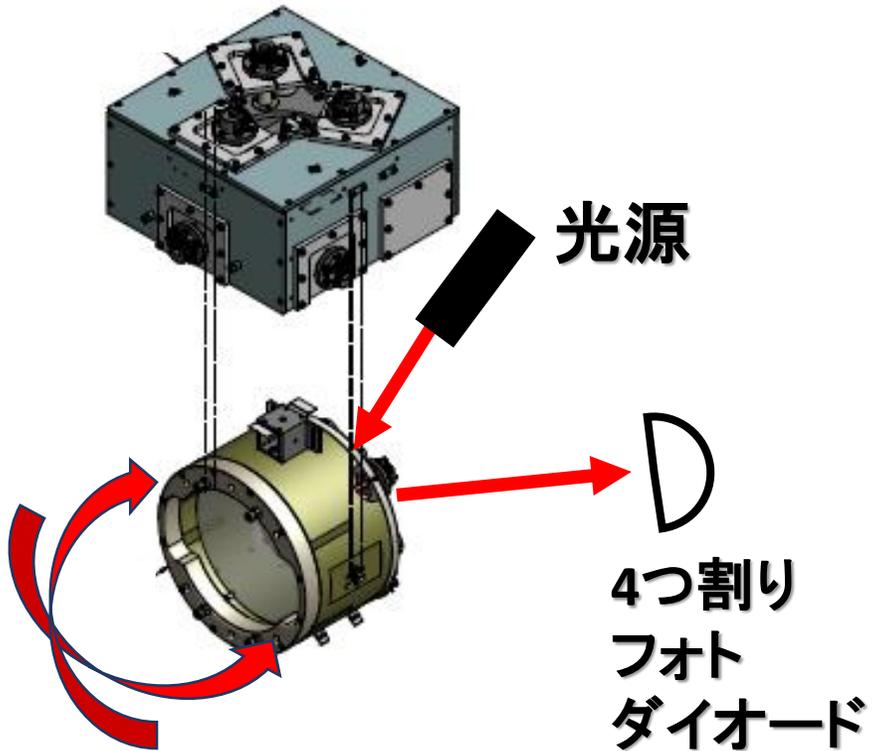
Flag



❖ PR3 防振装置 / センサ, アクチュエータ

光てこ (**Optical Lever**):

ビームスポットの変位 \rightarrow 角度変化



OSEM では見えない、地面に対する鏡の回転を測定するためのセンサ

Contents

□ はじめに / KAGRA

□ PR3 防振装置

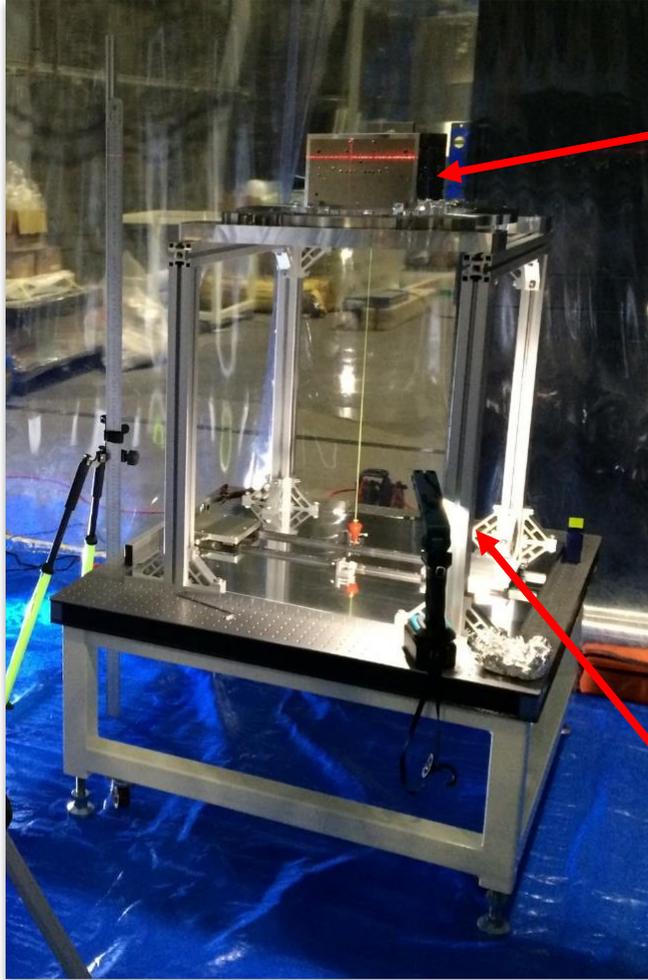
◆ Installation (@ 神岡KAGRAサイト)

◆ 組み立て手順

◆ 干渉計での利用

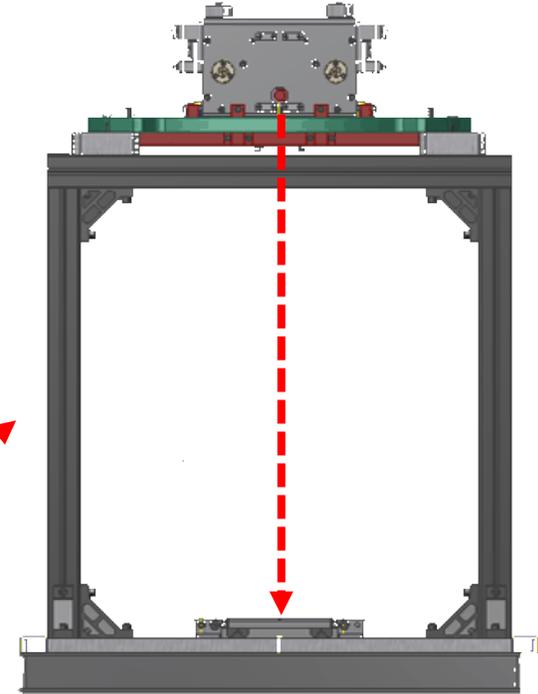
□ まとめ

❖ Installation / 組み立て手順

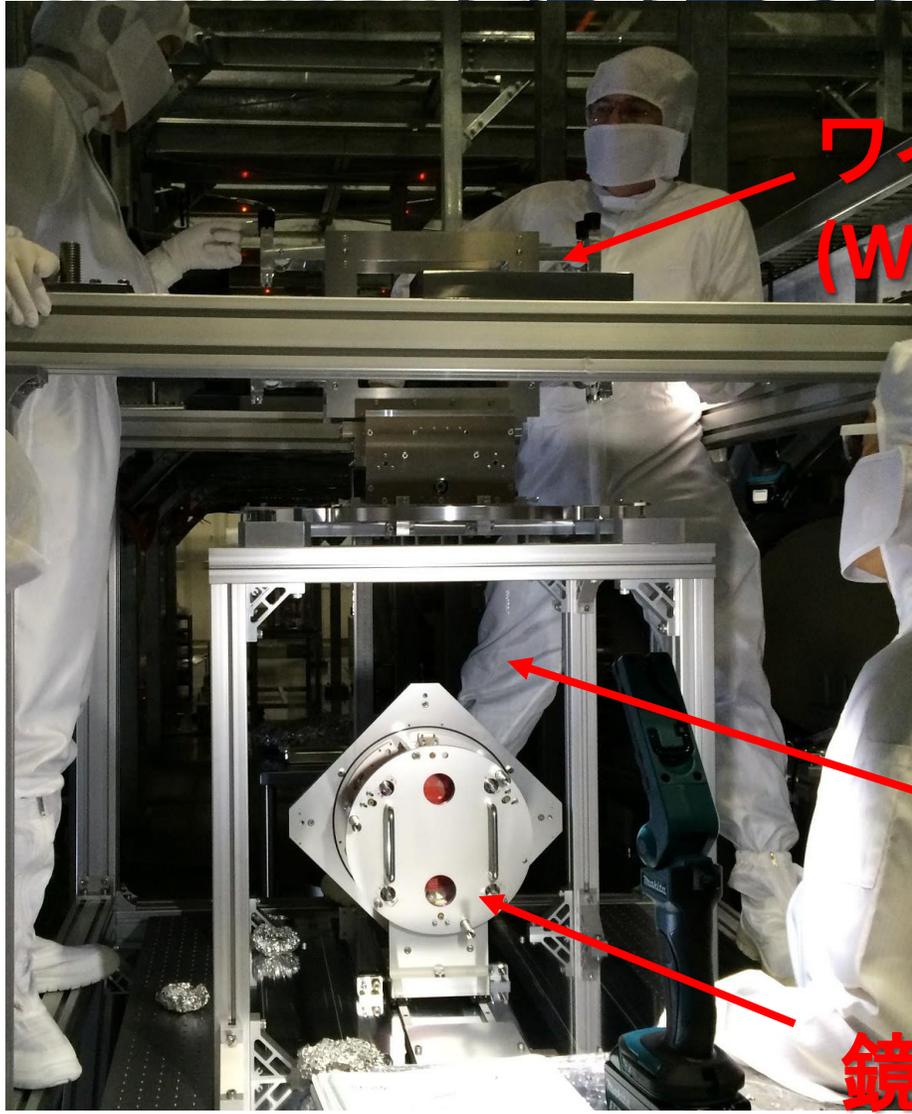


中段マス

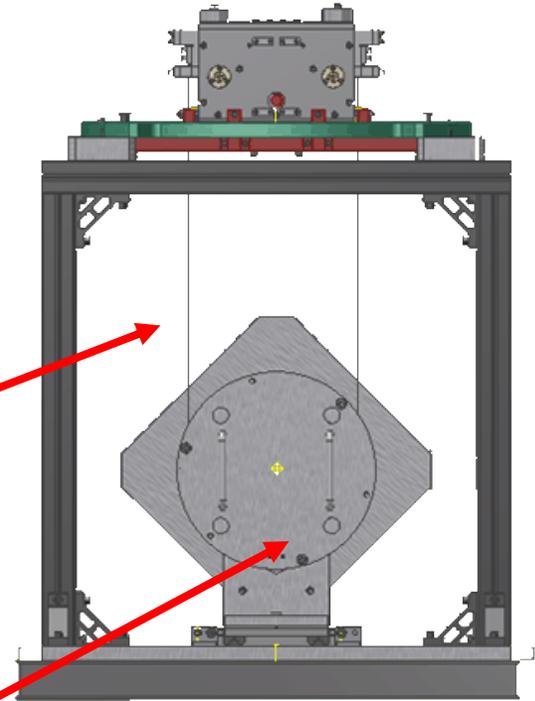
鏡懸架用ジグ



❖ Installation / 組み立て手順



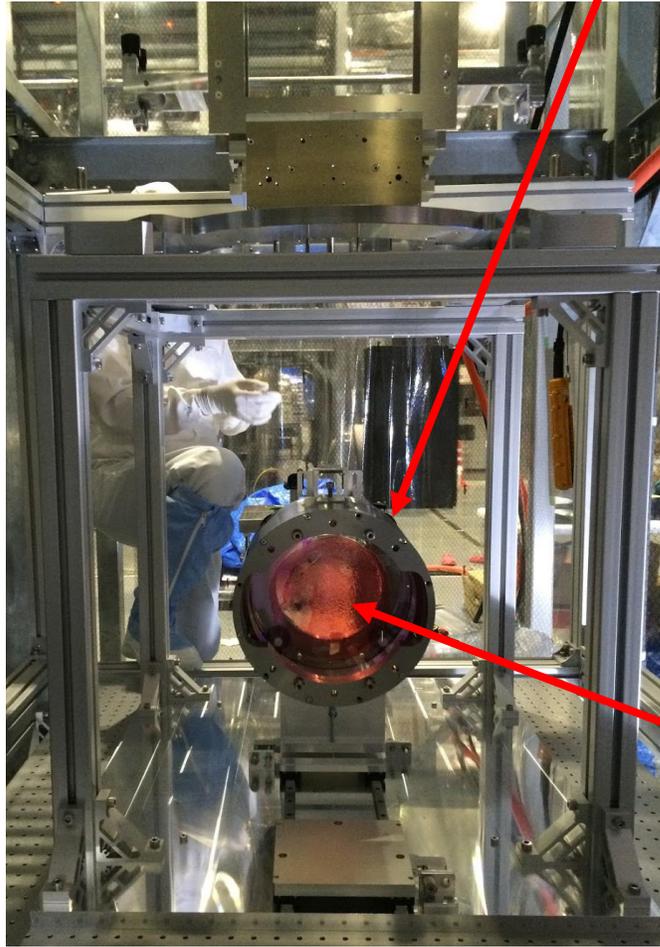
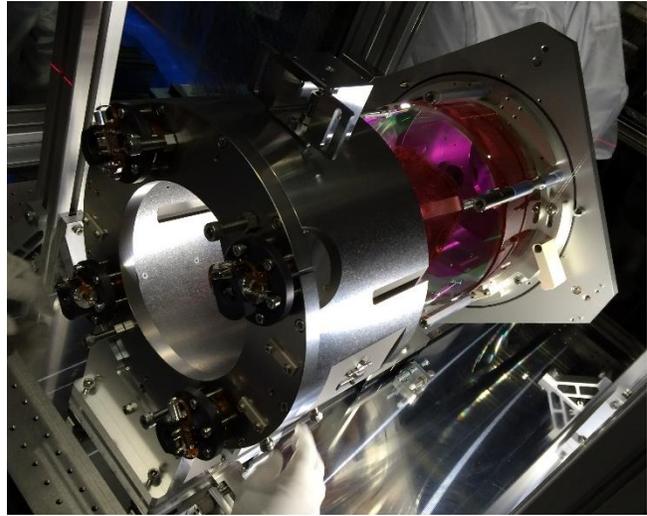
ワイヤ巻き付け用ジグ
(Winch)



ワイヤ

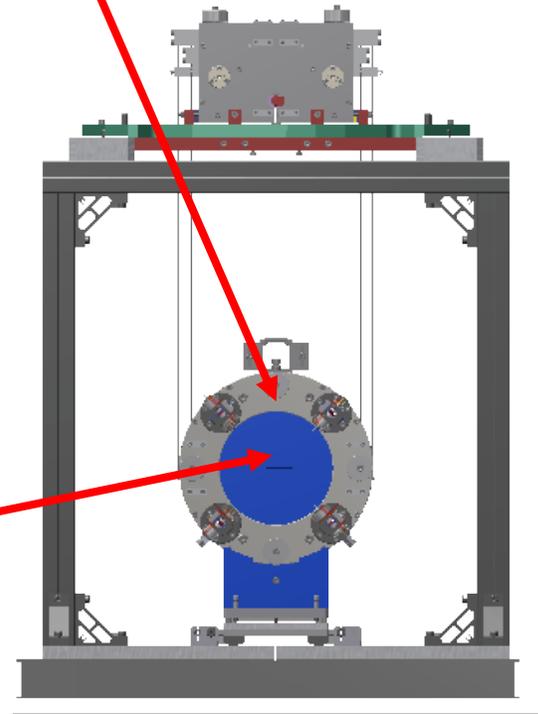
鏡保護・梱包用ジグ

❖ Installation / 組み立て手順

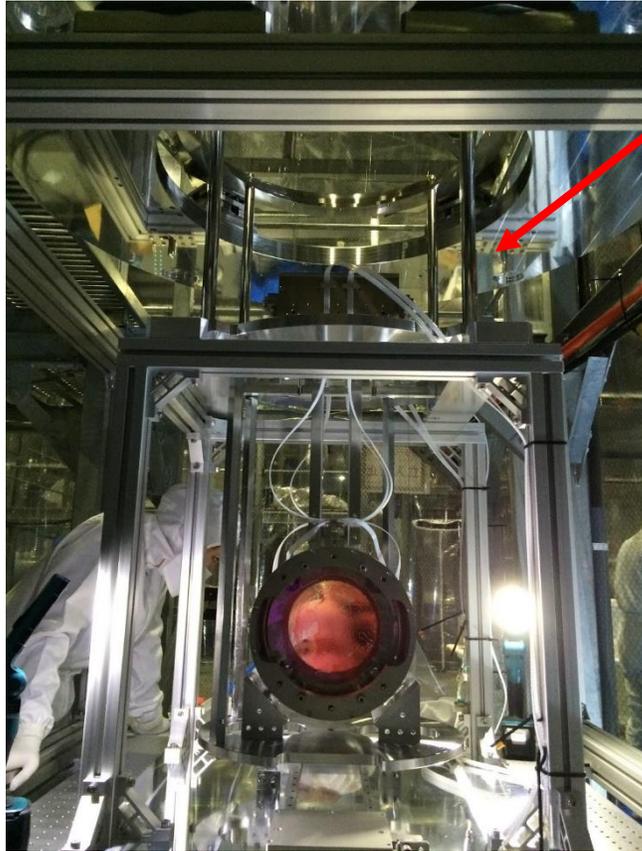


リコイルマス

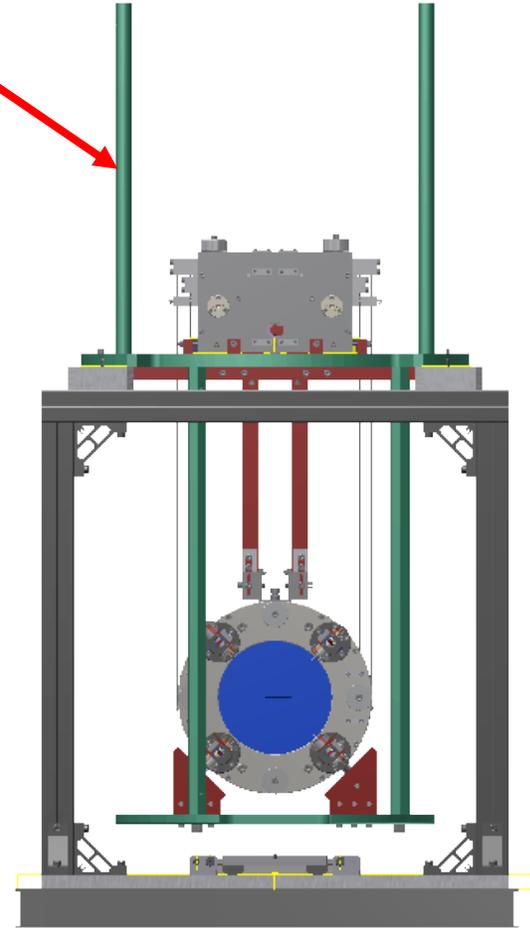
鏡



❖ Installation / 組み立て手順

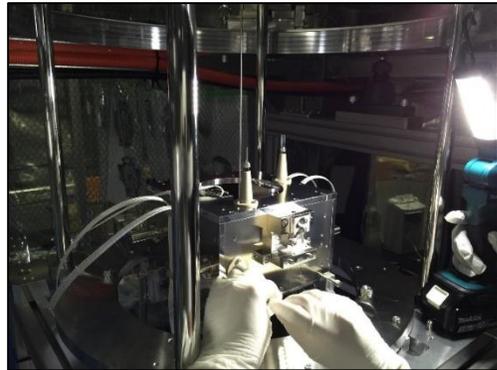
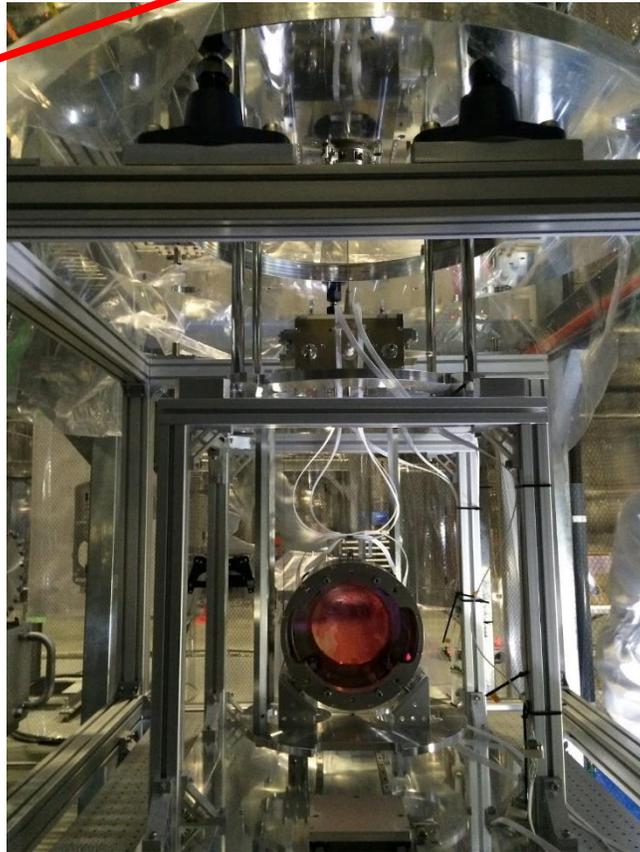
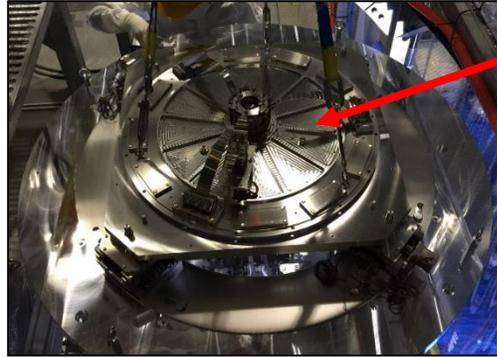
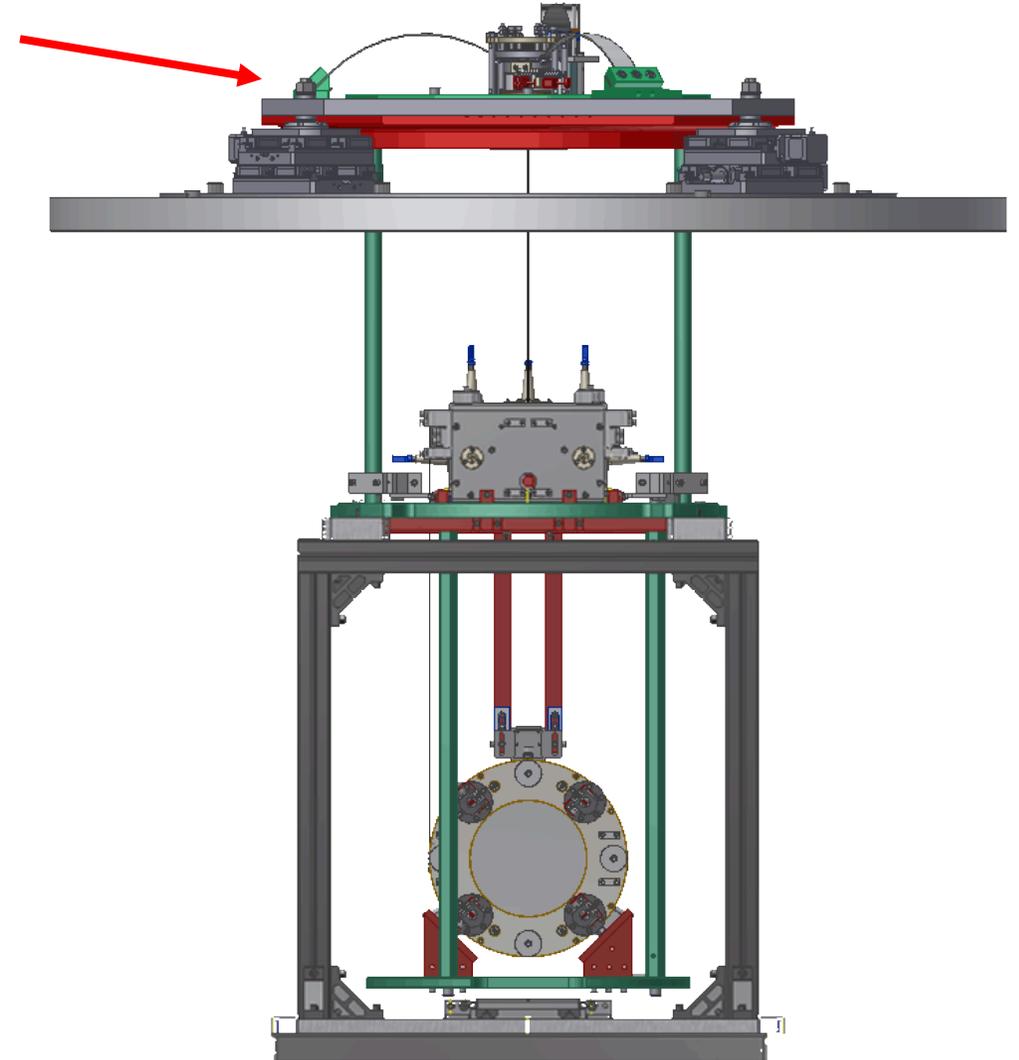


セキュリティ
フレーム

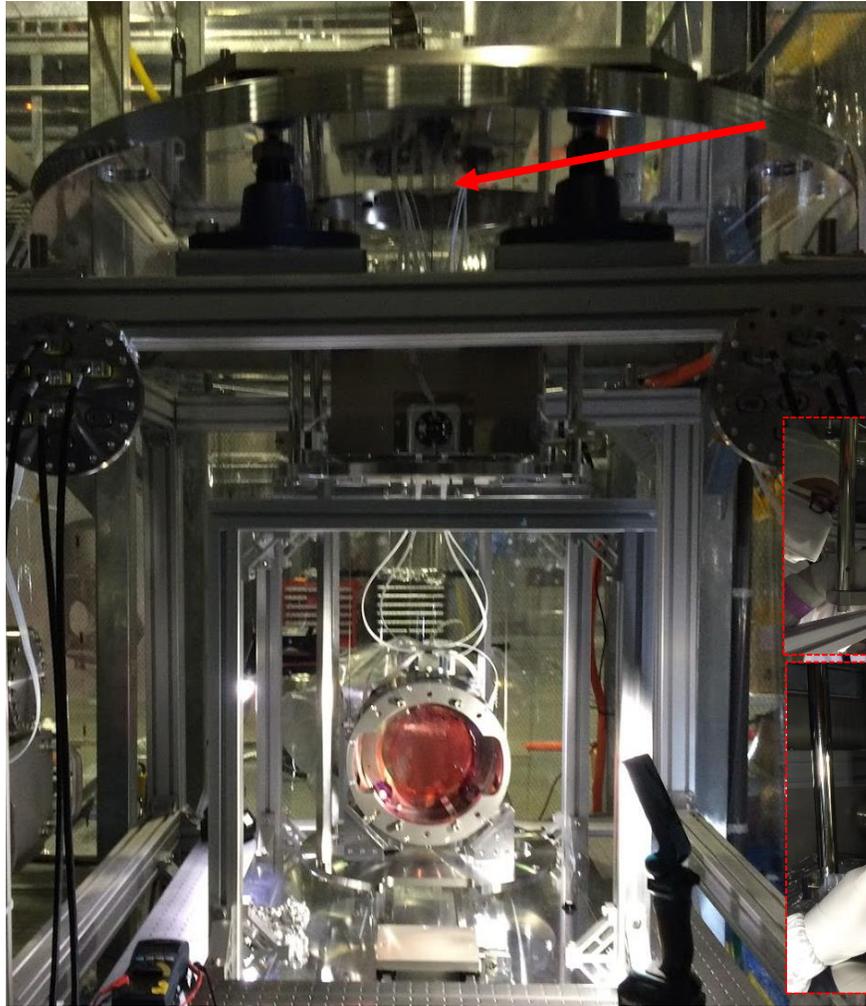


❖ Installation / 組み立て手順

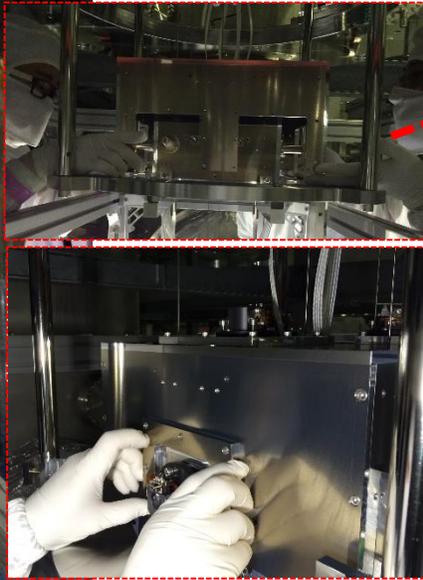
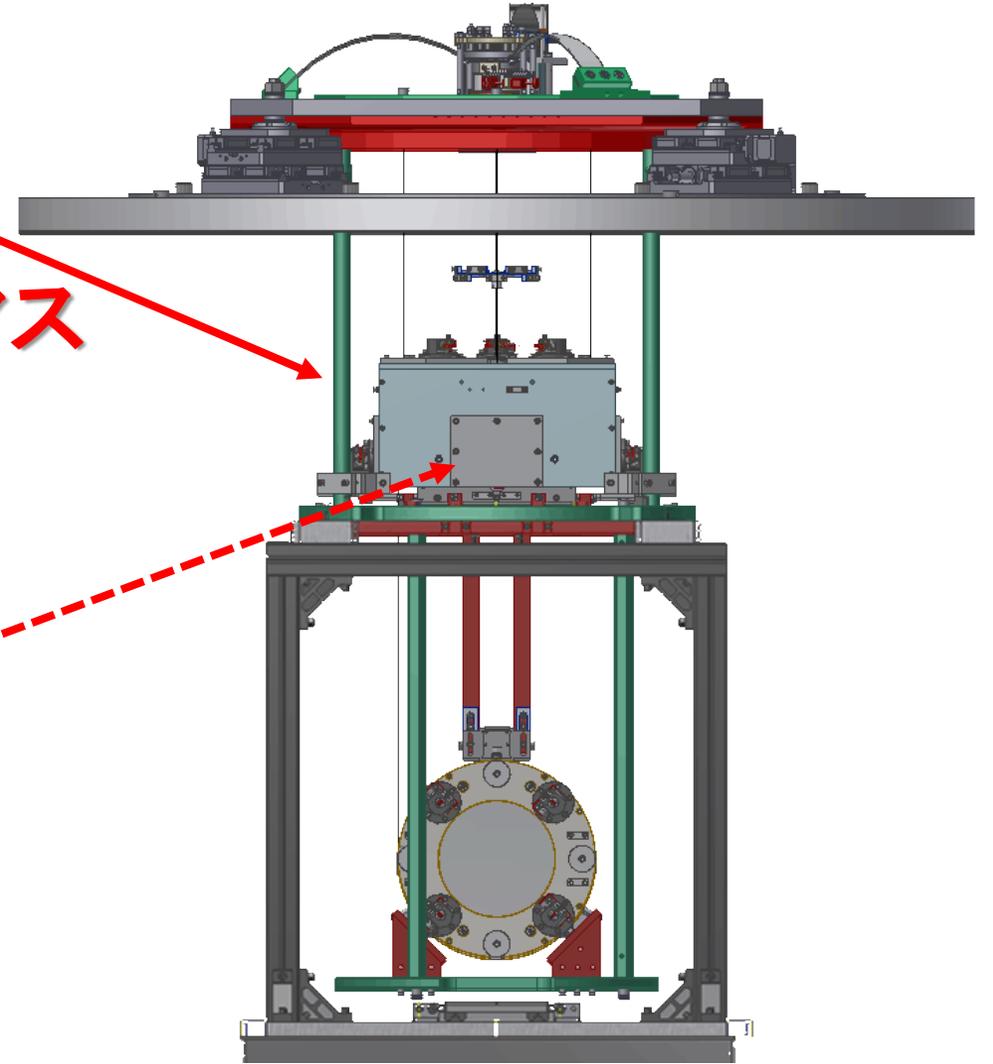
GAS filter



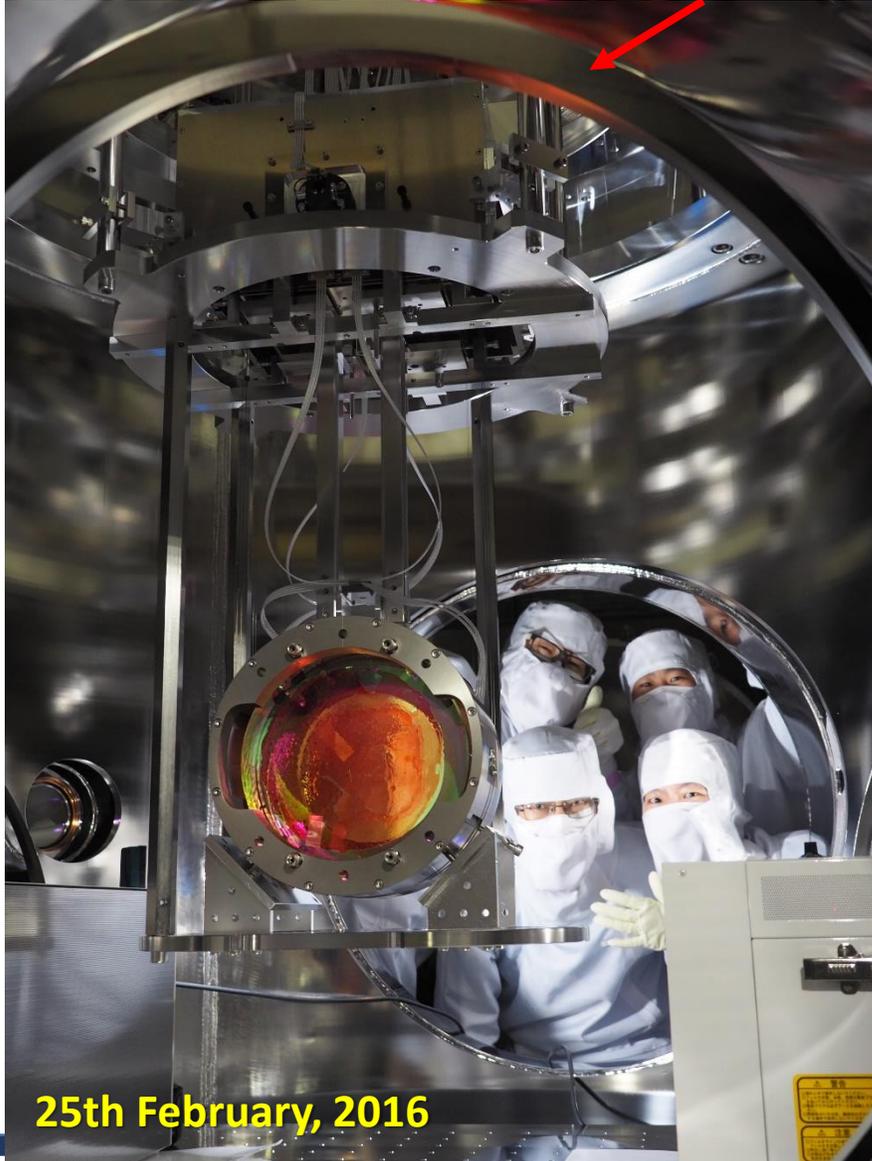
❖ Installation / 組み立て手順



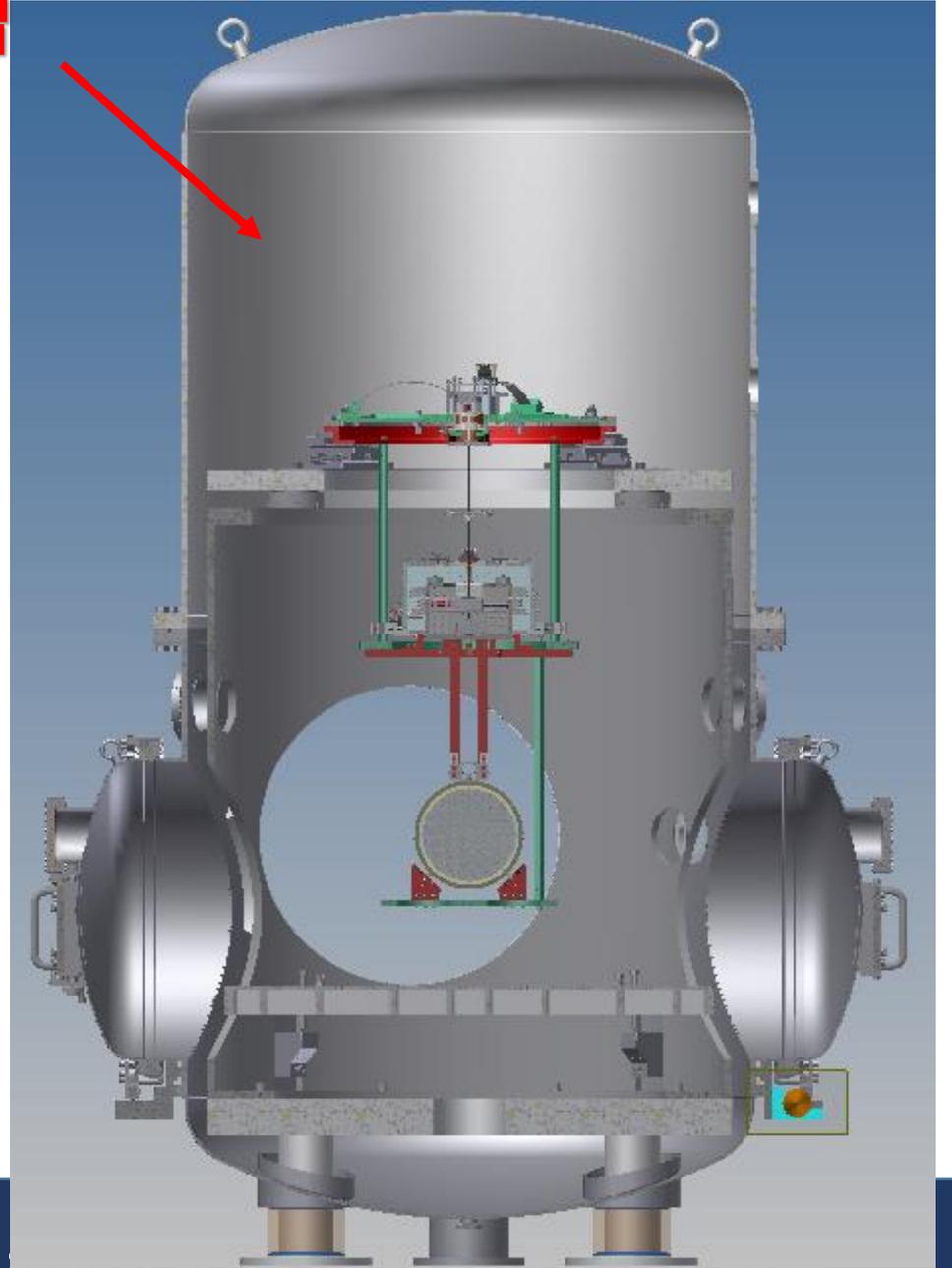
中段
リコイルマス



❖ Installation / 組み立て手順 真空槽



25th February, 2016

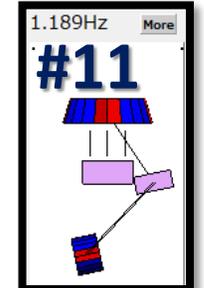
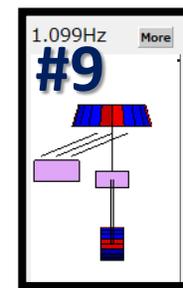
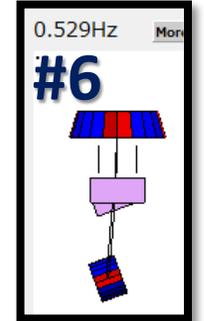
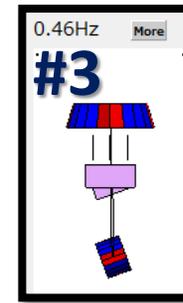
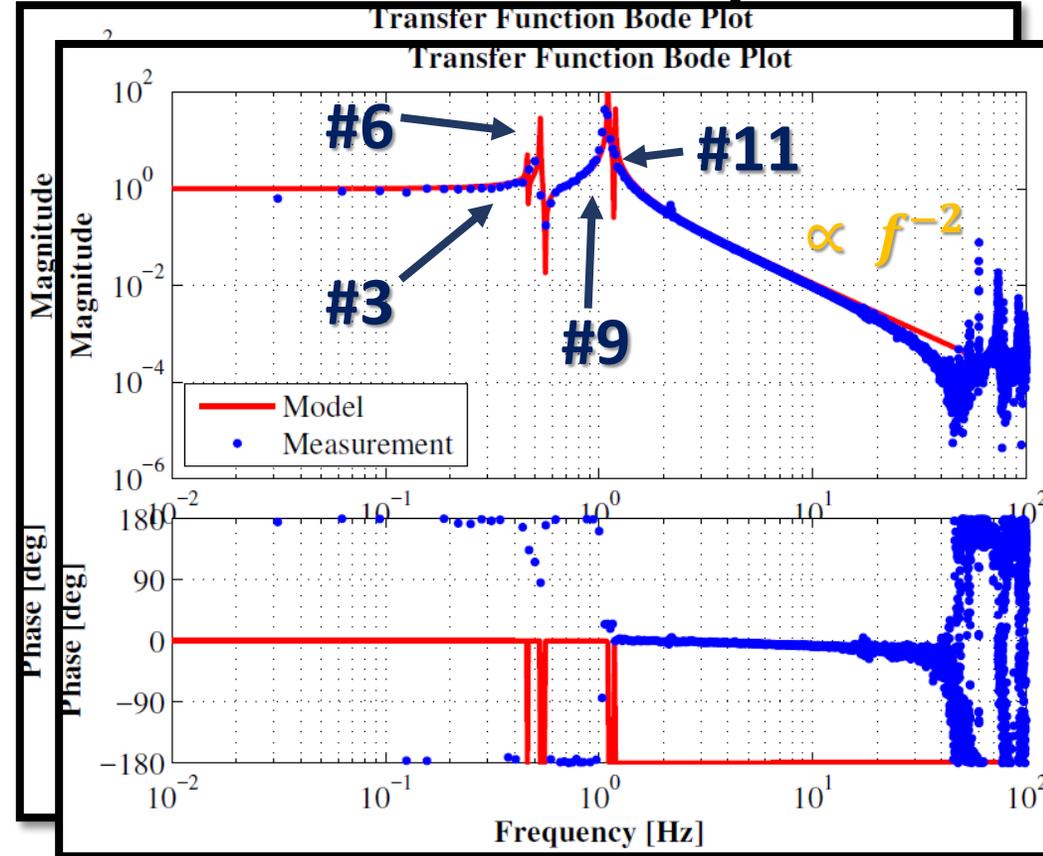
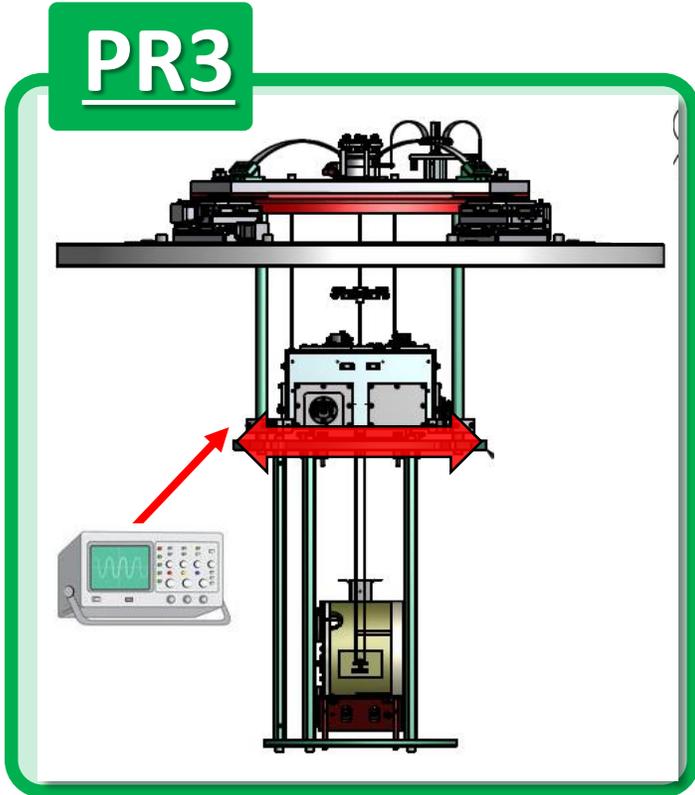


❖ Installation / 組み立て手順

* PR3 鏡とその防振装置のインストール中 →

力変位伝達関数
スペクトル
etc

を測定。



設計通りに懸架されているかの確認。

❖ Installation / 反省

Installation 手順 → payload・GAS (chain) の組立, 真空槽への吊入れの流れを一通り確認した。

* ただし細かな懸念事項・課題は残る。→ 手順修正の可能性有。

1) 鏡のOSEM flag が折れやすい(特に本物の鏡で)

- ① 鏡やリコイルマスをジグに固定(またはリリース)するときの確認事項の見直し
- ② OSEM (flag) の形状の見直し

2) 懸架系の Q 値が低い様子

- 別途 Q 値測定の後、場合によっては要手順の見直し

3) Wire のテンションの未調査

- wire の Violin mode の測定

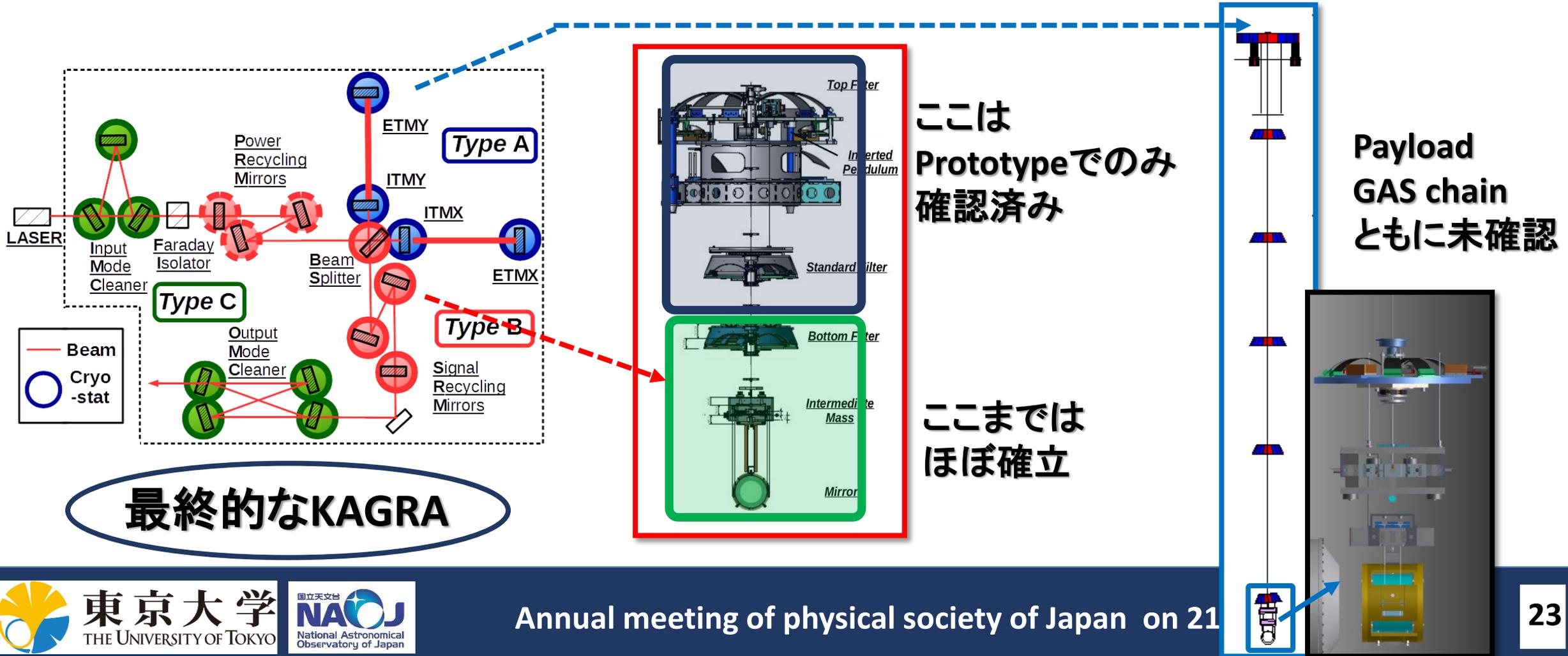
4) 真空槽内での作業

今回は真空槽の中に入って/身を乗り出して作業した。bKAGRAでの方法を要見直し



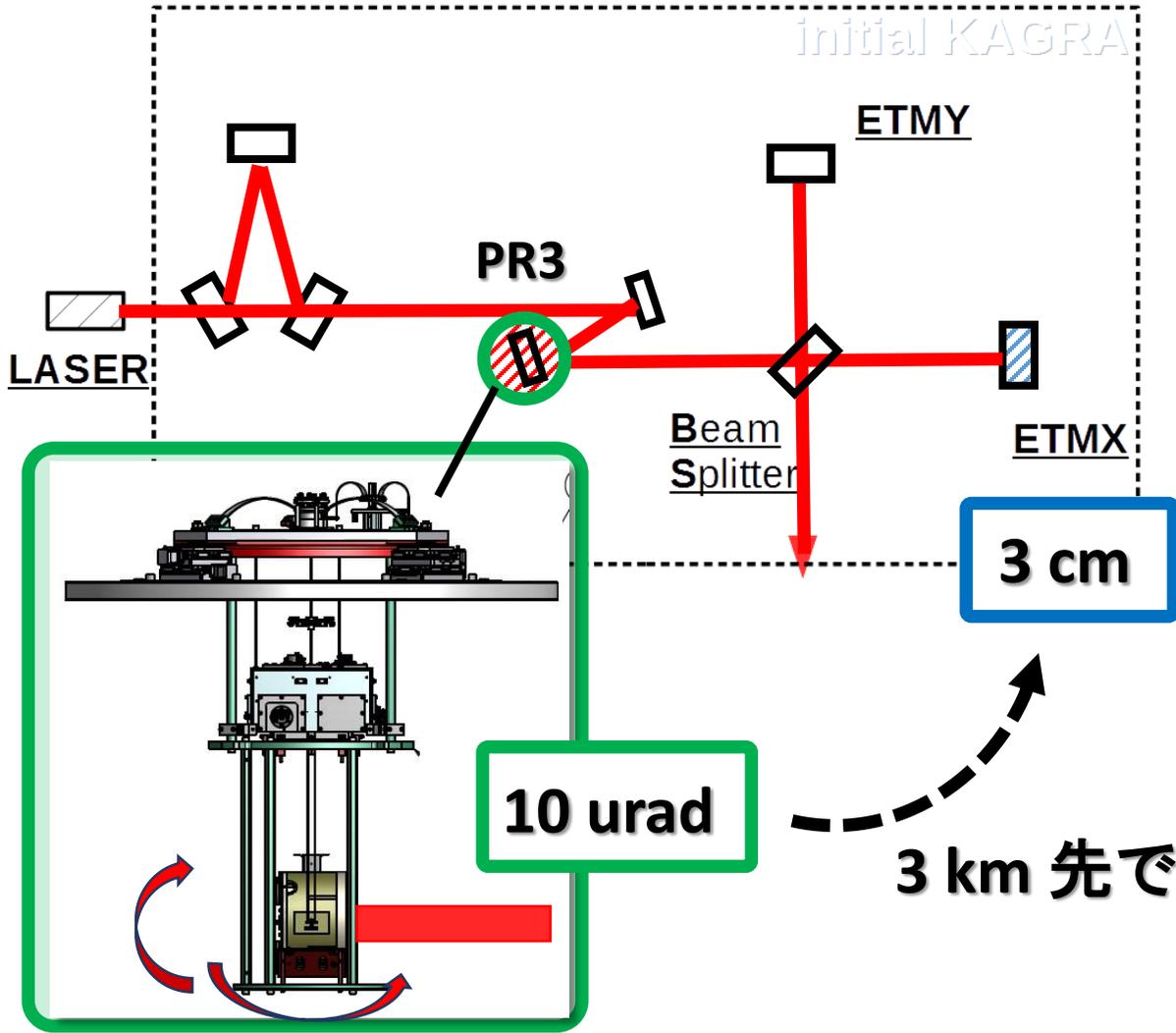
❖ Installation / 反省

その他の KAGRA防振装置の Installation procedure の現状



◆ 干渉計での利用

PR3 鏡 → 3 km 先に光を通すための調整用鏡



Traverser, 中段マス : 初期アライメント



中段マスのOSEM : 鏡の姿勢の微調整
+
ダンピング制御

PR3 鏡が揺れる (振り子の共振)
→ 3 km 先でビームスポットが大きく動く
→ PR3 鏡が揺れない状態が必要
→ 要PR3 のダンピング制御
(詳細 → 奥富 発表)

まとめ

- ❖ Installation 手順の確認を行った。
- ❖ iKAGRA干渉計のアライメント用の鏡(PR3鏡)とその防振装置を神岡KAGRAサイトにて組立てた。(2.25, 2016 に完了)
- ❖ その性能の確認と制御を実施。(→ 奥富 発表)

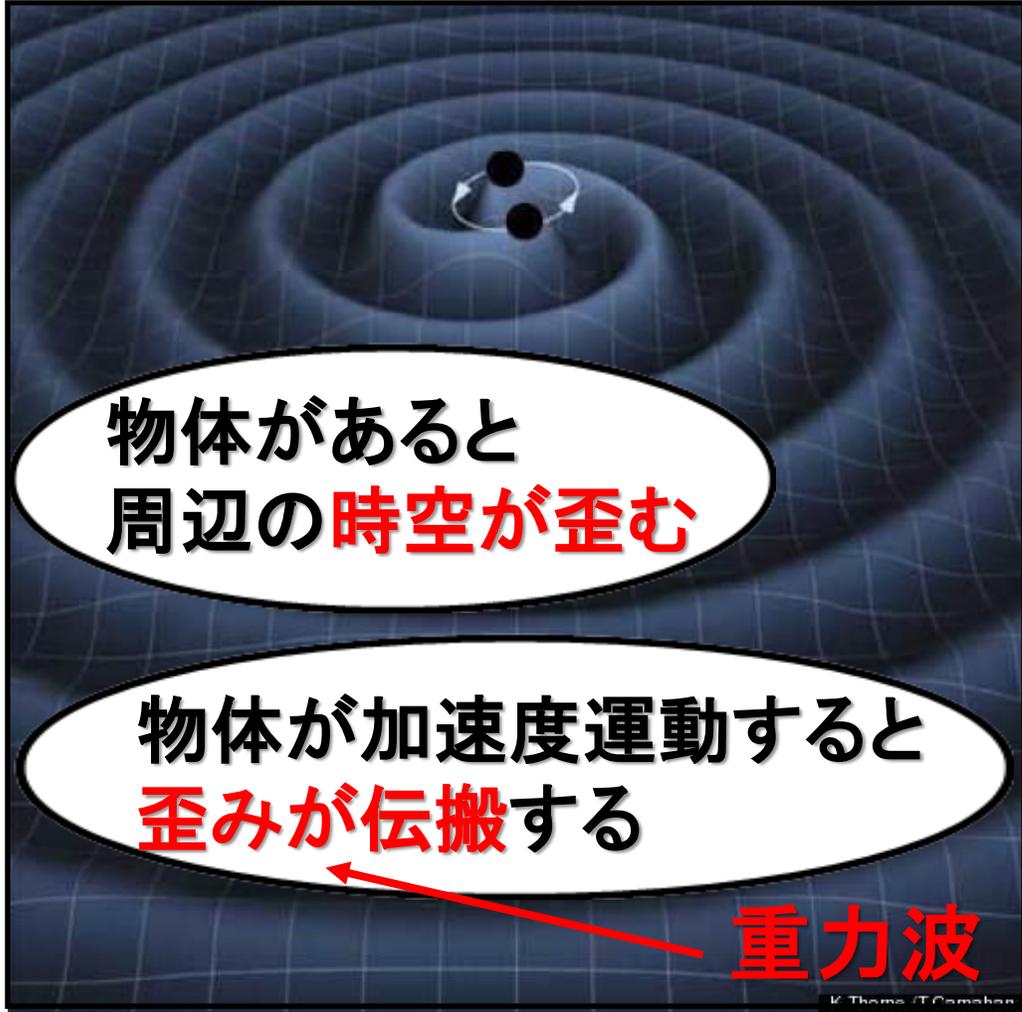
Next step

- ❖ PR3防振装置の評価、修正
- ❖ Installation 手順の確立

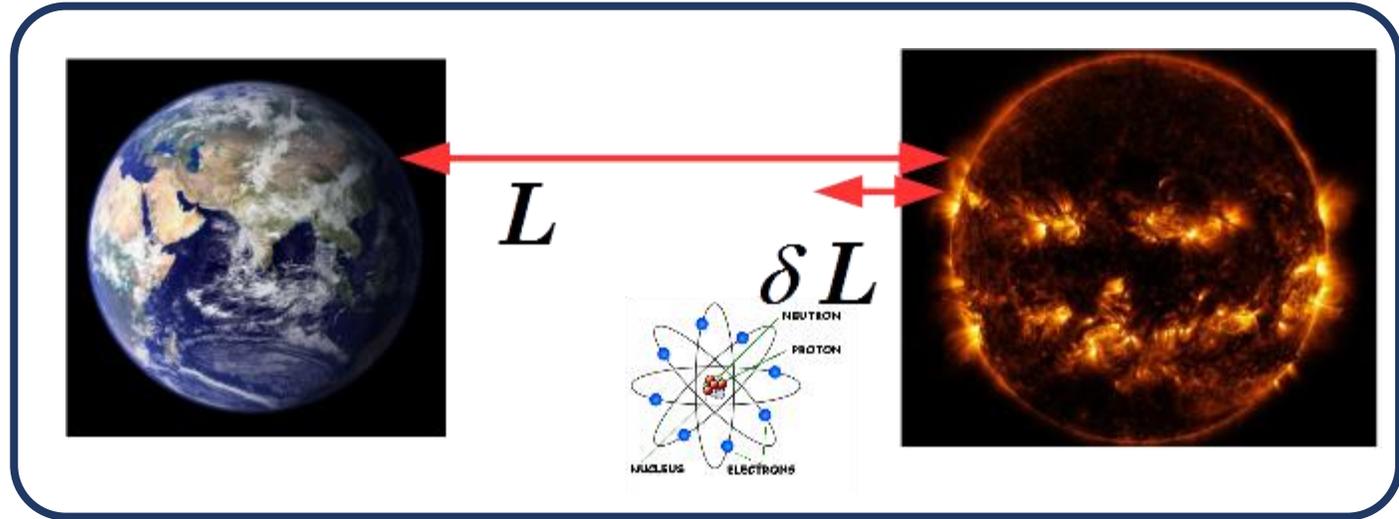
Thank you for your attention.

Back up

◆ はじめに：重力波



重力波振幅 $h \sim \delta L / L$

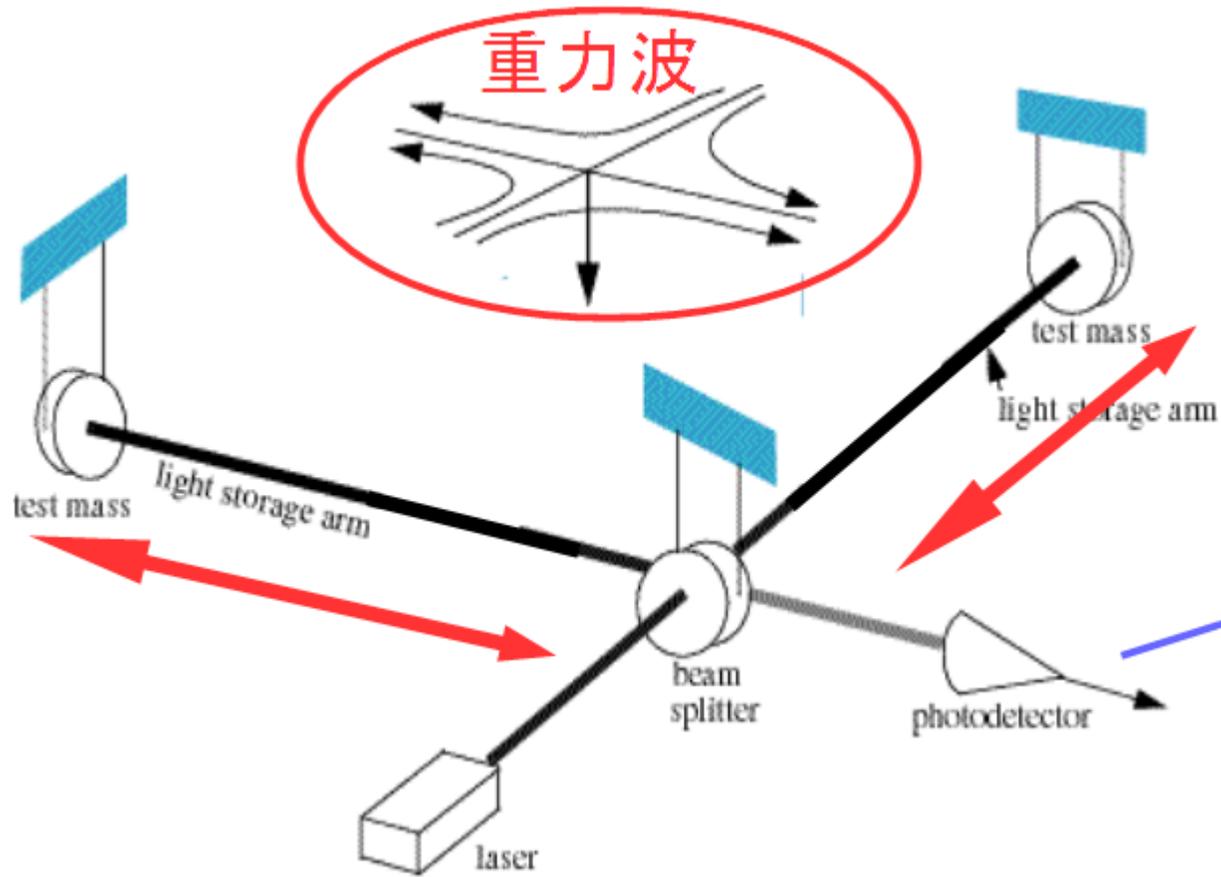


重力波による空間の歪み δL は非常に小さい。

Intro. of GW & GW detector

- 重力波は時空の歪み → 変位は非常に小さい → 干渉計で検出
- 大型低温重力波望遠鏡 KAGRA では、
熱雑音の低減のため → 主要な鏡の冷却 (@ 20 K)
地面振動低減のため → 地下への干渉計の設置 を行う。
- 干渉計の鏡は外乱による振動を抑えるために懸架される。

❖ Background : 検出原理

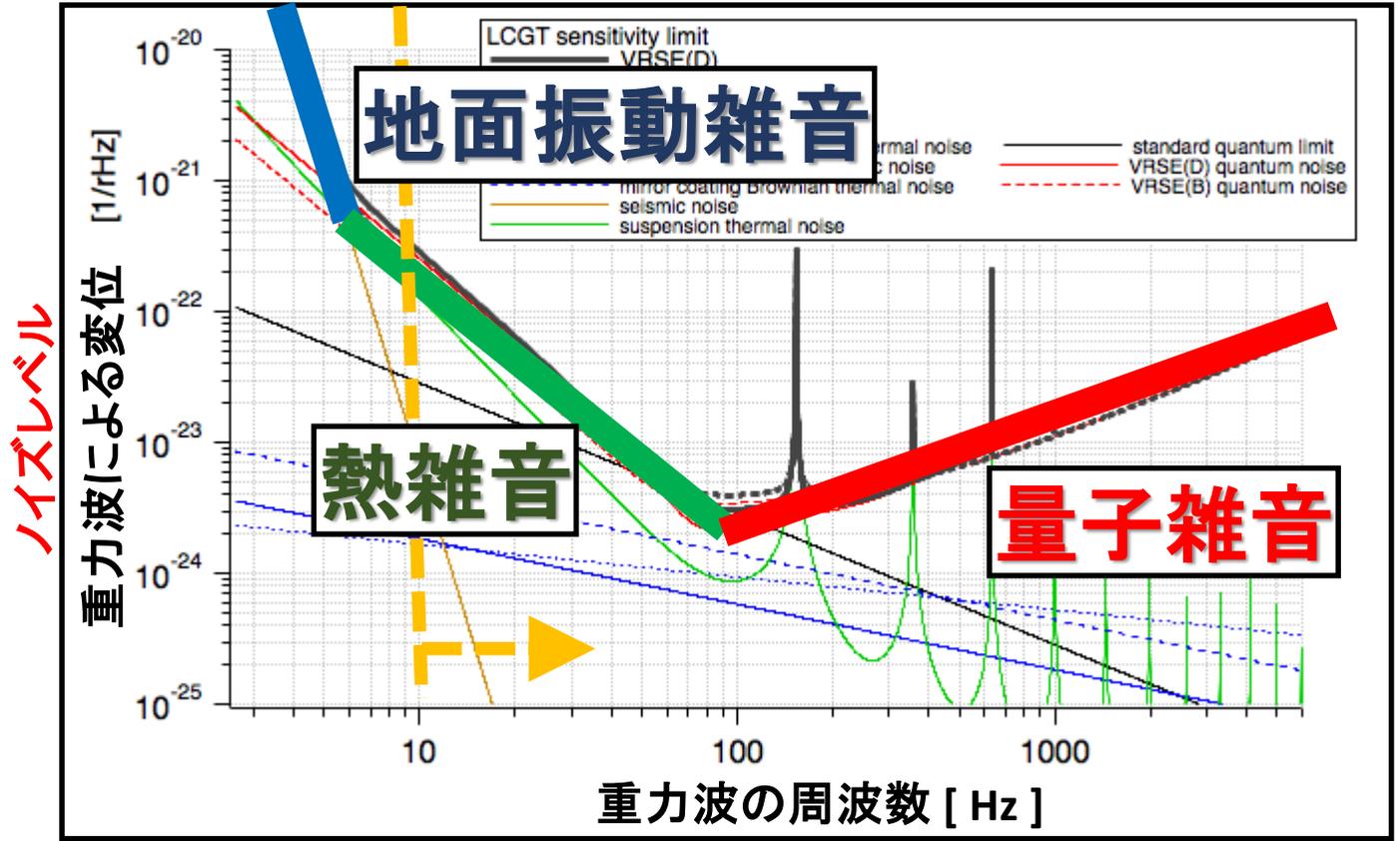


- ①重力波が到来
- ②光の位相が変化
- ③干渉により
光の明暗が変化
- ④重力波信号

◆はじめに：重力波検出器 / KAGRA

重力波信号は非常に小さい。

→ 多々ある雑音 (鏡を揺らす原因)をいかに除去するか。

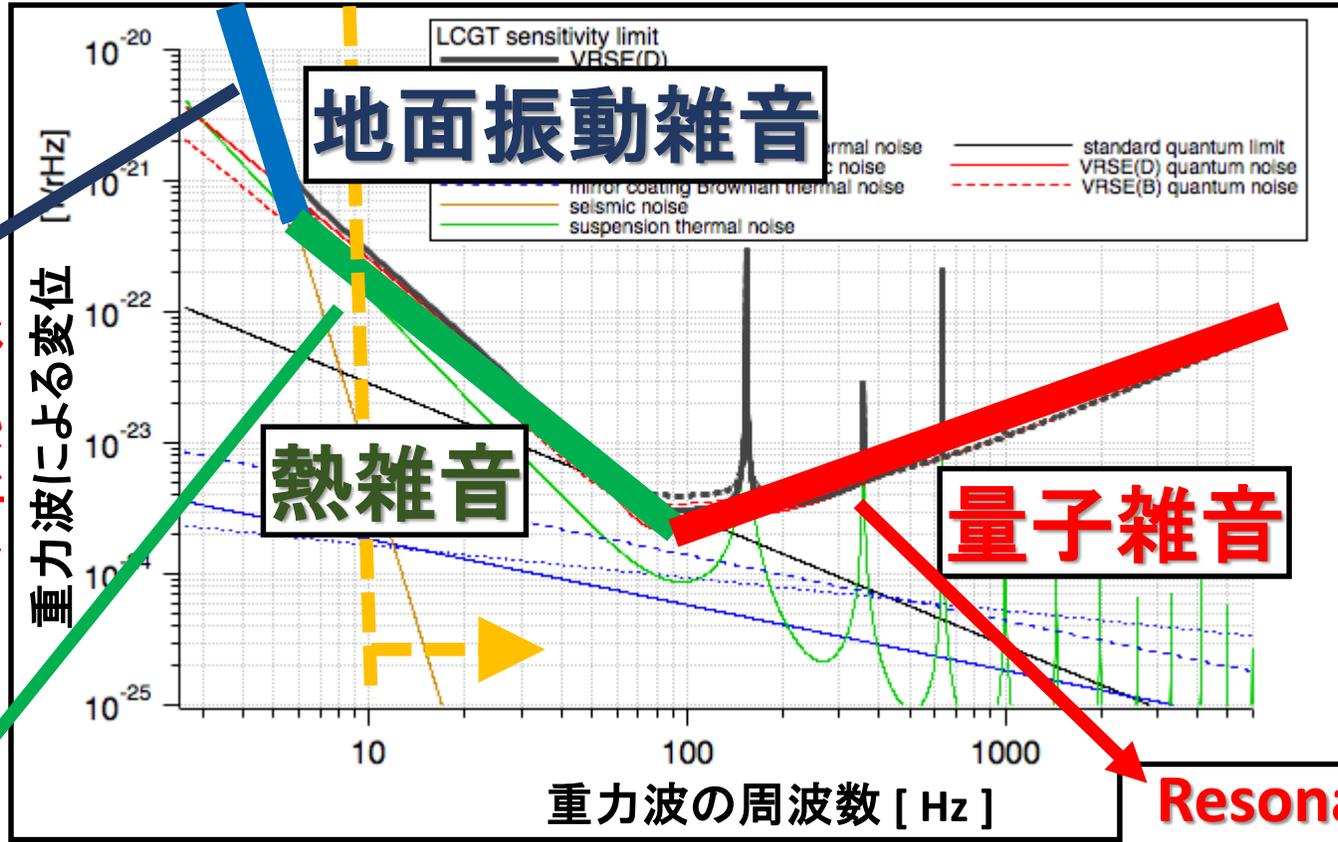


KAGRA の目標ノイズレベル

◆はじめに：重力波検出器 / KAGRA

雑音への対策；

懸架装置 & 地下への設置



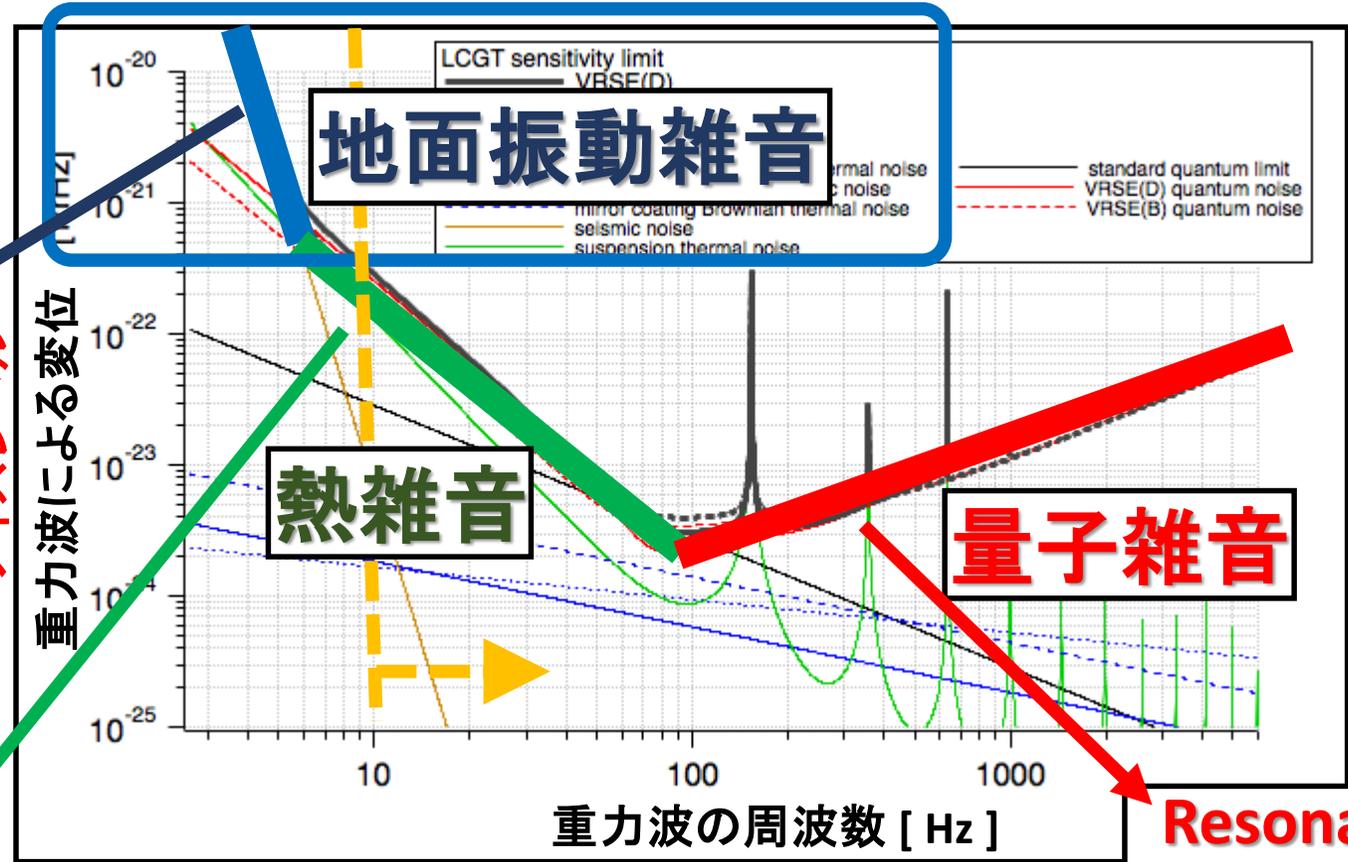
KAGRA の目標ノイズレベル

◆はじめに：重力波検出器 / KAGRA

雑音への対策；

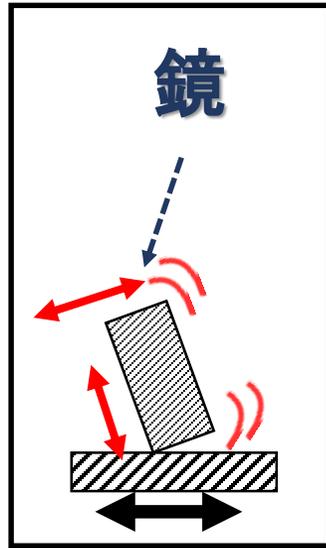
常温

懸架装置 & 地下への設置



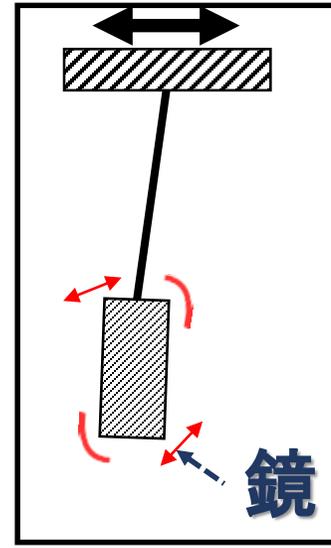
KAGRA の目標ノイズレベル

◆はじめに：懸架装置の役割



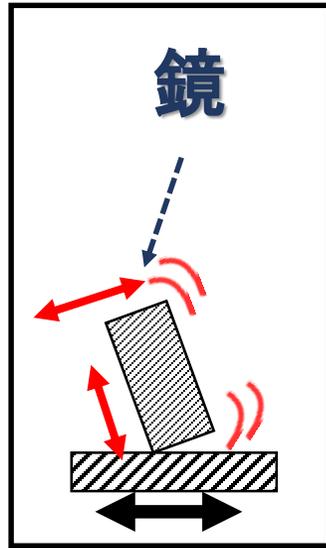
地面に置く

地面振動により
鏡は大きく揺れる。
(自由質点でなくなる)



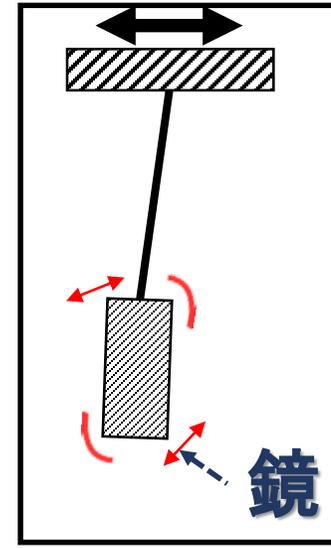
懸架する。

◆はじめに：懸架装置の役割



地面に置く

地面振動により
鏡は大きく揺れる。
(自由質点でなくなる)

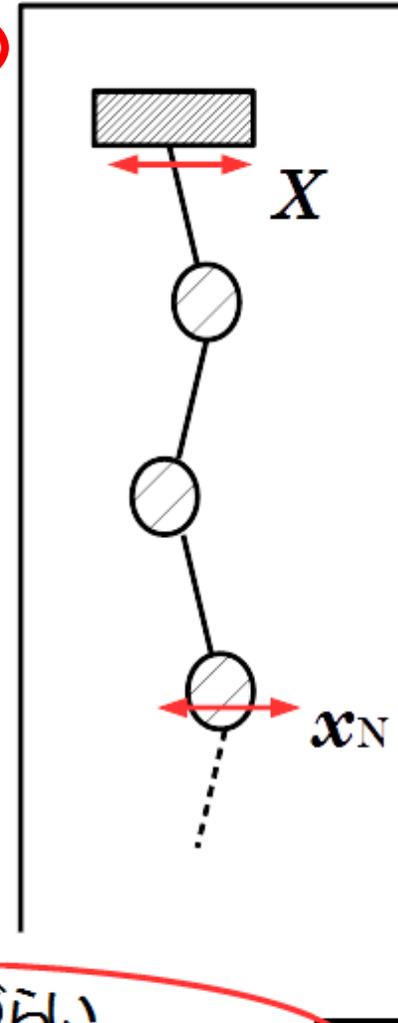
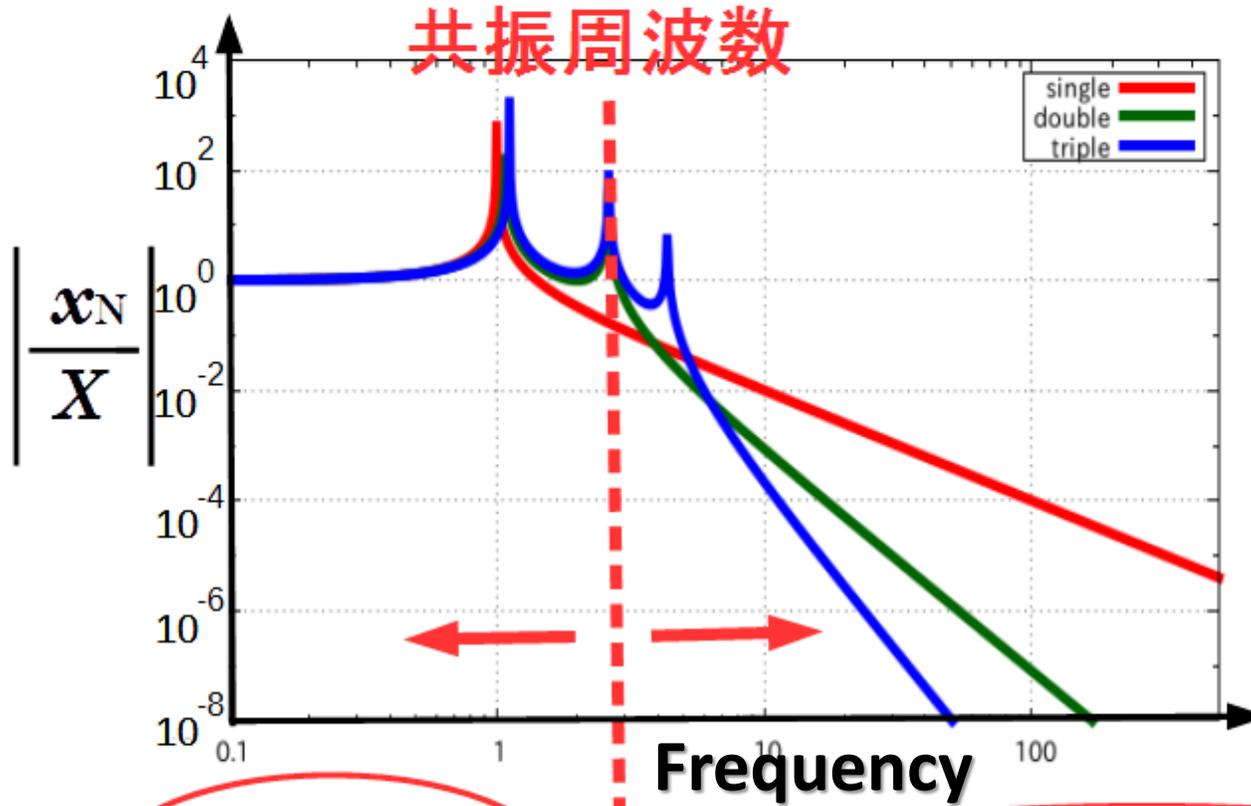


懸架する。

共振周波数より
高い周波数では
揺れにくくなる。

◆はじめに：懸架装置

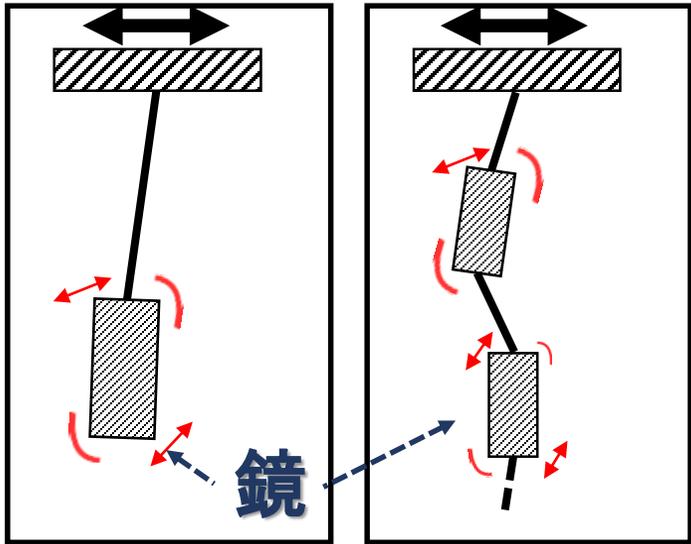
一番大きく揺れる



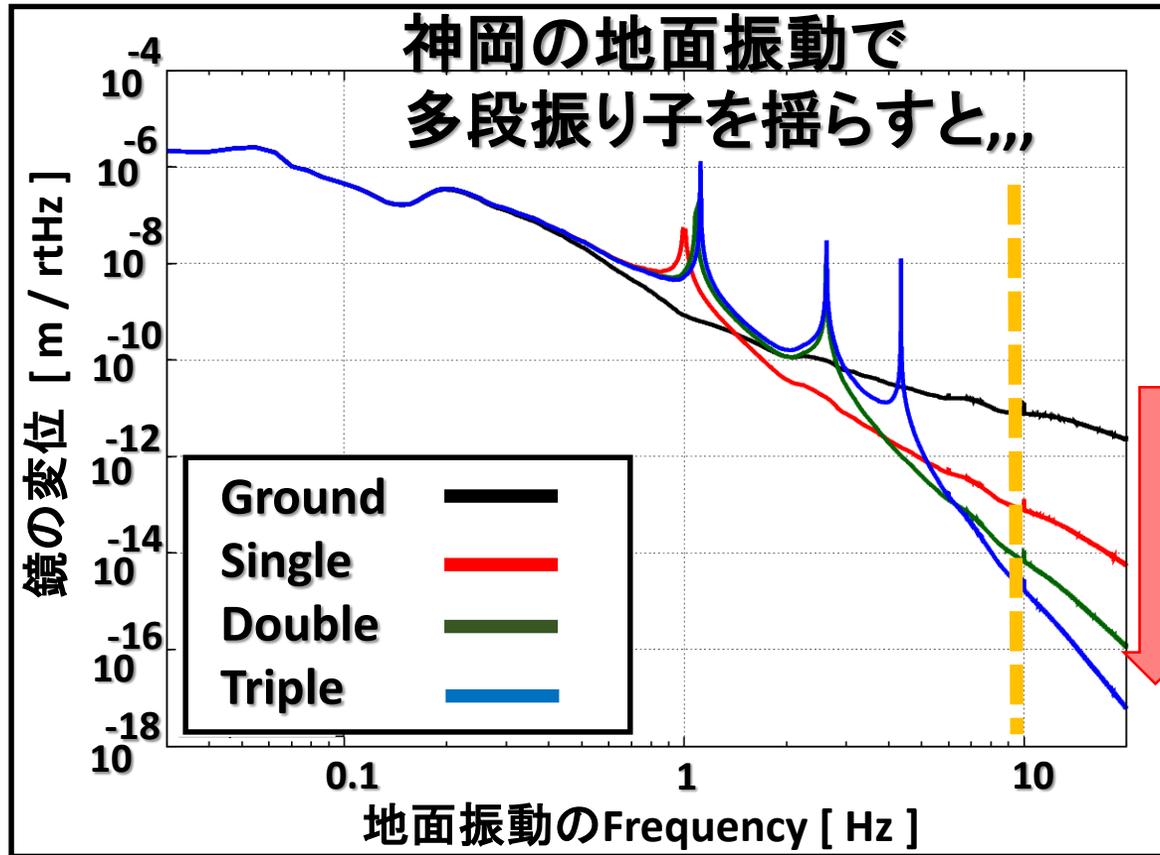
低周波では鏡は大きく揺れる

高周波では揺れづらい
段数が多いとより揺れなくなる

◆はじめに：懸架装置の役割



多段振り子として懸架する。

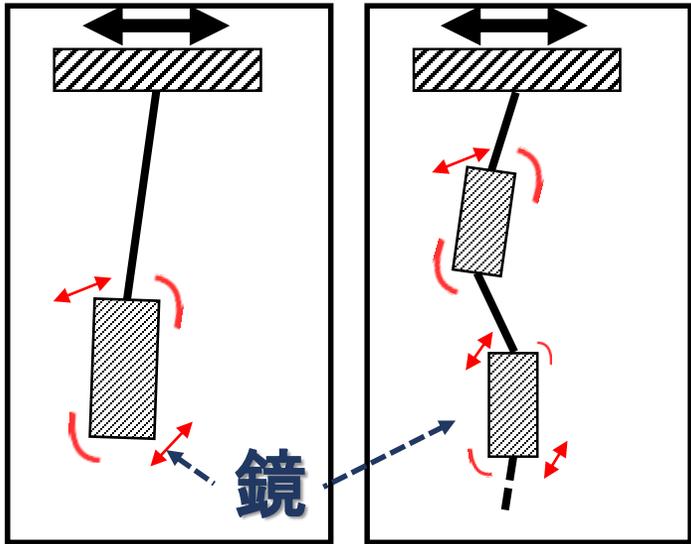


観測帯域の 10 Hz 以上では揺れにくくなる。

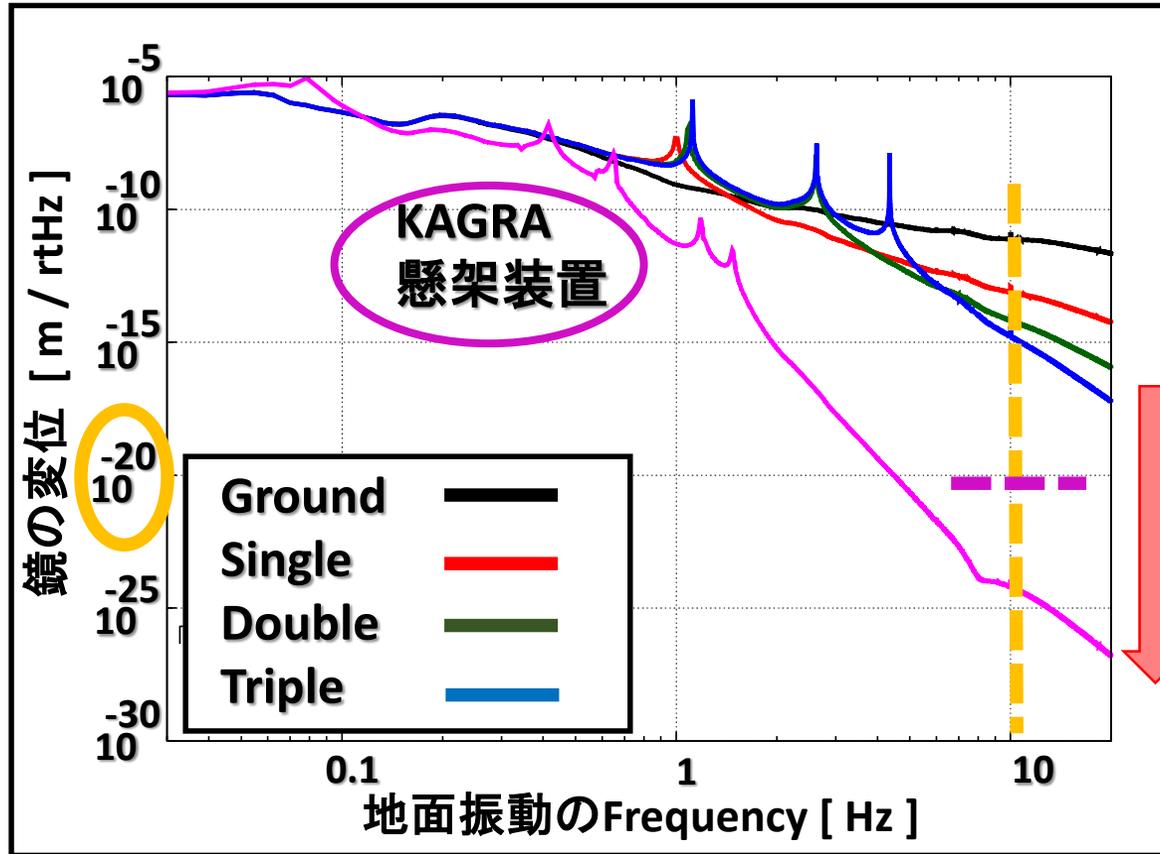
要求値

観測帯域の下端
10 Hz にて
鏡の揺れはおよそ
 2×10^{-20} m/rtHz
以下。

◆はじめに：懸架装置の役割 (例えば Beam Splitter の場合)



多段振り子として懸架する。



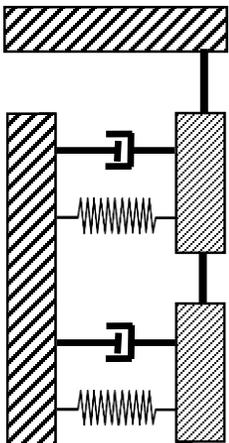
観測帯域の 10 Hz 以上では揺れにくくなる。
(ただし、Peak が出てくる。)

要求値

観測帯域の下端
10 Hz にて
鏡の揺れはおよそ
 2×10^{-20} m/rtHz
以下。

防振比を
高めるために
→ 5 段振り子
を使用。

◆はじめに：懸架装置の役割



懸架により揺れにくくしても、共振周波数で大きく揺れてしまう。
→ 鏡の振動を抑えたい。(より素早く)

damping が必要

① Passive damping

Mechanicalに減衰項を増やす。

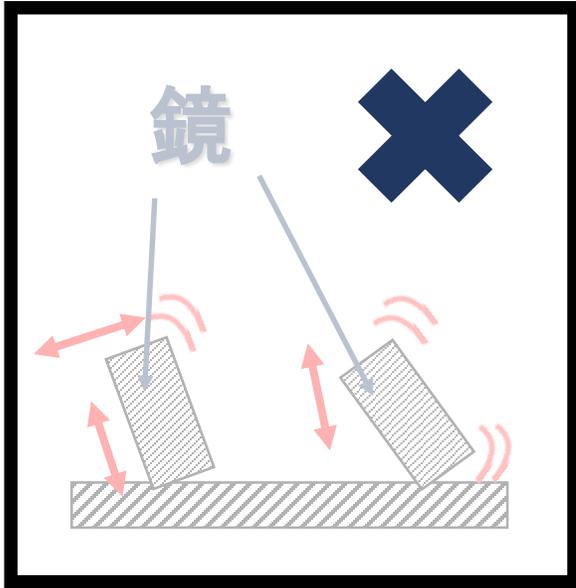
※高周波数帯 (= 観測帯域) で防振比を損なう。

② Active damping

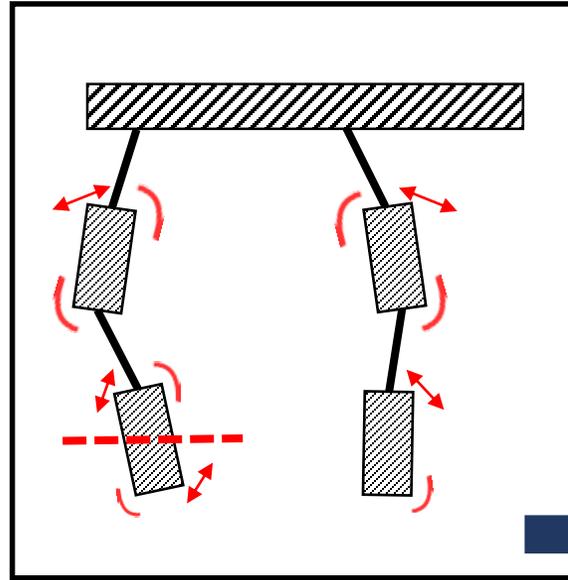
Sensor / Actuator を使った**Feedback** 制御

※Sensor / Actuator 雑音が加わる。

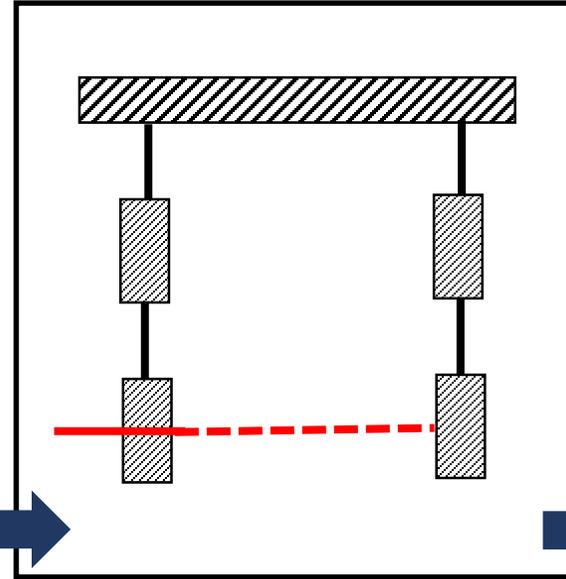
◆はじめに：防振(懸架)装置の役割



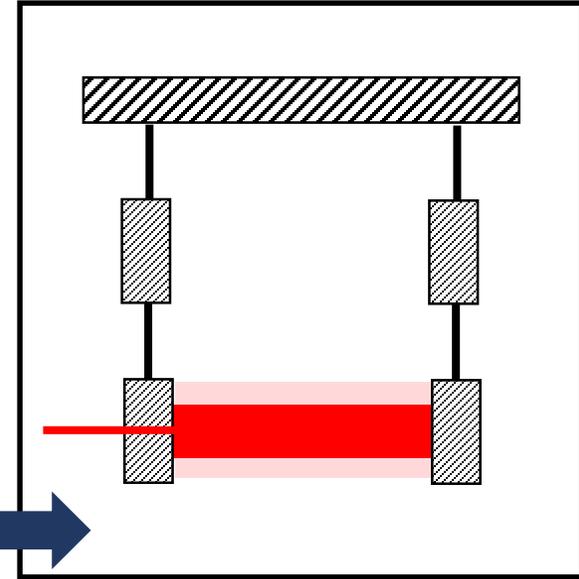
地面に置く



懸架する



Active
Damping

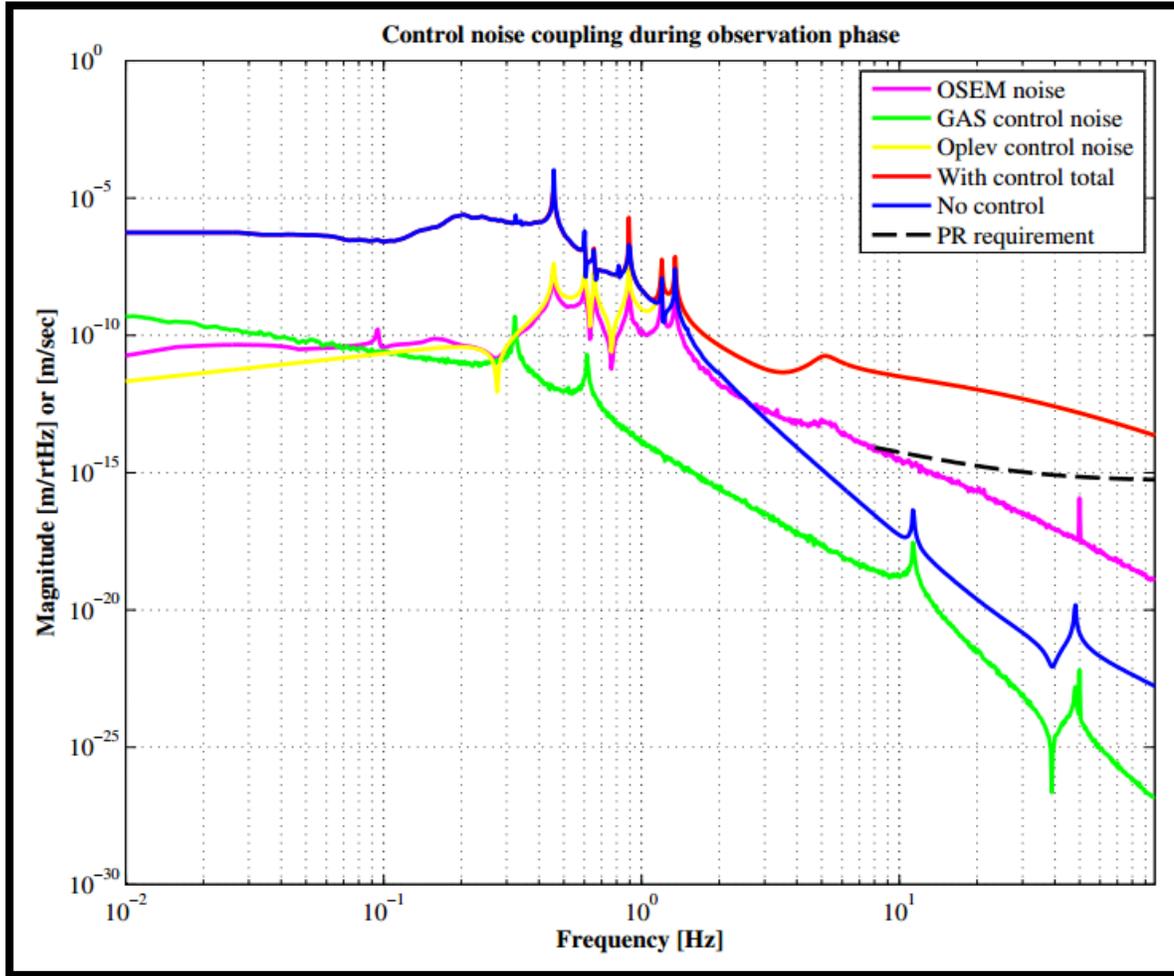


Observation

→ 外乱によって鏡が大きく揺れることを防ぐ。

= 懸架装置の役割

◆はじめに：懸架装置



**Displacement noise and
Sensor noise couplings
of the TypeBp SAS**

❖ Installation / 反省

Installation 手順 → ペイロード・GAS (chain) の組立, 真空槽への吊入れの流れを一通り確認した。

より詳しくは：
PR3 installation procedure
JGW-T1604756

Type-Bp' install procedure and checklist

1. Set the frames
 - The hanging frame is at the center of the assembly frame.
 - The optical table is leveled.
 - The hanging frame is fixed on the optical table.
 - Sliders are properly set and move smoothly.
2. Set the IM EQ stops and IM
 - EQ stop is at the center of the hanging frame with alignment pins.
 - EQ stop plate is fixed by the clamps.
 - IM is at the center of the EQ stop.
 - The distance between the IM and the base of the hanging frame is correct.
 - The direction of the IM is OK.
3. Set the Sliders
 - The plumb is properly suspended from the center of the IM
 - The two positioning screws are fixed tightly at the right position.
 -
4. Preparation for the mirror hanging
 - The winch is set properly.
 - Wires (#0.2 piano wire) are cut and wiped with acetone.
 - OSEM flags are fine
 -
5. Hang the mirror
 - The base of the mirror box is properly set.
 - Some PEEK zigs at the upper side of the mirror are removed.
 - The piano wires are fixed in the grooves on the winch drums.
 - The piano wires are wired around more than once on the winch drums.
 - Wires are at the grooves on the wire breakers.
 - The wires around the mirror is parallel
 - The wires go through the grooves on the wire clamps.
 - Mirror is not dirty.
6. Align the mirror & Fix
 - The distance between the wire clamps on the IM and the wire breakers are the same at the both side. (587mm)
 - Optical lever is properly set. (The input beam is horizontal. The distance between the mirror surface and the fiber collimator is 1m.)
 - The mirror (including the FC tags) is not touching to anywhere.
 - The wires are properly fixed with wire clamping plates and the positioning plates.

① Measurement vs. SUMCON : TypeBpp_iKAGRA

Model Construction Calculation Result Export Model

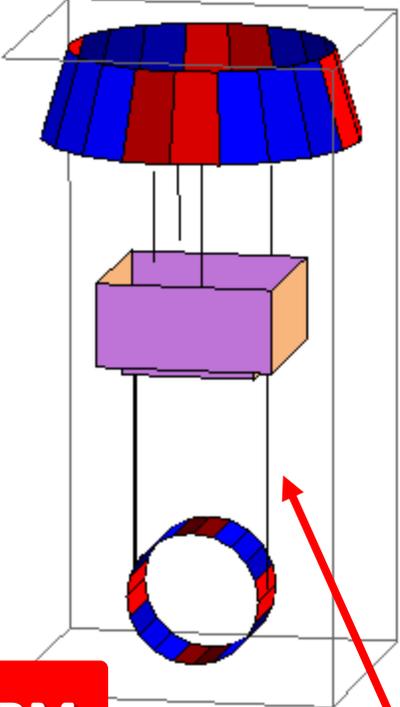
Model Basic Information

Degrees of Freedom:
18 State Variables
6 Input Variables
1 Float Variables

Ground Position:
xF2 → 0. yF2 → 0. zF2 → 0. pitchF2 → 0. yawF2 → 0. rollF2 → 0.

Equilibrium Point:
xIR → 0. yIR → -0.5026 zIR → 0. pitchIR → 0. yawIR → 0. rollIR → 0.
xIM → 0. yIM → -0.5519 zIM → 0. pitchIM → 0. yawIM → 0. rollIM → 0.
xRM → 0. yRM → -1.139 zRM → 0. pitchRM → 0. yawRM → 0. rollRM → 0.
hGAS2 → 0.0269

TypeBpp_iKAGRA



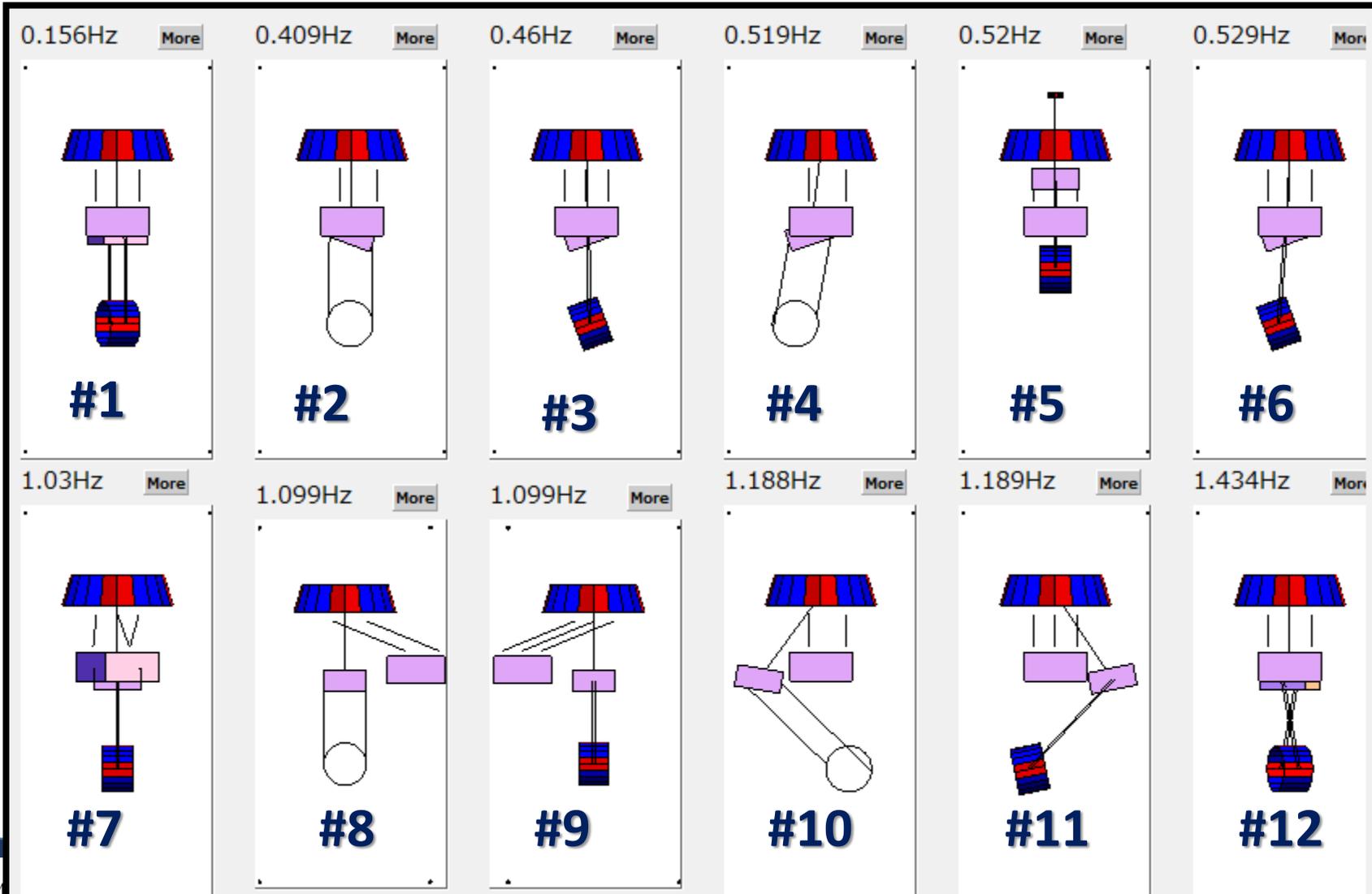
The PR TM fixed to the RM

RM is suspended by 4 wires

Eigen Mode List

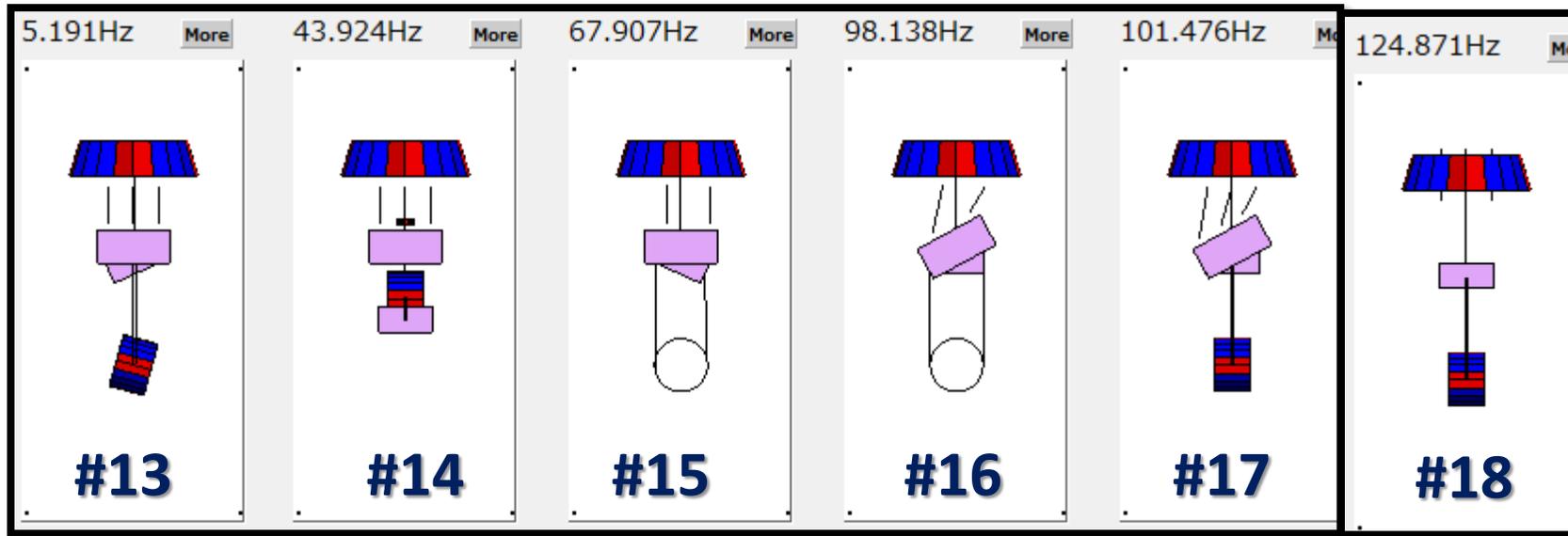
Eigen Mode Shape

TypeBpp for iKAGRA (real configuration)



Eigen Mode Shape

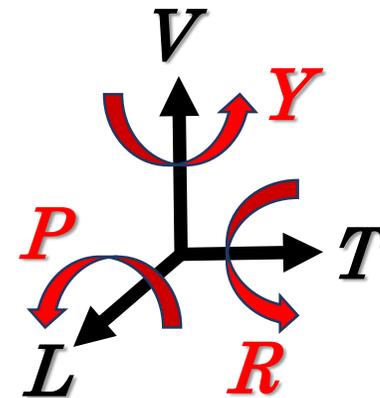
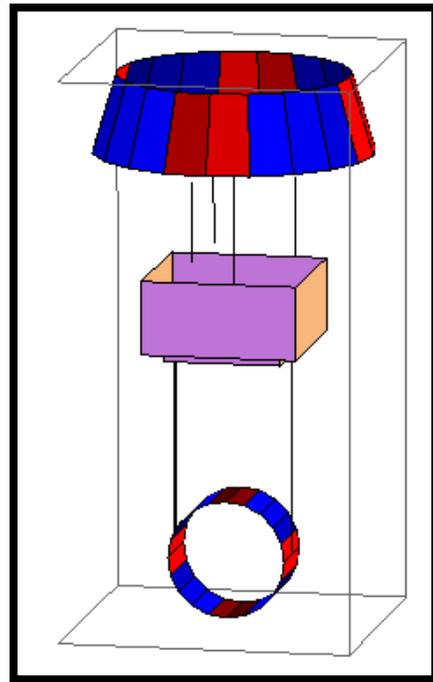
TypeBpp for iKAGRA (real configuration)



From 160301 measurement:

Force Transfer Functions with No Ctrl

(, which can be measured and actuated.)



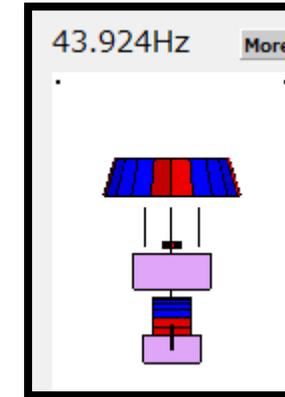
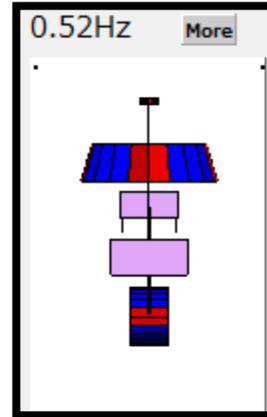
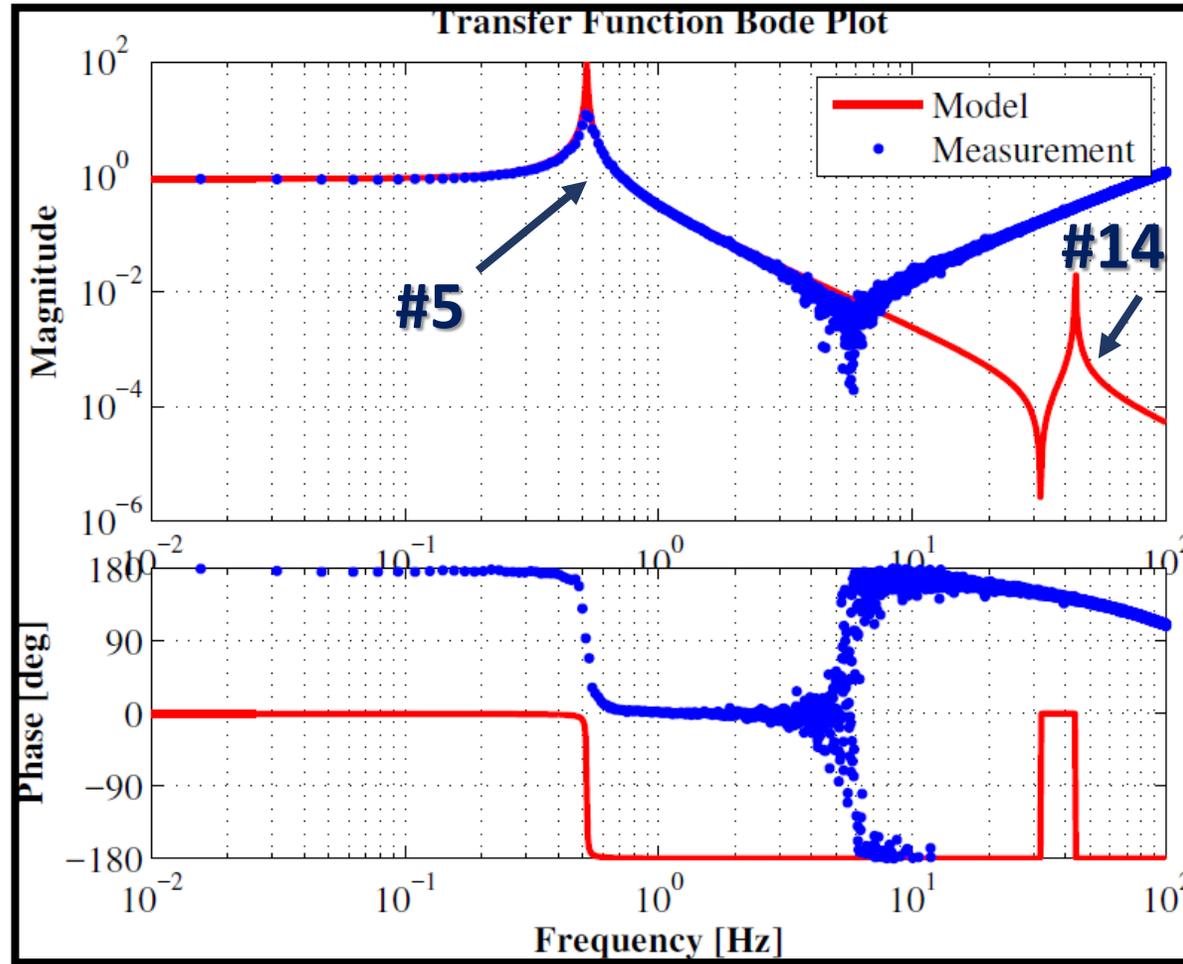
Force Transfer Function

TypeBpp for iKAGRA (real configuration)

LVDT_VBF / actVBF

#5 : GAS

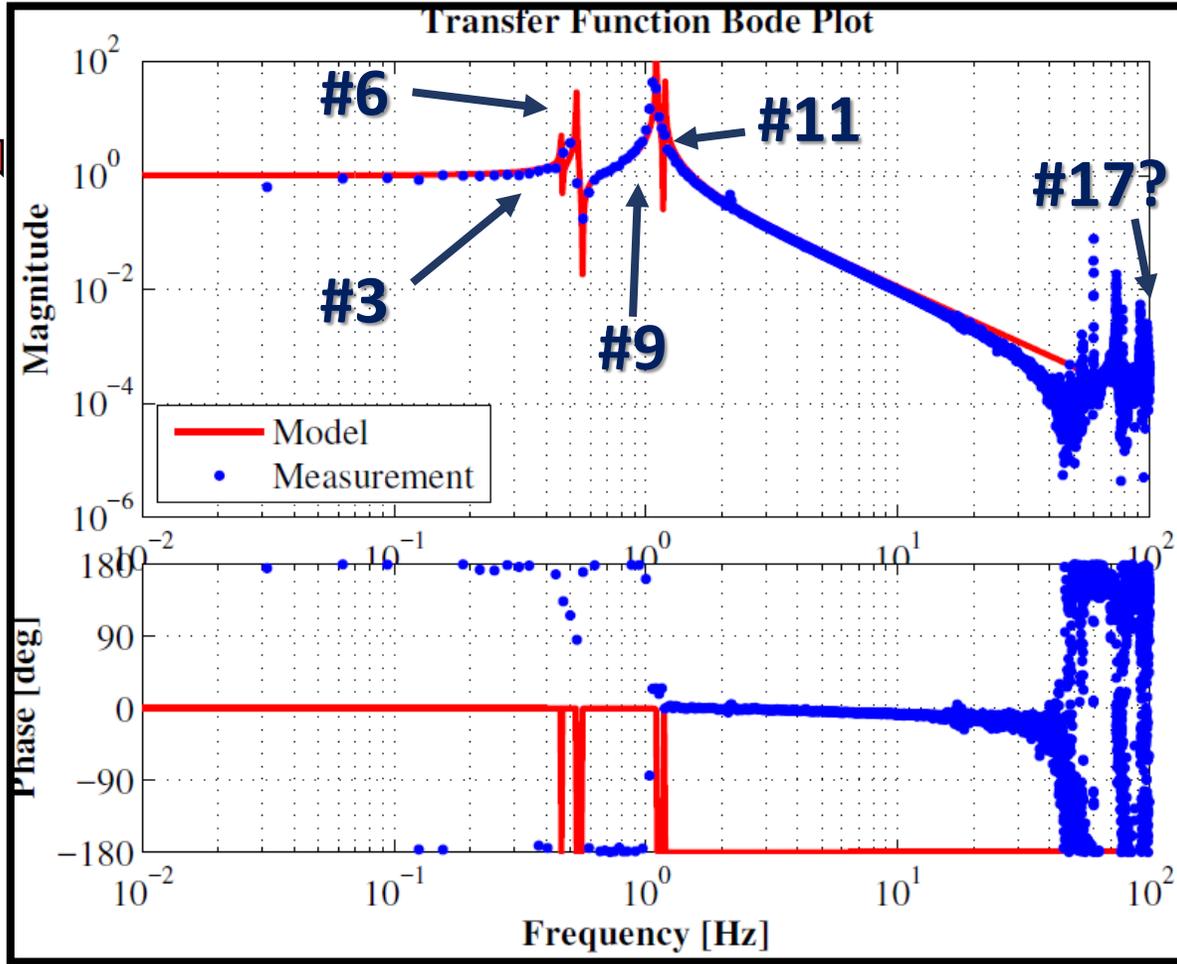
#14 : VRM



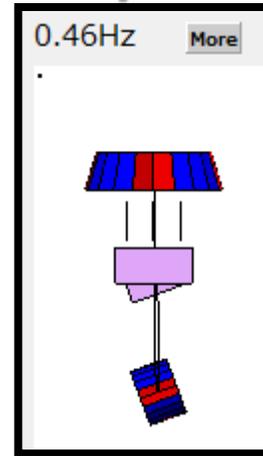
Force Transfer Function

TypeBpp for iKAGRA (real configuration)

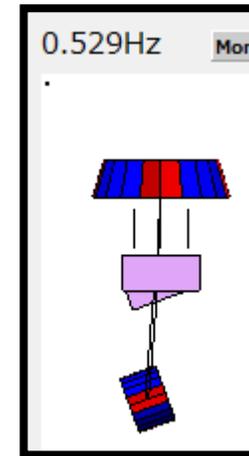
OSEM_LIM / actLIM



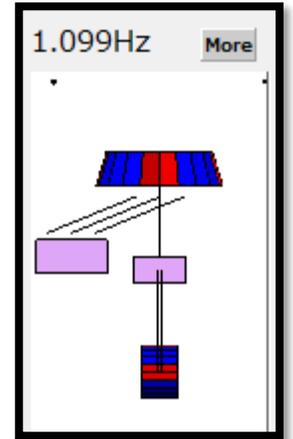
#3 : PIM /PRM



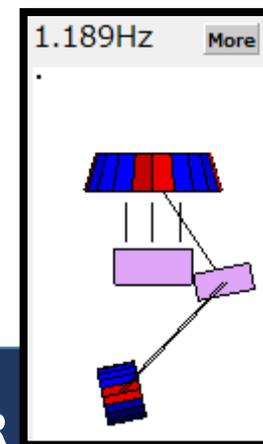
#6 : PIM /PRM



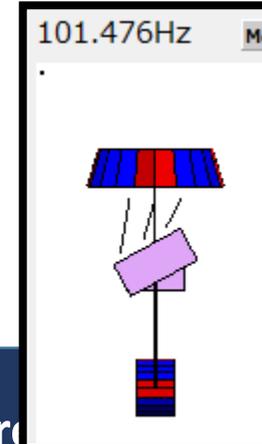
#9 : LIR



#11 : LIM



#17 : RIR ?



Force Transfer Function

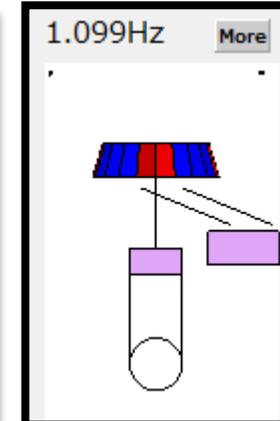
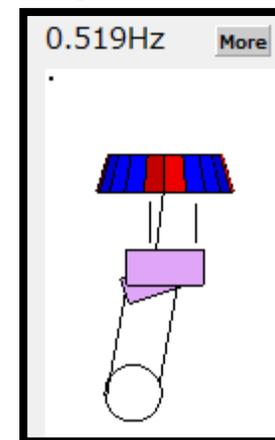
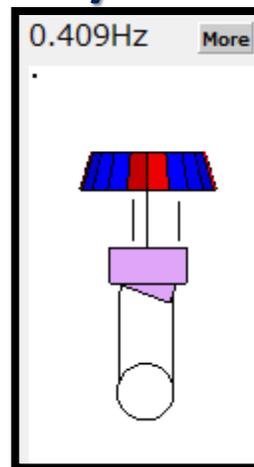
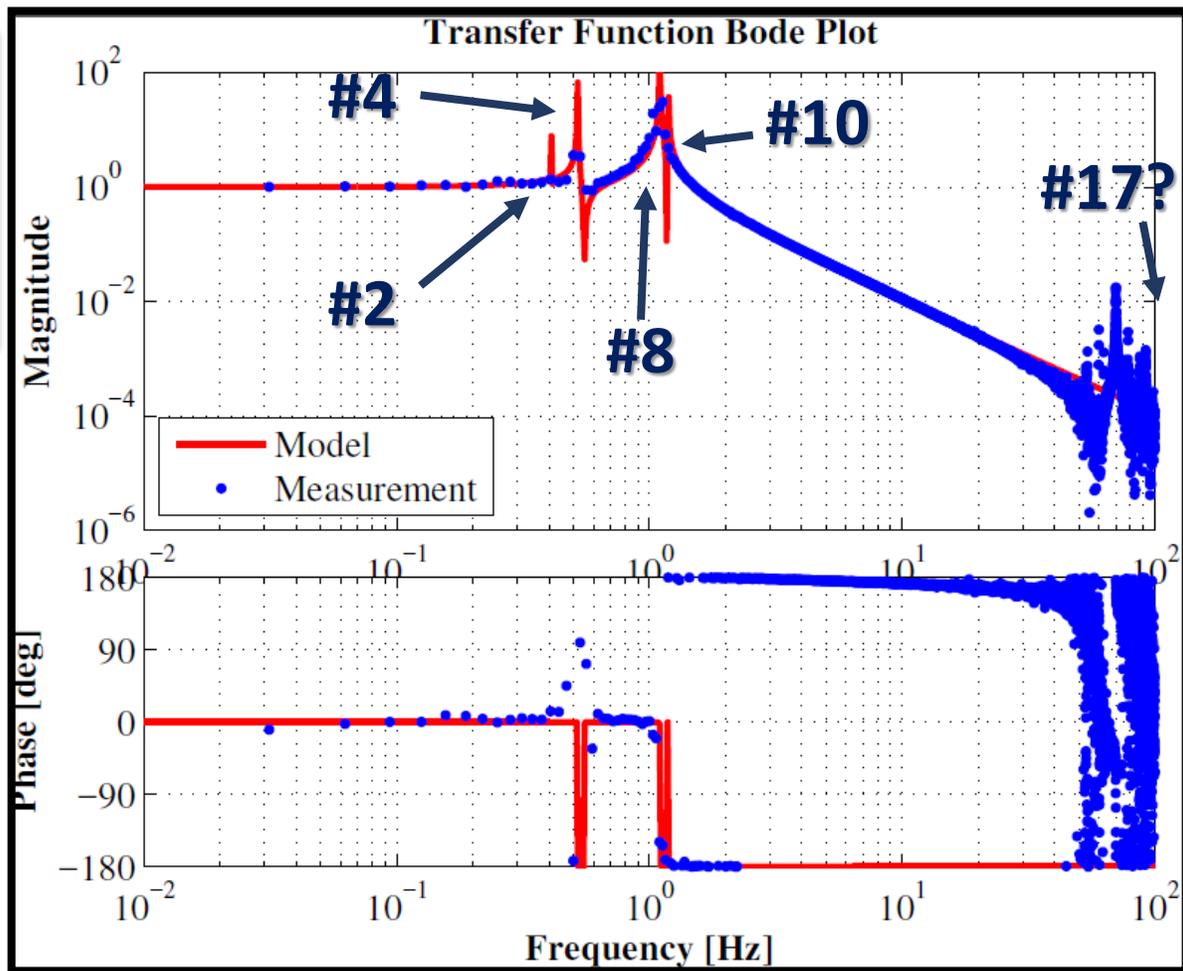
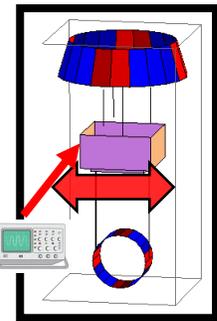
TypeBpp for iKAGRA (real configuration)

OSEM_TIM / actTIM

#2 : RIM
/RRM

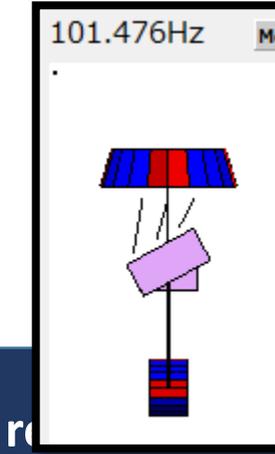
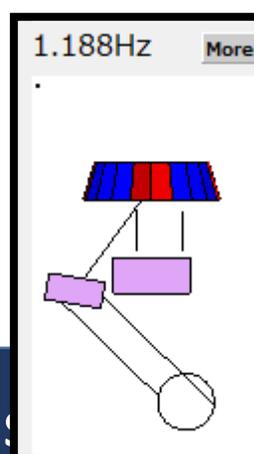
#4 : RIM
/RRM

#8 : TIR



#10 : TIM

#17 : RIR ?



Force Transfer Function

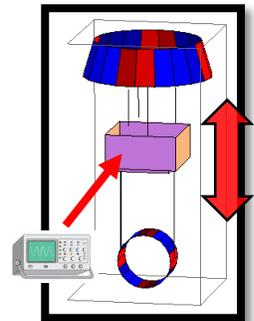
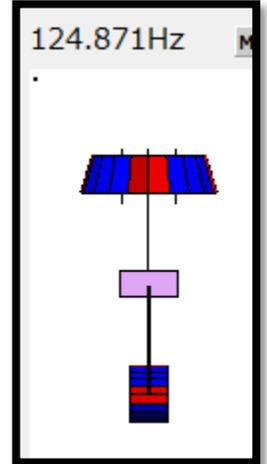
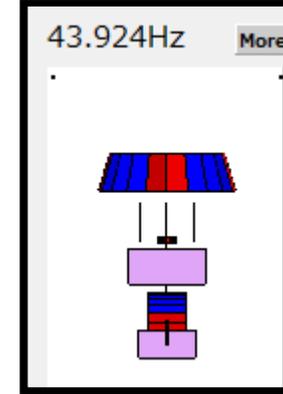
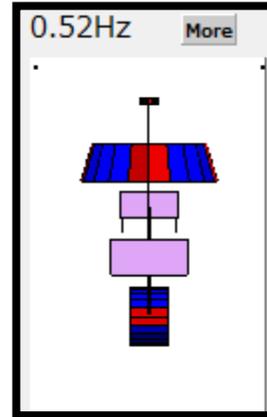
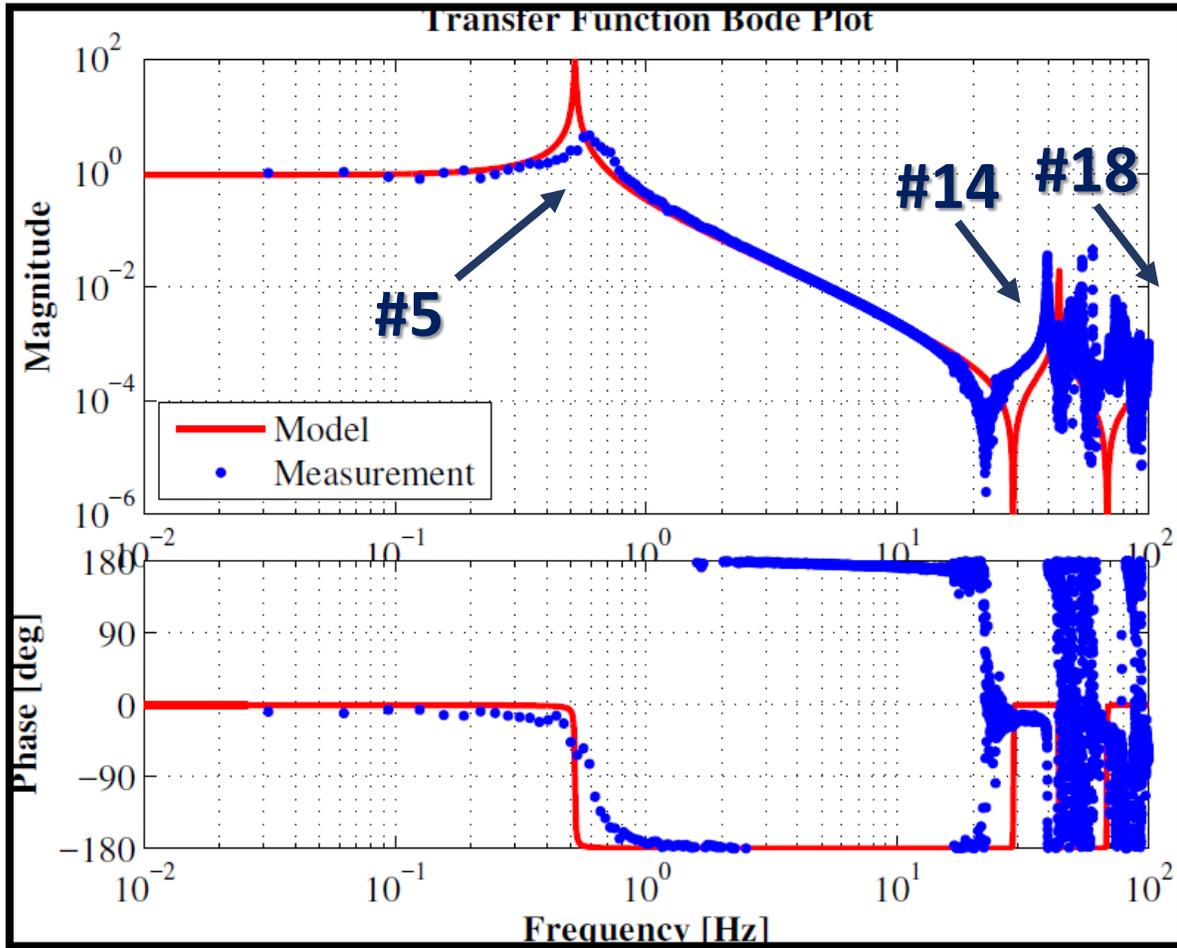
TypeBpp for iKAGRA (real configuration)

OSEM_VIM / actVIM

#5 : GAS

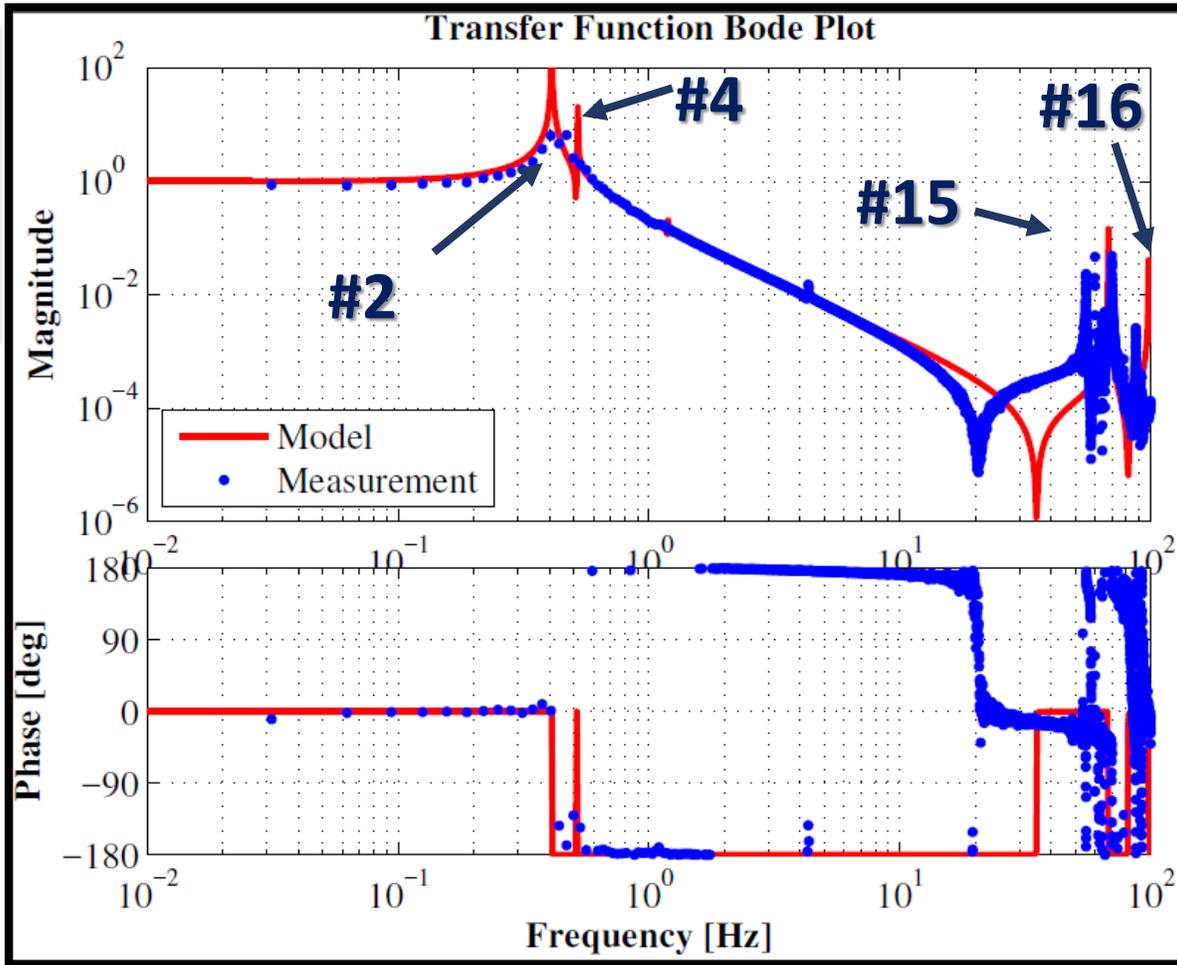
#14 : VRM

#18 : VIR

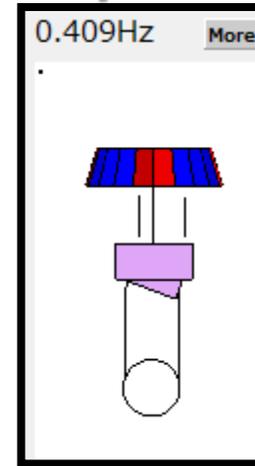


Force Transfer Function TypeBp with IP

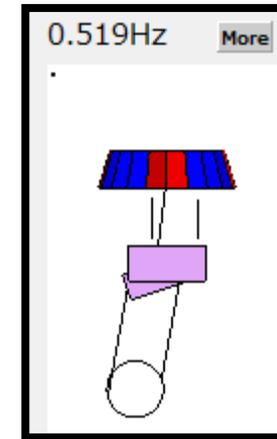
OSEM_RIM / actRIM



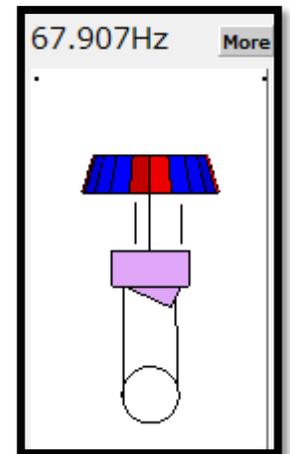
#2 : RIM /RRM



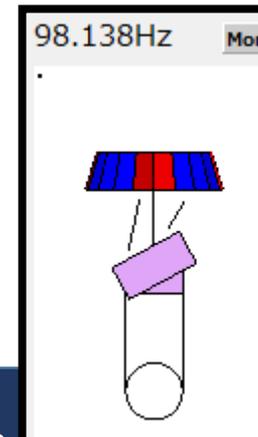
#4 : RIM /RRM



#15 : RIM



#16 : RIR

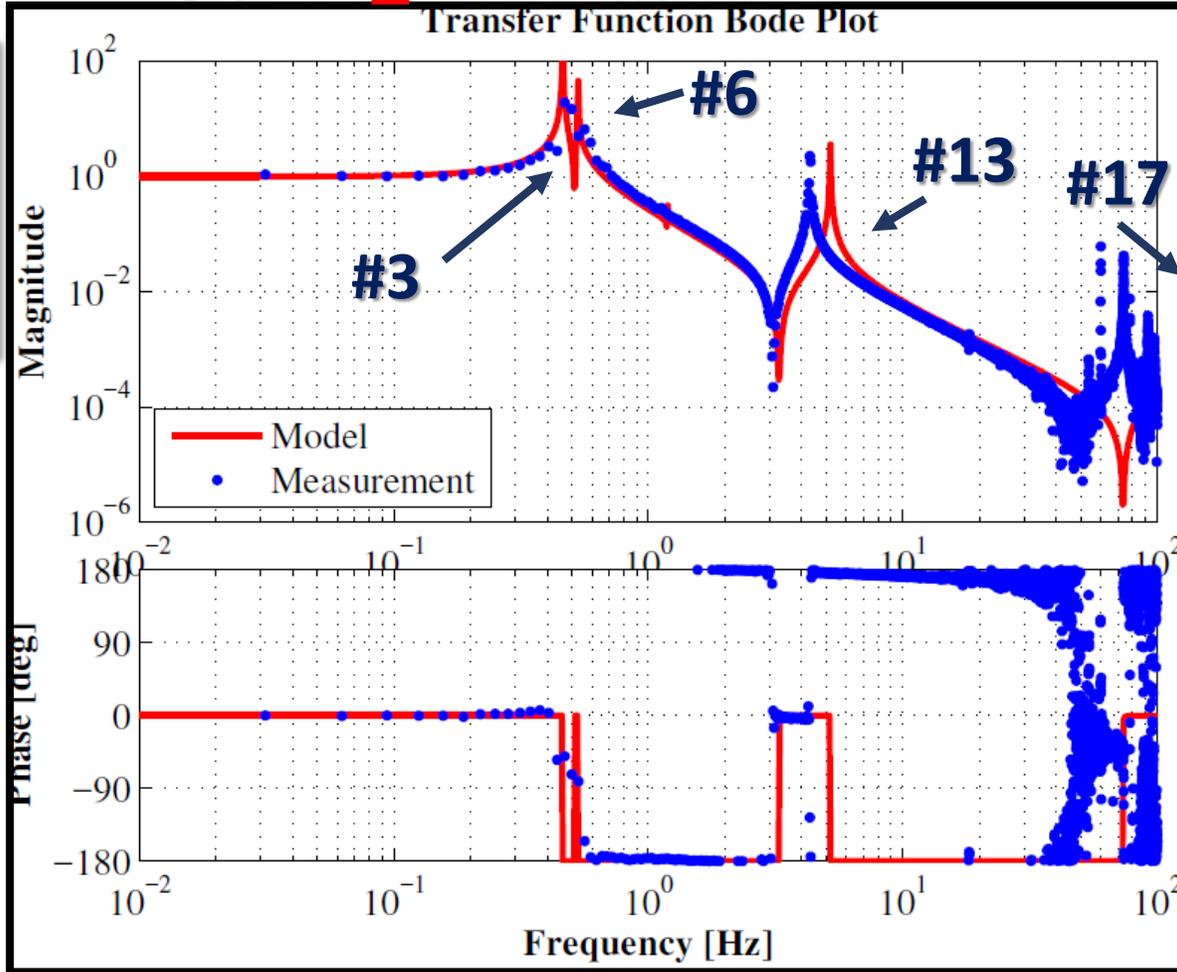


Force Transfer Function

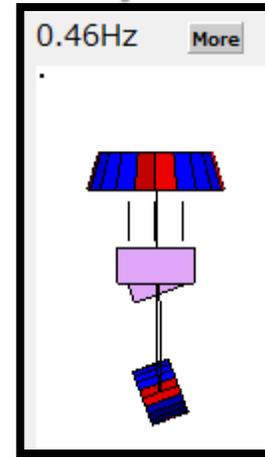
TypeBpp for iKAGRA (real configuration)

OSEM_PIM / actPIM

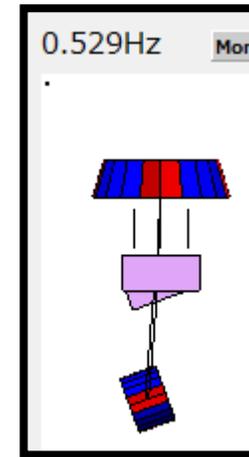
Transfer Function Bode Plot



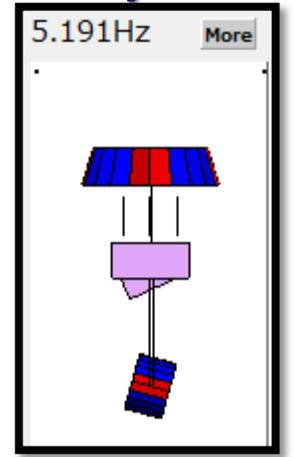
#3 : PIM
/PRM



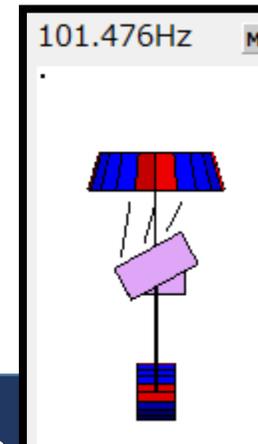
#6 : PIM
/PRM



#13 : PIM
/PRM



#17 : PIR



PR SAS Model for real iKAGRA PR3

Force Transfer Function

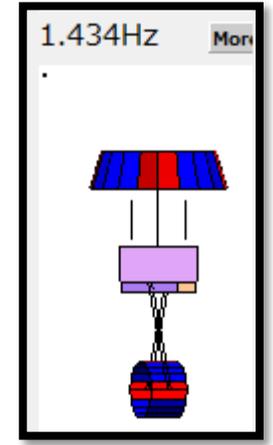
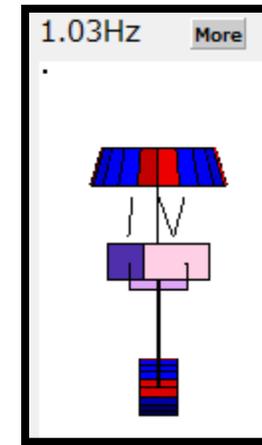
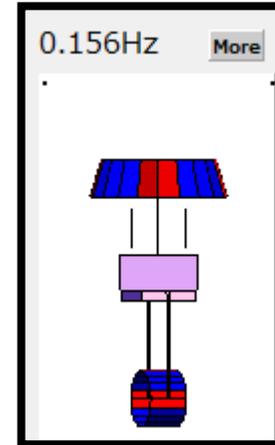
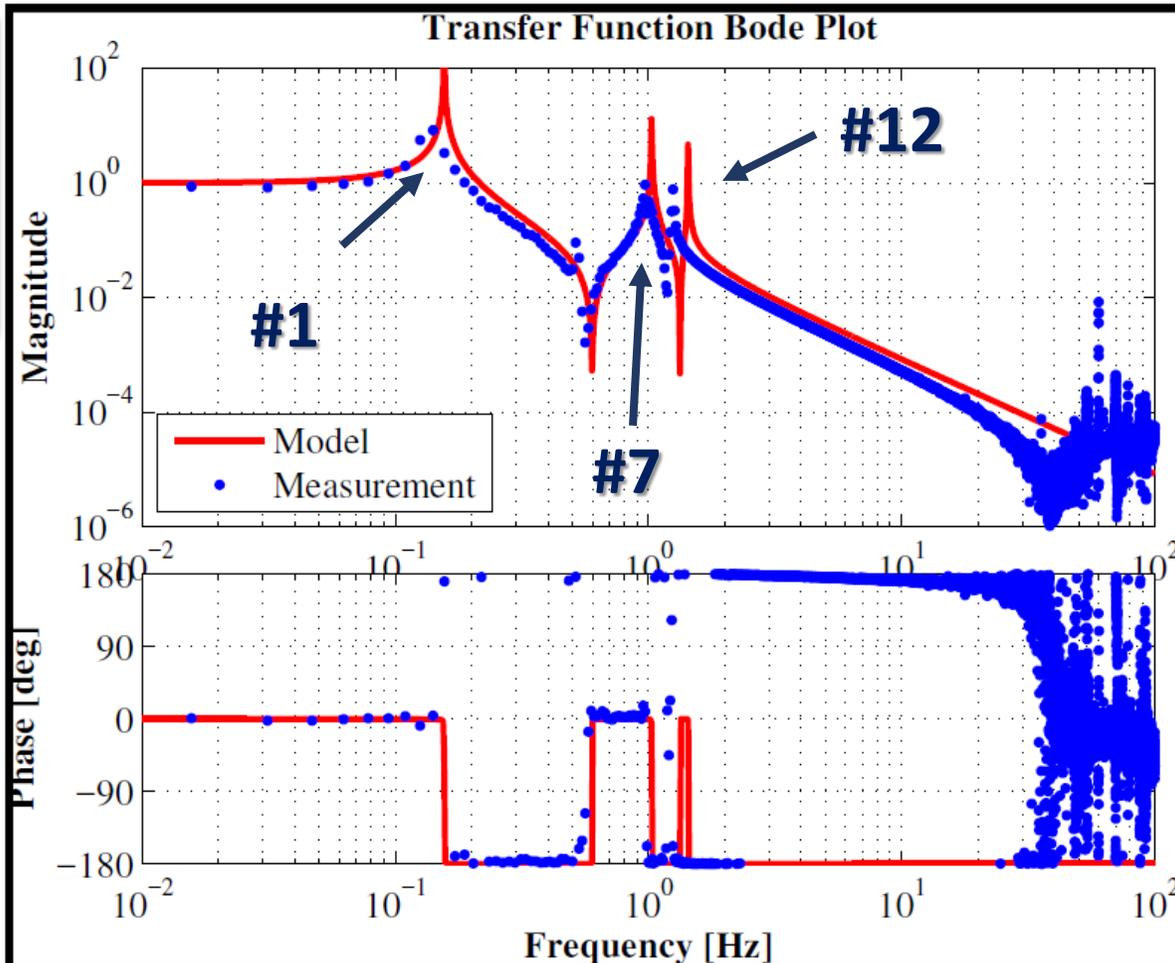
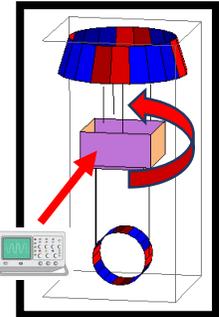
TypeBpp for iKAGRA (real configuration)

OSEM_YIM / actYIM

#1 : Whole chain

#7 : YIR

#12 : YIM /YIR

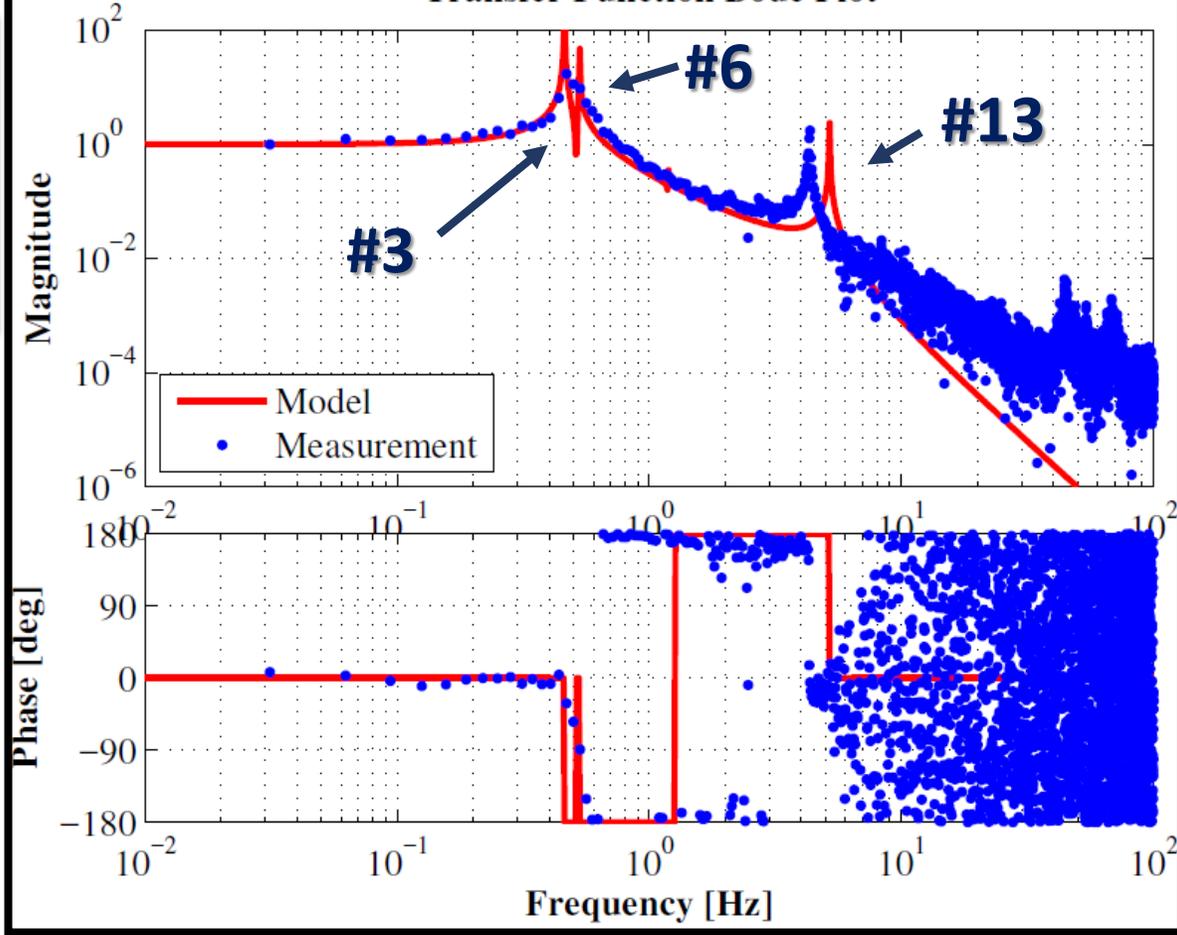


Force Transfer Function

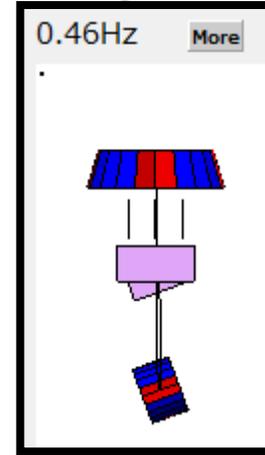
TypeBpp for iKAGRA (real configuration)

Oplev PTM / actPIM

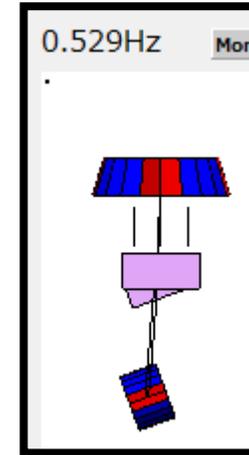
Transfer Function Bode Plot



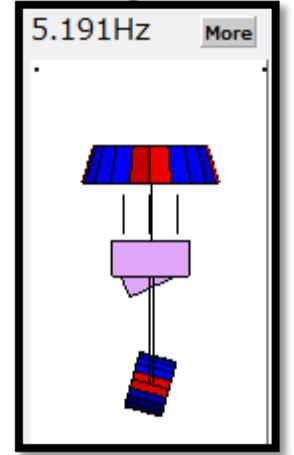
#3 : PIM
/PRM



#6 : PIM
/PRM



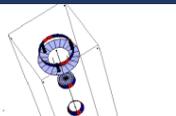
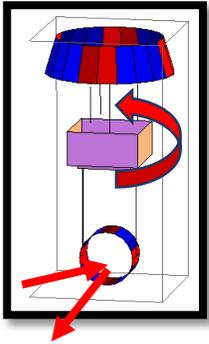
#13 : PIM
/PRM



Force Transfer Function

TypeBpp for iKAGRA (real configuration)

OpLev_YTM / actYIM



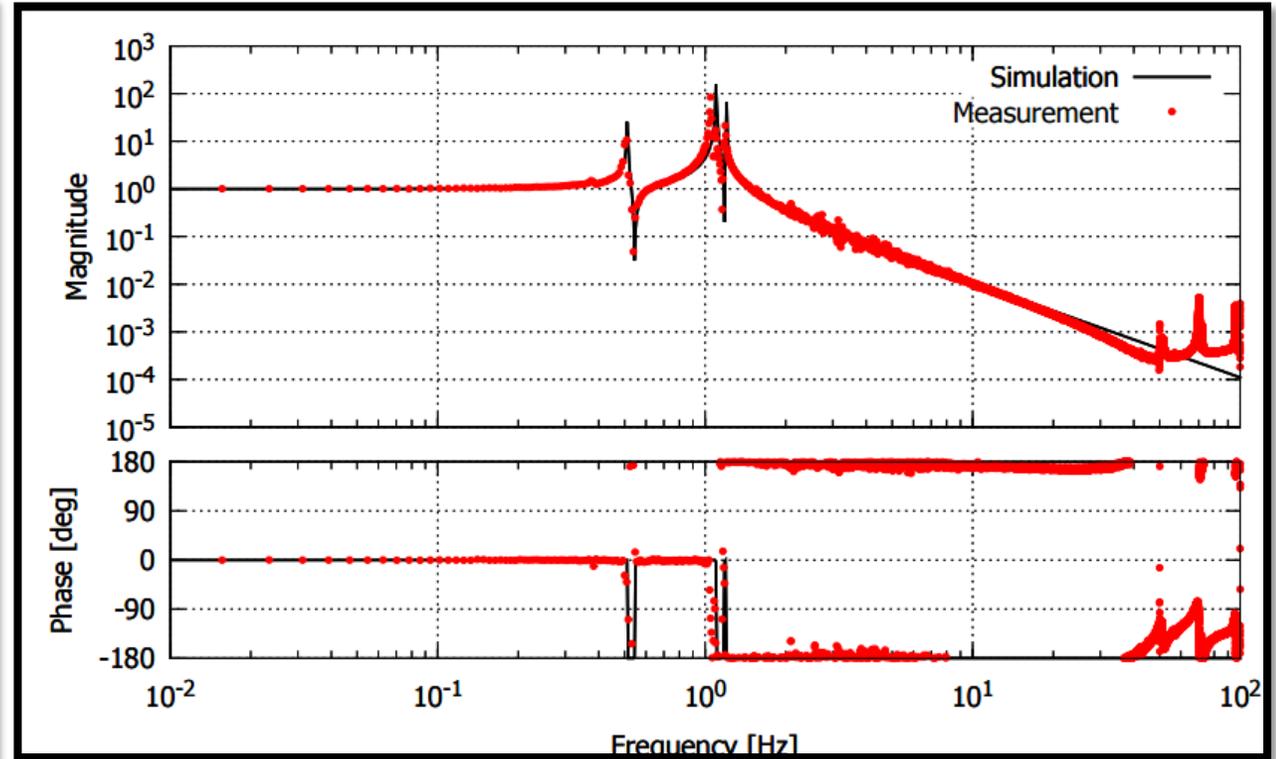
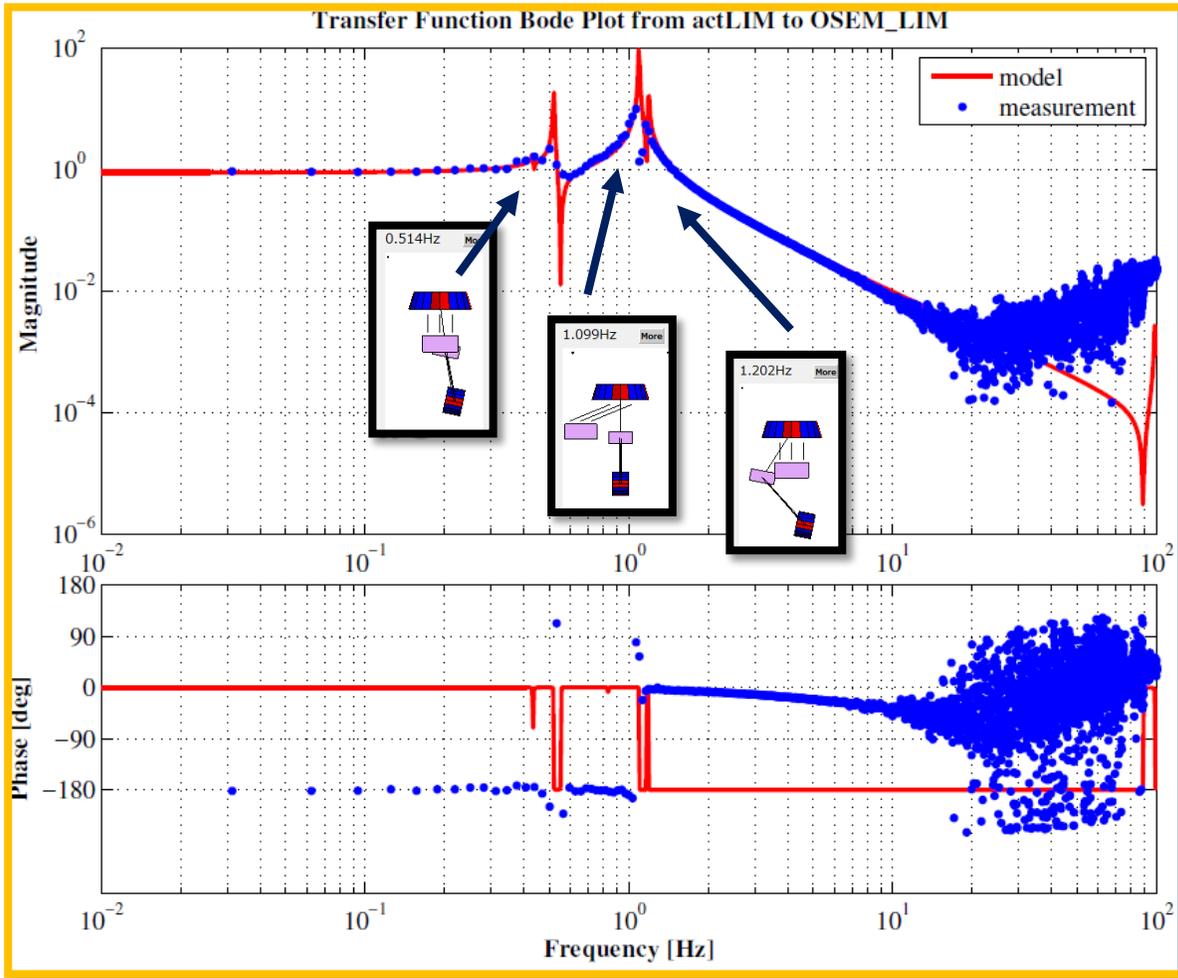
③ Installation test vs. SUMCON : TypeBpp_iKAGRA



Investigation of TypeBpp Frequency response

LIM (OSEM) TF

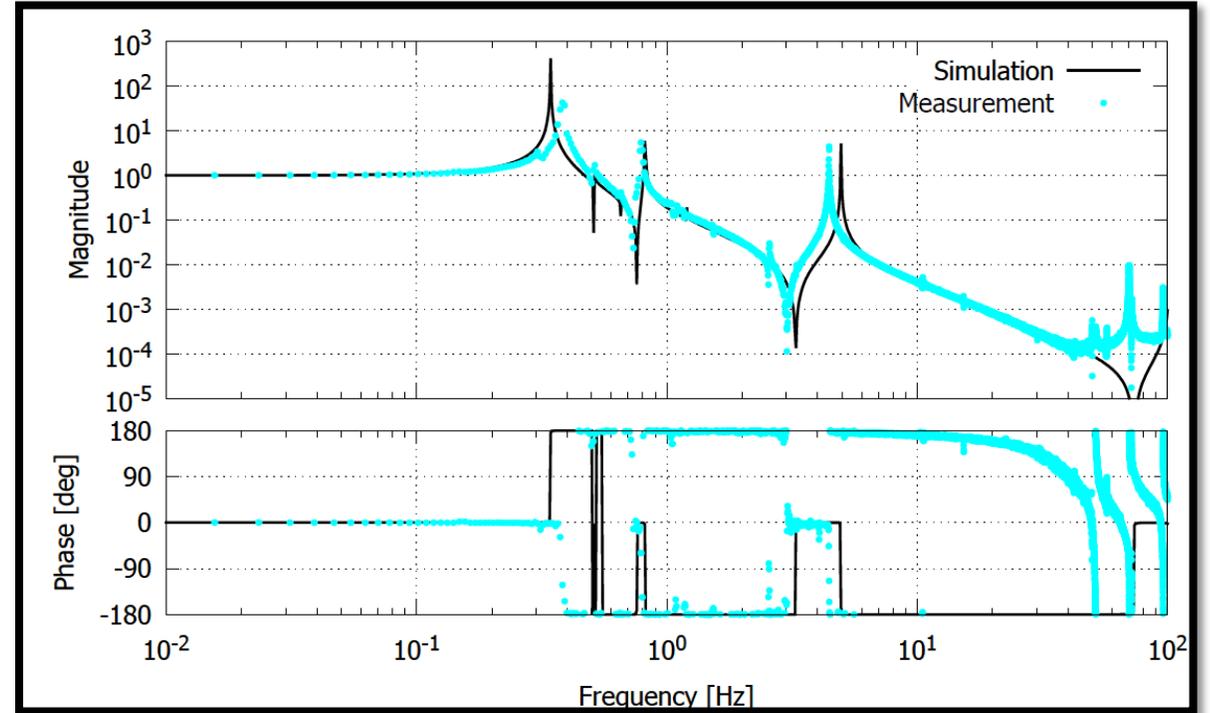
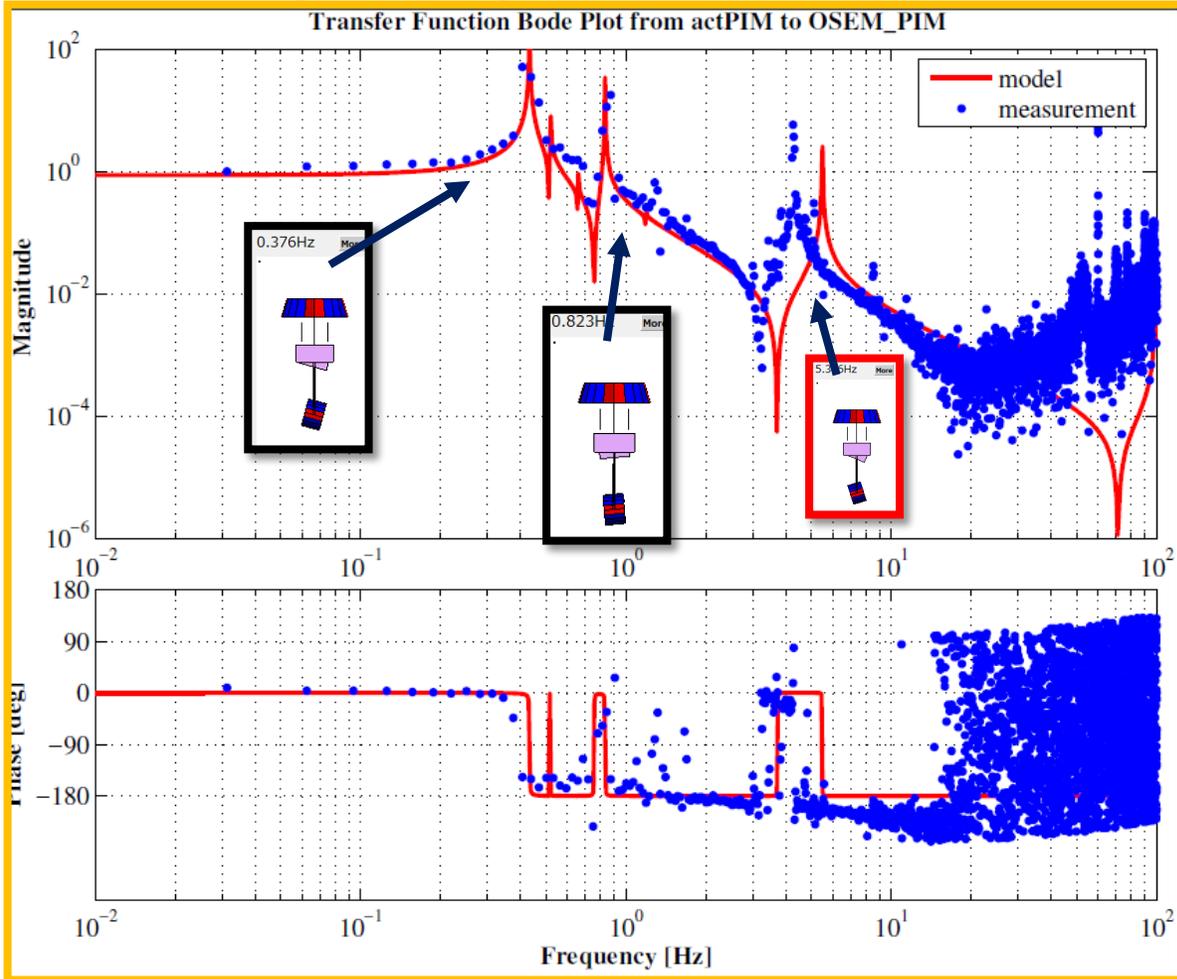
REF : LIM (OSEM) TF of 20 m SAS



Investigation of TypeBpp Frequency response

PIM (OSEM) TF

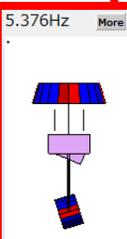
REF : PIM (OSEM) TF of 20 m SAS



Resonance frequency is lower than its prediction by around 1 Hz.



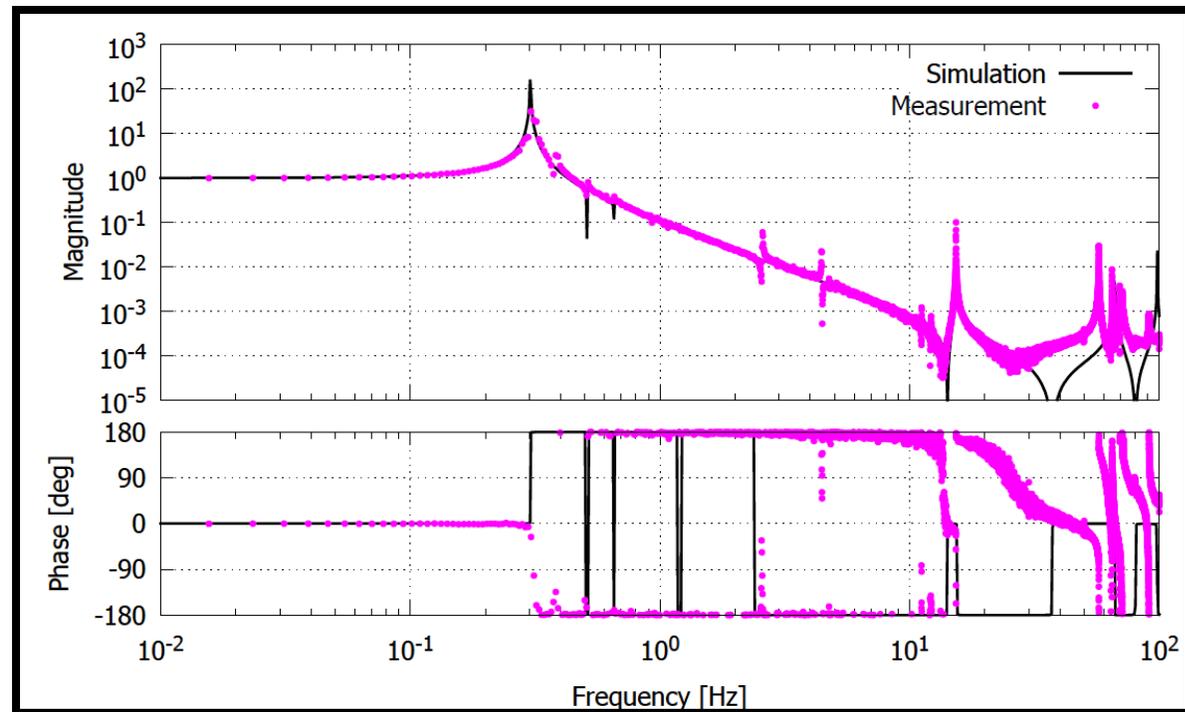
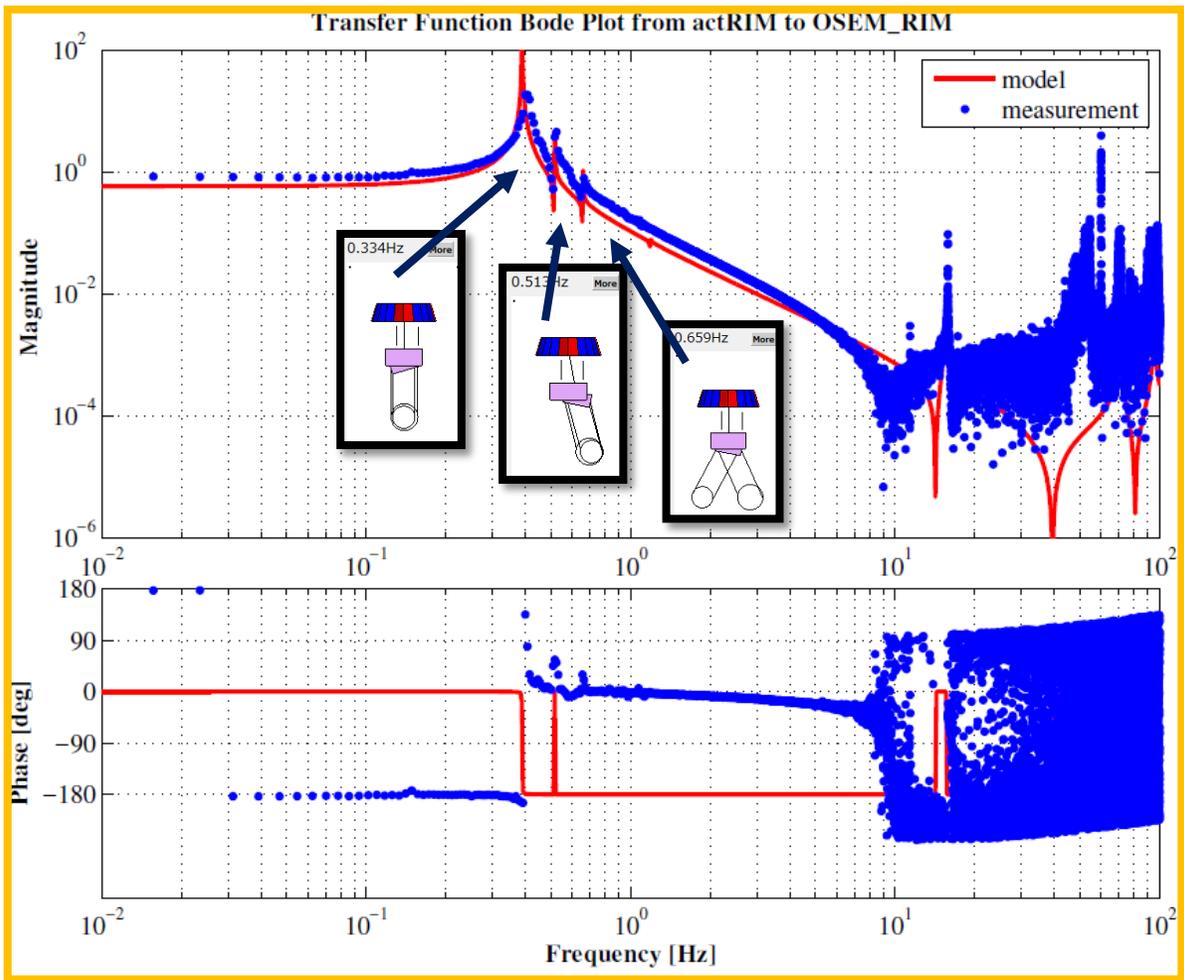
To be investigated.



Investigation of TypeBpp Frequency response

RIM (OSEM) TF

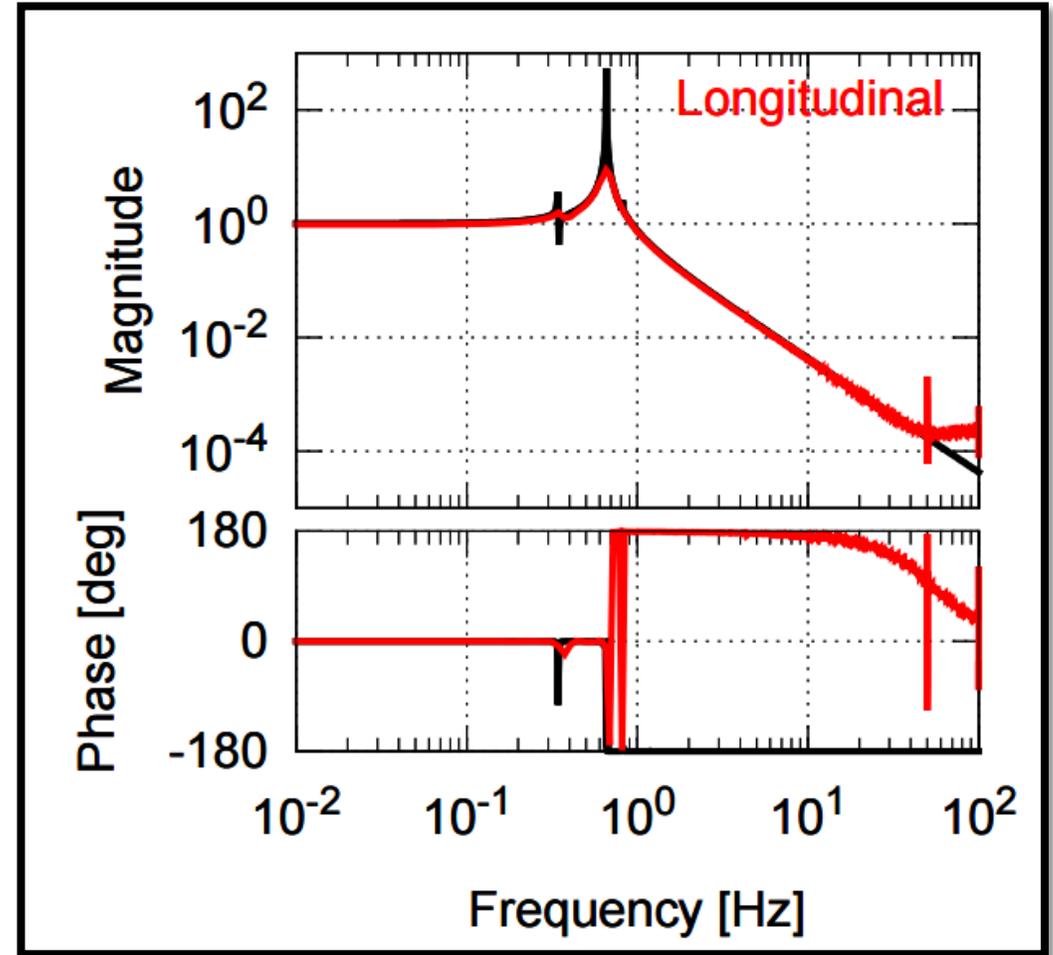
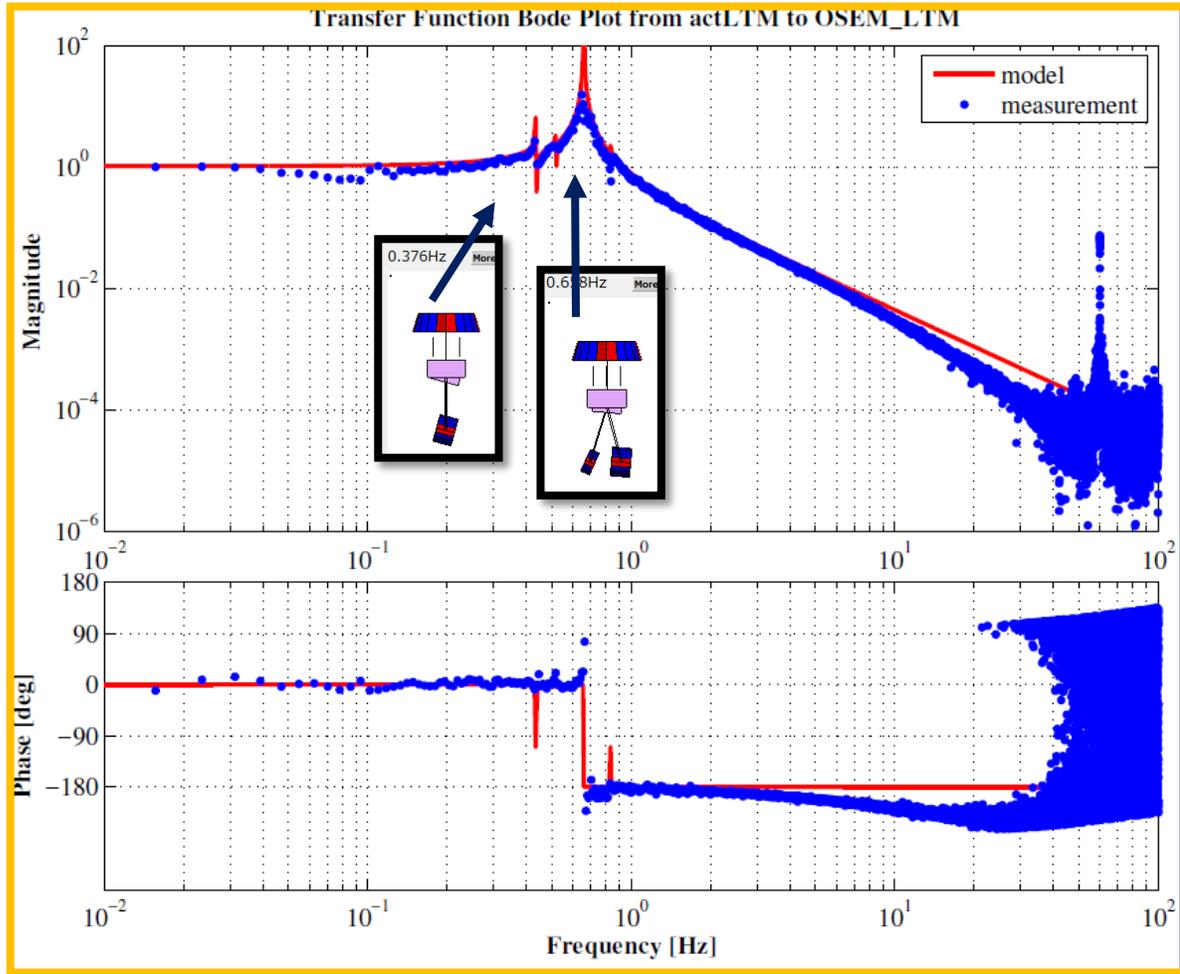
REF : RIM (OSEM) TF of 20 m SAS



Investigation of TypeBpp Frequency response

LTM (OSEM) TF

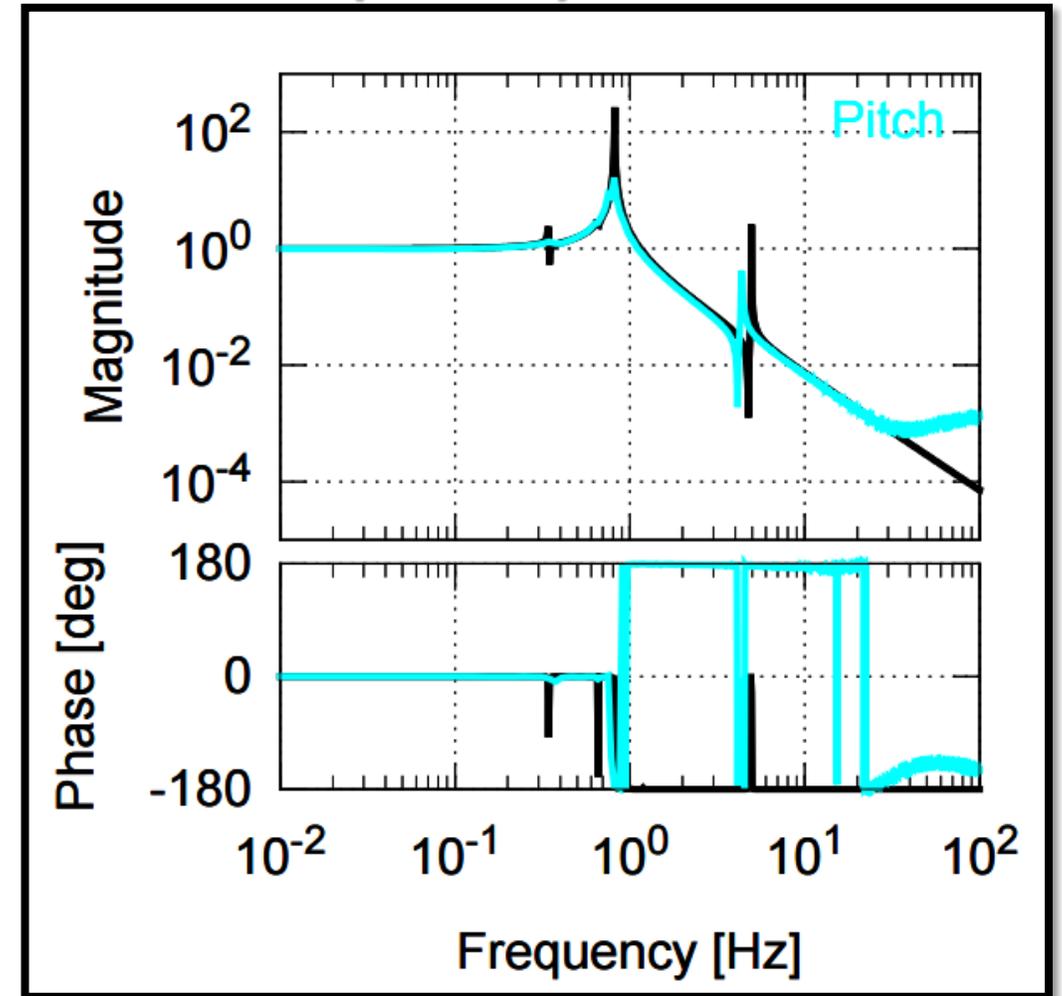
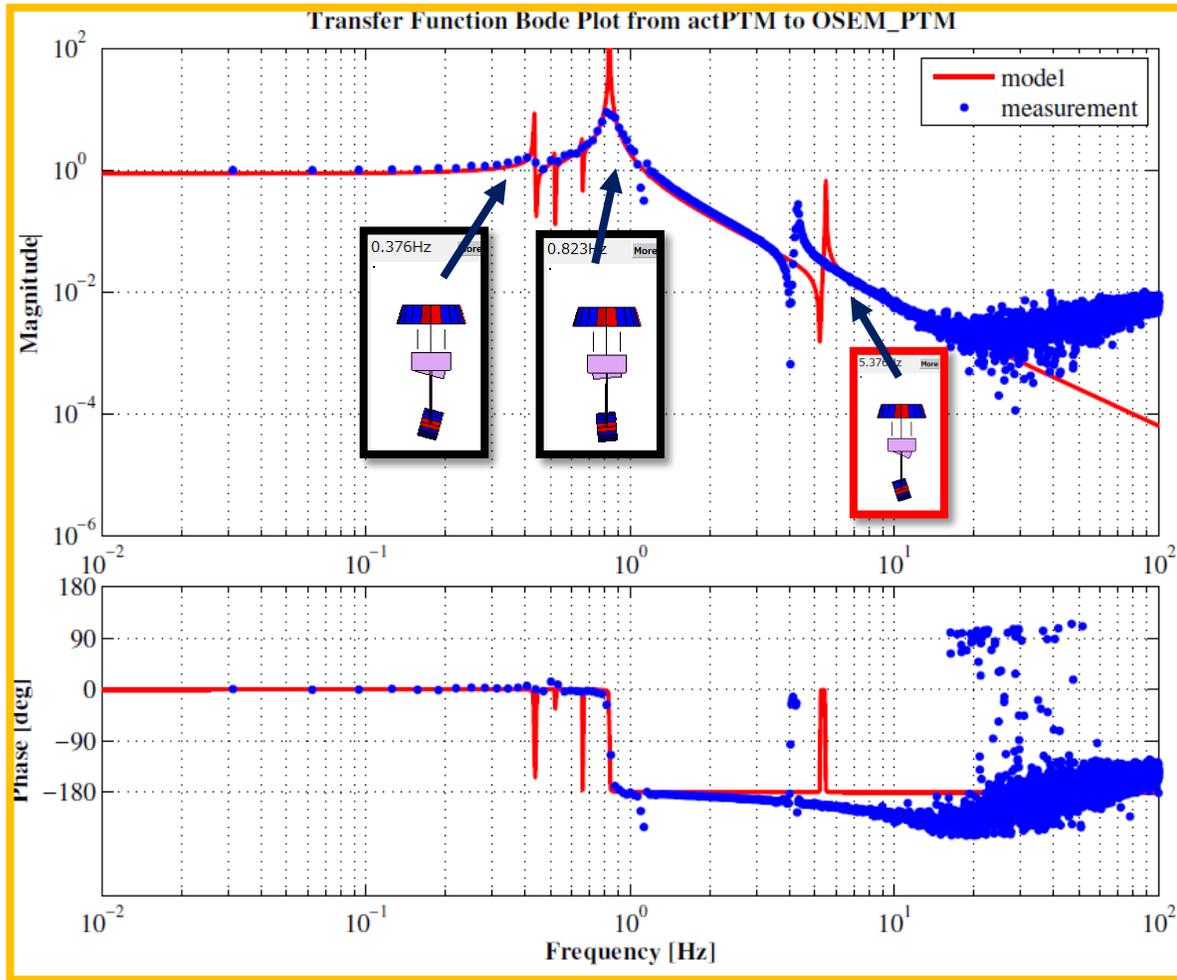
REF : LTM (OSEM) TF of 20 m SAS



Investigation of TypeBpp Frequency response

PTM (OSEM) TF

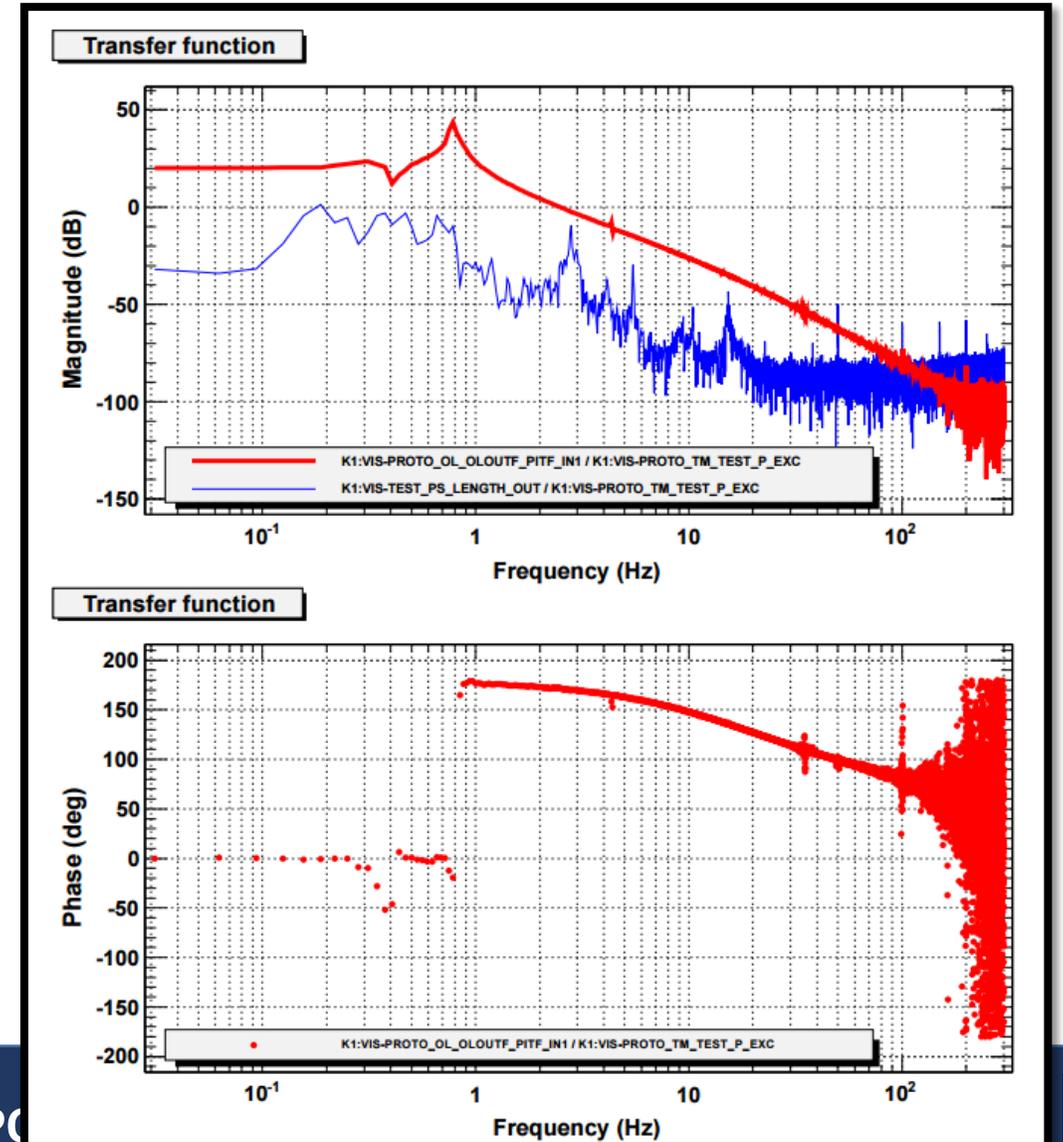
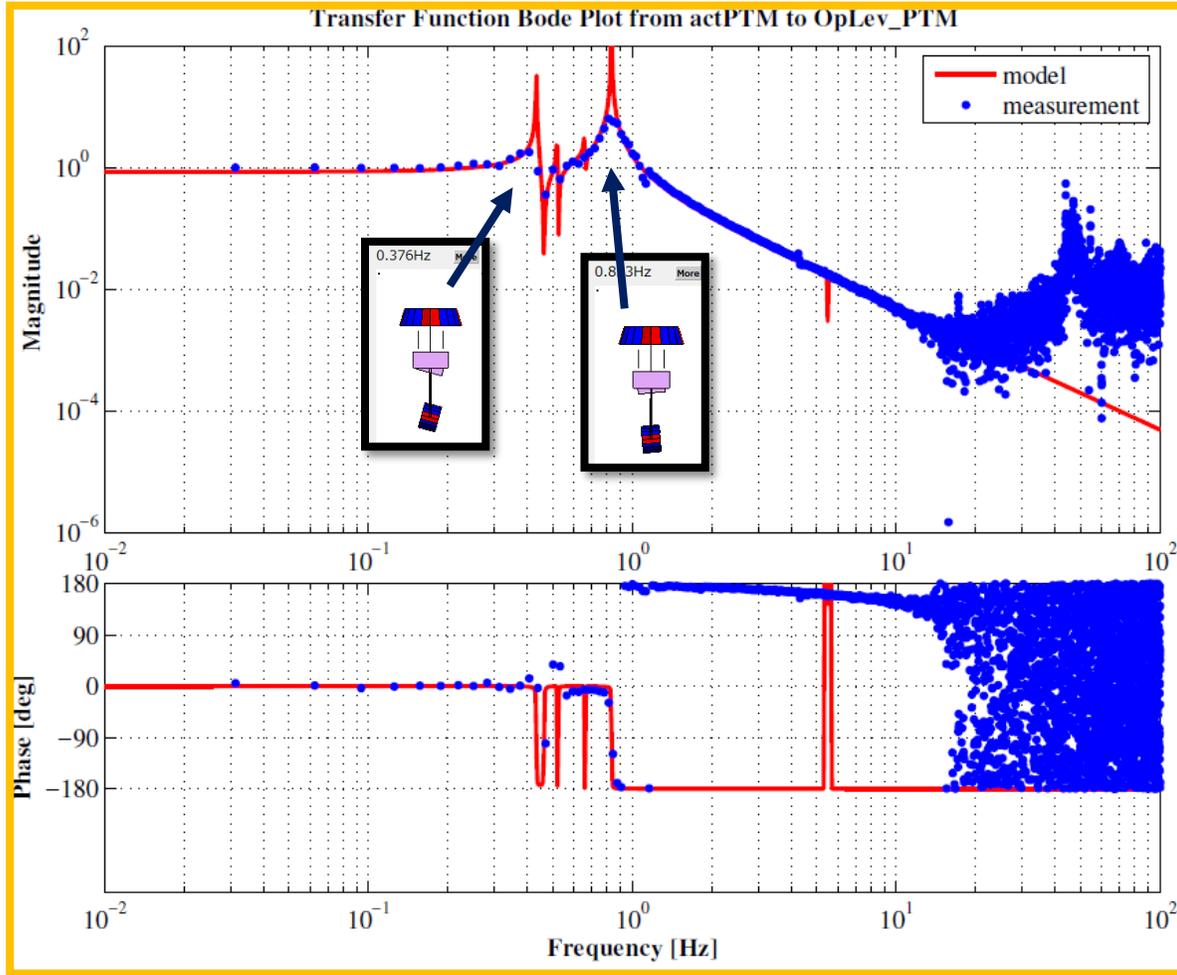
REF : PTM (OSEM) TF in 20 m SAS



Investigation of TypeBpp Frequency response

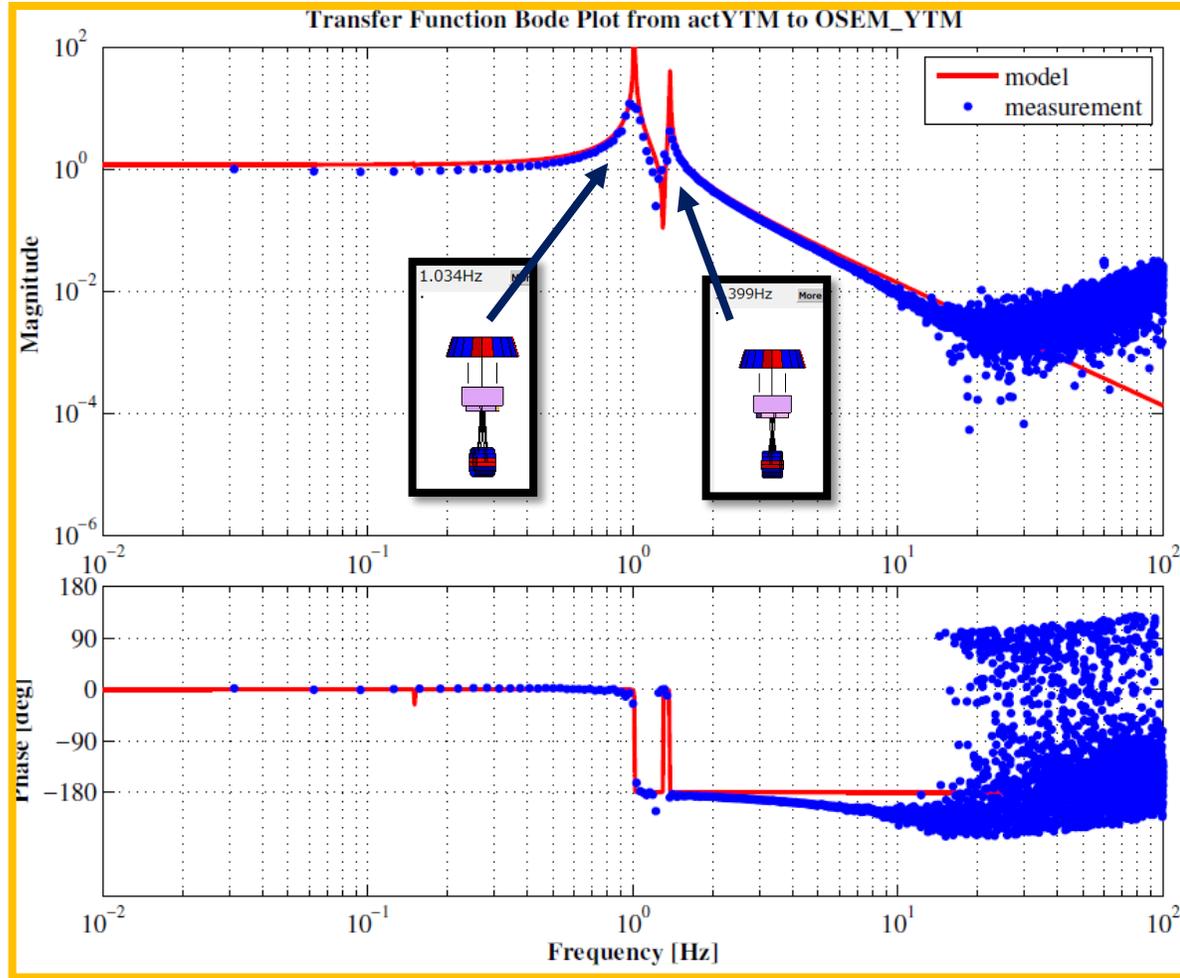
PTM (Oplev) TF

REF : PTM (Oplev) TF of Type B1

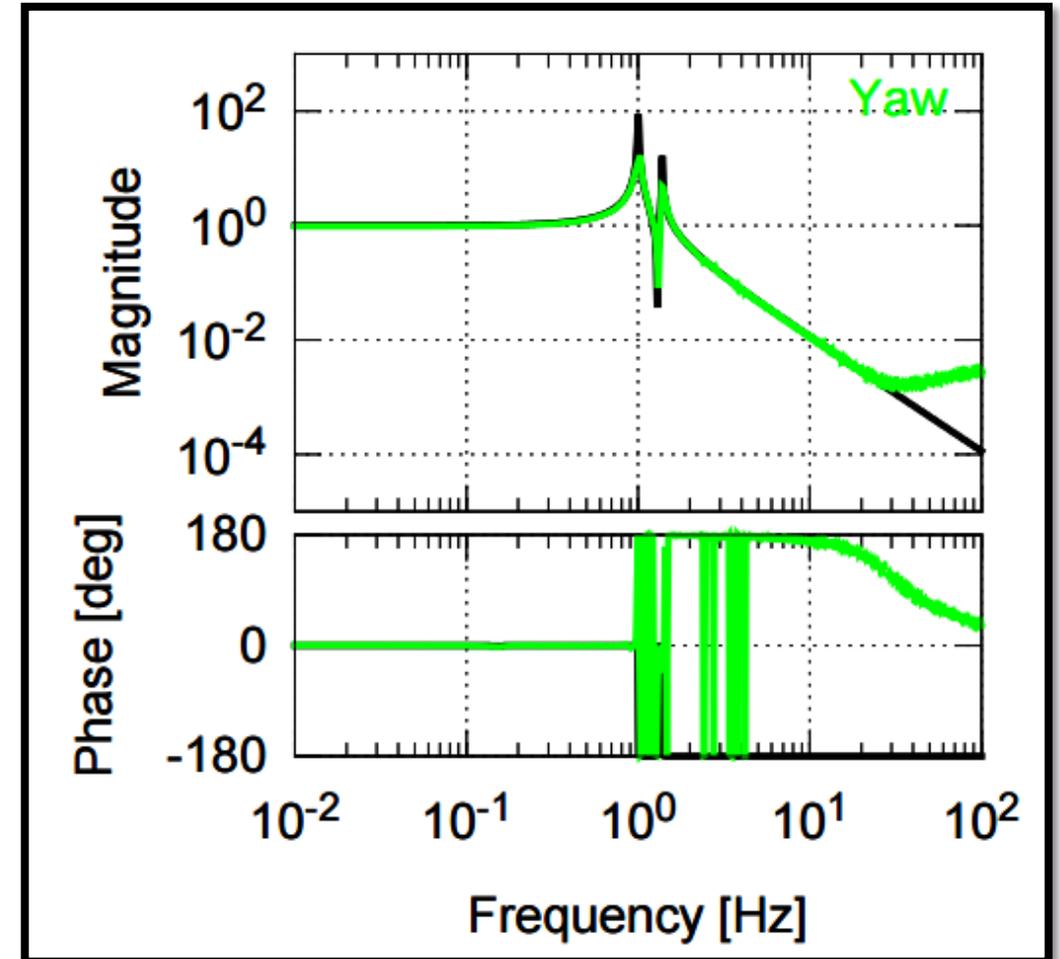


Investigation of TypeBpp Frequency response

YTM (OSEM) TF

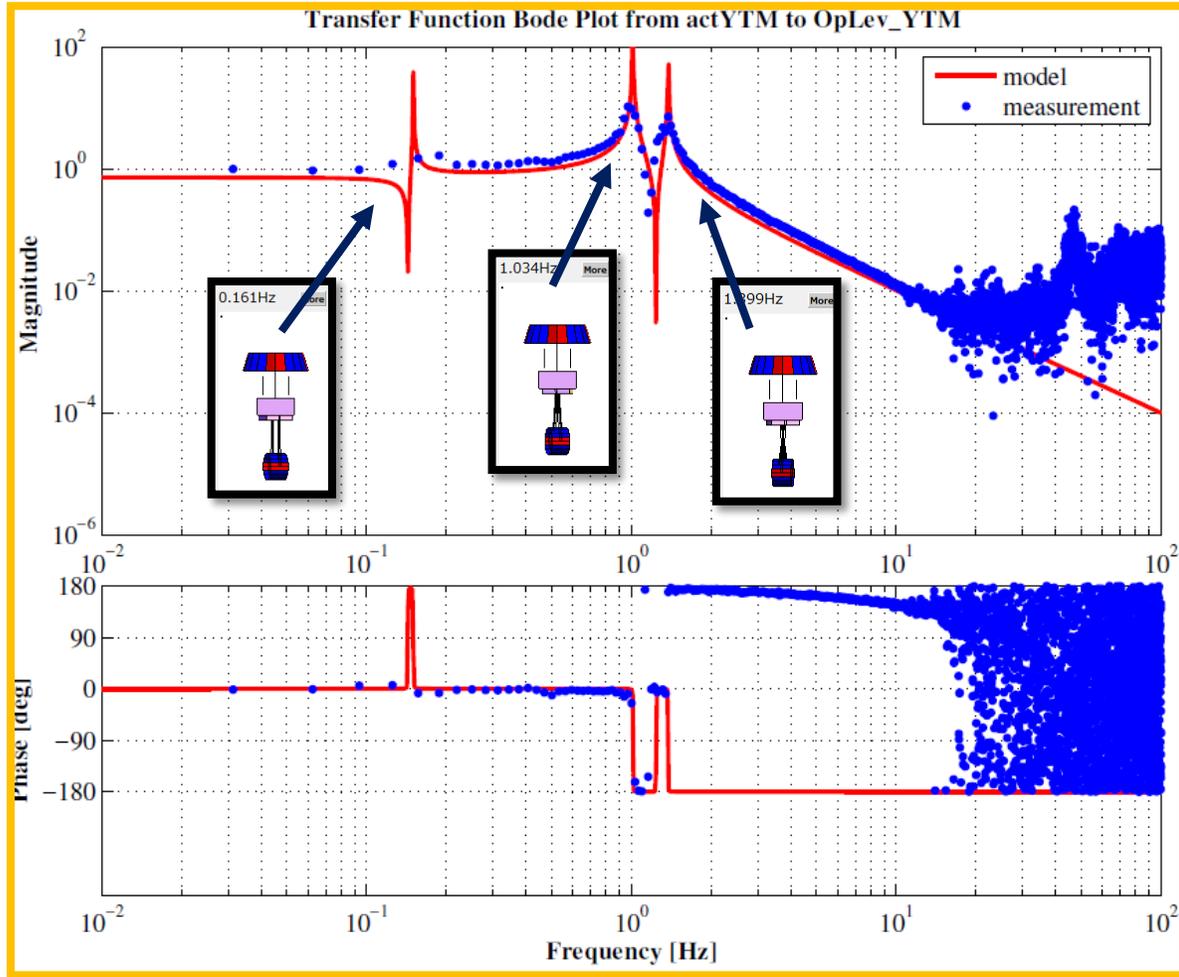


REF : LTM (OSEM) TF of 20 m SAS



Investigation of TypeBpp Frequency response

YTM (Oplev) TF



REF : YTM (Oplev) TF of Type B1

