Optical lever for M-SAS

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Objectives

- To see angular motion of M-SAS, we will prepare optical lever system.

$\Rightarrow$ enable to check RMS motion of M-SAS

$\Rightarrow$ enable to check out-of-loop measurement with the IP control.

$\Rightarrow$ Observation range is below ~10Hz

- By using the same type of optical lever as KAGRA, the result can contribute to KAGRA.

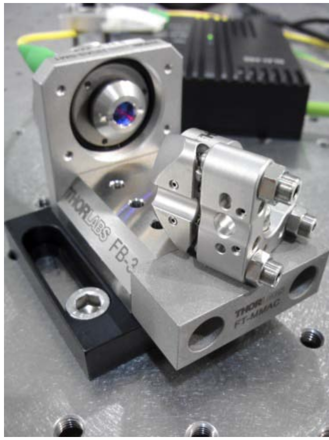
Selection of components

- **Light source**
  - SLD (Super Luminescent Diode)
  - Center wave length: 670 nm
  - Thermal control is included
  - Power: 1 mW

- **Collimator lens**
  - Beam-spot size：it affects the linear range and sensitivity

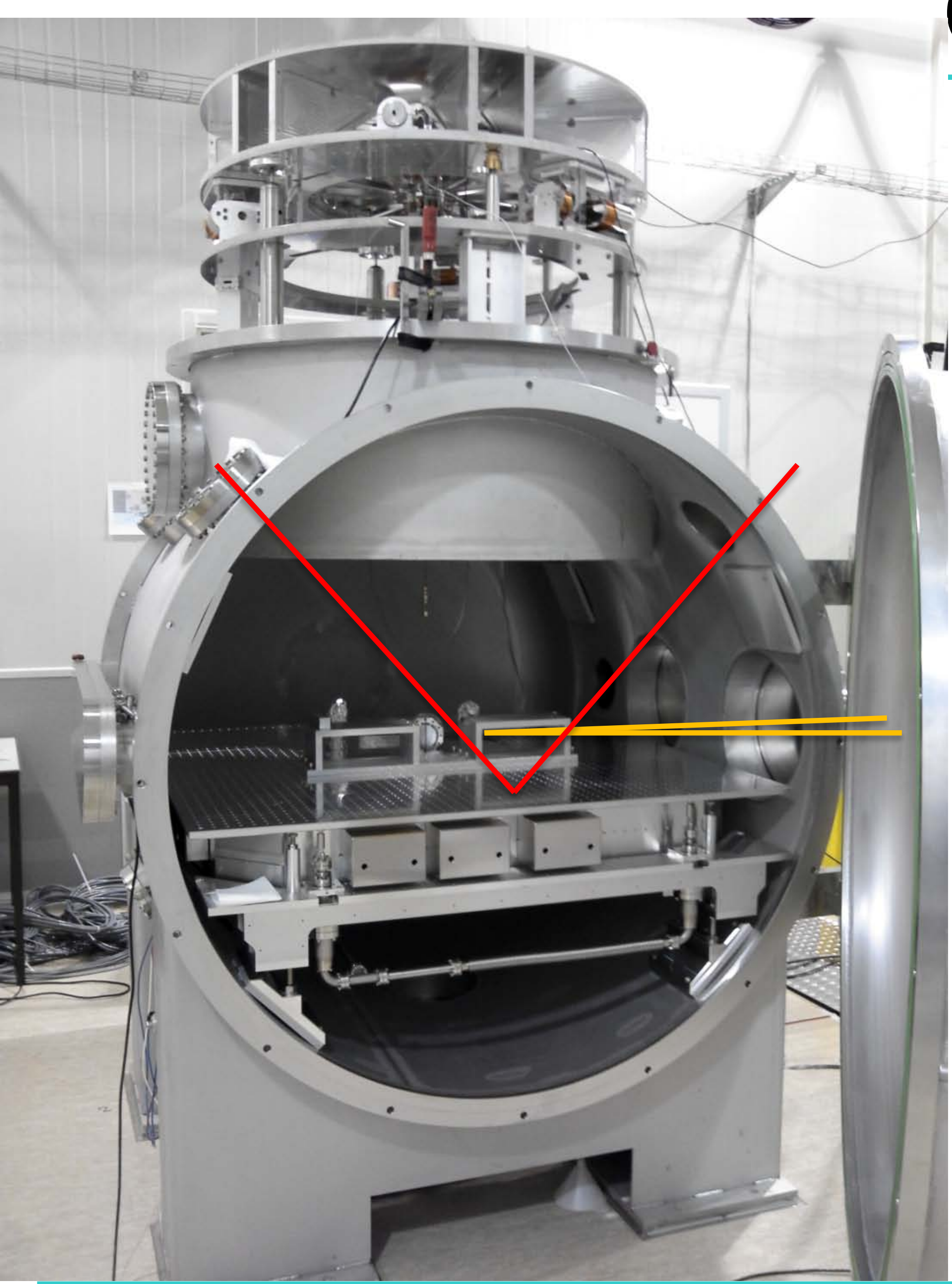
    ⇒ 0.5 - 2 mm for PSD

    (c.f. 2mm in case of aLIGO)

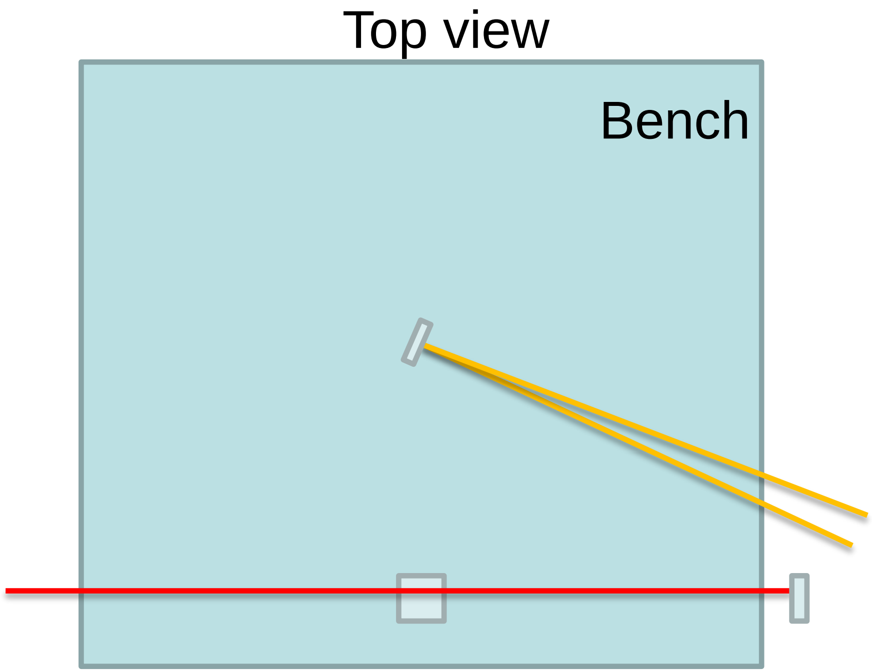


- **Photo receiver (Rec.)**
  - PSD (Position Sensitive Detector)
  - *Φ*: 9 mm x 9 mm

Optical layout

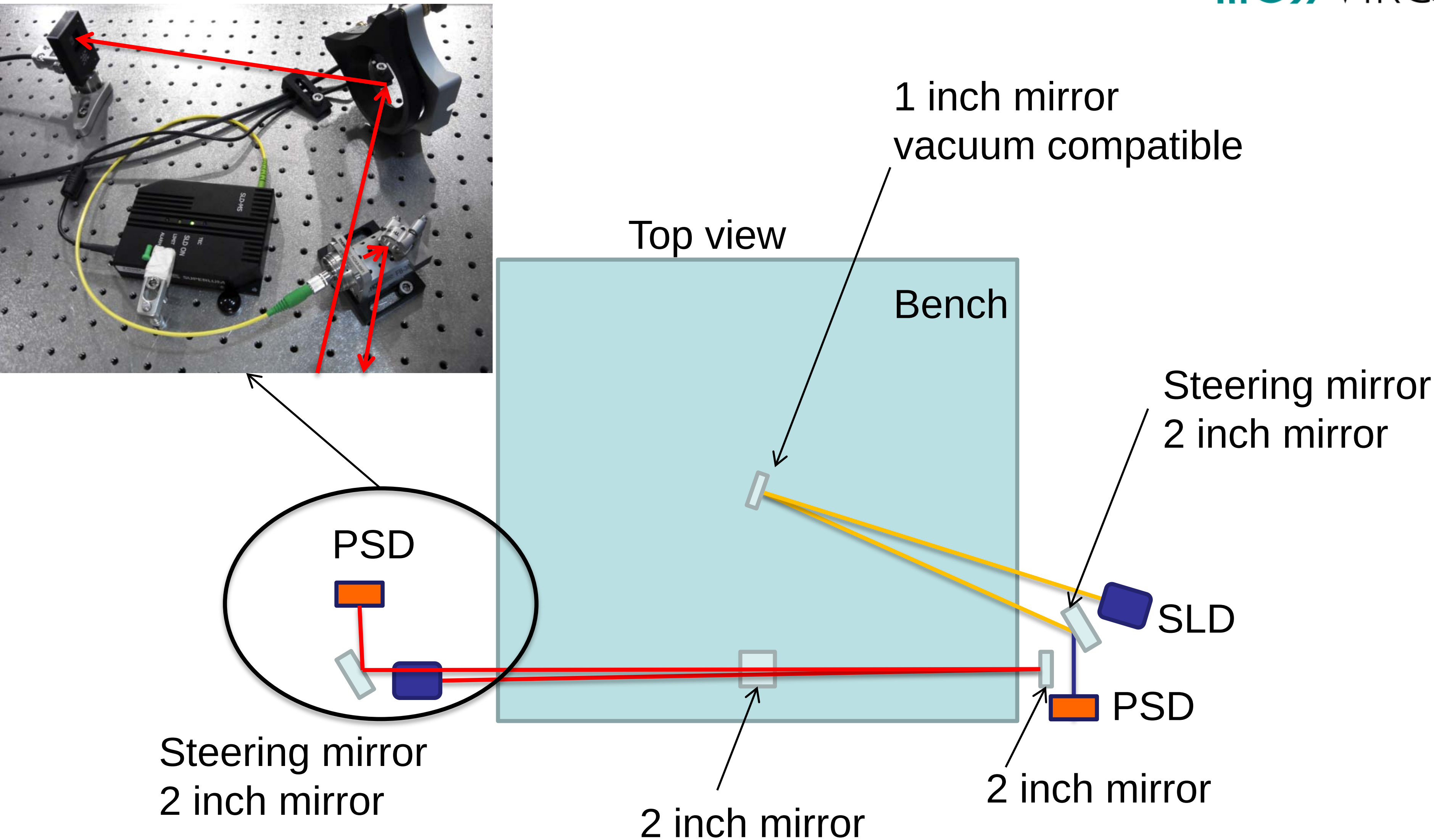


A SLD is shared for two paths by PM fiber

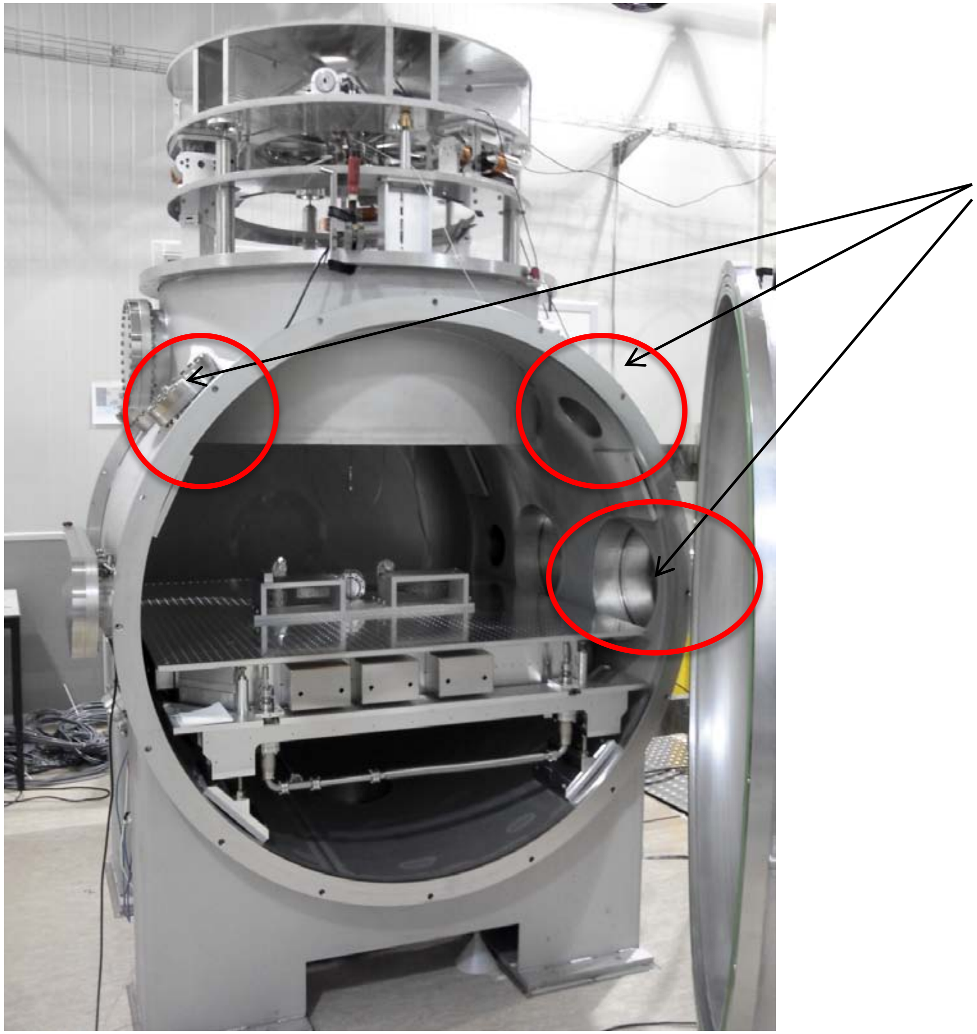


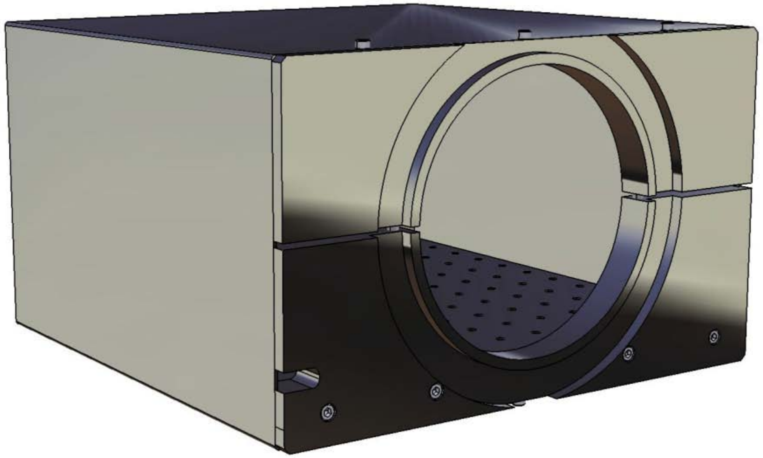
Red: roll and pitch motion
Yellow: Yaw and coupled signal (pitch + roll)

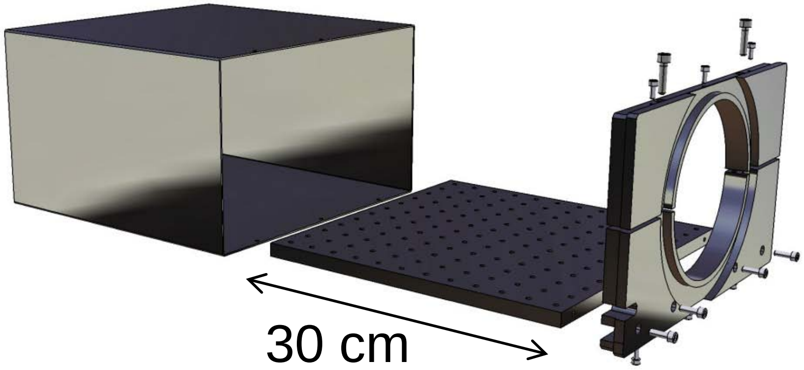
Optical layout



Stage and windshield



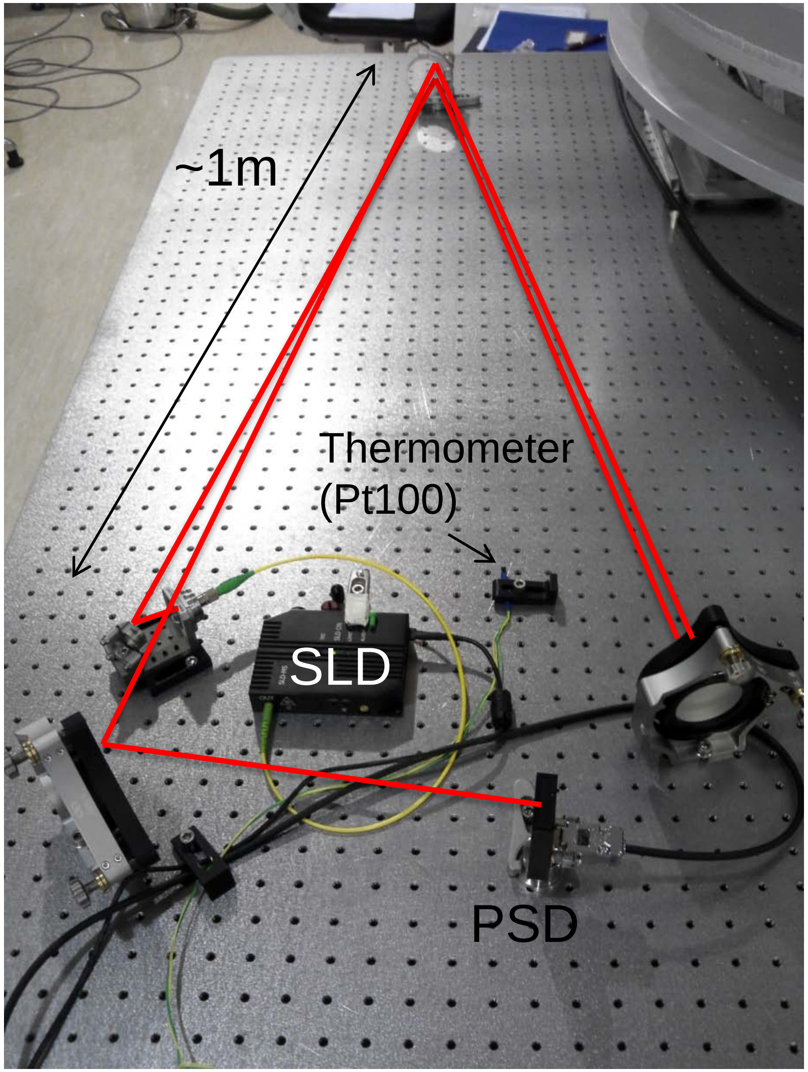


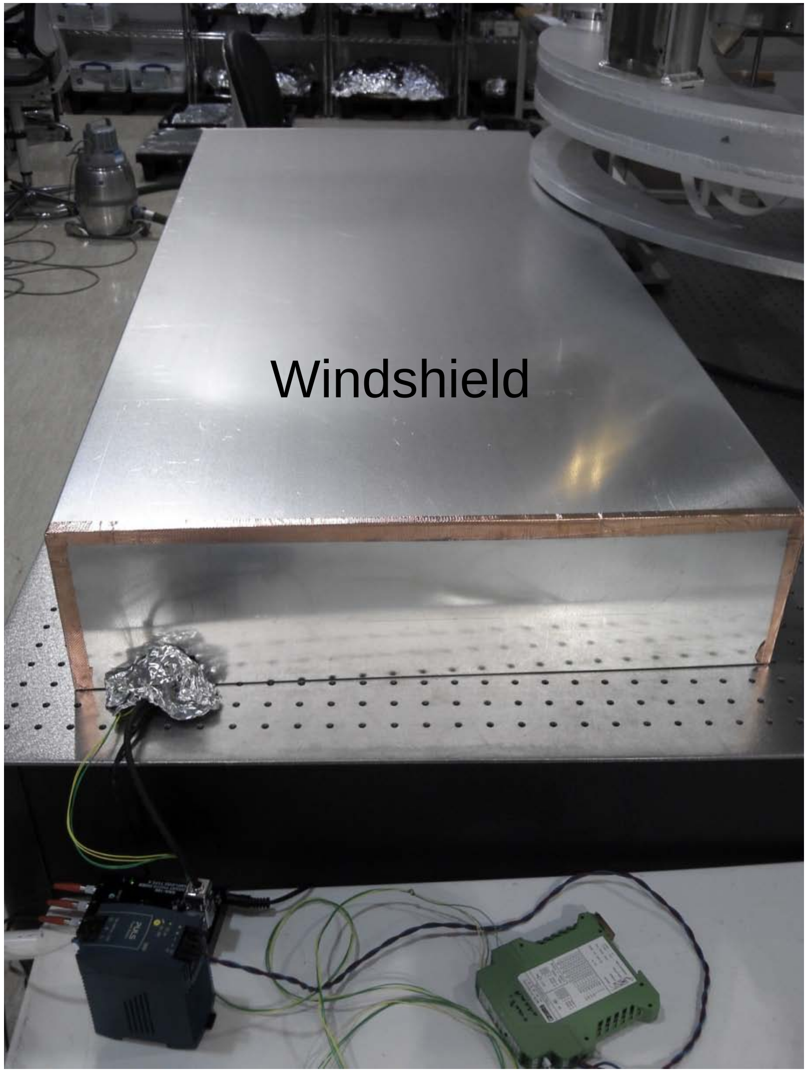


M. Doets

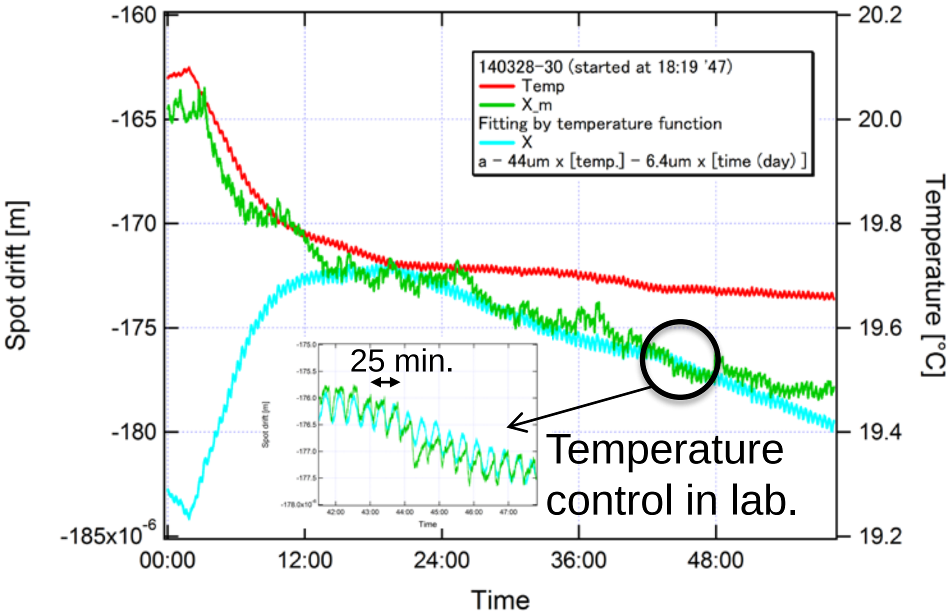
Performance test on optical table

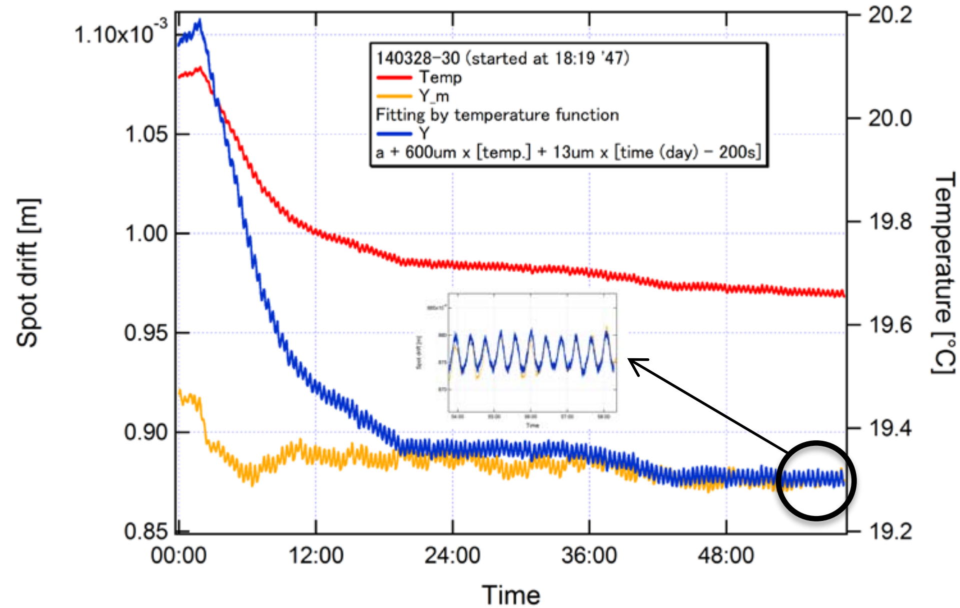
Drift measurement on an optical table





Drift measurement on an optical table





X direction:

β = 44 um/°C, γ = 6.4 um/day

=> 0.7 urad (0.1°C/day in Kamioka)

+ 1 urad(drift) = 1.7 urad/day

(OpLev length of 3m is assumed)

Y direction:

β = 600 um/°C, γ = 13um/day

=> 10 urad (0.1°C/day)

+ 2 urad(drift) = 12 urad/day

(OpLev length of 3m is assumed)

Fitting function: $Y = \alpha + \beta \times T + \gamma \times (x - t)$

T: temperature, β: temperature response

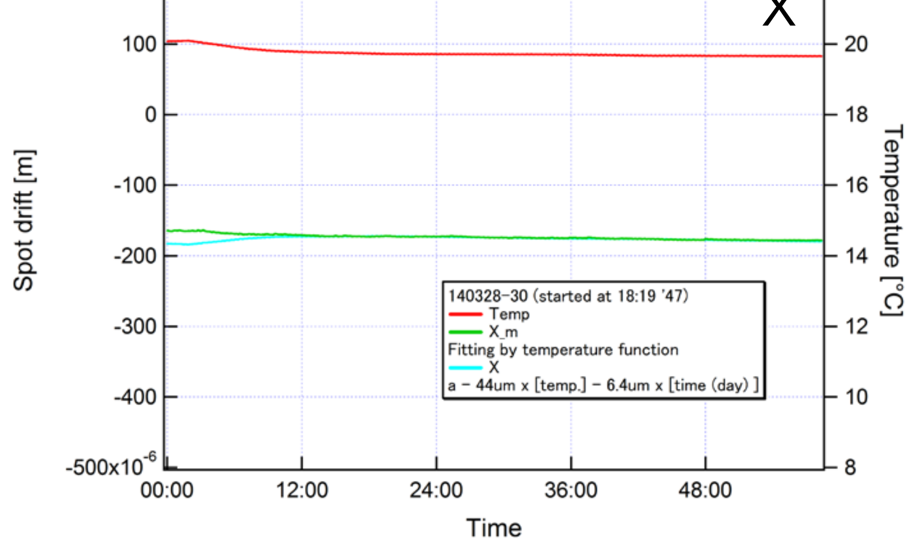
x: time, γ: constant drift

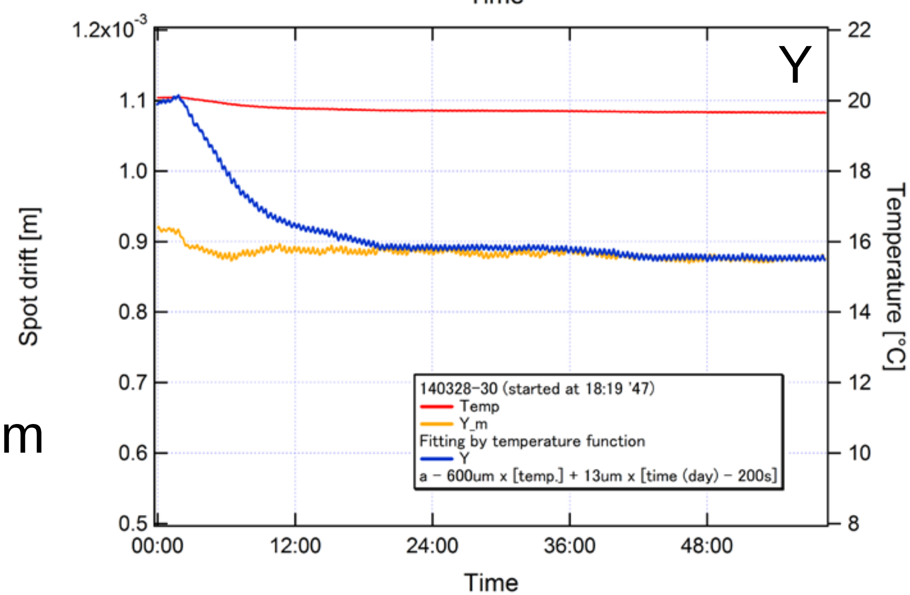
t: time delay

These results almost achieved the requirement of KAGRA (10 urad/day)

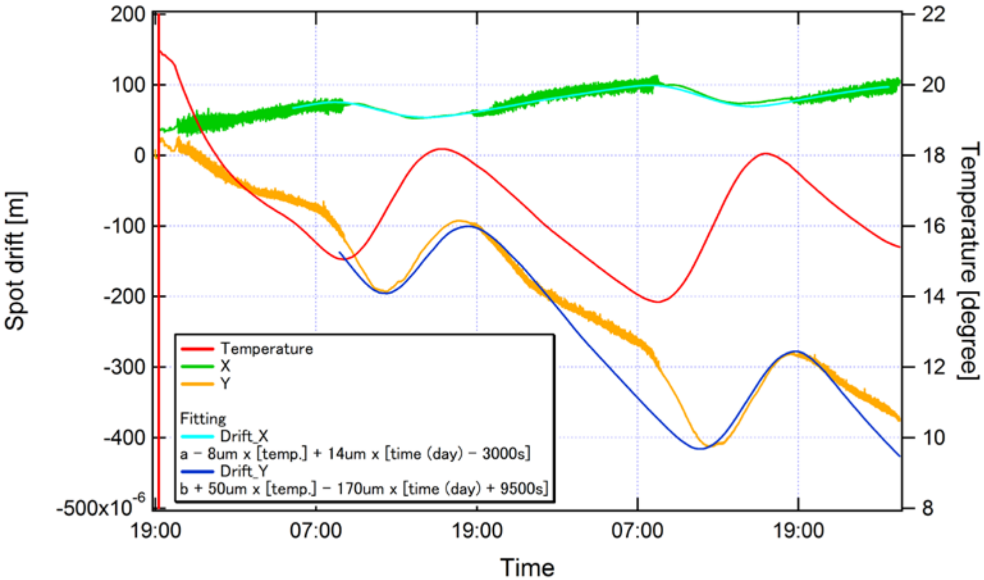
Comparison with NAOJ result

Nikhef





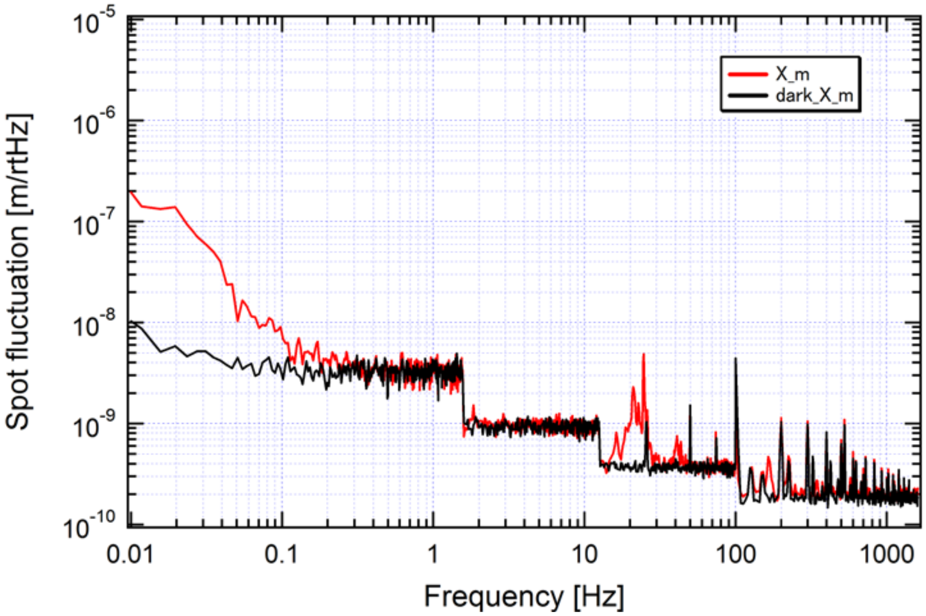
NAOJ (talk at 2nd ELiTES meeting)

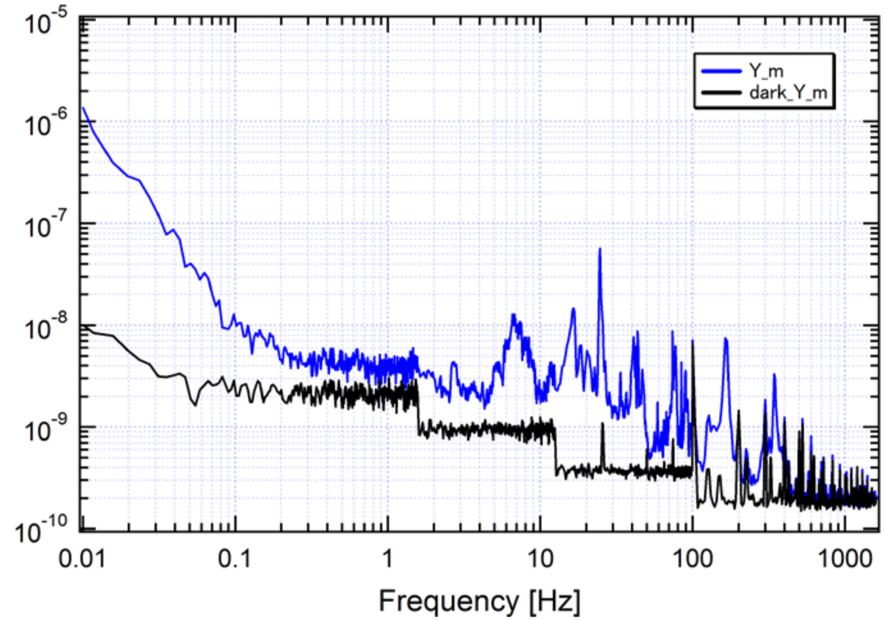


Condition is better than NAOJ

- all mirror use thread-pitch locks
- temperature is stable in the clean room
- heavy optical table
- metal windshield

Spectrum of spot fluctuation



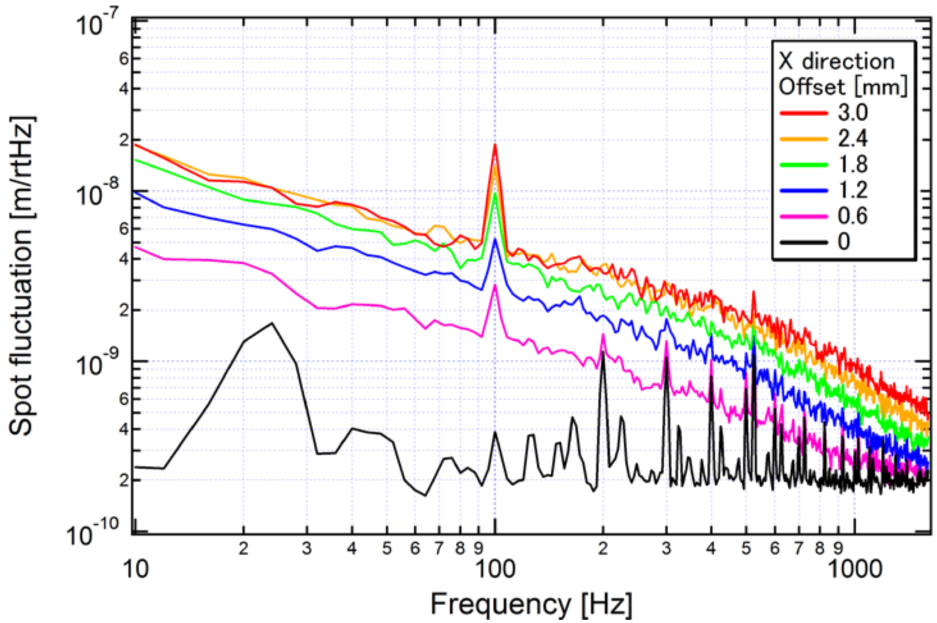


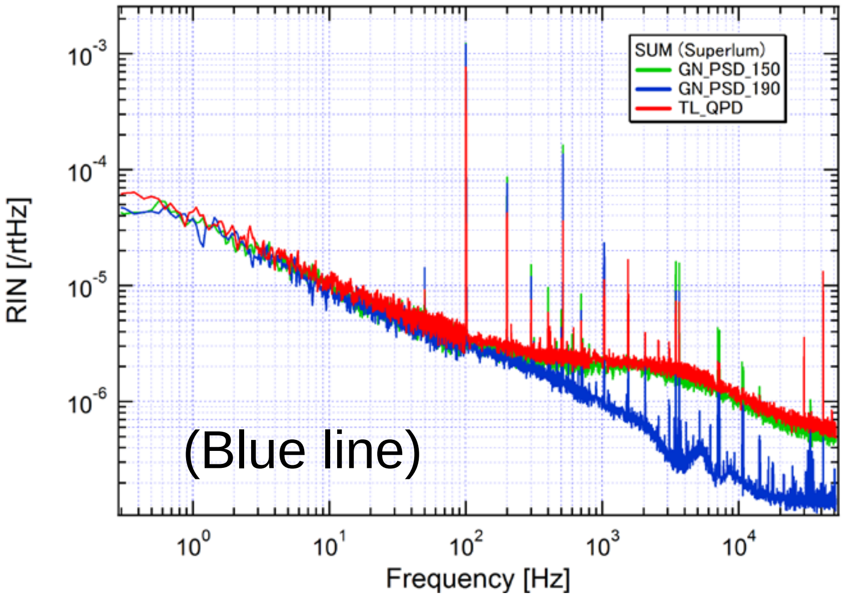
limited by digitization noise
Thermal drift is seen below 0.1 Hz

worse than X direction
=> mechanical vibrations

Optical lever length of 3 m is assumed
=> divided by factor of 6
=> ~ 1 nrad/rtHz at 1 Hz

Intensity noise by offset





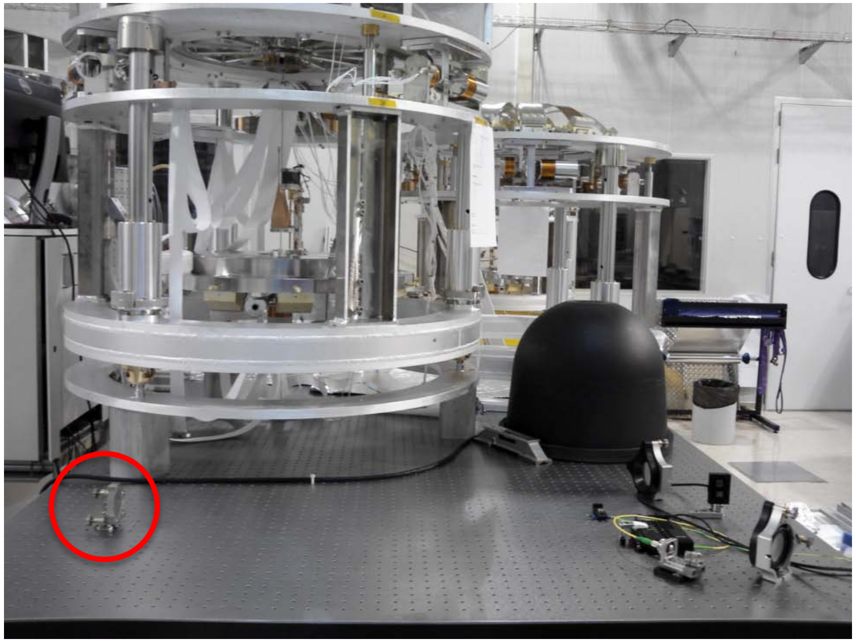
Consistent with RIN measurement within difference factor of 2

(The left response has two times smaller RIN than the right graph shows)

=> an individual difference of SLD

Investigation of large thermal response

The temperature response of Y direction is relatively worse:
(X: β = 44 um/°C, Y: β = 600 um/°C)



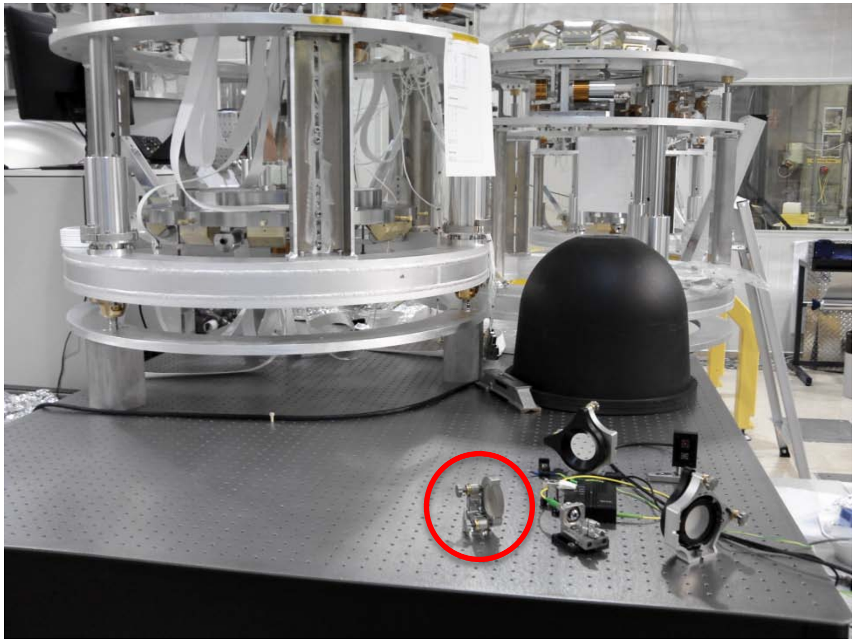
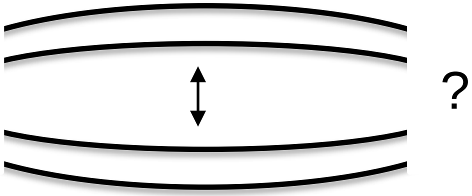
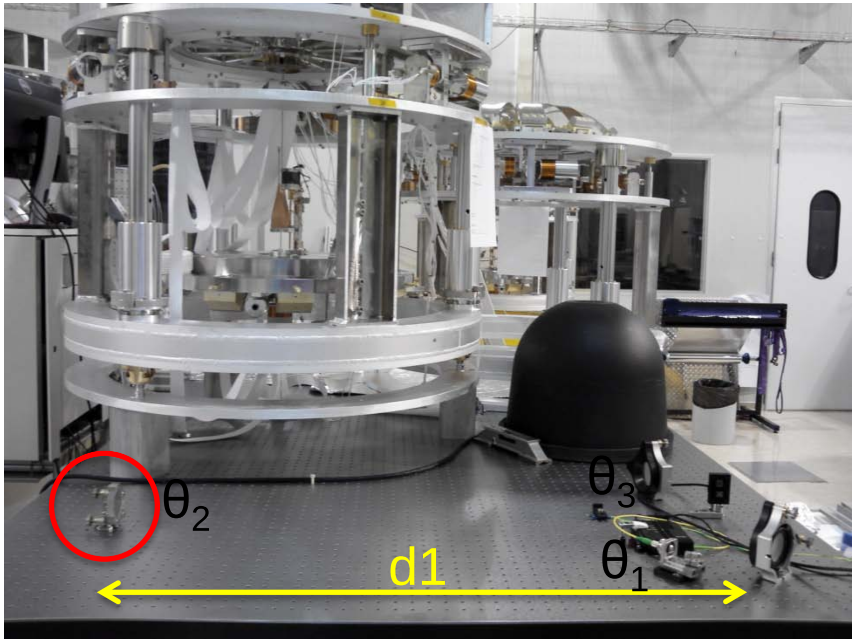


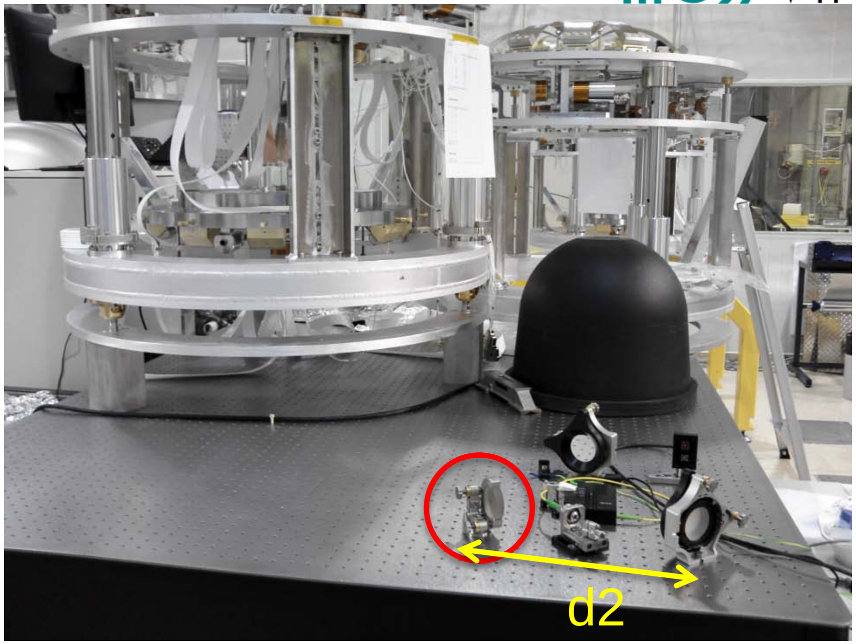
Table bending?



Short length setup
⇒ Scaling factor only?
⇒ Scaling factor + bending?

Investigation of large thermal response





(2.5 + 98) + 104 + 104 + 111 + 29 cm
= (100.5) + 348 cm, d1 = 111 cm
Optical path length: 449 cm
OpLev length: 348 cm
Return mirror OpLev: 244 cm

$L_{spot} = 2x(4.5x\theta_1 + 3.5x\theta_2 + 2.4x\theta_3)$

(2.5 + 12) + 29 + 29 + 27 + 29 cm
= (14.5) + 114 cm, d2 = 29 cm
Optical path length: 129 cm
OpLev length: 114 cm
Return mirror OpLev: 85 cm

$S_{spot} = 2x(1.3x\theta_1 + 1.1x\theta_2 + 0.9x\theta_3)$

L_{spot} / S_{spot} = ~3: Scaling factor ($\theta_1 = \theta_2 = \theta_3$)

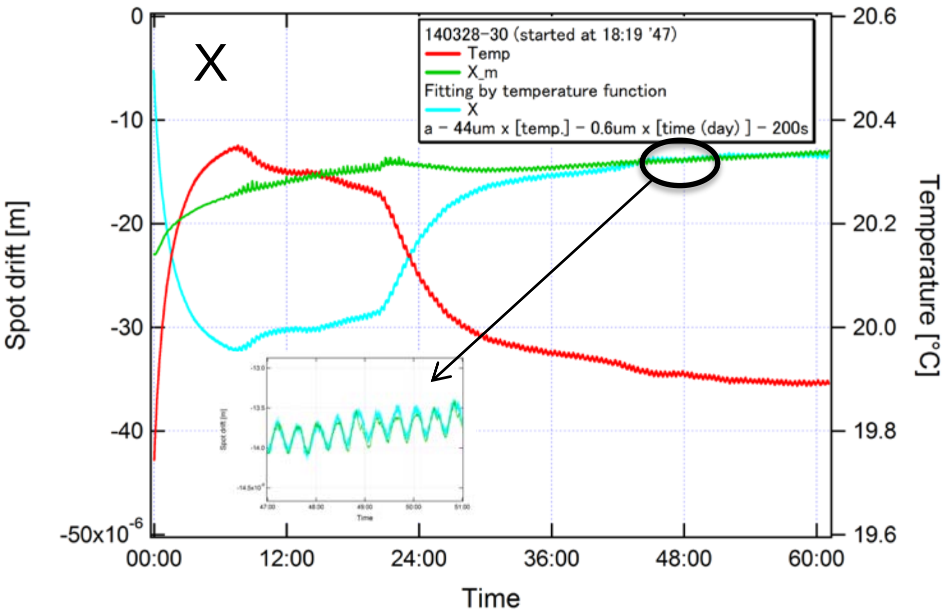
d1/d2 = 3.8 : Table deformation factor

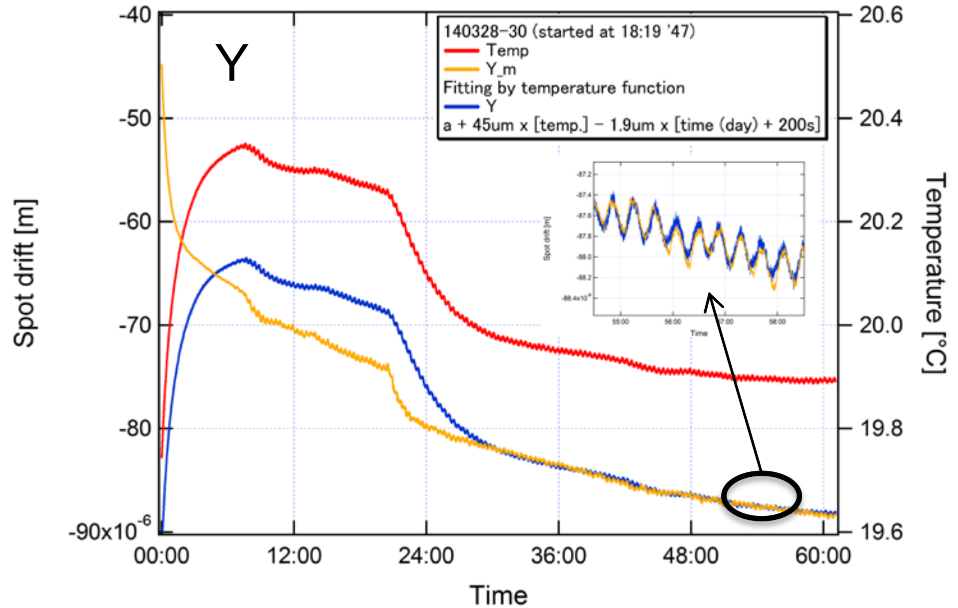
Which is the real factor?

3 (dominated by local mirrors) or

3x3.8=11 (dominated by table deformation)

Short length measurement





Short: β = 44 um/°C, γ = 0.6 um/day

x1 x10

Long: β = 44 um/°C, γ = 6.4 um/day

X temp: Translational motion of SLD or PSD

X drift: Table bending dominant

Short: β = 45 um/°C, γ = 1.9 um/day

x13 x7

Long: β = 600 um/°C, γ = 13 um/day

Y temp: Table bending dominant

Y drift: Table bending dominant (almost)

Fitting function: $Y = \alpha + \beta \times T + \gamma \times (x - t)$

T: temperature, β: temperature response

x: time, γ: constant drift

t: time delay

Expected drift

(scaling factor: x3 for 3m length, 0.1 °C/day)

X: β = 44 um/°C, γ = 2 um/day => ~1 urad/day

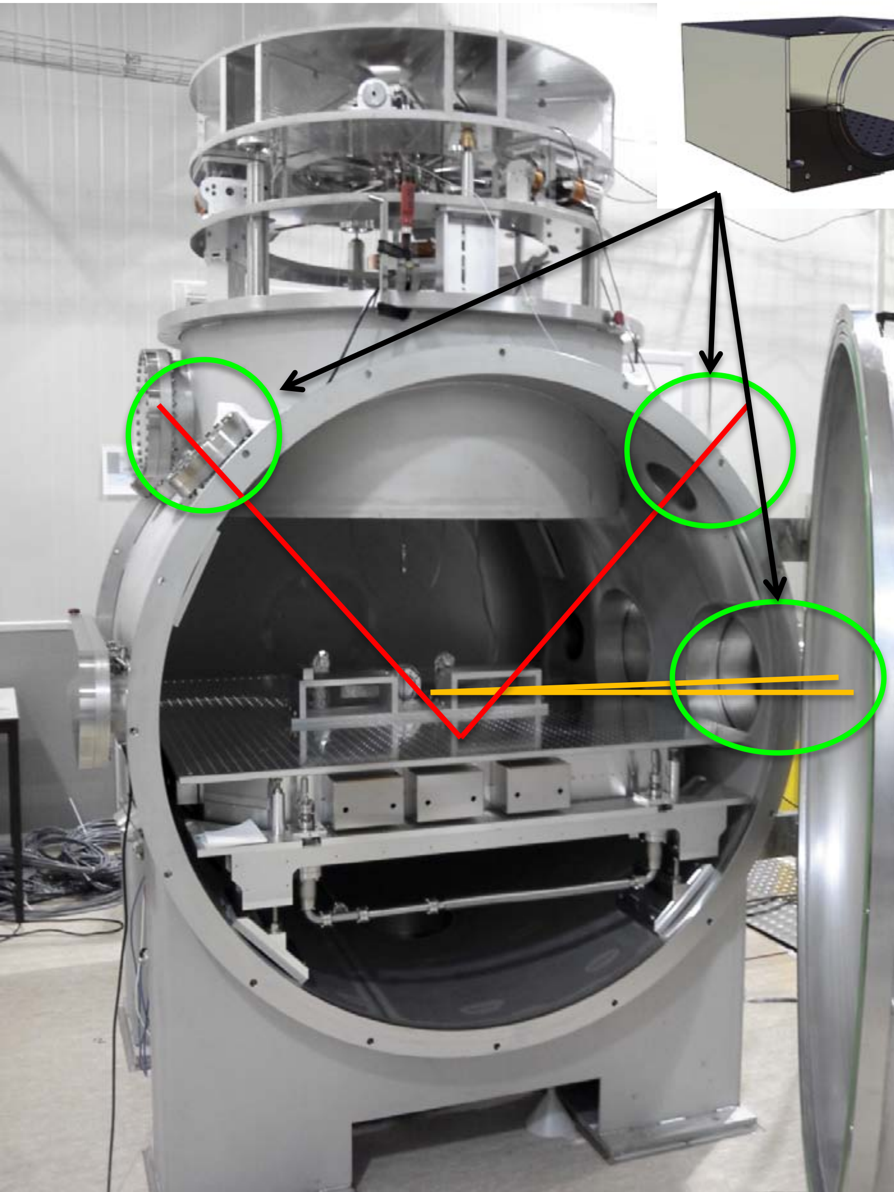
Y: β = 150 um/°C, γ = 6 um/day => ~3 urad/day

Brief summary

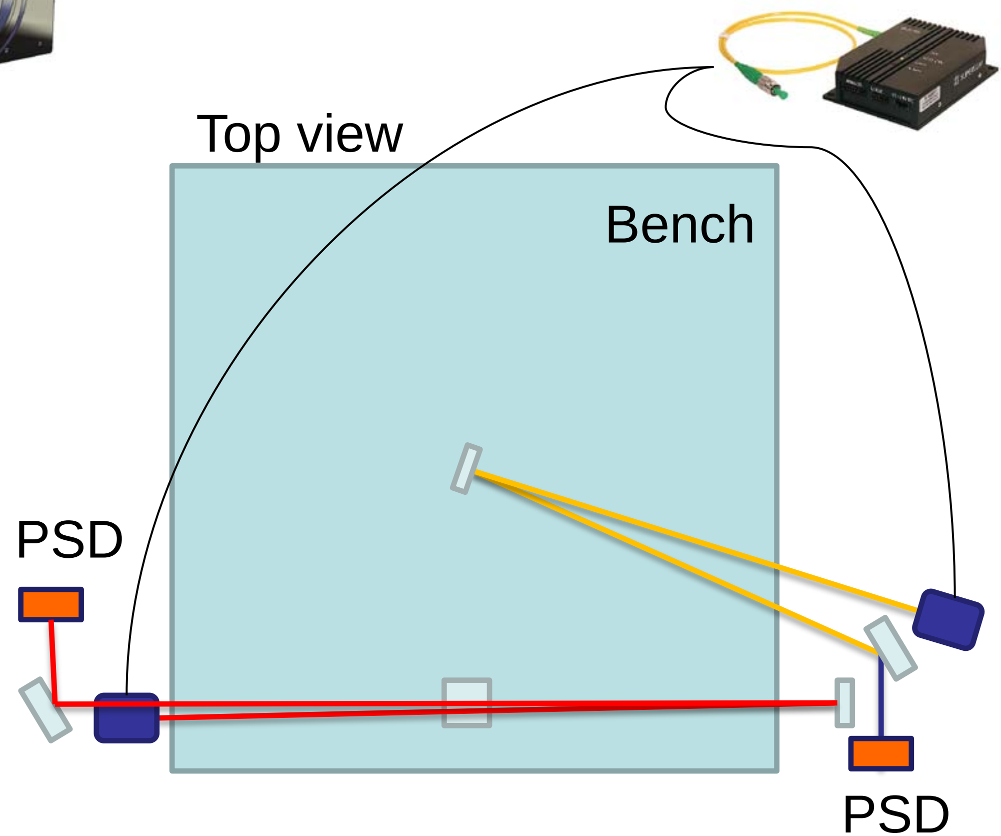
- Performance test was performed on an optical table
- There are two scales for temperature response
  - Large temperature change causes small response (first 12-24 hours)
  - Small temperature change causes large response (that change is made by temperature control in the clean room: 25 min. cycle)
- Noise spectrums show good performance of 1 nrad/rtHz at 1Hz
- Intensity noise due to offset is consistent with the previous RIN measurement within difference factor of 2
- Table deformation causes dominant drift for 3m-length setup
- Expected total drift (from the short length experiment, 3m length by scaling factor, 0.1 °C/day)
  - X: β = 44 um/°C, γ = 2 um/day => ~1 urad/day
  - Y: β = 150 um/°C, γ = 6 um/day => ~3 urad/day

This setup has a performance to meet KAGRA requirement (10 urad/day)

Optical layout



A SLD is shared for two OpLevs



Red: roll and pitch motion
Yellow: Yaw and coupled signal (pitch + roll)