Cryogenic system for KAGRA

- Status and results of performance test of a cryogenic duct shield -

ICRR, Univ. of Tokyo, KEK[A], JECC TORISHA[B], NAOJ[C]

Yusuke SAKAKIBARA,
Nobuhiro KIMURA[A], Masaki TANAKA[B], Tatsuya KUME[A],
Shigeaki KOIKE[A], Tomotada AKUTSU[C], Takayuki TOMARU[A],
Toshikazu SUZUKI[A], Kazuhiro YAMAMOTO, Kazuaki KURODA

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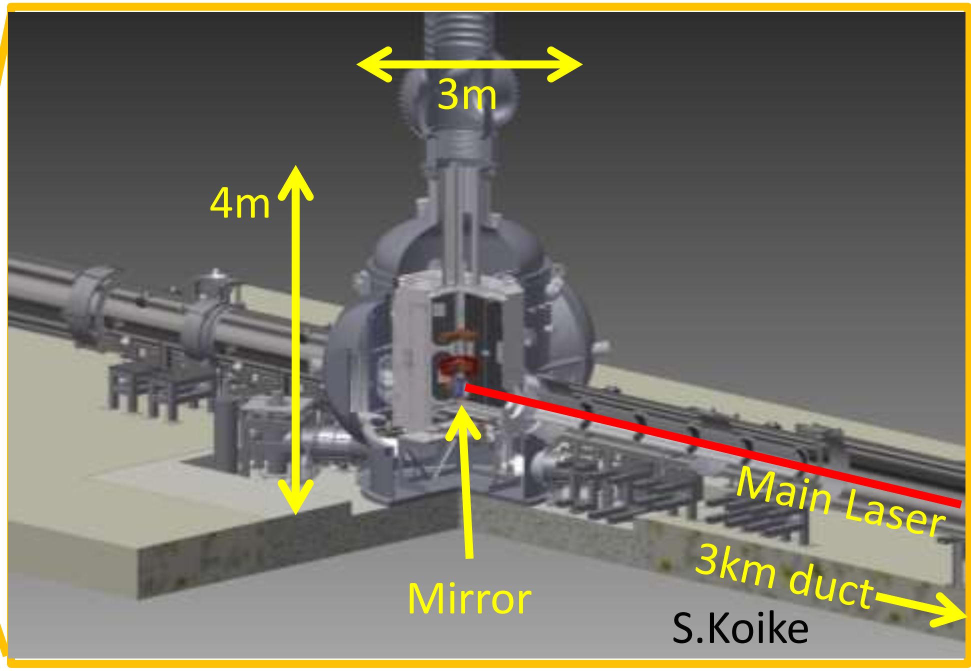
    - Calculation
    - Measurement (in Jecc Torisha)
- Future work

KAGRA (Large-scale Cryogenic Gravitational wave Telescope)

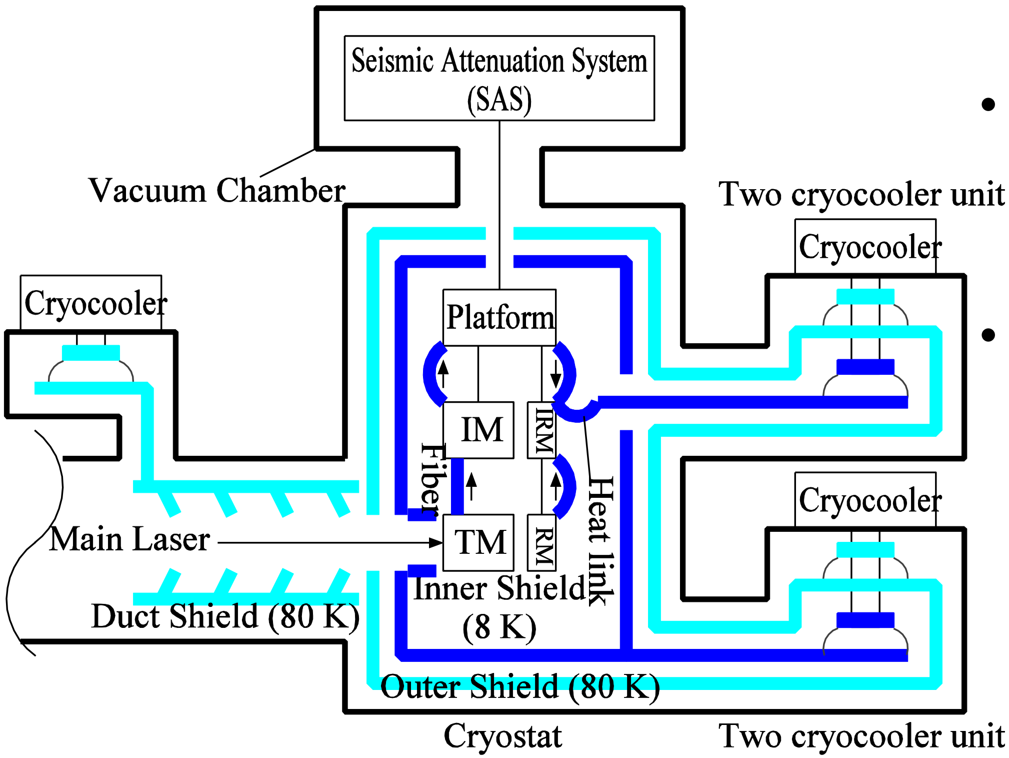
http://www.gw.hep.osaka-cu.ac.jp/openworks/whatisgw.html



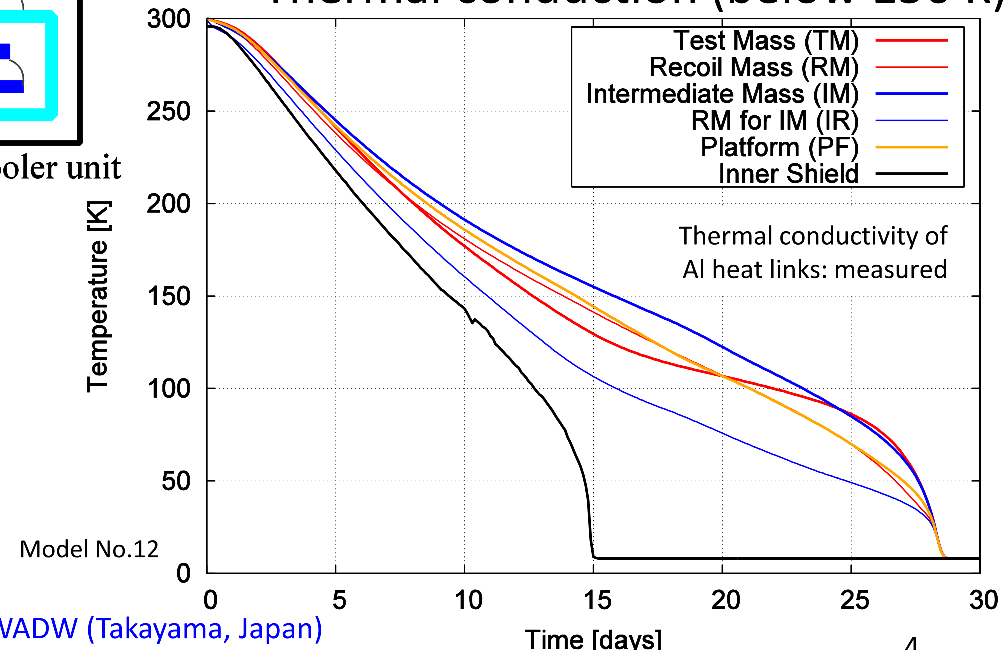
- Interferometer with 3 km arms
- Features
  - Kamioka underground with small seismic motion
  - Mirrors (~20 kg) are cooled down to 20 K
    - Reduce thermal noise

KAGRA cooling system

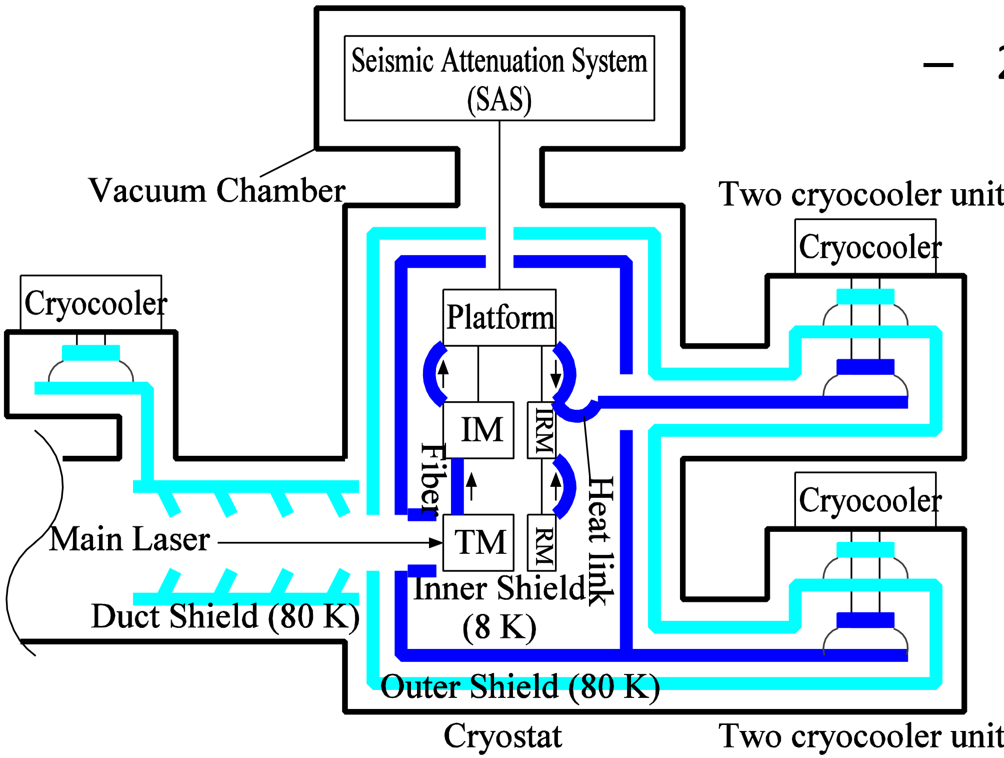
- Test masses is surrounded by double radiation shields
- Four cryocoolers per one mirror
  - Two cool inner shield (~400 kg)
  - Two cool bar to masses (~300 kg)
- Payloads including mirror (TM: Test Mass) is cooled by
  - Thermal Radiation (above 150 K)
  - Thermal conduction (below 150 K)



4m



KAGRA cooling system

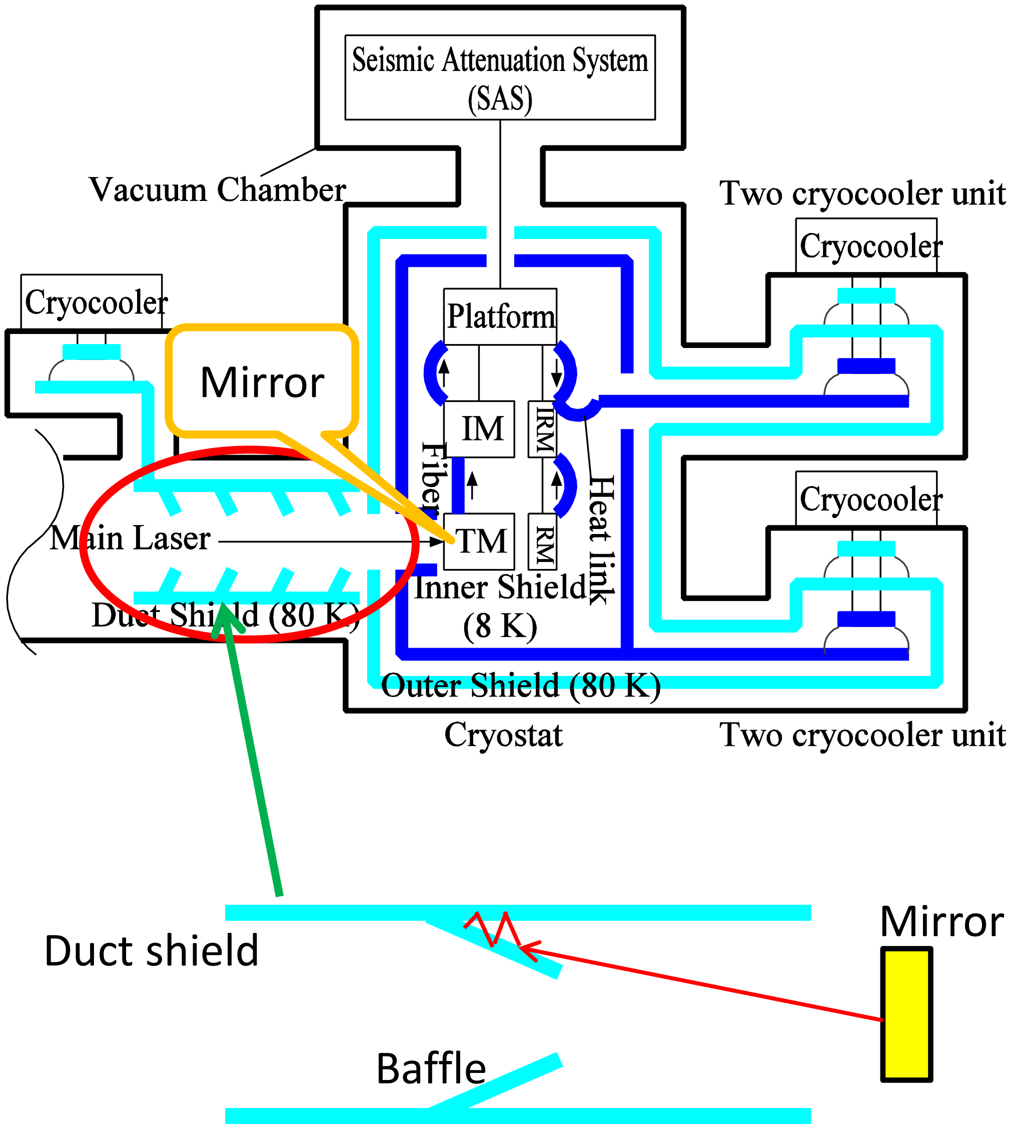


- Heat load[W]
  - 2nd stages
    - » Payload 1.3
      - Main Laser 1.0
      - Electric Cables 0.3
    - » Inner shield ~15
      - Scattered light ~10
      - View ports 0.4
      - Radiation from outer shield 2.2
      - Support from outer shield 2.4
      - Radiation through duct shield 0.4
  - 1st stages
    - » Outer shield 116
      - Eleven view ports 22
      - Radiation from chamber 70
      - Support from chamber 24

Cryocoolers
Pulse tube, 60Hz
0.9 W at 4K (2nd)
36 W at 50K (1st)

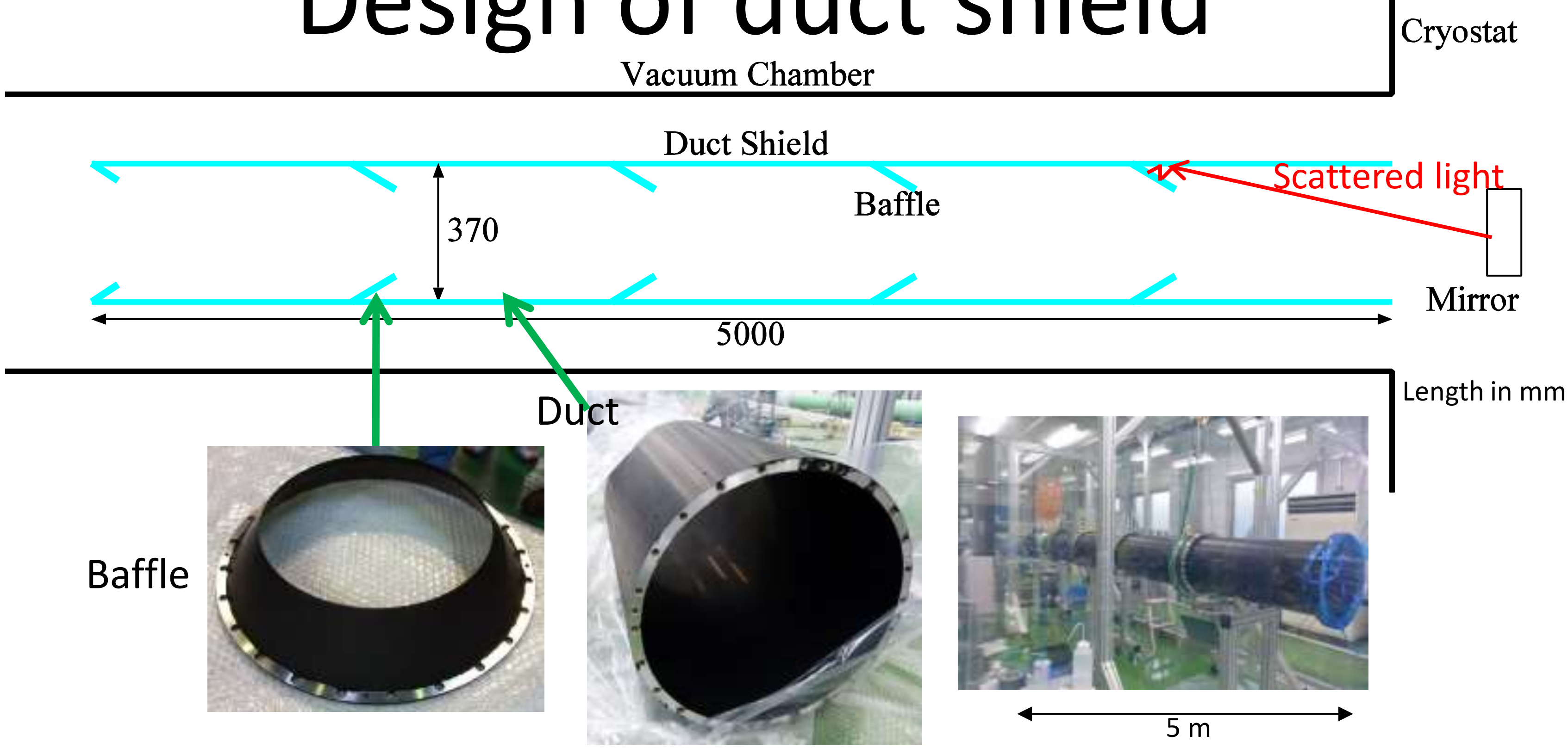
4m

Purpose of duct shields



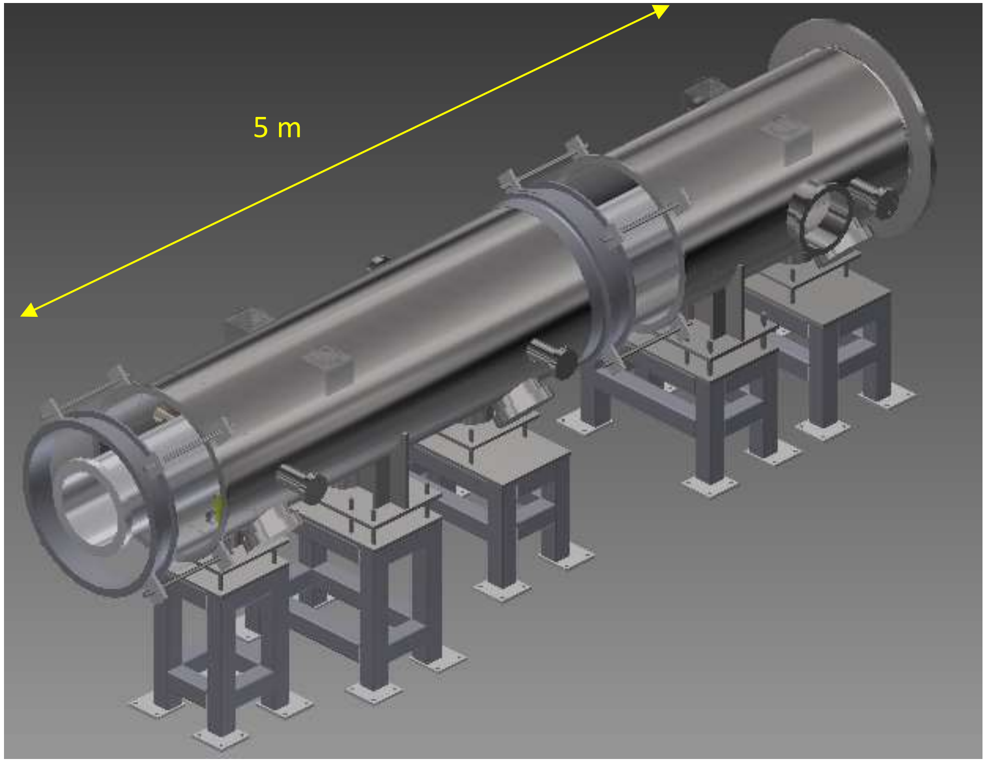
- Only suspension system is cooled down (3 km duct and SAS: 300 K)
- Mirror must be surrounded by radiation shields
- Holes for main laser are necessary
- Duct shields
  - To reduce thermal radiation
    - Duct to decrease solid angle to 300 K region
    - Duct reflects radiation
    - Baffles can reduce thermal radiation through duct shield
  - To cause no scattered light noise
    - Small vibration with rigid supports

Design of duct shield

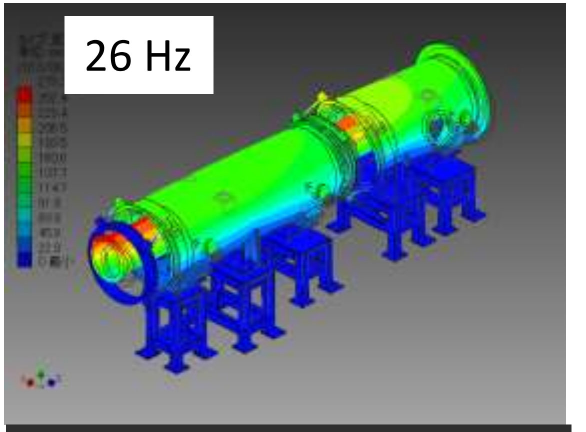


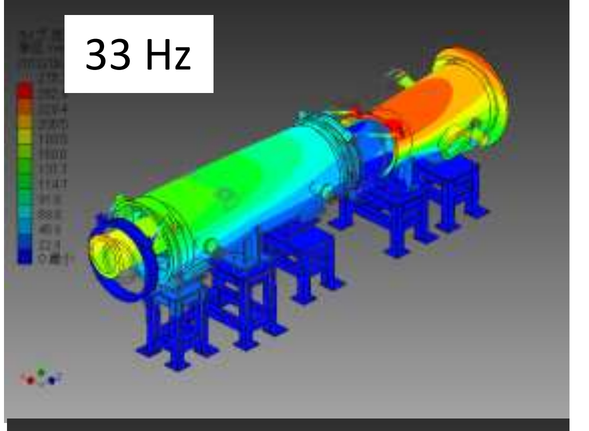
- Baffles are designed to satisfy KAGRA requirement of thermal radiation and scattered light
- Duct and baffles are coated with black coating Solblack to absorb thermal radiation and scattered light
- Baffles are tilted to catch scattered light
- Cooled down by one cryocooler

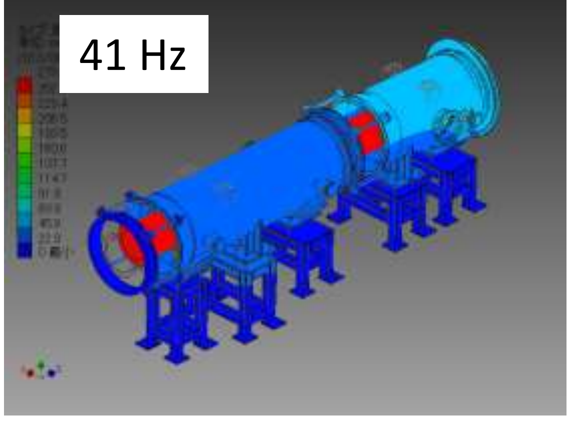
Design of duct shield



S. Koike



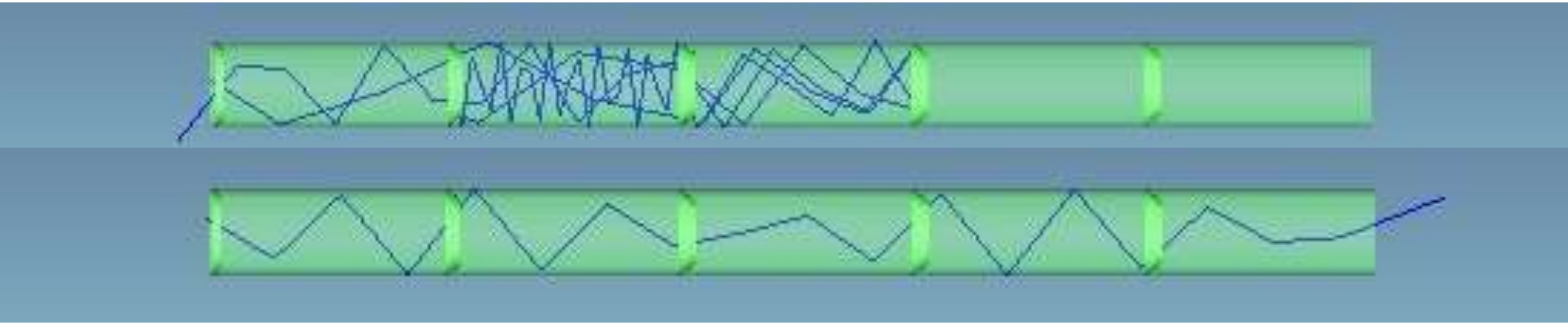




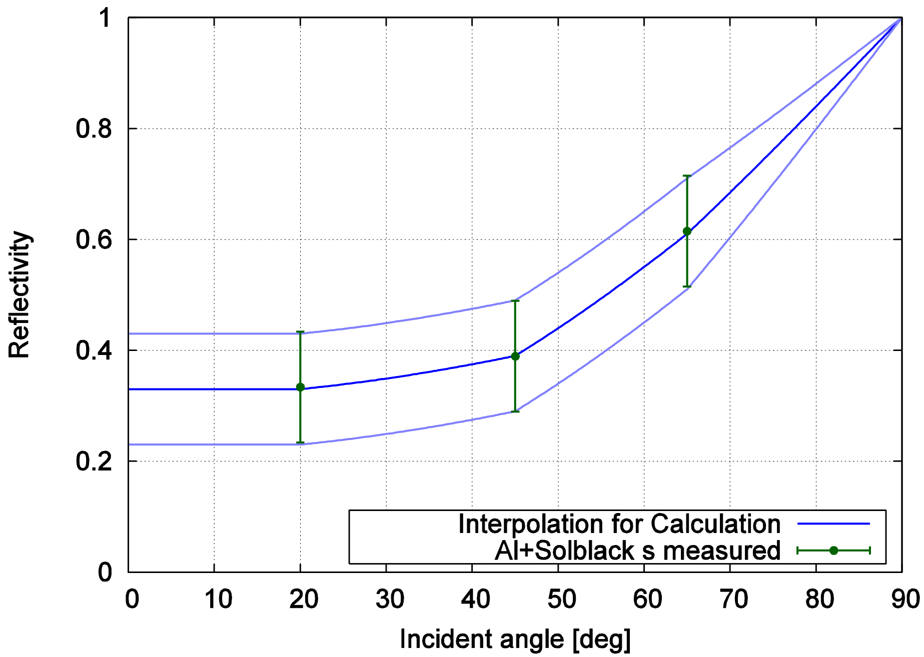
- Vacuum duct and duct shield was supported rigidly to the ground to reduce vibration

Thermal radiation

Calculation of thermal radiation



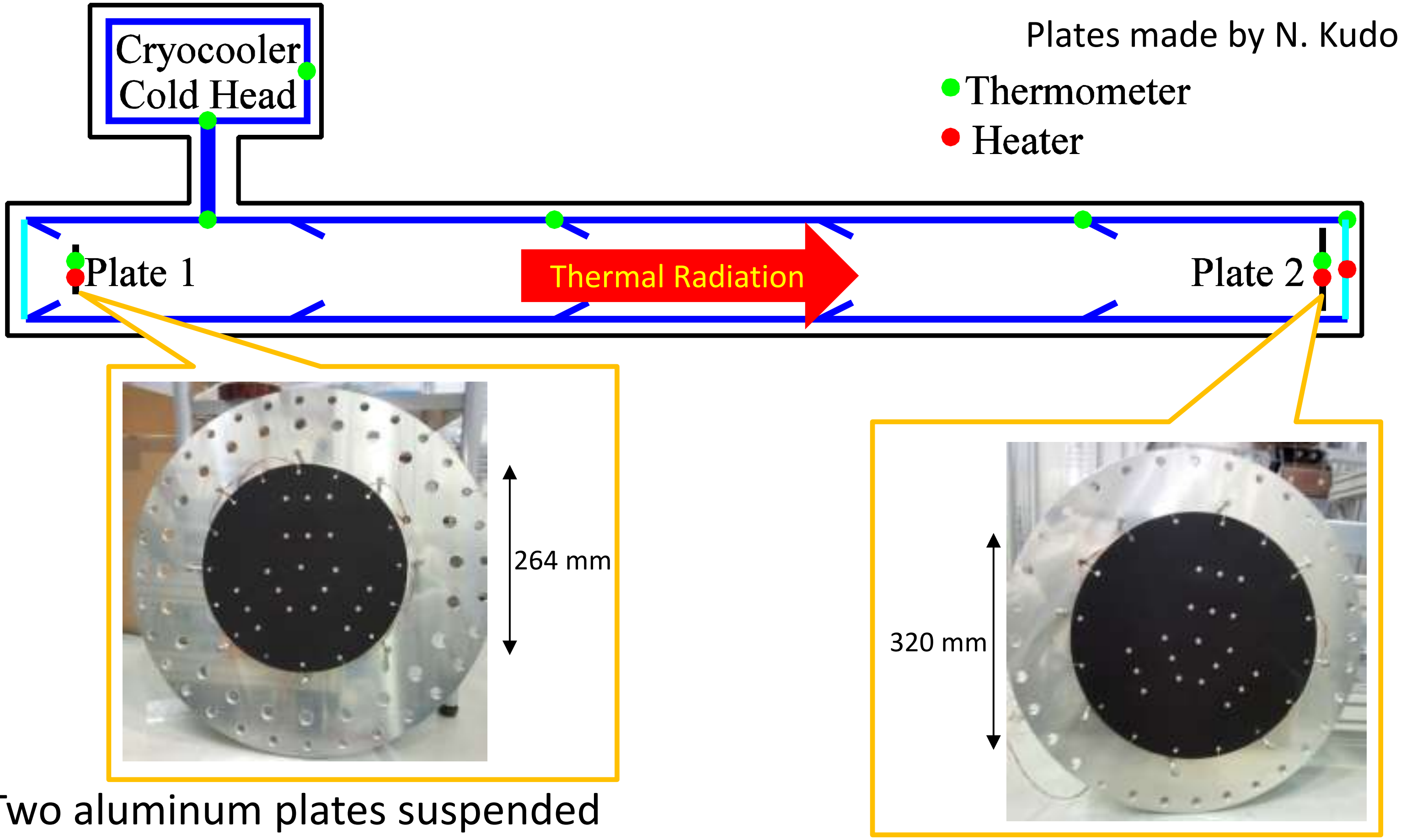
Reflectivity (Al + Solblack) used for calculation



- Rays are reflected by duct shield many times -> power of rays is reduced
- Radiation was calculated by commercial ray-tracing software ZEMAX
  - Rays of thermal radiation were emitted with random direction
  - When ray hits duct shield, power of ray is multiplied by reflectivity

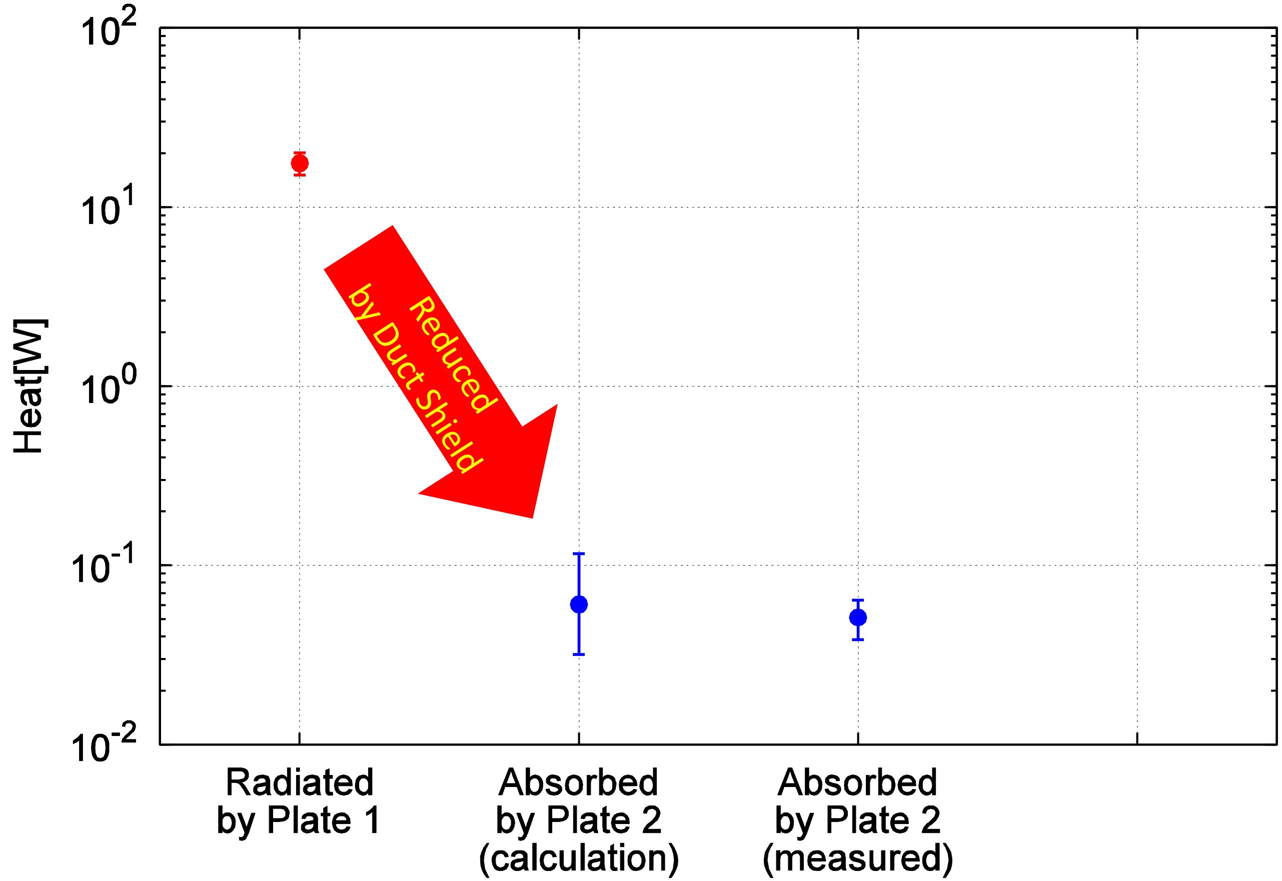
Measurement of thermal radiation

Plates made by N. Kudoh (KEK)



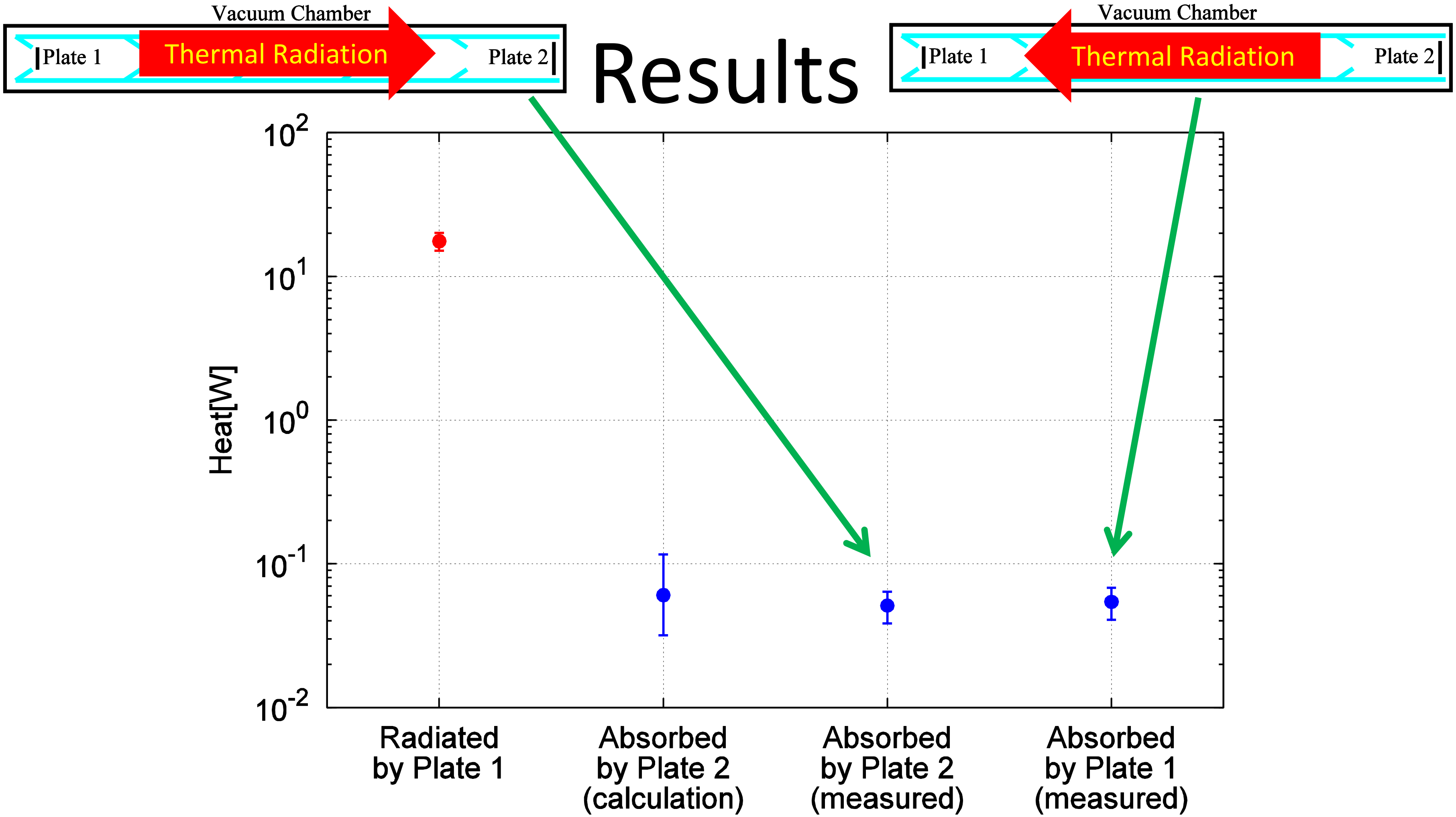
- Two aluminum plates suspended
  - Coated with Solblack to enhance emissivity or absorptivity
  - Plate 1 is heated up to 300 K and emits thermal radiation
  - Plate 2 absorbs radiation and is heated up
  - Calibration is conducted using heater on plate 2

Results



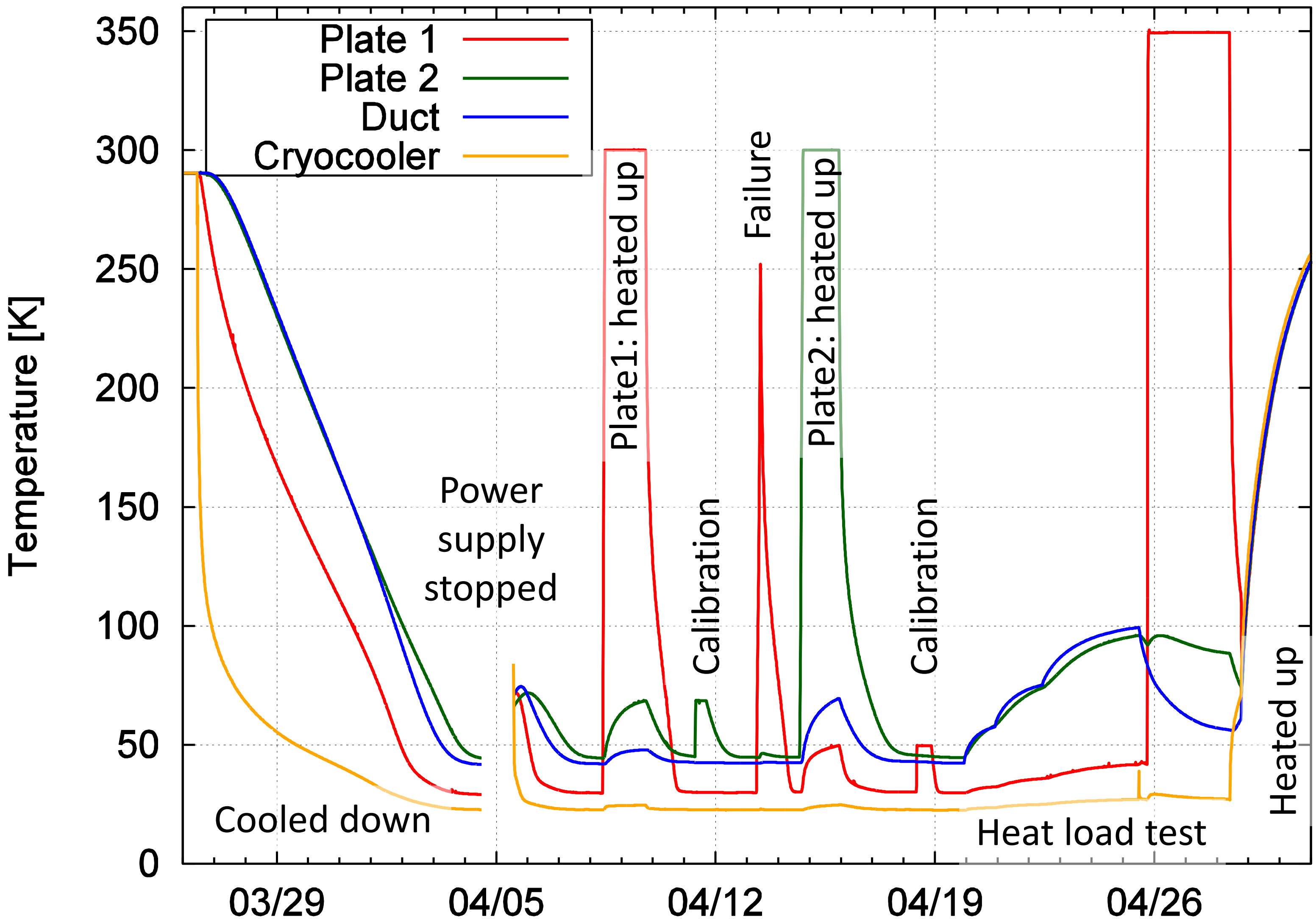
- Calculation predicts only order of magnitude of heat input
  - Measured reflectivity at 10 um of shield has error
  - Rays are reflected by shield many times
- Mirror will absorb 10 mW (It satisfies KAGRA requirement: 1 W including laser absorption)

Results



- Experiment where PLATE 2 is heated up to 300 K and PLATE 1 absorbs radiation was conducted
- Heat transfer of left and right direction should be equal
  - Otherwise, even if two plates have same temperature, heat will be transferred

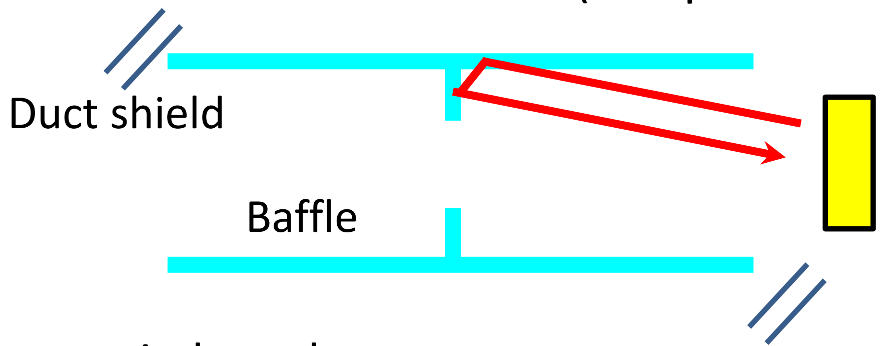
Temperature log



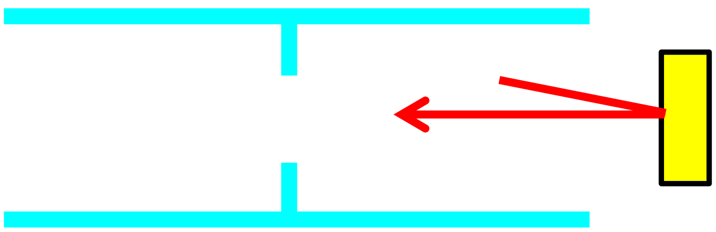
Scattered light

Scattered light noise

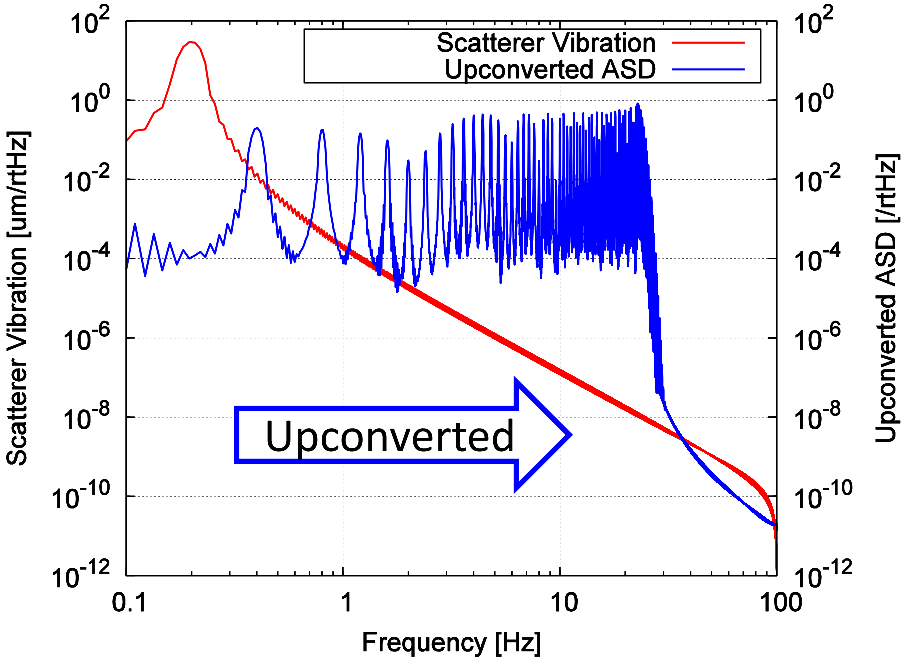
- Some of main laser beam
  - Scattered by mirror
  - Reflected by duct shield with vibration (comparable to seismic motion)



  - Recombined to main laser beam



Calculation of scattered light noise



- How much laser light recombine main laser beam
  - Rays were traced using ZEMAX
  - Rays were emitted with BRDF (angular distribution of scattered light) of mirror
- Upconversion of vibration of duct shield
  - It is necessary to include higher order terms about vibration amplitude
  - E.g. micro seismic peak at ~0.2 Hz can be upconverted to observation frequency band

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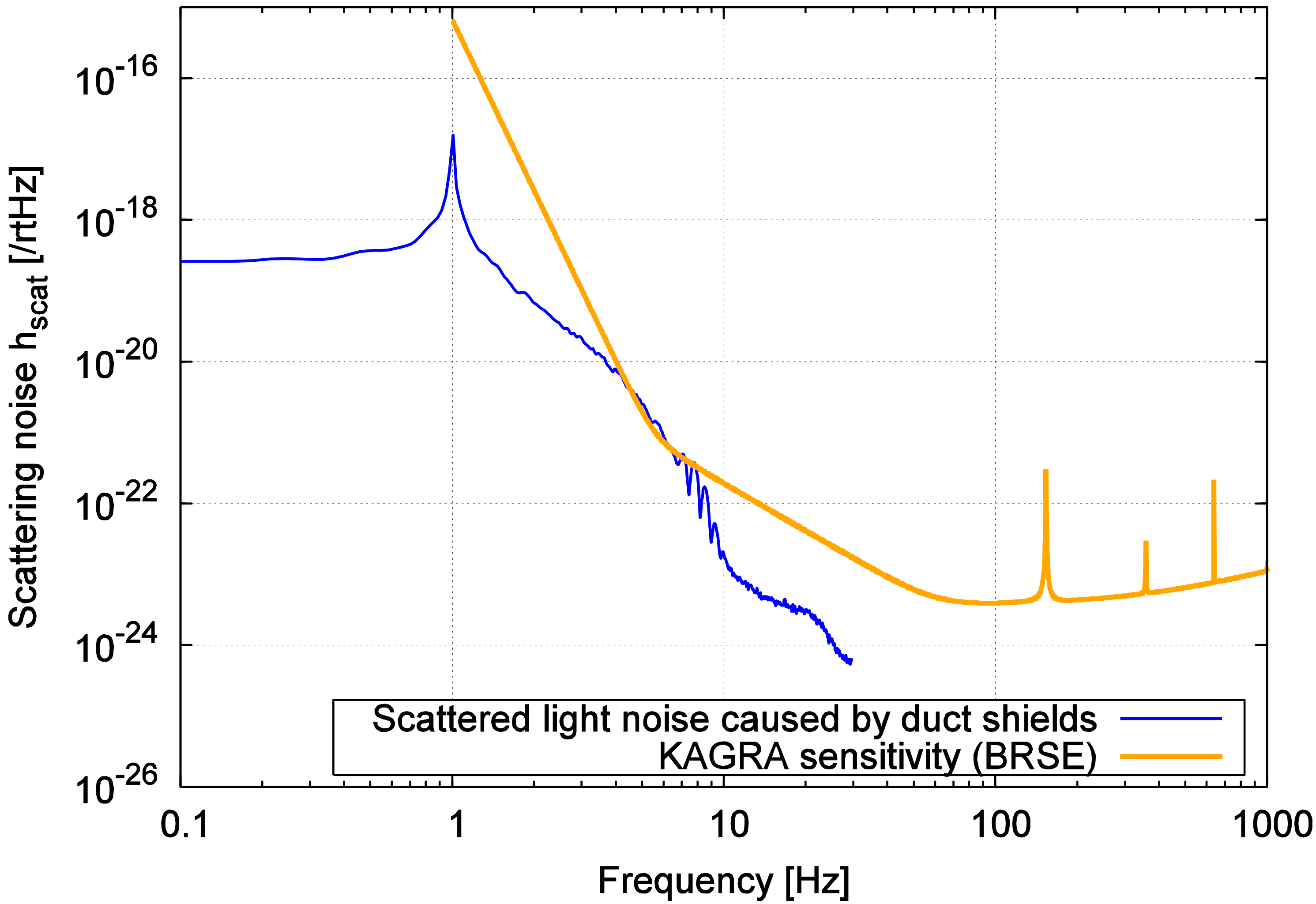
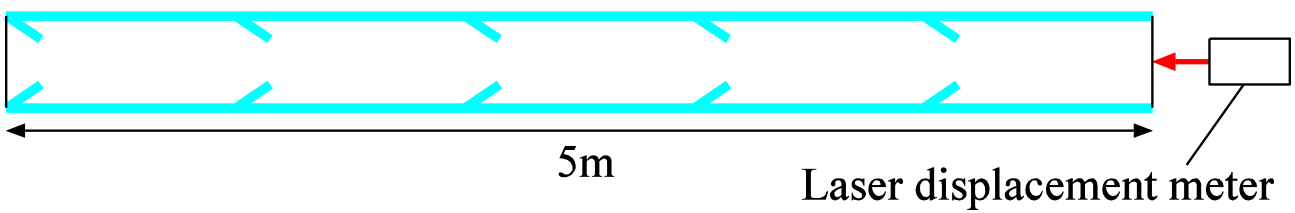
Calculated scattered light noise

- Seismic motion of Kamioka is assumed as vibration of duct shield
- One order of magnitude smaller in main frequency band (>10 Hz)

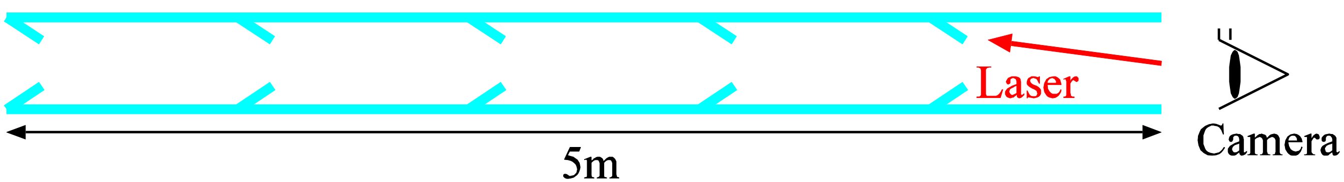


Measurement for scattered light

- It is difficult to measure scattered light noise without KAGRA interferometer
- What we can do now
  - Mechanical resonance frequency measurement
  - Vibration measurement (future work)

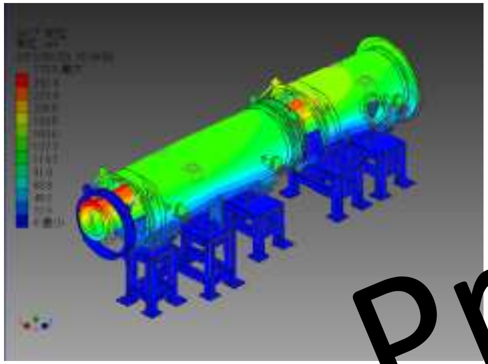


  - Taking photographs of scattering of red laser



Mechanical resonance frequency of duct shield

- Calculation



- Measurement

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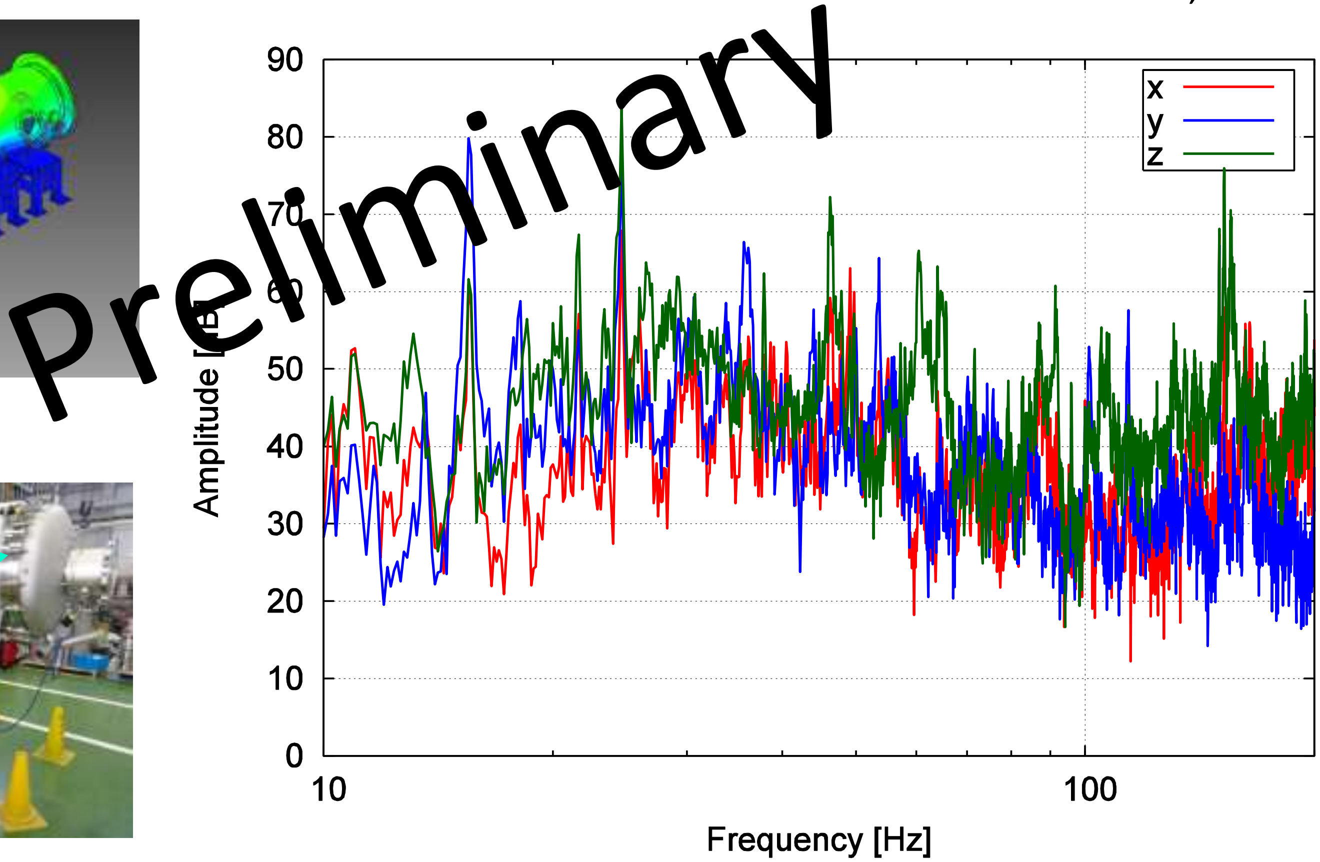
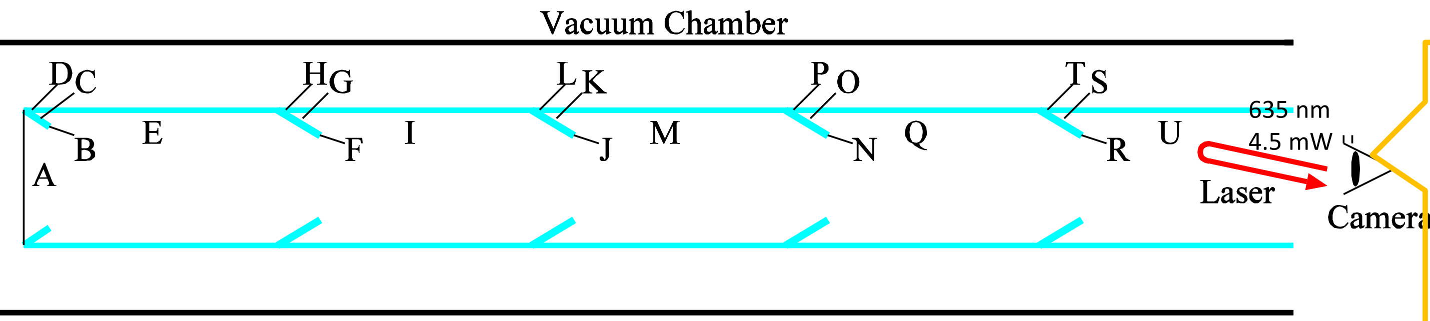
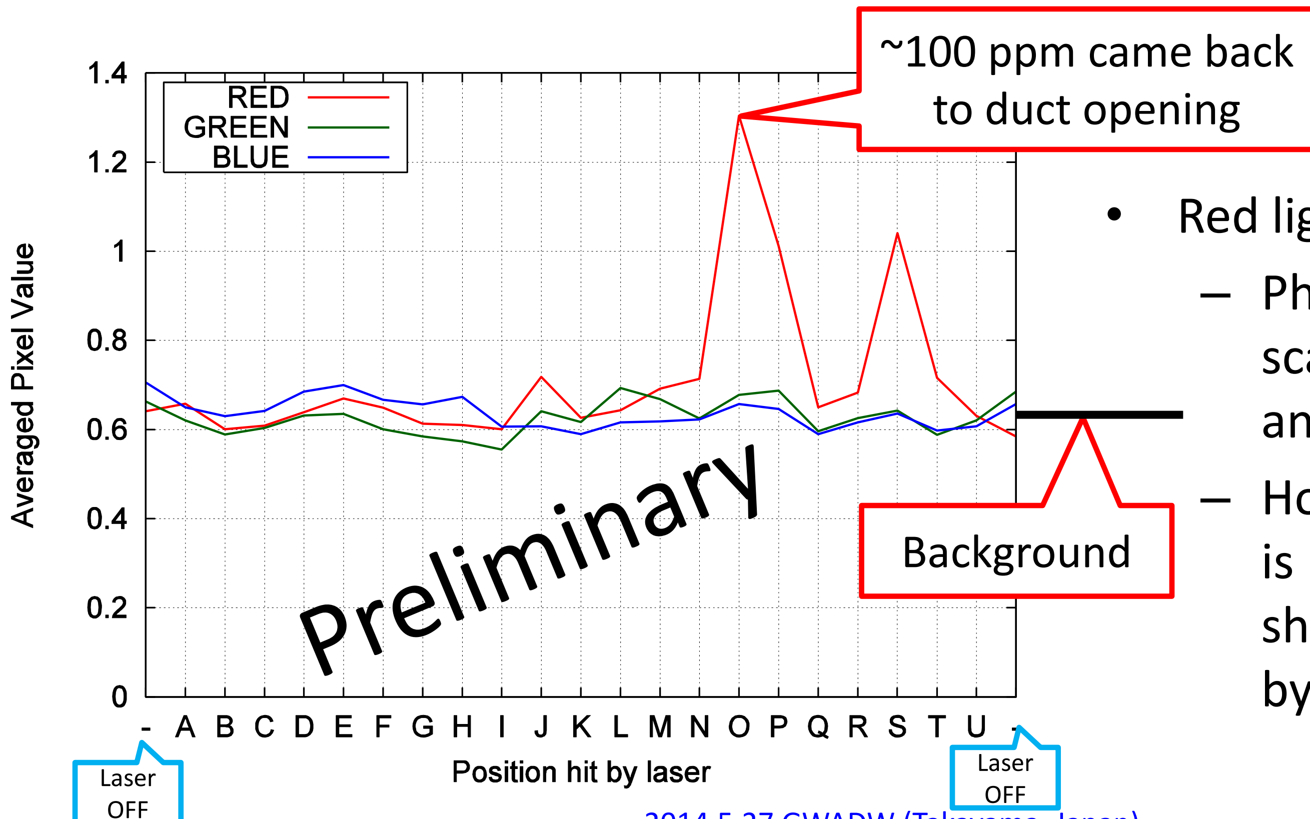


Photographs of scattering of red laser



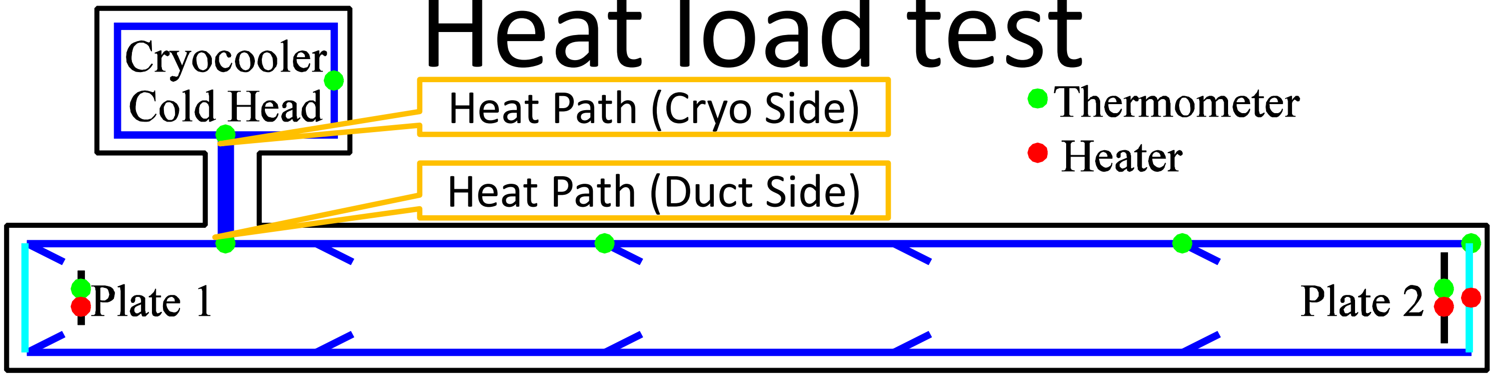


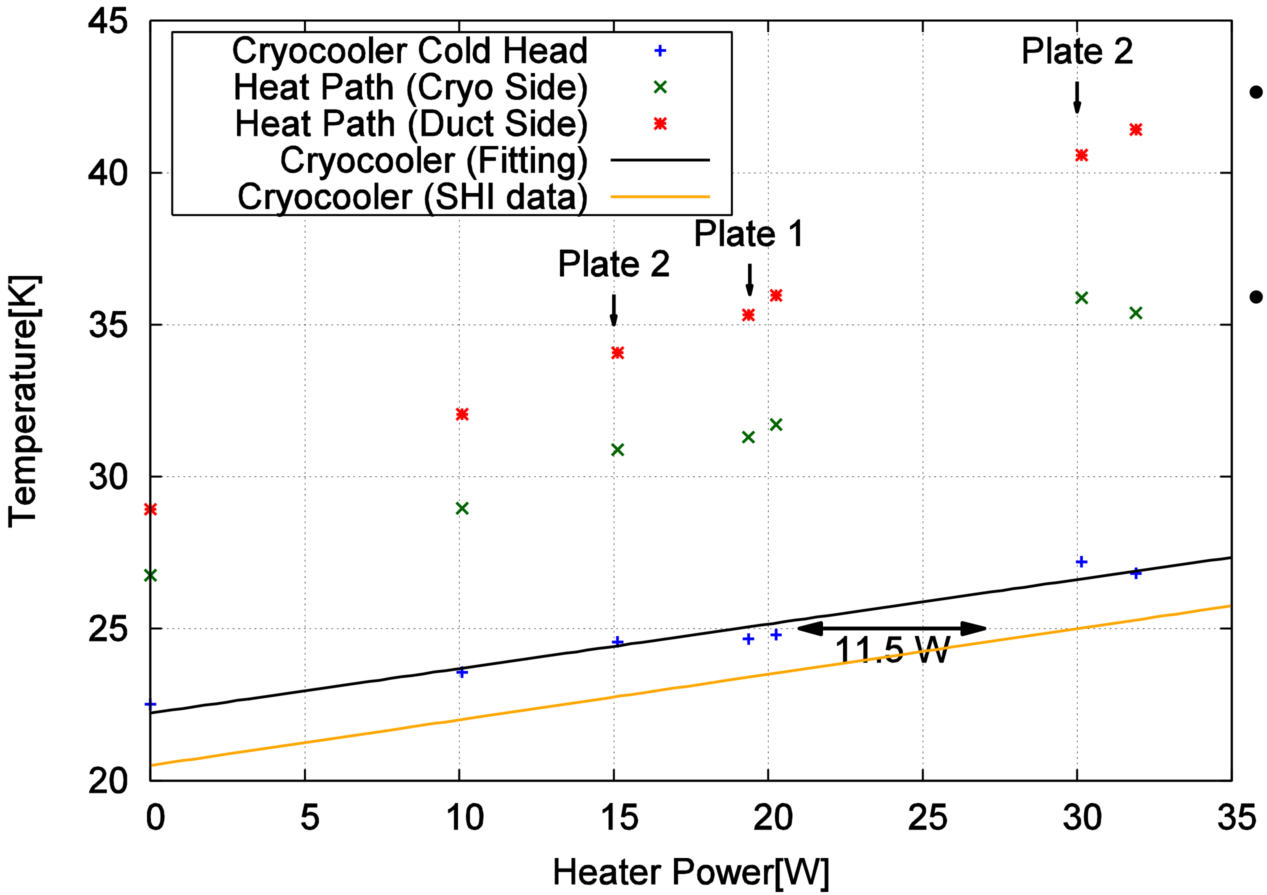
- Red light from laser diode
  - Photographs of scattered light when angle changes
  - How much laser power is reflected by duct shield can be obtained by calibration

Summary

- Summary
  - Thermal radiation through duct shield was measured
    - Result is consistent with calculation and satisfies KAGRA requirement
  - Scattered light noise was calculated
    - One order of magnitude smaller in main frequency band
- Future work
  - Vibration measurement of duct shield

Heat load test





- Heat load is applied by three heaters on duct shield
- Heat input without heater is consistent with thermal radiation from SI ~10 W