Verification of cooling time reduction of interferometric cryogenic gravitational wave detectors using high emissivity coating

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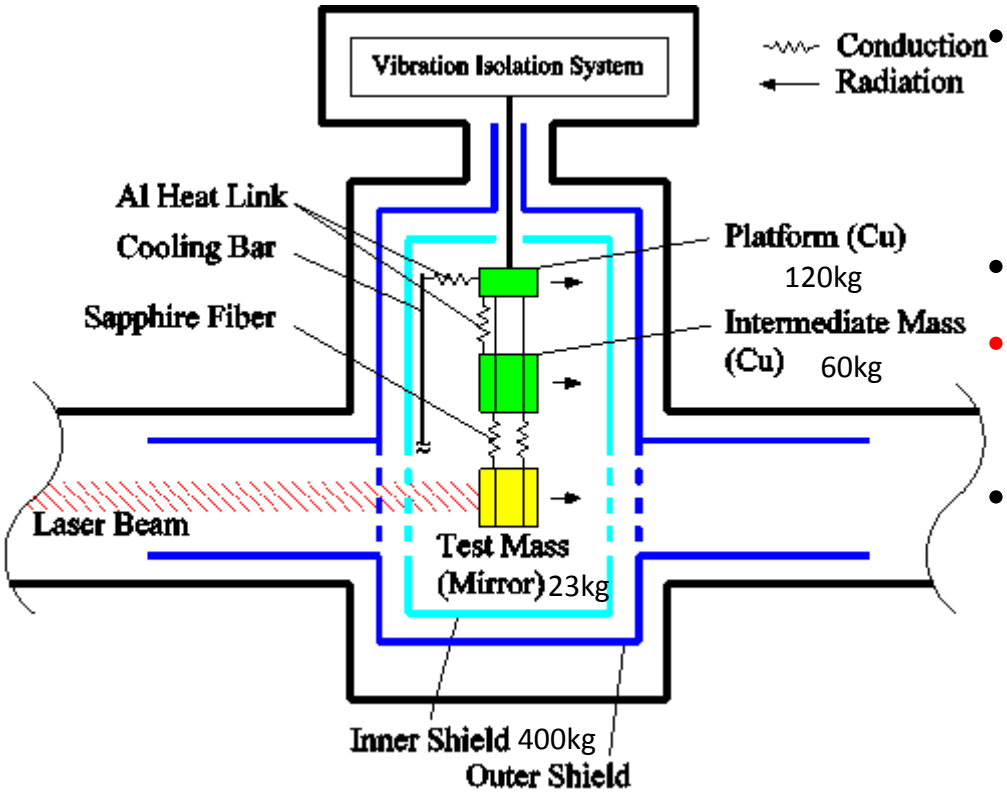
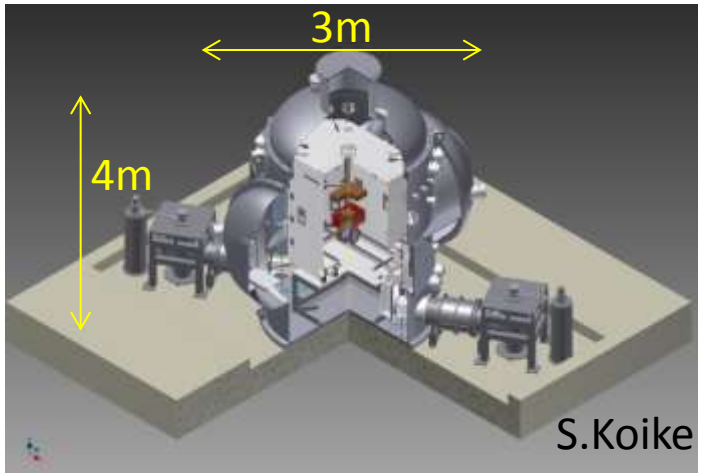
KAGRA

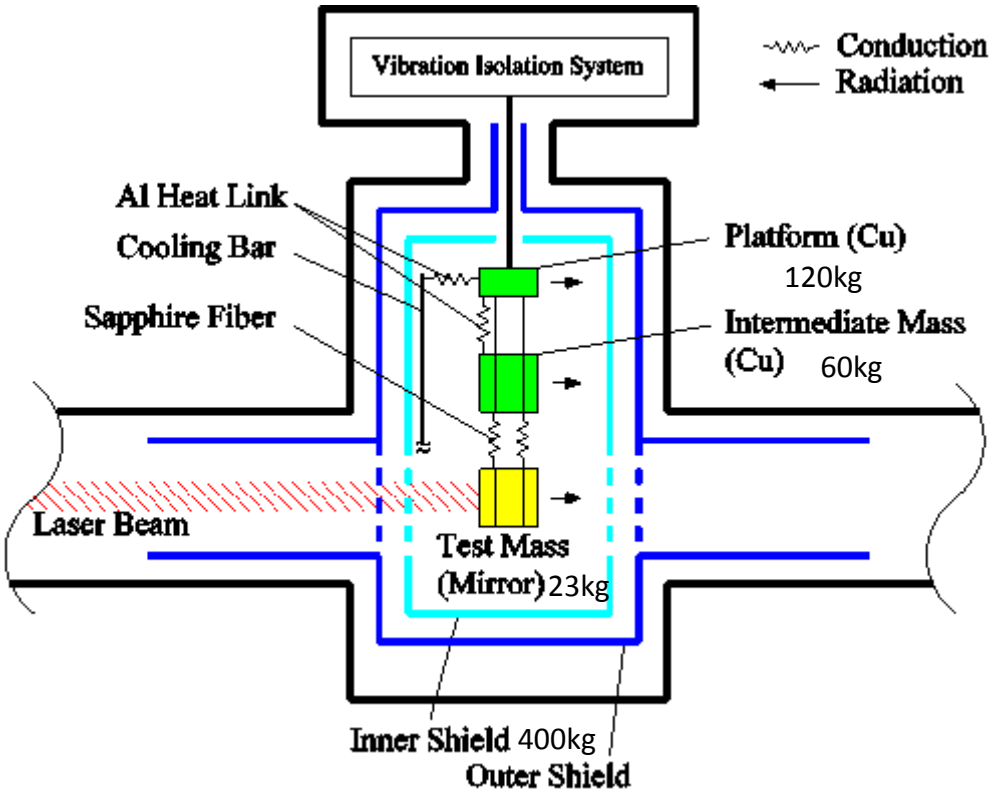




- Test masses is surrounded by double radiation shields
- Four cryocoolers per one mirror
  - Two cool inner shield (~400 kg)
  - Two cool bar to masses (~300 kg)
- It takes 2 months to cool down mirror
- It is necessary to reduce cooling time

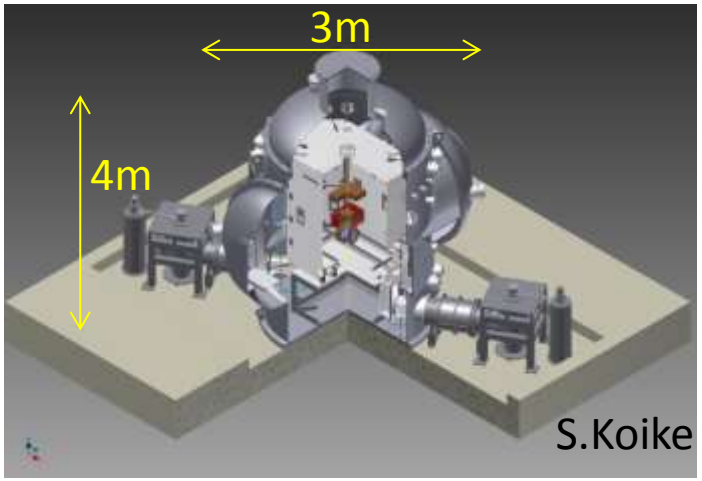
- How to reduce cooling time
  - Gas cooling
    - » Difficulty: mechanism to close and open holes of shield
  - Heat switch
    - » Difficulty: mechanism to contact and detach payloads
  - Increase radiation
    - » Slower but safer
    - » Adopted by KAGRA

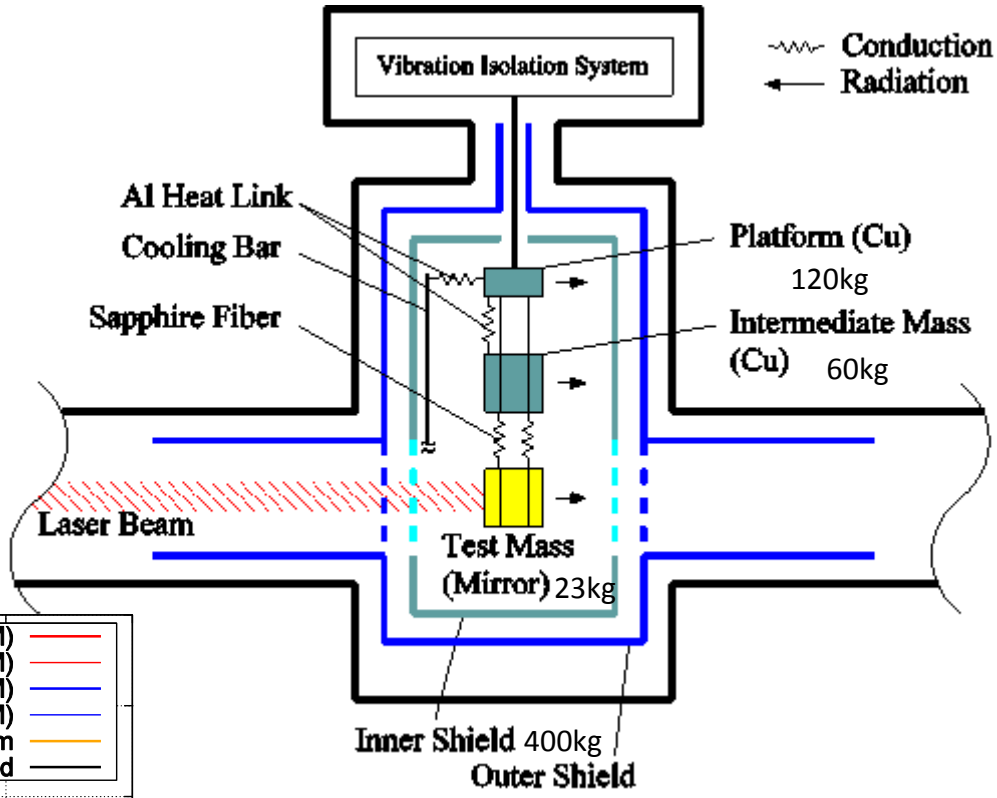
Contents

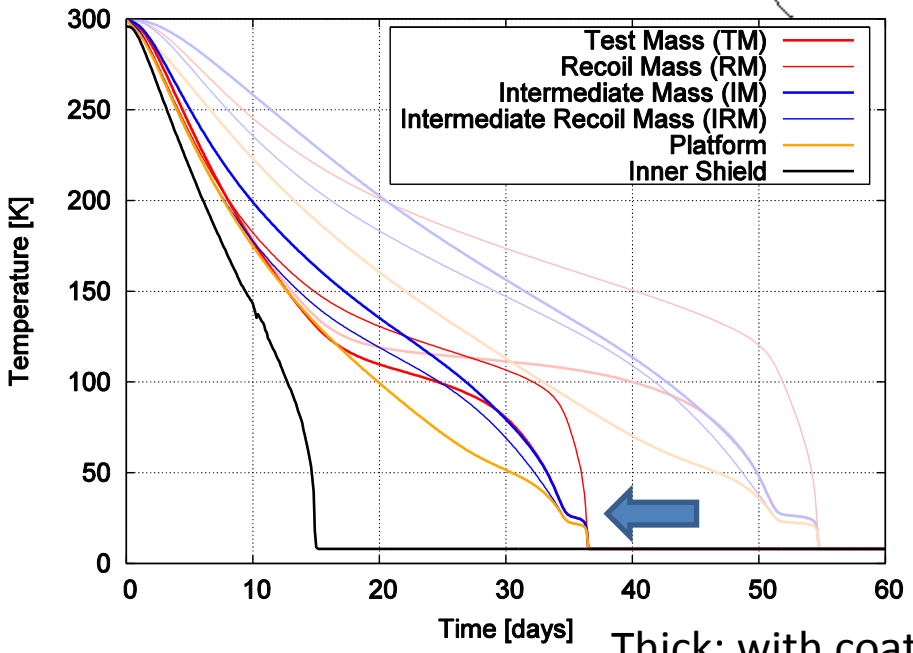


- Calculation of KAGRA cooling time
  - High emissivity coating (Diamond Like Carbon (DLC) coating) can reduce it to 40 days
- Experiment to verify
  - Calculation model of radiation
  - Effect of high emissivity coating
  - Small-scale experiment
  - Experiments in KAGRA cryostats
- Goal of cooling time reduction

Cooling time calculation of KAGRA



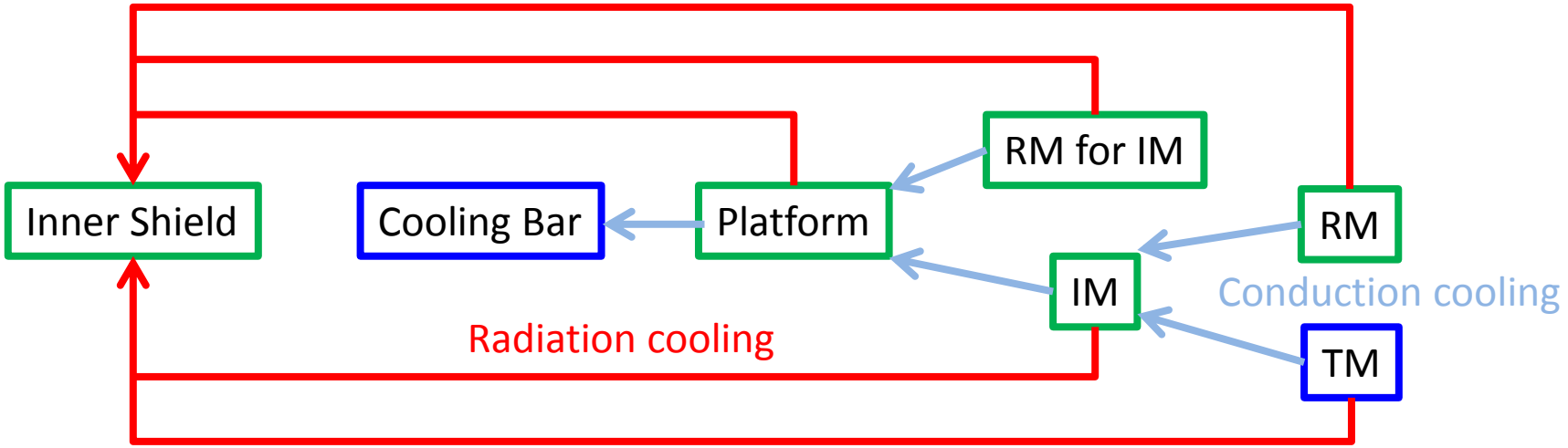




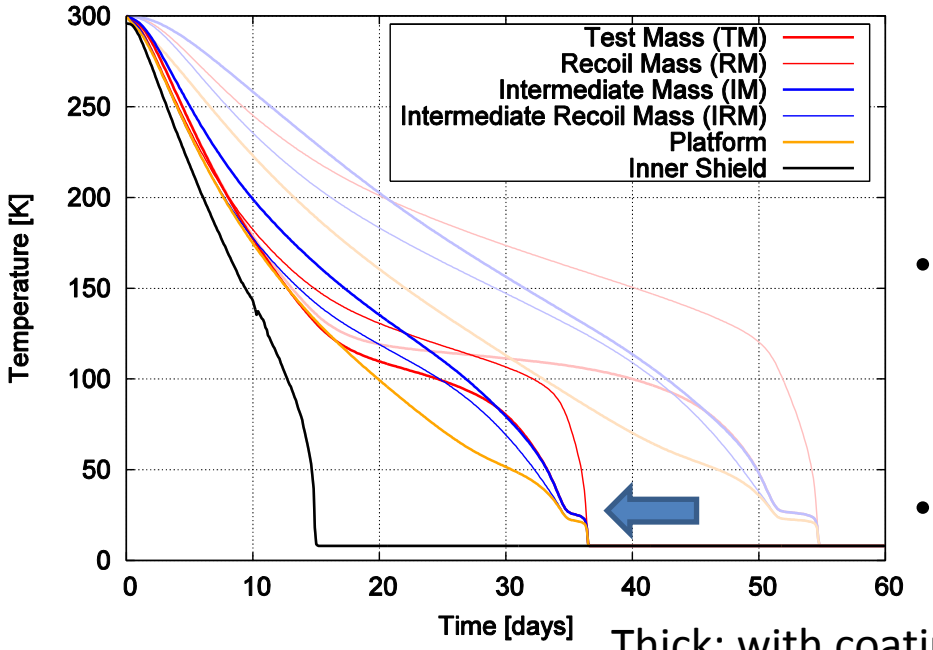
- Increased radiation by platform, IM, IRM, and inside of inner shield coated with high emissivity coating (DLC)
- Emissivity of DLC: 0.3*(T/300K)
  (Copper without DLC: 0.03)

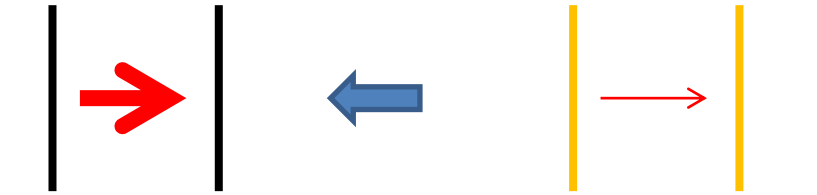
Thick: with coating Thin: without coating

Cooling time calculation of KAGRA



: Coated with DLC





With coating Without coating

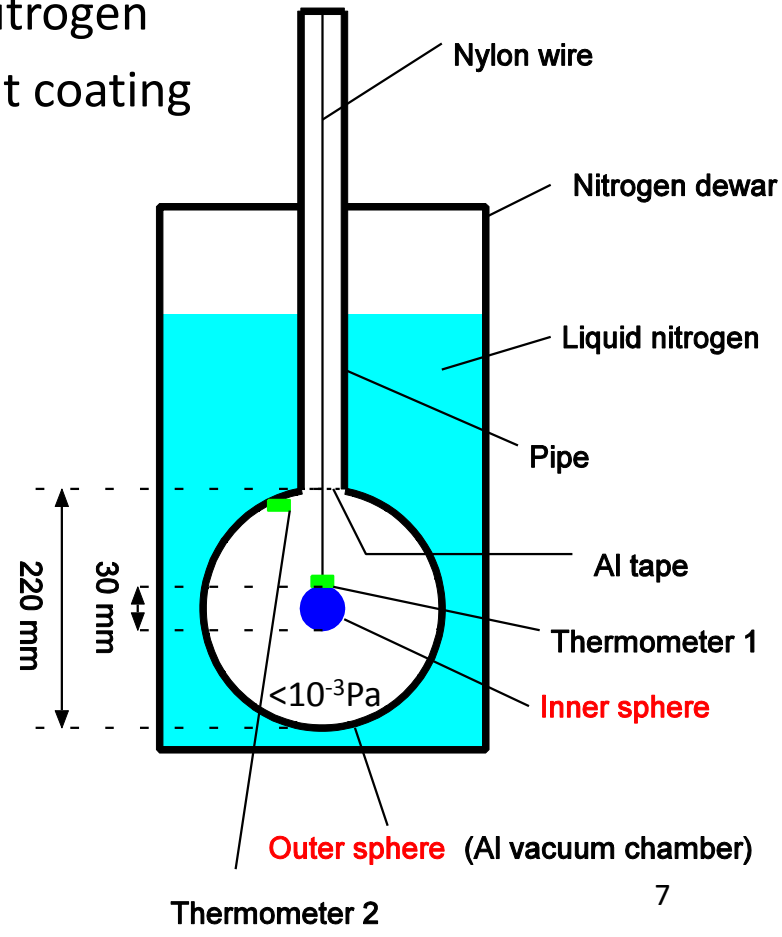
- Increased radiation by platform, IM, IRM, and inside of inner shield coated with high emissivity coating (DLC)
- Emissivity of DLC: 0.3*(T/300K)
  (Copper without DLC: 0.03)

Thick: with coating Thin: without coating

Experiment

Experiment with small-scale apparatus

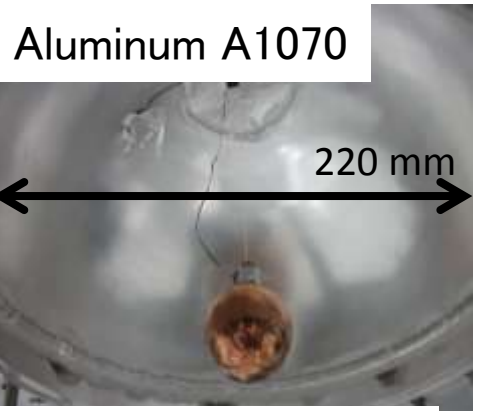
- Experimental test of calculation model of radiation and effect of high emissivity coating
  - Inner sphere (copper) is suspended inside outer sphere (aluminum)
    - Nylon wire: thermal conduction negligible
  - Outer sphere is kept at 77 K using liquid nitrogen
  - Cooling time is examined with and without coating



Measured samples

1	2	3	4
Inner: Not coated Outer: Not coated	Inner: DLC Outer: Not coated	Inner: DLC Outer: DLC	Inner: Not coated Outer: DLC

Aluminum A1070



Oxygen-free copper

Results (inner sphere: center)

- Fastest: both inner and outer spheres are coated

1. Inner: Not coated
Outer: Not coated

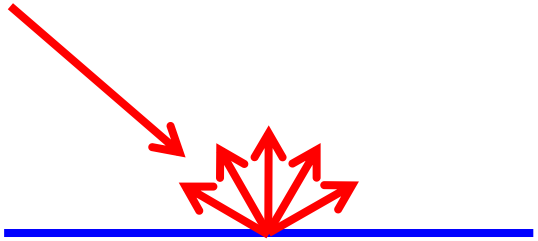
4. Inner: Not coated
Outer: DLC

3. Inner: DLC
Outer: DLC

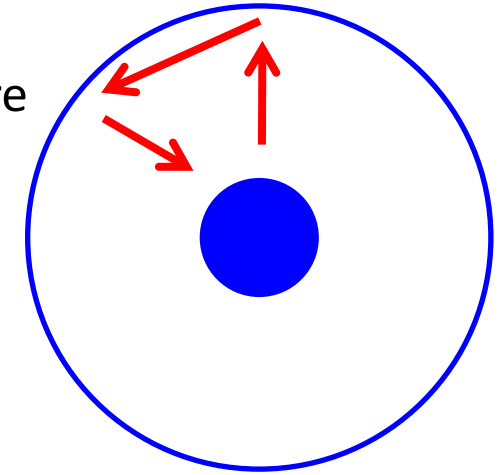
2. Inner: DLC
Outer: Not coated

Models of heat transfer via radiation

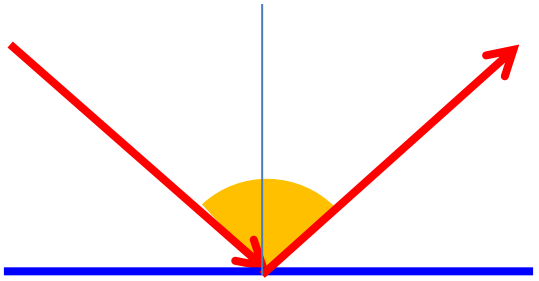
- Gray body model (diffusive reflection)
  - Surface reflects radiation to all angle
  - Heat transfer is independent of position of inner sphere

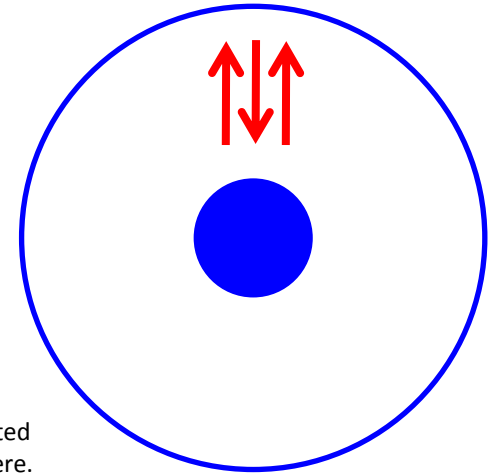


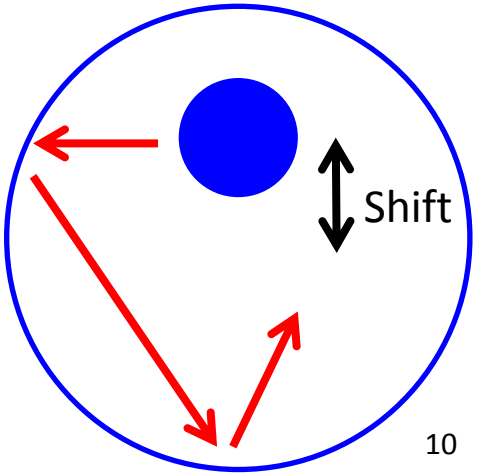
Some rays from inner sphere are reflected by outer sphere more than twice.



- Regular reflection model
  - Surface reflects radiation to the same angle as incident angle
  - Heat transfer depends on position of inner sphere

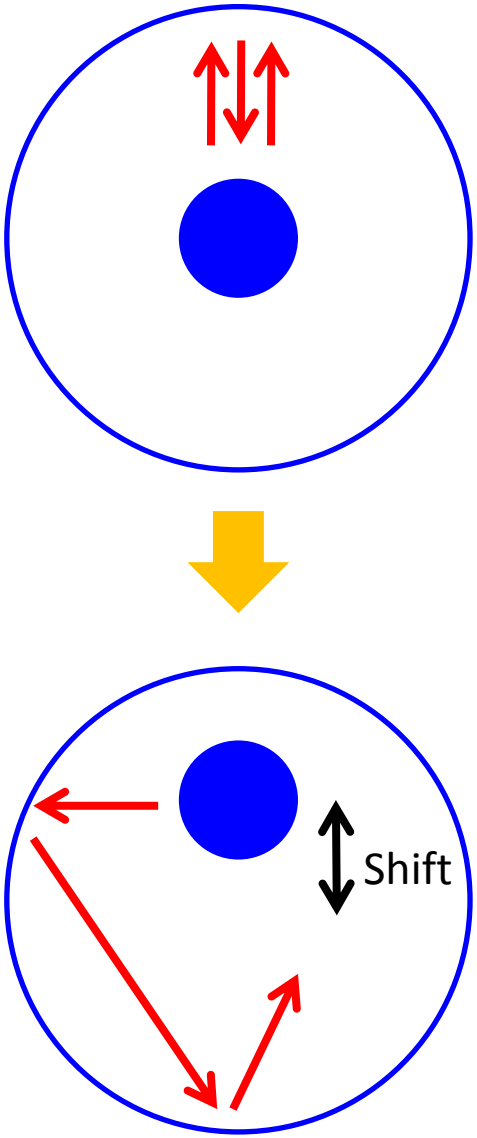






All rays from inner sphere are reflected alternatively by outer and inner sphere.

Results（inner sphere: shifted from center）



- Inner sphere shifted from center cools faster

Inner sphere: center

Shift 5cm

Comparison with calculation models

- Results are consistent with regular reflection model
  - Surface can be regarded as flat planes at wavelength of radiation (~10 um)

3
Inner: DLC
Outer: DLC

Emissivity DLC: 0.3*(T/300K)

Experiments with KAGRA cryostats

Experiments with KAGRA cryostats

Cryostat No.2
Aluminum sphere
Coated with DLC

- Manufacturing KAGRA cryostats completed
- Cooling test of cryostats conducted
- Aluminum sphere is suspended inside cryostats
  - Kevlar wires (aramide fibers): thermal conduction negligible
- Radiation was examined to verify scaling law

Sphere made by S.Koike, R.Kobayashi(KEK)

Results

- Temperature of sphere calculated from temperature of inner shield
- Diffusive and regular reflection yield same results (not so symmetric shield)

Consistent with calculation

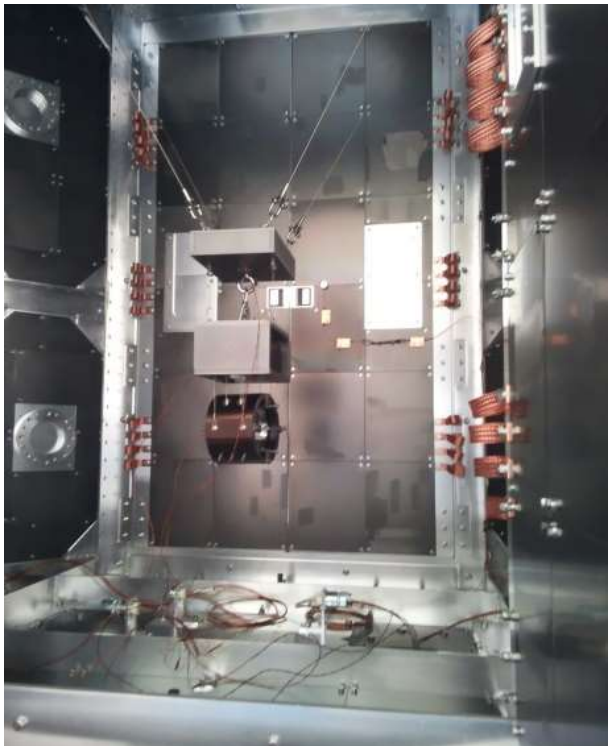
Cryostat No.2
Aluminum sphere
Coated with DLC

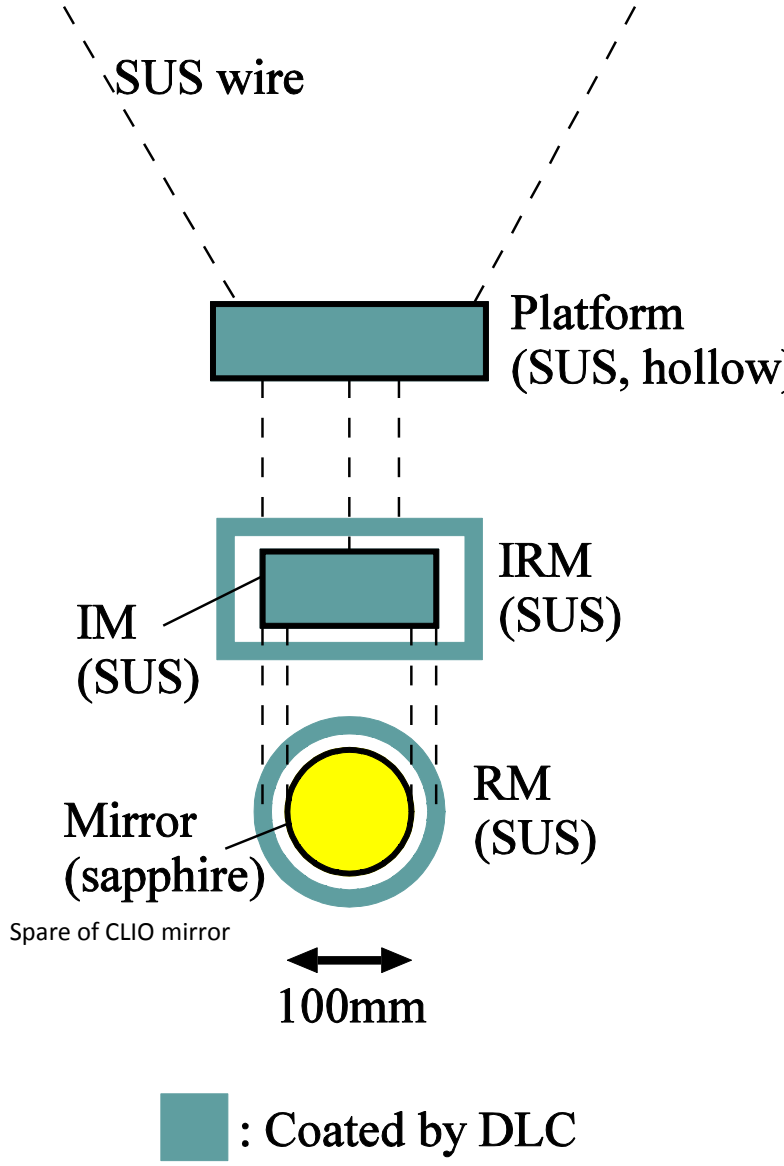
Emissivity DLC: 0.4*(T/300K)

Experiment with KAGRA cryostats

- 1/2 size dummy payload was suspended inside cryostat No.3
  - SUS wires: thermal conduction negligible
- Thermal radiation was examined

  (without any heat links)
  - Cooling from room temperature





Payloads designed and made by R.Kobayashi, S.Koike (KEK)

Results

- Temperature of payloads calculated from temperature of inner shield
- Diffusive and regular reflection yield same results (not so symmetric shield)

Consistent with calculation

Emissivity
Sapphire: 0.5
Platform: 0.3*(T/300K) IM: 0.4*(T/300K)

Goal of cooling time reduction

- Requirement of duty factor of KAGRA: 80%

- One maintenance 70 days
  - Cooling down 40 days
  - Heating up (using nitrogen gas) 10 days
  - Other maintenance >20 days
- Short time maintenance
- Unlocking of interferometer

- Cooling down & heating up < once in two years
- Another method to reduce cooling time is necessary

M.Punturo and K.Somiya, Int. J. Mod. Phys. D **22**, 1330010 (2013)

- Summary
  - Cooling time of KAGRA is calculated
  - Calculation model predicts cooing time correctly
    - Small-scale experiment verified
      - Calculation model
      - Effect of high emissivity coating on reduction of cooling time
    - Experiment with KAGRA cryostats
      - Consistent with calculation (emissivity of sapphire: 0.5)

- Future work
  - R&D of another method to reduce cooling time