Verification of cooling time reduction for KAGRA

ICRR, Univ. of Tokyo, KEK[A]

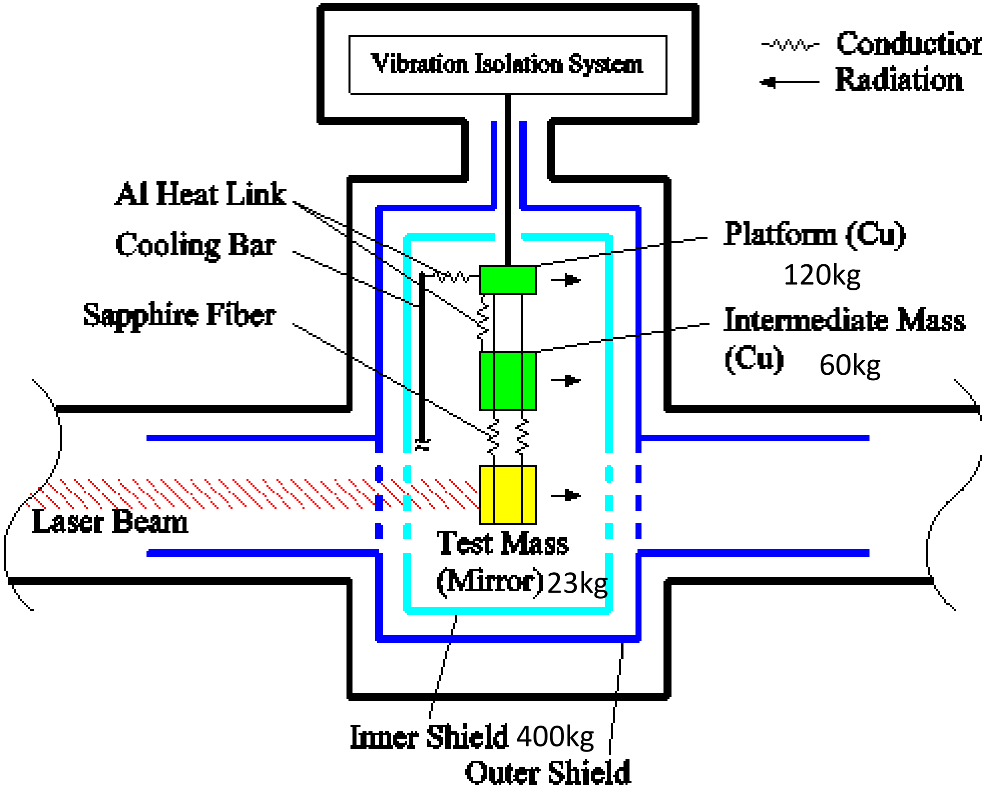
Yusuke SAKAKIBARA

N. Kimura[A], T. Suzuki[A], K. Yamamoto, D. Chen,

S. Koike[A], C. Tokoku, T. Uchiyama, and K. Kuroda

2013.4.19 Bilateral Italy-Japan Workshop (Italian Institute of Culture)

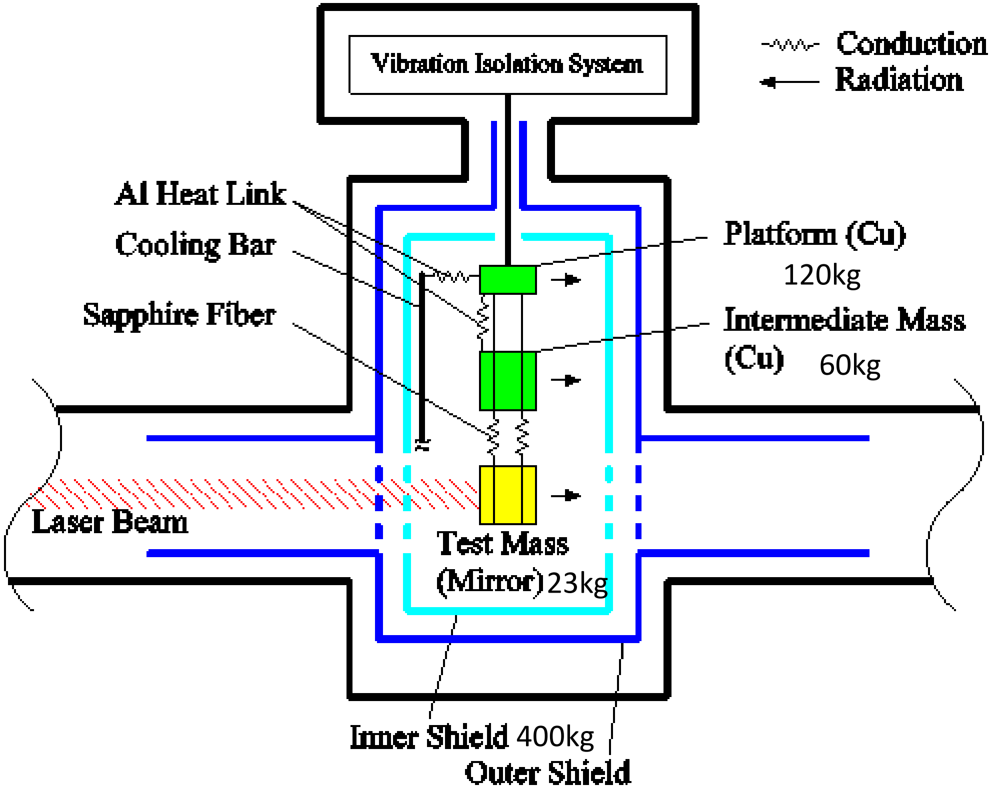
KAGRA

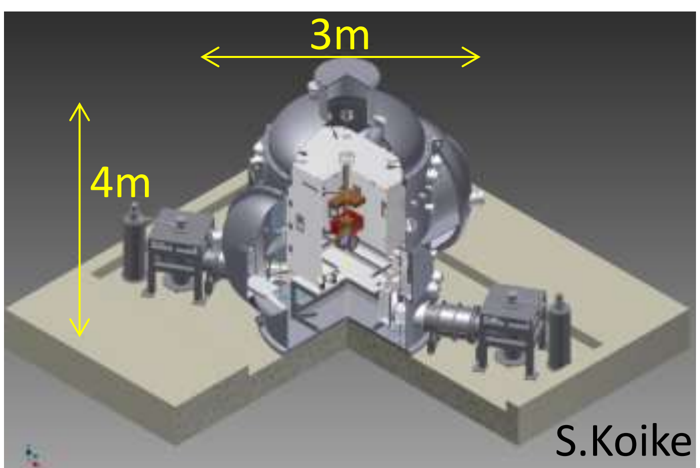


- Test masses is surrounded by double radiation shields
- Four cryocoolers per one mirror
  - Two cool inner shield (~400 kg)
  - Two cool bar to masses (~300 kg)
- It takes 2 months to cool down mirror
- It is necessary to reduce cooling time
- Cf. heating up by nitrogen (~10 days)

- 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

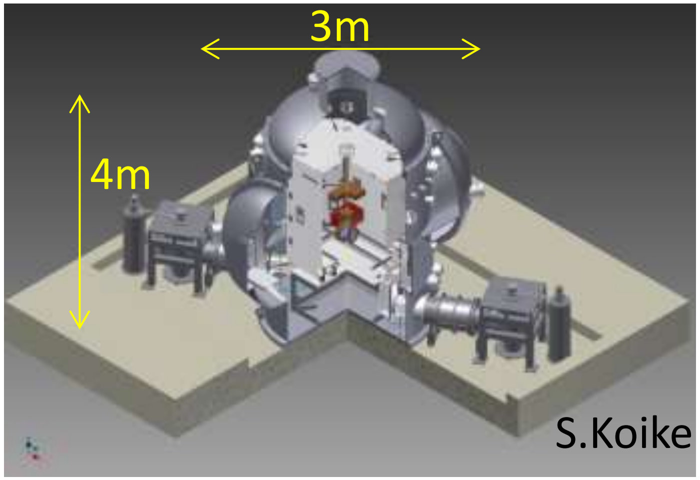
Contents

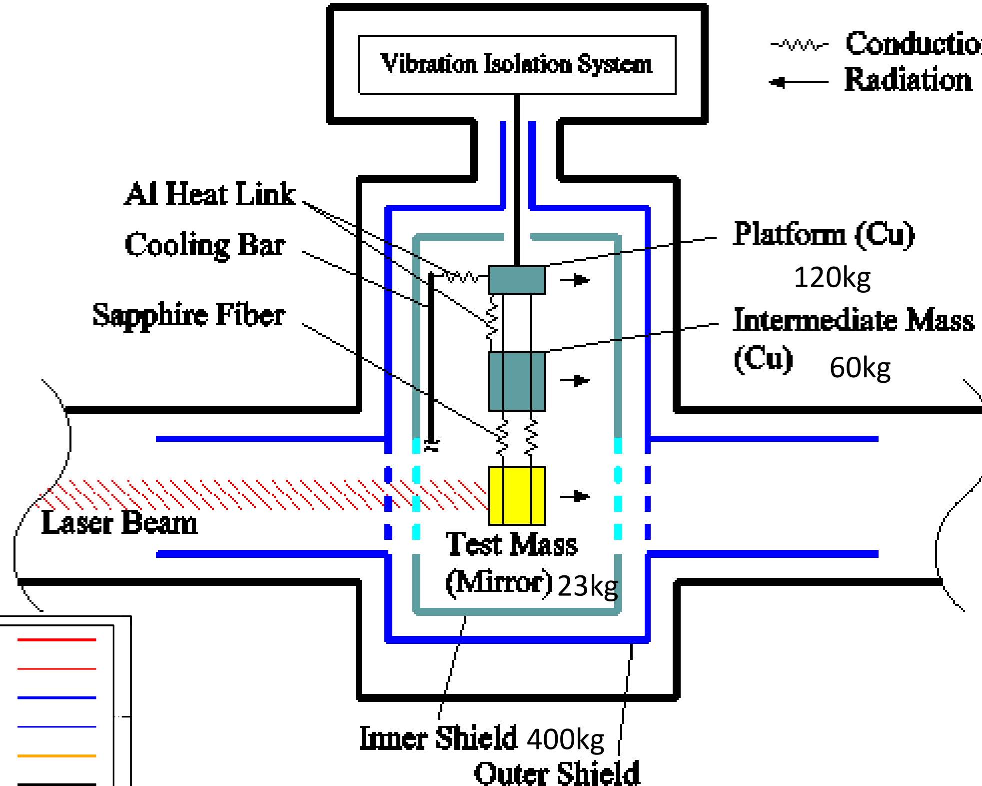


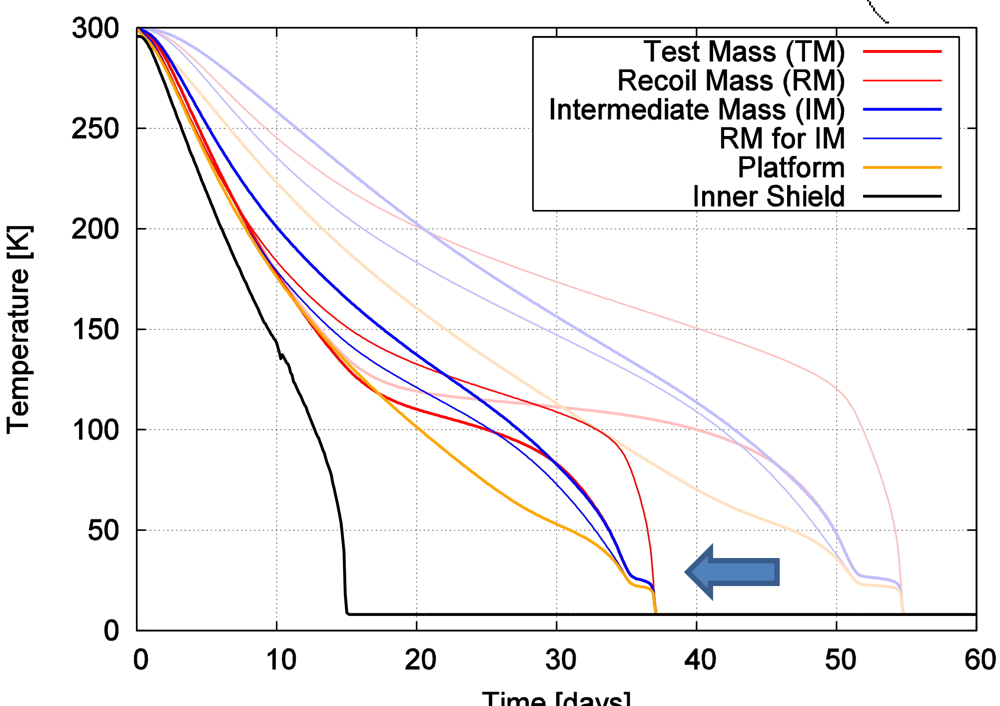


- Calculation of KAGRA cooling time
  - High emissivity coating (Diamond Like Carbon (DLC) coating) can reduce it to 40 days
- Experiment to verify
  - Calculation model of radiation
    - Reflecting diffusely
    - Reflecting specularly
  - Effect of high emissivity coating
  - Small experiment
  -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

Cooling time calculation of KAGRA



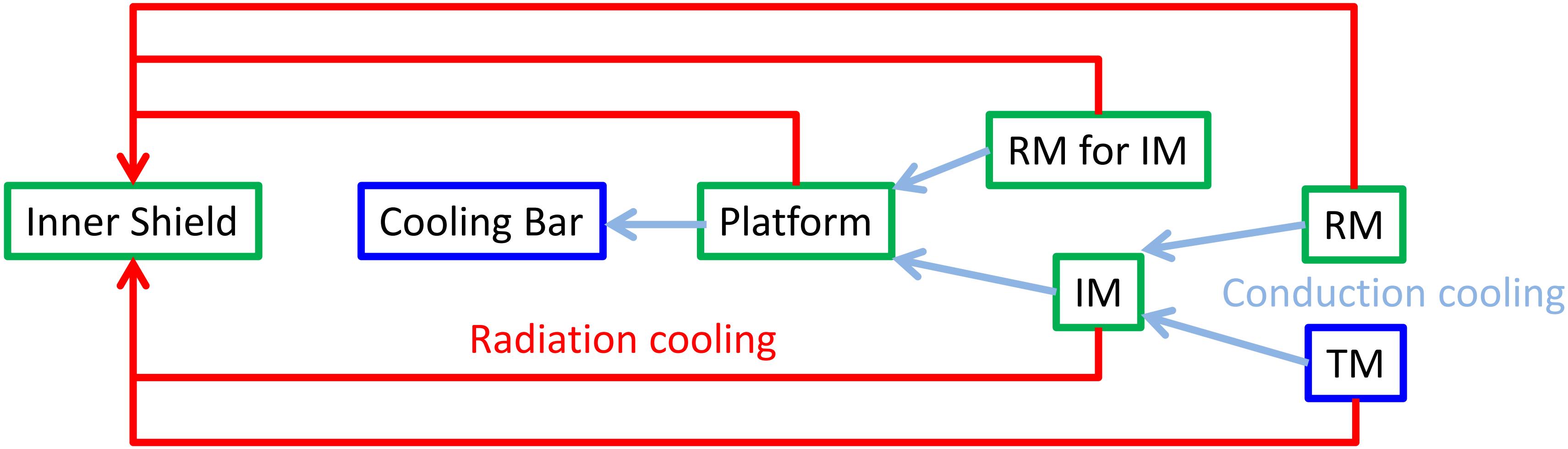




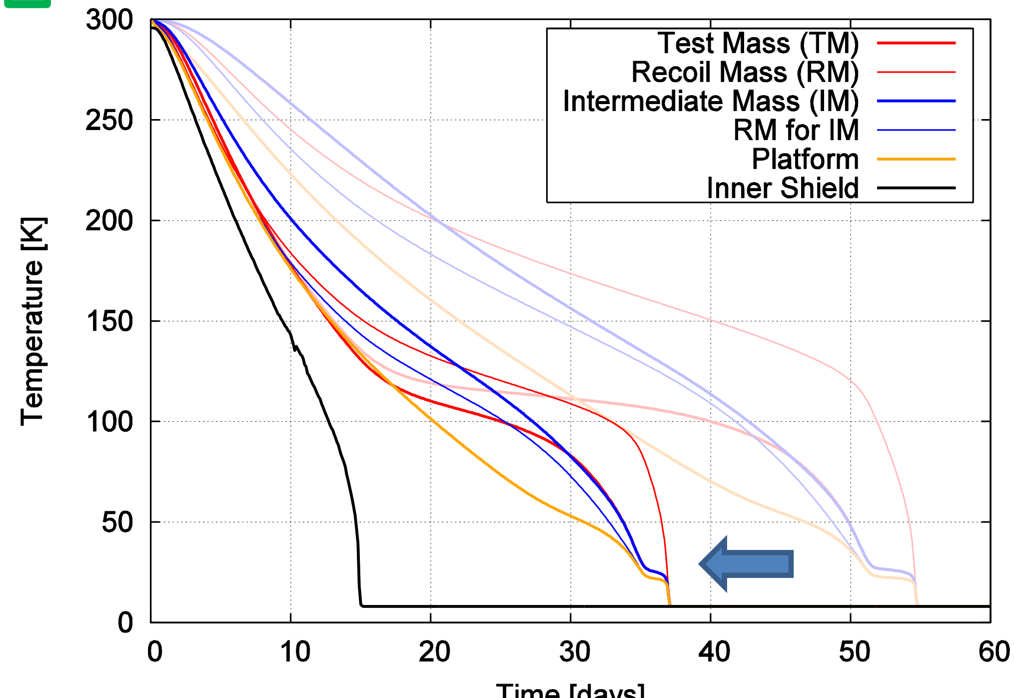
- Increased radiation by platform, IM, IRM, and inside of inner shield coated with high emissivity coating (DLC)
- Emissivity of DLC: 0.28*(T/300K)
  (cf. emissivity of Cu and Al is 0.03)

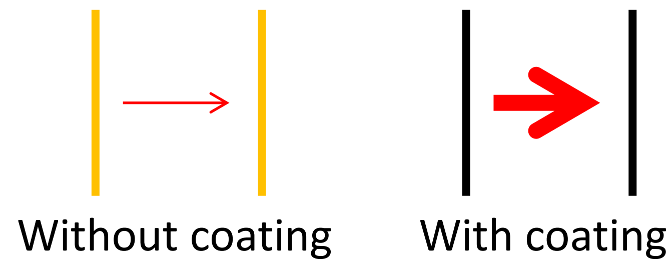
Thick: with coating Thin: without coating

Cooling time calculation of KAGRA



: Coated with DLC





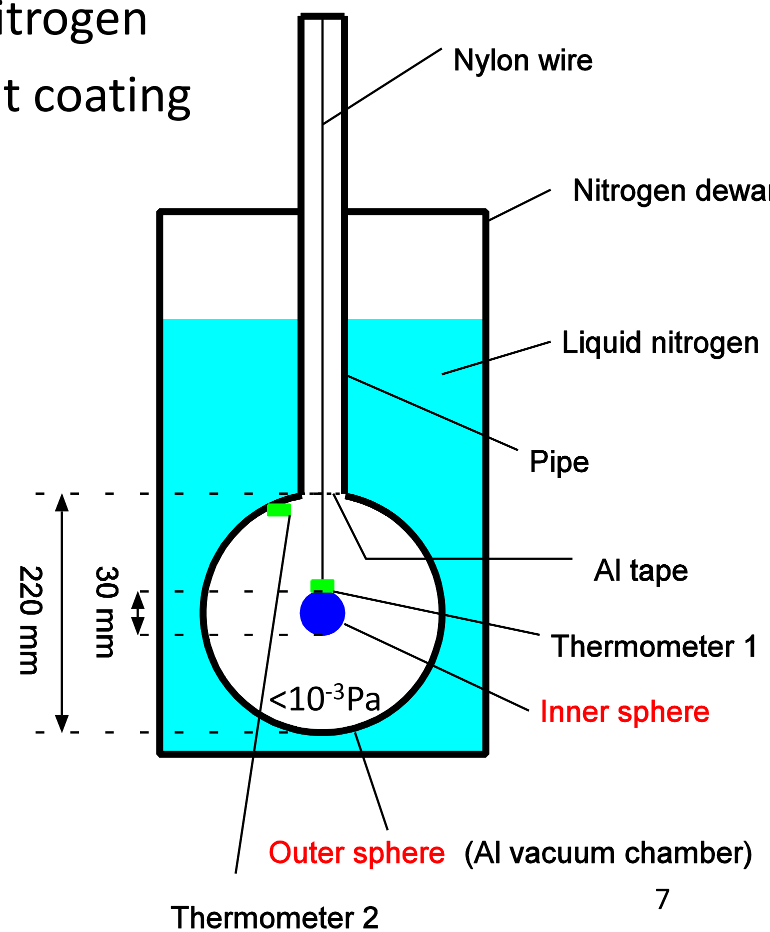
- Increased radiation by platform, IM, IRM, and inside of inner shield coated with high emissivity coating (DLC)
- Emissivity of DLC: 0.28*(T/300K)
  (cf. emissivity of Cu and Al is 0.03)

Thick: with coating   Thin: without coating

Experiment

Experiment with small 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

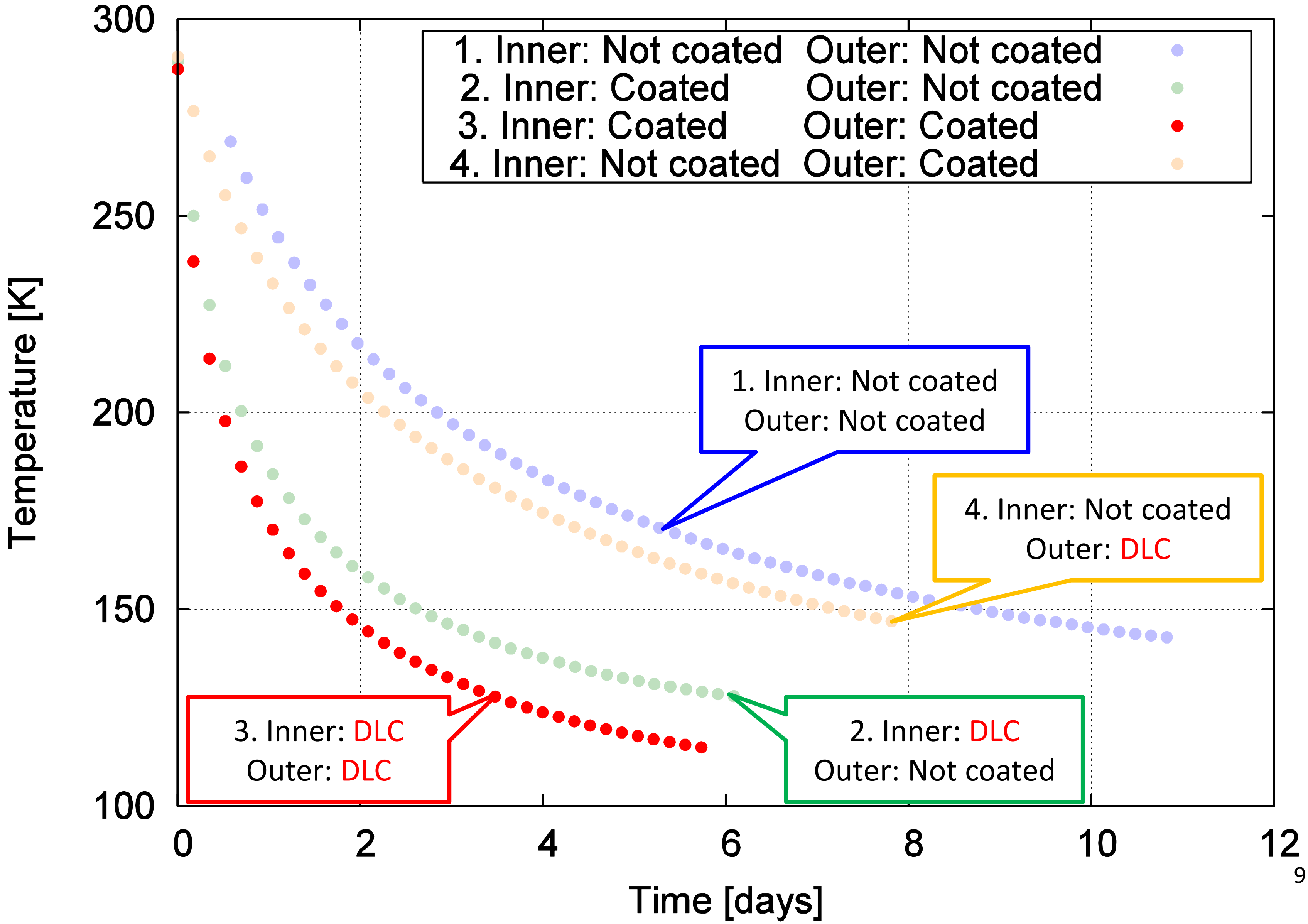


Samples to be measured

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

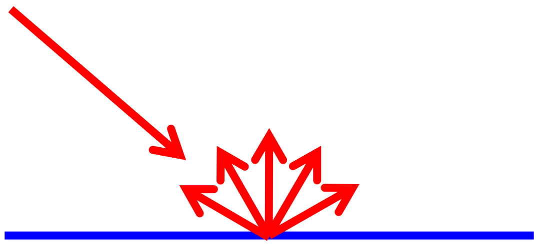
Results (inner sphere: center)

- Fastest: both inner and outer spheres are coated

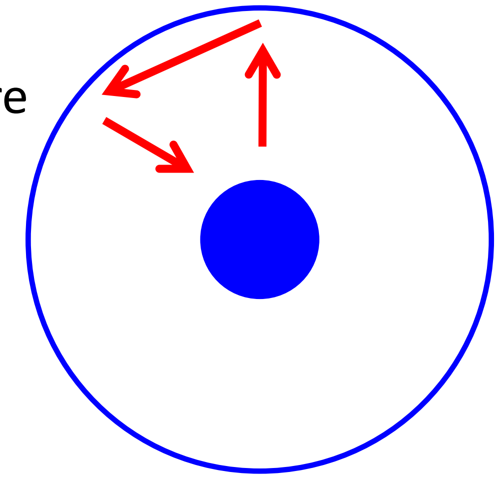


Models of heat transfer via radiation

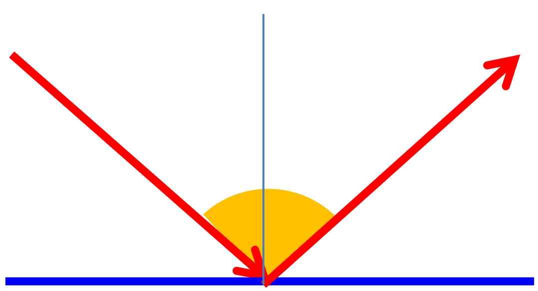
- Gray body model (diffusive reflection)
  - Surface reflects radiation to all angle
  - Heat transfer is independent of position of inner sphere

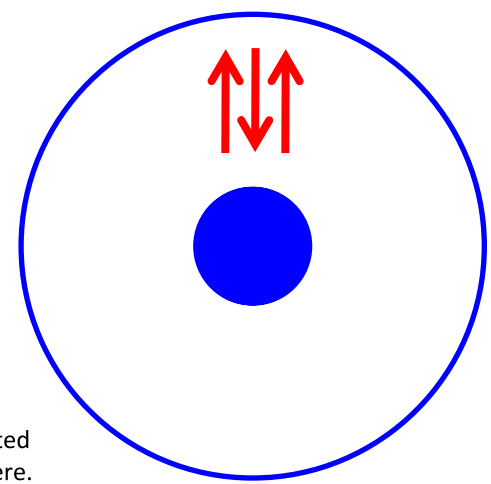


Some rays from inner sphere are reflected by outer sphere more than twice.

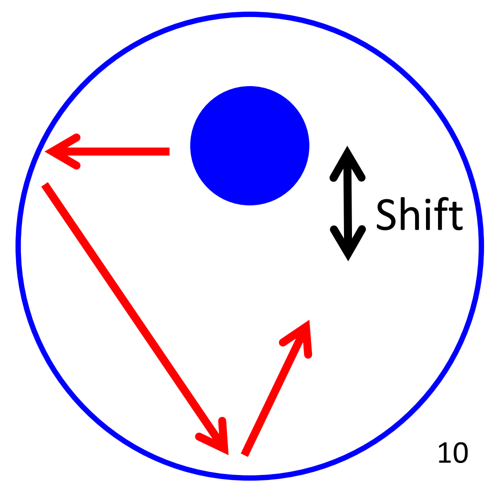


- Regular reflection model
  - Surface reflects radiation to the same angle as incident angle
  - Heat transfer depends on position of inner sphere



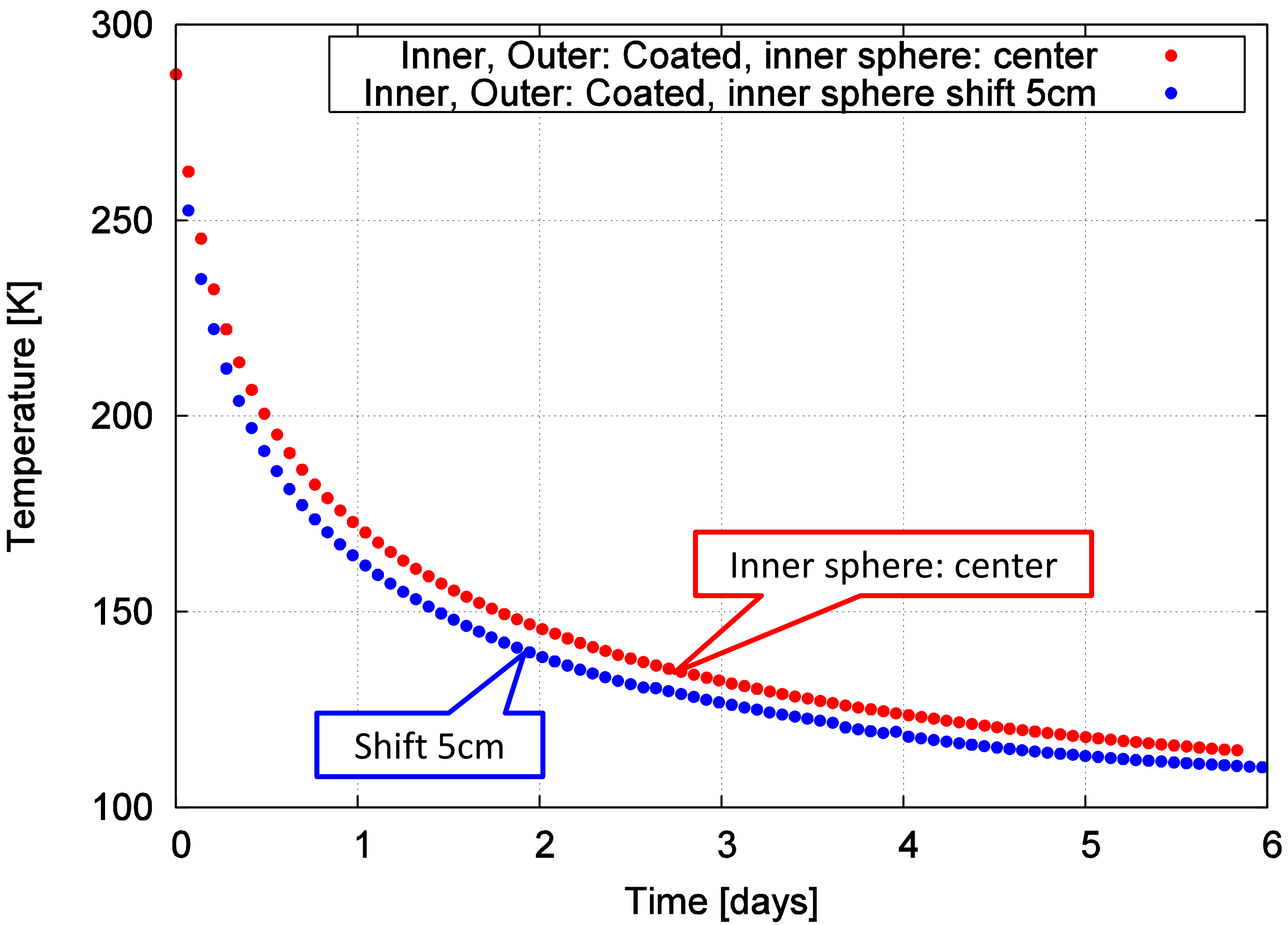


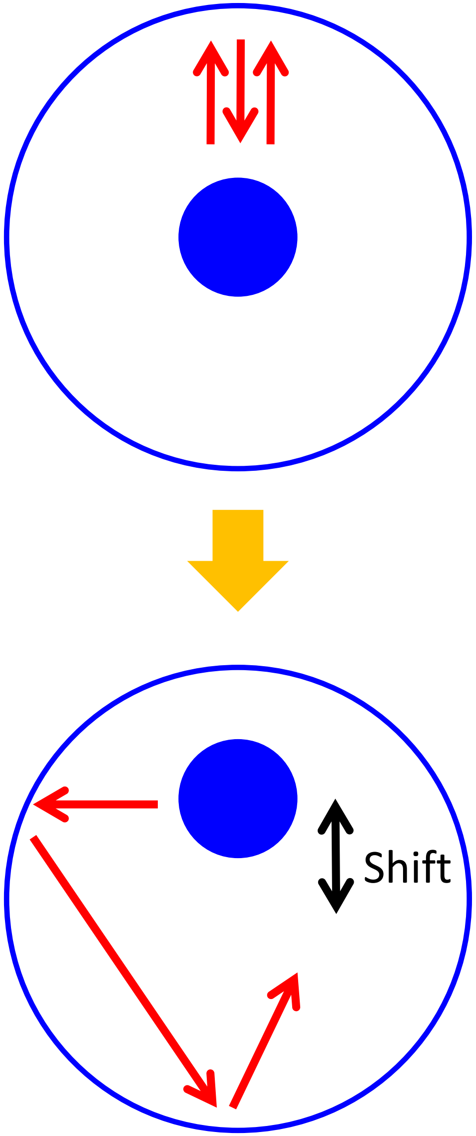
All rays from inner sphere are reflected alternatively by outer and inner sphere.



Results（inner sphere: shifted from center）

- Inner sphere shifted from center cools faster

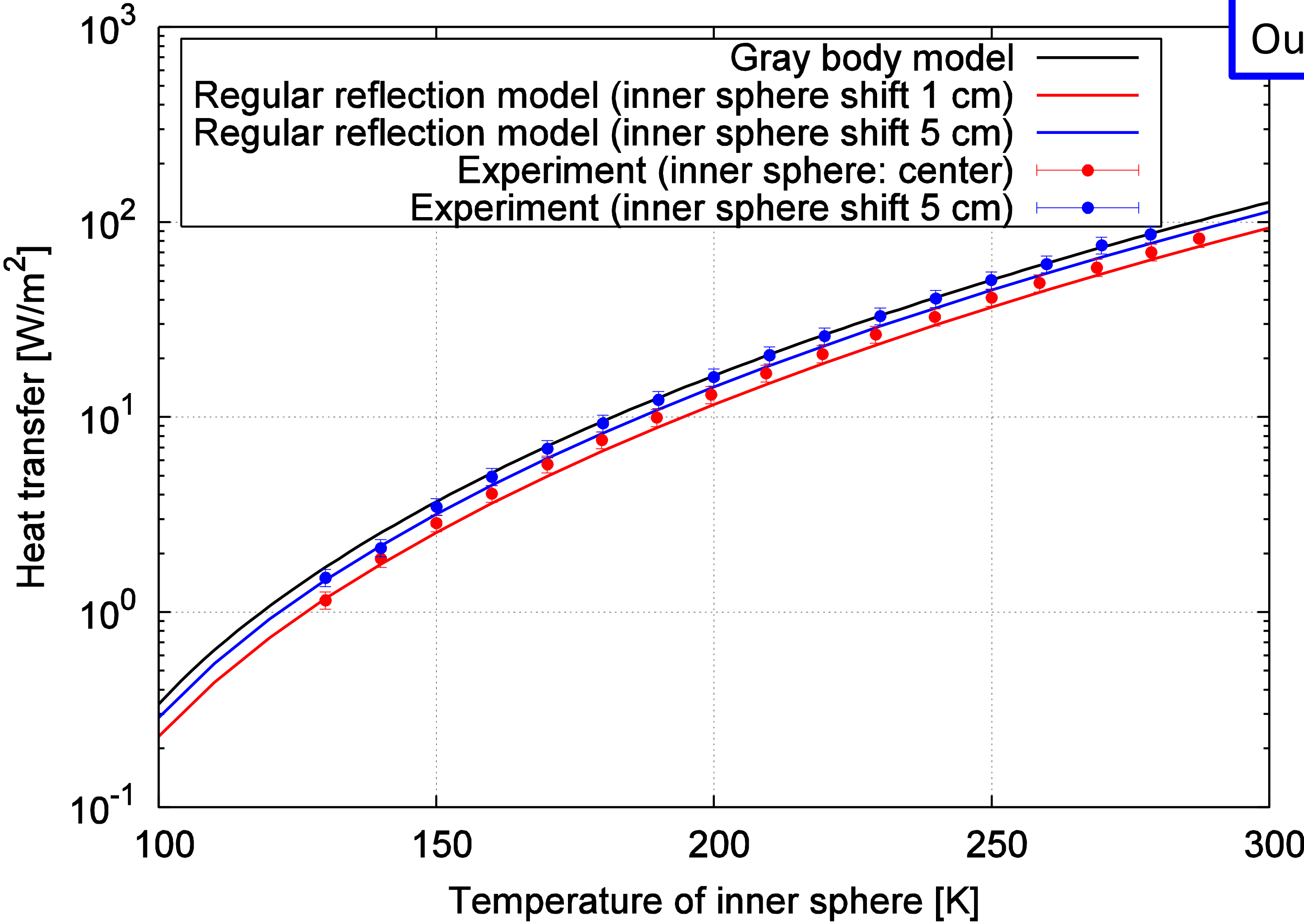




Comparison with calculation models

- Results are consistent with regular reflection model
  - Surface can be regarded as flat planes at wavelength of radiation (~10 um)
- Emissivity
  - Copper: 0.04 aluminum: 0.07 DLC: 0.28*(T/300K)

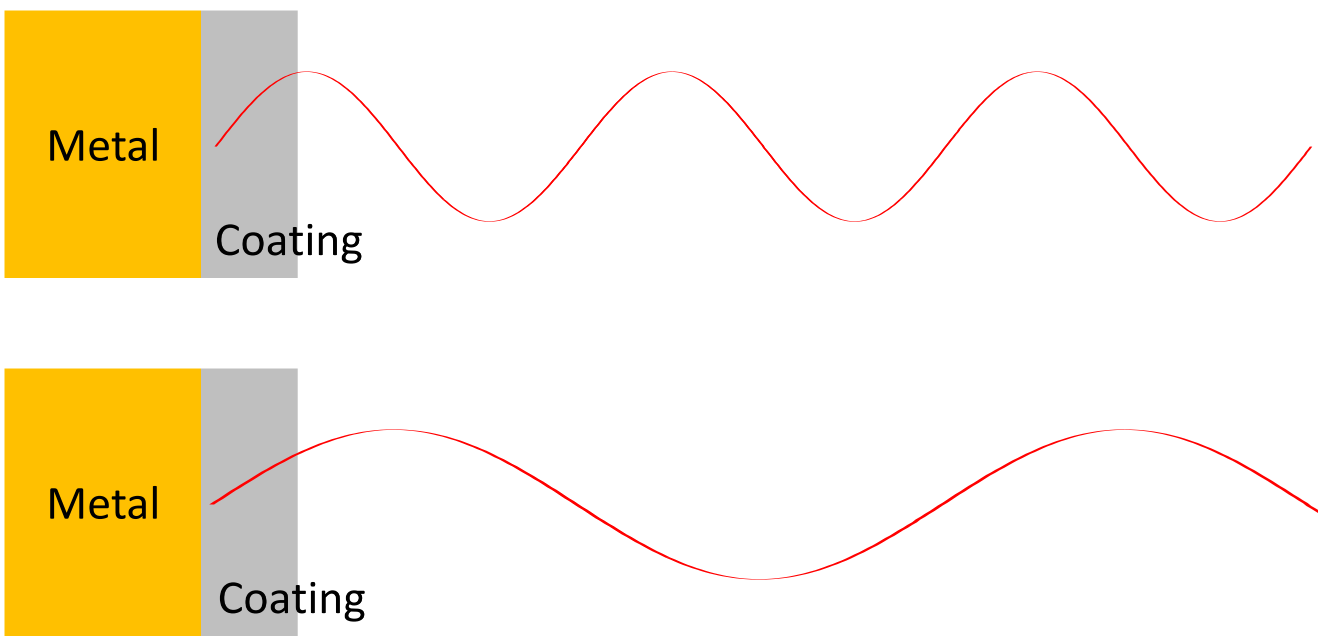
3
Inner: DLC
Outer: DLC



Emissivity of coating (under discussion)

- Emissivity
  - Absorptivity at wavelength λ of radiation (10 um at 300 K, $\lambda \propto T^{-1}$)
- Assumption: constant absorption coefficient
  - Absorptivity $\propto d/\lambda \propto T$

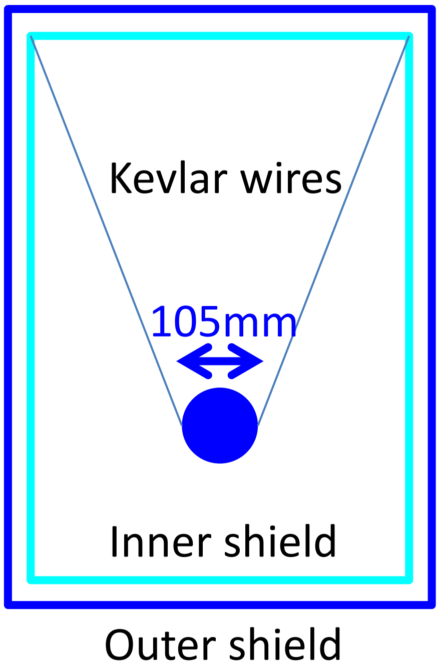
    d: thickness of coating (1 um in this experiment)
  - Coating effectively looks thin for radiation with long wavelength



Experiments with KAGRA cryostats

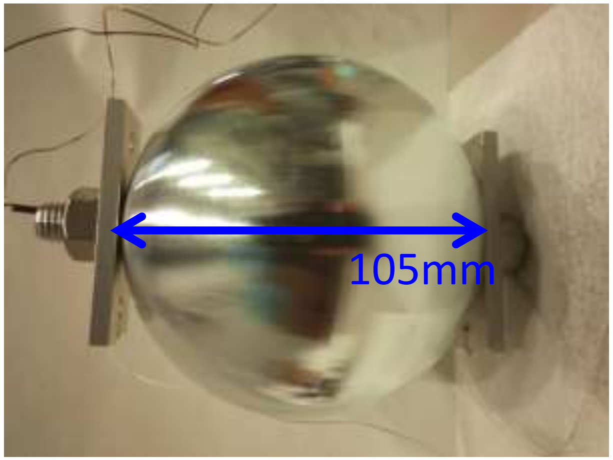
Experiments with KAGRA cryostats

- Cryostats made by Toshiba company
- Aluminum spheres are suspended inside KAGRA cryostats
  - Kevlar wires (aramide fibers): thermal conduction negligible
- Radiation was examined to verify scaling law



Spheres in KAGRA cryostats

Cryostat No.1
Aluminum sphere
Not coated



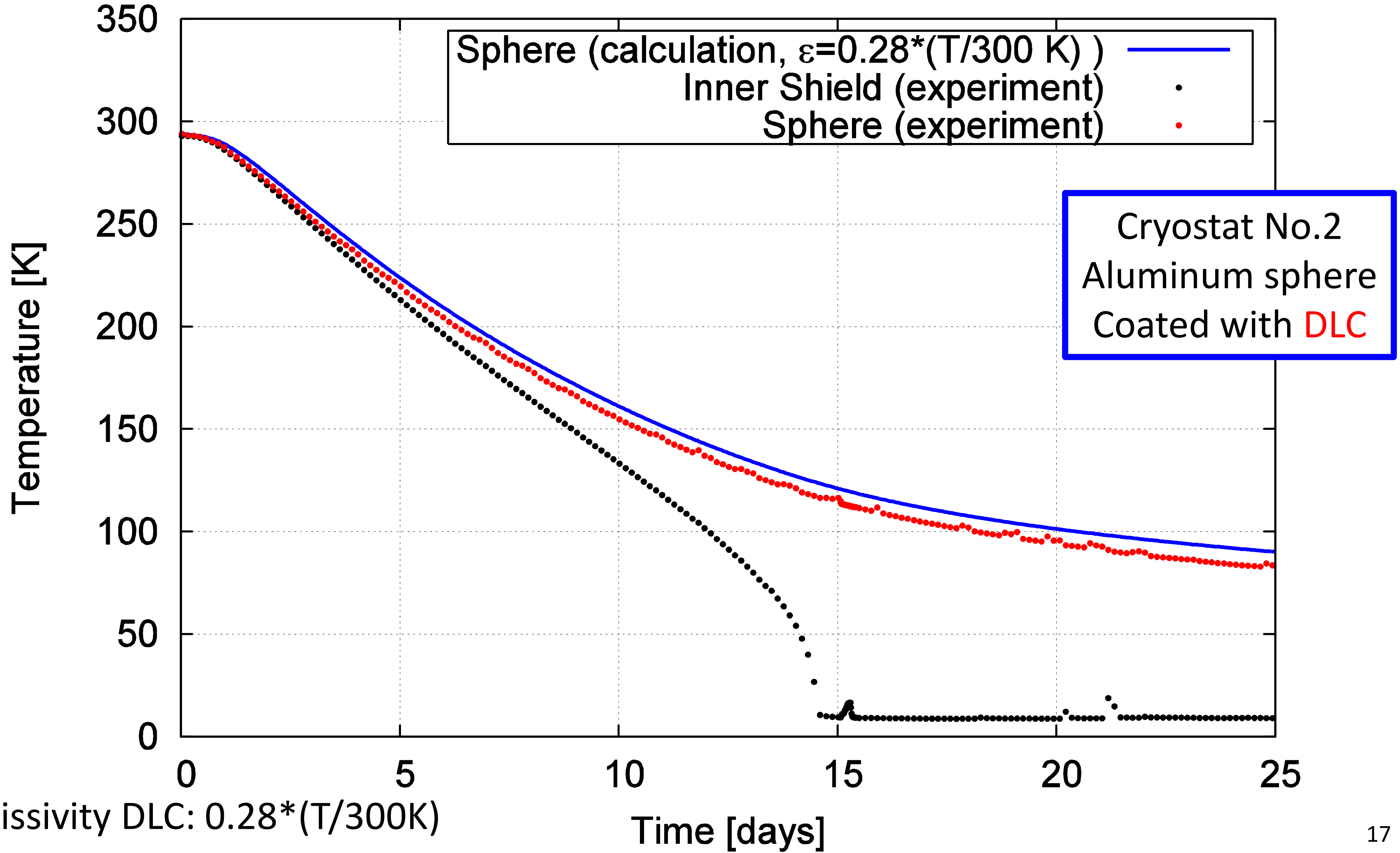
Cryostat No.2
Aluminum sphere
Coated with DLC

Cryostat No.4
Aluminum sphere
Coated with solblack

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

Results

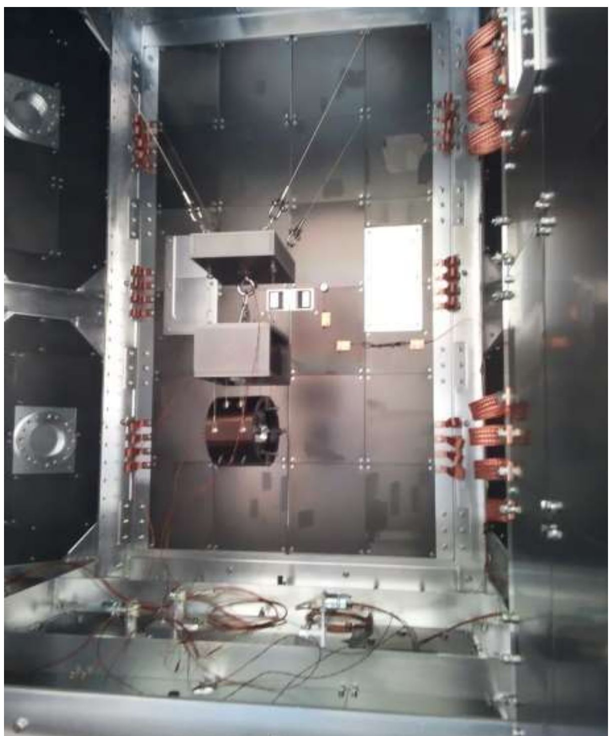
- Temperature of sphere calculated from temperature of inner shield
- Diffusive and regular reflection yield same results (not so symmetric shield)
- Results consistent with calculation

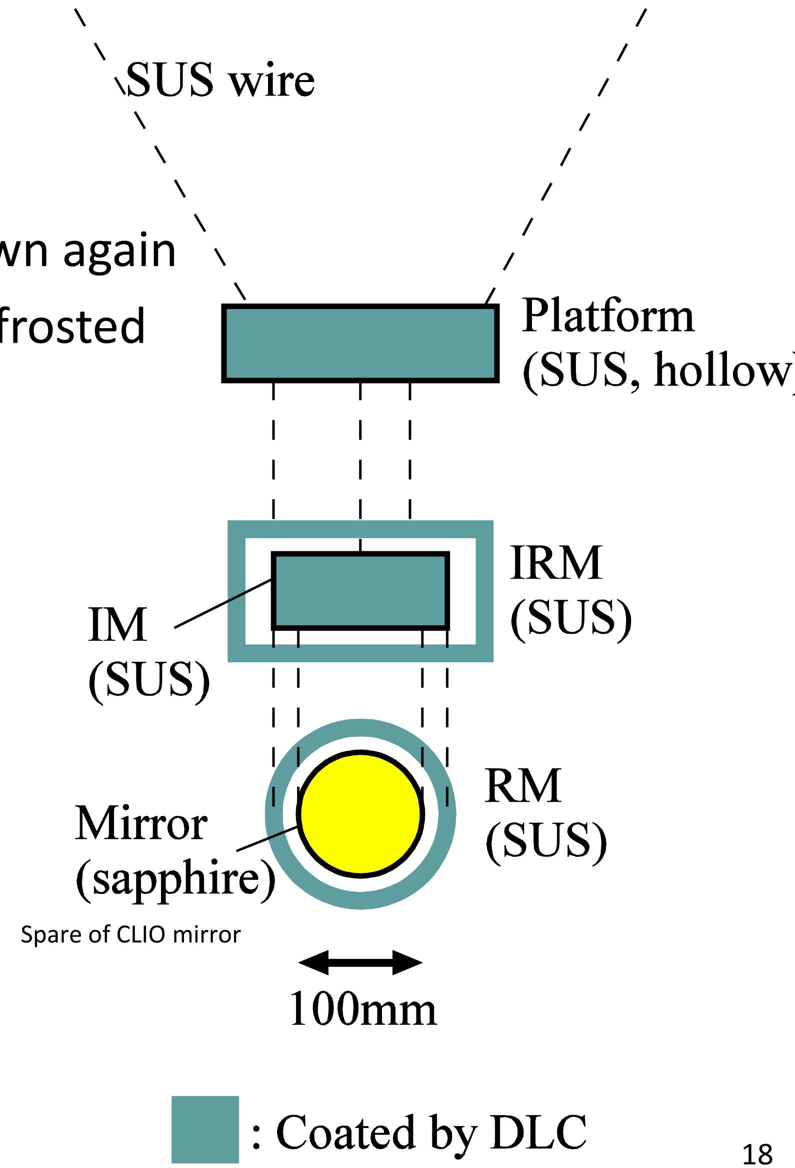


Emissivity DLC: 0.28*(T/300K)

Experiment with KAGRA cryostats

- 1/2 size dummy payload was suspended inside cryostat No.3
  - SUS wires: thermal conduction negligible
- Thermal radiation was examined
  - Cooling from room temperature
  - Payload heated up by heater and cooled down again
    - For cooling time when KAGRA mirror defrosted

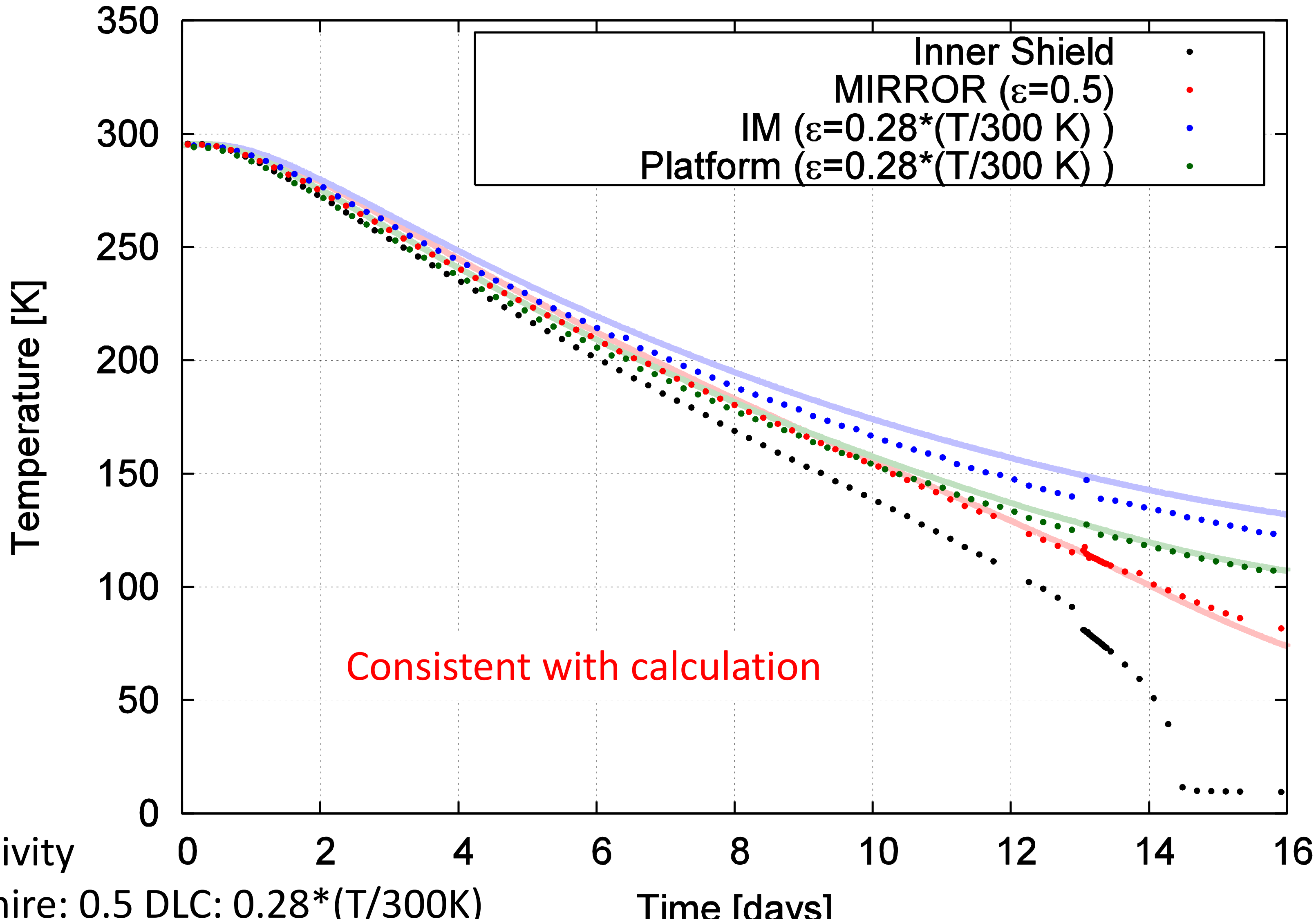




Payload designed and made by R.Kobayashi, S.Koike (KEK)

Results (cooling from 300 K)

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

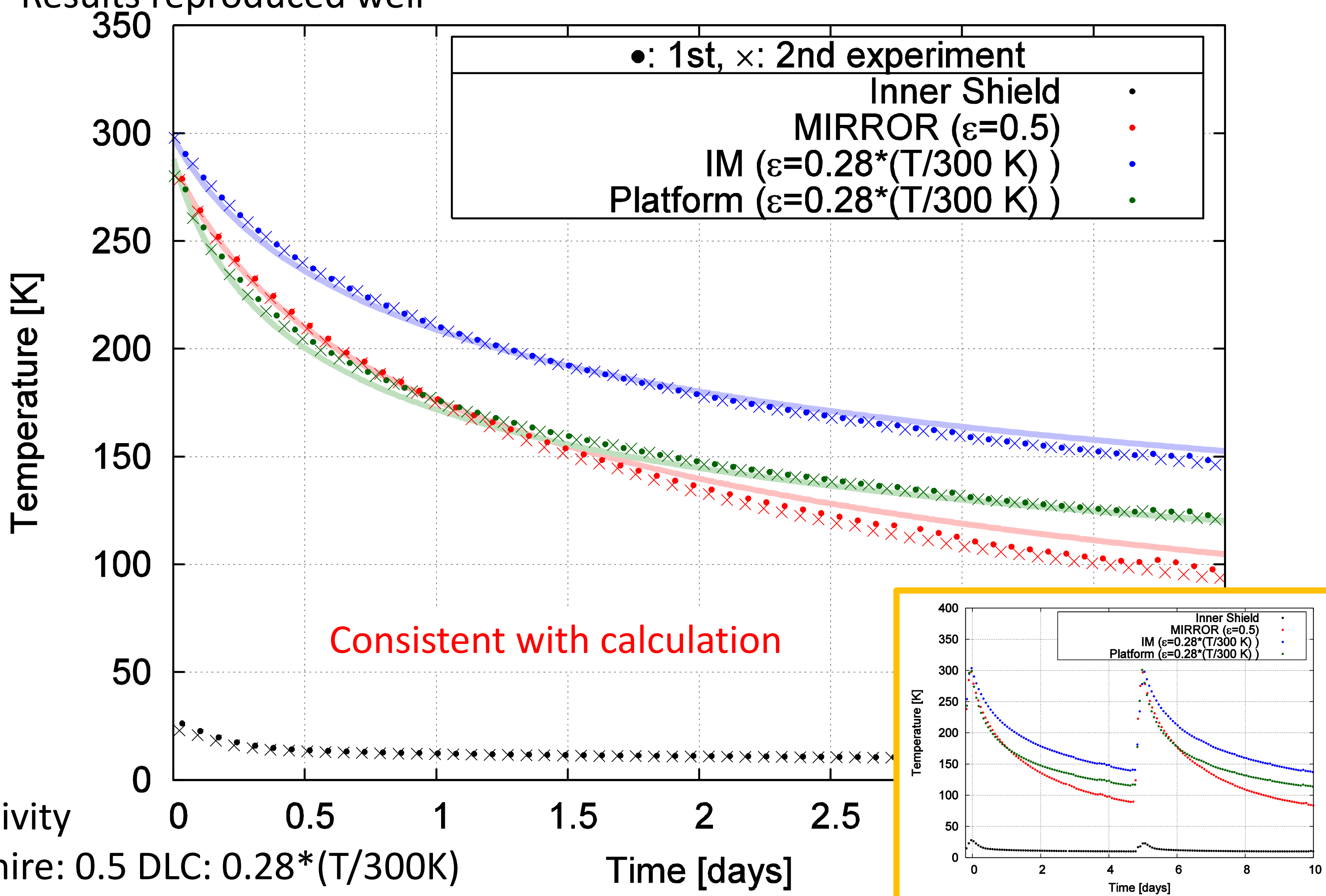


Emissivity

Sapphire: 0.5 DLC: 0.28*(T/300K)

Results (heating up and cooling down)

- After shield cooled down completely
- Data for cooling time when KAGRA mirror defrosted
- Results reproduced well



Emissivity
Sapphire: 0.5 DLC: 0.28*(T/300K)

- Summary
  - Cooling time of KAGRA is calculated
  - Calculation model predicts cooing time correctly
    - Small 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