Optical loss study using a cryogenic folded cavity

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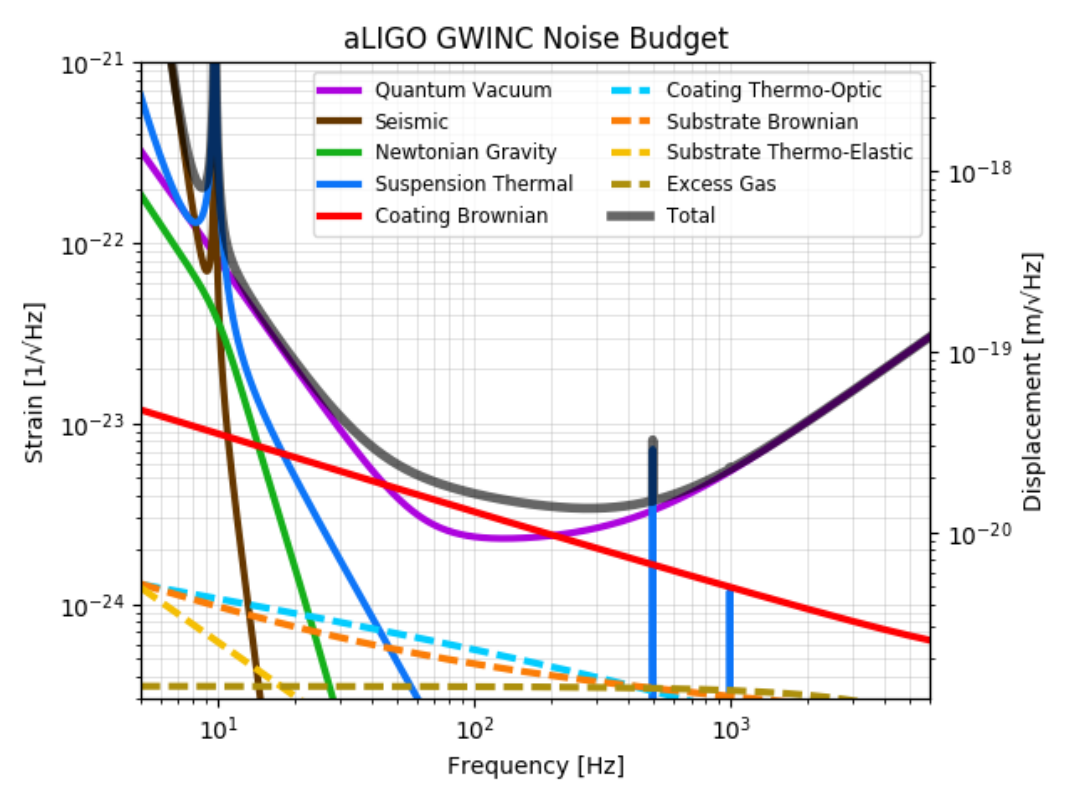
Abstract

- ✓Future gravitational-wave detectors (GWDs) will employ cryogenically cooled test masses to improve the sensitivity.
- ✓A cryogenic mirror in the GWD can suffer from the formation of the molecular layer on its surface.
- ✓The optical loss induced by the molecular layer can prevent the cryogenic operation of a cryogenic GWD.
- ✓We have developed a cryogenic folded cavity and investigated the impacts of the molecular layer.

Sensitivity of current GWD



- Thermal noise is a limiting noise source.
- Future gravitational-wave detectors will employ cryogenic mirrors.
  -> thermal noise reduction

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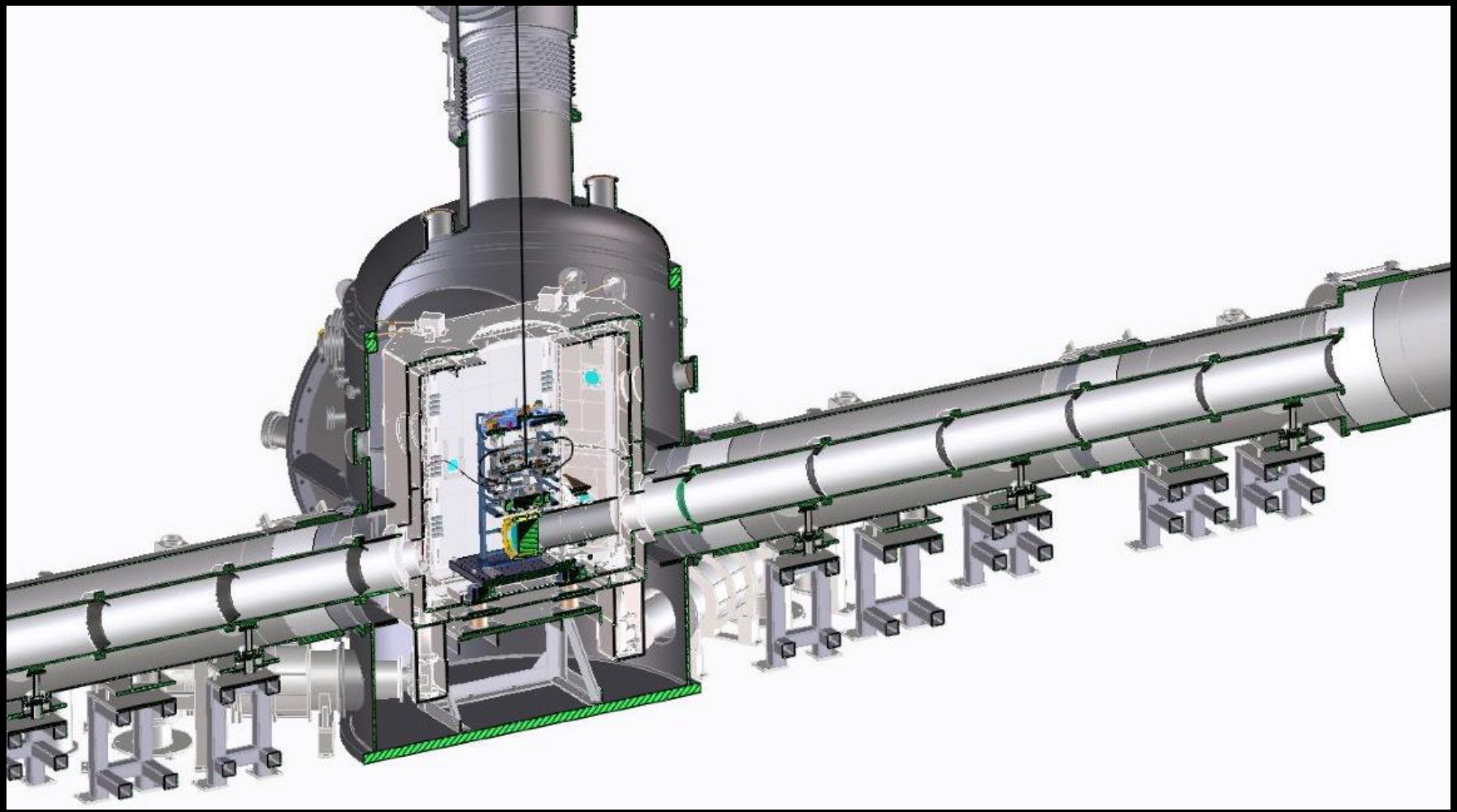
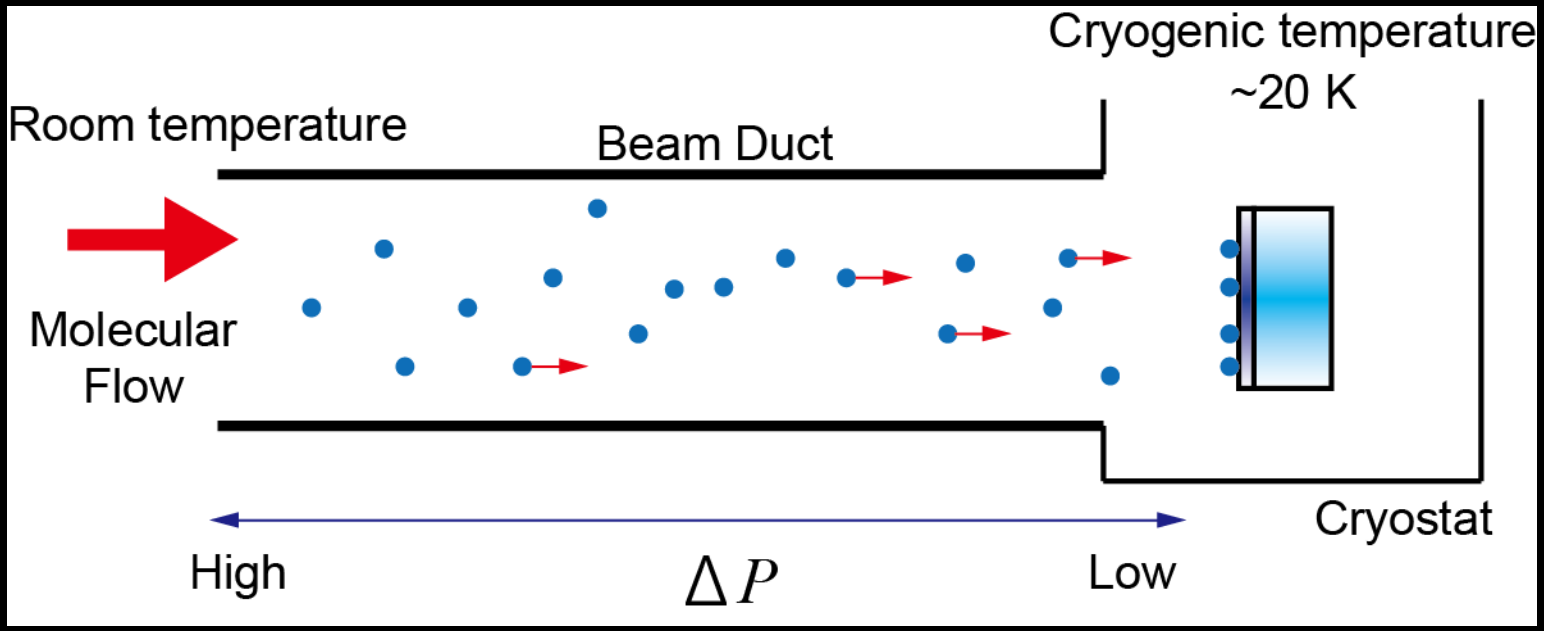
✓underground

✓cryogenic

Cryogenic system of KAGRA



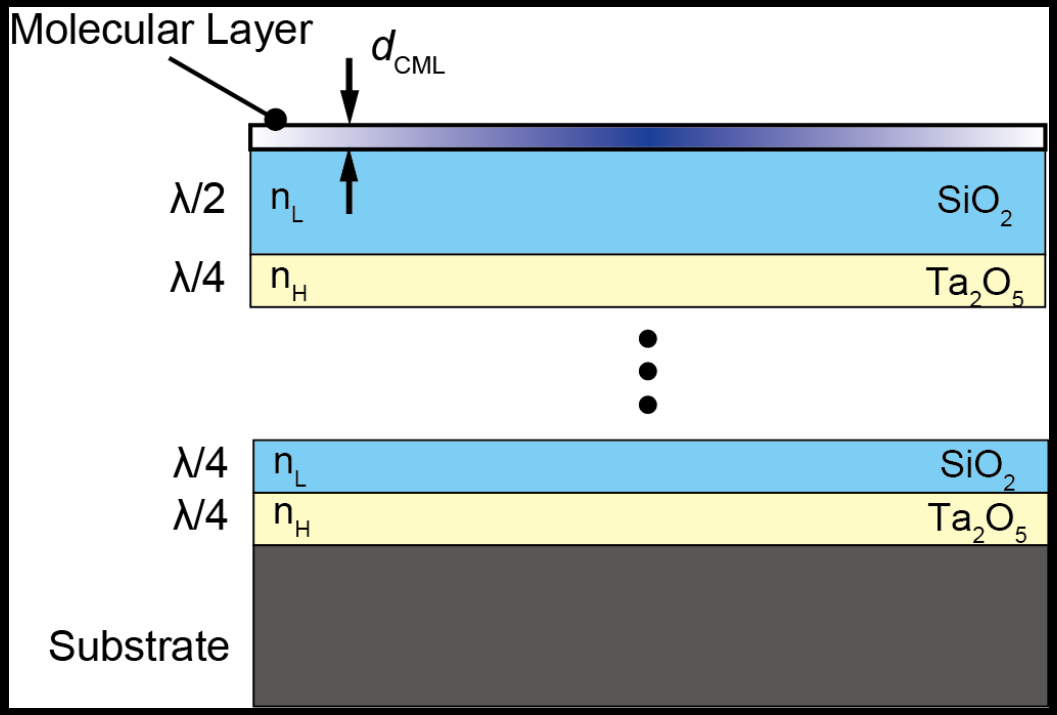
Molecular flow to the mirror



- ✓ Cryogenic mirror is exposed to the room temperature vacuum.
  -> molecules are adsorbed onto the mirror

Hasegawa+ PRD (2019)

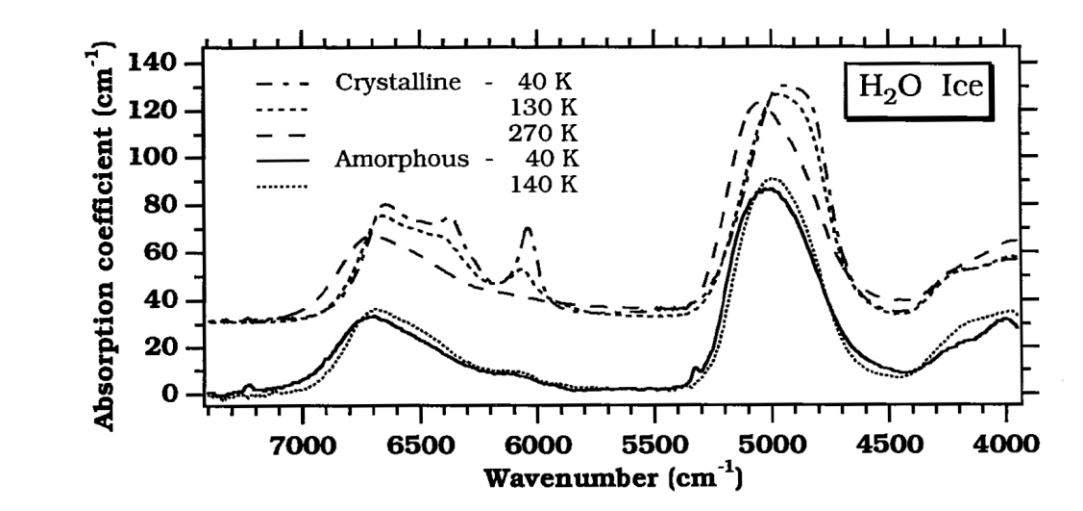
Cryogenic molecular layer (CML)



- ✓ Continuous molecular flow leads to the formation of cryogenic molecular layers (CMLs).
- ✓ Water molecules are main components.
  -> amorphous ice

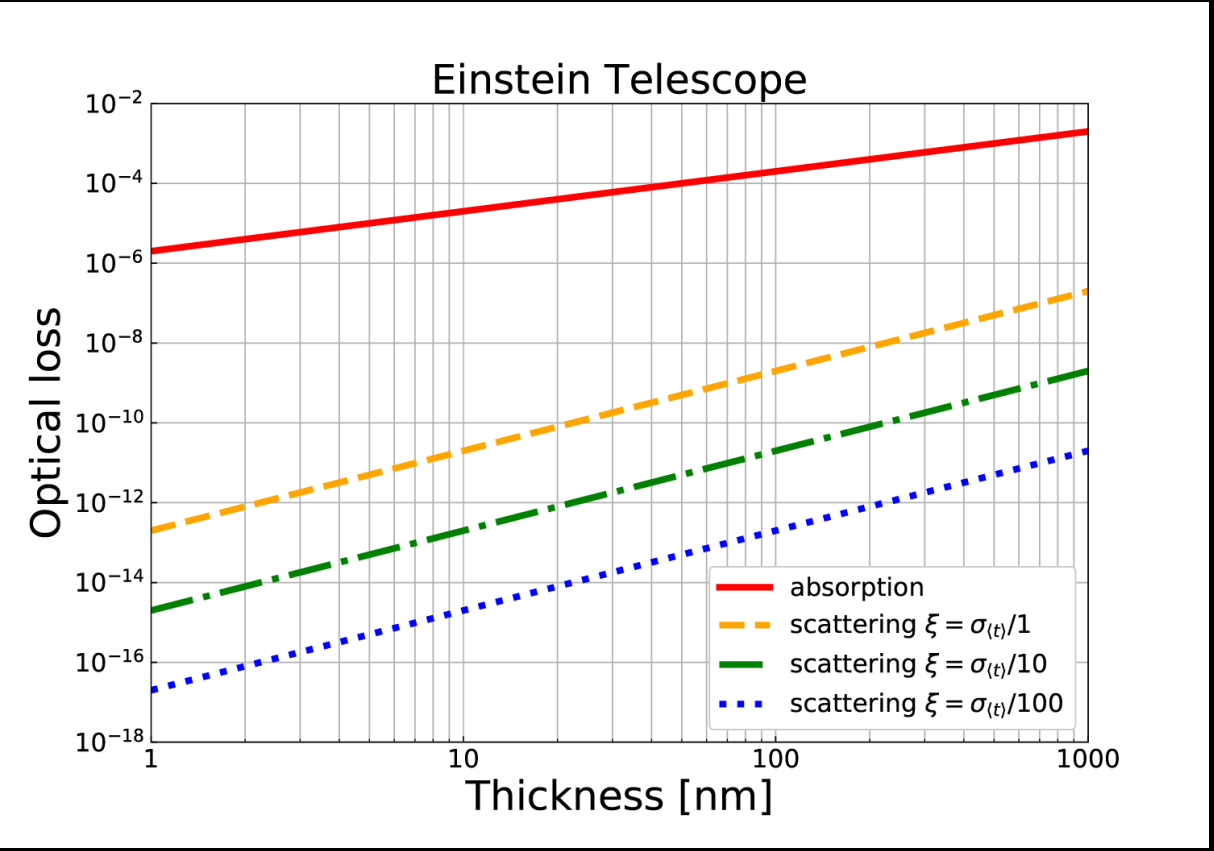
Absorption of amorphous ice

- ✓The Einstein Telescope will employ longer wavelength laser (1550 nm).
- ✓Amorphous ice has large absorption.
  -> large optical loss
- ✓This effect has not been taken into account.



Schmitt+ "Optical Properties of Ices From UV to Infrared", Springer (1998)

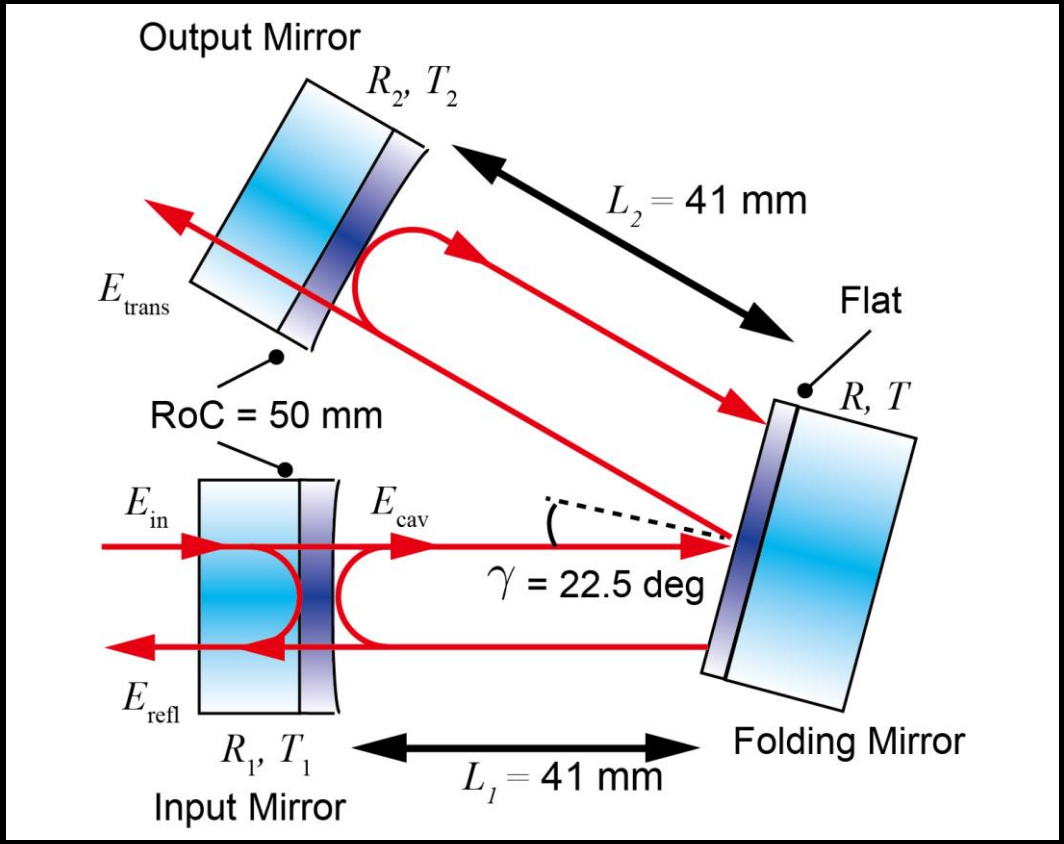
For the case of the ET



Tanioka+ PRD 2020

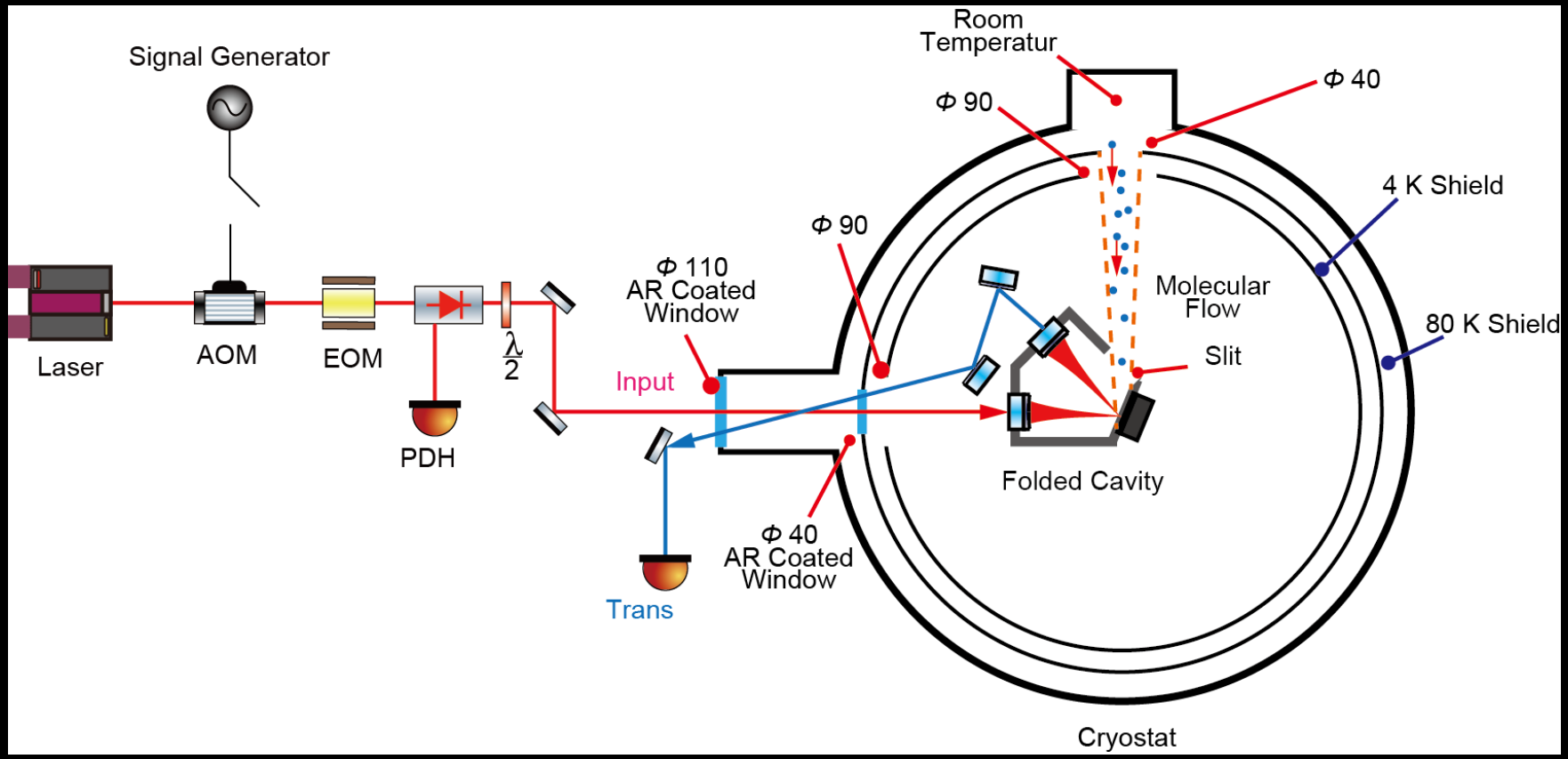
ξ: the correlation length which characterizes the periodic length of the roughness along the surface.
σ: the standard deviation of thickness.

Folded Cavity



- ✓ Composed by 3 mirrors.
- ✓ Finesse is $\sim 2 \times 10^5$.
- ✓ 1550 nm wavelength laser.

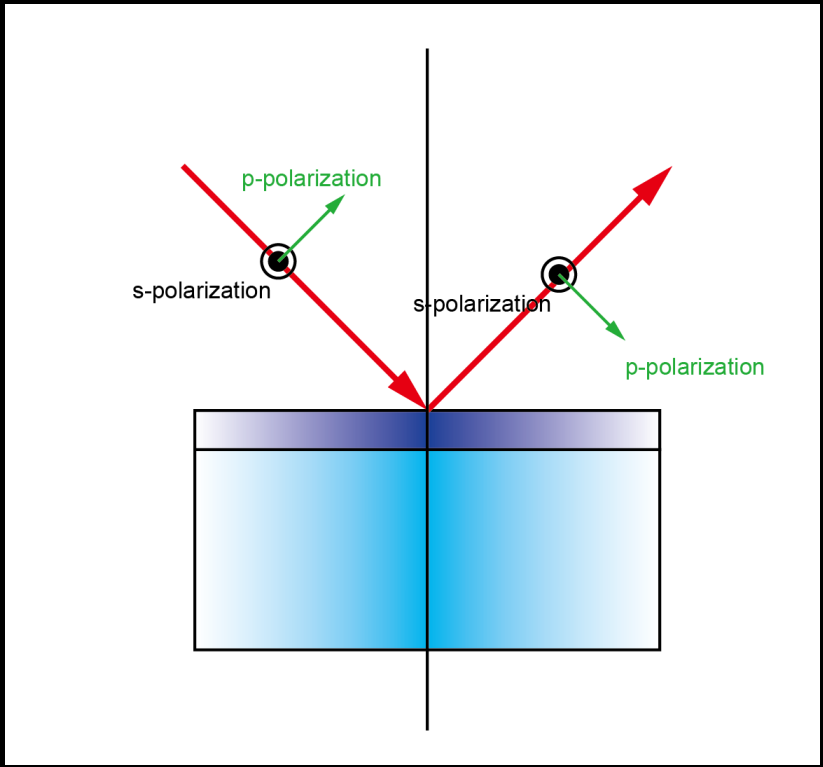
Overview of the setup

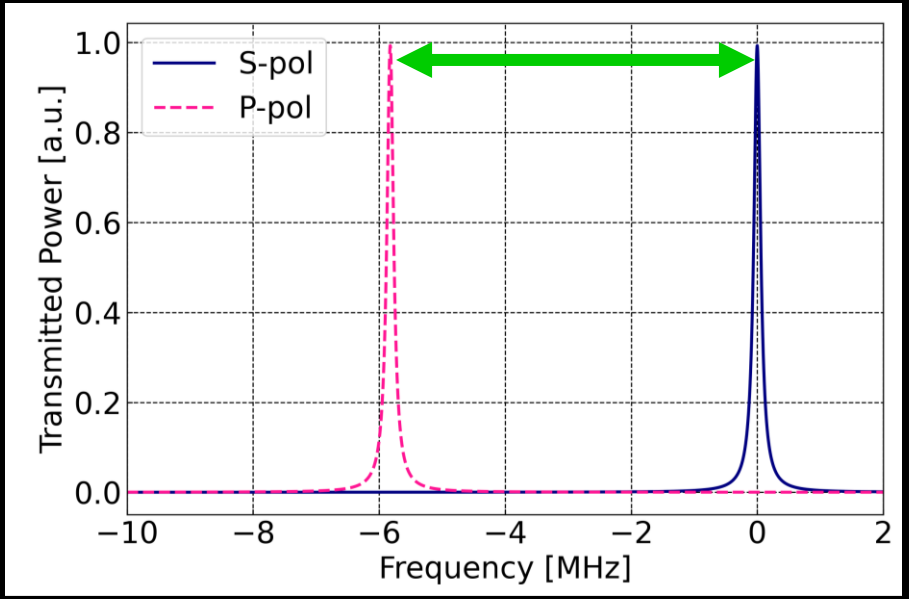


- ✓ The cavity is cooled down to 10 K.
- ✓ A folding mirror is exposed to the room temperature vacuum.
  -> CML formation

Cavity enhanced ellipsometry (CEE)

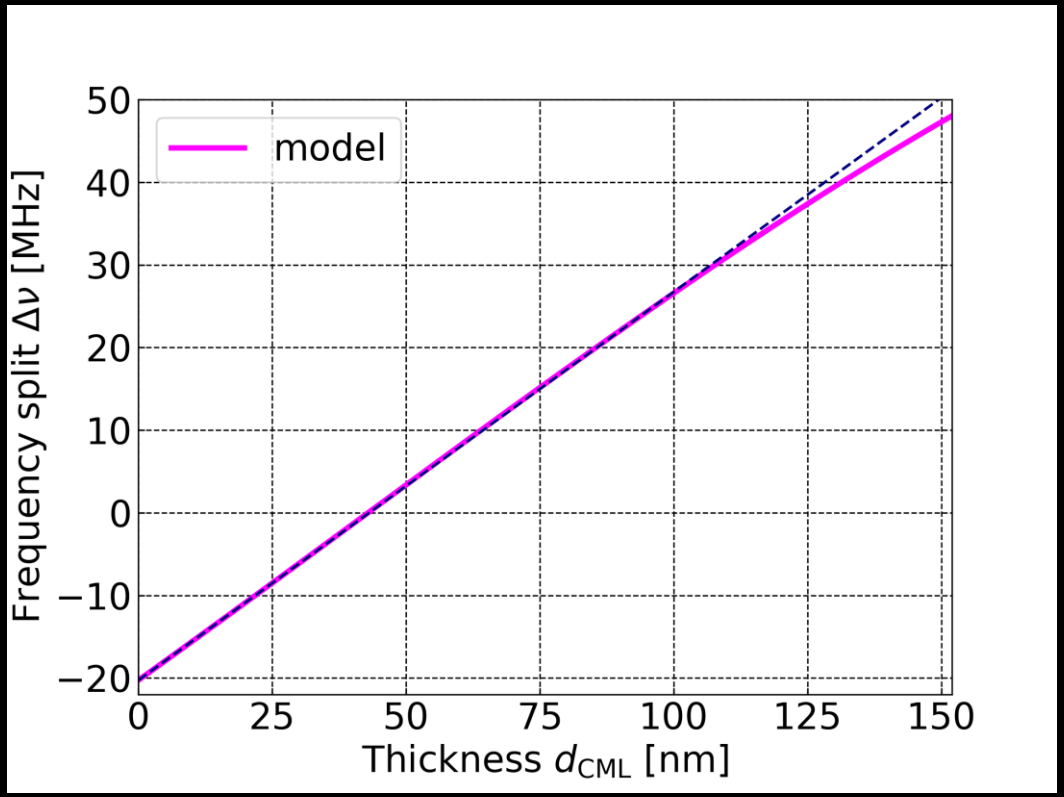
- ✓A folding mirror introduces a phase shift between P- and S-polarization
  -> resonant frequency split





Cavity enhanced ellipsometry (CEE)

✓The resonant frequency split drifts as the CML thickness increases.



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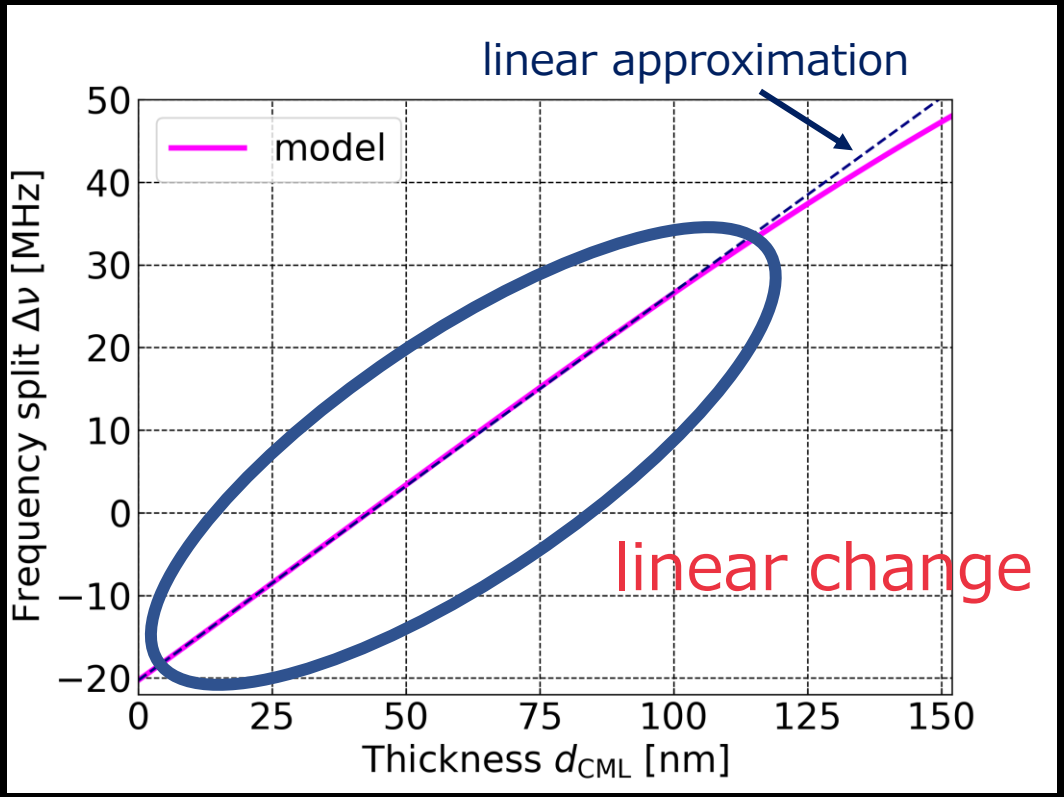
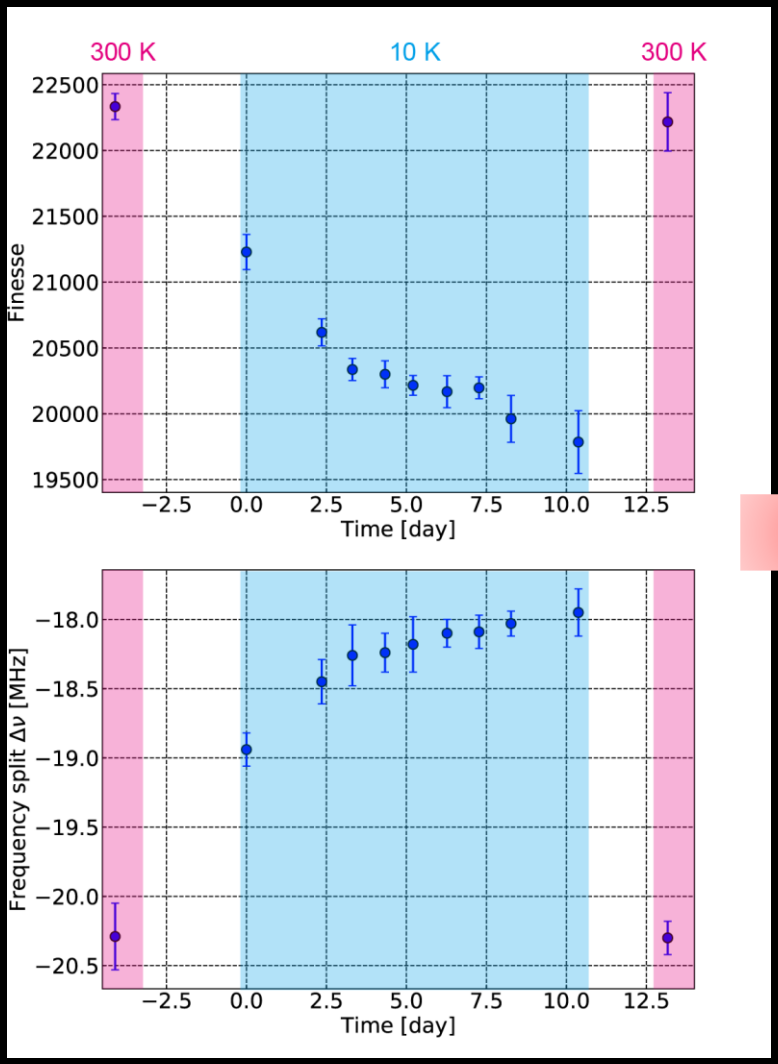
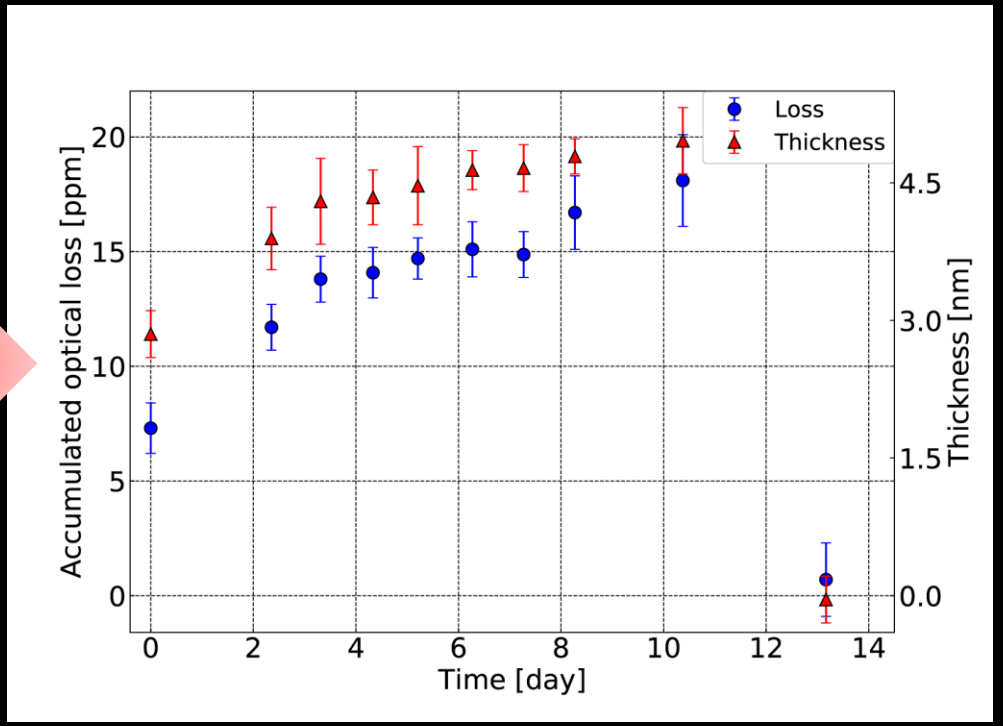
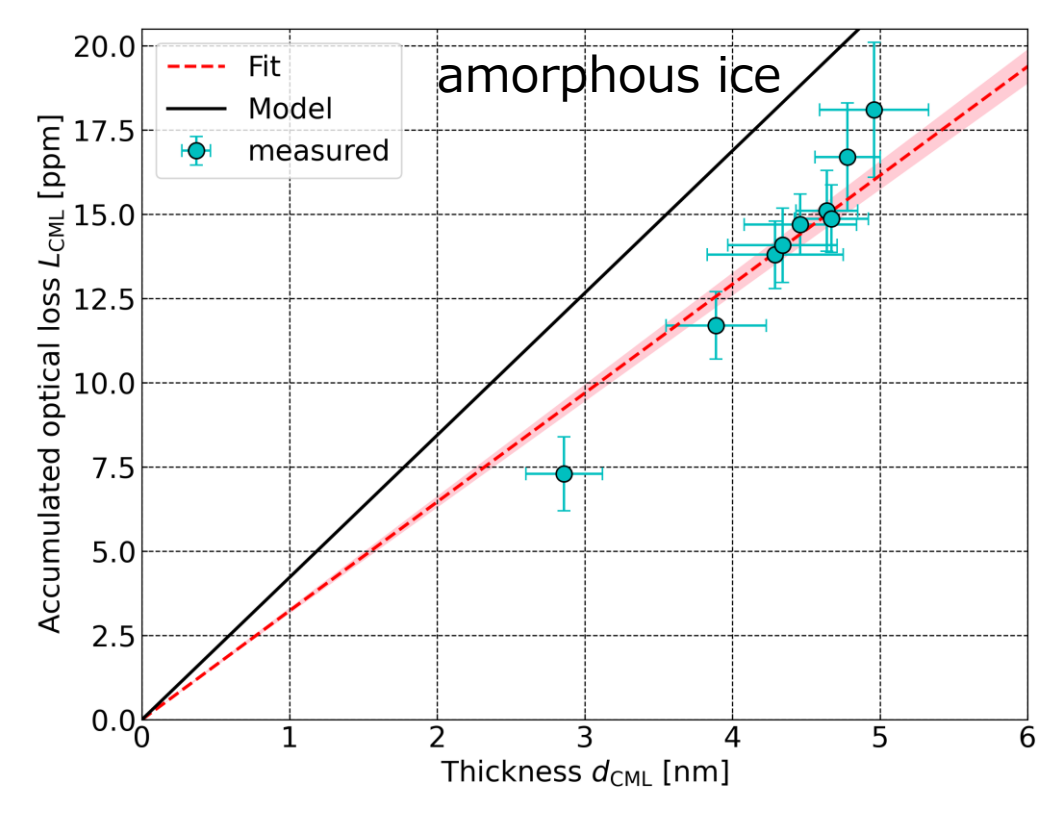


Finesse and CEE trends





Comparison to the amorphous ice model



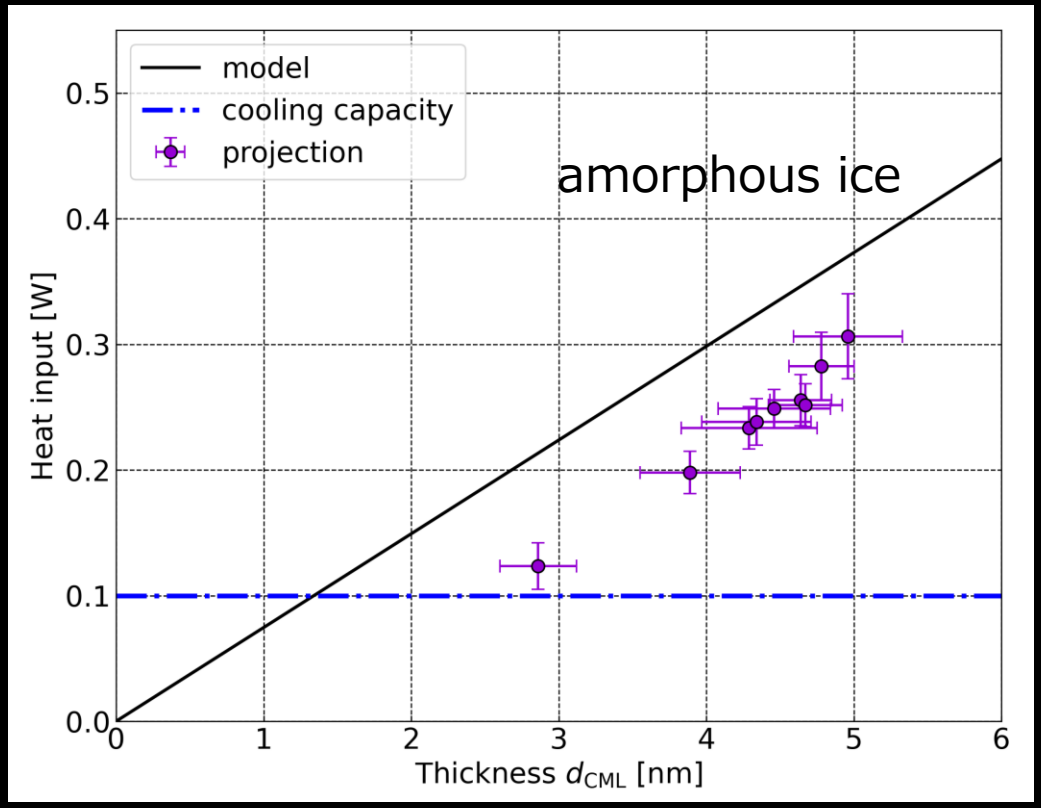
Lambert-Beer Law is assumed

$$L_{\mathrm{CML}} = 2\alpha d_{\mathrm{CML}}$$

α: absorption coefficient

- ✓ Assumed that the scattering is negligible.
- ✓ Measured value is assumed for the amorphous ice (Schmitt+ 1998).
- ✓ Smaller than compared to the amorphous ice model.
- ✓ Further studies are needed.

Implication to the ET



18 kW intra-cavity power

- ✓ The heat input induced by the CML can exceed the cooling capacity even though a few nanometer thickness.

Future prospect

- ✓A study on the CML toward the future GWDs has just begun.
- ✓Further investigations on the CML are important for the future GWDs.
  - ✓more precise characterization of the CML
- ✓Measurements in the prototype system.
  - ✓development of vacuum system
- ✓This setup can be used for the R&D to solve the problem of the CML.
  - ✓CO_2 laser induced desorption

Summary

- ✓Molecular layers formed on a cryogenic mirror surfaces will introduce optical loss.
- ✓The CML can be a crucial problem in the future cryogenic GWDs.
  - ✓even though a few nm thickness
- ✓We developed a cryogenic folded cavity.
  - ✓cavity enhanced ellipsometry
  - ✓estimation of the optical loss of the CML
- ✓Further investigations would be important for future cryogenic GWDs.