Current status of CSL experiment

Ando lab. seminar 3.2. 2018

Kentaro Komori

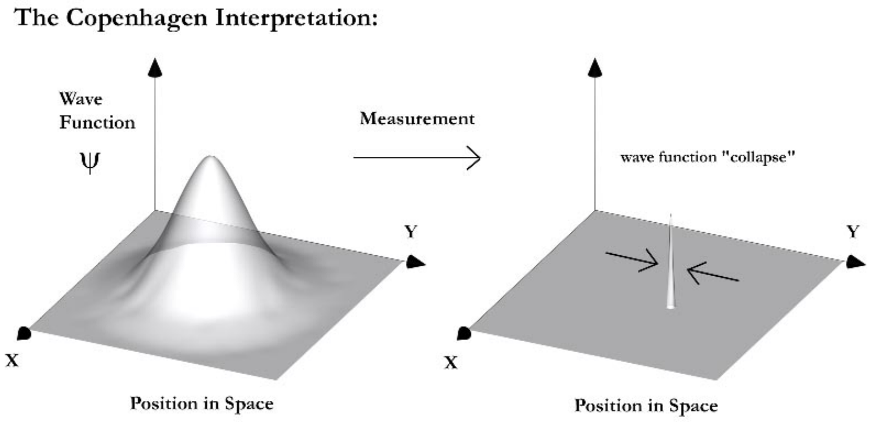
Contents

- Simple introduction of CSL model
- Picking up main experiments which set the upper limit of CSL model
- New ideas for improving the upper limit with a thin tungsten wire

Contents

Interpretations on quantum mechanics

- MANY!
- Most popular one: Copenhagen interpretation



Measurement → $\boxed{\text{System}}$

the set of probabilities → one value

- Many worlds interpretation, etc…

Bell inequalities violation

- There is an interpretation which was denied by experiments such as De Broglie-Bohm theory (an example of hidden variable theory).

Objective collapse model

- Similar to Copenhagen interpretation, but firmly objective

Copenhagen	Objective collapse
✓ Including collapse ✓ Non-committal about the objective reality of the wave function	✓ Regarding the wave function as real ✓ Random collapse (spontaneous localization)

- Ghirardi-Rimini-Weber theory → Contaneous Spontaneous Localization (today's topic)
- Penrose interpretation: gravitational stress in GR spacetime

Continuous Spontaneous Localization

- Improved GRW theory
- Stochastic non-linear modification of standard quantum mechanics

✓ Time scale of collapse is too long to observe. ✓ Quantum mechanics holds.	✓ Rapid localization ✓ Emergence of the classical world

small ⟵ typical size for collapse ⟶ large

- Characterized by two phenomenological constants, a collapse rate λ and a length r_C
- Can be tested experimentally!

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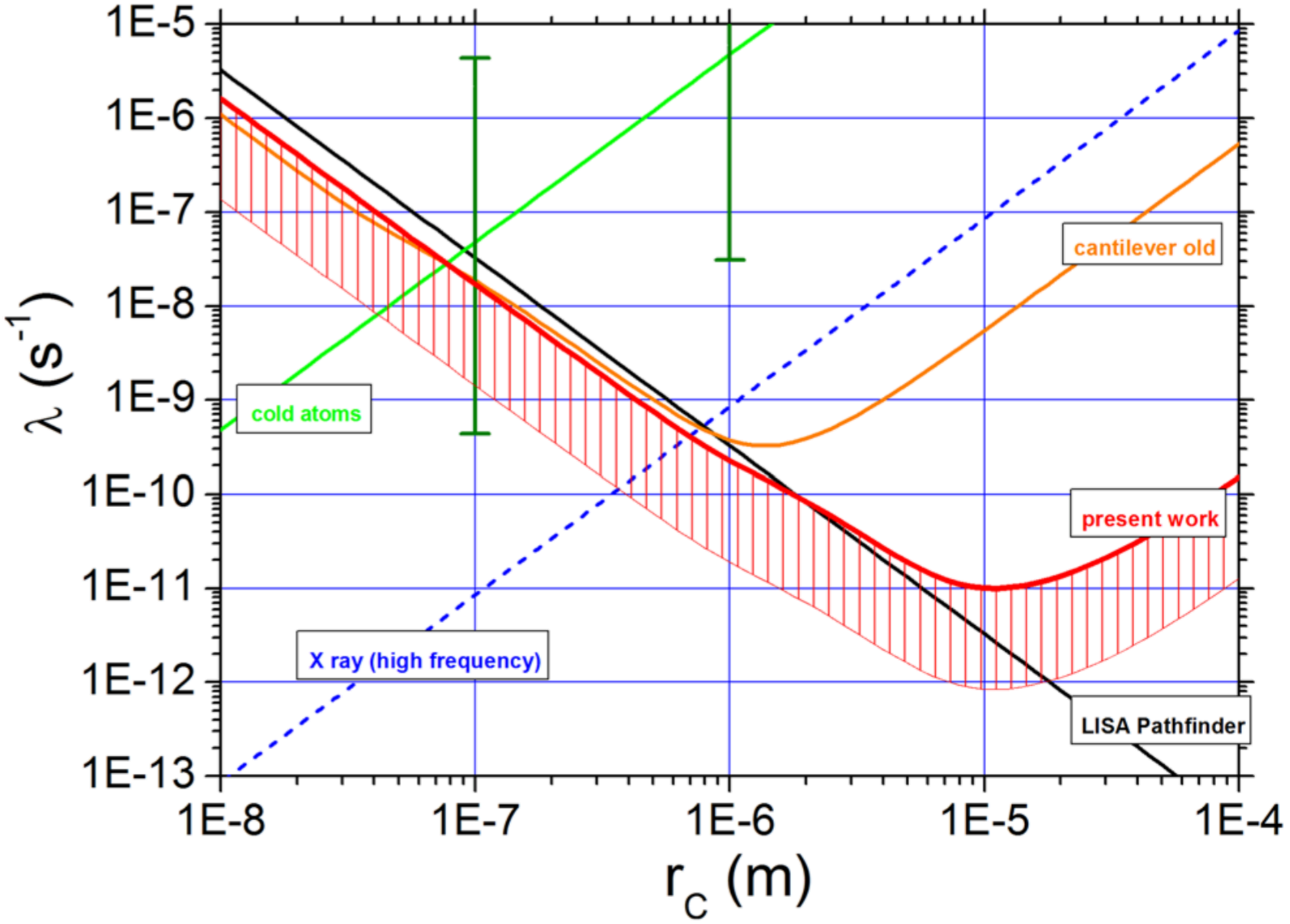
Current status of CSL model test

- Some experiments set the upper limits of two parameters.
- Having "lower limit", which is totally different from the other violation search
- Particle type: $\lambda / r_C^2 < \alpha$
- Oscillator type:

$$\lambda r_C^2 < \alpha \ (r_C < L)$$



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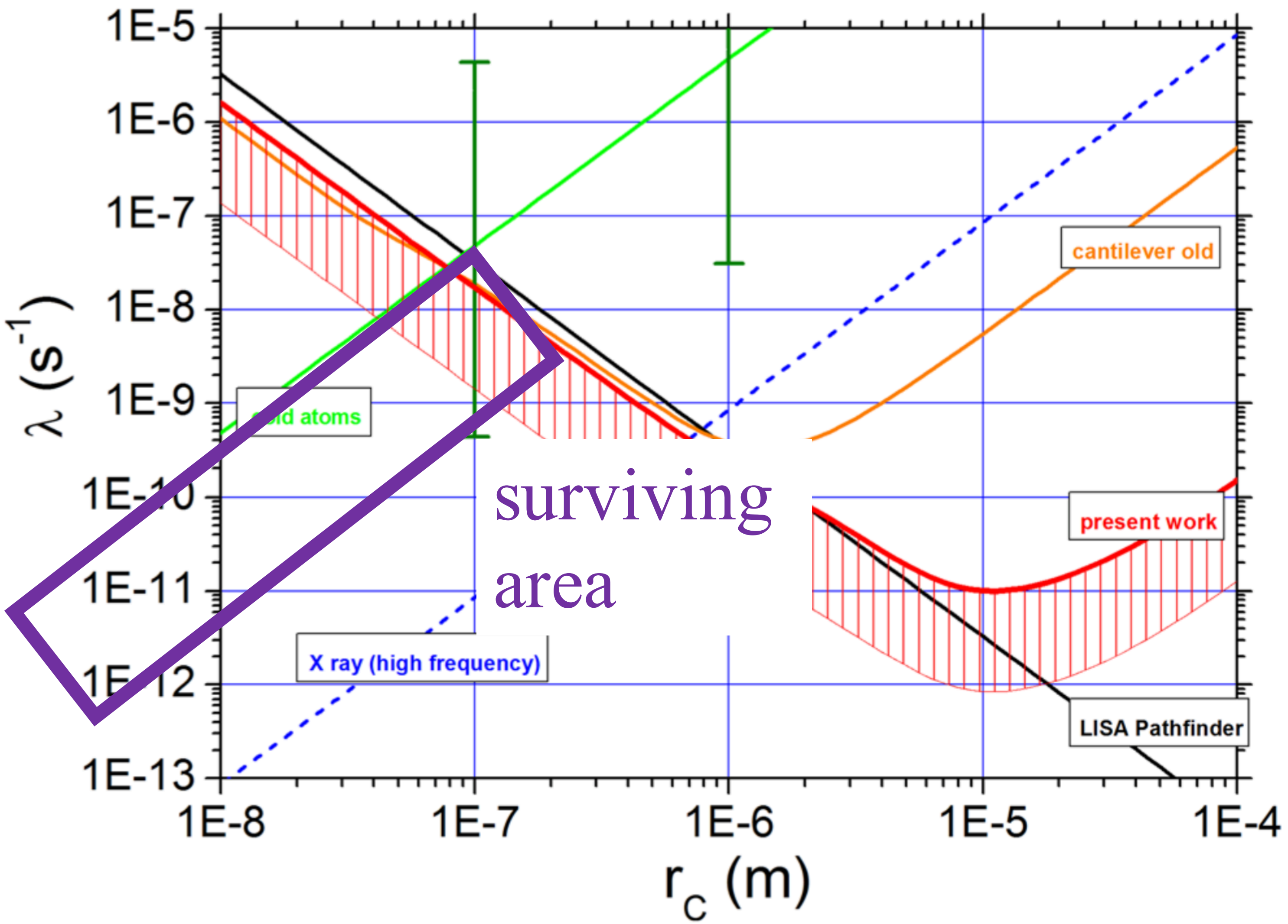

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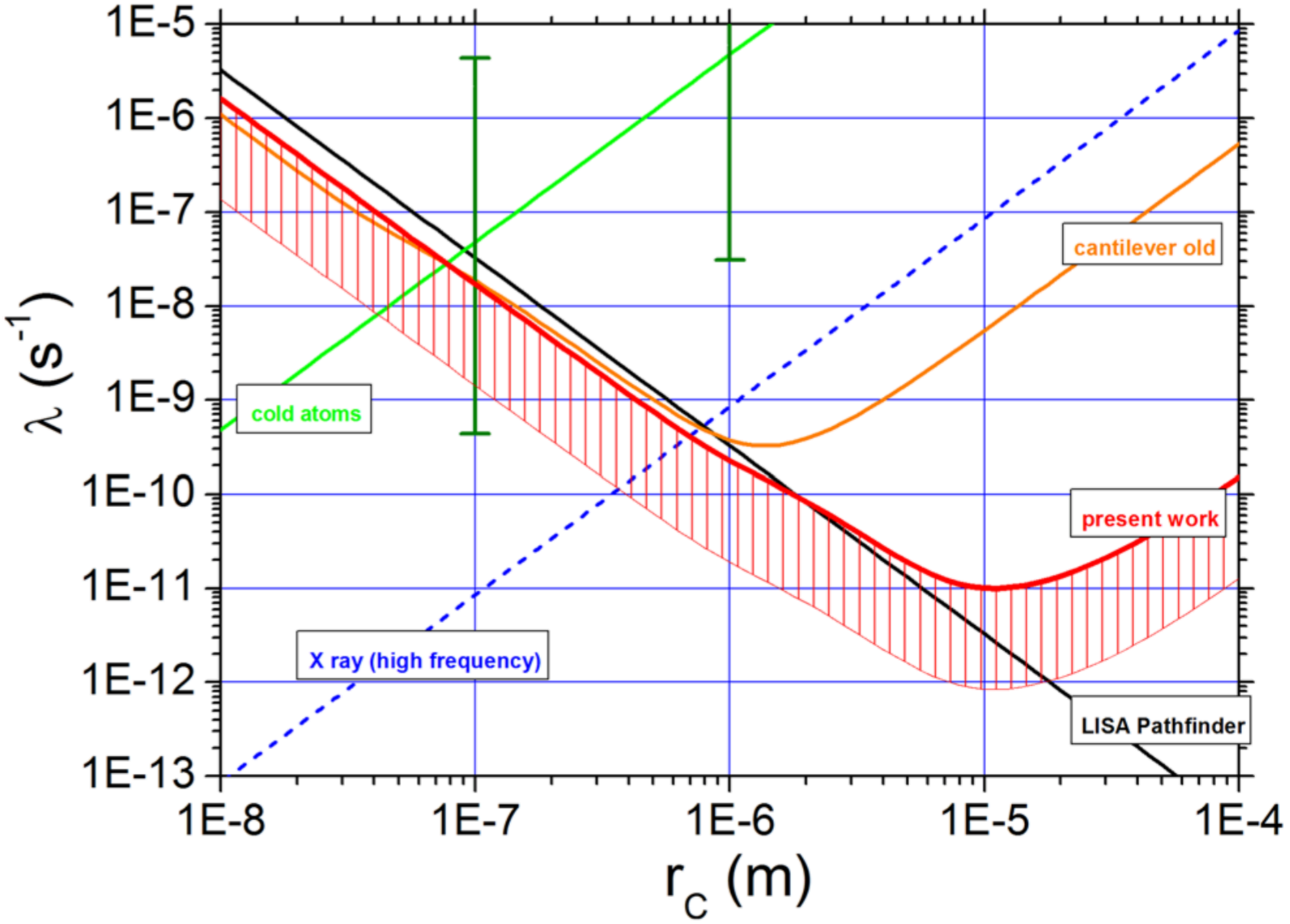
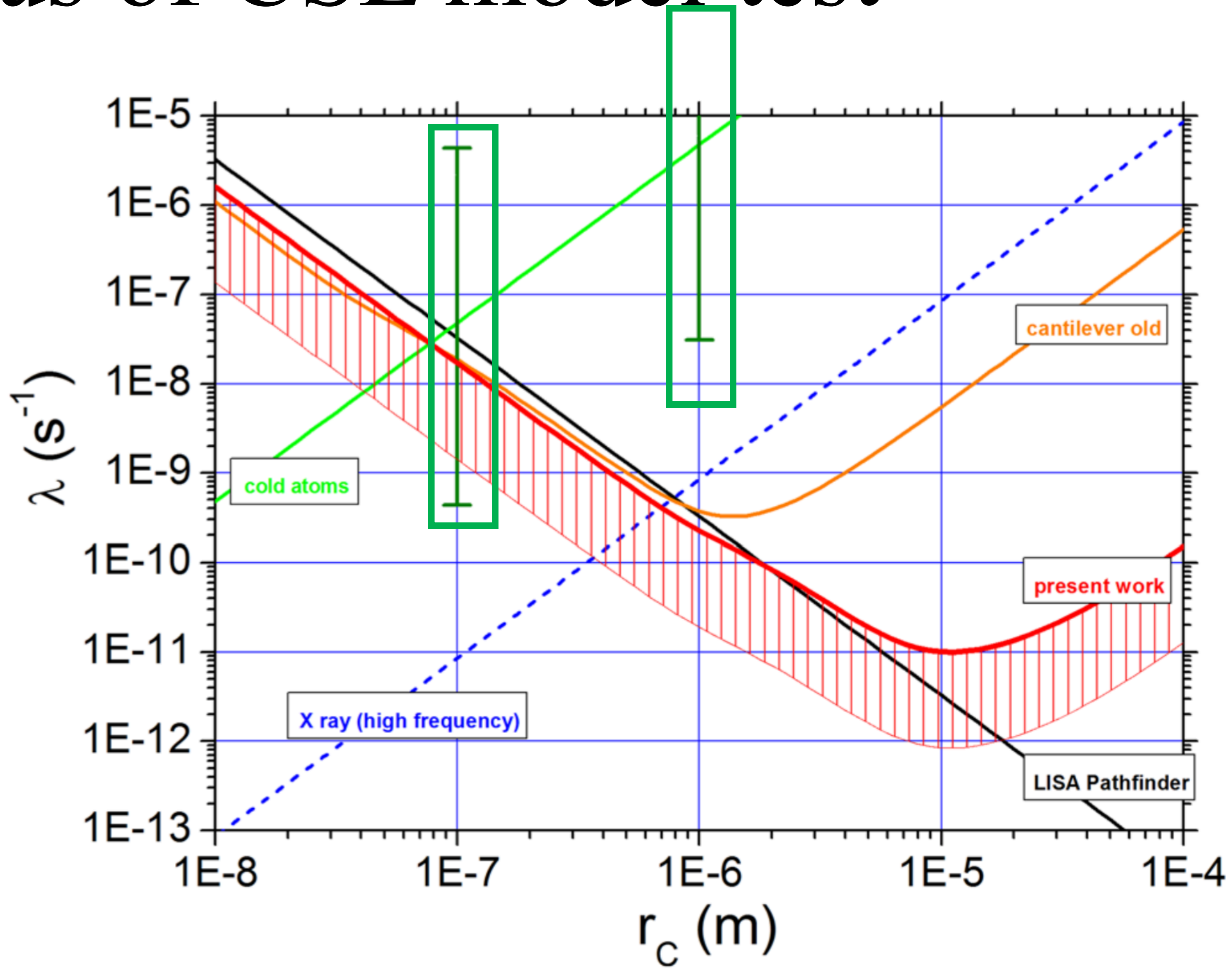


Current status of CSL model test

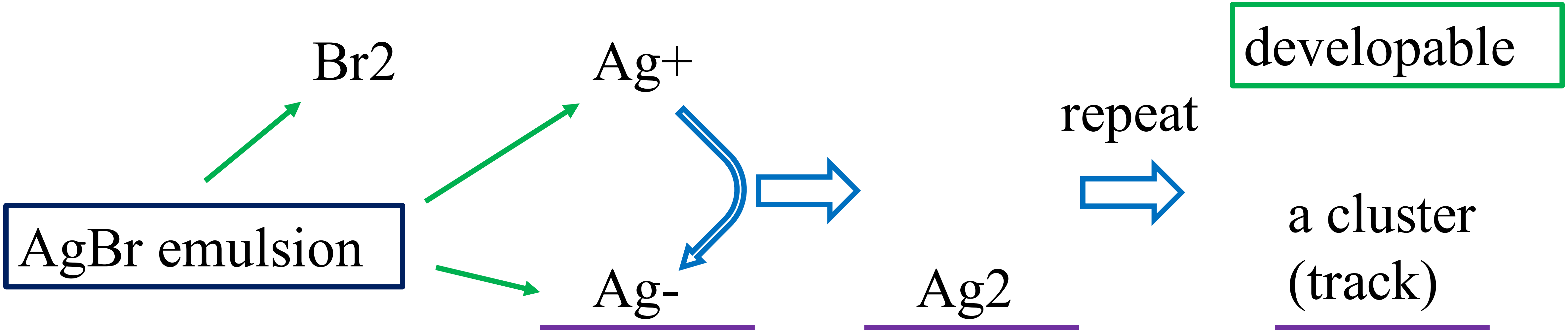
- Latent image formation in photography

Adler, J. of Phys. A, 40, 2935 (2007)



Latent image formation in photography

- Latent image formation process:



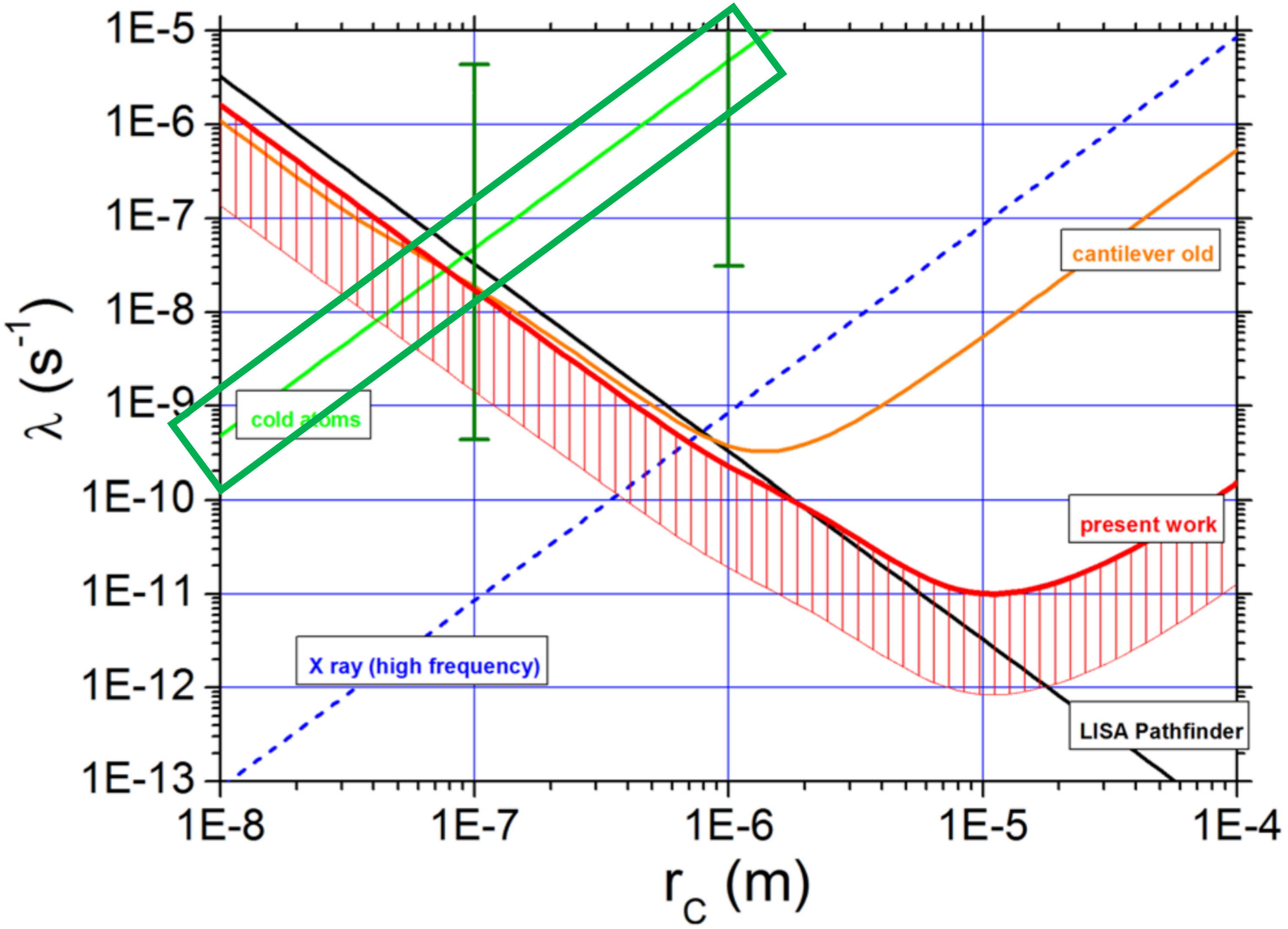
- If latent image formation constitutes measurement and CSL model is true, the state vector reduction must come from parameters:

$$\boxed{\lambda = 5\times 10^{-8\pm 2}\ \text{Hz}\ \ (r_C = 10^{-7}\ m)}$$

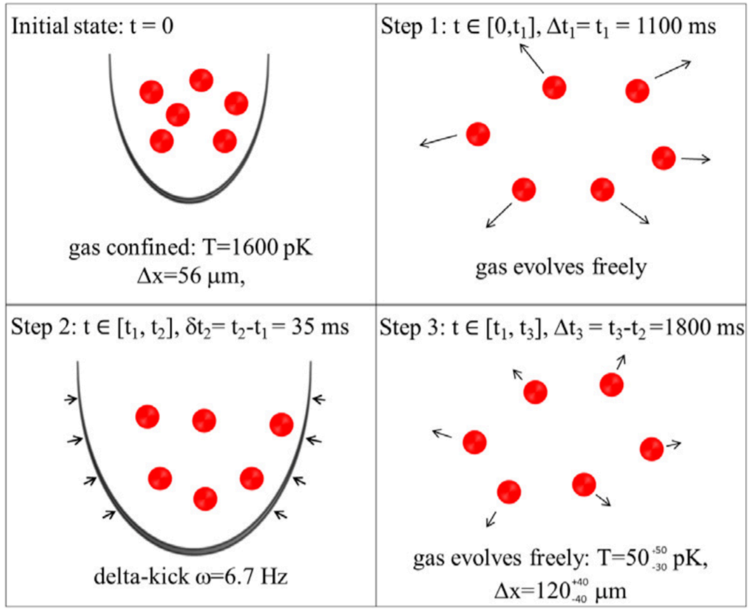
Current status of CSL model test

- Cold atoms

Bilardello+, Physica A, 462, 764 (2016)

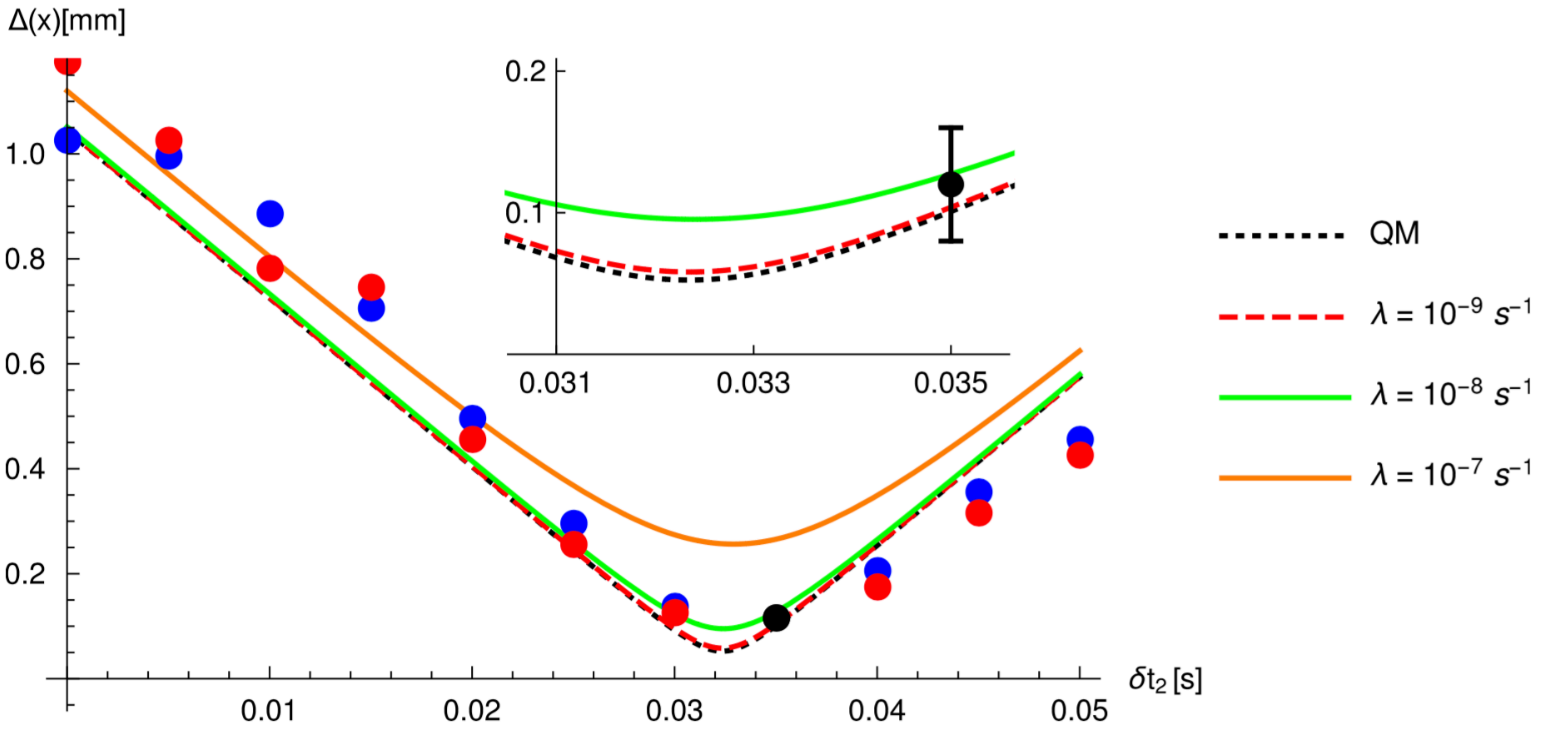


Cold atoms



- Observing position deviation of cold atoms after laser cooling
- The deviation could be larger due to CSL compared with following usual QM

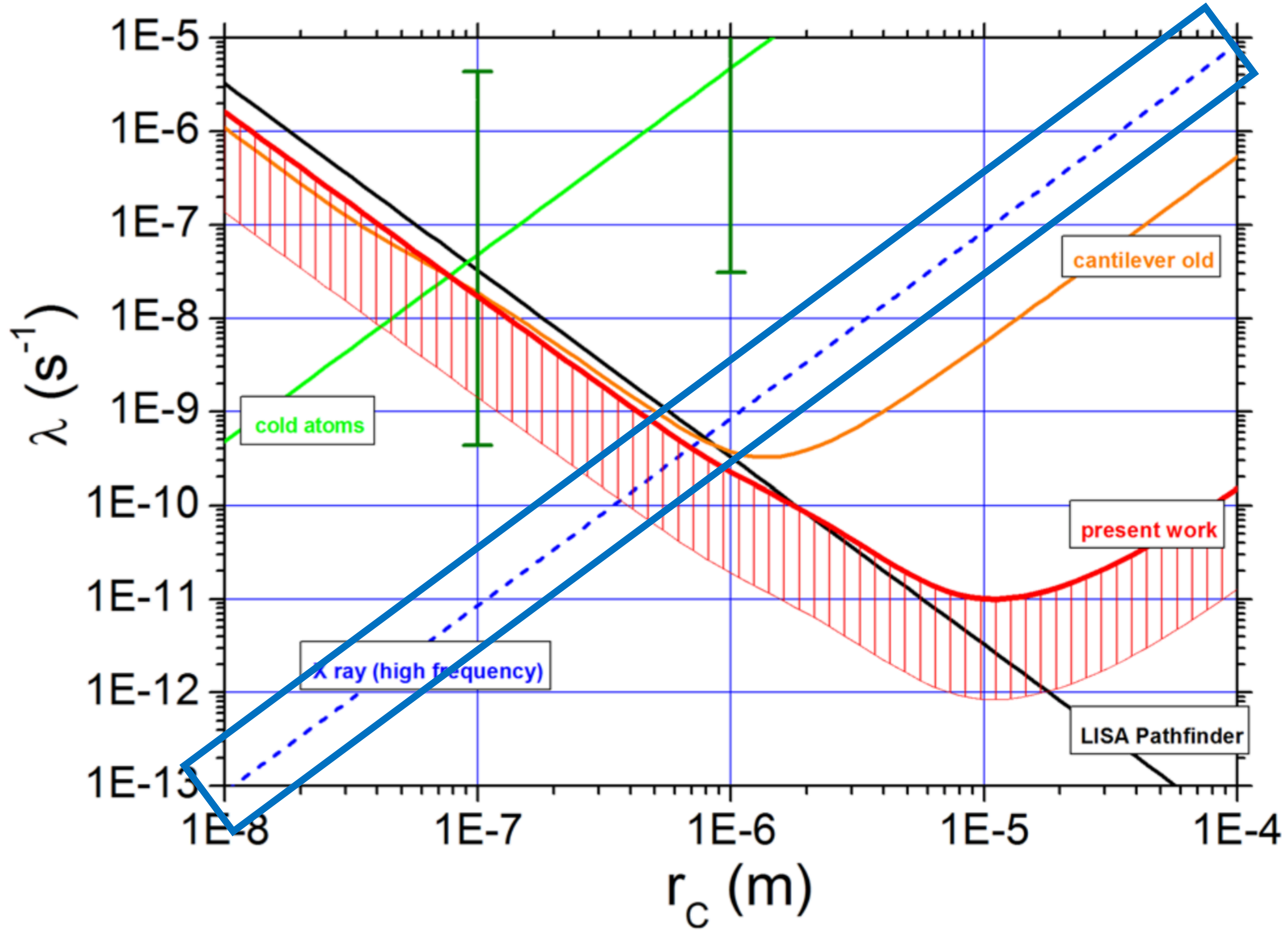
$$\boxed{\lambda/r_C^2 < 5\times10^6\ \mathrm{Hz}\ m^{-2}}$$



Current status of CSL model test

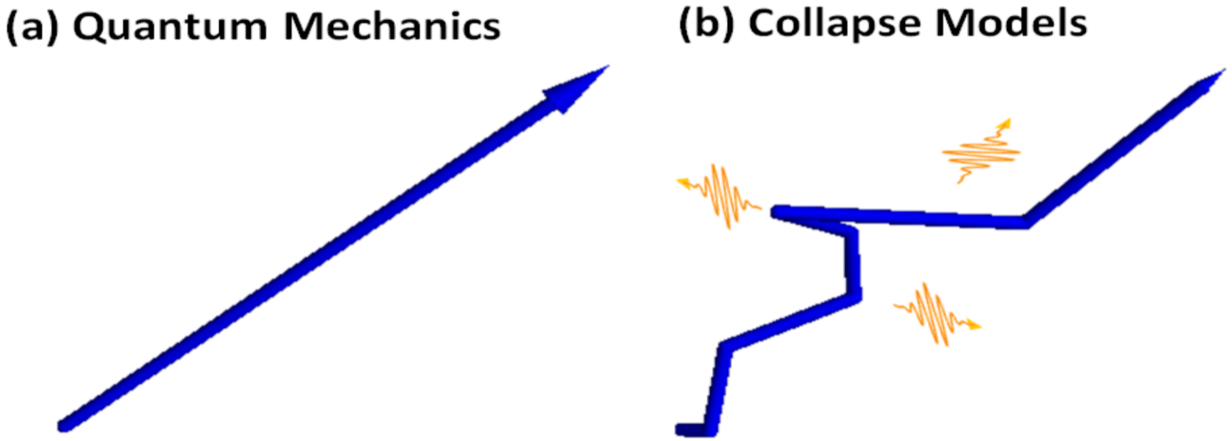
- X ray emission (very high frequency)

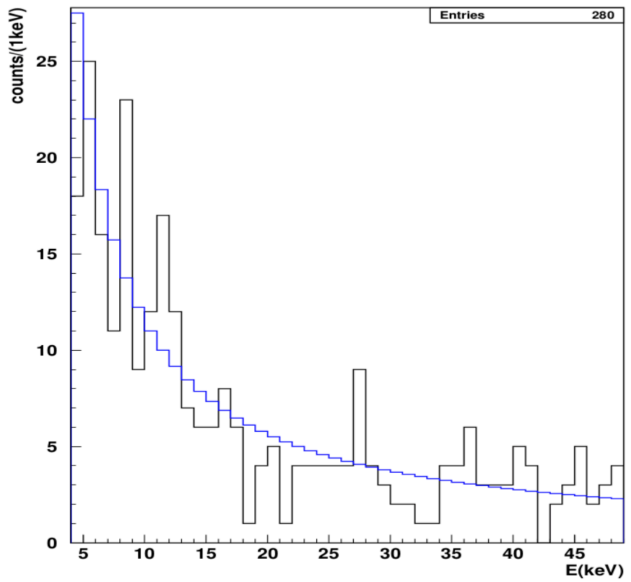
Curceanu+, J. Adv. Phys. 4, 263 (2015)



X ray emission

- Observing X ray emission from Germanium
- Energy spectrum of X ray could be larger when the electron is coupled with collapse field.
- Probing the collapse field at very high frequency ~ 1e18 Hz, where CSL may be not effective. $\boxed{\lambda/r_C^2 < 9\times10^2 \text{ Hz } m^{-2}}$

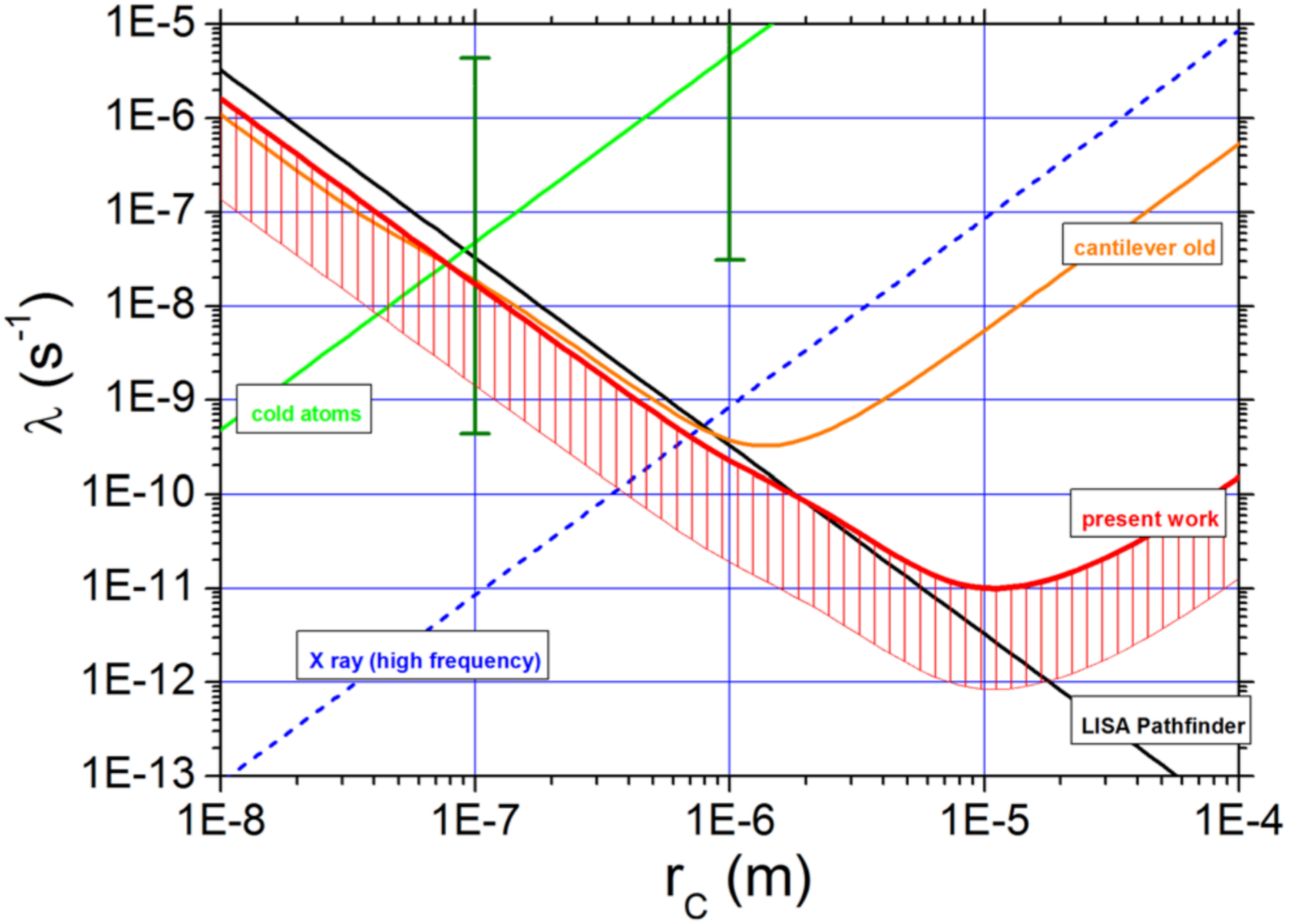




Current status of CSL model test

- Some experiments set the upper limits of two parameters.
- Having “lower limit”, which is totally different from the other violation search
- Particle type: $\lambda / r_C^2 < \alpha$
- Oscillator type:

$$\lambda r_C^2 < \alpha \ (r_C < L)$$



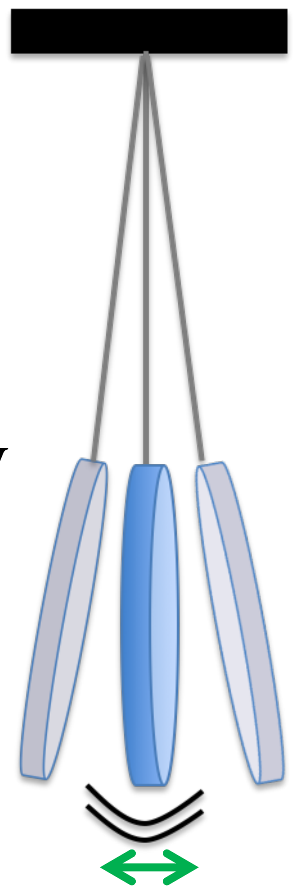
Oscillator type

- Random momentum diffusion occurring due to CSL

- White force noise like viscous thermal noise

$$S_{CSL} = \lambda r_C^2\, \rho / d$$
$$S_{th} = T\, Q / \omega_m$$

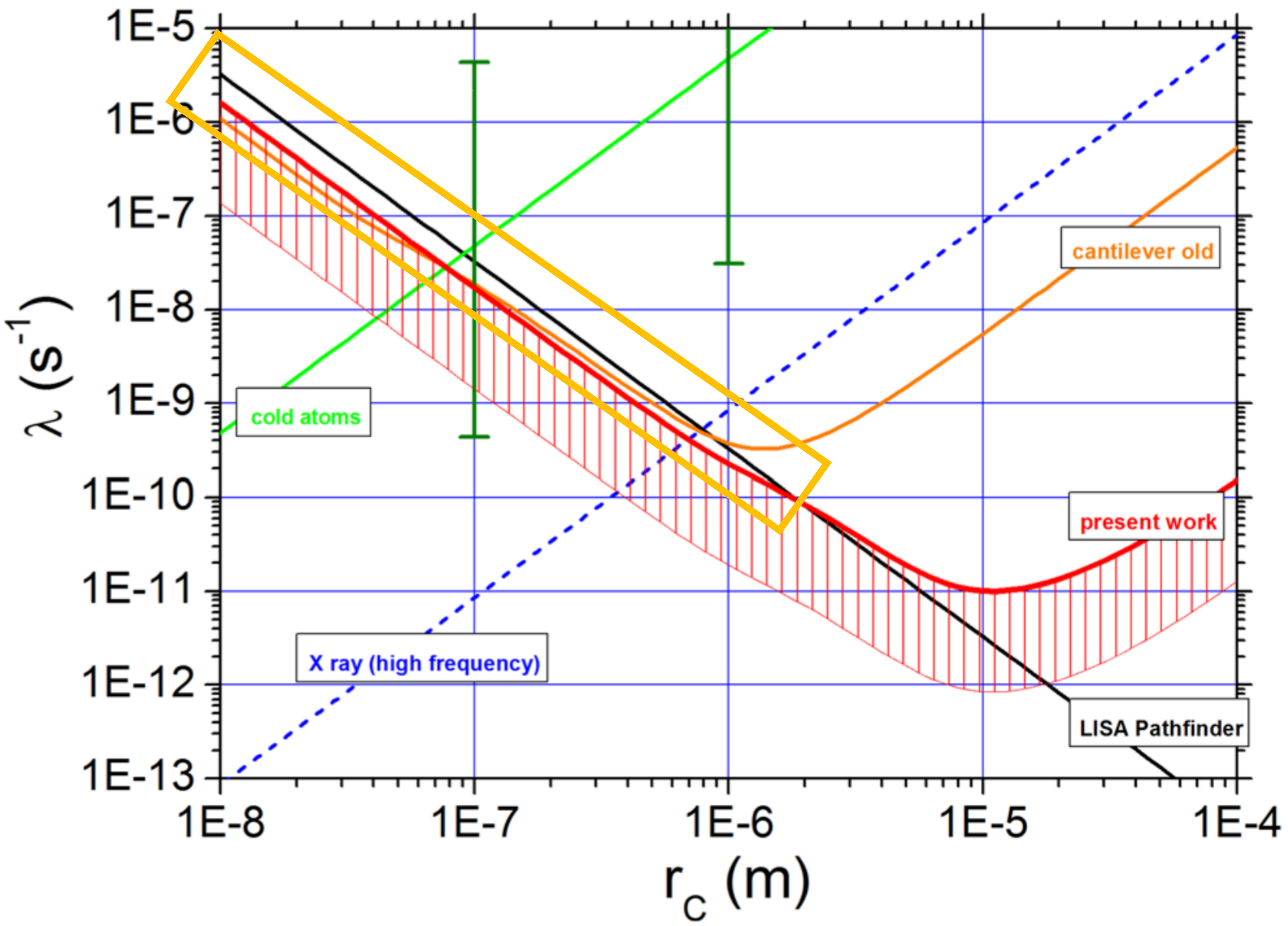
✓ Higher density, shorter width, lower temperature, higher Q value, lower resonant frequency is better.



Current status of CSL model test

- Previous cantilever

Vinante+, PRL 116, 090402 (2016)

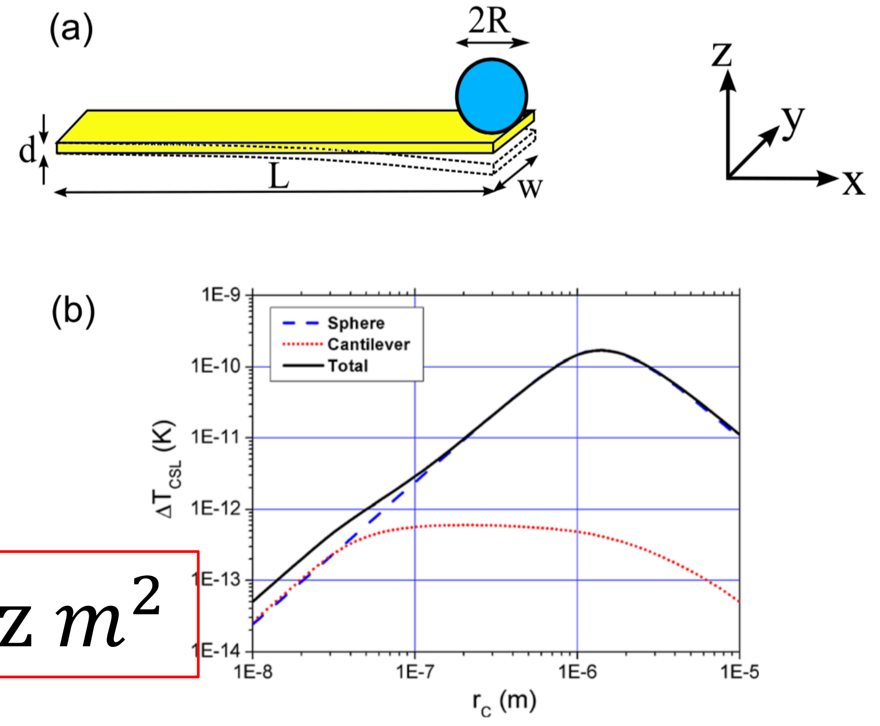


Previous cantilever

neodymium magnet: 4.5 um

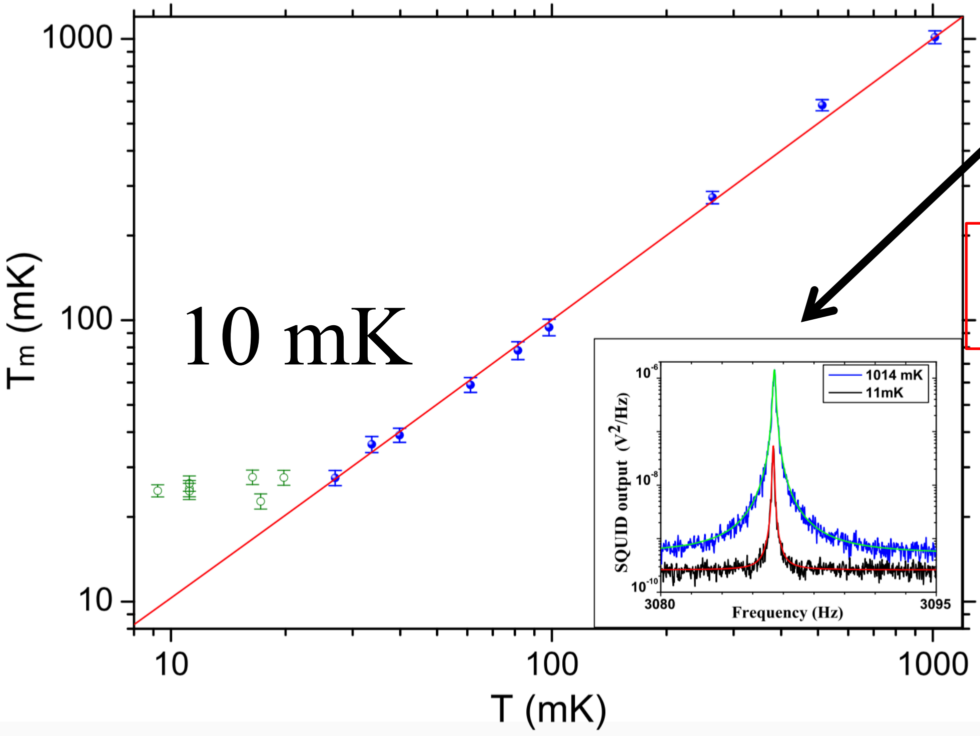
- Temperature dependence of displacement spectrum

silicon: 0.1 um



3.084 kHz

10 mK



$$\lambda r_C^2 < 2\times10^{-22}\ \text{Hz}\ m^2$$

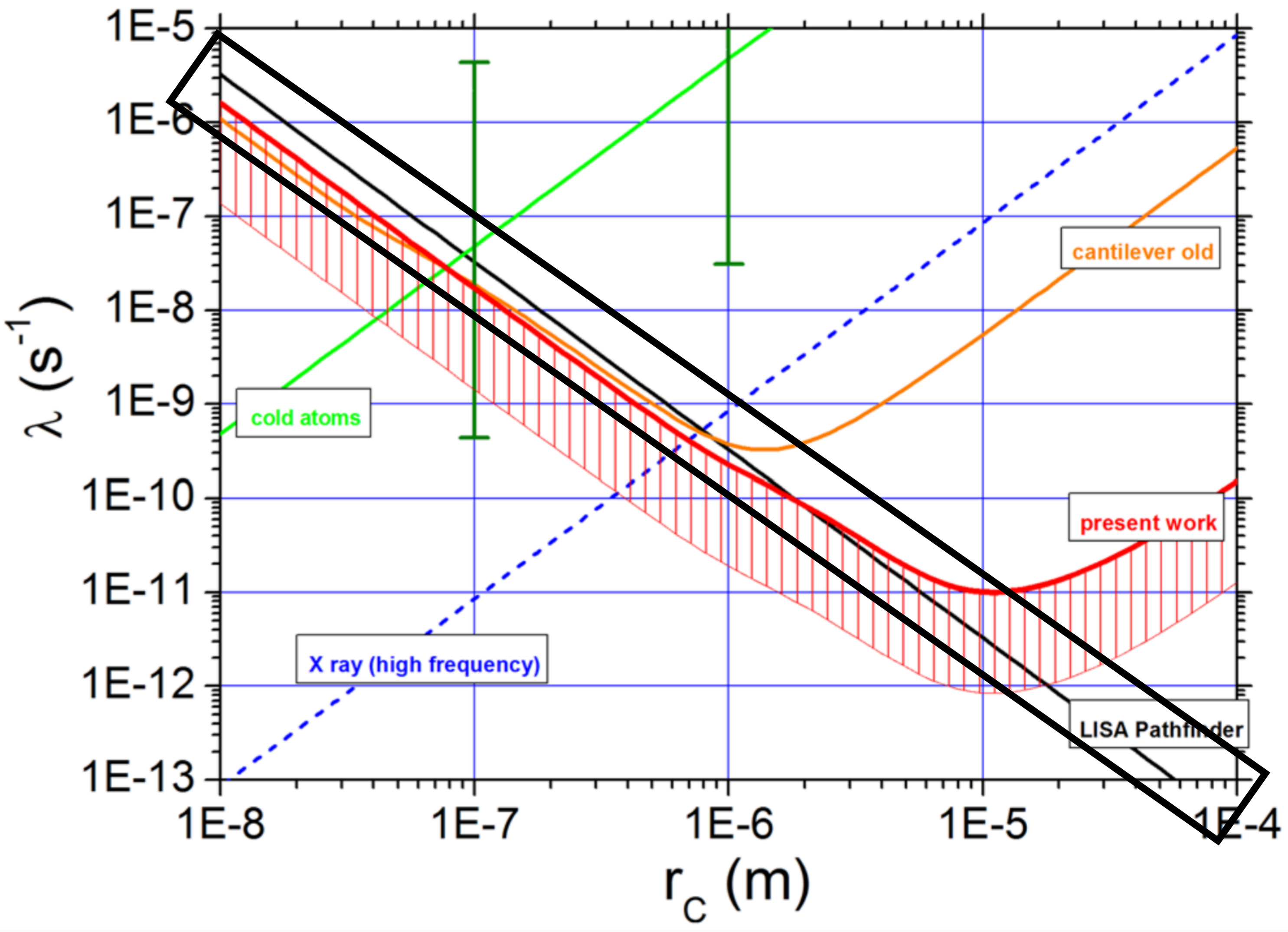
- ✓ 25 mK saturation: unknown heat leak to the cantilever
- ✓ CSL would appear as a positive intercept.

Current status of CSL model test

- Lisa Pathfinder

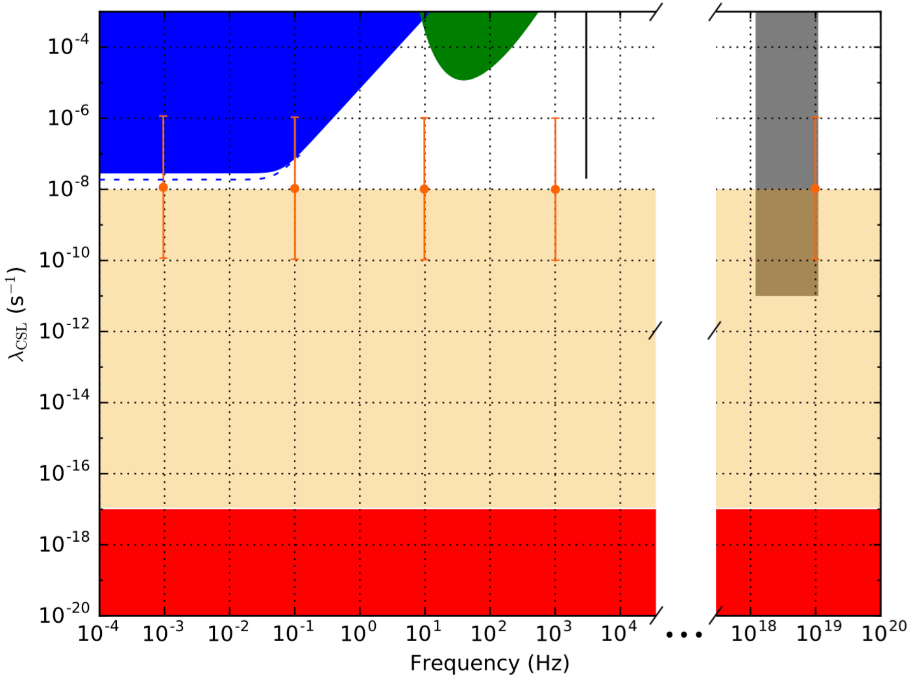
Carlesso+, PRD 94, 124036 (2016)

Helou+, PRD 95, 084054 (2017)

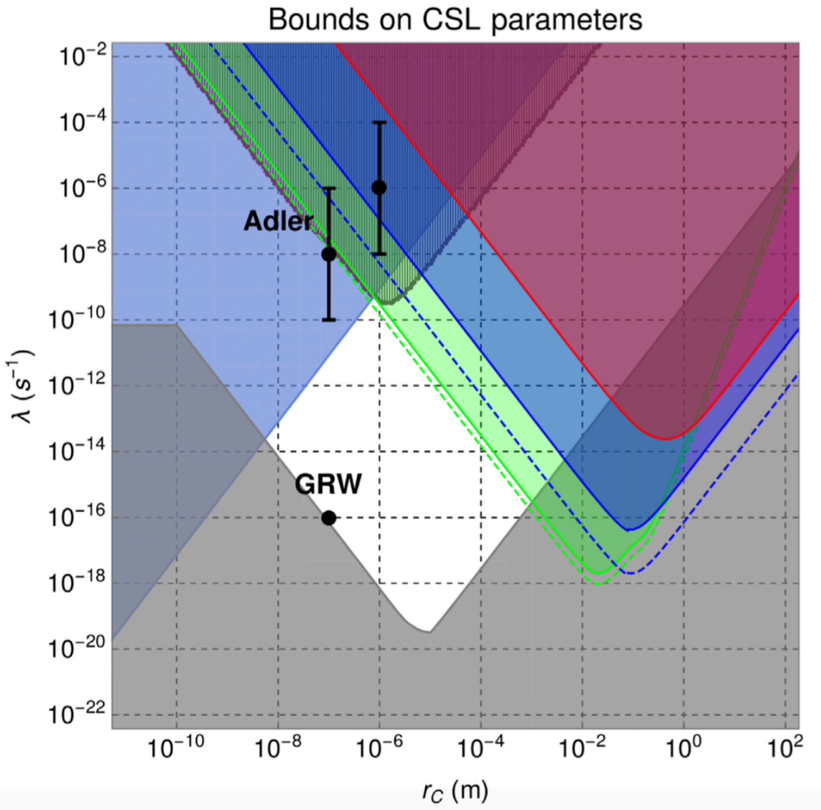


Lisa Pathfinder

- ➢ Free-falling oscillator without suspension thermal noise
- ➢ Wide frequency range



- ✓ Gold test mass: large density
- ✓ Wide width and room temperature, but ultra-low damping

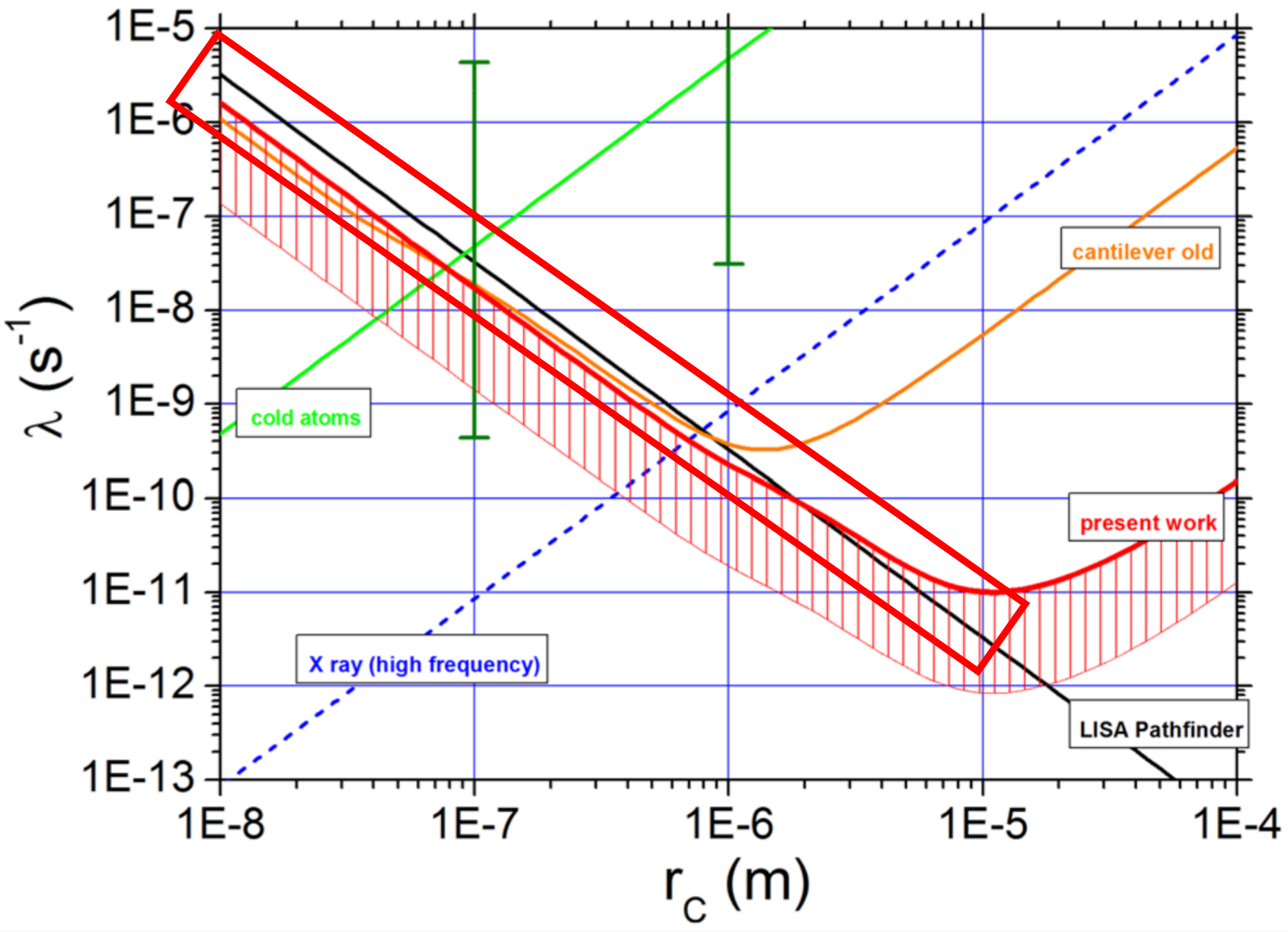


$$\boxed{\lambda r_C^2 < 2\times 10^{-22}\ \mathrm{Hz}\, m^2}$$

Current status of CSL model test

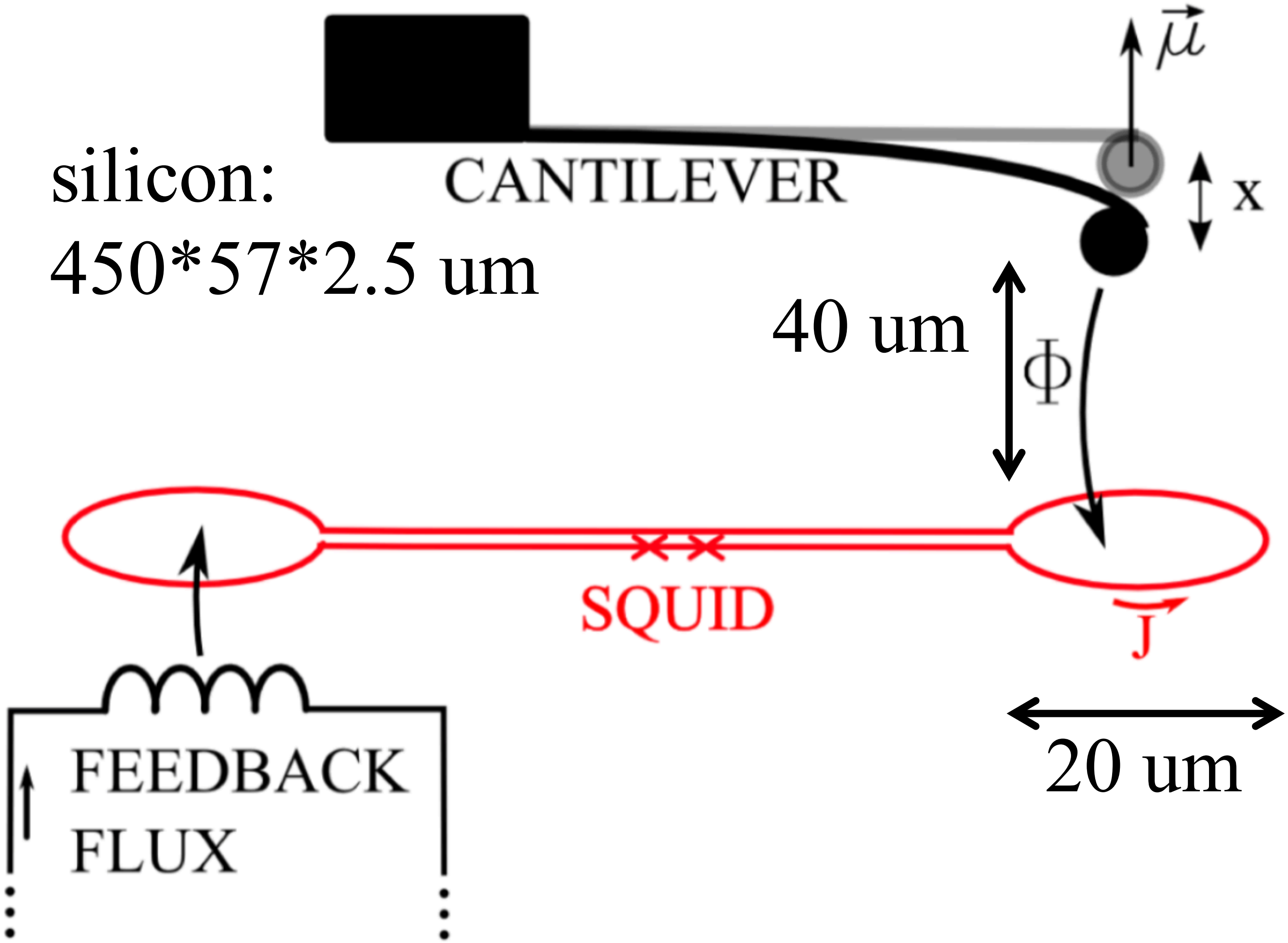
- Improved cantilever

Vinante+, PRL 119, 110401 (2017)



Improved cantilever

- The same group as previous cantilever
- Position measurement by superconducting quantum interference device (SQUID)
- Higher Q value: Q~1e7 at 20 mK



Improved cantilever

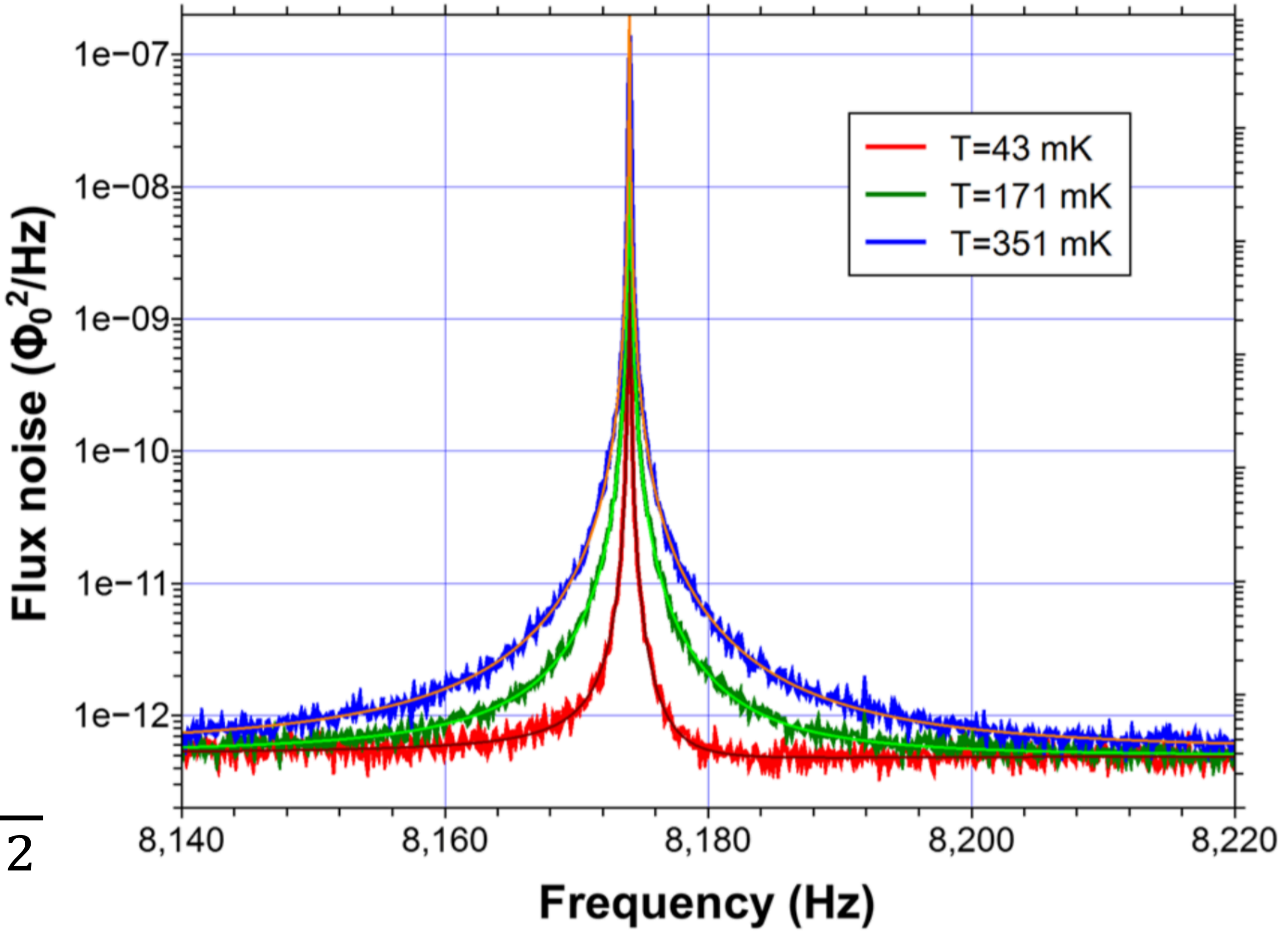
- Absolutely expected thermal noise limit

- Floor noise comes from SQUID additive noise.

- Fitting:

force noise

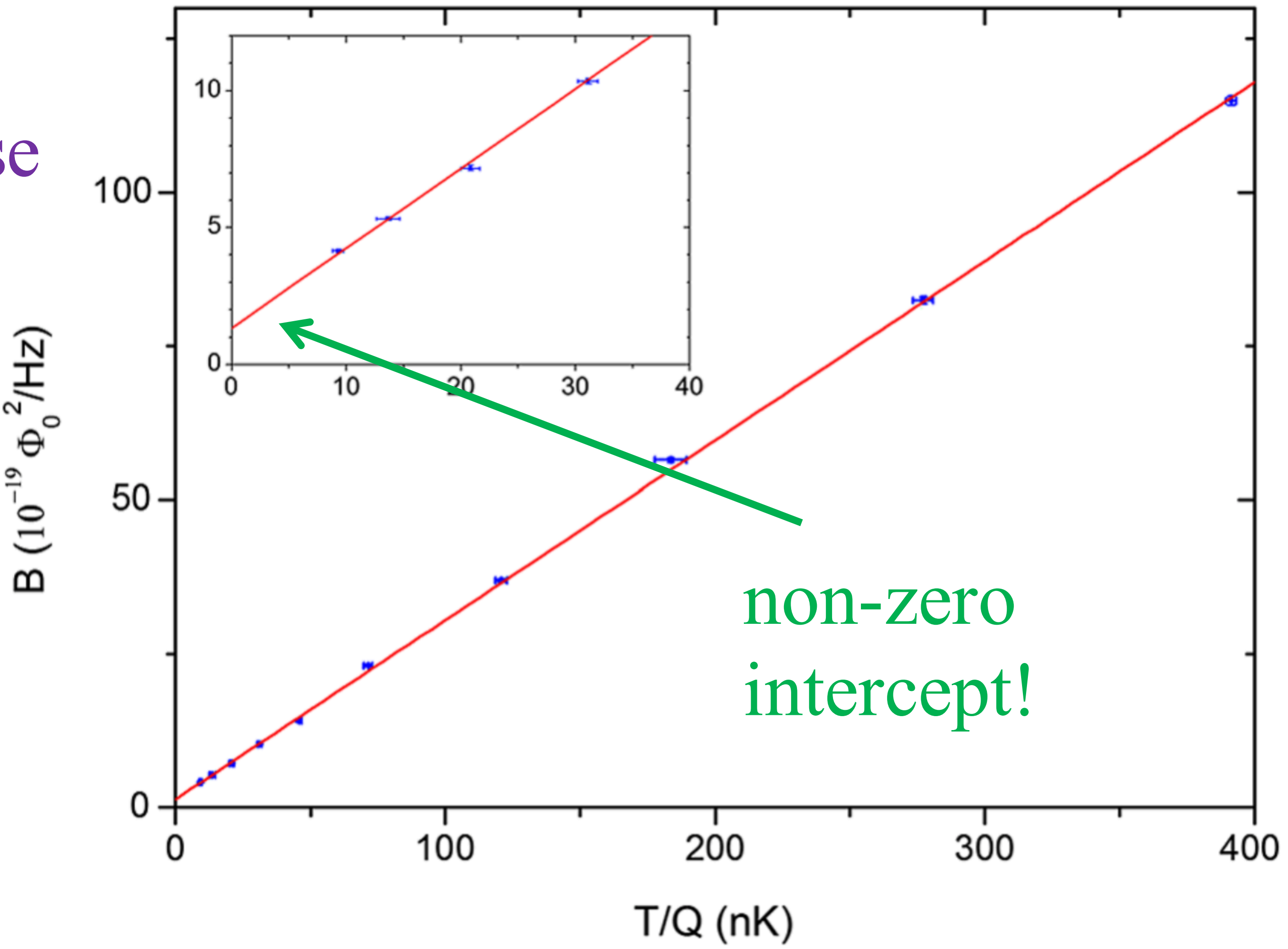
$$S_\Phi = A + \frac{B f_0^4 + C(f^2 - f_1^2)^2}{(f^2 - f_0^2)^2 + (f f_0/Q)^2}$$



Improved cantilever

$$B = \underbrace{B_0}_{\text{other force noise}} + \underbrace{B_1 T/Q}_{\text{thermal noise}}$$

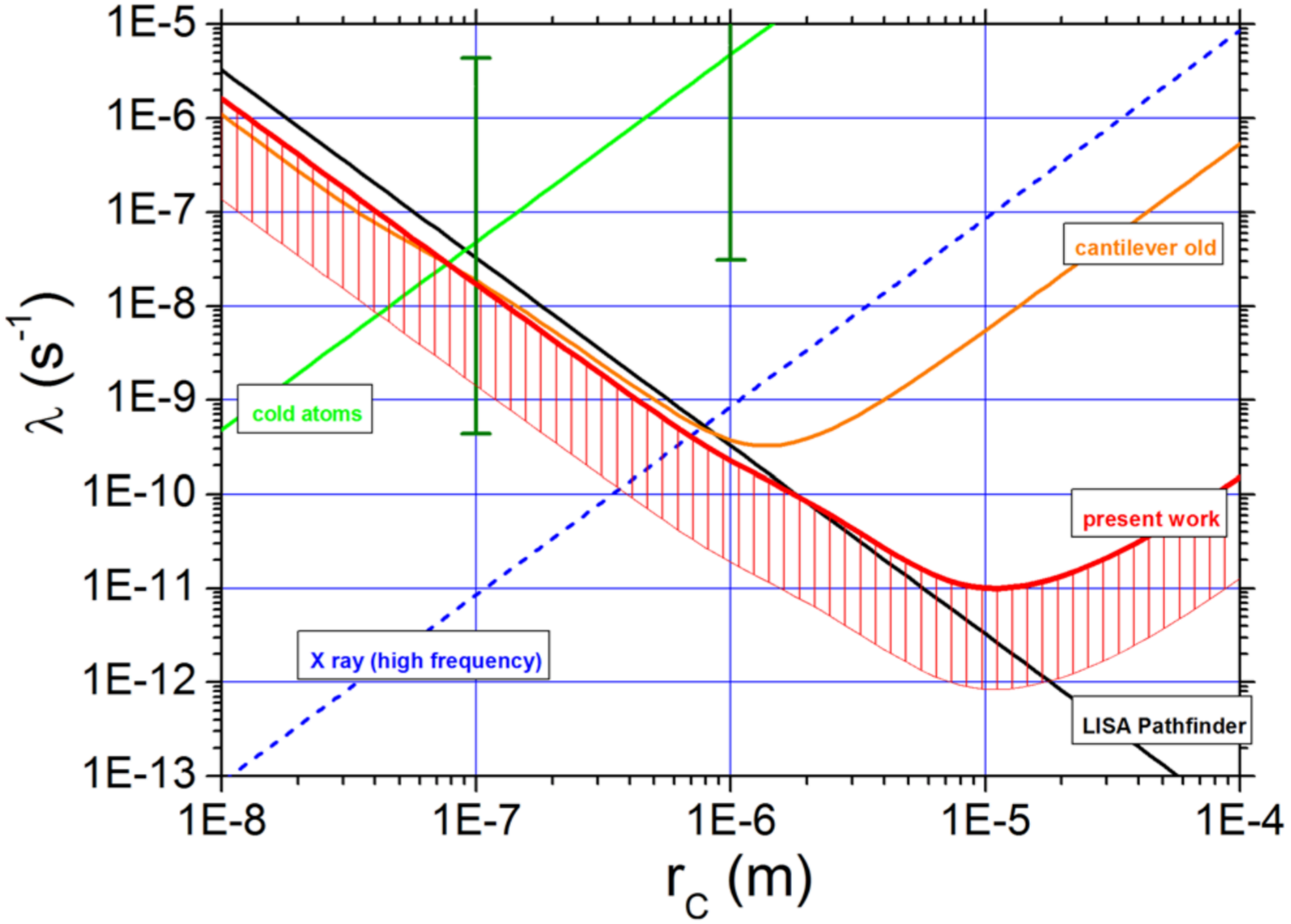
- Dependence of B on T/Q
- Agreement with a linear behavior over the whole range
- Positive intercept due to mysterious force noise



Improved cantilever

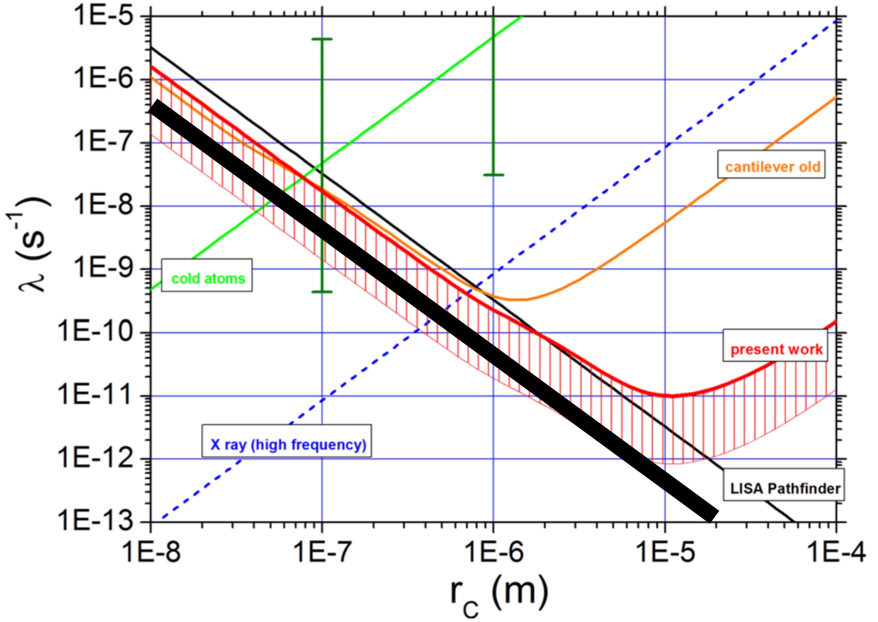
- Possible noise sources considered
  - ✓ back action
  - ✓ vibration
  - ✓ magnetization
  - ✓ thermo-mechanics
  - ✓ systematic error of Q

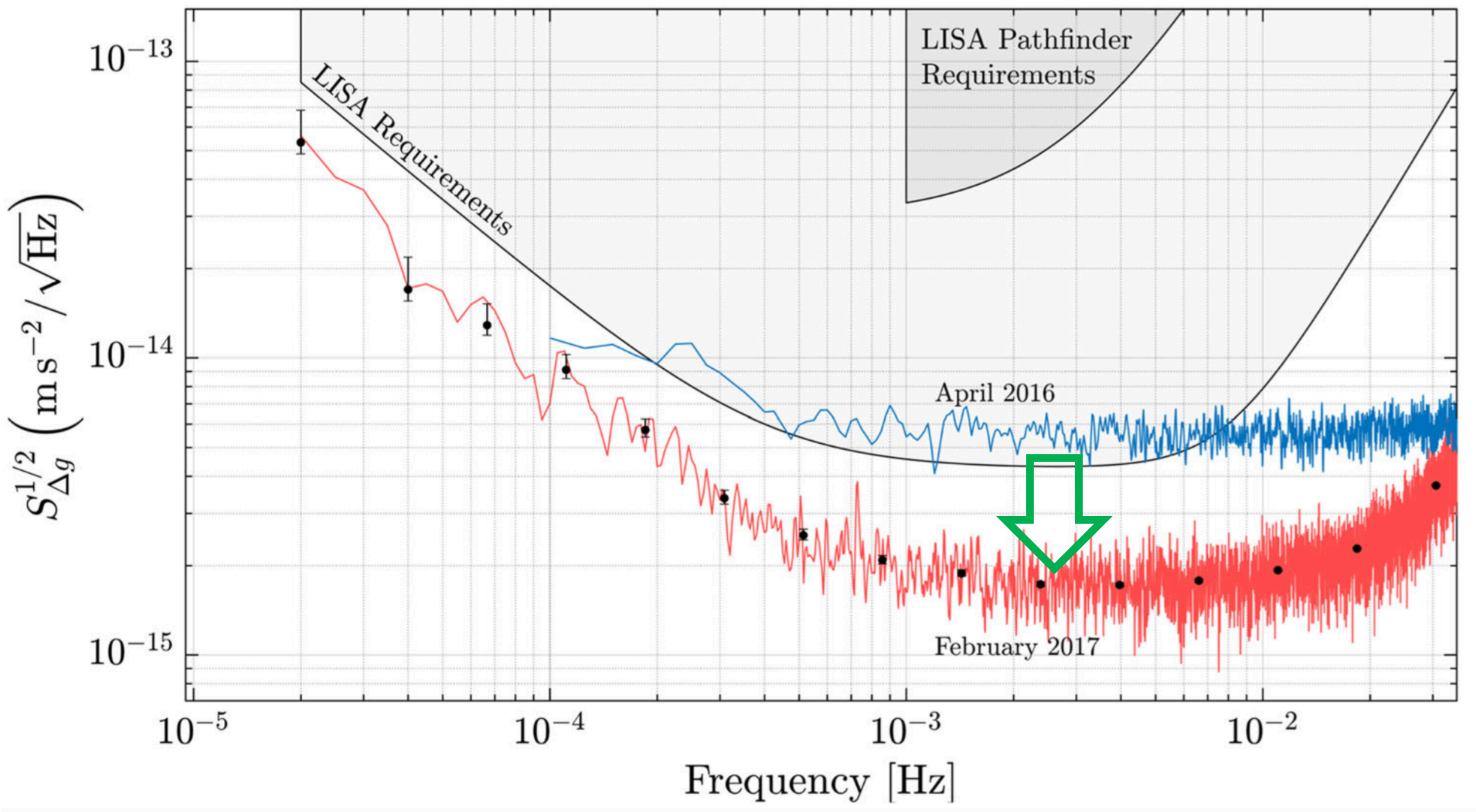
    → not dominant
- The shaded area would be excluded after identifying.



Improved Lisa Pathfinder

- Reduced force noise: 1/3
- CSL sensitivity: 9 times improved





- Most strict limit

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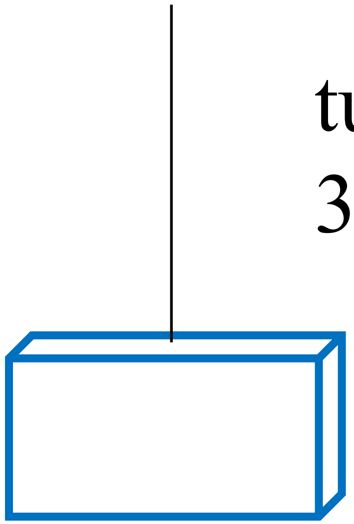
Original idea 1

$$S_{CSL} = \lambda r_C^2 \, \rho / d$$

$$S_{th} = T \, \omega_m / Q$$

- Larger density and thinner test mass: tungsten thin film (ρ =19.25 g/cm^3)

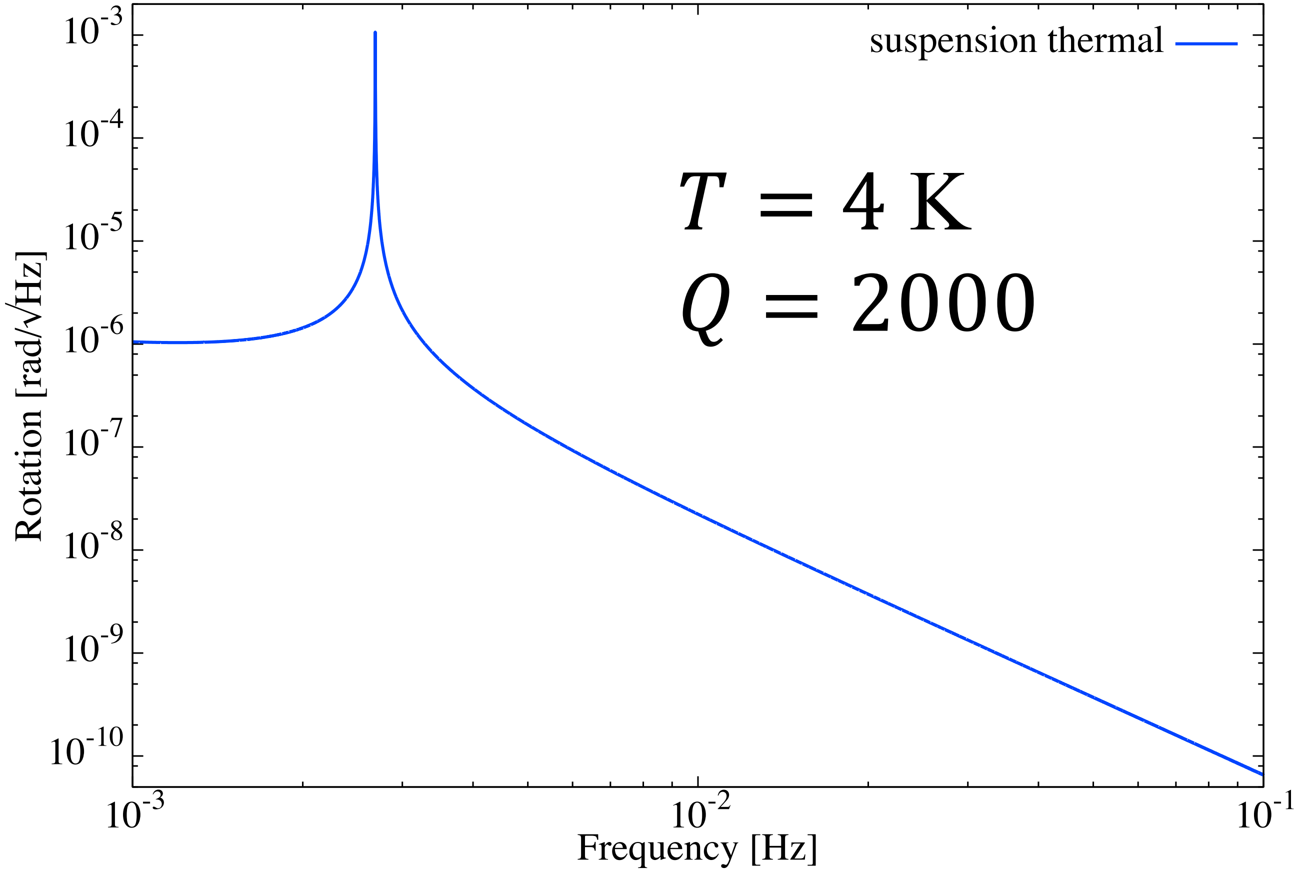


tungsten wire:
3 um, 5 cm

50*25*0.015 mm

$\omega_m / 2\pi = 2.7$ mHz

- Rotation sensed by optical lever



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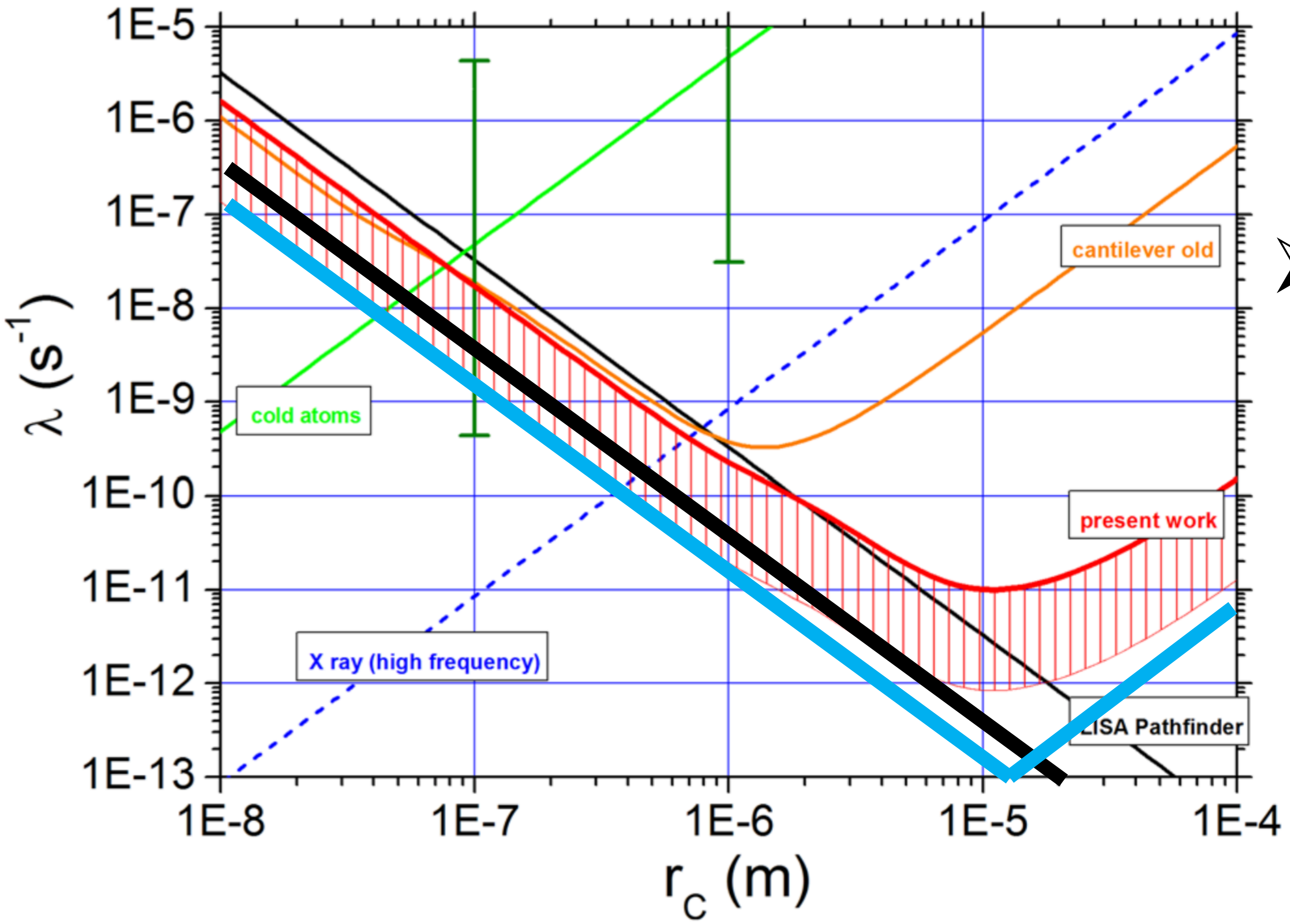
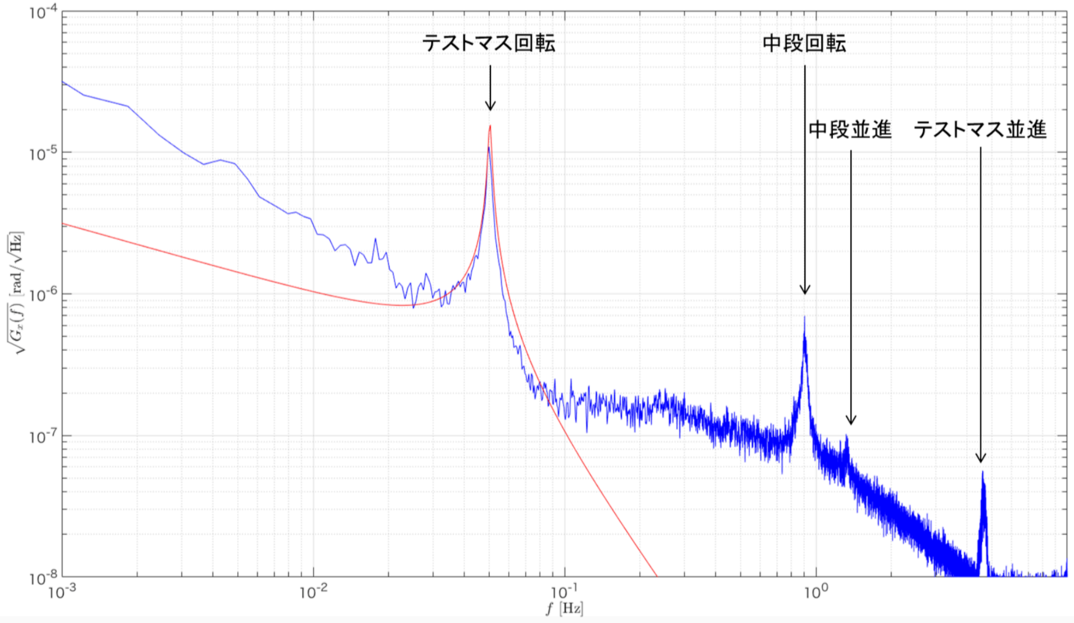


$$S_{CSL} = \lambda r_C^2\, \rho / d$$
$$S_{th} = T\, \omega_m / Q$$

- ➢ Demonstrated by Yoneta-kun

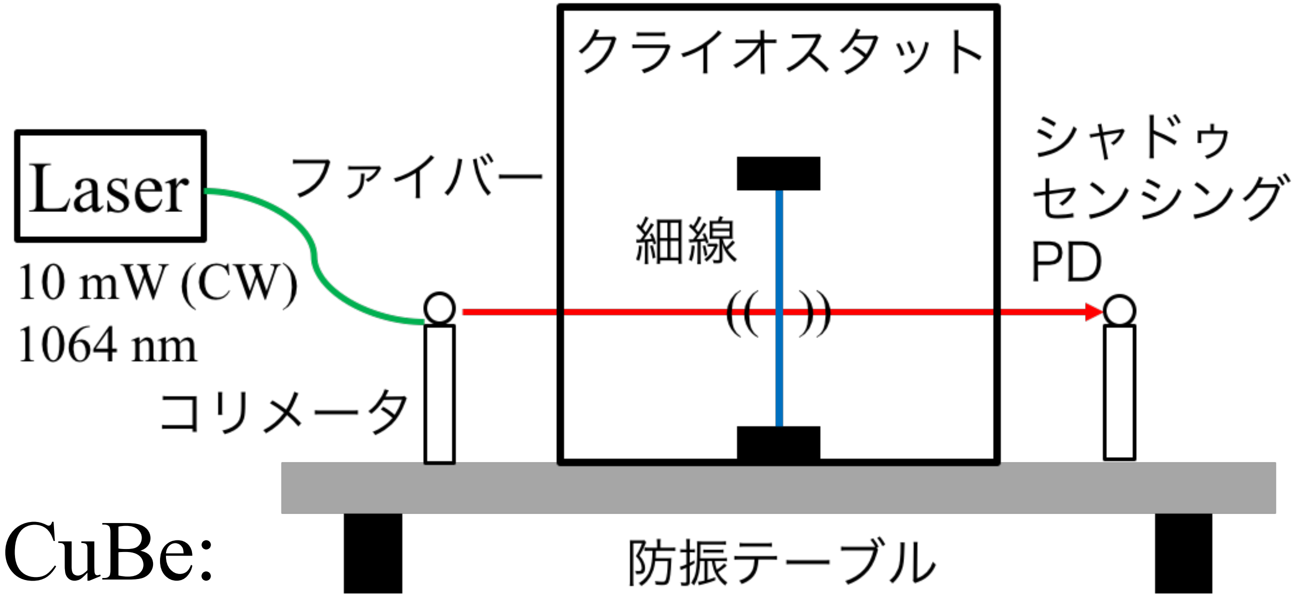


Original idea 2

- Making thin wire itself test mass
- Shadow-sensing a violin mode of thin wire (CuBe, tungsten)

$$S_{CSL} = \lambda r_C^2\, \rho/d$$

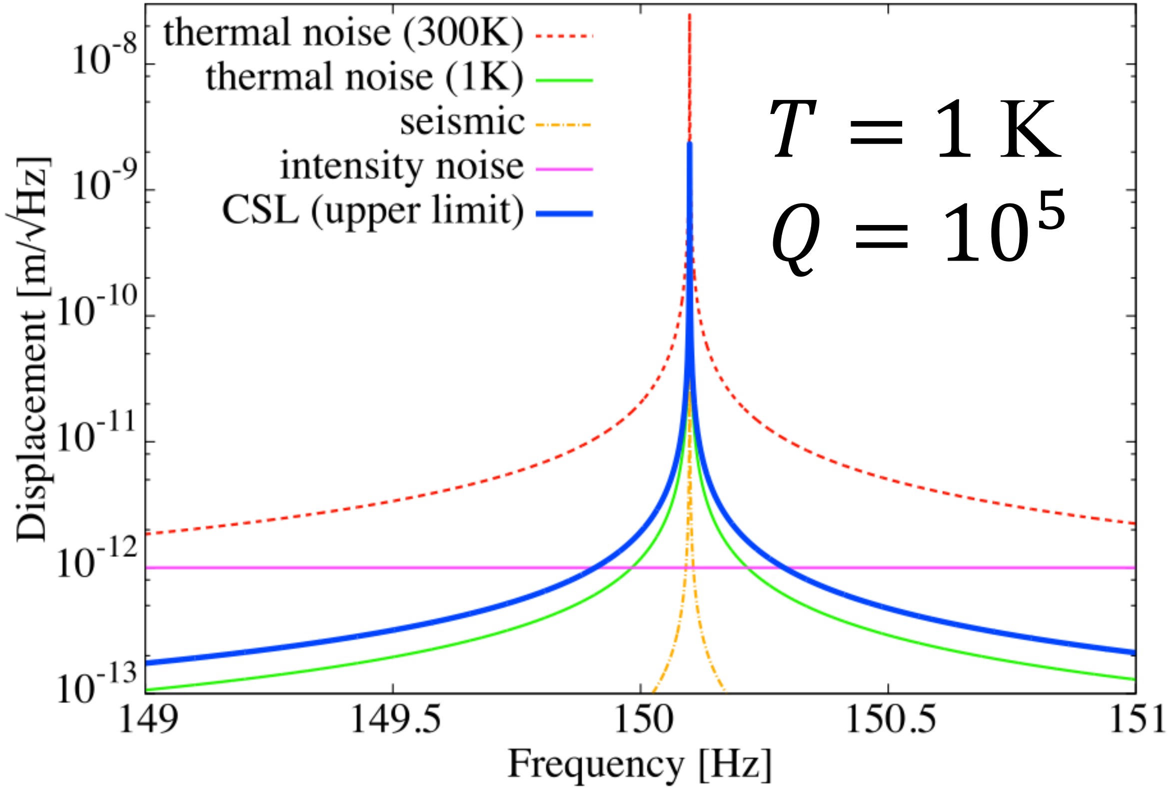
$$S_{th} = T\, \omega_m/Q$$



CuBe:
20 um

図1 実験装置の概念図

$\omega_m/2\pi = 150$ Hz

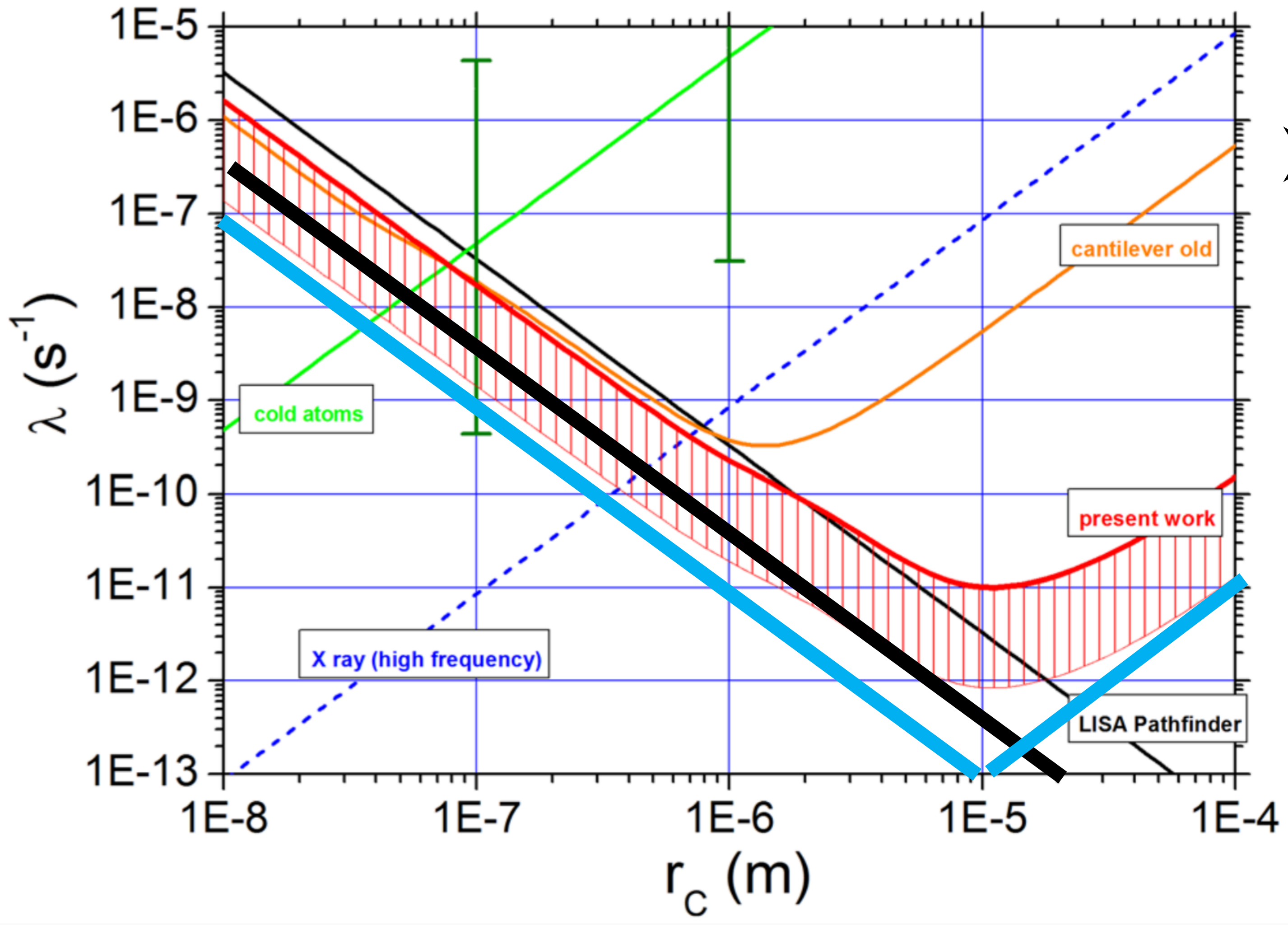


$T = 1$ K

$Q = 10^5$

図2 想定される変位スペクトル

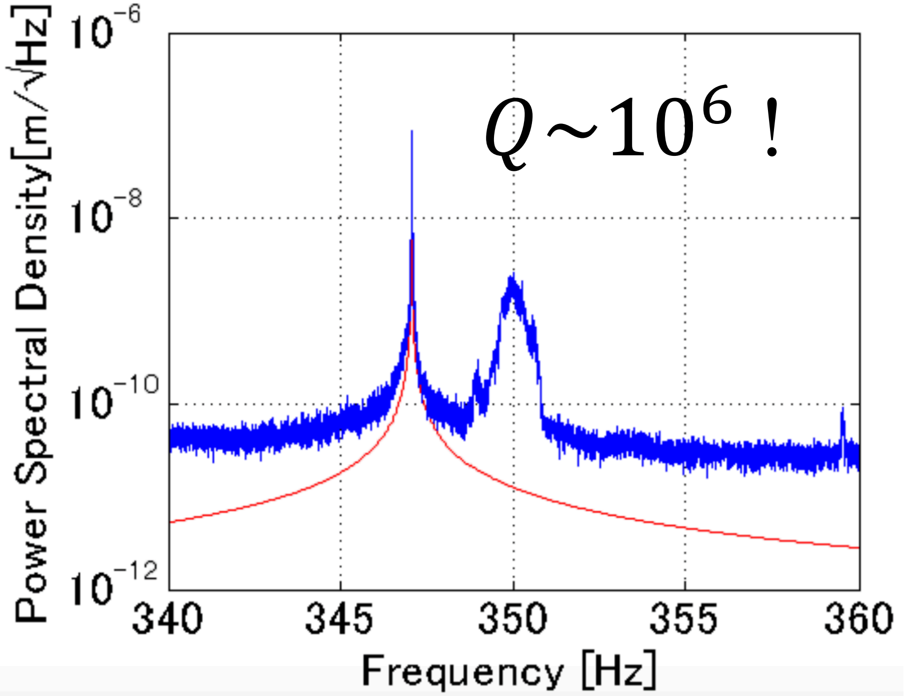
Original idea 2



$$S_{CSL} = \lambda r_C^2\, \rho/d$$

$$S_{th} = T\,\omega_m/Q$$

- Demonstrated by Oikawa-kun, Watanabe-kun



Summary

- CSL is one of interpretation of quantum mechanics which can be tested experimentally.
- Some experiments set good upper and lower limits resulting in a small surviving parameter space.
- Thin film as a torsion pendulum and thin wire as violin oscillating is an unique bed for improving the upper limit.
- Let’s do this ultra-hot CSL experiments!!!