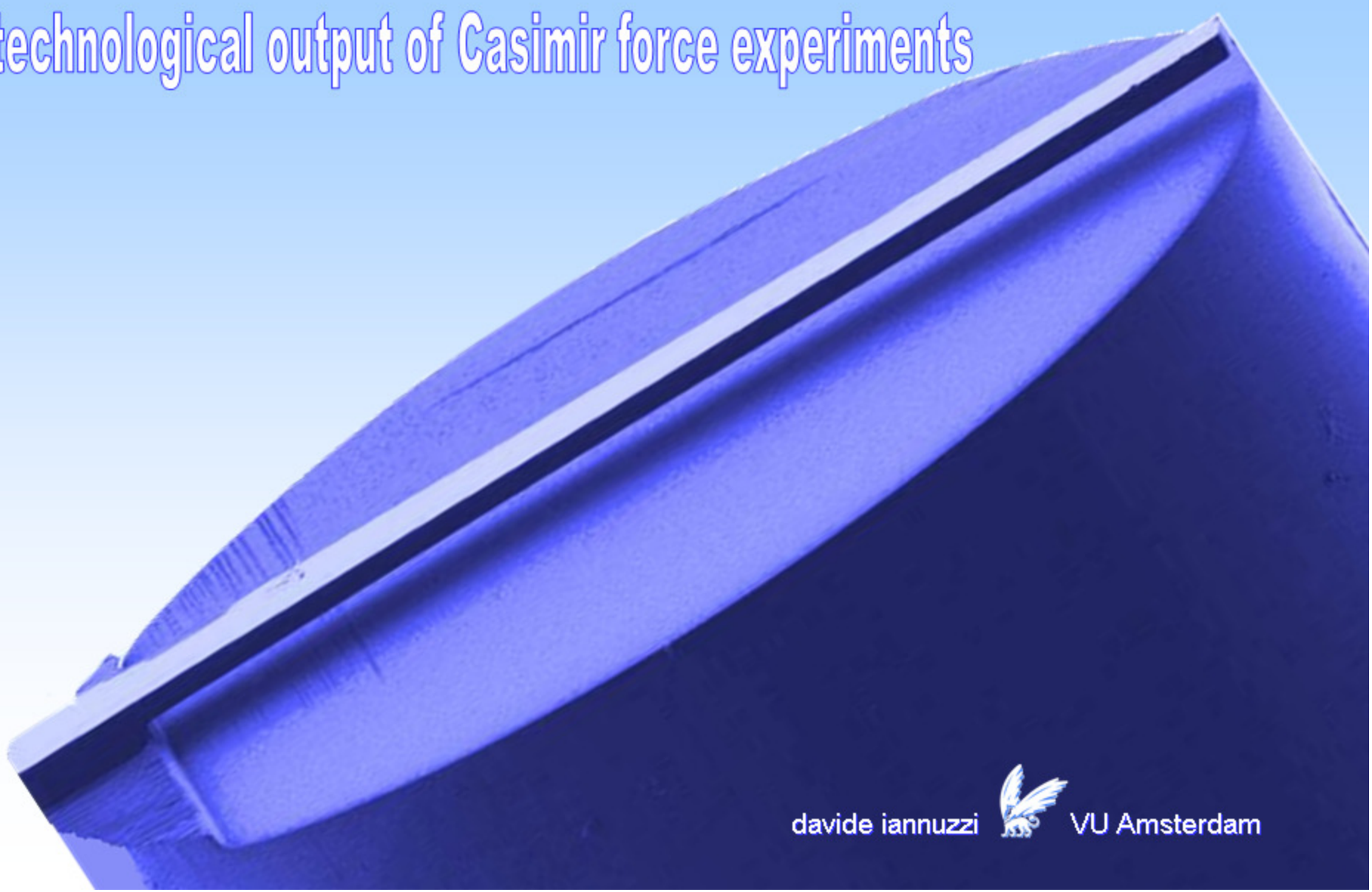
Fiber-top Micromachined Devices

technological output of Casimir force experiments



davide iannuzzi VU Amsterdam

A question of money…

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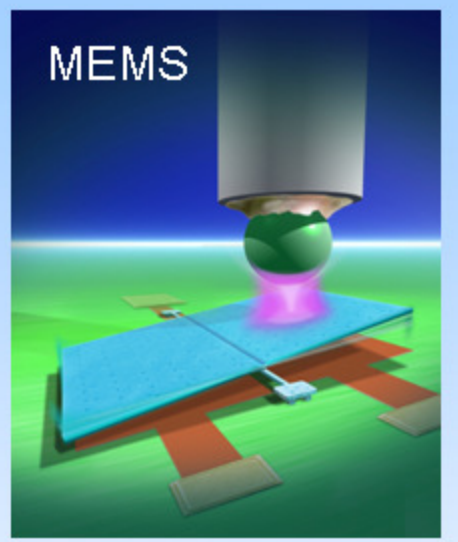
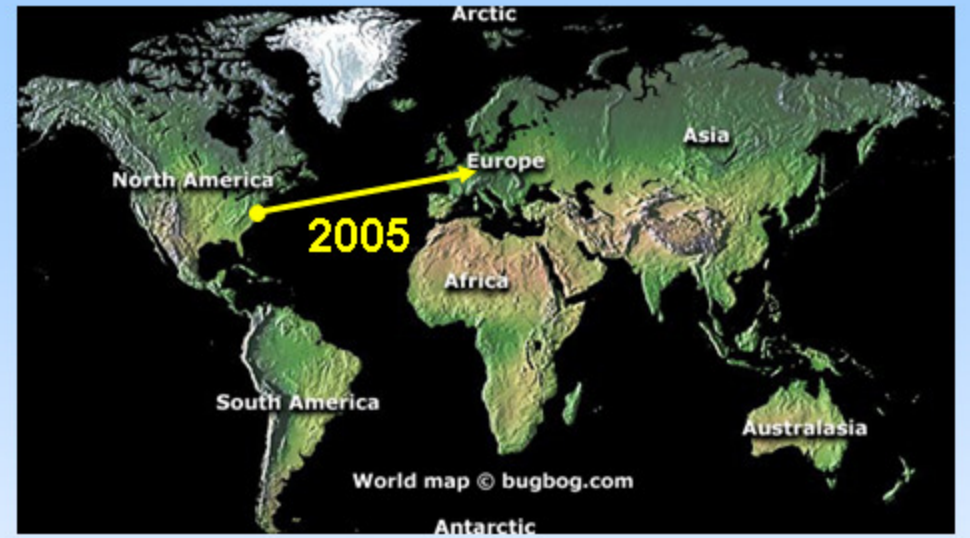
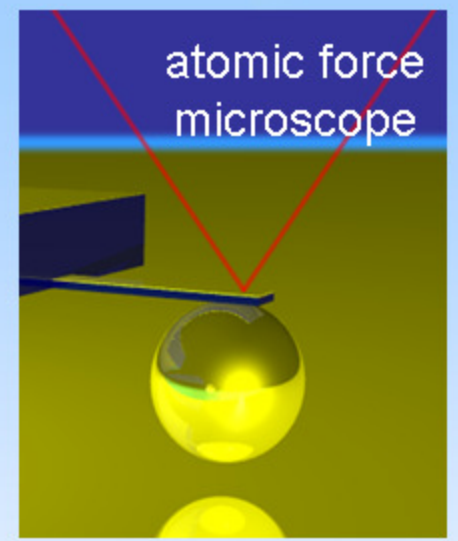
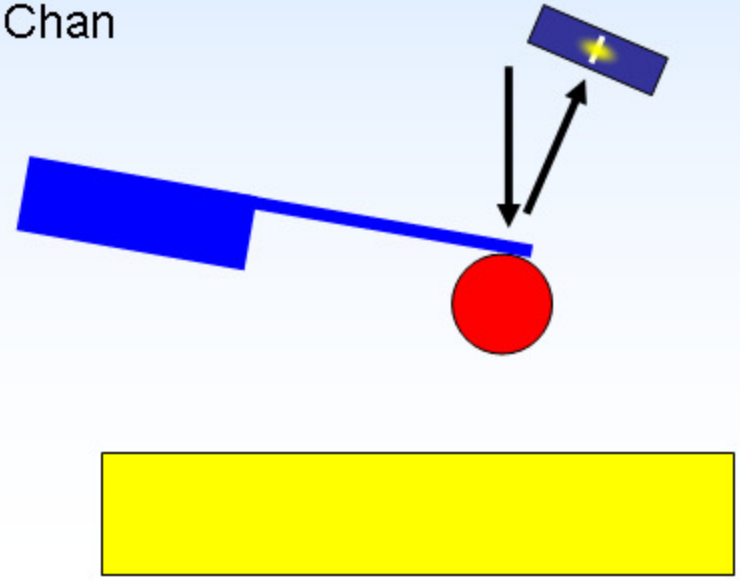
vrije Universiteit amsterdam



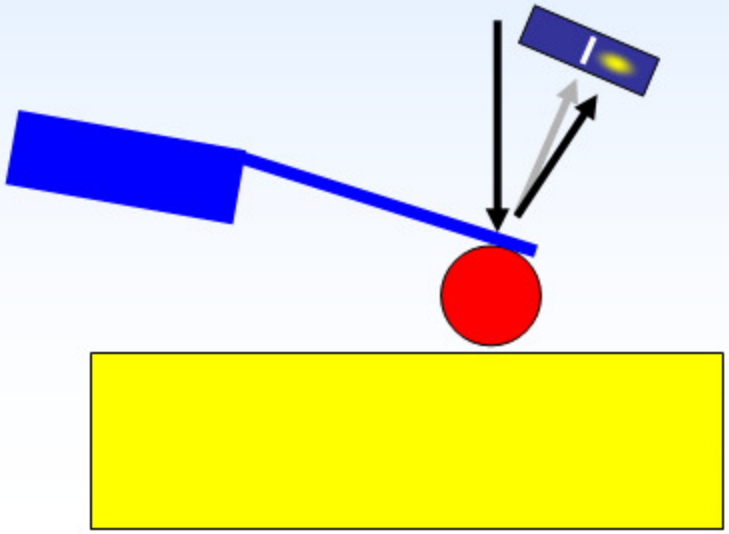




Pioneered by
H. B. Chan



Pioneered by
U. Mohideen



One little problem

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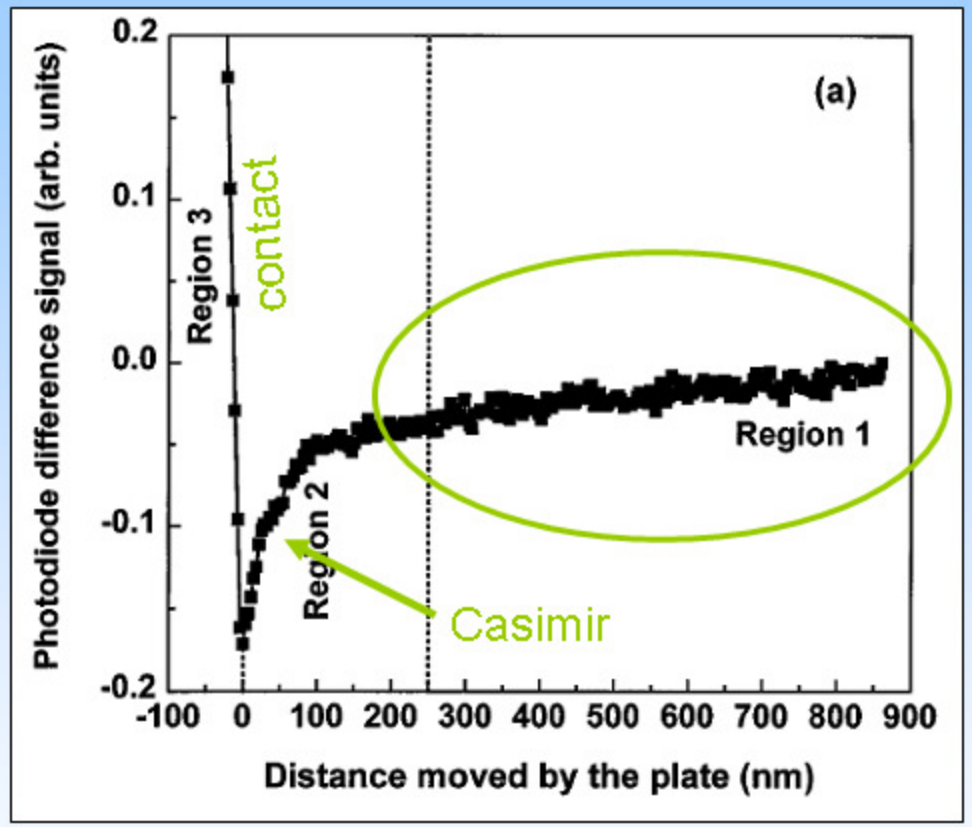
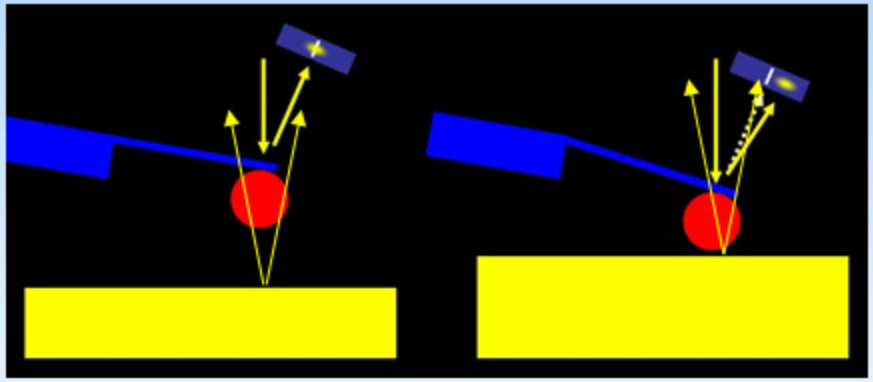


From Mohideen and Roy,
PRL 81 (1998) 4549



This is due to increased coupling of scattered light into the diodes from the approaching flat surface.

One little problem that shows up again

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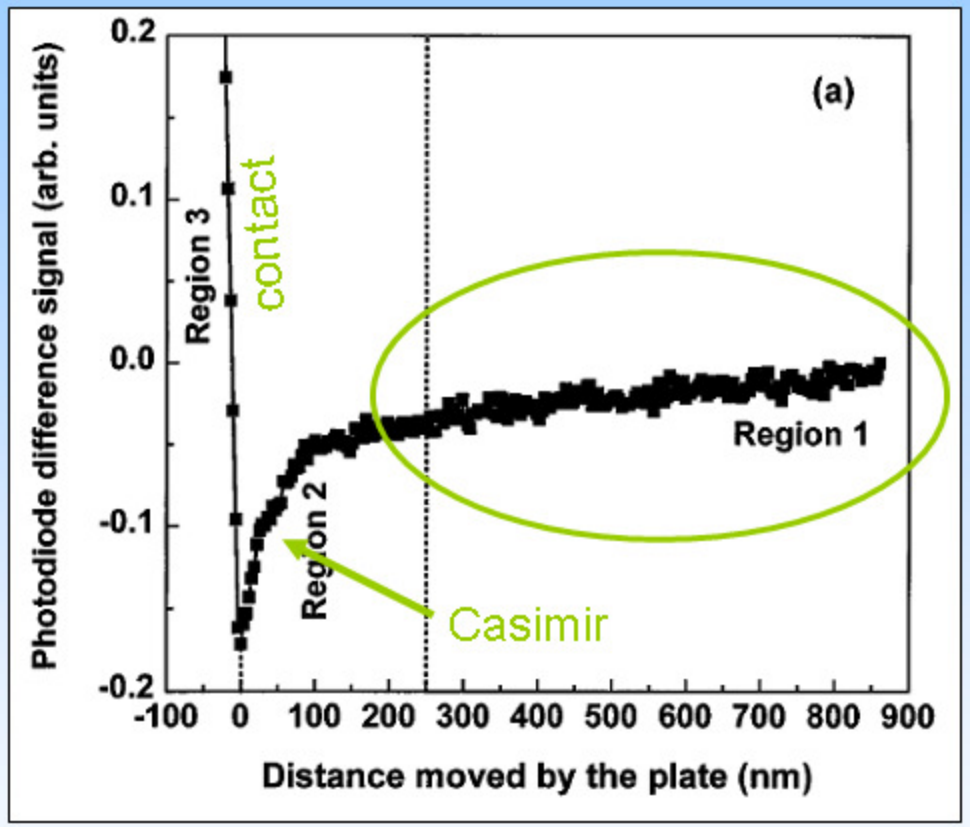

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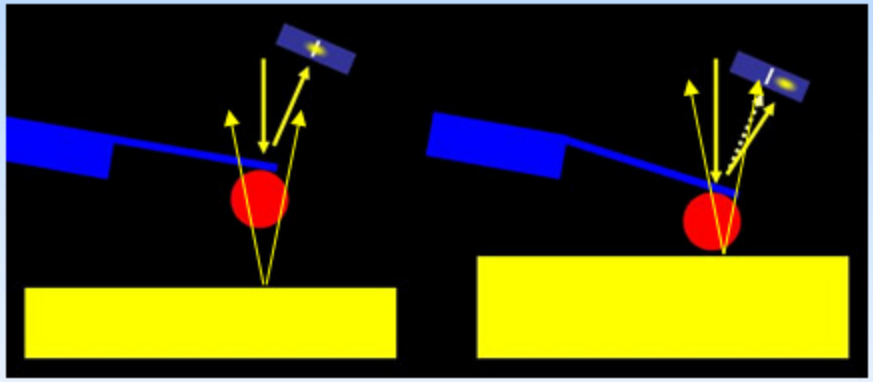

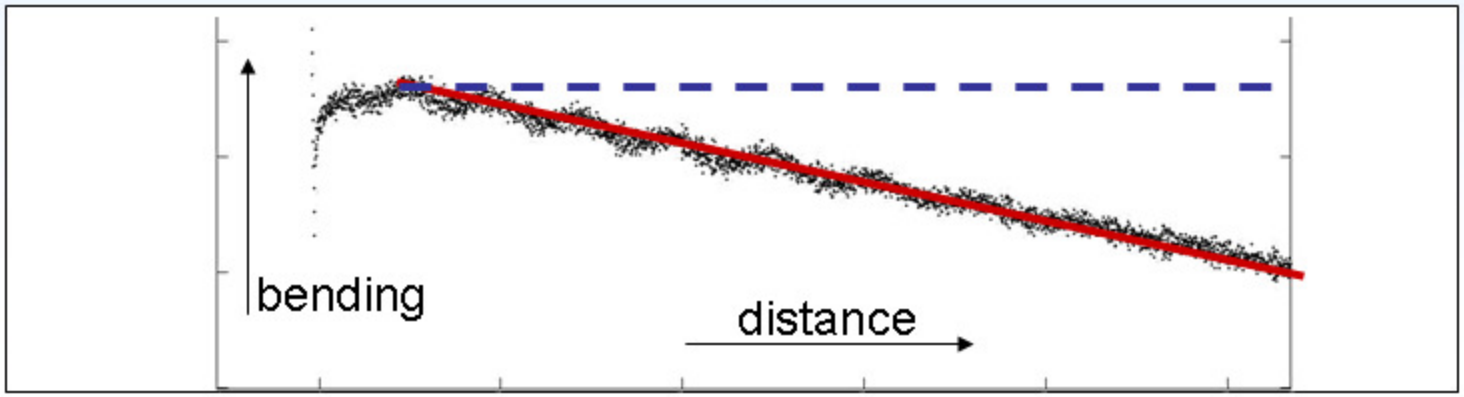

Fiber-top technology

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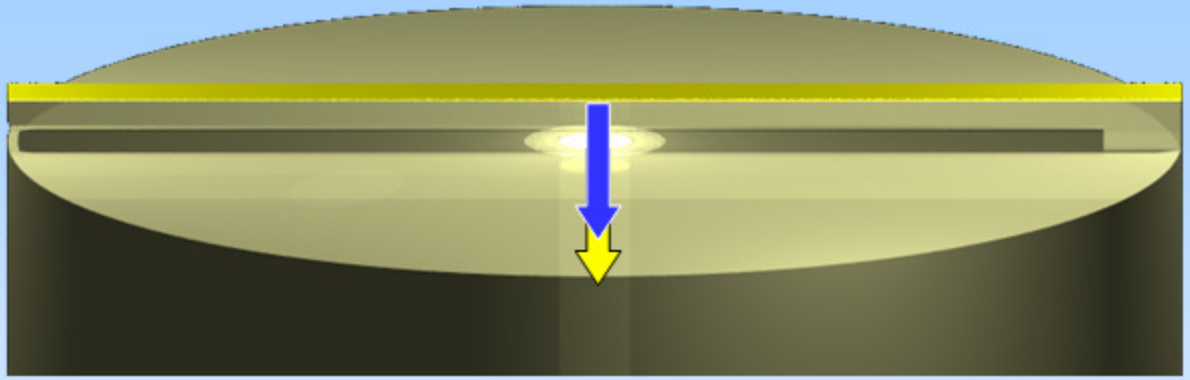

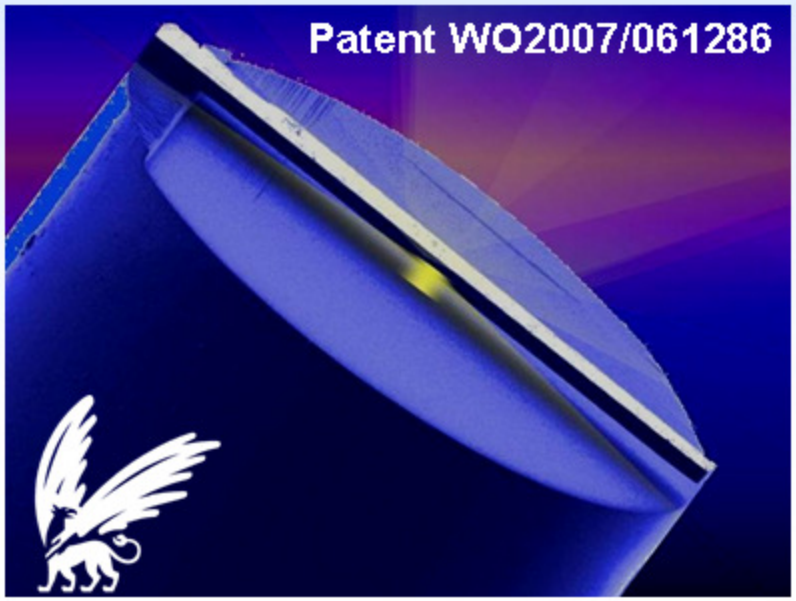

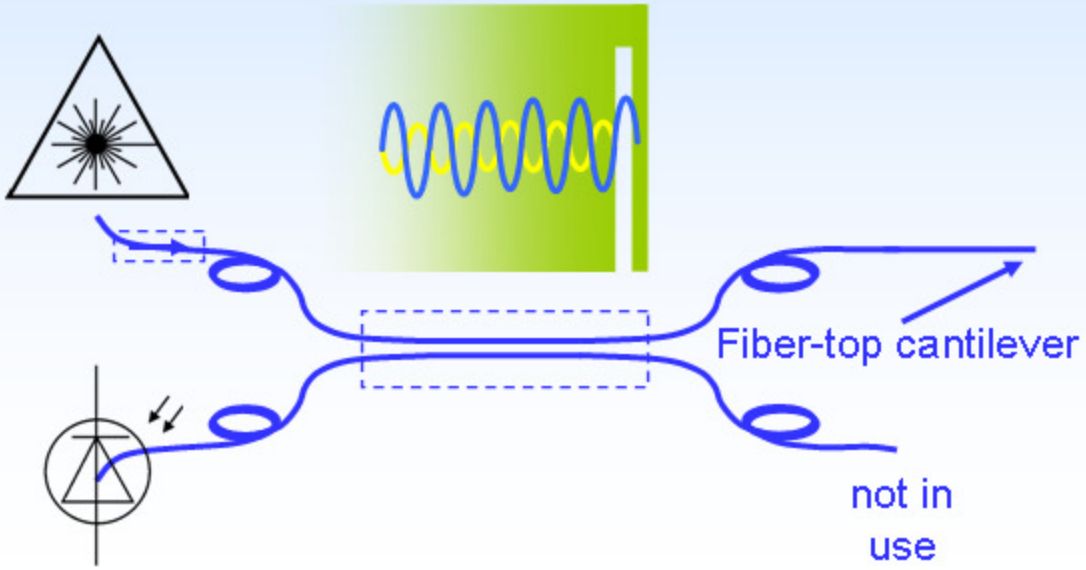

Fiber-top technology: is it useful?

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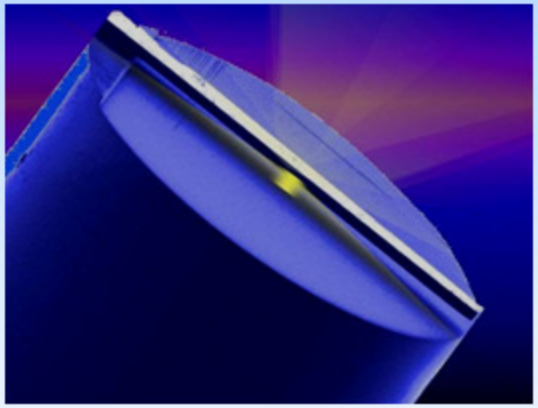
Research laboratories



SENSITIVE: based on optical interference

FLEXIBLE: working principle is not affected by the surroundings

COMPACT: just on the tip of a fiber

EASY-TO-USE: “plug-and-play” design

PORTABLE: readout in small volumes and light weight

Fiber-top technology: is it useful?

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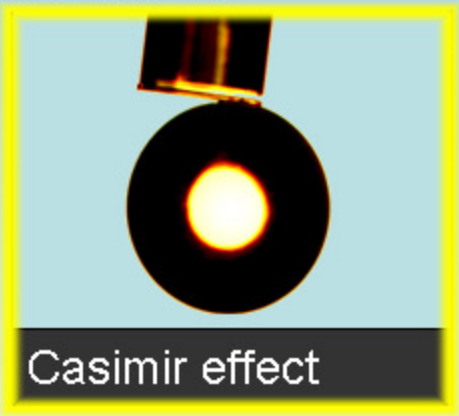
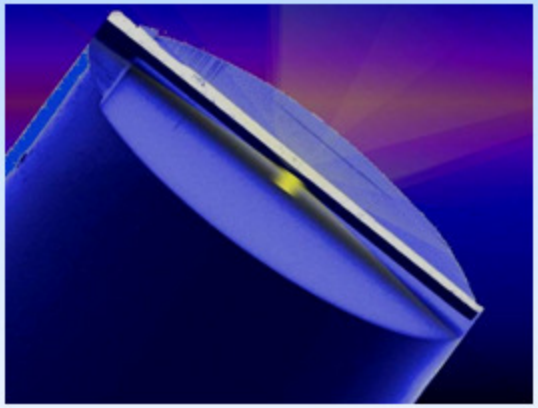
Research laboratories



Space missions



Homeland security

Quality inspection

Surgery rooms & medical applications

Environmental analysis

Fiber-top technology: is it useful?

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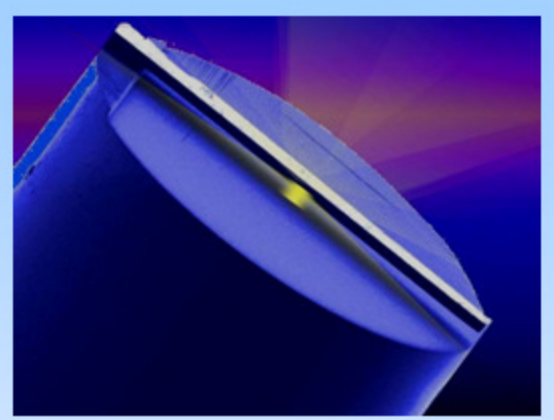
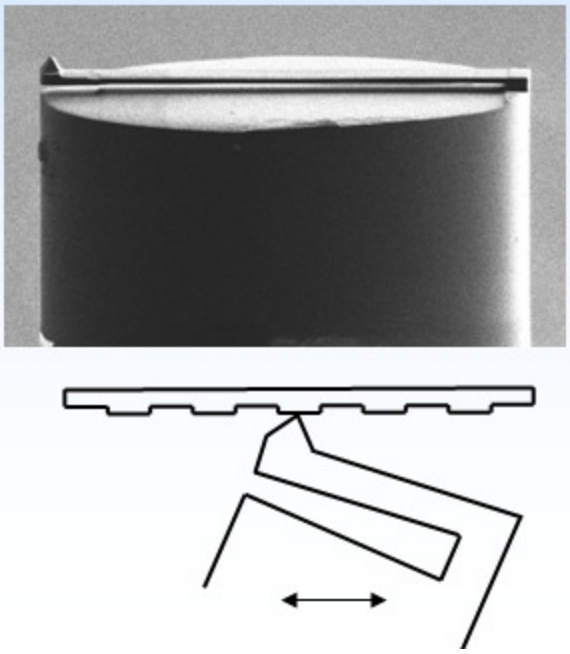
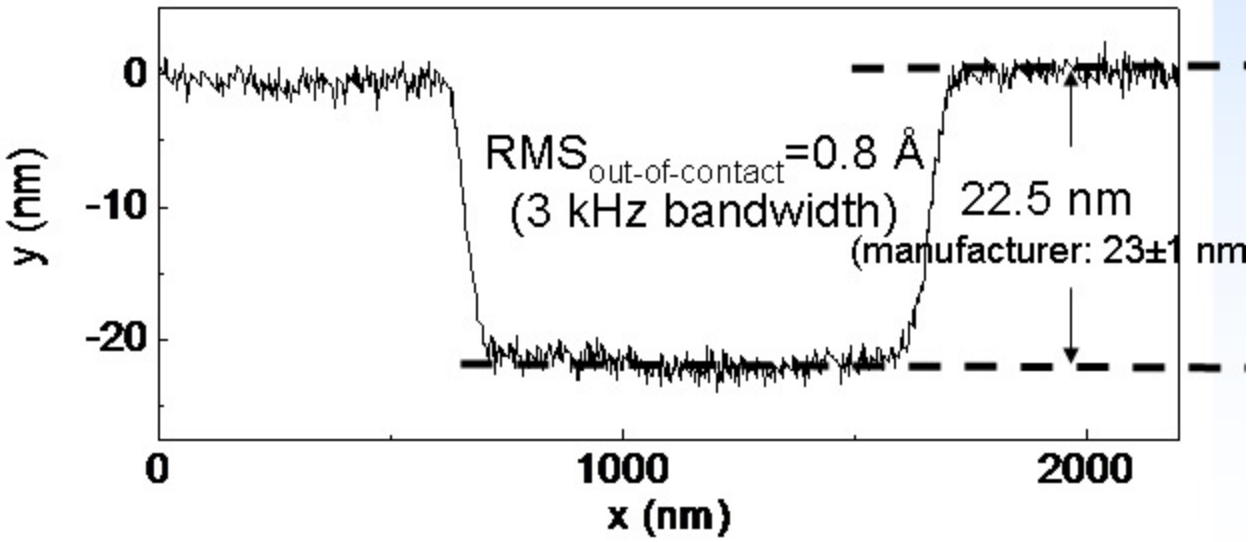


ATOMIC FORCE MICROSCOPY

Binnig, Quate, Gerber (1986)

one of the most spectacular application of microtechnology





Fiber-top technology: is it useful?

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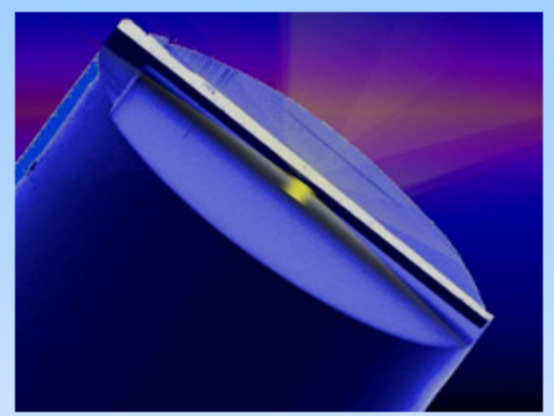
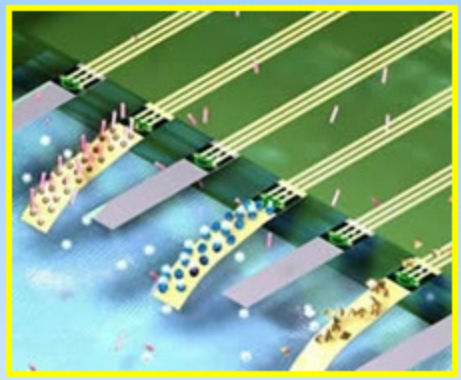
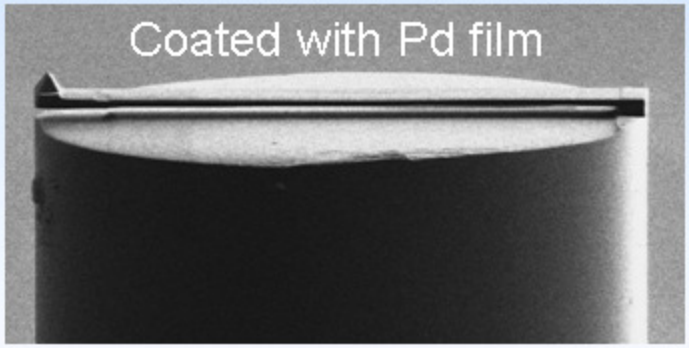
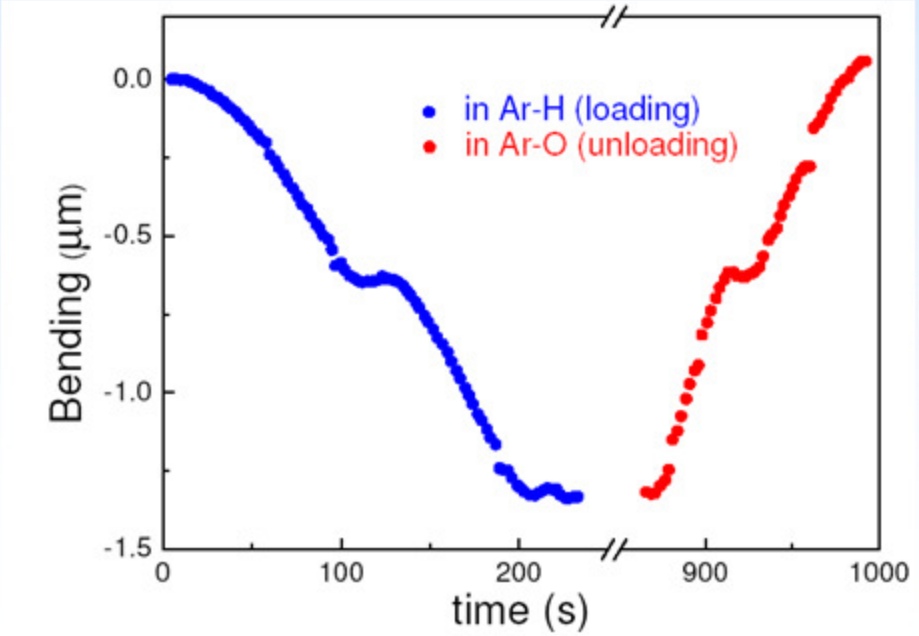


BIOCHEMICAL SENSING

Cantilevers are widely used as biochemical detectors







Going back to Casimir…

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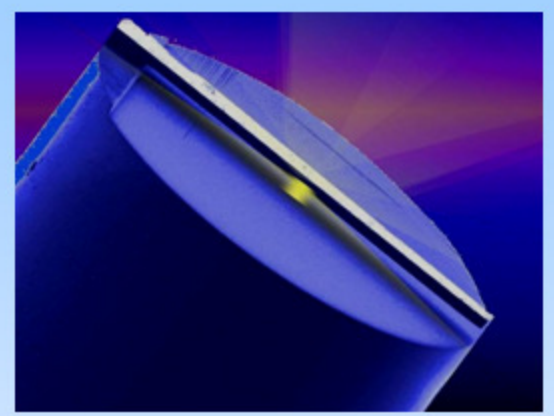
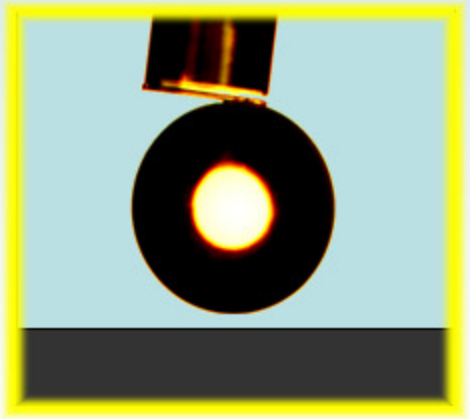


CASIMIR FORCE MEASUREMENTS



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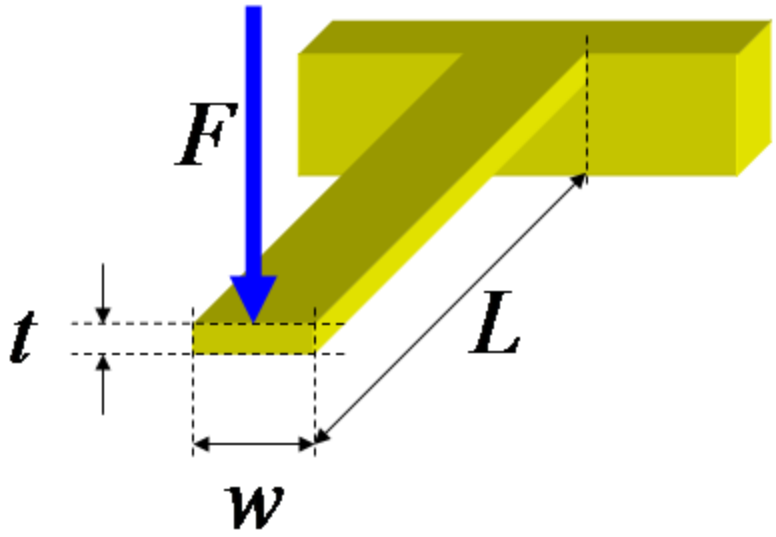
Considerations on the spring constant



$$k = \frac{1}{4} E w \left(\frac{t}{L} \right)^3$$

Young Modulus:
SiO_2: E = 73 GPa
Si: E = 170 GPa
Si_3N_4: E = 385 GPa

However… w > 10 μm, L < 100 μm, t > 4 μm → k >> 10 N/m

Can we decrease the spring constant?

Low k fiber-top devices

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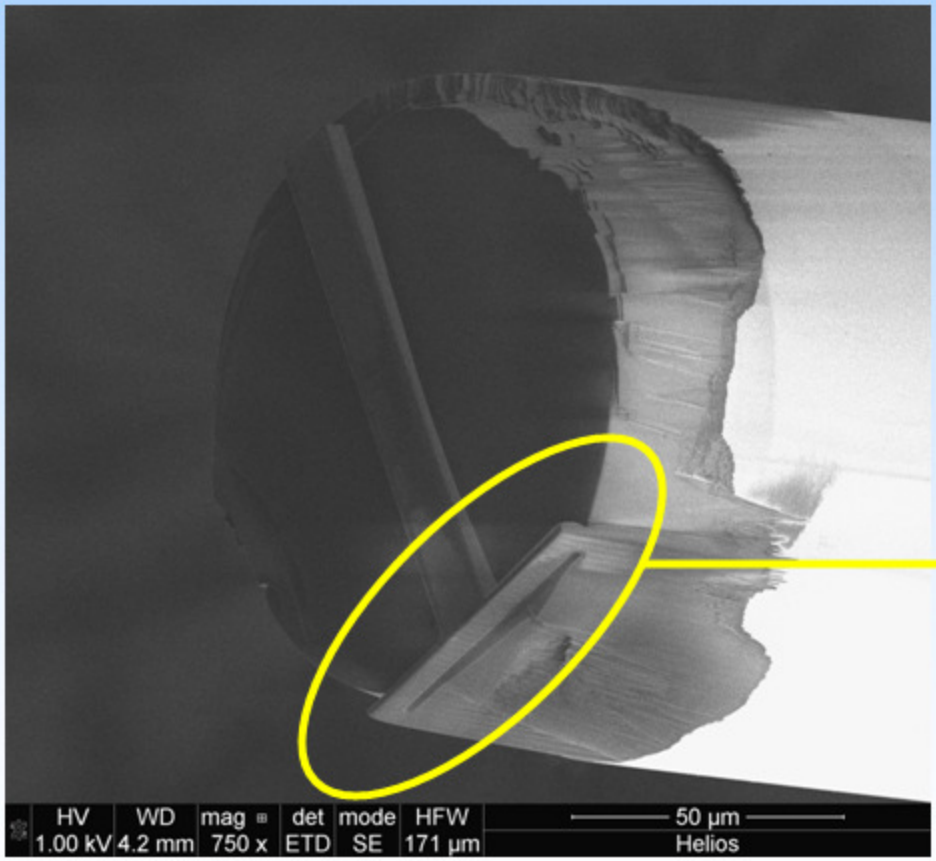
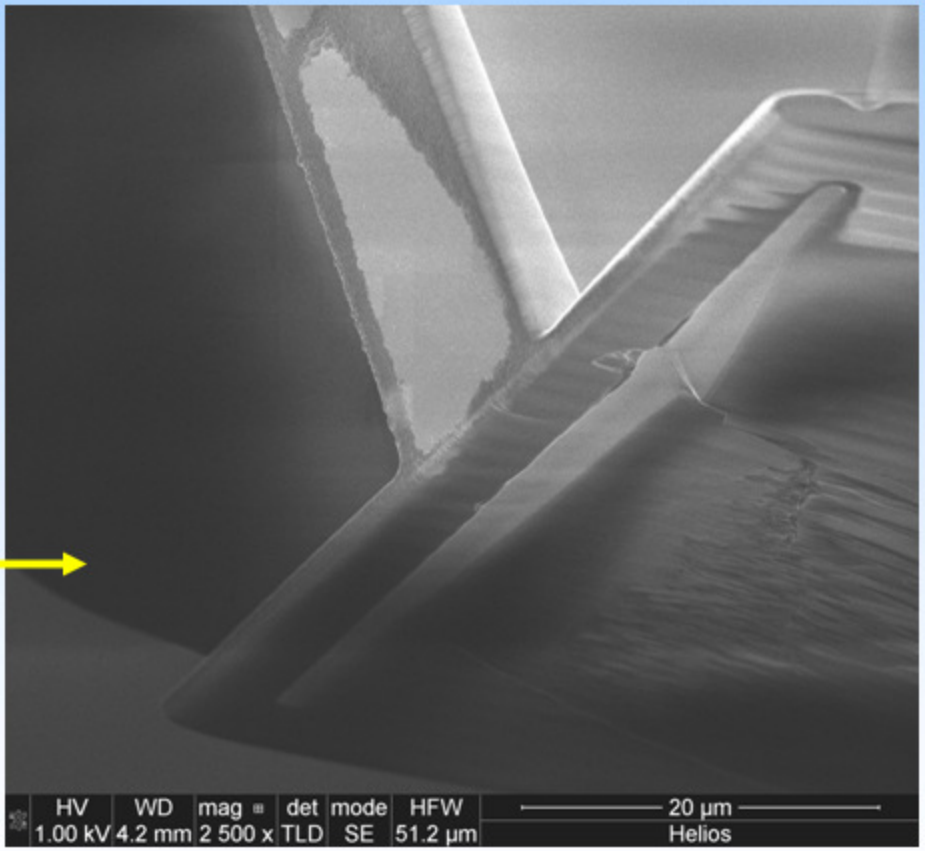
Torsional device





Low k fiber-top devices: test

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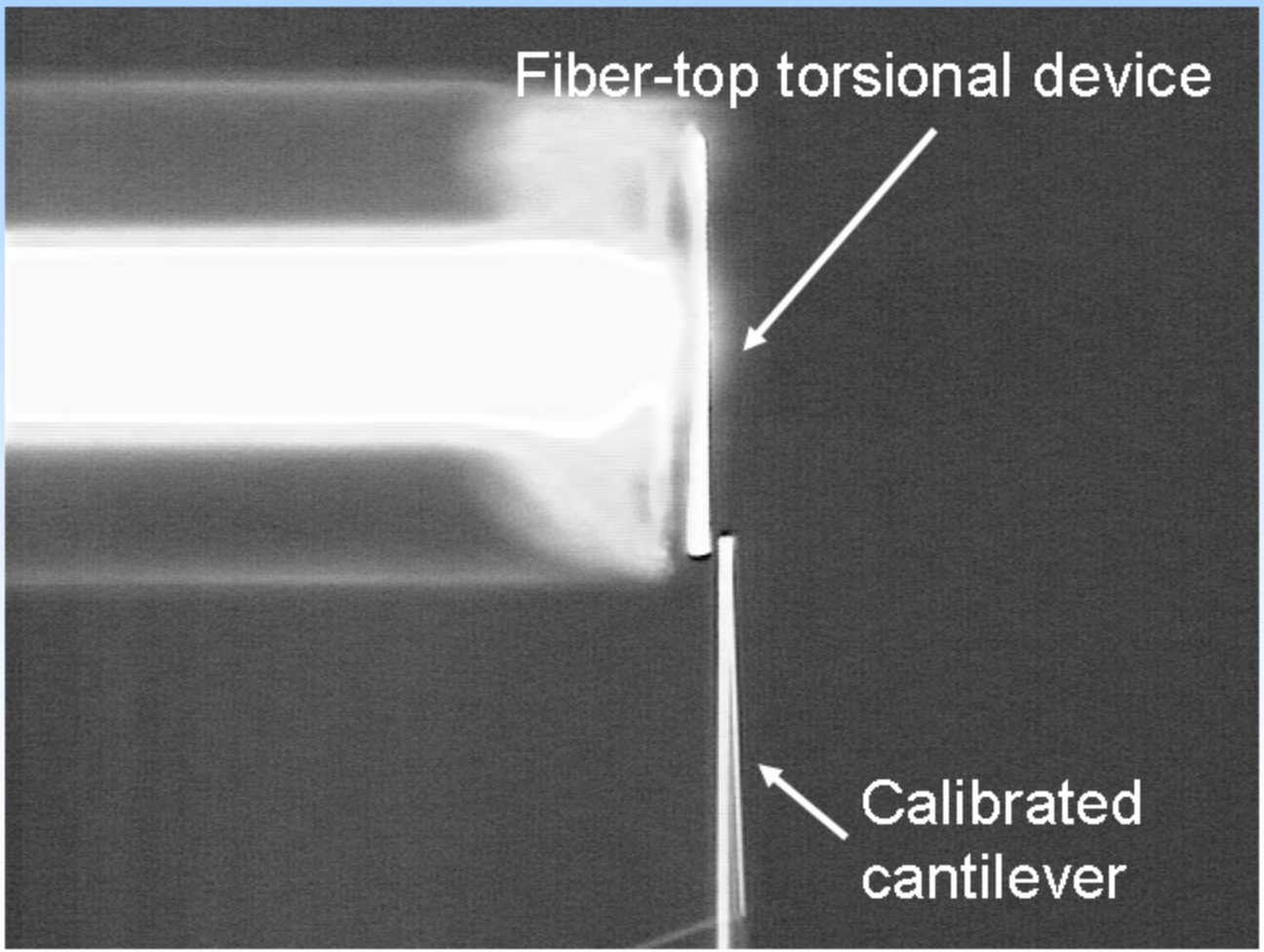
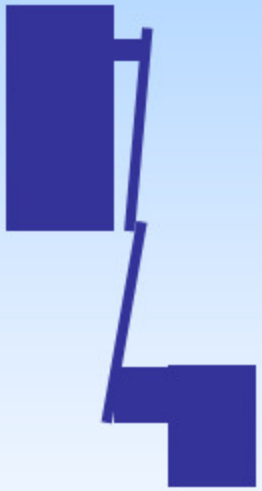
Torsional device: test





Low k fiber-top devices: test

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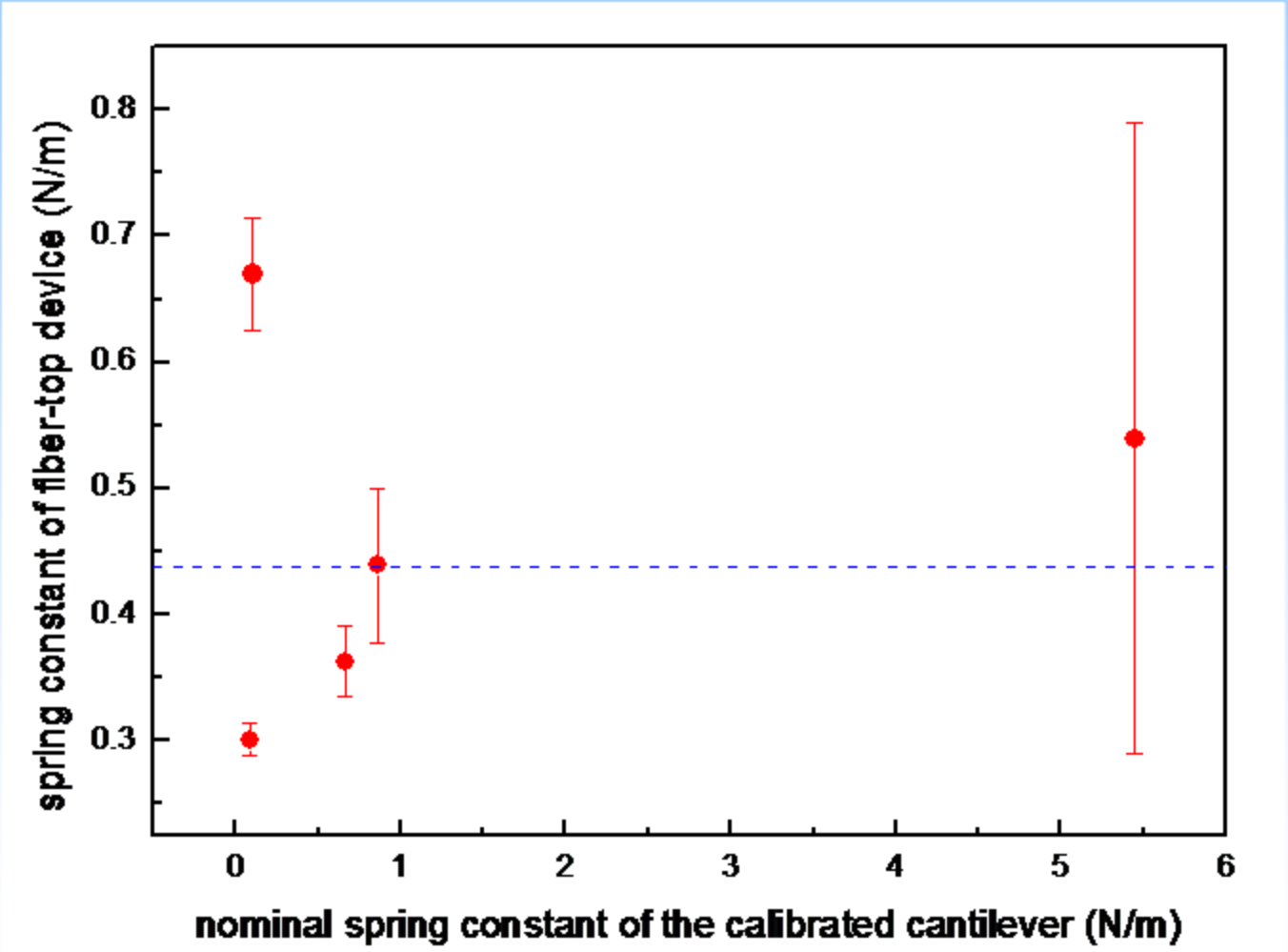

Casimir force measurements with fiber-top devices

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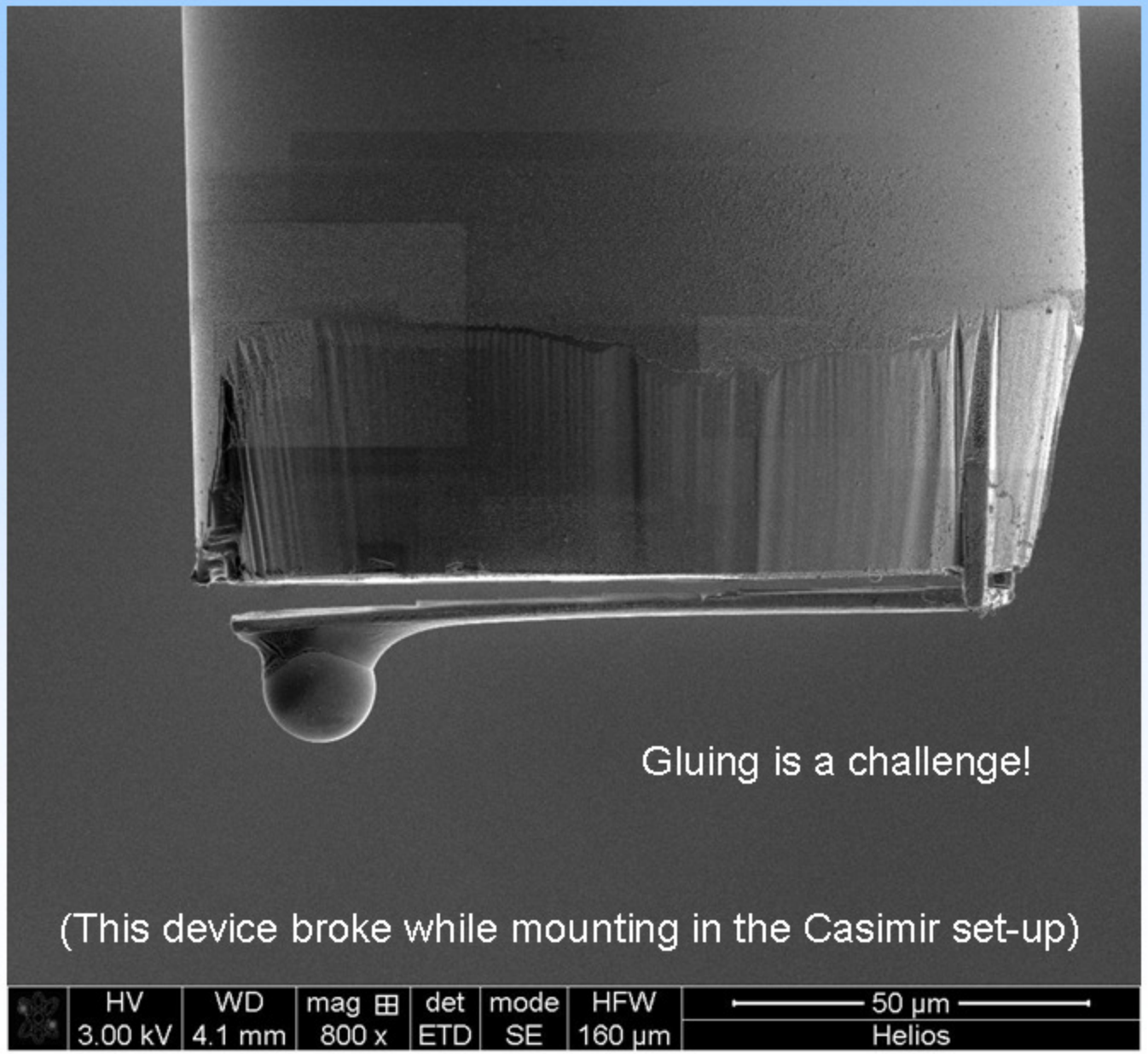

Casimir force measurements with fiber-top devices

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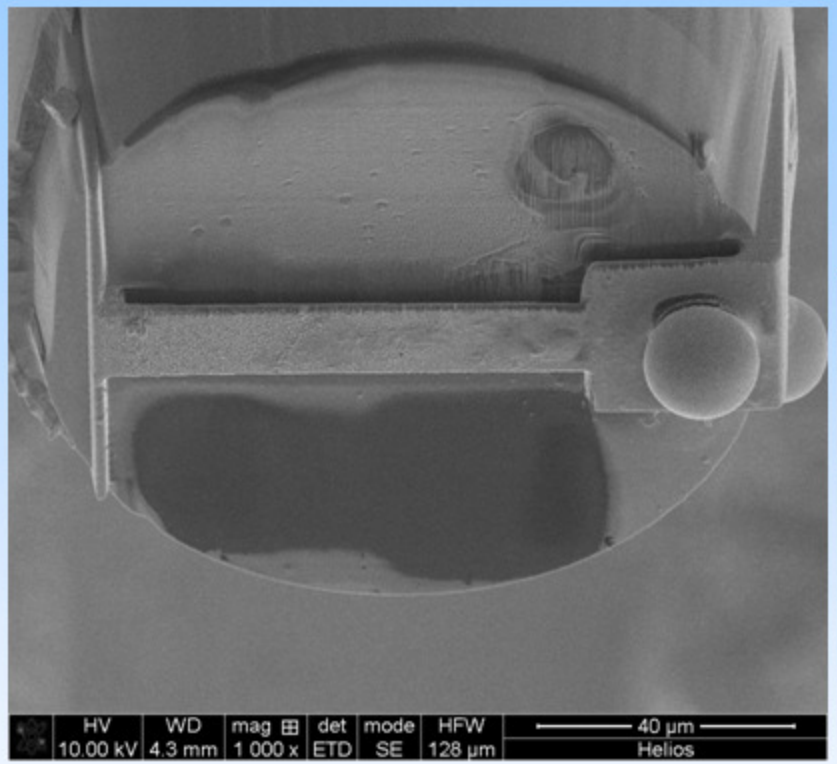
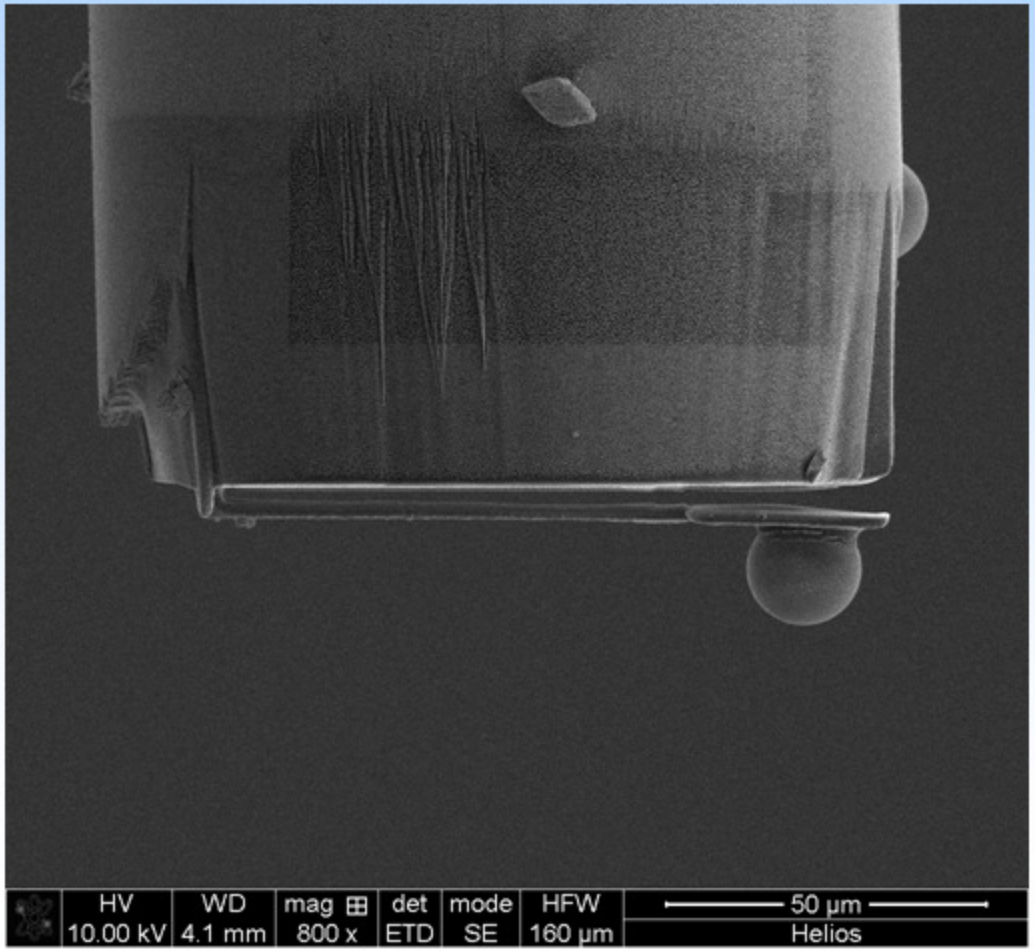


New device, no test:
directly plugged into Casimir set-up



Casimir force measurements: challenges

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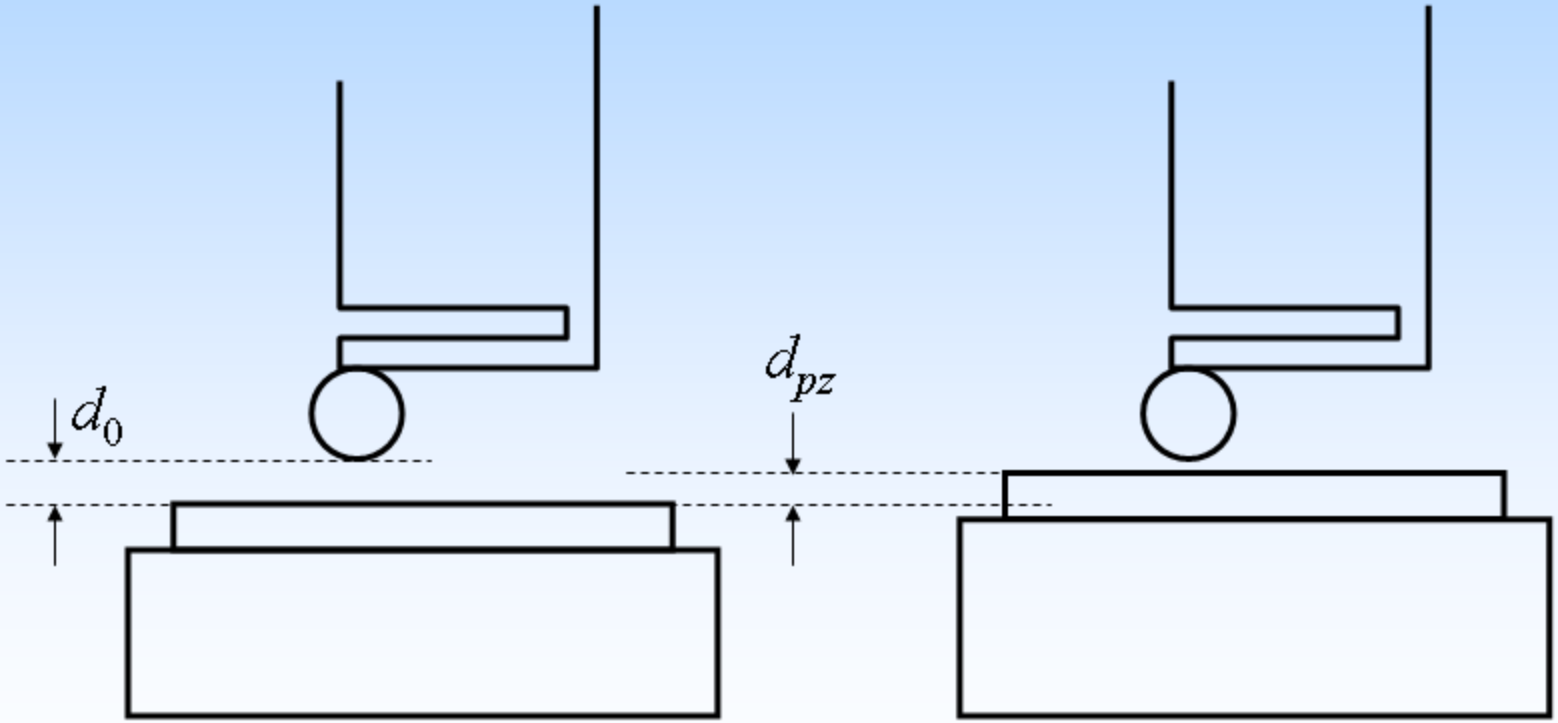
d_0 Initial separation between the two surfaces

ξ

V_0



Casimir force measurements: challenges

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d_0 Initial separation between the two surfaces

ξ Calibration constant (from V_{out} (in mV) to F_{out} (in pN))

V_0

Casimir force measurements: challenges

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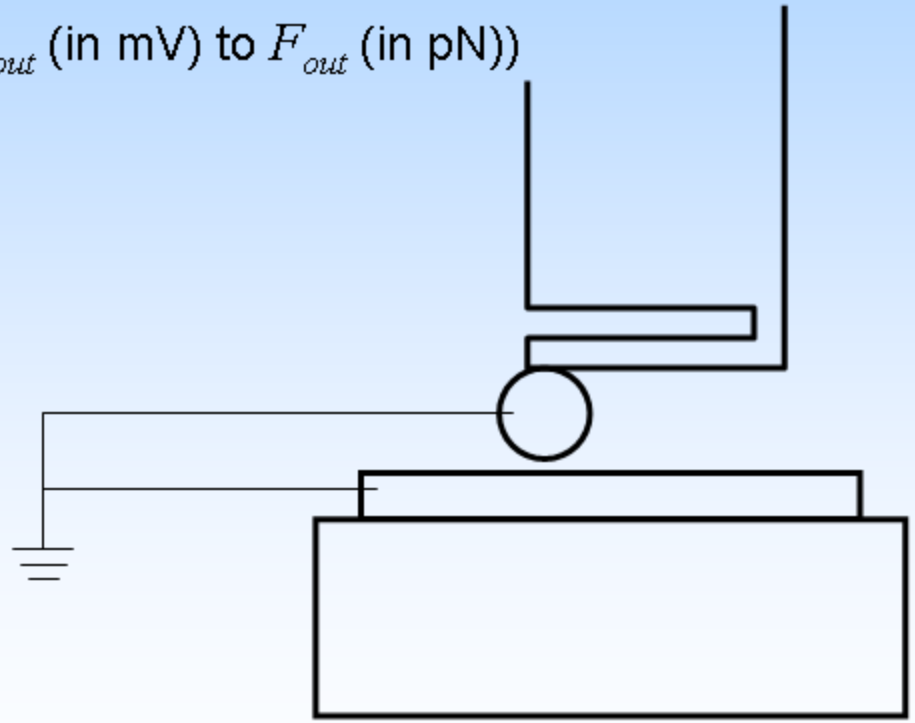
d_0 Initial separation between the two surfaces

ξ Calibration constant (from V_{out} (in mV) to F_{out} (in pN))

V_0 Volta potential



Casimir force measurements: method

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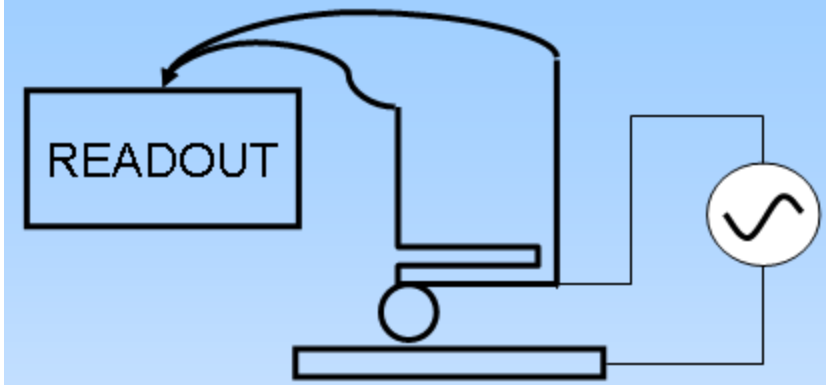
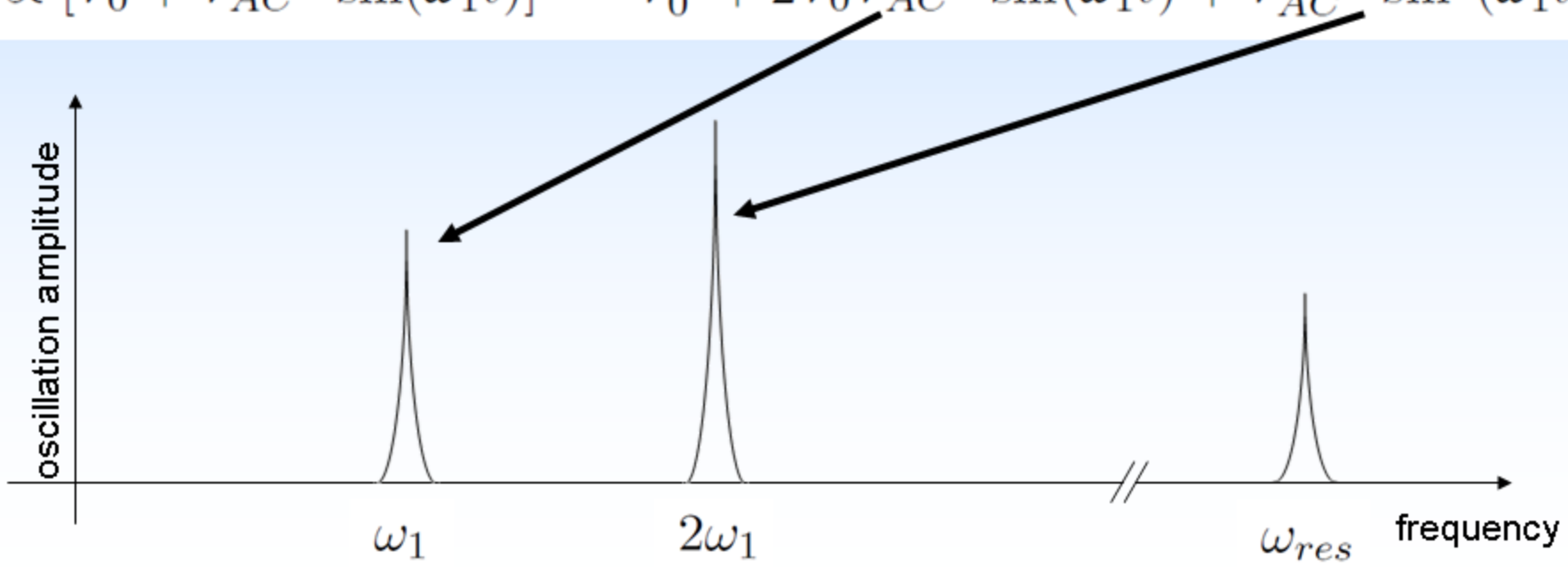


Fixed d.

$V_{AC} \cdot \sin(\omega_1 t)$ with $\omega_1 \ll \omega_{res}$

$$F_{el} = -\frac{\epsilon_0 \pi R V_{applied}^2}{d}$$

$$F_{el} \propto [V_0 + V_{AC} \cdot \sin(\omega_1 t)]^2 = V_0^2 + 2V_0 V_{AC} \cdot \sin(\omega_1 t) + V_{AC}^2 \cdot \sin^2(\omega_1 t)$$



Casimir force measurements: method

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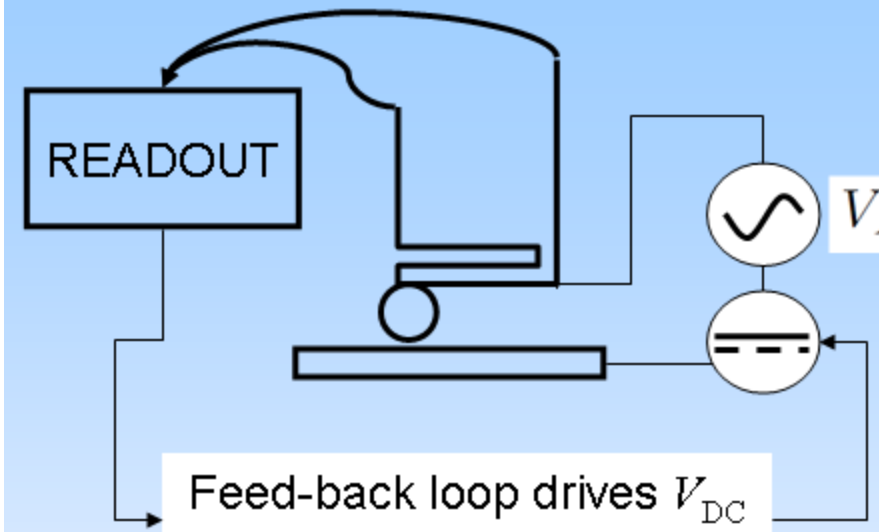
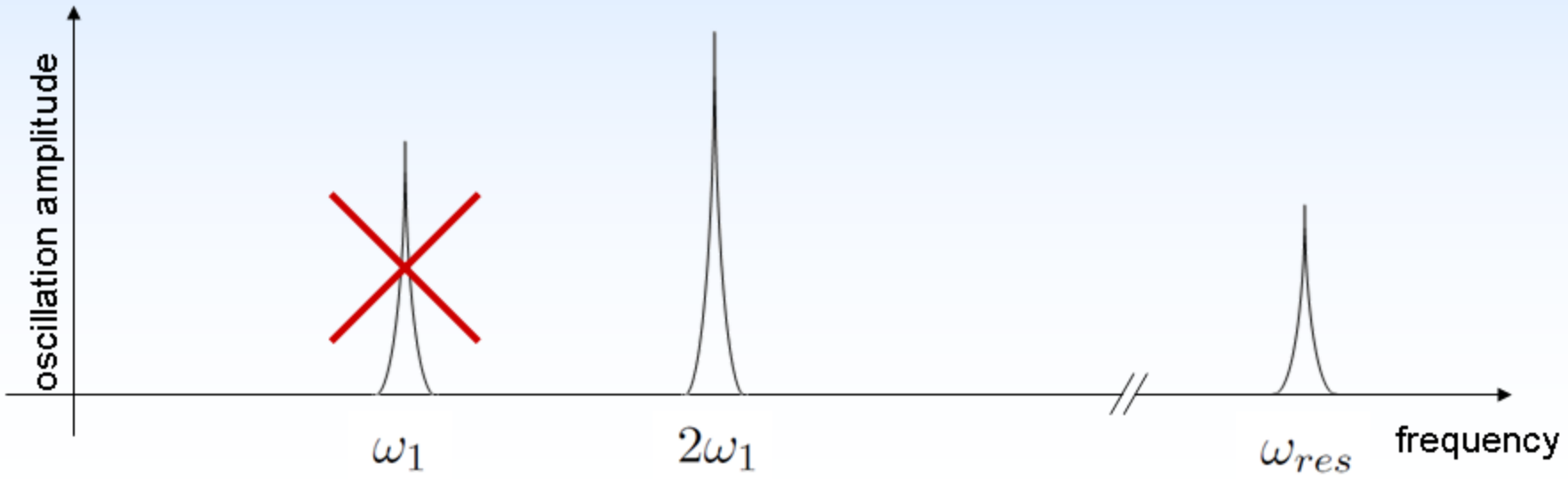


$V_{AC} \cdot \sin(\omega_1 t)$ with $\omega_1 \ll \omega_{res}$

Feed-back loop drives V_{DC} so that signal at ω_1 is zero



Casimir force measurements: method

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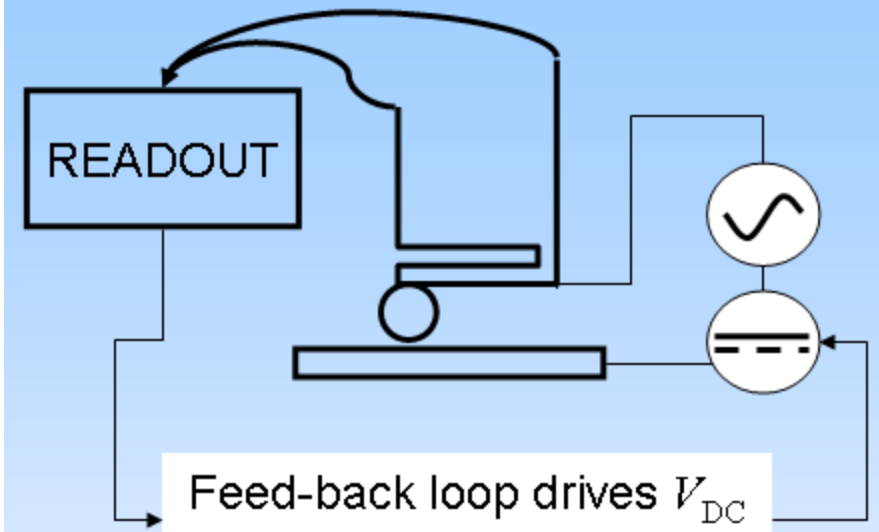
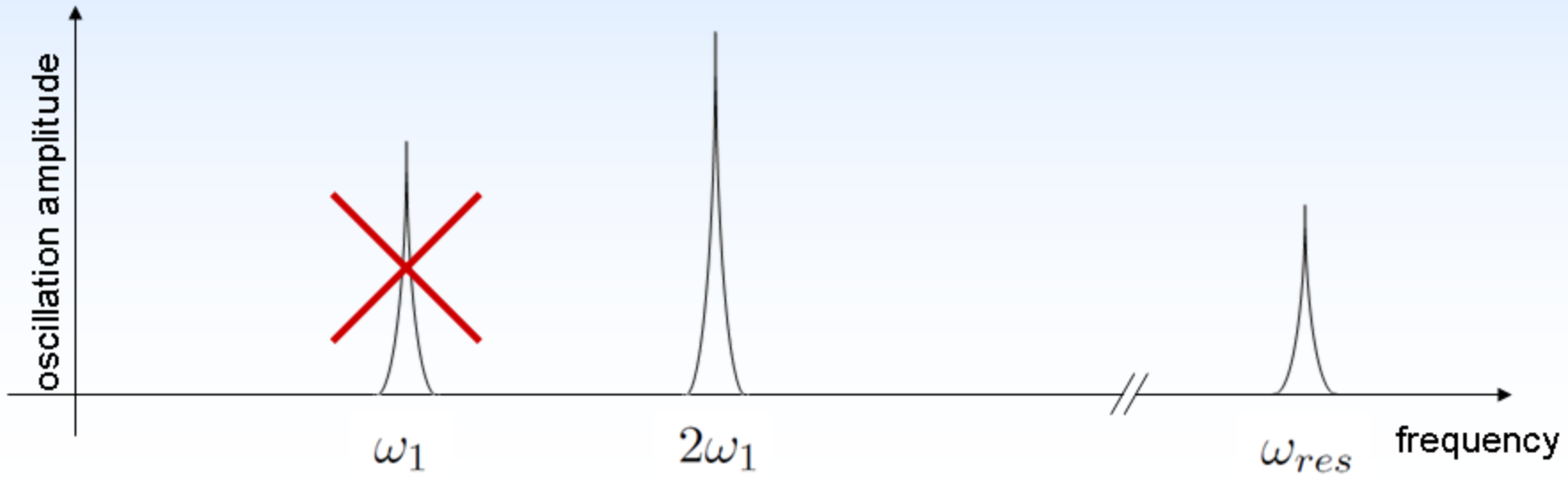


Feed-back loop drives V_{DC} so that signal at ω_1 is zero

V_0: feedback on!

$$F_{el} = \frac{\epsilon_0 \pi R V_{AC}^2}{d} \cos(2\omega_1 t)$$

$$S_{out} = \xi \frac{\epsilon_0 \pi R V_{AC}^2}{d} \cos(2\omega_1 t)$$



Casimir force measurements: method

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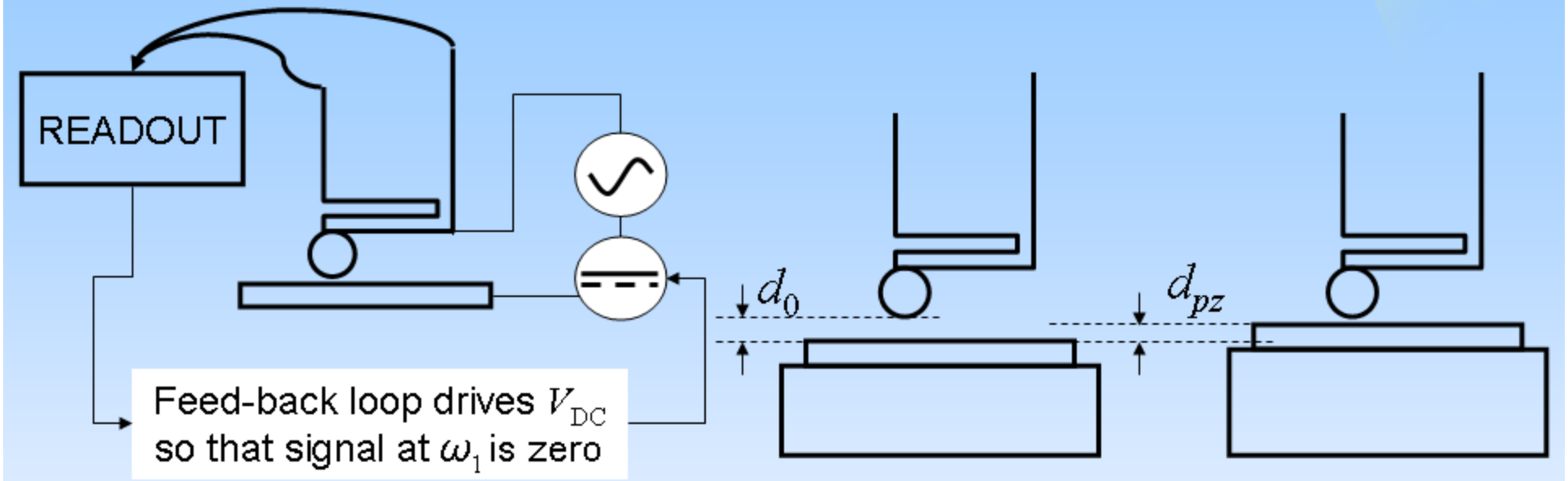
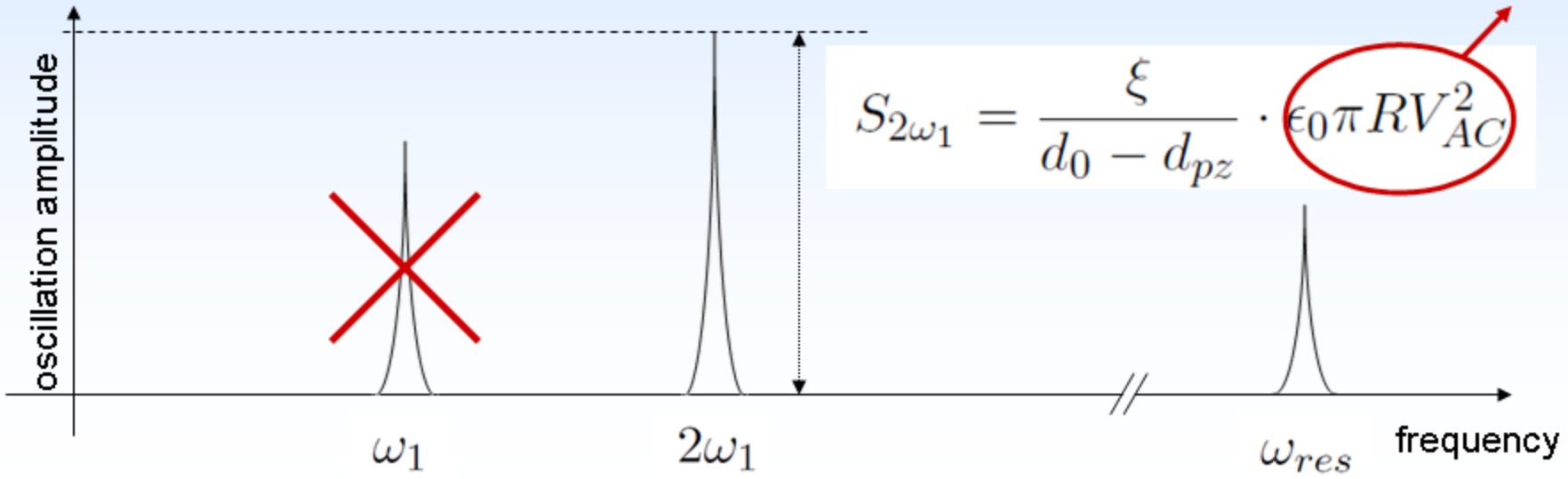


Feed-back loop drives V_{DC} so that signal at ω_1 is zero

known

$$S_{2\omega_1} = \frac{\xi}{d_0 - d_{pz}} \cdot \epsilon_0 \pi R V_{AC}^2$$



Casimir force measurements: method

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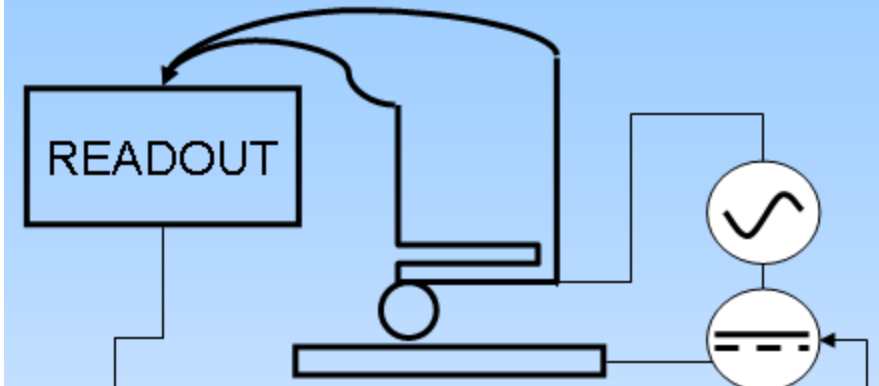
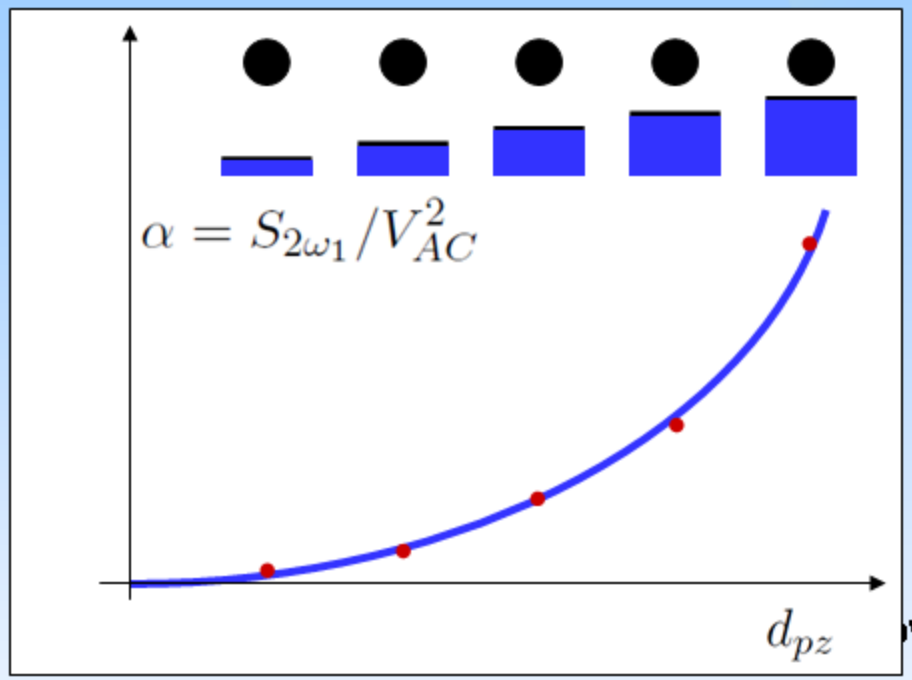


Feed-back loop drives $V_{\rm DC}$ so that signal at ω_1 is zero

Measure $S(2\omega_1)$



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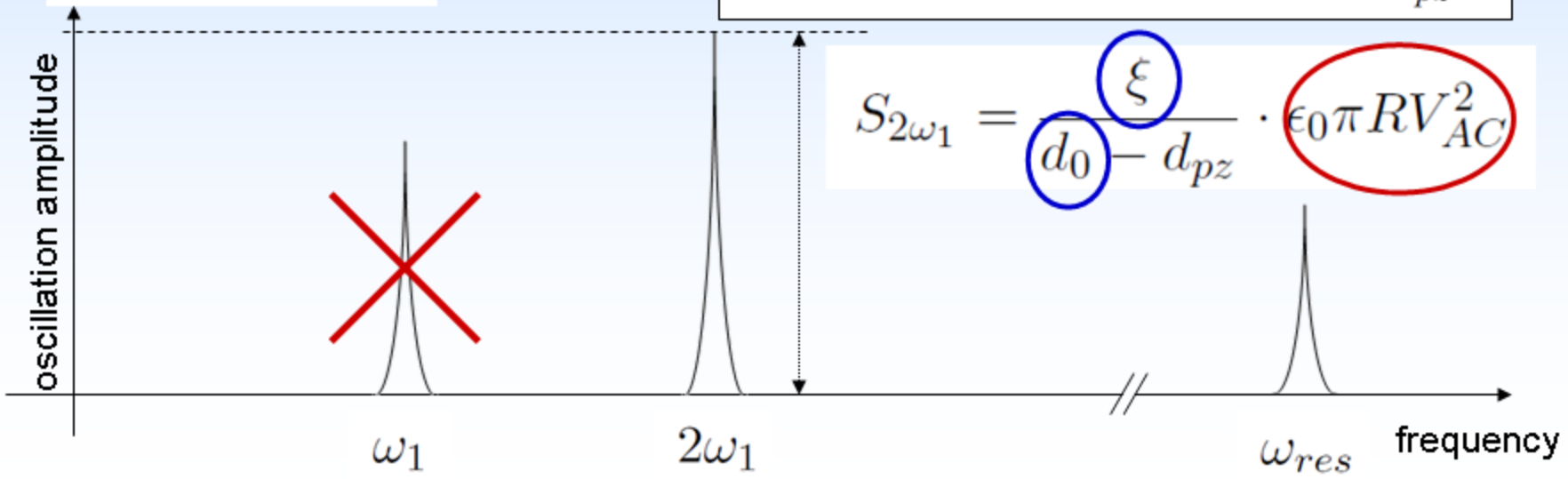

$$S_{2\omega_1} = \frac{\xi}{d_0 - d_{pz}} \cdot \epsilon_0 \pi R V_{AC}^2$$

Casimir force measurements: method

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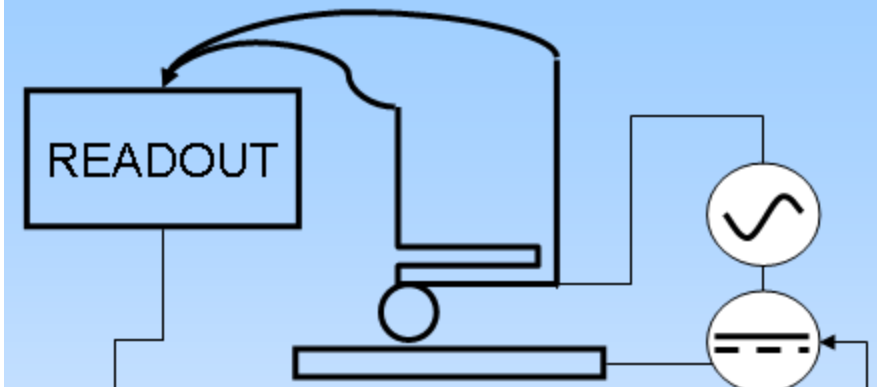
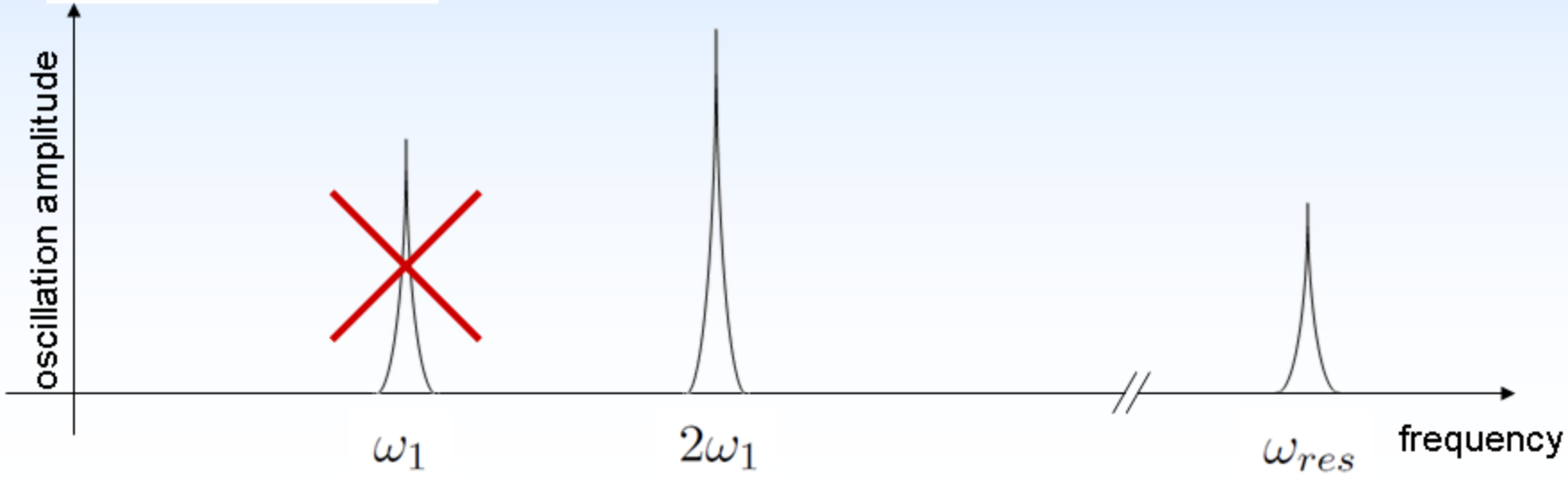


Add oscillation at ω_2

Feed-back loop drives V_{DC} so that signal at ω_1 is zero

Measure $S(2\omega_1)$



Casimir force measurements: method

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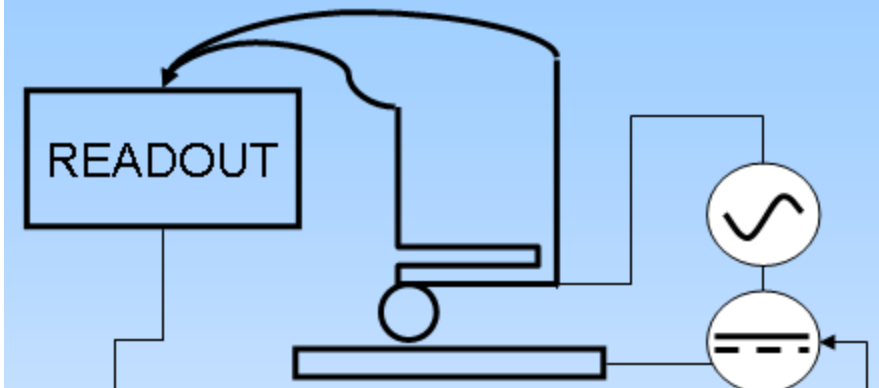
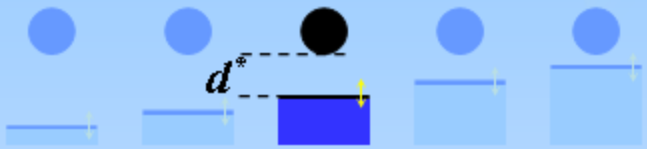




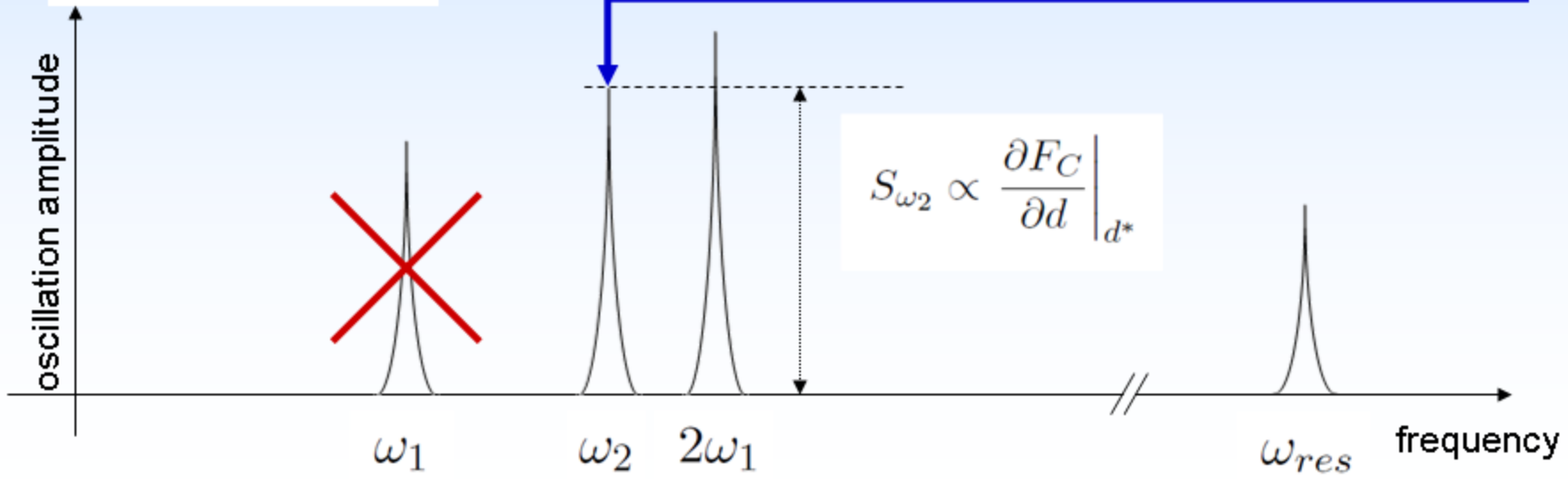
$$F_C(t) = F_C(d^* + \delta\cos(\omega_2 t)) \simeq$$

$$\simeq F_C(d^*) + \left.\frac{\partial F_C}{\partial d}\right|_{d^*} \cdot \delta\cos(\omega_2 t)$$

Feed-back loop drives V_{DC} so that signal at ω_1 is zero

Measure $S(2\omega_1)$

$$S_{\omega_2} \propto \left.\frac{\partial F_C}{\partial d}\right|_{d^*}$$



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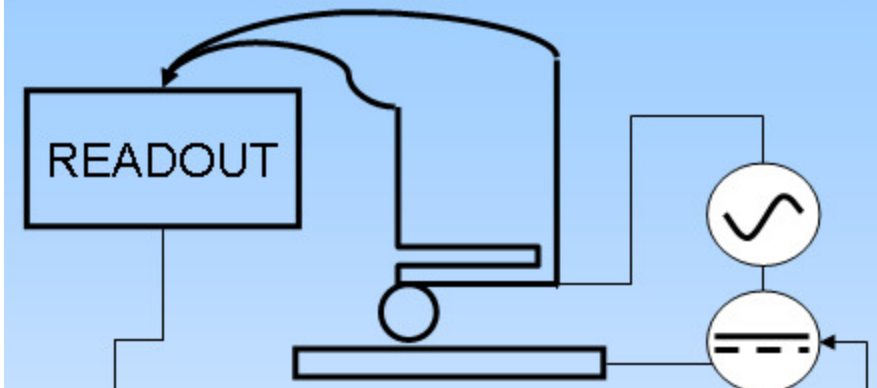
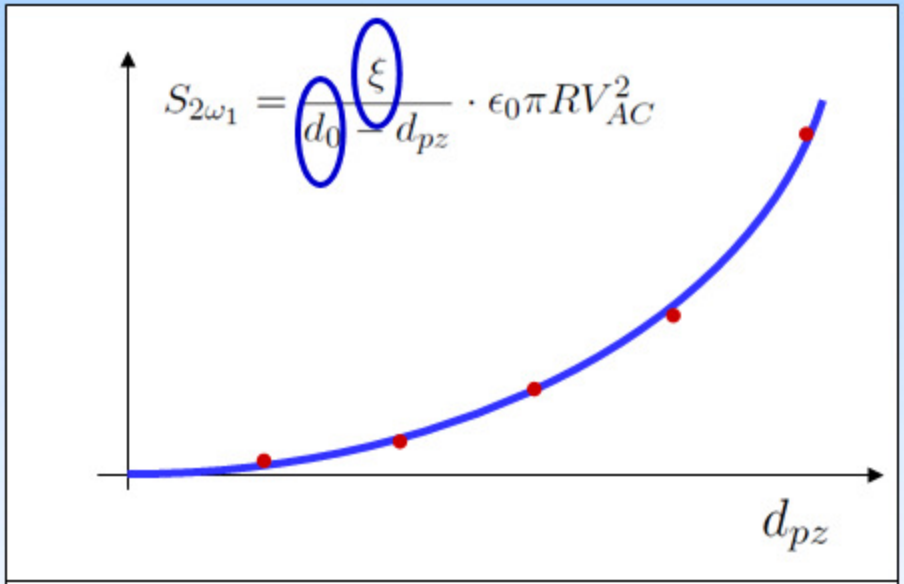
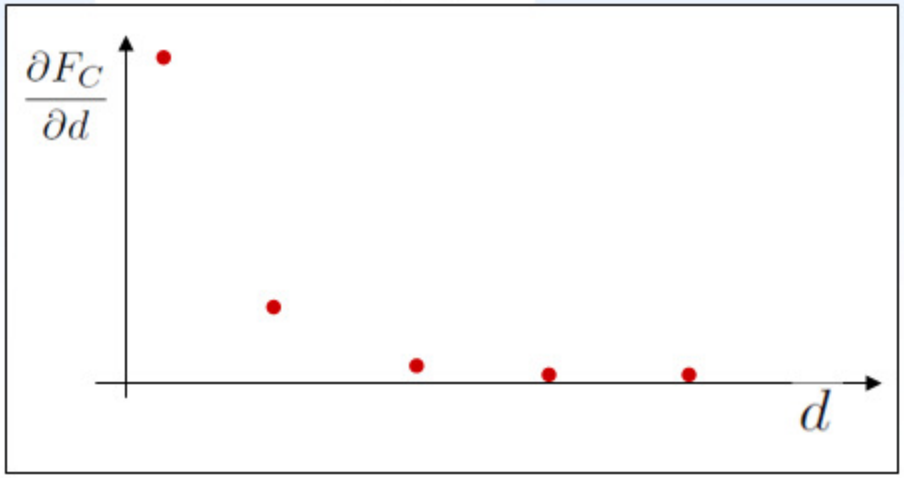


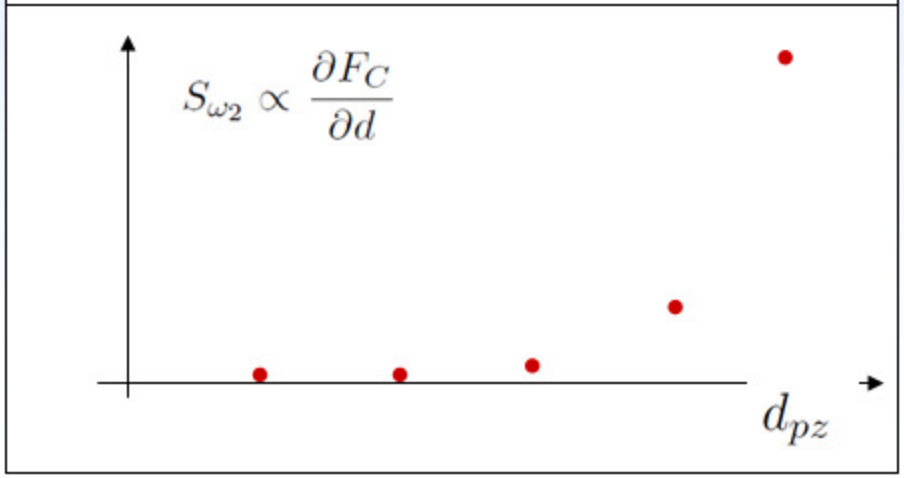
Feed-back loop drives $V_{\rm DC}$ so that signal at ω_1 is zero

Measure $S(2\omega_1)$

Measure $S(\omega_2)$







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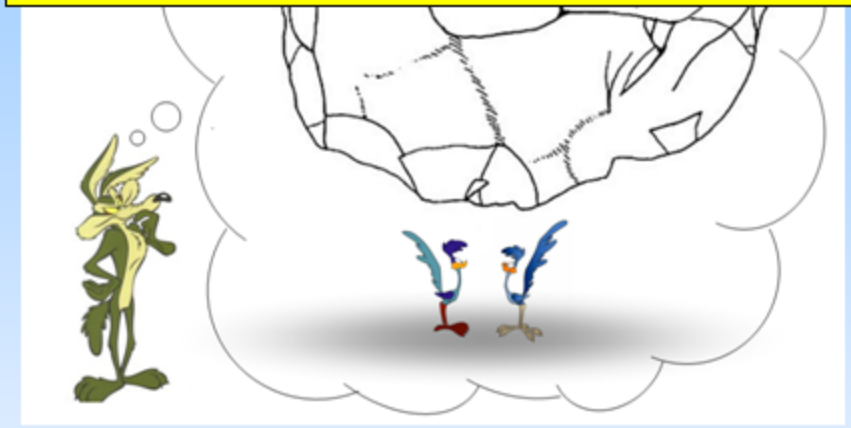
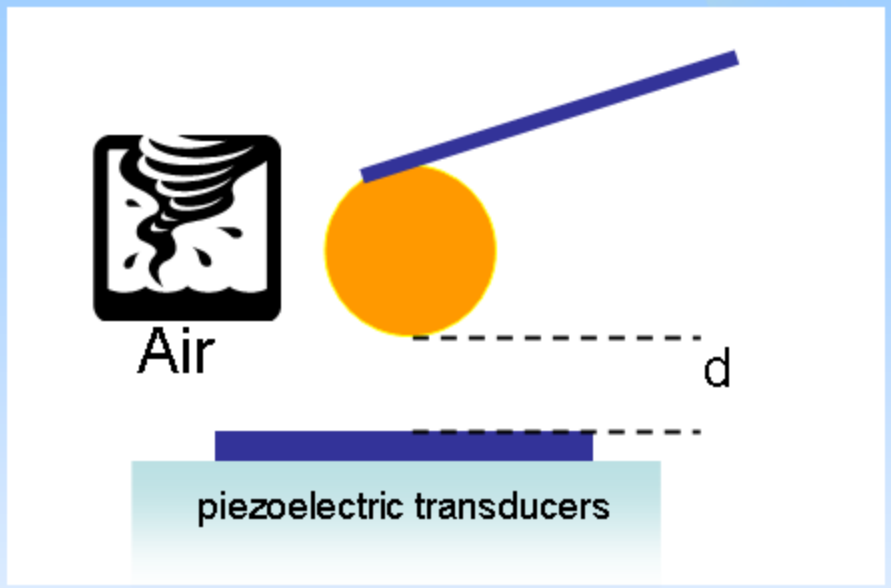
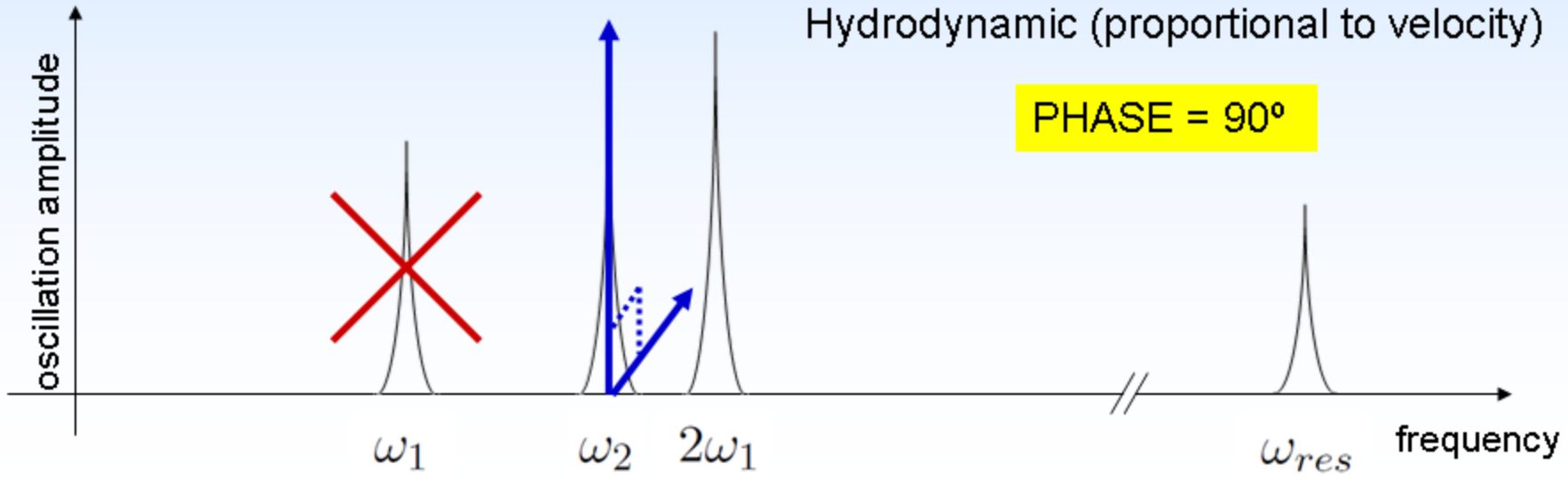
de Man, Heeck, Wijngaarden, and DI
Halving the Casimir force with conductive oxide
Phys. Rev. Lett. **103** (2009) 040402







Hydrodynamic (proportional to velocity)

PHASE = 90°

Halving the Casimir force with conductive oxides

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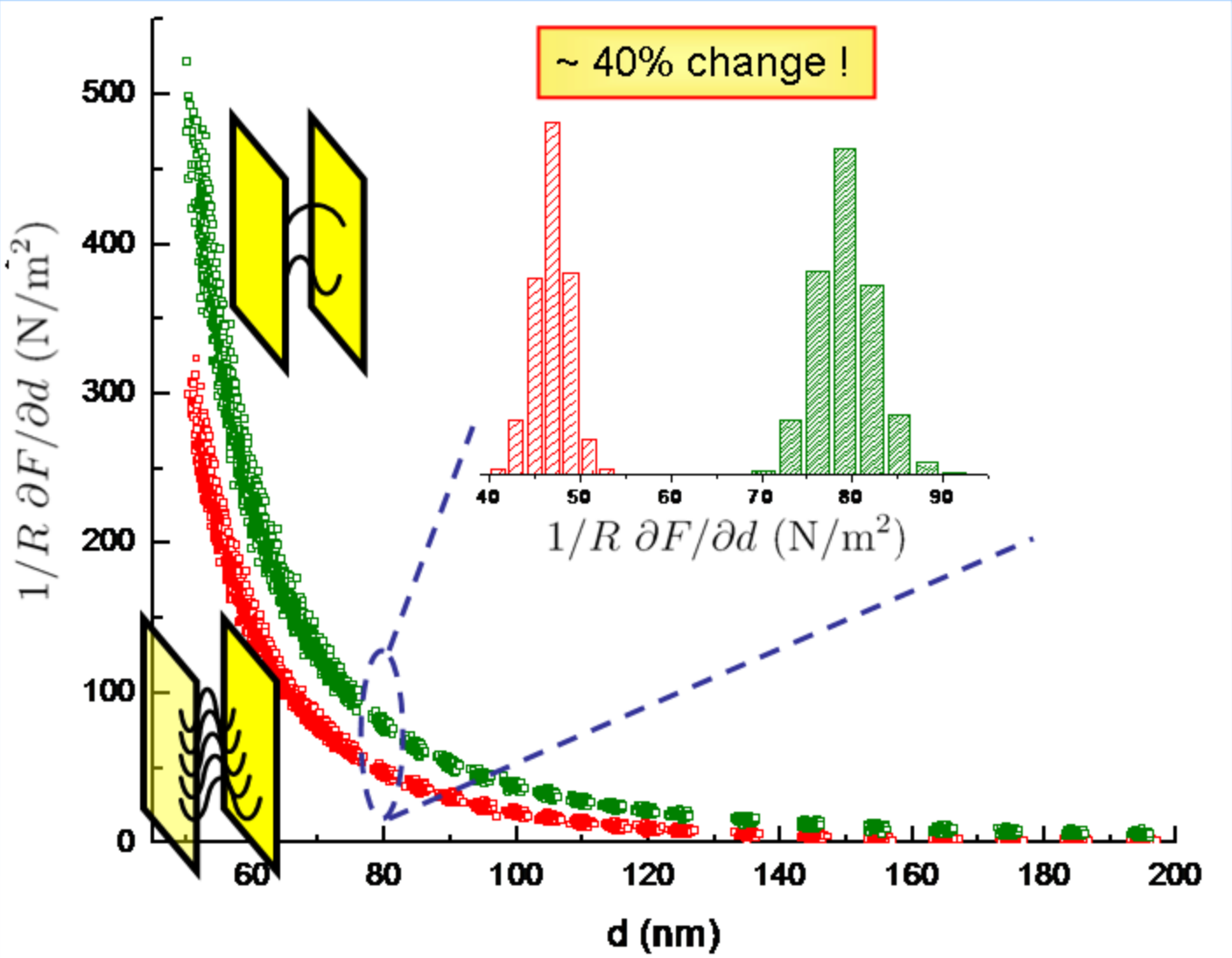

Casimir force measurements: our "fortress"

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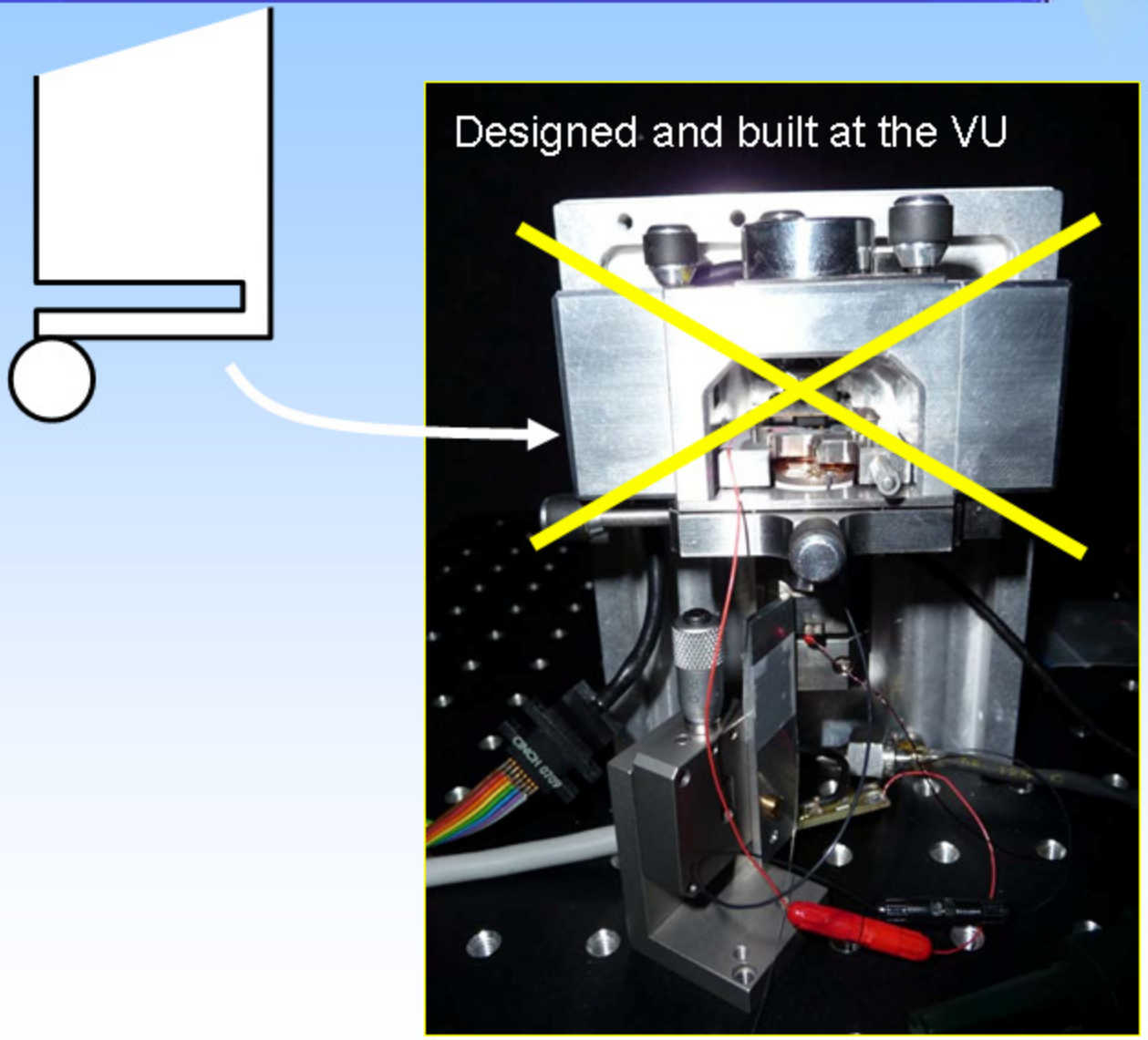

Casimir force measurements: where are we?

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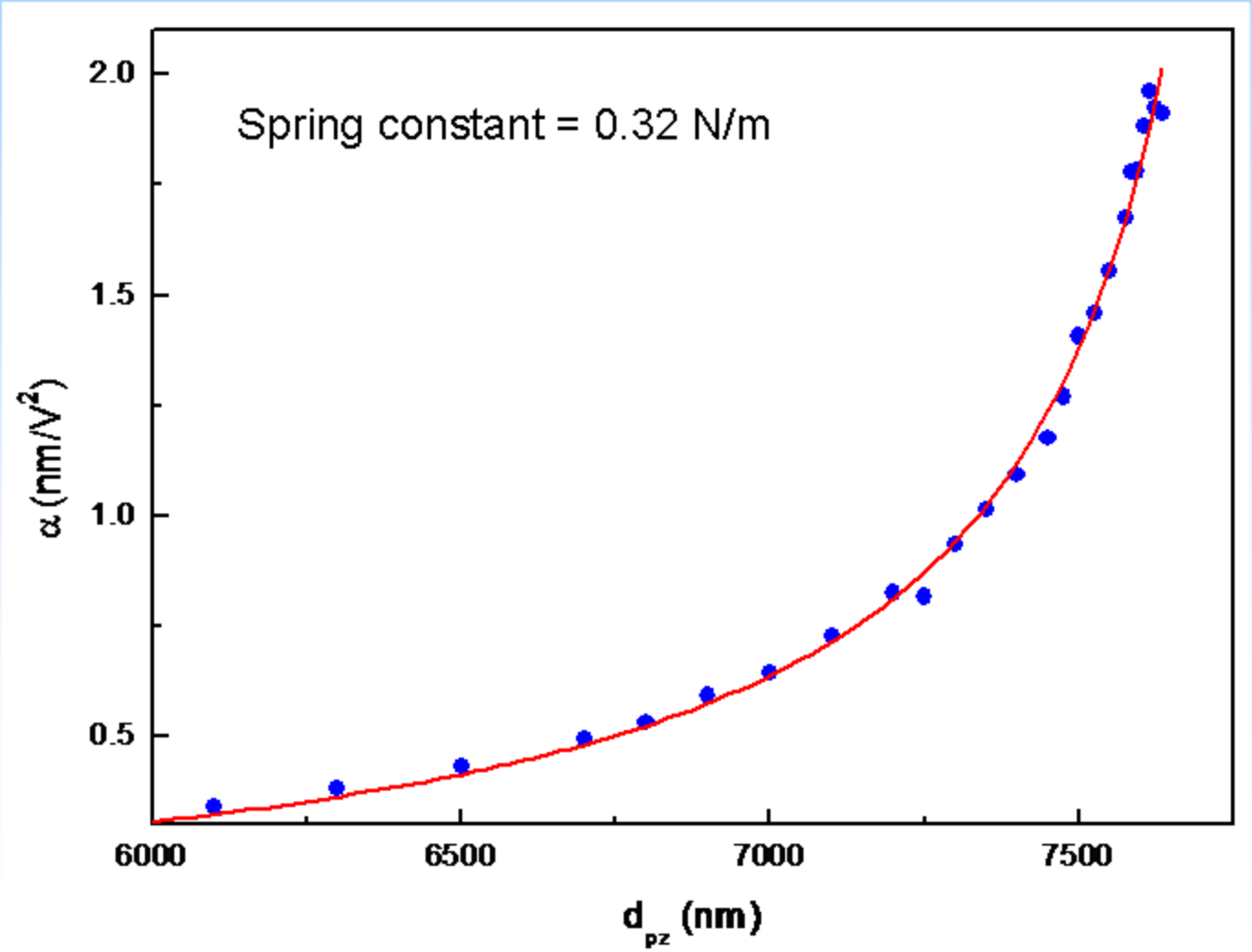
Calibration curve (oscillation off)



Casimir force measurements: where are we?

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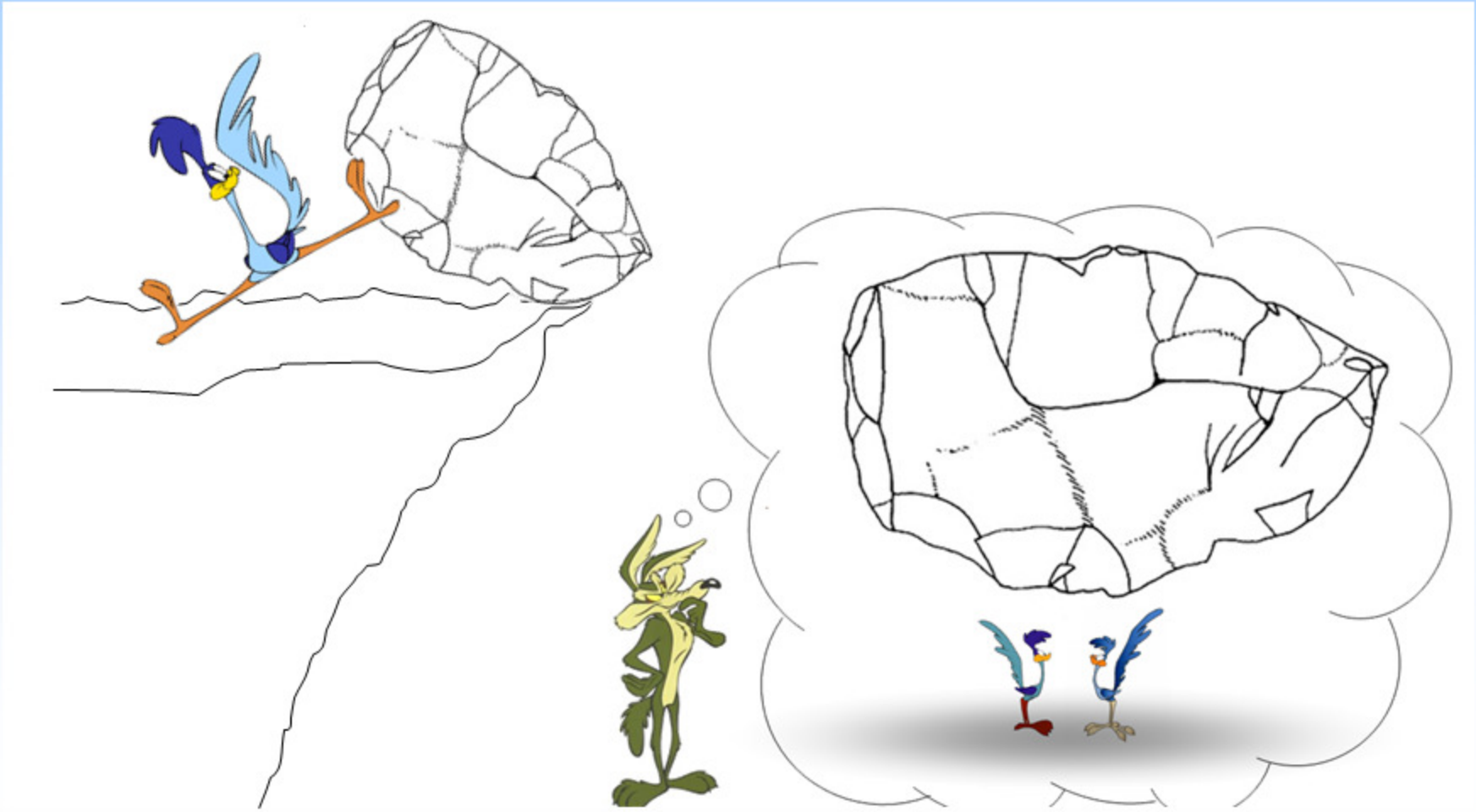
Casimir curve (oscillation on): non-reproducible results



Casimir force measurements: where are we?

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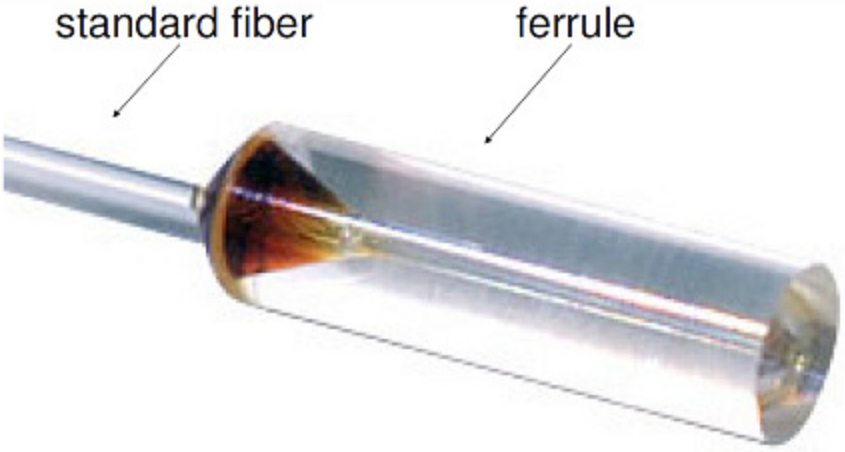
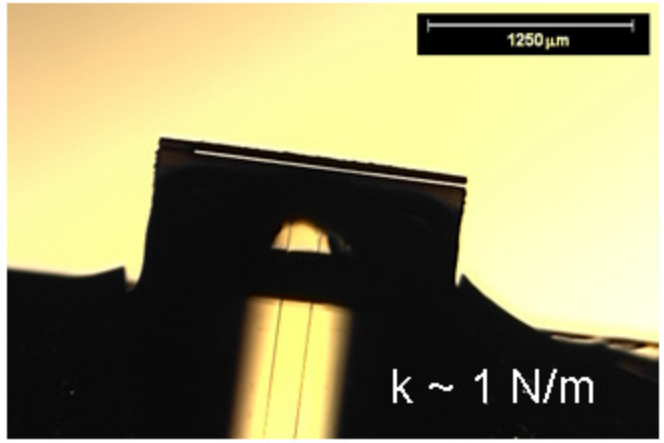
Casimir curve (oscillation on): a possible solution?





(also: much easier and less expensive fabrication process)

$(IDEAS)^{\mu m}$ = *InterDisciplinary Engineering and Applied Sciences at the micron scale*

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Jan Rector
(technical support)

Martin Slaman
(technical support)

Nienke Alberts
(Former member)

+ collaborations with the group of M. Elwenspoek (Twente University)