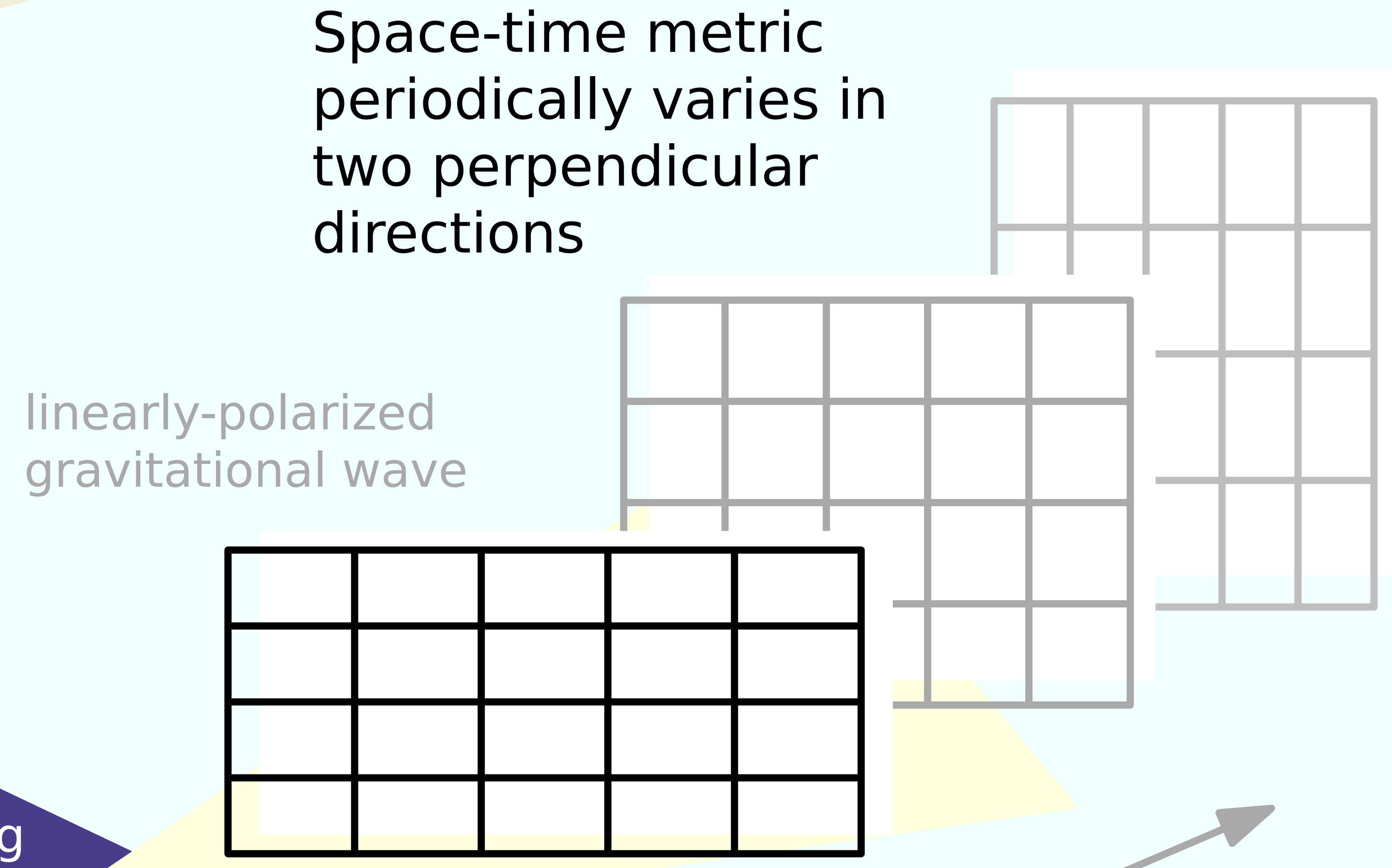
Time limits for measurement of gravitational waves with dynamical Casimir effect in solid-state detectors

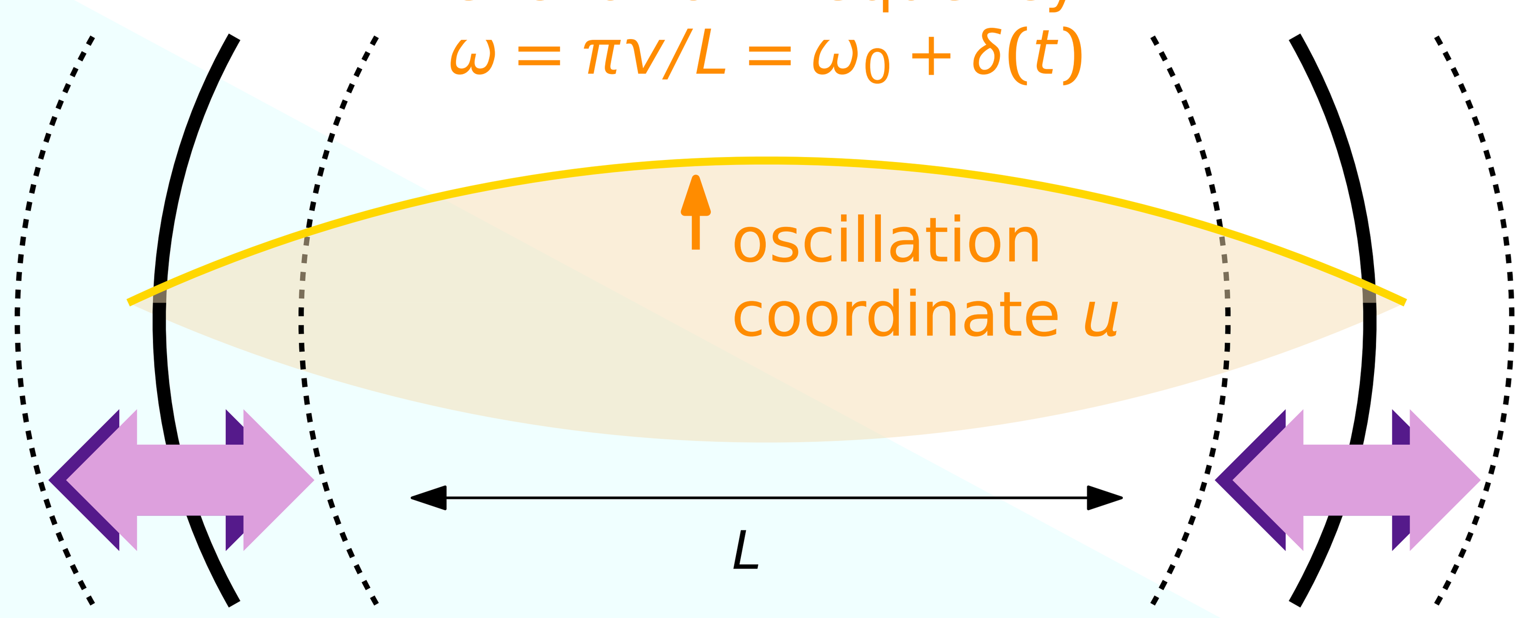
Andrii M. Sokolov of Institute of Physics, Kyiv

Can a gravitational wave change a resonator state?

Space-time metric periodically varies in two perpendicular directions



A distributed on-chip resonator:
a planar microwave resonator
or a surface-acoustic wave resonator



Resonator length varies as
$L = L_0(1 + h_+)$

Metric perturbation
$h_+ = \epsilon \sin \Omega t$

Dynamical Casimir effect

At $\Omega = \omega_0/2$, fluctuations are parametrically amplified—if the resonator length varies vigorously

$\epsilon \sim 10^{-20}$
@ $\Omega = 100\,\text{kHz}$
$\to \langle n \rangle = 1$ phonon in
$t \sim 1/\Omega\epsilon^2 \sim 10^{27}$ years

Gravitational waves are far too weak near Earth to excite photons or phonons

Some interesting sources

100 kHz
- primordial black holes and exotic compact objects
- axion decay
- superradiance

750 MHz
- phase transitions in the early Universe
- oscillons

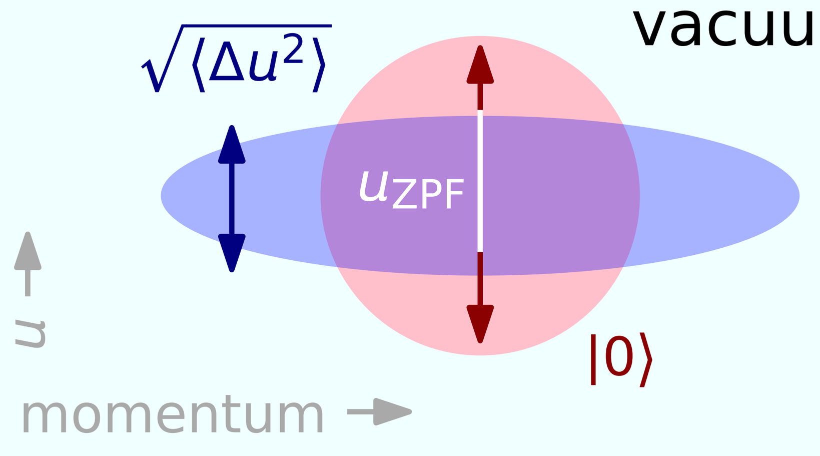
Still, they alter a quantum state. Can that be measured?

Consider a squeezed vacuum state:

$|r\rangle = e^{\frac{r}{2}(a^2 - a^{\dagger 2})}\,|0\rangle$

with squeezing

$V = \frac{\langle \Delta u^2 \rangle}{u_{\text{ZPF}}^2} = e^{-2r} = 10^{-\frac{V_{\text{dB}}}{10}}$



$H_\epsilon(t) = 2\omega_0^2 t^2 (1 + \sinh^4 r)$ information encoded by a wave

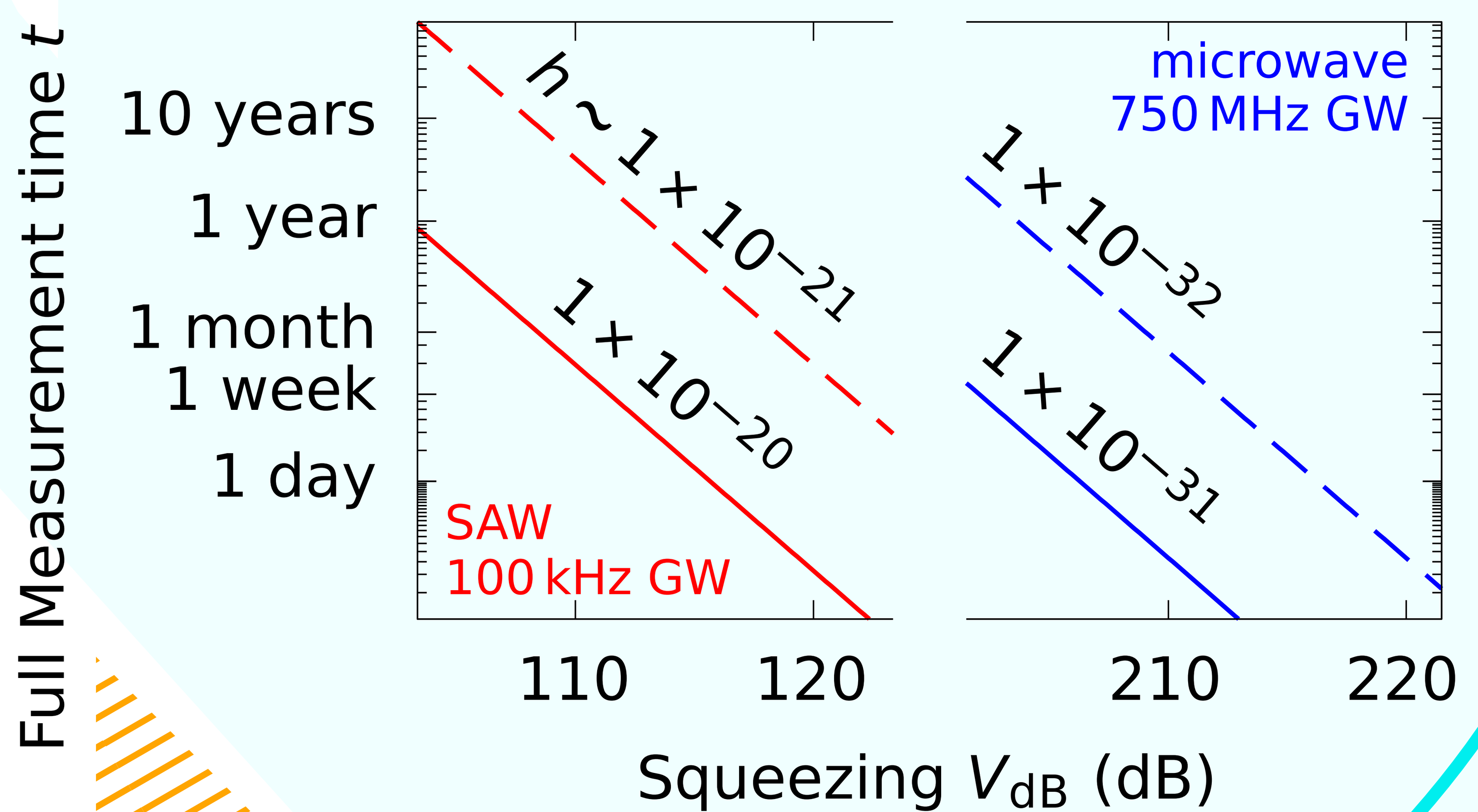
$N = \frac{1}{\langle \Delta\epsilon^2 \rangle H_\epsilon(t_{\text{bin}})}$ measurements —each t_{bin} long—

yield at least $\sqrt{\langle \Delta\epsilon^2 \rangle}$ error in the metric magnitude ϵ

Many mutually-incoherent measurements

$$t \sim \left(\frac{\omega_0/2\pi}{\text{MHz}}\right)^{-1} 10^{-13 - \lg\langle \Delta\epsilon^2 \rangle - \lg QD - \frac{1}{5}V_{\text{dB}}} \text{ years}$$

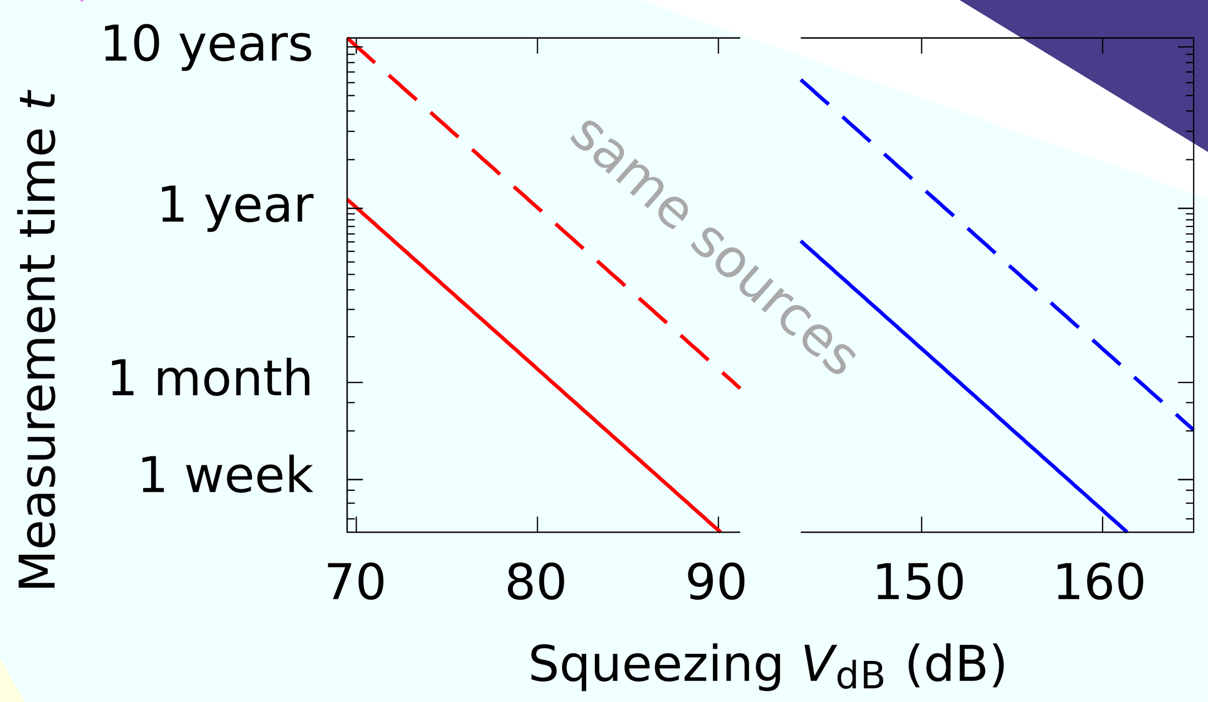
$D = 100$ devices operate simultaneously.
Each measurement bin ten is times shorter than the coherence time Q/ω, where $Q = 10^6$.



Such squeezing may be gained already this millenium. Currently, $V_{\text{dB}} \lesssim 10\,\text{dB}$.

Infinite coherence limit

$N = 1$ measurement with $D = 1$ device



$$t \sim \left(\frac{\omega_0/2\pi}{\text{MHz}}\right)^{-1} 10^{-14 - \frac{1}{2}\lg\langle \Delta\epsilon^2 \rangle - \frac{1}{10}V_{\text{dB}}} \text{ years}$$

This can be done even sooner—if a robust quantum error-correction is ever reached.

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