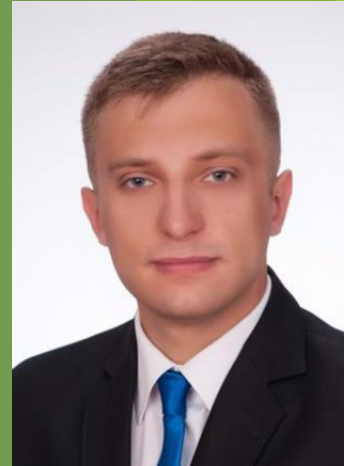


# Cooperatively-enhanced precision of hybrid light-matter sensors



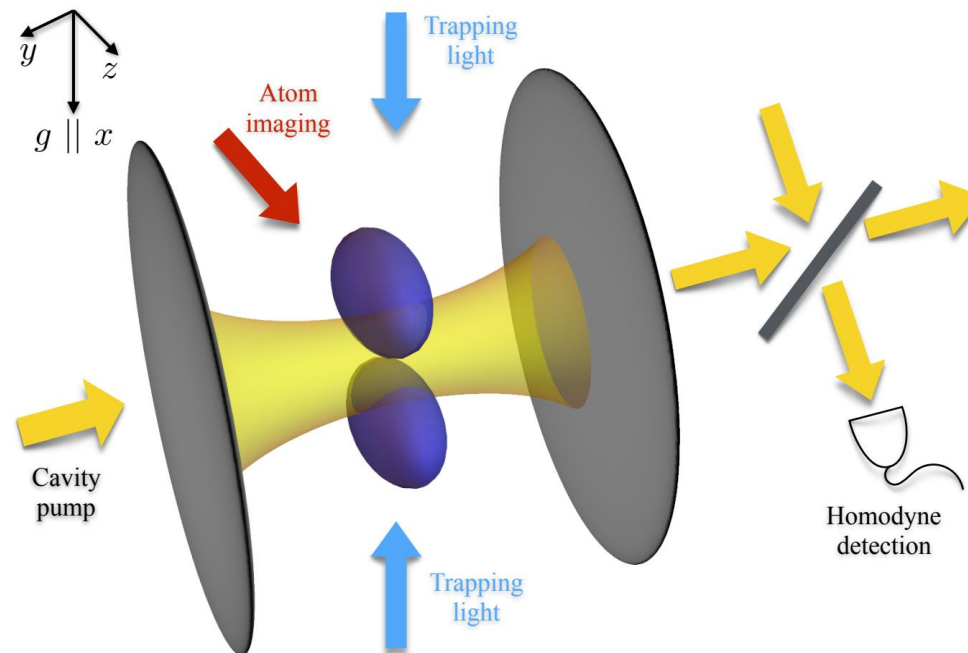
Artur Niezgoda<sup>a\*</sup>, Jan Chwedeńczuk<sup>a</sup>, Tomasz Wasak<sup>b</sup> and Francesco Piazza<sup>b†</sup>

<sup>a</sup> Faculty of Physics, University of Warsaw, ul. Pasteura 5, PL-02-093 Warsaw, Poland

<sup>b</sup> Max-Planck-Institut für Physik Komplexer Systeme, 01187 Dresden, Germany

\*[artur.niezgoda@fuw.edu.pl](mailto:artur.niezgoda@fuw.edu.pl)

†[piazza@pks.mpg.de](mailto:piazza@pks.mpg.de)



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# Cooperatively-enhanced precision of hybrid light-matter sensors

$$[1] \hat{H} = (-\Delta_c + a_1 N) \hat{n} + \eta(\hat{a} + \hat{a}^\dagger) + a_2 \hat{n} \hat{J}_x$$

$$\Delta\theta \geq \frac{1}{\sqrt{F_Q}} \quad F_Q = \sum_{i,j} \frac{(\lambda_i - \lambda_j)^2}{\lambda_i + \lambda_j} \left| \langle i | \hat{h} | j \rangle \right|^2$$

# Cooperatively-enhanced precision of hybrid light-matter sensors

$$|\psi\rangle = \frac{|-\frac{N}{2}\rangle + |\frac{N}{2}\rangle}{\sqrt{2}} \otimes |n\rangle$$

$$F_Q = t^2 a_2'^2 n^2 N^2$$

$$\Delta\theta \propto 1/(Nn)$$

$$|\psi\rangle = \sum_{m=-\frac{N}{2}}^{\frac{N}{2}} C_m |m\rangle \otimes |\alpha\rangle$$

$$F_Q = nt^2 \left[ 4\varphi'^2 + (a_2')^2 N(n+1) \right]$$

$$n = |\alpha|^2$$

$$\varphi = -\Delta_c + a_1 N$$

$$C_m = \frac{1}{2^{\frac{N}{2}}} \sqrt{\binom{N}{\frac{N}{2} \pm m}}$$

Quadrature of Light



$$\Delta\theta \propto 1/(N\sqrt{n})$$

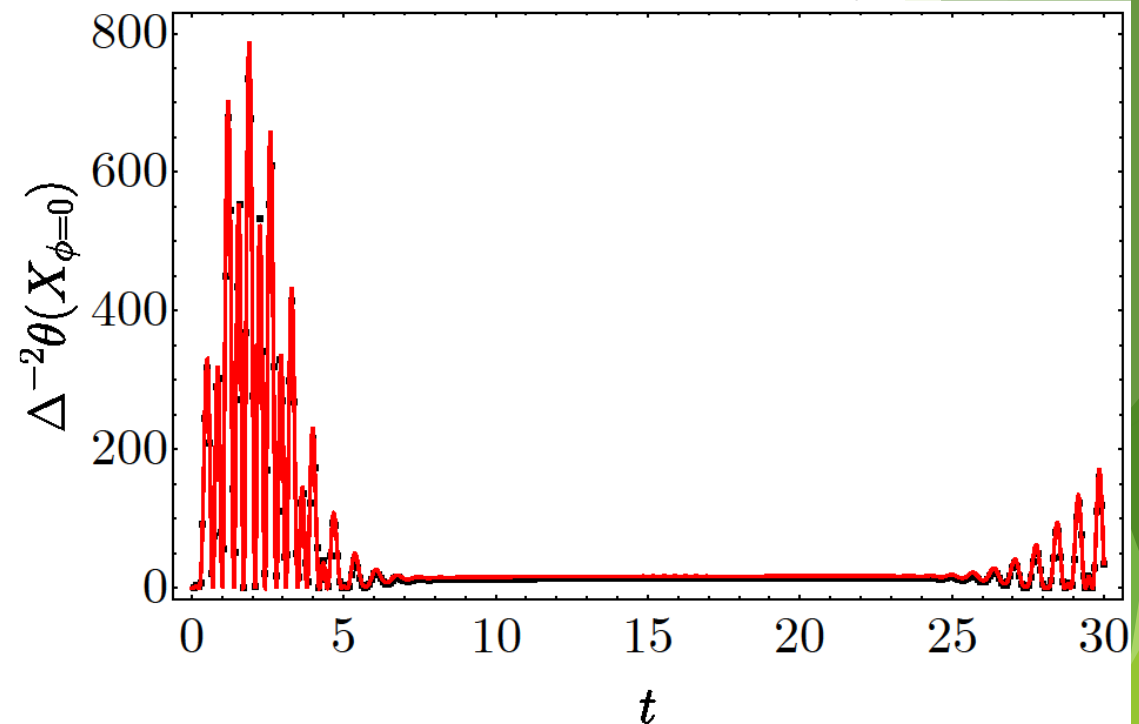
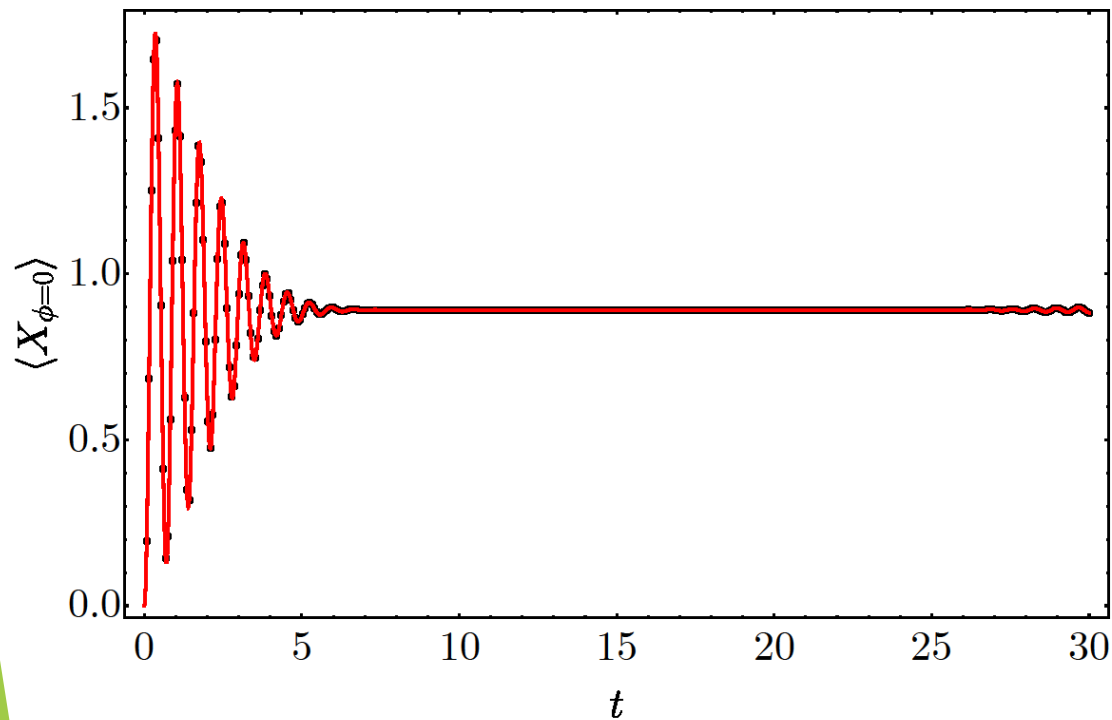


$$\Delta\theta \propto 1/(n\sqrt{N})$$

Imbalance between  
number of atoms in  
each well

# Cooperatively-enhanced precision of hybrid light-matter sensors

$$\hat{\rho}(0) = \sum_{n, n'=0}^{\infty} \sum_{m, m'=-\frac{N}{2}}^{\frac{N}{2}} \rho_{nn'}^{mm'} |n, m\rangle \langle n', m'|$$



The average value of the quadrature  $X$  for  $\phi = 0$  and inverse of the error propagation formula for quadrature as a function of time  $t$ . Black points represent results of numerical calculations, while red solid line stands for the analytic solution.