Super-Poissonian shot noise of squeezed-magnon mediated spin transport

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Fachbereich Physik, Universität Konstanz,
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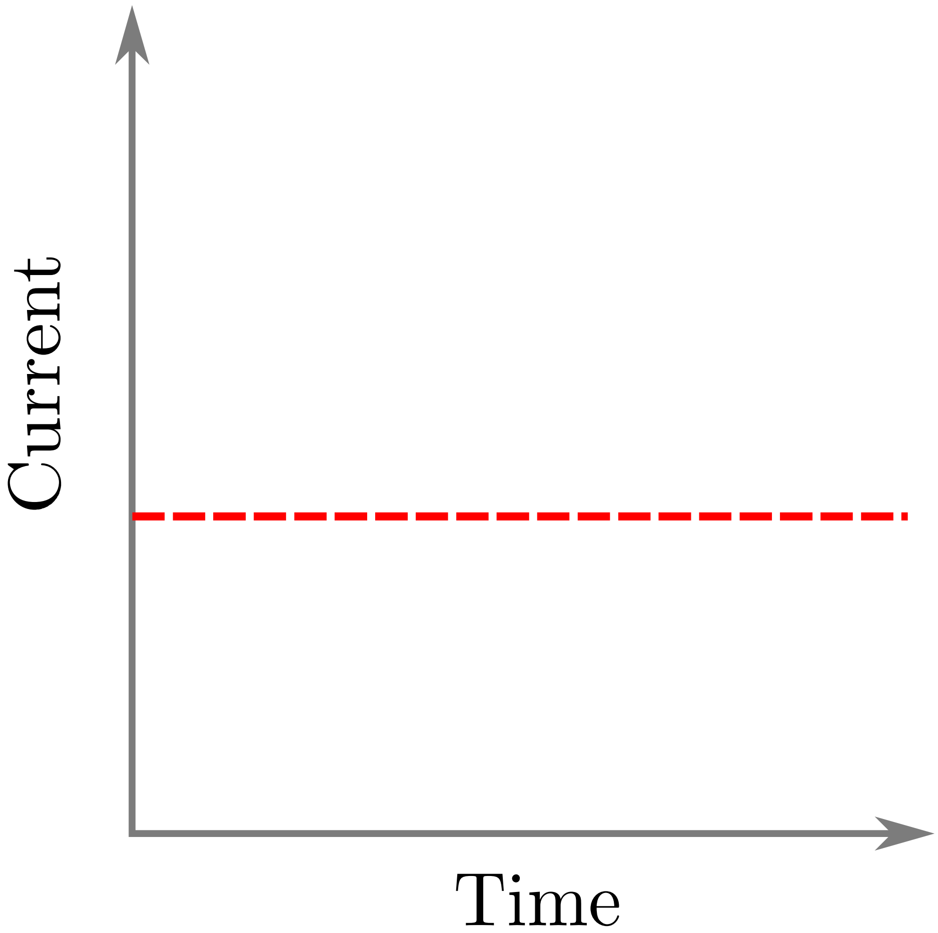
Reference: Phys. Rev. Lett. 116, 146601 (2016).

What's that noise!

DC current through a resistor *vs.* time



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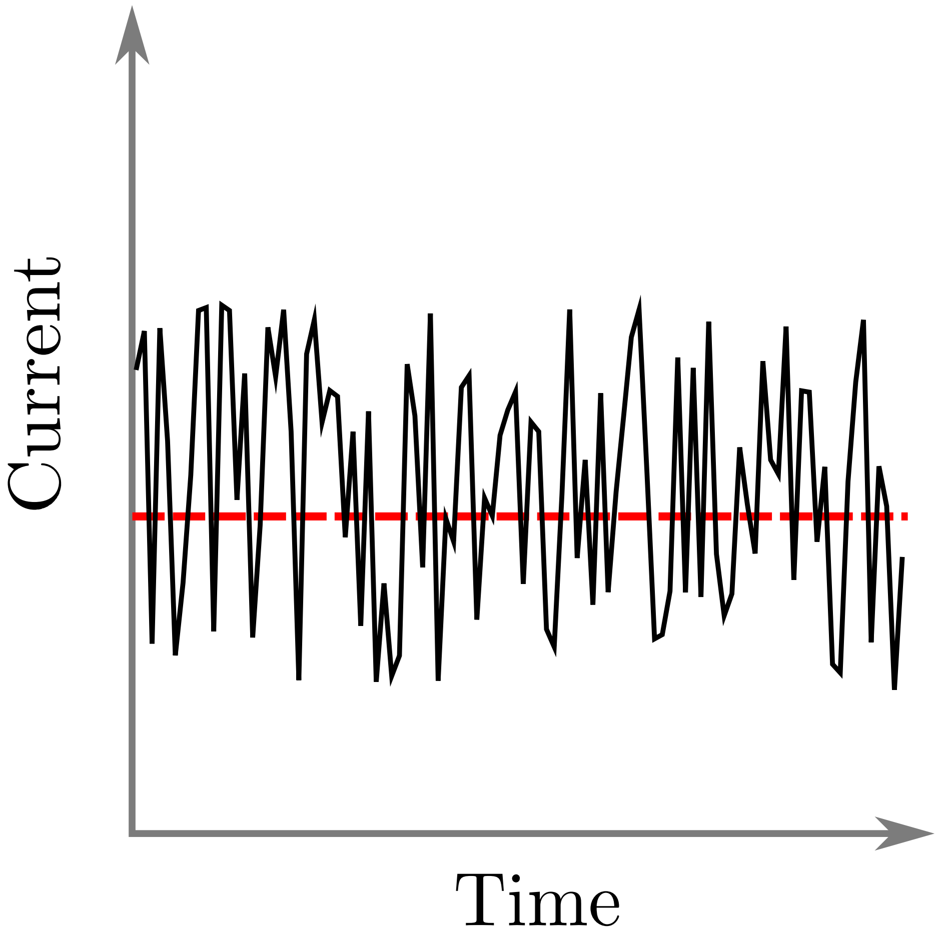

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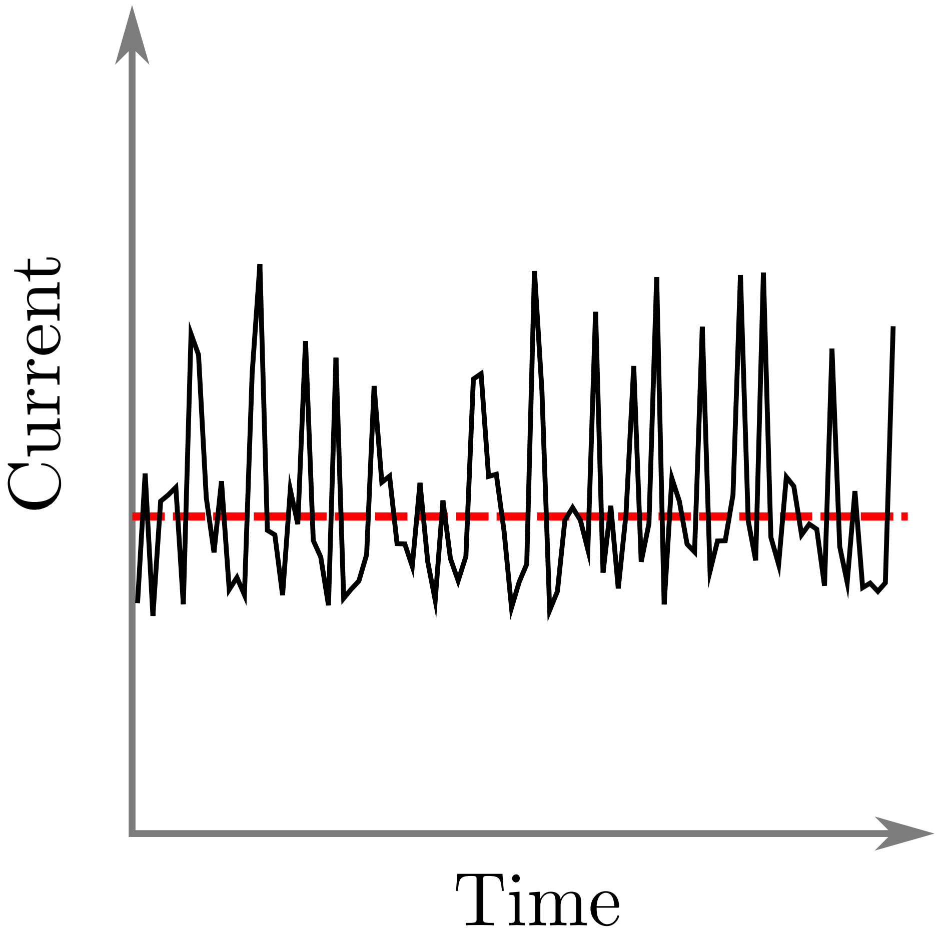

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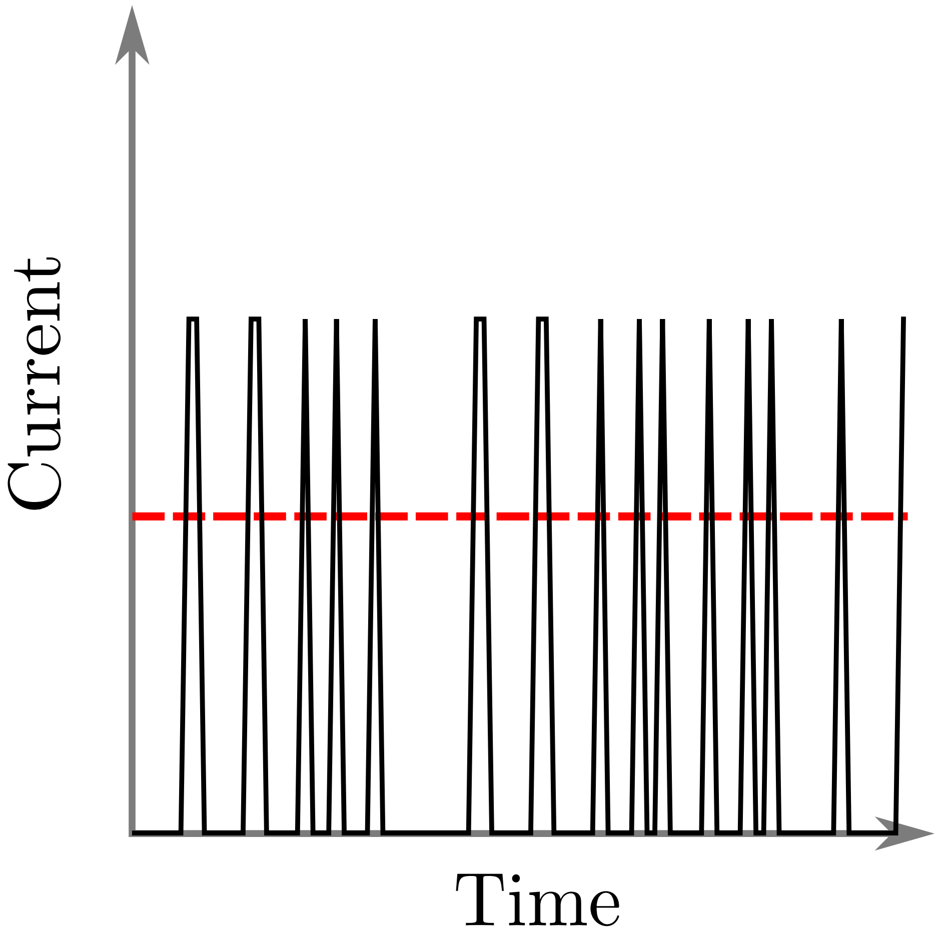
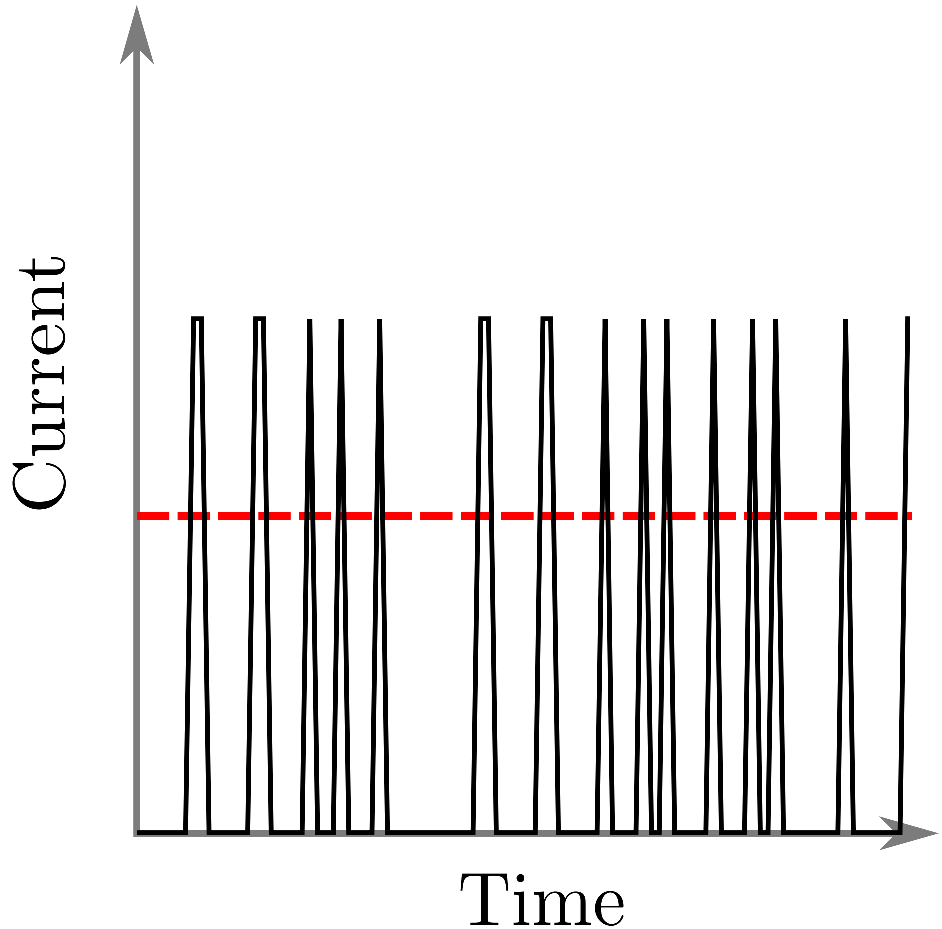


Shot Noise

DC current through a resistor *vs.* time



Discrete/Quantized nature of transport!

Quantifying Noise

Current fluctuation δI

$$\delta I = I - \langle I \rangle$$

Noise Power Spectral Density $S_{\delta I}(f)$

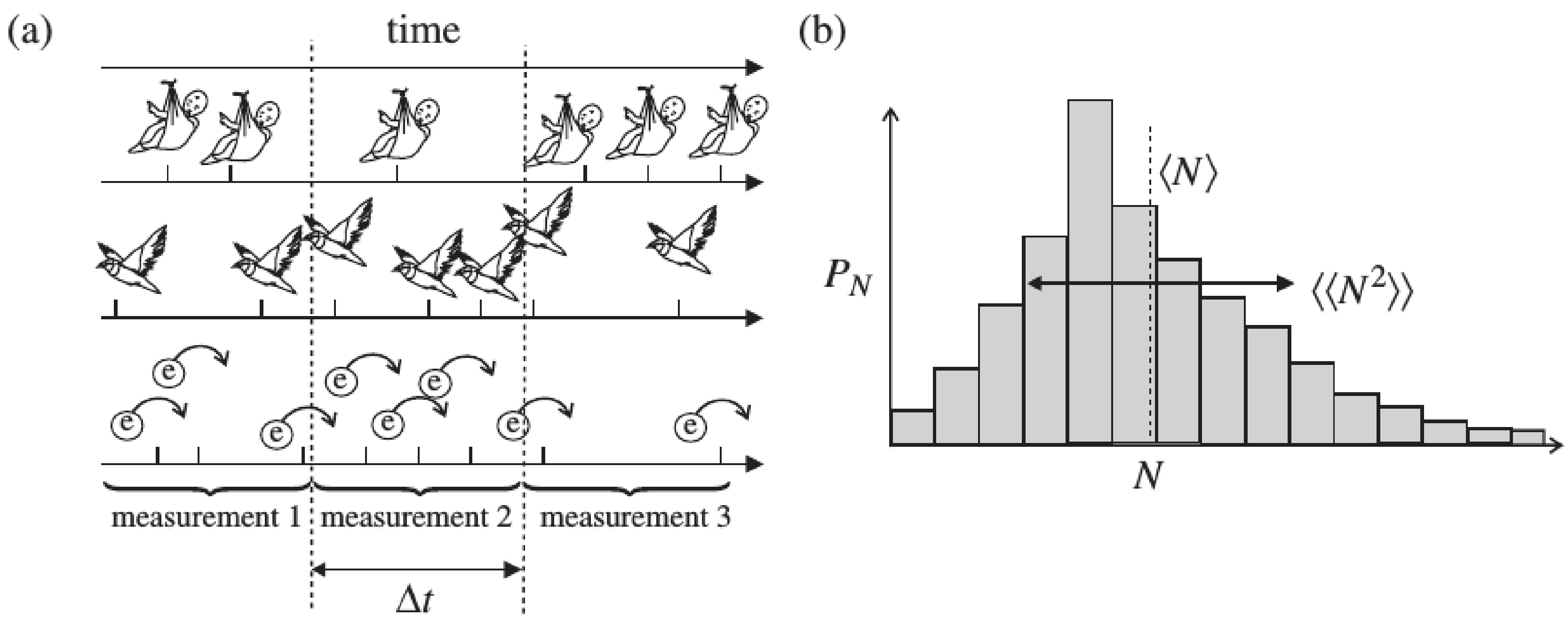
$$\langle (\delta I)^2 \rangle = \int S_{\delta I}(f) df$$

Poissonian Transport

Probability rate of a charge transfer event is constant.

Y. V. Nazarov and Y. M. Blanter, Quantum Transport Introduction to Nanoscience (Cambridge University Press, 2009).

Poissonian Transport



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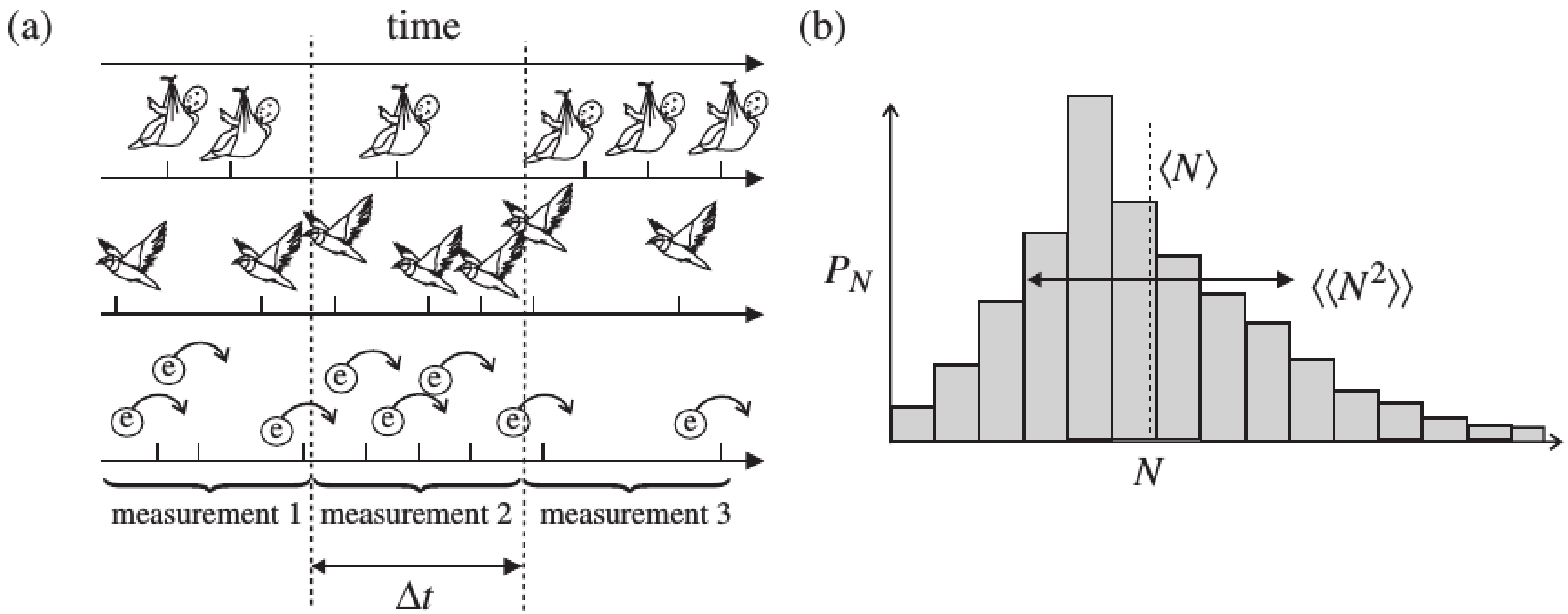
Poissonian Transport



Probability rate of a charge transfer event is constant.

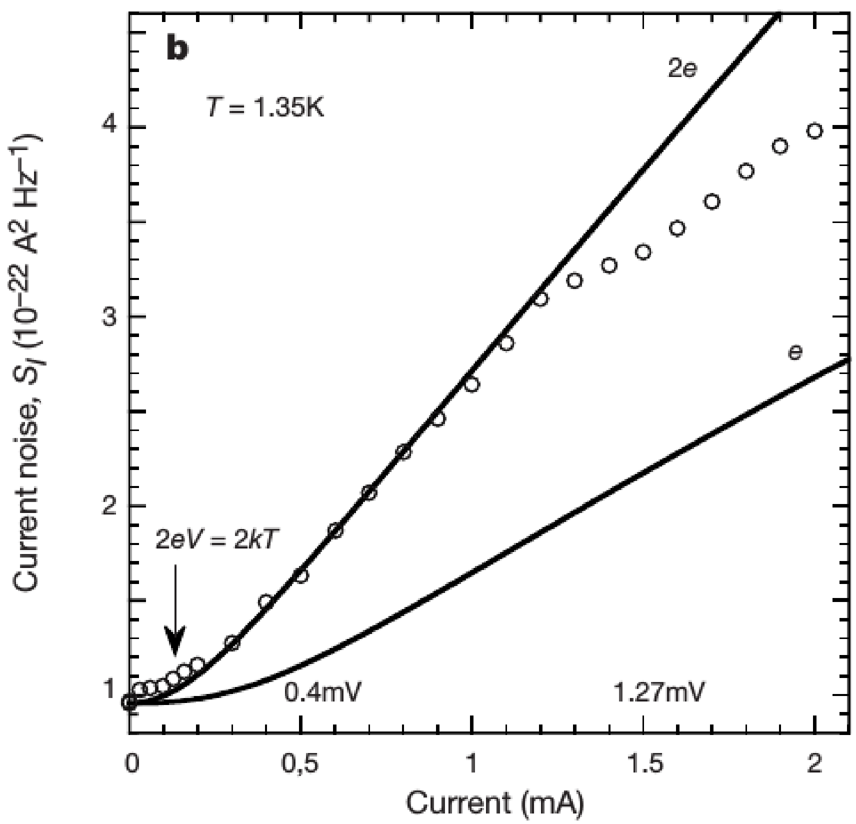
$$S(0) = 2q\langle I \rangle$$

Y. V. Nazarov and Y. M. Blanter, Quantum Transport Introduction to Nanoscience (Cambridge University Press, 2009).

Interacting Systems

Interacting Systems

Normal metal/superconductor junction



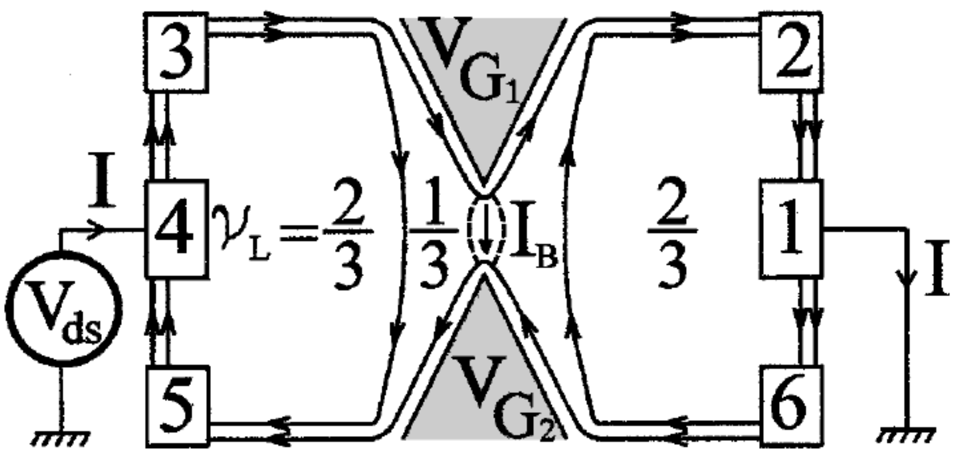
$2\,e$

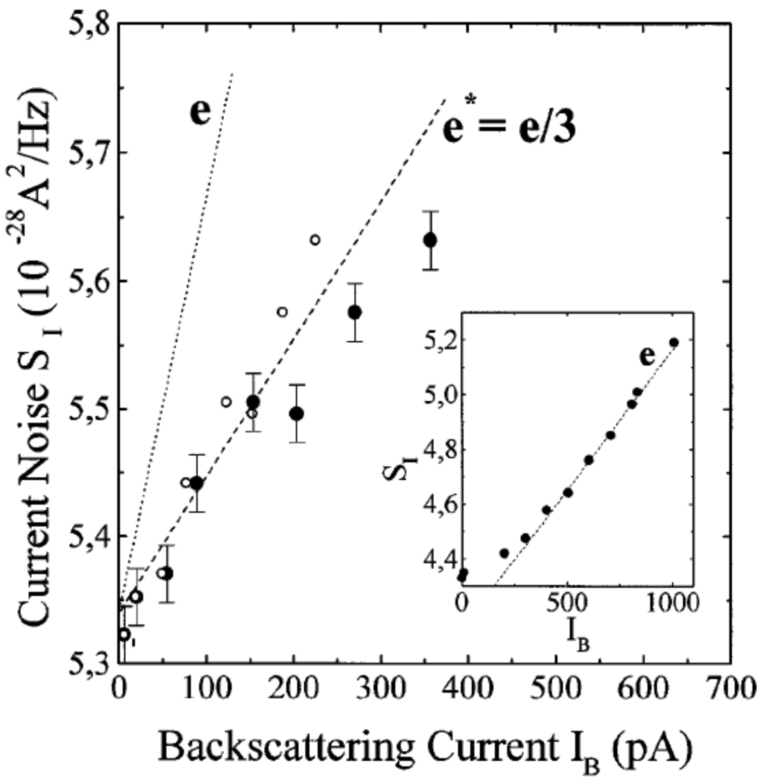
X. Jehl, M. Sanquer, R. Calemczuk, and D. Mailly, Nature 405, 50 (2000).

Interacting Systems

Fractional Quantum Hall Effect

$e/3$





L. Saminadayar, D. C. Glattli, Y. Jin, and B. Etienne, Phys. Rev. Lett. 79, 2526 (1997).

Shot Noise

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Physics Reports 336 (2000) 1–166

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Shot noise in mesoscopic conductors

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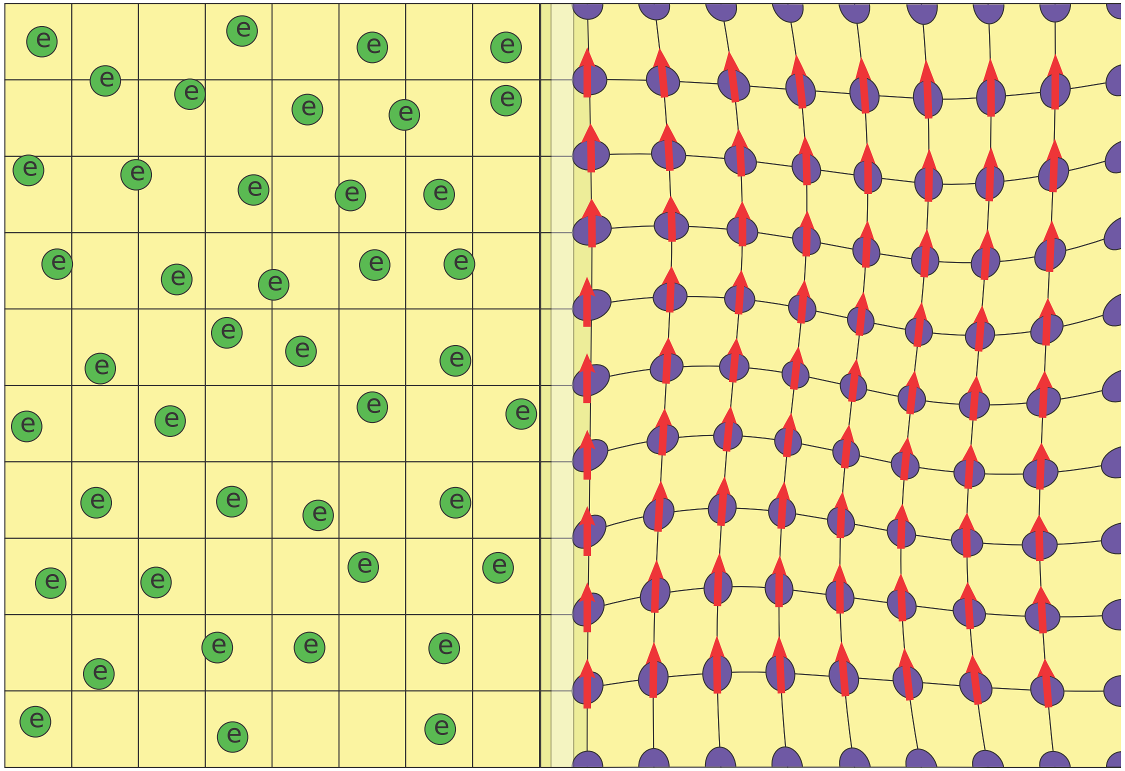
Received October 1999; editor: C.W.J. Beenakker

Spin Currents

Spin Currents

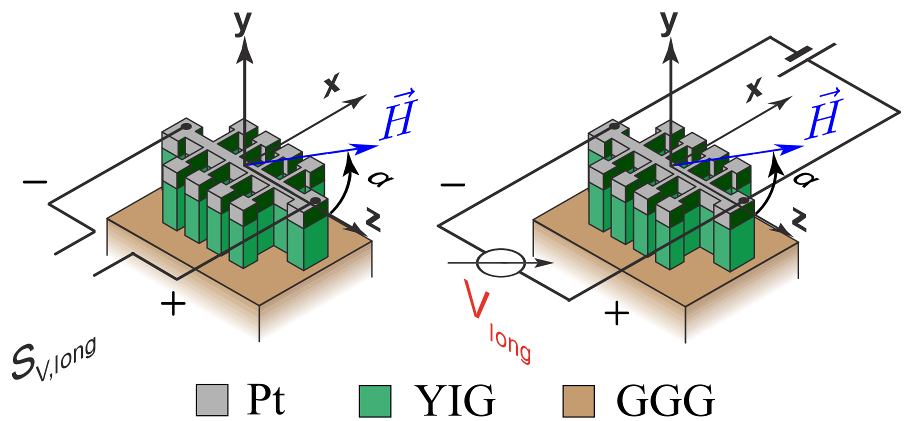
Ferromagnetic insulator (FI)/non-magnetic metal (N)

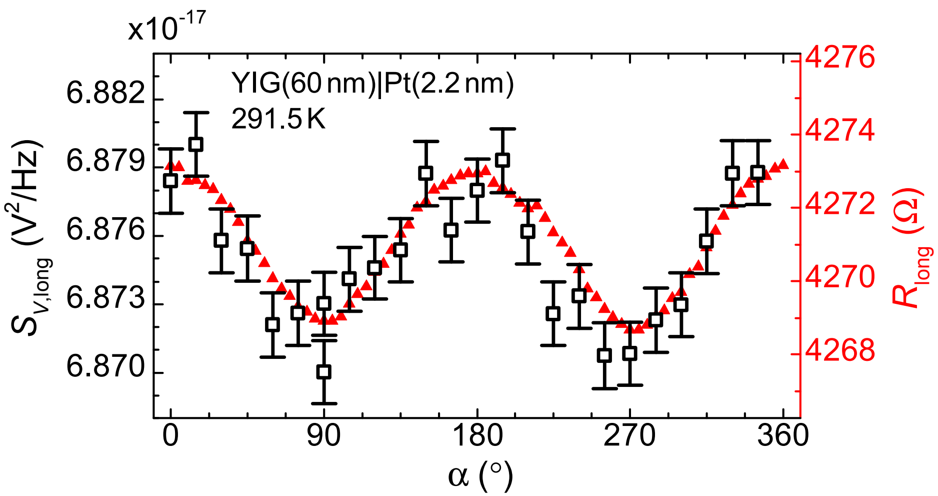


V. V. Kruglyak, S. O. Demokritov, and D. Grundler, Journal of Physics D: Applied Physics 43, 264001 (2010).

Thermal Spin Current Noise

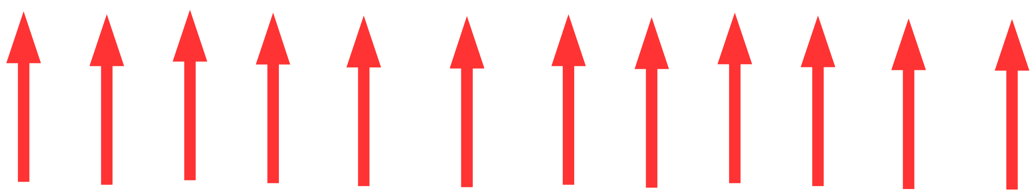
Ferromagnetic insulator (FI)/non-magnetic metal (N)





A. Kamra, F. P. Witek, S. Meyer, H. Huebl, S. Geprägs, R. Gross, G. E. W. Bauer, and S. T. B. Goennenwein, Phys. Rev. B 90, 214419 (2014).

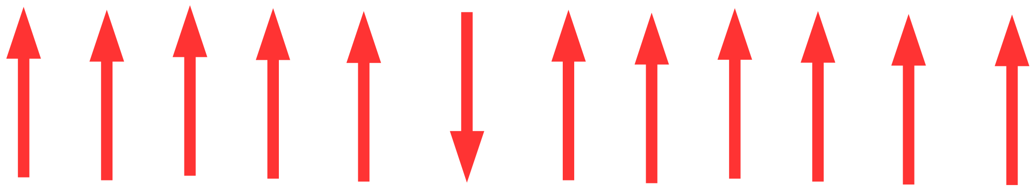
Magnon



Considering only exchange interaction and Zeeman energy!

C. Kittel, Introduction to Solid State Physics (John Wiley & Sons, New York, 1953)

Magnon



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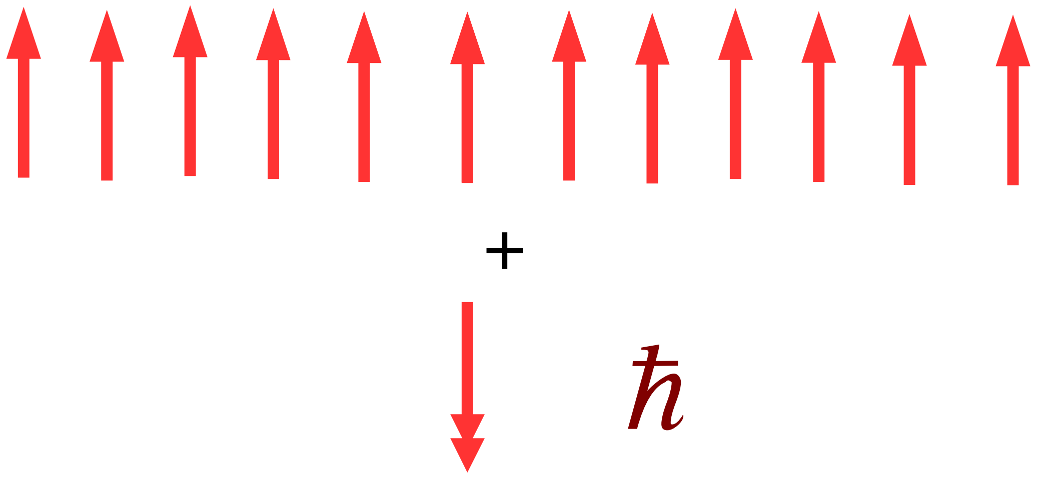

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Ferromagnet Eigenmodes

With magnon annihilation operators $\tilde{b}_{\boldsymbol{q}}$

$$\tilde{\mathcal{H}}_{\mathrm{F}} = \sum_{\boldsymbol{q}} \left[A_{\boldsymbol{q}} \tilde{b}_{\boldsymbol{q}}^{\dagger} \tilde{b}_{\boldsymbol{q}} + B_{\boldsymbol{q}}^{*} \tilde{b}_{\boldsymbol{q}}^{\dagger} \tilde{b}_{-\boldsymbol{q}}^{\dagger} + B_{\boldsymbol{q}} \tilde{b}_{\boldsymbol{q}} \tilde{b}_{-\boldsymbol{q}} \right]$$

Effect of dipolar interactions!

T. Holstein and H. Primakoff, Phys. Rev. 58, 1098 (1940).

Squeezed-magnons

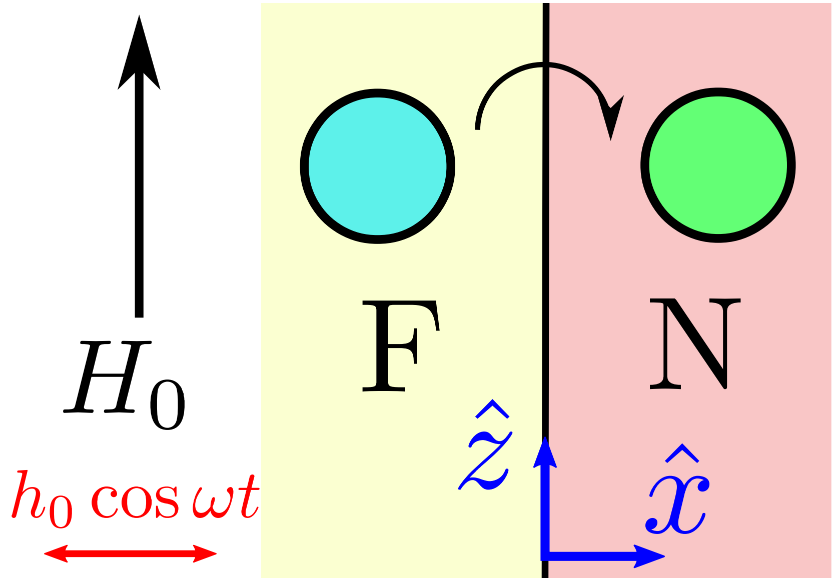
Bogoliubov transformation to new quasi-particles

$$\tilde{\beta}_{\boldsymbol{q}} = u_{\boldsymbol{q}} \tilde{b}_{\boldsymbol{q}} - v_{\boldsymbol{q}}^{*} \tilde{b}_{-\boldsymbol{q}}^{\dagger}$$

$$\tilde{\mathcal{H}}_{\mathrm{F}} = \sum_{\boldsymbol{q}} \hbar \omega_{\boldsymbol{q}} \tilde{\beta}_{\boldsymbol{q}}^{\dagger} \tilde{\beta}_{\boldsymbol{q}}$$

T. Holstein and H. Primakoff, Phys. Rev. 58, 1098 (1940).

Spin Current Injection



$$\tilde{\mathcal{H}} = \tilde{\mathcal{H}}_{\mathrm{F}} + \tilde{\mathcal{H}}_{\mathrm{N}} + \tilde{\mathcal{H}}_{\mathrm{int}} + \tilde{\mathcal{H}}_{\mathrm{drive}}$$

Ferromagnetic Resonance

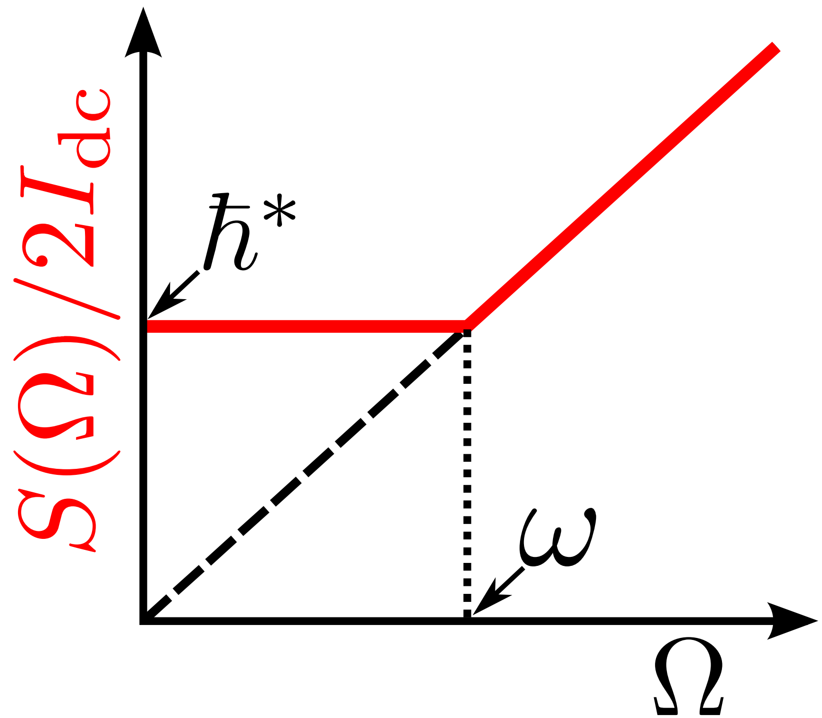
Under coherent excitation $\beta(t) = \langle \tilde{\beta}_{\mathbf{0}}(t) \rangle$

$$\beta(t) = \frac{\mu_0 h_0 B}{2\hbar} \frac{1}{(\omega_{\mathbf{0}} - \omega) - i\Gamma(u_{\mathbf{0}}^2 + v_{\mathbf{0}}^2)} e^{-i\omega t}$$

$$I_z(t) = \langle \tilde{I}_z(t) \rangle = I_{\mathrm{dc}} = 2\hbar\alpha'\omega|\beta|^2$$

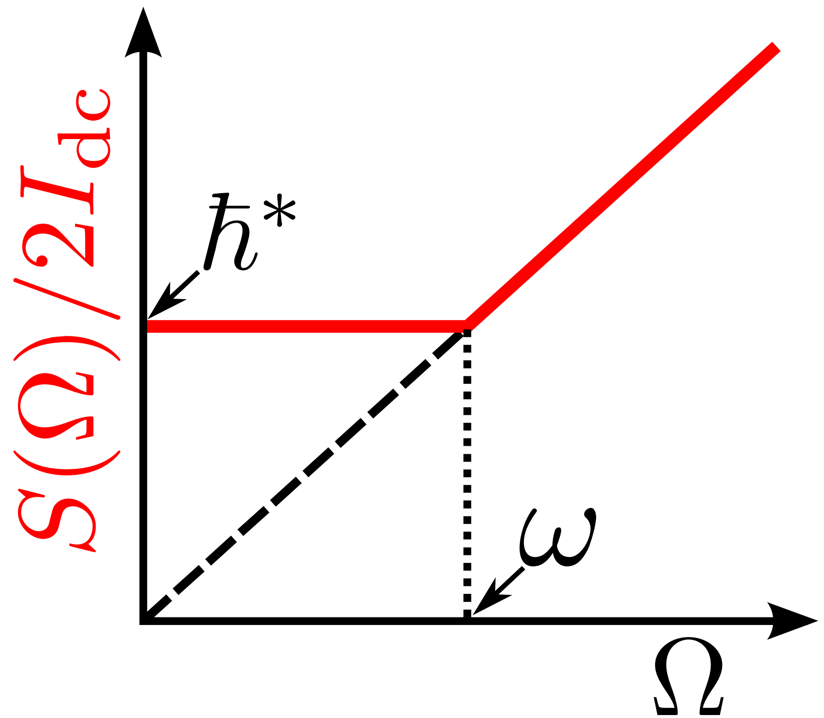
Resonant excitation of the uniform mode and spin current injection!

Spin Current Shot Noise



$$S(\Omega) = \hbar^* \frac{I_{\rm dc}}{\omega} \left(|\omega + \Omega| + |\omega - \Omega| \right)$$

Spin Current Shot Noise



$$S(0) = 2\hbar^* I_{\mathrm{dc}}$$

Squeezed-magnon

$$\hbar^* = \hbar(1+\delta)$$

$$\int_{V_{\mathrm{F}}} \langle \tilde{S}_{\mathrm{F}}^{z}(\boldsymbol{r}) \rangle d^3 r = -\frac{\mathcal{M}_0}{|\gamma|} + \sum_{\boldsymbol{q}} \hbar (1 + 2|v_{\boldsymbol{q}}|^2) n_{\boldsymbol{q}}^{\beta} + \sum_{\boldsymbol{q}} \hbar |v_{\boldsymbol{q}}|^2$$

T. Holstein and H. Primakoff, Phys. Rev. 58, 1098 (1940).

Squeezed-magnon

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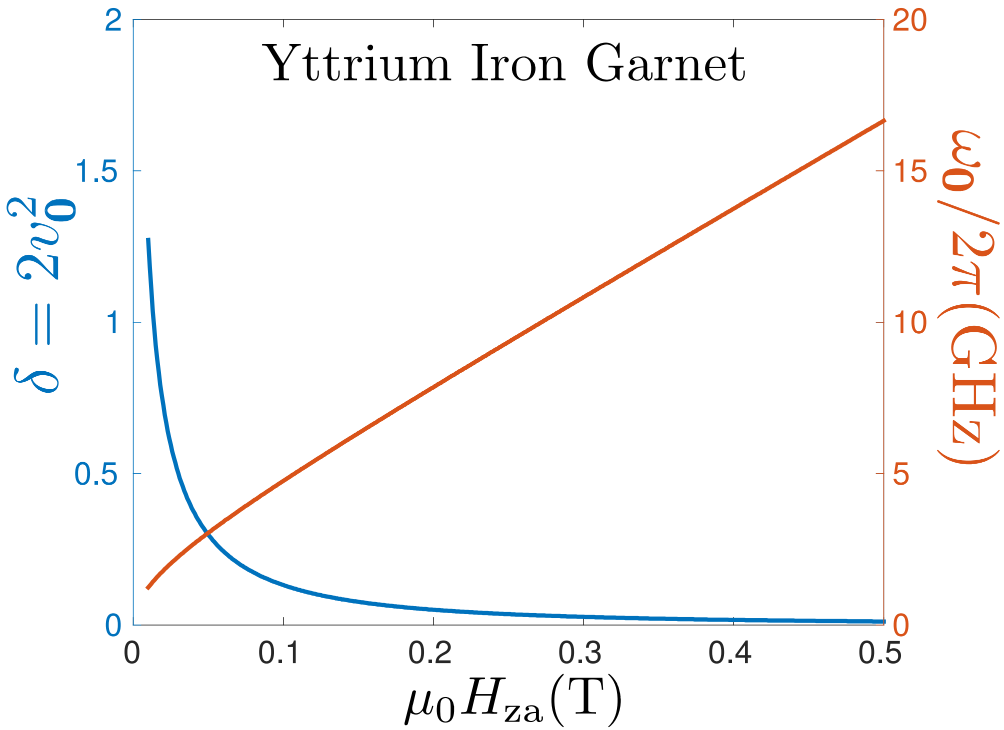

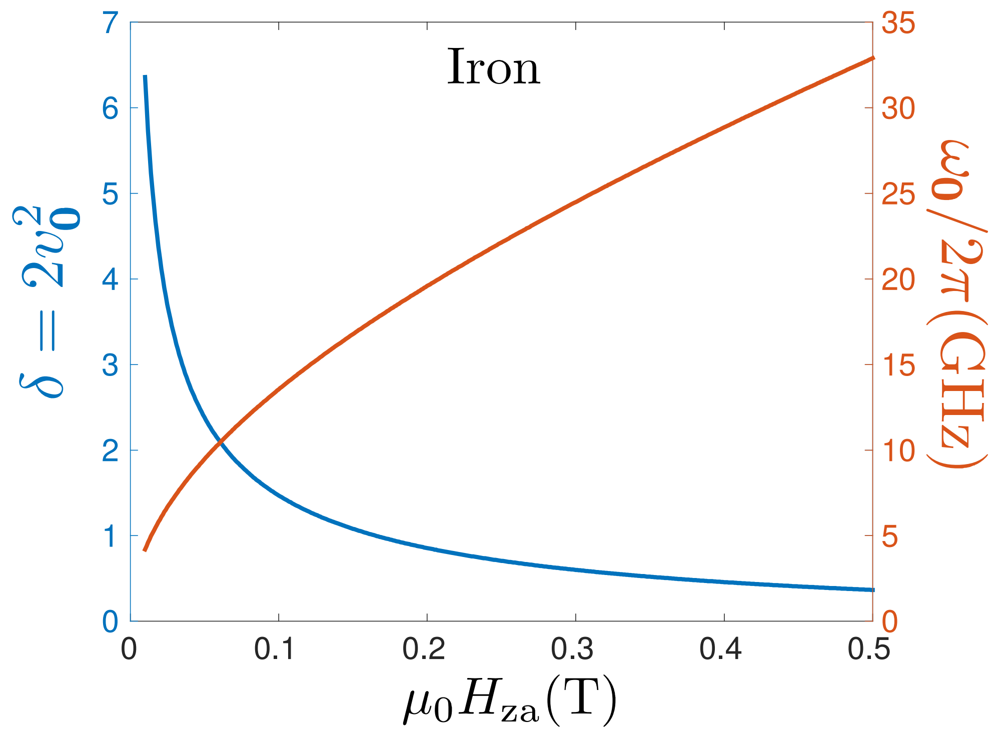

Specimens in the shape of films

Squeezed-magnon

What's in the name – relation to squeezed light

C. Gerry and P. Knight, Introductory Quantum Optics (Cambridge University Press, 2005).

Squeezed-magnon

What's in the name – relation to squeezed light

$$\left\langle \left(\delta \tilde{\mathcal{M}}_{x,y} \right)^2 \right\rangle_0 = \frac{|\gamma|\hbar\mathcal{M}_0}{2} \exp\left(\mp 2\xi_{\mathbf{0}}\right)$$

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Two mode squeezing

$$\left(u_{\boldsymbol{q}} \tilde{b}_{\boldsymbol{q}} - v_{\boldsymbol{q}}^{*} \tilde{b}_{-\boldsymbol{q}}^{\dagger} \right) \; |0\rangle_{\beta} \; = \; 0$$

C. Gerry and P. Knight, Introductory Quantum Optics
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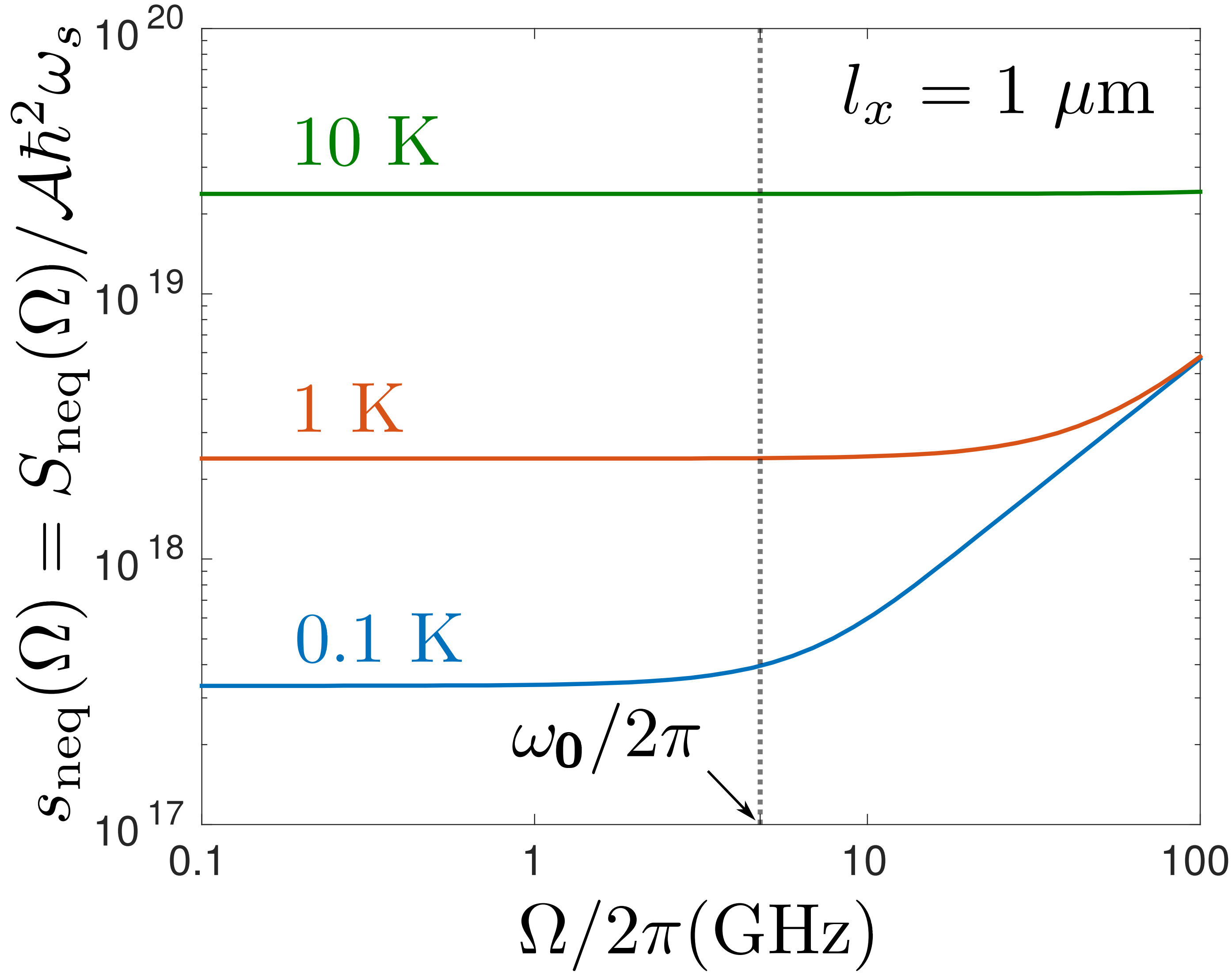
Finite Temperature Noise

A. Kamra and W. Belzig, arXiv:1604.02079 [cond-mat.mes-hall]

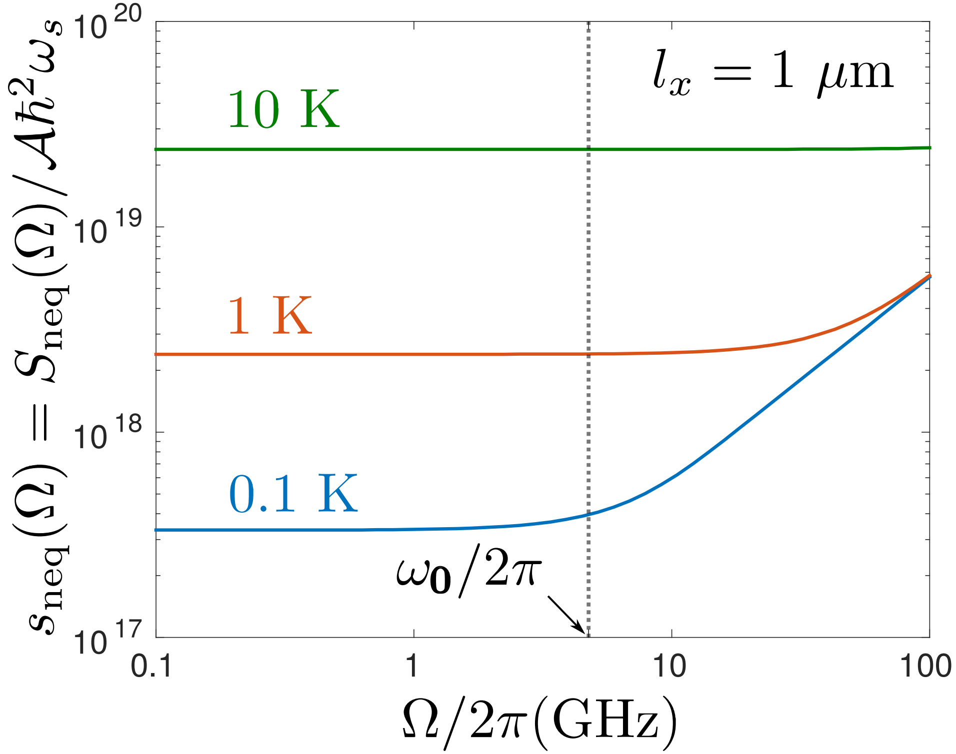
Finite Temperature Noise



A. Kamra and W. Belzig, arXiv:1604.02079 [cond-mat.mes-hall]

Finite Temperature Noise

$$S_{\mathrm{neq}}(\Omega) = 2\hbar^* I_{\mathrm{dc}} \frac{2k_B T}{\hbar\omega}, \quad k_B T \gg (\hbar\omega, \hbar\Omega)$$



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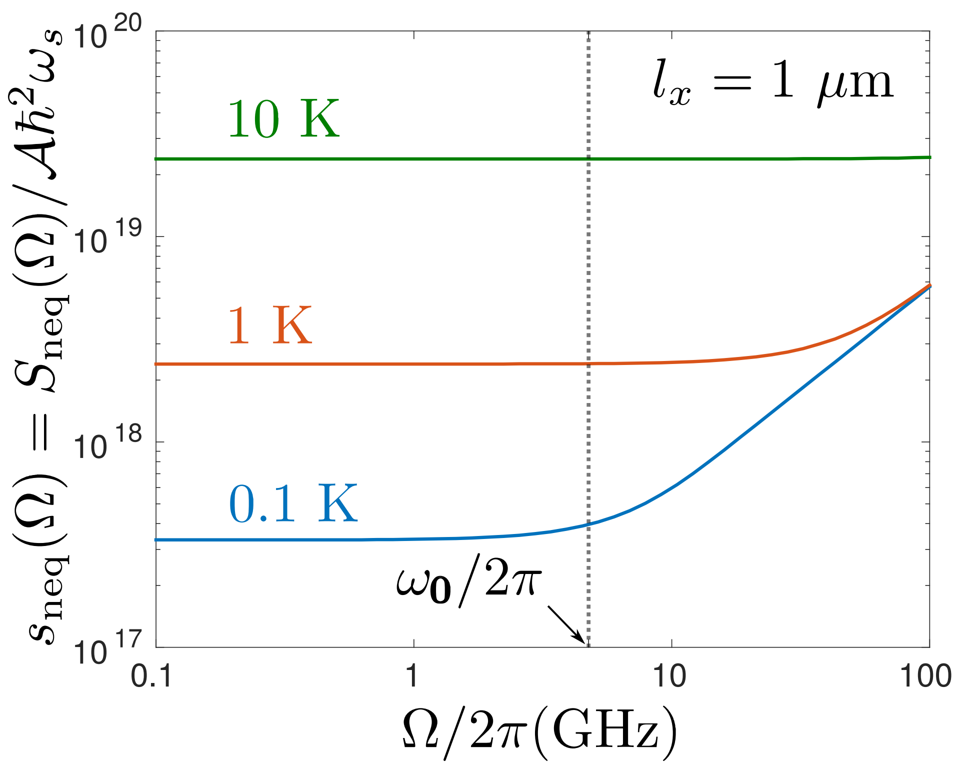

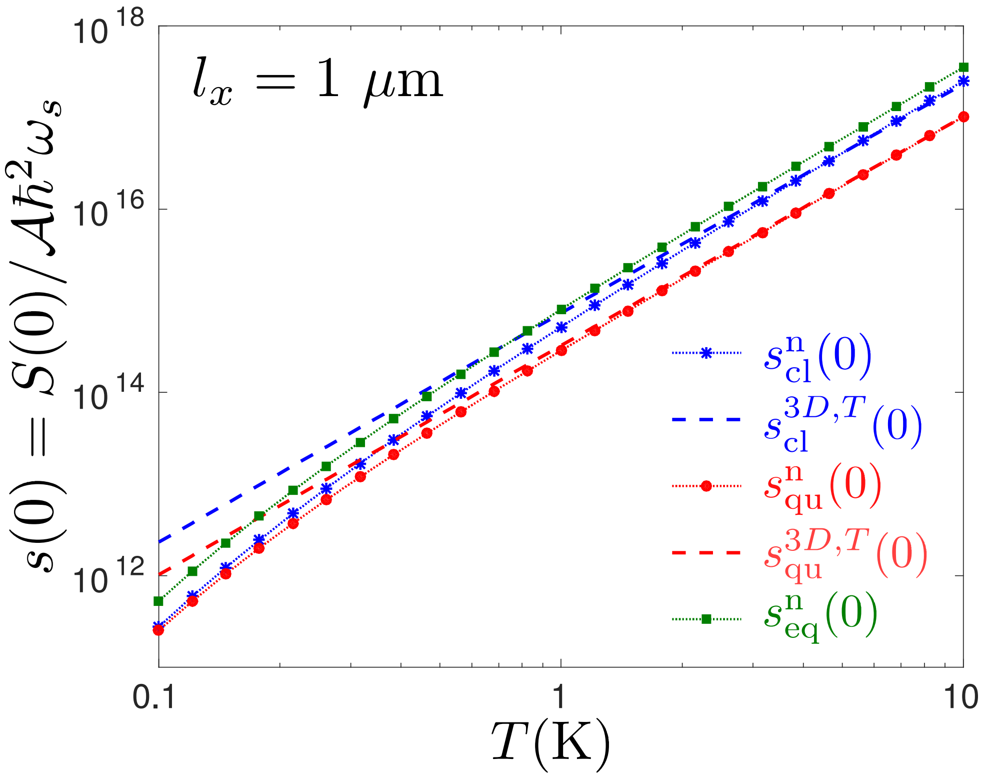

A. Kamra and W. Belzig, arXiv:1604.02079 [cond-mat.mes-hall]

Summary

Reference: Phys. Rev. Lett. 116, 146601 (2016).

- Dipolar interaction mediated squeezing of magnons
- Non-integer spin of squeezed-magnons
- Dominance of shot over thermal noise
- Quantum properties associated with squeezing