Spin Seebeck effect & Surface spin wave excitation

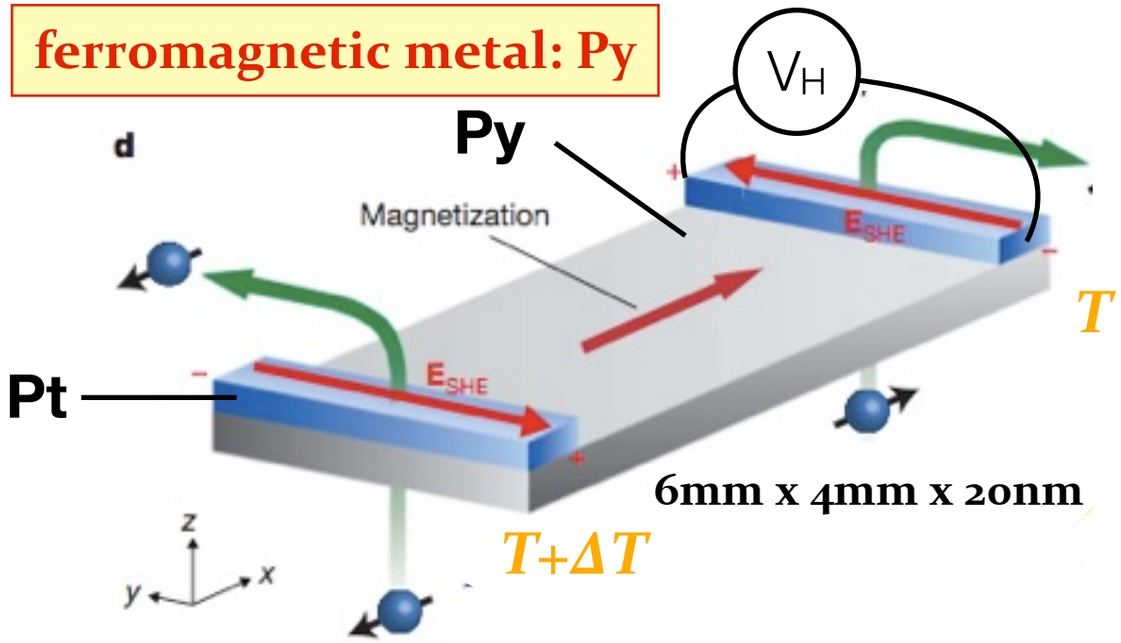
Jiang Xiao
Department of Physics, Fudan University, Shanghai, China

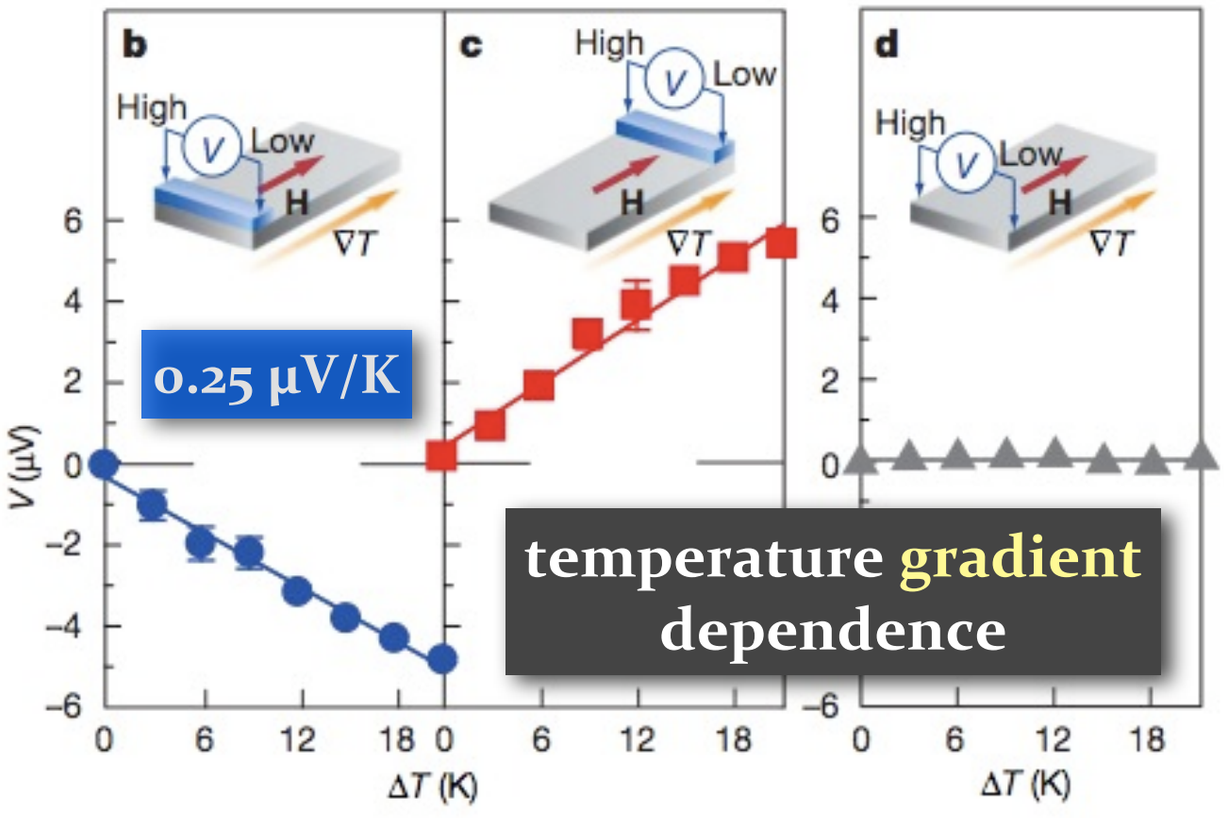
Gerrit E. W. Bauer
Institute for Materials Research, Tohoku University, Sendai, Japan
Kavli Institute of NanoScience, Delft University of Technology, Delft, The Netherlands

Spin Caloritrnoics III, Lorentz Center, Leiden, The Netherlands
Tuesday - May 10, 2011

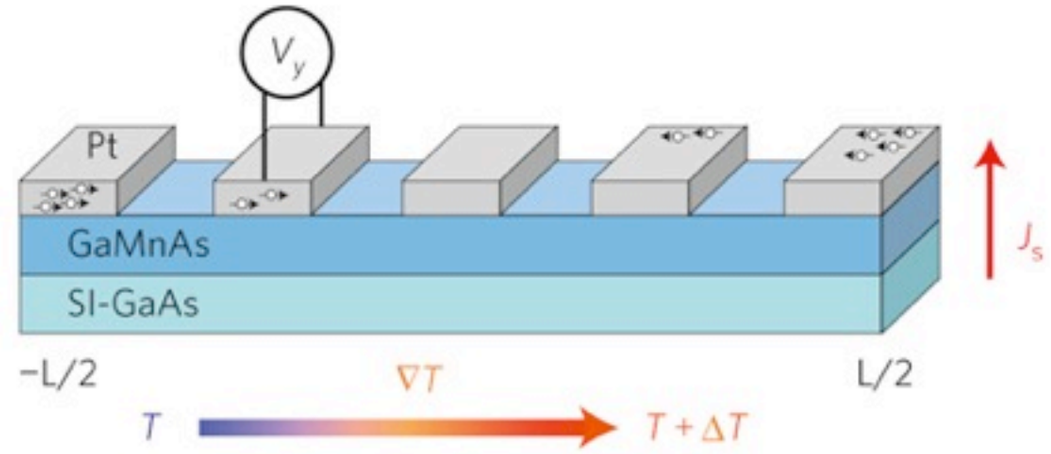
Experiment background - spin Seebeck

ferromagnetic metal: Py

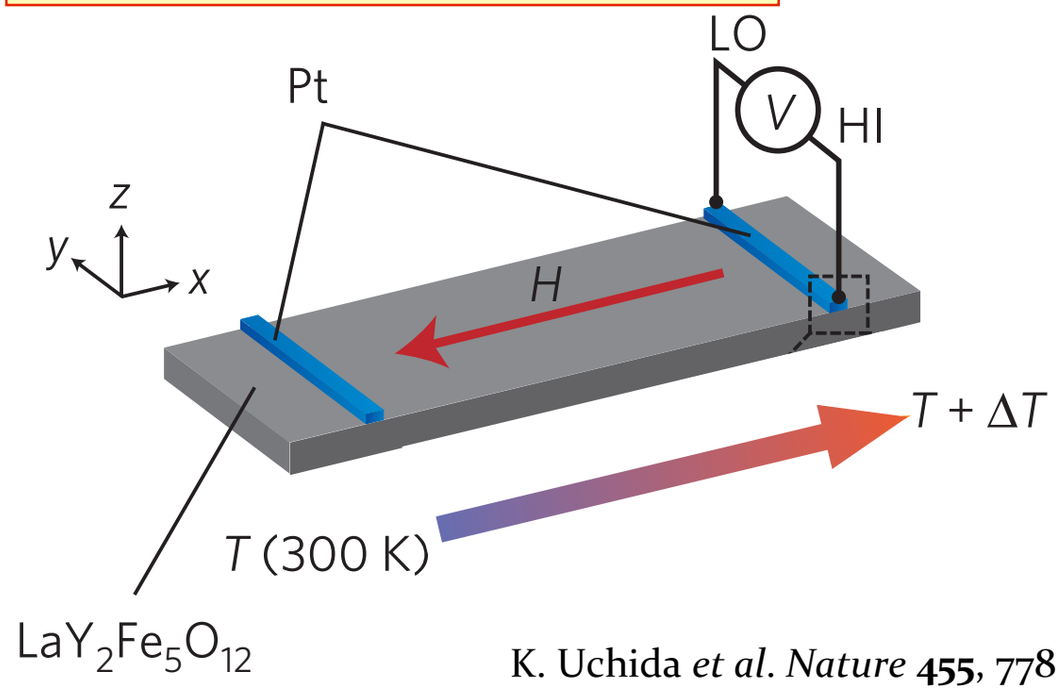




ferromagnetic semiconductor: GaMnAs

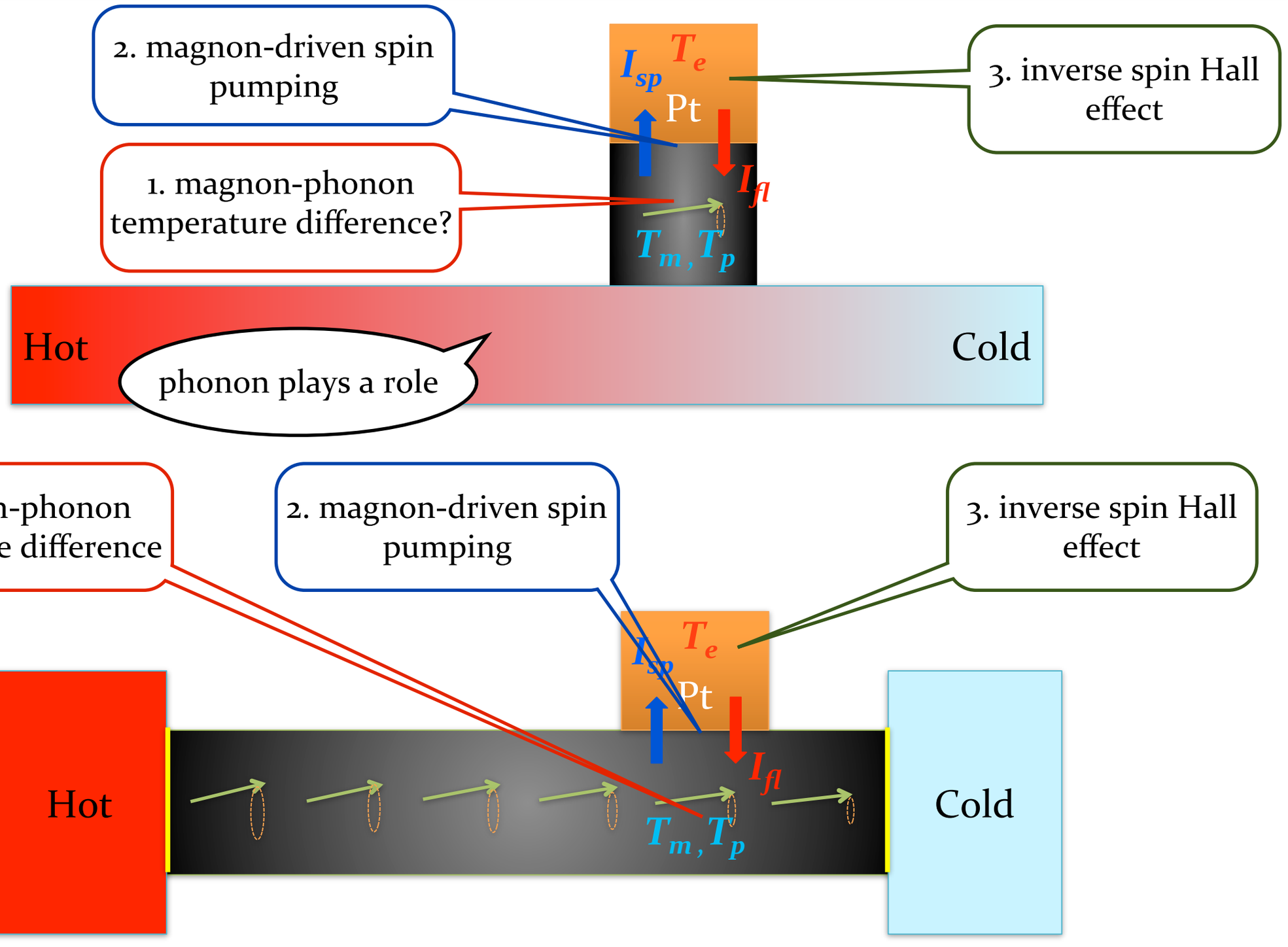


ferromagnetic insulator: YIG



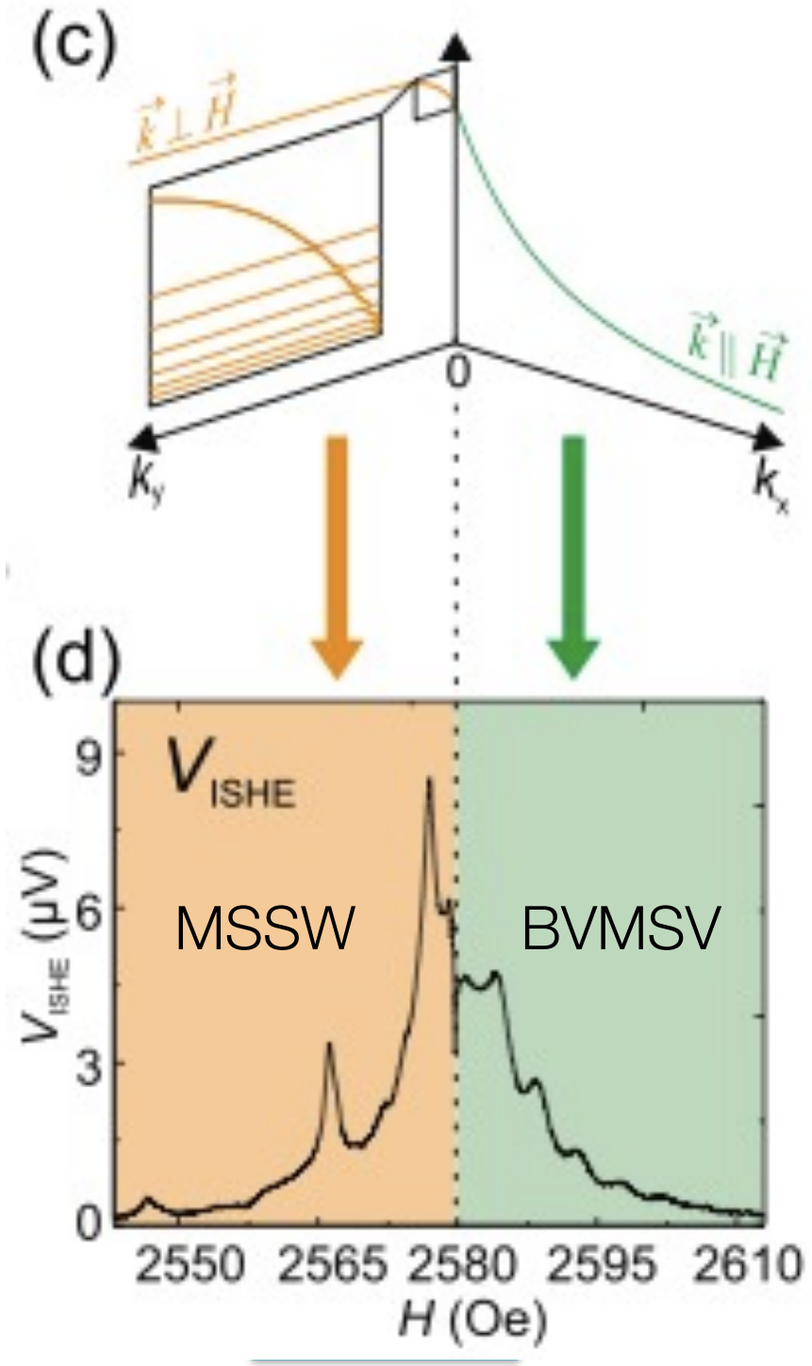
K. Uchida *et al. Nature* **455**, 778 (2008)
K. Uchida *et al. Nature Materials* **9**, 894 (2010)
C. M. Jaworski *et al. Nature Materials* **9**, 898 (2010)

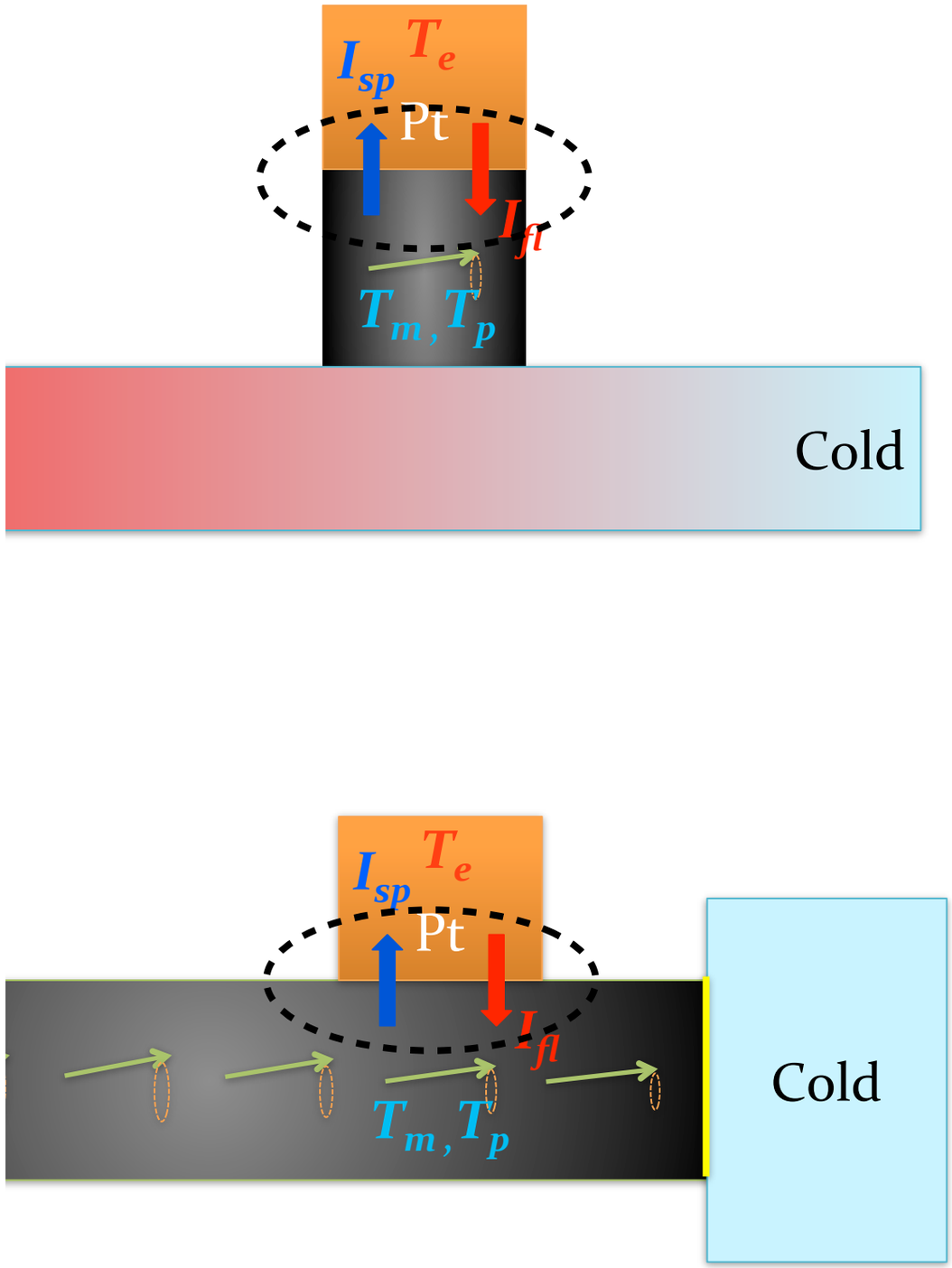
3-step explanation



J. Xiao *et al. Phys. Rev. B* **81**, 214418 (2010) - H. Adachi *et al*, *Phys. Rev. B* **83**, 094410 (2011) - C. M. Jaworski *et al*, *Phys. Rev. Lett.* **106**, 186601 (2011)

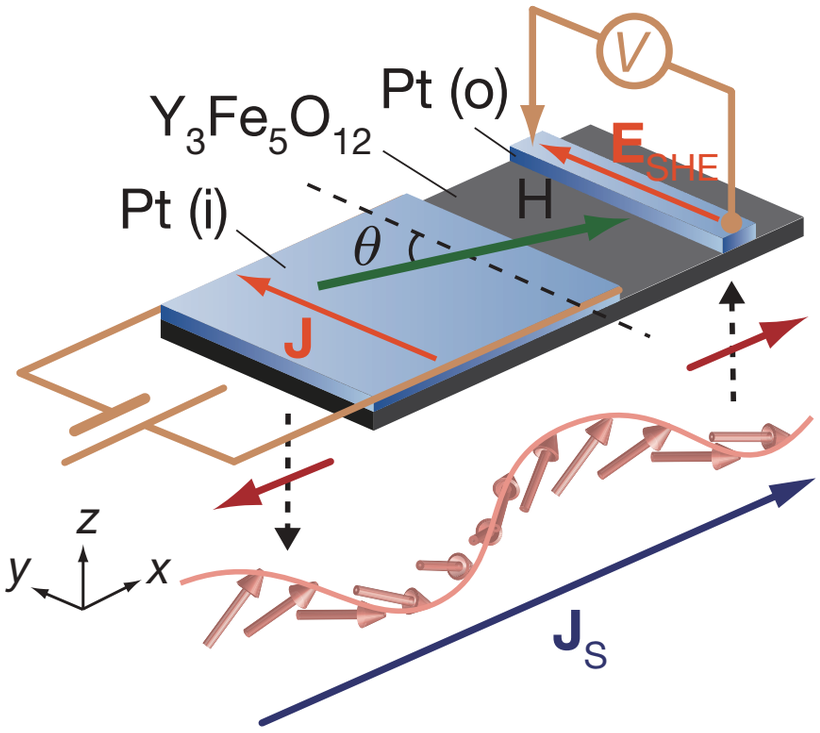
Pumping by surface and bulk magnons

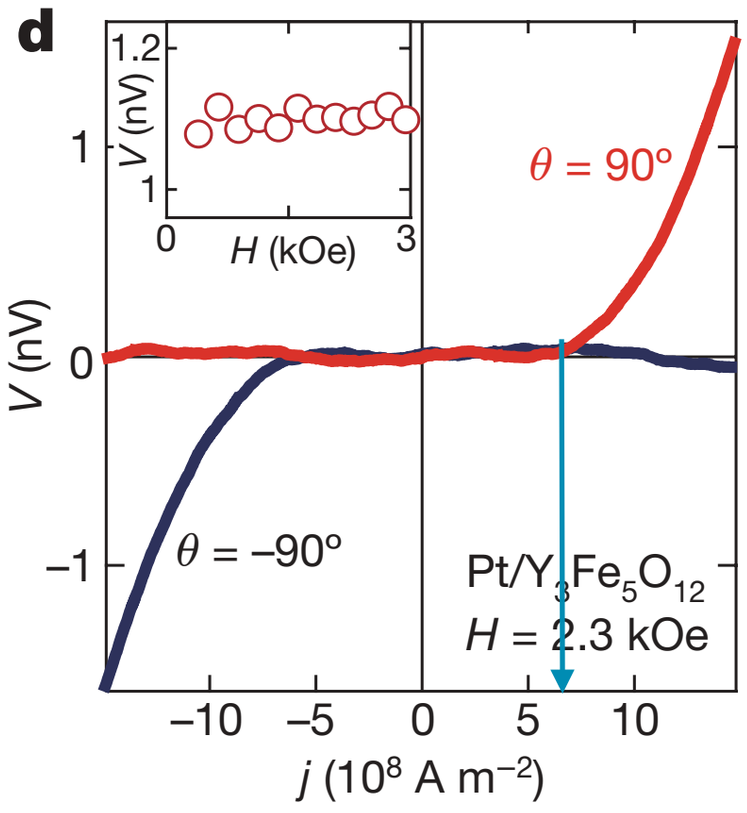


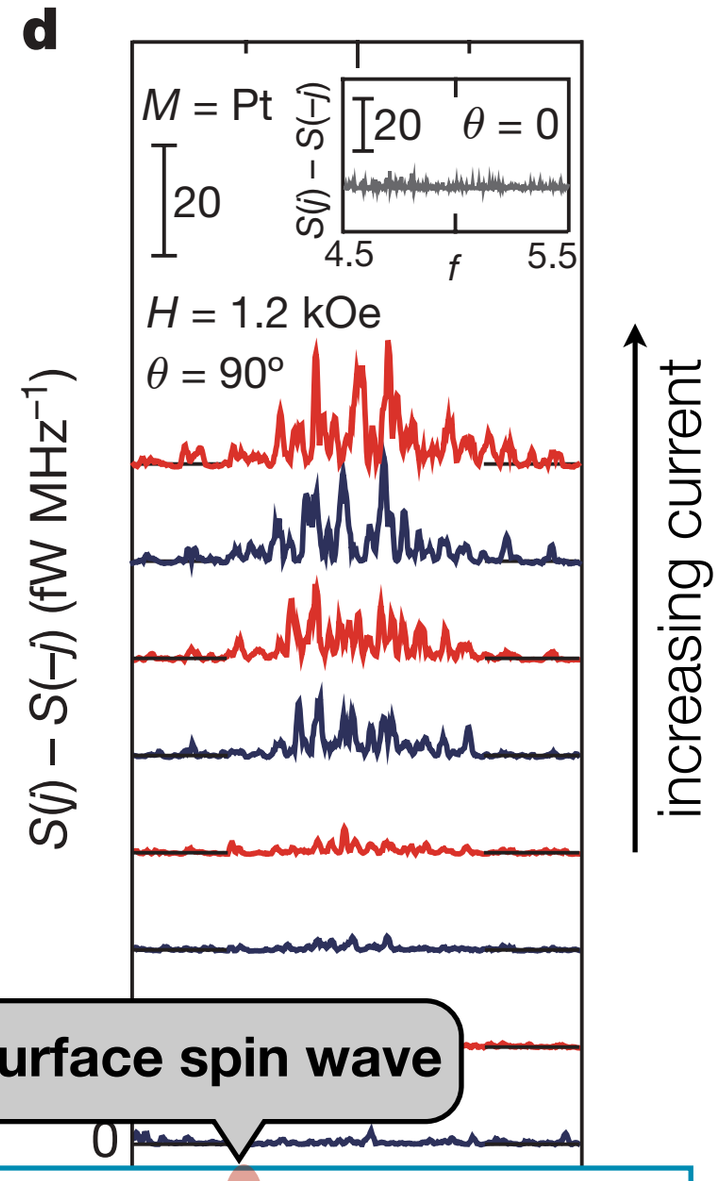


C. W. Sandweg *et al*. *Appl*. *Phys*. *Lett*. **97**, 252504 (2010)

Experiment background - spin wave excitation





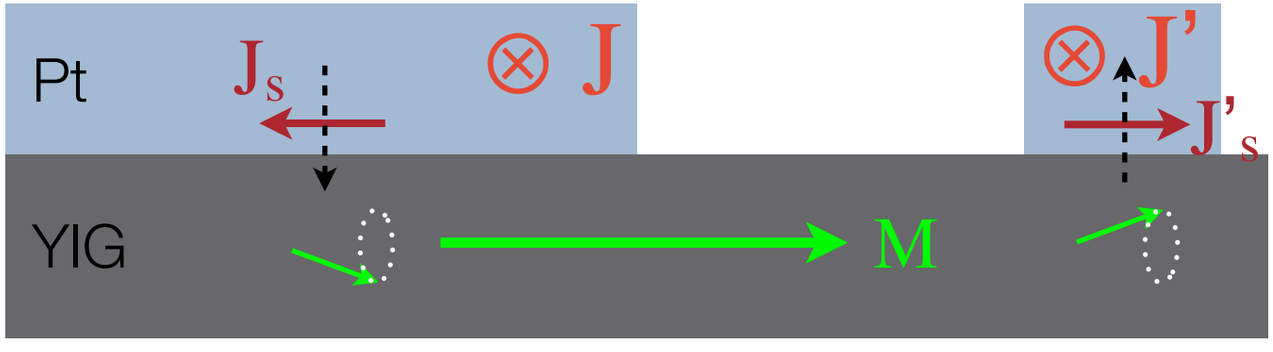


spin hall effect

$$\mathbf{J}_s = \theta_H \mathbf{J} \times \mathbf{s}$$

inverse spin hall effect

$$\mathbf{J}' = \theta_H \mathbf{J}'_s \times \mathbf{s}$$

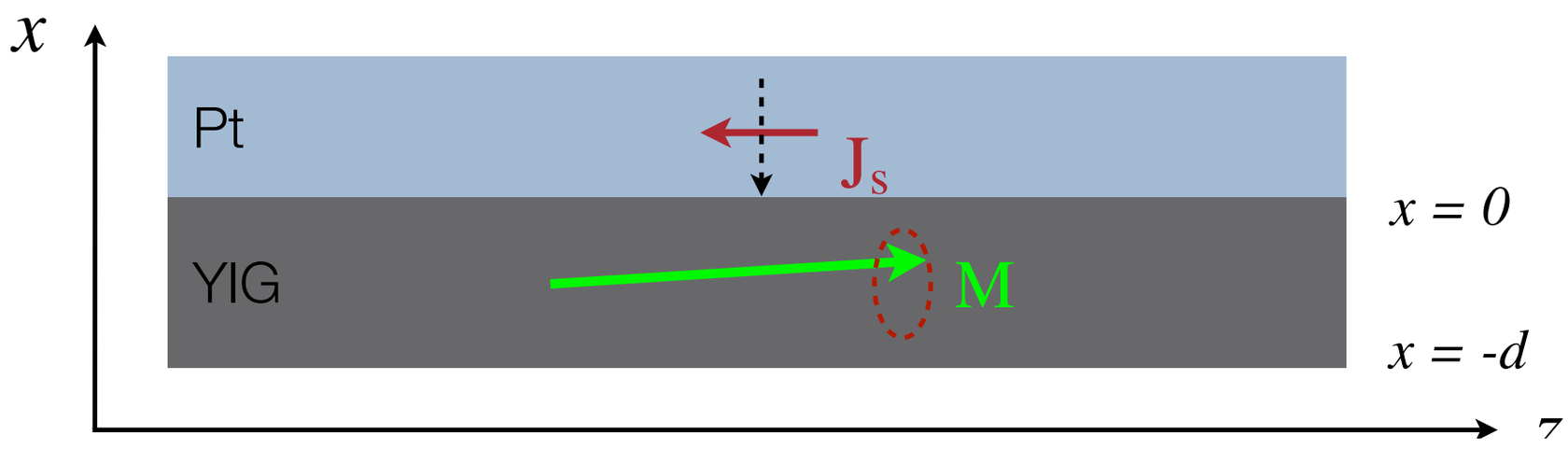


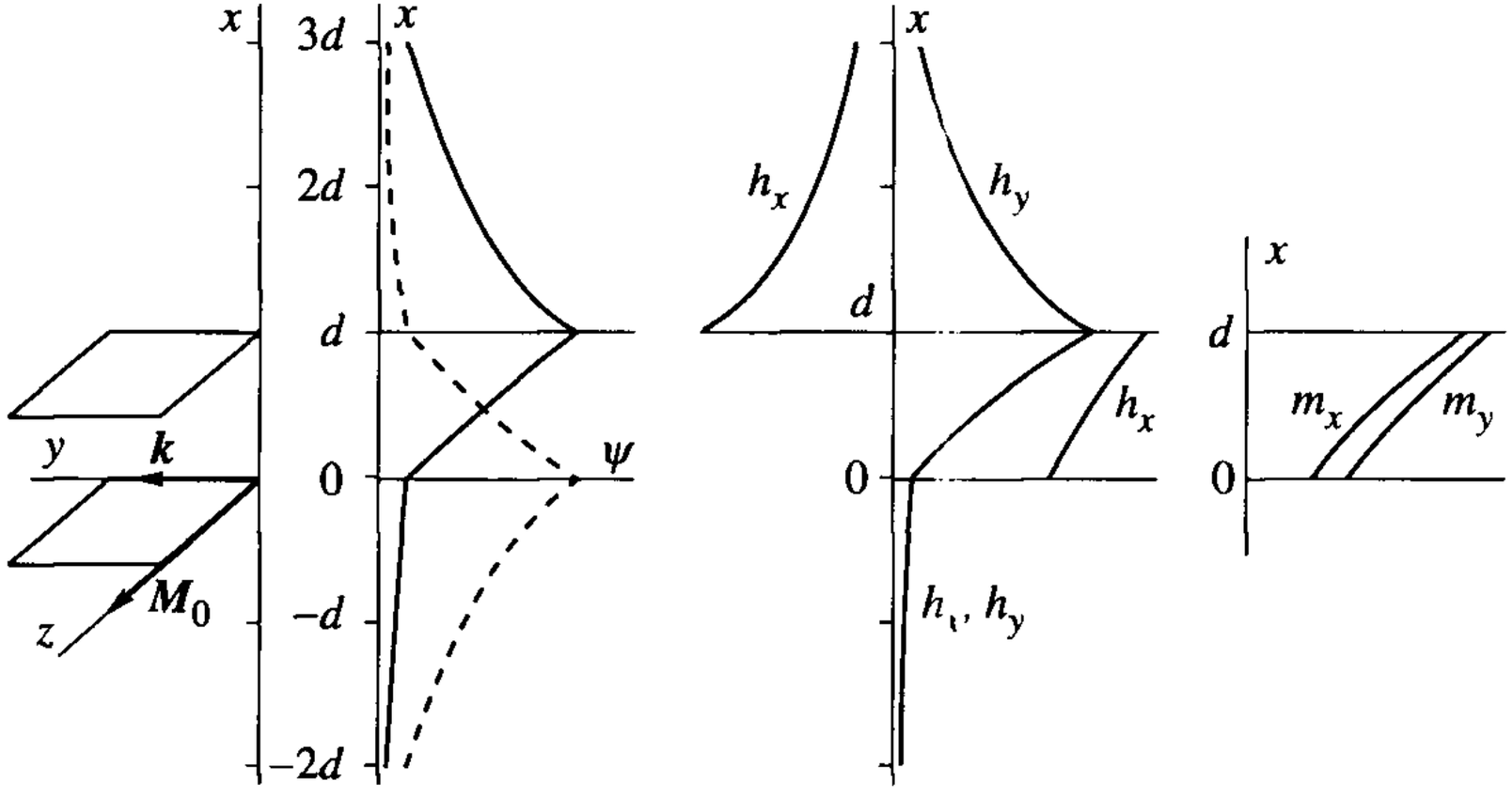
suggesting **surface spin wave**

$$j = \frac{1}{\theta_H} \frac{2e\alpha\omega_0 M_s d}{\gamma\hbar} \simeq 10^{11}\,\mathrm{A/m^2}$$

Y. Kajiwara *et. al.*, Nature **464**, 262-266 (2010)

Dipolar surface spin wave





Gurevich, A.G. & Melkov, G.A. Magnetization oscillations and waves. (CRC Press: 1996).

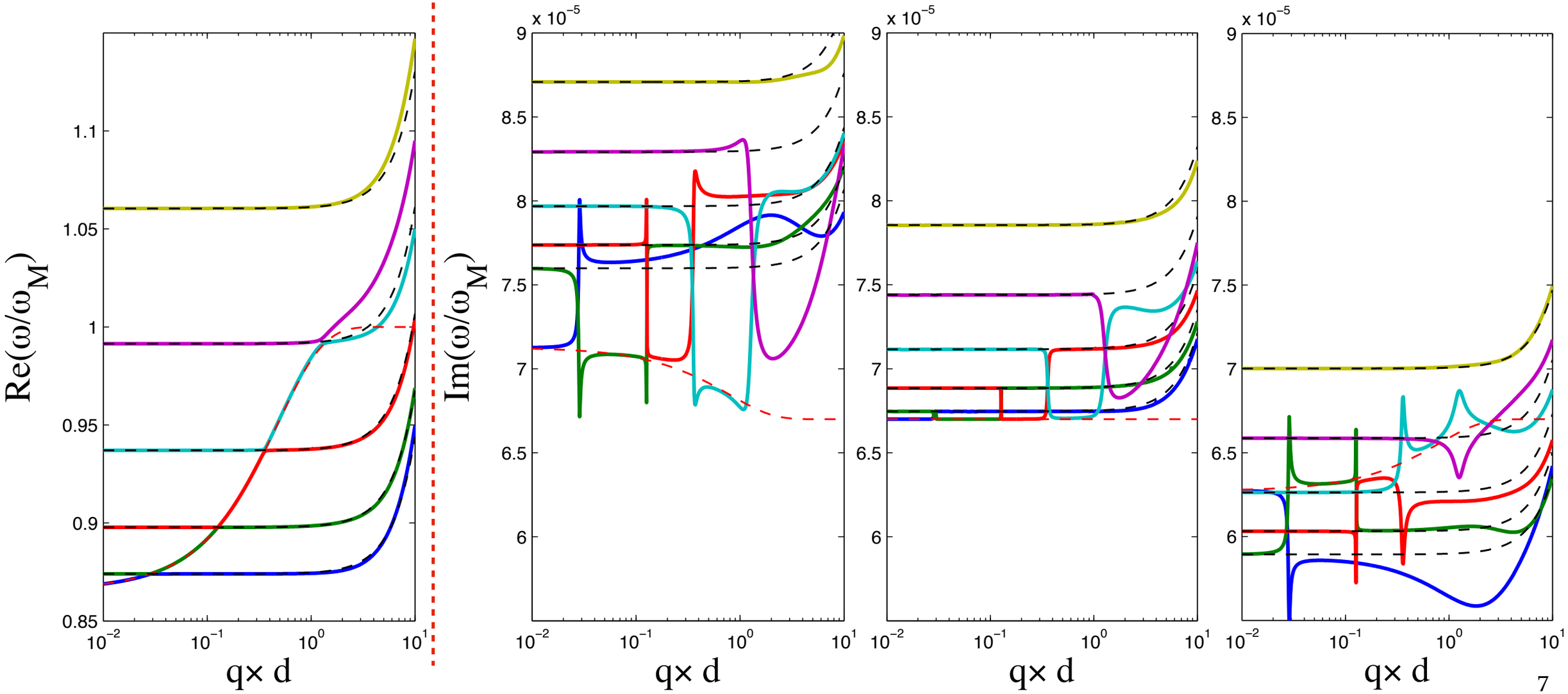
Dipole-exchange spin wave dispersion

real part: Re[ω(q)]

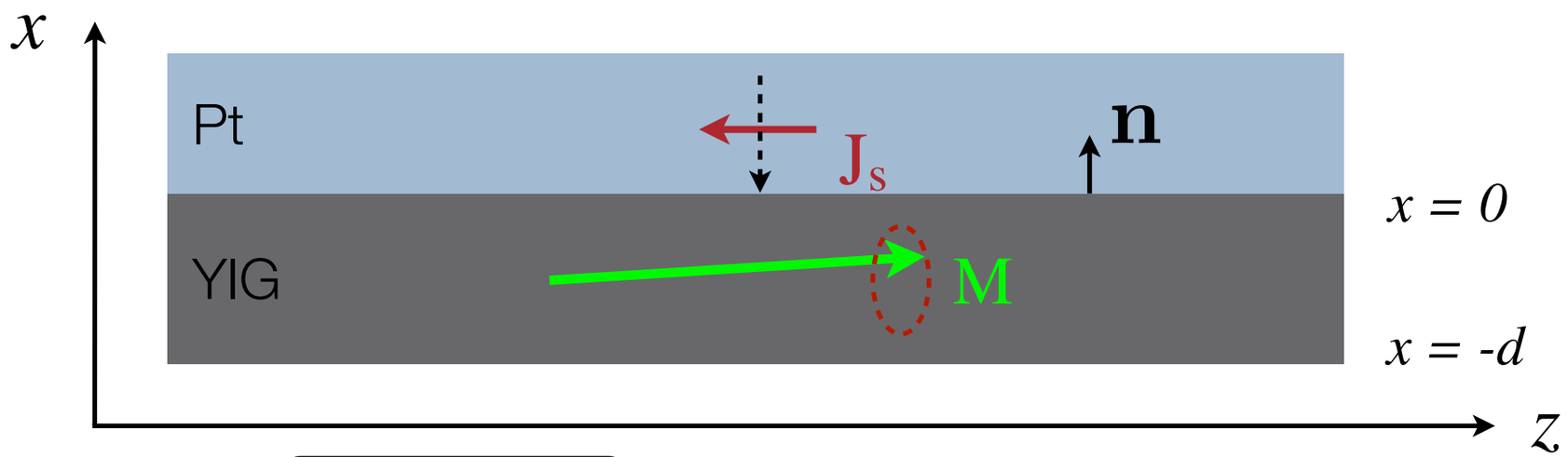
criteria for excitation: Im[ω(q, k_r)] < 0

imaginary part: Im[ω(q)]

current ~10^{10}A/m^2 | zero current | current ~ -10^{10}A/m^2



Surface spin wave by surface anisotropy



surface anisotropy

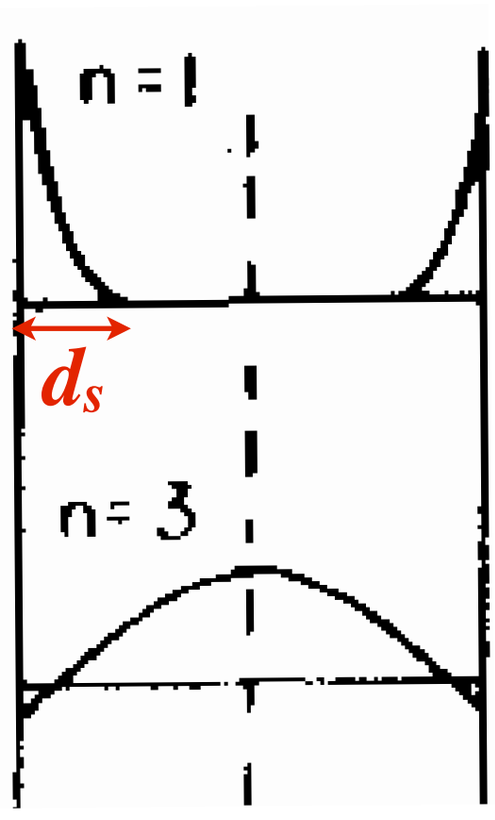
$$\mathbf{H}_s = \frac{2K_s}{M_s}(\mathbf{m}\cdot\mathbf{n})\mathbf{n}$$

$K_s < 0$

$$d_s \sim \frac{1}{k_s} \qquad k_s = \frac{2\gamma K_s}{A_{ex}} < 0$$

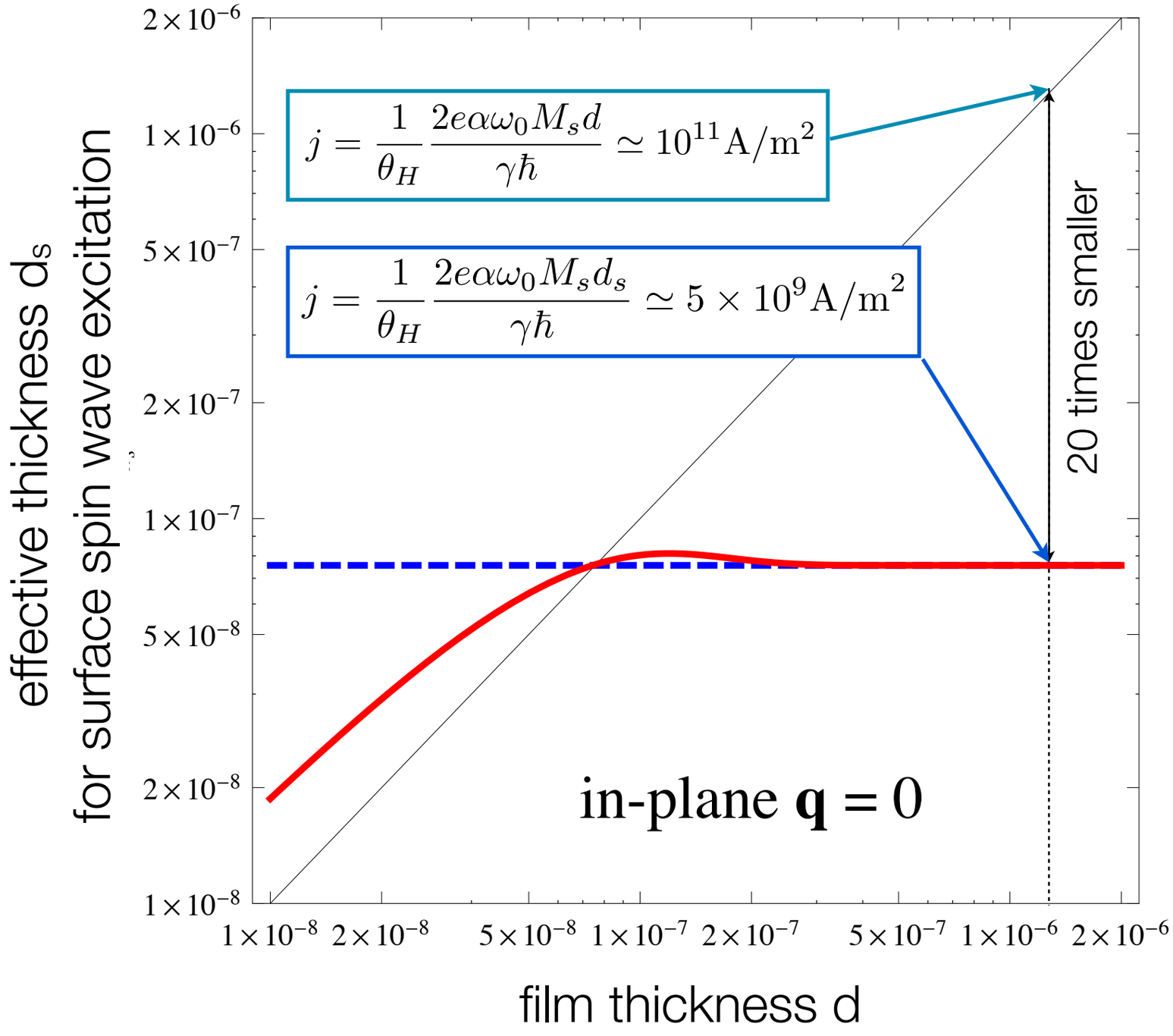
exchange constant

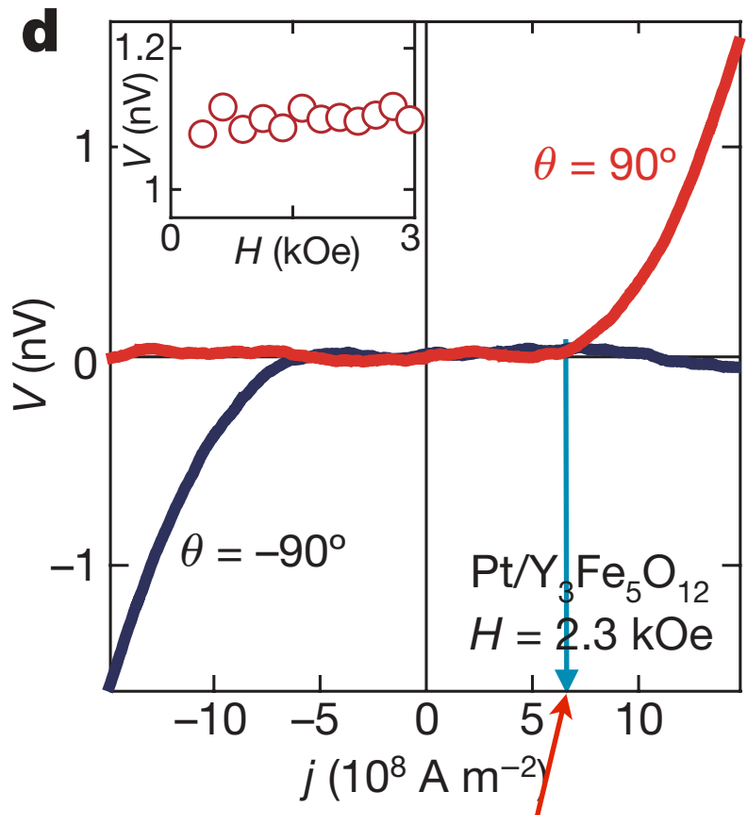
$$j = \frac{1}{\theta_H}\frac{2e\alpha\omega_0 M_s d_s}{\gamma\hbar}$$



P. E. Wigen, *Thin Solid Films* **114**, 135-186 (1984)

Surface spin wave by surface anisotropy

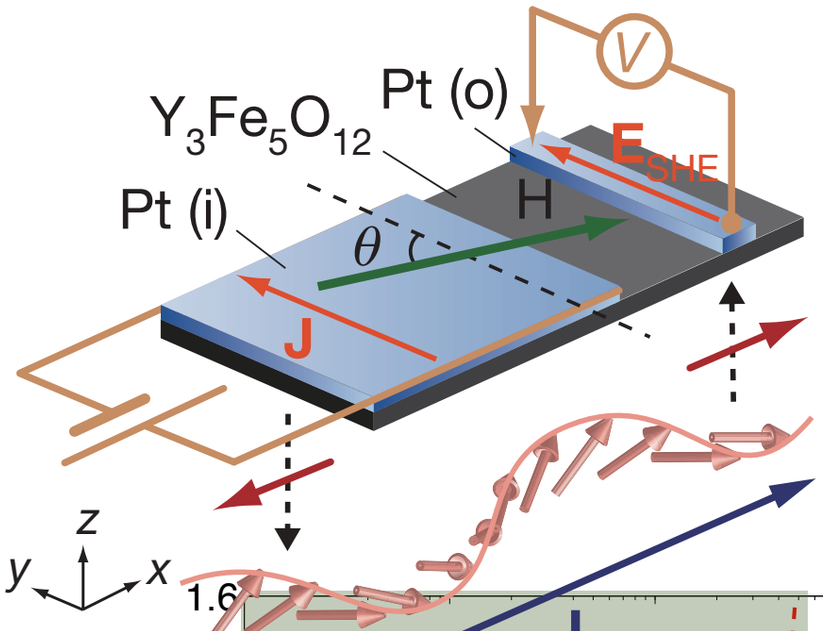




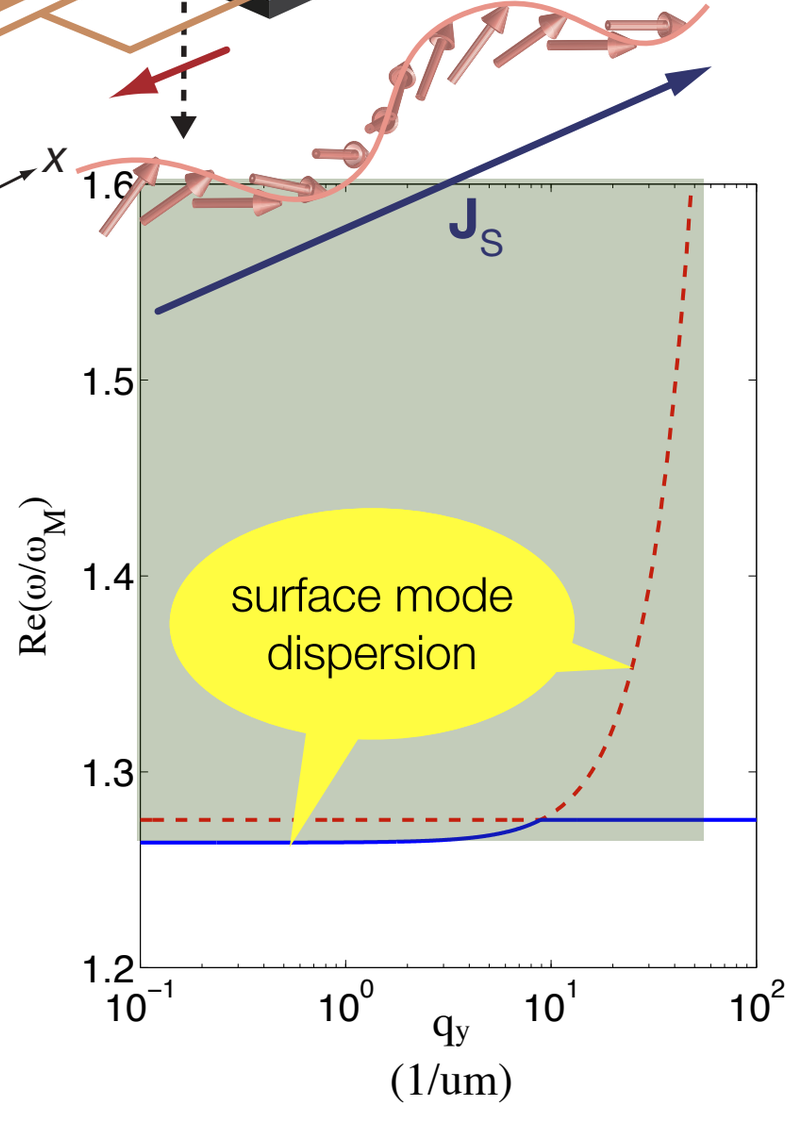
$j_c \simeq 6\times 10^{8}\,\mathrm{A/m^2}$

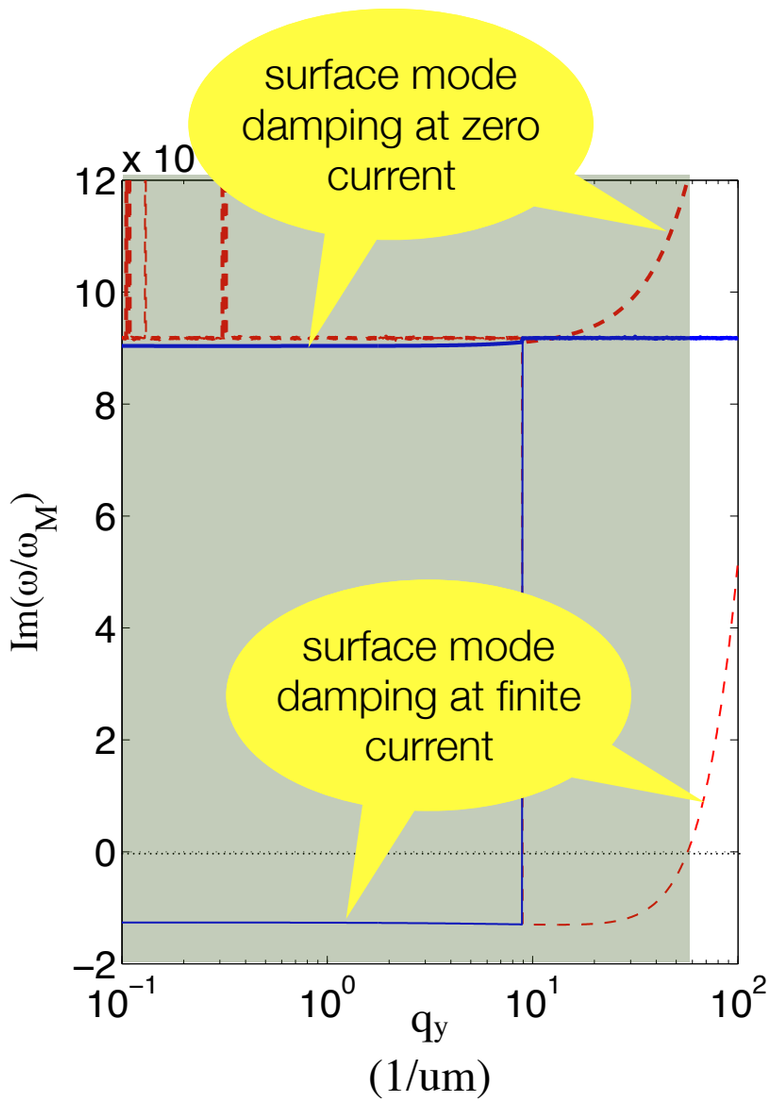
$d = 1.3\mu m$

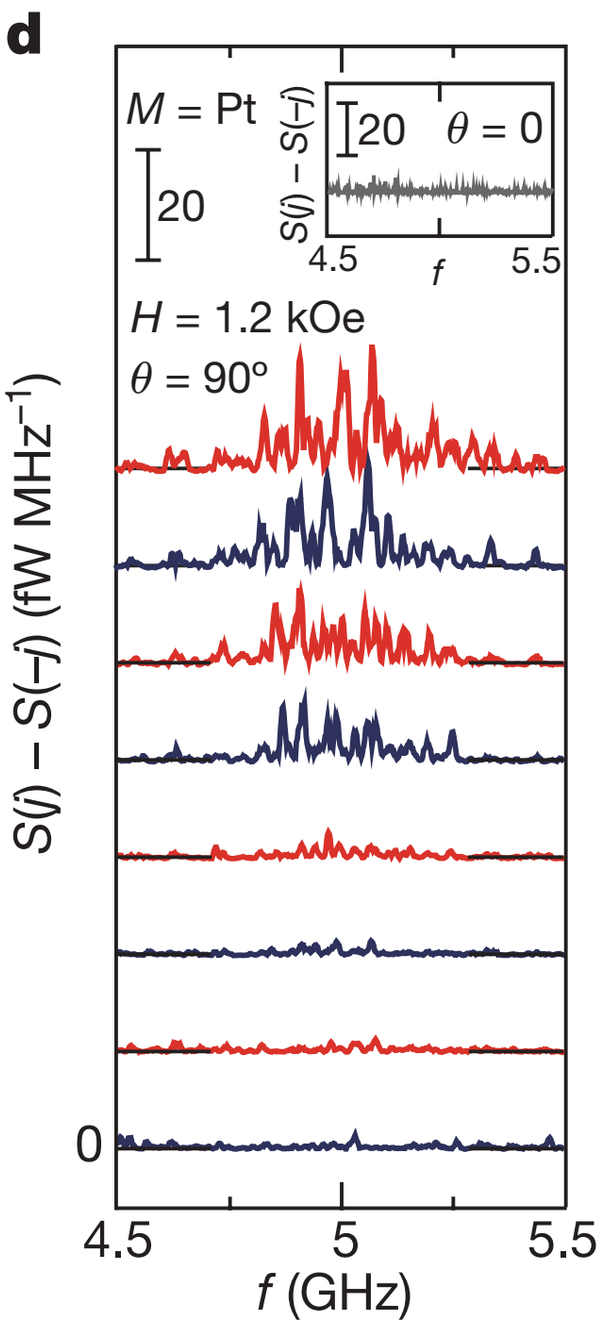
Surface spin wave by surface anisotropy



infinite film thickness
with non-zero in-plane **q**







Summary

- Spin Seebeck effect can be explained by the thermal spin pumping due to non-equilibrium magnon-phonon temperature originated from temperature gradient.
- The excitation of exchange surface spin wave due to surface anisotropy requires a current that is about 20 times smaller than that of bulk modes, and multiple frequencies are excited simultaneously.