spin pumping, spin Seebeck and SMR in YIG/AFM/Pt structure, AFM=NiO, CoO

Zhiyong Qiu, J. Li, **Dazhi Hou*** et al., Nature Communications 7,12670 (2016)

Dazhi Hou, Zhiyong Qiu, Joseph Barker, Koji Sato, Kei Yamamoto, Juan M Gomez-Perez, Luis E Hueso, Felix Casanova, Eiji Saitoh, Phys. Rev. Lett. 118,147202 (2017)

SPICE Young Leaders 2017.8.3

AIMR

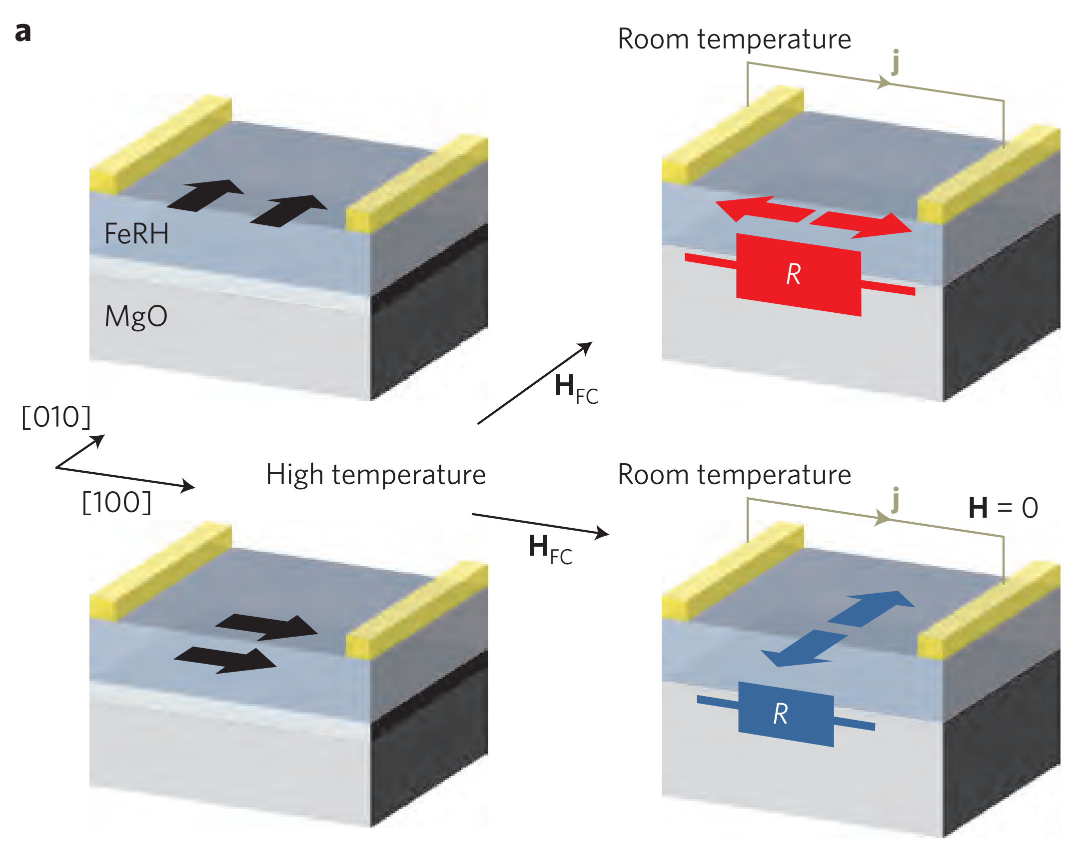
nature nanotechnology

REVIEW ARTICLE

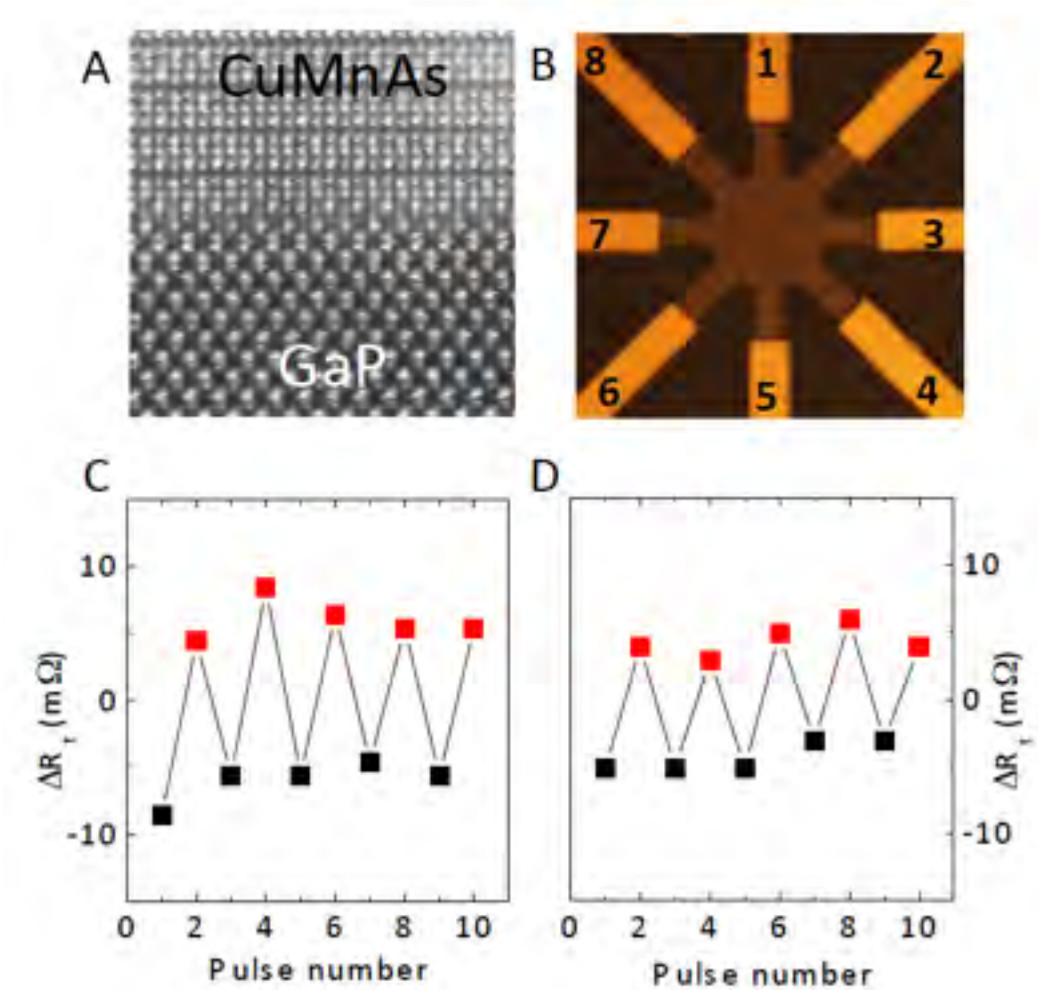
PUBLISHED ONLINE: 3 MARCH 2016 | DOI: 10.1038/NNANO.2016.18

Antiferromagnetic spintronics

T. Jungwirth[1,2]*, X. Marti[1], P. Wadley[2] and J. Wunderlich[1,3]

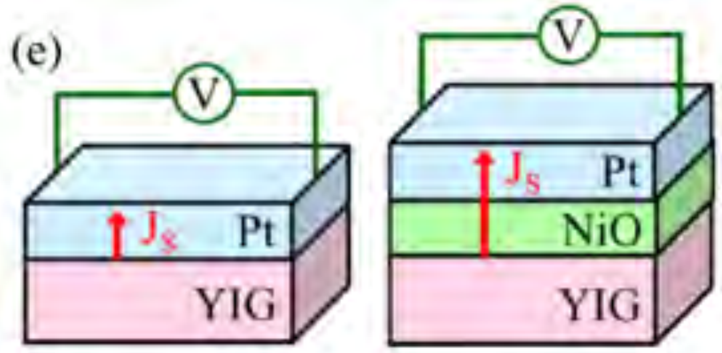


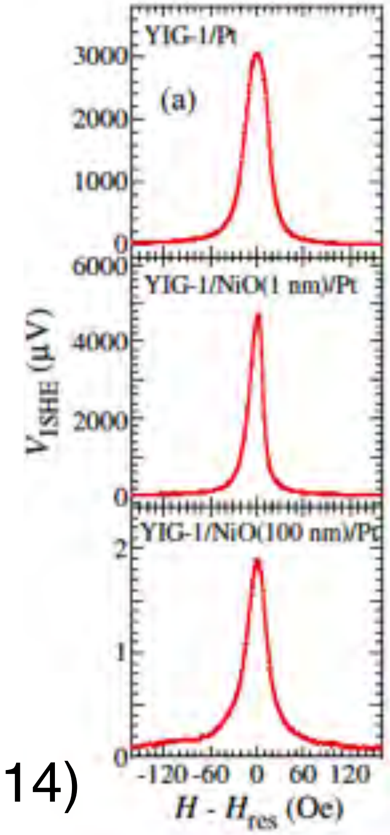
X. Marti *et al.*, Nature Materials 13, 367–374 (2014)



Peter Wadley *et al.*, Science, 2016

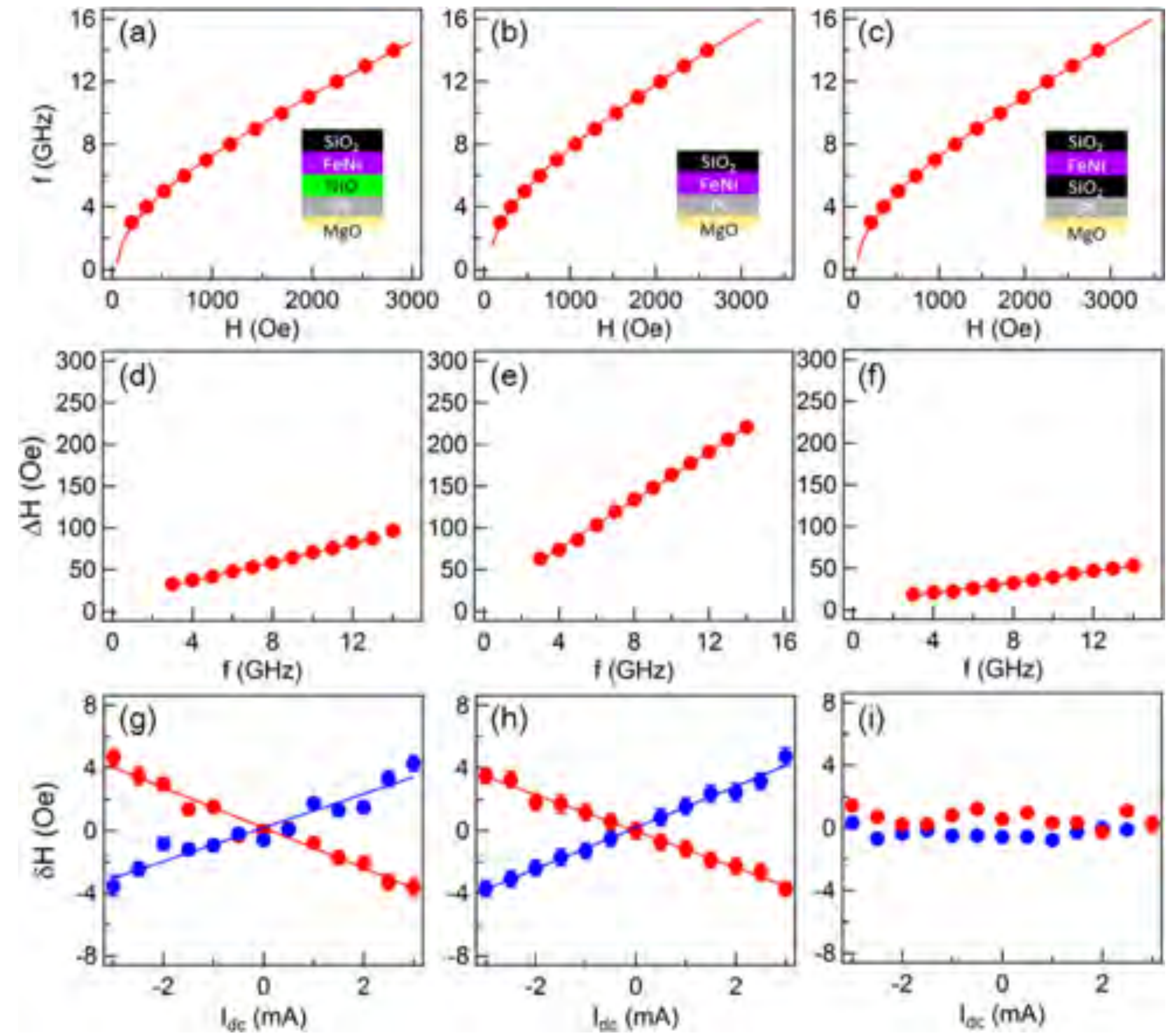
spin transport in AFM insulators





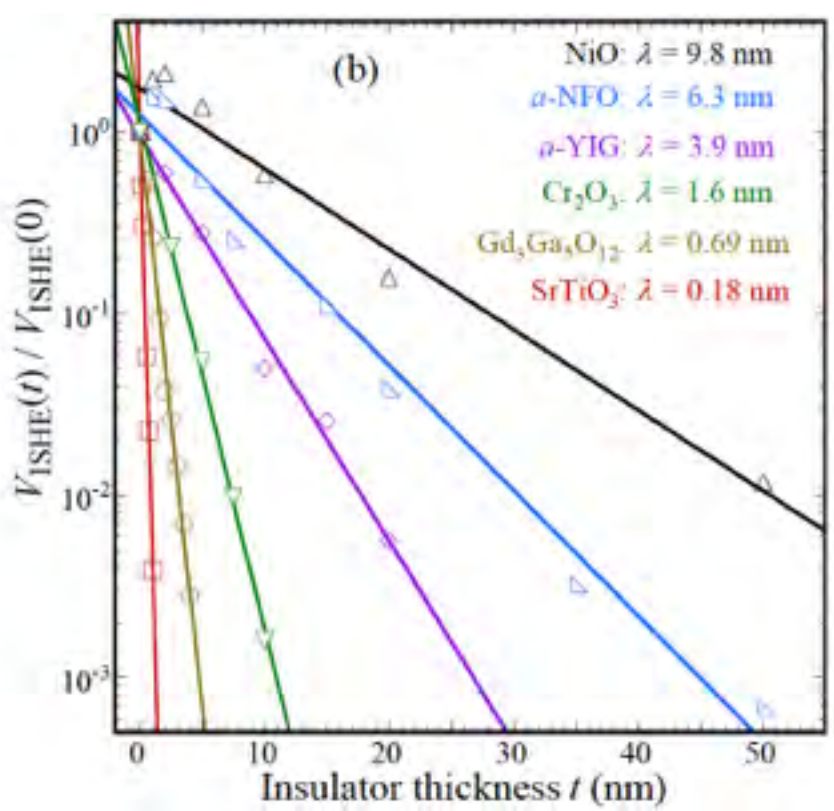
YIG/NiO transparency>1

H. Wang *et al.*, PRL 113, 097202 (2014)



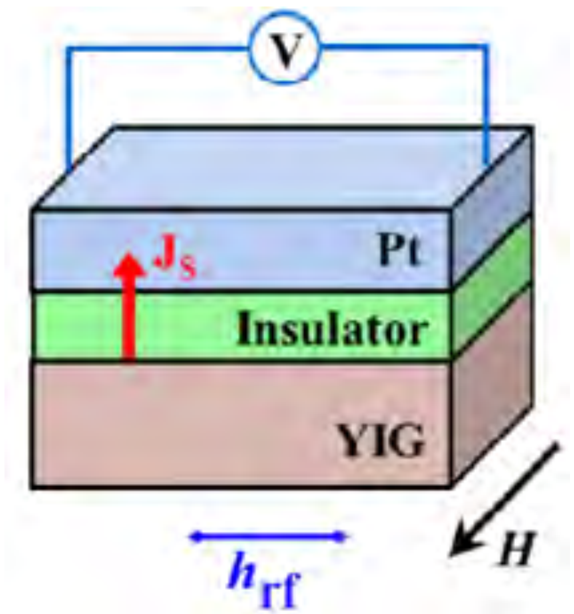
Moriyama *et al.* APL 106, 162406 (2015)

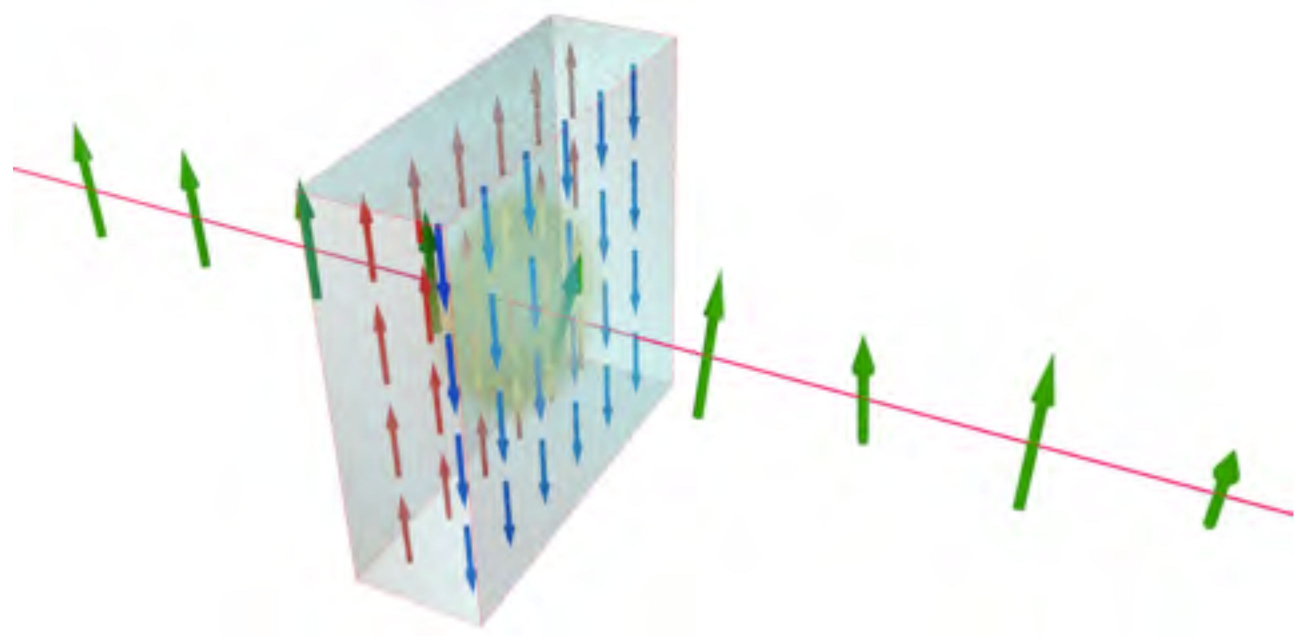
Py/NiO transparency~0.8



H. Wang *et al.*, Phys. Rev. B 91, 220410(R) 2015

spin current: pure spin beam

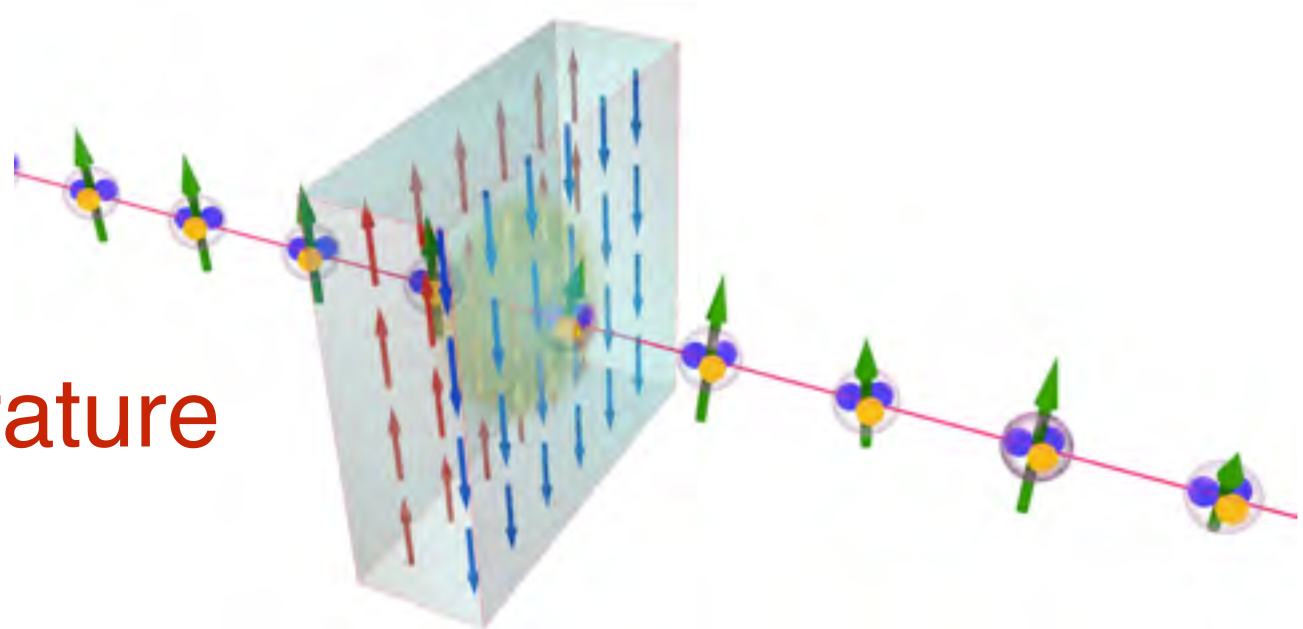




neutron scattering:

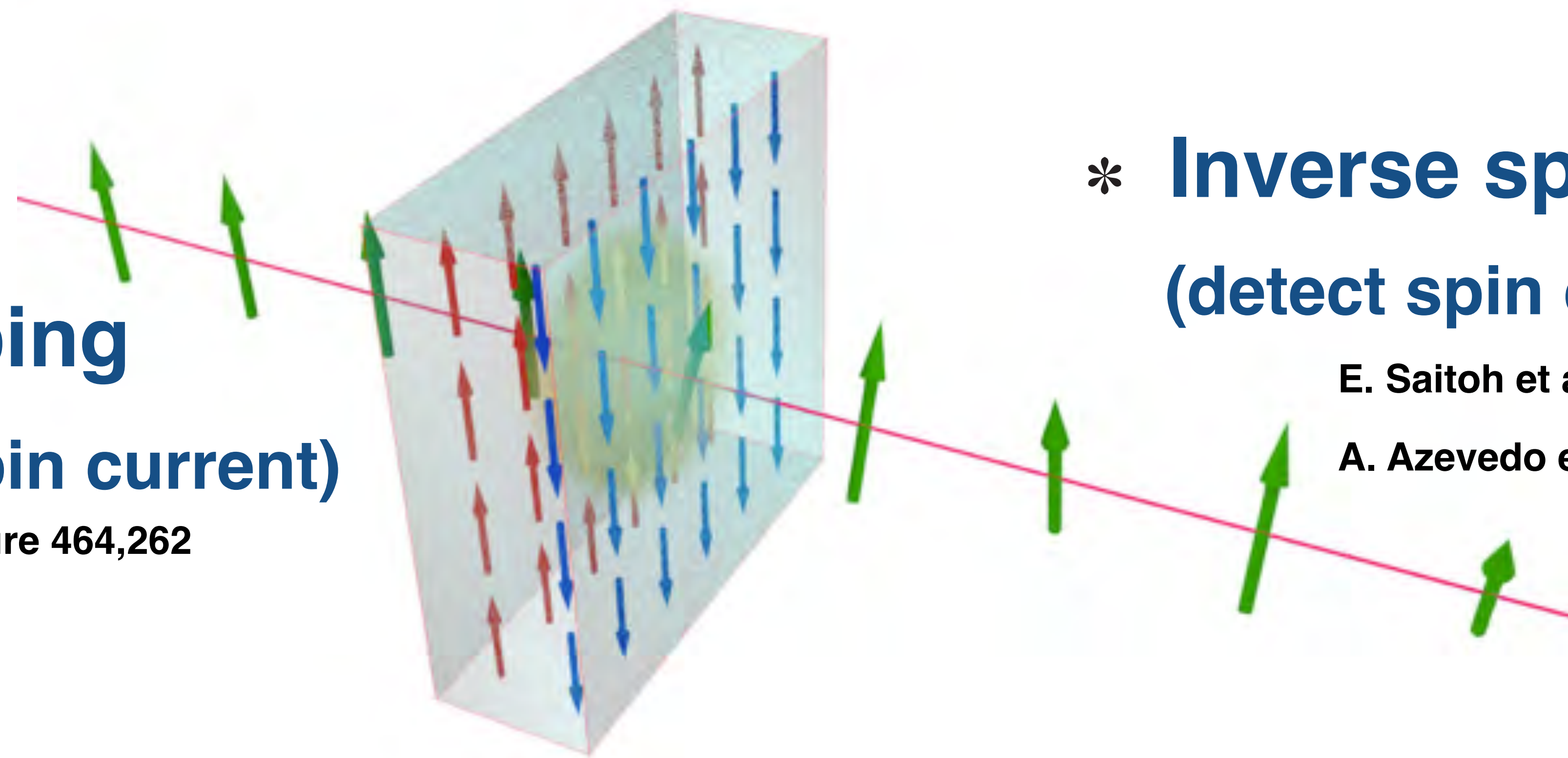
probe of spin fluctuation

determine ordering temperature



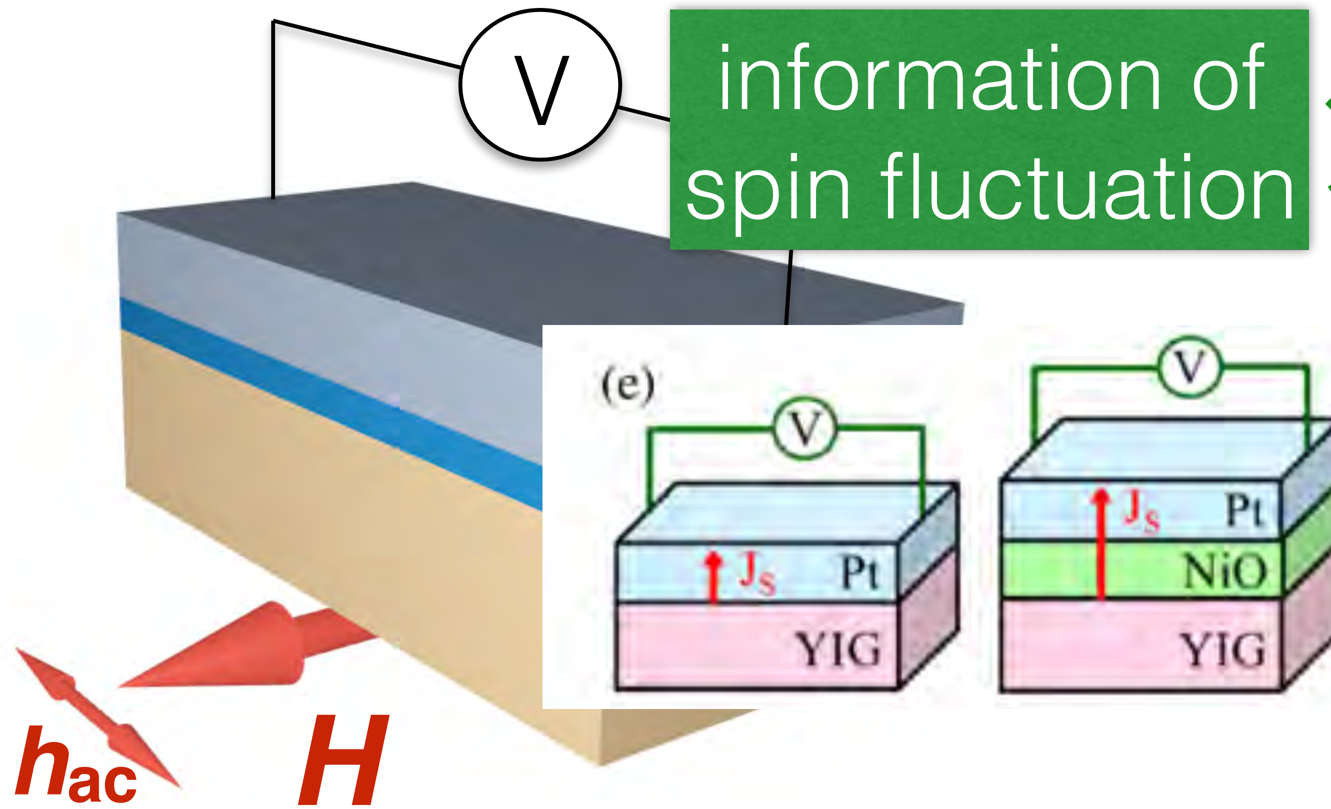
Our guess: spin current as desktop neutron source?

spin current in AFM: desktop neutron experiment?

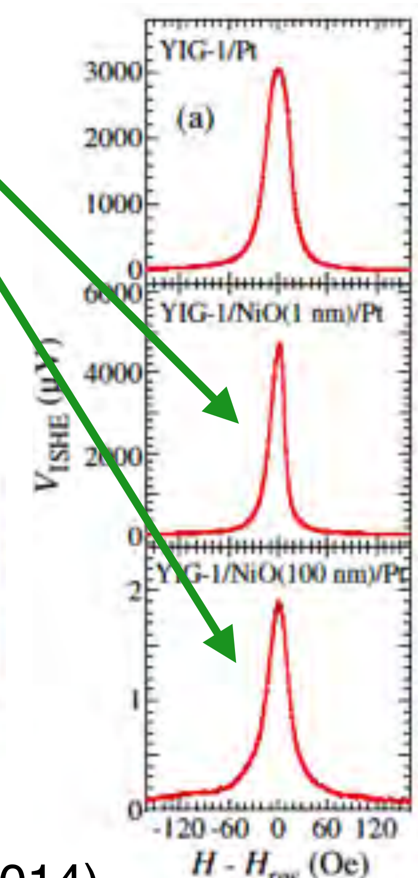


* **Spin pumping**
  (Generate spin current)
  Y. Kajiwara et al., Nature 464,262

* **Inverse spin Hall effect**
  (detect spin current)
  E. Saitoh et al., APL 88, 182509
  A. Azevedo et al., JAP 97, 10C715

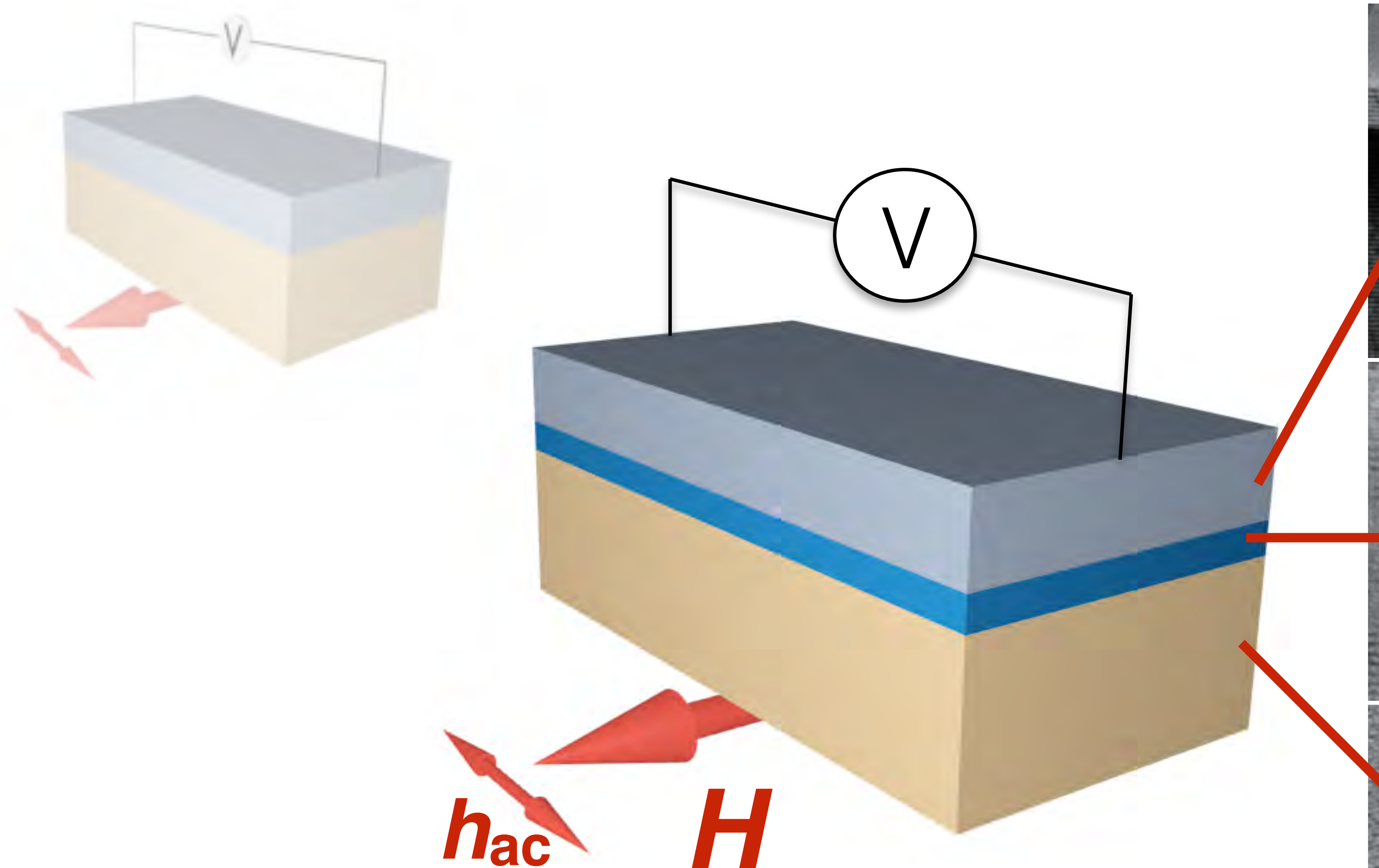


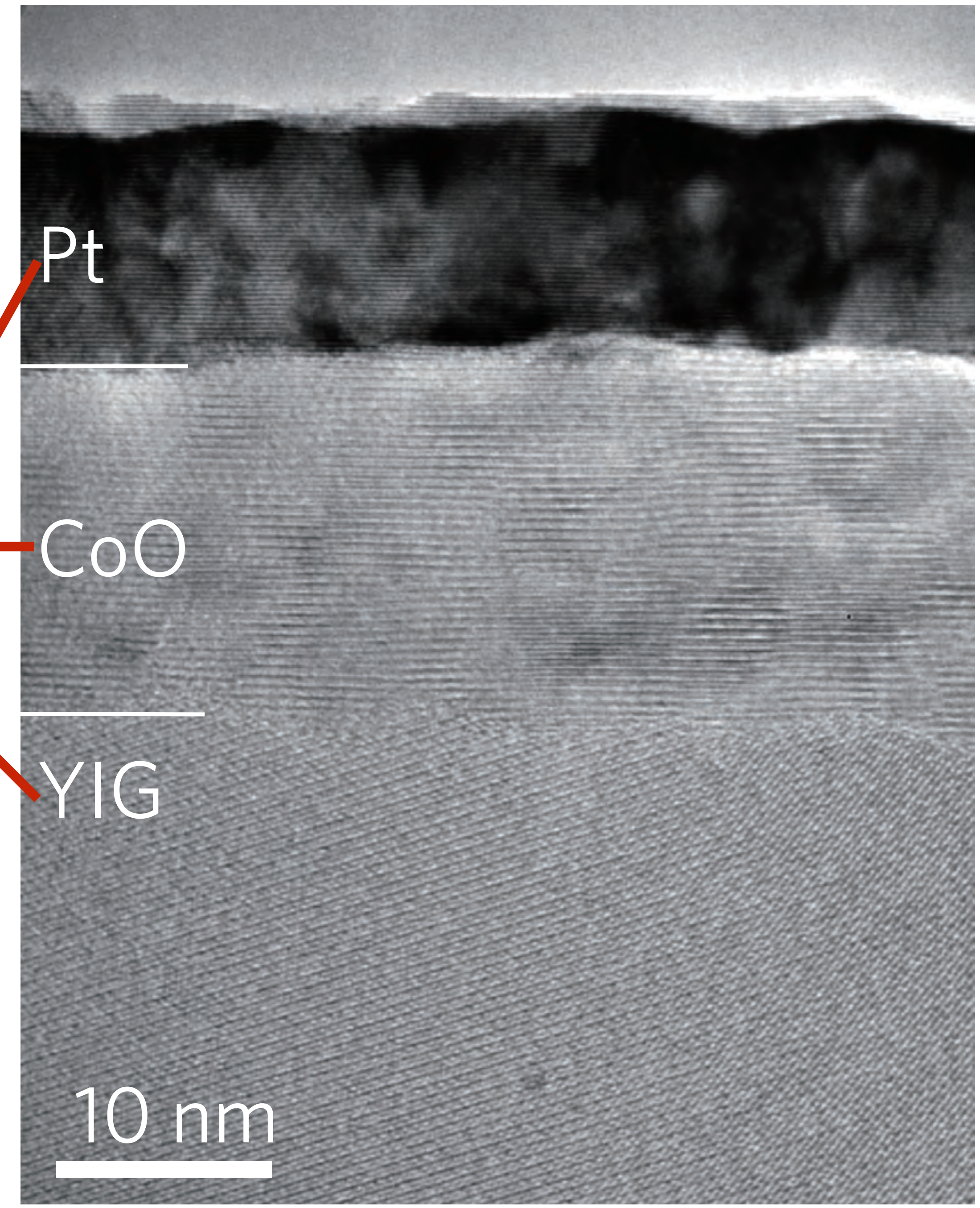
information of spin fluctuation

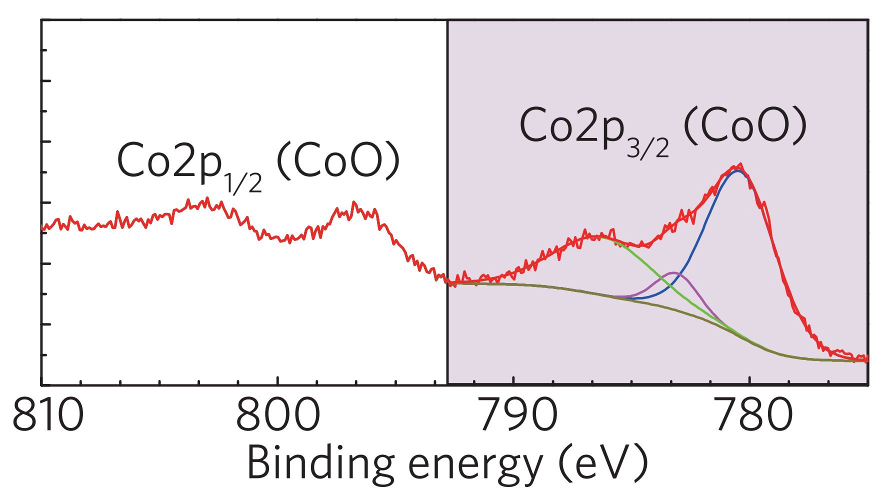


H. Wang *et al.*, PRL 113, 097202 (2014)

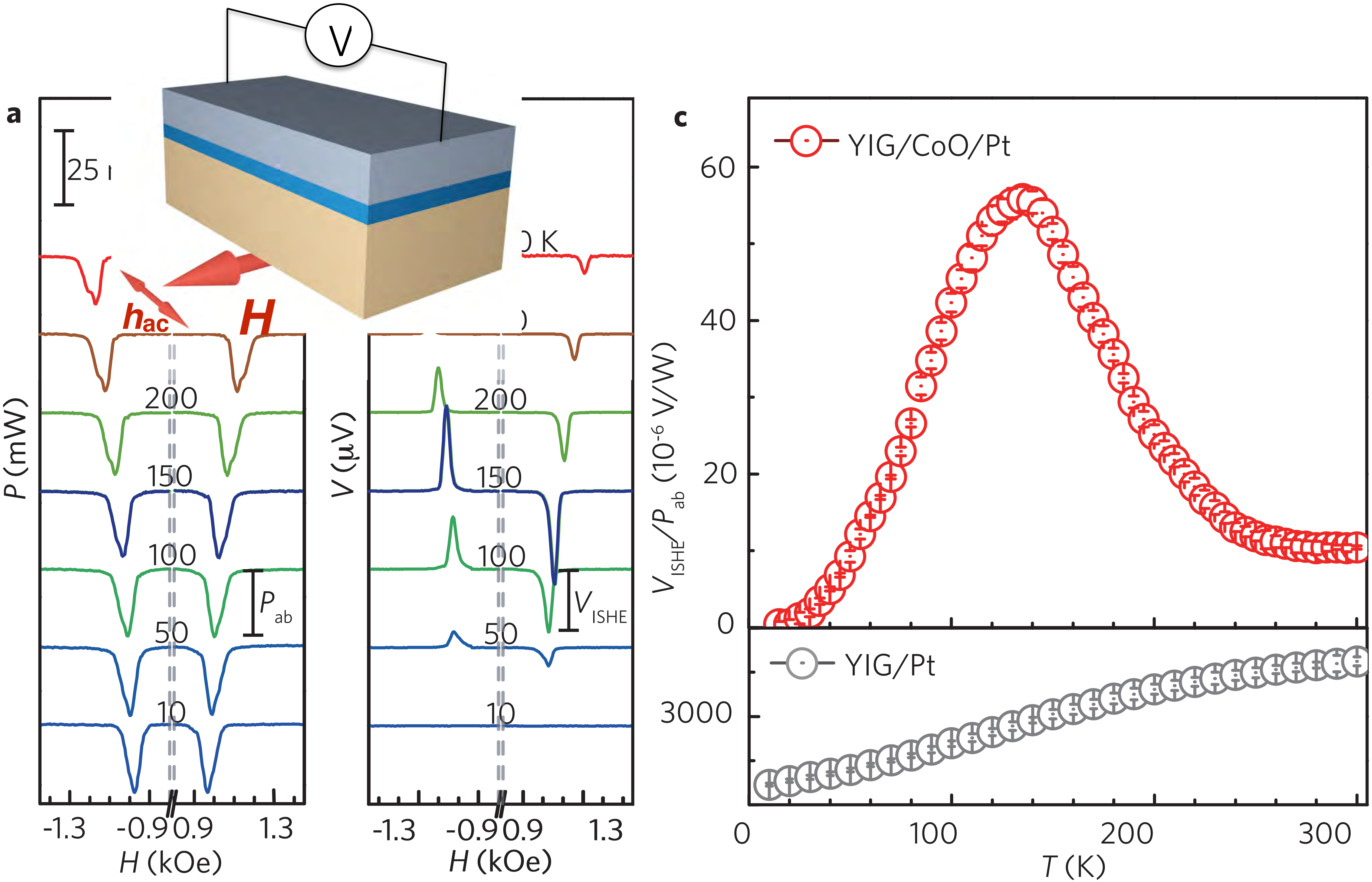
Device & Set-up







spin pumping ISHE in YIG/3nm CoO/Pt



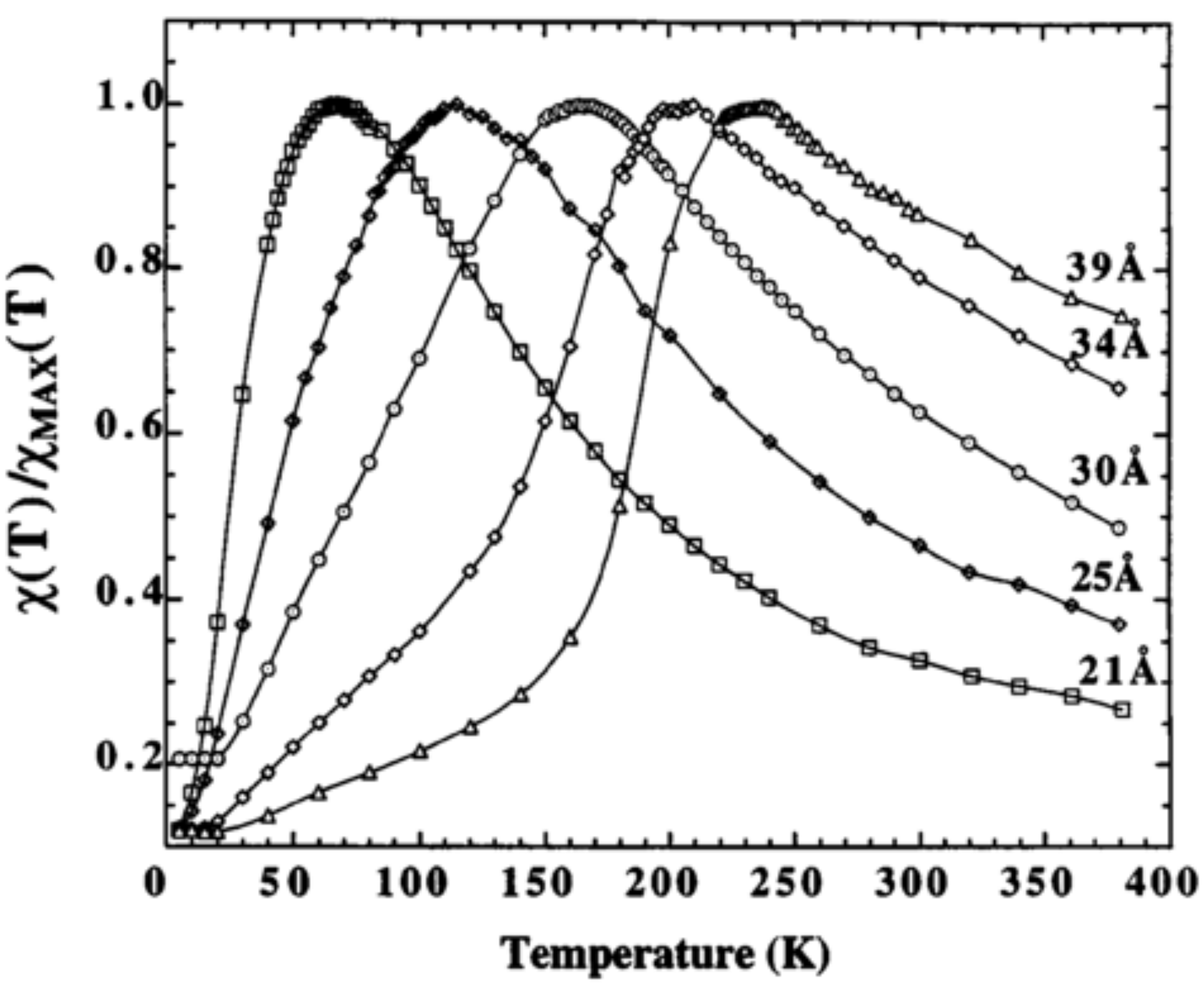
Results and discussion

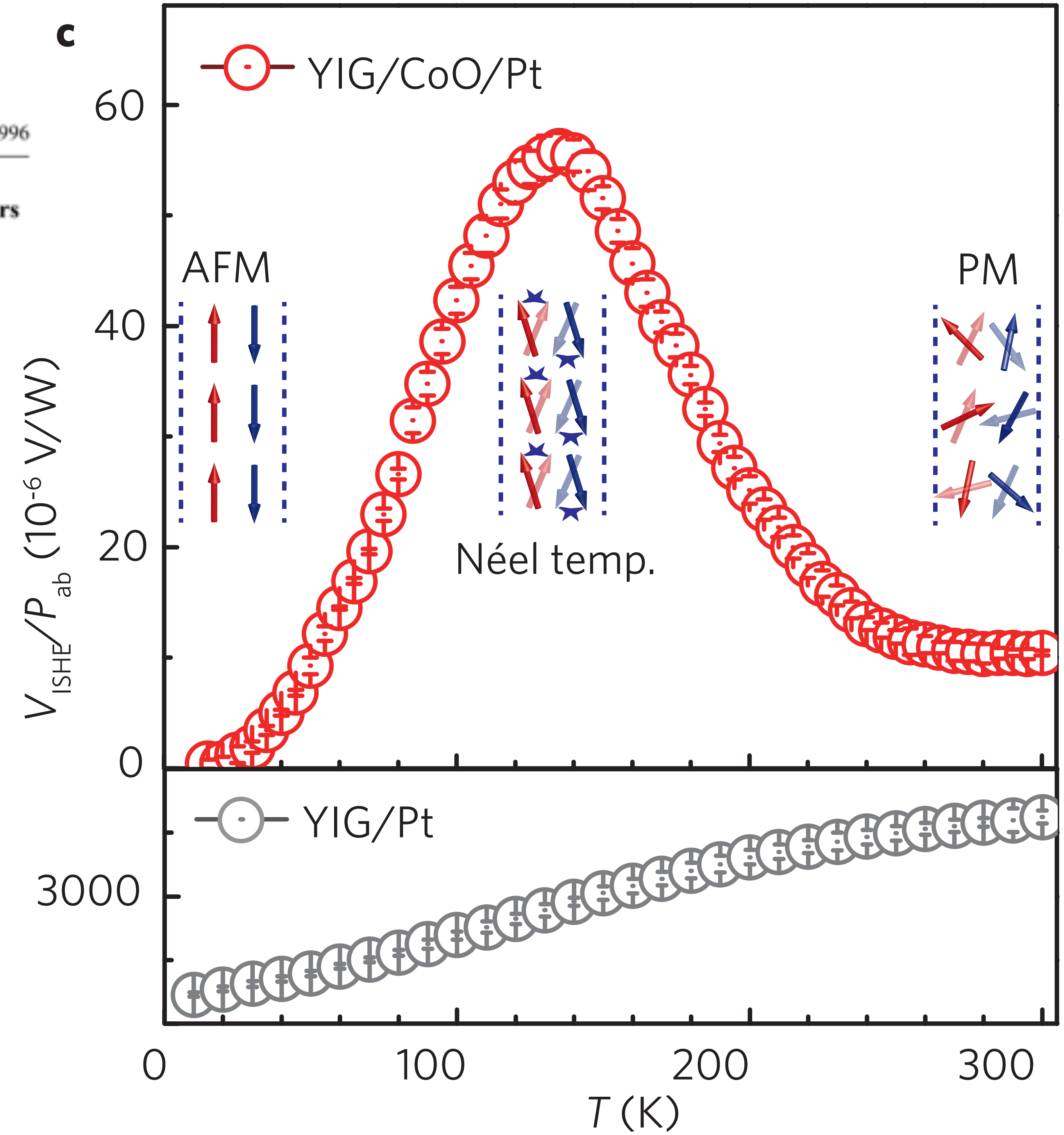
- **Susceptibility of CoO film**

VOLUME 76, NUMBER 10 PHYSICAL REVIEW LETTERS 4 MARCH 1996

Finite-Size Effects and Uncompensated Magnetization in Thin Antiferromagnetic CoO Layers

T. Ambrose and C. L. Chien





Results and discussion

- **Susceptibility of CoO film**
- **Finite size effect**

VOLUME 76, NUMBER 10 PHYSICAL REVIEW LETTERS 4 MARCH 1996

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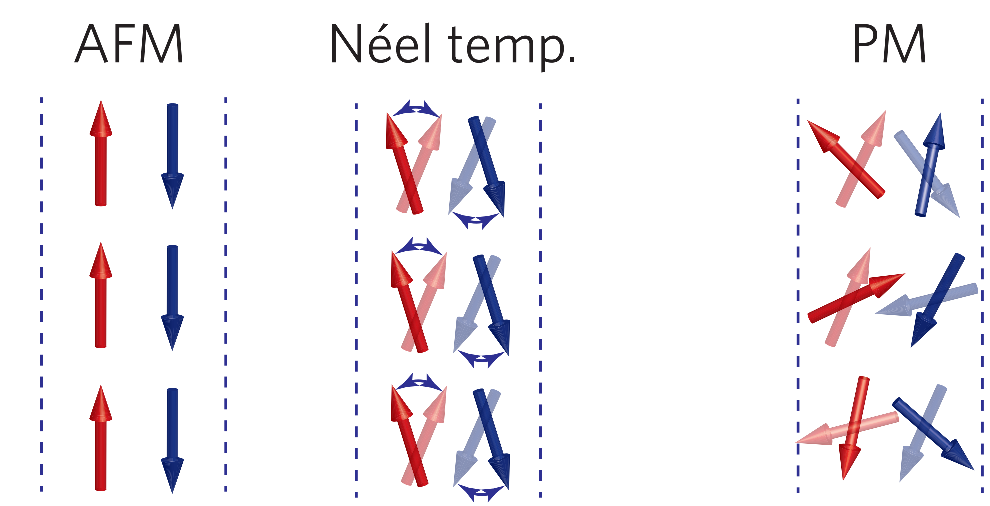
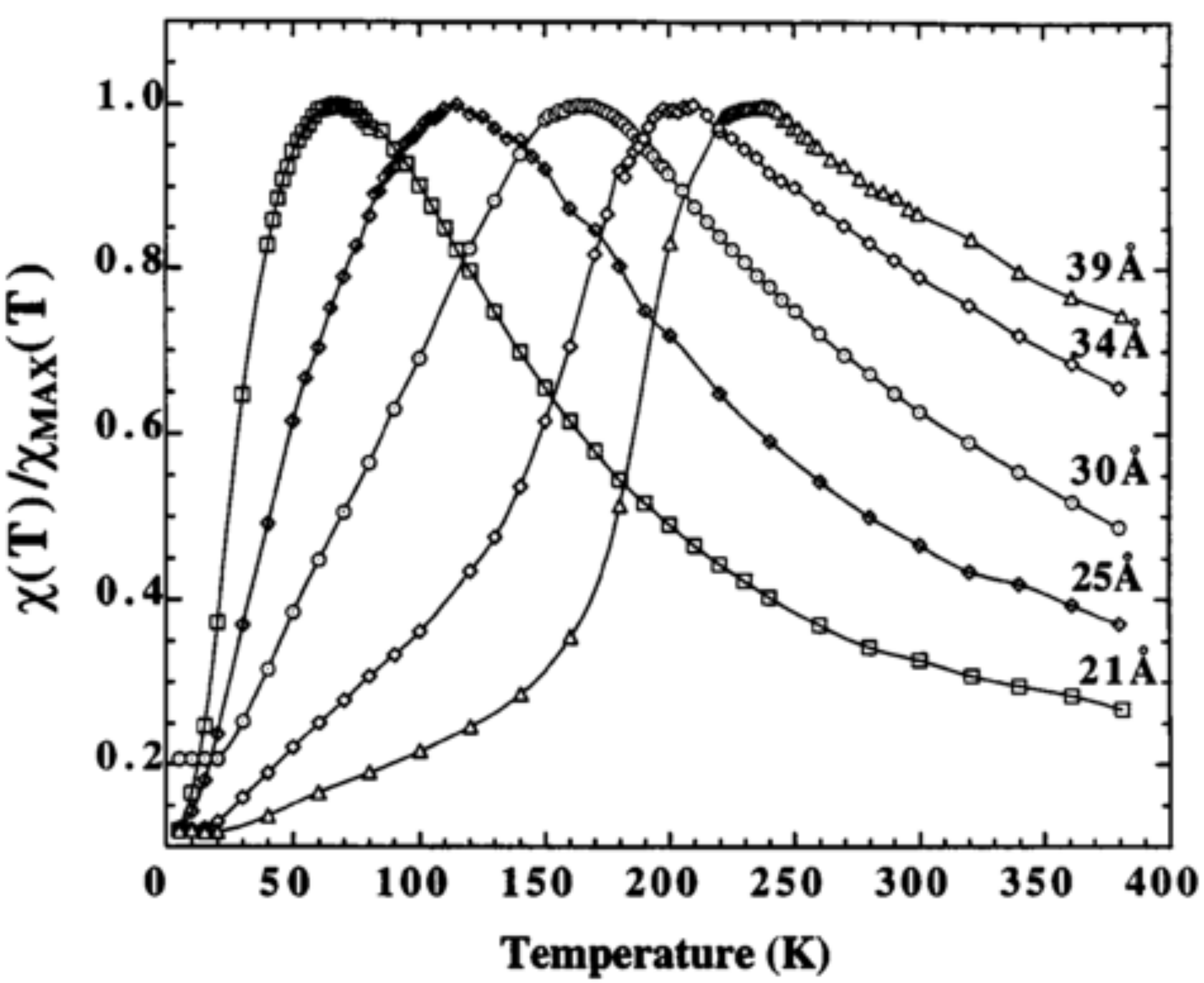
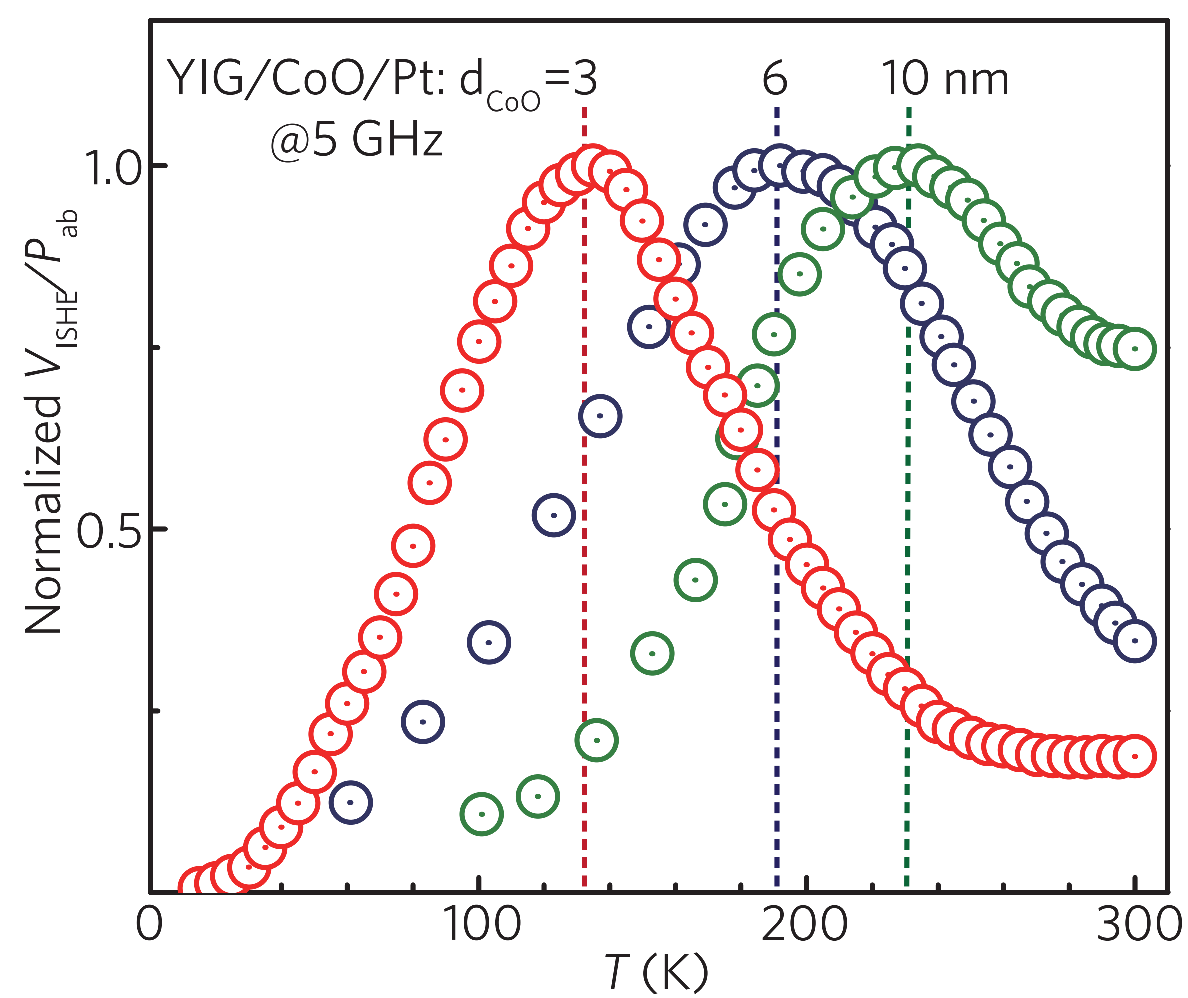
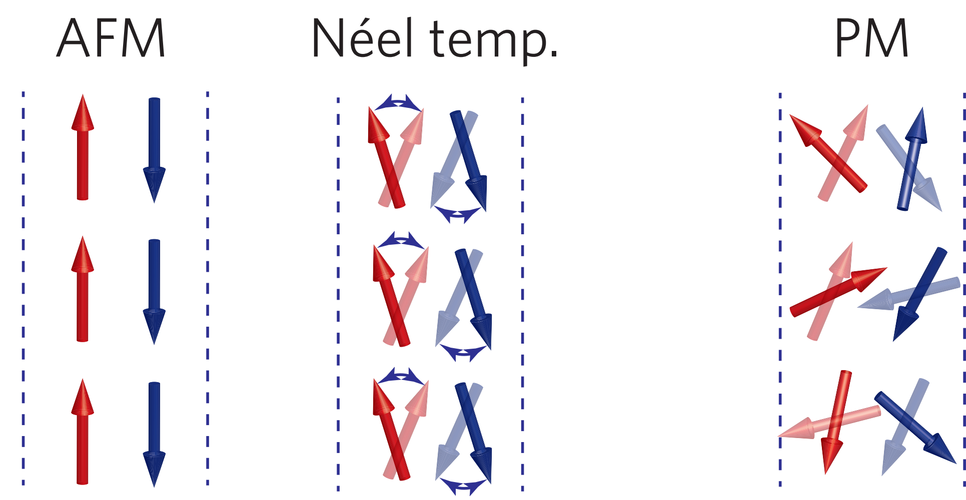


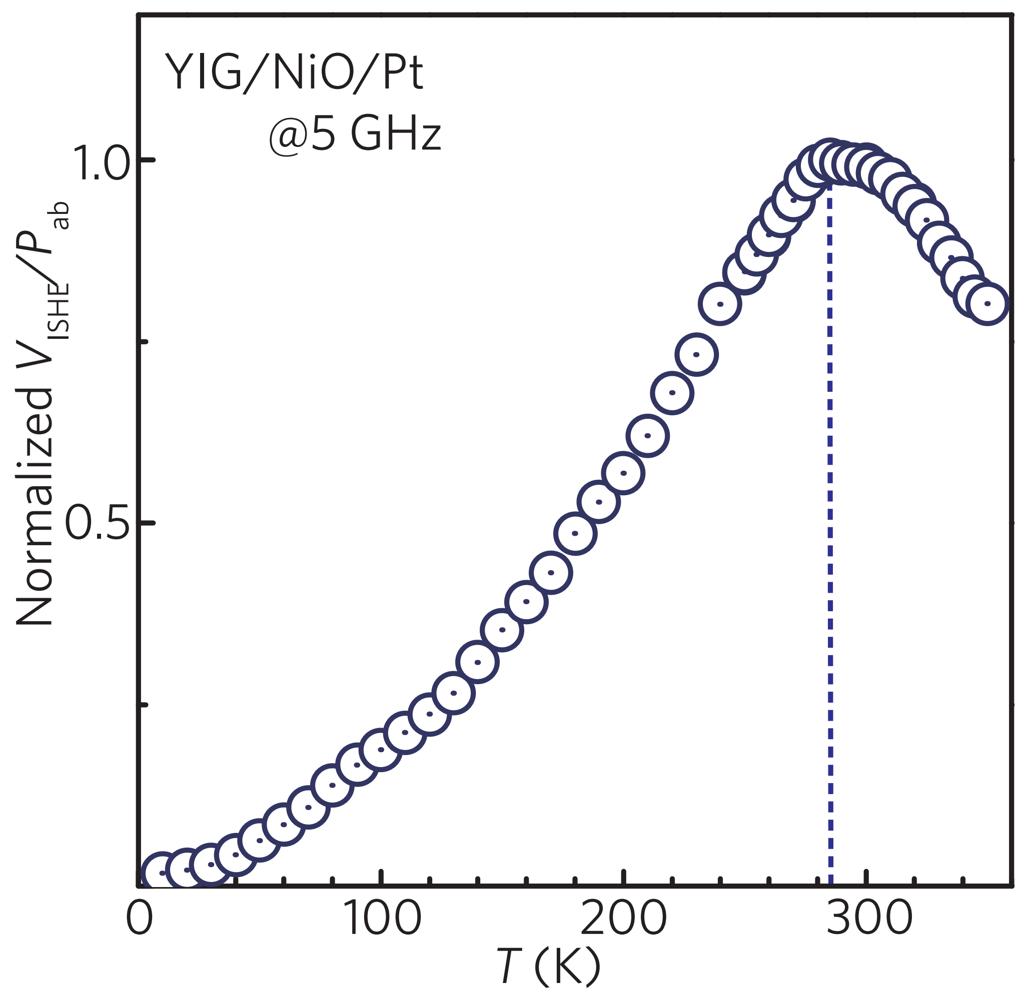


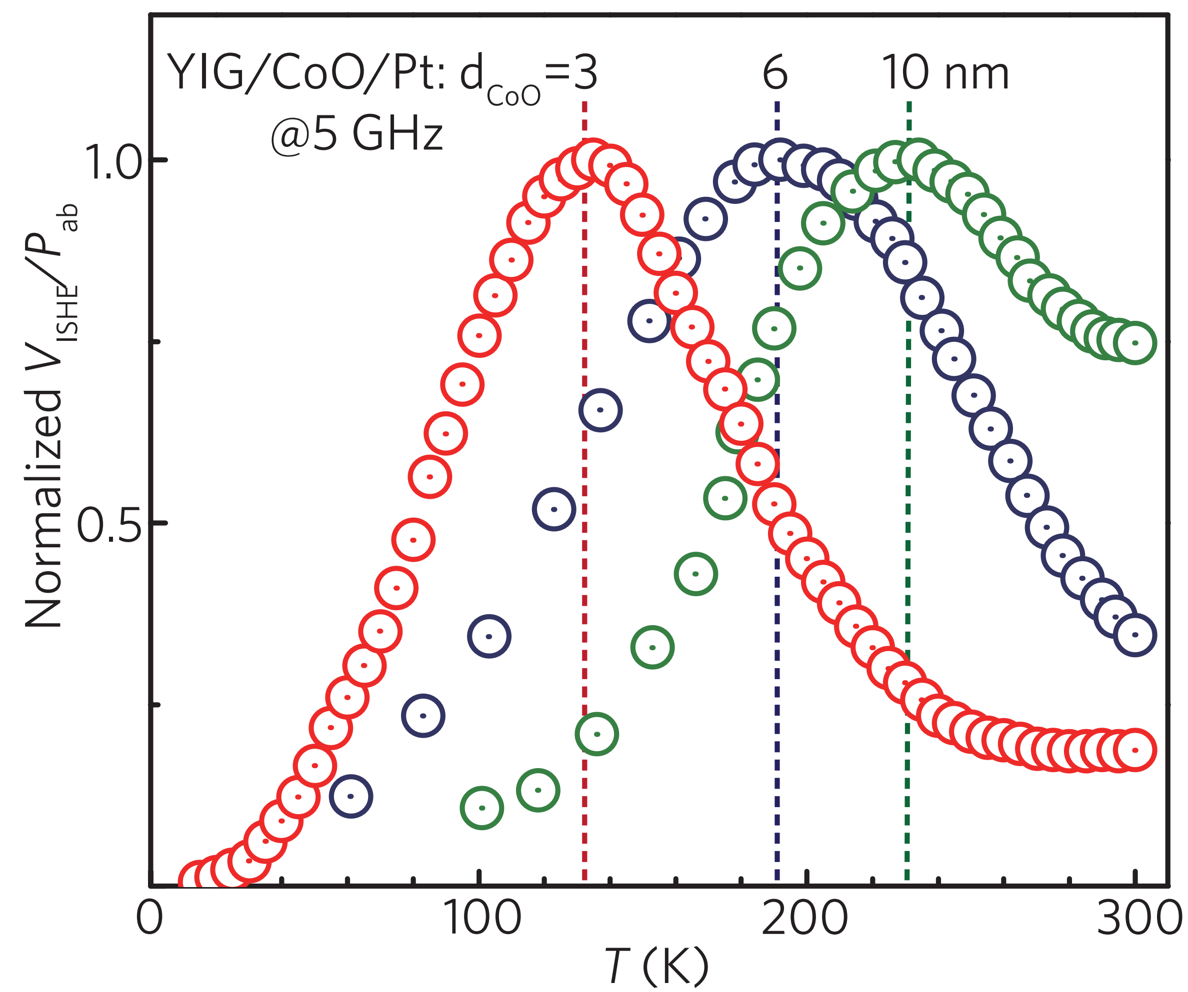


Results and discussion

- **Susceptibility of CoO film**
- **Finite size effect**
- **Double check in NiO**

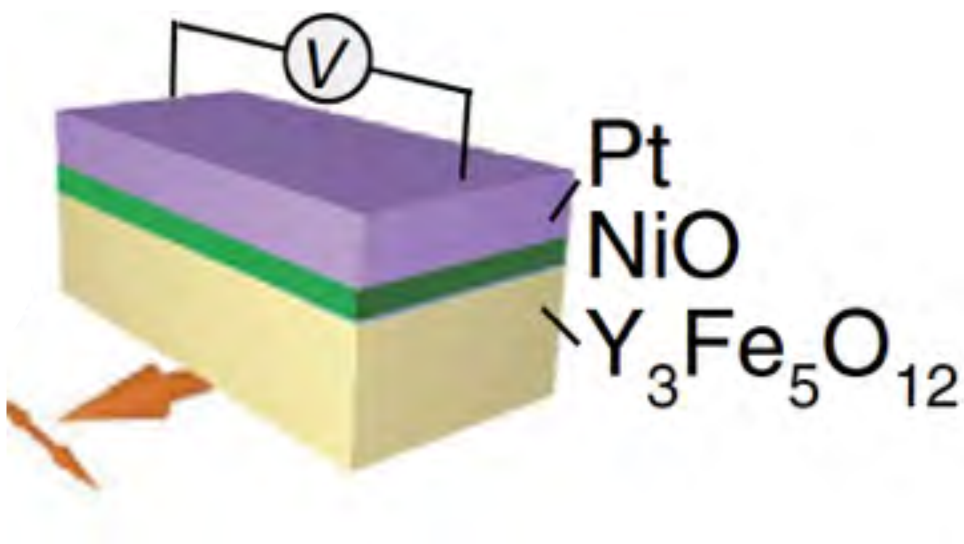


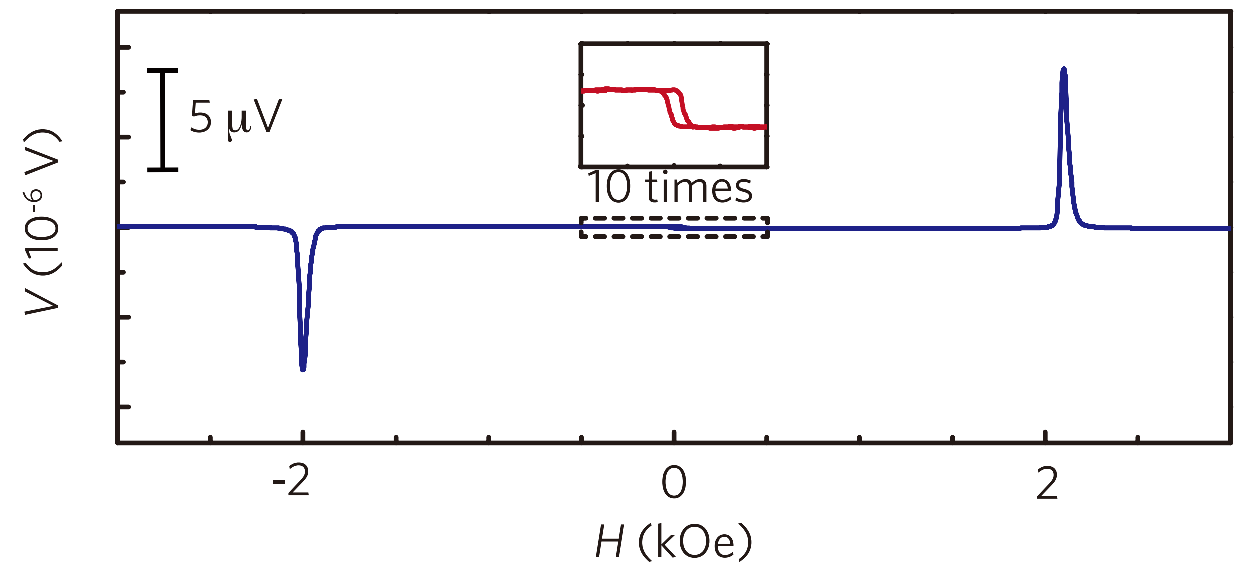


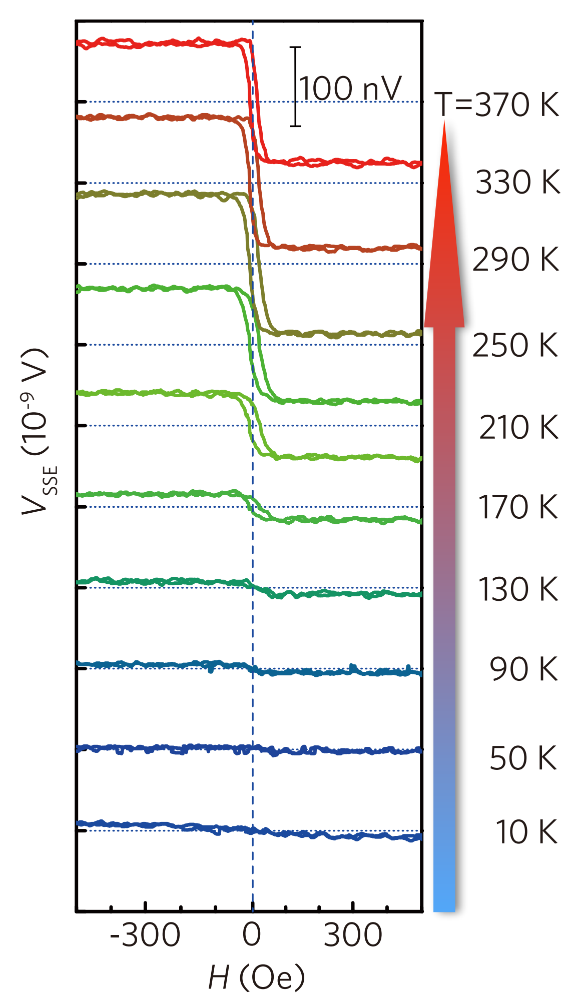


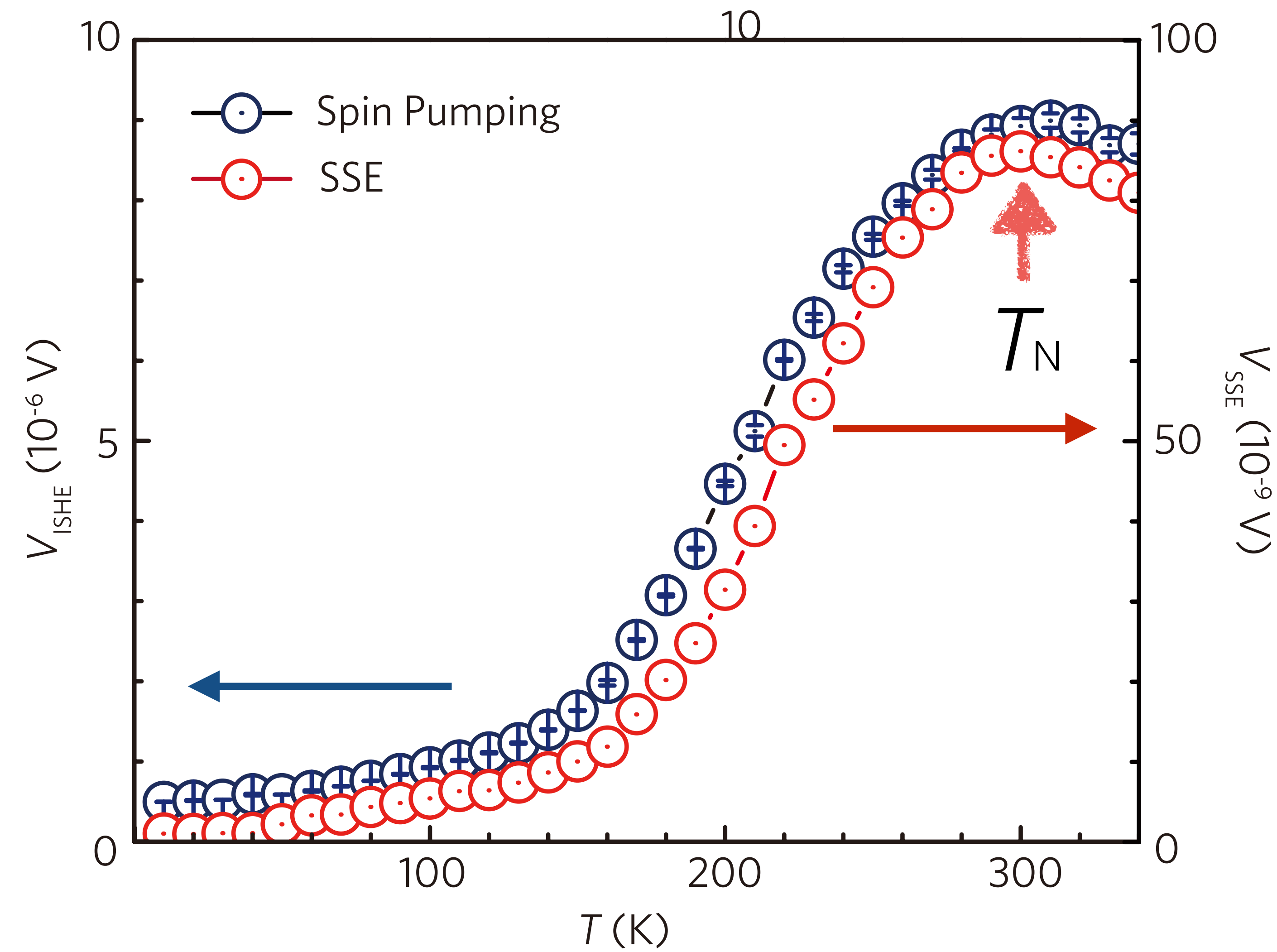
Z. Qiu *et al.*, Nature Communications 7, 12670 (2016).

spin Seebeck/pumping effect YIG/NiO/Pt



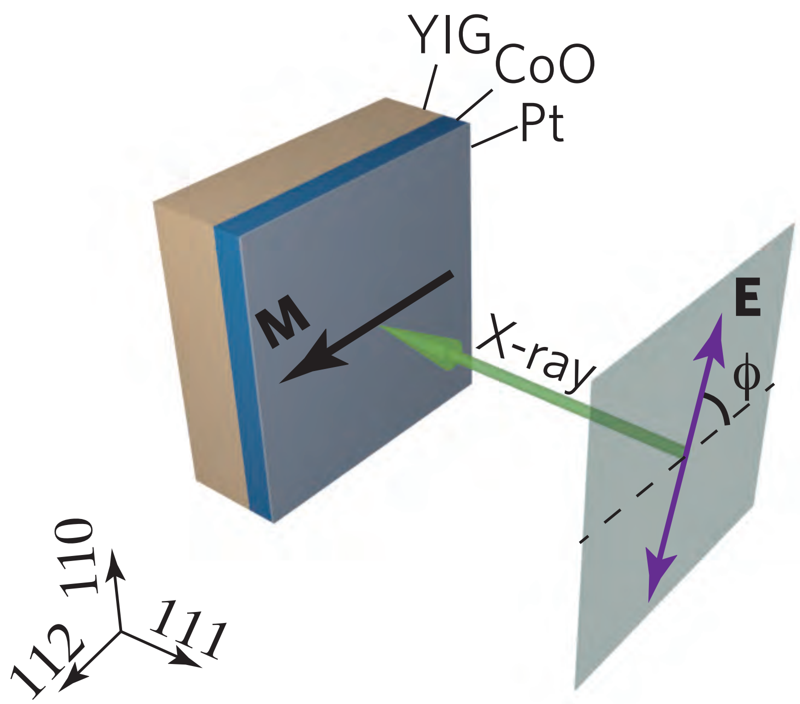


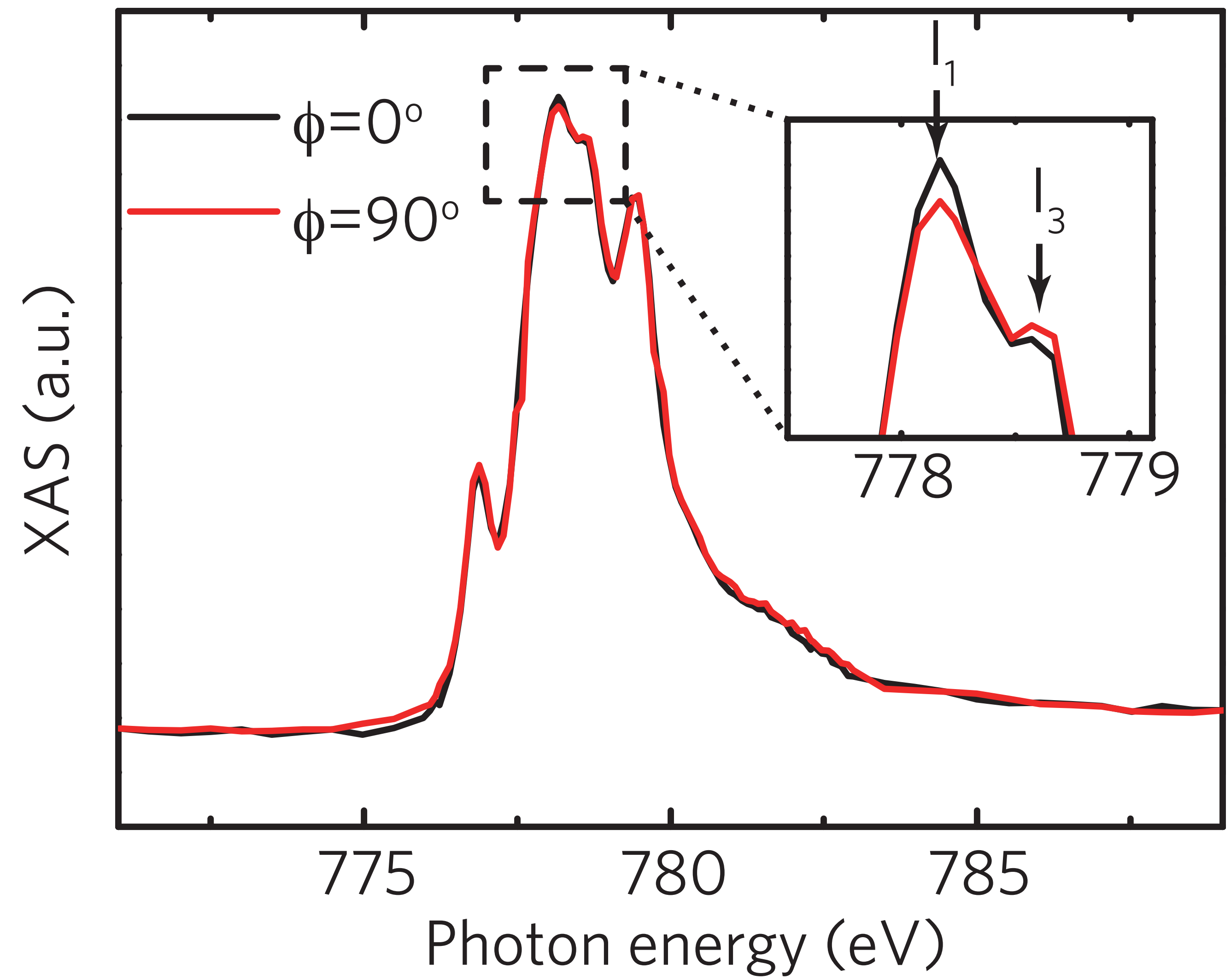


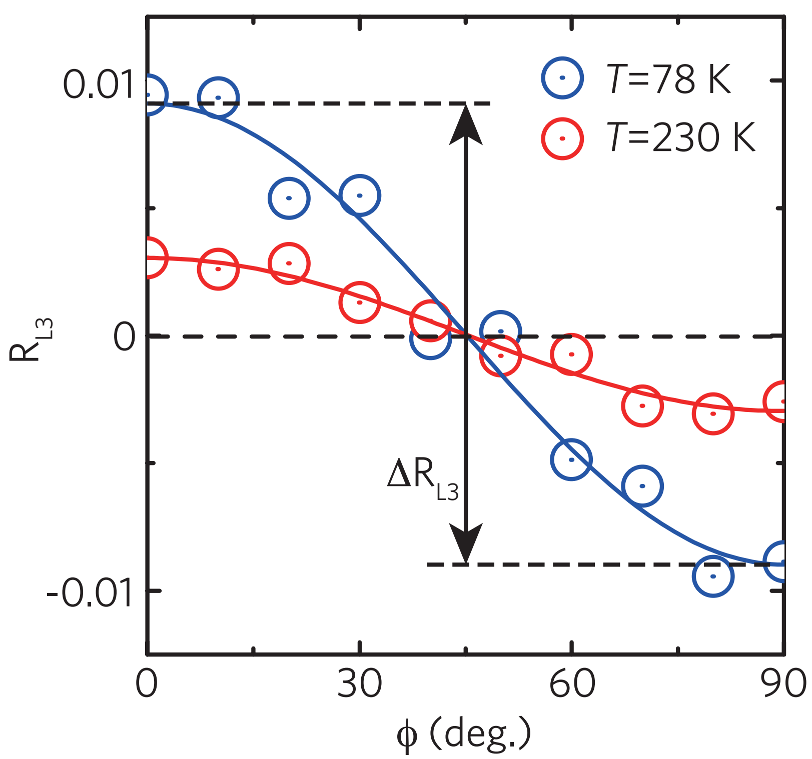


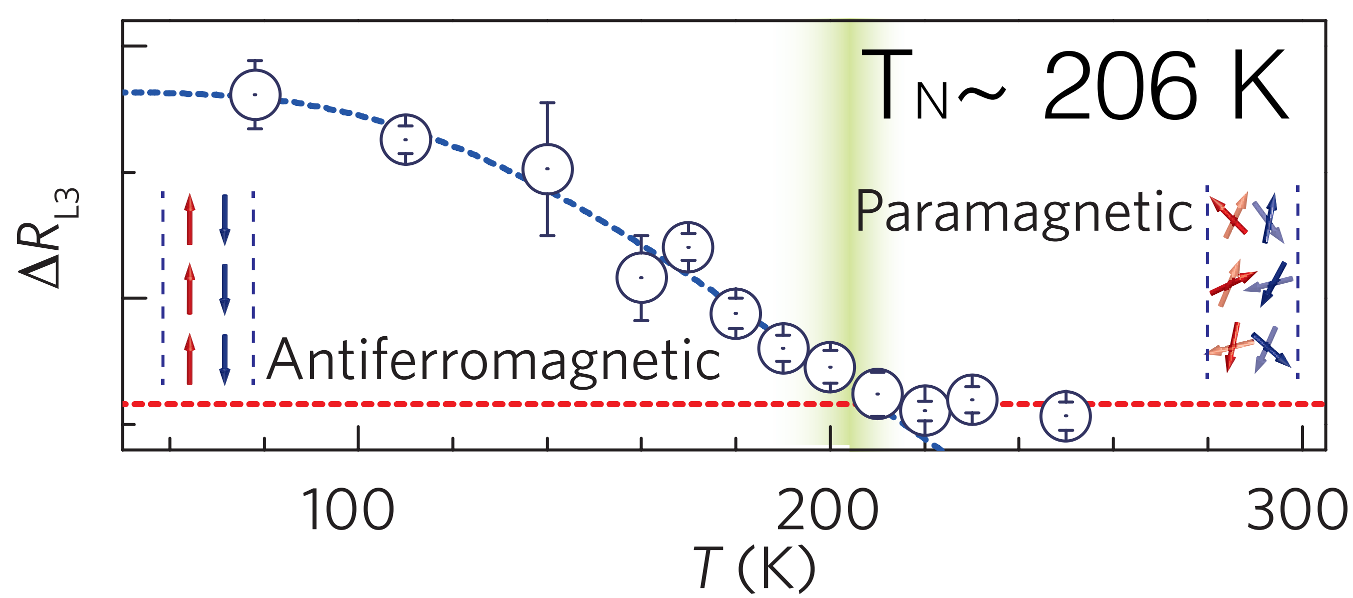
Zhiyong Qiu, J. Li, Dazhi Hou* et al., Nature Communications 7,12670 (2016)

XMLD result: YIG/ 6 nm CoO/Pt









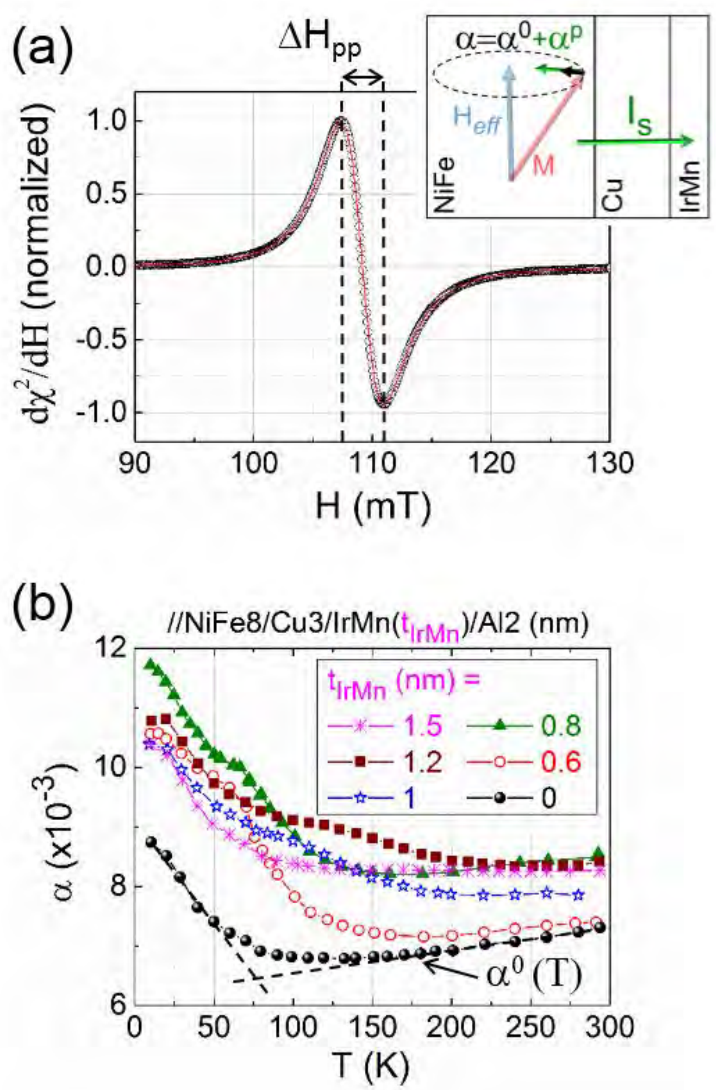
spin current as a probe of Neel temperature

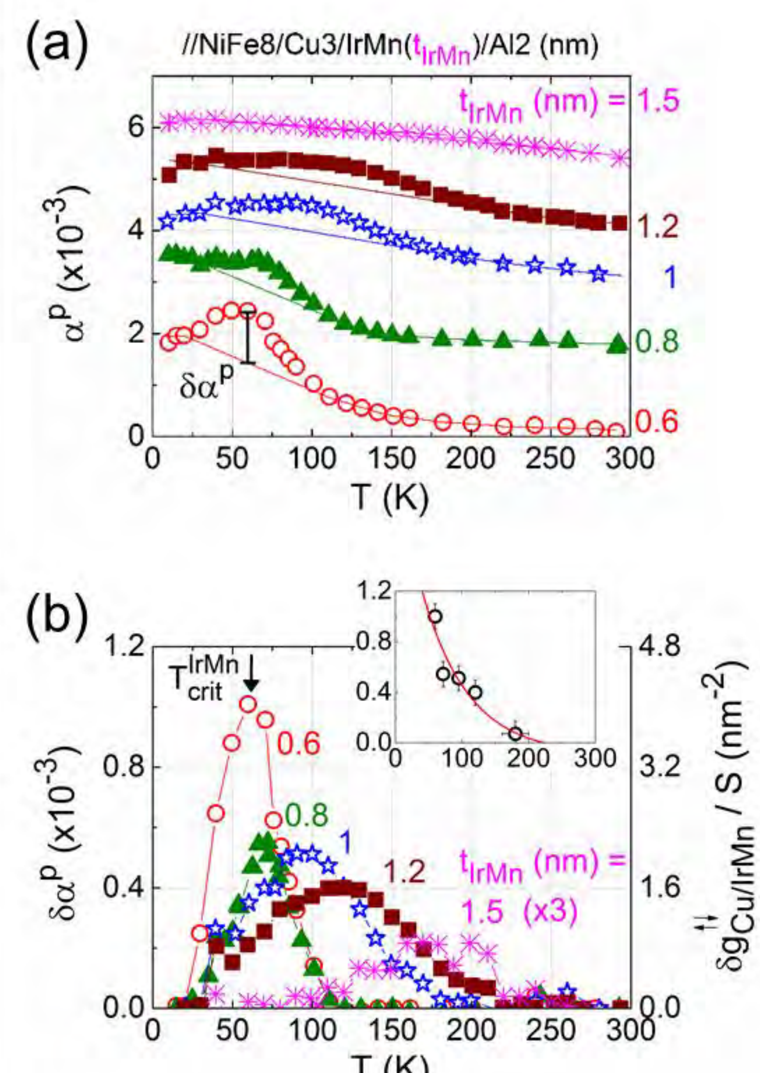
Enhanced spin pumping by antiferromagnetic IrMn thin films around the magnetic phase transition

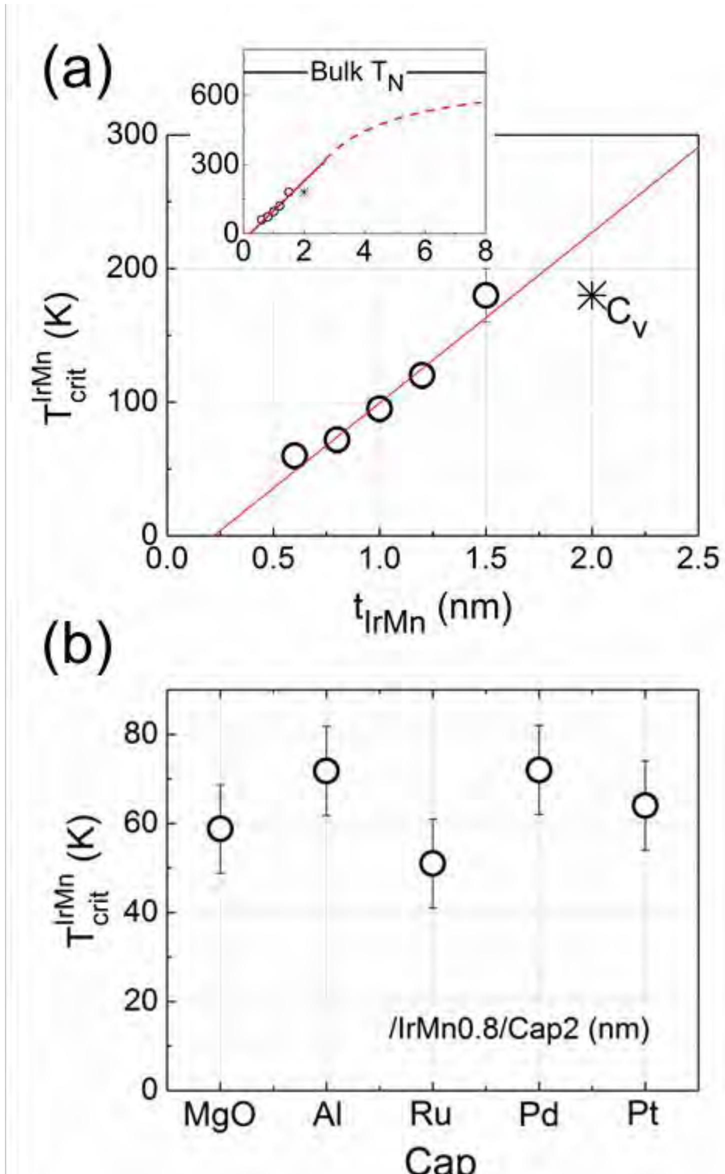
L. Frangou,[1,2,3] S. Oyarzun,[4,5] S. Auffret,[1,2,3] L. Vila,[4,5] S. Gambarelli,[6,7] and V. Baltz[1,2,3,*]

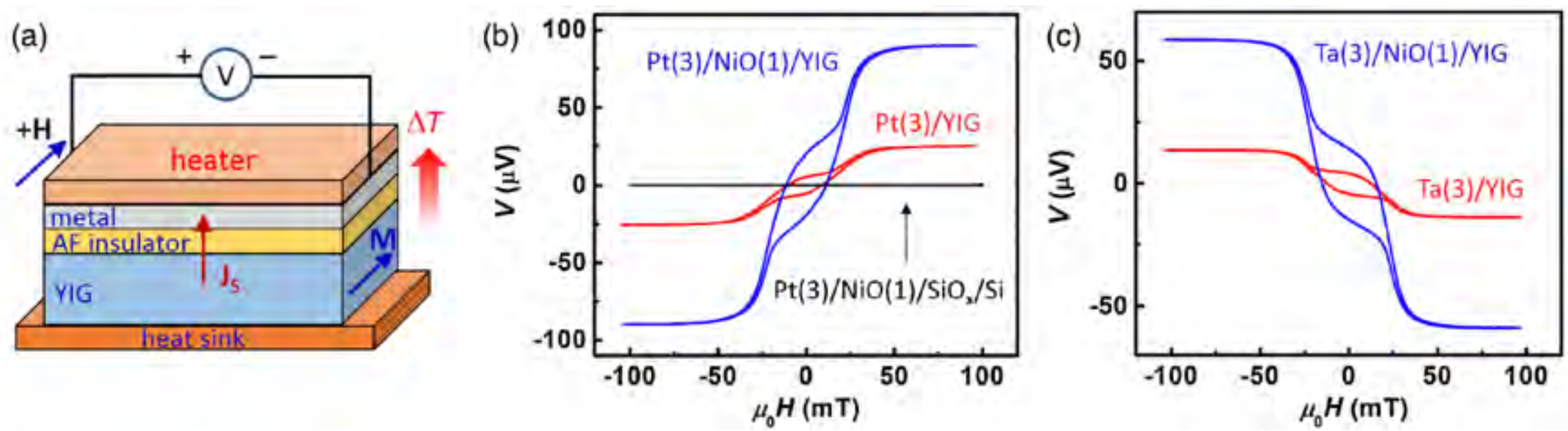
[1] *Univ. Grenoble Alpes, SPINTEC, F-38000 Grenoble, France*
[2] *CNRS, SPINTEC, F-38000 Grenoble, France*
[3] *CEA, INAC-SPINTEC, F-38000 Grenoble, France*
[4] *Univ. Grenoble Alpes, NM, F-38000 Grenoble, France*
[5] *CEA, INAC-NM, F-38000 Grenoble, France*
[6] *Univ. Grenoble Alpes, SCIB, F-38000 Grenoble, France*
[7] *CEA, INAC-SCIB, F-38000 Grenoble, France*
[*] *To whom correspondence should be addressed: vincent.baltz@cea.fr*

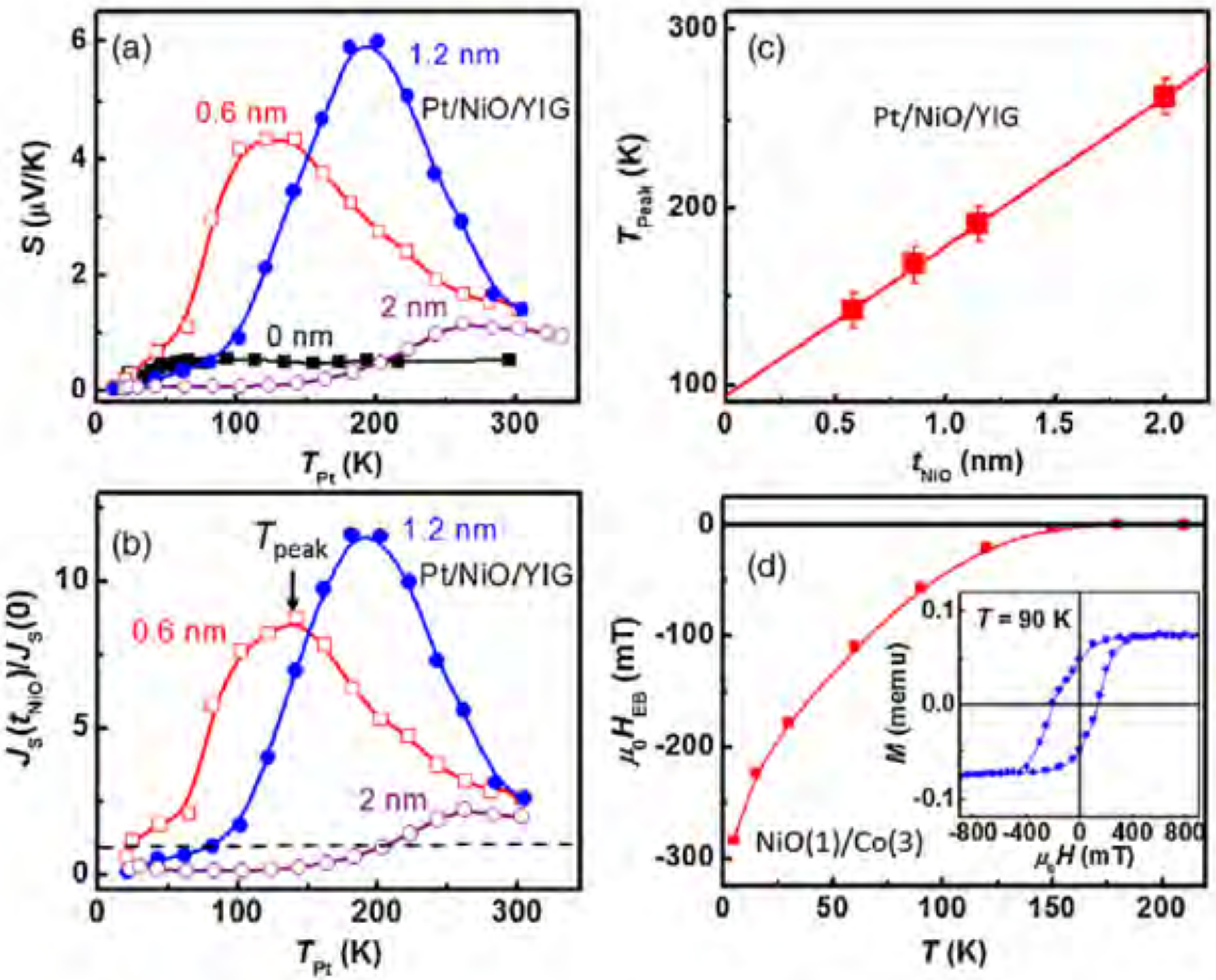
[v1] Fri, 11 Sep 2015
appears on PRL







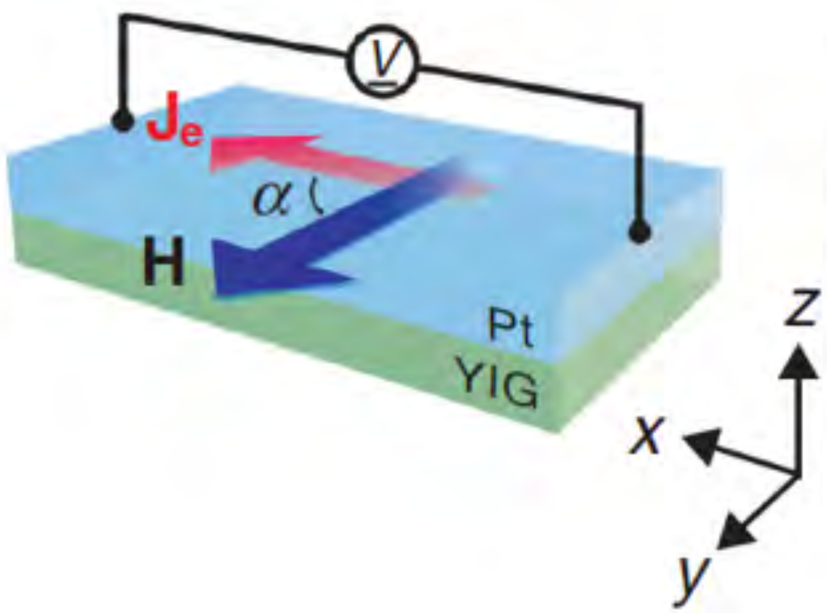


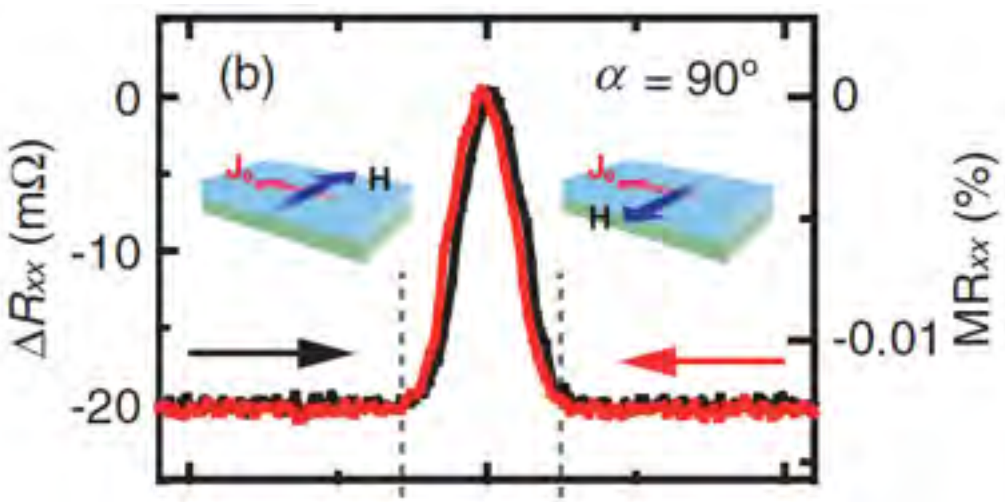


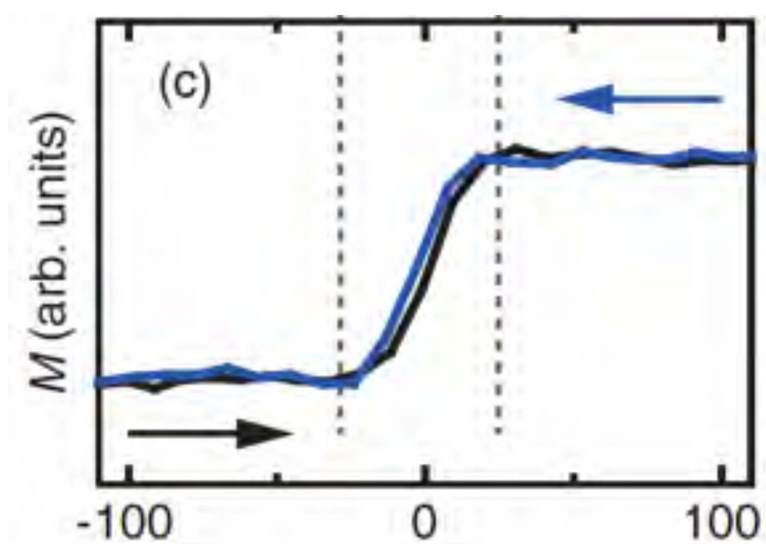
W Lin, K Chen, S Zhang, CL Chien Physical Review Letters 116 (18), 186601 (2016)

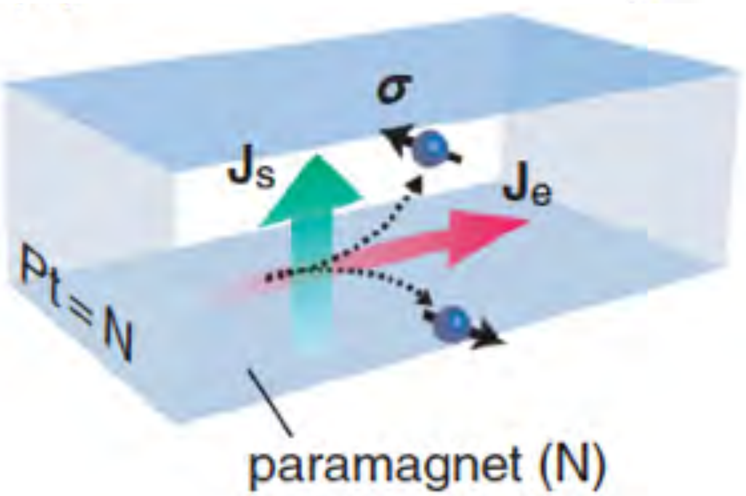
	spin pumping	spin Seebeck	SMR
Pt/YIG	○	○	○
Pt/AFM/YIG	○	○	

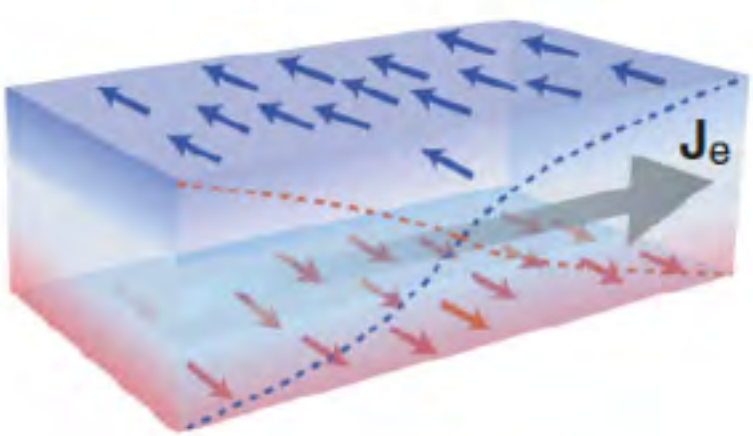
Spin Hall magnetoresistance (SMR)
in metal/Ferromagnetic insulator



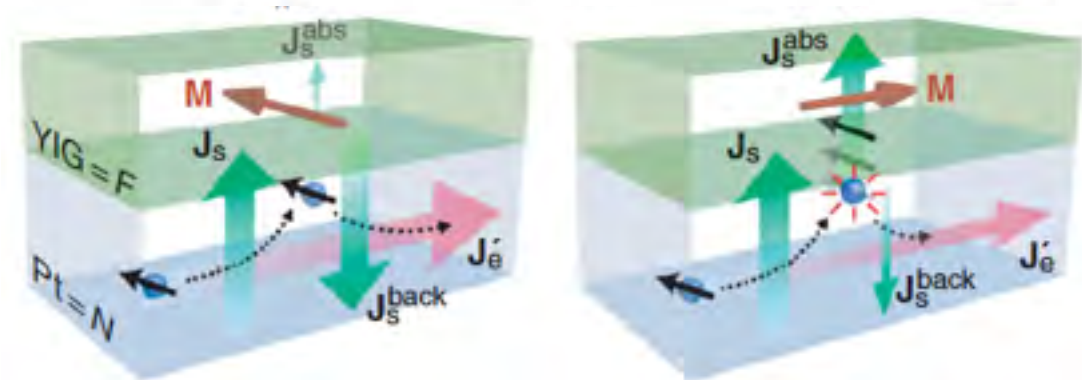








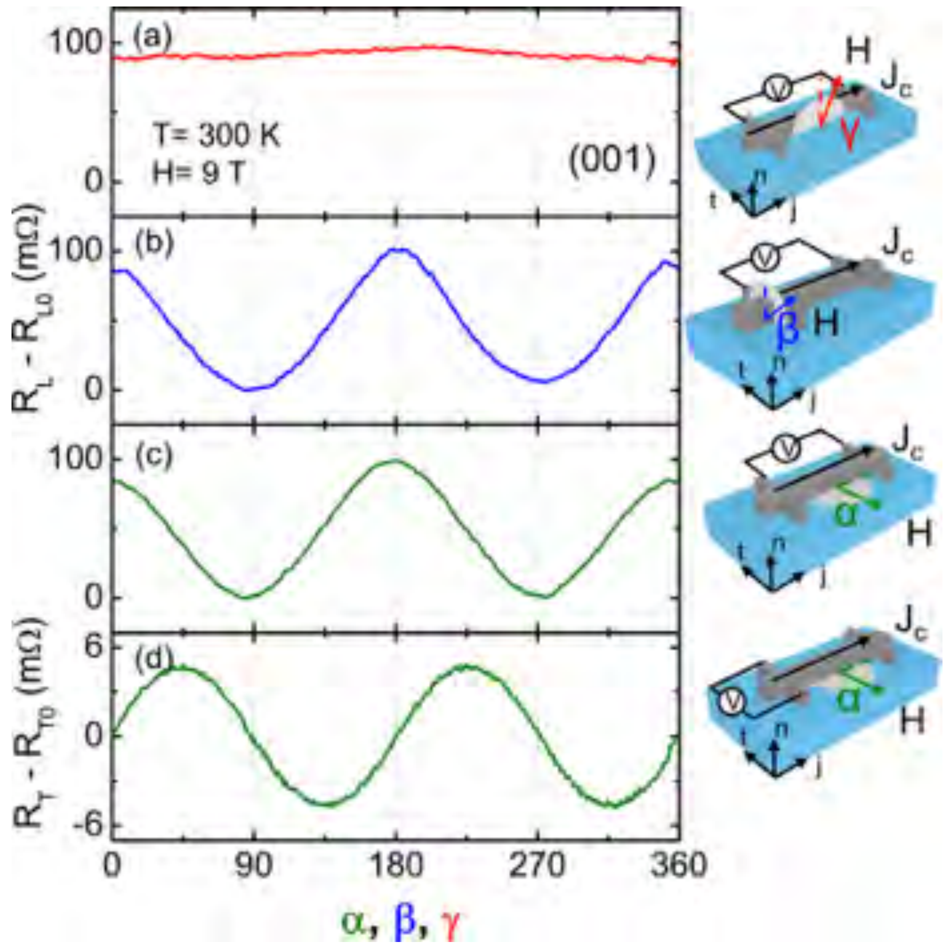
$$\vec{\tau}_{\mathrm{STT}} = -\frac{\hbar}{2e}\hat{m} \times \left(\hat{m} \times \vec{j}_s^{\,(\mathrm{F})}\right) = \frac{\hbar}{2e}\vec{j}_s^{\,(\mathrm{F})}$$



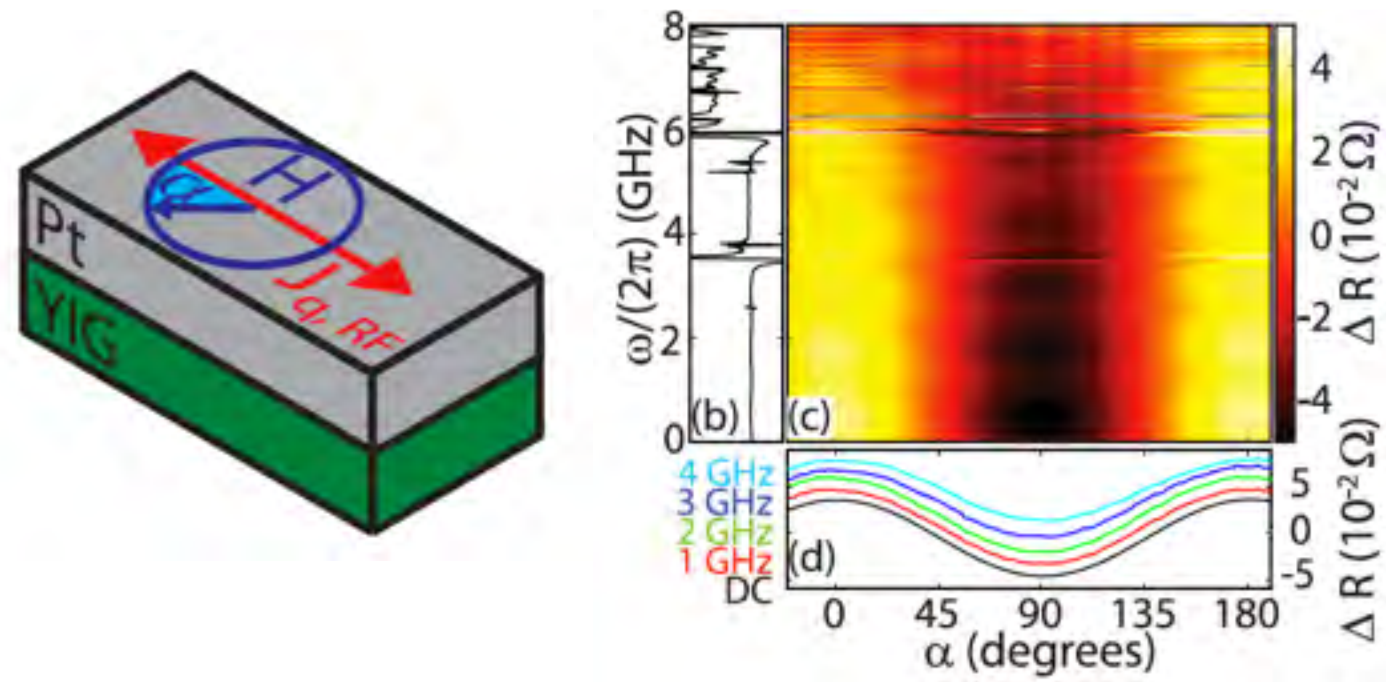
$$\rho_{||} > \rho_{\perp}$$

H. Nakayama et al., PRL 110, 206601 (2013)
Yan-Ting Chen et al., PRB 87, 144411 (2013)

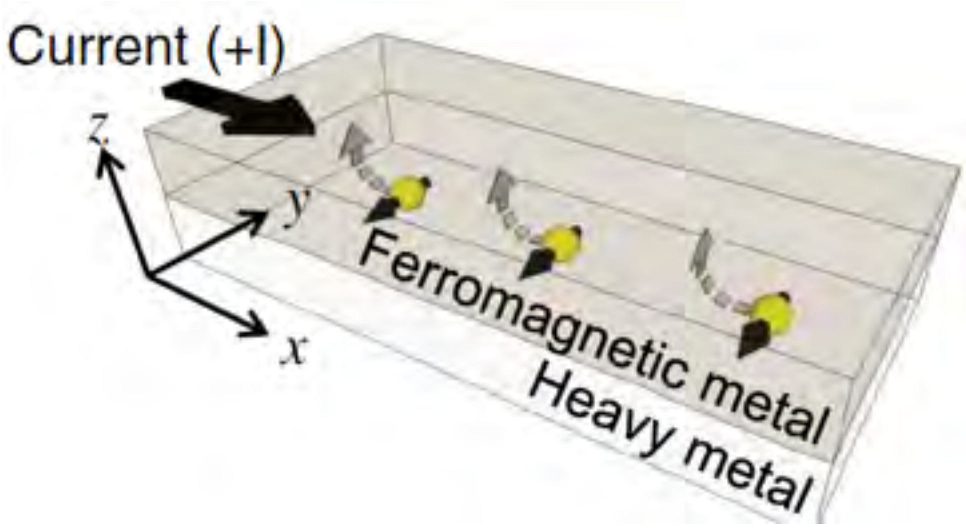
positive SMR in many systems…

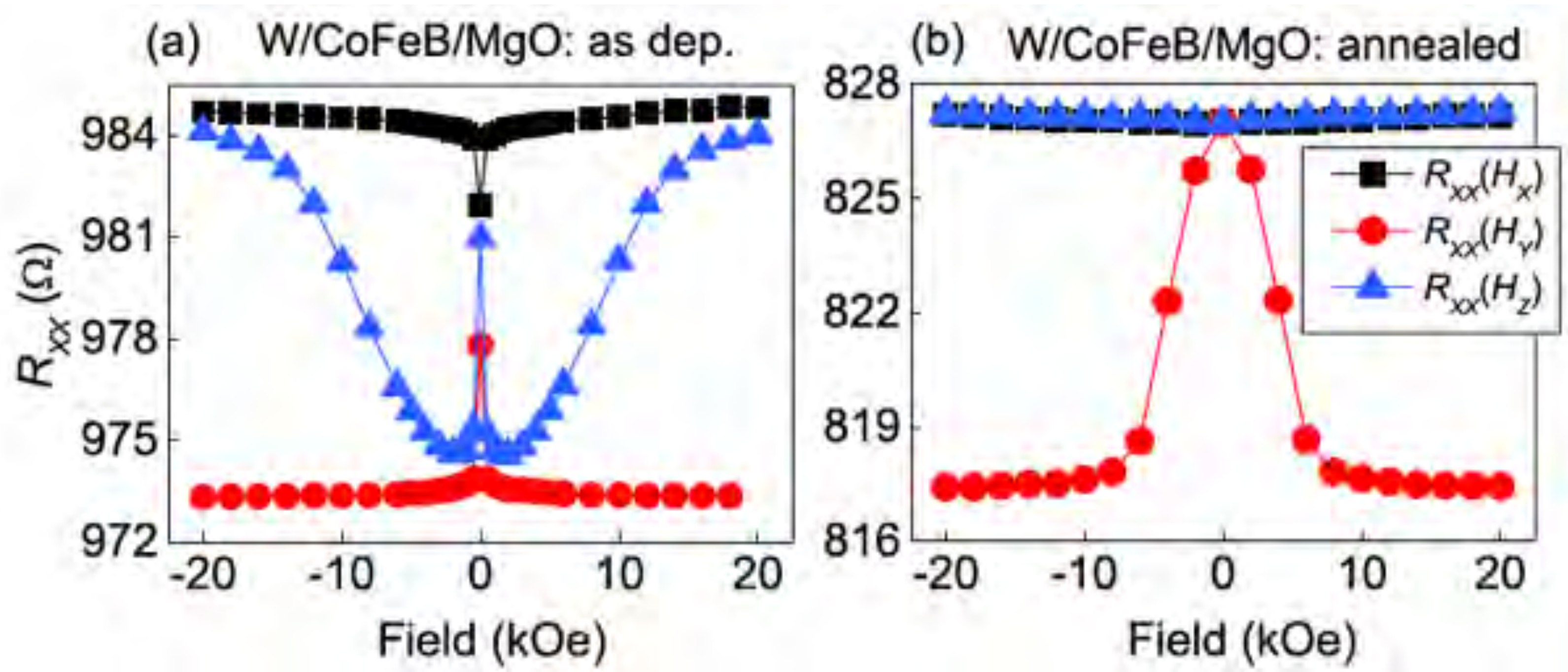


Isasa et al. APL 105, 142402 (2014)



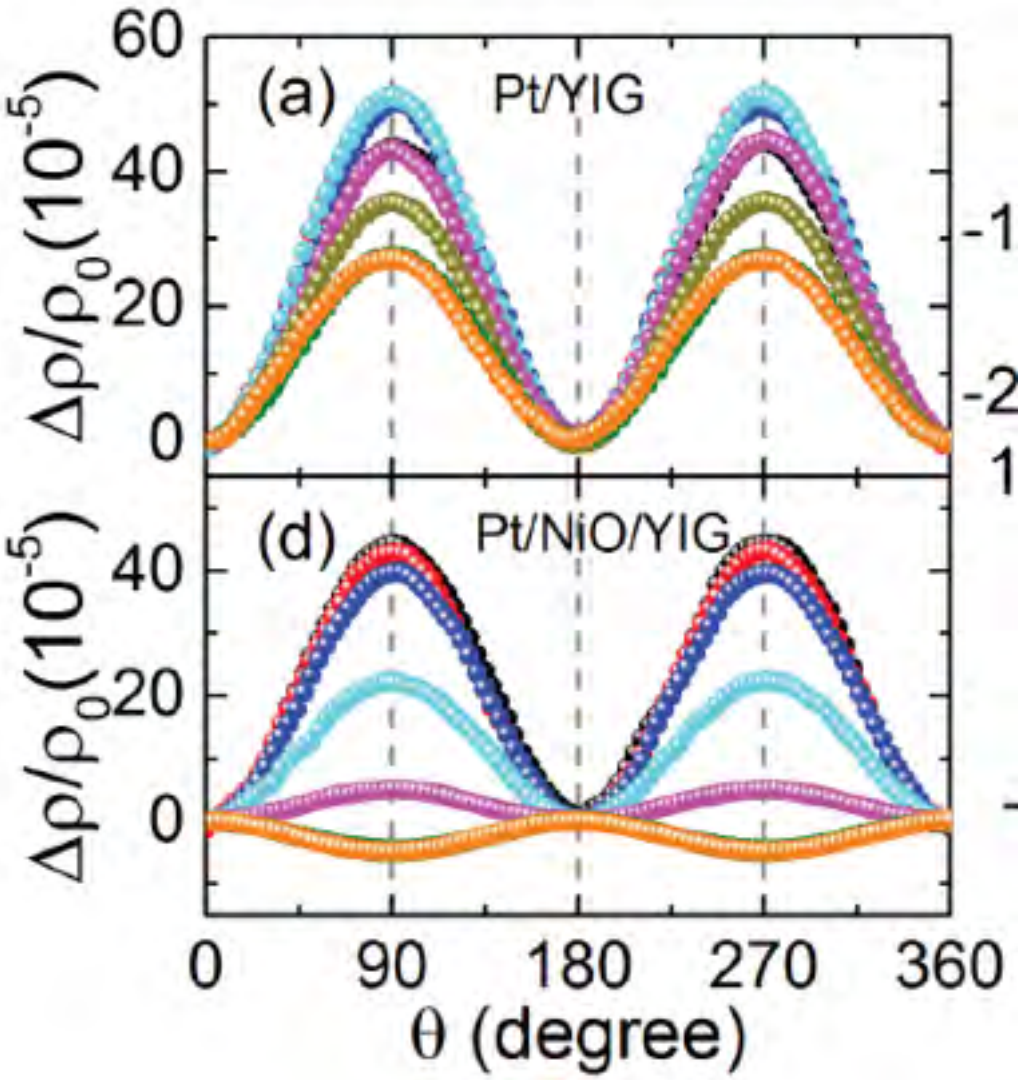
Johannes Lotze et al., PRB 90, 174419 (2014)

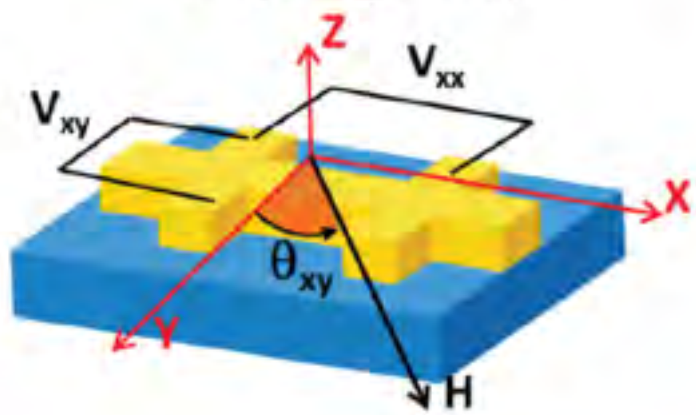


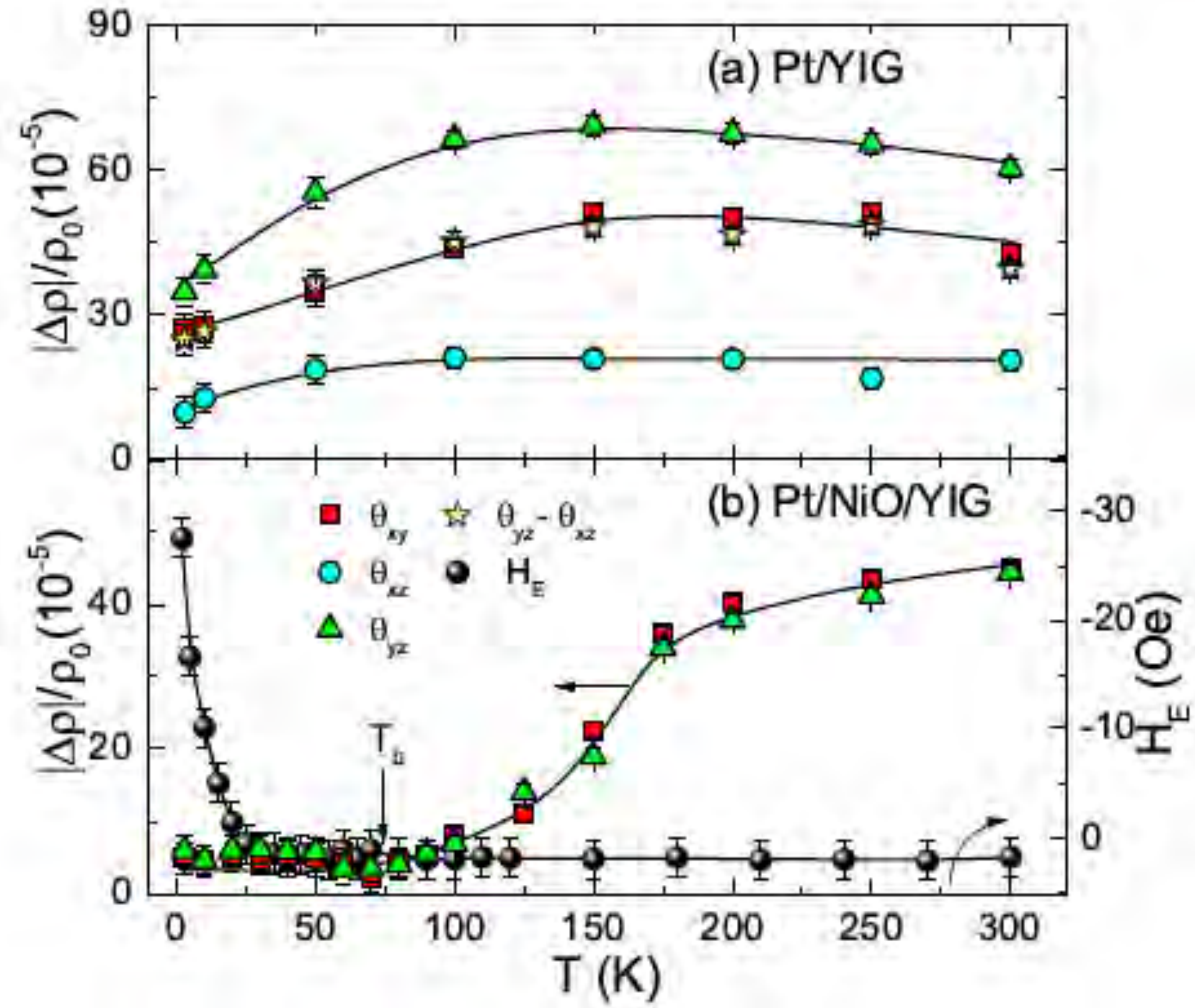


Junyeon Kim et al., PRL 116, 097201 (2016)

..so far so good, but…





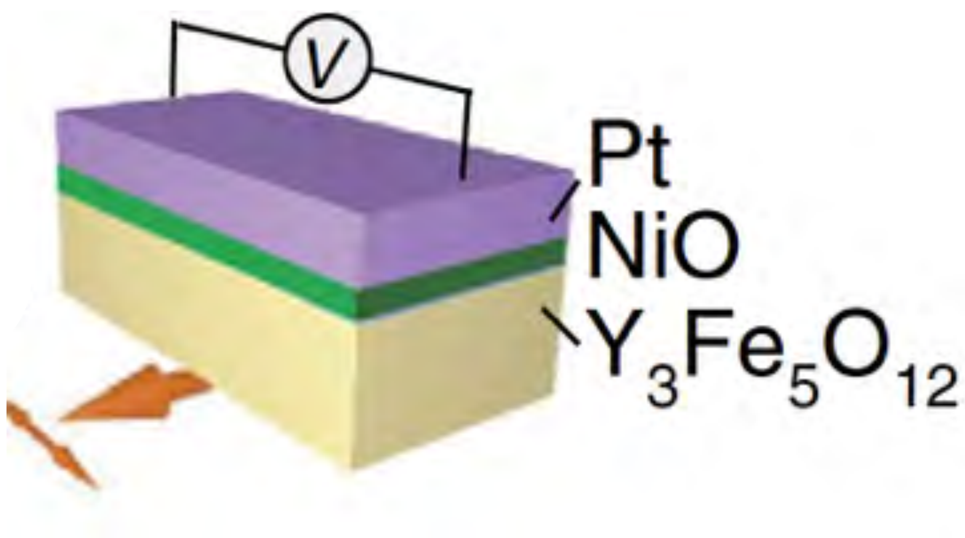


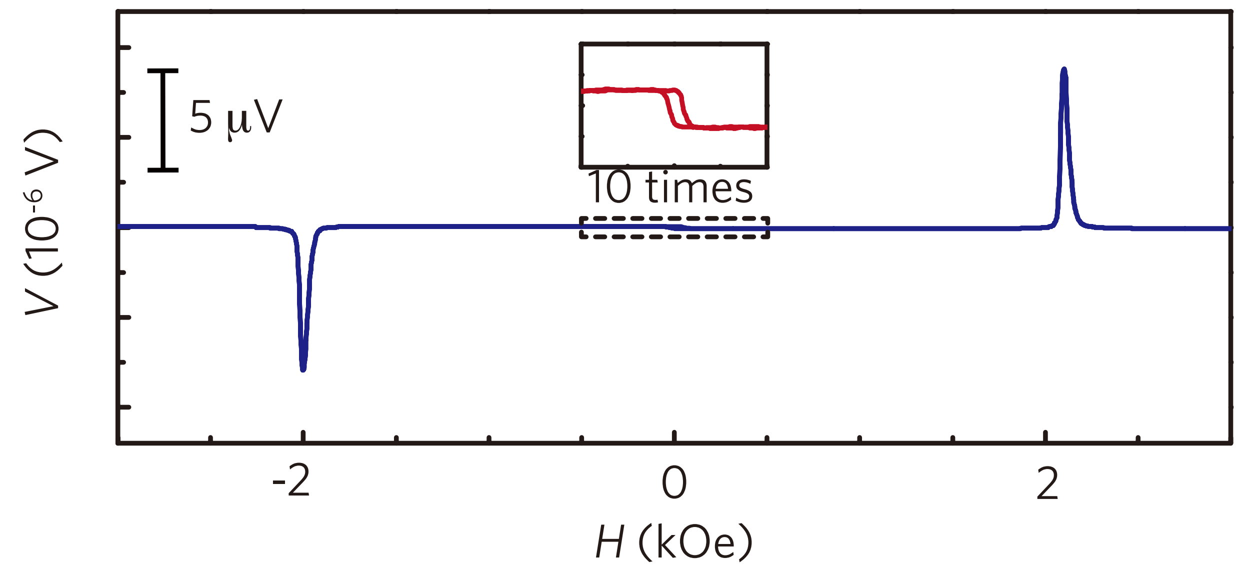
why the SMR sign change?

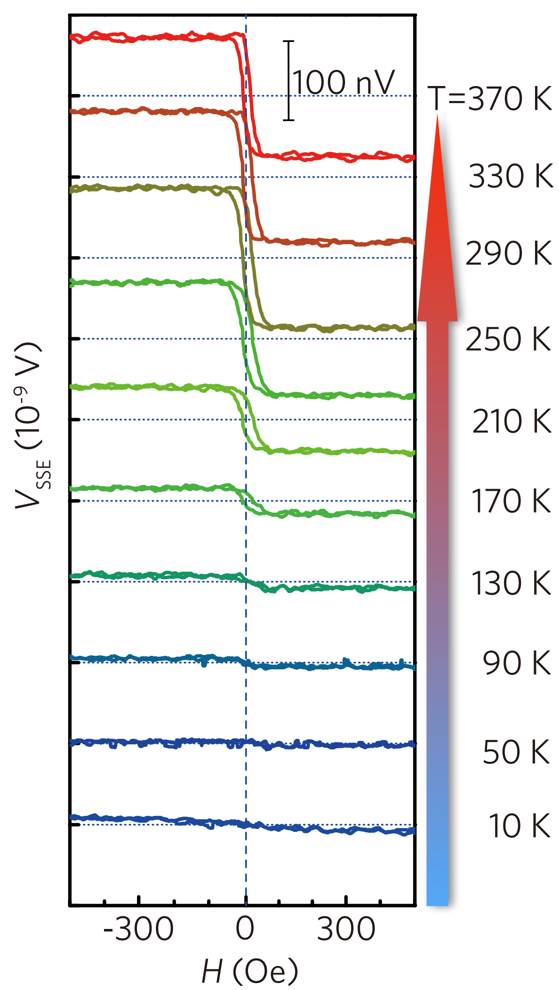
$$\frac{\Delta\rho_1}{\rho} = \theta_{\rm SH}^2 \frac{\lambda}{d_N} \,{\rm Re}\, \frac{2\lambda G_{\uparrow\downarrow} \tanh^2 \frac{d_N}{2\lambda}}{\sigma + 2\lambda G_{\uparrow\downarrow} \coth \frac{d_N}{\lambda}}$$

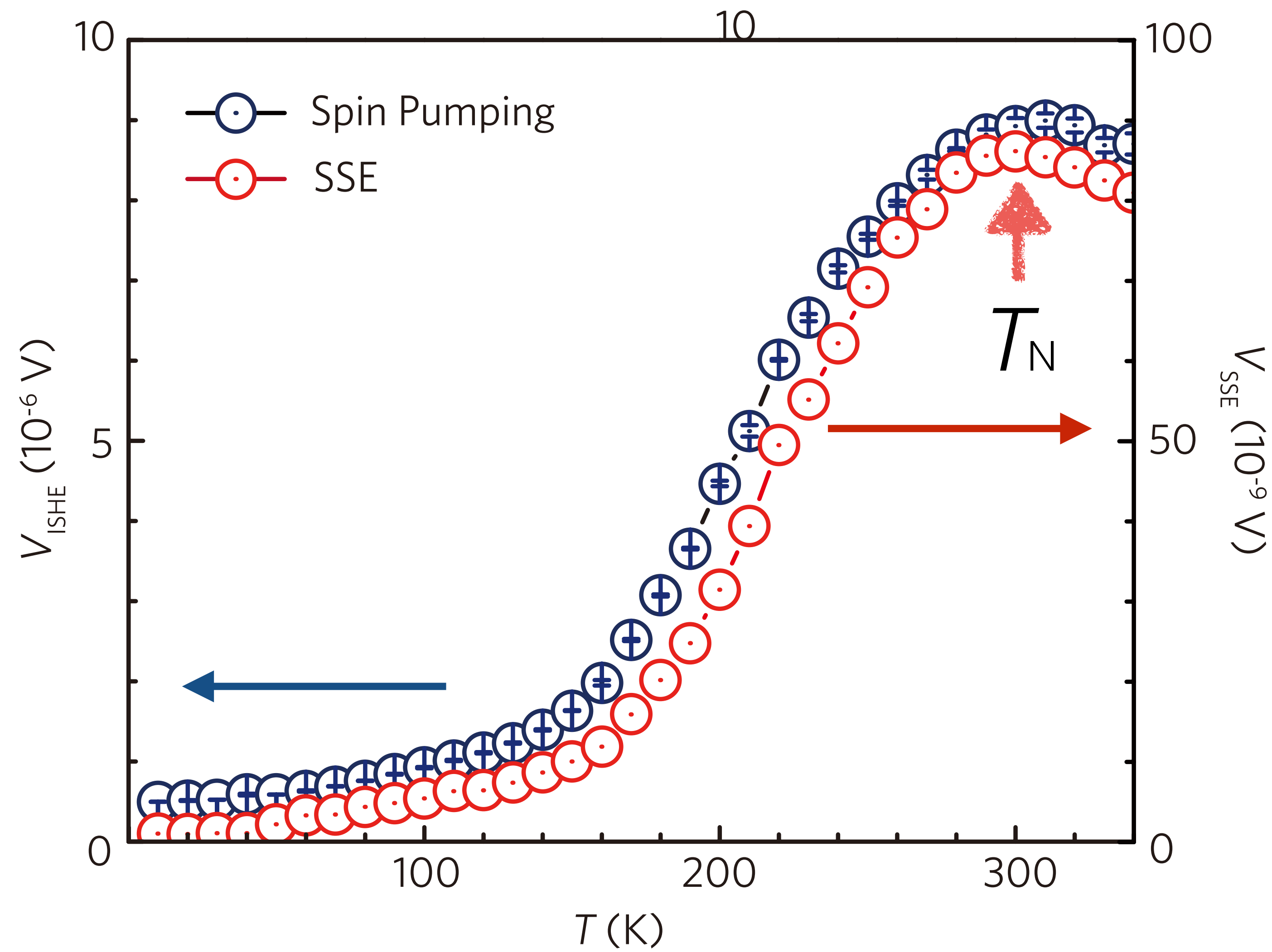
T. Shang et al., APL 109, 032410 (2016).

spin Seebeck/pumping effect YIG/NiO/Pt



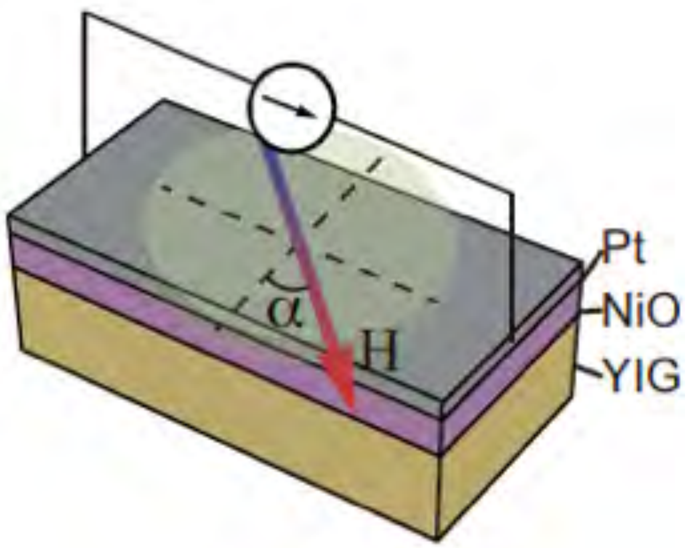


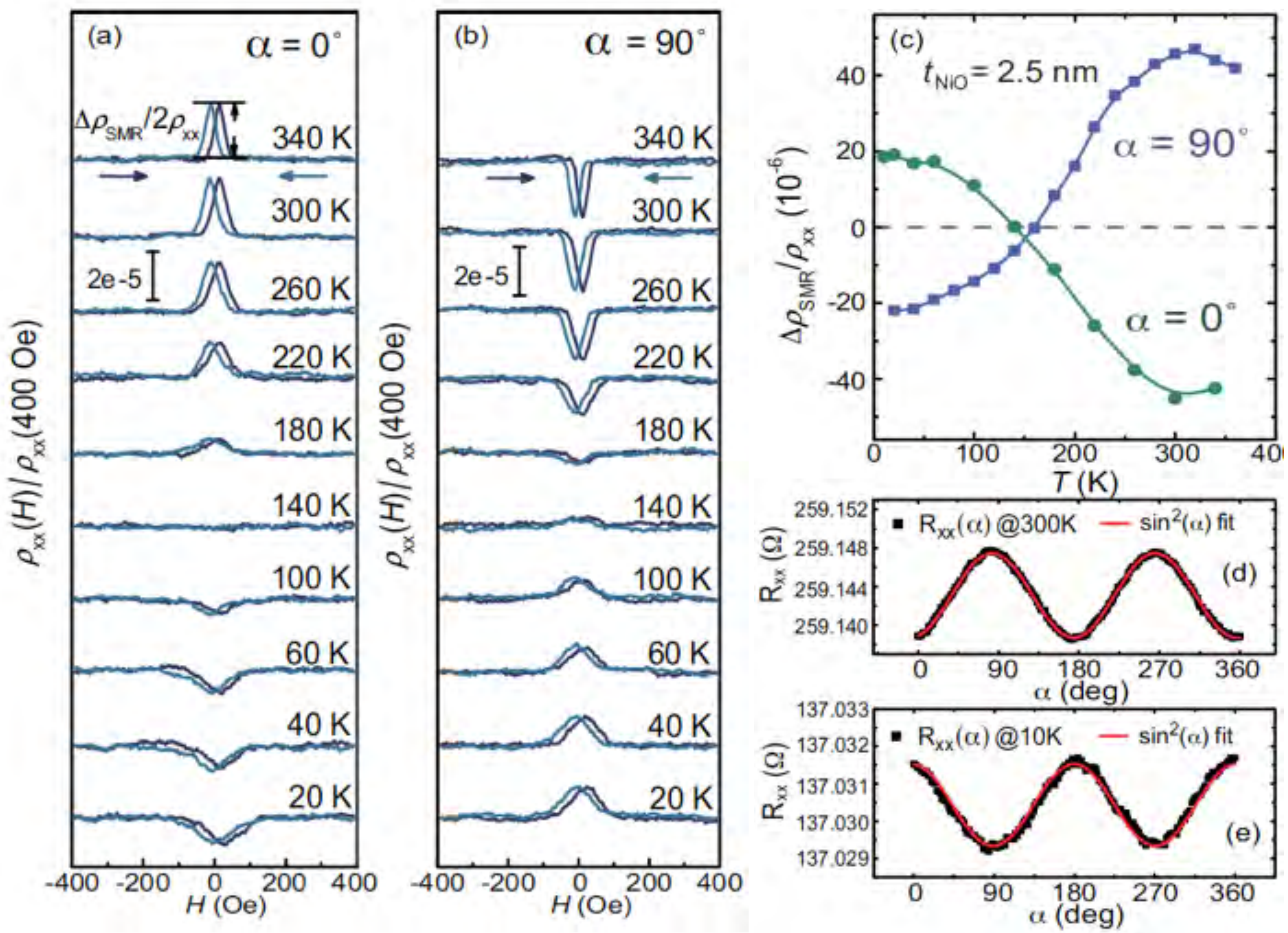




Zhiyong Qiu, J. Li, Dazhi Hou* et al., Nature Communications 7,12670 (2016)

SMR in our Pt/NiO/YIG



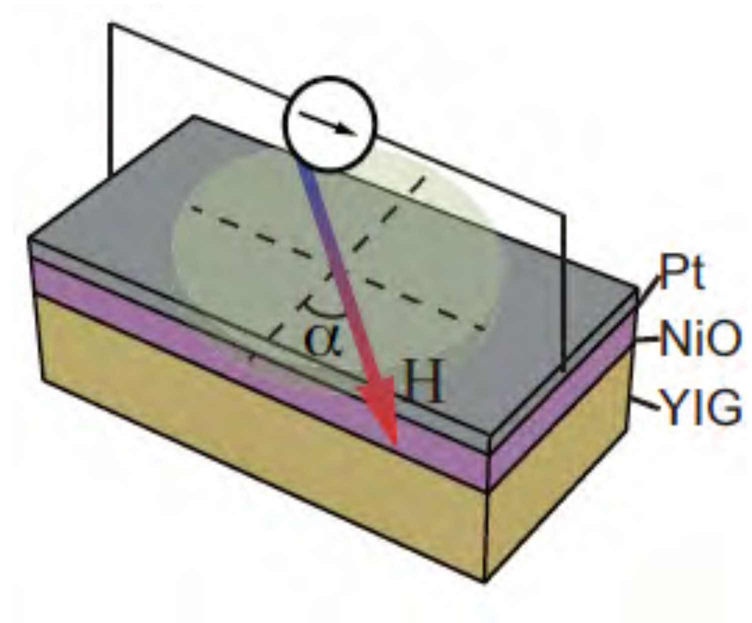


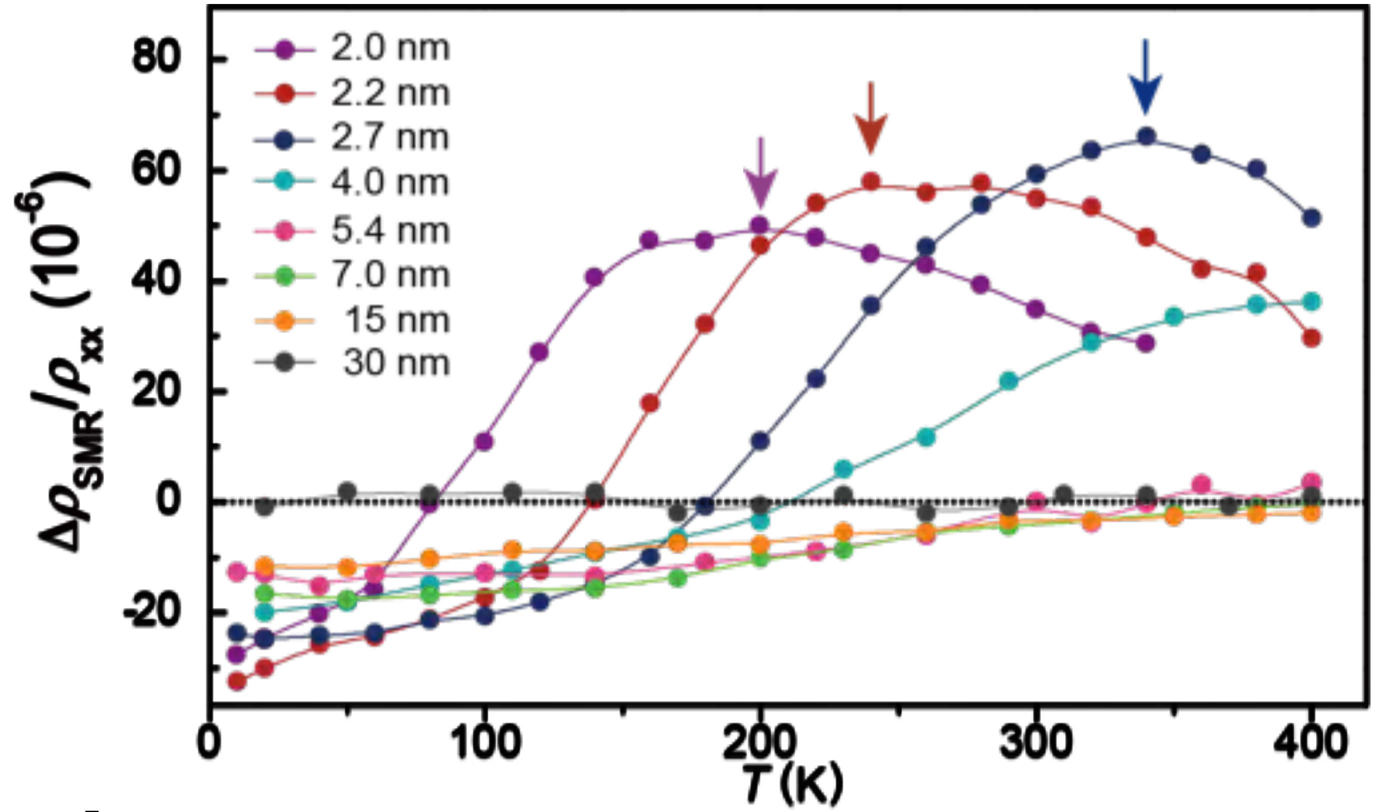
Negative SMR in Pt/NiO/YIG is a fact!

$$\frac{\Delta\rho_1}{\rho} = \theta_{SH}^2 \frac{\lambda}{d_N} \mathrm{Re} \frac{2\lambda G_{\uparrow\downarrow} \tanh^2 \frac{d_N}{2\lambda}}{\sigma + 2\lambda G_{\uparrow\downarrow} \coth \frac{d_N}{\lambda}}$$

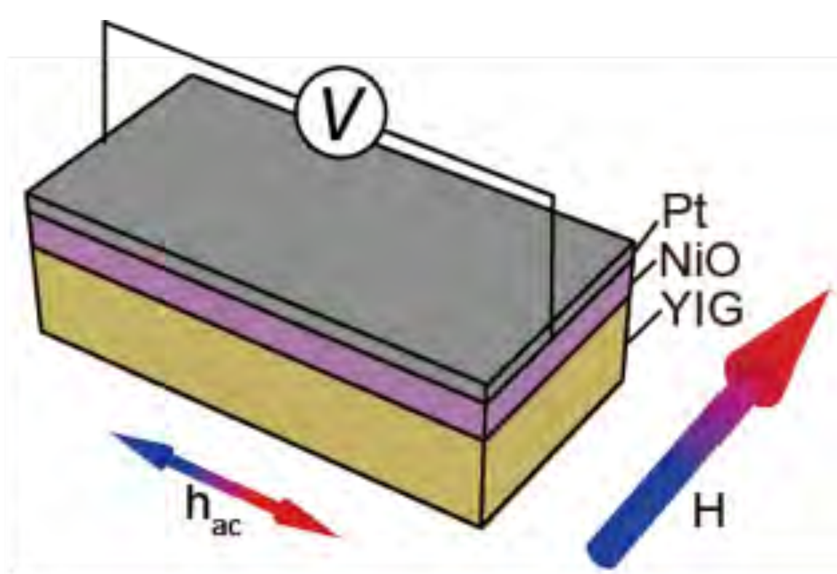
does not explain

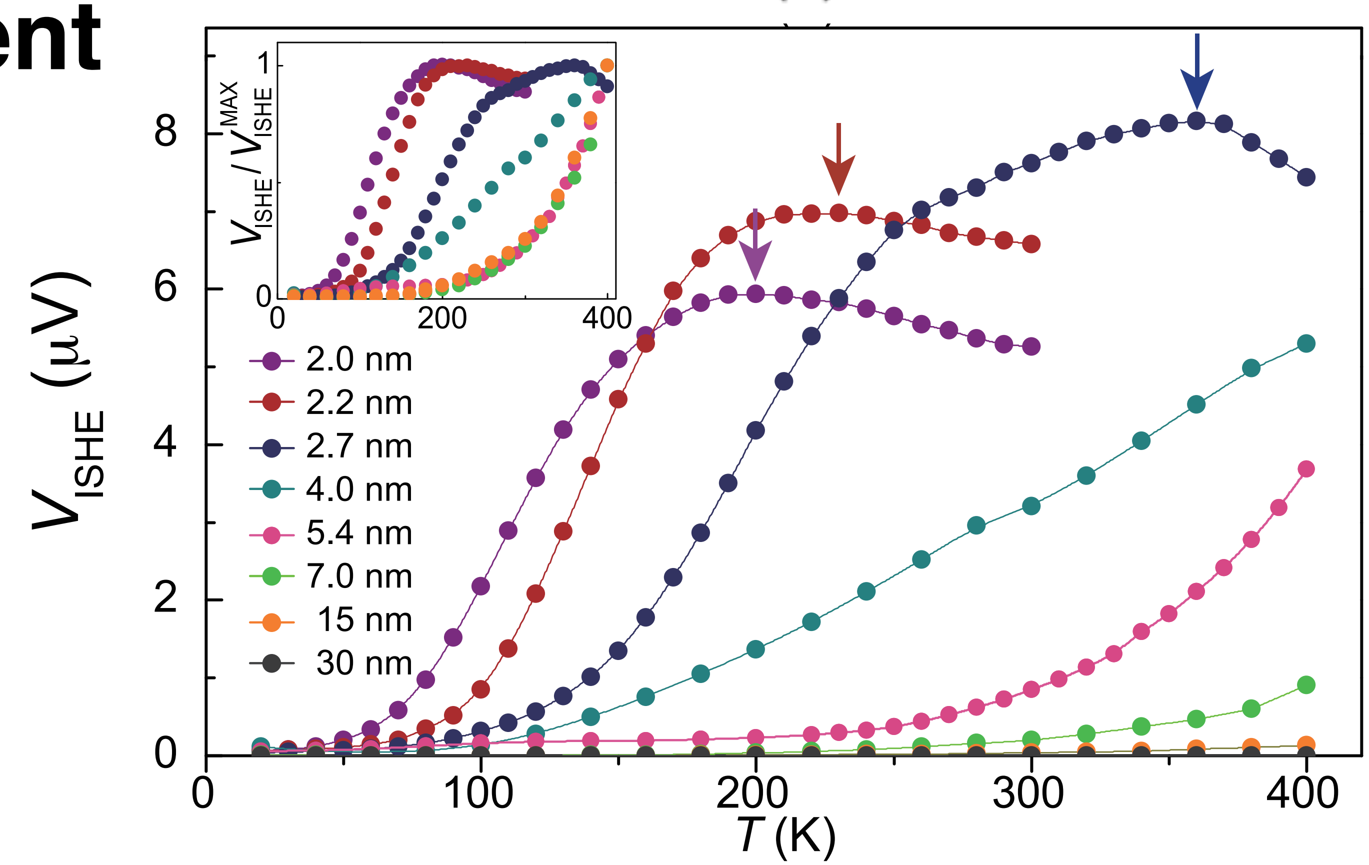
SMR measurement





spin pumping measurement



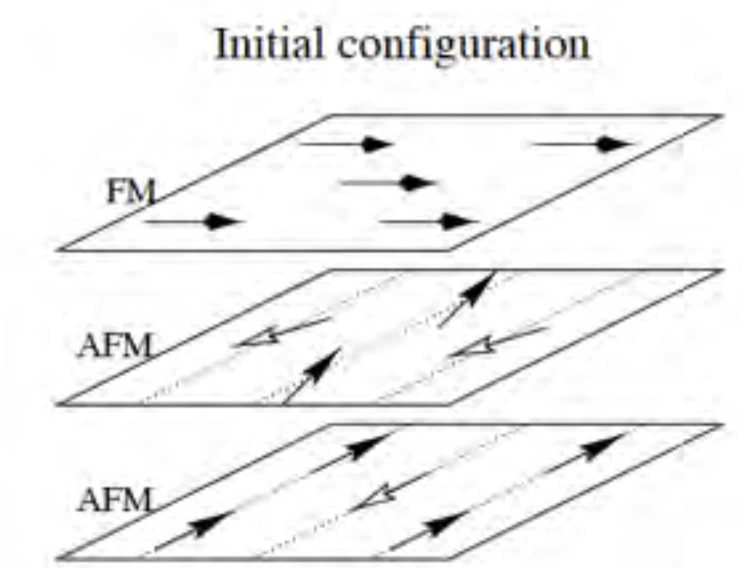


- SMR sign change point depends on NiO thickness
- negative SMR persists when spin current blocked by NiO

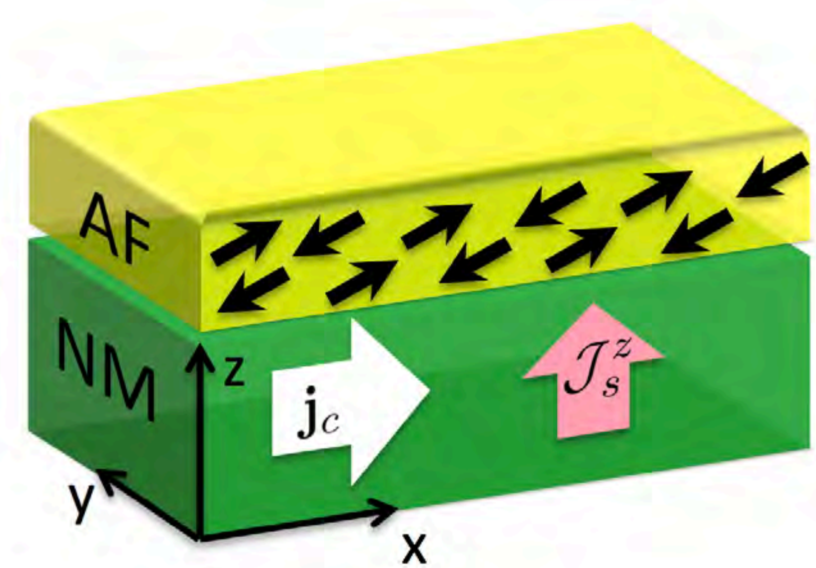
We need a scenario in which NiO dominates SMR at low T!

spin-flop coupling between NiO and FM

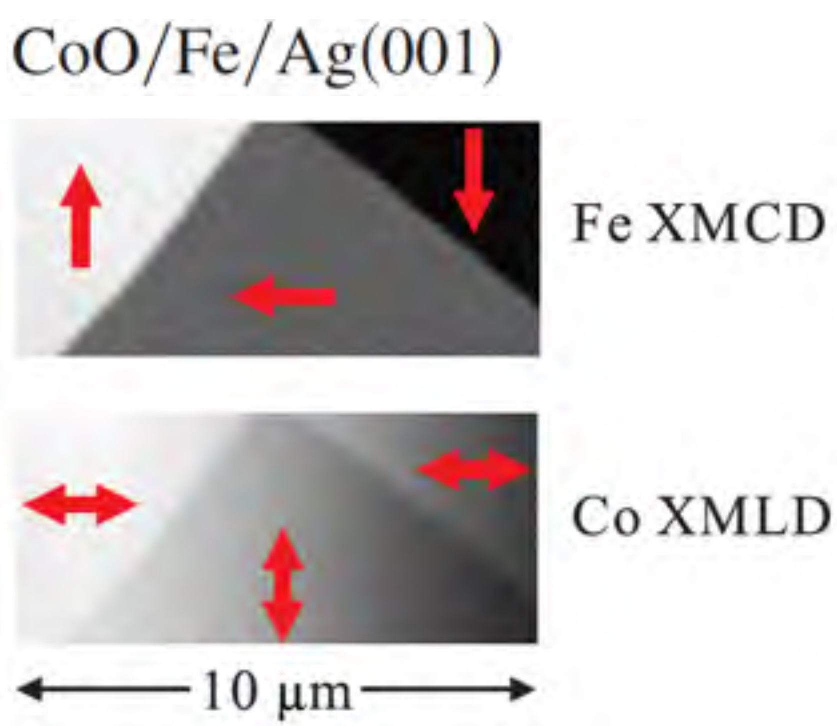
AFM SMR



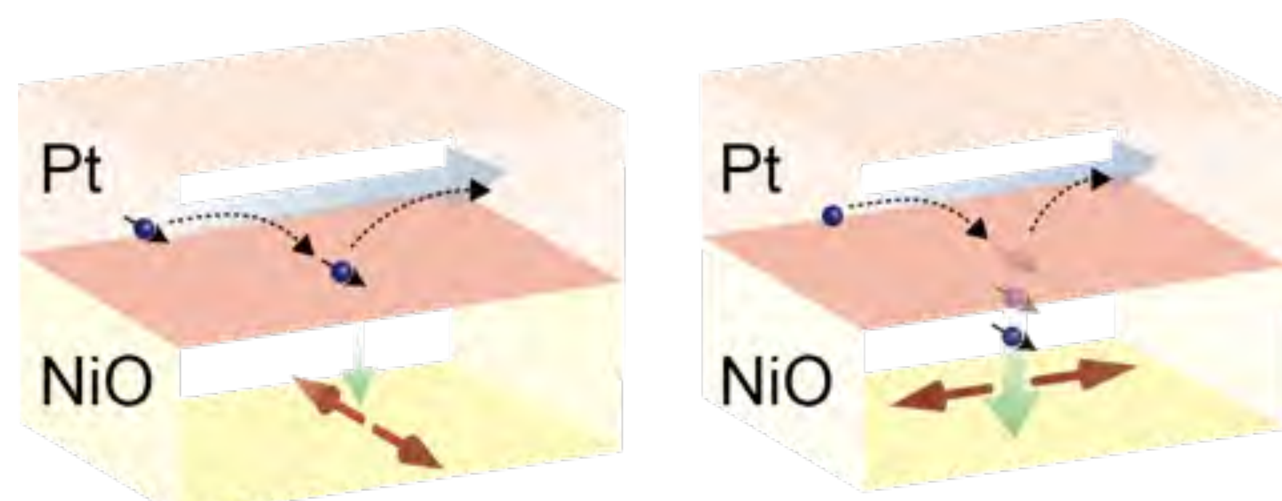
T. C. Schulthess,W. H. Butler, PRL, 81, 20 (1998)



Aurelien Manchon, arXiv:1609.06521v1

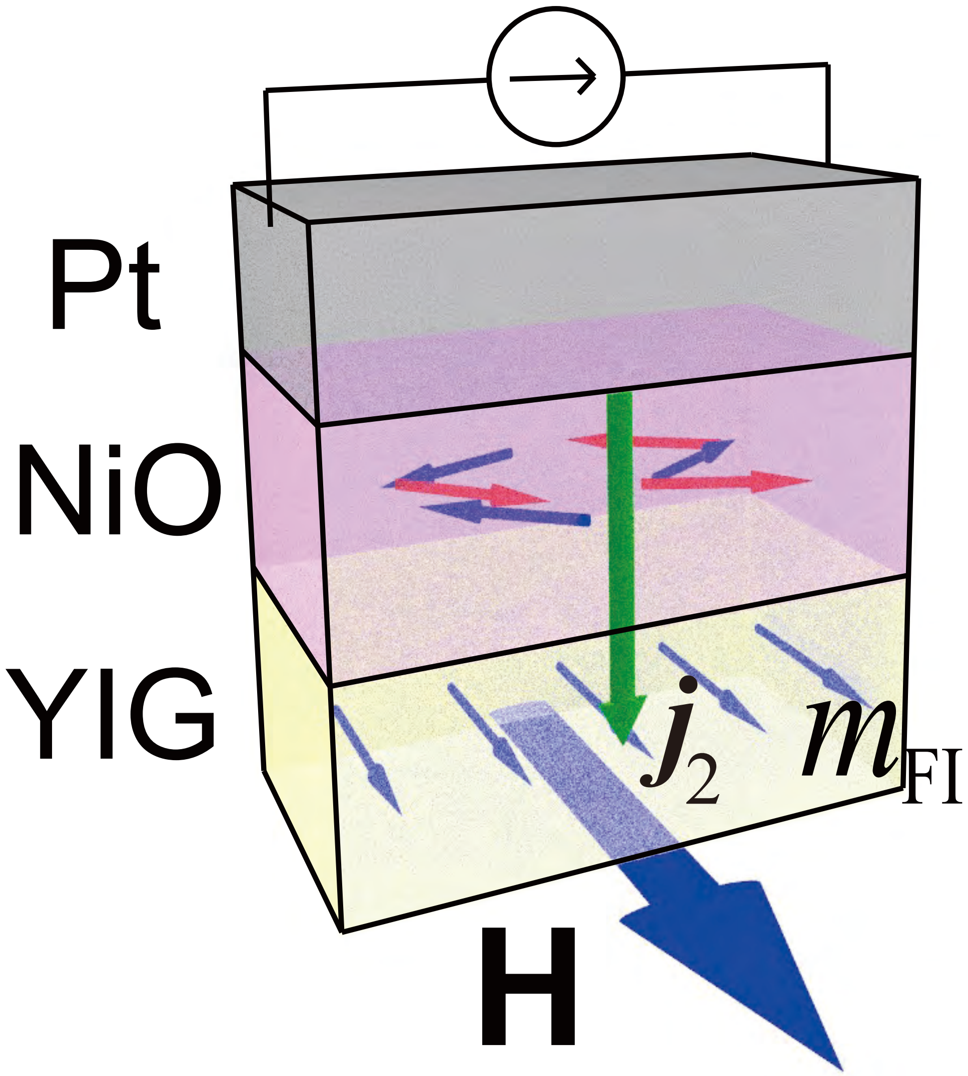


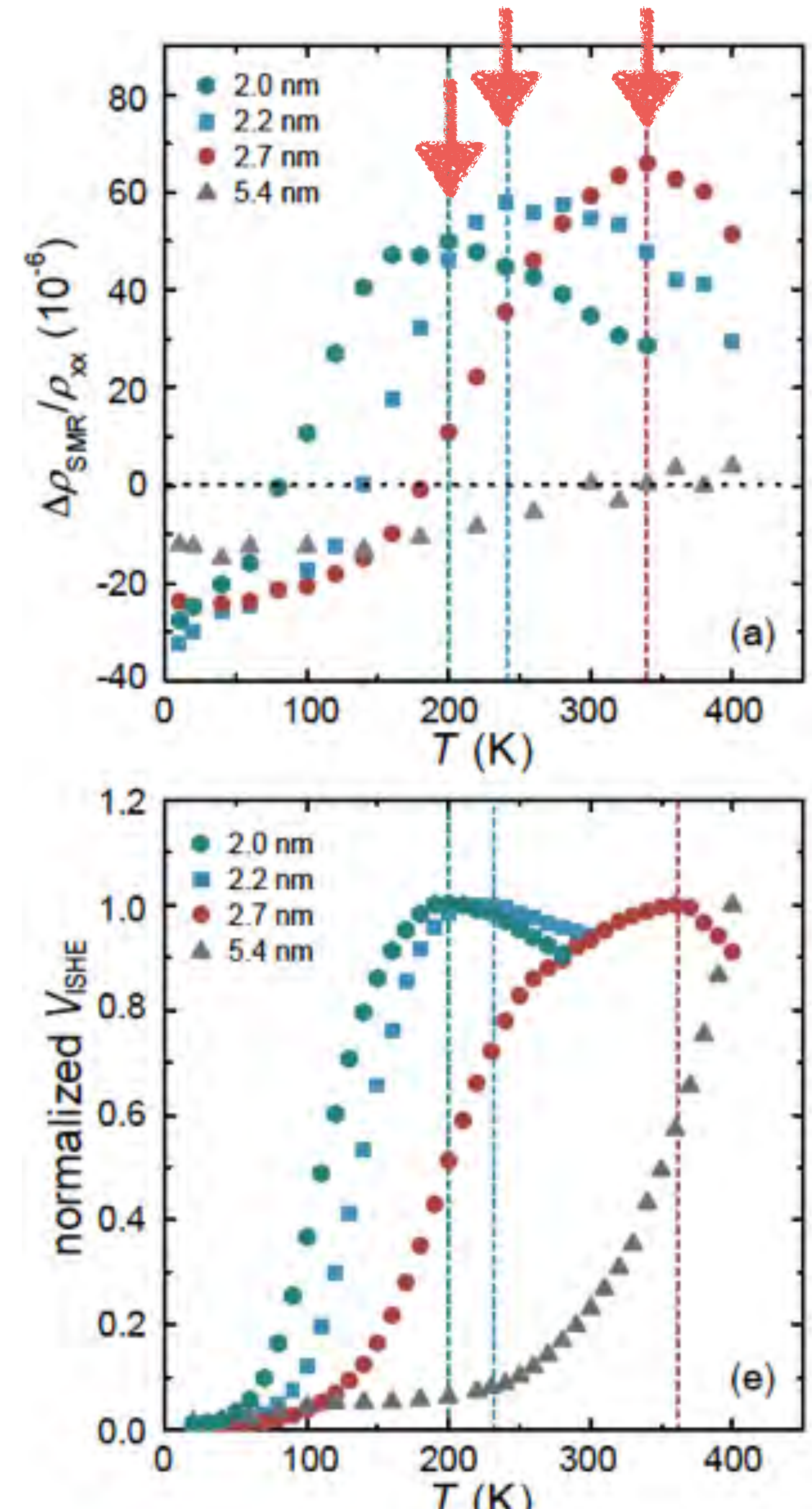
J. Wu et al., PRL 104, 217204 (2010)



SMR peak point

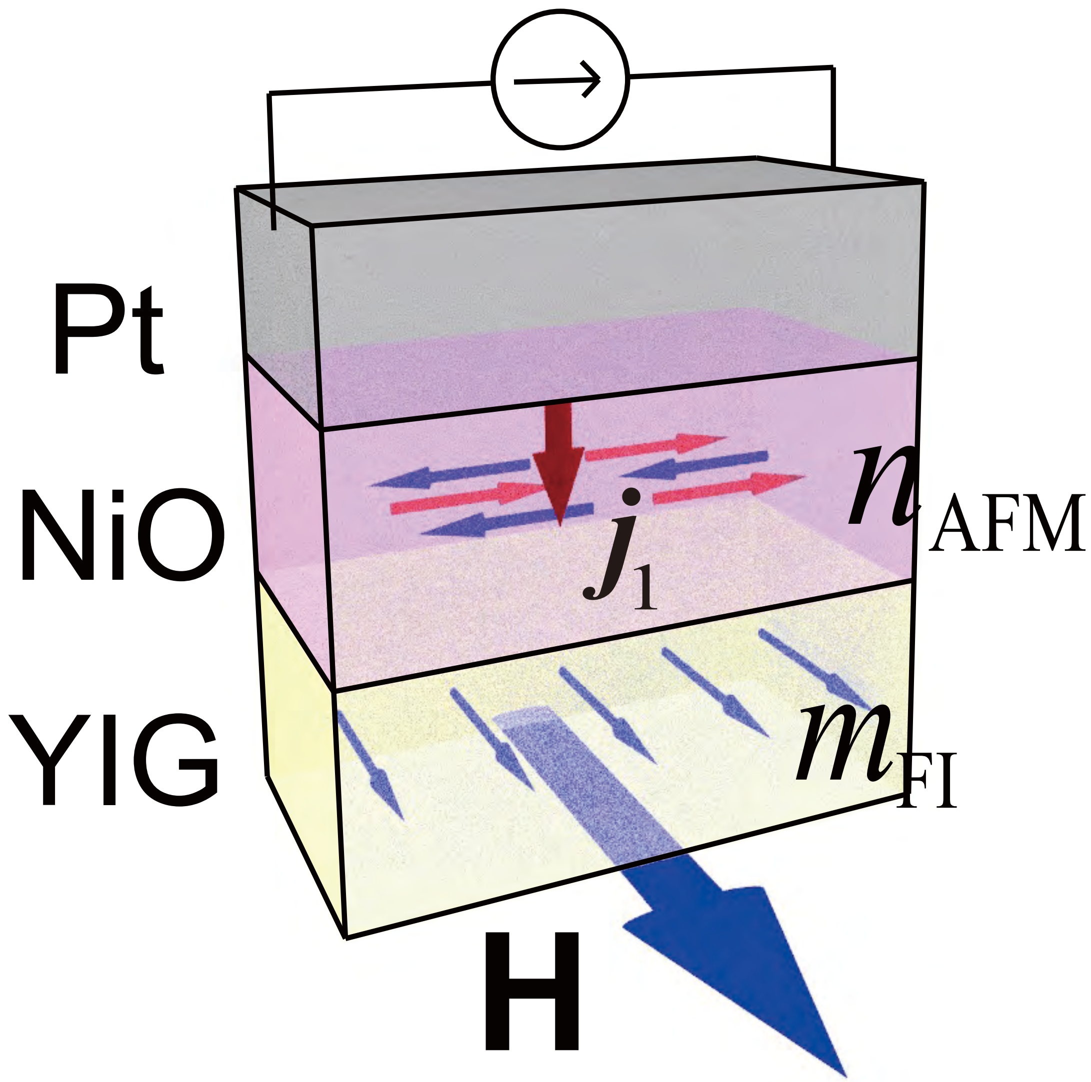
Neel point of NiO, spin transmission maximised

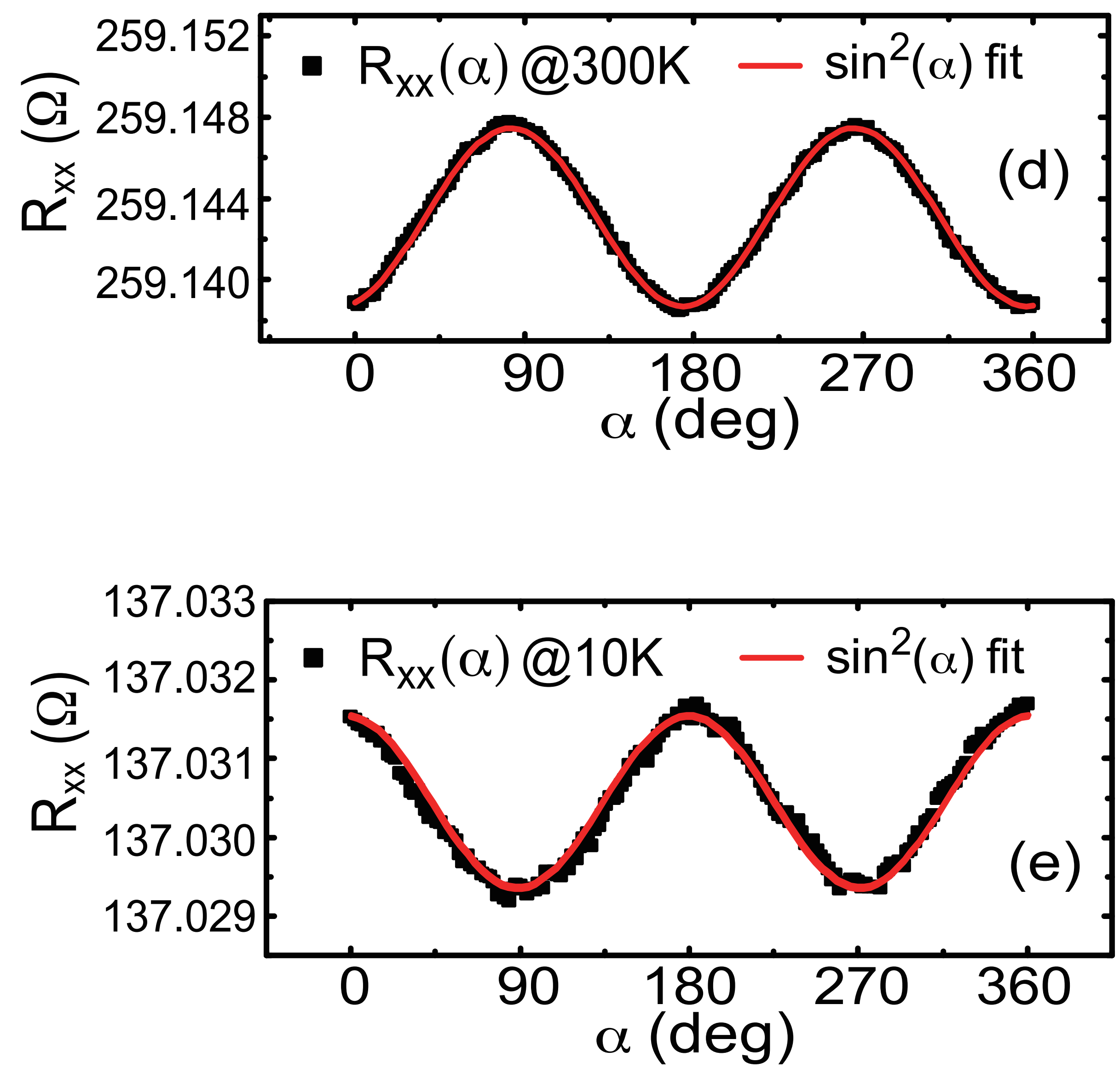




model for negative SMR at low T

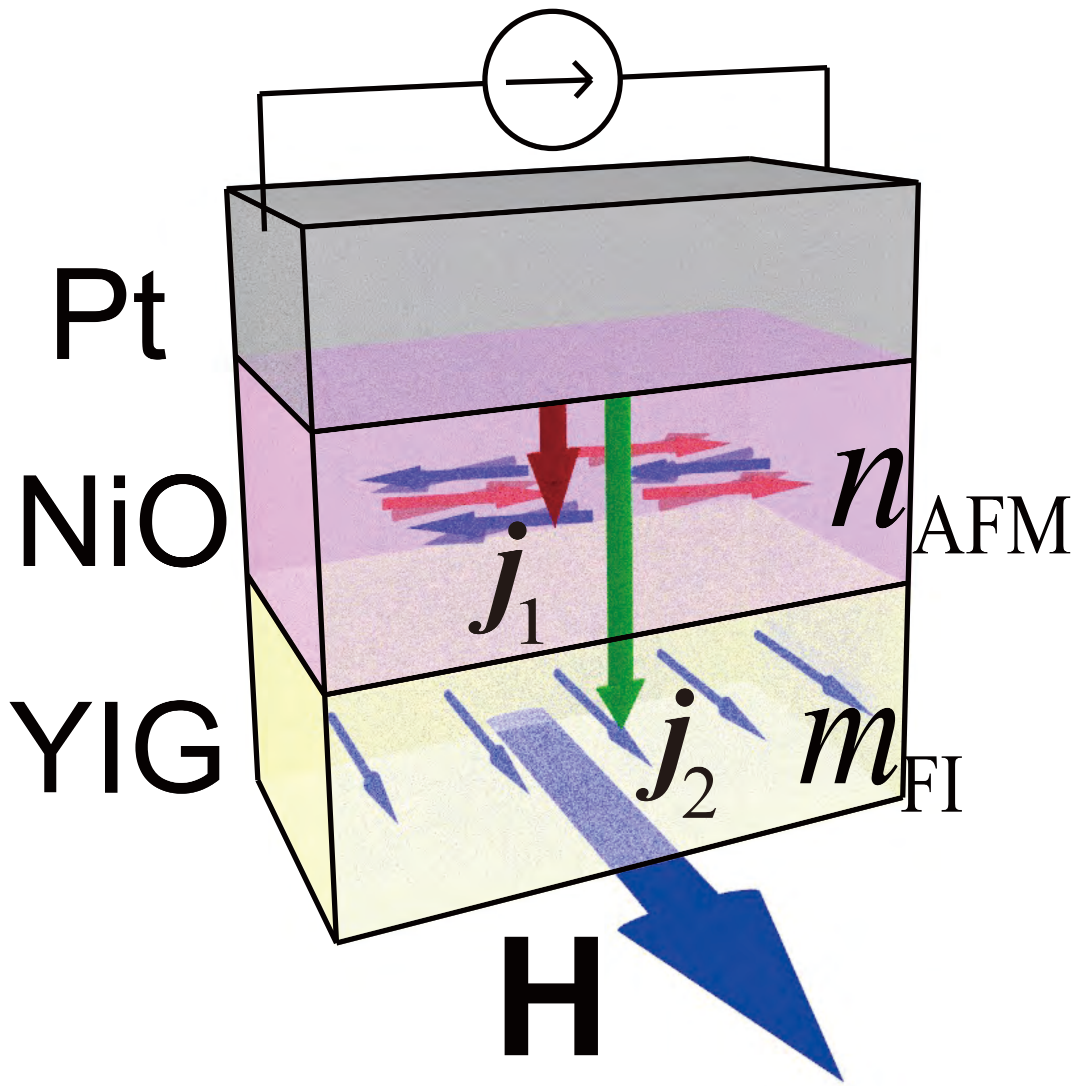
spin current from Pt can not reach YIG

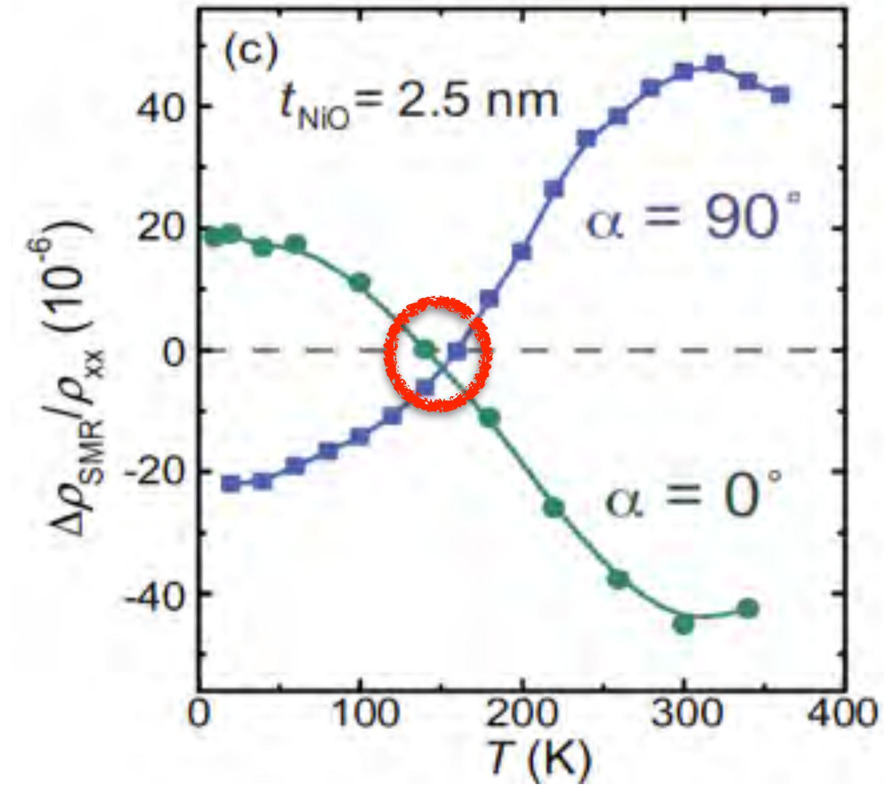


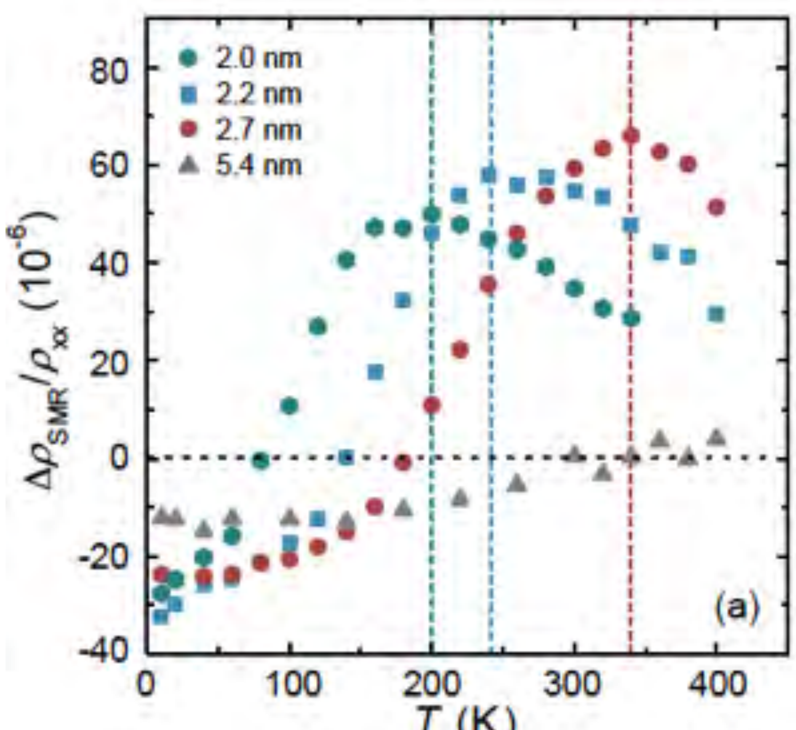


SMR sign change point

spin current from Pt reach both NiO and YIG, competition

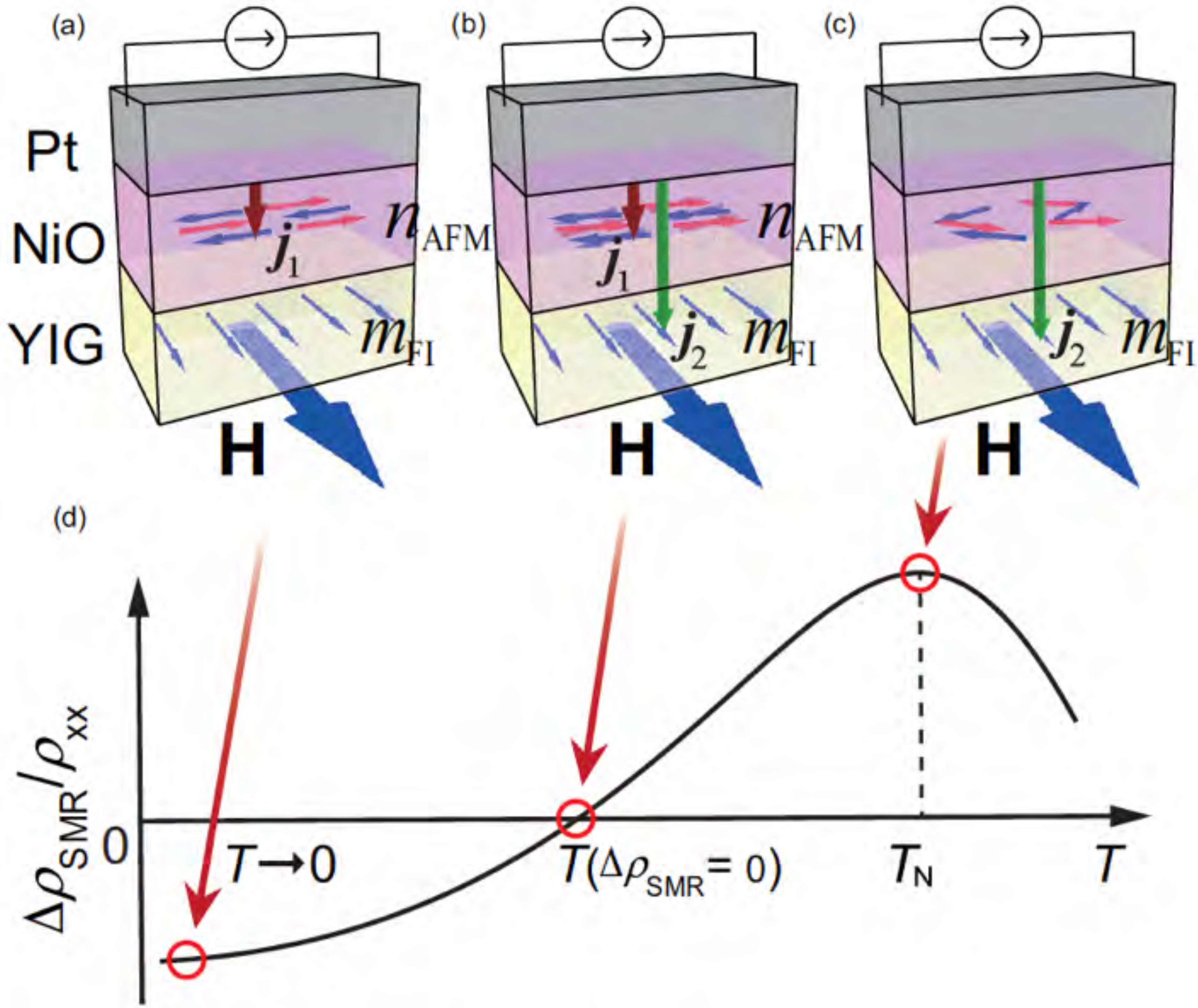






explains the NiO thickness dependence

Summary of phenomenological explanation:



D. Hou *et al.*, Phys. Rev. Lett. 118,147202 (2017)

Theoretical quantitative model

by J. Barker, K. Sato and K. Yamamoto

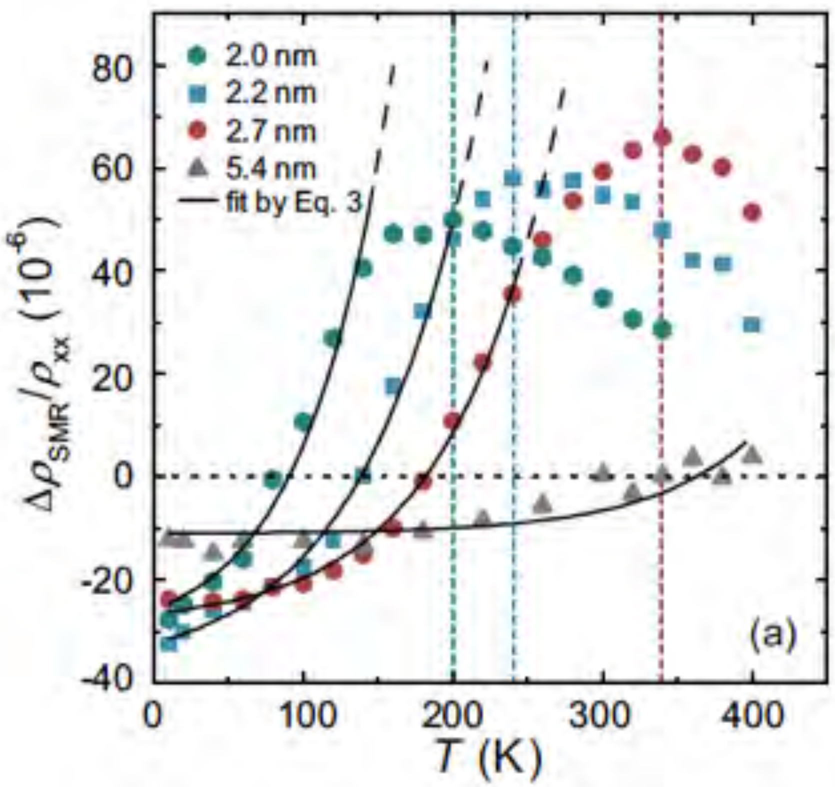
decompose of the spin current from Pt into two:

$$e\boldsymbol{j}_s = \underbrace{G_{AF}\boldsymbol{n}_{\mathrm{AFM}} \times (\boldsymbol{n}_{\mathrm{AFM}} \times \boldsymbol{\mu}_s)}_{\text{NiO SMR}} + \underbrace{t(T)\boldsymbol{m}_{\mathrm{FI}} \times (\boldsymbol{m}_{\mathrm{FI}} \times \boldsymbol{\mu}_s)}_{\text{YIG SMR}}$$

NiO SMR **YIG SMR**

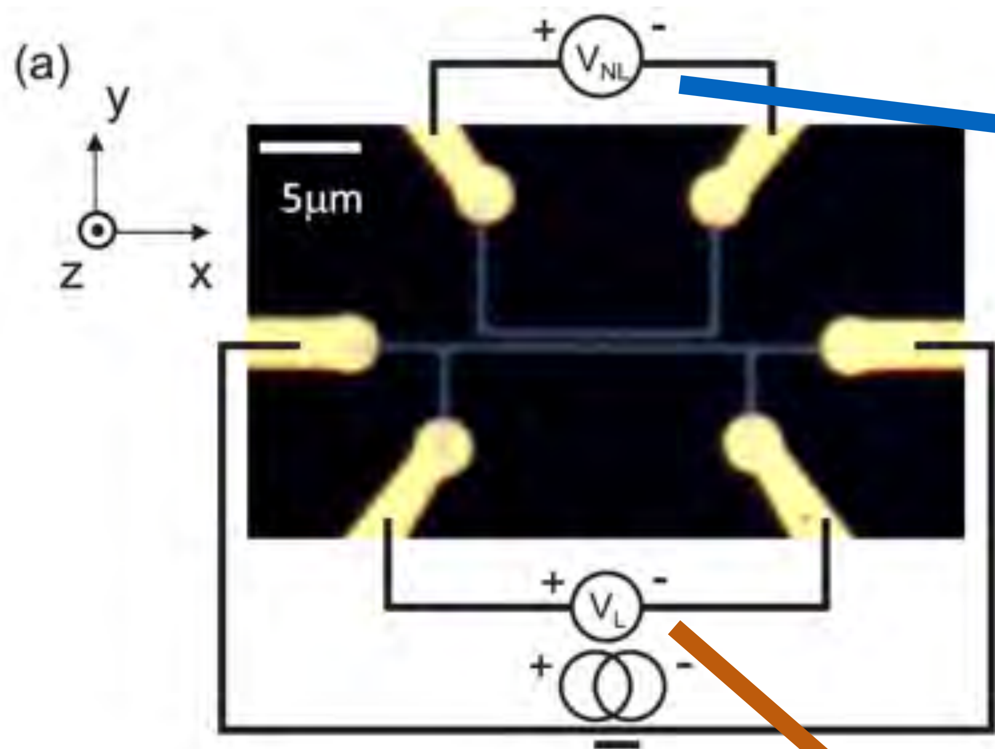
Expression for SMR:

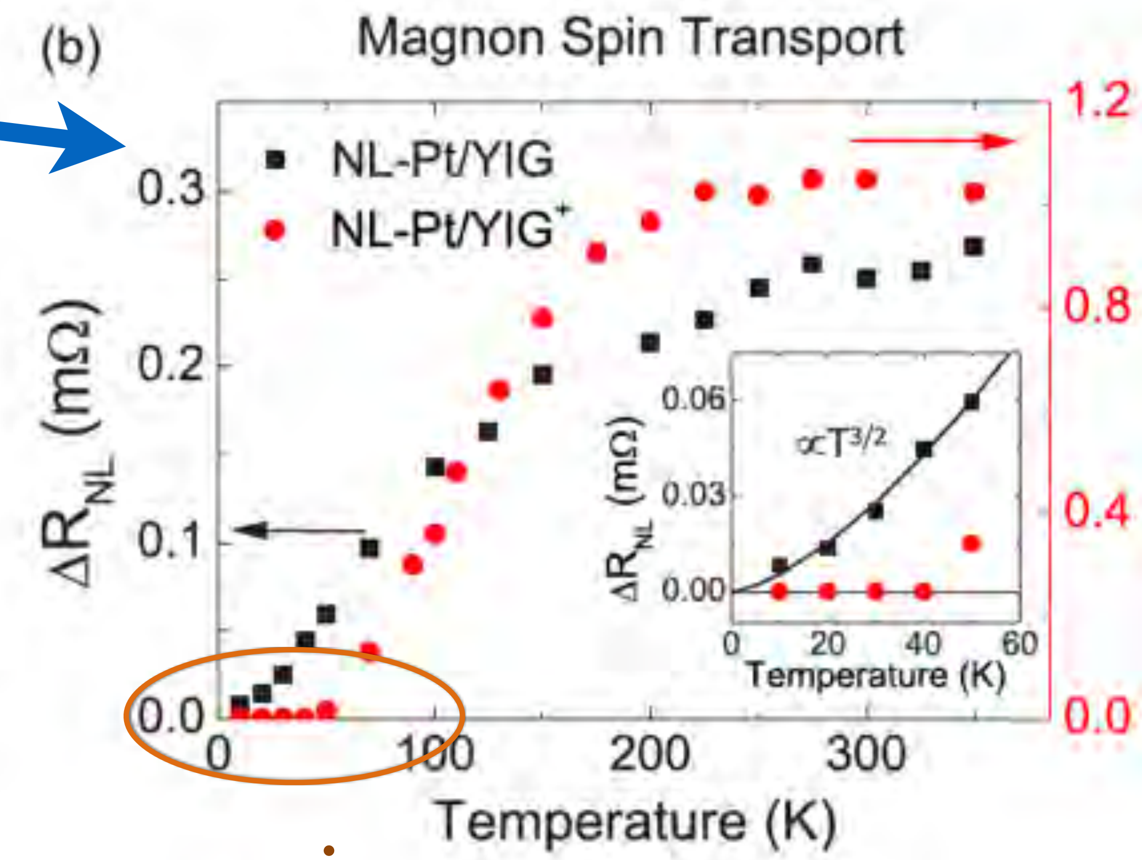
$$\frac{\delta\rho}{\rho_0} = \frac{2\theta_{SHE}^2\lambda_N^2}{d_N\sigma}\frac{G_{AF}\cos^2\phi_n + t(T)\cos^2\phi_m + \nu t(T)G_{AF}\sin^2(\phi_m-\phi_n)}{1+\nu G_{AF}+\nu t(T)+\nu^2 t(T)G_{AF}\sin^2(\phi_m-\phi_n)}\tanh^2\left(\frac{d_N}{2\lambda_N}\right)$$



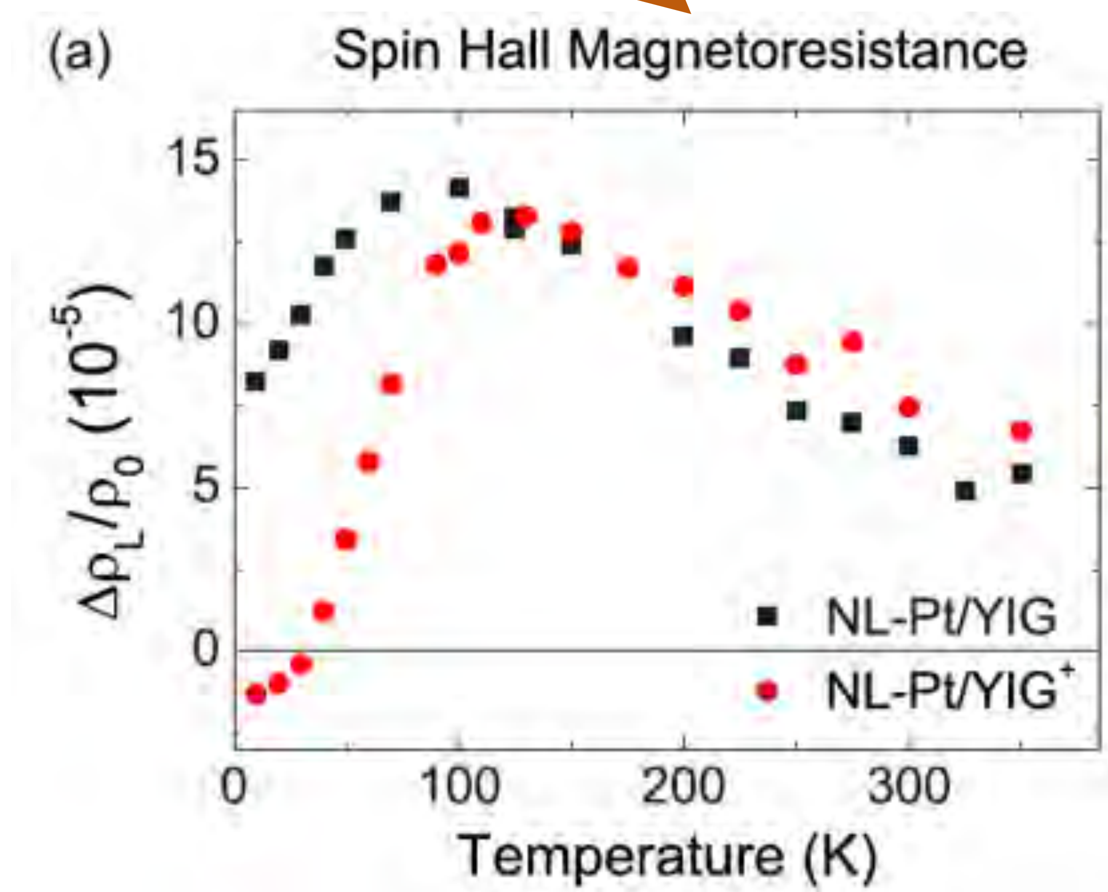
data fitting

d_{NiO}	$a[K^{-1}]$	G_{AF}	G_F
2.0	$1.83 \pm 0.22 \times 10^{-2}$	$3.58 \pm 0.32 \times 10^{12}$	$8.39 \pm 0.57 \times 10^{11}$
2.2	$1.38 \pm 0.19 \times 10^{-2}$	$4.48 \pm 0.17 \times 10^{12}$	$7.78 \pm 0.26 \times 10^{11}$
2.7	$1.42 \pm 0.10 \times 10^{-2}$	$3.67 \pm 0.09 \times 10^{12}$	$3.01 \pm 0.08 \times 10^{11}$
5.4	$1.44 \pm 0.02 \times 10^{-2}$	$1.51 \pm 0.15 \times 10^{12}$	$0.08 \pm 0.01 \times 10^{11}$





spin current blocked

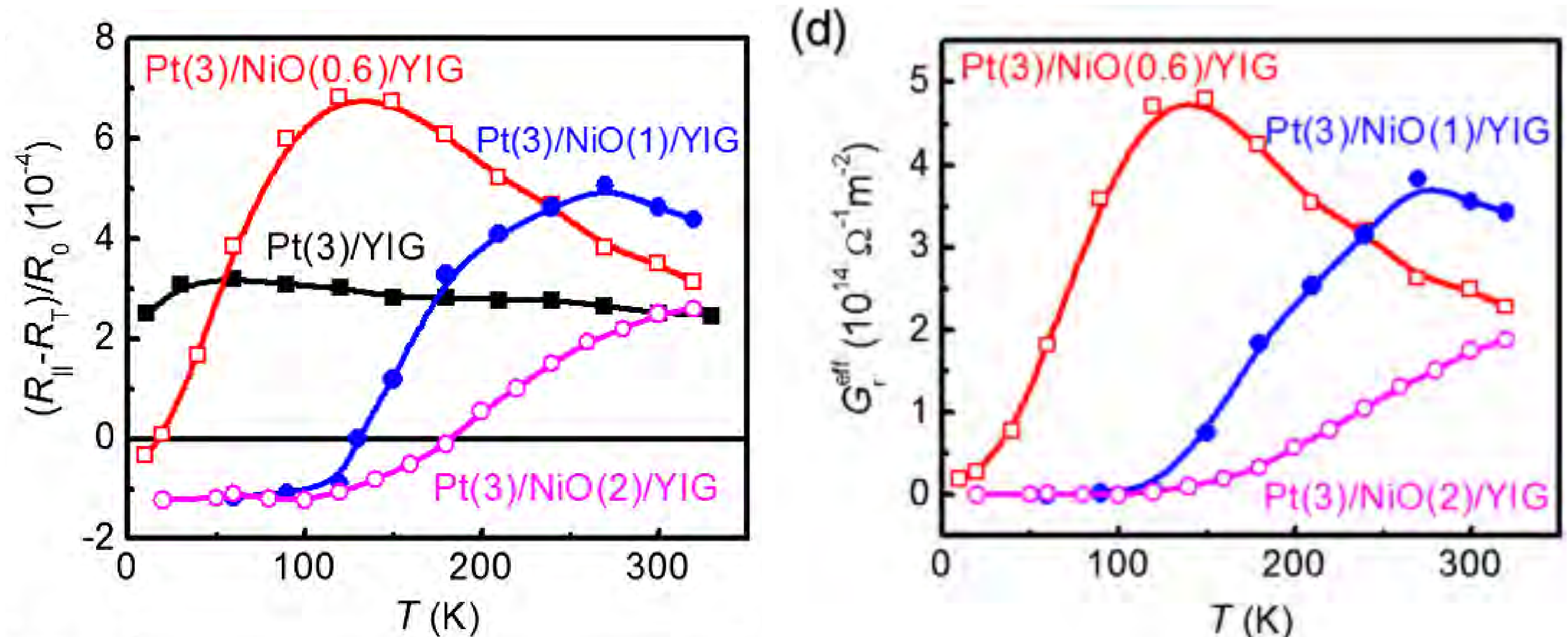


Saül Vélez, Amilcar Bedoya-Pinto, Wenjing Yan, Luis E. Hueso, and Fèlix Casanova, PRB,(2016)

Electrical Detection of Spin Backflow from an Antiferromagnetic Insulator/$Y_3Fe_5O_{12}$ Interface

Weiwei Lin* and C. L. Chien†

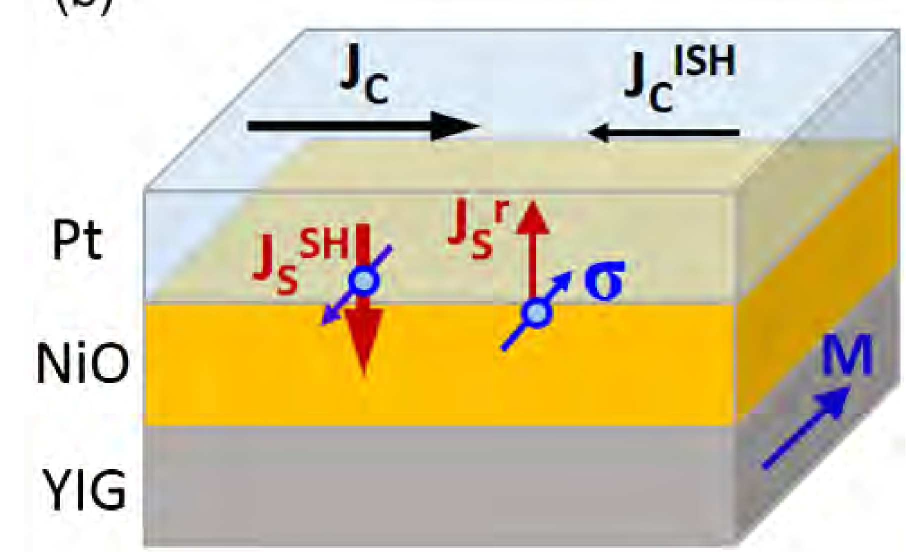
negative SMR



their explanation

If the spin current flowing back to the Pt from the NiO involves a spin flip, then the direction of $\mathbf{J}_C^{\mathrm{ISH}}$ would be *opposite* to that of the $\mathbf{J}_C$, as sketched in Fig. 4(b), leading to the *increase* of the measured R and, thus, $R_\perp \approx R_\parallel < R_T$, the inverted SMR, as apparently occurs in Pt/NiO/YIG at $T < T^*$. We suggest that the spin-flip scattering for the spin

(b)



Negative spin Hall magnetoresistance of Pt on the bulk easy-plane antiferromagnet NiO

Geert R. Hoogeboom,[1,*] Aisha Aqeel,[1,†] Timo Kuschel,[1] Thomas T.M. Palstra,[1,‡] and Bart J. van Wees[1]

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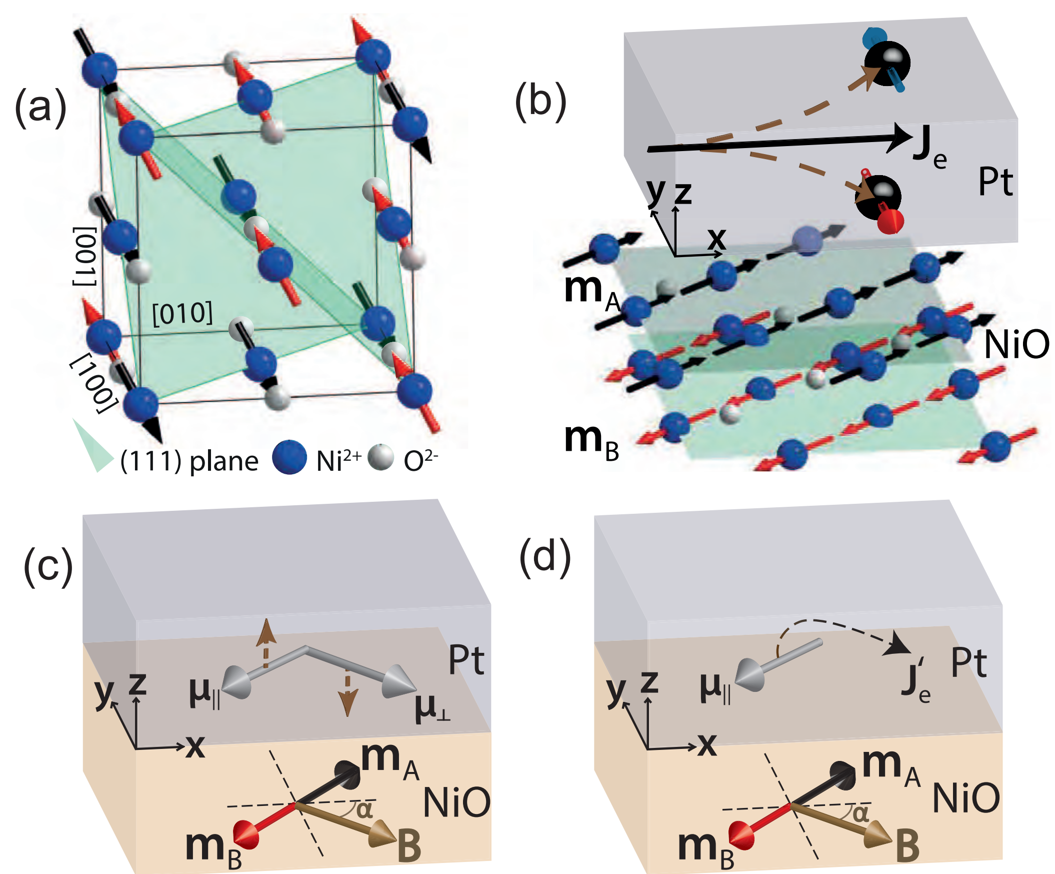
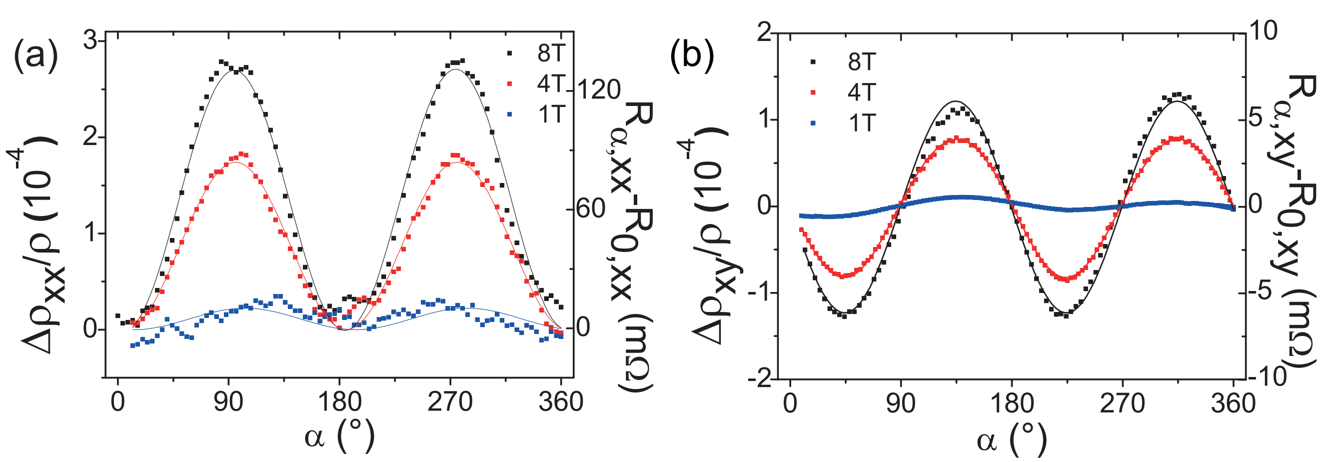
(Dated: June 12, 2017)





Seebeck effect,[25–27] propagate through the NiO layer and are detected in Pt by the ISHE. For NiO layers thicker than ∼5 nm, the transmitted spin current decreased rapidly with thickness. The sign of the SMR signal in these Pt/NiO/YIG stacks is observed to be positive at room temperature and becomes negative at low temperatures.[28–30] The authors explain this domination of the positive SMR at room temperature by spin currents injected at the Pt/NiO interface, transmitted through NiO and partly reflected when entering the YIG. At low temperatures, the spin currents towards and from the YIG are suppressed due to the vanishing spin transmittance in NiO, thus, the total signal is dominated by the negative SMR from NiO. For the Pt/NiO/YIG samples, the NiO magnetic moments are indirectly aligned perpendicular to the magnetic field via an exchange coupling with YIG which is saturated at 0.06 mT. [28–30]

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Saul Velez

Felix Casanova

Jia Li