Transmission of pure spin currents through ferroic collinear multilayers

Hvar workshop, October 2nd, 2017

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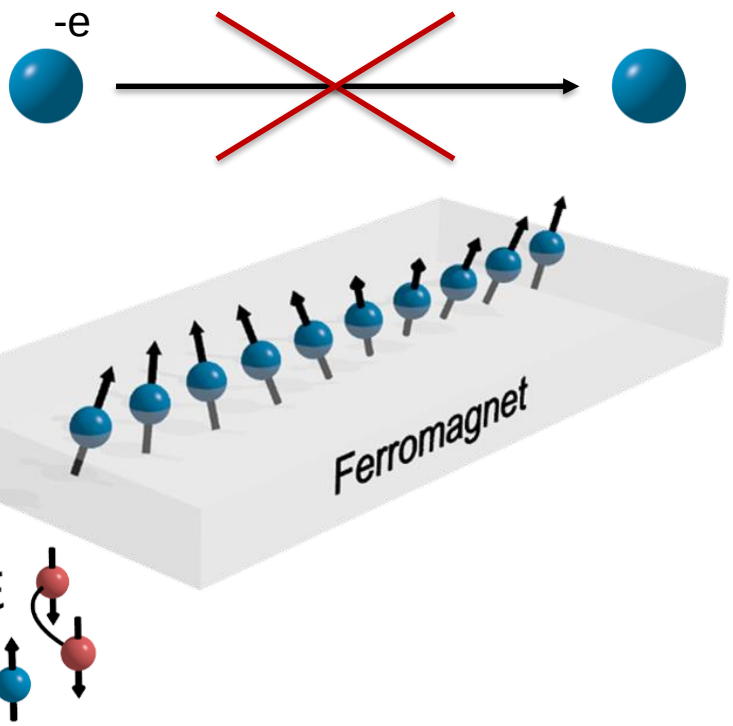
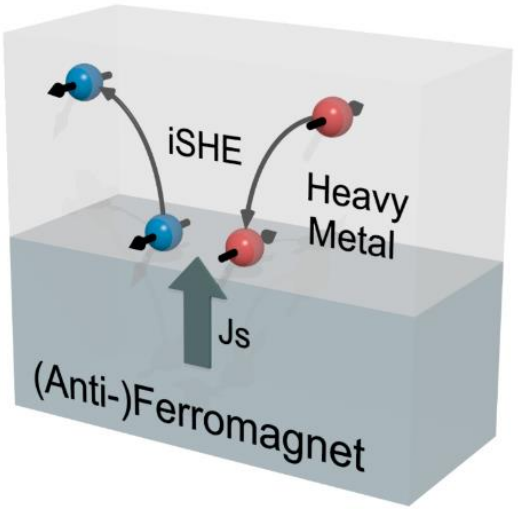
Magnonics – Magnon spintronics

- Magnonics – Magnon spintronics[1]
  - Transport/Processing of information via spin wave systems interfacing charge-driven spintronics

  → Wave-based computing

  → Insulator-based spintronics





- Magnon spin currents by FMR spin pumping[2]
- Electric detection of magnon spin currents by inverse SHE[4] (iSHE)

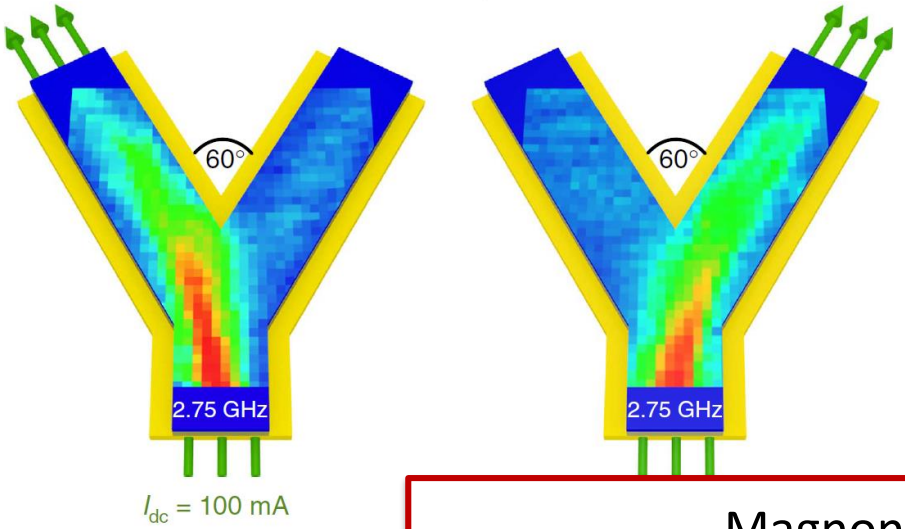
[1]Chumak *et al.*, Nat. Phys. **11**, (2016)

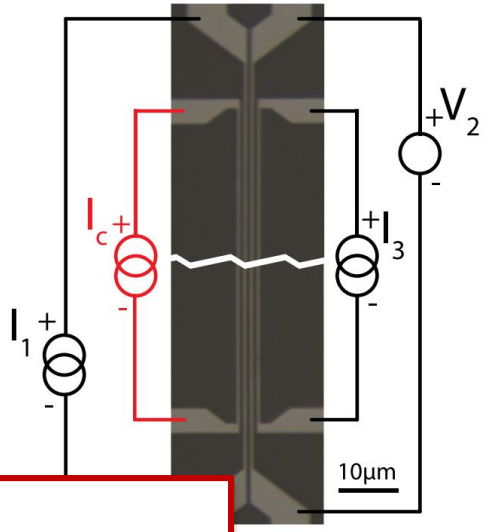
[2]Tserkovnyak *et al.*, Phys. Rev. Lett. **11**, 117601 (2002)

[3]Uchida *et al.*, Proc. IEEE **104**, 1946 (2016)

[4]Sinova *et al.*, Rev. Mod. Phys. **4**, 1213 (2015)

Magnon logic

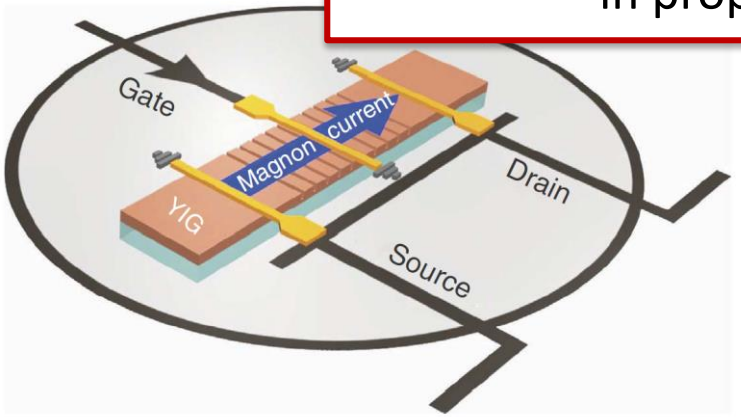




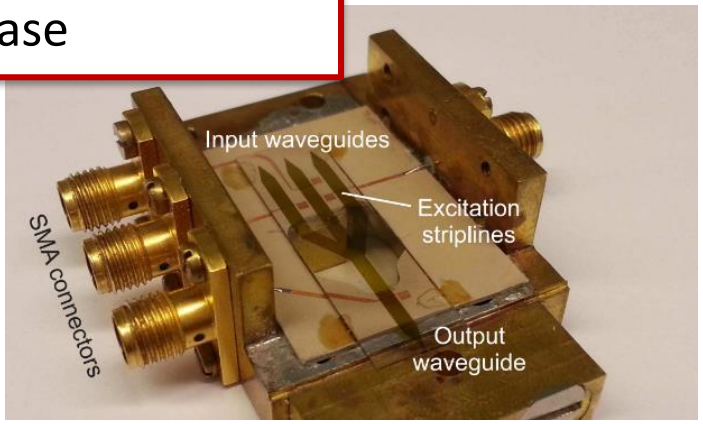
Vogt *et al.*, Nat. C ... ys. Lett. **109**, 022405 (2016)

Magnon logic via manipulation/superposition of spin waves in propagating phase

Magnon transistor schem

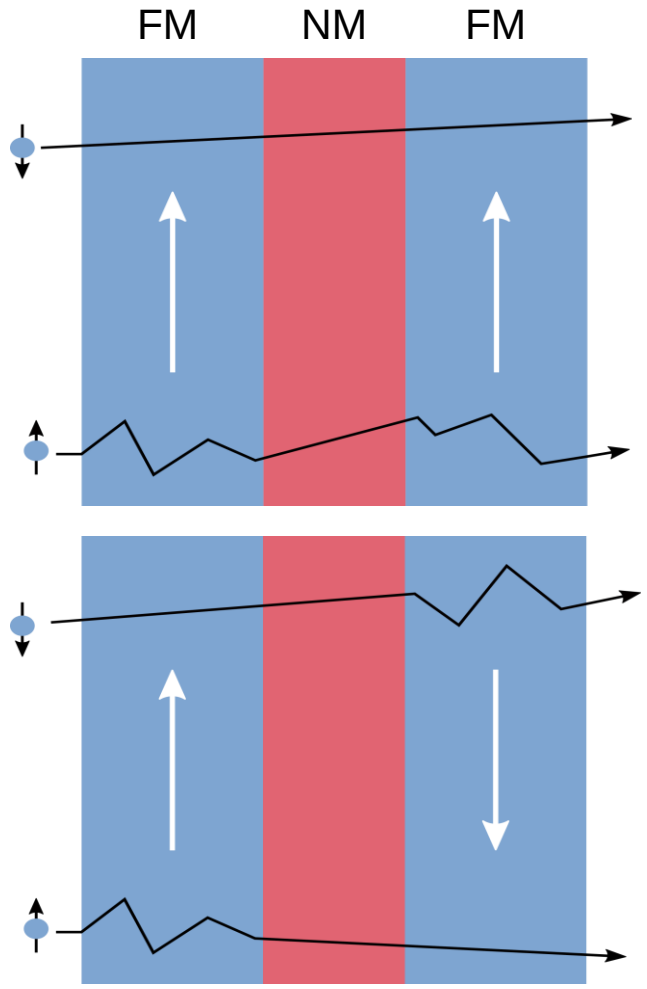


Chumak *et al.*, Nat. Commun. **5**, 4700 (2014)



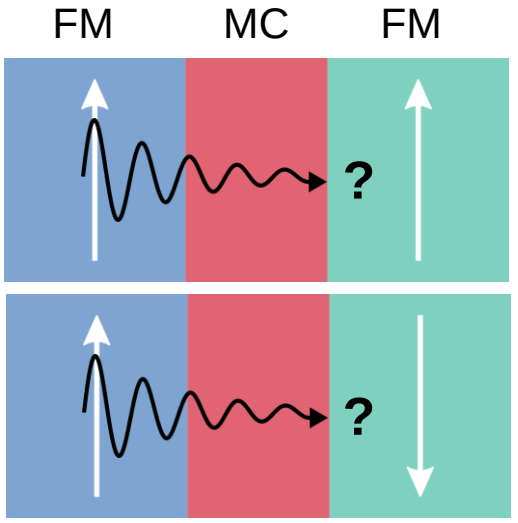
Fischer *et al.*, Appl. Phys. Lett. **110**, 152401 (2017)

Switching in charge-operated spintronics



Baibich et al., Phys. Rev. Lett. **61**, 2472 (1988)
Binasch et al., Phys. Rev. B **39**, 4828(R) (1989)

- Giant magnetoresistance
  → Film resistance depends on relative alignment of ferromagnets
- *Magnetoresistance* for spin currents?
  i. Type of ferromagnets
  ii. Magnon-conductive (MC) spacer
  iii. Method of spin-wave generation



Investigated system: YIG/CoO/Co

i. Type of ferromagnets

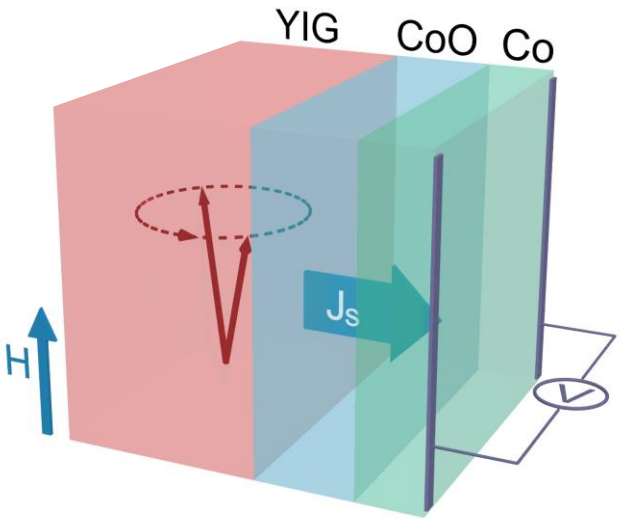
- Insulating ferrimagnetic $Y_3Fe_5O_{12}$ (5 µm)
  - Magnetically soft
  - No electronic spin current
- Metallic ferromagnet Co (4-6 nm)
  - Inverse spin Hall effect[1]

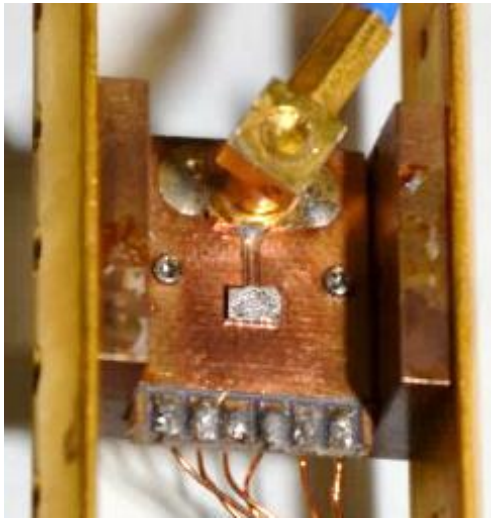
ii. Magnon-conductive spacer

- Insulating antiferromagnet CoO (2-5 nm)
  - De-coupling of ferromagnets
  - Exchange-biasing of Co layer

iii. Method of spin wave generation

- Ferromagnetic resonance spin pumping
  - Good signal-to-noise: $f \geq 4.5\ \mathrm{GHz}$

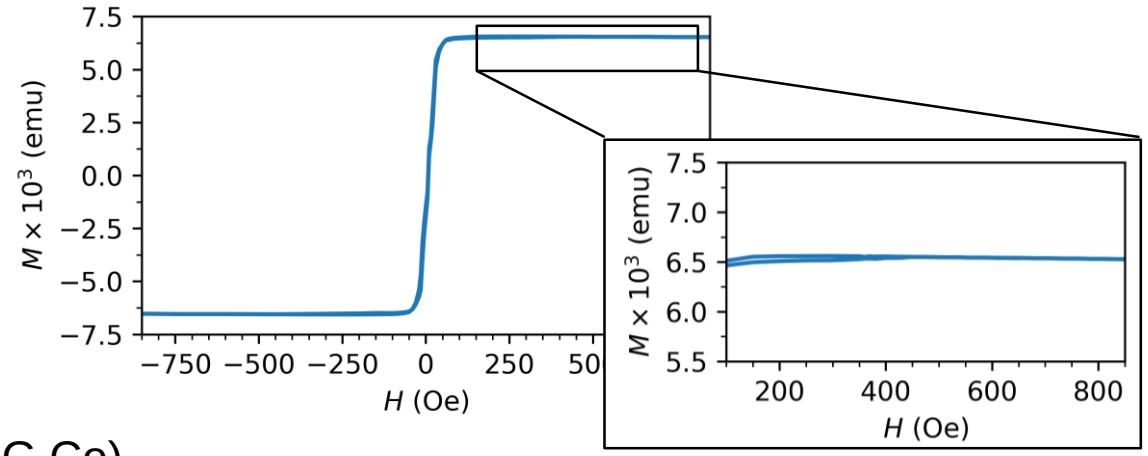




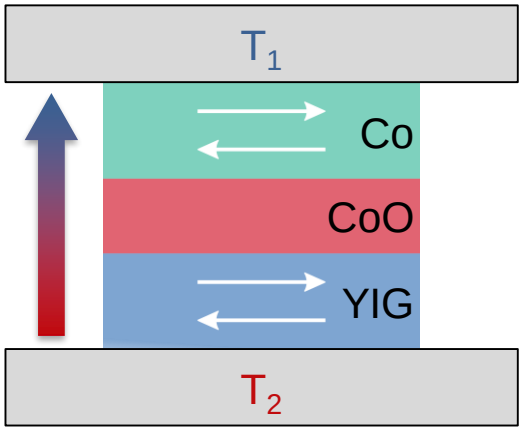
[1]Miao et al., Phys. Rev. Lett. **111**, 066602 (2013)

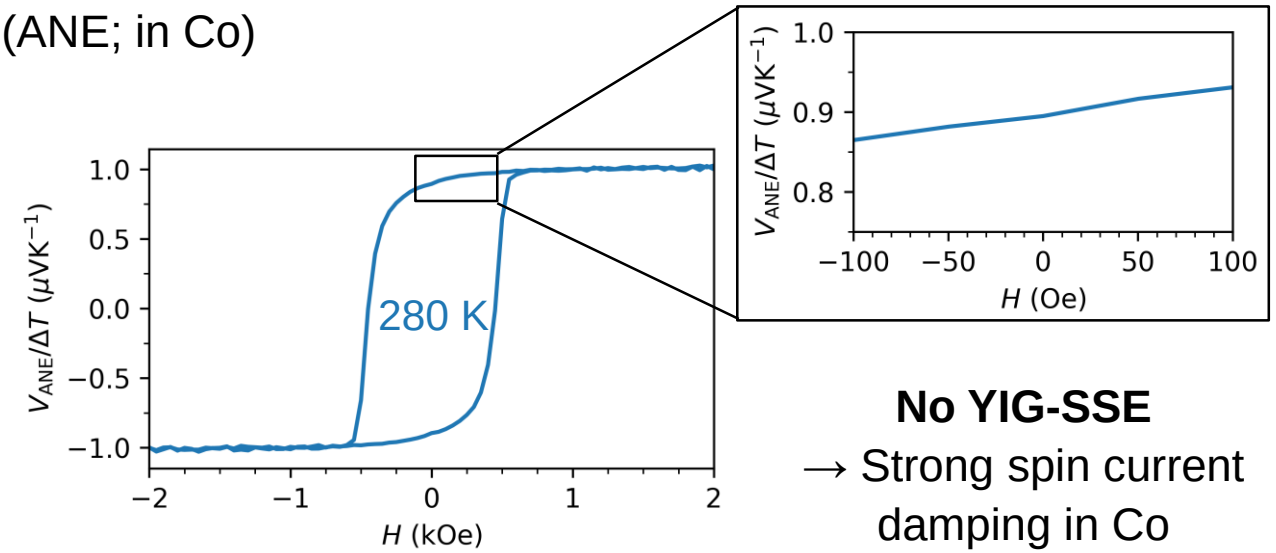
Magnetic properties of YIG (5 µm)/CoO (2 nm)/Co (4 nm)

- SQUID magnetometry
  - YIG switching at low field
  - Co switching not observable



- Spin-thermoelectric measurements
  - Spin Seebeck effect[1] (SSE; in YIG,Co)
  - Anomalous Nernst effect[2] (ANE; in Co)





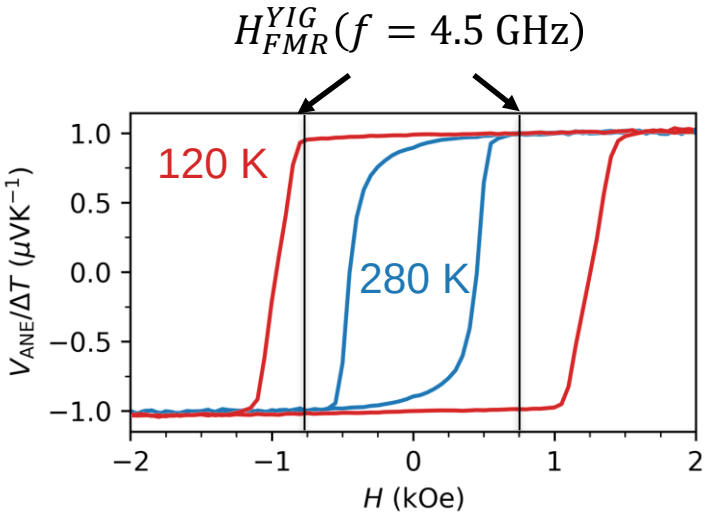
No YIG-SSE
→ Strong spin current damping in Co
→ No pinholes!

[1]Uchida *et al.*, Proc. IEEE **104**, 1946 (2016)

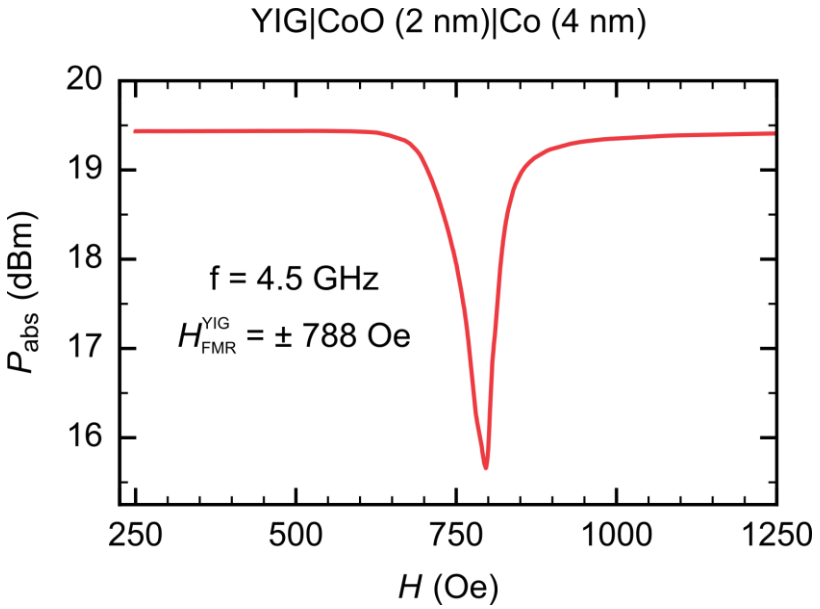
[2]Boona *et al.*, Energy Environ. Sci. **7**, 885-910 (2014)

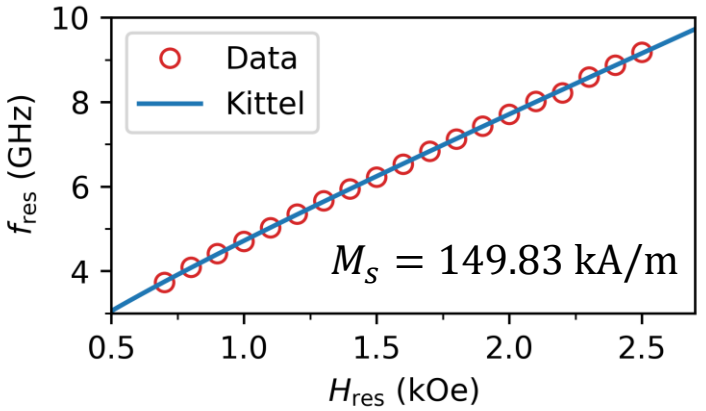
FMR in YIG/CoO (2 nm)/Co (4 nm)

- FMR resonance of Co not observed
- FMR resonance of YIG
  - YIG resonance further confirmed by Kittel formula
  - Resonance at RT above coercive field

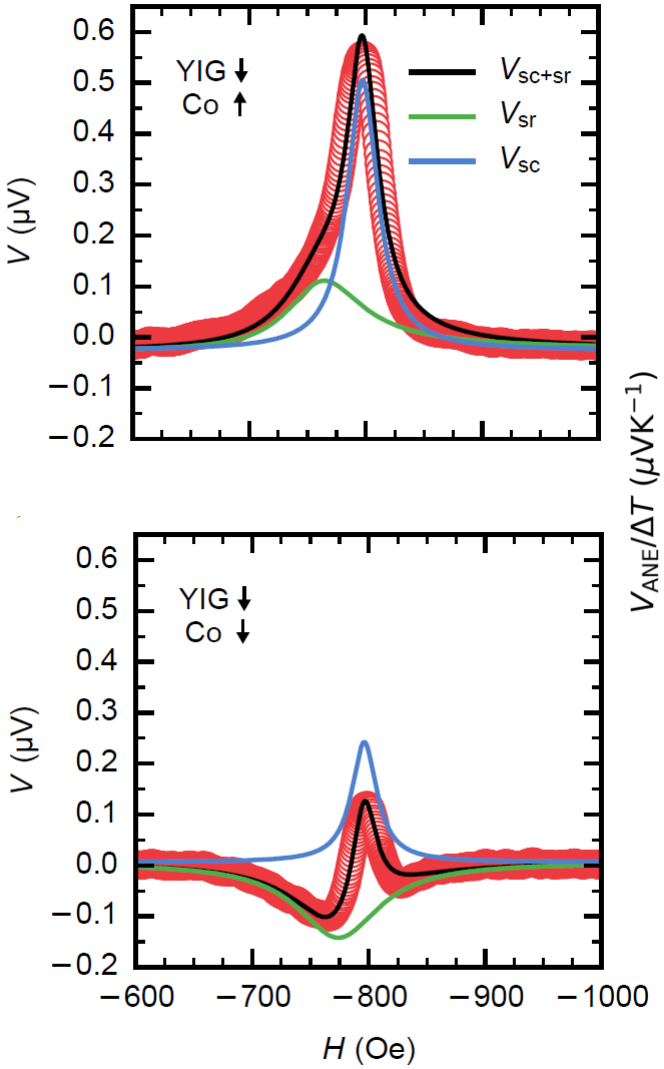


Exchange biasing enables independent switching of YIG/Co





Spin pumping in YIG/CoO (2 nm)/Co (4 nm)

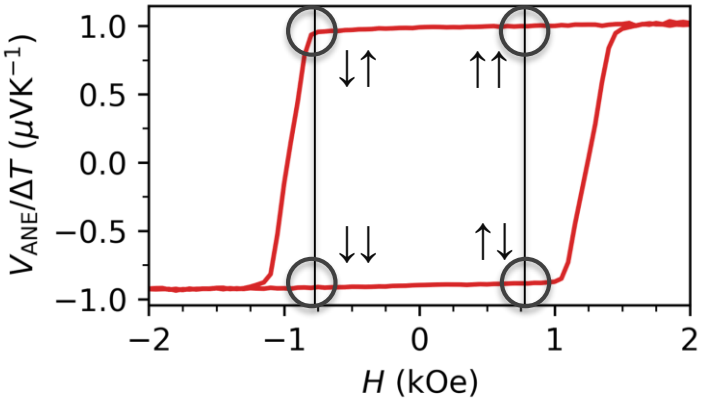


Raw data

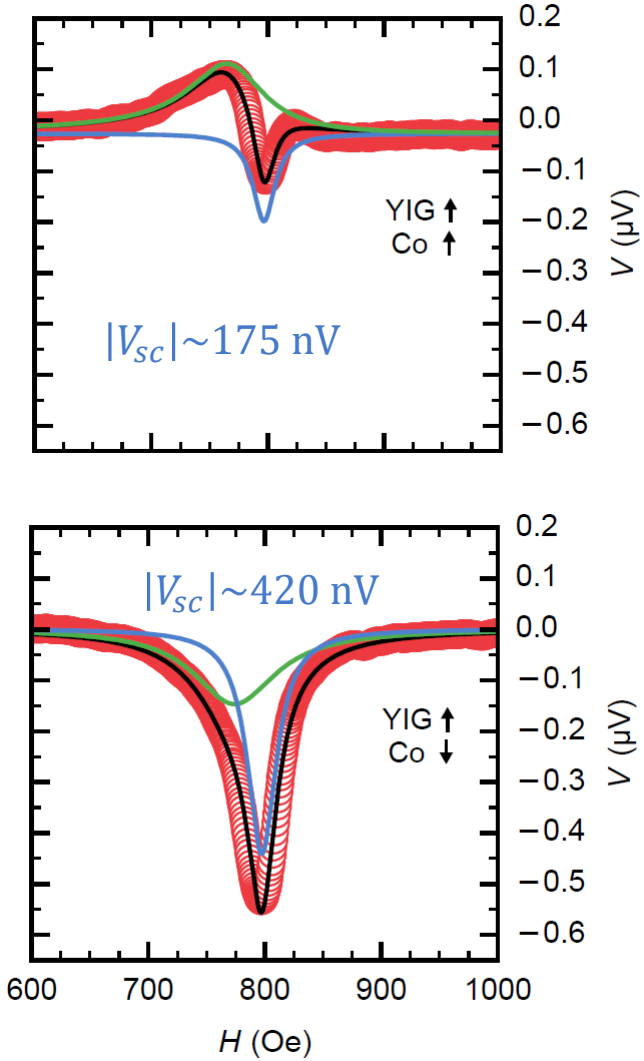
Spin Pumping (YIG)

Secondary signal (Co)

Cobalt magnetization

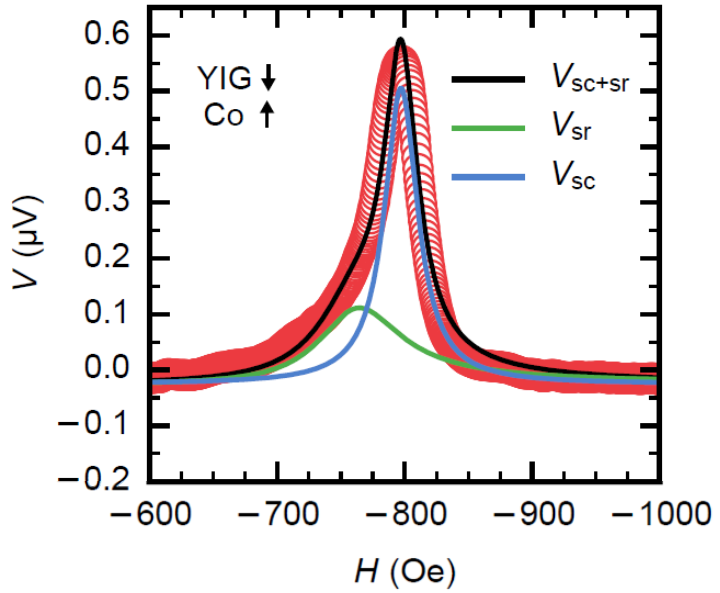


Relative change of pumped spin current voltage: ~ +140%

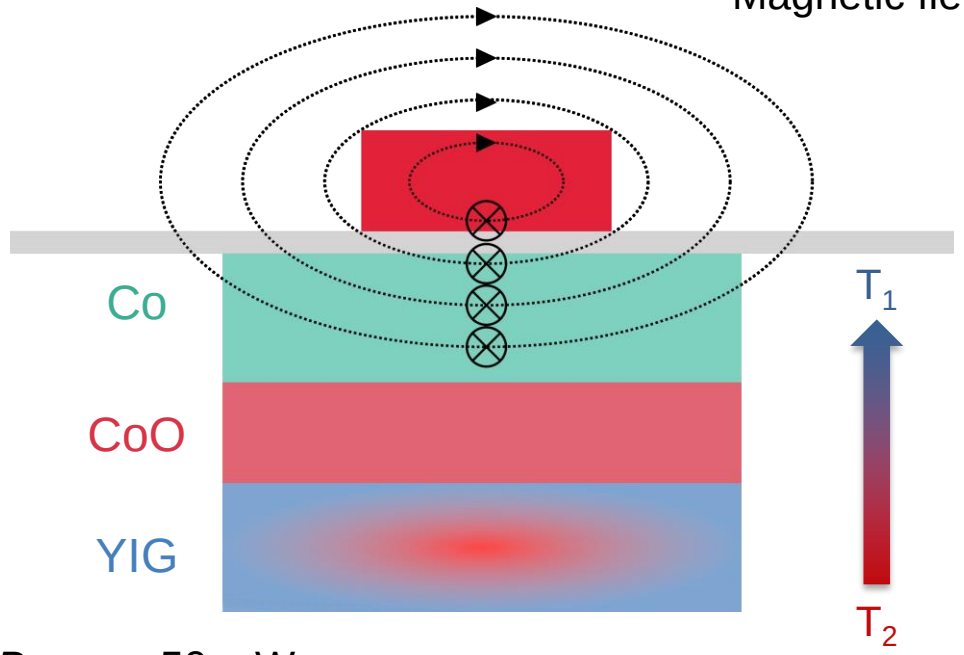


Cobalt-dependent voltage signal

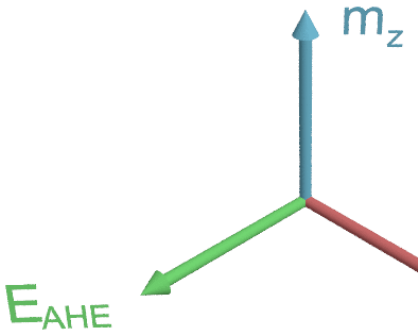
- Two possible origins of Co-peak
  - Anomalous Nernst signal due to microwave heating[1]
  - Anomalous Hall effect induced spin rectification[2]



Magnetic field



P_{absorb} ~ 50 mW



Time-dependent current flow and magnetization rotation in Co

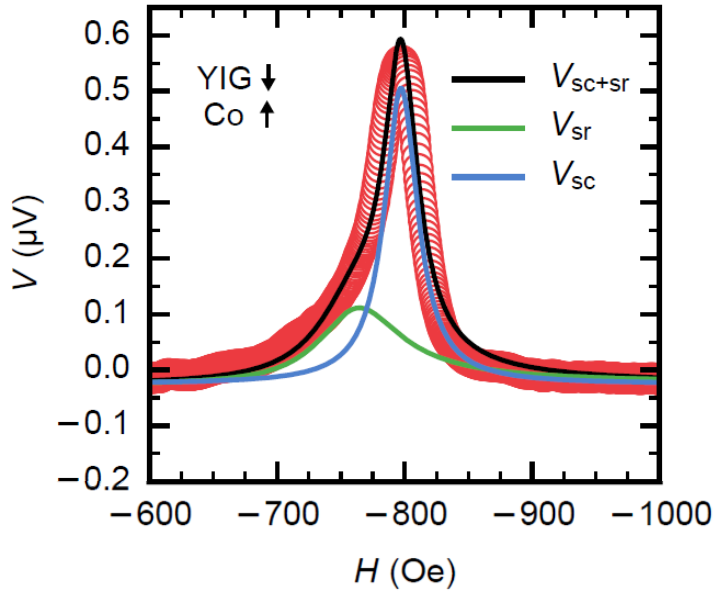
[1]Schultheiss *et al.*, Phys. Rev. Lett. **109**, 237204 (2012)

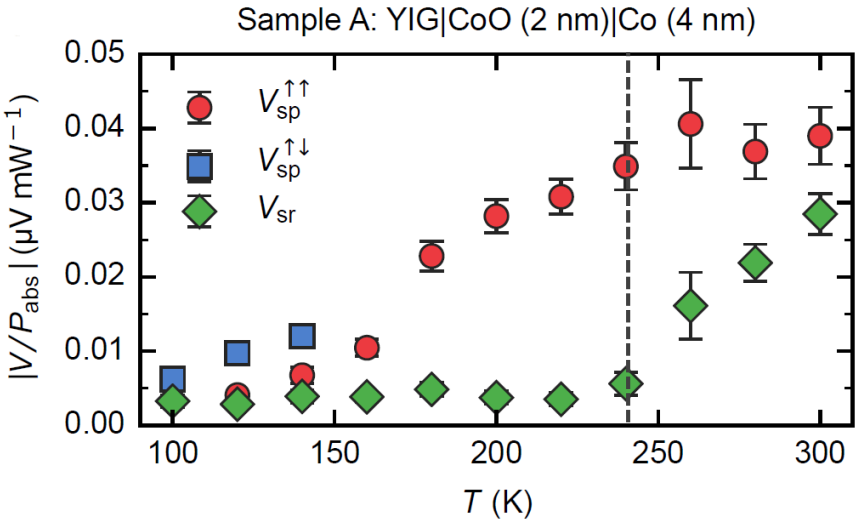
[2]Chen *et al.*, J. Appl. Phys. **113**, 17C732 (2013)

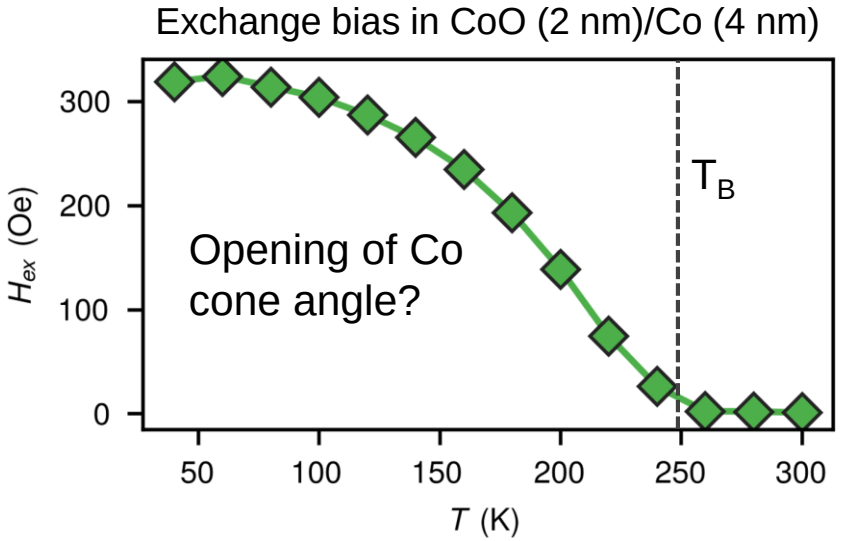
Cobalt-dependent voltage signal

- Two possible origins of Co-peak
  - Anomalous Nernst signal due to microwave heating[1]
  - Anomalous Hall effect induced spin rectification[2]

→ **Check temperature dependence**





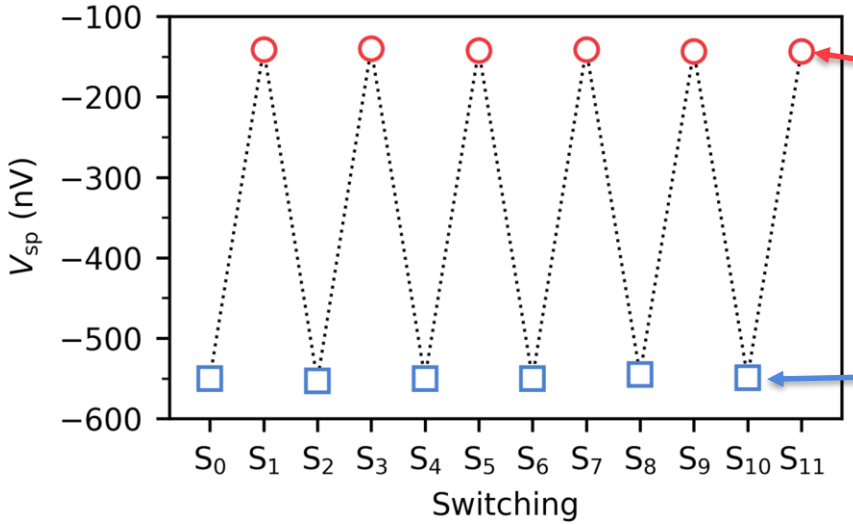


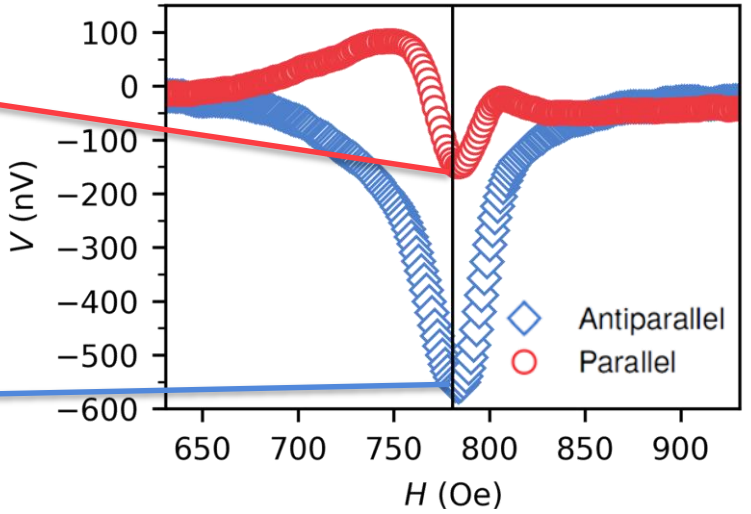
[1]Schultheiss *et al.*, Phys. Rev. Lett. **109**, 237204 (2012)

[2]Chen *et al.*, J. Appl. Phys. **113**, 17C732 (2013)

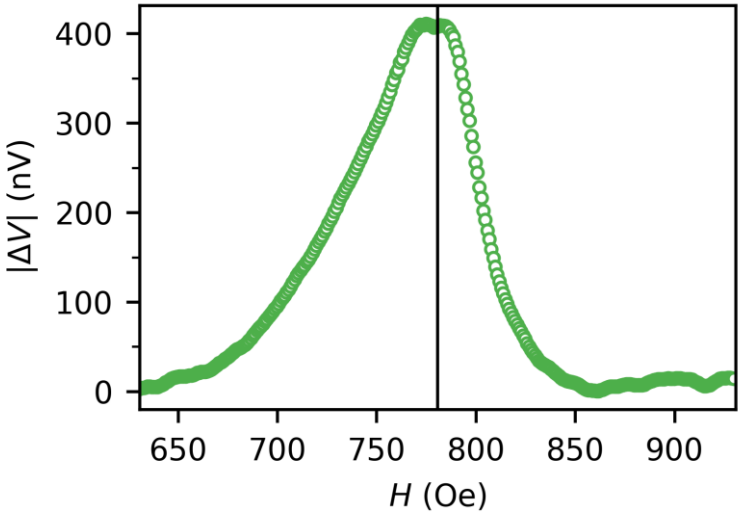
Switching (valve) effect

$$(V_{sc}^{\uparrow\downarrow} - V_{sc}^{\uparrow\uparrow})/V_{sc}^{\uparrow\uparrow} \cong 270\,\%$$



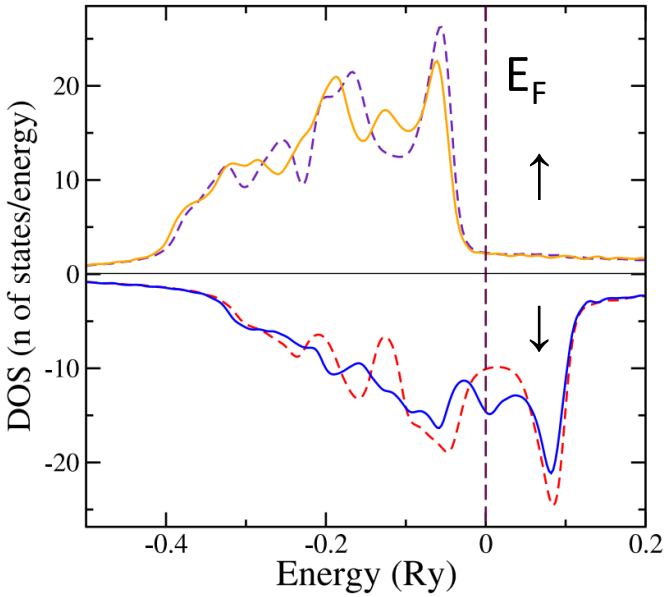


- Effective operation scheme
  - Spin pumping at fixed field
  - Determine field value with large and robust voltage changes
- Repetitive switching
  - Minor signal deviation



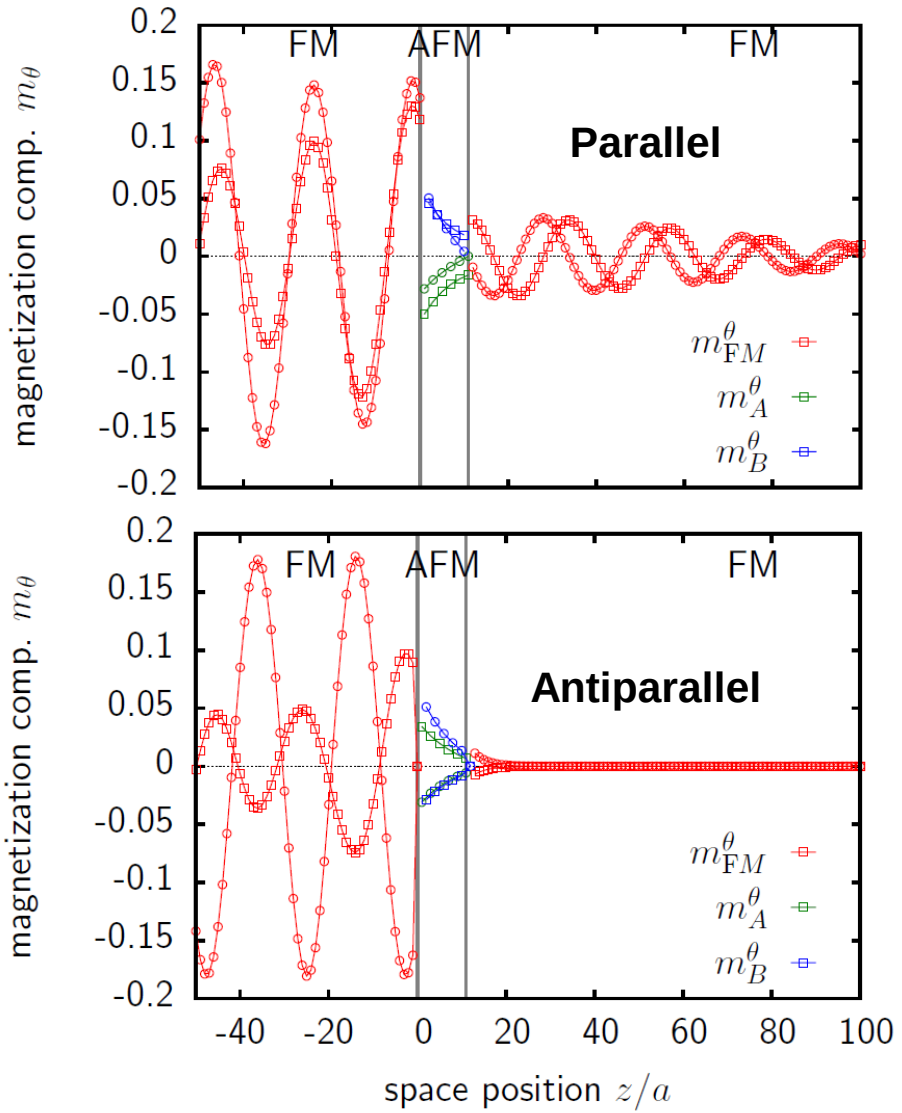
Origin of alignment-dependent signal

- Magnonic spin transport
  - Two magnon branches in AFM
  - Unique magnon polarization in FM
  - → Spin transmission in parallel state
- Electronic spin detection
  - Spin-dependent iSHE?



Lizárraga *et al.*, Sci. Rep. **7**, 3778 (2017)

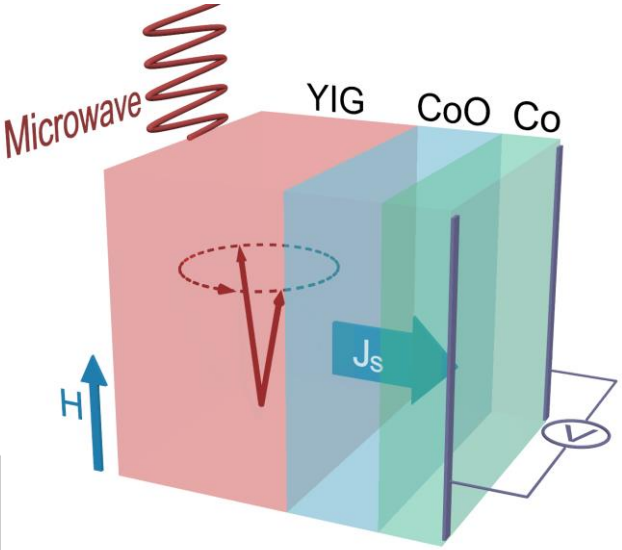
Theory by group of U. Nowak



Conclusion

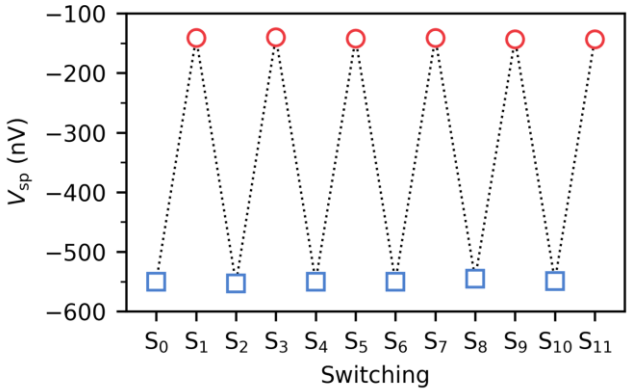
FMR spin pumping in YIG/CoO/Co

- Spin current detection amplitude depends on relative alignment of YIG/Co
  → Electronic origin likely
- Secondary signal appears at resonance
  → Anomalous Hall induced spin rectification



Effect amplitude:

$(V_{sc}^{\uparrow\downarrow} - V_{sc}^{\uparrow\uparrow})/V_{sc}^{\uparrow\uparrow} \cong 270\,\%$



Cramer *et al.*,
arXiv:1706.07592

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