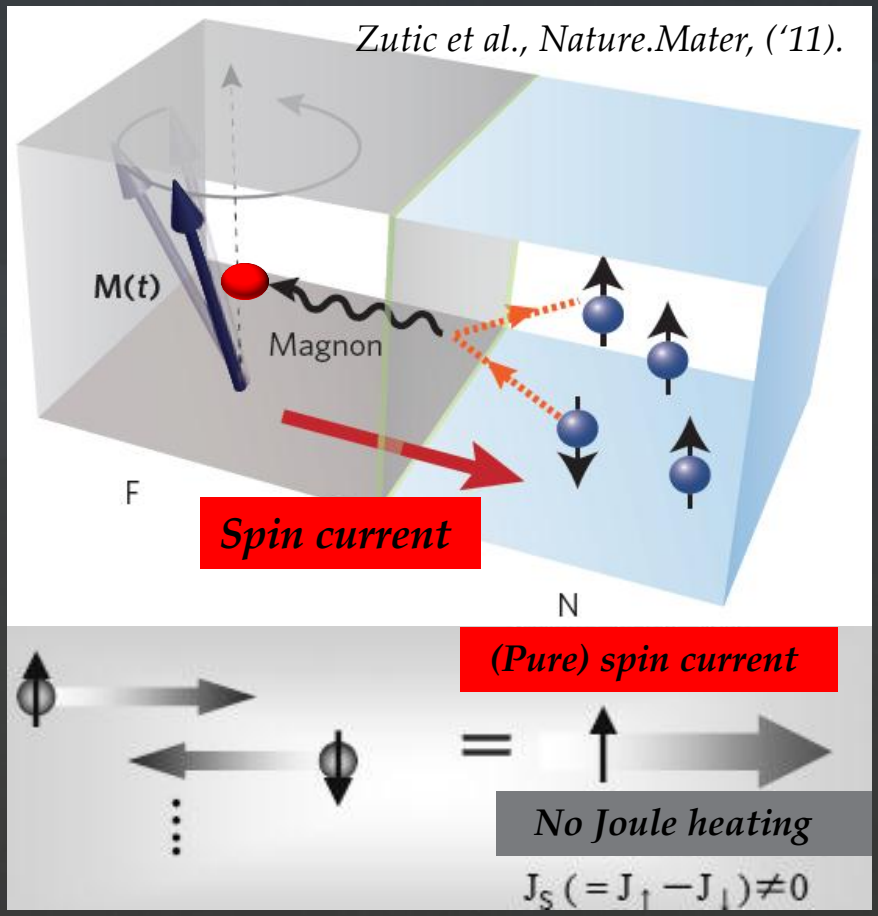
Spin Pumping Mediated by Magnon



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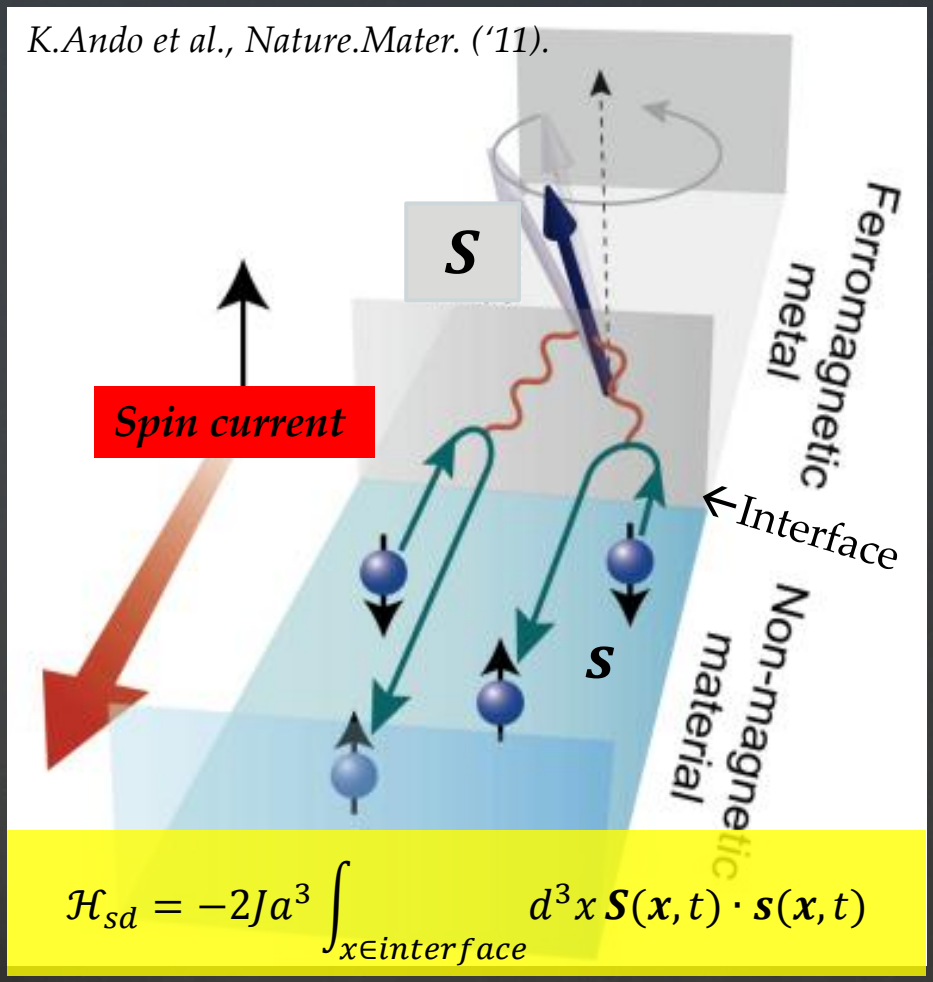
Spin Pumping

- A standard way to generate a ***(pure) spin current*** *-*



- ✓ Ferromagnet acts as a source of spin angular momentum.
- ✓ Electrons flip their spins from down to up by absorbing the momentum.
  - ➔ ***Spin currents*** are pumped into adjacent non-magnetic metal.

Y.Tserkovnyak et al.,
Rev. Mod. Phys. **77**, 1375('05)

"Except for ***the phenomenological treatment*** *of spin-flip scattering processes, the theory is derived from first-principles." (🡐 P. 1417)*

- ➢ Our aim is to go beyond phenomenology and to describe it as fully quantum dynamics.

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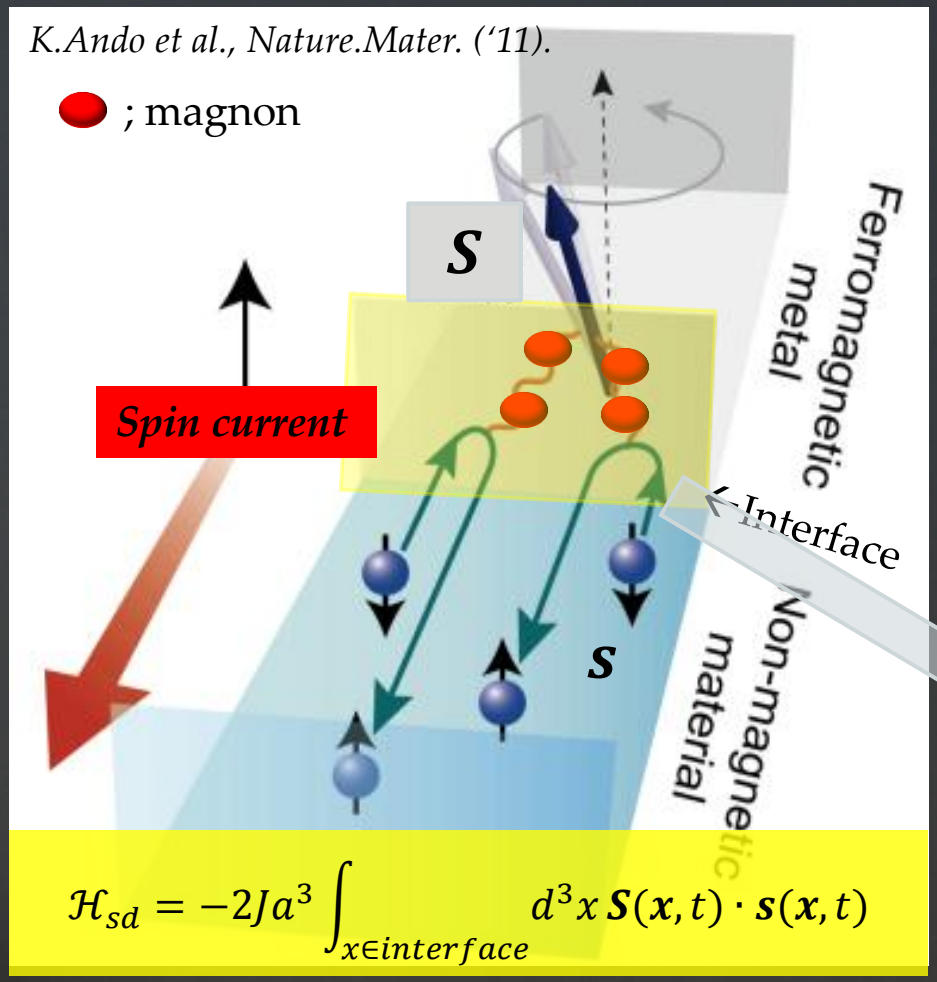
Spin Pumping

(I) Electron Spin Resonance
(II) Thermal gradient

- A standard way to generate a (pure) spin current -



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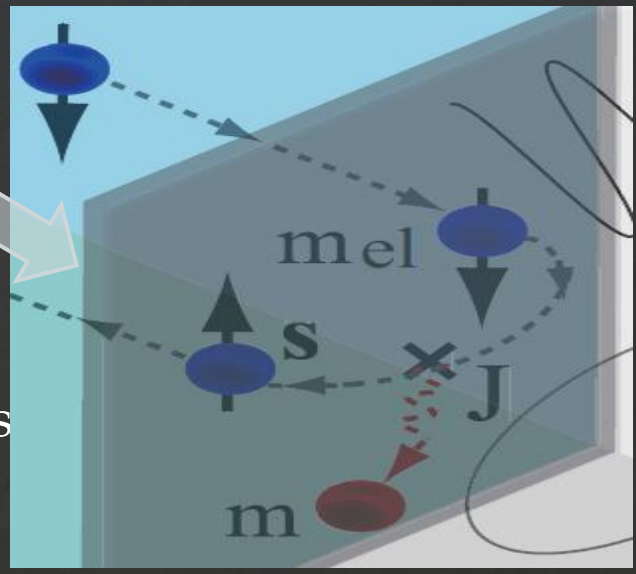

- ➢ The dynamics of the interface should be treated as ***(quantum) nonequilibrium transport.***

➔ ***"Schwinger-Keldysh formalism"***

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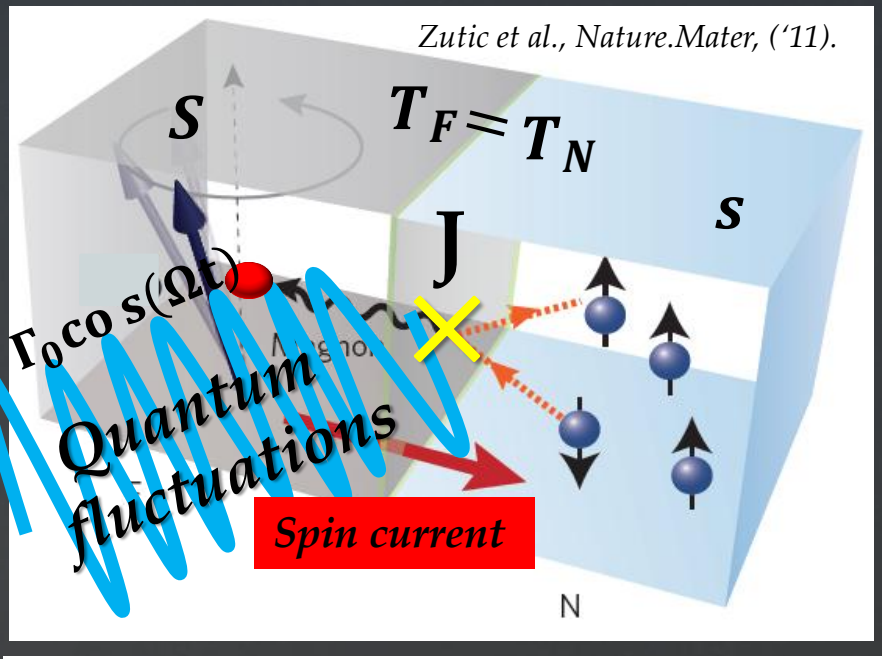
Spin pumping; (I) Electron Spin Resonance

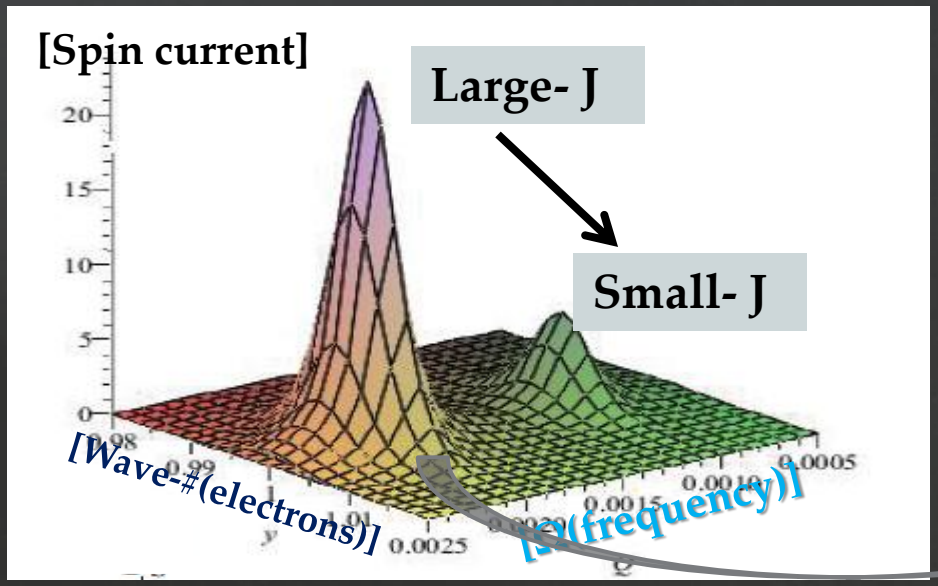


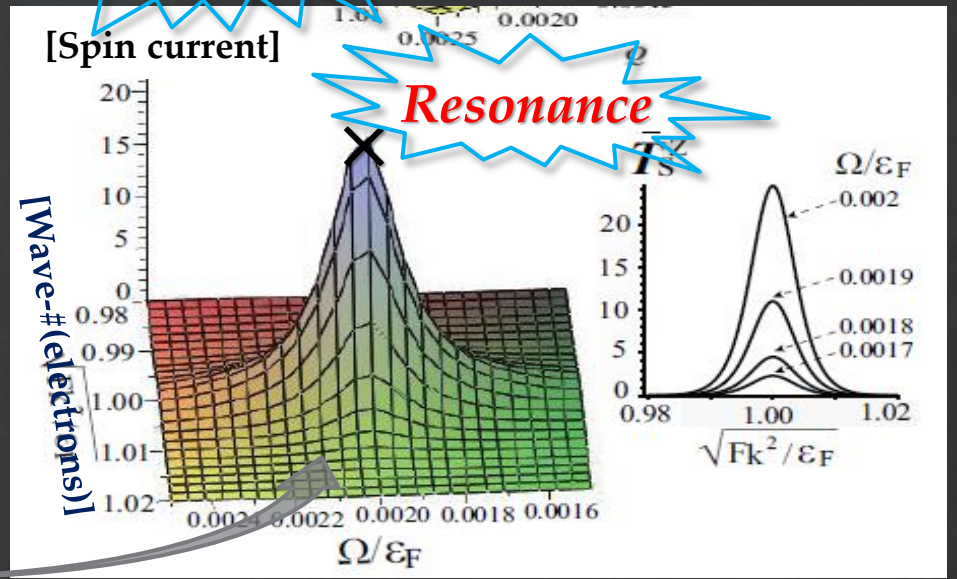
$$\mathcal{H}_{sd} = -2Ja^3 \int_{x \in interface} d^3x\, \boldsymbol{S}(\boldsymbol{x},t) \cdot \boldsymbol{s}(\boldsymbol{x},t)$$

✓ Apply transverse magnetic field;

$$\begin{cases} \Gamma(t) = \Gamma_0 cos(\Omega t) \\ V_{tra} = \Gamma(t) \int d^3x\, (S^x + s^x) \end{cases}$$

→ *Quantum fluctuation* generates a spin current at the interface.





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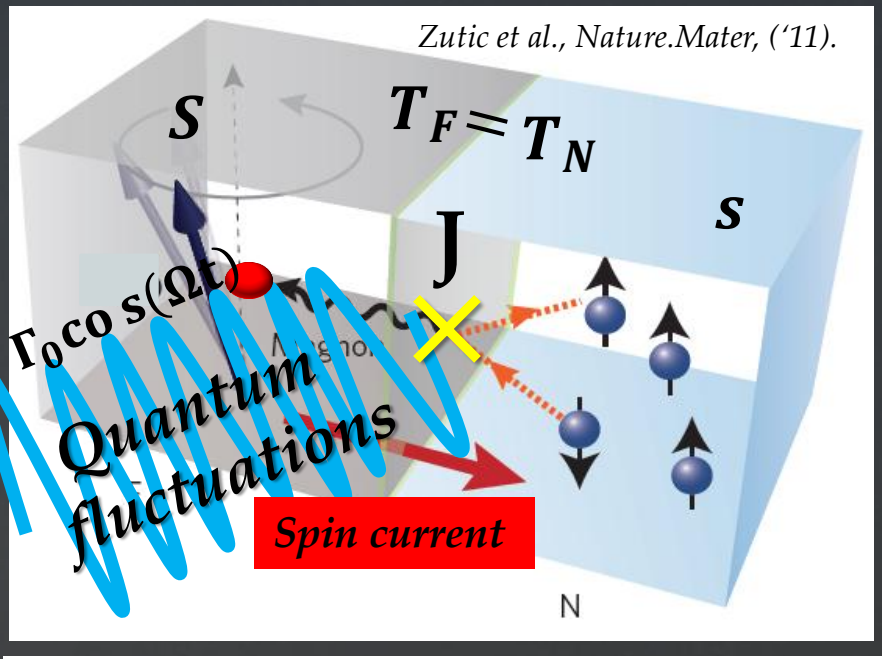
Spin pumping; (I) Electron Spin Resonance



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[Spin current]

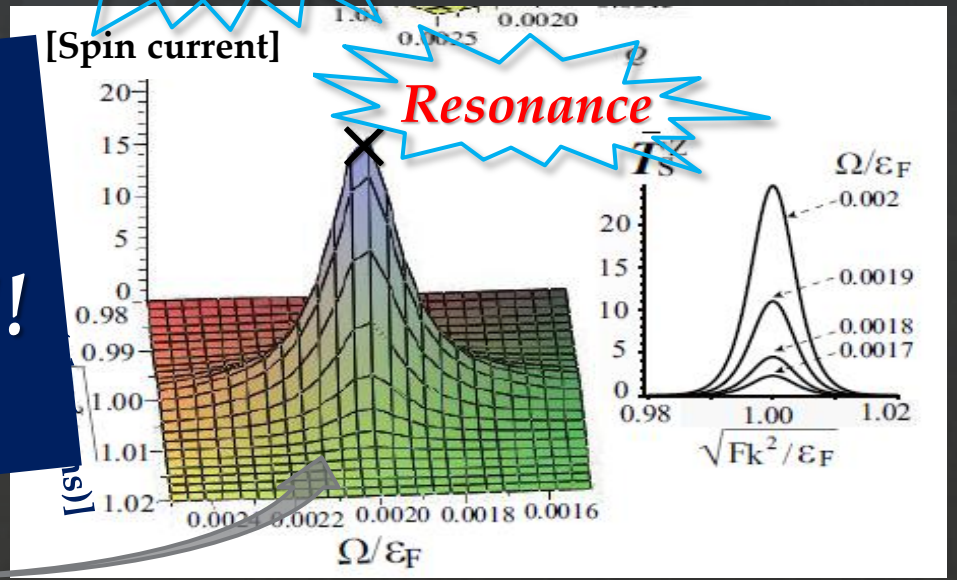
"Resonance"

→ (Spin current) ×16.9

→ Extremely enhanced!!

0.12A → 2.027A

[Spin current]



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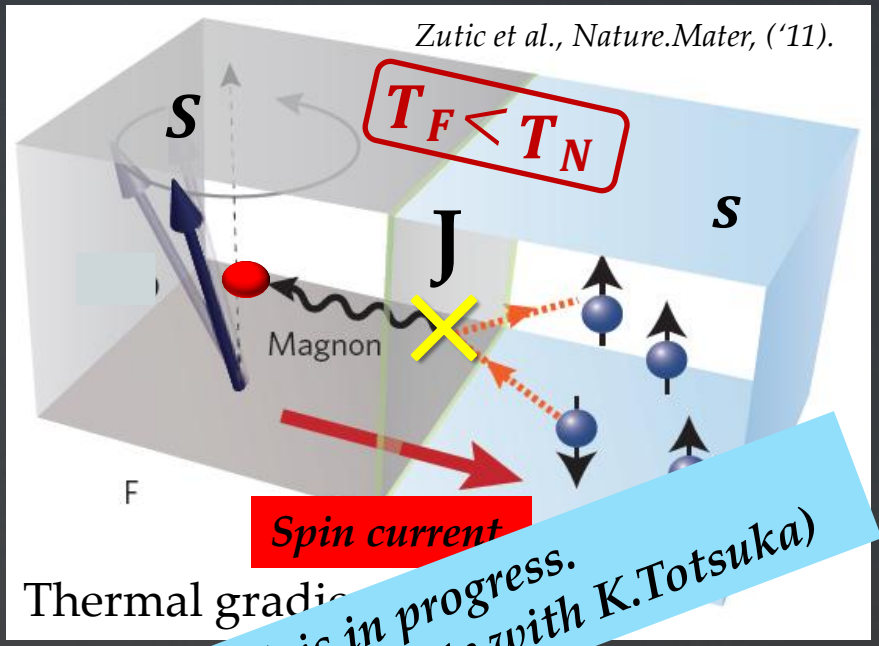
Spin pumping; (II) Thermal gradient



$$\mathcal{H}_{sd} = -2Ja^3 \int_{x \in interface} d^3x \, \boldsymbol{S}(\boldsymbol{x},t) \cdot \boldsymbol{s}(\boldsymbol{x},t)$$

← *"Two temperature model"*
S.I.Anisimov et al., Sov.Phys.JTEP **39**, *375 (1974).*

✓ (Spin current) $\propto (T_N - T_F)$

→ *Thermal gradient* also generates a spin current at the interface.

✓ *This work is in progress. (partly in collaborate with K.Totsuka)*