トポロジカル光波とテラヘルツレーザーによる高速スピン制御法の提案

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H. Fujita, and M. Sato, PRB**95**, 054421 (2017).
H. Fujita, and M. Sato, PRB**96**, 060407(R) (2017).
H. Fujita, and M. Sato, Sci. Rep. **8**, 15738 (2018).
H. Fujita, Y. Tada, and M. Sato, arXiv:1811.10617.
藤田・佐藤、固体物理2018年9月号「光渦レーザーによる磁性制御の展望」
佐藤・藤田、光学2018年4月号「光渦レーザーによる超高速ナノスピン構造制御」
佐藤、パリティ2019年3月号(予定)
H. Ishizuka and M. Sato, arXov:1811.11515.

KEK研究会「量子多体系の素核・物性クロスオーバー」@KEK 16th Jan. 2019

Outline

光渦ビーム

1, What is **optical vortex (vortex beam)**?

2, Chiral magnets and magnetic defects

3, Application of vortex beams to (chiral) magnets

スピン流版太陽電池

4, Photo-induced electric and spin current

5, Spin-current version of solar cells

6, Summary

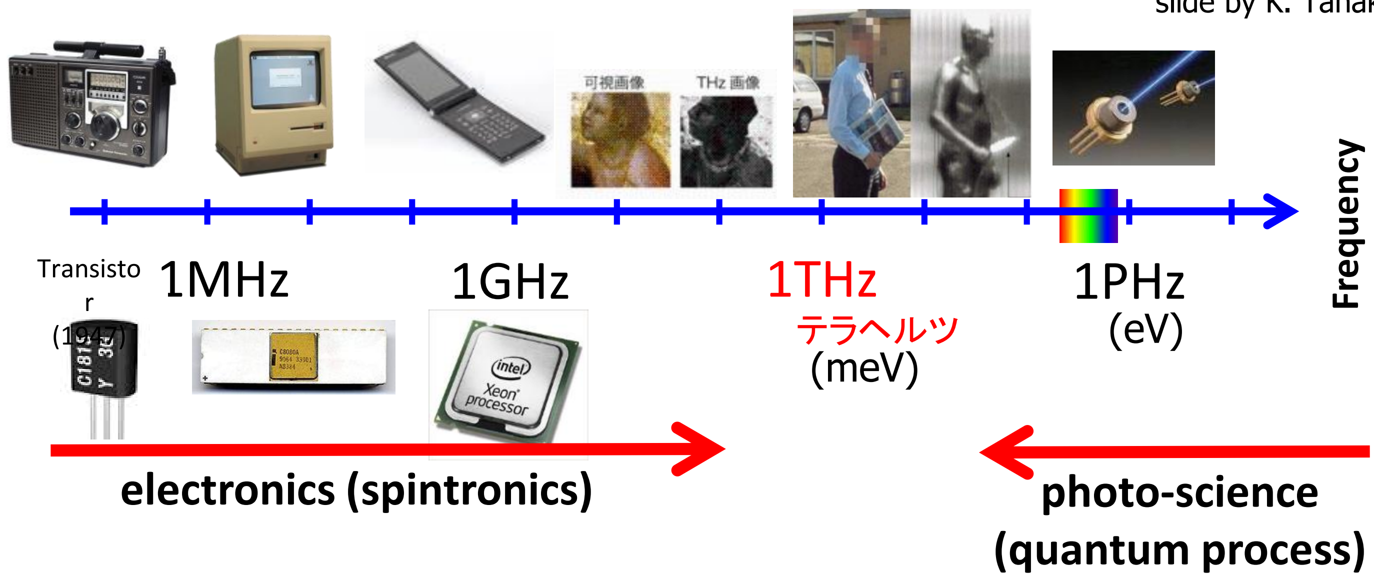
Recent development of laser science

laser science and laser-driven systems

Laser science has largely developed in recent years.
We can now use THz lasers as an external field for condensed matter.

Electronics vs photo-science
(spintronics)

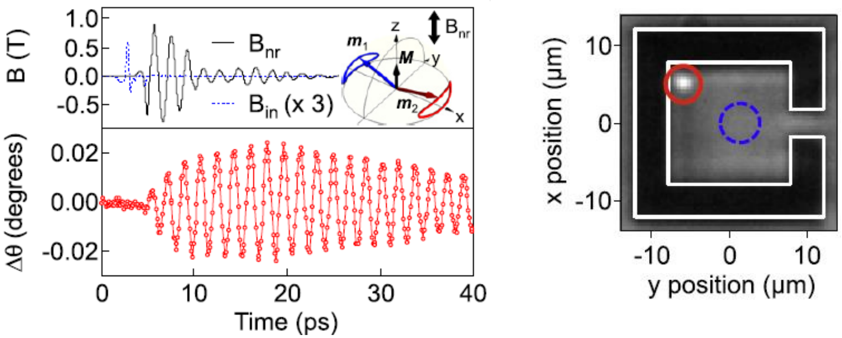
slide by K. Tanaka (Kyoto-U)



Energy scale of THz photons is comparable with
e.g., magnetic excitations, plasmons, phonons, superconducting gap, etc.

Magnet meets light (opto-spintronics)

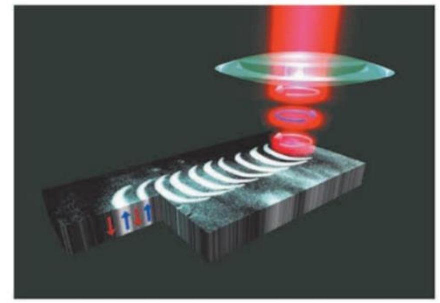
THz-laser driven magnetic resonance in an antiferromagnet $HoFeO_3$



Y. Mukai, H. Hirori, et al, New. J. Phys. 18, 013045 (2016).

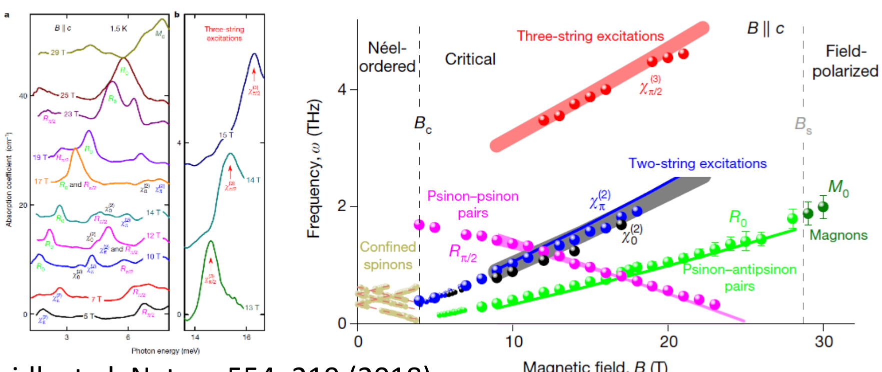
Laser induced (de)magnetization in a ferrimagnetic alloy $Gd_{22}Fe_{74.6}Co_{3.4}$

Inverse
Fraday effect (?)
by a circularly
polarized laser
(visible light)



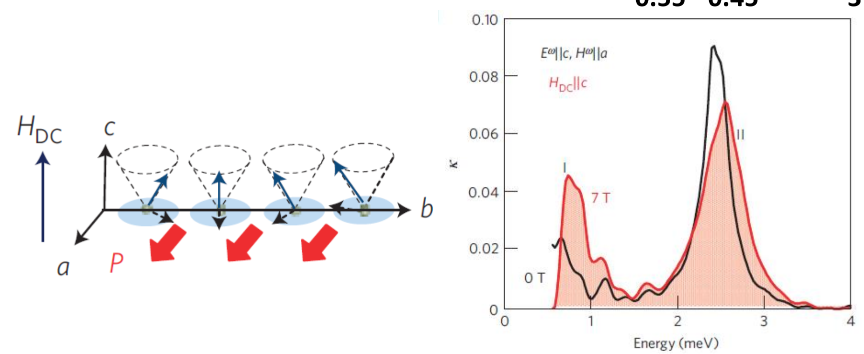
C. D. Stanciu, Th. Rasing, et al., PRL99, 047601 (2007).

THz-wave transmission spectrum by magnetic excitations in a 1D Ising-like magnet $SrCo_2V_2O_8$



A. Loidl, et al, Nature 554, 219 (2018).

THz-wave driven electromagnon resonance in a multiferroics $Eu_{0.55}Y_{0.45}MnO_3$



Y. Takahashi, et al, Nature Phys. 8, 121 (2012).

What is vortex beams (optical vortex)?
光渦

Hiroyuki Fujita (PhD student in ISSP, U. Tokyo)

光渦

What is optical vortex (vortex beam)?

軌道角運動量

Vortex beam : laser beam carrying intrinsic orbital angular momentum

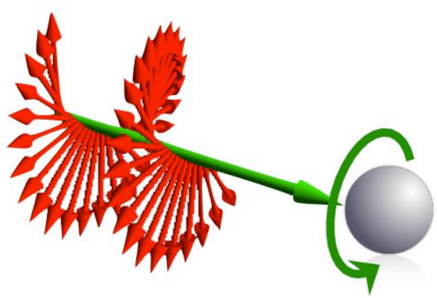
First proposed by Allen, *et al* (1992)

- Orbital angular momentum (OAM) ≠ spin of photons (polarization)
- Non-vanishing intrinsic OAM leads to spiral phase structure
- Total angular momentum J = S (spin) + L (intrinsic OAM)

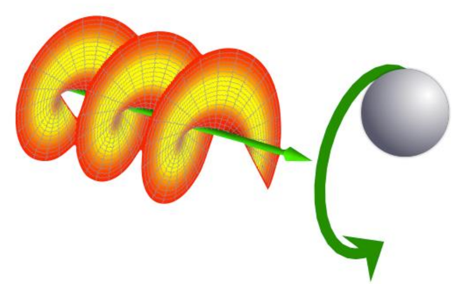
Image of orbital angular momentum of light

自転運動(局所的)

重心運動(大域的)



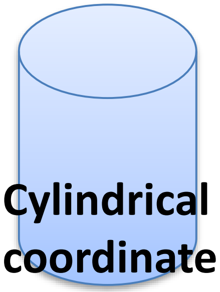
Spin
(left or right handed)



Orbital angular momentum (OAM)

Mathematical definition of optical vortex

Starting point: Maxwell's equation in vacuum $$\left(\Delta + \frac{\omega^2}{c^2}\right)\vec{E} = 0$$



— **Fixed the polarization vector** $$\vec{E} = \vec{e}_{\rm pol}\psi(\vec{r})$$

— **Wave propagation along the z-axis.** $$\psi(\vec{r}) = e^{ik_z z}u(\vec{r})$$

— **Paraxial approximation** $$\left|\frac{\partial^2 u}{\partial z^2}\right| \ll \left|\frac{\partial^2 u}{\partial x^2}\right|, \left|\frac{\partial^2 u}{\partial y^2}\right|, \quad \left|\frac{\partial^2 u}{\partial z^2}\right| \ll 2\frac{\omega}{c}\left|\frac{\partial u}{\partial z}\right|$$

Laguerre-Gaussian (LG) modes

$$u^{LG}(\rho,\phi,0) = \frac{\left(\frac{\rho}{w}\right)^{|m|} e^{-\frac{\rho^2}{w^2}+im\phi} L_p^{|m|}\left(\frac{2\rho^2}{w^2}\right)}{\sqrt{|w|}}$$ at focal plane (z = 0)

Two integers (m and p) characterize the modes

Waist *w* : size of vortex beam

U^{LG} is the eigenstate of $L^z = -i\hbar\partial/\partial\phi$

$$L^z u^{LG} = \hbar m u^{LG}$$

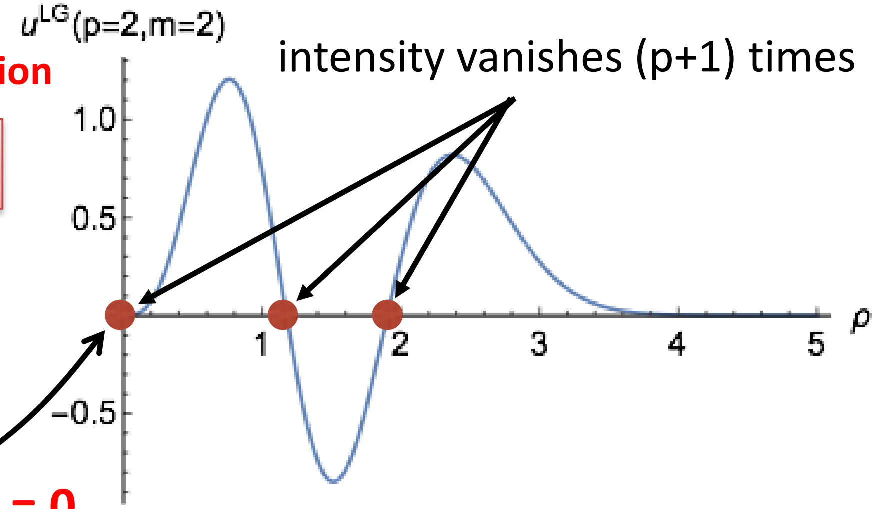
Orbital angular momentum (OAM)

- **m=0 mode : usual Gaussian beam**
- **Finite-m mode : optical vortex (vortex beam)**

Spatial profile of optical vortex (vortex beam)

Generalized Laguerre function

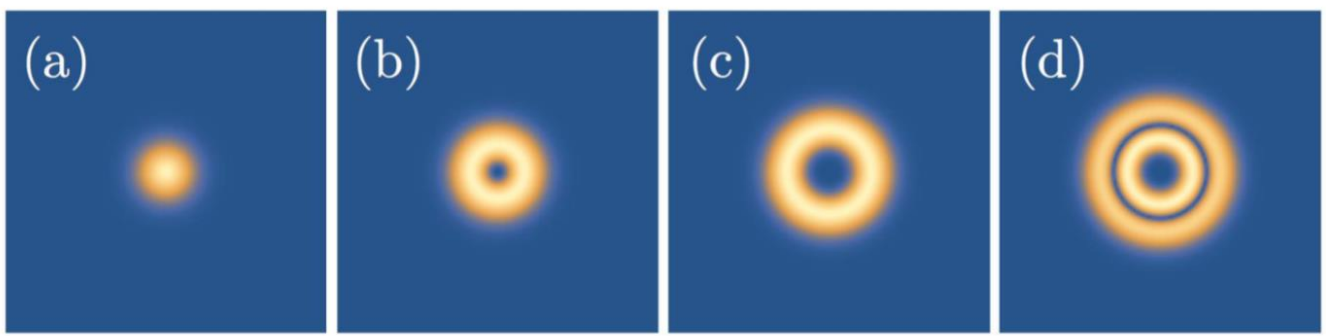
$$u^{LG}(\rho,\phi,0) = \frac{\left(\frac{\rho}{w}\right)^{|m|} e^{-\frac{\rho^2}{w^2}+im\phi} L_p^{|m|}\left(\frac{2\rho^2}{w^2}\right)}{\sqrt{|w|}}$$



Non-zero OAM requires
the topological singularity at the center ρ = 0.

(1) Intensity profile of LG modes at z=0 $|u^{LG}(z=0)|^2$

: Radial dependence

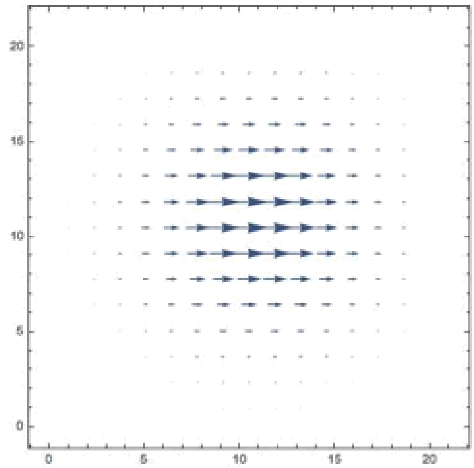


$m=0,\ p=0$ $m=2,\ p=0$ $m=5,\ p=0$ $m=5,\ p=1$

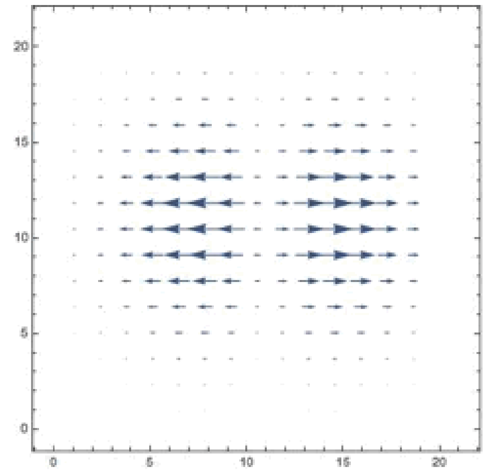
Gaussian beam **Vortex beams : (p+1)-fold ring structure**

(2) Electric (magnetic) field profile of LG modes

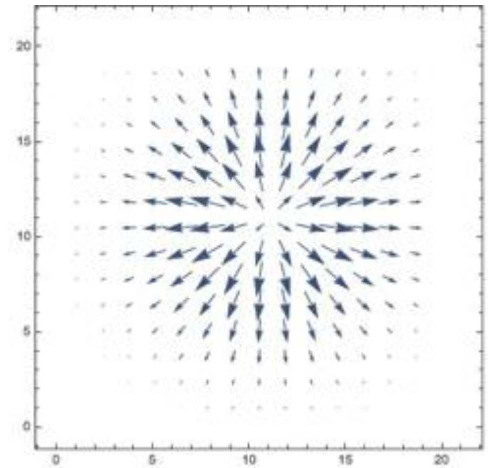
Circularly polarized Gaussian beam (円偏光ガウスビーム)



Linearly polarized OV (直線偏光光渦ビーム)



Circularly polarized OV (円偏光光渦ビーム)



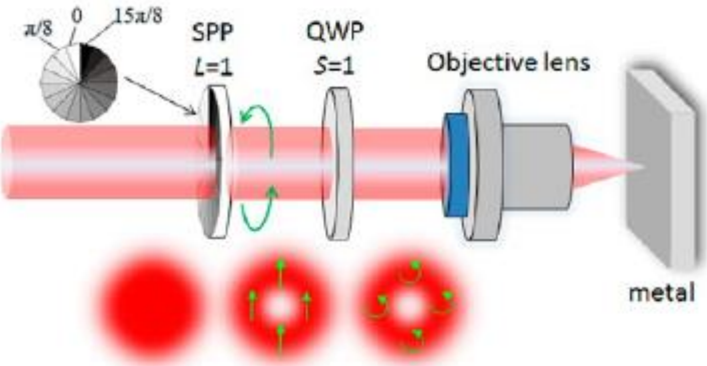
Angle ϕ (phase) dependence

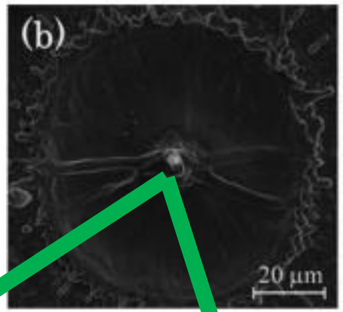
ρ=0 : singular point

Applications of vortex beams (optical vortex)

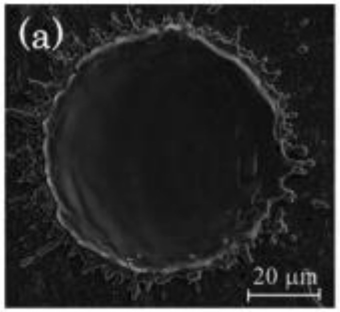
E.g.) Vaporize or melt the target material with vortex beams

Omatsu, *et al*, Nano Lett.(2012); PRL (2013)

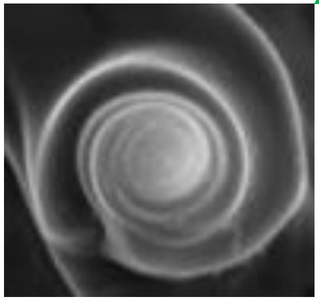




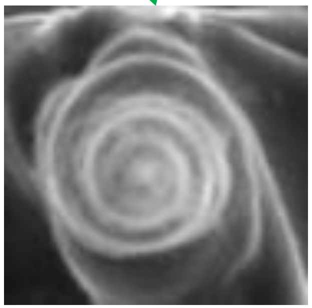
optical vortex



circularly polarized laser



positive OAM



negative OAM

- Printing the chiral phase structure onto materials
- We want to propose a way of controlling magnetic or electric properties of solids with vortex beams

Chiral magnets and magnetic defects

What are the proper targets for vortex beams?

Characteristics of vortex beams : spatial profile (ring structure)

- Candidates : Electron systems with stable nano structures
- Topological defects (トポロジカル欠陥) exist in films of chiral magnets

Phase diagram of Cu_2OSeO_3

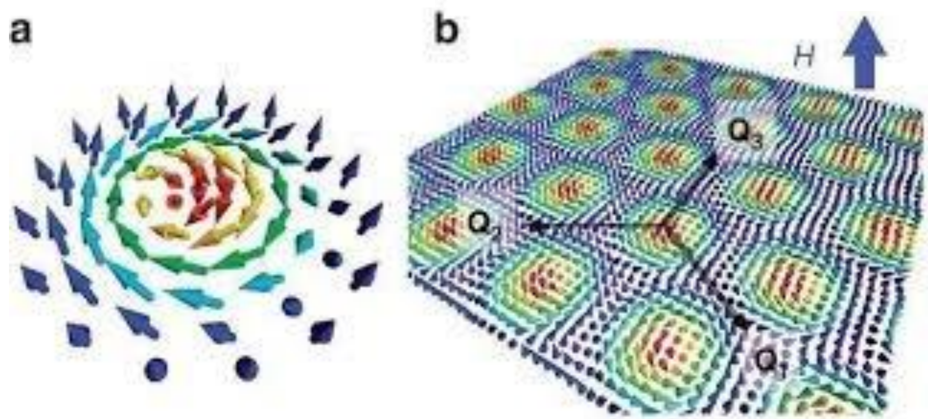
Chiral ferromagnets　(カイラル強磁性体)

e.g. B20-type alloy MnSi

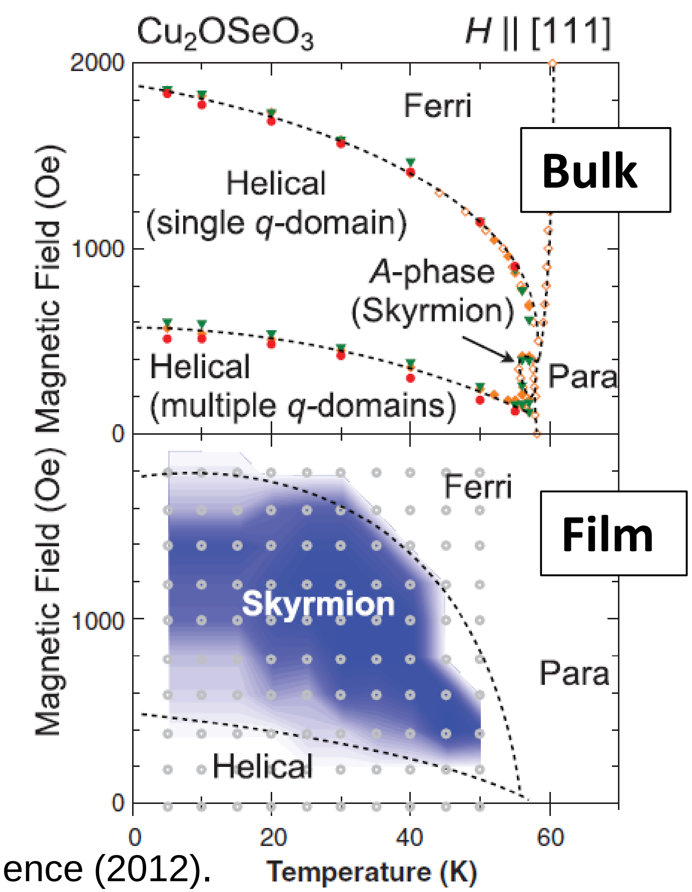
Multiferroic material Cu_2OSeO_3

Skyrmion structure (スキルミオン)

Skyrmion lattice phase (スキルミオン格子相)



1-1000 nm



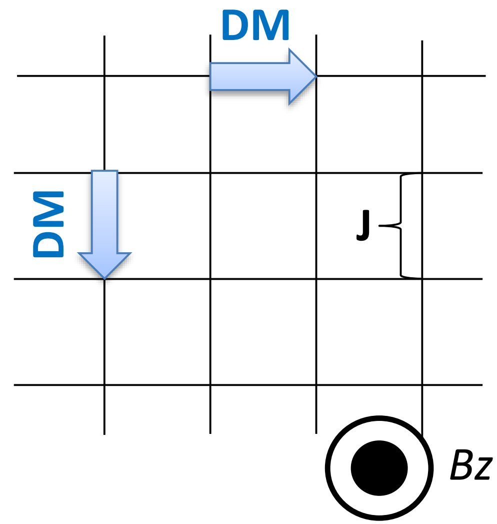
S.Seki, *et al*. Science (2012).

Simple classical spin model of 2D chiral ferromagnet

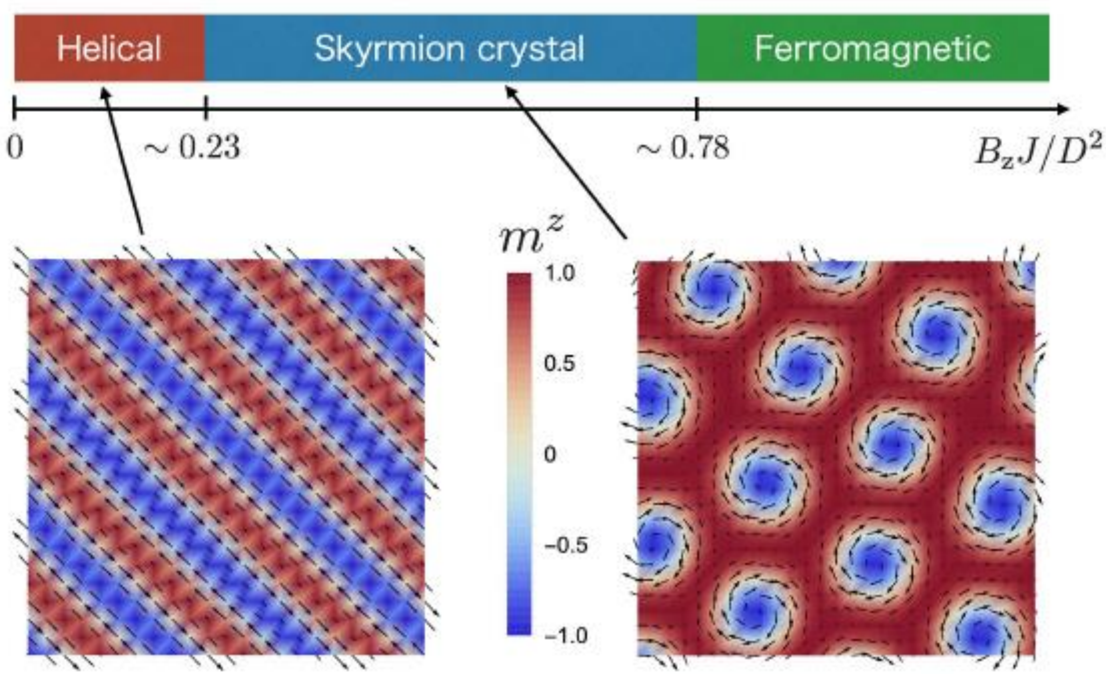
$$H = -J\sum_{\vec{r}} \vec{m}_{\vec{r}} \cdot (\vec{m}_{\vec{r}+a\vec{e}_x} + \vec{m}_{\vec{r}+a\vec{e}_x})$$ **Ferro exchange**

$$+\sum_{i,\vec{r}} \vec{D}_i \cdot (\vec{m}_{\vec{r}} \times \vec{m}_{\vec{r}+a\vec{e}_i})$$ **DM interaction**

$$-B_z \sum_{\vec{r}} m^z_{\vec{r}}$$ **Zeeman interaction**



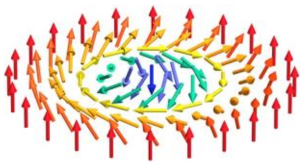
Ground-state phase diagram



Mismatch between chiral magnet and vortex beams

(1) Sizes of vortex beam and spin textures (skyrmions)

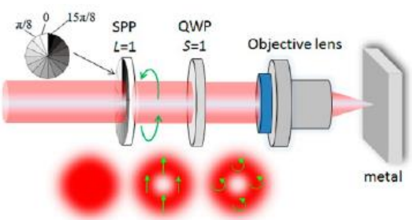
Size of skyrmions ～ 10-1000 nm

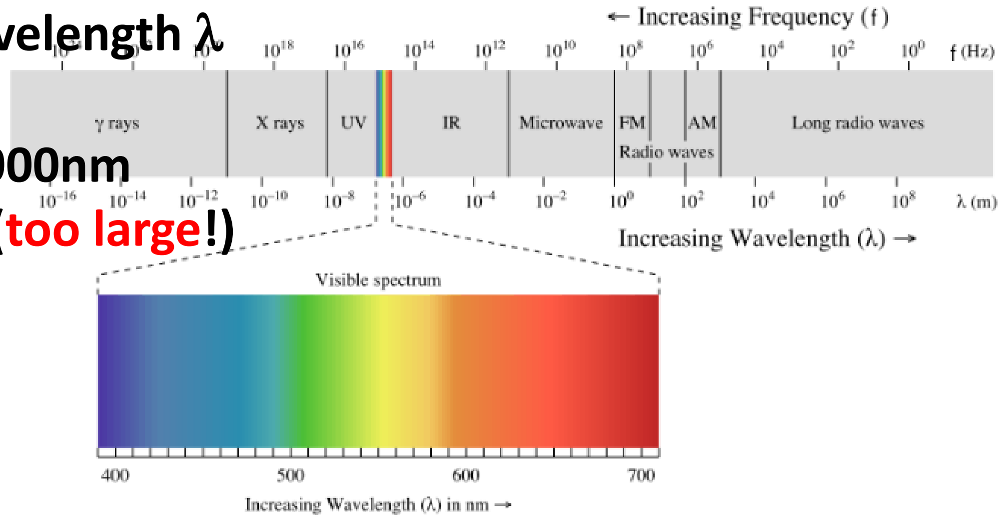


Diffraction limit of laser ～ wavelength λ

Ultraviolet-visible laser λ=10-1000nm

Infrared-THz laser λ= 1-100μm (too large!)





(2) Comparison between frequency of vortex beams and spin dynamics

Typical time scale of spin dynamics ～ Giga-Tera ($10^{9\text{-}12}$) Hz order

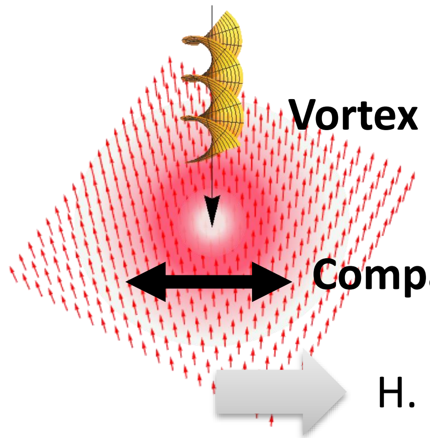
Frequency of visible laser ～ $10^{14\text{-}16}$ Hz order (too fast!)

Frequency of THz laser ～ 10^{12} Hz order

How to avoid the mismatch between chiral magnet and vortex beam

(1) Consider the heating effect driven by Ultraviolet-visible vortex beams

Indirect coupling between vortex beam and electron spins

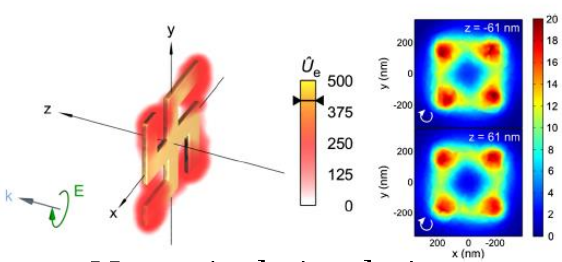


Vortex beams in ultraviolet or visible light range

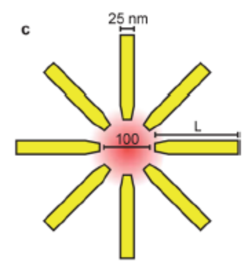
Comparable with size of skyrmions

H. Fujita and M. Sato, PRB95, 054421 (2017)

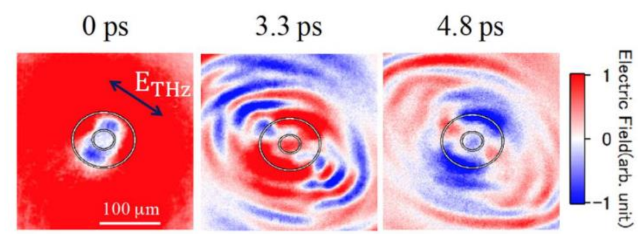
(2) Generating nano-focused Terahetz (THz) vortex beams by using techniques based on plasmonics and nanomaterials.



Numerical simulation
M. Schoaferling, et al,
PRX**2**, 031010 (2012).



Numerical simulation
Heeres and Zwiller,
Nano Lett. 14, 4598 (2014).



Realization of Focused THz VB
T. Arikawa, S. Morimoto, and K. Tanaka,
Opt. Exp. **25**, 13728 (2017).

H. Fujita and M. Sato, PRB96, 040706(R) (2017)

Application of vortex beams to magnets

H. Fujita and M. Sato, PRB95, 054421 (2017).

H. Fujita and M. Sato, PRB96, 040706(R) (2017).

Heating effect of vortex beams

H. Fujita and M. Sato, PRB95, 054421 (2017).

Ultrafast way of generating nano spin textures via heating effects of vortex beams

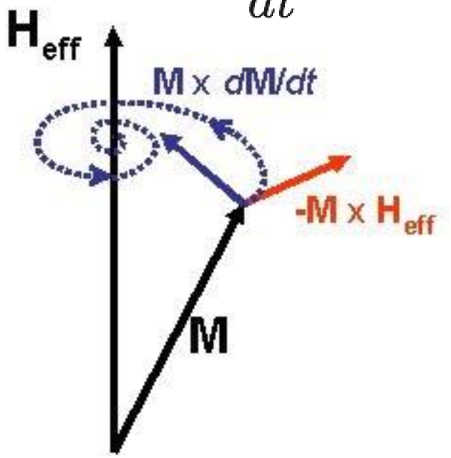
Numerical method : Stochastic Landau-Lifshitz-Gilbert equation

$$\frac{d\vec{M}_{\vec{r}}}{dt} = -\gamma \vec{M}_{\vec{r}} \times \left(-\frac{\partial H}{\partial \vec{M}_{\vec{r}}} + \vec{h}_{T(\vec{r})}(t) \right) + \alpha \vec{M}_{\vec{r}} \times \frac{d\vec{M}_{\vec{r}}}{dt}$$

Effective field (Torque)

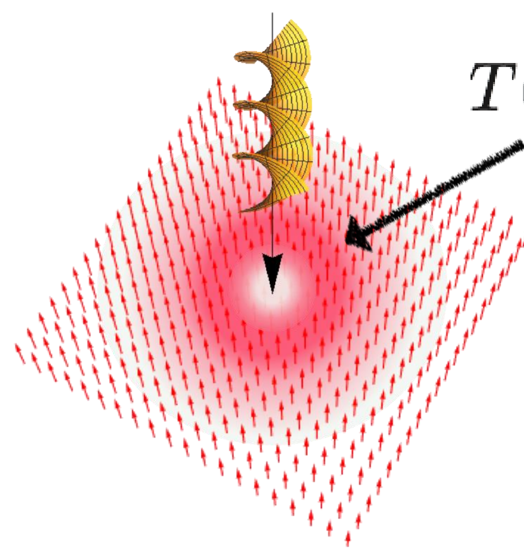
Random field (Temperature)

Gilbert damping



Δt=1 : 0.1-1 pico second

Vortex-beam induced temperature profile

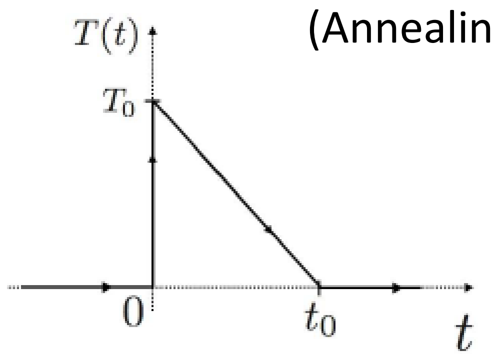


$$T(\vec{r}) \propto |u^{LG}(z=0)|^2$$

beam intensity

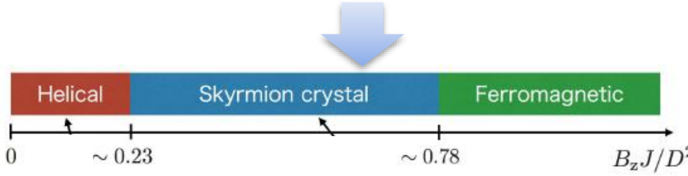
Time evolution of temperature

(Annealing type)



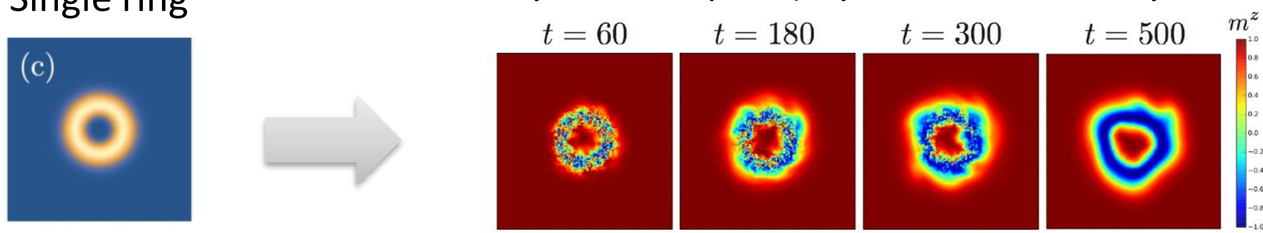
Typical numerical results

Initial state : metastable ferromagnetic state



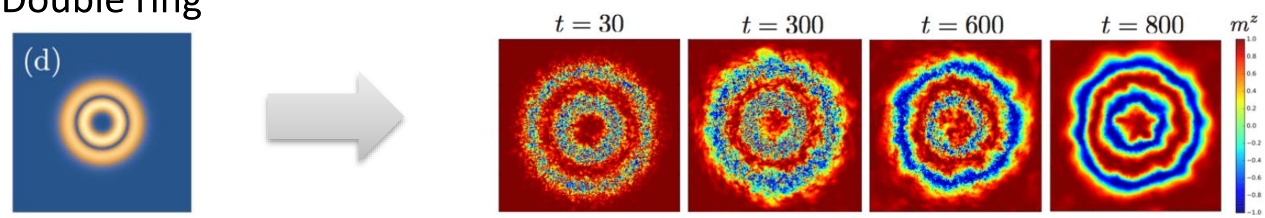
Single ring

Skyrmion duplex (skyrmion and antiskyrmion)



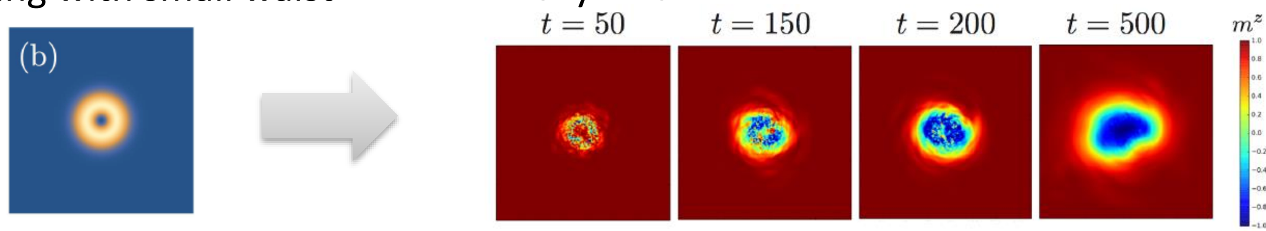
Double ring

Skyrmion quadplex (2-skyrmion and 2-antiskyrmion)



Single ring with small waist

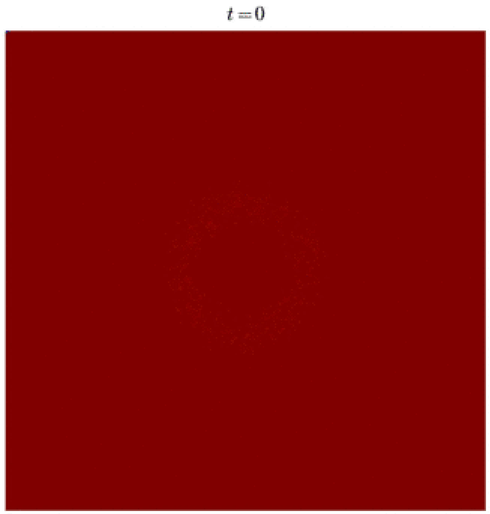
Skyrmion



We can print vortex beam profile on magnets !

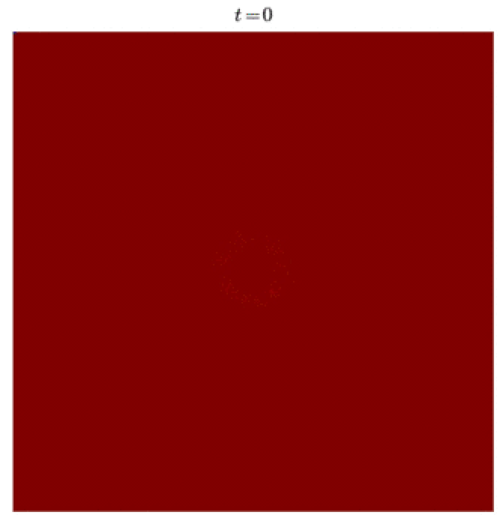
Processes of creating magnetic defects by heating effect of VB

Single ring



Skyrmionium (skyrmion duplex)

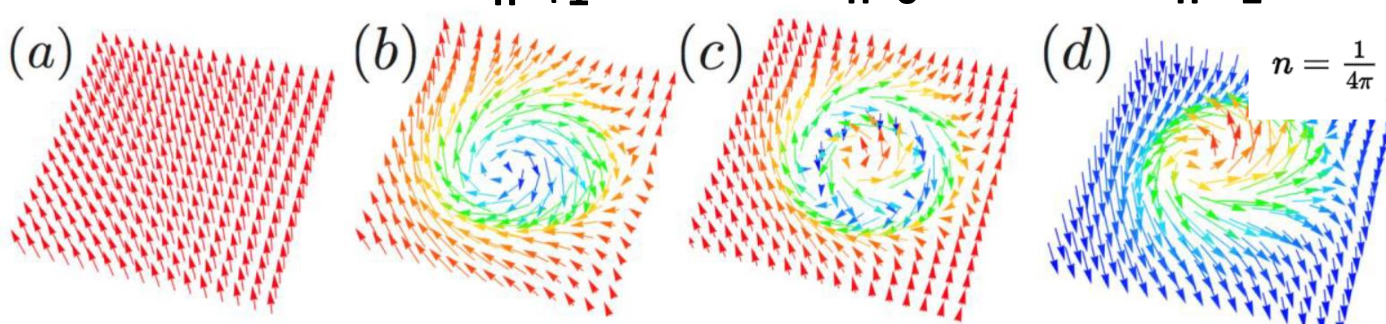
single ring with small waist



Skyrmion

Δt=1 : 0.1-1 pico second

n=+1 **n=0** **n=-1**



$$n = \frac{1}{4\pi} \int M \cdot \left(\frac{\partial M}{\partial x} \times \frac{\partial M}{\partial y} \right) \mathrm{d}x\mathrm{d}y$$

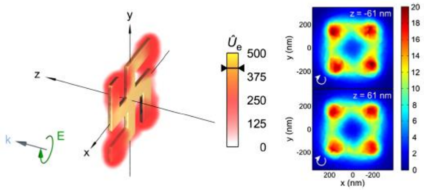
Ferromagnetic state **Skyrmion** **Skyrmionium** **Anti-skyrmion**

Bound state of skyrmion and antiskyrmion

Ultrafast control of nano spin structures with THz vortex beams

H. Fujita and M. Sato, PRB96, 040706(R) (2017).

(2) Generating nano-focused THz vortex beams by using techniques based on plasmonics and nanomaterials.



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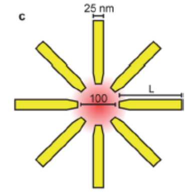

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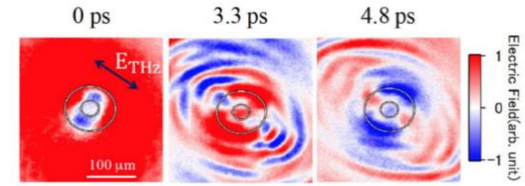

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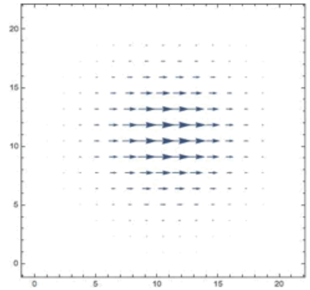
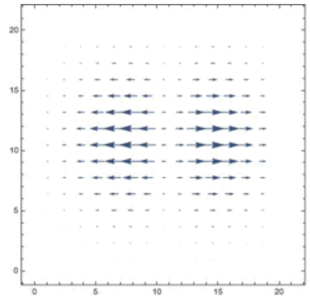
→ H. Fujita and M. Sato, PRB96, 040706(R) (2017)

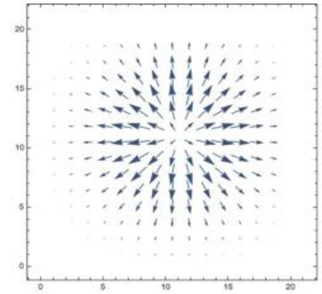
Circularly polarized Gaussian beam



Linearly polarized Vortex beam



Circularly polarized Vortex beam



Direct coupling between THz vortex beam and magnetic moments
Angular (phase) dependence of vortex beam → Rich physics

Application of THz vortex beam to ferromagnets

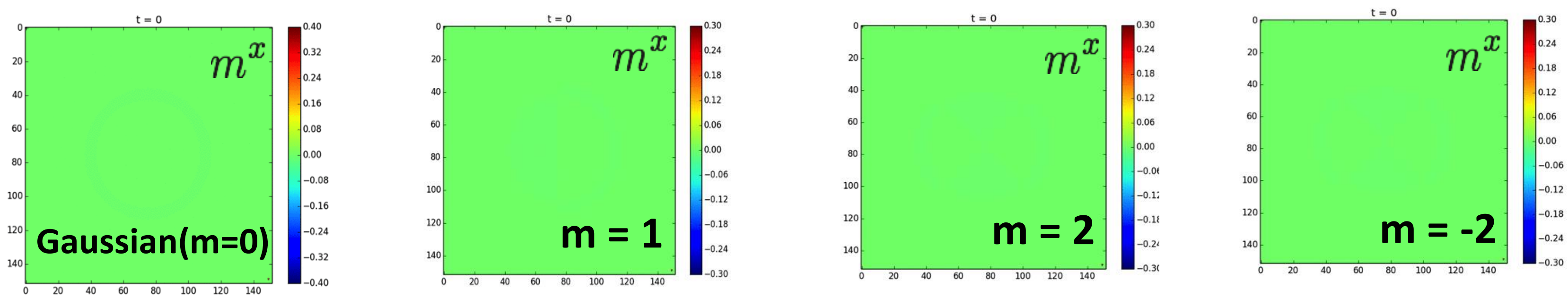
Ferromagnet under a linearly polarized THz vortex beam

$$H = -J \sum_{\vec{r}} \vec{m}_{\vec{r}} \cdot \left(\vec{m}_{\vec{r}+a\vec{e}_x} + \vec{m}_{\vec{r}+a\vec{e}_y} \right) - B_z \sum_{\vec{r}} m^z_{\vec{r}} - \sum_{\vec{r}} \vec{B}_{\mathrm{OV}}(\vec{r}) \cdot \vec{m}_{\vec{r}}$$

Ferromagnetic interaction — Static Zeeman coupling — Zeeman coupling of vortex beam

Based on LLG equation, we numerically analyze spin dynamics

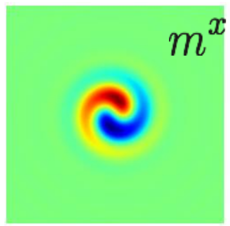
THz-laser driven magnetic resonance in a ferromagnet



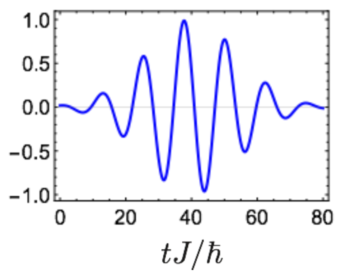
Information of orbital angular momentum is mapped to ferromagnets!

Vortex beam driven (transient) topological Hall effect

THz vortex beam driven FMR (Snap shot)

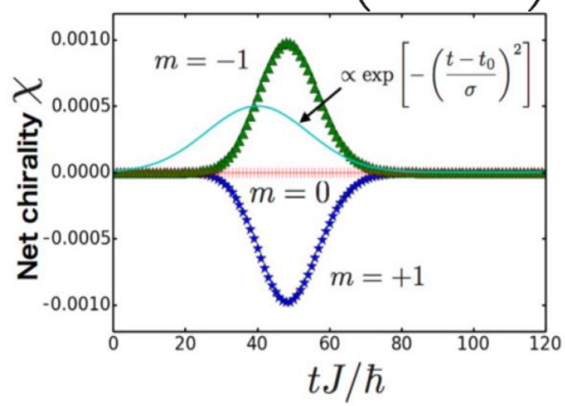


Magnetic field of THz pulse



Generation of scalar spin chirality (triple product of three spins)

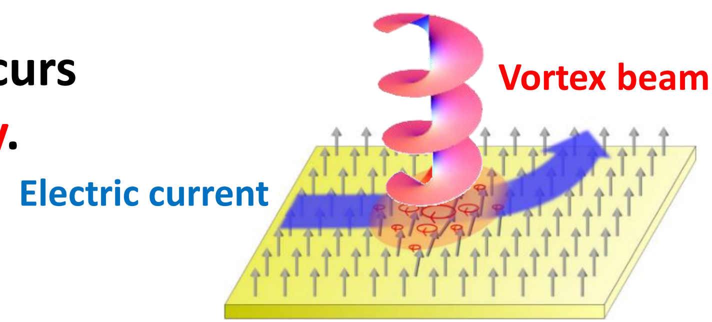
$$\chi_{i,j,k} = \vec{S}_i \cdot \left(\vec{S}_j \times \vec{S}_k \right)$$



Scalar spin chirality = non coplanar spin structure

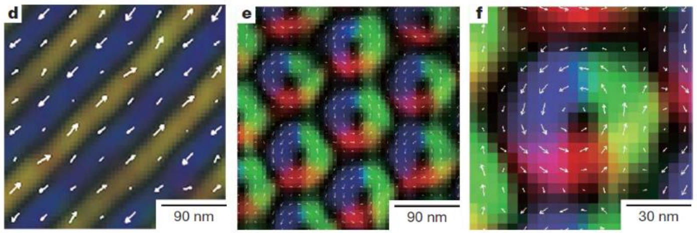
In metallic magnets, anomalous Hall effect occurs if the magnetic order has a scalar spin chirality.

K. Ohgushi, S. Murakami, and N. Nagaosa, PRB**62** (R) (2000).
G. Tatara and H. Kawamura, JPSJ**71**, 2613 (2002).



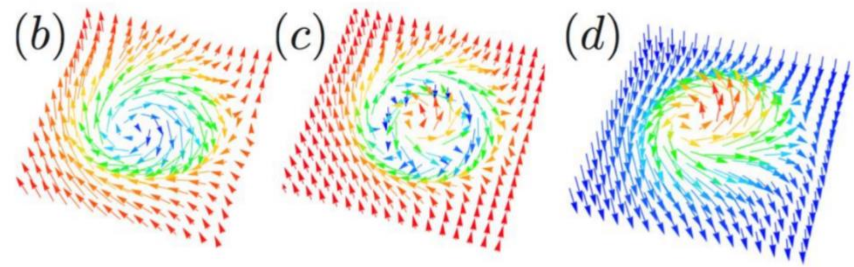
Vortex beam driven ultrafast Hall effect

Skyrmions in a film of chiral magnet $Fe_{0.5}Co_{0.5}Si$



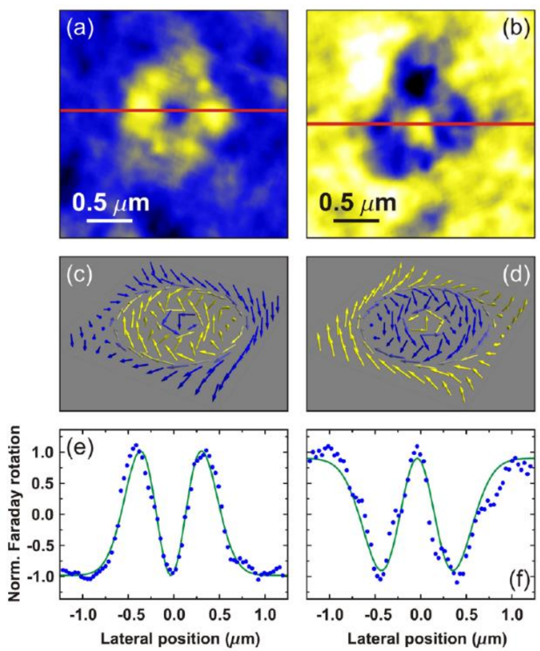
Yu, Tokura, et al, Science (2010).

Skyrmion **Skyrmionium** **Anti-skyrmion**



(Bound state of skyrmion and antiskyrmion)

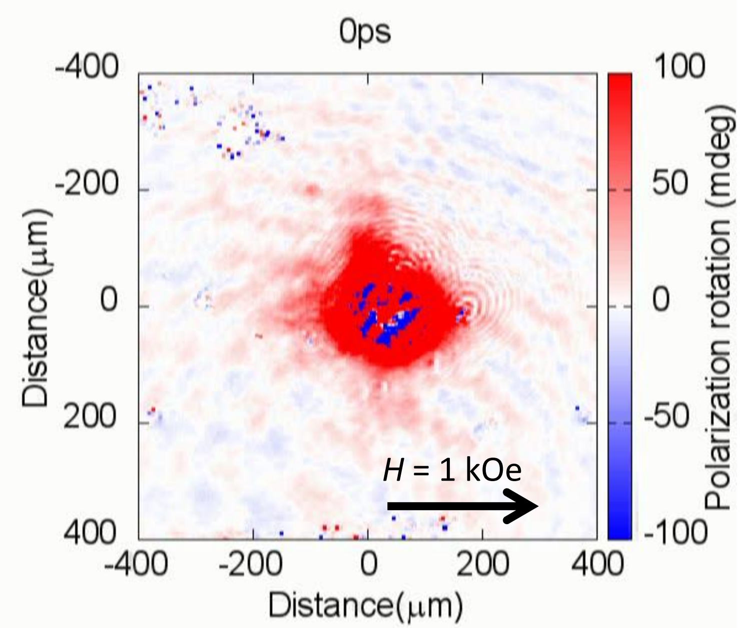
Skyrmioniums in a film of chiral magnet



Near-field Faraday rotation

Finazzi, Rasing, *et al*, PRL110 (2013).

Space-time resolved observation of laser-driven magnetization dynamics



By T. Satoh (Kyushu Univ.)

スピン流の整流効果

Spin-current rectification with linearly-polarized wave (Spin-current version of solar cell)

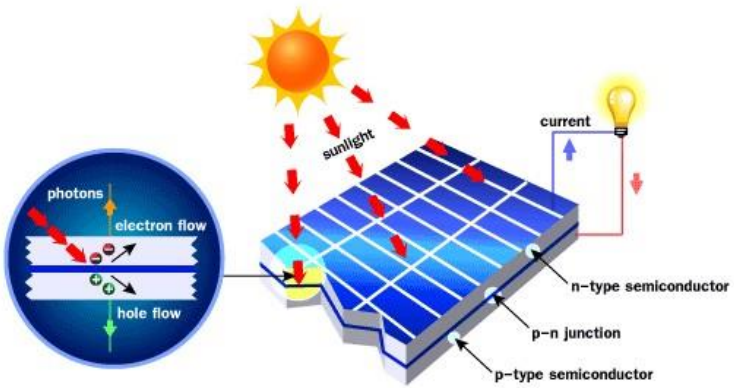
スピン流版太陽電池

H. Ishizuka and M. Sato, arXiv:1811.11515.

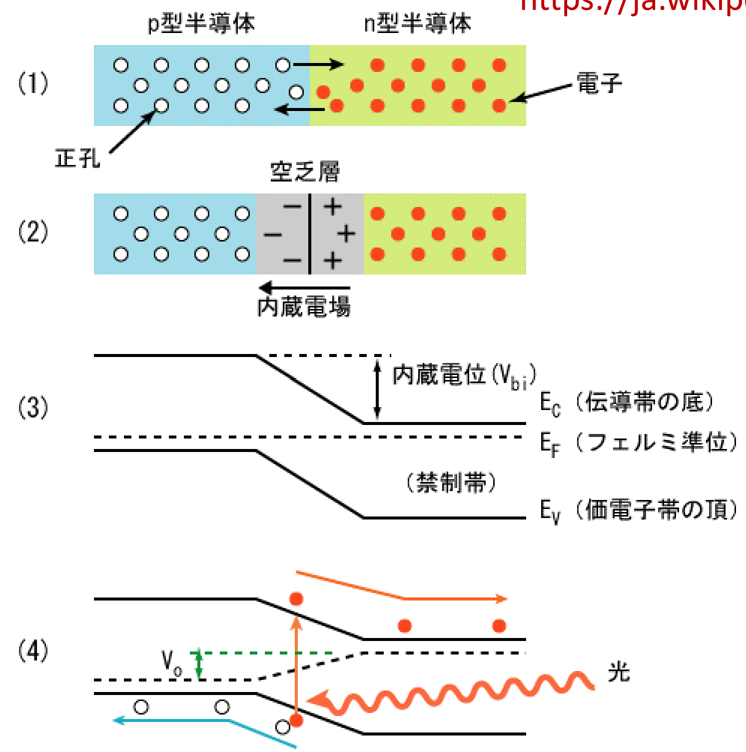
Hiroaki Ishizuka
(Dep. Applied Phys., Univ. Tokyo)

Photovoltaic Effect (a typical nonlinear optical phenomena)

Typical device using photovoltaic effect: solar cell (太陽電池)



https://ja.wikipedia.org



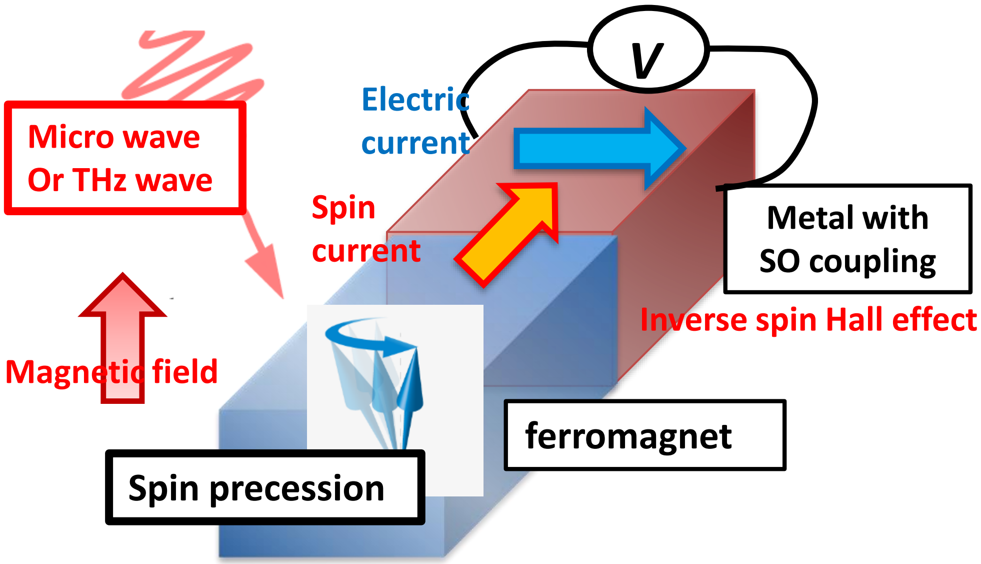
- Current induced by the drift of carriers.
- Physics governed by semiclassical motion of electrons and holes.

Inversion symmetry broken

Opto/ultrafast spintronics

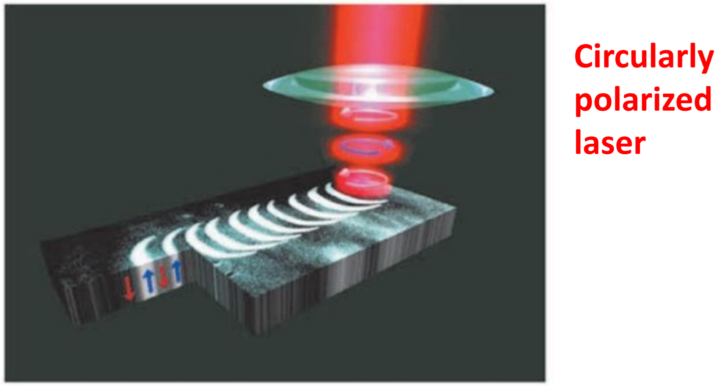
Various spintronic functions driven by electromagnetic waves have been explored intensively in recent years.

Spin pumping



Y. Kajiwara, E. Saitoh, et al., Nature 464, 262 (2010).

Laser induced (de)magnetization



C. D. Stanciu, et al., Phys. Rev. Lett. 99, 047601 (2007).

Symmetry argument for DC photovoltaic effect

2nd-order optical response of DC electric current

$$J_\alpha(\omega = 0) = \sigma^{\alpha}_{\beta\gamma} E_\beta(\omega) E_\gamma(-\omega) \quad \rightarrow \quad J_\alpha(\omega = 0) = -\sigma^{\alpha}_{\beta\gamma} E_\beta(\omega) E_\gamma(-\omega)$$

Nonlinear conductivity

Inversion operation

External
AC electric field

broken inversion symmetry necessary

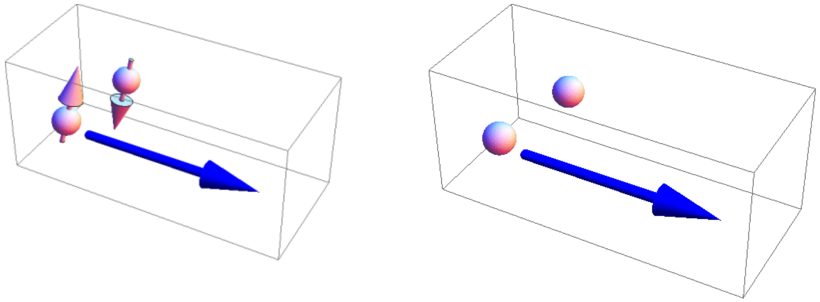
Is it possible to consider the spin current version of photovoltaic effect?

Yes!

Semiconductors	→	Magnetic insulators
Electric current	→	Spin current
Visible light (PHz AC electric field)	→	GHz or THz electromagnetic waves

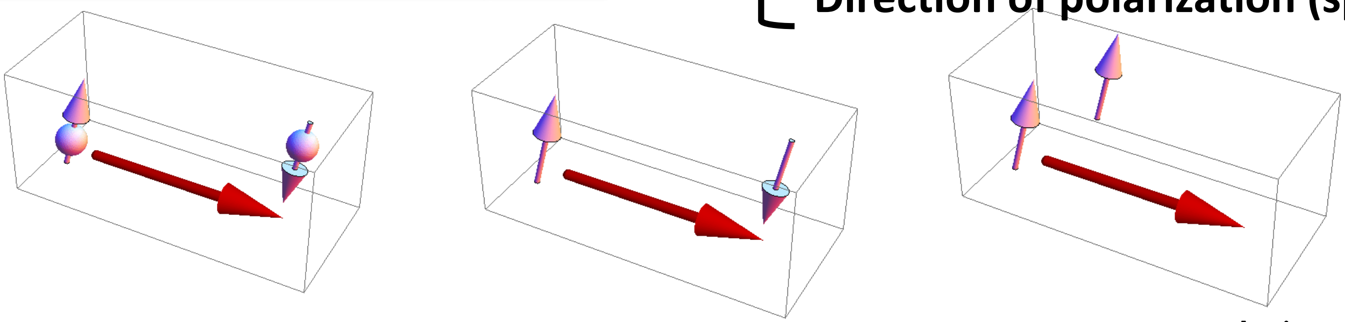
Spin current : flow of (spin) angular momentum

Electric current : Flow of charge



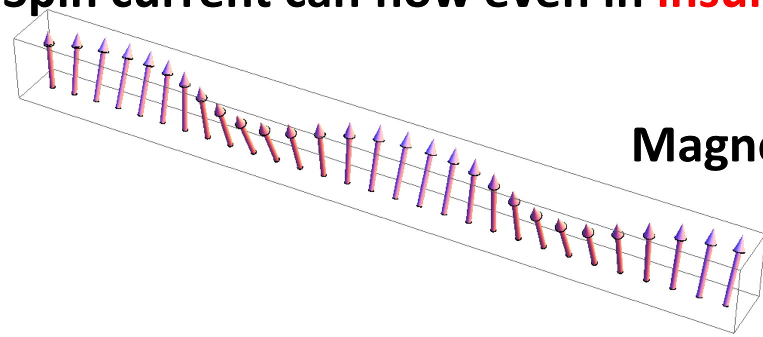
Spin current : Flow of spin

- Direction of flow
- Direction of polarization (spin)



Animation by Prof. M. Matsuo

Spin current can flow even in insulators.

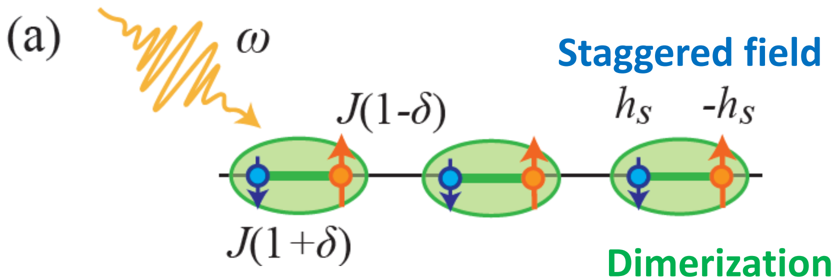


Magnon spin current in a ferromagnetic insulator

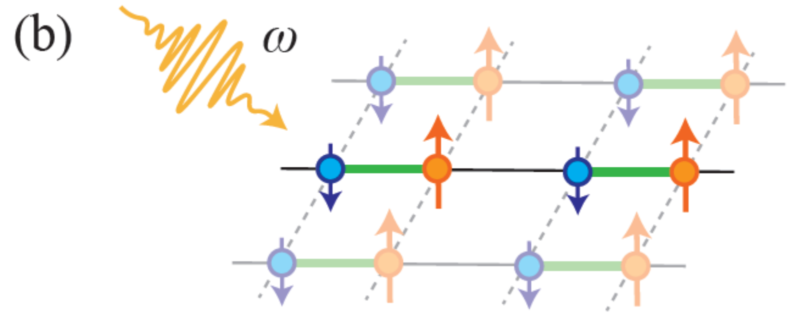
Our model (quantum spin system)

As a simple but realistic example,
we consider a noncentrosymmetric (inversion-asymmetric) quantum spin chain model.

Purely-1D spin chain



Weakly-coupled spin chains



Spin chain model

Dimerization

$$H = \sum_i J(1 + (-1)^i \delta)(S_i^x S_{i+1}^x + S_i^y S_{i+1}^y) - \sum_i (h + (-1)^i h_s) S_i^z .$$

Staggered field

Jordan-Wigner (JW) transform

Fermion chain model

$$H = \sum_i \frac{J(1 + (-1)^i \delta)}{2} \left(c_{i+1}^\dagger c_i + c_i^\dagger c_{i+1} \right) + (h + (-1)^i h_s) n_i .$$

Variety of spin-light couplings

Inverse DM interaction $H_{\mathrm{iDM}} = E_y(t)\sum_i (p + (-1)^i p_s)\,(\boldsymbol{S}_i \times \boldsymbol{S}_{i+1})^z$

Zeeman interaction $H_{\mathrm{Z}} = -B(t)\sum_i (\eta - (-1)^i \eta_s) S_i^z$

Magnetostriction $H_{\mathrm{ms}} = E_x(t)\sum_i \{A + (-1)^i A_s\}(S_i^x S_{i+1}^x + S_i^y S_{i+1}^y)$

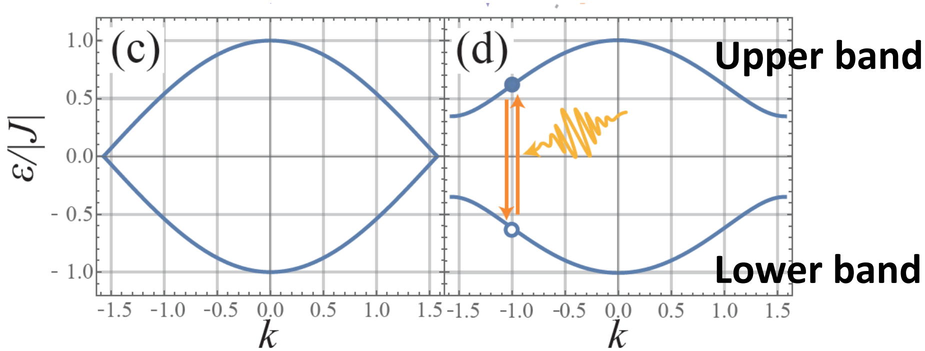
Electron system : minimal coupling $\frac{1}{2m}\boldsymbol{p}^2 \rightarrow \frac{1}{2m}(\boldsymbol{p} - e\boldsymbol{A})^2$

Without SO coupling

Unique form

Band structure of fermionized model

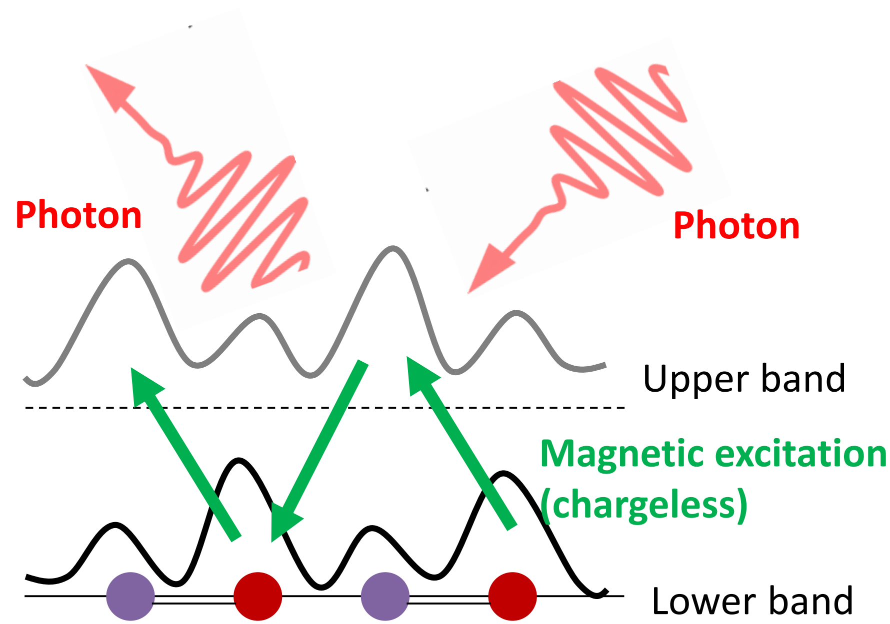
$$H = \sum_i \frac{J(1+(-1)^i\delta)}{2}\left(c_{i+1}^\dagger c_i + c_i^\dagger c_{i+1}\right) + (h+(-1)^i h_s)n_i.$$



Inversion symmetric **Inversion asymmetric**

Ground state = Zero magnetization $S^z_{tot}=0$
(Lower band is occupied)

Image of spin current flow



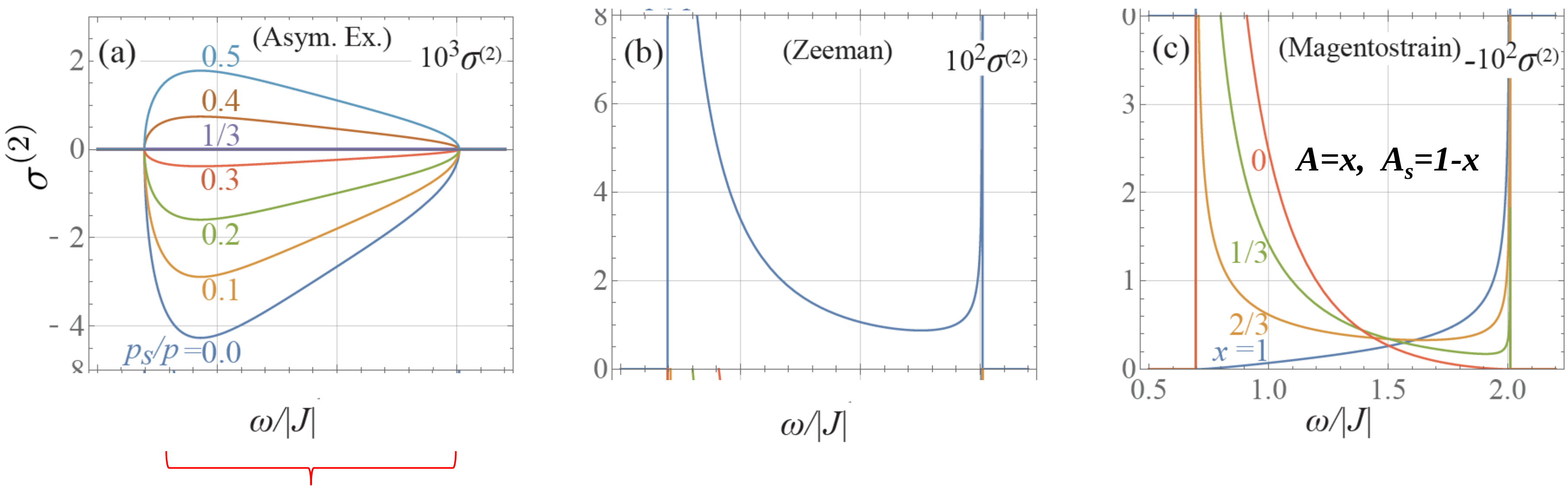
Calculation of nonlinear conductivity for spin current

Spin current operator $$J_{sc} \equiv \frac{1}{L}\sum_i J(1+(-1)^i\delta)(S^x_{i+1}S^y_i - S^y_{i+1}S^x_i)$$

Nonlinear conductivity $\sigma^{(2)}$ $$\langle J_{sc}\rangle = \sigma^{(2)}C^2$$

C: amplitude of electromagnetic wave

Inverse DM interaction | **Zeeman interaction** | **Magnetostriction**



Band width

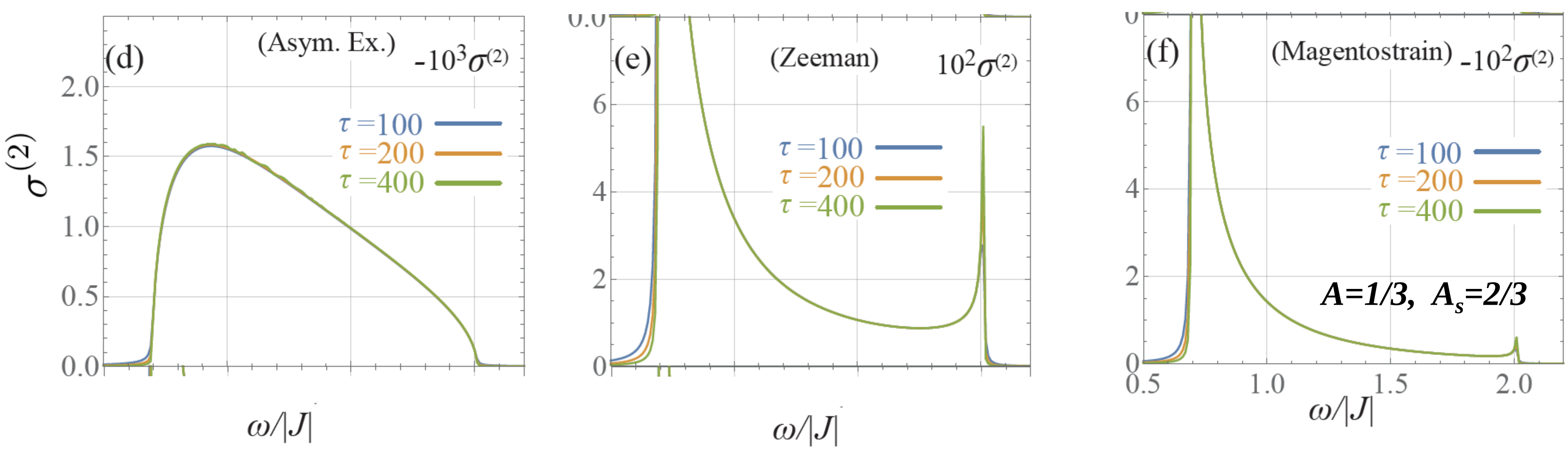
$J=1$, $\delta=1/3$, $h_s=0.1$

Life time of spinon in set to be infinity.

Three kinds of spin-light couplings all induce a finite spin current!

Insensitivity against spinon life time τ

Inverse DM interaction | **Zeeman interaction** | **Magnetostriction**



Our spin current is insensitive against the spinon life time τ (shift current like)

➡ **Long-distance propagation of spin current (small heating effect)**

Kraut-von Baltz formula (non-linear Kubo formula)

W. Kraut and R. von Baltz, Phys. Rev. B **19**, 1548 (1979); *ibid*. **23**, 5590 (1981).

$$
\begin{aligned}
\langle A\rangle(t) &= \left\langle \hat{\rho}(\beta)U(-\infty,t)\hat{A}_I(t)U(t,-\infty)\right\rangle, \\
&= \langle\psi_0|\,\hat{A}_I(t)\,|\psi_0\rangle + i\int_{-\infty}^{t} dt_1 \left\langle [H_{AS}(t_1),\hat{A}_I(t_1)]\right\rangle - \int_{t}^{-\infty} dt_1 \int_{-\infty}^{t} dt_2 \left\langle H_{AS}(t_1)\hat{A}_I(t)H_{AS}(t_2)\right\rangle \\
&\quad - \frac{1}{2}\int_{t}^{-\infty} dt_1 dt_2 \left\langle \bar{T}H_{AS}(t_1)H_{AS}(t_2)\hat{A}_I(t)\right\rangle - \frac{1}{2}\int_{-\infty}^{t} dt_1 dt_2 \left\langle \hat{A}_I(t)TH_{AS}(t_1)H_{AS}(t_2)\right\rangle .
\end{aligned}
$$

2nd-order response

$$
\langle A\rangle(\Omega) = \sum_{k_i}\int \frac{d\omega}{2\pi}\frac{(f_{k_1}-f_{k_2})B^{\mu}_{k_1k_2}}{\omega-\varepsilon_{k_2}+\varepsilon_{k_1}-i/(2\tau)}\left[\frac{B^{\nu}_{k_2k_3}A_{k_3k_1}}{\Omega+\varepsilon_{k_1}-\varepsilon_{k_3}-i/(2\tau)} - \frac{A_{k_2k_3}B^{\nu}_{k_3k_1}}{\Omega+\varepsilon_{k_3}-\varepsilon_{k_2}-i/(2\tau)}\right]F_{\mu}(\omega)F_{\nu}(\Omega-\omega)
$$

External field
With frequency ω

Quadratic AC conductivity with frequency Ω

$$
\sigma(\Omega;\omega,\Omega-\omega) = \frac{1}{2\pi}\sum_{k_i}\frac{(f_{k_1}-f_{k_2})B^{\mu}_{k_1k_2}}{\omega-\varepsilon_{k_2}+\varepsilon_{k_1}-i/(2\tau)}\left[\frac{B^{\nu}_{k_2k_3}A_{k_3k_1}}{\Omega+\varepsilon_{k_1}-\varepsilon_{k_3}-i/(2\tau)} - \frac{A_{k_2k_3}B^{\nu}_{k_3k_1}}{\Omega+\varepsilon_{k_3}-\varepsilon_{k_2}-i/(2\tau)}\right]
$$

Quadratic DC conductivity with Ω=0

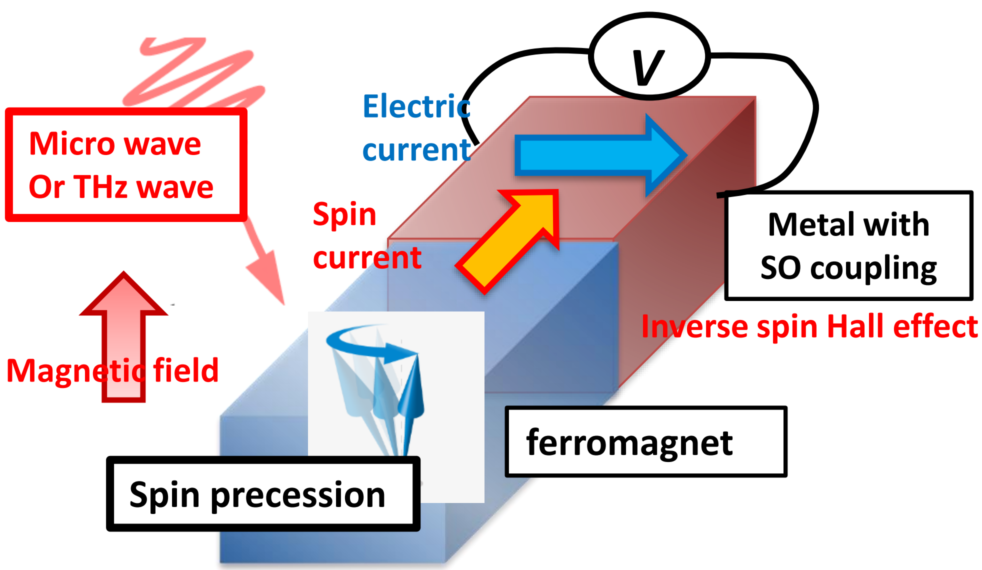
$$
\sigma(0;\omega,-\omega) = \frac{1}{2\pi}\sum_{k_i}\frac{(f_{k_1}-f_{k_2})B^{\mu}_{k_1k_2}}{\omega-\varepsilon_{k_2}+\varepsilon_{k_1}-i/(2\tau)}\left[\frac{B^{\nu}_{k_2k_3}A_{k_3k_1}}{\varepsilon_{k_1}-\varepsilon_{k_3}-i/(2\tau)} - \frac{A_{k_2k_3}B^{\nu}_{k_3k_1}}{\varepsilon_{k_3}-\varepsilon_{k_2}-i/(2\tau)}\right]
$$

We introduce relaxation time τ

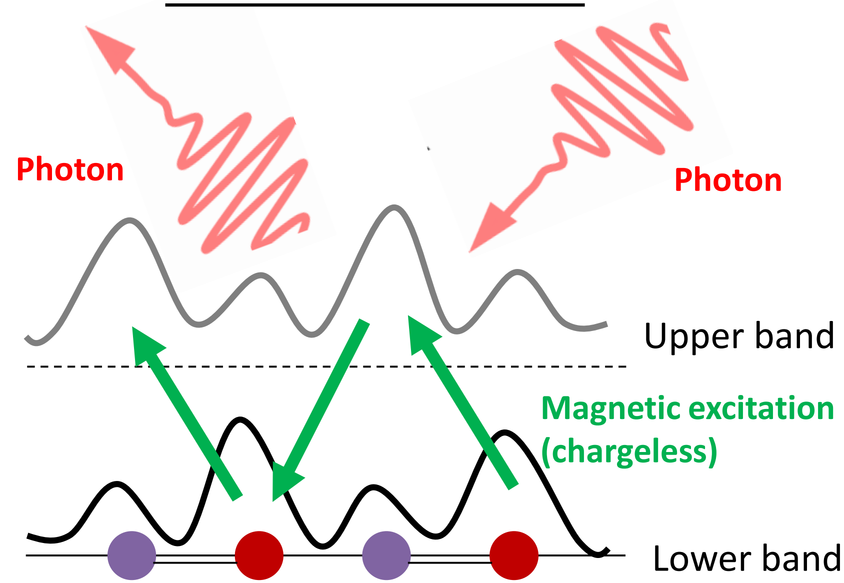
Difference from well-established spin pumping effect

(1) Insensitivity for the spinon life time (shift current like)
(2) Spin pumping : driven by a transverse AC field
Spin current rectification : can be driven by a longitudinal AC field
(3) Spin pumping : spin precession & magnon diffusion (ΔS^z : finite)
Spin current rectification : S^z is conserved (shift of magnetic excitations)

Spin pumping

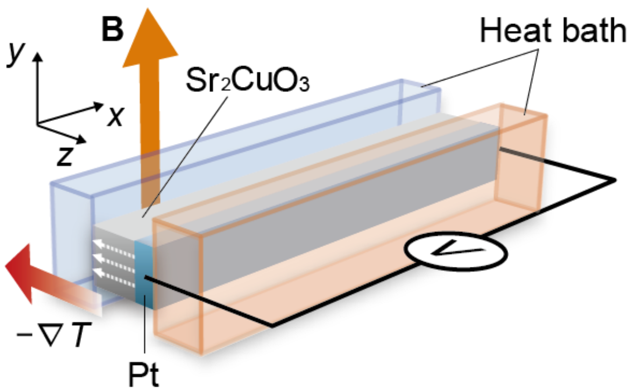


Our mechanism

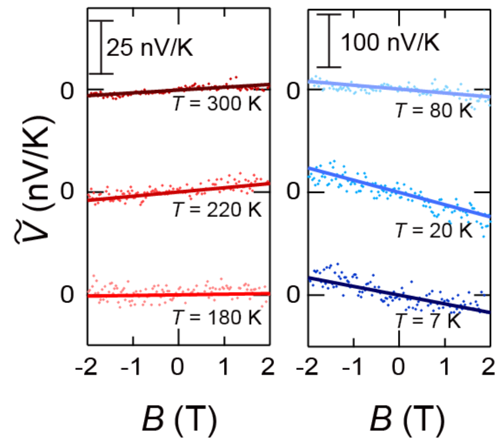


Required strength of electromagnetic waves

Previous study for spin current (spin Seebeck effect) in spin chain compound Sr_2RuO_3



D. Hirobe, MS, E. Saitoh, et al, Nature Phys 13, 30 (2017)



In order to observe the spin current with the same order as that of the spinon SSE

Inverse DM interaction	$E \sim 10^5 \ V/cm$
Zeeman interaction	$E \sim 10^4 \ V/cm$
Magnetostriction	$E \sim 10^2 \ V/cm$

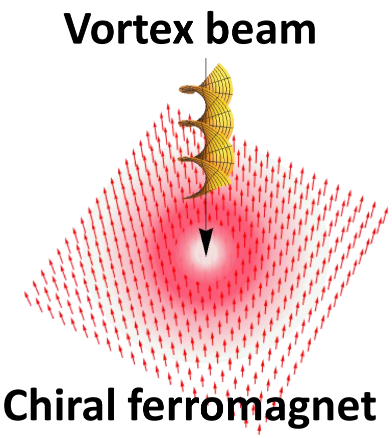
Summary

H. Fujita and M. Sato, PRB95, 054421 (2017); PRB96, 060407(R) (2017).

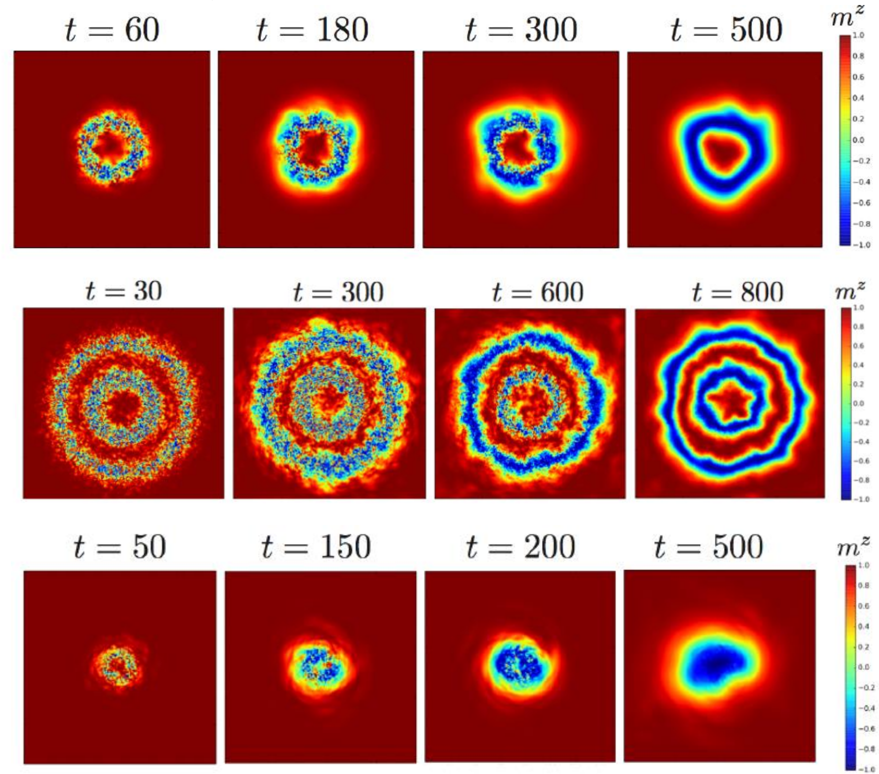
H. Ishizuka and M. Sato, arXiv:1811.11515.

Generation of topological spin textures by heating effect of VBs

H. Fujita and M. Sato, PRB95, 054421 (2017)
固体物理2018年9月号



Heating effect of vortex beams



Important messages

(a) Our method is faster than current-driven methods of generating skyrmions.

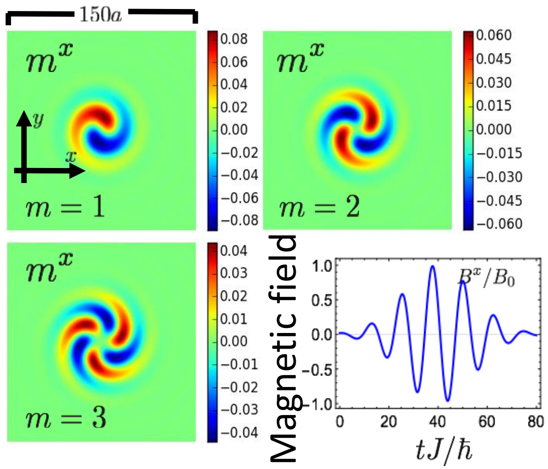
(b) Our method can be applied to both chiral ferro- and antiferro-magnets.

(c) Our method is probably used in both insulating and metallic magnets.

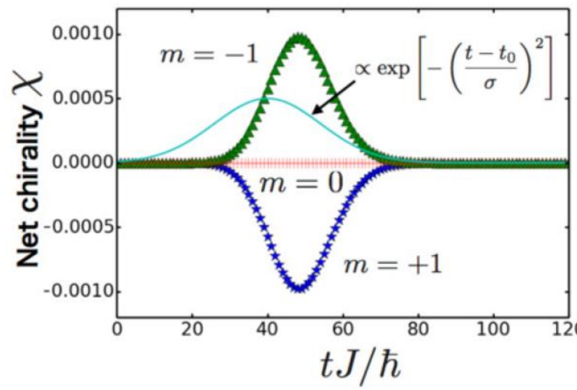
Direct coupling between THz vortex beam and magnets

H. Fujita and M. Sato, PRB96, 040706(R) (2017).
固体物理2018年9月号

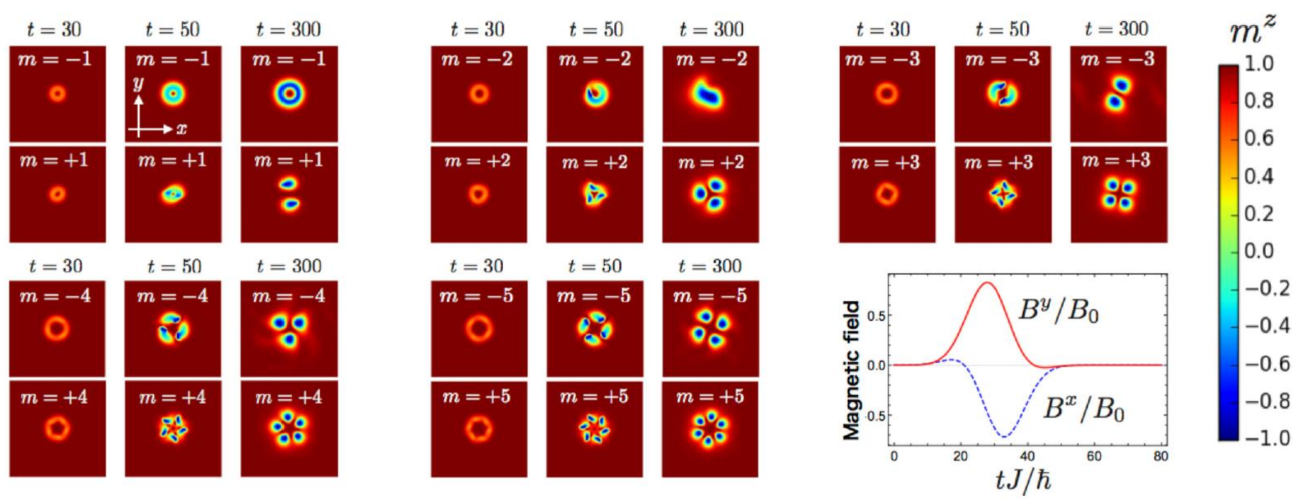
(1) THz vortex beam driven "spiral" spin-wave propagation and scalar spin chirality



$$\chi_{i,j,k} = \vec{S}_i \cdot \left(\vec{S}_j \times \vec{S}_k\right)$$



(2) Ultrafast generation of multiple skyrmions by half cycle pulse of THz vortex beam

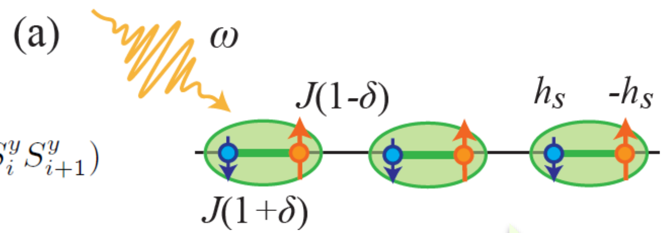


Spin-current rectification in noncentrosymmetric spin chains with linearly-polarized electromagnetic waves

H. Ishizuka and M. Sato, arXiv:1811.11515.

Spin chain model

$$H = \sum_i J(1+(-1)^i\delta)(S_i^x S_{i+1}^x + S_i^y S_{i+1}^y) - \sum_i (h+(-1)^i h_s) S_i^z.$$

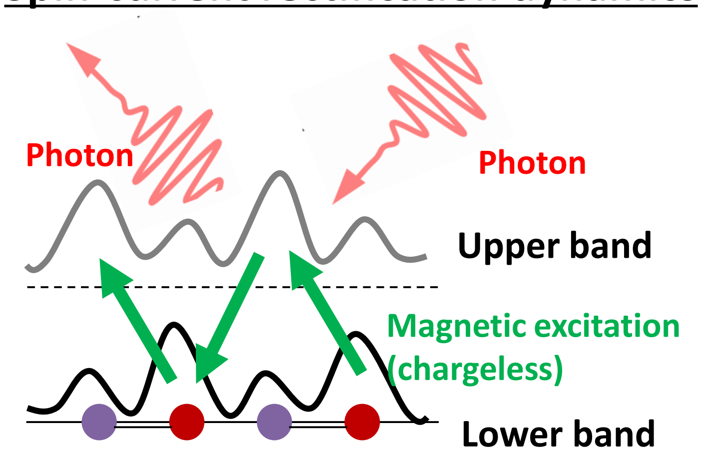


JW transform

Fermion chain model

$$H = \sum_i \frac{J(1+(-1)^i\delta)}{2}\left(c_{i+1}^\dagger c_i + c_i^\dagger c_{i+1}\right) + (h+(-1)^i h_s) n_i.$$

Spin-current rectification dynamics



Characteristics

(1) Insensitivity for the spinon life time
(Shift current like)

(2) Can be driven by a longitudinal AC field

(3) S^z-conserved dynamics
(shift of magnetic excitations)

Inverse DM interaction	$E \sim 10^5 \ V/cm$
Zeeman interaction	$E \sim 10^4 \ V/cm$
Magnetostriction interaction	$E \sim 10^2 \ V/cm$