Introduction to Skyrmions

---Discussion for Spintronics Lecture

From Qing Yan

Dec 22nd,2017

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- **Brief introduction to Skyrmions**
- **Individual skyrmions in multilayers**
- **Current-induced motion of skyrmions**
- **Nucleation and detection of skyrmions**
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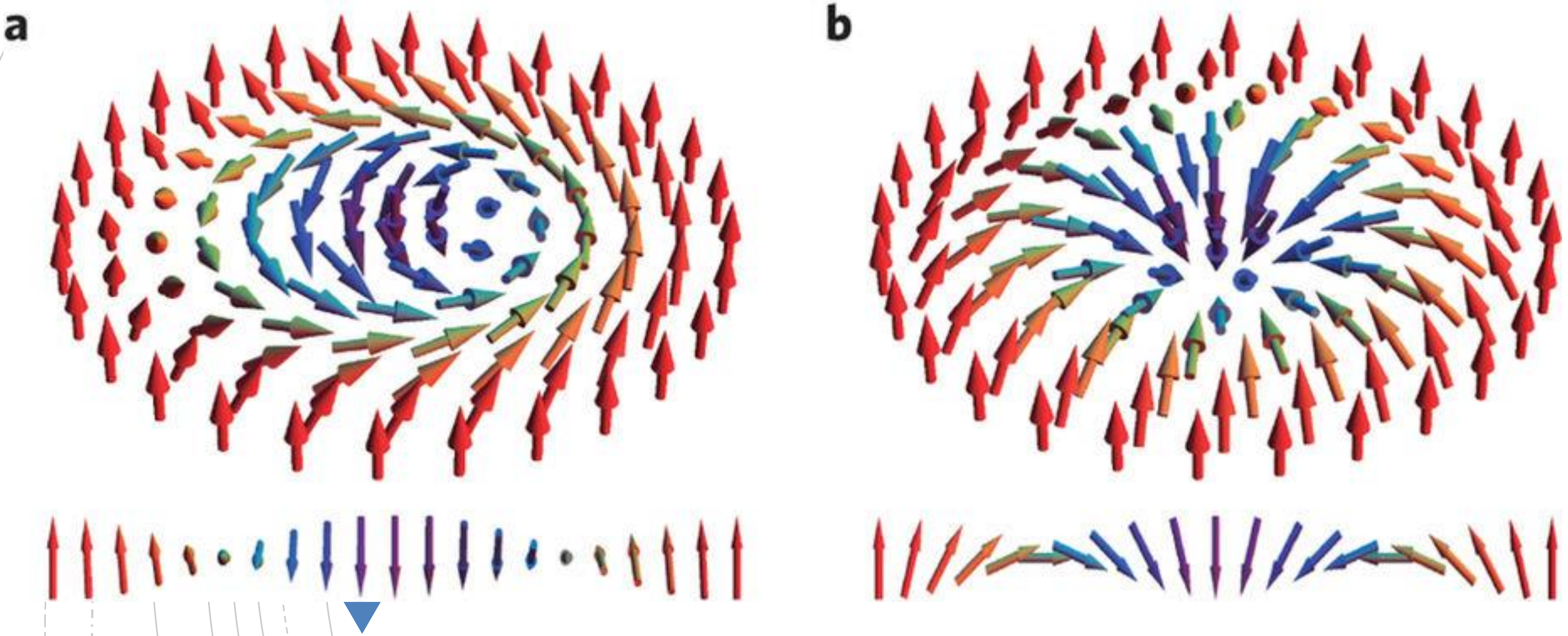
Brief introduction to Skyrmions



- a, In a Bloch-type skyrmion, the spins rotate in the tangential planes—that is, perpendicular to the radial directions—when moving from the core to the periphery.
- b, In a Néel-type skyrmion, the spins rotate in the radial planes from the core to the periphery. The cross-section of the vortex is also depicted in both cases.

X. Z. Yu et al., Nature,vol. 465, pp. 901–904, 2010.

Dzyaloshinskii–Moriya interaction

Qs -- skyrmion number

Qv -- vorticity number

Qh -- helicity number

- Interfacial Dzyaloshinskii–Moriya interaction

$$\mathcal{H}_{\mathrm{DMI}} = D[m_z(\boldsymbol{r})\nabla \cdot \boldsymbol{m}(\boldsymbol{r}) - (\boldsymbol{m}(\boldsymbol{r}) \cdot \nabla)m_z(\boldsymbol{r})]$$

for the Neel-type hedgehog skyrmion

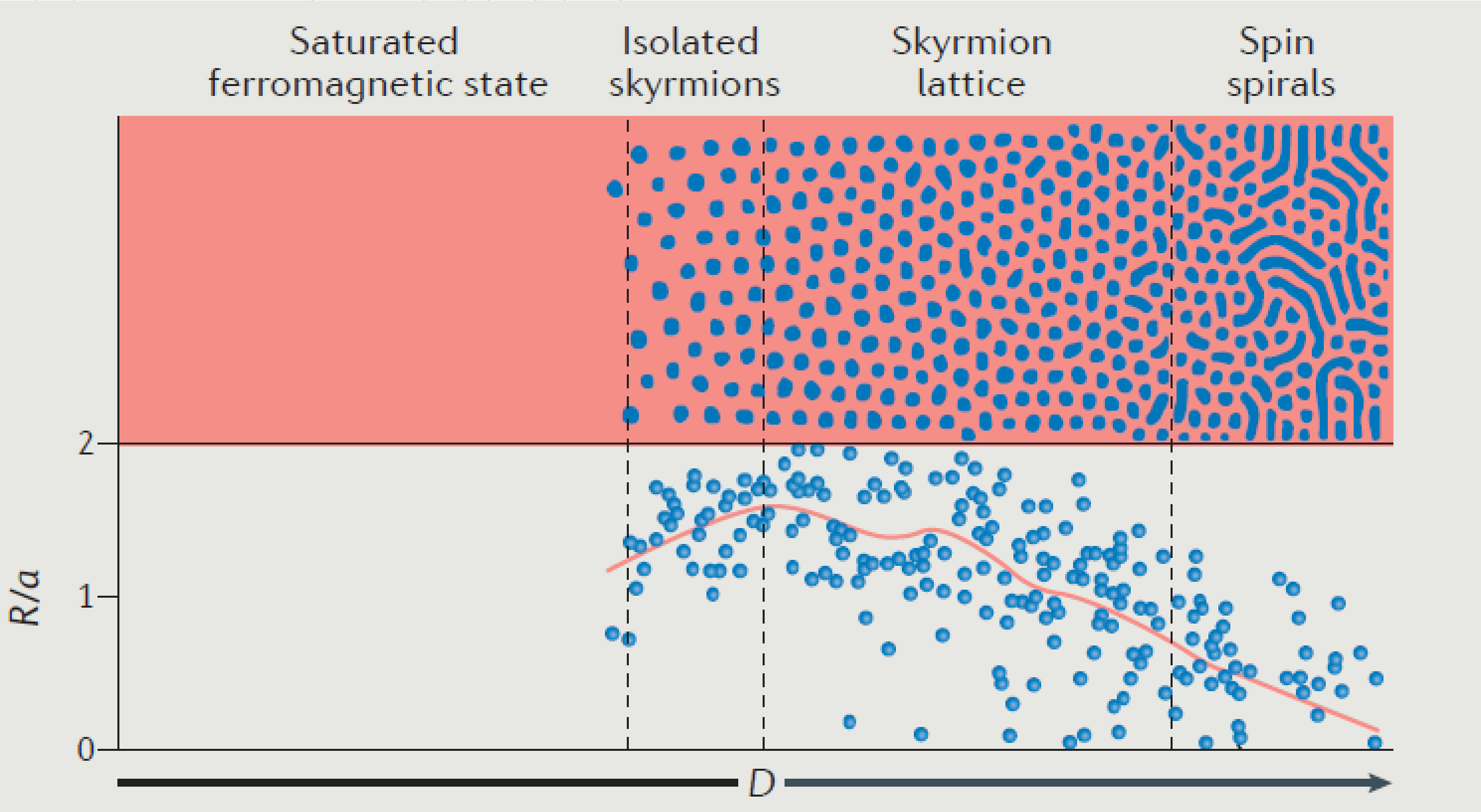
- Bulk Dzyaloshinskii–Moriya interaction

$$\mathcal{H}_{\mathrm{DMI}} = D\boldsymbol{m}(\boldsymbol{r}) \cdot [\nabla \times \boldsymbol{m}(\boldsymbol{r})]$$

for the Bloch-type chiral skyrmion

Lin, Shi Zeng. Phys.rev.b 94.2(2015).

Individual skyrmions in multilayers



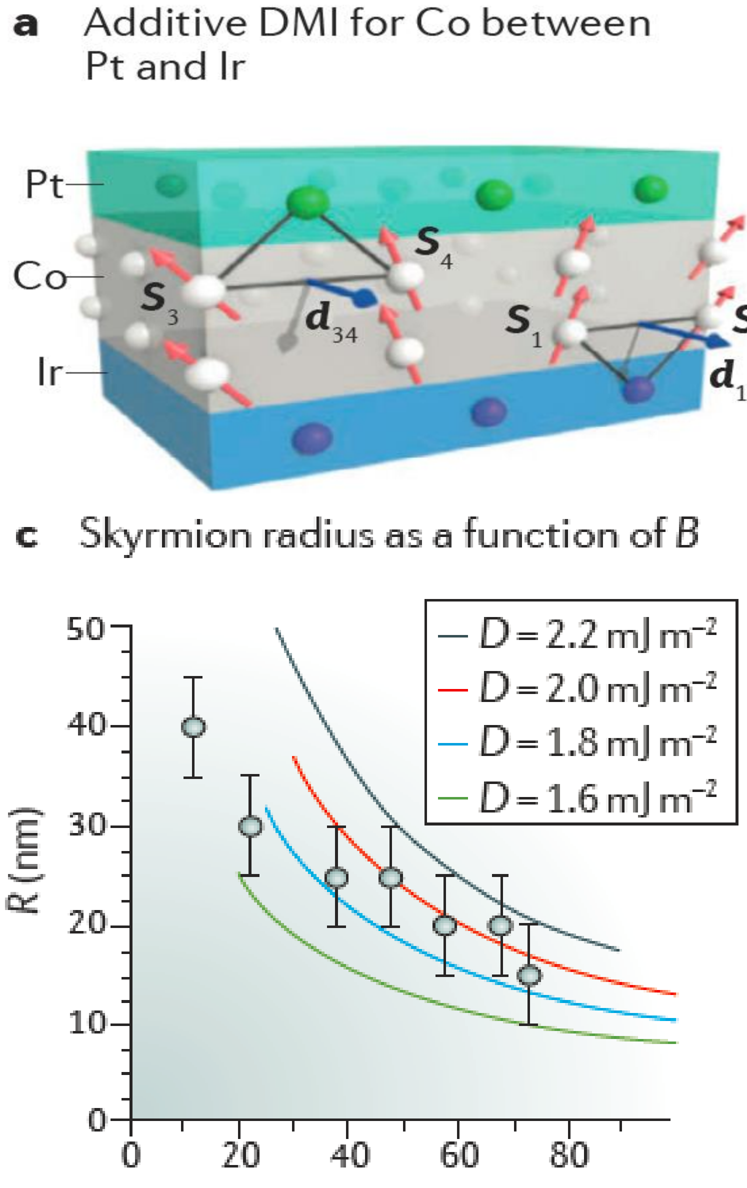
$$D < D_C = \frac{4\sqrt{AK}}{\pi}$$

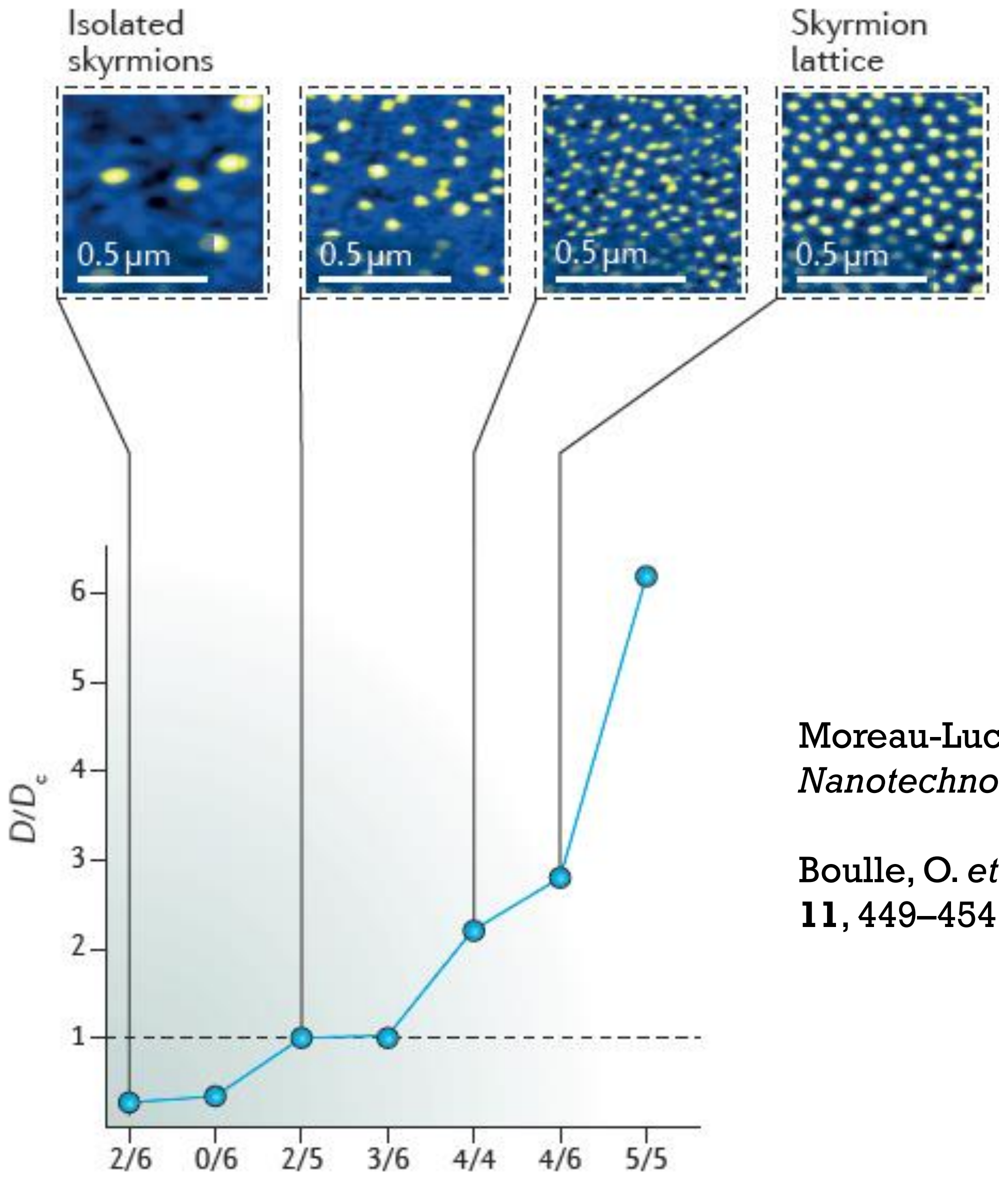
A :the exchange stiffness
K: the effective out-of-plane anisotropy

Variable: DMI coeffient
Constant: the exchange, anisotropy, applied field and temperature

Siemens, et al , New J. Phys. 18, 045021 (2016).

Individual skyrmions in multilayers



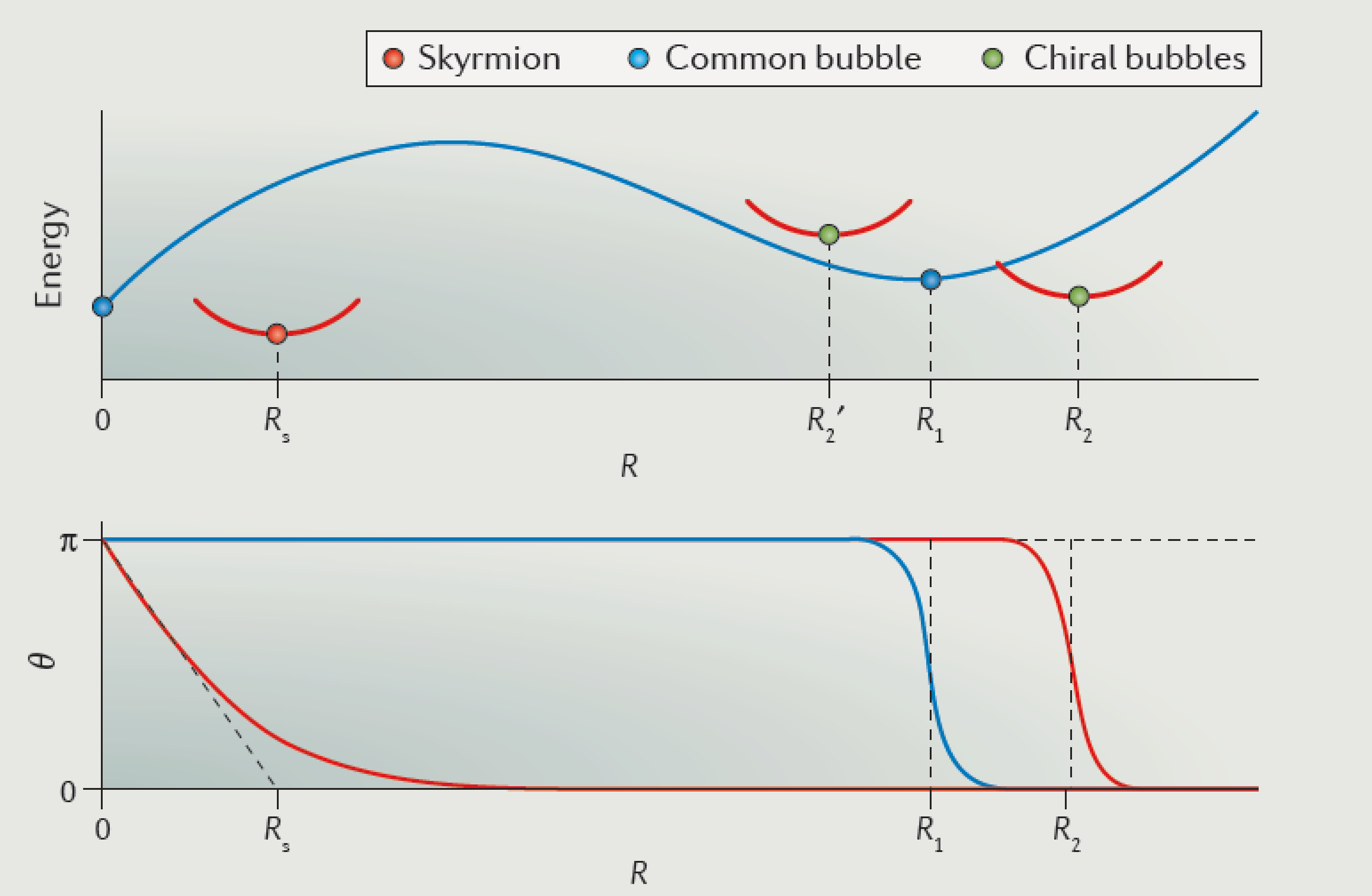


Transition from individual skyrmions to a skyrmion lattice with increasing D/Dc

Moreau-Luchaire, C. *et al. Nat. Nanotechnol.* **11**, 444–448 (2016)

Boulle, O. *et al.*. *Nat. Nanotechnol.* **11**, 449–454 (2016).

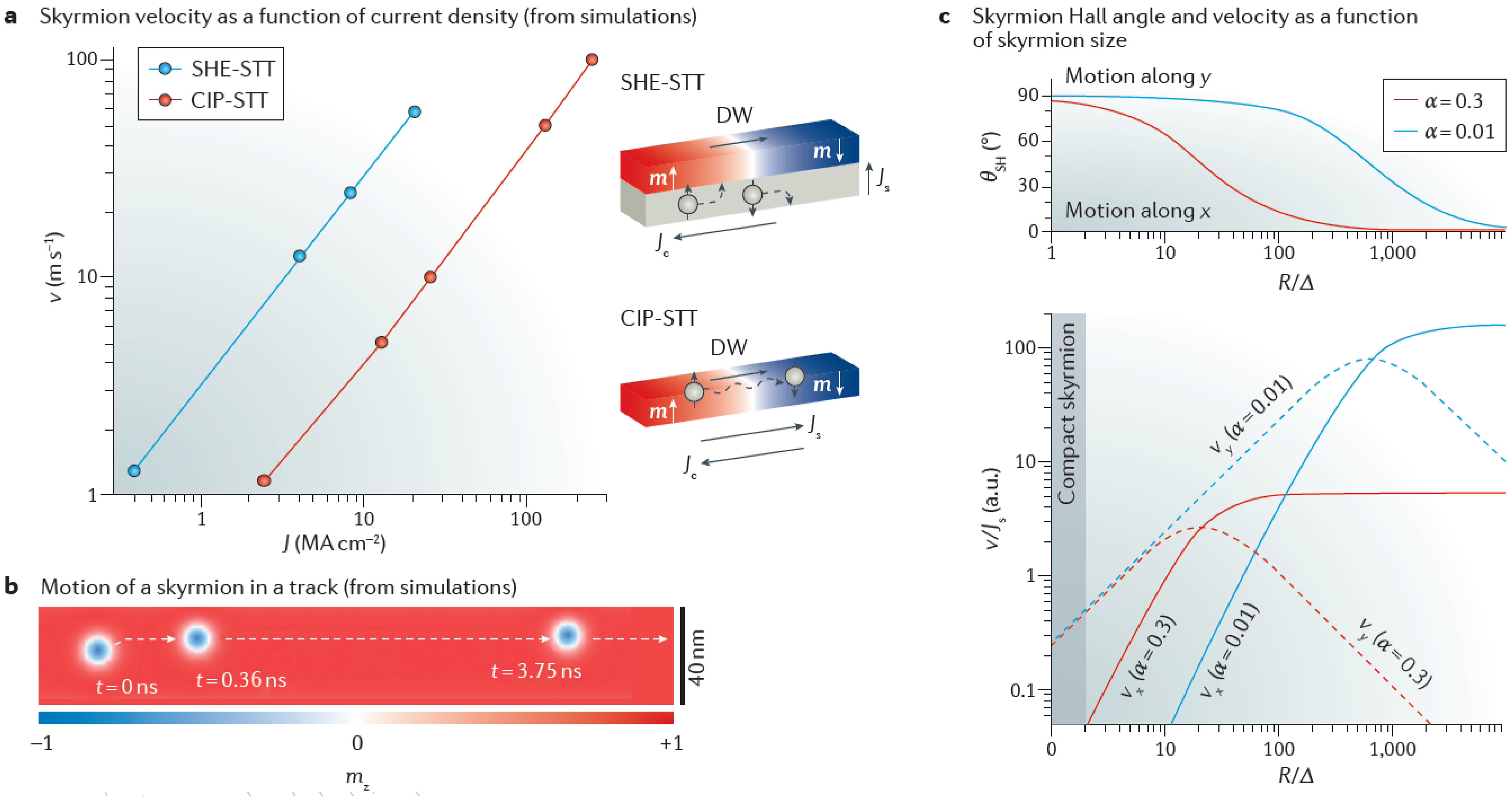
Individual skyrmions in multilayers



- Skyrmions and chiral bubbles
- ‘big skyrmions’ — that is, domains of reversed magnetization surrounded by a Néel domain wall with the chirality favoured by the DMI— with diameters in the micrometre range
- θ is the angle between the magnetization and the out-of-plane direction

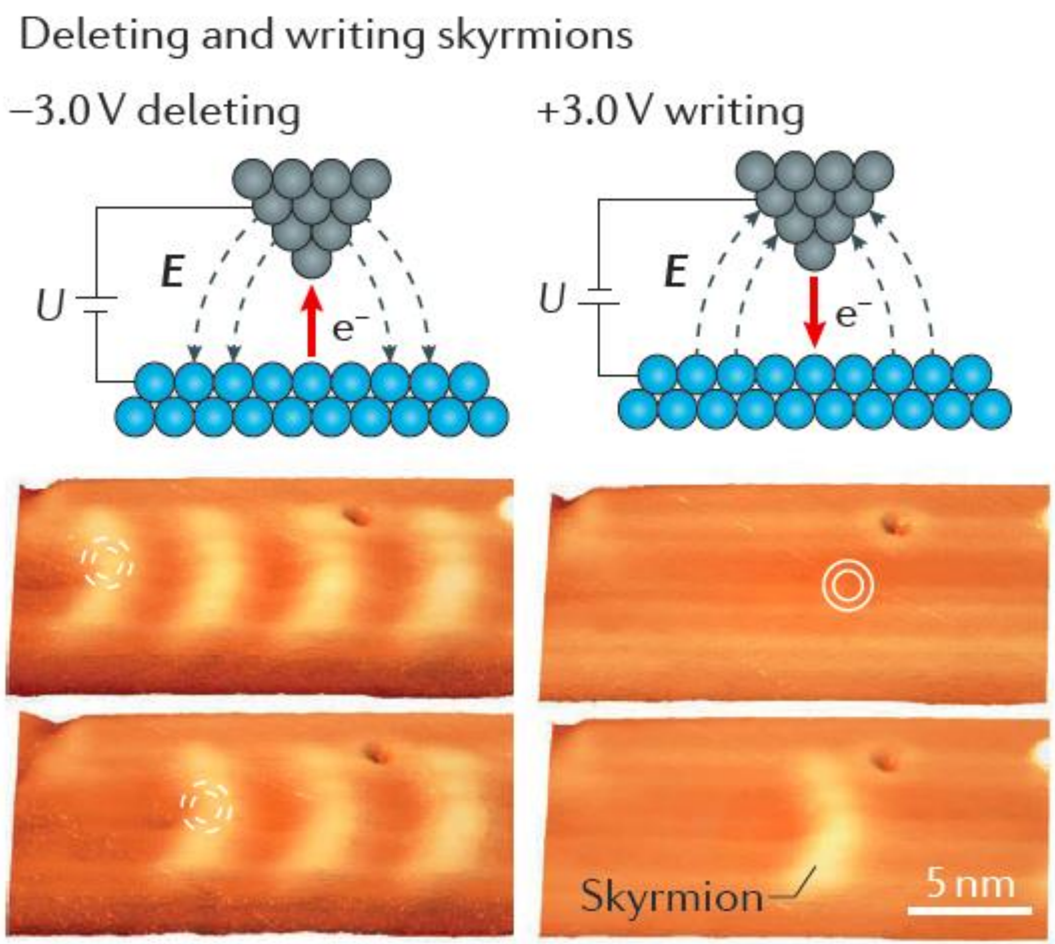
Kiselev, N. S,et al. *J. Phys. D* **44**, 392001 (2011)

Current-induced motion of skyrmions

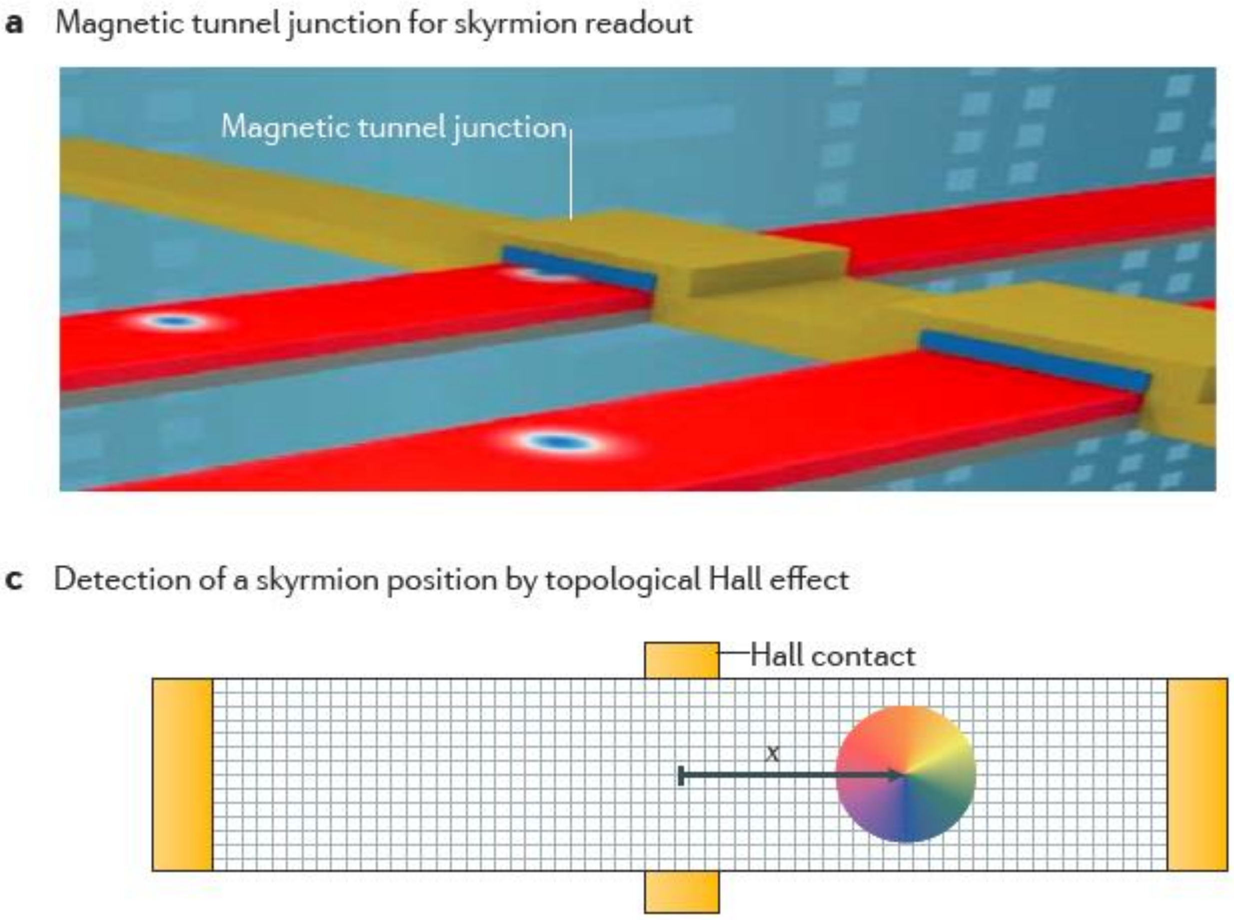


Sampaio, J.,et al . Nat. Nanotechnol. 8, 839–844 (2013).

Nucleation and detection of skyrmions

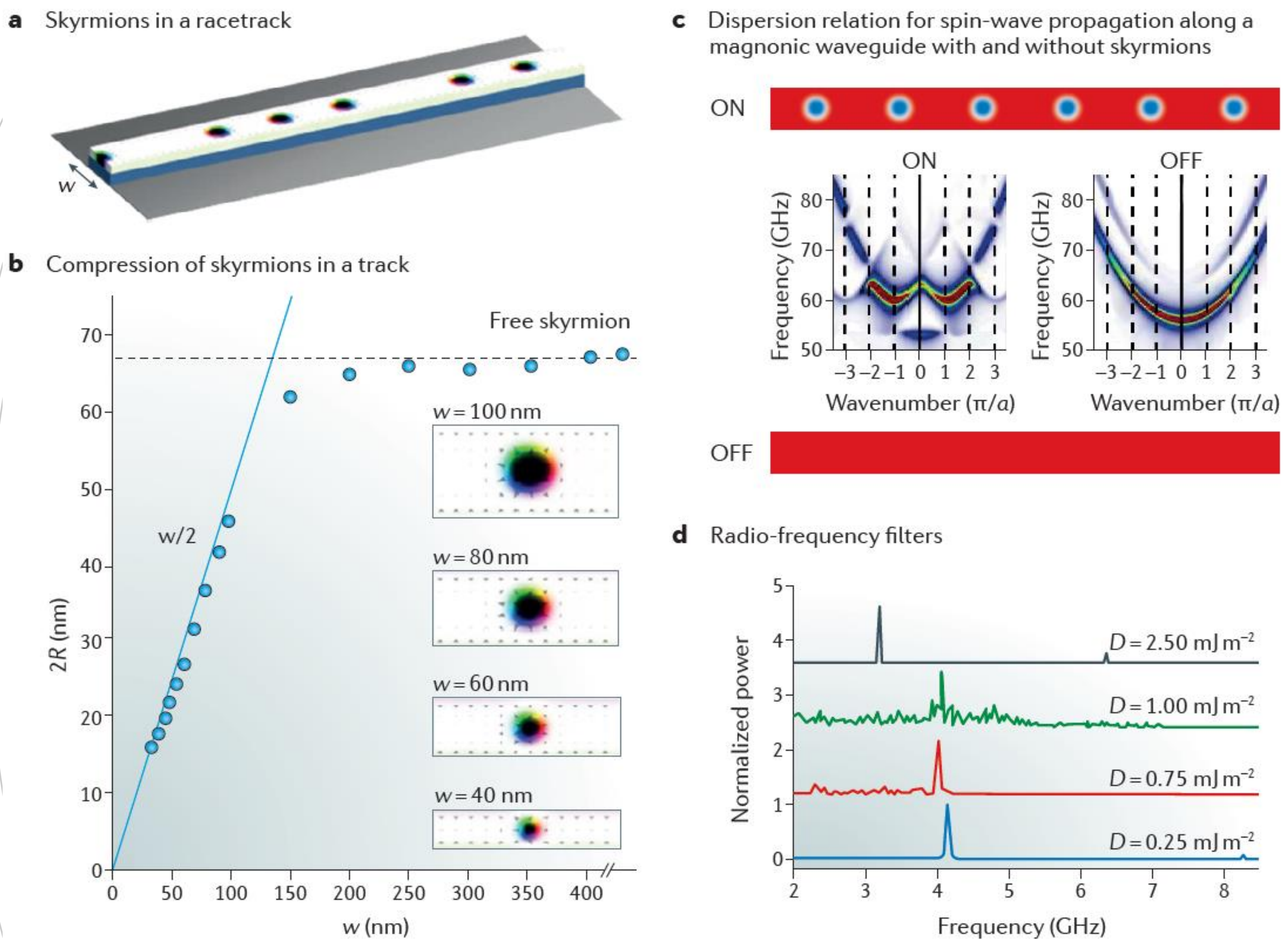


Hsu, P.-J. et al. Nat. Nanotechnol. 12, 123–126 (2017).



Hamamoto, K.et al. Appl. Phys. Lett. 108, 112401 (2016).

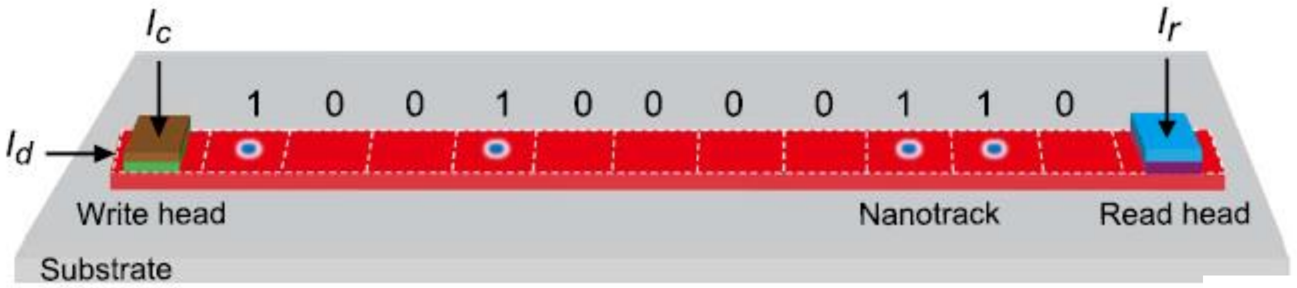
Topological room-temperature devices



- ***Skyrmion racetrack memory***
- ***Skyrmionic logic devices***
- ***Skyrmion magnonic crystals***
- ***Skyrmion-based radio-frequency devices***

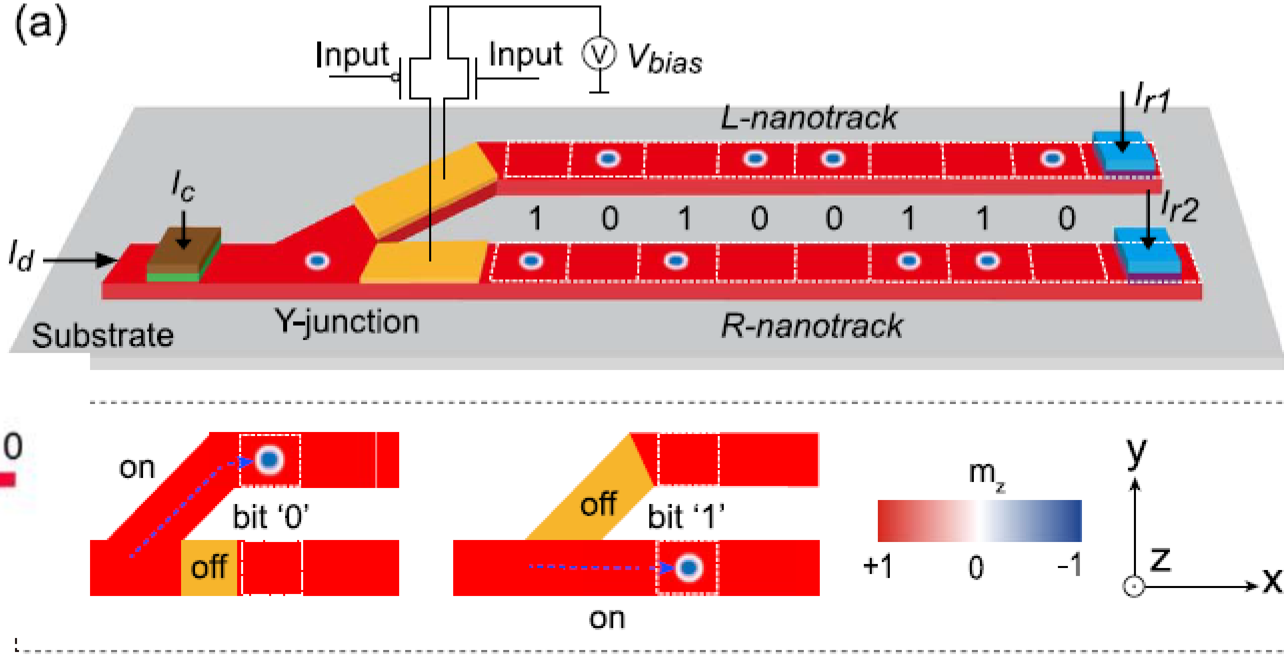
Fert, Albert, et al.Nature Reviews Materials 2(2017).

Topological room-temperature devices



Compared to DW :
Higher package density,
lower energy
more robust data stability

Schematic of a typical SK-RM:
- a write head for skyrmion creation
- a nanotrack for skyrmion motion
- a read head for skyrmion detection
- peripheral CMOS circuits.



A hybrid device based on DWs and skyrmions.
A sequence of information is encoded as a train of DWs and then converted into a train of skyrmions

Wang Kang, et al. *Proceedings of the IEEE* 104.10(2016)

Outlook and Challenge

Promising with Puzzles

- Material Challenges and Limitations
- Skyrmion Manipulation Challenges and Emerging Trends

  Small-size skyrmions

  Longer lifetime

  Stable at room temperature

  Higher velocity with lower current density

Fert, Albert, et al.Nature Reviews Materials 2(2017).
Wang Kang, et al. *Proceedings of the IEEE* 104.10(2016)

Thanks for Attention

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