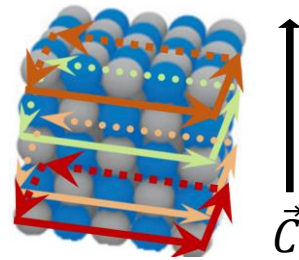




# Photonic 3D Chern insulators

With arbitrarily large and orientable Chern vectors

Chiara Devescovi



'Cubic 3D Chern photonic insulators with orientable large Chern vectors' *Nature Communication*, 12, 7330 (2021)



Mikel García Díez



Iñigo Robredo



María Blanco de Paz



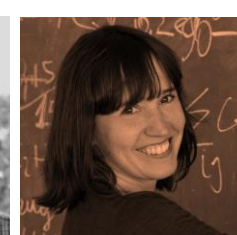
Jon Lasar Alonso



Barry Bradlyn



Juan Luis Mañes



Maia García Vergniory

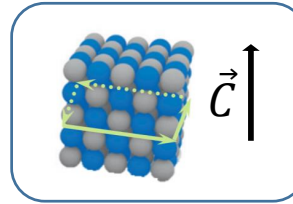


Aitzol García Etxarri

In this talk:

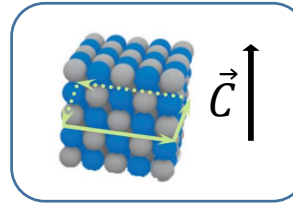
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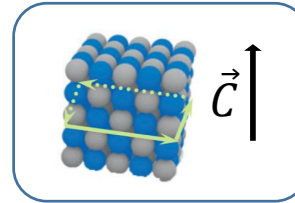
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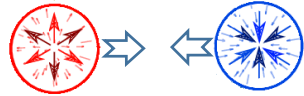


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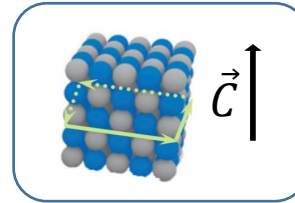


Weyl point annihilation

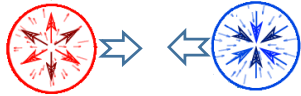


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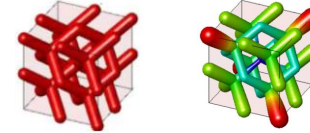
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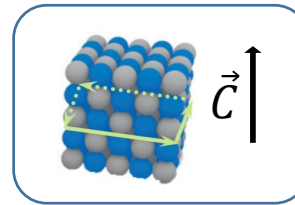


Supercell modulation



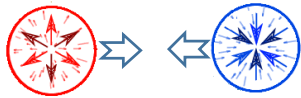
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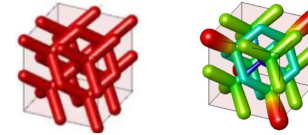


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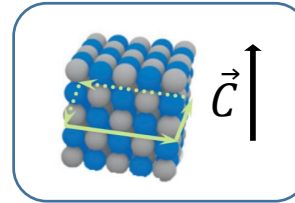


- Highlight key properties of the resulting phase:



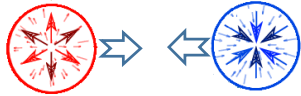
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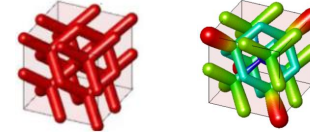


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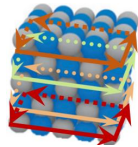


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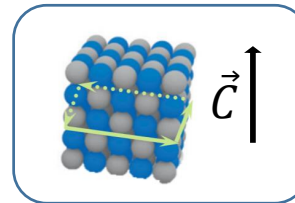
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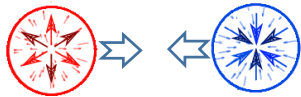
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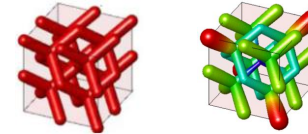


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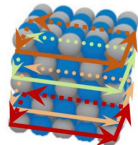


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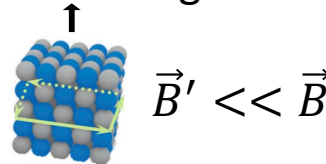


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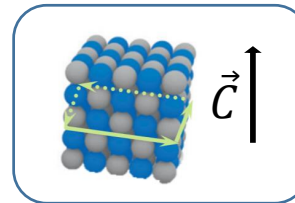


2. Reduced magnetization



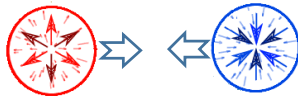
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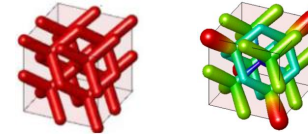


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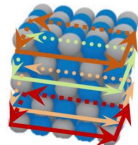


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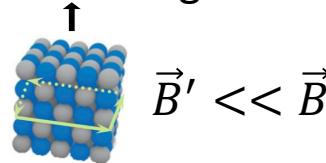


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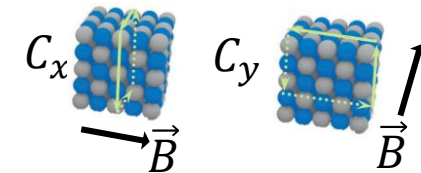
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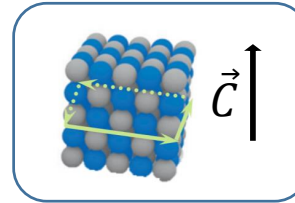


3. Orientability



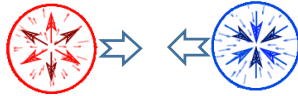
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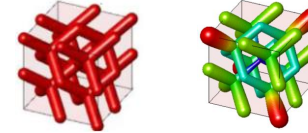


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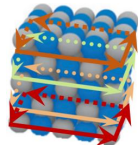


Supercell modulation

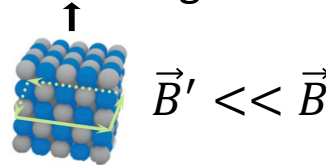


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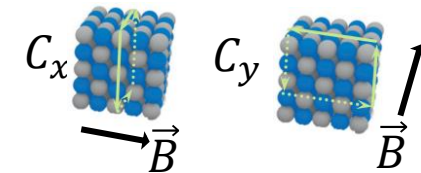
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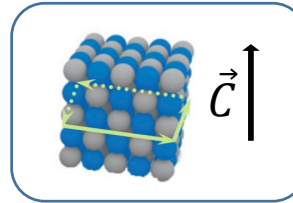
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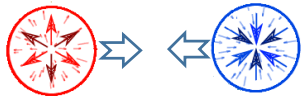
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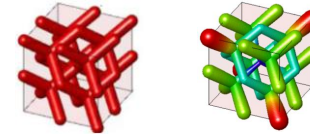


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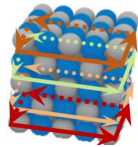


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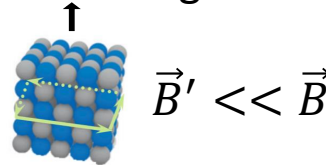


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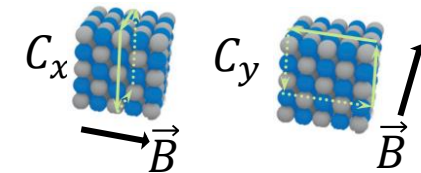
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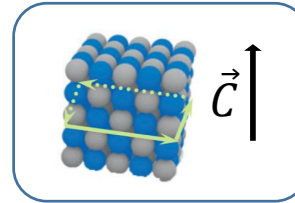


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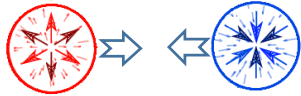
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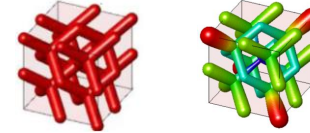


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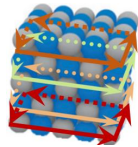


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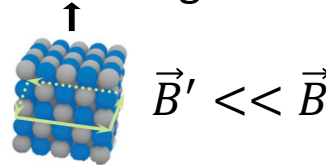


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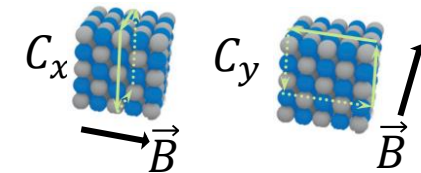
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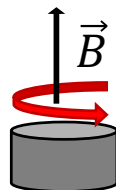
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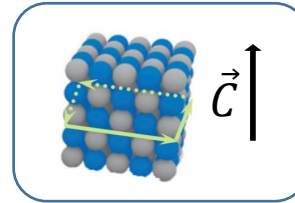
- Examples of applications and interfaces:

Conveyor-belt surface states



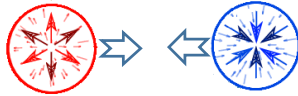
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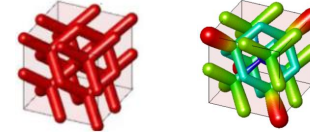


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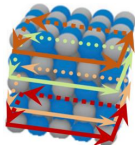


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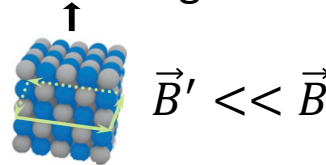


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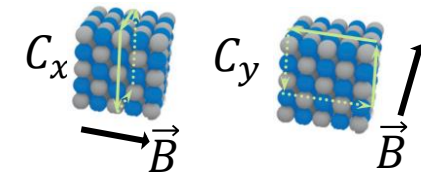
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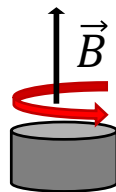
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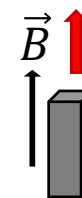
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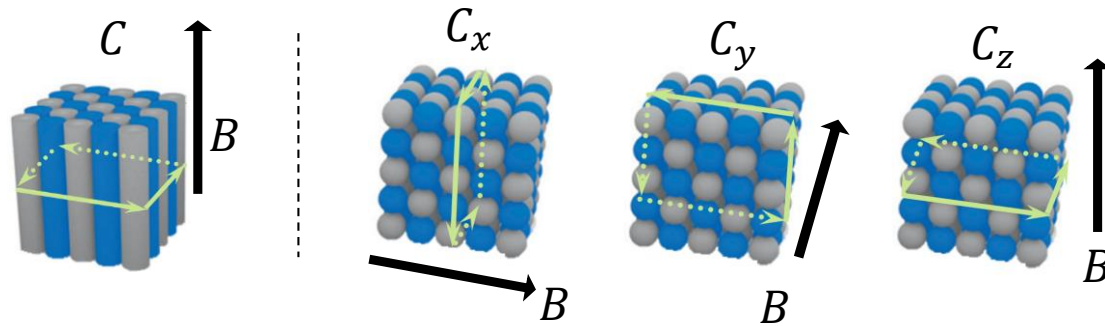
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Axial hinge currents

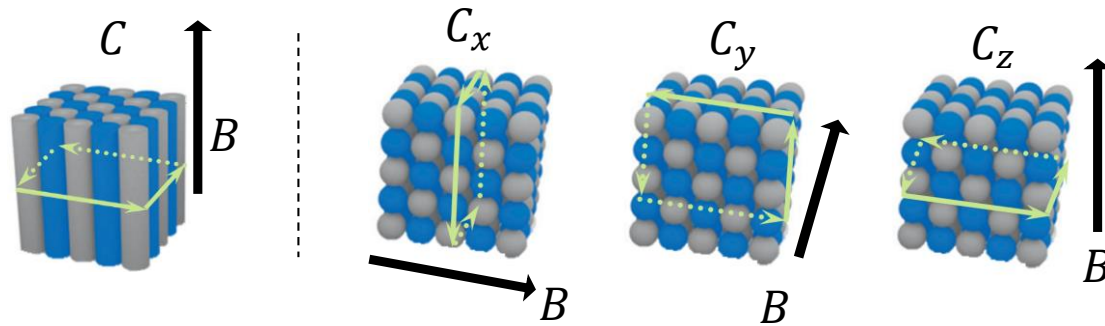


# What is a 3D Chern insulator?



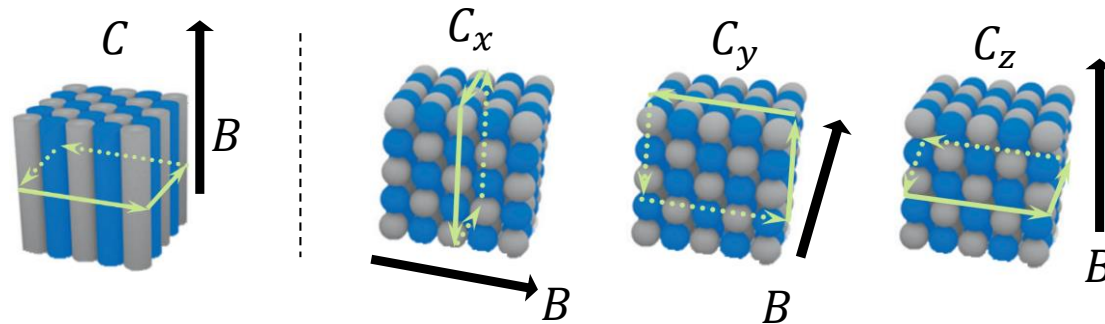


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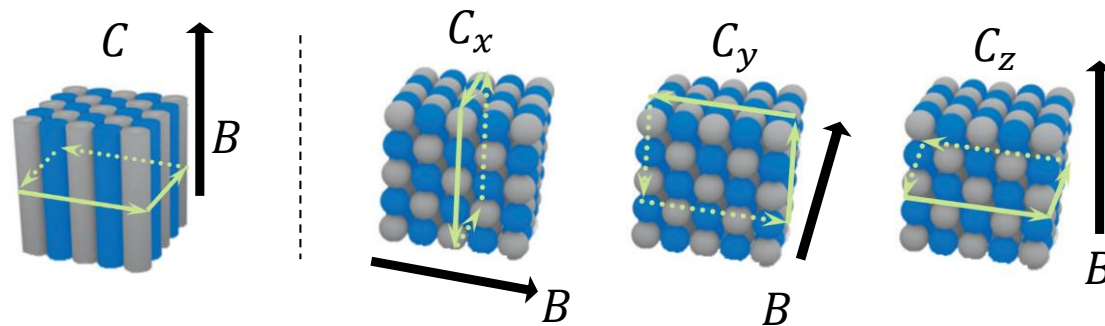
- Time Reversal Symmetry (TRS) broken topological phase

# What is a 3D Chern insulator?



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  - Topological protection of surface states regardless of any local symmetries

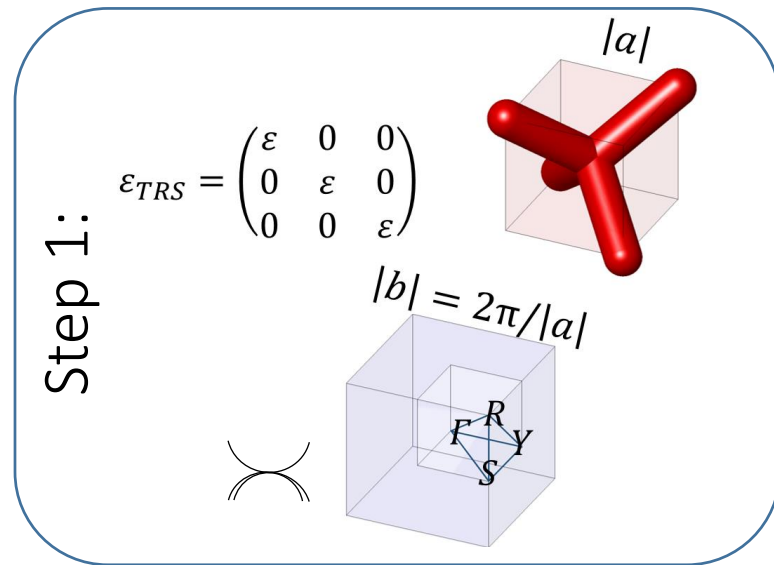
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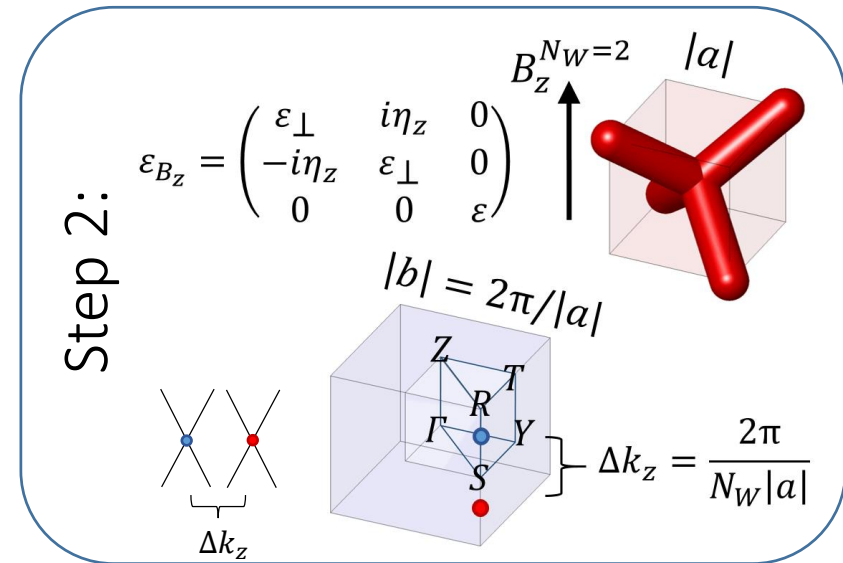
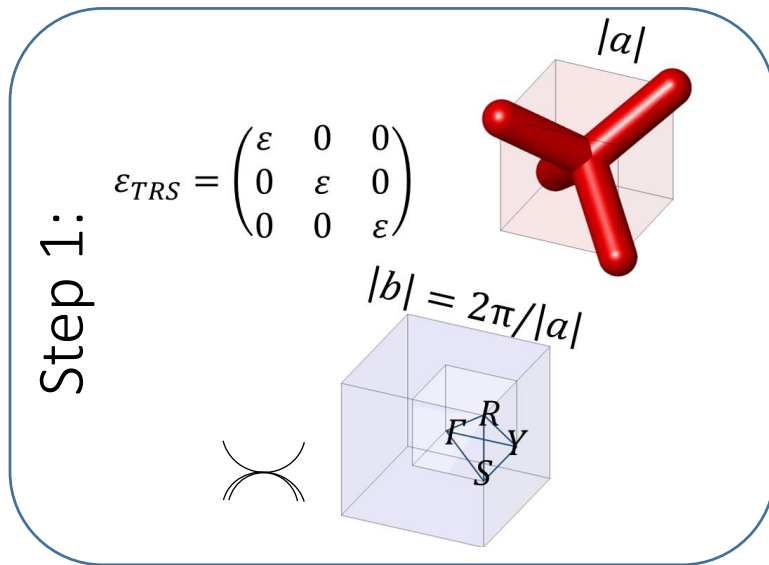
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- Vector of three first Chern invariants  $\vec{C} = (C_x, C_y, C_z)$

# 3D Chern design strategy

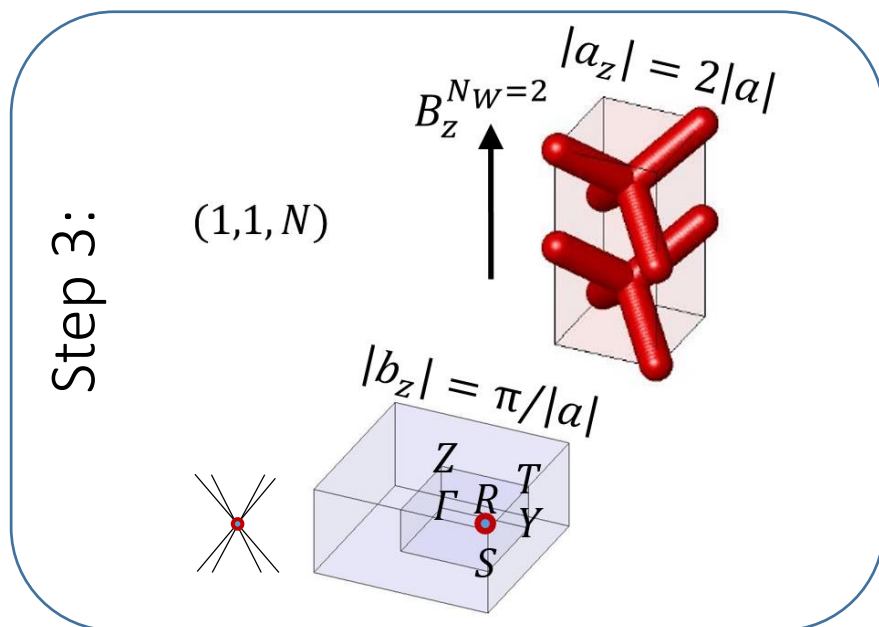
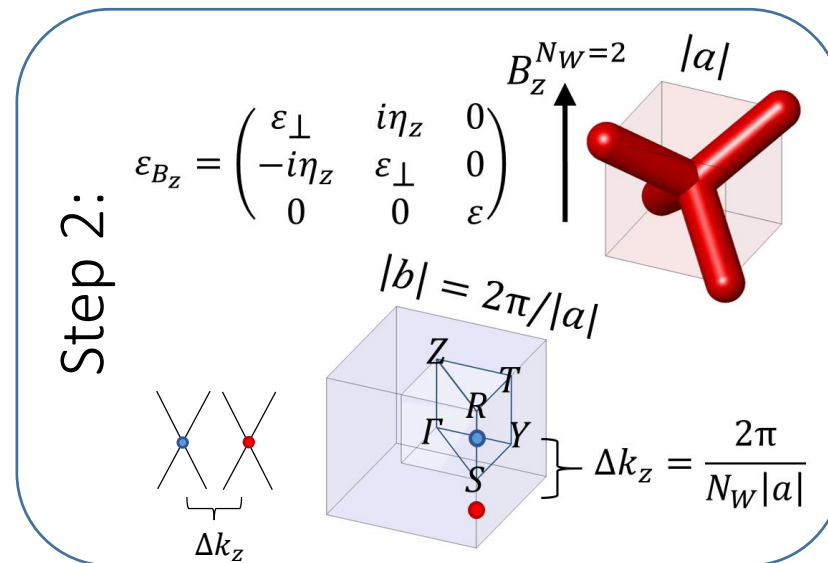
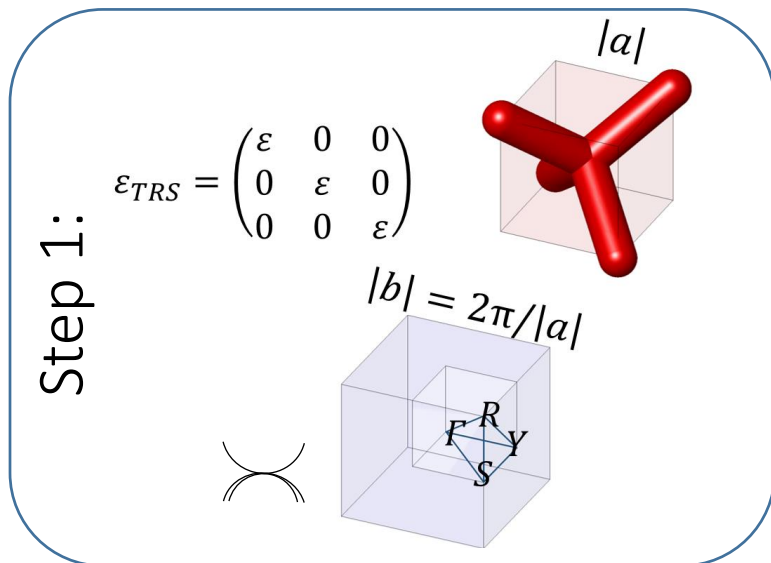
# 3D Chern design strategy



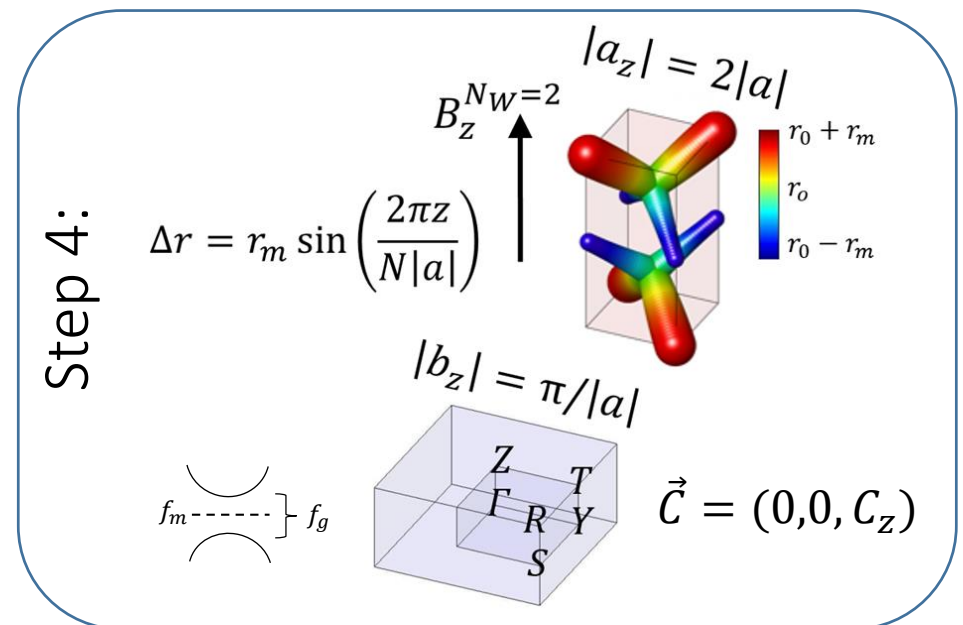
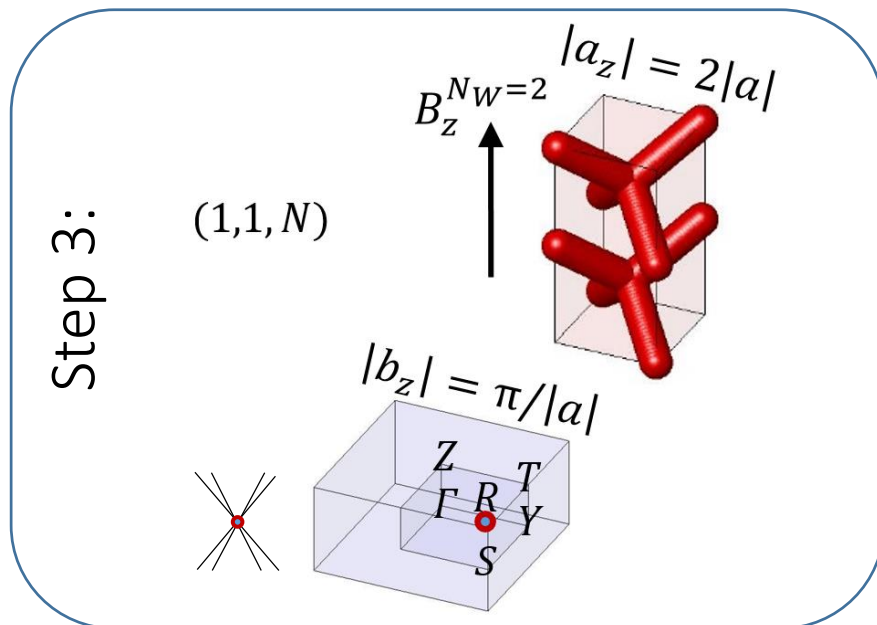
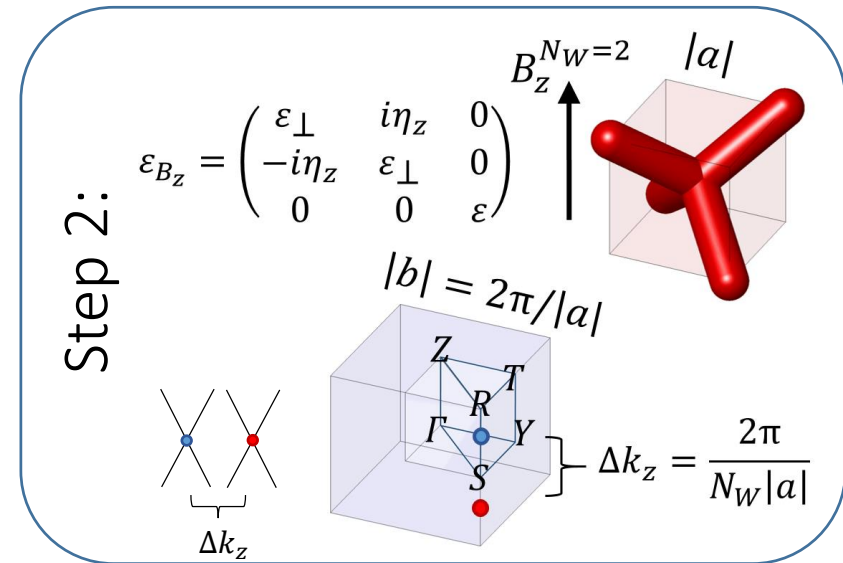
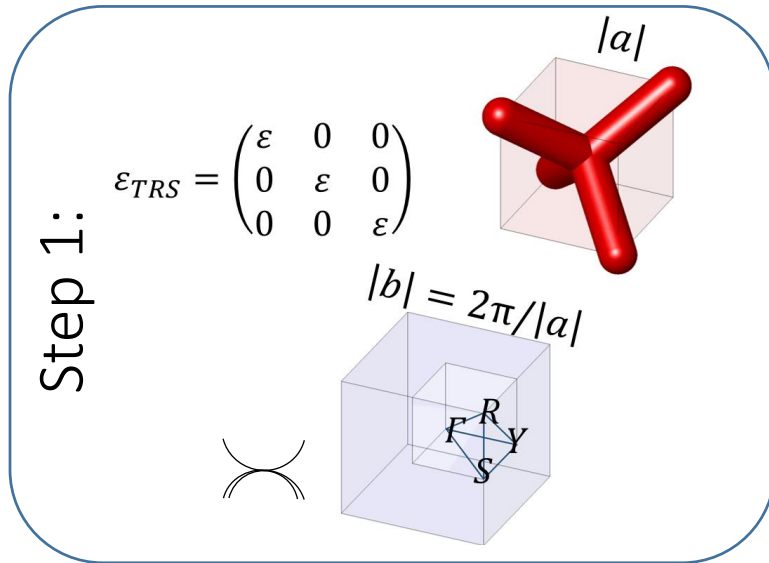
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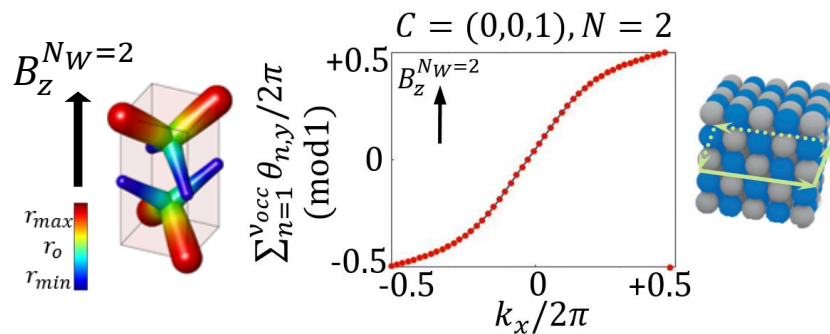
Goal 1: Large Chern vectors *by design*

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- Additivity of the Chern number on the reduced BZ
  - $N = 2, 4, 6 \dots$  supercell commensurate with  $N_W = 2$

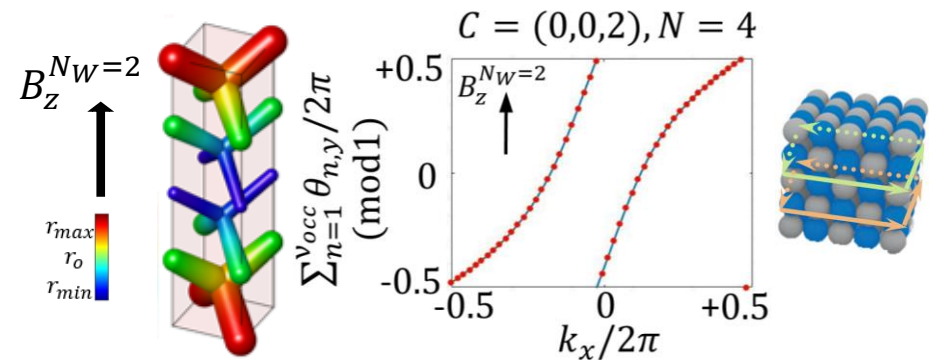
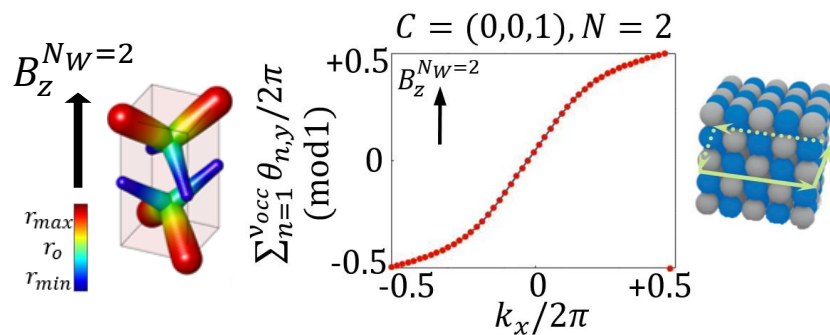
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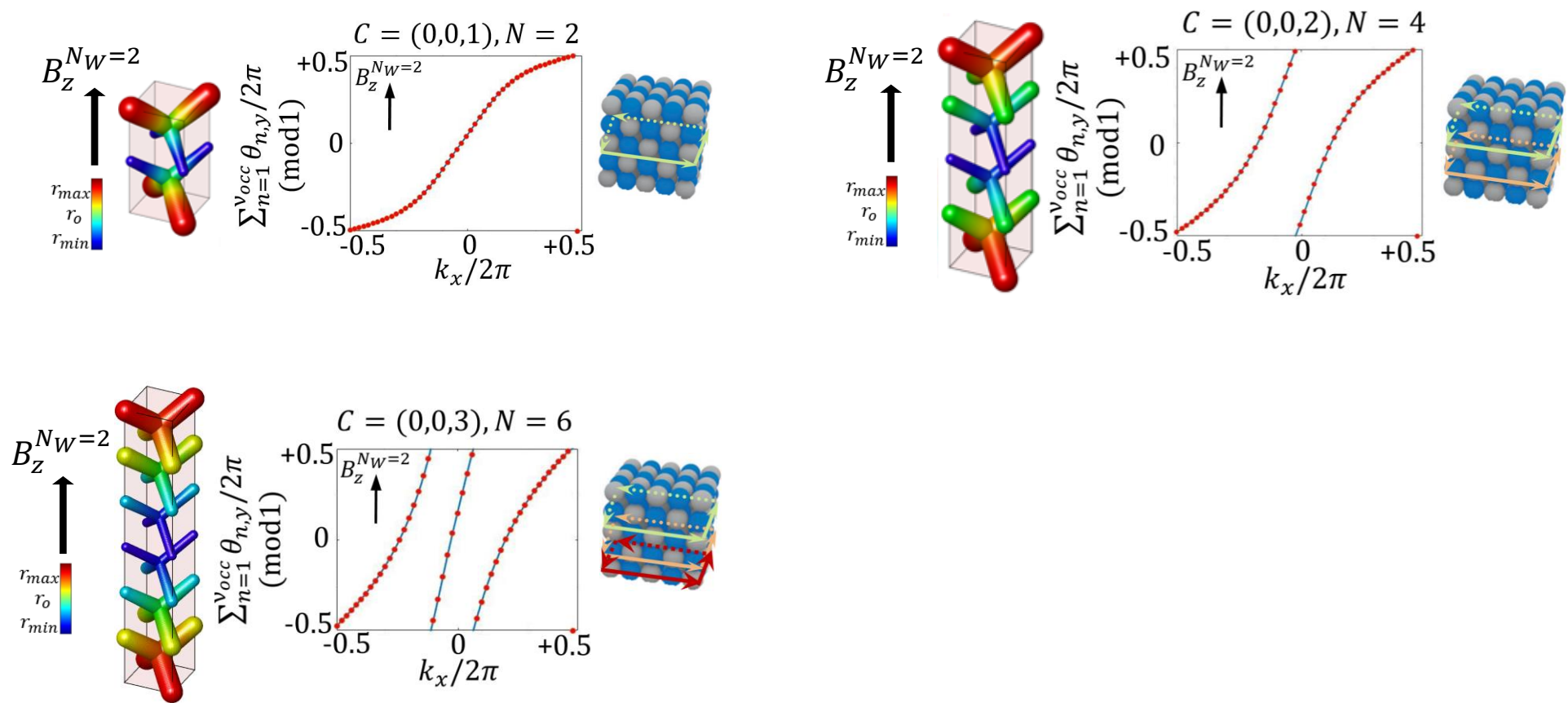
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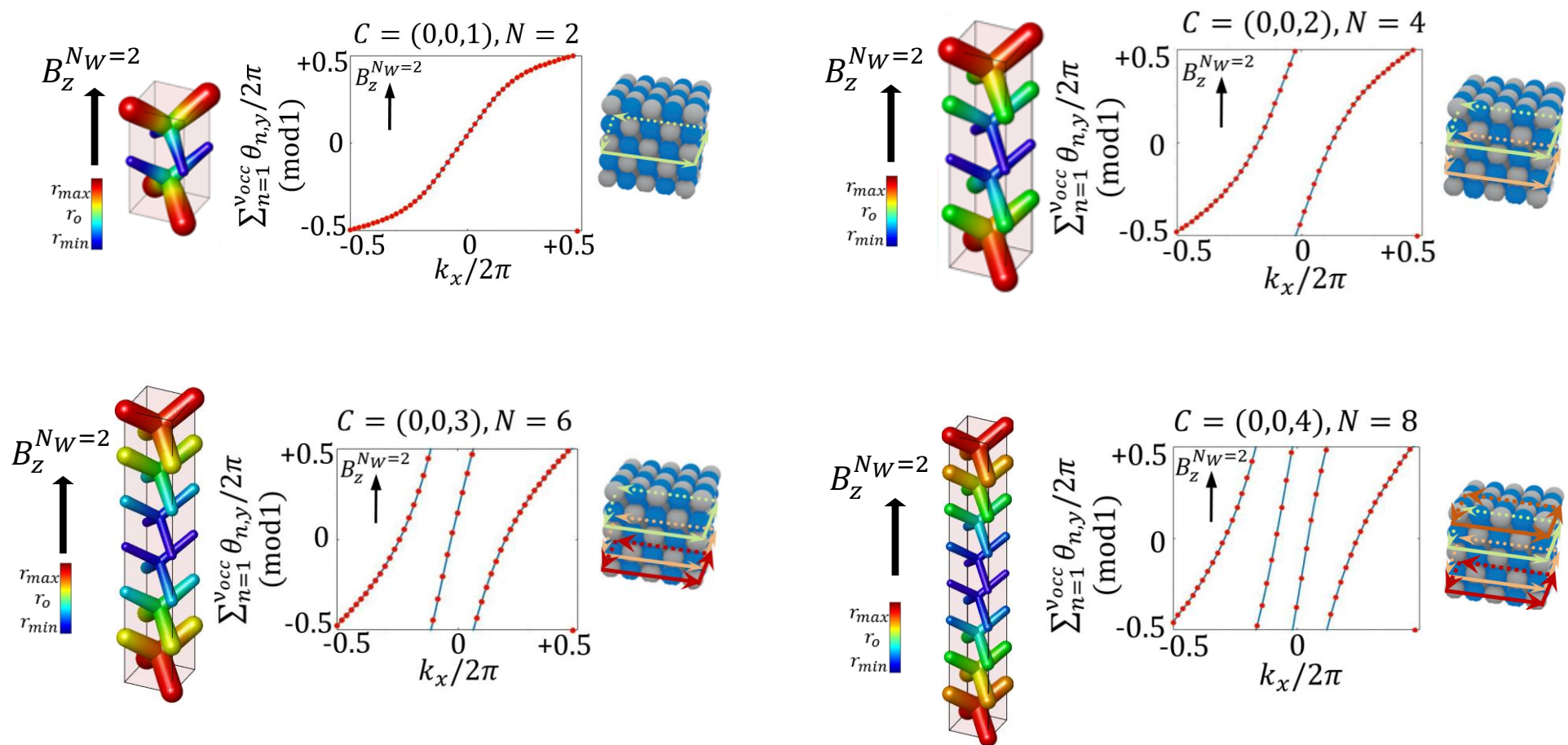
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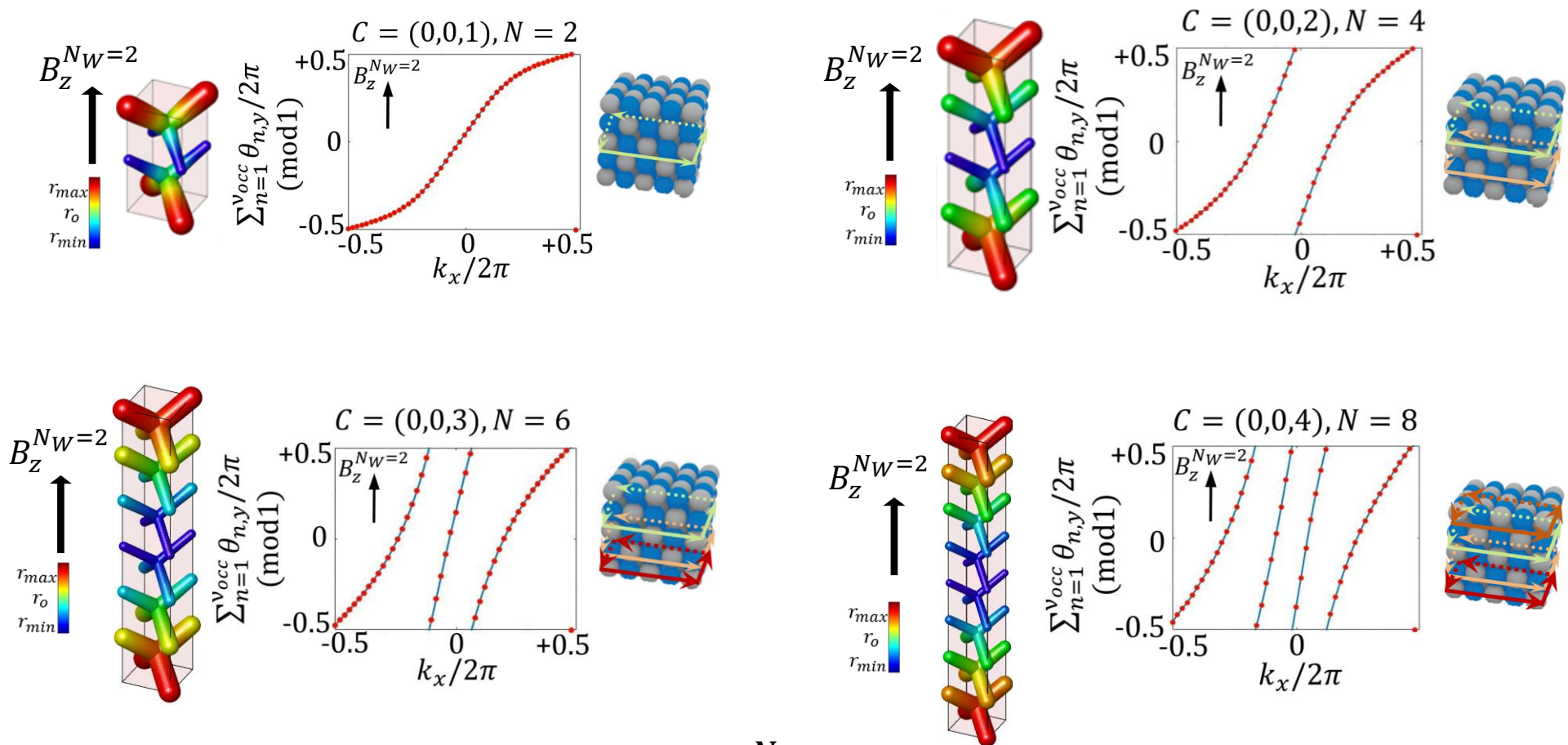
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$$C = \frac{N}{2} \geq 1$$

Goal 2: Reduced magnetic bias



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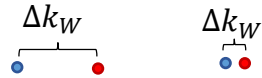
- Decreasing the field  $N = N_W > 2$  and increasing the modulation  $r'_m > r_m$

# Goal 2: Reduced magnetic bias

- Decreasing the field  $N = N_W > 2$  and increasing the modulation  $r'_m > r_m$

Reducing the Weyl dipole separation

$$\Delta k_z = \frac{2\pi}{N_W |a|}$$

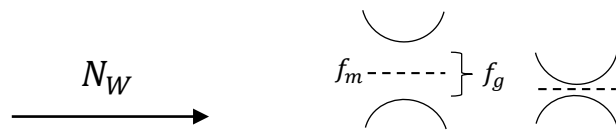


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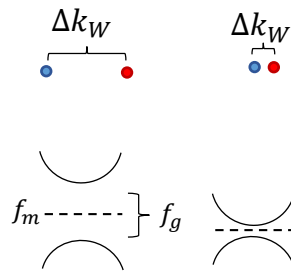
# Goal 2: Reduced magnetic bias

- Decreasing the field  $N = N_W > 2$  and increasing the modulation  $r'_m > r_m$

Reducing the Weyl dipole separation

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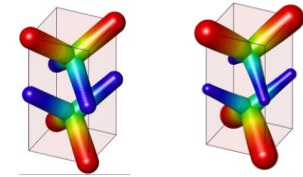
$N_W$   
→



+

Increasing the modulation intensity

$$r - r_0 = r_m \sin\left(\frac{2\pi z}{N|a|}\right)$$



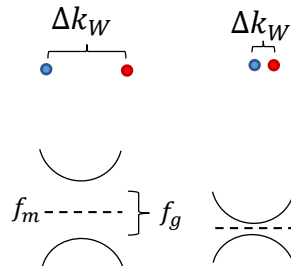
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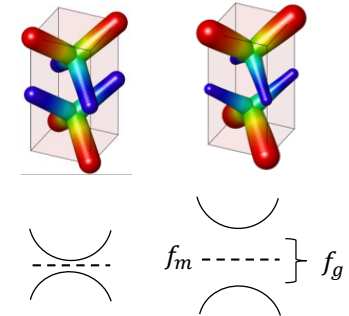


+

Increasing the modulation intensity

$$r - r_0 = r_m \sin\left(\frac{2\pi z}{N|a|}\right)$$

$r_m/r_0$  →



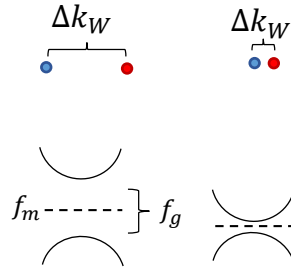
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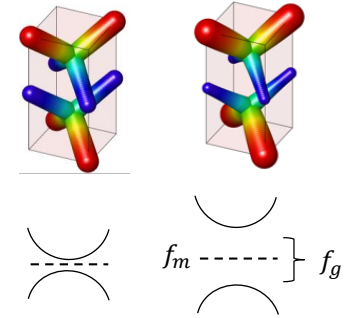
$N_W$



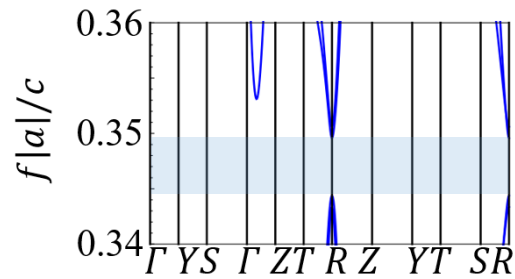
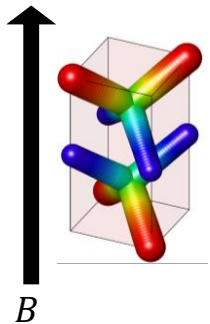
Increasing the modulation intensity

$$r - r_0 = r_m \sin\left(\frac{2\pi z}{N|a|}\right)$$

$r_m/r_0$



$\eta_z = 16$



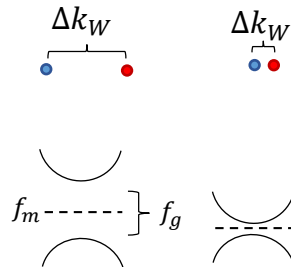
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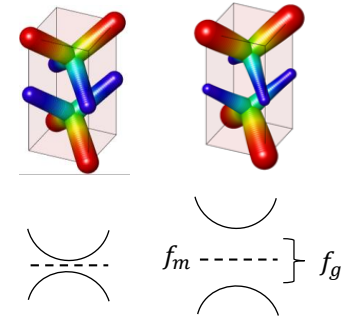
$N_W$



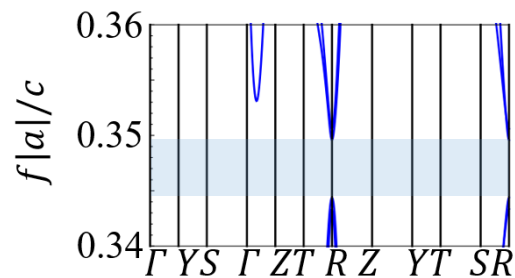
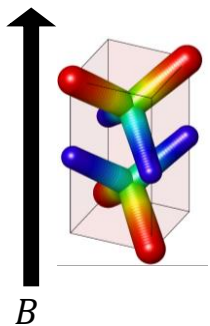
Increasing the modulation intensity

$$r - r_0 = r_m \sin\left(\frac{2\pi z}{N|a|}\right)$$

$r_m/r_0$

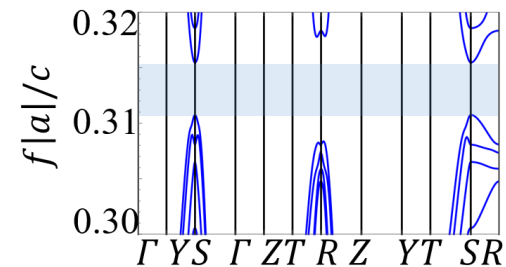
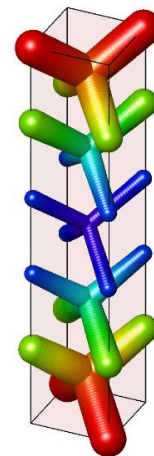


$\eta_z = 16$



$\eta_z = 3$

$B' < B$



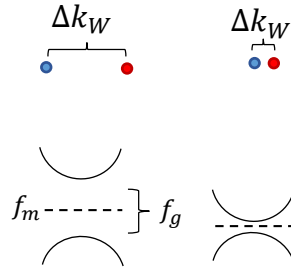
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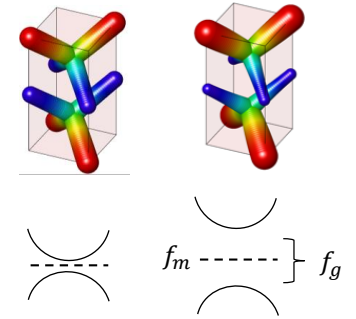
$N_W$



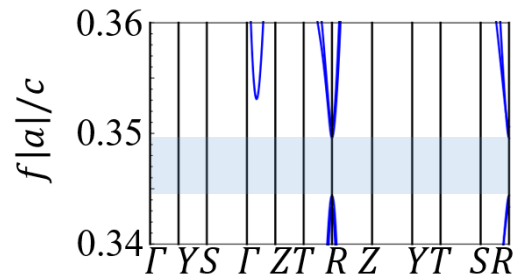
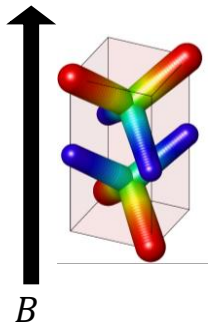
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$$r - r_0 = r_m \sin\left(\frac{2\pi z}{N|a|}\right)$$

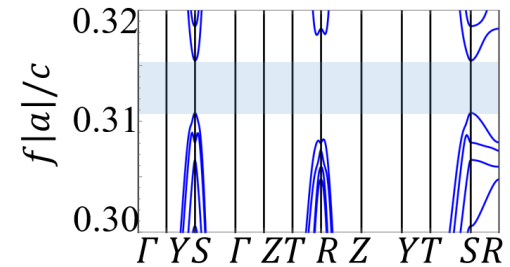
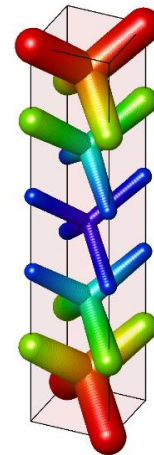
$r_m/r_0$



$\eta_z = 16$



$\eta_z = 3$   
 $B' < B$



$$f_{g_B}/f_{m_B} \sim f_{g_{B'}}/f_{m_{B'}}$$

$$\vec{C}_B = \vec{C}_{B'}$$



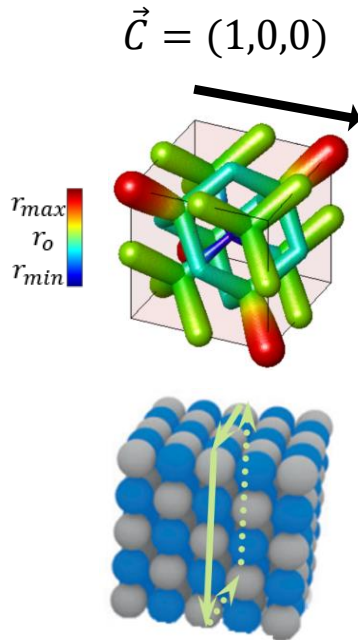
# Goal 3: Orientable Chern vectors

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- Multi-directional modulations:  $\Delta r = r_{m_x} \sin\left(\frac{2\pi x}{N_x|a|}\right) + r_{m_y} \sin\left(\frac{2\pi y}{N_y|a|}\right) + r_{m_z} \sin\left(\frac{2\pi z}{N_z|a|}\right)$

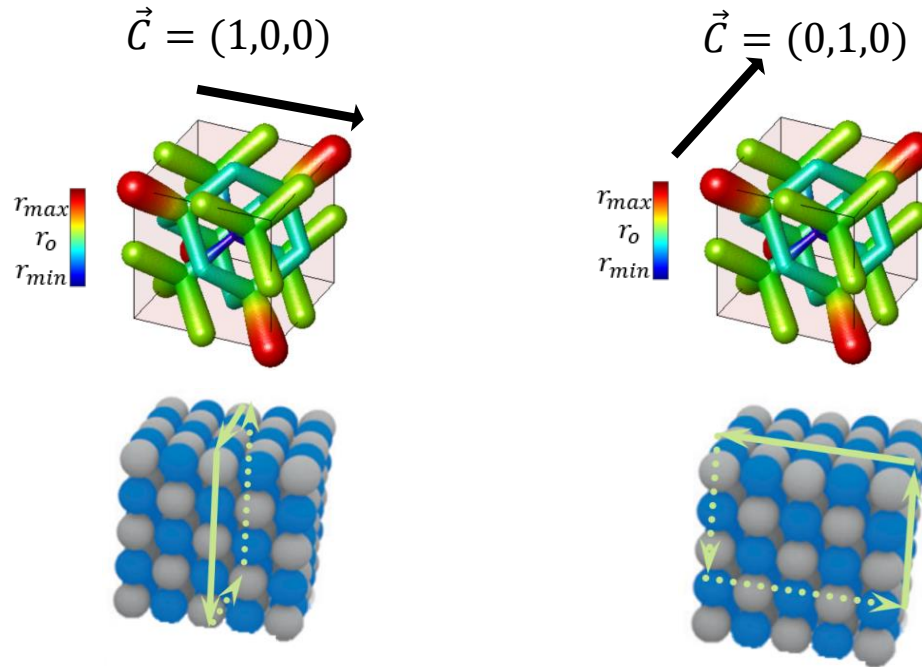
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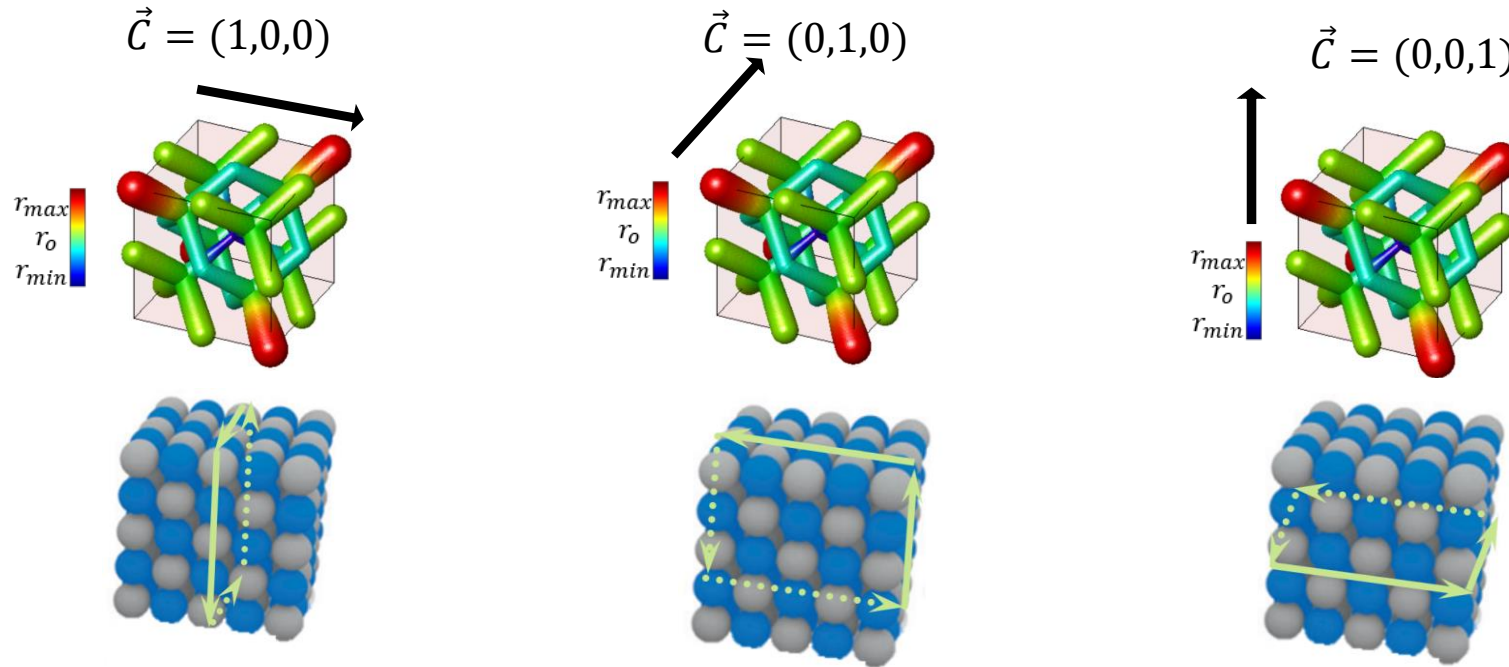
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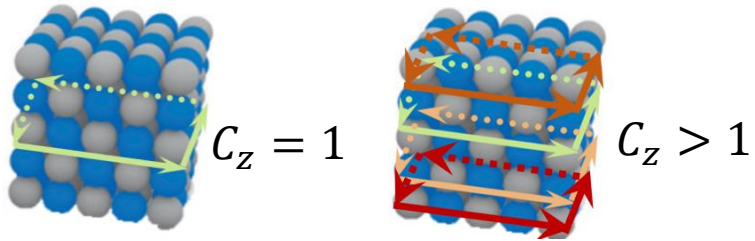




Summary: Chern vector engineering

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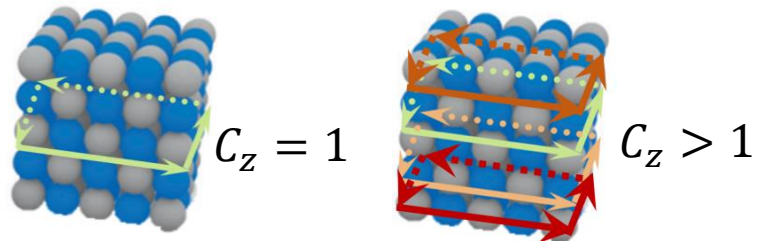
Arbitrarily large Chern vectors  
*by design*





# Summary: Chern vector engineering

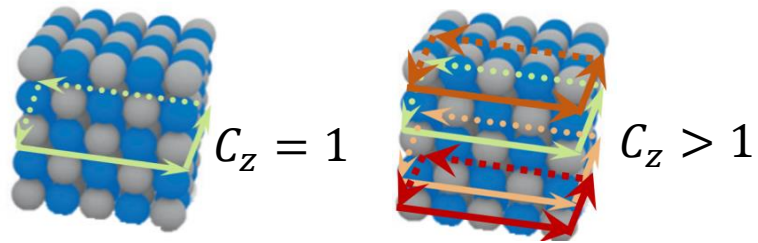
Arbitrarily large Chern vectors  
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Multimodal operation with unidirectional  
surface states

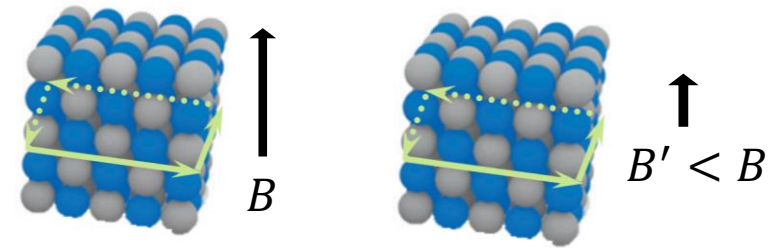
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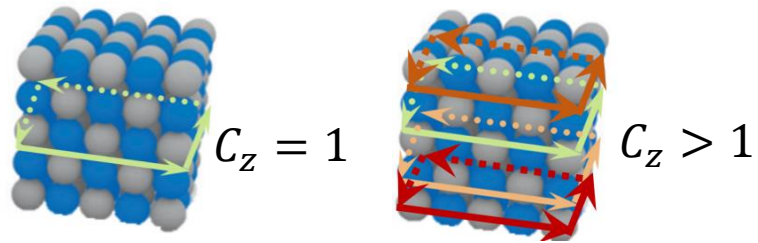
Multimodal operation with unidirectional  
surface states

Non-zero Chern vectors at reduced  
magnetization conditions



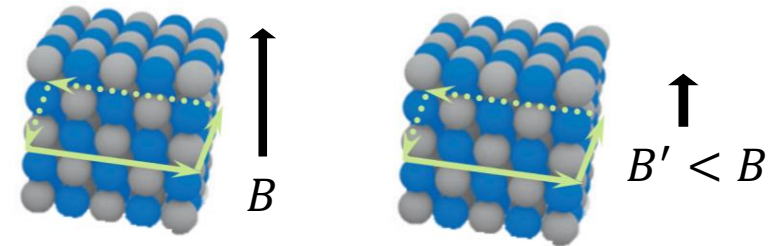
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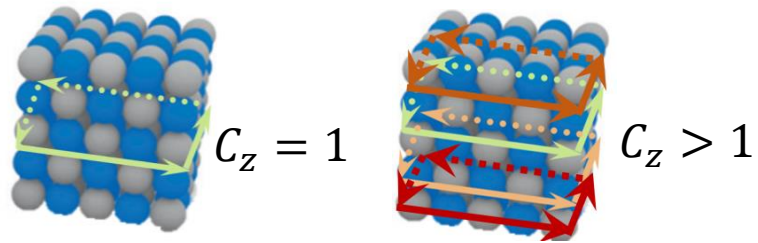
Non-zero Chern vectors at reduced  
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For frequencies where the gyrotropic  
response is weak

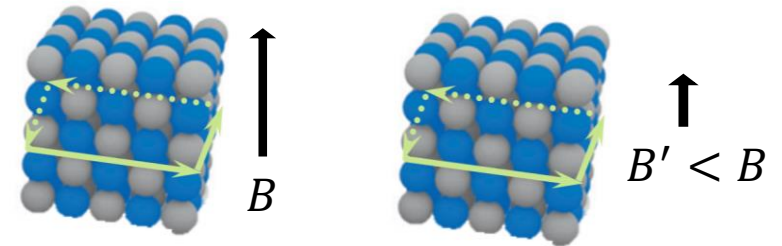
# Summary: Chern vector engineering

Arbitrarily large Chern vectors  
*by design*



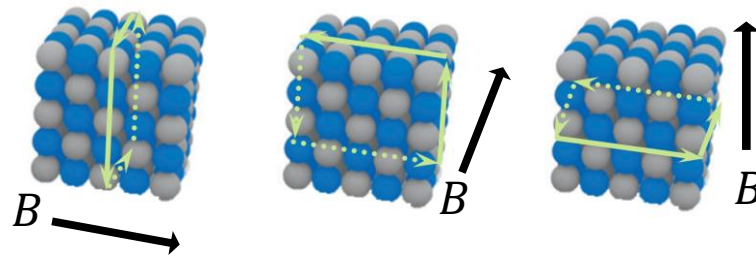
Multimodal operation with unidirectional surface states

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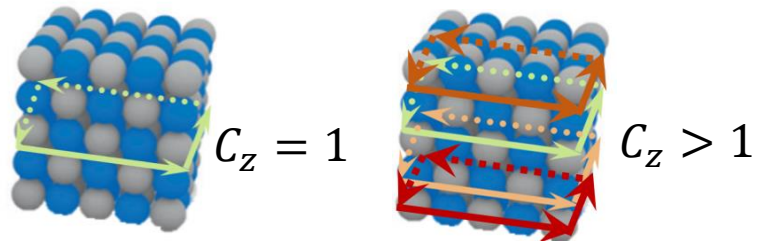
For frequencies where the gyrotropic response is weak

Orientable Chern vectors



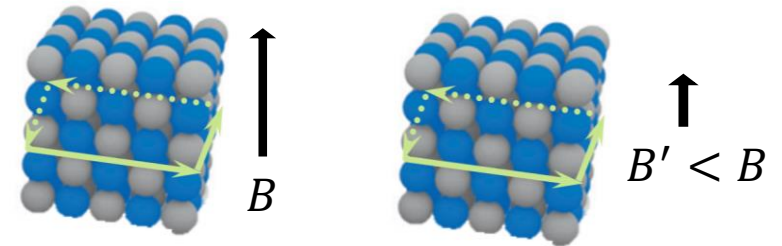
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*by design*



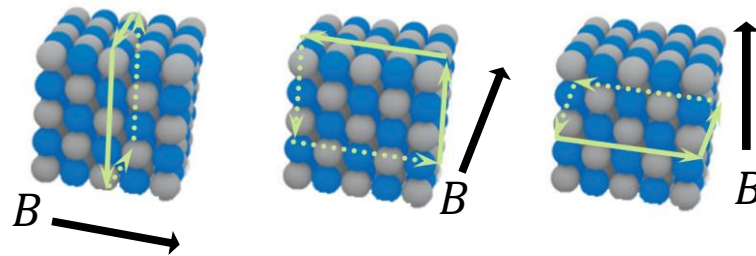
Multimodal operation with unidirectional surface states

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For frequencies where the gyrotropic response is weak

Orientable Chern vectors



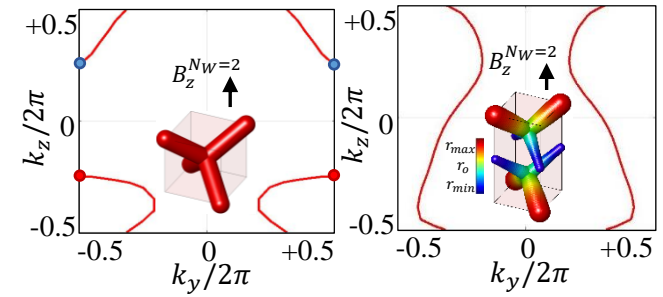
More interfaces and bulk-boundary configurations as compared to 2D

# Bulk-boundary correspondence

# Bulk-boundary correspondence

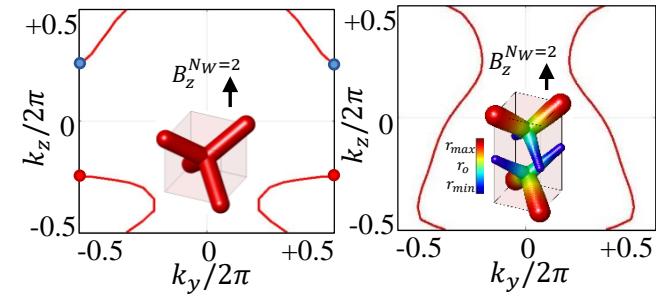
- Surface observable:
  - Fermi loops (3D CI) from 3D Fermi arcs (Weyl Semimetal)

‘Vectorial bulk-boundary correspondence in 3D CIs’, (under review in Adv. Opt. Mat)

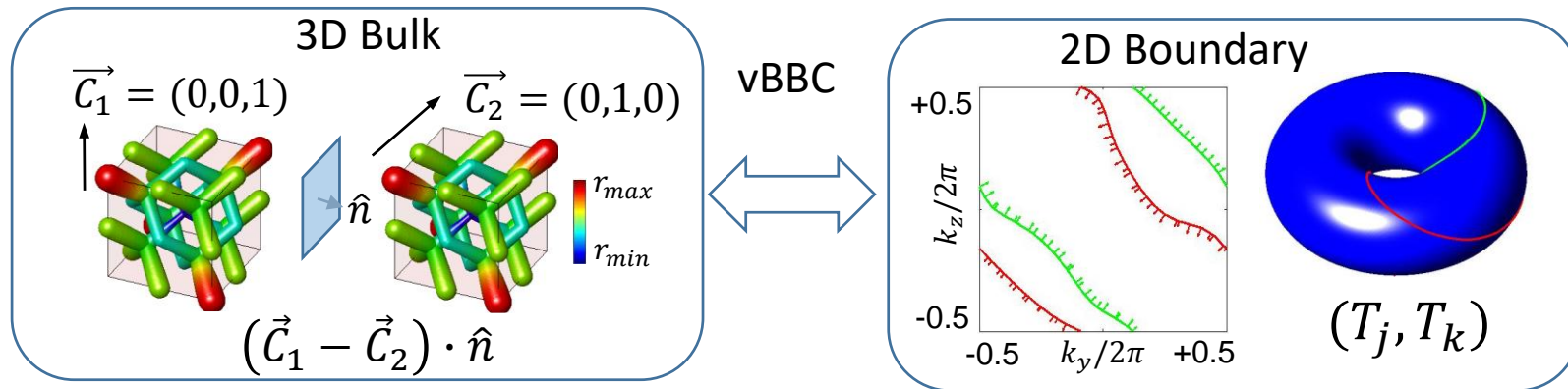


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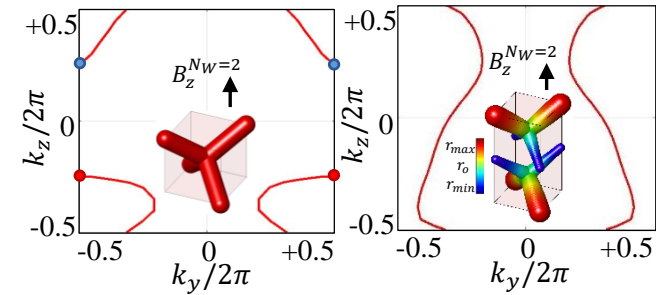
- Chern vectors: need to define a vectorial bulk-boundary correspondence



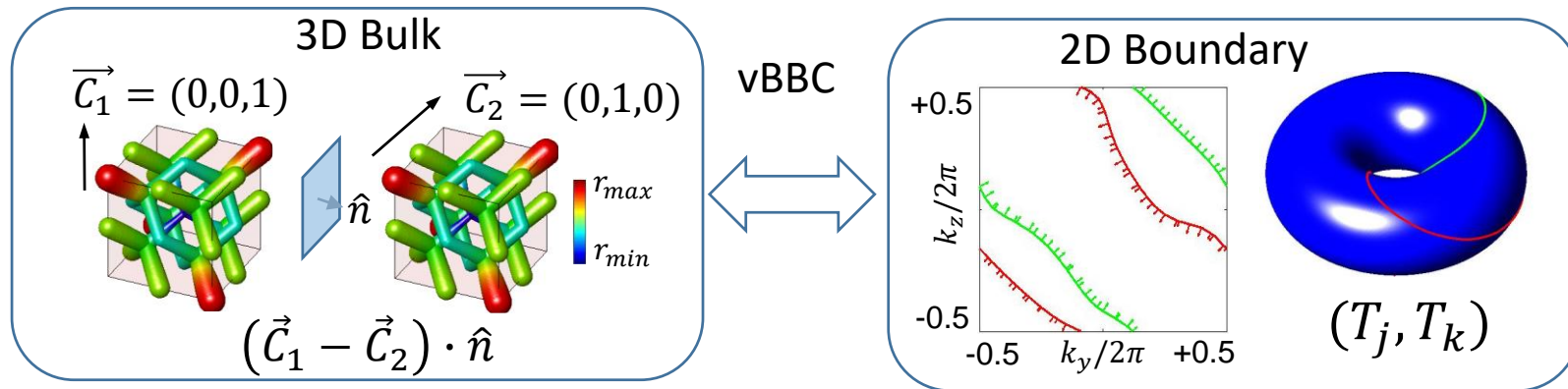


# Bulk-boundary correspondence

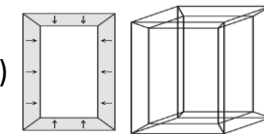
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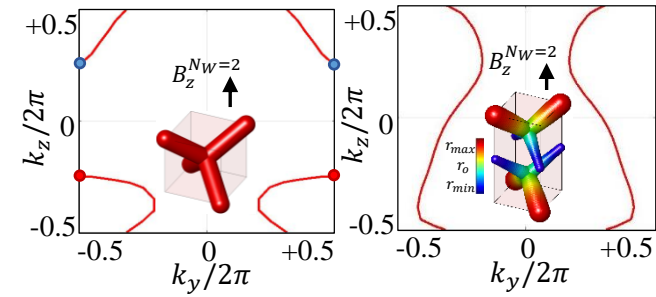
- 3D bulk response:
  - ME coupler vs Chern wrappers in 'Berry Phases in Electronic Structure Theory', D. Vanderbilt (2018)



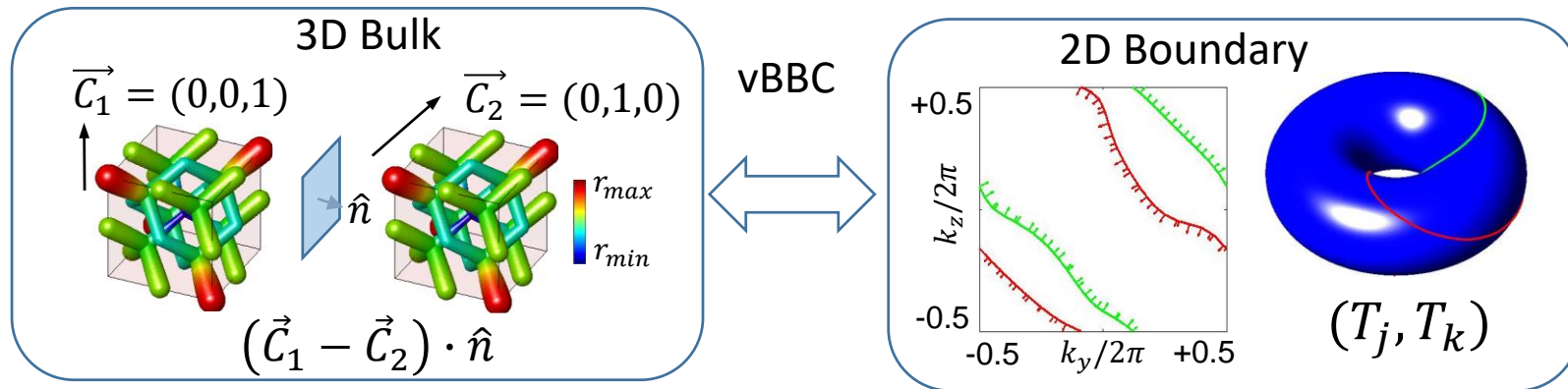
Trivial core embedded  
in  $\vec{C} = \hat{n}$

# Bulk-boundary correspondence

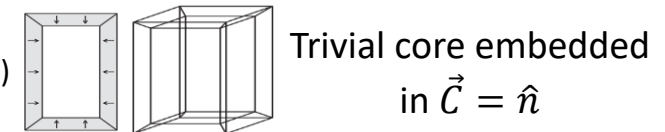
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- Chern vectors: need to define a vectorial bulk-boundary correspondence



- 3D bulk response:
  - ME coupler vs Chern wrappers in 'Berry Phases in Electronic Structure Theory', D. **Vanderbilt** (2018)



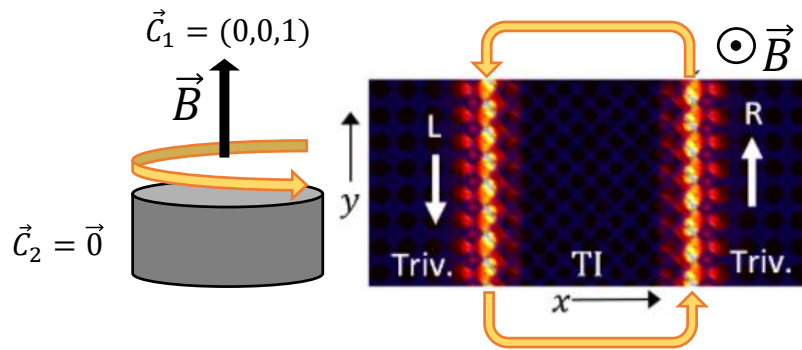
- Beyond a 2D layer construction:
  - Obstructed 3D CI in B. J. **Wieder**, *Phys. Rev. Research* 2, 042010 (2020)



# Photonic interfaces: unidirectionality

# Photonic interfaces: unidirectionality

Conveyor-belt 3DAHE current

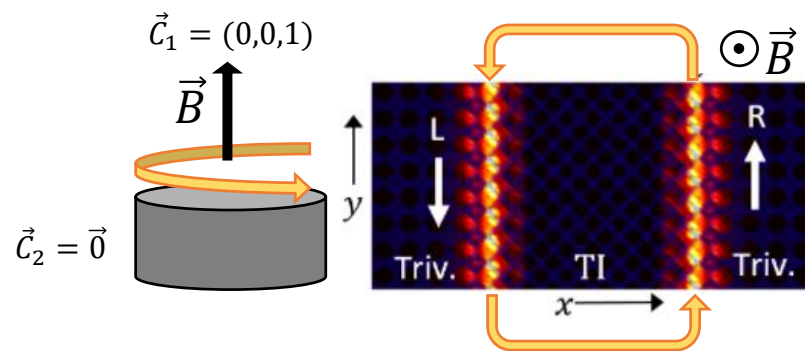


$$\vec{K} \propto \sigma_{AH} \vec{E} \times \hat{n}$$

*Nat. Comm.*, 12, 7330 (2021)

# Photonic interfaces: unidirectionality

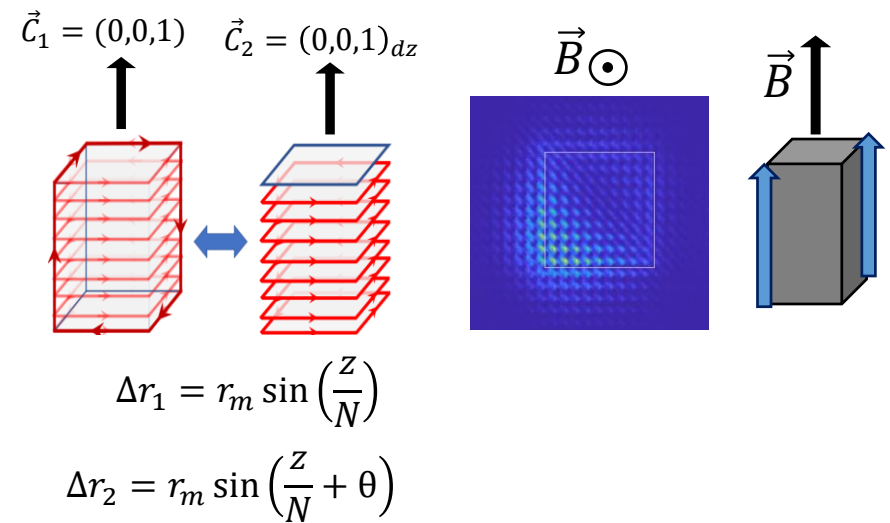
Conveyer-belt 3DAHE current



$$\vec{K} \propto \sigma_{AH} \vec{E} \times \hat{n}$$

*Nat. Comm.*, 12, 7330 (2021)

Axial hinge current



'Axial hinge obstructed photonic 3D CI',  
*in preparation*

# Thank you for listening!



Mikel García  
Díez



Iñigo Robredo



María Blanco  
de Paz



Jon Lasar  
Alonso



Barry Bradlyn



Juan Luis  
Mañes



Maia García  
Vergniory

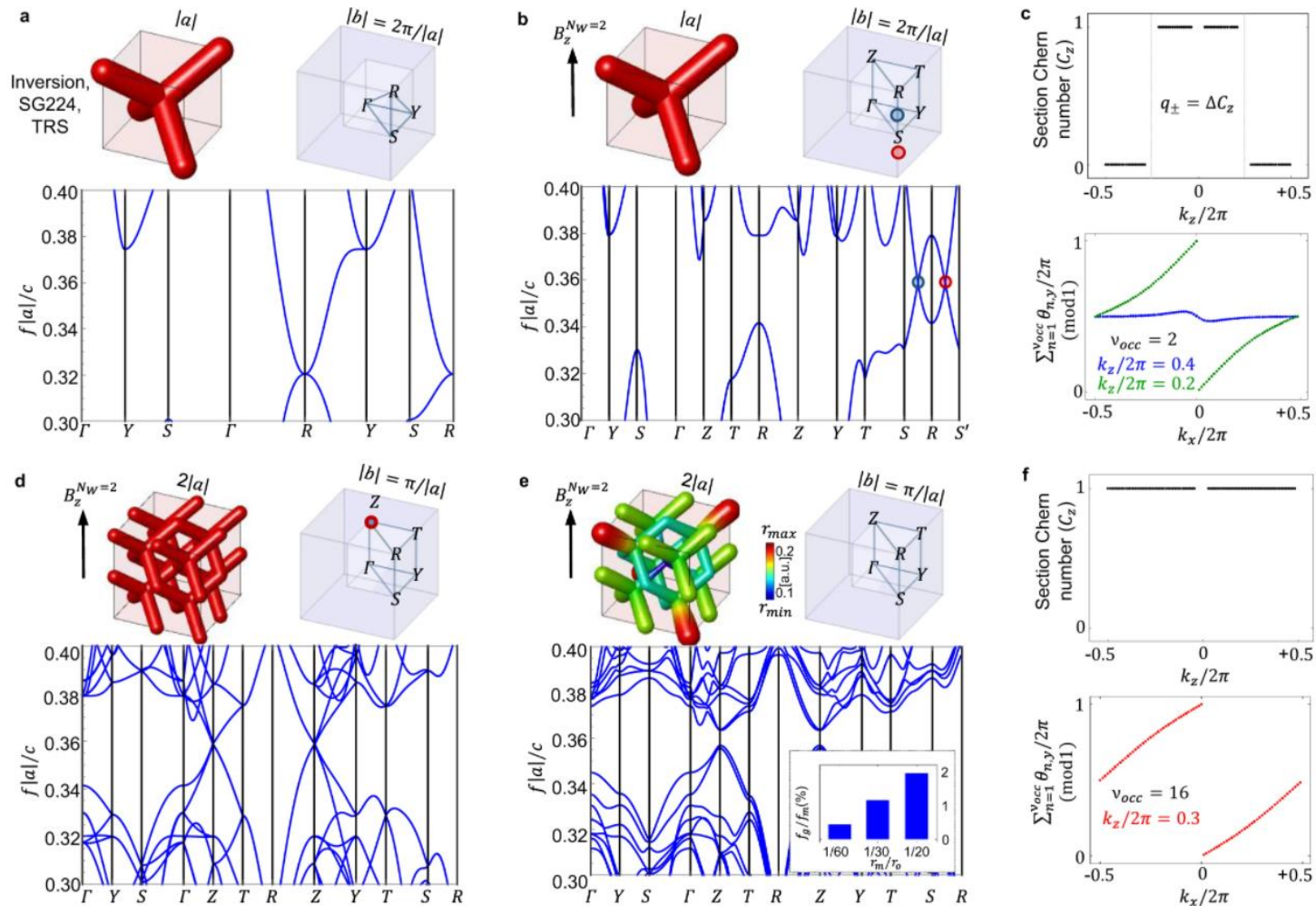


Aitzol García  
Etxarri

'Cubic 3D Chern photonic insulators with orientable large Chern vectors' *Nature Communication*, 12, 7330 (2021)

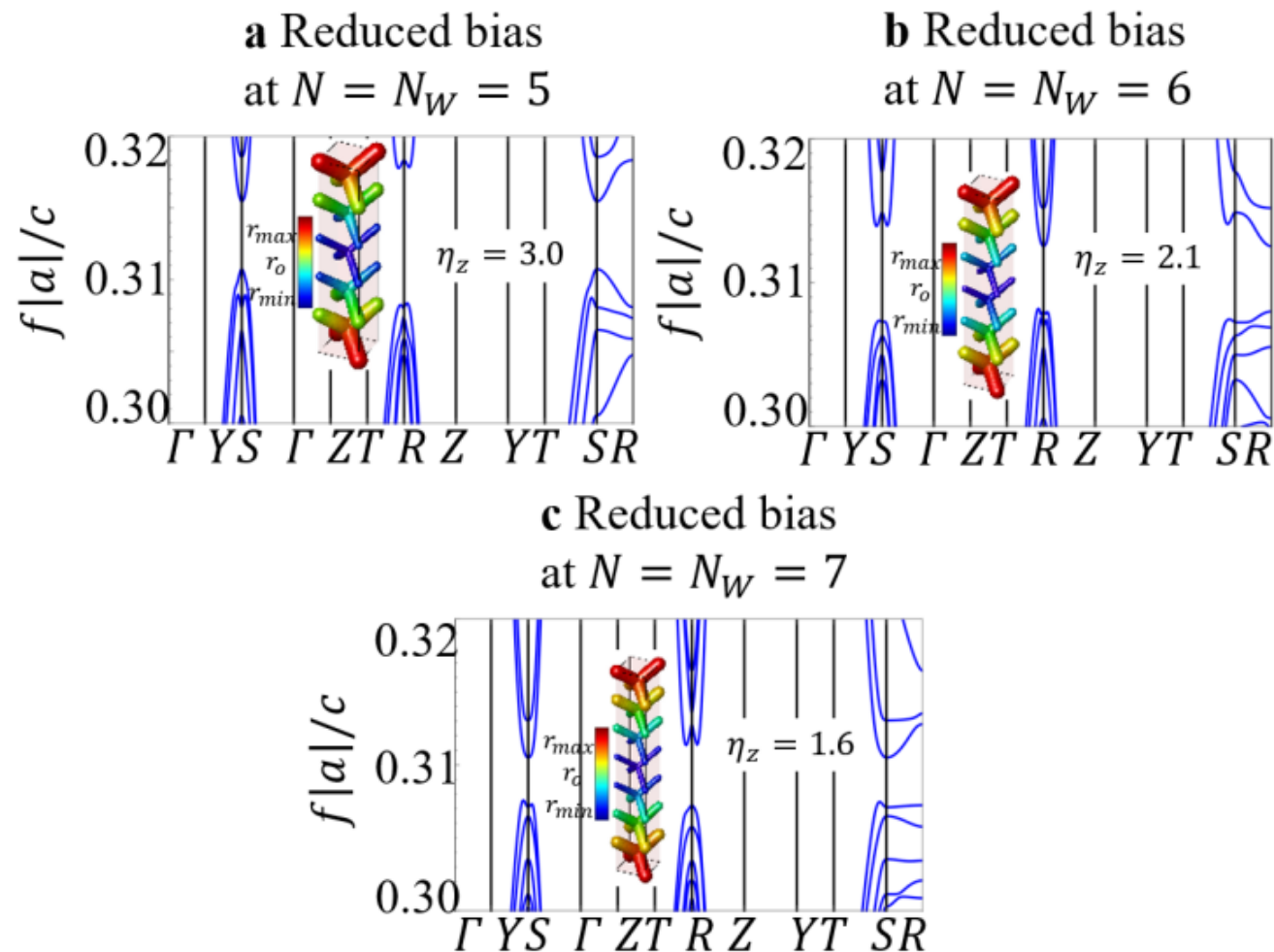


# Photonic 3D CI by cubic supercell

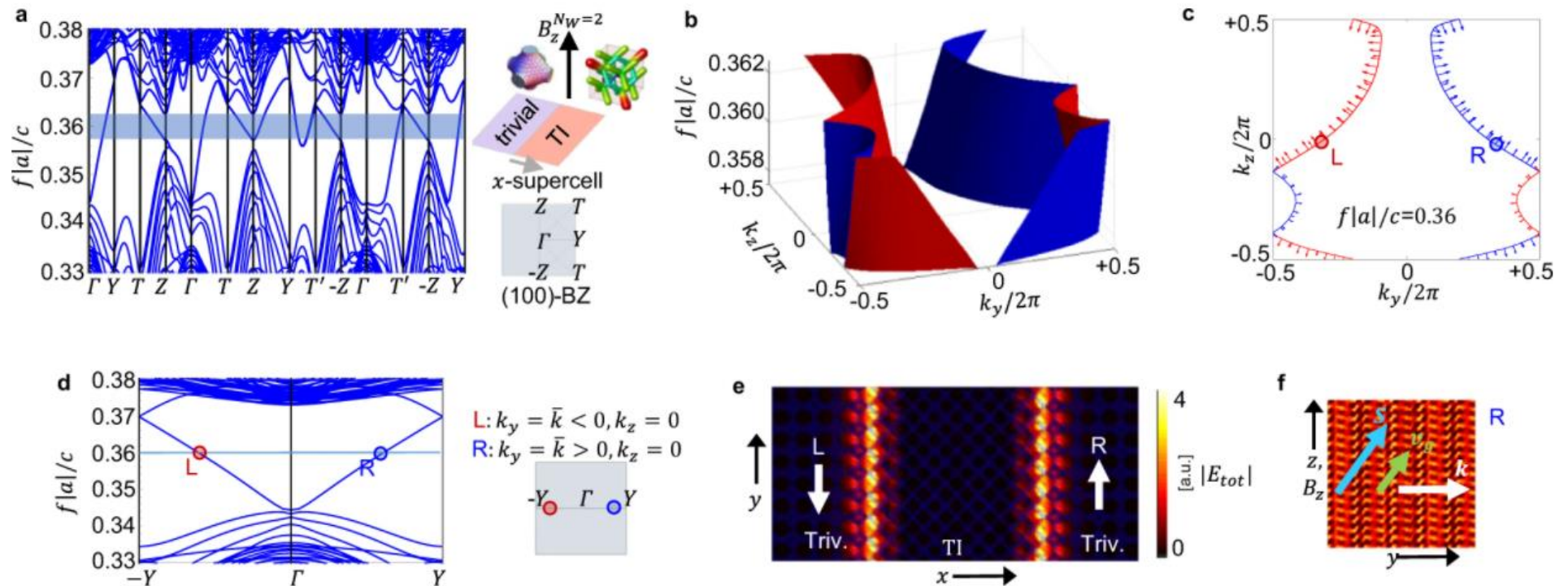




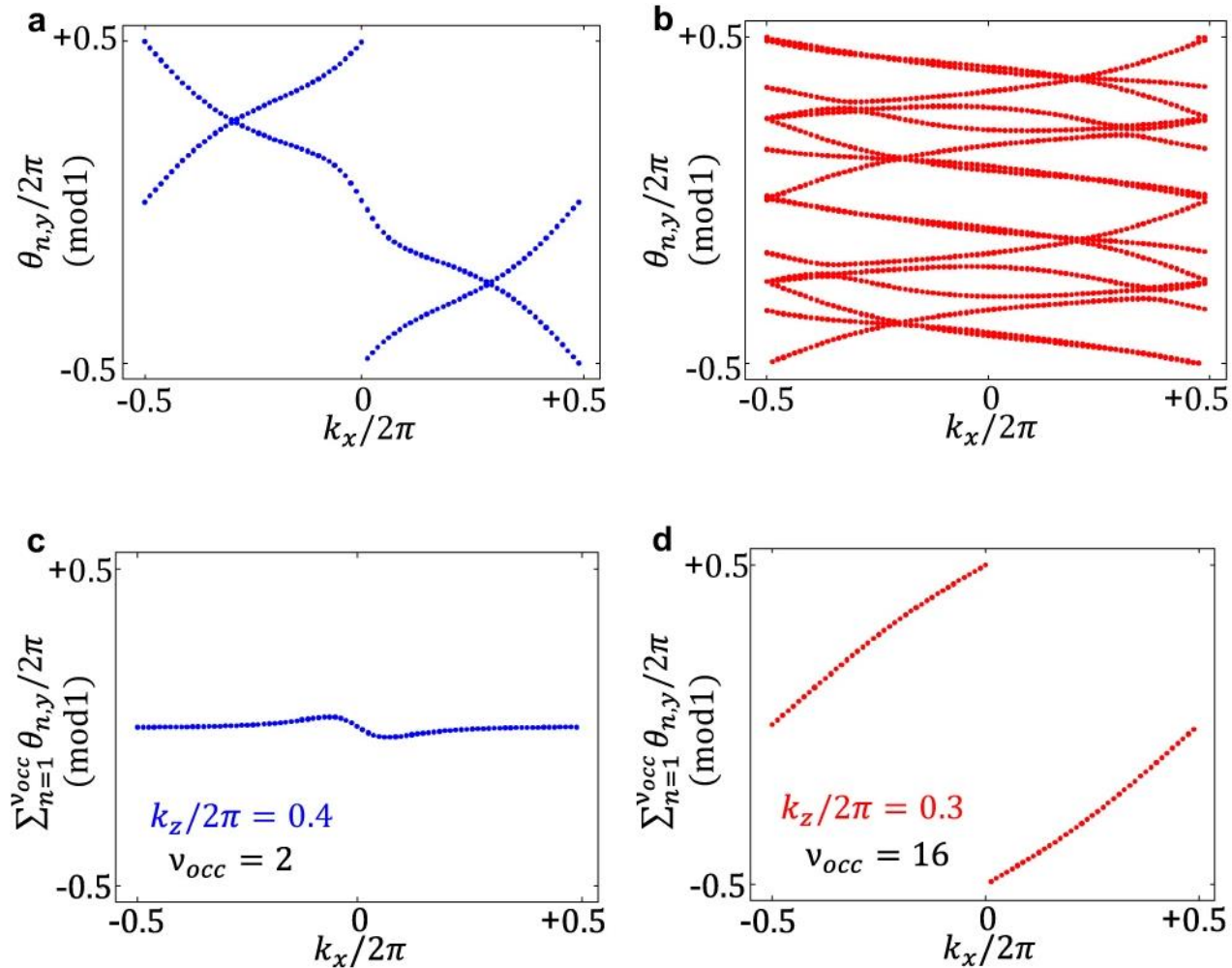
# 3D CI in a reduced magnetization



# 3D CI surface states



# Topological char. via Wilson loops



# Fermi arcs and Fermi loops

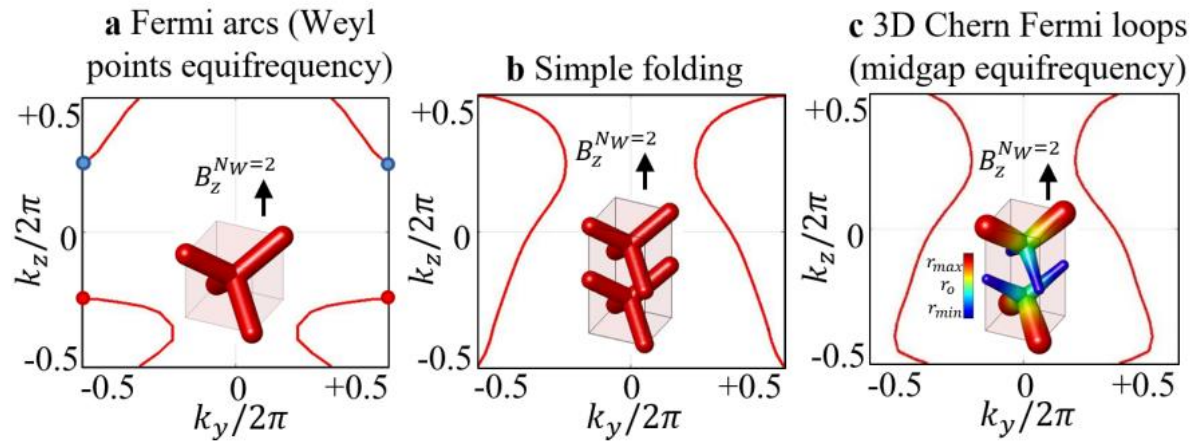
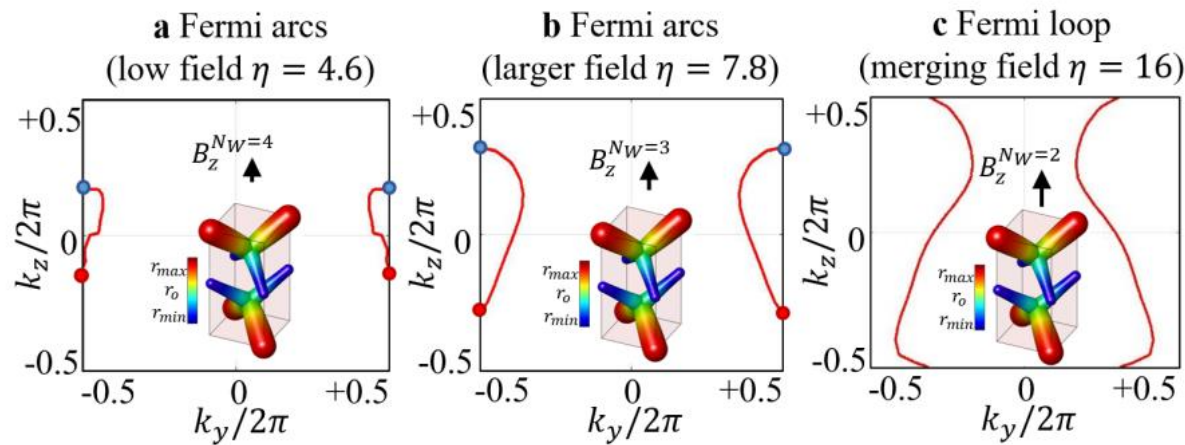


Figure 9: Evolution of the Fermi arcs (a) after Brillouin zone folding (b) and supercell modulation (c).



# Lattice mismatch

