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Ultrafast Spectroscopy

TRANSIENT TOPOLOGICAL STATE IN A POLAR CRYSTAL

F. Chassot, A. Pulkkinen, G. Kremer, J.H. Dil,
J. Krempaský, J. Minár, G. Springholz and C. Monney

Swiss National Science Foundation
frimat

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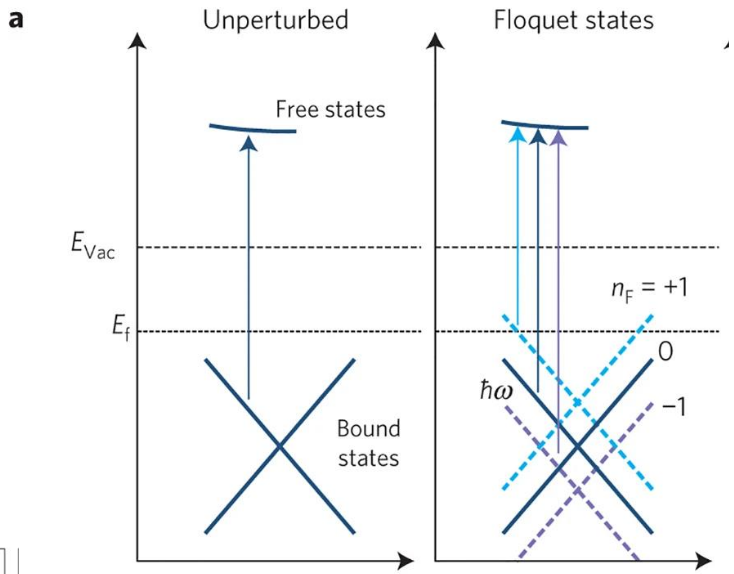
Strong-light matter interaction: Floquet physics

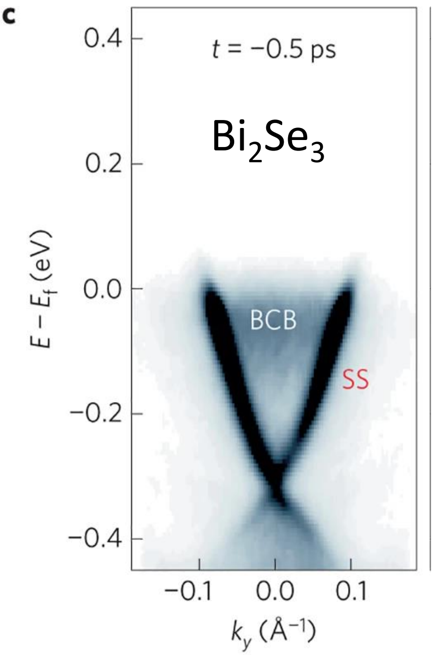
The electric field of an intense ultrashort pulse of light «dresses» the electronic structure of the solid.

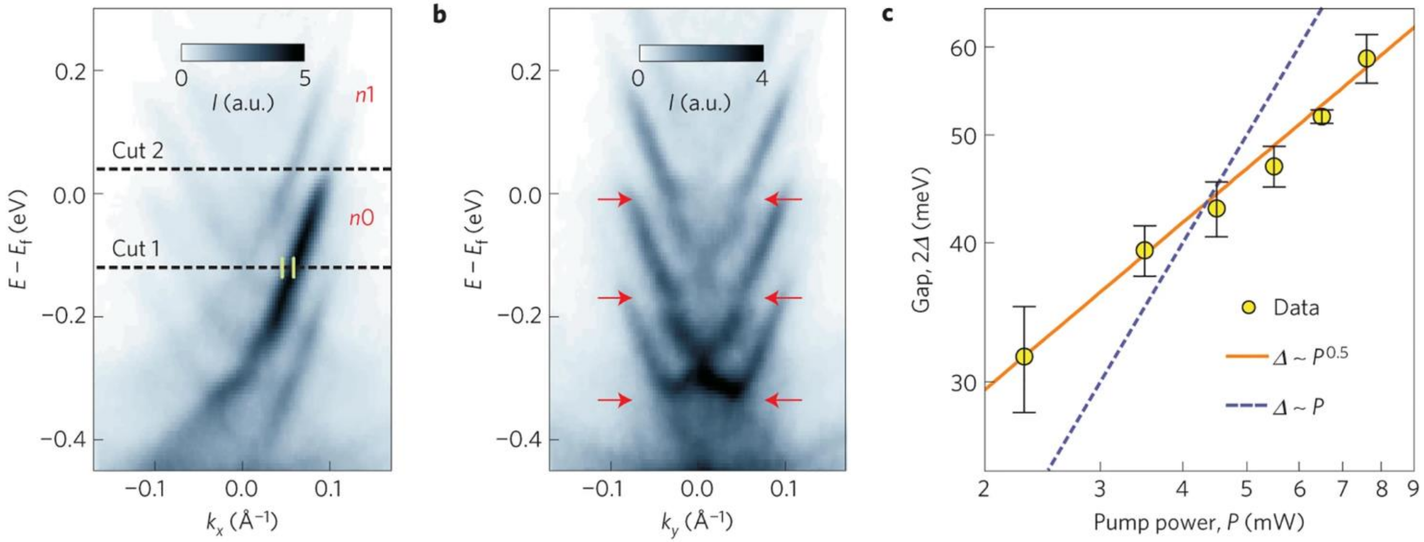


The «periodically driven solid» displays a new electronic structure.

The interaction (hybridization) between the initial and new bands can lead to band gaps.

F. Mahmood *et al.*, Nature Physics 12, 306 (2016)

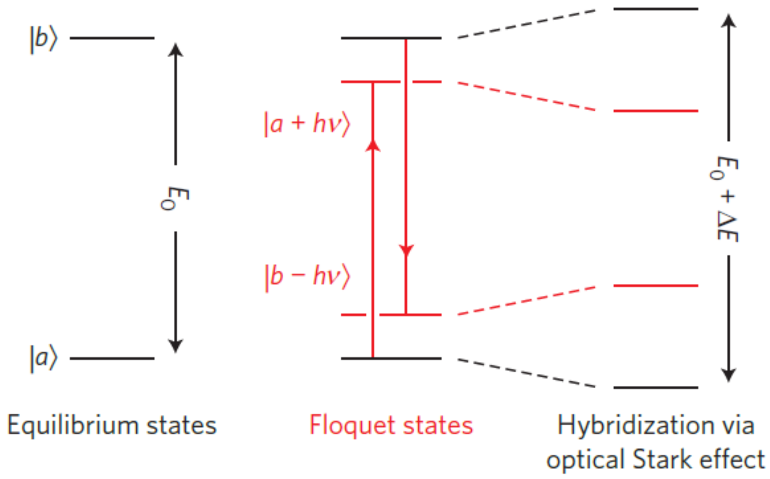


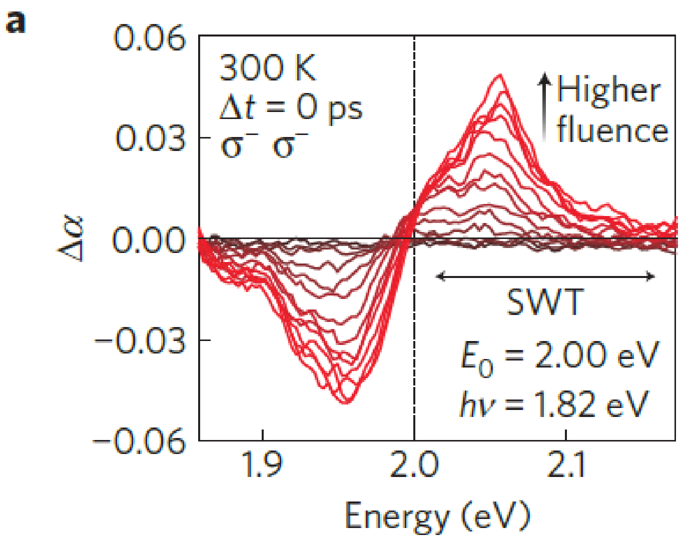


Effect $\propto \sqrt{\text{fluence}}$

Strong-light matter interaction: Floquet states → optical Stark effect

Broadband optical absorption on monolayer WSe_2





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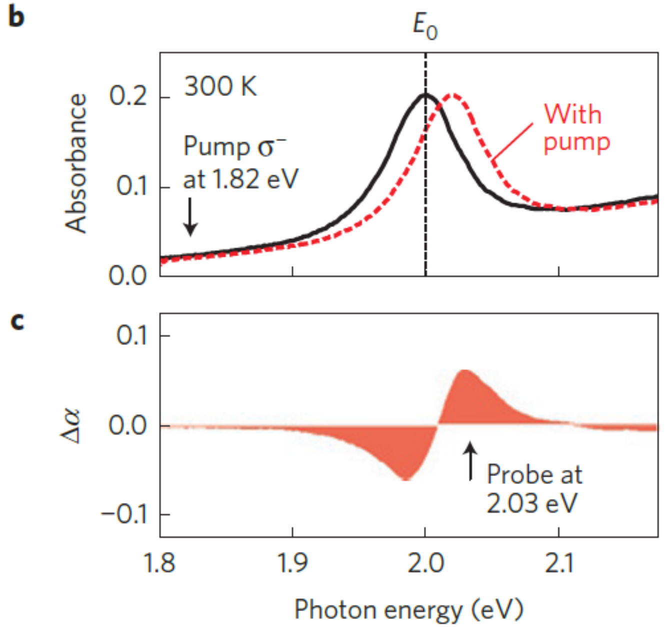
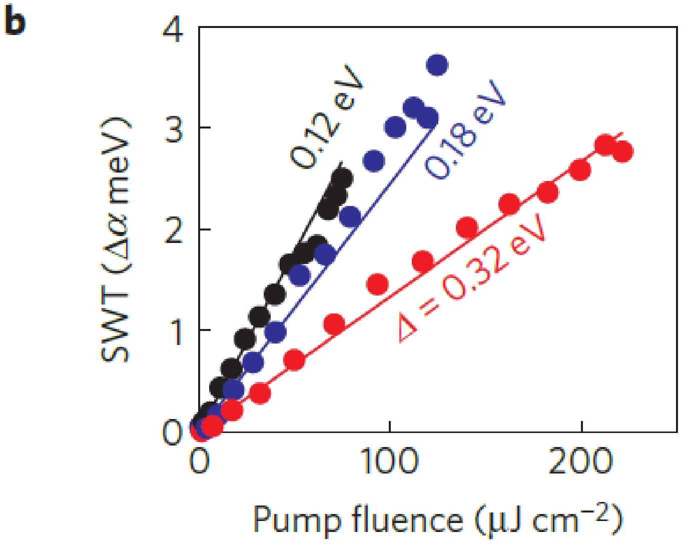


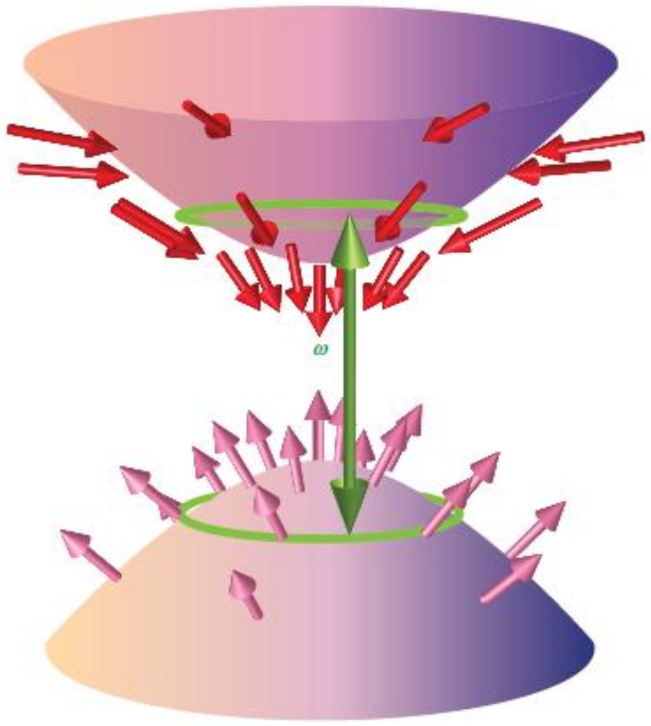


Effect ∝ fluence

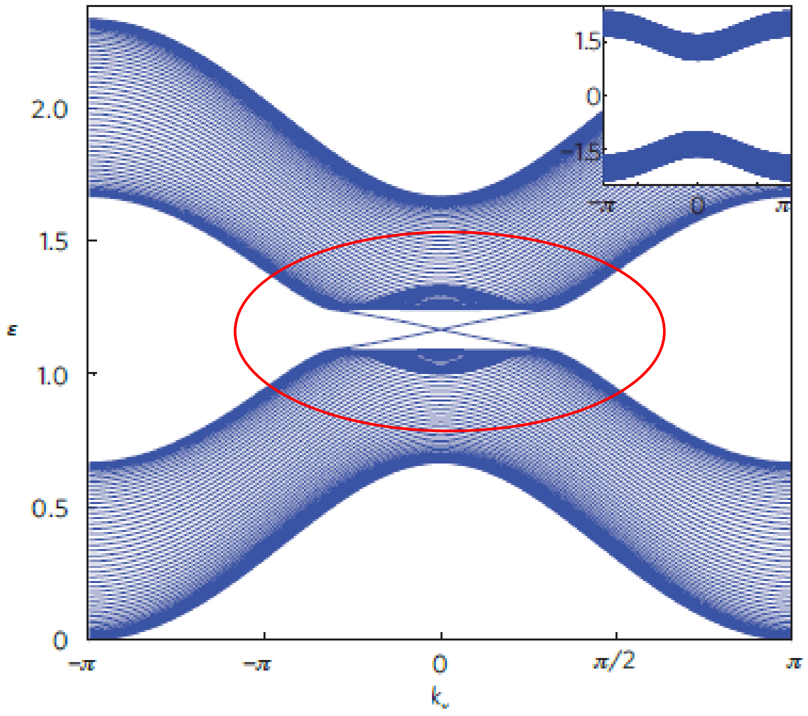
E.J. Sie *et al.*, Nature Materials 14, 290 (2015)

Proposition for a topological Floquet insulator

Is it possible to generate a topological insulator starting from a trivial semiconductor by Floquet engineering?



Quasi-energy spectrum in the Floquet model



Idea: resonant excitation between valence and conduction bands to reshuffle their character.

New: two linearly dispersing chiral edge modes

N.H. Lindner *et al.*, Nature Physics 7, 390 (2011)

Proposition for a topological Floquet insulator

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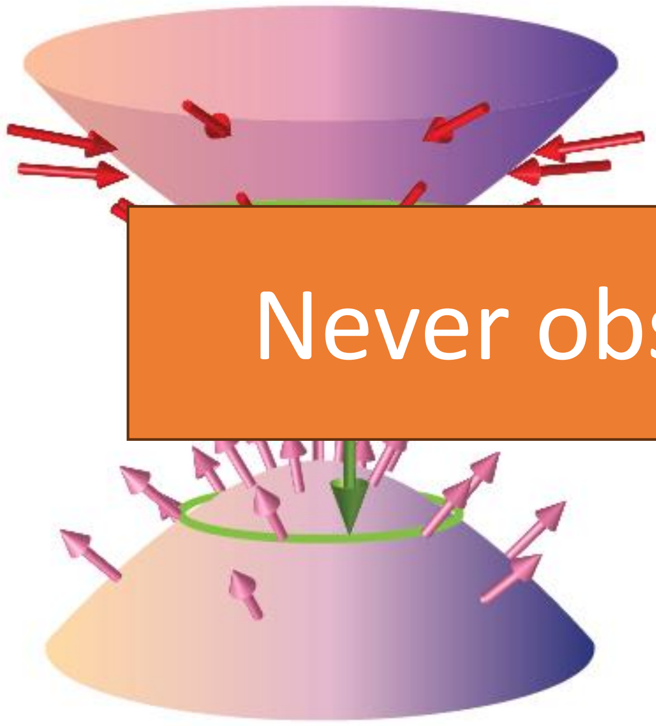

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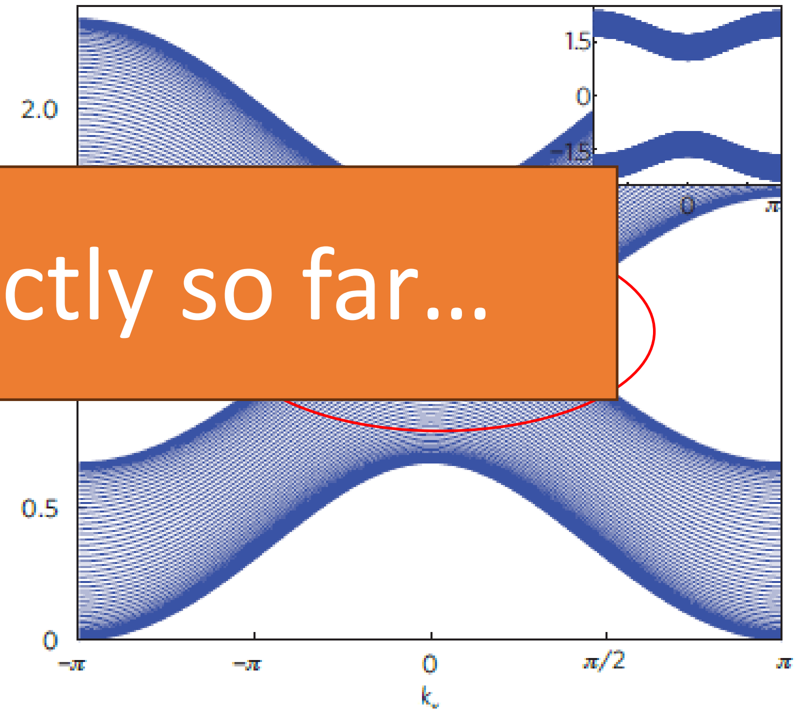


Original dispersions

Never observed directly so far…

Idea: resonant excitation between valence and conduction bands to reshuffle their character.

New: two linearly dispersing chiral edge modes

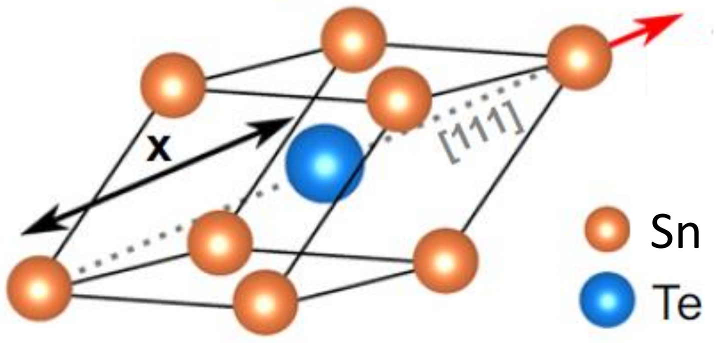
N.H. Lindner *et al.*, Nature Physics 7, 390 (2011)

ferroelectric semiconductor SnTe

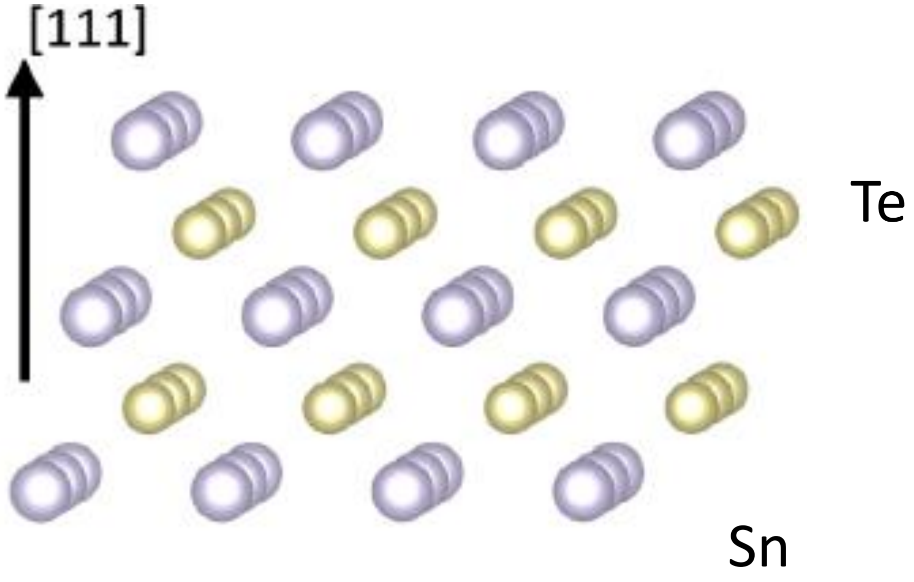
SnTe is a semiconducting and ferroelectric material.

Below about 100 K, SnTe adopts a rhombohedral structure.

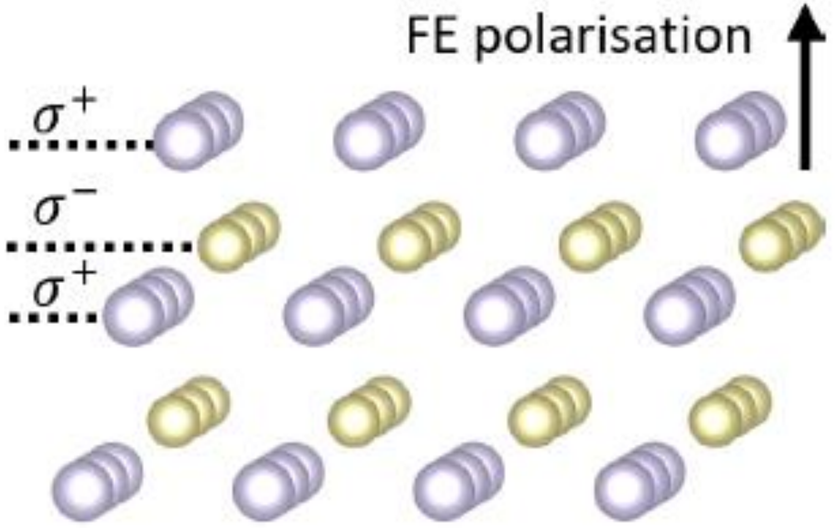
The lattice distortion occurs along the [111] direction.



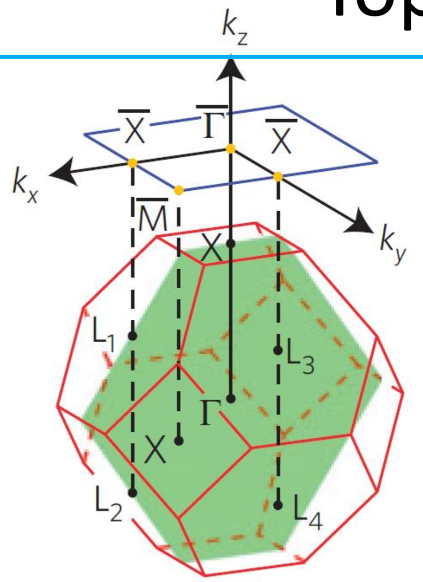
Cubic paraelectric phase

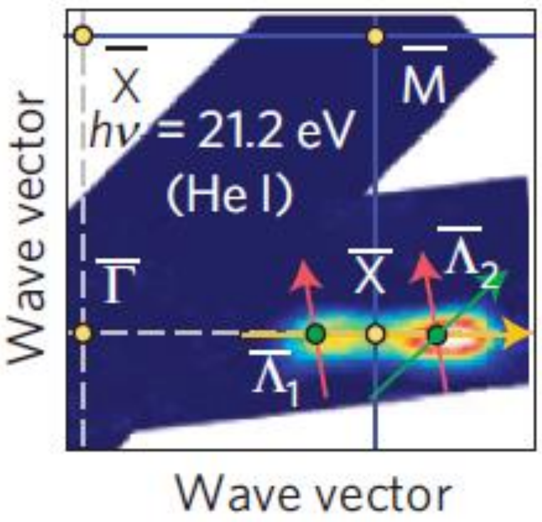


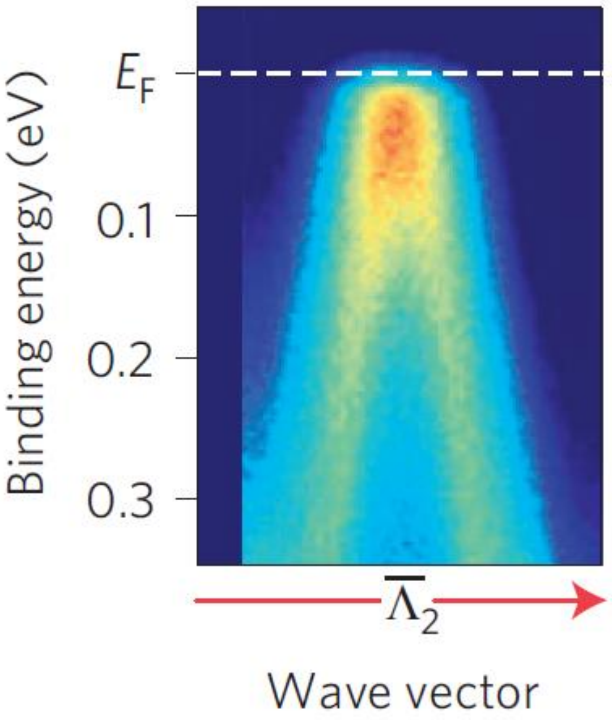
Rhombohedral ferroelectric phase

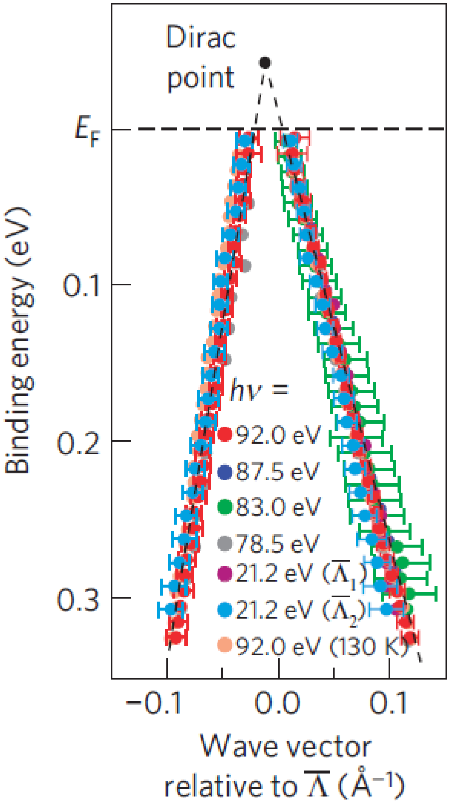


Topological crystalline insulator phase in SnTe

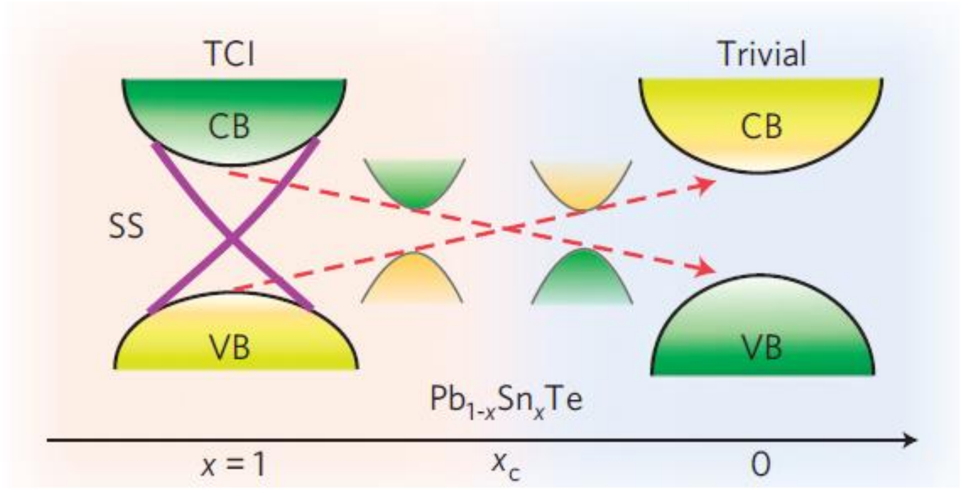








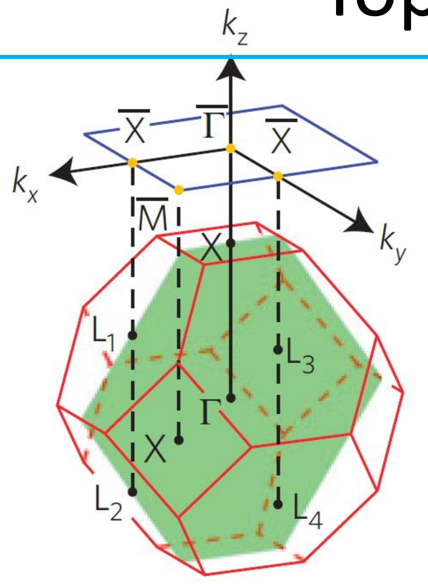
Static ARPES obtained for the **(001) surface**, around the X point

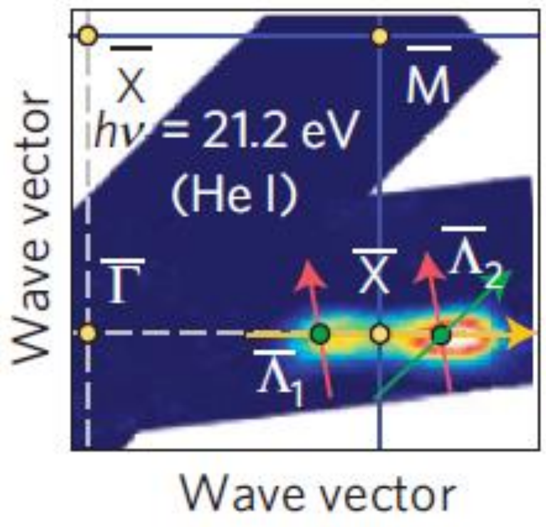


Topological phase transition upon Pb <-> Sn substitution

Tanaka *et al.*, Nature Physics 2012

Topological crystalline insulator phase in SnTe





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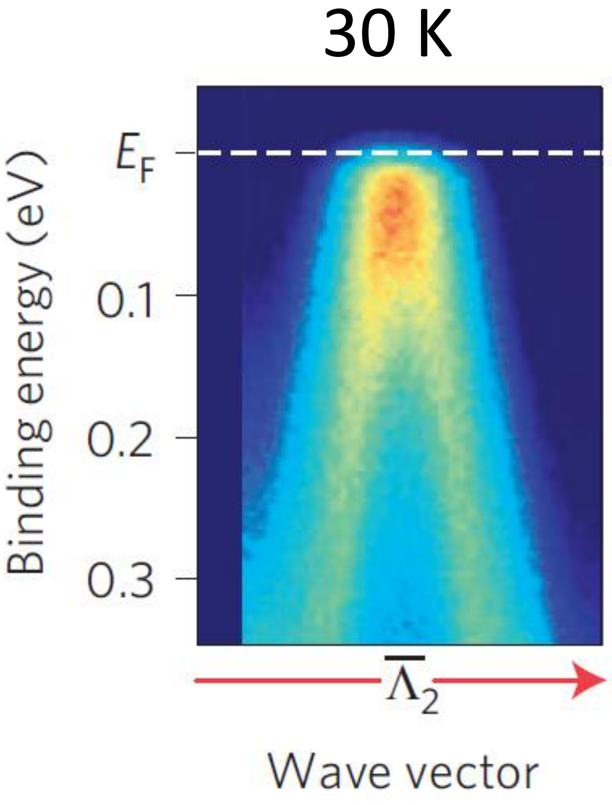
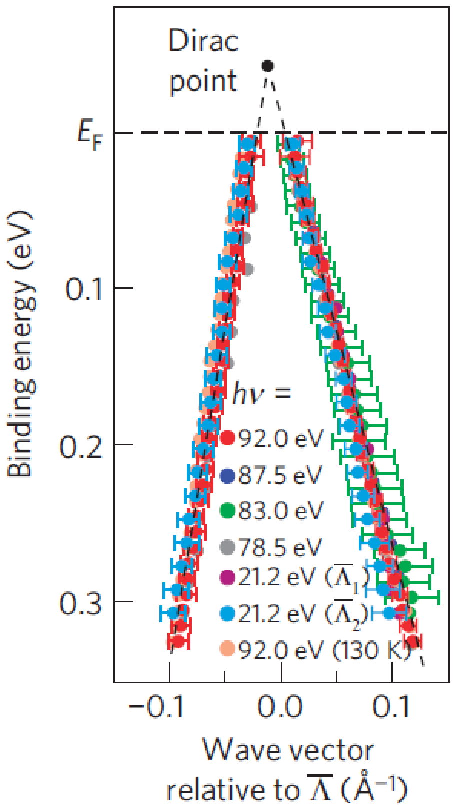
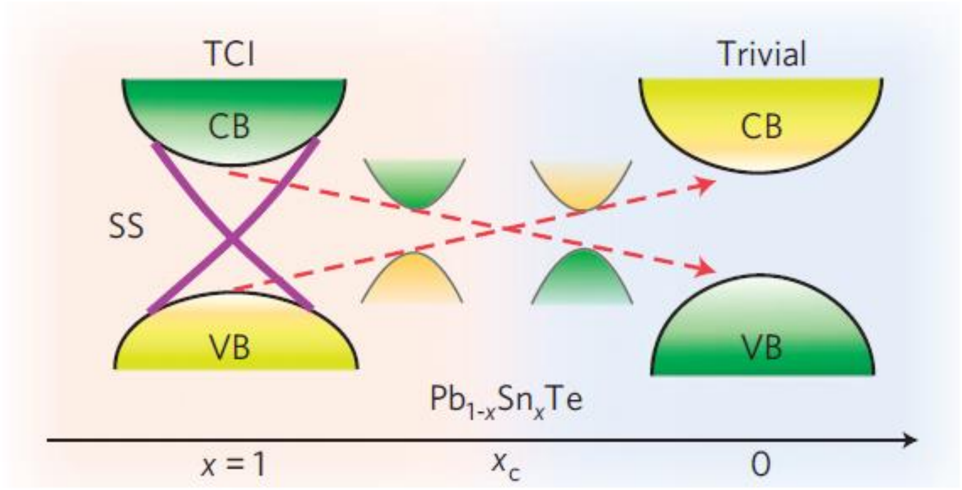






Topological phase transition upon Pb <-> Sn substitution

(110) and (100) mirror planes protect the TCI states.

SnTe was said to be measured in the paraelectric phase…

➢ **however, the ferroelectric distortion breaks (110) mirror plane symmetry**

Tanaka *et al.*, Nature Physics 2012

Rashba effect

Inversion symmetry

$$E(k,\uparrow) = E(-k,\uparrow)$$

Time-reversal symmetry

$$E(k,\uparrow) = E(-k,\downarrow)$$

→ Spin degenerate

$$E(k,\uparrow) = E(k,\downarrow)$$

~~**Inversion symmetry**~~

~~$E(k,\uparrow) = E(-k,\uparrow)$~~

Time-reversal symmetry

$$E(k,\uparrow) = E(-k,\downarrow)$$

→ Spin split

$$E(k,\uparrow) \neq E(k,\downarrow)$$

For a 2D electron gas: Rashba Hamiltonian

$$H_{eff} = H_0 + H_{SO}$$

$$H_0 = -\frac{\hbar^2}{2m}\vec{\nabla}^2$$

$$H_{SO} = \frac{\hbar}{4m^2c^2}(\vec{\nabla}V \times \vec{p})\,.\,\vec{s}$$

k dependent splitting

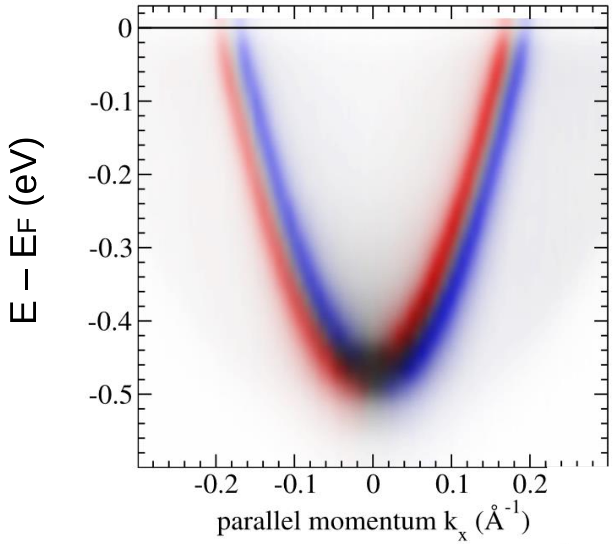
$$E_{\pm}(k) = \frac{\hbar^2 k^2}{2m} \pm \alpha_R k$$

α_R:

- Spin-orbit strength
- Surface gradient potential

Rashba systems measured by ARPES

(i) **Surface states of metals**: invertion symmetry is broken due to the existence of the surface (As(111), Au(111), Cu(111) …)

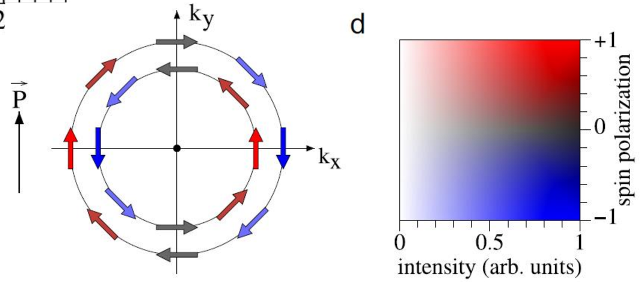


E – EF (eV)

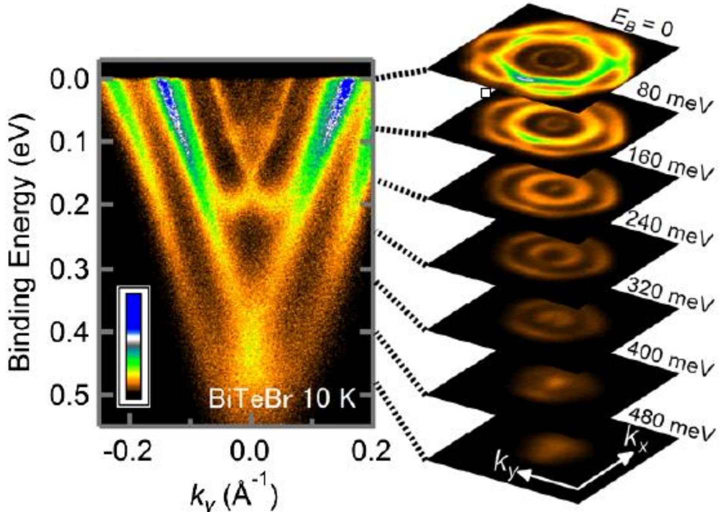
Au(111)

C. Tusche et al., Ultramicroscopy 159 (2015) 520–529

Spin-momentum locking



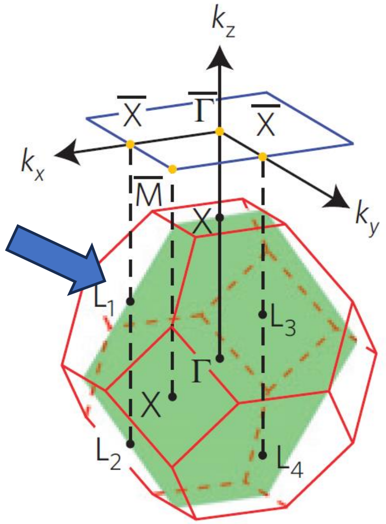
(ii) **Bulk states**: non-centrosymmetric semiconductors with a polar structure and a large spin-orbit interaction (BiTeBr, BiTeI, BiTeCl)



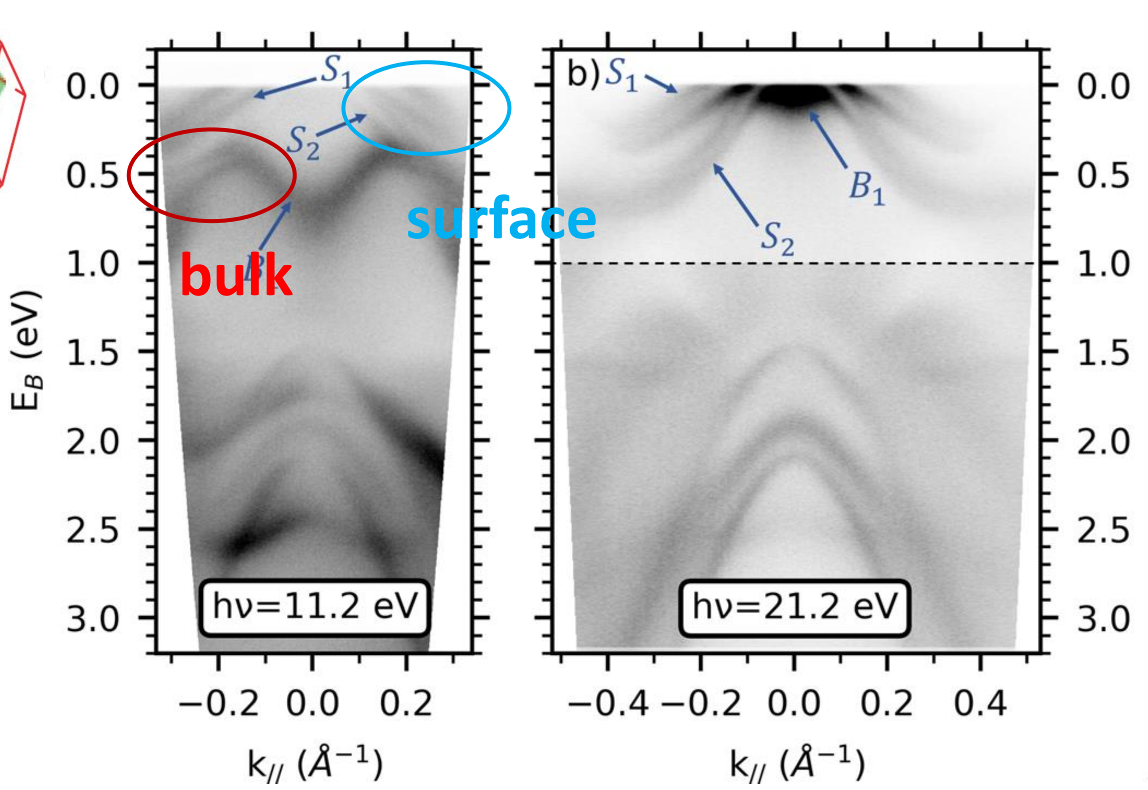
M. Sakano et al., Phys. Rev. Lett. **110**, 107204 (2013)

Ferroelectric phase transition in SnTe: ARPES for the (111) surface

Goal: identify the Rashba splitting in bulk states of SnTe and follow its splitting vs temperature.



30 K

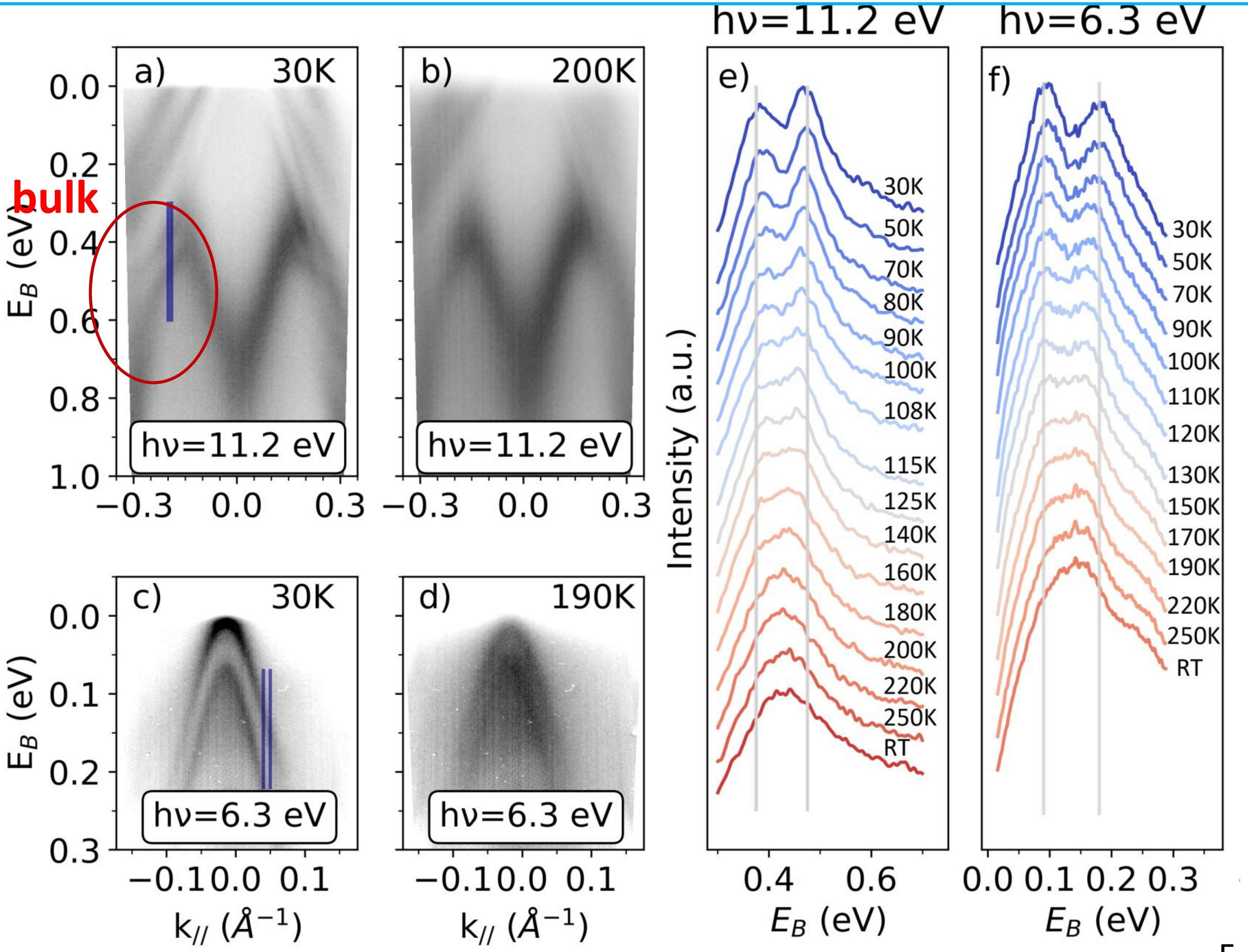


along $\overline{\Gamma K}$

Measurement at 30 K, in the ferroelectric phase.

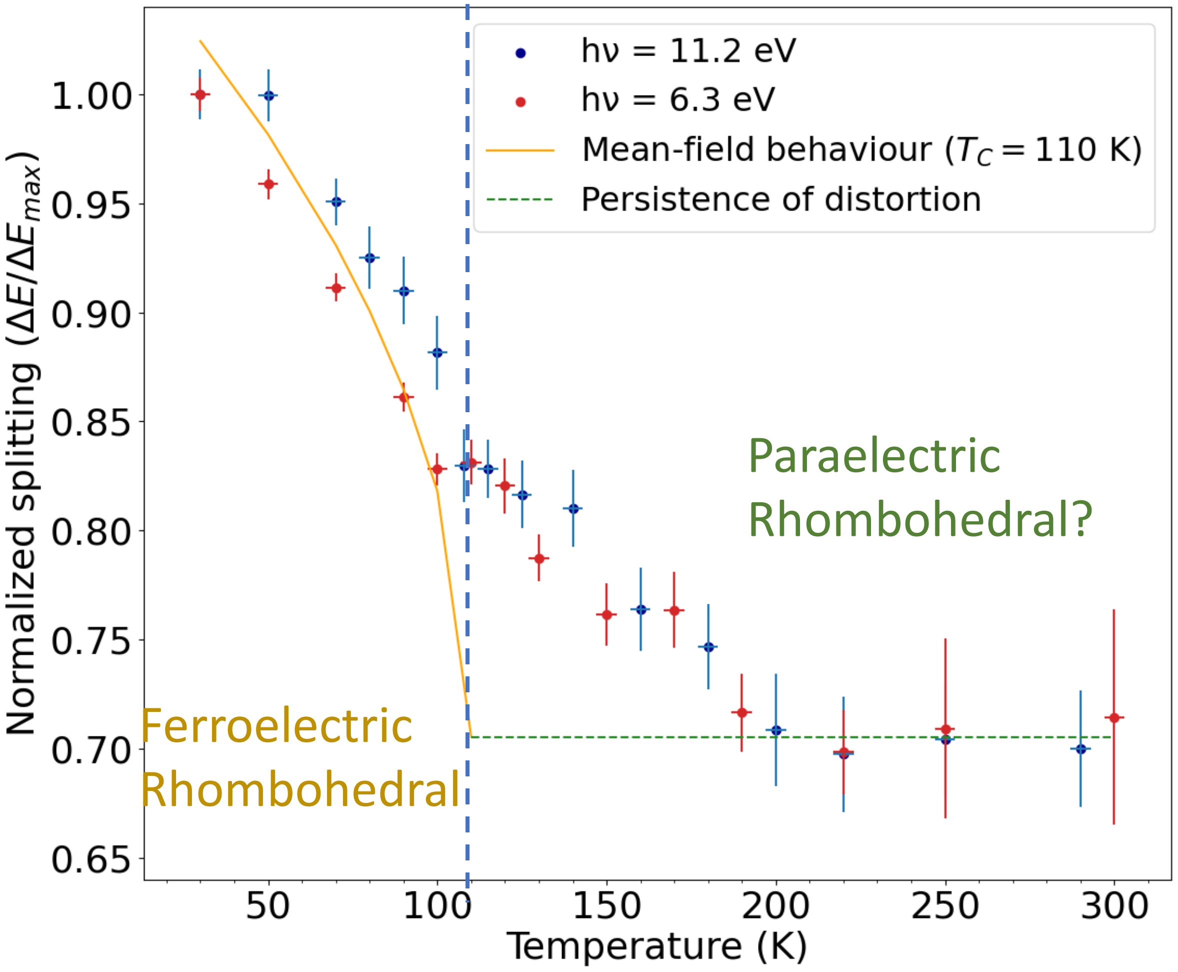
F. Chassot *et al.*, Nano Letters 24, 82 (2024)

Ferroelectric phase transition in SnTe: ARPES for the (111) surface



F. Chassot *et al.*, Nano Letters 24, 82 (2024)

Persistence of ferroelectric distortion at room temperature in SnTe



T_c ~ 110 K

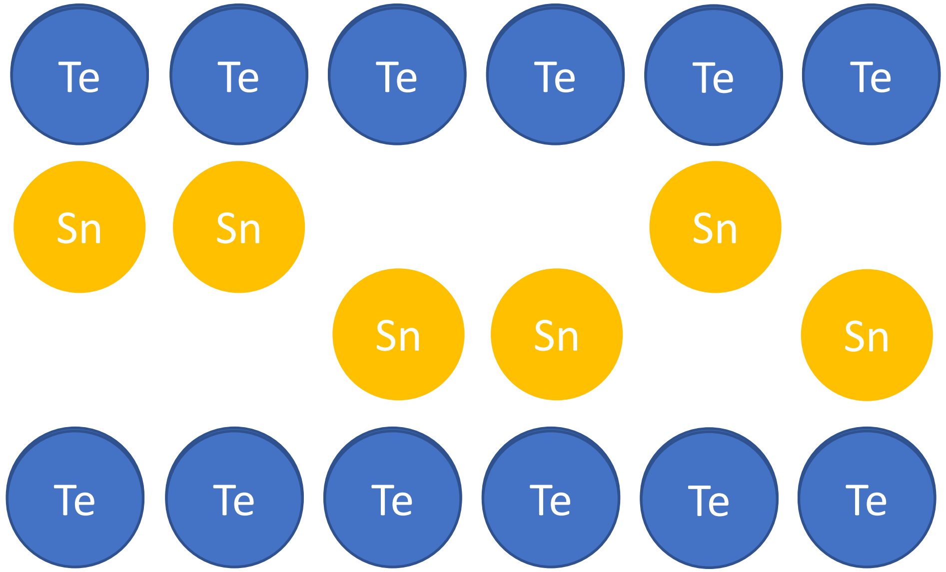
- We observe a mean-field like suppression of the Rashba splitting down to T_c ~ 110 K
- Above T_c splitting largely persists!

➢ Persistence of rhombohedral distortion at RT

F. Chassot *et al.*, Nano Letters 24, 82 (2024)

Order-disorder contribution to the phase transition in SnTe

$T > T_C$

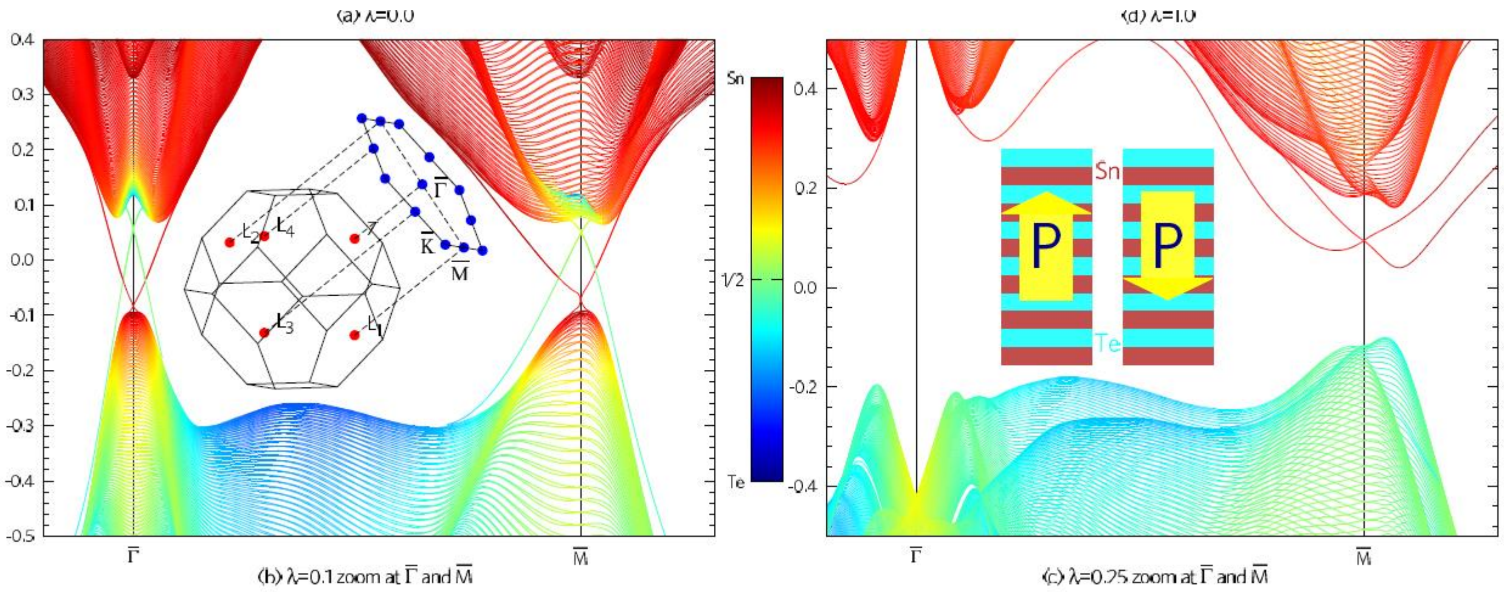


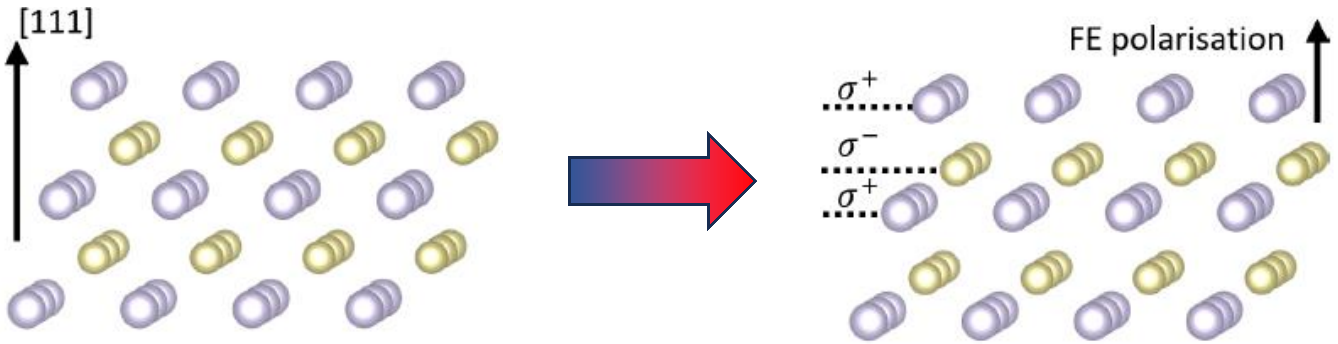
- SnTe : 2nd order displacive transition below T_c
- distorted clusters/unit cells above T_C

- No macroscopic ferroelectricity
- Consequence for topology?

F. Chassot *et al.*, Nano Letters 24, 82 (2024)

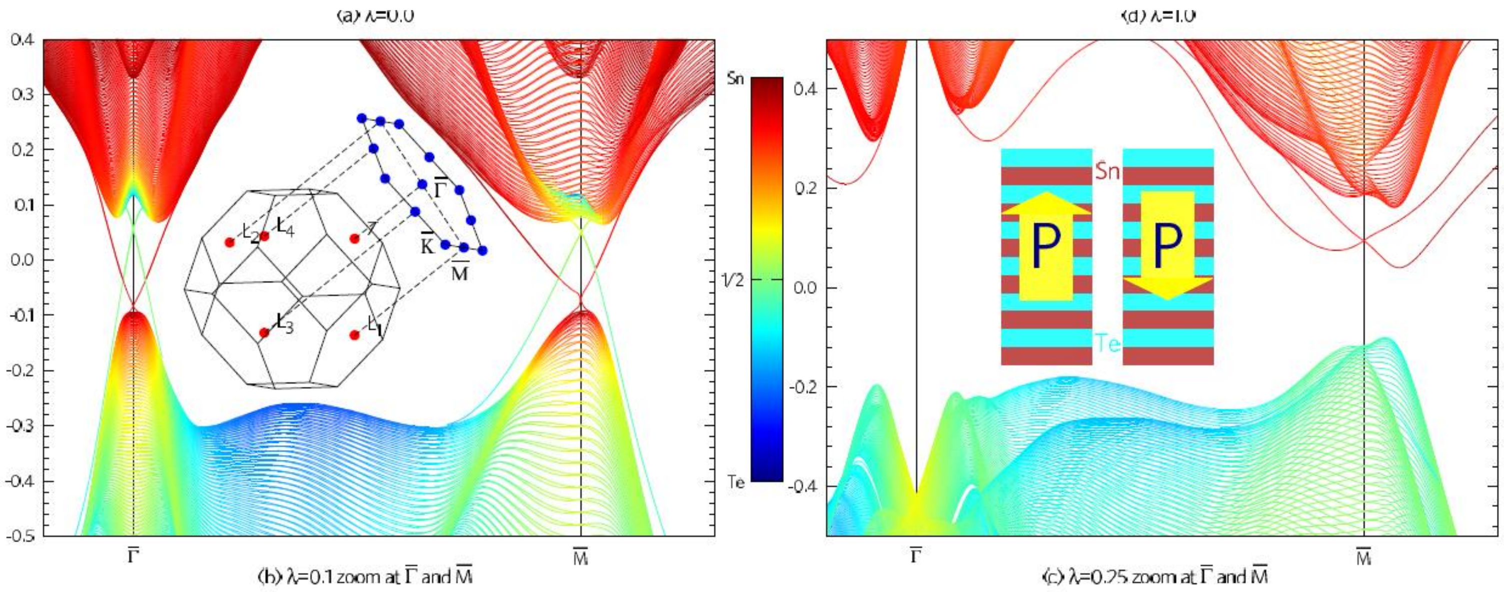
Implication for the topological states?

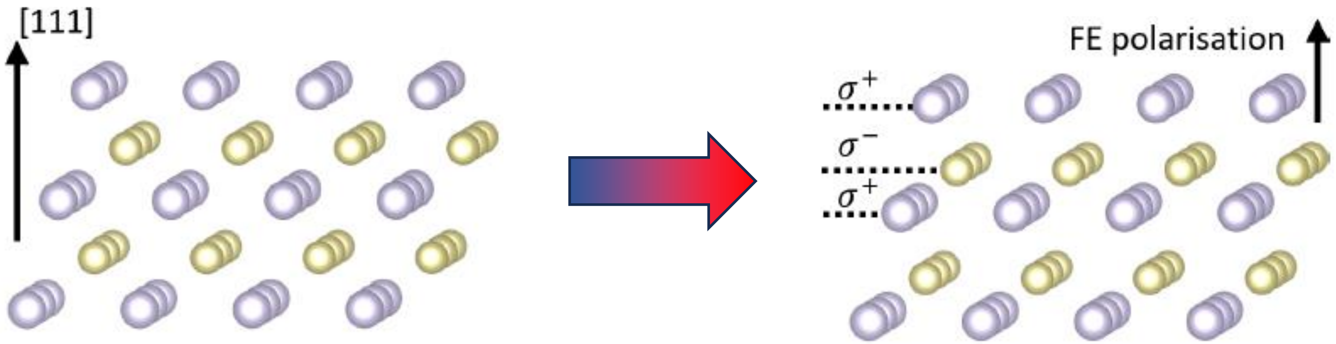


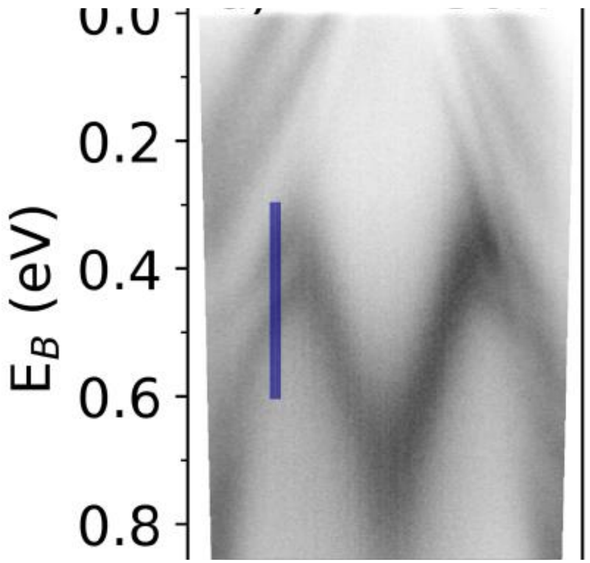


Plekhanov *et al.*, PRB 90, 161108(R) (2014)

Implication for the topological states?







Below T_c: ferroelectric rhombohedral

➢ **No topological surface state expected**

Plekhanov *et al.*, PRB 90, 161108(R) (2014)

Acknowledgements

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Jan Minár

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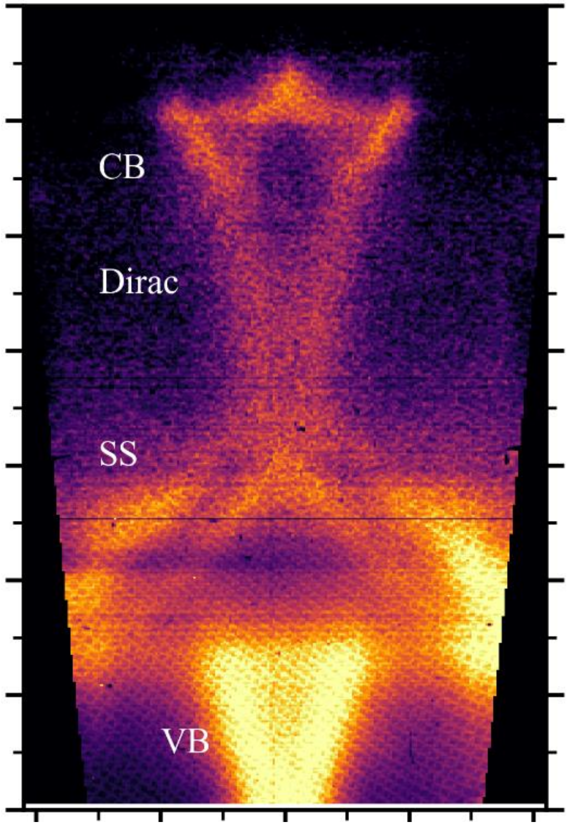
Conclusions

- We characterize a ferroelectric to paraelectric phase transition in SnTe at about 110 K. The distortion precludes any topological surface state at $\bar{\Gamma}$ on the (111) surface.
- We are able to photoinduce a topological state in the ferroelectric phase. It occurs because of the optical Stark effect.
- We have therefore created a Floquet topological insulator.



Thank you for your attention!