対称性に起因する特異なRashba効果

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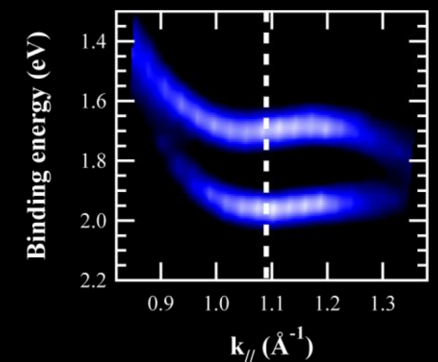
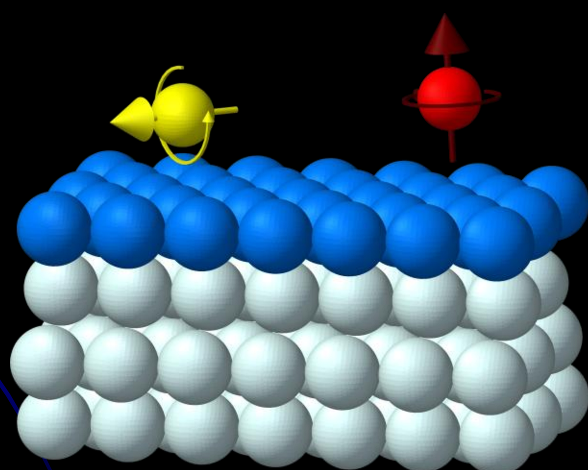
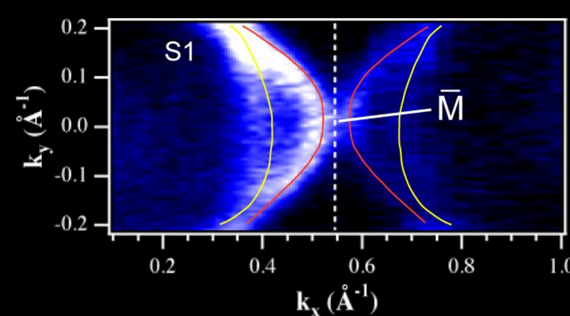
千葉大学大学院融合科学研究科







Dec. 18, 2009 @ ISSP

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対称性に起因する特異なRashba効果

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Outline
1. Introduction
2. Results and discussion
   Tl/Si(111)-(√3x√3), -(1x1)
   (PRL 102, 096805 (2009), PRB 74, 075335 (2006))
   Bi/Si(111)-(√3x√3)
   (PRL 103, 156801 (2009))
3. Conclusion

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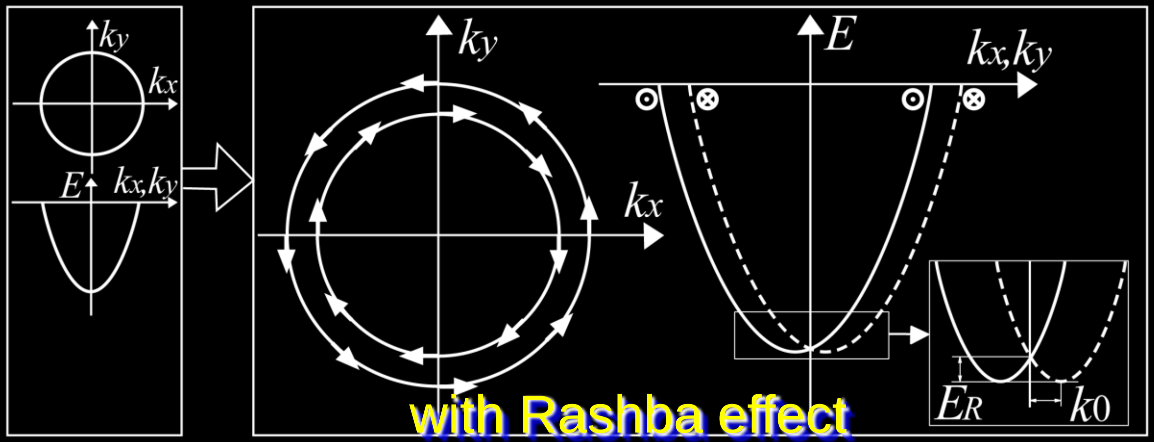
Introduction; Rashba effect



[$E(k,\uparrow) = E(-k,\downarrow)$] time-reversal symmetry

$$H_{RB} = \alpha_R(|\varepsilon|)\ \sigma \cdot (\mathbf{k}_{//} \times \hat{e}_z)$$

α_R ; Rashba parameter

$$\alpha_R = \hbar^2 k_0 / m^*$$

σ; Pauli spin matrices

ε; electric field determined by the potential gradient

Y.A. Bychkov and E.I. Rashba, JETP Lett. 39, 78 (1984).

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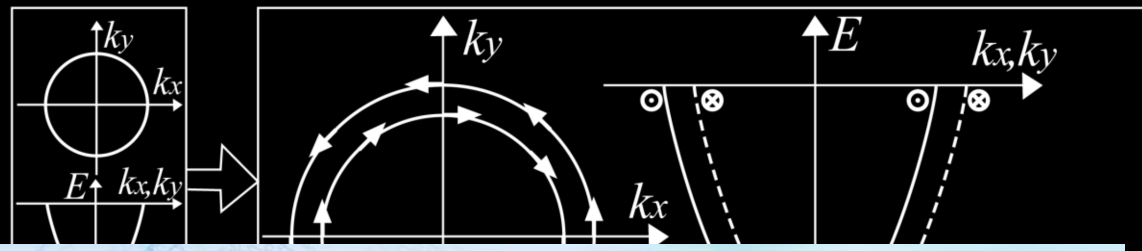
Introduction: Rashba effect



Materials			
Ag(111)	[illegible]	[illegible]	[illegible], 045419 (2005) [illegible], 195413 (2006)
Au(111)	[illegible]	[illegible]	PRB 73, 195413 (2006) PRL 77, 3419 (1996)
Bi(111)	[illegible]	[illegible]	[illegible], 046403 (2004)
Bi/Ag(111)	[illegible]	[illegible]	PRL 98, 186807 (2007)

Tl on a Si(111) surface
Bi on a Si(111) surface

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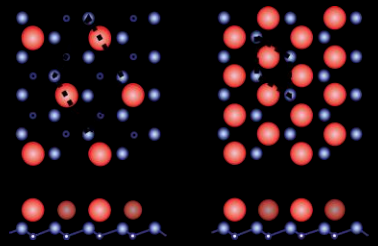
Introduction; Tl/Si(111)

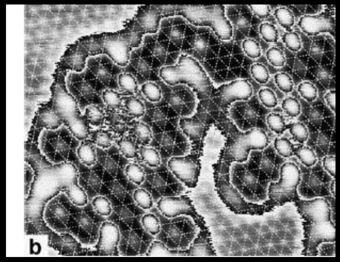
Group III metals (Al, Ga, and In) on Si(111);
magic cluster arrays at modest temperature (PRL **81**, 164 (1998))
(√3 × √3) reconstruction at higher temperature (PRL **81**, 164 (1998))

Tl; peculiar behavior in the form of the so-called “inert pair effect”
On a Si(111) surface; 1ML (1x1) phase **monovalent** atom
1/3 ML (√3 × √3) phase **trivalent**

variable valency for Tl on a Si(111) ?
(SS **543**, L663 (2003), PRB **66**, 233312 (2002))



SS 543, L663 (2003)



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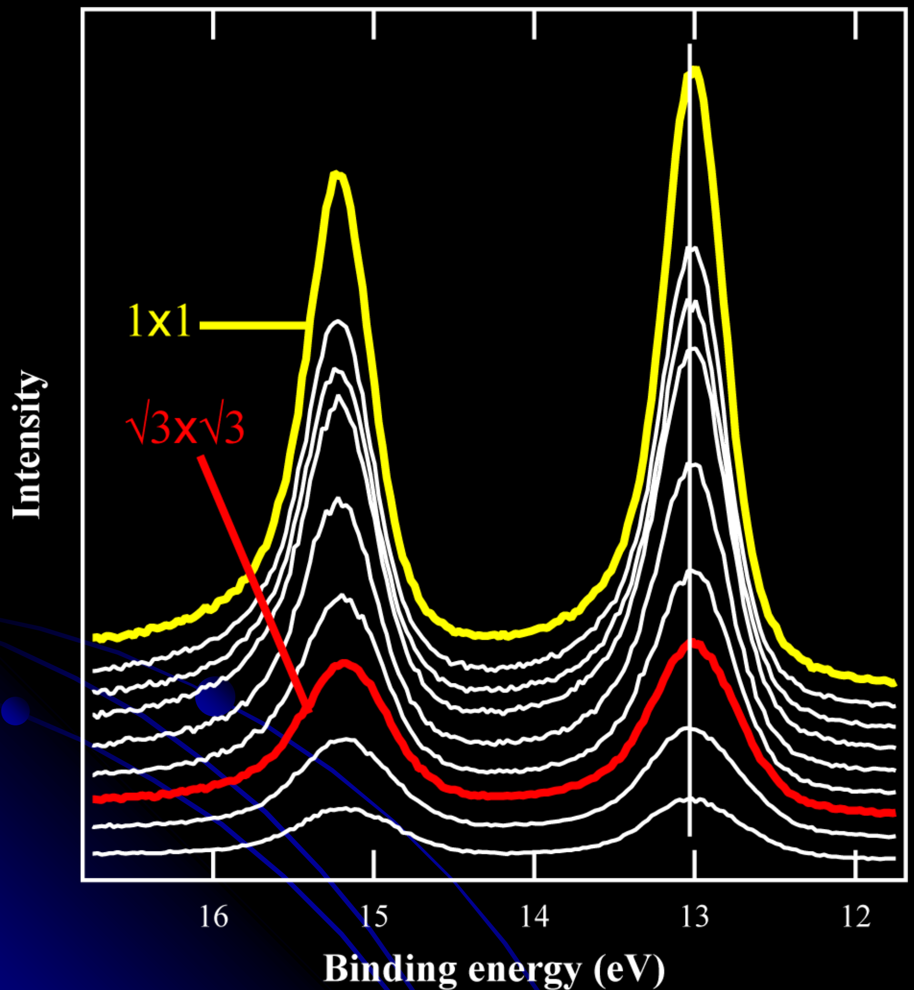
Results; Tl 5d core-level



Coverage-dependent Tl 5d core-level spectra obtained with a photon energy of 50 eV.

$I_{(1x1)}:I_{(\sqrt{3}\times\sqrt{3})}$ =3:1

(1x1) surface; **1ML,**
($\sqrt{3}\times\sqrt{3}$) surface;**1/3 ML**

constant binding energy

difference i E_B of the
5d core-level or the Tl^{1+}
and Tl^{3+} 0.58 eV
J.Phys.Soc.Jpn. , 1532 (2004)

Identical valence state

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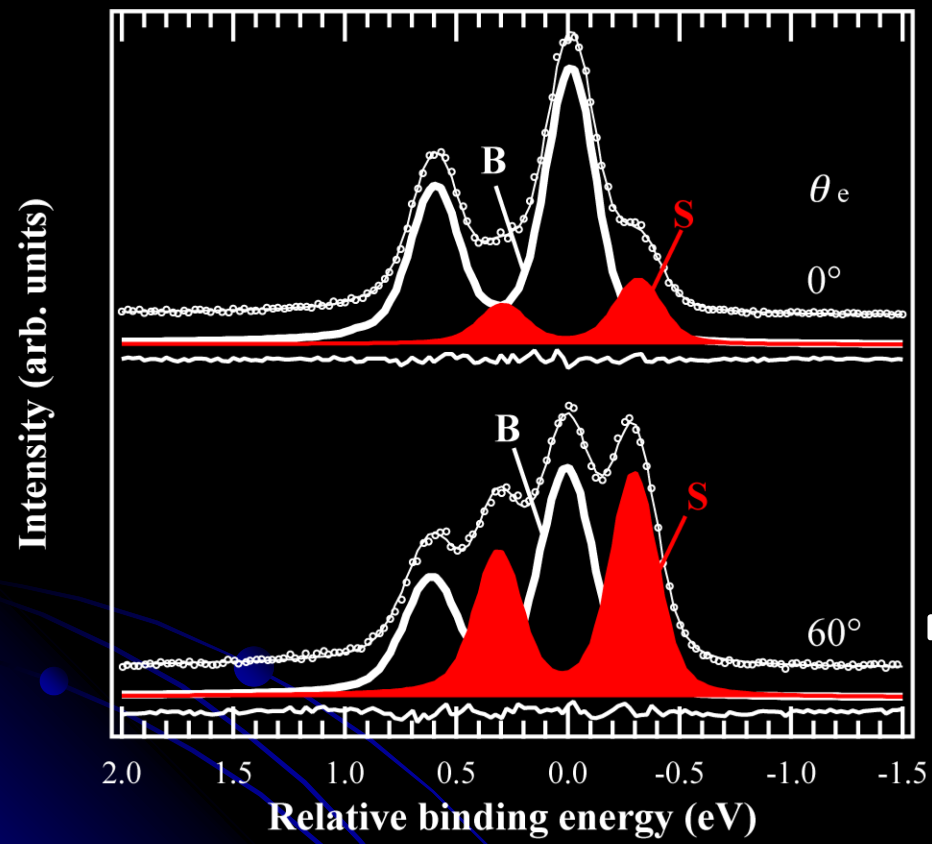
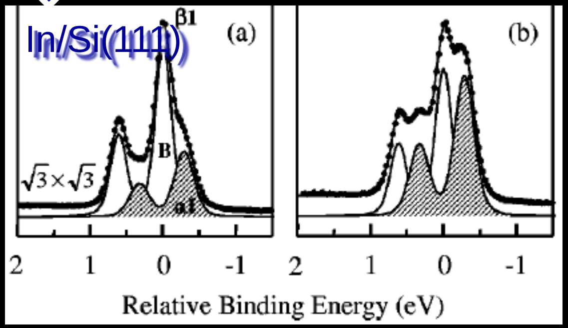
Results: Tl/Si(111)-(1x1) Si 2p core-level



Si 2p core-level spectra of the Tl/Si(111)-(1x1) surface measured with hν=135 eV .

common unreconstructed (1x1) structure



PRB 67, 035414 (2003)

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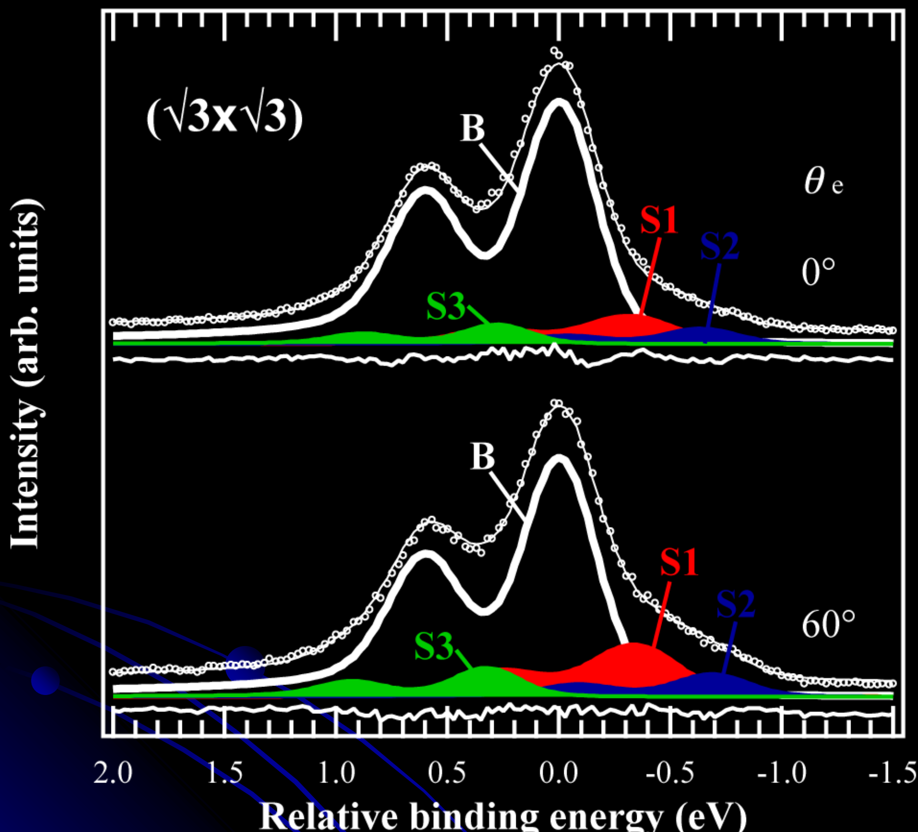
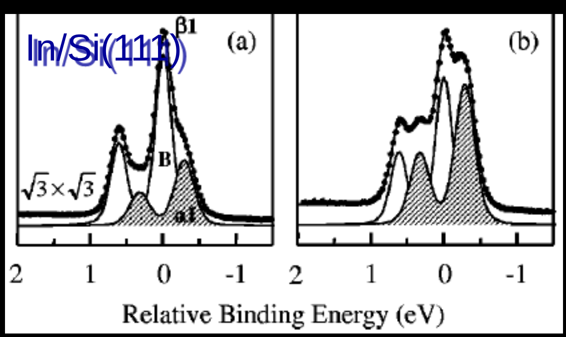
Results: Tl/Si(111)-(√3x√3) Si 2p core-level



Si 2p core-level spectra of the Tl/Si(111)-(√3x√3) surface measured with hν=135 eV .

the two (√3 × √3) surfaces have **different atomic structures**



PRB 67, 035414 (2003)

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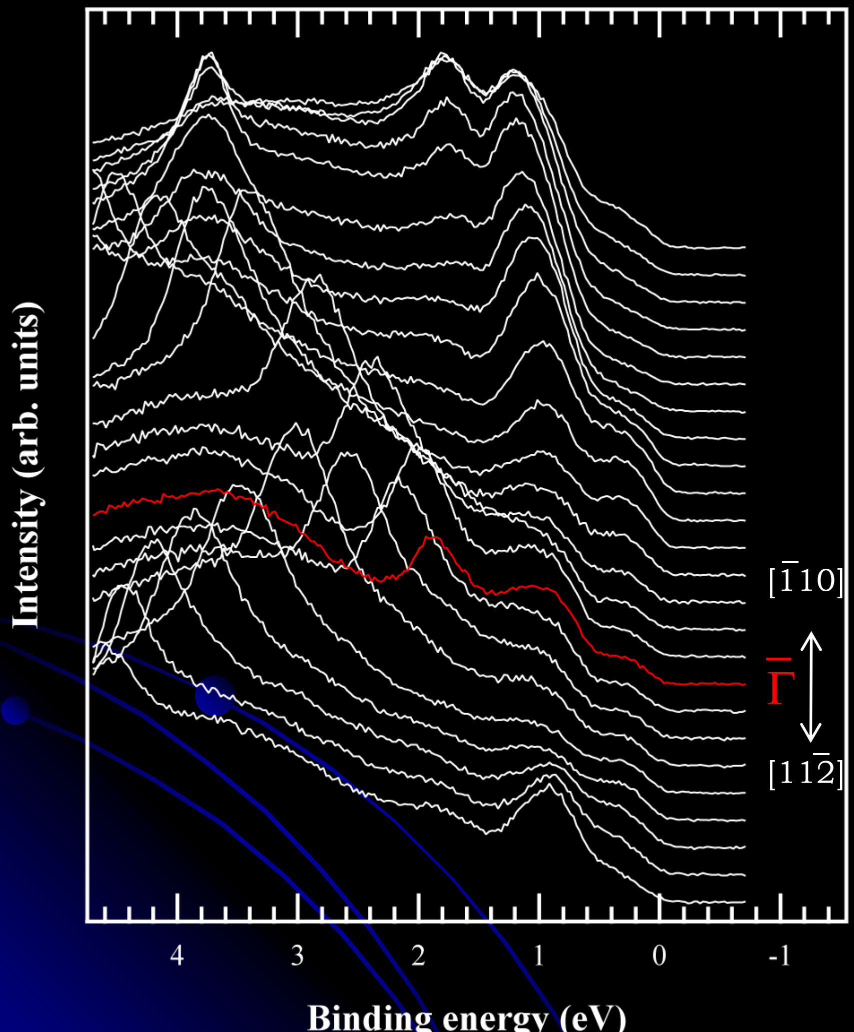
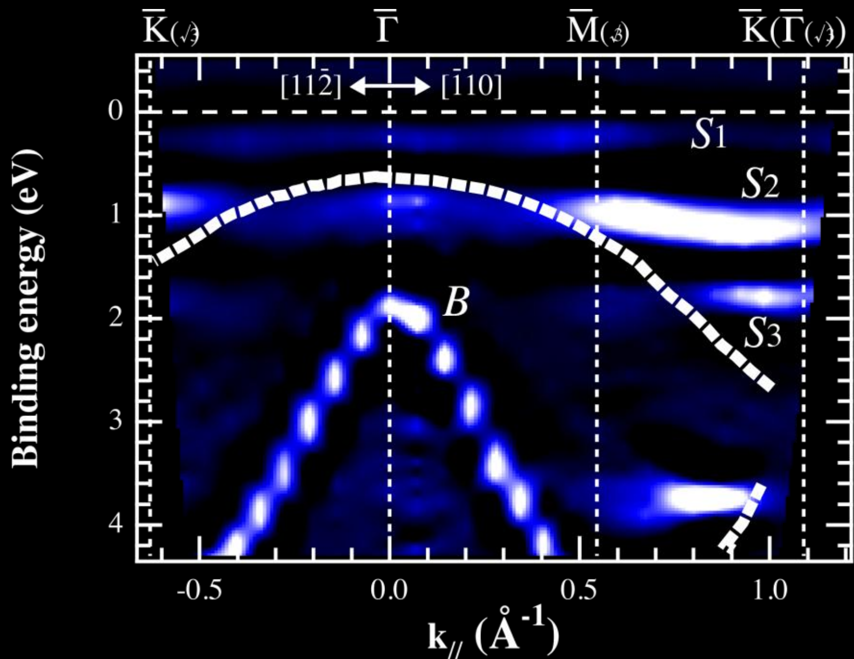
Results; Tl/Si(111)-(√3x√3) ARPES





ARPES spectra measured using hν=21.2 eV

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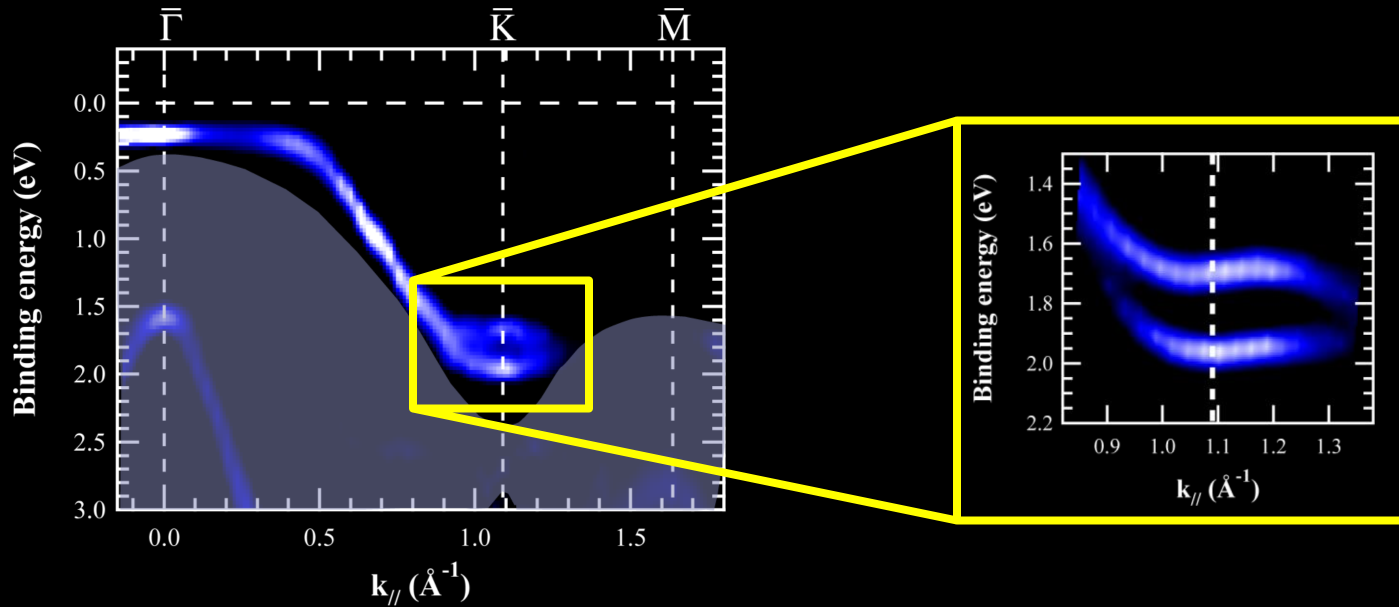
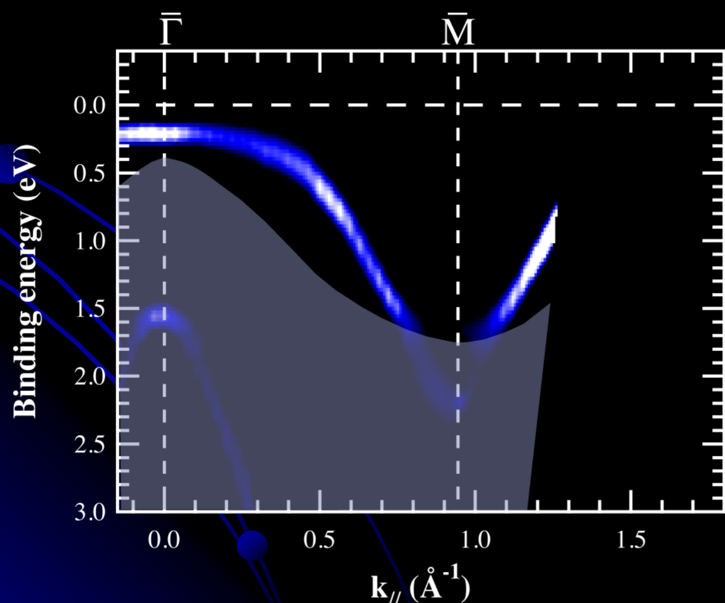
Results: Tl/Si(111)-(1x1) valence band





Band dispersions along the Γ-K and Γ-M directions

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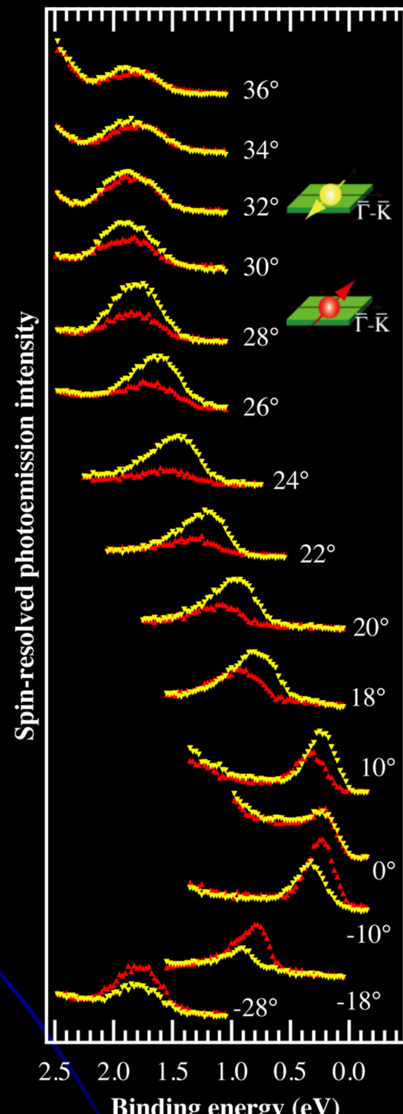
Results: Tl/Si(111)-(1x1) SR-ARPES



SR-ARPES spectra measured along the Γ-K direction

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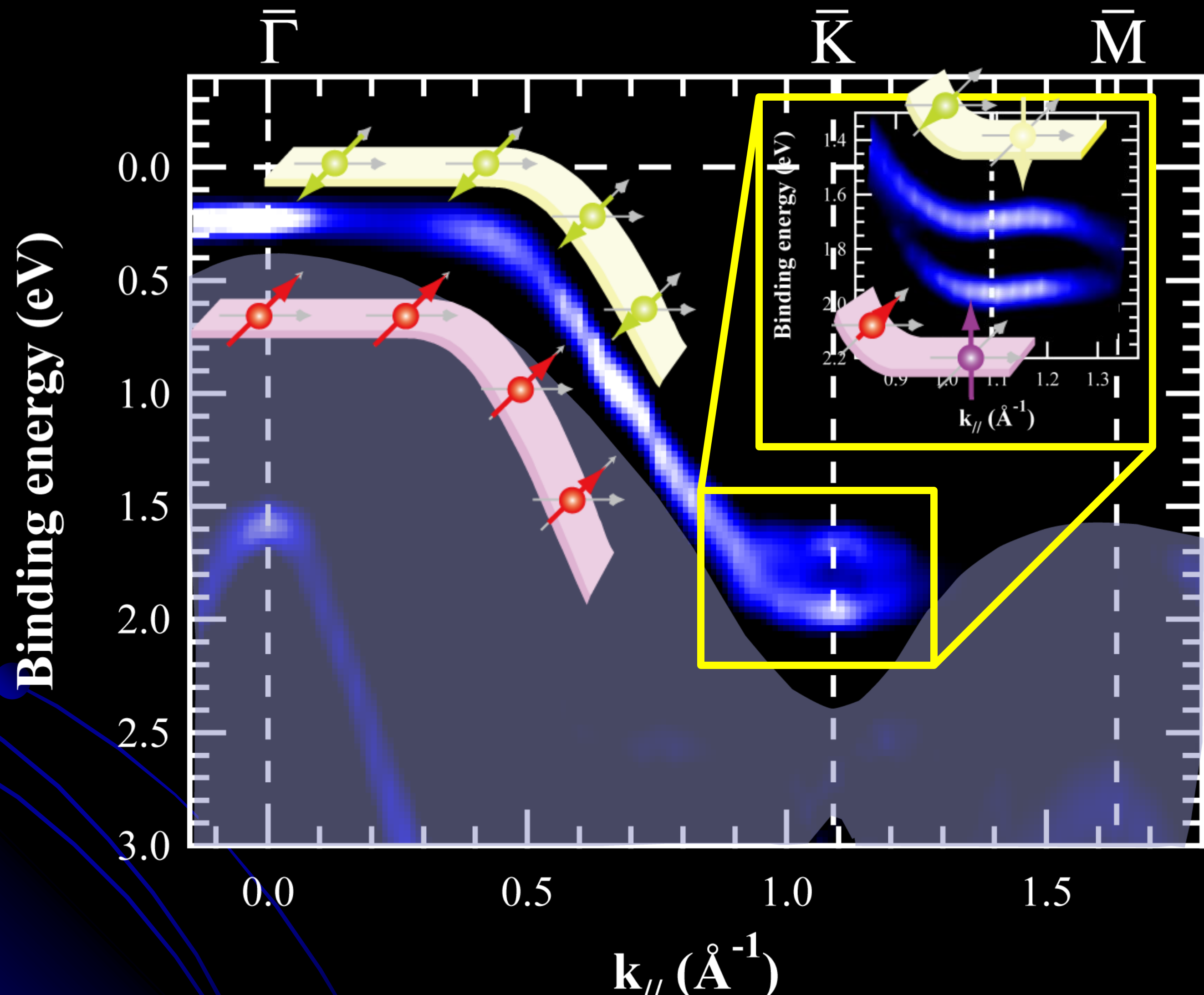
Results; Tl/Si(111)-(1x1) spin states



Valence band along the Γ-K direction

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Discussion; extended RB effect

$$\varphi_{n\mathbf{k}}(\mathbf{r}) = \frac{1}{\sqrt{\Omega}} \exp(i\mathbf{k}\cdot\mathbf{r}) u_{n\mathbf{k}}(\mathbf{r})$$

Effective SOI Hamiltonian of the "extended RB effect"

$$H_{SOI}(\mathbf{k}) = \boldsymbol{\sigma}\cdot(\boldsymbol{\alpha}_n(\mathbf{k})\times\mathbf{k}) + \underline{\boldsymbol{\sigma}\cdot\mathbf{B}_n(\mathbf{k})}$$

⇕

$$H_{RB} = \alpha_R(|\varepsilon|)\ \sigma\cdot(\mathbf{k}_{//}\times\hat{e}_z)$$

$$\vec{\alpha}_n(\vec{k}) = \frac{\hbar^2 N}{4m_e^2 c^2 \Omega} \int_{cell} d\vec{r} \left| u_{n\vec{k}}(\vec{r}) \right|^2 \nabla V(\vec{r})$$

$$\vec{B}_n(\vec{k}) = \frac{\hbar^2 N}{4m_e^2 c^2 \Omega} \int_{cell} d\vec{r} \frac{1}{r} \frac{dV(\vec{r})}{dr} u^*_{n\vec{k}}(\vec{r})(\vec{l}) u_{n\vec{k}}(\vec{r})$$

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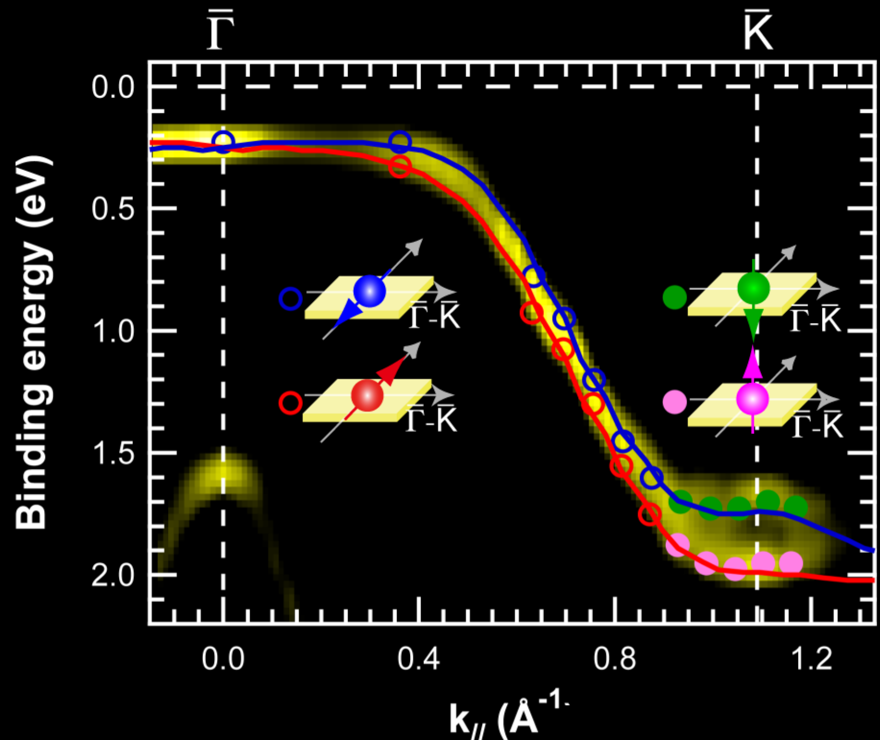
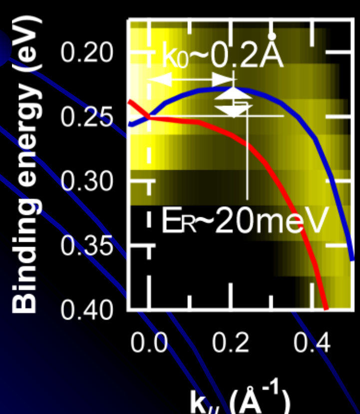
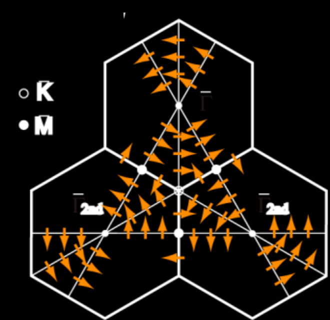
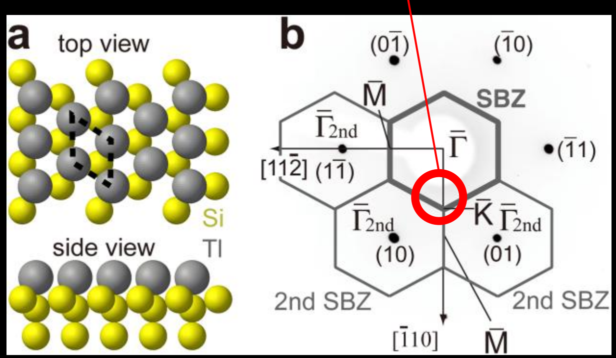
Discussion; origin of the standing spin



C_3







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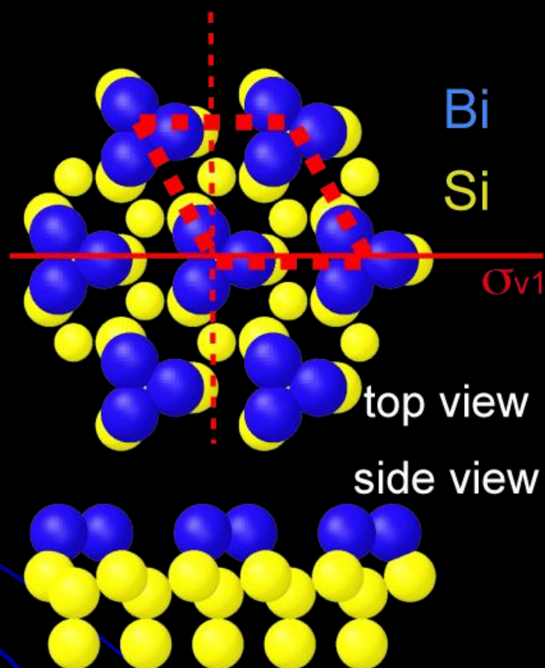
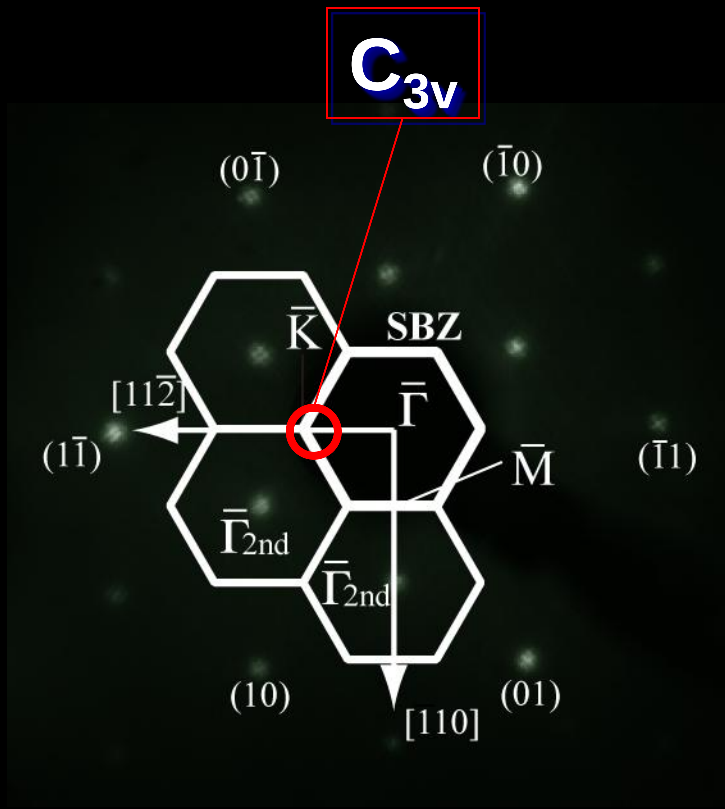
Introduction; Bi/Si(111)-(√3x√3)





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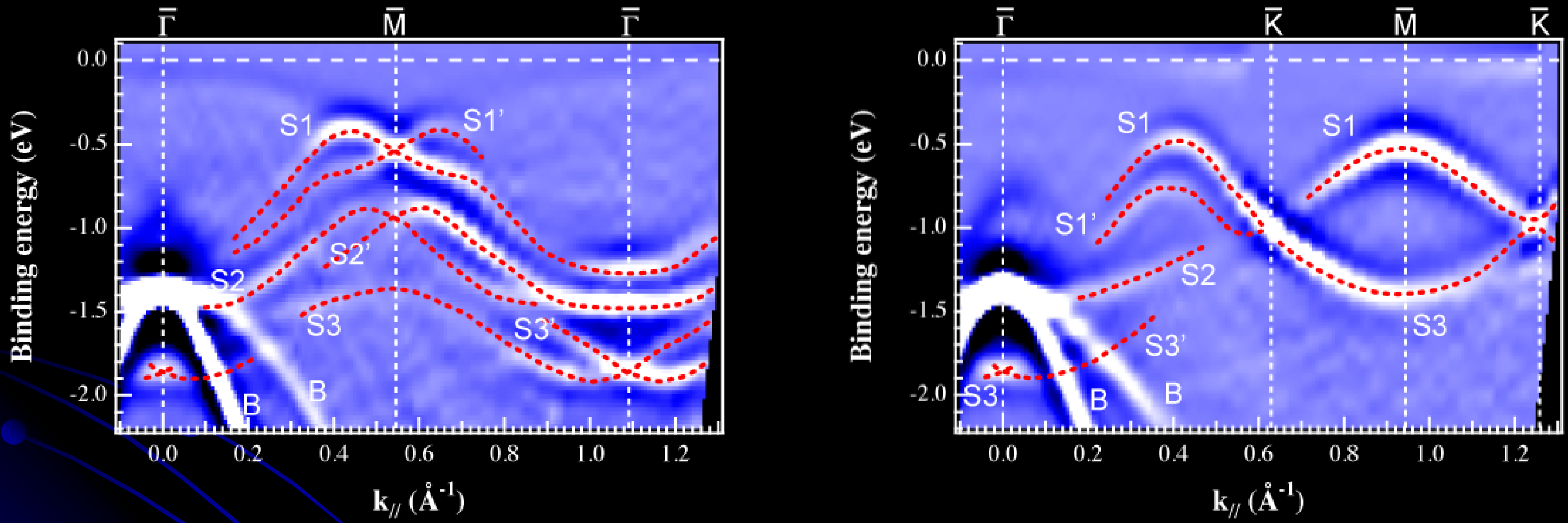
Results; Bi/Si(111)-(√3x√3) ARPES



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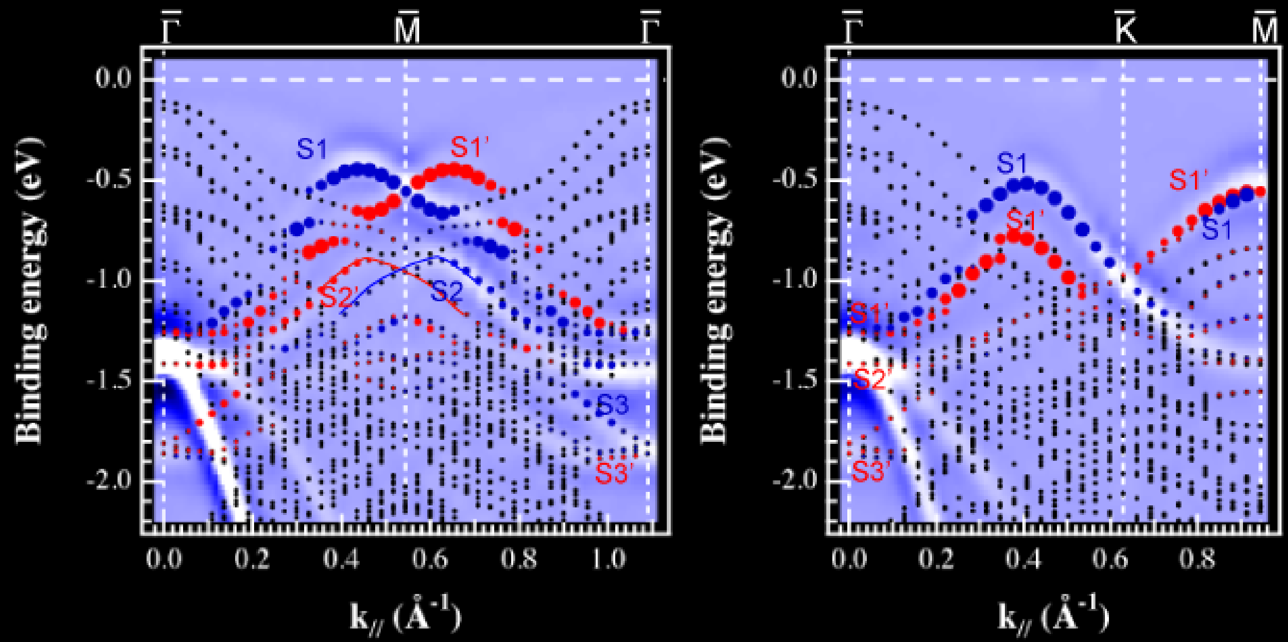
Results; Bi/Si(111)-(√3x√3) ARPES



Materials	E_R (meV)	k_0 (Å^{-1})	
S1	**120**	**0.105**	I. Gierz *et al.*, PRL 103, 046803 (2009)
S2	**70**	**0.08**	
S3	**70**	**0.08**	
Bi/Ag(111)	200	0.13	C. Ast *et al.*, PRL 98, 186807 (2007)

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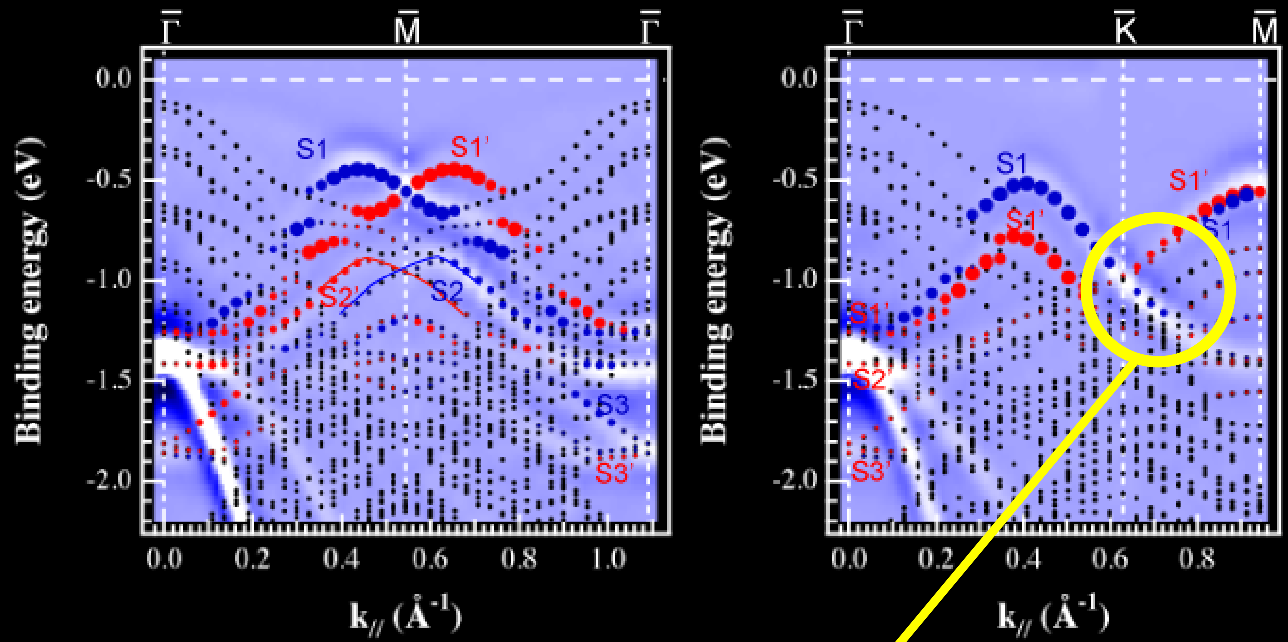
Results; Bi/Si(111)-(√3x√3) ARPES



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S2	**70**	**0.08**	
S3	**70**	**0.08**	
Bi/Ag(111)	200	0.13	C. Ast *et al.*, PRL 98, 186807 (2007)

Observation of a Rashba splitting though there is no time reversal

Peculiar Rashba splitting that originates from the C_{3v} symmetry

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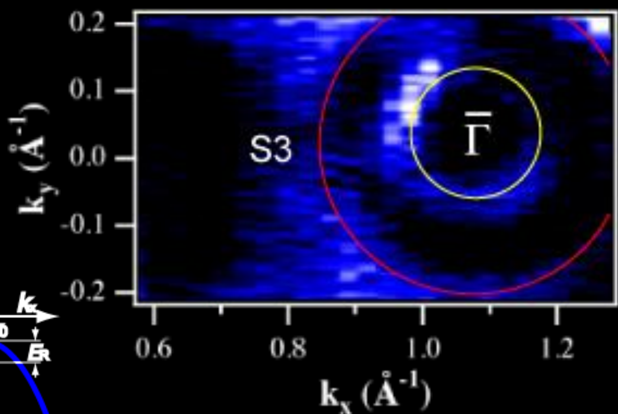
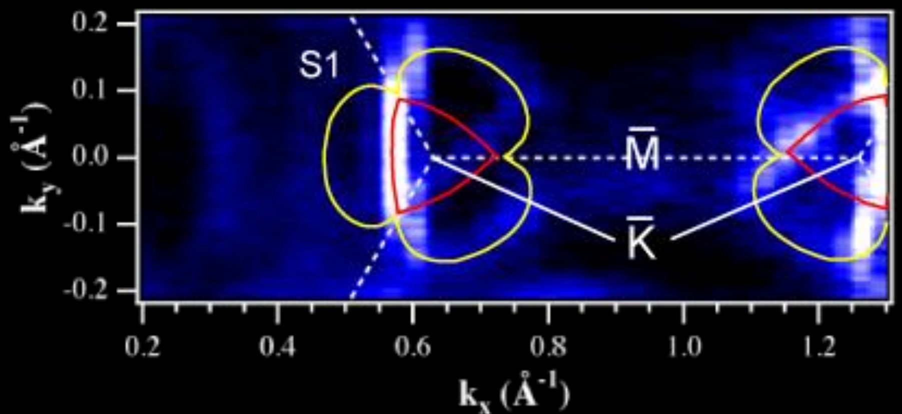
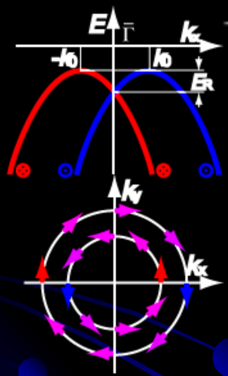
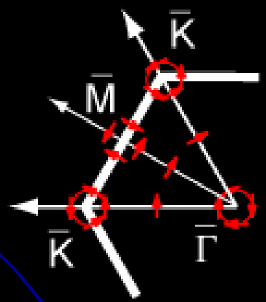
Results; Bi/Si(111)-(√3x√3) ARPES









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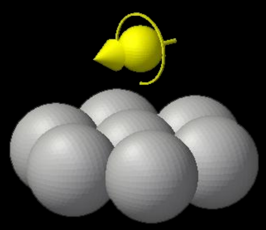
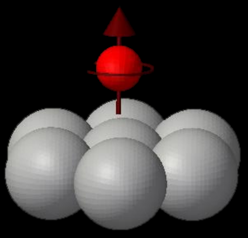
Conclusion

Observation of peculiar Rashba spins



Tl/Si(111)-(1x1)
Spin standing perpendicular



Bi/Si(111)-(√**3x**√**3**)
Rashba spin at a point without time-reversal symmetry
Non-vortical Rashba spin structure

⬇

knowledge on the 2D symmetry is indispensable
to understand the Rashba effect properly

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Acknowledgments

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