University of St Andrews
School of Physics and Astronomy

Remarks on two outstanding normal state issues in Sr_2RuO_4

Andy Mackenzie [1]
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K.M. Shen[2], N. Kikugawa[1], C. Bergemann[3], L. Balicas[4], F. Baumberger[1,2], W. Meevasana[2], N.J.C. Ingle[2], Y. Maeno[5], Z.X. Shen[2], S.R. Julian[3].

[1] St Andrews; [2] Stanford, [3] Cambridge; [4] Tallahassee, [5] Kyoto

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1. The origin of the mass renormalisation in Sr_2RuO_4

2. Using '5G' de Haas-van Alphen experiments to measure spin-orbit coupling

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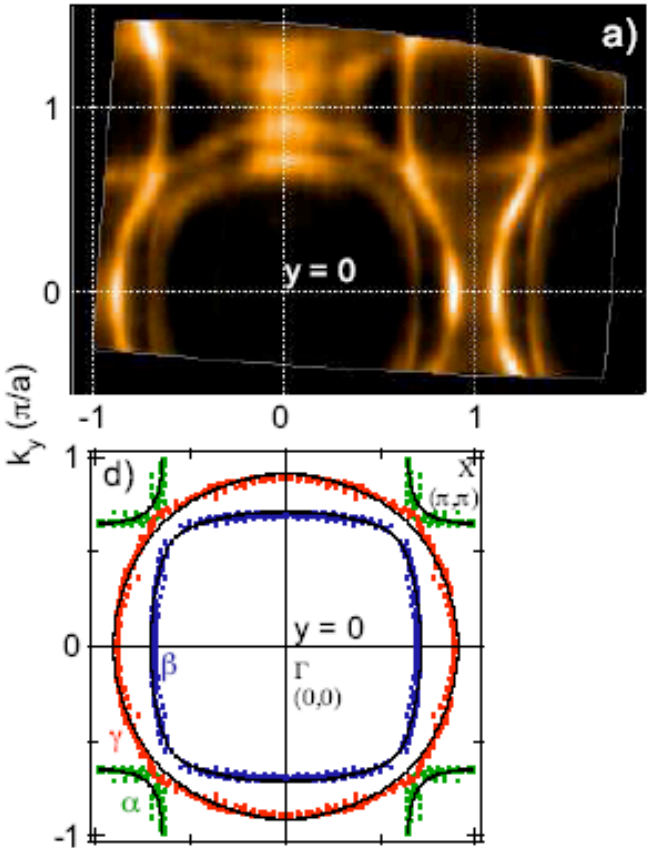
1. Remarks on the origins of mass renormalisation

Method: Combine ARPES and bulk thermodynamics on $Sr_{2-y}La_yRuO_4$



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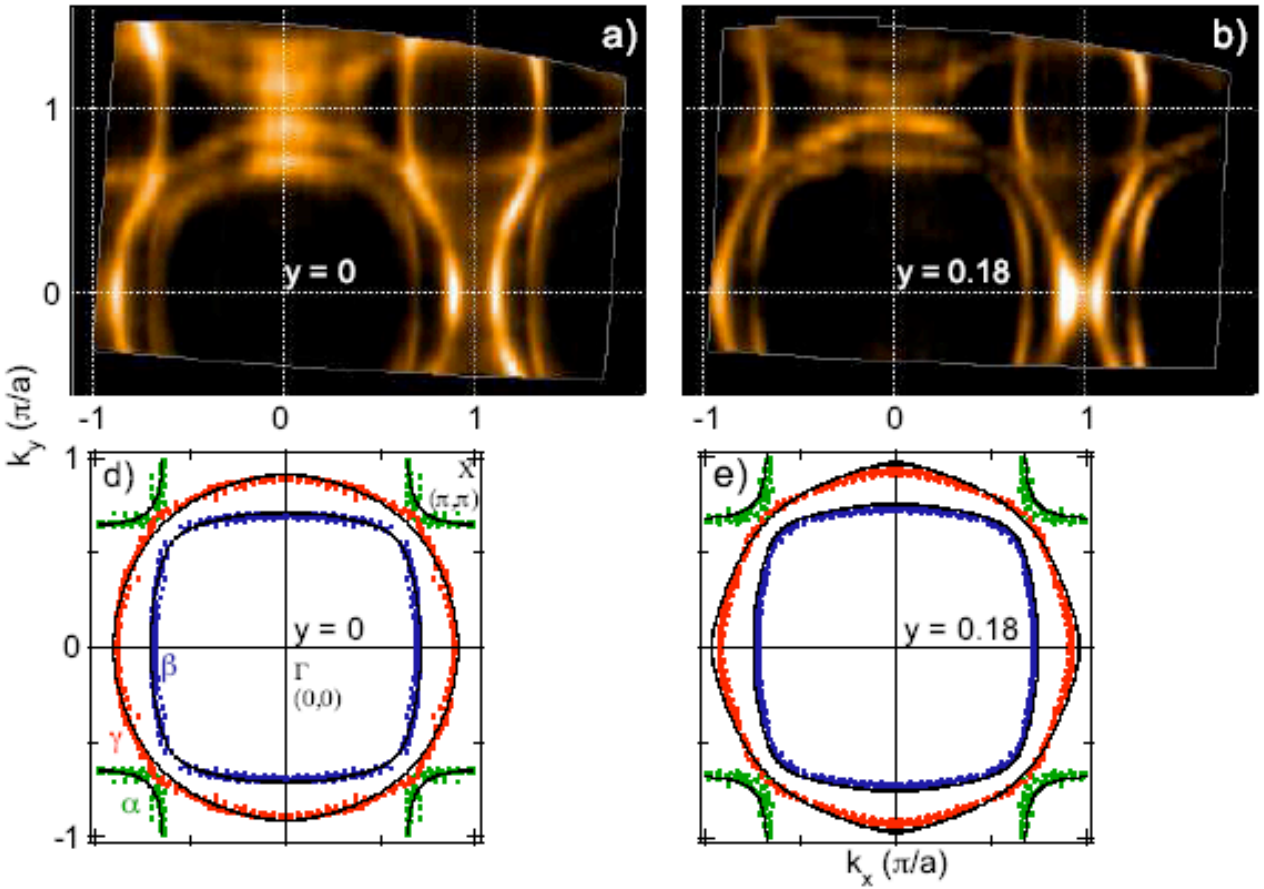

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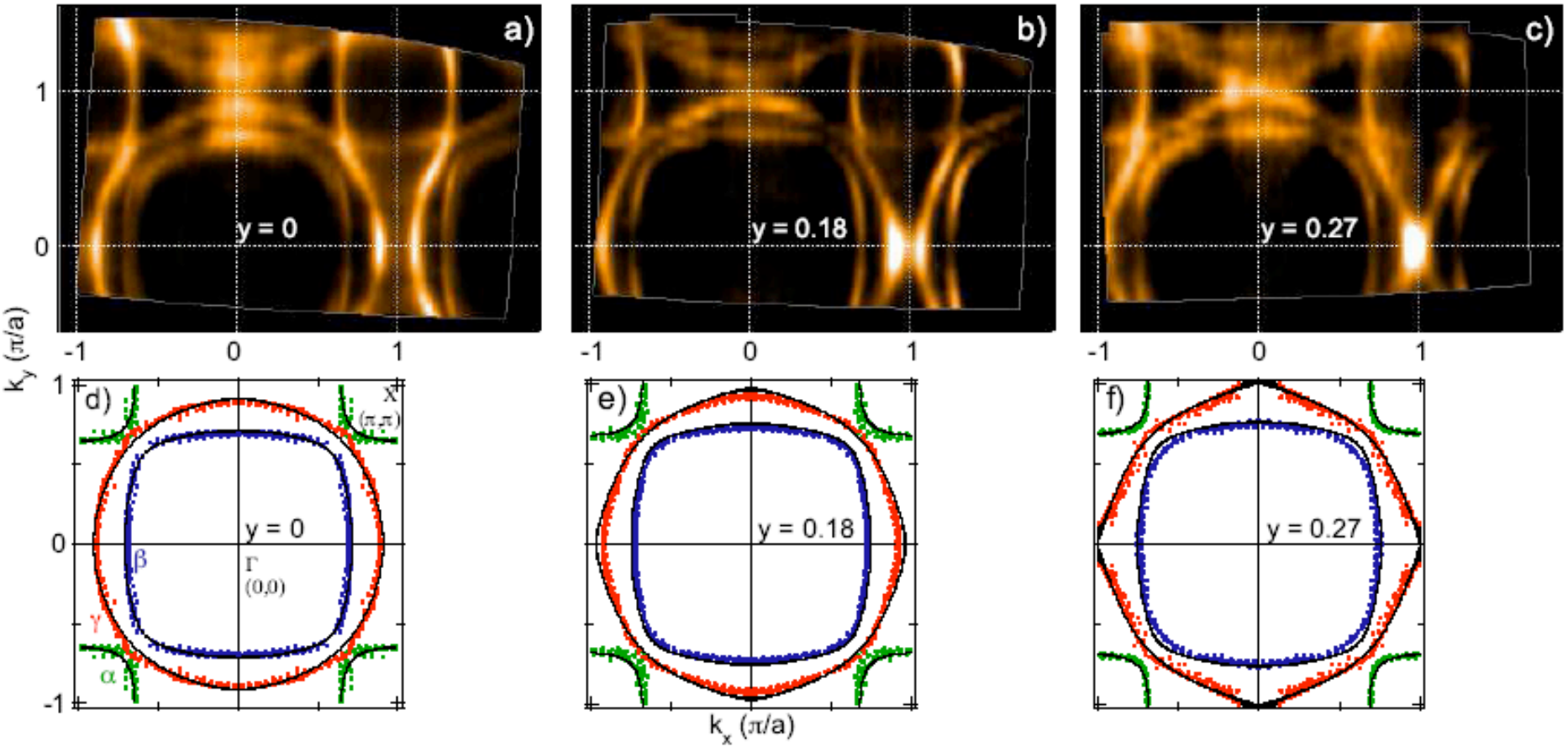

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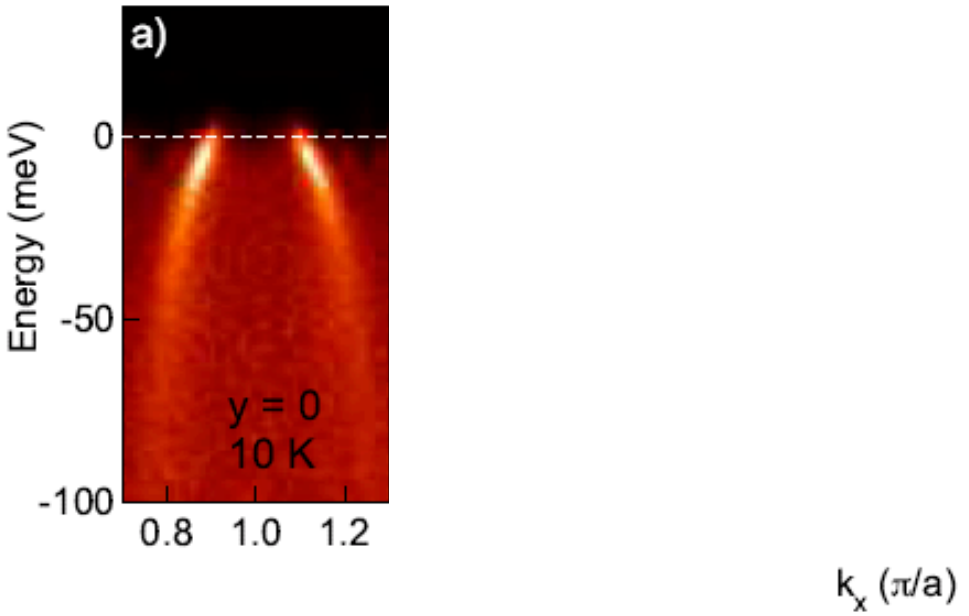
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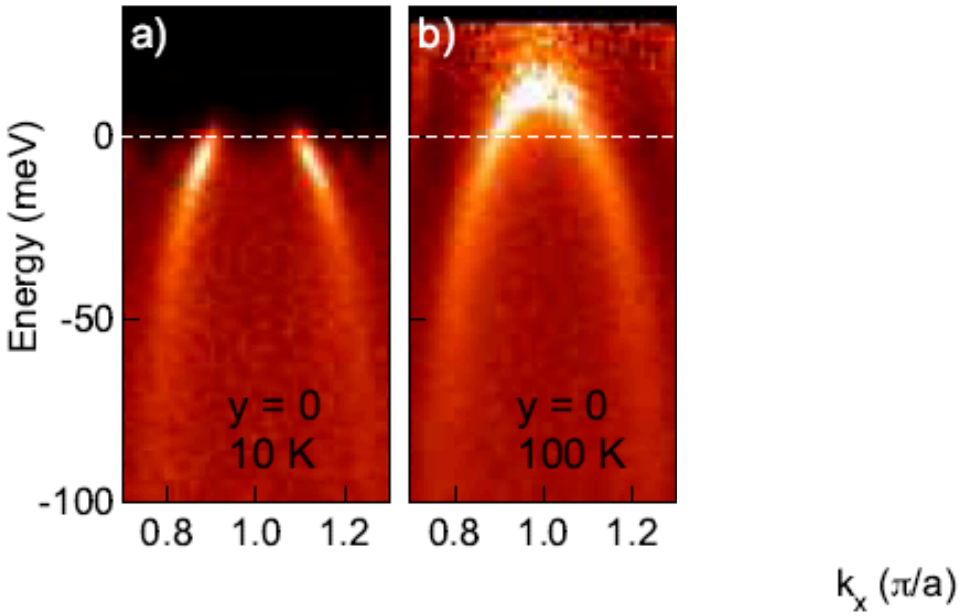
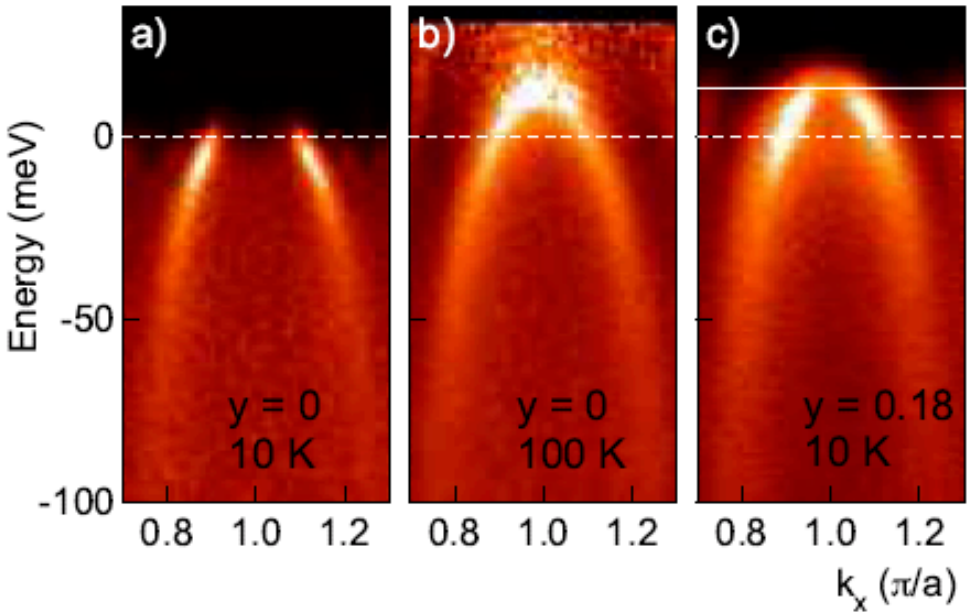
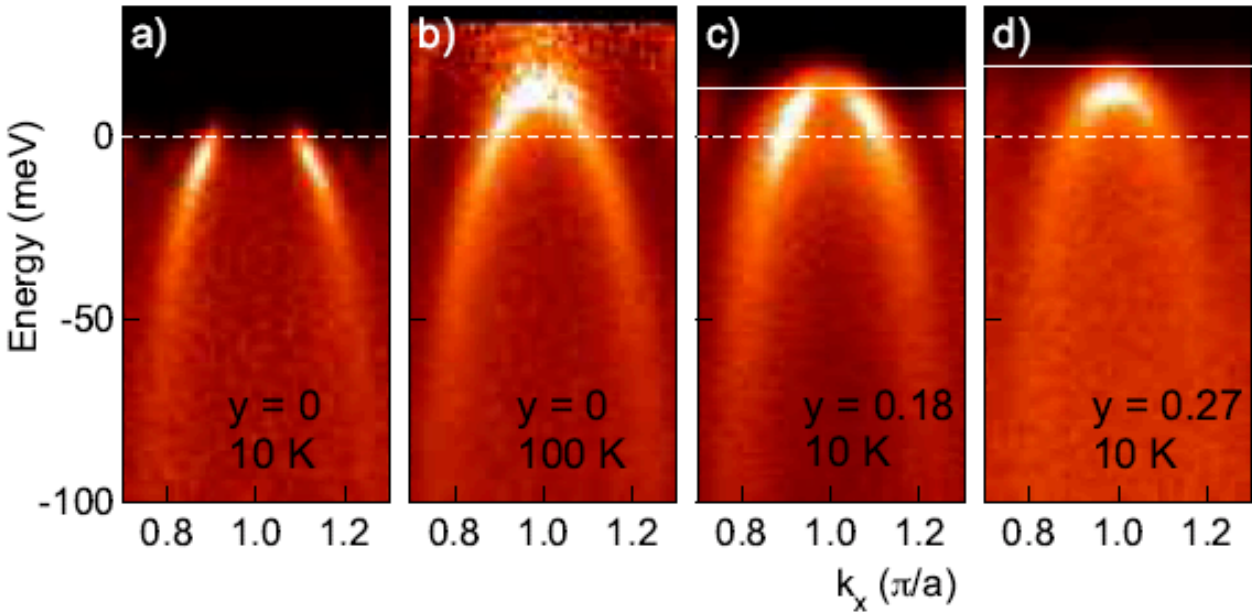
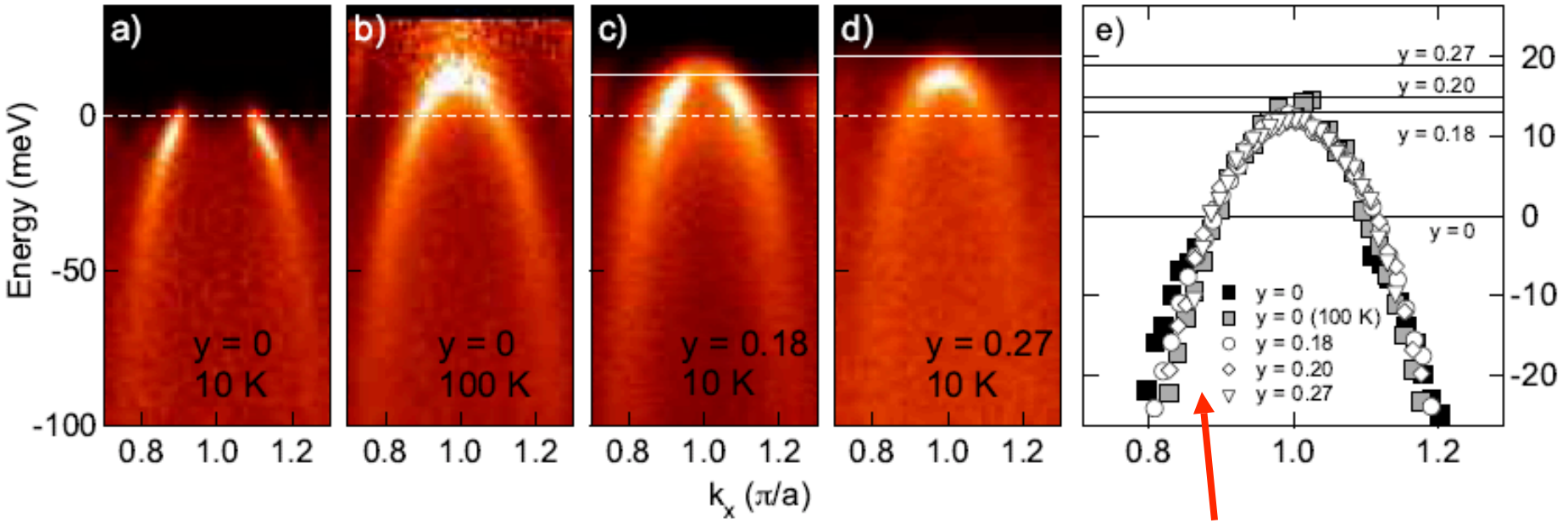
-50
-100
Energy (meV)
y = 0
10 K
0.8
1.0
1.2
k_x (π/a)

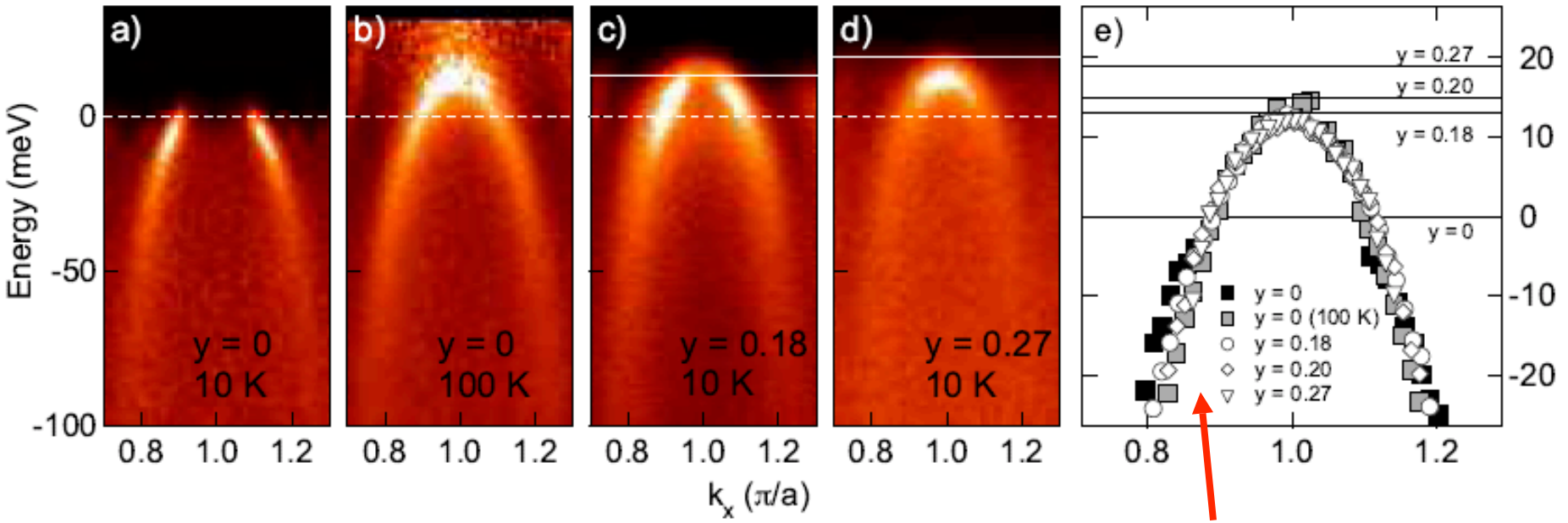

a)
b)
0
-50
-100
Energy (meV)
y = 0
10 K
y = 0
100 K
0.8
1.0
1.2
0.8
1.0
1.2
k_x (π/a)


a)
b)
c)
0
-50
-100
Energy (meV)
y = 0
10 K
y = 0
100 K
y = 0.18
10 K
0.8
1.0
1.2
0.8
1.0
1.2
0.8
1.0
1.2
k_x (π/a)


a)
b)
c)
d)
Energy (meV)
0
-50
-100
y = 0
10 K
y = 0
100 K
y = 0.18
10 K
y = 0.27
10 K
0.8
1.0
1.2
k_x (π/a)



Well-defined simple cosine over much of the Brillouin zone, renormalised from LDA by dHvA factor of ~ 6.



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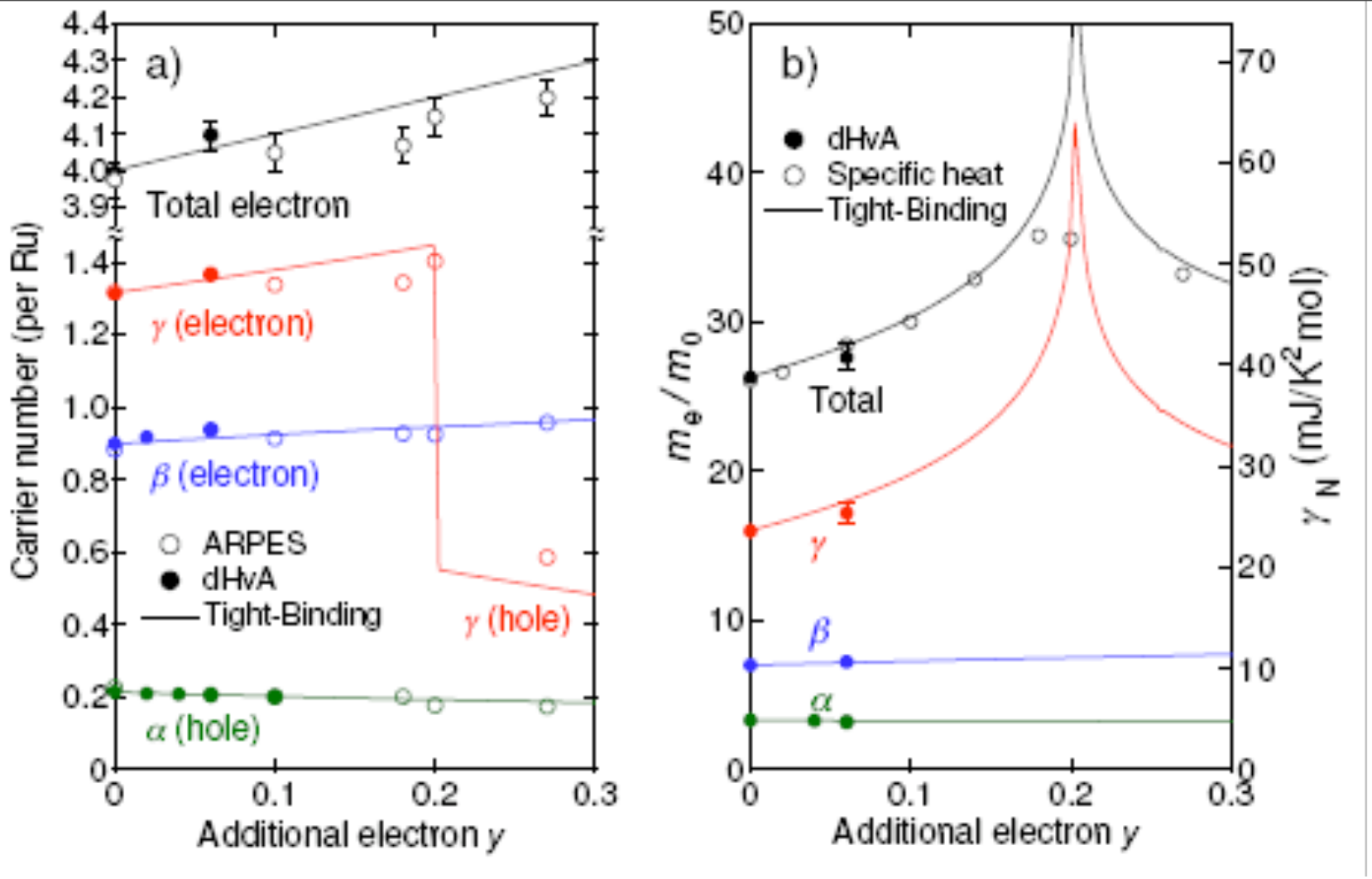
Renormalisation dominantly due to local real-space correlation: LDA + U in real life!

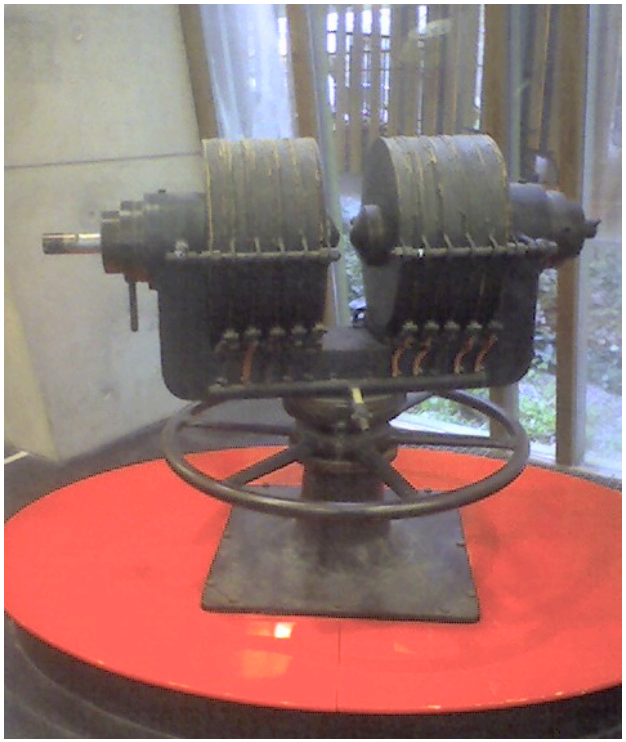


Beautiful rigid band shift; good fit to specific heat based on simple hypothesis that all bands are renormalised in same way.

Paper provides state-of-the-art tight binding parameterisation of real many-body quasiparticle dispersion.

2. dHvA as a probe of spin-orbit coupling

The technique



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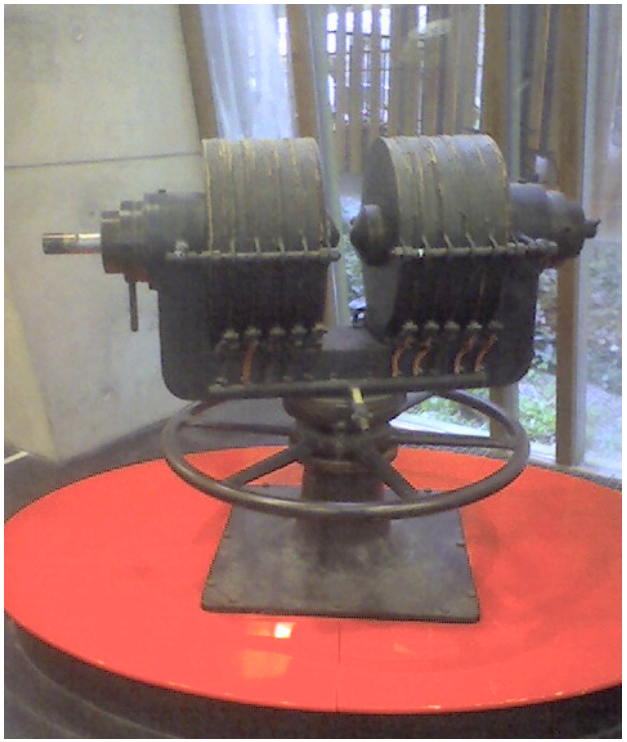

> 10^{15} improvement in sensitivity since 1930

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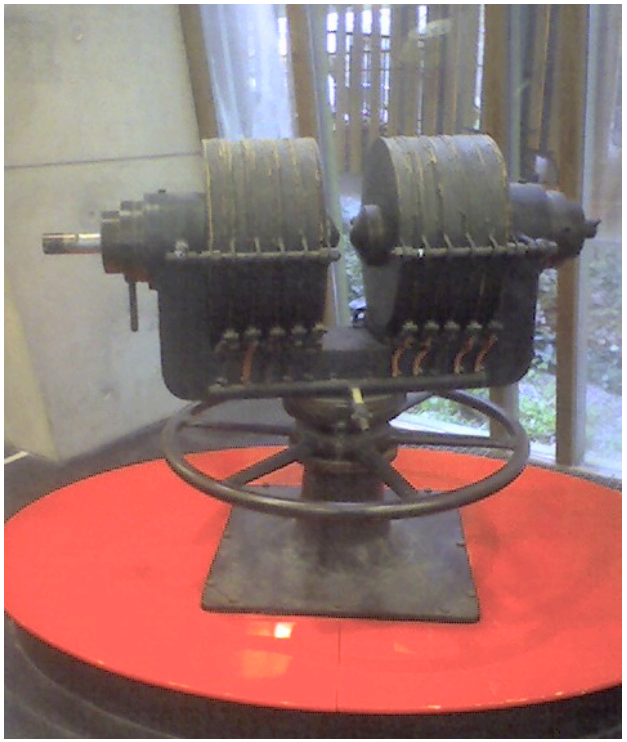
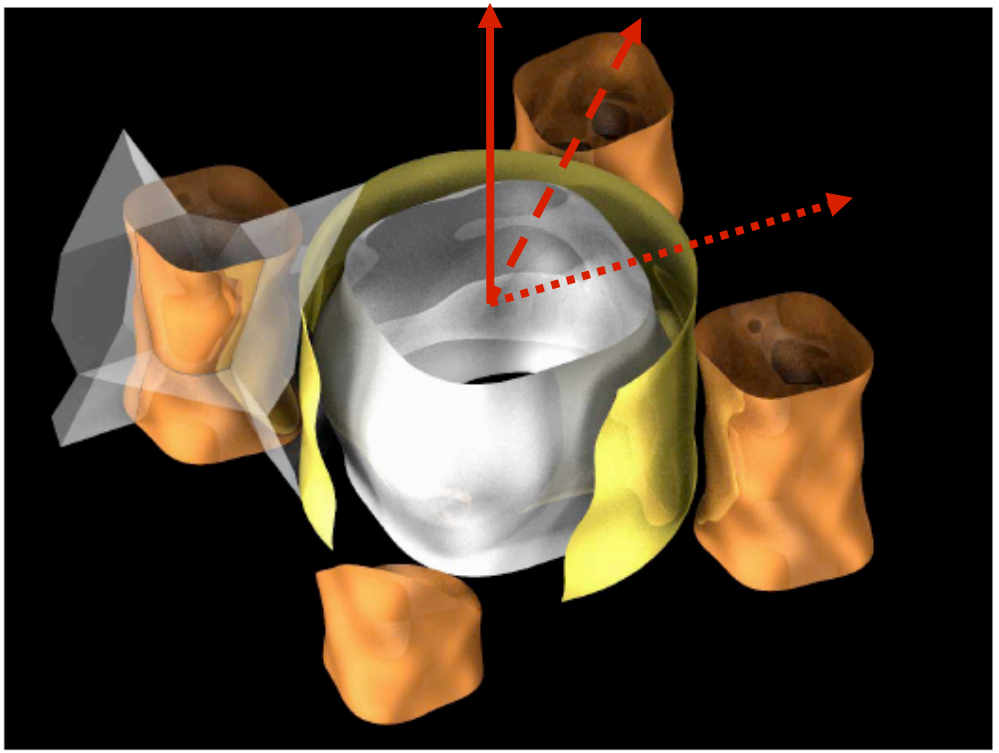


> 10^{15} improvement in sensitivity since 1930

The specific 21st century experiment

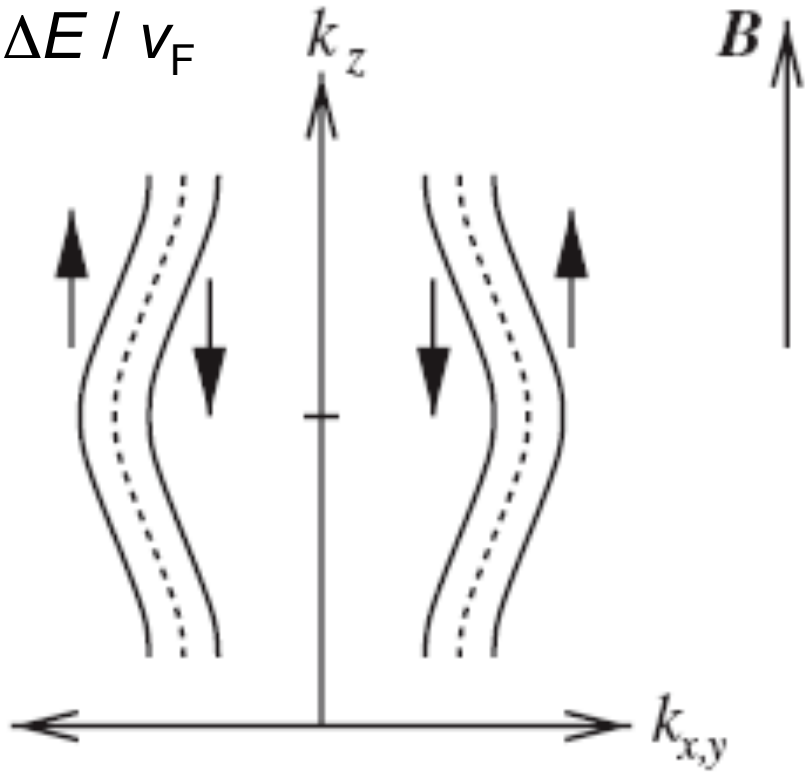


Rotate about two principal axes studying field and angle dependence of amplitude of dHvA oscillations.

Idea: Probe 'anomalous spin-splitting'

$\Delta E \sim g\mu_B B$

$\hbar\Delta k \sim \Delta E / v_F$



Conventional spin splitting

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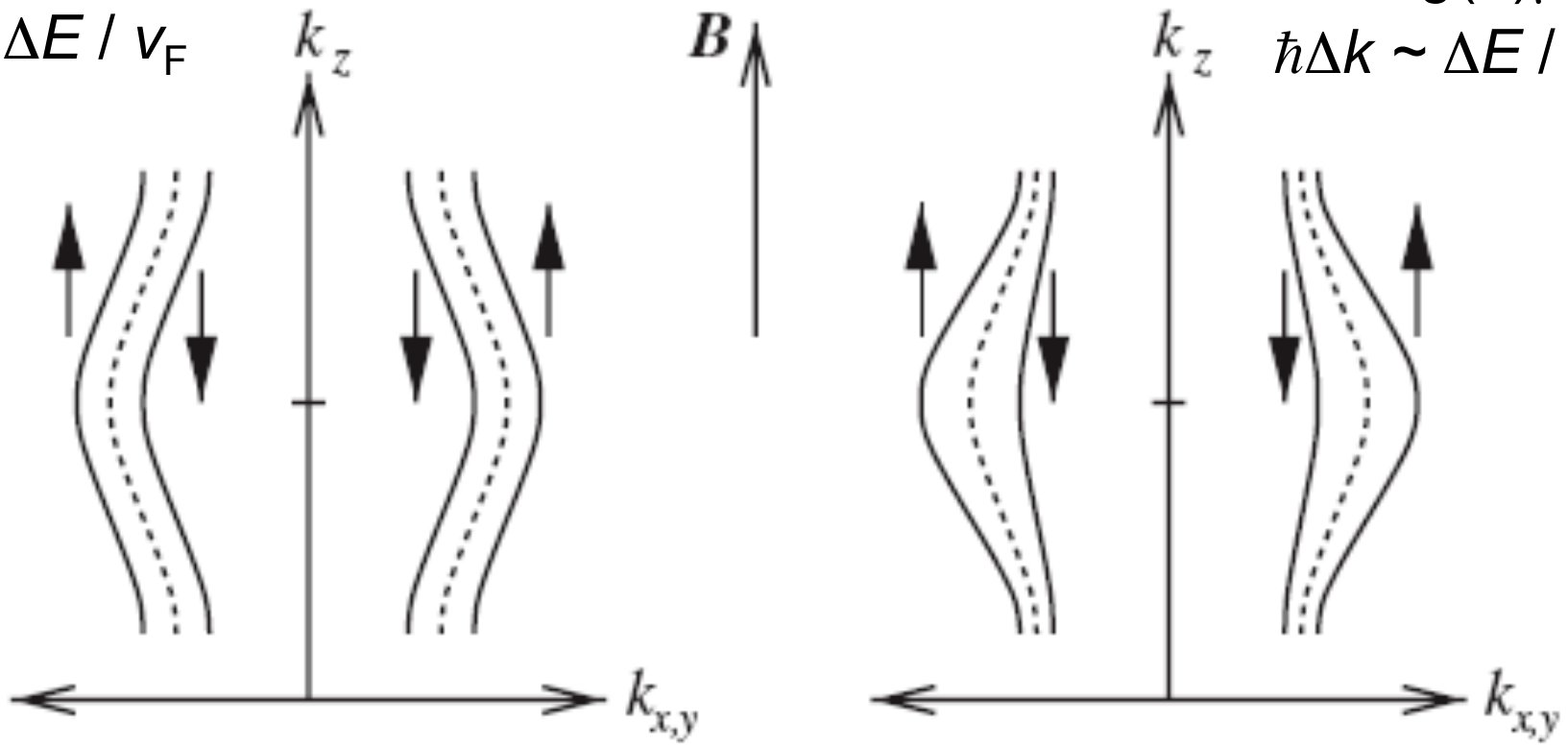

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Anomalous spin splitting

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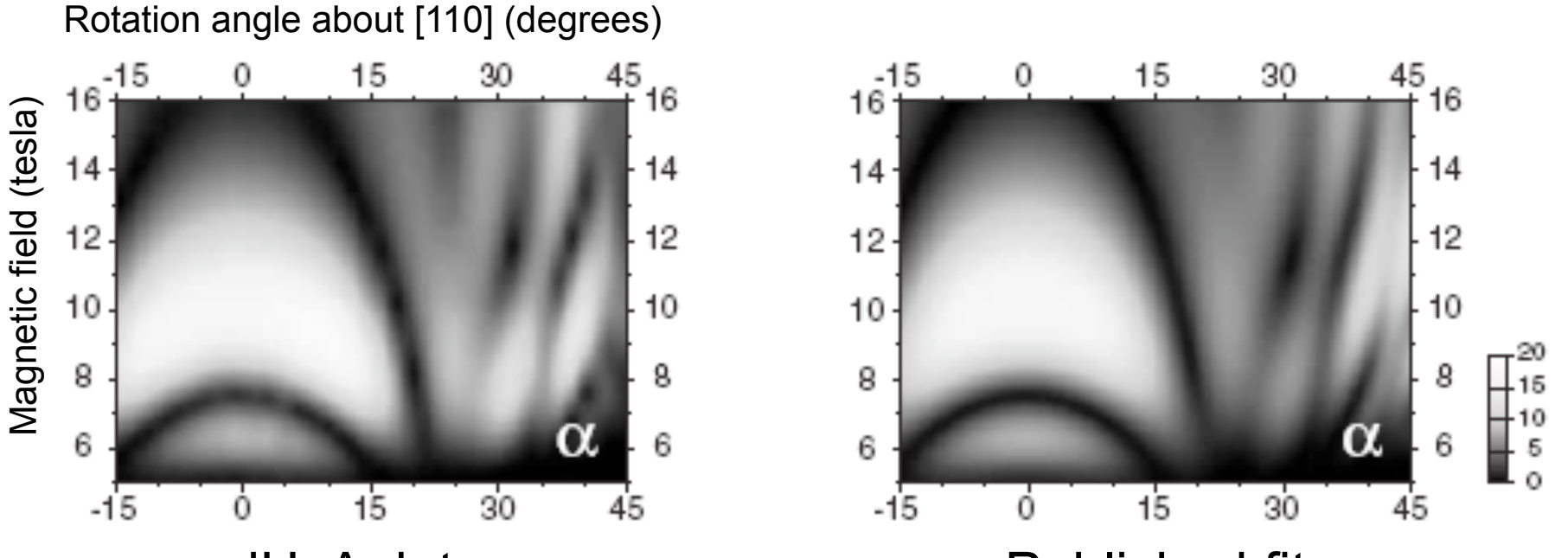
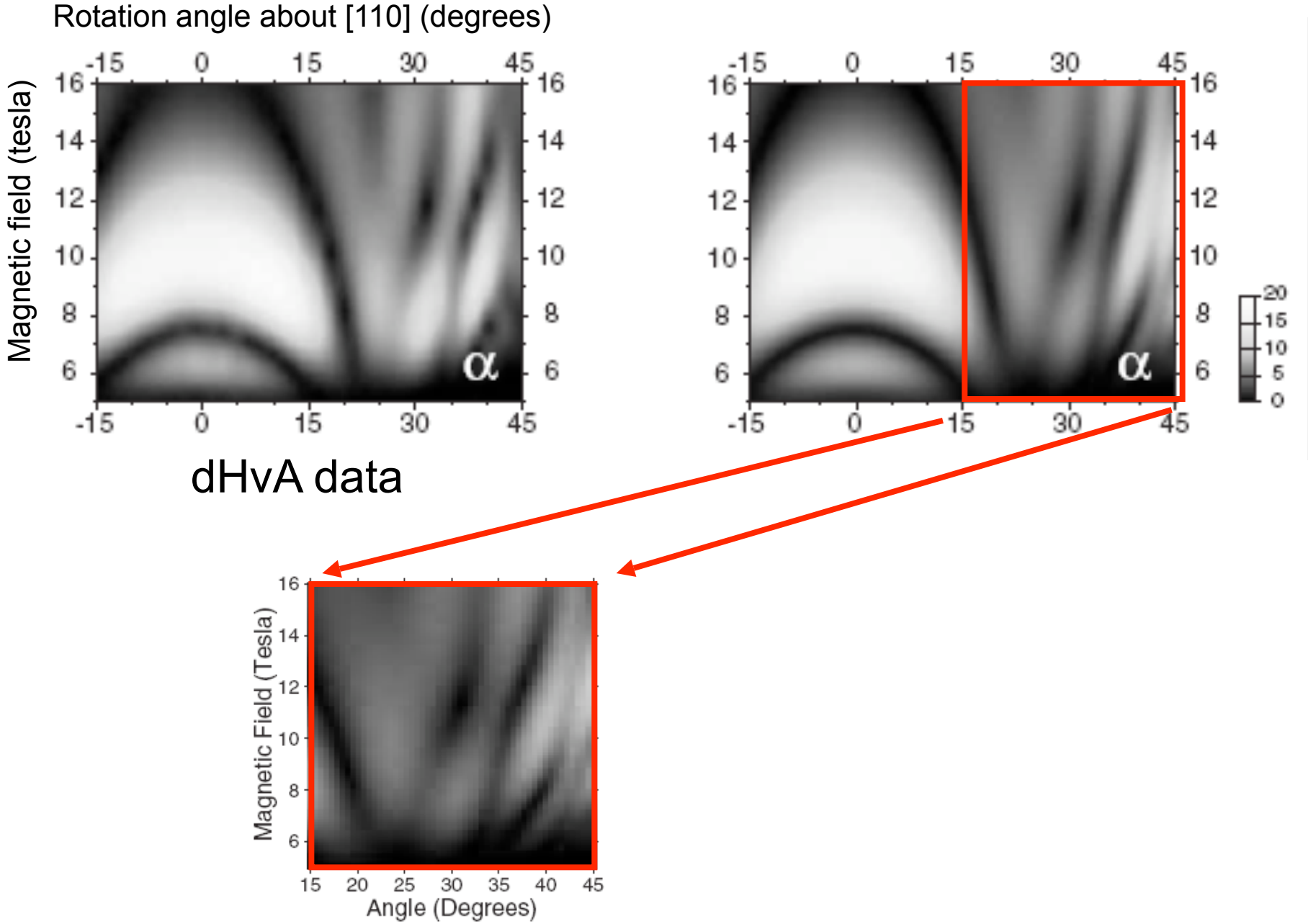

Rotation angle about [110] (degrees)
Magnetic field (tesla)
-15
0
15
30
45
16
14
12
10
8
6
α
20
15
10
5
0
dHvA data
Published fit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Magnetic Field (Tesla)
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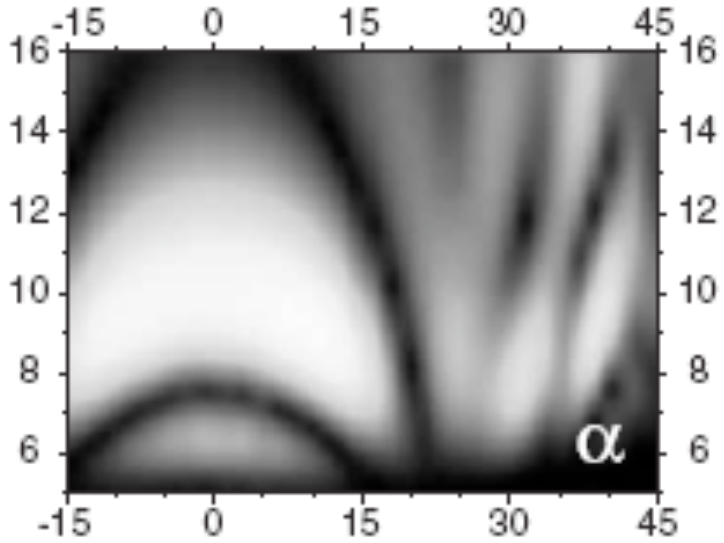
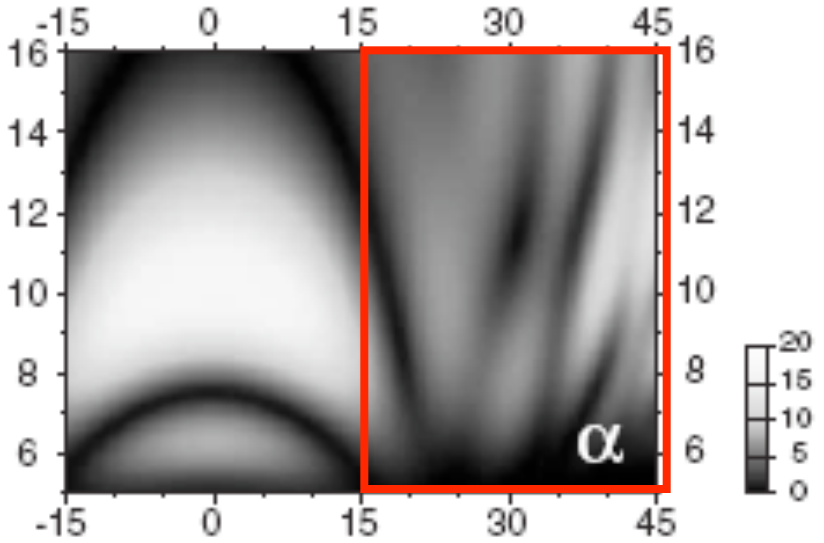
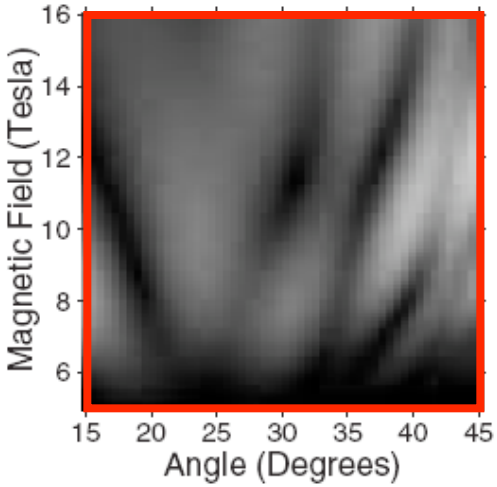
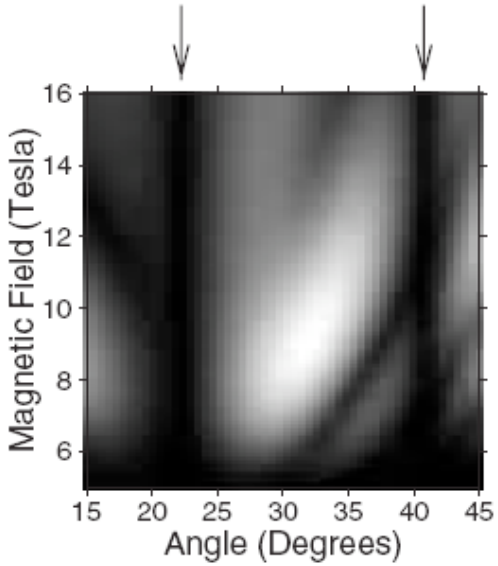
15
20
25
30
35
40
45





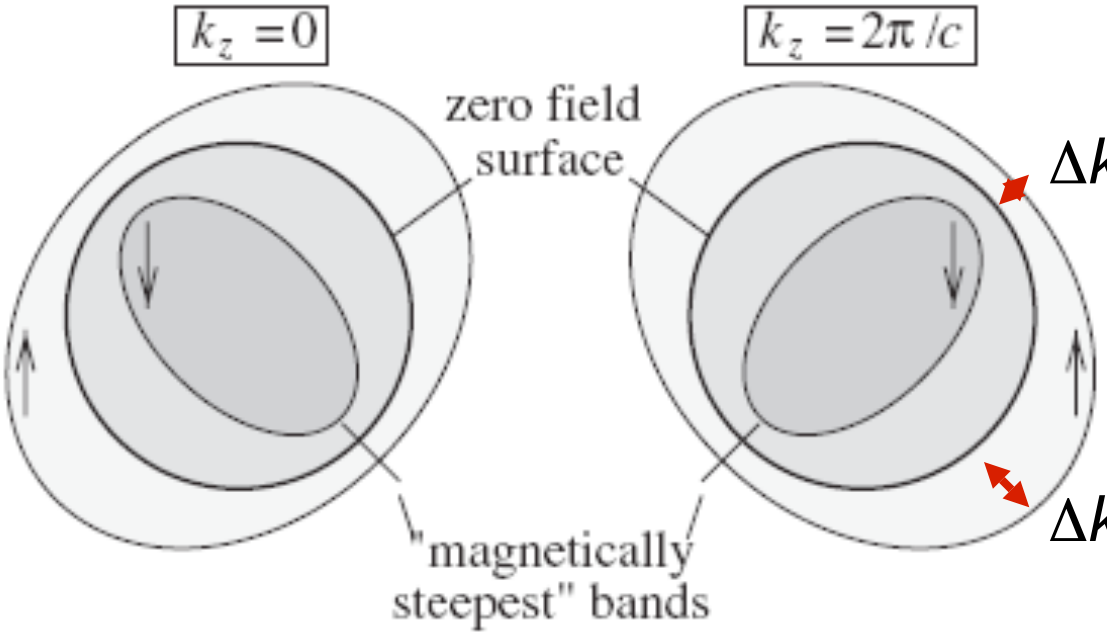
Best fit with anomalous term included





Best fit with only conventional splitting included

Anomalous warping is non-trivial in shape and magnitude from one point of view

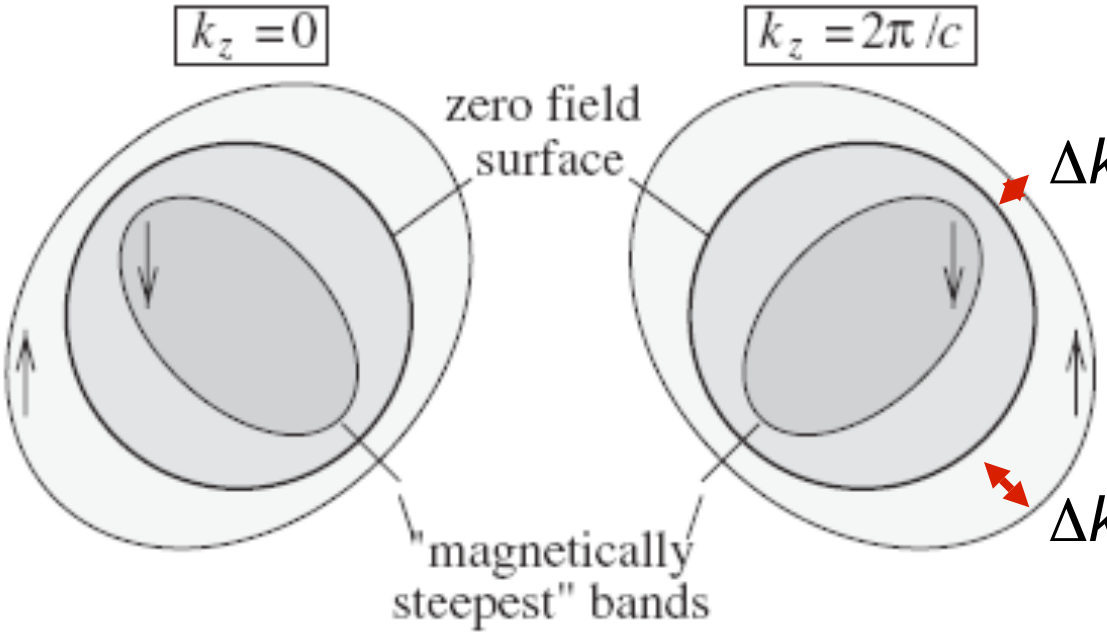


$\Delta k \sim 5 \times 10^5\ m^{-1}T^{-1}$

$\Delta k \sim 1.5 \times 10^6\ m^{-1}T^{-1}$

Split rate 3x larger along most rapidly dispersing directions.

Anomalous warping is non-trivial in shape and magnitude from one point of view



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BUT corresponds to an energy scale of only 70 μeV T^{-1} !

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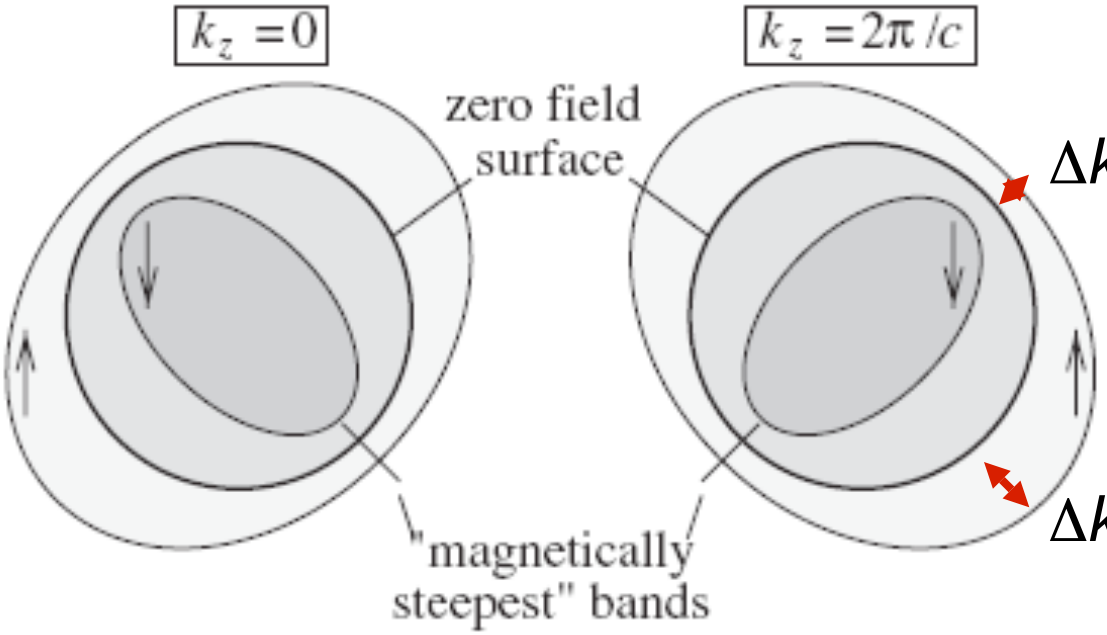

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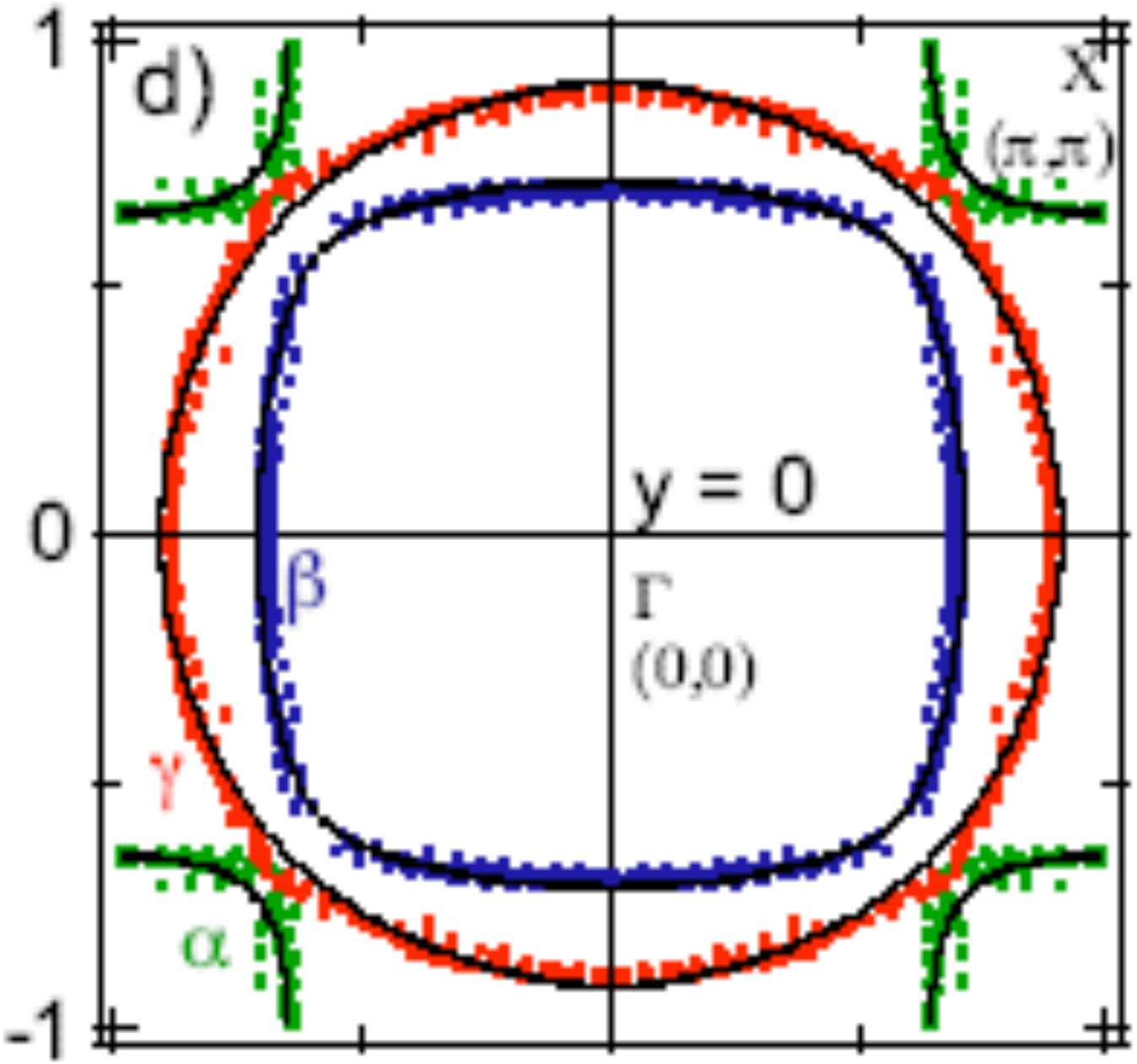
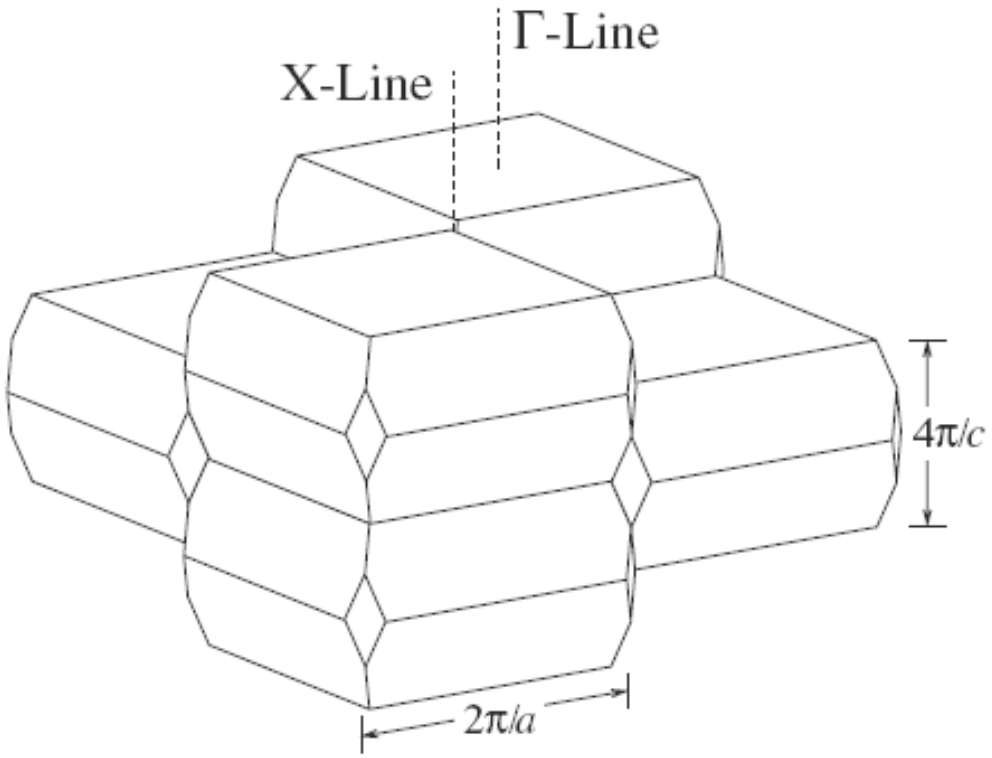
BUT corresponds to an energy scale of only 70 μeV T^{-1} !

Idea for future: use top quality modern samples to study this anomalous warping accurately for all surfaces and hence map out strength of spin-orbit coupling in **k**-space



‘100 meV scale bar’ based on conversion of many-body bandwidths


Γ-Line
X-Line
4π/c
2π/a