f-electron Fermi surface exclusion above $T_K$ in CeRu$_2$Si$_2$

**Luttinger counting theorem** $\Rightarrow$
f-electrons counted in Fermi surface
IF f-moments quenched.
(no matter what route to Fermi liquid)

**dHvA paradigm** (Tutz et al., 1999)

- large Z-point hole FS
  - $f^0$ LaRu$_2$Si$_2$
  - $f^1$ CeRu$_2$Si$_2$ high field (metamag)
  - $f^1$ CeRu$_2$Ge$_2$ ferromagnet

- reduced "pillow" hole FS
  counts $\approx \frac{1}{2}$ Ce f-electron
  in Kondo CeRu$_2$Si$_2$
  --at low temperature

**Conjecture (Fulde & Zwicknagl, 1988)**
f-electrons excluded from FS above
Kondo temperature $T_K$

Difficult to test with low-T dHvA.

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**LDA for LaRu$_2$Si$_2$ and CeRu$_2$Si$_2$ compared**

- LDA "band 4" hole
- Fermi surface
- no f-electron

$\approx \frac{1}{2}$ extra f-electron here

($\approx \frac{1}{2}$ f-electron in other multiply-connected complex FS piece)

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Dr. Jim Allen, Univ of Michigan (KITP Correlated Electrons Program 9/17/02)
f-electron Fermi surface exclusion above TK in CeRu$_2$Si$_2$
f-electron Fermi surface exclusion above TK in CeRu$_2$Si$_2$

LaRu$_2$Si$_2$ Fermi surface from ARPES
J.D. Denlinger (data from ALS)

X$\text{Ru}_2\text{Si}_2$—3d crystal
k-space arcs for varying photon energy

Brillouin Zone

ARPES arcs

$\nu f i x e s$ $k_z a n d$ $m a p c e n t e r$ ’ s $BZ$ point

Hole sheets (center = Z)

Electron sheets (center = Γ)

$h\nu = 122$ eV

$h\nu = 152$ eV

LDA
f-electron Fermi surface exclusion above TK in CeRu$_2$Si$_2$

**Same large hole FS for LaRu$_2$Si$_2$ and CeRu$_2$Si$_2$ for T= 120K > 6$T_K$**

**Experimental Fermi Surface — 4f weight at low mass $\Gamma$, Z points for CeRu$_2$Si$_2$**

- $h\nu = 91$ eV
- $h\nu = 122$ eV
- $dHvA$: $m/m_e = 4, 2.5, 1.6$
- $h\nu = 152$ eV
- $m/m_e = 120$
- $h\nu = 122$ eV
- $m/m_e = 13, 20$
- Hole sheets (center = Z)
- Electrons sheets (center = $\Gamma$)
f-electron Fermi surface exclusion above TK in CeRu_2Si_2

CeRu_2Si_2 ARPES good and bad cleaves

CeRu_2Si_2 angle integrated

“Good” surface
angle-integrated 4d RESPES from ARPES
53 angles, normalize at 5 eV, average

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f-electron Fermi surface exclusion above TK in CeRu₂Si₂

**Surface effect in CeRu₂Si₂**

- **Bold**—angle summed spectrum
- **Solid lines**—extremum behavior of this data set
- **Dashed lines**—extremum behavior in set with better angle resolution

**Low hv OK for CeRu₂Si₂**

- **Evidence that bulk behavior can be seen in 4d RESPES of this material**

  (d) Ce 3d edge RESPES with 0.2 eV resolution (consistent with SPring8 data)
  (c) angle summed 4d edge RES-ARPES
  (a) and (b) ARPES from center of normal emission Z-point

  Denlinger et al, SCES’01 proceedings
CeRu$_2$Si$_2$ why bulk at low hv?

- Crystal structure admits two cleavage planes, with and without Ce
  "Good cleaves" probably from surface without Ce.
  I.e., buried active layer—important for cuprates

- Really flat surface missing edges and steps, less "surface sensitive.

Anderson Lattice Model
2-band low energy ansatz

- renormalized hybridization to d
- renormalized f near $E_F$

Qualitatively similar to LDA for CeRu$_2$Si$_2$
possible origin of success for LDA FS of Ce materials
f-electron Fermi surface exclusion above TK in CeRu$_2$Si$_2$