成功大學物理學系
Physics@National Cheng Kung University

Introduction to Heusler compounds: From the case of Fe_2VAl

Chin Shan Lue (呂欽山)

2017-03-28-NTU

Outline

1) Introduction to Heusler compounds
   - Full-Heusler compounds
   - Half-Heusler compounds
2) Case study of Fe_2VAl
3) Promising characteristics of Heusler compounds
   - Thermoelectric properties
   - Spintronic applications
   - Topological materials
4) Summary

Heusler compounds

Full-Heusler compounds: X_2YZ

Half-Heusler compounds: XYZ

First full-Heusler Cu_2MnAl in 1903

First half-Heusler NiMnSb in 1951

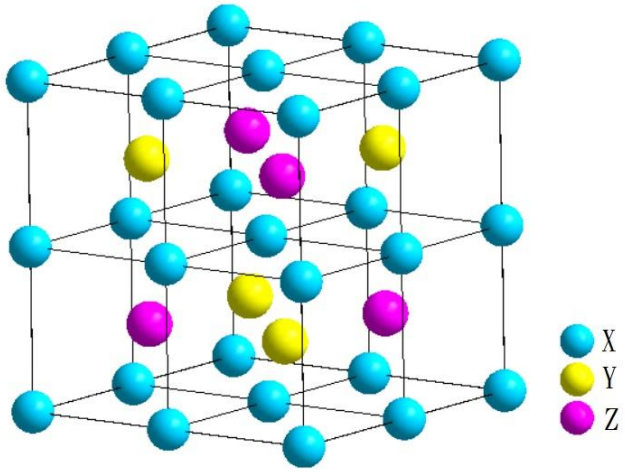
Fritz Heusler
(Germany)

More than 1000 real Heusler compounds

1																	18
1 H 1.008	2											13	14	15	16	17	2 He 4.0026
3 Li 6.94	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305	3	4	5	6	7	8	9	10	11	12	13 Al 26.982	14 Si 28.085	15 P 30.974	16 S 32.06	17 Cl 35.45	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.630	33 As 74.922	34 Se 78.97	35 Br 79.904	36 Kr 83.798
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.95	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57-71 *	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89-103 #	104 Rf (265)	105 Db (268)	106 Sg (271)	107 Bh (270)	108 Hs (277)	109 Mt (276)	110 Ds (281)	111 Rg (280)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (289)	116 Lv (293)	117 Ts (294)	118 Og (294)

* Lanthanide series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
# Actinide series	89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

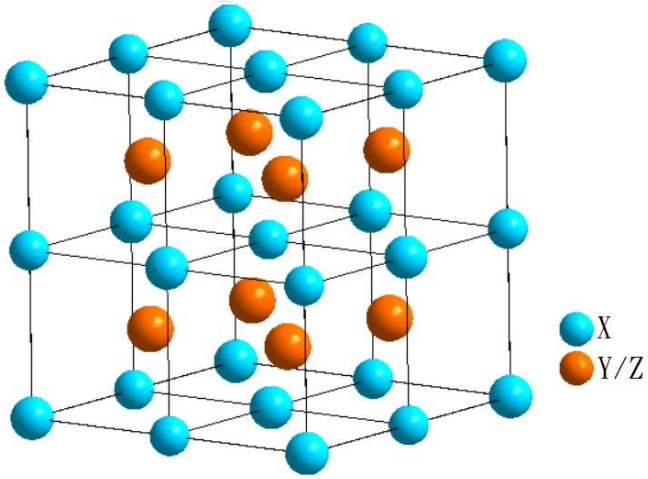
Common crystal structures of Heusler compounds



First determination of crystal structure for Cu_2MnAl by Otto Heusler in 1934

$L_2$1 structure

Cu_2MnAl-type
16 atoms per unit cell
Fe_2VAl, Ru_2NbGa, Ni_2MnGa (HT), …

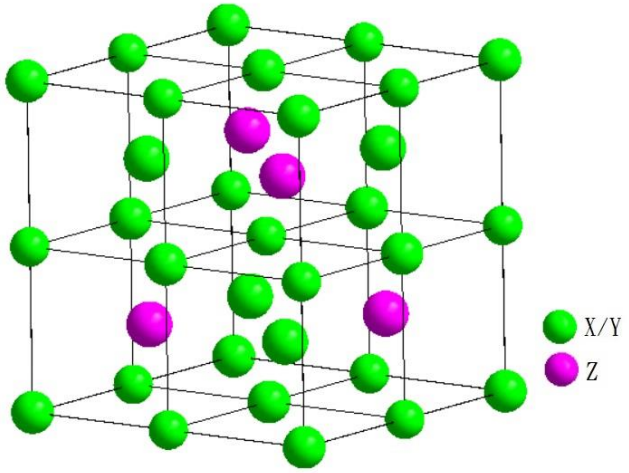


Anti-site disorder

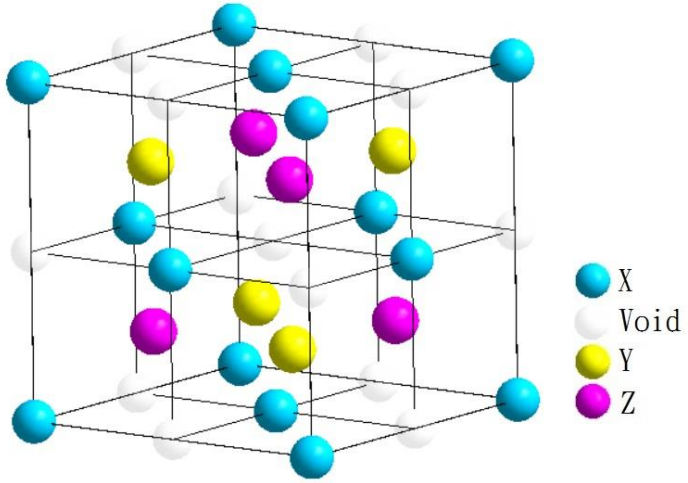
B2 structure

CsCl-type
2 atoms per unit cell
Co_2MnAl, Ru_2NbAl, Ru_2VAl, …

X = Y



X + void



Binary compounds X_3Z

DO_3 structure

BiF_3-type
16 atoms per unit cell
Fe_3Al; Fe_3Ga; Fe_3Si, ...

Half-Heusler XYZ

$C1_b$ structure

MgAgAs-type
12 atoms per unit cell
NiMnSb, NiZrSn, CoTiSb, …

Various properties of Heusler compounds

Ferromagnetism: Co_2MnZ, $Pd_2Mn(In,Sn)$, …

Superconductivity: Pd_2YSn (T_C = 4.9 K), Ni_2NbSn, Pd_2ErSn, …

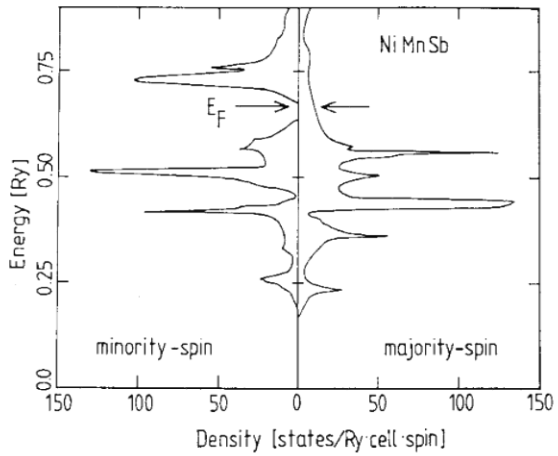
Shape memory behavior: Ni_2MnGa (Martensitic transformation T_M = 220 K), …

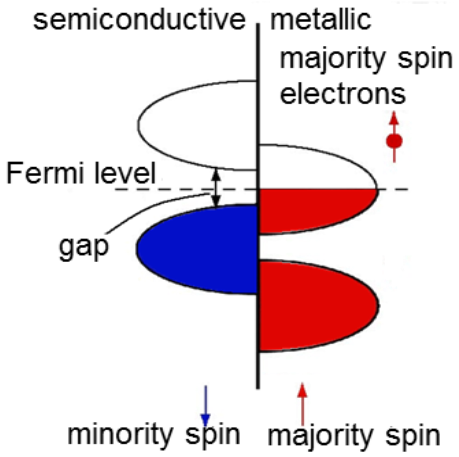
Semiconducting: Fe_2VAl, Ru_2TaAl, IrNbSb, NiHfSn, CoTiSb, …

VOLUME 50, NUMBER 25 PHYSICAL REVIEW LETTERS 20 JUNE 1983

New Class of Materials: Half-Metallic Ferromagnets

R. A. de Groot and F. M. Mueller





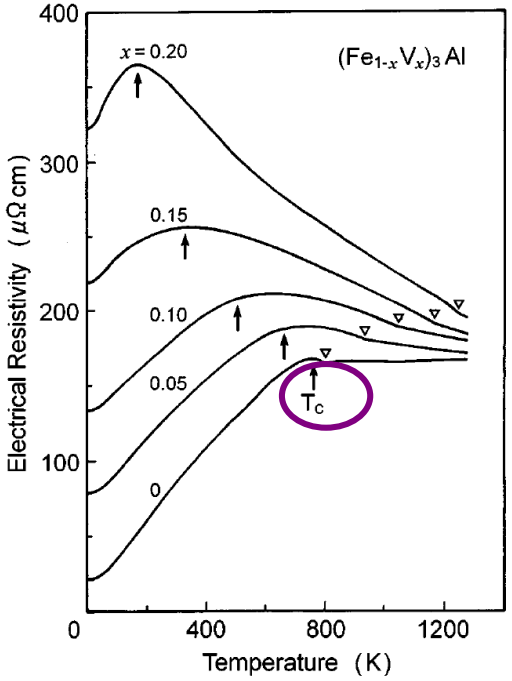
Unusual physical behavior in Fe_2VAl

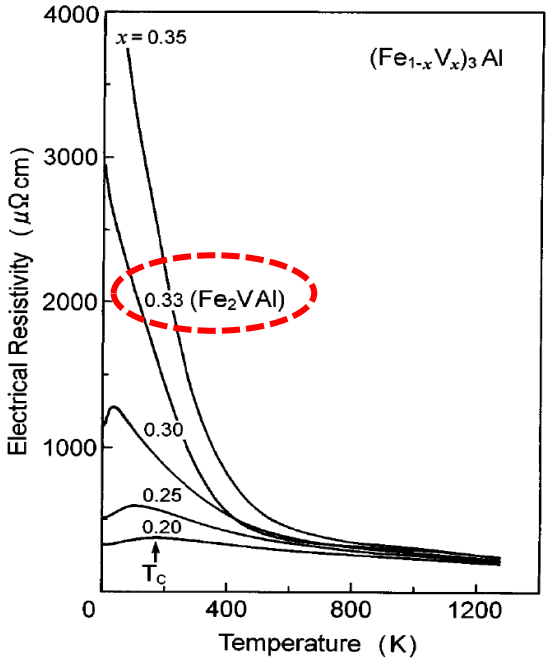
Paramagnetic behavior in Fe_2VAl by Webster & Ziebeck in 1983

VOLUME 79, NUMBER 10 PHYSICAL REVIEW LETTERS 8 SEPTEMBER 1997

Semiconductorlike Behavior of Electrical Resistivity in Heusler-type Fe_2VAl Compound

Y. Nishino, M. Kato, and S. Asano
Department of Materials Science and Engineering, Nagoya Institute of Technology, Showa-ku, Nagoya 466, Japan
K. Soda, M. Hayasaki, and U. Mizutani
Department of Crystalline Materials Science, Nagoya University, Chikusa-ku, Nagoya 464-01, Japan
(Received 7 March 1997)





Fe_3Al T_c = 790 K

⇓

$(Fe_{1-x}V_x)_3Al$

⇓

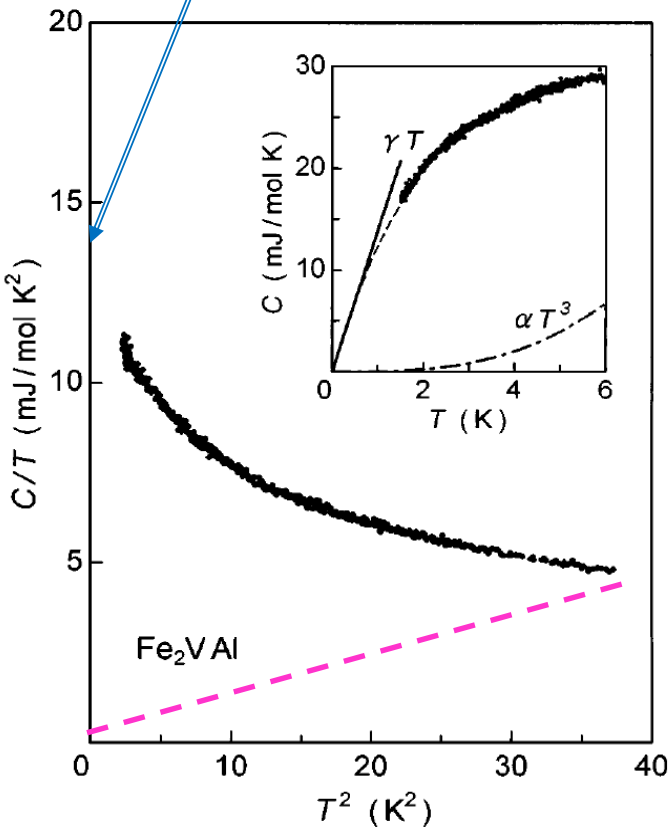
x=0.33 **Fe_2VAl** T_c = 0 K

Semiconductor-like in ρ

semimetal

Possible 3d heavy fermion for Fe_2VAl

γ = 14 mJ/mol K^2



Expected behavior for ordinary semimetals (low Fermi-level DOS)

γ = 1.07 mJ/mol K^2

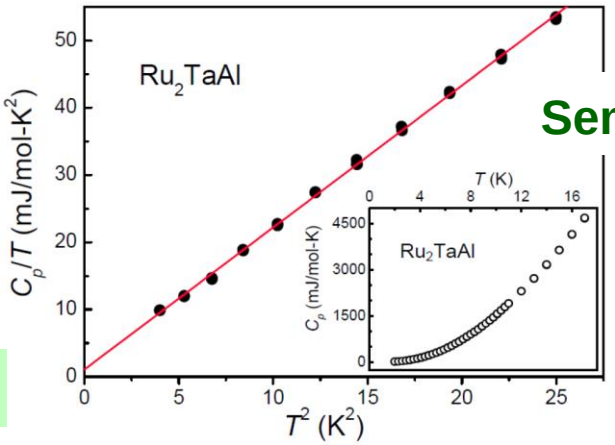
Low-T $C = C_e + C_{ph} = \gamma T + \beta T^3$

$C/T = \gamma + \beta T^2$

Sommerfeld coefficient based on free electron model

$$\gamma_{th} = \frac{\pi^2 k_B^2}{3} N(E_F) \propto m_e$$

$$\frac{\gamma_{exp}}{\gamma_{th}} = \frac{m^*}{m_e} \approx 50-100$$ for Fe_2VAl



Semimetallic Ru_2TaAl

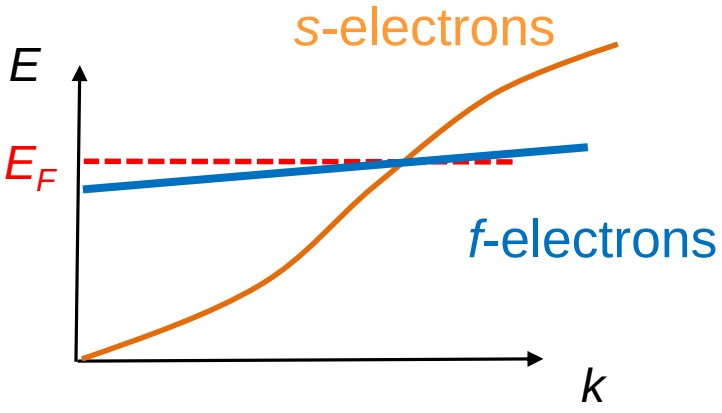
$$\frac{\gamma_{exp}}{\gamma_{th}} \approx 3$$

from C. M. Wei et al.

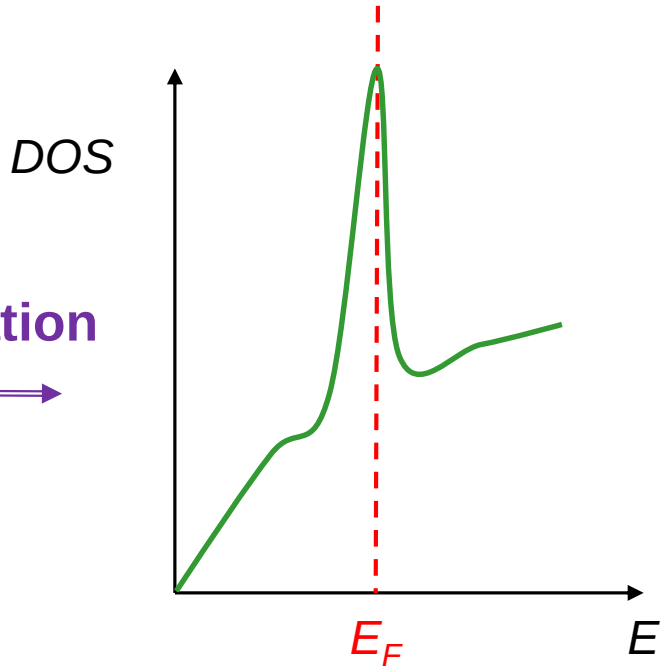
Simple concept for heavy fermions

f-electron heavy fermions

$CeAl_3$ γ=1620 mJ/mol K^2
$CeCu_6$ γ=1300 mJ/mol K^2
UBe_{13} γ=1100 mJ/mol K^2
U_2Zn_{17} γ= 500 mJ/mol K^2
…….



hybridization



It is less likely to observe heavy fermion behavior in *d*-electron systems since the corresponding wave-functions of *d*-orbitals are more dispersive.

d-electron heavy fermion???

Spinel LiV_2O_4 γ= 420 mJ/mol K^2

PRL 78, 3729 (1997); PRL 85, 1052 (2000)
PRL 89, 267201 (2002); PRL 99, 167402 (2007)
Nat. Comm. 3, 981 (2012); PRL 113, 236402 (2014);
…….

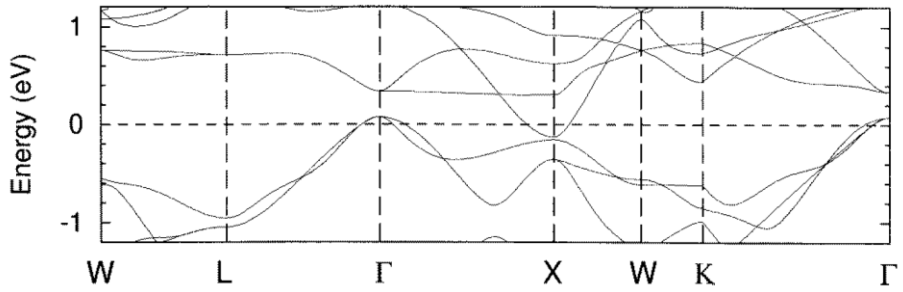
Band structure calculations for Fe_2VAl

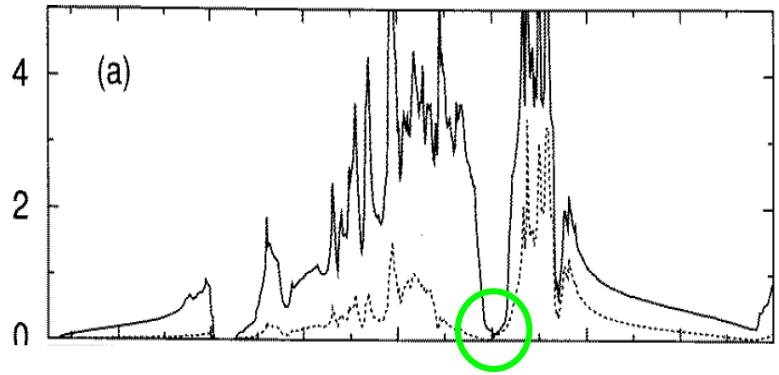
J. Phys.: Condens. Matter **10** (1998) L119–L126. Printed in the UK

LETTER TO THE EDITOR

Electronic structure of possible 3d 'heavy-fermion' compound Fe_2VAl

郭光宇 G Y Guo†, G A Botton‡ and Y Nishino‖





$N(E_F)$ = 0.08 states/eV atom

Electronic structure, local moments, and transport in Fe_2VAl,
D. J. Singh & I. I. Mazin, Phys. Rev. B 57, 14352 (1998)

Excitonic correlations in the intermetallic Fe_2VAl,
R. Weht & W. E. Pickett, Phys. Rev. B 58, 6855 (1998)

Hybridization-induced band gaps in transition-metal aluminides,
M. Weinert & R. E. Watson, Phys. Rev. B 58, 9732 (1998)

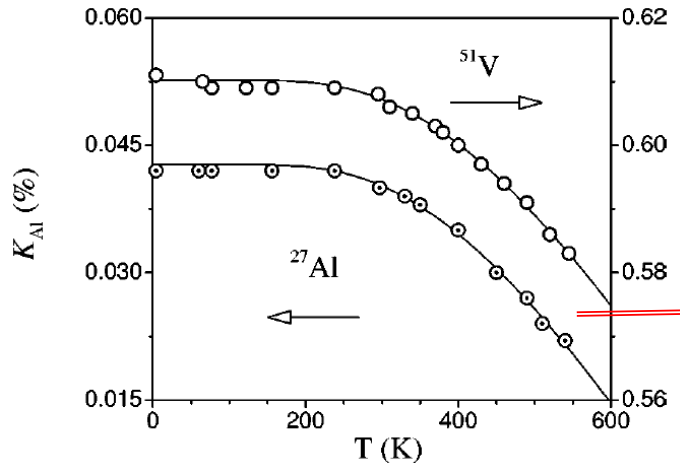
Electronic structure and magnetism of $Fe_{3-x}V_xX$ (X=Si, Ga, and Al) alloys by the KKR-CPA method, A. Bansil, et al., Phys. Rev. B 60, 13396 (1999)

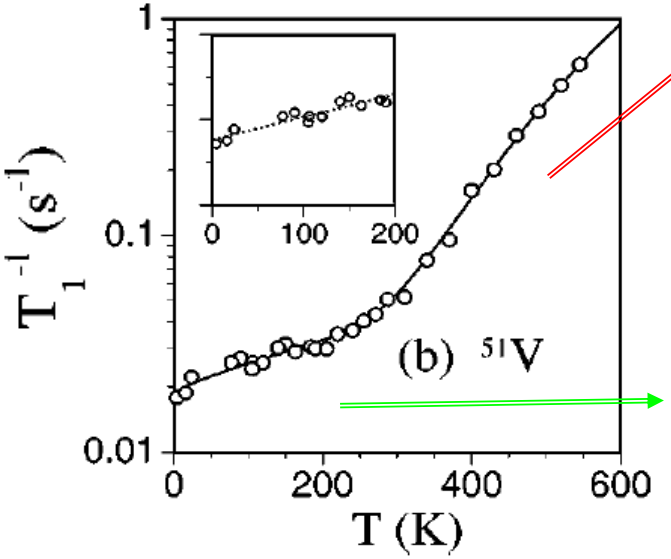
NMR evidence for semimetallic behavior in Fe_2VAl

PHYSICAL REVIEW B VOLUME 58, NUMBER 15 15 OCTOBER 1998-I

Semimetallic behavior in Fe_2VAl: NMR evidence

Chin-Shan Lue* and Joseph H. Ross, Jr.†
Department of Physics, Texas A&M University, College Station, Texas 77843-4242
(Received 3 June 1998)





Thermally excited carriers across electronic bands near E_F

Activation energy E_A ~ 0.27 eV

Korringa relation $1/T_1T \sim C[N(E_F)]^2$

Low *V-3d* $N(E_F)$ = 0.11 states/eV atom

Question of possible 3*d* heavy fermion for Fe_2VAl

THIRD SERIES, VOLUME 60, NUMBER 20 15 NOVEMBER 1999-II

RAPID COMMUNICATIONS

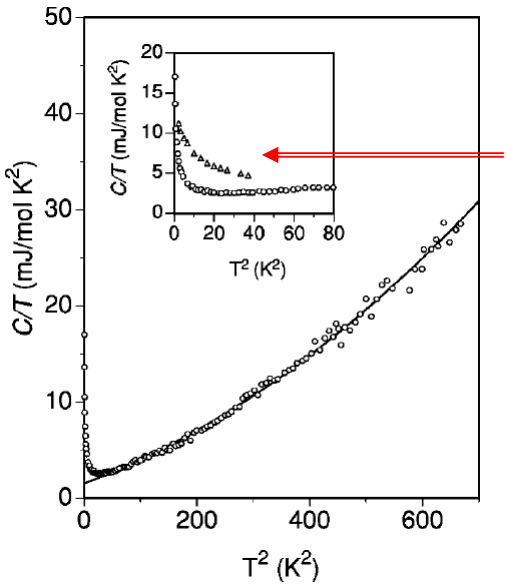
Rapid Communications are intended for the accelerated publication of important new results and are therefore given priority treatment both in the editorial office and in production. A Rapid Communication in **Physical Review B** *may be no longer than four printed pages and must be accompanied by an abstract. Page proofs are sent to authors.*

Field-dependent specific heat in Fe_2VAl and the question of possible 3*d* heavy fermion behavior

C. S. Lue* and Joseph H. Ross, Jr.†
Department of Physics, Texas A&M University, College Station, Texas 77843-4242

C. F. Chang and H. D. Yang
Department of Physics, National Sun Yat-Sen University, Kaohsiung, Taiwan

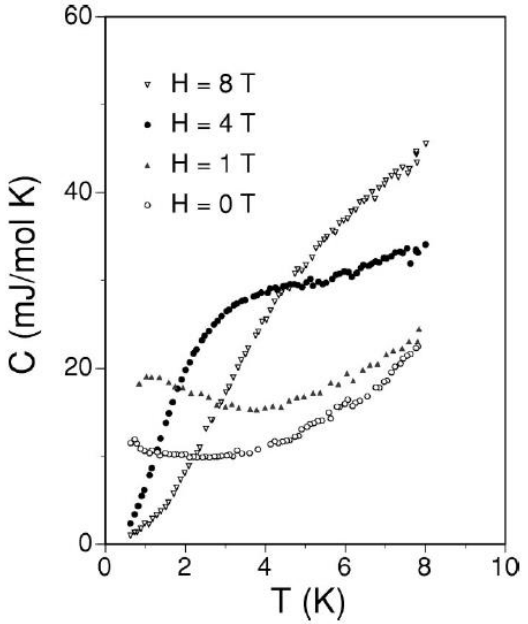
(Received 19 August 1999)



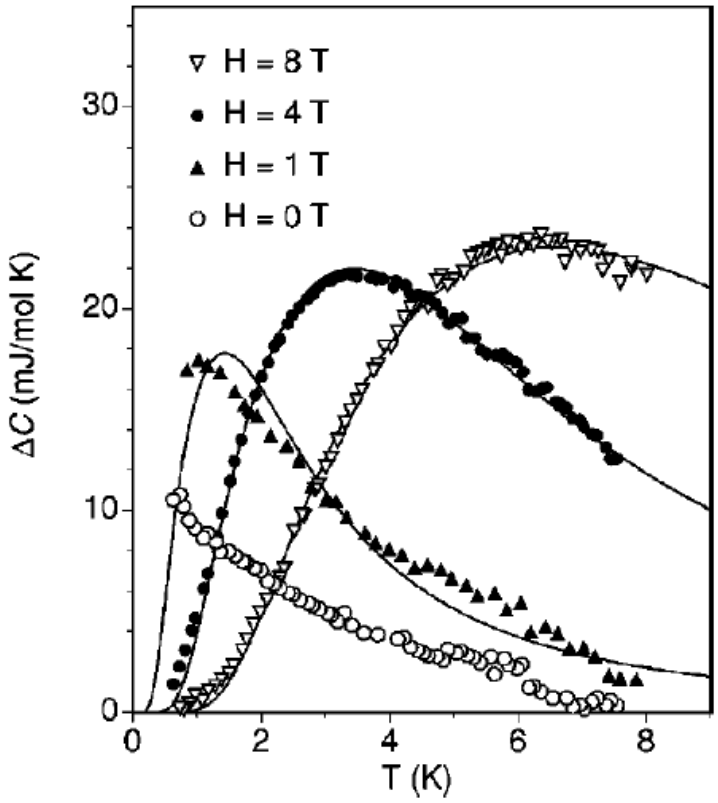
Sample-dependent

Field-dependent

Small γ = 1.5 mJ/mol K²



False heavy fermion behavior in Fe_2VAl



For non-interacting magnetic clusters with spin J >1/2, the magnetic specific heat can be generated by the so-called multi-level Schottky function as

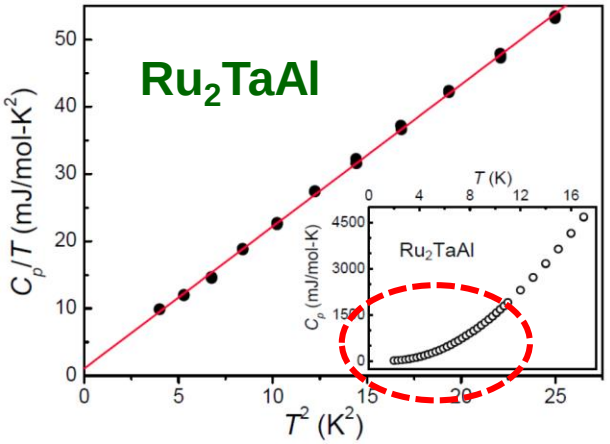
$$C_m = Nk_B\left[\frac{x^2e^x}{(e^x-1)^2} - (2J+1)^2\frac{x^2e^{(2J+1)x}}{(e^{(2J+1)x}-1)^2}\right]$$

$$x = \frac{g\mu_B H}{k_B T}$$

$$J = \frac{3}{2} \rightarrow \mu = g\mu_B\sqrt{J(J+1)} = 3.7\mu_B$$

$$f = 0.36\% \text{ population per formula unit}$$

The low-T upturn in C is not intrinsic; It is reasonably associated with magnetic clusters due to anti-site disorder in real samples.



Effects of magnetic clusters in Fe_2VAl, Fe_2VGa and Fe_2TiSn

"Weak ferromagnetism induced by atomic disorder in Fe_2TiSn",
A. Ślebarski, M. B. Maple, et al., Phys. Rev. B 62, 3296 (2000)
"Kondo-type behavior in $Fe_{2-x}M_xTiSn(M=Co,Ni)$",
A. Ślebarski, M. B. Maple, et al., Phys. Rev. B 63, 214416 (2001)
"Fe−3s core-level splitting and local magnetism in Fe_2VAl",
Phys. Rev. B 63, 054419 (2001)
"Superparamagnetism and magnetic defects in Fe_2VAl and Fe_2VGa",
J. Phys.: Condens. Matter 13, 1585 (2001)
"Structure and magnetic order in $Fe_{2+x}V_{1-x}Al$",
J. Phys.: Condens. Matter 13, 5487 (2001)
"NMR and Mössbauer study of spin dynamics and electronic structure of $Fe_{2+x}V_{1-x}Al$ and Fe_2VGa",
Phys. Rev. B 67, 224425 (2003)
"Transport and magnetic properties of the Heusler-type $Fe_{2-x}V_{1+x}Al$ system $(-0.01 \leqslant x \leqslant 0.08)$",
Phys. Rev. B 71, 094425 (2005)
"Evidence for cluster glass behavior in Fe_2VAl Heusler alloys",
Phys. Rev. B 78, 064401 (2008)

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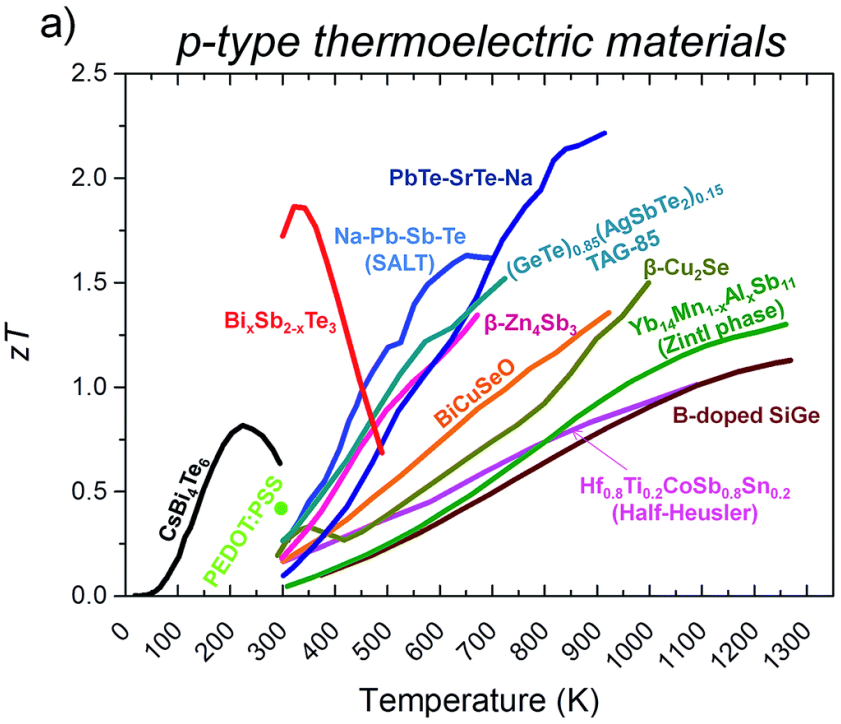
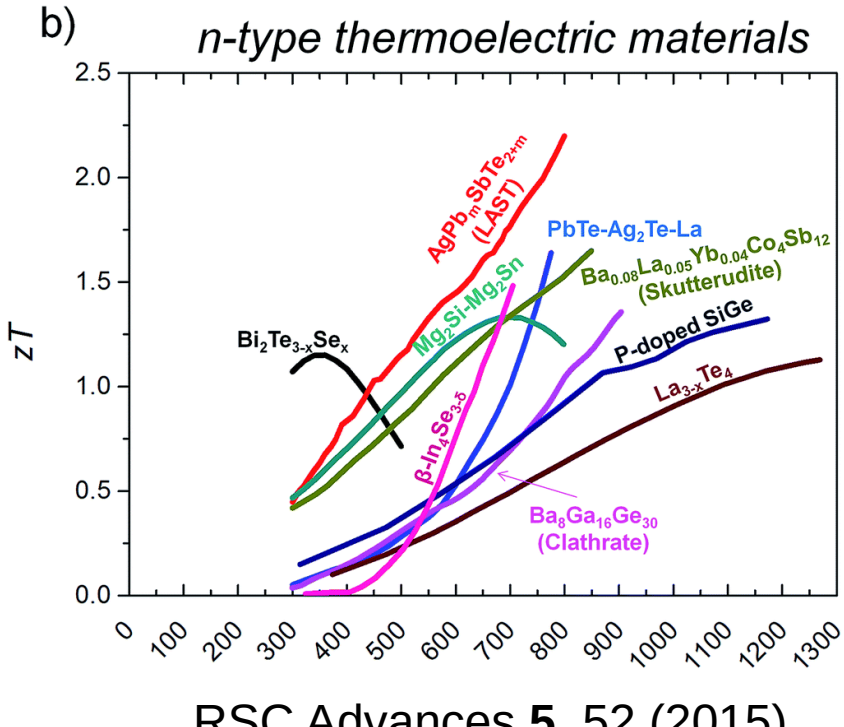
Electronic structure and magnetism of $Fe_{3-x}V_xX$ (X=Si, Ga, and Al) alloys by the KKR-CPA method, A. Bansil, et al., Phys. Rev. B 60, 13396 (1999)

More first-principles calculations on Fe_2VAl

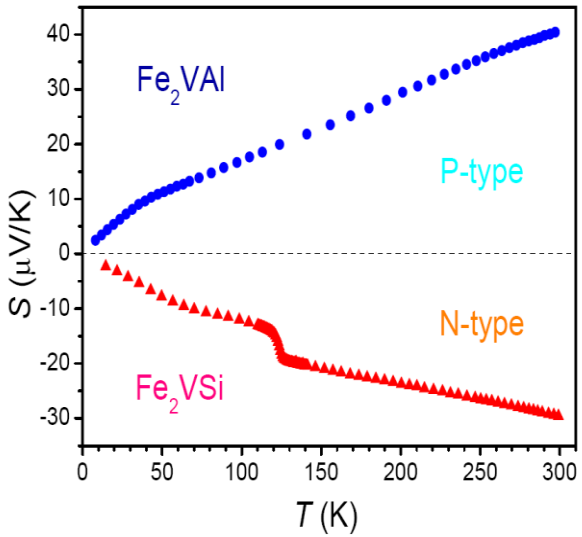
"Electronic structure and x-ray magnetic circular dichroism in Heusler-type $Fe_{2-x}V_{1+x}Al$: First-principles calculations",
Phys. Rev. B 77, 134444 (2008)
"Density functional study of elastic and vibrational properties of the Heusler-type alloys Fe_2VAl and Fe_2VGa",
Phys. Rev. B 80, 125108 (2009)
"Electronic and **thermoelectric properties** of Fe_2VAl: The role of defects and disorder",
Phys. Rev. B 83, 205204 (2011)
"Effect of onsite Coulomb repulsion on **thermoelectric properties** of full-Heusler compounds with pseudogaps",
Phys. Rev. B 84, 125104 (2011)
"Low-Dimensional transport and **large thermoelectric power factors** in bulk semiconductors by band engineering of highly directional electronic states",
Phys. Rev. Lett. 114, 136601 (2015)
"Quantum many-body intermetallics: Phase stability of Fe_3Al and small-gap formation in Fe_2VAl",
Phys. Rev. B 95, 045114 (2017)
……

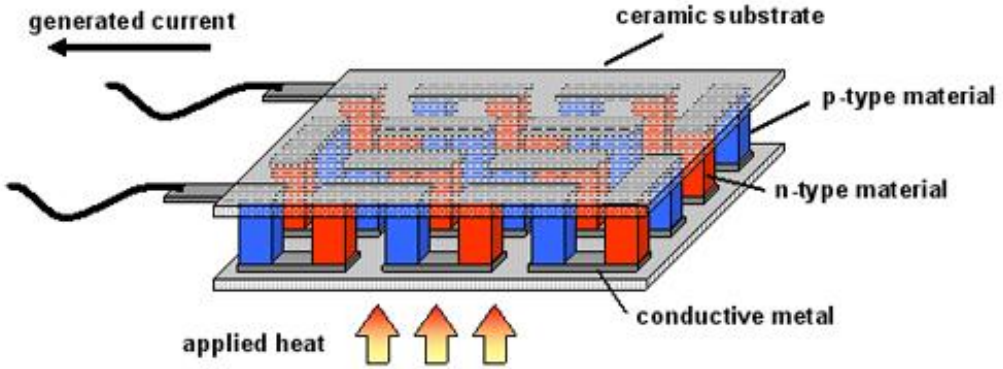
Thermoelectric materials





RSC Advances **5**, 52 (2015)





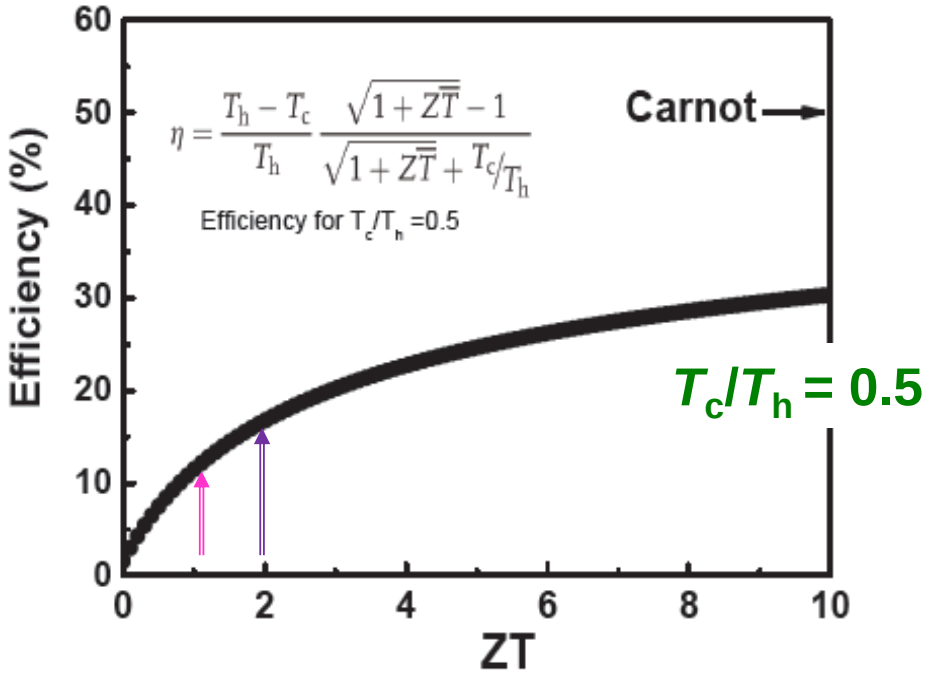
Thermoelectric generator module

Thermoelectric efficiency

η : Generated electrical energy/Absorbed heat energy

$$\eta_{\max} = \left(\frac{T_h - T_c}{T_h}\right)\frac{\sqrt{1+Z\bar{T}}-1}{\sqrt{1+Z\bar{T}}+T_c/T_h}, \quad \text{with} \quad Z = \frac{S^2}{\rho\kappa}, \quad \bar{T} = \frac{T_c + T_h}{2}.$$

ZT*: *Figure of merit
熱電優質



***ZT* = 1 → 10.8%**
***ZT* = 2 → 16.4%**

T_c/T_h = 0.5

Thermoelectric performance

$ZT = S^2T/\rho(\kappa_e+\kappa_l)$

S: Seebeck coefficient

ρ : electrical resistivity

κ_e: electronic thermal conductivity

κ_l: lattice thermal conductivity

Naive expectation:

S = 200 μV/K

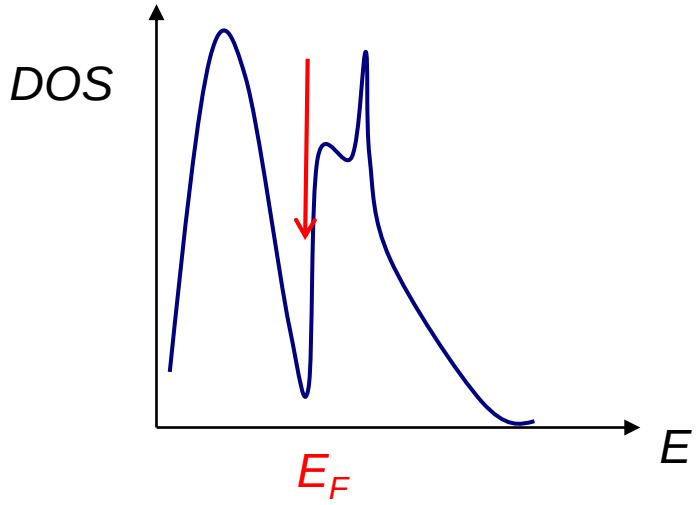
ρ = 1000 μΩ-cm

κ = 2 W/m-K

ZT=1 at 500 K

Physical approach based on Mott equation,

$$S_e \propto \frac{1}{e}\left(\frac{1}{N(E)}\frac{\partial N(E)}{\partial E}\right)_{E=E_F}$$



Chemical approach by partially substituting heavy elements and/or vacancies to enhance the phonons scattering and thus reduce the contribution of κ_l.

A simple rule with number of valence electrons

Full-Heusler compounds with $L_2$1-type structure

Total number of valence electrons per formula unit VEC = Z_t = 24

In principles → Semiconductors

In reality → Semimetals

Fe_2VAl, Fe_2VGa, Fe_2TiSn, Ru_2NbGa, Ru_2TaAl, Ru_2TiSi, ….

Half-Heusler compounds with C_b1-type structure

Total number of valence electrons per formula unit VEC = Z_t = 18

In principles → Semiconductors

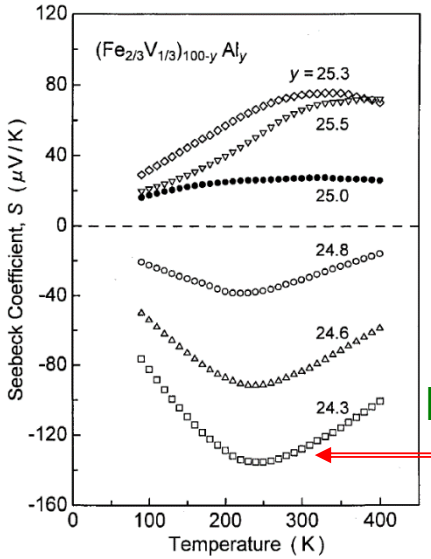
In reality → Semimetals

NiTiSn, NiZrSn, NiHfSn, CoTiSb, FeVSb….

Thermoelectric studies of Fe_2VAl and related compounds

Effect of off-stoichiometry on the transport properties of the Heusler-type Fe_2VAl compound

Nishino et al., Phys. Rev. B 63, 233303 (2001)



Large *S*

Nishino's group
Phys. Rev. B 71, 094425 (2005)
Phys. Rev. B 71, 245112 (2005)
Phys. Rev. B 74, 115115 (2006)
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C. S. Lue & Y. K. Kuo,
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Phys. Rev. B 72, 054116 (2005)
Phys. Rev. B 75, 064202 (2007)
Phys. Rev. B 78, 165117 (2008)

Other groups
J. Alloys Compd. 349, 37 (2003)
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J. Appl. Phys. 111, 093710 (2012)
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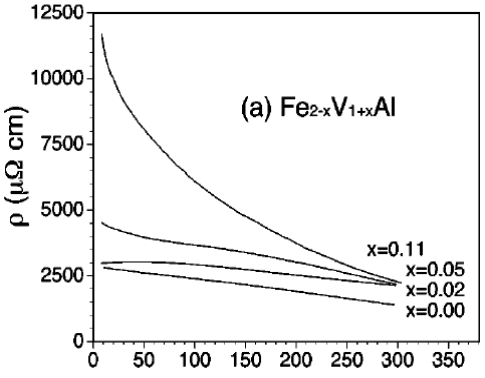
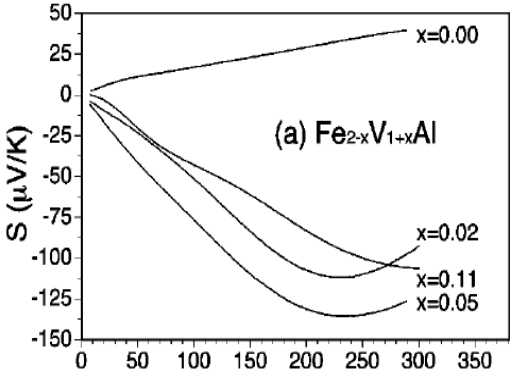
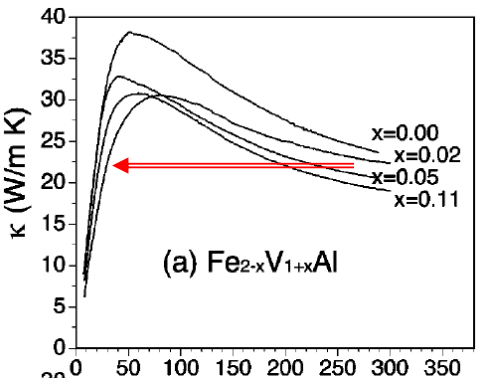
Thermoelectric properties of the semimetallic Heusler compounds $Fe_{2-x}V_{1+x}M$ (M = Al, Ga)

C. S. Lue & Y. K. Kuo, Phys. Rev. B 66, 085121 (2002)



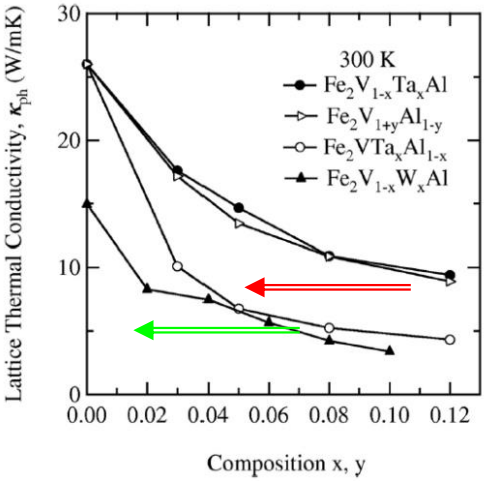


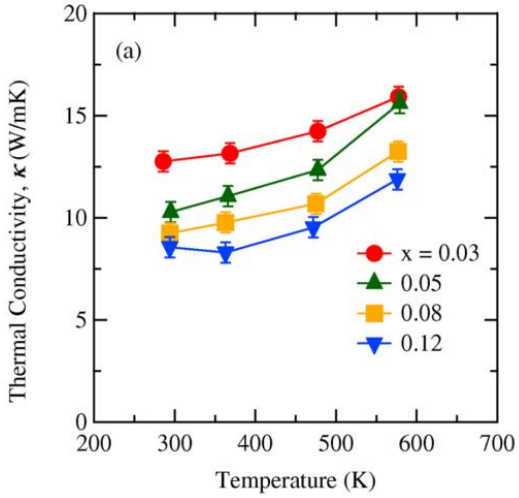


High κ

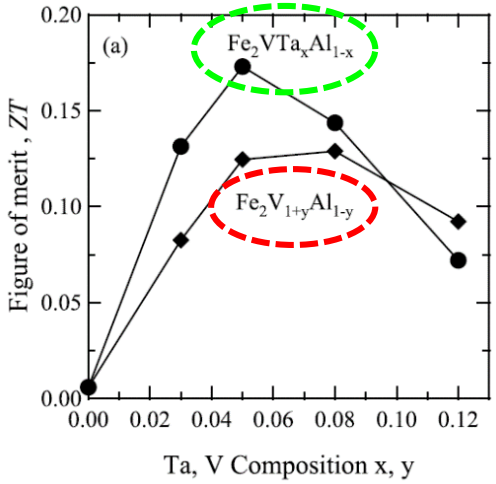
Thermoelectric studies of Fe_2VAl-based compounds

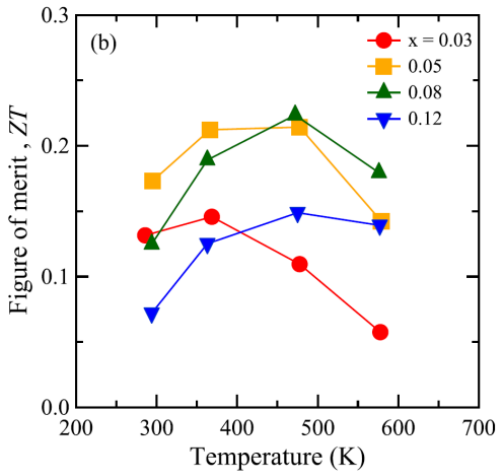
Thermoelectric properties of the Heusler-type $Fe_2VTa_xAl_{1-x}$ alloys J. Appl. Phys. 115, 033704 (2014)





Optimized *ZT* ~ 0.2





Thermoelectric studies of half-Heusler compounds with $Z_t = 18$

"Gap at the Fermi level in the intermetallic vacancy system *R*NiSn (*R*=Ti,Zr,Hf)",
Z. Phys. B 75, 116 (1989).
"Narrow band in the intermetallic compounds *M*NiSn (*M*=Ti,Zr,Hf)",
Z. Phys. B 80, 353 (1990).
"Band gap and stability in the ternary intermetallic compounds NiSn*M* (*M*=Ti,Zr,Hf): A first principles study",
Phys. Rev. B 51, 10443 (1995).
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"Effect of substitutions and defects in half-Heusler FeVSb studied by electron transport measurements and KKR-CPA electronic structure calculations",
Phys. Rev. B 70, 184207 (2004).
"Electronic structure and thermoelectric properties of half-Heusler $Zr_{0.5}Hf_{0.5}NiSn$ by first-principles calculations",
Appl. Phys. Lett. 113, 193705 (2013).
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PHYSICAL REVIEW B **95**, 045202 (2017)

Lattice thermal conductivity of $Ti_xZr_yHf_{1-x-y}NiSn$ half-Heusler alloys calculated from first principles: Key role of nature of phonon modes

"Effect of Ti substitution on the thermoelectric properties of (Zr,Hf)NiSn half-Heusler compounds", Appl. Phys. Lett. 86, 082105 (2005).
"Thermoelectric performance of half-Heusler compounds TiNiSn and TiCoSb", Appl. Phys. Lett. 105, 013709 (2009).
"Thermoelectric property study of nano-structured p-type half-Heuslers (Hf,Zr,Ti)$CoSb_{0.8}Sn_{0.2}$", Advanced Energy Materials 3, 1195 (2013).
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APPLIED PHYSICS LETTERS **107**, 041902 (2015)

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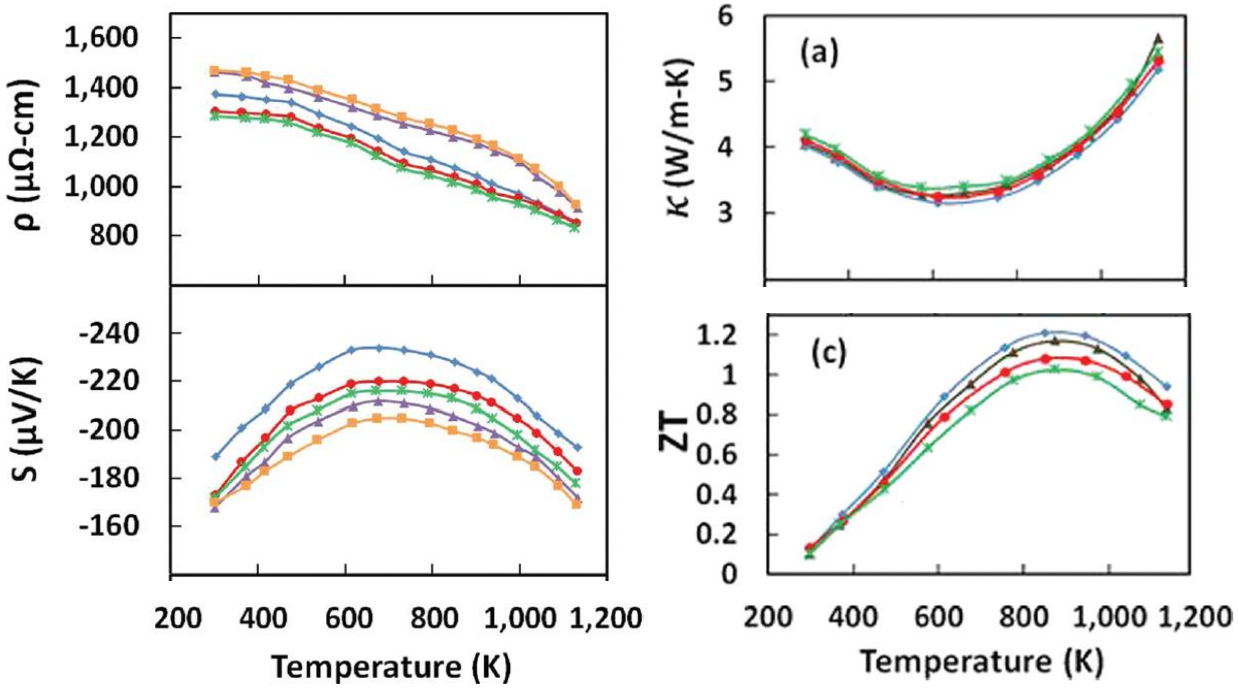
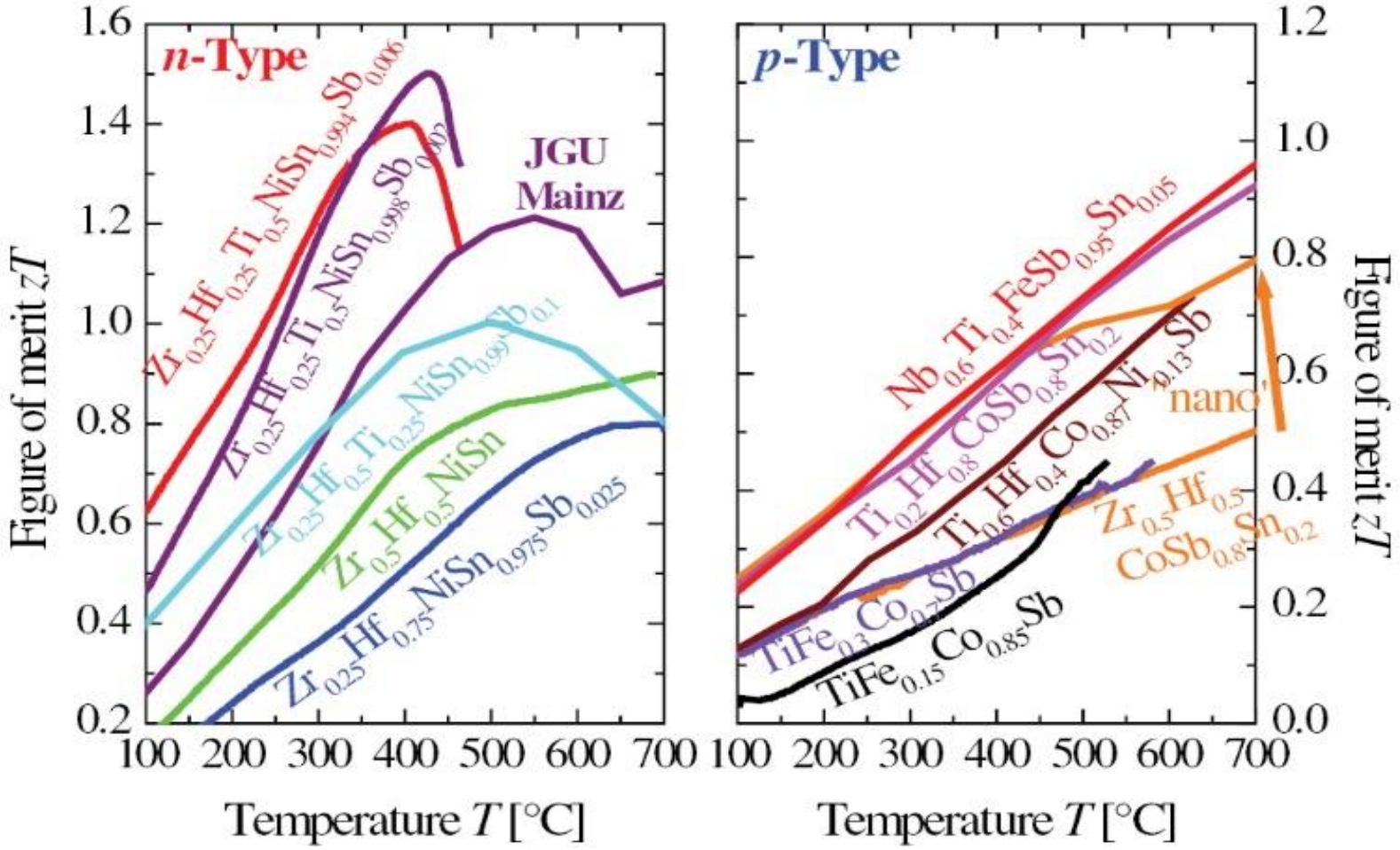
Uncovering high thermoelectric figure of merit in (Hf,Zr)NiSn half-Heusler alloys

L. Chen,[1] S. Gao,[1] X. Zeng,[2] A. Mehdizadeh Dehkordi,[3] T. M. Tritt,[2,3] and S. J. Poon[1,a)]



Thermoelectric materials based on half-Heusler compounds



Translational Materials Research **2**, 025001 (2015)

Half-metallic Heusler compounds

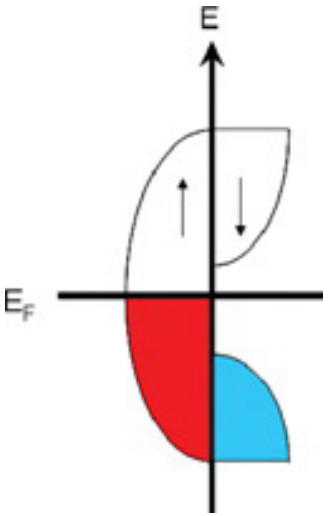
VOLUME 50, NUMBER 25 PHYSICAL REVIEW LETTERS 20 JUNE 1983

New Class of Materials: Half-Metallic Ferromagnets

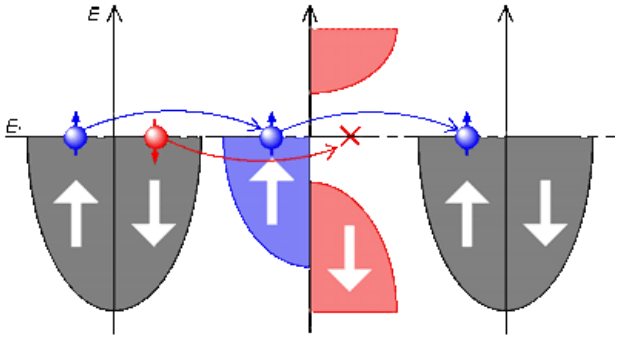
R. A. de Groot and F. M. Mueller
Research Institute for Materials, Faculty of Science, Toernooiveld, 6525 ED Nijmegen, The Netherlands

Compound	$N(E)\uparrow$	$N(E)\downarrow$	$n_{3d}^{Mn\uparrow}$	$n_{3d}^{Mn\downarrow}$	μ_{tot}^{cacl}	μ_{tot}^{exp}
NiMnSb	9.90	0	4.51	0.87	4.00	3.85
PtMnSb	10.05	0	4.57	0.79	4.00	3.97
PdMnSb	9.04	2.97	4.58	0.71	4.05	3.95
PtMnSn	9.78	19.31	4.40	0.78	3.60	3.42

Half-Heusler



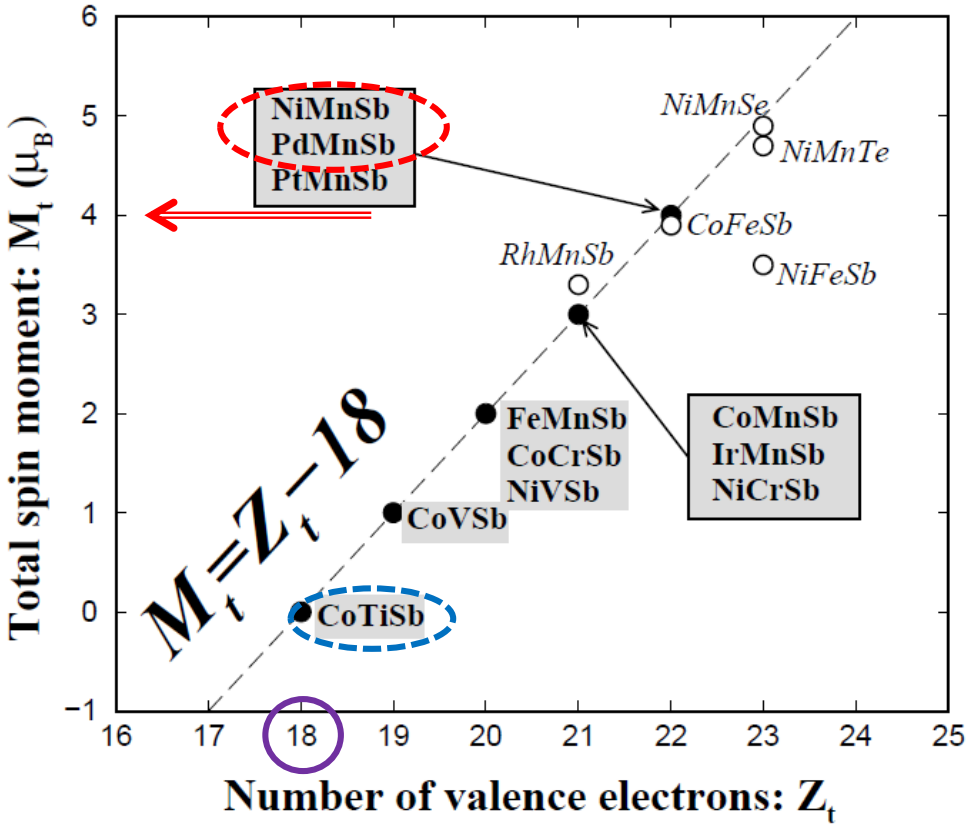
Half-metals



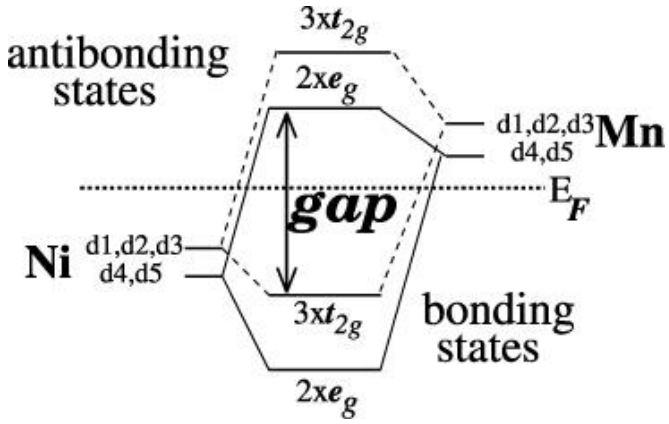
100% polarization

A semi-empirical general rule: Slater-Pauling curve

Half-Heusler compounds



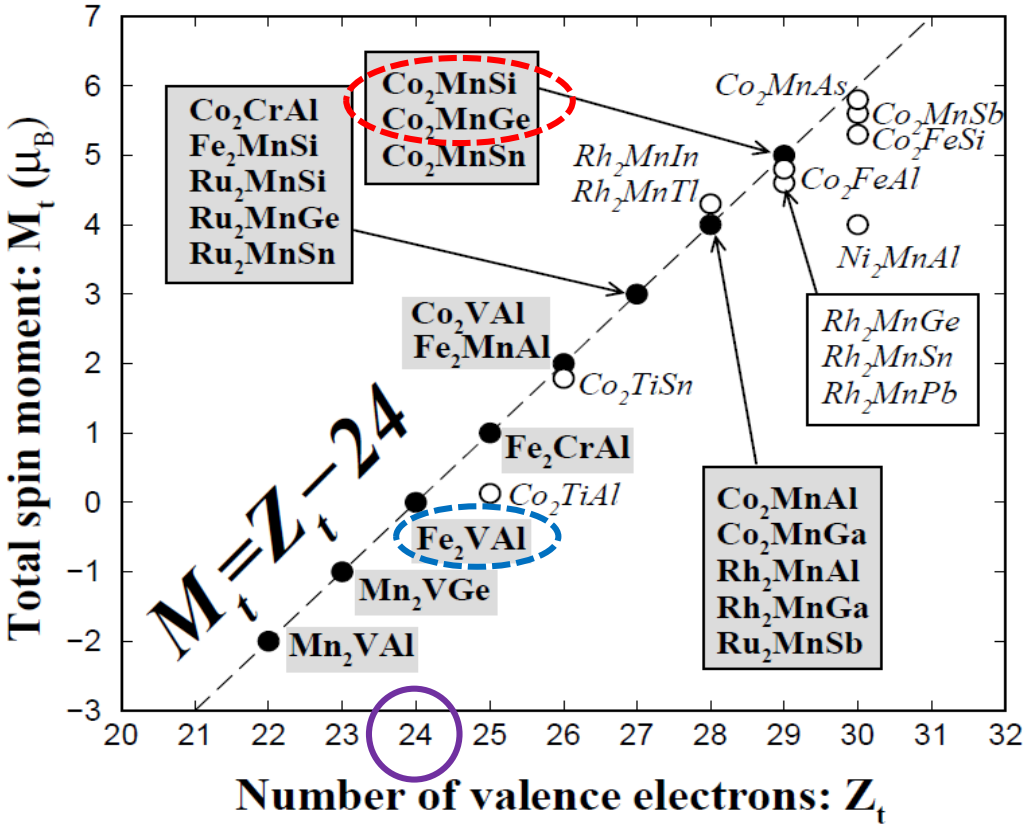
Hybridization between Ni and Mn in minority bands in NiMnSb



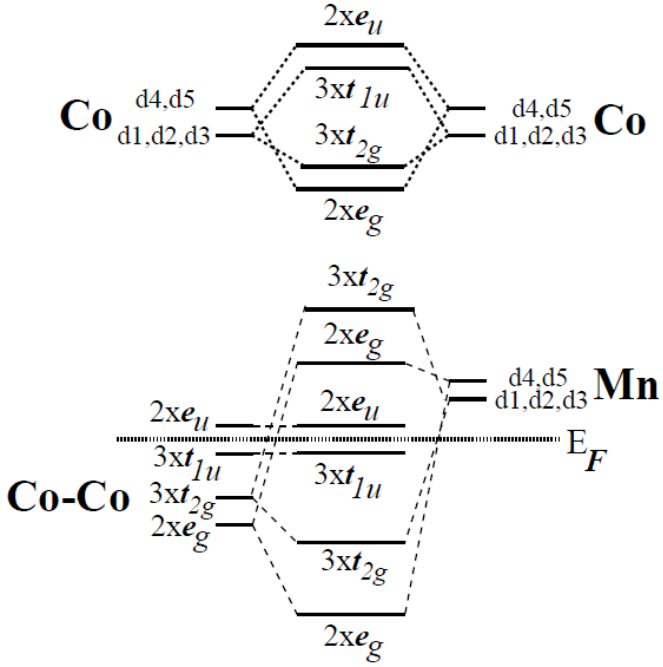
I. Galanakis, P. H. Dederiches, N. Papanikolaou, *Phys. Rev.* B **66** 134428 (2002).

Slater-Pauling curve for full-Heusler compounds

Full-Heusler compounds



Hybridization between Co-Co and Mn in minority bands in $Co_2MnSi(Ge)$



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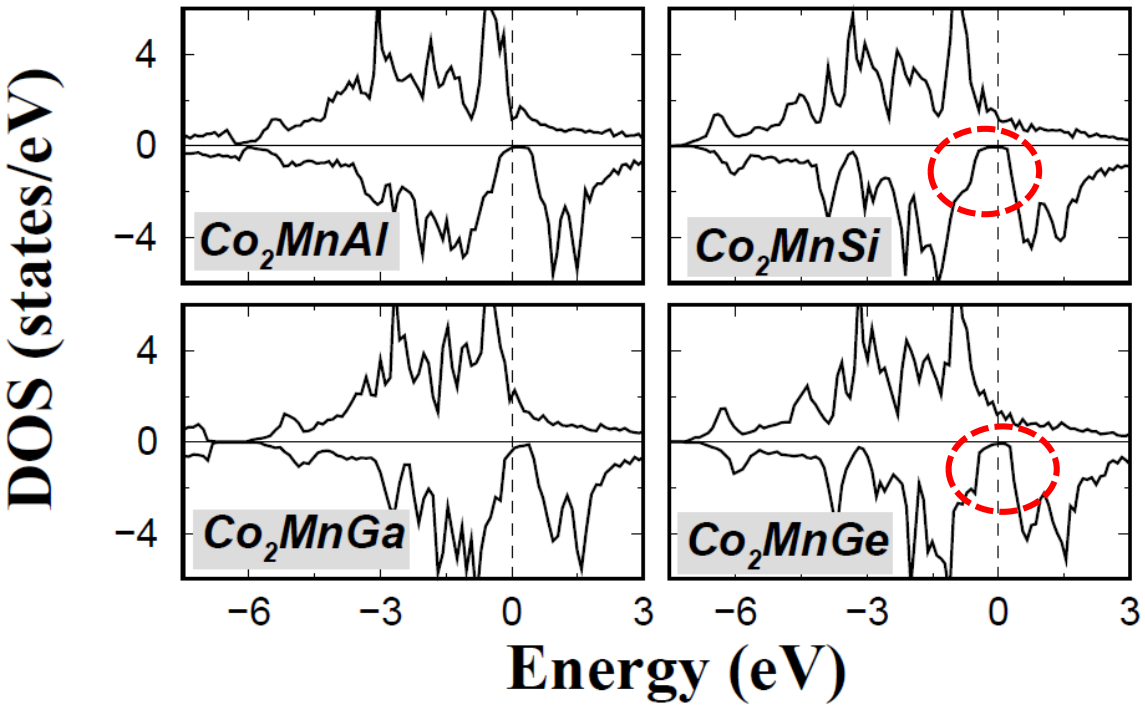
More first-principles calculations



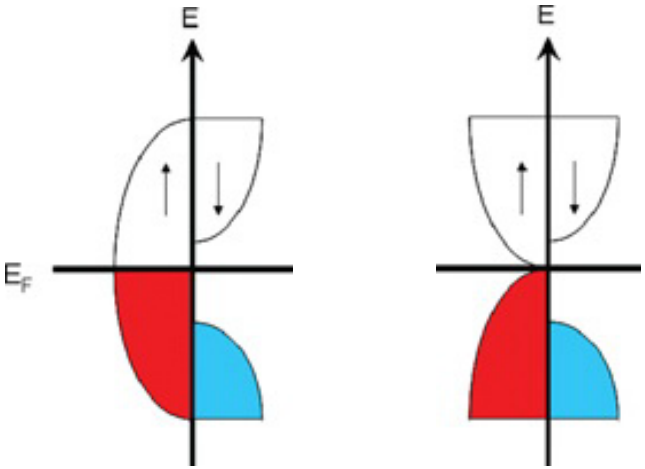
Spin-resolved DOS for Co_2MnZ

Review article: *J. Phys.: Condens. Matter* **19** 315213 (2007).

"First-principles calculation of the effects of partial alloy disorder on the static and dynamic magnetic properties of Co_2MnSi", Phys. Rev. B **95**, 094425 (2017).

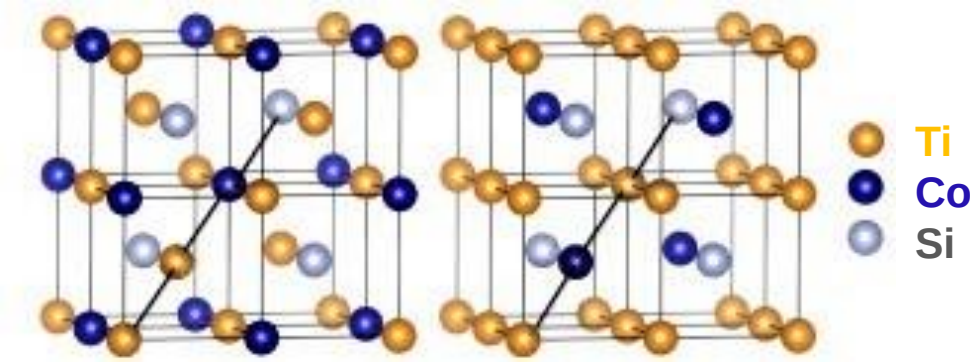
"Computational investigation of half-Heusler compounds for spintronics applications", Phys. Rev. B **95**, 024411 (2017).

Recent advances in the Heusler-based spin gapless semiconductors



HM SGS

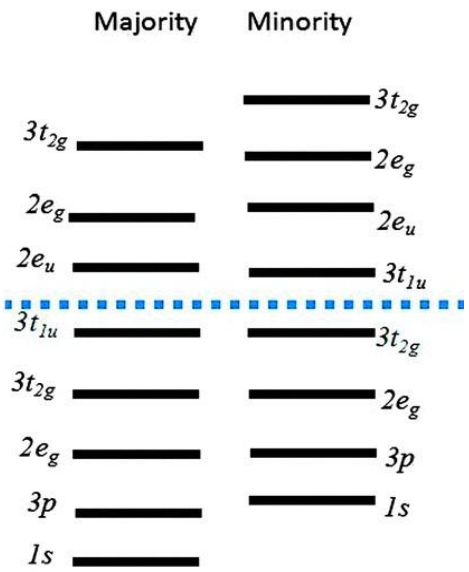
Ti_2CoSi



XA structure
$HgCu_2Ti$-type

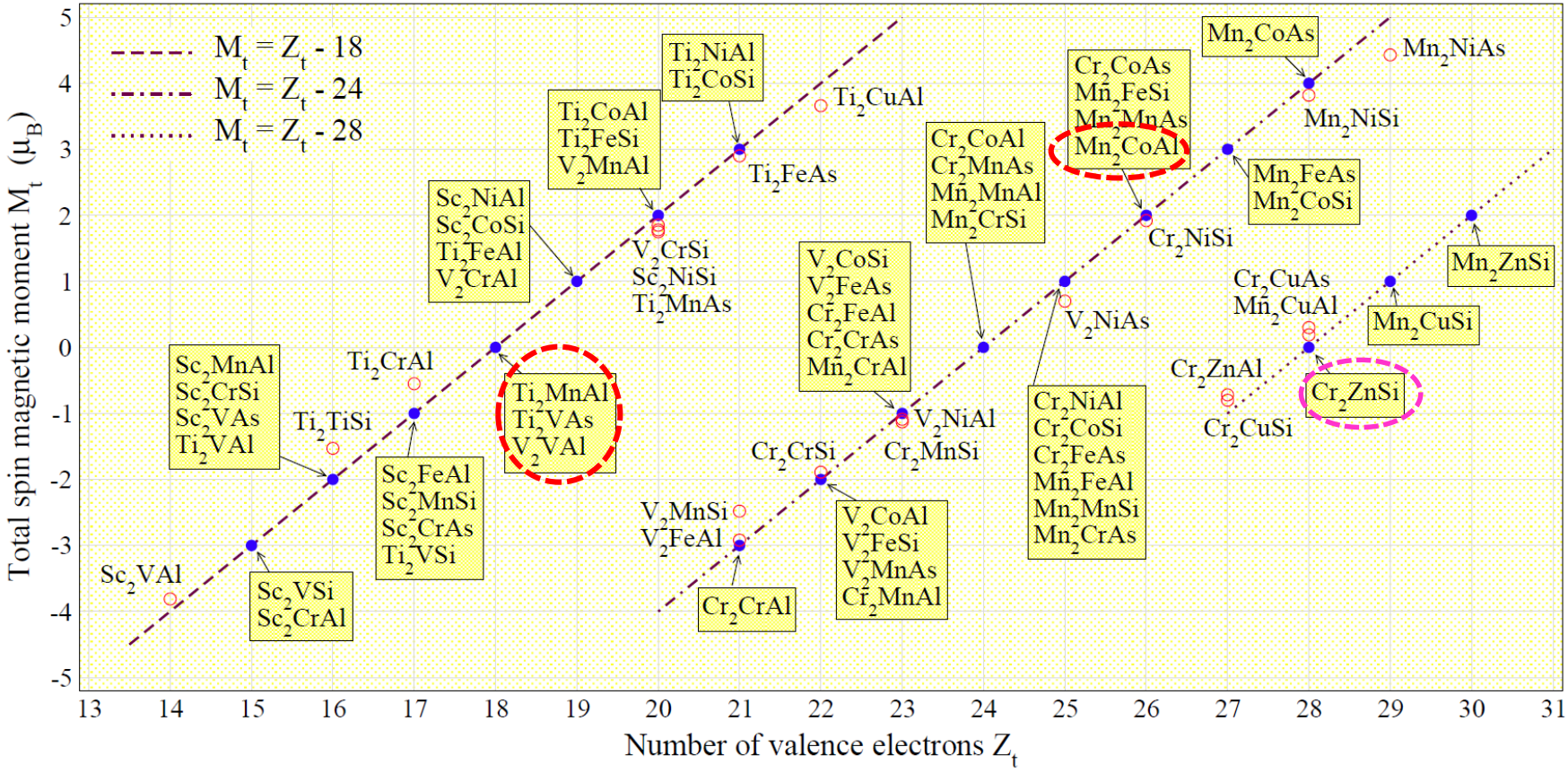
$L2_1$ structure
Cu_2MnAl-type

21-electrons

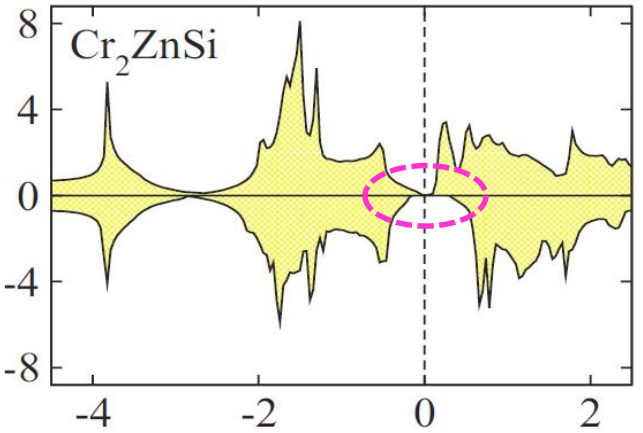


Inverse Heusler

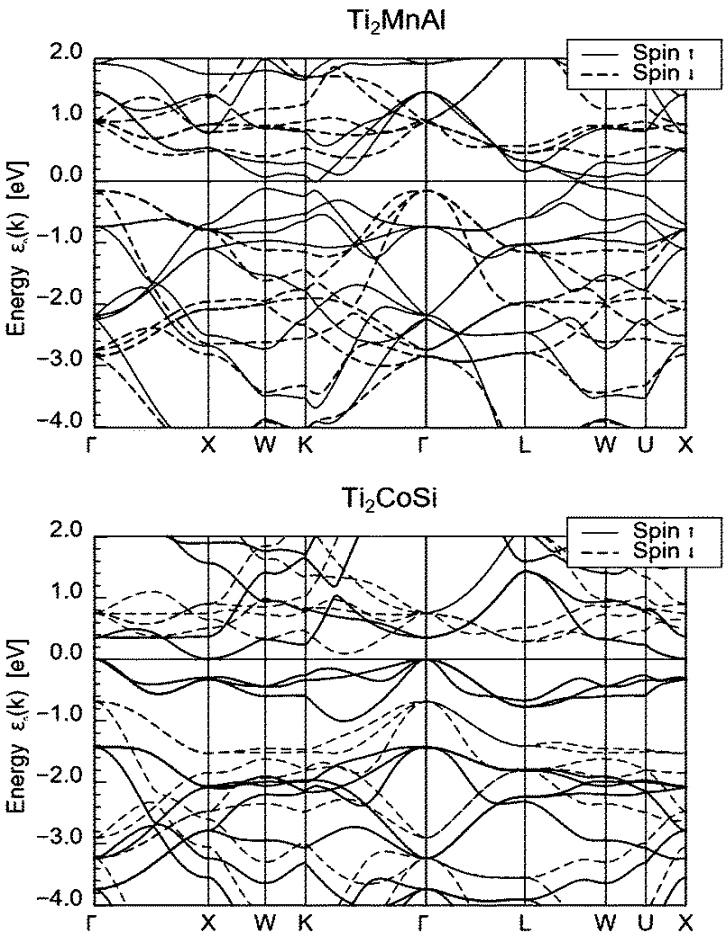
Generalized Slater-Pauling rule for inverse Heusler compounds



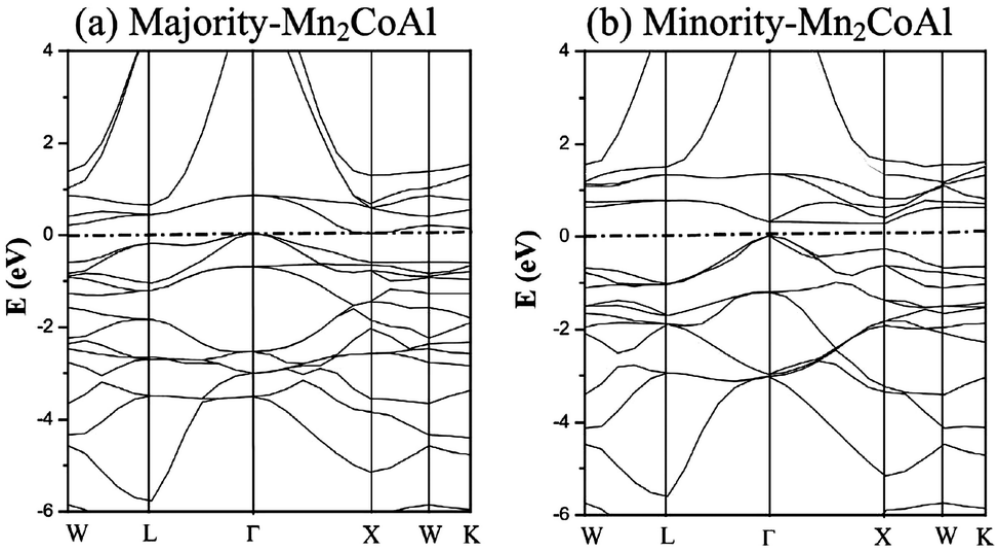
S. Skaftouros, K. Ozdogan, E. Sasioglu, I. Galanakis, *Phys. Rev.* B **87** 024420 (2013).



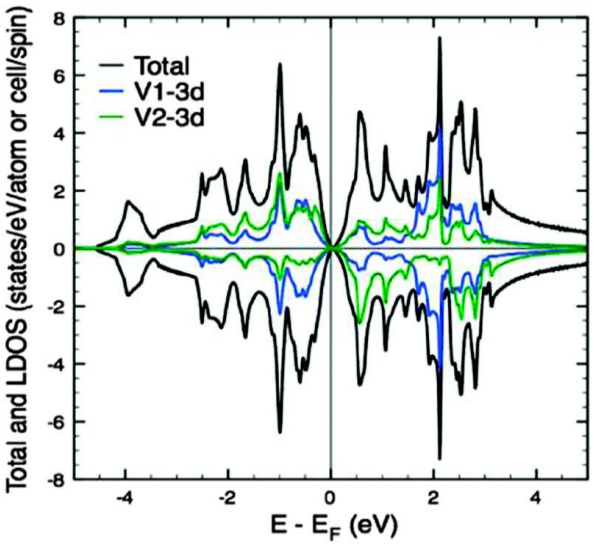
Possible SGSs: Theoretical studies



Appl. Phys. Lett. **102** 022402 (2013)



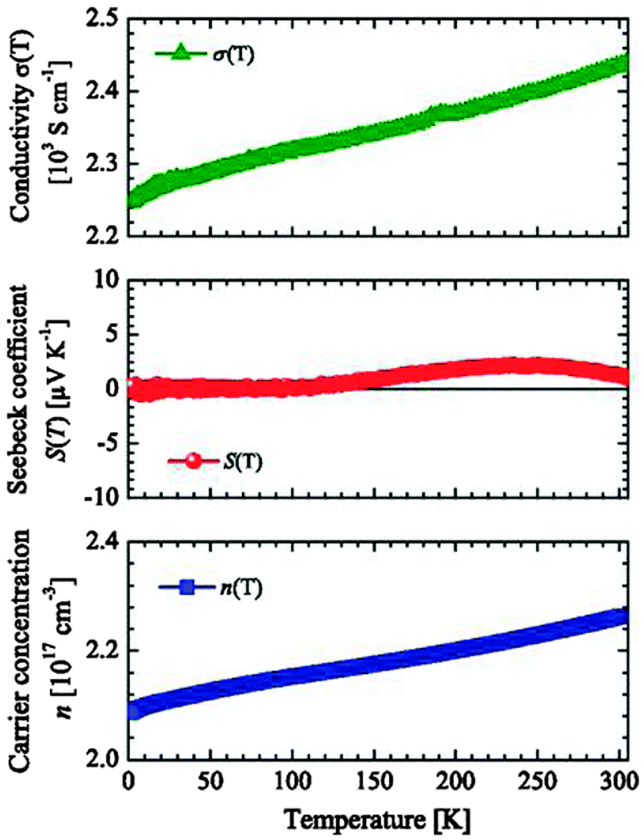
Phys. Rev. B **77** 014427 (2008)



Phys. Rev. B **91** 094409 (2015)

Possible SGSs: Experimental studies

Polycrystalline Mn_2CoAl



Phys. Rev, Lett. **110,** 100401 (2013)

Claudia Felser's group

Polycrystalline V_3Al

Phys. Rev. B **91** 094409 (2015)

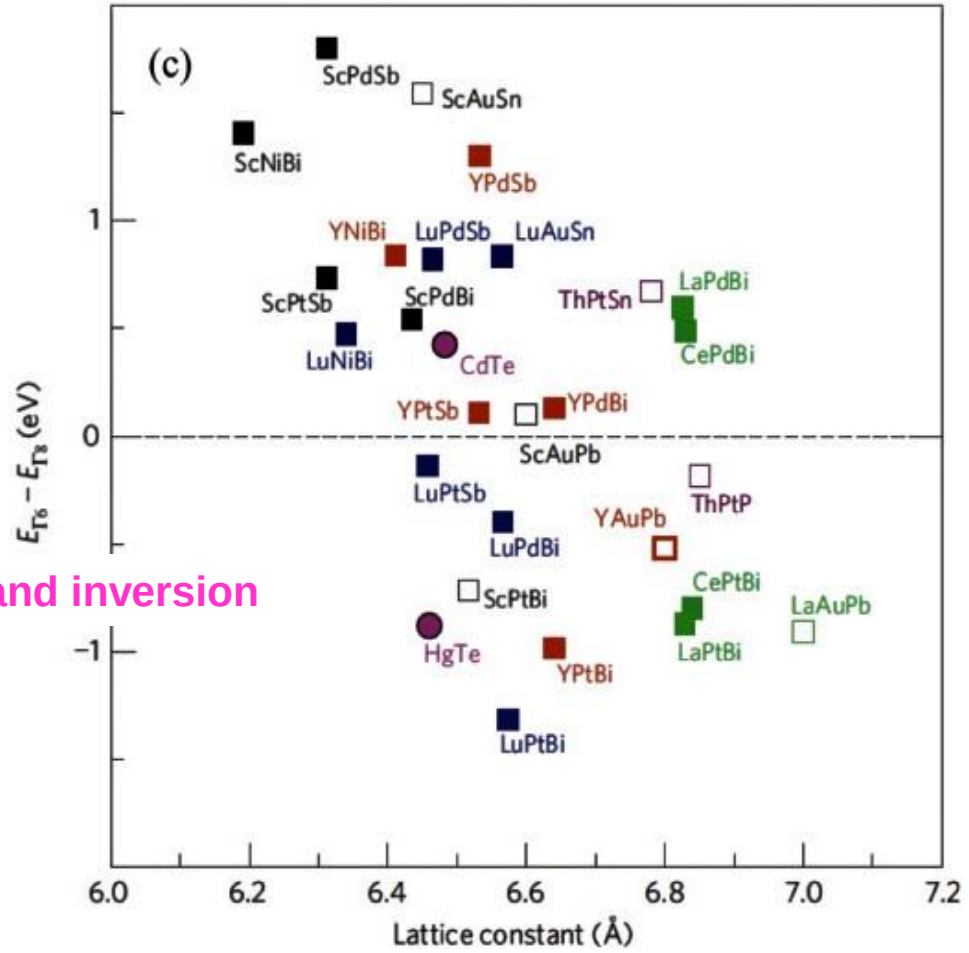
Polycrystalline CrVTiAl

Appl. Phys. Lett. **121** 053903 (2017)

Thin film Ti_2MnAl

Phys. Status Solidi RRL **9** 641 (2015)

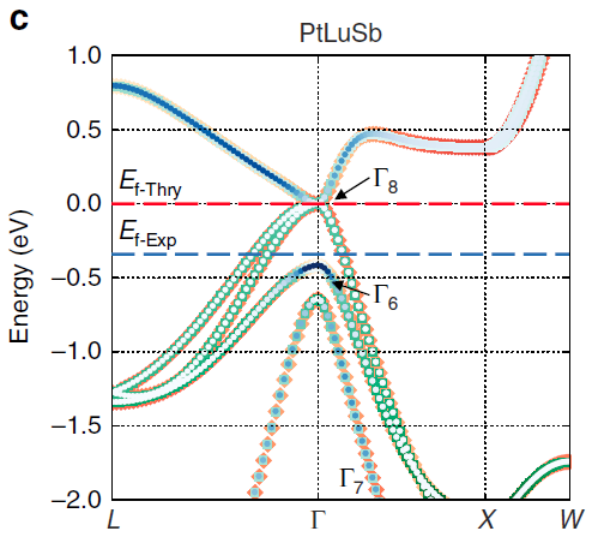
Topological materials in half-Heusler compounds



Band inversion

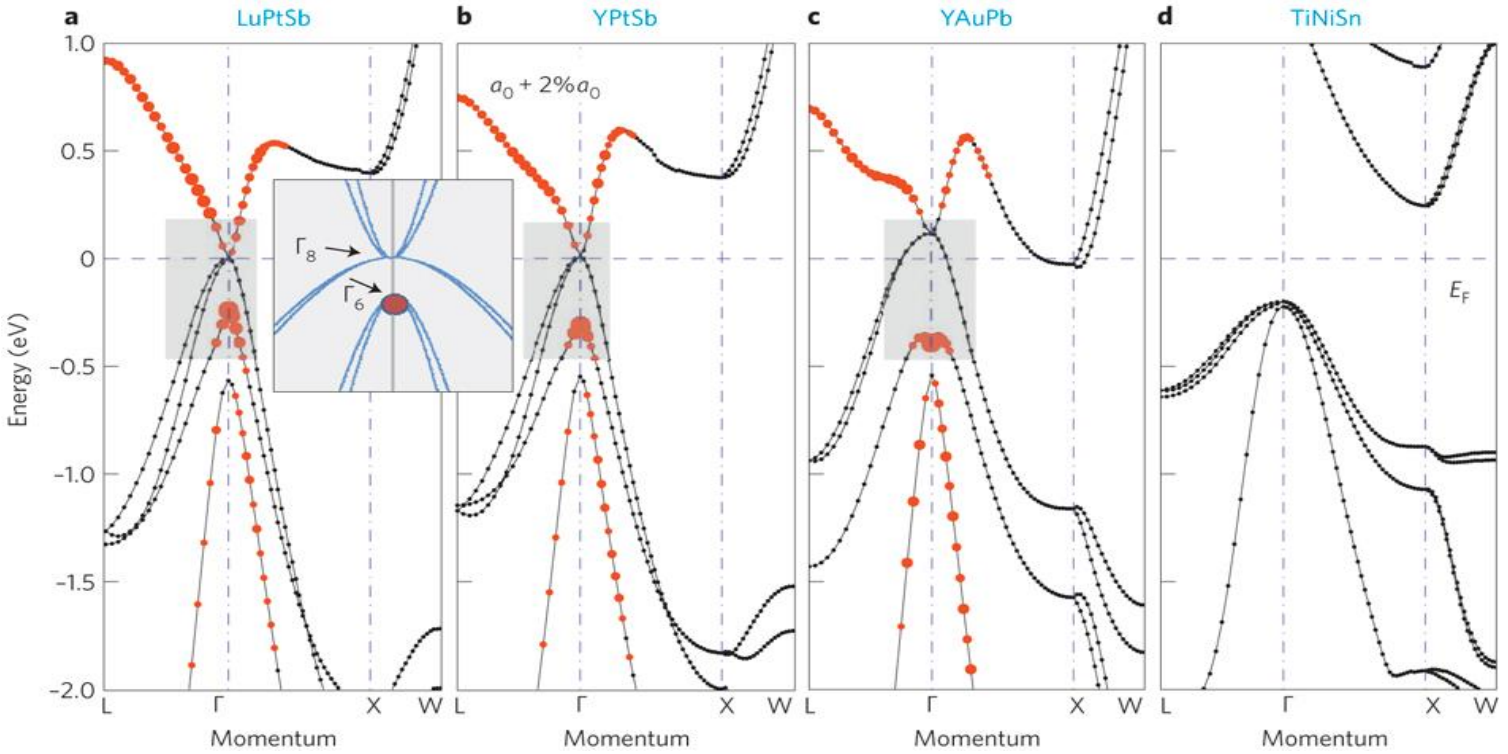
S. Chadov et al., *Nature Materials* **9,** 541 (2010)

Claudia Felser's group



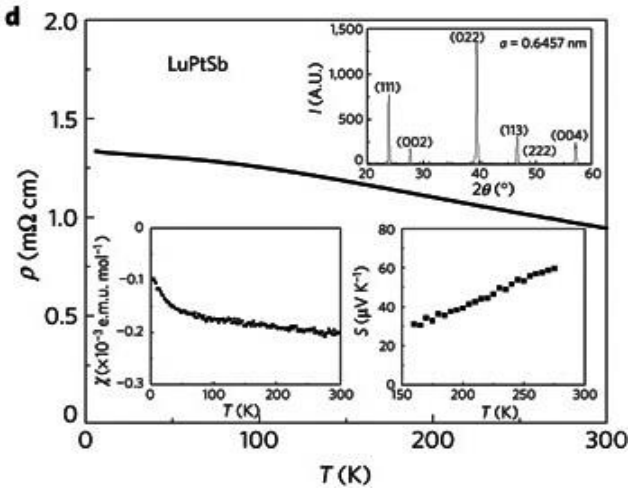
J. A. Logan et al., *Nature Communications* **9,** 11993 (2016)

Topological materials in half-Heusler compounds



Hsin Lin et al., *Nature Materials* **9,** 546 (2010)

Cava's group



Evidence for topological behavior in half-Heusler compounds

"Observation of a topologically non-trivial surface state in half-Heusler PtLuSb (001) thin films"
J. A. Logan et al., *Nature Communications* **9,** 11993 (2016)

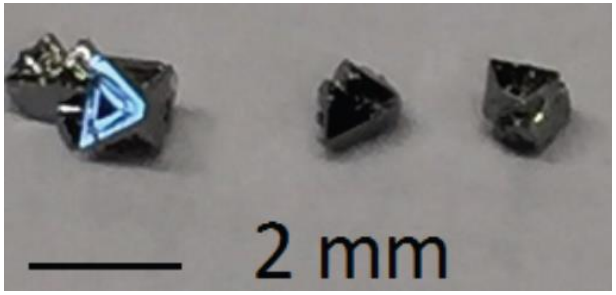
"Observation of unusual topological surface states in half-Heusler compounds LnPtBi (Ln=Lu, Y)"
Z. K. Liu et al., *Nature Communications* **7,** 12924 (2016)

"Large anomalous Hall effect in a half-Heusler antiferromagnet"
T. Suzuki et al., *Nature Physics* **12,** 1119 (2016)

Topological materials in full-Heusler compounds

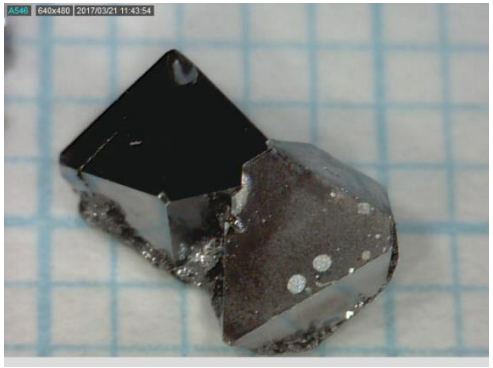
"Room-temperature magnetic topological Weyl fermion and nodal line semimetal states in **half metallic Heusler Co_2TiX (X=Si, Ge, or Sn)**"
Guoqing Chang et al., Scientific Reports 6, 38839 (2016).

"Time-reversal-breaking Weyl fermions in **magnetic Heusler alloys**"
Zhijun Wang et al., Phys. Rev. Lett. 17, 236401 (2016).



Single crystalline Co_2ZrSn

→ Cava's group



→ Our group

Summary

Theoretical people continue paying attention to Heusler compounds, focusing on their thermoelectric, half-metallic, and topological properties.

Experimental people continue synthesizing novel Heusler compounds and investigating their promising properties for further applications.

Thanks for your attention!