

Electronic, magnetic and structural properties of epitaxial Co_2MnZ Heusler compounds

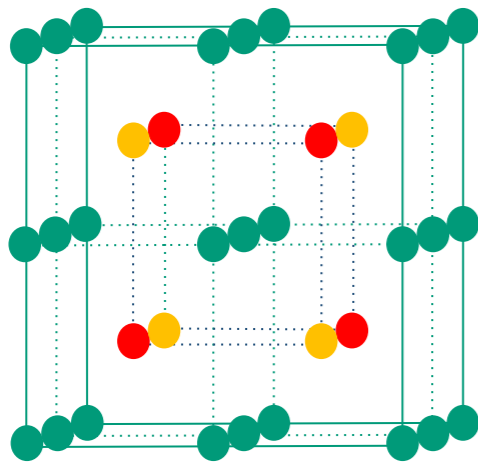
**C. Guillemard, S. Petit-watelot, F. Bertran, A. M. Bataille,
J.-C. Rojas-Sanchez, J. Ghanbaja, S. Andrieu**



Heusler compounds

Half-Metal Magnets (HMM)

F. Heusler, *Deutsche Physikalische Gesellschaft* **5**, p 219 (1903).

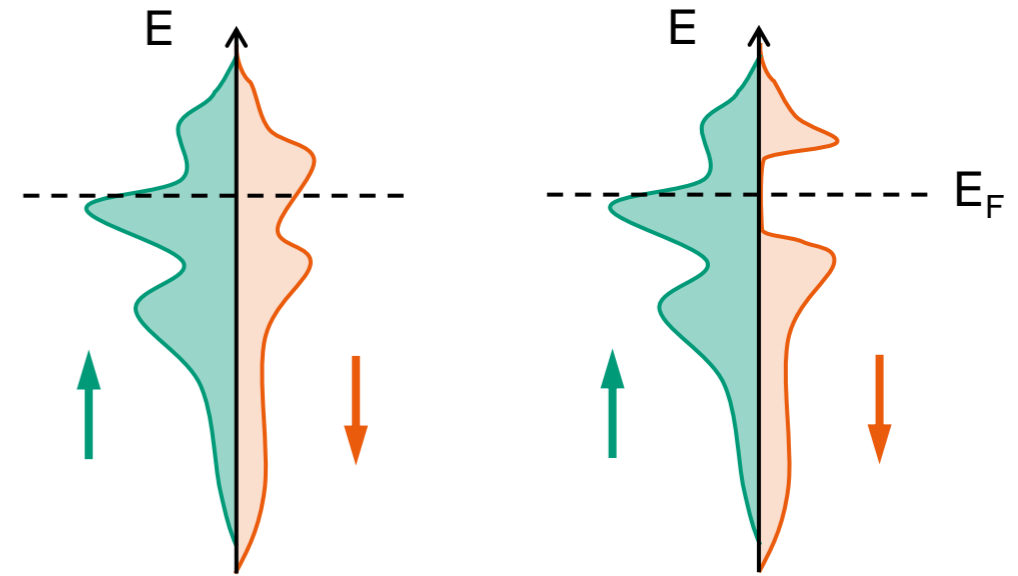


● X ● Y ● Z

Cu_2MnSn , W_2PdSb , Zr_2TiGe ...

R. A. De Groot *et al.*, *Phys. Rev. Lett.* **50**, 2024 (1983).

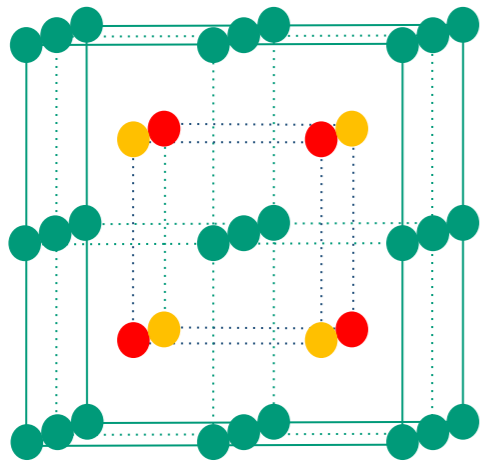
Some of them are predicted HMM



$$\frac{n_{\uparrow}(E_F) - n_{\downarrow}(E_F)}{n_{\uparrow}(E_F) + n_{\downarrow}(E_F)} = 1$$

Motivations

Why Co_2Mn -based compounds ?



● Co ● Mn ● Z

- High T_C (> 700 K)
- Lattice constants
- HMM (*ab initio* calc.)
I. Galanakis *et al.*, *Phys. Rev. B* **66**, 174429 (2002)
- Ultra low magnetic damping α (*ab initio* calc.)
B. Pradines *et al.*, *Phys. Rev. B* **95**, 094425 (2017)
- Experimentally confirmed in Co_2MnSi
M. Jourdan *et al.*, *Nature Comm.* **5**, 3974 (2014)
S. Andrieu *et al.*, *Phys. Rev. B* **93**, 094417 (2016)

Elaboration

Molecular Beam Epitaxy

Co-evap of each element (K-cells / e-guns)

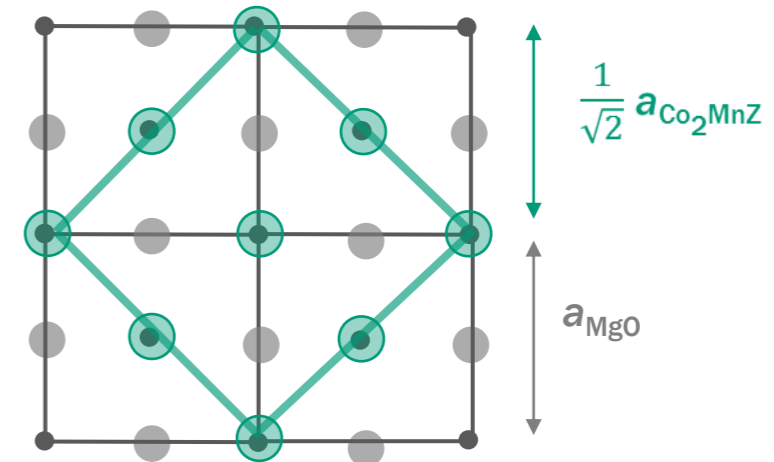


$\sim 20 \text{ nm}$

$T_{\text{growth}} \sim 450^\circ\text{C}$

- Misfits $< 5.4 \%$
- Coalescence of 3D islands (Volmer-Weber)
- $T_{\text{annealing}} \sim 800^\circ\text{C}$

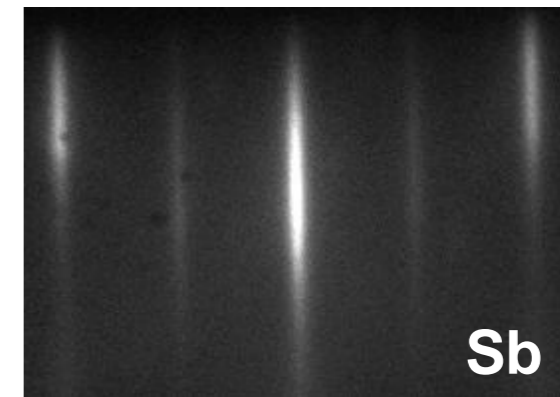
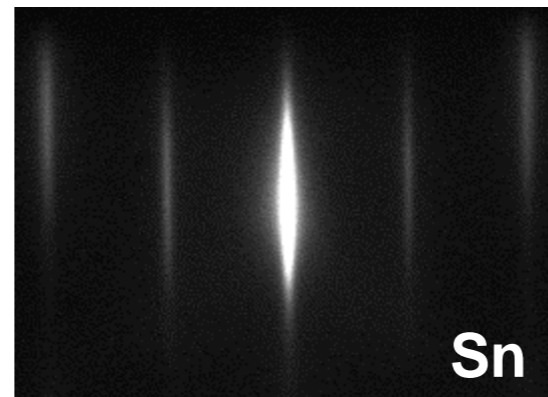
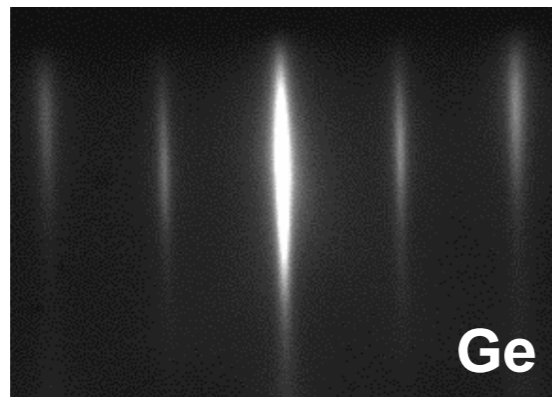
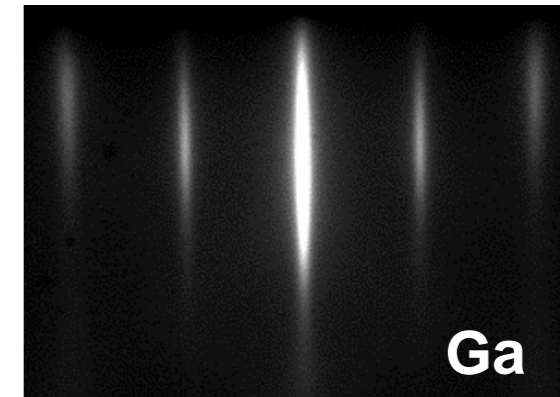
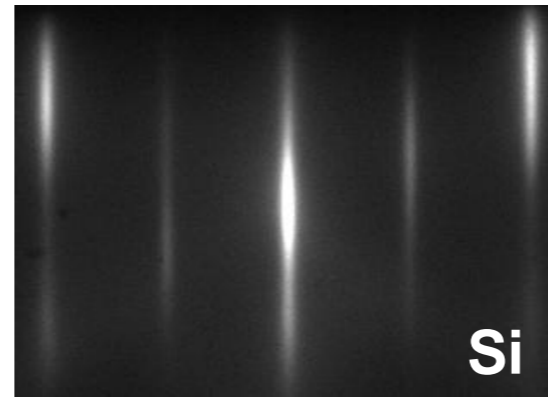
Epitaxial relationship:



$\text{Co}_2\text{MnZ} [100] (001) // \text{MgO} [110] (001)$

[110] RHEED patterns

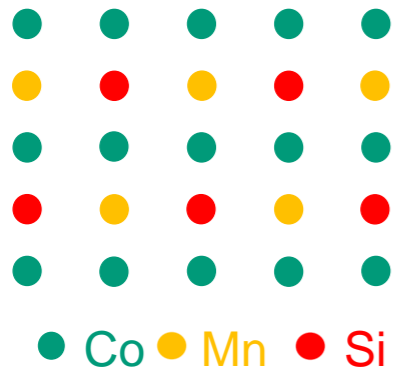
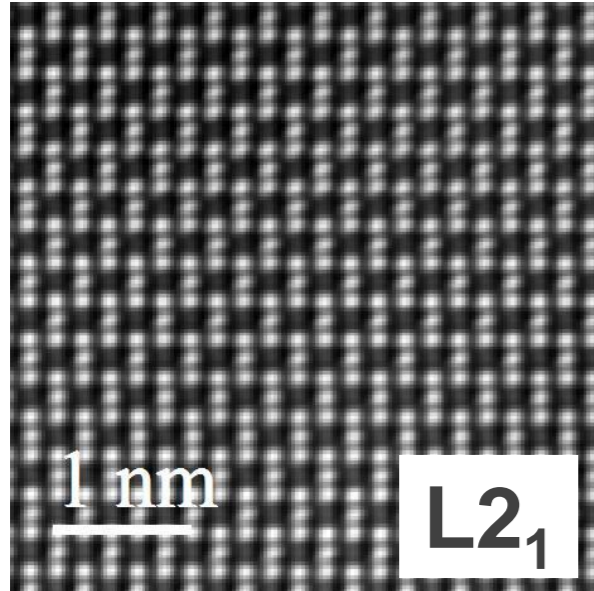
Co₂MnZ with Z=Al, Si, Ga, Ge, Sn, Sb



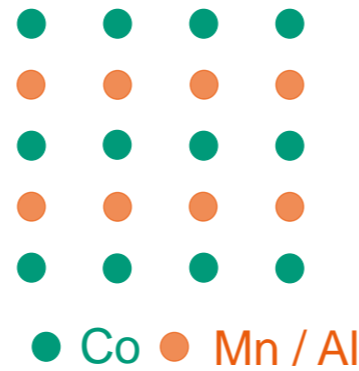
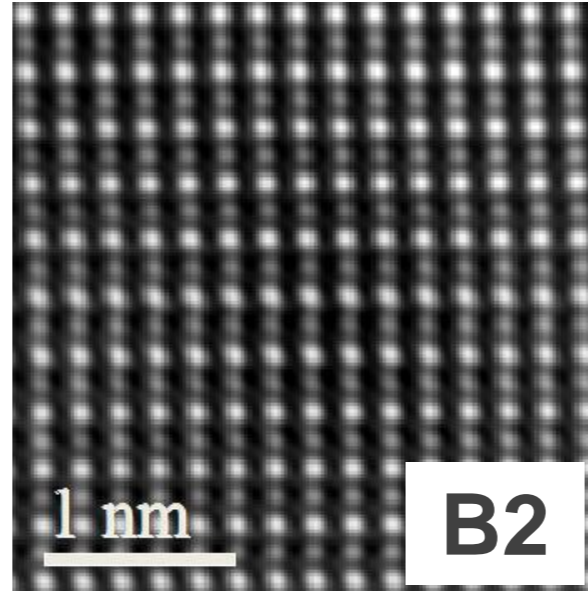
Excellent surface quality

STEM-HAADF

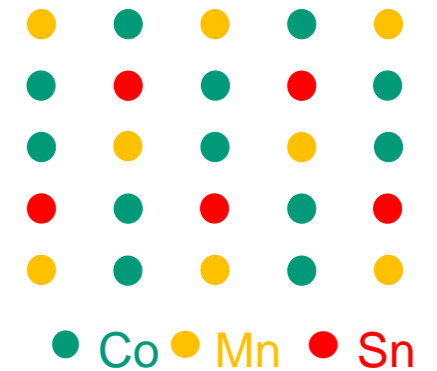
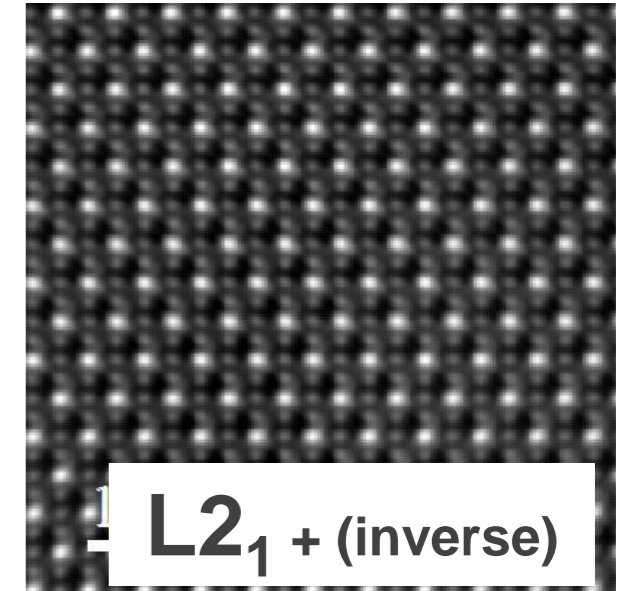
Co₂MnSi



Co₂MnAl



Co₂MnSn



Spin-Resolved PES

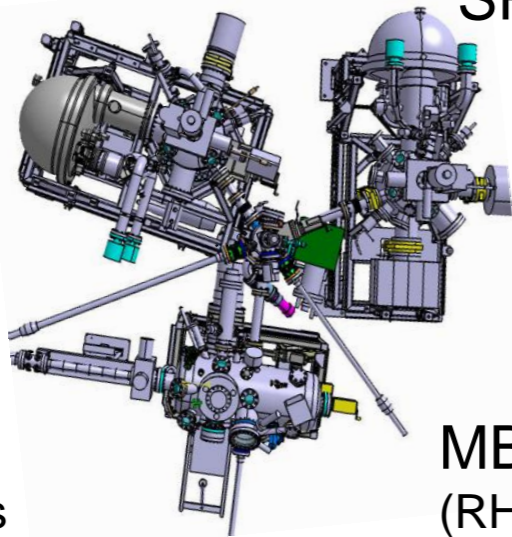
The Cassiopée Beamline



SOLEIL: 2,75 GeV storage ring, Saint Aubin, Fr.

SR-PES

AR-PES



2 e-guns (5 pockets)
4 effusion cells

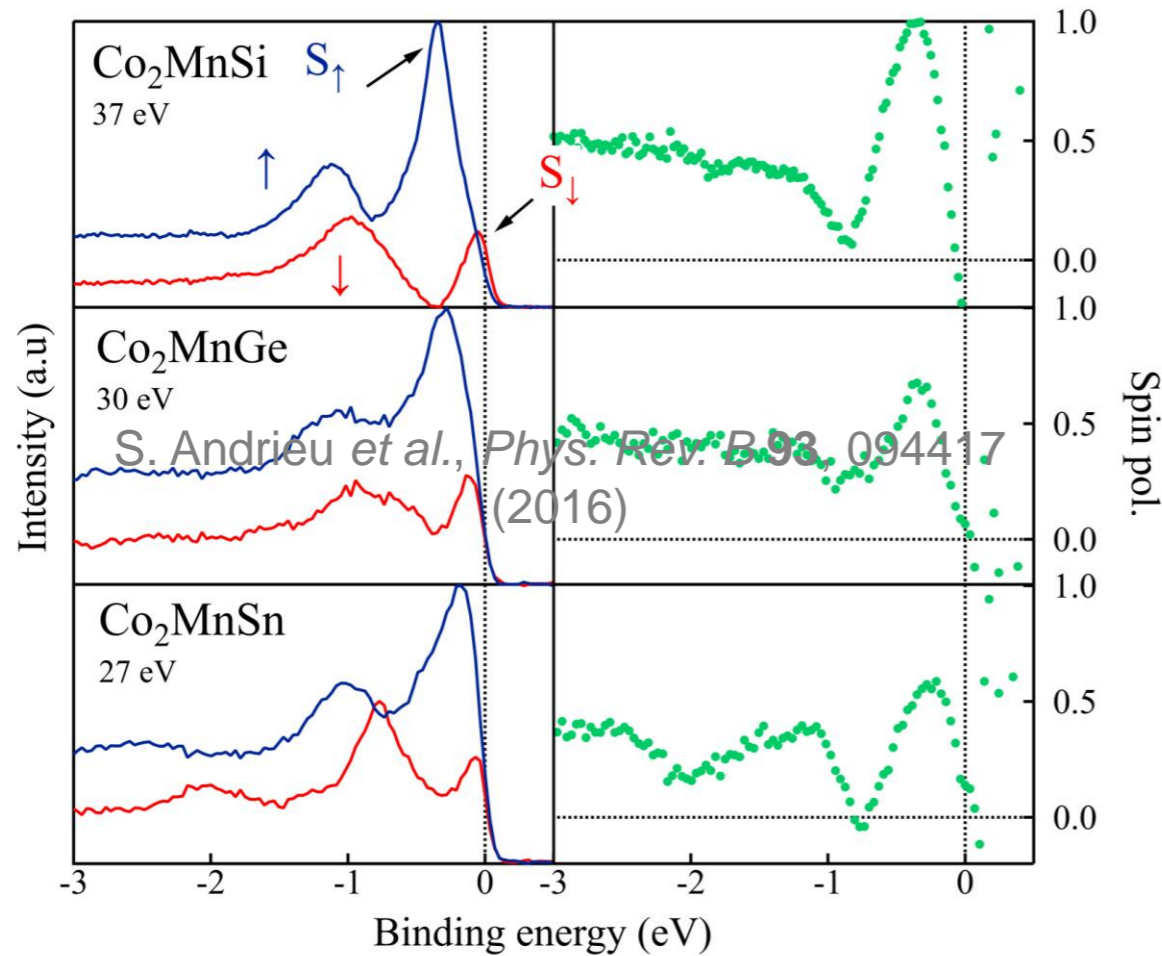
MBE
(RHEED, AES)

Mott detection SR-PES:

- ✓ Resolution ~ 120 meV (for $h\nu \sim 30$ eV)
- ✓ Integration over ~ 80 % of the BZ along Γ K (Σ)

Spin-Resolved PES

Co₂MnZ_{IV} with Z_{IV}=Si, Ge, Sn

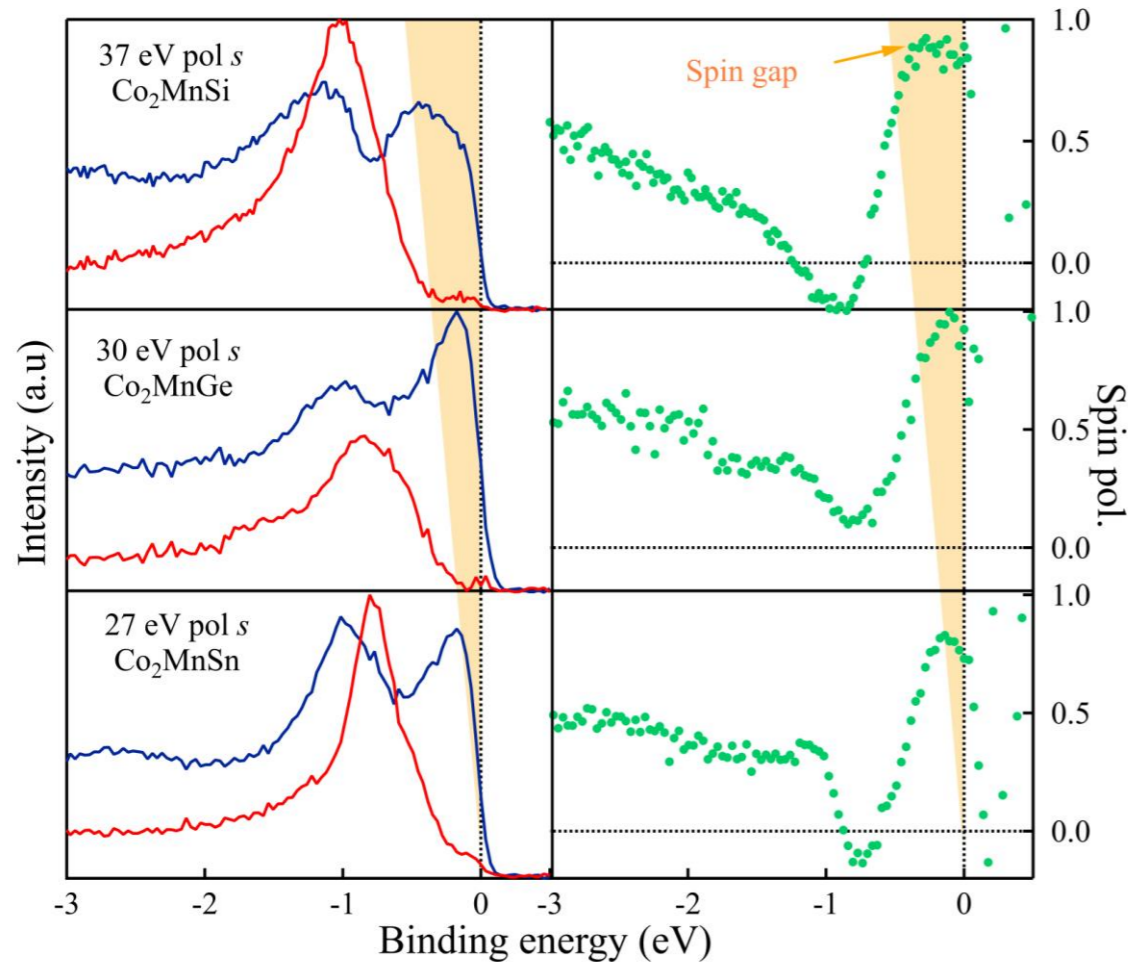


- Surface states $S_{\uparrow,\downarrow}$
 - Polarization drops at E_F
 - $S_{\uparrow,\downarrow}$: Δ_1 symmetry
- S. Andrieu *et al.*, *Phys. Rev. B* **93**, 094417 (2016)

← Photon polarization: "p"

Symmetry & Spin-Resolved PES

Co₂MnZ_{IV} with Z_{IV}=Si, Ge, Sn



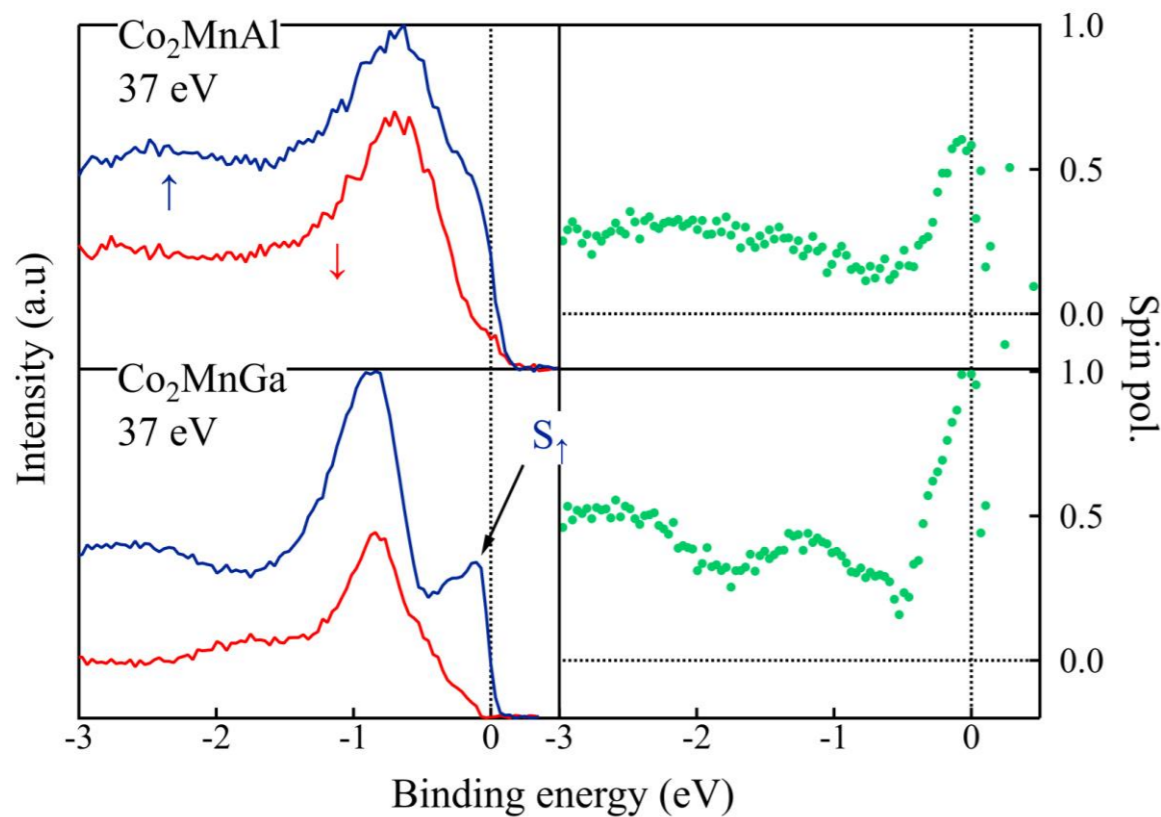
← Photon polarization: "s"

- $S_{\uparrow,\downarrow}$ no longer excited
- Spin gaps
- Δ_{Gap} decreases with a_{Co_2MnZ}

Consistent with *ab initio* calc.

Spin-Resolved PES

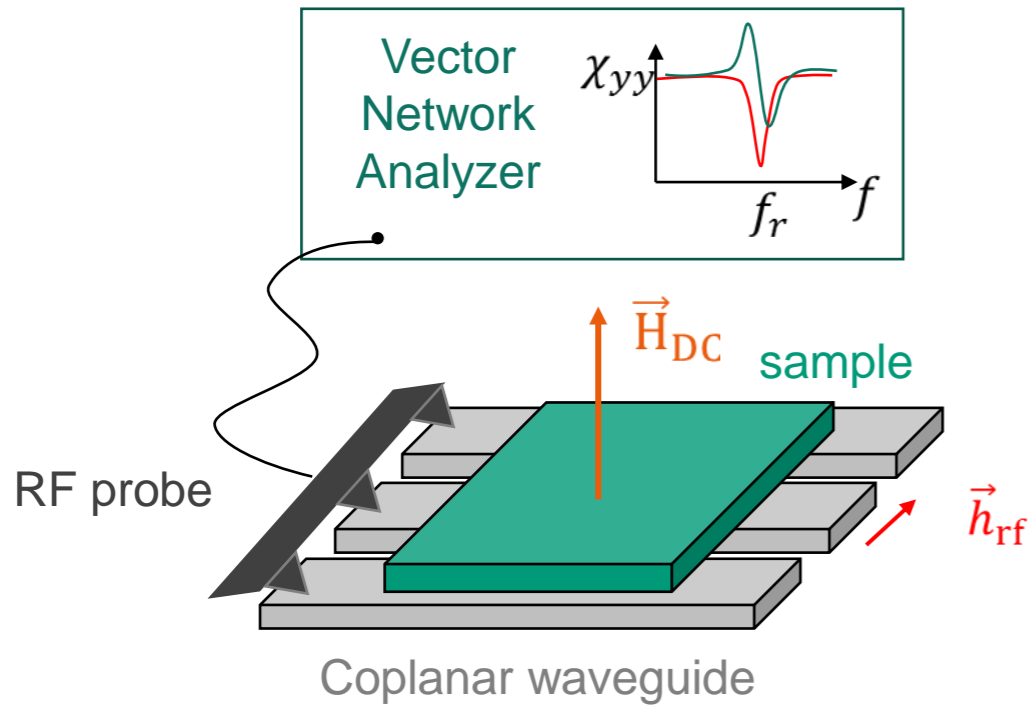
Co₂MnZ_{III} with Z_{III}=Al, Ga



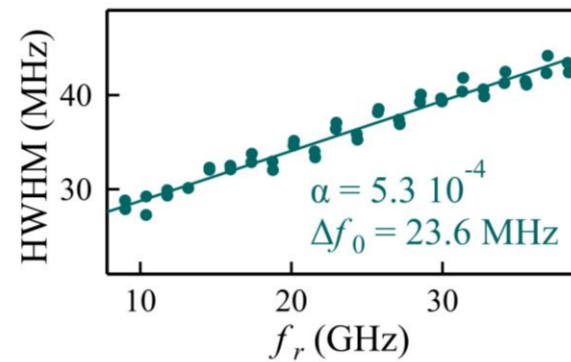
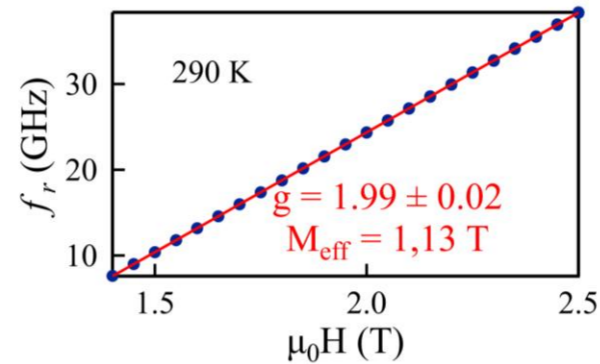
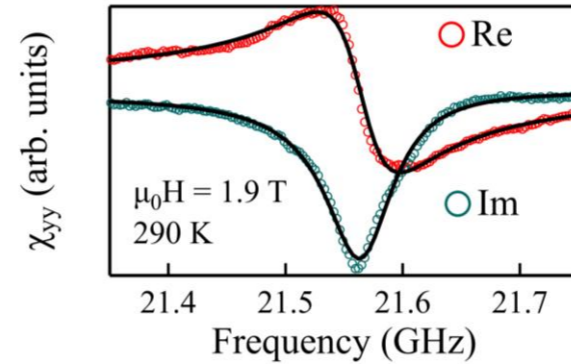
- E_F lowered in the band structure
- S_{↑,↓} in empty states
- Beginning of a spin gap

Consistent with *ab initio* calc.

⊥ VNA-FMR



- Kittel: $f_r = \gamma_0(H_{DC} - M_{eff})$
- Gilbert damping: $\Delta f = 2\alpha f_r + 2\Delta f_0$
- Effective values $\alpha = \alpha_{eff}$



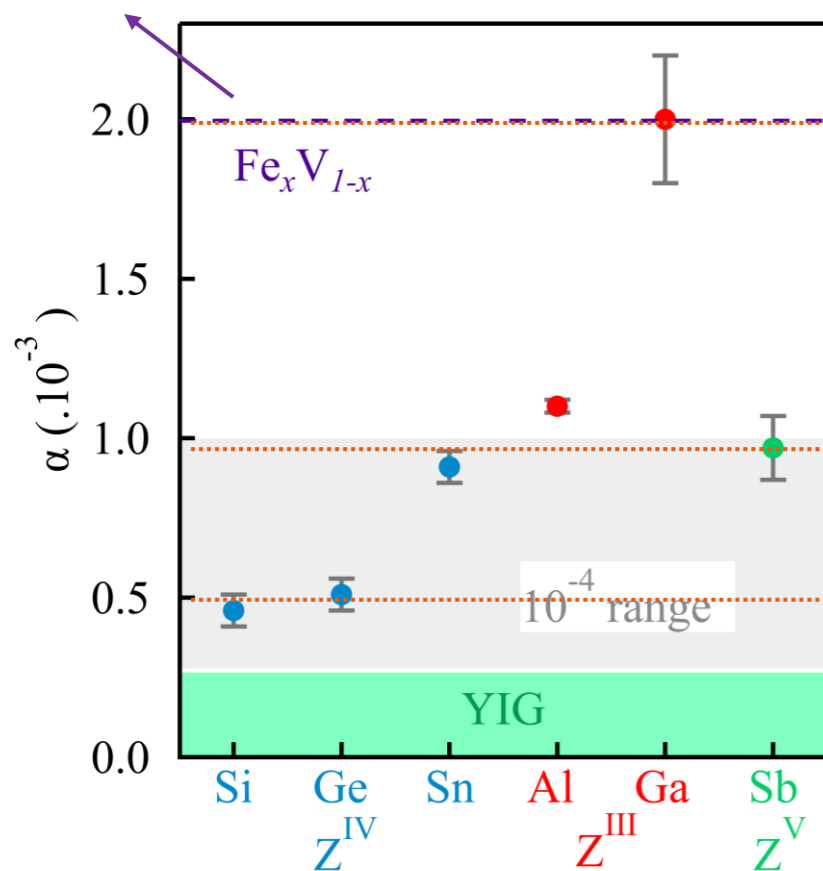
Co₂MnGe

- $\alpha = 5,3 \cdot 10^{-4}$
- $g = 1,99$
- $\Delta f_0 = 23,6$ MHz

⊥VNA-FMR

Ultra low damping values

T. Devolder et al., *Appl. Phys. Lett.* **103**, 242410 (2013)

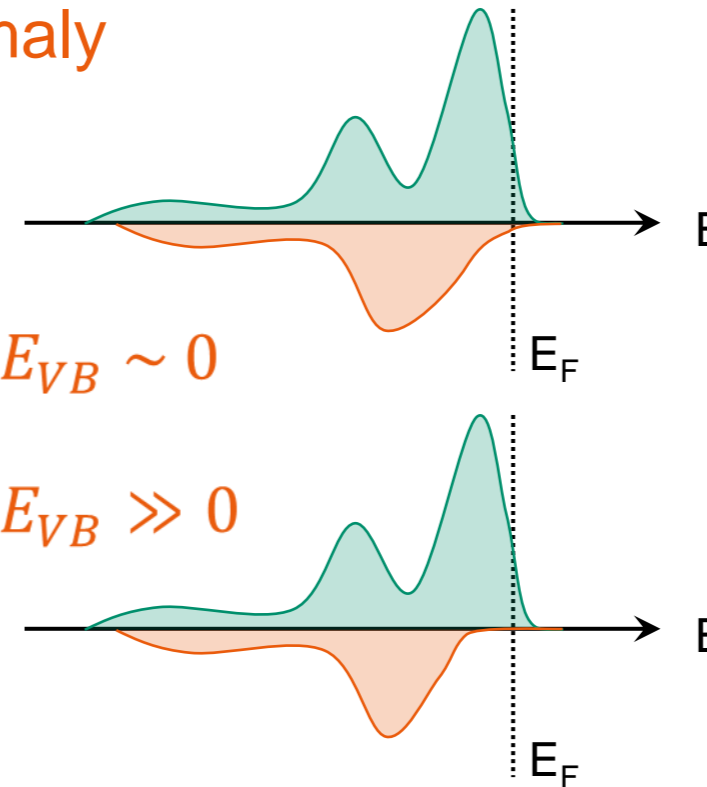


C. Guillemard et al., *Phys. Rev. Appl.* **11**, 064009 (2019)

Anomaly

$E_F - E_{VB} \sim 0$

$E_F - E_{VB} \gg 0$



Summary

- **Elaboration of 6 high quality epitaxial Heusler compounds**
- **Spin gaps & ultra low magnetic damping values confirmed**
- **Link between the Gilbert damping and the spin polarization**

Thank you & collaborators



S. Andrieu,
S. Mangin,
S. Petit-Watlot,
J.-L. Bello,
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L. Pasquier

F. Bertran,
P. Le Fèvre,
J. Rault

Organizers