Magnetism in Iron Implanted Oxides: A Status Report

H. P. Gunnlaugsson/R. Sielemann,

^{57}Mn Mössbauer collaboration at ISOLDE/CERN

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Motivation (Magnetism in TM doped oxides)

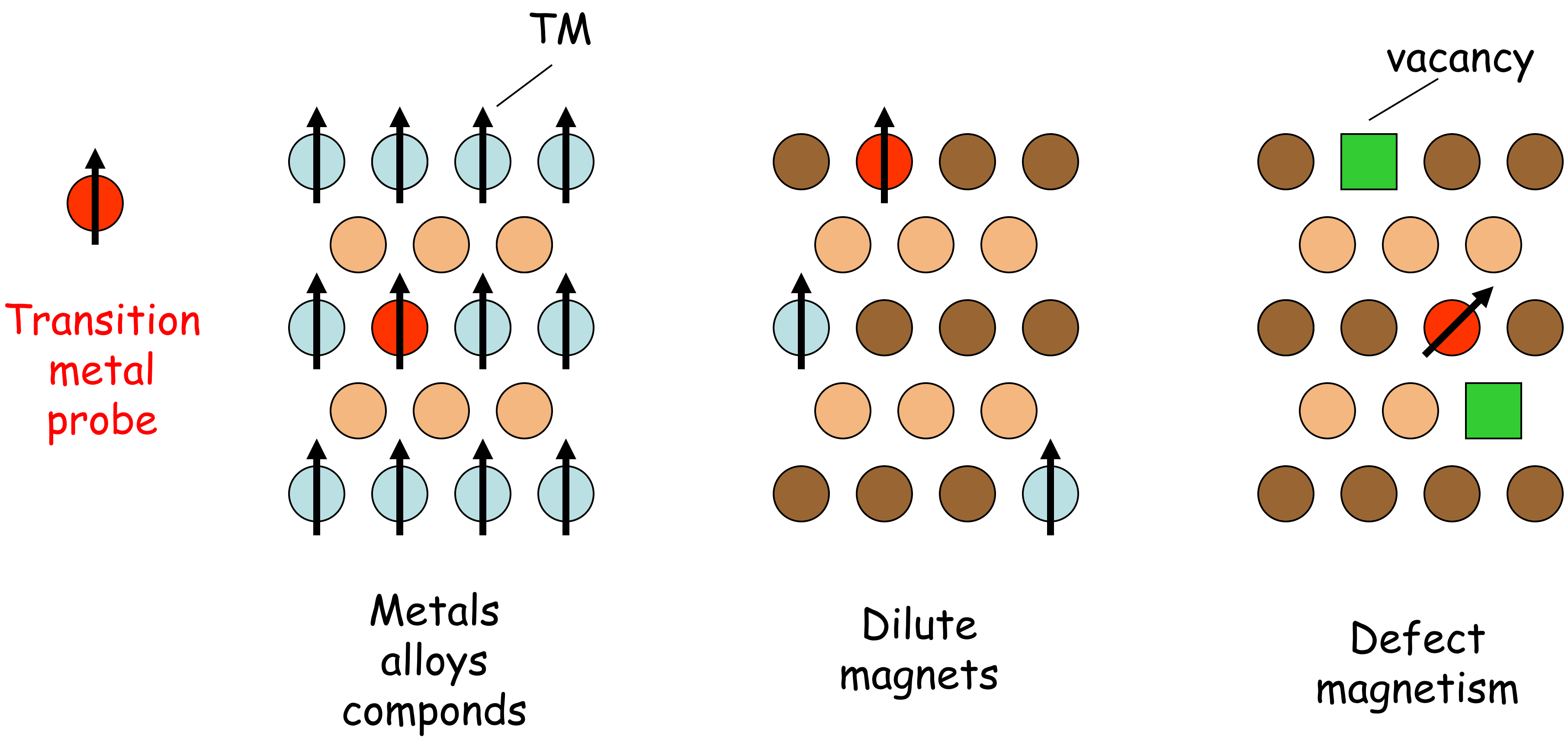
Physical/technical introduction (CERN Mössbauer)

Experimental spectra Mn/Fe in ZnO and others

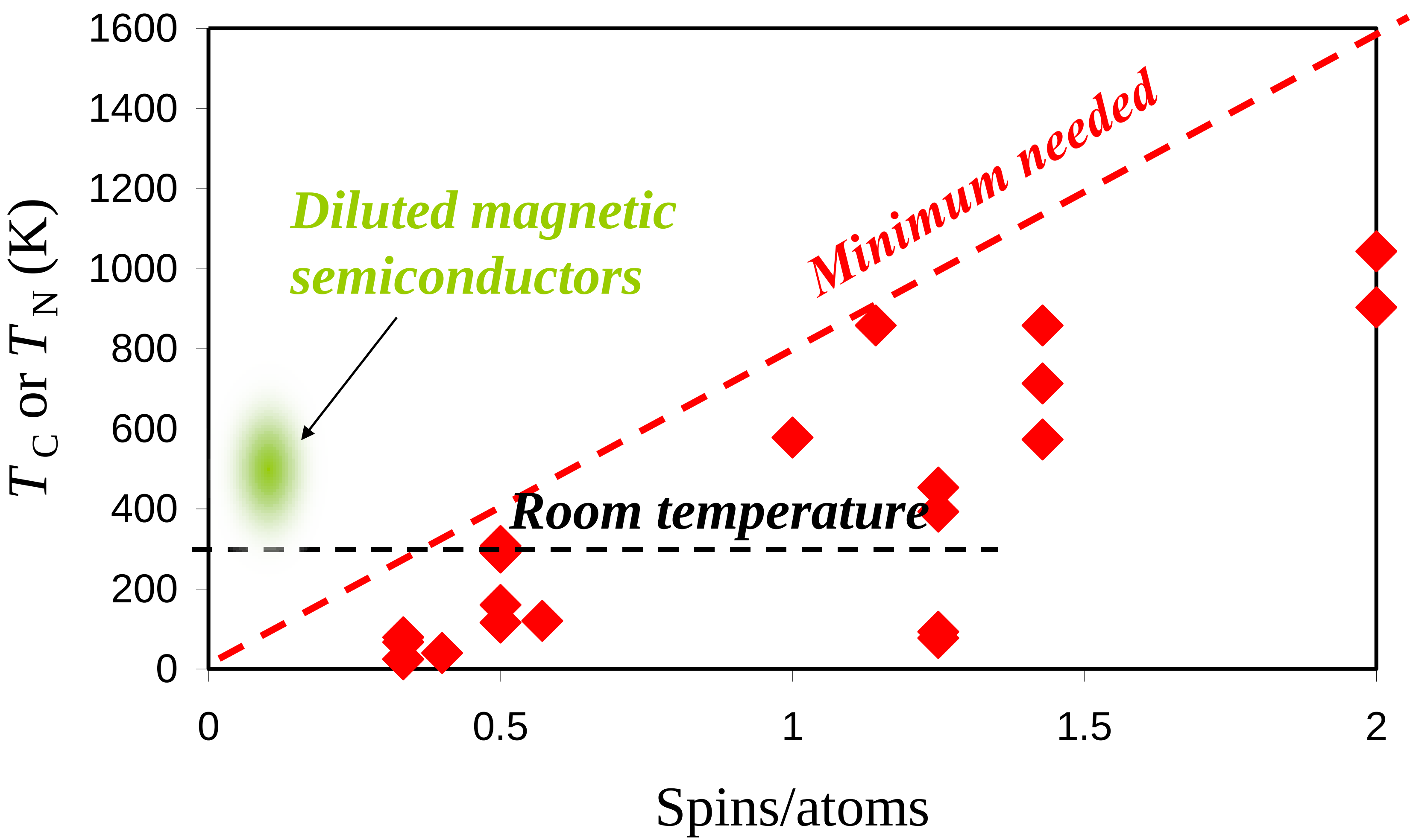
Ordered Magnetism versus Paramagnetism

Conclusion

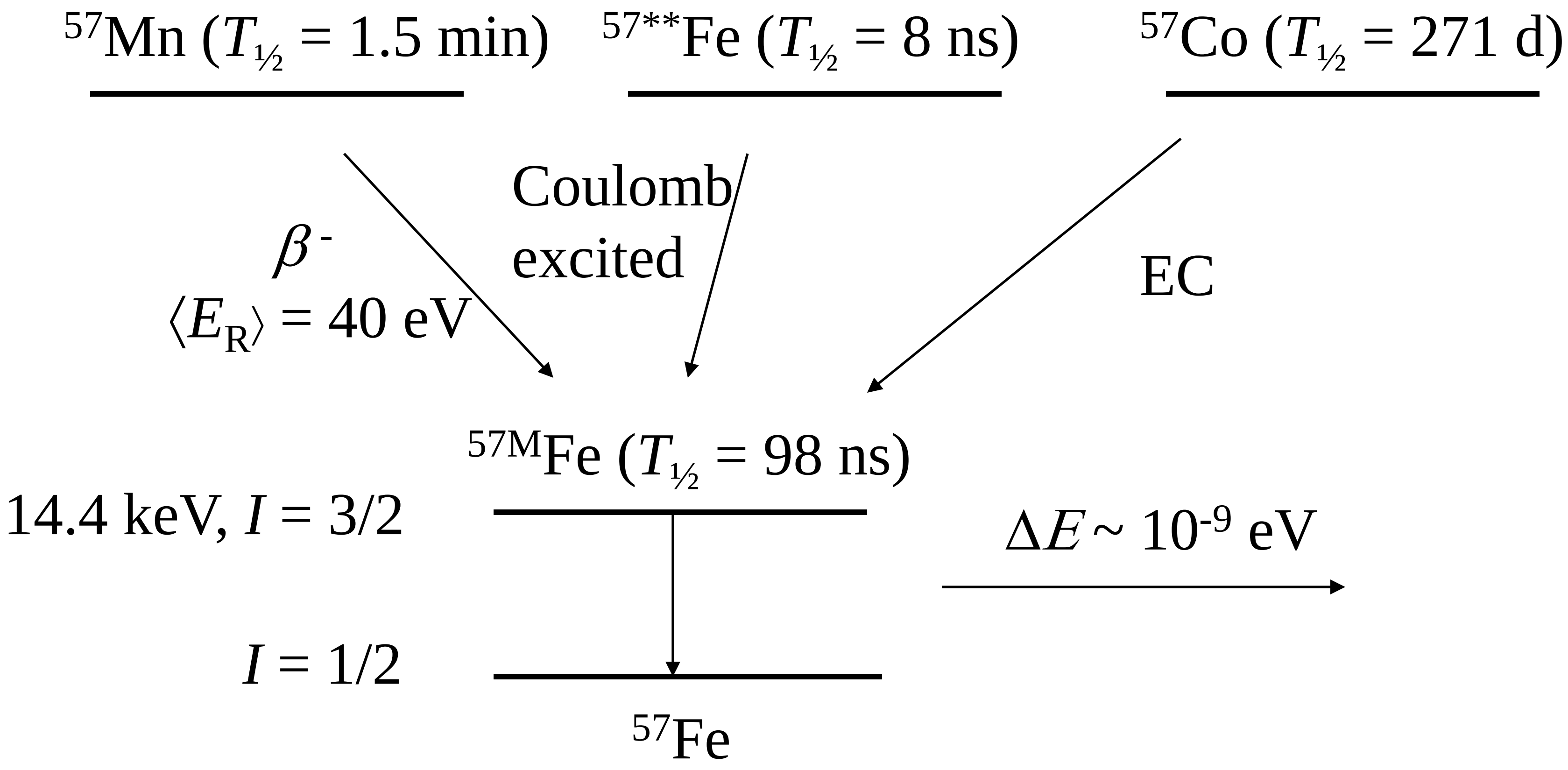
Magnetic inventory



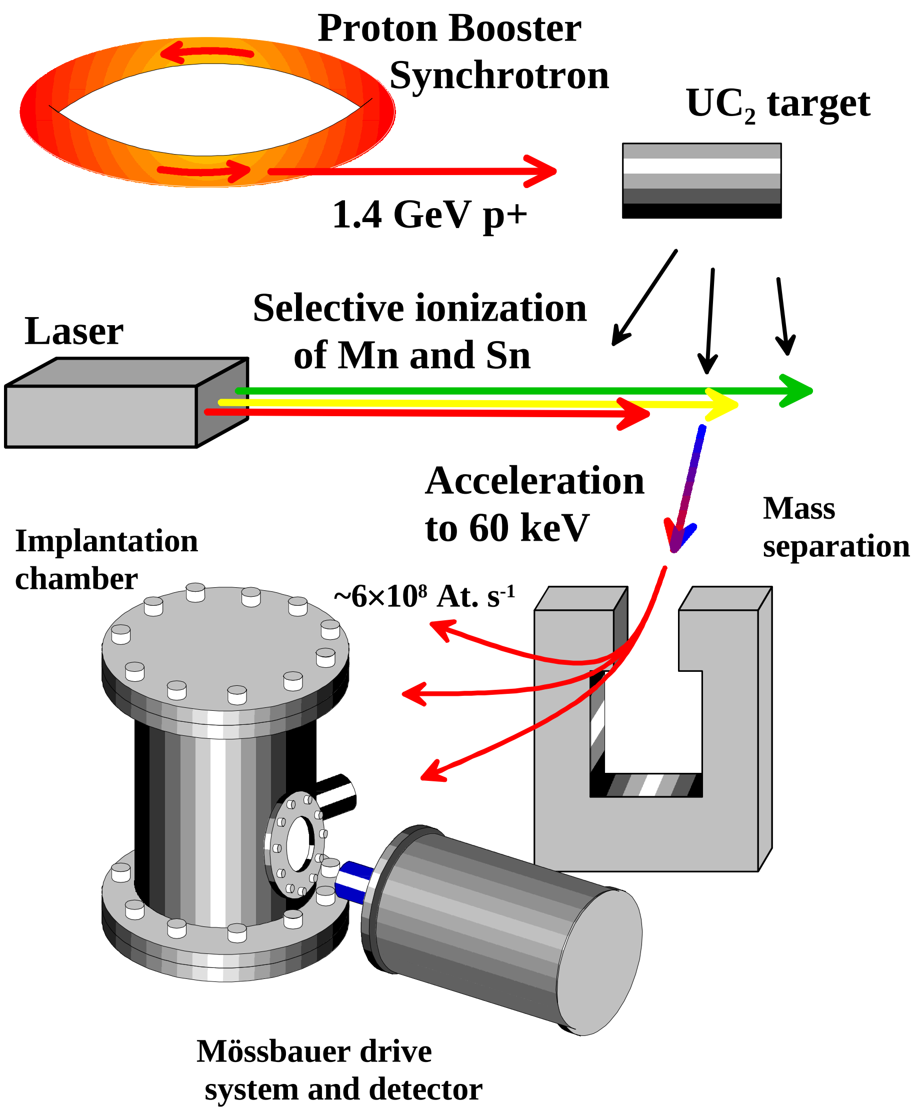
Ferromagnetism



^{57}Fe emission Mössbauer spectroscopy



Mössbauer spectroscopy at ISOLDE/CERN



<u>Highlights:</u>

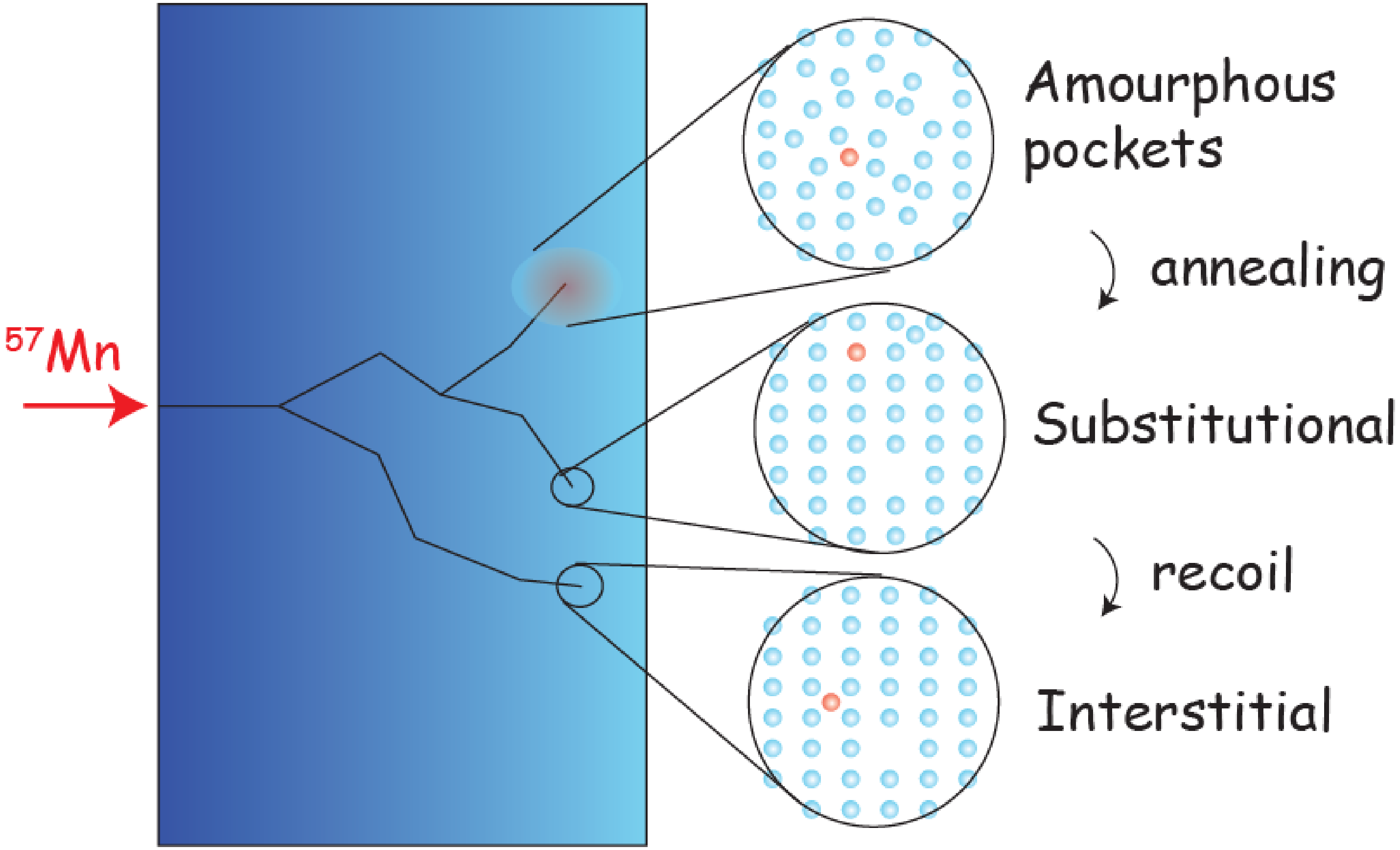
-Low concentrations of probe atoms (~10^{-4} At.%)

-Valence state of Fe

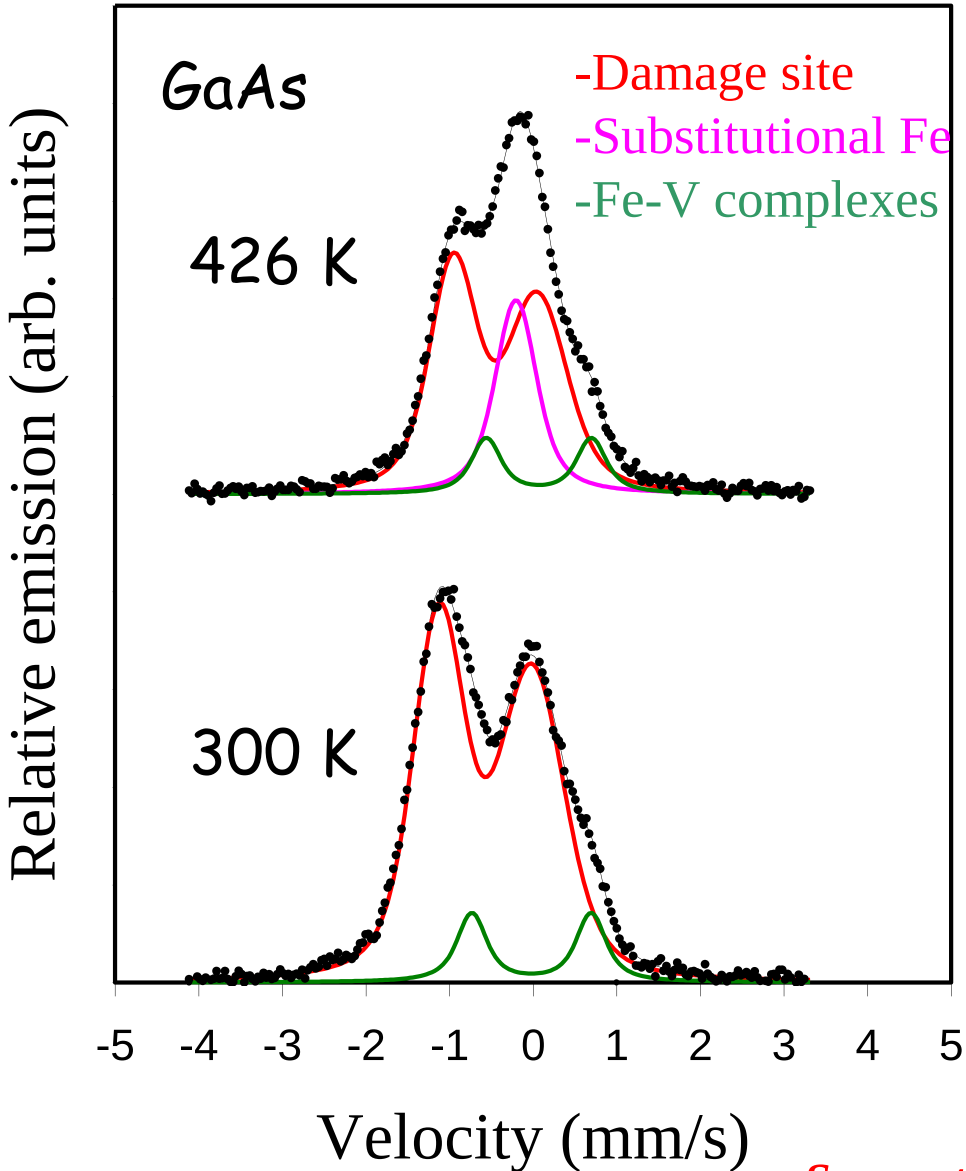
-Site symmetry

-Magnetic interactions

Implantation of ^{57}Mn



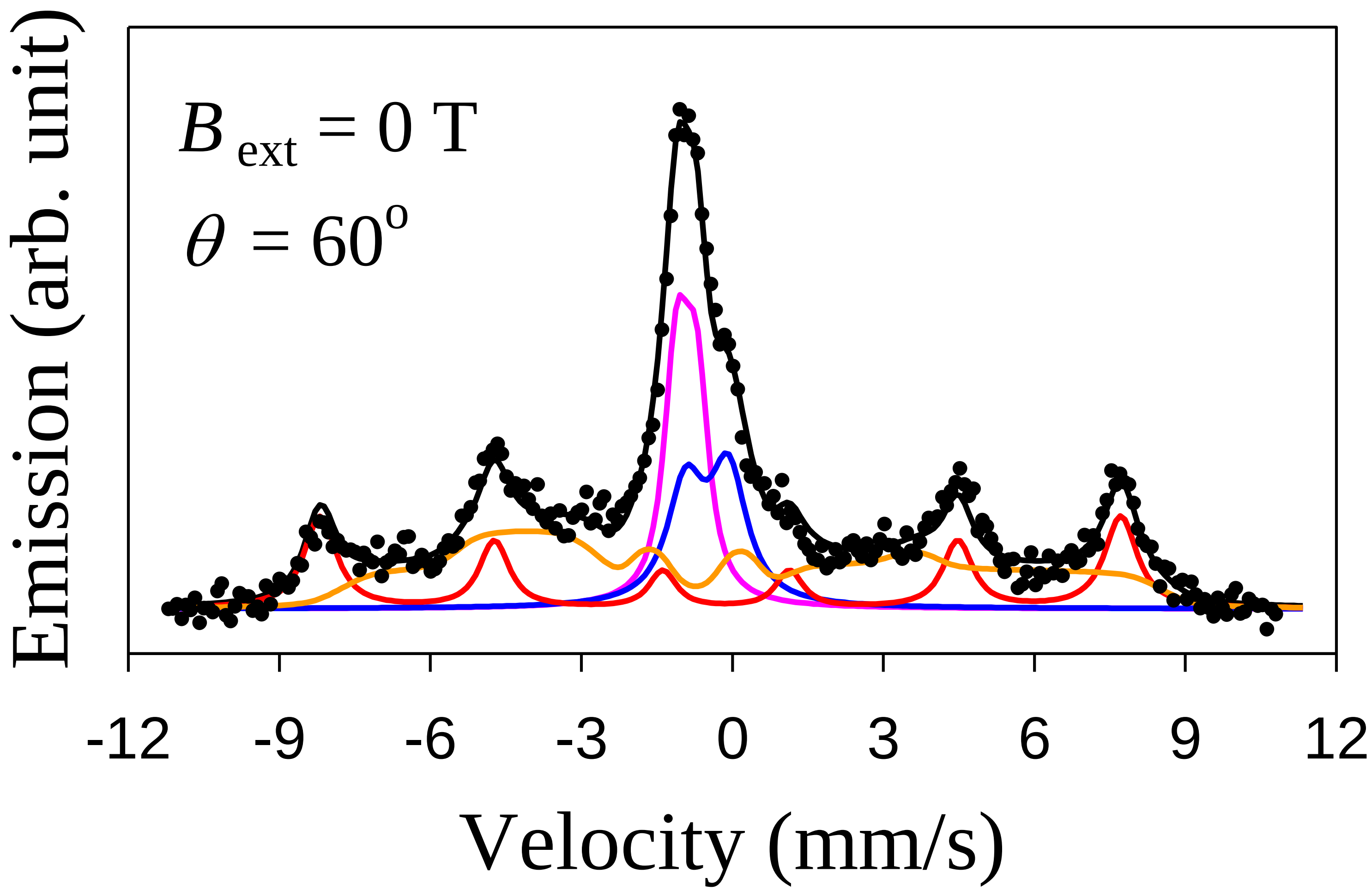
III-V semiconductors



No 6-line magnetic pattern!

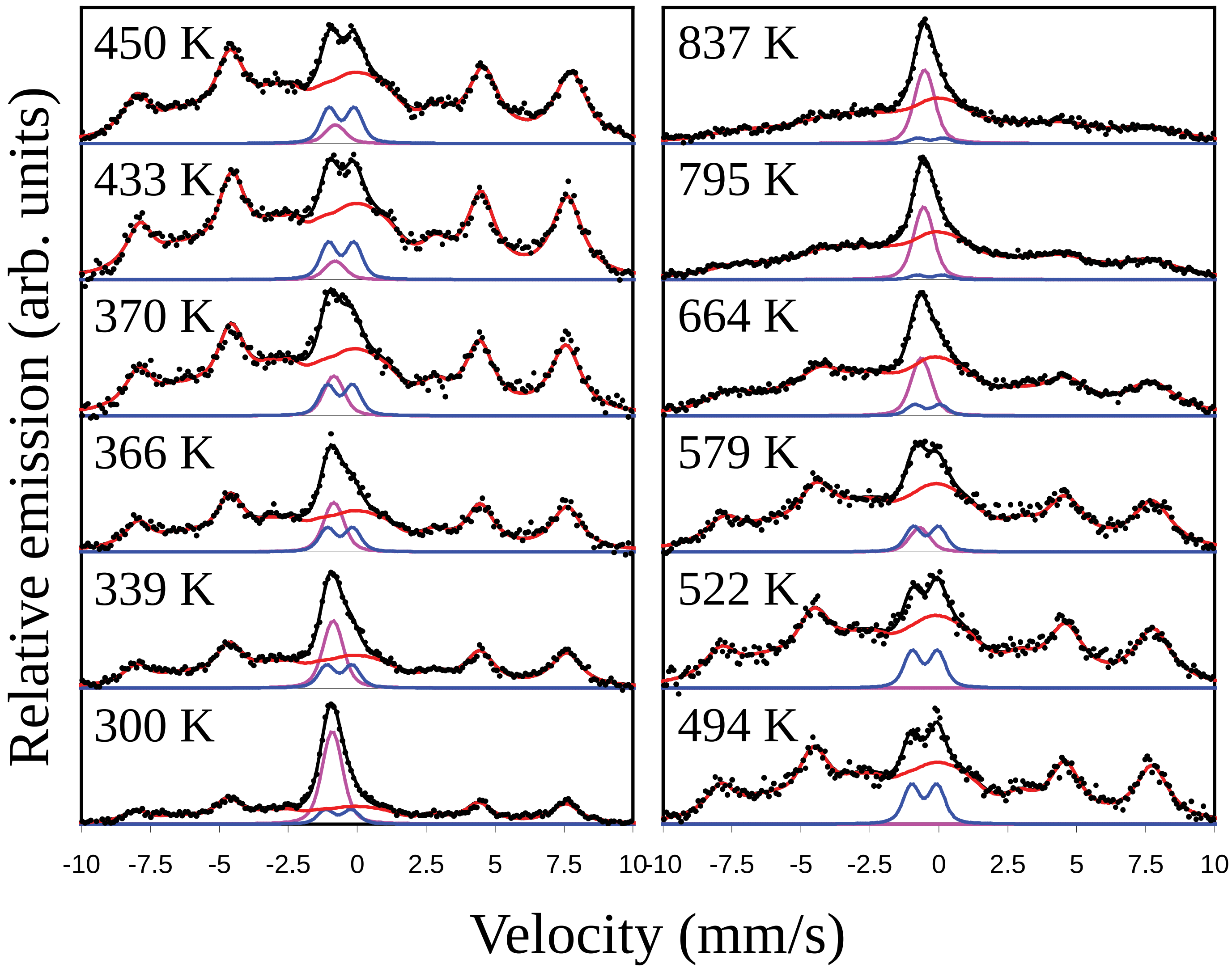
See poster presented by Hilary Masenda (PS3-24)

ZnO without external magnetic field



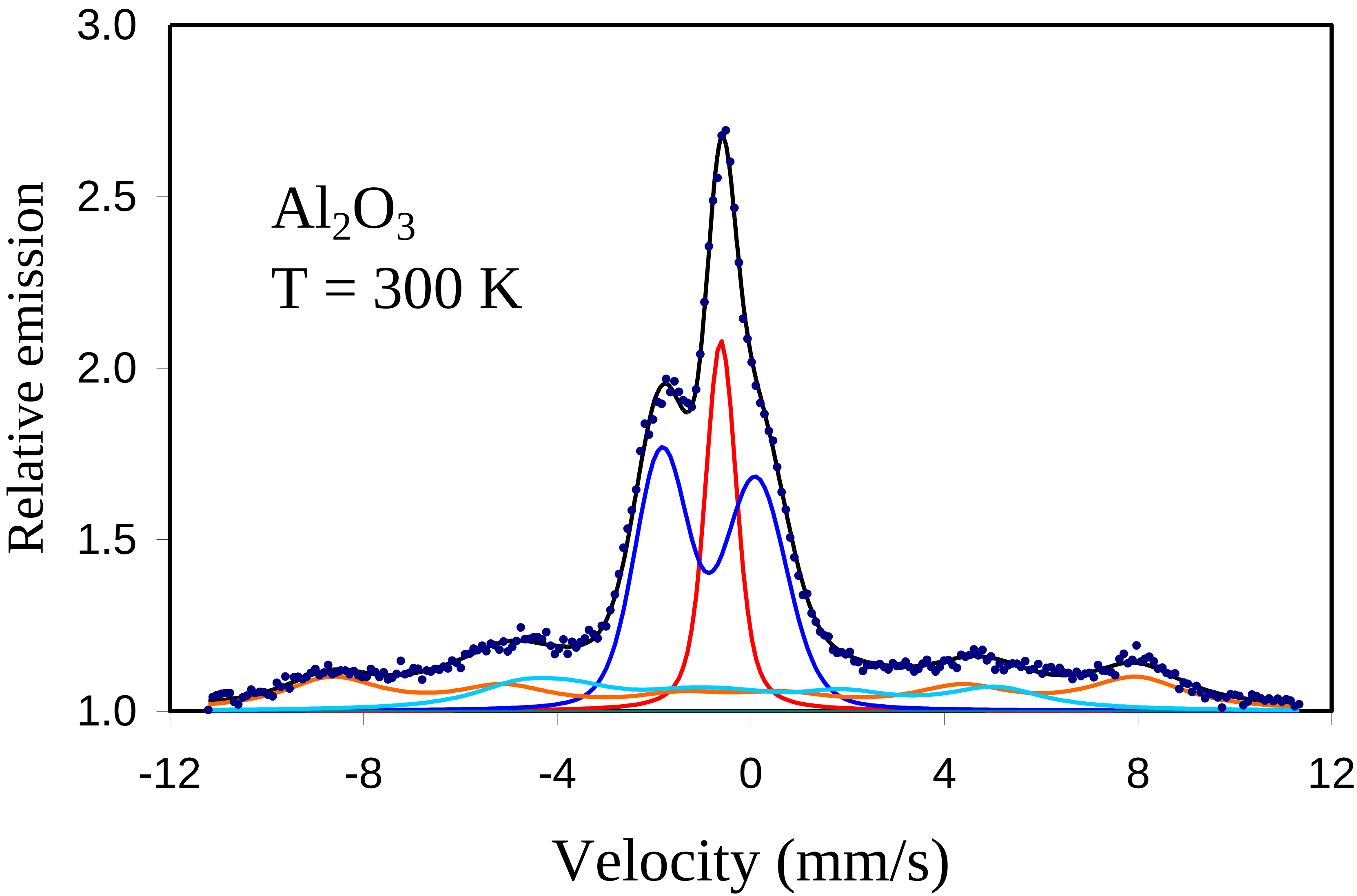
H. P. Gunnlaugsson et al., APL, 2010 (accepted)

ZnO temperature series



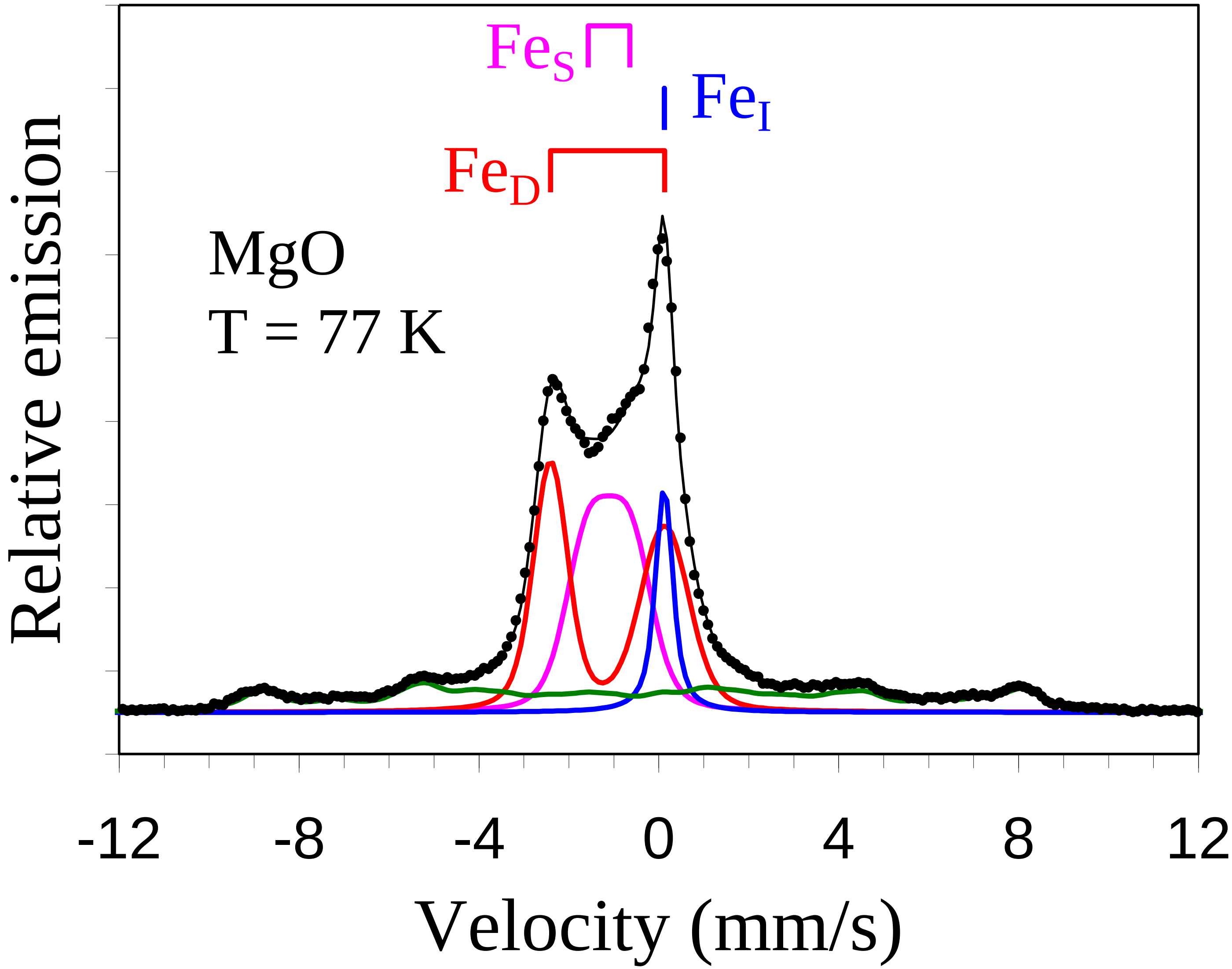
See talk given by T. Mølholt after this talk

Other oxides:



See poster presented by H. P. Gunnalugsson (PS3-23)

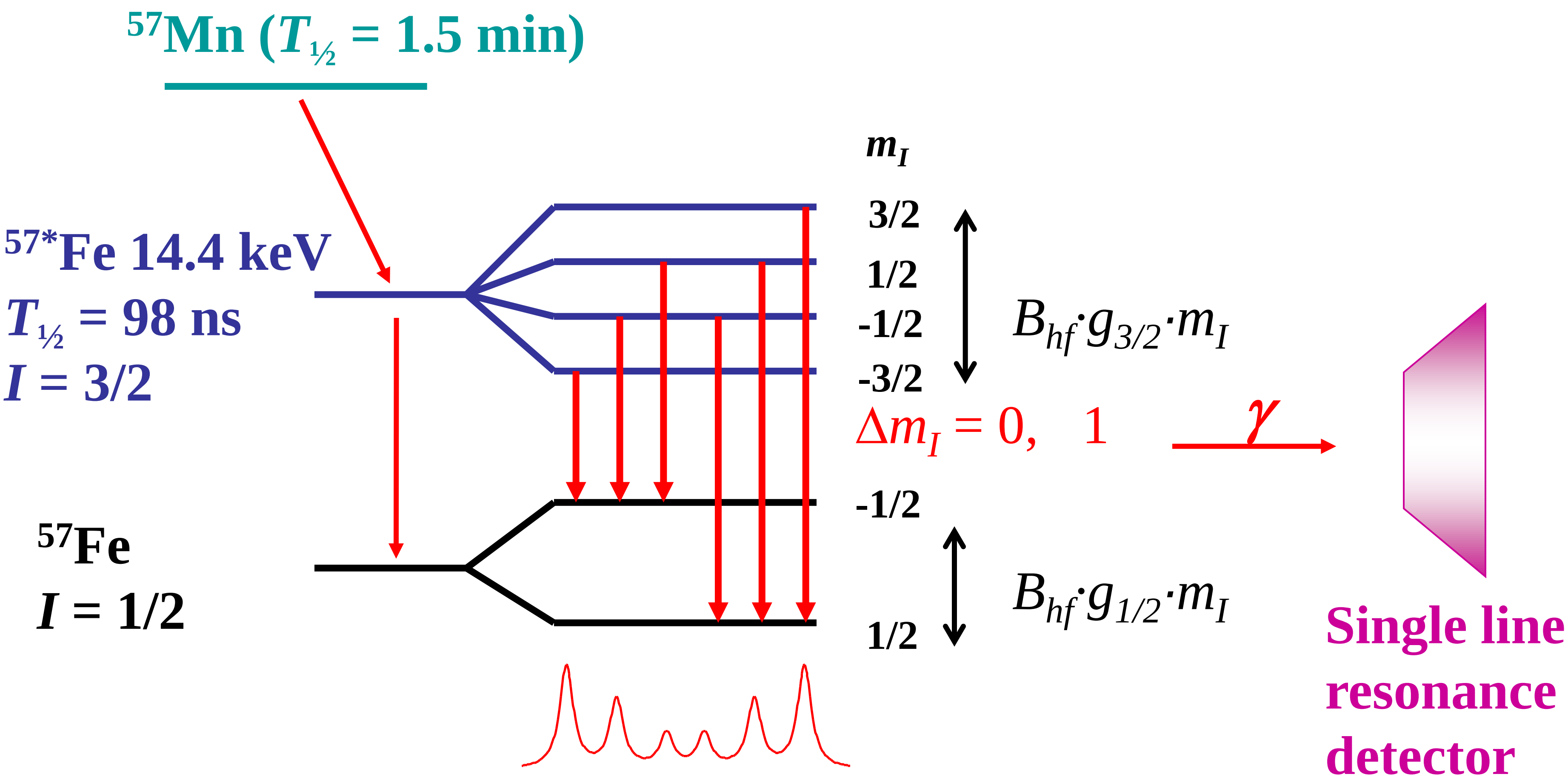
Other oxides:



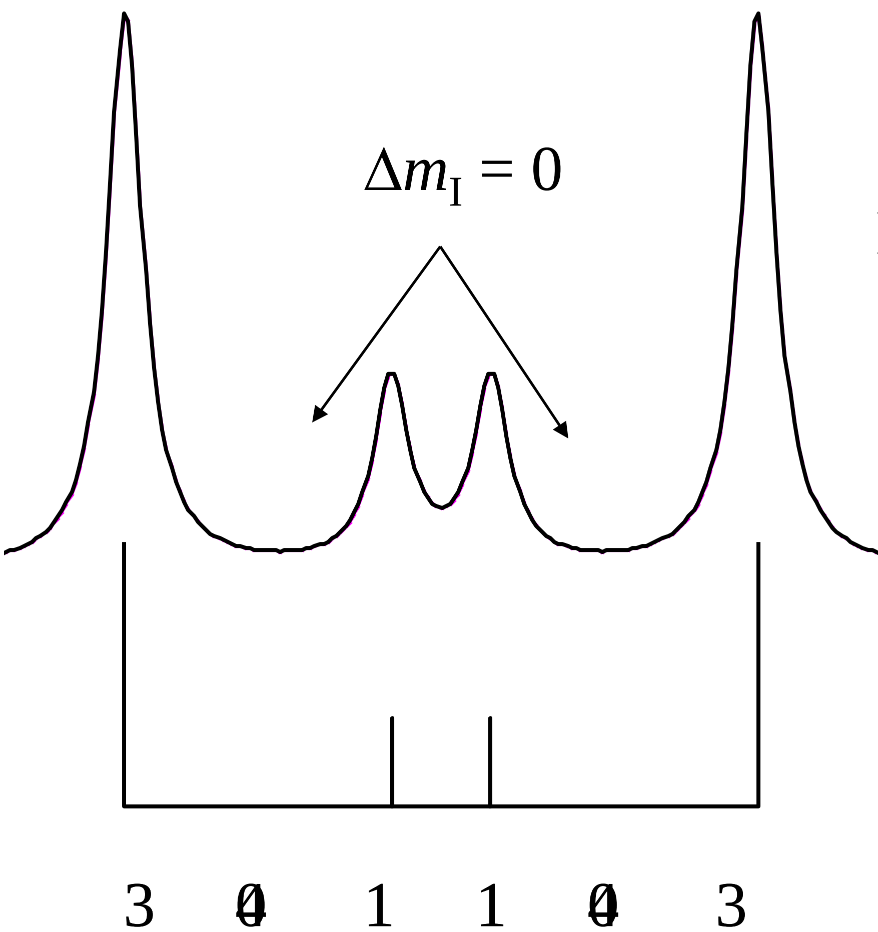
See talk given by T. Mølholt after this talk and (PS3-22)

Mössbauer spectroscopy of magnetic materials

$$\hat{H} = -\boldsymbol{\mu}\mathbf{B} = -g_N \beta_N \hat{I} \cdot \mathbf{B}$$

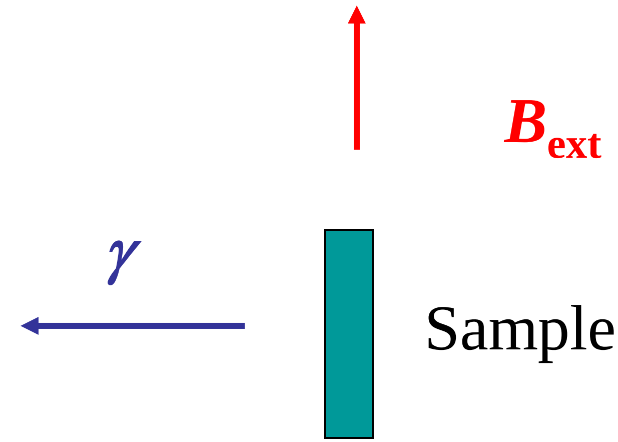


Ferromagnetism ($S = 5/2$ good quantum number)



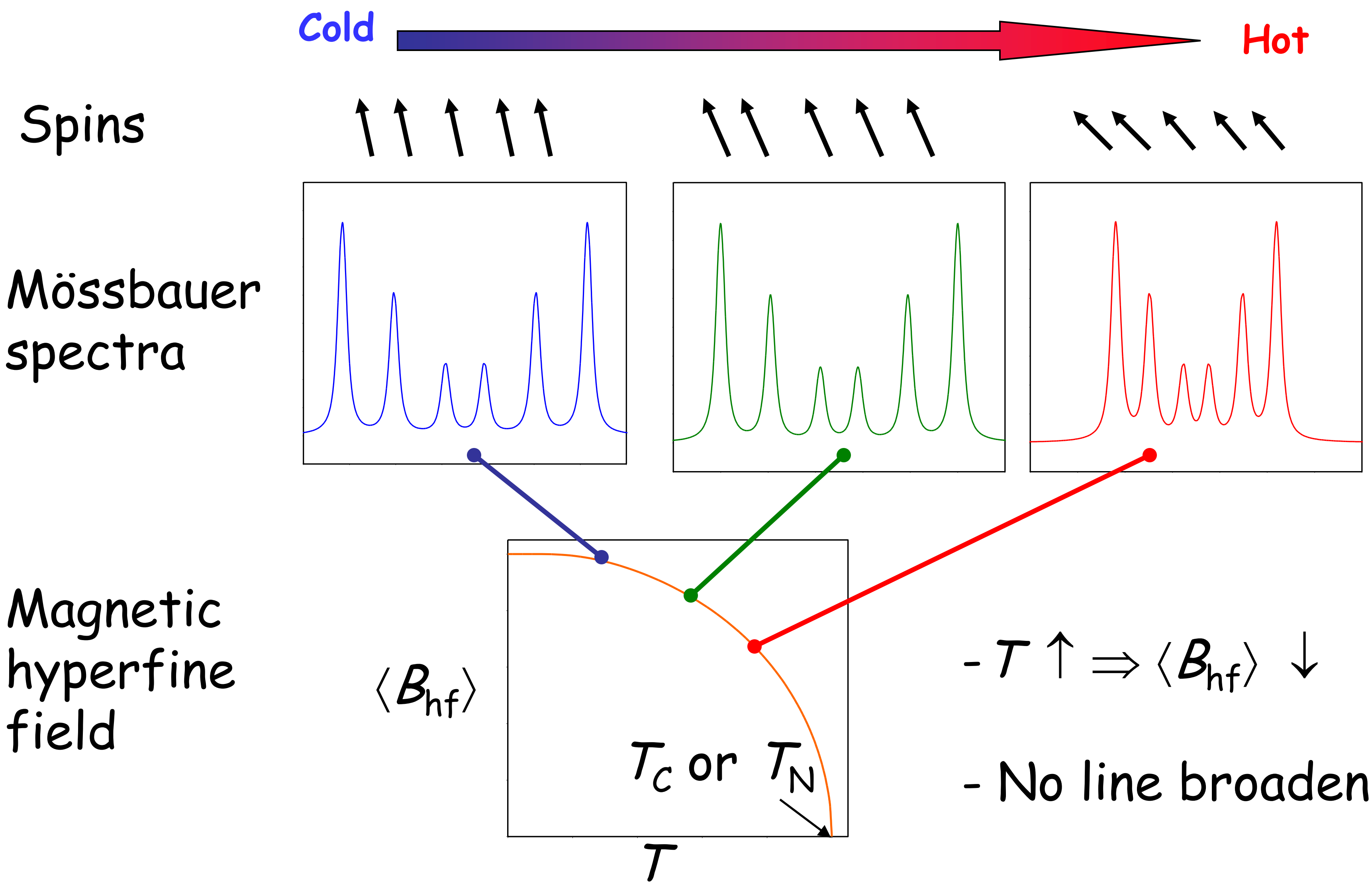
Mössbauer Spectrum

Relative line ratios



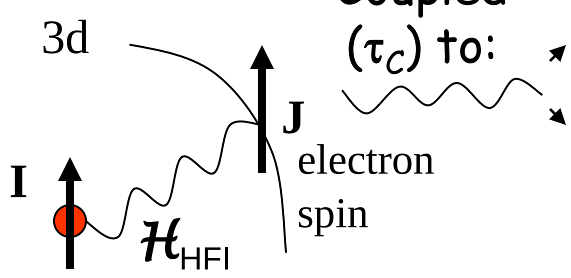
Individual line ratios depend on the angle between B_{ext} and γ

Temperatue dependent magnetic order



- $T \uparrow \Rightarrow \langle B_{hf} \rangle \downarrow$
- No line broadening

Slow paramagnetic relaxations



Coupled (τ_C) to:

Lattice
- charge,
- phonons

Spins
- nuclear-
- electron-

Conditions for static B_{hf}

$\tau_C \geq \tau_L$ (Nucl. Larmor time)
$\tau_C \geq \tau_N$ (lifetime of Mössbauer state)
$\Rightarrow$ B_{hf} not T dependent
$\Rightarrow$ Otherwise broadened

Spin lattice relaxations

	m_I			m_I	
Fe^{3+} ($3d^5$) $^6S_{5/2}$	-2	↑	Fe^{2+} ($3d^6$) $^5D_4$	-2	↑
	-1	↑		-1	↑
	0	↑		0	↑
	1	↑		1	↑
	2	↑		2	↑↓

Lattice vibrations

Spin-spin relaxations

H_{dd} or H_{ex}

$S_a \sim S_b$

Ω_{ss}

$S_\alpha \sim S_\beta$

$$\Omega_{ss} \propto \langle 2 | H_{dd} + H_{ex} | 1 \rangle \times \exp(-|E_2 - E_1|)$$

Broadening in MS if >~0.1 at.%

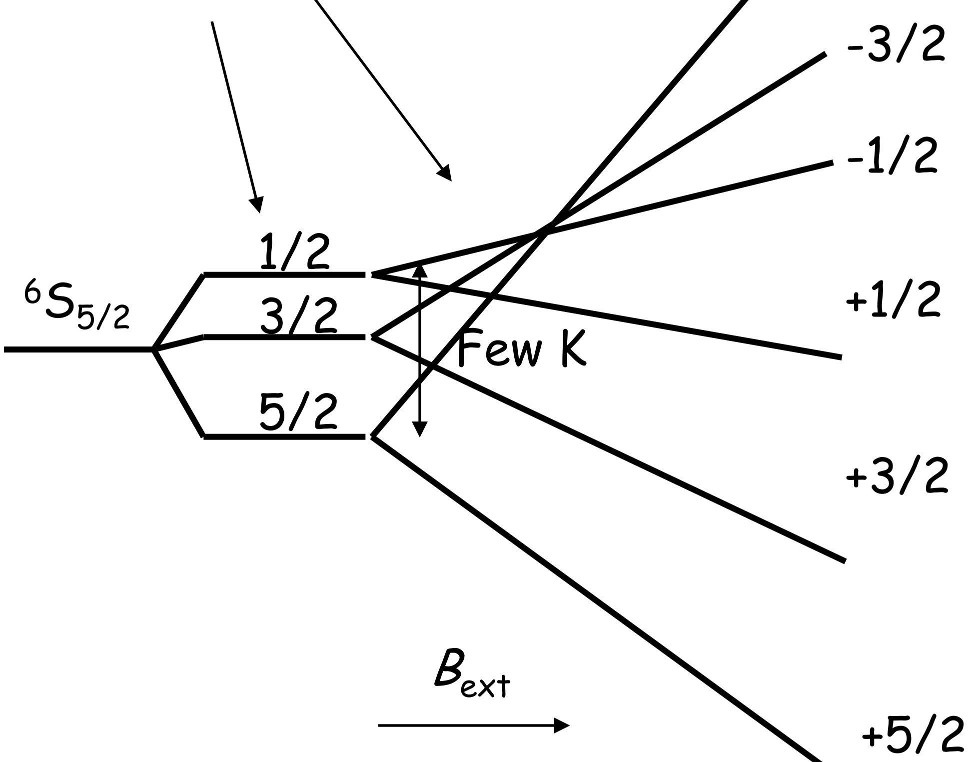
Mössbauer spectra of paramagnetic Fe^{3+}

Needs electron spin operators!

$$\hat{H} = \hat{H}_{CF} + \hat{H}_{EZI} + \hat{H}_{HFI} + \hat{H}_{NQI} + \ldots$$

$$\hat{H}_{CF} = \hat{S}\mathbf{D}\hat{S}$$

$$\hat{H}_{EZI} = \mu_B \mathbf{B}\cdot\mathbf{g}\hat{S}$$



High B (> 0.3 T)

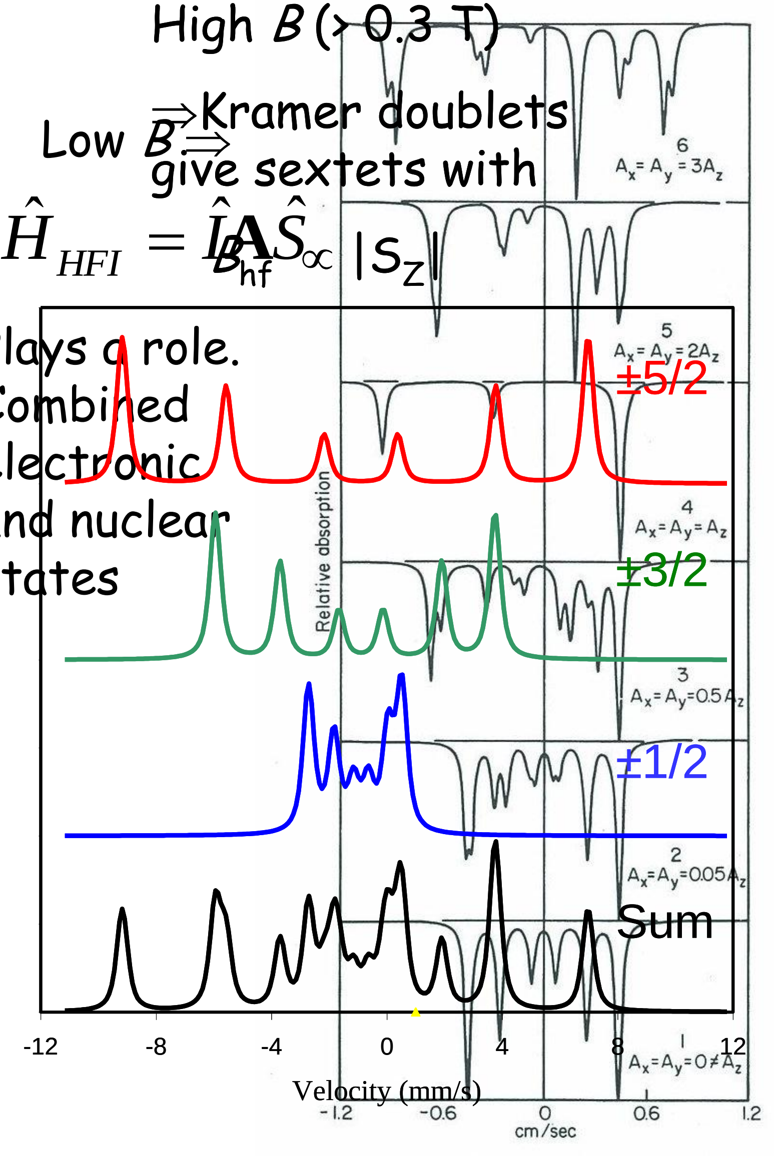
Low B ⇒

⇒Kramer doublets give sextets with

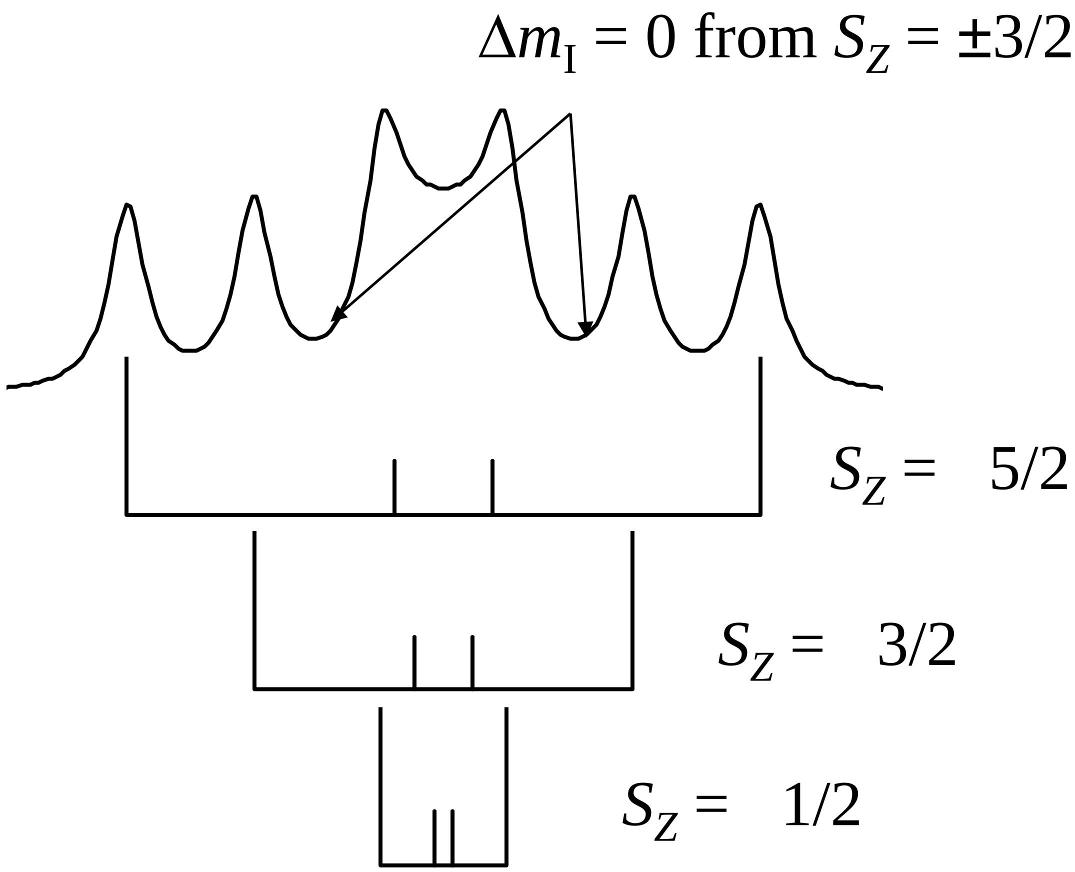
$$\hat{H}_{HFI} = \hat{I}\mathbf{A}\hat{S}$$

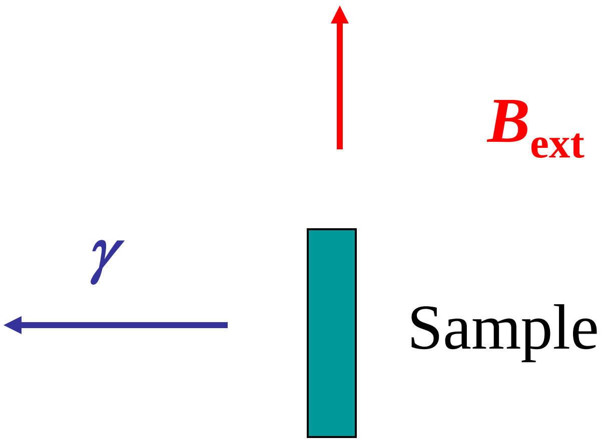
$B_{hf} \propto |S_z|$

Plays a role. Combined electronic and nuclear states



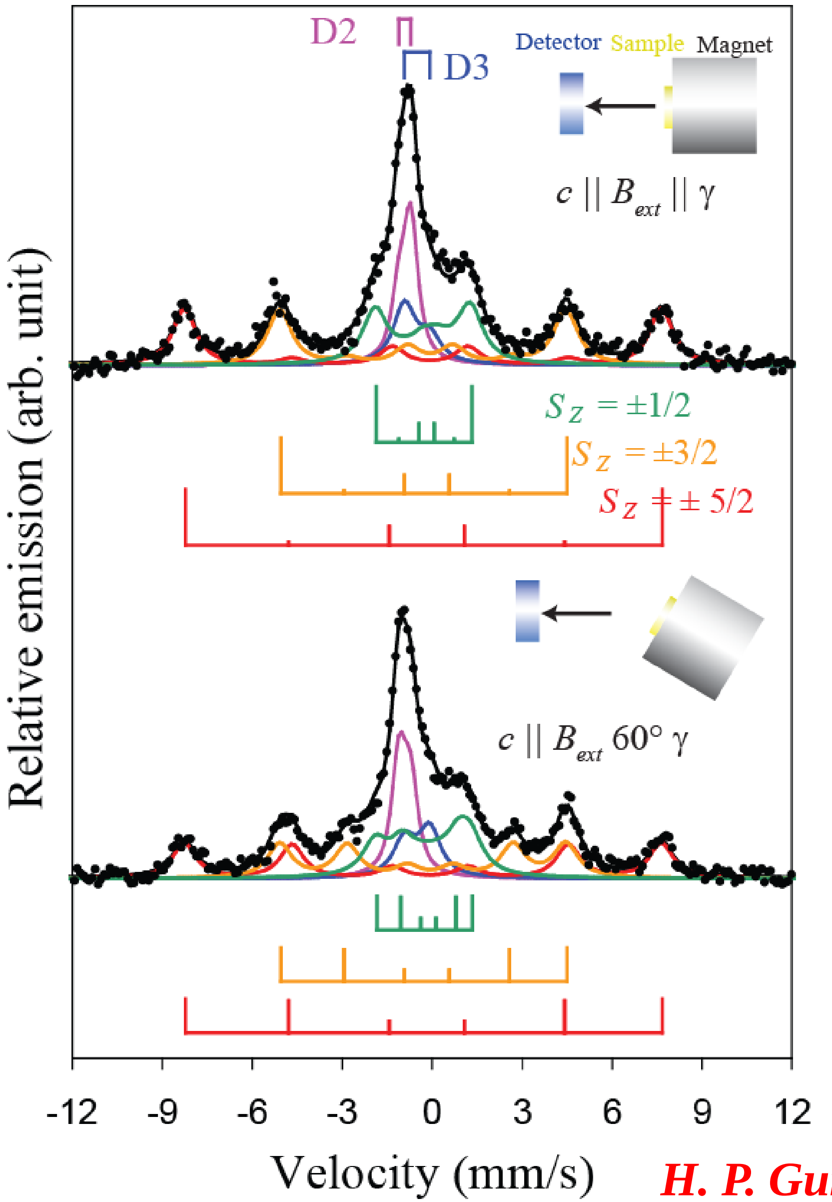
Paramagnetism (slow relaxation)





Individual line ratios depend on the angle between B_{ext} and γ

ZnO at RT in B_{ext} = 0.6 T

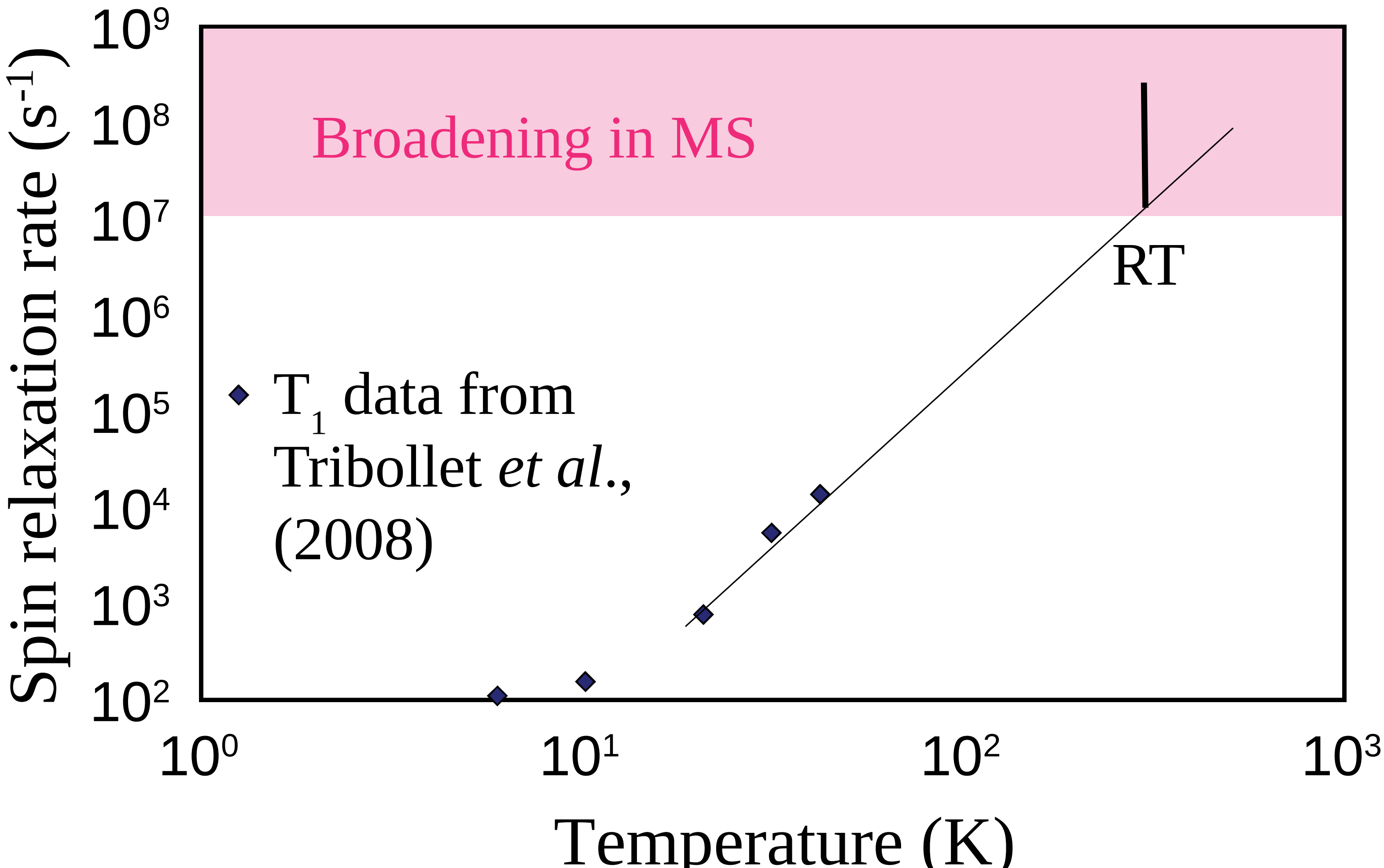


Sextet originating from Kramer doublets clearly observed

No relaxation at RT?

H. P. Gunnlaugsson et al., APL, 2010 (accepted)

Slow paramagnetic relaxations at RT plausible?



Does defect magnetism exist?

In ZnO, implanted Mn/Fe Fe^{3+} shows slow paramagnetic relaxations

-> No spin-spin relaxations with defects

<- Theory overestimates range of magnetism from isolated defects (Zunger et al., 2010), data misinterpretated and precipitation not documented (Potzger et al., 2008+)

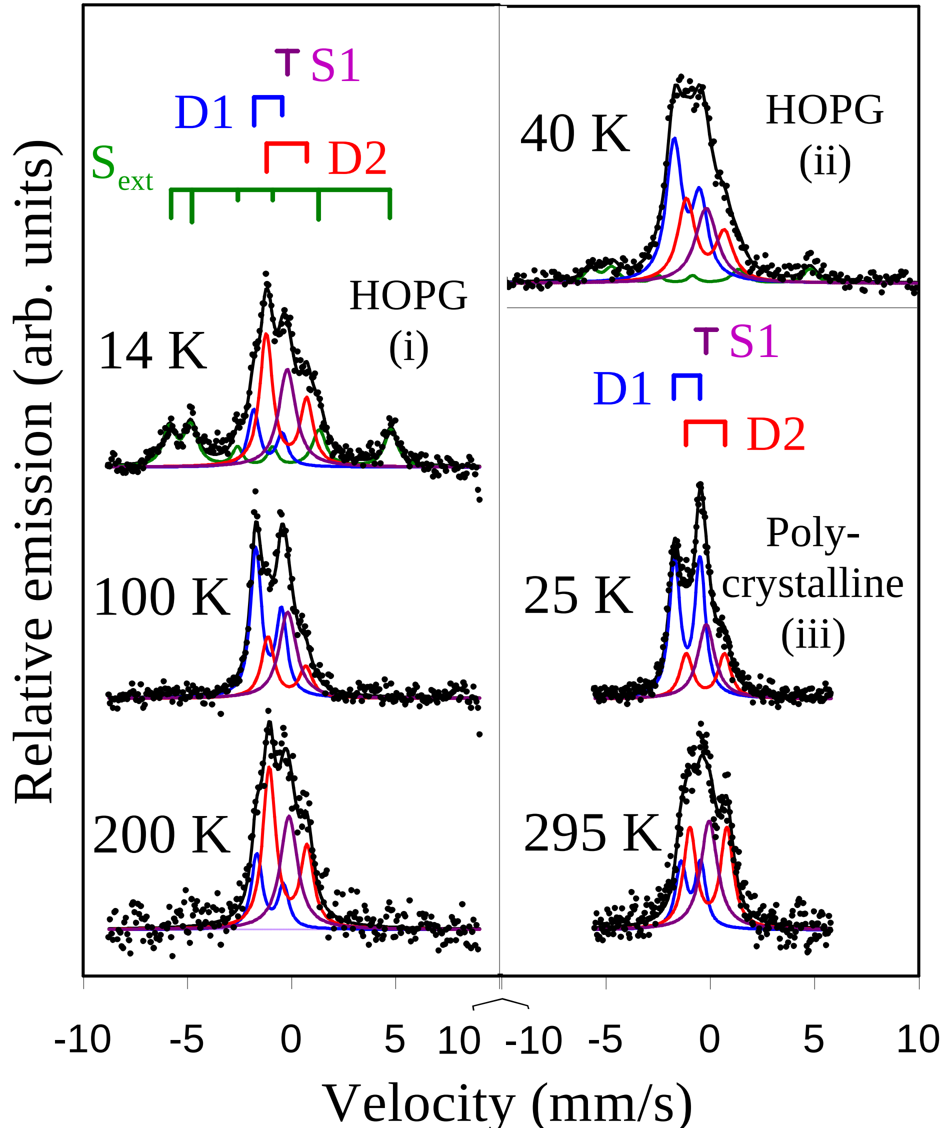
Is defect or dilute magnetism myth?

Defect magnetism exists!

-Implantation of $^{57**}Fe$ into Graphite

-Sextet (Fe^{2+}) observed at 14 K

-Reduced B_{hf} at 40 K (not a static B_{hf})



Sieleman et al., PRL, 2007

Conclusions/summary

-Implanted Mn/Fe ions in oxides lead to TM in various charge states and lattice sites

-Fe as 3+ state has extremely long relaxation time and displays static (para)-magnetic spectra. Most extreme case Fe in ZnO.

-Application of external magnetic field decouples perturbing fields and yields spectrum looking like an effective magnetic field.

-Identification of defect related magnetism by Mössbauer spectroscopy has been observed at very low temperatures in graphite.


Thank you
BECK'S
IS443 summer 2009
missing K. Johnston, M. Fanciulli,
K. Baruth-Ram, Y. Kobahashi