Mössbauer study of spin-lattice relaxations of dilute Fe^{3+} in MgO

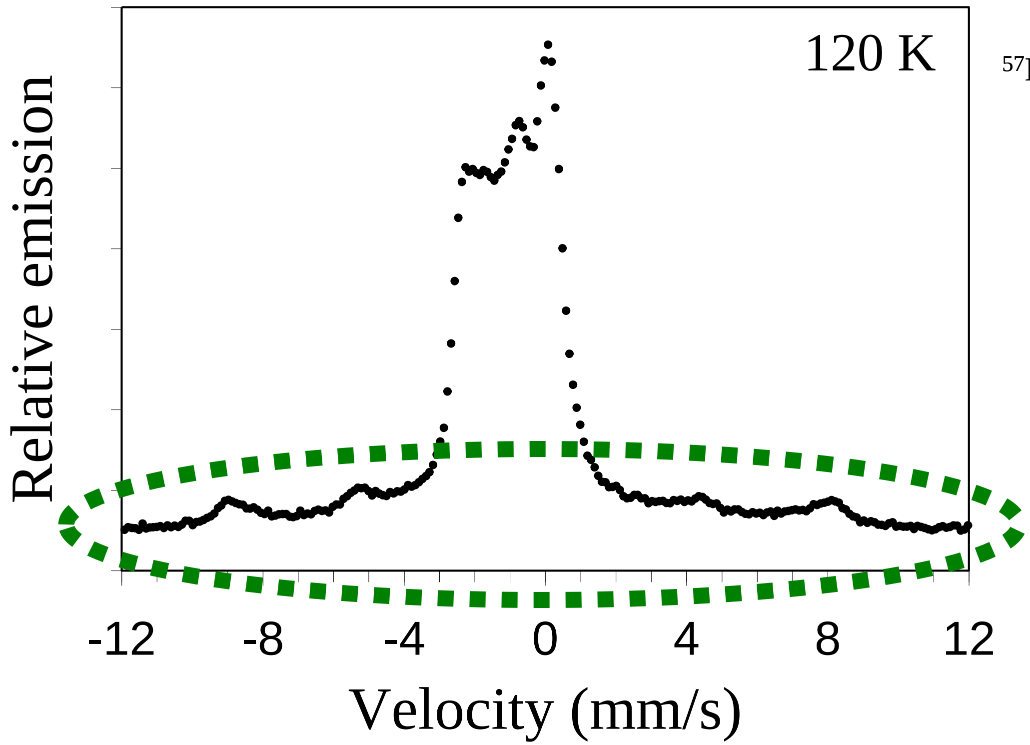
Torben E. Mølholt,
R. Mantovan, H. P. Gunnlaugsson, D. Naidoo, S. Ólafsson,
K. Bharuth-Ram, M. Fanciulli, K. Johnston, Y. Kobayashi,
G. Langouche, H. Masenda, R. Sielemann, G. Weyer and H. P. Gíslason

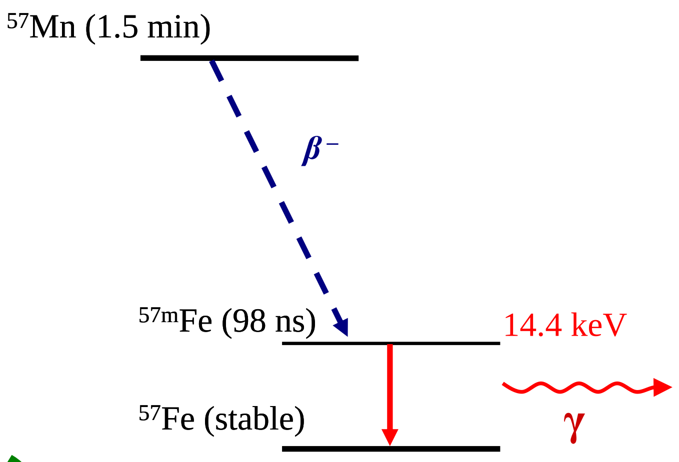
3rd Joint International Conference on Hyperfine Interactions and International Symposium on Nuclear Quadrupole Interactions

Outline

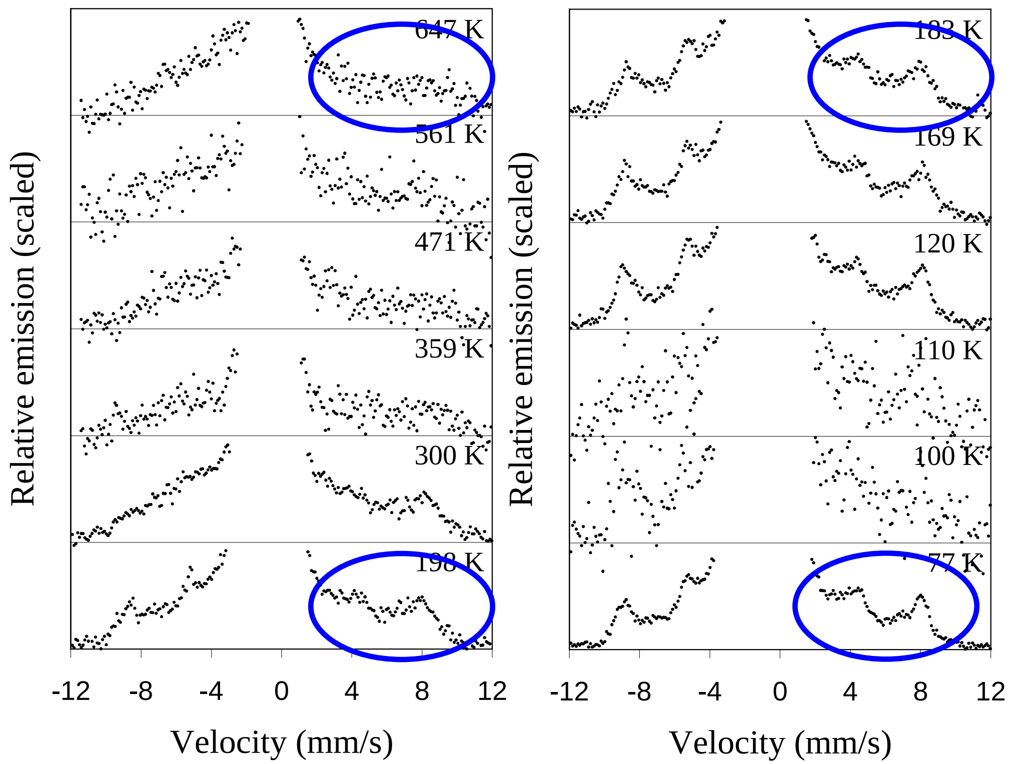
- Motivation / introduction
- Experimental details
- Results
- Discussion / conclusions

^{57}Fe Mössbauer spectrum of ^{57}Mn ion-implanted single crystal MgO





Motivation



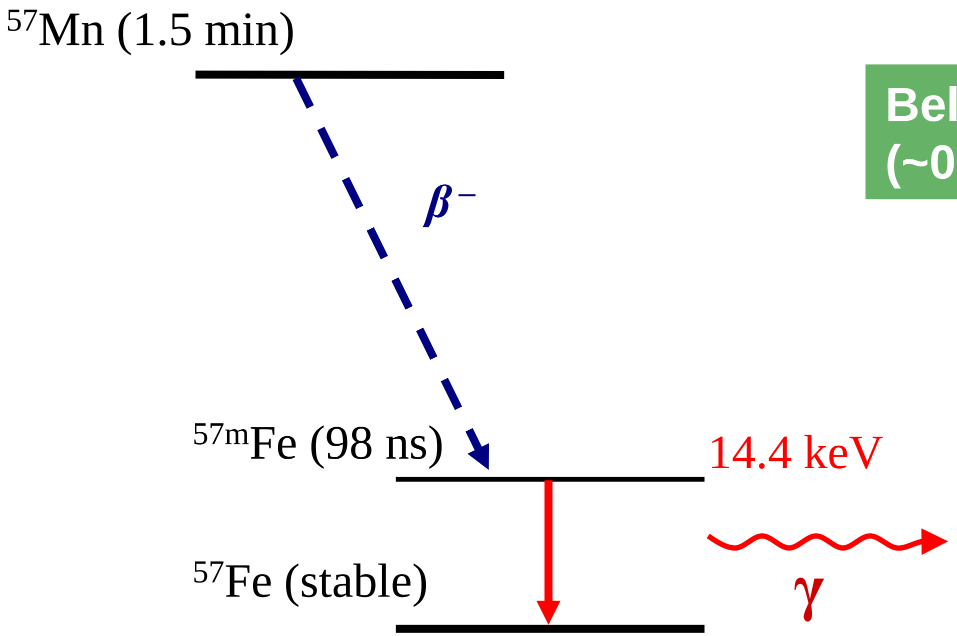
- Is the broadening consistent with Fe^{3+} spin-lattice relaxations at elevated temperatures?

- Can the broadening be a measurement of the relaxation rate, τ^{-1}?
  - Difficult to analyse, $B_{ext} = 0$ T

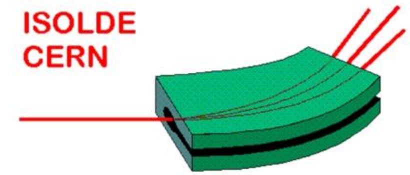
Decay of ^{57}Mn (probe atom)

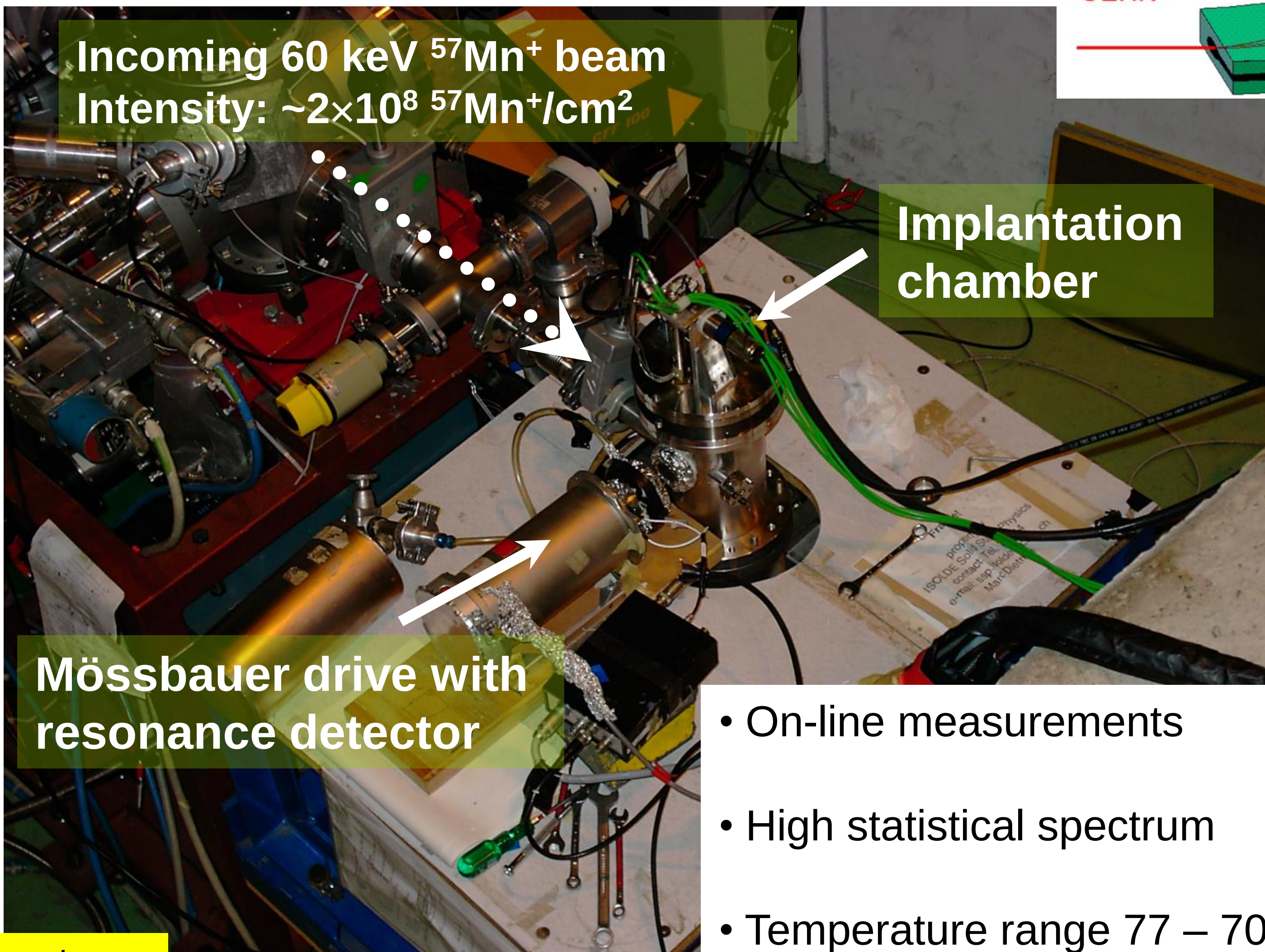
10^{-4} at. % implanted dilute Fe.

Below spin-spin relaxation effects (~0.1 at. %).



Experimental setup

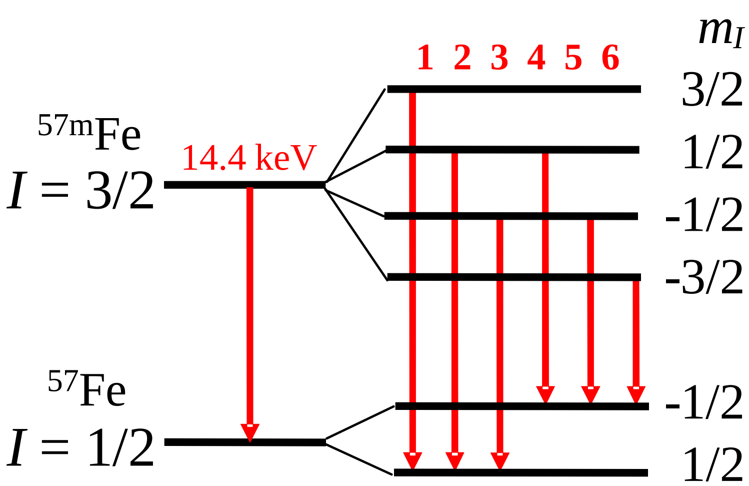




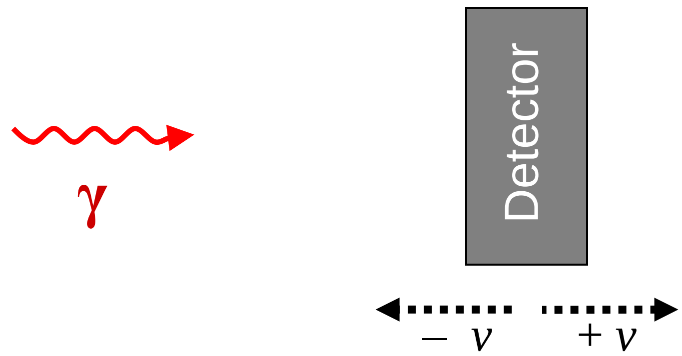
- On-line measurements
- High statistical spectrum
- Temperature range 77 – 700 K

1 week ago

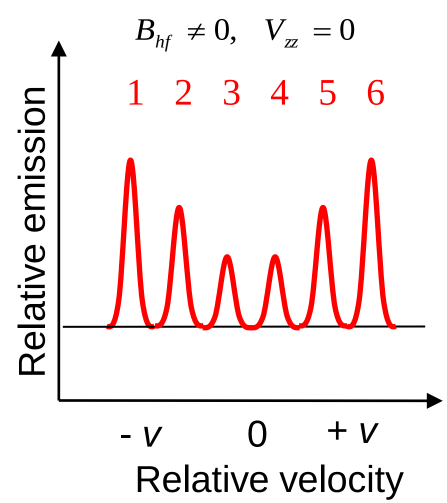
Magnetic hf. splitting of ^{57}Fe: Sextet



Source/sample:
Mn/Fe implanted MgO



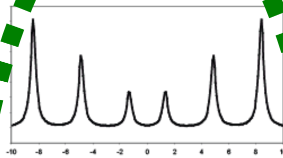
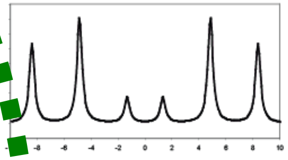
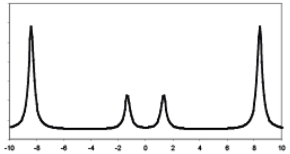
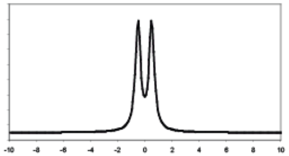
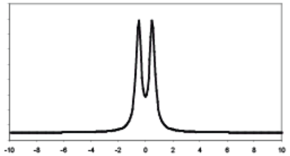
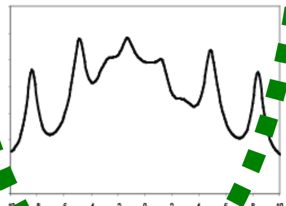
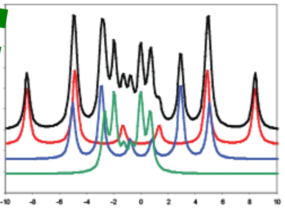
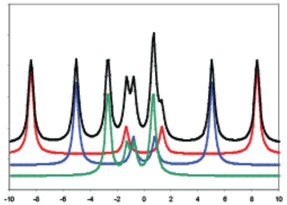
Absorber/detector:
Single line resonance detector



Case:
No external magnetic field.
Ferromagnetic material.

For Fe^{3+}: B_{hf} ~ 52 T

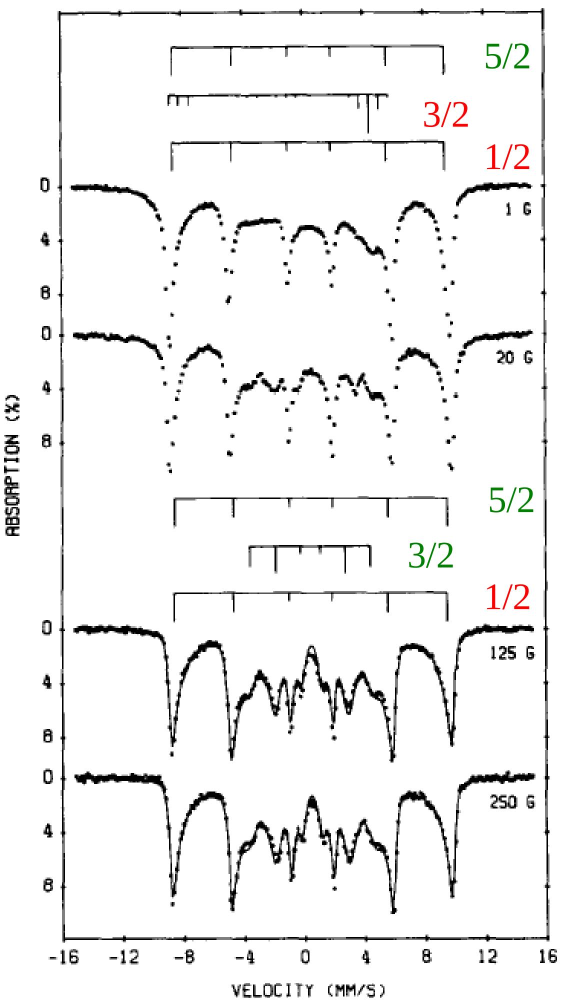
Magnetism in the Mössbauer spectrum

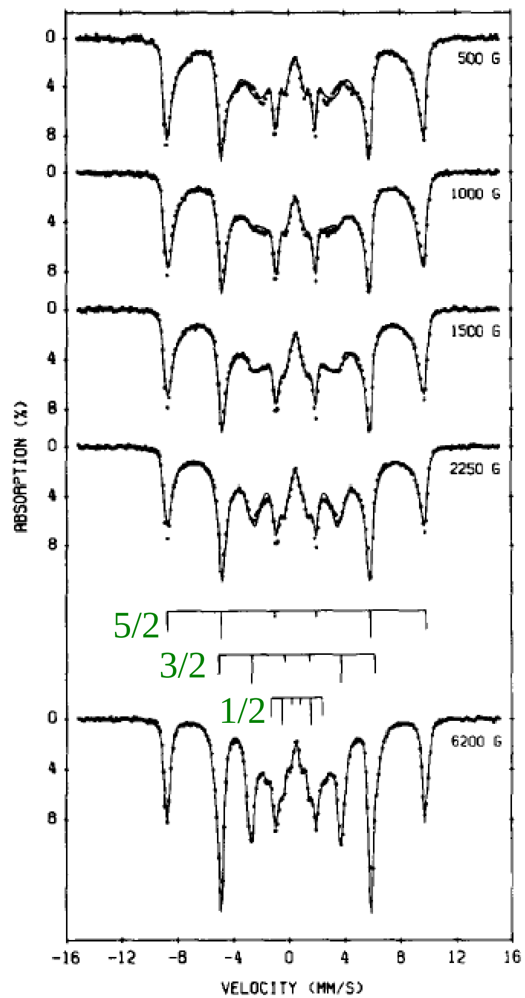
Fe concentration	Magnetism	$B_e = 0$	$B_e > \sim 0.3$ T: $B_e \perp \gamma$	$B_e > \sim 0.3$ T: $B_e \parallel \gamma$
High $\uparrow\sim\uparrow$	Ferro-magnetism			
Inter-Mediate $\uparrow \sim \uparrow$	Paramagnetism Fast spin-spin relaxations:			
Low $\uparrow \quad \uparrow$	Slow para-magnetism spin-lattice relaxations:			

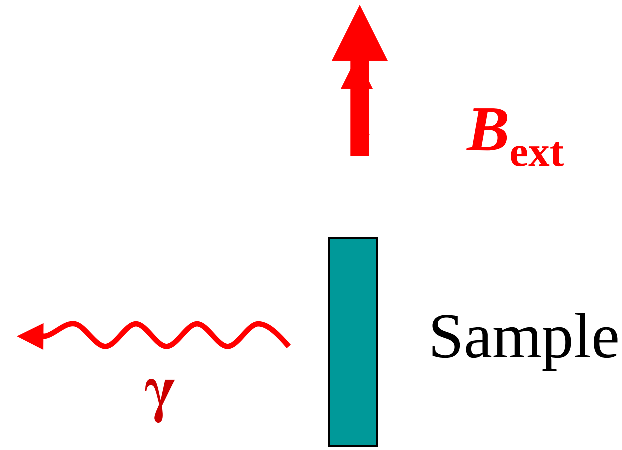
$S_z = \pm 5/2, \pm 3/2, \pm 1/2$

Kramers split lines

Slow relaxation rate in a magnetic field







Case:
Applied external magnetic field:
→B_{ext} > ~0.3 T
Kramers dublets ∝ $|S_z|$

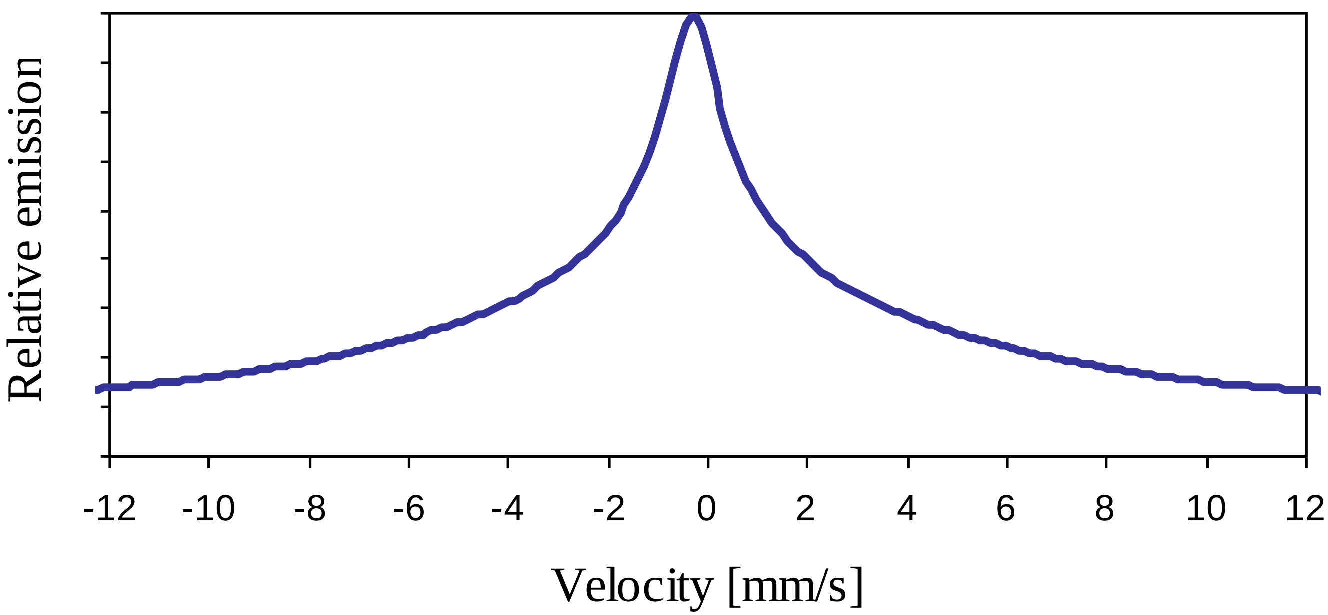
Case:
No/low external magnetic field:
→Overlapping lines/"smearing":
The eigenstates are combined nuclear and electronic states.

J. E. Knudsen, J. Phys. Chem. **38**, 883 (1977).
Dilute Fe in a frozen sample.

Paramagnetic sextet (spin-lattice relaxations)

Simulation

1/2/3/4/5/6



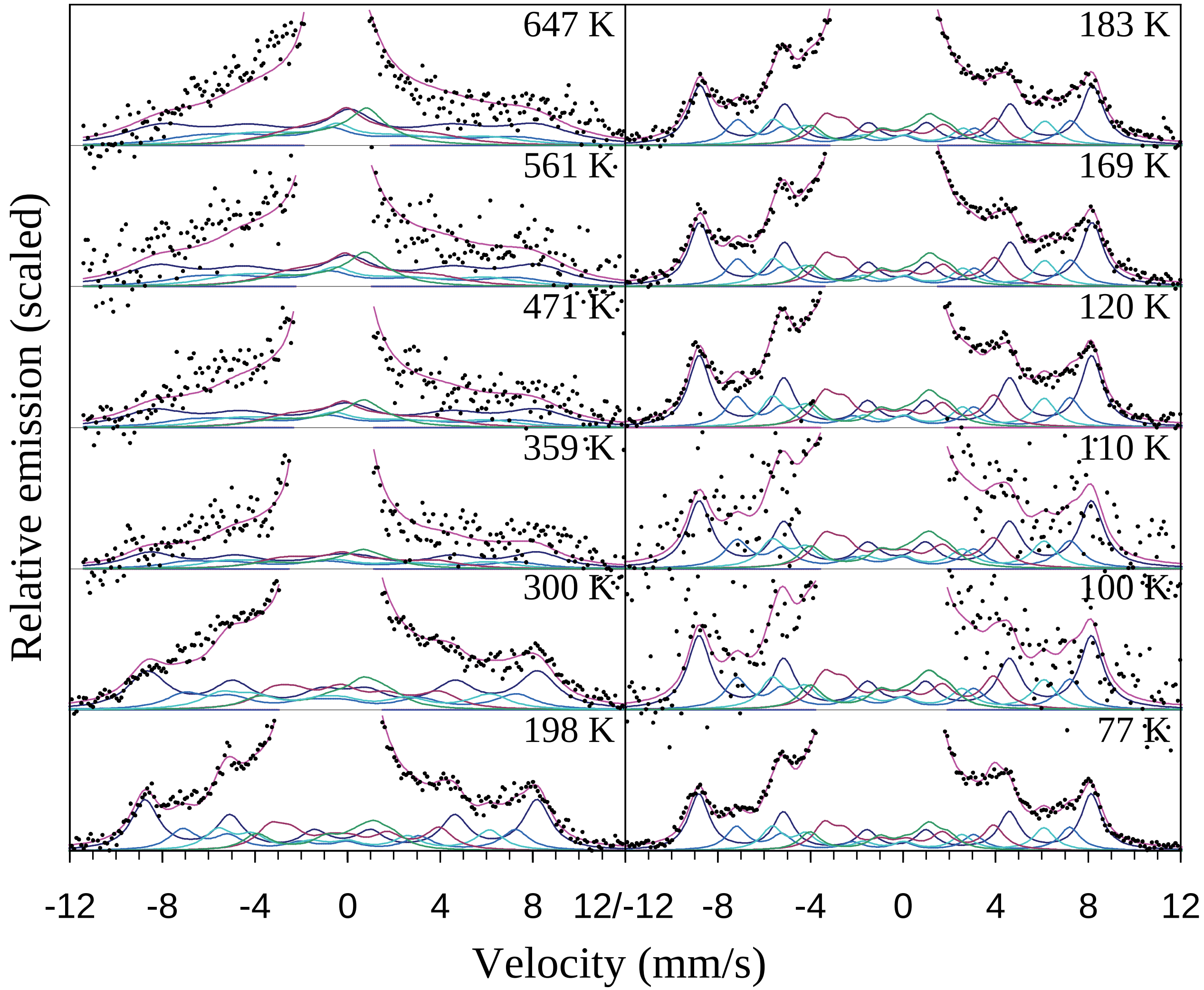
τ^{-1} = 500 MHz (high)

$$\Delta\Gamma = \frac{\;}{E_0} \cdot \tau^{-1}$$

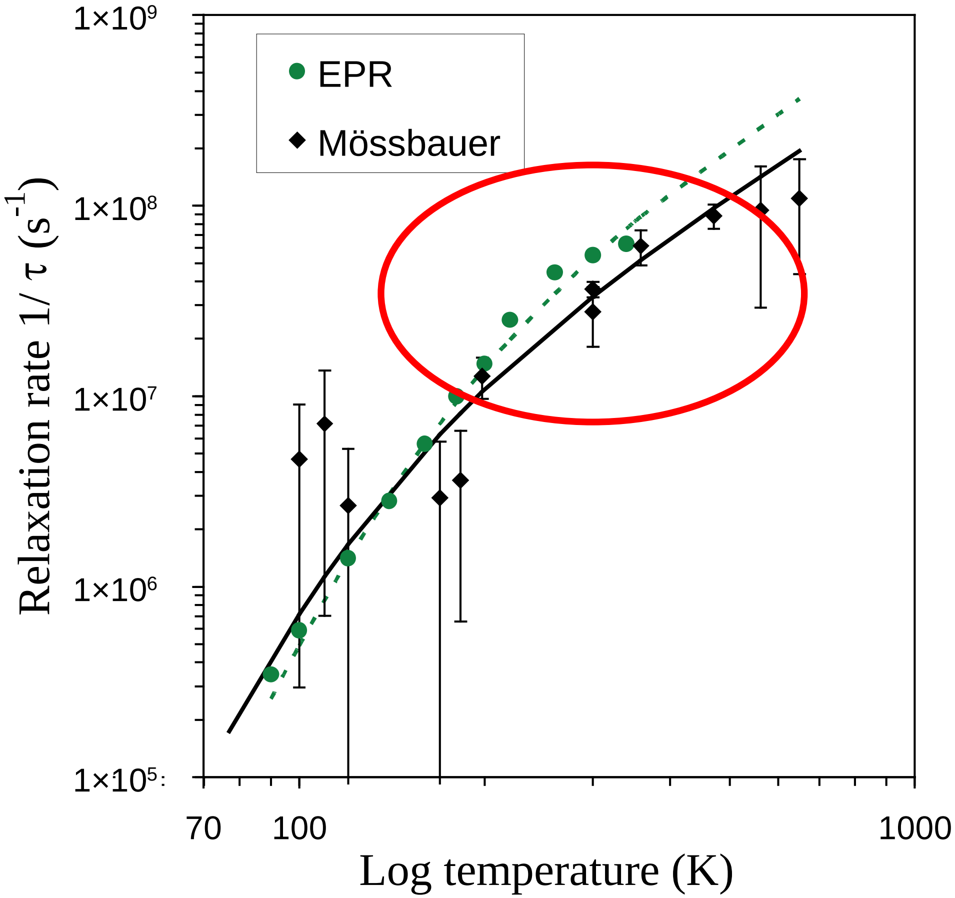
Total collapse of all spectral lines

Observed collapse of the relaxing sextet, due to change of the relaxation rate, τ^{-1}.

Results

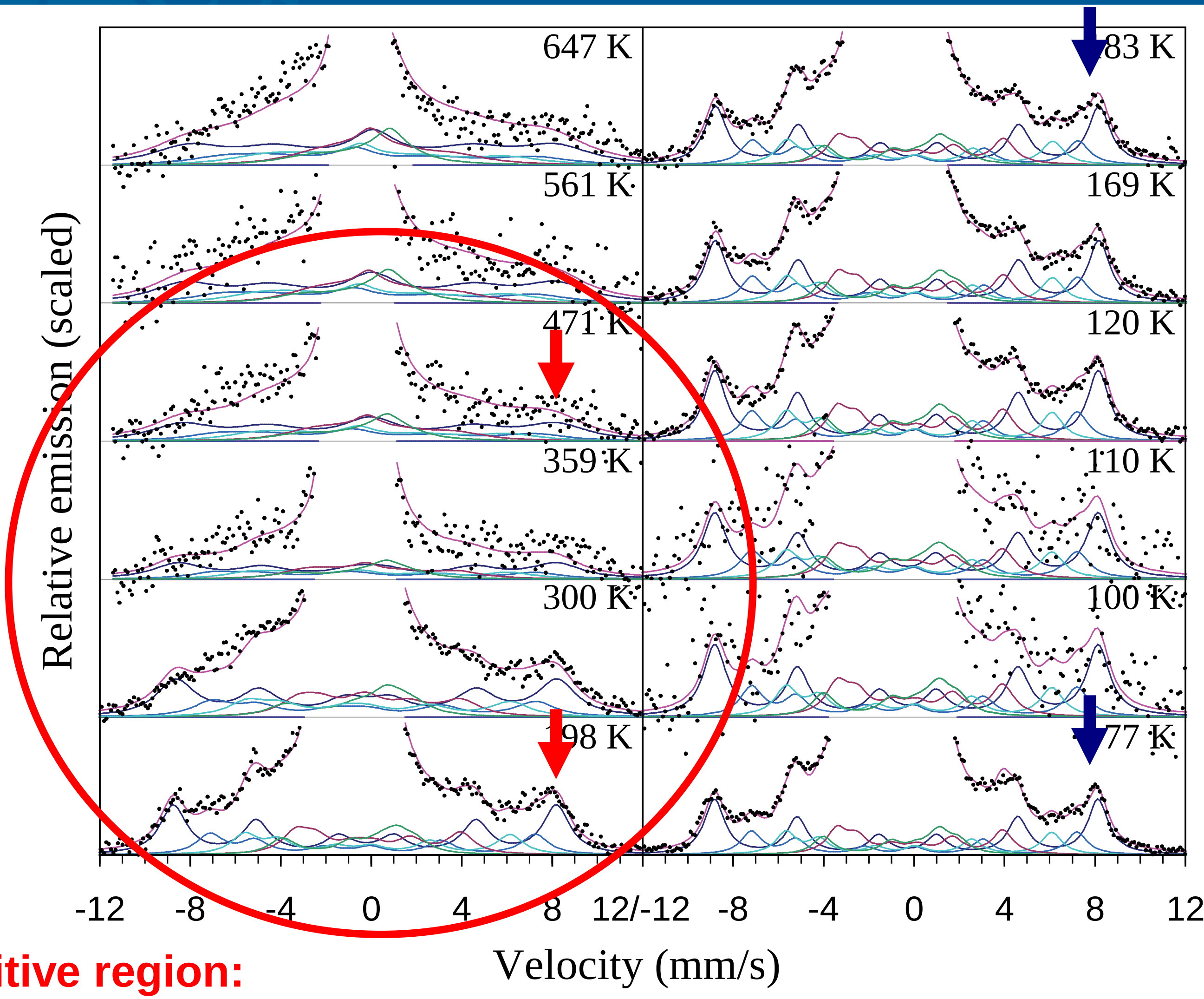


Temperature ↑ : Broadening ↑



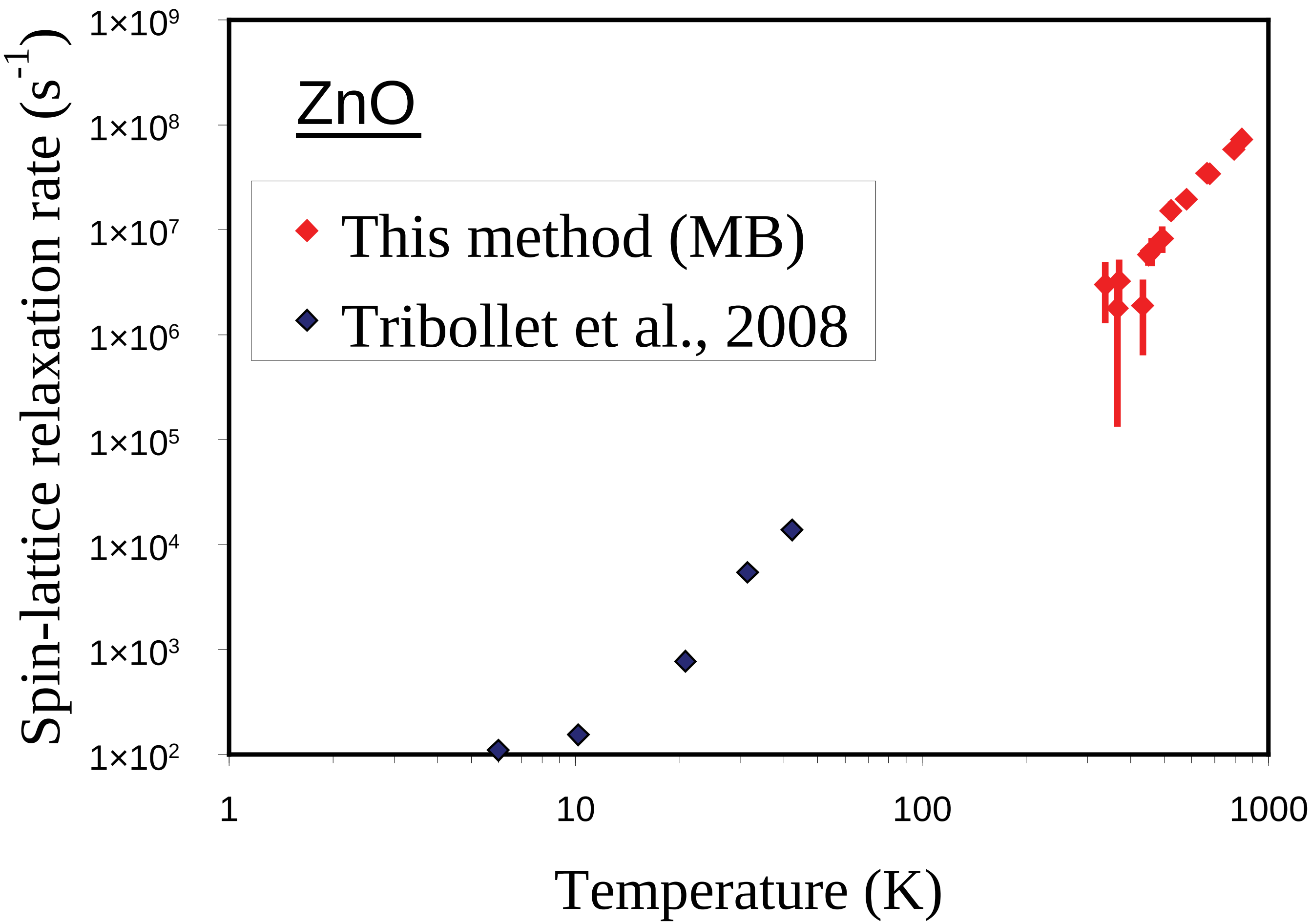
Sensitive region:
τ^{-1} = 10 – 100 MHz

EPR (electron paramagnetic resonance) data:
Biasi and Portella, Magnetism and Magnetic Materials. 15, 737 (1980)



Sensitive region:
τ^{-1} = 10 – 100 MHz

Temperature ↑ ⇒ Broadening ↑


ZnO
This method (MB)
Tribollet et al., 2008
Spin-lattice relaxation rate (s^{-1})
1×10⁹
1×10⁸
1×10⁷
1×10⁶
1×10⁵
1×10⁴
1×10³
1×10²
1
10
100
1000
Temperature (K)

Conclusions

- Observed slow spin-relaxation of Fe^{3+} in MgO.
  - →Negligible spin-spin relaxation (<10^{-4} at. %).
  - →Low Fe^{3+} relaxation rates (T < 200 K).
- Broadening is consistent with Fe^{3+} spin-lattice relaxation rates.
  - → Comparable to EPR data.
- Possible to obtain relaxation rates without B_{ext}.

Thank you for your attention