Magnetism of Eu and Dy under Extreme Pressures

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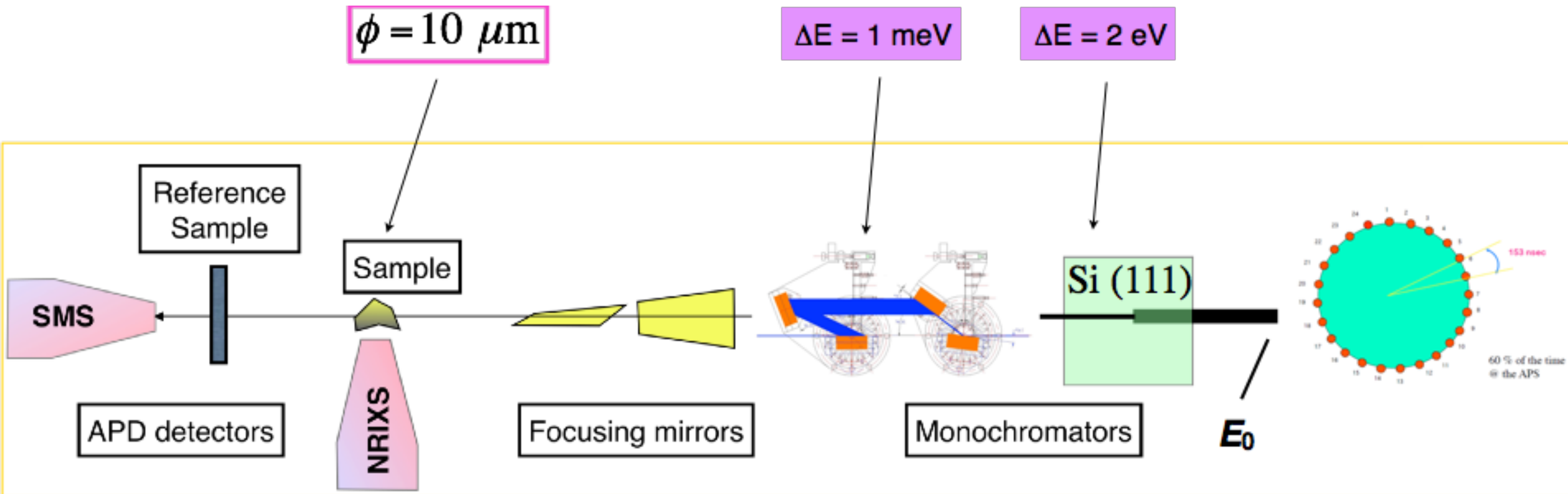
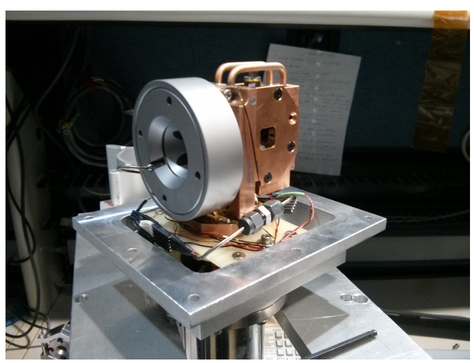
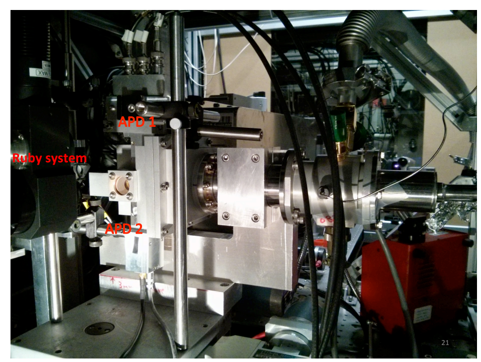
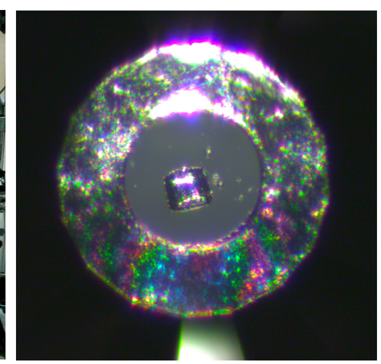
High pressure SMS experiment setup









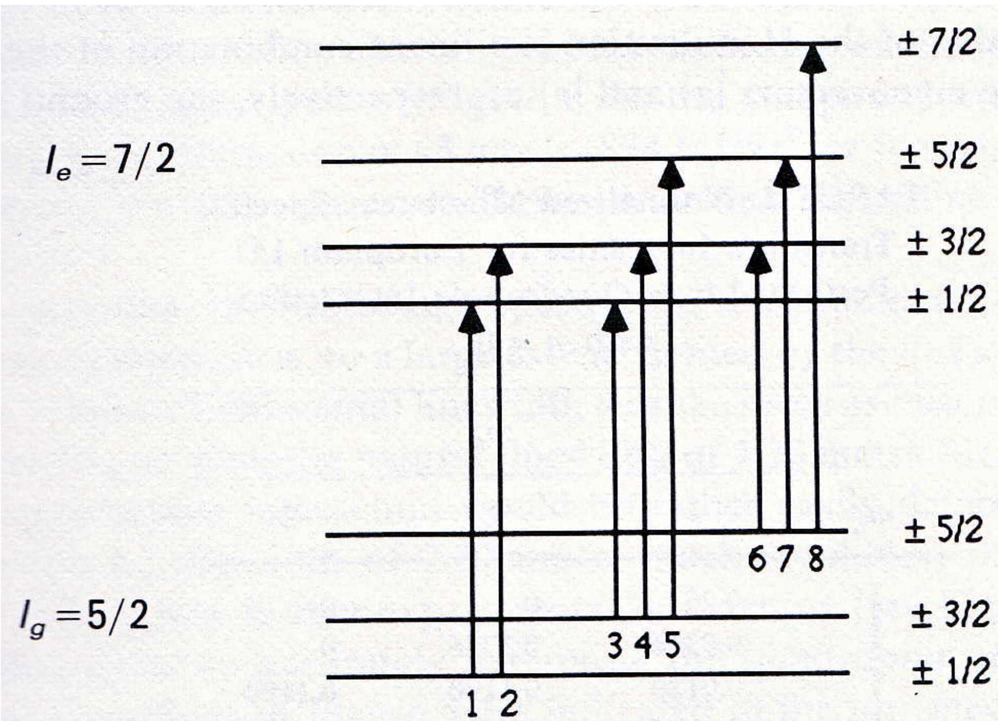
Basic Mössbauer parameters of ^{151}Eu

Isotope	E_γ [keV]	a [%]	Γ_0 [neV]	τ_0 [ns]	I_g	I_e	Multi-polarity
^{181}Ta	6.23	99.9	0.067	9870	7/2	9/2	E1
^{169}Tm	8.41	100	114	5.8	1/2	3/2	M1
^{83}Kr	9.40	12.0	3.3	212	9/2	7/2	M1
^{57}Fe	14.41	2.1	4.7	141	1/2	3/2	M1
^{151}Eu	21.53	47.8	47.0	14.1	5/2	7/2	M1
^{149}Sm	22.49	13.8	64.1	10.3	7/2	5/2	M1
^{119}Sn	23.87	8.6	25.7	25.7	1/2	3/2	M1
^{161}Dy	26.65	18.9	16.2	40.8	5/2	5/2	E1
^{121}Sb	37.13	57.25	130.0	5.0	5/2	7/2	M1
^{40}K	29.83	0.0117	160.5	4.13	4	3	M1
^{61}Ni	67.40	1.25	88.3	7.5	3/2	5/2	M1

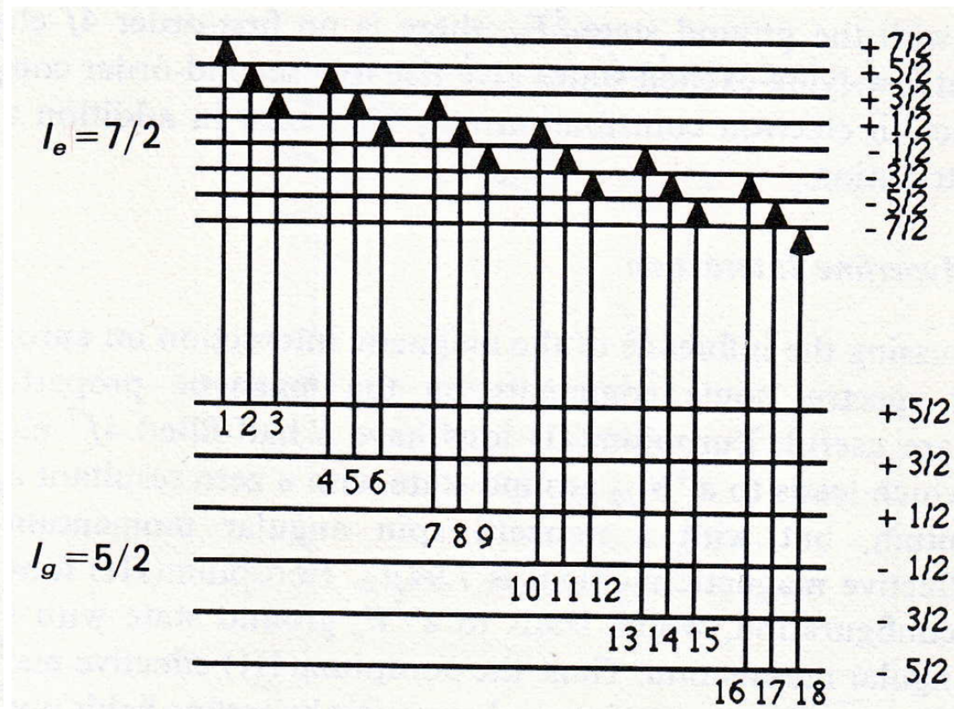
R. Röhlsberger, *Nuclear Condensed Matter Physics with Synchrotron Radiation*, (Springer Berlin Heidelberg, Berlin, Heidelberg, 2005), Ch. 2, p. 25.

Hyperfine interactions of ^{151}Eu

quadrupole interaction in Eu

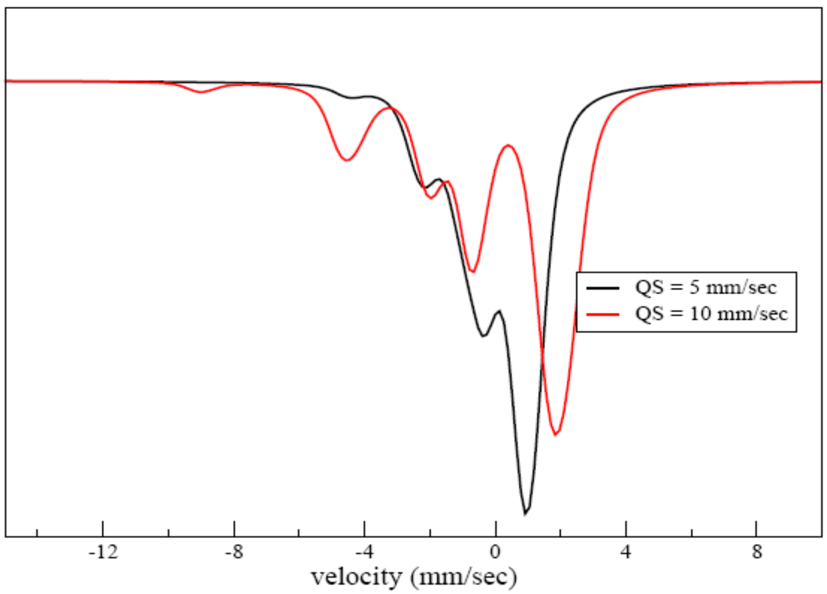


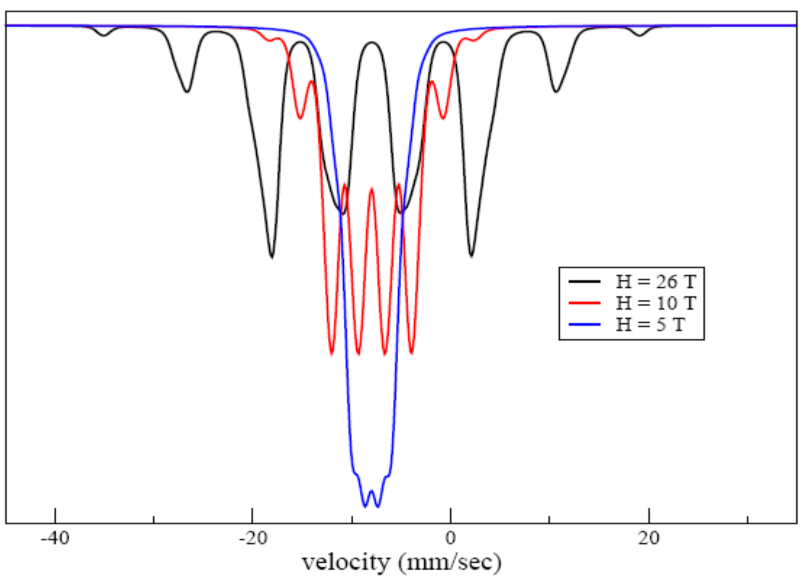
magnetic interaction in Eu



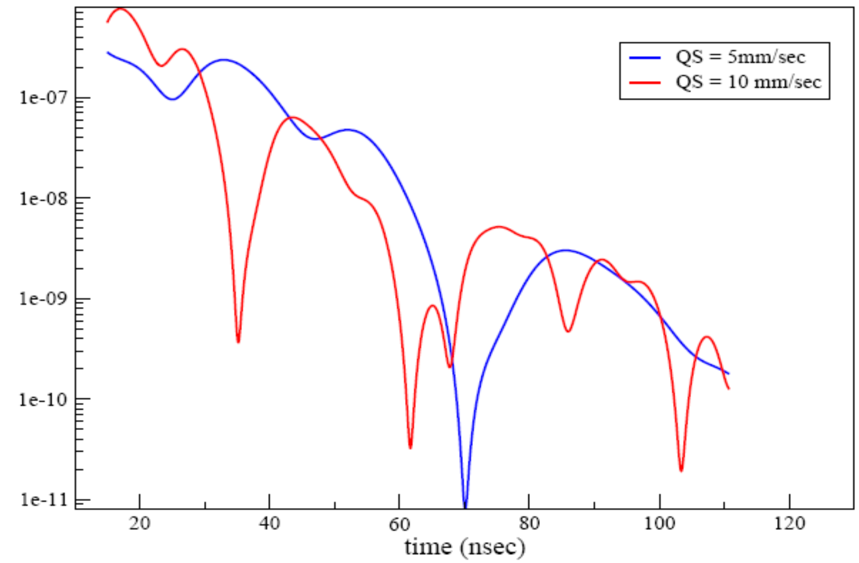
Simulated Mössbauer data in ^{151}Eu

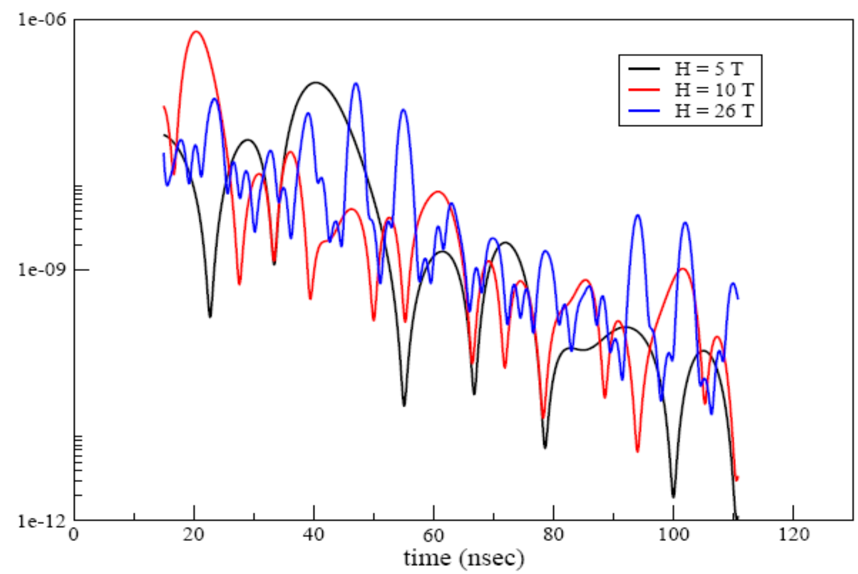
Energy domain



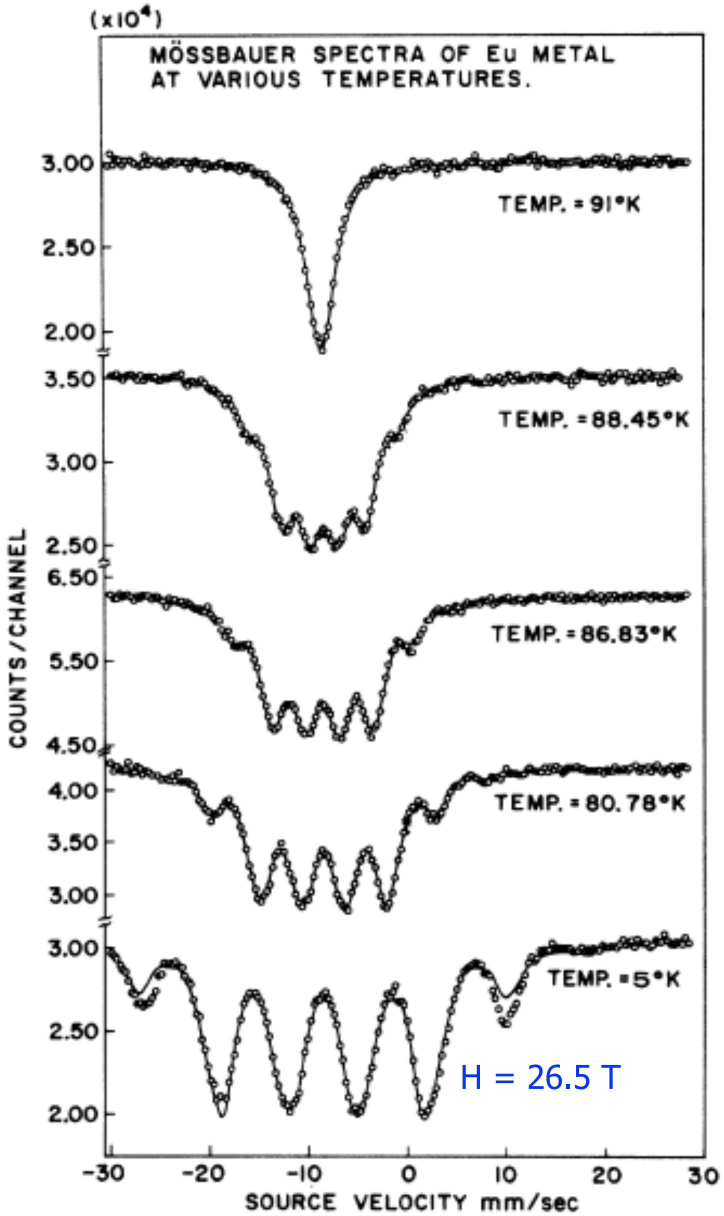


Time domain

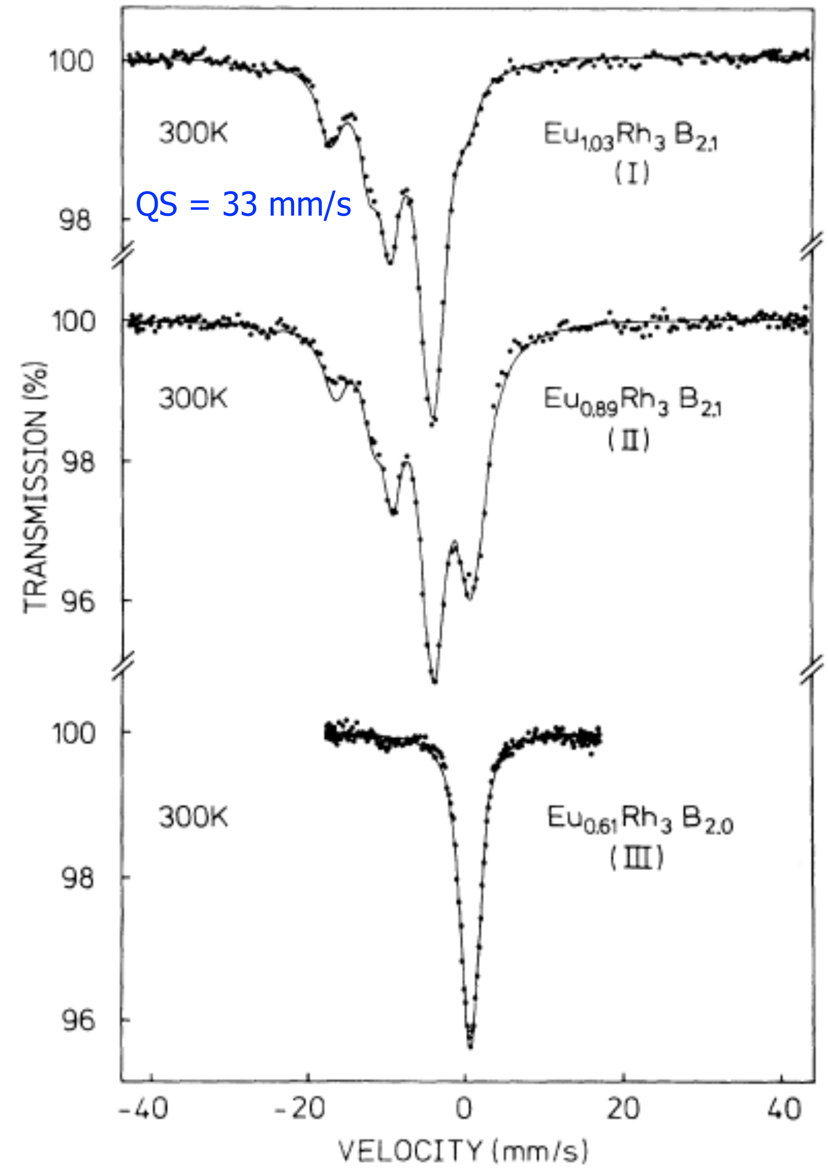




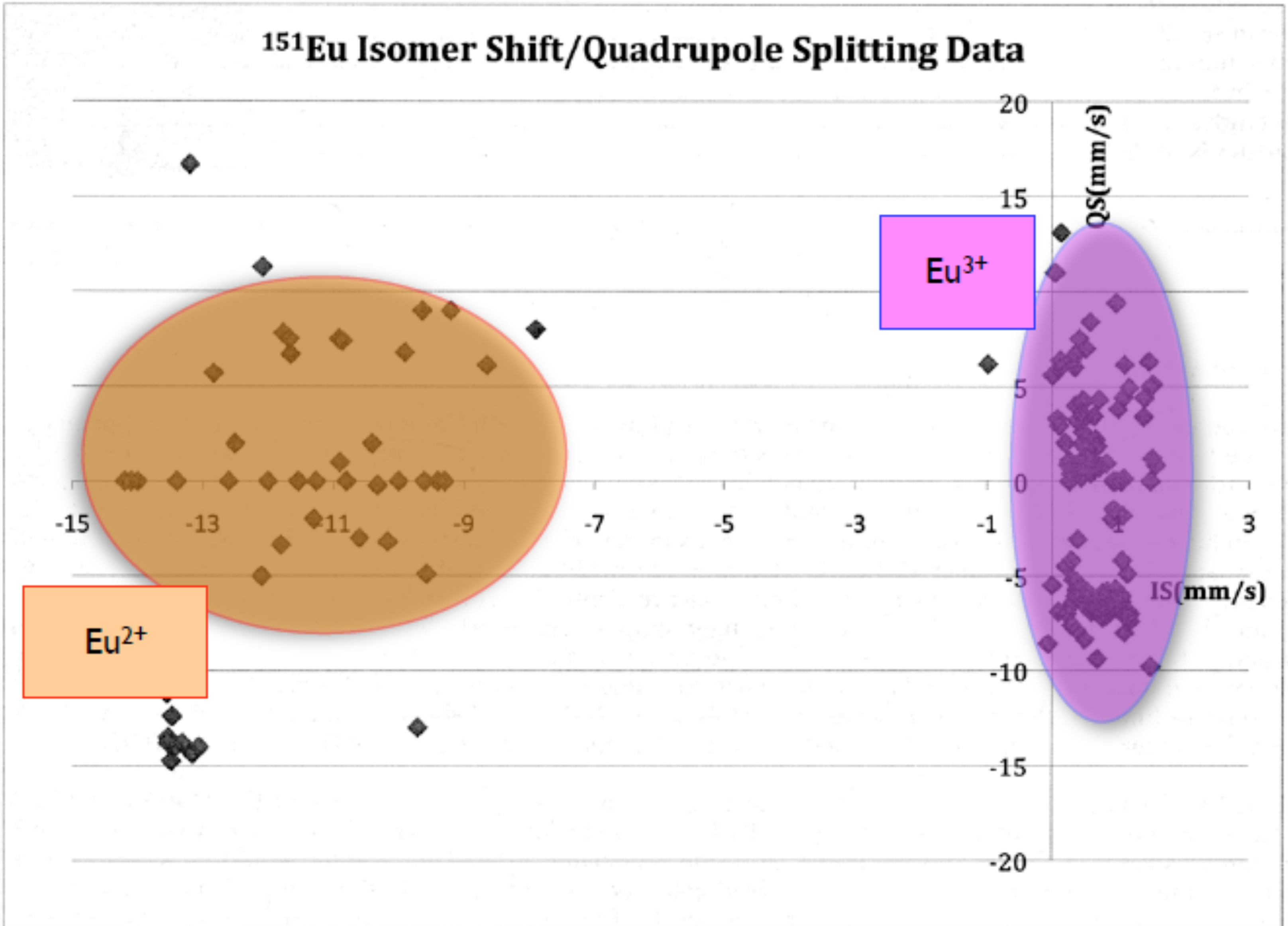
Experimental lab Mössbauer data in ^{151}Eu



Cohen et. al., Phys. Rev. 184, 263 (1969).
Barrett and D. Shirley, Phys. Rev. 131, 123 (1963).



Shaken et al., Phys. Rev. Lett. 55, 312 (1985).
Malik et al.,Phys. Rev. Lett. 55, 316 (1985).



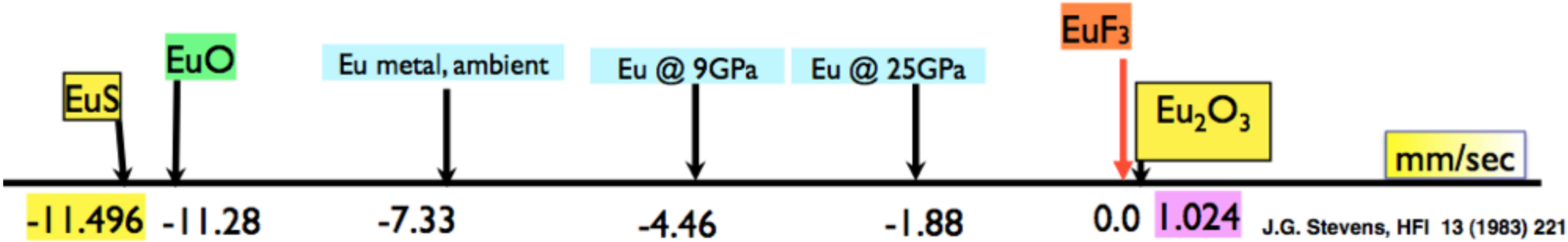
Eu^{2+}: ($4f^7$, $J=7/2$)

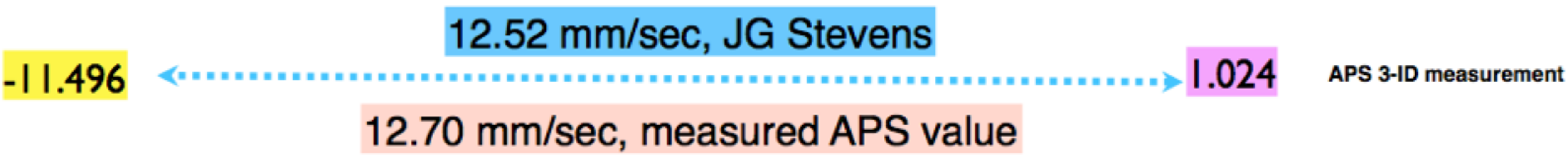
Eu^{3+}: ($4f^6$, $J=0$)

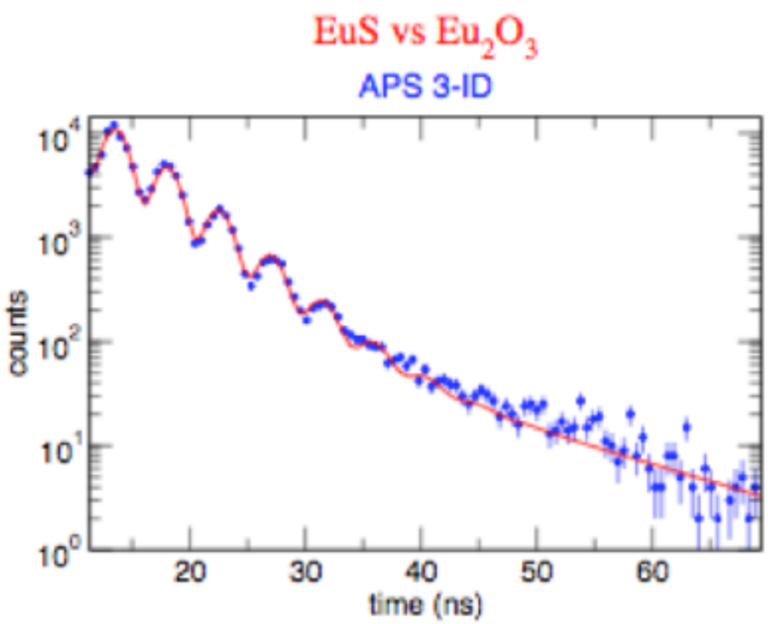
Data taken from Mössbauer effect data center, http://www.medc.dicp.ac.cn/

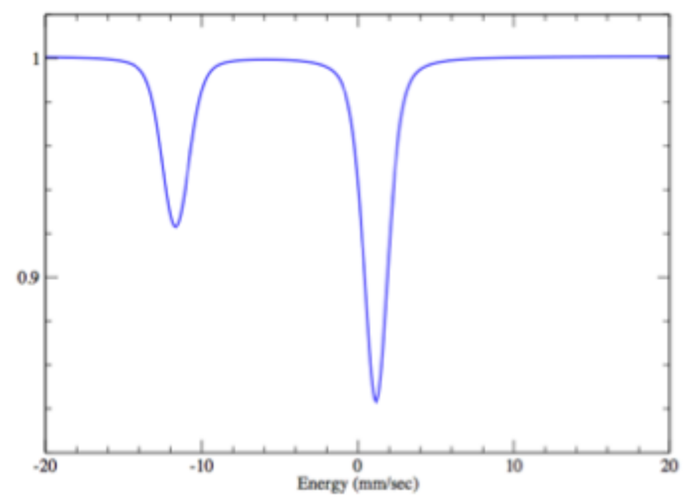
September 2010

Isomer shift scale of ^{151}Eu under pressure



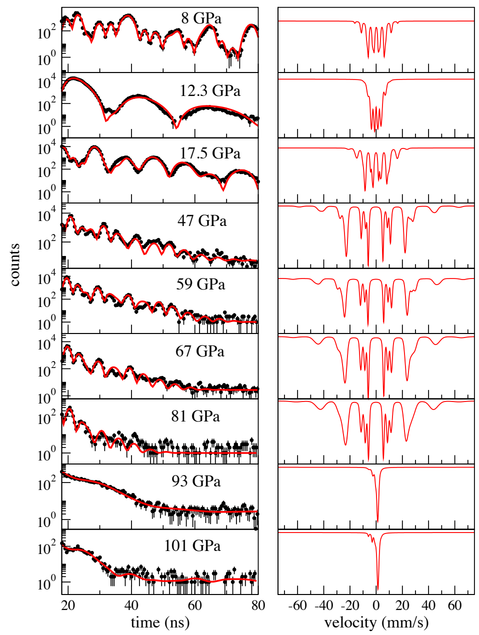


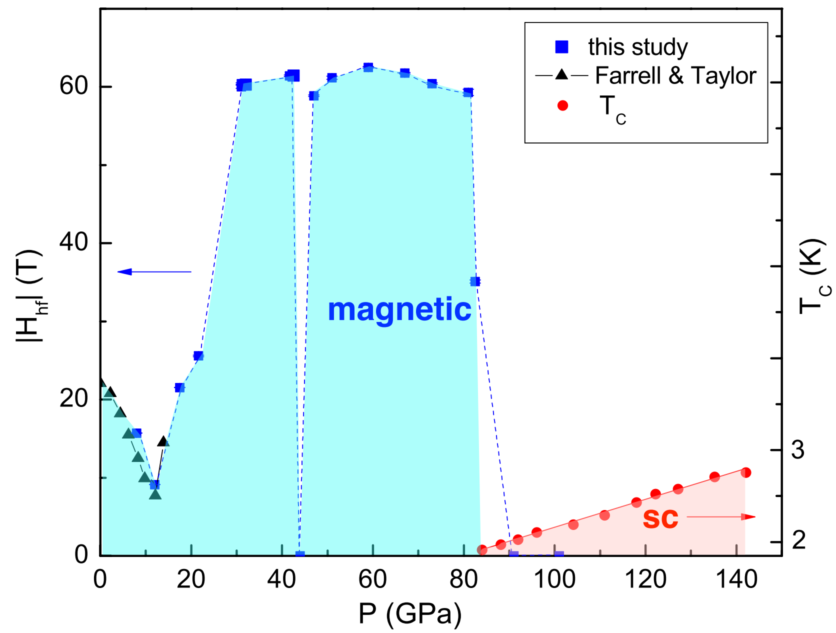


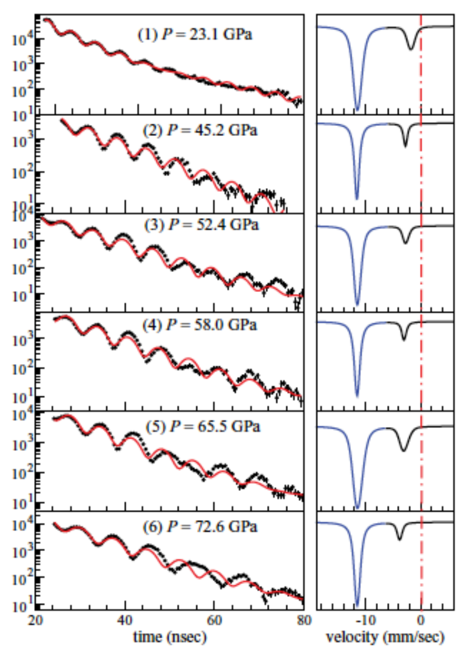


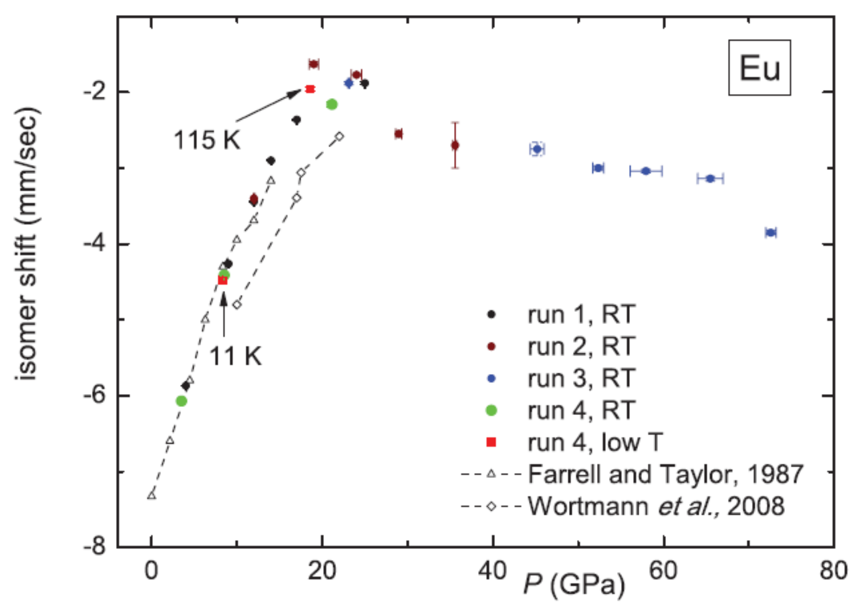
Courtesy of E. E. Alp

Pressure induced magnetic transition in Eu ($4f^7 5d^0 6s^2$ $J = 7/2$)



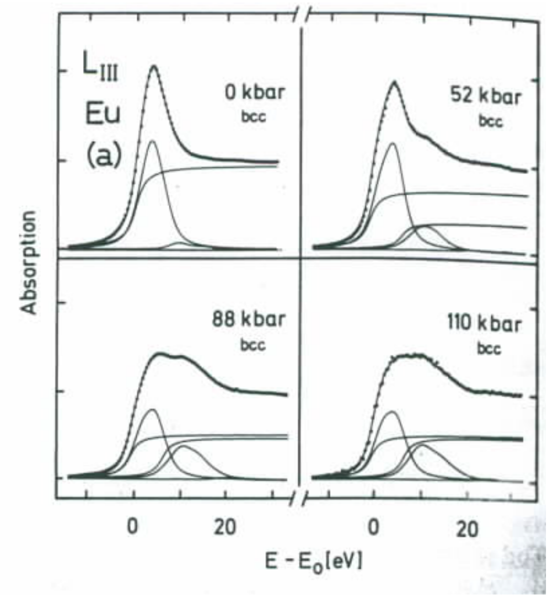


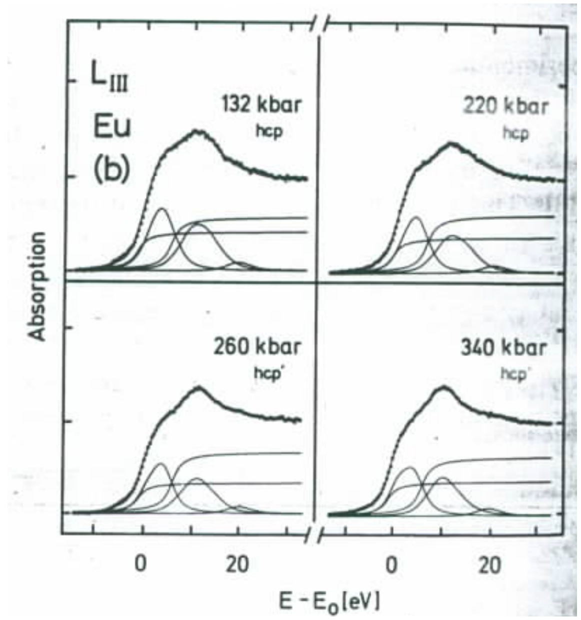


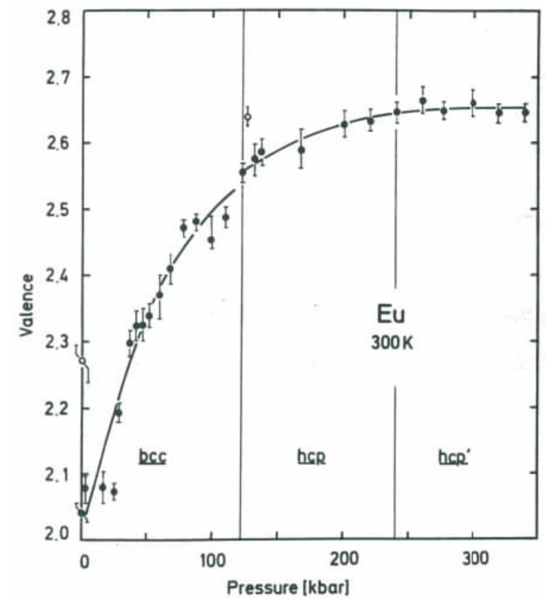


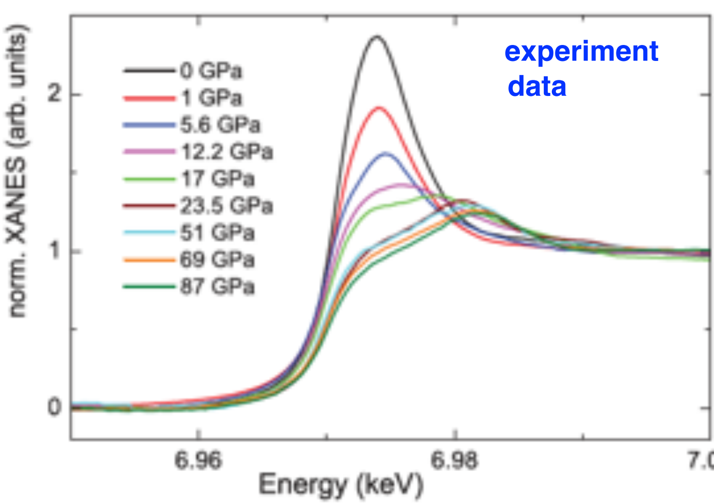
Bi *et al.*, *Phys. Rev. B.* **93**, 184424 (2016).

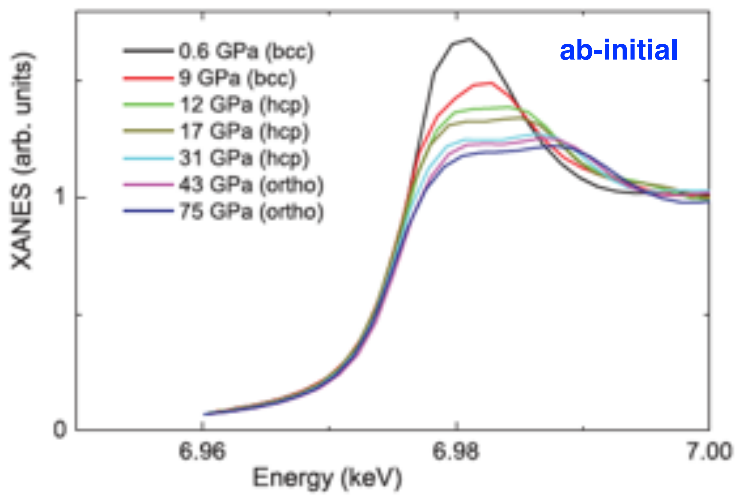
No significant valence change in Eu











Röhler, *Phys. B+C 144, 27 (1986).*
Bi *et al., Phys. Rev. B*. **93**, 184424 (2016).

Basic Mössbauer parameters of ^{161}Dy ($4f^9 5d^1 6s^2$, $J = 15/2$)

Isotope	E_γ [keV]	a [%]	Γ_0 [neV]	τ_0 [ns]	I_g	I_e	Multi-polarity
^{181}Ta	6.23	99.9	0.067	9870	7/2	9/2	E1
^{169}Tm	8.41	100	114	5.8	1/2	3/2	M1
^{83}Kr	9.40	12.0	3.3	212	9/2	7/2	M1
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^{121}Sb	37.13	57.25	130.0	5.0	5/2	7/2	M1
^{40}K	29.83	0.0117	160.5	4.13	4	3	M1
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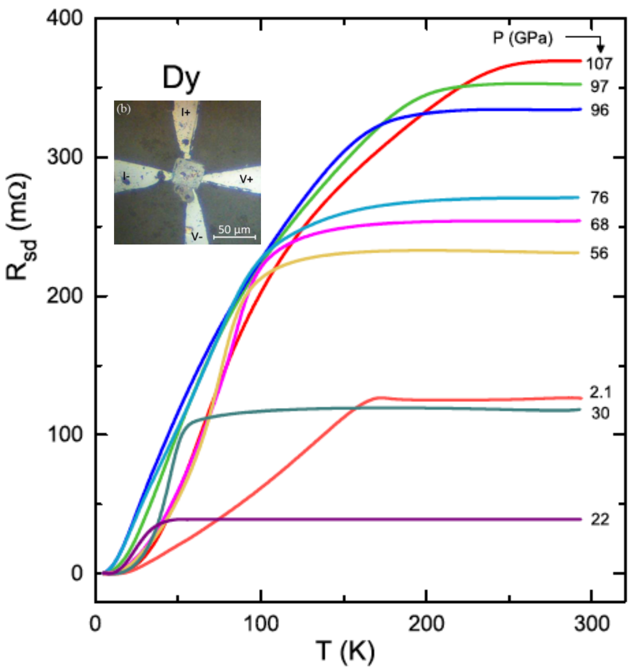
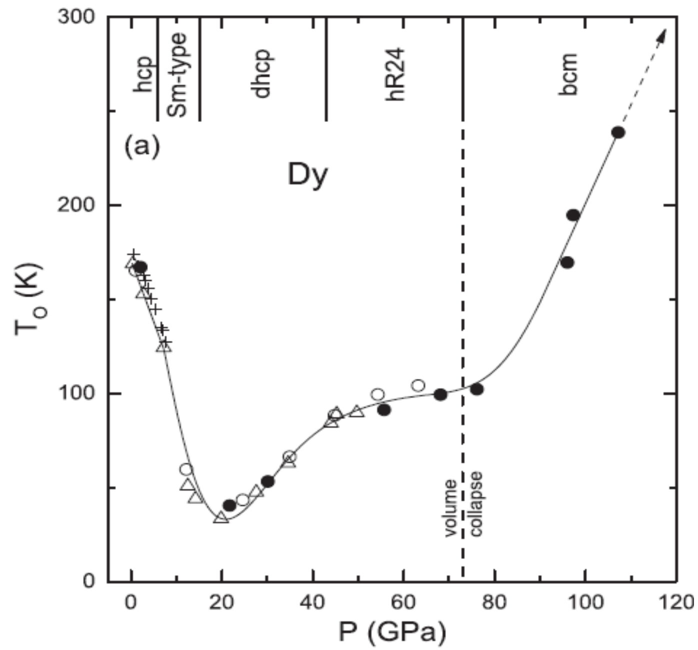
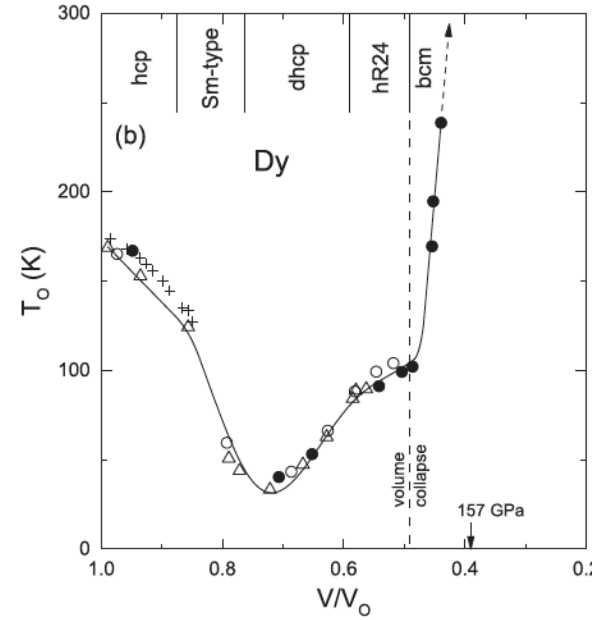
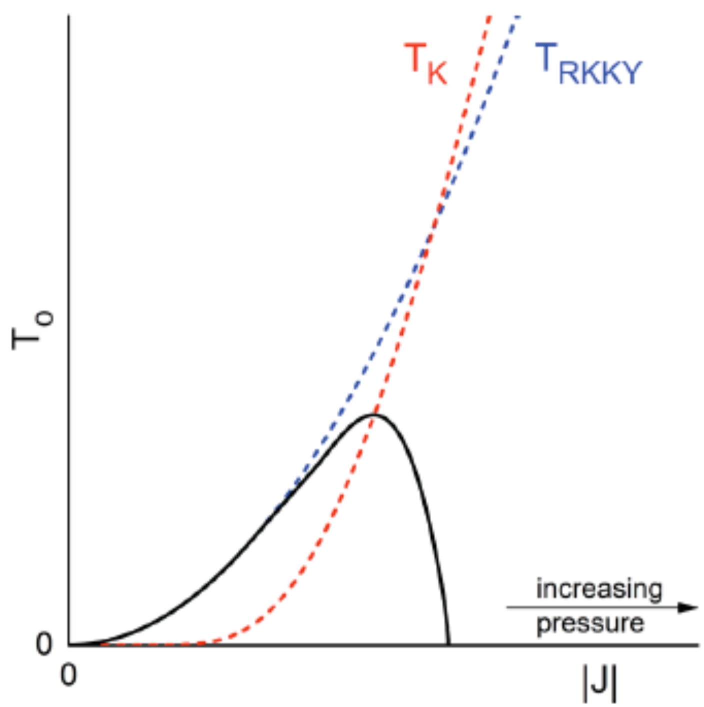
R. Röhlsberger, *Nuclear Condensed Matter Physics with Synchrotron Radiation*, (Springer Berlin Heidelberg, Berlin, Heidelberg, 2005), Ch. 2, p. 25.

Magnetism in Dy









Doniach model

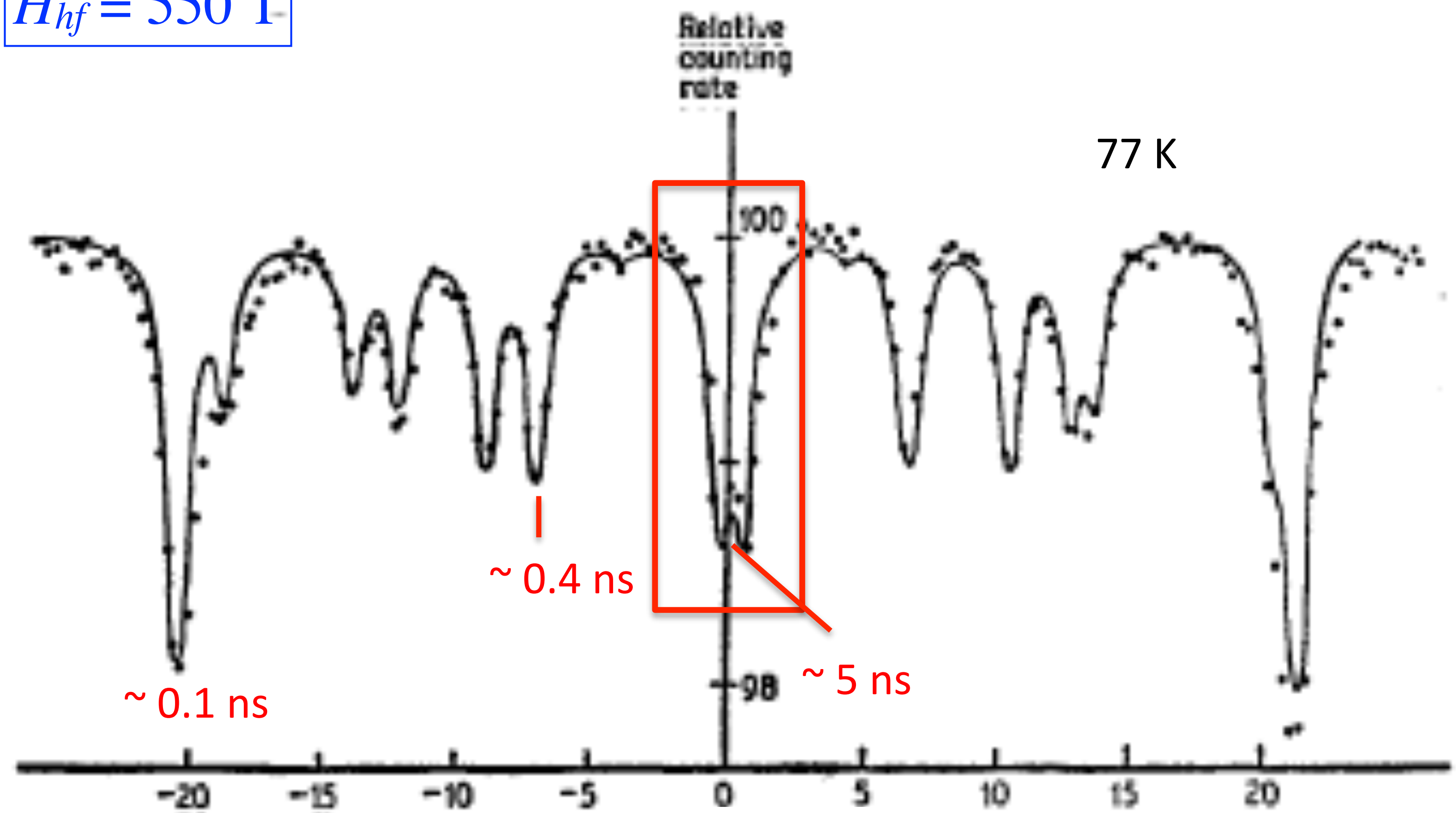
$T_{RKKY} \sim J^2$

$T_k \sim \exp(|J|)$

Lim *et al.*, *Phys. Rev. B* **91**, 045116 (2015).

Samudrala *et al.*, *High Press. Res.* **34**, 266 (2014).

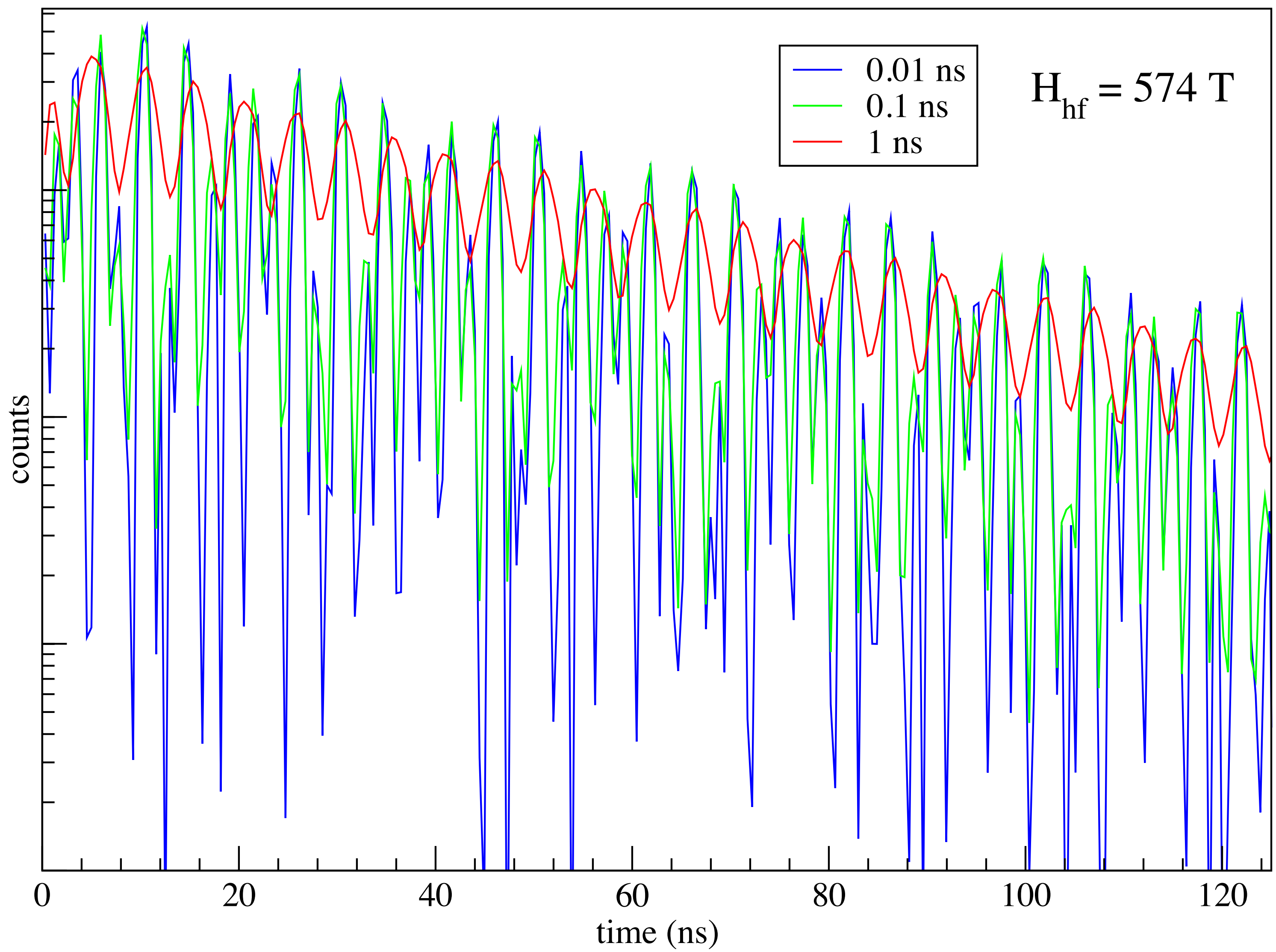
$H_{hf} = 550$ T

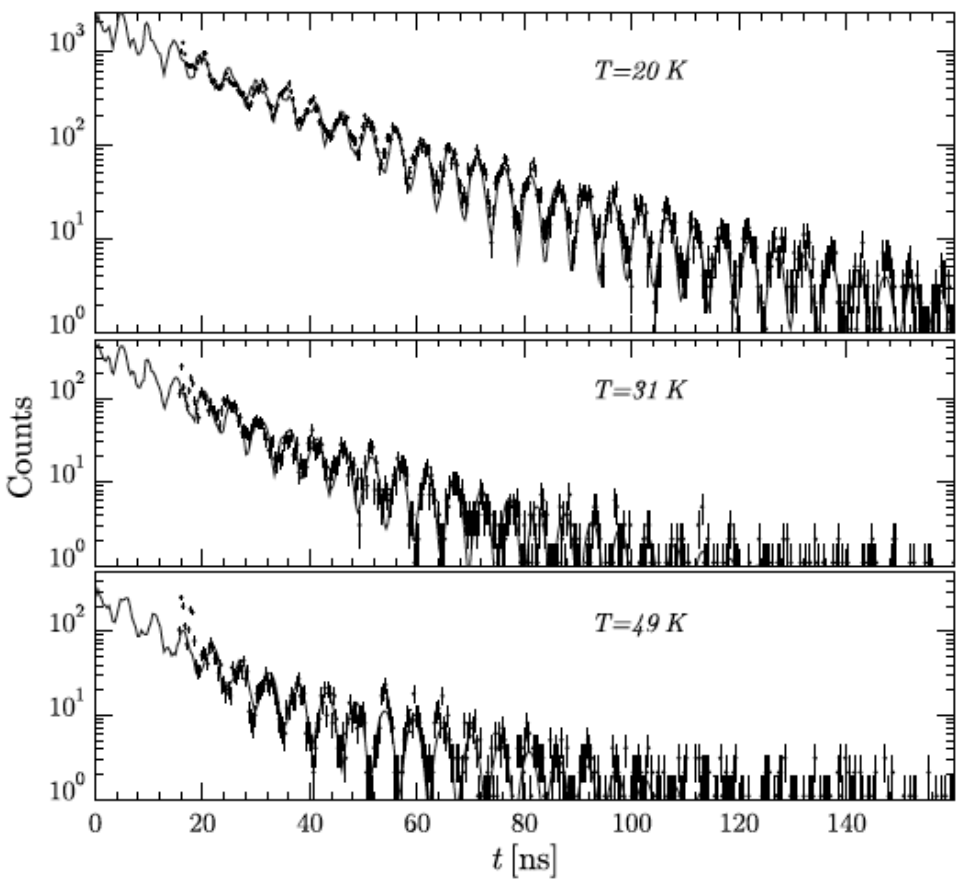


G.J. Bowden, D.S.P. Bunbury, and J.M. Williams, Proc. Phys. Soc. 91, 612 (1967).

40 cm/s splitting (0.12 ns), beyond the APD time resolution (1 ns).
As a result, only the inner splitting can be resolved from time domain spectrum.

Dy SMS simulation with different detector time resolution





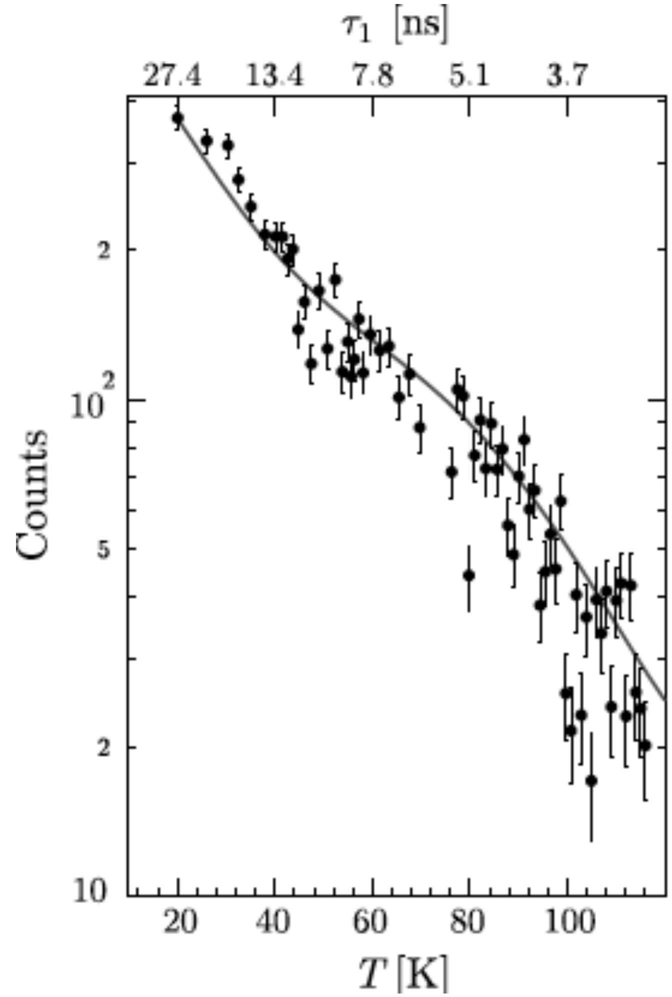


TABLE I –

T (K)	B (T)	f_{LM}	τ_1 (ns)
20	578.9(2)	0.78(5)	27(1)
31	577.6(4)	0.76(2)	16(1)
49	554.7(5)	0.74(2)	11(1)

Y. V Shvyd'ko *et al.,* Europhys. Lett. 56, 309 (2001).

Magnetic hyperfine field in Eu ($6s^2 4f^7 5d^0$)

$$H_{hf} = H_C + H_{CE} + H_n$$

at 4.2 K

TABLE III. Analysis of the hyperfine fields in Eu metal and Gd metal.

		H_{eff} (kOe) Eu	H_{eff} (kOe) Gd
H_C →	Core polarization	$-(340\pm20)$ [a]	$-(340\pm20)$ [b]
H_{CE} →	Conduction-electron polarization by own 4*f* electrons	$+(190\pm20)$ [c]	$+(240\pm50)$ [c]
H_n →	Neighbor effects: conduction-electron polarization+overlap+covalency	$-(115\pm20)$ [c]	$-(200\pm60)$ [d]
	Metal	$-(265\pm5)$ [e]	$-(350\pm35)$ [f]

H_C: insensitive to volume change.
H_{CE} and H_n: dependent of volume (pressure) change. RKKY interaction.

Elmegid and Kaindl, hyperfine interactions 4, 420 (1978).
Klein, Wortmann and Kalvius, 18,291 (1976);
Nowik, Dunlap and Wernick, Phys. Rev. B 8, 238 (1973).
Hüfner and Wernick, Phys. Rev. 173, 448 (1968)