MULTIPAC: a versatile tool to investigate multiferroic and magnetic materials

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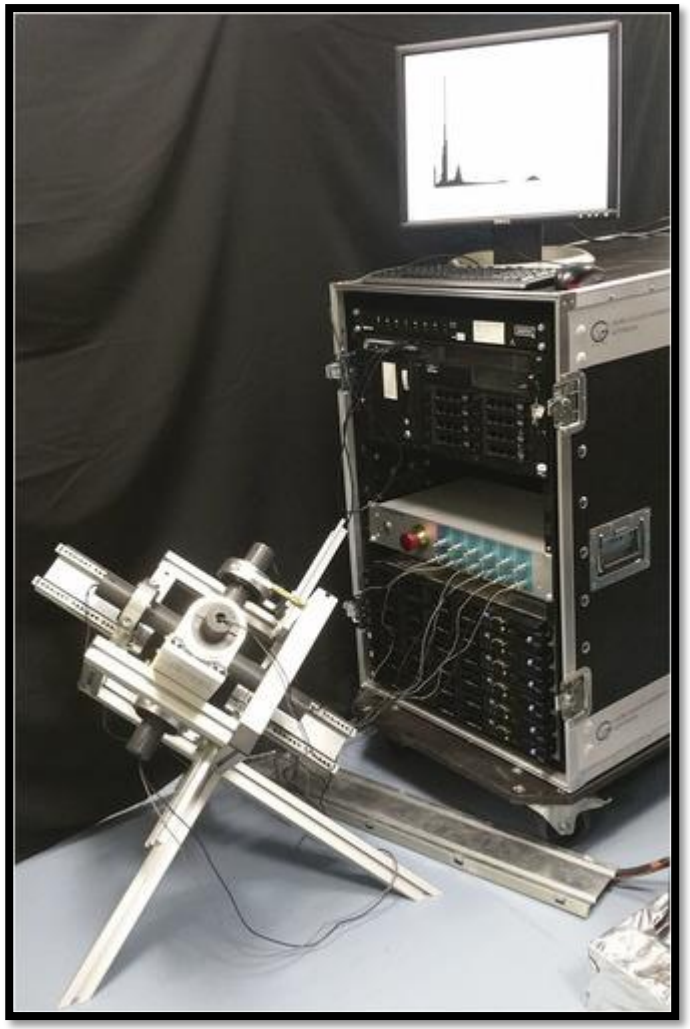
Contents

- Short Description of the PAC method
- Introduction to the MULTIPAC Setup
- Probes
- Selected material for the first run: BFO
- Conclusions and acknowledgments



KATAME setup. AIP Advances 7, 105017 (2017)
https://doi.org/10.1063/1.4994249
Review of Scientific Instruments 81, 073501 (2010)
https://doi.org/10.1063/1.3455186

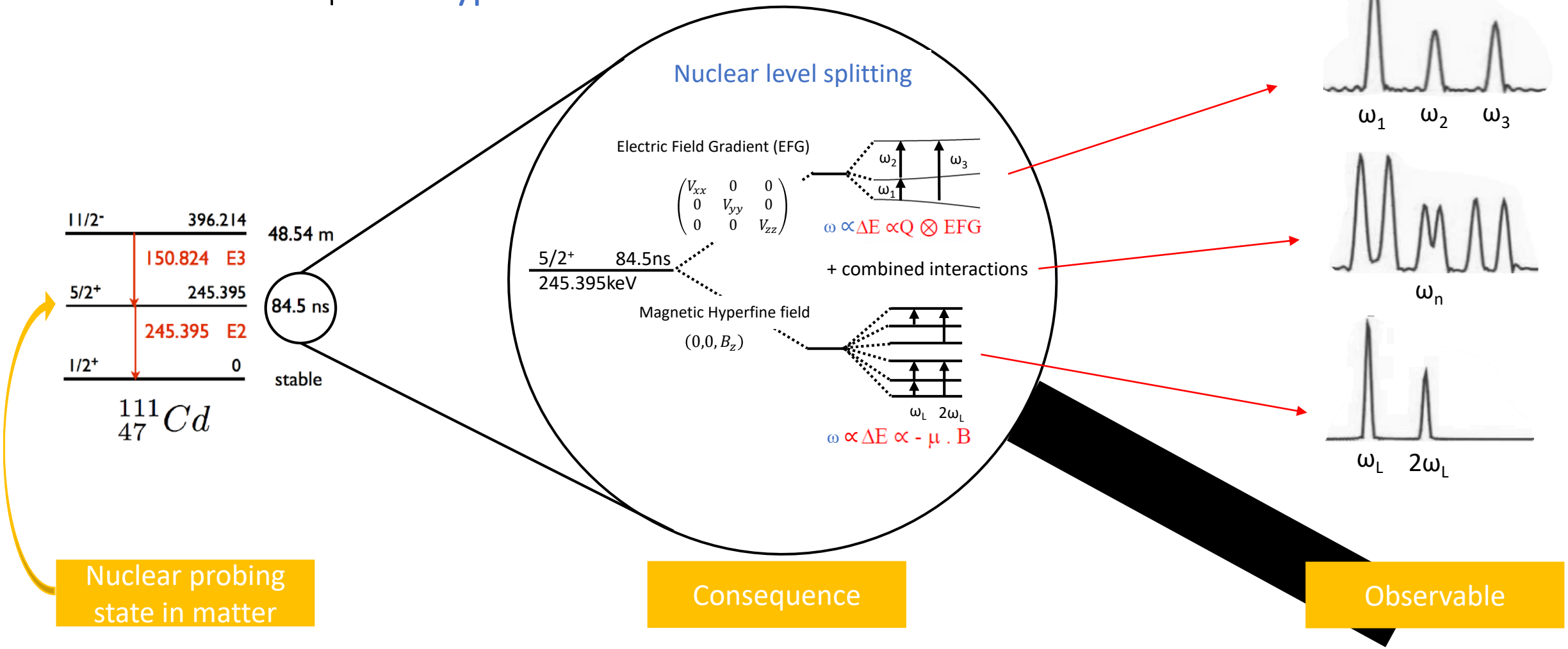
Perturbed Angular Correlation

Grindelwald city, Switzerland, 2021.
Analogy with the hyperfine interaction occurring in a material:
A city interacting with its surrounding countryside.

Ski slope after many skiers have skied on it

Perturbed Angular Correlation (PAC)

A method to probe **hyperfine interactions** in matter



A singular equipment in the world…

A singular equipment in the world…

MULTIPAC

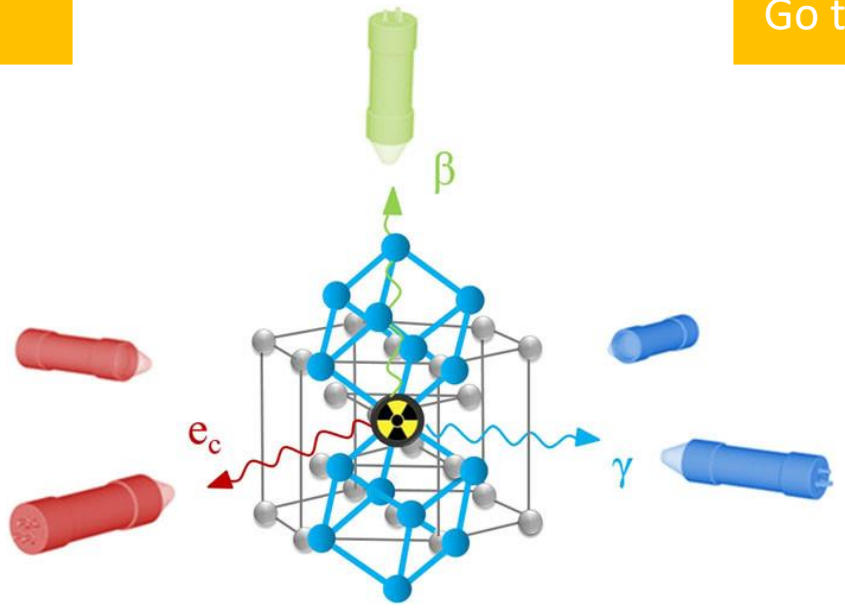
MULTIPAC goals

VSM ⟷ electric fields + low temperature

Up to 10 T

Go to 4 K (< 20 min)

vibrating sample magnetometer



AIP Advances 7, 105017 (2017)
https://doi.org/10.1063/1.4994249

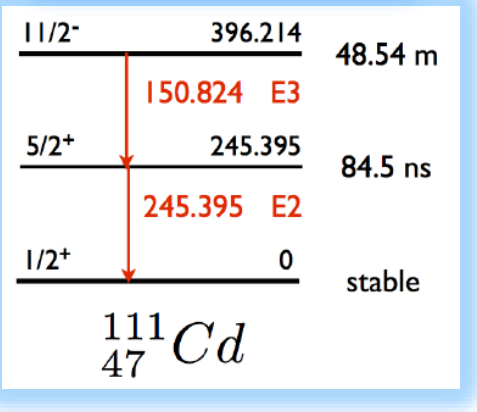
Simultaneous VSM and electric load

electric load

Digital PAC setup

Nuclear probes

Selected probe



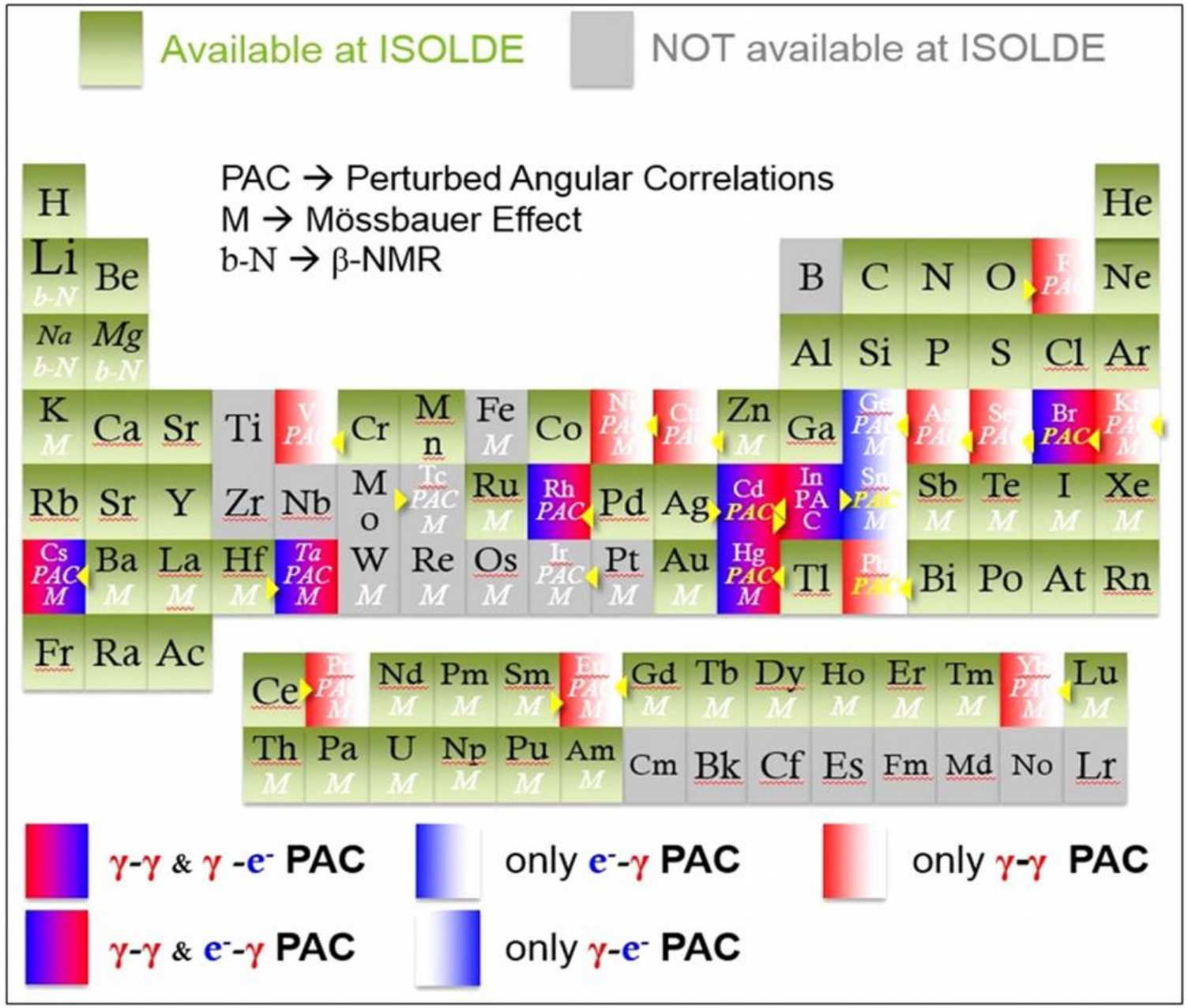


Figure source: K. Johnston, J. Schell, J. Correia, M. Deicher, H. Gunnlaugsson, A. Fenta, E. David-Bosne, A. Costa, and D. C. Lupascu, J. Phys. G 44, 104001 (2017).

Nuclear probes for a great start

Parent isotope	$t_{1/2}$	Decay	Probe isotope	γ_1–γ_2 E (keV)	I	$t_{1/2}$ (ns)	Q (b)	μ (μ_N)
^{68m}Cu	3.75 min	IT	^{68}Cu	526–84	2+	7.84(8)	(−)0.110(3)[a]	(+)2.857(6)[a]
^{99}Mo	2.7 d	EC	^{99}Tc	740–181	5/2+	3.61(7)	unknown	+3.48(4)
^{111}Ag	7.45 d	β^-	^{111}Cd	97–245	5/2+	84.5(4)	+0.68(2)[b]	−0.7656(25)
^{111m}Cd	48 min	IT	^{111}Cd	151–245	5/2+	84.5(4)	+0.68(2)[b]	−0.7656(25)
^{111}In	2.8 d	EC	^{111}Cd	171–245	5/2+	84.5(4)	+0.68(2)[b]	−0.7656(25)
^{172}Lu	6.7 d	EC	^{172}Yb	91–1094	3+	8.14(17)[c]	−2.9(3)	+0.65(4)
^{181}Hf	42.4 d	β^-	^{181}Ta	133–482	5/2+	10.8(1)	+2.28(2)	+3.29(3)
^{199m}Hg	42 min	IT	^{199}Hg	374–158	5/2−	2.46(3)	+0.95(7)	+0.88(3)
^{204m}Pb	67 min	IT	^{204}Pb	912–375	4+	265(6)	0.44(2)	+0.225(4)

MULTIPAC goals

E_{field} ⟷ VSM + Low temperature

Atomic shifts

μ_N value

spin ordering

Octahedron or tetrahedron rotations

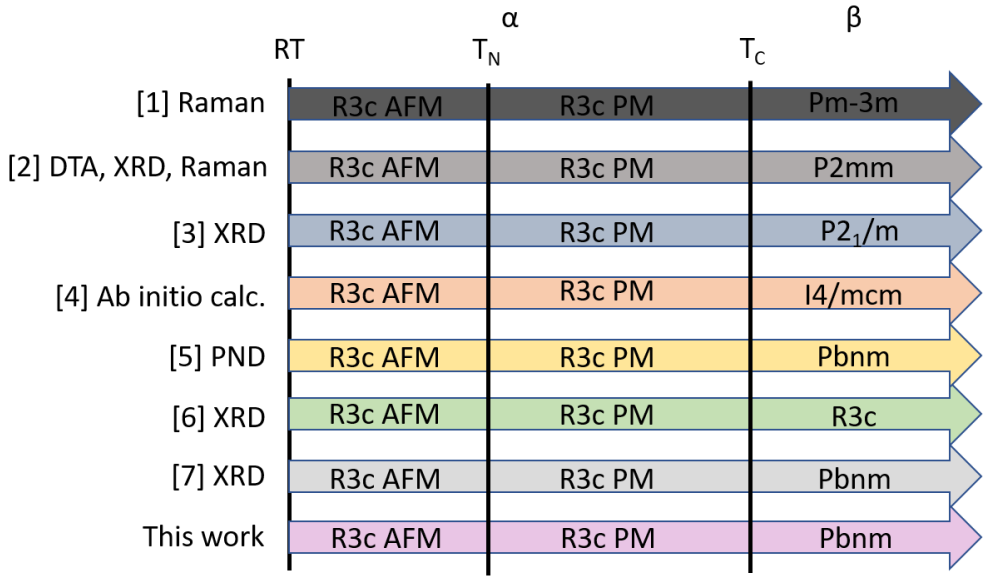
Defects and lattice deformation

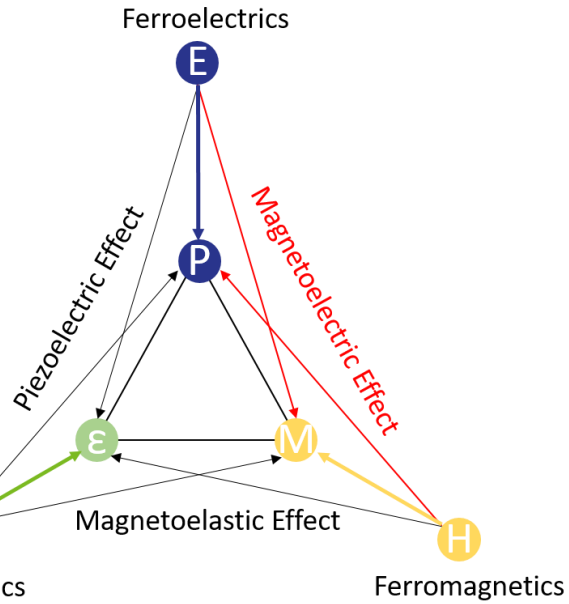
Lattice location of the probe

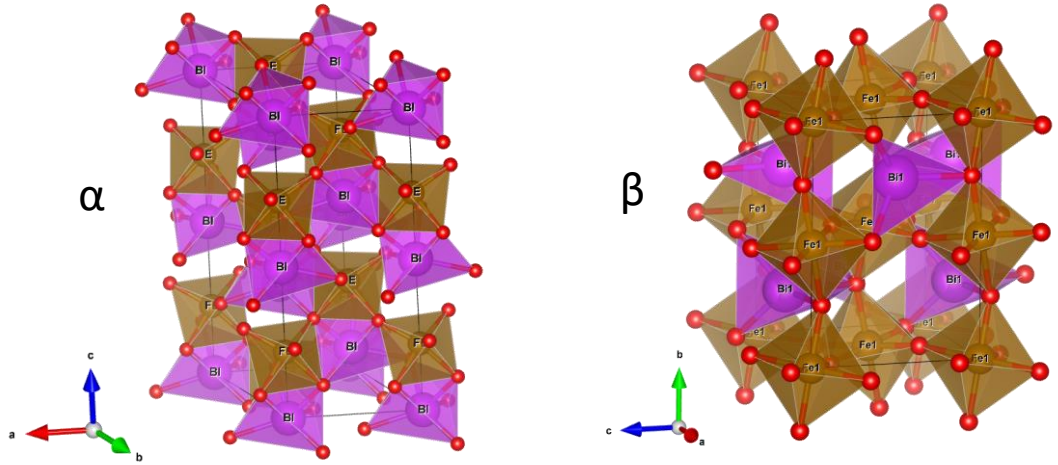
Bismuth Ferrite – $BiFeO_3$

- Curie Temperature ≈ 820°C
- Néel Temperature ≈ 370°C
  - Thus magnetoelectric at room temperature

- Rhombohedral α-phase
- Orthorhombic β-phase

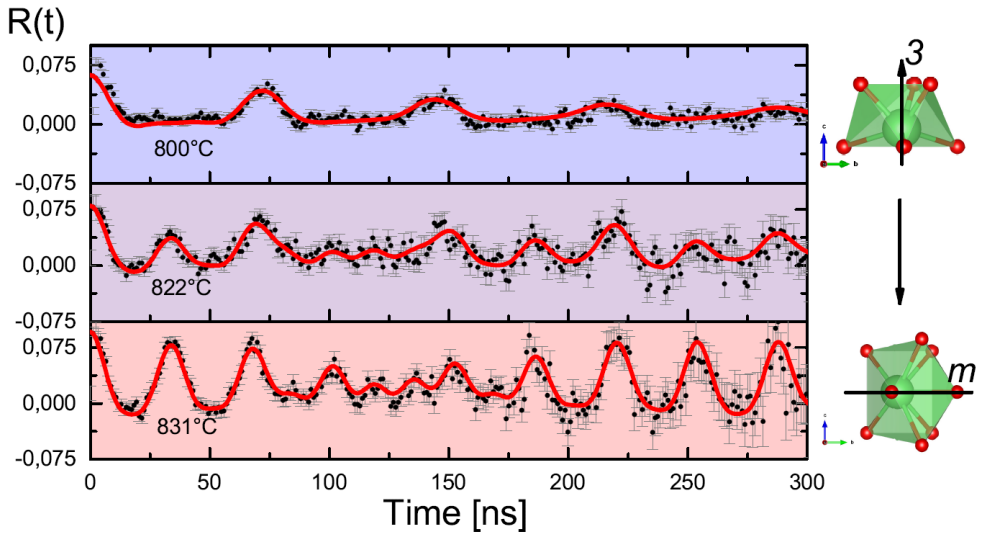


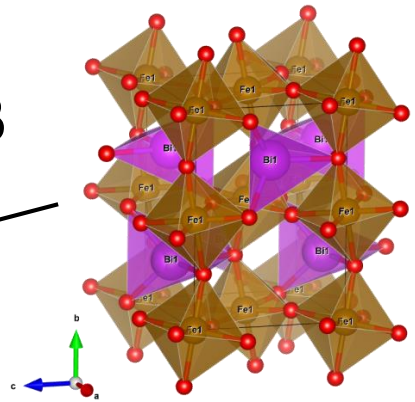


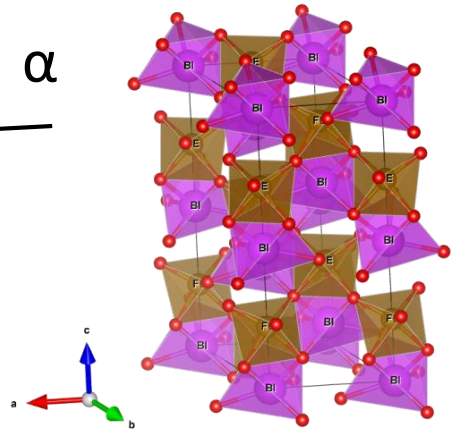


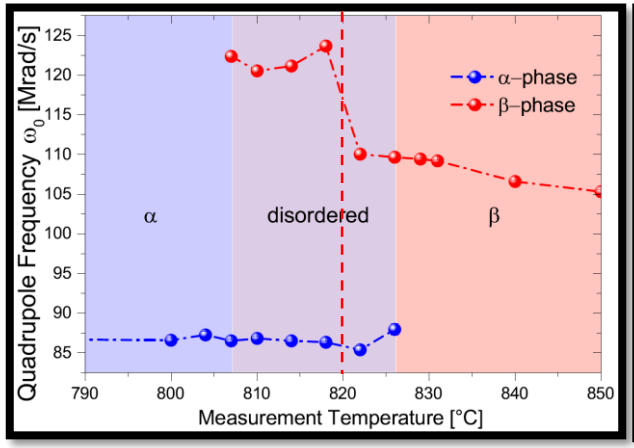
G. Marschick, J. Schell, B. Stöger, J. N. Gonçalves, M. O. Karabasov, D. Zyabkin, A. Welker, M. Escobar C., D. Gärtner, I. Efe, R. A. Santos, J. E. M. Laulainen, and D. C. Lupascu, Phys. Rev. B **102**, 224110.

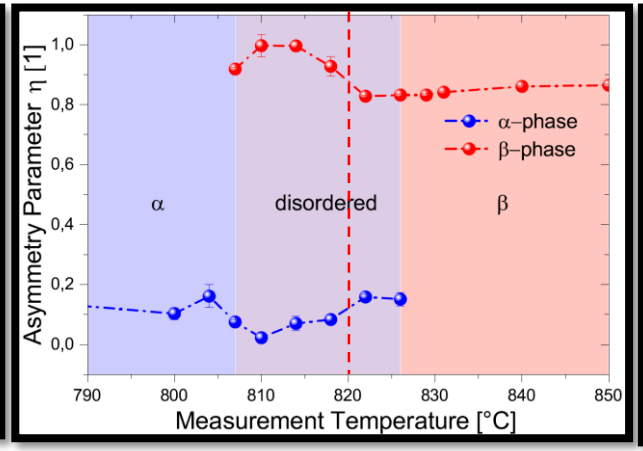
Temperature dependence of hyperfine parameters

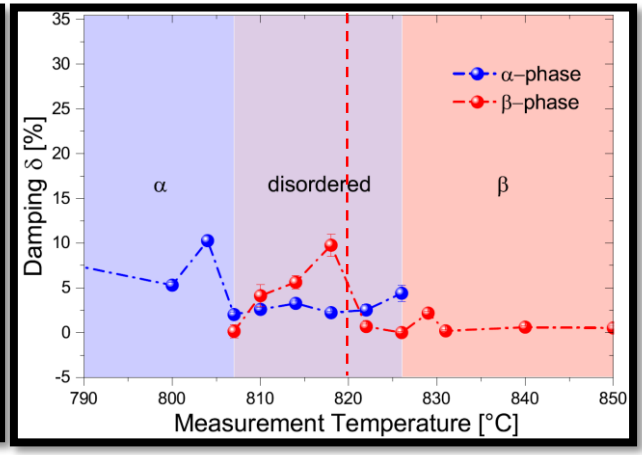


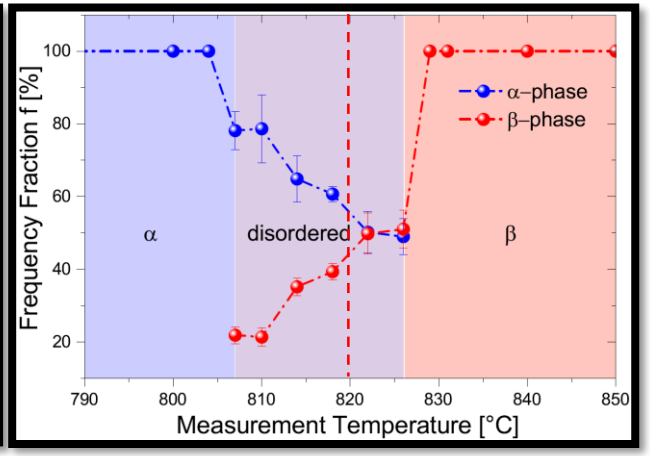






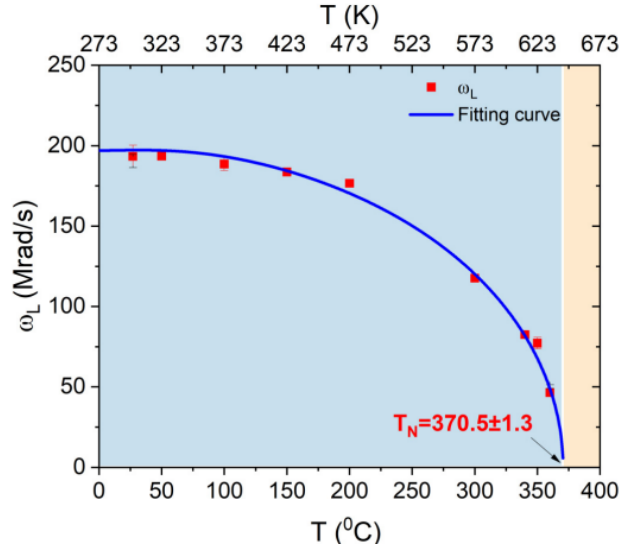






Below Tn: ^{111}In

PHYSICAL REVIEW B **106**, 054416 (2022)



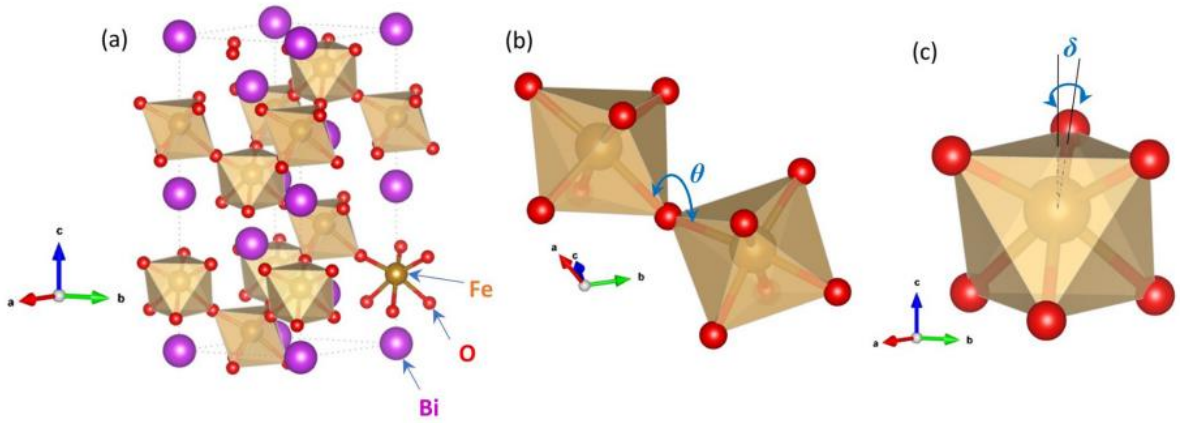


FIG. 1. (a) Unit cell representation of BFO where the Bi-O bonds are not shown. (b) Magnified view of two neighboring, interconnected FeO_6 octahedra. (c) FeO_6 octahedra viewed along the threefold axis to emphasize octahedral tilting. This picture was reproduced based on the work of Ruchi *et al.* (Fig. 1) [3] using the VESTA program [4].

Temperature dependence of the local electromagnetic field at the Fe site in multiferroic bismuth ferrite

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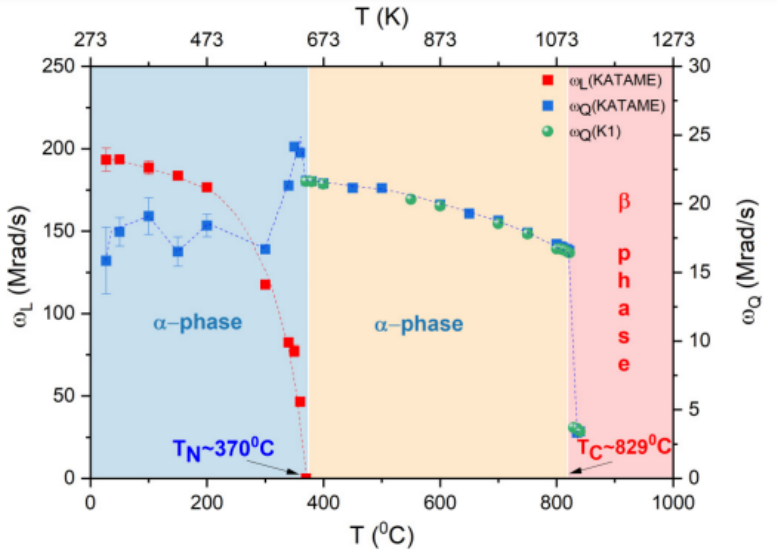

FIG. 4. Temperature dependence of the quadrupole (ω_Q) and Larmor (ω_L) frequencies according to the KATAME and K1 machines. The α phase is shown in orange ($T > T_N$) and light blue ($T < T_N$) layers, whereas the β phase is shown in the brick red layer. The red and blue dotted curves are shown for visual guidance.

Thank you very much!

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