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NanoMag

Philipp Bender [1], Diego Alba Venero [1], Luis Fernández Barquín [1], Rocío Costo [2], Mikkel Fougt Hansen [3], Cathrine Frandsen [3], Jeppe Fock [3], Sarah Rogers [4], Peter Svedlindh [5], Erik Wetterskog [5], Christer Johansson [6]

[1] CITIMAC, Universidad de Cantabria, Santander, Spain [2] Instituto de Ciencia de Materiales de Madrid, CSIC, Spain [3] Department of Physics/DTU Nanotech, Technical University of Denmark [4] ISIS-STFC, Rutherford Appleton Laboratory, United Kingdom [5] Faculty of Technology, Uppsala University, Sweden [6] Acreo Swedish ICT AB, Göteborg, Sweden

Introduction

Magnetization behavior of ensembles of Iron Oxide Nanoparticles (IONPs) primarily depends on their structural as well as magnetic properties + interparticle interactions.
Presence of dipolar interactions has significant implications in biomedical applications [1].

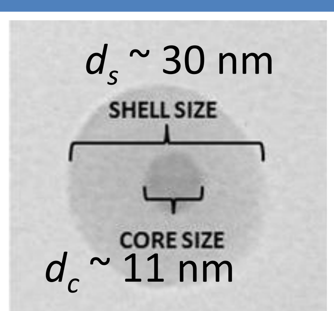
Standardizing the determination of magnetic parameters (e.g. chemical composition, magnetic moment distribution, dipolar interactions) driving those applications is a need for the future and goal of the **NanoMag** project.

[EC FP7 NMP project, grant no. 604448]

Current study: IONPs with different amounts of dipolar interactions are characterized by Mössbauer, SANS (structural properties) and combined M(H)/ZFC-FC-measurements (magnetic properties) to detect the influence of dipolar interactions on their magnetization behavior.

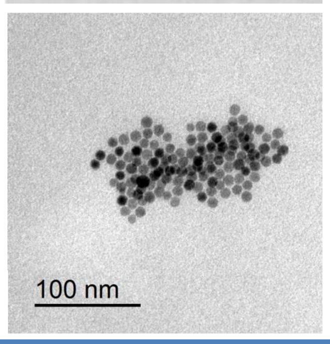
Samples

S1



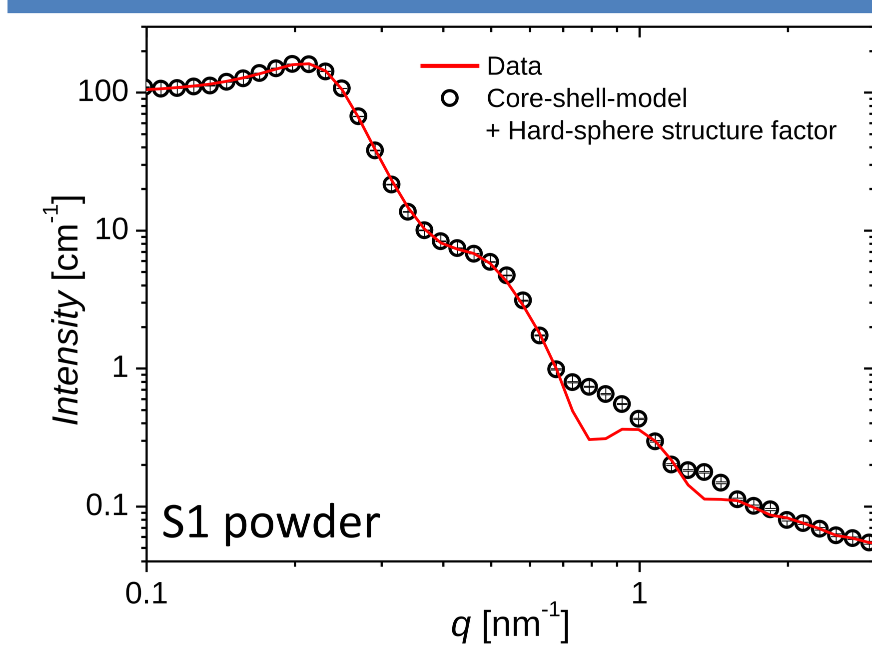
- IONPs surrounded with rigid silica shell. $d_c = 11\,nm$, $\sigma_{dc} = 0.7\,nm$
- Shell prevents agglomeration of IONPs.
- → Shell thickness determined by SANS.

S2



- Comparable d_c as S1 but agglomerates. $d_c = 10\,nm$, $\sigma_{dc} = 0.7\,nm$
- On average dipolar interactions should be higher than in S1 due to agglomerates.

Results: SANS



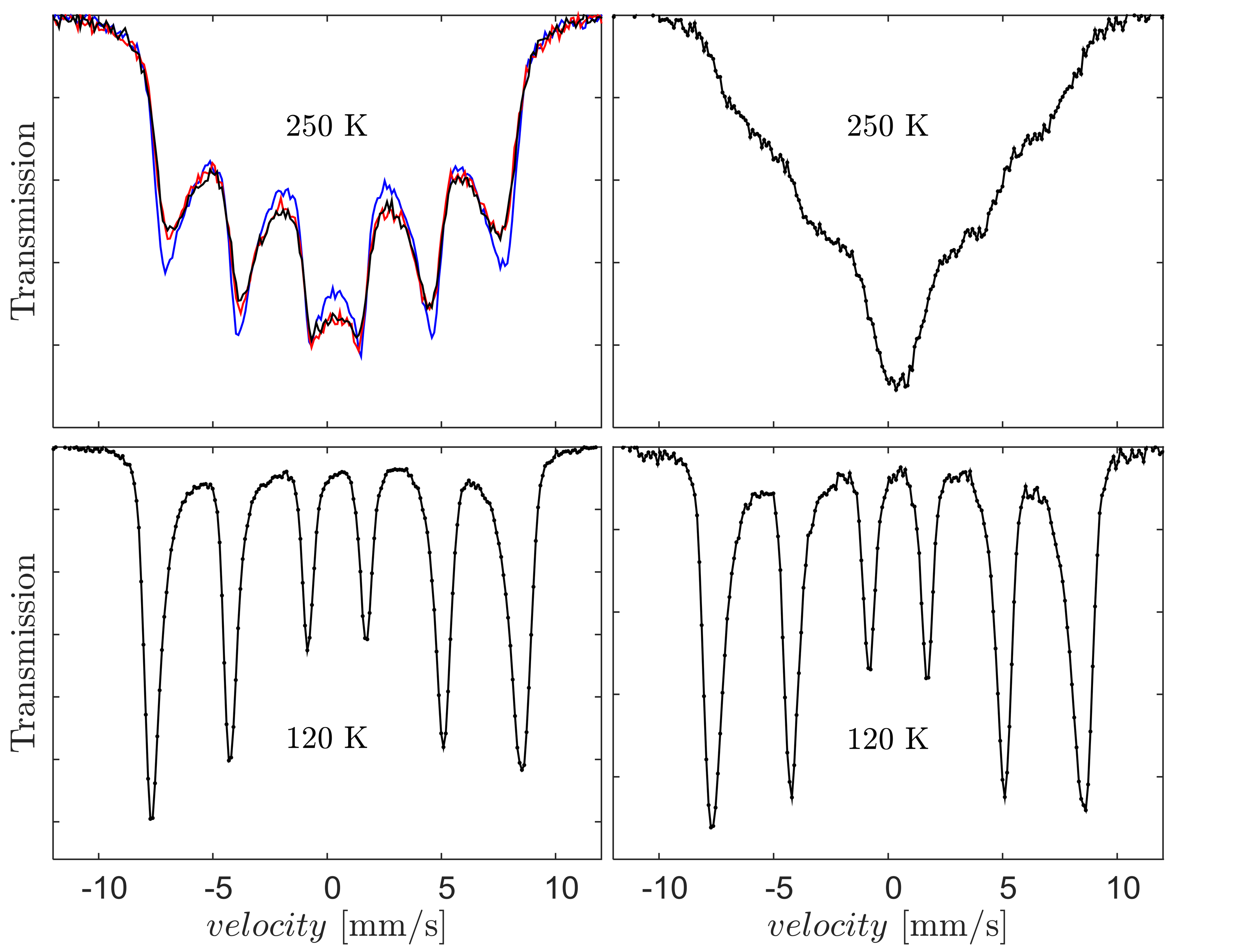
Adjusting scattering intensity with core-shell-model [2] enables exact determination of core (d_c) and shell (d_s) size distribution of S1:

$d_c = 11\,nm$, $\sigma_{dc} = 1\,nm$

$d_s = 26\,nm$, $\sigma_{ds} = 7\,nm$

Distance between magnetic cores in S1 is large enough so that dipolar interactions should be negligible!

Results: Mössbauer



i) Influence of sample preparation

S1: Mössbauer data of dispersion (black), powder (red) and gel (blue) at 250 K show no influence of sample preparation.

ii) Iron oxide composition

Maghemite/magnetite composition analysis using the mean isomer shift [3] corrected for 2nd order Doppler shift gives that main iron oxide is maghemite (at% Fe in magnetite: 25(5) for S1 and 0(5) for S2).

iii) Relaxation – size effect / dipolar interactions

S1: Using $K = 9.05\,kJ/m^3$, $V = \pi/6 \cdot d_c^3$, $\tau_0 = 1\,ns$ and a measuring time of $\tau \approx 5$ ns, we estimate a blocking temperature $T_B = KV/[k_B \ln(\tau/\tau_0)] \approx 300K$. Experimentally, we find $T_B \approx 300$ K (data not shown) consistent with the simple estimate. A more accurate analysis is topic for future work

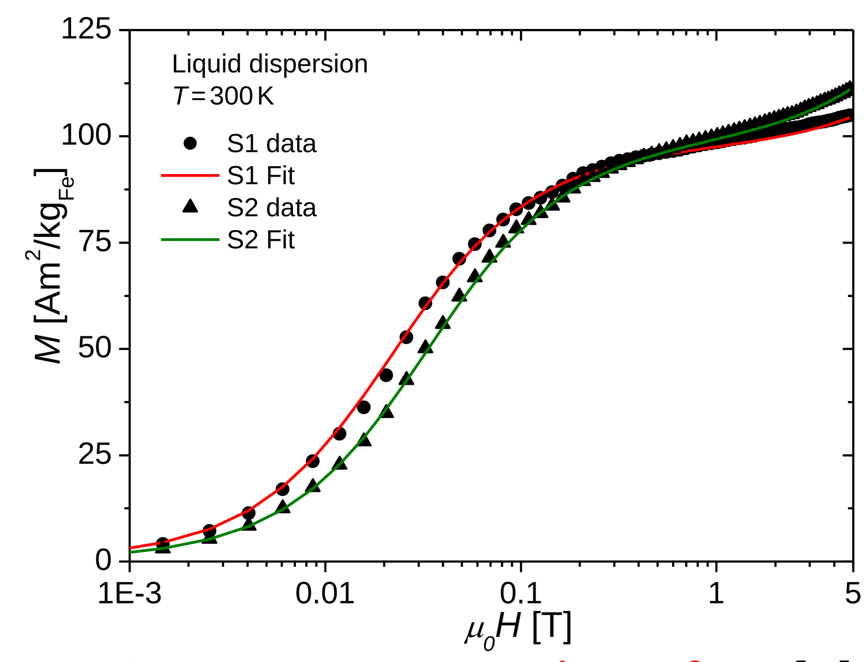
S2: We observe a lower blocking temperature than for S1, possible due to the slightly smaller size or due to dipolar interactions [4,5].

Results: Magnetic characterization

i) *M(H)* curves of dispersions

Fit with Langevin function, assuming a normal distribution of the core diameters d_c.

Fit results	S1	S2
d_c [nm]	11.1(1)	9.7(1)
σ_{dc} [nm]	2.2(1)	2.1(2)
M_S [Am²/kg$_{Fe}$]	98.5(1)	99.5(1)

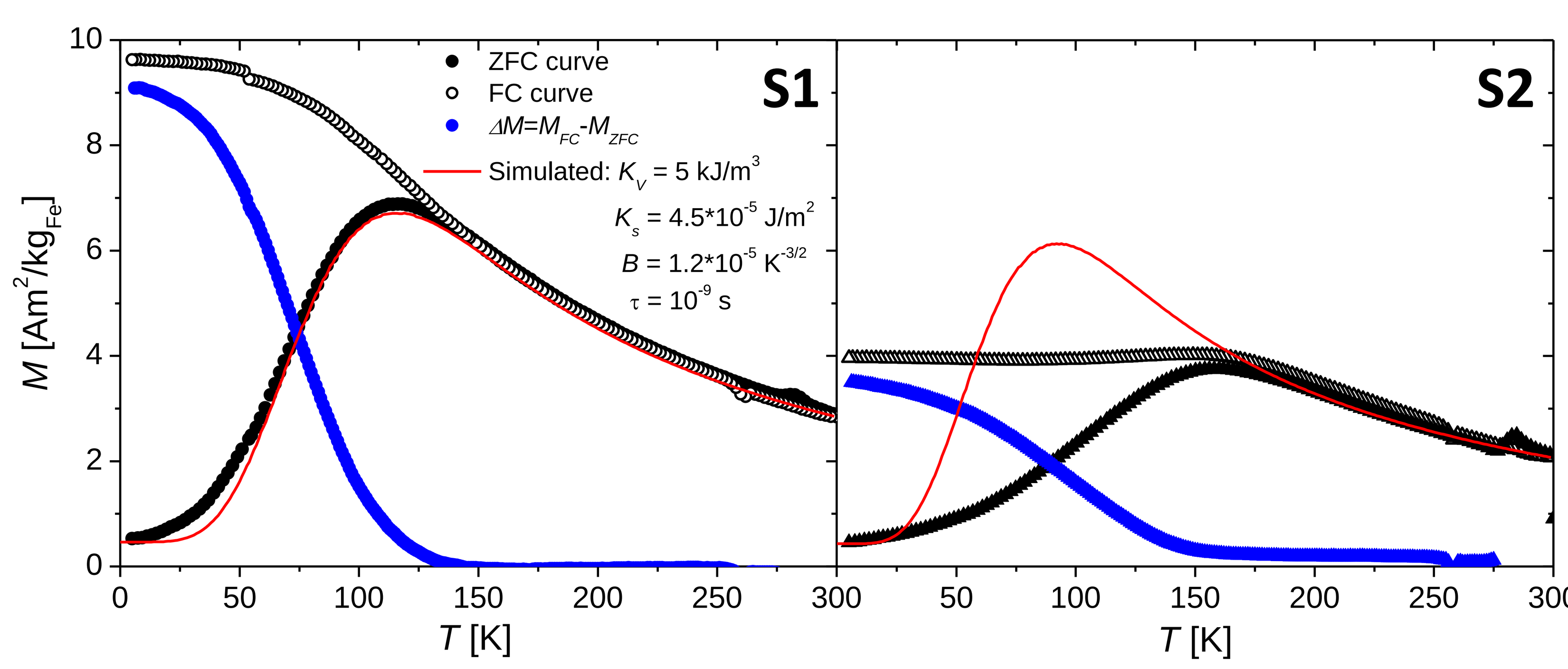


Reduced M_S values can be attributed to spin canting at particle surface [6].

ii) Simulation of ZFC curves including d_c distributions [7]

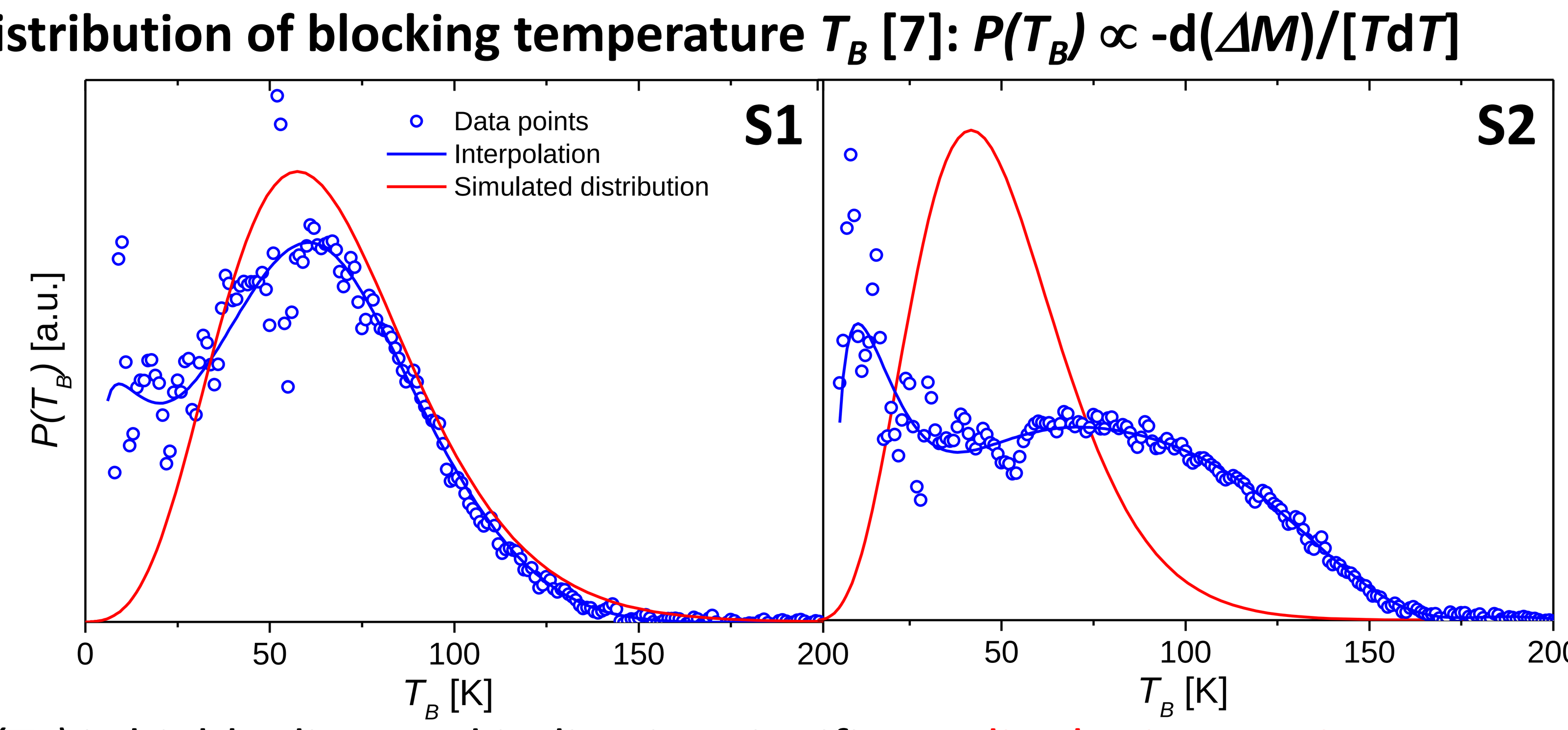
With: $M_S(T) = M_0(1-BT^{3/2})$ [6], $K = K_V + 6K_s/d_c$ [8]

K_V: Ansiotropy constant of particle volume, K_s: surface anisotropy constant



S1: Curve can be simulated by introducing a surface anisotropy constant K_s.
S2: Curve is shifted probably due to dipolar interactions [9].

iii) Distribution of blocking temperature T_B [7]: $P(T_B) \propto -d(\Delta M)/[TdT]$



S2: $P(T_B)$ is highly distorted indicating significant dipolar interactions.

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