Супермагнетизм:

свойства и приложения.

II Суперферромагнетизм.

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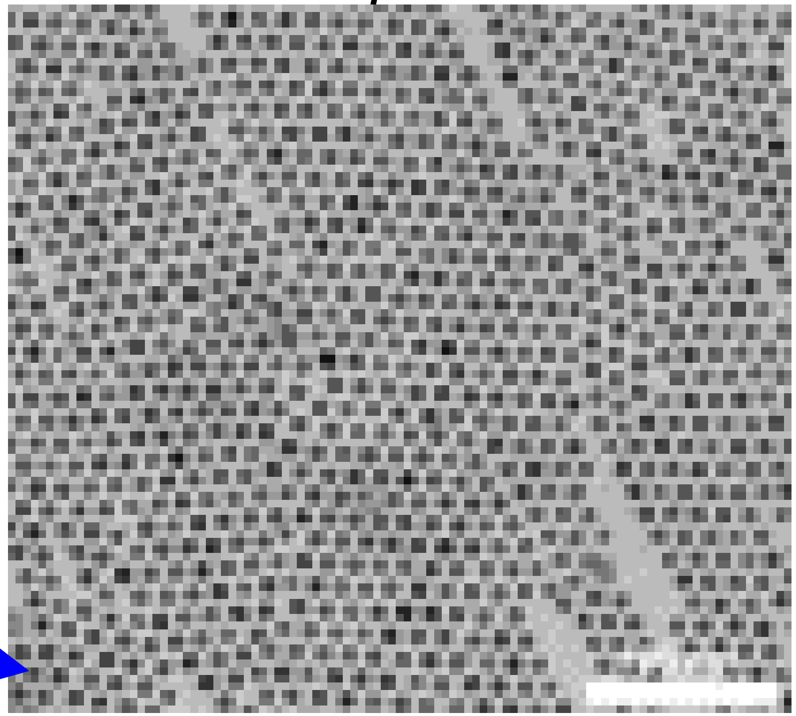
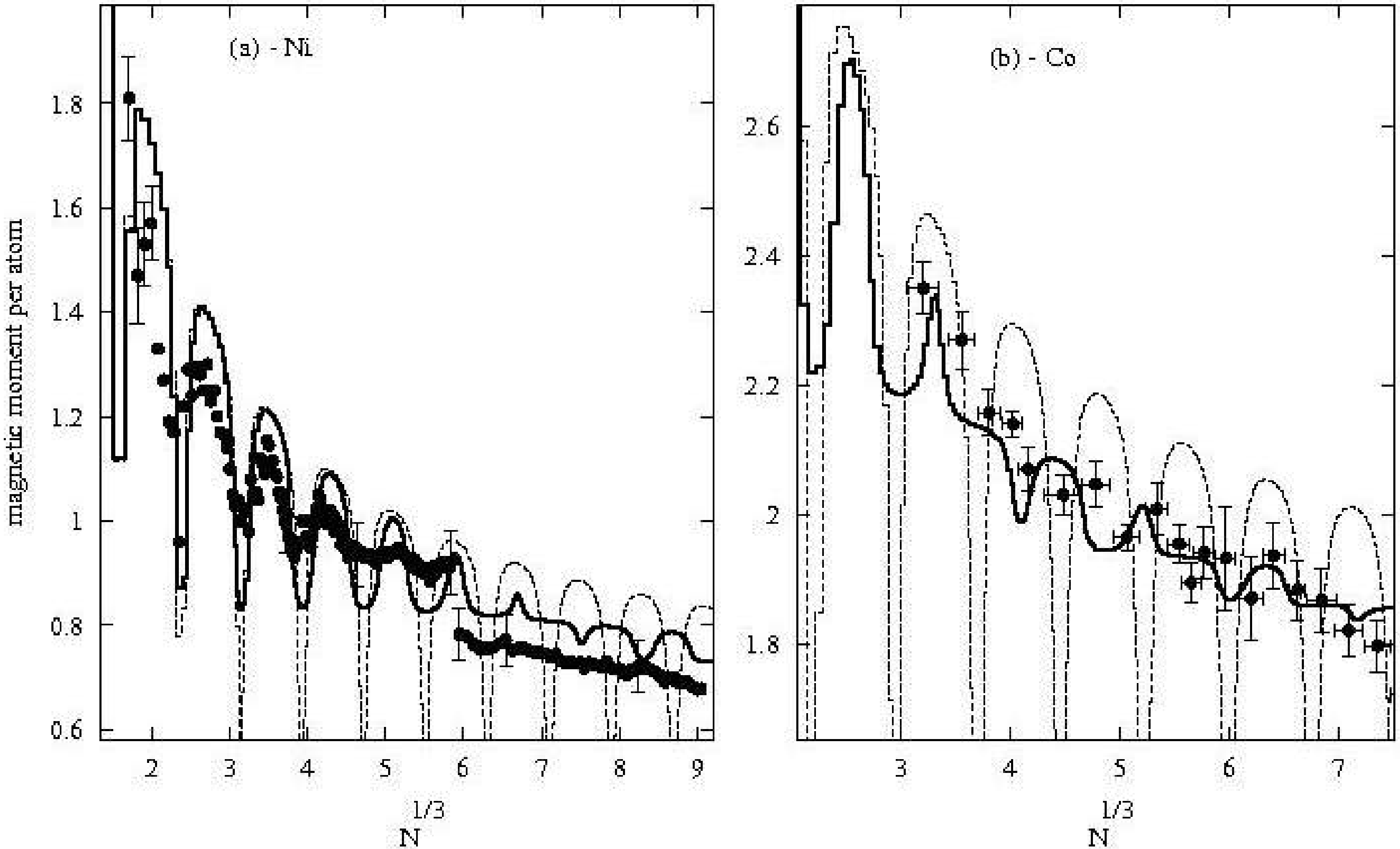
--- **SUPERPARAMAGNETS**

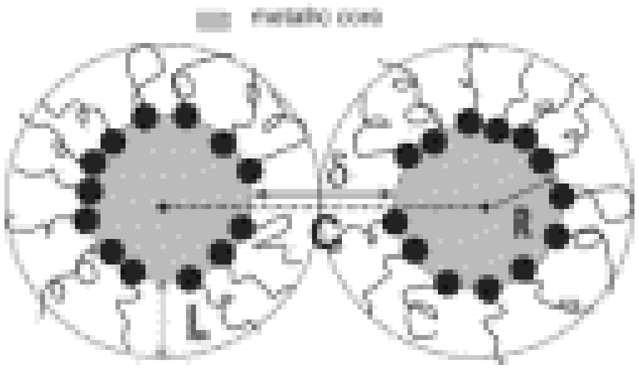


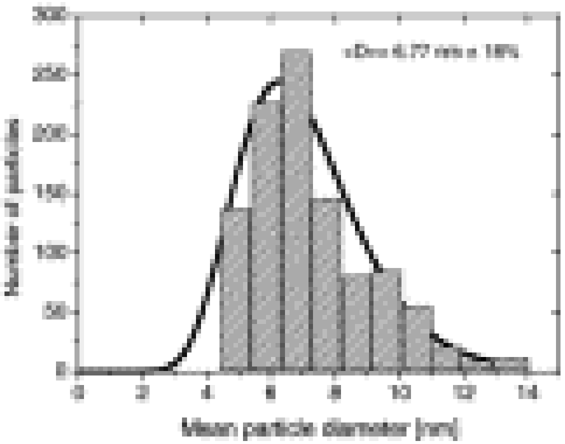
- **MAGNETIC Nano-Crystals**
  Transition metals if iron series
  Band Structure based shell model
- **MAGNETISM of Super-Crystals**
- **Magnetodynamics of**
  superferromagnets (SFM)
- Analytical Tools to probe **SFM**:
  MEAN VS STRONGEST SIGNALS
  FOR SELF-ORGANIZED CRITICALITY
- Implications to
  magnetoresistive (MR) sensors

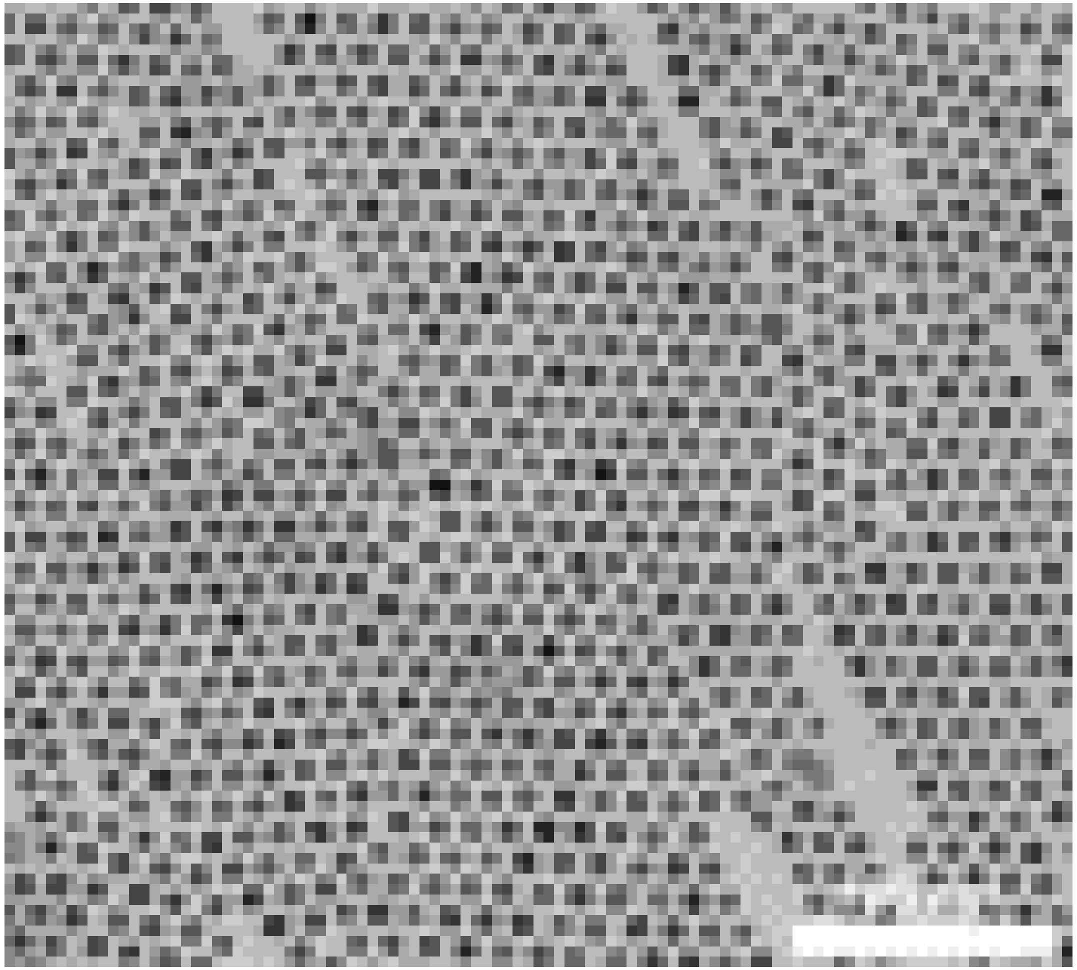
Size dependence of cluster magnetic moment per atom (measured in μ_B)



Ligand stabilized clusters



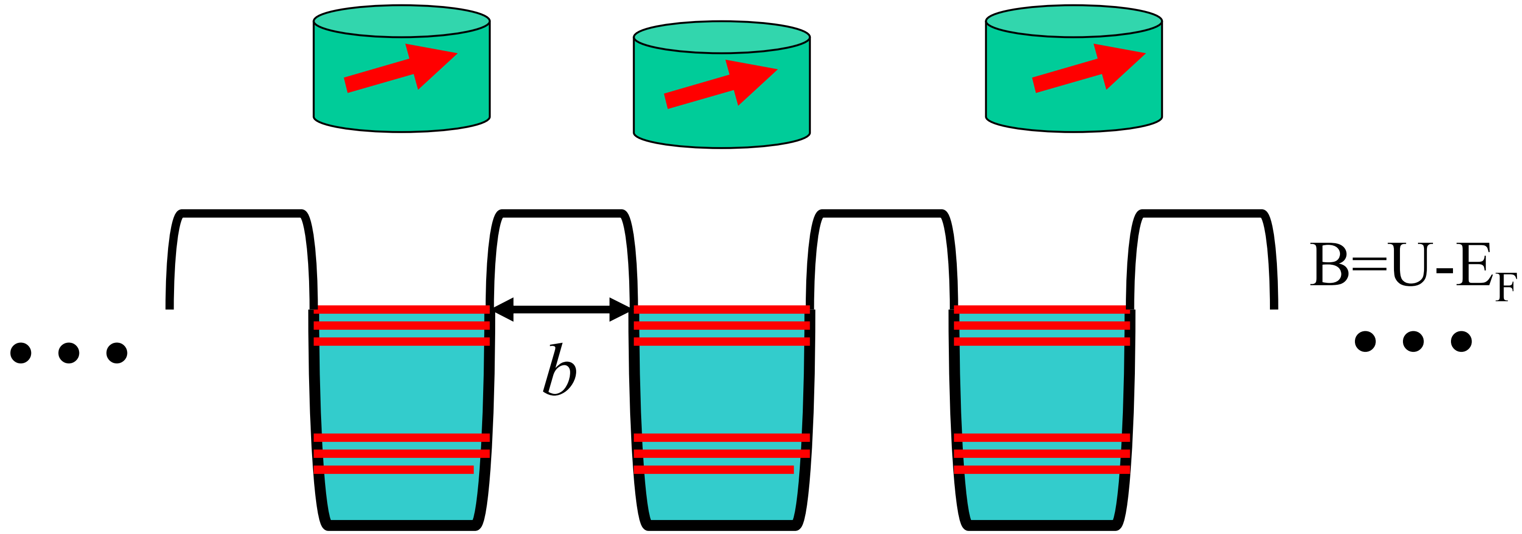




Exchange Coupling of dot supermoments

Insulator or semiconductor spacer

Coupling → mini-band splitting & modify s.p. level density



Possibility for coherent Bloch state
from dot supermoment wave function in an array

Anderson localization

$$\frac{\text{Level fluctuations}}{\text{mini-band splitting}} \equiv \Gamma / B \leq 2$$

Coherent state of supermoments

Coupling constant

$$J = \int d\varepsilon \; \varepsilon \; \delta\rho \; (\varepsilon) \, f(\varepsilon - \mu)$$

Bloch function with quasienergy

$$\varepsilon_n = \varepsilon_{\overline{n}} + \Delta\varepsilon(\mathrm{k})$$

$$\Delta\varepsilon(\mathrm{k}) = \sum_{i=1}^{D} B_i \sin^2(k_i a_i)$$

Quantum numbers n={<u>n</u>,k}
quasimomentum in D dimensions k

$$B_i = 2\omega_e P_i$$

Band Quantum number <u>n</u>
gives energy level in single dot

Level density change

$$\delta\rho^c = \int \prod_{i=1}^{D} d\left(\frac{k_i a_i}{2\pi}\right)\left[\rho\left\{\varepsilon - \Delta\varepsilon(\mathrm{k})\right\} - \rho\left\{\varepsilon\right\}\right]$$

Coupling constant

$$J = J_D \times J_B$$

Dot

$$J_D = \left(E_{\mathrm{F}} - U\right)\hbar\left[\rho_s'\left(E_F\right)\omega_s + \rho_\downarrow'\left(E_F\right)\omega_\downarrow\right]$$

Barrier

$$J_B = \frac{\alpha}{\sin\left(\alpha\right)} \times \frac{2\hbar^2}{m^*\left(\xi b\right)^2}\exp\left\{-\xi k_{\mathrm{F}} b / \hbar\right\}$$

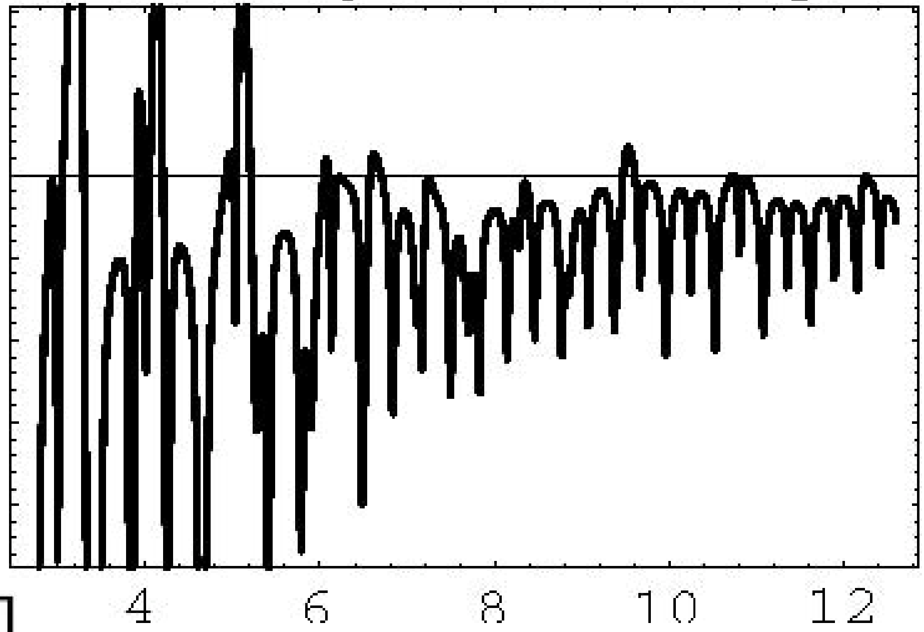
$$\alpha = \pi T / T_n$$

$$k_{\mathrm{F}} = \sqrt{2m^*\left(U - E_{\mathrm{F}}\right)}$$

$$T_n = k_{\mathrm{F}}\hbar / m^*\left(\xi b\right)$$

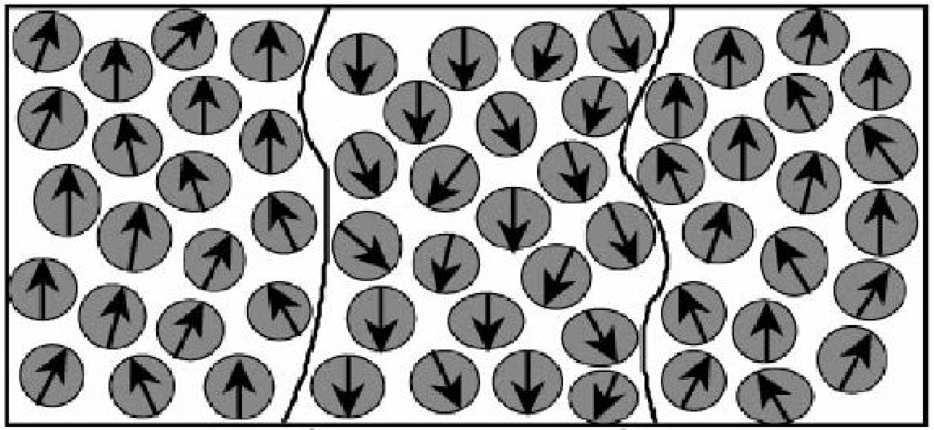
Transition metal **Nano-Crystal** Arrays

VNK, H.O.Lutz, PRL **81** (1998) 4508

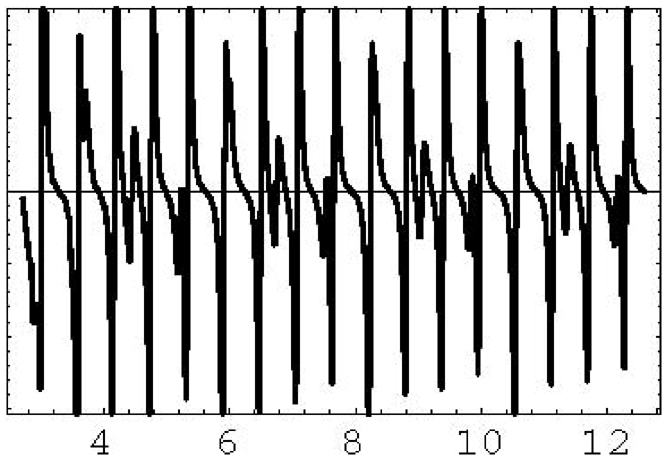


Coupling J

ferromagnetic



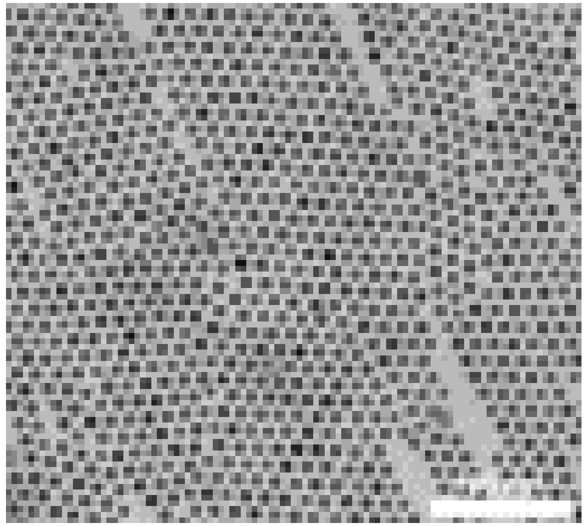
N$^{1/3}$



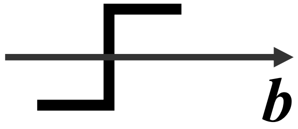
S. Sankar et.al. J. Magn. Magn. Mater. **221**, 1 (2000)

magnetodynamics in **Nano-Crystal** arrays

randomly jumping interacting moments (RJIM) model [VNK, PRL **88**, 221101 (2002); Phys. Lett. A **354**, 217 (2006)]



magnetic moment



Hamiltonian

$$\mathbf{H} = \sum_i \left(H + h_i + \sum_j J m_j \right) m_i$$

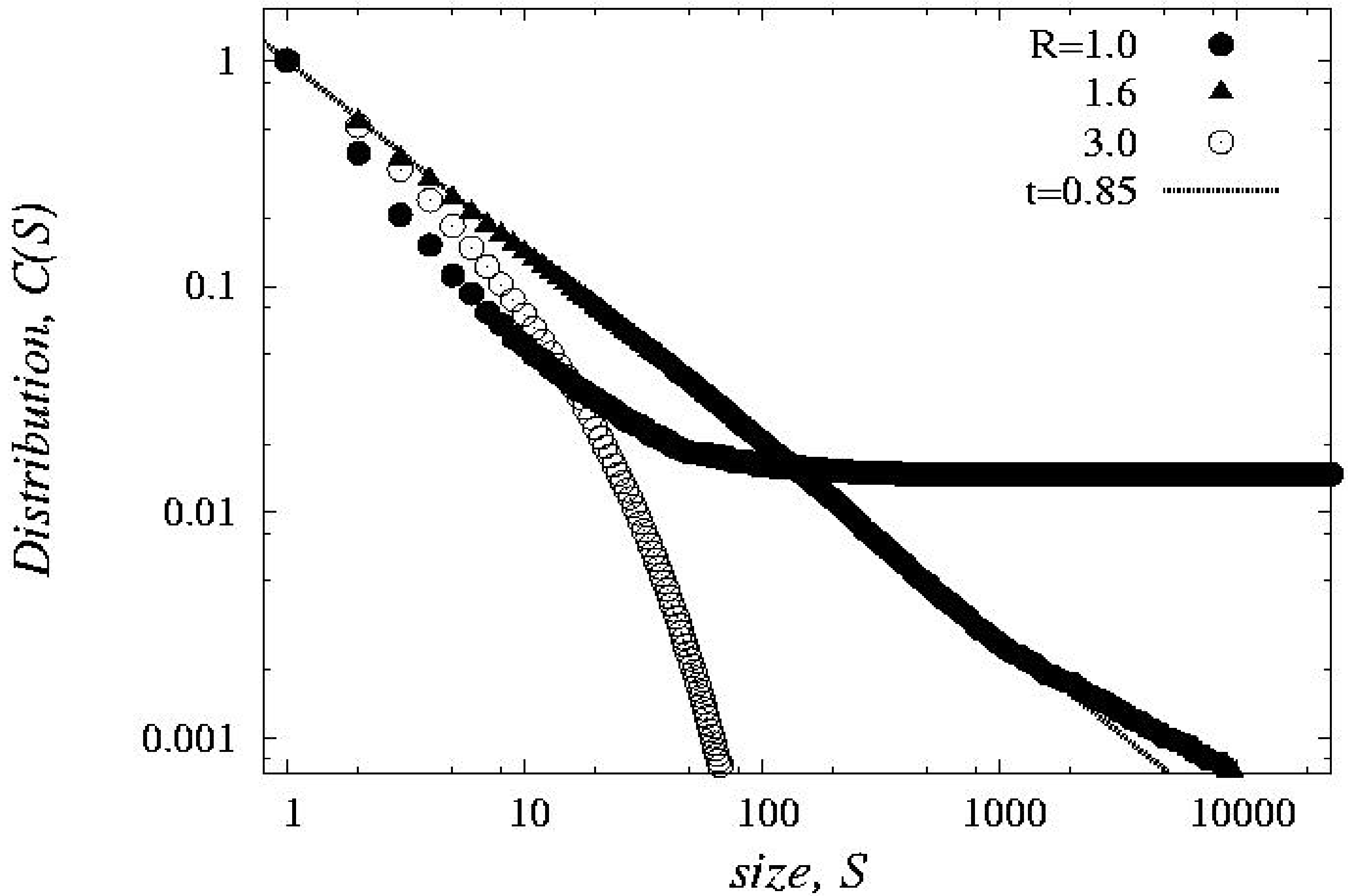
Ferromagnetic coupling -- $\boldsymbol{J}$

Random fields $\{h_i\}$ of Gaussian distribution

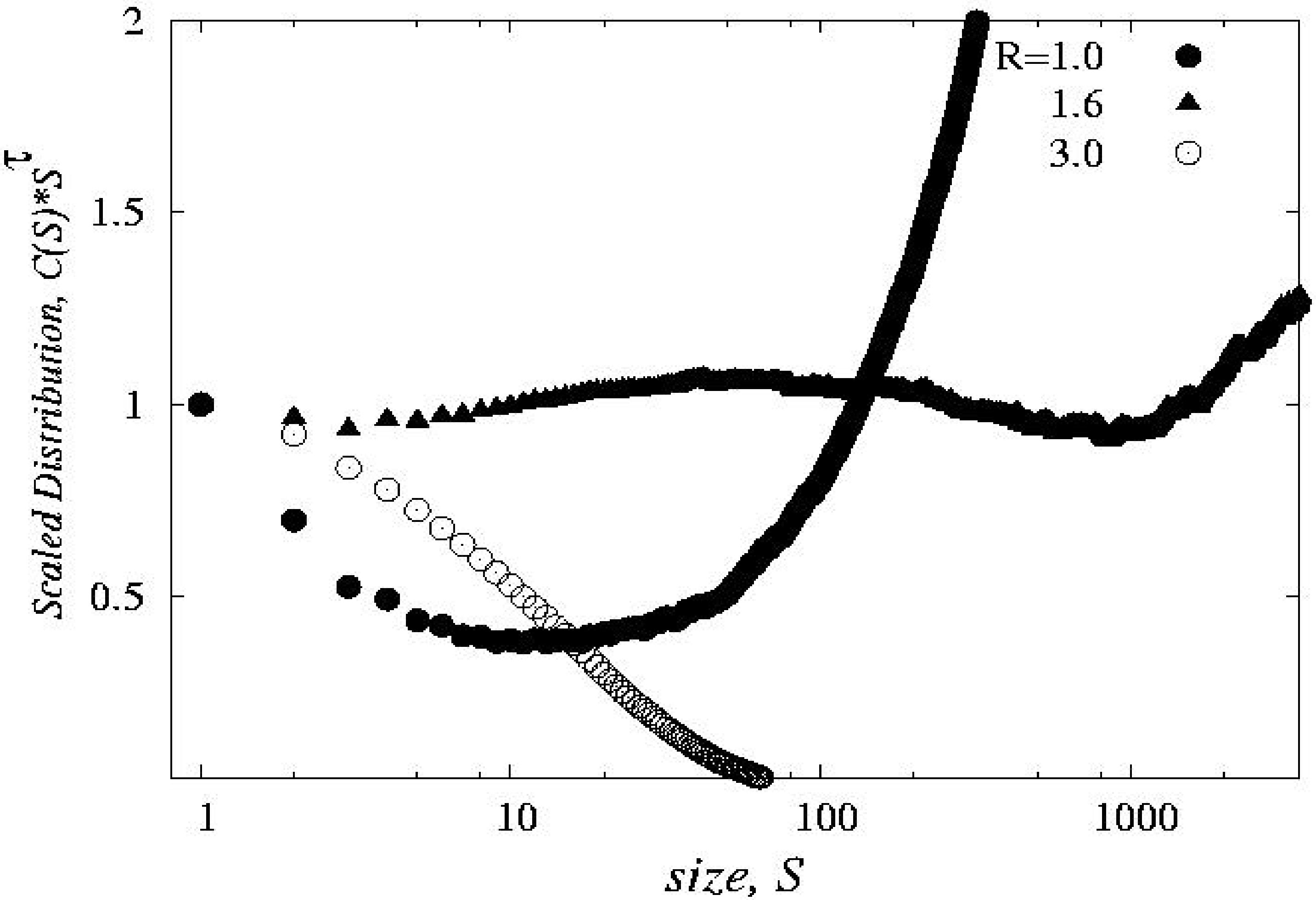
$$W(h) = \exp\left\{-h^2 / R^2\right\} / R\sqrt{\pi}$$

numerical simulations

Cumulative avalanche size distributions



Normalized size distributions



mean-field approximation

For all Dots coupling

$J_{ij} = J / \Pi$

→

Local magnetic field

$$b_i^{mf} = H(t) + JP + h_i$$

sample magnetization

$$P = \sum_i P_i / \Pi$$

magnetic state equation (MSE)

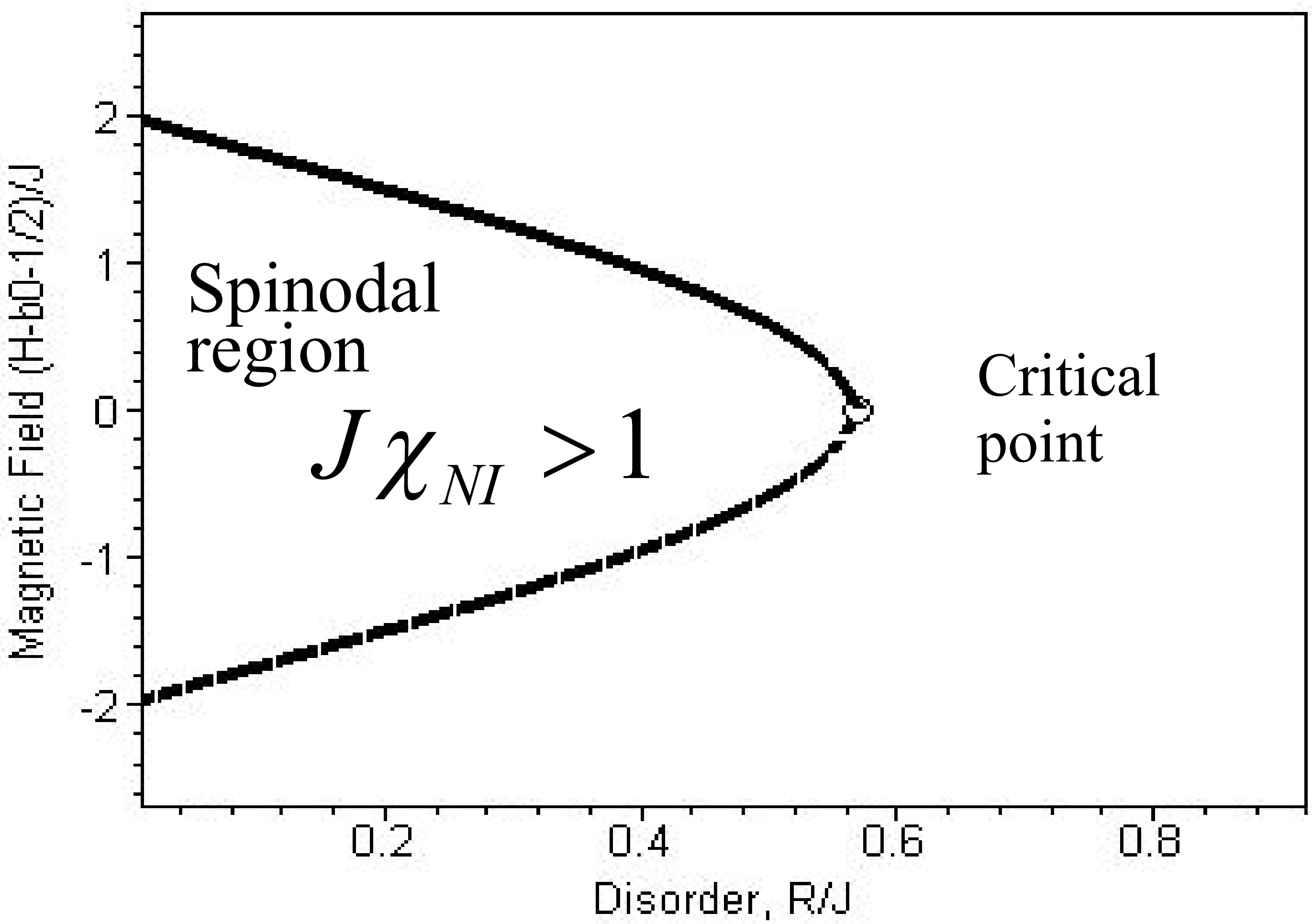
$$P = \int dh\ W(h) m(b)$$

magnetic susceptibility

$$\chi = -dP / dH = [\chi_{NI}{}^{-1} - J]^{-1}$$

$$\chi_{NI} = \sum_n W(b - b_n)$$

Magnetic phase diagram



avalanche size distribution: mean-field

$D_{mf}(S) = Q(S)/S$

probability $Q(S)$ of triggering S consequent jumps

For $S \ll \Pi$ the Poissonian probability

$$d = J\chi_{NI} - 1 \qquad Q(S) = \exp\{-S(1+d)\}[S(1+d)]^S / S!$$

vicinity of critical conditions

$$|d| \ll 1 \longrightarrow D_{mf}(S) \sim S^{-3/2} \exp\{-Sd^2/2\}$$

the largest avalanche size

$$S_b^{mf} \approx (J\chi_{NI}/2)\ \Pi$$

Analytical tools for SO criticality

[VNK, Phys. Lett. A **354**, 217 (2006)]

conditional moments

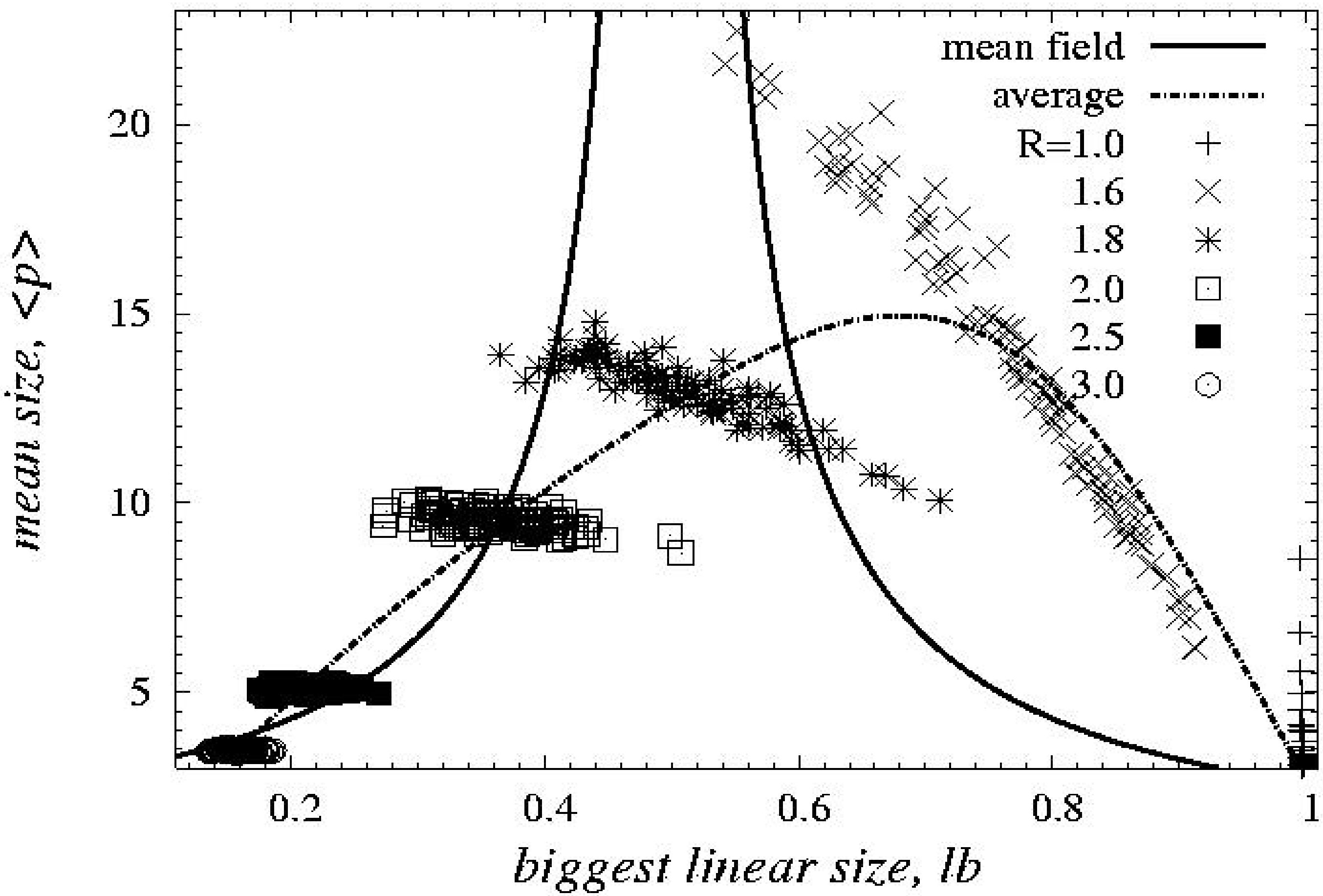
$$L_k = \sum_S S^k D(S)$$

$< p >= L_1 / L_0$ mean avalanche size

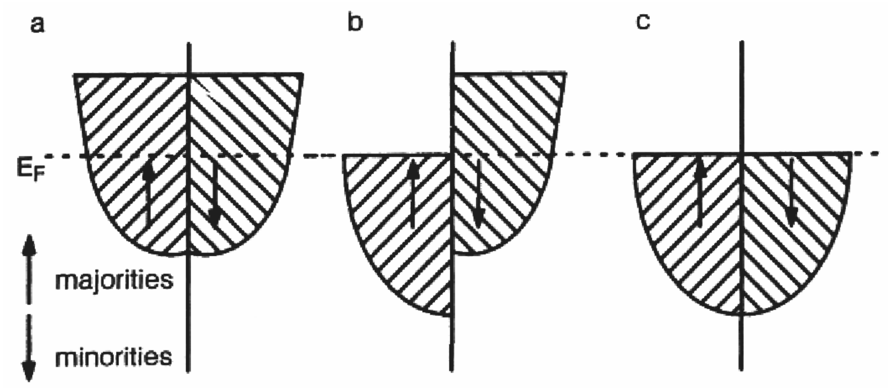
$$L_k^{mf} \sim | d |^{1-2k} + const(d)$$

moments with $k \geq 1$ diverge at critical conditions, $d \to 0$

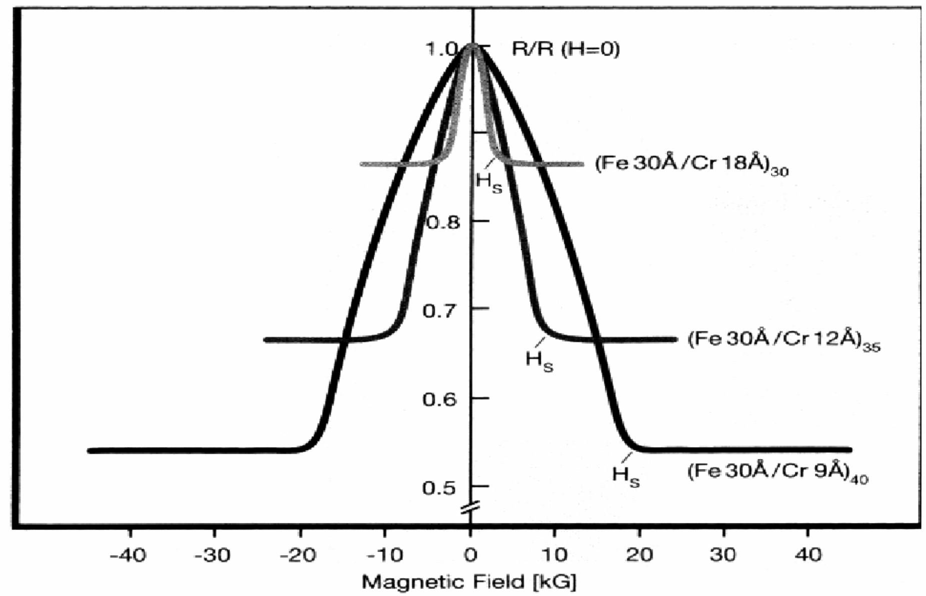
MEAN *VERSUS* **STRONGEST** SIGNALS FOR SELF-ORGANIZED CRITICALITY

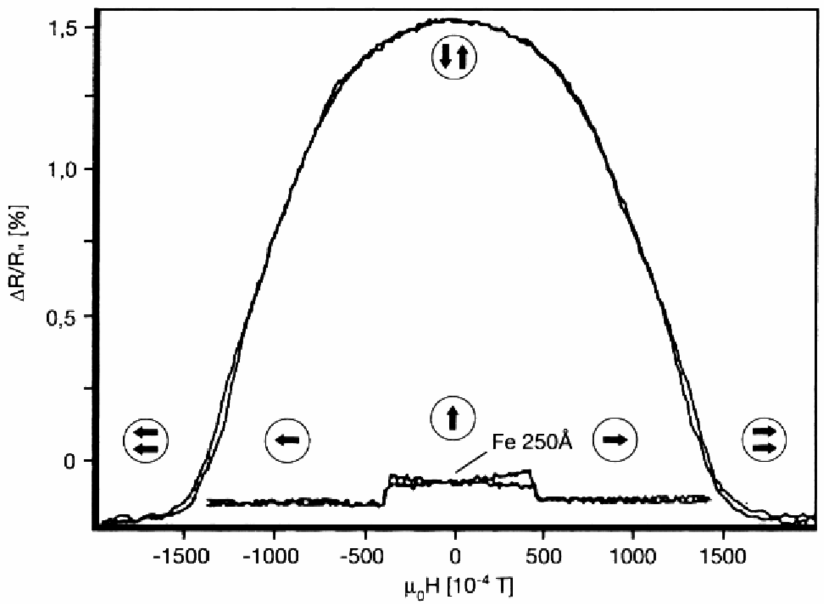


Giant magnetoresistance (GMR)



Schematic representation of the matching of the d bands of the magnetic



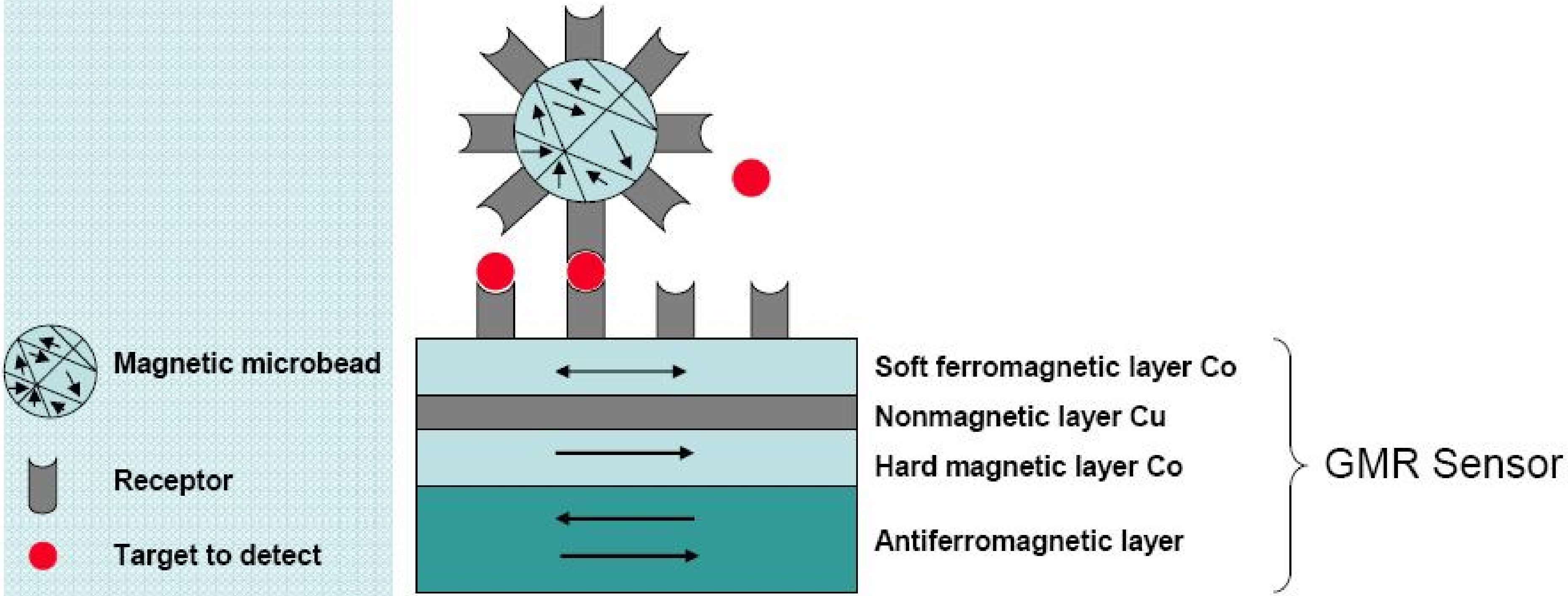


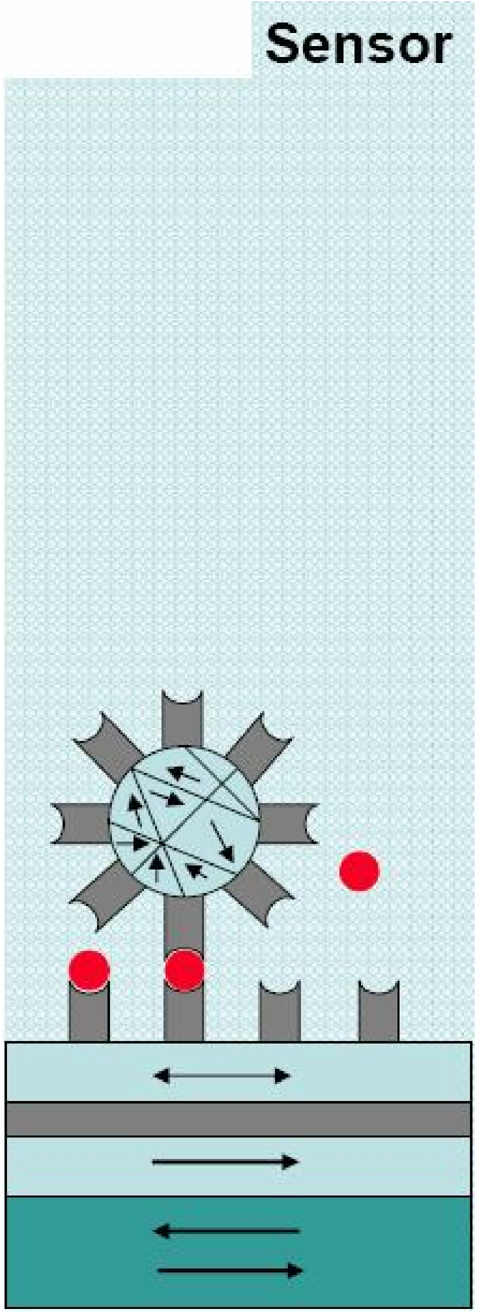
Resistivity versus applied field for Fe/Cr multilayers

Relative resistance change as a function of the external magnetic field for Fe/Cr/Fe and 250A thick Fe film

Sensor

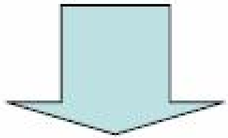
- GMR – sensor array = high sensitivity
- Application of Receptor molecules on GMR and microbead
- Solution of microbeads and target molecules
- DC field to carry not attached beads away
- AC field -> Magnetisation of the beads -> sensing field is generated.
- Measure the electric resistance and compare to a reference GMR array





Magnetic bead criteria:

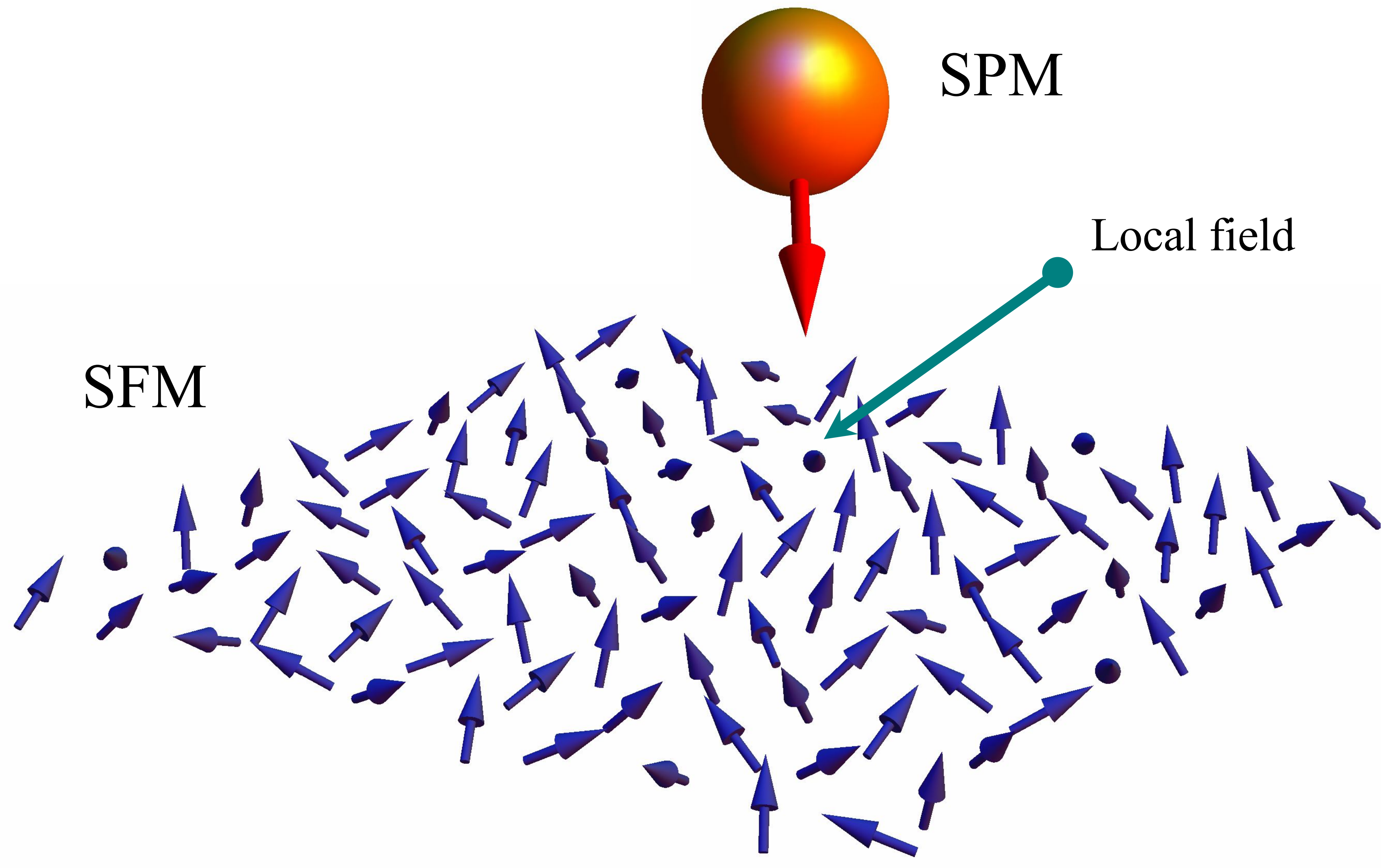
- High magnetisation to maximize the response of the sensor
- No clustering -> No remanent magnetisation



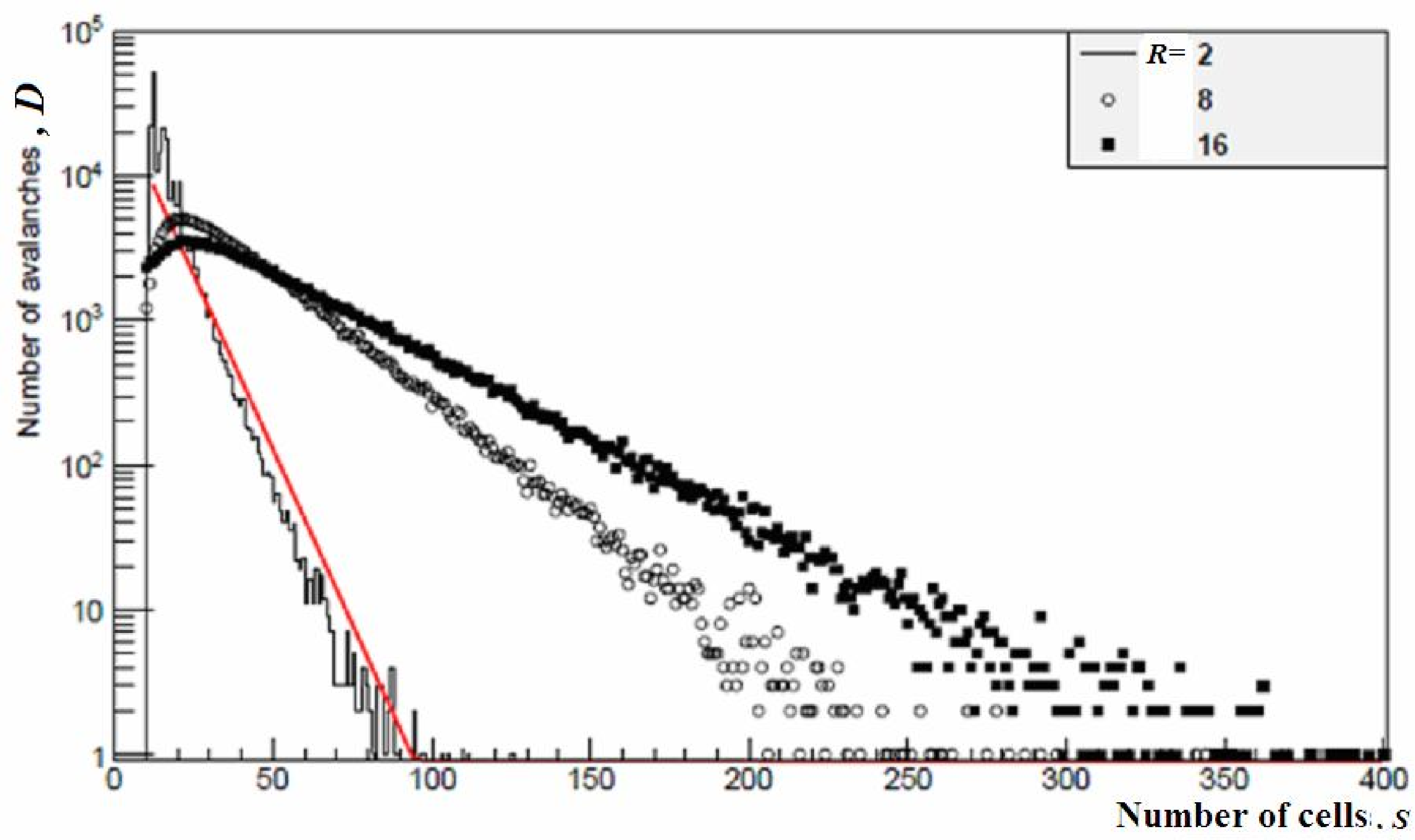
Microbeads composed of Fe, γ-Fe_2O_3, Fe_3O_4 superparamagnetic nanoparticles < 20nm dispersed in a polymer matrix.

MagnetoResistive (MR) sensors

VNK et al, J.Phys.CS **393** (2012) 012005

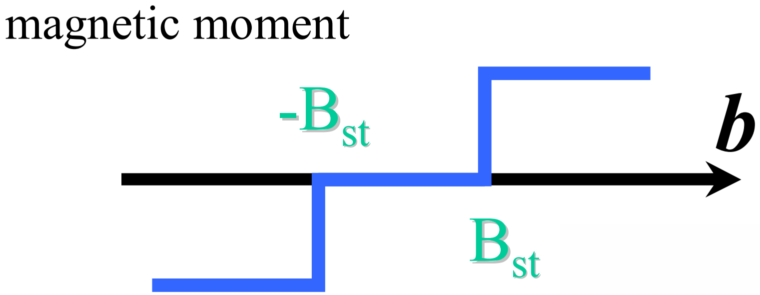


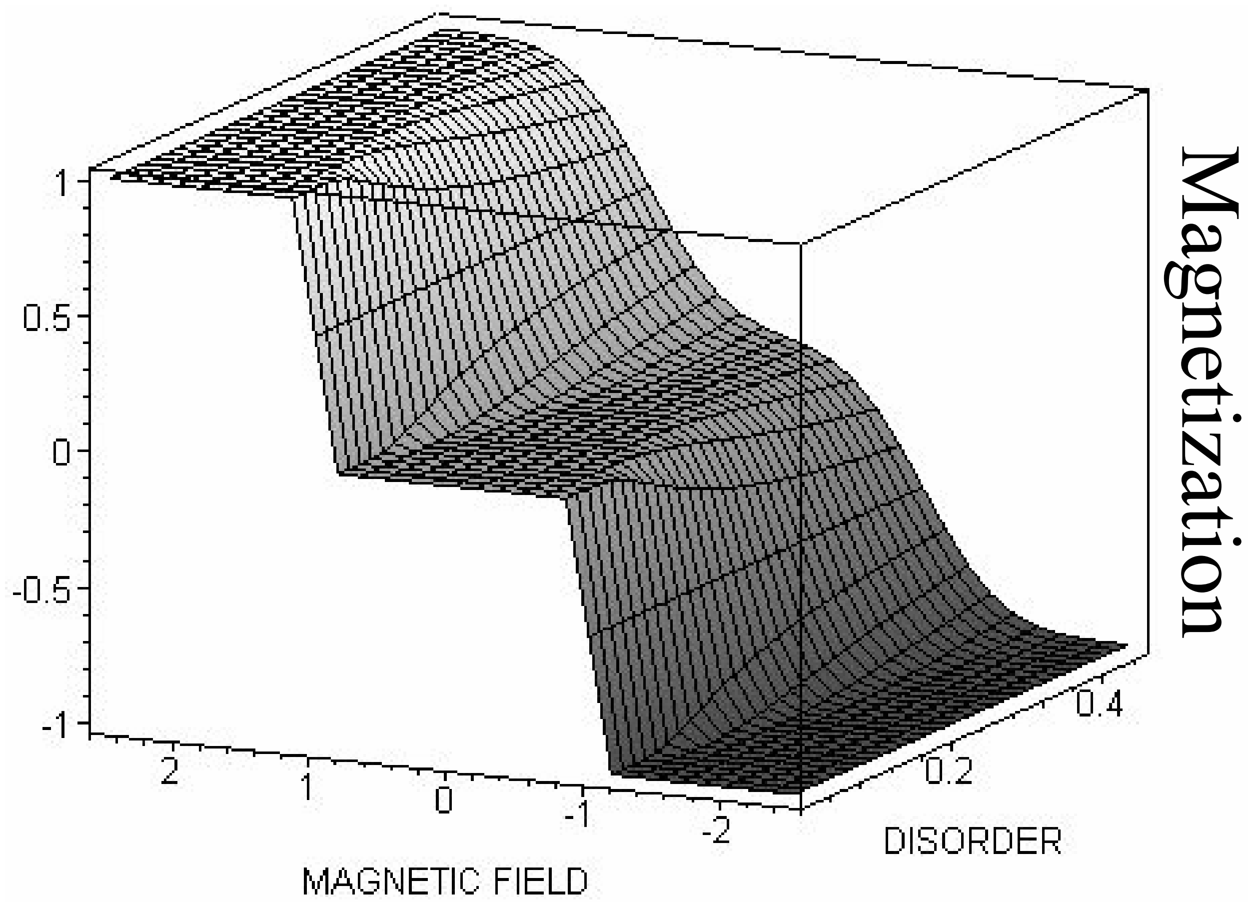
Response in local field



Nanoparticles with Singlet-Triplet transition

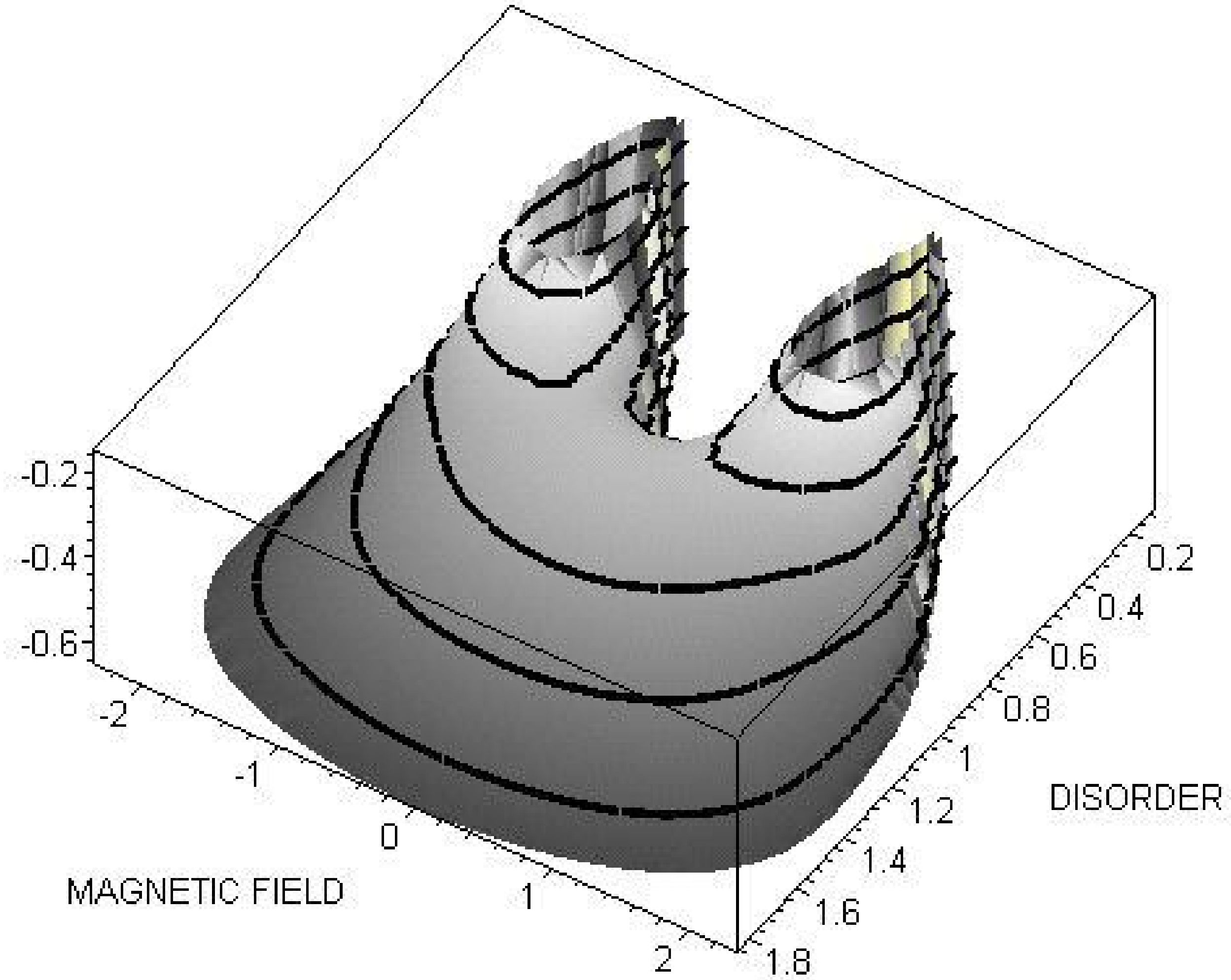
VNK, J.Phys.CS **129**, 012013 (2008)





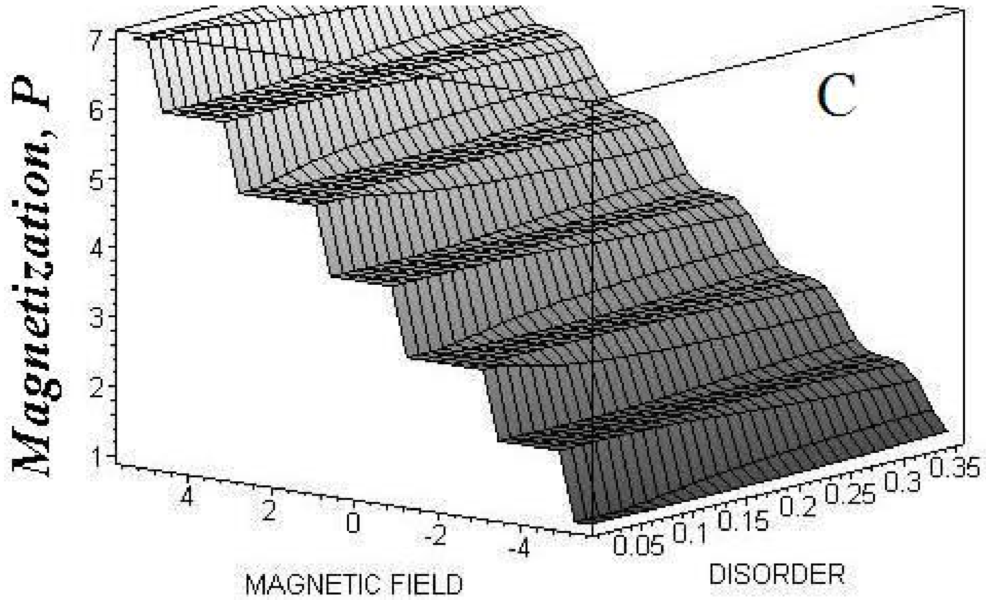
Phase diagram

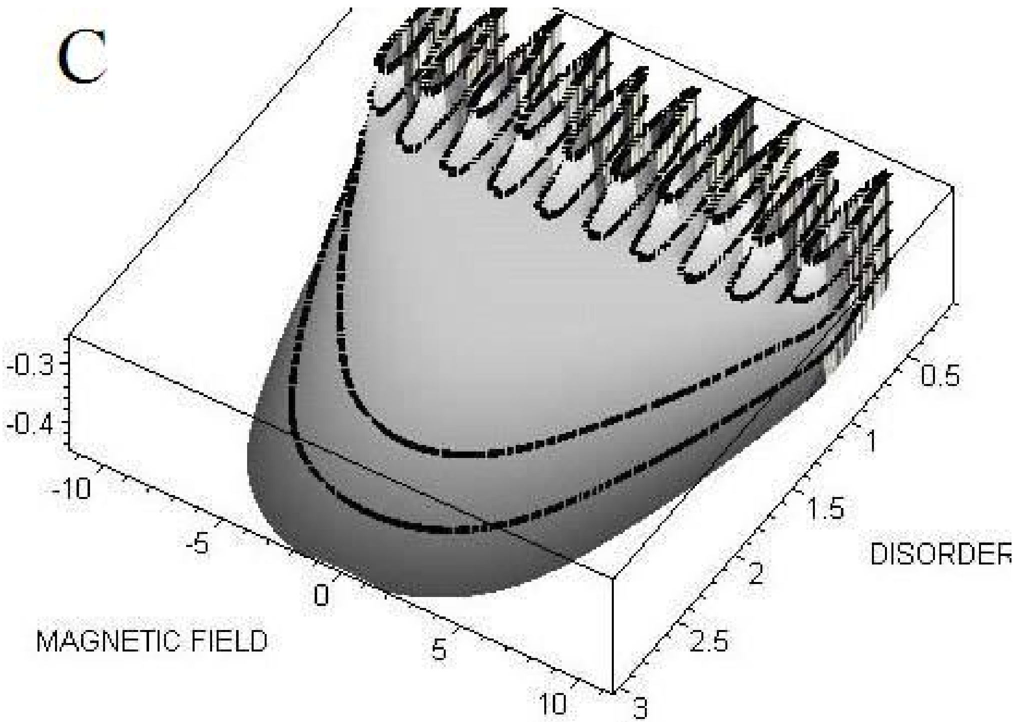
Nanoparticles with Singlet-Triplet transition



Multiple jumps

$$m = \mu \sum_n \nu_n \theta(b - b_n)$$





VNK, J.Phys.CS **248** (2010) 012027

Conclusions

MAGNETISM of Super-Crystals
accounting for inter & intra Dot structures
within Microscopic treatment

Band Structure based shell model
well suited for Superparamagnets

Magnetodynamics of QD arrays
Erratic jumps due to Magnetic Avalanches

Conditions of Self Organized Criticality
Universal Scaling

Analytical Tools: MEAN *VS* STRONGEST SIGNALS
FOR SELF-ORGANIZED CRITICALITY

Lab on a Chip systems, MR sensors