Идеи и методы физики конденсированного состояния
XIV Школа-конференция молодых ученых
"Проблемы физики твердого тела и высоких давлений"
Сочи, 11-20 сентября 2015г.

Magnetic resonance and quantum criticality

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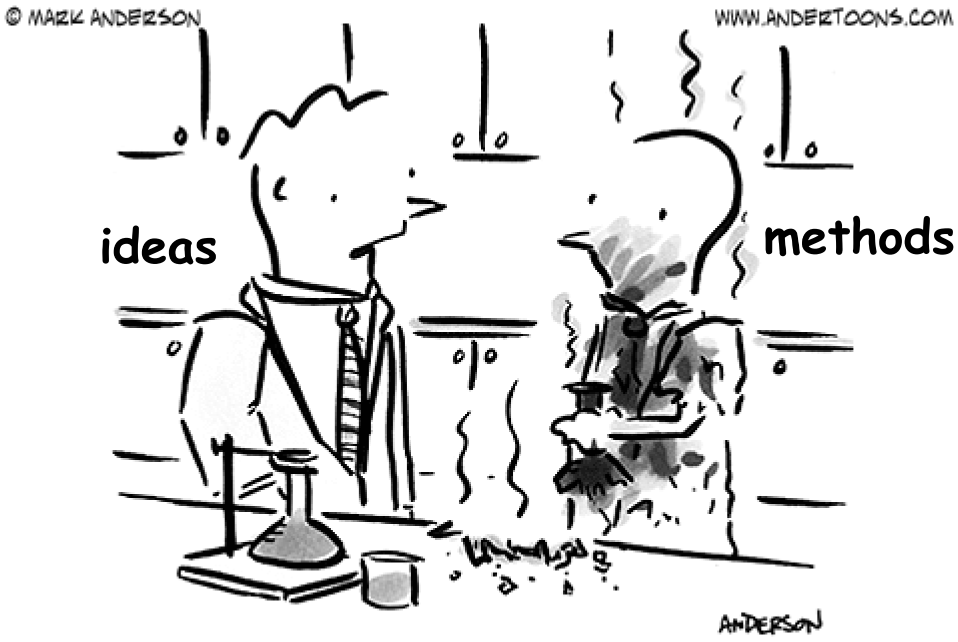

"And therein lies the problem."

Low temperatures and
Cryogenic Engineering Department
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http://www.gpi.ru

Идеи и методы…
Неполиткорректная лекция

…Уступая моде, распространенной среди физиков первой половины XX века, интерпретировать все формально получаемые результаты с помощью простых физических представлений, выделим…

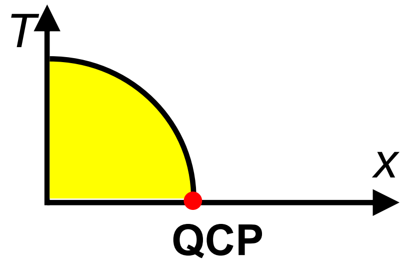
… Можно, конечно в духе классиков начала XX века еще порассуждать, например представить, что…

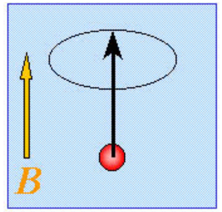
Иридий Александрович Квасников,
II, 270

"Pavlov had his dog. Schrödinger had his cat. But nobody's done anything with a *goldfish* yet!"

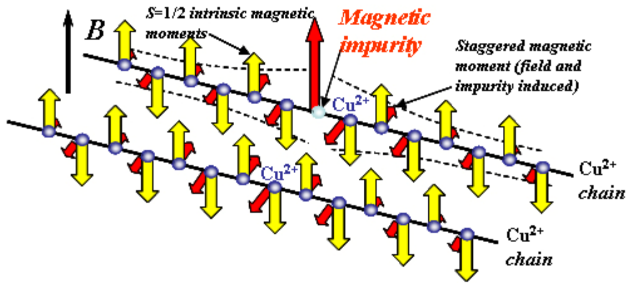
If there any regularities which link quantum critical phenomena and magnetic resonance?

Introduction. Quantum criticality and electron spin resonance

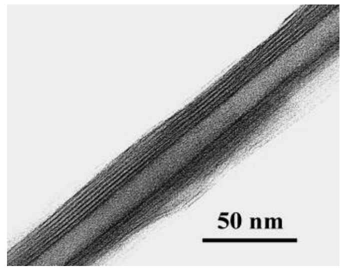




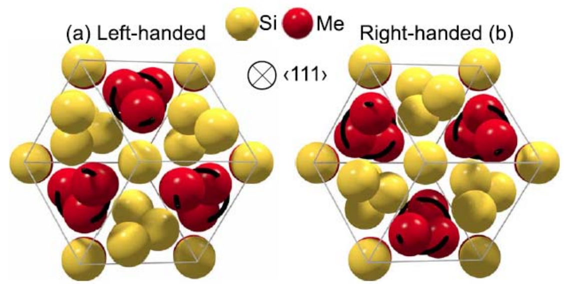
Quantum spin chains in disorder driven quantum critical regime. (Dielectrics, 1D systems).



Quantum critical phenomena in the nano-world. (Bad conductors, 2D systems).

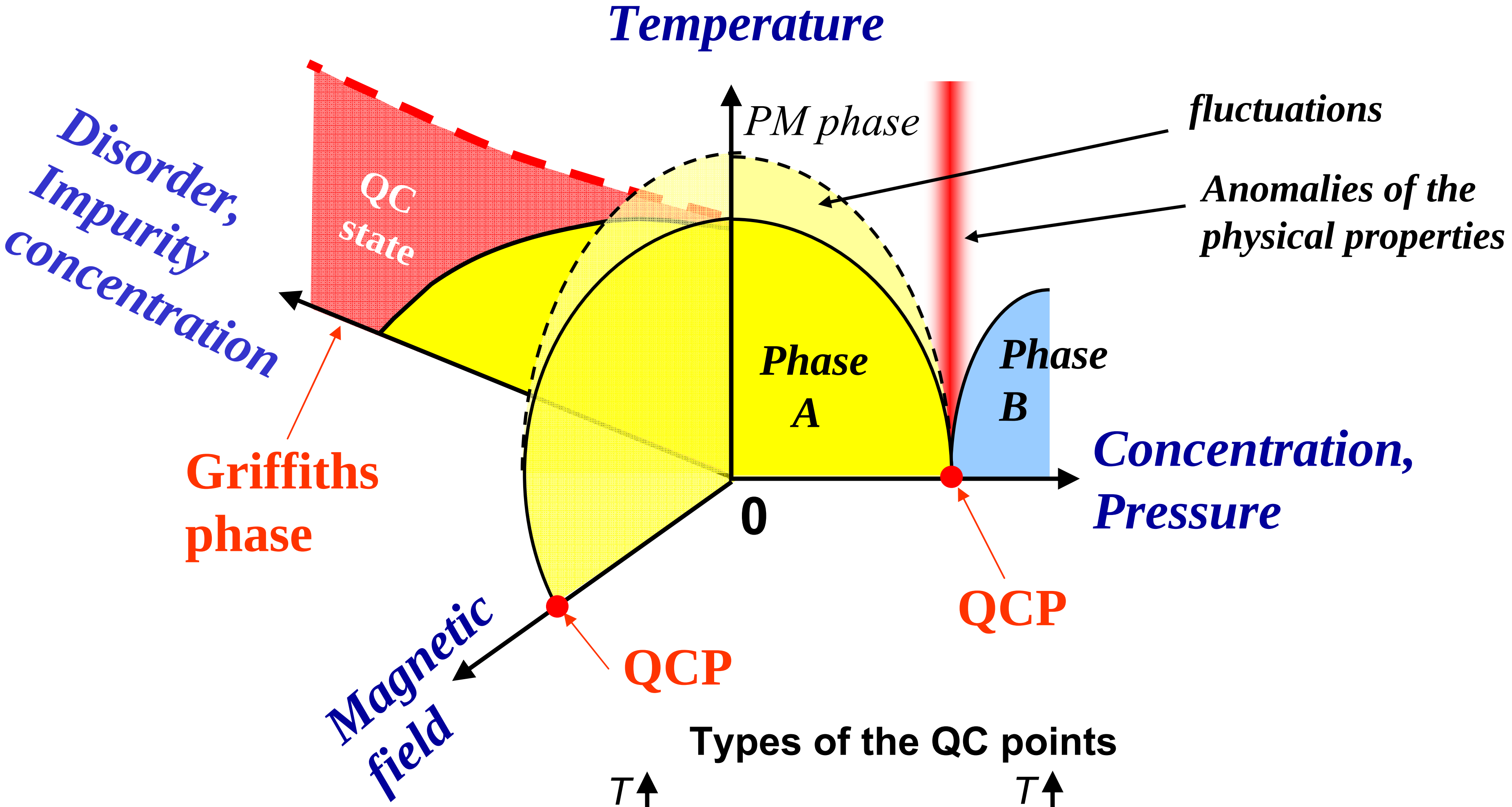


Quantum criticality in strongly correlated metals. (Good conductors, 3D systems)

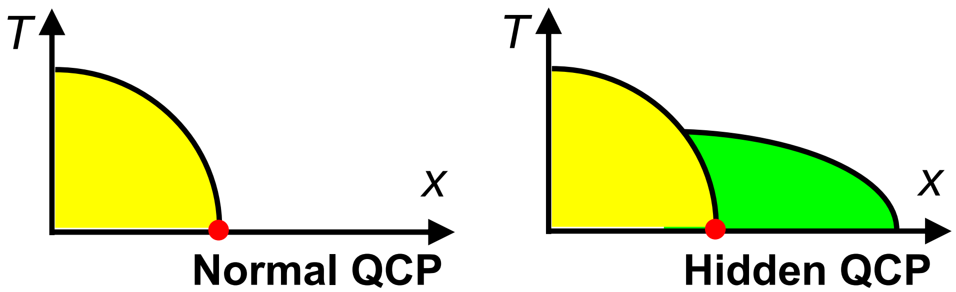


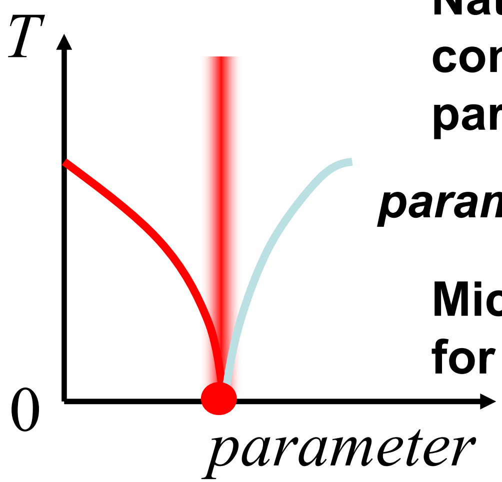
Final remarks

Quantum phase transitions are phase transitions at T=0.



Types of the QC points

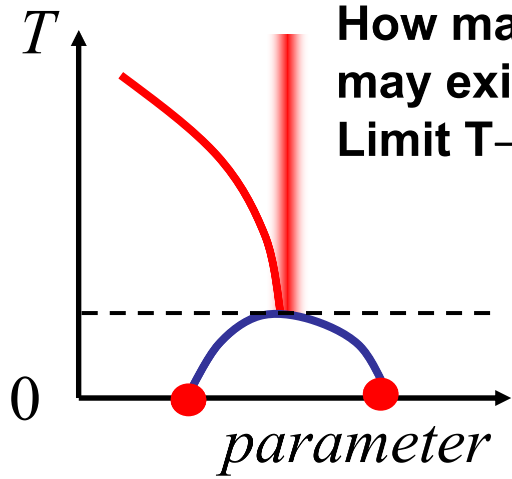




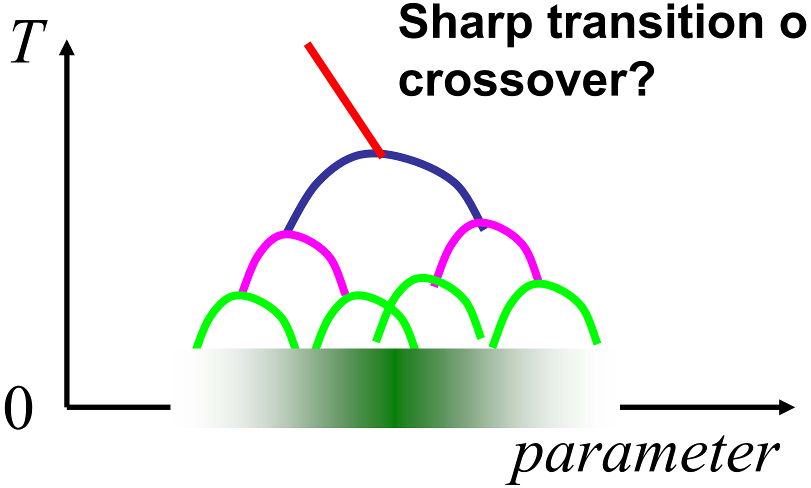
Nature of the controlling parameter?

parameter → p → pressure

Microscopic reasons for quantum criticality?

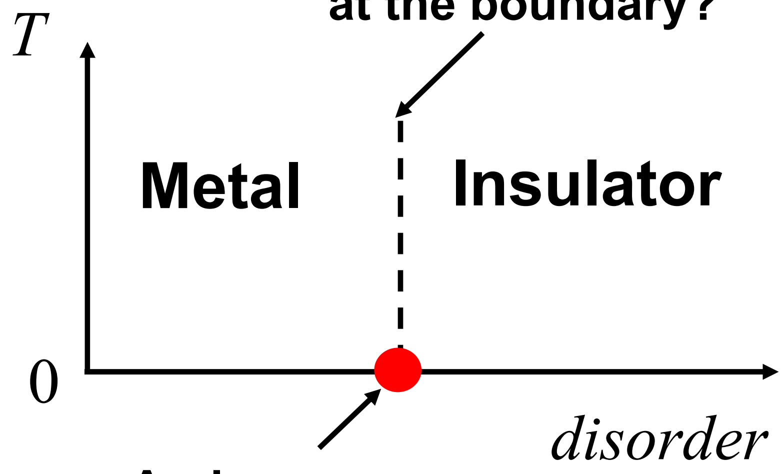


How many QCPs may exist?
Limit T→0 ?

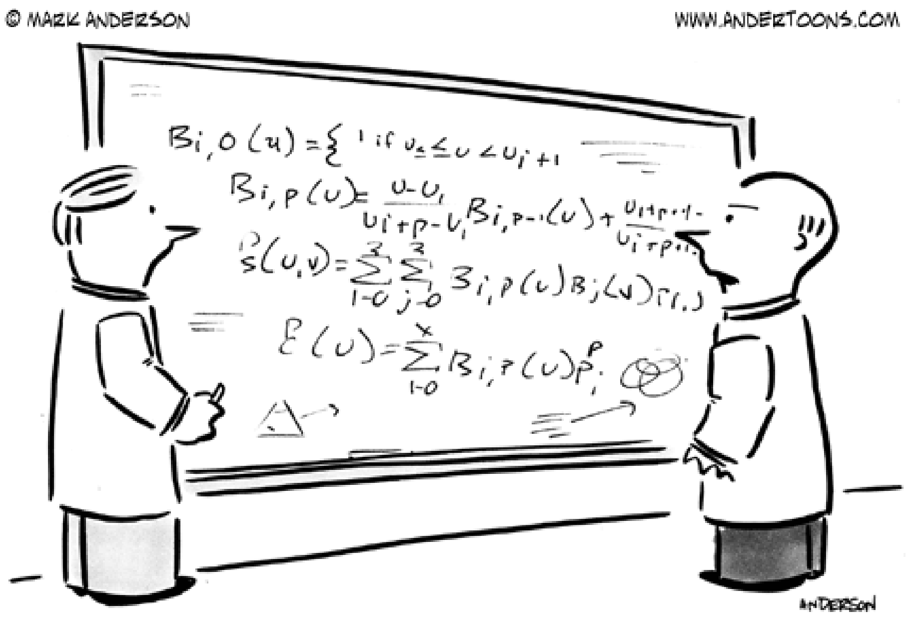


Sharp transition or crossover?

No specific anomalies at the boundary?



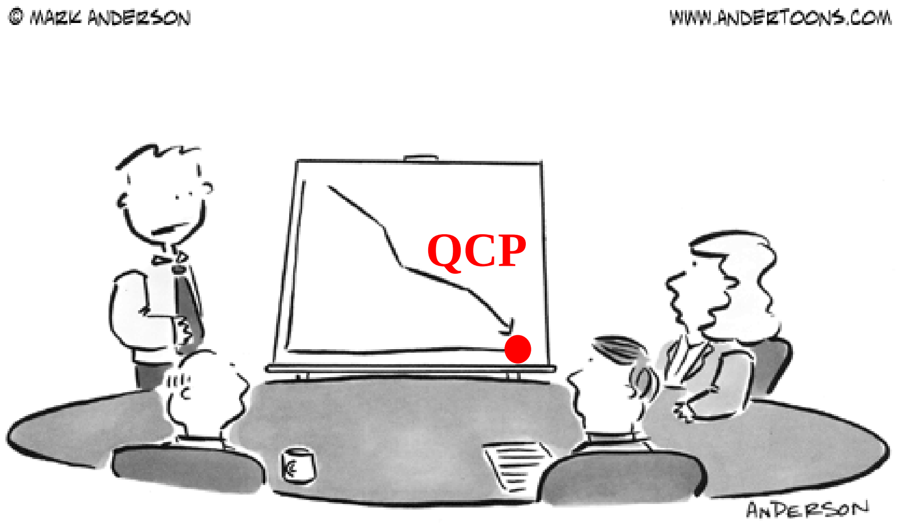
Anderson theorem



"What the hell is *that* supposed to mean?!"

Theory…

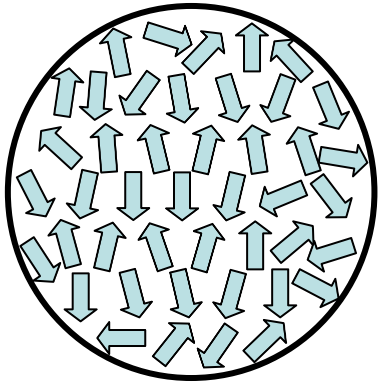
Experiment…



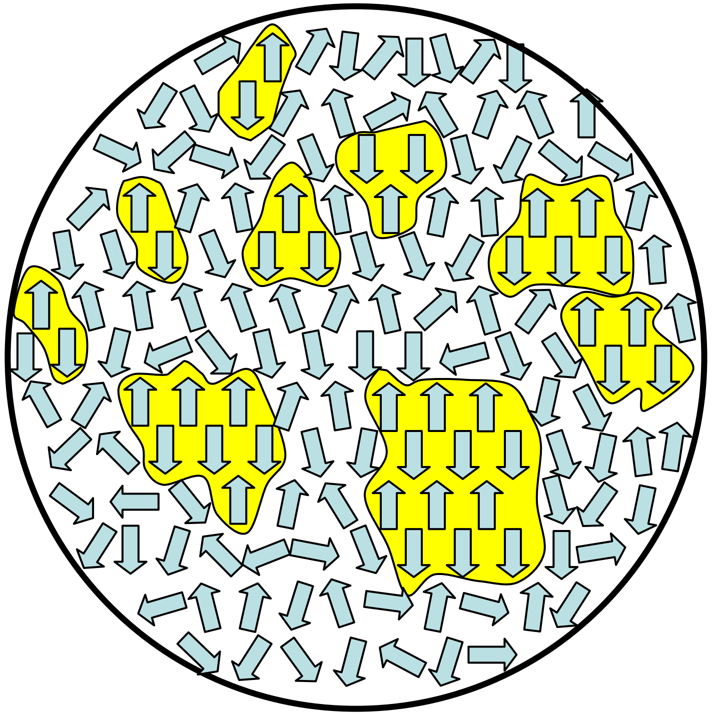
"As you can see, misery loves our company specifically."

"Please, be so kind to tell us what kind of transition do we have."

In a disordered magnet dispersion of the exchange constants *J* exists



Lowering temperature



Low temperarures

$$\chi \sim \frac{1}{T^{\xi}}$$

$$\xi < 1$$

High temperatures

$$\chi = \frac{C}{T-\theta}$$

Uncorrelared spins. Curie-Weiss law for susceptibility

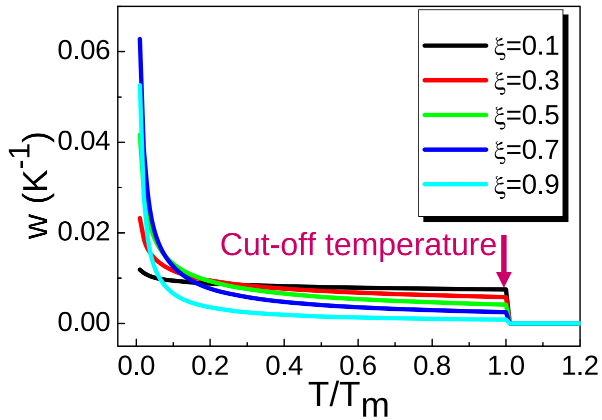
Correlated spin clusters. Power law for susceptibility.

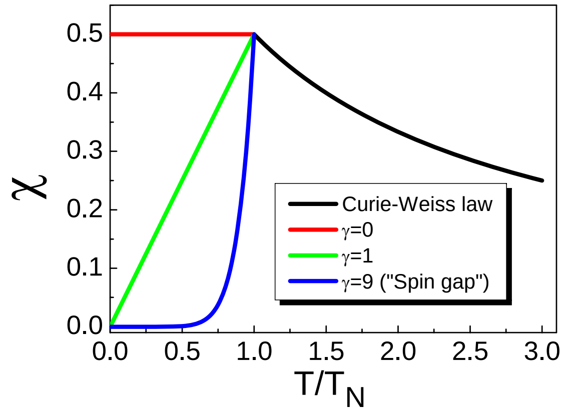
R.B.Griffiths. Phys. Rev. Lett., **23**, 17 (1969); A.J.Bray, Phys. Rev. Lett., **59**, 586 (1987)

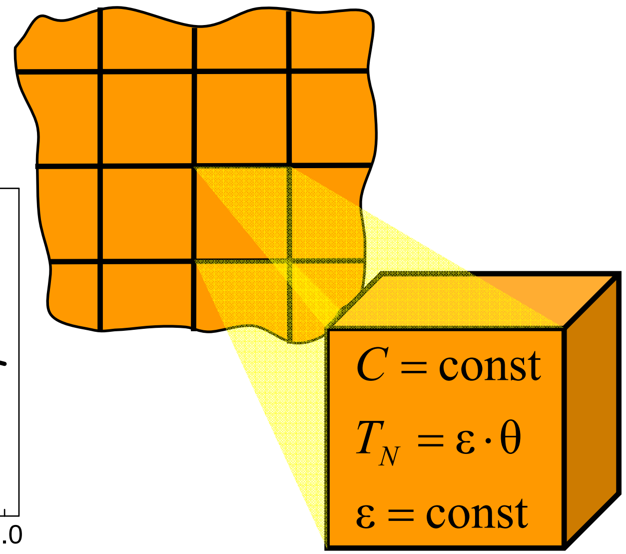
Disorder driven QC phenomena. The model.

The model:

S.V.Demishev, Phys.Sol.St., **51**(3), 514 (2009)
S.V.Demishev, Phys. Stat. Sol. B, **247**(3), 676 (2010)







Distribution of Neel temperatures in the sample:

$$w(T_N) = (1-\xi)(T_m / T_N)^{\xi} / T_m$$

Susceptibility of the cluster with T_N:

$$\chi = C / (T + \varepsilon^{-1} T_N) \qquad (T > T_N)$$

$$\chi = C (T / T_N)^{\gamma} / [T_N (1 + \varepsilon^{-1})] \qquad (T < T_N)$$

Result (susceptibility at an arbitrary temperature):

$$\chi = C / (T + \theta^*) \qquad (T > T_m)$$

$$\chi = [C / (T_m + \theta^*)](T / T_m)^{-\xi} \{1 + (1-\xi)(1 + \theta^* / T_m)[1 - (T / T_m)^{\gamma+\xi}] / [(1 + \varepsilon^{-1})(\gamma + \xi)]\}$$

$$(T < T_m)$$

$$\theta^* = T_m [\varepsilon (1-\xi) f(\varepsilon, \xi)]^{-1} - 1 \qquad f(\varepsilon, \xi) = -\xi^{-1} - \sum_{r=1}^{\infty} (-1)^r \varepsilon^r / (r + \xi) + \pi \varepsilon^{-\xi} / \sin[\pi(1-\xi)]$$

1951

C.Gorter *AFMR (discovery)*

C.Kittel *(theory)*

Nobel prize 1952

1946

F.Bloch, E.Purcell *NMR (discovery)*

J.Griffiths *FMR (discovery)*

1944

E.K.Zavoiskii *EPR (discovery)*

Nobel prize 1944

1937-1939

I.Rabi *Magnetic resonance in molecular beams*

1935

L.D.Landau, E.M.Lifshits *Equation of motion for magnetic moment*

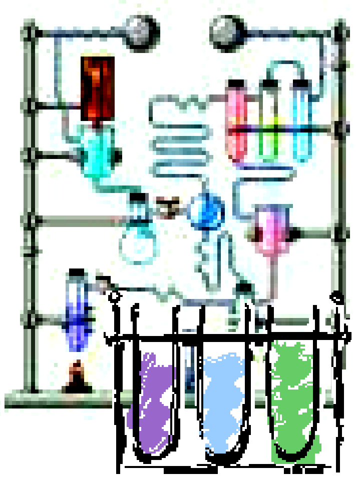
1923

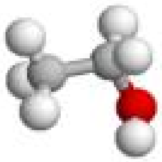
Ya.G.Dorfman *EPR (prediction)*

1913

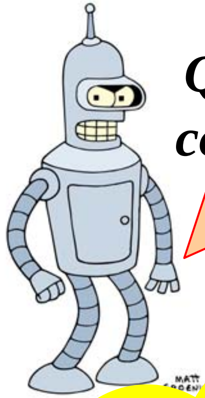
V.K.Arkad'ev *Ferromagnetic resonance (observation? prediction?)*

MAGNETIC RESONANCE in XX century

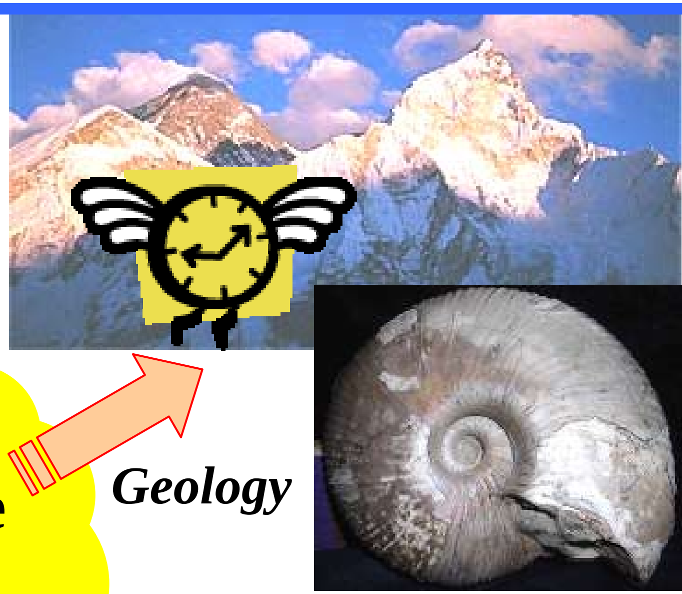




Chemistry



Quantum computers

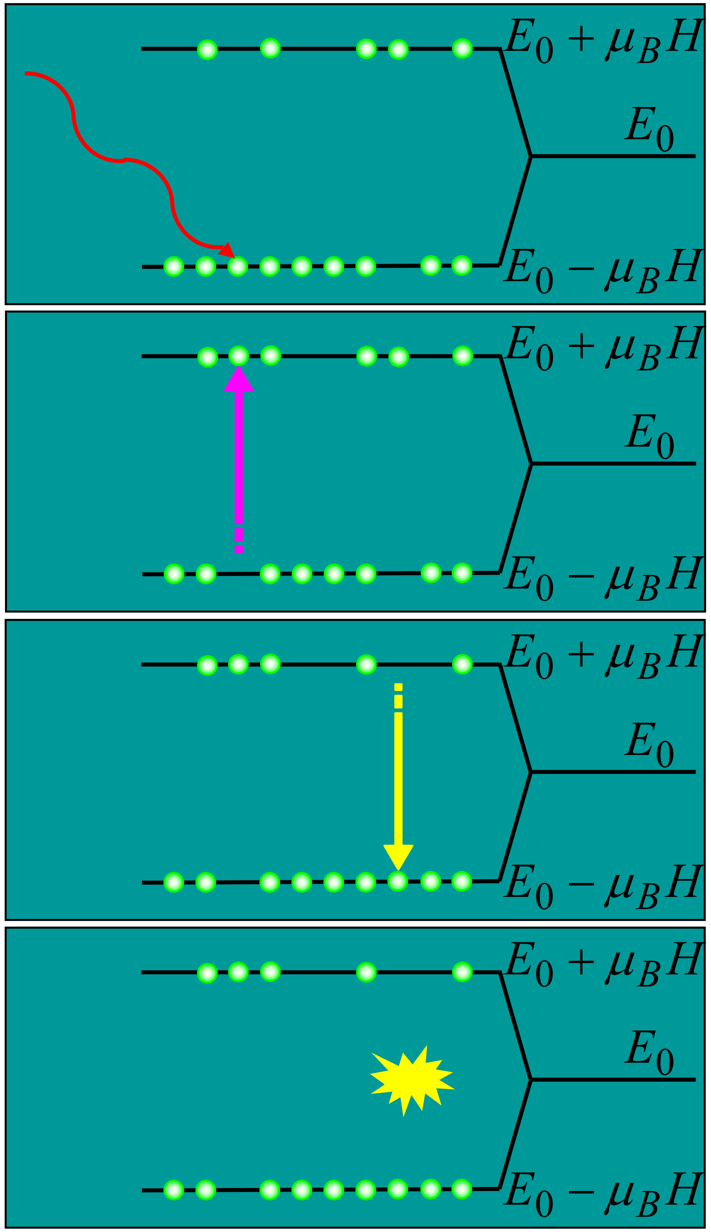


Geology

Do we still have something left to discover?

Biology and Medicine

Food industry



Radiation absorption

Quantum transitions

Dynamic susceptibility tensor

$$\vec{H} = \vec{H}_0 + \vec{h}$$

$$\vec{M} = \vec{M}_0 + \vec{m}$$

$$\vec{m} = \hat{\chi}(\omega, B_0, M_0) \cdot \vec{h}$$

$$\vec{h}, \vec{m} \sim \exp(i\omega t)$$

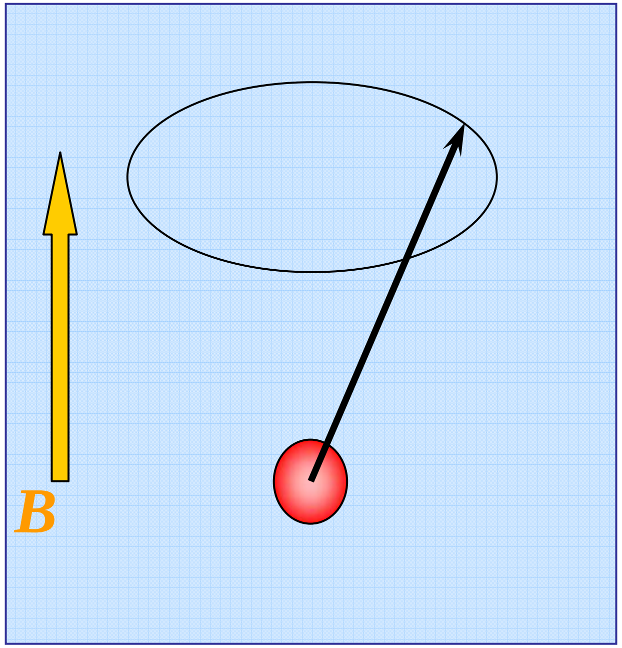
Difficult to calculate in general case!

But… There is a simple classical language…

Energy dissipation

Spin = magnetic arrow

Precession of a magnetic moment in magnetic field

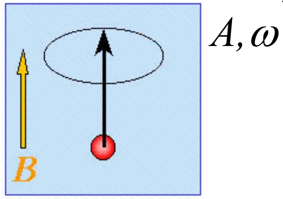


Landau-Lifshits equation of motion:

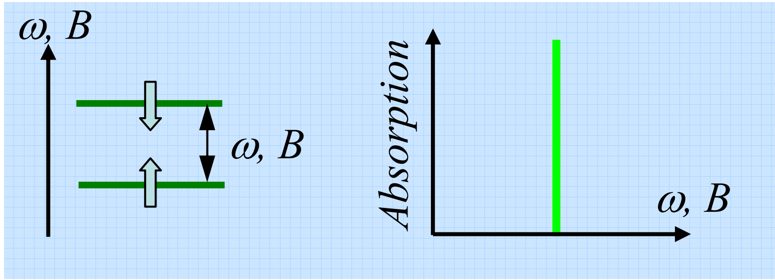
$$\frac{d\vec{M}}{dt} = -\gamma \cdot \vec{M} \times \vec{H}_{loc} + \vec{R}(\vec{M})$$

$$\hat{\chi} = \begin{pmatrix} \chi & i\chi_a & 0 \\ -i\chi_a & \chi & 0 \\ 0 & 0 & \chi_{II} \end{pmatrix} \qquad \vec{R} = \frac{\alpha}{M} \cdot \vec{M} \times \frac{\partial \vec{M}}{\partial t}$$

Single spin system

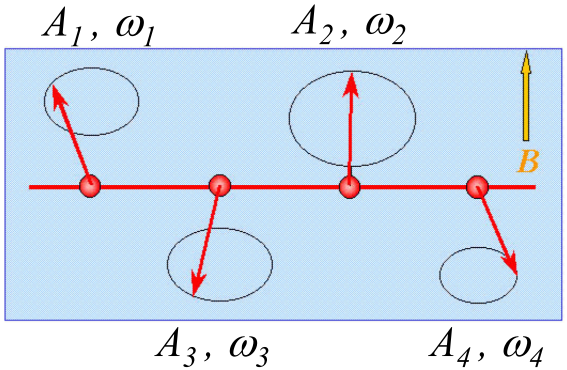


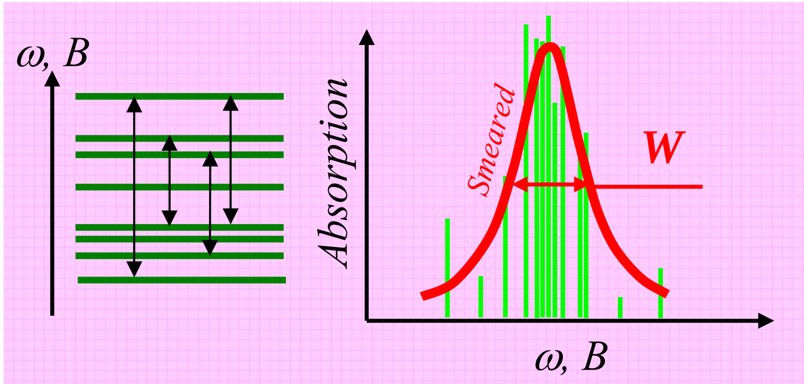
$T=0$



Strongly correlated spin system

$T=0$

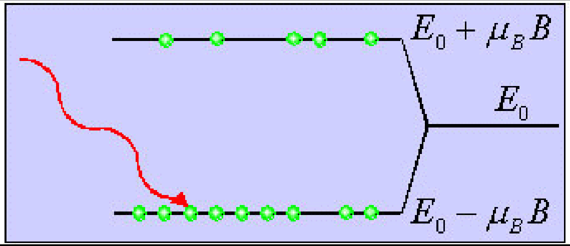
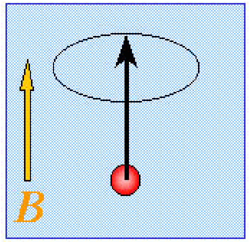




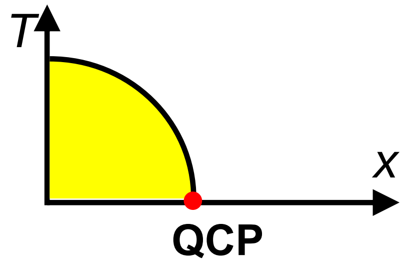
$T\neq 0$??

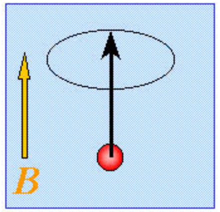
Quantum description is difficult and possible in a limited set of cases (AF S=1/2 quantum spin chain, Oshikawa-Affleck theory).

Classical spin rotation in quantum critical phenomena?

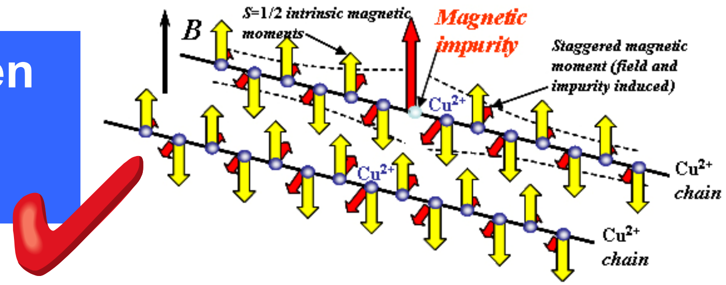
					
		We can	No way	We can	No way
Isolated spin	*Fine structure of absorption line*	🟢			🔴
	Line shape	🟢 Sometimes…		🟢 Incorrectly…	
	Selection rules	🟢			🔴
	Experimental geometry, polarization	🟢 If you a clever…		🟢 Easily!	
Strongly correlated system		AF S=1/2 chain 🟢 Abrahams-Wolfle theory 🔴		🟢	

Introduction. Quantum criticality and electron spin resonance

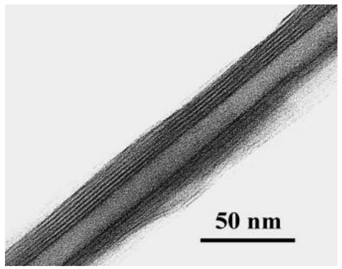




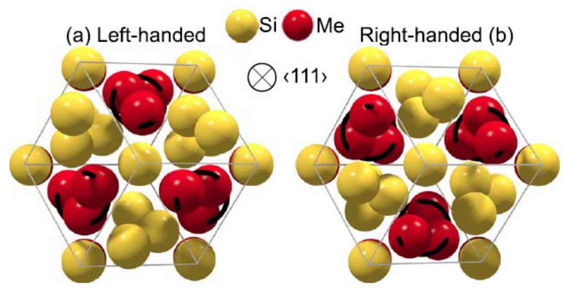
Quantum spin chains in disorder driven quantum critical regime. (Dielectrics, 1D systems).



Quantum critical phenomena in the nano-world. (Bad conductors, 2D systems).

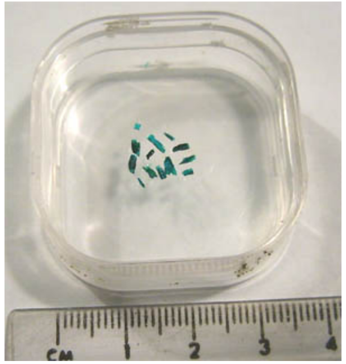


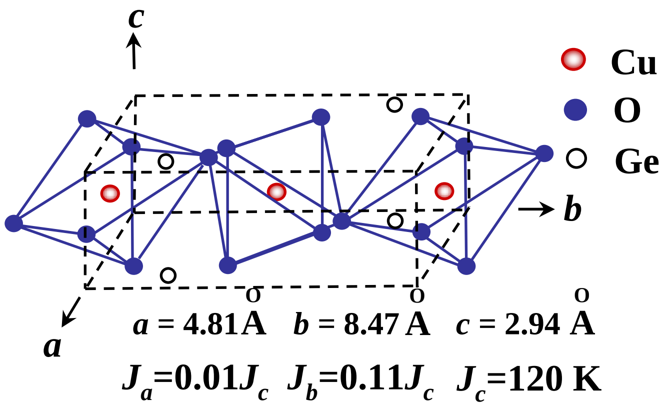
Quantum criticality in strongly correlated metals. (Good conductors, 3D systems)



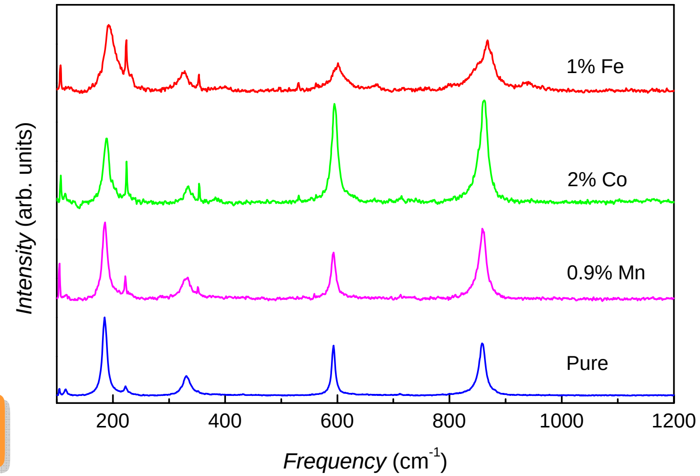
Final remarks

Doping of $CuGeO_3$ with magnetic impurities.

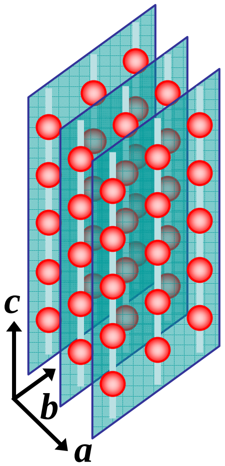




Raman spectra

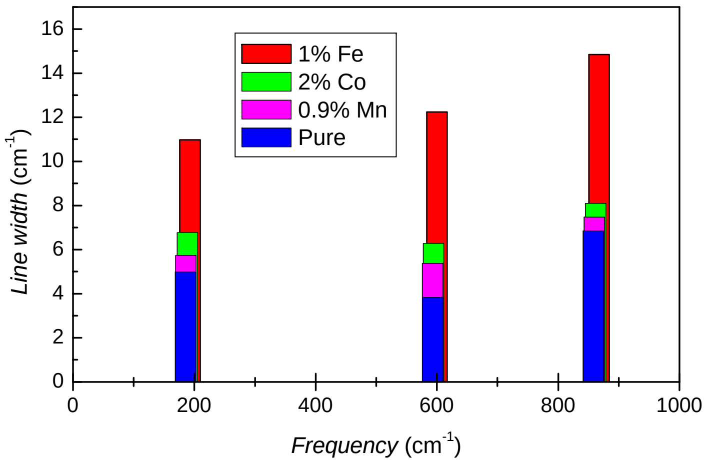


S=3/2 (Co) S=2 (Fe) S=5/2 (Mn)



- Doping of S=1/2 (Cu^{2+}) chains with S=3/2 (Co^{2+}) S=2 (Fe^{2+}) and S=5/2 (Mn^{2+}) impurities
- Effect of doping-induced structural disorder

Line width and position



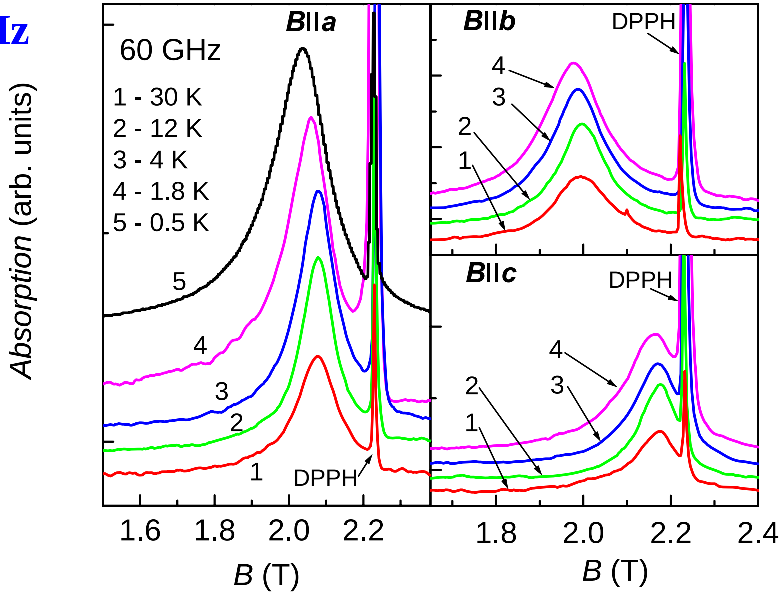
S=1/2 (Cu) AF chains

$Cu_{1-x}M_xGeO_3$ (x=0.02 M=Co; x=0.01 M=Fe, x=0.009 M=Mn)

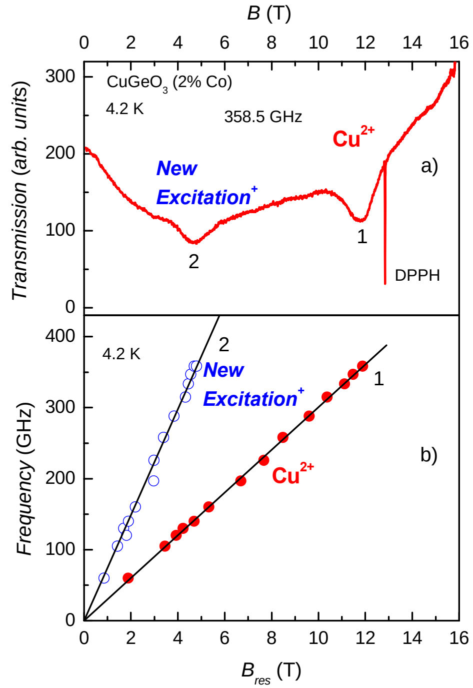
Experimental ESR spectra.

S=2 (Fe)

60 GHz cavity

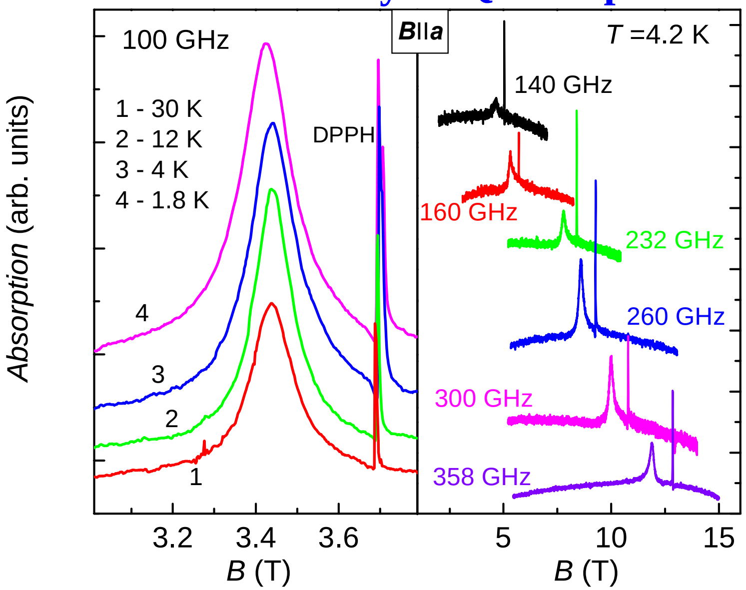


S=3/2 (Co)

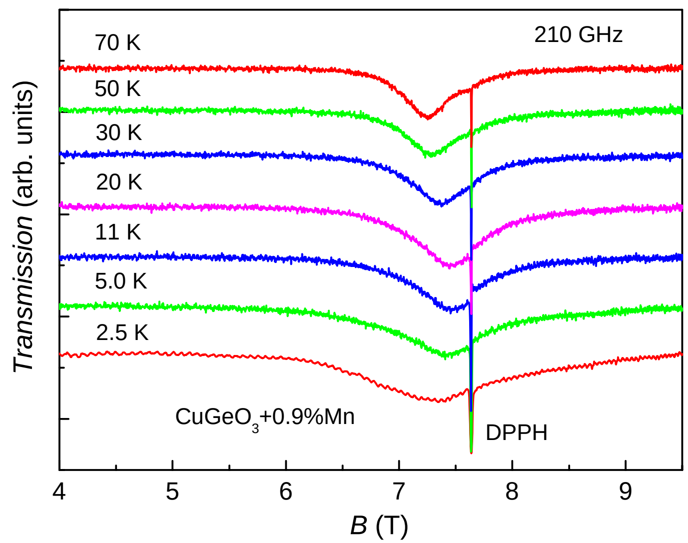


Quasi-optics

100 GHz cavity **Quasi-optics**

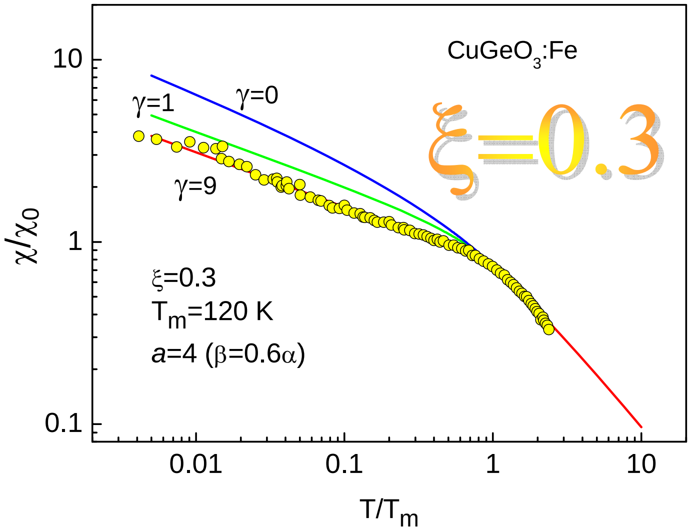


Quasi-optics

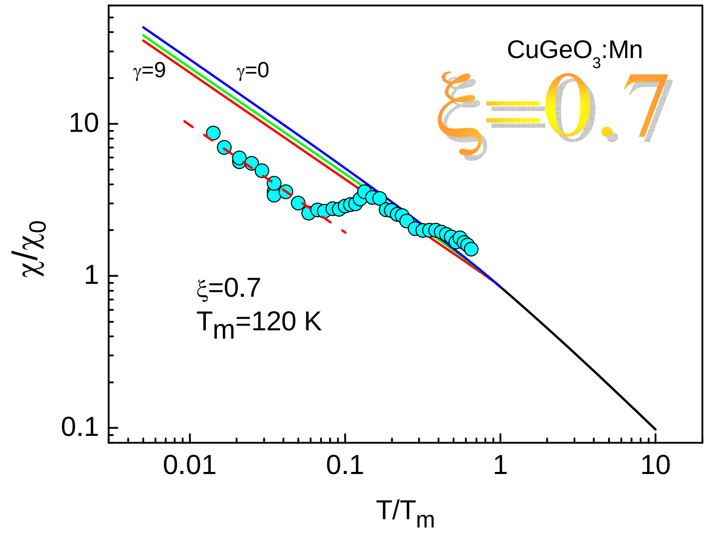


S=5/2 (Mn)

S=2 (Fe)



S=5/2 (Mn)

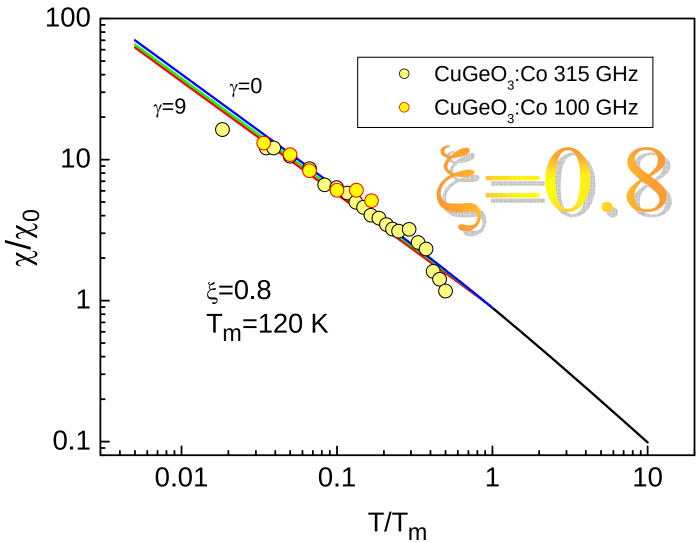


ESR monitors quantum spin chains

Spin-Peierls transition is suppressed by doping

In QC regime temperature vary more than two orders of magnitude.

S=3/2 (Co)



Theory works!

T_m~120 K~J_c !

New ESR regularities in QC systems. Oshikawa-Affleck theory.

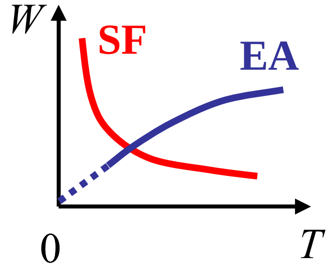
$$\hat{H} = \hat{H}_0 + \hat{H}_Z = J \cdot \sum_{j,k} \vec{S}_j \cdot \vec{S}_k - B \cdot \sum_j S_j^z$$

$$\hat{H} = \hat{H}_0 + \hat{H}_A + \hat{H}_Z$$

$$\hat{H}_A = h \cdot \sum_j (-1)^j \cdot S_j^x$$ *Staggered field*

$$\hat{H}_A = \delta \cdot \sum_j S_j^x \cdot S_{j+1}^x$$ *Exchange anisotropy*

M.Oshikawa, I.Affleck (1999- 2002)



Line width in presence of exchange anisotropy and staggered field

Universal relation in OA theory

$$\frac{w}{\Delta g} = 1.99 \frac{k_B}{\mu_B} \cdot T$$

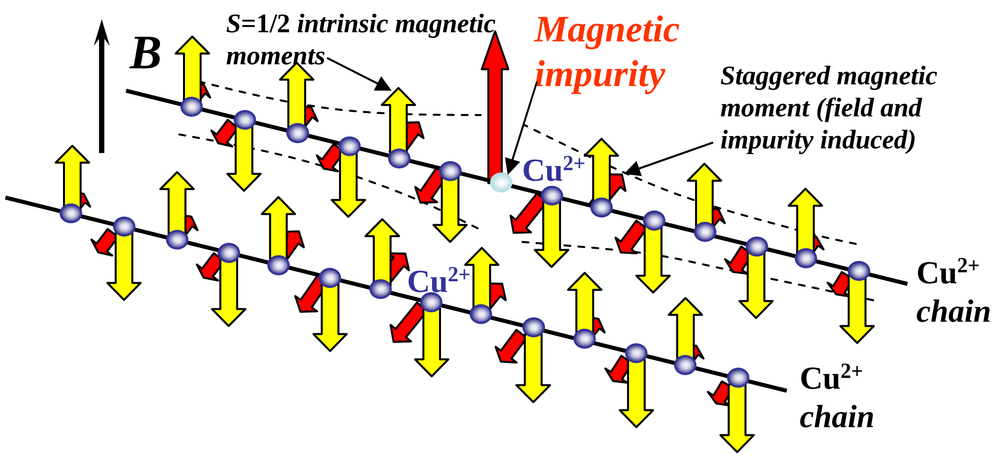
S.V.Demishev et al., Europhysics Lett. (2003)
S.V.Demishev et al., ProgTheor.Phys.Suppl.(2005)

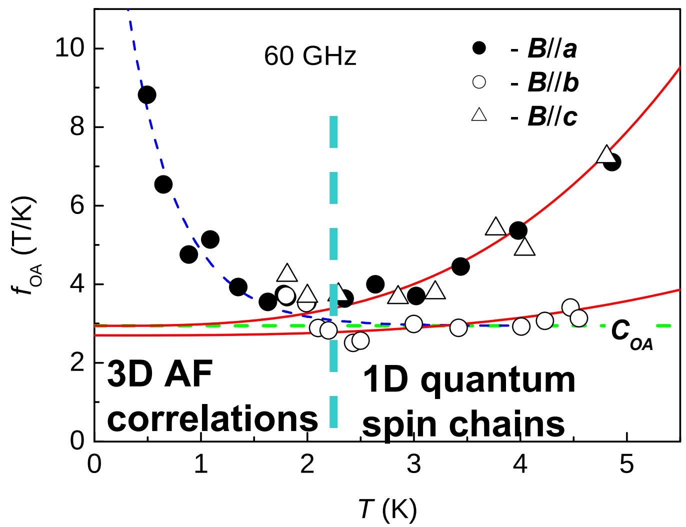
Oshikawa-Affleck function:

$$w(T) = a \cdot T + \gamma \frac{h^2}{T^2}; \quad \Delta g(T) = \zeta \cdot \frac{h^2}{T^3}$$

$$f_{OA}(T) \equiv \frac{w(T)}{\Delta g(T) \cdot T} \approx C_{OA} + \frac{a}{\zeta \cdot h^2} \cdot T^3$$

$$C_{OA} = 1.99 \cdot k_B / \mu_B$$





Staggered magnetization is a fingerprint of QC regime in $CuGeO_3$?

Estimate of the characteristic cluster size.

Lowering temperature results in freezing of the magnetic contribution of the spin clusters for which condition $T_N > T$ holds.

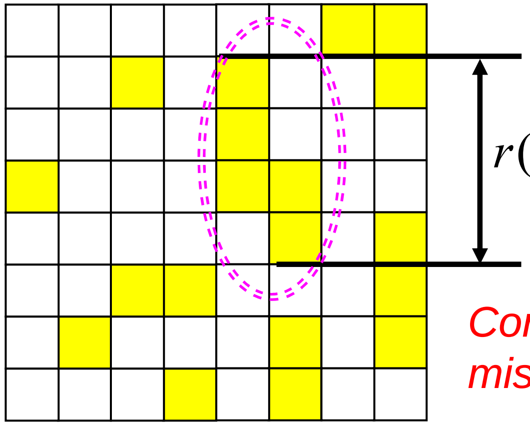
A two-phase model ("frozen" and "non-frozen clusters") may by introduced. The probability $W(T_N)$ defines "frozen" part of the sample volume.

$$v_{AF} = 1 - \left(\frac{T}{T_m}\right)^{1-\xi}$$

$$R < R_m$$

$$r = R_m / l_0$$

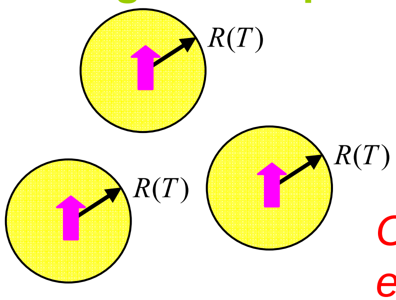
Percolation



$$r(T) \sim \frac{1}{\left|v_{AF}(T) - v_c\right|^{\eta}}$$

Correlation is missing

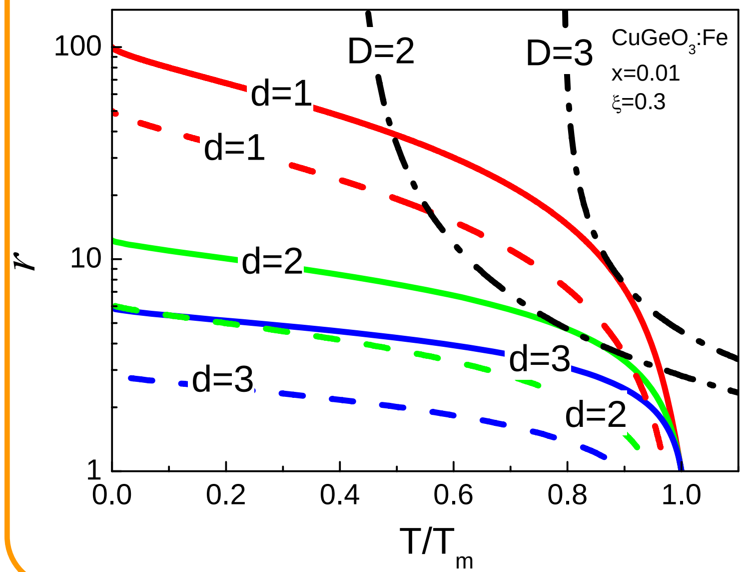
Cluster growth in vicinity of the magnetic impurity



$$\frac{T}{T_m} = \left[1 - \frac{2x}{d+1}\left(r^d - \frac{1}{r}\right)\right]^{\frac{1}{1-\xi}}$$

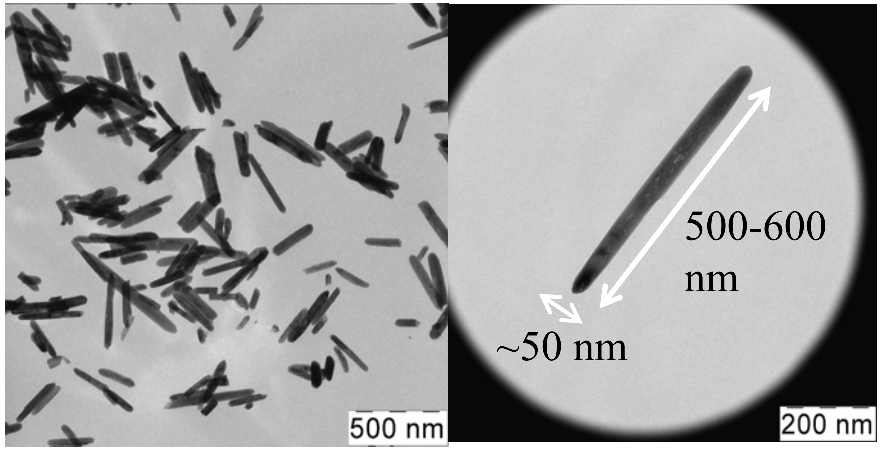
Correlation is essential

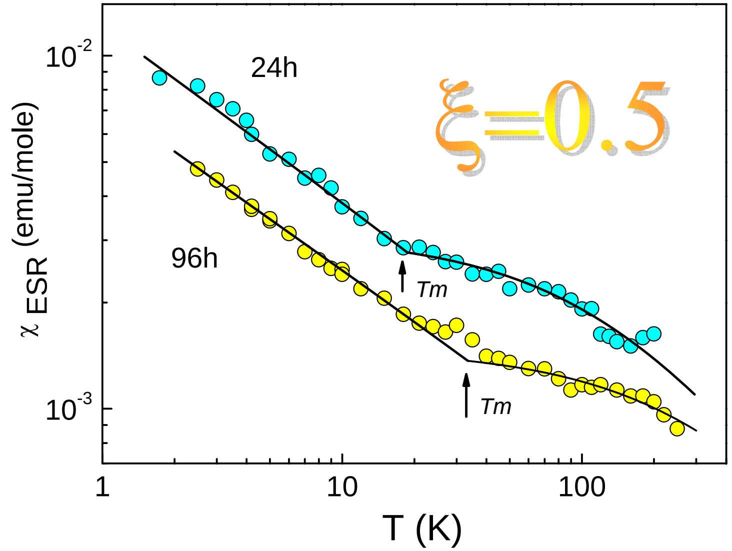
$Cu_{1-x}M_xGeO_3$ l_0~1 nm



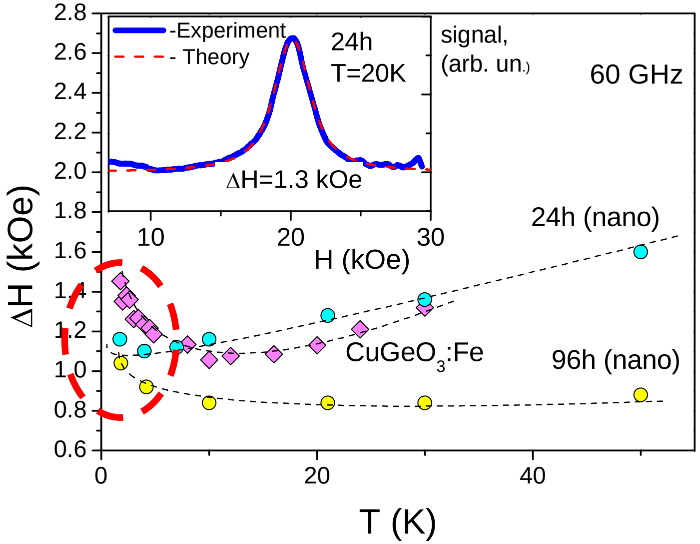
Griffiths phase is formed by nano spin clusters!

Synthesis by hydrothermal treatment



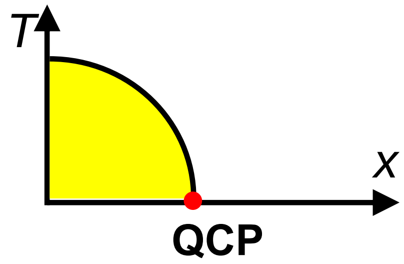


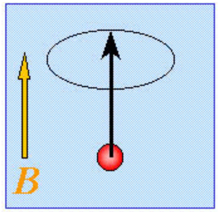
Suppression of spin-Peierls transition and QC behavior without any magnetic impurities!



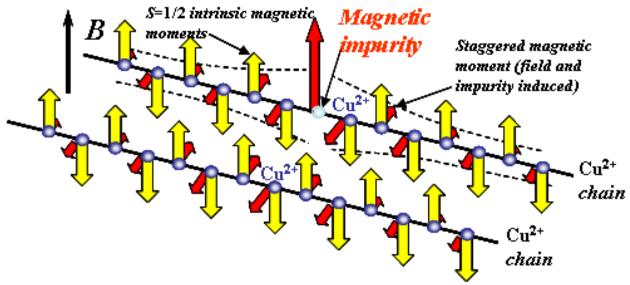
Line width simulation for a mixture with anisotropic g-factors suggests presence of the staggered field.

Introduction. Quantum criticality and electron spin resonance

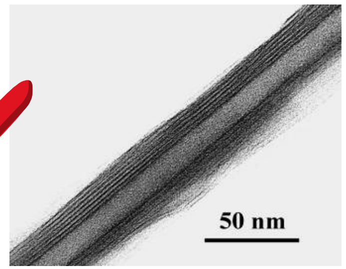




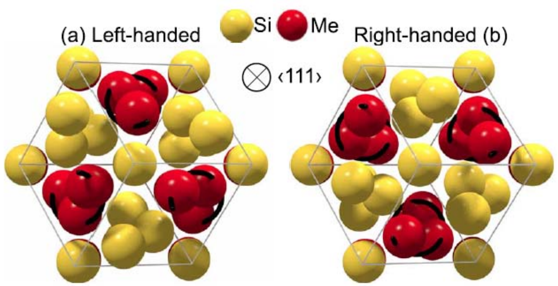
Quantum spin chains in disorder driven quantum critical regime. (Dielectrics, 1D systems).



Quantum critical phenomena in the nano-world. (Bad conductors, 2D systems).

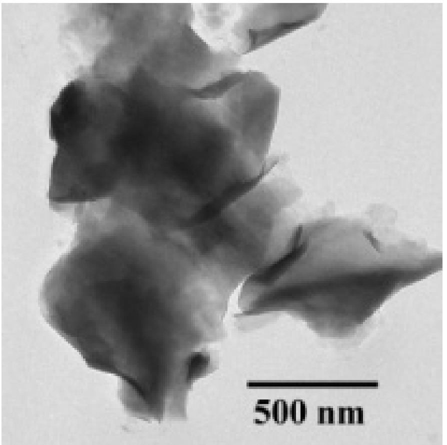


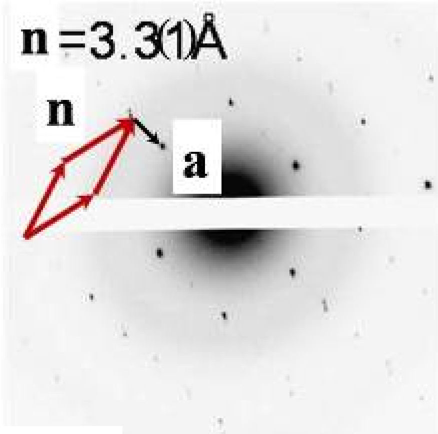
Quantum criticality in strongly correlated metals. (Good conductors, 3D systems)



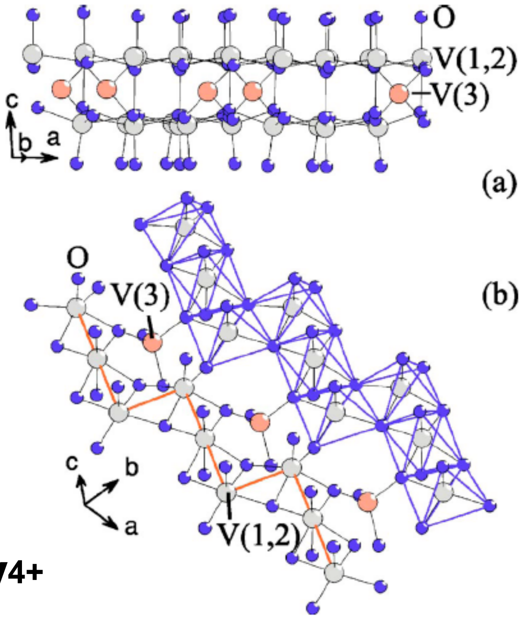
Final remarks

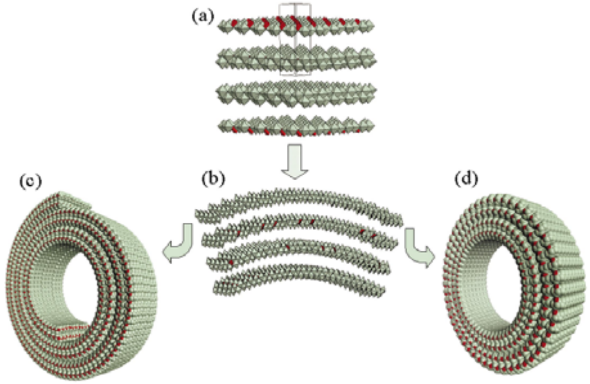
Vanadium oxide nanomaterials (nanolayers and nanotubes).

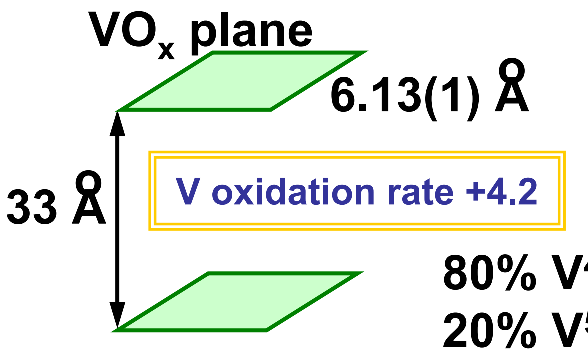




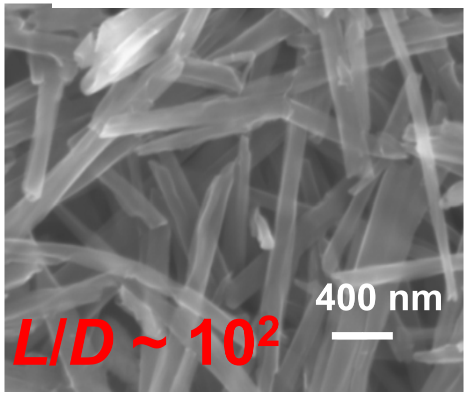
VO_x nanolayers (pre-VO_x-nanotubes)



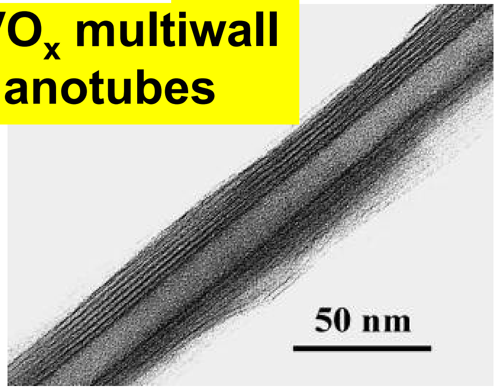


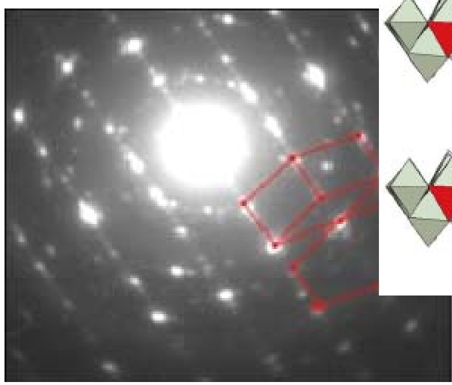


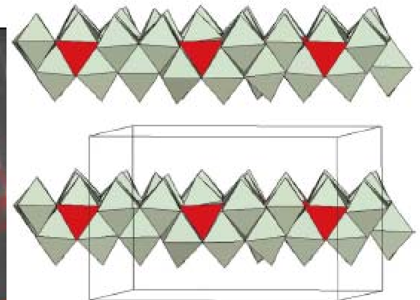
80% V^{4+}
20% V^{5+}



VO_x multiwall nanotubes

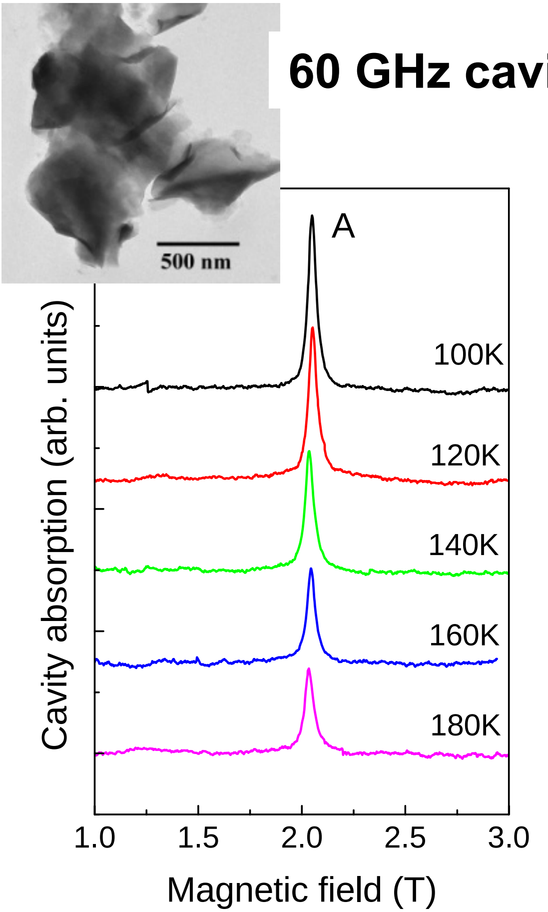


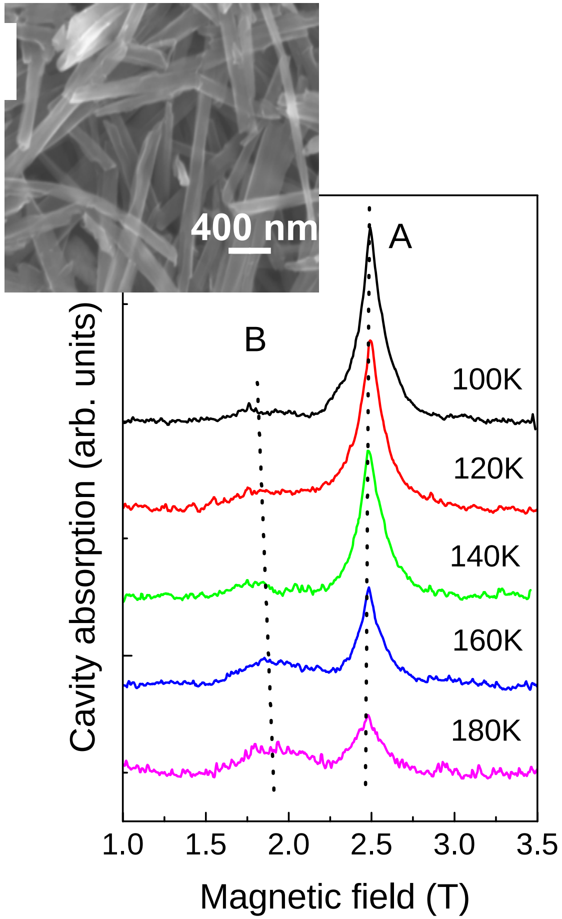


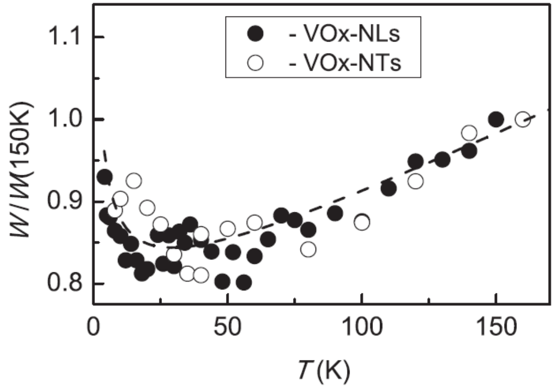


ESR in VO_x naolayers and nanotubes.

60 GHz cavity







Again staggered field?? 2D spin system rather than 1D…

VO_x nano layers

Single ESR line

g=1.96±0.02

VO_x nanotubes

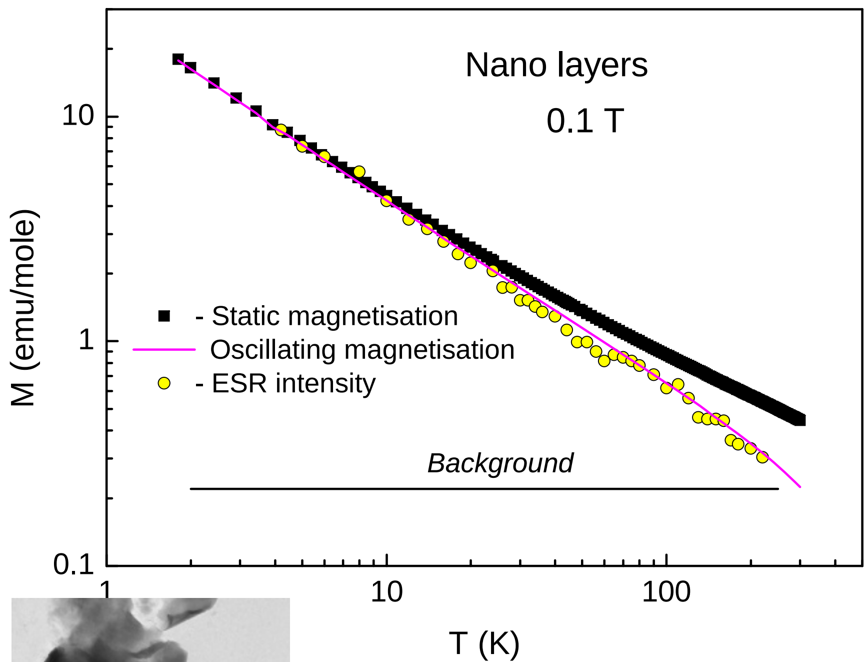
Two ESR lines

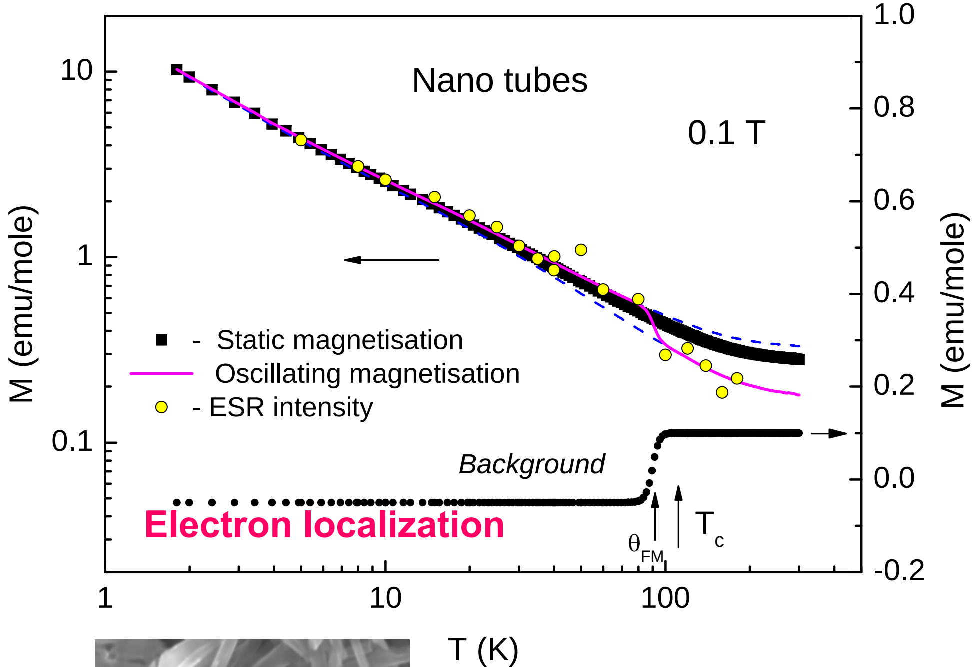
g_A=1.96±0.02 V^{4+}

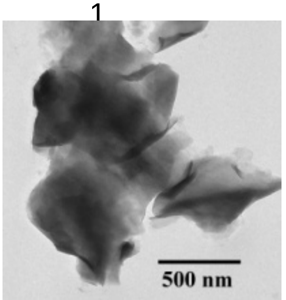
g_B=2.5±0.1 V^{4+}-V^{4+} AF dimer

V^{5+} S=0 – non-magnetic ion

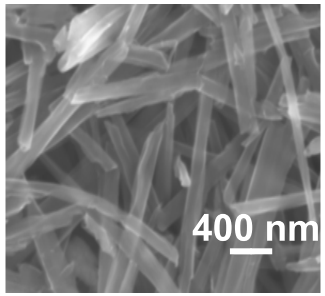
V^{4+} S=1/2 – magnetic ion







VO_x nano layers



VO_x nanotubes

$$M = M_{osc} + M_b$$

SQUID (static) | **ESR** (dynamic) | **Background**

Simple Van Vleck type background structure.

$$\chi_b = \chi_{VanVleck} + \chi_{Pauli} + \chi_{Hubbard}$$

Change of background — $V^{5+} + e \rightarrow V^{4+}$ **free electrons in the sample**

Absolute calibration — **Curie constants for V^{4+}(S=1/2) subsystem**

Chemical analysis + X-ray photoemission — **X and Y numbers in $VO_X(C_{16}H_{33}NH_2)_Y$. Average V charge ζ .**

ESR — **V^{4+} localized nagnetic moments form dimers and quasi free spins. *g*-factors for quasi free spins and dimers are known.**

The model:

$$\varsigma = 5 - x = 5 - (x_l + x_e) = 5 - (x_f + x_d + x_e)$$

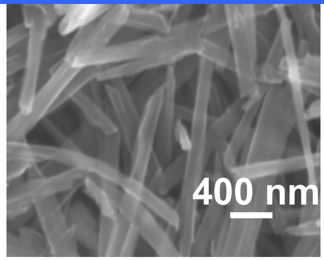
$$x_{empty} = 1 - (x_f + x_d + x_e)$$

$$C_f m = \frac{N_A \mu_B^2}{k_B} g_f^2 \frac{S(S+1)}{3} x_f = \frac{N_A \mu_B^2}{4k_B} g_f^2 x_f$$

$$x(V^{4+}) = x_f + x_d$$

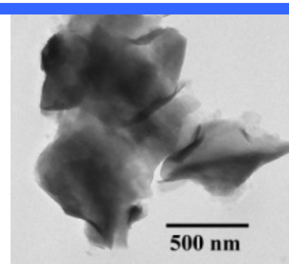
$$C_d m = \frac{N_A \mu_B^2}{k_B} g_d^2 x_d$$

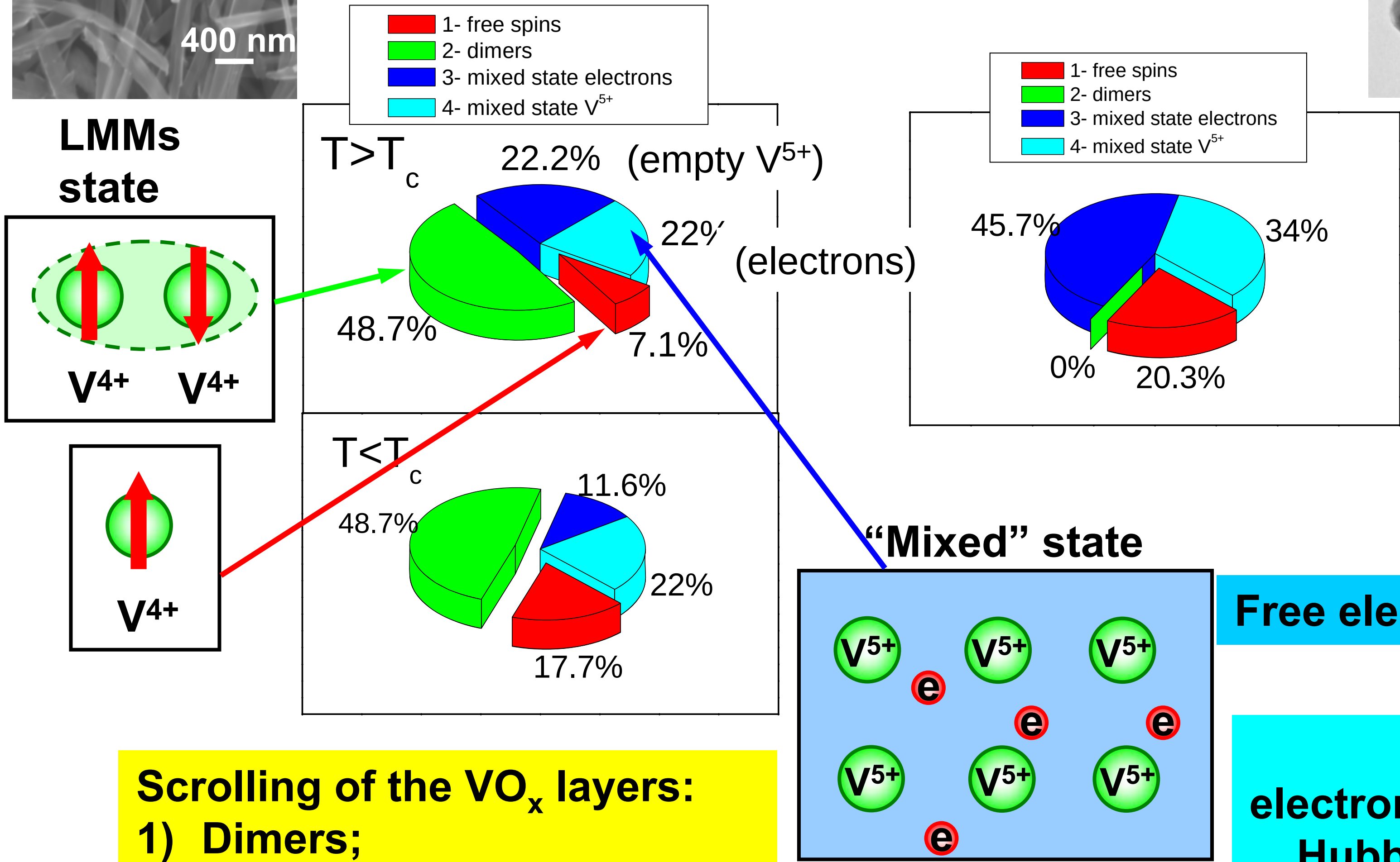
x_f, x_d – electrons localized at V^{5+} making them V^{4+}, x_e- some other electrons, different from those in V^{4+} state,*m*- molecular mass



VO_x nanotubes

VO_x nano layers





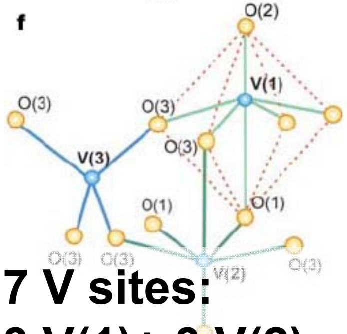
Free electrons + V^{5+}

or electrons in upper Hubbard band

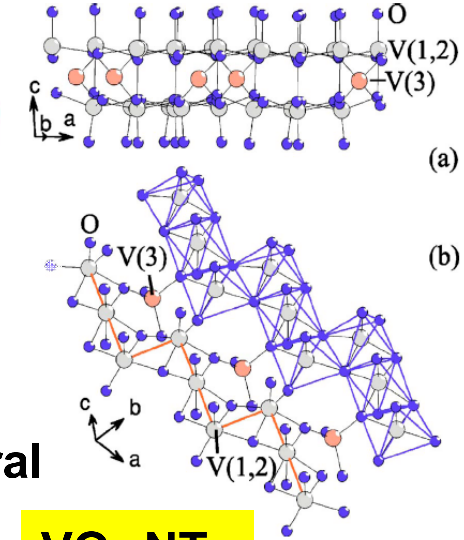
Scrolling of the VO_x layers:

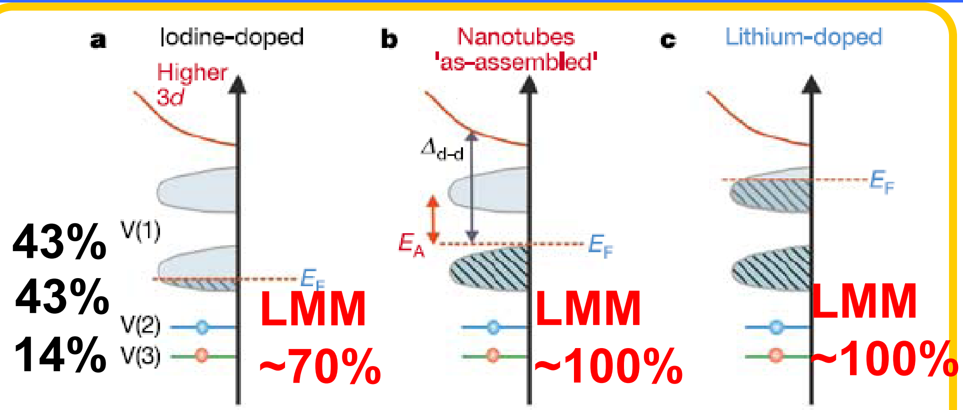
1) **Dimers;**
2) **Localization of electrons at low temperatures ($T<T_c$).**

Concentration estimates and DOS of various spin states.



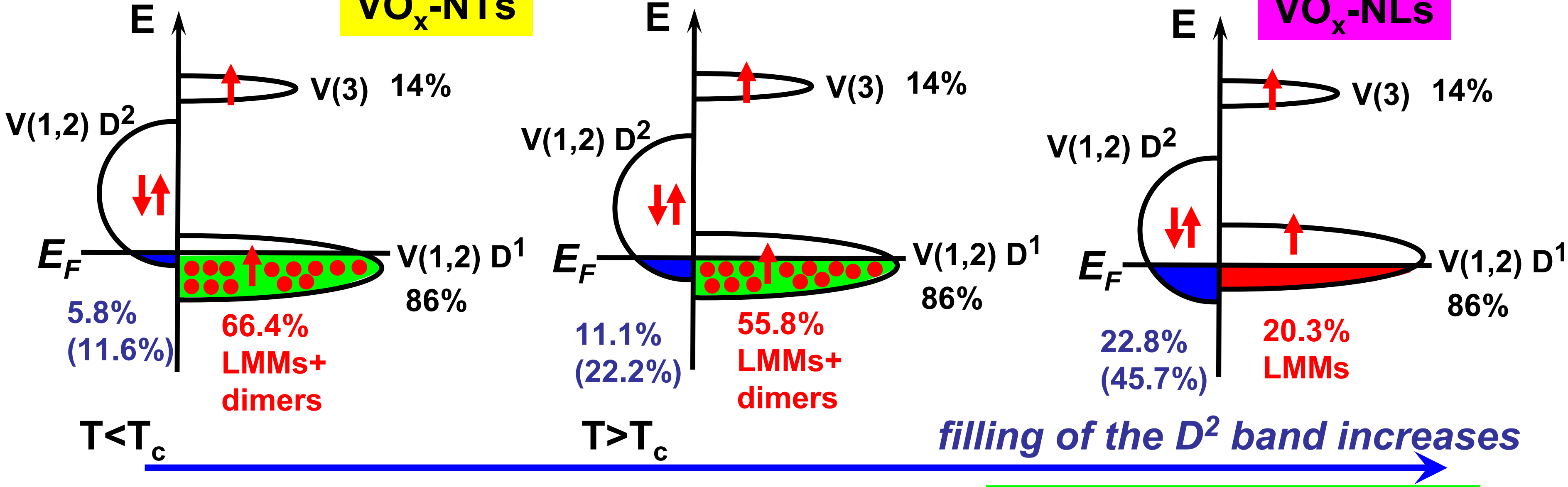
7 V sites:
3 V(1)+ 3 V(2) octaherdal
1 V(3) tetrahedral





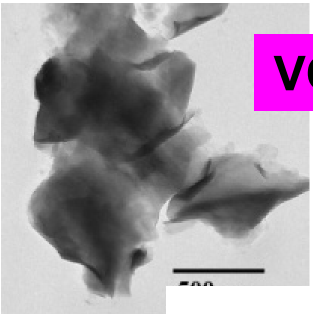
Energy spectrum Nature, **431**,672 (2004)

VO_x-NTs **VO_x-NLs**

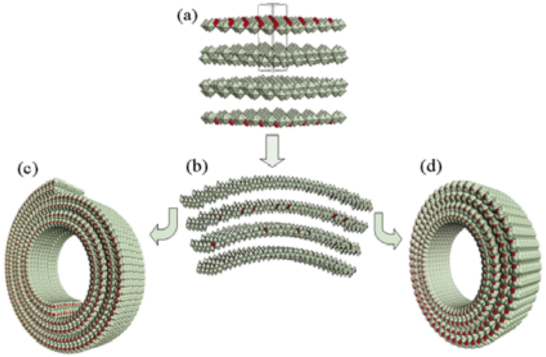


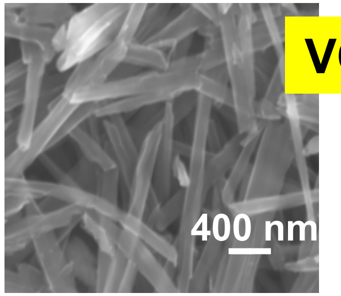
Magnetic transition= shift of the relative positions of D^1 and D^2.

Scrolling= enhancement of Hubbard repulsion

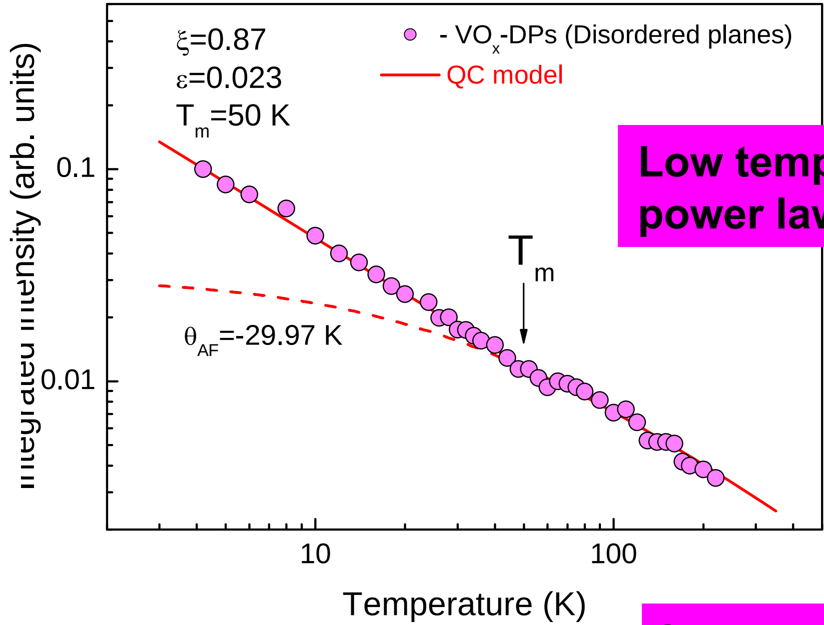


VO_x **nanolayers**

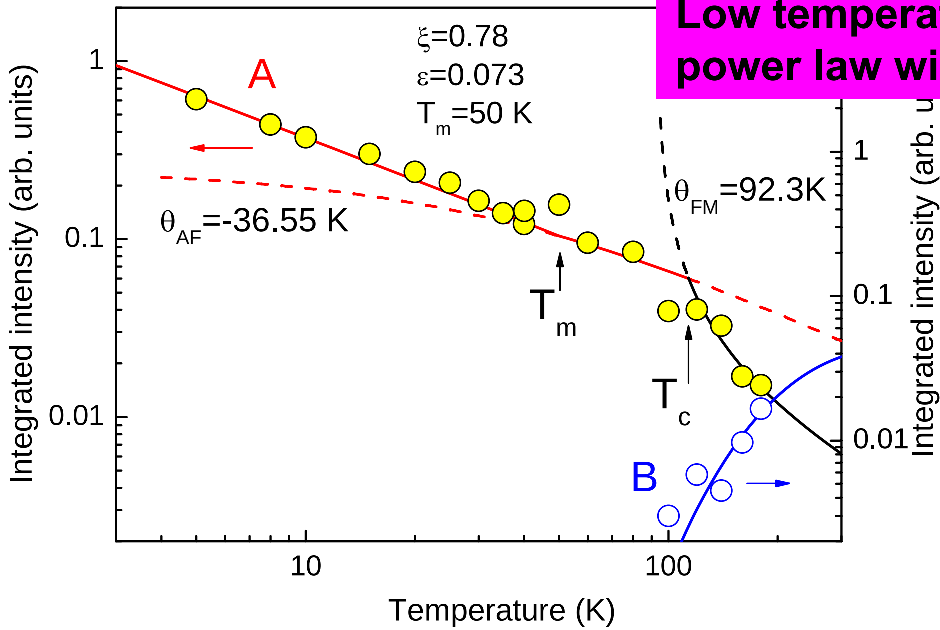




VO_x **nanotubes**



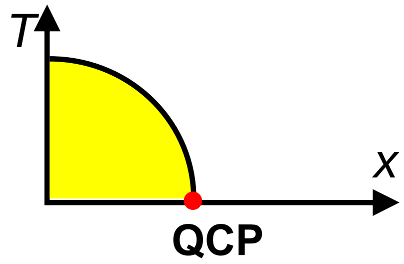
Low temperature power law with ξ=0.87

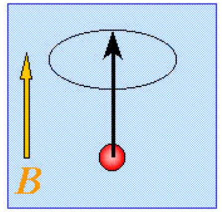


Low temperature power law with ξ=0.78

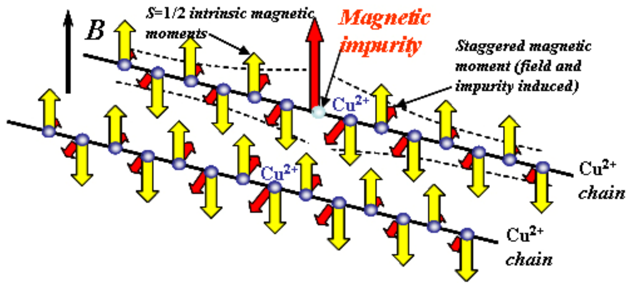
Good agreement between experiment and quantum critical model.

Introduction. Quantum criticality and electron spin resonance

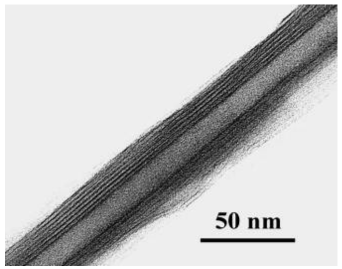




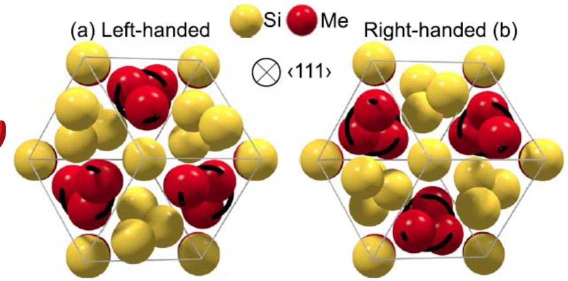
Quantum spin chains in disorder driven quantum critical regime.
(Dielectrics, 1D systems).



Quantum critical phenomena in the nano-world.
(Bad conductors, 2D systems).

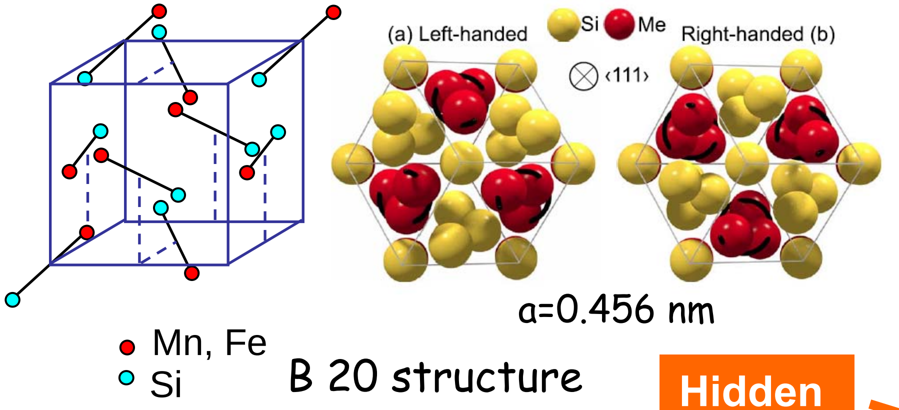


Quantum criticality in strongly correlated metals.
(Good conductors, 3D systems)

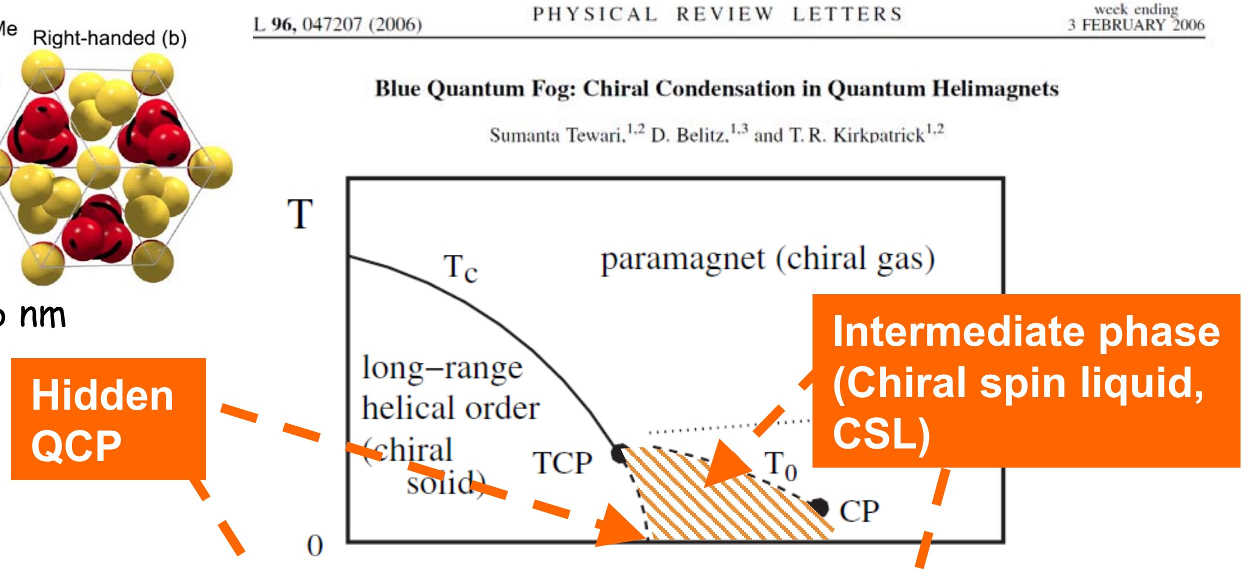


Final remarks

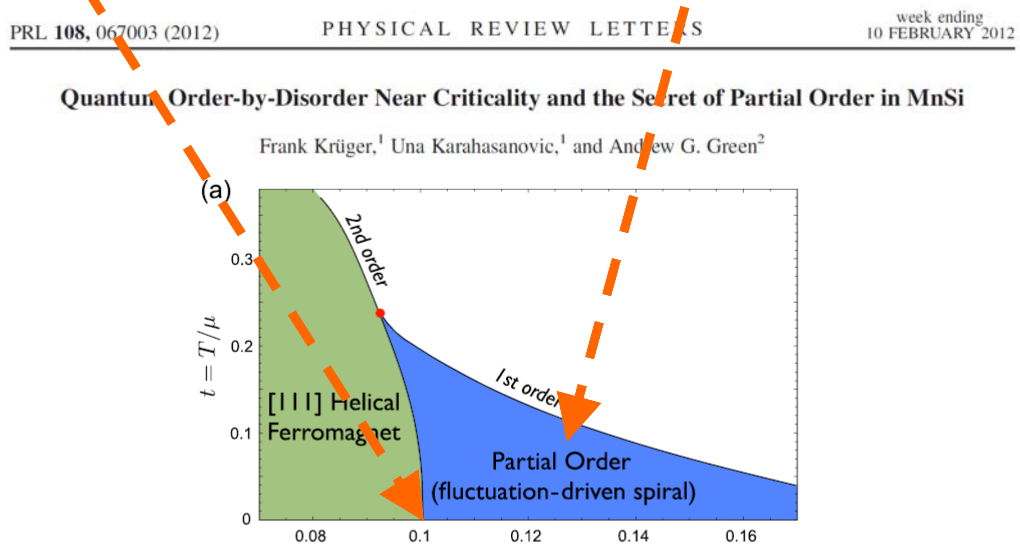
Quantum criticality in $Mn_{1-x}Fe_xSi$. Theoretical expectations.



$Mn_{1-x}Fe_xSi$ substitutional solid solutions ($x<0.3$).



Parameter controlling quantum criticality (pressure, concentration, etc.)



Parameter controlling quantum criticality (pressure, concentration, etc.)

After decay of the phase with long-range magnetic order an intermediate phase with short-range (fluctuation-driven) magnetic order should be formed. There is hidden QCP.

Intermediate phase may mask quantum critical anomalies like divergent magnetic susceptibility.

PHYSICAL REVIEW B **83**, 224411 (2011)

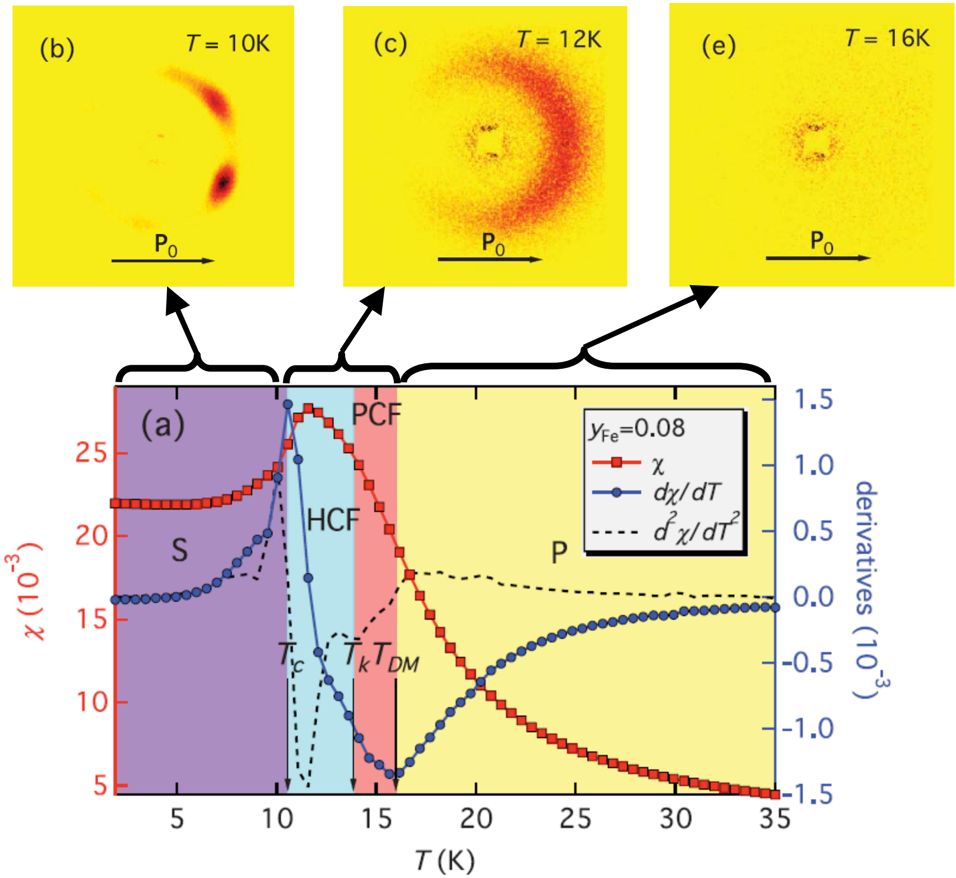
Chiral criticality in the doped helimagnets $Mn_{1-y}Fe_ySi$

Sergey V. Grigoriev,[1] Evgeny V. Moskvin,[1] Vadim A. Dyadkin,[1] Daniel Lamago,[2,3] Thomas Wolf,[3]
Helmut Eckerlebe,[4] and Sergey V. Maleyev[1]

Long-range magnetic order (Chiral solid)

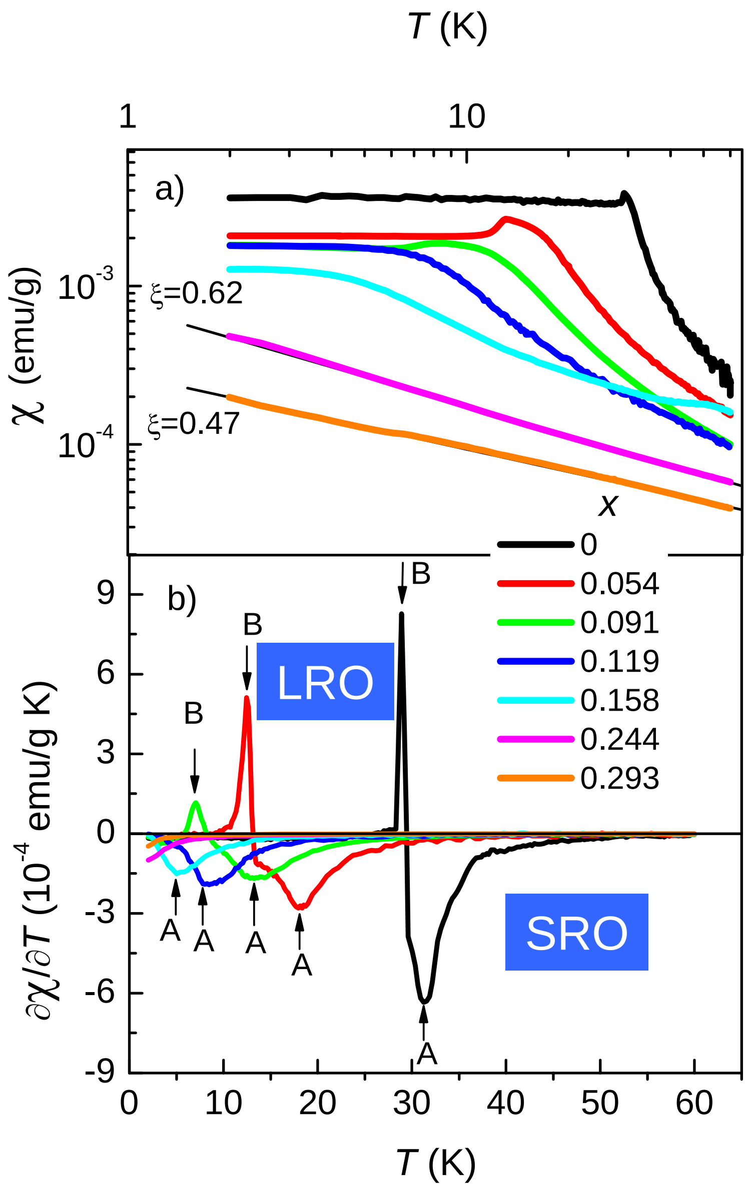
Short-range magnetic order (Chiral liquid)

Paramagnet (Chiral gas)



Correlation between magnetic susceptibility and polarized neutron scattering data is established in $Mn_{1-x}Fe_xSi$.

The extrema of the $\partial\chi/\partial T$ derivative may be used for identification of the magnetic phases with long-range and short-range magnetic order.

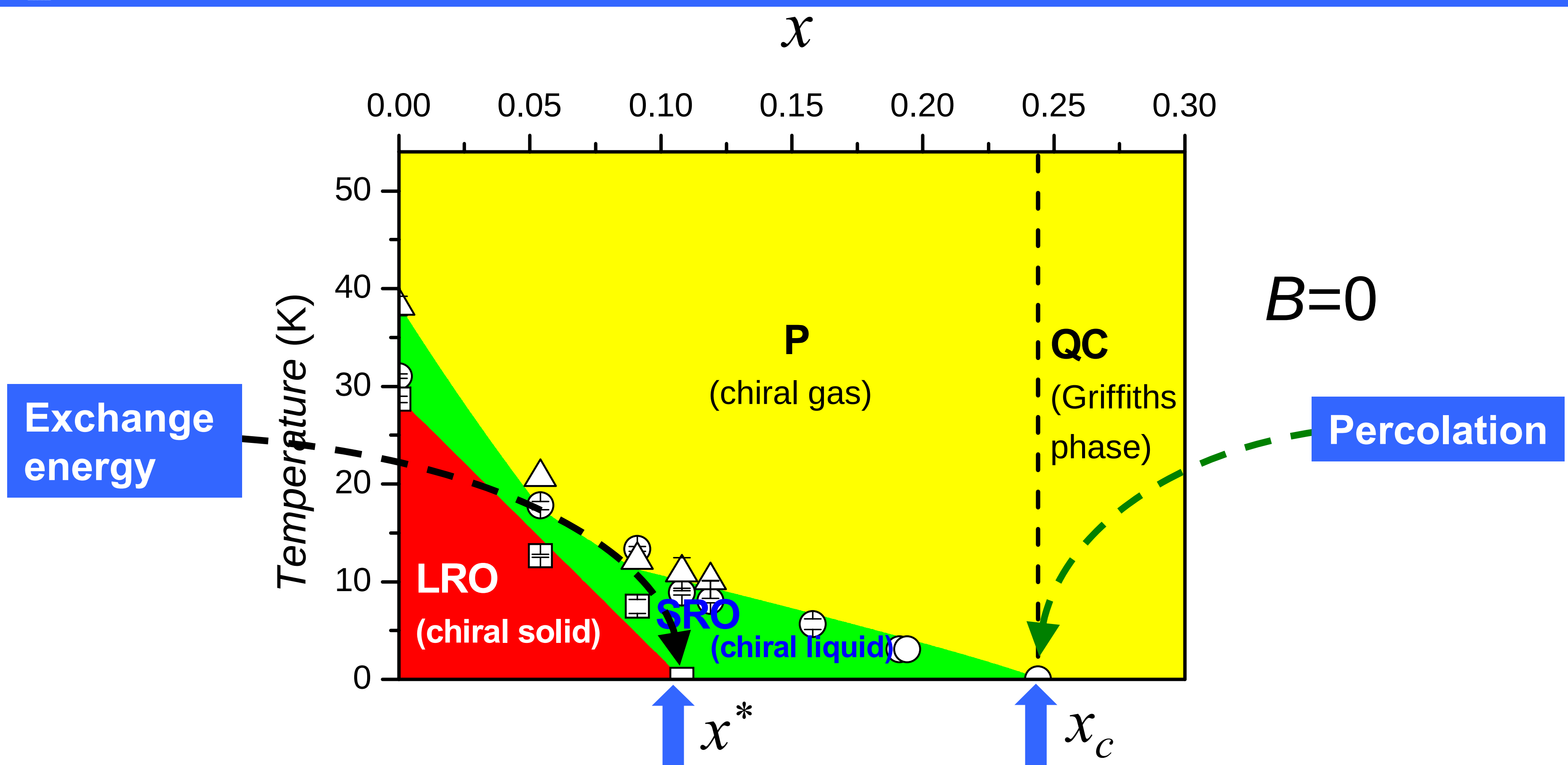


Griffiths-type QC anomaly for *x* >0.24

$$\chi \sim \frac{1}{T^{\xi}} \quad \xi \sim 0.5 - 0.6$$

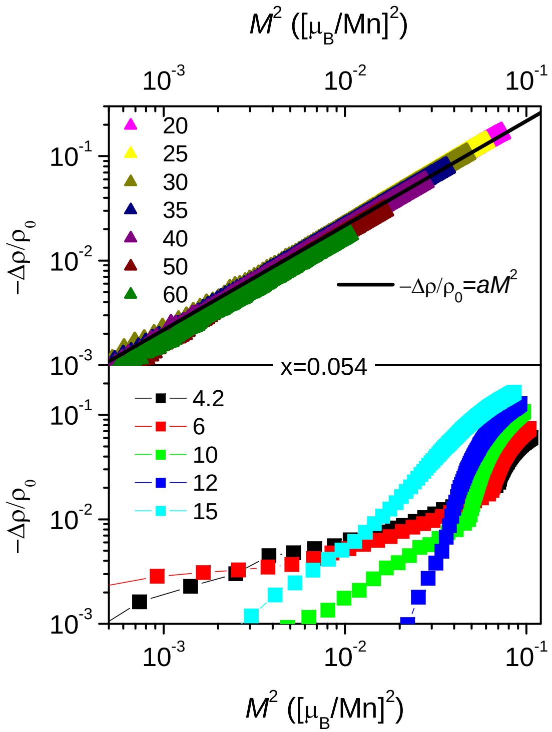
Peak B is a marker of long-range magnetic order (LRO).

Minimum A is a marker of short-range magnetic order (SRO).

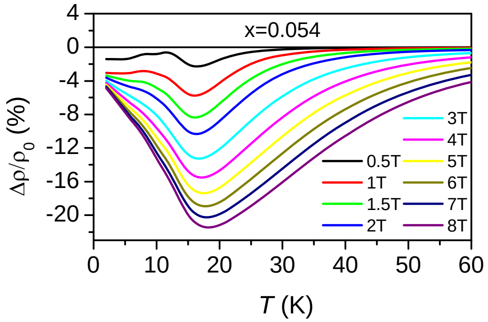


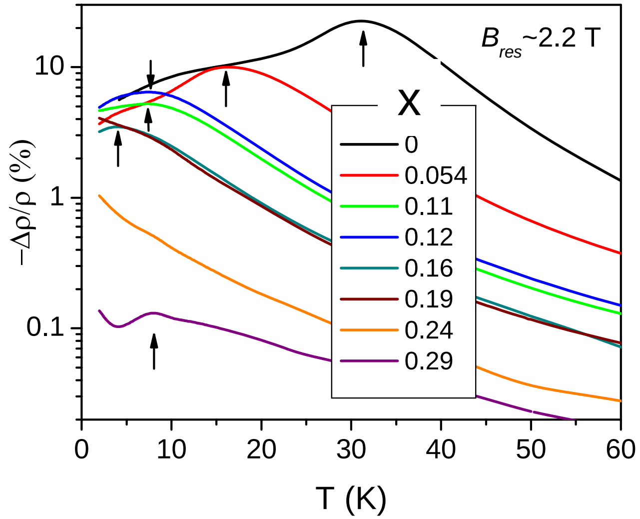
There are two quantum critical points, x^* and x_c. The first QC point x^* ~ 0.11 corresponds to disappearance of LRO and is a hidden one, which is located inside the SRO phase. The second QC point x_c ~0.24 is a "true" one and marks suppression of the magnetic phase with SRO (chiral spin liquid).

Yosida mechanism holds in $Mn_{1-x}Fe_xSi$.

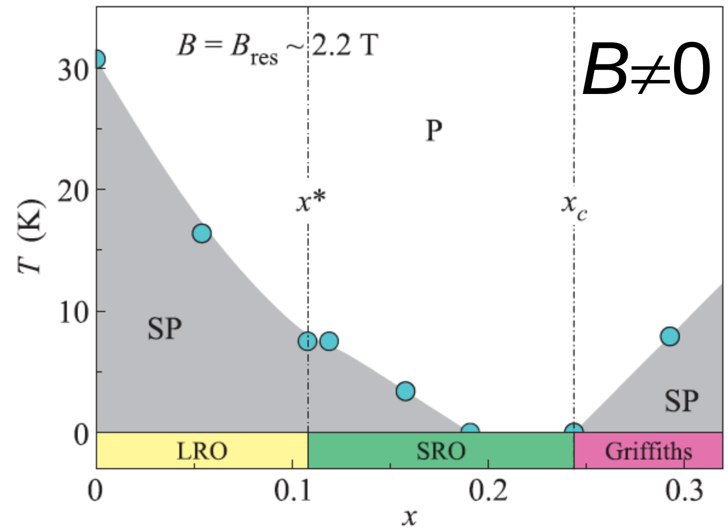


Magnetoresistance maximum evolution with iron concentration.





Phase diagram in magnetic field corresponding to magnetic resonance



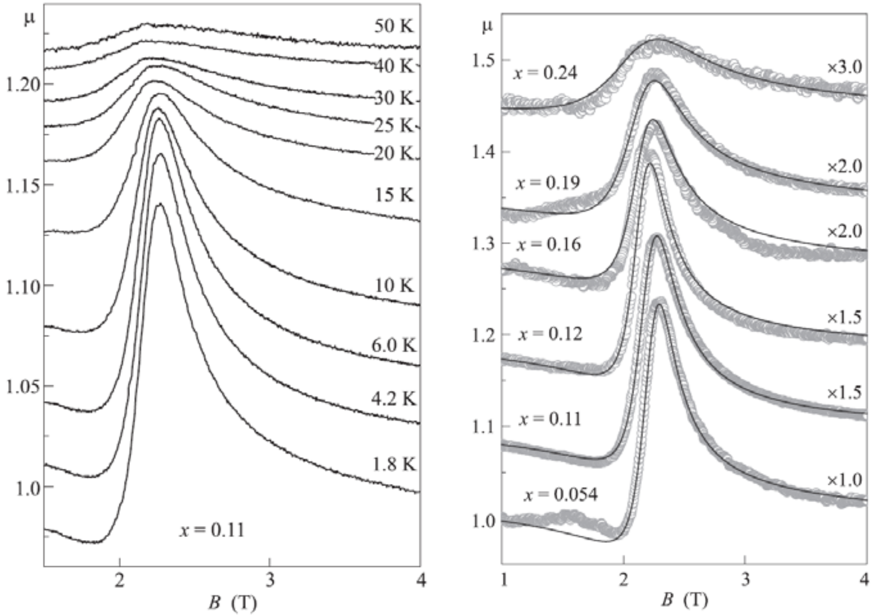
Pis'ma v ZhETF, vol. 100, iss. 1, pp. 30–33 © 2014 July 10

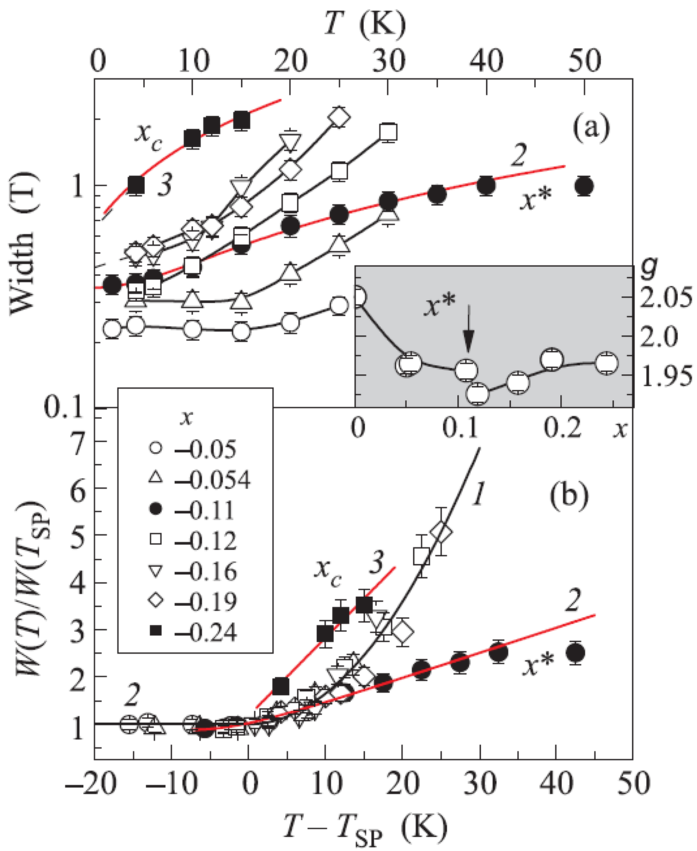
Anomalous spin relaxation and quantum criticality in $Mn_{1-x}Fe_xSi$ solid solutions[1)]

S. V. Demishev[+*2)], A. N. Samarin[+*], V. V. Glushkov[+*], M. I. Gilmanov[+*], I. I. Lobanova[+*], N. A. Samarin[+], A. V. Semeno[+], N. E. Sluchanko[+], N. M. Chubova[×], V. A. Dyadkin[×], S. V. Grigoriev[×]

ESR in $Mn_{1-x}Fe_xSi$. Results.

60 GHz ESR spectra





Strong broadening of the line width (enhancement of spin fluctuations) with iron concentration.

Universal scaling $W(T)/W(T_{SP})=1+a(T-T_{SP})^2$ for all concentrations except quantum critical points x* and x_c.

Violation of the standard Korringa relaxation law $W(T)\sim 1/\chi(T)\sim(T-T_{SP})$.

Weakening of the W(T) temperature dependence just at quantum critical points.

Theory of the ESR in strongly correlated metals

Korringa relaxation should be valid even in strongly correlated metallic case

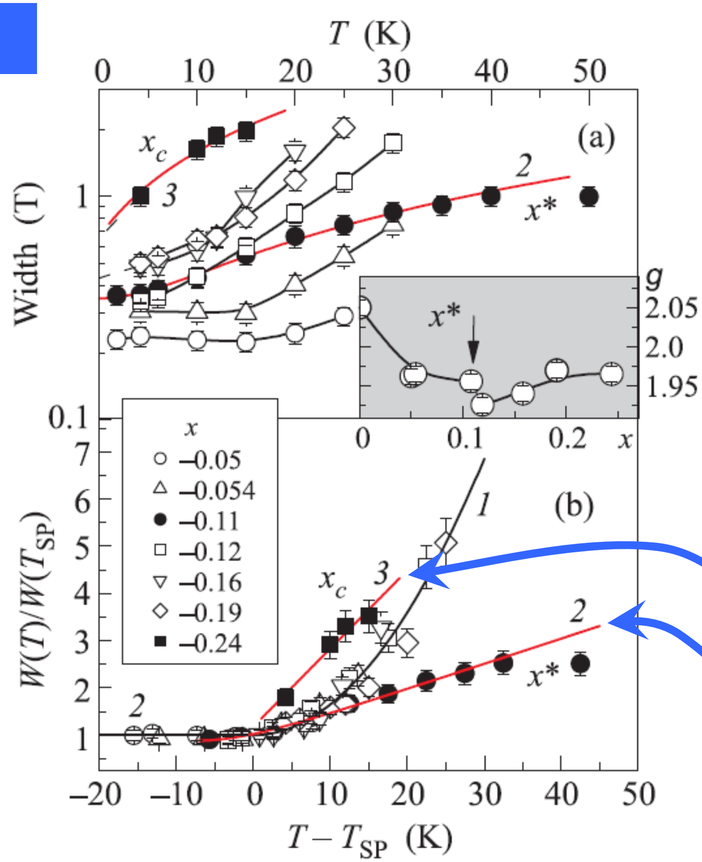
P. Schlottmann, Phys. Rev. B **86**, 075135 (2012)

Expression for ESR line width in strongly correlated metal in vicinity of the QC point:

$$W(T) = AT \arctan(T/T_x) + W_0$$

T_x is a crossover temperature between Fermi-liquid $(T \ll T_x)$ and non-Fermi-liquid $(T \gg T_x)$ regimes.

P. Wölfle and E. Abrahams, Phys. Rev. B **80**, 235112 (2009).



Reasonable fit of the experimental data assuming $T_x \sim T_{SP}$, i.e. $T_x \sim 11$ K for x^* and $T_x \sim 0$ K for x_c.

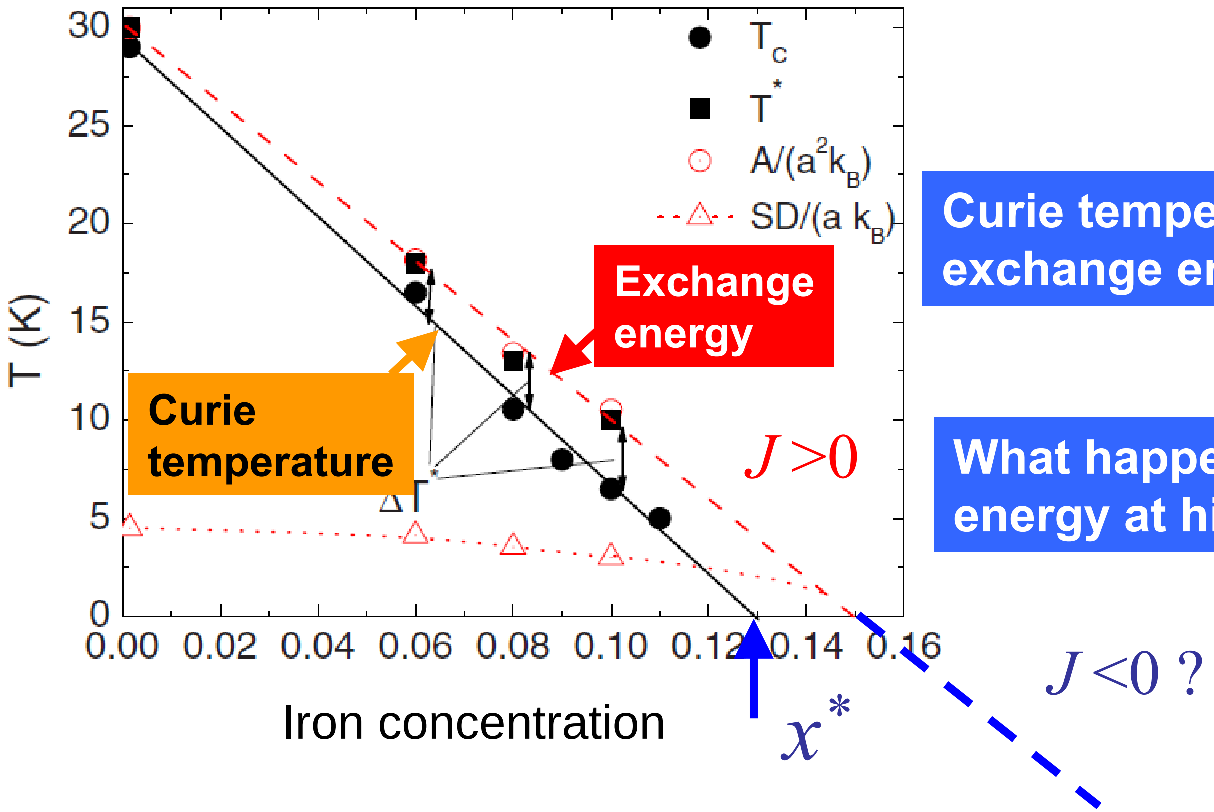
Even in strong magnetic field QC points x* and x_c derived in the limit B→0 are still here.

ESR is a right tool to visualize QC points including hidden QC point.

PHYSICAL REVIEW B **79**, 144417 (2009)

Helical spin structure of $Mn_{1-y}Fe_ySi$ under a magnetic field: Small angle neutron diffraction study

S. V. Grigoriev,[1] V. A. Dyadkin,[1] E. V. Moskvin,[1,2] D. Lamago,[3,4] Th. Wolf,[4] H. Eckerlebe,[5] and S. V. Maleyev[1]



Curie temperature does not follow exchange energy.

What happens with the exchange energy at higher concentrations?

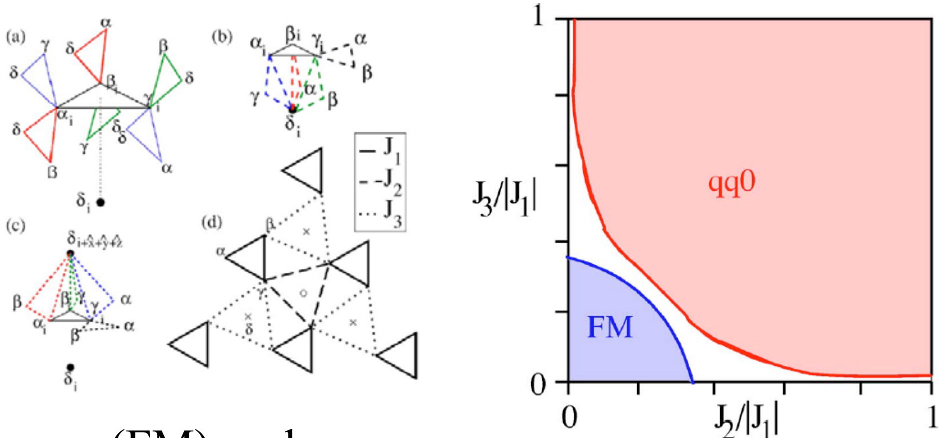
Why Mn subsystem breaks into spin clusters at relatively low concentrations, where the formal percolation may exist (x_c~0.83 instead of observed x_c~0.24) ?

Why intermediate phase is formed? Why LRO phase is supressed?

PHYSICAL REVIEW B **75**, 064430 (2007)

Microscopic model for spiral ordering along (110) on the MnSi lattice

John M. Hopkinson* and Hae-Young Kee†



J_1 – nn (FM) exchange

J_2 – next nn (AFM) exchange

J_3 – third nn (AFM) exchange

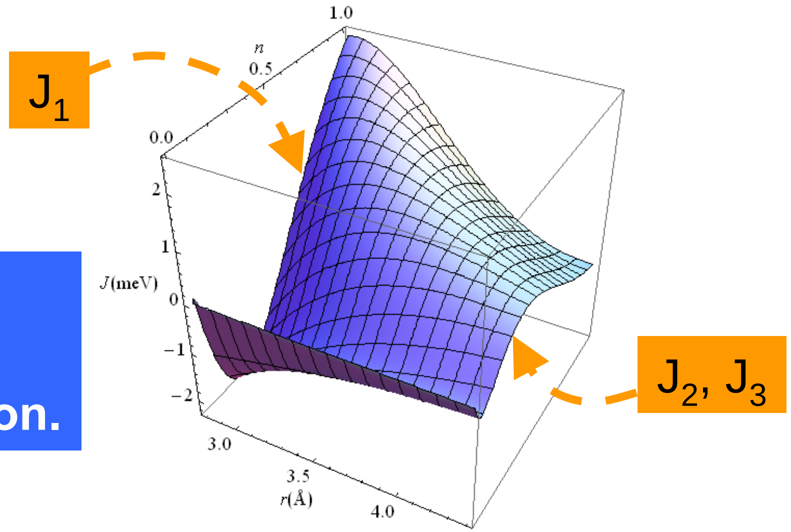
$J_2 \cong J_3$

$$|J_2/J_1|_{cr} \sim 0.21 - 0.32$$

Frustration try to align spirals along (110).

DM interaction try to align spirals along (111)

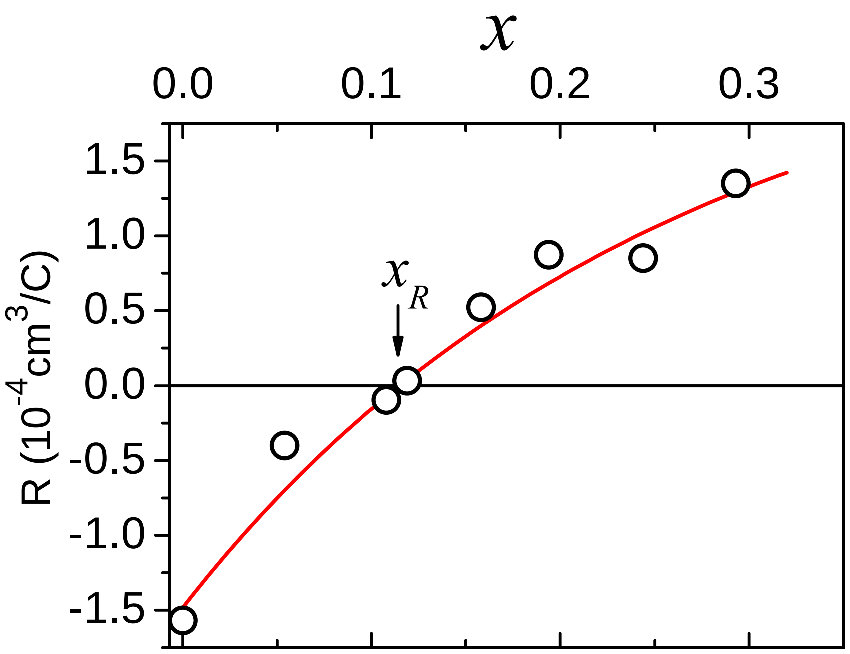
Competition between two interactions may lead to loosing of the long-range order and formation of the chiral liquid state.



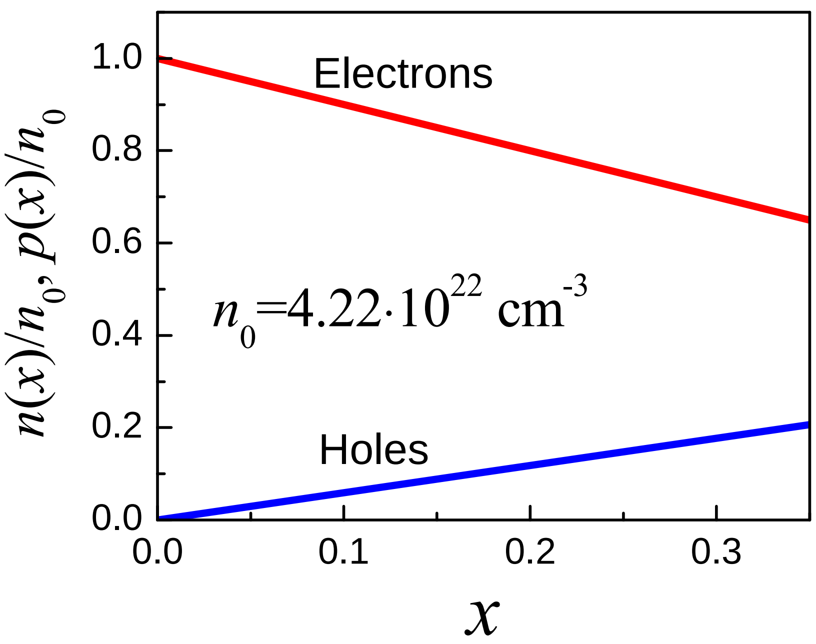
In Heisenberg paradigm RKKY exchange defines J_1, J_2, J_3 parameters, which may be tuned by variation of the electron concentration.

Ordinary Hall effect coefficient in $Mn_{1-x}Fe_xSi$

(Glushkov, Lobanova, 2015)



The model:



Two groups of charge carriers: electrons and holes

$$x_R = 0.115 \sim x^*$$

$$|\mu_h / \mu_e| = 0.28$$

Electrons are from Mn, holes are from Fe.

Estimation of RKKY interaction in $Mn_{1-x}Fe_xSi$.

$$J_{RKKY}(r) = const \frac{m}{r^4}\varphi(2k_F r)$$

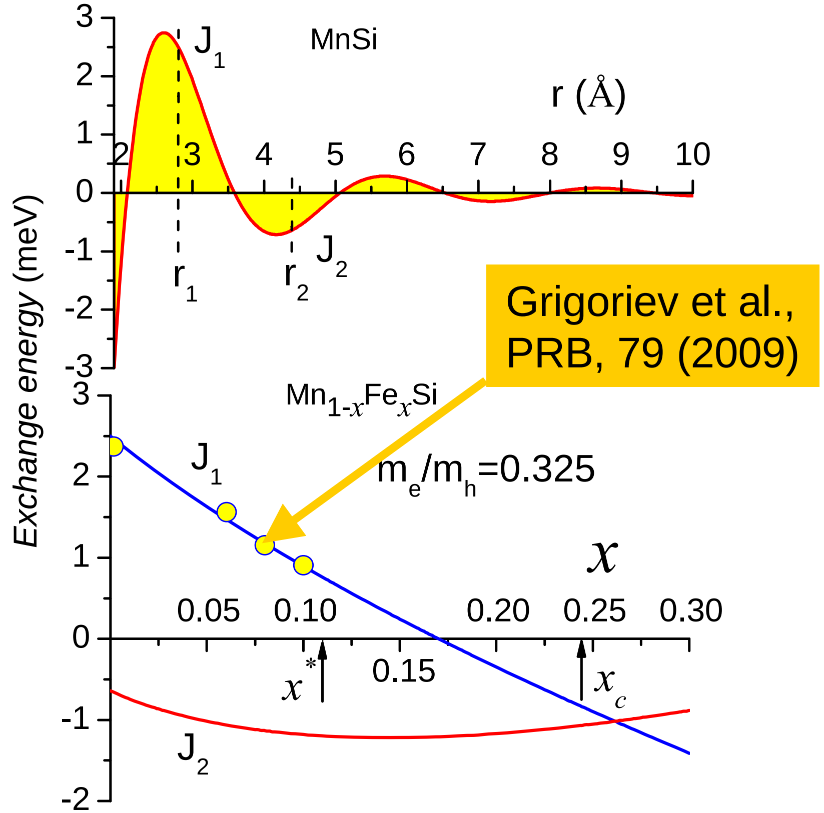
$$\varphi(x) = x\cos(x) - \sin(x)$$

$$J = J_e + J_h = \frac{const}{r^4}[m_e\varphi(2k_{Fe}r) + m_h\varphi(2k_{Fh}r)]$$

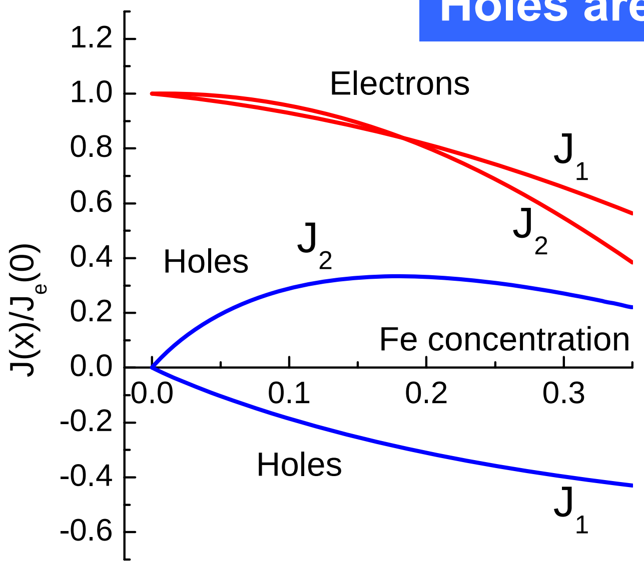
$$k_{Fe}(x) = k_{Fe}(0)[n(x)/n_0]^{1/3}$$

$$k_{Fh}(x) = k_{Fe}(0)[p(x)/n_0]^{1/3}$$

$$k_{Fe}(0) = (3\pi^2 n_0)^{1/3}$$



Holes are important!



In the vicinity of QC points $|J_1| \sim |J_2|$. Frustration is essential.

Frustration: T_c goes to zero faster than J_1.

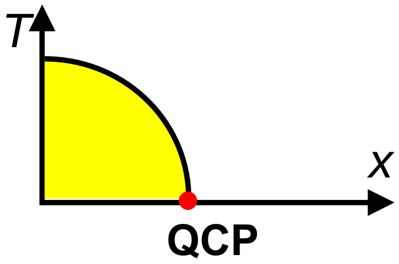
Frustration: breaks coherence of the magnetic state of Mn ions and "helps" forming separated spin clusters at x_c.

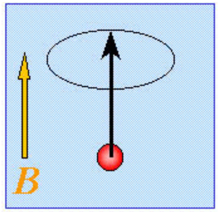
Nature of quantum criticality in $Mn_{1-x}Fe_xSi$.

"Scientists now believe that there may be a connection between the recent earthquakes and the record snowfall."

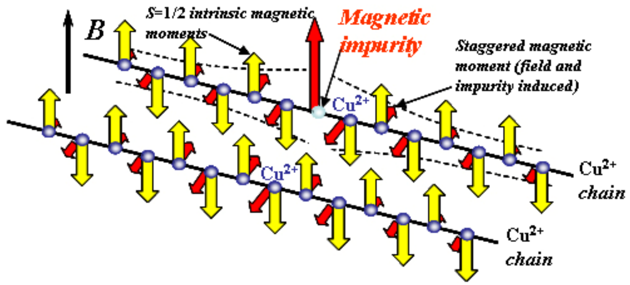
Quantum criticality in $Mn_{1-x}Fe_xSi$ is driven by change of electrons and holes concentration (i.e. change of the Fermi surface) together with disorder effects.

Introduction. Quantum criticality and electron spin resonance

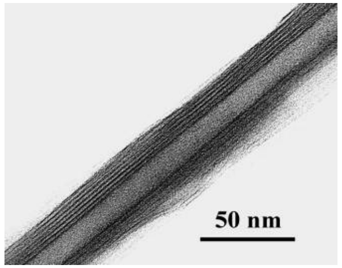




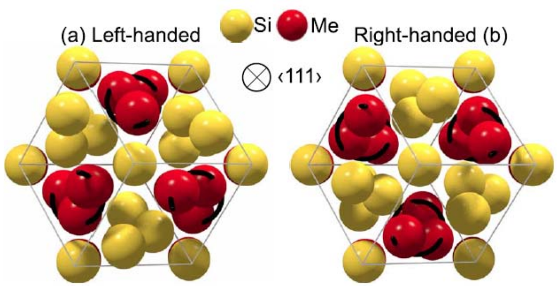
Quantum spin chains in disorder driven quantum critical regime. (Dielectrics, 1D systems).



Quantum critical phenomena in the nano-world. (Bad conductors, 2D systems).



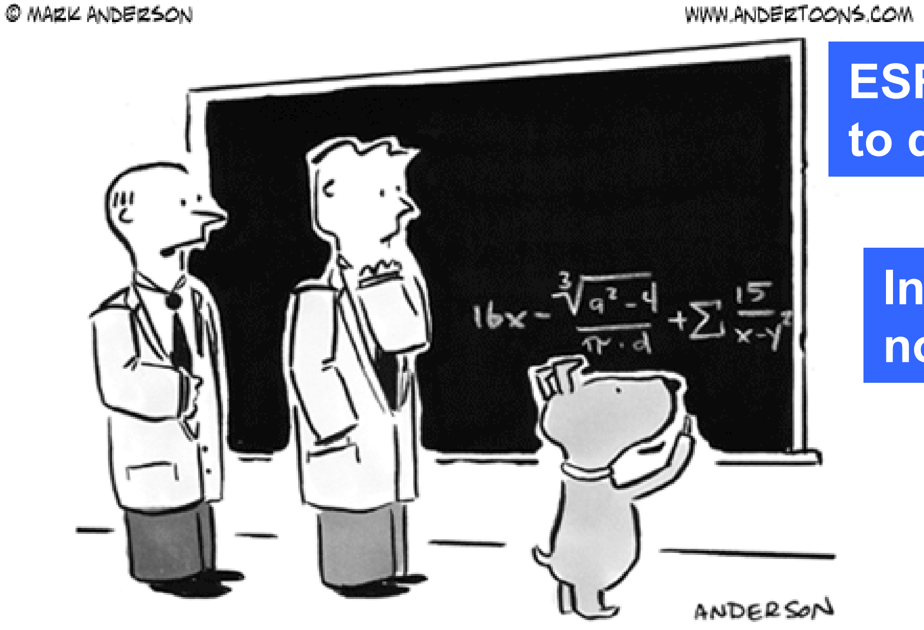
Quantum criticality in strongly correlated metals. (Good conductors, 3D systems)



Final remarks

ESR is a right tool to study quantum criticality. Are other tools right?

Look for staggered field (low temperature growth of the line width) and you will find QC phenomena!



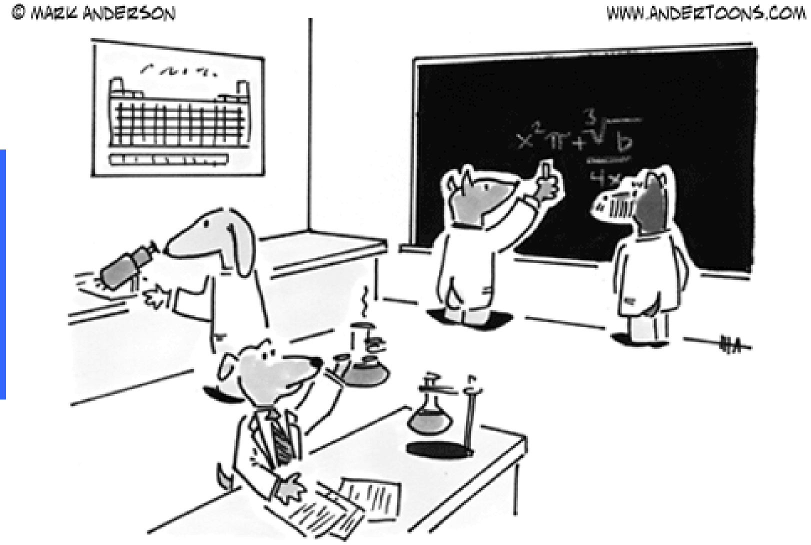
"I think he's trying to tell us something."

ESR in metals is almost unexplored route to quantum criticality.

In many cases quantum criticality is nothing but a section of nanomagnetism.

Special thanks to my colleagues and co-authors:
A.V.Semeno, N.E.Sluchanko, V.V.Glushkov, T.V.Ischenko, N.A.Samarin, I.I.Lobanova, A.N.Samarin, A.L.Chernobrovkin (GPI), A.V.Grigorieva, E.A.Goodilin (MSU), S.V.Grigoriev, N.Chubova (PNPI), H.Ohta (Kobe University)

Thank you for your attention!



In search of dognip.

Acknowledgements

Programmes of Russian Academy of Sciences "Electron spin resonance, spin-dependent electronic effects and spin technologies", "Electron correlations in strongly interacting systems" and RFBR grant 13-02-00160

Theory

ISSN 1063-7834, Physics of the Solid State, 2009, Vol. 51, No. 3, pp. 547–551. © Pleiades Publishing, Ltd., 2009.
Original Russian Text © S.V. Demishev, 2009, published in Fizika Tverdogo Tela, 2009, Vol. 51, No. 3, pp. 514–517.

MAGNETISM AND FERROELECTRICITY

Physics of the Solid State, 51 (2009)

Modeling of Magnetic Susceptibility of an Antiferromagnetic System with Disorder-Driven Quantum Critical Behavior

S. V. Demishev

Phys. Status Solidi B **247**, No. 3, 676–678 (2010) / **DOI** 10.1002/pssb.200983003

physica status solidi b
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basic solid state physics

phys. stat. sol. (b), 247 (2010)

Magnetic susceptibility of an antiferromagnetic system with disorder-driven quantum critical behavior

Sergey Demishev*

PHYSICAL REVIEW B **84**, 094426 (2011)

PRB, 84 (2011)

Magnetic properties of vanadium oxide nanotubes and nanolayers

S. V. Demishev,[1,*] A. L. Chernobrovkin,[1,2] V. V. Glushkov,[1] A. V. Grigorieva,[3] E. A. Goodilin,[3] H. Ohta,[4] S. Okubo,[4] M. Fujisawa,[4] T. Sakurai,[5] N. E. Sluchanko,[1] N. A. Samarin,[1] and A. V. Semeno[1]

$CuGeO_3$:Fe

JETP Letters, Vol. 73, No. 1, 2001, pp. 31–34. Translated from Pis'ma v Zhurnal Éksperimental'noĭ i Teoreticheskoĭ Fiziki, Vol. 73, No. 1, 2001, pp. 36–40.
Original Russian Text Copyright © 2001 by Demishev, Bunting, Leonyuk, Obraztsova, Pronin, Sluchanko, Samarin, Terekhov.

JETP Jett., 73 (2001)

New Scenario for the Decay of Spin-Peierls State in $CuGeO_3$: Fe. Onset of a Quantum Critical Point

S. V. Demishev*, R. V. Bunting, L. I. Leonyuk†, E. D. Obraztsova, A. A. Pronin,
N. E. Sluchanko, N. A. Samarin, and S. V. Terekhov

Journal of Superconductivity and Novel Magnetism, Vol. 20, No. 2, February 2007 (© 2006)
DOI: 10.1007/s10948-006-0214-3

J. Supercond. Novel Magn., 20 (2007)

Quantum Criticality and Collective Effects in Low-Dimensional Magnet $CuGeO_3$:Fe Probed by High Frequency EPR

S. V. Demishev,[1] A. V. Semeno,[1] A. A. Pronin,[1] N. E. Sluchanko,[1]
N. A. Samarin,[1] H. Ohta,[2] S. Okubo,[2] M. Kimata,[3] K. Koyama,[4]
M. Motokawa,[4] and A. V. Kuznetsov[5]

Oshikawa-Affleck theory

EUROPHYSICS LETTERS 1 August 2003

Europhys. Lett., **63** (3), pp. 446–452 (2003)

Europhys. Lett., 63 (2003)

Anomalous temperature dependence of the ESR linewidth in $CuGeO_3$ doped with magnetic impurities and the universal relations in the Oshikawa-Affleck theory

S. V. Demishev[1], Y. Inagaki[2], H. Ohta[2], S. Okubo[2], Y. Oshima[2], A. A. Pronin[1], N. A. Samarin[1], A. V. Semeno[1] and N. E. Sluchanko[1]

Progress of Theoretical Physics Supplement No. 159, 2005 387

Prog. Theor. Phys. Suppl., No 159 (2005)

The Competition between Staggered Field and Antiferromagnetic Interactions in $CuGeO_3$:Fe

Sergey Demishev,[1] Alexey Semeno,[1] Alexey Pronin,[1] Nikolay Sluchanko,[1] Nikolay Samarin,[1] Hitoshi Ohta,[2] Susumu Okubo,[2] Motoi Kimata,[3] Keiichi Koyama[4] and Mitsuhiro Motokawa[4]

$CuGeO_3$:Co

Physics of the Solid State, Vol. 46, No. 12, 2004, pp. 2238–2248. Translated from Fizika Tverdogo Tela, Vol. 46, No. 12, 2004, pp. 2164–2174.
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MAGNETISM
AND FERROELECTRICITY

Physics of the Solid State, 46 (2004)

Microwave EPR Spectroscopy of Cobalt-Doped Germanium Cuprate

S. V. Demishev[1, 4], A. V. Semeno[1], N. E. Sluchanko[1], N. A. Samarin[1], A. A. Pronin[1], Y. Inagaki[2], S. Okubo[2], H. Ohta[2], Y. Oshima[2], and L. I. Leonyuk[3†]

ISSN 0021-3640, JETP Letters, 2006, Vol. 84, No. 5, pp. 249–253. © Pleiades Publishing, Inc., 2006.

JETP Jett., 84 (2006)

New Polarization Effect and Collective Excitation in $S = 1/2$ Quasi-one-dimensional Antiferromagnetic Quantum Spin Chain¶

S. V. Demishev[a, *], A. V. Semeno[a], H. Ohta[b], S. Okubo[b], I. E. Tarasenko[a], T. V. Ishchenko[a], and N. E. Sluchanko[a]

$CuGeO_3$:Mn

Available online at www.sciencedirect.com
SCIENCE DIRECT
Physica B 378–380 (2006) 115–116
PHYSICA B
www.elsevier.com/locate/physb

Quantum critical behavior induced by Mn impurity in $CuGeO_3$

A.V. Semeno[a,*], N.E. Sluchanko[a], N.A. Samarin[a], A.A. Pronin[a],
H. Ohta[b], S. Okubo[b], S.V. Demishev[a]

Physica B, 378-380 (2006)

Appl. Magn. Reson. (2008) 35, 327–335
DOI 10.1007/s00723-008-0164-y
Printed in The Netherlands
Applied Magnetic Resonance

ESR Probing of Quantum Critical Phenomena in Doped $S = 1/2$ AF Quantum Spin Chain*

S. V. Demishev[1], A. V. Semeno[1], N. E. Sluchanko[1], N. A. Samarin[1], I. E. Tarasenko[1], H. Ohta[2], and S. Okubo[2]

Appl. Magn. Reson., 35 (2008)

VO_x nanomaterials

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phys. stat. sol. (RRL), 1–3 (2008) / **DOI** 10.1002/pssr.200802108

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Electron spin resonance and quantum critical phenomena in VO_x multiwall nanotubes

phys. stat. sol. (RRL), 1-3 (2008)

S. V. Demishev[*,1], A. L. Chernobrovkin[1], E. A. Goodilin[2], V. V. Glushkov[1], A. V. Grigorieva[2], N. A. Samarin[1], N. E. Sluchanko[1], A. V. Semeno[1], and Yu. D. Tretyakov[2]

ISSN 0021-3640, JETP Letters, 2010, Vol. 91, No. 1, pp. 11–15. © Pleiades Publishing, Inc., 2010.
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JETP Jett., 91 (2010)

FM–AFM Crossover in Vanadium Oxide Nanomaterials

S. V. Demishev[a,*], A. L. Chernobrovkin[a], V. V. Glushkov[a], A. V. Grigorieva[b], E. A. Goodilin[b], N. E. Sluchanko[a], N. A. Samarin[a], and A. V. Semeno[a]

PHYSICAL REVIEW B **84**, 094426 (2011)

PRB, 84 (2011)

Magnetic properties of vanadium oxide nanotubes and nanolayers

S. V. Demishev,[1,*] A. L. Chernobrovkin,[1,2] V. V. Glushkov,[1] A. V. Grigorieva,[3] E. A. Goodilin,[3] H. Ohta,[4] S. Okubo,[4] M. Fujisawa,[4] T. Sakurai,[5] N. E. Sluchanko,[1] N. A. Samarin,[1] and A. V. Semeno[1]

$Mn_{1-x}Fe_xSi$ system

ISSN 0021-3640, JETP Letters, 2011, Vol. 93, No. 4, pp. 213–218. © Pleiades Publishing, Inc., 2011.
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JETP Jett., 93 (2011)

Is MnSi an Itinerant-Electron Magnet? Results of ESR Experiments

S. V. Demishev*, A. V. Semeno, A. V. Bogach, V. V. Glushkov, N. E. Sluchanko, N. A. Samarin, and A. L. Chernobrovkin

PHYSICAL REVIEW B **85**, 045131 (2012)

PRB, 85 (2012)

Magnetic phase diagram of MnSi in the high-field region

S. V. Demishev,* V. V. Glushkov, I. I. Lobanova,† M. A. Anisimov, V. Yu. Ivanov, T. V. Ishchenko, M. S. Karasev, N. A. Samarin, N. E. Sluchanko, V. M. Zimin, and A. V. Semeno

ISSN 0021-3640, JETP Letters, 2013, Vol. 98, No. 12, pp. 829–833. © Pleiades Publishing, Ltd., 2013.

JETP Jett., 98 (2013)

Quantum Bicriticality in $Mn_{1-x}Fe_xSi$ Solid Solutions: Exchange and Percolation Effects¶

S. V. Demishev[a, *], I. I. Lobanova[a, b], V. V. Glushkov[a, b], T. V. Ischenko[a], N. E. Sluchanko[a], V. A. Dyadkin[c], N. M. Potapova[c], and S. V. Grigoriev[c]

$Mn_{1-x}Fe_xSi$ system

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JETP Jett., 100 (2014)

Anomalous Spin Relaxation and Quantum Criticality in $Mn_{1-x}Fe_xSi$ Solid Solutions¶

S. V. Demishev[a, b, *], A. N. Samarin[a, b], V. V. Glushkov[a, b], M. I. Gilmanov[a, b], I. I. Lobanova[a, b], N. A. Samarin[a], A. V. Semeno[a], N. E. Sluchanko[a], N. M. Chubova[c], V. A. Dyadkin[c], and S. V. Grigoriev[c]