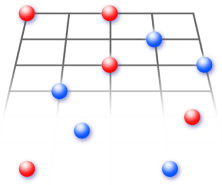
Universal probes of antiferromagnetic correlations and entropy in cold fermions on optical lattices

Nils Blümer

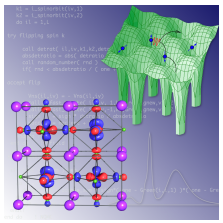
Institut für Physik, Johannes Gutenberg-Universität Mainz

[arXiv:1201.5576]



TR 49: *Condensed matter systems with variable many-body interactions*
Frankfurt / Kaiserslautern / Mainz

FOR 1346
LDA+DMFT
Augsburg *et al.*



Acknowledgements

Elena Gorelik

Daniel Rost

Andreas Klümper
Univ. Wuppertal

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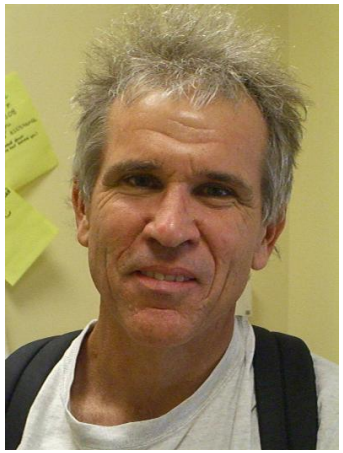
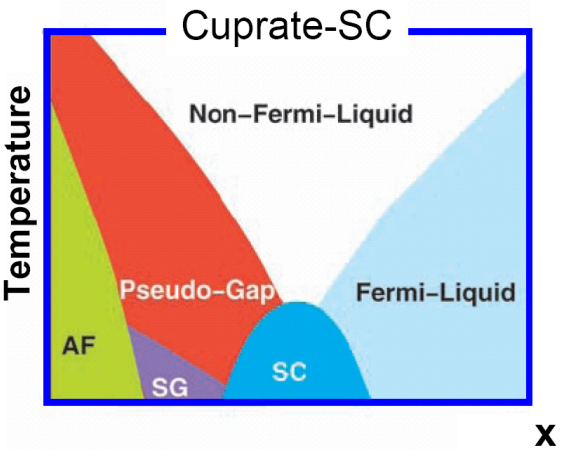
Rio de Janeiro



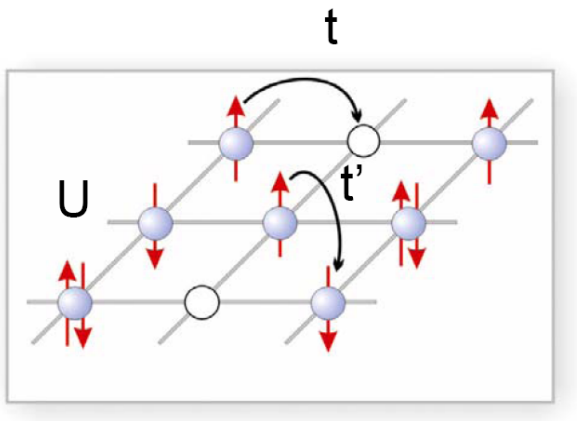
Richard Scalettar
UC Davis

Motivation: Ultracold lattice fermions as quantum simulators?

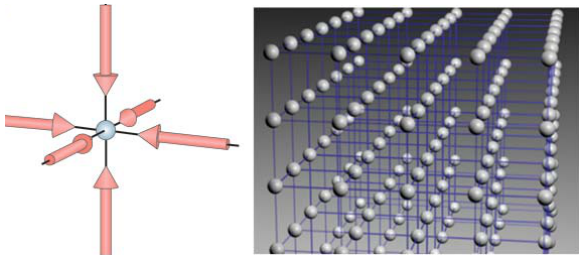
Correlated materials



Fermionic Hubbard model



Ultracold fermions on optical lattices



$\mathcal{O}(10^5)$ atoms

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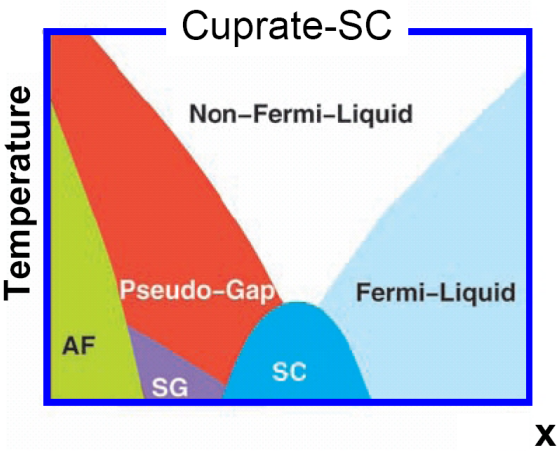

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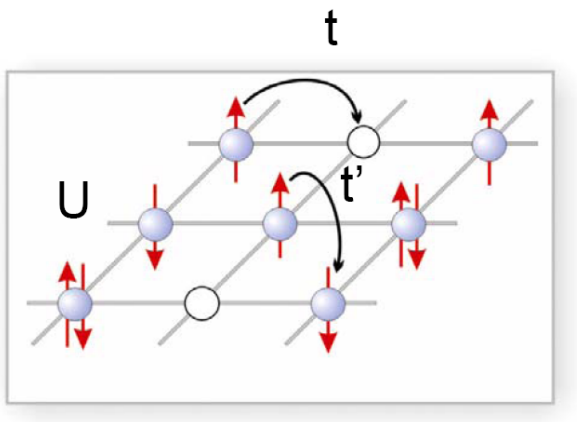

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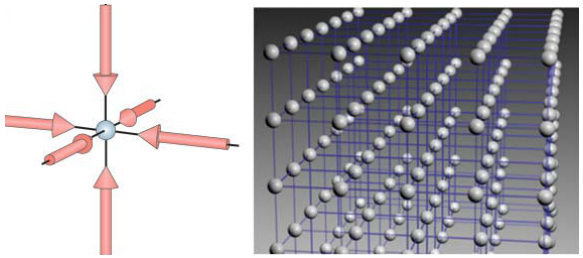

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Recent breakthrough: paramagnetic Mott transition in fermionic 2-flavor mixtures

[Schneider et al., Science **322**, 1520 (2008), Jördens et al., Nature **455**, 204 (2008)]

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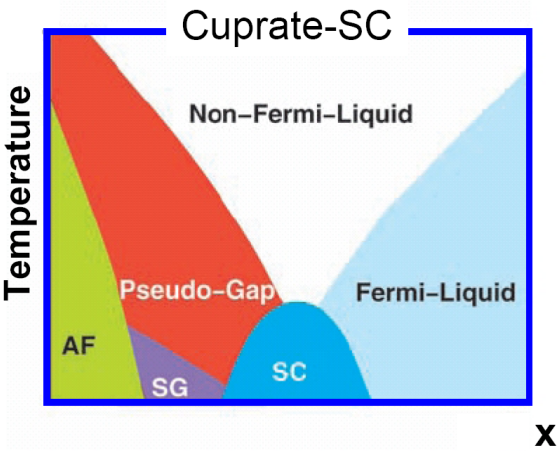

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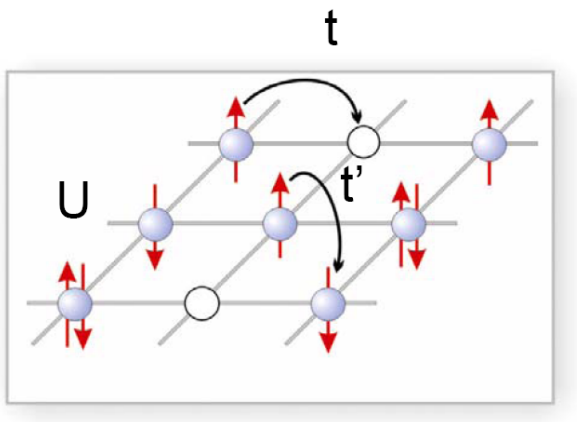

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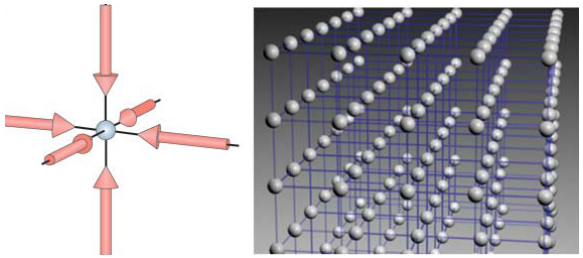

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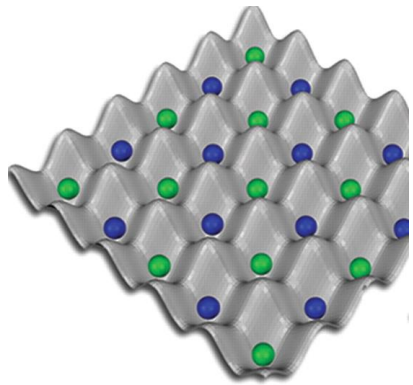
Remaining challenge: antiferromagnetism (staggered order)



Specifics of ultracold fermions on optical lattices

1) Main complication: trap $\rightsquigarrow$ inhomogeneity

$\rightsquigarrow$ Numerics expensive, e.g. using RDMFT

$\rightsquigarrow$ AF core radius (at best) only 10-20 lattice spacings

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[Gorelik et al., PRL **105**, 065301 (2010)]

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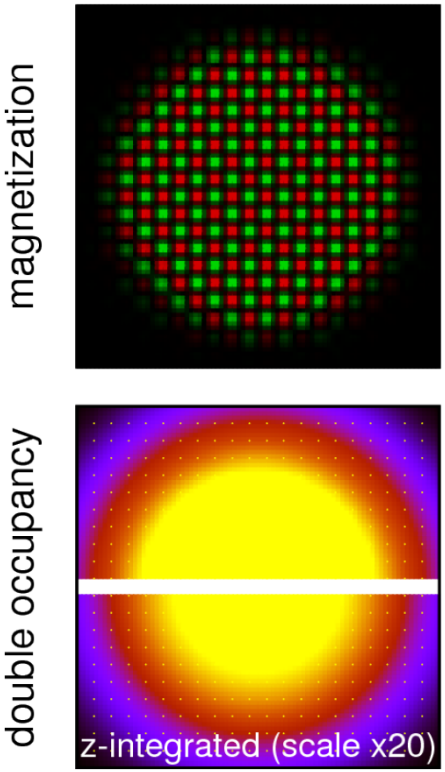

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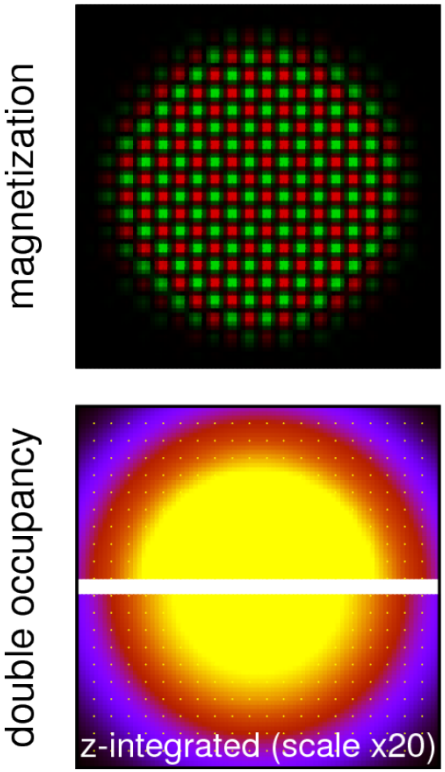

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Now: focus on central region $\rightsquigarrow$ half-filled Hubbard model
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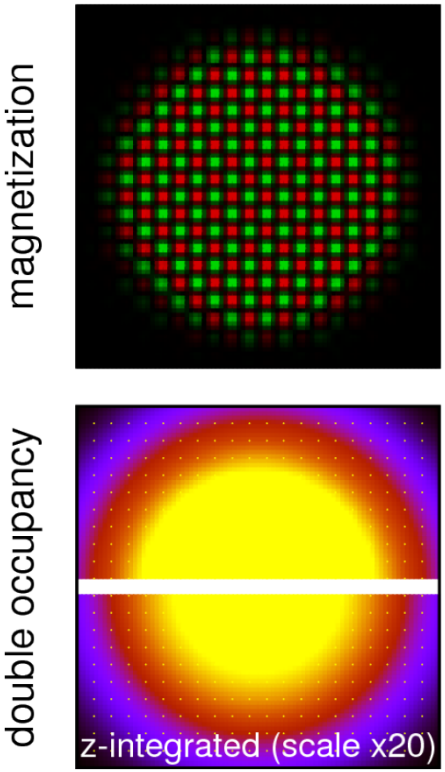

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Now: focus on central region $\rightsquigarrow$ half-filled Hubbard model (at strong coupling)

2) Temperature in trap unknown, but loading $\sim$ adiabatic

$\rightsquigarrow$ use *entropy* as thermal parameter

Questions for this talk

- How to detect AF order/correlations?

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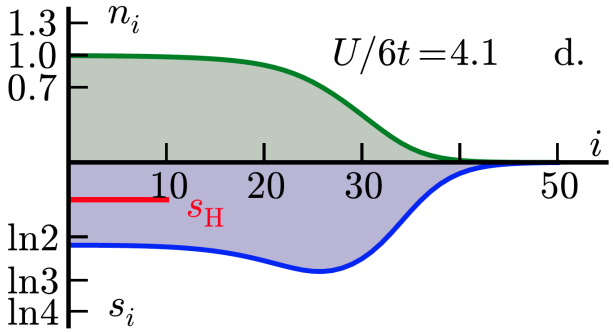

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- How to detect AF order/correlations?
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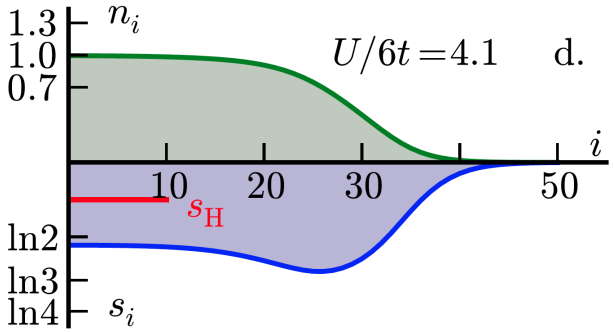
- General impact of dimensionality?

Mermin-Wagner: LRO $\leftrightarrow d = 3$



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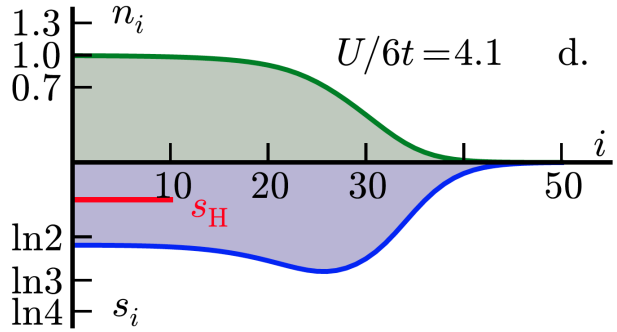

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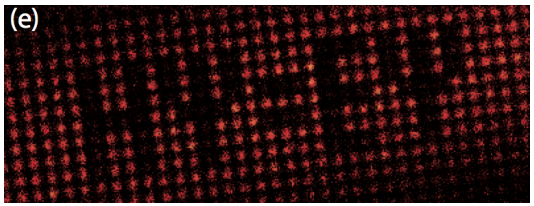
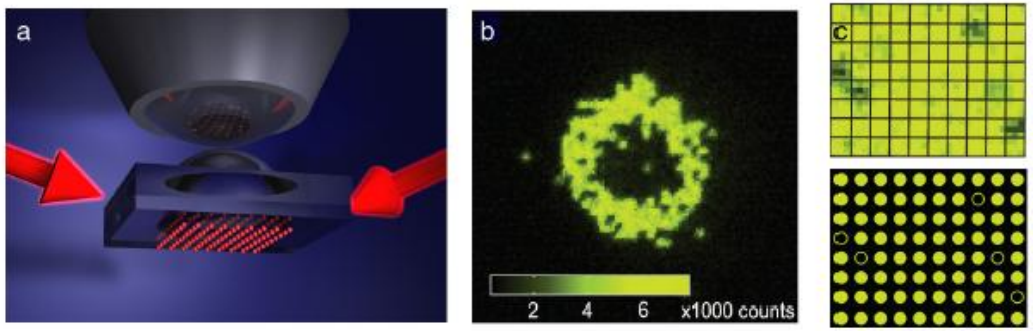
Mermin-Wagner: LRO $\leftrightarrow d = 3$

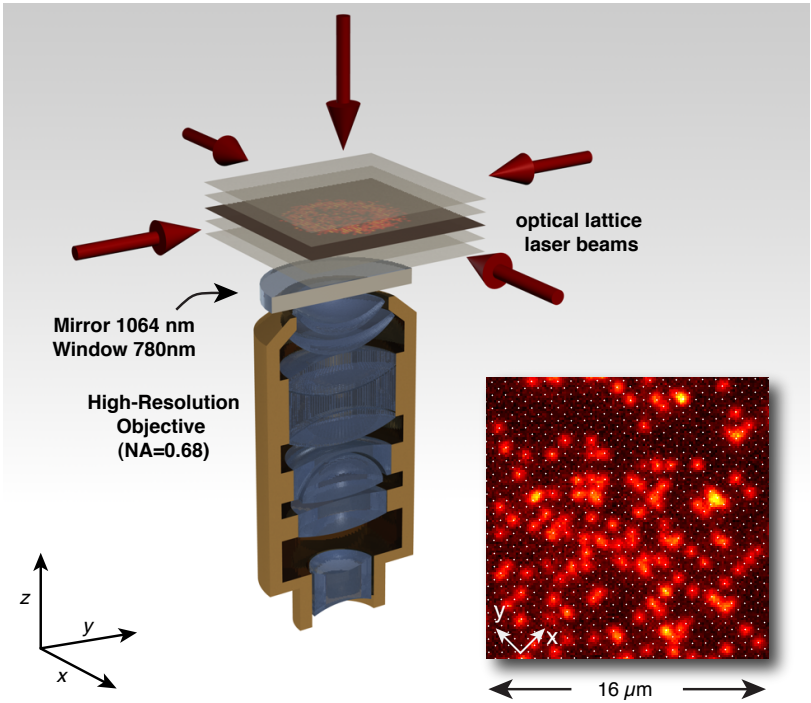
Experimental advantage of 2 dimensions: single-site resolution (for bosons)



[Würtz et al., PRL **103**, 080404 (2009)]



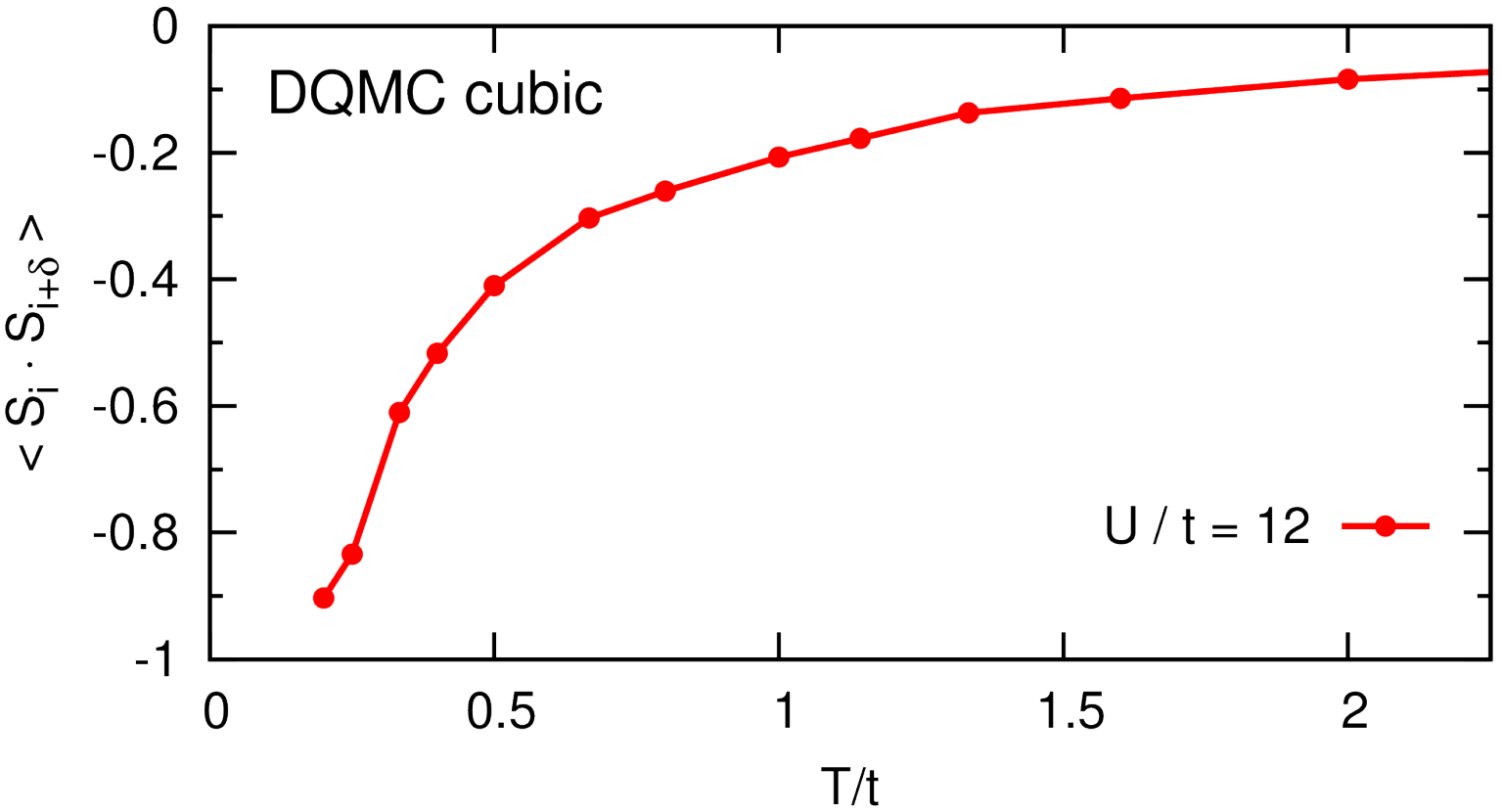
[Bakr et al., Science **329**, 547 (2010)]



[Sherson et al., Nature **467**, 68 (2010)]

Current experimental focus: nearest-neighbor spin correlation function

Modulation spectroscopy (Esslinger group), super-lattice (Bloch group)



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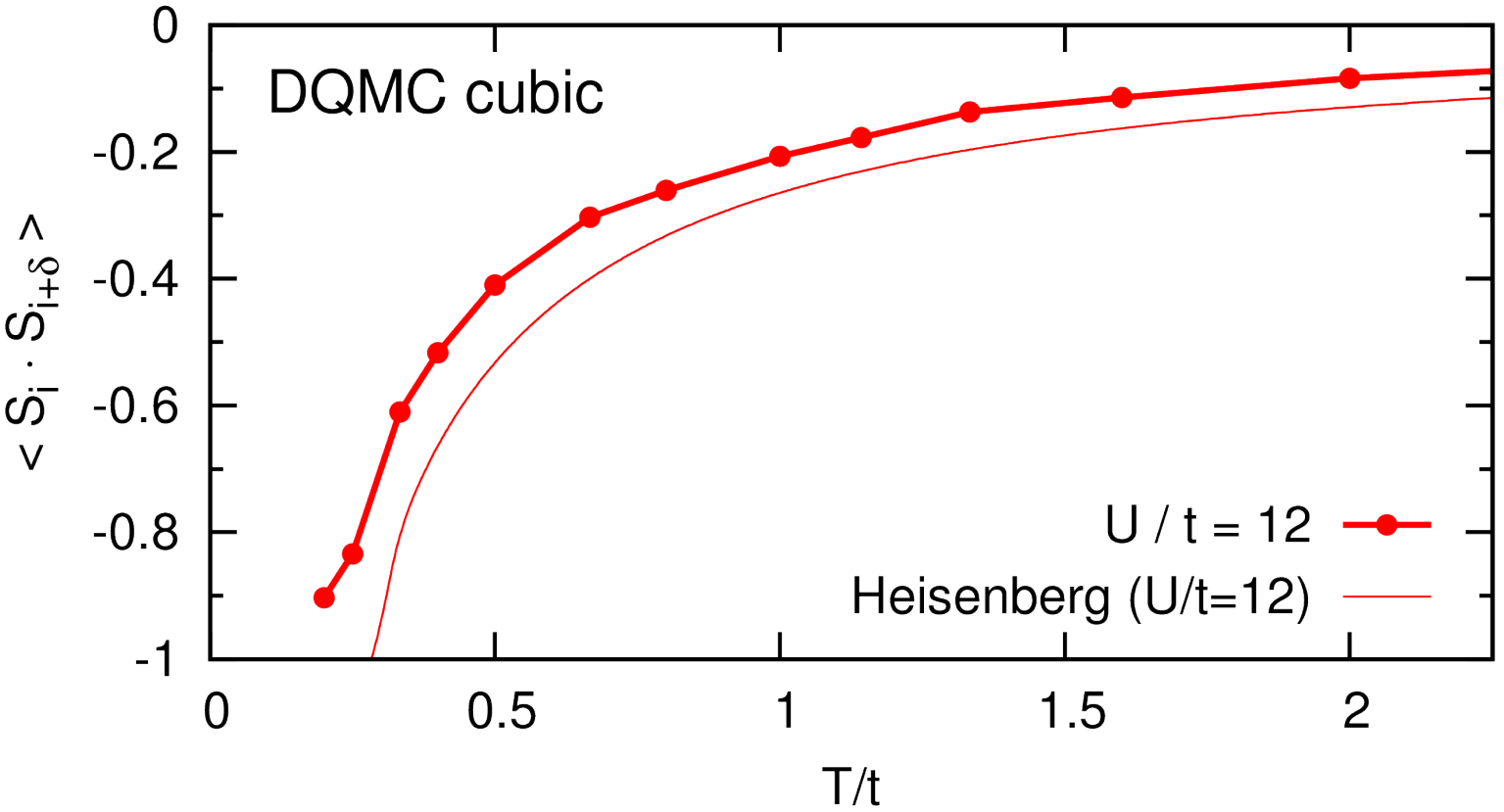

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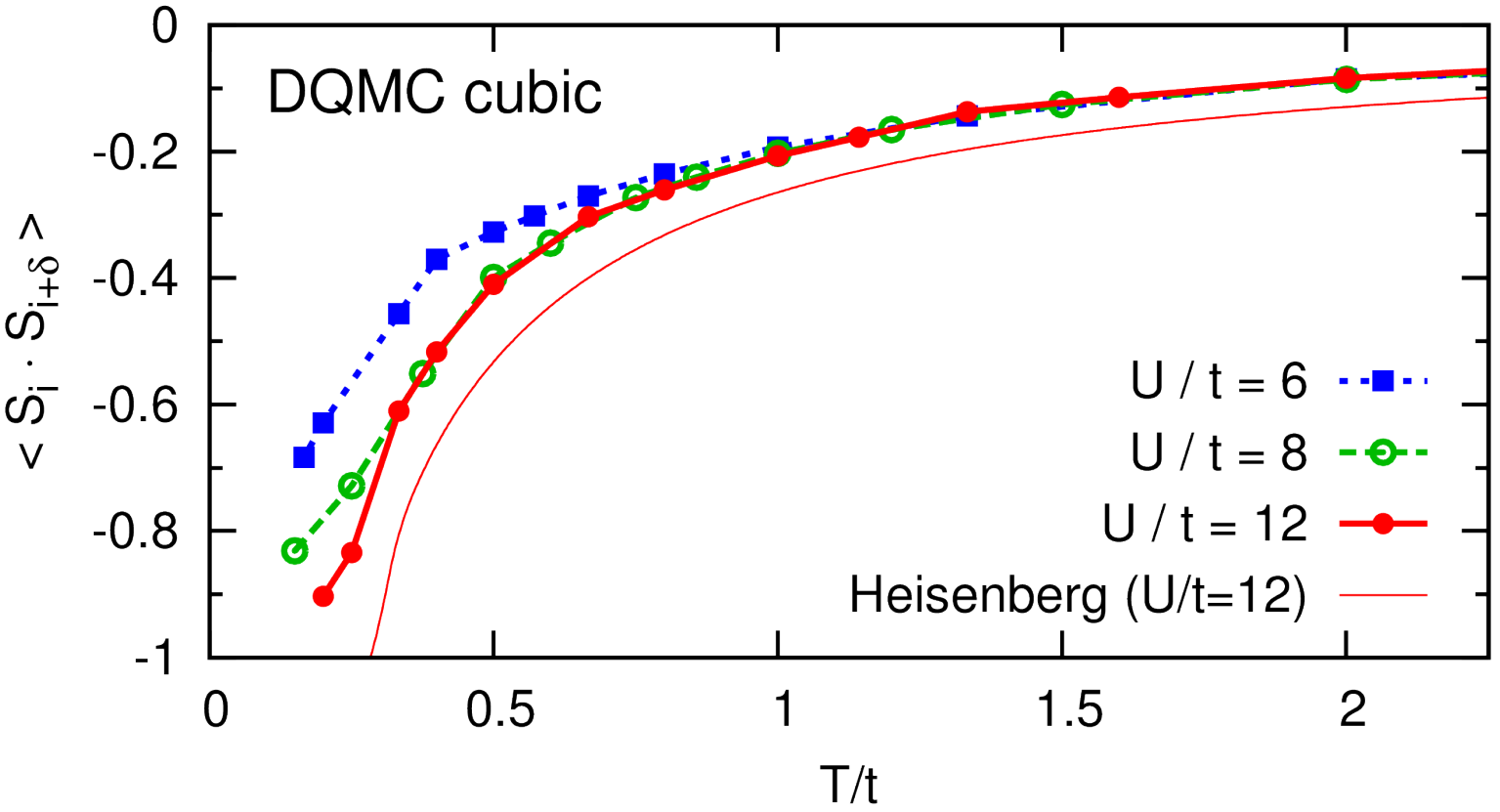

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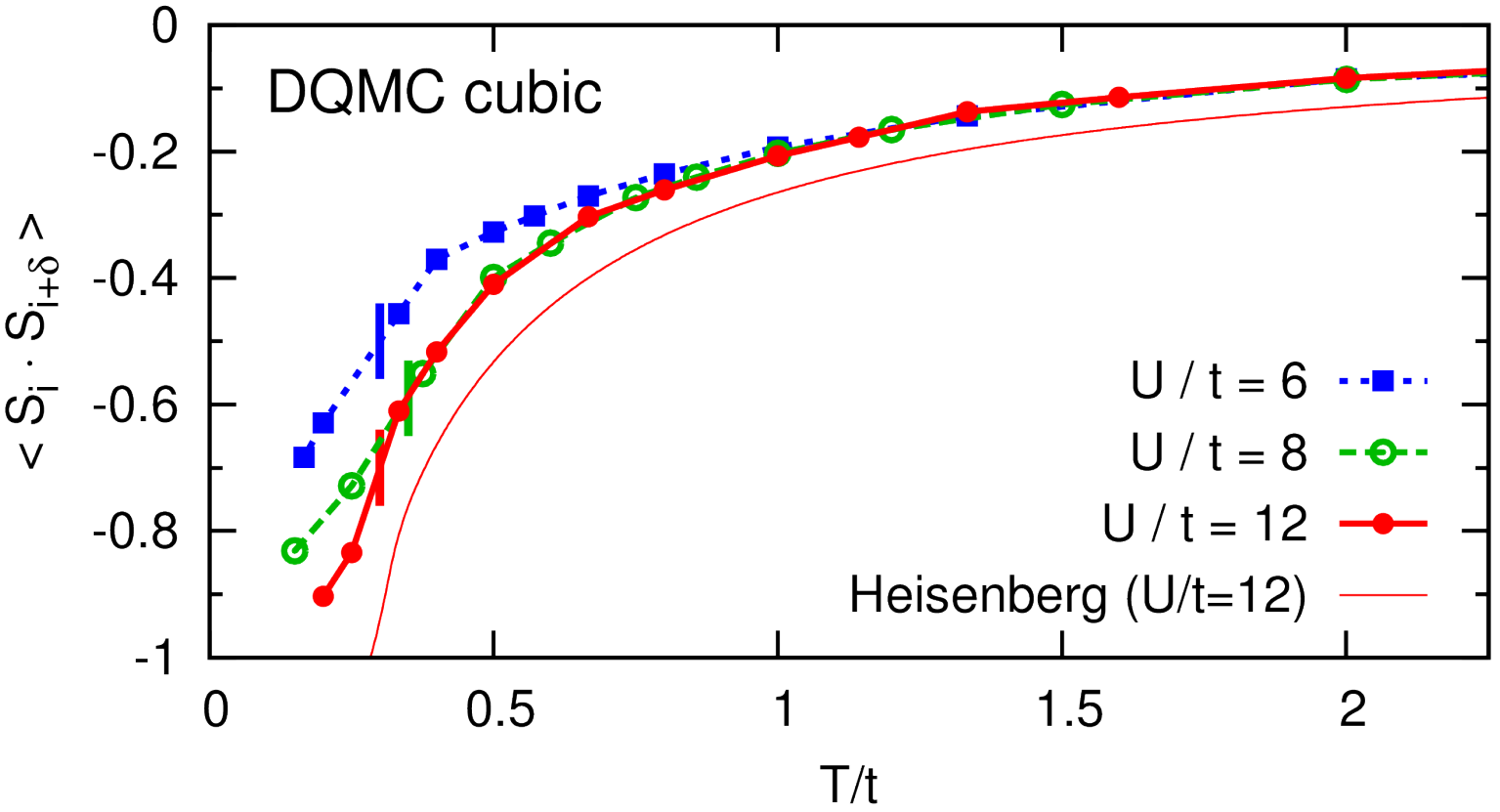

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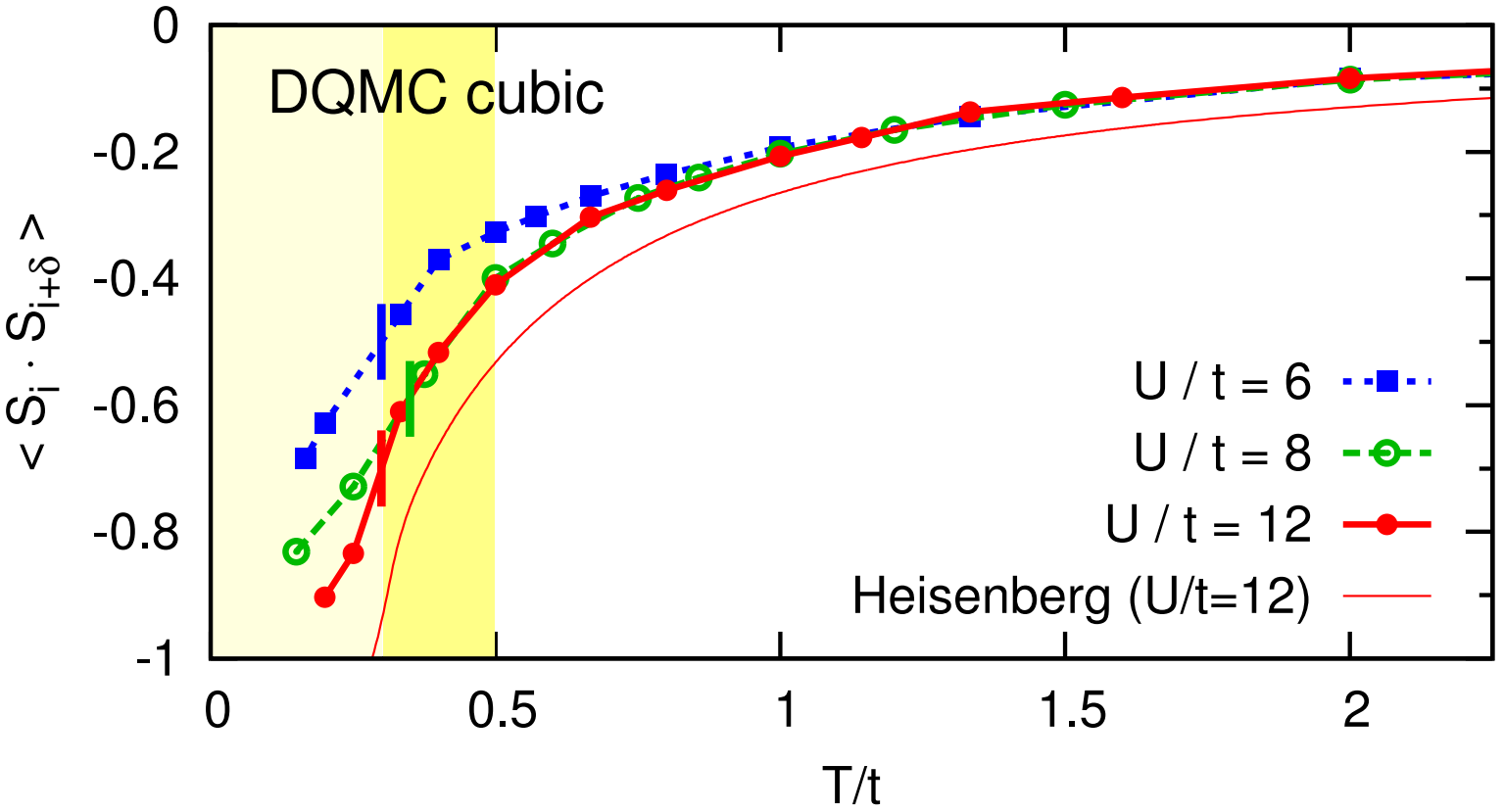

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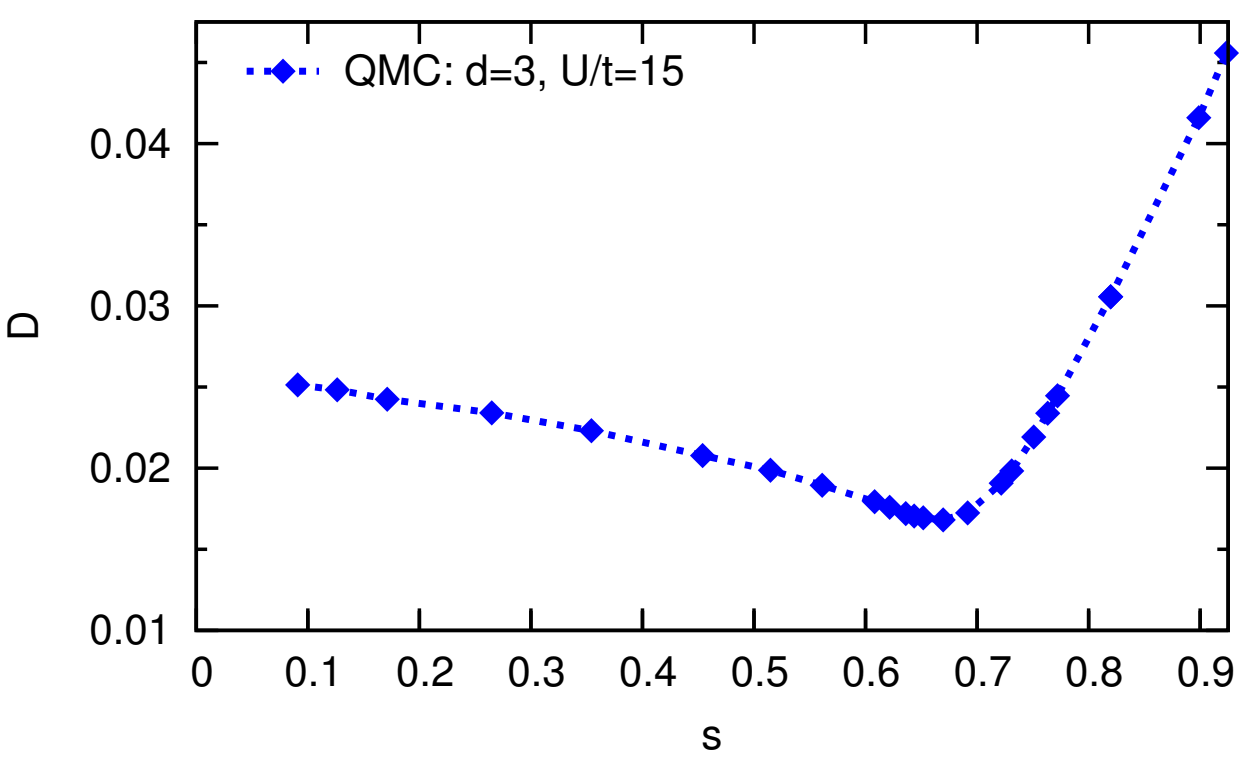
Interesting spin physics above T_N, not visible in NN correlations

Double occupancy as a universal measure of AF correlations + entropy



Exact determinantal QMC:

AF enhances D at low-s

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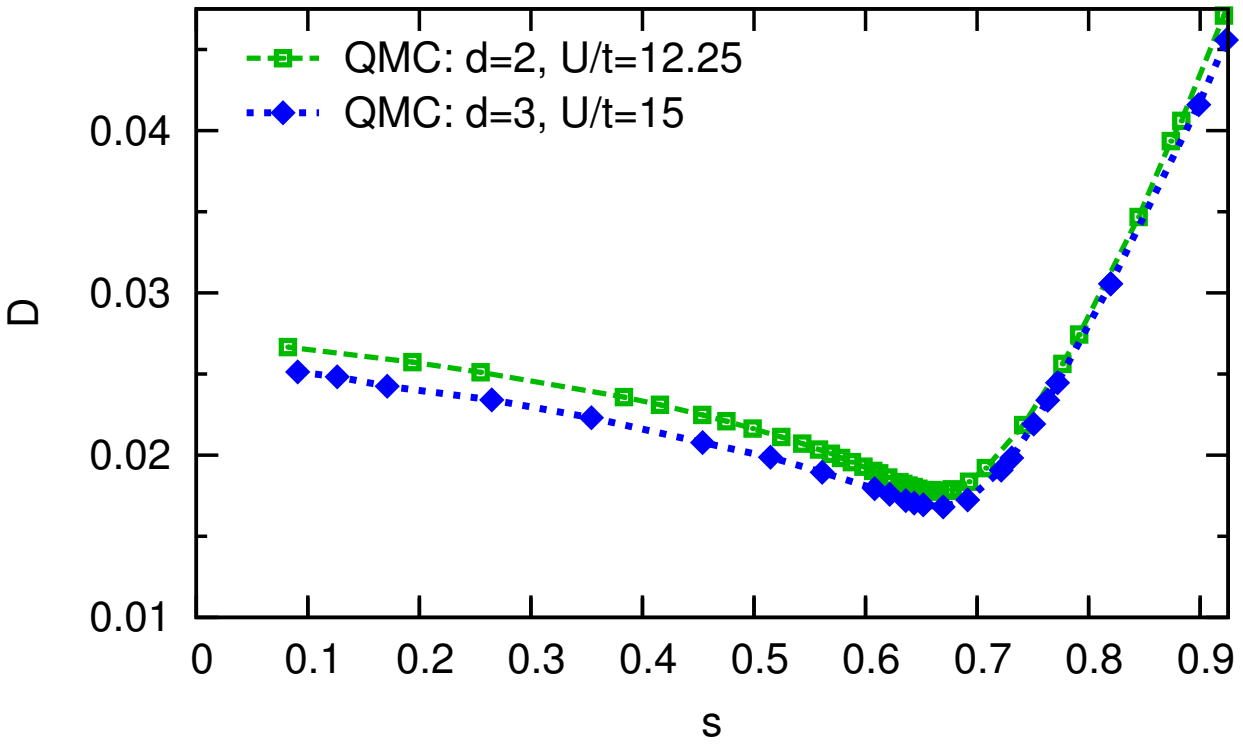

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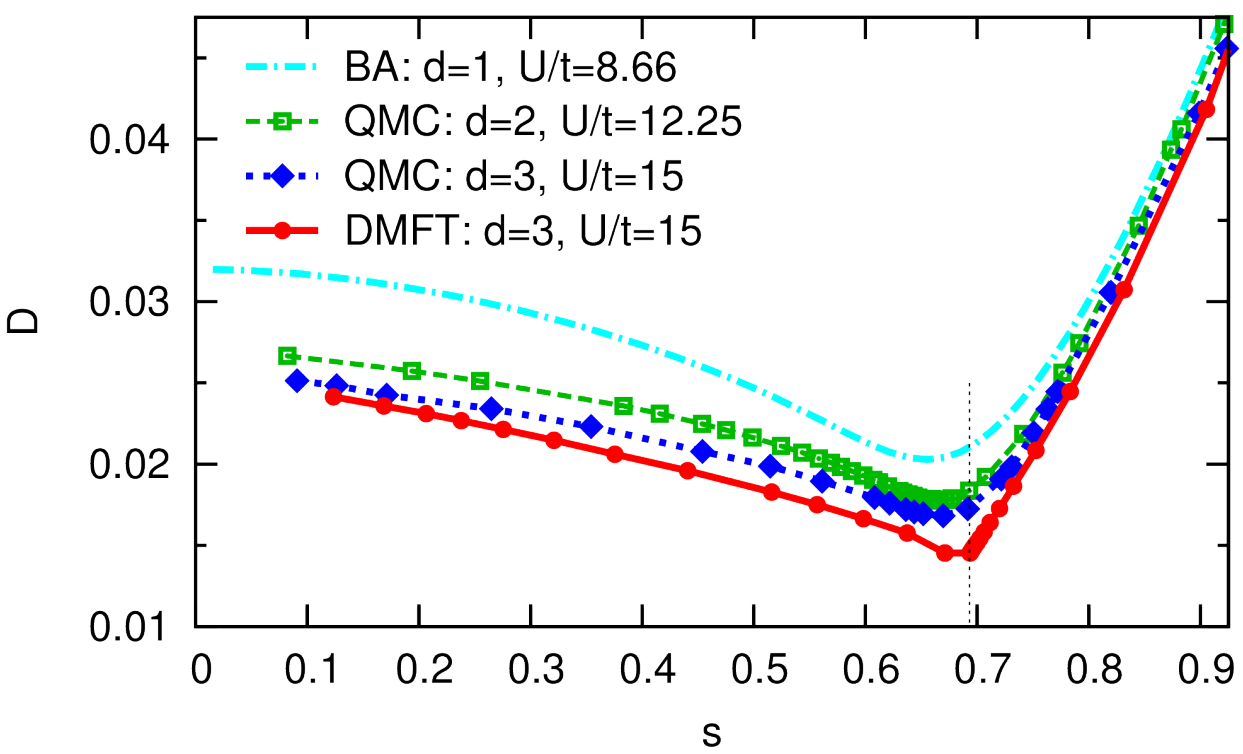

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Universal minimum at

$s \approx \ln 2$ for $1 \leq d \leq \infty$

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$\ln(2)/2 \lesssim s \lesssim \ln(2)$!

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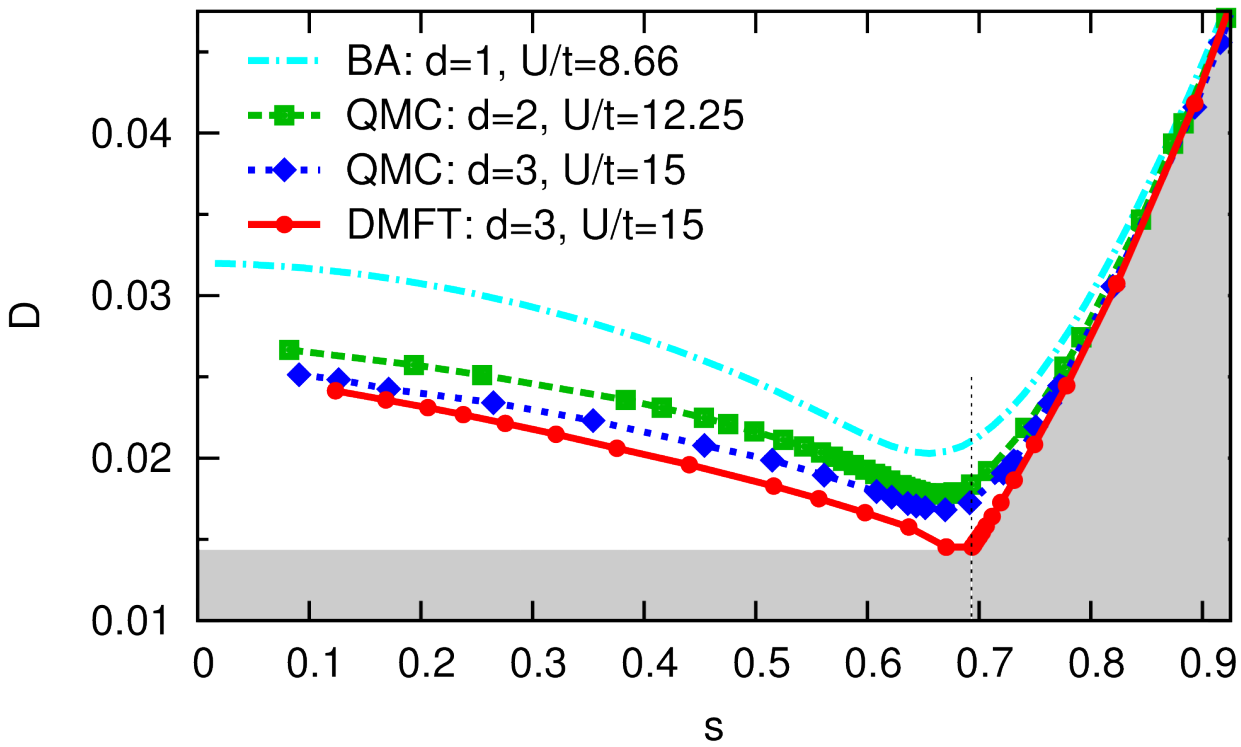

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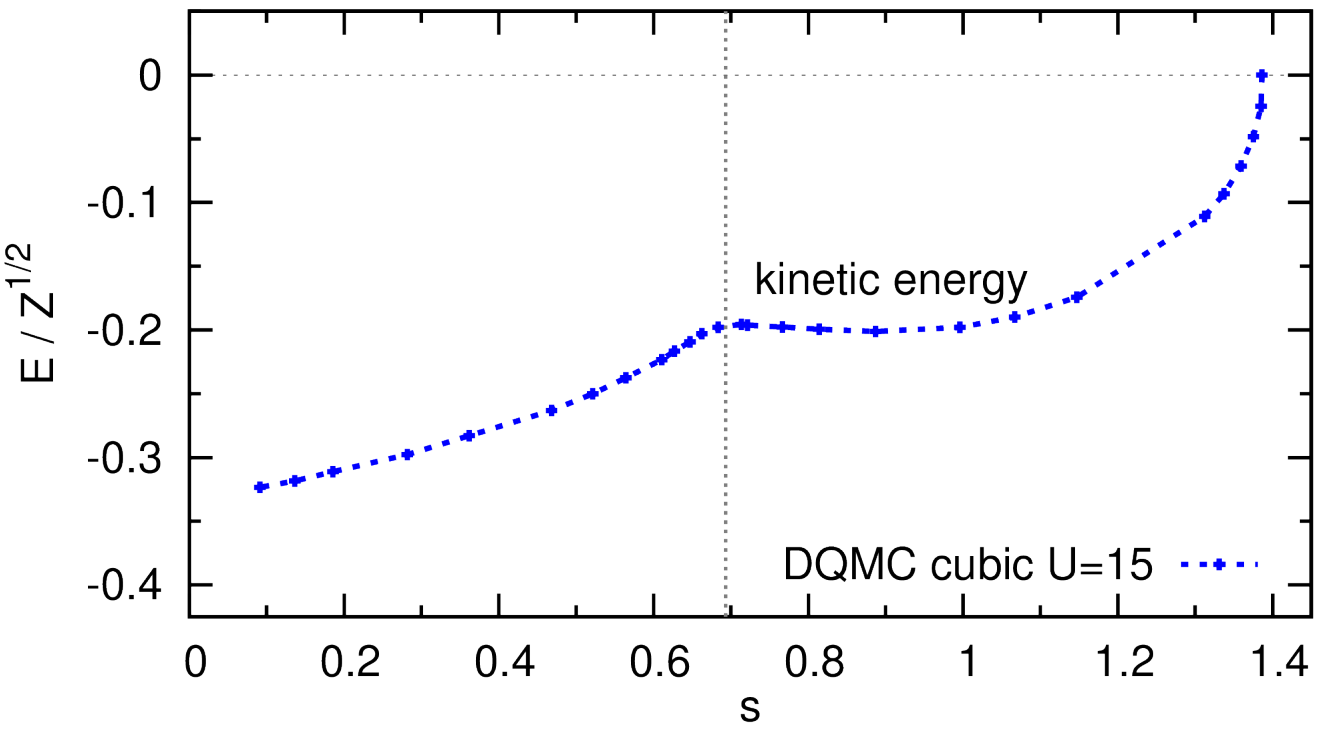
AF enhancement of D is larger
in lower dimensions:

$$D_0 = (1 - \langle \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \rangle)\, Z \frac{t^2}{2U^2} + \mathcal{O}\left(t^4/U^4\right)$$

$$\langle \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \rangle_0 = \begin{cases} -1.00 & DMFT \\ -1.20 & (d=3) \\ -1.34 & (d=2) \\ -1.77 & (d=1) \end{cases}$$

Related observable: kinetic energy



Kink in kinetic energy (only) at $s \approx \log(2)$

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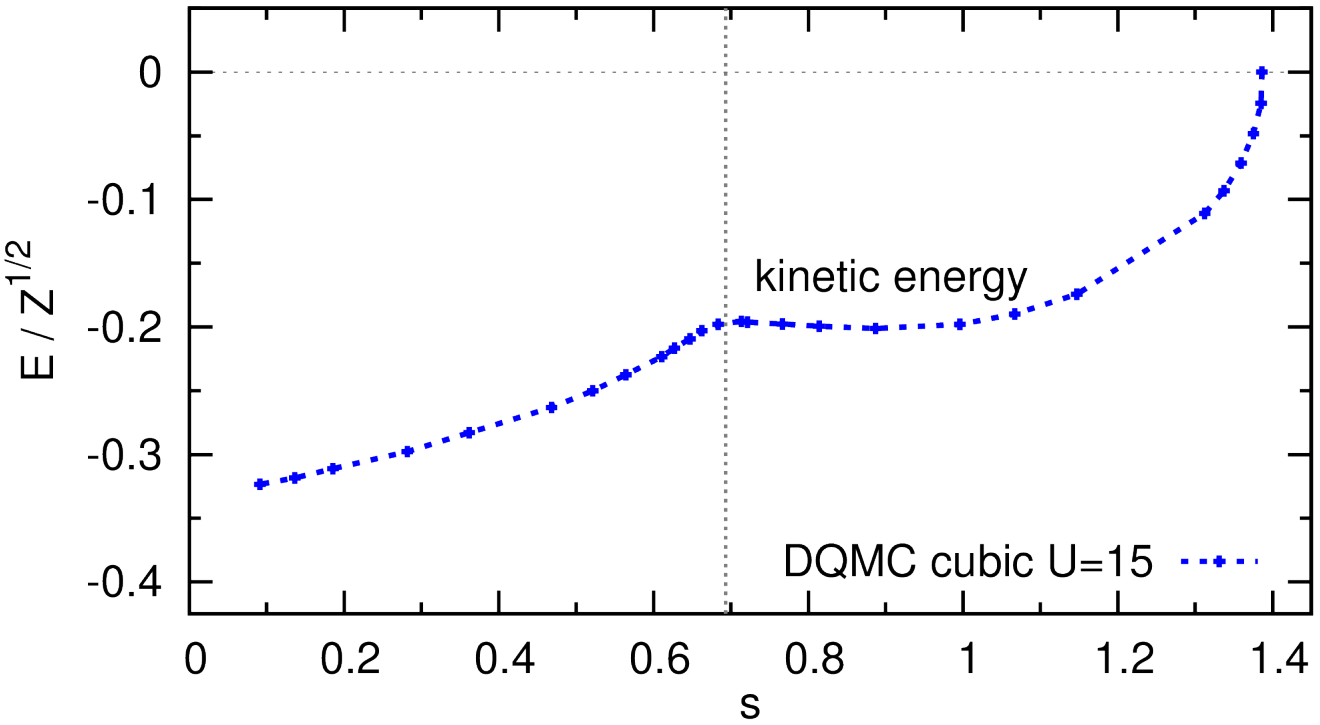

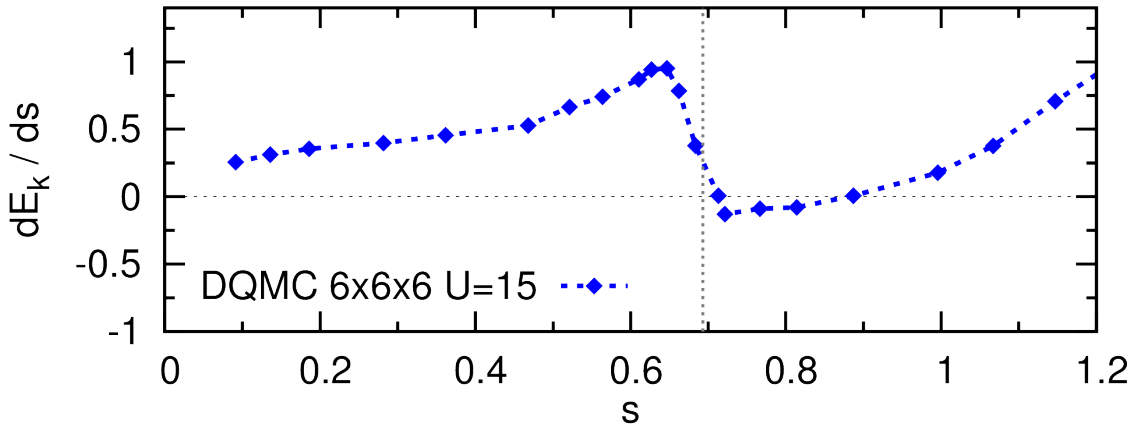

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Negative slope at $s \gtrsim \log(2)$ in $d = 3$?

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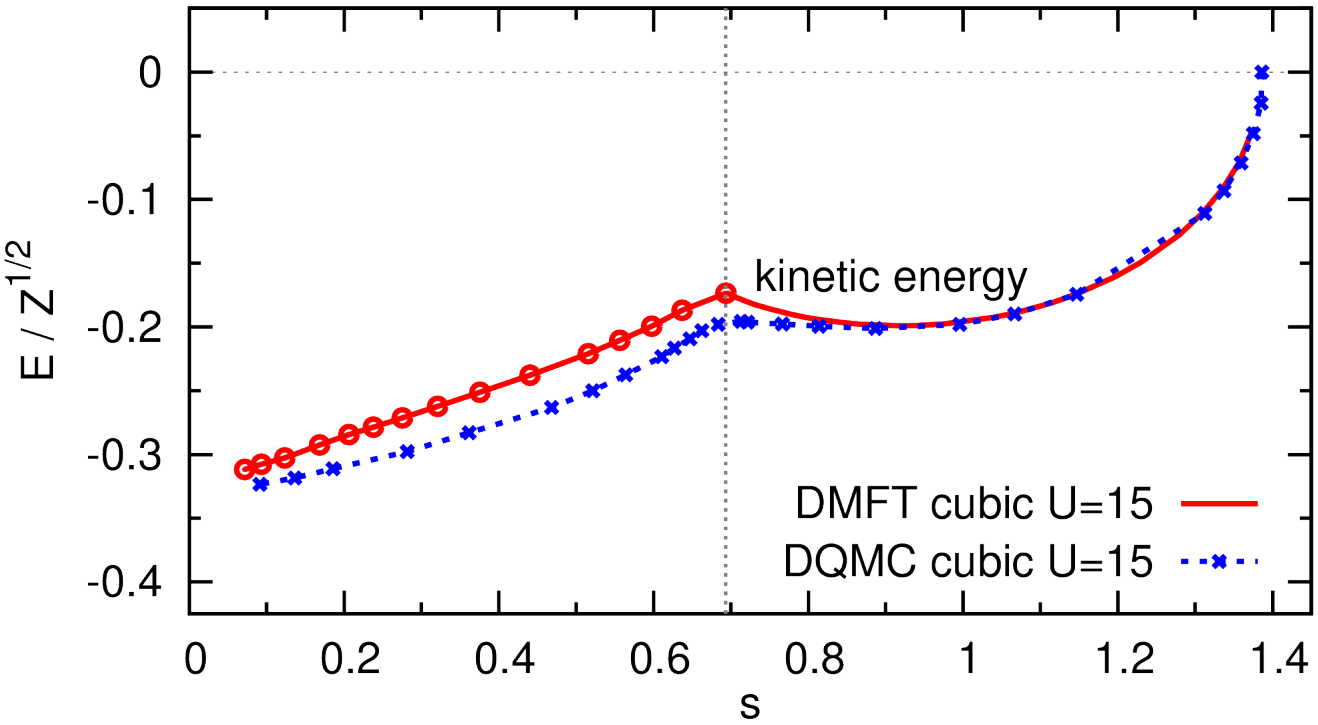

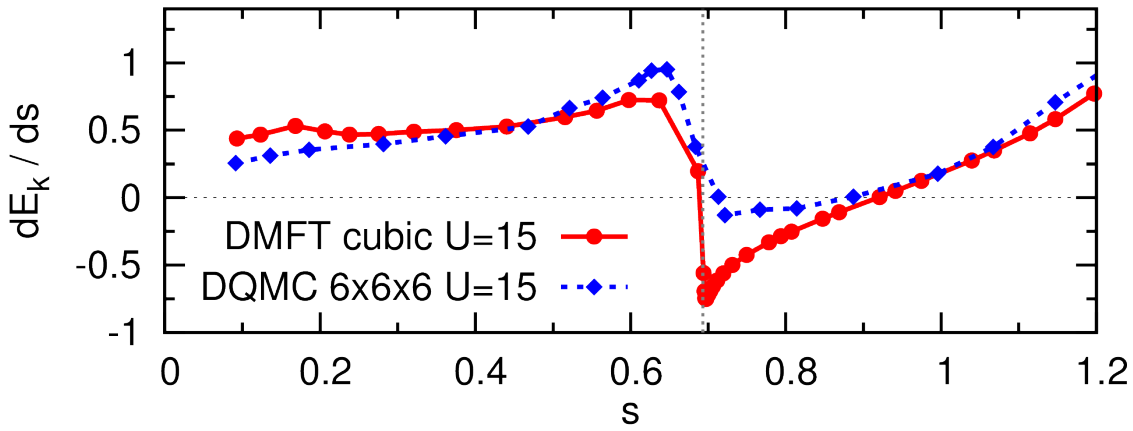

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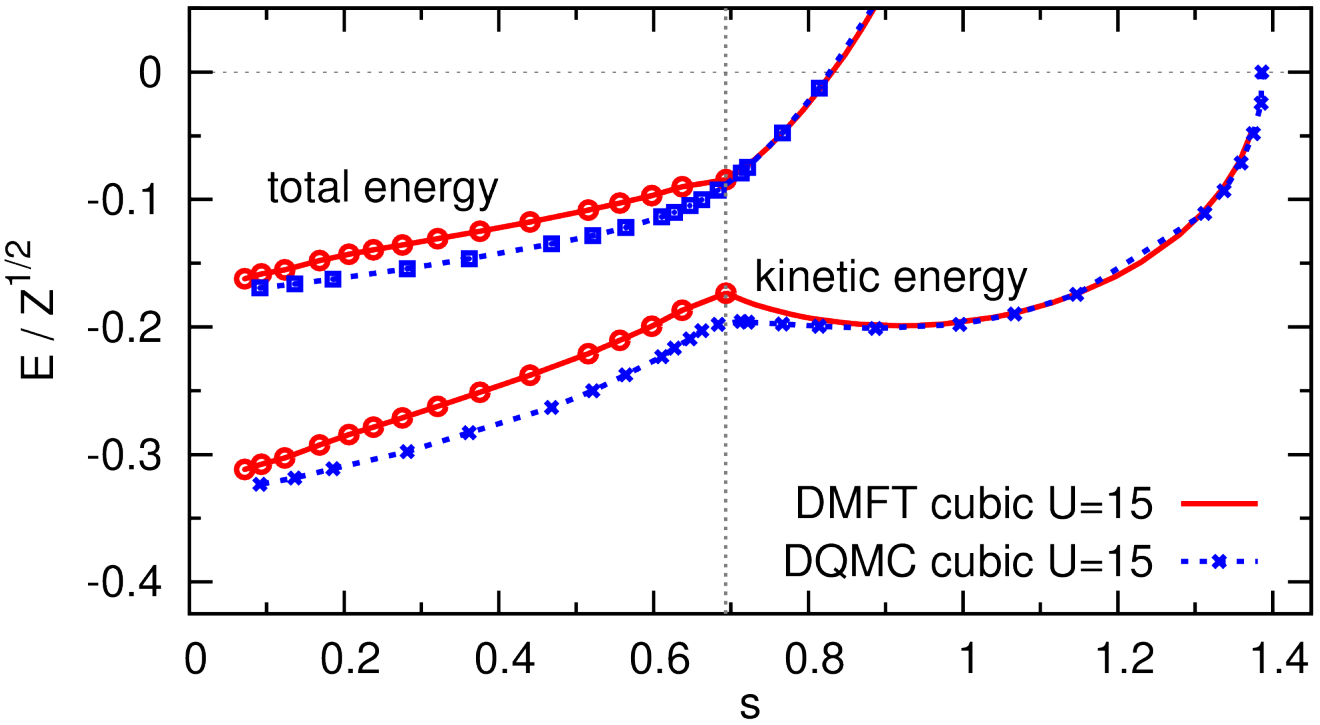

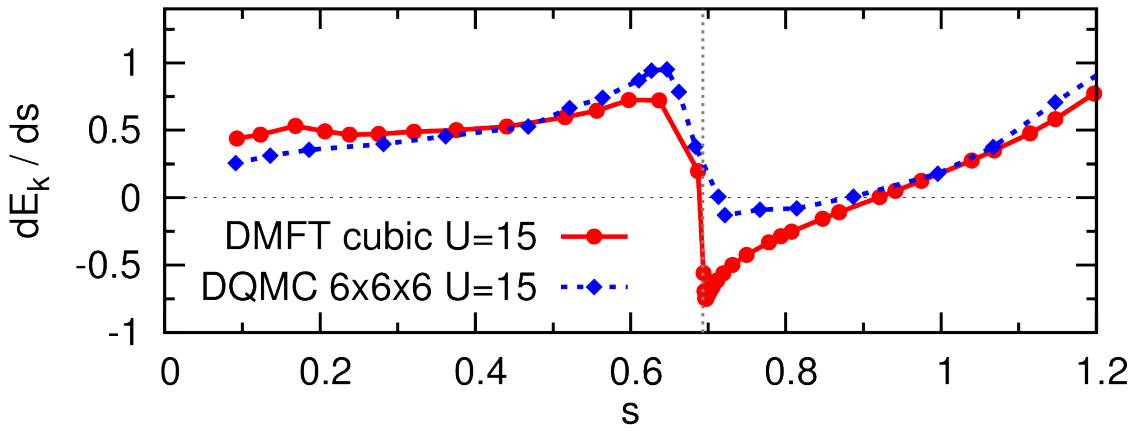

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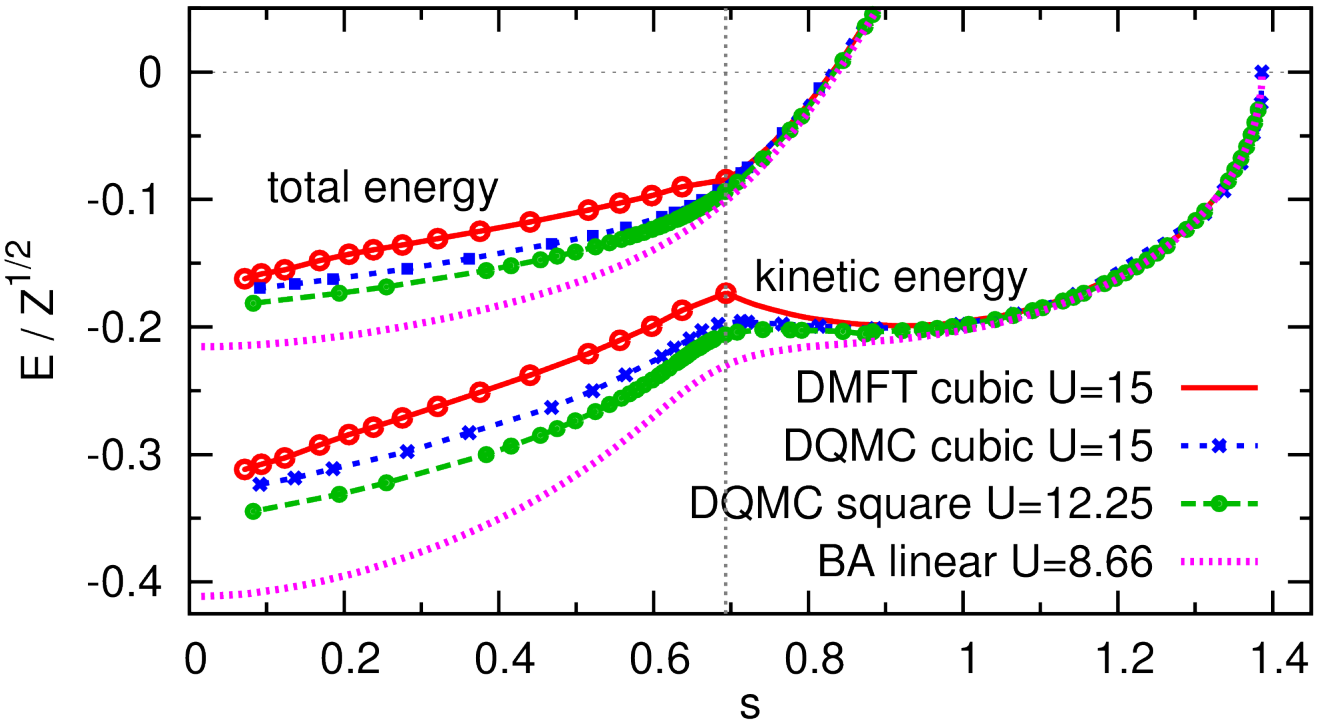

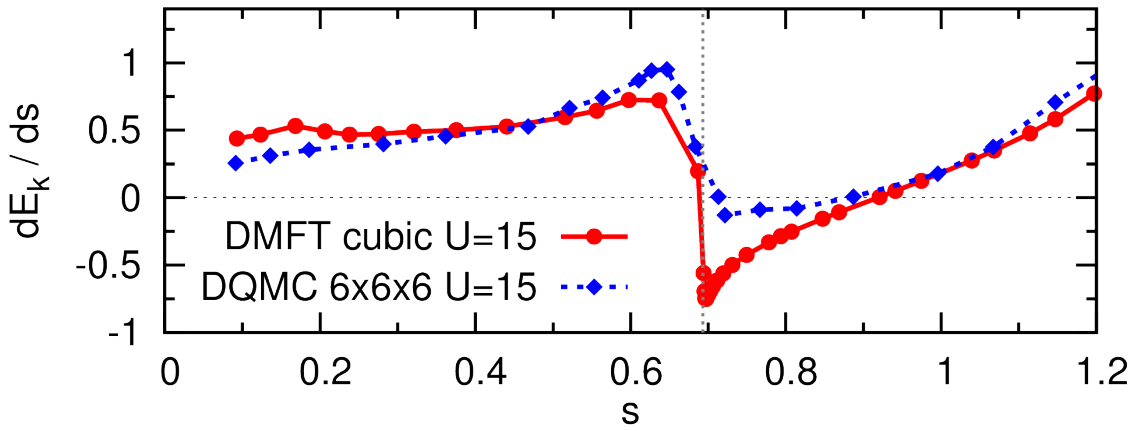

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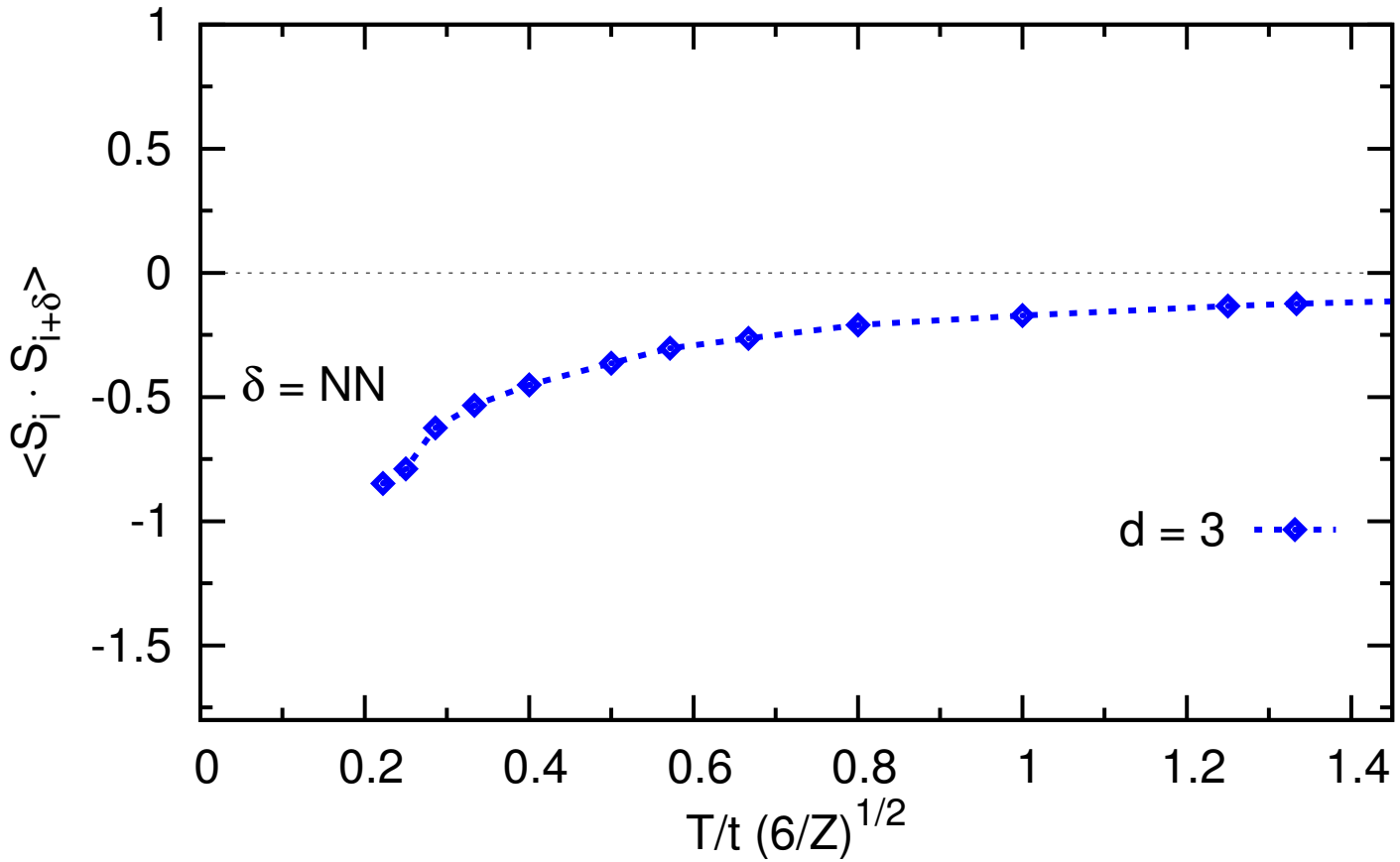
Spin correlation functions: what range is needed?

NN spin correlations: high-T tails



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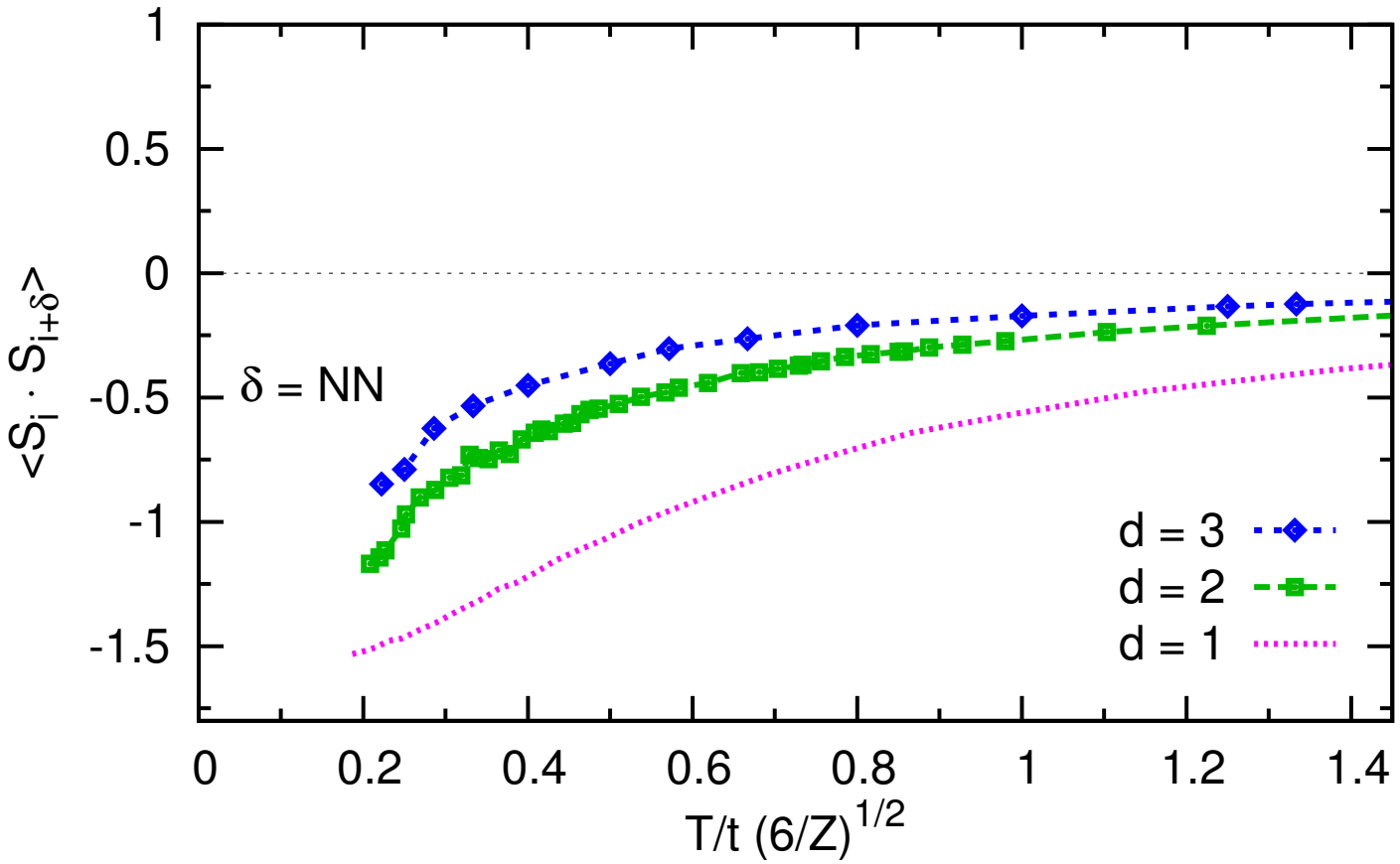
NN spin correlations: high-T tails, similar for $d = 2, 3$

increase with lowering d



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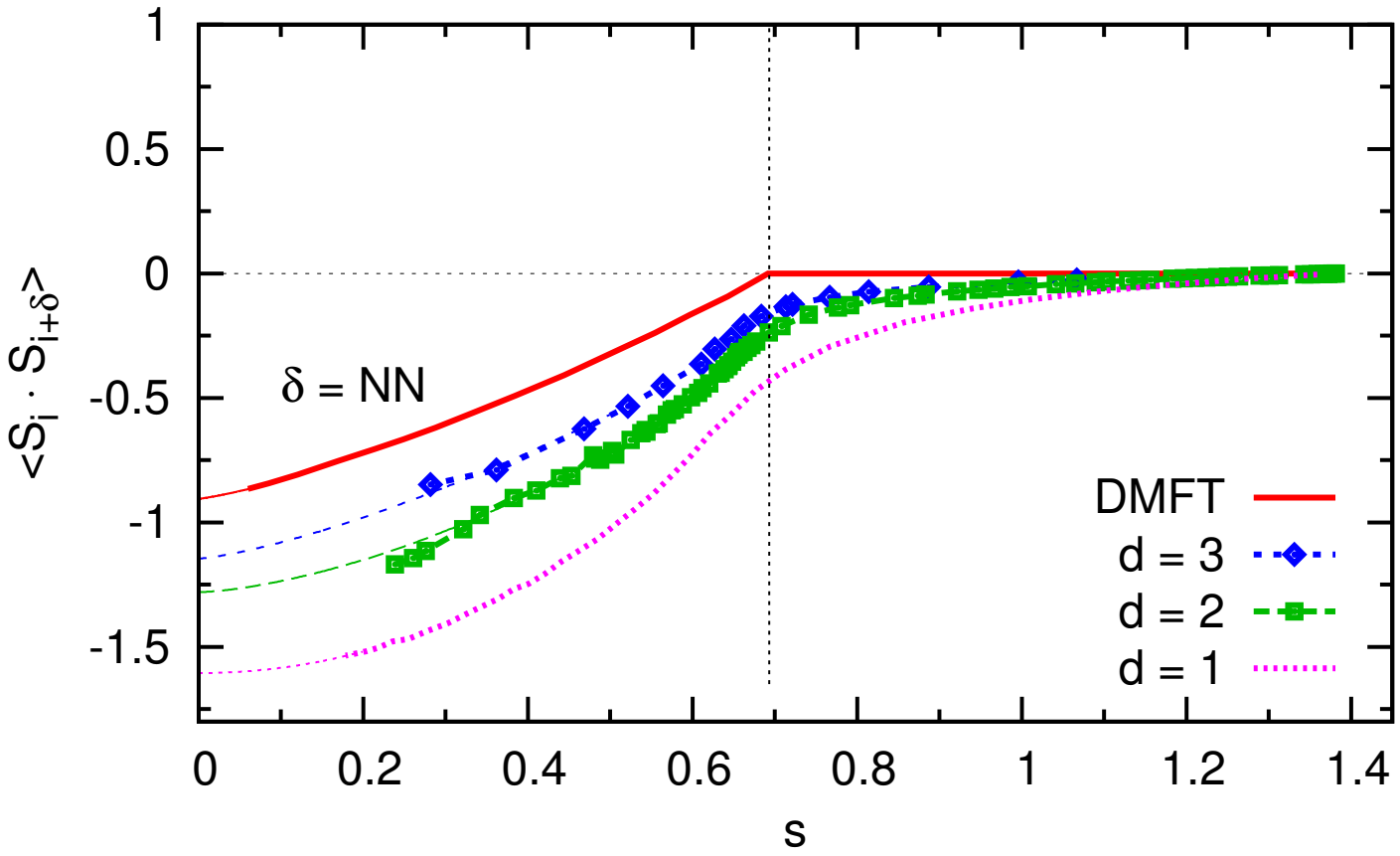

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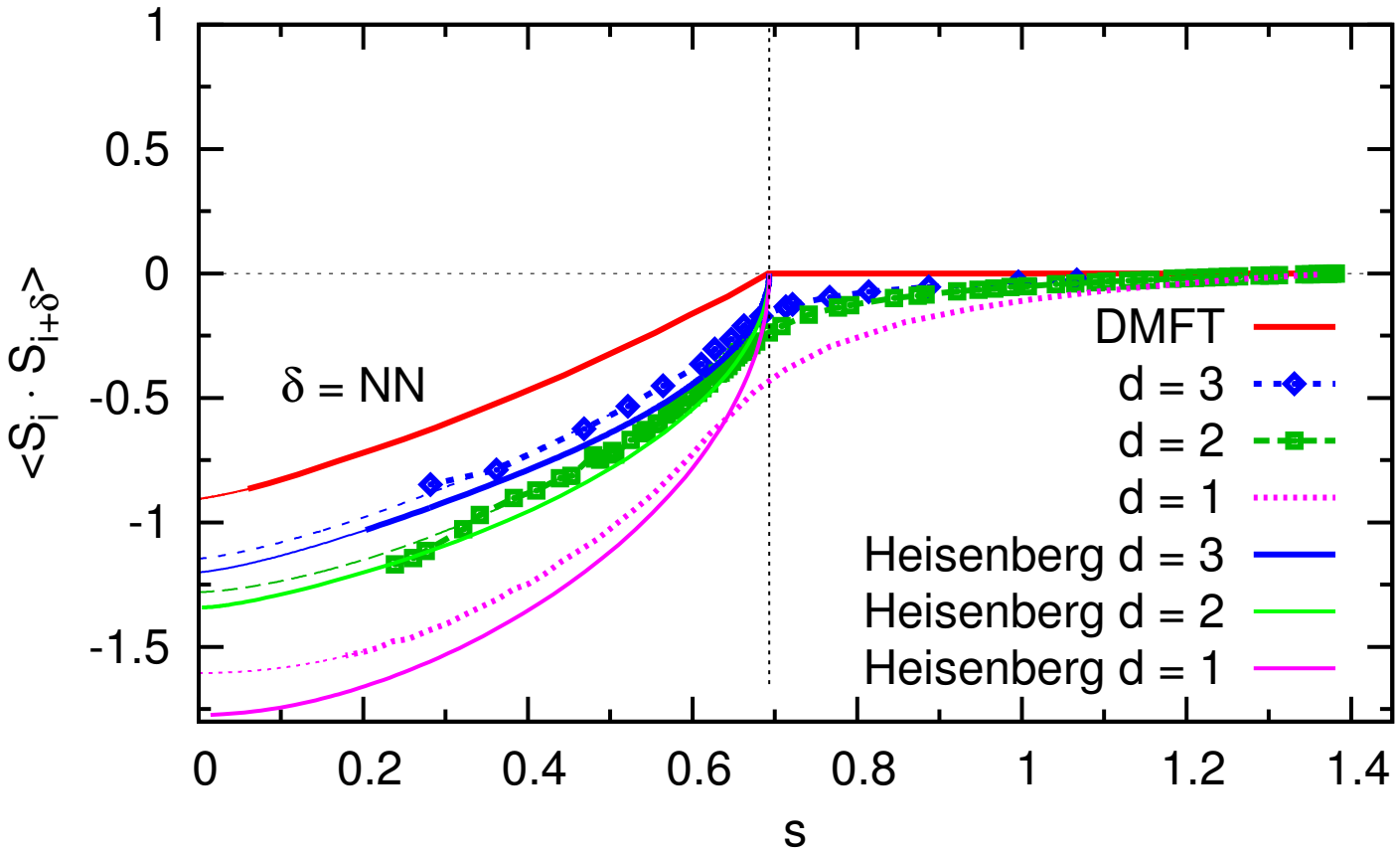
$\sim$ Heisenberg for $s \lesssim 0.65$



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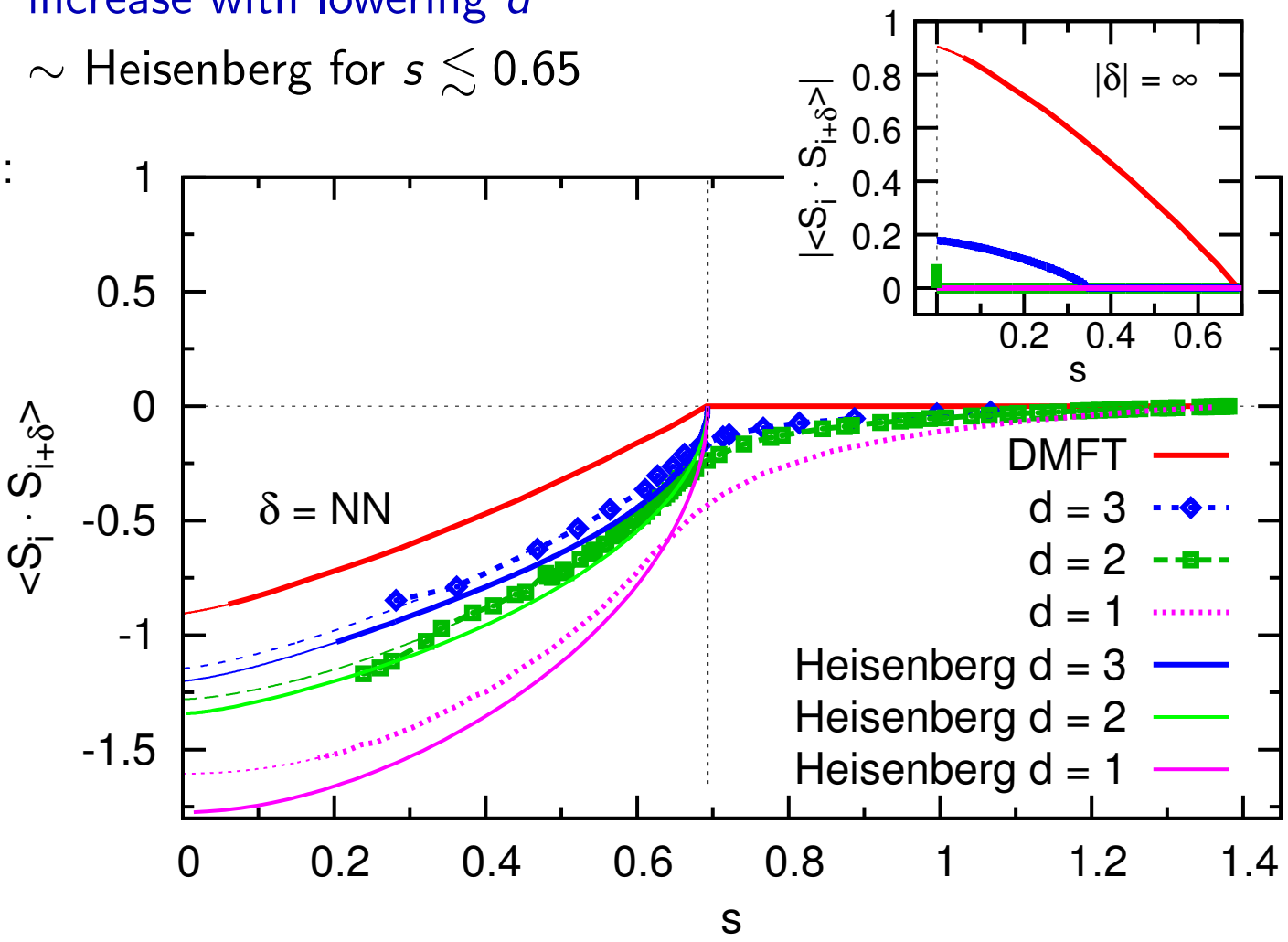

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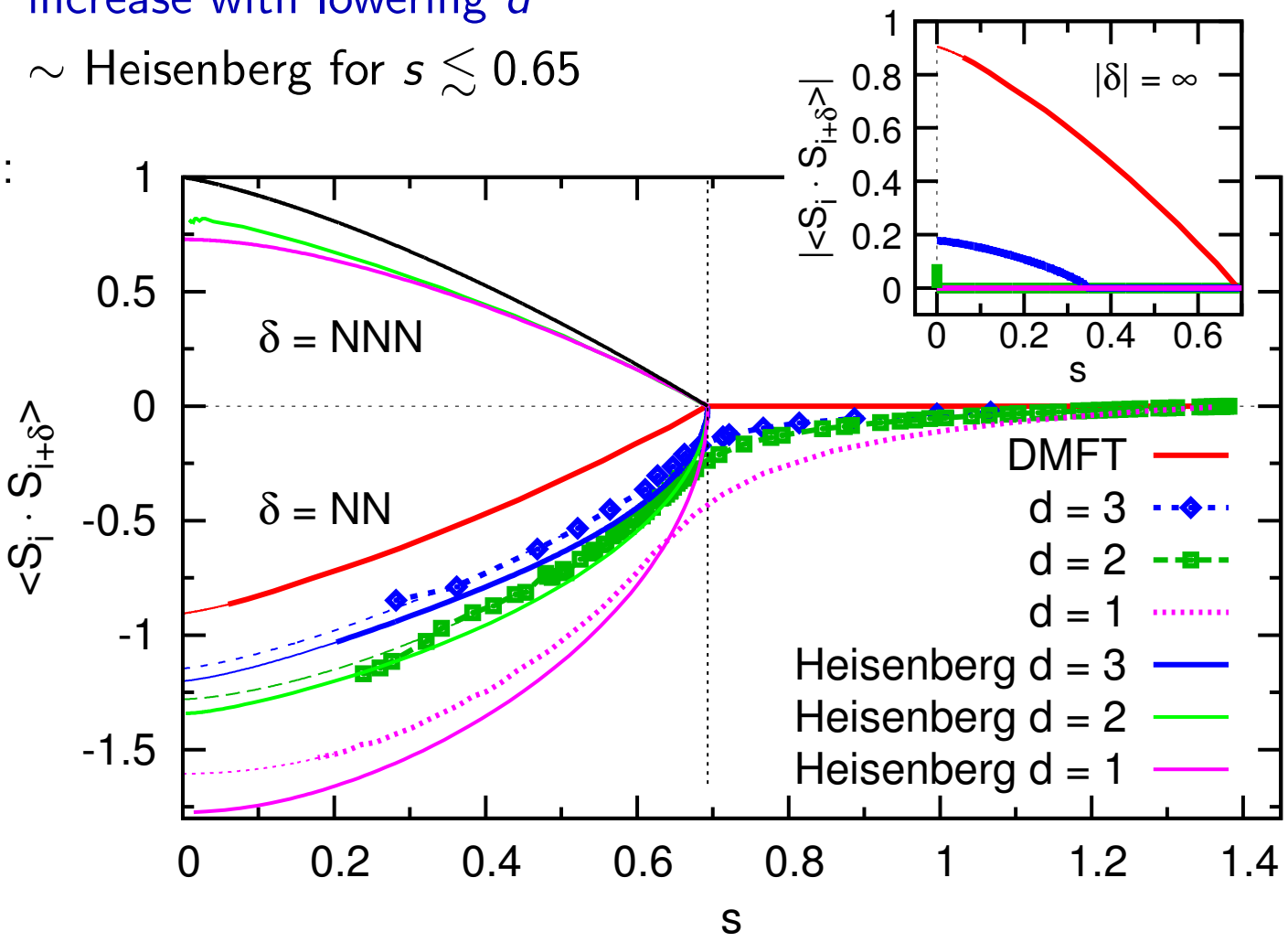

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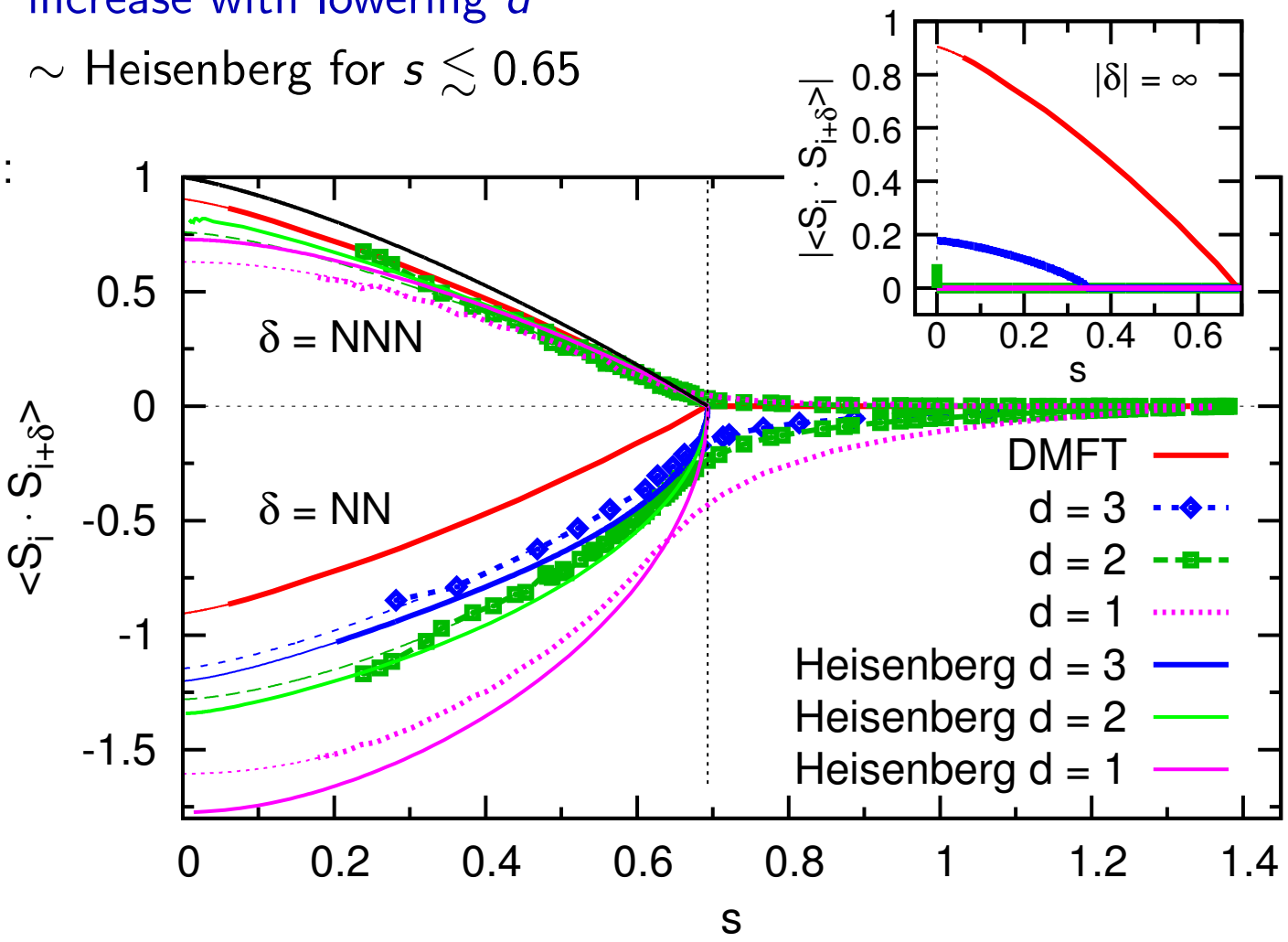

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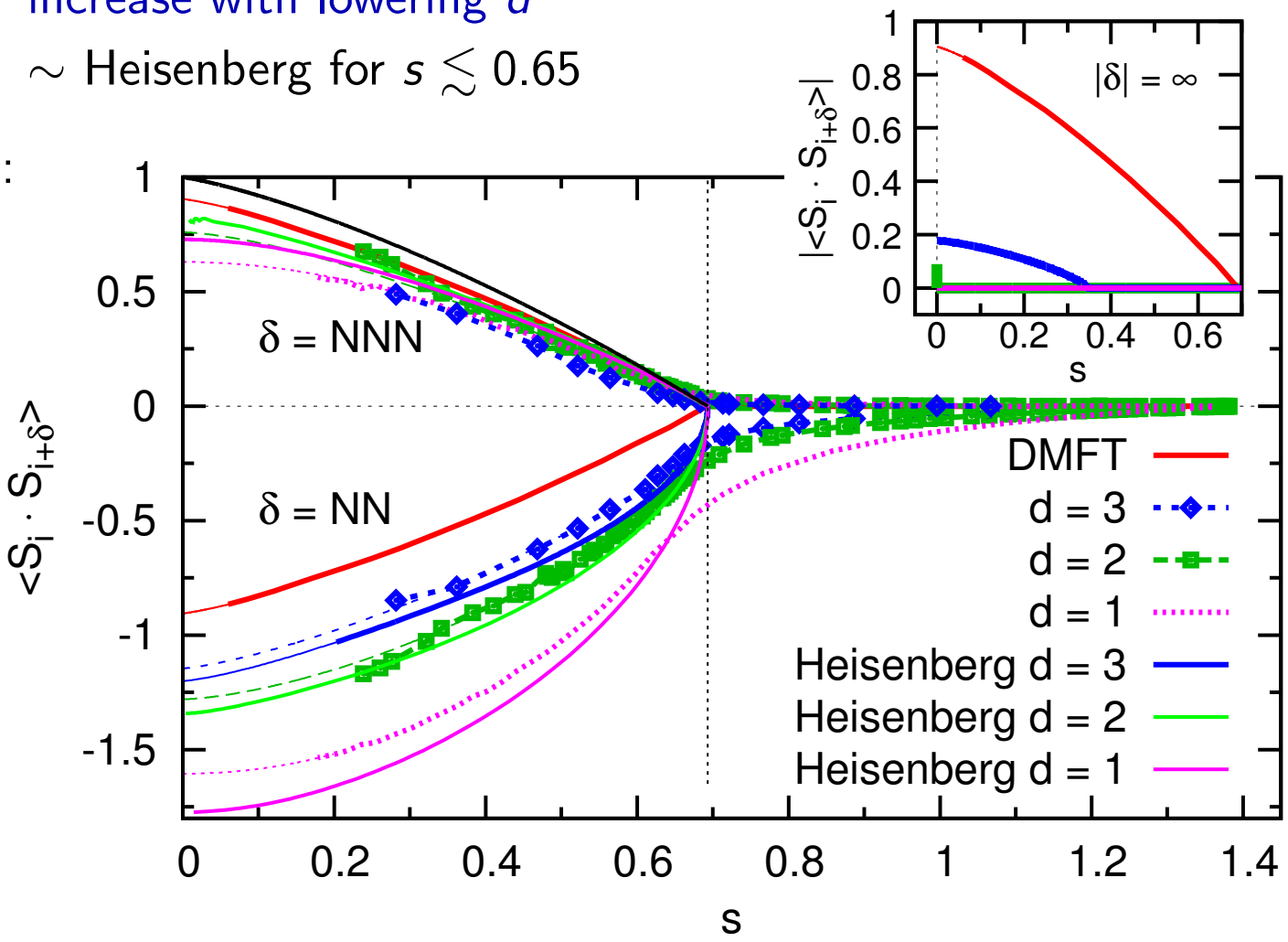

NNN spin correlation function signals: Heisenberg regime, low entropy

Summary

NN AF correlations

LRO

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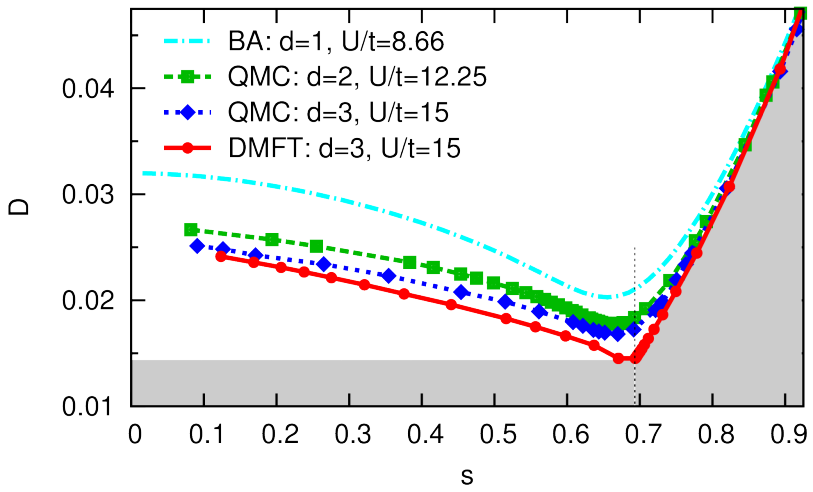

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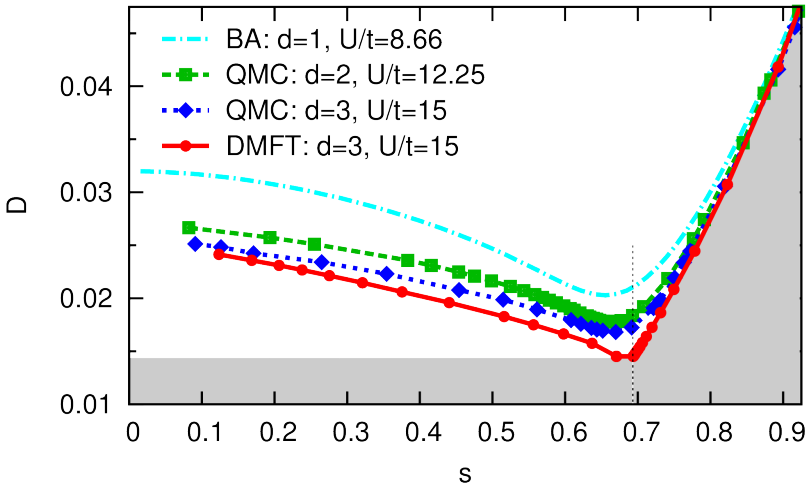

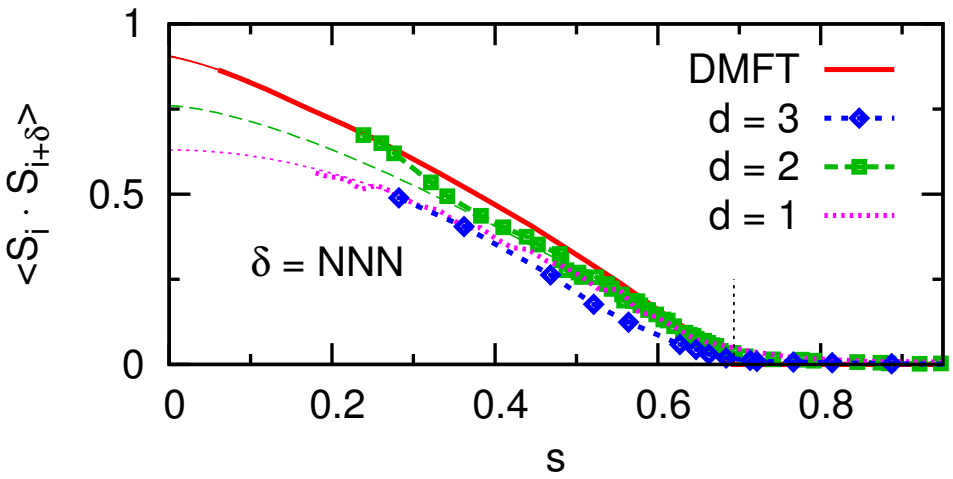

NNN spin correlations: universal signature of Heisenberg regime, low s

[arXiv:1201.5576]