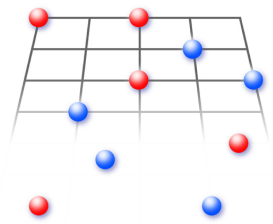


New routes to frustration and the suppression of antiferromagnetic signatures

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Transregional Collaborative Research Centre SFB / TRR 49
Condensed matter systems with variable many-body interactions
Frankfurt / Kaiserslautern / Mainz

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Motivation: AF signatures in ultracold fermions

Current experimental focus: search/find long-range antiferromagnetic order ($d = 3$)

- But:**
- direct (\mathbf{k} space) detection difficult:
 - high $T \rightsquigarrow$ small order parameter \rightsquigarrow small signal/noise
 - inhomogeneity, finite size \rightsquigarrow \mathbf{k} broadening, averaging
 - system may not live long enough (heating) for long-range order

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Experiment (^{40}K with $U < 0$):

adiabaticity time scale

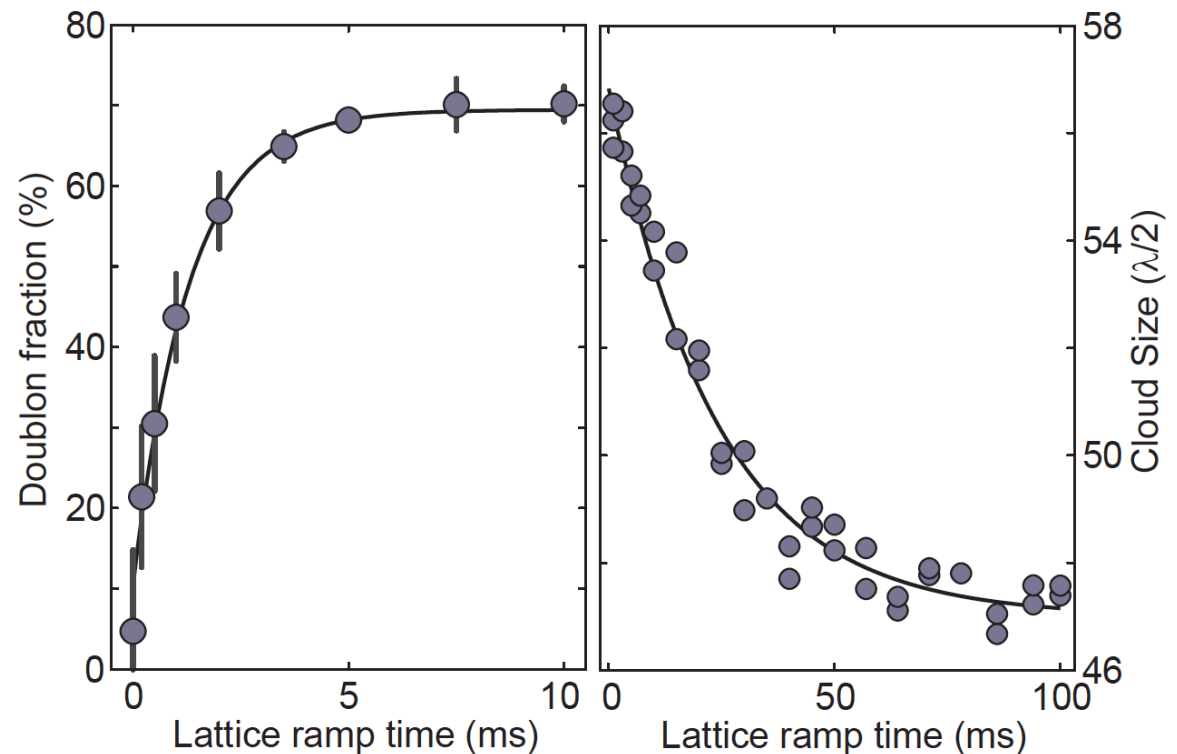
much longer for

cloud size (global property)

than for

pair formation (local property)

[U. Schneider, PhD thesis, 2010]

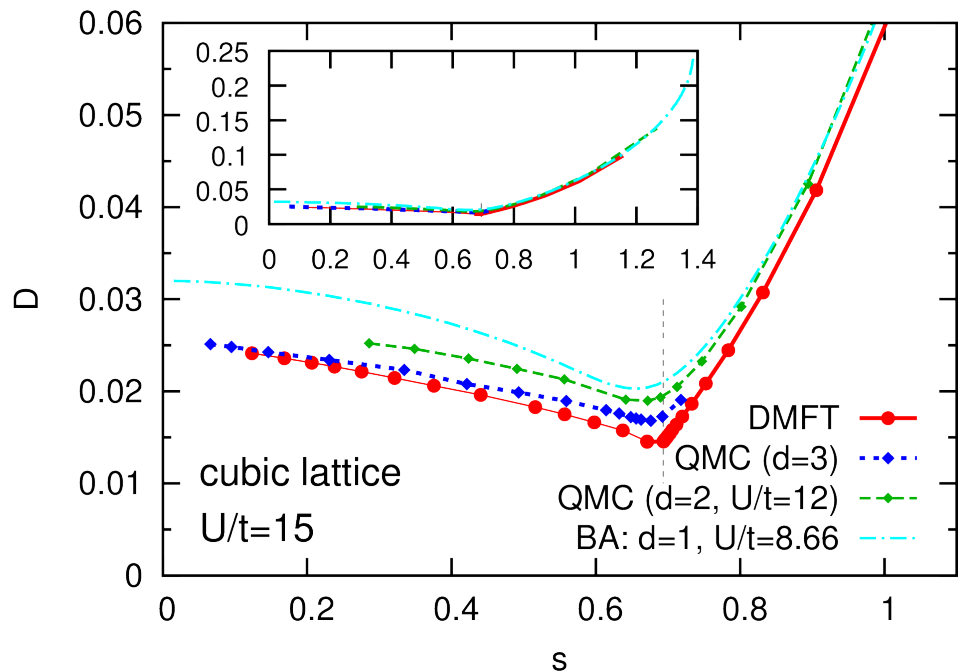


What can be learned from local observables regarding AF?

Various strategies for measuring NN spin correlation function $\langle \mathbf{S}_i \cdot \mathbf{S}_j \rangle$:

- double occupancy D [Gorelik et al., 2010]
- D generation rate (modulation spectroscopy) [Esslinger / Demler groups]
- superlattice [Bloch group]

But: hardly traces of AF long range order (below T_N) in $\langle \mathbf{S}_i \cdot \mathbf{S}_j \rangle$ or $D(T)$ (even in simulations at $n = 1$ [cf. previous talk])

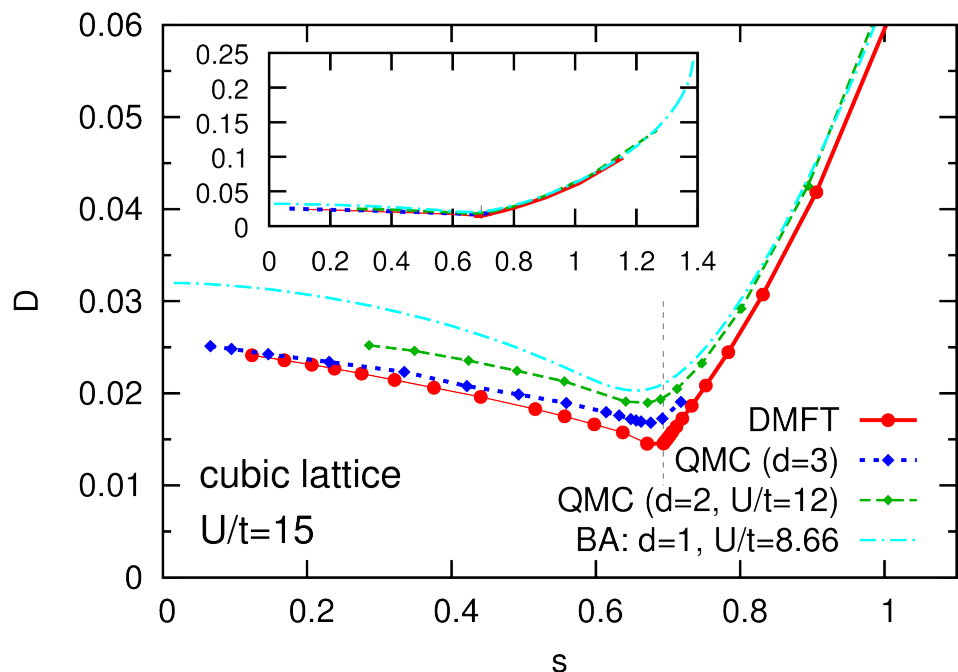


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\rightsquigarrow **LRO irrelevant** (at least for) current generation cold-atom experiments

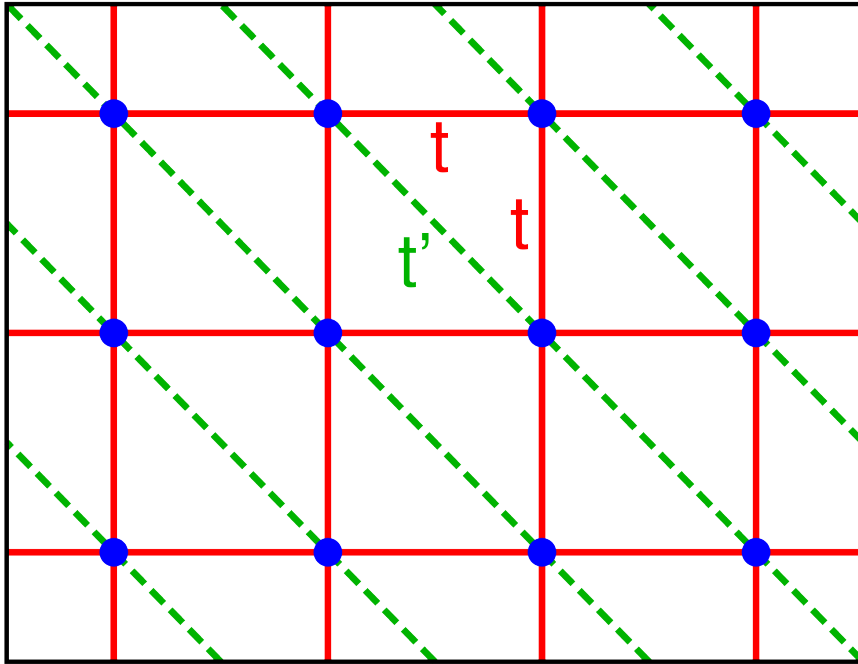
\rightsquigarrow no reason to limit experiments to cubic lattices ($d = 3$)

General strategy: search for signatures (e.g. in D) upon variation of

- temperature T / entropy S/N
- **lattice: frustration/dimensionality**

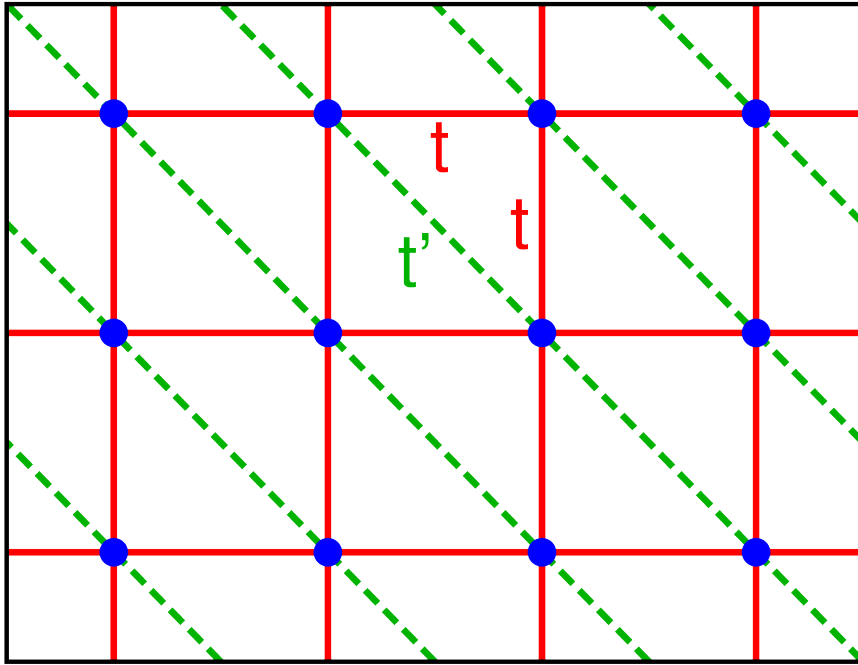
Impact of frustration: towards the triangular lattice

Introduce frustration in controlled way
as diagonal hopping in square lattice:



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Introduce frustration in controlled way
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$t' \rightarrow 0$: square lattice

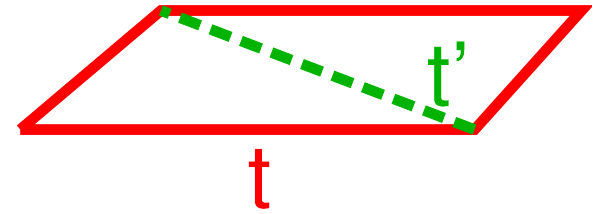
$t' \rightarrow t$: equivalent to triangular lattice

(general t' : “anisotropic triangular lattice”, relevant e.g. for copper chlorides)

- Imai, Kawakami, PRB **65**, 233103 (2002)
- Merino, Powell, McKenzie, PRB (2006)
- Tohyama, PRB **74**, 113108 (2006)
- Aryanpour, Pickett, Scalettar, PRB (2006)
- Lee, Kuneš, Scalettar, Pickett, PRB (2007)
- Kyung, PRB **75**, 033102 (2007)
- Lee, Li, Monien, PRB **78**, 205117 (2008)
- Sahebsara, Sénéchal, PRL **100**, 136402 (2008)
- Davoudi, Hassan, Tremblay, PRB (2008)
- Ohashi, Momoi, Tsunetsugu, Kawakami, PRL(2008)
- Gao, Wang, J. Phys. Cond. Matt. (2009)
- Yoshioka, Koga, Kawakami, PRL (2009)
- Galanakis, Stanescu, Phillips, PRB (2009)
- Liebsch, Ishida, Merino, PRB **79**, 195108 (2009)
- Lechermann, PRL **102**, 046403 (2009)
- Yoshioka, Koga, Kawakami, PSSB **247**, 635 (2010)

Problem: t' also changes bandwidth

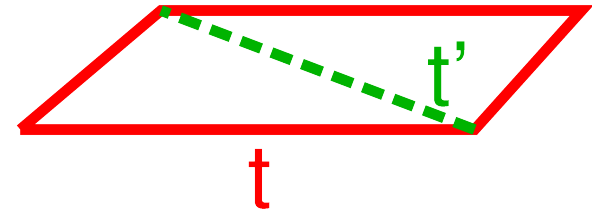
$$\langle \epsilon^2 \rangle \equiv \int_{-\infty}^{\infty} d\epsilon \epsilon^2 \rho_0(\epsilon) = 4t^2 + 2t'^2$$



\rightsquigarrow increasing t' not only suppresses AF order/correlations (**frustration** effect)
but also changes **energy scale** for interaction U and temperature T

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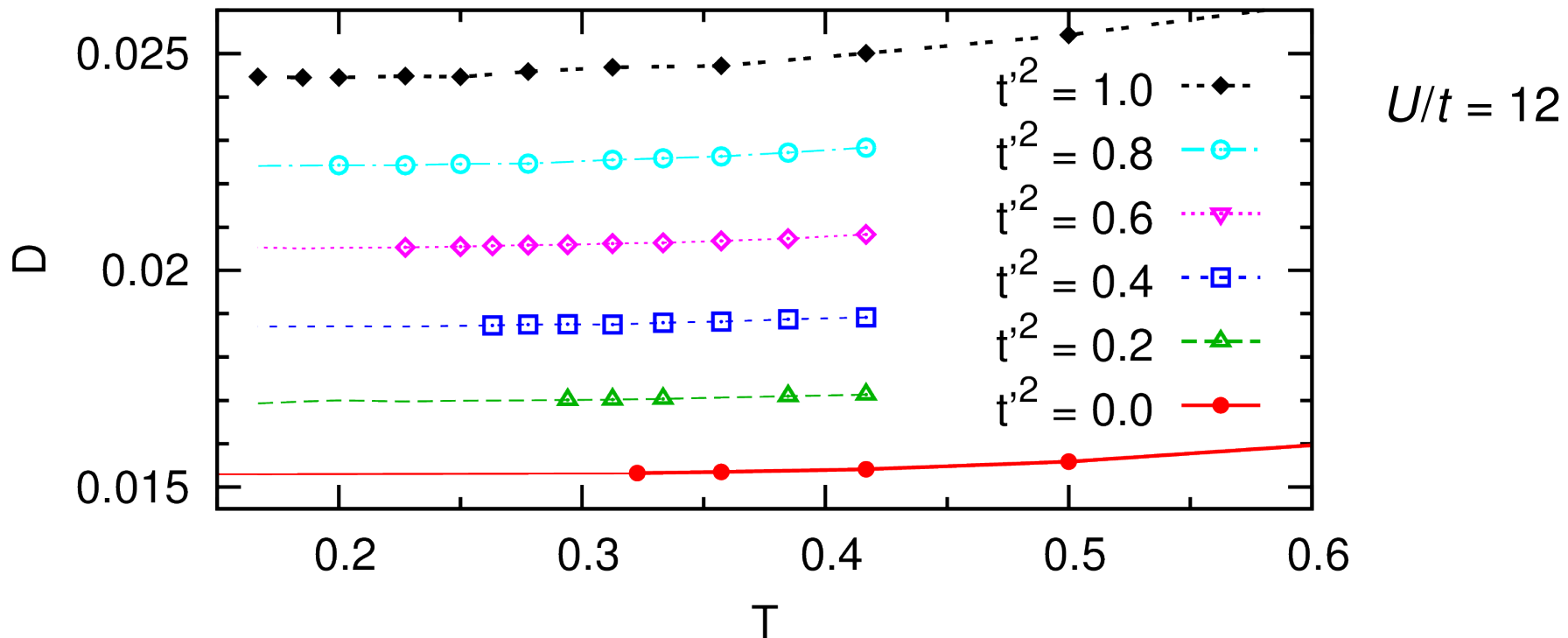
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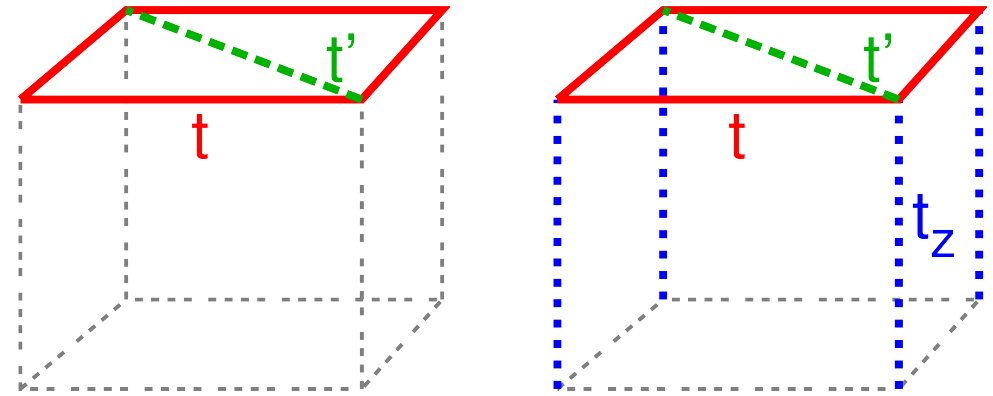
\rightsquigarrow (at fixed U, T): properties change already in nonmagnetic phase



Solution: add third dimension
and hopping t_z between planes

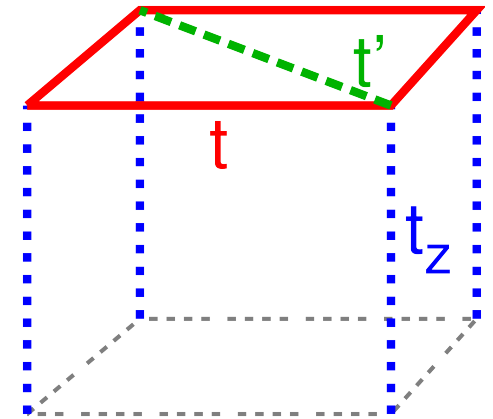
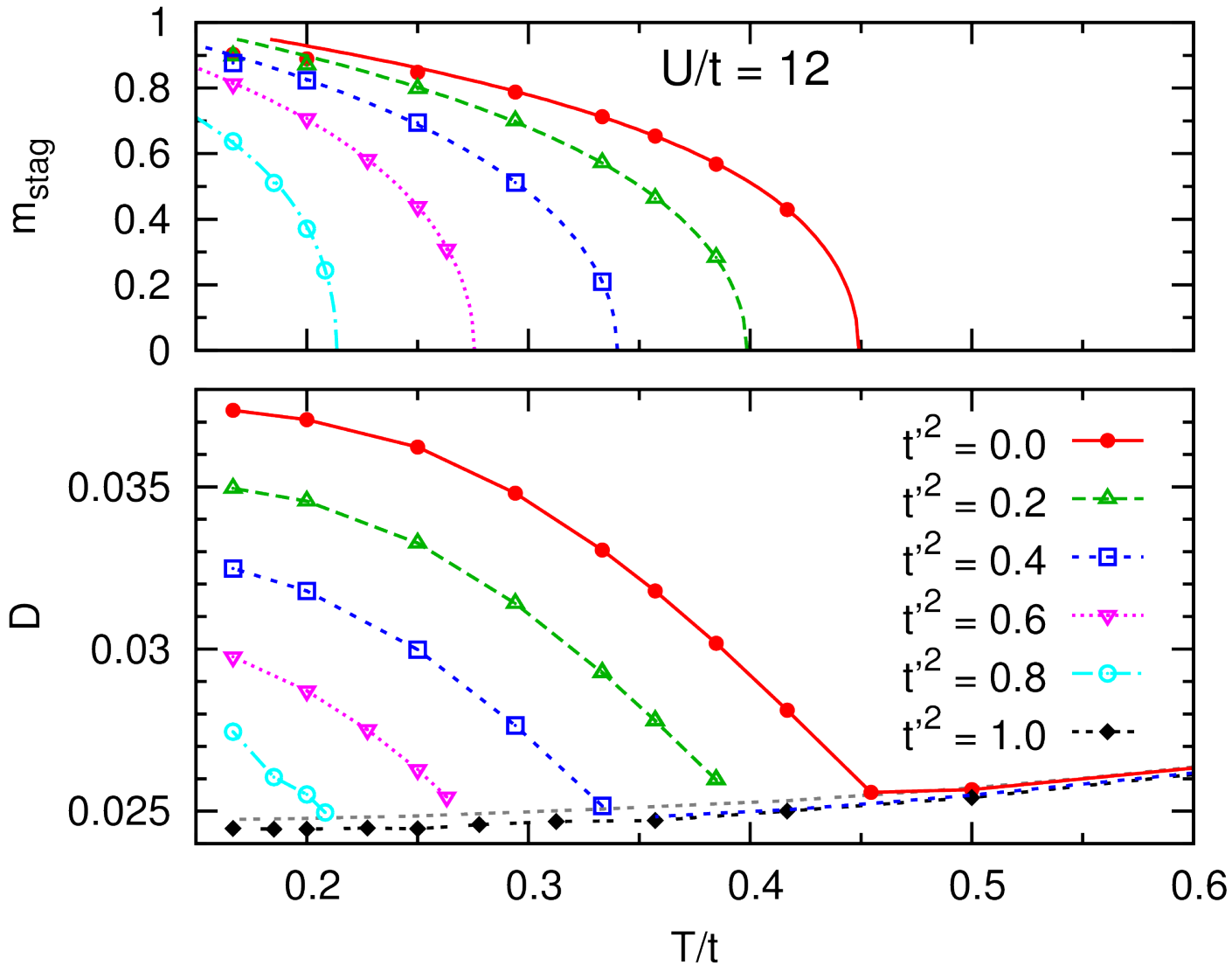
$$\text{with } t_z^2 = t^2 - t'^2$$

\rightsquigarrow eff. coordination number $Z = 6 \forall t'$



Hope: t' should act as pure **frustration parameter**, affecting only magnetic phases

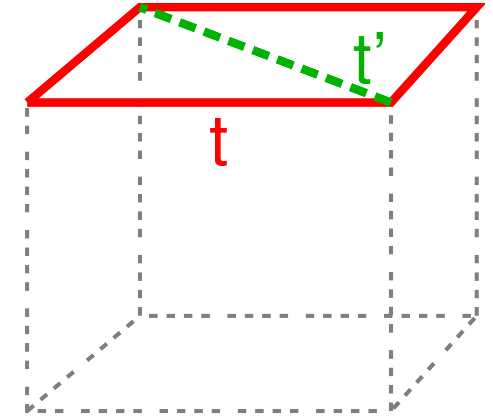
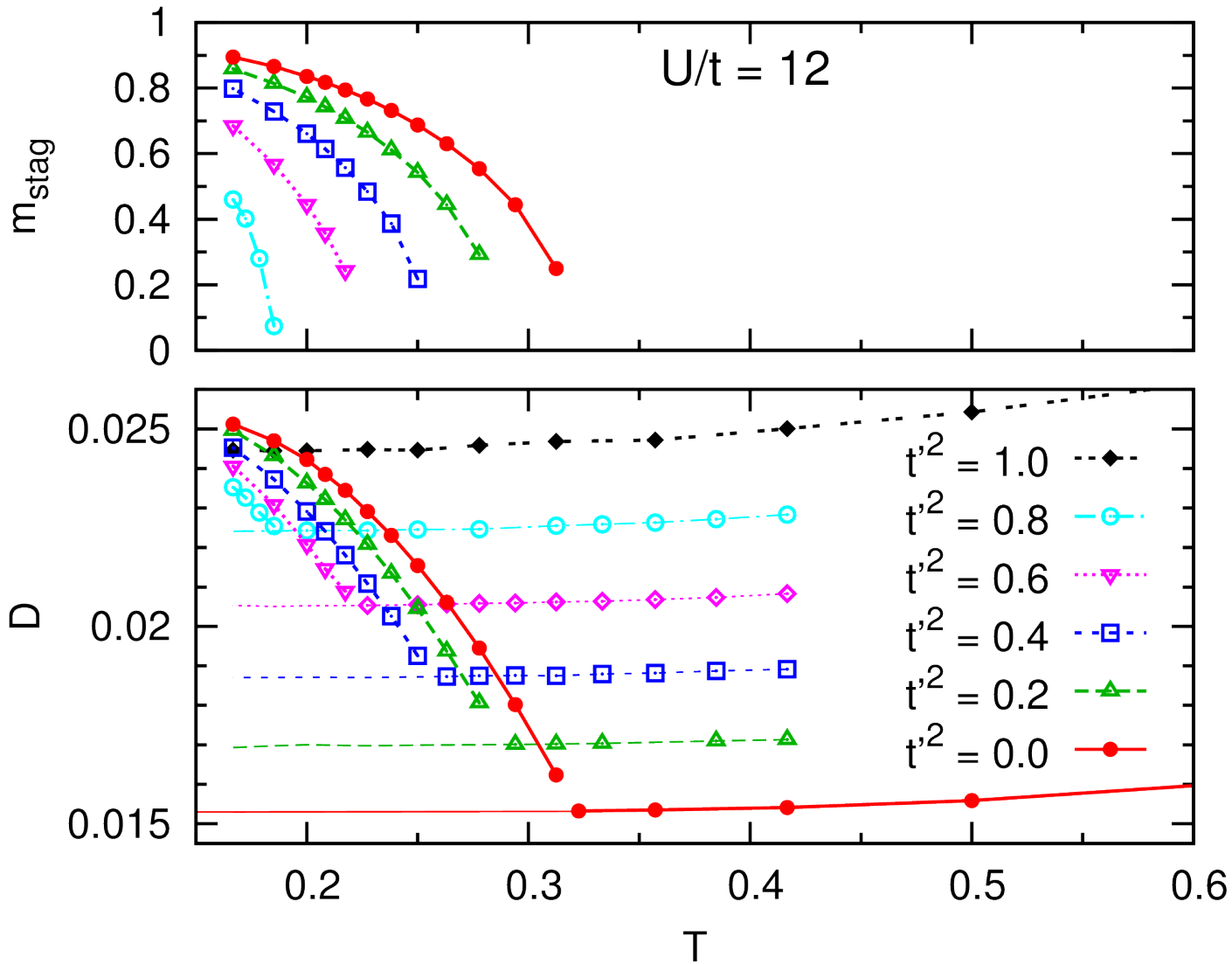
Tuning the frustration from the cubic to the triangular lattice



D suppressed before
AF breaks down

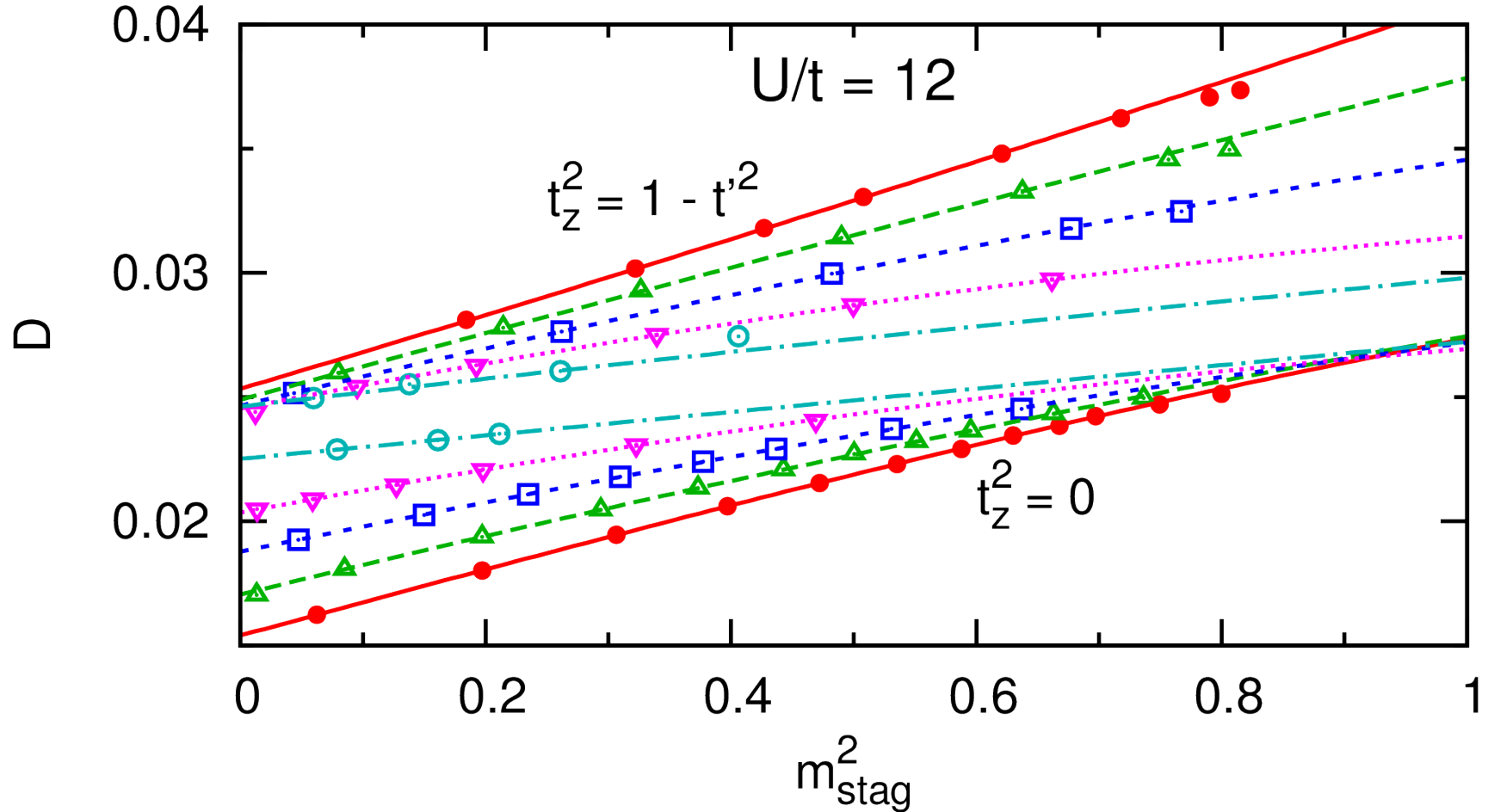
paramagnetic phase
hardly affected by t'

Tuning the frustration from the square to the triangular lattice



Now situation reversed: strong t'^2 dependence only in paramagnetic phase

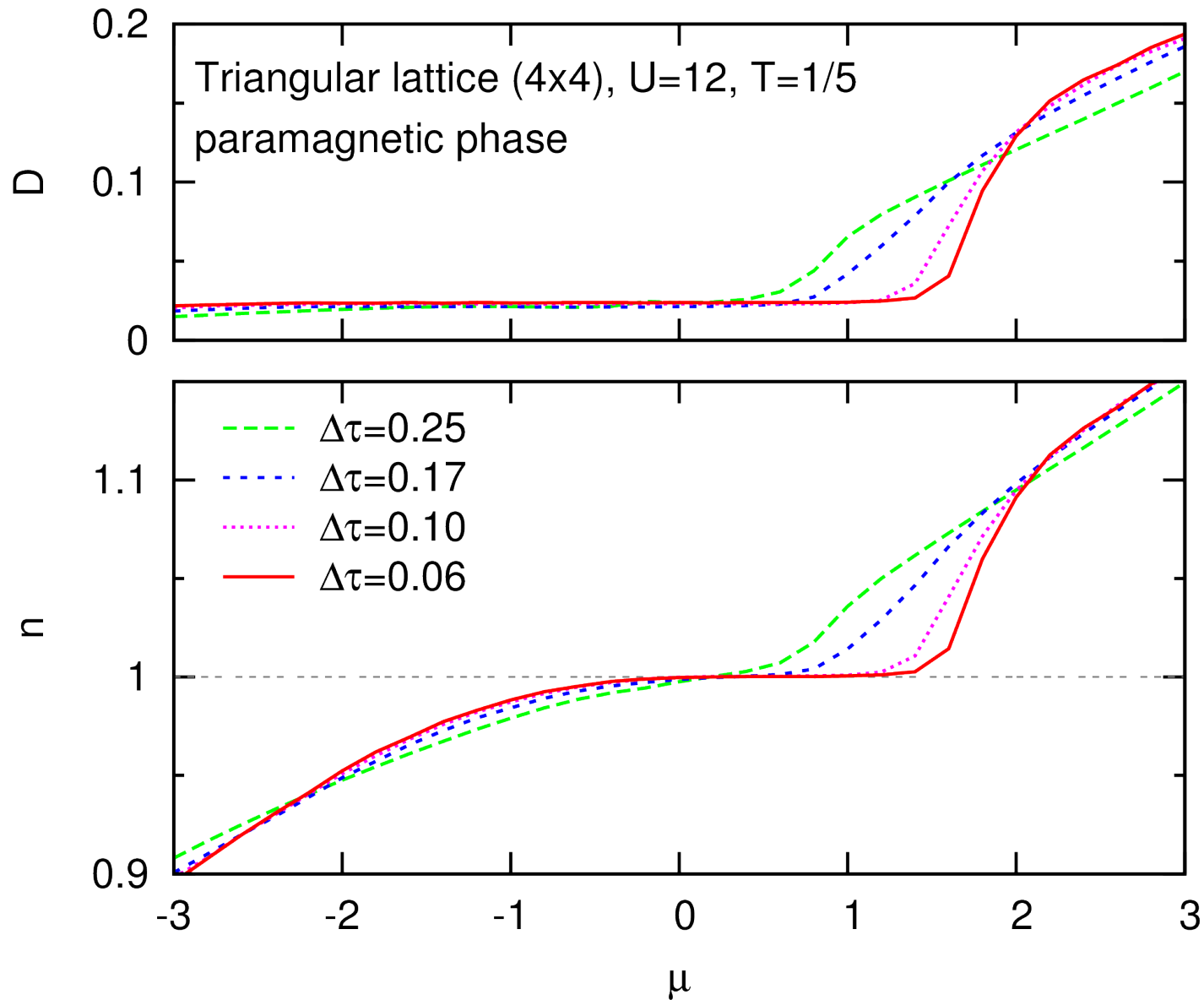
Direct connection between double occupancy and $\langle \mathbf{S}_i \cdot \mathbf{S}_j \rangle(T)$? Yes!



Quantitative confirmation of strong coupling picture: results collapse in

- paramagnetic limit for $t_z^2 = 1 - t'^2$
- AF limit for $t_z^2 = 0$

Effects of lost particle-hole symmetry for cubic \rightarrow triangular lattice?



Summary

AF correlations at finite T measurable via double occupancy *

[E. V. Gorelik, I. Titvinidze, W. Hofstetter, M. Snoek, N. Blümer, PRL **105**, 065301 (2010)]

DMFT surprisingly accurate in low d – charge physics local (large U)?

Long-range order and dimensionality irrelevant for cold atoms

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DMFT surprisingly accurate in low d – charge physics local (large U)?

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Tuning of frustration: separate magnetic from nonmagnetic physics

most cleanly for cubic \rightarrow triangular lattice at constant $Z = 6$

D is quantitative measure of $\langle \mathbf{S}_i \cdot \mathbf{S}_j \rangle$ (variation of t' and/or T)

* Related: $\langle \mathbf{S}_i \cdot \mathbf{S}_j \rangle$ from D creation rate in modulation spectroscopy

[Jordens et al., Nature **455**, 204 (2008); Sensarma, Pekker, Lukin, Demler, PRL **103**, 035303 (2009)]

DMFT deviations typically **smaller** than QMC $\Delta\tau$ errors

