Robustness of Quantum Simulators

Quantum Technologies Conference II

2 Sept 2011

Krakow

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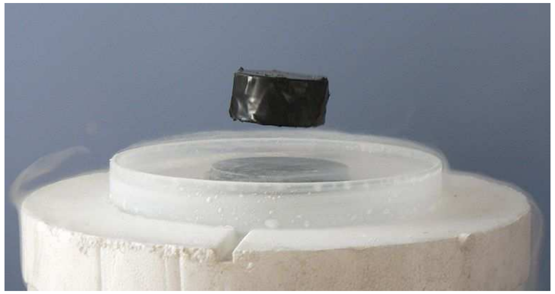
Many quantum phenomena are not understood

Reason: exponential growth of Hilbert space

Example: high Tc



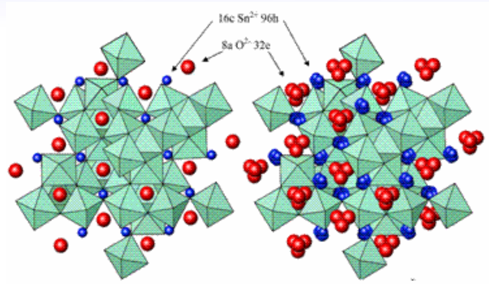
Solution: Quantum simulator!

R.P. Feynman, Int. J. Theor. Phys. **21**, 467 (1982)

Definition:

A system which behaves
as a particular model.

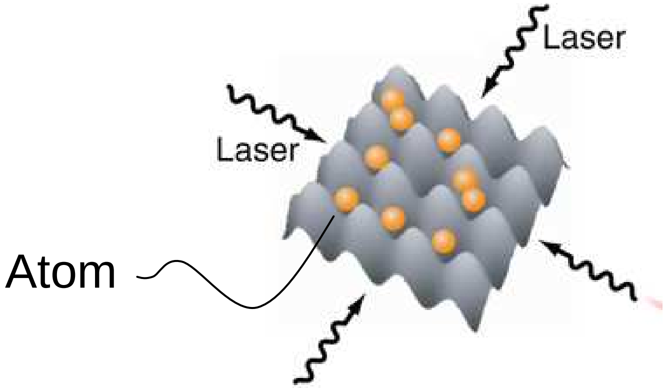
Example: Bose–Hubbard model



Complicated “real” system

Simplified,
well to control
model system

simulates



Jaksch et al., PRL **81**, 3108 (1998)
Greiner et al., Nature **415**, 39 (2002)

We say:

“***Quantum simulators are robust***, *because we measure physical quantities like correlations.*”

But are they?

To date, there is **little quantitative analysis** of non-ideal quantum simulators!

Bosons:	Bakr et al., Science **329**, 547 (2010)
	Trotzky et al., Nature Phys. **6**, 998 (2010)
Fermions:	Jördens et al., PRL **104**, 180401 (2010)

Outline

How does disorder affect

static properties ?

dynamical properties ?

Conclusions & Perspectives

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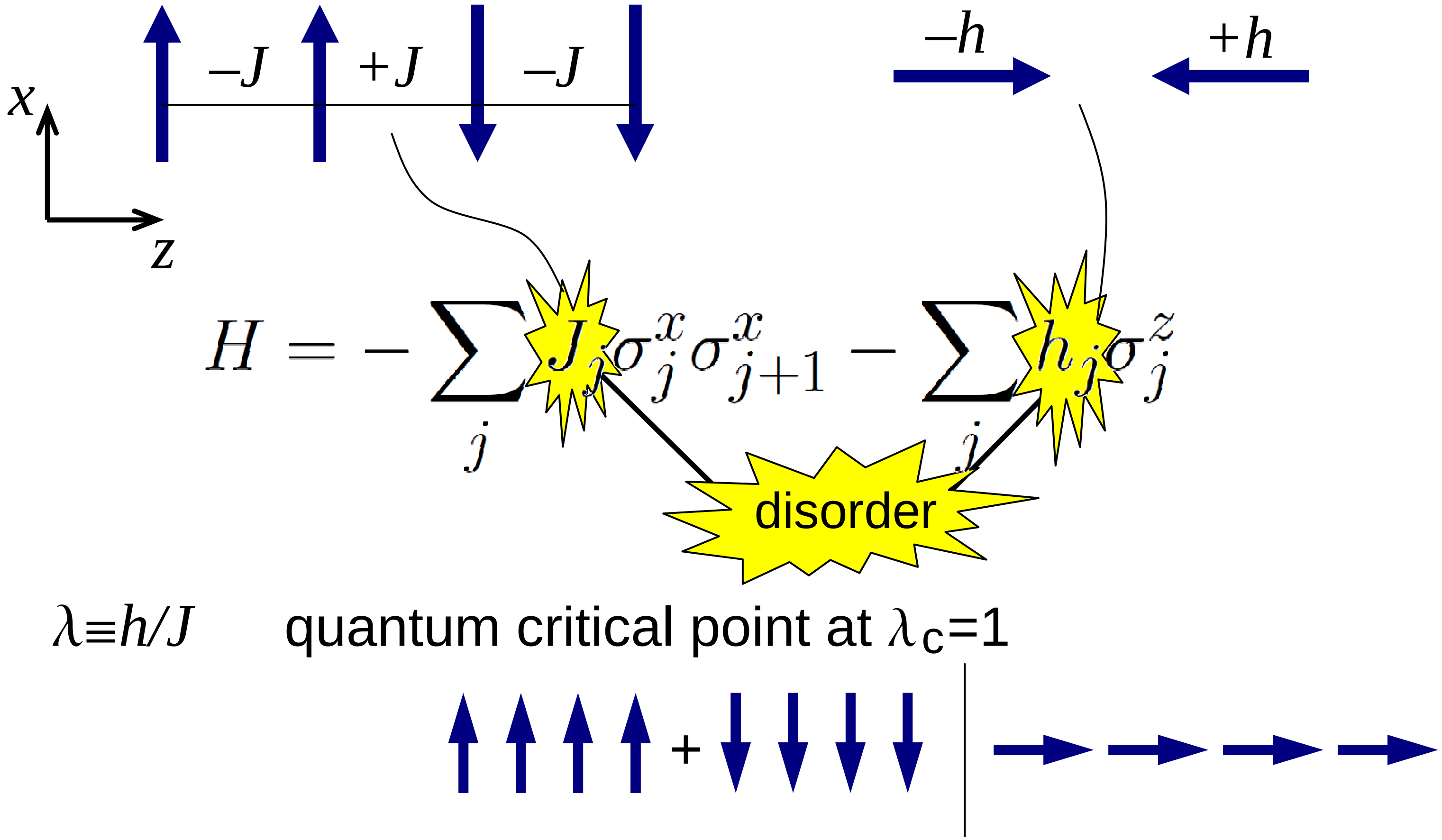
Conclusions & Perspectives

We start with a simple and solvable model, the Ising chain in a transverse field



$$H = -\sum_j J_j \sigma_j^x \sigma_{j+1}^x - \sum_j h_j \sigma_j^z$$

$\lambda \equiv h/J$ quantum critical point at $\lambda_c = 1$

Problem:
Disorder changes the critical behavior

Any amount of disorder drives the transverse Ising chain at long distances to a random quantum critical point.

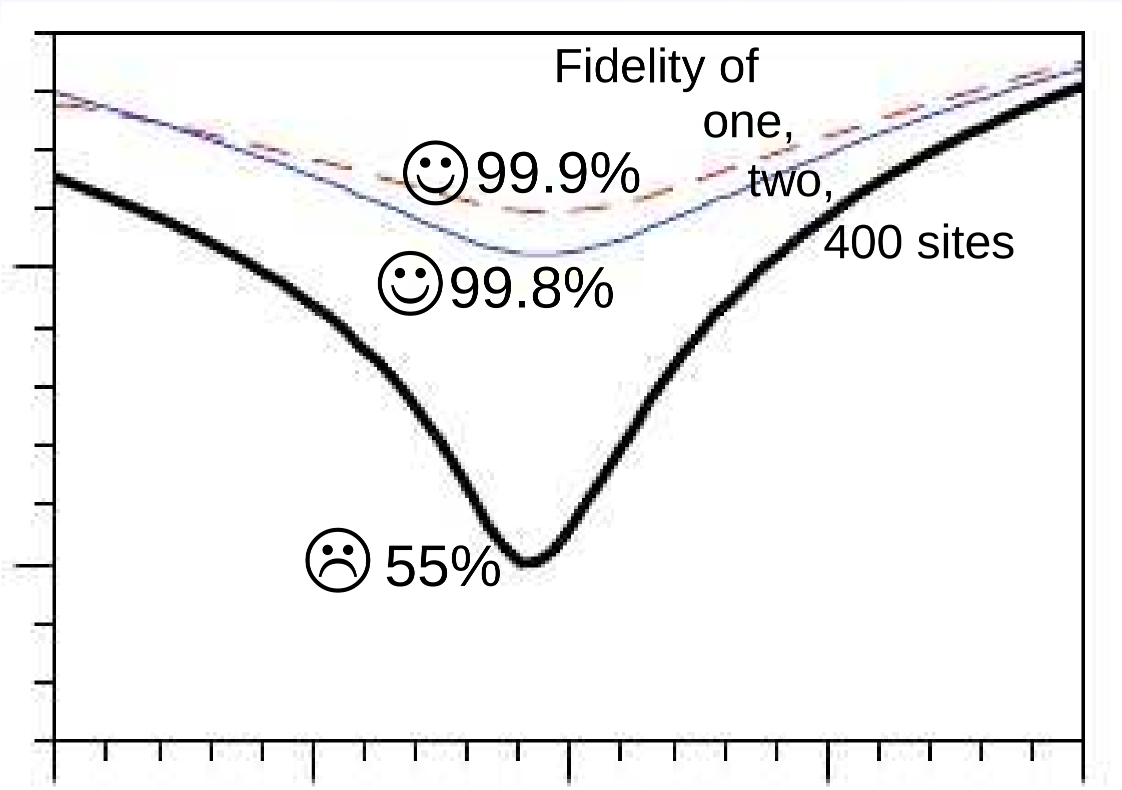
Fisher PRB (1995)

Can we still learn about the ideal system from a disordered quantum simulator?


Just a first step

Disorder reduces **simulator fidelity**

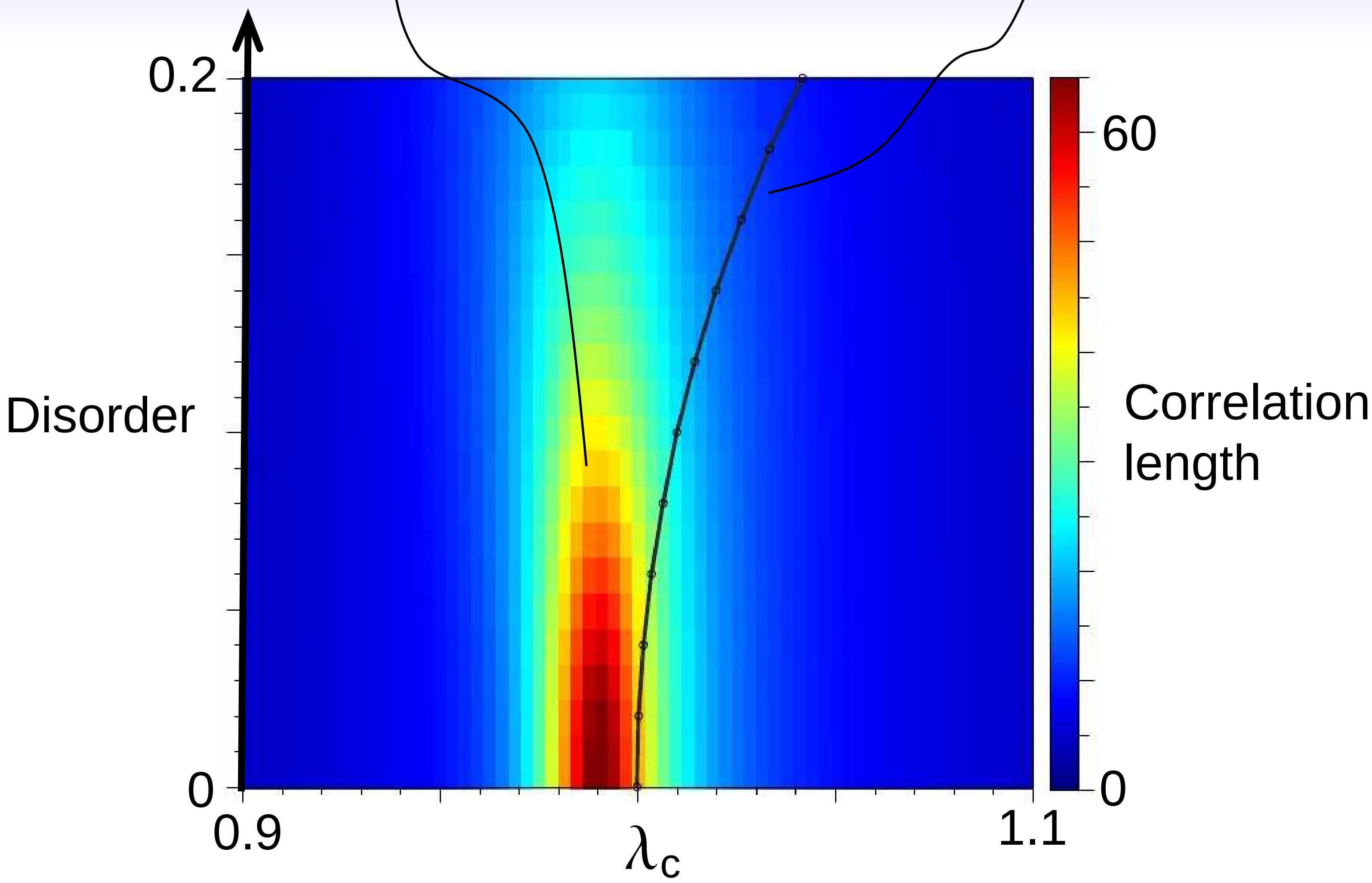
$$|\langle\Psi_{\text{no disorder}}|\Psi_{\text{disorder}}\rangle|$$



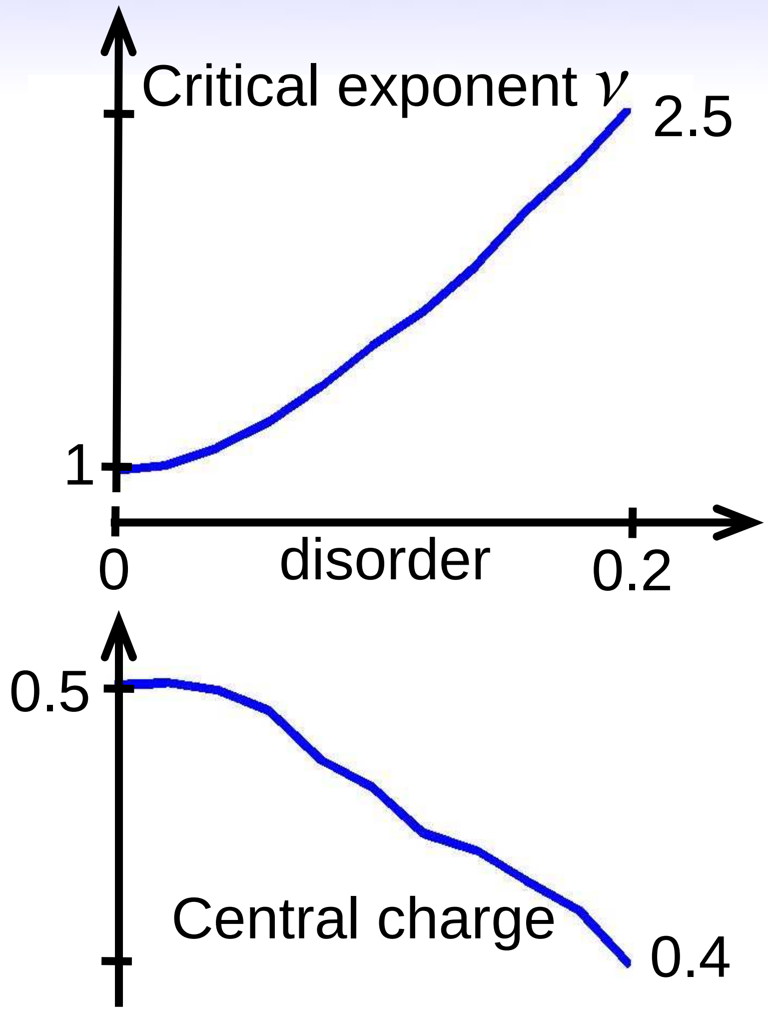
☹ Suppression stronger around critical point

☺ Local properties robust

Disorder suppresses correlations and moves the critical point



Disorder changes critical behavior ☹



But **change is smooth** ☺

Experiments should be able to work in regime where effects of disorder are small

Conclusions statics

- ☹ Disorder changes ground state and critical behavior
- ☹ Changes are stronger around critical point

- ☺ Changes are smooth
- ☺ Disorder needed for sizeable changes is relatively large

Outline

How does disorder affect

static properties ?

dynamical properties ?

Conclusions & Perspectives

2^{nd} part: Dynamics

Procedure:

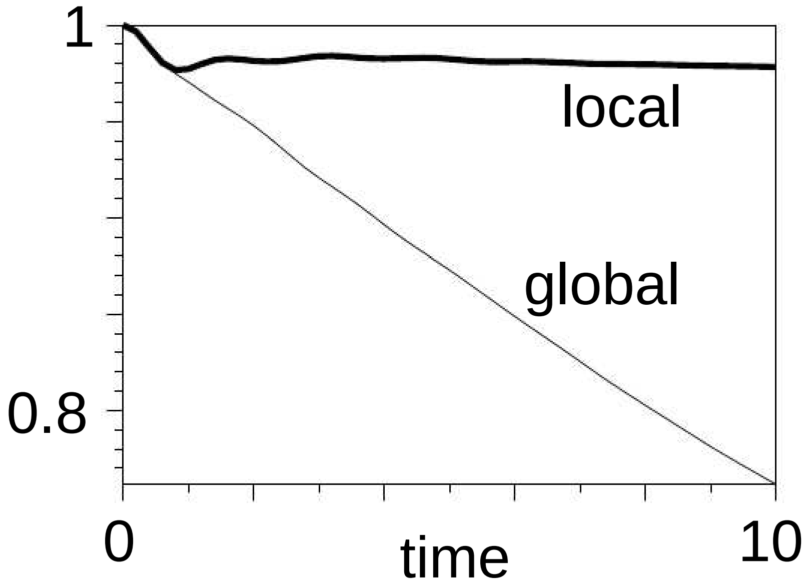
Prepare system in **ground or thermal state**,
quench magnetic field,
and let **evolve** under this new field value

Analysis: We compare fidelities

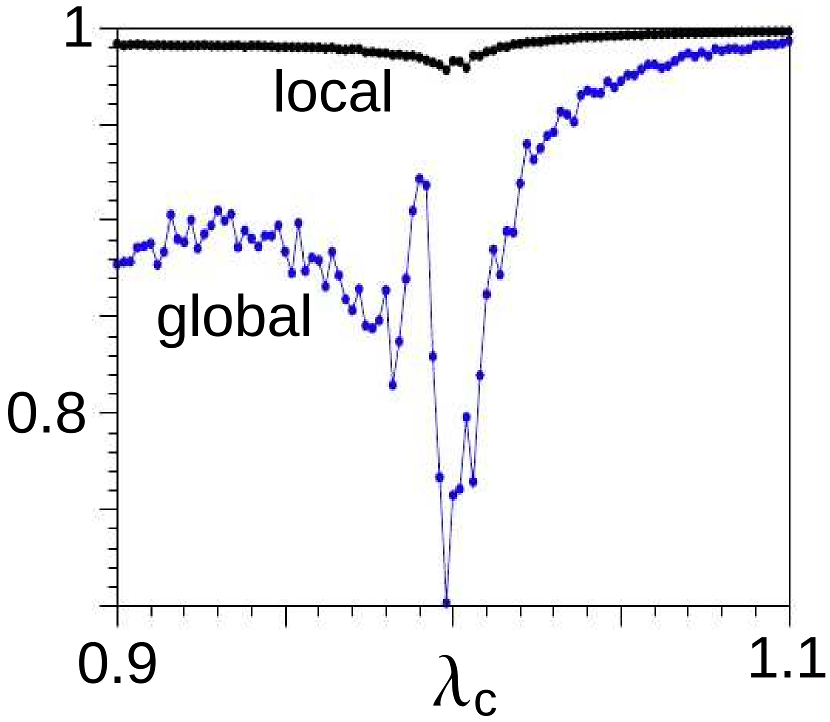
- after local and global quenches
- for different starting temperatures (as a measure for complexity)

Simulator fidelity (at T=0) in **local quench** is **more robust** than in global quench

as a function of time

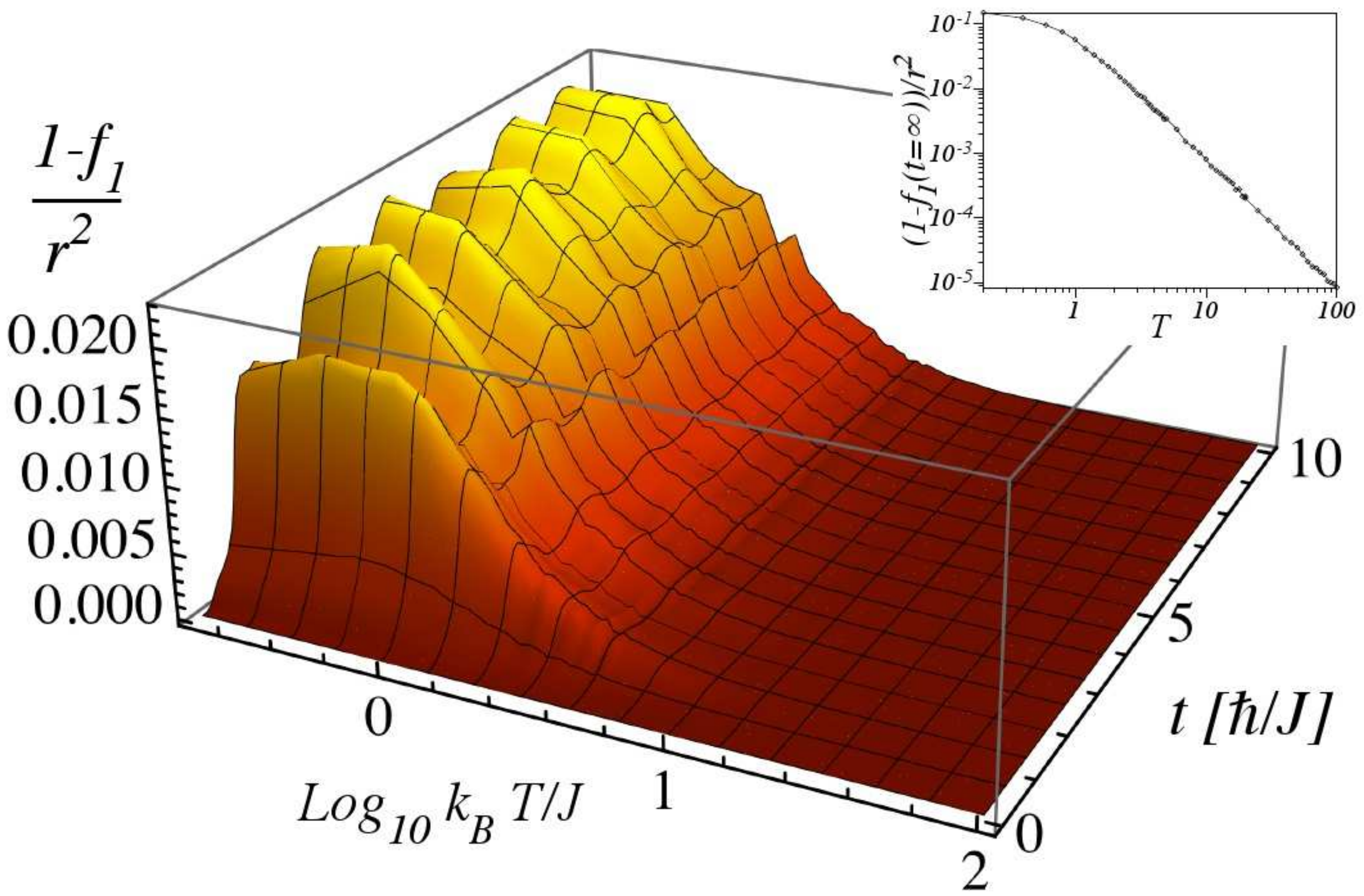


at large time



☹ around critical point less robust

Dynamics at **lower temperatures** (more complex states) is **less robust**



Conclusions dynamics

Dynamics seems pretty robust

Global quenches less robust

Lower temperature (more complex) less robust

→ Where numerical techniques perform worse,

[Prosen and Znidaric, PRE **75**, 015202 (2007)]

[Perales and Vidal, PRA **78**, 042337 (2008)]

also quantum simulator would perform worse (but less so).

Many more questions:

Here: everything relatively robust. What about **exotic phases**?

Can a **disordered analog QS** do more than a **classical computer**?

no → Are there **error correction** strategies?

yes → Can we exploit it?

What about **digital QS**?

...

Thank you!

PH, F. Cucchietti, L. Tagliacozzo, I. Deutsch, M. Lewenstein, in preparation

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QUAGATUA