Towards Experimental Quantum Gravity with Ultracold Atoms

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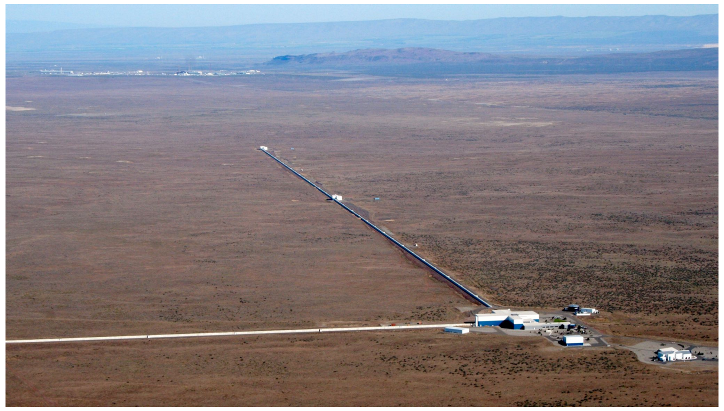
Kyoto/Stanford/Livermore

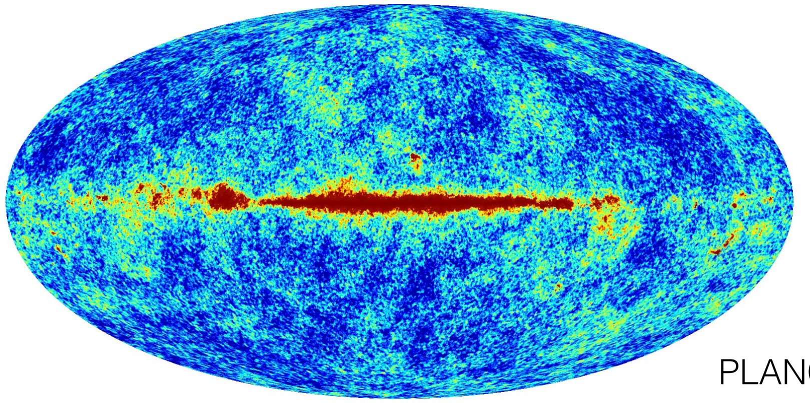
Based on 1606.02454 with I. Danshita and M. Tezuka

(I believe)

We can test String Theory in the Sky



LIGO



PLANCK

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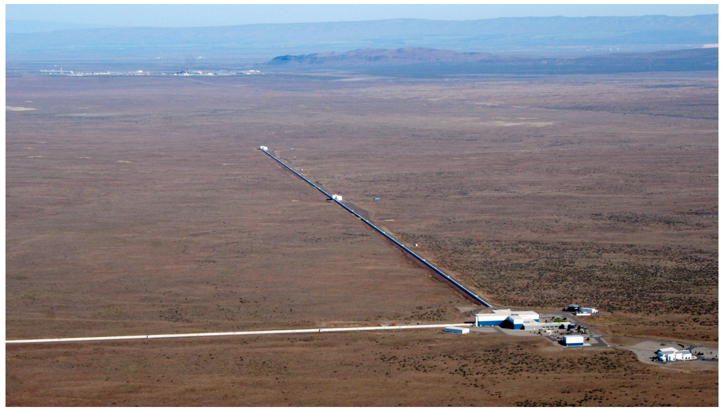
We can test String Theory in the Sky



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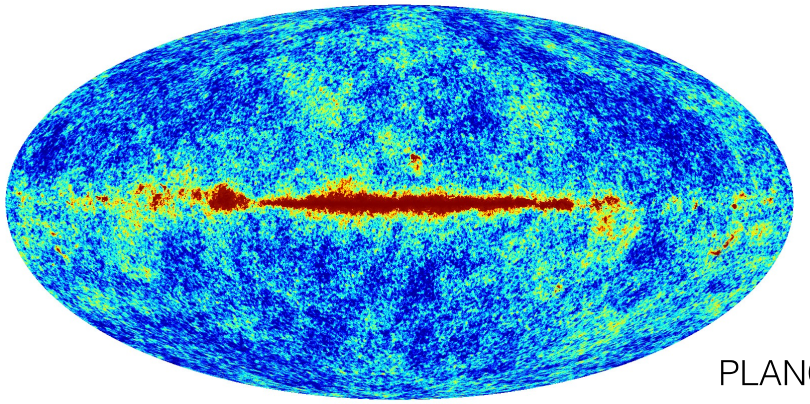
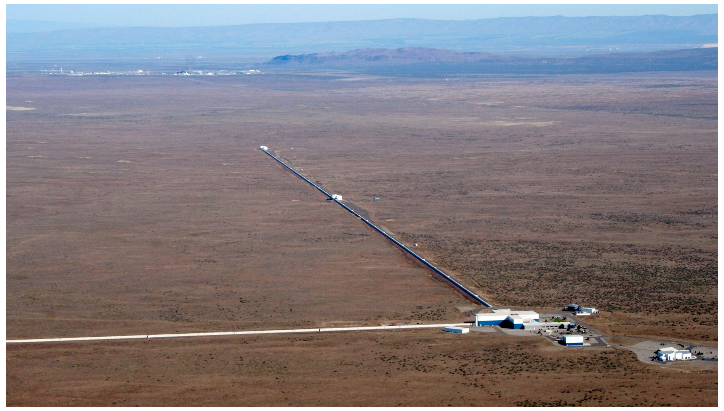


PLANCK

But why don't we create a black hole by ourselves and study its property experimentally?

(I believe)

We can test String Theory in the Sky



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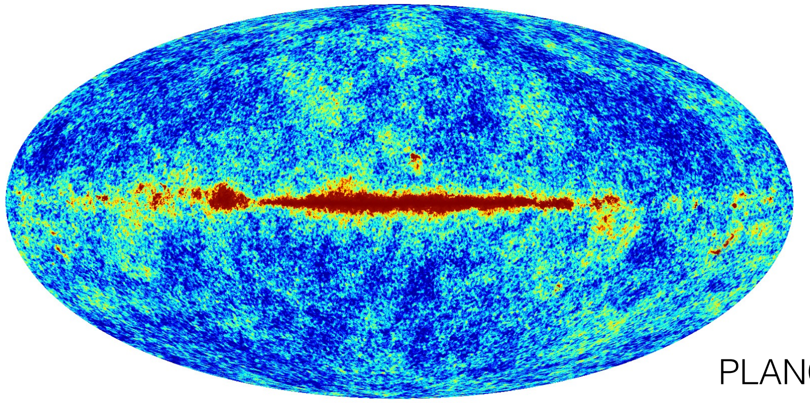
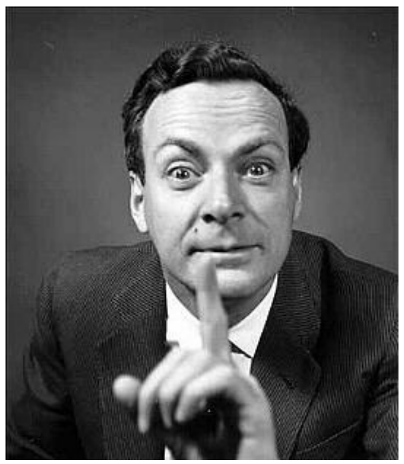


PLANCK

But why don't we create a black hole by ourselves and study its property experimentally?

And it has a close connection to some of LATTICE participants' research.

Quantum Simulation



Simulating Physics with Computers

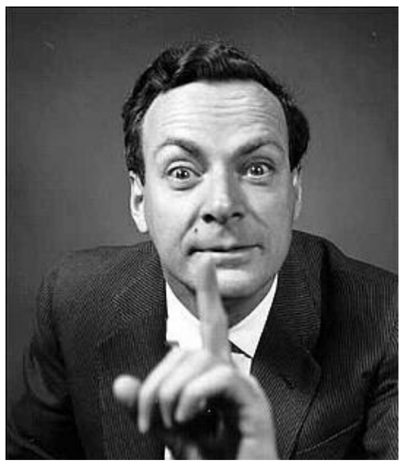
Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981

As a first step toward the quantum simulation…

Hamiltonian Engineering



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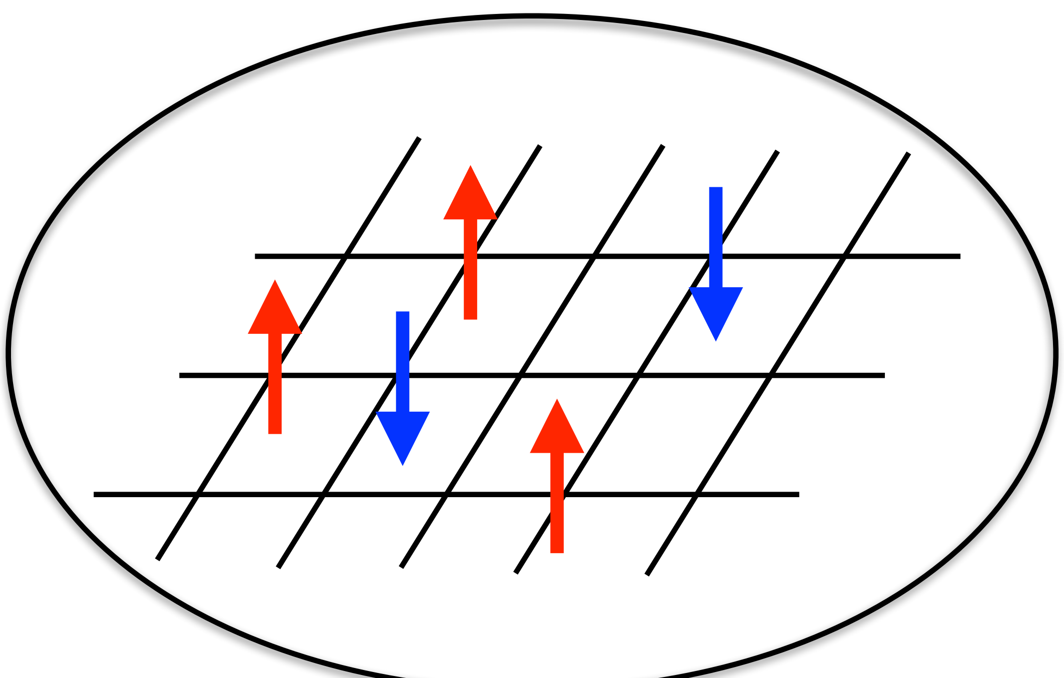
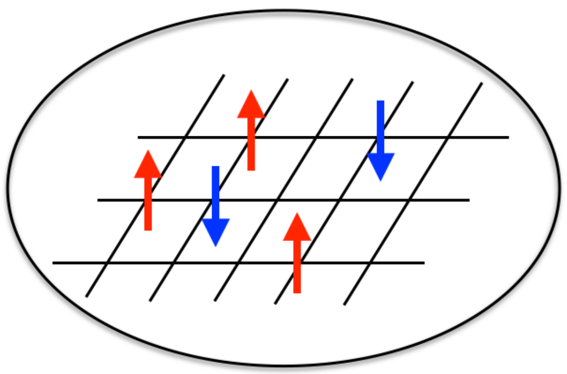
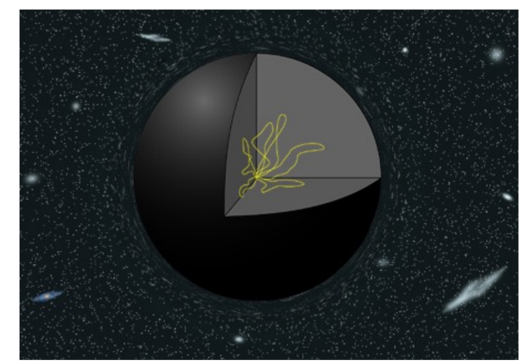


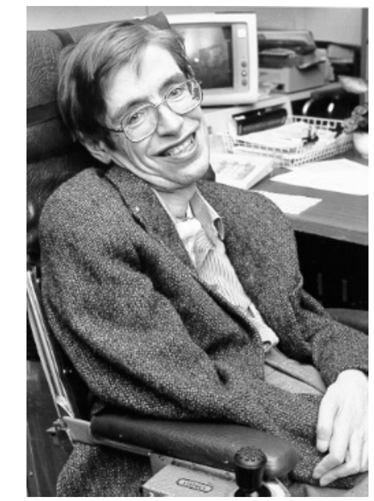
Your Hamiltonian

Actually make such system by using lasers, atoms, …

Gauge/Gravity Duality







Super Yang-Mills
(SYM)

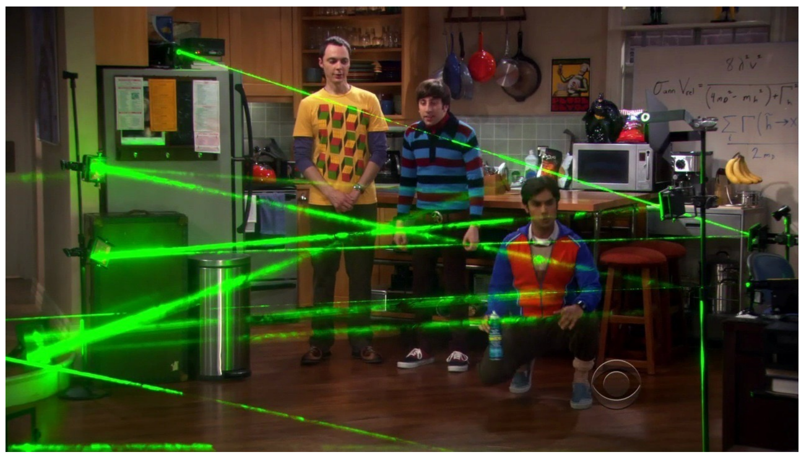
Maldacena 1997

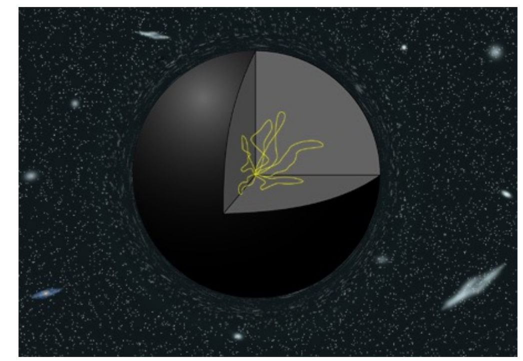
IIA/IIB-string
M-theory
(BH, black brane)

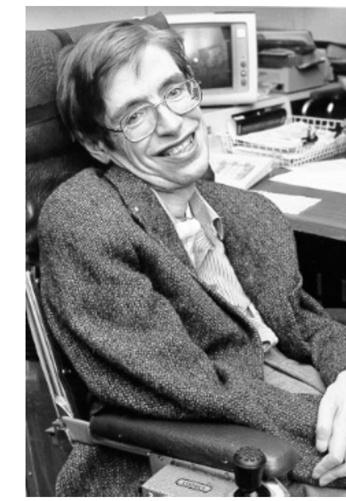
<u>indistinguishable</u> even in principle

cf) Talks by Berkowitz, Kadoh

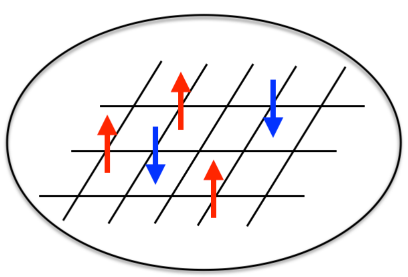
Gauge/Gravity Duality







Super Yang-Mills
(SYM)



IIA/IIB-string
M-theory
(BH, black brane)

<u>indistinguishable</u> even in principle

Experimental Realization of Quantum Gravity
in our almost flat spacetime would be possible.

Quantum Field Theory	Gravity
Supersymmetric matrix model	Black hole in Superstring/M-theory
4d maximal SYM	IIB string on $AdS_5 \times S^5$
3d O(N) vector model 3d Gross-Neveu model	Higher Spin Gravity in AdS_4
Sachdev-Ye-Kitaev model (SYK model)	Black hole in AdS_2 ?

Super Yang-Mills ⟷ IIA/IIB-string
M-theory
(BH, black brane)

Sachdev-Ye-Kitaev model ⟷ BH in AdS_2

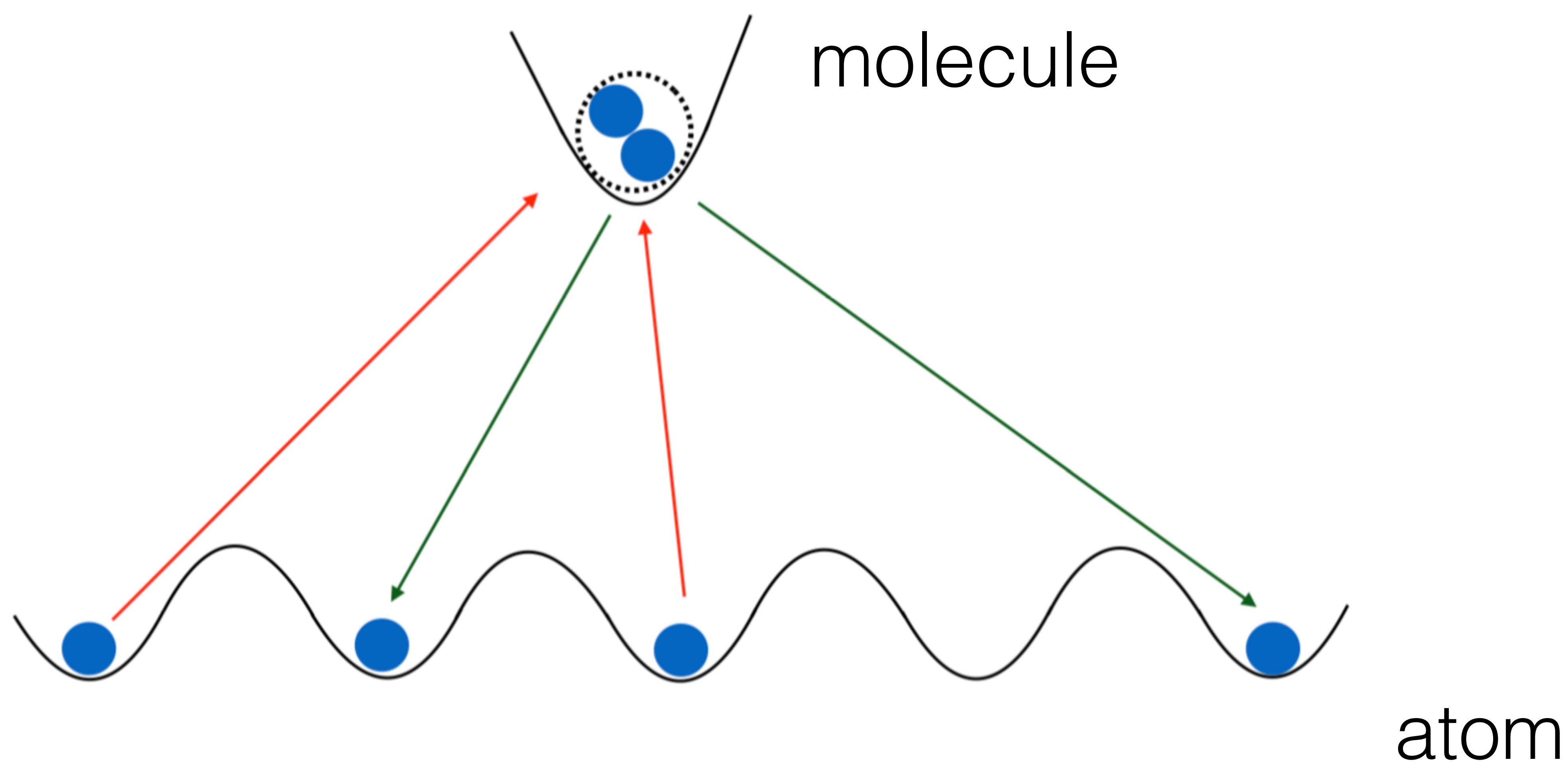
Make it from atoms and lasers!

$$H = \frac{1}{(2N)^{3/2}} \sum_{ijkl} J_{ij;kl} \hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l$$

N fermions with random Gaussian couplings

- Emergent (almost) conformality at strong coupling
- dual AdS_2 BH description
- Maximally chaotic ($\lambda_L = 2\pi T$)

How to make 4-fermi interaction



$$\hat{H}_{\mathrm{m}} = \sum_{s=1}^{n_s} \left\{ \nu_s \hat{m}_s^\dagger \hat{m}_s + \sum_{i,j} \left(g_{s,ij} \hat{m}_s^\dagger \hat{c}_i \hat{c}_j - g_{s,ij}^* \hat{m}_s \hat{c}_i^\dagger \hat{c}_j^\dagger \right) \right\}$$

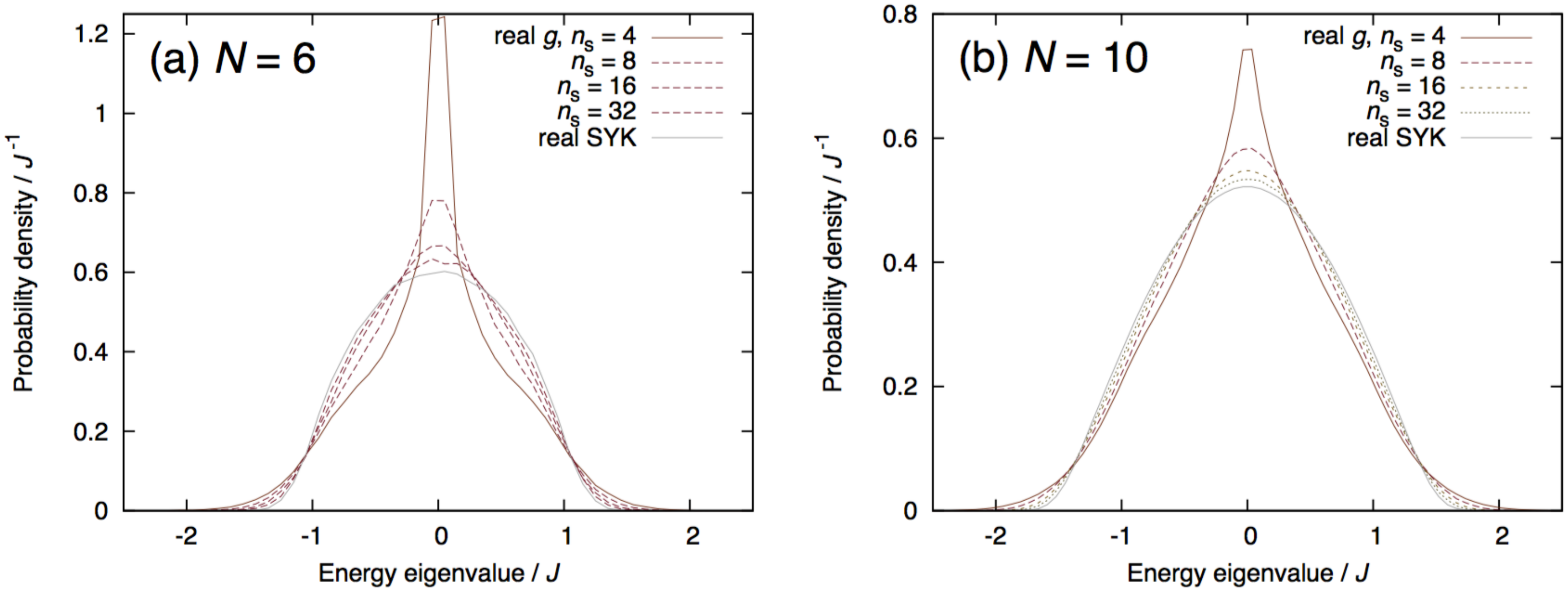
↓ integrate out molecular intermediate states

$$\hat{H} = \sum_{s,i,j,k,l} \frac{g_{s,ij} g_{s,kl}^*}{\nu_s} \hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l$$

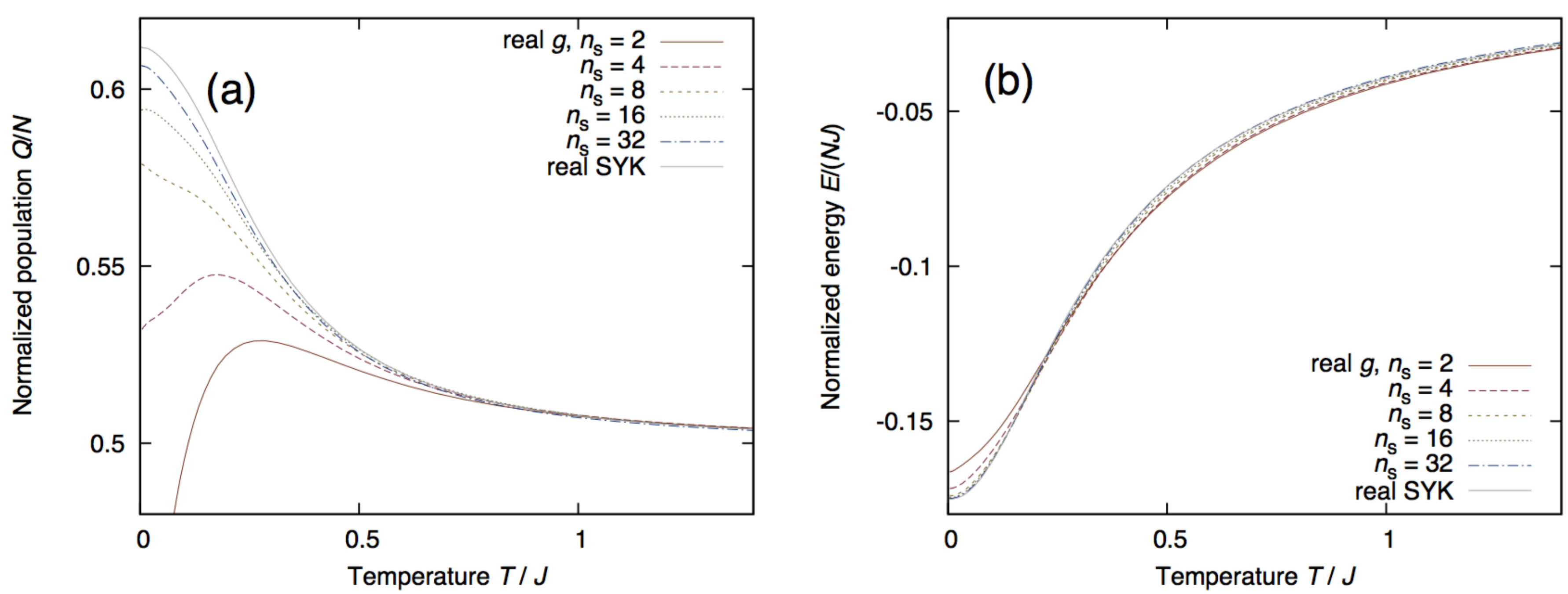
$\nu_s = \pm \sqrt{n_s}$ for even/odd s

$\xrightarrow{n_s = \infty}$ **SYK**

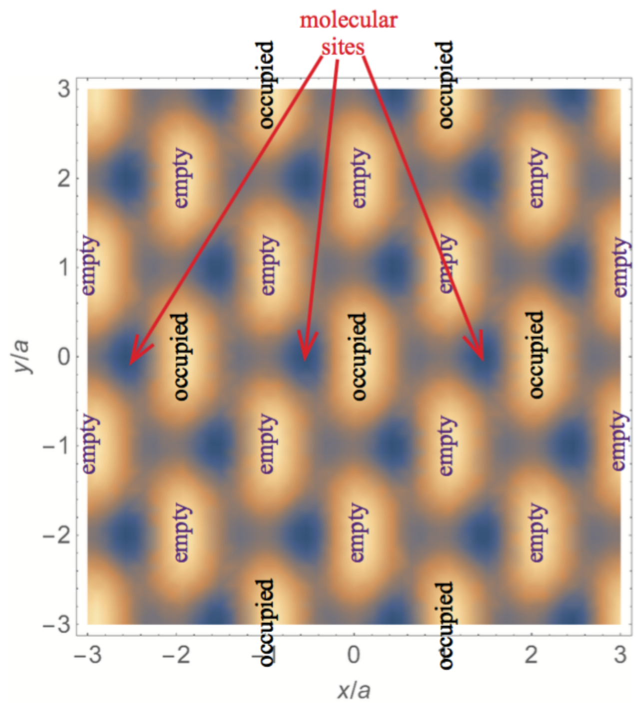
$$H = \frac{1}{(2N)^{3/2}} \sum_{ijkl} J_{ij;kl} \hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l$$

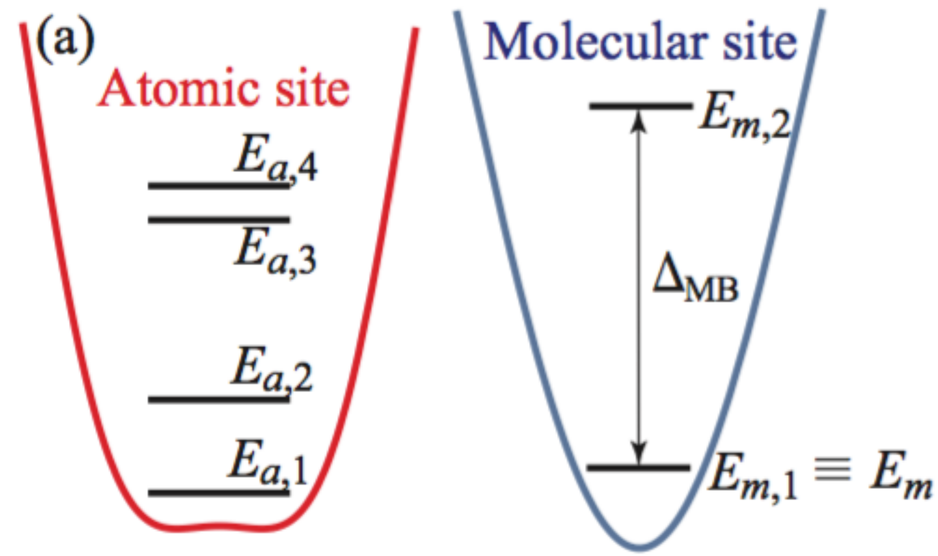


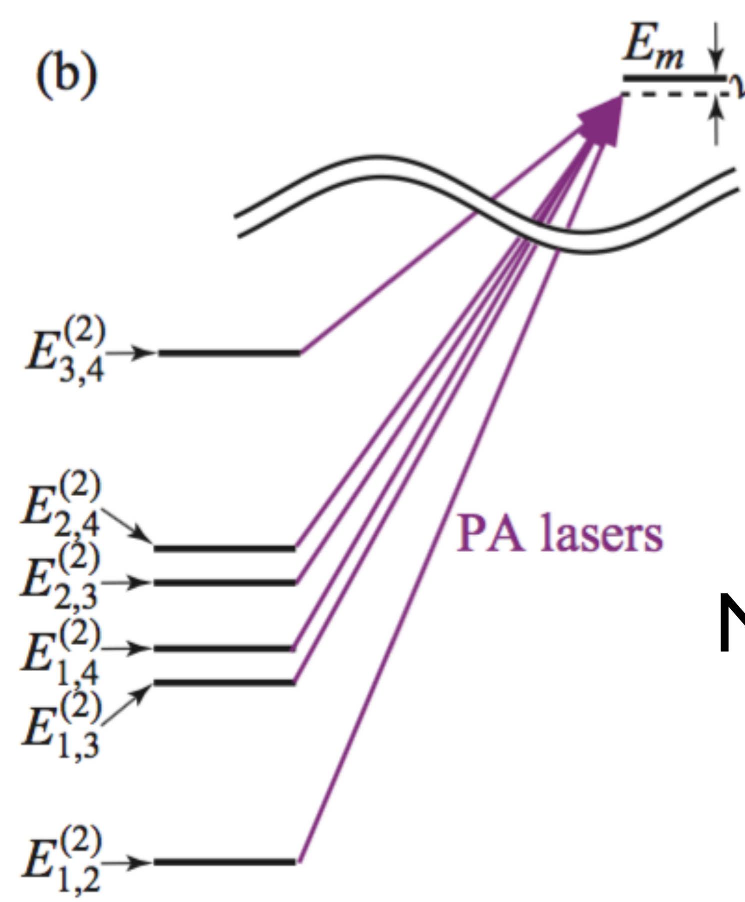
(a) N = 6
real g, n_s = 4
n_s = 8
n_s = 16
n_s = 32
real SYK
Probability density / J^-1
Energy eigenvalue / J
(b) N = 10
real g, n_s = 4
n_s = 8
n_s = 16
n_s = 32
real SYK
Probability density / J^-1
Energy eigenvalue / J



(a)
real g, n_s = 2
n_s = 4
n_s = 8
n_s = 16
n_s = 32
real SYK
Normalized population Q/N
Temperature T / J
(b)
real g, n_s = 2
n_s = 4
n_s = 8
n_s = 16
n_s = 32
real SYK
Normalized energy E/(NJ)
Temperature T / J







$N(N-1)n_s/2$ beams needed

- Doable in principle.
- Needs improvements in practice.

— Simpler disorder?
— Different interaction?
} theory

— Deeper optical lattice
— Narrower line-width
} experiment

We hope it serves as the first step to a big goal!

backup

(1) Many beams are needed. → Is Gaussian randomness really needed? Other randomness or some structures are allowed?

(2) Laser line-width must be narrow. Only N≦16 (1Hz) would be possible with current technology. → Situation could change by changing lattice. Simplifying the model may work as well?

(3) Deep optical lattice for molecules is needed so that multiple molecules are not excited. → Result may not change much even if it happened (i.e. molecular states cannot be completely integrated out?)