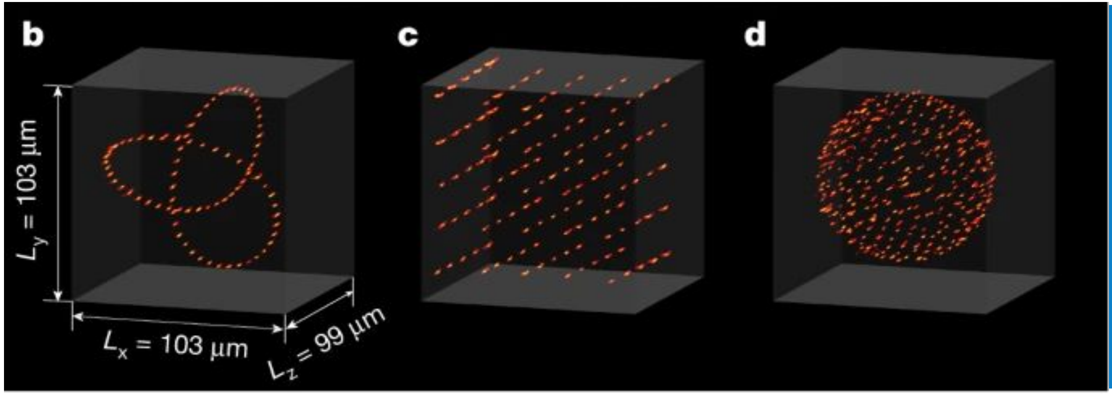
QUANTUM SIMULATION OF LATTICE GAUGE THEORIES WITH RYDBERG ATOMS

Federica Surace

Quantum Science Seminar - Young Researcher Session - November 5th, 2020

WHY GAUGE THEORIES AND QUANTUM SIMULATIONS?



High degree of **control** and **tunability** of quantum systems

Daniel Barredo, Vincent Lienhard, Sylvain de Léséleuc, Thierry Lahaye & Antoine Browaeys, *Nature* **561**, 79-82 (2018)

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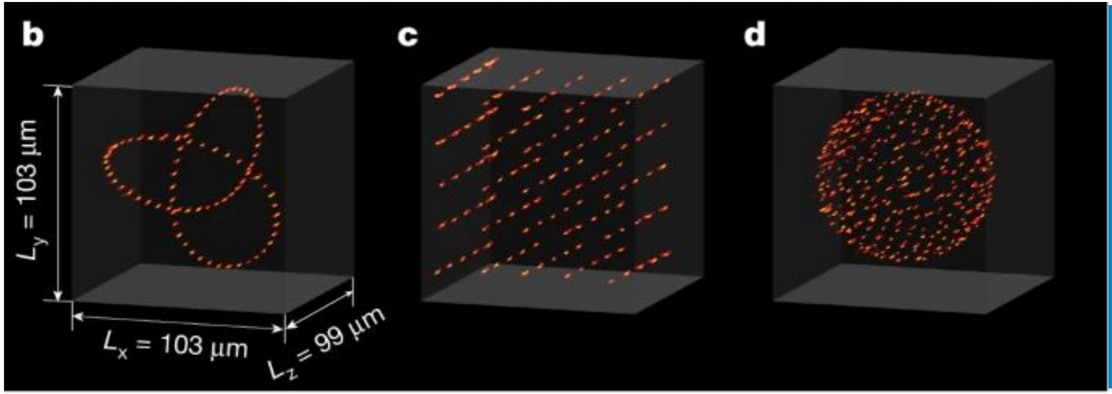

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- Use of **quantum simulators** for **strongly correlated** matter

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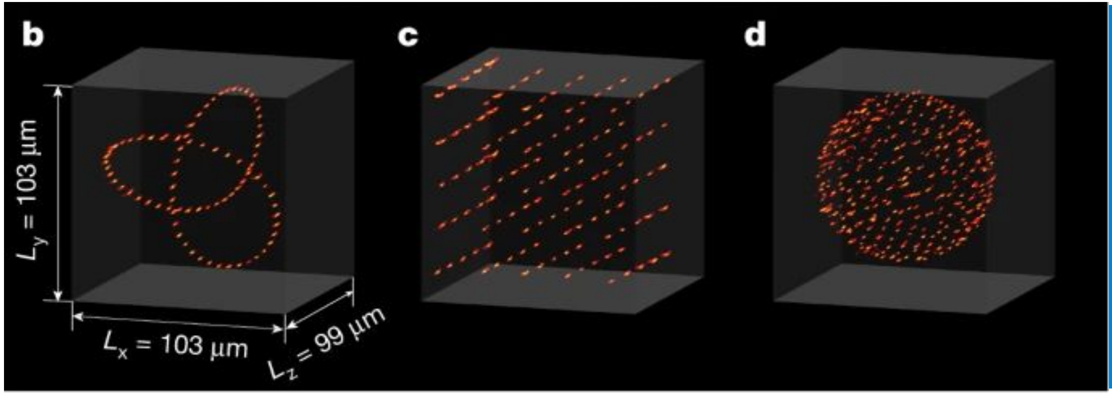
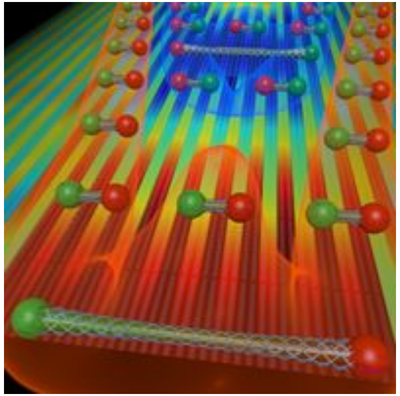


High degree of **control** and **tunability** of quantum systems

- Use of **quantum simulators** for **strongly correlated** matter
- **Time evolution** of many-particle quantum systems

WHY GAUGE THEORIES AND QUANTUM SIMULATIONS?

- Access to **real-time** dynamics: perspectives for **high energy** physics



picture from T. Pichler, et al
Phys. Rev. X 6, 011023

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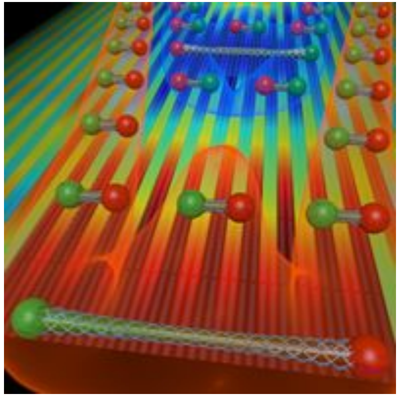

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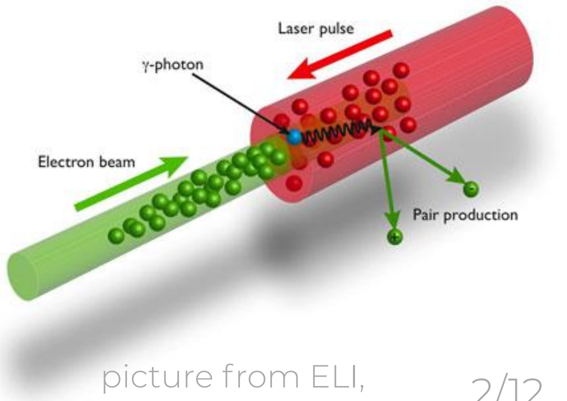
- Hope (long-term): overcome limitations of **experiments**, **classical computation**?



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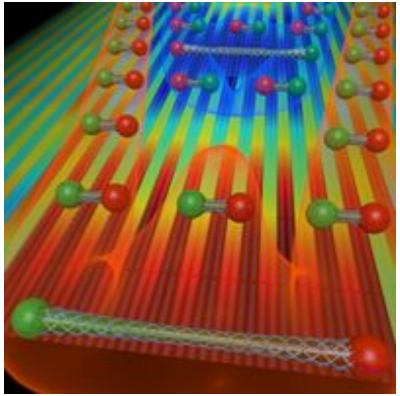

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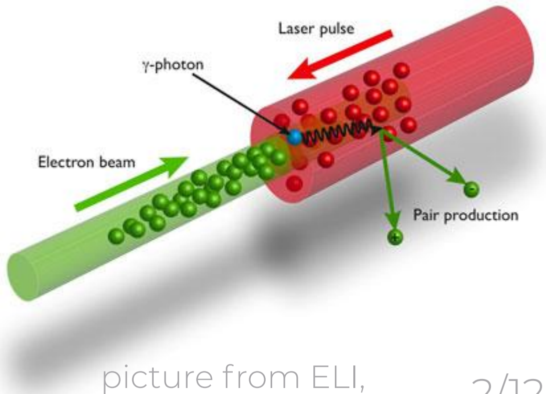
→ LATTICE GAUGE THEORIES

Wiese, *Annalen der Physik*, 2013
Zohar et al, *Rep. Progr. in Phys.*, 2015
Dalmonte, Montangero, *Contemp. Phys* 2016.
Preskill, arXiv:1811.10085
Bañuls et al, *Eur. Phys. J. D*, 2020



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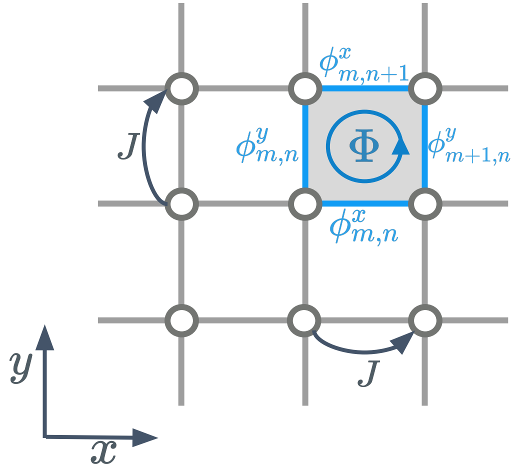
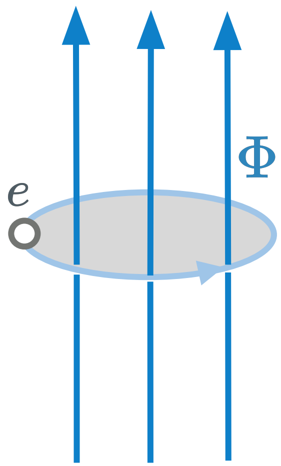
STATIC VS DYNAMICAL GAUGE FIELDS

Static gauge fields





Particles hopping around a plaquette acquire a phase

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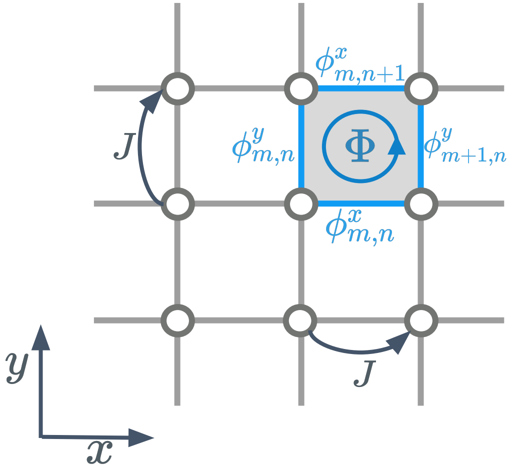

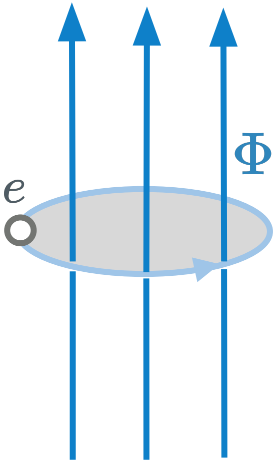

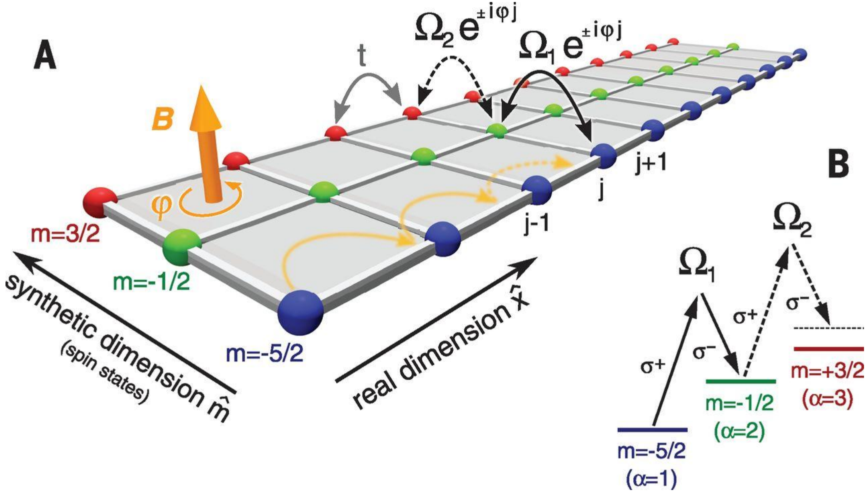

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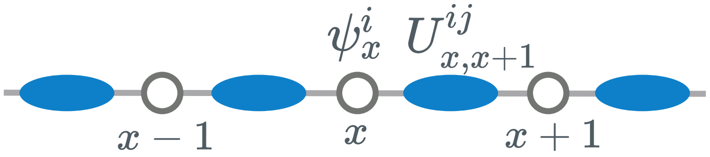
Mancini, M., Pagano, G., Cappellini, G., Livi, L., Rider, M., Catani, J., ... & Fallani, L., *Science*, **349**, 1510-1513 (2015).

STATIC VS DYNAMICAL GAUGE FIELDS

Dynamical gauge fields

- additional degrees of freedom on links



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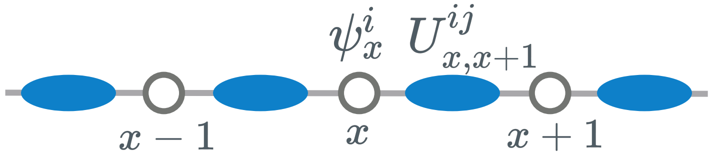

condensed matter
frustrated magnets

quantum computing
toric code

high energy physics
standard model

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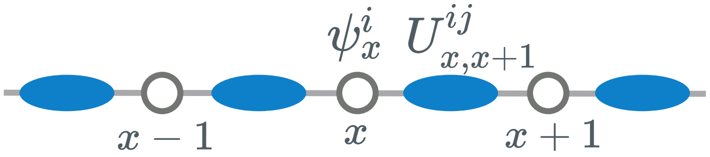
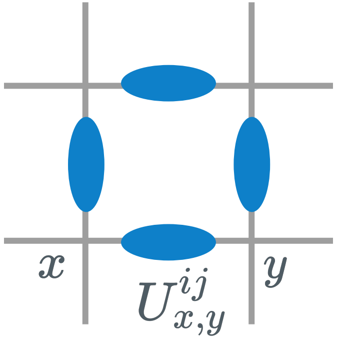


- Problem:
  - complex many-body interactions
  - local (gauge) symmetries



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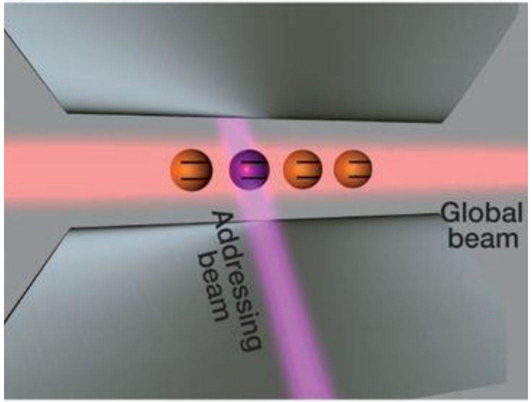
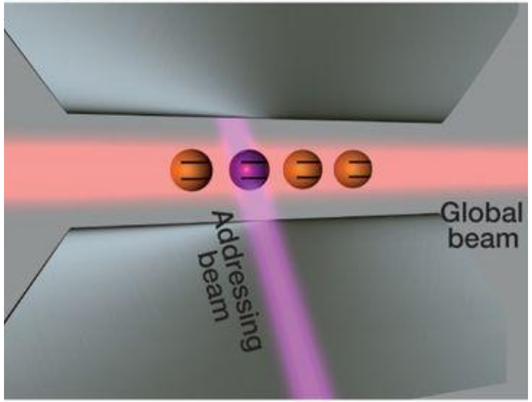


So far, no experimental evidence that atomic systems can simulate gauge theories at large scale

Martinez, E. A., Muschik, C. A., Schindler, P., Nigg, D., Erhard, A., Heyl, M., … & Blatt, R., *Nature*, **534**(7608), 516-519 (2016).



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We show that this has been done:

U(1) GAUGE THEORY in 1+1d

exploiting dynamics induced by **Rydberg** interactions

OUTLINE

1. **The model**

- Rydberg: FSS model
- U(1) gauge: quantum link model

OUTLINE

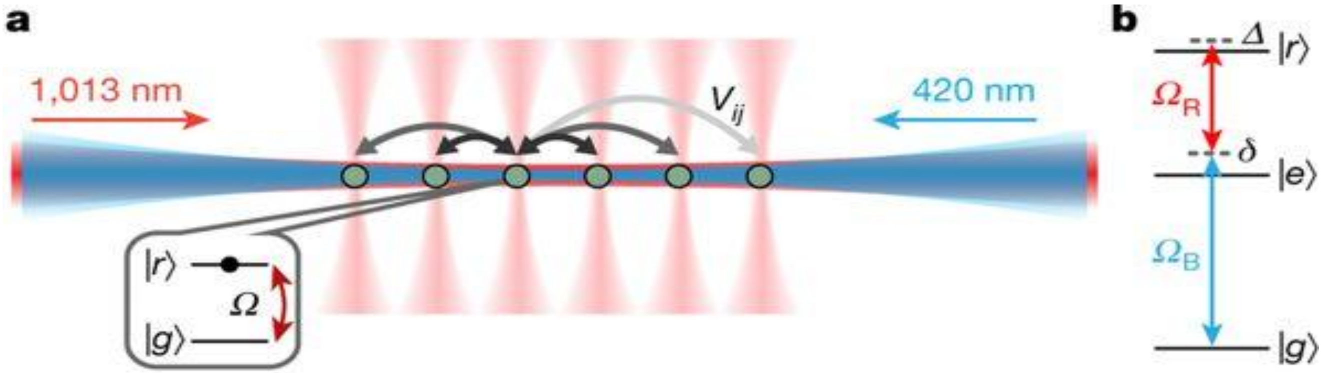
1 The model

- Rydberg: FSS model
- U(1) gauge: quantum link model

2 Slow dynamics

- Density oscillations
- String inversion

RYDBERG ATOM EXPERIMENT



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$$\hat{H}_{\text{Ryd}} = \sum_{j=1}^{L}(\Omega\,\hat{\sigma}_j^x + \delta\,\hat{n}_j) + \sum_{j\neq\ell=1}^{L} V_{j,\ell}\hat{n}_j\hat{n}_\ell$$

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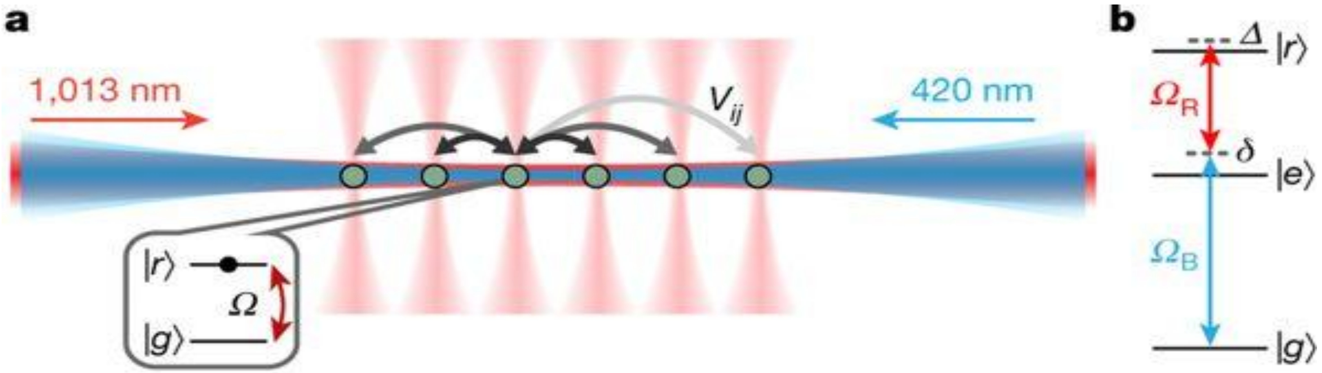

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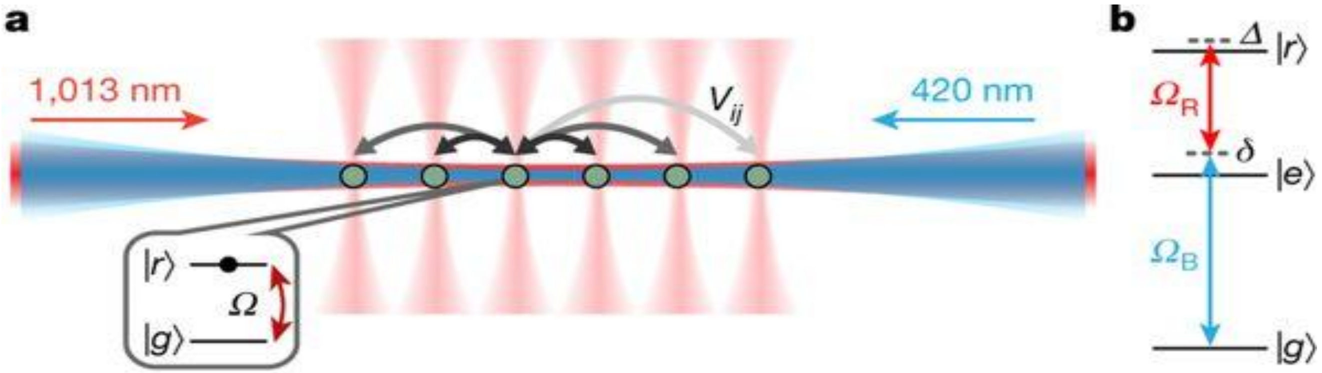

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Phase diagram, non-equilibrium dynamics (scars), ...

Fendley *PRB* 2004, Turner *Nat Phys* 2018, Lin *PRL* 2019, ...

Here: **gauge theory**

U(1) LATTICE GAUGE THEORIES

Matter (sites)

Fermions $\{\hat{\Phi}_i^\dagger, \hat{\Phi}_j\} = \delta_{i,j}$

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Even sites			Odd sites		
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Gauge fields (links)

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Local symmetry

$$\hat{G}_j = \hat{E}_{j,j+1} - \hat{E}_{j-1,j} - \left(\hat{\Phi}_j^\dagger \hat{\Phi}_j - \frac{1-(-1)^j}{2}\right)$$

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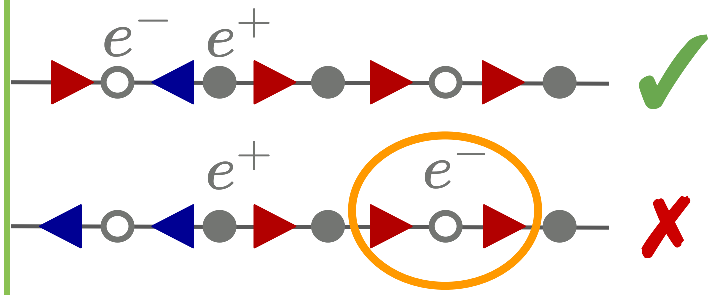
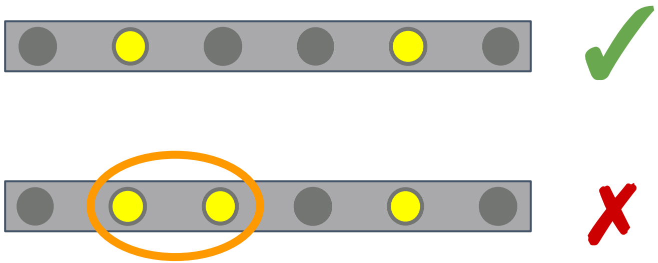
Gauss law

$$[\hat{H}, \hat{G}_j] = 0$$

U(1) lattice gauge theory constrained by Gauss Law



Rydberg atoms constrained by Rydberg blockade



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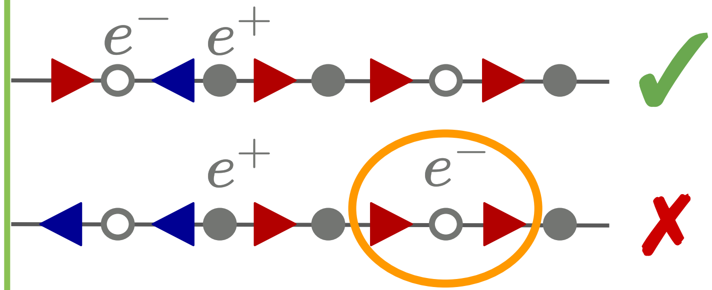

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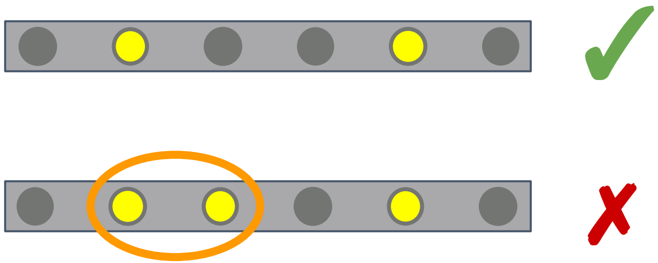

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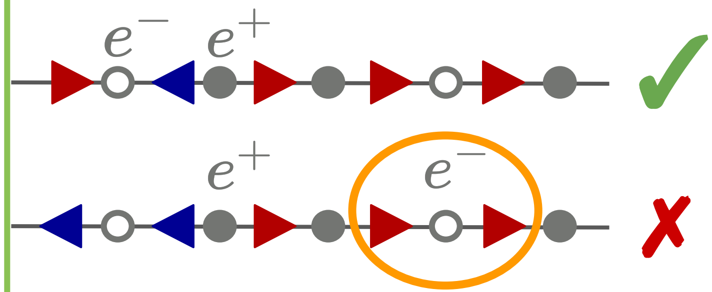

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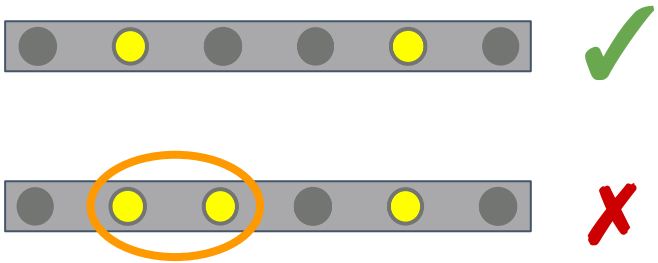

?

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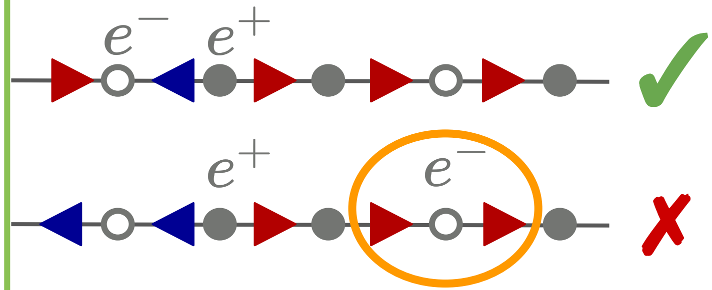
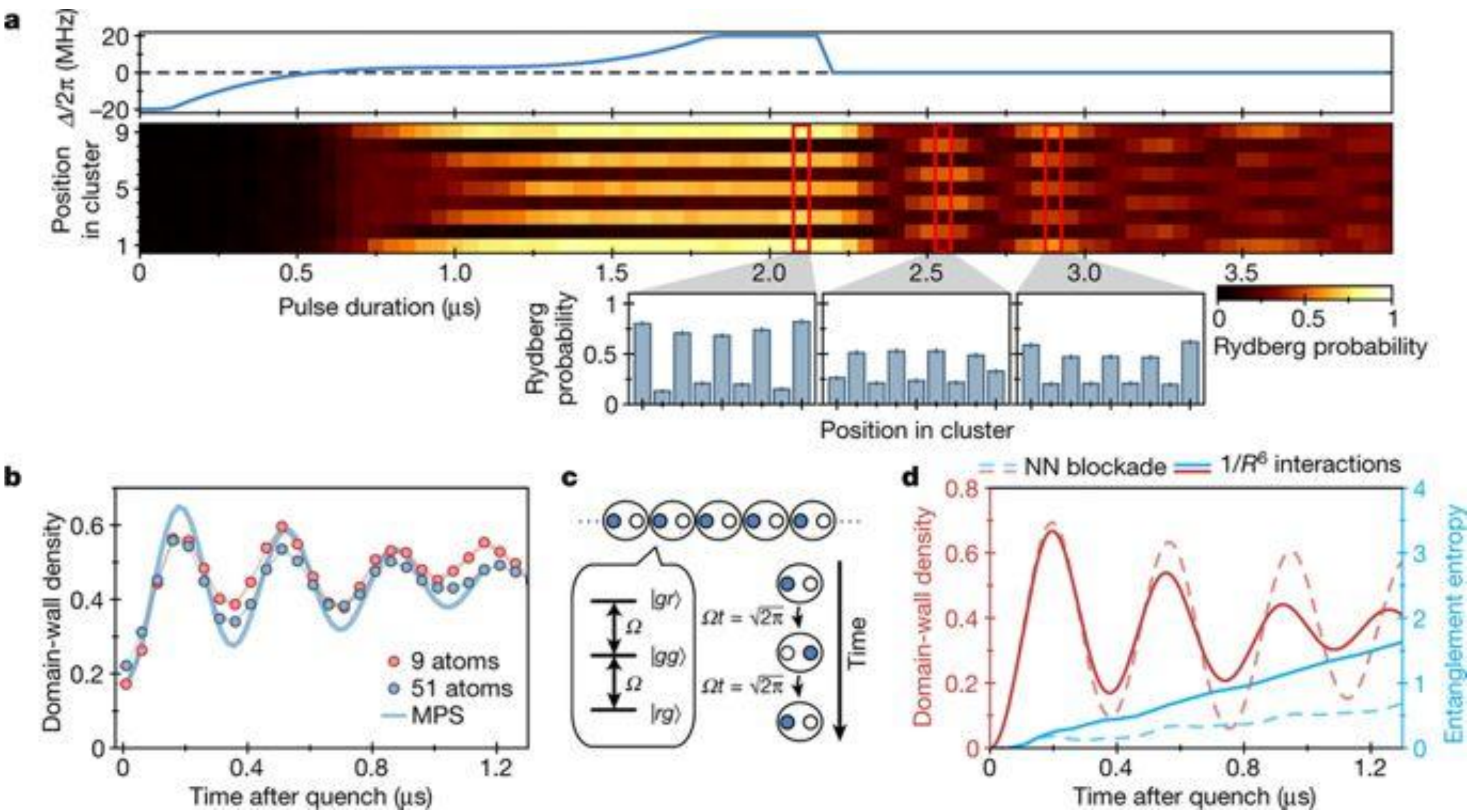


There is an **exact mapping** of states and Hamiltonians

EXPERIMENT: SLOW DYNAMICS



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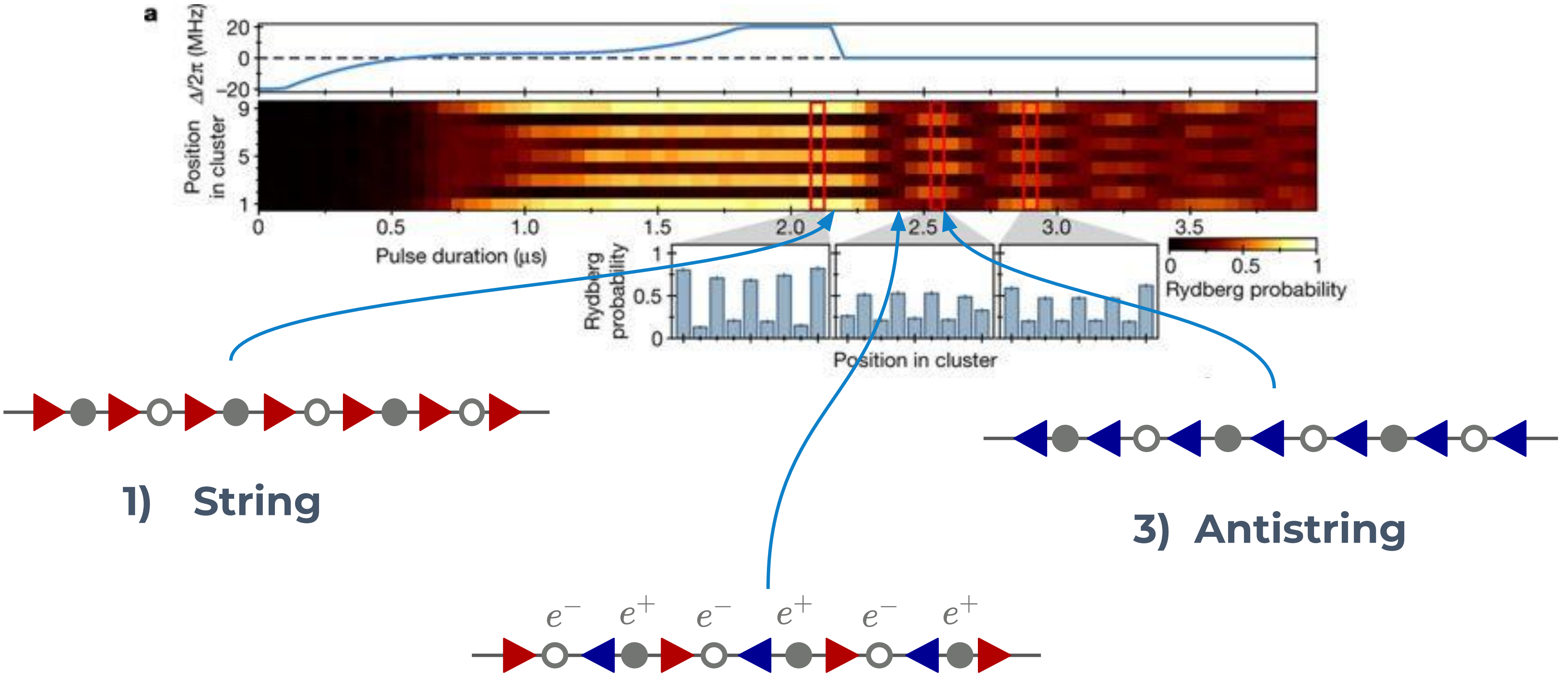

1) **String**

3) **Antistring**

2) **Pairs**

SUMMARY AND CONCLUSIONS

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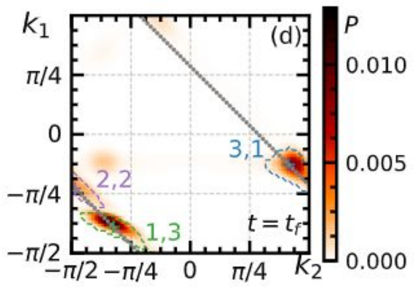

Scattering of mesons

in preparation

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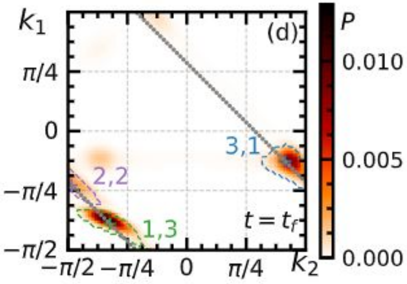

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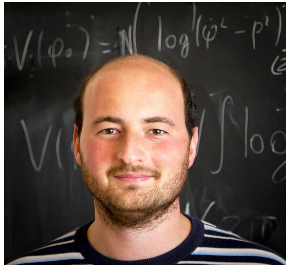
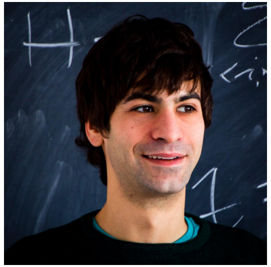
Perspective: Non-Abelian? Higher dimensionality?

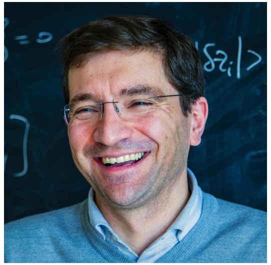


Paolo P. Mazza

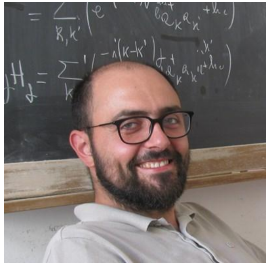


Giuliano Giudici

Alessio Lerose



Andrea Gambassi

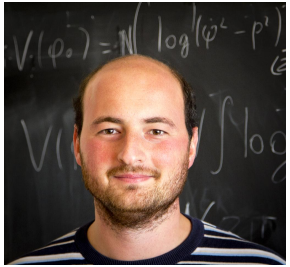


Marcello Dalmonte

SISSA 40!

ICTP

Phys. Rev. X 10, 021041 (2020)



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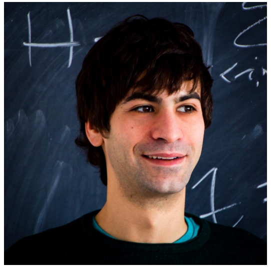
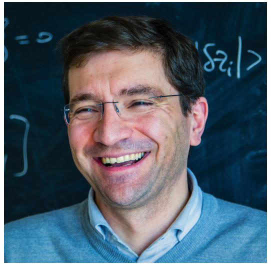
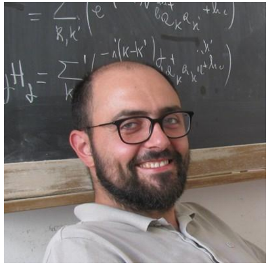


Giuliano Giudici

Alessio Lerose



Andrea Gambassi



Marcello Dalmonte

PER SEGUIR VIRTUTE E CANOSCENZA

SISSA

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THANK YOU FOR YOUR ATTENTION!