A cold-atom approach to chiral symmetry restoration and charge confinement

Daniel González Cuadra

University of Innsbruck / IQOQI - Austrian Academy of Sciences

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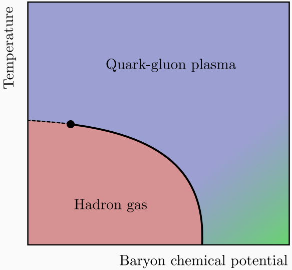
The confinement problem

QCD phase diagram



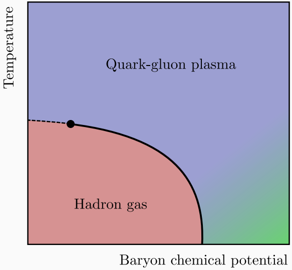
Open questions

- Nature of confinement
- Deconfinement phase transition
- Chiral symmetry breaking

N. Brambilla *et al.*, *Eur. Phys. J. C* **74**, 2981 (2014)

The confinement problem

QCD phase diagram



Open questions

- Nature of confinement
- Deconfinement phase transition
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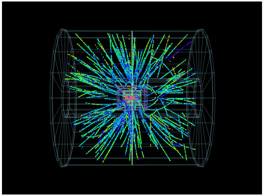
N. Brambilla *et al.*, *Eur. Phys. J. C* **74**, 2981 (2014)

Heavy-ion collisions

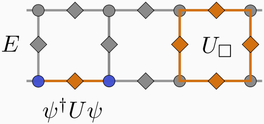


ALICE/CERN

Lattice gauge theories

K.G. Wilson, *Phys. Rev. D* **10**, 2445 (1974)

J. Kogut *et al.*, *Phys. Rev. D* **11**, 395 (1975)



Outline

1. Atomic quantum simulators

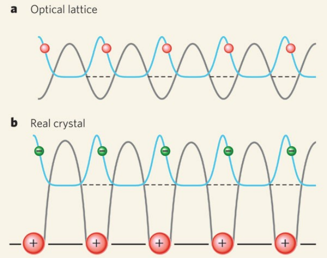
2. The rotor Jackiw-Rebbi model

Conclusions

1. Atomic quantum simulators

From low to high energy physics

Simulating quantum physics



M. Greiner *et al.*, *Nature* **453**, 736–738 (2008)

Ultracold atoms in optical lattices

- From solid state to high energy

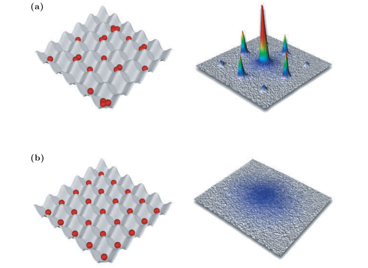
D. Jaksch *et al.*, *Ann. Phys.* **315**, 52–79 (2005)

M. Lewenstein *et al.*, *Adv. Phys.* **56**, 243–379 (2007)

(Analog) quantum simulators

- Special-purpose devices
- Quantum advantage

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



I. Bloch *et al.*, *Nat. Phys.* **1**, 23–30 (2005)

Quantum simulation of lattice gauge theories

Theory

H. P. Büchler *et al.*, *Phys. Rev. Lett.* **95**, 040402 (2005)

E. Zohar *et al.*, *Phys. Rev. Lett.* **107**, 275301 (2011)

D. Banarjee *et al.*, *Phys. Rev. Lett.* **110**, 125303 (2013)

L. Tagliacozzo *et al.*, *Ann. Phys.* **330**, 160 (2013)

M. C. Bañuls *et al.*, *Eur. Phys. J. D* **74**, 165 (2020)

Experiments

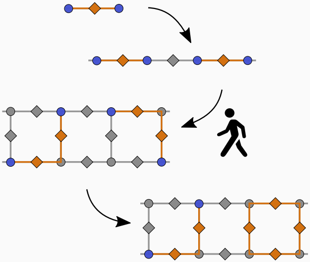
E. A. Martinez *et al.*, *Nature* **534**, 516 (2016)

C. Schweizer *et al.*, *Nat. Phys.* **15**, 1168 (2019)

F. Görg *et al.*, *Nat. Phys.* **15**, 1161 (2019)

A. Mill *et al.*, *Science*, **367**, 1128–1130 (2020)

B. Yang *et al.*, *Nature* **587**, 392–396 (2020)



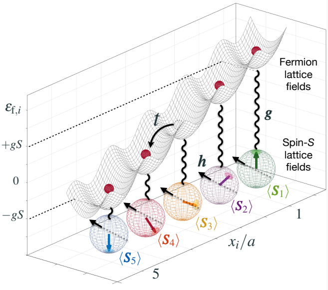
Challenges

- Gauge invariance
- Plaquette interactions
- Alternatives?

2. The rotor Jackiw-Rebbi model

Emergent particle physics

Dynamical mass generation

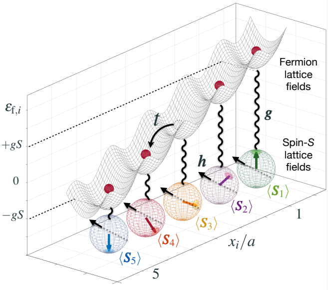


The rotor Jackiw-Rebbi model

$$H = -t \sum_i \left(c_i^\dagger c_{i+1} + c_{i+1}^\dagger c_i \right) + g \sum_i S_i^z c_i^\dagger c_i - \sum_i \left(h_\ell S_i^z + h_t S_i^x \right)$$

PRX Quantum 1, 020321 (2020)

Dynamical mass generation



R. Jackiw *et al.*, *Phys. Rev. D* **13**, 3398 (1976)

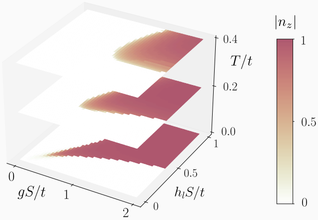
Continuum limit

$$\boldsymbol{S}_i = (S_i^z, S_i^x) \approx S\cos(\pi x_i/a)\,\boldsymbol{n}(x)$$

$$\mathcal{L} = \overline{\Psi}(\boldsymbol{x})\left(i\gamma^\mu\partial_\mu + gSn_z(\boldsymbol{x})\right)\Psi(\boldsymbol{x}) + \ldots$$

Chiral symmetry breaking/restoration

D. Gross *et al.*, *Phys. Rev. D* **10**, 3235 (1974)



$$\langle n_z\rangle \neq 0 \rightarrow \Sigma_0 = \langle\overline{\Psi}\Psi\rangle \neq 0$$

The rotor Jackiw-Rebbi model

$$H = -t\sum_i \left(c_i^\dagger c_{i+1} + c_{i+1}^\dagger c_i\right) + g\sum_i S_i^z c_i^\dagger c_i - \sum_i \left(h_\ell S_i^z + h_t S_i^x\right)$$

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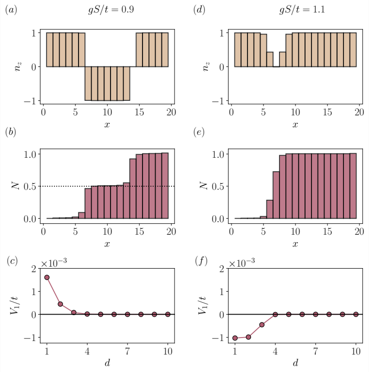
A cold-atom approach to quark confinement

Fractionally-charged quasi-particles



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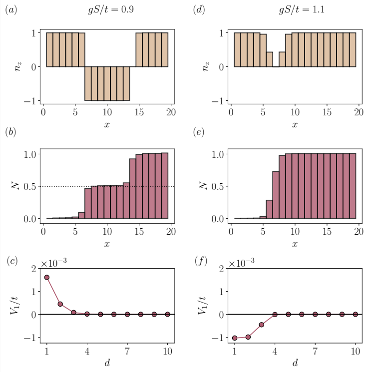

Emergent particle physics

- Deconfinement phase transition
- Chiral symmetry restoration

A cold-atom approach to quark confinement

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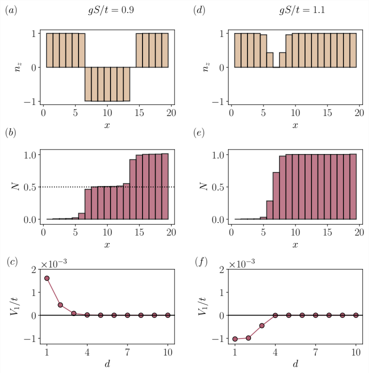

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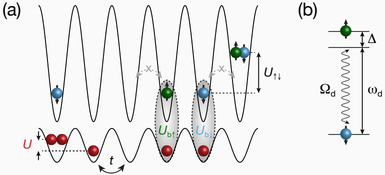
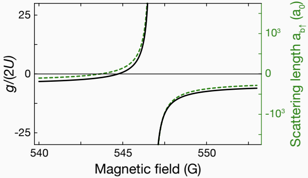
Quantum simulation



$$\sum_{i,\sigma} U_{b\sigma} \hat{f}^\dagger_{i\sigma} \hat{f}_{i\sigma} \hat{b}^\dagger_i \hat{b}_i \rightarrow g \sum_i S^z_i \hat{c}^\dagger_i c_i$$

$$g = 2(U_{b\uparrow} - U_{b\downarrow})$$

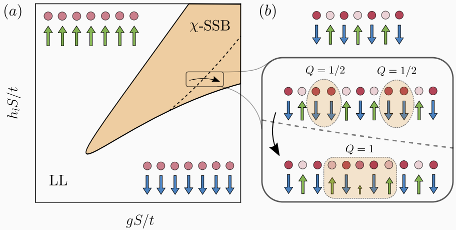


Summary

Rotor Jackiw-Rebbi model

- Dynamical mass generation
- Chiral symmetry restoration
- Confinement-deconfinement transition of fractional charges

PRX Quantum 1, 020321 (2020)



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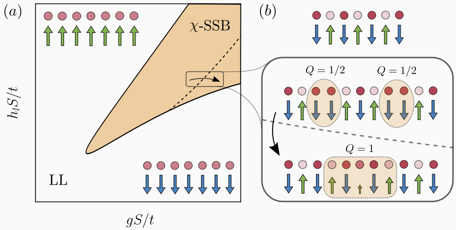

Alexandre Dauphin (ICFO)

Monika Aidelsburger (LMU)

Maciej Lewenstein (ICFO)

Alejandro Bermudez (UCM)