Simulating Complexity

Grantee: Francesco V. Pepe

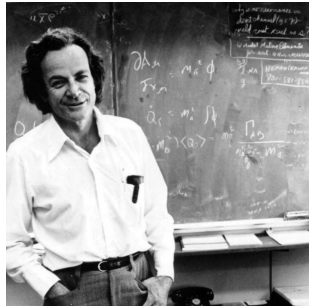**Expiration of the Grant:** 31 May 2017

Work Institution:
Dipartimento Interateneo di Fisica, Università degli Studi di Bari
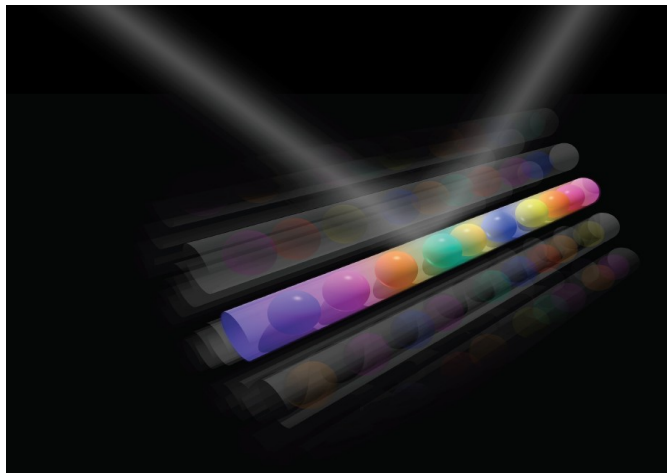INFN Sezione di Bari

Scientific Supervisor:
Prof. Saverio Pascazio, Bari

Simulating complexity

FEYNMAN: since nature is quantum, it would be better simulated by *quantum* rather than *classical* computation
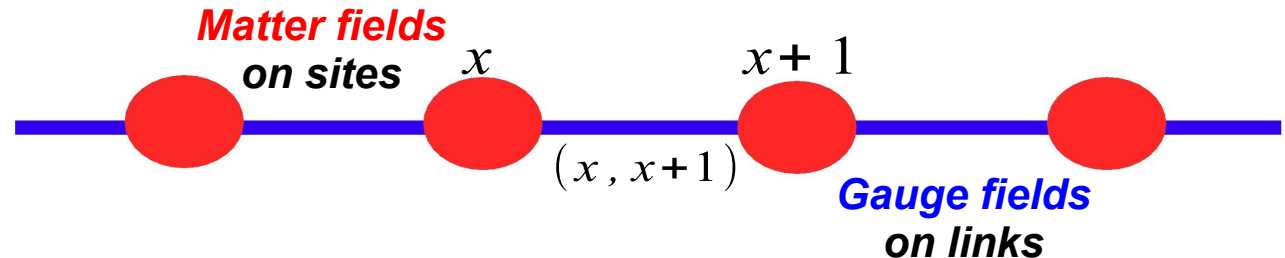
QUANTUM SIMULATOR: a special purpose Quantum Computer realized in a cold-atom platform

- Reduce computational time

- Overcome classical computation obstructions (e.g. sign problem)

Simulating complexity

Simulation of (1+1) QUANTUM ELECTRODYNAMICS

Discretization on a 1D lattice

Matter fields on sites x $x+1$

$(x, x+1)$

Gauge fields on links

$$H = \sum_x \left(\psi_x^\dagger U_{x,x+1} \psi_{x+1} + \text{H.c.} \right) + m \sum_x (-1)^x \psi_x^\dagger \psi_x + \frac{g^2}{2} \sum_x E_{x,x+1}^2$$

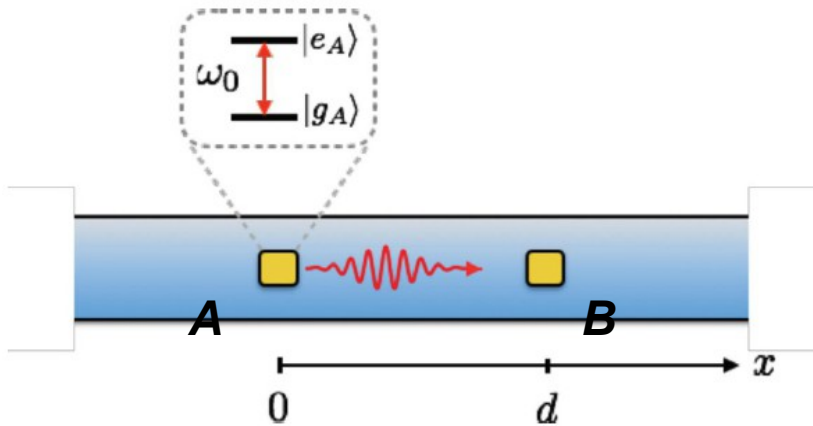$\mathbb{Z}_n$ operator: **discretization of gauge group**

Research in progress (collaboration with E. Ercolessi, Bologna)**:**

- Existence and properties of quantum phase transition

- Dynamical phenomena: string breaking and meson production

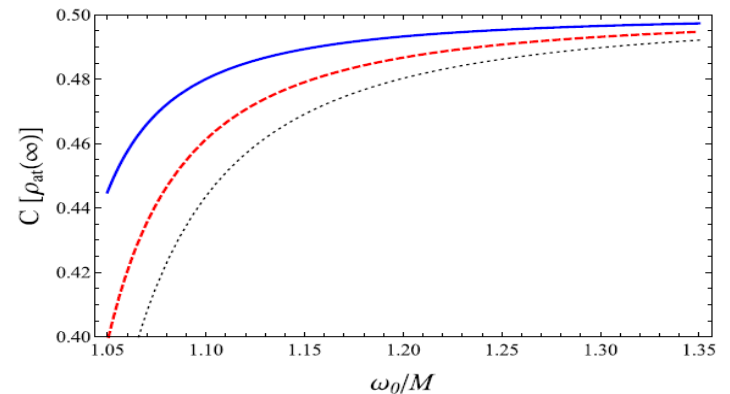F. V. Pepe, G. Magnifico et al, in preparation

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ENTANGLEMENT GENERATION in WAVEGUIDE QED

Two atoms can sponteneously relax toward an entangled bound state

$$|\Psi\rangle = \frac{\left|e_A, g_B\right\rangle \pm \left|g_A, e_B\right\rangle}{\sqrt{2}}$$

Atom-photon coupling in a waveguide:

- Strong-coupling effects

- Nontrivial bound states!

Concurrence of asymptotic state

P. Facchi, M.S. Kim, S. Pascazio, F. V. Pepe, D. Pomarico and T. Tufarelli, **PRA 94**, 043839 (2016)

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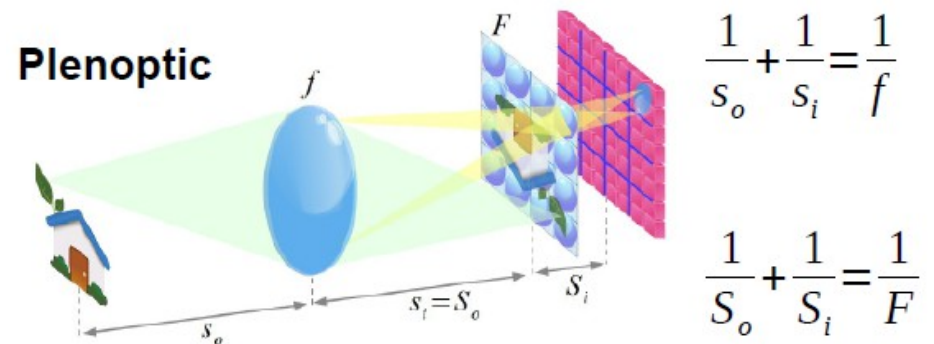**Plenoptic imaging**: a novel optical technique that attempts to reconstruct *direction of light* in the imaging device.

➡️
- Refocusing, **extension of depth of field**
- Single-shot **3D imaging**

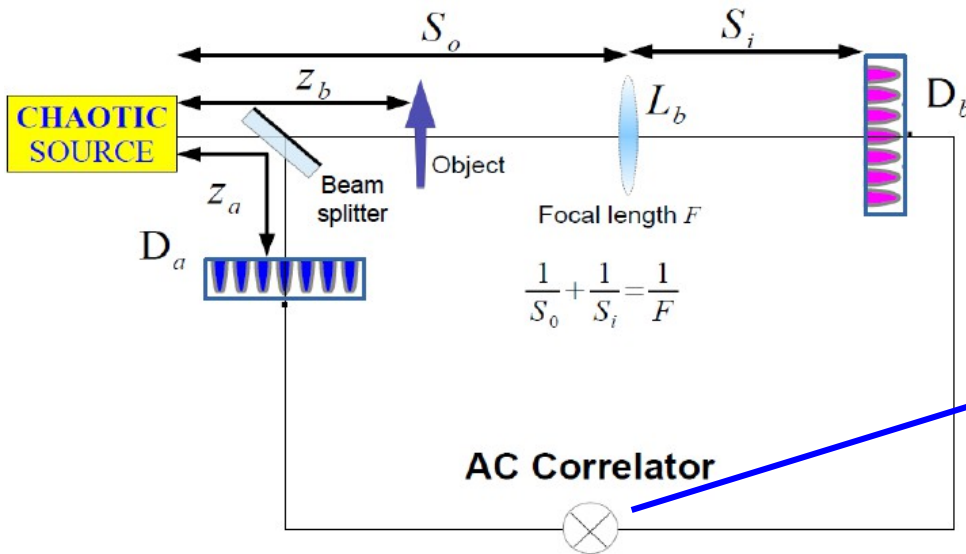R. Ng et al (2005)

PLENOPTIC CAMERA WITH MICROLENSES

Plenoptic

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{F}$$

Main drawback:
LOSS OF RESOLUTION
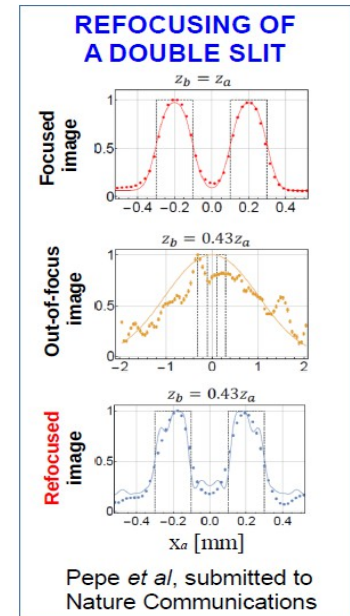
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CORRELATION PLENOPTIC IMAGING

Spatial and directional measurement on two distinct sensors

➡ overcome the trade-off between resolution and depth of field

using quantum properties of light

$$\frac{1}{S_0} + \frac{1}{S_i} = \frac{1}{F}$$

CORRELATION OF INTENSITY FLUCTUATIONS

REFOCUSING OF A DOUBLE SLIT

Pepe *et al*, submitted to Nature Communications

Information on position and direction of light **without losing resolution**

M. D'Angelo, F. V. Pepe, A. Garuccio, and G. Scarcelli, **PRL 116**, 223602 (2016)
F. V. Pepe, F. Di Lena, A. Garuccio, G. Scarcelli, M. D'Angelo, **Technologies 4**, 17 (2016)

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BOSE-EINSTEIN CONDENSATES with SPIN-ORBIT COUPLING

$$E[\Psi] = \int_V d\boldsymbol{r} \left\{ \Psi^\dagger h_0 \Psi + \frac{g_0}{2} (\Psi^\dagger \Psi)^2 + \frac{g_2}{2} (\Psi^\dagger \boldsymbol{F} \Psi)^2 \right\}$$
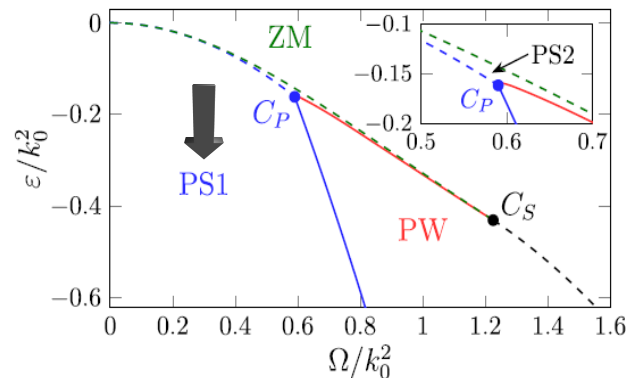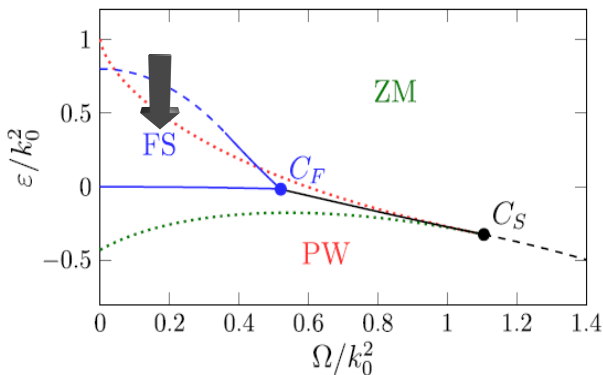
$$h_0 = \frac{1}{2}(p_x - k_0 F_z)^2 + \frac{p_\perp^2}{2} + \frac{\Omega}{2} F_x + \frac{\delta}{2} F_z + \frac{\varepsilon}{2} F_z^2$$

$\boldsymbol{F}$
Spin-1 vector operator

Phase diagrams for different sign of spin-spin interactions

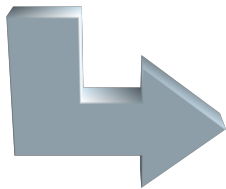*Ferromagnetic*

Antiferromagnetic

Emergent striped phases

Spontaneous breaking of translation symmetry

G. I. Martone, F. V. Pepe, P. Facchi, S. Pascazio, and S. Stringari, **PRL 117**,125301 (2016)

Simulating Complexity

Publications and plan of activities:

- 6 published papers in 2016.

- 2 papers in peer review.

- 3 papers in preparation, to be submitted within June 2016

Dynamics of spin-1 BECs with spin-orbit coupling

Entanglement by relaxation of multilevel atoms

Phase transitions in $\mathbb{Z}_n$ gauge models, large-n limit

Correlation Plenoptic Microscopy

Grazie
per l'attenzione