Fellini project QE-TherMa
Quantum Equilibrium Thermal Machines

Ugo Marzolino

INFN, Trieste Unit

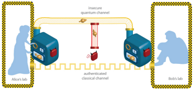
Supervisor: Prof. Fabio Benatti, University of Trieste & INFN Trieste

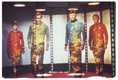
Background and motivation

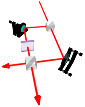
Quantum technologies

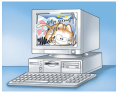
Quantum effects and enhancements in information technologies

- EPR paradox
- Schrödinger's cat
- Bell's tests
- quantum teleportation
- quantum cryptography
- quantum computing
- quantum metrology



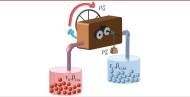






Quantum thermodynamics

Heat engines using quantum systems



Quantum metrology and phase transitions

Cramér-Rao bound and the Fisher information

$$\mathrm{Var}\, X \geqslant \frac{1}{F_X}, \qquad F_X[\rho_X] = \lim_{\epsilon \to 0} \frac{8}{\epsilon^2}\left(1 - \mathrm{Tr}\sqrt{\sqrt{\rho_X}\,\rho_{X+\epsilon}\,\sqrt{\rho_X}}\right)$$

Quantum criticality as a resource for enhanced metrological devices

✓ D. Braun, G. Adesso, F. Benatti, R. Floreanini, U. Marzolino, M. Mitchell, S. Pirandola, *Rev. Mod. Phys.* **90**, 35006 (2018)

Phase separation at critical points

$$\frac{F_X}{N} \xrightarrow[N\to\infty]{} \infty \qquad \text{or superextensive finite size scaling} \quad F_X = \mathcal{O}(N^\alpha), \quad \alpha > 1$$

- thermal phase transitions
- quantum phase transitions
- topological phase transitions
- quantum non-equilibrium phase transitions
- excited state quantum phase transitions

Precision magnetometry

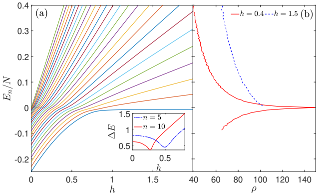
Excited state phase transitions

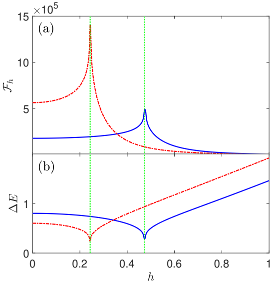
Phase transitions at each excited state formin a continuous set of critical points

✓ Q. Wang, U. Marzolino, *Precision magnetometry exploiting excited-state quantum phase transitions*, under review

Lipkin-Meshkov-Glick model in nuclear systems and superconductors

$$H = h\,S_z - \frac{S_x^2}{N}, \qquad S_\alpha = \sum_{i=1}^{N} \sigma_i^\alpha, \qquad |h| < 1$$



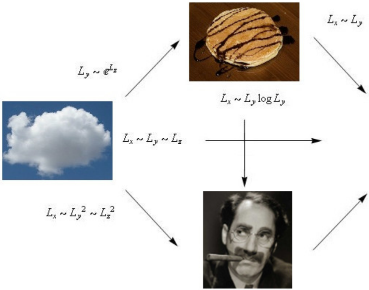


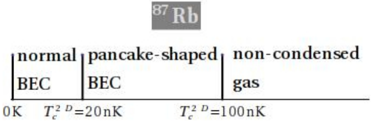
- Best accuracy for measuring the magnetic field: $\delta^2 h \sim \frac{1}{F_h} \sim \frac{1}{N^{2.07}}$
- Excited state quantum phase transtions overcome the shot-noise benchmark (central limit theorem) $\delta^2 h \sim \frac{1}{N}$

Bose-Einstein condensates

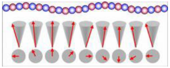
BECs depending on the spatial dimensions

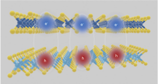
Macroscopic occupation of a set of modes with zero measure

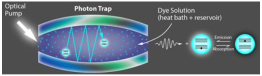




- Atom species: Lithium, Sodium, Potassium, Rubidium, Caesium, Chromium, Calcium, Strontium, Ytterbium, Dysprosium, Erbium







- Quasi-particles (room temp.): Magnons, Polaritons, Exitons
- Photons in cavity with dye molecules (room temp.)

Quantum chemical engines

Conversion of chemical into mechanical energy

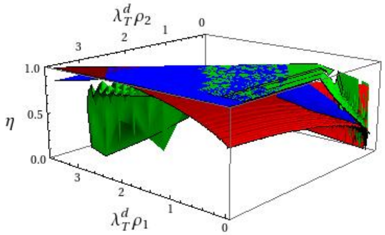
Role of quantum statistics $\begin{cases} \text{Realisable with quantum simulators} \\ \text{Potential applications in biologyical systems} \end{cases}$

✓ U. Marzolino, *μPT statistical ensemble*, under review
✓ U. Marzolino, F. Benatti, *Quantum chemical engines*, work in progress

- Chemical Carnot engine: iso-μT → iso-NT → iso-μT → iso-NT

$$\eta = \frac{\text{mech. work}}{\text{abs. chem. work}} = 1 - \frac{\mu_1}{\mu_2}, \qquad \text{BEC chemical source} \Longrightarrow \mu_1 \simeq 0, \quad \eta \simeq 1$$

- Chemical Otto engine: iso-VT → iso-NT → iso-VT → iso-NT



Quantum degenerate working fluid (fermionic or bosonic)

$\Longrightarrow \quad \eta \simeq 1$

Perspectives

Complex models

- Stong interactions
- Mean field models

Irreversible effects

- Dissipation
- Endoreversible engines

Applications

- Realisability with atoms, quasi-particles, and photons
- Connection with biological phenomena