

Towards Relativistic and Quantum Technologies

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based on many papers - ask for references

1 Introduction

- Relativistic Quantum Information
- Relativistic Quantum Information: tools

2 On Earth

- Earth-based RQI
- Detecting gravitational waves

3 In Space

- Quantum Communications
 - Relativistic effects on QKD protocols

4 Conclusions

The “Quantum Era”

Quantum Technologies in the Quantum Era...

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...well described and based on Quantum Mechanics...

The “Quantum Era”

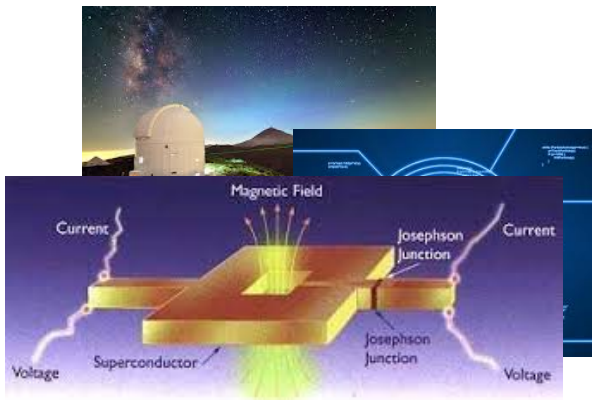
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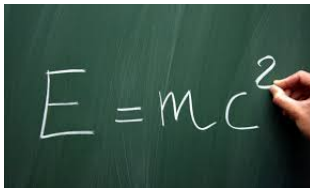
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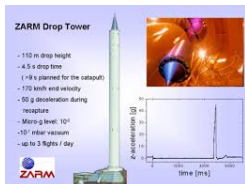
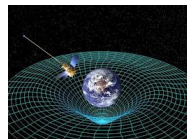
... but what about **RELATIVITY**?

Relativistic Quantum Information: aims and motivations

Aim

Use relativistic effects to:

- improve technologies
- develop new ones.



Motivations

- Quantum systems are reaching regimes where relativistic effects play a role.
- Relativity cannot be ignored when measuring relativistic parameters such as: gravitational potential in BEC drop towers.
- Nature is both relativistic and quantum.

The “Holy Grail” ...

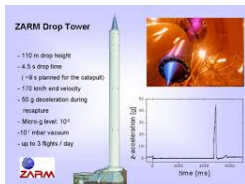
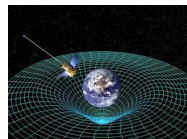
Deepen our understanding of the overlap of Quantum Theory and Relativity.

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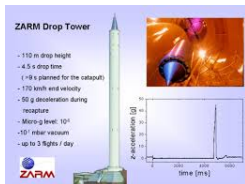
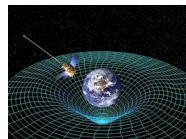
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Relativistic ingredients

- **Special Relativity:** high speeds.
- **General Relativity:** curvature.

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Specific areas to be considered

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Possible arenas of experimental investigation

- Analogue Gravity. (**NO** Einstein equations in AG systems)

On Earth

Earth-based RQI

Analogue gravity and tabletop experiments

Relativistic quantum effects on Earth

Possible to propose and perform experiments on Earth to verify the predictions in the field.

On Earth

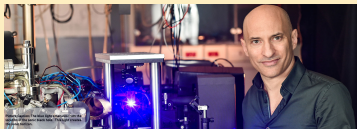
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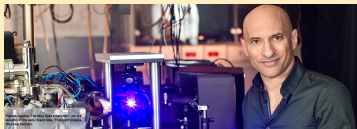


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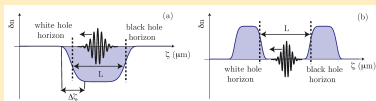
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Analogue gravity: Fibre optics

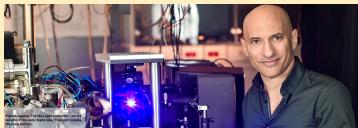


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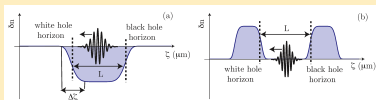
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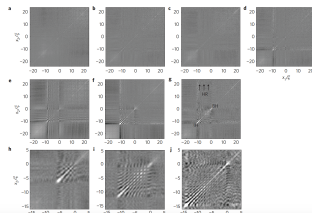
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BEC Experiments

NATURE PHYSICS DOI: 10.1038/NPHYS3304

ARTICLES



Nature Physics 12, 959–965 (2016)

Gravitational Waves

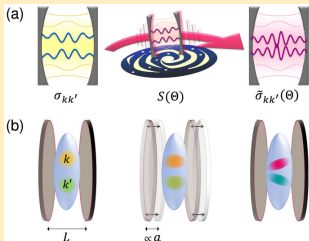
Current experiments: LIGO



Current experiments: AURIGA



A figure



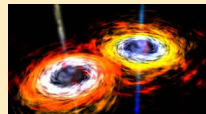
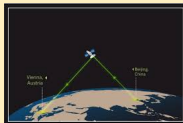
Our results

- Error $\Delta\Theta$ bound by $1/\sqrt{N QFI}$
- $QFI = \frac{k'}{4k} \omega_k^2 t^2 (1 + \sinh^4 r)$
- Gravitational and phonon frequencies are resonant.
- Typical fundamental phonon frequency: $\omega_1 \sim 1 - 10\text{kHz}$.

Entanglement distribution for Quantum Technologies

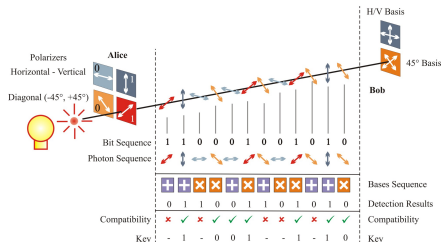
Future tasks...

- Distribute entanglement across globe.
- Observe universe through gravitational ripples.



...and goals

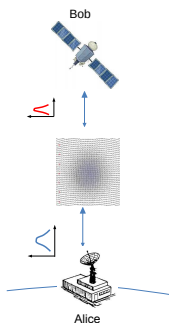
- Quantum Key Distribution.
- Distributed Quantum Computing.
- Quantum certification.
- Quantum sensors.
- GW detectors.
- ... More?



Communication setup

What Alice and Bob want to achieve

- Detect relativistic effects and use to measure distances or mass.



Protocol specifications

- Use $|\Psi_{\pm}\rangle = \frac{1}{\sqrt{2}}[|01\rangle \pm |10\rangle]$ or $|\Psi\rangle = \sum_{n=0}^{\infty} \frac{\tanh^n r}{\cosh r} |n, n\rangle$.
- Spectrum: $F_{\omega_0}(\omega)$, where $\omega_0 \sim 400\text{nm}$ (visible).
- $r_{\text{Alice}} = 6371\text{km}$ and $r_{\text{Bob}} = 6771\text{km}$ (or GEO).
- Spectrum: $F'_{\Omega_{0,A}}(\Omega_A) \neq F_{\Omega_{0,B}}(\Omega_B)$.
- Figure of merit: Quantum Bit Error Rate (QBER)
- Quant. Fisher Info. (QFI) and Cramér-Rao: $\Delta\Theta \geq \frac{1}{\sqrt{N}\sqrt{QFI}}$

Results

- Obtain: $\rho_{AB}(\Theta) = p_+(\Theta)\mathbf{P}_+ + p_-(\Theta)\mathbf{P}_-$.
- QBER increased up to 0.7%. **Measurable**
- Bound on distances: $\frac{\Delta r_s}{r_s} \sim \frac{\Delta L}{L} \geq \frac{8\sigma r_A^2}{\sqrt{2} N \Omega r_s L \sinh r}$

Summary

- * We have seen applications of quantum and relativistic physics.
- * Relativity and quantum can appear in quantum technologies.
- * There are many feasible proposals being put forward.

Outlook

- * Merging quantum and gravitational physics can provide novel technological applications.
- * Can teach us more about the physics at the overlap of relativity and quantum mechanics.
- * In the long run: discover novel physics.

Relativistic and Quantum Information groups

Nottingham and Vienna, Warsaw, Brisbane, Durban, Seoul, Vancouver...

