Call 2021
Final Evaluation

QUANTERA
DECADE OF IMPACT 2016-2026

MOCA

Integrated microwave to optical conversion on a superconducting atom chip

József Fortágh

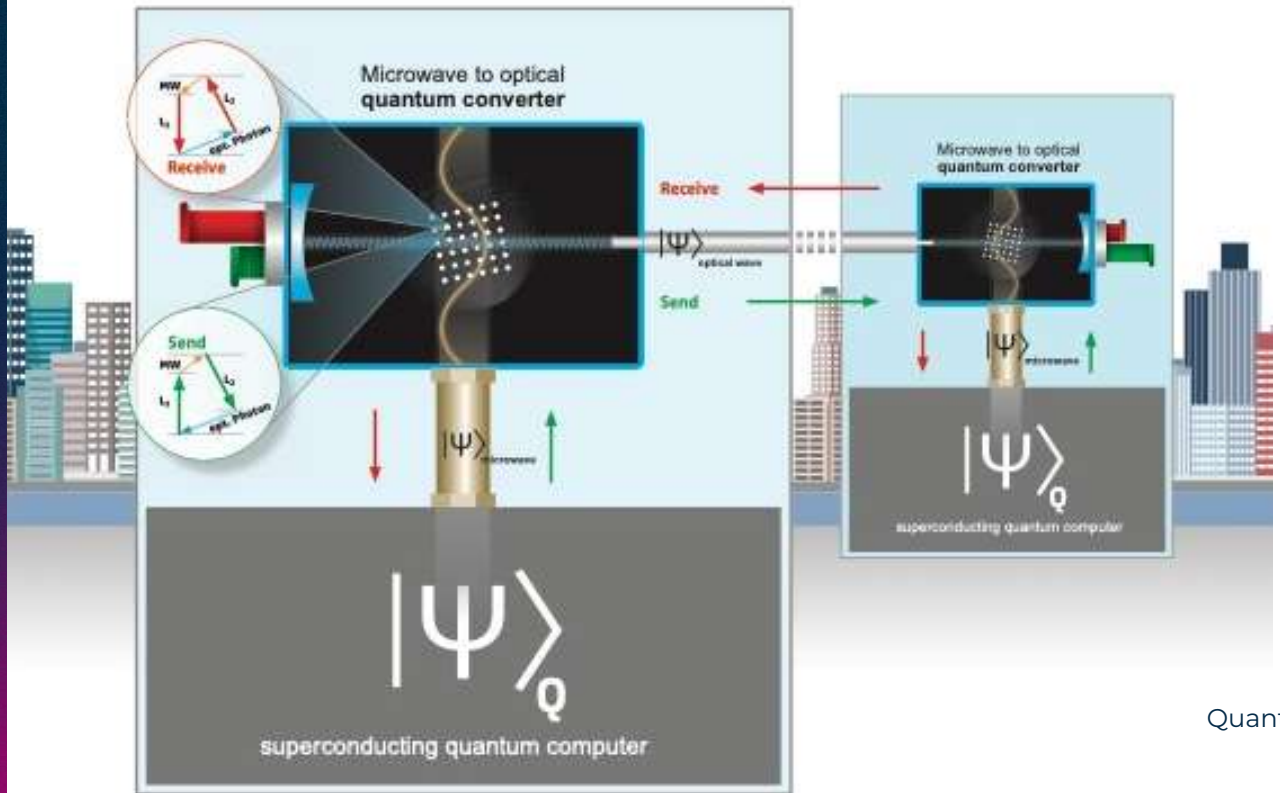
https://quantera.eu/moca/

VISION


Quantumcomputer QC
Quantumsimulator QS
Quantumsensor
ECONOMICS
QC
QC
QC
QC
EARLY WARNING - SYSTEMS
AUTONOMOUS DRIVING
LOGISTICS
QS
MATERIAL SYNTHESIS

SUCCESS STORY (highlights)

CHALLENGE – Integrated microwave to optical conversion



COLLABORATION (overview)

GEOGRAPHICAL BREADTH



EBERHARD KARLS UNIVERSITÄT TÜBINGEN

LP2N Laboratoire Photonique Numérique & Nanosciences

wigner

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

FORTH INSTITUTE OF ELECTRONIC STRUCTURE AND LASER

Countries involved:
France, Germany, Greece, Hungary, Italy

VARIETY OF DISCIPLINES

Atomic physics
Quantum optics
Solid state physics
Nanofabrication
Hybrid quantum technology platform

QUALITY OF COOPERATION

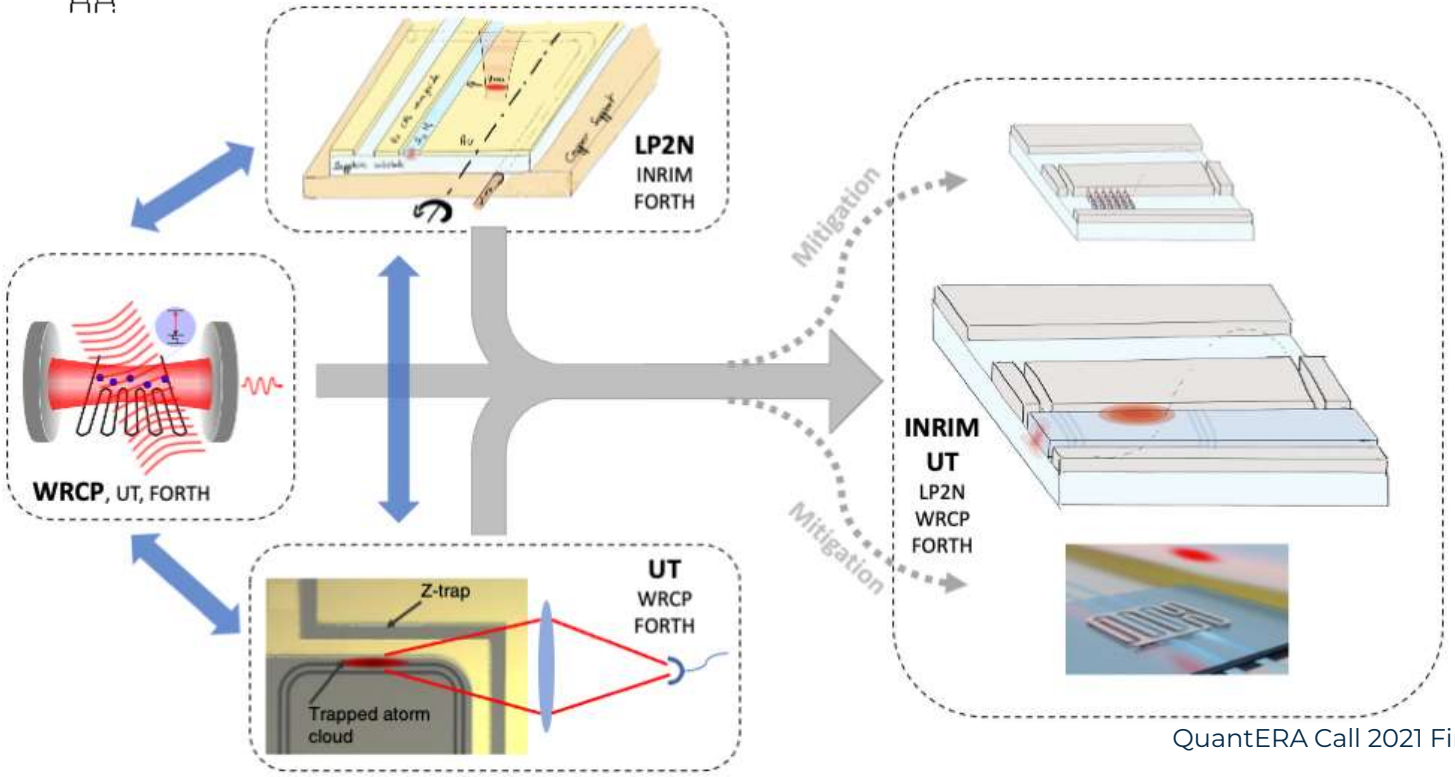
Interdisciplinary scientific and technological exchange
Coordination by UT & LP2N
Efficient bi-and multilateral meetings
Regular in-person workshops

INFRASTRUCTURE SHARING

Testing & characterisation of atom chips

SUCCESS STORY (highlights)

SOLUTION – chip-integration of enabling quantum components



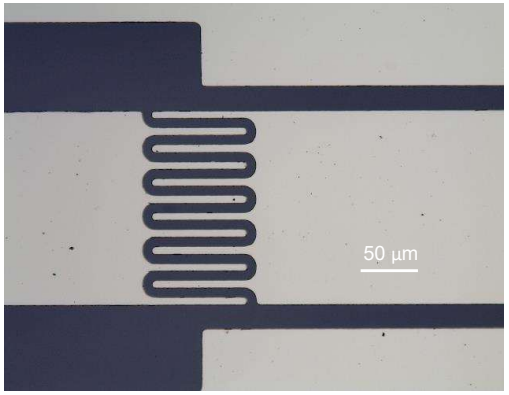
SUCCESS STORY (highlights)

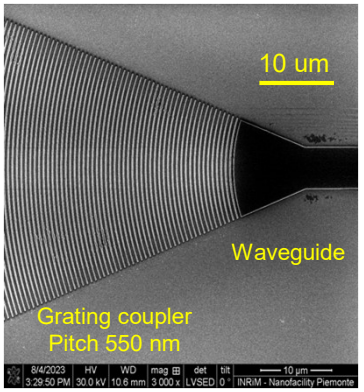
OUTCOMES

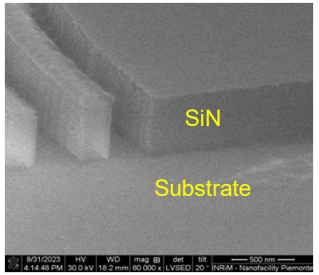
Nanofabrication of superconducting and optical waveguide cavities

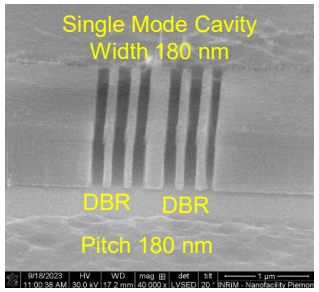
Superconducting cavities
200 nm Nb film thick with a T_c of 9 K

Optical cavities
Si_2N by ICP-CVD
Thickness: 300 nm
Refr. index = 2.3 + i1e^{-3}









SUCCESS STORY (highlights)

OUTCOMES

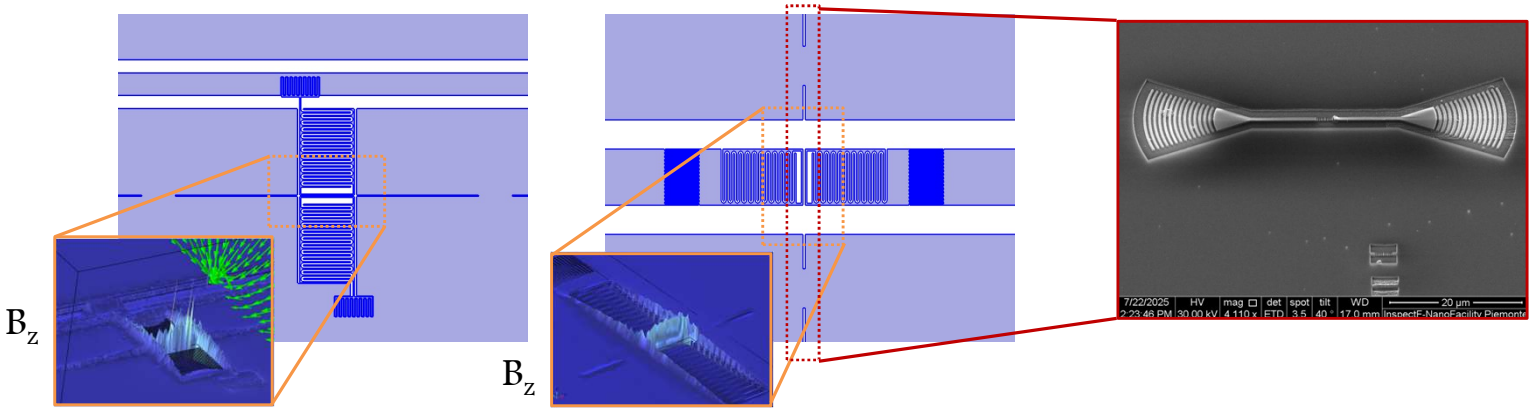
Optimized superconducting MW resonator geometries

for reduced effective mode volume and efficient coupling to elongated atomic clouds

Side-coupled
MW resonator

In-line coupled
MW resonator

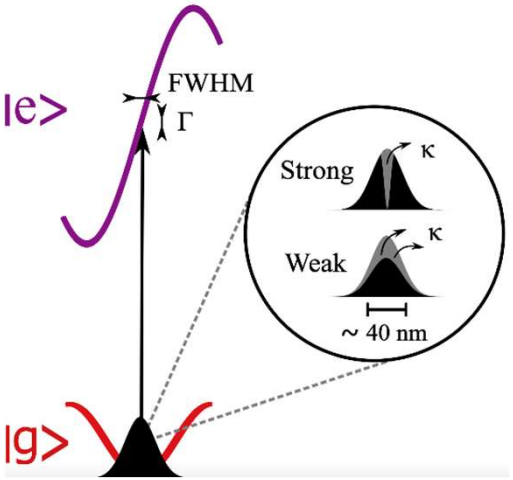
Integrated optical
waveguide resonator



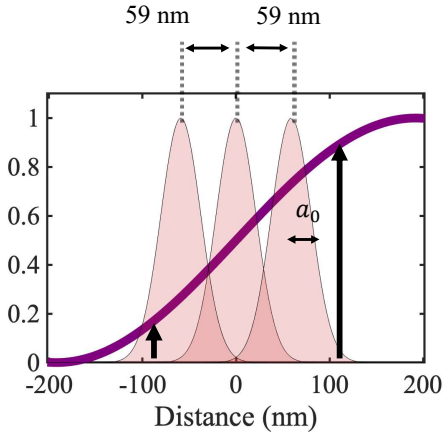
SUCCESS STORY (highlights)

OUTCOMES

Manipulating atoms in subwavelength volumes



Engineering subwavelength scattering properties can exploit both the strong and weak interaction regime



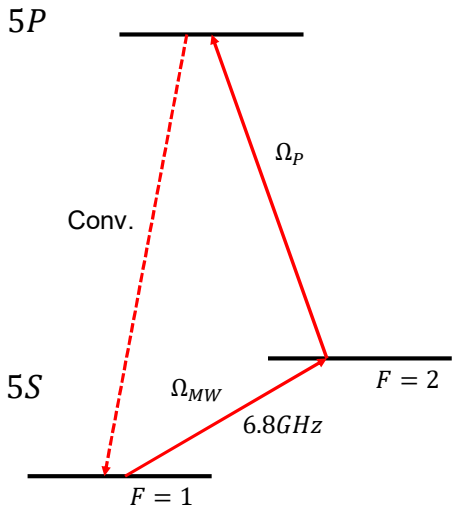
Selectively addressing and imaging wavefunctions separated by 59 nm

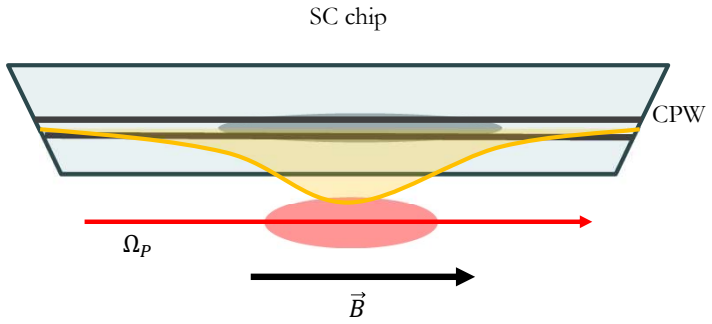
Veyron et al, PRX Quantum 5, 030349 (2024)

SUCCESS STORY (highlights)

OUTCOMES

Microwave to optical conversion in ^{87}Rb ground state manifold – basic scheme



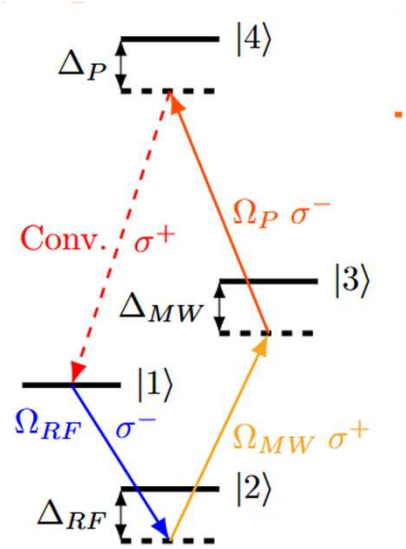


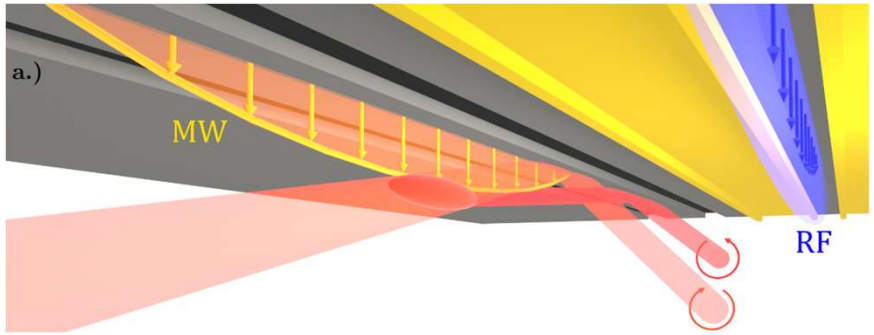
- ^{87}Rb hyperfine magnetic transition at 6.834 GHz
- Elongenated cloud close to SC chip surface
- Atoms collectively couple to CPW resonator

SUCCESS STORY (highlights)

OUTCOMES

Microwave to optical conversion in ^{87}Rb ground state manifold – realisation



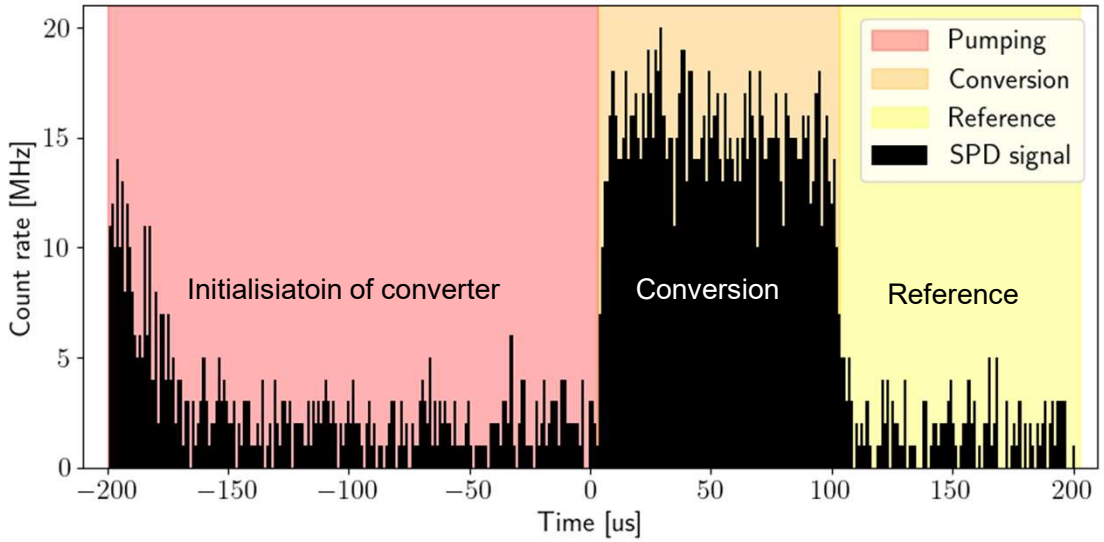


- 4-wave mixing to ensure orthogonal polarization
- Spatial separation of pump and converted signal beam
- Fiber coupling of Gaussian converted signal beam

SUCCESS STORY (highlights)

OUTCOMES

On-chip microwave to optical conversion



PRELIMINARY RESULT:

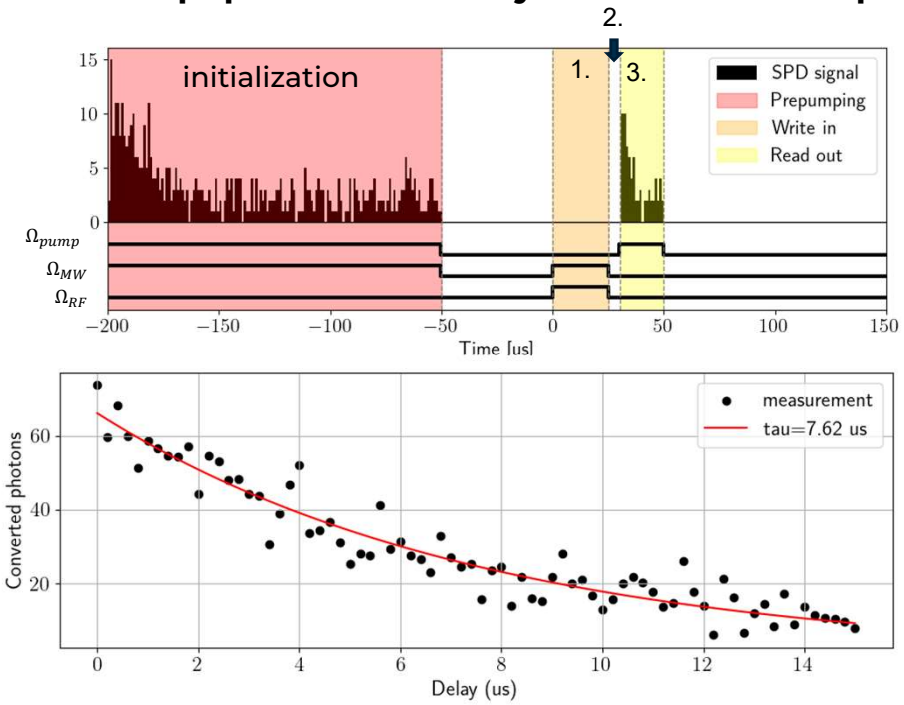
Measured efficiency at strong MW drive: . $\eta_{meas} \sim 5 \cdot 10^{-6}$

Theoretical maximum for this system at $n_{MW} = 1$: $\eta_{theo} \sim 5 \cdot 10^{-5}$

SUCCESS STORY (highlights)

OUTCOMES

On-chip quantum memory & microwave to optical conversion



1. Write in via MW+RF
2. Time evolution (memory)
3. Read out via pump pulse

PRELIMINARY RESULT:

Coherence time $\sim 10\mu s$

limited by magnetic

inhomogeneity ($\sim 100kHz$)

SUCCESS STORY (highlights)

OUTCOMES

Coherent Trapping of Rydberg states

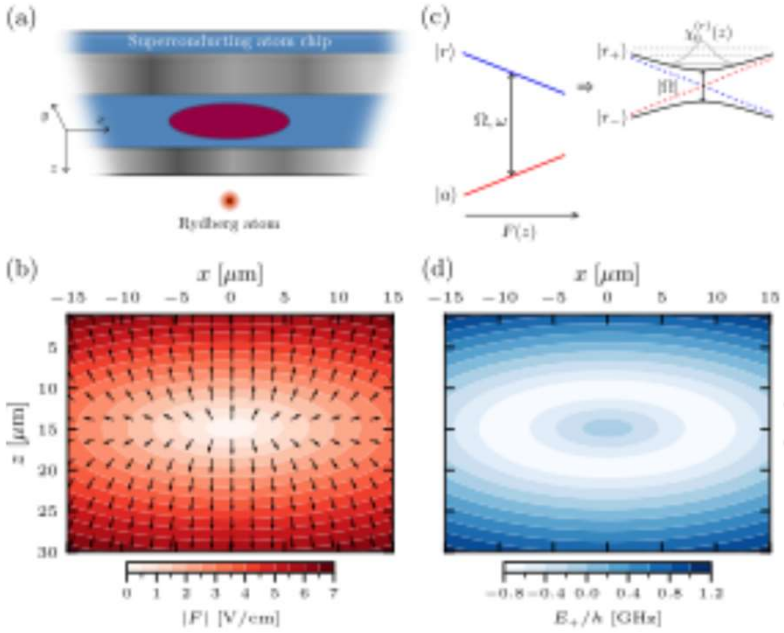
(a) Adsorbates on chip surface produce strong inhomogeneous electric field F_{ad}. Adding homogeneous bias field F_{b}
⇒ total field $F = F_{\mathrm{ad}} + F_{\mathrm{b}}$

(b) Atom in Rydberg-Stark eigenstate $|r\rangle$ with static dipole moment d_r experiences mechanical force $\boldsymbol{\nabla}(d_r|F|)$

(c) We select another Rydberg state $|a\rangle$ with $d_a \approx -d_r$ and couple it to $|r\rangle$ by a MW field with frequency $\omega = \omega_{ra} + (d_r - d_a)|F|/\hbar$
⇒ Trapping potential E_+ for eigenstate $|r_+\rangle$

(d) In 3D, the minimum of the trapping potential E_+ forms a surface (ellipsoid) at const $|F| = \hbar\Delta/(d_{\mathrm{r}} - d_{\mathrm{a}})$

Phys. Rev. Res. **8**, 013088 (2026)



SCIENTIFIC OUTPUTS

PUBLICATIONS AND PRESENTATIONS (highlights)

>40

AVS Quantum Science
EPJ Quantum Technology
Nature Communications
Phys. Rev. A
Phys. Rev. Research
Phys. Rev. Applied
Phys. Rev. X Quantum
Phys. Rev. Letters

International Conferences

NUMBER OF BACHELOR, MASTER AND PhD THESES
prepared under the QuantERA Project

>15

Bachelor: 4
Master: 4
PhD: 7

IMPACT (potential users)



RELEVANT **INDUSTRY BRANCH:**

Quantum Information Technologies



KEY COMMERCIALLY RELEVANT **APPLICATIONS:**

Quantum Memory & Converter



COOPERATION WITH THE **QUANTUM FLAGSHIP** OR OTHER QUANTUM INITIATIVES

Quantum Flagship project EuRyQa

European Metrology Network for Quantum Technologies - EURAMET EMN-Q

QuantERA projects PACE-IN, V-MAG, QuSiED

IMPACT (RRI aspects)

GENDER:
Female PI and PhD student, Girls day, International Day of Women and Girls in Science 2023

OPEN SCIENCE:
Publication in open access journals, preprints on arXiv server

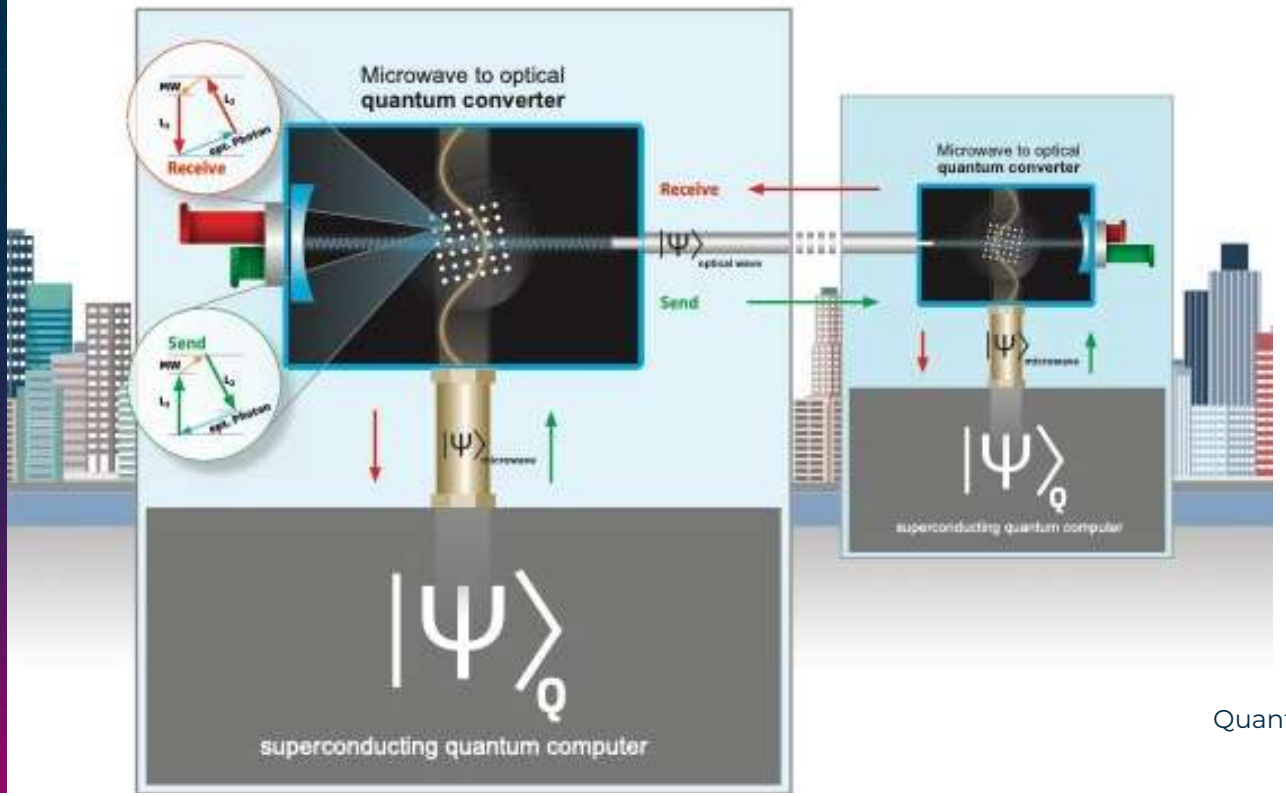
SCIENCE EDUCATION:
Science exhibition in Stuttgart and Talence, school & public lectures in Budapest & youtube

PUBLIC ENGAGEMENT: :
“Research night” – lab visit for interested public, research days for school children

WHAT'S NEXT

Quantum state storage with long coherence + near-unity conversion

Continuation with members of the consortium



QUANTERA

DECADE OF IMPACT 2016-2026

Co-funded by
the European Union