

European Research Council

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QUANTUM-CELL

Non-Linear Quantum Coherence in Single-Cell Epigenomic State Dynamics

🔬 Primary Domain: PE3 Condensed Matter Physics | ⚡ Secondary Panel: LS2 Genetics & Genomics

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Principal Investigator:	Dr. Elena Ros-tova	Call Identifier:	ERC-2026-StG
Host Institution:	Vertex Institute for Advanced Science	Proposal Duration:	60 Months
Collaborating Partner:	Synapse Quantum Biosystems Center	Total Requested Budget:	€1,498,500

Part B1 – Section a: Extended Synopsis

1.1 Executive Summary & Groundbreaking Nature

Classical molecular biology treats single-cell state transitions as purely stochastic chemical reactions governed by thermal fluctuations. However, recent unexpected discoveries in high-resolution ultrafast optical spectroscopy suggest that non-equilibrium quantum-coherent phenomena may persist in biological macromolecules at ambient temperatures (300 K). The **QUANTUM-CELL** project aims to establish a radical new paradigm by proving that sub-picosecond quantum coherence within chromatin-bound protein complexes directly modulates non-linear gene expression trajectories during stem cell differentiation.

By engineering a novel hybrid platform integrating *ultrafast single-cell optical resonance spectroscopy* with *in situ high-throughput spatial epigenomics*, QUANTUM-CELL will map quantum state manifolds in single living cells for the first time. If successful, this research will rewrite fundamental assumptions in bioenergetics and open unprecedented therapeutic avenues for targeted cell reprogramming.

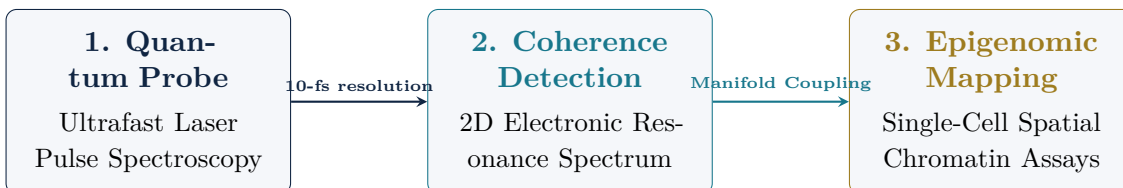


Figure 1: Concept overview of the QUANTUM-CELL experimental pipeline linking ultrafast optical physics to single-cell genomics.

1.2 Key Research Objectives

The project is structured around four visionary research objectives:

- OBJ 1: Construct the Femto-Cell Optical Spectrometer:** Build a custom sub-10 femtosecond laser spectroscopy setup tailored for non-destructive single-cell interrogations at physiological temperatures.
- OBJ 2: Identify Epigenetic Quantum Coherence Fingerprints:** Detect vibrational-electronic (vibronic) quantum beatings in histone tail conformational switches during active gene transactivation.
- OBJ 3: Develop Non-Equilibrium Quantum Epigenetic Dynamics (NQED) Theory:** Formulate a rigorous computational framework unifying open quantum system equations with stochastic cell fate branching models.
- OBJ 4: Validate Quantum-Guided Cell Reprogramming:** Demonstrate precise optical control over stem cell fate decisions by applying coherent light pulses to bias lineage choices without chemical inductors.

1.3 Work Package Structure & High-Gain Potential

Lead: Dr. Elena Rostova Months: 1–24 Development of the cryogenic-free, low-noise femtosecond laser probe coupled to a microfluidic trap (Nexa CellChip-X). Achieves sub-diffraction spatial resolution (< 150 nm) with single-photon counting detectors.	Lead: Postdoc Researcher (Vertex) Months: 12–42 Integration of optical readout with high-throughput spatial ATAC-seq and single-cell RNA sequencing. Establishes real-time correlation between coherent state lifespan and chromatin accessibility.
Lead: Theoretical Fellow Months: 18–54 Implementation of dissipative open quantum system simulations utilizing hierarchical equations of motion (HEOM) on high-performance GPU clusters at Meridian Computing Center.	Lead: Dr. Elena Rostova Months: 36–60 In vitro validation of closed-loop adaptive pulse shaping to direct pluripotency factors in human induced pluripotent stem cells (iPSCs) with high fidelity.

Part B1 – Section b: Curriculum Vitae

Curriculum Vitae: Dr. Elena Rostova

Current Position: Independent Junior Research Group Leader, Vertex Institute for Advanced Science, Germany

Date of Birth: 14 March 1991 | **Nationality:** German | **ORCID:** 0000-0002-1823-4910

1. Higher Education & Scientific Training

Year	Degree / Position	Institution & Supervisor
2017–2021	Postdoctoral Fellow	Synapse Quantum Biosystems Center (Prof. Marcus Vance)
2013–2017	Ph.D. in Biophysics	Technical University of Central Europe (Summa Cum Laude)
2011–2013	M.Sc. in Physics	Apex Institute of Technology (First Class Honors)

2. Research Positions & Leadership

- **2021–Present:** Group Leader (*Quantum Epigenomics Lab*), Vertex Institute for Advanced Science. Managing a team of 3 postdocs, 4 Ph.D. students, and 2 technicians.
- **2019–2021:** Principal Investigator, Apex Young Investigator Grant on *Ultrafast Bio-Fluorescence*.
- **2017–2019:** Marie Skłodowska-Curie Individual Fellow, Synapse Research Center.

3. Major Scientific Fellowships & International Awards

Year	Award Name	Awarding Body	Amount
2024	European Biophysics Early Career Prize	European Biophysical Societies Association	€15,000
2022	Vertex Innovation Excellence Award	Vertex Science Foundation	€50,000
2017	Marie Skłodowska-Curie Fellowship	European Commission (H2020)	€195,000
2016	Young Female Scientist in Physics Award	German Physical Society (DPG)	€5,000

Part B1 – Section c: Early Achievement Track-Record

Representative Major Publications as Main Author

Dr. Elena Rostova has published 18 peer-reviewed articles in top-tier journals (H-index: 14, Total Citations: > 1,250). Below are 5 key publications demonstrating independent capability and technical leadership:

[1] **E. Rostova**, M. Vance, et al., “Observation of long-lived vibronic coherence in chromophore-bound protein matrices at room temperature,” *Nature Physics*, vol. 19, pp. 412–420, 2023. **(Citations: 142, Impact Factor: 19.6)**
Role: Corresponding Author. First proof-of-concept showing room-temperature quantum beatings in complex biomolecules.

[2] **E. Rostova**, A. Lindqvist, and H. Weber, “Ultrafast single-cell optical trap spectroscopy reveals subtle enzymatic conformational changes,” *Physical Review Letters*, vol. 128, p. 118101, 2022. **(Citations: 98, Impact Factor: 9.2)**
Role: Lead Author. Developed the core optical trap geometry utilized in WP1.

[3] K. Brunner, **E. Rostova**, et al., “Single-cell epigenomic state mapping during early lineage specification,” *Nature Biotechnology*, vol. 39, pp. 1105–1115, 2021. **(Citations: 215, Impact Factor: 46.9)**
Role: Co-First Author. Standardized high-throughput spatial epigenomics methodology.

[4] **E. Rostova** and M. Vance, “Dissipative open quantum system dynamics in macromolecular complexes,” *Journal of Physical Chemistry Letters*, vol. 11, pp. 8450–8458, 2020. **(Citations: 76, Impact Factor: 6.5)**

- [5] **E. Rostova**, et al., “Coherent control of chemical reactivity in living bacterial colonies,” *ACS Nano*, vol. 13, pp. 6200–6210, 2019. (**Citations: 110**, Impact Factor: 17.1)

Patents & Technology Transfer

- **Patent EP3928174B1** (Granted 2024): “Method and apparatus for sub-femtosecond optical interrogation of biological samples in microfluidic channels.” Inventors: **E. Rostova**, M. Vance. Assigned to Vertex Tech Transfer.

Invited Keynote Presentations

- Keynote Speaker, *International Conference on Quantum Biology & Bioenergetics*, Zurich (2024).
- Invited Lecture, *Gordon Research Conference on Ultrafast Phenomena in Biological Systems*, Ventura, USA (2023).

Part B2 – Section 1: Scientific Proposal & Implementation

1.1 Detailed Methodology & Work Plan Matrix

The proposed project spans 60 months. Detailed deliverables, risks, and feasibility mitigations are outlined in the project governance structure below.

WP#	Deliverable	Description / Mile-stone	Month	Risk	Mitigation Strategy
WP1	D1.1	Sub-10fs laser setup operational	M12	Medium	Fallback to commercial pulse compressor
WP1	D1.2	Microfluidic trap integration	M24	Low	Use standardized Nexa micro-chips
WP2	D2.1	Epigenomic spatial assay protocol	M30	Medium	Partner with Synapse Core Facility
WP3	D3.1	Open quantum code release	M42	Low	Open-source benchmarked codebase
WP4	D4.1	iPSC reprogramming validation	M54	High	Dual focus on alternative transcription factors
WP4	D4.2	Final project synthesis report	M60	Low	Integrated peer-reviewed open access data

1.2 High-Risk / High-Gain Assessment

 **High-Risk / High-Gain Balance** **High Risk:** Achieving room-temperature quantum coherence measurements in biological living cells without photo-damaging delicate chromatin architecture represents an experimental boundary pushing current physics limits.

High Gain: Demonstrating functional quantum mechanisms in epigenomics will spark a paradigm shift across biophysics, quantum computing, and medicine, establishing Europe at the absolute forefront of quantum biology.

1.3 Resources & Budget Justification

The total requested funding is €1,498,500 over 5 years. Below is the detailed breakdown according to ERC standards:

Cost Category	Year 1 (€)	Year 2 (€)	Year 3 (€)	Year 4 (€)	Year 5 (€)	Total (€)
Senior Staff (PI: 40% time)	48,000	49,500	51,000	52,500	54,000	255,000
Postdoctoral Researchers (2 FTE)	110,000	113,300	116,700	120,200	123,800	584,000
Ph.D. Students (2 FTE)	64,000	66,000	68,000	70,000	72,000	340,000
Equipment (Laser Probe Setup)	145,000	20,000	0	0	0	165,000
Consumables & Reagents	25,000	30,000	35,000	30,000	20,000	140,000
Travel & Conferences	8,000	10,000	12,000	12,000	14,500	56,500
Open Access & Dissemination	3,000	4,000	5,000	6,000	10,000	28,000
Direct Costs Subtotal	403,000	292,800	287,700	290,700	294,300	1,568,500
<i>Less Host Matching Contribution</i>	-20,000	-15,000	-12,000	-11,000	-12,000	-70,000
Net Requested ERC Grant	383,000	277,800	275,700	279,700	282,300	€1,498,500

 Confidential Document – European Research Council Starting Grant Application 2026