SOFIA UNIVERSITY ST. KLIMENT OHRIDSKI

project 3.1.4

Advanced Quantum and Optical Technologies

Prof. Nikolay V. Vitanov

Faculty of Physics

The Team

- leading researcher
  - acad. Nikolaj V. Vitanov (R4)
- 3 established researchers:
  - prof. Asen Pashov (R4)
  - assoc. prof. Andon Rangelov (R4)
  - assoc. prof. Peter Ivanov (R4)
- 3 postdoctoral researhcers:
  - Dr. Kaloyan Zlatanov (R2)
  - Dr. Hristina Hristova (R2)
  - Dr. Ivayla Bojinova (R2)
- 5 PhD students (R1):
  - Branislav Ilikj
  - Velizar Stoyanov
  - Stancho Stanchev
  - Ivo Mihov
  - Bogomila Nikolova
- 3 technical assistants:
  - Lidiya Laskova-Slavova
  - Venelin Pavlov
  - Christo Tonchev

Tasks	Start/end	Expected results	Deliverables
WP1 Quantum control	**M1/M42**	**WP leader: N. Vitanov**	
1.1 Adiabatic quantum control	M1/M24	A new adiabatic quantum control method using pulse shaping	publication
1.2 Composite quantum control	M1/M36	New composite pulse sequences for two-qubit gates	publication
1.3 Machine-learning quantum control	M30/M42	New quantum control method based on machine learning	publication
1.4 Quantum control of qudits	M21/M42	Qudit quantum gates	publication
1.5 Dynamical decoupling	M13/M42	A new dynamical decoupling scheme	publication
WP2 Quantum computation	**M1/M42**	**WP leader: B. Torosov**	
2.1 High-fidelity single-qubit quantum gates	M1/M24	High-fidelity single-qubit quantum gates on IBM Quantum	publication
2.2 High-fidelity two-qubit quantum gate	M1/M24	High-fidelity two-qubit quantum gate on IBM Quantum	publication
2.3 Optimized quantum circuits	M19/M36	Demonstration of a quantum circuit on IBM Quantum	publication
2.4 Quantum algorithms	M25/M42	Demonstration of a quantum algorithm on IBM Quantum	publication
WP3 Quantum tomography and quantum sensing	**M1/M42**	**WP leader: N. Vitanov**	
3.1 High-fidelity quantum-gate tomography	M1/M24	New method for quantum gate tomography	publication
3.2 Spatial localization	M1/M36	New method for spatial localization	publication
3.3 Quantum sensing of weak electric and magnetic fields	M13/M42	Highly sensitive robust quantum sensors for electric and magnetic fields	publication
3.4 Quantum thermometry	M7/M30	Techniques for optimal temperature estimation	publication

WP4 Quantum simulation of critical phenomena	**M1/M42**	**WP leader: P. Ivanov**	
4.1 Quantum metrology with open quantum systems	M1/M42	Stable quantum sensor for detecting weak magnetic and electric fields	publication
4.2 Quantum simulation of ergodic quantum systems	M1/M24	Connection between quantum phase transition and thermalization in isolated quantum systems	publication
4.3 Quantum simulation of dissipative quantum systems	M13/M36	Scheme for entanglement and spin squeezing by system-environment interaction	publication
4.4 Quantum simulation of nonlinear bosonic models	M18/M42	Novel quantum phase transition in finite size bosonic models	publication
WP5 Control over molecular quantum states	**M1/M42**	**WP leader: A. Pashov**	
5.1 Experimental study of hyperfine structure of KRb c^3S^+ state	M1/M18	Measurement of HFS of selected levels, modeling	publication
5.2 Analysis of coupled excited states in diatomic molecules	M1/M42	PECs and matrix elements, experimental accuracy	publication
5.3 Experimental determination of R-dependent transition dipole moment	M18/M42	Modification of existing code, application to real data	publication
5.4 Detection of molecular chirality	M25/M42	New method for chiral resolution	publication
WP6 New optical technologies	**M1/M42**	**WP leader: A. Rangelov**	
6.1 New efficient broadband and scalable frequency conversion schemes	M12/M42	Robust frequency conversion	publication
6.2 Robust polarization manipulation devices	M1/M18	Novel polarization manipulation devices	publication
6.3 Novel antireflection optical coatings	M18/M42	Robust antireflection optical coating	publication
6.4 Broadband nonreciprocal wave plates or broadband nonreciprocal arbitrary rotators	M6/M24	Broadband nonreciprocal wave plates and broadband optical isolators	publication

WP7 Management and dissemination	M1/M42	WP leader: S. Ivanov	
7.1 Project web page	M1	Design of project web site	web site
7.2 Regular project meetings	M3, M12, M21, M27, M36, M42	Regular project meetings	meeting reports
7.3 Public outreach	continuous	One public lecture per year	public lectures

Work Package 1

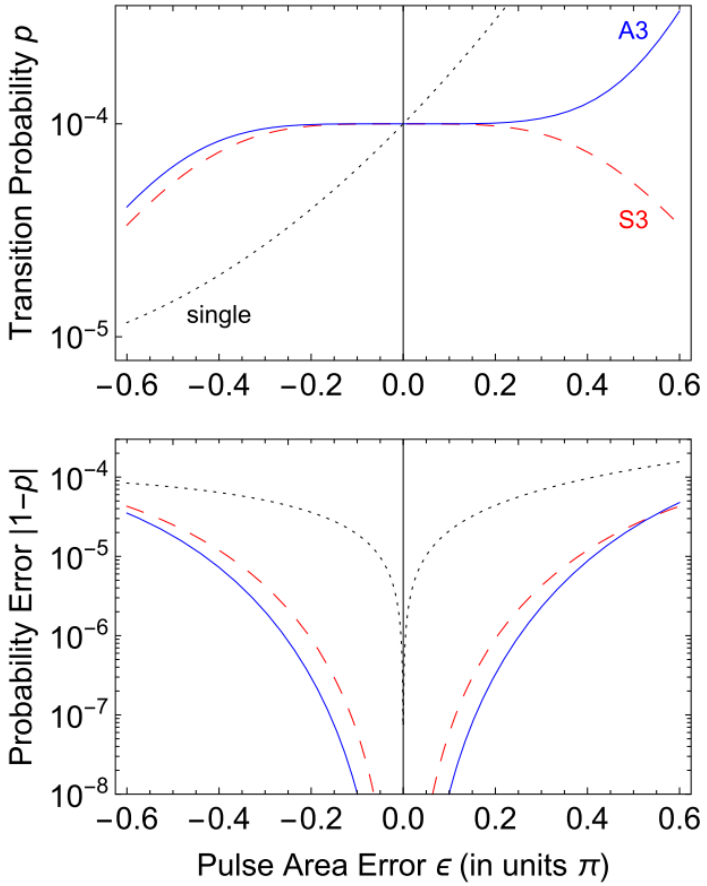
The following articles were published or submitted for publication under this activity:

1. R.G. Unanyan, N. V. Vitanov and M. Fleischhauer, *Controlled quantized adiabatic transport in a superlattice Wannier-Stark ladder*, J. Phys. B: At. Mol. Opt. Phys. **56**, 044001 (2023), subtask 1.1
2. A. A. Rangelov, B . T, Torosov and N. V. Vitanov, *Creation of coherent superpositions of Raman qubits by using dissipation*, arXiv:2401.02535), subtask 1.1
3. H. L. Gevorgyan and N. V. Vitanov, *Deterministic generation of arbitrary ultrasmall excitation of quantum systems by composite pulse sequences*, Physical Review A **108**, 032614 (2023), subtask 1.2
4. S.G. Stanchev and N. V. Vitanov, *Coherent interaction of multistate quantum systems possessing the Majorana and Morris-Shore dynamic symmetries with pulse trains*, J. Phys. B: At. Mol. Opt. Phys. **56**, 014001 (14pp) (2023), subtask 1.4

Work Package 1: Highlight

H. L. Gevorgyan and N. V. Vitanov, *Deterministic generation of arbitrary ultrasmall excitation of quantum systems by composite pulse sequences*, Physical Review A **108**, 032614 (2023), subtask 1.2

We proposed a method for generating extremely small transition probability between two quantum states, paving the way toward new methods for single-photon generation.



Work Package 2

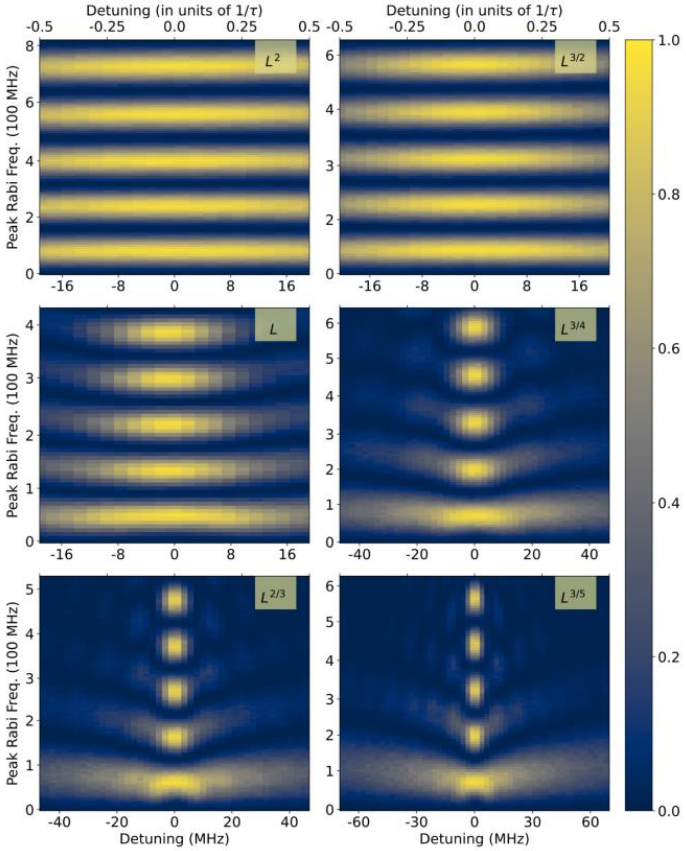
The following articles were published or submitted for publication under this activity:

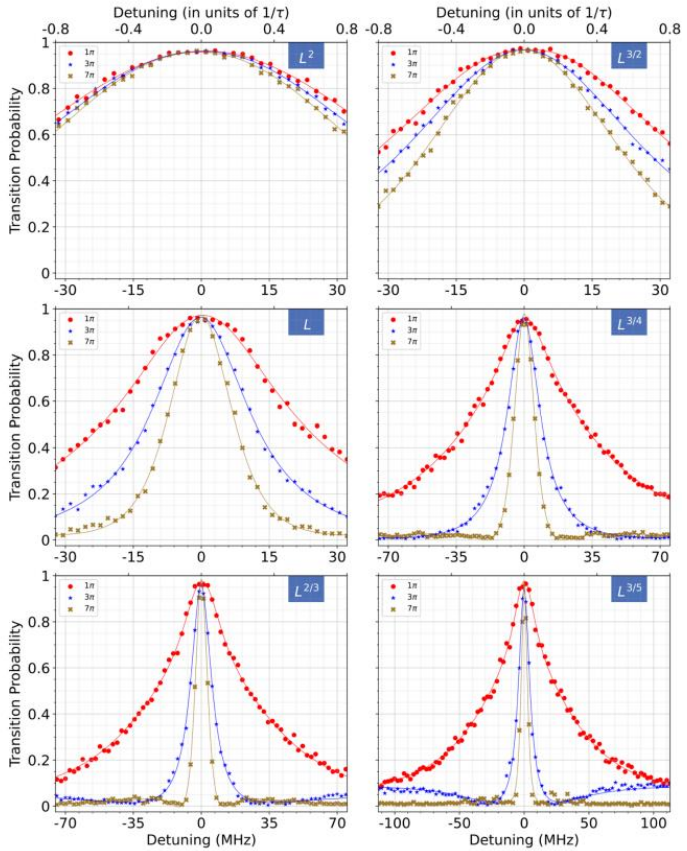
1. I. S. Mihov and N. V. Vitanov, *Defying conventional wisdom in spectroscopy: Power narrowing on IBM quantum*, Physical Review Letters **108**, 020802 (2024), subtask 2.1
2. B.T. Torosov and N.V. Vitanov, *Narrowband composite two-qubit gates for crosstalk suppression*, Physical Review A **107**, 032618 (2023), subtask 2.2

Work Package 2: Highlight

I. S. Mihov and N. V. Vitanov, *Defying conventional wisdom in spectroscopy: Power narrowing on IBM quantum*, Physical Review Letters **108**, 020802 (2024), subtask 2.1

We have defied a century-old paradigm in spectroscopy which stipulated that atomic spectral lines broaden as the power of the driving electromagnetic field increased. We have shown with experiments on a IBM Quantum processor that when the driving field has Lorentzian shape, the opposite effect – power narrowing – is observed.





Work Package 3

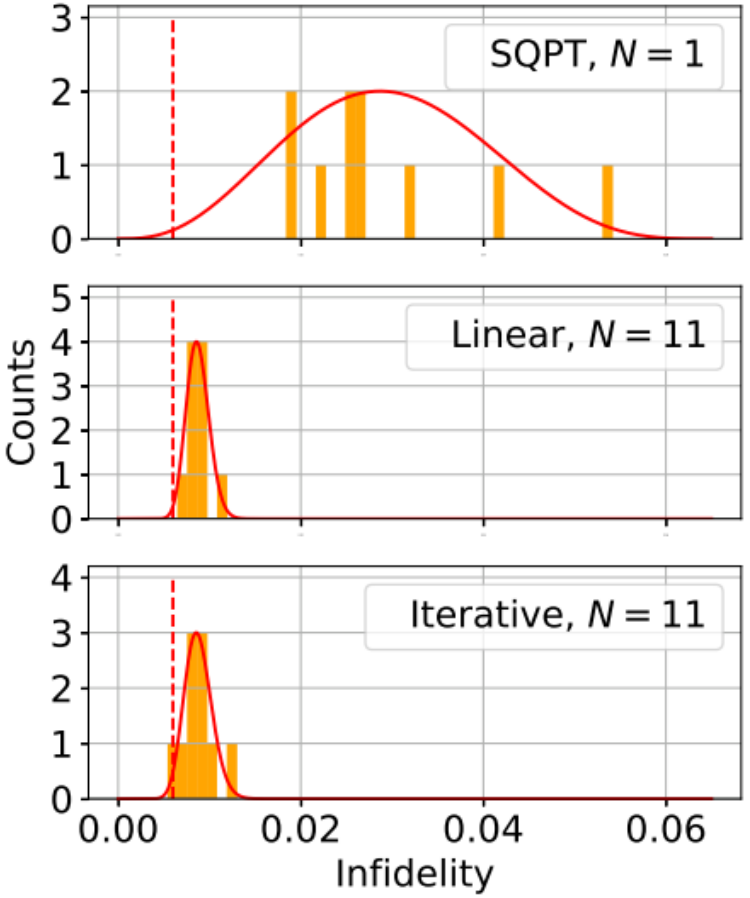
The following articles were published or submitted for publication under this activity:

1. S. G. Stanchev and N. V. Vitanov, *Characterization of high-fidelity Raman qubit gates*, Physical Review A **108**, 012605 (2024), subtask 3.1
2. S. G. Stanchev and N. V. Vitanov, *Multipass Quantum Process Tomography: Precision and Accuracy Enhancement*, arXiv:2402.04128), subtask 3.1
3. M. Mallweger, M. Guevara-Bertsch, B. T. Torosov, R. Thomm, N. Kuk, H. Parke, C. F. Roos, G. Higgins, M. Hennrich, and N. V. Vitanov, *Motional state analysis of a trapped ion by ultra-narrowband composite pulses,* arXiv:2402.10041, subtask 3.4

Work Package 3: Highlight

S. G. Stanchev and N. V. Vitanov, *Multipass Quantum Process Tomography: Precision and Accuracy Enhancement*, arXiv:2402.04128), subtask 3.1

We proposed theoretically and demonstrated experimentally on a IBM Quantum processor a new, faster, more accurate and more precise method for Quantum Process Tomography.



Work Package 4

The following articles were published or submitted for publication under this activity:

1. V. P Pavlov, D. Porras and P. A Ivanov, *Quantum metrology with critical driven-dissipative collective spin system*, Physica Scripta **98**, 9 (2023), subtask 4.1
2. V. P. Pavlov, Y. R. Chorbadzhiyska, C. Nation, D. Porras, P. A. Ivanov, *Random Matrix Theory Approach to Quantum Fisher Information in Quantum Many-Body Systems*, arXiv:2402.09029, subtask 4.2
3. B. S. Nikolova and P. A. Ivanov, *Laser-free method for creation of two-mode squeezed state and beam-splitter transformation with trapped ions*, Physica Scripta **98**, 6 (2023), subtask 4.4

Work Package 5

The following articles were published under this activity:

1. V. Stoyanov, A. Pashov, *Investigation on the fine and hyperfine structure of the c3Σ+ state in KRb* J. Quant. Spectrosc. And Rad. Trasfer. **316**, 108908 (2024), subtask 5.1
2. V. Stoyanov, A. Pashov, *Investigation on the fine structure of the B1Π − c3∑+ complex in KRb* Journal of Physics: Conference Series **2710**, 012036 (2024), subtask 5.1

Work Package 6

The following articles were published or submitted for publication under this activity:

1. R. Alrifai, V. Coda, T. Alhaddad, H. Taleb, A. A. Rangelov, and G. Montemezzani, *Broadband mode converters in three-waveguide couplers based on quantumlike adiabatic transfer*, Phys. Rev. A **107**, 013527 (2023), subtask 6.1
2. H. L. Gevorgyan, A. A. Rangelov, and N. V. Vitanov, *Broadband composite nonreciprocal polarization wave plates and optical isolators*, Optics Communications **549**, 129884 (2023), subtask 6.4

Work Package 7

This Work Package concerns management and dissemination. The main topics to report are:

- Work has been conducted in all research Work Packages, which has resulted in 16 papers, of which 12 published and 4 submitted for publication.
- The web site of the project is at https://aqot.quantum-bg.org, which is subtask 7.1.
- Three working meetings (subtask 7.2) have been organized as follows:
  - a meeting of the PIs in M1, at which the Work Program has been considered in detail and the leaders of each subtask have been determined;
  - a meeting in M4, during the annual conference CAMEL (Control of Atoms, Molecules and Ensembles by Light), at which most of the participants have been present and many of them gave talks;
  - a meeting of the PIs in M8, during which the progress has been discussed;
  - a meeting of the PIs and other senior researchers in M11, during which the tasks fulfilled in the first year have been reviewed.

- A number of conference participations have been delivered:
  - Scientists from the team organized the CAMEL18 conference in Nessebar, https://camel18.quantum-bg.org, with the involvement of Nikolay Vitanov (main organizer), Petar Ivanov (report), Andon Rangelov (report), Kaloyan Zlatanov (report), Stancho Stanchev (report) participated), Ivo Mihov (report), Branislav Ilich (report), Venelin Pavlov, Hristo Tonchev, Bogomila Nikolova, Lidiya Slavova.
  - Doctoral student V. Stoyanov visited the VEIT 2023 conference in Sozopol.
  - Asen Pashov and V. Stoyanov attended the conference The 28th Colloquium on High-Resolution Molecular Spectroscopy, Dijon 2023.
  - Nikolay Vitanov participated with an invited paper in the conference Humboldt Kolleg on Synthetic Quantum Matter, 2-6 July, Vilnius, Lithuania, https://www.hk23.ff.vu.lt/.
  - Nikolay Vitanov participated with an invited report and participation in a discussion panel at the European Quantum Technology Conference, Hannover, 16-20.10.2023, which is the main conference in Europe on quantum technologies and is organized once every two years.
  - Scientists from the team participated in the conference of the German Physical Society in Freiburg, March 10-15, 2024, as follows: oral presentation by Nikolay V. Vitanov and 3 poster presentations by Ivo Mihov, Stancho Stanchev and Kaloyan Zlatanov.

- The Academic Council of Sofia University established the Center for Quantum Technologies on November 29, 2023. The Rector of Sofia University appointed acad. Nikolay Vitanov to serve as the Director of CQT.
- Ivo Mihov received the prestigious award of the Karoll Knowledge Foundation for doctoral studies, https://www.karollknowledge.bg/phd.
- Several researchers participated in public outreach events:
  - Boyan Torosov and Ivo Mihov talked about quantum technologies on the Bulgarian National Television;
  - Nikolay Vitanov and Ivo Mihov discussed the research ambitions of the Center for Quantum Technologies on the Bulgarian National Radio;
  - Ivo Mihov discussed the research achievements which led to his Karoll Knowledge award on the Bulgarian National Radio;
  - Ivaylo Ivanov talked about “quantum money” on the Bulgarian National Radio.

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PhD student Ivo S. Mihov won the prestigious Karoll Knowledge stipend