2nd TLL-COLIMA-FOTONIKA Joint Workshop

on Manipulation of Light by Matter and Matter by Light

Vilnius, Lithuania, 1–5 September 2013

PROGRAM & ABSTRACTS

2nd TLL-COLIMA-FOTONIKA Joint Workshop

on Manipulation of Light by Matter and Matter by Light

We acknowledge the support by the EU FP7 Centre of Excellence project FOTONIKA-LV, the EU FP7 IRSES Project COLIMA, and the trilateral project supported by the Latvian, Lithuanian and Taiwanese research councils.

Workshop Program

Registration, all talks and coffee breaks will take place at the Old Campus of Vilnius University, Universiteto st. 3, room 238.

Sunday, 1 September 2013

09:00–21:00	Arrival

Monday, 2 September 2013

08:45–09:00	Registration
09:00–09:15	Introductory remarks
09:15–10:00	Igor Ryabtsev, Laser spectroscopy of mesoscopic cold Rb Rydberg ensembles in a MOT and of nonlinear resonances in a Rb vapor cell
10:00–10:30	Coffee break
10:30–10:50	Andris Berzins, Magnetic gradiometer with nanometric spatial resolution based on a layer of cesium vapor with a width of several hundred nanometres
10:50–11:10	Laima Busaite, Investigation of Nonlinear Magneto-Optical Rotation in Atomic Rubidium at 420 nm Excitation
11:10–11:30	Martins Bruvelis, Formation of multiple dressed states in hyperfine level systems of Na
11:30–12:00	Coffee break
12:00–13:30	Discussion on the progress of the TLL/COLIMA projects
13:30–14:30	Lunch break. The lunch will be for all participants in a restaurant of Old Campus of Vilnius University
14:30–16:30	Excursion to the Old Campus of Vilnius University
19:00–	Conference reception in a restaurant of Old Campus of Vilnius University

Tuesday, 3 September 2013

09:00–09:45	Valdas Sirutkaitis, Research activities at the Laser Research Centre of Vilnius University
09:45–10:05	Donatas Majus, Ultrafast supercontinuum in solid media: statistical properties and infrared extension
10.05–10:30	Coffee break
10:30–11:15	Ite A. Yu, High-Storage Efficiency EIT-based Quantum Memory
11:15–12:00	Audrius Dubietis, Nonlinear optics in the mid infrared
12:00–13:00	Lunch break. The lunch will be organised for all participants at the Old Campus of Vilnius University
13:00–19:00	Visit to the Molėtai Obvervatory of the ITPA, Vilnius University (situated 70 km to the north from Vilnius).
19:00–	Free evening. The participant can explore Vilnius and have dinner on their own.

Wednesday, 4 September 2013

09:00–09:20	Uldis KALNINSH, Quasi-stationary approach for modeling coherent atomic excitation within a laser beam profile
09:20–09:40	Linards KALVANS, Squeezing of molecular angular momentum by an external electrical field at stationary excitation
09:40–10:00	Arturs MOZERS, Level-crossing signals of $\Delta m = 1$ coherences at rubidium D_2 excitation
10:00–10:30	Coffee break
10:30–10:50	Julius RUSECKAS, Synthetic magnetic flux in optical lattices with extra dimension
10:50–11:10	Tomas ANDRIJAUSKAS, Topological properties of band structure of coupled triangle and hexagonal optical lattices
11:10–11:30	Viačeslav KUDRIAŠOV, Fast and superluminal light effects in multiple Raman gain media
11:30–12:00	Coffee break
12:00–12:20	Dmitry EFIMOV, Stochastic properties of atom-light interaction and its application to control and measurements of Rydberg states
12:20–12:40	Roman ILENKOV, Laser cooling of two-level atoms with full account of recoil effects
12:40–13:00	Closing remarks
13:30–14:30	Lunch break. The lunch will be organised for all participants at the Old Campus of Vilnius University
14:30–16:30	Visit to the planetarium of the ITPA, Vilnius University (situated walking distance from the Old campus of Vilnius University).
19:00–	Dinner at a restaurant of the Old Campus of Vilnius University.

Thursday, 5 September 2013

09:00–21:00	Departure.

Contents

Laser spectroscopy of mesoscopic cold Rb Rydberg ensembles in a MOT and of nonlinear resonances in a Rb vapor cell

I. I. Ryabtsev[1,2,3,*], D. B. Tretyakov[1], V. M. Entin[1], E. A. Yakshina[1,2,3], I. I. Beterov[1,2], A. A. Chernenko[1], Ch. Andreeva[4], A. Cinins[4], Z. Iftikhar[5], M. Saffman[6]

[1] *Rzhanov Institute of Semiconductor Physics SB RAS, 630090 Novosibirsk, Russia*

[2] *Novosibirsk State University, 630090 Novosibirsk, Russia*

[3] *Russian Quantum Center, Skolkovo, Moscow Reg., 143025, Russia*

[4] *University of Latvia, LV-1002 Riga, Latvia*

[5] *Institut dOptique, 91127 Palaiseau, France*

[6] *University of Wisconsin, Madison, Wisconsin 53706, USA*

[*] *E-mail:* ryabtsev@isp.nsc.ru

In this report we will review our recent experimental and theoretical results on the research activity within COLIMA and other projects.

First we will present the experiments on three-photon laser excitation of cold Rydberg atoms, which is of interest for high-fidelity Rydberg quantum gates and precision spectroscopy [1]. Three-photon transitions $5S \rightarrow 5P \rightarrow 6S \rightarrow nP$ in cold Rb atoms in a magneto-optical trap (MOT) have been investigated in various conditions, including various intermediate Rabi frequencies and detunings [1]. Rydberg atoms were detected by selective field ionization with single-atom resolution. The peculiarities of the experimental excitation spectra and of the multi-atom spectroscopy of mesoscopic Rydberg ensembles will be discussed.

We have also studied how dipole blockade affects the laser excitation and detection statistics of cold Rb Rydberg atoms. Long-range interactions were obtained via the Stark-tuned Forster resonance [3, 4]. Single-atom detection resolution has allowed us to distinguish between various multi-atom excitations, as well as to study the excitation statistics. The signatures of the dipole blockade in the detection statistics will be discussed.

We will also present a new scheme for the implementation of quantum logic gates with atomic ensembles consisting of an arbitrary number of strongly interacting atoms. Protocols using double sequences of stimulated Raman adiabatic passage or adiabatic rapid passage pulses have been developed [5,6].

Finally, our experimental and theoretical studies on the nonlinear laser spectroscopy of hot Rb atoms in a vapor cell will be briefly presented. These include rf-modulated VCSEL laser for chip-scale atomic clocks, the spectroscopy of EIT in a Hanle configuration [7], and inversion of saturated absorption resonances [8].

This work was supported by RFBR (Grant No. 13-02-00283), by the Russian Academy of Sciences, by the Presidential Grants No. MK-7060.2012.2, by the EU FP7 IRSES Project “COLIMA”, and by the Russian Quantum Center.

[1] I. I. Ryabtsev *et al.*, Phys. Rev. A **84**, 053409 (2011).

[2] V. M. Entin *et al.*, JETP **116**, 621 (2013).

[3] I. I. Ryabtsev *et al.*, Phys. Rev. Lett. **104**, 073003 (2010).

[4] D. B. Tretyakov *et al.*, JETP **114**, 14 (2012).

[5] I. I. Beterov *et al.*, Phys. Rev. A **84**, 023413 (2011).

[6] I. I. Beterov *et al.*, Phys. Rev. A **88**, 010303(R) (2013).

[7] D. V. Brazhnikov *et al.*, JETP Lett. **91**, 625 (2010).

[8] E. G. Saprykin *et al.*, Optics and Spectroscopy, **113**, 530 (2012).

Magnetic gradiometer with nanometric spatial resolution based on a layer of cesium vapor with a width of several hundred nanometres

A. Berzins[1,*], M. Auzinsh[1], R. Ferber[1], F. Gahbauer[1], U. Kalnins[1], L. Kalvans[1], R. Rundans[1], A. Papoyan[2], and D. Sarkisyan[2]
[1] *The University of Latvia, Laser Centre, Rainis Boulevard 19, LV-1586 Riga, Latvia*
[2] *Institute for Physical Research, NAS of Armenia, Ashtarak-0203, Armenia*
[*] *E-mail:* andris.beerzinsh@gmail.com

There is an interest in measuring magnetic field gradients with spatial resolution on the nanometre scale. These measurements are possible thanks to extremely thin cells (ETCs) [1] which confine alkali vapours between two YAG crystal walls separated by only hundreds of nanometres. When the wall separation is equal to the transition wavelength of the cesium D_1 line, observations of the hyperfine spectrum with a reduced Doppler width on the order of 50 MHz (FWHM) are possible.

Using these unique properties of the ETC, it is possible to measure the magnetic field in a nanometre thick layer of atomic vapour, and also to measure steep magnetic field gradients if the cell is moved. The sensitivity of this system adds new challenges not only from an experimental point of view but also for the theoretical model. The reduced Doppler width makes measurements very sensitive to the laser frequency detuning Δ of the exciting laser radiation. This dependence provides a sensitive test of the theoretical model, which is based on the optical Bloch equations. This model has been applied successfully to signals from an ETC for excitation of the D_1 line of rubidium [2]. The signal acquisition methods and the first results will be discused.

This work was sponsored by the ERAF project
Nr. 2010/0242/2DP/2.1.1.1.0/10/APIA/VIAA/036

[1] D. Sarkisyan, D. Bloch, A. Papoyan, M. Ducloy, Opt. Commun. **200**, 201 (2001).

[2] M. Auzinsh *et al.*, Phys. Rev. A **81**, 033408 (2010)

Investigation of Nonlinear Magneto-Optical Rotation in Atomic Rubidium at 420 nm Excitation

Laima Busaite[1,*], Alexander Akulshin[2], Marcis Auzinsh[1], Dmitry Budker[3], Szymon Pustelny[3,4]

[1]*Laser Centre, University of Latvia, 19 Rainis Boulevard, Riga, Latvia, LV-1586*

[2]*Swinburne University of Technology, PO Box 218, Hawthorn Victoria, Australia 3122*

[3]*University of California at Berkeley, Department of Physics, Berkeley, CA 94720-7300, USA*

[4]*Institute of Physics, Jagiellonian University, Reymonta 4, 31-007, Krakow, Poland*

[*]*E-mail:* Laima.Busaite@gmail.com

Nonlinear magneto-optical effect causes the rotation of the polarization plane of a light beam, propagating through medium in presence of magnetic field. As this effect has a wide range of potential applications, it has already been a subject of interest for different theoretical and experimental studies. Furthermore the interest is also caused because of the fundamental physical processes involved (see [1] for review). Among possible applications of these properties are atomic clocks, magnetometers, narrow-band optical filters and others.

NMOR has been studied extensively for alkali D_1 and D_2 having the hyperfine structure of the excited state partially of fully resolved. In current research we consider excitation to higher excited states of rubidium atom ($5^2S_{1/2} \rightarrow 6^2P_{1/2}$).The hyperfine splitting of the state 6^2P_{Je} is much smaller than that of 5^2S_{Je} and it becomes completely unresolved under the Doppler broadening at room temperature. The creation of ground state alignment depends on the hyperfine splitting, which makes the rotation signals more complex for this transition. The excited state coherences are transferred to the ground state through cascade transitions.

The experiment is done with the frequency doubled laser radiation at 420 nm, which passes through a rubidium vapor cell. The rotation of transmitted light polarization plane is then measured. The theoretical model is based on an analytical study of how the creation of alignment in the ground state depends on the hyperfine splittings of the ground and excited states [2]. Description of the rotation is done as a three-stage process of optical pumping, atomic precession in a magnetic field, and optical probing. Spontaneous relaxation of the excited state is described in a simplified way, substituting all the cascade relaxations with one integral parameters, showing the rate at which atoms return to initial state.

The theoretical dependence of the rotation angle on the magnetic field at different laser power densities (Rabi frequencies) was compared with experimental data, and the agreement was satisfactory at low excitation power density.

The research is being supported by the NATO Science for Peace project CBP.MD.SFPP. 983932, "Novel Magnetic Sensors and Techniques for Security Applications" and the Latvian Science Council Grant No 119/2012.

[1] D. Budker *et al.*, Rev. Mod. Phys. **74** 1153 (2002).

[2] M. Auzinsh, D. Budker, and S. M. Rochester, Phys. Rev. A **80**, 053406 (2009)

Formation of multiple dressed states in hyperfine level systems of Na

M. Bruvelis[1], T. Kirova[1], N. N. Bezuglov[1,2], A. Cinins[1], K. Miculis[1], A. Ekers[1], L. Kalvans[1], M. Auzinsh[1], D. K. Efimov[1,2], I. I. Ryabtsev[3]

[1]*Laser Centre and Institute of Atomic Physics and Spectroscopy, University of Latvia, Riga, Latvia.*

[2]*Faculty of Physics, St. Petersburg State University, 198904 St. Petersburg, Russia.*

[3]*Institute of Semiconductor Physics, SB RAS, 630090 Novosibirsk, Russia.*

We discuss the dependence of the dark state formation on the configuration of strongly coupled HF levels. In a system of atomic states with hyperfine (HF) structure coupling by a strong laser field forms dressed states [1]. In the case of a generalized ladder scheme of three hyperfine manifolds multiple dark states are created by increasing the laser field coupling. We perform numerical calculations for the typical Autler-Townes type experiments in a three-level ladder system (see Fig. 1), where a weak probe field is used in the first excitation step and a strong coupling field is used in the second step.

Depending the involved HF levels, the coupling by a sufficiently strong laser field can lead to the formation of dark states. The dependence of the dark state formation on the configuration of strongly coupled HF levels has dramatic effects on addressability of the dressed-state components by a weaker probe field. We have obtained an explicit representation for bright and dark states for a number of excitation ladder schemes in sodium atoms [2]. By examining the specific case of the selection rule $\Delta F = 0$ in two-photon transitions that result from strong interference of the atomic states in the middle step of the ladder, we suggests schemes for selective addressing of unresolved or partly resolved HF components.

When a multilevel two-state quantum system interacts with a strong laser field the coupling operator forms the structure of both bright and dark states. We show that the coupling operator for these systems (1) determines slightly varying dark states energies and (2) performs mixing of the bright and dark states. Sharing population between dark and bright states is manifested in a number of new "dark" peaks in the AT spectra.

Our numerical calculations of excitation spectra demonstrate that the excitation peaks appear when the probe laser frequency is resonant with the dressed states both bright and dark ones. The bright peak intensities are preserved at increased Rabi frequencies of the coupling field, while the resonance

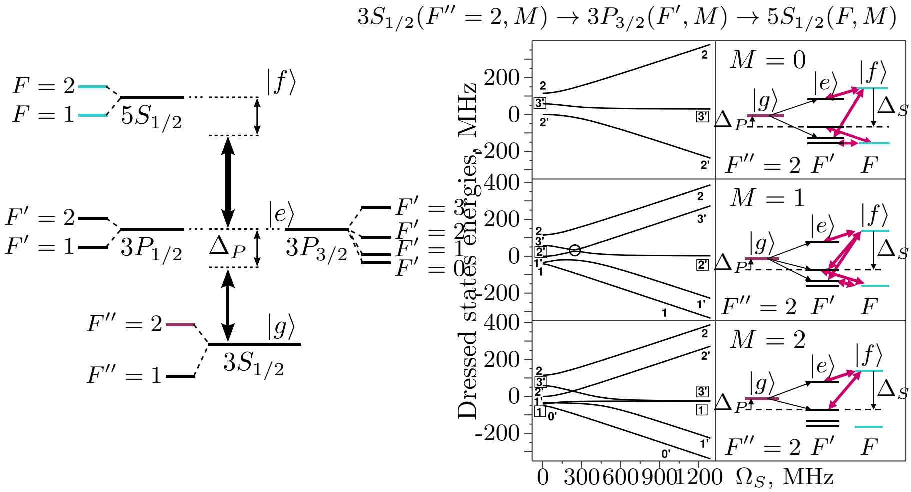

Figure 1: The dashed lines show zero-energy positions related to the energy of $3P_{3/2}F' = 2$ state. The numbering of the dressed states corresponds to the HF F-quantum numbers of the initial bare states at $\Omega_S = 0$; the square boxes indicate the states which evolved into dark states.

frequencies increasingly shift from the initial ("bare") values at zero coupling field strength. The dark peaks, in contrast, do not noticeably change their frequencies, while they lose intensity until they effectively vanish at strong coupling. For a number of three-level ladder schemes (a weak probe field in the first excitation step and a strong coupling field in the second step) in sodium we gave the explicit representation for bright states via Rabi frequencies of the coupling laser.

We acknowledge the support of EU Seventh Framework Programme Centre of Excellence project "FOTONIKA-LVFP7-REGPOT-CT-2011-285912", EU FP7 IRSES project COLIMA and ONR Global NICOP Grant Electromagnetic Field Mapping and Population Switching by Coherent Manipulation of Laser-Dressed Rydberg States.

[1] A. A. Rangelov, N. V. Vitanov, and B. W. Shore, Phys. Rev. A **74**, 053402 (2006).

[2] I. Sydoryk, N. N. Bezuglov, I. I. Beterov, *et al.*, Phys. Rev. A **77**, 042511 (2008).

Research activities at the Laser Research Centre of Vilnius University

Valdas Sirutkaitis*, Andrius Melninkaitis, Domas Paipulas, Mangirdas Malinauskas, Rytis Butkus
Laser Research Center, Vilnius University, Sauletekio av. 10, 10223 Vilnius, Lithuania
* *E-mail:* `valdas.sirutkaitis@ff.vu.lt`

Laser Research Center (LRC) was established in 1982 as an integral part of Department of Quantum Electronics (QED) at Vilnius University. LRC and QED carries out teaching and research in different fields of laser science: laser physics, nonlinear optics, laser spectroscopy, biophotonics and laser engineering. The laboratories at VU LRC are fully equipped with state of the art laser systems, and experimental instrumentation. In brief facilities available include: several laser systems devoted for study of different phenomena in nonlinear optics in the range of pulse durations from 10 ns to 10 fs; pump-and-probe laser spectrometers based on UV-IR tunable parametric light amplifiers providing temporal resolution down to 10 fs; facility for standardized laser-induced damage tests of optical components in the range of pulse durations from 10 ns to 40 fs; laboratory for biomedical laser applications, installations for laser material processing research [1].

During previous years important research achievements were obtained in field of parametric interaction of high-intensity light fields with crystals, liquids and atomic gases; development of optical parametric generators and amplifiers for the production of broadly UV, VIS and IR tunable ultrashort light pulses including pioneering works on parametric chirped pulse amplification; nonlinear optical phenomena in Bessel type light beams, the space-time localization of wave packets in solids, liquids and gases. The research personnel at VU LRC have a world-wide recognized expertise in standardized measurements of laser-induced damage thresholds of optical components and coatings, ultrafast spectroscopy of energy transfer and relaxation processes in condensed matter, organic and biological molecular complexes, shaping and characterization of beams with different topological charges. The references for those works could be found in subsection “Publications” on website of LRC [1].

In this presentation will be given brief overview of the recent achievements of LRC in such fields:
a) development of the LRC infrastructure creating the transnational access

laser facility “Naglis”,

b) development of LRC research possibilities creating laser infrastructures funded by Sunrise Valley,
c) recent works in laser-induced damage,
d) recent works in time-resolved digital holography,
e) fabrication of 3D micro/nanostructures by multi-photon polymerization with fs pulses,
f) micromachining of 2.5D structures by ablation with high reprate fs pulses,
g) modification and diffraction patterns creation in transparent materials by fs high reprate pulses.

---

[1] `http://www.lasercenter.vu.lt/?lang=en`

Ultrafast supercontinuum in solid media: statistical properties and infrared extension

D. Majus[1,*], V. Jukna[1,2], J. Galinis[1], G. Tamošauskas[1] and A. Dubietis[1]
[1] *Department of Quantum Electronics, Vilnius University, Sauletekio Ave. 9, Building 3, LT-10222 Vilnius, Lithuania*
[2] *Centre de Physique Théorique, CNRS, Ecole Polytechnique, F-91128 Palaiseau, France*
[*] *E-mail:* donatas.majus@ff.vu.lt

We present a study of spectral broadening and supercontinuum (SC) generation in sapphire crystal using 800 nm, 130 fs pulses in variable numeric-aperture focused Gaussian and axicon-generated Bessel beam geometry. The statistical analysis performed at different stages of the spectral broadening reveals that shot-to-shot fluctuations of the spectral intensity are associated with four-wave-mixing-induced spectral correlations [1]. Despite the markedly higher input energy used in the case of the Bessel beam, the dynamics of spectral broadening appears to be very similar in both cases, eventually producing a flat SC spanning across the visible and near-infrared spectral range with low shot-to-shot fluctuations (standard deviation $< 1\%$) of the spectral intensity. Also we demonstrate that the supercontinuum spectra produced in loose focusing conditions have much larger infrared extent, while the spectral blue-shift remains fairly the same [2, 3]. Our numerical simulations reproduce the experimental results in great detail and reveal that loose focusing results in an increased nonlinear propagation of the leading sub-pulse which is responsible for red-shifted spectral broadening after the pulse splitting event.

[1] D. Majus and A. Dubietis, J. Opt. Soc. Am. B **30**, 994–999 (2013).

[2] A. L. Gaeta, Phys. Rev. Lett. **84**, 3582 (2000).

[3] A. Brodeur and S. L. Chin, J. Opt. Soc. Am. B **16**, 637 (1999).

High-Storage Efficiency EIT-based Quantum Memory

Ite A. Yu[1,*], Yi-Hsin Chen[1], Meng-Jung Lee[1], I-Chung Wang[1], Shengwang Du[2], Yong-Fan Chen[3], and Ying-Cheng Chen[4,1]

[1] *Department of Physics and Frontier Research Center on Fundamental and Applied Sciences of Matters, National Tsing Hua University, Hsinchu 30013, Taiwan*

[2] *Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*

[3] *Department of Physics, National Cheng Kung University, Tainan 70101, Taiwan*

[4] *Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei 10617, Taiwan*

[*] *E-mail:* yu@phys.nthu.edu.tw

Processing a particular logical operation or waiting for the completion of others requires a quantum state to be stored in memory for a long enough time. High storage efficiency (SE) and long storage time of the memory are the keys to successful operation of long-distance quantum communication utilizing photons, where SE is defined as the ratio of read-back to write-in photon energies. We report a high-performance EIT-based memory with an SE of 78% which is the best up-to-date record [1]. Such high SE was achieved with a cold atomic medium of a very large optical density plus an ultralow decoherence rate.

Information carried by photons, inert to the environment and each other, is robust. On the other hand, information stored in matters is fragile and its signal amplitude can decay due to likely interaction with the environment or each other. A long decay time constant of about 100 μs was observed in this EIT memory. This time constant gives the delay-bandwidth product (DBP) of 74 at 50% SE, another best up-to-date record, where DBP is defined as the ratio of storage time to the full-width-half-maximum pulse duration. The work also demonstrated that the fidelity of the recall pulse is better than 90% and nearly independent of the storage time.

The result of high SE, large DBP, as well as excellent fidelity has suggested that the EIT-based quantum memory is a great candidate for practical quantum information applications with photons.

[1] Y. H. Chen, M. J. Lee, I. C. Wang, S. Du, Y. F. Chen, Y. C. Chen, and I. A. Yu, Phys. Rev. Lett. **110**, 083601 (2013).

Nonlinear optics in the mid infrared

A. Dubietis[1], J. Darginavičius[1], N. Garejev[1], I. Gražuleviciūtė[1], D. Majus[1], G. Valiulis[1], V. Jukna[2], A. Couairon[2]

[1] *Department of Quantum Electronics, Vilnius University, Saulėtekio Ave. 9, Building 3, LT-10222 Vilnius, Lithuania*

[2] *Centre de Physique Théorique, CNRS, Ecole Polytechnique, F-91128 Palaiseau, France*

High peak power few optical-cycle pulses, which are exclusively produced by optical parametric amplification open exciting possibilities in high field physics, laser-matter interactions and ultrafast nonlinear optics, in particular. Recently, unprecedented high harmonic generation and few attosecond pulse synthesis in noble gases [1], ultrabroadband supercontinuum (SC) generation in solids [2], and qualitatively new regime of femtosecond filamentation in transparent dielectric media [3] were demonstrated.

In this Contribution we report on ultrabroadband SC generation by filamentation of two optical-cycle (15 fs), carrier envelope phase (CEP)-stable pulses at 2 μm [4] in wide-bandgap solids: sapphire, fused silica, CaF_2, and YAG, in the regime of anomalous group velocity dispersion (GVD). The measured SC spectra span from 450 nm to more than 2.5 μm, and their particular shapes crucially depend on digression of the pump wavelength from the the zero GVD wavelength. In that regard, CaF_2 and YAG provide the SC radiation with the smoothest spectral coverage across the entire detected spectral range. We also detect third harmonic (TH) generation at 660 nm, which occurs prior to spectral superbroadening. Periodic modulation of the TH spectrum reveals a double-peaked temporal structure of the TH pulse, consisting of *free* and *driven* components, which are generated in the regime of large phase and group-velocity mismatch, and those existence is directly measured by cross-correlation technique. We find that double-peaked TH structure persists also in the regime of spectral superbroadening and coexists with strong SC emission, as verified experimentally and by the numerical simulations [5].

We also devised an experimental setup, which simultaneously measures the CEP stability of the SC pulses by means of f-2f and f-3f interferometry. Given a good agreement between the results obtained by f-2f and f-3f techniques, the f-3f interferometry based on intrinsic TH generation, suggests a simple and straightforward method to measure CEP fluctuations, despite rather complex temporal structure of the TH pulse. In tight focusing conditions, alongside TH generation, we observe fifth harmonic generation at 400 nm, which is contributed both by six-wave mixing due to quintic nonlinearity and by cascaded four-wave mixing between fundamental and TH pulses due to cubic nonlinearity.

This research was funded by Grant No. VP1-3.1-ŠMM-07-K-03-001 from the Lithuanian Science Council.

[1] T. Popmintchev *et al*, Science **336**, 1287 (2012).

[2] F. Silva, D. R. Austin, A. Thai, M. Baudisch, M. Hemmer, D. Faccio, A. Couairon, and J. Biegert, Nature Commun. **3**, 807 (2012).

[3] M. Durand, A. Jarnac, A. Houard, Y. Liu, S. Grabielle, N. Forget, A. Durécu, A. Couairon, and A. Mysyrowicz, Phys. Rev. Lett. **110**, 115003 (2013).

[4] J. Darginavičius, N. Garejev, and A. Dubietis, Opt. Lett. **37**, 4805 (2012).

[5] J. Darginavičius, D. Majus, V. Jukna, N. Garejev, G. Valiulis, A. Couairon, A. Dubietis, Opt. Express, submitted (2013).

Quasi-stationary approach for modeling coherent atomic excitation within a laser beam profile

Uldis Kalninsh, Marcis Auzinsh, Ruvins Ferbers, and Linards Kalvans
The University of Latvia, Laser Centre, Rainis Boulevard 19, LV-1586 Riga, Latvia

The typical approach for modeling steady state coherent atomic excitation with the optical Bloch equations is to use average laser power density and the laser beam width to calculate the absorption and fluorescence signals. This approach works reasonably well for cases where laser power is sufficiently low so that the main contribution is only from the laser beam center. However, it fails to deliver good results for high laser powers.

In this study we present an alternative approach for steady state calculations, which accounts for the off-center region of the laser beam. For this we split the laser beam into number of sections and apply the previously defined stationary approach [1] to each section. This allows us to model location dependent atomic state evolution within laser beam and incorporate realistic laser beam energy distribution into the theoretical model. By using this approach we can obtain good agreement between theoretical and experimental data at higher laser powers.

This work was supported by Latvian Science Council grant 119/2012.

[1] K. Blushs and M. Auzinsh, Phys. Rev. A **69**, 063806 (2004).

Squeezing of molecular angular momentum by an external electrical field at stationary excitation

Linards Kalvans* and Janis Smits

The University of Latvia, Laser Centre, Rainis Boulevard 19, LV-1586 Riga, Latvia

**E-mail:* linards.kalvans@lu.lv

A molecule that is prepared in a stretched state has a well defined angular momentum along some particular direction in space. In a plane orthogonal to that direction the uncertainty of angular momentum has a lower limit defined by uncertainty relation. The stretched state can be further squeezed: the uncertainty is further reduced along one axis at the minimum-uncertainty plane at the expense of the other one [1]. A molecule can be prepared in the stretched state by optical pumping and squeezed by application of an external electrical field [2].

We study by theoretical modeling of a molecular system that is being prepared in the stretched state by a cw σ polarized laser while attempting to squeezing by a DC electrical field. Optical Bloch equations are used to model the system. A squeezing parameter is calculated for different pumping and electrical field intensities to seek for optimal squeezing conditions.

The support from ERAF project
Nr. 2010/0242/2DP/2.1.1.1.0/10/APIA/VIAA/036 is kindly acknowledged.

[1] H. Prakash and R. Kumar, J. Opt. B **7**, S757 (2005).

[2] S. Rochester, M. Ledbetter, T. Zigdon, A. Wilson-Gordon, and D. Budker, Phys. Rev. A **85**, 022125 (2012).

Level-crossing signals of $\Delta m = 1$ coherences at rubidium D_2 excitation

Marcis Auzinsh, Andris Berzins, Ruvin Ferber, Florian Gahbauer, Linards Kalvans, Arturs Mozers*, Agris Spiss
Laser Centre, University of Latvia, LV 1063 Riga, Latvia
**E-mail:* `art.mozers@gmail.com`

When atomic rubidium is exposed to an external magnetic field **B**, the energies of its magnetic sublevels (distinguished by their projection m_F of atomic hyperfine total angular momentum F on the quantization axis **z**) change according to the nonlinear Zeeman effect. At particular values of the magnetic field this leads to sublevel crossings with $\Delta m_F = 1$. The two sublevels that cross can be excited if the polarization vector of the exciting radiation **E** makes an angle θ with the quantization axis **z** (here taken to be parallel to the magnetic field **B**) with $0 < \theta < \pi/2$. When these coherences are excited, circularly polarized laser induced fluorescence (LIF) is observed in the direction perpendicular to **B** and the exciting laser field polarization direction **E**.

In effect, the interaction of the magnetic field with the coherent excitation has created a state with an axially asymmetric angular momentum distribution with respect to the quantization axis **z**.

We performed experiments in a vapour of rubidium atoms at D_2 excitation, recorded the LIF signals as a function of magnetic field, and compared these results with theoretical calculations. The theoretical model, used to describe in detail signals obtained from experiment, is based on the Optical Bloch equations, which use the density matrix formalism. The density matrix calculations include the hyperfine structure of the atomic levels, strong magnetic sublevel mixing in an external magnetic field, and the Doppler effect. From the steady state equations it is possible to calculate the fluorescence signal. This theoretical model was developed to describe zero-field resonances [1] and was also successfully applied to LIF signals in larger magnetic fields (up to 120 G) where coherences with $\Delta m = 2$ could be detected [2]. The investigation presented here builds on the results of previous work [3] by applying a more advanced theoretical model and improving the experiment.

We are grateful for support from ERAF project no. 2DP/2.1.1.1.0/10/APIA/VIAA/036.

[1] M. Auzinsh *et al.*, Phys. Rev. A **79**, 053404 (2009).

[2] M. Auzinsh *et al.*, Phys. Rev. A **85**, 033418 (2012).

[3] J. Alnis *et al.*, Phys. Rev. A **63**, 023407 (2001).

Synthetic magnetic flux in optical lattices with extra dimension

J. Ruseckas[1,*], G. Juzelūnas[1], I. Spielman[2,3], N. Goldman[4], A. Celi[5], P. Massignan[5], M. Lewenstein[5,6]

[1] *Institute of Theoretical Physics and Astronomy, Vilnius University, A. Goštauto 12, Vilnius 01108, Lithuania*

[2] *Joint Quantum Institute, University of Maryland, College Park, Maryland 20742-4111, USA*

[3] *National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA*

[4] *Center for Nonlinear Phenomena and Complex Systems - Université Libre de Bruxelles, 231, Campus Plaine, B-1050 Brussels, Belgium*

[5] *ICFO – Institut de Ciències Fotòniques, Mediterranean Technology Park, E-08860 Castelldefels (Barcelona), Spain*

[6] *ICREA – Institució Catalana de Recerca i Estudis Avançats, E-08010 Barcelona, Spain*

**E-mail:* julius.ruseckas@tfai.vu.lt

Recently it was suggested to extend the dimension of optical lattices by using atomic internal degrees of freedom as an extra dimension [1]. Here we demonstrate that one can engineer a two-dimensional lattice with nonzero synthetic magnetic flux using atoms in a standard one-dimensional optical lattice. The additional dimension appears due to laser-assisted transitions between the atomic sub-levels in the ground state manifold. The synthetic magnetic flux is generated by a combination of an ordinary tunnelling in the real space and laser-assisted transitions characterised by the complex amplitudes in the extra dimension. A distinctive feature of the proposed scheme is the sharp boundaries in the extra dimension, a feature that is difficult to implement for the atoms in optical lattices in the real-space. The boundaries of the extra dimension can be closed down using additional laser-assisted transitions. Closing the boundaries of the extra dimensions leads to a remarkably simple realisation of the fractional (Hofstadter butterfly-type) spectrum.

[1] O. Boada, A. Celi, J. I. Latorre, and M. Lewenstein, Phys. Rev. Lett. **108**, 133001 (2012).

Topological properties of band structure of coupled triangle and hexagonal optical lattices

T. Andrijauskas[1,*], E. Anisimovas[1,2], N. Goldman[3], G. Juzeliunas[1]
[1] *Institute of Theoretical Physics and Astronomy of Vilnius University, A. Gostauto 12, Vilnius, Lithuania*
[2] *Faculty of Physics, Vilnius University, Lithuania*
[3] *Center for Nonlinear Phenomena and Complex Systems, Université Libre de Bruxelles, Belgium*
[*] *E-mail:* tomas.andrijauskas@tfai.vu.lt

Since the discovery of the quantum Hall effect, topological properties of band structure of periodic quantum systems has been a very interesting topic in condensed matter physics. In particular, the quantised Hall conductance of each magnetic band is directly related to the topological Chern number [1]. The quantised Hall conductance of each energy band is proportional to the Chern number, associated with the band. The Chern number is insensitive to various perturbations of the system and is related only to the bulk system properties. This allows to use it by characterising various topological system phases. In our work we analyse the topological properties of band structure of the coupled hexagonal and triangle optical lattices. The couplings are induced by the laser-assisted hopping between sub-lattices [2]. The lattice has hexagonal geometry and can be described by three-level tight-binding model in the k-space. The laser-assited coupling introduces non-trivial magnetic flux and the ultra-cold atoms in this lattice may have Chern insulator or non-trivial conducting phases. In the presentation we describe phase diagrams of various topological phases of the lattice. We show that such three-level quantum system may exhibit various Chern number values from minus three up to three. Finally we compare the results with topological phases of a simpler two-level hexagonal optical lattice [3].

[1] M. Kohmoto, Phys. Rev. B **39**, 11943 (1989).

[2] F. Gerbier and J. Dalibard, New J. Phys **12**, 033007 (2010).

[3] N. Goldman, E. Anisimovas, F. Gerbier, P. Öhberg, I. B. Spielman and G. Juzeliūnas, New J. Phys. **15**, 013025 (2013).

Fast and superluminal light effects in multiple Raman gain media

V. Kudriašov[1,*], A. Mekys[1], J. Ruseckas[1], G. Juzeliūnas[1], N. N. Bezuglov[2]
[1] *Institute of Theoretical Physics and Astronomy, Vilnius University, Lithuania*
[2] *Faculty of Physics, Institute of Physics, St. Petersburg State University, Russia*
[*] *E-mail:* viaceslav.kudriasov@ff.vu.lt

The concepts of light velocity and speed of information transfer have been discussed by many outstanding scientists in the past [1]. There are different definitions for a velocity of a light pulse. Frontal velocity ultimately defines the speed of information transfer and never exceeds the vacuum speed of light [1]. On the other hand, there are no such hard restrictions for the phase and group velocities of a light pulse. These parameters depend on the material properties and may have arbitrary values corresponding to sub- or superluminal propagation [2].

The group velocity of a light pulse can be managed through the dispersion control of the medium. Particularly, conditions corresponding to the superluminal (fast) light propagation may be fulfilled in the mediums anomal dispersion region. This is, however, inefficient under the mediums absorption band. Therefore, some advanced methods to achieve superluminal light were proposed based on the inverted atomic populations far from resonances or gain doublet schemes [3].

Up to now all used schemes employed only a single probe pulse to demonstrate superluminal light. Recently, it was shown that atomic schemes of particular coupling configuration may support formation of two-component light fields exhibiting slow group velocity [4]. Here, we demonstrate that the fast light may be achieved using similar schemes with the coupled light fields. Particularly, we consider the propagation of a two-component light in the media with multiple Raman gain transitions. This scheme supports uncoupled and coupled light states where the coupled state exibits superluminal motion.

This study has been supported by the EU FP7 project COLIMA (contract PIRSES-GA-2009-247475).

---

[1] L. Brillouin, *Wave Propagation and Group Velocity* (Academic Press, New York, 1960).

[2] P. W. Milonni, *Fast Light, Slow Light, Left-Handed Light* (Institute of Physics, Bristol, UK, 2005).

[3] A. Dogariu, A. Kuzmich, and L. J. Wang, Phys. Rev. A **63**, 053806 (2001).

[4] J. Ruseckas, V. Kudriašov, G. Juzeliūnas, R. G. Unanyan, J. Otterbach, and M. Fleischhauer, Phys. Rev. A **83**, 063811 (2011).

Stochastic properties of atom-light interaction and its application to control and measurements of Rydberg states

D. K. Efimov[1,*], N. N. Bezuglov[1] A. N. Klyucharev[1], K. Miculis[2], and A. Ekers[2]
[1]*Faculty of Physics, St.Petersburg State University, 198904 St. Petersburg, Russia*
[2]*Laser Centre, University of Latvia, LV-1002 Riga, Latvia*
[*]*E-mail:* `dmitry.efimov@de29866.spb.edu`

Stochasticity may appear in atomic-scale quantum mechanical processes when its classical description is possible according to Borh correscondence rule. Motion of classical Rydberg electron appears to be unstable under wide range of atomic (electron shell configuration) and external (value, frequency and geometry of EM field) conditions. Thus under big times of evolution such a motion may lead to stochastic observables even if dynamical system is initially determined. It can make values measured in experiment to be hardly predictable. Such parameters are particularly widths of optical ionization of Rydberg atoms in microwave field [1] and associative ionization of colliding Rydberg atoms [2]. External parameters can influence ionization selectively, making ionization rates of atoms sensitive to its quantum numbers. This may be applied to controlling population of each Rydberg state. Measurement of total gas charge after full depopulation of the atomic level gives the quantative description of selected level population.

Ionization rate of Rydberg atoms under microwave field is defined not only by Rydberg energy dynamics, as was supposed in earlier studies [3], but also by angular moment dynamics. We have realized a new stable algorithm of computing the classical Rydberg electron dynamics in hydrogen under constant and alternating electric field. The algorithm is based on Split operator method and Floquet technique that allow us to carry out numerical Monte-Carlo experiments with high accuracy. The experiments will allow us to find the proper conditions for selective manipulation of Rydberg states population.

[1] M. W. Noel, W. M. Griffith, and T. F. Gallagher, Phys. Rev. A, **62**, 063401 (2000).

[2] N. N. Bezuglov, V. M. Borodin, A. Ekers, and A. N. Klyucharev, Opt. Spect. **93** (5), 661–669 (2002).

[3] V. P. Krainov, J. Exper. Theor. Phys. **11** (2) 171–179 (2010).

Laser cooling of two-level atoms with full account of recoil effects

R. Y. Ilenkov[1,*], D. V. Brazhnikov[1,2], A. V. Taichenachev[1,2], V. I. Yudin [1,2,3]

[1]*Institute of Laser Physics SB RAS, Ac. Lavrentyev's prosp., 13/3, Novosibirsk, 630090 Russia*
[2]*Novosibirsk State University, ul. Pirogova 2, Novosibirsk, 630090 Russia*
[3]*Novosibirsk State Technical University, pr. Karla Marksa 20, Novosibirsk, 630073 Russia*
[*]*E-mail:* ilenkov.roman@gmail.com

Scientific task is investigation of two-level atoms laser cooling. For this purpose developed an exact quantum calculation method with taking into full account recoil effects. A new effect of anomalous localization of atoms in a strong laser field was discovered. The quantum regime was investigated and cooling absence with decreasing the detuning was confirmed.

The idea to control matter by electromagnetic fields originated in the minds of the scientists at the beginning of the last century. However only invention such precise and powerful tool as a laser has opened before us a wide range of capabilities for atom manipulation: acceleration, deceleration, localization, deflection, and focusing. So laser cooling has become an integral part of both fundamental science and many practical applications: high-precision frequency and time standards, nanolithography, quantum information and many others. In addition, strong evidence of the importance and interest to this area is the Nobel Prize 1997., which have been awarded some of the pioneers in the field of laser cooling (eg, Nobel lecture [1]).

The theoretical description of the kinetics of neutral atoms in the polarized light fields with all the atomic levels, the coherence, the recoil effect is both important and challenging problem. The first step toward understanding mechanisms of interaction between atoms and light was called quasi-classical approach [2]. It lies in the fact that the equations for the density matrix can be reduced to the Fokker-Planck equation for the Wigner function in the phase space. Simplicity of this approach has allowed understanding many of cooling mechanisms in the usual and ordinary terms of force and diffusion. However, this approach can only be applied in certain cases. First, the small recoil frequency parameter compared to the rate of spontaneous decay, and secondly, the momentum of a light field photon should be much smaller than the width of the momentum distribution of the atoms. Later quantum methods were developed [3, 4], for example, the secular approach which describes cooling and localization of atoms in the optical potential. In this approximation distance between the energy bands in the optical potential is greater than their broadening caused by optical pumping. At a fixed depth of the optical potential this approximation is valid in the limit of large detuning, and thus, for a given configuration is disrupted in a deep optical potential. Moreover, the secular approximation is valid only for the lower vibrational levels, and fails for the higher, where the distance between the levels becomes smaller due to the effects of anharmonicity. This approximation is not applicable to atoms undergo above-barrier motion.

We have developed an own quantum method [5] to obtaining the stationary distribution of two-level atoms in a standing wave of arbitrary intensity, allowing full account the recoil effect. The method used is to decompose the density matrix elements in the Fourier series for the spatial harmonics, which is possible due to periodicity of the light wave.

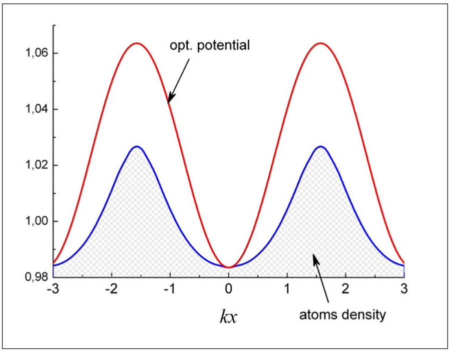

Figure 1: Anomalous localization of the atoms at the maximum of optical potential

Using the developed method kinetics of atoms in light fields of varying intensity was investigated. The new and most important result was mode which we called the anomalous localization (Fig. 1). Usually at a low recoil and weak field stationary momentum distribution has a typical Gaussian profile and atoms are located in the region of minimum optical potential (at the antinodes of the standing wave in the red detuning). This result is well known and has been studied previously (see monograph [2, 6] and references) However, in strong standing wave (Rabi frequency greater than the constant

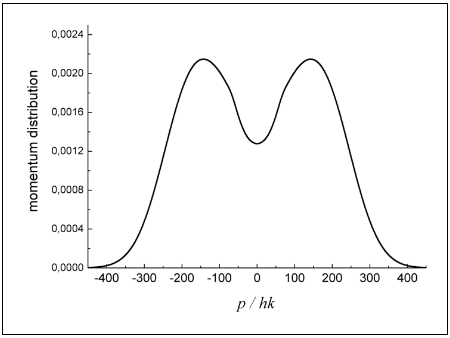

Figure 2: Stationary momentum distribution of the atoms in a strong field

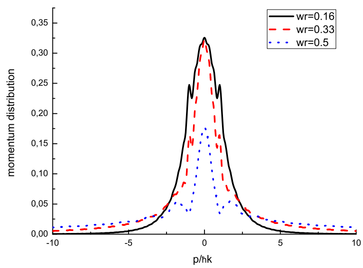

Figure 3: Stationary distribution destruction with detuning decrease

spontaneous relaxation) was detected a anomalous behavior of atoms, namely, the concentration at the peaks of the optical potential.

Research showed that such localization is always accompanied by a pronounced double-humped distribution of atoms in momentum space (Fig. 2). We proposed following mechanism of anomalous localization: If in the case two-humped distribution the most probable kinetic energy of the atoms is greater than potential depth, atoms are concentrated in the peaks of the optical potential, but if the energy is less than depth of potential, localization will occur in the classical turning points. A bit later it has been successfully validated.

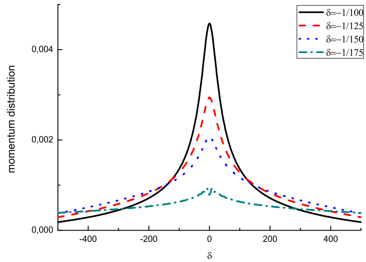

Figure 4: Quantum regime. Narrow structures of order of single photon recoil.

The next step in study of atomic kinetic was to examine the stationary distribution destruction with decreasing detuning. For small detunings of the momentum distribution (Fig. 3) loses its Gaussian shape, wing area is increased, and, finally, at the approach to the $\delta = -1/200$ detuning the non-physical narrow unstable structure appear. Total exact quantum calculation confirmed statements quasiclassics and responded about how far you can reduce the detuning.

Further, it was decided to carry out a detailed comparison of the results of our method with the results of other authors [4, 7]. In general, was obtained qualitative agreement forms, including narrow structures of order of $\hbar k$, for an example (Fig. 4) the momentum distribution in a weak field ($\Omega = 0.1$, $\delta = -0.5$) for different parameters of recoil. This work was supported by RFBR (grants nos. 12-02-31208, 12-02-00454, 12-02-00403, 11-02-00775, 11-02-01240), the Presidential Grant (SP-1518.2012.3, MK-3372.2912.2) and programs of RAS.

[1] C. Cohen-Tannoudji, *Manipulating atoms with photons*, Nobel Lecture, 1997.

[2] . P. Kazantsev, G. I. Surdutovich, and V. P. Yakovlev, *Mechanical Action of Light on Atoms*, (World Sci., Singapore, 1990).

[3] A. Aspect, E. Arimondo, R. Kaiser, N. Vansteenkiste, and C. Cohen-Tannoudji, Phys. Rev. Lett. **61**, 826 (1988).

[4] S. M. Yoo and J. Javanainen, *Wigner-function approach to laser cooling in the recoil limit*, JOSA B **8**, 1341 (1991).

[5] O. N. Prudnikov, R. Ya. Il'enkov, A. V. Taichenachev, A. M. Tumaikin, V. I. Yudin, *Steady state of a low-density ensemble of atoms in a monochromatic field taking into account recoil effects*, Journal of Experimental and Theoretical Physics **112**, 939 (2011).

[6] V. G. Minogin, V. S. Letochov, *Laser light pressure on atoms* (Gordon and Breach, New York u.a., 1987).

[7] M. R. Doery, E. J. Vredenbregt, T. Bergeman, *Quantum dynamics and cooling of atoms in one-dimensional standing-wave laser fields: Anomalous effects in Doppler cooling*, Phys. Rev. A **51**, 4881 (1995).

Author Index

Notes

Notes