Self-presentation

1.First name and surname

Michał Zawada

2. Diplomas obtained, academic / artistic degrees – including the title, place and year of issue, and the title of thesis

- 6.11.2003 – PhD in Physics, Jagiellonian University in Kraków, specialisation: atomic physics, the title of thesis: "Collective effects in a cloud of cold, dense atoms", thesis defended 29.08.2003, *cum laude*
- 06.1999 – MSc in Physcis, Jagiellonian University in Kraków, specialisation: atomic physics, the title of thesis: "Diagnostyka pułapki Magneto-Optycznej"

3. Information concerning employment in scientific / artistic institutions

- 2006-2013 Assistant Professor in the Institute of Physics of the Nicolaus Copernicus University in the Department of Atomic, Molecular and Optical Physics
- 2010-2011 Postdoctoral Research Fellow at SYRTE-l'Observatoire de Paris (Sytèmes de Référence Temps Espace), France, 12 months
- 2003-2006 Assistant Lecturer in the Institute of Physics of the Jagiellonian University in the Department of Photonics
- 2002-2003 Visiting Fellow in the European Laboratory for Non-linear Spectroscopy (LENS) in Firenze, Italy, 6 months
- 1999-2003 PhD studies at the Institute of Physics of the Jagiellonian University

4. Indication of the achievement pursuant to Article 16 Paragraph 2 of the Law on the Academic Degrees and the Academic Title 14 (March 2003) as well as on the Degrees and the Title within the scope of Art (Dz. U. nr 65, poz. 595, with later amendments):

I indicate the monothematic set of 6 publications "Development of the experimental studies of cold atoms in the National Laboratory FAMO" as the achievement fulfilling the requirements of the aforementioned Act.

H1.Studies of the hydrodynamic properties of Bose-Einstein condensate of 87Rb atoms in a magnetic trap,
F. Bylicki, W. Gawlik, W. Jastrzębski, A. Noga, J. Szczepkowski, M. Witkowski, J. Zachorowski, M. Zawada,
Acta Phys. Pol. A, **113**, 691-705 [15 pages] (2008)
I estimate my personal contribution to the publication as 40%.

H2.Free-fall expansion of finite-temperature Bose-Einstein condensed gas in the non Thomas-Fermi regime,
M. Zawada, R. Abdoul, J. Chwedeńczuk, R. Gartman, J. Szczepkowski, L. Tracewski, M. Witkowski, W. Gawlik,
J. Phys. B: At. Mol. Opt. Phys. **41,** 241001 [4 pages] (2008)
I estimate my personal contribution to the publication as 60%.

H3.Analysis and calibration of absorptive images of Bose-Einstein condensate at non-zero temperatures,

J. Szczepkowski, R. Gartman, M. Witkowski, L. Tracewski, M. Zawada, W. Gawlik,
Rev. Sci. Instr. **80**, 053103 [7 pages] (2009),
I estimate my personal contribution to the publication as 50%.

H4. Experiments on the dynamics of the Bose–Einstein condensate at finite temperatures,
W. Gawlik, W. Jastrzebski, J Szczepkowski, M Witkowski, J Zachorowski, M Zawada,
Phys. Scr. **T135**, 014028 [3 pages] (2009),
I estimate my personal contribution to the publication as 50%.

H5. Production of spinor condensate of ^{87}*Rb released from a magnetic trap,*
R. Gartman, M. Piotrowski, J. Szczepkowski, M. Witkowski, M. Zawada, W. Gawlik,
Optica Applicata **40**, 565-570 [6 pages] (2010)
I estimate my personal contribution to the publication as 50%.

H6. Matter-wave interference versus spontaneous pattern formation in spinor Bose-Einstein condensates,
M. Witkowski, R. Gartman, B. Nagórny, M. Piotrowski, M. Płodzień, K. Sacha, J. Szczepkowski, J. Zachorowski, M. Zawada, W. Gawlik,
Phys. Rev. A., **88**, 025602 [5 pages] (2013)
I estimate my personal contribution to the publication as 50%.

Detailed description of my personal contributions to the presented publications and the statements of all co-authors with concerning their personal contributions to the monothematic set "Development of the experimental physics of cold atoms in the National Laboratory FAMO" are attached as separate annexes.

The Nobel Prize in Physics 2001 was awarded jointly to E. Cornell, C. Wieman and W. Ketterle for experimental studies which led to the observatoion of the first Bose-Einstein condensate in a dilute atomic vapour[1,2]. First condensates were created in vapours of rubidium[1] and sodium[2] in 1995. In the same year also the first indications of the condensation in lithium[3] were reported. This concluded many years of experimental work started by theoretical studies of Bose and Einstein[4]. With the possibility of study of a macroscopic and at the same time a quantum object, the door to the whole new area of experimental physics opened up. The first Bose-Einstein condensate in Poland was obtained in 2007 at the National Laboratory of Atomic, Molecular and Optical Physics (KL FAMO).

The submitted set of publications concern initial studies leading to production of the first Bose-Einstein condensate in Poland and the experiments that followed.

The publication [H1] describes the set-up and procedures necessary to obtain the Bose-Einstein condensate and first measurements of its basic hydrodynamical properties. The condensate is obtained by an evaporative cooling of atoms in the magnetic trap (MT). This type of cooling requires a large quantity of atoms and ultra-high vacuum environment (below 10^{-11} mbar), therefore the magnetic trap is loaded from the system of two separated magneto-optical traps (MOT). The MOTs are in two separate vacuum chambers connected by a graphite tube for differential pumping (Fig. 1a). In the upper MOT the rubidium atoms are captured from hot atomic vapour in the vacuum of the order of $1 \cdot 10^{-8}$ mbar. Simultaneously with the process of pre-cooling the atoms are pushed to

---

[1] M. H. Anderson, J. R. Ensher, M. R. Matthews, C. E. Wieman, E. A. Cornell, *Science* **269**, 198 (1995)

[2] K. B. Davis, M. -O. Mewes, M. R. Andrews, N. J. van Druten, D. S. Durfee, D. M. Kurn, W. Ketterle, *Phys. Rev. Lett.* **75**, 3969 (1995)

[3] C. C. Bradley, C. A. Sackett, R. G. Hulet, *Phys. Rev. Lett.* **78**, 985 (1997)

[4] S. N. Bose, *Z. Phys*, **26**, 178 (1924), A. Einstein, *Sitzber. Kgl. Preuss. Akad. Wiss.* 261 (1924), A. Einstein, *Sitzber. Kgl. Preuss. Akad. Wiss.* 3 (1925)

the second MOT system by an appropriately shaped laser beam. The lower MOT is placed 41.5 cm below in the ultra-high vacuum chamber.

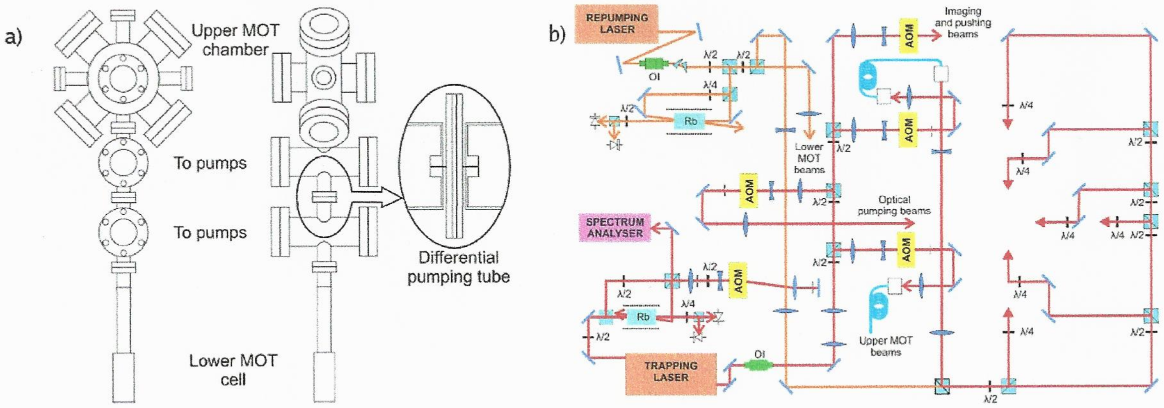

Fig. 1. a) Vacuum system of the two magneto-optical traps. b) Optical setup. Figs 1 and 5 from publication [H1].

The MOTs for rubidium atoms require two separate lasers set-ups: the laser tuned to the closed transition and the so-called repumping laser, optically pumping back atoms which leaved the closed transition. These lasers are stabilised to the atomic transition using a magnetically assisted saturated rotation spectroscopy [O8] and afterwards are tuned to the required frequencies with acousto-optic modulators. The optical set-up preparing the laser beams for the whole experiment and shaping the beams for one of the MOTs is shown in Fig. 1b. There are 14 beams in total delivered to the vacuum system, each of different frequency, shape, intensity and polarisation.

Atoms captured in the second MOT are subsequently cooled with the so-called polarisation gradient cooling and optically pumped to the hyperfine $|F=2, m_F=2>$ state of the ground state, to allow magnetic trapping. The atoms are loaded afterwards into the magnetic trap with the potential space-matched to the MOT potential to avoid heating. This potential is later changed in the process of the adiabatic compression to the shape with cylindrical symmetry in which the atomic cloud has a shape of cigar. The compression dramatically increases the rate of collisions, crucial in the next cooling step. The MT is constructed in the quadrupole Ioffe-Pritchard configuration (QUIC) modified[5] such that the position of the potential minimum does not shift in the process of adiabatic compression. The trap has the axial frequency of $2\pi\cdot 12{,}1$ Hz. The radial frequency is tunable in the range of $2\pi\cdot 170$ Hz to $2\pi\cdot 200$ Hz.

The evaporative cooling of atoms in the MT is the last stage in production of the Bose-Einstein condensate. The fastest atoms are transferred by a suitably tuned RF field into the non-trapping states and thus are removed from the MT. An RF frequency decreases exponentially from 18 MHz to about 0,7 MHz within 60 s. The resulting condensate is then released from the trap and is allowed to expand freely in the gravitational field. After a given time of a free fall (1-20 ms) the condensate is detected with the absorption imaging technique. The absorption images of the atomic cloud yield information about its column density and allow derivation of other important parameters like the number of atoms and the temperature. The whole procedure takes about 90 s and is controlled with the accuracy of 15 μs by the real-time computer system. The timing of the experiment is presented in Fig. 2.

---

[5] J. Söding, D. Guéry-Odelin, P. Desbiolles, F. Chevy, H. Inamori, J. Dalibard, *Appl. Phys. B.* **69**, 257 (1999)

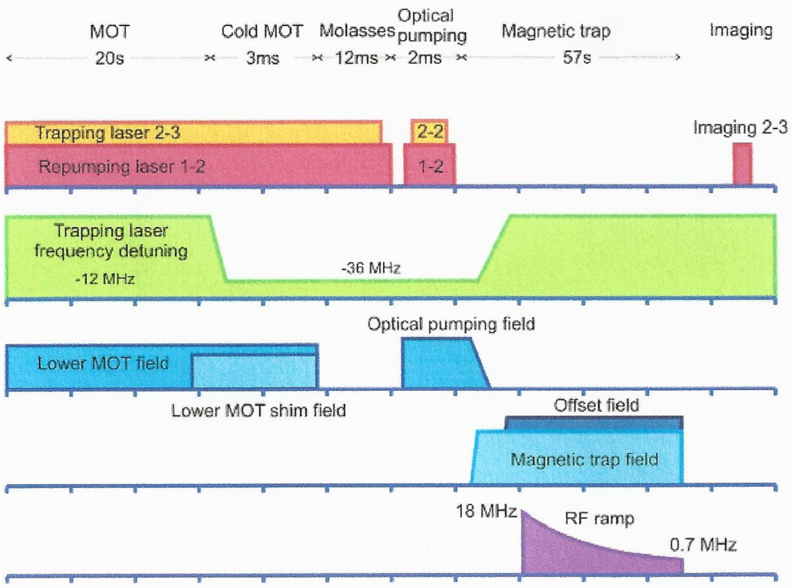

Fig. 2. Timing of the experiment. Two top lines refer to laser fields, two next lines to the magnetic fields, and the bottom line to the RF evaporation field.[H1].

The publication [H1] also describes methods developed for measuring basic hydrodynamic properties of the condensate along with the results of these measurements. The basic modes of oscillations of the atomic cloud were induced by a small, instantaneous change of the trapping potential. The axial and radial dipole modes and the fundamental quadrupole mode of the Bose-Einstein condensate were measured and compared with the theoretical predictions. Additionally, the change of the shape of the condensate in the Thomas-Fermi regime during the free fall was determined.

The publications [H2, H3, H4] are devoted to the series of experiments with the Bose-Einstein condensate in finite temperatures, i.e., surrounded by the cloud of thermal, nondegenerated atoms. The main difficulty of such experiments consists in evaluation of the percentage fraction of tcondensed and noncondensed atoms. The publication [H3] describes a solution of this problem. The absorptive imaging study the shadow of the atomic cloud under the resonant light. This atomic cloud is usually released from the trap and is balling freely in the gravitational field. The recorded image reflects the two-dimensional distribution of optical density corresponding to the spatial density profile of the atomic cloud. In the finite temperature such distribution consists of two overlapping modes, corresponding to thermal and degenerate atoms (a bimodal distribution). A simplistic analysis of this distribution by fitting a sum of the Gaussian and Thomas-Fermi functions leads to systematic errors. Well above the critical temperature, i.e., temperature of the phase transition, the observed distribution of the column density is indeed described by the Gaussian function. For temperatures close to and lower than the critical value, the density distribution is described by the Bose distribution and the observed column distribution by the so-called “Bose-enhanced Gaussian function”. The condensate fraction is described by the Thomas-Fermi function, or by the Gaussian function, depending on the number of condensed atoms.

In the cloud below the critical temperature, described by the bimodal distribution, the absorption image consists of two regions: the external region representing the thermal cloud only and the internal one where two fractions coexists. In the internal region and close to its border the density distribution is distorted by the interaction between the fractions and by the Bose enhancement of the thermal fraction. The precise distinction between these two regions is required for correct estimation of the temperature and size of both fractions. However in most experiments described in literature this distinction was made rather arbitrary. The publication [H3] presents the algorithm which verifies and ensures correctness of the distinction. The procedure is based on a calibration of the thermal fraction region based on the well-known theoretical analysis of the dependence of temperature on the condensate fraction.

The dependence of the determined temperature on the assumed size of the internal region is shown in Fig. 3a. The size of that region is defined by a scaling parameter S. T_z and T_r are the axial and radial temperatures, respectively[6]. These two temperatures are used to determine initial temperature T of the cloud *in-situ* in the MT. The marked region indicates the range of the S values for which the determined temperature T does not change by more than one standard deviation of the mean. The data with determined temperatures can be plotted on the graph which describe the phase transition. Fig. 3b depicts four realisations of the condensate, each with set of data determined for different value of S, presented on the plot of the dependence of condensate fraction N_0/N on the normalised temperature T/T_C, where T_C is the critical temperature. The solid line represents function[7]: $N_0/N=1-[T/T_C(N)]^3$ and the broken line represents the behaviour of a trapped, semi-ideal Bose gas[8]. The data marked by the elliptical contours, corresponding to the marked region in Fig. 3a, concentrate close to the values calculated from the well-known theoretical predictions, therefore the average value of theirs S parameters is the best estimation of the size of the internal region.

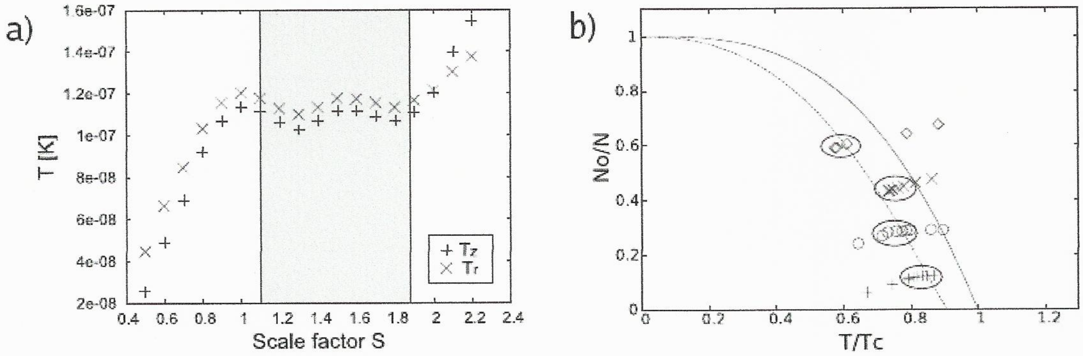

Fig. 3. a) Temperature values determined for differently assumed size of internal region on the single absorption picture. b) Four realisations of the condensate, each with set of data determined for differently assumed size of internal region between fractions, presented on the plot of the dependence between normalized condensate fraction and temperature. The lines correspond to the theoretical predictions, as described in text. The elliptical contours depict the data corresponding to the marked region in Fig a). Figs 2 and 3 from the publication [H3].

---

[6] F. Gerbier, J. H. Thywissen, S. Richard, M. Hugbart, P. Bouyer, A. Aspect, *Phys. Rev. Lett.* **92**, 030405 (2004)

[7] S. R. de Groot, G. J. Hooyman, C. A. ten Seldam, *Proc. R. Soc. London, Ser. A* **203**, 266 (1950)

[8] M. Naraschewski, D. M. Stamper-Kurn, *Phys. Rev. A* **58**, 2423 (1998)

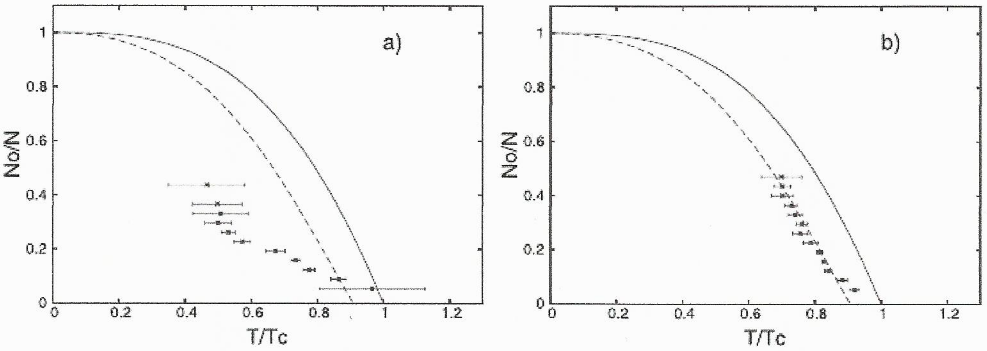

Fig. 4. The dependence of the condensate fraction N_0/N on the normalised temperature T/T_C determined from analysis of 210 images. The points in a) result from simple fitting of sum of Gaussian and Thomas-Fermi functions, whereas points in b) correspond to the fitting procedure described in the publication [H3]. The lines represent the theoretical predictions, as described in text. Fig. 7 from the publication [H3].

The dependence of the condensate fraction N_0/N on the normalised temperature T/T_C determined from analysis of images and the theoretical predictions are presented in Fig. 4. The points result from either simple fitting of sum of Gaussian and Thomas-Fermi functions (Fig. 4a) or from the fitting procedure described in the publication [H3] (Fig. 4b).

Another factor influencing the precision of analysis are unwanted interferometric fringes present in the absorption images. An algorithm for removing those fringes is described in the publication [H3]. A single absorption image with optical density distribution is in fact calculated from three pictures recorded by a CCD (images of atoms, background and thermal noise of the CCD), separated by the time needed for digital processing of the image. In theory, all interferometric patterns created in the imaging beam should be removed by subtracting the background correction. In practice, however, even the smallest thermal fluctuation during digitalisation time slightly shifts the pattern between the images and generate the residual interference fringes in the final image. These fringes can be removed by the Fast Fourier Transform filtering of the image. Examples of the fringed and defringed images of the condensate in finite temperature are presented in Fig. 5.

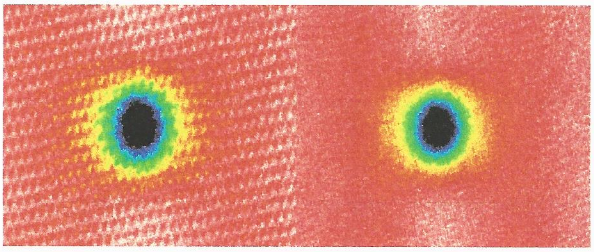

Fig. 5. Absorption image of the Bose-Einstein condensate in finite temperature before and after the defringing procedure. Data are presented in false colours. Fig. 4 from the publication [H3].

Publications [H2, H4] present study of the free-fall expansion of the Bose-Einstein condensate in finite temperature. In the Thomas-Fermi approximation the aspect ratio, i.e., the ratio of the radii of the condensate, during the free-fall depends only on the time of flight, not on the number of atoms[9]. Most of the experimental work on the condensed gases in finite temperature were analysed with an assumption that the sample fulfilled conditions of the Thomas-Fermi regime. The number of atoms in the condensed fraction in temperatures close to T_C, however, is usually small and the condensates should not be described by this approximation. Fig. 6 presents the dependence if the aspect ratio of a pure condensate on the number of condensed atoms after 15 ms

---

[9] Y. Castin, R. Dum, *Phys. Rev. Lett.* **77**, 5315 (1996)

of the condensate free expansion. The black dotted and solid red lines illustrate the aspect ratios obtained by solving the equations valid for the Thomas-Fermi regime and by solving the 3D Gross-Pitaevskii equation, respectively. The measurements prove that in our experiments the aspect ratio is no longer constant for the number of atoms below 30000.

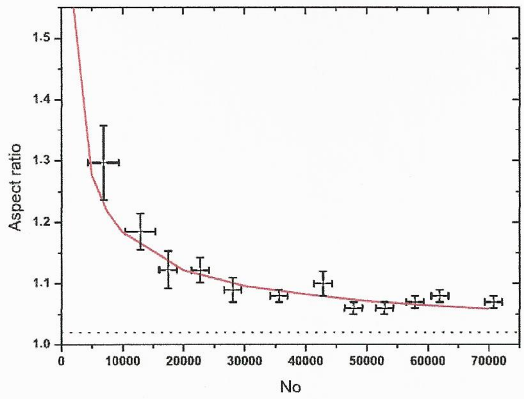

Fig. 6. Aspect ratio of a pure condensate as a function of a number of condensed atoms after 15 ms of free expansion. The solid red line shows the numerical predictions of the 3D Gross-Pitaevskii equation for a pure condensate. The dotted black line illustrates the aspect ratio predicted within the Thomas-Fermi approximation. Fig. 1 from the publication [H2].

Fig. 7 presents the dependence of the aspect ratio of the degenerate fraction of the condensate in finite temperature on the relative size N_0/N after 15 ms and 22 ms free-fall expansion. Solid red lines show the numerical predictions of a pure condensate behaviour, based on the 3D Gross-Pitaevskii equation. The predictions reflect the dependence of the aspect ratio of the degenerate fraction on the number of atom populating the fraction. The observed discrepancy between theory and experimental data results from the existence of the thermal fraction and from the interaction between the thermal and degenerate fractions. Experimental determination of such interaction consists in performing a series of measurements with constant number of atoms in the degenerated fraction.

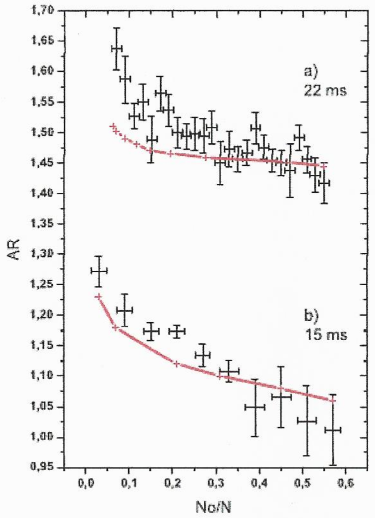

Fig. 7. The dependence of the aspect ratio of the degenerate fraction of the condensate in finite temperature on the relative size N_0/N after a) 22 ms b)15 ms of free-fall expansion. The solid red lines show the numerical predictions for pure condensate behaviour, based on the 3D Gross-Pitaevskii equation. Fig. 4 from the publication [H4].

Fig, 8a presents the dependence of the aspect ratio of the degenerate fraction on the relative size of this fraction for three fixed numbers of condensed atoms after 22 ms of free expansion. Horizontal lines depict the numerical 3D Gross-Pitaevskii predictions for pure condensates. The effect of distortion of the condensate is even more evident in Fig. 8b, which shows changes of the radial and axial radii of the degenerated fraction. Dashed horizontal bands represent radii of a pure condensate with 95000 atoms. It can be seen that for low values of N_0/N the radii of the condensate after long time of expansion are larger than expected for a pure condensate. One possible explanation of the effect might be that before expansion, while still trapped in the MT, the atomic cloud of the condensed fraction is compressed by a shell of surrounding them thermal atoms. This first experimental observation of interaction between degenerate and thermal fraction inside the trap was highlighted (at the request of the editor) in Europhysics News [P1].

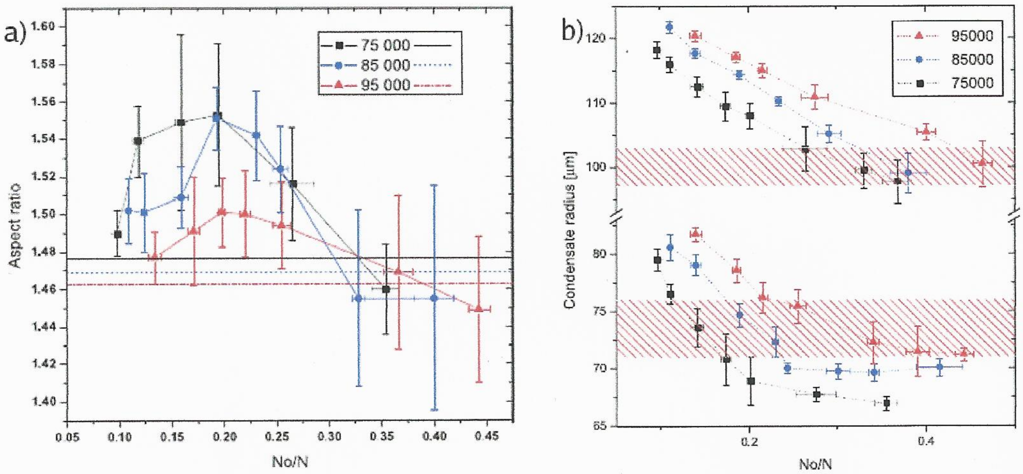

Fig. 8. a) The aspect ratio and b) the radii (radial top and axial bottom) of the degenerate fraction of the condensate versus the size of that fraction, for three sets of measurements with three different fixed numbers of atoms, after 22 ms of free expansion. Figs 3 and 4 from the publication [H2].

The publication [H5] describes the process of creation of spinor condensates[10,11] during the free fall expansion by a non-adiabatic (compared to the Larmor frequency) change of the direction of the local magnetic field. Due to that change the magnetic substates m_F of the hyperfine F=2 state are projected onto a new quantisation axis. The populations of the resulting spinor components can be controlled by changing the angle θ between the initial and final directions of the quantisation axes – the relative populations are scaled as squares of the corresponding elements of the Wigner matrix. In the simplest case of $\theta = \pi/2$, the probabilities of the transitions from the F=2, m_F=2 state to the m_F = -2, -1, 0, 1, 2 substates are equal to 1/16, 1/4, 3/8, 1/4, 1/16, respectively. Fig. 9 shows an absorption picture of five spinor components corresponding to this case, split by a vertical Stern-Gerlach force.

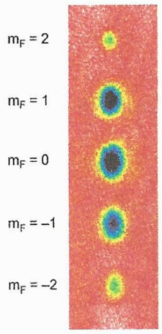

Fig. 9. The absorption picture of five spinor components split by a vertical Stern-Gerlach force. The relative populations of the components are scaled as squares of the corresponding elements of the Wigner matrix when the quantisation axis is rotated by $\theta = \pi/2$. Fig. 2 from the publication [H5].

An extension of this experiment, a matter-wave interferometer with spinor condensate, is presented in the publication [H6]. The substates of the F=2 state are repopulated and mixed by a forced Majorana transition during turning off the MT. Subsequently, the spinor condensates fall freely due to gravity in a small inhomogeneous magnetic field and acquire relative velocities

---

[10] D. M. Stamper-Kurn, M. R. Andrews, A. P. Chikkatur, S. Inouye, H.-J. Miesner, J. Stenger, W. Ketterle, *Physical Review Letters* **80**(10), 2027–2030 (1998)

[11] Ho Tin-Lun, *Physical Review Letters* **81**(4), 742–745 (1998).

depending on the value of m_F. After a given time of expansion the components are projected onto a new quantisation axis. The separation by the strong Stern-Gerlach force allows to observe resulting interference pattern. Moreover, publication [H6] shows that the interferometric effects may appear in experiments even if linear gradients of the magnetic field components are eliminated but higher order inhomogeneity is present. Fig. 10 presents a comparison of experimental observations of the interference with theoretical predictions for different free fall times. As shown in the publication [H6], the resulting matter-wave interference patterns can mimic spontaneous pattern formation in the quantum gas, a phenomenon studied by top experimental groups worldwide[12,13,14].

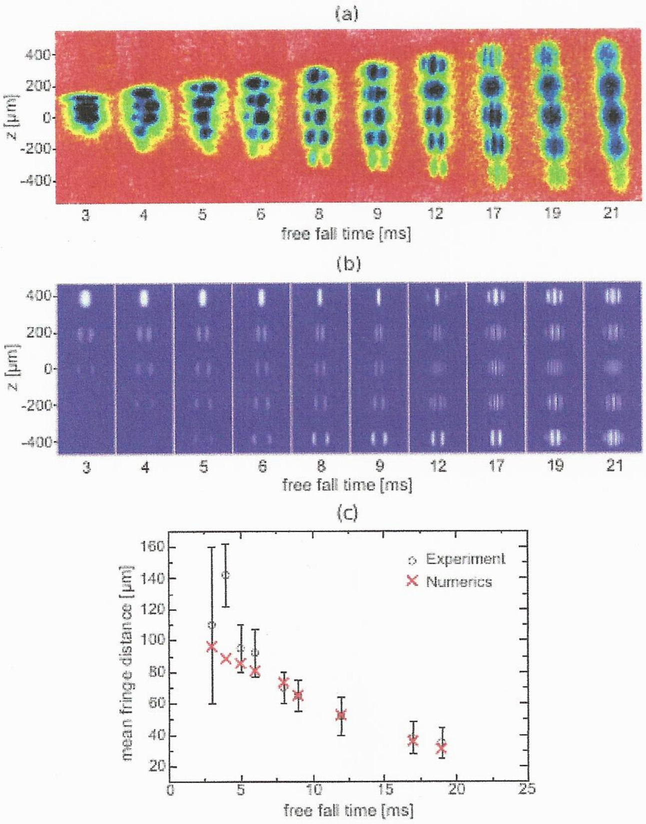

Fig. 10. Comparison of experimental observations a) with theoretical predictions b) for different times of expansion. Plot c) depicts the dependence on mean distances between interferometric fringes on the free-fall time. Fig. 1 from the publication [H6].

5. Other scientific achievements.

I had my first encounter with science during early years of the MSc study, thanks to the Scientific Association of Physics Students of the Jagellonian University (NKF). With the NKF I attended in four International Conferences for Physics Students (ICPS), contributing a poster and two oral presentations.

In the fourth year of the MSc study I joined the group of prof. dr hab. Wojciech Gawlik and started systematic scientific work. At that time I was involved in construction of the first magneto-optical trap in Poland. As a part of the MSc thesis I constructed a set-up for non-demolishing measurements of the temperature of atoms in MOT. The results were reported at two conferences and in the publication [P4].

---

[12] J. Kronjäger, C. Becker, P. Soltan-Panahi, K. Bongs, K. Sengstock, *Phys. Rev. Lett.* **105**, 090402 (2010).

[13] E. M. Bookjans, A. Vinit, C. Raman, *Phys. Rev. Lett.* **107**, 195306 (2011)

[14] D. M. Stamper-Kurn, M. Ueda, *Rev. Mod. Phys.* **85**, 1191 (2013).

During my MSc study I also took part in the experiment of dr Laurence Pruvost in Laboratoire Aimé-Cotton in Paris, thanks to the scholarship from the "Pollonium" programme. The experiment focused on the continuous production of a beam of cold atoms, released from the MOT. At that time, in 1998, three years after obtaining the first Bose-Einstein Condensate, all experiments which used the set-up of two MOTs were based on the pulsed transfer of cold atoms between traps. The successful experiment of dr L. Pruvost consisted in obtaining the cold atomic beam from the MOT by blocking part of the laser beams used for repumping atoms back to the trapping transition.

In 1999 I started my PhD study at the Faculty of Physics, Astronomy and Applied Computer Science of the Jagiellonian University in the group of prof. dr hab. W. Gawlik. Initially, my research was devoted to a nonlinear spectroscopy in the cloud of cold atoms. The measurements of four-wave mixing and nonlinear absorption in the MOT provided high resolution (~10^4 Hz) spectroscopic data. I continued that topic also in the first years after the PhD.

Our measurements allow for precise diagnostics of the MOT and an observation of the so-called Recoil-Induced Resonances (RIR) in the spectrum of the nonlinear absorption. These resonances, which an the analogue of the Bragg resonances in the solid-state physics, were used for a precise thermometry and magnetometry of local areas inside the cold atomic cloud. Additionally, the measurements of the nonlinear absorption showed that the atoms within the MOT can be localised in the optical lattice of polarisations made by trapping laser beams. Those results were presented at six conferences, two invited lectures at conferences and published in three publications [O1, O3, O5].

At the same time, during the first three years of my PhD study, we constructed second, upgraded set-up of the MOT, under supervision of prof W. Gawlik. That set-up has been utilised up to now in the Photonic Division of the Institute of Physics of the Jagiellonian University .

With the new MOT we developed a method of precise measurement of the temperature of the atomic cloud, a variation of the time-of-flight method in conditions where the distance between the MOT and a beam probing the falling atoms is very small. That method was reported at three conferences and in the publication [O2].

In 2002 I received the scholarship of the European Commission, the Marie Curie Fellowship, for six months stay at the European Laboratory for Non-linear Spectroscopy (LENS) in Florence. I joined the group of prof. Massimo Inguscio experimenting with the rubidium Bose-Einstein Condensate. Our most important researchconcerned modification of an effective mass of the condensate by Bragg diffraction on a moving optical lattice. As a consequence, the effective scattering length can be tuned (alternatively to the Feshbach resonances method) and the wavefunction of the condensate can be focused or defocused.

During my stay at LENS I also carried out an experiment on creation of squeezed states of the condensate in the phase space of positions and momenta. We measured both squeezing and increasing of the uncertainties in both positions and momenta, by absorption imaging and Bragg spectroscopy, respectively.

The two experiments described above became the basis of my PhD dissertation "Collective effects in a cloud of cold, dense atoms", which was defended in 2003 at the Faculty of Physics, Astronomy and Applied Computer Science of the Jagiellonian University. My PhD degree was awarded cum laude.

My further cooperation with the group of prof. M. Inguscio resulted in creation of the so-called bright soliton. The results were reported in the publication [O4].

In 2003-2006, as an assistant lecturer in the Photonic Department of the IF UJ, I participated in construction of the first optical dipole trap (ODT) in Poland in the IF UJ and the first set-up of the Bose-Einstein condensate in Poland, in National Laboratory of Atomic, Molecular and Atomic Physics (KL FAMO). The construction of the ODT was described in the publication [O6].

Since 2006, as an assistant professor in the Institute of Physics of the Nicolaus Copernicus University, I continued the work on the Bose-Einstein condensation set-up. The condensate was obtained in 2007. Since that time I have been the primary investigator in the experimental group at KL FAMO investigating this new, extraordinary state of matter. That achievement and further research of the Bose-Einsten condensate have been described in the monothematical set of publications [H1-H6]. The results were also presented at twelve conferences and three invited lectures at conferences [R1-R3].

In 2010 I started the collaboration with the group of Pierre Lemonde and Jérôme Lodewyck from SYRTE-l'Observatoire de Paris (Sytèmes de Référence Temps Espace) in France. As a postdoctoral fellow I spent one year in Paris working with a set of two optical lattice atomic clocks. We studied the shifts of the clock transition frequency due to the lattice light at the fractional uncertainty of 10^{-17}. The results were reported at five conferences and in the publication [O9]. We also measured the influence of the dc Stark effect, caused by residual charges on dielectric materials inside the vacuum, on the clock transition frequency. The results and the method for controlling this effect was published in [O13]. The cooperation continues under the "Pollonium" and TEAM FNP programmes. In the recent years, one MSc and three PhD students from KL FAMO worked at SYRTE and two researchers and two PhD students from SYRTE visited my group at KL FAMO. The measurements from the last three years were reported at two conferences and joint publications [O10, O12, O15] which described the experimental realisation of an optical second with the strontium lattice clocks with precision limited only by the best possible realisation of the SI second.

At present I am the primary investigator of the experimental group at KL FAMO. Our group is currently involved in three experimental projects:

- The experimental studies of the Bose-Einstein condensate. We are investigating the possibilities to create cold molecules by the photoassociation close to the narrow two-photon transition 5S-7S in rubidium. We measured the frequency of this transition with the optical frequency comb with the accuracy an order of magnitude better than previously known values. That result was reported at three conferences and in the publication [O16].
- Design and construction of the experimental set-up for creation of cold molecules in the double species (mercury and rubidium) trap. Most recent achievement was the successful magneto-optical trapping of the cold mercury atoms (up to now only four other groups in the world reported mercury MOT). Results to date were presented at two conferences.
- Design and construction of the frequency standard with atoms of strontium isotope 87 in the optical lattice for the programme Polish Optical Atomic Clock (POZA). The project is carried out in collaboration with colleagues from Jagiellonian University and Warsaw University. We reported out results in two conferences and in the publications [O11, O14, O17].