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EDITORIAL

The scientific career of V S Letokhov (10 November 1939–21 March 2009)

Guest Editor

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Vladilen Stepanovich Letokhov, a prominent scientist in the field of laser physics and its applications, died on 21 March 2009.

The scientific career of Letokhov began in the third year of his studies at the Moscow Physico-Technical Institute (MIPT) through investigations in the P N Lebedev Physical Institute (LPI; Russian Academy of Sciences). At the time, MIPT was an elite-level-of-education institute, training researchers for a wide range of professions—from fundamental physics to aeromechanics. In LPI, Letokhov got, for the first time, some idea of the incipient, radically new field of physics—lasers. He was a student in the Institute's Optical Laboratory, where studies on quantum electronics were just beginning. Major investigations were focused on these at the Laboratory of Oscillations, in which worked Alexander M Prokhorov and Nikolay G Basov, the future Nobel laureates in physics (together with Charles H Townes, 1964) for their discovery of principles of quantum electronics (lasers and masers) (see figure 1).

At that time, a splendid seminar on quantum radiophysics was held at LPI under the direction of Prokhorov. It was at the LPI Laboratory of Oscillations' famous seminar that the first contact was made between Letokhov and Prokhorov. In his book of memoirs, Letokhov describes the meeting, which significantly determined his scientific destiny, as follows: '…It was winter of 1961–1962. Then a fifth-year student in optics at the radiophysics department of MIPT, I spent two or three days a week at LPI. My favorite place in LPI was not the optical laboratory, but a small cosy room in the reading hall in the main building of LPI. There I read the first articles on nonlinear optics by Peter Franken—about the generation of second harmonic in the pale-blue region while focusing red-color ruby laser pulse in a quartz crystal. In his papers for the prestigious journal *Physical Review Letters*, Franken observed that the intensity of the second harmonic varies noticeably with the change of quartz crystal position. I perceived that the reason for the variations has to do with a difference in the velocity of blue and red light propagation due to the quartz crystal dispersion. Simple calculations confirmed the consideration. I told my professor at the LPI's Optical Laboratory about the reason, but my interest in a "side problem" did not meet a positive reaction. Since I was a persistent student, after the next LPI Laboratory of Oscillations' seminar, directed by Prokhorov, I came up to him in a corridor, related briefly the essence of the idea and asked his permission to speak at the seminar. The reaction of Prokhorov was instantaneous: "Speak, but take into account that our seminar is a serious one" … .'

In the 1960s, Prokhorov's seminar was a great school and *scenery* for Letokhov, where just in front of his eyes science was made, where science's front line passed. The seminar was headed by two people: Prokhorov and Basov. Their relationship was tinctured by competition which stimulated scientific activity, particularly in application fields.

At the LPI's Optical Laboratory, Letokhov carried out his theoretical diploma work on the statistical theory of photoheterodyning of incoherent and coherent light, which he successfully defended in the spring of 1963. The most interesting result was his interpretation of spatial effects in light heterodyning. Later he published his thesis. The same results, obtained independently in the USA by Anthony E Siegman, are known as *antenna theory*.

That same year, Letokhov began a postgraduate course, headed by Basov (figure 1) at the Laboratory of Quantum Radiophysics. His first impressions about

Figure 1. The first scientific teachers of Letokhov (center): Prokhorov (left) and Basov (right).

the laboratory were the spirit of creative work, the search for new solutions and the scientific competition of ideas with American scientists. Basov was possessed by new ideas. At that time (the early 1960s) Basov was carried away by the ideas and potential of semiconductor lasers, which had just been created—in many respects owing to his ideas. (It is to semiconductor lasers that Basov dedicated his Nobel lecture in 1964.) In these, as well as in subsequent undertakings (laser thermonuclear fusion, laser weapons, etc), Basov put the cart far (several decades) before the horse. Later on, Letokhov wrote in his book of memoirs: 'I also caught his *ailment* from my teacher. The spirit of almost everyday discussions directly next to a laboratory facility (I had become a *theorist* by then) was very interesting and productive, it often started from the very fundamentals of quantum electronics, i.e. from the number of photons in one mode of electromagnetic radiation.'

I, in turn, still remember Letokhov's words: '… I can advise young investigators—it is best to begin your careers as post-graduates or PhD students in the most advanced research groups. Then you automatically find yourselves on the front line of investigations and, if you have adequate faculties, you can display them exactly in the front-line investigations.'

While still a post-graduate, Letokhov demonstrated his amazing ability to *lase* ideas. Here is an example. Basov was possessed by the problem of laser thermonuclear fusion. To do this, powerful nanosecond laser pulses were required. Basov's laboratory started to devise a unique facility—a multistage amplifier for nanosecond pulses of a Q-switched ruby laser. However, even switching on the first two amplifying stages presented unexpected difficulties: despite the precautions taken to optically isolate the amplifiers, they easily switched into a self-excitation mode, i.e. instead of an amplification mode they developed a generation one due to spurious feedback from accidental reflections. A surprising thing was that this occurred even when they inserted a sheet of lusterless white paper, which was used as a test screen for optical adjustment of the chain of amplifiers. An explanation given by Letokhov for the observed effect was as follows: the radiation scattered backwards from the diffuse reflector was enough to exceed the threshold of generation. He called this effect a *non-resonant energy feedback*, distinct from usually utilized resonant feedback in the open Fabry–Pérot cavity, where the feedback is achieved with the phase preservation of the light field reflected from a mirror (figure 2). This resembles a nuclear reactor where feedback is achieved by the backward scattering of neutrons, owing to which the critical radius of a chain reaction develops in the nuclear reactor. This work was forgotten for a long time, but 20 years later it was revived under the name *random laser*.

One line of research in the Laboratory of Quantum Radiophysics was microwave generation with high frequency stability (atomic clock). Seeing that Letokhov coped rather easily with current, seemingly complicated tasks, Basov steered him to the problem of lasers with high frequency stability. He probably foresaw the future development of laser optical standards. The main limitation was Doppler broadening of spectral lines with relative width $\Delta\omega/\omega_0 \simeq 10^{-6}$. Therefore, to obtain the frequency stability at a level of 10^{-12}–10^{-13}, it was necessary to have a spectral

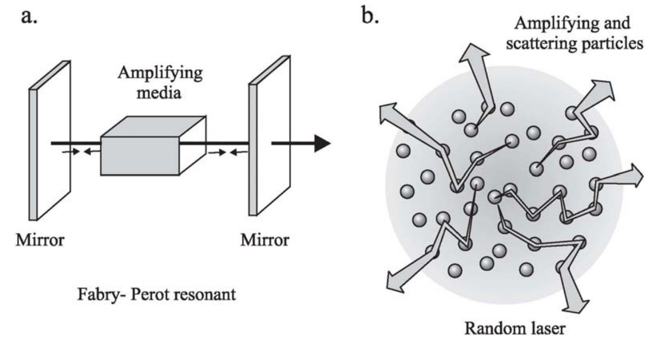

Figure 2. Sketch showing the *random laser* principle of operation: one of Letokhov's first work-ideas.

Figure 3. Letokhov and Chebotaev: more than 20 years of friendship and partnership.

resonance with a relative width of at least 10^{-9}–10^{-10}. It is clear that one had to find a method to eliminate the Doppler broadening.

Letokhov arrived at the idea of using the Lamb dip in CH_4 in an absorption cell placed inside the resonator of a 3.39 μm He–Ne laser. Two years later the idea was realized by John Hall at the National Bureau of Standards in Boulder, USA. Independently of Letokhov, Veniamin Chebotaev from the Novosibirsk Institute came to a similar idea. Afterwards, Letokhov and Chebotaev became good friends, worked together on the problem of narrow optical resonances and lasers with high frequency stability, and wrote several works together, including the joint monograph *Nonlinear Laser Spectroscopy* (1977). Later on, for their joint works they were awarded the Lenin Prize in science and technology, the most prestigious one in the USSR (figure 3).

It was then that a more radical idea emerged of the necessity to completely suppress Doppler broadening for all quantum transitions in atoms and molecules. This resulted from the paper by Daniel Kleppner and Norman Ramsey on the hydrogen maser with an accumulating bulb which eliminates Doppler broadening in the 21 cm line in accordance with the Lamb–Dicke idea of atomic motion in a region smaller than the wavelength of radiation. The challenge was to realize the situation in the optical region with wavelength less than 1 μm. Letokhov was the first to suggest the idea of utilizing the potential gradient force to localize an atom. The potential barrier for moving atoms was many orders smaller than their thermal energy, and the effect could be observed only for a small fraction of the atoms moving almost parallel to the front of the light standing wave. The idea was realized in full and was widely taken up only after the invention of laser cooling of atoms. At present, an ensemble of atoms localized in a light standing wave is called an *optical grating*, and it is of great importance for modern fundamental and applied research. Letokhov managed in 1968, with some difficulty, to publish the idea.

In the autumn of 1969, Basov suggested that the Foreign Department of the Academy of Sciences should send Letokhov, within the framework of the scientific exchange between the Soviet and American Academies of Sciences, on a three-month visit to the laboratory of Ali Javan at the Massachusetts Institute of

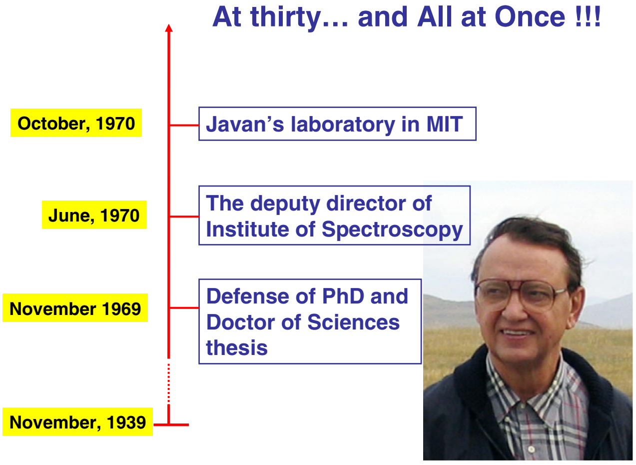

Figure 4. The two years 1969 and 1970 were vital ones in the scientific career of Letokhov.

Figure 5. Javan and Letokhov: 30 years after their first meeting at MIT.

Technology (MIT), USA. That same year, Sergei L Mandelshtam, who had just established, not far from Moscow, a small Institute of Spectroscopy of the USSR Academy of Sciences, suggested he set up a Department of Laser Spectroscopy and become his scientific deputy. That same year Letokhov defended his candidate thesis (PhD) and simultaneously he was conferred a Doctor's degree. It was certainly not a normal occurrence for a 30-year-old junior researcher to obtain this position at such a prestigious institute as the LPI (figure 4).

Letokhov's three-month visit to the laboratory of Javan (figure 5) started in October 1970. Javan headed the group 'Optical and IR lasers' in the Department of Physics. Javan's scientific biography included the creation of the first He–Ne laser back in 1960. At that time he was considered one of the world leaders in laser physics and his laboratory was one of the most advanced ones in the USA. Intensive research on laser spectroscopy was conducted there. Javan's right-hand man in this research was his young assistant, Michael Feld, with whom later Letokhov was connected during many years of fruitful cooperation. Undoubtedly, that visit to MIT was of decisive importance for Letokhov's formation as a scientist. He always considered MIT his other *alma mater*. During those three months, Letokhov learned a lot at the laboratory and at MIT on the whole. For many years he maintained friendly relations with Javan and Feld despite all subsequent mutual problems between the two countries.

One of the *highlights* of Letokhov's visit to the USA was his meeting with Kleppner, the head of the MIT group of atomic physics, who carried out very interesting experiments with beams of hydrogen atoms in magnetic fields, spin-dependent scattering of atoms, etc.

Figure 6. Townes (right) and Prokhorov (left) during their visit to the Institute of Spectroscopy, Troitsk, Russia.

At the end of his stay in Javan's laboratory, Letokhov got an opportunity to visit other advanced US laser laboratories: the National Bureau of Standards (NBS) in Boulder, University of California at Berkeley, Stanford University, etc. In Boulder, Letokhov met John Hall, the future Nobel laureate, an American pioneer and enthusiast of frequency-stable lasers.

In Berkeley, Letokhov met Townes, who back in 1964 together with Basov and Prokhorov had been awarded the Nobel Prize 'for fundamental research in quantum electronics'. Later on, Letokhov regularly met him in Russia and the USA, and corresponded with him for 40 years (figure 6).

By that time Townes had switched over entirely to astrophysical investigations, especially to the radiospectroscopic search for molecular astrophysical masers. At his seminar at Berkeley, Letokhov described his model of non-resonance feedback in space masers due to scattering. Townes agreed that the scattering of microwave radiation could be of great importance for the transformation of a space maser amplifier into an oscillator. Much later, Letokhov would return to laser effects in outer space—astrophysical lasers.

Another *highlight* was his visit at Stanford to the groups headed by Arthur Schawlow, Steve Harris and Siegman. There he became acquainted with the experiments of Theodor Hänsch on the spectroscopy of cross-saturation of absorption in an I_2 cell with the use of a krypton laser. These were initial experiments, which later turned into excellent precise experiments on the hydrogen atom with the use of tunable dye lasers.

The last of the *highlights* was his visit to the laboratories of Nicolaas Bloembergen at Harvard University, to William Bennett Jr at Yale and to the Bell Laboratories at Murray Hill and Holmdel, New Jersey.

At Yale, Letokhov met for the first time Willis Lamb, whom he saw many times afterwards at the University of Arizona in Tucson. Lamb was continuing to investigate the 'Lamb shift' in atomic hydrogen and hydrogen-like ions in a magnetic field. Later, Lamb visited Moscow, the Institute of Spectroscopy and Letokhov's house in the village of Puchkovo near Troitsk (figure 7).

For Letokhov the Bell Laboratories were, according to him, *smithy* for many laser inventions and high-class research, beginning with the invention of the He–Ne laser by Javan, Bennett Jr and Donald R Herriott. The visit to the Bell Laboratories impressed Letokhov immensely.

Summing up his trip to America, Letokhov wrote in his book of memoirs: 'As a result of the whole three-month tour around the most advanced laser research laboratories of the USA, I got quite a clear idea about the front line of research. Besides, I saw that the laboratory equipment for laser investigations differs considerably from ours... I profited also from the cases of critical attitude shown by American scientists regarding some LPI work. In particular, many of them were amazed by the engineering and technical orientation in a number of LPI's laser

Figure 7. Lamb with Letokhov's wife, Tina Karu, during Lamb's visit to the Institute of Spectroscopy (in Letokhov's house).

research projects. In the USA, such work was conducted at firms with professional advice from university scientists. Inwardly I agreed with the estimations and tried to refrain from these mistakes in my future laboratory. In this connection, I can give a piece of advice to the young professors setting up their laboratories for new lines of inquiry: make a many-month tour around the best international laboratories to adopt practical experience, methods of investigations, etc, to develop your own avenue, your original ideas.'

After his return from the USA, Letokhov got a unique opportunity to realize his earlier ideas and those generated during the trip. He had seen a dozen of the best laser groups in American universities and companies. This experience was very valuable in many respects—from organizational and technical to scientific ones.

The scientific work at the Institute of Spectroscopy was launched in two main areas: methods of laser spectroscopy and photoselective action of laser radiation on atoms and molecules. Over the course of ten years, the Department of Laser Spectroscopy, headed by Letokhov, was shaped with a total staff of about 40 people, mostly students and postgraduates of MIPT. It constituted roughly one quarter of the Institute's personnel, i.e. was fully autonomous and a viable part of the Institute: it became an important part of the laser community of the USSR. Avenues of investigations on laser spectroscopy were rather diverse and addressed the main problems of optical spectroscopy, which could not be solved by the methods of classical spectroscopy:
(i) achievement of limiting spectral and temporal resolution, (ii) elimination of Doppler broadening and (iii) attainment of ultimate sensitivity. Long-term development of these scientific directions resulted in the birth of a new application of laser radiation, which was called *laser control of atoms and molecules*. Later on, Letokhov wrote a book *Laser Control of Atoms and Molecules*, where he summed up much of the work in the area.

Basic experiments on the laser control of atoms and molecules were commenced by his collaborators, who came with Letokhov from LPI: Rafail V Ambartsumian, Peter E Kriukov, Sergei N Chekalin, as well as graduates of MIPT: Victor I Balykin, Georgy I Bekov, Vyachislav I Mishin, Evgeny A Ryabov and others. In 1971–1973, two key experiments were conducted: isotopically selective two-step ionization of rubidium atoms and isotopically selective two-step (IR+UV) photodissociation of simple molecules HCl and NH_3 (figure 8). These experiments attracted the widespread attention of the international community to the problem of laser isotope separation. Nowadays, it looks rather obvious to enhance the selectivity of photoionization and photodissociation by means of two laser photons. The first experiments were made in the Department of Laser Spectroscopy with rubidium atoms and ammonia molecules.

Afterwards, experiments on isotopically selective ionization of atoms formed the basis for the programs of laser isotope separation in uranium atom vapor (atomic-vapor laser isotope separation (AVLIS)) at the Lawrence Livermore National Laboratory (LLNL) and, to a lesser extent, in many other countries (figure 9). In

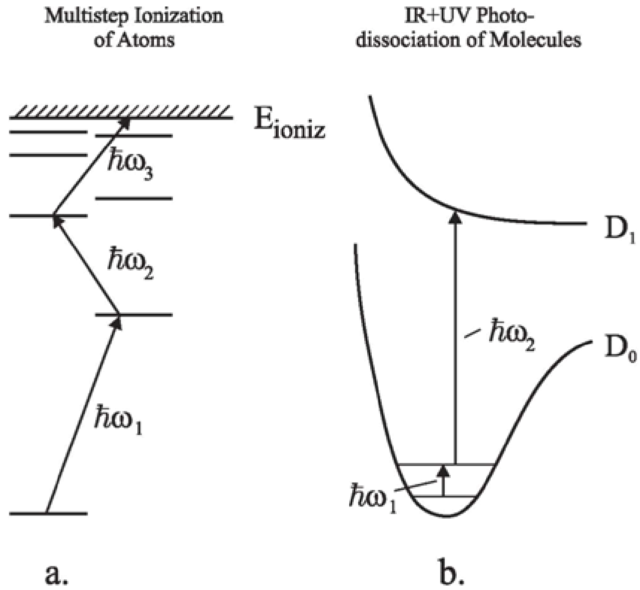

Figure 8. Enhancement of the selectivity of nonresonant photoionization and photodissociation processes by means of two laser pulses.

Figure 9. The method of laser separation of atoms and molecules was a subject of long and productive cooperation between Letokhov and Moore.

scientific respects, the method of selective ionization of atoms later proved to be very promising as applied to the resonance-ionization detection of single atoms, especially rare-earth short-lived radioactive ones, including laser separation of isomeric nuclei.

An important application of resonance-ionization spectroscopy (RIS) was the analysis of traces of elements in natural materials with a complex composition, such as seawater, ores, soils and biological tissues. This opened up new possibilities to study the distributions of ultralow concentrations of rare elements in the Earth's crust and seawater and, consequently, provided deeper insight into the geological history of the Earth. At present, the RIS method makes it possible to detect traces of elements with sensitivity at the level of 1 ppt (10^{-12}). An expeditionary version of the spectrometer was installed by scientists of the Institute of Spectroscopy and the Institute of Oceanology RAS on board a research ship to measure ultralow concentrations of noble metals in seawater, and during a world cruise it was utilized to estimate concentrations of gold and platinum metals in seawater, suspension, sediments, minerals and sulfide ores (figure 10).

RIS for research on short-lived radioactive atoms turned out to be most fruitful. Having comprehended its potential, Letokhov started successful experiments—at first in cooperation with the Leningrad Institute of Nuclear Physics (Laboratory at

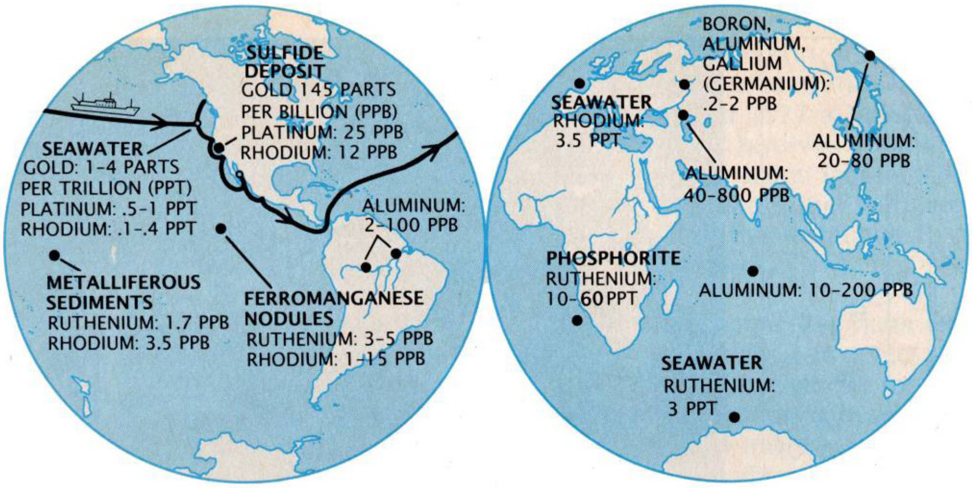

Figure 10. Multistep ionization of atoms became the most sensitive method for the measurement of trace elements in seawater, river water and various sediments. A resonance-ionization spectrometer on board a research ocean ship made a cruise to measure trace elements in seawater.

Gatchina) and then with the European Organization for Nuclear Research (CERN, Geneva).

The effects of resonance photodissociation and isotopically selective photodissociation of polyatomic molecules by powerful IR-laser radiation, discovered at the Department of Laser Spectroscopy, became the subject of extensive experimental and theoretical work and discussions at conferences. Everyone was attracted by the tempting similarity of the SF_6 and UF_6 molecules. Since a high isotopic selectivity in SF_6 isotope separation with the use of a simple CO_2 laser was demonstrated, at that time the effect seemed to be repeated with uranium isotopes in the UF_6 molecule with use of a 16 μm IR laser. Such lasers were available, but then, at the supersonic expansion of a UF_6 molecular jet, the utilization of gas-dynamic cooling was required to simplify the vibration–rotation spectrum of the molecule. Powerful laboratories in the USA, Japan, Germany, etc, joined in these investigations, and they involved a great deal of expenditure.

Pioneering work in the Department of Laser Spectroscopy on isotopically selective multiphoton dissociation of molecules made it possible to create afterwards the world's first experimental factory for laser separation of carbon isotopes.

In the flourishing period of the Institute in the 1970s, many scientists from all over the world expressed a wish to visit the Department of Laser Spectroscopy. Our Department, in cooperation with other laser laboratories, began to hold international conferences in various cities of the country (Moscow, Novosibirsk, Vilnius, Samarkand, Baku, etc). These annual undertakings were visited by hundreds of scientists from different countries, many of whom, naturally, also called in to Institute. Many of them became Letokhov's friends for many years: e.g. Bradley Moore (University of California, Berkeley), Herbert Walther (Munich and Max Planck Institut, Garching), Fritz Schäfer (MPI of Biophysical Chemistry, Göttingen) and Gisbert zu Putlitz (Heidelberg).

Later on, during the period of financial crisis in our science in the 1990s, wide personal international connections of the Institute became essential. Letokhov's colleagues from the USA organized substantial financial assistance to the Institute within the framework of collaborative scientific projects. Of particular value was the assistance from the laser department of the Lawrence Livermore National Laboratory of the USA Department of Energy and the USA Department of Defense through the University of Arizona in Tucson (Franken).

One of the remarkable achievements of the Department of Laser Spectroscopy of the Institute of Spectroscopy was laser control of atoms: laser cooling and trapping of atoms. First, as far back as at the LPI's Laboratory of Quantum Radiophysics, when Basov had advised him to tackle the problem of lasers with high frequency

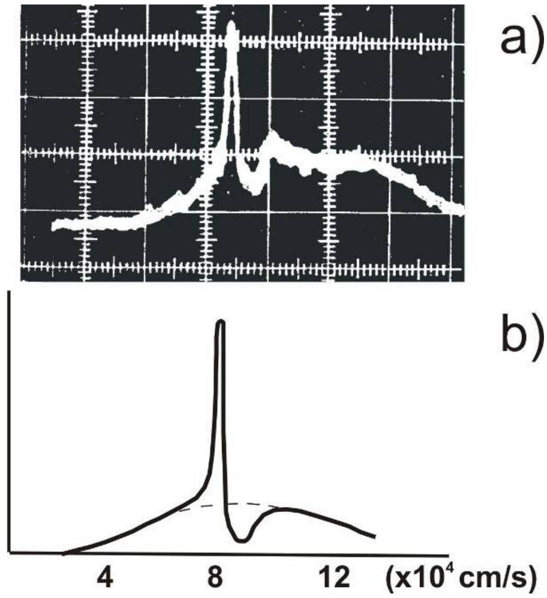

Figure 11. The first cooling of sodium atoms by laser light: (a) the experimental curve showing a decrease of temperature from 600 K to 1.5 K; (b) theory.

stability, Letokhov came to the idea of the possibility to act directly on the translational degree of freedom. The main limitation was Doppler broadening of spectral lines. It was necessary to find a method to eliminate the Doppler broadening.

The absence of high-potential barriers for localization of atoms stimulated the scientific community to look for ways to reduce the kinetic energy of the ensembles of neutral atoms. After the first suggestion to cool neutral atoms by their all-round irradiation with laser light from the *red* wing of the Doppler line (Hänsch and Schawlow, 1975), intensive theoretical work on laser cooling of atoms began at the Institute of Spectroscopy. Calculations showed that laser cooling has a limiting temperature, which for an allowed radiative transition of a two-level atom is in the neighborhood of a millikelvin. Much later, it turned out that, utilizing forbidden transitions, it is possible to provide still greater cooling of atoms—down to nanodegree kelvin temperatures, i.e. lower than the temperature determined by the recoil velocity.

In 1978, Letokhov succeeded in inspiring me (then his PhD student) with new ideas of laser cooling of atoms. In our situation the problem seemed to me absolutely intractable: we had one home-made cw tunable dye laser and one commercial Spectra-Physics argon laser. The case in point is that it was the world's first experiment on laser cooling of atoms, which I had started in 1976–1977! We managed to cool a beam of sodium atoms lengthwise by a factor of 400: from the initial temperature 600 K to 1.5 K (figure 11). This was followed by an experiment by William Phillips's group with collaborators at the National Institute of Science and Technology (NIST; Gaithersburg), experiments of Stephen Chu's group at the Bell Telephone Laboratories (Murray Hill) and subsequent *outbursts* of work. Additionally, the first experiment on transverse cooling (collimation) of a sodium atomic beam down to 35 millikelvin was carried out in our laboratory. This was accompanied by many experiments on atom optics with the use of laser light, first conducted here at that time.

In 1981, Letokhov and Minogin, prior to the appearance of their first work abroad, published a review on laser pressure on atoms and later—their first book, *Laser Light Pressure on Atoms*, containing many predictions and calculations essential for the development of this direction in the future.

Long ago, the interconnection of atomic and nuclear physics had been brought to light on the basis of hyperfine interactions and isotope shifts in atomic spectra. From the very beginning of experiments on laser spectroscopy, Letokhov considered laser radiation as an effective instrument of nucleo-physical research for those cases when high sensitivity at the level of single atoms (rare isotopes, short-lived nuclei) and high spectral resolution of optical spectral transitions are required. After the progress in laser separation of atomic and molecular isotopes, Letokhov made a proposal about the possibility to separate by laser radiation not only isotopes of atoms with nuclear ground states, but also atoms with long-lived isomeric nuclei. An atom with an isomeric nucleus has a different hyperfine structure of spectral lines, resulting from the large spin of the excited nucleus. This difference can be used for the separation of isomeric nuclei by the method of laser resonance ionization. Letokhov published the idea back in 1973. The paper attracted the attention of Edward Teller, who highly appreciated it in his invited report on laser separation of isotopes (Vail, USA, 1973). The idea was also closely related to the problem of creation of a γ-laser on stimulated transitions of excited nuclei. Letokhov suggested that the separation of excited (isomeric) and non-excited nuclei by laser radiation (by analogy with separation of excited and non-excited NH_3 molecules in the first maser) should be utilized.

Another of Letokhov's *laser-nuclear* ideas was related to the possibility of controlling the spectral line of γ-radiation with the use of laser excitation by the so-called mixed quantum transitions of the nucleus in an atom or a molecule. As is generally known, the displacement between the lines of emission and absorption of a γ-quantum by a nucleus exceeds Doppler broadening. The recoil energy of the nucleus in an atom or a molecule should be transferred to the electron shell of the atom or to oscillations of the molecule. Because of this, γ-lines may have electron or oscillation satellites. Laser radiation can excite the electron and oscillation state and thus change the structure of the spectral satellites. This *intersection* of laser and nuclear spectroscopy, which was actively discussed by Letokhov in the scientific literature, is still unrealized.

Letokhov was the generator of many remarkable ideas. In many cases the Department of Laser Spectroscopy implemented them. Approximately one out of every several dozen of his ideas was selected at the time and proved successful. Many of them, apparently, are still waiting for their time to come! One of those is laser photoelectron microscopy. In experiments on resonance ionization of atoms and molecules by laser pulses, the place of a photoelectron (or a photoion) ejection is localized in space with nanometric accuracy. Therefore, utilizing the methods of projection photoelectron microscopy—such as Erwin Müller's field-emission one—it is possible to obtain on a screen a 100 000 times magnified image of the sample surface, which ejected photoelectrons or ions. One of the breathtaking applications could be selective photoionization of chromophores, attached to specific bases of DNA, and the resulting direct-image plots of single DNA molecules. Many problems are on the way to being solved. One of them is the thermal desorption of molecules under laser light. Our department implemented work on photodesorption of certain chromophores of biomolecules under powerful femtosecond laser pulses, but it is still doubtful whether this method will be suitable for laser visualization of biomolecules.

The spectrum of Letokhov's scientific interests was extraordinarily wide. One of his convictions was: 'The periodic change of subject for a scientist, a change of scenery and surroundings are his only benefit.' In the years of *perestroika slackening*, astrophysical lasers became his principal scientific interest. Pining after his youth, he called it 'my first and last passion' (figure 12). In his student years (the early 1960s) he bought a used book, *Lines of the Chemical Elements in Astronomical Spectra* (1956) by Paul W Merrill, translated into Russian. In his book of memoirs Letokhov writes: 'While reading Merrill's book, I came across many interesting observations on mysterious stellar spectral lines. Evidently, they were caught by my long-term memory and by my subconscious. Later on, in the early 1970s, these facts came up from my memory with the obvious surmise of possible connection between these mysterious lines and laser effects.'

It should be noted that the discovery of lasers in outer space was quite nontrivial, since in the visible region spontaneous emission prevails and masks a possible induced one. Onset of an inverted population in atomic and ionic transitions, which is necessary for laser action, is much less probable than for molecular transitions in the microwave region.

Figure 12. Letokhov's first and last passion: astrophysics (Sweden, 2008).

In 1972, Letokhov presented to the Montreal International Quantum Electronics Conference (IQEC-1972) a report on the hypothesis of the existence of astrophysical lasers, and afterwards he discussed the issue in several articles. They went unnoticed. Much later, in 1986, gas condensations were found in the neighborhood of the stellar system Eta Carinae and the spectrum of their radiation was measured by the Hubble Space Telescope. It turned out that two lines of UV radiation of the iron ion condensate were abnormally bright. The density of these condensations is high for the interstellar medium, and they are situated only several hundreds of radii from the central star: they are therefore subject to action (optical pumping) by the intense radiation from the central star. Thus arose the idea of an astrophysical laser. This was corroborated later in joint work with Sveneric G Johansson (Lund University). Research on astrophysical lasers and nonlinear optical effects was summed up in the book *Astrophysical Lasers* by Johansson and Letokhov (2009).

Letokhov made a profound impact on so many aspects of science. His scientific heritage is enormous; it is represented in more than 850 scientific publications and 16 monographs. The memory of Letokhov will always remain in the hearts of all those who admired his remarkable talent as researcher, inventor and teacher.

According to data from the Institute of Scientific Information (Philadelphia, USA), Letokhov is the most frequently cited Russian scientist in all fields of science in the period 1973–88 (Pendlebury D 1990 *The Scientist* **4** 18).

Curriculum vitae

Name Vladilen S Letokhov

Born 10 November 1939, Irkutsk, Siberia, USSR

Education
1957–63 Moscow Physical-Technical Institute, Dolgoprudnyi
1963–6 P N Lebedev Physical Institute: graduation under Professor N G Basov

Professional Experience
P N Lebedev Physical Institute
- Researcher (1966–70)
- PhD (1969)
- Degree of Science (1970);

MIT Cambridge, Visiting Professor (1970);
Institute of Spectroscopy of USSR Academy of Sciences, Troitsk
- Associate Director for Research (1971–89)
- Head of Laser Spectroscopy Department (1970–2009);

Moscow Physical-Technology Institute, Dolgoprudnyi, Professor of Quantum Optics (1972–2009);
University of California, Los Angeles, Blacet Lecturer in Physical Chemistry (1989);
Israel Academy of Sciences, James Franck Lecturer (1989);
Universität Bayreuth, Emil Warburg Lecturer (1990);
University of Iowa, Ida Beam Lecturer (1990);
Cleveland Clinic Foundation, International Visiting Professor (1991);
University of California, Berkeley, Regent Professor (1993);
Université Paris-Nord, Visiting Professor (1993–96);
University of Arizona, Visiting Professor (1996–97);
Ecole Normale Supérieure, Paris, Visiting Professor Condorcet Chair (1998);
Lund University, T Erlander Professor (2000);
Lund University, Lund Observatory, Visiting Professor (2001–2009)

Awards
Lenin State Prize for Science and Technology (1978);
Honorary Jubilee International Medal of the 600 Year Anniversary of Heidelberg University (1986);
Docteur Honoris Causa, Université Paris-Nord (1995);
Quantum Electronics Prize of the European Physical Society (1998);
Rojdestvenskii Prize of the Russian Academy of Sciences (2001);
State Prize of the Russian Federation in Science and Technology (2002);
Doctor Honoris Causa, Lund University (2004)

Coeditor
Lasers Sciences and Technology; *Journal of Laser Chemistry*; *Lasers in the Life Sciences*; *Journal of Nonlinear Optics*

Member of editorial boards
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Associations
Fellow of the American Optical Society (1977);
External Member of the Max Planck Society (1989);
Member of the European Academy of Arts and Sciences (1996);
Fellow of the World Innovation Foundation (2000);
Member of European Academia (2002);
Member of the Leibniz Society, FRG (2003)

Publications
More than 850 scientific articles and 12 monographs in the field of laser physics, spectroscopy, chemistry and biomedicine

V S Letokhov's publication list

1. Vatzura V V, Letokhov V S and Pukhlik Yu A 1962 Photoelectronic system for monitoring the direction of a linear image element *Opt.—Mekh. Prom.* **6** 29–32 (in Russian)
2. Letokhov V S 1963 Statistical image analysis *Opt.—Mekh. Prom.* **11** 7–12 (in Russian)
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4. Vatzura V V, Letokhov V S, Plotnikov V S, Andreyev M I, Pukhlik Yu A and Sveshnikov V V 1964 Electron-optical vibration detector *Opt.—Mekh. Prom.* **3** 24–7 (in Russian)
5. Letokhov V S 1964 On the measurement of oscillation frequency fluctuations by the delay line technique *Radiotekh. Elektron*. **9** 1628–33 (in Russian)
6. Vatzura V V, Letokhov V S and Pukhlik Yu A 1964 Astroguide *Pribor. Sreds. Avtomatizatsii* **12** 37–41 (in Russian)
7. Letokhov V S 1965 Spatial effects in optical wave heterodyning *Radiotekh. Elektron*. **10** 1143–5 (in Russian)
8. Basov N G, Belenov E M and Letokhov V S 1965 Diffraction locking of laser oscillators *Dokl. Akad. Nauk SSSR* **161** 556–9 (in Russian)

9a. Basov N G, Belenov E M and Letokhov V S 1965 Synchronization of oscillations in a semiconductor laser having several p–n junctions *Fiz. Tverd. Tela* **7** 337–9 (in Russian)

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12a. Letokhov V S and Markin E P 1965 On the statistics of laser radiation *Zh. Eksp. Teor. Fiz.* **48** 770–1 (in Russian)

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13. Letokhov V S 1965 Diffraction loss of a cavity formed by mirrors with an absorption stripe *Zh. Tekhn. Fiz.* **35** 809–12 (in Russian)
14. Basov N G, Belenov E M and Letokhov V S 1965 Maximal beam cross section of an optical quantum generator *Dokl. Akad. Nauk SSSR* **161** 799–801 (in Russian)
15. Basov N G, Belenov E M and Letokhov V S 1965 Diffraction locking of optical quantum generators *Zh. Tekh. Fiz.* **35** 1098–105 (in Russian)
16. Basov N G, Ambartsumian R V, Zuyev V S, Kryukov P G and Letokhov V S 1965 Propagation velocity of a powerful light pulse in an inverted medium *Dokl. Akad. Nauk SSSR* **165** 58–60 (in Russian)
17. Belenov F M and Letokhov V S 1965 On the generation of a sharply directed coherent radiation *Opt. Spektrosk.* **19** 465–7 (in Russian)
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21. Ambartsumian R V, Basov N G, Kryukov P G and Letokhov V S 1966 A laser with a nonresonant feedback *Pis. Zh. Eksp. Teor. Fiz.* **3** 262–4 (in Russian)

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