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Mikhail Tretyakov's scientific legacy☆

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ABSTRACT

Mikhail Yurievich Tretyakov (1958–2024) was a leading spectroscopist working at terahertz and microwave wavelengths. He made substantial advances in sub-millimeter spectrometers and performed spectroscopic studies on isolated gaseous, molecular complexes and, in particular, the water dimer. He also studied molecular interactions and line shapes, using them to develop ideas about the physics of the water continuum. In this memorial paper, we review Mikail Tretyakov's life and his major scientific achievements.

Contents

1. Introduction

Mikhail Yurievich Tretyakov, see Fig. 1, was a talented spectroscopist, coming from the famous Nizhny Novgorod, Russia (called Gorky from 1932 to 1990) school of radiophysics. He made a world-wide recognized contribution to the understanding of the microwave molecular spectra, including the spectra of weakly interacting dimers and the continuum. His scientific interests were in high resolution molecular spectra experimental studies in the millimeter (mm) and submillimeter (submm) wave ranges, as well as the development of new microwave (MW) techniques and methods.

Mikhail Tretyakov passed away on December 14th, 2024 at the age of 66. The end of life of a fit and healthy person at such an age is rarely expected by others. The loss of Mikhail caused a tremendous shock for those who knew him as a very strong and active person both in science and in everyday life. All his life he undertook long-distant hiking through the forests, in the mountains, along the wild rivers in many hardly accessible regions of the vast ex-Soviet Union. He loved that kind of extreme tourism because, like he did in science, he was fond of being able to open new frontiers, which were too difficult to reach at first glance.

Many of his acquaintances called him Misha, the diminutive of his first name. He was an example of an open-hearted person, very easy

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Fig. 1. Mikhail Tretyakov on the Volga river, Nizhny Novgorod, September 2024. Photo courtesy of S. E. Tretyakova.

and pleasant to communicate with. At the same time, Misha expressed much rigor as far as the clearness of the data issued from his lab was concerned; he really detested any kind of bias in interpretation of experimental results, be it of fresh data of his own or results already published in the literature. His scientific reputation was indisputable because the data he published were always reliable and accompanied by the well-thought-out subsequent conclusions.

Misha was an undergraduate at the Gorky State University until 1980, when his MS work was recognized to be “The Best Students Scientific Work” of a year in the USSR. Then he moved to the Institute of Applied Physics, Russian (USSR at that time) Academy of Sciences in Nizhny Novgorod, where he made significant advances in the field of microwave spectroscopy within terahertz spectral range. His Candidate of Sciences (PhD equivalent) thesis work (1995) entitled “Development of methods of microwave spectroscopy in Terahertz frequency range” was supervised by Andrei F. Krupnov. In it he obtained for the first time Schottky diode assisted frequency multiplied emission from the BackWard Oscillator (BWO) up to 1.5 THz and used it to do molecular spectroscopy. Precise broadband spectroscopy within an interval of dozens of GHz was realized using a Phase Locked Loop (PLL) with submillimeter waves. In these early works, Misha demonstrated his brilliant qualities as an experimentalist having profound understanding of the underlying physics.

In 2016, Misha published a monograph entitled “High Accuracy Resonator Spectroscopy of Atmospheric Gases at Millimetre and Submillimetre Waves” [1]. Soon afterwards, in 2017 he obtained his Doctor of Sciences degree (higher grade), also from the Institute of Applied Physics, where he had been Head of the Microwave Spectroscopy Lab since 2005, replacing A.F. Krupnov. The monograph published initially in Russian was then translated into English and published by Cambridge Scholars Publishing in 2021. The same year, Misha was awarded The Ninth Hans Liebe Lectureship in microwave and optical spectroscopy as applied to radio science, remote sensing, and telecommunications.[1] He was the scientific supervisor of several undergraduate and Ph.D. students. Many of them are still successfully working in various scientific laboratories over the world. As a reviewer he served for a number of journals such as Radiophysics and Quantum Electronics, Journal of Chemical Physics, Journal of Molecular Spectroscopy, Molecular Physics, Physical Chemistry Chemical Physics, Journal of Quantitative Spectroscopy and Radiative Transfer, and Canadian Journal of Physics. Between 2011 and 2012 he was a member of the Editorial board of the Journal of Spectroscopy and Dynamics (India), from 2016 to 2018 he was on the Editorial board of the Journal of Molecular Spectroscopy; since 2023 he was on the Editorial board of the journal Atmospheric and Oceanic Optics which is published in Tomsk in Russian and translated into English by Springer.

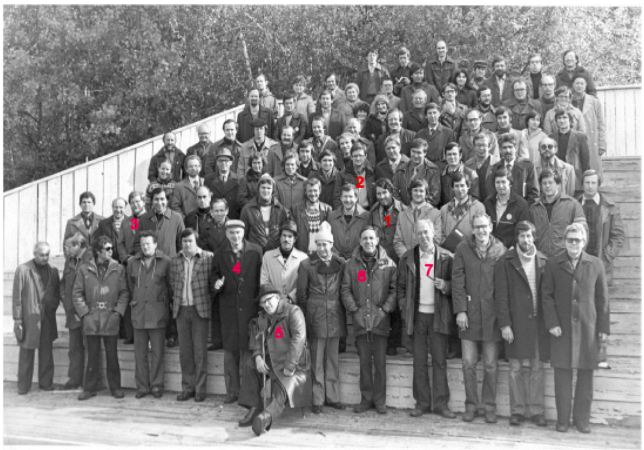

Fig. 2. All-Union Symposium on High and Ultra-High Resolution Molecular Spectroscopy, Tomsk, USSR, 1982. 1 — M.Yu. Tretyakov; 2 — O.L. Polyansky; 3 — A.A. Vigasin; 4 — S.A. Zhevakin; 5 — M.A. Kovner; 6 — A.F. Krupnov; 7 — M.O. Bulanin.

Misha contributed much to the organization and delivery of the international HighRus symposium[2] being held for many years, mainly by the Institute of Atmospheric Optics in Tomsk. He first attended this symposium in 1982, Fig. 2, when the frontiers of the Soviet Union were still virtually impenetrable to both sides.

Soon afterwards, political warming started to be more and more perceptible; this manifested itself first in the legendary Liblice and Dobriš symposia in Czechoslovakia on the high-resolution molecular spectroscopy, in which Soviet and Western researchers have had a chance to enjoy meetings in person. Misha attended several of these meetings with great success. His always brilliant presentations and contacts resulted in numerous visits abroad as soon as Perestroika came to its force. During 1991–1993 he spent several months at NIST (Gaithersburg, USA), then at the universities in Germany (Cologne,1993–1995), France (Lille,1995–1997) and Canada (New Brunswick,2001–2002). In cooperation with colleagues from the Universities of Cologne and Lille, he developed the THz video-spectrometer based on phase-locked BWO and liquid nitrogen cooled bolometer. Also, he was involved in development of the CO_2-laser/MW side-band spectrometer with a slit nozzle (jointly with the University of New Brunswick, Saint John) and in the set-up of the first frequency stabilization of a far-infrared laser against a harmonic of a millimeter-wave synthesizer (jointly with the University of Lille).

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[1] https://usncursi.org/nrsm_videos.php#2022_h_liebe_lecture.

[2] https://symp.iao.ru/en/hrms

Between 1995 and 1998 he was the Russian Principal Investigator of a joint project with Argonne National Laboratory, USA, aimed at developing a mm/submm-wave sweeper and gas analyzer. From 1998 Misha gave invited lectures at HighRus symposiums in Russia (Krasnoyarsk, Irkutsk) as well as at various other meetings abroad (Prague, Bratislava, Qingdao, Bologna, Caserta). His outstanding experimental skills manifested themselves in the building of a synthesizer, based for the first time on frequency stabilization of a subTHz primary radiation source using a femtosecond laser induced comb. One of the top achievements in the field resulted in development of the mm/submm-wave resonator spectrometer for atmospheric absorption measurements (in collaboration with A.F. Krupnov, V.V. Parshin, M.A Koshelev et al.). Much attention was paid to the study of spectra of individual molecules H_2O, H_2Se, SO_2, CF_3H, CH_3CHO, O_2 , OCS at high resolution, as well as to H_2O–HF, $(CH_3OH)_2$, CH_3OH–CO molecular dimers. For the last few years, Misha was deeply involved in studying the nature of continuum absorption. His major achievement in this domain concerns the first ever detection of bound water dimer absorption features at near room temperature [2]. The scientific community vividly appreciated this excellent result.

The first detection of the water dimer spectroscopic fingerprints in equilibrium water vapor deserves some more comments. This discovery is intrinsically connected to the origin of the atmospheric water vapor continuum, whose cause has been debated for many decades. Interestingly, the idea that water dimers could be the carriers lying behind the atmospheric continuum was put forward for the first time in Nizhny Novgorod, Misha's native town, by A.A. Victorova and S.A. Zhevakin [3,4] almost 60 years ago. At that time, this idea was ferociously opposed by Elsasser's hypothesis dated back to the late thirties [5], that connected the origin of a continuum with the cumulative effect of distant line wings in the spectrum of H_2O monomers. In his famous book [6] published in 1964 R.M. Goody claimed that the only reliable hypothesis about the origin of the water vapor continuum is that suggested by Elsasser. It looked like that the two schools of believers would never find any common ground. However, in the early nineties it was suggested that both hypotheses can rightfully be considered as a possible partial cause of a continuum depending on the gas temperature, which is a key factor in statistical balance of various type of molecular pairs [7]. Two extremes – true bound dimers and nearly free pairs of monomers – are linked together by the domain of quasibound dimers which can form in phase space. In this respect, the theory of a continuum is very close to that of the so-called collision induced absorption in gases, the molecules of which have no permanent dipole. Misha was deeply inspired by this concept. With great enthusiasm, he explored these ideas in attempts to prove the validity of such a viewpoint. This resulted in a number of publications concerning interpretation of microwave data thoroughly measured in his lab with trajectory-based simulation of induced spectra in various gas mixtures. Misha was inspired by his aim of confirming this physically justified model and extending it to the description of the water vapor continuum in the atmosphere. The unexpected end of his life deprived him of further advances; this work is now left to his pupils and collaborators.

2. Review of Tretyakov's major scientific contributions

In this section, we review the following themes of Misha's research: Sub-millimeter spectrometers and the improvement in their characteristics; Gaseous spectra of isolated molecules; Molecular interactions, in particular line shapes; Line broadening and shifts; Molecular complexes in the gas phase, and Water dimers in the gas phase.

2.1. Spectrometers, frequency stabilization and sensitivity increases

The first spectrometer designed by Misha [8] was during his diploma work at the Gorky State University under the supervision of A.F. Krupnov. This design was a brilliant idea, which was never actually put into metal for various reasons. At the time Misha joined A.F. Krupnov's laboratory, it had a set of home-made spectrometers capable of conducting high-quality studies of molecular rotational spectra up to 1100 GHz [9], spectrometer with radioacoustic detection of absorption, the so-called RAD spectrometer, with a backward wave oscillator (BWO). This allowed for high-resolution, sensitive observations and the recording of spectra across the entire tunable frequency range. The BWO operated in free-running mode. This spectrometer is very simple in its design and operation, but its frequency scale was determined using the etalon spectrum of a reference molecule. This significantly limited the accuracy of line frequency determination from the experimental spectra. For precision measurements, a RAD spectrometer with a phase-stabilization system for the BWO radiation frequency (which we will call RAD-2) was developed. It allowed for line frequency measurements with a relative accuracy of 10^{-8} in the range up to 600 GHz and 10^{-7} up to 1.1 THz (in BWO-only frequency-stabilized mode). RAD-2 was a very complex spectrometer: in addition to a low-frequency synthesizer, it included a 200 MHz LC-oscillator and three phase-locked loops for the BWO phase stabilization system for the 3-cm, 4-mm, and submm wavelength regions. The home-made submm mixer-multiplier utilized an AsGa point-contact Schottky diode, which had to be frequently adjusted and even replaced to obtain a signal strong enough to operate the submm BWO frequency stabilization system. In addition to the diode issues, the harmonic numbers in all PLL loops had to be manually selected and further verified to avoid errors in determining the molecular line frequencies. For these reasons, the RAD-2 was used only for measuring the frequencies of individual spectral lines, and on average, only five to ten lines were measured per day, while the spectrum could contain thousands.

When the idea for the automated RAD-3 spectrometer emerged [10], (see also [11]), Misha enthusiastically participated in its implementation together with Sergei P. Belov. Their fruitful collaboration resulted in the construction of the RAD-3 spectrometer, which, for the first time in microwave spectroscopy, not only enabled the recording of molecular spectra over a wide-range but also automatically calculated the frequencies of all observed lines in the spectrum under study with an uncertainty of ≤ 1 MHz. Among the technical innovations of the RAD-3, notable was the first use of a package-free planar GaAs Schottky diode, which, in addition to contact stability, ensured operation over a range of several hundreds GHz without any adjustments. Of particular note was the invention of a wide-range active suppressor of high-voltage pulsations on the BWO, which subsequently made it possible to narrow the emission spectrum of the phase-stabilized BWO from 300 kHz to less than 100 Hz. The RAD-3 was successfully used to study the spectra of a number of molecules [12–17] and the HF…HF [11] and HF…H_2O [18] molecular complexes. RAD-3 recordings of the HF…H_2O spectrum are still used to identify lines of the complex in excited vibrational states and with high values of the quantum number K [19].

The modern version of the RAD spectrometer [20] developed by Misha and his colleagues remains a powerful instrument for studying molecular spectra and their characteristics in the mm and submm ranges. Misha pioneered the use of an extra high power microwave radiation gyrotron source for molecular spectroscopy [21–25]. Record-breaking sensitivity for the subterahertz frequency range was demonstrated in the detection of weak, rotational lines in the nonpolar molecule CH_4 obtained using the RAD spectrometer and frequency-stabilized gyrotron radiation [25].

An important and vital part of Misha's scientific work was related to the resonator spectrometer [26–33] which allows accurate and sensitive absorption measurements both in gases and dielectrics. His work with this spectrometer started with the implementation in an existing setup of a modified PLL system to provide a fast phase-continuous scan of the BWO frequency for proper excitation of the Fabry–Perot resonator [26]. This was realized by the use of a radio-frequency direct digital synthesizer (DDS) as a local heterodyne at the intermediate frequency of the phase-lock loop which yielded at least a tenfold improvement in sensitivity compared to the previous spectrometer of Liebe [34] which was in use for studies of atmospheric absorption.

Misha made many improvements which ensured stable conditions for recording absorption spectra using a resonator spectrometer and achieved many results quickly using improvised methods. It all started with the use of a plastic bag near the resonator to minimize the effect of air flows and variations of ambient atmosphere conditions [35]. Stable conditions allowed accurate subtraction of the spectrometer baseline (recorded in pure nitrogen blown through the bag) in atmospheric experiments. The results inspired further development of a climate chamber, based on a household refrigerator, for the resonator equipped by cooling and heating elements which provide an experimental temperature range from −30 to 60 C with 0.2 C accuracy. The modern version of the resonator spectrometer [33] is equipped with a vacuum chamber which ensures stable conditions over a wide range of thermodynamic parameters.

Studies of wet gas samples performed using the resonator spectrometer [36] revealed a significant systematic uncertainty in the water-related continuum measurement which was caused by the water adsorbed on the resonator elements (mirrors, coupling film). The lower the temperature the larger the uncertainty. This was a common problem for this type of techniques which can be solved in part, for example, by mirrors heating [37]. A length variation method was suggested by Misha with colleagues to be able to guarantee almost 100% accounting for the water adsorption. This was elegantly realized in the spectrometer [29] using a double Fabry–Perot cavity consisting of two rigidly bounded identical resonators differing in length by exactly a factor of two. Employing this method for a study of absorption by moist nitrogen demonstrated significant improvement in the systematic accuracy of the measured water-related continuum [38] and led to the first laboratory study of the continuum at temperatures below freezing. These data are presumed to be the most accurate ones ever obtained in the mm-wave range.

Misha participated in many collaborative research projects with both domestic and foreign laboratories. An important breakthrough was the advancement of submillimeter spectroscopy into the terahertz range, up to 1.5 THz [39–42]. Together with the Institute of Electronic Measurements KVARZ he developed frequency multipliers [43–45] used for spectroscopic studies and PLL systems. Misha collaborated on development of a Terahertz video-spectrometer [46] with Giesbert Winnewisser and colleagues from the University of Cologne and with Li-Hong Xu and Ronald M. Lees from the University of New Brunswick on development of CO2-laser/MW side-band spectrometer [47–49]. After the invention of the frequency comb, he was inspired to use one to stabilize the BWO frequencies [50,51] and apply this for microwave spectroscopy [52].

2.2. Molecular spectra

A significant part of Misha’s studies of molecular spectra, determination of the line positions and assignment of these lines were performed at a time when no accurate laser measurements in the infrared were available: there were no combs to give accurately determined line positions. Thus, precise knowledge of the molecular absorption and emission lines relied heavily on microwave techniques. Before Misha’s and his colleagues work, the upper frequency limit for achieving microwave accuracy was about 100 GHz. The rotational lines though do not stop there. Especially for the light molecules such as water, hydrogen sulfide, ammonia, phosphine, and the like, the rotational spectrum extends far beyond that limit, towards the terahertz region. Misha’s work on ammonia NH_3 [53–55], water’s $H_2{}^{18}O$ isotopologue [56–58] and parent $H_2{}^{16}O$ [58–60] are good example of studies of rotational spectra of such molecules.

The first observation of the 4-fold clustering in H_2Se [14,15] is another example of a necessity of a sub-millimeter region for the observation of interesting phenomena in the molecular spectra. This phenomenon could be observed only in the sub-millimeter region and without the techniques developed by Misha and his colleagues was not observable. Studies of THz spectra of other important molecules such CH_3F [12,13,61,62] and H_2S [63] also followed. Other important molecules studied by Misha in the terahertz region include acetaldehyde [16,17], CO [64], SO [65], SO_2 [66], D_3SF [67,68], OCS [48] and CH_3OH [49].

2.3. Line shapes and shifts

From an early stage of Misha’s career, a significant portion of his scientific efforts were related to the problem of absorption line shapes. This problem is among the most intriguing enigmas in the list of still unsatisfactorily understood problems in theoretical physics. The brilliant but obviously unsatisfactory impact approximation needs to be supplemented by taking into account the complexity of real intermolecular forces as well as many other factors which are capable of contributing to the distortion of the far wings of absorption lines from a conventional Lorentzian shape. In his early works with S.P. Belov, A.F. Krupnov and others [64,69–73], Misha studied lineshifts and broadening of microwave lines, in particular, for inversion-rotational transitions of NH_3 isotopologues. His inspiration to unearth the physics underlying the formation of the line profiles in real gases coexisted with the desire to refine the available models of microwave absorption, such as the millimeter-wave propagation model (MPM), which are required for practical atmospheric radiometry and remote sensing. In this way, Misha and his collaborators contributed much to the study of oxygen and water vapor absorption line broadening, shifting, and intensities.

Misha’s meticulous studies [74–79] of the O_2 fine structure line at 118 GHz resulted in the excellent confirmation of the line coupling and “wind” effects, important for a highly accurate description of the line profile. The advent of new sensitive instruments such as resonator and RAD spectrometers, made it possible to thoroughly study a variety of weak transitions, e.g. rotational transition of water vapor at 183 GHz at atmospheric pressures in the broad frequency range 130–205 GHz down to far wings [35,80,81]. The fine-structure transitions within the 60 GHz oxygen magnetic-dipole band were thoroughly investigated in a series of studies [82–87] which precisely established their central frequencies, self-broadening, and N_2-broadening parameters.

The pioneering discovery of water dimer spectral signatures in equilibrium water vapor [2] and especially the impressive success of theoretical trajectory based description of collision induced spectra in several systems, inspired Misha to try to disentangle the line shape problem relying upon trajectory based simulation supported by highly accurate *ab initio* potential and dipole surfaces. From an experimental perspective, this dream was supported by very precise measurements of CO molecule line profiles in pure gas [64,88,89] or perturbed by Ar [90–92] or N_2 [93]. From a theoretical perspective, this work is still far from being completed.

2.4. Molecular complexes

Misha’s first studies of molecular complexes focused on the HF dimer [11] and the HF–H_2O complex, which originally was published only as a local preprint in 1986 and was subsequently published in an international journal only in 2007 [94]. A feature of this work was the ability to observe the molecular complexes directly in the gas phase. The majority of the spectroscopic studies of complexes have been made in jets and beams, which provide detailed information but have little to do with the absorption in the equilibrium environments. However, the HF–HF and HF–H_2O complexes had already been observed in the gas phase in the microwave region by Suenram and coworkers [95], and Legon and coworkers [96], respectively. Use of a RAD spectrometer in the sub-millimeter region had two important advantages — higher pressure in the cell and much higher frequencies, which allowed the observation of lines with higher rotational quantum numbers and larger tunneling splittings. However, in the back of Misha's mind there was always the similarity with the water dimer, not least because all these dimers are iso-electronic. Because of the immense importance of water dimers for continuum absorption in the Earth atmosphere and possibly other atmospheres [97], a hidden purpose of the studies of the HF dimer and DF–H_2O dimers was always to pave the way to the final observation of the gas phase spectrum of the water dimer. Therefore, alongside observations of the HF dimer and the HF–H_2O dimer, Misha and his colleagues began attempts to observe the water dimer. These first attempts failed. Misha and his colleagues perseverance resulted in the triumph of his 2013 Physical Review Letter [2] on the water dimer, which is described in the next section.

Meanwhile, Misha's work on the other dimers and complexes: studies included those on the methanol dimer [95], the CH_3OH–CO dimer [98], Ar.H_3^+ [99], further work on HF–H_2O dimer [94] as well as observations of the CO_2–CO_2 and CO_2-Ar continua [100]. HF-dimer, comparison of spectra with ab initio calculations [101]. New measurements of the HF–H_2O dimer [19], another step towards comparison of isoelectronic to water dimer spectrum of HF–H_2O with the high accuracy ab initio calculations - a step towards accurate modeling of water dimer spectrum.

2.5. Water dimer in the gas phase and collision-induced spectra

The problem of the water vapor continuum absorption has been vividly discussed over many decades, especially in its close relation to transmission of radiation through the Earth's atmosphere [102–104]. Many attempts were made by researchers to pick out the water dimers spectral signatures against structureless continuum absorption in close to ambient water vapor, all these attempts failed, however, one after another (see Ref. [105] for example). The breakthrough came in 2013 when the pioneering study by Tretyakov et al. [2] was published in the Physical Review Letters. The success of this long-sought detection of the dimers' "spectral fingerprint" under environmentally relevant conditions was determined by a fortunate combination of three factors: the skill and profound physical understanding of the researchers involved, their use of an extremely sensitive resonator spectrometer, and the support from accurate quantum mechanical calculations of the water dimer spectrum carried out previously by Y. Scribano and C. Leforestier [106]. It is worth mentioning that prior to detection of the dimer's signatures by Tretyakov et al. [2], the possibility of their observation using a resonator spectrometer had been thoroughly examined [107,108]. Also, much attention was paid to the modeling of the IR spectra at high densities, which favor the formation of dimers [85], as well as to making estimates of the dimer content [109,110].

The spectral range in which dimer signatures could be observed was subsequently extended to 188–258 GHz [111], thus confirming the assignment of spectral features observed initially between observed 100 and 150 GHz. There followed a series of papers [57,112,113] reporting retrieval of dimer signatures in continua spectra recorded using the SOLEIL synchrotron radiation source. The measurements at the SOLEIL facility also extended to studies of the foreign continuum [60], which is roughly one order of magnitude weaker than the self-continuum in pure water vapor. The results of an ensemble of investigations carried out at SOLEIL in collaboration with French researchers (A. Campargue, O. Pirali, P. Roy) were summarized in the review [114]. The latest of Misha's works on the subject were devoted to practical modeling of the water continuum relying on its physical background as well as on possible refinement of existing models, such as MPM and MT_CKD [115,116].

Fig. 3. Mikhail Tretyakov near Klyuchevskaya Sopka volcano, Kamchatka, Russia, 2006. Photo courtesy of Svatopluk Civiš.

Misha was convinced that the physical nature of the water continuum has much in common with that of collision-induced spectra. With great enthusiasm, he greeted the use of the trajectory-based method developed by A. Vigasin's group (D. Chistikov, A. Finenko et al.) for collision-induced spectral simulation [117–119]. In a series of works, this method was successfully employed to describe continua spectra in various pure gases (N_2, CO_2) [100,120], or binary mixtures, such as CO_2–Ar [100,121], N_2–Ar [122], CH_4–N_2, and CH_4–CO_2 [123,124]. Trajectory-based simulations make it possible to distinguish contributions to the spectral profiles arising from various type of molecular pairs, including quasibound (metastable) and true bound dimers. The extension of this method to the water vapor continuum problem was hopefully anticipated by Misha. Once a convincing solution of the problem of water vapor continuum and some related problems up to even the enigma of liquid water is found, Misha's excellent work will be appreciated as an important step forward that helped to decipher an extremely challenging phenomenon.

3. Conclusions

Misha, see Fig. 3, died suddenly whilst cross-country skiing in a suburban forest near his dacha. It can be said that he died as he lived — being on a permanent move ahead, just as he did during all his life in science.

For many of Misha's colleagues and friends, his unexpected death was as a stroke of a black lightning and stab in a back. So many plans, focused on Misha's skills, ideas, and personality, suddenly exploded and became destroyed. It was impossible to believe, once we discussed with him how many pushups should make a man at once to keep one fit. He suggested that it should be a number of years of one's life. How a man like that could die so prematurely is behind comprehension.

Paying tribute to Mikhail Tretyakov scientific legacy, we express our support and condolence to his beloved family as well as to his friends and colleagues over the world.

CRediT authorship contribution statement

Andrei A. Vigasin: Writing – original draft, Writing – review & editing. **Jonathan Tennyson:** Writing – review & editing. **Oleg L. Polyansky:** Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

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Data availability

No data was used for the research described in the article.

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