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Nikolai Voshchinnikov: From light scattering by spheroids to Large Interstellar Polarisation Survey

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ABSTRACT

This paper outlines the life and scientific legacy of Professor Nikolai Vasil'evich Voshchinnikov (1951–2017) who had many coauthors and friends among the *JQSRT* community.

1. Introduction

Nikolai Voshchinnikov was born in Leningrad, Soviet Union (now St.Petersburg, Russia) in 1951 to a family of a factory worker. He attended a special mathematical school and graduated from the Astronomy Division of the Mathematics Department of the Leningrad University in 1973. He worked at this University his whole professional life. In 1995 he became Professor of the Chair of Astrophysics. Around this time the Soviet Union dissolved, the iron curtain fell, and NV[1] started contacting and visiting foreign scientists; hence, his wide international collaborations began. His favorite places were Jena and Amsterdam, and more recently Heidelberg and Bonn.

In this paper I outline NV's scientific activities, which largely focused on *light scattering by small particles* (see Section 2) and *radiative transfer in dusty media* (see Section 3). The latter can be divided into two fields related to polarized scattered light and polarized transmitted light, both being considered in the astrophysical context. Generally, there was a gradual drift from the development of requisite light-scattering tools toward analyses of optical manifestations of cosmic dust based on these tools. While the characterization of non-sphericity of scatterers was the overarching goal, analyses of the observed polarization served as the main research tool.

Note that the scientific overview is accompanied by informal notes printed in smaller font.

2. Light scattering by small particles

The starting point of this research was a study of radiation pressure on non-spherical particles. Following this study, NV began his life-long work on light scattering by spheroids (see Section 2.1). Occasionally he considered other problems, such as different light-scattering approximations (Section 2.2), optical effects of particle shape and morphology (Section 2.3), and certain related issues (Section 2.4).

2.1. Light scattering by spheroids

Initiated in 1981, his work on light scattering from spheroids continued for over 35 years, mostly in collaboration with Victor Farafonov of the St.Petersburg University of Aerospace Instrumentation. Note that by the early 1980s, not too much work had been done on light scattering by spheroids (see the review by Onaka [1]). There was an approach developed in 1975 by Asano and Yamamoto [2] based on the separation of variables method (SVM)

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[1] Some colleagues called Nikolai so because his family name was very long and his name was too often met in Russia.

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Fig. 1. NV at the age of 50. Note that smoking was not yet as restricted in Russia as last years.

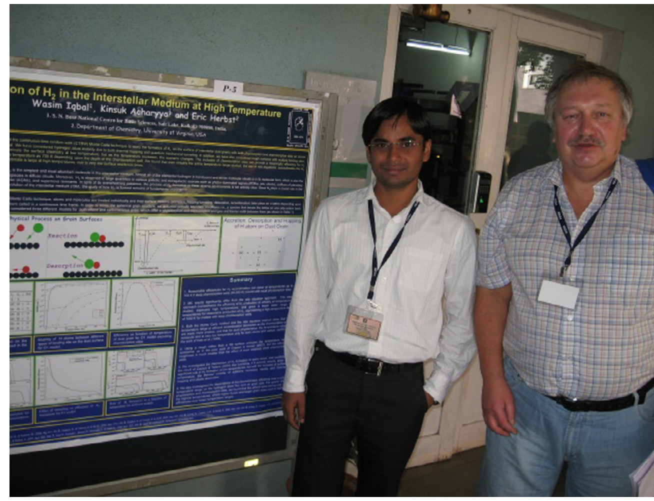

Fig. 2. At an astronomical conference in India in the 2010s.

with a spheroidal-function basis. The book [3] published in 1980 by Varadan and Varadan clearly demonstrated that the *T*-matrix method was a powerful approach, but was, however, impracticable in application to spheroids with aspect ratios greater than 5–10. In 1973, Purcell and Pennypacker had yet suggested the idea of the discrete dipole approximation [4]. So, in fact, the *exact* solutions of the Maxwell equations were mostly limited to spheres and infinite circular cylinders.

Voshchinnikov and Farafonov developed a new version of the SVM wherein the fields were divided into two parts having suitable properties, and appropriate scalar potentials were used for each part (for more details, see the work by Farafonov [5]). This approach is especially beneficial in application to spheroids with high eccentricities [7]. A serious problem was the absence of reliable computer subroutines to calculate the requisite spheroidal functions, in particular, those of complex argument. A new technique was developed and several known methods were adapted to address this problem [8,9]. The main outcome was a widely applied program that calculates the optical properties of homogeneous spheroids and an accompanying code for core-mantle spheroids with confocal layer boundaries, as well as extensive analyses of the optical properties of spheroids. A review of this research reported in many publications can be found in the NV's most cited paper [10] and his third most cited work [11]. The computer programs for spheroids and some other light-scattering codes developed by NV are available on the DOP website[2]. The last years featured serious efforts intended to develop a method to treat multi-layered spheroids lacking confocallity of the layer boundaries, the first step of which was reported by Farafonov and Voshchinnikov [12], but unfortunately this work remains unfinished.

It is amusing that in the years of perestroika, there was hope that the efficient computer program for spheroids could serve as a source of extra income, especially given the inadequate salaries of scientists in the Soviet Union. Unfortunately, only one buyer was found, a worker at the FujiFilm company, and he could only pay, and did pay, with their 35-mm film. [3] *Reselling so much film became an insurmountable problem). (Fig. 1)*

Fig. 3. NV with his wife and daughter in the 1990s.

2.2. Light scattering approximations

In the times when computers and computational methods were not as powerful as they are today, different approximations were very popular in the discipline of light scattering. NV made several studies in this field by considering the quasistatic approximation [13,14], the *S*-approximation [15], concentric multi-layered models of inhomogeneous particles [16], and the effective medium theory [17]. Some results can be found in his extensive review [18].

To realize how primitive the computers were during those times, it is worth noting that NV's work on the spheroidal code in 1985–1992 was done on a Model ES 1030 computer with just 500 Kb of

[2] http://www.astro.spbu.ru/DOP/6-SOFT/ours.html

[3] And a couple of big boxes arrived.

Fig. 4. NV on a rest in Germany in the 2000s.

memory and a frequency of about 10 KHz[4]*. Moreover, this computer was available only during a couple of nights per week. Of course, this is hard to imagine now!*

2.3. Effects of scatterer shape and structure

NV's first paper on light-scattering theory was devoted to a study of a particle's nonsphericity on the radiation pressure force using the model of infinite circular cylinders [19]. It had an interesting application: it was found that the non-radial component of this force on interplanetary particles in the Solar system could be comparable to the well-known Pointing-Robertson force [20]. Later these results were confirmed in the case of spheroidal grains [21].

One of the applications of the research on light scattering by spheroids was the study of shape effects on the temperature of cosmic dust grains [22]. Heating of aerosol particles with diverse morphologies was considered [23]. The effects of morphology on the optical properties of inhomogeneous (porous) spheres also was studied [24].

In the 1990s, one presently well-known scientist, who was a student at the time, told a Russian colleague that he was so impressed by the paper [20] that he believed that its authors were like Gods. NV would always smile softly when remembering that story.

2.4. Miscellaneous

NV performed other studies on light scattering. Among them, the works Hovenier et al. [25] and Wolf and Voshchinnikov [26] are particularly well cited. The former discusses computations of scattering matrices for four types of non-spherical particles using diverse methods. The latter presents a Mie code to calculate scattering by ensembles of spheres with very large size parameters. An interesting application of light scattering by spheres and spheroids to nano-optics was recently reported [27].

A remarkable story is related to these studies. One of NV's PhD students who was working in this field suddenly disappeared, but after two years of silence returned with a complete thesis. NV was much impressed, as it had never happened before. It was the only time when he attained the result he was looking for without any effort on his part.

3. Radiative transfer in astrophysical media

NV did his first scientific work on the interpretation of polarization observations of reflection nebulae in 1975–1980 (his first paper was on M20 [28]). This became the subject of his PhD thesis and later resulted in an interesting application to young stars (see Section 3.1). After several papers on light scattering (see above), in 1985 he began to work on astrophysical applications. First he focused on modeling interstellar extinction and polarization curves, which became his strongest interest for years (Section 3.3). Several works on modeling radiative transfer were produced without the use of the single-scattering approximation (Section 3.2). There were naturally some other studies (Section 3.4).

3.1. Polarized scattered radiation in the single-scattering approximation

This approach was used by NV in many studies of objects, such as nebulae (see, e.g., Voshchinnikov [29]), envelopes of young stars (e.g., [30]), and the debris disk of β Pic [31]. The most interesting one was the quantitative development of Vladimir Grinin's idea [6] regarding the variability of young Herbig Ae/Be stars as being caused by variable circumstellar extinction. These results were published in [32] and NV's second most cited paper [33].

This segment of NV's work could, but did not, include comets. These objects had always fascinated him, but when he started seriously working on them, one of his co-authors suddenly died, another one lost his job soon thereafter, and a student involved in this study left the University abruptly. So, when the next student still could not continue working on this topic, it was decided that comets certainly bring bad luck, and NV never returned to them, albeit with regret (Fig. 2).

3.2. Multiple scattering of polarized radiation

NV contributed to applications of the Monte Carlo method to the modeling of the transfer of polarized cosmic radiation done by Vladimir Karjukin and Sebastian Wolf. The first computer program [34] was developed for homogeneous circumstellar envelopes and was based on an innovative approach. It allowed NV to gain a deeper insight into circumstellar extinction of young stars (see, e.g., Voshchinnikov et al. [35]). The second code [36] developed for anisotropic media (e.g., those including aligned dust grains) was definitely well ahead of its time.

NV worked on these Monte Carlo programs using a 486 IBM PC with a frequency of about 50 MHz and 8 Mb of memory. This PC was bought by the MPG Arbeitsgruppe "Staub in Sternentstehungsgebieten"[5] *in Jena as a part of the grant for NV and brought from Germany on 1 March 1993, i.e., on the first day when the CoCom*[6] *ban was removed and such then-powerful computers could be officially transported to the Former Soviet Union.*

3.3. Polarized transmitted radiation in the single-scattering approximation

Analyses of interstellar extinction and polarization curves were pursued by NV since the 1980s, with much research having been done in collaboration with Thomas Henning, Vladimir Il'in, and,

[4] https://en.wikipedia.org/wiki/ES_EVM.

[5] Max-Planck-Gesellschaft working group "Dust in star-formation regions".

[6] https://en.wikipedia.org/wiki/Coordinating_Committee_for_Multilateral_Export_Controls.

later, Ralf Siebenmorgen. Cosmic dust was modeled first by homogeneous and coated very long (infinite) cylinders (see, e.g., Voshchinnikov et al. [37]), then by homogeneous and layered (porous) spheres [38,39], and finally by homogeneous spheroids [40,41]. Many results thus obtained were summarized in NV's reviews [18,42].

In the last years, NV performed several interesting studies related to the following: i) the development of a spheroidal model of cosmic grains (see, e.g., Das et al. [43]); ii) the development of a detailed model of dust in diffuse interstellar media [44]; iii) the evolution of dust grains in dense clouds [45]; and iv) the explanation of the excess mid-infrared interstellar extinction [46].

NV's final studies were related to the Large Interstellar Polarisation Survey (LIPS) of the European Southern Observatory (see, e.g., Siebenmorgen et al. [47]). This survey included a spectropolarimetric (in the spectral range 380–950 nm, with resolving power $\sim$900) study of about 130 carefully selected bright early-type stars widely distributed throughout the galactic disk ($|b| < 30°$). The observations were mostly made at the Very Large Telescope (VLT) with the FORS2 spectrograph and yielded a large, new set of interstellar polarization measurements in the diffuse to translucent interstellar clouds. Many LIPS targets were studied in other ways (e.g., applying high-resolution spectroscopy at the VLT with UVES), which makes it possible to select single-cloud lines of sight and find correlations between polarization and other parameters. Thus, LIPS had provided the proper material for applications of the spheroidal model developed by NV to interpret interstellar polarization and extinction in detail. NV was full of energy and enthusiasm regarding this survey and the interpretation of its results, but was unable to finish this work...

The work on modeling interstellar extinction and polarization began one day in 1985 when NV solemnly brought a paper folder titled WC12 to his office at the University. A younger colleague asked him what was inside. NV responded by citing a relevant passage from his favorite humorous fiction book "The Golden Calf" by Il'f & Petrov (1931) that "inside the folder was everything: palm trees, girls, blue expresses, blue sea, white steamboat, only slightly worn-out tux,..." The excited colleague opened the folder and found out that it was empty!

Actually, WC12 was the name of the computer program that was developed in 1985 to model interstellar polarization curves. The methodology and parts of that code were used for many years, including the final work on LIPS in 2017. So, one can say that to some extent those joking words of NV have come true.

3.4. Miscellaneous

Somewhat outside NV's mainstream research was a series of papers on the Sunyaev–Zel'dovich effect and thermal emission of dust, published together with Valeri Khersonski (see, e.g., Voshchinnikov and Khersonskii [48]).

Much time was also spent by NV on collecting and analyzing available data on element depletion in the interstellar medium [49]. These data revealed valuable correlations between the abundances and interstellar polarization parameters.

NV was known to be pedantically serious as far as Science was concerned. Hence it can be unexpected to learn that from his early days onward, he liked to work long evenings lying in the bathtub with a cup of coffee and cigarettes at hand. Without doubt, his family was not exceedingly happy about this habit. Colleagues also tell that one of his favorite places in Jena was Volksbad[7], but of course there was no chance to work inside it.

[7] https://de.wikipedia.org/wiki/Volksbad_Jena.

4. His private life

NV liked to think and talk about Science, while other topics were not discussed by him as often. However, naturally he thought about and loved very much his family (Fig. 3), his summer cottage, the local football (soccer) team, delicious food, a game of cards with close friends, some Russian songwriter singers, walking about his favorite places, and many other things.

NV's family included his wife Galina, daughter Lisa (b. 1974), and wonderful grand-daughter Polina (b. 2002). NV met his wife in school at the age of 14 and married her when he left the University, so they stayed together for 44 years. A very important family member was his adorable Chow Chow. Yet it was not simple for all of his family members to share his excitement for Science.

As soon as the weather and lecture schedule allowed, NV would go to his summer cottage, where he extensively did scientific work, but also had a good rest. The cottage, located about 100 km from St.Petersburg on the shore of Lake Ladoga, is surrounded by a thin forest. Walking in the autumn forest was traditionally accompanied by harvesting mushrooms. Everyone knows that after special cooking, mushrooms go very well with famous Russian vodka.

NV watched on TV all games played by the local football team Zenit. During the games he would turn off his phone, while after the games he would always relax and do no work. Some colleagues could not accept that habit.

Another priority was playing the Russian national card game called Preferans[8] with permanent partners. This would happen every month or so for over 30 years. Being a serious, yet somewhat adventurous player, NV won very often.

NV very much enjoyed well or unconventionally cooked food and good wines. Sherry and Chianti were his favorite ones, and Armenian brandy was always preferred over French cognac. During his latter years he would often say with a smile that all his life was a big mistake, since ... he never knew that Sherry was to be served cold!

He also liked to listen to the music full of meaning and popular among Russian intellectuals in the 1970s. The singers most liked by NV were Yuri Vizbor, who was very popular in the 1970–80s, and Timur Shaov, who is popular today.

NV liked very much his Peterhof (a town located close to the University campus and in the vicinity of St.Petersburg), where he had lived for the last 40 years. He often remembered Amsterdam, where he worked for several months, and enjoyed Paris, just as many Russians of his generation. His Amsterdam address at Prinsengracht was his password on several computers (Fig. 4).

5. How do we remember him

In their reactions to Nikolai's death, his colleagues wrote that he was a very kind, life-affirming person, an open and critical but always very motivating mentor with a lot of expertise which he was eager to share with others, a very positive person with a good sense of humor... . We miss him dearly.

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[8] https://en.wikipedia.org/wiki/Preferans.

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