

**Control, more control:
Studying Practical Forms
of Scientific Rationality
in a Bulgarian Holographic
Laboratory**

Almagest

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Abstract

This paper is concerned with the social embeddings of experiment and practical forms of rationality as they are revealed through the case study of holographic research in Bulgaria. The paper consists of three parts: the first, introductory part, and the second part trace the political and economic environment in which holography as a particular research field has developed in Bulgaria. The third part follows the scientists inside their laboratory. It reveals what was at stake in their scientific work and it sheds light on how they proceeded to catch it. Based on in-depth interviews with scientists, participant observation and analysis of literature, the author examines the establishment of an "experimental situation" as a *particular* kind of balance between the preset, imposed and uncontrolled, on the one hand, and the manipulable and controllable, on the other. Tracing the course of holographic research, a peculiar functional difference between theory and experiment is revealed. The "mystery" of their interrelation is interpreted as specific transition from the "seen" to the "spoken" in the process of study. It is also considered as an efficient tool for convincing the centers of power in society and gaining their support.

Once upon a time...

In a late autumn morning of 1974, a group of people, bewildered, were waiting in front of the office of Todor Zhivkov – First Secretary of the Bulgarian Communist Party and President of the country. Among them were several functionaries of the upper Communist Party apparatus, ministers and civil servants in high positions, professors from the Bulgarian Academy of Sciences, and a 33 year old research associate, named Methodius, who had just surrendered at the entrance check-point a small briefcase full of research equipment and files with some drawings and formulae. Most of those present, intimidated by the solid walls, the long corridors, and the repeated check-ups on the way to the office, were in vain trying to guess why they had been summoned to the office of the First Secretary of the Communist Party. (It was a habit of Zhivkov, once he made a decision, to have people surprised – remembered one of his advisors.)

Methodius, a physicist and chief player in this story, remembers:

"When we came in and those present were introduced, I realized that everything had been prepared in advance – the functionary of the Communist party Central Committee in charge of the new technologies and investments, the Minister of Electronics, representatives of the Ministry of Finance, of the State Planning Committee, and the President of the Bulgarian Academy of Sciences were there. Zhivkov explained the object of the meeting and gave me the floor. I reported my and my colleague's findings and their possible applications. Then I took out the laser (a small helium-neon laser), bought privately by a colleague of mine from a specialist in France, and the plates pattern from the briefcase, and reproduced the holograms on the spot. Out of each of them, with an area of less than one square millimetre, an entire page of text appeared on the screen. It was 1974, most of those present saw a laser in action for the first time. Then, out of the other plate I showed them the red-and-black three-dimensional image of Vassil Levsky, the Bulgarian national hero... When the demonstrations were over, Zhivkov said: 'That was it, you heard it. I also hear of it for the first time. Now, what are we going to do?' Almost no one wanted to say what was to be done. Zhivkov even got a little angry, pounded on the table and exclaimed: 'This man, these people must be given an opportunity to work!' He directly started dictating; the Council of Ministers was to issue a directive for the establishment of a laboratory, the required funds were to be allocated, vacancies... Then a few found the courage to object that it was premature, that it was better to wait a while... Rather harshly, the First Secretary replied that they were short-sighted and could not see the prospects and the strategic importance of this area of research".

Thus, six months later, in the spring of 1975, the Central Laboratory for Optical Storage and Processing of Information (CLOSPI) was established with the aim of "conducting fundamental and applied science research in the area of optical storage and processing of information" (Bulgarian Government Decree, spring of 1975). It was clear to everyone, however, though it was

not mentioned expressly, that the strategic task was the "great computer memory" (Prof. A. Lohmann, personal interview) – the holographic storage which was to revolutionize the computer memory technology.

How did such a meeting become possible? How did the strongest figure in the state, the all-powerful "absolute monarch" of Bulgaria for more than 30 years suddenly turn out to be *interested* in the achievements of two young scientists, who had been chucked out of everywhere so far and had taken shelter in a small one-room laboratory at the Solid State Physics Institute? And the reverse question – why did the two scientists become so important as to enter the fortress at the center of Sofia and be "blessed" by Zhivkov?

I would like to suggest a hypothesis, which frames, in a sense, the analysis to follow: there are two key elements, which closely bound the Bulgarian Communist leader with the scientists. First, it was the imagination and the dreams of both parties for another world. It did not matter that the world these parties dreamt of were quite different – the totalitarian utopia of Bulgaria as a "technical nation, communist nation" (Zhivkov) and the modest utopia of a new, fascinating, optical computer memory, to be produced in Bulgaria and conquer the world computer market (Methodius). What mattered was that they both believed in their utopia and were ready to invest all available resources to make their dreams come true.

Second, they became allies and mutually interdependent because of the complimentary resources they controlled. On the one hand, Zhivkov had at his disposal the enormous resources of a totalitarian party-state. On the other hand, Methodius and his collaborator Cyril were in the early 1970-s the only people in Bulgaria (and among very few people in the world), who had managed to "enter some crystals" and to record and reproduce from minor spots real, three-dimensional images. They became the "spoke-persons" of the light beams, promising to "tame" the incredible power of these beams if captured in the designed optical computer. The Communist leader was convinced that one of the shortest ways to the planned "developed socialist society" passed through the holographic computer memory project. From their part, the two physicists realized that the totalitarian utopia for a technical nation, communist nation at that moment, was the most reliable source of funding. It were these minute holograms which enchanted the small audience at Zhivkov's office in the autumn of 1974 and made them put their incredible power into action – more than \$1 million were allocated, the Council of Ministers of the country met and issued ordinances, laboratories and personnel were moved, and overseas representative offices made the utmost efforts to break through the Western embargo and to equip the laboratory with the latest apparatus.

However, the two researchers had already gone a long way in order to learn how to master the holograms and thus convince the top political leadership of the country. So it is our aim in this paper to trace some of the key events in their research path that made possible the meeting with the Communist Party's Central Committee. As we will see below, their path passed through a series of pitfalls, which were overcome by courage, ingenuity and persistence during the many years of tireless work through out the day but also through out the night.

The situation in Bulgarian physic's community in early 1960s and Methodius' path in it

This section traces the early years of Methodius' research career; the work that made him suitable, through the acquisition of the specific knowledge and expertise needed, for carrying out holographic research for the newly emerging field of holography. At the same time, this section also sheds light on the gradual development of research and industrial infrastructure in Bulgaria, indispensable in making such a career possible at all.

The origin and advancement of holographic research in Bulgaria in the mid-1960s was an integral part of the lifework of two people, Methodius and Cyril, who, through their personal contribution, played the key roles. I will introduce them into our story through the memoirs of academician Milko Borisov, a leading Bulgarian solid-state physicist, I interviewed in 1996:

"Maybe light is the most delicate matter and at the same time, one of the most powerful information carriers. However, as a medium for information transfer and processing, light has a considerable deficiency – unlike the electromagnetic waves which are coherent, i.e. whose length and phase are constant, light is incoherent as it is composed of waves of a different length and phase. Furthermore, some random processes occur in ordinary light. This is why the designing of the laser in the early 60s effected a U-turn in the way light was handled in the field of informatics and technical cybernetics. As regards coherence, the laser resembles radio waves. Altogether, after the first laser was designed, events followed close upon one another and soon after, there started research work on a very high level. For instance, our colleague Nikola Sabotinov designed and upgraded one of the most interesting lasers on copper vapors with which the highest service power ever obtained in the world was attained.

Around that time, optoelectronics too came into the limelight. No doubt, lasers provided broad opportunities for extensive development. Because, as it turned out, information processing could be effected through laser rays and optical methods, and not only through electricity, which was the way used in conventional electronics. In the meantime, electronics was making its first steps in Bulgaria and its promotion involved a great deal of effort. The first Minister of electronics in Bulgaria was Jordan Mladenov. Previously, he had worked at the State Committee for Scientific and Technical Progress where we actually met. He took part in the setting up of unified centers, which brought together the Bulgarian Academy of Sciences and universities, and rendered great help. He was a prudent man, unlike his successors who crippled electronics...

Before that, a small group, the group of Methodius and Cyril, had started work at the In-

stitute of Microelectronics. But for various reasons, both subjective and objective, it felt like a pea on a drum there. However, we, at the Institute of Solid State Physics (ISSP), got interested and besides, other colleagues too had started work on the lasers. We gathered at a seminar to discuss things but, above all, we spoke about new media for information storage. The seminar went on for quite a long time. *Then I took both of them on the staff and it did not cost me a lot of trouble. Today the same would involve much greater effort. Yet, there was a problem - finding working premises for them. Finally I managed to arrange a room at the university where I was the head of the Solid State Physics Department. So, they could start work on holography. All this happened late in the 60s or maybe, between the mid- and the late 60s, I do not remember exactly...* [It must have been from the end of 1971 to the beginning of 1974 – I.Tch.] *Then the two researchers did something very interesting and it came to be one of their top achievements: they worked out a technology of constructing ordinary photographic media for hologram recording...* [italics mine – I.Tch.]" (Borisov, Interview with the author, 1996)

This extensive excerpt not only does it introduce the main characters of holographic research in Bulgaria but also, it outlines the cognitive and institutional context in which they were immersed. In the remainder of this section, the main focus will be on Methodius. Cyril, as he himself has stressed time and again, was his disciple. Some ten years later, Cyril would succeed Methodius as director of the lab, but this is another story.

Methodius venturing into holography

Methodius graduated from the Optical Technical School in Sofia and then entered Sofia University in 1956 to study theoretical physics. Prior to that, he had already acquired substantial experience in the field of photography. His school friend Pavel Kulev recalls this passion of Methodius:

"He already deepened his knowledge of photographic chemistry in high school. He arranged an improvised photographic laboratory in the attic of his home and *he was strongly "infected" by (photo) chemistry* – he was able to produce color photographs before he entered the university! In the 1950s it was a very complex task to mix the developing agents guided by intuition alone".

In 1961 Methodius joined the Research Institute of Cinematography and Radio Engineering (RICRE), at that time the only Bulgarian applied research institute in optics. Pavel Kulev, who followed him in studying theoretical physics at the university, remembered again:

"One day –being only a first year student at the university– Methodius went to the director of RICRE and impertinently began to talk with him about color photography ... I don't know what they were talking about, but when he graduated from the university he was hired immediately by the "Photography" department at the same institute. This was a miracle, because all graduates had three years mandatory appointments

in industry and elsewhere to complete, all planned long in advance". (Kulev, Interview with the author, 1995)

It was here that Methodius gained proficiency in *diffraction optics*:

"At RICRE I was expected to develop some objective criteria for image quality in film-making. This actually means describing fine art by means of technical criteria. It was uphill work ... Take photography as an example – there are lenses which when examined more closely, will be found to be definitely outdated. Nevertheless photographers take fine pictures with them and say: 'This lens is a perfect *artist*'. At the same time they discard modern lenses with very good performance and say: 'These lenses are not good for art photography'. Hence, *I understood that some other characteristics of the lenses, like frequency, contrast, etc., would have to be measured*. But to do this we needed special instruments, and we had almost none. Soon after that I read some papers on diffraction and it turned out that diffraction with a lens and light could help obtain *two-dimensional Fourier transformation*.¹ In around 1959 I got involved with the issues of diffraction optics, optical information transformations, information arrays, etc. Later when I read the first publications about holography, I found them easy to understand because I had already assimilated this mathematical apparatus [...]" (Methodius, Interview with the author)

The experience in *storage media* is another precondition for holography. In the jargon of physicists, "storage media" refer to all physical agents that change their optical properties when exposed to light. The compounds of silver used in photography are a typical example of such a medium. Methodius got into the swing of this field in a way that proved to be bound up with microelectronics – *photolithography* is the method of making the fine contours of the plates and integrated circuits:

"In the mid-1960s microelectronics was taking its first steps in Bulgaria. There was a need for photosensitive materials with great resolution to be used for integrated circuit templates. A unit at RICRE was assigned this task [...] I have been in photography since my school years. I was keen on development (of photographic plates)² and that is why I joined in the research work. I was more interested in development than in the emulsion itself". (Methodius, Interview with the author)

1 "In Russia the best specialists in holography are graduates of the Moscow Institute of Aviation. They are neither physicists nor chemists, but they are well grounded in the Fourier transformations" (V. Monovski, a physicist at CLOSP).

2 "Development" is a technical term in photography describing the consecutive chemical treatment processes on the plate after it has been exposed to light.

Later, when Methodius learnt about holography, it occurred to him that "these plates could provide a good basis for the production of a holographic plate". Himself dealing mostly with emulsion development, he decided that [...] "for a start, the processing of the emulsion for microelectronics could be optimized for the purposes of holography".

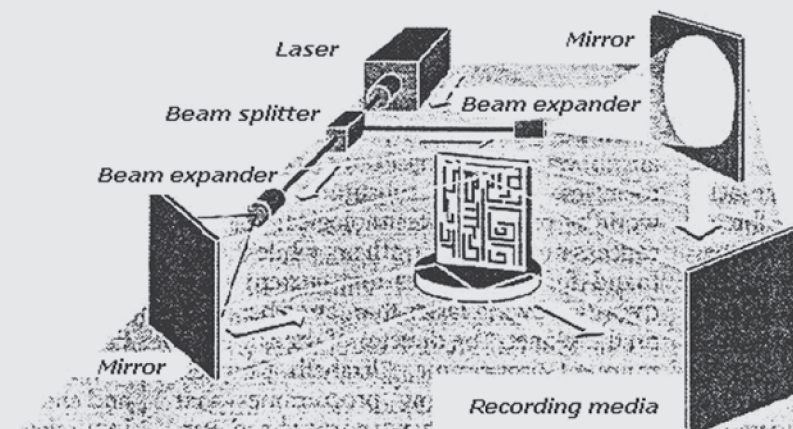
These two events in Methodius' research path, his engagement with two different and seemingly non-related research tasks, made him "fit" for holography: he had mastered the mathematical apparatus of diffraction optics, which was the basis for holography, and he had become familiar with high-resolution photosensitive materials. To put it in the words of Pavel Kulev:

"Methodius already anticipated the path towards holography – coherent optics, and acquaintance with refractive lens properties to produce Fourier transforms. His dream at the time was to use Fourier transformations in the analysis of optical systems. This is exactly what holography is in its core – analysis and synthesis of images, multiple application of Fourier transforms. We discovered Fourier transform in 1959 with the Russian translation of Marechall & Franson's book *Diffraction Structure des Images*, describing in detail the application of Fourier transformations in image analysis and synthesis. This book had enormous influence on us – it stimulated us to specialize in coherent optics". (Kulev, Interview with the author)

Consequently, when the first publications about holography appeared in the journals in the early 1960s, Methodius "became interested in holography and recording". Trivial as these words may be, they underlie his accomplishments for the next 40 years – holography and coherent optics became his destiny.

Together with experiments and the understanding of the "physics of the things under study", *computerized mathematical modeling* lies at the heart of work in coherent optics, in general, and holography in particular. Here, too, RICRE was the nucleus of Methodius' experience in this field. Early in the 1960s, he familiarized himself with computers and realized their capacity to resolve research problems. He became one of the few physicists-researchers (and not engineers, professionally engaged in the designing of computer machinery), who were then aware of the important changes that computers necessitated in the organization of research:

"Today it may seem quite natural and a matter of course but in those years the problem for us, the physicists and chemists, was to define our task in a way that would involve a computer for its resolution. *Color photography opened my eyes to the advantages of using a computer.* I took up color photography while I was at secondary school. Selecting filters for the negative in the enlarger is something that really matters for a good color photo. Photographers would do it by eye. In the early 1960s I went on a business trip to Czechoslovakia, where I visited a film studio and I saw that the technical parameters, transmission data, etc., had been fed into a computer. So, filtration was computerized. Then and there I realized the potential of the computer. Since that time the computer has been my highly valued aide". (Methodius, Interview with the author)



Picture 1: Principle scheme of recording a hologram
(Image taken from Чалъков 1998, 32)

Lasers are yet another of the component of holography. So Methodius did not hesitate to leave RICRE to join the first laser research team in Bulgaria:

"In the mid-1960s my colleague Georgy Kostov was head of a laboratory at Sofia Technical University. When I was working at RICRE, he promised to buy a laser. He did buy one, a Soviet argon laser, if with a very low coherence length. But it was *the first laser in Bulgaria*, and we used it to record the first hologram in Bulgaria". (Methodius, Interview with the author)

Hence, about 5 years after the invention of the laser, in 1967 Methodius left RICRE to find himself standing beside the first imported laser, which he used to record holograms! Although the work on the first holograms at the Sofia Technical University lab was not successful,³ it was of exceptional importance for the future scientific path of Methodius. Scientific circles in Bulgaria and in the former Soviet Union at that time firmly associated the name of Methodius with holography and optic technologies in general and did so for a long time. In the mid-1960s lasers and holography emerged as one of the neoteric fields of solid-state physics – the fact that there was a laser in Sofia and that the first hologram had been recorded, caused quite a stir and was widely discussed among scientific circles in the country. Academician Angel Balevsky, chairman of the Bulgarian Academy of Sciences during the period of 1968-1988, recalls:

"I heard about optical recording a long time ago. It was again Methodius who told me

3 Here he met for the first time Cyril, who will become his close collaborator and friend for the next twenty years.

about it. He was working at Sofia Technical University at that time [...] some kind of recording in crystals. I went to see what it was all about. And he explained to me that when recorded in a crystal, one and the same image could be reproduced entirely from every single point of the recording and each point would hold the whole information contained in the image, though from a given perspective. After that he came to the Academy of Sciences and what followed was something I would define as explosive [...]. In a way, suddenly hopes went high that an external memory for computing machinery could be thus designed. Already at that time *he proved he could enter crystals and store information in them*. I guess, at the time he was one of the few scientists, if not the only one, who had become highly proficient in this field. This gave him the courage to get down to work on the external holographic memory". (Balevsky, Interview with the author)

The Deputy Minister of the then newly founded Ministry of Electronics also visited the laboratory and invited Methodius to join his advisory group as an expert in photolithography and optical methods – the same group that drafted the first "Complex program for the development of electronics in Bulgaria". The participation in this group familiarized Methodius with an actor (agency) as important as lasers, computers, storage media and the Fourier analysis – the *modern methods of optimization of the experiment*, a special statistical techniques called *D-planning* (the term obviously comes from "dynamic optimization" or "dynamic programming" – see Belmann 1957, and Bevington and Robinson 1991). They were discovered in the USA in the early 1950s and were used in nuclear and missile weapons design. Dynamic optimization made it possible to set the target after several shots only, or to specify the area in which the results could be expected after a couple of experiments only, etc. The D-planning accelerated the work and decreased the expenses in research. Soviet mathematicians, led by Kolmogorov, rediscovered the principles of dynamic optimization a few years later. Thereby these methods were gradually declassified, but at the time when Methodius became familiar with them, they were exceptionally efficient tools, though still seldom used and difficult to apply.

The next steps – the idea of a holographic memory

Almost four years, from late 1967 to 1971, Methodius "wandered about" and moved from place to place. In the course of these years he changed five research teams. After leaving RICRE in 1967, he moved to the G. Kostov laboratory at Sofia Technical University, then, next year, to the BAS Institute for Metal Science and Metal Technology (IMTM), and in early 1970 he joined Jordan Kasabov's group of optical methods of information processing at the newly founded Institute of Electronics at BAS. One year later he got a job at the Central Institute of Information Technology (CIIT). There he worked in the group that was directly subordinate to the director of the institute Angel Angelov. This group was involved in the development of optical methods and their application in electronics. In the second half of that period, in late 1969, his younger collaborator Cyril too quitted his job at the laboratory of G. Kostov at the Sofia Technical University and joined Methodius' group at ITMT.

Here is what Methodius recalls about his pursuits at that time:

"There wasn't what we can call an optical laboratory at the Institute of microelectronics. We elaborated on ideas, attended conferences but, anyway, they couldn't fix a laboratory for us. Earlier we had the same experience at IMTM with Balevsky and Rasheev. It was much the same thing later when we went to work with A. Angelov – we did not have a program, but pencils and sheets of paper to put ideas down and time to read literature. If I ever managed to do some experiments, it was during my business trips to the Soviet Union. Having nothing else to do, I returned to the D-plans and set about planning and optimizing the experiment. I would often ask my colleagues to let me make the calculations for their experiments... Anyway, that period was over and it turned out that we had been sitting idle and getting salaries for this... We got in touch with Milko Borisov and he took us on at the Faculty of physics where he fixed up a room for us". (Methodius, Interview with the author)

To the memoirs of Methodius I will add the words of Cyril: "That's the way it was, we were turned out and went wherever we could go". What lies between the lines of the words of the two researchers, is actually called "research policy": that policy was pursued by the IMTM directors (Balevsky and Rasheev), and especially so, by the directors of the two institutes of microelectronics – A. Angelov from CIIT and J. Kasabov from the Institute of Microelectronics. As it became clear from the above quotations from Prof. M. Borisov and BAS President A. Balevski, in the early '70s the scientific, industrial and political circles in Bulgaria were already well informed on the scale of research on optical (holographic) memory in the Western countries and the Soviet Union. Within few years only, holography evolved into what was considered as the future of computer memory. For Angelov and Kasabov the promotion of such a research unit as part of the structure of their institutes would prove advantageous – it would attest vision and prudent management, justify demands for extra funds, etc. But as it transpired only several years later, Methodius together with Cyril, had been but *an instrument* in the long-term policy of these directors and not a real *objective* of their policies. That is why these directors did not take the trouble to invest in the group of Methodius – they did not create adequate working conditions, did not purchase equipment, etc. They simply treated them as a team to show around, they had been pawns in the big chess game of the bosses of electronic industry in Bulgaria. However, in social life, in science as one of its forms included, there is an interaction between actors, where the ratio of forces is never set once and for all. Although treated as instruments for the fulfillment of someone else's interests, Methodius and Cyril followed their own strategy. They "kicked" and "stung" any time the pursuit of those interests jeopardized their own purpose. Ultimately, they gained independence and drew level with their former bosses in terms of power and abilities.

But what did actually Methodius do during all these years of apparent passivity and inertness, with little or no experimental research? He read books on optical processing and holography, of course, attended conferences in the countries of the former COMECON (he did not visit coun-

tries of the West before the setting up of CLOSPI), and was successful in carrying out several experiments in the Soviet Union. Actually, during that period he established contacts with the international scientific community in the field of holographic research – with the Russian school of holography of Denisjuk and with colleagues from Czechoslovakia, Poland, and Germany. Yet, in his own words, he did "nothing serious".

As mentioned above, during the second half of the '60s and early in '70s, holographic research boomed and generated hopes that its results would find application in computing equipment:

"At the beginning, holography developed as art holography too but basically, it advanced as a method of information processing and recording. Experts in the world of holography believed in the possibility of designing an optical memory with a large capacity... Several centers in the world were busy working in this field". (Methodius, Interview with the author)

We can only guess what he had been through during those years. He had recorded the first hologram already in 1967. In the meantime, the journals abounded in evidence of the formidable opportunities that the method might afford and of its possible versatile applications. Also, he could see how year after year the Russians, Americans, French and Japanese were making headway. There appeared theoretical and experimental evidence of the phenomenal holographic memory and rumor had it that holography helped pattern recognition for the military... With such progress in the world of holography, he was doing nothing more than sitting idle in an institute waiting for a certain boss to be graciously willing to allocate a humble sum of money for real experimental research.

So, Methodius considered *reading books, attending conferences, getting salaries* as insignificant and considered himself as staying idle, because he compared his situation to what his colleagues in the Soviet Union, USA and Japan were doing. But was it really "nothing much" for a small country like Bulgaria, situated on the periphery of Europe, which was making its first steps towards a large-scale industry? Favorable conditions were created for a handful of people that read and racked their brains to get money to do it...

"Still, I felt depressed and since there was nothing else to do... I set to study methods for planning and optimization of the experiments (D-planning), and being unable to conduct my own experiments I often asked my colleagues to let me do the calculations of their experiments in their stead... When I returned from the business trip to the Soviet Union, I was the first in Bulgaria at the time to start the multi-program mode of the big IBM computer at the Central Co-operative Union which provided for the simultaneous performance of 2-3 programs. The programs of experimental data processing are very time-consuming. However, the Central Institute of Information Technology could have the computer for its needs from 5.30 in the afternoon to 6 o'clock in the morning. I myself could work on it for a couple of hours only and usually late at night. When I was running a complex task, it was not possible to do anything else meanwhile,

for instance, work with other programs. Moreover, we had to check for syntactic mistakes. We did it on punch cards which was an awful experience sometimes it took me several weeks to detect a mistake... The multi-program mode solved this problem too". (Methodius, Interview with the author)

However, "simply reading about holography" continued until one day in 1971 Prof. Milko Borisov organized a seminar, and hired them before long at his Solid States Physics Institute at BAS. Then in 1972 his old friend Pavel Kulev lent him a small helium-neon laser he had bought privately from France. All of a sudden they got the minimum they need for "real experiments" in holography. The long years of wandering in diffraction optics ended and intensive practical work in designing the first high quality holograms in Bulgaria begun.

Inside the laboratory – experimental work in designing the first high-quality holograms in Bulgaria

After having traced the early research carrier of Methodius, out of which he emerged as one of the few Bulgarian scientists able to carry our research in the field of holography, it is time now to approach the events that made possible the meeting with the Bulgarian Communist Party's Central Committee, where he got approval ignore for the establishment of his own laboratory. As it became clear in the introduction, Methodius would not have been able to convince the top political and scientific leadership of the country without the minute holograms he demonstrated at that meeting. With their fascinating and indisputable three-dimensional presence, they anchored Methodius words and made them stronger than those of his opponents. This section focuses on the production of the holograms, on the experimental practices of Methodius and his collaborators, and reveals the fascinating events that took place on the optical tables –inside the silver-halide plates– when beamed by the laser, in their developing and tannage, but also the silence of libraries during the heated discussions among his colleagues.

Here is the beginning of the story, developing at the Faculty of Physics of the Sofia University, in the autumn of 1973, as told by Methodius:

"By the late 1960s with the development of microelectronic industry in Bulgaria, the necessity emerged of light-sensitive materials with high resolution... for stencils for integrated circuits. At RICRE [where he worked at the time] there was a unit of photography where they used to make media, i.e. photographic emulsions... At that time the idea was born to create a medium with high resolution which would serve in electronics. These were plates of silver halide mediums in gelatin, bichromated gelatin. I took part [as well] – not in the making of emulsion itself but in the process of developing...

[...]When I heard about holography later on I decided that maybe these plates are a good basis for the invention of holographic emulsion... It is very difficult to create a new emulsion and I decided that in the short run one could only optimize the process of processing of this emulsion for microelectronics... At that time, I was already at the Institute of Microelectronics but it came out that almost nothing could be done there [in holography], we only got our salaries... We contacted Prof. M. Borissov from the Faculty of Physics of the Sofia University and he associated us with his Faculty and gave us a room to use. At the same time, my colleague Pavel came home from a specialization course in France and brought, privately, a small helium-neon laser with 2,5 microwatt power but with a good coherence length. In the Faculty, we started with Cyril, and Prof. Borissov assigned two laboratory assistants to us.

We did not have the resources to start a new project at RICRE. All we could do was ask [our colleagues], on a friendly basis, to cast some of those plates. We started optimizing these plates on the basis of the knowledge and experience that I had accumulated and it occurred to me to use these new statistical methods of optimization of experiment, the D-plans. So eventually we managed to record holograms – several pages of text, as the whole page was in a dot of about one millimeter of diameter and it would be restored directly by a non-widened laser beam onto a white sheet of paper and it was perfectly readable.

Interviewer: Was it intentionally that you started producing micro holograms or just wanted to make a fine, high-quality hologram, by whatever means happen to be at hand?

Initially, it was both intentional and because of lack of choice. We had a He-Ne laser which had a power of 2,5 microwatts. You cannot make a large spot with this power; it gets diffracted and should be exposed for a much longer time. Besides this, we worked in the laboratory [ordinary] tables and we had made ourselves a working table: we put some vibration isolating material on a table and a small slab, a little granite tile stolen from one of the subways in Sofia. We simply had no money for special granite plates. This piece of granite, though, was heavy enough for a small device – for that small laser of Pavel's.

In this situation, we were restricted from two sides: by the power of the laser and by the stability of our equipment. We cannot expose for a long time without a very stable equipment. It "crawls", disturbances come about. The recording time depends on the area of the record and the energy: the smaller the power of the beam, the smaller the energy reaching the plate and respectively the exposure time becomes longer. With constant energy, the smaller the area, the greater the intensity on this area and the time decreases... most of the recordings were done at night time since whenever a streetcar passed vibrations would appear and the record would be spoiled.

What was in our hands was the developer. We could model it as we pleased. For to make

this thing [a good hologram] we only needed to mix up the proportions – to provide ourselves the developing substances (we had the opportunity for this from NIKRA) and to start doing one experiment after another.

Interviewer: *Did you know from your experience of photography that developing may significantly affect parameters, that this freedom is hidden in the developing itself?*

Of course; we wouldn't otherwise have taken this path. It was clear to me that [through developing] it is possible to modify sensitivity, to modify the grain of the crystal and the resolution etc. An enormous number of parameters of the medium can be modified with the developing. With the developing, you cannot increase too much the resolution, although we proved that it rises with our developing. Thus before we made the holograms we did a rather long process of *optimization of developing*, using D-plans. And it was not until after we finished with the optimization that we recorded the micro holograms and obtained very high results, very high diffraction efficiency'. (Methodius, Interview with the author)

This long excerpt from the interview with Methodius functions as a kind of "window": it opens our view to certain situations and specific intentions, meanings, and "intrigues" therein.⁴ There are also significant incidents that parallel incidents in other cases I have studied. The researchers "come as if from somewhere" (from other spaces, from other "worlds") so that a new situation of research is established. And they bring with them many things from those other worlds: *old friendships* or contacts; *things* – such as the laser of Pavel and silver-halide media of Anton from RICRE; *knowledge* – presented in the scientific books or periodicals; and their "*bodily capacities*" (such as the skills of making precise measurements, the skills of using statistical methods in processing the results of experiments, or the art of wonderful "bricolage" (Levy-Strauss) that they acquired from the experiments in the improvised laboratory in the attic room in the student years in school and the university); and *time* – in the literal sense of the word, computer time for the powerful, initially secret IBM computer installed several years before in the building of the Central Co-operative Union.

These diverse elements –friendships, things, knowledge, and time– are interconnected and interchangeable: friendship is transformed into things, the common knowledge accumulated in different ways is transformed into friendship and partnership in the research, etc.

4 However, this "window" also hides a lot of things indispensable for the experimental work and which have taken into account when trying to unveil its secrets: for instance, the exhaustive struggle with the vibrations, dust, and humidity is barely mentioned. There are absent the hardships in the mechanic assembly of the holographic device, the efforts in equalization of the two light beams, etc. Almost absent are the other conditions and problems such as qualities of the recording medium and the vibration resistance of the device, successful solving of which has made this research possible. Not to mention the well-intended professor who granted salaries, a room, and laboratory assistants...

There is also one more thing that the researchers had brought with them from the other spaces: the insatiateness, the *desire to create something genuinely new*. Methodius' entire scientific biography before the autumn of 1973 may be reduced to one denominator: migration, guided by the search for a place beneficial for the production of holograms. This means a place with a laser, with some, even elementary, equipment, and with possibilities for optical and chemical experiments, with funding, with laboratory assistants and collaborators. It is for this reason that he changed five research institutions in a period shorter than six years. However, the migration in those places enriched him in all the assets enumerated above: contacts, skills, things...

Another and maybe most important feature of the experiments Methodius described are the restrictions, control and degrees of freedom. For, on the one hand, "we were under pressure from two sides..", but on the other hand, "what was in our hands was the developer... an enormous number of parameters of the medium can be modified with the developing".

If one is to generalize right from the beginning, the experiment in holographic research is a struggle with preset restrictions which are beyond your sway: the laser is the right kind of equipment, but with a fixed power and wave-length, the device cannot wholly cope with vibrations; the silver emulsions for the microelectronics part are good as well (high resolution), but they cannot be modified. What remains to be controlled is the exposure time, the area of the spot of the recording, but most of all the developer: it is there that the great opportunity for manipulation and variation lies.

Experimenting in holography is searching for "free spaces", for opportunities for maneuver... Or, more precisely, to organize a series of experiments in holography means to create a specific balance –different in every concrete case– between that which is beyond your control and which you must accept as given, and the other which is partly or entirely under your power. And then you have to extract from this balance the most you can. What is that is extracted? – Let us continue with Methodius' own narrative again:

"We started to modify the developing of this medium for microelectronics with the purpose to make a holographic emulsion. [First] we made preliminary experiments with different developing substances, in an intuitive attempt just to see where the effects are strongest. The first experiments showed that there is a lot to optimize. Then we began optimizing with the use of D-optimal plans... We started with an efficiency of 1.5%. After the optimization, diffraction efficiency (DE) reached first 2%, then 3%. After every increase of DE we went to the *Tenekiyite* pub near the Pioneer Palace (former Ecclesiastical School) – it never went right if we did not have a drink on it. Thus we reached 7%, then 7.6%, i.e. we surpassed the theoretical figure of 7.2% for amplitude reflection holograms we have been working on. [See Table 1]

Table 1: *The maximal values of diffraction efficiency (in %) for various types of hologram, according to the dominant theories in mid-1970s*

Volume holograms				Flat holograms		
Transparent holograms		Reflection holograms		Transparent holograms		Reflection with metal relief
amplitude holograms	phase holograms	amplitude holograms	Phase holograms	amplitude holograms	phase holograms	phase holograms
3,7	100	7,2	100	6,25	33,9	100

(Съинов, В., С. Съинов 1985: 86)

There were already reports in the literature that it was possible for the efficiency of amplitude holograms⁵ to surpass the theoretical one. This, however, used to be explained by changes in the physical mechanical properties of the gelatin medium, the so-called "tannage": a process accompanying the processing of the emulsion in which the relief of the layer is changed and eventually the refraction coefficient becomes modified. If DE is a little higher than the theoretically expected, this would seem to be possible. But we reached values like 15% DE and it went on growing. This amazed us and we carried out exclusive experiments. After the "tannage", we bleached the emulsion completely, i.e. we completely cleaned out the silver and the residual DE that we obtained was... of the order of 0,5-1%, not more... We could not at the time explain the high efficiency by the process of tannage alone.

When the efficiency began rising above the theoretical expectation, I had the suspicion that this was not due to the tannage. I had made attempts earlier to make something like a photo-resistor through tannage and I knew that there were a lot of unpleasant things there... I did not believe in tannage. But I had no theory then. By general considerations and by what we read in Mie's book we knew that similar media have a complex refraction coefficient, i.e. they behave both as amplitude and as phase media... We did not even make any experiments on this account: this was theory. There had been developed theories concerning solutions, concerning opalescence of solutions, concerning

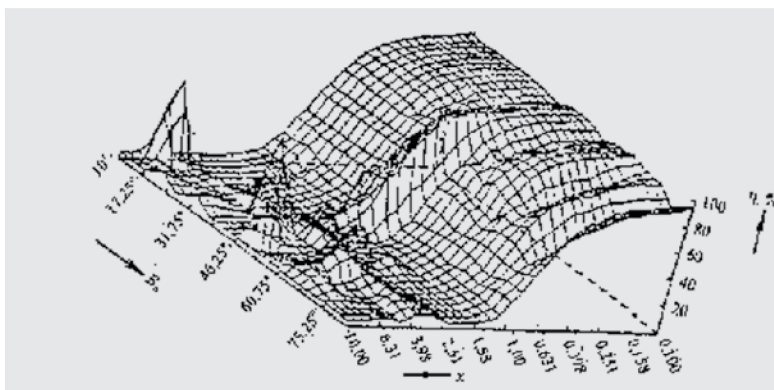
5 An explanation for non-specialists: holograms are subdivided into amplitude and phase holograms depending on the capacity of the registering light-sensitive material to transform the illumination of the interference image into correspondent changes in its optical characteristics such as the light absorption coefficient and the light refraction coefficient. In the first case the absorption modifies the amplitude of the light-wave and an amplitude hologram results. When the medium transforms the difference in the illumination in interference into changes in the refraction coefficient, a modification occurs of the phase of the light-wave and respectively phase holograms are produced. At the time of the beginning of the first experiments in the autumn of 1973, it had already been calculated theoretically that the maximum DE for amplitude holograms is 7,2% and or the phase holograms - 100%.

turbidimetry etc., a lot of calculations that had already been done. These were old, well known results. However, nobody had calculated all this for gelatine medium and silver. Then, after doing the discriminating experiments –to see if that was a phase modulation from the tannage and find out it was not– the full need for a theory arose. Which was, to explain theoretically what we got. Besides this, the efficiency went on increasing continuously and we needed to know how far it would go on increasing...

Interviewer: *Does this mean that during all this time, the autonomous process is the increase of diffraction efficiency of recorded holograms?*

Yes, I have somewhere preserved notebooks of the time... So this was going on and we started developing the theory along with it. Tsetsa Mateeva began calculations on a computer. We wrote a FORTRAN program, I explained her how to do it, I think it was on the machine in the CKS... She obtained the first results and, before we reached the maximum efficiency, we already knew that we could not get more than 80% in our case, however much we tried". (Methodius, Interview with the author)

"I even went to Prague to look for this Mie's theory, as the original text could not be found in Sofia. Mie was a German scientist who created, as early as in 1903, his theory of the so-called complex refraction coefficient... When I reported our results at a conference, Denisyyuk [one of the fathers of holography] came up to me in person to talk about my presentation. So on the basis of Mie's theory we calculated the complex refraction coefficient of silver medium. We showed theoretically, that diffraction efficiency may reach 80%, and this in a relatively wide range of parameters, and in some very special cases even more – over 99%. This article which we wrote with Methodius and Tsetsa Mateeva is one of our most quoted". (Excerpt from an interview with Cyril)



Picture 2: Topography, revealing the dependence of hologram's diffraction efficiency (η) from the size (x) of the silver crystals and so-called Bragg's angle (B_j), i.e. the direction in which the three-dimensional image was reconstructed

(From Ковачев, М., В.Съйнов, Ц. Матеева 1976, 118)

Looking at the second excerpt, one can hardly overlook the clear "experiment surpasses theory" fictional motif: everybody, i.e. people, scientists, colleagues believe in one thing, but in the experiments, during the battle to "outsmart" the crystals and emulsions, another thing comes out. A number of interviews that I have been conducted with researchers in the lab contain this *leitmotif of surprise*, of the unexpected they come upon in experiment, which is contrasted to their preliminary expectations, to what is written in literature, or to the common opinion among colleagues. They "see", or measure, or record something that should not have happened; they see something new. In holography, one most often literally sees.⁶ The experiment turns out to be an autonomous and independent authority in scientific judgment: it shakes the well known, it questions the established and the commonly accepted. And on the other hand, it is exactly there, through the peculiar balance of controlled and uncontrolled that this autonomous and independent authority is "tamed" and becomes predictable instead of unpredictable; from unexpected and fortuitous it becomes reproducible at will.

Here, a particular functional division between experiment and theory insinuates itself in the course of the experimental work. Theory very often is the basis which serves as the starting point for "everybody", the starting point also for oneself when one plan an experiment. But for the investigator himself it often appears as something very functional for his work – as the necessary precondition for knowledge of the future ("we needed to know how far will the diffraction efficiency increase!") – which gives the possibility of a "computer modeling". And on the other hand, it comes as the opportunity to pronounce the observed and subsequently make theoretical sense of what is observed.

Problems arise from the fact that although a given theory is more or less "universal", it is still bound to the initial scope of experiments and related studied materials, apparatuses, research skills, etc., and which Ian Hacking claims are the source of *stability* in laboratory sciences.⁷ In our case Mie's theory aimed to explain refraction of light in opaque *solutions* – its "complex refraction coefficient" as he eventually put it. However, for about seventy years after 1903 none had a whim

6 One of the interviewed scientists confessed: "It was exactly this that charmed me in and made me come to optics – you see so much there!"

7 "[...]When the laboratory sciences are practicable at all, they tend to produce a sort of self-vindicating structure that keeps them stable. This is not to suggest that they are mental or social constructs. I am not about to argue for idealism but rather for down-to-earth materialism... It is my thesis that *as laboratory science mature, it develops a body of types of theory and types of apparatuses and types of analysis that are mutually adjusted to each other* [italics mine – I.Tch.]. They become what Heisenberg (e.g. 1948) notoriously said Newtonian mechanics was, 'a closed system' that is essentially irrefutable. They are self-vindicating in the sense that any test of theory is against apparatus that has evolved in conjunction with it – and in conjunction with modes of data analysis. Conversely, these criteria for the working of the apparatus and for the correctness of analysis is precisely the fit with theory". (Hacking 1992, 29-30)

to apply this theory *not to solutions, but to the properties of solidified materials* such as dried dichromated gelatin. The step undertaken by Methodius and his group obviously shook both Mie's theory and the practices it presupposed – for it is really hard to call "solution" the thin layer of transparent solidified emulsion and bring it under that particular theory. Unlike Hacking, however, it is our claim that experiment, or rather the specific research practices at hand, remains all the time autonomous and relatively independent of the theories which were previously thought to be bound to. It is like an "element" that is never entirely controlled, full of surprises not withstanding the expectations, and which eventually allows the bonds to a particular theory to be broken and a new theory to emerge – or, as in our case, to be brought under an already existing theory, but by modifying both the theory itself and its empirical base. No scientist could allow himself, however, to stay for long with such "unbounded" research practices Methodius and his fellows experienced before they decided to stick to Mie's theory – because the theory is secure and cozy; it gives you the assurance that things will happen in this and not in any other way; it enlarges the sway of control, and it changes the balance in your favour.

Finally, there is something else in the experiment, something that Polanyi called "personal knowledge" – the residue of lasting experience which cannot be reduced to theories, devices, or procedures and is designated by dim words like intuition, feeling etc. (Polanyi 1958). The people dealing with holography (and more generally with diffraction optics) realized this very well. To the sociologist, a person coming from other spheres of knowledge, the reason for this seems to be the need of "breaking" the bodily notions and attitudes towards light inherited from everyday life. They are inherited from everyday life because there, light is ray rather than wave, it is energy and intensity rather than phase. In the world of holography and diffraction optics, you cannot interfere if you only have this kind of knowledge; rather, you also have to develop skills peculiar to the wave nature of light. The training for this begins as early as in the last years in the university when, in the laboratory exercises or in writing your thesis, you must force the ray to pass through the micron-wide slit and obtain the diffracted image...

This is very well expressed in the following quotation from an interview with another experienced researcher in the lab, Margarita Miteva, a former PhD student of Methodius:

"For a young postgraduate student in the field of photoreactive crystals, an induction period is needed, so to say. He or she must touch them, see them... see what happens in different circumstances, record, erase, illuminate, apply a magnetic field, read - study crystallographic orientations, see these orientations, calculate a little, try to see how will appear the tensor character... For most effects depend on the direction". (Miteva, Interview with the author)

Despite all that was said above, we have not yet touched what maybe the most impressive part in the narratives on holography: the exciting events and process which, manipulated by the scientists carrying out the experiment, take place within the studied media. Yes, within the crystal or emulsion: when the laser ray falls onto them, when they are electrified or abundantly "bathed"

in a developer, fixer, bleacher etc. Exciting events of whose description sometimes even an experienced playwright would be envious. It is in the confluence of these two elements that novelty is born: the one of the immediately seen in the course of experiment or taken from the indications of the measuring devices, and the other of the invisible world within emulsions and crystals. Pondering over this division, I remember Plato's metaphor of the observer in the cave who, sitting with his back turned to the entrance, can only see the shadows of the events happening in the world outside; in some unexplainable for scientists way, what they actually see – the trembling of the hologram in the crystal, the dimmed or clear image of the poster, turns out to be only a shadow of the actual events and processes that happen within the microworld of the crystal and are inaccessible to their unequipped eyes.

Let us again give the floor to our physicists. The "drama" of developing told by Methodius and Cyril:

"In illuminating the silver halide crystal, a photochemical reaction takes place in which the *electron knocked out* by the photon passes into the conductivity zone *and migrates until it is captured* by the electronic traps – defects or intrusions in the crystal lattice. The electron reduces the positively charged silver ion of the crystal lattice to an atom of elementary silver which is unstable, having a restricted lifetime of seconds. During this period, a second capturing is possible of an electron and the reduction of another silver ion to the formation of a stable cluster of two or more silver atoms. According to up-to-date research, four and more atoms are necessary for the developing. They are localized on the surface as well as within the volume of the silver halide crystal in developing centers also called centers of the latent image... In developing, the *centers grow* and silver particles (*grains*) are formed containing millions of atoms of silver each. It comes both from the crystal during its chemical reduction (direct or chemical developing) and by the precipitation of the silver complexes contained in the developing solution (physical developing)."

The silver crystals are, on their part, in a medium of gelatin which "...is a complex, many-component protein of animal origin. Its molecules are built up of aminoacids including sulphur in their structure. The compounds containing sulphur are effective chemical reducers by which the unique role of gelatin is explained. The *halide atoms, liberated* by the photochemical reaction, (positive charged holes) *can migrate, capture knocked out electrons* or oxidize silver atoms of the latent image to silver halide. The probability for these undesirable processes diminishes significantly since *halide atoms are captured and blocked* by the sulphur containing compounds in the gelatin bearer matrix... The network structure of gelatin permits the absorption of large quantities of water, water solutions, and suspensions in the process of gelatinization. After the evaporation of the water in the gelatin bearer matrix, only the compounds, the additions and the particles of the water solution remain evenly distributed. By this mechanism, silver halide emulsion layers are created as well. The *gelatin molecules wrap up the silver halide crystals and participate both in their formation (ripening) and in their sensibilization*". [Italics mine - I.Tch.] (Съйнов, В., С. Съйнов 1985, 106-109)

We see that within the emulsion laid in a micron-thin layer onto the glass plate, an animated and intense "life" is boiling; electrons and photons "knock" or "push" one another out, silver atoms "migrate" or are "captured", crystals "ripen" or "sensibilize" etc. And all this turns out to be unexplainably connected immediately to the above told story of the recording of a "good (micro)hologram", to the struggle for still higher diffraction efficiency, to what researchers see immediately by their yes. This is seen from the following continuation of Methodius's story:

"Interviewer: As you said, you had no resources to order a new medium and that is why you set off to optimization of the existing one. And at that time you did not know that silver particles in this same micro-grain medium for microelectronics behave as spheres and they have a phase... they have refraction?"

Speculatively, we knew it. And it was not fortuitous that we started optimization on purpose. We were informed that there were developers for reflection holograms. In these, the dimensions of the grain must be minimal. These developers are on the basis of pyrocatetine. It does not extract the silver but makes not so spherical silver threads. Normally in chemical development, centers begin appearing on the surface of the crystal. It grows "from its butt", to use a metaphor – the new silver begins to push away the already obtained one, as a result of which a thread is formed. It is very thin. Growing and pushing itself out, the thread confronts the resistance of the wrapping of the grain, the protective colloid – the gelatine – and it starts bending. Something like a ball of thin metal thread is formed. The ball's size measures microns and the thread is a hundred angstroms thin. As a result of this, an ideal model of black body is formed, since every photon which falls there is many times reflected by the metal and is absorbed. The result of this is that in chemical developing, we have the ideal model of a black body. One can also say, an ideal amplitude medium. In these circumstances, we must also obtain practically a diffraction efficiency...

Interviewer: Ideal efficiency, one of 99,9%...

No, not 99,9%, but the maximum possible for an amplitude medium - near to those little percentages – 7,2% (showing the table), as much as has been calculated theoretically..." (Methodius, Interview with the author)

Two points of importance arise from these excerpts.

First, within the emulsion "life is boiling" indeed, but this is a life of "witless idiots" who behave always in the same way in the same circumstances; they have no personal character or unpredictability. As Kant has said, there is nothing "internal" in them which cannot be expressed in terms of relations in outer space of observation, i.e. which cannot be reduced to received energy, direction of movement, angle of reflection etc. Imagine what would happen if some of these balls of silver threads, these "ideal models of a black body" of which Methodius speaks, all at once "decide" to

free all the absorbed photons and start emanating tiny lightnings... But this cannot happen: they are all *disciplined and obedient*... Well, it is this that permits the following claim.

Second, the discipline and obedience at photons allows for the use of mathematics in their description; i.e. physicists can pass on to the *third level of description* – to the quiet and calm world of mathematical figures. In some way with the help of mathematics we can verify the truth of the stories we invent about the world within the crystal or emulsion. This is simply because this third level of mathematical description is applicable at the same time to both kinds of stories, both repertoires (the one about our "first" world of immediate observation and the other about the micro world of atoms, photons, electrons, holes, centers etc.) Thus "calculating" the behaviour of brainless idiots in the crystal or emulsion, we can predict the effects we will observe with our senses or our apparatus.

One can say that "the full necessity to get down and make a theory" (Methodius) appears when in the repertoire of the micro world the micrograin silver crystals, under the influence of the pyrocatechin, begin behaving in an unpredictable manner and cease to be described as "ideal models of black body". Or when in the repertoire of our bodily world of observation in the optimization of developing, in the play with the different components of the developer, the holograms become better and better and we do not know how far it will be so. Or at the third repertoire of mathematics the diffraction efficiency starts growing above the theoretically calculated one.

Having separated these three levels in the process of experimentation in holography we are able to shed light on other interesting aspects. They are interesting for us who, like anatomists, have dissected the "body" of experimental life and are now observing *separately* the changes in the three repertoires, as it is not until after this that we reconstruct their mutual interrelations. It is clear for every physicist that this is a harsh violation of the course of real-life experiment which is a hardly discernible unity... But still it makes sense for there to be anatomy, although we know that in real-life there are no skeletons by themselves... The grounds for this dissection are given to us by the conflicting interpretations expressed by the physicists themselves, when the immediately observed is related to two or more different versions about the micro world, i.e. to different and even conflicting "translations" at the level of atoms, photons, holes, centers. And respectively, two or more alternative mathematical descriptions have appeared.

When holograms become better than expected, when diffraction efficiency surpasses the theoretical one, all at once "life in the emulsion" becomes problematic, unclear. Did the gelatin chains connect themselves to transverse sulphur bridges in the tannage and thus caused a fine rippling of the surface? Or perhaps is there something else – maybe now the silver spheres reflect, rather than absorb, the photons that writhe in light waves? Maybe not only Bessel's functions, Maxwell's equations or Kogelnick's theory can help, but also Lipman's and Mie's formulas can?

But who can make the transition from the *model* (here is another significant word – the physicists themselves call models the stories of the events in the micro world and their mathematical equiv-

alent) to the immediately observed and back? There is more than one model and, to a great extent, they all fit equally well in the different repertoires. The answer is: experiment again, this time the "exclusive" or "sifting" experiment for which, however, all that was said above is valid as well...

So finally we arrive at something we have almost forgotten about: *the truth*. It was mentioned almost nowhere in our story. And there was no way for it to appear, since it was not present in the stories of our scientists – all the time, we only interpreted what was said, we did not add anything new. Thus instead of the "thirst for knowledge" and "quest for truth" which are so well known to us from the textbooks and the philosophers, we discover a "hunger for control", or "manipulation", for "governing the parameters". To be fair, one of the researchers I interviewed, Margarita, Methodius' collaborator, did once use the term "true". It is indicative that she used this term not when describing the process of research, the experiments, the events in the crystal etc., but later, when the talk came to the presentation of the results to the colleagues, when they were to be published:

"Otherwise, we will write something, but the international community will say: OK, those people connect it to this, but this is not it! And, on the whole, we strive for it to be true".

Truth is not in the bosom of experiment, as there are other stakes and other criteria. Truth is convincing your colleagues in science. But taken together –the gained degree of control over the initially untamed entities studied in the experiment, *and* public recognition of it (i.e. the "truth")– they become efficient tools for convincing the centers of power in society and gaining their support.

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