The Life and Times of Edward Shuryak*

Larry McLerran

Physics Department and Riken Brookhaven Center

PO Box 5000, Brookhaven National Laboratory, Upton, NY 11973 USA

February 15, 2009

Abstract

Edward Shuryak has made important seminal contributions to the theory of high energy density strongly interacting matter. This anecdotal account covers some of his accomplishments and personal history.

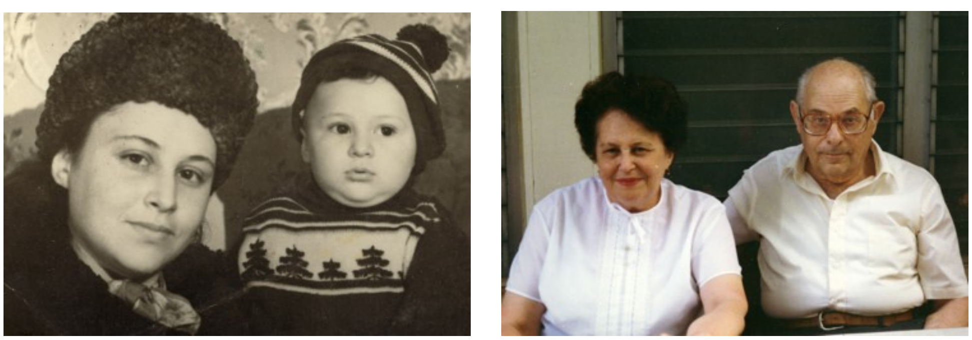

Figure 1: (a) Edward as a baby with his mother. (b) Edward's mother and father.

*This paper is based in part on a talk given in 2008 at a meeting at Stony Brook, The Extra Strong Quark Gluon Plasma, to celebrate the 60'th birthday of Edward Shuryak

1 Introduction

Fig. 1a shows Edward with his mother, in a shot taken nearly 60 years ago. A more recent picture of his mother and father are shown in Fig. 1b. A recent photo of Edward and his mother is offered as Fig. 2.

Figure 2: Edward and his mother in a recent photograph.

Edward's family came from Odessa, a city situated on the western shore of the Black Sea, not far north of the border with Romania. The earliest recorded settlement in this area was the Greek colony of Olbia. The area surrounding Odessa was once part of the Byzantine empire, and later part of the Turkish. It became a part of Russia as a result of the Russian-Turkish War of 1787-1792. The Duc de Richelieu, a relative of the Count Richelieu of the French revolution, governed the city from 1803-1814, and is fondly remembered as a planner and builder of the city. During the early 1800's, Odessa was a free port, and had a large multi-ethnic population. By the late 1800's the population was almost 1/2 Jewish.

The 19'th century was good for Odessa; the 20'th century was not. During the turmoil of the Russian revolution, Odessa was occupied by Reds, Whites and the French. There was starvation during 1921-1922, and again during the collectivization of the farms in the Ukraine. During the Nazi occupation 60,000 Jews were slaughtered in most hideous ways. During the era of Stalin, many people of all ethnic groups and diverse backgrounds disappeared in the gulags.

Some Jews survived both the Nazis and the Stalinists. Edward's mother was evacuated by train before Odessa was captured by the Germans. His father was in the Army, and lived through the war despite the tremendous losses suffered by the Red Army from the Nazis and various forms of decimation by the Stalinists.

In Edward's own words: " It is true that the 19'th century was better than the 20'th. Yet even during Soviet time, Odessa remained different from the rest of the Soviet Union. In the 1920's, a terrible time after the civil war and during the "golodomor" (starvation) induced by Stalin, Odessa city authority made a call for city people giving them small parcels of land in the fields around the city to grow some fruits and vegetables. My grandfather, an accountant by trade, had never touched any land before that, perhaps as his predecessors for a hundred generations or so. He took it and with some people built eventually 1/4 of a house, standing in the corner of four parcels. It was then far from the city, and of course nobody had a car or could hire a taxi, and yet the thing was growing, and survived the war and German occupation (robbed of course but not burned). When I remember myself there in the early fifties, there were splendid gardens all around. It was a real suburbia along the sea, except that still nobody had a car, and all travelled there by a tram and a long walk. We spent all summers there, till my parents finally left in 1989. Similar "dachas" appeared around most cities in the sixties, after the Stalin time, but still mostly for "nomenclatura". On the other hand, I don't recall anyone around our place having any noticeable positions: it was just ordinary city folks enjoying time outside Soviet style apartments."

One of Odessa's most famous citizens is Anna Akhmatova, one of the great poets of the 20'th Century. Akhmatova was born in 1889. She married Nikolai Gumilev in 1910; they were divorced in 1918. Nikolai Gumilev was exectued in 1921. Her poetry was banned in 1925-1940. A second marriage to Vladimir Shileiko in 1918 and

Figure 3: (a) The famous painting of Anna Akhmatova by Natan Altman. (b) Anna Akhmatova as a young woman.

they separated in 1921. She married again to Nikolai Punin, who died in a Siberian labor camp in 1953. Her son, Lev Gumilev, was imprisoned in 1949-1956. For many years while her son was imprisoned she tried writing poetry in praise of the "Great Leader" Stalin and his accomplishments, but the poems are practically unknown.

One of Akhmatova's better known poems is

Wind and honey has the scent of freedom,
Dust - of a ray of sun,
A girls mouth - of violet,
And gold - has no perfume.

Watery - the mignonette,
And like an apple - love,
But we have found out forever,
That blood smells only of blood.

During 1970-2000, the majority of Odessa's Jewish population emigrated.

2 Early Education

Figure 4: (a) Edward off to the mountains. (b) A young Edward prepared for the Siberian winter.

While still in their teens, Edward and his friends Simon Eidelman and Victor Krasnov successfully solved some physics and mathematical problems that were published in the Soviet newspapers, in association with the Siberian Olympiad system. The reward for solving the problems was an invitation to a summer school in Akademgorodok, the science city near Novosibirsk in central Siberia. Edward, Simon and Victor solved the puzzles together and made a condition of winning the prize that they all be invited to the school. They all were, and subsequently were admitted into the Physics and Mathematics High School in Akademgorodok, and all eventually graduated from the University at Novosibirsk.

Akademgorodok is a truly remarkable place. Scientists who were there during the Soviet era remember it as an island of sanity in a sea of failed utopian visions. This special community was located far from the centers of political power. In the early days of the Akademgorodok, it was supported both spiritually and financially by Khruschev, which induced the envy of the local political bosses. As the moral support from Khruschev waned, the local political bosses closed institutions that they did not like, even though the money for supporting them remained. Nevertheless, Akademgorodok was treated with sufficient benign neglect that it could thrive. In addition, by all accounts the director of the then Institute of Nuclear Physics, Gersh Budker, was an exceptional person with both a good sense of physics, and an uncanny ability to build both institutions and instruments in a politically and technologically challenged environment. The institute built up by Gersh Budker is now named the Budker Institute of Nuclear Physics.

A pair of photos of Edward during his youth are shown in Fig. 4a-b.

Edward graduated from the Physics and Mathematics high school, and went on to receive his degree from Novosibirsk State University. He received his PhD at the Institute for Nuclear Physics in Novosibirsk in 1974. He received his full doctors degree, the equivalent of a Habilitation in the German system (there is no equivalent in American universities) in 1982. He was an associate professor at Novosibirsk State University from 1975 until 1989, and was a junior and eventually a chief scientist at the Institute for Nuclear Physics from 1973 -1989. He left Russia in 1989.

Edward's first teacher was Yuri Borsiovich Rumer. Prof. Rumer was educated in Moscow State University and worked as an assistant of Max Born in Goettingen. He returned to Russia in 1932, and was arrested simultaneously with Landau as a "collaborator of the enemy of the people Landau" and later convicted as a spy. That was a time when almost anyone with experience outside of Russia had a high probability of being imprisoned. He miraculously survived 20 years in gulags and exile. He was "rehabilitated" when Krushchev came to power. Rumer eventually became the director of the Radio-Physics Institute in Novosibirsk, a Professor at Novosibirsk State University, and later worked as a Researcher in the Budker Institute. Edward learned the word "quark" from Rumer. Prof. Rumer is shown in Fig. 5

Edward's PhD advisor was Spartak Belyaev, shown in Fig. 6. Belyaev was then head of Theoretical Physics at the Institute for Nuclear Physics at Novosibirsk and also Rector at Novosibirsk State University. He was most recently Director of the Institute of General and Nuclear Physics at the Kurchatov Institute in Moscow. Two of his

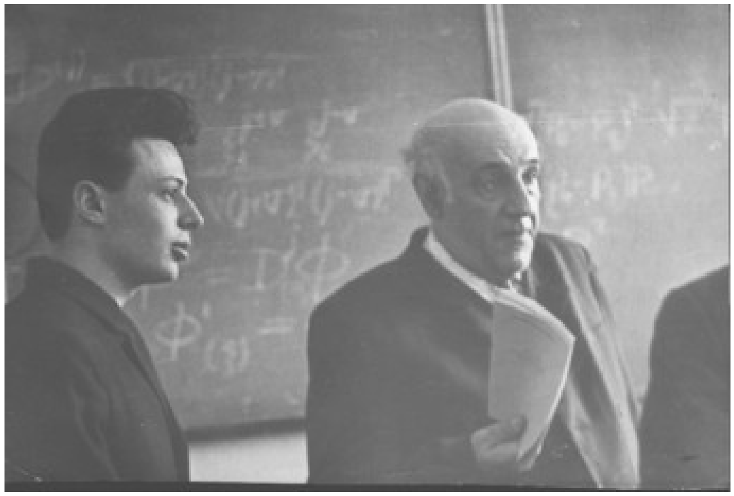

Figure 5: Edward together with his teacher Yuri Borisovich Rumer.

quotes are: “Theorists must grow through asphalt,” and “I will never accept a student or post-doc who cannot fill out his own forms.” These statements reflect the general attitude to education in the Soviet system: Students should be independent and develop their own ideas. A teacher is there only to help them develop the tools needed to address the problems they choose. According to Edward, Belyaev was perhaps exceptional in this regard.

One of Edward’s teachers was Vladimir Zelevinsky, now a professor at Michigan State University. He encouraged Edward to focus on the area of nuclear physics – in particular, to work on the “cranking model for SU(3)”. He recalls Edward as a a good lecturer and teacher, but remarked recently that Edward was never interested in nuclear physics.

I will return to Novosibirsk later, concluding this section with a couple of pictures of Siberia, Fig. 7. I offer the first photo as a typical winter scene in Siberia. It is actually a picture of Finland, but the general idea is correct. The second is of Siberian tigers. There are unfortunately none near Novosibirsk. The third is of ice statues. This photo comes from Siberia, although not from Novosibirsk. The point is that Siberia is a much different place than Odessa, not just intellectually, but physically, and that it is difficult to get touristic photos of Novosibirsk.

 

Figure 6: (a) Edward's PhD advisor, Spartak Belyaev. (b) Edward's teacher, Valdimir Zelevinsky.

I was privileged to meet the mayor of Novosibirsk during my time at Minnesota during the late Gorbachev era. Minneapolis is the sister city of Novosibirsk. The mayor was a brave man, trying to find innovative ways to solve old problems and bring Novosibirsk into a new era. He had energy and courage, the latter quality being extremely rare among politicians in general, and sometimes fatal for Russian politicians.

  

Figure 7: (a) A typical winter scene in Siberia. (b) Siberian tigers. (c) Ice statues.

3 Edward's Early Work

Edward's scientific work is always full of new ideas, and often seminal. It typically is unconventional; Edward invents, rather than following trends. He seems guided by the quote:

Always drink upstream from the herd.
Will Rodgers

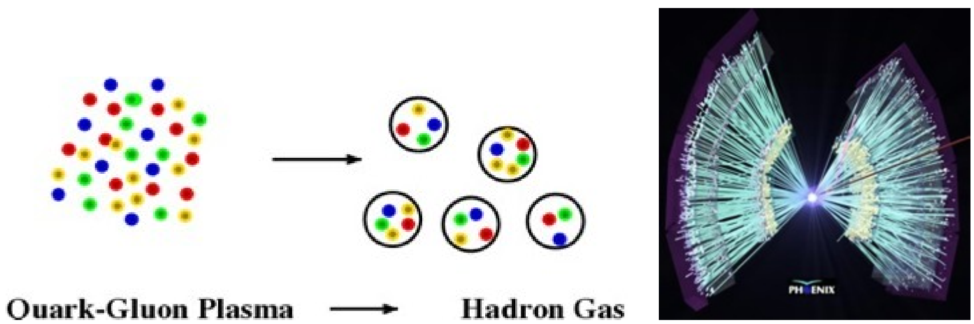

Figure 8: (a) The quark gluon plasma as it decreases its density converts into a gas of hadrons. (b) The high multiplicity of particles produced in heavy ion collisions as seen in the Phenix detector.

Edward's first works concerned the properties of systems with many pions.[1] He wrote papers about collective phenomena in multi-pion systems, and Landau hydrodynamics.[2] He began thinking about the plasma of quarks and gluons.[3] This paper contained a treatment of the QCD plasma and had a derivation of quasi-particles and screening. He coined the phrase Quark Gluon Plasma for the high temperature system of de-confined quarks and gluons predicted by QCD, also in 1978.[4] Fig. 8a shows a Quark Gluon Plasma expanding and cooling as it would in Big Bang cosmology. At very high densities, the constituents of nucleons and mesons are free to roam around the volume of the system unconfined. As the density is lowered so that the typical separation between a quark or a gluon is of order 1 fm, they eventually must recombine into a hadronic plasma. The Quark Gluon Plasma is the subject of study explored by heavy ion collisions. Fig. 8b shows the result of a collision as seen in the Phenix detector at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory.

At the time these ideas were being developed, they seemed very remote from experiment. There was some small interest in them on the part of the high energy and the astrophysics communities, but by and large it was very difficult for those with a primary interest in such problems to find positions. It was also not clear whether this field should be thought of as particle physics or nuclear physics. Often when ideas fall between two fields, they are lost because neither field feels such concepts belong to them. To obtain a reasonable position at a respectable university working solely on the properties of such matter would have been impossible. This lack of academic respectability remained largely so until the experiments at CERN and RHIC began, many years later. To quote Will Rodgers again:

If you're riding ahead of the herd, take a look back now and then to see if it's still there.

4 First Meetings with Edward

I first met Edward at a 1984 meeting at the Physikzentrum of Bad Honnef. The Physikzentrum is an elegant old building near Bonn, shown in Fig. 9a. The meeting was organized by Richard Weiner, who had experience in dealing with Eastern Europe and Russia, and knew how to invite people from those areas. One of the rules at that time was that people needed to be invited in pairs. Edward made his first trip to the West with Evgenii Feinberg. Evgenii was one of the grand old men of Russian theoretical physics, and like Edward had done work on the fluid dynamics aspects of high energy collisions. This was also a specialty of Richard Weiner.

The title of the meeting was *First International Workshop on Local Equilibrium in Strong Interaction Dynamics.* The meeting's focus was discussion of to what degree matter made in high energy collisions of strongly interacting particles might be described as an almost non-viscous, or perfect, fluid. Now, with the results of RHIC experiments, there are very good reasons to accept that the Quark Gluon Plasma is to a good approximation a perfect fluid – but at the time of the meeting, very few were willing to accept such a hypothesis. Edward's talk was *Mean Free Path in Strong Interactions.* My own was *Mean Free Paths, Viscosity and the Limitations of Perfect Fluid Hydrodynamics.* For Edward, this first trip to the West was exciting. I spent much time talking with him and Evgenii. Edward was full of energy, and obsessed by physics. I found that he was someone to whom you never

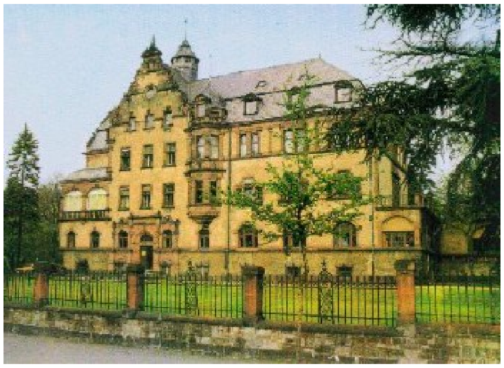 

Figure 9: (a) The Physikzentrum at Bad Honnef. (b) Edward Shuryak and Evgenii Feinberg.

had to explain things twice. He also had thought carefully about what he strongly believed. To paraphrase Will Rodgers,

There are two theories about how to win an argument with Edward Shuryak. Both of them are wrong.

I met Edward again later, when I visited Novosibirsk as part of a DOE delegation in 1986. Budker is shown together with the former Director of SLAC, Wolfgang Panofsky in Fig. 10 a. Edward is acting as translator. The charismatic Budker had died nine years before, but what he built continued to be strong. In 1986, the directorship of the Budker Institute of Nuclear Physics was under Skrinsky, who was to become very influential later as the Head of the Nuclear and Particle Physics Division of the Russian Academy of Sciences. (Skrinsky still holds both positions.) Skrinsky is shown in Fig. 10b. Novosibirsk was famous both for its work on colliding beams, and its work on electron accelerators. Novosibirsk scientists continue to provide accelerator technology around the world. They have been important at RHIC for their idea related to polarized particle acceleration and electron cooling of proton and nuclear beams. They also produced equipment for the LHC.

In some ways, the Institute for Nuclear Physics at Novosibirsk is similar to Brookhaven National Laboratory. As shown in Fig. 11 a, there is a beach, and as shown in Fig. 11b, there are pleasant walks through the woods. Also, in the woods, there are ticks as shown in

Figure 10: (a) Budker, Panofsky and Shuryak (b) Skrinsky.

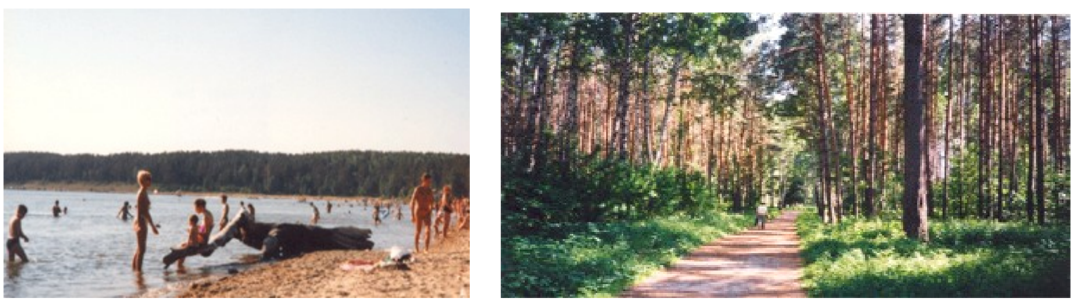

Figure 11: (a) The beach in Akademgorodok. (b) A path through the woods near Akademgorodok.

Fig. 12. About the only major difference between the Institute for Nuclear Physics and BNL, is that the cafeteria in Akademgorodok serves better food than does the BNL cafeteria, and that, even during the middle of the cold war, the security was less intrusive than it is now at Brookhaven.

At the time of my visit, Edward was interested in instantons and their effect on the structure of strongly interacting particles.[5]-[7] Instantons are solutions of the classical field equations of the theory of strong interactions and are associated with quantum mechanical effects like tunneling under potential barriers. At that time, some

Figure 12: A sign in the woods near Akademgorodok warning of ticks.

physicists thought they might be responsible for both confinement and mass generation. It is now widely believed that they are responsible for mass generation. Edward's work in this area was seminal in generating effective theories that include the effects of intsantons.

He had, back then, completed a review[8], whose eight chapters had been published in a single volume of Physics Reports. He had just finished further developing the ideas in the Physics Report, and had written in English a 600 page manuscript that was to be later published as a book. The Soviet authorities were however requiring him to retranslate it back into Russian for their own archives. There needed to be a Russian text for any article published in English. Now as often happens in such situations, these authorities had no idea what such papers meant, so Edward got the brilliant idea of using a computer translation of the work to accomplish the required task. Edward himself had written the program which translated his English language paper into Russian.

In Edward's own words "The idea to make a full scale translation program evolved gradually: Let me tell you my first thought which was to use the editor to cancel out all 'the' in all 600 pages, which was about 10,000 times. Then I did simple things like changing standard words like 'quark' and other physics terminology. There was no escaping grammar, for which I wrote crude programs. The worst of all is different word order. Those I rearranged manually for a few pages and then gave up. So my sentences in Russian had English word order, although grammatically it was more or less OK. It sounded like I came from Mars and learned language from a wrong textbook. But it did pass the censor"

There are many popular stories about computers that translate one language into another. The way such computers are tested is by translation into one language and then back into the original language For example, under this transformation in early computers

English → Chinese → English
Out of sight out of mind → Invisible Insanity

English → Japanese → English
Grapes of Wrath → Angry Raisins

English → Russian → English
The spirit is willing but the flesh is weak → The vodka is good, but the meat has gone bad.

I think we can safely assume that Edward did not care so much that the authorities could understand the translation, and neither did the authorities.

Over the next several years, Edward and I converged in a number of places around the world. We met at the physics and astrophysics of the Quark Gluon Plasma in Mumbai in 1988. Also in 1988, there was a joint meeting of Soviet and American scientists in Nor Amberd on the slopes of Mount Aragats in Armenia. At this meeting Edward took the picture below which shows my wife Alice, Arkady Vainshtein, Alyesha Young, me, Misha Shifman, Valery Rubakov, David Gross and Misha Shaposhnikov on a hike together, Fig. 13. Edward has a very good collection of photos he has taken at scientific meetings.

This meeting was a very special one, where Soviet and American scientists got to know one another and their physics, with little interference by the security apparatus of either side, and in a setting of great natural beauty.

5 Edward Leaves Russia

In 1989, Edward was visiting CERN for a month. At this time, the USSR was regularly allowing scientists to travel abroad. I know this

Figure 13: A hike during the US Soviet joint meeting in Armenia of 1988.

very well, as I was at the University of Minnesota, and was successfully inviting a large number of Russians to visit the Fine Theoretical Physics Institute in Minnesota.

While at CERN, Edward invited me outside for a talk. He told me that he was planning to emigrate legally from Russia. I was very surprised by this, as I could imagine many ways of visiting the west for long term visits, effectively emigrating, but without ever having to apply explicitly for emigration. An explicit application, if refused, would mean that you would lose your job and have no possibility to work, while being forced to remain in Russia. There were large communities of such Refusenik's in major Russian cities. Edward nevertheless wanted to make a legal application since he wanted to emigrate with not only his immediate family, but with parents. I have always greatly admired Edward's courage.

Edward asked about job possibilities in the US. I mentioned the possibility of Brookhaven Lab or the State University of New York at Stony Brook. Both of these institutions, I suspected, might very much like to hire Edward. Upon return to the US, I called up Sid Kahana at BNL, who talked with Gerry Brown. I waited until my return to the U.S. to make these calls, as I was somewhat worried about the possibility of intercepted international telephone or e-mail communications. There had been an incident before when I was trying to help a Russian colleague, and a prominent US physicist who had high level connections made a point of quoting verbatim from an e-mail message I had sent while in Europe. The colleague could not warn me directly.

Gerry wanted to hire Edward at Stony Brook, and both Sid and Gerry fully understood the necessity to do this as quietly as possible. While this was going on, I met Edward again at Quark Matter in Lenox, Massachusetts. Edward needed a long term invitation from somewhere in the US, and I arranged for a one-year invitation for use with his emmigration application with the Russian authorities to be sent by the Fine Theoretical Physics Institute.

Gerry Brown, shown in Fig. 14, was the hero of these negotiations. He arranged for the faculty at Stony Brook to produce a formal offer, and negotiated a good research contract for Edward from DOE. I also understand that Peter Paul was essential in setting up the offer of a position.

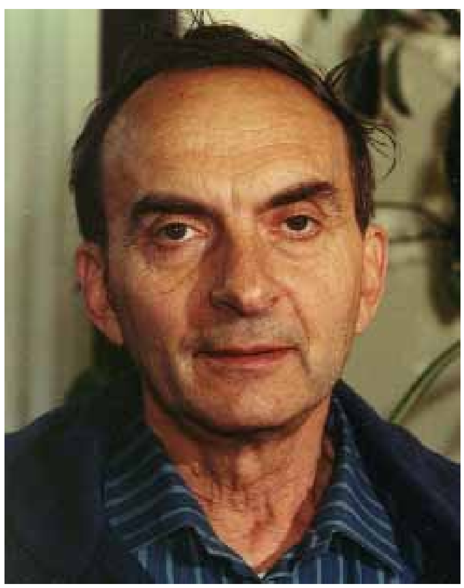

Figure 14: (a) Gerry Brown (b) Gerry and his wife dancing.

I learned that Edward had been successful in his application during a dinner party at Misha Voloshin's apartment in Moscow. Nelly

Vainshtein was there, and she with Arkady were planning to visit the University of Minnesota for a year. (Arkady later took a prestigeous job at the the University.) Nelly spoke little English and I less Russian. We managed to slip away for a few minutes on to a balcony where she informed me that Edward had been successful in his application.

Edward emigrated, and he first went to a refugee center in Rome. Gerry Brown was watching over the whole process very carefully, and was in contact with the relevant authorities in the US who could allow Edward to enter the U. S. In a few months, Edward was in Stony Brook.

6 Edward Physics with Instantons

Much of Edward's career has dealt with instantons. In Fig. 15, we see how instanton transitions appear in gauge theories. The figure is for the theory of electromagnetic and weak interactions but the figure would be much the same for the theory of strong interactions. In the upper part of the figure, a minimum potential is shown. The red ball shows the energy of a field configuration which interpolates between two minima. At degenerate minima, the physics is assumed to be identical by a symmetry of the theory. For example, all the energy levels of the Dirac equation are the same, as shown in the lower left hand and right hand plots.

If one makes a transitions between these two minima, however, physical effects can occur. To see this, assume that for the vacuum, all the negative energy states of the Dirac equation are filled, and all the positive are unoccupied, as shown in the lefty hand bottom of Fig. 15. Then as we move from one minima to the next, these energy levels will move. Upon arrival at the new minimum, there is an occupied positive energy state, and the configuration (right hand side) is the vacuum (left hand side) plus a particle (the occupied positive energy state). Therefore such transitions can induce particle production and break the symmetry which we thought was there for the multi-minimum potential. For this reason, such processes are called anomalous. In strong interactions, such transitions break a symmetry associated with zero mass quarks, and therefore may be responsible for generating the masses of quarks.

For processes at low energies, the only way of making such transitions is by tunneling under the barrier between the degenerate minima.

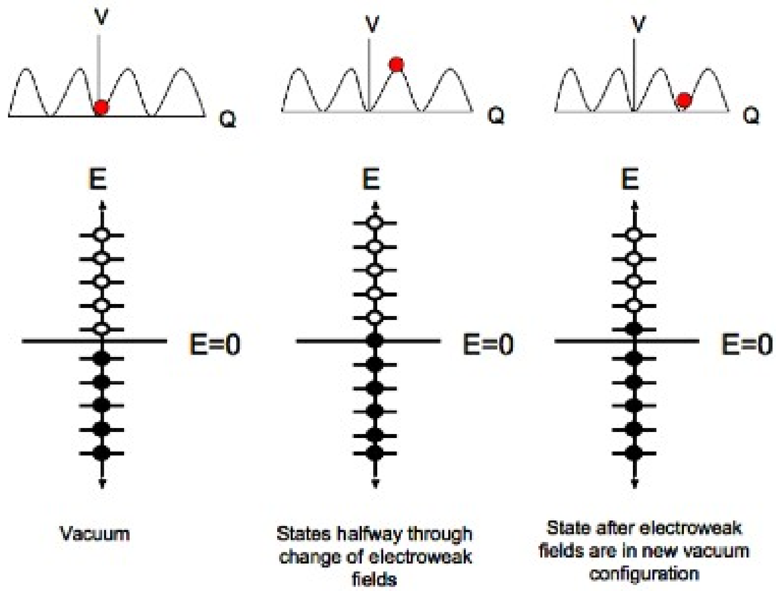

Figure 15: Barrier penetration and anomalies in theories like QCD and Electroweak Theory.

The configuration of fields that can do this is called an instanton. I like to think of instantons as worms. Early in the development of the theory of strong interactions, there was much enthusiastic hope that instantons would solve the basic problems of strong interaction physics. Callan, Dashen and Gross wrote a famous paper originally entitled "A Theory of Strong Interactions" that when published became "Toward a Theory of Strong Interactions".[9] I think it is fair to say that instantons provide a mechanism for mass generation, and instanton motivated models provide a good phenomenological description of many aspects of particle spectroscopy and low energy interactions. Edward was very influential in these developments, which are summarized in his book.[8]

Of course these developments were very controversial at the time, and remain somewhat controversial. When you are advocating new ideas and there is controversy, such controversy is in the end often good for both your career and for physics, but it can be very painful at the time. Often times an innovator may feel that like Galileo, he is unjustly being persecuted for heresy, but still hope that in the end he too may emerge victorious. One should note however that it took almost four hundred years to clear Galileo's name.

I suggest to all innovative young theoretical physicists, and Edward too if he ever feels the need, that this song may help raise their morale at difficult moments:

Nobody likes me,
Everybody hates me,
I'm gonna eat some worms.

Long slim slimy ones,
Short fat juicy ones,
Itsy bitsy fuzzy wuzzy worms.

Nobody likes me,
Everybody hates me,
I'm gonna eat some worms.

First you get a bucket,
Then you get a shovel,
Look how they wiggle and squirm.

Nobody likes me,
Everybody hates me,
I'm gonna eat some worms.

First you pull the heads off,
Then you suck the guts out,
Oh how they wiggle and squirm.

Nobody likes me,
Everybody hates me,
I'm gonna eat some worms.

7 Edward's Recent Work

Edward continues to make prolific contributions to theoretical physics. Perhaps he took some advice on investing from Will Rogers:

Don't gamble: Take all your money and buy some good stock. If it goes up, sell it. If it don't go up, don't buy it.

His work has covered many areas: Random matrix models,[10] hydrodynamics, flow and Mach cones in the quark gluon plasma,[12], the

Figure 16: (a) Edward and Jac Verbaarschot (b) Edward and Stan Mrowczynskii.

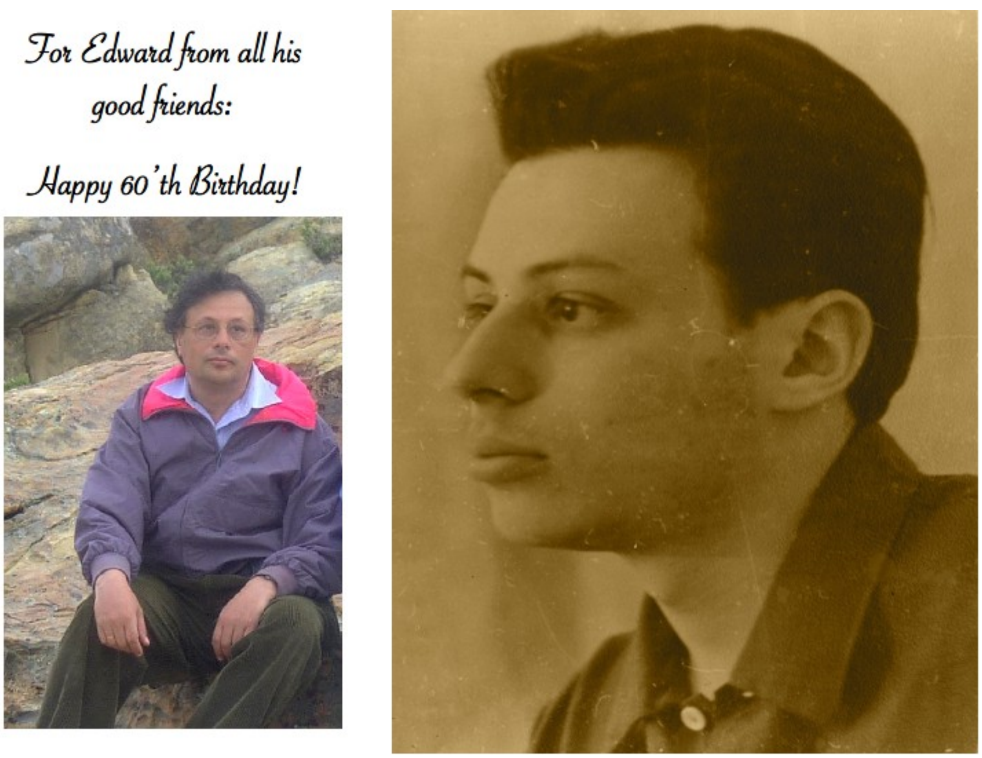

Figure 17: Happy Birthday!

critical end point at finite temperature and density,[11] cosmology,[13] and the the strongly interacting quark gluon plasma.[14]. He and Thomas Shaefer wrote a very well received and cited review on the properties of instantons.[15]

Perhaps his most famous work is that of recent years on color suprconductivity.[16]. At very high baryon density, Edward and others argue that there will always be a color superconducting phase.[16]-[17] This phase has novel transport properties, and may affect the phenomenology of neutron stars with quark cores.

Edward appears here in two fairly recent photos. In Fig. 16 a, Edward is enjoying a Japanese dinner with the main organizer of the celebration of Edward's 60th birthday, Jac Verbaarschot. In Fig. 16 b, he is skiing at the famous school in Schladming Austira. All that day, Edward had been skiing with a camera underneath his parka, taking photos of everyone. I remember seeing him skiing most carefully, so as to avoid falls. Fortunately, someone was allowed to take a photo of Edward.

8 Summary

The last Figure, Fig. 17, is a composite I put together of Edward when he was very young and as he is now. Indeed, there is a strong resemblance.

9 Acknowledgements

I thank Jac Verbaarschot, who was lead organizer, and Thomas Shafer and Arkady Vainshtein who were co-organizers of The Extra Strong Quark Gluon Plasma, and for their suggestions in the preparation of this paper, and my wife Alice for her help in editing it. Arkady was particularly helpful, correcting many errors in the early version of this manuscript and providing information of which I had no knowledge.

This manuscript has been authorized under Contract No. DE-AC02-98H10886 with the U. S. Department of Energy.

References

[1] E. Shuryak, *Phys. Lett.* **B44**, 387 (1973);

[2] E. Shuryak and O. Zhirov, *Sov. J. Nucl. Phys.* **28**, 247 (1978); *Yad. Fiz.* **28** 485 (1978).

[3] E. Shuryak *Sov. Phys. JETP*, *47* 212 (1978); **Zh. Eksp. Teor. Fiz. 74**, 408 (1978).

[4] E. Shuryak, *Phys. Lett.* **B78**, 150 (1978), **Sov. J. Nucl. Phys. 28**, 408 (1978), *Yad. Fiz.* **28**, 796 (1978).

[5] E. Shuryak, *Phys. Lett.* **B81**, 65 (1979).

[6] E. Shuryak, *Phys. Rept* **61**, 71 (1980).

[7] E. Shuryak, *Nucl. Phys.* **B203**, 93 (1982); **B203**, 116 (1982).

[8] E. Shuryak, *Phys. Rept.* **115**, 151 (1984).

[9] C. Callan, R. Dashen and D. Gross, *Phys. Rev.* **D17**, 2717 (1978).

[10] E. Shuryak and J. Verbaarschot, *Nucl. Phys.* **A560**, 306 (1993).

[11] M. Stephanov, K. Rajagopal and E. Shuryak, *Phys. Rev. lett.* **81**, 4816 (1998).

[12] D. Teaney, J. Lauret and E. Shuryak, *Phys. Rev. Lett.* **86**, 4781 (2001); nucl-th/0011058, nucl-th/0110037.

[13] V. Flambaum and E. Shuryak, *Phys. Rev.* **D65** 103503 (2002).

[14] E. Shuryak and I. Zahed, *Phys. Rev.* **D70**, 054507 (2004).

[15] T. Shaefer and E. Shuryak, *Rev. Mod. Phys.*, 323 (1998).

[16] R. Rapp, T. Shaefer, and E. Shuryak, *Phys. Rev. Lett.*, **81**, 53 (1998).

[17] M. Alford, K. Rajagopal and F. Wilczek, *Phys. Lett.* **B422**, 247 (1988).