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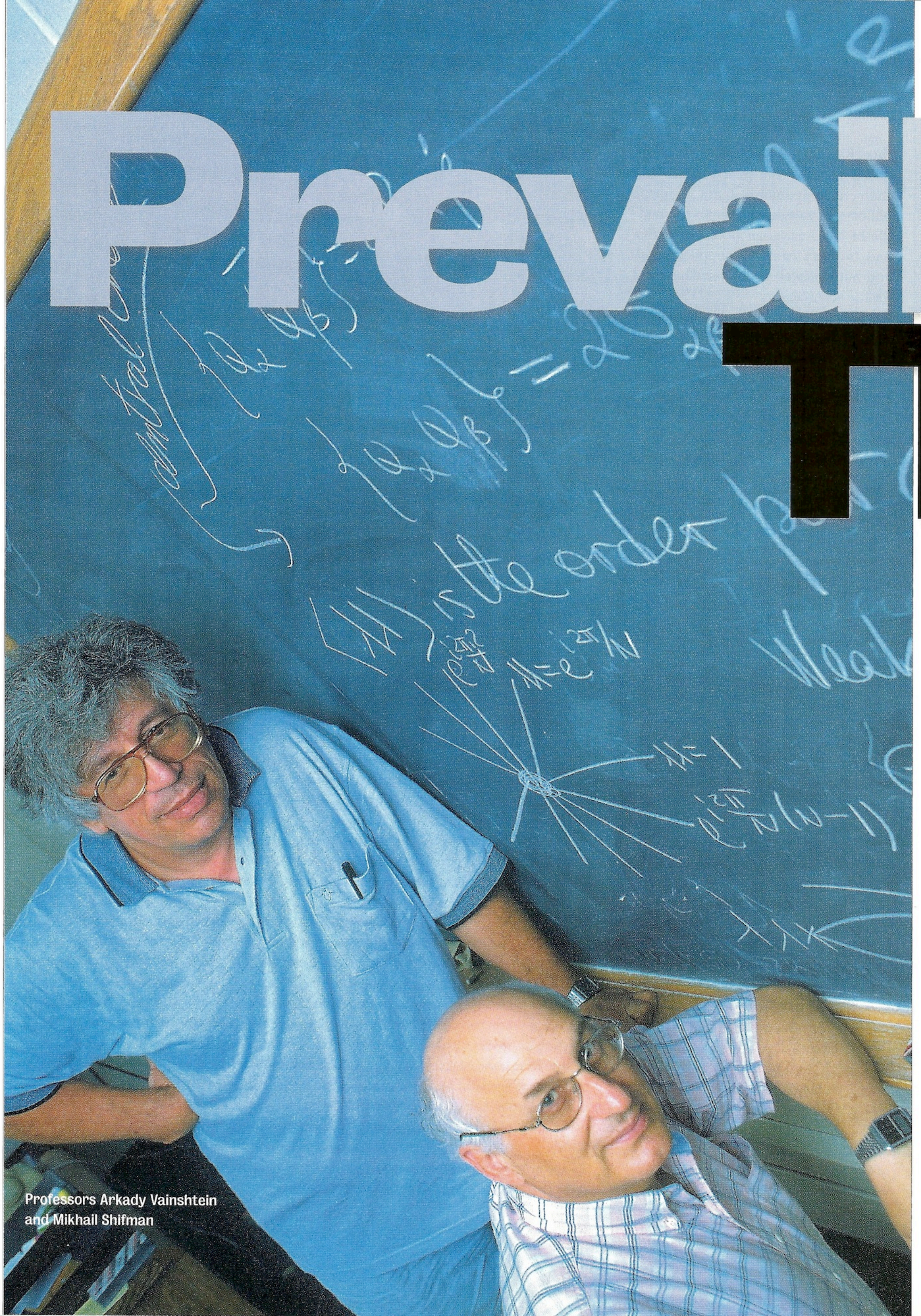

Professors Arkady Vainshtein and Mikhail Shifman

PHOTO BY SCOTT ROMBA

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Groundbreaking research in theoretical particle physics has earned international acclaim for two University physicists and their collaborator

by Joe Carlson

The 1970s were an exciting decade for young physicist Arkady Vainshtein. His ideas were coming to fruition, his papers were getting published, and his theories were gaining acceptance in the international arena. He was developing a closely-knit group of colleagues who together aspired to make major contributions to theoretical particle physics. The fact that his collaborators Mikhail Shifman and Valentine Zakharov were in Moscow while he was hours away in Novosibirsk, Siberia, didn't matter; their passion for physics would overcome the difficulty of long-distance collaboration.

Twenty-odd years later, Vainshtein and Shifman still work side-by-side, now as full-time faculty in the Theoretical Physics Institute (TPI), tucked away on the fourth floor of the University's Tate Laboratory of Physics. Zakharov is currently at the Max Planck Institute for Physics in Munich, Germany.

From the beginning, the three always aimed to be at the forefront of cutting-edge physics. But it wasn't until this year that the international physics community confirmed their status as world-class theorists.

Last March, more than 12,000 physicists, including Nobel laureates and leading theorists, descended on the World Conference Center in Atlanta, Georgia—site of the 1996 Summer Olympic Games—for the American Physical Society's centennial celebration. During that unprecedented meeting, the society honored Shifman, Vainshtein, and Zakharov with the 1999 J.J. Sakurai Prize for Theoretical Particle Physics.

The prestigious award bears the name of the late Jun John Sakurai, a noted physicist born in Tokyo in 1933. His theories encouraged particle physicists to examine major ideas in diverse ways and to seek out new theories that crossed distinct genres of physics research. Established in 1985, the prize is given annually to physicists judged by their peers to have made major contributions to theoretical particle physics. The list of the award's recipients reads like a "who's who" of the high-energy physics community.

Shifman, Vainshtein, and Zakharov were honored for their contributions to three major research areas. The Sakurai prize citation credits them with "fundamental contributions to the understanding of nonperturbative QCD, nonleptonic weak decays, and the analytic properties of supersymmetric gauge theories."

That's a pretty concise description, considering that it represents about 25 years of work by the three physicists.

The first penguin flies

In the early days, Vainshtein often traveled to the Institute of Theoretical and Experimental Physics in Moscow, where Shifman and Zakharov worked. Time was never wasted during those visits, and the group would spend days trying to resolve a single problem.

When travel wasn't possible, Vainshtein and his friends consulted each other frequently by telephone and began to formulate new theories in the burgeoning field of quantum chromodynamics (QCD).

Because new theories are meaningless until they are published and debated, the three colleagues submitted an article for publication in *Nuclear Physics*, a leading international journal. For a year and a half, the journal's referees tried to refute the trio's QCD theories on nonleptonic decay. In 1977, following an appeal to the editorial board, the journal finally agreed to publish the paper without any revisions.

Finally, Vainshtein quips, the penguins were starting to fly.

Two decades later, that odd phrase became the title of Vainshtein's acceptance speech for the Sakurai prize, awarded to the three researchers in part for their 1975 discovery of so-called penguin diagrams.

"It was an exciting period, with quantum chromodynamics emerging as the theory of strong interactions," Vainshtein wrote in the transcript of his Sakurai address, "when three of us . . . started in 1973 to work on QCD effects in weak processes."

Physicists have concluded that the universe has four fundamental forces: gravity, the electromagnetic force, the nuclear or strong force, and the weak force. Scientists believe that these forces, which determine the interactions between the tiniest bits of matter, are also related.

Shifman, Vainshtein, and Zakharov were studying the weak force, a factor

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in some radioactive decays. They wanted to learn why two similar mesons, charged kaon K+ and neutral kaon K_S, decayed at different rates. Theoretical estimates predicted that the two particles would have similar life spans, but experiments proved that the K+ meson lived about 500 times longer than the K_S meson.

"The puzzle was to explain this number," Vainshtein says. "The answer [to the puzzle] was strong interaction."

Each force employs its own set of particles to do its work, he explains. Normally, the weak force causes quarks to decay when they interact with W bosons, which serve as a mediator of weak forces. The three researchers discovered that a mediator of strong interaction—a gluon—enhanced the decay of K_S at a rate 500 times faster than normal.

News of the discovery gradually seeped from Russia to the outside world. By about 1977, their gluon interference theory gained acceptance after prominent American physicist Mary K. Gaillard, now at the Lawrence Berkeley National Laboratory, discussed it in one of her summary talks. She also incorporated the theory into one of her works on *b* quark decays, written with John Ellis of the world-renowned European Laboratory for Nuclear Physics (CERN) in Geneva, Switzerland.

In a preface written for Shifman's 1999 book, *ITEP Lectures on Particle Physics and Field Theory*, Ellis recalls how the gluon interference diagram came to be called a penguin diagram.

One night in spring 1977, Ellis lost a bet during a game of darts. His penalty required that he use the word "penguin" in a journal article.

"For some time, it was not clear to me how to get the word into this *b* quark paper that we were writing at the time," Ellis wrote. "Then, one evening . . . I stopped on my way back to my apartment to visit some friends living in Meyrin, where I smoked some illegal substance. Later, when I got back to my apartment and continued working on our paper, I had a sudden flash that the famous diagrams looked like penguins. So we put the name into our paper, and the rest, as they say, is history."

The threshold of existence

During the 1970s, the three researchers also focused on QCD sum rules, the method used to find the mass and other properties of hadrons, a type of strongly interacting particle. This problem had challenged theoretical high-energy physicists for decades.

The approach taken by Shifman, Vainshtein, and Zakharov traces the evolution of quarks and gluons in the vacuum. From the perspective of modern science, Shifman explains, the vacuum is a very complicated medium, full of fluctuating fields that are responsible for the basic properties of hadrons.

This new approach—dubbed the SVZ sum rules in honor of the authors—later was formulated in three papers that comprised the entire 1979 issue of *Nuclear Physics*.

Vainshtein vividly recalls the days they spent preparing for publication. Using manual typewriters, the three

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men painstakingly retyped multiple copies of their manuscripts, some required for prepublication review and others needed for KGB approval.

After the papers were finally dispatched, the three were exhausted, "not just from thinking about physics itself, but [from] physically writing out all the equations," Vainshtein says.

A profound discovery

According to Shifman, supersymmetry is one of the hottest areas of physics research, involving hundreds of physicists around the world, including TPI researchers.

But it wasn't always so.

"We started working on aspects of supersymmetry in the early 1980s, at the time when it seemed rather exotic," he says. "Very few people in the world worked in this direction. Now, 15 years later, the results we obtained then turned out to be very important. They are intertwined in the fabric of the recent breakthrough developments in high-energy physics by Seiberg and Witten of Princeton University, today's leading researchers in high-energy physics."

Every particle in nature is one of two subatomic varieties, either a boson or a fermion. During the 1970s, researchers in Russia and Switzerland uncovered a symmetrical relationship between the two species, known as supersymmetry. Studies have determined that the relative quantity of bosons and fermions may have major ramifications for the physical sciences.

"The discovery of supersymmetry is comparable to what Einstein did in the early part of this century," says Shifman.

Supersymmetry picks up where the revolutionary ideas of quantum mechanics left off. According to quantum mechanics, fields of subatomic particles—such as electrons—can never stop moving completely.

"When fields fluctuate, they store some energy in themselves," Shifman says. Because there is so much matter in the universe, all of which stores energy, there should be an abundance of energy floating around. In fact, space should be lit up with energy, like a billboard along an interstate at night.

But that level of energy is ruled out by direct experimental measurements.

Astrophysicists are pretty good at calculating energy levels present in the far reaches of space, known as vacuum energy density. But when they calculated that density—the cosmological constant—and compared it with quantum mechanics calculations, they discovered a mind-boggling numerical discrepancy.

"We don't have a name for this number," Shifman says. "It's billions of billions of billions."

Clearly, something was wrong, but no one knew what.

"Before supersymmetry," Shifman says, "there was no hint [of] how to deal with it."

Physicists eventually reasoned that the balance of bosons and fermions may eliminate the discrepancy. Supersymmetry theorizes that because bosons contribute positive density and fermions contribute negative density, the densities neutralize each other. The remaining energy level is much closer to astrophysicists' original calculations.

"This is going to be *the* theory of the 21st century," Shifman asserts. "It's such a hot topic that in many places it's the only thing people are working on.

An oasis of physics

During the academic year, TPI teems with activity, as visiting scholars, graduate students, and postdoctoral researchers mingle with faculty. Russian is the preferred language spoken here, for six of the institute's eight full-time faculty members are Russian.

Tucked away in the back of Tate laboratory, TPI may seem isolated from the outside world, but a unique combination of international geopolitical factors made TPI what it is today.

Without perestroika, TPI's staff roster would likely be completely different. "Before 1989, I don't think I would have been able to come here," Vainshtein says. "During a period of more than 20 years, the KGB only granted permission for me to travel to the West twice. 1989 was a different year, you could feel it."

About the same time, thousands of miles away, several factors converged to create a world-class advanced physics institute at the University. Physics professor Stephen Gasiorowicz and William Fine, a Minneapolis real estate developer and former attorney, had been working for three years to stir up interest in such an institute at the University. Those efforts were finally starting to pay off.

The drive to create TPI met resistance at first, but eventually found a supporter in Professor Ken Keller, then University president. TPI was launched in 1986 with a $2 million gift from Fine that established three endowed chairs and with a strong commitment of additional funds from the University.

Today, TPI physicists are advancing the science in three main areas: astroparticle physics, including supersymmetry; high-energy physics such as QCD; and condensed-matter physics.

Fine currently sits with Gasiorowicz and six others on TPI's oversight committee. Fine may seem to be an unlikely donor for a theoretical physics institute, but he explains his interest in the science quite simply: "Physics is the most fundamental of the sciences."

He adds, "I don't know the language of physics, which is mathematics, but I do have enough of an inkling to appreciate its advancement."

Experts and professors from all over the world often write to this group of Russian physicists, expressing their desire to work at the institute. They want to participate in what Shifman calls "a critical mass of physics minds" at TPI.

"We're having young people from all over the world writing letters," Shifman says of TPI's many bright-eyed visitors. "They come not for the money but for the atmosphere, the knowledge."

FOR MORE INFORMATION see **www.tpi.umn.edu.**

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