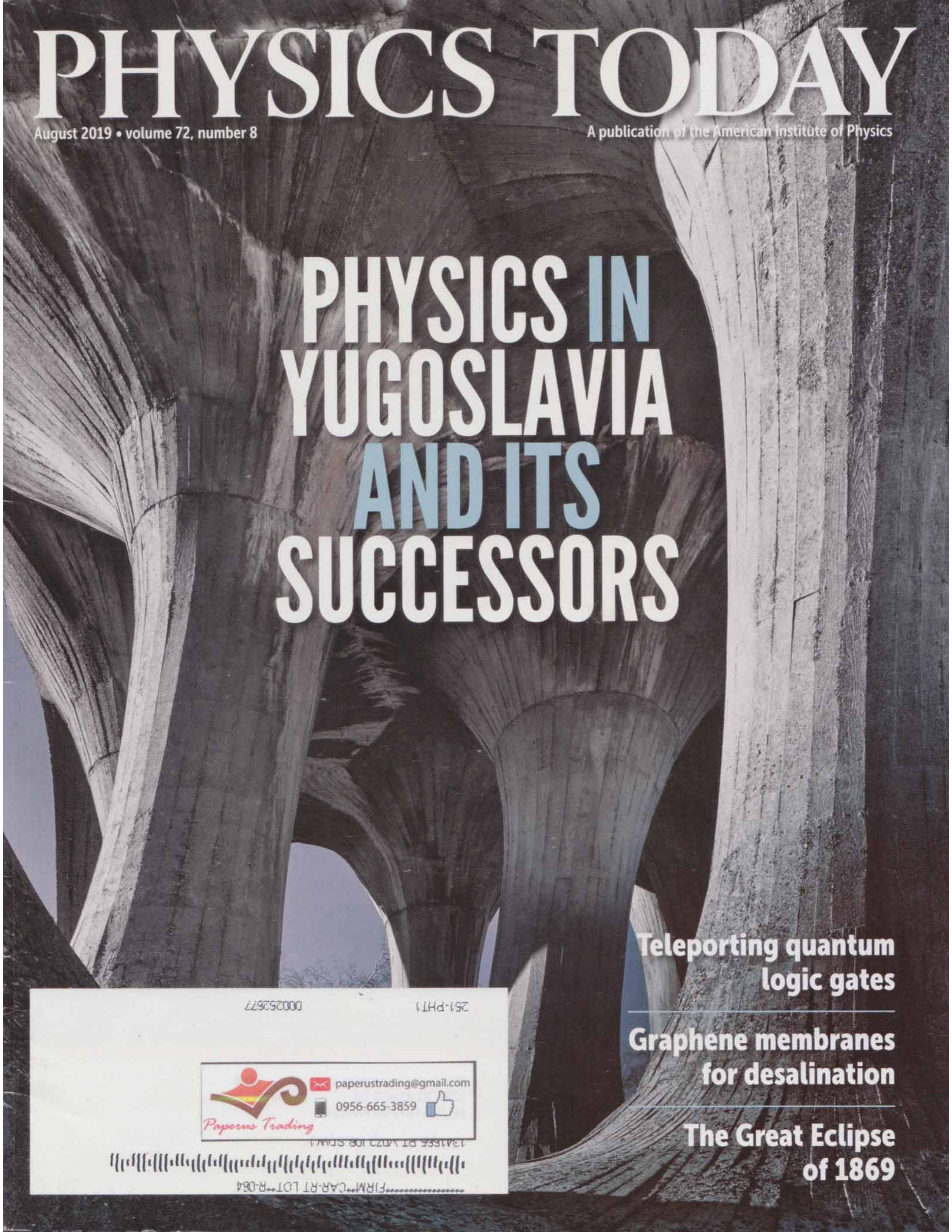

PHYSICS TODAY

August 2019 • volume 72, number 8

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PHYSICS IN YUGOSLAVIA AND ITS SUCCESSORS

Teleporting quantum logic gates

Graphene membranes for desalination

The Great Eclipse of 1869

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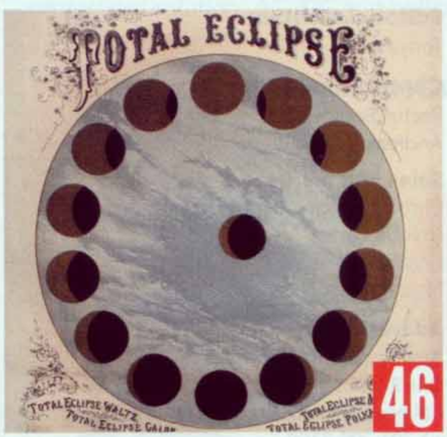

ON THE COVER: Designed by architect Živa Baraga and sculptor Janez Lenassi, the *Monument to the Fighters Fallen in the People's Liberation Struggle* (1965) stands in a park in Ilirska Bistrica, Slovenia. Physics flourished in Yugoslavia after World War II but foundered during and after the Yugoslav Wars of the 1990s. For an account of the history and current state of physics in the region, read Mićo Tatalović and Nenad Jarić Dauenhauer's article, which begins on **page 30**. (Photo © Valentin Jeck, commissioned by the Museum of Modern Art, 2016.)

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In 1944 Albert Einstein invited Mexican physicist Carlos Graef Fernández to discuss a theory of gravity that was an alternative to general relativity. Gustavo Arciniega chronicles the physicists' debate and explains how it signaled the rising prominence of physics in Mexico.
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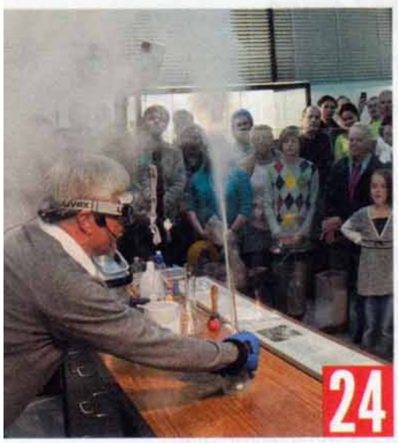
DEPARTMENTS



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Commentary

On the quality and costs of science publication

CYNTHIA B. CUMMINGS

Next to the spoken word, scholarly journals have always been the most immediate and important way for scientists to communicate. Maintaining their quality is therefore crucial to the success and advancement of the scientific enterprise. For centuries, learned societies have taken on the task of reviewing, producing, and monitoring publications for their field. By enabling publishing by scientists for scientists, they have helped the scientific community to self-organize.

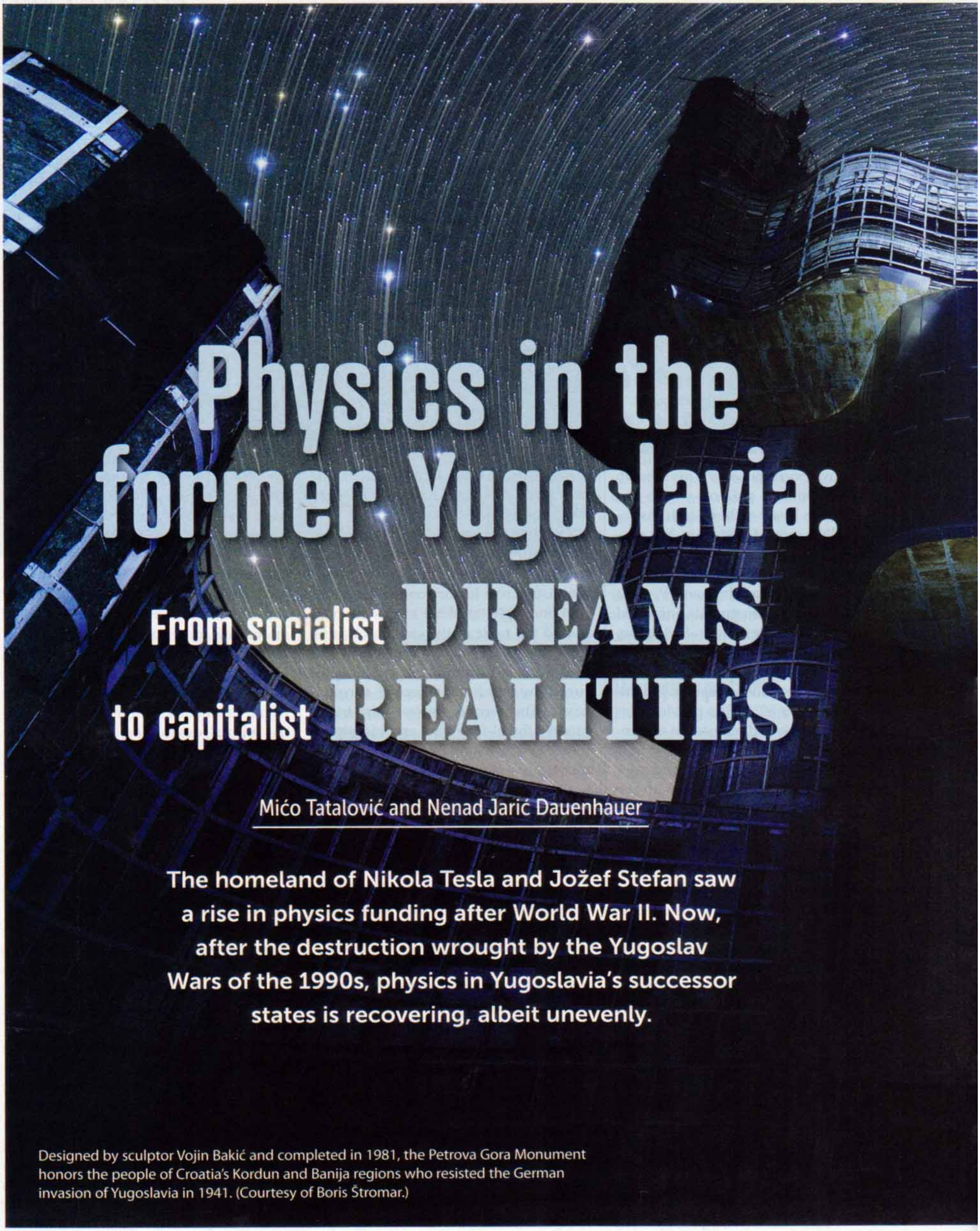
Examples of such societies include the Royal Society, the National Academy of Sciences, the French Academy of Sciences, the American Association for the Advancement of Science, and the American Institute of Physics (which publishes PHYSICS TODAY). Also included are the many university presses—Cambridge, Oxford, Harvard, and others.

The society and university presses are nonprofit. Many have evolved over centuries, and each has a great tradition of reporting scientific advances and discoveries. Because scientists see the value in the scholarly publishing enterprise, they are willing to volunteer their time as journal editors, referees, or authors. Their input is invaluable in offering the scientific community a degree of quality control over publications.

In contrast, commercial publishers have discovered that there is money to be made in the growing market for science publications. Commercialization of journals has contributed significantly to an explosion in their price, their numbers, and the quantity of papers they seek to publish. As a consequence, college and university libraries often can no longer afford all the journals.

A way that commercial publishers have maintained their profits is to change the publishing concept from a pay-to-read strategy, which places the financial burden mostly on libraries and thus their universities, to a pay-to-publish scheme in which authors pay a fee to get their papers published. The pay-to-publish approach allows commercial publishers to circumvent quality control both for existing journals and for new journals that often have minimal prepublication review. Thus both the number of publications—and of paying authors—and the publishers' revenue are dramatically increased. The marketing strategy for pay-to-publish is to call it "open access." It plays on the idea that the results of research financed by the public should also be freely accessible to the public.

For more than 25 years, however, the scientific community has benefited from an effective solution to the problem of open, cheap, and easy access to scientific publications: The preprint server



Physics in the former Yugoslavia: From socialist DREAMS to capitalist REALITIES

Mićo Tatalović and Nenad Jarić Dauenhauer

The homeland of Nikola Tesla and Jožef Stefan saw a rise in physics funding after World War II. Now, after the destruction wrought by the Yugoslav Wars of the 1990s, physics in Yugoslavia's successor states is recovering, albeit unevenly.

Designed by sculptor Vojin Bakić and completed in 1981, the Petrova Gora Monument honors the people of Croatia's Kordun and Banija regions who resisted the German invasion of Yugoslavia in 1941. (Courtesy of Boris Štromar.)

Mićo Tatalović is a science journalist from Rijeka, Croatia. He is based in London. **Nenad Jarić Dauenhauer** is a science journalist from Zagreb, Croatia.

Houston, we have a problem! A fictional Slovenian documentary by that name shook the Western Balkans three years ago by positing that Yugoslav leader Josip Broz Tito had sold his country's secret space program to the US for $3 billion in aid money a few years before the Apollo Moon landings. A secret underground hangar, faked deaths of scientists working on the Yugoslav program to cover their actual transfer to the US, and a visit to Washington, DC, where Tito narrowly escaped an assassination attempt months before President John F. Kennedy was killed made for some tense viewing. Could any of it be true?

Yugoslavia did have an active rocket program. Some of its citizens worked for NASA. Slovenian astronautics pioneer Herman Potočnik Noordung had published ideas in 1928 that were ahead of his time. And Tito once reportedly asked Mike Vucelić, a Yugoslav NASA engineer who worked on the Apollo program, to bring space travel "back home." The media and scientists have since debunked most of *Houston, We Have a Problem!*, but what stood out is that it needed debunking in the first place.

The movie's reception testifies to the murkiness and lack of consensus regarding the region's own recent events and to the legendary status that Tito and his regime still hold in many Yugoslavs' minds. After all, it was under socialism that Yugoslavia rose during the Cold War from poverty and insignificance to become a potent political, diplomatic, and military force. The period also saw the rise in the status of science, which Tito considered a tool for realizing his dream of worldwide socialism.

A major part of the push for science was the establishment of several elite physics institutes with the goal, at least partly, of developing a nuclear weapon. Tito's socialist dream collapsed in the early 1990s with the fall of the Communist regimes in Eastern Europe and the bloody wars that tore Yugoslavia apart.

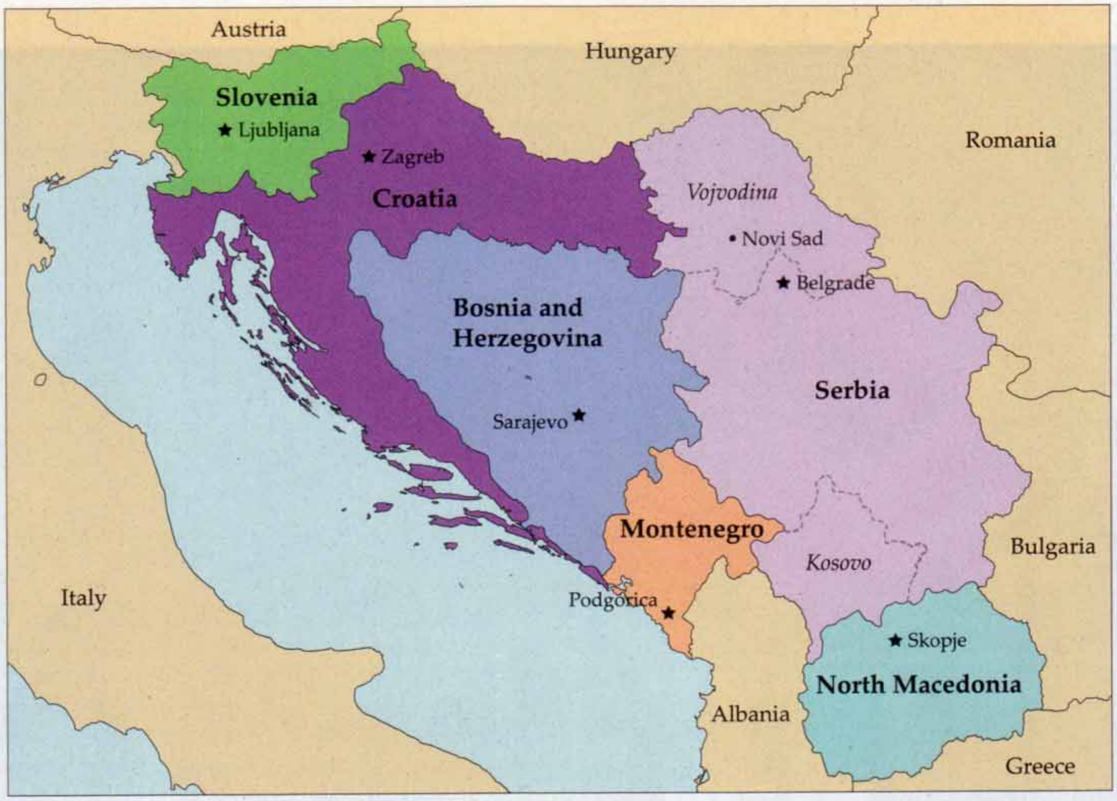
One consequence of the wars was the dissolution of collaborations among physicists from Yugoslavia's six republics—Slovenia, Croatia, Bosnia and Herzegovina (BiH for short), Serbia, Montenegro, and North Macedonia. They have yet to fully recover. International collaboration also suffered, and the region entered a dark period of isolation as the wars dragged on and the economy slumped. Some republics got off lightly. Slovenia's struggle for independence lasted 10 days. Others, notably Serbia, entered a prolonged period of military conflict and economic sanctions. Brain drain surged.

The six republics continue to share similarities that stem from their common, socialist-era history. But differences are emerging in how physics is faring. Slovenia and Croatia belong to the European Union (EU) and enjoy the benefits of membership. Montenegro and North Macedonia await full integration into the West. Brain drain barely affected Slovenia, but it has devastated research in BiH, where scientists' salaries are half those in Slovenia. In Serbia, past brain drain is having a positive effect as Serbian physicists who left are now returning, and collaborations with Serbian physicists abroad burgeon.

EU funding based on merit has helped the region's best physicists improve further, but lack of domestic merit-based grants means that with a handful of exceptions overall research is underfunded and mediocre.

R&D investment as percentage of GDP is generally still well below what it was in Yugoslavia. Once-strong links with industry are gone.

Much remains to be done to make the region attractive to researchers and relevant globally. But despite the challenges, the region has several strong institutes and many groups doing excellent work in physics, including a few recipients of large grants from the EU's European Research Council (ERC). Pockets of excellence were a feature of science in the former Yugoslavia. In its successor nations, they are likely to continue.



FORMER YUGLOSLAVIA is divided into six states, whose capitals are indicated by stars. The status of Kosovo is disputed. Vojvodina is an autonomous province within Serbia.

A proud tradition

For much of its history, the region that became Yugoslavia has been near, next to, or part of large, advanced civilizations, among them the Roman Empire, the Venetian Republic, and the Austro-Hungarian and Ottoman Empires. A long and proud tradition of scholarship was the result.

The tradition goes back to at least the 12th century, when philosopher and astronomer Herman the Dalmatian (Dalmatia is the southern part of modern Croatia) translated Ptolemy's *Planisphaerium* from the only language it had survived in—Arabic—to Latin and helped to transmit the work to the rest of medieval Europe. Ruđer Bošković (1711–87) introduced the idea of a force that is repulsive at short distances but attractive at long ones. Croatia's largest research institute bears his name. Stefan–Boltzmann's law is named in part after Jožef Stefan (1835–93), who conducted experiments on the radiation of dark bodies. Andrija Mohorovičić (1857–1936) discovered the Mohorovičić discontinuity, the physical boundary between Earth's crust and the upper mantle. Milutin Milanković (1879–1958) discovered Milankovitch cycles, changes in climate driven by changes in Earth's orbit around the Sun.

Nikola Tesla (1856–1943) is the most famous scientist from the region. His innovations with alternating current paved the way for modern electricity. He remains celebrated in Croatia and Serbia, where museums and airports bear his name. An ethnic Serb, he was born in what is now Croatia. He is held as an exemplar of ethnic tolerance, having said that he was proud of his Serbian ethnicity and his Croatian homeland.

Mihajlo Idvorski Pupin (1858–1935) was one of the developers of the loading coil, a device that boosts the range of telegraph transmission. He became rich when AT&T bought the US rights to his patent. His book, *From Immigrant to Inventor*, was awarded the 1924 Pulitzer Prize for biography.

Although the region gave the world these eminent physicists, all of them worked abroad. Physics began to blossom in Yugoslavia itself only after World War II. Before then, when Yugoslavia was a constitutional monarchy, it was typically taught in university philosophy departments in big cities, such as Belgrade, Ljubljana, and Zagreb.

The Federal People's Republic of Yugoslavia was proclaimed on 29 November 1945. Two aspects of the regime's vision helped fuel the postwar development of physics. One was the establishment of nuclear programs for military and civilian purposes. The other aspect was a belief that science and technology are important for industrialization, for the improvement of the well-being of the working class, and for the general prosperity of the newly born confederation.

Tito's Communist partisans liberated Yugoslavia from its German occupiers without an invasion by Western or Soviet forces. His regime was not beholden to either postwar superpower. Though avowedly Communist, Tito broke with Joseph Stalin in 1948. With Indian prime minister Jawaharlal Nehru, he led the "third way" diplomacy of the Non-Aligned Movement. Tito knew that physics could help the country develop economically and militarily and remain independent. He also took a personal interest in promoting science and technology. In 1962, for example, he attended the launch of the cyclotron built at the Ruđer Bošković Institute (IRB) in Zagreb. At the time, the device was the fourth most powerful particle accelerator in Europe.

From today's perspective, the resources that were being invested in the development of physics were astonishing. Serbian physicist and journalist Slobodan Bubnjević of the Institute of Physics Belgrade recounts the period: "New institutes were being set up, and even the educational system was being changed to respond to the need to create new physicists. These physicists were being sent overseas in large numbers for further education to both the USSR and the US." Physics became one of the country's most developed sciences.

Despite being one of the poorest countries in postwar Europe, Yugoslavia twice attempted to develop a nuclear weapon. The first attempt occurred in 1947. Tito spent $35 million between 1948 and 1953 to build and equip three nuclear institutes: the Boris Kidrič Institute in Vinča near Belgrade, the Jožef Stefan Institute (IJS) in Ljubljana, and the IRB. The Vinča institute was headed by Pavle Savić, whose work on the action of neutrons on heavy elements done at the Radium Institute in Paris in the 1930s helped pave the way for the discovery of nuclear fission. Anton Peterlin, who trained at Humboldt University in Berlin, led the IJS. Ivan Supek led the IRB until 1958, when his open, forthright pacifism triggered his dismissal.

The country's first nuclear research program included the development of manufacturing capabilities. The Boris Kidrič Institute housed a department for recycling nuclear waste and a 6.5 MW reactor. In 1958 six young scientists were irradiated because of sloppy procedure. One died; the five others were saved by bone marrow transplants in Paris. The accident may have been one of the reasons Tito abruptly ended the program in the early 1960s. Another factor may have been his leading role in the Non-Aligned Movement, which declared its opposition to nuclear weapons in 1961.

In 1974 Tito revived Yugoslavia's nuclear program. A nuclear test carried out by India, another prominent member of the Non-Aligned Movement, was a likely impetus. One part of the new nuclear program, led by the Military Technical Institute in Belgrade, pursued a plutonium implosion bomb like the one dropped on Nagasaki. The other part, led by Energoinvest and based in Sarajevo, pursued civilian uses. As a company that produced power lines, transformers, and other energy infrastructure, Energoinvest was an excellent cover for a clandestine nuclear program. At its peak, the company employed 44 000 people and was Yugoslavia's largest exporter.

The second nuclear program was suspended mysteriously in 1987, possibly because of an economic crisis, which had begun four years earlier. Besides strong research and industrial capacities, the program left Yugoslavia with 50 kg of enriched uranium—enough for two atomic bombs. Stored at Vinča, the material was eventually removed in 2002 by Russia and the US under the auspices of the International Atomic Energy Agency.

The breakup of Yugoslavia

By the 1980s Yugoslavia was in such poor fiscal condition that it struggled to pay even the interest on the foreign loans that had propped up its economy. Ethnic, religious, and ideological issues seething amid state-imposed austerity eventually led to the breakdown of Yugoslavia, already weakened by the death of Tito in 1980. Some academics also contributed: In 1986 a leaked memorandum prepared by 16 members of the Serbian Academy of Sciences and Arts laid out a case that Serbia and Serbians were victims of a Yugoslavian state that had been purposely set up to discriminate against them.

Slovenia and Croatia seceded from Yugoslavia on 25 June 1991; BiH on 3 March 1992. How violent and protracted the ensuing wars for independence were depended on the extent and complexity of ethnic mixing. Slovenia's war lasted 10 days and cost 63 lives. BiH's, the bloodiest, lasted 3 years and 8 months and cost more than 100 000 lives.

By 1999 Yugoslavia had broken into five states: Slovenia, Croatia, BiH, Serbia and Montenegro, and Macedonia. Later, in 2006 and 2008, respectively, Montenegro and Kosovo proclaimed independence from Serbia. This year, under pressure from Greece, Macedonia renamed itself North Macedonia.

What happened to physics during the upheaval? Besides ending collaboration among the five states, the conflict and its aftermath saw declines in science funding and industrial activity. Yugoslavia invested around 1.5% of its GDP in R&D. Today none of the individual states except Slovenia invests more than 1% of its GDP in R&D.

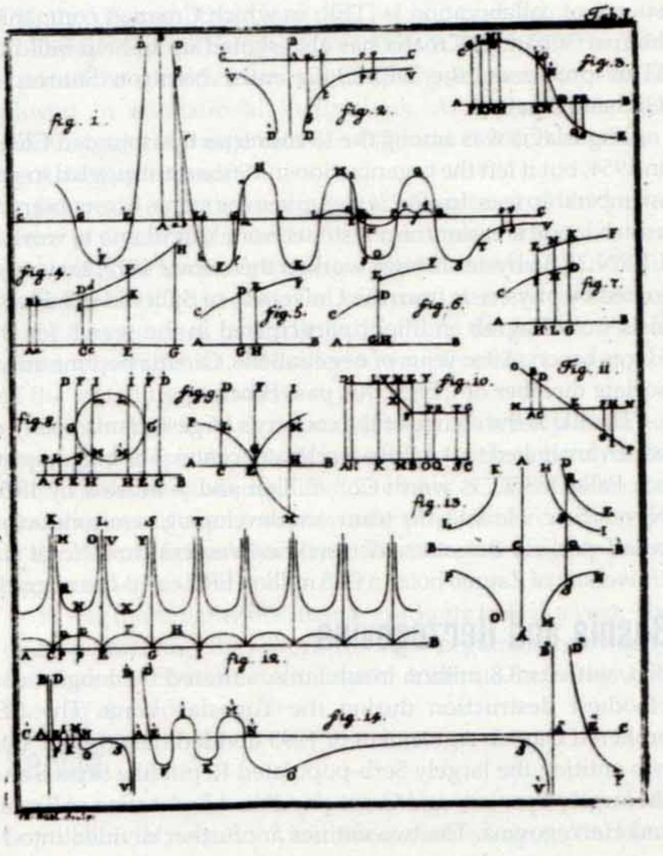
Cronyism, low levels of investment, and brain drain beset science to some degree in all the newly independent states. Yet the condition of physics in the individual states has turned out to be different. Some, like Croatia, Slovenia, and Serbia, had strong research centers during the Yugoslavian period; they continue to harbor centers of excellence. Others, such as BiH and North Macedonia, never had the same quantity or quality of physics research; they remain at the periphery of the global scientific community. Let's look at each state in turn.

Slovenia

Slovenia, with a population of about 2 million, was the most developed of the Yugoslav republics. It suffered lightly in the breakup, and in 2004 it was the first to join the EU.

Physics is mainly done at the IJS and at the University of Ljubljana. Smaller centers of physics exist at the University of Maribor and the University of Nova Gorica, which was established in 1995. The Society of Mathematicians, Physicists and Astronomers of Slovenia focuses on pedagogical activities.

Slovenia is home to the Krško Nuclear Power Plant, the only one in the former Yugoslavia. Operational since 1981, the 700 MW plant supplies 25% of Slovenia's electricity and 15% of



FIGURES FROM *THEORIA PHILOSOPHIÆ NATURALIS* by Ruđer Bošković. First published in 1758, the treatise expounded Bošković's theory of atoms and forces.

Croatia's. Physicists from the IJS work at the plant, but in supporting and educational roles rather than in research.

After gaining independence in 1991, Slovenia opened up to the world. It joined CERN, ITER, and the European Space Agency. Pre-war cooperation with physicists in other Yugoslav republics was good, especially with condensed-matter physicists at the IRB and the Institute of Physics in Zagreb. Collaborations continued after independence, though at a lower level, mainly because many excellent researchers left Zagreb in the 1990s.

Slovenia continued to develop all the areas of physics that were strong in Yugoslavia, particularly condensed matter, statistical physics, biophysics, and elementary particles. New areas have also emerged, such as quantum optics, laser spectroscopy, and soft matter.

Slovenia's R&D allocations, at about 2.39% of GDP, are significantly higher than in other former Yugoslav republics. Yet, says Dragan Mihailović of the IJS, the figures are misleading. Of R&D funding, 77% comes from the private sector, mainly from just two pharmaceutical companies: Krka and Lek. What's more, the actual spending on private-sector R&D is likely lower, given the tax breaks that, Mihailović says, "incentivize companies to class all sorts of activities as research."

Slovenia was comparatively free of brain drain until recently. In 2011 the government cut spending in science and other areas in response to the global financial crisis of 2007–8. "This is a new problem for Slovenia, and it is becoming a serious one, because the best researchers are leaving," says Mihailović.

Physics is the leading scientific discipline in Slovenia, according to criteria such as the number of ERC projects and papers published in leading journals. The highest-ranking scientists and professors at universities and institutes earn around €2500 ($2804) per month.

Croatia

With approximately 4 million inhabitants, Croatia was one of the most developed republics in Yugoslavia. When Europe's socialist regimes collapsed in the late 1980s and early 1990s, the country seemed poised for success. Many Croatians expected their small country to become rich, a "new Switzerland."

Croatia suffered some of the greatest devastation in the Yugoslav Wars. Lower salaries, fewer jobs, and a lack of resources prompted many physicists to emigrate. A 2007 World Bank study found that at 29.4%, Croatia's emigration rate of highly skilled people was the highest in Europe. Investment in R&D has fallen to around 0.9% today. Croatia is last in the EU for registered patents and other indicators of economic development. Around 80% of science funding is spent on salaries. Nationally funded research projects typically get the equivalent of only a few thousand US dollars a year. Because funds are not allocated on a competitive basis, mediocrity is sustained at the expense of supporting the country's best researchers.

Poorly executed—and often corrupt and illegal—privatization of state-owned companies in the late 1990s and early 2000s led to a drop in private-sector investment in science. Today it accounts for only about 40% of the total. For example, Končar, a manufacturer of turbines for hydroelectric plants, electrical appliances, and other equipment, has drastically cut its investment in science. The company still manufactures cutting-edge devices, such as magnets for CERN's Large Hadron Collider, but its involvement with physics has significantly diminished.

Physicists can readily get jobs in Croatia, but because funding for fundamental research is too low to support serious career development, many move abroad. Salaries for physicists at public institutions range from €1200 to €2000 a month.

Foreign scientists rarely visit Croatia; when they do, they generally don't stay for long. Still, Croatia is gradually attracting more and more physicists from abroad, especially to the best institutions. The IRB's permanent staff includes two from Italy, one from China, and one from Greece. David Smith, an Australian chemist, became the IRB's head in 2018.

For Croatia, joining the EU in 2013 has led to increased brain drain but also to closer cooperation with international institutions and access to EU grants. Physicist Tome Antičić directed the IRB until his recent appointment as state secretary for science. He cites CMS, ALICE, and NA61 experiments at CERN as examples of collaborations. Croatia also participates in MAGIC, a pair of imaging atmospheric Cherenkov telescopes on La Palma, one of the Canary Islands. Another fruitful source of collaboration is ITER, in which Croatian companies are participating. Croatia has also signed up to help build an ITER precursor, the DEMO Oriented Neutron Source, in Granada, Spain.

Yugoslavia was among the 12 countries that founded CERN in 1954, but it left the organization in 1961 as it struggled to pay membership fees. In 1962 it was given the status of an observer, which made it easier for physicists from Yugoslavia to work at CERN. IRB physicists have worked there since 1977; they were joined by physicists from the University of Split in 1993. Physicists from Zagreb and Split participated in the search for the Higgs boson. After years of negotiations, Croatia became an associate member of CERN this past February.

The EU is the source of the country's largest grants, many of which are linked to the IRB's accelerator center. The biggest project, PaRaDeSEC, is worth €2.5 million and is headed by IRB's Neven Soić. He and his team are developing semiconductor-based particle detectors. Astronomer Vernesa Smolčić of the University of Zagreb holds a €1.5 million ERC early-career grant.

Bosnia and Herzegovina

BiH, with its 3.8 million inhabitants, suffered the longest and bloodiest destruction during the Yugoslav Wars. The US-brokered Dayton Agreement of 1995 divided the republic into two entities, the largely Serb-populated Republika Srpska and the largely Bosniak- and Croat-populated Federation of Bosnia and Herzegovina. The two entities are further divided into 10

JOSIP BROZ TITO (seated) visited the Ruđer Bošković Institute in Zagreb, Croatia, in October 1965 to inspect the institute's new cyclotron, then the fourth most powerful in Europe. (Courtesy of IRB.)

autonomous cantons. No well-functioning state-level science institutions exist in BiH, as each entity and each canton sets its own science policies. Universities in BiH are now administered locally. Before Dayton there were four—in Sarajevo, Banja Luka, Tuzla, and Mostar. Now there are 8 state and 35 private ones.

Nenad Tanović, a physicist at the University of Sarajevo, notes that physics in BiH was never as strong as in Croatia, Slovenia, and Serbia. Even the country's premier physics center, University of Sarajevo's department of physics, has struggled because, says Tanović, "there were no capital investments in instruments such as reactors, accelerators, or other types of equipment." Despite the dearth of funding, the university has established a metal-physics laboratory. Physicists educated there work today as professors and researchers in the UK, the US, and other countries.

On average, BiH invests less than 0.1% of GDP in R&D; some of the cantons invest nothing. Physicists are mostly employed in educational institutions. At universities, their monthly salaries range between €800 and €1200. Brain drain is persistent and severe.

Cooperation between academic physicists and the private sector is practically nonexistent. Zrak, a precision optics company based in Sarajevo, made gunsights and binoculars for the Yugoslav People's Army. The company remains in business, but it has cut back its R&D and, with it, the need to employ physicists. In Zenica, BiH's steel town, physicists used to work in the metallurgy industry.

Because BiH lacks a national strategy to develop its physics programs, cooperation with foreign institutions barely exists. "For almost two decades," Tanović says, "CERN has been organizing a yearly seminar for young physicists from the region at the Natural Science Faculty in Sarajevo, but the state has not supported it."

Fewer than 15 physics majors graduate in BiH a year. They end up teaching, they work for state organizations such as the Federal Hydrometeorological Institute in Sarajevo, or they go abroad.

Serbia

Serbia is the largest of the former Yugoslav republics with a population of around 7.5 million. According to Bubnjević, there were almost no physicists in Serbia immediately after World War II. He credits Yugoslav policy for building up significant research capacity. Nuclear physics was the first priority. Then, starting in the early 1960s, investment in physics broadened. In 1961 the Institute of Physics was established in Belgrade and explored other fields of physics, such as atomic, condensed matter, complex systems, photonics, and ionized gases. Those areas remain the institute's focus of research.

In 1996 armed clashes broke out in Kosovo between Serbian authorities, who wanted the territory to remain part of Serbia, and the Kosovo Liberation Army, which wanted independence. The conflict that ensued, the Kosovo War, lasted from February 1998 to June 1999. Serbia, already weakened by earlier wars, saw the development of physics halted by economic sanctions and NATO airstrikes. A large number of researchers emigrated to the West, though some of them continued to help the young scientists left behind. Conditions have since improved. In the past 10 years, about 40 researchers have returned to the Institute of Physics.

Although Serbia is not an EU member, its scientists are eligible for some EU grants, which have attracted returnees. Milan Ćirković of the Astronomical Observatory of Belgrade is encouraged: "In the last five years, the observatory has employed six researchers with PhDs obtained from US and European universities, which is a huge relative improvement given that the total number of researchers in astronomy and astrophysics in Serbia is about 50."

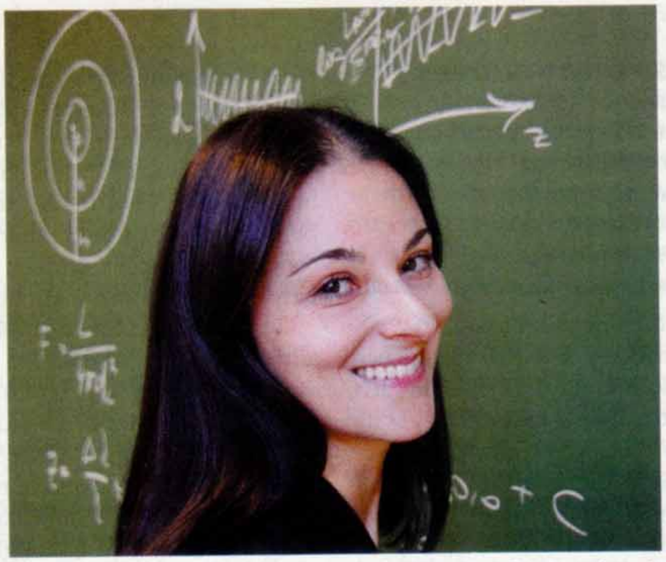
The largest physics centers in Serbia are the Institute of Physics (around 200 researchers), the faculty of physics of the University of Belgrade (around 100 researchers), and the Institute of Nuclear Sciences in Vinča. Universities in Novi Sad and Niš also have significant physics departments.

Despite the positive role Yugoslavia played in physics, many negative aspects of the socialist regime have survived, especially in Serbia. "The first and most obvious is hypercentralization of everything, including science, and civil servants' obsession with controlling everything," says Ćirković. He cites strict controls over the governing boards of scientific institutes and infringements of universities' autonomy. "It is impossible for any noteworthy science to be done outside the two main centers of Belgrade and Novi Sad."

Serbia's economy is dominated by services and agriculture. Private-sector R&D is almost nonexistent. Bubnjević sums up the situation: "The long-term cooperation of physicists with a dedicated industry that provided heavy financing was drastically weakened after the breakup of Yugoslavia, and there was no new branch of the economy with a clear need for physicists." Serbia's growing IT sector is an exception. IT companies work with researchers who study complex systems and supercomputing. BioSense in Novi Sad, for example, combines data analytics and remote sensing to improve agriculture.

Serbia now invests around 0.87% of GDP in R&D, and physics gets an above-average portion compared with other sciences. Most labs in Serbia also have international grants for their research at an average of one grant per two researchers. EU grants that support centers of excellence helped equip several research centers in Serbia. In 2016 Magdalena Djordjevic of the Institute of Physics received an ERC grant worth €1.4 million for the study of quark–gluon plasma.

Serbia has been an associate member of CERN since 2012, and in 2019 it became a full member. Several Serbian groups have been collaborating on CERN experiments such as ATLAS and CMS since 2001, when economic sanctions were lifted.



VERNESA SMOLČIĆ of the University of Zagreb uses surveys and multiwavelength observations to study the formation and evolution of galaxies. (Courtesy of Petar Krajačić Vilović.)

Montenegro

Montenegro has just 0.6 million inhabitants. While Yugoslavia remained intact, Montenegro's physicists typically studied at the University of Belgrade and then went on to do postdocs in the Soviet Union. Most research focused on high-energy particle physics, nuclear physics, isotopes, and radiation.

After the dissolution of the Socialist Federal Republic of Yugoslavia in 1992, Montenegro remained part of the smaller Federal Republic of Yugoslavia with Serbia. Although it was largely spared in the wars of independence, its association with Serbia exposed it to the sanctions that the United Nations Security Council had imposed on Slobodan Milošević's Serbian regime. Montenegro was a target of NATO's 1999 bombing campaign.

Physicist Gordana Jovanović from the University of Montenegro in Podgorica recalls the sanctions' impact on science: "Studying was very difficult because there was no money for laboratory equipment, for computers, for literature. We had to use textbooks that our teachers brought with them from Russia when they studied." Russia did not strictly obey the sanctions, and cooperation continued with Russian universities and institutes.

In 1996 Jovanović enrolled at the University of Belgrade. When NATO aircraft bombed Belgrade three years later, she took a train back to Podgorica, where, half an hour before her arrival, the city's airport had been struck. "At that moment," she said, "it was hard to think of anything but survival."

Things are looking up. The University of Montenegro has signed a cooperation agreement with 118 universities in 34 countries. Montenegro is a member of the Europlanet network. Since 2017 it has been a full member of the CMS experiment at CERN. The current science minister, Sanja Damjanović, is a theoretical physicist, who has held positions at the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, and at CERN.

Physicists mainly find work in state institutes such as the meteorology and seismological institutes, but they are valued and often appointed to ministerial and diplomatic posts. A former deputy prime minister, Dragiša Burzan, is a theoretical physicist.

The main lines of research in Montenegro are particle and nuclear physics, condensed-matter physics, and ionized gases.

Modest conditions, primarily with regard to laboratory equipment, limit research opportunities for students and scientists. For now, students try to leave the country and stay abroad.

North Macedonia

North Macedonia has a population of just over 2 million. It was not involved in the wars of the 1990s. The small, poor, landlocked country took a step toward greater Western integration this year when it agreed to drop its claim, disputed by its neighbor Greece, to the name Macedonia, which is shared by a northern Greek region.

The situation for science is dire. During the past 20 years, North Macedonia has been spending about 0.2% of GDP on R&D, mainly on salaries in institutes dedicated to soft sciences. National grants barely exist. Physicist Viktor Urumov of Saints Cyril and Methodius University in Skopje recalls that the decline began after Tito's death, when subscriptions to international scientific journals were no longer renewed. "Luckily there is the internet and access to whatever is freely available," he says.

Few physicists work in North Macedonia, and their numbers are decreasing. The staff of Urumov's department, the Institute of Physics, includes 21 physicists with PhDs. That's down from around 30 when, 15 years ago, the government decided to save money by not backfilling the positions of people who retired. Urumov estimates that fewer than 50 physicists are employed outside elementary and secondary schools. Very few work in industry. Urumov says the average monthly salary in his department is €600.

North Macedonia now has six public universities and more than a dozen private ones. Physics degrees can be earned from universities in Skopje and Tetovo. "For more than a decade, the number of students studying physics has been very small, fewer than 10 new students annually," says Urumov. "But this has increased in recent years because the government began offering larger scholarships."

Optics and metals used to be the main research areas, but metals research has been abandoned. The country's modest number of physicists work in several areas, including thin films, the interaction of electromagnetic waves with matter, nonlinear phenomena, complex systems and networks, natural radiation, and radiation for medical purposes and environmental studies. The number of North Macedonians who study physics abroad has been growing, and the lack of jobs back home means few ever return.

The country's largest grants (up to €250 000) were obtained by the Institute of Physics through the EU's Trans-European Mobility Programme for University Studies. The projects are for establishing new curricula and modernizing higher education. North Macedonia does not yet participate officially in large European collaborations.

"In early 2000 UNESCO made a survey of equipment worth more than €100 000," Urumov recalls. "It was very easy to provide an answer for Macedonia, since there were no such instruments and the situation is unchanged." Nevertheless, the publication record of physicists from North Macedonia registered in international journals is steadily rising and the field of physics is among the best represented. PT