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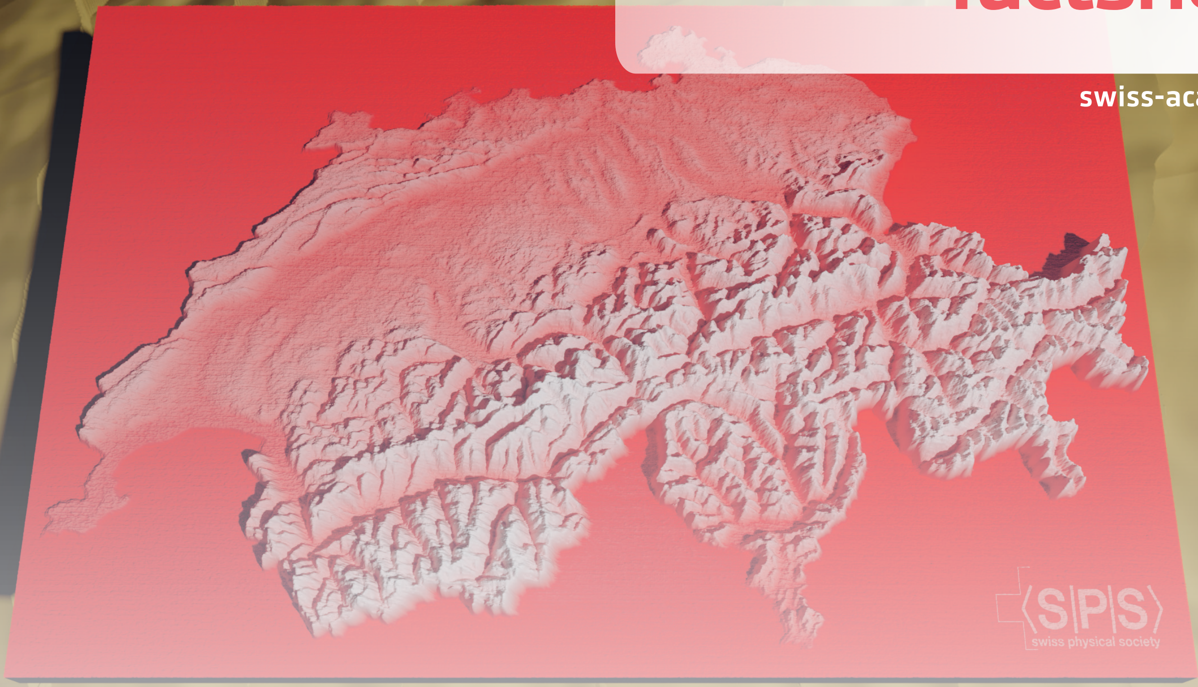

Physics in Switzerland – driving economy, triggering innovation, empowering citizens

The impact of physics on society and economy is paramount. In the last centuries, physics has shaped the way how we understand the world we live in and has underpinned the largest industrial revolutions. Today, physics, which encompasses a vast range of scientific topics, is omnipresent in all technically oriented industrial sectors. The successful Swiss economy is the fruit of long-term support for physics in education and research. In a society so strongly shaped by science and technology, literacy in physics is essential. For these reasons, the *Swiss Physical Society* (SPS) has evaluated the influence of physics on the Swiss economy and on the society as a whole in the *SPS Focus* 'Impact of Physics on Swiss Society'[1]. The main results and conclusions are summarised in this factsheet.

Key messages

1. Physics-based industries play an important role in the Swiss economy, comparable to the importance of sectors such as production or trade. The economic efficiency of physics-based industries outperforms the production, trade and construction sectors.

2. The collaboration between basic research in physics and industry is as valuable as it is diverse: From the development of products stemming from academic research to the contribution of physics graduates in small and medium companies.

3. Swiss physics institutes are active in all areas covering fundamental to applied research. The Swiss research contribution is of high international standing in a wide range of areas, from condensed matter physics to particle physics; from astrophysics to biophysics.

4. To address the biggest challenges of our time, such as the climate and the energy supply crises, as well as global health concerns, we increasingly depend on the development of new technologies derived from physics research.

5. A solid basic education in physics is central to a functioning democracy, in a world that heavily relies on modern technologies. It is thus essential that Switzerland succeeds in maintaining the population's interest in physics throughout their school years.

1 The SPS Focus No. 2 'Impact of Physics on Swiss Society' produced by the Swiss Physical Society is available at www.sps.ch/artikel/sps-focus/sps-focus-2

Kohli A (2022) Physics in Switzerland – driving economy, triggering innovation, empowering citizens. Swiss Academies Factsheets 17 (5)

An important driver for industry

Since the beginning of industrialisation in the nineteenth century, technical knowledge stemmed from university research. Promising results were passed on to technical universities, where they were developed to technical pre-maturity. Then, industry took over and developed first application prototypes, which finally lead to market ready products.

Today, academic knowledge transfer still is the backbone of spin-off companies and start-ups. However, the physical complexity has increased dramatically over the last decades. Computing chips have spatial structures in the nanometre range, and the modern diagnostic instruments use lasers of femto- and attosecond pulse widths to understand the dynamics of chemical reactions.

It is obvious that physics plays an important role in today's technologies and it is essential for a modern economy to fully exploit the potential of this discipline. Therefore, the Swiss Physical Society (SPS) has set itself the task of quantitatively analysing the influence of physics on the Swiss economy.

Currently, the turnover of Physics-Based Industries (PBI) in Switzerland is estimated to exceed CHF 274 billion in revenue and is expected to be growing further. The industries classified as PBI are strongly reliant on modern technologies developed by physicists. Hence, the eleven PBI categories represented in figure 1 cover a relatively wide range from pharmaceutical industry and medical instruments to electricity supply and general manufacturing.

The share of PBI in the Gross Value Added (GVA) of Switzerland was CHF 91.5 billion, or 13 percent out of a total CHF 701.6 billion for the year 2019. The number of Full-time Equivalent Jobs (FTE) was 417 000, or 9.8 percent out of a total of 4 237 000 (Fig. 1 and 2).

An interesting indicator is the specific GVA, defined as the ratio of GVA per FTE, which is a measure of the economic efficiency. This ratio is CHF 219 400 per FTE for PBI in 2019, which is larger, for instance, than the specific GVA in production or trade. The specific GVA for PBI clearly exceeds the average value for Switzerland of CHF 165 600 per FTE. In conclusion, PBI are as economically important for Switzerland as production or trade. Comparing the economic efficiency of PBI with those of the direct neighbouring countries Germany, France, Italy and Austria shows that the Swiss PBI are in the leading position.

Furthermore, in Switzerland the specific GVA for PBI increased by 6.3 percent from 2015 to 2019, which is much more than the average increase of 2.3 percent among all economic activity sectors during the same period.

Not included in these measures of GVA and FTE are the contributions of physicists who are employed in other industries. Additional economic impact due to downstream effects is not considered, in particular the induced effects of private household spending associated with economic activity in PBI. It is therefore expected that the overall impact of physics in the Swiss economy exceeds the direct impacts reported in the performance of PBI.

The GVA multiplier associated with the impact of PBI has been estimated to be between 2.31 and 2.49,[2] implying that for every CHF 1.00 of direct physics-related output, a total of CHF 2.31 to 2.49 of economy-wide output is realised (Tab. 1).

2 Adapted from: 'The Importance of Physics to the Economies of Europe. A study by Cebr for the period 2011–2016', Centre for Economics and Business Research for the European Physical Society, 2018. https://www.eps.org/resource/resmgr/policy/eps_pp_physics_ecov5_full.pdf

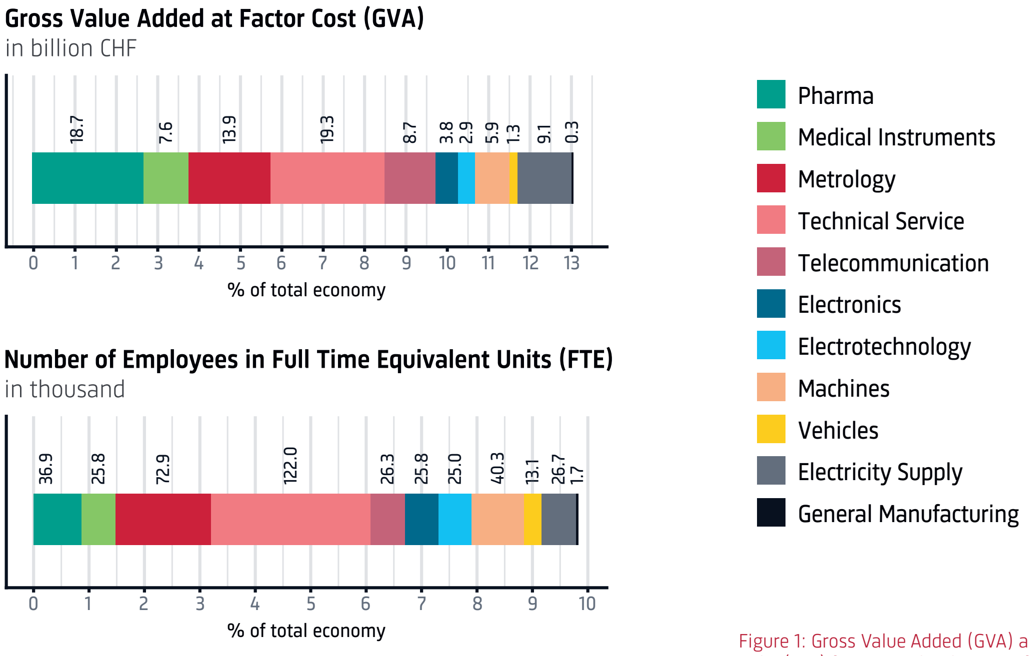

Figure 1: Gross Value Added (GVA) and Full-time Equivalent Jobs (FTE) for Switzerland in 2019 for 11 industrial clusters, which constitute the category of Physics-Based Industries (PBI).

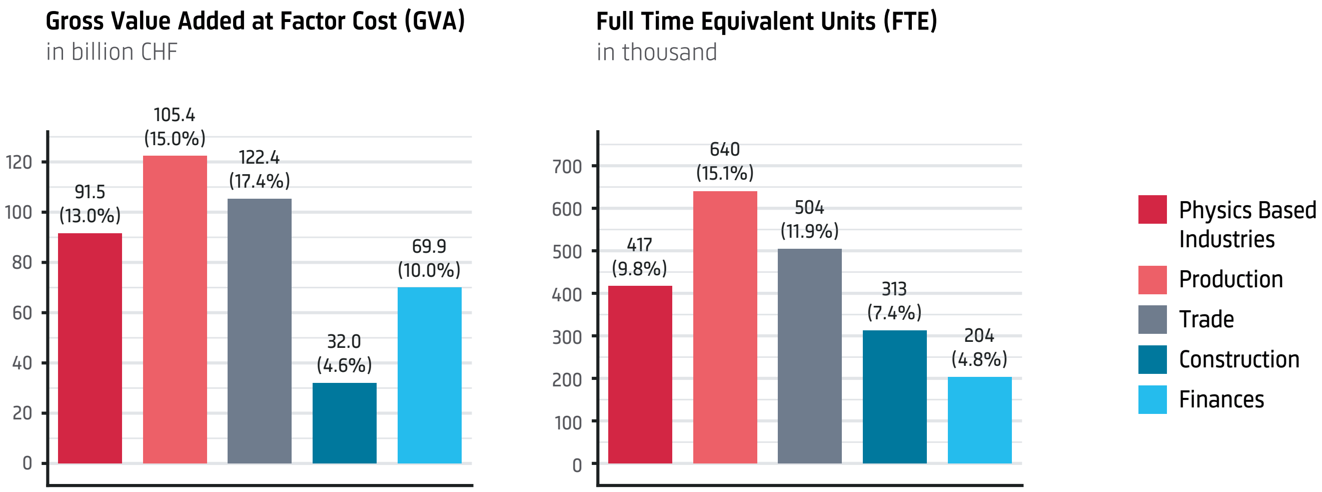

Figure 2: GVA in billion CHF and number of FTE in thousands for the five categories of the Statistical Classification of Economic Activities in the European Community (NACE) for 2019.

Physics-based industries' GVA Multiplayer (= 2.31)	
Direct Impact CHF 1.00	Expenditure on the physics-based sector triggers the physics industry's supply response. in providing its services, the physics industry generates additional value added. Assume sufficient expenditure to generate CHF 1.00 of GVA. This CHF 1.00 of GVA is the direct GVA impact of the relevant increment in expenditure on physics-based industry.
Indirect Impact CHF 0.65	To increase its supply, the physics-based industry must increase its demands on its suppliers, who increase demands on their suppliers and so on down the supply chain. This generates the indirect impact, an increase in GVA throughout the supply chain of CHF 0.65 for every additional CHF 1.00 of GVA in the physics-based industry.
Induced Impact CHF 0.66	The combined direct and indirect impacts have an impact on household income throughout the economy, through increased employment, profits etc. A proportion of this income will be respent on final good and services, producing a supply response by the producers of these goods / services and further impacts through their supply chains. This produces the induced impact of CHF 0.66 for every additional CHF 1.00 of GVA in the physics-based industry.

Table 1: Composition of the GVA Multiplier.

From lab to product

It is crucial to connect physics research with its successful exploitation in the marketplace. Doing so and even increasing the efforts and extending them into novel fields – like quantum technology, computational information processing and artificial intelligence – are vital for the Swiss economy.

The collaboration between basic research in physics and industry happens on several levels. An important transfer occurs, when results from physics experiments are developed further until a product is available on the marketplace. This happens either via researchers who found a start-up company or via established companies and the help of specialized programs that foster this knowledge and technology transfer such as Innosuisse or the European research framework programs.

An established scheme to assess this progress from a physics experiment to a tangible product is the Technology Readiness Level (TRL), which describes the different maturity levels of a technology. For the physics and technology sector in Switzerland, figure 3 sketches the interlocked structure between the various stakeholders in this process.

Aside from direct technology transfer, hiring university physics graduates is one of the most effective ways to infuse state-of-the-art knowledge into a company. Therefore, the excellent academic physics education in Switzerland is an important factor for the industry, as evidenced by the fact that more and more global high-tech companies try to hire these talents by establishing R&D labs in Switzerland.

Another form of collaboration is the use of research facilities by industrial companies. Basic physical research requires increasingly complex experimental methods and machines, such as the large accelerators at CERN and Paul Scherrer Institute (PSI). These facilities can often be used advantageously to answer industrial questions.

The road from fundamental physics research to a tangible market product can be long and winding. As we have

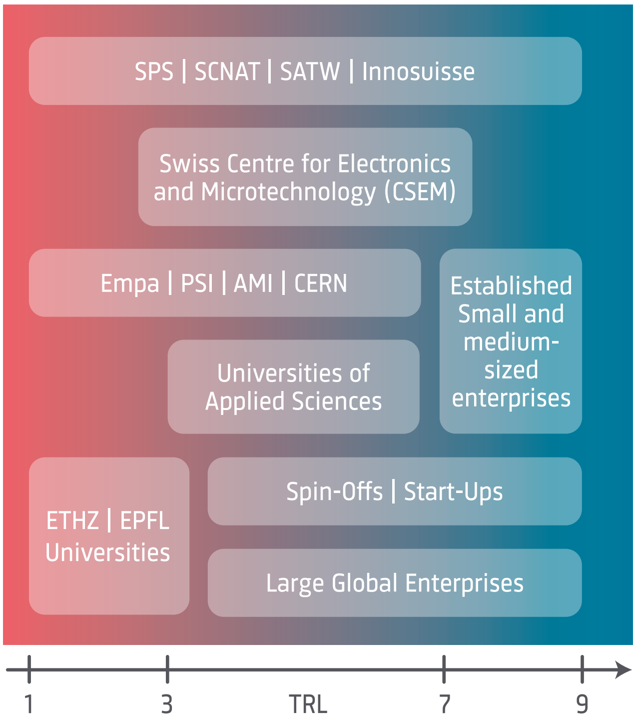

Figure 3: The relevant stakeholders and their Technology Readiness Levels (TRL) in the innovation landscape of the physics- and technology-related sector in Switzerland. TRL = 1: basic principles observed, TRL = 9: actual system proven in operational environment.

seen, the impact of physics on industry is diverse and widespread, both over many disciplines and as a pivotal enabler for certain processes or technologies.

Driving innovation at the forefront of technology remains a perpetual struggle and requires persistent efforts from academia, industry and engagement from organisations like Innosuisse, the Swiss Academy of Engineering Sciences (SATW), the Swiss Academy of Sciences (SCNAT), and SPS to build and maintain these bridges over the life cycle of innovative products.

Selected technological fields relevant for Switzerland

Basic research in physics in Switzerland is mostly supported by the Swiss National Science Foundation (SNSF) and covers the following fields:

- **Condensed matter physics** for the development of novel materials and instrumentation, such as semi- and supra-conductors, as well as nano and quantum materials and technologies.
- **Neutron science** used for non-destructive neutron imaging of various samples both *in-situ* and *in-operando*.
- **Photon science** for the development of laser technology and light sources used in high-tech imaging with fast response, in particular for medical applications.
- **Muon spectroscopy** for fundamental studies in particle physics and the analysis of very sensitive samples, such as archaeological artifacts.
- **Particle physics** for understanding the constituents of matter and their interactions at the most fundamental level.
- **Astronomy and astrophysics** for understanding the universe, the galaxies, the stars and the planets, and extreme objects such as black holes and neutron stars.
- **Geophysics** (Earth, atmosphere and environmental physics) for the monitoring and simulating of climate change, pollution, seismic hazards, and natural resources.
- **Energy Science** for the exploration of new energy sources, and innovations in energy distribution nets and storage.
- **Soft matter, bio- and medical physics** for understanding biological processes, developing novel organic materials, and improving diagnostic and treatment methods in medicine.
- **Plasma physics** for fusion energy production and microelectronics.

Against the shortage of skilled workers and the gender gap

The shortage of highly qualified workers in the fields of 'hard' and technical sciences and engineering has been a preoccupation in Switzerland for many years. It has been highlighted that the phenomenon also has a significant gender dimension, which has been found to be particularly pronounced in Switzerland. Since the early 1990s, figures have improved, but progress is remarkably slow. This is apparent in the still extremely low number of girls who, when entering high school at 14 to 15 years of age, opt for a curriculum with a focus on physics and applied mathematics.

Trying to increase the interest, and hence the number, of women from the bottom is important, but not sufficient to solve the issue of gender imbalance in physics and in technical and engineering fields generally. The issue must also be addressed from the other end, by improving career conditions for women and increasing their numbers in leading positions in these fields, in order to prevent the 'leaky pipeline' phenomenon, which is the gradual disappearance of women at different stages throughout their careers in STEM (Science, Technology, Engineering, and Mathematics).

There are several current initiatives by SCNAT, SNSF, the universities, and other professional bodies to provide encouragement and 'identification anchors' by female role models. Many of these actions promote STEM subjects in general. However, this is not sufficient to effectively address stereotypes about the 'hard' and technical sciences in particular. Actions must specifically focus on physics, technology and engineering subjects.

Informal or 'out-of-school' outreach initiatives can help to foster curiosity and interest in the population towards STEM in general, and physics in particular, with important long-term objectives: First, to motivate more students, and in particular female ones, to choose school tracks and studies in the field. Secondly, to provide the general public with first-hand information about research, beyond often dubious sources on the internet, where easy availability too often replaces quality and open-minded reflection, which is the hallmark of science.

The potential of physics for Swiss industries

Physics and its derived technologies play a central role in many sectors of industries and for the development of the economy by producing goods, services and creating many high-skilled jobs.

Photonics

Rapidly developing markets require significantly faster, more powerful, miniaturised, and energy-efficient systems and components that cannot be realized using standard electronic technologies available today. With photonics, completely new technologies become available, with numerous applications, such as new image processing concepts and measurement technology, medical instruments, optical components, communication technology (with data-transfer rates of terabytes per second), powerful light sources, photovoltaics, production technology, information technology, security and defence technology. The annual growth rate of photonics is 6 to 8 percent.

Sensing, imaging, measurement and instrumentation

Switzerland has a long-standing reputation for formidable time-keeping instruments. Their high-tech versions are atomic clocks, which are essential for satellites and time standards. Moreover, satellite-based referencing has become critical for precise localisation in applications from agriculture to logistics. Over the last decades, the Swiss tradition and excellent skills for fine, high-quality measurement and instrumentation have been extending to many other modern, physics-augmented fields, like nuclear magnetic resonance spectrometry, cryo-electron microscopy, atomic force microscopy and micro-wave/millimetre-wave/terahertz technologies which impact biological, pharmaceutical and environmental research and related product applications.

Medical and biological physics

Particle physics is a major driver in novel diagnostics and imaging techniques. Some of those innovations have become mainstream applications; as in numerous flag-ship medical institutes worldwide, proton beams at Paul Scherrer Institute (PSI) treat cancer patients. Protons can deposit controlled amounts of energy limited to accurately defined regions of tissue, with much higher resolution than common radiotherapy, and thereby help to destroy tumours. In contrast to such large-scale installations, physics also serves in the med-tech and biotech sector with the tiniest components through advances in micro- and nanotechnology.

Communication

Modern communication technologies often combine high frequency electrical components with integrated, miniature optical components. Both rely on the advancements of materials and micro- and nanofabrication methods where physics is playing a key role. Another dimension is opened up by quantum communication, where quantum mechanics ensures proven, completely secure communications.

Big data processing and quantum computers

Particle physics colliders and large astronomical infrastructures require big data processing centres. New methods, such as deep learning, are being explored as tools for tera- and petabyte data processing. In addition to the prevailing digital technology, quantum computers use the basic principles of quantum mechanics (so-called quantum superposition and quantum entanglement) to solve problems. Switzerland is excellently positioned in quantum research.

Simulation and modelling

Alongside advances in available computing capability, simulation and modelling has become the third pillar of science next to experimental and theoretical research. A prominent example are the Earth system models used for daily weather forecasting and projections of the Earth's future climate. The basis of these complex models rely on fluid dynamics, thermodynamics, electromagnetic radiation and physical chemistry.

Cyber-physical systems

Simulation and modelling of physical systems have increasing impact in inherently industrial topics: The complete digitalisation of production systems is considered worldwide as fourth major step in the industrial revolution and has been termed 'Industry 4.0'. It connects subsystems with each other, but also with external sources such as the Internet of Things (IoT) for optimal information exchange. To correctly apply virtual modules, a profound understanding of physics, especially at the system noise level, is indispensable. Then the real and the virtual world can be merged by powerful estimation algorithms to minimize stochastic process errors leading to more accurate and robust production systems.

Science museums or centres play a major role for science outreach and informal education. In Switzerland, the leading institution of this kind is the Swiss Science Center Technorama in Winterthur. Well-known centres run by large science institutions are the CERN public exhibitions nearby Geneva and the visitor centre 'psi forum' of the PSI in Villigen. Additionally, there are many interesting, more specific offers with a reference to physics.

Scientific literacy – A backbone of citizen empowerment

There are more reasons for a thorough physics education than just creating motivated, innovative employees for the industry. Most importantly, the concepts and laws of physics provide students with a foundation for scientific literacy. Whether you use your smartphone, have to undergo magnetic resonance imaging for medical purposes, or marvel at the discovery of extrasolar planets – there is a wealth of physics behind all this, and at the basis of understanding what you are doing, what is happening, and how the world you live in is made up.

A democracy, by definition, makes decisions by democratic means, which is only successful if there is a broad public understanding of the questions to be decided upon. Physics, as a fundamental science has a special role here. It is not a matter of understanding quantum physics and relativity theory in detail, but of having a basic understanding of essential concepts and relations, as well as of the scientific approach of gaining and validating knowledge in general. Especially when questions related to energy, climate or health need to be decided at the ballot box.

This is the only way to empower citizens to recognise fake news in the media, to form a well-founded opinion, and to participate in the discussion about issues of social importance (such as the energy supply system), and eventually in votes and elections regarding these.

SDGs: The UN's International Sustainable Development Goals

With this publication, the Swiss Academy of Sciences contributes to SDGs 4, 5 and 9:
'Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all', 'Achieve gender equality and empower all women and girls', 'Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.'

4 QUALITY EDUCATION
5 GENDER EQUALITY
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

> sustainabledevelopment.un.org
> eda.admin.ch/agenda2030/en/home/agenda-2030/die-17-ziele-fuer-eine-nachhaltige-entwicklung.html

A pdf version of this factsheet is available at scnat.ch/en/id/8Vqd7
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LAYOUT
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COVER PHOTO
Atomic force microscopy data of probably the smallest topographic map of Switzerland ever created. With its 30 × 20 micrometer size it would easily fit on a human hair, and the Matterhorn measures less than 400 atoms in height (vertical scale exaggerated in the image). It embodies the evolution and connection from Nobelprize-winning physics made in Switzerland to the paradigm-changing field of nanotechnology.

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