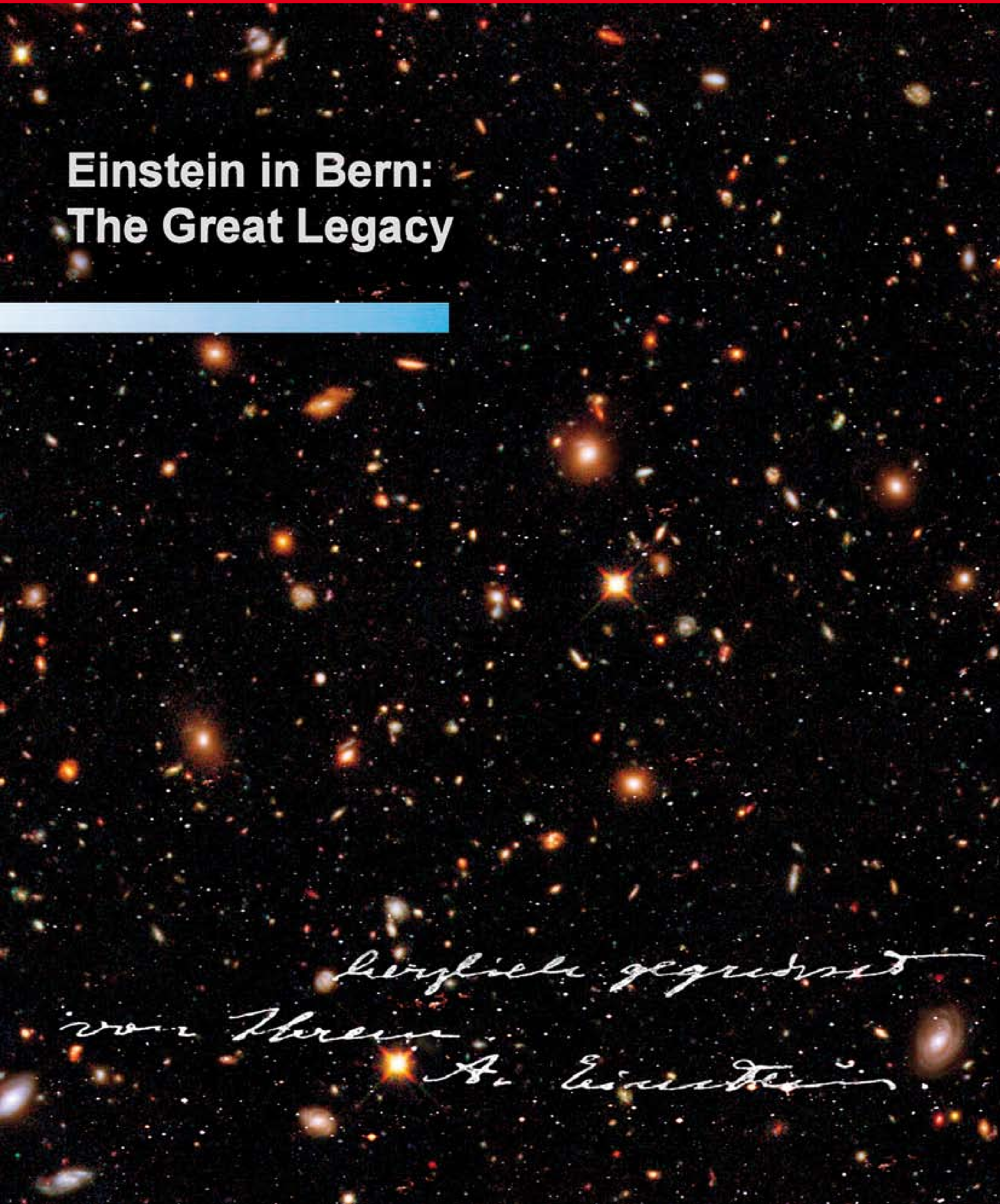
INTERNATIONAL SPACE SCIENCE INSTITUTE

# SPATIUM

Published by the Association Pro ISSI
No. 18, February 2007

## Einstein in Bern: The Great Legacy



# Editorial

*Omnia rerum principia parva sunt.* The beginnings of all things are small.

This famous quote of Marcus Tullius Cicero is more than true for the middle drawer of an ordinary desk at the Kramgasse 49 in Bern. This drawer was called the office for theoretical physics by its owner, clearly a euphemism initially, but more than appropriate by the time when its contents prompted nothing less than a revolution of theoretical physics.

The desk belonged to the patent clerk of third rank Albert Einstein, who during the office hours had to treat the more or less ingenious inventions filed to the Patent Office, while in his spare time had set out to invent a new physics.

One might expect that such high-flying studies could at best occupy a few scientists in their laboratories. It was worse off: even the brightest representatives of the world-wide science community needed at least twenty years to fully grasp the epochal power of the patent clerk's ideas while for the great public Einstein's theories continue to stand for the inaccessibility of science.

Nevertheless, much has been said about Albert Einstein on the occasion of the hundredth anniversary of the annus mirabilis 1905 in Bern, the year, when the middle drawer of his desk became really *the* office for theoretical physics. Rudolf von Steiger, Professor at the University of Bern and Director of the International Space Science Institute together with Thomas H. Zurbuchen, Associate Professor at the University of Michigan have endeavoured successfully to translate the fascinating ideas of Albert Einstein for a larger audience, not just in Bern, but in many stations all over the world and to highlight some of the traces he continues to leave in our daily life. We are greatly indebted to the authors for their kind permission to publish herewith a revised version of their multi-media presentation.

***Hansjörg Schlaepfer***
Brissago, January 2007

## *Impressum*


SPATIUM
Published by the
Association Pro ISSI

Association Pro ISSI
Hallerstrasse 6, CH-3012 Bern
Phone +41 (0)31 631 48 96
see
www.issibern.ch/pro-issi.html
for the whole Spatium series

***President***
Prof. Heinrich Leutwyler
University of Bern
***Layout and Publisher***
Dr. Hansjörg Schlaepfer
CH-8173 Neerach
***Printing***
Stämpfli Publikationen AG
CH-3001 Bern


***Front Cover***
This composite image provides a glimpse to the remotest regions of the universe explored by the Hubble Space Telescope so far. The evolution of the cosmos is certainly a topic that Albert Einstein discussed with his two colleagues of the Akademie Olympia in Bern, Conrad Habicht and Maurice Solovine. The overlay image shows an excerpt of a message he wrote to the latter. (Credit: ESA, NASA, Hansjörg Schlaepfer)

# Einstein in Bern: The Great Legacy[1]

*Thomas H. Zurbuchen, University of Michigan, Ann Arbor, MI, USA*
*Rudolf von Steiger, International Space Science Institute, Bern, Switzerland*
*Brian Grimm, Paper Cardinal Design, Oakland, CA, USA*

## Introduction

The French philosopher and mathematician Henri Poincaré[2], in 1902, published a book entitled "La Science et l'Hypothèse". In this book he identified what were – in his opinion – the most important unsolved problems in science. One problem concerned the way light interacts with metal surfaces and obviously is able to eject electrons out of these surfaces. The second problem had to do with the apparently random zig-zag motion of pollen observed under the microscope, called Brownian Motion. The third problem was the failure of experimental physics to detect how light propagates, for example, from stars to astronomical telescopes. The assumption of a thin, nearly massless ether had been questioned by an experiment by Michelson and Morley some 25 years earlier that failed to find any evidence for such an ether.

Only a few years later a young patent clerk by the name of Albert Einstein had solved all three of these problems in a convincing manner.

**Figure 1: Beautiful Bern.** Looking over the roofs of downtown Bern to the hills of the Bernese Mittelland to the permanently snow-covered High Alps with the Blüemlisalp in the centre. (Credit: Bern Tourism, Bern)

[1] The present text follows a lecture by R. von Steiger in the Historisches Museum in Bern, 22 August 2006. Similar talks were held by T. Zurbuchen and R. von Steiger in over 20 locations world-wide

[2] Jules Henri Poincaré, 1854 Nancy, France – 1912 Paris, French mathematician, physicist and philosopher.

**Figure 2: Bern, Kramgasse 49.** It is here that the Einsteins lived between 1903 and 1905. From this house Albert Einstein revolutionized physics by his publications in 1905. (Credit: Einsteinhaus Bern)

# Setting the Stage

The story plays in Bern, the capital of Switzerland, in the very heart of Europe. The historical roots of Bern date back to the La Tène time, the 5th to 1st centuries B.C. Modern Bern was founded by Duke Berchtold V von Zähringen in 1191. A legend tells us that he decided to name the new city after the first animal he would catch on a hunt; this was a bear, prompting him to name the place Bern. Bern is considered one of the most beautiful cities in Europe. It is located close to the Aare, a river originating in the Swiss Alps that brings clean water from the mountains to the city. Naturally, the U-shaped river bend was an attractive location for the city in medieval times, providing protection from three directions. Today, Bern houses approximately 150,000 people. To outsiders, Bern is known for its history, spanning many centuries, its bear pit housing the animal also found in the Bern flag, and its ambiance that is certainly unrivalled. To its visitors, Bern is often described as "gemütlich" – you immediately feel the warmth of its people, and its beauty.

In the old part of the city, in a house whose origins date back to the first city expansion in 1218, a story unravelled that was so groundbreaking and new that it still has effects today. In this house at Kramgasse 49[3] **(Figure 2)** Albert Einstein lived from October 1903 to May

1905. It was one of the seven different locations where he resided during his seven year stay in Bern.

For all practical purposes, things did not go very well during that time. He had finished his exams, allowing him to submit a doctorate at the University of Zurich. Out of the three graduating students applying for a doctorate, two were hired as teaching assistants, but Einstein was not. He was married to Mileva Maric and they had a child, so the sheer economical necessities forced him to accept a job at the "Amt für geistiges Eigentum" – the Swiss office for intellectual property, or, as we now call it, the Patent Office. He was hired as a clerk of third rank. The office hours were from 7 a.m. to 6 p.m. every working day and from 7 a.m. to 5 p.m. on Saturdays. Only Sundays were off. The Einsteins shared the kitchen and the bathroom with four other families, while their own apartment contained two rooms and a foyer. Nothing of this simple setting revealed that here one of the most ingenious human spirits ever silently was at work. And his objective was nothing less than to answer the three major open issues identified by Henri Poincaré three years before while dealing with such mundane items as shower heads or refrigerators, during his office hours. He did not even have unlimited access to libraries as he generally worked in the patent office during the time when the library was open.

We will now concentrate on what Einstein wrote in three of his most important papers, but let's not forget how, under what conditions he lived when writing these papers.

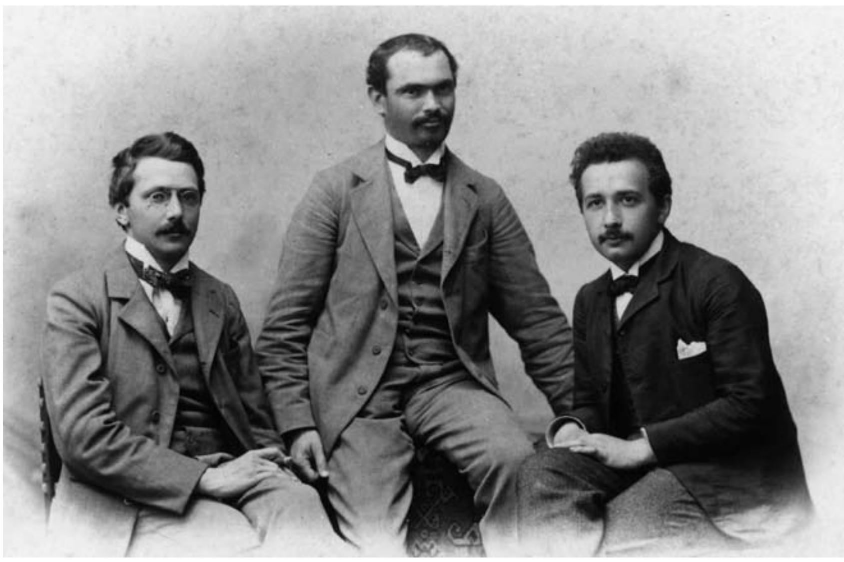


***Figure 3: The members of the Akademie Olympia.*** From left to right: Conrad Habicht, Maurice Solovine and Albert Einstein. (Credit: ETH-Bibliothek, Zürich)

[3] Today, this is the location of the Einstein house.

## The Great Scientific Trilogy

The genius could not be halted by the measly setting. Rather he discussed the ardent problems together with his colleagues of the Akademie Olympia, Conrad Habicht and Maurice Solovine **(Figure 3)**, and then went back to his desk, the middle drawer of which he called his office for theoretical physics, and put his thoughts to paper.

### The Photoelectric Effect

In March 1905 Albert Einstein published a short article in the *Annalen der Physik* entitled *Über einen die Erzeugung und Verwandlung des Lichts betreffenden heuristischen Gesichtspunkt,* a paper that in 1921 earned him the Nobel Prize. At that time, all physicists knew what light was. Whether from stars, the Sun, or from radio antennas, light clearly propagated as a wave. Just like sound, light can propagate around the corner – you can easily see this for yourself. Just drop a coin in a mug, then back away until you lose sight of the coin. Next fill the mug with water. Voilà, the coin reappears though it still rests on the bottom of the mug. Light propagates very much like sound, bending, adding, and subtracting, and very much behaving like liquid waves on a lake or sound-waves in air. Just like sound-waves in air, light-waves were assumed to propagate in a medium, the so-called ether, which spanned the universe.

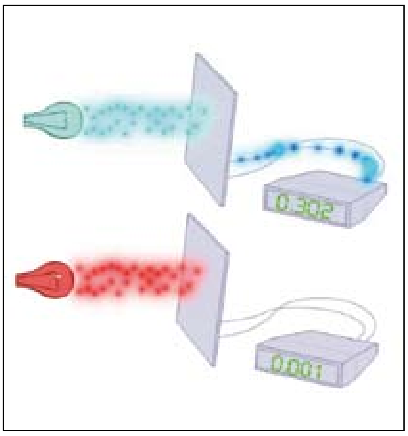



***Figure 4: The photoelectric effect.*** The experimental setup demonstrating the different properties of blue and red light respectively.

There was, however, a problem with this notion as illustrated in **Figure 4.** The experimental arrangement consists of two lamps, one red and one blue, shining on a metal plate. The metal plate is hooked up with a wire, so that electric current from this plate can be measured. Electric current basically is made out of a bunch of moving electrons, negatively charged particles. Now, without any lamp on, there is a very slight current, almost nothing at all. Then, the red lamp is turned on. The current increases only slightly, but does not become really strong at all. The blue lamp has exactly the same wattage and therefore emits exactly the same power as the red lamp. But when this blue lamp is turned on, the current really jumps. What happened? Although we irradiated the plate with exactly the same power, the blue light causes the electrons to leave the metal plate, while the red light has practically no effect.

Einstein's explanation shook the understanding of light at its basic roots. He argued that light is made of particles, called photons. Each photon has an energy content which is determined only by its colour. So, with that new concept, the explanation of this intriguing experiment becomes quite simple: when the photons of the light sources hit the metal surface, they interact with the electrons in the metal. A certain minimum energy is required for an electron to be freed from the metal and to contribute to the electric current. The red light is made from lower-energy photons in larger quantity whose energy content is not sufficient to free the electrons in the metal. This is why the red light does not cause a significant increase of current. In contrast, the blue photons, when hitting the surface, cause an electric current to flow, as they possess enough energy to free electrons in the metal plate. Note that this effect works no matter how dim the light may be. Blue light particles do simply have sufficient energy, and increasing the brightness just brings more of them out of the metal and thus further increases the current.

Einstein's interpretation was highly controversial at that time. Based on

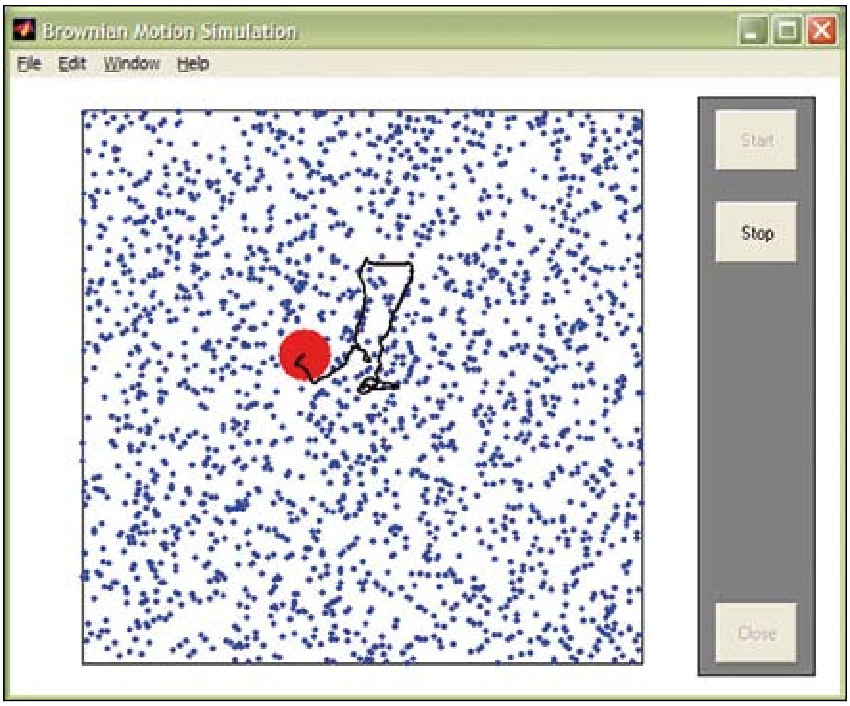



***Figure 5: Brownian Motion.*** The British botanist Robert Brown observed in 1827 that the pollen of plants suspended in water was moving around in a random way. This sketch shows what might have been the path of one such pollen, bumped by billions of collisions with the smaller and hence invisible water molecules in the solution.

[4] Robert Andrews Millikan, 1868 Morrison, Illinois – 1953 San Marino, California, American physicist, Nobel Prize 1923.

a series of experiments, Robert Millikan[4] validated all predictions made by Einstein relative to the photoelectric -effect, but he came to the conclusion that *despite the apparently complete success of the Einstein equation for the photoelectric effect, the physical theory on which it was designed to be the symbolic expression is found to be untenable.* Einstein's theories continued to be controversial and only through the wise foresight of the Nobel committee did Einstein get the ultimate recognition for this paper in 1921.

## Brownian Motion

Only two months later, in May 1905, Albert Einstein solved the second of Henri Poincaré's great challenges. The Scottish botanist Robert Brown[5], during extensive work with his microscope some seventy years earlier, had made a strange observation. The pollen of *Equisetum* suspended in a water solution untiringly rushed around in a random zig-zag motion, **Figure 5**. Such observations had been made prior to Brown, but were generally interpreted as showing that the pollen grains were really little animals swimming in the water. Brown was aware of this and therefore performed a series of experiments that involved sprinkles of glass, rock and other inorganic material in the water. No matter what type of small particles he used, Brown observed the very same motion in all experiments. Therefore he had to exclude the earlier interpretation and progress to a notion that the motion was not of biological origin, but had its roots in the physical properties of water and its interaction with these grains.

Einstein's view of Brownian Motion is surprisingly straightforward: the suspended small particles are constantly bombarded by the water molecules which in turn are much smaller and therefore not visible under the microscope. If a water molecule had the diameter of a tennis ball, the size of the pollen would be approximately 100 metres. These tiny water molecules restlessly strike the particle and push it continuously. Billions of such collisions occur every second. Random fluctuations may cause a whole convoy of particles to hit the pollen knocking it this way and some time later it may experience a push from another direction and so on, as shown in **Figure 5**.

Einstein solved the problem by interpreting water to be made of small particles and not, as was assumed before, a jelly-like, continuous liquid. It was already known at the time that many issues in thermodynamics, the part of physics that describes how heat is created, ex-

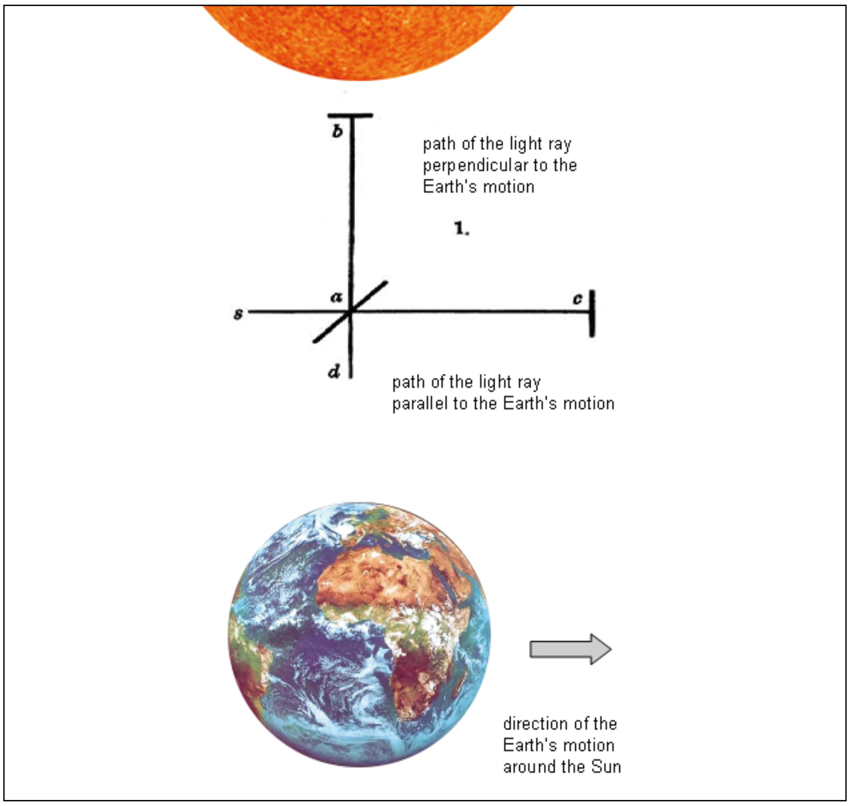



***Figure 6: The Michelson-Morley experiment*** Before Einstein, it was assumed that light propagates in the ether at rest in the universe. Therefore, the light ray parallel to the Earth's motion (a-c) should return faster to the semi-reflective mirror as compared to the perpendicular light beam (a-b). But the experiment proved otherwise.

[5] Robert Brown, 1773–1858, Scottish botanist, discoverer of Brownian Motion.

changed and transported, could be explained in the context of average properties of particles, bumping into each other and moving around. On the average, the model of these interacting particles describes quite well how heat behaves. However, this picture was largely assumed to be a model only and leading scientists refused to assume that there would be any departures from that average behaviour on the level of the individual particle. Einstein's interpretation established two very important new aspects. Firstly, the fact that water consisted of small, individual particles was established firmly. While this idea was brought up long before Einstein, his interpretation of Brownian Motion established this new notion without any doubt. Secondly, and much more importantly, his interpretation of the statistical nature of fluids opened the door to the modern, statistical description of particles. On the average, things are pretty predictable, but for an individual particle, things become random and therefore unpredictable.

## *Special Relativity*

One month later, in June 1905, Albert Einstein addressed the theory of relativity, which of the three problems is perhaps farthest away from our everyday experience. In contrast to the first two topics, Einstein based his reasoning not on a particular experiment, but rather he was motivated by the problems scientists had with light and its propagation. At the time, physicists thought that light, just like sound in air, propagated in a medium, generally called ether, as we have seen above. That ether would presumably sit at rest in the universe. This hypothesis was tested by Albert Michelson[6] and Edward Morley[7] in Cleveland in 1887, **Figure 6**. The basic idea of their experiment is quite straightforward: the Earth orbits around the Sun at a speed of about 30 kilometres per second, or 1/10,000 of the speed of light. The light beam in a laboratory directed along the path of the Earth's mo-

***Figure 7: The heart of downtown Bern.*** The Kramgasse, where the Einsteins lived between 1903 and 1905, seen from the Münster tower (Photo: Frank Rutschmann).

tion should speed up or slow down in the ether at that rate depending on the actual direction while its speed should not be affected by the Earth's velocity when it is directed perpendicular to the Earth's motion. The outcome of this experiment was very disappointing: the speed of the light was found to be independent of the direction relative to the Earth's motion. While this experiment was a failure in the eyes of many scientists, it was an inspiration for Einstein.

To understand Einstein's reasoning, we have to introduce the concept of a co-ordinate system. A co-ordinate system is a three-dimensional map allowing points in space to be brought in relation to each other. A co-ordinate system attached to the Earth can be used, for example, to measure distances between two cities. We may centre the co-ordinate system, for example, in Bern. Then, Zurich is some 80 km to the north-east. As we are free to centre our co-ordinate system where we like, we might centre it at the Sun constantly oriented relative to the stars. In this co-ordinate system, the Earth is roughly 150 million kilometres away circling the Sun approximately in one year. So far, so good and simple. But now we can add time to the picture by labelling each point of space with time by letting a clock run there. By doing so, our co-ordinate system has become four-dimensional: three space dimensions and one time dimension, but it continues to be quite simple. The question Einstein asked himself is how events in one system can be transferred into another co-ordinate system, or more specifically, how physical experiments in one co-ordinate system relate to physical experiments in another system which is moving relative (this is why we speak of relativity!) to the first one with a constant speed. Such systems are called inertial co-ordinate systems. Of course, the results of the ex-

[6] Albert Abraham Michelson, 1852 Strelno, Poland – 1931 Pasadena, California, German-American physicist, Nobel Prize 1907.
[7] Edward Williams Morley, 1838 Newark, New Jersey – 1923, American scientist.

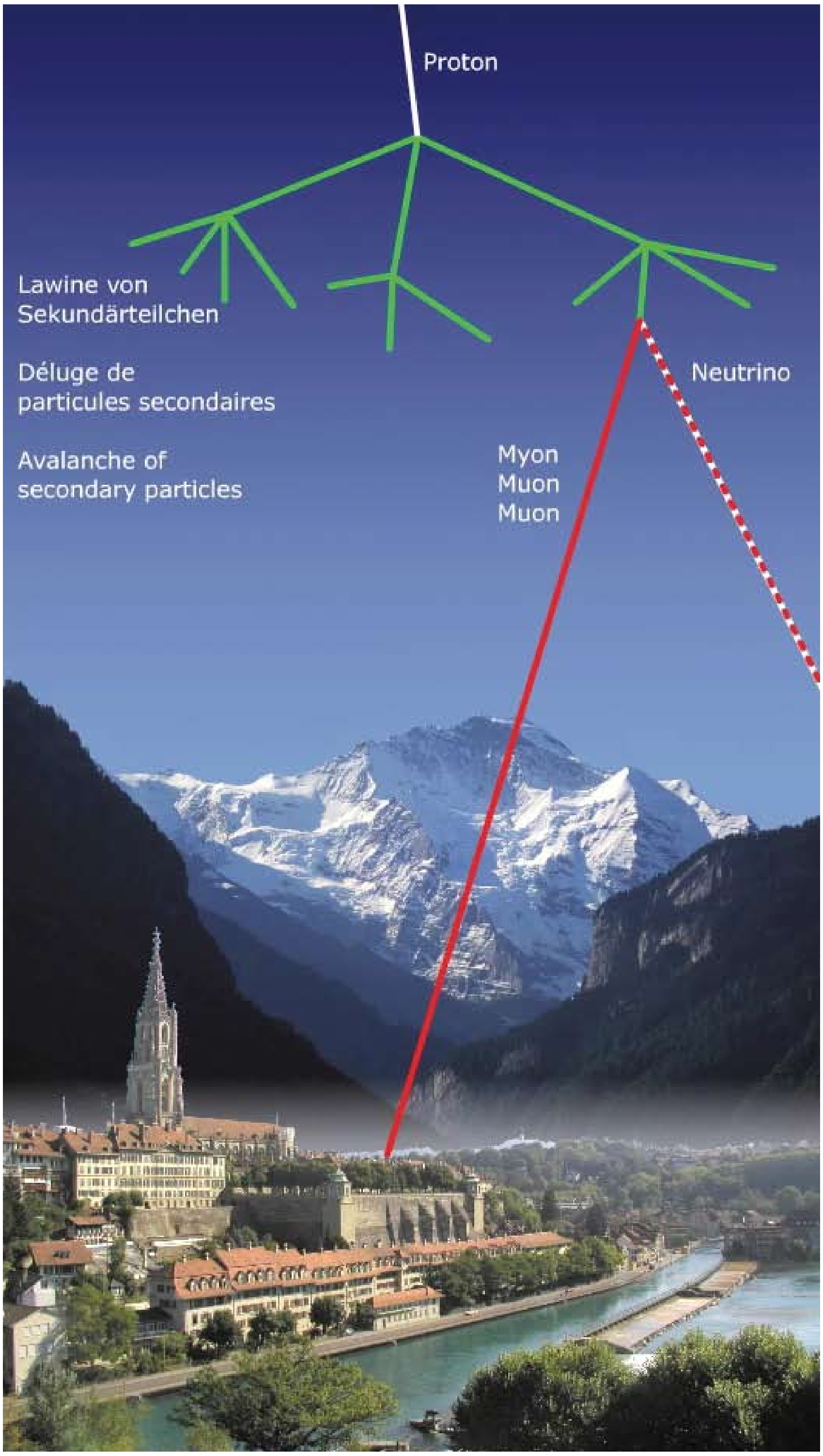



***Figure 8: Demonstrating the relativity of space and time.*** The fast moving muons experience the dilatation of time that allows them to travel farther than their limited lifetime would suggest. (Credit: BHM)

periments should be independent of the co-ordinate system much like the distance between Bern and Zurich must be independent of the co-ordinate grid we use. This, however, is particularly tricky for a field of physics called electrodynamics, the science that describes the propagation of light as well as the electrical and magnetic phenomena, like for example the processes on the surface of the Sun or the behaviour of the European electrical network.

Einstein focused his analysis on two principles and their consequences. The first principle is the Principle of Relativity: the laws of physics are the same in each co-ordinate system, or the other way round: one cannot distinguish between (inertial) co-ordinate systems based on physical experiments. The second principle is a direct consequence of the negative result of the Michelson-Morley experiment. It simply states that the speed of light is absolute and constant in all co-ordinate systems.

When defining these principles, Einstein was firmly guided by observable phenomena: time is what you can read off a clock. Clocks can be synchronized only by exchanging signals at finite speed such as the speed of light. The conclusions drawn by Einstein are truly amazing: if the speed of light is absolute, time and space must be relative!

We can verify this striking conclusion by an experiment, see **Figure 8**. It starts in the depths of space when an exploding star accelerates particles to very high speeds, nearly to the speed of light. Some of these so-called cosmic rays enter the upper atmosphere of the Earth and collide with air particles. These collisions create a whole shower of new and mysterious particles; most of them collide with other air molecules or decay very quickly so they don't make it very far. Some particles in the shower, however, the so-called muons, interact only weakly with the air molecules. They can travel therefore all the way to the ground. Muons are the heavy cousins of electrons, but while electrons have an unlimited lifetime, the lifetime of a muon is a mere 2.2 microseconds. So, we expect no muon to make it from the upper atmosphere down to the ground, as it will decay before getting there, even when propagating at the speed of light. More specifically, we expect the muon to travel no more than 660 metres before decaying. But our experiment proves otherwise!

In order to identify the muons, we use spark chambers. These are stacks of metal plates separated by thin gaps with a high voltage across. When a muon passes through, it leaves a trace of visible sparks in the chamber, which allows us to notice its presence. Now, we set up one such spark chamber at the Jungfraujoch at an altitude of 3,580 metres and the other in Bern at 560 metres. While we expect the spark chamber on the Jungfraujoch to see many muon counts thanks to its high elevation, no counts in Bern are expected as it is deeper in the atmosphere than the muon's expected travelling distance of 660 metres before decaying. In the experiment both chambers happily count muons, the one in Bern a bit fewer than the one high up on Jungfraujoch. So, apparently about half the muons counted at the altitude of Jungfraujoch make it to Bern without any problems and are seen as small sparks in this chamber.

What happened? We argued before that no muon can travel further than 660 metres even at the speed of light before decaying. And still they travel through the altitude difference of 3,020 metres, five times as much. Einstein's notion of relativity helps us to explain our findings. We can do so from two different points of view, either in a co-ordinate system fixed to the Earth, or in a co-ordinate system fixed to the flying muon. In the Earth-fixed co-ordinate system, we know that the distance from Jungfraujoch down to Bern is 3,020 metres, and the particle's speed is roughly the speed of light. Due to the muon's high speed, Einstein argues that the time as experienced by the muon slows down dramatically. That means, that, as seen by our clocks, the muon's life is extended or, in Einstein's terminology, time is relative. By translating from the muon's co-ordinate system to our coordinate system attached to the Earth, time is dilated.

On the other hand, we can look at this experiment as if we were sitting on the muon. Again, we know that the muon lives a mere 2.2 mi-

***Figure 9: The world-famous Zytglogge tower.*** The tower itself was part of the original city walls at the beginning of the 13th century. The great bell was cast in 1405. The clock is more recent, its mechanism dates back to 1530. (Photo Hansjörg Schlaepfer)

croseconds on average. Its speed is nearly the speed of light. But now, what happens with the distance? Einstein again explains this. As seen by the muon, the distance experienced between Jungfraujoch and Bern contracts. As Einstein puts it: space is relative also. Thus, neither space nor time remain absolute, but rather they are relative to their state of motion. What remains absolute is the speed of light.

# Einstein and Us Today

As stated above, Albert Einstein's interpretations were highly controversial at his time. So it is no wonder that it took many years to fully grasp their content. Eventually though, the strengths of his ideas became obvious and scientists and engineers began to exploit their potential in favour of our everyday world. Each one of the three papers discussed here marked the beginning of a whole new field of physics. We will now look at some examples where his contributions are fundamental.

### Photo Effect ➔ The Laser

Einstein's explanation of the photoelectric effect prompted scientists over the next two decades to develop quantum theory, and engineers endeavoured to manipulate these tiny components of light. The laser is just one device which exploits the notion of light quanta. Incidentally, Einstein himself laid the groundwork for the laser through his later discovery of stimulated emission in 1918. The term laser is an abbreviation of *Light Amplification by Stimulated Emission of Radiation*. This type of light – which does not exist in nature – has a wealth of applications today, such as for example, transmitting billions of bits per second between spacecraft, or as scalpels that make extremely sharp cuts with much less bleeding than conventional scalpels. They can also be used to burn and evaporate tumours. The laser seen in **Figure 10** is a carbon dioxide laser operating at a wavelength of 10.6 micrometres. This is in the invisible infrared – the red ray is merely a small conventional laser to guide the operator. In the picture you can see Dr. Berchtold von Fischer from the Lindenhof hospital in Bern operating on an apple. He normally operates on breast cancer and has co-developed a new scheme that allows sparing as many lymph nodes as possible, thus reducing post-operation complications considerably. This is only one of countless applications today that can trace their source back to Einstein's photon hypothesis.

### Brownian Motion ➔ Nanotechnology

Brownian Motion gave Einstein the hint that matter is indeed composed of atoms. An atom is extremely small. Most of the things we use in our everyday life have sizes of metres, like our bodies, or a fraction of millimetre like our hair. For the much smaller world at Brownian Motion, microscopes allow us to ac-

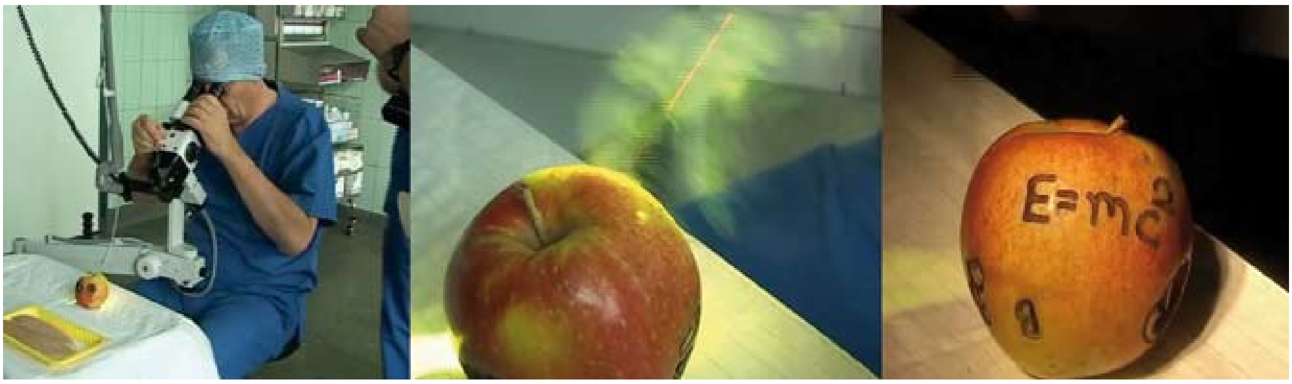



***Figure 10: Einstein in the operating theatre.*** The coherent light of lasers finds an overwhelming variety of applications today. This sequence shows a surgeon demonstrating a carbon dioxide laser writing Einstein's famous formula on the skin of an apple.

tually see how cells evolve and how viruses attack; but the most amazing microscope ever developed is the Scanning Tunnelling Microscope (STM) which won the Nobel Prize for Gerd Binnig[8] and Heinrich Rohrer[9] in 1986. A very small tip, made only of a few atoms, is moved very close to a material. Then, some electrons can jump (or "tunnel") from the material to this tip and are detected as a current, see **Figure 11**. The closer the tip, the more electrons can jump the gap. Atoms are like bumps in materials and the tip, moved very accurately, allows one to measure a landscape this extremely small. Let's just quickly get a sense of the dimensions we are dealing with here: Washington, D.C. is roughly 4,500 km away from Los Angeles. Stretching a platinum wedding ring from coast to coast, from Los Angeles to Washington, would lead to a distance between two neighbouring atoms of just one centimetre. On this scale the thickness of a hair would be roughly 3,000 metres.

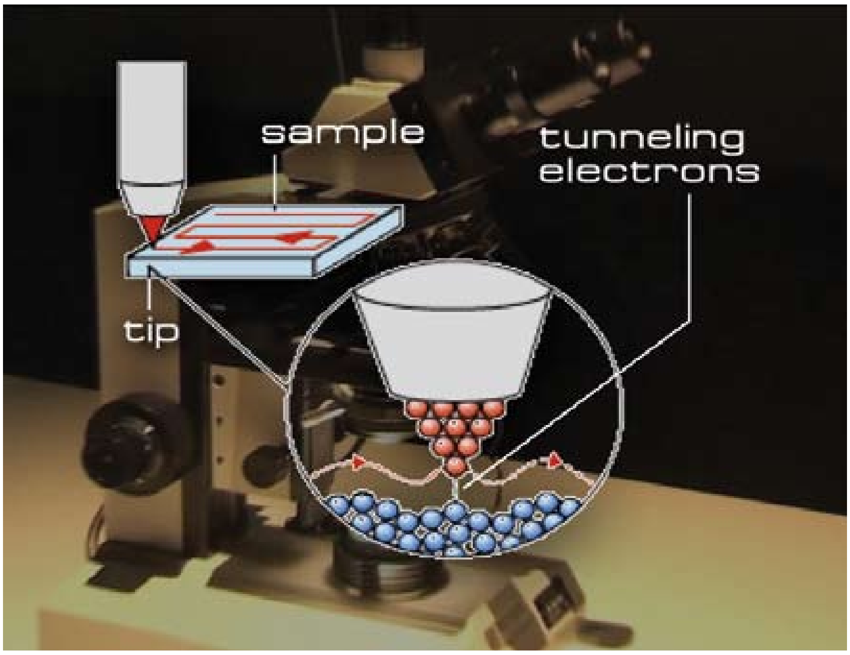



*Figure 11: The principle of the Scanning Tunnelling Microscope.* A very small tip only a few atoms wide is moved closely over the surface of a sample. With decreasing distance of the tip from the surface an increasing number of electrons become able to jump to the tip and be detected in the form of an electric current. This allows generating an image of the sample's surface.

These nanoworlds have the most amazing structures. **Figure 12** to the left shows a nanostructure that has been getting a lot of press recently: a carbon nanotube. These tubes have a thickness of only 10 atoms or so, but are unbelievably strong, about a hundred times stronger than steel at only a sixth of the weight. We are currently learning to grow these structures and to use them. The trick is to grow such tubes en masse, leading to materials that have almost miraculous properties. There are already prototypes of a new display type allowing for monitors that are a lot sharper than what we use today. Also, nanotubes will certainly have countless applications for air and space travel.

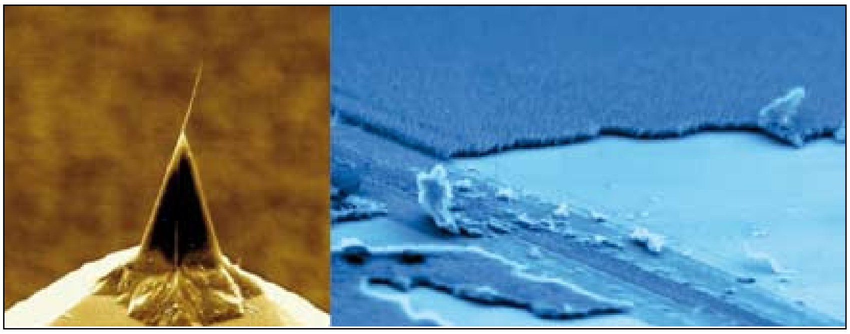


*Figure 12: Glimpses into the nanoworld.* On the left side, a carbon nanotube is depicted. Its thickness is a mere 10 atoms. The image to the right shows the structure of a carpet made up of such nanotubes.

[8] Gerd Binnig, 1947 Frankfurt am Main, German physicist, Nobel Prize 1986.
[9] Heinrich Rohrer, 1933 Buchs, Switzerland, Swiss physicist, Nobel Prize 1986.

## *Special Relativity → Cosmology*

Finally, let's look at the consequences of the paper on special relativity, written in June 1905, with its three-page addendum of September 1905. In this short text, Einstein came to his famous equation $E=mc^2$ . This notion states that energy and mass are equivalent and thus may be exchangeable. Simple as it sounds it changed our view of the world. Together with his paper on general relativity, which included gravity, Einstein described all the processes around us, how the Sun creates its energy, how planets orbit the way they do. When we explore these worlds, we take advantage of his theories in many different ways. We use them in building rockets and in getting spacecraft into orbit.

One of the most popular applications using Einstein's theory of relativity is the Global Positioning System, GPS for short. It consists of a constellation of 24 spacecraft orbiting the Earth at a distance of 20,183 kilometres. There, the Earth's gravity is slightly weaker than here on the surface. According to the theory of general relativity, this causes the clocks aboard the satellites to tick a bit slower than ours. While the difference is minute, it would cause the GPS to provide position information with an error of some 100 metres, which would make the system useless, if it weren't adjusted for Einstein's equations. So, when you next take a taxi in the city of Bern, remember that the taxi driver, guided by a GPS receiver, tacitly applies the laws found here by Albert Einstein a century ago.

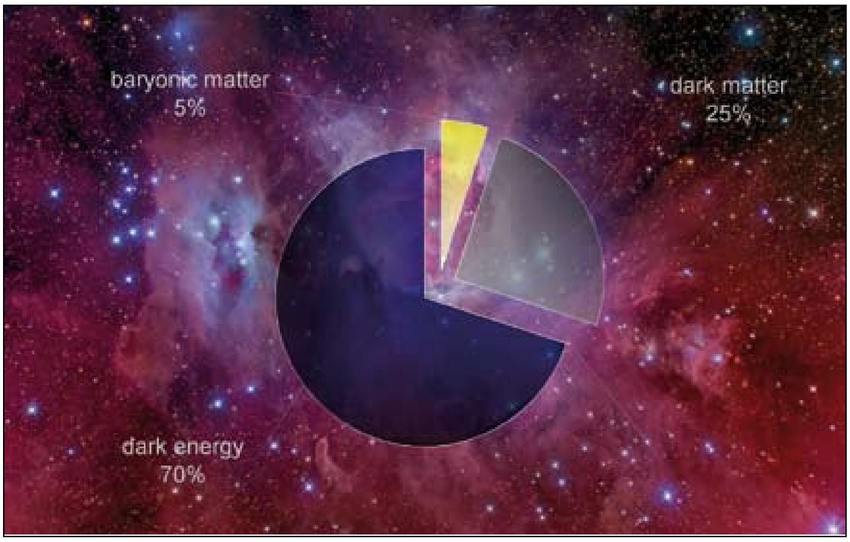



***Figure 13: Mysterious cosmos.*** Baryonic matter (including neutrinos, etc.) forms the stars and the galaxies. It is this type of matter which we experience in our daily life. But this is only a small fraction of what constitutes the universe. The vast majority, namely dark matter and dark energy, is a theoretical assumption required to explain astronomical observations.

Relativity perhaps has the most important consequences for our understanding of the universe and the diverse objects we find in it. One consequence was observed first in 1919 by Sir Arthur Eddington[10] on his famous scientific expedition (see also Spatium 14). The Sun seems to deflect light, like a giant lens, moving the apparent location of stars ever so slightly. Light from a distant star may be distorted just like a lens distorts it. Einstein's theory of general relativity predicts this, and the theory of relativity triumphs. The reason light gets deflected is because gravity curves space itself. Light looks for the fastest path, which is not necessarily straight.

Einstein's theories have their most important consequences when applied to the history, the current state, and the future of the universe. Those belong to the most important questions humans have struggled with over the last millennia: What happened to the universe before the solar system was formed? This question has an amazing and unexpected answer, which actually was derived from Einstein's equations: The universe, we observe, started roughly 14 billion years ago and is now ex-

---

[10] Sir Arthur Stanley Eddington, 1882 Kendal, UK – 1944 Cambridge, British astrophysicist.
[11] Abbé Georges Henri Lemaître, 1894 Charleroi, Belgium – 1966 Löwen, Belgium, Belgian priest and physicist.
[12] Alexander Alexandrovich Friedman, 1888 St. Petersburg – 1925 Leningrad, Russian cosmologist and mathematician.

panding at a rapid speed. In 1927, a Belgiam catholic, Montsignor Le Maitre[11], concluded that such an expanding universe was a solution that came directly out of Einstein's equations. A Russian physicist, Alexander Friedman[12], had come to the same conclusion even before, but he died of typhus fever during WWI, before his solution was widely known. This expansion was first observed by Edwin Hubble[13], an astronomer working at the Californian Institute for Technology, in 1929. Hubble found that every galaxy seemed to move away from us, at a speed that increased with increasing distance – similar to a huge explosion. But not an ordinary one at that: It's not that galaxies explode into a previously existing empty space, but space itself is created in the "explosion", and it looks to everyone anywhere in the universe, not just us, that we are at its centre. The Hubble Space Telescope has continued these observations and has managed to even go beyond that. Looking at the largest distances and comparing to observations at the smaller distances, the Hubble telescope provided one of the most exciting and puzzling results of the last few years: In contrast to what we would expect, the expansion of the universe appears to be accelerating: the explosion is still powered today by a mysterious force. Cosmologists found an appropriate name for it: dark energy. It turns out that Einstein had even put this effect into his equations – even though he personally never believed in the actual existence of dark energy. In order to solve his equations in the way he considered reasonable, and only a static, eternal universe appeared reasonable back then, he had to put in an additional term called the cosmological constant. When he realized that the universe is indeed expanding, he dropped the term and called it his "biggest blunder" (grösste Eselei), because it made him fail to predict that the universe cannot be static and eternal. And yet this very term is now used by cosmologists when describing the accelerating expansion of the universe.

This adds to the puzzle we have today, summarized in **Figure 13**. In fact, we have an almost embarrassing situation right now: We know that the universe is made of multiple constituents. We observe stars and galaxies made of atoms. This constituent is called baryonic matter, the ordinary matter we know from our daily life. But there is another class of matter, called dark matter, as it does not directly interact with photons, therefore we cannot see it, but we can measure its gravitational force on ordinary matter. Both ordinary matter and dark matter together are still only a minor part of the universe. The major part is made up of the mysterious dark energy that drives the expansion. Neither dark matter nor dark energy, however, is fully understood today.

## *Conclusions*

Does this sound familiar? We are in a situation again where somebody, like Henri Poincaré, could write a paper summarizing the most important problems we do not currently understand, and a successor to Albert Einstein should come and solve these open issues. Certainly, for most physicists, dark matter and dark energy are such problems: What is the nature of our universe, and what is it made of? Or, more specifically, what is the nature of dark matter and of dark energy?

Our story started in Bern. This city, with its beauty, and its charm, affected the world in one of the most profound ways thanks to one of its most important inhabitants ever: Albert Einstein. On 31 December 1999 *Time* magazine selected him as the Person of the Century – a lonely patent clerk who was asking important questions and did not back off when people did not agree with him. For those of us who have been affected by Einstein throughout our professional and personal lives, the Bern year of 1905 will always remain a miracle.

But the most important effect Einstein's work has on our world is that it became more beautiful. Einstein pointed out the underlying texture of nature that people did not see before he came along. Science can do that, and will do that again in the future.

[13] Edwin Powell Hubble, 1889 Marshfield, Missouri – 1953 San Marino, California, U.S. American astronomer.

# The Project and its Authors

In late 2004, when preparations for the centennial of Einstein's annus mirabilis got intense, the two first authors independently received invitations to give a talk about that singular event in the history of science. Even though neither of us is a theoretical physicist or a historian of science we decided to team up and jointly develop such a talk, together with video specialist Brian Grimm with whom we had worked before.

Our principal qualification for giving such a talk is that we had both studied in Bern, the city, where Einstein lived 100 years ago. So we decided to begin our presentation with some impressions of this beautiful town. The second message is that Einstein did not only develop relativity, but also gave theoretical explanations of Brownian Motion and of the photoelectric effect, each of which can rightly be considered as of equally fundamental importance. In the third part of the talk we advance time by 100 years to see what came to be of these three seminal topics by giving examples of the numerous applications today.

The talk has been given by both of us numerous times in 2005 and 2006 in the USA, in Asia and Europe. It is a pleasure to thank here our supporters and hosts: the Swiss Department of the Exterior, the Swiss Embassies in Washington, D.C., Seoul, Beijing, and Tokyo, the Swiss Centers in Boston and San Francisco, the Adler Planetarium in Chicago, the Historical Museum in Bern and more.


Rudolf von Steiger was born in Bern. He completed his Diploma (1984) and Ph.D. (1988) in Physics also at the University of Bern. After a postdoctoral year at the University of Maryland he returned to Bern, where he joined the newly founded International Space Science Institute (ISSI) in 1995. Today he works as a director of ISSI with a guest professorship at the University of Bern.

Thomas H. Zurbuchen was born in Heiligenschwendi. He completed his Diploma (1992) and Ph.D. (1996) in Physics at the University of Bern. Then he moved to the University of Michigan in Ann Arbor, where he works today as an Associate Professor for Space Science and for Aerospace Engineering.

Brian Grimm is a video artist and the owner of Paper Cardinal Design based in Oakland, California. He specializes in technical and scientific animations for facilitating efficient and effective communication. Together with his partner Tanja Andrews he is also the author of the award-winning video blog on www.freshtopia.net.