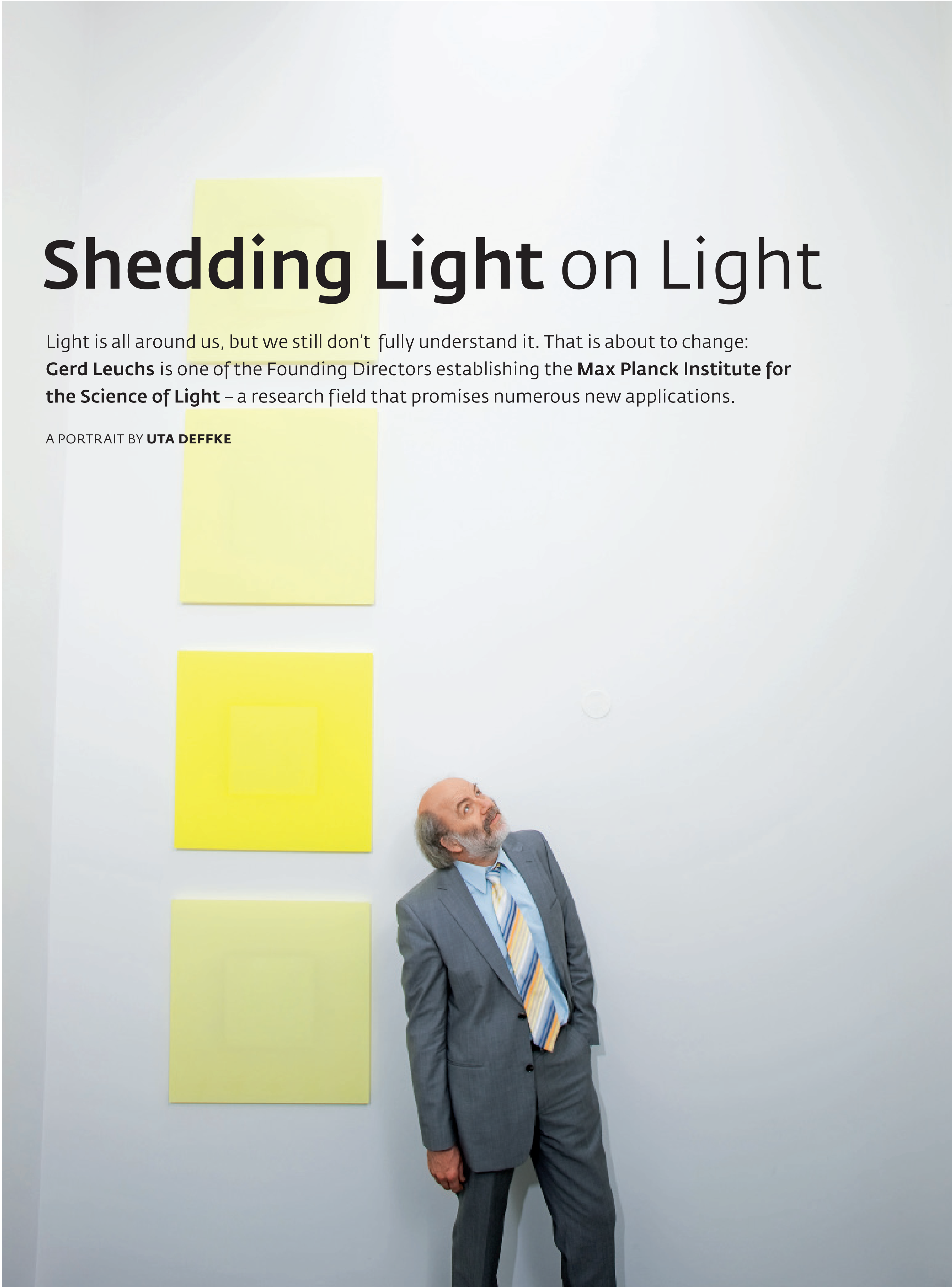
Shedding Light on Light

Light is all around us, but we still don't fully understand it. That is about to change: **Gerd Leuchs** is one of the Founding Directors establishing the **Max Planck Institute for the Science of Light** – a research field that promises numerous new applications.

A PORTRAIT BY **UTA DEFFKE**



Everything is lit up in Building 25 at the Siemens factory site in Erlangen. Just past the first steps, the Sun beams down at visitors from a large photo, together with a color spectrum of its light. The walls in the bright hallway are decorated with colorful pictures – abstract artworks in intense red, orange and yellow – just the right ambiance for a light researcher.

"Nice pictures, shapes, figures, colors, and all of it connected by the physics behind it – I like that," says Gerd Leuchs. "And light is a part of it – light itself has always fascinated people, and it is crucial to our very existence." That's about the full extent of the physicist's philosophizing about his element. Although he is quiet and pensive, he is still more the practical type, a doer. And a successful one, at that: since January 1, 2009, 58-year-old Gerd Leuchs is one of two Founding Directors at the Max Planck Institute for the Science of Light, together with Philip St. John Russell. This is the crowning achievement of his scientific career to date.

But he doesn't act like a king, even if he did play a major role in the creation of his kingdom of light. Instead, he comes across as rather modest and full of respect for the achievements of other researchers. The portraits that hang in the hallway also bear witness to this: they depict Joseph von Fraunhofer, Max Planck – and Herbert Walther, the now-deceased Ph.D. supervisor and mentor who, as a Director at the Max Planck Institute of Quantum Optics in Garching, was an important advisor to Leuchs, also in recent years.

There is also a colorful poster there filled with photos of research groups that staff members placed around the sentence, "We are the light!" – written in the many languages that are spoken at the institute. "We in science benefit greatly from the unprejudiced ideas of young people," says Leuchs. "And in return, we want to bring them into contact with the most up-to-date methods in physics, and with issues at the outer limits of what is possible today, so that they will then hopefully be equipped for their future tasks."

TEENAGE YEARS IN TEHRAN

Optics is an ideal playground for this. Light makes it possible to visualize and verify quantum physics phenomena that are often difficult to grasp, such as how an individual atom emits a particle of light. To be able to use light systematically, the researchers must shape it, as a function of time, in its color (its frequency) or in its polarization (the oscillation plane of the light wave). For this purpose, it is passed through numerous optical elements, some of which are just being developed – specially coated mirrors, for example, or entirely new materials, such as photonic crystals. Information transmission by means of light – for instance through standard fiber optic cables or with particularly secure quantum cryptography encryption – is especially interesting for technical applications. All this and quite a bit more is what Gerd Leuchs and his colleagues will be researching at the new Max Planck Institute.

The path that would eventually lead him there began in Wuppertal, which his speech still betrays, even after spending decades in southern Germany. The family moved around a lot. First within the Rhineland area, and then his father, who was working in crop protection, finally took them to Tehran. Here, in the Shah's (perhaps much-too-quickly) reforming Persia, is where Gerd Leuchs spent his early teenage years and, at the internationally influenced German school, the longest continuous schooling period of his life.

Day-to-day activities took place with little contact with the city life: a school bus took the kids to school from their residential neighborhood on the campus of the research institute where Leuchs' father worked. The latter sometimes also took Leuchs to the bazaar with him and showed him how to bargain properly. Some "lofty" excursions turned into a new hobby: his physics teacher inspired him and a few friends to try out gliding. Gerd Leuchs also learned Persian, but hardly enough to forge any close contacts with locals. Nevertheless, a tinge of nostalgia set in when, after five years, the family returned to Europe in 1967. On one of his last nights there, in late autumn, sitting on a warm wall, Leuchs was comforted by the thought that at least the moon was visible from Germany, too.

He still remembers those days, the summer holidays at the Caspian Sea, the country's cultural highlights. "Back then, it was still a rather laid-back country," says Leuchs. Today, he no longer has any ties to Persia. Even just ten years later, when he last visited the country, things had changed a lot – for the worse, he feels. "There was more money, but also more fear," says Leuchs. It had become less laid back. At that time, the revolution was approaching.

"Today, whenever I find myself in a taxi somewhere and read the driver's name on the sign, I think: Man, that sounds Persian. I ask, and then maybe we strike up a conversation," says Leuchs. Three months ago, an Iranian doctoral student also joined his group. "The application came by e-mail, and

Photo: Axel Griesch

the student had never traveled to any Western country before," says Leuchs. "That's a sure sign of entrepreneurial spirit."

And he had, and has, a fair amount of that himself. The physicist started out pursuing a largely traditional career: he studied in Cologne, wrote his dissertation on atomic physics and laser spectroscopy and completed his postdoctoral lecture qualification at LMU in Munich. This was followed by two and a half years as a visiting researcher in Colorado, USA, on a Feodor Lynen and Heisenberg stipendium. Then he became head of a research group at the Max Planck Institute of Quantum Optics in Garching.

Light has been a recurrent theme in his research life, penetrating it like a laser beam. Even as a student, he was fascinated by this light source, whose unique – coherent – light owes to the fact that many atoms are excited simultaneously to be emitted in an avalanche of light. Anyone who builds their own laser will experience this as a very special moment: "You can actually feel the phase transition," reports Leuchs, almost reverently. Even now, he still raves about the first dye lasers that had just come out in the seventies: "Such a beautiful orange, green, blue light …"

Laser light is also very useful, for example, as an extremely precise sensor in an interferometer. The two wave trains of a split light beam travel different paths and are then recombined. When this happens, the peaks and valleys of the two beams amplify or cancel each other, either fully or in part. A characteristic wave pattern results based on tiny differences in the beam paths.

At the Max Planck Institute in Garching, Leuchs used these effects in his quest for gravitational waves. Albert Einstein predicted these fluctuations in space-time – essentially a compression and expansion of space – in his general theory of relativity, but they have thus far been proven only indirectly by experiment. The idea for proving it directly is to use an interferometer to detect the change in path length, which is caused by gravitational waves and measures just fractions of a billionth of a nanometer. Today, there is a separate Max Planck Institute dedicated to gravitational physics at its two branches in Potsdam and Hannover.

INTERESTING EXPERIENCES IN A COMPANY

In the meantime, Gerd Leuchs took on new tasks. "As sometimes happens in life, I received an offer and took a position as Technical Director at a small, newly established company for optical instruments in Switzerland," explains the physicist. The first project was a user-friendly laser interferometer for industrial applications – such as for measuring machine tools.

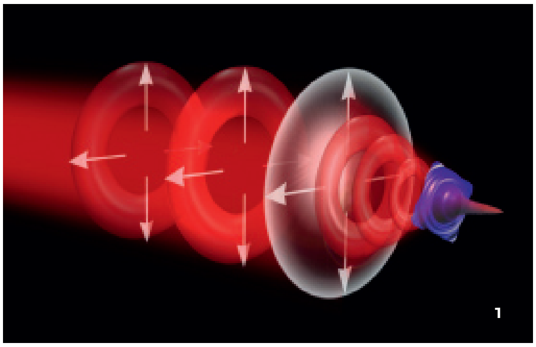
What was it that particularly appealed to him about a job in industry? One could say it was the money. More specifically, the money that others are willing to pay for the things you develop. Gerd Leuchs vividly recalls the first time the company attended a trade fair in Zurich: "We had set up several interferometers and had throngs of visitors who had heard that we were making some great things." Things are different in companies than they are in science: excellent researchers will hopefully be invited to give lectures, and they may be visited in the lab by colleagues, or perhaps even win an award. In companies, however, these honors are useless. "Here, one isn't considered successful until other people are ready to pay money for a device," says Leuchs. "And that is an interesting experience, too."

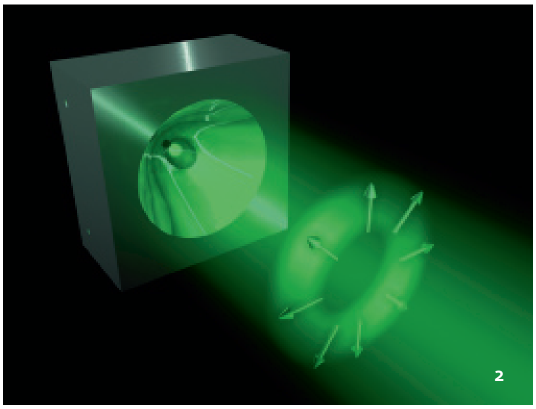
But apparently not interesting enough. The physicist resisted two calls from science, but gave in to the third. That call came from the Faculty of Physics in Erlangen. It wasn't an easy decision for Leuchs, and of course he discussed it with his wife, son and daughter. Finally, they reached a joint decision to return to Germany after five years.

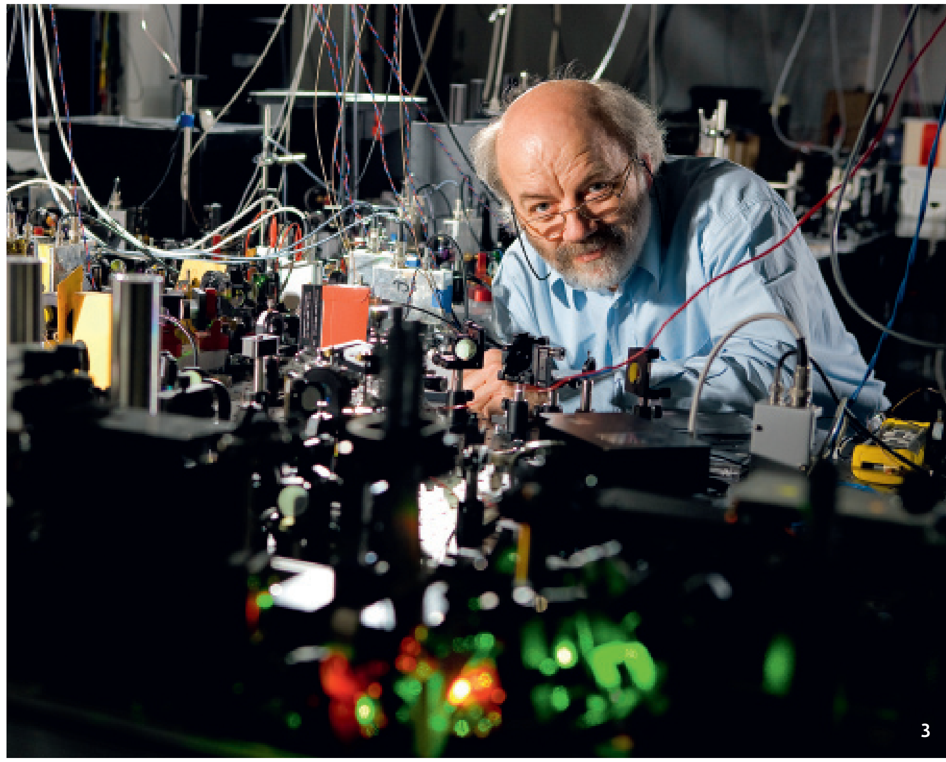
Now Gerd Leuchs has been conducting research in Erlangen since 1994. Here, at the Chair of Optics, he established new projects in the field of quantum information. This field includes such topics as quantum computers and quantum cryptography. For the latter, the researchers use the quantum properties of light to make data encryption and transfer wiretap-proof. They are developing, for instance, techniques to imprint the information on light, and suitable methods to receive and read it out.

Among other things, they are working on wiretap-proof data transmission using continuous laser beams. For the recipient to be able to determine what message was sent based on the signal registered, he must also know what changes the signal underwent along the way. That is because quantum information is very sensitive to environmental influences. The physicists built a 100-meter-long outdoor testing range on the roof of the institute to analyze the impact of atmospheric interference. "The key is to construct the apparatuses in such a way that they can handle such interference," says Leuchs.

In addition, Leuchs continued the well-established traditional applied optics program in Erlangen. For this, he was able to rely on the outstanding staff from his predecessor's tenure, including Gerd Häusler and Johannes Schwider. He was particularly moved by Johannes Schwider's background – he had fled the GDR three years before the Berlin Wall fell. "Much of what he told me, I recognized in the film *The Lives of Others*," says Leuchs, and he is certain that "Under normal circumstances, someone with his scientific profile would have his own chair in a faculty."







1 Focusing a laser wheel: Gerd Leuchs and his colleagues polarize laser light radially. This means that it oscillates, figuratively speaking, only along the spokes of a wheel. This light permits a particularly sharp focus.

2 What comes out of an atom must fit back into one. The researchers in Erlangen want to use a parabolic mirror to focus the radially polarized light on an atom.

3 Gerd Leuchs sends a laser beam on a journey through a setup of mirrors, lenses and other instruments to prepare the light for the particularly sharp focusing or for other optical feats.

At some point, he realized that a lot of know-how would be lost when Schwider and Häusler retired: "The way it was structured before, I would never again be able to get people of that caliber." And thus was born the idea of something greater that would offer more than just a single chair for the outstanding optical research in Erlangen, and that would also offer an ideal long-term outlook. At the recommendation of his former boss Herbert Walther, Leuchs initially established a center for modern optics, and then turned to the Max Planck Society. In the first ten years after the fall of the Berlin Wall, the Society had focused on new projects exclusively in the former East, and was now open to such ideas again.

Then came December 5, 2000, which Gerd Leuchs remembers very clearly. The then-Vice President of the Max Planck Society, Gerhard Wegner, came for an appraisal. "Thanks to Schwider and Häusler, and of course all the other staff, we were able to present a broad scientific spectrum that apparently impressed the visitor," relates Leuchs. At first he wanted to authorize "only" a junior research group – which he could have signed immediately himself. But Leuchs made it clear to him that that was too little for his plan for the future of optics in Erlangen. Even if it meant that he was setting himself up for a tedious process with an uncertain outcome. As the Vice President was leaving, he turned around once more at the door and said: "Mr. Leuchs, if I were you, I would reach for the stars, too."

MAJOR SUPPORT FROM THE UNIVERSITY

What came next was a great deal of persuasive effort: using a lot of paper and enthusiastic lectures to present his ideas and impress various commissions. "I don't know whether I would have done it if I had realized how much and what kind of work it would entail," says the researcher, who now had even more administrative and organizational tasks to manage. The family often had to make do without him: "Sometimes I would call my wife, and then something else would come up, and in the end, I'd completely forget that she was still on the line," he guiltily admits.

But everyone's efforts, as well as the great support from the faculty and the administration of the University of Erlangen, paid off: first came the Max Planck Research Group for Optics, Information and Photonics in 2004, followed by the Max Planck Institute for the Science of Light on January 1, 2009, which will soon comprise four departments and some 300 staff.

Science of Light – that sounds very basic. And indeed, light still presents many mysteries. Even things that were considered to be understood and that have long since been incorporated in textbooks sometimes still harbor surprises. Like focusing a laser beam. How well light can be bundled – that is, concentrated to a focus – impacts the precision of measurements and lithography methods, as well as the data density on optical storage media. Actually, it has been clear since the statements of physicist Ernst Abbe more than 100 years ago that the size of the focus is limited by the wavelength of the light.

Photos: Peter Banzer (top + bottom left), Axel Griesch (right)


LASER
DANGER
DANGER
DANGER
DANGER
DANGER
DANGER

1

2


MELLES GRIOT

3

1 Warning, light: Caution is advised when the Erlangen-based researchers step into the laser lab. The intense light beam can cause injuries.

2 Decorative optics: Glass spheres act like lenses and produce an inverted image of Leuchs on his desk.

3 Lasers on the roof: The physicists use a laser system on top of the institute building to analyze how a light signal is interfered with on its path through the atmosphere.

"But when we approach something as if we were complete novices, we sometimes come up with ideas that one who is already very familiar with that thing would never think of," says Leuchs. His group simply considered the question of what it is that limits the focus. "A lot more often than you'd think, it is probably just such an open-minded approach that drives progress," says Leuchs. "That's also why my colleagues and I enjoy working with students so much, because their view is frequently still less influenced by traditional knowledge."

WHY NOT FOCUS LIGHT ON AN ATOM?

In this case, a closer look at nature showed that light is actually emitted by atoms, so at least at one time, it must have been concentrated in the space that an atom takes up. And the diameter of an atom is about 10,000 times smaller than the wavelength of light. Why shouldn't it be possible, then, to focus it on such a small space?

And that's when things suddenly got interesting. The researchers analyzed precisely which properties the light emitted by an atom has in space, time and polarization. And they found that a short light beam that has a profile like a fat bicycle tire and that is polarized in the direction of the spokes, as it were, and focused back on the atom had to be fully absorbed by that atom, and thus would also be bundled to match its size.

The situation is slightly different, however, when the same light packet is focused but the atom is left out of the picture. Then it is no longer quite so easy to argue with the reversibility of the process. But the calculations showed that, here, too, the spot is three times smaller than had previously been achieved using a simple polarized light beam. And then, in an experiment two years later, the researchers in Erlangen set a new world record for focus. "This also marks significant progress for applications in, for instance, data storage," says Leuchs, not without a hint of pride.

With all this focus on light, does he even have any time left over for private interests? Gerd Leuchs already gave up gliding twenty years ago. He sometimes still rides along with friends, but his real hobby is very down-to-earth: an old house in need of repairs, on the Mosel river, where his wife is from. The unsettled years of his childhood and the frequent business trips have apparently left their mark. "We've been working on it for twenty years," he says. On weekends, during holidays, whenever there is time. Luckily, houses like that are patient.

And it isn't yet needed as a residence. After all, Gerd Leuchs still has a lot of plans for Erlangen. "With the funding now available to us, we have actually begun the experiment in which we hope to have an atom capture a single photon," says Leuchs. The idea is this: The single atom sits at the focus of a very deep, perfect parabolic mirror. Onto that atom, the mirror focuses a wave packet that is rigged to act like a light particle that is spontaneously emitted by an atom.

It sounds easier than it is. Among other things, this experiment requires a perfect parabolic mirror that should also be useful in applications beyond this specific project. And one student spent a year studying in the US just to learn the technology to rig up a single atom and hold it in such a way that a light particle can access it freely from all sides.

Gerd Leuchs himself has also just returned from abroad. He spent a research semester in Paris that had been postponed many times. At the invitation of the *Centre National de Recherche Scientifique* (CNRS), he spent three months as research director at Pierre and Marie Curie University in the heart of the city. He has planned new experiments with his colleagues there on two very different topics: quantum correlations in special light fields, and optical characterization of individual nanocrystals. Leuchs finds that "the atmosphere was very stimulating." And it also brought some new ideas and collaboration projects for the perfect parabolic mirror.

In the meantime, the activities above the rooftops at the Siemens factory site also continue. The researchers hope to soon extend the data transmission route to two kilometers. Incidentally, the location of the institute on the factory premises is just a coincidence: the required space was up for rent when the Max Planck research group was established. However, a new building closer to the University is set to house the Max Planck Institute in the future. So an additional house project is on the agenda – but Gerd Leuchs is now familiar with that topic, too. ◀

GLOSSARY

Polarization
Oscillation direction of light waves.

Photonic crystal
Material that exhibits ordered structures with periods of the magnitude of the light wavelength; this makes it possible to control the propagation of light almost arbitrarily.

Quantum information
Is concerned with quantum properties of, for instance, light. Applications include particularly efficient processing and encryption of information.

Photos: Axel Griesch