A rock that fell from the sky: In April 2002, this meteorite fell to Earth close to the famous castle built by the Bavarian King Ludwig II – hence its name, "Neuschwanstein". The photograph shows a 360° view composed of 20 images.

Photos: Tost/DLR

The Secrets of **Cosmic Grains**

The end of a meteorite's journey is abrupt by definition, as the chunk of cosmic material slams into Earth. A celestial rock like this conceals a great many secrets. **Ulrich Ott** from the **Max Planck Institute for Chemistry** in Mainz is a scientific detective. He deciphers, for instance, how long the meteorite traveled through space.

TEXT **THORSTEN DAMBECK**

On the evening of January 17, 2009, a brilliant light show caused a great deal of excitement. At the same time as the main evening news was being broadcast, a meteor lit up the sky over northern Germany for a few seconds. Coming from the direction of Poland, the ball of fire moved across the Baltic Sea toward Denmark on a westerly trajectory. Close to 600 eye witnesses reported the sight, some even reporting noises like gun shots and rolling thunder. In Sweden, a surveillance camera documented the spectacle, and people in the Netherlands also photographed the fireball. Although the images turned out to be unsuitable for pinpointing a potential impact site with any degree of precision, fragments of the meteorite were already being discovered in early March.

The spectacular find was the result of a systematic search undertaken by the meteorite hunter Thomas Grau from Brandenburg, who was also the first to find a piece of the "Neuschwanstein" meteorite in the Alps back in 2002 (MaxPlanckResearch 1/2003, page 16 ff.). This time, Grau found his treasure on the Danish island of Lolland, where he netted a small piece of rock about the size of a ping-pong ball; it had broken up and was wedged a few centimeters deep in a hole in the ground close to the town of Maribo.

Scientists such as Ulrich Ott from the Max Planck Institute for Chemistry benefit from the instinct of the celestial rock hunter. "This is not the first time we have obtained our samples in this way," he says. The grain of material the postman delivered this time came from the Museum of Geology in Copenha-

> The Max Planck scientists in Mainz have been working with meteorites for decades. The work at the institute is interdisciplinary. The scientific home of the experts is at the interface between astrophysics, chemistry and the geosciences.

gen, where Grau had handed in his find. The laboratory scales recorded a mere 115 milligrams – but still more than enough for the analysis to be performed. Prior to this, colleagues in Denmark and Münster had already carried out a classification: Maribo – the official name of the Baltic meteorite – is a carbonaceous chondrite, a specimen rich in carbon. Less than five percent of meteorite falls belong to this rare class.

NOBLE GASES HOLD THE KEY TO THE JOURNEY TIME

The Max Planck scientists in Mainz have been researching meteorites for decades. Since 1969, they have also been analyzing samples brought back by lunar travelers – no scientific institution outside the USA received as many moon rocks back then as the Cosmochemistry Department in Mainz. Ott's cosmic research objects have always been meteorites, however: "Our work has an interdisciplinary approach," explains the researcher, whose scientific home is at the interface between astrophysics, chemistry and the geosciences.

"Here we are running a temperature series," explains Ulrich Ott on the way to the laboratory where the Maribo sample is already being strongly heated. Temperatures of between 400 and 1,800 degrees Celsius are applied over a period of several days to gradually drive the gaseous components out of the celestial rock. Ott and his fellow scientists are particularly interested in the noble gases, or to be more precise, in the ratios of the noble gas isotopes, because they can be used to calculate the time taken to travel from the realm of the planetoids to the point of impact in the Danish countryside.

And this is how it is done: After the rock was knocked out of its parent body, it became exposed to the omnipresent cosmic radiation. Nuclear reactions began to take place in its interior and the isotope ratios started to change. As Ott explains, "The interesting effects can best be seen for the rare isotopes, such as neon-21." The nuclei of this special form of the noble gas contain a total of 21 protons and neutrons. Neon normally contains only 0.3 percent of this isotope. "We can use the Ne-21 content of a meteorite to accurately determine its irradiation age," says Ott. Cosmic ray exposure age is the technical term for the duration of the cosmic journey.

The laboratory is filled with the whirring of pumps – the measurements require an ultrahigh vacuum. Atop the pipes of the apparatus, which are heat-insulated with aluminum foil, sits a glass vessel from which a dozen finger-like protuberances point downward. These contain the samples wrapped up in silvery nickel foil. The samples come from a wide variety of different meteorites. In addition to the sample from Maribo and a number of others, there is also a very special sample: "A colleague from Vienna sent us this one," says Ott. "The mineralogists were not sure whether it was a meteorite at all. They suspected that if it really was from space, it was possibly from Mars."

The noble gas analysis of the mysterious object is already complete, and Ott is certain that it is not from Earth. On the contrary, it has completed a long cosmic odyssey. "The high concentrations of Ne-21 are evidence of a

A GOOD NOSE FOR NOBLE GASES

It is difficult to investigate the noble gases in meteorites because the concentrations involved are often very low. The noble gas mass spectrometer in Mainz operates essentially like this: The gaseous components of the sample are first heated gradually to vaporize them. Chemical methods remove the gases that are not noble gases from the gas mixture, as they are not important in the extended analysis. Helium and neon enter the measuring apparatus first, while the other noble gases are trapped on the surface of liquid-nitrogen-cooled (minus 196 degrees Celsius) activated carbon. They are released from this "interim storage" by heating, each atomic species at a specific temperature. Argon is freed first, at minus 123 degrees Celsius, followed by krypton. An even higher temperature (about plus 150 degrees Celsius) is applied to release xenon.

The analysis operates on the following principle: A heating filament emits electrons, which collide with the noble gas atoms, causing them to ionize. The high voltage that is then applied ensures that the ions of the individual noble gas isotopes are deflected according to their mass. In contrast to conventional mass spectroscopy, the pumps are closed off during the measurement. These sensitive measurements depend on not a single gas atom being lost.

1 | Ulrich Ott examines the printout of a mass spectrum. This is how the spectra were recorded 20 years ago; now it is done electronically. But the conventional technology is always used in parallel just to be on the safe side.

2 | Weighed – and found to be a lightweight. If you expect to find a large piece of rock in the laboratory, you will be disappointed. A tiny amount of material is sufficient for the analysis. The tiny grain of material from the Maribo meteorite weighed just 115 milligrams.

3 | The samples from the meteorites are stored in Plexiglas bottles like these until they are analyzed in Ott's laboratory.


1

1 The meteorites carefully wrapped in nickel foil in the glass sample vessel, where they are freed from adsorbed gases by moderate heating.

2 It looks a little like modern art but is really a cryogenic separation trap. This is a kind of interim storage for the noble gases driven out of the meteorite samples by heating.


2

high irradiation age, around 20 million years." But that would indicate that it is not from Mars, because meteorites from Mars manage the space transfer more rapidly, typically within a few million years.

NANODIAMONDS MADE OF A MERE 1,000 CARBON ATOMS

The gas mass spectrometer that helps Ulrich Ott and his fellow scientists decipher the celestial rock is a very sensitive piece of equipment. It has to be, because noble gases are often present in meteorites in low concentrations (see box on page 46). These measurements have nevertheless been routine at the Max Planck Institute for Chemistry for some time, sort of a service that forms part of a standard series of analyses in meteorite research. As the numbers for the noble gases from helium to xenon appear on the screen, Ott talks about his real research field: presolar grains. These phases are embedded in some meteorites and can be investigated separately.

"We are mainly concerned with tiny diamonds that contain a mere 1,000 carbon atoms," explains the Max Planck scientist. These nanodiamonds are older than the solar system. It was noble gas analyses that identified them as relics from interstellar space, and that first showed that meteorites contain such ancient components.

In addition to the miniature diamonds, the scientists also analyze larger grains, although even these are still on the micrometer scale. They use complex methods to extract the grains from the matrix of the meteoritic rock. Some of the isotopes in these grains exhibit dramatic, distinctive features. Investigations by Peter Hoppe, also from the Max Planck Institute for Chemistry in Mainz, show that, while the isotope ratio of carbon with atomic weights 12 and 13 is around 90 almost everywhere in the solar system, these grains are completely out of the ordinary: some have values two orders of magnitude lower, while others exhibit an isotope ratio almost 100 times higher.

Why is this? It is assumed that stars eject dust at the end of their life. Ancient stellar matter from red giants or exploding supernovae thus reached the primeval solar cloud from which the Sun, the meteorites and the planets formed. The isotope anomalies thus provide insight into the interior of these stars and the synthesis of the chemical elements that occur there – a sort of genetic fingerprint of our stellar ancestors.

NEW MEASURING EQUIPMENT FOR INTERSTELLAR DUST

The Maribo meteorite may also contain the primeval grains; Ott's measurements indicate a nanodiamond content in the parts per thousand range. An important condition for this is that Maribo was subjected to only relatively mild heating, no more than 200 degrees Celsius, in the four and a half billion years of its existence. There will probably be no detailed search for presolar material, however, because only a small amount – just 30 grams – of Maribo material has been found in Denmark so far.

The institute in Mainz will see a leap in the sensitivity of its noble gas analyses this year, as a new piece of measuring equipment for the analysis of micrometeorites, interstellar dust and individual presolar grains goes into operation. In the meantime, all noble gases from the Maribo sample have been determined in the laboratory and the measurement data evaluated. Ott is not surprised by the result: "Maribo's radiation age is around one million years," he explains. This is a very short journey time compared to the ordinary stony meteorites, but not unusual for this class of meteorite. The crumbly material could probably not resist the harsh conditions in space for much longer. And in the end, the heating process in Mainz also proved too much for the grain of cosmic dust: "It vaporized," says Ott unmoved. "After all, our measurements aren't a non-destructive technique." ◂

GLOSSARY

Isotope
Term for various types of atoms of a given chemical element whose nuclei have the same atomic number (number of protons) but different numbers of neutrons and thus also different mass numbers.

Cosmic radiation
High-energy particle radiation from space that consists mainly of protons, electrons and completely ionized atoms. The radiation originates from the Sun, but also from supernovae and neutron stars, as well as extragalactic sources such as active galaxies and quasars.

Meteoroid, meteor, meteorite
These terms are often confused. A meteoroid is a small or large chunk of material that orbits in space. If such a meteoroid enters Earth's atmosphere, it produces a bright phenomenon called a meteor. A particularly bright meteor is also called a fireball or bolide. Most of the grains are only the size of a speck of dust and burn up, but the larger chunks fall to Earth as meteorites.

Supernova
The sudden bright flare-up of a star, increasing its brightness several million to several billion times. There are several types of supernovae, and two basic mechanisms: the explosion of an individual massive star that has used up all of its nuclear fuel at the end of its life; and the detonation of one of the stars of a binary star system, caused by the transfer of material between two stars (white dwarves).