As the central star of our solar system the sun plays a special role in astronomy. No other star is as close to the planet Earth as the sun. No other celestial body appears to us so bright and so hot. Special solar telescopes have to be constructed to observe the sun, and they are fundamentally different from other telescopes. At present, the most powerful is the Swedish 1-m Solar Telescope (SST) located on La Palma, one of the Canary Islands. The Institute for Solar Physics of the Royal Swedish Academy of Sciences has been operating it since 2002. With this telescope it was possible for the first time ever to detect structures of just 75 kilometers in size on the sun’s surface.

**Sunspots with fascinating details**

Sunspots represent darker, cooler areas on the sun’s surface. They occur primarily in times of increased solar activity and can grow to diameters as large as planets. The center of a sunspot, the umbra, is surrounded by a brighter outer part called the penumbra. This penumbra consists of long filaments that are wrapped around the center like hair. With the help of the Swedish Solar Telescope, astronomers discovered for the first time that many of these filaments have a dark inner core. According to Professor Göran Scharmer, Director of the Swedish Institute for Solar Physics, these cores are between 150 and 180 kilometers wide and possibly originate from magnetic flux tubes that transport hot plasma. However, scientists are still unclear about their exact explanation.

**Mountains several hundred kilometers high**

Using an oblique angle, spectacular images have also been obtained of the areas at the solar limb. Due to the large observation angle to the sun’s surface, objects can be viewed there from a different perspective. The images show for the first time ever three-dimensional structures of the sun’s surface: for example, mountains and valleys of hot plasma with differences in height of up to 450 kilometers. The sunspots appear as dark cavities surrounded by mountains. Scientists used to see them only as darker areas that could not be differentiated as flat, deep or high. Furthermore, many bright spots called faculae, which extend above the sun’s surface, can also be observed. These faculae are hotter than their surroundings and release an especially large amount of energy.

**Special features of solar telescope constructions**

The many new discoveries are even more surprising considering that the Swedish Solar Telescope is not even the largest. However, it has a highly advanced design with adaptive optics and thus produces sharper and more detailed images than all other solar telescopes. With adaptive optics the flickering of the image caused by differences in density of the Earth’s atmosphere is corrected by a selective deformation of a mirror. This principle is widely established in large modern night-time telescopes, but not in solar telescopes. The reason for this is that no other stars can be used as reference points with a solar telescope. Instead one has to make use of fine structures on the sun’s surface, and this requires far more computation capacity. The Swedish Solar Telescope is the first one to be designed from the beginning with adaptive optics. Its adaptive mirror corrects the image 1,000 times per second.

Another fundamental difference between night-time telescopes and solar telescopes is the fact that the latter suffer not only under the influence of the Earth’s atmosphere, but also under the sun’s extreme heat. Both the optical system and the air inside the tele-
The source of all life

The sun is our nearest star. Its distance to Earth is some 150 million kilometers. Although it is considered the source of all terrestrial life, our sun is just average in size compared with the billions of other stars in the universe.

Stars like the sun are giant balls of gas in a hydrostatic equilibrium, which means that their inward-directed gravitational forces are balanced by the outward-directed gas and radiation pressure. The temperature and pressure are so high at the center that nuclear fusion occurs, in which hydrogen atoms are fused to helium. The energy released in the process is transported to the sun’s surface and radiated into space.

Sunspots can hinder this energy transmission because of their strong magnetic fields. This is why they are cooler and darker than their surroundings. The frequency of sunspots and thus also the sun’s activity fluctuate over about an 11-year cycle.

Facts about the sun

| Age: | 4.6 billion years |
| Diameter: | 1,392,000 km |
| Mass: | 2 x 10³⁰ kg |
| Temperature: | |
| at the surface: | 5,750 K |
| in sunspots: | 4,000 K |
| at the center: | 15 million K |
| Chemical composition: | |
| of the surface: 73% hydrogen, 25% helium, 2% other elements |
| at the center: 35% hydrogen, 63% helium, 2% other elements |
scope heat up. For the optical element it is possible to solve this problem by choosing materials that have a very low thermal expansion, for example the lenses are made from fused silica and the mirrors from “Zerodur” glass ceramic. The heated up air that causes the image to become blurred – a phenomenon that can be seen above hot asphalt – can be avoided by evacuating the telescope, thus the name vacuum telescope.

In the case of the Swedish Solar Telescope, this problem is solved in a particularly ingenious way. Instead of the usual flat vacuum window, a 1-meter lens made from fused silica takes care of this function as well, thus eliminating an optical component. Together with two 1.4-meter flat deflecting mirrors made from “Zerodur” glass ceramic, the 1-meter lens forms the main optical system. It is movable as a whole in order to track the...
The Royal Swedish Academy of Sciences is probably best known throughout the world for the Nobel Prize, but it also operates seven scientific institutes, including one for solar physics. The Director of the Institute, Professor Göran Scharmer, created the optical and mechanical design of the Swedish Solar Telescope and played a major role in the development of the adaptive optics of the telescope.

**Interview**

Professor Scharmer, why is Sweden operating a solar telescope on La Palma?

**Prof. Scharmer:** It is a long story. Sweden already had a solar telescope on Capri, Italy, in the 1950s. Around 1970 Swedish scientists together with British and Spanish astronomers began to look for a location with better conditions. They decided on La Palma, which is clearly one of the best sites for solar telescopes in the world. The Swedish Observatory thus moved from Capri to La Palma. A 50-centimeter telescope, the predecessor of the 1-meter telescope, was built there in the 1980s. Plans for the new 1-meter telescope began in 1995, as it became clear that adaptive optics for a solar telescope could be realized.

The Swedish 1-meter telescope currently supplies the best images in the world. Who is allowed to use it for research purposes?

**Prof. Scharmer:** Since it is a Swedish telescope, it is obviously mainly used by astronomers of the Swedish Institute for Solar Physics. However, we have two partners: the Institute for Astrophysics in Oslo, Norway and the U.S. company Lockheed Martin. Each shared 10 percent of the costs and is therefore allowed 10 percent of the observation time. There was also a grant from the European Union so that a small part of the observation time has been dedicated to other European astronomers.

What investigations are you planning next?

**Prof. Scharmer:** We plan to further investigate the magnetic field of the sun, and particularly the sunspots. There are still many unanswered questions here. For example, what exactly is the explanation for the dark cores in the filaments of sunspots?

Can you make conclusions about the effects on the Earth’s climate from your results?

**Prof. Scharmer:** No, not really up to now. But this may be possible in 10 to 20 years.