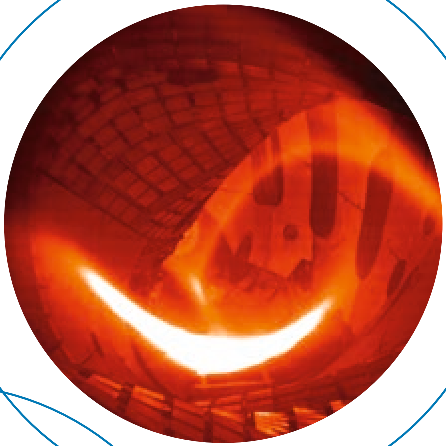
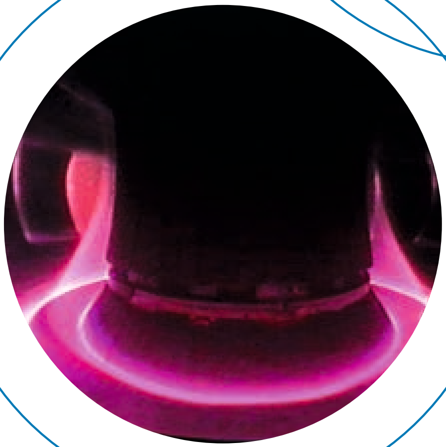
Max-Planck-Institut
für Plasmaphysik





Research for the energy of the future

The sun – a huge plasma ball. For millions of years it has been emitting light and heat.

Fusion – a new energy source

Nuclear fusion is an important natural process: many chemical elements originate from hydrogen through fusion. Fusion is the energy source of the stars. There is also a fusion fire continually burning in the sun, which is a huge plasma ball. In its hot core, light hydrogen atomic nuclei fuse to form helium.

Despite the high temperature and extreme pressure in the sun – 15 million degrees Celsius and 200 billion atmospheres – fusion takes place just slowly. Another fuel is therefore to be used for a terrestrial power plant: the two heavy hydrogen isotopes, deuterium and tritium. At a temperature of 100 million degrees and a pressure similar to that in a car tyre, they fuse to form helium. Furthermore, neutrons and large quantities of energy are released: one gramme of fuel could generate as much energy as eleven tons of coal.

The raw materials needed are available in virtually unlimited quantities and are distributed throughout the world: deuterium is contained in seawater and tritium can be derived from lithium. Moreover, as a fusion power plant has the potential to afford favourable safety and environmental properties, nuclear fusion could make a sustainable contribution to energy supplies in the future.

What is plasma?

With increasing temperature, materials are successively transformed from the solid to the liquid and then to the gaseous state. If the temperature is further increased, the electrons separate from the nuclei of the gas atoms, creating plasma – a gas consisting of charged particles.

It can therefore be influenced by electric and magnetic fields. This property is used in fusion devices to confine and thermally insulate the hot plasma in a “magnetic field cage” and largely isolate it from material walls. The hot low-density plasma would otherwise immediately cool down.

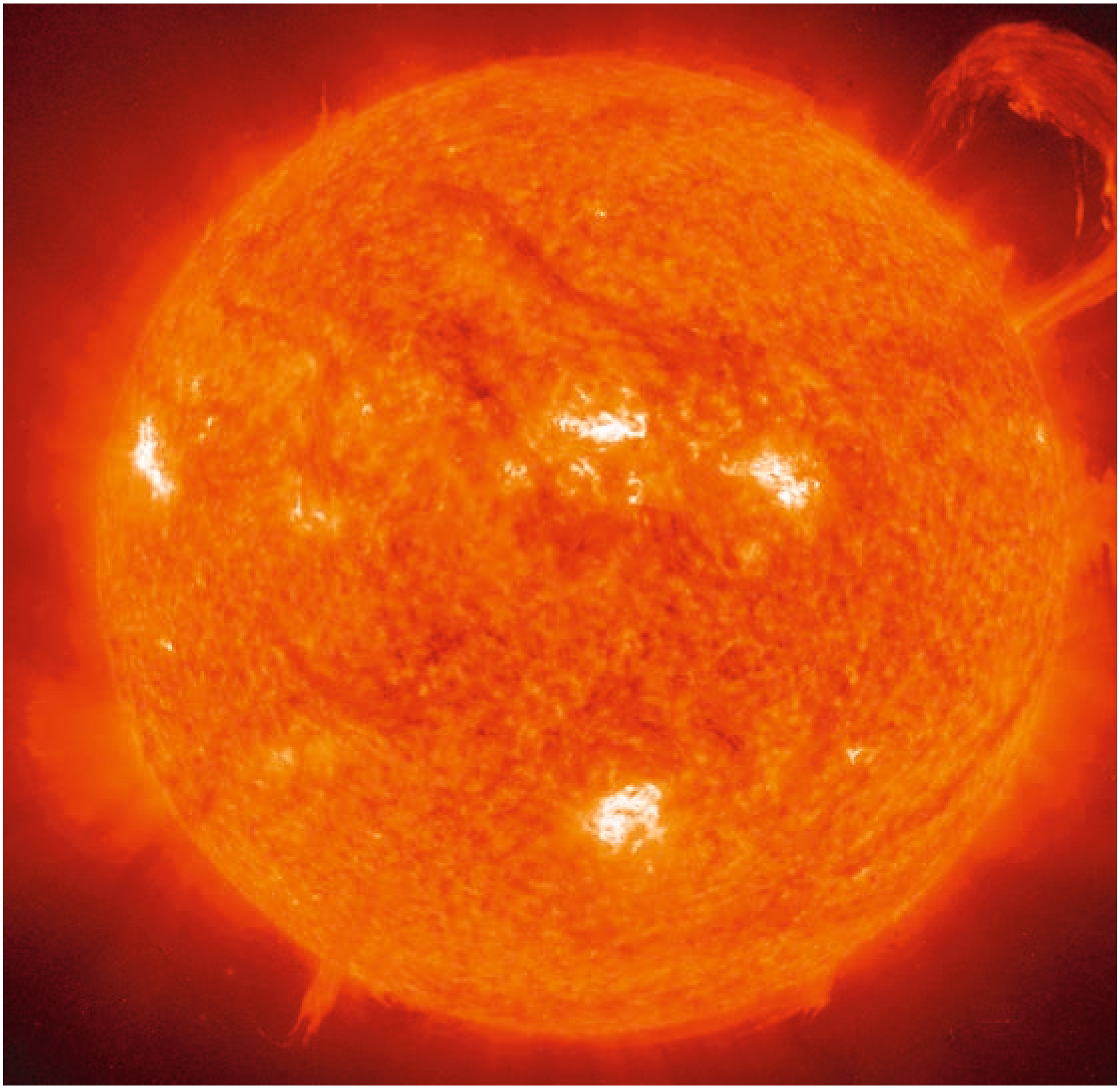


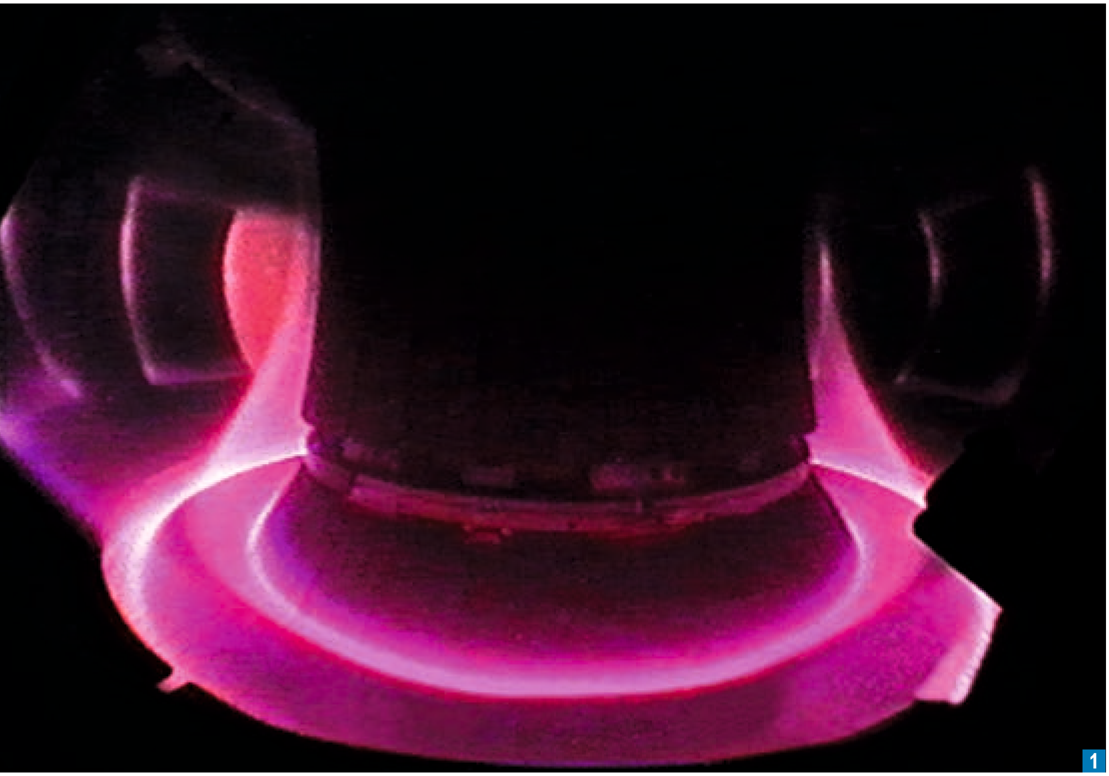
Photo: SOHO, ESA&NASA

Tokamaks and stellarators

The types of devices used today, the tokamak and the stellarator, are the result of a long selection process.
Both confine the plasma in a ring-shaped magnetic field.
In tokamaks, the field is partly generated by external magnetic coils and partly by an electric current flowing in the plasma. It is induced pulsewise by a transformer.
In contrast, the magnetic field cage of a stellarator is created without plasma current solely by means of complexly-shaped external coils. This allows stellarators to operate in continuous mode.

ASDEX Upgrade

The ASDEX Upgrade tokamak, which has been in operation at Max Planck Institute for Plasma Physics (IPP) in Garching since 1991, is investigating all key issues relating to tokamaks. ASDEX stands for "Axially-Symmetric Divertor Experiment". It is named after the divertor, a special magnetic field configuration. It allows the interaction between the hot fuel and the surrounding walls to be controlled. Its tungsten wall cladding, which is suitable for use in power plants, and its flexible, powerful plasma heating makes ASDEX Upgrade one of the world's most important tokamaks.



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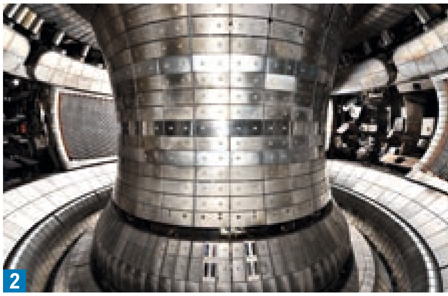
Photos: IPP



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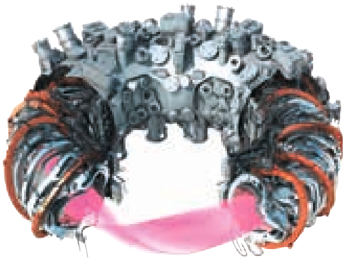

Graphic: IPP

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Wendelstein 7-X

Wendelstein 7-X, the world's largest fusion device of the stellarator type, went into operation at the Greifswald branch of IPP in 2015. Fifty specially-shaped, superconducting magnetic coils produce a magnetic field optimised to meet power plant requirements. This is to put the quality of plasma confinement in a stellarator on a par with that of a tokamak for the first time. The experiments hitherto have already yielded record values for a stellarator plasma. With plasma discharges lasting 30 minutes, Wendelstein 7-X is to demonstrate the fundamental advantage of stellarators – the ability to operate continuously. The objective is to demonstrate that stellarators also have power plant potential.

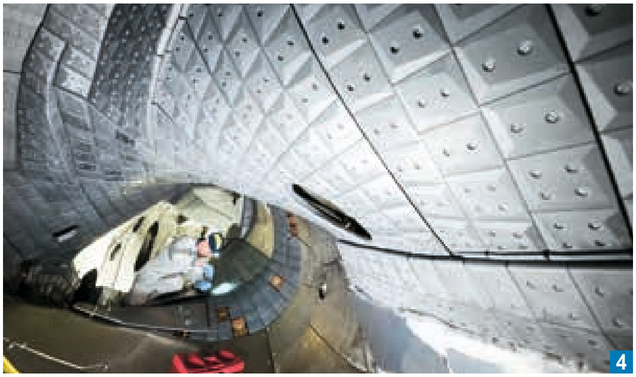

Photo: IPP, Jan Michael Hosan

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1 The ASDEX Upgrade tokamak: view of the plasma at a temperature of 100 million degrees.

2 The ASDEX Upgrade plasma vessel. It is coated with tungsten, the metal with the highest melting point.

3 Design of the Wendelstein 7-X stellarator.

4 The plasma vessel of Wendelstein 7-X. Graphite tiles protect the vessel walls.

5 Wendelstein 7-X: the first hydrogen plasma.

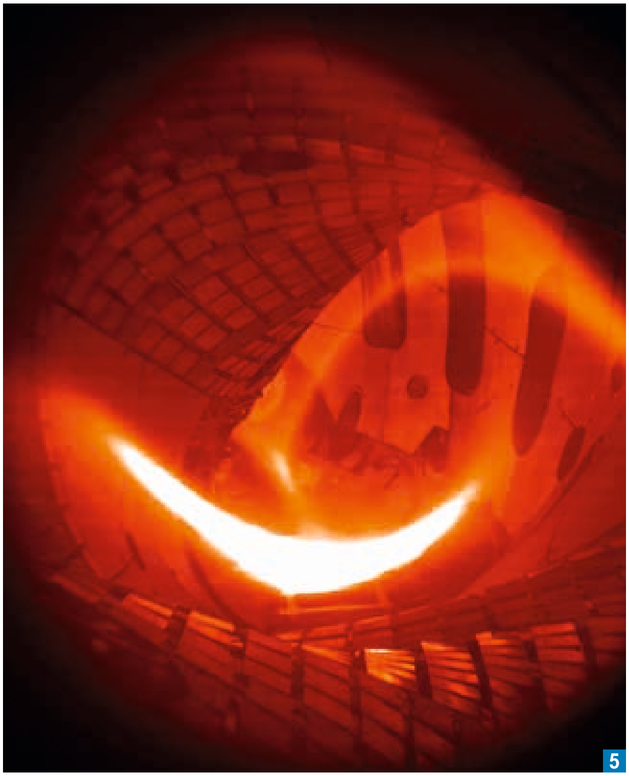

Photo: IPP

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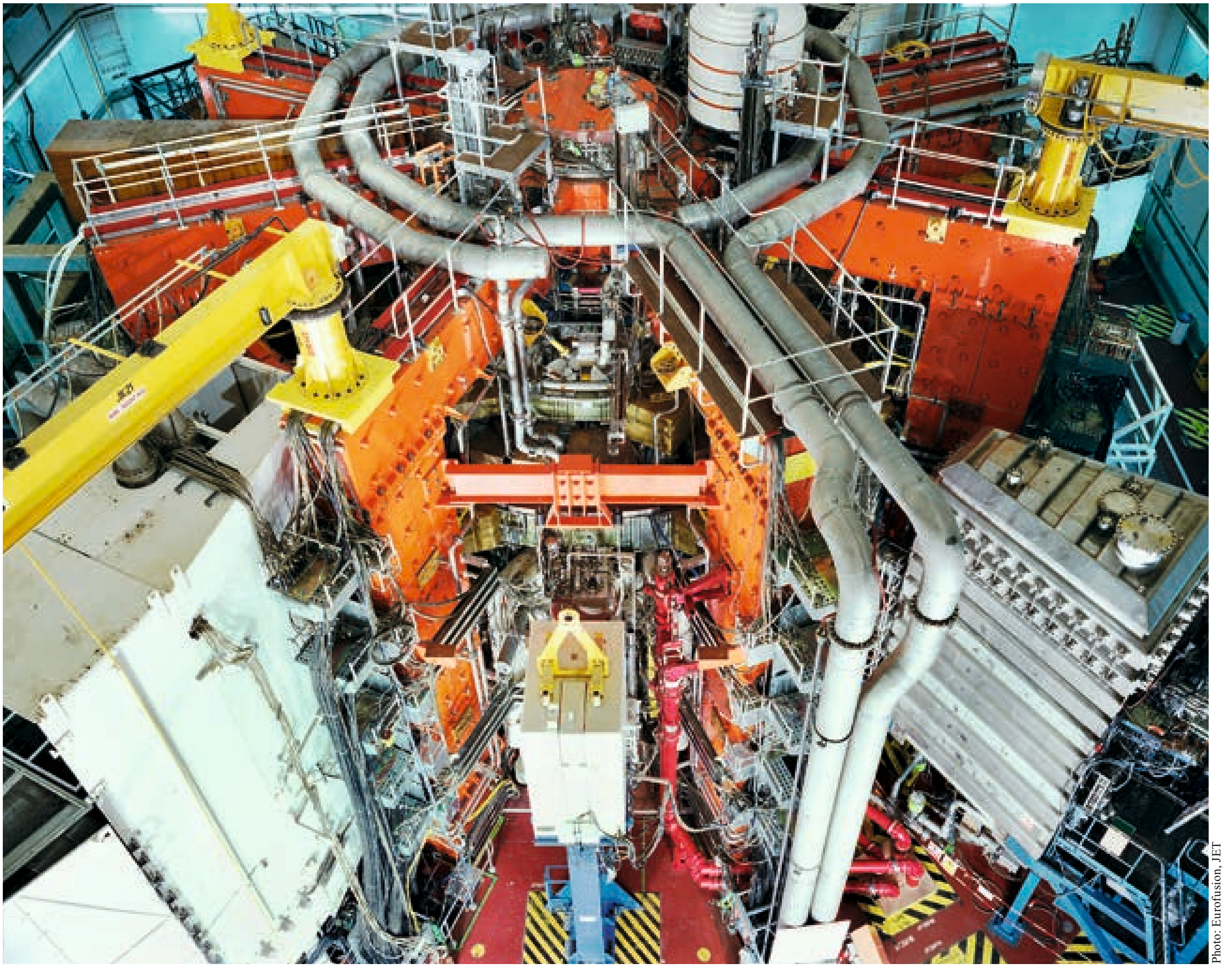


Photo: Eurofusion, JET

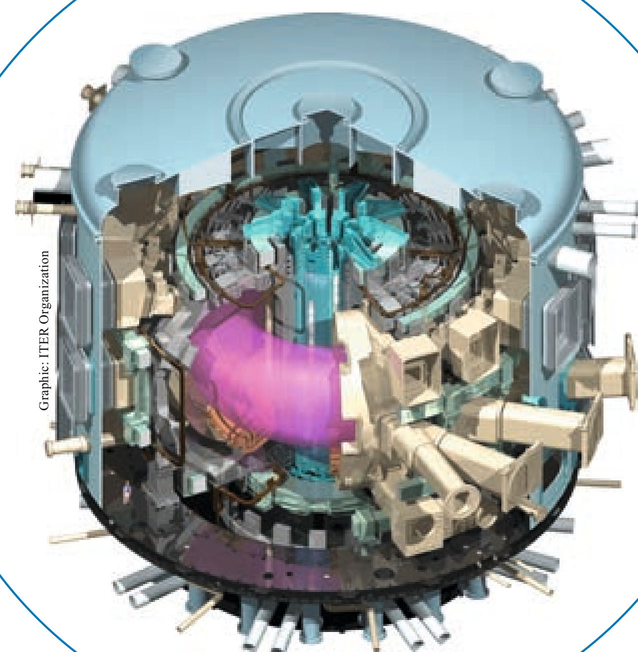
The Joint European Torus (JET) at Culham, England, Europe's joint experiment, is currently the world's largest fusion device.

JET and ITER

Within the framework of the European Fusion Programme, IPP is participating in the world's largest fusion experiment, the Joint European Torus (JET) in England. In 1997, operation with deuterium and tritium produced a short-term fusion power of 16 megawatts – around 65 per cent of the input applied to heat the plasma.

Scientists at IPP are also involved in the next step on the way to a power plant, the ITER (Latin for "the way") experimental reactor. The tokamak is being built at Cadarache, France, as an international collaboration. ITER is designed to produce 500 megawatts of fusion power – ten times as much as needed to heat the plasma.

Design of the ITER international experimental reactor. Its objective: a burning plasma producing long-term energy.



Graphic: ITER Organization

The way to a power plant

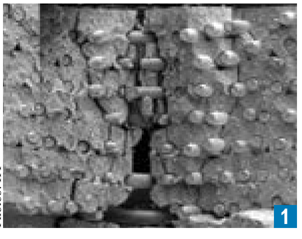
The research done on tokamaks and stellarators is providing the fundamental physical principles for a power plant. IPP is taking part in investigations on the design of a fusion power plant and its function in the energy landscape of the future. DEMO, the successor to ITER, is now being prepared by IPP in collaboration with European partners. This demonstration power plant is to exhibit all the functions of a power plant. This could be followed up with the first commercial fusion power plant.

Wall materials

The loads exerted on the inside surface of the plasma vessel are being investigated in detail at IPP. For example, high-energy plasma particles can dislodge particles from the vessel walls, thereby contaminating the plasma. This can also erode the wall material and change its properties. The envisaged use of tungsten as wall material for a power plant is of particular interest.

For areas subjected to particular stress, IPP is testing new materials and coatings which are thermally conductive and resistant to heat and erosion, such as tungsten composites reinforced with tungsten wire.

Photos: IPP



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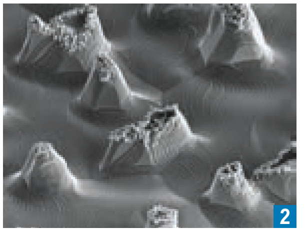

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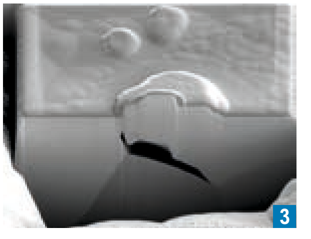

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Photos: IPP

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Plasma heating

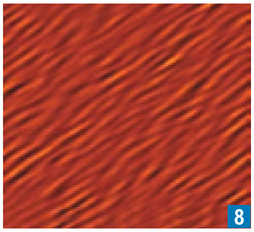
The plasma is heated to a temperature of many million degrees by injection of high-energy, neutral hydrogen atoms. Injectors with powers of a few megawatts fire the particles into the plasma, where they transfer their energy through collisions. High-frequency waves are also being used for heating: waveguides or transmitter antennas at the edge of the plasma emit high-power microwaves or radio waves into the plasma.

Plasma diagnostics

To optimise the properties of the plasma, many plasma parameters, e.g. temperature, particle density and magnetic field strength, have to be measured with high spatial and temporal resolution. For this purpose, IPP is developing innovative measuring methods which do not perturb the plasma and can function under extreme conditions.

Theory

An important tool for evaluating the results of these measurements and achieving a better understanding of the microprocesses in the plasma is computer simulation of plasma physics processes. In the theory divisions of IPP, mathematicians and physicists are developing new computing methods and calculating the motion of plasma particles in the magnetic field, their confinement behaviour, equilibrium states of hot plasma and the origin of instabilities.



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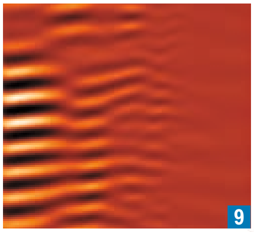

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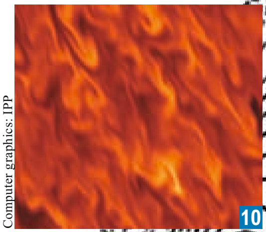

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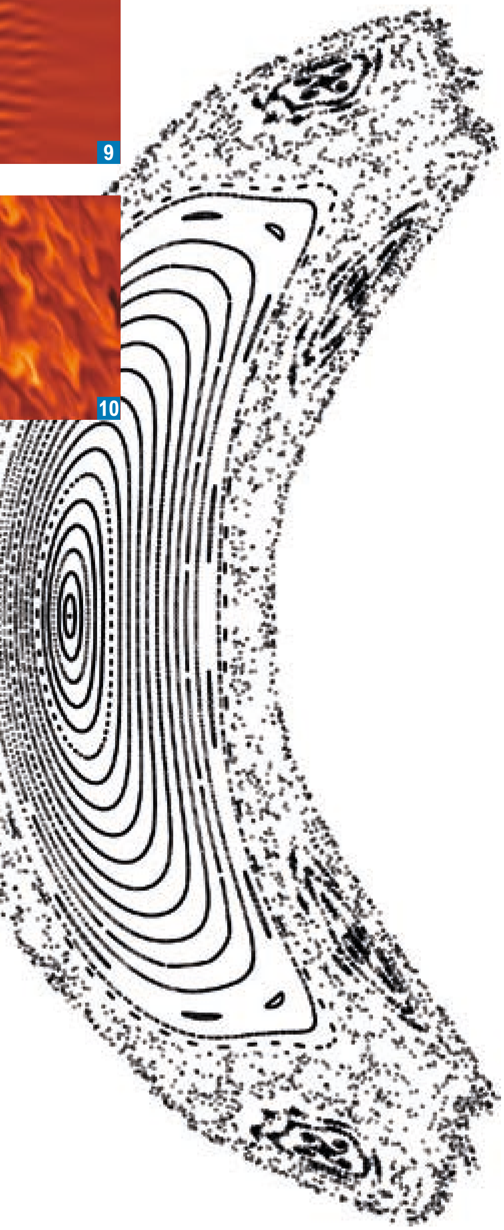
Computer graphics: IPP



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1 Investigation of material for the vessel wall: tungsten-fibre-reinforced tungsten after rupture test.

2 Under the scanning electron microscope: steel sample after plasma erosion.

3 Section of a tungsten sample after exposure to a hydrogen plasma.

4 Tungsten sample after testing (top view).

5 Transmission line for the microwave heating of Wendelstein 7-X. The microwaves are guided into the plasma by metal mirrors.

6 ELISE test rig for developing the neutral beam heating for ITER.

7 Computer calculation of a stellarator plasma equilibrium: Cross section of the magnetic surfaces.

8 to 10
Turbulence in the plasma, modelled with the computer.

Photo: IPP, Mathias Gottschewsky

The Greifswald Branch of IPP, established in 1994.

Cooperation

IPP has contact with German universities through numerous cooperation projects. For example, the transmission lines for the microwave heating of Wendelstein 7-X were developed at the University of Stuttgart. Together with the University of Augsburg, the institute is developing an ion source for heating the ITER plasma. Joint appointments link IPP with the University of Greifswald, as well as the Technical Universities of Berlin and Munich. In addition, IPP scientists are involved as lecturers in training the next generation of scientists at some ten other universities.

The work of the institute is also integrated in the European fusion research programme, the EUROfusion consortium. IPP is coordinating this consortium, whose members can use for their experiments all large fusion devices in Europe, including those of IPP. In addition, IPP is working closely with fusion laboratories throughout the world.

Development and organisation

IPP is one of the largest centres for fusion research in Europe, having a staff of some 1,100, approximately 400 of them at Greifswald. IPP was established in 1960 as "Institute for Plasma Physics GmbH". The shareholders were the Max Planck Society and Professor Werner Heisenberg. In 1971 IPP was reinstated as Max Planck Institute for Plasma Physics. The plasma diagnostics department operated in Berlin from 1992 to 2003. In 1994 the Greifswald Branch Institute was established.

Since 1961 the research work of IPP has been integrated in a joint European fusion programme. The institute receives annual funding of around 130 million euros from the German federal government, the federal states of Bavaria and Mecklenburg-Western Pomerania and the European Union.

Photo: IPP, Peter Bornemann

Visitors centre at Garching.

Visit us!

Visitors by appointment are most welcome to IPP at Garching and Greifswald. Tours are available to both groups and individuals, who are then assigned to a group. Please book your visit in good time:

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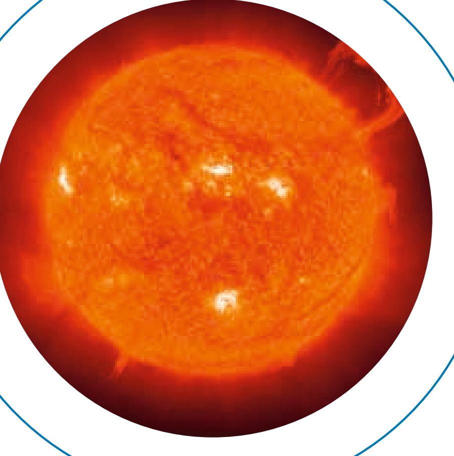

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