DLR magazine

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EYES IN THE SKY SEE THE WORLD CHANGING

FLYING AT THE EDGE – Atmospheric research with HALO

TO SPACE – ROCKETS ALIGHT: future launchers are to be ignited by lasers

OTTO LILIENTHAL – The man who brought order to aerodynamics

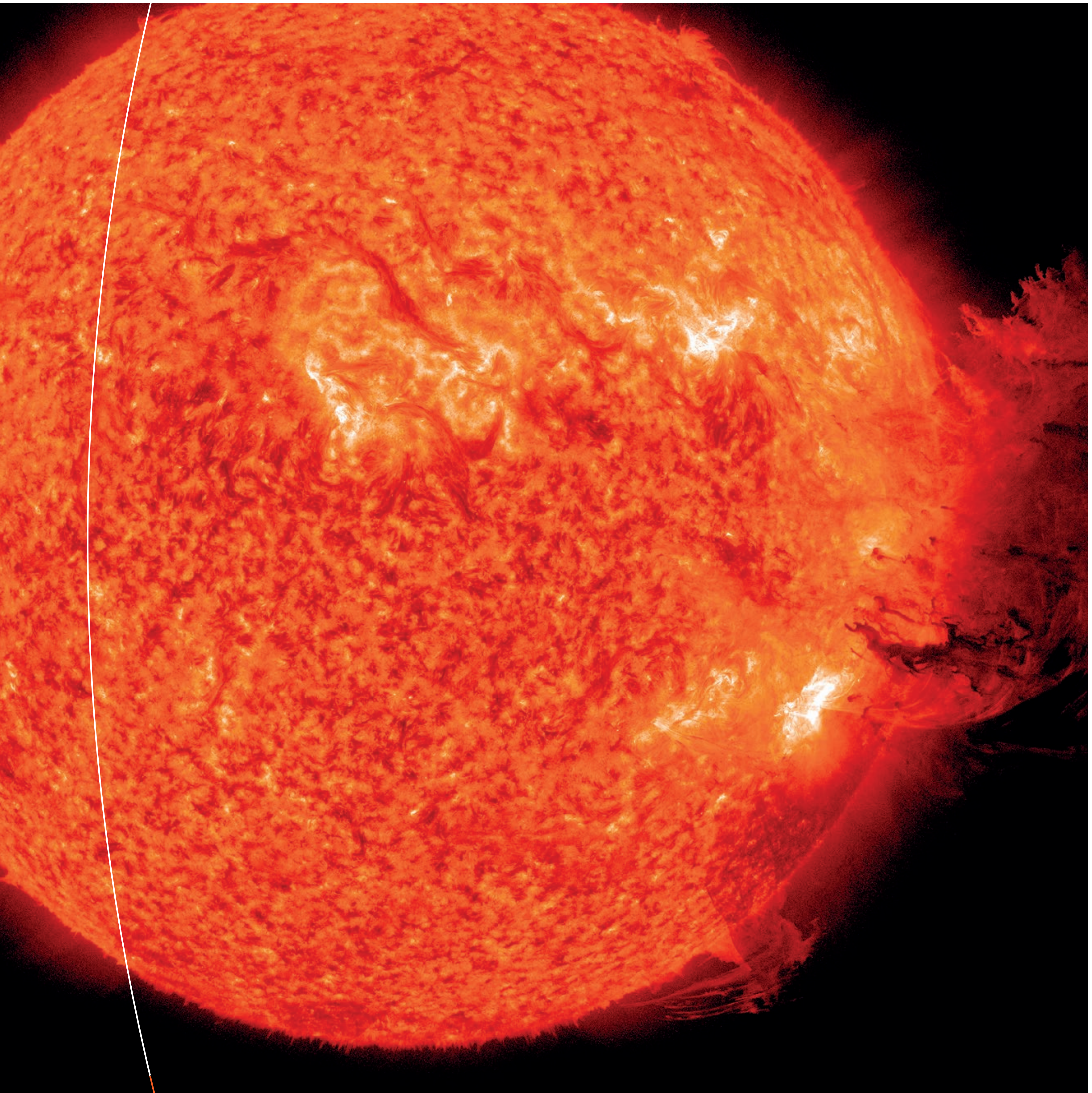
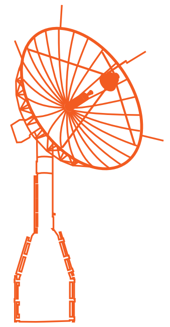


Image: NASA/SDO and the AIA, EVE, and HMI science teams

A medium-sized solar flare. The image shows a spectacular coronal mass ejection that occurred on 7 June 2011 in the extreme ultraviolet.

WEATHERING THE SOLAR STORM



Researchers in Neustrelitz work on predicting space weather

By Fabian Locher

The Universe – endless, silent, peaceful… or is it? Massive solar eruptions can cause extreme solar winds. Energetic particles from the Sun's corona are hurled into space. Solar storms can trigger ionospheric disturbances in the atmosphere, and thus endanger the sensitive infrastructure of our modern, high-tech society. After all, our daily communication and navigation relies on satellites. DLR scientists are studying the causes and effects of space weather. Researchers from the DLR Institute of Communications and Navigation and the German Remote Sensing Data Center are working on establishing the Ionosphere Monitoring and Prediction Center (IMPC) at DLR's Neustrelitz site. The IMPC is a space weather monitoring, prediction and warning centre for industry, government, academia and interested laypersons.

Highly active central star

Over 4.5 billion years ago, the Solar System was formed from a cloud of gas and dust. Even today, the Sun is a very active star. Not only does it emit warming light, but also sends out a stream of electrically charged particles – the solar wind. Without any warning, explosive eruptions can take place on its scorching surface, which has a temperature of 5500 degrees Celsius. At that point, the particle stream that is hurled into space can be much stronger than usual for a short time and in a limited area – researchers refer to this as a solar storm. If these highly charged particles hit the Earth's atmosphere, they can damage the technical systems in our orbit. But an accurate prediction of such eruptions is not yet possible, and the mechanisms underlying the ejection of solar storms are not fully understood.

DLR researchers are using data from solar observatories to determine whether a solar storm will hit the Earth, how strong it will be and how to mitigate this effect. These 'warning sensors' are 1.5 million kilometres away from the Earth. Three satellites – SOHO, ACE and DSCOVER (see glossary, page 37) – keep watch in this hostile environment. Here, the Lagrange point L1 serves as a base. L1 is a stable point in the Earth-Sun system, where the satellites can remain with a low expenditure of energy.

In this way, the satellites fulfil special observation tasks: SOHO, among other things, photographs the Sun in the UV range. ACE has been active since 1997, and was supplemented by DSCOVR in 2015. The latter two satellites measure the interplanetary magnetic field and the velocity of the solar wind, in addition to temperature and proton density.

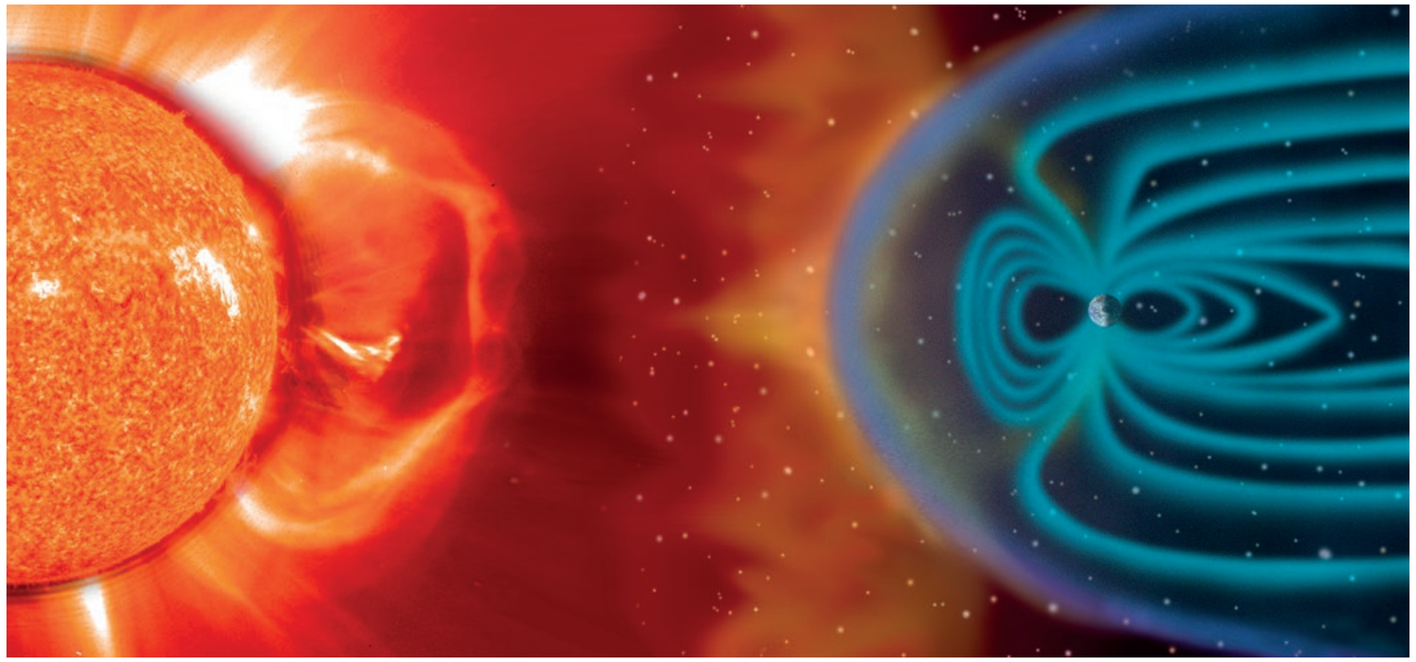


Image: NASA/SDO and the AIA, EVE, and HMI science teams

Illustration of a coronal mass ejection of the Sun and its consequences for the Earth

Clouds of high-energy particles

When a particle storm is forming, charged particles are flung into the expanse of space as a plasma cloud. As soon as the extreme solar wind passes Lagrange point L1, the ACE and DSCOVR satellites measure the changed parameters. The signal is sent to the receiving station at the speed of light. The storm, however, moves appreciably slower. It makes its way as a gigantic plasma cloud at 800 to 2000 kilometres per second through the heliosphere. The signals from the satellites are received by the powerful antennas in Neustrelitz. This DLR site in Mecklenburg-Vorpommern is the only European receiving station in the real-time solar wind observation network. Other stations are located in the United States, South Korea and Japan.

DLR scientists evaluate the data and can quickly react to sudden changes in solar wind parameters. Researchers analyse the interplanetary magnetic field and calculate the dynamic pressure of the solar wind at Lagrange point L1. At this point, there is some certainty: Yes, it is a solar storm; Yes, it is moving towards the Earth; And yes, it will reach our planet. Space weather experts call this 'effective injection of plasma particles into the Earth's atmosphere'.

From this moment, researchers have a lead time of 30 to 60 minutes, depending on how fast the solar wind is moving. And the calculation begins. How strong will the effects of the solar storm be? How efficiently will the penetration in the Earth's atmosphere be? With this information, scientists can make forecasts and predict possible disturbances to communication and navigation technical systems.

Aurora and communication disturbances

Earth is – to a great extent – protected from weak solar storms by the atmosphere and its magnetic field. The incoming charged particles travel at a distance of about 10 earth radii (approximately 70,000 kilometres) along the magnetic field lines around the Earth. At high altitudes and in the polar regions, this protection is weaker. There, the magnetic field lines are more inclined towards the Earth's surface. Due to this, these regions are more vulnerable to the effects of solar storms.

The reflection of shortwaves on the bottom side ionosphere allows global radio communications. The ionosphere consists of free electrons and ions. This makes it a charged layer, thereby susceptible to currents of charged solar wind particles or changes in the magnetic field. Short, yet intense disturbances are caused by so-called flares, or intensive bursts of radiation. It is common for charged particles to be ejected during one of these flares – a phenomenon known as a coronal mass ejection. These particles in the form of a giant plasma cloud travel 150 million kilometres from the Sun to the Earth. The consequences of this are not just wonderful aurorae; the particles also affect spacecraft, technical systems in space and on the Earth, as well as the lives and health of human beings. They change the number of free electrons and thereby the thickness of the ionosphere. The ionospheric plasma causes refraction, diffraction, scattering and absorption of radio signals and is the largest source of errors in the single frequency positioning systems that are integrated into navigation devices and smartphones.

In order to accurately determine the position – even during extreme solar storms – it is very important to correct for the ionospheric propagation error. This error (known as 'range error') occurs in the dispersion of the signal from the satellite to the ground station and is caused by delays in signal travel time in the ionosphere. During strong geomagnetic storms, however, not only navigation, but also high-frequency radio communication is disturbed. This affects civilian air transport. Space Based Augmentation Systems (SBAS) play a decisive role in modern, rapidly scheduled series of take-offs and landings. They complement existing satellite navigation systems, and thus compensate for certain disadvantages of GNSS in terms of accuracy, integrity, continuity and availability. If the precision that is required for safety can no longer be ensured, these support systems can no longer be used. This causes delays in air traffic.

Consequences for agriculture and the power supply

Air traffic is not the only sector affected by space weather. For example, snowploughs in Norway require highly exact positioning data in order to manoeuvre through the dense snow. Farmers involved in 'precision farming' use automated fertilising vehicles, which can significantly reduce the excessive use of fertilisers thanks to GPS data. In maritime transport, precise navigation data are used to achieve exact positioning within harbours or to calculate the best route over the water. If the geomagnetic storms are very strong, operators of electrical networks must also take into account the induced currents, which may lead to technical problems or electrical current outages. In addition, high-energy particle radiation in an extreme solar storm can destroy the electronics of TV or mobile communication satellites, which will result in signal interruptions. For astronauts, the increased quantities of radiation present a life-threatening hazard. Outside of the Earth's protective atmosphere, space travellers are directly exposed to the hazardous high-energy particle radiation.

In general, the atmosphere protects 'normal' air passengers – at typical flight altitudes of 11 kilometres – from heavy doses of radiation. However, since this natural protection is weaker in the polar regions, polar routes are avoided during strong solar storms and aircraft fly at lower altitudes to stay within the protective zone of the atmosphere.

Observe, warn, protect

Even if the strength and course of a solar storm is not exactly predictable, one can prepare for this event (similarly to a predicted hurricane). Space weather experts are able to use the altered numbers of electrons in the ionosphere to estimate which disturbances are to be expected in the information exchange between ground station and satellite and vice versa. "A reliable and accurate prediction of space weather is crucial to be able to take appropriate precautionary measures," says Jens Berdermann of the DLR Institute of Communications and Navigation. The corrections calculated on the basis of ionospheric models can also serve as early warning systems for users. The information from ACE/DSCOVR allows satellite operators to orient the sensitive measurement and communication systems away from the solar wind or to turn it off completely when a severe event is predicted. In this way, the electrical charging of sensitive electronic systems due to the solar wind can be avoided.

Thus, through improved predictions of space weather effects on our highly technical society, DLR scientists are working to build and expand an observation and prediction centre called the Ionosphere Monitoring and Prediction Center (IMPC). With the Space Weather Application Center (SWACI), DLR researchers at Neustrelitz have already demonstrated that it is possible to analyse and evaluate Earth- and space-based ionospheric data in real time. The next step is the construction of the IMPC. "With the IMPC, we want to extend and improve the existing automatic warning system to the needs of various users," explains Berdermann, Team Leader at the DLR site in Neustrelitz. The warning system is interesting to both scientists and systems operators in the area of satellite communication and navigation.

Service adapted to different users

Depending on needs and requirements, users will be able to register for one or more services ('stages').

Stage one – early recognition, using real-time observation data from the Royal Observatory of Belgium (ROB) and data from the recently developed Global Flare Detection System (GIFDS). Flares and coronal mass ejections are detected and arrival probabilities are calculated. Thus, an approximate prediction can be made (two to three days ahead), although the exact time cannot yet be determined. This stage is mainly of interest to scientists rather than industrial users.

Stage two – Lagrange point L1 is involved. If the ACE and DSCOVR satellites are able to measure a solar storm, it will also reach the Earth. The

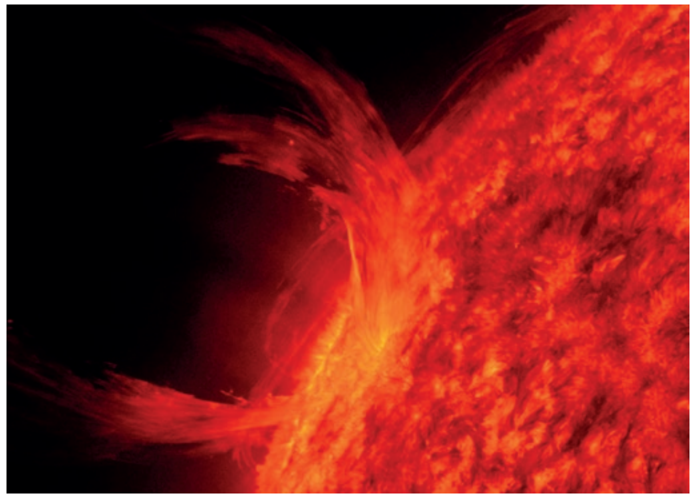


Image: NASA/SDO and the AIA, EVE, and HMI science teams

SHORT HISTORY OF SPACE WEATHER

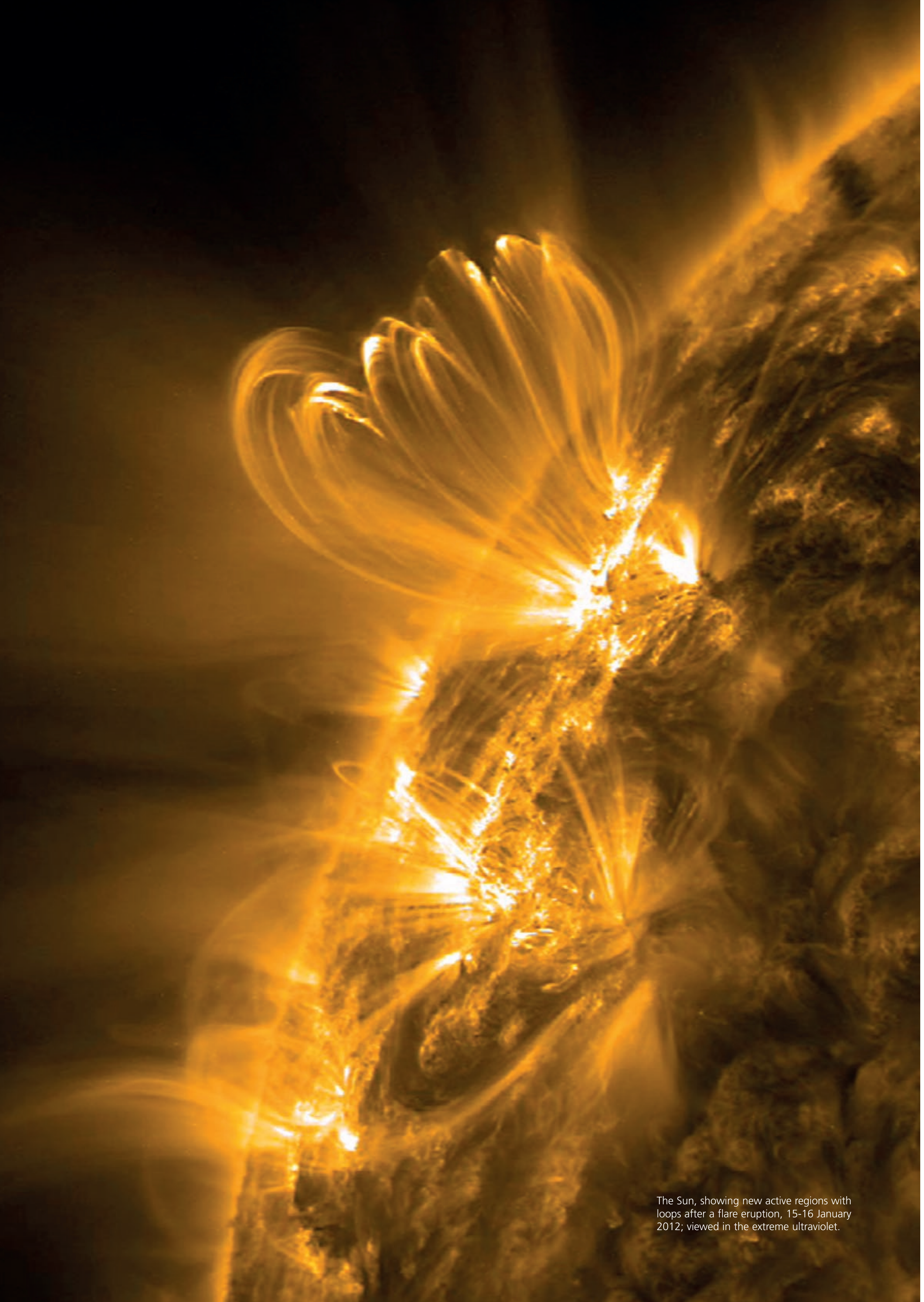
1859 – Carrington event: When sketching sunspots, the amateur astronomer Richard Carrington discovered a massive eruption on the Sun. This event is the largest scientifically observed magnetic storm ever observed and marks the beginning of space weather research. Employees at telegraph stations are said to have suffered electric shocks. Today, such a strong event would have catastrophic consequences.

1921 – storm in May: One of the greatest solar storms of the 20th century generated extremely high currents in transmission lines. The northern hemisphere was affected as far as Mexico and Puerto Rico, while the southern hemisphere was affected down to the latitude of Samoa. A similar storm today would cause the collapse of half of the electrical grids in North America.

1989 – Quebec, Canada: A mighty geomagnetic storm led to a nine-hour power outage in the Montreal region. Traffic control systems, airports and district heating supply centres failed. Some six million people were affected.

2003 – Halloween storm: Seventeen large flares were observed within two weeks. There were very strong, but short-lived disturbances of radio communication. In Malmö, Sweden, a part of the electrical grid failed. Air corridors in northern Canada were closed to passenger flights. Signals from satellite and navigation systems were temporarily out of order. The particle cloud was up to 13 times as large as the Earth and was moving at 1.6 million kilometres per hour. One satellite was completely destroyed and 27 others displayed anomalies in their functioning.

Outlook: Destroyed communication and positioning systems, restriction of air and ship traffic and economic damages in the billions – an extreme geomagnetic storm is a rare but very consequential event. A space weather forecast would give satellite operators time to react and to reduce the costs of damage resulting from solar storms. Since the beginning of 2000, DLR has been running workshops to bring together decision makers in order to make them aware of the topic. The group called 'Ionospheric Effects and Corrections' of the Institute of Communications and Navigation has been working at DLR Neustrelitz to set up a permanent space weather service, the Ionosphere Monitoring and Prediction Service (IMPC).



The Sun, showing new active regions with loops after a flare eruption, 15-16 January 2012; viewed in the extreme ultraviolet.

Image: NASA/SDO and the AIA, EVE, and HMI science teams

Antenna system at DLR Neustrelitz that is used to receive space weather data

Image: DLR/Manuel Tennert

Jens Berdermann, theoretical physicist. He obtained a doctorate in astroparticle physics on 'Equation of state and neutrino transport for superconducting quark matter in neutron stars'. He has been working at the DLR Institute of Communications and Navigation in Neustrelitz since 2011; there, he leads the Ionospheric Effects and Corrections Group and is working toward the establishment of the Ionosphere Monitoring and Prediction Centre (IMPC).

strength of the storm will depend on a number of factors, particularly the interplanetary magnetic field and whether solar storm particles can penetrate well into the Earth's atmosphere. At this time it is already possible to make an accurate prediction and to issue a warning. From the time of measurement at L1 and depending on the speed of the solar wind, the solar storm will reach the Earth's atmosphere within 30-60 minutes. Disturbances in the ionosphere will then spread from the polar regions to the lower latitudes (Germany) within another two to three hours. This time frame is very helpful for industry. It gives enough warning time for many applications, so that technical systems can be promptly adjusted or switched off.

Stage three – prediction. Using empirical models and, in the future, physical models, a prediction of when and where any such disturbance is expected can be made.

Stage four – real-time tracking. The calculation models are constantly compared to and adjusted on the basis of real-time measurements of the ionosphere. In this way, scientists on site can accurately determine if the storm has passed and give the corresponding all-clear signal.

DLR's space weather expertise

Since the turn of the millennium, DLR has been running national space weather workshops and has thus created a platform for this important topic. In the 4th workshop, in 2015, a joint position paper was proposed that is still under development. This document should help national decision-makers to adequately consider current aspects of complex space weather issues in their decisions and to use existing national resources appropriately.

The silent, vibrant energy of the Sun makes life on the Earth possible. In our daily lives we are generally not aware of the destructive energy of the gigantic eruptions on its surface. But these charged solar wind energy particles are real and affect our society at its most sensitive point: its networks.

When will there be a large solar storm? No one can say precisely. That it will come, however, is certain. DLR is working so that society will be as ready as possible to weather the solar storm.

Five questions for Jens Berdermann

1. "To me, my job means …"
: … new daily challenges and interesting research, but also application-oriented science.

2. "If I could obtain the answer to a scientific question, my question would be…"
: Hmm, difficult. (thinks) General, perhaps – what is the Universe made of? What existed before the Big Bang? It is hard to find a limit to this question. From my work point of view, I wonder how large the maximum solar storm could be so we know what to prepare for in the extreme case.

3. "When I look up at the sky, I see…"
: … clouds? (Laughs) No, I move around normally in everyday life, without directing my gaze constantly at the sky …

4. "If I was not working on space weather, then I would…"
: … be studying another exciting field in physics.

5. "In 30 years, space weather research will have progressed to the point that…"
: … space weather is as well understood as weather on the Earth. The greatest progress that I foresee is in the field of physical modelling with data assimilation and forecasts. I hope that we will have more direct observation data from satellites, but can also integrate ground-based data into a physical model. This will make it possible to improve the temporal and spatial precision of the forecasts concerning the state of the ionosphere and more accurately predicting disturbances.

GLOSSARY

SOHO – SOlar and Heliospheric Observatory – European-US solar observatory, delivers data about the solar interior, the solar atmosphere, the corona and the solar wind.

ACE – Advanced Composition Explorer – NASA satellite to analyse the solar wind and solar, interplanetary and cosmic particles, which transmits the data to the US, Japan and DLR Neustrelitz.

DSCOVR – Deep Space Climate Observatory – measures the strength of the solar wind and the interplanetary magnetic field and determines its orientation. In addition, back-scattered radiation from the sunlit side of the Earth is investigated.

GPS – Global Positioning System – satellites orbiting at an altitude of 20,000 kilometres and used for positioning and navigation on Earth.

About DLR

DLR, the German Aerospace Center, is Germany's national research centre for aeronautics and space. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

DLR has approximately 8000 employees at 16 locations in Germany: Cologne (Headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Göttingen, Hamburg, Jülich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stade, Stuttgart, Trauen and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington DC.

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Cover image
The 30-metre antenna at DLR Weilheim. Researchers at the DLR Institute of Communications and Navigation have received and analysed navigation signals using the antenna.

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